Mr. Ryan Post
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Subject: Delineation of Contributing Recharge Areas; Eastern Boundary of the Minesing Wetland Complex

Dear Mr. Post:

1 INTRODUCTION

Nottawasaga Valley Conservation Authority (NVCA) retained Matrix Solutions to conduct particle tracking to identify contributing recharge areas for two distinct areas of interest. Contributing recharge areas are defined as a geographical area where recharging water that enters the groundwater flow system will be eventually removed by discharge to surface water. The main area of interest is a fen area in the southeast portion of the Minesing Wetland complex (Figure 1). A secondary area of interest in Snow Valley (along Snow Valley road) was also considered, to illustrate and differentiate between flow paths that discharge within Snow Valley and flow paths that discharge to the fen.

The calibrated groundwater flow model for the Barrie Tier Three Risk Assessment (AquaResource et al, 2000) was used to delineate recharge areas. Details regarding the conceptual model and numerical model development can be reviewed in the appendices of AquaResource et al, 2000. The delineation of the contributing recharge area was achieved using both forward and reverse particle tracking methods. In addition, an uncertainty analysis was conducted to delineate potential recharge areas under alternative but plausible hydrogeologic conceptualizations. Additional information that provides insight into the recharge that feeds the wetland is also presented, including: travel time, recharge distribution, modelled recharge/discharge areas, and modelled flow divides within the area.

2 BACKGROUND

The Minesing Wetland Complex, located 20 km west of Barrie, is one of the most significant wetland systems in Southern Ontario. The fen-dominated portion of the Minesing Wetlands is located in the central-east part of the wetland; the vegetation of this portion is associated with relatively constant groundwater discharge areas (NVCA, 2000). As such, discharge of groundwater has been found to play an important role in maintaining the ecological integrity of the fen complex.

The hydrostratigraphic units underlying the study area are part of a regionally extensive and complex aquifer system. Four major sand and gravel aquifer units are identified in this system and are named, in...
order of depth, A to A4 (AquaResource et al, 2010; Appendix A). The aquifers are separated by lower permeability overburden (i.e. clay or fine grained tills) aquitards which are named, in order of depth, C1 to C4. A till-based surficial aquitard, known as UC, can also be found in the study area, overlying parts of A. The units are defined based on their relative stratigraphic positions (i.e. Mackinaw Interstadte) and are commonly identified based on relative elevation and characterization.

The regional A2 aquifer is the principal source of groundwater to the eastern portion of the wetland complex (Beckers and Frind, 2005). Outcrops of A2 on the western margin of the Snow Valley Upland result in discharging springs and spring-fed creeks found along the eastern edge of the wetland. This aquifer is locally recharged in the Snow Valley Uplands where the surficial geology is dominated by sands and gravels and subordinate tills. Several small watercourses that originate in the uplands and discharge into the fen are classified as cold and cool water fisheries habitats (e.g., Mink and Keast Creeks).

3 METHODOLOGY

3.1 Particle Tracking Methods

Particle tracking is a technique used in numerical modelling to illustrate the paths that water may take through porous media. This technique can be used to provide potential links between recharge areas with corresponding discharge areas, such as wetlands. Information such as travel time, travel length, and travel velocity can be extracted. The same approach is commonly used to delineate zones of contributions to production wells, commonly referred to as capture zone analysis.

Particle tracking techniques can be conducted in the forward or reverse direction. Forward particle tracking involves releasing a set of particles proximal to a recharge location (e.g. at the water table) and tracking them forward in time to the point until they reach a discharge location (e.g. well or gaining surface water feature). Reverse particle tracking involves releasing a set of particles at the discharge location (e.g. well or gaining surface water feature) and tracking them using the reverse flow field to their potential origin.

The primary advantage of forward particle tracking is that multiple particles are allowed to converge on a discharge feature without limitation. As such, particles are less sensitive to release location; this allows forward particles released proximal to each other to converge on the same discharge location and provides for an improved representation of a feature’s recharge zone. The primary disadvantage to forward particle tracking is that typically a much larger quantity of particles are released to ensure that all path lines are represented, making forward particle tracking more computationally expensive.

