COLLABORATIVE INTERAGENCY WATER PROJECTS IN BRITISH COLUMBIA: INTRODUCTION TO THE NORTHEAST BRITISH COLUMBIA AQUIFER PROJECT AND STREAMFLOW MODELLING DECISION SUPPORT TOOL

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ABSTRACT

Allocation of water to domestic, agricultural and industrial uses that is mindful of environmental requirements requires knowledge of the surface and below-ground water resources. The allocation of water in northeastern British Columbia has recently become significant due to demands associated with the development of the unconventional shale gas resource through hydraulic fracturing.

To address the lack of surface water information in northeast British Columbia, a streamflow modelling project has been initiated to provide information to government agencies and water licence applicants. Groundwater aquifers in the Montney gas play area are being described using traditional and geophysical investigation techniques.

The projects involve provincial and federal government agencies, the British Columbia Oil and Gas Commission, Simon Fraser University, private well owners and the oil and gas industry. This paper provides an overview of these projects.

Wilford, D., Hickin, A.S., Chapman, A., Kelly, J., Janicki, E.P., Kerr, B., van Geloven, C., Dessouki, T., Henry, K., Heslop, K., Kirste, D., McCarville, M., Ronneseth, K., Sakals, M. and Wei, M. (2012): Collaborative interagency water projects in British Columbia: introduction to the Northeast British Columbia Aquifer Project and Streamflow Modelling Decision Support Tool; *in* Geoscience Reports 2012, *British Columbia Ministry of Energy and Mines*, pages 79-89.

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Key Words: Water, Groundwater, Hydrogeology, Aquifer, Water wells, Observation wells, Montney gas play, Shale gas, Unconventional gas, Northeast British Columbia Aquifer Project, Hydrology Modelling and Decision-Support Tool, Groundbirch paleovalley

INTRODUCTION

Water is a valued resource in British Columbia and there are a variety of stakeholders concerned with its sustainable use. The Northeast British Columbia Aquifer Project and Streamflow Modelling Decision Support Tool Project are two interagency collaborative initiatives directed at understanding water source options for industrial, domestic, agricultural and environmental use in British Columbia's traditional oil and gas development region. These projects are a collaboration of the British Columbia Ministry of Forests, Lands and Natural Resource Operations (FLNRO), the British Columbia Ministry of Environment (MoE), the British Columbia Ministry of Energy and Mines (MEM), the British Columbia Oil and Gas Commission (OGC), Simon Fraser University (SFU), Geoscience BC (GBC) and the Geological Survey of Canada (GSC).

Shale gas development is a substantial contributor to British Columbia's energy inventory and development is increasing in the Horn River Basin, the Liard Basin, the Cordova Embayment and the Montney gas play area (Fig. 1). To develop this unconventional shale gas resource, gas wells are stimulated through hydraulic fracturing, whereby the relatively impermeable shale is fractured, providing a conduit for the gas to flow from the rock to the wellbore. Hydraulic fracturing requires substantial quantities of water (Johnson, 2012); therefore, secure water supplies could be a limiting factor in development. Industry, the public and various levels of government are seeking sufficient information to appropriately manage these resources. Two collaborative projects have been initiated to begin addressing ground- and surface-water sustainability: the Northeast British Columbia Aquifer Project and the Streamflow Modelling Decision Support Tool.

