Hydrological Modelling and Decision-Support Tool Development for Water Allocation, Northeastern British Columbia

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Introduction

In northeastern British Columbia, unconventional gas development requires large quantities of water, with the largest volumes of water used for hydraulic fracturing for well stimulation and completion. The management of water for industrial uses is the responsibility of the BC Oil and Gas Commission (OGC), through short-term water use approvals, and the BC Ministry of Forests, Lands and Natural Resource Operations (FLNRO), through long-term water licenses. For much of northeastern BC, there is a dearth of hydrometric measurements to directly support decision-making under the Water Act. As a result, there is a strong need for hydrological modelling to provide quantified estimates of monthly, seasonal and annual runoff thus allowing estimations of water availability for water use approvals. A hydrological modelling pilot project (Chapman and Kerr, 2011), utilizing available gridded climate data and land cover/vegetation data, and encompassing the Horn River Basin and Liard Basin gas play areas, concluded that there is utility in pursuing a monthly water balance modelling approach. Following the pilot project, the OGC, in partnership with Geoscience BC and FLNRO, is now extending and fine-tuning the hydrological modelling to all of northeastern BC. This paper summarizes the current status of the modelling project as of November 2011. The project is anticipated to be completed in early 2012.

Objectives

The project will complete overview hydrological modelling for northeastern BC, and will produce a decision-support tool (in Arc Server format) to be used by the OGC and FLNRO for water use approvals and water licenses under the Water Act. The modelling information and decision-support tool will be available to industry, First Nations and others, and will be valuable in helping communicate and understand the water resources of northeastern BC. The model will provide estimates of monthly and annual natural runoff, and will provide guidance on hydrological thresholds necessary for the maintenance of environmental flows.

Keywords: *hydrological modelling, hydrology, water allocation, northeastern British Columbia*

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Study Area

This study within northeastern BC includes the unconventional gas play areas of the Montney Trend, Liard Basin, Horn River Basin and the Cordova Embayment, from south of Dawson Creek to the Yukon and Northwest Territories boundaries in the north, and east of the Rocky Mountains to the Alberta border (Figure 1). Adjacent areas of Alberta, the Yukon and NWT have been incorporated to facilitate the hydrological modelling in BC. The total area in BC under study is approximately 175 500 km^2. The climate varies from cold continental in the south to cold subarctic in the north, characterized by sustained cold winters and warm summers. Average monthly temperatures for November to March are below freezing. There are few climate stations with long-term records, however, Fort Nelson has a measured 30-year Normal precipitation of 451 mm, while Fort St. John has a Normal precipitation of 465 mm. Precipitation amounts increase to the west of the study area, in the higher elevation terrain of the Rocky Mountain foothills.

The streamflow regime is typically nival (snowmelt dominated), with a sustained cold winter period characterized by low rates of streamflow and competent river ice. This is 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 freshet period, river levels generally recede slowly through the summer and autumn until the winter freeze-up. Frontal or convective storm systems bring varying amounts of rain from late spring to autumn, often resulting in increases in river levels and discharge, and occasionally producing flooding. The timing of the annual peak flow usually coincides with the timing of the annual freshet snowmelt runoff, except for small river basins, which, on occasion, can experience their largest peak flows from summer frontal or convective rain storms.

