Hydrogeologic Mapping and Characterization of the Aquifer at Grand Forks, Southern British Columbia to Support Local Planning and Protection

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ABSTRACT
The unconfined aquifer at Grand Forks, British Columbia is one of the most productive aquifers in the province and is a major source of water supply for the community. On-going concerns about elevated nitrate in the well water and community interest in groundwater protection has created a need for information about the characteristics of the aquifer to support more effective local management and protection of the resource. Mapping and characterization of the aquifer was carried out jointly by Simon Fraser University and the BC Ministry of Water, Land and Air Protection to provide a regional hydrogeologic framework for local planning and protection efforts. This paper presents and discusses some of the results of this work.

RÉSUMÉ
L'aquifère Grand Forks en Colombie Britannique est l'une des aquifères les plus productives dans la province et aussi une source importante d'approvisionnement en eau pour la communauté. Les soucis sur le nitrate élevé dans l'eau de puits et l'intérêt de communauté pour la protection d'eaux souterraines a créé un besoin des informations sur les caractéristiques de l'aquifère. Tracer et caractérisation de l'aquifère ont été effectués conjointement par l'Université de Simon Fraser et le Ministère de la Protection de l'Eau, de Terre et d'Air pour fournir un cadre hydrogéologique régional pour des efforts locaux de planification et de protection. Cet article présente certains des résultats de ce travail.

1 INTRODUCTION AND PHYSICAL SETTING

British Columbia (BC) has some of the most productive, yet intrinsically vulnerable aquifers in Canada. The management and protection of groundwater and aquifers in BC have relied primarily on non-regulatory approaches, due to paucity of regulations historically (Wei and Allen, 2004). In 1994, the Ministry of Water, Land and Air Protection (WLAP-then Ministry of Environment, Lands and Parks) developed a system of mapping and classifying aquifers (Wei et al., 1995). Although aquifer classification mapping has been useful for inventory and priority setting, it was recognized as far back as 1996, that more detailed mapping and characterization of the Province's critical aquifers were needed to support resource and land use decision-making in order to minimize impacts and guide sustainable development of the groundwater resource (MELP, 1996). Hydrogeologic mapping and characterization would also support future development of science-based aquifer protection regulations for specific areas where there are groundwater quantity or quality concerns.

One such area is the community of Grand Forks located in south-central BC, along the Canada-USA border (Figure 1). Grand Forks is located on a broad, relatively flat alluvial terrace at the confluence of the sediment filled Kettle and Granby River valleys. The elevation of the valley bottom ranges from approximately 550 metres above sea level (m a.s.l.) in the west, where the Kettle River flows north into BC to 520 m a.s.l. in the east, downstream of the confluence of the Kettle and Granby Rivers. The width of the Kettle River valley in Grand Forks ranges from 4 km just west of the Granby River confluence near the city to about 1.5 km on the east and west sides of the city. Bedrock hills rise on all sides

Figure 1 Location of the Grand Forks study area

from the valley bottom up to elevations of approximately 1600 m a.s.l.. An estimated seven thousand residents live in the city and surrounding areas (Grand Forks Chamber of Commerce, pers. comm., 2004). The annual average daily maximum, minimum and mean temperature are 13.8ºC, 1.3ºC, and 7.6ºC, respectively. The highest daily mean temperatures occur in July and August and the lowest daily mean temperatures occur in December and January. Approximately 353 mm of precipitation falls as rain and 118 mm falls as snow, with a total annual average precipitation of 471 mm. November to January and May and June are months of greatest precipitation. March, September, and October are typically the driest months of the year. Land use is mainly agricultural and residential, with commercial and industrial land use within the city limits.

The aquifer at Grand Forks is an important source of water supply for the community. The area is arid and groundwater provides water for both domestic and irrigation uses. The occurrence of nitrate-nitrogen in well water from non-point source pollution was first identified in 1989 (Wei et al., 1993) and the Ministry has been monitoring ambient groundwater quality in the aquifer ever since. In 1997, the local water suppliers, Regional District of Kootenay-Boundary, and interested residents formed the *Grand Forks Aquifer Protection Society* to develop and implement a groundwater protection plan to better safeguard the water quality of the underlying aquifer for now and for future generations. The importance of the Grand Forks Aquifer as a source of water supply, the high level of local community interest in developing a protection plan, and the Ministry's on-going interest in ambient groundwater quality monitoring in Grand Forks makes the aquifer an ideal candidate for mapping and characterization. This paper presents the preliminary results of hydrogeological mapping and characterization conducted in partnership between Simon Fraser University (SFU) and the Ministry.