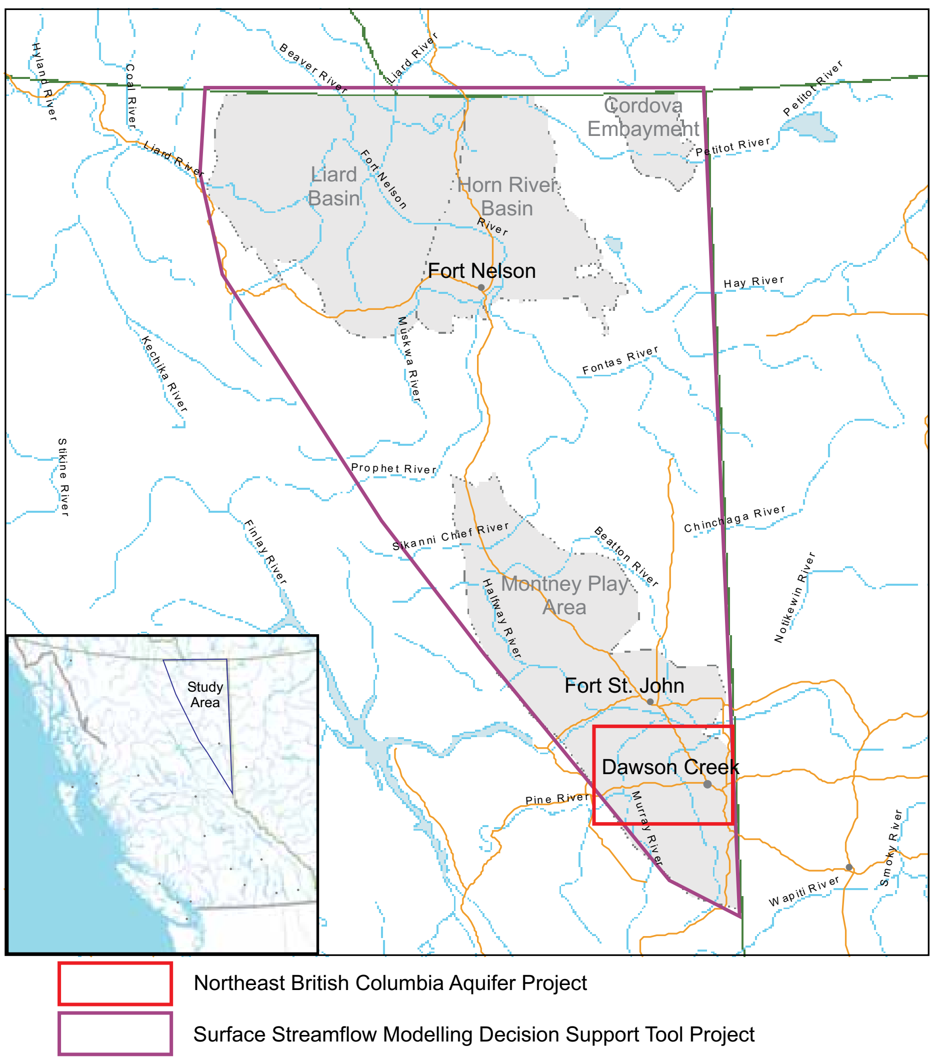

Figure 1. The Northeast British Columbia Aquifer Project is being conducted in the Dawson Creek area within the Montney gas play area (red box). The Streamflow Modelling Decision Support Tool Project is being conducted across northeast British Columbia (purple polygon).

NORTHEAST BRITISH COLUMBIA AQUIFER PROJECT

This project is in the process of exploring groundwater aquifers in the Montney gas play area from two different, but complementary, perspectives. One component of the project focuses on traditional groundwater investigations using groundwater wells to determine stratigraphy, water chemistry, water table elevations and fluctuations over time, and the hydraulic characteristics of aquifers. Each drilled well provides a one-dimensional view of aquifers. Interpolating between a series of wells allows for a more extensive description of an aquifer. The second component of the project investigates aquifers using geophysical techniques to delineate the geological units that define the aquifers. A series of lines are run across the landscape enabling a two-dimensional delineation of subsurface aquifers. Interpolating between a series of lines allows for a three-dimensional description of the aquifers. Hydraulic characteristics of the aquifers and the subsurface calibration of the geophysics are determined using groundwater wells (this is where the two approaches are complementary—in fact, essential). The project includes four components: 1) a well water survey, 2) expansion of the British Columbia Observation Well Network, 3) the geological framework of the Groundbirch paleovalley and 4) a groundwater level (GWL) interface data update. In the following sections, we introduce each of these components.

Water well survey

Basic water well information and water chemistry are essential for understanding groundwater systems. A survey of more than 100 water wells in the study area was initiated with the objective of having at least one sample well per 20 km^2. The survey involved several steps: updating well records for the area, establishing contact with well owners and undertaking well sampling and measurement.

Well records for the area are not complete; in some cases information was lacking, whereas in other cases the wells had not been used. Where well logs were available, the information was not of consistent quality. These data are critical for understanding the hydrogeology of the area and were verified or added during discussions with well owners (depth of well, depth to water at time of drilling, geology and type of aquifer).

Establishing contact with the well owners was challenging. Many individuals were only home at night, resulting in long days for team members. Some individuals were suspicious of any research to do with their groundwater, whereas others had already participated in other well water sampling projects sponsored by the industry. As a result, a short brochure was prepared that explained the project and provided contact information (Fig. 2). In addition, a cover letter was prepared, specifically requesting participation in the project and stressing that the source of any groundwater information would be kept confidential.

