Groundwater Withdrawal Sustainability, Sydney Wellfield, Cape Breton Regional Municipality, Nova Scotia, Canada

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ABSTRACT
The Sydney Wellfield, as one of the largest fractured bedrock groundwater supplies in Canada, has provided high quality raw water to the Sydney area of the Cape Breton Regional Municipality since 1996. The wellfield has consistently provided a withdrawal rate of 15,900 m^3/d (3.5 million imperial gallons per day) with a maximum of 19,000 m^3/d (4.2 million imperial gallons per day) over the past 13 years. The groundwater withdrawal sustainability is supported by the long-term stability of groundwater levels and groundwater chemistry within the wellfield and surrounding area over that period.

RÉSUMÉ
La nappe phréatique de Sydney, une des plus grandes sources d'eau sous-terraine provenant d'une roche mère fracturée au Canada. Elle approvisionne la région de Sydney de la Municipalité Régional du Cape Breton depuis 1996. Les puits produisent un rendement de 15,900 mètres cube par jour (3.5 million gallon impérial par jour) régulièrement depuis les 13 dernières années; avec un maximum de 19,000 mètres cube par jour (4.2 million gallon impérial par jour). La stabilité des niveaux d'eau sous-terraine et de la qualité chimique des eaux de la nappe phréatique sous le réseau de puits et ses environs permet de prévoir un rendement d'approvisionnement viable à long terme.

1 INTRODUCTION

The Sydney Wellfield, located approximately 2 km southeast of Sydney, Nova Scotia, was commissioned in 1996 to replace the 100 year old surface water supply (5 Lakes) for the City of Sydney, Nova Scotia. The Sydney Wellfield, located on Middle Lake Road, is comprised of 11 production wells with a maximum of 8 wells in service at any one time under normal operation conditions. The Sydney Wellfield has provided high quality groundwater with a licensed withdrawal rate of 15,900 m^3/d (3.5 million imperial gallons per day (migpd)) since April 22, 1996.

The Sydney Wellfield is one of the largest fractured bedrock groundwater supplies in Canada. The primary aquifer of the wellfield, identified as the largest Class 1 aquifer in Nova Scotia, is comprised of a massive grey sandstone bedrock unit of Carboniferous age and overlaid by Quaternary glacial till. The long-term groundwater withdrawal from the Sydney Wellfield was projected by using numeric groundwater flow modeling prior to and following groundwater supply production. Modeling applications were based on data collected from a series of groundwater exploration, testing and monitoring programs undertaken by Dillon Consulting Ltd (Dillon). Following changes in the hydraulic conditions induced by initial groundwater extraction in 1996, the hydrogeological system achieved its new dynamic equilibrium in a short period of time. The stabilized status of the wellfield has been confirmed by long-term groundwater level monitoring (pre-production/post-production) from production and observation wells. This stability is further demonstrated by the constancy of hydrogeochemical characteristics of groundwater in the wellfield and surrounding area. The location of the wellfield and observation wells is shown in Figure 1. This equilibrium response suggested the massive sandstone unit aquifer in the study area has sufficient storage and recharge mechanisms to meet the demand of this supply and potential future expansion. In addition, a source water protection and management plan has been established to support a safe and secure groundwater supply for future use (Dillon 2006a). In this paper, analysis of the long-term water level data and water chemistry results from both the production and observation wells are presented to demonstrate the groundwater system of the Sydney Wellfield is under a sustainable withdrawal.

2 PRECIPITATION

Sydney, Nova Scotia is situated in the Maritime region of Canada, which demonstrates a climate with cold stormy winters and warm summers. Historical meteorological recordings indicated that the mean annual precipitation was 1630 mm for the last 13 years and 1583 mm for the last 114 years. In general, the dry season for the Sydney area is typically from June to September with historical averaged monthly amounts less than 100 mm. Maximum precipitation usually occurring in the fall. The Sydney Wellfield is situated at an elevation of 100 m above sea level.