2 AQUIFER CHARACTERIZATION

Assessing and characterizing the aquifer at Grand Forks entailed analyzing and interpreting available data to develop an understanding of the aquifer's hydrogeologic characteristics to allow impacts of water use and/or human activities to be assessed or simulated. The study focussed on a regional, aquifer-wide scale. The primary sources of data were the 600+ water well records in the Ministry's WELL database, well water chemistry data from the Ministry's Ambient Ground Water Quality Monitoring program, and additional well logs, water chemistry, pumping test, water use information, soils and geologic mapping in available reports, and hydrometric and meterological data from Environment Canada for the study area. Hydrogeologic mapping and development of a regional numerical groundwater model were the two main tools used to assess, portray, characterize, and simulate conditions of the aquifer at Grand Forks. Prior to interpretation, well locations were verified against field location sketches in the original well records. Elevation of the wells in the valley bottom was determined from 1:5,000 scale mapping with 1 m contours. The lithologic descriptions from the water well records were standardized using software developed by SFU to correct any errors in syntax, grammar and spelling. The standardization process recognizes equivalent terms and

Table 1. Listing of hydrogeological and other maps developed for the Grand Forks Aquifer.

Map themes	**Description of maps**	**How maps were developed**
Water well characteristics	Well location map of wells, by type of construction (e.g., drilled, dug)	From reported water well record data
	Map of reported well depths	From reported water well record data
	Map of reported well yields	From reported water well record data
	Contour map of potential well yield in the aquifer	Empirically from Jacob's equation relating allowable well pumping rate to aquifer thickness
Aquifer architecture	Series of contour maps showing the thicknesses and top and bottom elevations of the major surficial geological units (Table 2)	Interpreted from reported water well record data
	Series of north-south and east-west vertical cross-sections showing the subsurface arrangement of the major surficial geologic units and underlying bedrock surface	Interpreted from reported water well record data
	Contour map of aquifer thickness	Interpreted from reported water well record data
	Contour map of bedrock surface elevation	From Digital Elevation Model
Groundwater flow characteristics	A contour map of groundwater level elevation in the aquifer under non-pumping conditions	From numerical model calibrated against reported well water level data
	A contour map of groundwater level elevation in the aquifer under pumping conditions	From numerical model
	A map of the major community wells and their capture areas	From numerical model
Groundwater quality characteristics	Six contour maps of relevant groundwater chemistry parameters (TDS, specific conductance, hardness, alkalinity, chloride, nitrate-nitrogen)	From available water chemistry data
	A DRASTIC map of the aquifer's intrinsic vulnerability	Interpreted from reported water well and meterological data, soil mapping, and information on irrigated lands
	A map of areas where groundwater quality has been significantly impacted by human activities	Interpreted from the nitrate-nitrogen map
Other	A map of land use and location of septic systems	From 1993 land use survey by Sheppard (1995)

classifies lithological descriptions into standard dominant types. The water well records provided the fundamental data to develop a series of maps portraying the general characteristics of wells and aquifer architecture.

These data and maps, together with pumping test, water use, meterological and hydrometric data allowed the development of a 5-layer finite-difference MODFLOW model to simulate the direction and rate of groundwater flow, delineate recharge areas for major pumping wells (i.e., capture zones) and water balance within the aquifer. Model development is described by Allen (2000; 2001) and summarized in Allen et al. (2003). Refinements to the model were made in a recent study on the transient effects of climate change on groundwater and are summarized by Allen et al. (2004). Table 1 shows the series of maps (and cross-sections) produced in this study. The type of hydrogeological information displayed in the maps range from basic data (e.g., map of well types, reported well yield and well depths) to interpretive (e.g., map of recharge area for community wells, potential well yield, areas where groundwater quality has been impacted by human activities).

3. RESULTS

This section presents and discusses preliminary results related to four characteristics of the Grand Forks Aquifer:

- stratigraphy and architecture;
- potential well yield;
- regional groundwater flow characteristics; and
- intrinsic vulnerability and water quality characteristics.

3.1 Stratigraphy and aquifer architecture

Interpretation of the stratigraphy, recent geological history and the architecture of the Grand Forks Aquifer were based primarily on lithologic descriptions in the water well records and landforms from air photographs. The surficial sediments and underlying bedrock can be categorized into seven distinctive units, from youngest to oldest as shown in Table 2. The gravel, upper sand, silt, and clay units are major units and are represented in the numerical model; the corresponding model layer is shown in column two of Table 2. Column three briefly describes each unit and its location, and column four provides the interpreted hydrogeologic significance.

