A DISTURBANCE-SENSITIVITY BASED APPROACH TO PRIORITIZING WATER MONITORING IN NORTHEAST B.C.

1/19/2017

PART 1: REPORT

A Disturbance-Sensitivity Based Approach to Prioritizing Water Monitoring in northeast B.C.

REPORT

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INTRODUCTION

A Disturbance-Sensitivity based (DS) approach has been developed as a tool to support the identification and prioritization of enhanced water monitoring sites across northeast B.C. It summarizes and communicates the status of complex surface water and groundwater systems using a format that is appropriate for water management applications and public understanding. The DS was developed in partnership with the Province, First Nations and stakeholders under the Northeast Water Strategy (NEWS). At three stages throughout its development, First Nations and stakeholder workshops were held in Fort Saint John attended by representatives from: local and regional government; industry including agriculture, oil and gas and mining; nongovernmental organizations; and First Nations. The feedback gained from these workshops was used to develop and evolve the model.

The goal of NEWS is the responsible use and care of water resources through conservation and sustainable practices to ensure human and ecosystem needs are met now and into the future. The DS approach aligns with the NEWS' action area of enhancing information to support decision-making.

Decisions about the location of monitoring stations and the availability of monitoring data affects a broad cross section of people from First Nations to Provincial, local and regional government decision makers and interested stakeholders. As a result, any model that seeks to prioritize monitoring locations needs to be public, transparent, and easily understood in its construction, method and presentation of results. In alignment with NEWS' commitment to enhance public access to water data and information, the DS approach uses publically available data through a Geographic Information Systems (GIS).

METHOD

The DS approach is an Intensity-Weight type of GIS-based assessment where data from variables that represent disturbance (in the case of water quality) or demand (in the case of water quantity) are rated according to their presence (Intensity) in standardized reporting units, and then assigned extra emphasis (Weight) to reflect their relative importance in the determination of risk. By converting data to an intensity measure, it allows for a variety of data types to be combined. The methods employed are parallel to Risk Assessment Model by Mattson and Angermeier (2007), Falcone et al (2010), Danz et al (2007), Paukert et al (2011), Smith et al (2008), Wang et al (2008), Tran et al (2010), and Davies and Hanley (2010).

A simplified example of this model (Figure 1) shows how the total disturbance on a basin is the weighted sum of its component parts. In this example, there are just five stressor layers (modified from Tardiff, 2012). Removing redundancies in the variables set generally produced improves the performance of indices (Falcone et al., 2010).

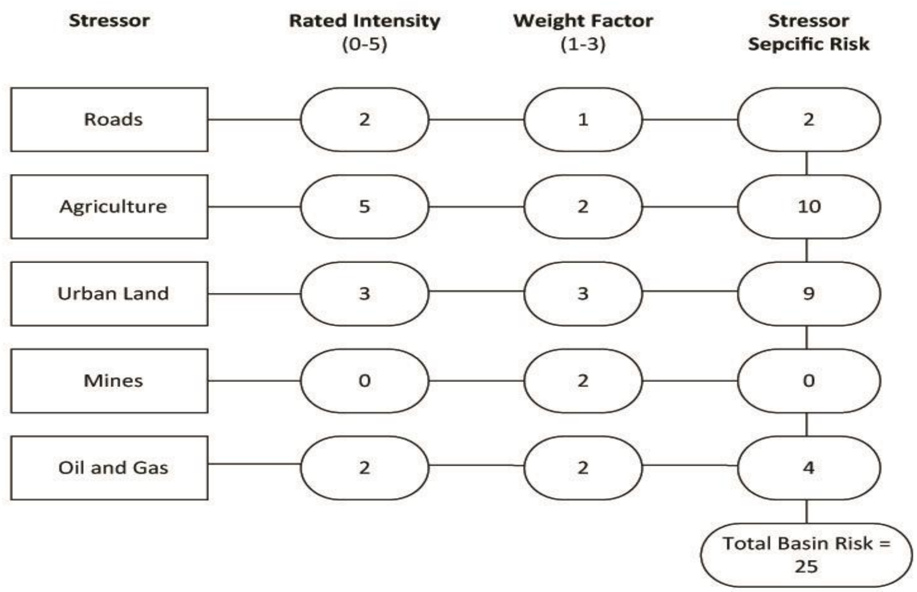


Figure 1. Example of an intensity-weight model (modified from Tardiff, 2012)

To maintain public accessibility, the DS approach used the BC government database of publically available geographically based information to support this modelling. In similar studies, most literature refers to national and regional databases as sources of data with the most common spatial data layers being: land use (urban, crop and pasture land cover), census (human population density), roads, dams, mines, emitting facilities (discharging sites) (Landis and Wiegers, 1997; Mattson and Angermeier, 2007; Danz et al., 2007; Wang et al., 2008; Smith et al., 2008; Bartolo et al., 2008; Falcone et al., 2010; Davies and Hanley, 2010; Paukert et al., 2011).

Data Variables

Two Provincial technical committees were established; one committee for developing the surface water quality and quantity tools and another committee for developing the groundwater quality and quantity tools (committee members listed in the associated Part 2: Data Package). Data and methods were developed collaboratively with interested First Nations and stakeholders through a series of workshops throughout the development of the approach. The technical committees took the feedback from the workshops and led the development of the products. The selection of the data layers were made by consensus. The goal for information layers was that they be: representative of a stressor without being duplicative of each other. Criteria for data selection also necessitated that data are consistent across the study region with good data quality, both in terms of locational accuracy and attributes accuracy. Additionally, in keeping with Provincial Open Government policy, data sources needed to be free and publically accessible. The study used primarily data from the B.C. Geographic Warehouse (BCGW) which is primarily supplied by the Ministry of Forests, Lands and Natural Resource Operations (FLNRO), Ministry of Environment (MOE) or the BC Oil and Gas Commission (OGC). Some national data and a minor component of data from alternate sources supplemented where needed. The data and explicit methods to reproduce results are documented in the companion report labelled Part 2: Data Package (Johnson, 2015).

Data redundancy and spatial scale were considered in selection of variables. Redundancy occurs when the same areas receive extra consideration because of overlapping data sources (e.g., areas of higher population density that overlap areas of urban land cover, areas of higher well density that overlap agricultural development rather than crown land). Spatial scale affects data availability. The finer the spatial scale, the more variables are available, but the data becomes less uniform across the entire region.

Four sets of variables were compiled for northeast B.C. that indicate current and future disturbance from development activity on water quantity and water quality, both for surface water and groundwater. Primary water consumption in the northeast region relates to: oil and gas, 32%; rural domestic and community water supply, 25%; mining, 20%; forestry,16%; agriculture and range, 6%; and road maintenance, 1% (Ministry of Forests, Lands and Natural Resource Operations, 2015). Since road maintenance was nominal, it was disregarded as a major source of disturbance. Table 1 indicates the industries attached to disturbance and the data chosen as being reflective of that disturbance. More detailed data on specific data sets and how it each set was manipulated is available in the companion document (Johnson, 2015). Those four sets of variables were augmented with variables that highlight ecosystems or population areas sensitive to potential effects from disturbance to surface water or groundwater quantity or quality (Table 2).

Table 1: Data Selection for Disturbance

	Source	Surface Water Quantity	Surface Water Quality	Ground Water Quantity	Ground Water Quality
Current Activity	Oil and Gas	Current water demand relative to watershed discharge	Footprint related to infrastructure development including pipelines, well sites, facilities etc.	Water Use for Hydraulic Fracturing by well	Footprint related to infrastructure development including pipelines, well sites, facilities etc.
	Mining	Current water demand relative to watershed discharge	Footprint related to mining activity		Footprint related to mining activity
	Forestry	Current water demand relative to watershed discharge	1. Footprint related to cut blocks less than 20 years old 2. Burn scar area		Footprint related to cut blocks less than 20 years old
	Agriculture	Current water demand relative to watershed discharge	Footprint related to agricultural activities and residential agriculture mixtures		Footprint related to agricultural activities and residential agriculture mixtures
	General	Areas of insufficient	1. Footprint related to roads, railway	1. Groundwater well density	1. Footprint related to roads, railway

		surface water	lines and transmission lines 2. Footprint related to urban built up areas	2. Areas of insufficient surface water	lines and transmission lines 2. Footprint related to urban built up areas
Future Activity	Oil and Gas	Water Use for Hydraulic Fracturing by pool	Areas overlying prospective development areas	Water Use for Hydraulic Fracturing by pool	Areas overlying prospective development areas
	Mining	Footprint related to all leased and licensed areas	Footprint related to all leased and licensed areas	Footprint related to all leased and licensed areas	Footprint related to all leased and licensed areas
	Forestry		Areas of forested crown land		
	Agriculture	Footprint related to agricultural activities and residential agriculture mixtures			
	General			Areas of insufficient surface water	

Table 2: Data Selection for Sensitivity

Area of concern	Surface Water Quantity	Surface Water Quality	Ground Water Quantity	Ground Water Quality
Ensuring water sufficient to meet human needs	Population density	Population density	Population density	DRASTIC model of groundwater susceptibility to contamination
Ensuring water sufficient to meet ecosystem needs	1. Headwater density 2. Lake density	1. Headwater density 2. Lake density		DRASTIC model of groundwater susceptibility to contamination

Intensity

Spatial data for each information variable was transformed into a density or intensity measure. The 'presence' of a variable was normalized by the land area of the reporting unit. For example, a layer of polygon-based agriculture data was transformed into intensity for a surface water model by using total polygonal area of agriculture in a given watershed relative to the total area of that watershed. If agriculture polygons overlapped two watersheds, then the agriculture polygon was divided along the watershed boundary. Point layers were transformed into number or count relative to the area of the reporting unit. Layers with road or pipeline like data were assigned appropriate widths for each segment so a polygonal area per reporting unit could be calculated. Explicit procedures are listed in the companion document (Johnson, 2015).

Reporting units for surface water and groundwater were created by subdividing the region into identified watersheds for surface water and by using 1:50,000 scale National Topographic Service (NTS) map sheets for groundwater (Figure 2).

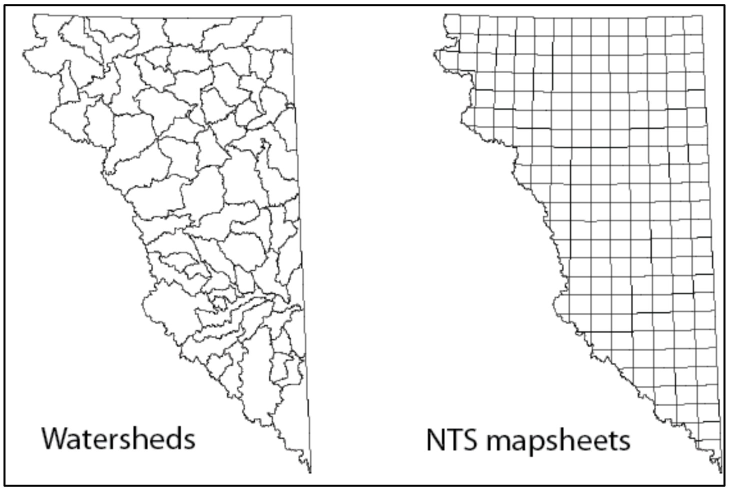


Figure 2. Reporting units for surface water (watersheds; left) and groundwater (NTS map sheets; right).

The spectrum of intensity values for the 69 watershed or 219 NTS map sheets were modified through either standardization or categorization (Table 3). This step was needful so that the various data layers were able to be combined at a later stage. For the range-standard method, the intensity values were normalized between the maximum and minimum values to redistribute the data in a range from zero to one. For the categorization methods, a series of threshold cutoff values used to place the intensity values into bins. Only one method is needed to condition the data but results were generated for several methods in order to choose the most appropriate approach.

Table 3: Summary of intensity rating systems tested

Rating System	Number of categories	Range or Scale	Relative Merits	Examples of Similar Systems
Range standardized	none	(Best) 1 – 0 (Worst)	Pro: Spreads data across a broad range so that there is more discernment of differences. Con: the highest and lowest value may not represent a true high or low, so data can be skewed	Wang et al., 2008; Falcone et al., 2010
Threshold-based by thirds	4	0 → 0 0 < Values ≤ 33rd percentile → 1 33rd percentile < Values ≤ 66th	Pro: Simplifies data and reduces influence of extreme values	Mattson and Angermeier, 2007; Paukert et

		percentile → 2 66th percentile < Values ≤ 100th percentile → 3	Con: coarse generalization of the data	al., 2011
Threshold-based by fifths	5	0 < Values ≤ 20th percentile → 1 20th < Values ≤ 40th percentile → 2 40th < Values ≤ 60th percentile → 3 60th < Values ≤ 80th percentile → 4 80th percentile < Values → 5	Pro: Simplifies data and reduces influence of extreme values Con: generalizes the data; more categories to consider	Falcone et al., 2010
Threshold-based for high disturbance only	5	50 < Values ≤ 60th percentile → 1 60th < Values ≤ 70th percentile → 2 70th < Values ≤ 80th percentile → 3 80th < Values ≤ 90th percentile → 4 90th percentile < Values → 5	Pro: Simplifies data and reduces influence of extreme values; focus solely on areas of intensity Con: generalizes the data; ignores areas with low level disturbance as not a priority for monitoring	Falcone et al., 2010
Binary	2	0 < Values ≤ 0.5 → 0 0.5 < Values ≤ 1 → 1	Pro: Simple method that can produce similar results to more complicated methods Con: generalizes the data such that any degree of subtlety is lost	Paukert et al., 2011

Weighting Data Layers

A secondary reassessment of data layers was done to ensure that one variable isn't over-represented when capturing a category of stress was completed (Smith et al., 2008). This is done by re-grouping the heavily represented variables into one variable by using average value. Falcone *et al* (2010)completed a comparison test of three weighting methods (Chi-squared, χ^2; principle component analysis, PCA; and no weighting) and concluded that weighting the variables is important to the degree that redundancy is present in the final dataset, but it is less important, or even undesirable, if variables have already been well reduced.

For the surface water tools, overrepresentation was avoided by having one layer represent each contributing factor or industry. In many cases several layers were combined into one. For example, disturbance associated with oil and gas infrastructure required combining data layers for well sites, facilities, and pipelines. Explicit procedures are listed in the companion document (Johnson, 2015). For groundwater tools, knowledge is too limited to apply reduction techniques to the data layers either through data layer grouping. Some weighting was applied where warranted by expert opinion.

Imbalances were also be dealt with as part of the weighting process. For this study, weight factors based on expert opinion were assigned independently of a variable's intensity. Weighting helps ensure data layers will represent the magnitude of the potential impact to the environment. This approach is supported by similar studies. Mattson and Angermeier (2007) proposed a structured and rational system to compile expert opinion to determine the importance, or weight, of each stressor variable in the determination of risk. Paukert *et al* (2011) compared results from a weighting system against a no weighing system and concluded that simpler and less subjective risk assessment methods produce similar results to the more complex and subjective methods.

The surface water committee and peer review workshop participants agreed on a simple weighting scheme with 50% of the focus for enhanced monitoring based on current disturbance. The remaining weight was split with 30% weight on areas with higher population or sensitive ecosystems and 20% weight on areas where enhanced monitoring could precede future development activity. In general, the variable layers were weighted equally within those broad categories as seen in the following tables 4-8. Occasionally expert opinion weighted one layer more heavily. For instance, future development in mining, agriculture and oil and gas development is equally weighted for surface water quality (Table 5), but more heavily weighted for future impact on water quantity demand by the oil and gas industry (Table 4).

Table 4: Surface Water Quantity Weighting System for Monitoring

Indicator Layer	Weight		
Future Development • Potential oil and gas consumption • Potential consumption by mining • Potential consumption by agriculture	**20%**	**20%**	12% 4% 4%
Current Demand versus Supply • Water allocation relative to mean annual discharge • Restrictions on Surface Water use	**50%**	**50%**	35% 15%
Sensitivities **Rural and domestic water use** • Population	**30%**	**15%**	15%
Aquatic ecosystem sensitivity • Wetland density per watershed • River headwater density per watershed • Lake density per watershed		**15%**	5% 5% 5%

Table 5: Surface Water Quality Weighting System for monitoring

Indicator Layer	Weight		
Future Development **Land tenure** • Oil and Gas • Mining • Forestry	**20%**	**20%**	8% 8% 4%

Current Development	50%		
Land disturbance		35%	
• agriculture			5%
• forestry - clear cuts			5%
• forest burn areas			5%
• municipal / urban			5%
• oil and gas infrastructure			5%
• linear projects			5%
• mining			5%
Waste discharge permits		15%	
• Sewage - total discharge / annual runoff			7.5%
• Industrial - total discharge / annual runoff			7.5%
Sensitivities	30%		
Rural and domestic water use		15%	
• Population			15%
Aquatic ecosystem sensitivity		15%	
• Wetland density per watershed			7.5%
• Headwater River density per watershed			3.75%
• Lake density per watershed			3.75%

The first groundwater quantity assessment (Table 6) identifies areas for enhanced ambient monitoring of quantity primarily a function of industrial activity. The second groundwater quantity assessment (Table 7) uses data about areas of potential abundant water supply to indicate areas enhanced well information from monitoring wells, private wells, geology or geophysics would provide valuable targets for aquifer characterization efforts. For groundwater quality, similar to surface water quality, the assessment considers current and future industrial activity as well as environmental sensitivity (Table 8). The groundwater committee tried various approaches but in the end, in conjunction with feedback for peer review workshops, the best approach was considered one that mirrored the surface water process. Groundwater quality is prioritized equally across various possible disturbances because there is little information with which to weight indicator layers. The DRASTIC indicator layer is weighted more heavily because it considers sensitivity; the ability for a contaminant to infiltrate through the soil horizon and enter groundwater.

Table 6: Groundwater Quantity Weighting System Based on Demand

Indicator Layer	Weight
Future Demand	5%
• Potential water use Oil and Gas	

Current Demand • Density of Water Wells and Source Wells • Surface Water Restrictions • Water used for hydraulic fracturing in Oil and Gas • Mining Tenure • Population	25% 25% 15% 15% 15%

Table 7: Groundwater Quantity Weighting System Based on Productivity

Indicator Layer	Weight
Supply **Development indications** • Yield from water wells, source wells and springs	55%
Natural Resource indications • Surficial Geology • Aquifer Size • Paleovalleys	15% 15% 15%

Table 8: Groundwater Quality Weighting System Based on Vulnerability

Indicator Layer	Weight
Future Development • Unconventional Gas Play • Mining Tenure	7% 7%
Current Disturbance • Agriculture • Forest clear cuts • Urban development • Oil and Gas - wells • Oil and gas - facilities • Oil and gas - pipelines • Linear – transmission lines • Linear – Roads • Linear – Rail lines • Active mines	7% 7% 7% 7% 7% 7% 7% 7% 7% 7%
Sensitivities • Potential Groundwater vulnerability to contamination – DRASTIC	16%

Once the data was divided into reporting units, classified according to intensity and weighted according to importance, the data was summed by reporting unit. The results were ranked for the 69 watersheds and 219 NTS map sheets. The results were categorized by percentile into thirds.

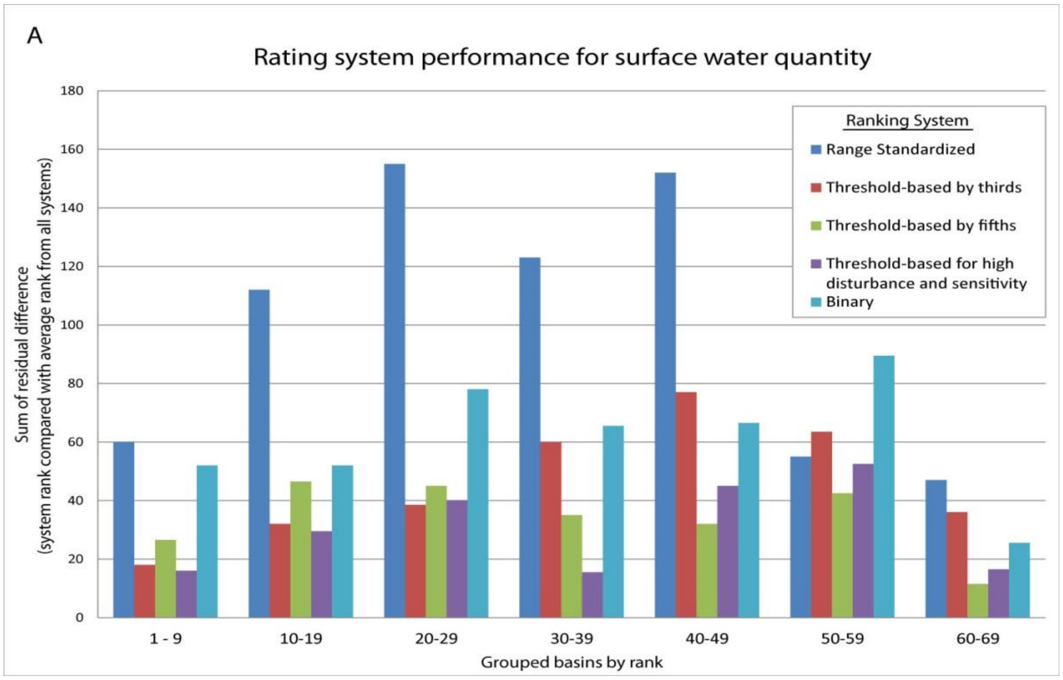
Comparison of Intensity Rating Systems

To compare intensity rating systems, the ranks generated in all five systems (range standardized, X1; threshold-based by thirds, X2; threshold-based by fifths, X3; threshold-based for high disturbance only, X4; and binary, X5) were compared for each of the 69 basins. An average rank for each basin was assigned based on the average of the five rating system results. Basins were sorted according to the average rank and then assigned a new rank based on the order of the 69 basins. This new rank was taken to be the dependent variable 'Y'. A regression was generated between the each system rating (X1 – X5) and Y. Each of the regressions was detrended to generate the remainders. The remainders were summed into bins (0-9, 10-19, 20-29, 30-39, 40-49, 50-59, and 60-69).

RESULTS

Weighting System

The surface water committee tested several weighting systems including: 1) range standardized; 2) threshold-based by thirds; 3) threshold-based by fifths; 4) threshold-based for high disturbance only; and 5) binary. Since there is no absolute measure available for the amount of disturbance or the sensitivity of a basin, the ranking results were compared with each other using the average of the five rankings (Figure 3 and Table 9). Three of the rating systems generated very similar results: threshold-based by thirds; threshold-based by fifths; and threshold-based for high disturbance only. Ninety percent of the rankings these three systems assigned to a basin were within 10 places or less than average ranking from all five systems. The range standardized system was substantially differently than the other systems in rankings. From a qualitative perspective, the binary and threshold-based by thirds systems were the easiest to comprehend quickly and intuitively. As a result, the threshold-based by thirds rating system was chosen for this project. It is not as good as the threshold-based by fifths for high disturbance only system, but it provides generally the same results and is far simpler to execute and understand.



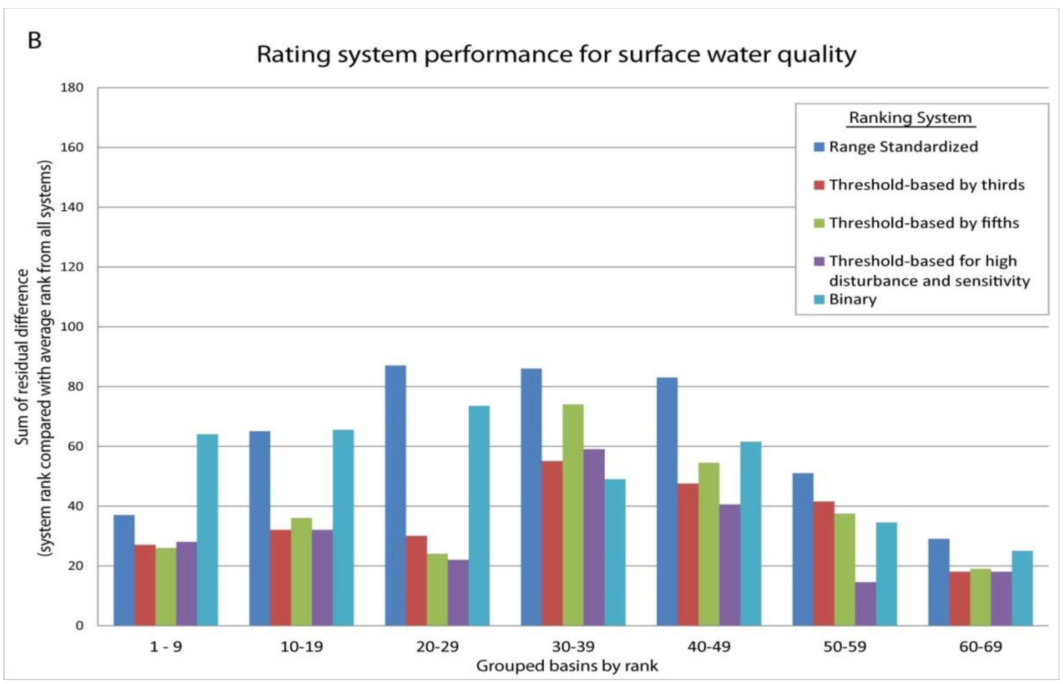


Figure 3. Comparison of five intensity rating systems for (a) quantity and (b) quality in surface water basins. For each system a linear regression was run against the average basin ranking. The remainders were summed. The lower the sum of the remainders, the better that rating system approximates the average.

Table 9: Performance comparison of five intensity rating systems

	Range Standard -ized	Threshold -based by thirds	Threshold -based by fifths	Threshold-based for high disturbance and sensitivity	Binary
Quantity - Sum residual difference	704	325	239	215	429
Percent basins over 10 ranking points different than average	42%	10%	3%	1%	25%
How representative is the rating system for surface water quantity? (1 = results are similar to average, 5 = results are very different from average)	5	3	2	1	4
Quality - Sum residual difference	438	251	271	214	373
Percent basins over 10 ranking points different than average	17%	4%	4%	3%	20%
How representative is the rating system for surface water quantity? (1 = results are similar to average, 5 = results are very different from average)	5	2	3	1	4
How difficult is the rating system to implement? (1=simple, 5= complicated)	5	2	3	4	2
How intuitive is the rating system? (1=clear, 5= obscure)	5	1	3	4	1

Prioritization of Basins for Surface Water Monitoring

For surface water quantity and quality monitoring (Figures 4 and 5), the 69 basins were classified according to the threshold-based by thirds intensity rating system and weighted according to tables 4 and 5 respectively. The individual data layers and their associated intensity ratings are presented in Appendices A and B for surface water quantity and quality respectively. The results for ranking surface water quantity and quality are available in Appendices F and G. These models are generated to prioritize basins in need of monitoring, so it is important that the results be presented in conjunction with the location of current monitoring efforts.

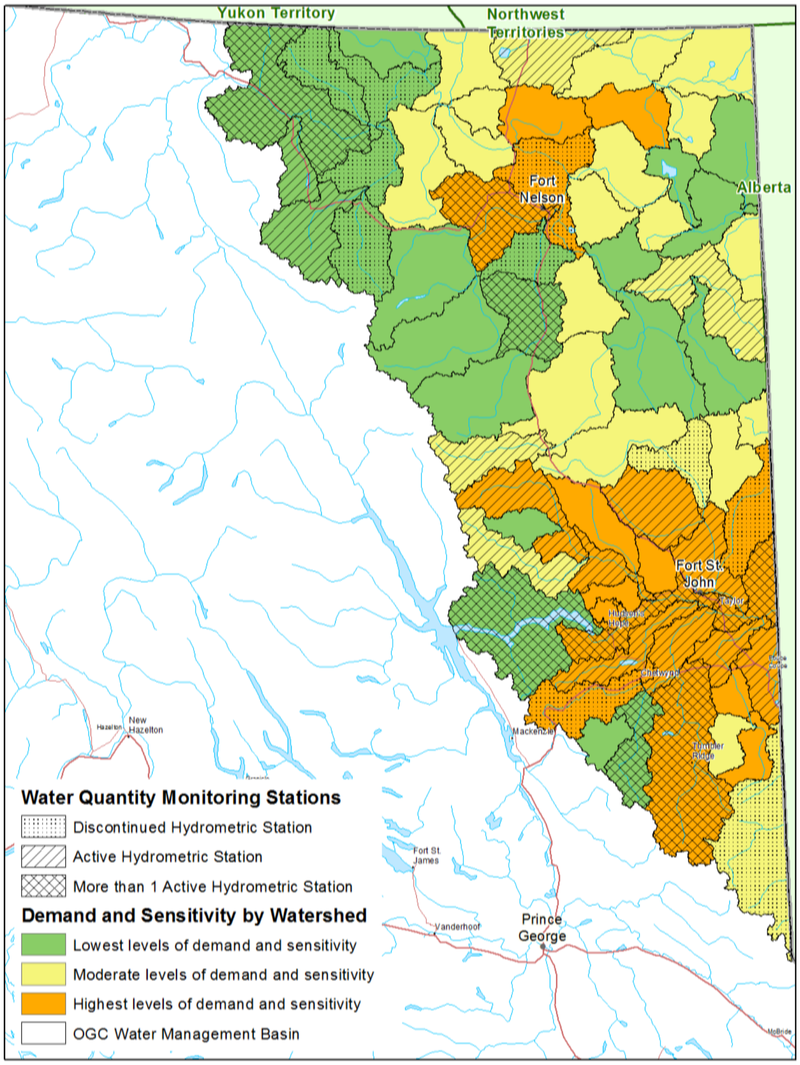


Figure 4. Prioritized basins in Northeast BC for surface water monitoring of quantity. The comprising data layers are in Appendix A. The relative rankings for each watershed are available in Appendix F.

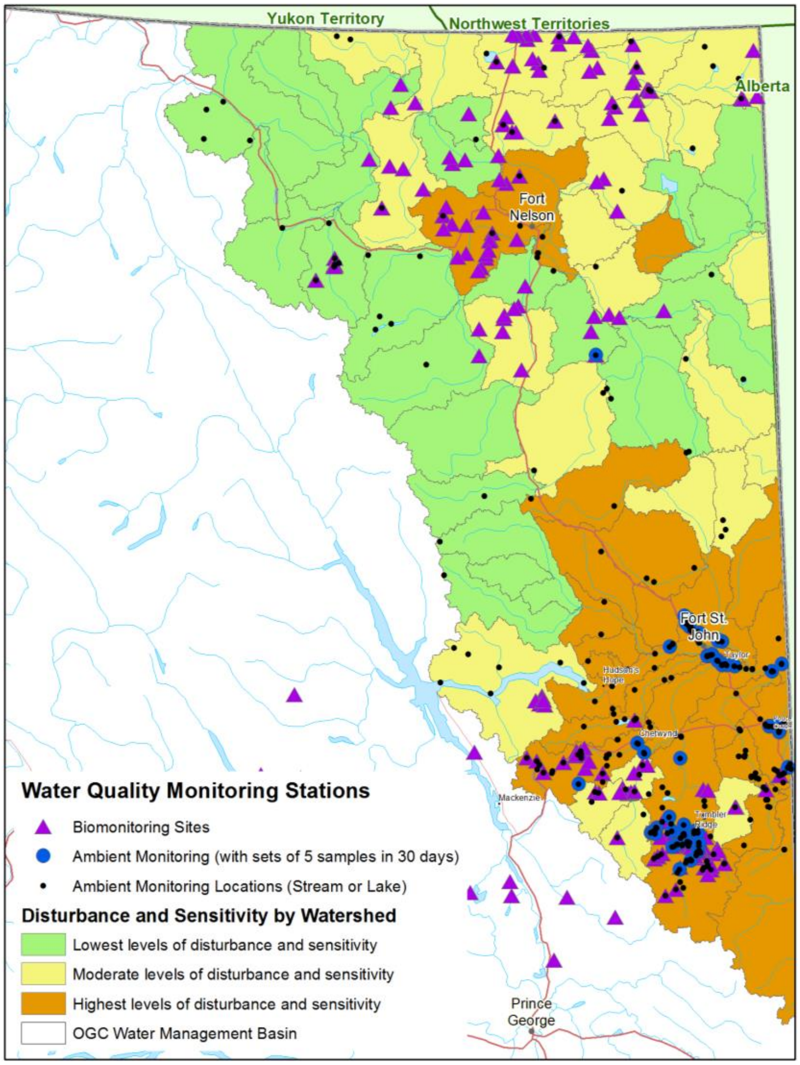


Figure 5. Prioritized basins in Northeast BC for surface water monitoring of quality. The comprising data layers are in Appendix B. The relative rankings for each watershed are available in Appendix G.

For prioritizing groundwater quantity monitoring by demand, for regional supply characterization (Figure 6 and 7) or for prioritizing groundwater quality monitoring (Figure 8), the 219 NTS map sheets were classified according to the threshold-based by thirds intensity rating system and weighted according to tables 6, 7 and 8 respectively. The individual data layers and their associated intensity ratings are presented in Appendices C, D, and E respectively. The results for ranking groundwater quantity and quality are available in Appendices H and I.