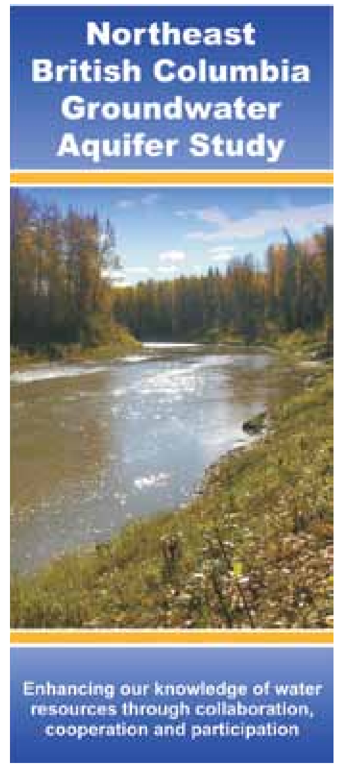

Figure 2. A three-panel public information brochure for the Northeast British Columbia Aquifer Project was distributed to landowners within the study area.

Fieldwork focused on the physical and chemical nature of water in each well (Fig. 3). Physical aspects included depth to groundwater using an ultrasonic meter (Ravensgate Sonic 200U Well Depth Sounder). The elevation of the well was established using a precision GPS unit (Magellan MobileMapper CX). A multiparameter flow-through meter (YSI Pro Plus) was used in the field to determine pH, electrical conductivity, dissolved oxygen and oxidation/reduction potential. Samples were shipped to SFU and analyzed for anions, cations, isotopes, trace metals, alkalinity, total dissolved solids and nutrients. Given the scope of the project—to determine the physical aspects of aquifers in the study area—we are not sampling or analyzing for volatile organic compounds (VOCs, BTEX, i.e., benzene, toluene, ethylbenzene and xylenes). Well owners were asked a series of questions related to level of use, historical water sampling, proximity to other water wells or oil and gas wells, land use around the well and if they were interested in potentially having their well pump tested/slug tested at a later date.

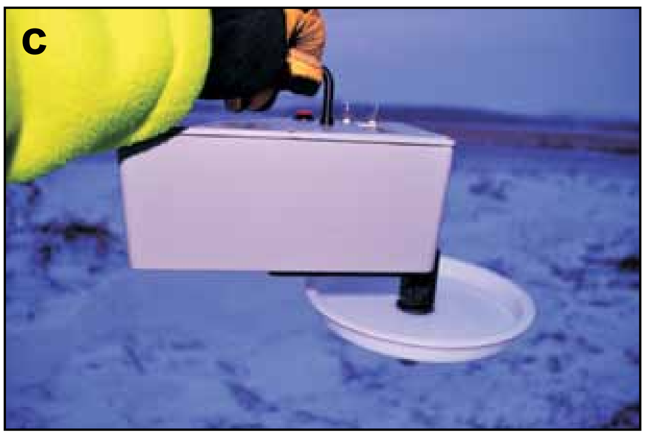

Figure 3. a) Wells included in the water well survey were visited by a contractor and measurements and samples were collected; b) the location and elevation (±50 cm) of each well was determined by precision GPS measurement; c) the static water level was established using a handheld ultrasonic meter; d) a multiparameter flow-through meter was used to determine pH, electrical conductivity, dissolved oxygen and oxidation/reduction potential.

Expansion of British Columbia Observation Well Network

The Government of British Columbia maintains a provincial network of approximately 140 groundwater observation wells. The wells are monitored regularly for groundwater level and groundwater chemistry to determine, over the long-term, whether aquifers are being impacted through natural and human-induced factors (Janicki, 2011). Most of the observation wells in British Columbia are concentrated in heavily populated southern regions where groundwater usage has historically been most intense. Only two observation wells are located in northeastern British Columbia, where most of the province's oil and gas development takes place. Neither of these wells are within the Montney gas play area.

Informed decisions regarding water resource allocation and authorizations cannot be made without a clear understanding of the water resource. The Government of British Columbia is currently exploring ways to modernize the Water Act, which will include formula-based in-stream flow assessment for surface allocations and regulating groundwater use (British Columbia Ministry of Environment, 2010). It is recognized that water authorizations or approvals granted may be compromised by the lack of information. The Northeast British Columbia Aquifer Project, in conjunction with funding through the Climate Action, Clean Energy (CACE) initiative, constructed six new observation wells in the rural areas surrounding Dawson Creek (Fig. 4). The publicly available observation well data will provide fundamental information on aquifer water levels necessary for responsible resource allocation and authorization.