An extensive layer of glaciofluvial and fluvial gravel directly underlie the valley floor. The gravel unit is approximately 10 m thick, is generally above the water table, and forms a permeable vadose zone above the aquifer. An areally extensive layer of sand underlies the gravel unit and is the main unit comprising the Grand Forks Aquifer. The sand unit varies in thickness (Figure 2), ranging from up to >80 m thick in the west, to <20 m thick in the east. Records for deeper wells in the valley reveal the presence of a silt layer underlying the sand unit. There is limited information on this silt unit because drilling is usually stopped below the sand unit when the percentage of silt in the drill cuttings increases. The boundary between the overlying sand unit and the silt unit appears to be gradational. In the northwest area of the aquifer, a deeper sand unit occurs underneath the silt unit. The lower sand unit comprises outwash (fan) sediments ranging from fine-grained to medium-grained sand to pebbles. This lower sand unit occurs at about 75 m depth and forms the lower part of the Grand Forks Aquifer. Little is known about the lateral extent of this unit. The occurrence of the lower sand unit may be limited to the northwest part of the aquifer – two deep wells drilled in the central portion of the aquifer did not encounter the lower sand unit at depth. The lower sand unit was not expected to be important in the modelling process due to the overall flow in the aquifer taking place largely in the upper gravel and sand units, and therefore was not included in the model. Records for the deepest wells in the valley bottom indicate the presence of a clay layer below the silt unit. Very little information exists for the clay unit. The till unit is of minor hydrogeological significance, because it occurs in the upland slopes, above the valley bottom, outside of the aquifer. The bedrock, which occurs beneath the valley bottom and the mountains adjacent to the Grand Forks Aquifer, forms the no-flow boundary of the numerical model as it is assumed to be relatively impermeable.

Table 2. Schematic column showing the general hydrostratigraphy in Grand Forks.

Lithology	**Layer in numerical model**	**Description of lithologic unit**	**Hydrogeologic significance**
	Layer 1	Glaciofluvial gravel, minor fluvial gravel (along river channel), minor colluvium (locally along edge of valley bottom)	Vadose zone, unconfined aquifer (where saturated)
	Layer 2	Glaciofluvial sand	Upper unconfined aquifer zone
	Layer 3	Glaciolacustrine silt, fine sand	Aquitard
	Not part of model	Lower glaciofluvial sand (northwest part of the aquifer only)	Lower confined aquifer zone
	Layer 4	Glaciolacustrine clay	Aquitard
	Not part of model	Till (underlies upland slopes outside of aquifer)	Aquitard
	No-flow model boundary	Bedrock - altered dioritic (igneous) rocks, metamorphic rocks (underlies the upland slopes)	Aquiclude (actually a limited aquifer in the uplands, where wells are drilled into bedrock for domestic supply)

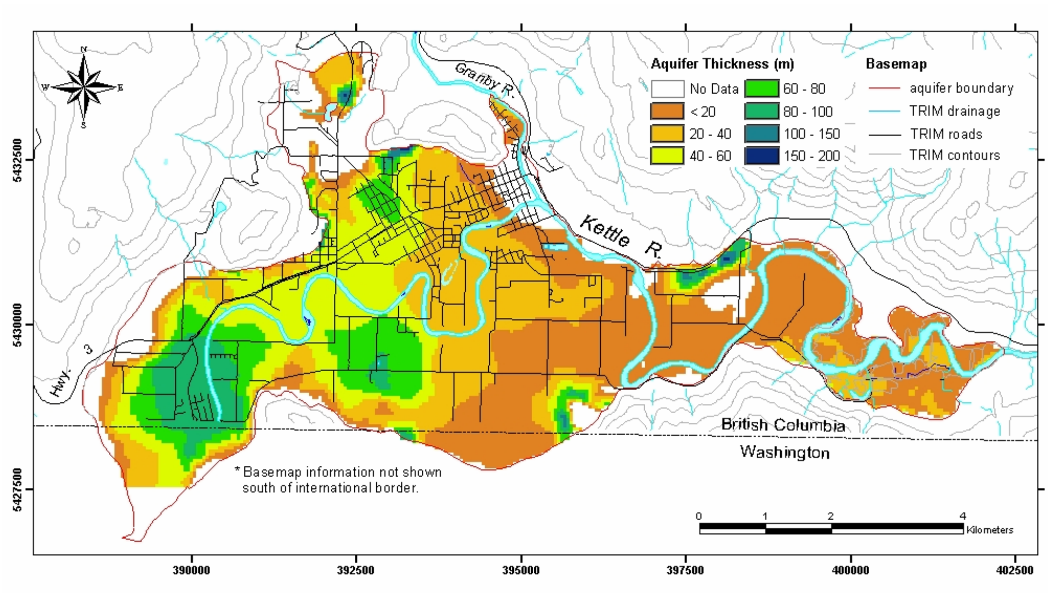

Figure 2. Aquifer thickness.