The primary advantage of reverse particle tracking is that it typically requires fewer particles to delineate a zone of contribution and is thus considered a fast and computationally efficient method. However, the primary disadvantage of reverse particle tracking is that areas of contribution can be missed, due to the convergent nature of flow toward discharge locations. Reverse traces will represent only one of the particle traces that converge at a specific discharge point. Contrary to common assumptions, areas that have been missed are not less important that captured areas, nor are they due to lower recharge volumes.
In this study, both forward and reverse particle tracking were used to delineate a zone of contribution to the Minesing fen and adjoining Snow Valley. In the forward direction, particles were released from the modelled water table using a 00 m grid resolution. This resolution was chosen after testing various resolutions with a subset of particles, and balancing computation time and resolution of results. In the reverse direction, particles were released from discharging model nodes within the area of interest, at depths of 2 m below ground surface.

3.2 Uncertainty Analysis Scenarios

While the Barrie Tier Three model has been calibrated to observed groundwater elevations on a regional scale, there remains uncertainty due to limitations in the dataset for the upland regions of Snow Valley. Recognizing this uncertainty, an uncertainty analysis was conducted with a series of plausible scenarios in which hydraulic conductivity and recharge were adjusted. The following scenarios were simulated:

1. - Base Case: Calibrated model

2. - High K A2: A lower conductivity zone within regional Aquifer A2 was increased to the upper limit of measured A2 estimates (Golder, 2004). This low conductivity zone, which had been previously assigned with a conductivity of $e^{-9}$ m/s, was increased to with a hydraulic conductivity of $e^{-5}$ m/s.

3. - Lower K A and UC: A higher conductivity zone in the upper mode model layers (representing A and UC) exists on the slope of the Snow Valley uplands, within the areas of interest. The hydraulic conductivity in this zone was decreased from $7e^{-4}$ m/s to $2e^{-6}$ m/s. The intent of this scenario was to increase the hydraulic head in this area to investigate impacts on local potential discharge.

4. - High K A2, High K A: Lower conductivity zones exist in the highest elevations of the upland regions. These zones result in less lateral transmissivity towards wetlands, resulting in deeper recharge to A2 with the eventual discharge to the wetland. In this scenario, the hydraulic conductivity of A and UC was increased from $2e^{-6}$ m/s to $e^{-4}$ m/s, over the entire upland region. In addition, the hydraulic conductivity of A2 was increased from $e^{-9}$ to $e^{-5}$ m/s, as in scenario 2.

5. - Reduced Recharge: Recharge throughout the model was reduced by 0% to simulate a plausible range in uncertainty (+/- 0%) in the recharge distribution.

6. - Increased Recharge: Recharge throughout the model was increased to 0% to simulate a plausible range in uncertainty (+/- 0%) in the recharge distribution.

Contributing recharge areas were delineated for each of these scenarios and combined to create a zone of possible contributing recharge.
4 RESULTS

4.1 Base Case Particle Tracking

The FEFLOW modelling code was applied to track fictitious particles of water through the Barrie Tier Three model to delineate contributing recharge areas to the fen portion of the Minesing Wetland. Forward particle traces ending within the area of interest were identified and extracted for the delineation. Reverse particle traces originating from discharge locations within the areas of interest were added to the forward particle track results. Both sets of particle end points were attributed according to their discharge location and time of travel.

Figure shows the particle track end points for both the forward and reverse particle tracking exercises. Two groundwater flow divides (dashed lines) have been estimated using the particle results to discern between particles that discharge to the fen area (blue outline) and those that discharge to the Snow Valley area (yellow outline), as well as to illustrate the furthest extent of particles that discharge north towards the Minesing Wetland/Snow Valley as opposed to south towards Bear Creek. The groundwater flow divide between the discharge locations in the areas of interest indicates a difference between the groundwater flow directions and the surface water flow directions, as particles placed at the headwaters of Mink Creek flow towards west and north towards Snow Valley, rather than north and east. The southern flow divide illustrates the approximate furthest extent of the particles that discharge northwards towards the Minesing Wetland; beyond this extent, particles discharge at Bear Creek. This southern extent of the particle track end points coincides with subwatershed boundaries, indicating that the modelled groundwater flow divides are similar to the surface water flow divides.

