

**Review of Groundwater Assessment Methodology
(Province of Prince Edward Island)**

Submitted by

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to

The Department of Environment, Labour and Justice

Province of Prince Edward Island

December 29, 2014

1. Background

This review was requested by the Province of Prince Edward Island (PEI), which has the responsibility to manage the allocation of water resources within the province. The goal of the review was to provide an independent, scientific opinion regarding the methodologies presented by the PEI Department of Environment, Labour & Justice (DELJ) to assess groundwater availability. In particular, the focus of this review was on the science basis for groundwater extraction assessments and groundwater quantity estimates. These methodologies were recently consolidated in the *Water Extraction Permitting Policy* (DELJ, 2013).

The three specific aspects that have been reviewed, and which are discussed in detail in this document, are:

- The groundwater assessment modeling methodology utilized by the DELJ,
- The protocol presented within the *Water Extraction Permitting Policy* (DELJ, 2013) that is used for the initial screening of groundwater extraction requests, and
- The accuracy/reliability of the estimated amount of water within the groundwater flow system, including annual recharge, seasonal groundwater discharge, etc.

The *Water Extraction Permitting Policy* (DELJ, 2013) contains information that deals with issues, including in-stream flow requirements and surface water extractions, which are outside the scope of this review. The following aspects have not been evaluated:

- The appropriateness of the “35% policy”, which indicates that “ ... groundwater extraction should not be permitted to reduce the mean summer base flow in the main branch of streams by more than 35 per cent” (DELJ, 2013: p. 7). This in-stream discharge is a measure of aquatic ecosystem flow requirements, which is a topic outside my area of expertise,
- Surface water withdrawals,
- Groundwater quality (which is not addressed in the *Water Extraction Permitting Policy*), and
- Specific PEI case studies dealing with groundwater extraction permitting.

2. What information was reviewed?

All literature included in the **References** section of this report has been reviewed. This includes the *Water Extraction Permitting Policy* prepared by the PEI Department of Environment, Labour & Justice (DELJ, 2013) and a number of scientific papers and reports dealing with groundwater

resources and hydrogeological conditions on PEI. To the best of my knowledge, all of the documents are publically available.

Project reports and internal DELJ documents, which may be associated with specific groundwater supply assessments or water extraction applications, have not been reviewed. For this reason, details related to how specific hydrogeological assessments have been conducted or the implementation protocol/guidance provided by DELJ during such assessments are not considered.

3. The groundwater assessment modeling methodology utilized by the Department of Environment, Labour and Justice (DELJ)

DELJ technical staff and their collaborators have, for at least a decade, performed a number of numerical simulations of groundwater flow and quality (the groundwater quality studies have mainly related to elevated nitrate concentrations) in selected watersheds in PEI. Many of these investigations have used state-of-the-practice numerical models, such as the widely-used and well-regarded United States Geological Survey (USGS) finite-difference groundwater model MODFLOW (e.g. Jiang and Somers, 2009) or the finite-element model FEFLOW (e.g. Rivard et al., 2008). As with all groundwater modeling studies, the quality of the results is highly dependent on having a correct conceptual model (or physical understanding of the groundwater flow system) and sufficient physical data to: a) construct a realistic model, and b) appropriately test its utility via calibration and validation.

The conceptual model for the PEI sedimentary rock aquifer(s) is, in my opinion, well developed and founded on research carried out within PEI (e.g. Carr, 1969; van der Kamp, 1981; Jacques, Whitford & Associates et al., 1990; Jiang et al., 2004; Jiang and Somers, 2009). The conceptual model has been presented in public and scientific formats such as scientific conferences, academic theses, and peer-reviewed journal papers. As is normal convention in the field of hydrogeology, the term conceptual model is used to describe the basic state of understanding regarding the surficial and bedrock geology, how water enters (recharges) the aquifer, the main features that govern flow within the aquifer (e.g. layering of sedimentary rock sequences, occurrence of fractures), and how groundwater is discharged from the flow system. Having a well-developed conceptual model does not mean that there is no longer a need to collect basic information regarding the hydrogeological conditions on PEI. As methods for groundwater and aquifer characterization continue to evolve and improve (especially for fractured rock aquifers), they should continue to be utilized to advance the basic understanding and hydrogeological database for PEI, and to obtain data in additional areas. However, the current high-level (or

conceptual) understanding of how the shallow groundwater flow system functions on PEI is considered sufficiently developed for groundwater-supply management purposes.