3.2 Potential yield to wells

Figure 3 is the map of potential well yield. Analysis of available pumping test data and results from the numerical model of the aquifer by Allen (2000; 2001) suggests the aquifer is relatively homogeneous with respect to hydraulic conductivity and specific storage – the aquifer's transmissivity and storativity essentially varies with the aquifer thickness. This allows Jacob's equation to be used to empirically relate allowable pumping rate, Q (potential yield to individual wells) to the square of the aquifer thickness, b (maximum available drawdown) using equation 1 below, to develop a map of potential well yield:

$$Q \text{ (USgpm)} = 0.15523 \times (b \text{ (feet)})^2 \qquad [1]$$

The potential well yield within the Grand Forks Aquifer is represented as zones. Because reported well yield is log-normally distributed in Grand Forks, the zones are represented in half orders of magnitude intervals (e.g., 10 to 30 gpm, 30 to 100 gpm, etc.). Figure 3 shows that a significant portion of the aquifer has the potential to yield over one thousand gpm to wells, and much of the aquifer has the potential to supply hundreds of gpm to wells. The areas of greatest potential yield lie in the western half of the aquifer where the saturated thickness of the aquifer is greatest. A comparison of the potential well yield map (Figure 3) and the map of aquifer thickness (Figure 2) shows a high degree of correlation, which is expected from equation (1). The estimate of potential well yield is supported by well yields reported in the WELL database. Many of the largest capacity wells (located away from the river) are found in the western portion of the aquifer. Potential well yield decreases towards the eastern portion of the aquifer as the thickness of the saturated sand and gravel decreases there. However, the map suggests that wells of tens of gpm to hundreds of gpm may still be constructed in that area. The high reported well yields (several hundreds of gpm to over 1000 gpm) for two irrigation wells in the east portion of the aquifer is because these wells are located adjacent to the Kettle River and receive recharge from induced infiltration of river water during pumping. Potential yield in the east portion of the aquifer for wells located further away from the river is expected to be lower. Overall, the aquifer is very productive; areas identified with potential yield of <10 gpm are limited to a few areas along the Kettle River and downstream from the confluence with the Granby River where the saturated thickness is limited.

3.3 Regional groundwater flow characteristics

3.3.1 Distribution of hydraulic head, groundwater flow directions, and water balance

Figure 4 is the hydraulic head contour map for the upper sand unit developed from hydraulic head values calculated from the numerical model, simulating pumping from the major municipal and irrigation wells. The hydraulic head contours show that regional groundwater flow in the aquifer is predominantly from west to east, in the same general direction as flow in the Kettle River. The hydraulic head in the aquifer drops 40 m across the aquifer, from 530 m a.s.l. in the west to 490 m a.s.l. in the east. The hydraulic head contours also show significant drawdown around the major municipal and irrigation wells. The area affected by pumping is in fact quite large, altering ambient groundwater flow direction in much of the western part of the aquifer. The hydraulic head contours in the east portion of the aquifer reflect more what groundwater flow directions would be like under ambient conditions as the amount of well pumping is much less there.

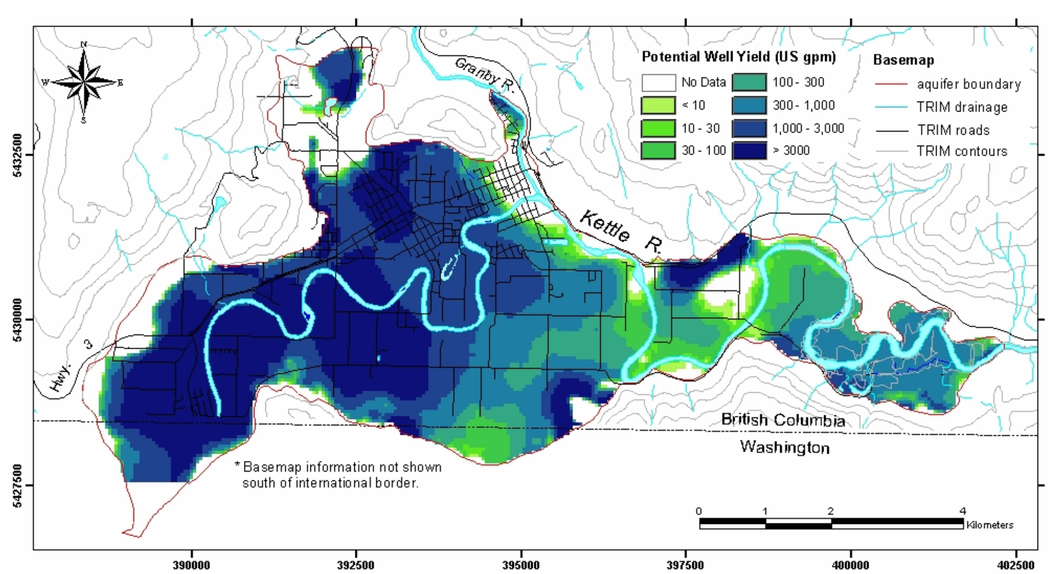

Figure 3. Potential well yield to wells.