Particle tracks with travel times of less than 0 days were not used to delineate recharge areas for the fen, as this residence time is not sufficient to support coldwater or wetland habitat. Particle tracks with travel times more than 25 years were also removed from the analysis, as per NVCA’s request. The remainder of the particles show an average of 4.5 years of residence time in the groundwater system for the fen, and 4 years for Snow Valley area.

4.2 Contributing Recharge Areas

The recharge contributing area was delineated based on the particle tracking results in Section 4. (Figure 2), excluding travel times less than 0 days and greater than 25 years. The model elements flagged as contributing recharge to the selected discharge areas were grouped together, along with a 50 m buffer (i.e. half the distance of the maximum particle release resolution), to delineate a 25-yr recharge zone for the areas of interest (dark green shaded area on Figure 2). The resulting area is approximately 8 km².

The contributing recharge area is overlain with estimated recharge rates to illustrate areas of higher and lower potential recharge contribution (Figure ). As the areas of interest and their corresponding contributing area of recharge lie predominately in the upland area, the average recharge volumes are relatively high with an average of 0.07 mm/year. Recharge volume within the 25-yr zone accounts for approximately 67% and 89% of the discharge volume to the fen and Snow Valley area, respectively. The remainder is from beyond that travel time, or occurs within 0 days.
4.2.1 Uncertainty Analysis

Model predictions should be expressed as a range of possible outcomes that reflect uncertainty in the calibrated model parameters. As described in Section 2, the parameters, the variation of each parameter, and the geographical location of the variation were chosen to reflect the most likely range of uncertainty for this area. In this manner, the analysis was designed to provide a measure of the possible variability of the recharge area delineation.

The predictions from the scenarios outlined in Section 2 provide insight into the possible range in the delineated recharge area. The analysis showed that the model was most sensitive to changes in hydraulic conductivity, particularly of Aquifer A, and least sensitive to changes in recharge. The recharge areas delineated through each individual scenario were superimposed to create an area of possible recharge contribution (Figure 2). This area provided an additional 2 km² area of recharge in addition to the base case delineated zone of contributing area.
5 SUMMARY AND CLOSURE

The forward and reverse particle tracking conducted using the Barrie Tier Three model provides an understanding of the groundwater flow system that leads to discharge at two identified areas of interest connected to the Minesing Wetland Complex (eastern edge of the wetland). The two areas of interest are the edge of a fen (located just west of the Snow Valley Uplands) and Snow Valley area (located along the northwest edge of the Snow Valley Uplands).

In general, recharge originating from across the entire area of the Snow Valley Uplands was simulated to discharge from aquifer A2 to the areas of interest. The delineated recharge area within a 25 year travel-time was found to extend approximately 2-4 km southeast from the areas of interest across the upland area (Figure 2). The delineated recharge area is comprised of variable vegetation, slope and surface/subsurface soil conditions and thus the recharge rate within each recharge zone varies from 50-450 mm/yr (Figure 3).

An uncertainty analysis was also performed and showed that the recharge area (25-yr travel-time) could possibly extend to a maximum of 4 km from the area of interest (Figure 2). Added characterization (including any updated OGS data and NVCA stream flow/water level data from local monitoring efforts) into the model in this vicinity could reduce this uncertainty by narrowing down the plausibility of the tested scenarios.

We trust that this letter report suits your present requirements. If you have any questions or comments, please call either of the undersigned at 519.772.777.

Yours truly,

MATRX SOLUTIONS INC. Reviewed by

Water Resource Scientist Principal

MB/**
Attachments

copy: Ryan Post, Nottawasaga Valley Conservation Authority, Utopia, Ontario

DISCLAIMER

We certify that this letter report is accurate and complete and accords with the information available during the site investigation. Information obtained during the site investigation or provided by third parties is believed to be accurate but is not guaranteed. We have exercised reasonable skill, care and diligence in assessing the information obtained during the preparation of this letter report.

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REFERENCES


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Nottawasaga Valley Conservation Authority
Minesing Fen Recharge Delineation

Recharge Delineation including Area of Uncertainty