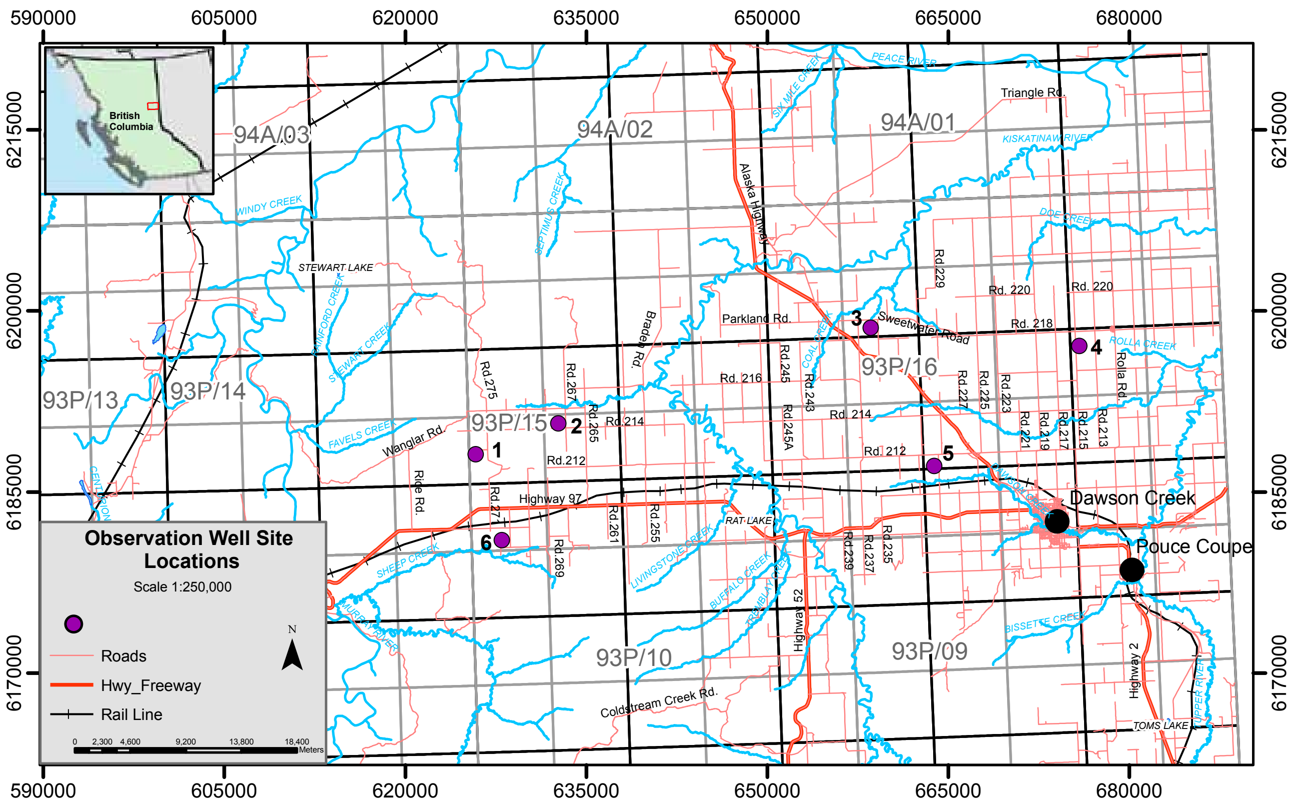

Figure 4. All of the new observation wells were constructed in the rural area around Dawson Creek.

The six observation wells were constructed in November 2011 and will be equipped with water-level monitoring equipment. Production capability and basic aquifer parameters (transmissivity, hydraulic conductivity, etc.) will be determined during the upcoming field season. Water samples will also be collected, analyzed and included with the water well survey (described above).

REGIONAL HYDROGEOLOGY

Mapping completed by the MoE (Berardinucci and Ronneseth, 2002) indicates the presence of several unconsolidated aquifers of limited extent overlying more widespread bedrock aquifers. The unconsolidated aquifers are mapped as confined sand and gravel of glacial or preglacial age (Hickin and Best, 2012), whereas the bedrock aquifer is identified as the Kaskapau Formation of Upper Cretaceous age (Glass, 1990). At surface, and overlying the aquifers, is a thick layer of impermeable clay. Vulnerability of aquifers in the area has been classified as low to moderate using the British Columbia Ministry of Environment Aquifer Classification System (Lowen, 2011). A review of water well records on the MoE website indicates that the likely source of groundwater for water wells in the study area is from bedrock aquifers, although the presence of suitable aquifer materials, such as gravel, is reported at shallower depths in some locations. The observation well drilling program included completing wells in both shallow unconsolidated and deeper bedrock aquifers, depending on geological conditions.