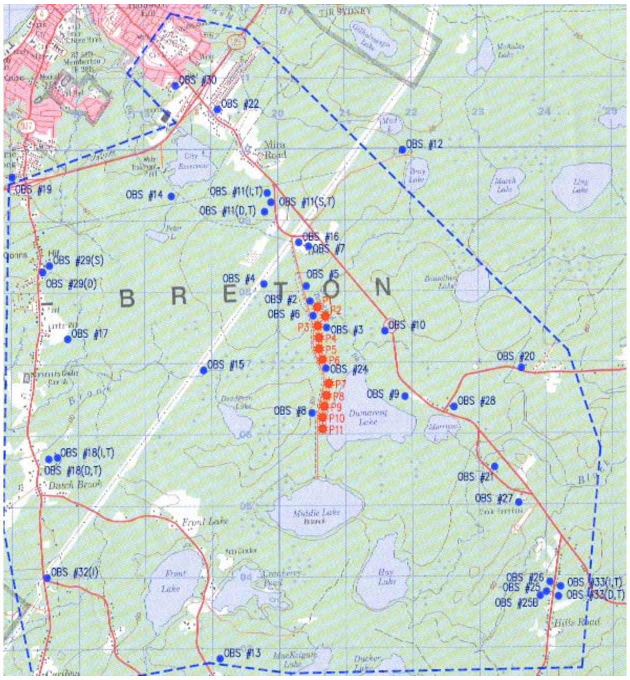

Figure 1. Sydney Wellfield & Observation Well Network (Note: red solid dot indicates production well and blue solid dot denotes observation well)

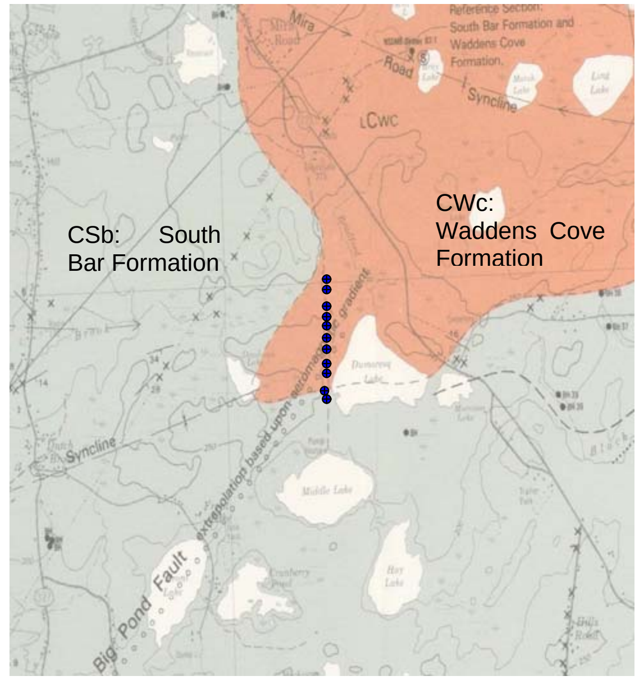

Figure 2. Bedrock Geology, Boehner and Giles, 1986 (Note: blue solid dot indicates production well)

3 GEOLOGIC AND HYDROGEOLOGIC SETTINGS

The surficial geology consists of glacial till, a mixture of unsorted debris deposited beneath glacier ice. The glacial till overlies the majority of the area to an average depth of 5 to 10 meters. Permeability of the glacial till can be expected to vary widely since its composition varies from sandy and silty till to a hummocky marine complex. Wet areas are present during the wet season in areas with low permeability till. The land around the Sydney Wellfield is primarily covered by mixed hardwood and softwood Acadian Forest. As well, numerous lakes exist within a 5 km radius of the Sydney Wellfield.

The bedrock in the area of the wellfield belongs to Carboniferous age sediments and consists of two major geologic formations that belong to the Lower Morien Group: the Waddens Cove formation and the South Bar Formation. The Waddens Cove formation represents the transition zone between the massive South Bar sandstone and the economic coal bearing bedrock of the Upper Morien Group. The Waddens Cove Formation occurs in the northeast portion of the wellfield where it consists of predominantely brown sandstone with thin coal stringers. This formation occurs at relatively shallow depths, is less than 100 meters thick and consists of grey and red siltstone and mudstone in most other areas. The remaining portion of the wellfield consists of the South Bar Formation which is composed primarily of massive grey sandstone, pebbly sandstone with minor conglomerate and mudstone and rare coal. The contact between the two formations is inclined to the northeast.

The general geology of the study area is characterized by a variety of large and small scale discontinuities. There are three prominent geologic structures in the area of the Sydney Wellfield, including the Mira Road Syncline, the Dutch Brook Syncline, and the Big Pond Fault (Boehner and Giles 1986), as presented in Figure 2. Some small scale faults may also exist in this area based on the studies from Baechler 1986 and Cross 1997. Under the folding activities the massive grey sandstone of the South Bar Formation has relatively frequent, open, well developed discontinuities.