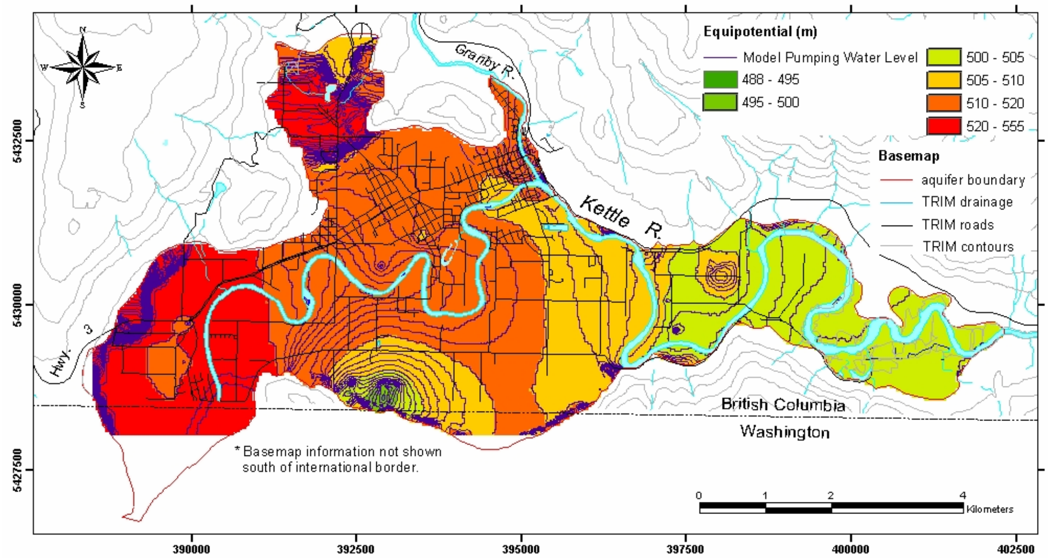

Figure 4. Hydraulic head elevation of upper sand unit.

The hydraulic head contours adjacent to the Kettle River reveal the inter-action between surface water in the river and the underlying groundwater. Much of the Kettle River west (upstream) of the confluence with the Granby River appears effluent (loses water to the aquifer), under simulated pumping conditions. The water balance also shows the influence of the river. In assessing the preliminary water balance[1] within the aquifer under conditions of uniformly applied surface recharge, the model was divided into four discrete zones: Zone 1 – West Grand Forks, Zone 2 – Central Grand Forks, Zone 3 – North Grand Forks, and Zone 4 – East Grand Forks. Water flow in and out of each zone was partitioned into constant head nodes (the rivers), evapotranspiration (ET), recharge and water entering/exiting the zones from/to exterior zones. Water balances were calculated for both the non-pumping and pumping conditions and the changes were compared. Under non-pumping conditions, recharge accounted for 41- 57% of the total inflow to the zones. Water from constant head nodes (rivers) accounted for 6-14% and water from external zones 32-45% of the total inflow. Water loss was primarily to constant head nodes (rivers) and loss to other zones. Under simulated pumping conditions, there is a significant re-distribution of water. The total volume of inflow and outflow for zones 1 and 2 is almost twice as large as it

[1] Note: the model has been modified to include distributed recharge.

was under non-pumping conditions. For inflow, recharge accounts for a smaller percentage of the total inflow (29-53%) and the percentage of inflow from constant heads rose (in zones 1 and 2 there is a 32-39% increase of inflow from constant heads) and reflect that pumping is inducing infiltration of river water into the aquifer. Water outflow under pumping conditions resulted in a general decrease in outflow to the constant head nodes (rivers) and to exterior zones, especially in zones 1 and 2 where much of the pumping is occurring.

3.3.2 Recharge areas for municipal and irrigation wells

Forward and reverse particle tracking allowed recharge areas, or capture zones, for the major municipal and irrigation wells to be delineated. The capture zones for 5, and 10 years time of travel are shown in Figure 5.