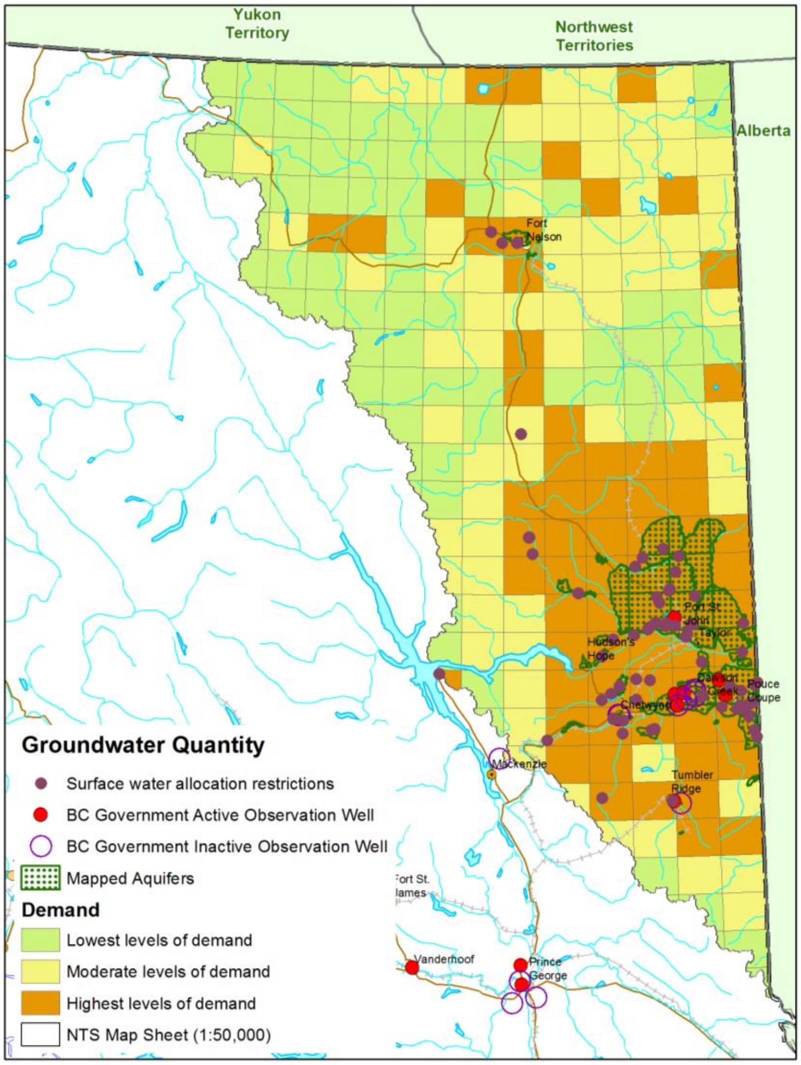


Figure 6. Prioritized NTS mapsheets in Northeast BC for groundwater monitoring of quantity on the basis of demand. The comprising data layers are in Appendix C.

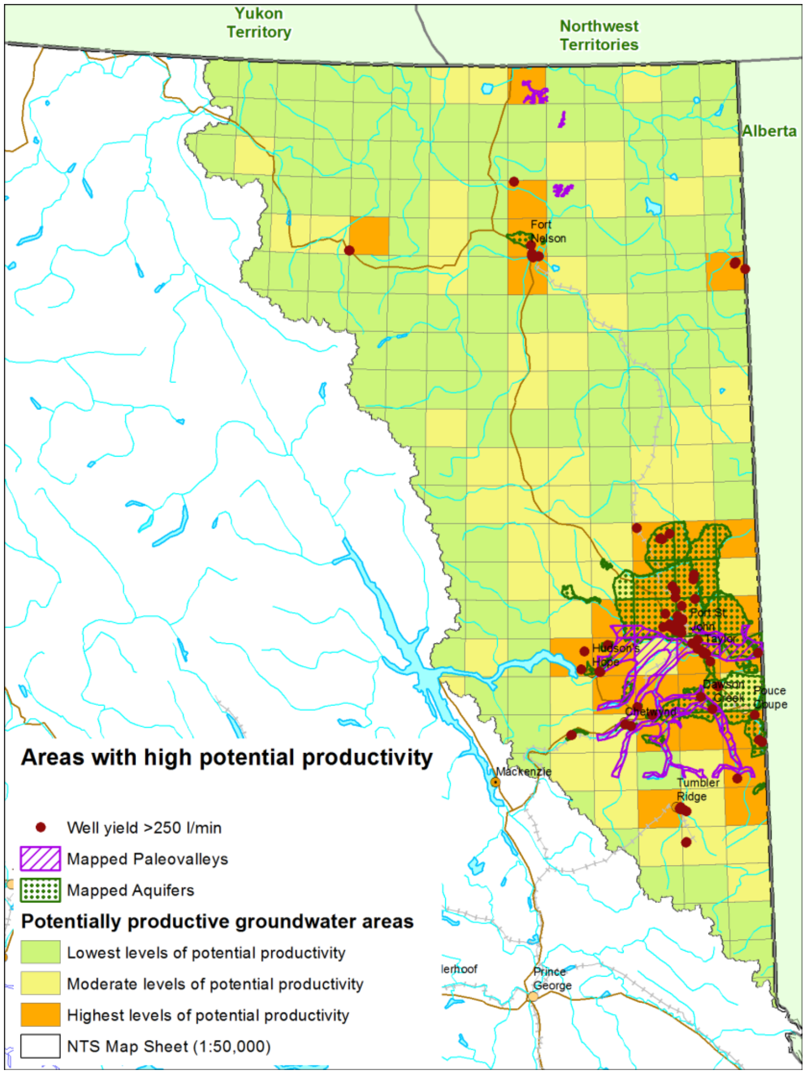


Figure 7. Prioritized NTS mapsheets in Northeast BC for where there is potential producibility from groundwater flow systems. The comprising data layers are in Appendix D.

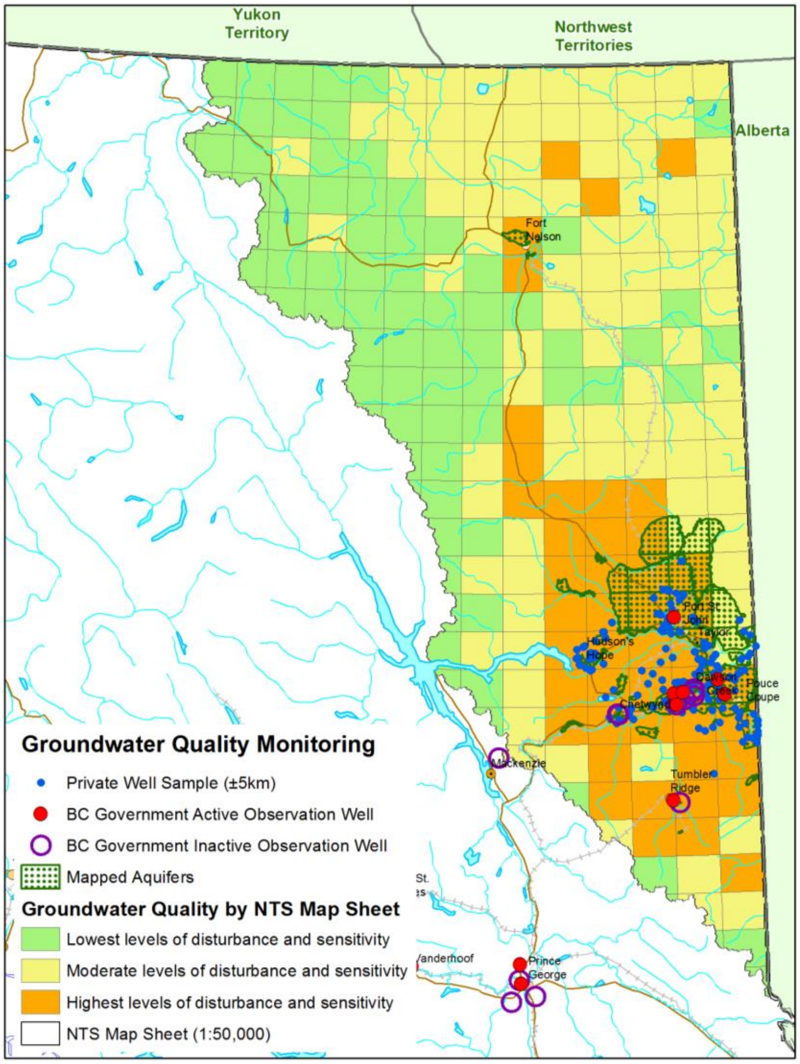


Figure 8. Prioritized NTS mapsheets in Northeast BC for groundwater monitoring of quality. The comprising data layers are in Appendix E.

DISCUSSION

Improvements to the method

Most of the approaches to modelling cited in the introduction do not consider upstream-downstream spatial relationships with the exception of Paukert et al (2011). Paukert *et al* (2011), while computing the intensities per reporting unit for downstream watersheds, included the stressor variables for that downstream watershed plus the stressor variables from upstream watershed(s) and considered the reporting unit to be the combination of the downstream and upstream watershed(s). Then, the risk indices for the combined upstream-downstream watersheds were assigned to the downstream watersheds (Figure 9). This method was not employed here but was actively considered by the surface water committee.

It was considered too labour intensive for the initial tool development but is recommended for incorporation in future work.

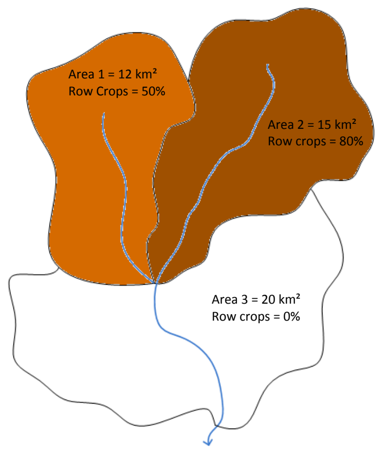


Figure 9. Example of stressor intensity per basin. Most models don't integrate upstream stressors in downstream basins (left), however it can be incorporated like Paukert *et al* (2011) (right).

Surface Water

The DS tool for surface water quantity (Figure 4) indicates that watersheds in the Peace River region and those around the City of Fort Nelson have the highest monitoring needs based on current and future water demand by industry, environmental sensitivity and population based constraints. These results were congruent with the expert opinions of the surface water committee. When the need for monitoring is compared with the location of monitoring stations in the Provincial network, more than half of the watersheds in the highest disturbance and sensitivity category have active hydrometric monitoring (Table 10). However a third of the watersheds have had no monitoring. This tool is useful for planning enhanced monitoring and regionalization models.

Table 10: Surface water quantity monitoring in basins with the highest level of disturbance and sensitivity

Watershed	Intensity rating for basins with the highest level of demand and sensitivity	Total hydrometric stations	Active hydrometric stations
Pouce Coupe River	2.73	5	1
Lower Pine River	2.63	1	1
Cache Creek	2.58	0	0
Lower Beatton River	2.54	4	1
Lower Kiskatinaw River	2.53	1	1
Murray River	2.39	4	3
Lower Halfway River	2.39	2	1
Blueberry River	2.38	1	1
Lower Peace River	2.36	4	3

East Kiskatinaw River	2.34	0	0
Middle Fort Nelson R.	2.30	2	0
Lower Muskwa River	2.21	2	2
Lynx Creek	2.21	0	0
Cameron River	2.19	0	0
Middle Kiskatinaw River	2.12	0	0
Doig River	2.04	1	0
Upper Peace River	1.94	2	2
Moberly River	1.92	1	1
Tsea River	1.91	0	0
Kiwigana River	1.91	0	0
Upper Halfway	1.87	2	1
Upper Pine River	1.87	2	0
Farrell Creek	1.82	0	0

The DS tool for surface water quality (Figure 5) was similar to that of surface water quantity indicating that watersheds in the Peace River region and those around the City of Fort Nelson have the highest monitoring needs based on current and future water disturbance by industry, environmental sensitivity and population based constraints. Again, these results were congruent with the expert opinions of the surface water committee. Existing monitoring is more difficult to indicate. Unlike water quantity measurements with hydrometric stations, water quality can be assessed by a water grab sample and can be heavily impacted by the sample location relative to sewage outfall, industrial development etc. Additionally, water quality can vary widely over time. It is considered good procedure to revisit the same site at least 5 times within a 30 day period to show reproducibility in water analyses. The sampling sites indicated above are for ambient monitoring and those sites meeting the 5 samples in 30 days protocol are flagged. The monitoring site is only reflective of upstream conditions, so monitoring sites near the outflow for the 69 watersheds are more reflective of the overall condition of the watershed. There are few watersheds where this is the situation.

Additionally, the province has partnered with environment Canada in using biomonitoring to assess water quality. A biomonitoring program requires a baseline model to be established for comparison purposes. A Canadian Aquatic Biomonitoring Network (CABIN) model has been constructed for most areas of BC including, most recently the Liard Watershed area of northeast BC. Biomonitoring is still required in order to build a CABIN model for the Peace Watershed. The absence of biomonitoring stations in the Peace Region is noticeable in Figure 5.

Groundwater

Groundwater quantity is prioritized by demand in Figure 6. Sensitivity is not included as a factor here because there is no strong GIS indicator layer that would indicate human or ecosystem sensitivity from exigent groundwater withdrawal. Surface water restrictions are weighted fairly heavily because in areas where surface water is restricted, it is expected that groundwater will be used to meet that demand. The highest demand is in the Peace Region and Montney gas play area. Population centers like Fort Nelson, Dawson Creek, Hudson Hope, Tumbler Ridge and Pouce Coupe are also considered high demand areas. Mapped aquifers only cover a small component of northeast BC but the mapped areas and observation wells coincide with high demand areas.

As there are large areas yet to be mapped with respect to groundwater in northeast BC, a priority decision support for characterization of the groundwater flow systems was generated (Figure 7). Areas in the Montney play and near the city of Fort Nelson have higher priority because knowledge about wells with greater yield, and the prospect of paleovalleys and large aquifers indicates these areas result in information about large groundwater flow systems.

Areas of higher groundwater vulnerability are prioritized in Figure 8. The highest levels of disturbance and sensitivity are in developed areas and where mapped aquifers are vulnerable to surface related contamination. The Peace Region and near the City of Fort Nelson are in the highest category. Monitoring wells have been installed in the area around Dawson Creek and geochemical sampling of private wells in the Peace Region is providing some information about groundwater quality. Areas north of Fort St John have little monitoring of water quality.

Gathering information to characterize groundwater is expensive and information collection surveys tend to be deployed around large groundwater flow systems with greater potential to meet water demand. These information collection surveys include sampling water from private wells, monitoring wells, geological studies and drill holes and regional airborne, ground-based and downhole geophysics. Prioritization of areas for groundwater characterization can be considered through a process that combines both demand and potential productivity. The combined ranking of groundwater demand and potential productivity provides prioritized locations for information collection surveys. The results are presented in Figure 10 and are available in Appendix H. Much of the active information survey work and groundwater characterization is already occurring in the most needful areas. More characterization work is needed near Fort Nelson, Tumbler Ridge and the areas around Blueberry River and Halfway River.

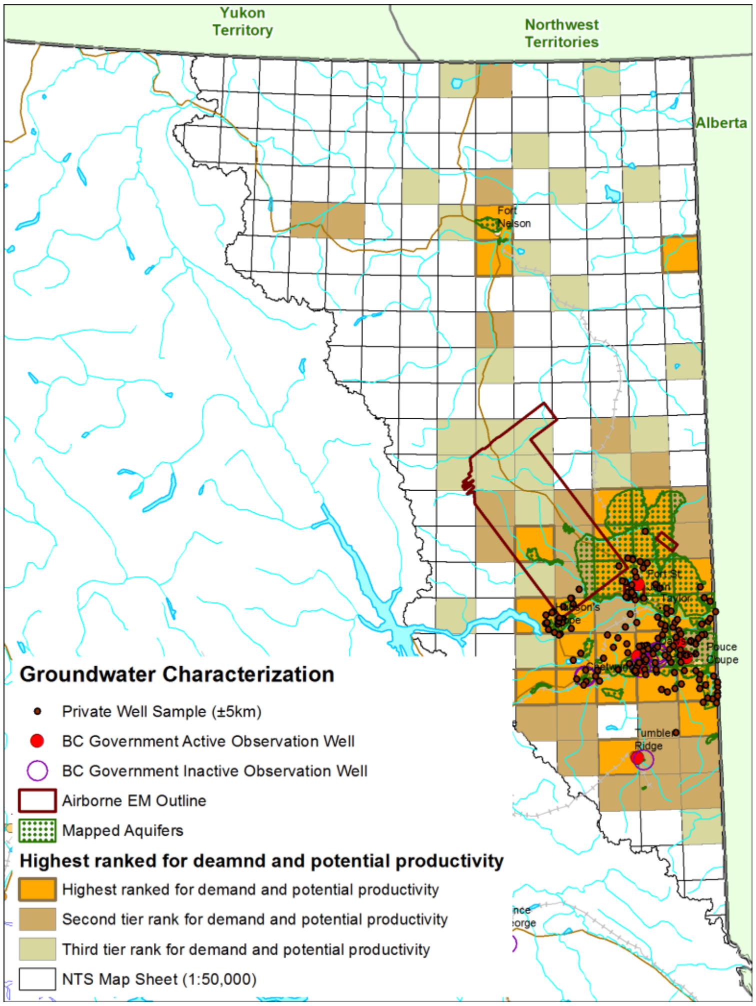


Figure 10. Prioritized NTS mapsheets in Northeast BC for groundwater characterization. The rankings for groundwater demand and potential productivity were combined. This map shows those mapsheets with the highest combined priorities. The relative rankings for each mapsheet are available in Appendix H.

Since groundwater monitoring requires a single well for both water quality and quantity monitoring, monitoring prioritization can be considered through a combination of both vulnerability and demand. The results for the combined ranking of groundwater demand and vulnerability are available in Appendix I. Figure 11 shows the combination of the highest priority areas for demand and for vulnerability for only the map sheets in the top third of their respective DS assessment. The resultant map indicates a need for monitoring near all the population centers in Northeast BC and also in the industrially active zone just north of Fort St. John along the Halfway, Blueberry and Beatton Rivers. Several monitoring wells have already been installed near Dawson Creek.

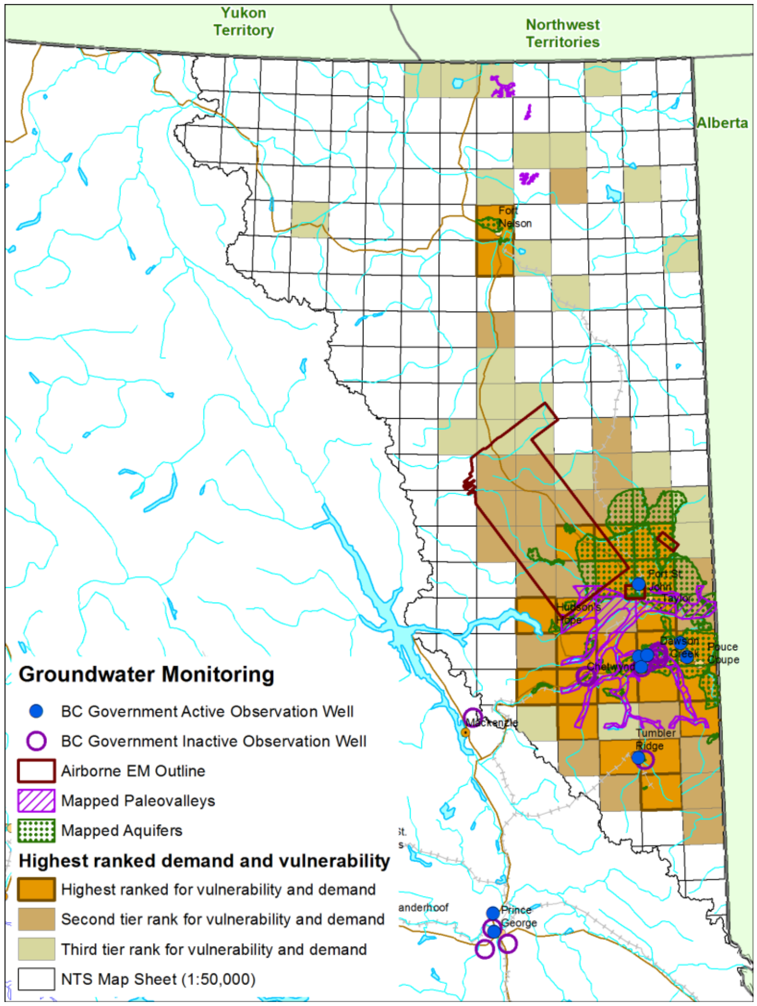


Figure 11. Prioritized NTS mapsheets in Northeast BC for groundwater monitoring. The rankings for groundwater vulnerability and groundwater demand were combined. This map shows those mapsheets with the highest combined priorities. The relative rankings for each mapsheet are available in Appendix I.

SUMMARY AND IMPLICATIONS

The DS tools for surface water quantity and quality are designed as a preliminary ranking tool to help prioritize a series of watersheds for enhanced monitoring and characterization. The DS tool for surface water quantity has been used to support discussions for enhanced surface water monitoring in the Peace Region. Two watersheds with the highest levels of disturbance and sensitivity and with no monitoring were targeted for monitoring; the East Kiskatinaw River and Lynx Creek. The DS tool for surface water quality has highlighted a need for more broad scale characterization of surface water quality reflective of larger watersheds. This prioritization exercise supports continued development of biomonitoring for the construction of the CABIN model in the Peace Region. Many watersheds in the highest category for disturbance and sensitivity are in need of water quality monitoring.

The DS tools for groundwater demand, characterization and vulnerability are helpful but provide more utility when used in combination to consider areas for groundwater characterization (Figure 10) or groundwater monitoring (Figure 11).

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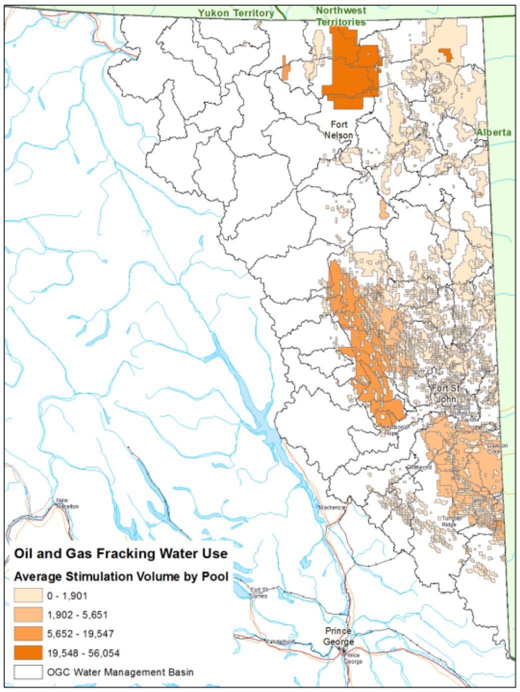
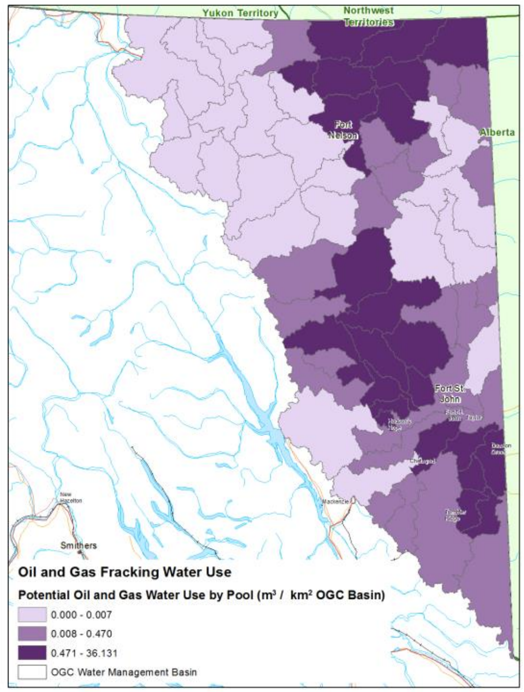
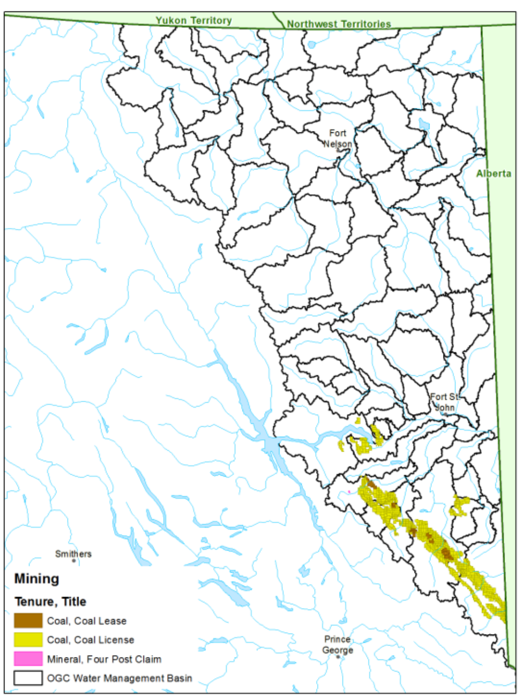
Appendix A – Data Layers for Surface Water Quantity

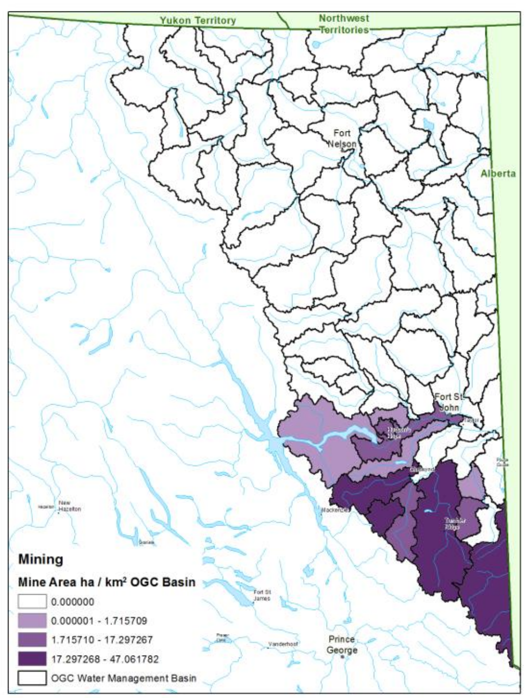
Future demand – potential oil and gas surface water consumption



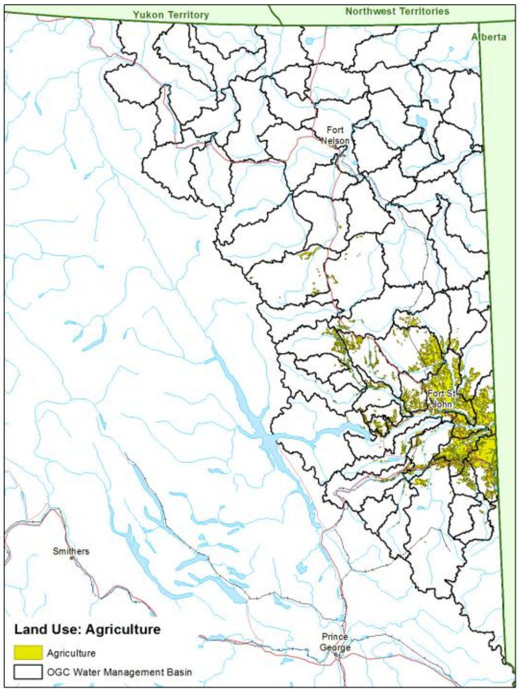


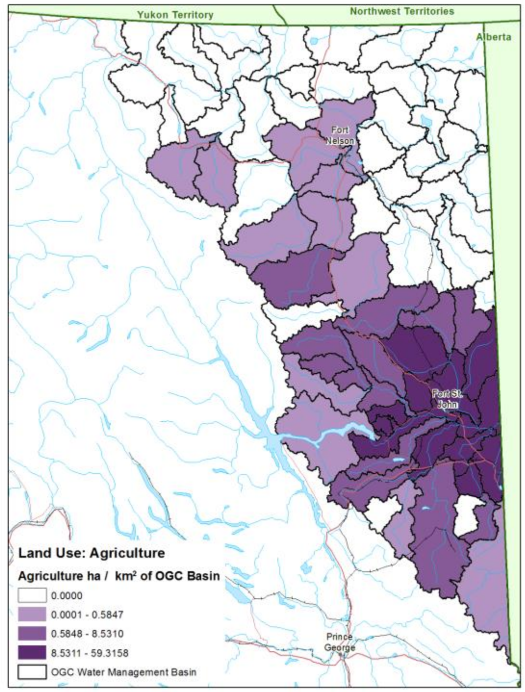
Future demand – potential surface water consumption by mining



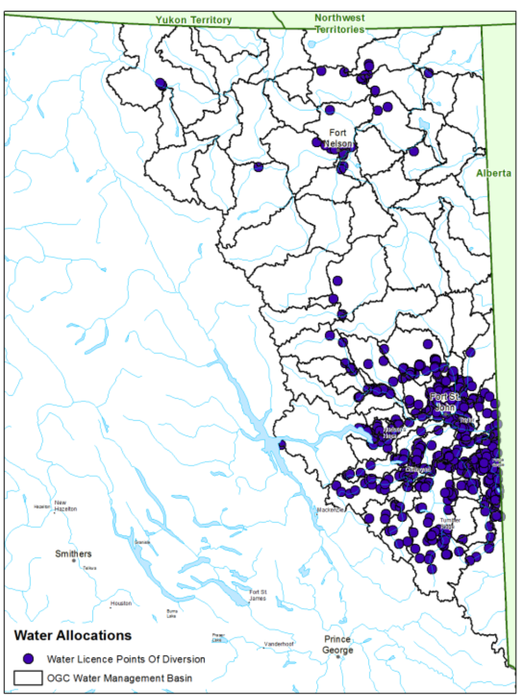


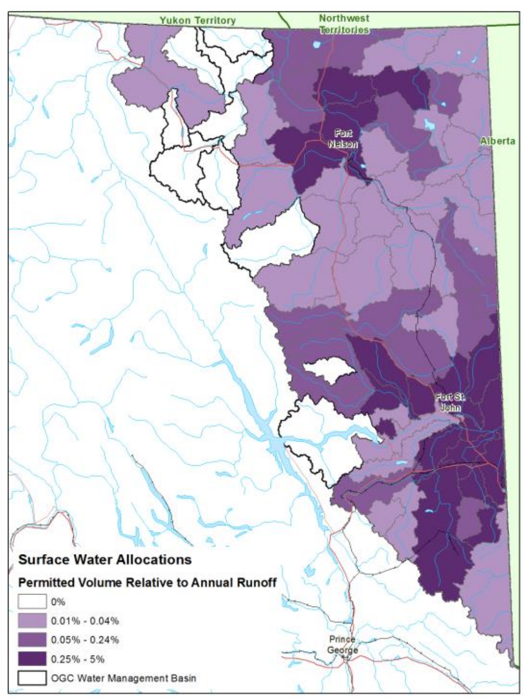
Future demand – potential surface water consumption by agriculture



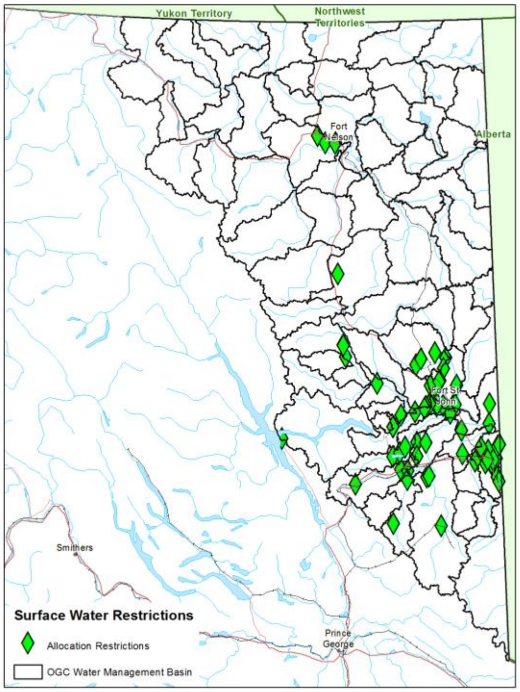


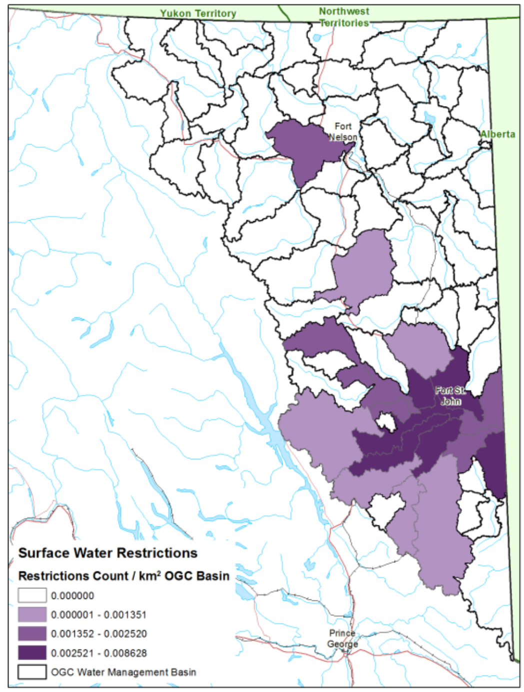
Current demand versus supply –water allocation relative to mean annual discharge surface water



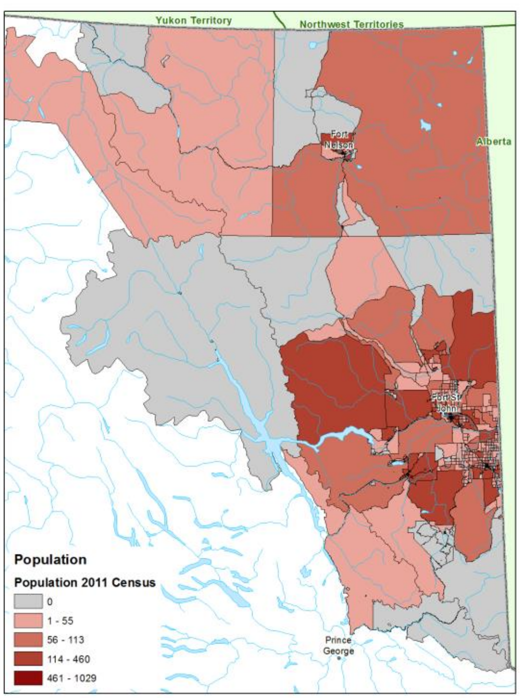


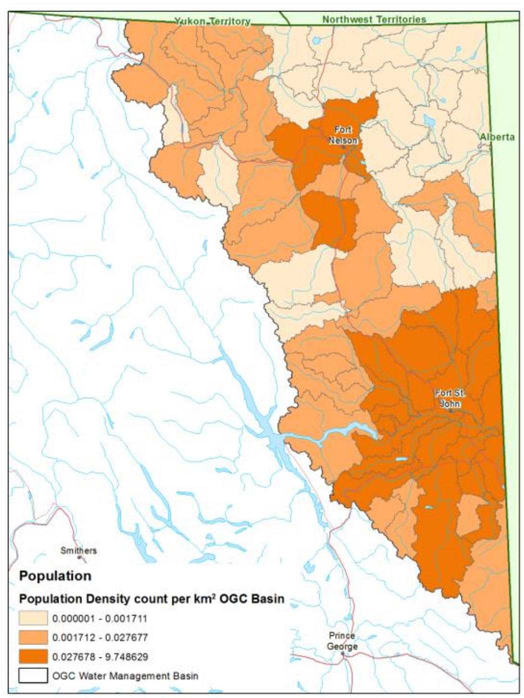
Current demand versus supply – restrictions on surface water use