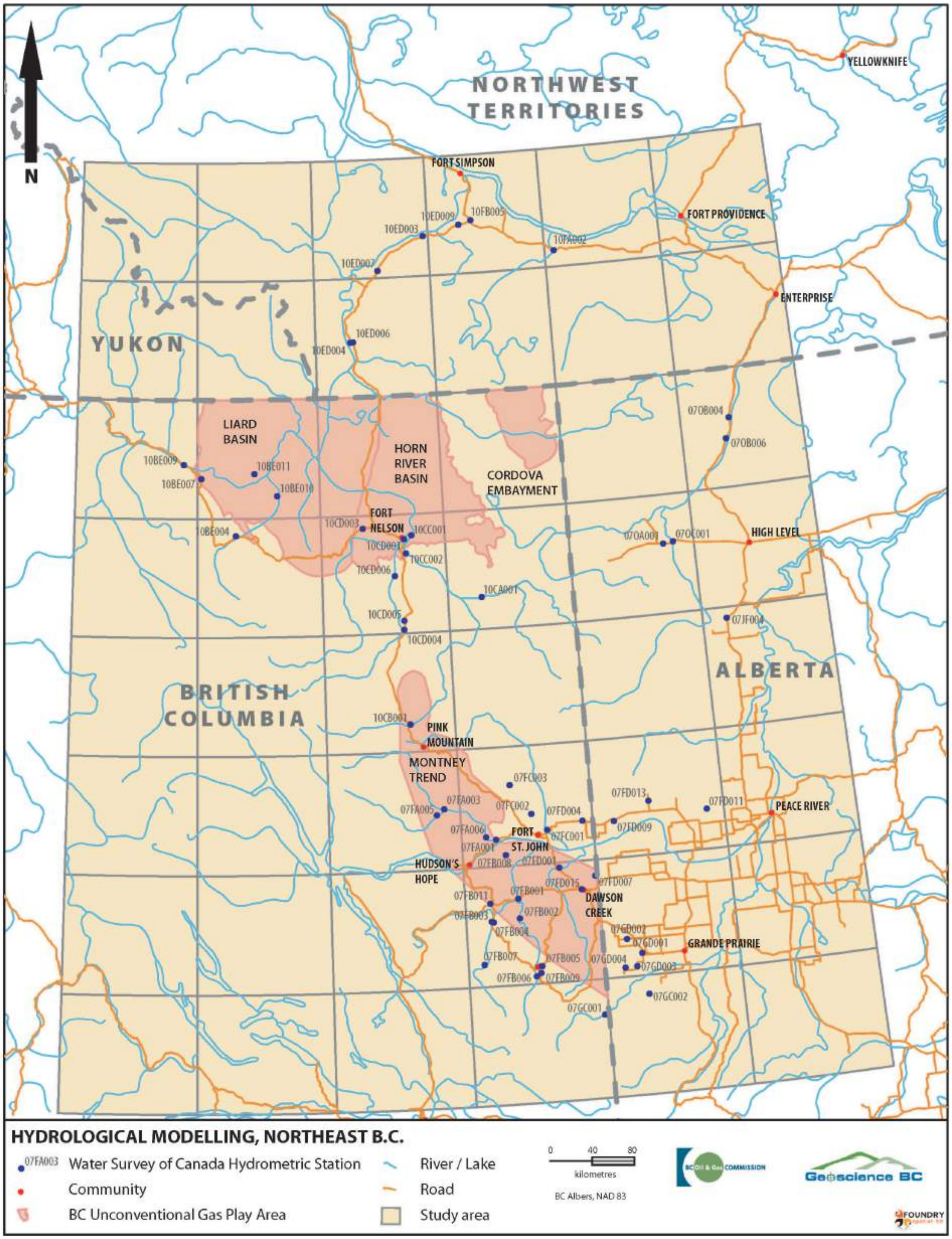

Figure 1. Modelling study area in northeastern British Columbia, showing natural gas play areas and hydrometric stations used in the model calibration.

Data

The water balance model takes a conservation of mass approach and follows on a concept originally applied by other researchers (Solomon, 1968; Moore et al., in press). Key inputs to the application for northeastern BC are

- monthly and annual precipitation and temperature grids from the ClimateWNA program (Wang et al., in press), which are derived from the PRISM methodology (Daly et al., 2008),
- gridded evapotranspiration data produced by the Consultative Group on 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 (WSC).

An interim product resulting from the model development is a gridded dataset representing actual evapotranspiration (AET), incorporating both climate and vegetative controls.

Actual evapotranspiration data produced by CGIAR accounts for water availability using a modified Hargreaves approach and takes climate inputs from the WorldClim database, a 1 km gridded climate surface representing the time period 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. The authors have transformed this estimate of evapotranspiration by incorporating a vegetation factor for northeastern BC. For this procedure, a vector coverage of vegetation and land cover was converted to raster values numerically equivalent to the ratio of the actual evapotranspiration for the land cover or vegetation type to that of the estimated agronomic evapotranspiration rate in the region. The evapotranspiration values used for each land-cover type were determined from several sources (Chapman, 1988; Spittlehouse, 1989; Liu et al., 2001; Barr et al., 2007) and were adjusted within the model.

Model Calibration

Estimates of monthly and annual runoff, the ultimate end product of the modelling component of the project, were not produced by running a defined routine through a piece of software. Instead, routines and components of other modelling projects (Solomon et al., 1968; Hock, 2003; McCabe and Markstron, 2007; Moore et al., in press) were evaluated, tested and incorporated by closely monitoring regional data inputs and results. These were evaluated against prior knowledge of the study region, 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 northeastern BC as effectively as possible given available data.

The results of the annual runoff modelling were calibrated against hydrometric data collected by the WSC. Fifty-three hydrometric stations were selected for calibration (Table 1). Not included were gauges on very large drainages (Peace River, Liard River), lake outlet stations or stations on drainages with man-made controls. The size of drainage area ranges from 38 to over 43 200 km^2. The stations are located in BC, 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 BC, these transborder stations and stations wholly located in adjacent jurisdictions provided critical representation of portions of BC that are ungauged.