The application of numerical models by DELJ to investigate groundwater flow has been at a level that is considered consistent with the state-of-practice in the field of hydrogeology. Modeling studies (e.g. Jiang et al., 2004; Jiang and Somers, 2009) have used up-to-date software, been consistent with the conceptual model, incorporated available field data, and included the important steps of model calibration and, in some cases (Jiang et al., 2004), validation (to the extent such models can be validated). Independent research groups (e.g. Paradis et al., 2007; Danielescu et al., 2009) have also undertaken groundwater flow modeling studies for selected watersheds on PEI and, in general, have used data sets and numerical modeling approaches that did not deviate significantly from those employed by the DELJ.

The knowledge regarding regional hydrogeological parameters (for example, bulk hydraulic conductivity and transmissivity) that characterize the physics of groundwater flow in the PEI aquifer(s) is considered adequate for regional groundwater resource assessments. Some site-specific parameters, such as stream bed hydraulic properties, which are important for assessing pumping impacts on stream flow, appear to be less well defined. For example, it is unclear how many field studies have been specifically designed to investigate the groundwater-surface water interactions resulting from pumping wells.

The manner in which groundwater flow models have been applied by DELJ is considered appropriate for making assessments of the cumulative impacts of groundwater extraction on water availability within specific watersheds - thus they have great value in water management. When utilizing such approaches to investigate groundwater-surface water interactions, such as the impact of pumping wells on stream base flow, the issue of spatial scale has to be acknowledged. Models with the spatial resolution that is commonly used when simulating entire watersheds are most useful for assessing discharges in the main branch of streams in the middle to lower portions of watersheds. However, local scale surface water impacts, for example changes to the flow for a particular spring or discrete stream bed seepage area, cannot typically be simulated in regional (i.e. watershed) scale numerical groundwater models. For example, the horizontal resolution (cell size) of such models is often on the order of 100 m, and the stream bed hydraulic parameters, which appear to have been directly measured only in the Winter River watershed, are typically assumed uniform across, and within, watersheds on PEI (e.g. Jiang et al., 2004).

For assessment of local scale impacts more detailed (i.e. field based) studies would be required on a case-by-case basis, and this requirement is reflected in the *Water Extraction Permitting Policy* (DELJ, 2013; e.g. top of p. 5; top of p. 8). Methods exist to make such local-scale assessments and may include pumping tests combined with monitoring hydraulic heads (water

levels) in monitoring wells and stream-bed piezometers, and changes in stream discharge (e.g. Pattle Delamore Partners Ltd and Environment Canterbury, 2000). Such information could then be used to develop and apply locally-refined groundwater flow models.

4. The protocol of assessing groundwater extraction requests (i.e. Figure 1 and related text; DELJ, 2013)

This protocol is presented as an initial screening method that would be used to determine if a permit will be: a) issued for groundwater exploration with standard conditions (for rate less than $106 \text{ m}^3/\text{d}/\text{km}^2$). This value of $106 \text{ m}^3/\text{d}/\text{km}^2$ is close to 30% of the lowest historical (1961-2005) NRBF for the Mill River, which is reported as $108 \text{ m}^3/\text{d}/\text{km}^2$ (DELJ, 2013: Table 1, p. 11); b) issued for groundwater exploration with the requirement of detailed investigations (for rate between $106 \text{ m}^3/\text{d}/\text{km}^2$ and $902 \text{ m}^3/\text{d}/\text{km}^2$); or c) rejected (for rate greater than $902 \text{ m}^3/\text{d}/\text{km}^2$).

The crux of the protocol is that groundwater extractions will be screened by:

- a. determining the catchment area that is located topographically up-gradient of (“above”; DELJ, 2013; Fig. 1, p. 9) the proposed pumping well location, and
- b. comparing the proposed pumping rate divided by the catchment area to historical base flow data (expressed as Normalized Reference Base Flow, NRBF).