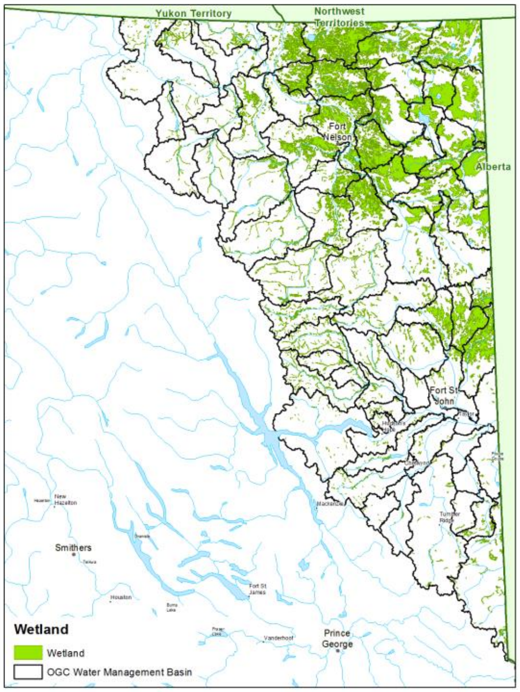


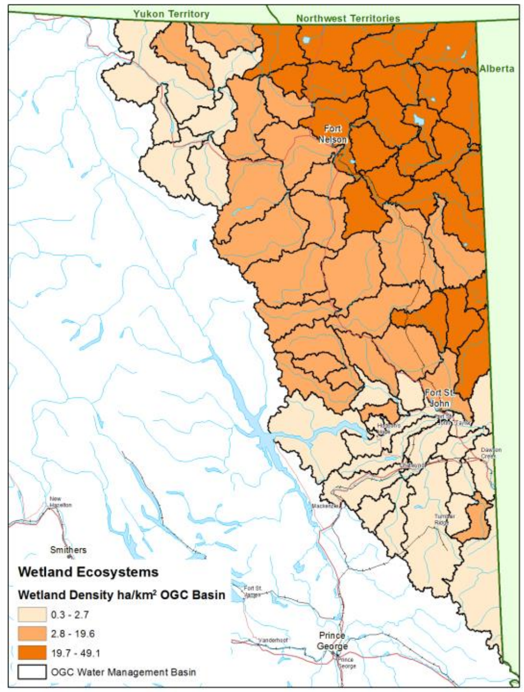
Sensitivities – rural and domestic water use - Population



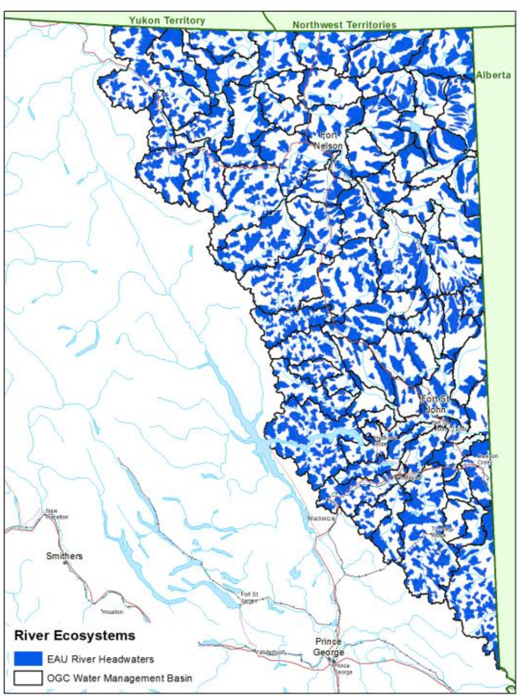


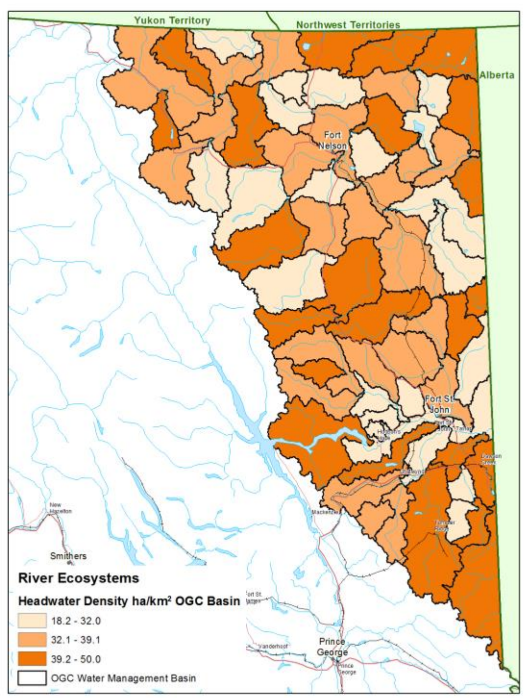
Sensitivities – aquatic ecosystem sensitivity - wetland density per watershed



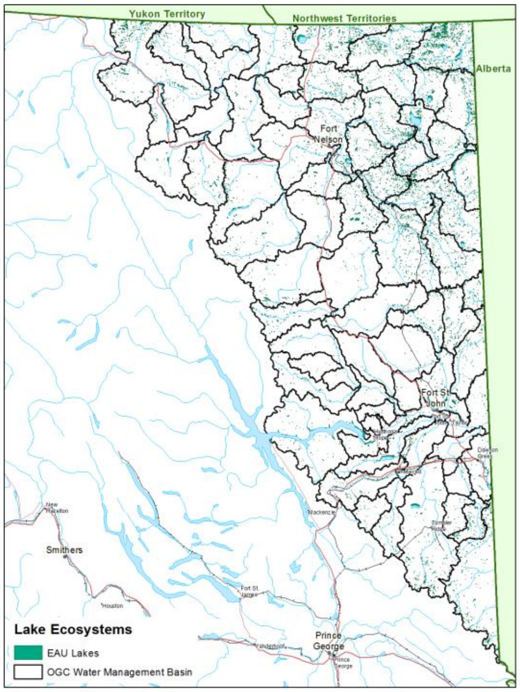


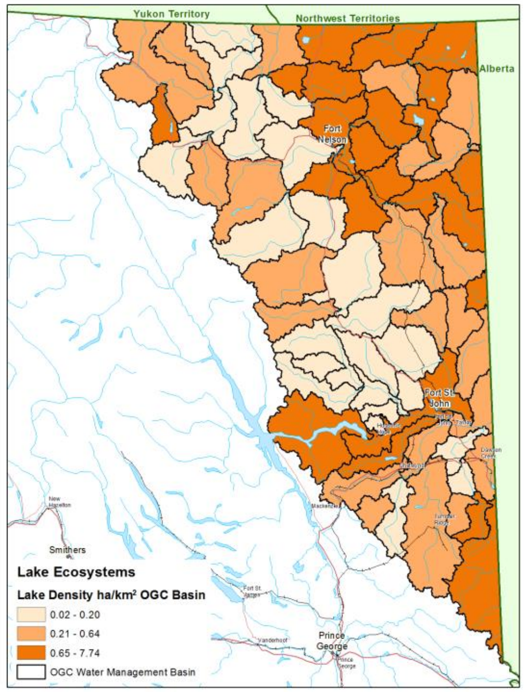
Sensitivities – aquatic ecosystem sensitivity - river headwater density per watershed





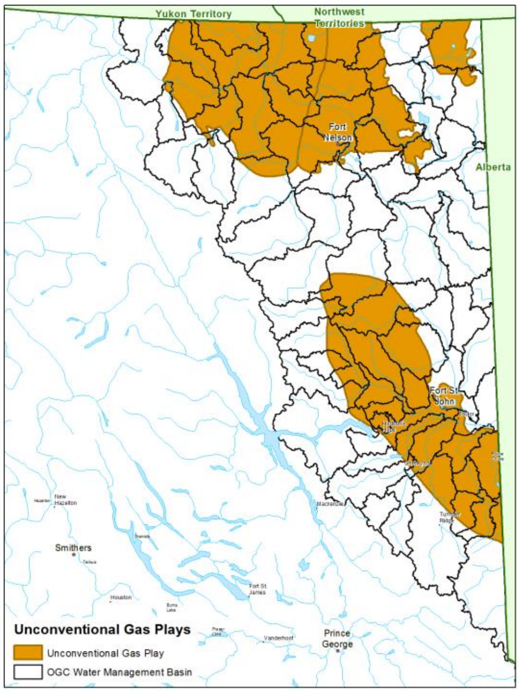
Sensitivities – aquatic ecosystem sensitivity - lake density per watershed

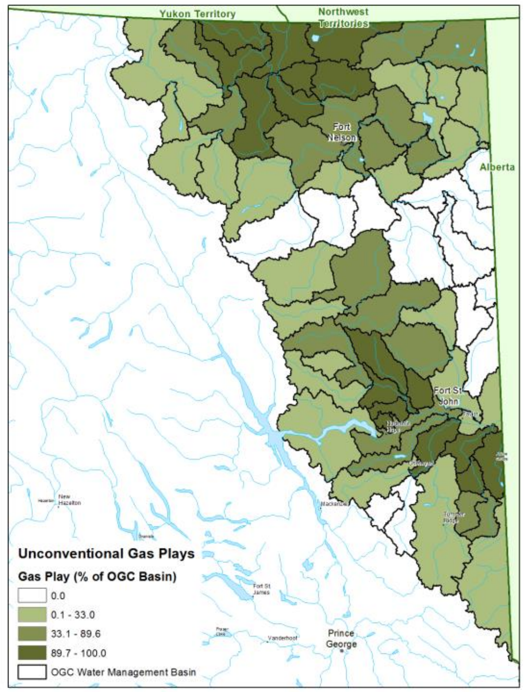




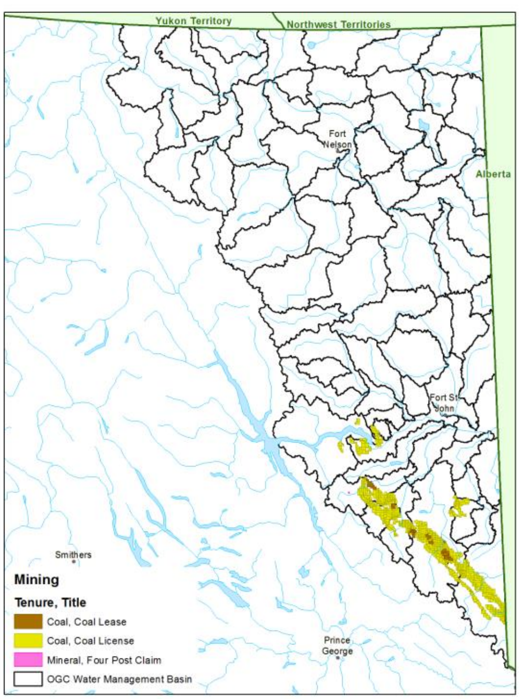
Appendix B – Data Layers for Surface Water Quality

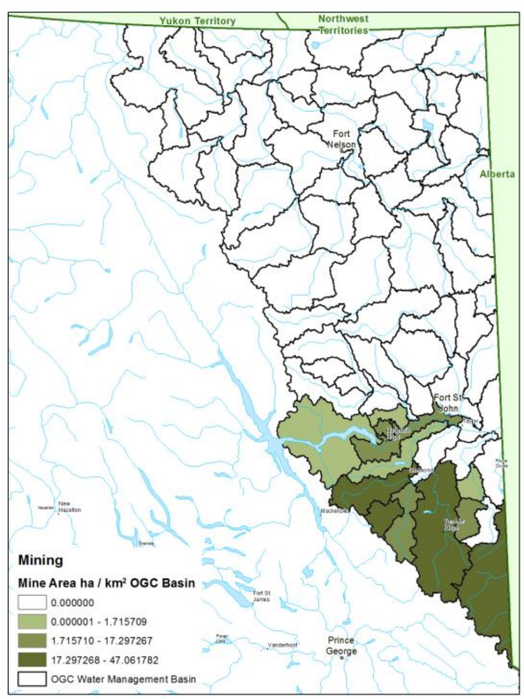
Future development – land tenure - oil and gas



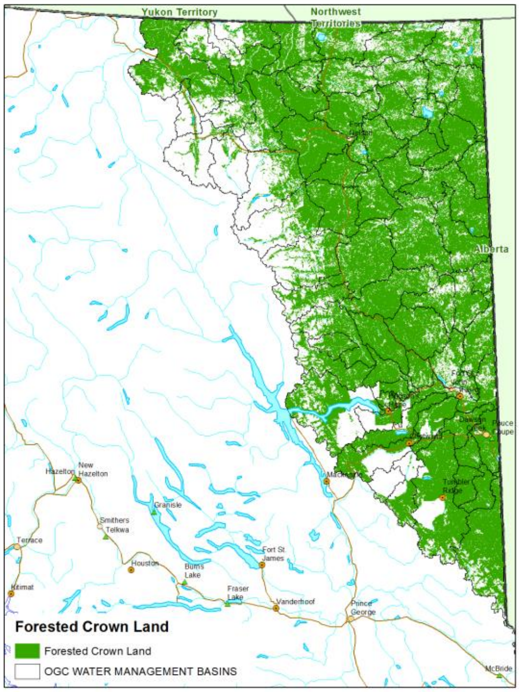


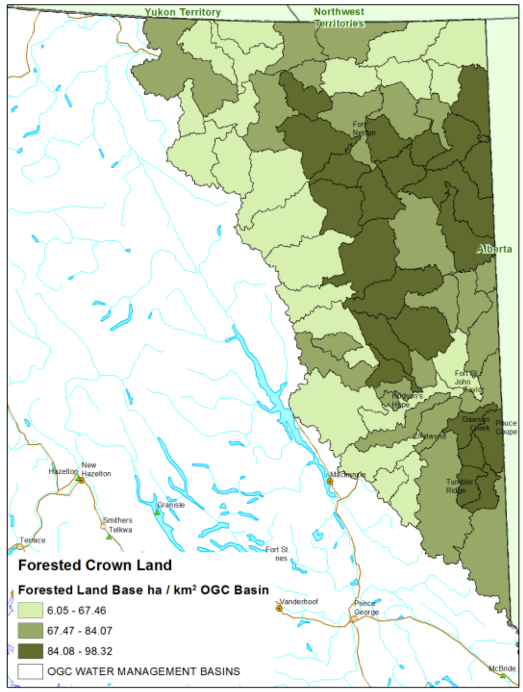
Future development – land tenure - mining



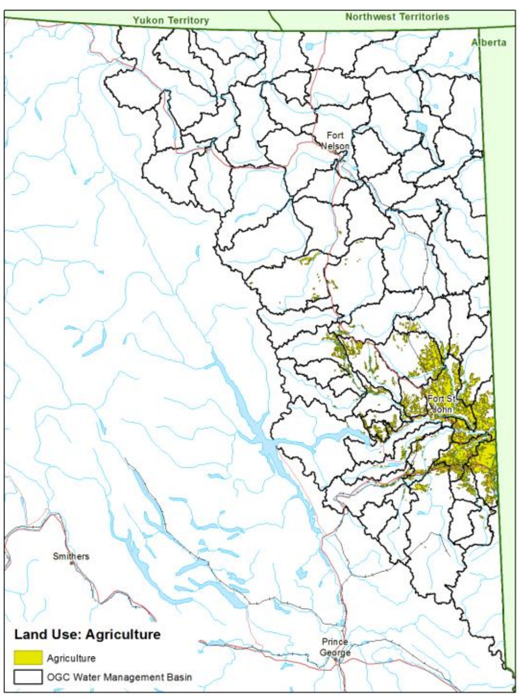


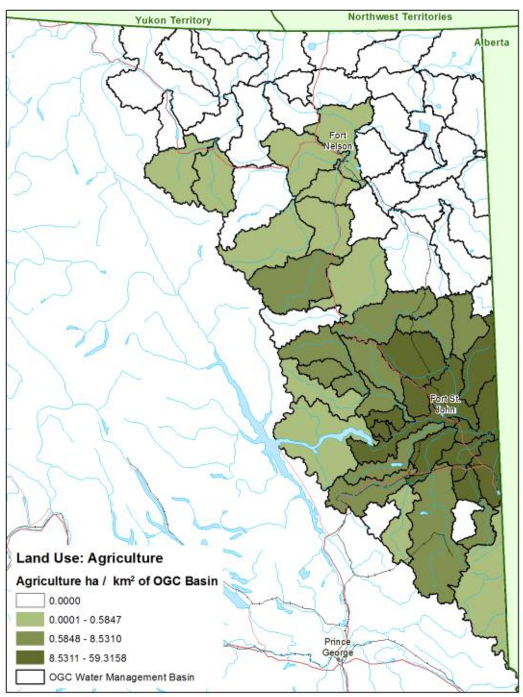
Future development – land tenure - forestry



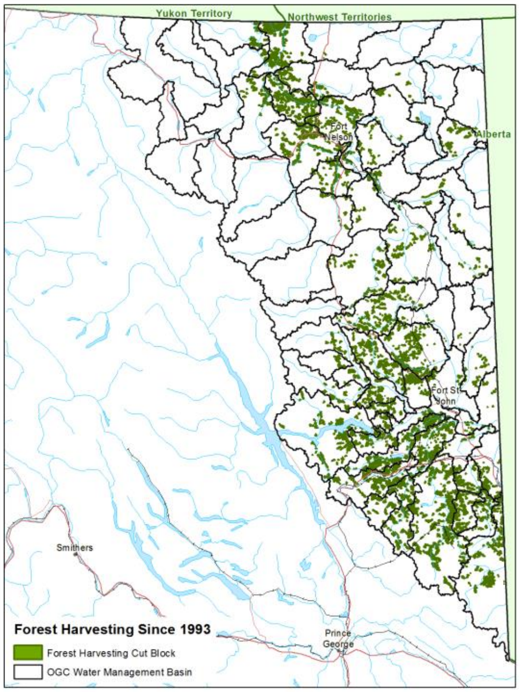


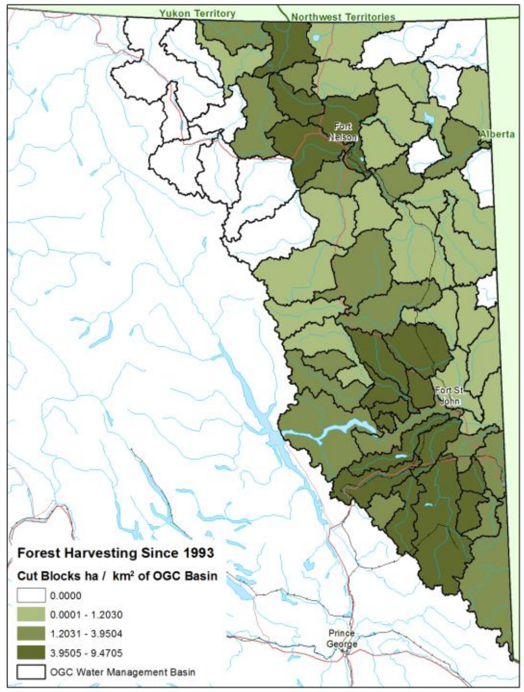
Current development – land disturbance - agriculture



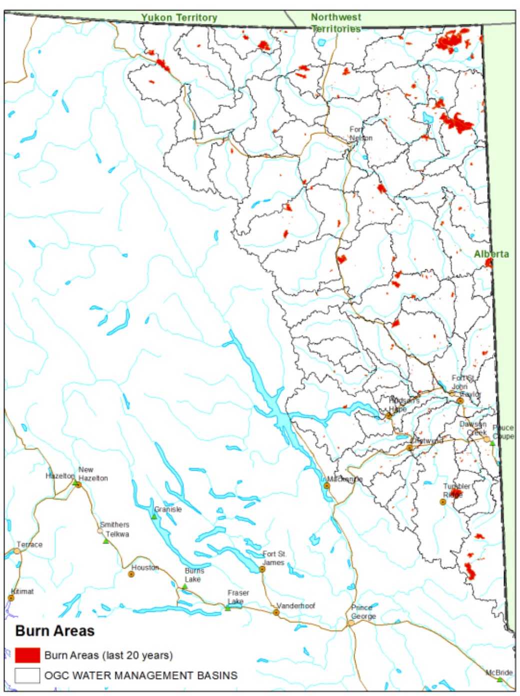


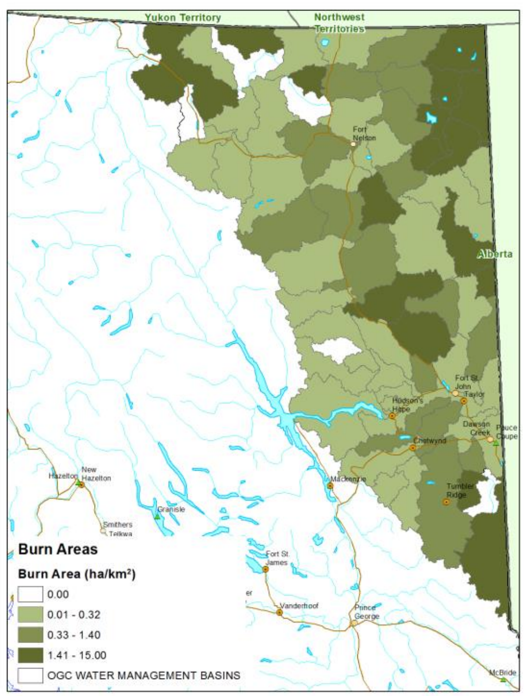
Current development – land disturbance – forestry clear cuts



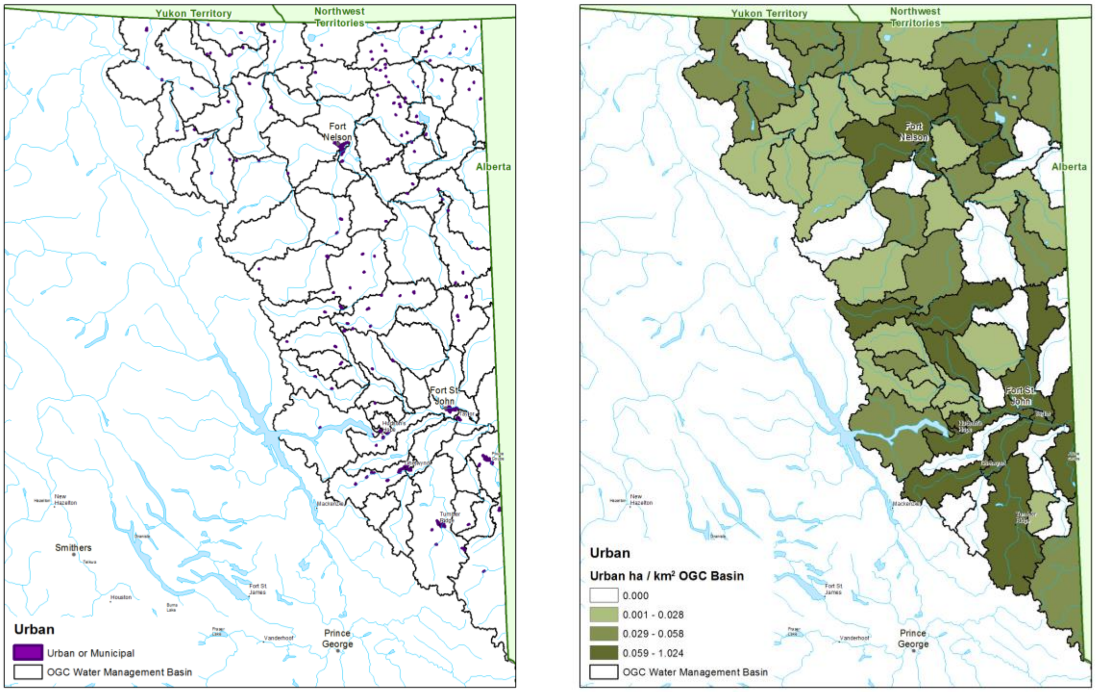


Current development – land disturbance – forestry burn areas

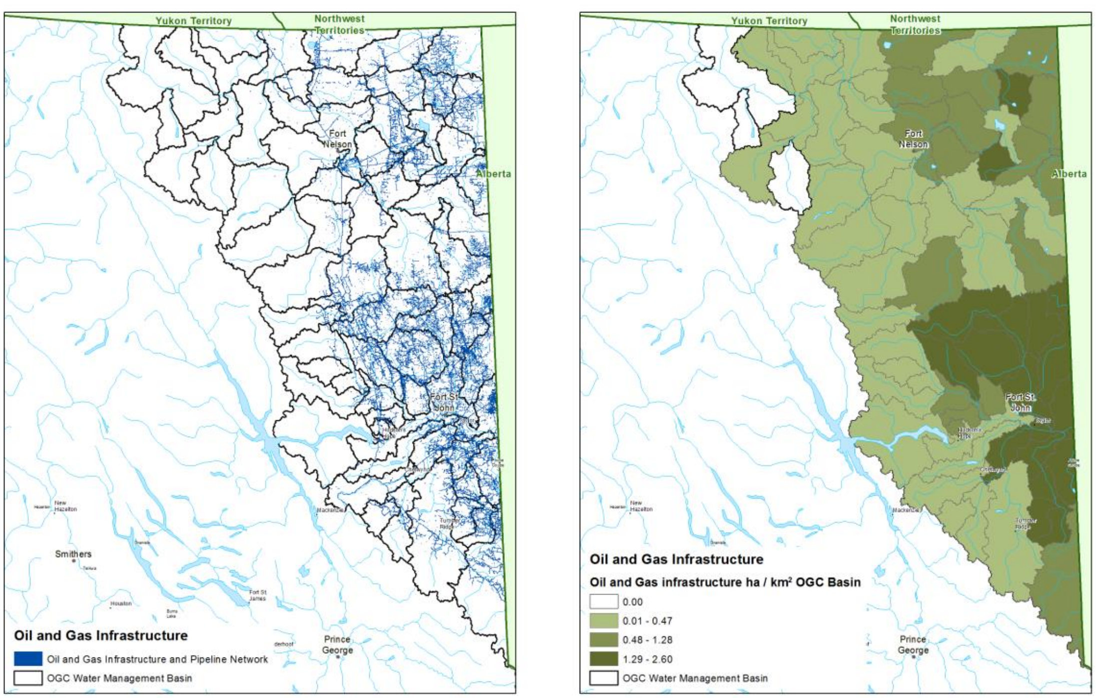




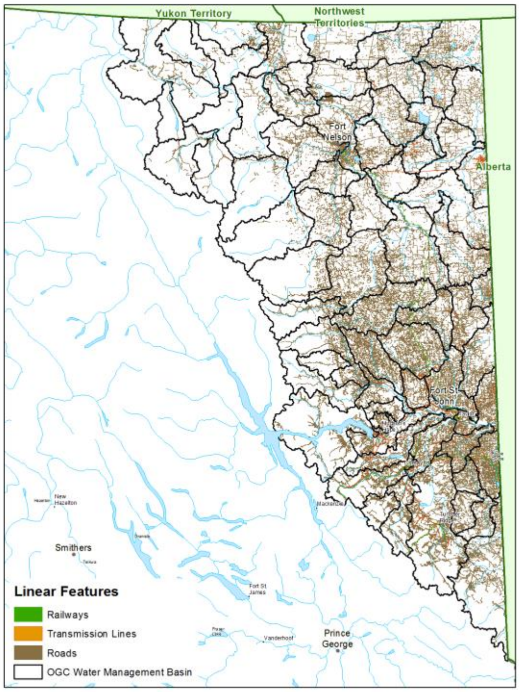
Current development – land disturbance – municipal/urban

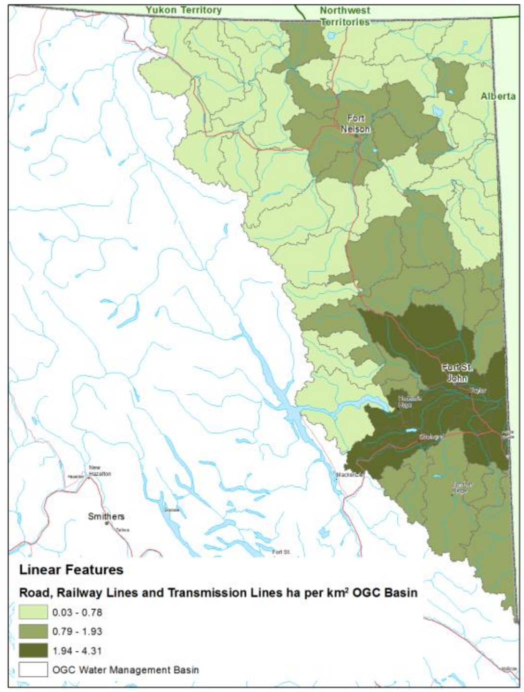


Current development – land disturbance - oil and gas infrastructure

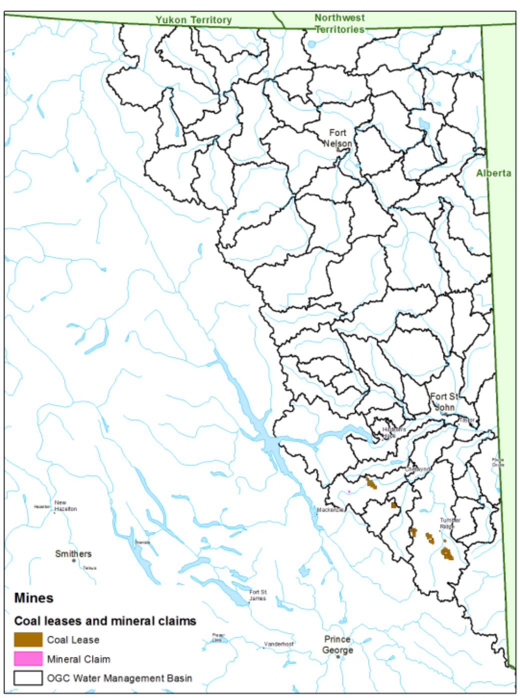


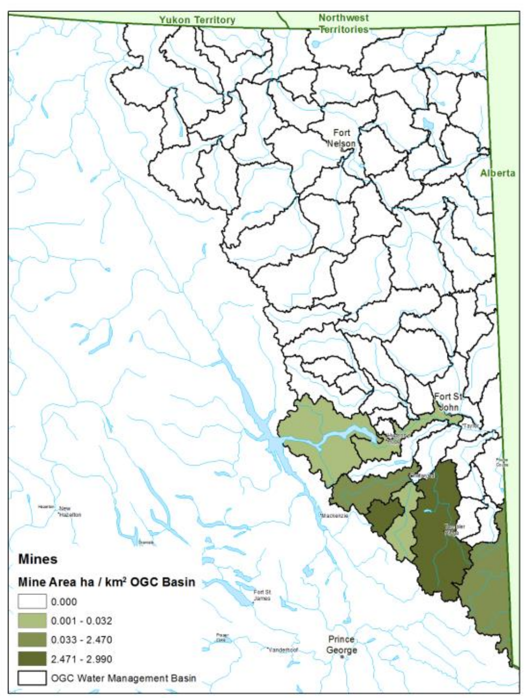
Current development – land disturbance – linear projects



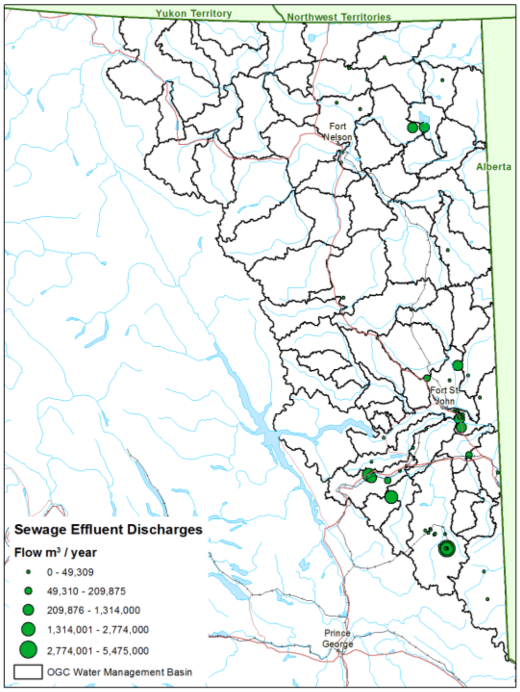


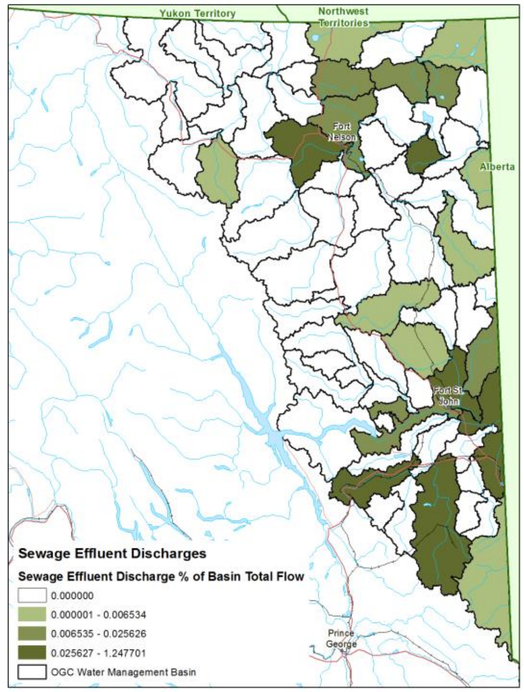
Current development – land disturbance - mining