LOCATION SELECTION

Six observation well locations were selected using the following criteria:

- within the Montney play trend and in proximity to recent shale gas activity;
- within a vulnerable aquifer(s) as mapped by the MoE;
- access along a British Columbia Ministry of Transportation and Infrastructure road rights-of-way;
- south of the Peace River within a MoE priority area for new observation wells;
- a good chance of water production based on nearby water well records;
- reasonable depth to bedrock so that no individual well would be overly expensive; and
- establishment of three wells within a single aquifer so groundwater flow and gradient can be determined.

Figure 4 shows the location of the observation wells. The observation well at location 6 was selected to test the aquifer potential of the Groundbirch paleovalley and was expected to be deeper than the other five observation wells (Hickin, 2011). This well had polyvinyl chloride (PVC) casing installed and was logged with downhole geophysical instruments. The results will be correlated with a ground-based geophysical program designed to characterize the paleovalley (see below; Hickin and Best, 2012).

DRILLING AND COMPLETION

The six observation wells were drilled in late November and early December 2011 using an air-rotary drilling rig (Fig. 5) with a casing hammer. Drilling began with either an auger or an oversized bit of 19 cm (7.5 in.; water-well drilling operations use Imperial units). After roughly 3 m (10 ft.) of penetration, steel casing was pounded into the ground with the casing hammer. Drill cuttings were collected from the end of a discharge hose every 3 m (10 ft.) and logged.

Figure 5. In November 2011, six new water observation wells were drilled along on road rights-of-way using an air rotary water well drilling rig with a casing hammer.

After bedrock was encountered, the remainder of the hole was drilled open-hole. After reaching total depth of the borehole, a 12.7 cm (5 in.) PVC liner was inserted from the bottom of the borehole to near the ground surface. The lowest 6–12 m (20–40 ft.) of the liner was screened or perforated to allow inflow of groundwater. Approximately 75 cm (2.5 ft.) of steel casing remained above ground level as a 'stick-up' (Fig. 6). A MoE-issued well identification plate (Table 1, well plate number) was welded onto the side of each observation well casing. The well was then developed and an approximate measurement of the well yield was made using a stopwatch and bucket. Several days after drilling and completing the construction of the observation wells, the total depth and static water level were measured using a wet tape (Heron Instruments dipper-T water tape). Observation wells 1–6 have been incorporated into the MoE observation well network database and assigned well tag numbers (WTN) and observation well numbers (Table 1).

Figure 6. Following completion, approximately 1.5 m of steel casing remained above ground to mark the well. The casing was tagged with a well number and a lock cap was installed.

RESULTS

All wells recovered water but locations 1, 4 and 6 were particularly productive, based on informal measurements using a stopwatch and a bucket. Location 3 was drilled considerably deeper than expected in order to intersect the water table. Only location 6, which was drilled within the interpreted Groundbirch paleovalley, encountered a small volume of groundwater in a gravel bed of indeterminate extent at roughly 40 m (130 ft.) of depth. In this same well, a more significant aquifer was intersected at the bedrock sediment interface at approximately 80 m.

All wells were screened in bedrock and were constructed with a surface seal with a minimum of 4.5 m (approximately 15 ft.) in length. Bedrock generally consists of weathered carbonaceous shale with interbeds of siltstone and fine-grained sandstone. Water is likely contained within both the thin sandstone interbeds and secondary pore space created by weathering and jointing.

Geological framework of the paleovalley

Delineation of the geological framework within the Groundbirch paleovalley will aid in modelling the hydrogeology of the unconsolidated aquifers within this feature. This will be achieved by integrating three geophysical surveys with other geological datasets. A downhole electromagnetic and gamma survey was conducted in the recently drilled 85 m deep British Columbia observation well, constructed with a nonconductive casing (location 6 described above; Fig. 4). The detailed geology provided from this well was used to calibrate the other surveys. A ground-based time-domain electromagnetic survey was conducted in February 2012 and a shallow seismic reflection survey is anticipated to be carried out in the spring of 2012. These surveys will provide 2D sections across the paleovalley. This information will be augmented with field data from

TABLE 1. GENERAL PARAMETERS FOR SIX NEW OBSERVATION WELLS.