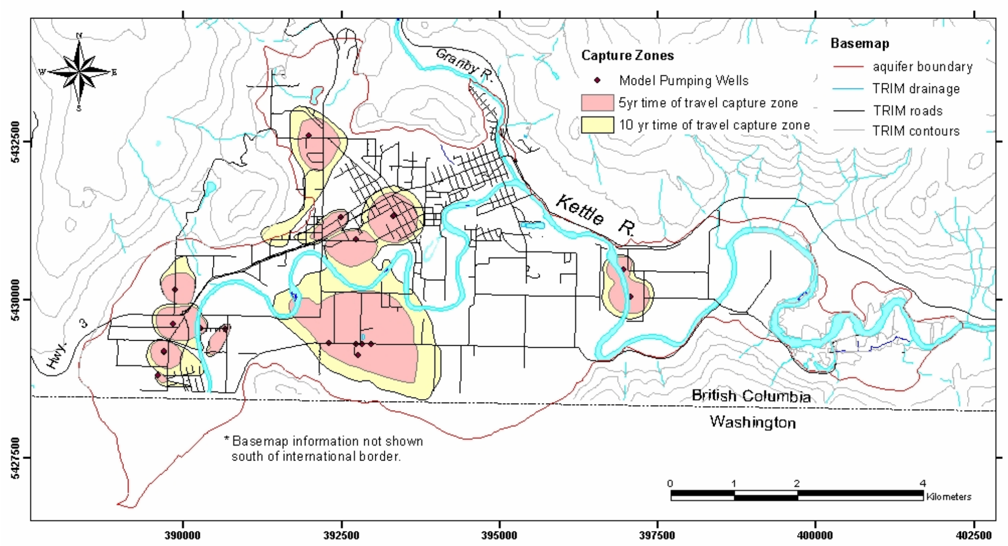

Figure 5. 5- and 10-year capture zones.

For the most part, the capture zones are relatively circular in shape and extend predictably in a radial direction away from the well, with a slight tendency to tail back up gradient. The generally circular shape of the capture zones reflect the isotropic nature of the aquifer (in the horizontal direction) and the low ambient hydraulic gradient. Most capture zones extend to the Kettle River, providing evidence that pumping wells derive much of their water directly from induced infiltration of surface water from the Kettle River into the aquifer. This source of recharge is also evident in the pumping test data. Reverse particle tracking also revealed that minor portions of some capture zones extend underneath the Kettle River to land on the other side (see capture zone for the two irrigation wells in the east part of the aquifer in Figure 5).

Capture zone analysis has several well protection implications. The capture zone areas allow well owners to define areas for source water protection, including areas on the other side of the Kettle River, which was not originally anticipated. Of significance is the fact that the 25 year capture zones (not shown) for many of the major municipal and irrigation wells in the valley coalesce and occupy a major portion of the aquifer, particularly the western half of the aquifer where large capacity wells are located (Figure 5). This suggests that the City of Grand Forks and neighbouring irrigation districts share common well protection areas and could work cooperatively and pool their energy and resources to jointly protect their well supplies. Joint protection efforts make sense, especially for small communities where resources and capacity are issues.

3.4 Intrinsic vulnerability of the aquifer and occurrence of nitrate

3.4.1 DRASTIC map

The DRASTIC method (Aller et al., 1987) was applied to develop a map of the intrinsic vulnerability of the aquifer. Information in the water well records, soils and topographic mapping allowed most of the DRASTIC parameters to be determined. The US EPA model, HELP (UnSat Suite, Waterloo Hydrogeologic Inc.), was used to estimate groundwater recharge rates. In this study recharge from irrigation, in addition to recharge from precipitation, was also included in calculating the R-rating. Figure 6 shows the DRASTIC vulnerability map for the Grand Forks Aquifer. Areas considered highly vulnerable to contamination occupy much of the aquifer, with the highest DRASTIC areas located in the eastern half of the aquifer where the depth to water is shallow. The extent of the highly vulnerable area (DRASTIC index >160), surrounded by moderately vulnerable areas (DRASTIC index of 120–160) is consistent with the overall unconfined nature of the aquifer.