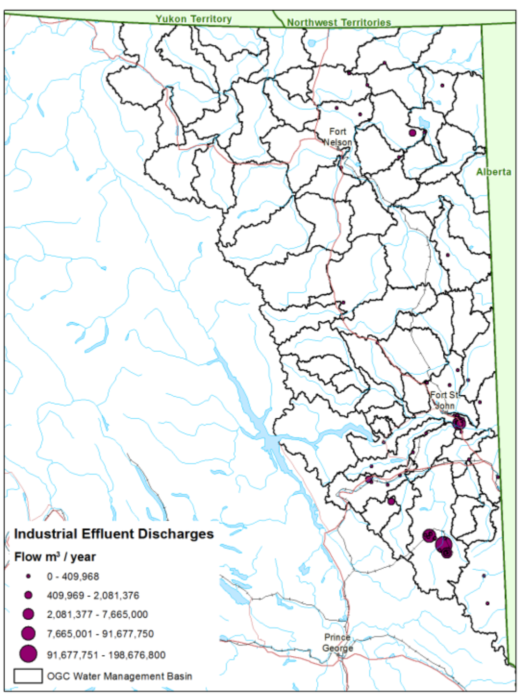


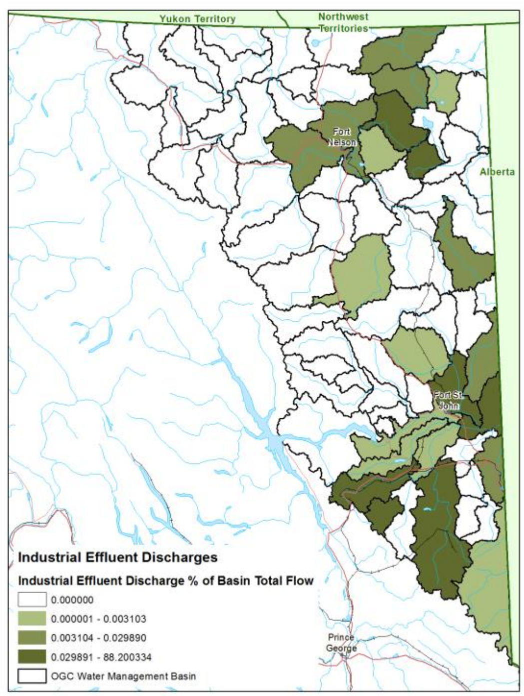
Current development – waste discharge permits - sewage



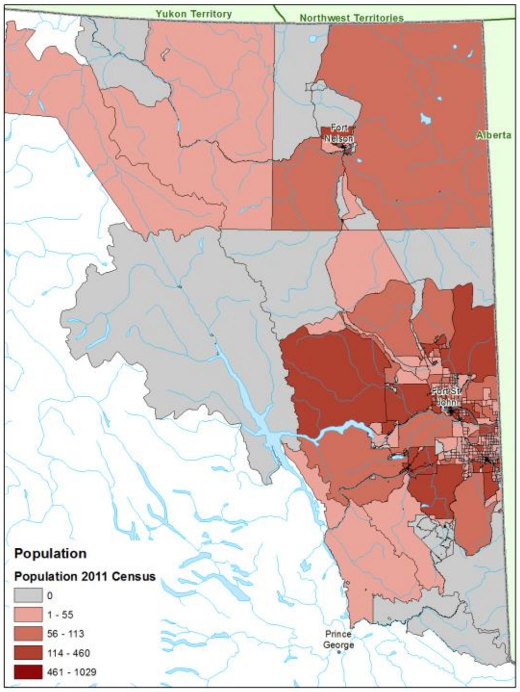


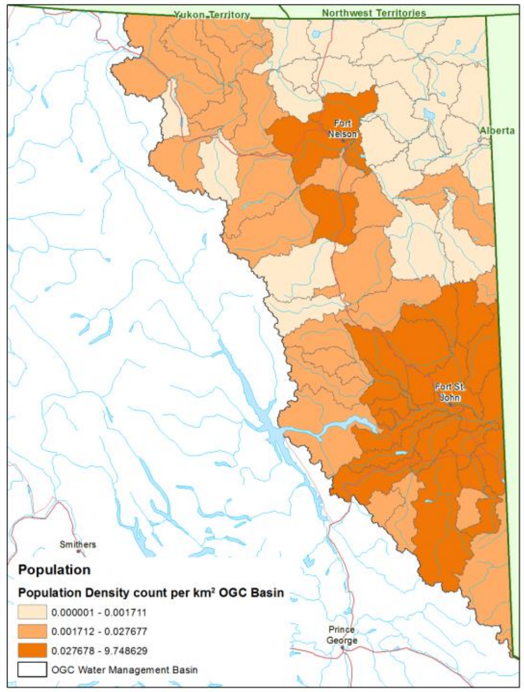
Current development – waste discharge permits – industrial



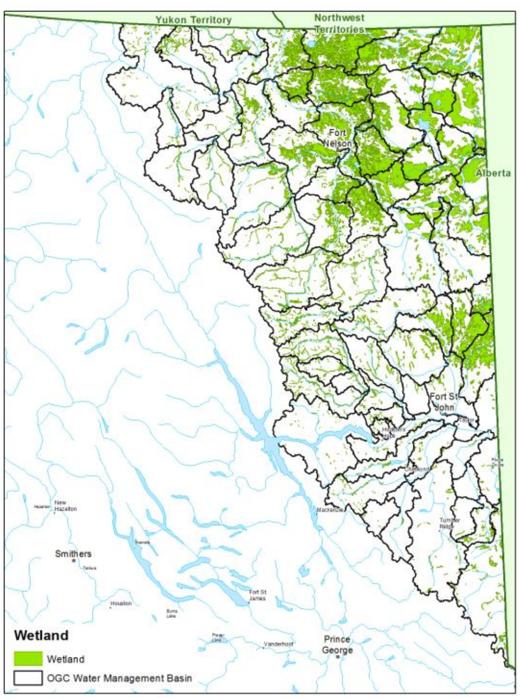


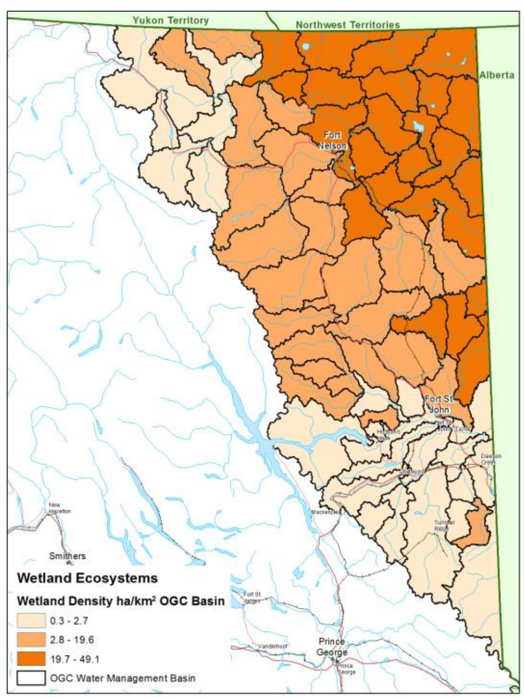
Sensitivities – rural and domestic water use - Population



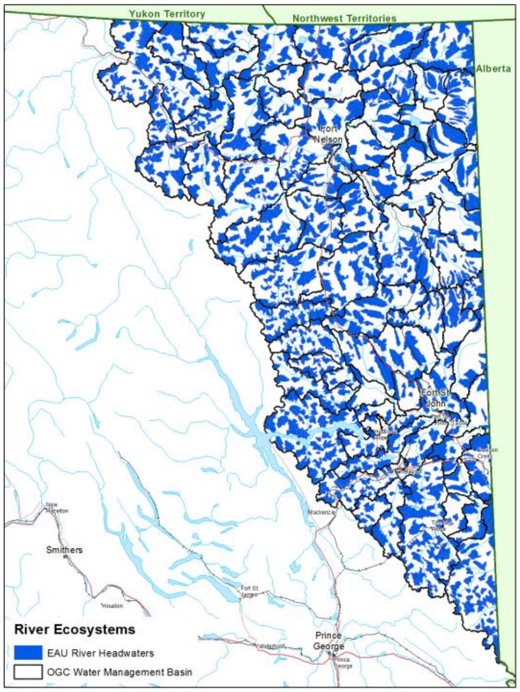


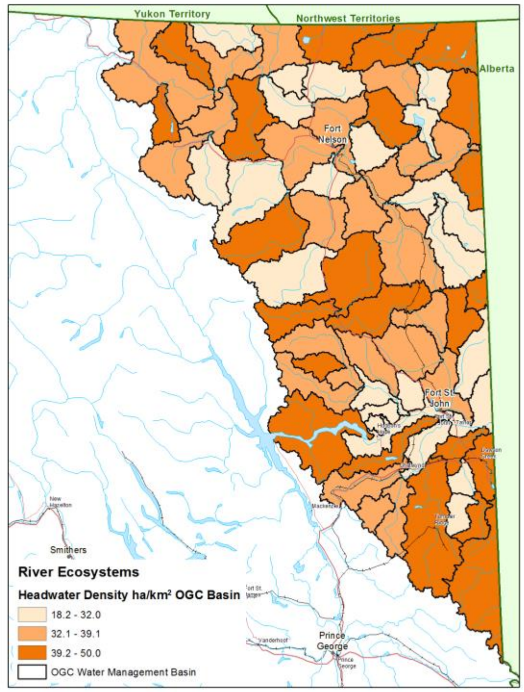
Sensitivities – aquatic ecosystem sensitivity - wetland density per watershed



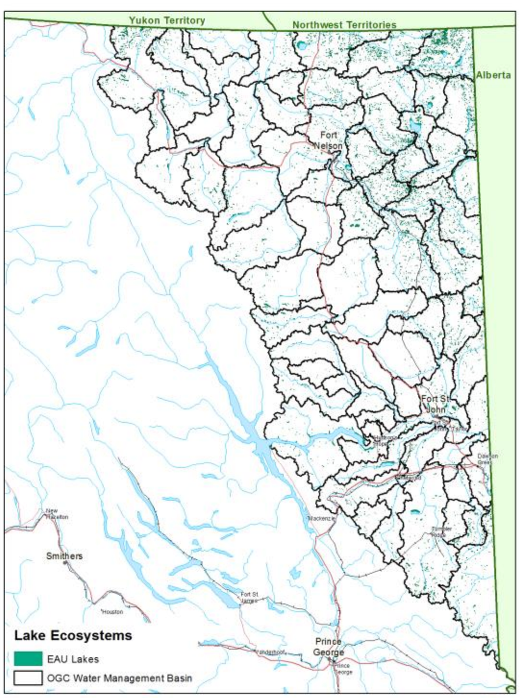


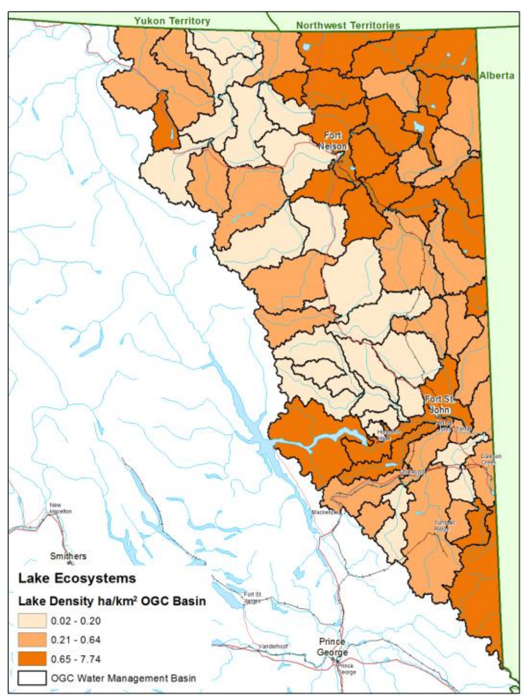
Sensitivities – aquatic ecosystem sensitivity - river headwater density per watershed





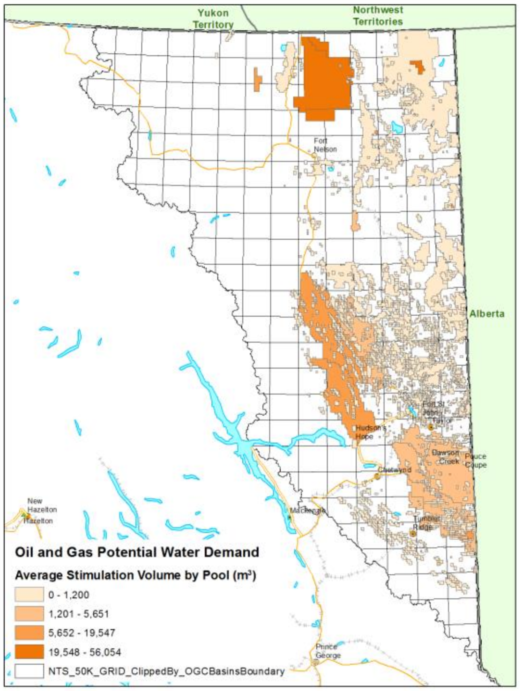
Sensitivities – aquatic ecosystem sensitivity - lake density per watershed

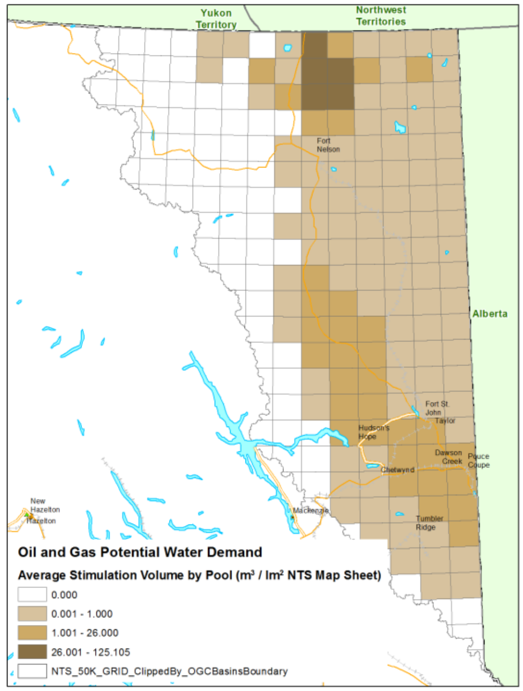




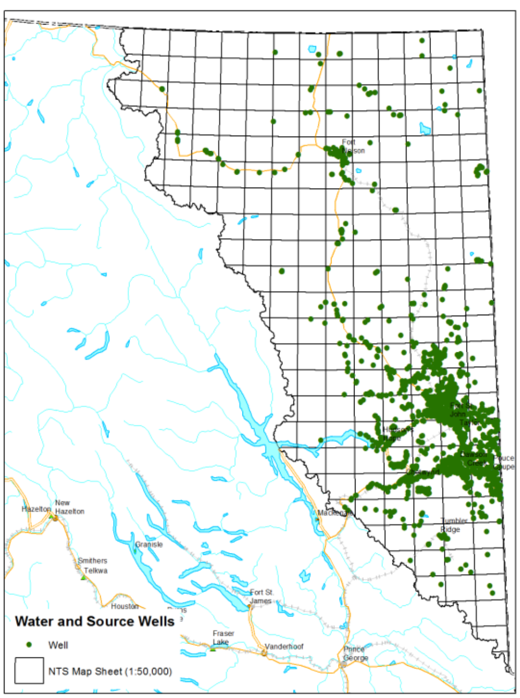
Appendix C – Data Layers for Groundwater Demand

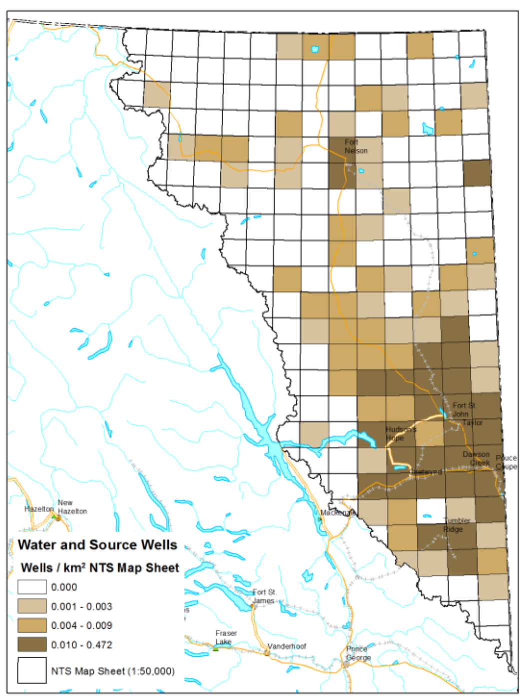
Future demand – potential water use in oil and gas



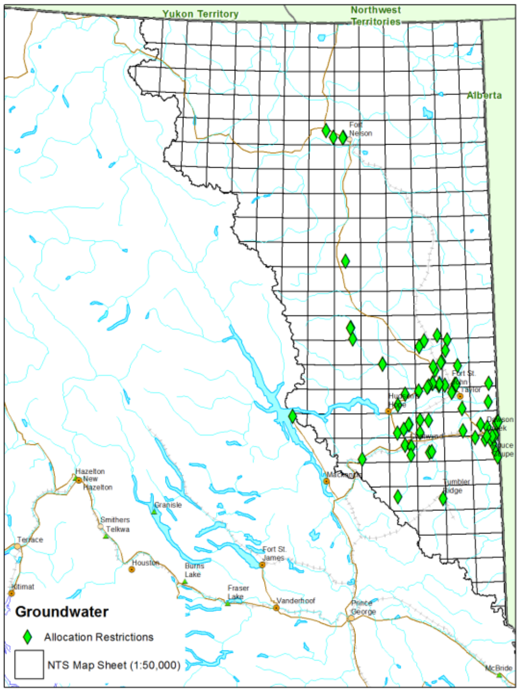


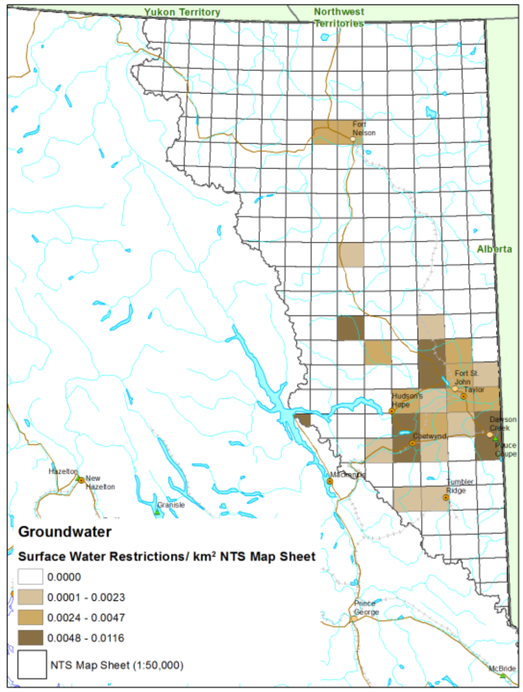
Current demand – density of water we;;s and source wells



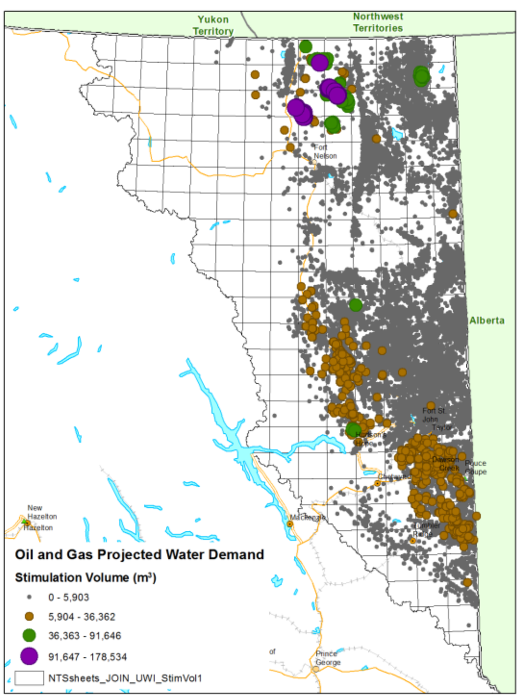


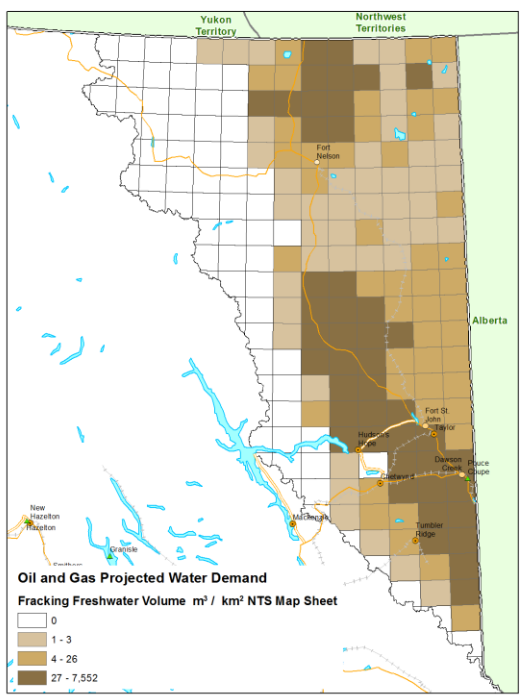
Current demand – surface water restrictions



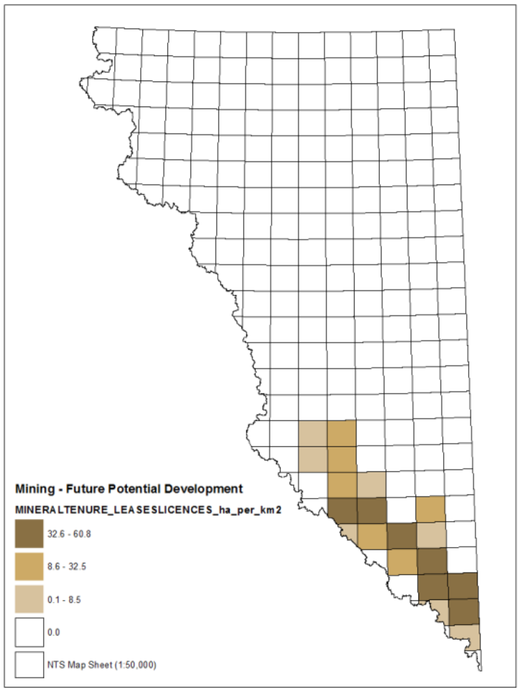


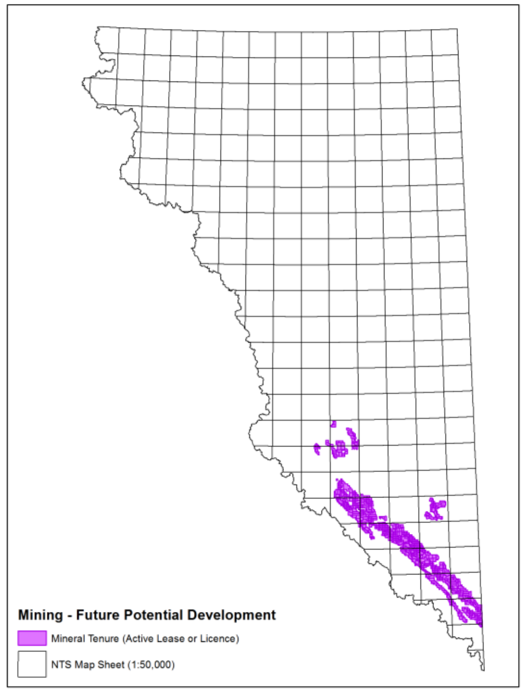
Current demand – water used for hydraulic fracturing in oil and gas



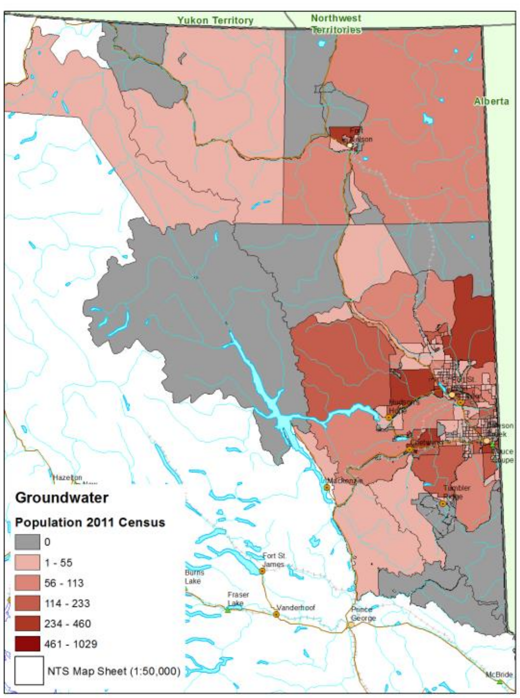


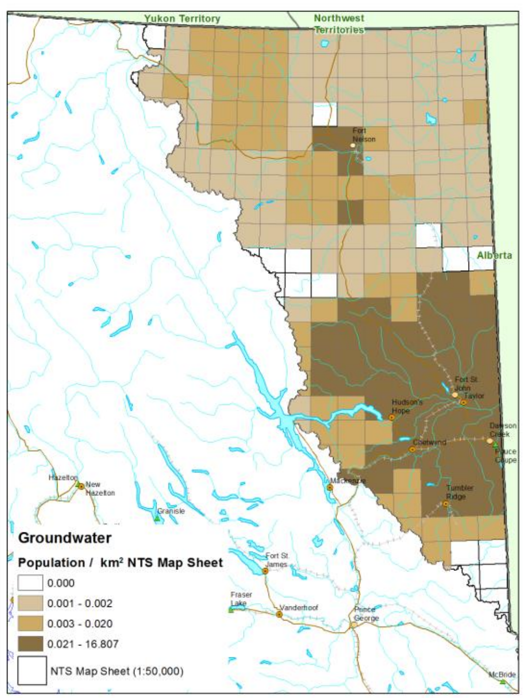
Current demand – mining tenure





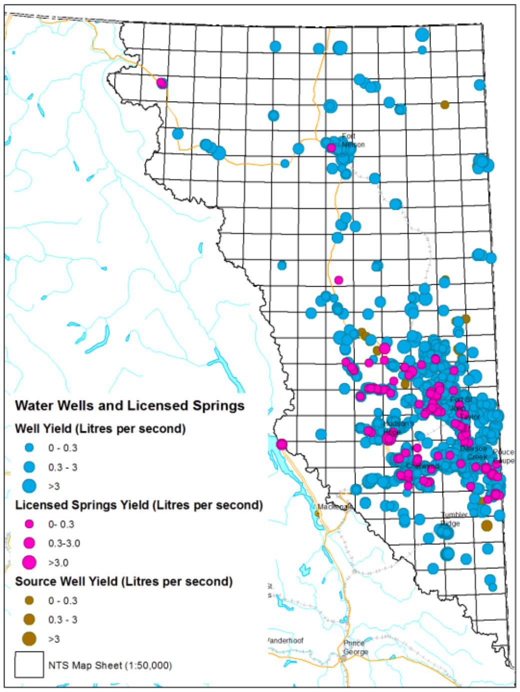
Current demand – population

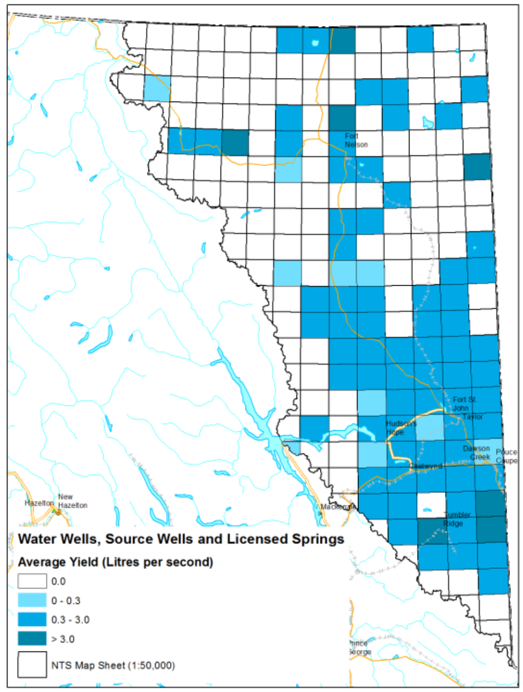




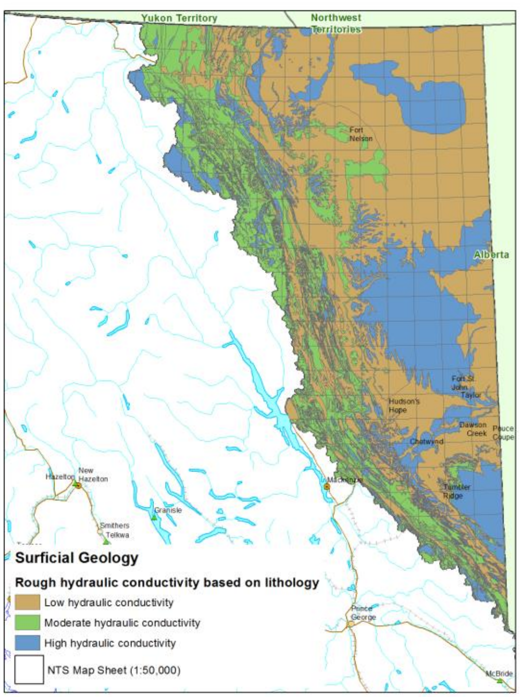
Appendix D– Data Layers for Characterization of Regional Supply

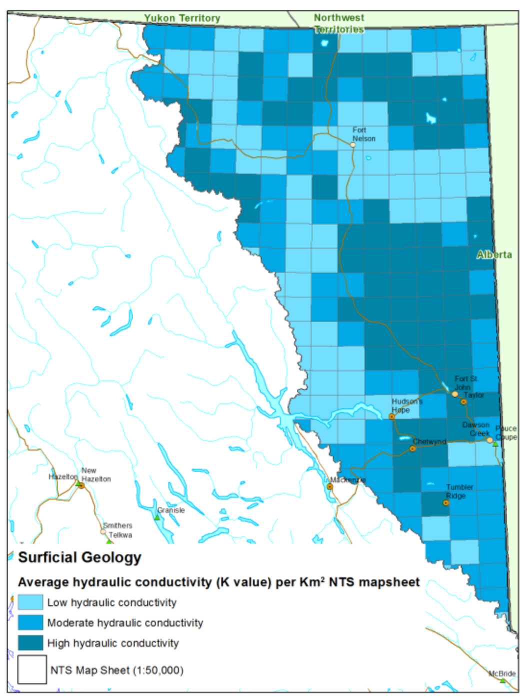
Supply – development indications – yield from water wells, source wells and springs



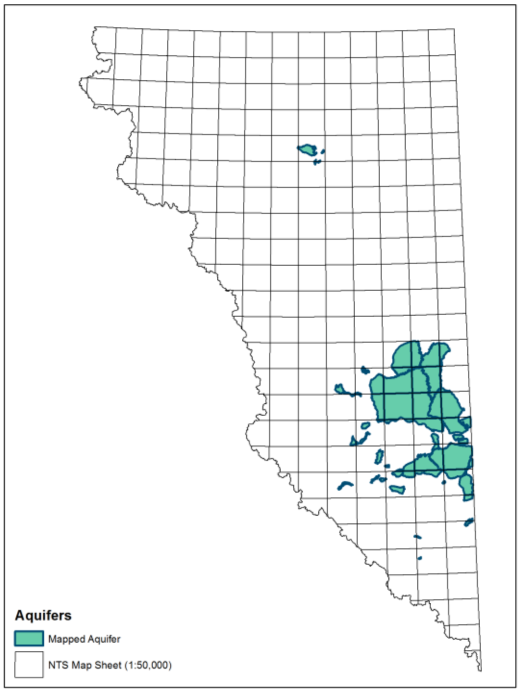


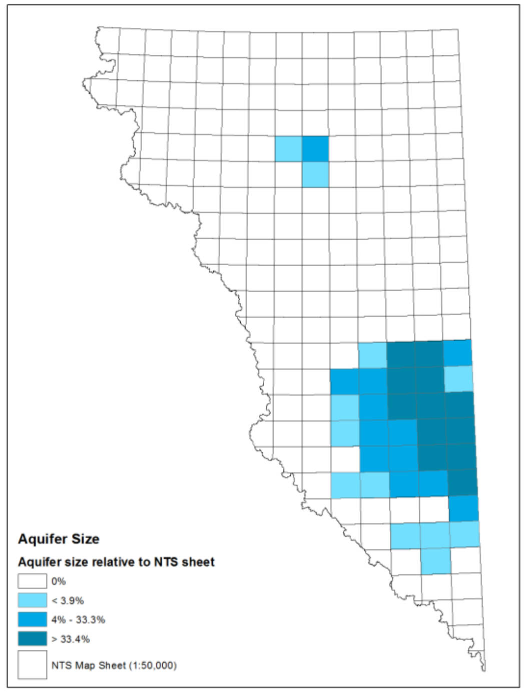
Supply – natural resource indications – surficial geology