Location	Well Plate Number	Well Tag Number*	Easting (NAD83)	Northing	Total Depth		Depth to Bedrock		Depth to Uphole Aquifer		Screened Interval		Estimated Well Yield		Static water level below ground	
					(metres)	(feet)	(metres)	(feet)	(metres)	(feet)	(metres)	(feet)	litres/second	US gallons/minute	(metres)	(feet)
1	31673	104707	626795	6188502	31.7	104	6.1	20	-	-	25.6-31.7	84-104	2.3	30	19.6	64
2	31674	104708	633333	6189602	25.6	84	13.7	45	-	-	18.6-24.7	61-81	1.5	20	5.2	17
3	31676	104709	659162	6198993	91.4	300	18.3	60	-	-	79.2-91.4	260-300	0.02	0.25	57.3	188
4	31677	104710	673846	6196989	65.6	84	8.5	28	-	-	18.2-24.4	60-80	2.3	30	surface	surface
5	31675	104711	664182	6187977	48.8	160	21.3	70	-	-	42.7-48.8	140-160	0.4	5	19.2	63
6	31672	104712	628709	6180490	85.3	280	79.9	262	40.8	134	73.8-79.9	242-262	0.75	10	21.9	72

* Well data can be accessed using the Well Tag Number at the link below:
http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/index.html

Well locations can be found on a map using Well Tag Numbers using the following link:
http://webmaps.gov.bc.ca/imf5/imf.jsp?site=wrbc

an exposure of the paleovalley succession along the Coldstream River canyon, together with water well data from the MoE's WELLS database, the latter of which houses British Columbia's water well information (see Hickin and Best [2012] for details on this component of the project).

Groundwater level interface data update

British Columbia's observation wells provide data on groundwater-level fluctuations and groundwater quality information on developed aquifers in British Columbia. Water-level data from observation wells are continuously collected via instrumentation in the well. The water-level data is referenced from ground level and the data is downloaded by regional staff. Data are checked and validated for errors and omissions before being published and stored on the groundwater level (GWL) website.

Validated groundwater data collected from the Provincial Groundwater Observation Well Network are available in tabular, graphical and csv formats through the GWL public interface (https://a100.gov.bc.ca/pub/gwl/). Although the central database stores unvalidated data, it is not made available through the GWL public interface. The development of satellite telemetry equipment allows for the near–real-time upload of groundwater level data from across the province, potentially providing users with timely data on the condition of more than 55 aquifers throughout British Columbia. Unfortunately, near–real-time data from observation wells retrofitted with satellite telemetry equipment cannot be displayed in the GWL because it is unvalidated and thus, is not available to the public. The GWL public interface is currently being updated to include validated and unvalidated data in its outputs using support from the British Columbia Ministry of Forests, Lands and Natural Resource Operations and the British Columbia Ministry of Environment. This will allow for improved management of groundwater resources and support the Government of British Columbia's open-data initiative.

HYDROLOGY MODELLING AND DECISION-SUPPORT TOOL DEVELOPMENT FOR WATER ALLOCATION, NORTHEAST BRITISH COLUMBIA

The British Columbia Oil and Gas Commission (OGC), with support from Geoscience BC and the British Columbia Ministry of Forests, Lands and Natural Resource Operations, is undertaking a hydrology modelling project in northeast British Columbia. This project follows a pilot project undertaken in early 2011 by Chapman and Kerr (2011). The pilot project used available gridded climate data and land cover and vegetation data within the Horn River and Liard Basin gas play areas to model discharge in several watersheds. From the success of the pilot project, it was concluded that there is utility in pursuing a monthly water-balance modelling approach. The current project is now extending and fine-tuning the hydrology modelling to all of northeast British Columbia. The objective of the project is to complete overview hydrology modelling for northeast British Columbia and to produce a GIS-based decision-support tool, which would be used to provide estimates to guide water license applicants and short-term water-use approval decisions (British Columbia Water Act, Section (8) – Short Term Water Use).

Study area

This study encompasses the area of northeast British Columbia that includes the unconventional Montney gas play area, the Liard Basin, the Horn River Basin and the Cordova Embayment, from south of Dawson Creek to the Yukon and Northwest Territories boundary in the north, and east of the Rocky Mountains (Fig. 7). The total area in British Columbia under study is approximately 175 500 km^2.