Regarding point a., the implicit assumption being made is that the groundwater that is extracted from a pumping well is derived from an up-gradient land area (or more correctly, aquifer volume) that can be defined topographically. Such contributing areas represent the source location for the water that is eventually pumped from the well. For example, if defined topographically, a proposed well located near an up-land watershed boundary would have a relatively small contributing area, compared to a location lower in the watershed (and presumably closer to a stream or river). For the same proposed pumping rate, the up-land well therefore could have a larger prorated extraction because the proposed pumping rate would be divided by a smaller catchment (i.e. contributing) area.

For item b., 30% of the lowest historical normalized RBF (NRBF) has been selected to determine where an exploration permit would have “standard conditions” or “requirements for detailed investigations”. It is not entirely clear what the differences are between “standard conditions” and “requirements for detailed investigations”, although it is stated that “If a detailed assessment is determined to be required, it would consist of stream flow monitoring, detailed pumping test requirements and, in many cases, the numerical modeling of possible impacts from pumping on the local water table and stream flow rates.” (DELJ, 2013; p. 8). In general

such addition requirements are appropriate, but it may be beneficial to provide more explicit technical guidance for detailed investigations when impacts to stream flow are a concern.

The distance between a proposed well and a stream(s) is not directly considered in the screening protocol. As noted above a well located near a watershed boundary, and likely relatively far from a stream, could have a larger area-normalized rate than one located lower in the watershed. On the other hand, a well that is located a large distance from a stream will have a smaller impact on stream flow than one located closer to the stream (all other factors being equal), especially for a case of intermittent pumping. An additional factor that might warrant consideration in the initial screening process is the separation distance between a well and a stream (e.g. Pattle Delamore Partners Ltd and Environment Canterbury, 2000).

It is also uncertain how accurately the catchment area for individual wells could be determined using only topographic information. As topographically-defined catchment areas for wells become smaller, it would be expected that the delineation and representativeness (with respect to the area recharging the well) would become more uncertain.

The addition of new wells, or pumping rates that vary at other wells in the vicinity, may change the area contributing recharge to any particular well, even if its discharge is constant (Franke et al., 1998). For the situation of multiple wells in a relatively small watershed, or area, the reasonable approach (and interpreted to be the case in the *Water Extraction Permitting Policy*) is that the cumulative impact of all wells would be assessed.

Within the assessment of groundwater extraction requests, the definition of the pumping rate could be clarified. For example, this could be interpreted as the peak rate at which pumping may occur, or the volume of groundwater extracted averaged over a specified period of time (e.g. week, month, year). Some consideration might be given to providing guidelines for determining how the pumping rate is to be calculated when stream flow impacts are being considered (e.g. Pattle Delamore Partners Ltd, 2012).

5. Accuracy/reliability of the estimated amount of water within the groundwater flow system, including annual recharge, seasonal groundwater discharge, etc.

A relatively large number of studies have been carried out to assess, using a variety of indirect methods, the annual recharge rate for the PEI aquifer(s). For example, Jiang et al. (2004) report that "Simulations indicate the mean recharge rates are 400, 400 and 450 mm/yr in Mill, Wilmot and Winter river watersheds respectively, which represent 36 to 40% of mean annual precipitation (=1100 mm/yr.). Annual recharges vary from 200 to 500 mm/yr depending on

annual precipitation and its temporal distribution.” Rivard et al. (2003; 2008) used numerical simulations of groundwater flow (SEEP/W finite element model) for a simplified two-dimensional vertical model domain running across PEI (from approximately Augustine Cove to North Rustico) to determine that steady-state, regional, annual recharge values of 250 to 350 mm may be realistic. For five hydrometric stations (i.e. sub-watersheds) located between Summerside and Borden, Rivard et al. (2003) reported average annual recharge rates from 173 to 354 mm (stream hydrograph separation method applied to time series ranging from 12 to 36 years). Using the well-known HELP soil moisture balance model, the average recharge for the entire island has been estimated as 369 mm/year for the period 1960-2001 (Vigneault et al. 2007); during calibration of this model the simulated seasonal recharge was estimated to be within 4 to 17% of the recharge estimated from water well hydrographs. This analysis therefore gives some idea of the variability/uncertainty in estimating historical recharge. In general, although previous studies produce somewhat different estimates (as would be expected) for recharge on PEI, I concur with the earlier statement of Rivard et al. (2003; p. 51) that “... the evaluation of recharge rates have provided a fairly reliable range of values ...”.