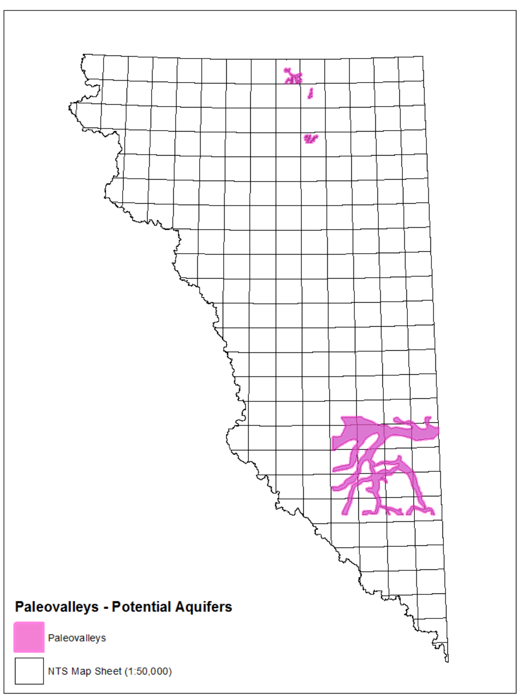


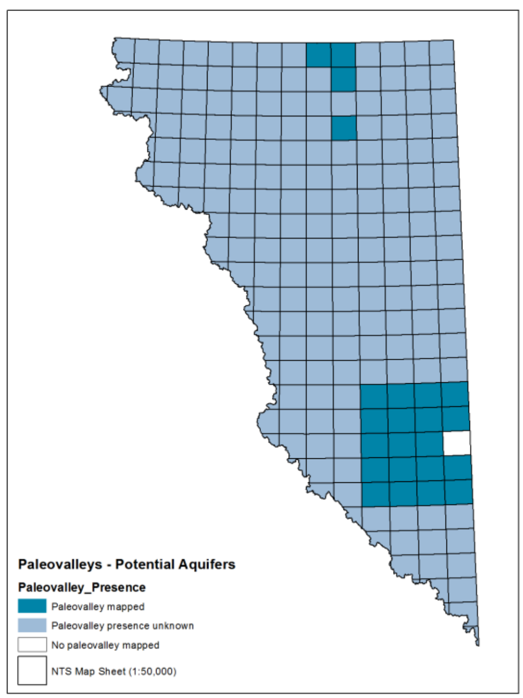
Supply – natural resource indications – aquifer size





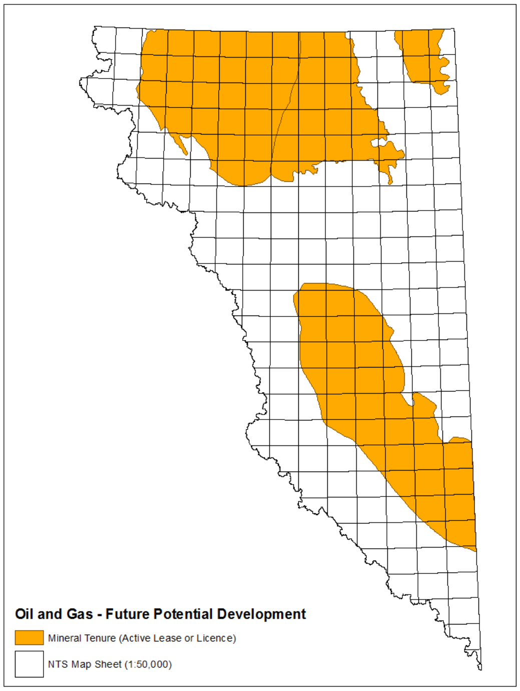
Supply – natural resource indications – paleovalleys

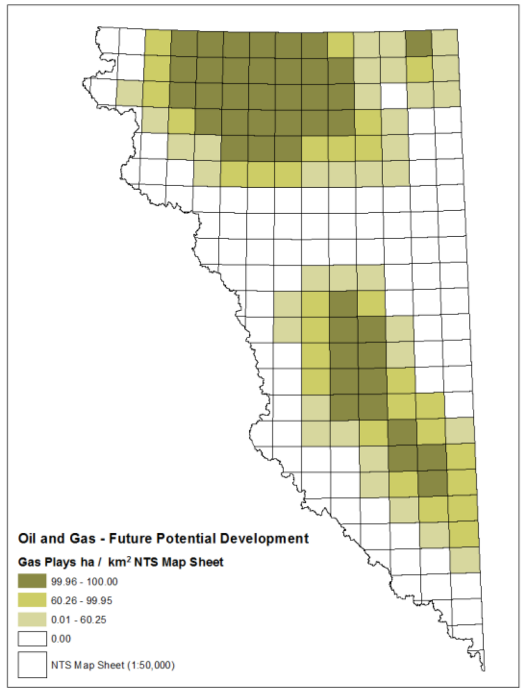




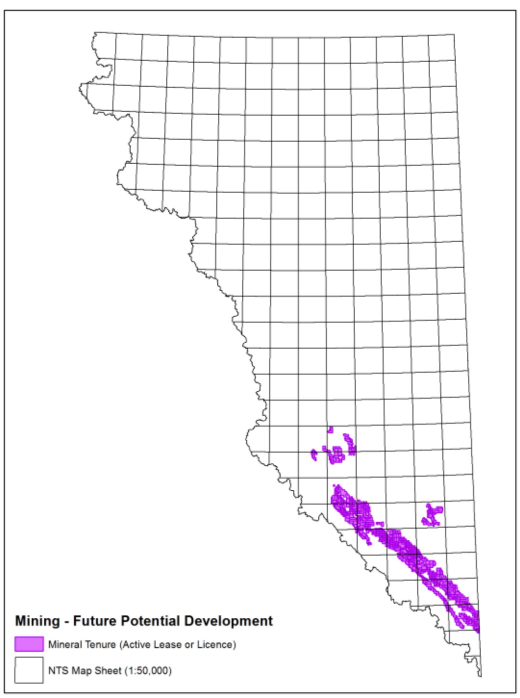
Appendix E– Data Layers for Groundwater Quality

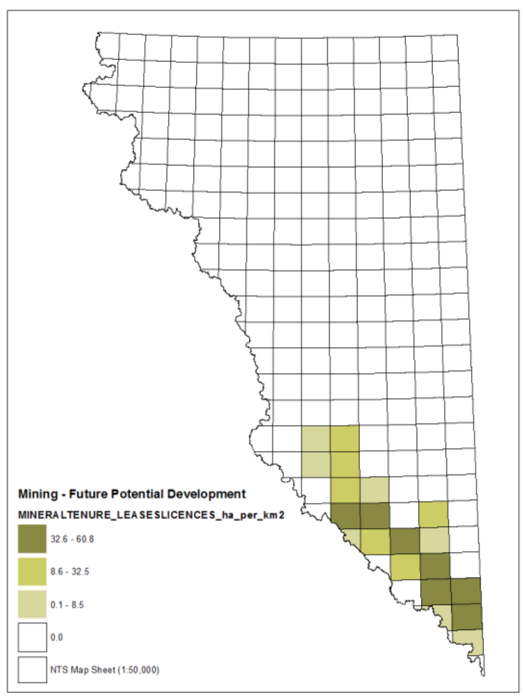
Future development – unconventional gas play



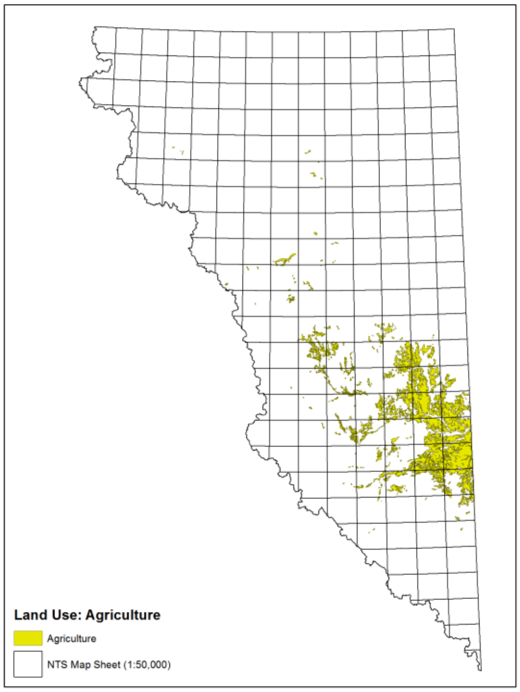


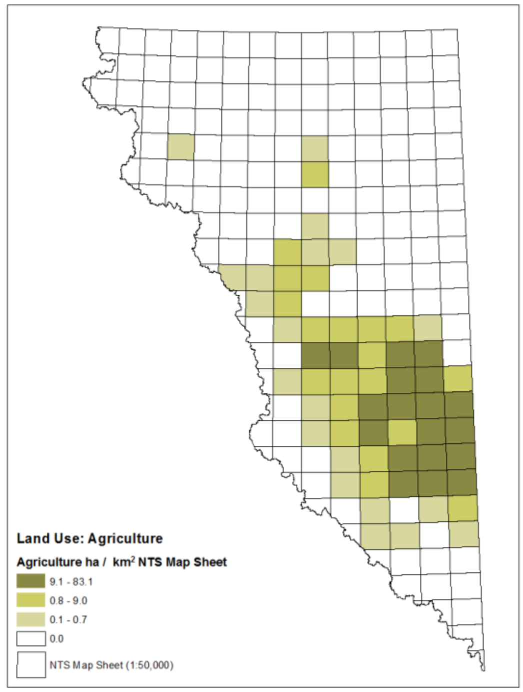
Future development – mining tenure



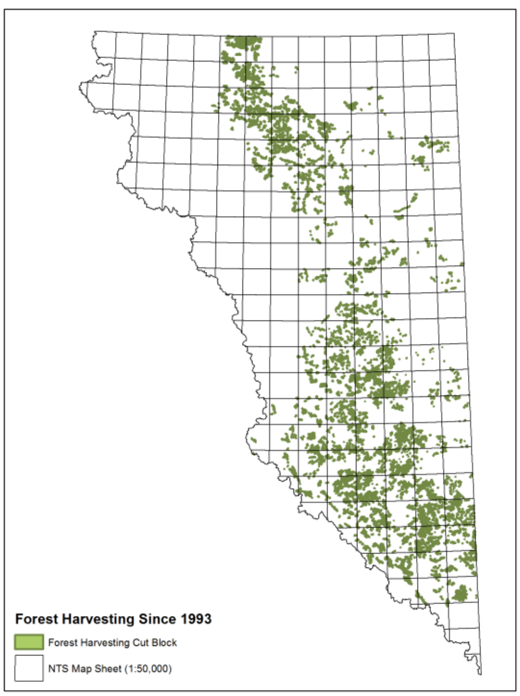


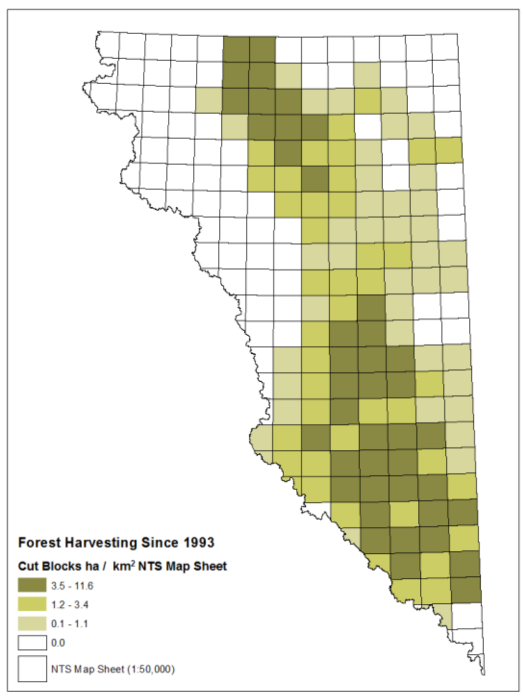
Current disturbance – agriculture



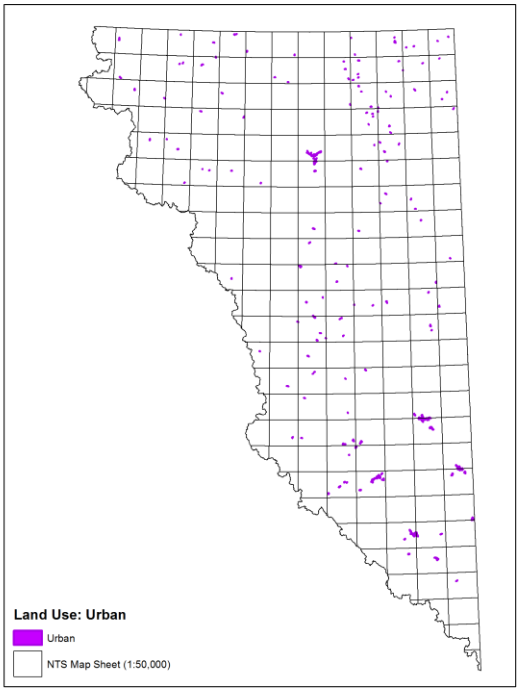


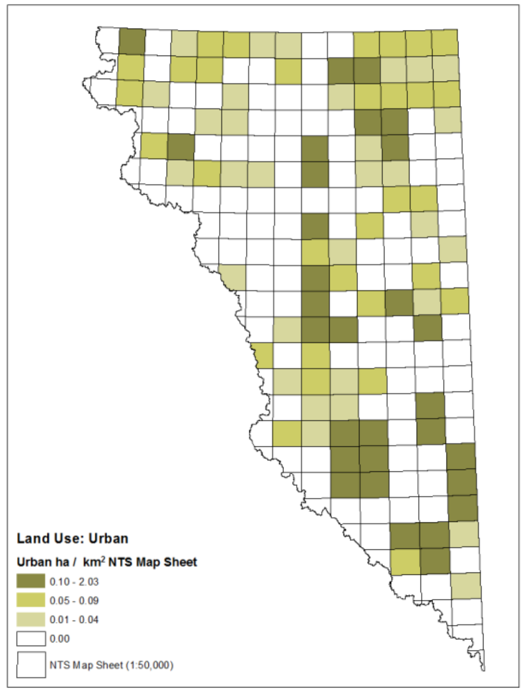
Current disturbance – forest clear cuts



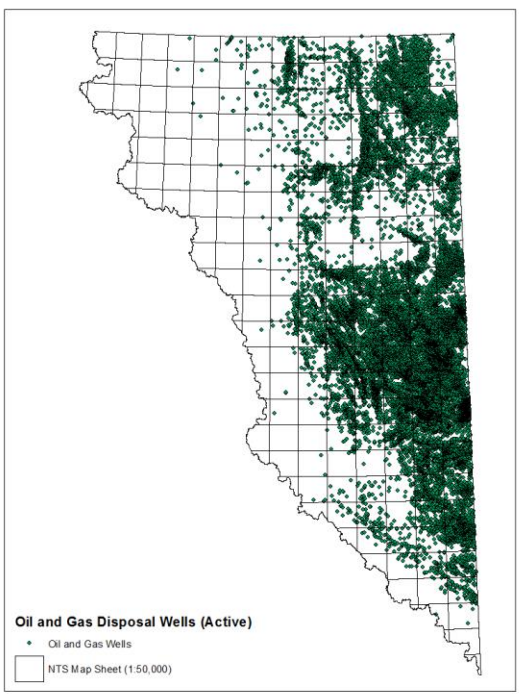


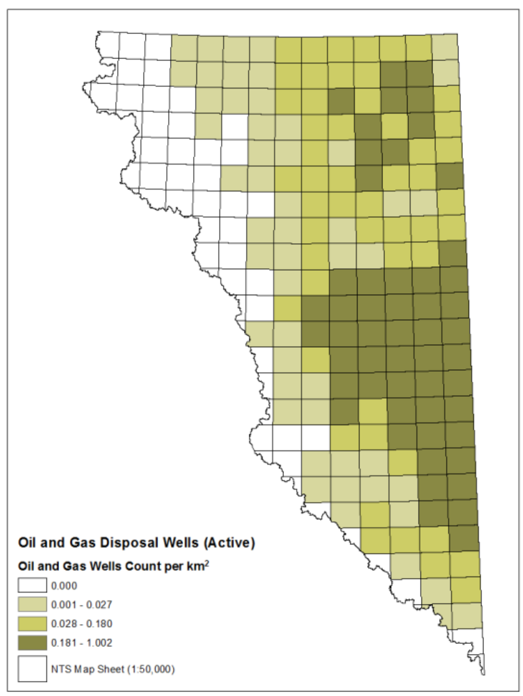
Current disturbance – urban development



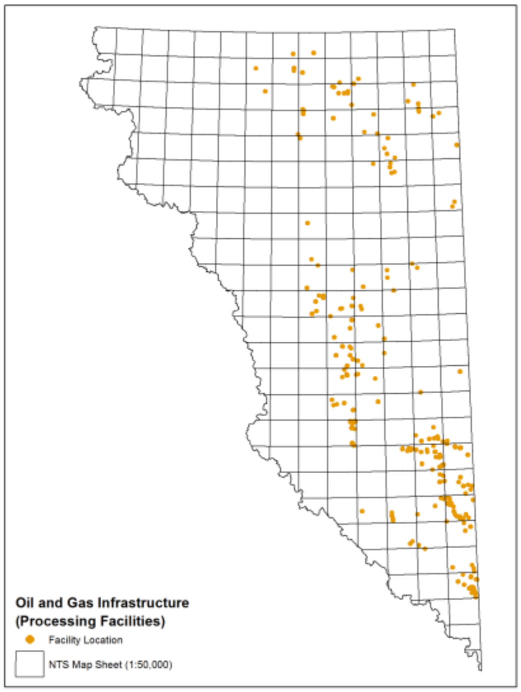


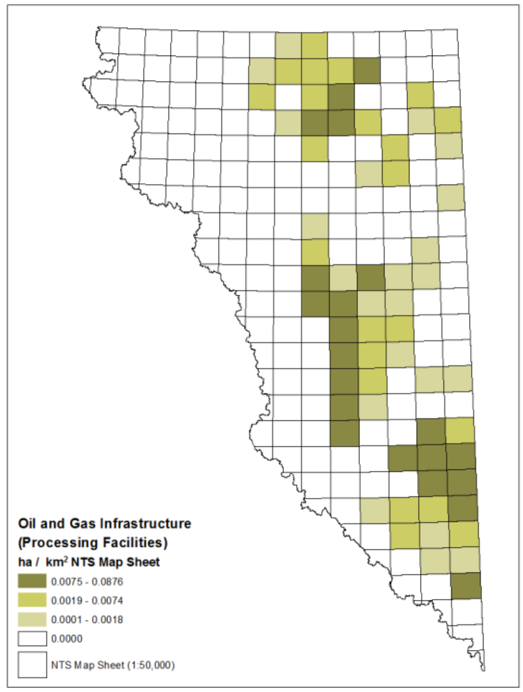
Current disturbance – oil and gas wells



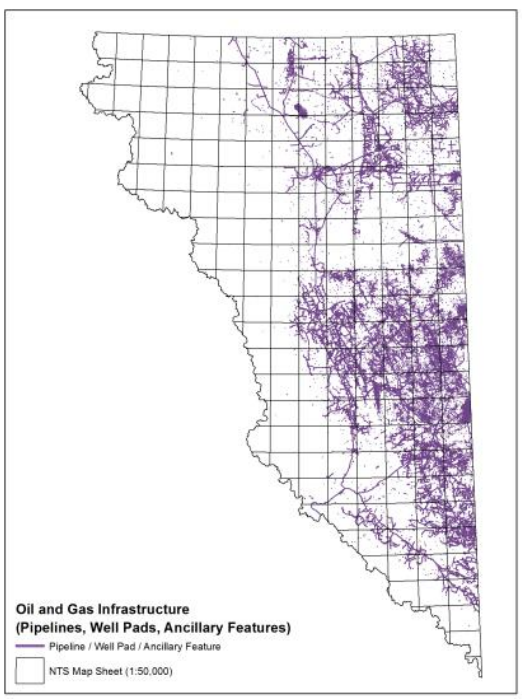


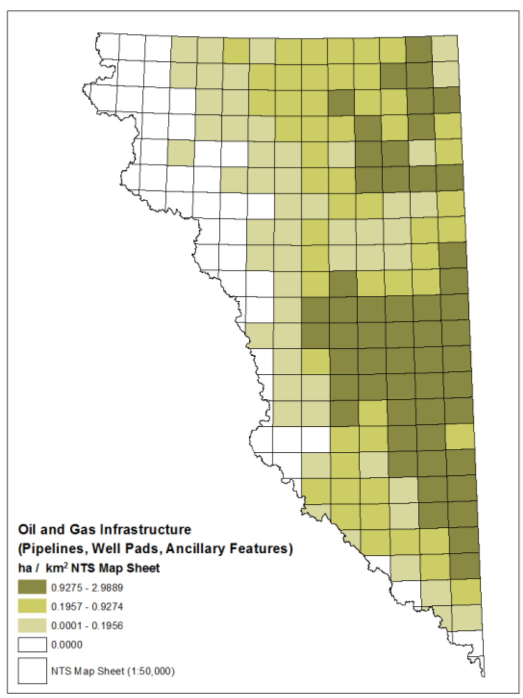
Current disturbance – oil and gas facilities



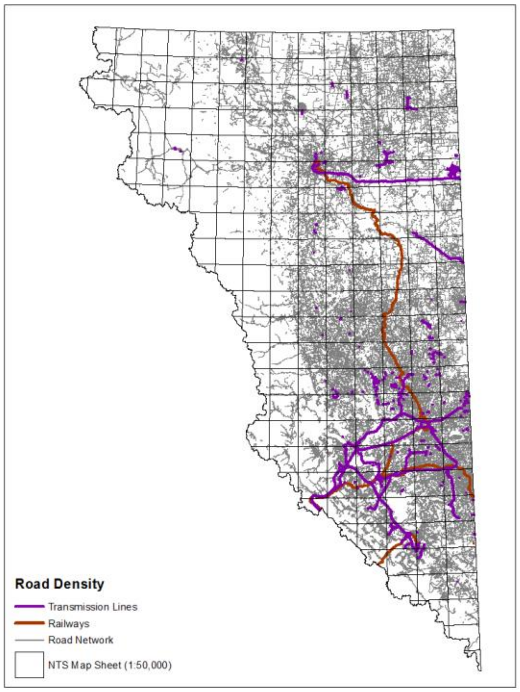


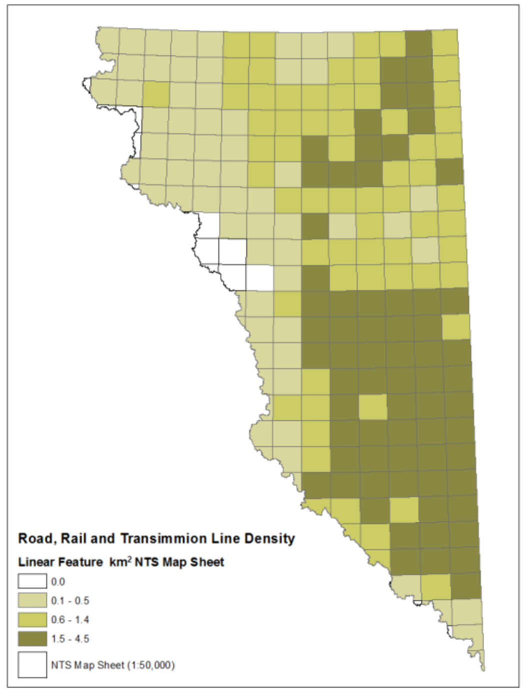
Current disturbance – oil and gas pipelines



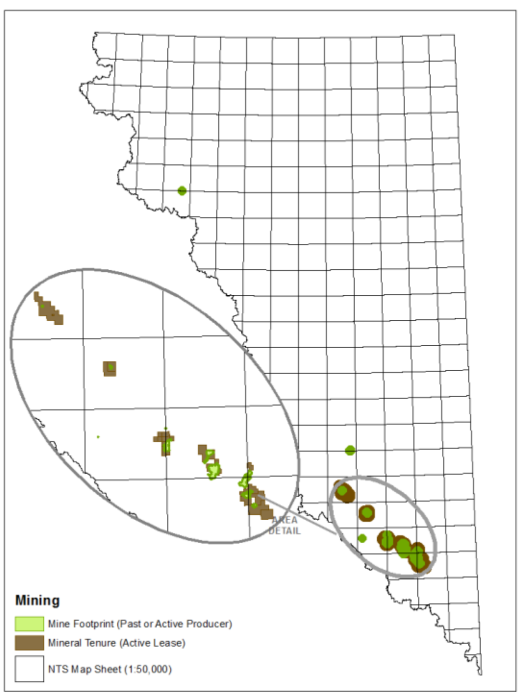


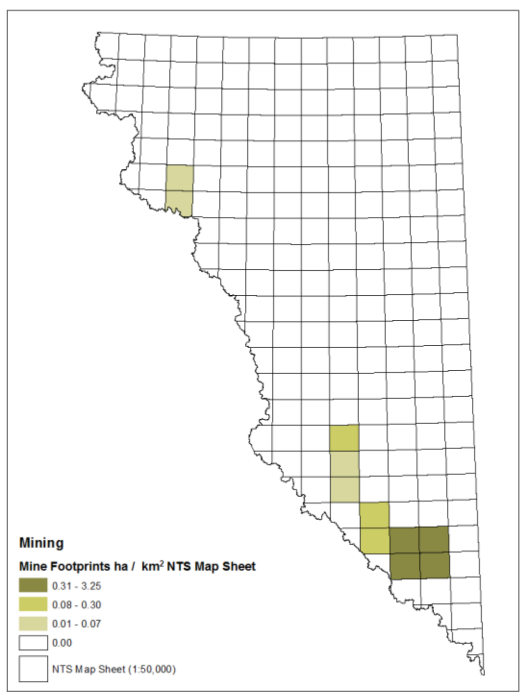
Current disturbance – transmission lines, roads, and rail lines



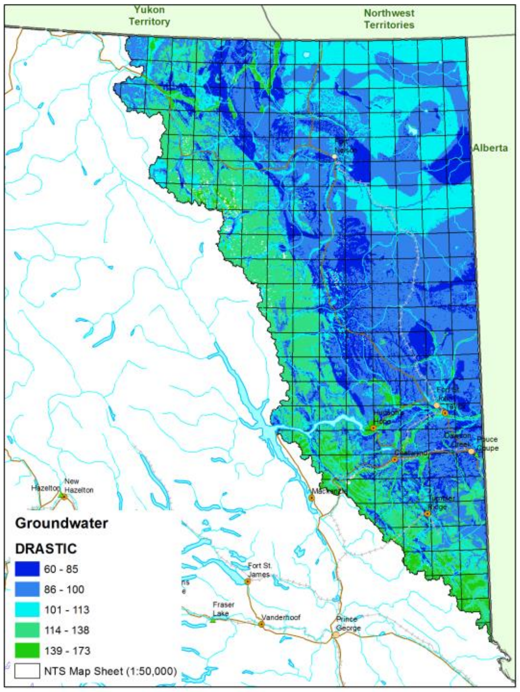


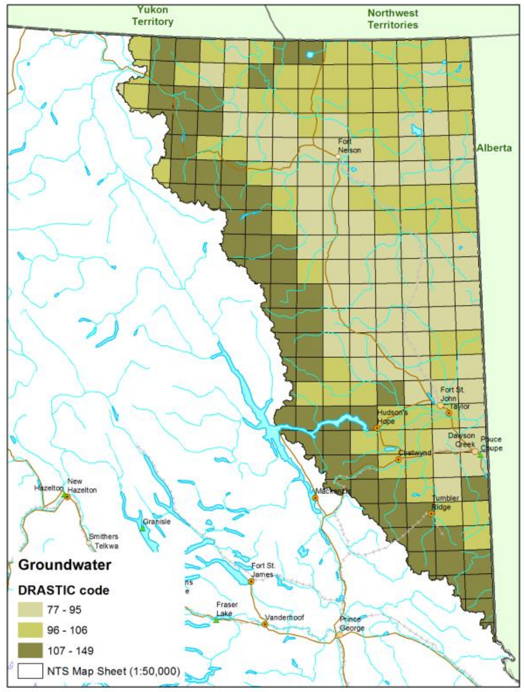
Current disturbance – active mines





Sensitivities – potential groundwater vulnerability to contamination – DRASTIC





Appendix F – Disturbance Sensitivity Results and Watershed Rankings for Surface Water Quantity

Water Management Basin	Water Quantity Disturbance and Sensitivity	Rank of Watershed by Quantity
Pouce Coupe River	2.73	1
Lower Pine River	2.63	2
Cache Creek	2.58	3
Lower Beatton River	2.54	4
Lower Kiskatinaw River	2.53	5
Murray River	2.39	6
Lower Halfway River	2.39	7
Blueberry River	2.38	8
Lower Peace River	2.36	9
East Kiskatinaw River	2.34	10
Middle Fort Nelson River	2.3	11
Lower Muskwa River	2.21	12
Lynx Creek	2.21	13
Cameron River	2.19	14
Middle Kiskatinaw River	2.12	15
Doig River	2.04	16
Upper Peace River	1.94	17
Moberly River	1.92	18
Kiwigana River	1.91	19.5
Tsea River	1.91	19.5
Upper Halfway	1.87	21
Upper Pine River	1.87	22
Farrell Creek	1.82	23
Milligan Creek	1.75	24
Upper Beatton River	1.74	25
Middle Sikanni Chief River	1.73	26
Capot-Blanc River	1.71	27
Chinchaga River	1.69	28
Sahdoanah River	1.67	29
Lower Petitot River	1.66	30.5
Sahtaneh River	1.66	30.5
West Kiskatinaw River	1.64	32
Hay River	1.54	33

Graham River	1.53	34
Fontas River	1.47	35.5
Middle Beatton River	1.47	35.5
Kyklo River	1.44	38
Lower Liard River	1.44	38
Upper Sikanni Chief River	1.44	38
Smoky River	1.36	40
Snake River	1.32	41
Middle Petitot River	1.31	42
Dunedin River	1.3	43
Klua River	1.29	44
Sukunka River	1.24	45
Kahntah River	1.22	46
Middle Prophet River	1.21	47
Upper Petitot River	1.19	48
Burnt River	1.14	49.5
Upper Fort Nelson River	1.14	49.5
Lower Prophet River	1.11	51
Upper Prophet River	1.07	52
Lower Fort Nelson River	1.05	53
Shekilie River	1.02	54
Upper Kotcho River	0.97	55
Lower Kotcho River	0.97	56
Lower Sikanni Chief River	0.92	57
Middle Muskwa River	0.9	58
Chowade River	0.87	59
Peace Arm	0.73	60
Grayling River	0.65	61
Upper Muskwa River	0.64	62
Beaver River	0.62	63
Middle Liard River	0.62	64
Upper Liard River	0.55	65
Upper Toad River	0.54	66
Muncho River	0.5	67
Lower Toad River	0.5	68
Racing River	0.39	69

Appendix G – Disturbance Sensitivity Results and Watershed Rankings for Surface Water Quality

Water Management Basin	Water Quality Disturbance and Sensitivity	Rank of Watershed by Vulnerability
Murray River	2.3875	1
Pouce Coupe River	2.3225	2
Upper Peace River	2.285	3
Upper Pine River	2.135	4
Middle Fort Nelson River	2.1325	5
Blueberry River	2.0925	6
Farrell Creek	2	7
Lower Beatton River	1.9875	8
Lower Pine River	1.9575	9
Lower Peace River	1.9475	10
Cameron River	1.8725	11
Lynx Creek	1.83	12
Lower Muskwa River	1.8225	13
Moberly River	1.815	14
Smoky River	1.8	15
Kyklo River	1.73	16
Doig River	1.7175	17
Middle Kiskatinaw River	1.715	18
Upper Beatton River	1.68	19
East Kiskatinaw River	1.655	20
Lower Kiskatinaw River	1.635	21
Cache Creek	1.62	22
Lower Halfway River	1.61	23
Milligan Creek	1.5925	24
West Kiskatinaw River	1.5775	25
Middle Beatton River	1.535	26
Tsea River	1.5	27
Middle Sikanni Chief River	1.48	28
Sahtaneh River	1.465	29
Kiwigana River	1.455	30
Sahdoanah River	1.445	31
Burnt River	1.415	32
Upper Petitot River	1.4	33

Lower Petitot River	1.37	34
Snake River	1.355	35
Lower Liard River	1.345	36
Upper Fort Nelson River	1.3125	37
Middle Petitot River	1.3	38
Sukunka River	1.2875	39
Middle Prophet River	1.2825	40
Kahntah River	1.2575	41
Beaver River	1.255	42
Peace Arm	1.25	43
Chinchaga River	1.23	44
Dunedin River	1.22	45
Hay River	1.22	46
Shekilie River	1.2125	47.5
Upper Halfway	1.2125	47.5
Chowade River	1.2025	49
Upper Kotcho River	1.185	50
Klua River	1.1825	51
Upper Liard River	1.165	52
Lower Prophet River	1.15	53
Fontas River	1.145	54
Graham River	1.0725	55
Capot-Blanc River	1.0575	56
Lower Kotcho River	1.045	57
Lower Fort Nelson River	1.035	58
Middle Liard River	1.0175	59
Upper Sikanni Chief River	1.0075	60
Grayling River	0.9875	61
Upper Muskwa River	0.94	62
Upper Prophet River	0.8825	63
Middle Muskwa River	0.8825	64
Lower Sikanni Chief River	0.88	65
Upper Toad River	0.8575	66
Lower Toad River	0.8375	67
Racing River	0.7825	68
Muncho River	0.72	69

Appendix H – Disturbance Sensitivity Results and Map Sheet Rankings for Groundwater Demand and Potential Productivity

Map Sheet	Potential Productivity	Rank of Potential Productivity	Groundwater Demand	Rank of Groundwater Demand	Rank of Potential Productivity + Groundwater Demand
093P09	2.45	3	2.05	6.5	1
094A06	2.15	14.5	2.15	3	2.5
094A07	2.15	14.5	2.15	3	2.5
094A04	2.3	9	1.8	15.5	4
094A01	2.15	14.5	1.9	11	5.5
094J15	2.15	14.5	1.9	11	5.5
094A11	2	23.5	2.15	3	7
094A08	2.3	9	1.65	20.5	8
093P03	2.1	18	1.85	13	9
093P13	2	23.5	2	8	10
094A02	2.15	14.5	1.75	18	11
093P08	2.7	1	1.3	32	12
094A10	2	23.5	1.9	11	13
093P15	2.15	14.5	1.55	23.5	14
093P11	2	23.5	1.8	15.5	15.5
093P14	2	23.5	1.8	15.5	15.5
093P10	2.3	9	1.3	32	17
093P12	1.85	42	2.3	1	18
093O09	1.85	35	1.95	9	19.5
094A14	2	23.5	1.65	20.5	19.5
094B01	2	23.5	1.6	22	21
094I09	2.4	5.5	1.1	41	22
094B09	1.85	35	1.8	15.5	23
094A15	2	23.5	1.4	28	24.5
094J10	2	23.5	1.4	28	24.5
093I15	1.85	35	1.7	19	26
094B15	1.7	49.5	2.1	5	27
094A05	2.15	11	1.05	45.5	28
093P02	1.85	35	1.55	25	29
094A12	1.85	35	1.3	32	30.5
094O15	2.55	2	0.8	65	30.5
094K15	2.4	5.5	0.8	65	32