The streamflow regime is typically nival (snowmelt dominated), with a sustained cold winter period characterized by low rates of streamflow and competent river ice, followed by a spring freshet from approximately mid-April to late June, characterized by high rates of streamflow as the winter's accumulated snow melts. After the spring

Figure 7. There are more than 55 hydrometric stations throughout northeast British Columbia and adjacent Northwest Territories and Alberta.

freshet period, river levels generally recede slowly through the summer and autumn until the winter freeze. Frontal or convective storm systems bring varying amounts of rain from late spring to autumn, often resulting in temporary increases in river levels and discharge, and occasionally producing flooding (which is randomly distributed in the watersheds within the study area).

Data

The water balance model takes a 'conservation of mass approach' and follows a concept originally applied by Solomon et al. (1968) and Moore et al. (2011). Key inputs to the model for northeast British Columbia are monthly and annual precipitation and temperature grids from the ClimateWNA program (Wang et al., 2012), which are derived from the PRISM methodology (Daly et al., 2008); gridded evapotranspiration data produced by the Consultative Group for International Agricultural Research (CGIAR); land cover and vegetation mapping from Natural Resources Canada and the Province of British Columbia; and hydrometric data from the Water Survey of Canada.

Actual evapotranspiration data produced by CGIAR modelling accounts for water availability using a modified Hargreaves (Trabucco and Zomer, 2010) approach and takes climate inputs from the WorldClim database—a 1 km gridded climate surface representing the time period of 1950–2000 (Hijmans et al., 2005; Trabucco and Zomer, 2010). Within the CGIAR data, evapotranspiration is adjusted according to soil moisture content factors and assumes agronomic land cover. Evapotranspiration values were obtained from several sources (Chapman, 1988, Spittlehouse, 1989; Liu et al., 2003; Barr et al., 2007) and were adjusted within the model.

Model calibration

Estimates of monthly and annual runoff were derived using the simple continuity equation: Q = P–ET, where Q = annual runoff (mm), P = annual precipitation (mm) and ET = annual evapotranspiration (mm). Exploratory spatial data analysis was a large component of this work, and as such the end result will be a product that represents the hydrology of northeast British Columbia as effectively as possible given available data.

The results of the annual runoff modelling were calibrated against hydrometric data collected by the Water Survey of Canada. A total of 55 hydrometric stations were selected for calibration. Not included were gauges on very large drainages (e.g., Peace River, Liard River), lake outlet stations or stations on drainages with manmade controls. The stations are located in British Columbia, western Alberta and the southern Northwest Territories and in several cases the watersheds cross provincial/territorial borders. Although the objective of this work was only to create estimates for ungauged drainages in British Columbia, these transborder stations and stations wholly located in adjacent jurisdictions provided critical representation of portions of British Columbia that are ungauged.

Significant variability and error exists in the natural processes represented by all components of the model and the hydrometric data to which model results are compared. A multivariate regression technique was used to remove some modelling error. Results for the annual runoff modelling indicate a median error of 3.7%, with 78% of the calibration basins having estimates within ±20% of the measured mean annual runoff. A statistical model was then used based on a multivariate regression technique to distribute the modeled annual runoff to individual months of the year. In general, the monthly runoff modelling is quite good, with hydrograph fits that are visually accurate (Fig. 8) and with reasonable statistics (median Nash-Sutcliffe efficiency = 0.90, with 58% of the calibration basins having Nash-Sutcliffe efficiency statistics of greater than 0.90).

Project workshop

A workshop was held on January 11, 2012 to review and comment on the modelling approach and the proposed decision support tool. Participating in the workshop were scientists, managers and operational staff from provincial ministries (FLNRO, MEM and MoE), a federal ministry (Environment Canada–Water Survey of Canada), industry (Nexen, Esso and Conoco-Philips), Geoscience BC, FOR-REX, the OGC and academia (The University of British Columbia and University of Victoria). The objectives of the workshop were to receive scientific and operational input on the model and tool, gauge support for the approach in using the model and tool, and to communicate the project to stakeholders. This was a successful workshop with fully engaged discussion and constructive suggestions presented.

Summary

The hydrology modelling approach outlined in this paper is yielding consistent and reliable estimates of annual and monthly runoff for rivers in northeast British Columbia. The modelling is not yet complete and further enhancements based on workshop input are being tested. Included in the enhancement is the ability to locate a point of interest on a river and generate runoff data for that point based on the upstream watershed. This multipoint ability within a watershed will allow for point-specific identification of water availability. It is anticipated that the modelling will be completed by early 2012.