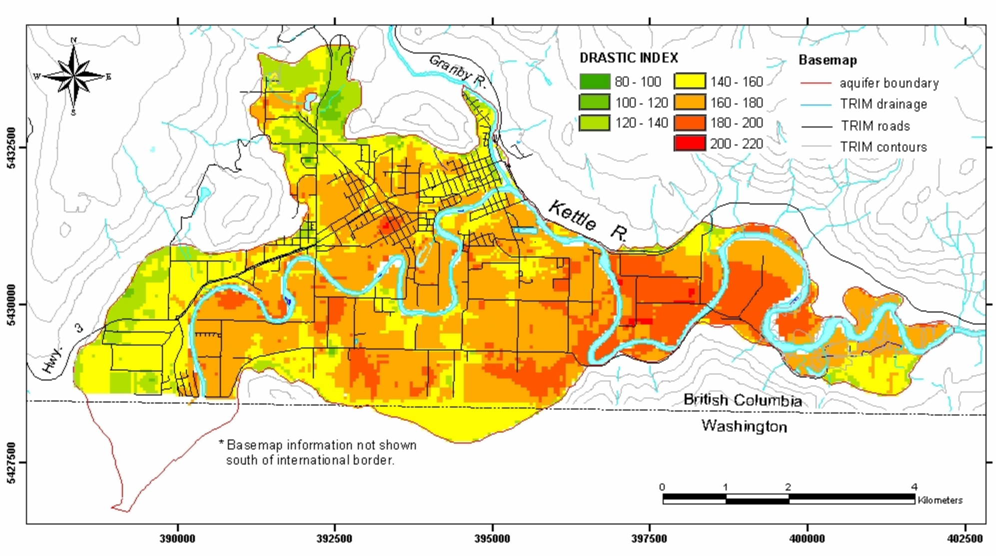

Figure 6. DRASTIC map.

The influence of recharge from irrigation return flow and depth to water on the DRASTIC results is evident in Figure 6. Irrigation return flow increases the R-rating and overall DRASTIC vulnerability index. In the south-central area of the aquifer along the Canada-USA border, the irrigated area north of the border has a higher DRASTIC vulnerability than the adjacent non-irrigated land south of the border. This difference in vulnerability is clearly reflected in increased recharge from return flow in irrigated areas. Since the R-rating considers irrigation return flow, the DRASTIC vulnerability can change slightly over time in some areas, if irrigation practices change. The effect of depth to water is evident on either side of the Kettle River in the west, where the river flows into Canada. The west bank of the river is terraced and the water table is deeper, resulting in a lower vulnerability rating than in the east bank of the river where the land is not terraced and the water table is shallower.

3.4.2 Occurrence of nitrate

Available well water quality data from >100 wells were used to develop a map of nitrate-nitrogen in the aquifer (Figure 7). Nitrate-nitrogen (NO_3-N) in the Grand Forks Aquifer ranges from a low of <0.01 mg/L to >30 mg/L, with a median concentration of 3.4 mg/L. In the east half of the aquifer, south of the Kettle River, and in one area north of the Kettle River, NO_3-N concentrations are elevated (>3 mg/L) and locally exceed the Canadian Drinking Water Guideline of 10 mg/L NO_3-N. Wei et al. (1993) concluded that the natural background concentration of NO_3-N in the aquifer is <0.1 mg/L, and elevated NO_3-N concentrations (greater than a few mg/L) reflect sources from human activities. Areas of NO_3-N above Canadian Drinking Water Guidelines correlate with nurseries and vegetable growing areas, but not generally with areas of high septic density. Preliminary isotopic study of ^{15}N in the nitrate suggests the source of nitrate is inorganic (Wei, 2001). Follow-up analysis of ^{15}N and ^{18}O in the nitrate by Allen and Bishop (2003) indicates manure sources can not be ruled out at this time. The intrinsic vulnerability of the aquifer and presence of elevated nitrate, locally exceeding the Canadian Drinking Water Guidelines, underscore the need for aquifer protection at Grand Forks.

4 LESSONS LEARNED

Mapping and characterizing the Grand Forks Aquifer reflect the interest the Ministry has in gaining a better understanding of groundwater and aquifers in areas where there is a heavy reliance on the resource. Key lessons learned from this project relate to the following:

- Additional data on the status of well use and well pumping. There are an estimated 200+ abandoned wells in Grand Forks as residents connect to community wells over the years. These abandoned wells pose a risk and need to be identified for closure. Although pumping volumes were obtained for the major wells, additional pumping information for private irrigation wells, would help refine modelling and water balance calculation results.
- Minimum standards for information in the water well records, such as accuracy of location and use of standard lithological descriptions, would improve the overall quality and consistency of water well record data, which would be especially critical for mapping and characterizing aquifers in hydrogeologically complex regions.
- Greater emphasis on dialogue between scientists and decision-makers, from the start, to better understand the types of hydrogeological information desired and how it can be more effectively portrayed and weaved into the local decision-making process to ensure protection and management of this hidden but valuable resource.