093P04	1.7	49.5	1.55	23.5	33
094B10	1.85	35	1.15	38.5	34
093P01	2.4	5.5	0.8	70	35
093P07	1.85	35	1.1	42	36
094A16	2	23.5	0.9	54	37
093O08	1.7	49.5	1.35	30	38
093P05	1.7	57.5	1.45	26	39
093I16	1.7	49.5	1.15	36	40.5
093P16	1.45	79	2.05	6.5	40.5
094J02	1.7	49.5	1.15	38.5	42
094A09	1.85	35	0.9	54	43
094A03	1.6	59	1.25	34	44
094H02	1.55	69	1.4	28	45
094K14	1.85	35	0.8	65	46
094A13	1.7	57.5	1.05	45.5	47
093I14	1.85	35	0.8	70	48.5
094O02	2.4	5.5	0.5	99.5	48.5
094H06	1.55	69	1.15	38.5	50
094P14	1.7	49.5	0.85	59	51
094I05	1.85	35	0.75	74.5	52.5
094J09	1.85	35	0.75	74.5	52.5
094B16	1.55	69	1.05	45.5	55
094G01	1.55	69	1.05	45.5	55
094G02	1.55	69	1.05	45.5	55
094B03	1.85	35	0.7	83	57
093O16	1.15	83.5	1.2	35	59
094P02	1.55	69	1	49.5	59
094P04	1.55	69	1	49.5	59
094H03	1.55	69	0.9	54	61.5
094H07	1.55	69	0.9	54	61.5
094G03	1.7	49.5	0.75	74.5	63
094B08	1.3	80.5	1.05	45.5	64
094J14	0.9	89	1.15	38.5	65
094G15	1.55	69	0.85	59	67
094H16	1.55	69	0.85	59	67
094O14	1.55	69	0.85	59	67
093I09	1.7	49.5	0.75	79	69.5
094G07	1.7	49.5	0.75	79	69.5
094G06	1.7	49.5	0.7	81.5	71
094G08	1.55	69	0.8	65	73

094O04	1.55	69	0.8	65	73
094O08	1.55	69	0.8	65	73
093O13	1.15	83.5	0.9	54	75
094P08	1.7	49.5	0.6	89.5	76
094J01	1.55	69	0.75	74.5	77.5
094P05	1.55	69	0.75	74.5	77.5
094J13	1.7	49.5	0.55	95	79.5
094O13	1.7	49.5	0.55	95	79.5
094G09	1	86.5	0.85	59	81
094H10	1.55	69	0.7	81.5	82
094G10	1	86.5	0.8	70	83
094J12	1.15	83.5	0.55	95	84.5
094M08	1.15	83.5	0.55	95	84.5
094G12	1.3	80.5	0.5	99.5	86
094K13	1.7	49.5	0.4	136.5	87
094H09	1.55	69	0.45	122.5	88
094J16	0.75	117.5	0.75	74.5	89
093P06	0.75	117.5	0.65	85.5	90.5
094B07	0.75	117.5	0.65	85.5	90.5
093I10	0.75	117.5	0.65	88	92
094B02	0.75	117.5	0.6	91.5	93
094O16	0.9	89	0.4	136.5	94
094I08	0.75	117.5	0.5	111	99
094I10	0.75	117.5	0.5	111	99
094I11	0.75	117.5	0.5	111	99
094I12	0.75	117.5	0.5	111	99
094J07	0.75	117.5	0.5	111	99
094J08	0.75	117.5	0.5	111	99
094N15	0.75	117.5	0.5	111	99
094P11	0.75	117.5	0.5	111	99
094P13	0.75	117.5	0.5	111	99
093O15	0.75	117.5	0.45	129	107
094B06	0.75	117.5	0.45	129	107
094B11	0.75	117.5	0.45	129	107
094B12	0.75	117.5	0.45	129	107
094B13	0.75	117.5	0.45	129	107
094B14	0.75	117.5	0.45	129	107
094J04	0.75	117.5	0.45	129	107
094J11	0.6	165.5	0.65	85.5	111
094H04	0.45	203	0.95	51	113

094K10	0.75	117.5	0.4	136.5	113
094P10	0.75	117.5	0.4	136.5	113
093I08	0.6	165.5	0.6	91.5	115
093I13	0.6	165.5	0.55	95	116
094I02	0.75	117.5	0.35	146	120.5
094I03	0.75	117.5	0.35	146	120.5
094I04	0.75	117.5	0.35	146	120.5
094I06	0.75	117.5	0.35	146	120.5
094I07	0.75	117.5	0.35	146	120.5
094O12	0.75	117.5	0.35	146	120.5
094P09	0.75	117.5	0.35	146	120.5
094P16	0.75	117.5	0.35	146	120.5
094O01	0.9	89	0.25	175.5	125
094H05	0.45	203	0.8	65	126
094H08	0.6	165.5	0.5	111	129.5
094I13	0.6	165.5	0.5	111	129.5
094I16	0.6	165.5	0.5	111	129.5
094J03	0.6	165.5	0.5	111	129.5
094N16	0.6	165.5	0.5	111	129.5
094P15	0.6	165.5	0.5	111	129.5
093O06	0.75	117.5	0.3	164.5	138
093O14	0.75	117.5	0.3	164.5	138
094B05	0.75	117.5	0.3	164.5	138
094G14	0.75	117.5	0.3	164.5	138
094J05	0.75	117.5	0.3	164.5	138
094N03	0.75	117.5	0.3	164.5	138
094N06	0.75	117.5	0.3	164.5	138
094N11	0.75	117.5	0.3	164.5	138
094N12	0.75	117.5	0.3	164.5	138
094N14	0.75	117.5	0.3	164.5	138
094O10	0.45	203	0.75	79	138
094O09	0.6	165.5	0.45	122.5	144
094H01	0.45	203	0.65	85.5	145
094H12	0.45	203	0.6	89.5	146
093O01	0.6	165.5	0.45	129	148
093O07	0.6	165.5	0.45	129	148
093O10	0.6	165.5	0.45	129	148
094G11	0.75	117.5	0.2	178	150
094P12	0.45	203	0.55	98	151
093I06	0.75	117.5	0.15	194	155

094B04	0.75	117.5	0.15	194	155
094G04	0.75	117.5	0.15	194	155
094G13	0.75	117.5	0.15	194	155
094K09	0.75	117.5	0.15	194	155
094M09	0.75	117.5	0.15	194	155
094N05	0.75	117.5	0.15	194	155
094I14	0.45	203	0.5	111	161.5
094I15	0.45	203	0.5	111	161.5
094P01	0.45	203	0.5	111	161.5
094P03	0.45	203	0.5	111	161.5
094P06	0.45	203	0.5	111	161.5
094P07	0.45	203	0.5	111	161.5
094O07	0.6	165.5	0.3	154	165
093I11	0.6	165.5	0.3	164.5	169.5
093I12	0.6	165.5	0.3	164.5	169.5
093O11	0.6	165.5	0.3	164.5	169.5
094K16	0.6	165.5	0.3	164.5	169.5
094N02	0.6	165.5	0.3	164.5	169.5
094N08	0.6	165.5	0.3	164.5	169.5
094N09	0.6	165.5	0.3	164.5	169.5
094N13	0.6	165.5	0.3	164.5	169.5
093H16	0.75	117.5	0	214	176
094F01	0.75	117.5	0	214	176
094F08	0.75	117.5	0	214	176
094F10	0.75	117.5	0	214	176
094G05	0.75	117.5	0	214	176
094J06	0.45	203	0.45	129	179
094H15	0.6	165.5	0.2	178	180
094G16	0.45	203	0.35	146	184
094H11	0.45	203	0.35	146	184
094H13	0.45	203	0.35	146	184
094I01	0.45	203	0.35	146	184
094N10	0.45	203	0.35	146	184
094O05	0.45	203	0.35	146	184
094O11	0.45	203	0.35	146	184
093I07	0.6	165.5	0.15	194	194
094F15	0.6	165.5	0.15	194	194
094F16	0.6	165.5	0.15	194	194
094K01	0.6	165.5	0.15	194	194
094K08	0.6	165.5	0.15	194	194

094K11	0.6	165.5	0.15	194	194
094L08	0.6	165.5	0.15	194	194
094L09	0.6	165.5	0.15	194	194
094M02	0.6	165.5	0.15	194	194
094M07	0.6	165.5	0.15	194	194
094M10	0.6	165.5	0.15	194	194
094M16	0.6	165.5	0.15	194	194
094O03	0.6	165.5	0.15	194	194
094N01	0.45	203	0.3	164.5	201.5
094N07	0.45	203	0.3	164.5	201.5
094O06	0.45	203	0.25	175.5	203
093I01	0.6	165.5	0	214	206.5
093I02	0.6	165.5	0	214	206.5
094F09	0.6	165.5	0	214	206.5
094M06	0.6	165.5	0	214	206.5
094M11	0.6	165.5	0	214	206.5
094M15	0.6	165.5	0	214	206.5
094H14	0.45	203	0.2	178	210
094K02	0.45	203	0.15	194	215
094K03	0.45	203	0.15	194	215
094K05	0.45	203	0.15	194	215
094K06	0.45	203	0.15	194	215
094K07	0.45	203	0.15	194	215
094K12	0.45	203	0.15	194	215
094L16	0.45	203	0.15	194	215
094M01	0.45	203	0.15	194	215
094N04	0.45	203	0.15	194	215

Appendix I – Disturbance Sensitivity Results and Map Sheet Rankings for Groundwater Demand and Vulnerability

Map Sheet	Groundwater Demand	Rank of Groundwater Demand	Groundwater Vulnerability	Rank of Groundwater Vulnerability	Rank of Groundwater Demand + Groundwater Vulnerability
093P09	2.05	6.5	2.05	6	1
093P03	1.85	13	2.37	1	2
094A02	1.75	18	2.35	2	3
093P08	1.3	32	2.3	3	4
094A04	1.8	15.5	1.79	15	5
093P14	1.8	15.5	2.07	5	6
094A07	2.15	3	1.7	22	7
094B01	1.6	22	2.23	4	8
094A11	2.15	3	1.77	18.5	9
093P15	1.55	23.5	1.84	13	10
093O09	1.95	9	1.95	9	11
093P12	2.3	1	1.86	12	12
093I15	1.7	19	2.02	7	13
094A06	2.15	3	1.56	31	14
094J15	1.9	11	1.56	29	15
093P13	2	8	1.58	28	16
093P11	1.8	15.5	1.65	23.5	17
093P02	1.55	25	1.86	11	18
093P10	1.3	32	1.63	25	19
094A10	1.9	11	1.51	34	20
094A12	1.3	32	1.77	17	21
093P16	2.05	6.5	1.98	8	22
093P05	1.45	26	1.88	10	23
094J10	1.4	28	1.63	26	24
094A01	1.9	11	1.35	48.5	25.5
094B09	1.8	15.5	1.56	31	25.5
094A05	1.05	45.5	1.6	27	27
094A14	1.65	20.5	1.49	36	28
094A03	1.25	34	1.79	15	29
093I14	0.8	70	1.74	20.5	30.5
093P01	0.8	70	1.51	34	30.5
094A15	1.4	28	1.37	47	32

094A08	1.65	20.5	1.21	64	33
094G01	1.05	45.5	1.77	18.5	34
093P07	1.1	42	1.49	39.5	35
093P04	1.55	23.5	1.46	43	36
094B08	1.05	45.5	1.79	15	37
094B15	2.1	5	1.28	54	38
093O16	1.2	35	1.65	23.5	39
094B16	1.05	45.5	1.56	31	40
094A13	1.05	45.5	1.49	39.5	41
093I09	0.75	79	1.74	20.5	42
094G02	1.05	45.5	1.49	39.5	43
094B10	1.15	38.5	1.23	61.5	44
094J02	1.15	38.5	1.28	54	45
093I16	1.15	36	1.23	58.5	46
094H03	0.9	54	1.49	39.5	47
094H06	1.15	38.5	1.28	54	48.5
094P04	1	49.5	1.44	45	48.5
094O08	0.8	65	1.51	34	50
093O08	1.35	30	1.18	71	52
094G07	0.75	79	1.49	39.5	52
094H02	1.4	28	1.21	64	52
094A09	0.9	54	1.21	67.5	54
094O02	0.5	99.5	1.21	64	55
094J09	0.75	74.5	1.21	67.5	56
094A16	0.9	54	1.09	86.5	57.5
094G08	0.8	65	1.35	50.5	57.5
094G10	0.8	70	1.42	46	59
094I09	1.1	41	0.93	114	60
094O15	0.8	65	0.95	108	61
094O14	0.85	59	1.11	81	62
094G09	0.85	59	1.21	67.5	63
094I05	0.75	74.5	1.02	98	65
094O13	0.55	95	1.18	71	65
094P02	1	49.5	1.07	91.5	65
094H04	0.95	51	1.49	39.5	67
094G15	0.85	59	1.07	91.5	68
094P14	0.85	59	0.95	108	69
094K14	0.8	65	0.88	118	70.5
094P05	0.75	74.5	1.09	86.5	70.5
094G06	0.7	81.5	1.04	93.5	72

093P06	0.65	85.5	1.16	75	73
094I12	0.5	111	1.21	67.5	74
094H16	0.85	59	1	102	75
094P08	0.6	89.5	1.02	95	76
093I10	0.65	88	1.11	81	77
094B02	0.6	91.5	1.11	81	78
094H05	0.8	65	1.35	50.5	79
094I11	0.5	111	1.14	78.5	80
094B03	0.7	83	0.83	124.5	81
094H07	0.9	54	0.86	121.5	82
094O01	0.25	175.5	1.23	58.5	83
094J08	0.5	111	1.09	86.5	84.5
094P11	0.5	111	1.09	86.5	84.5
094J14	1.15	38.5	0.86	121.5	86
094G03	0.75	74.5	0.83	124.5	87
094I13	0.5	111	1.23	61.5	88
094H10	0.7	81.5	0.93	111.5	89
094O09	0.45	122.5	1.3	52	90
094B07	0.65	85.5	0.95	108	91
093O10	0.45	129	1.25	56	92
094N16	0.5	111	1.16	75	93.5
094P15	0.5	111	1.16	75	93.5
094P07	0.5	111	1.44	44	95
094O12	0.35	146	1.09	86.5	96.5
094P13	0.5	111	0.95	108	96.5
094H09	0.45	122.5	0.86	119.5	98.5
094O04	0.8	65	0.79	134.5	98.5
094P12	0.55	98	1.23	58.5	100
094I14	0.5	111	1.35	48.5	101
093O15	0.45	129	0.97	104.5	102
094I10	0.5	111	0.93	114	103
094P10	0.4	136.5	1	102	104
094I02	0.35	146	1.02	98	105.5
094I04	0.35	146	1.02	98	105.5
094J12	0.55	95	0.79	134.5	107
093I13	0.55	95	0.97	104.5	108
094B11	0.45	129	0.9	116.5	109.5
094O16	0.4	136.5	0.81	129.5	109.5
094M08	0.55	95	0.76	139.5	111
094H12	0.6	89.5	1.14	78.5	112

094I08	0.5	111	0.81	129.5	113
094J13	0.55	95	0.72	150.5	114
093I08	0.6	91.5	0.9	116.5	115.5
094H08	0.5	111	1	102	115.5
094O10	0.75	79	1.02	98	117
094K15	0.8	65	0.46	207	118
094J16	0.75	74.5	0.72	150.5	119
094N09	0.3	164.5	1.18	71	120
093O07	0.45	129	1.04	93.5	121
094O11	0.35	146	1.23	58.5	122
094K13	0.4	136.5	0.69	157.5	123
093O13	0.9	54	0.62	171.5	124.5
094B14	0.45	129	0.76	139.5	124.5
094P06	0.5	111	1.09	86.5	126
094I16	0.5	111	0.86	119.5	127
094I06	0.35	146	0.81	129.5	128.5
094P16	0.35	146	0.81	129.5	128.5
094O07	0.3	154	1.09	86.5	130
094K10	0.4	136.5	0.76	139.5	131
094O05	0.35	146	1.16	75	132
094J11	0.65	85.5	0.72	150.5	133
094B13	0.45	129	0.69	157.5	134
094J07	0.5	111	0.65	166	135.5
094N15	0.5	111	0.65	166	135.5
094I03	0.35	146	0.74	145.5	138
094I07	0.35	146	0.74	145.5	138
094P09	0.35	146	0.74	145.5	138
094N08	0.3	164.5	1.02	98	140
094O03	0.15	194	1.16	75	141
094P01	0.5	111	0.95	108	142
094G12	0.5	99.5	0.55	186	143
094P03	0.5	111	0.93	114	144
093O14	0.3	164.5	0.76	139.5	145
094H01	0.65	85.5	0.79	134.5	146.5
094N05	0.15	194	0.83	124.5	146.5
094B06	0.45	129	0.6	175	148
094N14	0.3	164.5	0.74	145.5	149
094J01	0.75	74.5	0.44	208	150
093O01	0.45	129	0.76	139.5	151
094O06	0.25	175.5	1.09	86.5	152

094I15	0.5	111	0.81	129.5	153
094B12	0.45	129	0.55	186	154
094H11	0.35	146	0.93	111.5	155.5
094N06	0.3	164.5	0.69	157.5	155.5
094J04	0.45	129	0.53	193.5	157.5
094K09	0.15	194	0.74	145.5	157.5
094N11	0.3	164.5	0.65	166	159
094N03	0.3	164.5	0.62	171.5	160
094G04	0.15	194	0.69	157.5	162
094G13	0.15	194	0.69	157.5	162
094M09	0.15	194	0.69	157.5	162
094G11	0.2	178	0.67	163	164
094N10	0.35	146	0.81	129.5	165
093I07	0.15	194	0.83	124.5	166
094B05	0.3	164.5	0.55	186	167
094B04	0.15	194	0.62	171.5	168
093I11	0.3	164.5	0.69	157.5	170
093O11	0.3	164.5	0.69	157.5	170
094N13	0.3	164.5	0.69	157.5	170
094I01	0.35	146	0.74	145.5	172
094H15	0.2	178	0.72	150.5	173
094N12	0.3	164.5	0.53	193.5	174
094G14	0.3	164.5	0.51	195	175
094M16	0.15	194	0.76	139.5	176
093O06	0.3	164.5	0.48	201	177
094J03	0.5	111	0.37	214.5	178
094H14	0.2	178	0.79	134.5	179
094N02	0.3	164.5	0.58	177.5	180
094G05	0	214	0.62	171.5	181
094J05	0.3	164.5	0.39	211	182
094G16	0.35	146	0.65	166	183
094K11	0.15	194	0.69	157.5	184
093I06	0.15	194	0.48	201	185
094J06	0.45	129	0.58	177.5	186
094H13	0.35	146	0.58	177.5	187
093H16	0	214	0.55	186	189
094F01	0	214	0.55	186	189
094F08	0	214	0.55	186	189
094N01	0.3	164.5	0.65	166	191
093I12	0.3	164.5	0.48	201	192

094F10	0	214	0.48	201	193
094F09	0	214	0.62	171.5	194
094N07	0.3	164.5	0.58	177.5	195
094K01	0.15	194	0.55	186	196.5
094K08	0.15	194	0.55	186	196.5
094K16	0.3	164.5	0.37	214.5	198
094N04	0.15	194	0.62	171.5	199
093I01	0	214	0.55	186	200
094F15	0.15	194	0.48	201	201.5
094F16	0.15	194	0.48	201	201.5
094K05	0.15	194	0.55	186	204.5
094K06	0.15	194	0.55	186	204.5
094K07	0.15	194	0.55	186	204.5
094K12	0.15	194	0.55	186	204.5
094L09	0.15	194	0.39	211	208
094M07	0.15	194	0.39	211	208
094M10	0.15	194	0.39	211	208
093I02	0	214	0.48	201	210
094L08	0.15	194	0.32	217	211.5
094M02	0.15	194	0.32	217	211.5
094K02	0.15	194	0.48	201	214.5
094K03	0.15	194	0.48	201	214.5
094L16	0.15	194	0.48	201	214.5
094M01	0.15	194	0.48	201	214.5
094M15	0	214	0.39	211	217
094M11	0	214	0.32	217	218
094M06	0	214	0.16	219	219

Disturbance-Sensitivity Based Approach to Prioritizing Water Monitoring in Northeast B.C.

7/22/2015

PART 2: DATA PACKAGE

Disturbance-Sensitivity Based Approach to Prioritizing Water Monitoring in Northeast B.C.

DATA PACKAGE

Table of Contents

INTRODUCTION

This report documents the data sources and geoprocessing methods applied to the indicator layers to generate the disturbance-sensitivity based assessment. The goal is to record the data used and the manipulations applied so that the results are reproducible. The rationale for the selection of data comprising an indicator layer is not the focus of this paper. Data choices were made by two technical committees (surface water and groundwater) of government experts and presented to public focus groups multiple times for review and modification. The goal for indicator layers was that they be representative without being duplicative of each other. The criterion for data was that it be publically available and universally available at the same standard across northeast British Columbia. Preference was given to data available from the British Columbia Geographic Warehouse (BCGW) which is primarily supplied by the Ministry of Forests, Lands and Natural Resource Operations (FLNRO), Ministry of Environment (MOE) or the British Columbia Oil and Gas Commission (OGC).

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This paper presents the indicator layers included in each of the four disturbance-sensitivity based approaches: surface water quantity, surface water quality, groundwater quantity and groundwater quality. Some indicator layers are used in more than one approach and the metadata is presented for each occurrence.

Polygonal Coverage

Surface Water Polygons - OGC Basins

REPRESENTATION

For the surface water analysis, northeast British Columbia was assessed using watershed subdivisions. There are several watershed definitions in B.C. including the older B.C. Watershed Atlas at 1:50,000, the Freshwater Atlas at 1:20 000, the TRIM Watershed Atlas (not publically available) and Water Management Basins as defined by the B.C. Oil and Gas Commission (OGC). For this analysis, the 69 watersheds from the OGC's water management basins were used.

Hay River Drainage (4 Watersheds): Hay River, Kyklo River, Lower Kotcho River, Shekilie River

Liard River Drainage (36 Watersheds): Beaver River, Capot-Blanc River, Chinchaga River, Dunedin River, Fontas River, Grayling River, Kahntah River, Kiwigana River, Klua River, Lower Fort Nelson River, Lower Liard River, Lower Muskwa River, Lower Petitot River, Lower Prophet River, Lower Sikanni Chief River, Lower Toad River, Middle Fort Nelson River, Middle Liard River, Middle Muskwa River, Middle Petitot River, Middle Prophet River, Middle Sikanni Chief River, Muncho River, Racing River, Sahdoanah River, Sahtaneh River, Snake River, Tsea River, Upper Fort Nelson River, Upper Kotcho River, Upper Liard River, Upper Muskwa River, Upper Petitot River, Upper Prophet River, Upper Sikanni Chief River, Upper Toad River

Peace River Drainage (29 Watersheds): Blueberry River, Burnt River, Cache Creek, Cameron River, Chowade River, Doig River, East Kiskatinaw River, Farrell Creek, Graham River, Lower Beatton River, Lower Halfway River, Lower Kiskatinaw River, Lower Peace River, Lower Pine River, Lynx Creek, Middle Beatton River, Middle Kiskatinaw River, Milligan Creek, Moberly River, Murray River, Peace Arm, Pouce Coupe River, Smoky River, Sukunka River, Upper Beatton River, Upper Halfway, Upper Peace River, Upper Pine River, West Kiskatinaw River

Groundwater Polygons - NTS Map Sheets

REPRESENTATION

For the groundwater analysis, northeast British Columbia was assessed using NTS map sheet subdivisions. Alternate methods included using the 69 OGC water management basins (above) or defined aquifer units. Watersheds were not used because aquifers are not confined by those boundaries and there was some concern that the natural extent of groundwater aquifers might be confused with the overlying arbitrary surficial boundaries. There are insufficient aquifers mapped at this time for aquifer boundaries to provide a feasible option. The map sheets at 1:50,000 scale provide a more uniform grid-like approach to the assessment and there was no concern that grid boundaries would be confused with natural groundwater boundaries.

NTS Map Sheets (219 map sheets): 093H(16), 093I(1-2, 6-16), 093O(1, 6-11, 13-16), 093P(1-16), 094A(1-16), 094B(1-16), 094F(1, 8-10, 15-16), 094G(1-16), 094H(1-16), 094I(1-16), 094J(1-16), 094K(13, 5-16), 094L(8-9, 16), 094M(1-2, 6-11, 15-16), 094N(1-16), 094O(1-16), 094P(1-16)

DATA SOURCES

Table 1: Data Sources for Polygon-Based Subdivisions

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
OGC Basins	WHSE_MINERAL_TENURE.OG_WATER_MANAGEMENT_BASINS_SP	Y	OGC	Y	2012-04-10
NTS Map Sheets	WHSE_BASEMAPPING.NTS_50K_GRID	Y	OGC	Y	2003-04-23

GEOPROCESSING METHOD

Data for each indicator layer is processed and presented as a categorized value per watershed or NTS map sheet. Each individual watershed or map sheet represents an "Area of Interest" (AOI) polygon. There are four pathways to a final result for any indicator layer where the method used is dependent upon the nature of the data available. These four methods are listed below and referred to through the remainder of the document as each indicator layer is described.

Table 2: Geoprocessing of Polygon-Based Subdivisions to Create Indicator Layers

Source Data	Modification	Result Format
Polygonal Area	Create an intersection between the polygon layer (watersheds or NTS map sheets) and the indicator layer. Use watershed polygons to summarize indicator layer polygons within each unit. Save data as a table. Join the new summary table data to watershed (or NTS map sheet) polygons in a new layer. Complete conversion calculations to express indicator data as hectare per square kilometer.	Hectare per square kilometre (ha/km^2)
Polygonal Data	Create an intersection between the polygon layer (watersheds or NTS map sheets) and the indicator layer. Use watershed polygons to summarize data from indicator layer polygons within each watershed by summing (or averaging) the field of interest (e.g. stimulation volume, population) and summing the area of the	Data unit per square kilometer (e.g. m^3/km^2,

Source Data	Modification	Result Format
	polygons. Save as a table. Join the newly created summary table to watershed polygons in a new layer. Calculate a weighting factor from the sum of the area of indicator polygon(s) within each watershed relative to the total area of that watershed. Multiply the field of interest by the newly created area-based weighting factor. Divide the resultant weighted field of interest by the watershed polygon area. Complete conversion calculations to express indicator data per square kilometer.	count/km^2)
Point Count	Create an intersection between the polygon layer (watersheds or NTS map sheets) and the indicator layer. Use watershed polygons to summarize indicator points for each watershed by counting the points within the watershed. Save as a table. Join summary table data to watershed polygons in a new layer. Complete conversion calculations to express indicator data as count per square kilometer.	Count per square kilometre
Point Data	Create an intersection between the polygon layer (watersheds or NTS map sheets) and the indicator layer. Use watershed polygons to summarize indicator points for each watershed by summing or averaging the field of interest for the points within the watershed. Save as a table. Join the newly created summary table to watershed (or NTS map sheet) polygons in a new layer. Normalize the data (e.g. by dividing the contaminant discharge volume by the total flow in the basin). Complete conversion calculations to express normalized volume relative to area in square kilometers for the watershed.	Percent total flow

SURFACE WATER QUANTITY

The disturbance-sensitivity based approach to enhanced monitoring of surface water quantity focuses on areas of higher current industrial demand and future potential industrial demand. It also emphasizes areas of importance for monitoring the trend and condition of surface water supply for human and ecosystem needs.   The indicator layers used to determine enhanced monitoring needs for surface water quantity are listed below.

Table 3: Indicator Layers for Surface Water Quantity Monitoring

Topic	Indicator Layer
Current Disturbance	Allocated Water Versus Runoff
Current Disturbance	Surface Water Restrictions
Future Disturbance	Possible Future Water Demand for Hydraulic Fracturing
Future Disturbance	Possible Water Demand by Mining
Future Disturbance	Possible Water Demand by Agriculture
Sensitivity	Population
Sensitivity	Wetland Density
Sensitivity	Headwater Density
Sensitivity	Lake Density

Current Disturbance Indicator Layers

Current water demand would ideally be represented by the actual water usage relative to the total runoff in a basin. However actual water use data is not currently captured by water licenses issued through the Ministry of Forests, Lands and Natural Resource Operations (FLNRO). There is an intention to modify this practice as the new Water Sustainability Act is implemented. At present, the closest metric for current water usage is volume of water allocated under a license relative to the runoff in a basin.

In some locations, requests for water exceed available supplies and a water source is closed to further licensing. Such restrictions can be temporary, set certain limitations or permanent.   This data indicates locations where water demand outpaces supply.

Water licenses are issued for long periods, but both current demand and available water can fluctuate. In future, a proviso will be built into licenses under the Water Sustainability Act which will ensure environmentally sustainable flows in basins. This is a future data source that may provide a useful indicator layer for the disturbance-sensitivity based approach. Additionally, while environmental flow needs may be met on a basin-wide level when evaluated annually, they may be exceeded locally over short time frames. Drought reporting may provide useful information in the next year or two.

Allocated Water Versus Runoff (AllocVRunoff)

REPRESENTATION

The diversion and use of all surface water in British Columbia must be authorized. The vast majority of water licenses are for domestic and irrigation purposes. Other purposes include industrial, power, conservation, mining, stock watering and land improvement. Only water uses which are consumptive in nature are included for this indicator layer. The overall volume licensed relative to runoff indicates the level of demand per basin on an annual basis.

Consumptive Water Uses

Purpose	Detail
Agriculture	IRRIGATION
	PONDS
	STOCKWATERING
	WATERING
Domestic, Water works, etc.	BOTTLE SALES
	DOMESTIC
	ENTERPRISE
	INSTITUTIONS
	SNOW MAKING
	TRUCK WASHING
	WATER DELIVERY
	WATERWORKS (OTHER)
	WATERWORKS LOCAL AUTH
Mining	Dust Control - Mining
	MINING EQUIPMENT
	MINING-WASHING COAL
	ROAD MAINTENANCE - Mining
	SEDIMENT CONTROL
Oil and Gas	MINING EQUIPMENT - O&G
	OIL FIELD INJECTION
	PROCESSING - O&G
	ROAD MAINTENANCE - O&G
Pulp Mills, Forestry	PULPMILLS
Road Maintenance	DUST CONTROL
	ROAD MAINTENANCE
	PROCESSING - Road Maintenance

Non-consumptive Water Uses

Purpose	Detail

Conservation	CONSERV.-STORED WATER
	LAND IMPROVE
	LAND IMPROVE - Mining
Cooling	COOLING
Fire Protection	FIRE PROTECTION
Power	POWER-GENERAL
	POWER-RESIDENTIAL
Storage	STORAGE-NON POWER
	STORAGE-POWER

DATA SOURCES

Table 4: Data Source for Water Allocation

Topic	Source Location	LDRW /BCGW	Data Provider	Public Data	Data Last Modified
Water Allocation relative to OGC Basin Runoff	BC OGC 2013 Annual report Appendix 2 http://www.bcogc.ca/node/11263/download	N	OGC	Y	

GEOPROCESSING METHOD

Table 5: Geoprocessing of Water Allocation Source Data

Topic	Query or Process
Water Allocation relative to OGC Basin Runoff	(OGC volume approved (2013) + OGC permitted + FLNRO permitted)/ Mean annual runoff (2013) Peace Arm = 0 because the OGC approved volumes are managed in conjunction with BC Hydro who has a large reserve in that basin.

Table 6: Geoprocessing to Create a Water Allocation Indicator Layer

Result	Source Layer	Target Layer	Action
Water allocation relative to runoff per AOI polygon (percent of total flow)	Water Allocation relative to OGC Basin Runoff	AOI polygon layer	Join

Surface Water Restrictions (SWRestrictions)

REPRESENTATION

Occasionally a restriction notification is placed on water bodies to limit future water allocation decisions. A water allocation restriction is an indication that water demand has, at least temporarily, outpaced availability. A restriction may range from including minimum fish flow clauses in a water license, to suspending the issuance of any further licenses on a water body. Basins with more restrictions indicate stress or limitation on water resources.

Types of Allocation Restrictions

Restriction Type	Description
Refused No Water	A previous application for a water license was refused because there was insufficient water in the stream to grant the application.
Possible Water Shortage	This stream is nearing the Fully Recorded stage and there is the potential for periods of insufficient water.
Fully Recorded	No further licenses should be considered on this stream.
Fully Recorded except for	No further licenses should be considered on this stream except for licenses for the specified purposes and/or quantities.
Office Reserve	A specialized comment should be taken into consideration before making any water allocation decisions regarding this stream.

DATA SOURCES

Table 7: Data Source for Surface Water Restrictions

Topic	Source Location	LDRW /BCGW	Data Provider	Public Data	Data Last Modified
Surface water restrictions	WHSE_WATER_MANAGEMENT.WLS_WATER_RESTRICTION_LOC_SVW	Y	FLNRO	Y	2015-03-31

GEOPROCESSING METHOD

Table 8: Geoprocessing of Surface Water Restriction Source Data

Topic	Query or Process
Surface water restrictions	All restriction types included

Table 9: Geoprocessing to Create a Surface Water Restrictions Indicator Layer

Result	Source Layer	Target Layer	Action
Surface water restrictions count per AOI polygon (count/km^2)	Surface water restrictions	AOI polygon layer	Point Count as per Table 2

Future Disturbance Indicator Layers

Future water demand is expected to be highest for the petroleum and mining industries. For petroleum development, the highest water demand is associated with unconventional gas development through hydraulic fracturing. Water demand for water flood and other petroleum development operations is not expected to be a major source of water demand in the future. Future water demand related to mining is primarily associated with coal mining where water may be required for washing coal, slurries, dust maintenance and more. The agricultural sector may also experience increased demand for water owing to increased irrigation. Irrigation practices are minimal at present, but are expected to increase. Climate change predictions for northeast B.C. are for warmer temperatures and decreased snow in winter. The forest sector is not expected to place any significant demands on water quantity in the future.