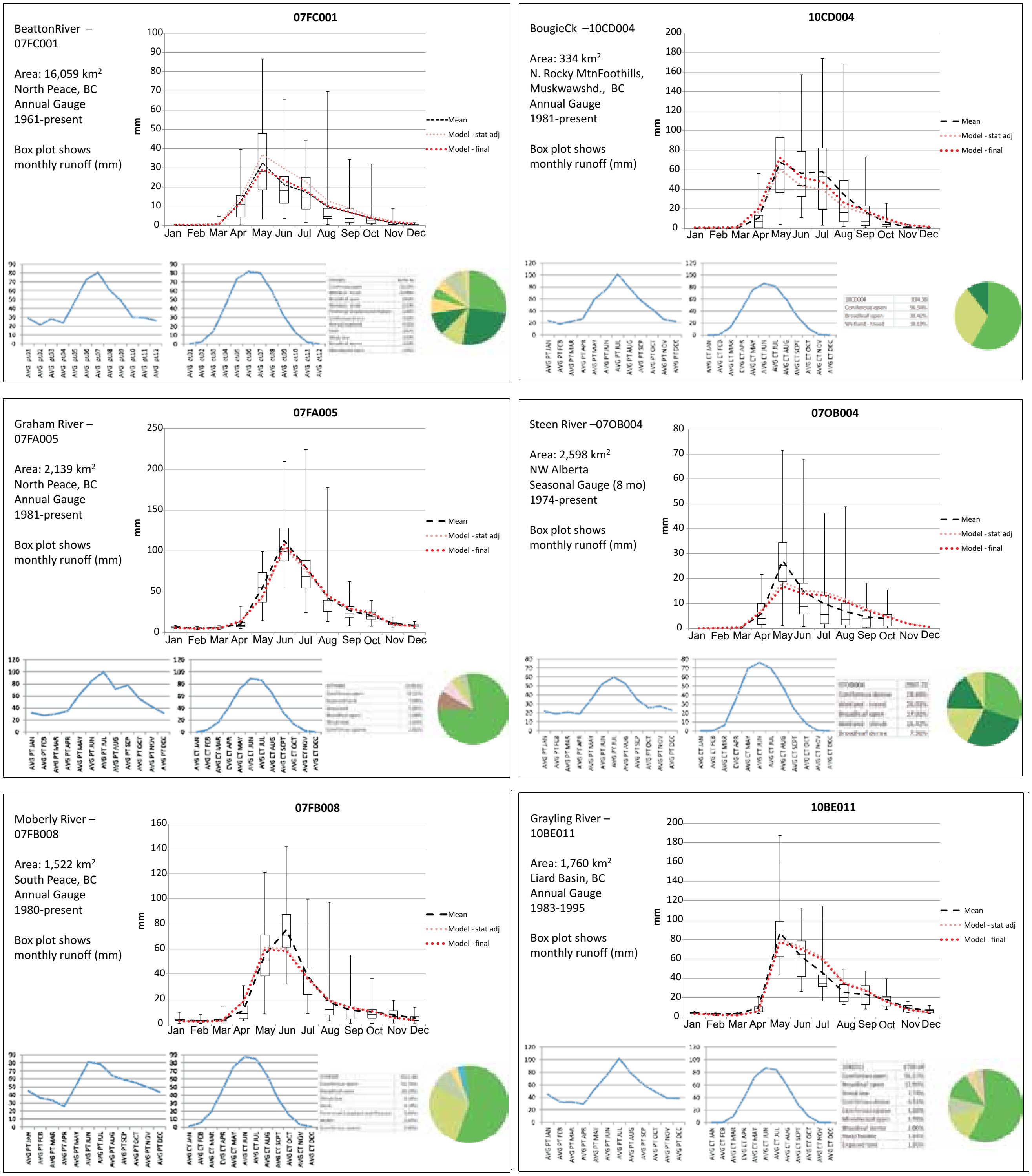

Figure 8. Several examples show how the modelled data fits the average monthly discharge measured at the hydrometric stations. The blue plots on the bottom left of each example show modelled precipitation (mm) and modelled actual evapotransporation (AET). The pie chart shows the proportion of each vegetation cover category within the watershed (the pie size is proportional to the table provided and is read from the 12 o'clock position clockwise).

ACKNOWLEDGMENTS

The projects described in this report have received funding from Geoscience BC; the British Columbia Ministry of Forests, Lands and Natural Resource Operations; the British Columbia Ministry of Energy and Mines; the British Columbia Ministry of Environment; and the Oil and Gas Commission. Additional funding has been provided by the Climate Action, Clean Energy (CACE) Fund. The projects have benefitted from the cooperative approach shown by all participants and the principal authors thank everyone involved for their collaboration. Water wells were drilled by Cariboo Water Well Drilling Limited.

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