It should be noted that groundwater recharge varies with time and that the estimation of groundwater recharge is influenced by the time period considered in the analysis. Rivard et al. (2009) have indicated that two of three groundwater monitoring wells (located in PEI) exhibited small annual mean groundwater level declines based on an analysis of 30-year historical time series (Rivard et al., 2009; Figure 3). Such trends could not, however, be attributed to specific climate factors because land use and groundwater extraction changes were not considered in the study (Rivard et al., 2009). When compared to historical recharge values for PEI, recharge for the period of 2040-2069 has been projected to range between -12% (decrease) to 7% (increase), depending on the particular climate change scenario considered (4 scenarios were simulated; 3 of these forecast a decline in recharge (Vigneault et al., 2007)). These climate-related changes, however, fall within the range of variability for the historical recharge estimates determined by Vigneault et al. (2007). Going forward, annual and seasonal groundwater recharge estimates may need to factor in projected changes in the climate variables (e.g. precipitation, temperature) that partly drive this process.

Stream base flow (that is, the groundwater component of total stream discharge) has often been used as a measure of groundwater discharge, and thus aquifer “yield”, for PEI. Stream discharge hydrograph separation (e.g. Rivard et al., 2003) has been applied to estimate annual base flow, and during annual low-flow periods (e.g. July – September) the base flow is often shown to, or is assumed to, comprise the majority of the stream discharge (e.g. DELJ, 2013; p. 4). The approaches used to estimate base flow (including the numerical modeling discussed previously) are subject to some uncertainty, but they are widely used and the groundwater

discharge results seem reasonable and well supported. Although there are suggestions that stream base flows in Atlantic Canada may be exhibiting long-term declining trends (Rivard et al., 2009), the annual base flow data for two hydrometric stations located in PEI did not reveal a significant trend for 30-year time series (Rivard et al., 2009; Figure 2).

Taken together, the recharge estimates and ranges for PEI and the base flow studies provide a representative picture of the amount of water entering and discharging from the shallow (less than approximately 50 to 60 metres) groundwater flow system. Information from greater depths is generally limited as few production wells or groundwater investigations extend to greater than 100 metres. However, in the context of groundwater recharge and discharge (e.g. base flow to streams), it is expected that the greatest interactions will be with the shallow groundwater flow systems. These components of the hydrologic cycle will vary spatially and temporally due to hydrogeological conditions, land use, and climate factors, but such variability can be addressed in the future with existing methods (e.g. Rivard et al., 2014), many of which have already been applied in PEI. There will be value in continued long-term monitoring of water resources, analysis of such data sets, and assessments of the impact of climate change on PEI groundwater resources, particularly given the uncertainty associated with future climate projections and their influence on estimates of groundwater recharge (e.g. Kurylyk and MacQuarrie, 2013).

6. Concluding Remarks

The review of the *Water Extraction Permitting Policy* (DELJ, 2013) and publically-available literature dealing with groundwater resources and hydrogeological conditions on PEI lead me to the following concluding remarks:

1. The current high-level (or conceptual) understanding of how the shallow groundwater flow system functions on PEI is considered sufficiently developed for groundwater-supply management purposes.
2. The application of numerical models by DELJ to investigate groundwater flow at regional or watershed scales has been at a level that is consistent with the state-of-practice in the field of hydrogeology.
3. The groundwater flow models that have been applied by DELJ are considered appropriate for making assessments of the cumulative impacts of groundwater extraction on water availability within specific watersheds.

4. Assessment of local-scale interactions between pumping wells and streams will require detailed (e.g. field based) studies on a case-by-case basis, with a focus on obtaining the hydraulic properties required to evaluate the magnitude and timing of pumping impacts (if any) on stream flow.
5. The protocol for screening groundwater extraction requests could be refined in several areas, including how the pumping rate(s) are to be defined, how the catchment area(s) is determined, and being more explicit in terms of the factors that need to be considered in detailed assessments.
6. The groundwater recharge estimates and base flow studies conducted for PEI provide a representative range of values for the amount of water entering and discharging from the shallow groundwater flow system.
7. Going forward, annual and seasonal groundwater recharge and base flow estimates may need to account for projected changes in climate, and water permitting policy must be adaptable to such changes.

7. References

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