Possible Future Water Demand for Hydraulic Fracturing (PotOGWater)

REPRESENTATION

Water demand for unconventional gas development is not uniform across northeast B.C. but varies according to geology. Water demand is a function of the hydraulic fracturing style necessary for development of a specific formation in specific area. This indicator layer, Potential Water Demand for Hydraulic Fracturing, addresses water demand by area as a function of geology and development style. It presents the average stimulation volume needed per well in a given pool where a pool represents both the region and the horizon at depth specifically being targeted.

The relative stimulation volumes currently needed across pools in northeastern B.C. is considered a proxy for future development needs. There has been rapid technological advancement in hydraulic fracturing. The style of hydraulic fracturing (e.g. high volume slickwater or energized foams) in a given pool is not expected to change very quickly. The water volume required by a select style of fracturing can be highly dynamic. For example, the stimulation volume of water per well for high volume slickwater fracturing has increased by ten-fold in the past seven years.

DATA SOURCES

Table 10: Data Sources for Potential Water Demand for Hydraulic Fracturing

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Oil and Gas Pools	WHSE_MINERAL_TENURE.OG_POOL_DESGNTN_AREA_PUB_SP	Y	OGC	Y	2015-03-31
Well completion data with water volumes	Well completion data File = compl_wo.csv	N	OGC	Y	2015-03-31
Well location by Unique Well identifier (UWI)	WHSE_MINERAL_TENURE.OG_BOTTOM_HOLE_EVENT_SP	Y	OGC	Y	2015-03-31

GEOPROCESSING METHOD

Table 11: Geoprocessing of Potential Water Demand for Hydraulic Fracturing Source Data

Topic	Query or Process
Well completion data with water volumes	Only well events (UWI) where stimulation fluid was used (i.e. Stimultn_vol>0). A pool identifier was created by concatenating Field Area, Formation and Pool

Topic	Query or Process
	Sequence. Stimulation volume was summed by UWI for each pool.
Oil and Gas Pools	A pool identifier was created by concatenating Field Area, Formation and Pool Sequence.
Well location by unique Well identifier	Well completion data table Joined to Location data by UWI.

Table 12: Geoprocessing to Create a Potential Water Demand for Hydraulic Fracturing Indicator Layer

Result	Source Layer	Target Layer	Action
Average stimulation volume per pool	Well completion data with water volumes	Oil and Gas Pools	Joined well point data to pool polygons. Pools assigned the average UWI stimulation volume per well.
Average stimulation volume per AOI polygon (m^3/km^2)	Average stimulation volume per pool	AOI polygon layer	Polygon Data as per Table 2

Possible Water Demand by Mining (Mine)

REPRESENTATION

Mining is primarily limited to coal operations in northeast B.C. The land area for active mines is represented by lease areas. Areas of future expansion are held by license. Mineral and placer-based mines are represented by licensed areas, but they are almost nonexistent in northeast B.C. Potential future mining areas are not well captured under the current system. Claims represent a potential area much larger than that which may potentially be mined. Possible Water Demand by Mining therefore is limited mainly to coal leases and licenses.

DATA SOURCES

Table 13: Data Source for Possible Water Demand by Mining

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Mining Tenure	WHSE_MINERAL_TENURE.MTA_ACQUIRED_TENURE_SVW	Y	MEM	Y	2015-03-31

GEOPROCESSING METHOD

Table 14: Geoprocessing of Possible Water Demand by Mining Source Data

Topic	Query or Process
Mining Tenure	TENURE_SUB_TYPE_DESCRIPTION = lease or License

Table 15: Geoprocessing to Create a Possible Water Demand by Mining Indicator Layer

Result	Source Layer	Target Layer	Action
Mining Tenure per AOI polygon (ha/km^2)	Mining Tenure	AOI polygon layer	Polygonal Area as per Table 2

Possible Water Demand by Agriculture (Ag)

REPRESENTATION

Currently there is little excess water demand by agriculture. It is anticipated that there may soon be a switch to irrigation. Changes to the land area are unknown so the current agricultural coverage is used to represent future areas of potential irrigation.

DATA SOURCES

Table 16: Data Source for Possible Water Demand by Agriculture

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Agriculture	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y	FLNRO	Y	1997-07-01

GEOPROCESSING METHOD

Table 17: Geoprocessing of Possible Water Demand by Agriculture Source Data

Topic	Query or Process
Agriculture	PRESENT_LAND_USE_LABEL = Agriculture (Land based agricultural activities undifferentiated as to crop (i.e. land is used as the producing medium) and Residential Agriculture Mixtures (Areas where agriculture activities are intermixed with residential and other buildings with a density of between 2 and 0.2 hectares).

Table 18: Geoprocessing to Create a Possible Water Demand by Agriculture Indicator Layer

Result	Source Layer	Target Layer	Action
Agriculture per AOI polygon (ha/km^2)	Agriculture	AOI polygon layer	Polygonal Area as per Table 2

Layers Indicative of Human or Ecosystem Sensitivity

The stewardship of water resources for people and the environment is considered an important duty. Population and ecosystem indicator layers prioritize areas where it is most important that water condition and trend be tracked.

Population (Pop)

REPRESENTATION

Water of sufficient quantity and quality are a necessity of life and a requirement for regions of human habitation. There are two ways to capture domestic water needs: 1) by licensed volume and 2) by population concentration. Since volume data from government issued water licenses does not capture First Nations water needs, the population data is used for this assessment.

DATA SOURCES

Table 19: Data Sources for Population

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Population Boundary	Population Boundary data	N	Statistics Canada	Y	
Population	Population data	N	Statistics Canada	Y	

GEOPROCESSING METHOD

Table 20: Geoprocessing of Population Source Data

Topic	Query or Process
Population by dissemination block area	Population boundary and population were joined BC dissemination blocks were selected and exported to a new feature class which was then reprojected from geographic to BC Albers. A new field was added "DisseminationBlock_AREA" and calculated to equal the SHAPE_AREA (using area-weighting, the new field can subsequently be used for estimating population in a dissemination block which has been split by intersection with a watershed/basin).

Table 21: Geoprocessing to Create a Population Indicator Layer

Result	Source Layer	Target Layer	Action
Population per AOI polygon (count/km^2)	Population by dissemination block area	AOI polygon layer	Polygonal Data as per Table 2

Wetland Density (Wetland)

REPRESENTATION

Wetlands affect water quality and quantity by serving to improve water quality and buffer flow volumes. They also serve as habitat for terrestrial and aquatic species. Wetland has been mapped in a variety of forms, the newest and most comprehensive mapping of wetland being by Ducks Unlimited. However that data set is not in the public realm. Sections of northeast B.C. are mapped in great detail, but universal coverage was sought for the entire northeast region. Options include the freshwater atlas (FWA), the enhanced base map (EBM), and baseline thematic map (BTM). The BTM was chosen because it is accurate to 250m across the entire region and provides polygonal data for several indicator layers including wetland, freshwater, agriculture, and urban areas so it provides more congruence across indicator layers in the project.

DATA SOURCES

Table 22: Data Source for Wetland

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Wetland	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y	FLNRO	Y	1997-07-01

GEOPROCESSING METHOD

Table 23: Geoprocessing of Wetland Source Data

Topic	Query or Process
Wetland	PRESENT_LAND_USE_LABEL = Wetland (Wetlands including swamps, marshes, bogs or fens. This class excluded lands with evidence of knowledge of haying or grazing in drier years)

Table 24: Geoprocessing to Create a Wetland Density Indicator Layer

Result	Source Layer	Target Layer	Action
Wetland per AOI polygon (ha/km^2)	Wetland	AOI polygon layer	Polygonal Area as per Table 2

Headwater Density (Headwater) and Lake Density (LakeDensity)

REPRESENTATION

It was challenging to find a good indicator layer for aquatic species sensitivity. Species surveys are spotty and inconsistent in the northeast. Absence of species does not necessarily indicate a change in population. The environments that most support aquatic species diversity and population were used as indicator layers instead: riverine headwaters and lakes. Mapping comes from the Ecological Aquatic Units of British Columbia (EAU BC), a hierarchical classification of freshwater ecosystems that integrates many factors including zoogeography, physiography and climatic patterns as well as more localized physical habitat and dominant environmental processes.

DATA SOURCES

Table 25: Data Source for Headwaters

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Headwaters	WHSE_LAND_AND_NATURAL_RESOURCE.EAUBC_RIVERS_SP	Y	ENV	Y	2007-11-30

GEOPROCESSING METHOD

Table 26: Geoprocessing of Headwater Source Data

Topic	Query or Process
Headwaters	RIVER_ECOSYSTEM_CLASS = H

Table 27: Geoprocessing to Create a Headwater Density Indicator Layer

Result	Source Layer	Target Layer	Action
Headwaters per AOI polygon (ha/km^2)	Headwaters	AOI polygon layer	Polygonal Area as per Table 2

DATA SOURCES

Table 28: Data Source for Lakes

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Lakes	WHSE_LAND_AND_NATURAL_RESOURCE.EAUBC_LAKES_SP	Y	ENV	Y	2007-11-30

GEOPROCESSING METHOD

Table 29: Geoprocessing of Lake Source Data

Topic	Query or Process
Lakes	All lakes

Table 30: Geoprocessing to Create a Lake Density Indicator Layer

Result	Source Layer	Target Layer	Action
Lakes per AOI polygon (ha/km^2)	Lakes	AOI polygon layer	Polygonal Area as per Table 2

SURFACE WATER QUALITY

The disturbance-sensitivity based approach to enhanced monitoring of surface water quality focuses on areas of current industrially related disturbance and future areas of potential industrial disturbance. It also emphasizes areas of importance for monitoring the trend and condition of surface water quality for human and ecosystem needs. The indicator layers used to determine enhanced monitoring needs for surface water quality are listed below.

Table 31: Indicator Layers for Surface Water Quality Monitoring

Topic	Indicator Layer
Current Disturbance	Disturbance from Agriculture
Current Disturbance	Disturbance from Forest Clear Cutting
Current Disturbance	Disturbance from Forest Burn Scars
Current Disturbance	Disturbance from Urban
Current Disturbance	Disturbance from Oil and Gas Industry Related Infrastructure
Current Disturbance	Disturbance from Linear Features (Roads, Railway Lines and Transmission Lines)
Current Disturbance	Disturbance from Mining
Current Disturbance	Contamination from Effluent
Future Disturbance	Potential Disturbance from Unconventional Gas Development
Future Disturbance	Potential Disturbance from Mining
Future Disturbance	Potential Disturbance from Forestry
Sensitivity	Population
Sensitivity	Wetland Density
Sensitivity	Headwater Density
Sensitivity	Lake Density

Current Disturbance Indicator Layers

There are two main categories considered in this analysis where the quality of water may be impaired: impact from surface disturbance; and point source impact from the authorized release of effluent into streams.

Disturbance from Agriculture (Ag)

REPRESENTATION

Disturbance from agriculture can affect water quality through drainage of pesticides, herbicides and nutrients into nearby freshwater.

DATA SOURCES

Table 32: Data Source for Agricultural Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Agriculture	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y	FLNRO	Y	1997-07-01

GEOPROCESSING METHOD

Table 33: Geoprocessing of Agricultural Disturbance Source Data

Topic	Query or Process
Agriculture	PRESENT_LAND_USE_LABEL = Agriculture (Land based agricultural activities undifferentiated as to crop (i.e. land is used as the producing medium) and Residential Agriculture Mixtures (Areas where agriculture activities are intermixed with residential and other buildings with a density of between 2 and 0.2 hectares).

Table 34: Geoprocessing to Create an Agricultural Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Agriculture per AOI polygon (ha/km^2)	Agriculture	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Forest Clear Cutting (ForCuts)

REPRESENTATION

Areas denuded of forest cover can shed sediment via overland flow into nearby freshwater. Disturbance from agriculture can affect water quality through drainage of pesticides, herbicides and nutrients into nearby freshwater.

DATA SOURCES

Table 35: Data Sources for Disturbance from Forest Clear Cutting

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Consolidated cut blocks	Consolidated_Cutblocks_2013.gdb	N	FLNRO	Y	
Consolidated cut blocks	Consolidated_Cutblocks_2012.gdb	N	FLNRO	Y	
Harvest Authority	WHSE_FOREST_TENURE.FTEN_HARVEST_AUTH_POLY_SVW	Y	FLNRO	Y	2015-03-31

The process for capturing Consolidated Cut blocks changed for the 2013 model. It is speculated that wildfire data may have been dropped from the 2013 data.

Comparison of Consolidated Cut blocks for 2012 and 2013

Consolidated Cut block data set	Area
Common polygons (2012 and 2013)	242,055
2013 only	23,598 (includes some new 2013 cut blocks)
2012 only	43,584
Total	309,237

GEOPROCESSING METHOD

Table 36: Geoprocessing of Disturbance from Forest Clear Cutting Source Data

Topic	Query or Process
Consolidated cut blocks	None
Harvest Authority	Not used FTEN Harvest Authority contains information from occupant license to cut authorizations from tenures such as wind power; coal tenures; that are not documented in the consolidated cut blocks. Although geometry exists for these tenures, the current status of the tenures is unknown.

Table 37: Geoprocessing to Create a Disturbance from Forest Clear Cutting Indicator Layer

Result	Source Layer	Target Layer	Action
Union of Consolidated Cut blocks	Consolidated cut blocks 2012	Consolidated cut blocks 2013	Union
If one wanted to use Harvest Authority data	Harvest Authority	Union of Consolidated Cut blocks	Intersection
If one wanted to use Harvest Authority data (continued)	Intersection of Harvest Authority and Union of Consolidated cut blocks	Union of Consolidated Cut blocks	Union
Forestry Cut blocks per AOI polygon (ha/km^2)	Union of Consolidated Cut blocks	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Forest Burn Scars (ForBurn)

REPRESENTATION

Areas denuded of forest cover through fire can shed substantial sediment loads into nearby freshwater resources. Burned forested areas can be slower to regrow than recently logged areas.

DATA SOURCES

Table 38: Data Source for Disturbance from Forest Burn Scars

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Forest Burn Scars	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y		Y	1997-07-01

GEOPROCESSING METHOD

Table 39: Geoprocessing of Disturbance from Forest Burn Scars Source Data

Topic	Query or Process
Forest Burn Scars	PRESENT_LAND_USE_LABEL = Recently Burned (Area virtually devoid of trees due to fire within the past 20 years. Forest less than or equal to 15% cover).

Table 40: Geoprocessing to Create a Disturbance from Forest Burn Scars Indicator Layer

Result	Source Layer	Target Layer	Action
Forest Burn Scars per AOI polygon (ha/km^2)	Forest Burn Scars	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Urban (Urban)

REPRESENTATION

Urban data is taken from a land use analysis of mostly Landsat 5 image mosaics. It is spatially accurate to 250m.

DATA SOURCES

Table 41: Data Source for Urban Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Urban	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y	FLNRO	Y	1997-07-01

GEOPROCESSING METHOD

Table 42: Geoprocessing of Urban Disturbance Source Data

Topic	Query or Process
Urban	PRESENT_LAND_USE_LABEL = Urban (all compact settlements including built up areas of cities, towns and villages as well as units away from settlements such as manufacturing plants, rail yards and military camps. In most cases residential use will predominate in these areas. Open space which forms an integral part of the urban agglomeration, e.g. parks, golf courses, etc. are included as urban)

Table 43: Geoprocessing to Create an Urban Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action

Result	Source Layer	Target Layer	Action
Urban per AOI polygon (ha/km^2)	Urban	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Oil and Gas Industry Related Infrastructure (OGinfr)

REPRESENTATION

Oil and Gas infrastructure data is a combination of pipelines, well pads, facilities and other ancillary activity such as borrow pits, decking sites and temporary disturbances. Data comes from a variety of sources in a variety of forms. If line data is provided, the line is buffered along its length to provide a representative area value.

DATA SOURCES

Table 44: Data Sources for Oil and Gas Infrastructure Related Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
CROWN TENURES	WHSE_TANTALIS.TA_CROWN_TENURES_SVW	Y	FLNRO	Y	2015-03-31
TANTALIS – SURVEY PARCELS	WHSE_TANTALIS.TA_SURVEYED_ROW_PARCELS_SVW	Y	FLNRO	Y	2015-03-31
OG Pipeline RW	WHSE_MINERAL_TENURE_OG_PIPELINE_RW_PUB_SP	Y	OGC	Y	2015-03-31
OG Well Sites	WHSE_MINERAL_TENURE_OG_WELL_SITES_PUB_SP	Y	OGC	Y	2015-03-31
OG Facilities	WHSE_MINERAL_TENURE_OG_FACILITY_SITES_PUB_SP	Y	OGC	Y	2015-03-31
OG Ancillary	WHSE_MINERAL_TENURE_OG_ANCILLARY_OTHER_APPS_PUB_SP	Y	OGC	Y	2015-03-31
OG Surface Hole	WHSE_MINERAL_TENURE.OG_SURFACE_HOLE_STATUS_SP	Y	OGC	Y	2015-03-31
TRIM Pipelines	WHSE_BASEMAPPING.TRIM_CULTURAL_LINES	Y	FLNRO	N	

GEOPROCESSING METHOD

Table 45: Geoprocessing of Oil and Gas Infrastructure Related Disturbance Source Data

Topic	Query or Process
CROWN TENURES	TENURE_PURPOSE = UTILITY AND TENURE_SUBPURPOSE = GAS AND OIL PIPELINE OR TENURE_PURPOSE = ENERGY PRODUCTION And proposed tenures were removed from the analysis by two additional query conditions: TENURE_TYPE <> 'RESERVE/NOTATION' and TENURE_STAGE <> 'APPLICATION'

Topic	Query or Process
TANTALIS – SURVEY PARCELS	FCODE = FA91300120 or FCODE = FA91400120
OG Pipeline RW	Pipelines under application (not constructed) were removed from the analysis by a query: APPLICATION_STATUS <> 'APPROV'
OG Well Sites	All well site polygons
OG Facilities	Facilities under application (not constructed) were removed from the analysis by a query: APPLICATION_STATUS <> 'APPROV'
OG Ancillary	ANCILLARY_OTHER_APP_TYPE not equal to “ROAD” or “INV”
OG Surface Hole	Wells never constructed were removed from the analysis using the WELL_ACTIVITY field to query out wells cancelled before being constructed ('CANC') and wells authorized but not constructed ('WAG') Point data. Data may be duplicated in Tantalis and OGC datasets; buffer 1.44 hectares (60 metres buffer radius); In ArcGIS, use the Feature Envelope To Polygon tool to convert the circle buffer to a square buffer.
Trim Pipelines	FCODE = EA21400000; buffer 10 metres

Table 46: Geoprocessing to Create an Oil and Gas Infrastructure Related Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Oil and Gas infrastructure	CROWN TENURES TANTALIS – SURVEY PARCELS OG Pipeline RW OG Well Sites OG Facilities OG Ancillary OG Surface Hole TRIM Pipelines	New layer (Oil and Gas Infrastructure)	Merge; dissolve created on outer boundaries
Oil and Gas infrastructure per AOI polygon (ha/km^2)	Oil and Gas infrastructure	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Linear Features (Linear)

Disturbance associated with linear features is calculated as an amalgamation of disturbance from roads, railway lines and transmission lines. Data comes from a variety of sources in a variety of forms. If line data is provided, the line is buffered along its length to provide a representative area value.

Disturbance from Linear Features - Roads

DATA SOURCES

Table 47: Data Sources for Road Disturbance

Topic	Source Location (with hyperlink where possible)	BCGW	Data Provider	Public Data	Data Last Modified
Digital Road Atlas (DRA)	WHSE_BASEMAPPING.DRA_DGTL_ROAD_ATLAS_MPAR_SP	Y	FLNRO	Y	2014-12-10
Forest Service Roads (FTEN)	WHSE_FOREST_TENURE.FTEN_ROAD_SECTION_LINES_SVW	Y	FLNRO	Y	2015-03-31
Petroleum Development Roads (PDR)	WHSE_MINERAL_TENURE.OG_PETRLM_DEV_ROADS_PUB_SP	Y	OGC	Y	2015-03-31
Petroleum Development Roads Pre06 (PDR)	WHSE_MINERAL_TENURE_OG_PETRLM_DEV_RDS_PRE06_PUB_SP	Y	OGC	Y	2010-03-25
Petroleum Access Roads (PDR)	WHSE_MINERAL_TENURE_OG_PETRLM_ACCESS_ROADS_PUB_SP	Y	OGC	Y	2015-03-31
Trails (TR)	WHSE_FOREST_TENURE.FTEN_RECREATION_LINES_SVW	Y	FLNRO	Y	2015-03-31

Note: Currently there is a provincial project to produce a consolidated road network product, the Integrated Transportation Network (ITN), which would replace the multiple sources used in this initial analysis.

GEOPROCESSING METHOD

Table 48: Geoprocessing of Road Disturbance Source Data

Topic	Query or Process
Digital Road Atlas (DRA)	Road Class = Highway; buffer 15 metres Road Surface = Paved; buffer 15 metres Road Surface = Loose; buffer 10 metres Road Surface = Rough; buffer 7.5 metres Road Surface = Overgrown; buffer 7.5 metres Road Surface = Decomissioned; buffer 7.5 metres Road Surface = Unknown; buffer 7.5 metres
Forest Service Roads (FTEN)	FILE_TYPE_DESCRIPTION = FSR; buffer 10 metres FILE_TYPE_DESCRIPTION = RP; buffer 7.5 metres
Petroleum Development Roads	PETRLM_DEVELOPMENT_ROAD_TYPE = High Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Low Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Winter; buffer 3.5 metres PETRLM_DEVELOPMENT_ROAD_TYPE = blank; buffer 3.5 metres
Petroleum Development Roads Pre06	PETRLM_DEVELOPMENT_ROAD_TYPE = High Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Low Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Winter; buffer 3.5 metres PETRLM_DEVELOPMENT_ROAD_TYPE = blank; buffer 3.5 metres
Petroleum Access Roads	PETRLM_ACCESS_ROAD_TYPE = High Grade; buffer 10 metres PETRLM_ACCESS_ROAD_TYPE = Low Grade; buffer 10 metres PETRLM_ACCESS_ROAD_TYPE = Winter; buffer 3.5 metres PETRLM_ACCESS_ROAD_TYPE = blank; buffer 3.5 metres
Trails (TR)	Right of Way not null; buffer ½ of RIGHT_OF_WAY attribute value Right of Way null; buffer 2.5 metres

Table 49: Geoprocessing to Create a Road Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action

Result	Source Layer	Target Layer	Action
Consolidated Roads	Digital Road Atlas (DRA) Forest Service Roads (FTEN) Petroleum Development Roads Petroleum Development Roads Pre06 Petroleum Access Roads Trails (TR	New layer (Consolidated Roads)	Merge; dissolve created on outer boundaries
Consolidated Roads per AOI polygon (ha/km^2)	Consolidated Roads	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Linear Features – Railway Lines

DATA SOURCES

Table 50: Data Sources for Railway Line Disturbance

Topic	Source Location (with hyperlink where possible)	BCGW	Data Provider	Public Data	Data Last Modified
Trim Railways	WHSE_BASEMAPPING.TRIM_TRANSPORTATION_LINES	Y	FLNRO	N	2015-03-31
Federal Railways	National Railway Network (NRWN) - BC, British Columbia	N	NRCan	Y	2013-11-03
Tantalis Survey Parcels	WHSE_TANTALIS.TA_SURVEY_PARCELS_SVW	Y	FLNRO	Y	2015-03-31
Tantalis Transportation	WHSE_TANTALIS_TA_TRANSPORTATION_SVW	Y	FLNRO	Y	2014-12-11

Trim railway features are not available to the Public. This data was added to ensure as complete dataset as possible.

GEOPROCESSING METHOD

Table 51: Geoprocessing of Railway Line Disturbance Source Data

Topic	Query or Process
Trim Railways	DE22850000, DE22850110, DE22850120, DE22900000, DE22950000, DE22950001, DE22950120, DF28850000, F28850000; buffer 17.5 metres
Federal Railways	buffer 17.5 metres
Tantalis Survey Parcels	Feature Code = FA91200130
Tantalis Transportation	Feature Code = FA91200120

Table 52: Geoprocessing to Create a Railway Line Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action

Result	Source Layer	Target Layer	Action
Merged Transportation and Survey Parcels	Tantalis Survey Parcels Tantalis Transportation	New layer Transportation and Survey Parcels	Merge
Consolidated Railway lines	Merged Transportation and Survey Parcels TRIM Railways Federal Railways	New layer (Consolidated Railways)	In areas where the merged Transportation and Survey Parcels layer does not have any polygons, TRIM Railways and National Railway Network were buffered and added. Then a dissolve to create the outer boundaries of railways.
Railway Lines per AOI polygon (ha/km^2)	Consolidated Railway lines	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Linear Features – Transmission Lines

DATA SOURCES

Table 53: Data Sources for Transmission Line Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
CROWN TENURES	WHSE_TANTALIS.TA_CROWN_TENURES_SVW	Y	FLNRO	Y	2015-03-31
TANTALIS- SURVEY PARCELS	WHSE_TANTALIS.TA_SURVEYED_ROW_PARCELS_SVW	Y	FLNRO	Y	2015-03-31
BC Hydro Transmission	Circuit.shp	N	BC Hydro	Y	

GEOPROCESSING METHOD

Table 54: Geoprocessing of Transmission Line Disturbance Source Data

Topic	Query or Process
CROWN TENURES	Subpurpose = ELECTRIC POWER LINE
TANTALIS- SURVEY PARCELS	FEATURE_CODE = FA91400110
BC Hydro Transmission	Buffer 9.15 metres

Table 55: Geoprocessing to Create a Transmission Line Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Merged Survey Parcels and Crown Tenure	Tantalis Survey parcels Crown Tenures	Merged Survey Parcels and Crown Tenure layer	Merge
Consolidated Transmission lines	Merged Survey Parcels and Crown Tenure BC Hydro Transmission	New layer (Consolidated transmission lines)	In areas where the Merged Survey Parcels and Crown Tenure layer does not have any

Result	Source Layer	Target Layer	Action
			polygons, BC Hydro Transmission lines were buffered and added. Then a dissolve to create the outer boundaries of transmission lines.
Transmission Lines per AOI polygon (ha/km^2)	Consolidated Transmission Lines	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Mining (Mining)

REPRESENTATION

Mining is primarily limited to coal operations in northeast B.C. The land area for active mines is represented by lease areas.

DATA SOURCES

Table 56: Data Source for Mining Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Mining Tenure	WHSE_MINERAL_TENURE.MTA_ACQUIRED_TENURE_SVW	Y	MEM	Y	2015-03-31

GEOPROCESSING METHOD

Table 57: Geoprocessing of Mining Disturbance Source Data

Topic	Query or Process
Mining Tenure	TENURE_SUB_TYPE_DESCRIPTION = Lease

Table 58: Geoprocessing to Create a Mining Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Mining Tenure per AOI polygon (ha/km^2)	Mining Tenure	AOI polygon layer	Polygonal Area as per Table 2

Contamination from Effluent (Industrial Waste and Sewage)

REPRESENTATION

Permits are granted to dispose of liquid waste into freshwater resources. The data can be analyzed by the type of contaminant, the over tonnage of disposal, tonnage by contaminant type or the number of sites where disposal occurs. For this analysis, the number of sites for disposal was used.

DATA SOURCES

Table 59: Data Sources for Effluent Contamination

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Waste Discharge	Waste Discharge Authorizations- All Discharges Information limited to location of discharge points as they relate to authorizations. Data sporadic and requires QA/QC	N	ENV	Y	2015-03-31
Environmental Monitoring System Locations	WHSE_ENVIRONMENTAL_MONITORING.EMS_MONITORING_LOCN_TYPES_SVW	Y	ENV	Y	2015-03-31
Waste Discharge Codes	EMS Codes	N	ENV	Y	

GEOPROCESSING METHOD

Table 60: Geoprocessing of Effluent Contamination Source Data

Topic	Query or Process
Waste Discharge	Combine the Waste Discharge authorizations table with Environmental Monitoring System Locations by joining the EMS Site attribute field to MONITORING_LOCATION_ID attribute field. Then select points with DischargeType = effluent; EMSPurposeCode = 3; EMSDischargeCode = 1 or 5;

Table 61: Geoprocessing to Create an Effluent Contamination Indicator Layer

Result	Source Layer	Target Layer	Action
Waste Discharge Sites per AOI polygon (Count/km^2)	Waste Discharge	AOI polygon layer	Point Count as per Table 2

Future Disturbance Indicator Layers

Future water quality expected to be most impacted by industrial-related disturbance in the following industries: unconventional gas development, forestry and mining.

Potential Disturbance from Unconventional Gas Development (OGPlays)

REPRESENTATION

In this analysis, potential future oil and gas development is limited to unconventional gas plays because since 2005 a strongly increasing to dominant number of new well licenses is related to unconventional development. There are four large areas considered prospective for unconventional gas development on the basis of geology: the Montney Play Trend, the Horn River Basin, the Cordova Embayment and the Liard Basin. For future petroleum-related disturbance, any land surface physically above a potential unconventional play is possibly subject to water quality impact from development activities.

DATA SOURCES

Table 62: Data Source for Disturbance from Unconventional Gas Development

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Unconventional Gas Plays	WHSE_MINERAL_TENURE.OG_UNCONVENTNL_PLAY_TRENDS_SP	Y	OGC	Y	2010-03-25

GEOPROCESSING METHOD

Table 63: Geoprocessing of Disturbance from Unconventional Gas Development Source Data

Topic	Query or Process
Unconventional Gas Plays	All four play trends (Montney, Horn River, Cordova, Liard)

Table 64: Geoprocessing to Create a Disturbance from Unconventional Gas Development Indicator Layer

Result	Source Layer	Target Layer	Action
Unconventional Gas Development per AOI polygon (ha/km^2)	Unconventional Gas Plays	AOI polygon layer	Polygonal Area as per Table 2

Potential Disturbance from Mining (Mine)

REPRESENTATION

Mining is primarily limited to coal operations in northeast B.C. The land area for active mines is represented by lease areas. Areas of future expansion are held by license. Mineral and placer-based mines are represented by licensed areas, if they exist. Potential future mining areas are not well captured under the current system. Claims represent a potential area much larger than that which may potentially be mined. Possible impact to water quality by mining therefore is limited mainly to coal leases and licenses.

DATA SOURCES

Table 65: Data Source for Potential Disturbance from Mining

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Mining Tenure	WHSE_MINERAL_TENURE.MTA_ACQUIRED_TENURE_SVW	Y	MEM	Y	2015-03-31

GEOPROCESSING METHOD

Table 66: Geoprocessing of Potential Disturbance from Mining Source Data

Topic	Query or Process
Mining Tenure	TENURE_SUB_TYPE_DESCRIPTION = lease or License

Table 67: Geoprocessing to Create a Potential Disturbance from Mining Indicator Layer

Result	Source Layer	Target Layer	Action
Mining Tenure per AOI polygon (ha/km^2)	Mining Tenure	AOI polygon layer	Polygonal Area as per Table 2

Potential Disturbance from Forestry (ForestCrwn)

REPRESENTATION

The largest impact from forestry activity to water quality is in areas of cut blocks. Future forest industry activity will predominantly occur in the cutting of crown forested areas. For this analysis, all crown forest areas are considered potential for clear cutting activities.

DATA SOURCES

Table 68: Data Source for Potential Disturbance from Forestry

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Crown forest areas	WHSE_FOREST_VEGETATION.VEG_COMP_LYR_R1_POLY	Y	FLNRO	Y	2014-12-16

GEOPROCESSING METHOD

Table 69: Geoprocessing of Potential Disturbance from Forestry Source Data

Topic	Query or Process
Crown forest areas	FOR_MGMT_LAND_BASE_IND = Y

Table 70: Geoprocessing to Create a Potential Disturbance from Forestry Indicator Layer

Result	Source Layer	Target Layer	Action
Crown Forest area per AOI polygon (ha/km^2)	Crown forest areas	AOI polygon layer	Polygonal Area as per Table 2

Layers Indicative of Human or Ecosystem Sensitivity

The stewardship of water resources for people and the environment is considered an important duty. This section is designed to flag basins where monitoring should be prioritized as a safeguarding feature. The indicator layers prioritize represent areas where it is most important that water condition and trend be tracked.

Population (Pop)

REPRESENTATION

Water of sufficient quantity and quality are a necessity of life and a requirement for regions of human habitation. There are two ways to capture domestic water needs: 1) by licensed volume and 2) by population concentration. Since volume data from government issued water licenses does not capture First Nations water needs, the population data is used for this assessment.

DATA SOURCES

Table 71: Data Sources for Population

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Population Boundary	Population Boundary data	N	Statistics Canada	Y	
Population	Population data	N	Statistics Canada	Y	

GEOPROCESSING METHOD

Table 72: Geoprocessing of Population Source Data

Topic	Query or Process
Population by dissemination block area	Population boundary and population were joined BC dissemination blocks were selected and exported to a new feature class which was then reprojected from geographic to BC Albers. A new field was added "DisseminationBlock_AREA" and calculated to equal the SHAPE_AREA (using area-weighting, the new field can subsequently be used for estimating population in a dissemination block which has been split by intersection with a watershed/basin).

Table 73: Geoprocessing to Create a Population Indicator Layer

Result	Source Layer	Target Layer	Action
Population per AOI polygon (count/km^2)	Population by dissemination block area	AOI polygon layer	Polygonal Data as per Table 2

Wetland Density (Wetland)

REPRESENTATION

Wetlands affect water quality and quantity by serving to improve water quality and buffer flow volumes. They also serve as habitat for terrestrial and aquatic species. Wetland has been mapped in a variety of forms, the newest and most comprehensive mapping of wetland being by Ducks Unlimited. However that data set is not in the public realm. Sections of northeast B.C. are mapped in great detail, but universal coverage was sought for the entire northeast region. Options include the freshwater atlas (FWA), the enhanced base map (EBM), and baseline thematic map (BTM). The BTM was chosen because it is accurate to 250m across the entire region and provides polygonal data for several indicator layers including wetland, freshwater, agriculture, and urban areas so it provides more congruence across indicator layers in the project.