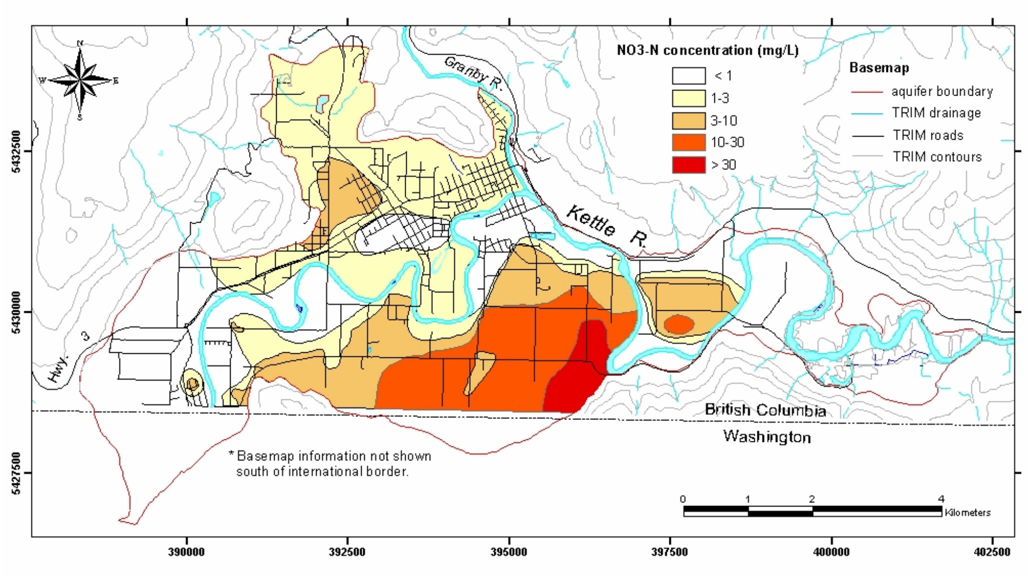

Figure 7. Distribution of NO_3-N.

5 ACKNOWLEDGEMENTS

Funding for this work was provided by the Climate Change Action Fund and the Ministry of Water, Land and Air Protection.

6 REFERENCES

Allen, D.M. 2001. Groundwater and Climate Change: A Case Study Sensitivity Analysis for the Grand Forks Aquifer, Southern British Columbia. Final Report prepared for Groundwater Section, Water Management Branch, BC Ministry of Environment, Lands and Parks, 227 p.

Allen, D.M. 2000. Numerical Modelling of the Grand Forks Aquifer, Southern British Columbia. Report prepared for the BC Ministry of Environment, Lands and Parks,126 p.

Allen, D. and Bishop, T. 2003. Nitrate isotope sampling program 2002-2003. Report to the Kootenay Boundary Community Health Services Society, 22 p.

Allen, D.M., Mackie, D.C. and Wei, M. 2003. Groundwater and climate change: a sensitivity analysis for the Grand Forks aquifer, southern British Columbia. *Hydrogeology Journal, on line publication*, June 2003.

Allen D.M., Scibek, J., Whitfield, P. and Wei, M. 2004. Climate Change and Groundwater: Summary Report. Prepared for Natural Resources Canada, Climate Change Action Fund, March 2004.

Aller, L., Bennett, T., Lehr, J., Petty, R. and Hackett, G. 1987. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Using Hydrogeologic Settings. National Water Well Association, Dublin, Ohio / EPA Ada, Oklahoma. EPA-600/2-87-035.

Ministry of Environment, Lands and Parks 1996. Groundwater Inventory and Assessment in British Columbia. Ministry of Environment, Lands and Parks, Groundwater Section, 44 p.

Sheppard, C. 1995. *Grand Forks Land Use Survey*. Report to the Ministry of Environment, Lands and Parks and Ministry of Agriculture, Fisheries and Food. File: 38000 NTS82E/1.

Waterloo Hydrogeologic Inc. 1997. UnSat Suite Plus software.

Wei, M. 2001. Summary of 1991 and 1993 isotope results from Grand Forks. Letter-report to the Kootenay Boundary Community Health Services Society. Ministry of Water, Land and Air Protection, Groundwater Section. File: 38000-35/MON, 5 p.

Wei, M. and Allen, D. M. 2004. Groundwater Management in British Columbia, Canada: Challenges in a Regulatory Vacuum. In Managing Common Pool Groundwater Resources An International Perspective, ed. Mary Brentwood and Stephen F. Robar, pp. 7-29.

Wei, M., Kreye, R., and Ronneseth, K. 1995. An Aquifer Classification System for Groundwater Management in British Columbia, Canada. In Proceedings, Solutions '95, International Association of Hydrogeologists, 6 p.

Wei M., Kohut, A. P. Kalyn, D. and Chwojka, F. 1993. Occurrence of nitrate in groundwater, Grand Forks, British Columbia. Quaternary International, Vol. 20, pp. 39-49.