A GIS was used to generate statistics for each watershed used in the calibration through a simple overlay operation. Once precipitation and climate-adjusted evapotranspiration for each of the gauged watersheds were calculated, these values were collated into a spreadsheet for further analysis and incorporation of the vegetation component of evapotranspiration. The percentage of each type of vegetative cover was determined for each watershed through a GIS overlay and added to the calculation.

Significant variability, as well as error, exists in the natural processes represented by all components of the model and also in the hydrometric data to which model results are compared. Preliminary results for the annual runoff modelling indicate a mean error of 5.5%, with 75% of the calibration basins having estimates within ±20% of the measured mean annual runoff. Unlike Moore et al. (in press) who used a water balance modelling approach to estimate monthly runoff, the authors used a statistical model based on a multivariate regression technique to distribute the modelled annual runoff to individual months over the year. Monthly runoff (as a percentage of annual runoff) is estimated as a function of grid cell elevation, UTM northing, UTM easting, monthly mean temperature and monthly mean precipitation. Adjusted R2 values range from 0.50 to 0.76, with the lowest values for July, August and September, and the highest values for October to June. In general, the monthly runoff modelling is quite good, with hydrograph fits that are visually accurate (Figure 2), and with reasonable statistics (median Nash-Sutcliffe efficiency = 0.94, with 65% of the calibration basins having Nash-Sutcliffe efficiency statistics of >0.90).

Summary

The hydrology modelling approach outlined in this paper is yielding consistent and reliable estimates of annual and

Table 1. Water Survey of Canada hydrometric stations used for model calibration.

Watershed	Name	Drainage area (km^2)	Years of record	Annual mean runoff measured (mm)
07FA001	Halfway River near Farrell Creek (lower station)	9351	23	256
07FA003	Halfway River above Graham River	3764	19	298
07FA005	Graham River above Colt Creek	2139	26	388
07FA006	Halfway River near Farrell Creek	9296	25	253
07FB001	Pine River at East Pine	11906	48	503
07FB002	Murray River near the mouth	5558	32	474
07FB003	Sukunka River near the mouth	2591	32	667
07FB004	Dickebusch Creek near the mouth	85	31	220
07FB005	Quality Creek near the mouth	38	24	165
07FB006	Murray River above Wolverine River	2383	32	756
07FB007	Sukunka River above Chamberlain Creek	928	9	818
07FB008	Moberly River near Fort St. John	1522	29	239
07FB009	Flatbed Creek at kilometre 110 Heritage Highway	479	27	270
07FC001	Beatton River near Fort St. John	16059	48	106
07FC002	St. John Creek near Montney	212	13	87
07FC003	Blueberry River below Aitken Creek	1775	45	95
07FD001	Kiskatinaw River near Farmington	3601	54	91
07FD004	Alces River at 22nd Base Line	313	25	59
07FD007	Pouce Coupe River below Henderson Creek	2856	36	73
07FD009	Clear River near Bear Canyon	2876	39	56
07FD011	Hines Creek above Gerry Lake	373	36	42
07FD013	Eureka River near Worsley	755	35	32
07GC002	Pinto Creek near Grande Prairie	494	24	106
07GD001	Beaverlodge River near Beaverlodge	1621	42	46
07GD002	Beavertail Creek near Hythe	678	27	40
07GD003	Redwillow River near Beaverlodge	1605	11	94
07GD004	Redwillow River near Rio Grande	1240	17	142
07JF004	Boyer River near Paddle Prairie	140	29	19
07OA001	Sousa Creek near High Level	820	40	62
07OB004	Steen River near Steen River	2598	36	73
07OB006	Lutose Creek near Steen River	292	33	68
07OC001	Chinchaga River near High Level	10370	41	89
10BE004	Toad River above Nonda Creek	2549	48	537
10BE007	Trout River at kilometre 783.7 Alaska Highway	1191	39	434
10BE009	Teeter Creek near the mouth	210	30	177
10BE010	Toad River near the mouth	6890	13	490
10BE011	Grayling River near the mouth	1760	13	297
10CA001	Fontas River near the mouth	7439	17	132
10CB001	Sikanni Chief River near Fort Nelson	2181	65	374
10CC001	Fort Nelson River at Fort Nelson	43200	19	244
10CC002	Fort Nelson River above Muskwa River	22560	27	193
10CD001	Muskwa River near Fort Nelson	20250	65	332
10CD003	Raspberry Creek near the mouth	275	30	135
10CD004	Bougie Creek at kilometre 368 Alaska Highway	334	28	251
10CD005	Adsett Creek at kilometre 386.0 Alaska Highway	109	26	252
10CD006	Prophet River above Cheves Creek	7277	8	324
10ED003	Birch River at Highway No. 7	563	36	156
10ED004	Rabbit Creek below Highway No. 7	122	6	161
10ED006	Rabbit Creek at Highway No. 7	110	7	162
10ED007	Blackstone River at Highway No. 7	1381	19	243
10ED009	Scotty Creek at Highway No. 7	137	15	159
10FA002	Trout River at Highway No. 1	9111	41	141
10FB005	Jean-Marie River at Highway No. 1	1351	38	122