DATA SOURCES

Table 74: Data Source for Wetland

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Wetland	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y	FLNRO	Y	1997-07-01

GEOPROCESSING METHOD

Table 75: Geoprocessing of Wetland Source Data

Topic	Query or Process
Wetland	PRESENT_LAND_USE_LABEL = Wetland (Wetlands including swamps, marshes, bogs or fens. This class excluded lands with evidence of knowledge of haying or grazing in drier years)

Table 76: Geoprocessing to Create a Wetland Density Indicator Layer

Result	Source Layer	Target Layer	Action
Wetland per AOI polygon (ha/km^2)	Wetland	AOI polygon layer	Polygonal Area as per Table 2

Headwater Density (Headwater) and Lake Density (LakeDensity)

REPRESENTATION

It was challenging to find a good indicator layer for aquatic species sensitivity. Species surveys are spotty and inconsistent in the northeast. Absence of species is does not necessarily indicate a change in population. The environments that most support aquatic species diversity and population were used as indicator layers instead: riverine headwaters and lakes. Mapping comes from the Ecological Aquatic Units of British Columbia (EAU BC), a hierarchical classification of freshwater ecosystems that integrates many factors including zoogeography, physiography and climatic patterns as well as more localized physical habitat and dominant environmental processes.

DATA SOURCES

Table 77: Data Source for Headwaters

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Headwaters	WHSE_LAND_AND_NATURAL_RESOURCE.EAUBC_RIVERS_SP	Y	ENV	Y	2007-11-30

GEOPROCESSING METHOD

Table 78: Geoprocessing of Headwater Source Data

Topic	Query or Process
Headwaters	RIVER_ECOSYSTEM_CLASS = H

Table 79: Geoprocessing to Create a Headwater Density Indicator Layer

Result	Source Layer	Target Layer	Action
Headwaters per AOI polygon (ha/km^2)	Headwaters	AOI polygon layer	Polygonal Area as per Table 2

DATA SOURCES

Table 80: Data Source for Lakes

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Lakes	WHSE_LAND_AND_NATURAL_RESOURCE.EAUBC_LAKES_SP	Y	ENV	Y	2007-11-30

GEOPROCESSING METHOD

Table 81: Geoprocessing of Lake Source Data

Topic	Query or Process
Lakes	All lakes

Table 82: Geoprocessing to Create a Lake Density Indicator Layer

Result	Source Layer	Target Layer	Action
Lakes per AOI polygon (ha/km^2)	Lakes	AOI polygon layer	Polygonal Area as per Table 2

GROUNDWATER QUANTITY

A disturbance-sensitivity based approach to enhanced groundwater monitoring is challenging. Groundwater occurs almost everywhere beneath the land surface but there is very limited information on whether the groundwater is part of an aquifer and the water quality within that aquifer. Substantially more groundwater mapping is required. In this section, groundwater quantity monitoring is directed toward current industrial groundwater demand, potential future industrial demand and monitoring the trend and condition of groundwater supply for human and ecosystem needs. The indicator layers used to determine enhanced monitoring needs for groundwater quantity are listed below.

Table 83: Indicator Layers for Groundwater Quantity Monitoring

Topic	Indicator Layer
Current Disturbance	Well Density
Current Disturbance	Current Water Demand for Hydraulic Fracturing
Future Disturbance	Possible Future Water Demand for Hydraulic Fracturing
Future Disturbance	Possible Water Demand by Mining
Future Disturbance	Surface Water Restrictions
Sensitivity	Population

Current Disturbance Indicator Layers

Current water demand is difficult to accurately represent at this time because the only information available comes from the Wells Database. This database is largely populated by information collected by drillers at the time of well installation. It is error-prone and lacking in reproducible information about well yield.

Well Density (WellDensity)

REPRESENTATION

Domestic and industrial wells (with the exception of some oil and gas industry source wells) are listed in the wells database. The density of wells in a region is a general indication of relative demand on the groundwater resources.

DATA SOURCES

Table 84: Data Source for Well Density

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Well Density	WHSE_WATER_MANAGEMENT.GW_WATER_WELLS_WRBC_SVW	Y	ENV	Y	2015-03-31

GEOPROCESSING METHOD

Table 85: Geoprocessing of Well Density Source Data

Topic	Query or Process
Well Density	All wells

Table 86: Geoprocessing to Create a Well Density Indicator Layer

Result	Source Layer	Target Layer	Action
Well Density per AOI polygon (ha/km^2)	Well Density	AOI polygon layer	Point Count as per Table 2

Current Water Demand for Hydraulic Fracturing (OGFracWater)

REPRESENTATION

Water demand for unconventional gas development is not uniform across northeast B.C. but varies according to geology. Water demand is a function of the hydraulic fracturing style necessary for development of a specific formation in specific area. This indicator layer addresses water demand by area as a function of geology and development style. It presents the average stimulation volume needed per well. Water sources for hydraulic fracturing include surface water, fresh groundwater, saline groundwater and recycled water. The source of water for hydraulic fracturing is not broken out on this layer.

DATA SOURCES

Table 87: Data Sources for Current Water Demand for Hydraulic Fracturing

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Well Completions	https://iris.bcogc.ca/download/drill_csv.zip File = compl_wo.csv	N	OGC	Y	2015-03-31
Well locations	WHSE_MINERAL_TENURE.OG_BOTTOM_HOLE_EVENT_SP	Y	OGC	Y	2015-03-31

GEOPROCESSING METHOD

Table 88: Geoprocessing of Current Water Demand for Hydraulic Fracturing Source Data

Topic	Query or Process
Well completion data with water volumes	Only well events (UWI) where stimulation fluid was used (i.e. Stimultn_vol>0). Stimulation volume was summed by UWI.

Table 89: Geoprocessing to Create a Current Water Demand for Hydraulic Fracturing Indicator Layer

Result	Source Layer	Target Layer	Action
Stimulation volume per well per AOI polygon (ha/km^2)	Stimulation volume per well	AOI polygon layer	Point Count as per Table 2

Future Disturbance Indicators

Future water demand is expected to be highest for unconventional gas development through hydraulic fracturing. Water demand for water flood operations and other petroleum development activities is not expected to be a major source of water demand in the future. Future demand related to mining is expected primarily from coal mining where water may be required for washing coal, slurries, dust maintenance and more. The agricultural sector may also demand water through irrigation. Irrigation practices are minimal at present, but are expected to increase according to climate change predictions for northeast B.C. of warmer temperatures and decreased snow in winter. The forest sector is not expected to place any significant demands on water quantity in the future.

Possible Future Water Demand for Hydraulic Fracturing (PotOGWater)

REPRESENTATION

Water demand for unconventional gas development is not uniform across northeast B.C. but varies according to geology. Water demand is a function of the hydraulic fracturing style necessary for development of a specific formation in specific area. This indicator layer, Potential Water Demand for Hydraulic Fracturing, addresses water demand by area as a function of geology and development style. It presents the average stimulation volume needed per well in a given pool where a pool represents both the region and the horizon at depth specifically being targeted.

The relative stimulation volumes currently needed across pools in northeastern B.C. is considered a proxy for future development needs. There has been rapid technological advancement in hydraulic fracturing. The style of hydraulic fracturing (e.g. high volume slickwater or energized foams) in a given pool is not expected to change very quickly. The water volume required by a select style of fracturing can be highly dynamic. For example, the stimulation volume of water per well for high volume slickwater fracturing has increased by ten-fold in the past seven years.

DATA SOURCES

Table 90: Data Sources for Possible Future Water Demand for Hydraulic Fracturing

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Oil and Gas Pools	WHSE_MINERAL_TENURE.OG_POOL_DESGNTN_AREA_PUB_SP	Y	OGC	Y	2015-03-31
Well completion data with water volumes	Well completion data File = compl_wo.csv	N	OGC	Y	2015-03-31
Well location by Unique Well identifier (UWI)	WHSE_MINERAL_TENURE.OG_BOTTOM_HOLE_EVENT_SP	Y	OGC	Y	2015-03-31

GEOPROCESSING METHOD

Table 91: Geoprocessing of Possible Future Water Demand for Hydraulic Fracturing Source Data

Topic	Query or Process
Well completion data with water volumes	Only well events (UWI) where stimulation fluid was used (i.e. Stimultn_vol>0). A pool identifier was created by concatenating Field Area, Formation and Pool Sequence. Stimulation volume was summed by UWI.
Oil and Gas Pools	A pool identifier was created by concatenating Field Area, Formation and Pool Sequence.
Well location by unique Well identifier	Well completion data table Joined to Location data by UWI.

Table 92: Geoprocessing to Create a Possible Future Water Demand for Hydraulic Fracturing Indicator Layer

Result	Source Layer	Target Layer	Action
Average stimulation volume per pool	Well completion data with water volumes	Oil and Gas Pools	Joined well point data to pool polygons. Pools assigned the average UWI stimulation volume per well.
Average stimulation volume per AOI polygon (m^3/km^2)	Average stimulation volume per pool	AOI polygon layer	Polygon Data as per Table 2

Possible Water Demand by Mining (Mine)

REPRESENTATION

Mining is primarily limited to coal operations in northeast B.C. The land area for active mines is represented by lease areas. Areas of future expansion are held by license. Mineral and placer-based mines are represented by licensed areas, if they exist. Potential future mining areas are not well captured under the current system. Claims represent a potential area much larger than that which may potentially be mined. Possible Water Demand by Mining therefore is limited mainly to coal leases and licenses. Mines use water for washing coal and equipment. Water is also used for dust control on roads.

DATA SOURCES

Table 93: Data Source for Possible Water Demand by Mining

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Mining Tenure	WHSE_MINERAL_TENURE.MTA_ACQUIRED_TENURE_SVW	Y	MEM	Y	2015-03-31

GEOPROCESSING METHOD

Table 94: Geoprocessing of Possible Water Demand by Mining Source Data

Topic	Query or Process
Mining Tenure	TENURE_SUB_TYPE_DESCRIPTION = Lease or License

Table 95: Geoprocessing to Create a Possible Water Demand by Mining Indicator Layer

Result	Source Layer	Target Layer	Action
Mining Tenure per AOI polygon (ha/km^2)	Mining Tenure	AOI polygon layer	Polygonal Area as per Table 2

Surface Water Restrictions (SWRestriction)

Occasionally a restriction notification is placed on water bodies to limit future water allocation decisions. A water allocation restriction is an indication that water demand has, at least temporarily, outpaced availability. A restriction may range from including minimum fish flow clauses in a water license, to suspending the issuance of any further licenses on a water body. Basins with more restrictions indicate stress or limitation on water resources.

REPRESENTATION

In areas of surface water shortage, restrictions can be placed on water bodies, either limiting or prohibiting further water extraction water license applicants. A water allocation restriction is an indication that water demand has, at least temporarily, outpaced availability. A restriction may range from including minimum fish flow clauses in a water license, to suspending the issuance of any further licenses on a water body. Basins with more restrictions indicate stress or limitation on water resources.

It is anticipated that there will be a greater future demand on groundwater as a result of surface water restrictions. Currently, restrictions are available in point form. There is a restriction lines layer that is generated on an annual basis using stream network base mapping. However, it isn't possible to represent all restrictions as stream network lines at this time.

DATA SOURCES

Table 96: Data Source for Surface Water Restrictions

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Surface Water Restrictions	WHSE_WATER_MANAGEMENT.WLS_WATER_RESTRICTION_LOC_SVW	Y	FLNRO	Y	2015-05-04

GEOPROCESSING METHOD

Table 97: Geoprocessing of Surface Water Restrictions Source Data

Topic	Query or Process
Surface Water Restrictions	All restrictions

Table 98: Geoprocessing to Create a Surface Water Restrictions Indicator Layer

Result	Source Layer	Target Layer	Action
Surface Water Restrictions per AOI polygon (ha/km^2)	Surface Water Restrictions	AOI polygon layer	Point Count as per Table 2

Layers Indicative of Human or Ecosystem Sensitivity

The stewardship of water resources for people and the environment is considered an important duty. This section is designed to flag basins where monitoring should be prioritized as a safeguarding feature. The indicator layers prioritize areas where it is most important that water condition and trend be tracked.

At this time, it is not feasible to include indicator layers for environmental sensitivity. In future, there may be sufficient data to include layers associated with groundwater-surface water interaction or drought associated with lowering of the groundwater table.

Population (Pop)

REPRESENTATION

Water of sufficient quantity and quality are a necessity of life and a requirement for regions of human habitation. There are two ways to capture domestic water needs: 1) by licensed volume and 2) by population concentration. Since volume data from government issued water licences does not capture First Nations water needs, the population data is used for this assessment.

DATA SOURCES

Table 99: Data Sources for Population

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Population Boundary	Population Boundary data	N	Statistics Canada	Y	
Population	Population data	N	Statistics Canada	Y	

GEOPROCESSING METHOD

Table 100: Geoprocessing of Population Source Data

Topic	Query or Process
Population by dissemination block area	Population boundary and population were joined BC dissemination blocks were selected and exported to a new feature class which was then reprojected from geographic to BC Albers. A new field was added "DisseminationBlock_AREA" and calculated to equal the SHAPE_AREA (using area-weighting, the new field can subsequently be used for estimating population in a dissemination block which has been split by intersection with a watershed/basin).

Table 101: Geoprocessing to Create a Population Indicator Layer

Result	Source Layer	Target Layer	Action
Population per AOI polygon (count/km^2)	Population by dissemination block area	AOI polygon layer	Polygonal Data as per Table 2

GROUNDWATER QUALITY

A disturbance-sensitivity based approach to enhanced groundwater monitoring is challenging. Groundwater occurs almost everywhere beneath the land surface but there is very limited information on whether the groundwater is part of an aquifer and the water quality within that aquifer. Substantially more groundwater mapping is required. This section focuses on assessing the relative importance of monitoring groundwater quality where it is potentially affected by current and future industrially related disturbance and in areas where groundwater quality is important for human and ecosystem needs. The indicator layers used to determine enhanced monitoring needs for groundwater quality are listed below.

Table 102: Indicator Layers for Groundwater Quality Monitoring

Topic	Indicator Layer
Current Disturbance	Disturbance from Agriculture
Current Disturbance	Disturbance from Forest Clear Cutting
Current Disturbance	Disturbance from Urban
Current Disturbance	Disturbance from Oil and Gas Industry Related Infrastructure
Current Disturbance	Disturbance from Linear Features (Roads, Railway Lines and Transmission Lines)
Current Disturbance	Disturbance from Mining
Future Disturbance	Potential Disturbance from Unconventional Gas Development
Future Disturbance	Potential Disturbance from Mining
Sensitivity	DRASTIC model of Groundwater Vulnerability

Current Disturbance Indicator Layers

Disturbance from Agriculture (Ag)

REPRESENTATION

Disturbance from agriculture can affect water quality through drainage of pesticides, herbicides and nutrients into nearby freshwater.

DATA SOURCES

Table 103: Data Source for Disturbance from Agriculture

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Agriculture	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y	FLNRO	Y	1997-07-01

GEOPROCESSING METHOD

Table 104: Geoprocessing of Disturbance from Agriculture Source Data

Topic	Query or Process
Agriculture	PRESENT_LAND_USE_LABEL = Agriculture (Land based agricultural activities undifferentiated as to crop (i.e. land is used as the producing medium) and Residential Agriculture Mixtures (Areas where agriculture activities are intermixed with residential and other buildings with a density of between 2 and 0.2 hectares).

Table 105: Geoprocessing to Create a Disturbance from Agriculture Indicator Layer

Result	Source Layer	Target Layer	Action
Agriculture per AOI polygon (ha/km^2)	Agriculture	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Forest Clear Cutting (ForCuts)

REPRESENTATION

Areas denuded of forest cover can shed sediment via overland flow into nearby freshwater Disturbance from agriculture can affect water quality through drainage of pesticides, herbicides and nutrients into nearby freshwater.

DATA SOURCES

Table 106: Data Sources for Disturbance from Forest Clear Cutting

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Consolidated cut blocks	Consolidated_Cutblocks_2013.gdb	N	FLNRO	Y	
Consolidated cut blocks	Consolidated_Cutblocks_2012.gdb	N	FLNRO	Y	
Harvest Authority	WHSE_FOREST_TENURE.FTEN_HARVEST_AUTH_POLY_SVW	Y	FLNRO	Y	2015-03-31

The process for capturing Consolidated Cut blocks changed for the 2013 model. It is speculated that wildfire data may have been dropped from the 2013 data.

Comparison of Consolidated Cut blocks for 2012 and 2013

Consolidated Cut block data set	Area
Common polygons (2012 and 2013)	242,055
2013 only	23,598 (includes some new 2013 cut blocks)

2012 only	43,584
Total	309,237

GEOPROCESSING METHOD

Table 107: Geoprocessing of Disturbance from Forest Clear Cutting Source Data

Topic	Query or Process
Consolidated cut blocks	None
Harvest Authority	Not used FTEN Harvest Authority contains information from occupant license to cut authorizations from tenures such as wind power; coal tenures; that are not documented in the consolidated cut blocks. Although geometry exists for these tenures, the current status of the tenures is unknown.

Table 108: Geoprocessing to Create a Disturbance from Forest Clear Cutting Indicator Layer

Result	Source Layer	Target Layer	Action
Union of Consolidated Cut blocks	Consolidated cut blocks 2012	Consolidated cut blocks 2013	Union
If one wanted to use Harvest Authority data	Harvest Authority	Union of Consolidated Cut blocks	Intersection
If one wanted to use Harvest Authority data (continued)	Intersection of Harvest Authority and Union of Consolidated cut blocks	Union of Consolidated Cut blocks	Union
Forestry Cut blocks per AOI polygon (ha/km^2)	Union of Consolidated Cut blocks	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Urban (Urban)

REPRESENTATION

Urban data is taken from a land use analysis of mostly Landsat 5 image mosaics. It is spatially accurate to 250m.

DATA SOURCES

Table 109: Data Source for Urban Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Urban	WHSE_BASEMAPPING.BTM_PRESENT_LAND_USE_V1_SVW	Y	FLNRO	Y	1997-07-01

GEOPROCESSING METHOD

Table 110: Geoprocessing of Urban Disturbance Source Data

Topic	Query or Process
Urban	PRESENT_LAND_USE_LABEL = Urban (all compact settlements including built up areas of cities, towns and villages as well as units away from settlements such as manufacturing plants, rail yards and military camps. In most cases residential use will predominate in these areas. Open space which forms an integral part of the urban agglomeration, e.g. parks, golf courses, etc. are included as urban)

Table 111: Geoprocessing to Create an Urban Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Urban per AOI polygon (ha/km^2)	Urban	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Oil and Gas Industry Related Infrastructure (OGinfr)

REPRESENTATION

Oil and Gas infrastructure data is a combination of pipelines, well pads, facilities and other ancillary activity such as borrow pits, decking sites and temporary disturbances. Data comes from a variety of sources in a variety of forms. If line data is provided, the line is buffered along its length to provide a representative area value.

DATA SOURCES

Table 112: Data Sources for Oil and Gas Infrastructure Related Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
CROWN TENURES	WHSE_TANTALIS.TA_CROWN_TENURES_SVW	Y	FLNRO	Y	2015-03-31
TANTALIS – SURVEY PARCELS	WHSE_TANTALIS.TA_SURVEYED_ROW_PARCELS_SVW	Y	FLNRO	Y	2015-03-31
OG Pipeline RW	WHSE_MINERAL_TENURE_OG_PIPELINE_RW_PUB_SP	Y	OGC	Y	2015-03-31
OG Well Sites	WHSE_MINERAL_TENURE_OG_WELL_SITES_PUB_SP	Y	OGC	Y	2015-03-31
OG Facilities	WHSE_MINERAL_TENURE_OG_FACILITY_SITES_PUB_SP	Y	OGC	Y	2015-03-31
OG Ancillary	WHSE_MINERAL_TENURE_OG_ANCILLARY_OTHER_APPS_PUB_SP	Y	OGC	Y	2015-03-31
OG Surface Hole	WHSE_MINERAL_TENURE.OG_SURFACE_HOLE_STATUS_SP	Y	OGC	Y	2015-03-31
TRIM Pipelines	WHSE_BASEMAPPING.TRIM_CULTURAL_LINES	Y	FLNRO	N	

GEOPROCESSING METHOD

Table 113: Geoprocessing of Oil and Gas Infrastructure Related Disturbance Source Data

Topic	Query or Process
CROWN TENURES	TENURE_PURPOSE = UTILITY AND TENURE_SUBPURPOSE = GAS AND OIL PIPELINE OR TENURE_PURPOSE = ENERGY PRODUCTION And proposed tenures were removed from the analysis by two additional query conditions: TENURE_TYPE <> 'RESERVE/NOTATION' and TENURE_STAGE <> 'APPLICATION'
TANTALIS – SURVEY PARCELS	FCODE = FA91300120 or FCODE = FA91400120
OG Pipeline RW	Pipelines under application (not constructed) were removed from the analysis by a query: APPLICATION_STATUS <> 'APPROV'
OG Well Sites	All well site polygons
OG Facilities	Facilities under application (not constructed) were removed from the analysis by a query: APPLICATION_STATUS <> 'APPROV'
OG Ancillary	ANCILLARY_OTHER_APP_TYPE not equal to “ROAD” or “INV”
OG Surface Hole	Wells never constructed were removed from the analysis using the WELL_ACTIVITY field to query out wells cancelled before being constructed ('CANC') and wells authorized but not constructed ('WAG') Point data. Data may be duplicated in Tantalis and OGC datasets; buffer 1.44 hectares (60 metres buffer radius); In ArcGIS, use the Feature Envelope To Polygon tool to convert the circle buffer to a square buffer.
Trim Pipelines	FCODE = EA21400000; buffer 10 metres

Table 114: Geoprocessing to Create an Oil and Gas Infrastructure Related Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Oil and Gas infrastructure	CROWN TENURES TANTALIS – SURVEY PARCELS OG Pipeline RW OG Well Sites OG Facilities OG Ancillary OG Surface Hole TRIM Pipelines	New layer (Oil and Gas Infrastructure)	Merge; dissolve created on outer boundaries
Oil and Gas infrastructure per AOI polygon (ha/km^2)	Oil and Gas infrastructure	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Linear Features (Linear)

Disturbance associated with linear features is calculated as an amalgamation of disturbance from roads, railway lines and transmission lines. Data comes from a variety of sources in a variety of forms. If line data is provided, the line is buffered along its length to provide a representative area value.

Disturbance from Linear Features - Roads

DATA SOURCES

Table 115: Data Sources for Road Disturbance

Topic	Source Location (with hyperlink where possible)	BCGW	Data Provider	Public Data	Data Last Modified
Digital Road Atlas (DRA)	WHSE_BASEMAPPING.DRA_DGTL_ROAD_ATLAS_MPAR_SP	Y	FLNRO	Y	2014-12-10
Forest Service Roads (FTEN)	WHSE_FOREST_TENURE.FTEN_ROAD_SECTION_LINES_SVW	Y	FLNRO	Y	2015-03-31
Petroleum Development Roads (PDR)	WHSE_MINERAL_TENURE.OG_PETRLM_DEV_ROADS_PUB_SP	Y	OGC	Y	2015-03-31
Petroleum Development Roads Pre06 (PDR)	WHSE_MINERAL_TENURE_OG_PETRLM_DEV_RDS_PRE06_PUB_SP	Y	OGC	Y	2010-03-25
Petroleum Access Roads (PDR)	WHSE_MINERAL_TENURE_OG_PETRLM_ACCESS_ROADS_PUB_SP	Y	OGC	Y	2015-03-31
Trails (TR)	WHSE_FOREST_TENURE.FTEN_RECREATION_LINES_SVW	Y	FLNRO	Y	2015-03-31

Note: Currently there is a provincial project to produce a consolidated road network product, the Integrated Transportation Network (ITN), which would replace the multiple sources used in this initial analysis.

GEOPROCESSING METHOD

Table 116: Geoprocessing of Road Disturbance Source Data

Topic	Query or Process
Digital Road Atlas (DRA)	Road Class = Highway; buffer 15 metres Road Surface = Paved; buffer 15 metres Road Surface = Loose; buffer 10 metres Road Surface = Rough; buffer 7.5 metres Road Surface = Overgrown; buffer 7.5 metres Road Surface = Decomissioned; buffer 7.5 metres Road Surface = Unknown; buffer 7.5 metres
Forest Service Roads (FTEN)	FILE_TYPE_DESCRIPTION = FSR; buffer 10 metres FILE_TYPE_DESCRIPTION = RP; buffer 7.5 metres
Petroleum Development Roads	PETRLM_DEVELOPMENT_ROAD_TYPE = High Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Low Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Winter; buffer 3.5 metres PETRLM_DEVELOPMENT_ROAD_TYPE = blank; buffer 3.5 metres
Petroleum Development Roads Pre06	PETRLM_DEVELOPMENT_ROAD_TYPE = High Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Low Grade; buffer 10 metres PETRLM_DEVELOPMENT_ROAD_TYPE = Winter; buffer 3.5 metres PETRLM_DEVELOPMENT_ROAD_TYPE = blank; buffer 3.5 metres
Petroleum Access Roads	PETRLM_ACCESS_ROAD_TYPE = High Grade; buffer 10 metres PETRLM_ACCESS_ROAD_TYPE = Low Grade; buffer 10 metres PETRLM_ACCESS_ROAD_TYPE = Winter; buffer 3.5 metres PETRLM_ACCESS_ROAD_TYPE = blank; buffer 3.5 metres

Topic	Query or Process
Trails (TR)	Right of Way not null; buffer ½ of RIGHT_OF_WAY attribute value Right of Way null; buffer 2.5 metres

Table 117: Geoprocessing to Create a Road Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Consolidated Roads	Digital Road Atlas (DRA) Forest Service Roads (FTEN) Petroleum Development Roads Petroleum Development Roads Pre06 Petroleum Access Roads Trails (TR	New layer (Consolidated Roads)	Merge; dissolve created on outer boundaries
Consolidated Roads per AOI polygon (ha/km^2)	Consolidated Roads	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Linear Features – Railway Lines

DATA SOURCES

Table 118: Data Sources for Railway Line Disturbance

Topic	Source Location (with hyperlink where possible)	BCGW	Data Provider	Public Data	Data Last Modified
Trim Railways	WHSE_BASEMAPPING.TRIM_TRANSPORTATION_LINES	Y	FLNRO	N	2015-03-31
Federal Railways	National Railway Network (NRWN) - BC, British Columbia	N	NRCan	Y	2013-11-03
Tantalis Survey Parcels	WHSE_TANTALIS.TA_SURVEY_PARCELS_SVW	Y	FLNRO	Y	2015-03-31
Tantalis Transportation	WHSE_TANTALIS_TA_TRANSPORTATION_SVW	Y	FLNRO	Y	2014-12-11

Trim railway features are not available to the Public. This data was added to ensure as complete dataset as possible.

GEOPROCESSING METHOD

Table 119: Geoprocessing of Railway Line Disturbance Source Data

Topic	Query or Process
Trim Railways	DE22850000, DE22850110, DE22850120, DE22900000, DE22950000, DE22950001, DE22950120, DF28850000, F28850000; buffer 17.5 metres
Federal Railways	buffer 17.5 metres
Tantalis Survey Parcels	Feature Code = FA91200130

Topic	Query or Process
Tantalis Transportation	Feature Code = FA91200120

Table 120: Geoprocessing to Create a Railway Line Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Merged Transportation and Survey Parcels	Tantalis Survey Parcels Tantalis Transportation	New layer Transportation and Survey Parcels	Merge
Consolidated Railway lines	Merged Transportation and Survey Parcels TRIM Railways Federal Railways	New layer (Consolidated Railways)	In areas where the merged Transportation and Survey Parcels layer does not have any polygons, TRIM Railways and National Railway Network were buffered and added. Then a dissolve to create the outer boundaries of railways.
Railway Lines per AOI polygon (ha/km^2)	Consolidated Railway lines	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Linear Features – Transmission Lines

DATA SOURCES

Table 121: Data Sources for Transmission Line Disturbance

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
CROWN TENURES	WHSE_TANTALIS.TA_CROWN_TENURES_SVW	Y	FLNRO	Y	2015-03-31
TANTALIS- SURVEY PARCELS	WHSE_TANTALIS.TA_SURVEYED_ROW_PARCELS_SVW	Y	FLNRO	Y	2015-03-31
BC Hydro Transmission	Circuit.shp	N	BC Hydro	Y	

GEOPROCESSING METHOD

Table 122: Geoprocessing of Transmission Line Disturbance Source Data

Topic	Query or Process
CROWN TENURES	Subpurpose = ELECTRIC POWER LINE
TANTALIS- SURVEY PARCELS	FEATURE_CODE = FA91400110
BC Hydro Transmission	Buffer 9.15 metres

Table 123: Geoprocessing to Create a Transmission Line Disturbance Indicator Layer

Result	Source Layer	Target Layer	Action
Merged Survey Parcels and Crown Tenure	Tantalis Survey parcels Crown Tenures	Merged Survey Parcels and Crown Tenure layer	Merge
Consolidated Transmission lines	Merged Survey Parcels and Crown Tenure BC Hydro Transmission	New layer (Consolidated transmission lines)	In areas where the Merged Survey Parcels and Crown Tenure layer does not have any polygons, BC Hydro Transmission lines were buffered and added. Then a dissolve to create the outer boundaries of transmission lines.
Transmission Lines per AOI polygon (ha/km^2)	Consolidated Transmission Lines	AOI polygon layer	Polygonal Area as per Table 2

Disturbance from Mining (Mining)

REPRESENTATION

Mining is primarily limited to coal operations in northeast B.C. The land area for active mines is represented by lease areas.

DATA SOURCES

Table 124: Data Source for Disturbance from Mining

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Mining Tenure	WHSE_MINERAL_TENURE.MTA_ACQUIRED_TENURE_SVW	Y	MEM	Y	2015-03-31

GEOPROCESSING METHOD

Table 125: Geoprocessing of Disturbance from Mining Source Data

Topic	Query or Process
Mining Tenure	TENURE_SUB_TYPE_DESCRIPTION = Lease

Table 126: Geoprocessing to Create a Disturbance from Mining Indicator Layer

Result	Source Layer	Target Layer	Action
Mining Tenure per AOI polygon (ha/km^2)	Mining Tenure	AOI polygon layer	Polygonal Area as per Table 2

Future Disturbance Indicator Layers

Future water quality expected to be most impacted by disturbance from the following industries: unconventional gas development, forestry and mining.

Potential Disturbance from Unconventional Gas Development (OGPlays)

REPRESENTATION

In this analysis, potential future oil and gas development is limited to unconventional gas plays because since 2005 a strongly increasing to dominant number of new well licenses is related to unconventional development. There are four large areas considered prospective for unconventional gas development on the basis of geology: the Montney Play Trend, the Horn River Basin, the Cordova Embayment and the Liard Basin. For future disturbance, land physically above any potential unconventional play is possibly subject to water quality impact from development activities.

DATA SOURCES

Table 127: Data Source for Potential Disturbance from Unconventional Gas Development

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Unconventional Gas Plays	WHSE_MINERAL_TENURE.OG_UNCONVENTNL_PLAY_TRENDS_SP	Y	OGC	Y	2010-03-25

GEOPROCESSING METHOD

Table 128: Geoprocessing of Potential Disturbance from Unconventional Gas Development Source Data

Topic	Query or Process
Unconventional Gas Plays	All four play trends (Montney, Horn River, Cordova, Liard)

Table 129: Geoprocessing to Create a Potential Disturbance from Unconventional Gas Development Indicator Layer

Result	Source Layer	Target Layer	Action
Unconventional Gas Development per AOI polygon (ha/km^2)	Unconventional Gas Plays	AOI polygon layer	Polygonal Area as per Table 2

Potential Disturbance from Mining (Mine)

REPRESENTATION

Mining is primarily limited to coal operations in northeast B.C. The land area for active mines is represented by lease areas. Areas of future expansion are held by license. Mineral and placer-based mines are represented by licensed areas, if they exist. Potential future mining areas are not well captured under the current system. Claims represent a potential area much larger than that which may potentially be mined. Possible impact to water quality by mining therefore is limited mainly to coal leases and licenses.

DATA SOURCES

Table 130: Data Source for Potential Disturbance from Mining

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
Mining Tenure	WHSE_MINERAL_TENURE.MTA_ACQUIRED_TENURE_SVW	Y	MEM	Y	2015-03-31

GEOPROCESSING METHOD

Table 131: Geoprocessing of Potential Disturbance from Mining Source Data

Topic	Query or Process
Mining Tenure	TENURE_SUB_TYPE_DESCRIPTION = Lease or License

Table 132: Geoprocessing to Create a Potential Disturbance from Mining Indicator Layer

Result	Source Layer	Target Layer	Action
Mining Tenure per AOI polygon (ha/km^2)	Mining Tenure	AOI polygon layer	Polygonal Area as per Table 2

Layers Indicative of Human or Ecosystem Sensitivity

The stewardship of water resources for people and the environment is considered an important duty. This section is designed to flag map sheets where monitoring should be prioritized as a safeguarding feature. The indicator layers prioritize areas where it is most important that water condition and trend be tracked.

Initially, the density of licensed springs was used as a proxy for the depth to groundwater. Recently a DRASTIC model for northeast B.C. has been completed. DRASTIC models provide an indication of the groundwater susceptibility. In future, there may be sufficient data to include layers associated with groundwater-surface water interaction or drought associated with lowering of the groundwater table.

DRASTIC model of Groundwater Vulnerability (DRASTIC)

REPRESENTATION

DRASTIC models provide an indication of the groundwater susceptibility to contamination. The DRASTIC model incorporates spatial data on depth to groundwater, hydraulic conductivity, recharge and more. A DRASTIC model was recently completed by Simon Fraser University and is publically available.

DATA SOURCES

Table 133: Data Source for Groundwater Vulnerability

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified

Topic	Source Location	BCGW	Data Provider	Public Data	Data Last Modified
DRASTIC model	Shannon Holding sholding@sfu.ca to be published later in 2015	N	Simon Fraser University	Y	2015-05-29

GEOPROCESSING METHOD

Table 134: Geoprocessing of Groundwater Vulnerability Source Data

Topic	Query or Process
DRASTIC model	Convert Tiff raster cells to polygons

Table 135: Geoprocessing to Create a Groundwater Vulnerability Indicator Layer

Result	Source Layer	Target Layer	Action
Average DRASTIC Index per AOI polygon (ha/km^2)	DRASTIC model	AOI polygon layer	Polygonal Data as per Table 2