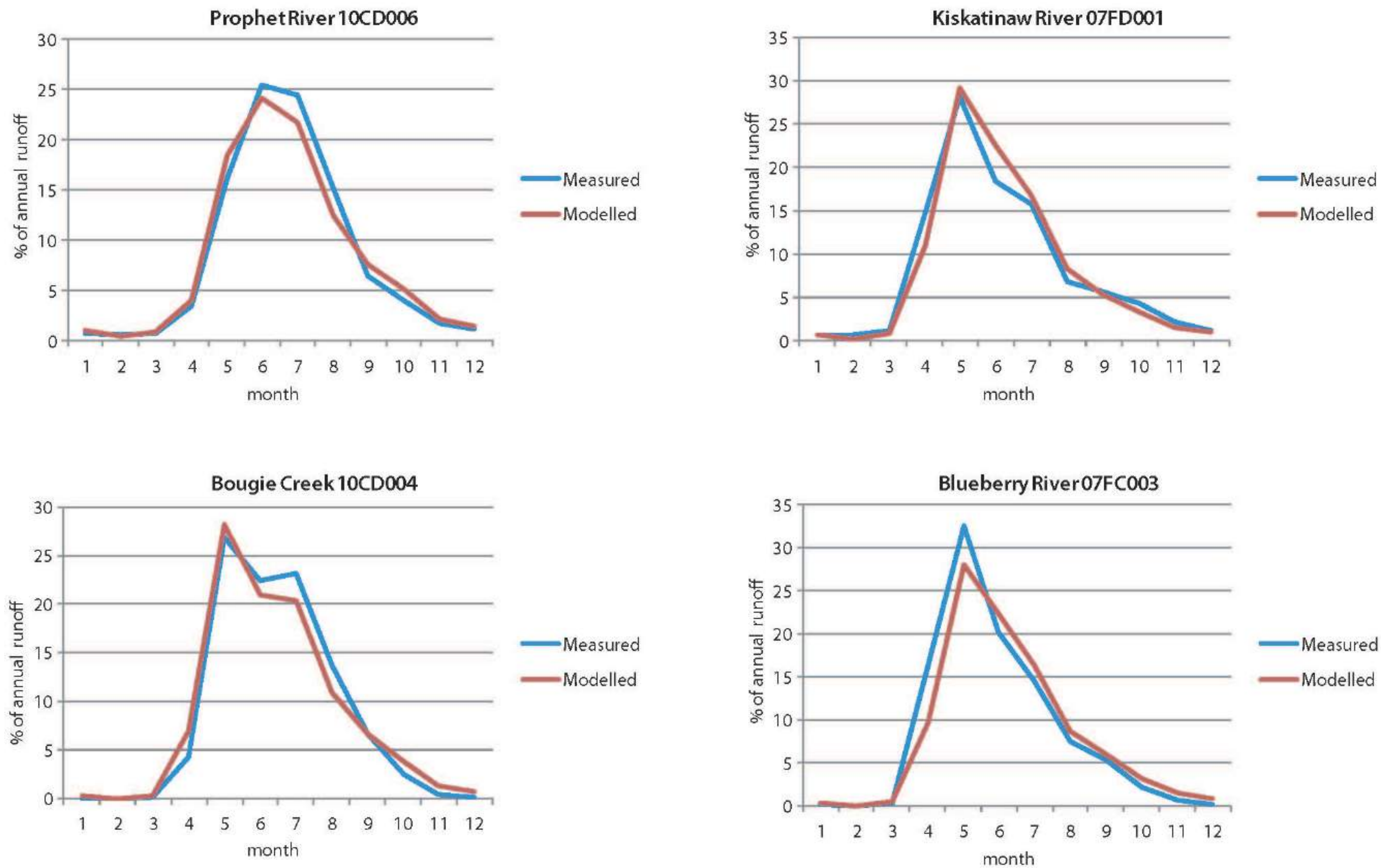

Figure 2. Examples of monthly hydrographs for four river basins in northeastern British Columbia.

monthly runoff for rivers in northeastern BC. At the time this paper was prepared, the modelling was not complete, and further enhancements are being tested. It is anticipated that the modelling will be completed by the end of 2011, with the development of a decision-support tool in early 2012.

Acknowledgments

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