The hydrogeologic setting of the study area is defined by the glacial till-fractured sandstone bedrock aquifer system. Groundwater is primarily stored in the fractured bedrock aquifer and moves under hydraulic gradients through the bedding planes, joints and fractures. The sandstone aquifer exhibits both primary and secondary permeability with the latter as the dominant system. Recharge to the overlying bedrock aquifer is by vertical infiltration of precipitation through the glacial till and bedrock outcrop, and by the lateral movement and vertical infiltration of water from the lake/bog areas.

Based on geological records and 30 years working experience in the geologic environment, three distinct bedrock aquifer zones can be defined in the Sydney Wellfield and surrounding area (Dillon 1994, 1995, 2004-2008). Each zone is characterized by major horizontal fracturing of the bedrock and the three zones are hydraulically interconnected by minor vertical fractures. The aquifer zones occur consistently at depths of 0 ~ 10 m (0 ~ 30 feet), 10 ~ 50 m (30 ~ 165 feet), 50 ~ 183 m (165 ~ 600 feet) throughout the South Bar Formation and are referred to as the shallow, intermediate and deep aquifers. The first aquifer zone at the shallow depth occurs in the weathered bedrock top. The water quantity and quality of this water bearing zone varies frequently

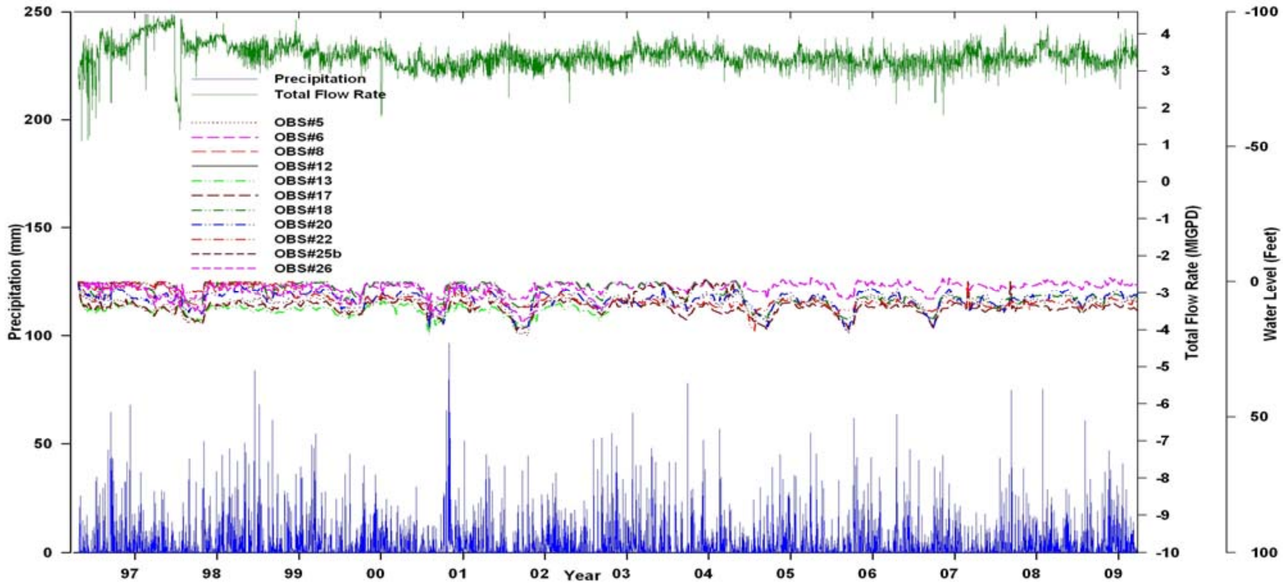

Figure 3. Groundwater Level Drawdown from Observation Wells

following seasonal fluctuations. The intermediate 10 ~ 50 m (30 ~ 165 feet) aquifer zone is utilized by most residential wells drilled in the South Bar Formation. The fracture patterns in the shallow and intermediate aquifer are inferred to have been a direct result of glacial advance compression and glacial retreat rebound. The fractured 50 ~ 183 m (165 ~ 600 feet) deep aquifer zone in the massive grey sandstone offers a potential high yield of groundwater with stable water quality. The aquifer of the Sydney Wellfield consists primarily of fractured water bearing zones encountered in the grey sandstone between 60 m (200 feet) and 120 m (400 feet). Individual production well yields range from 1800 to 4500 L/m (400 to 1000 igpm) (Dillon 1994, 1995).

4 WELL CHARACTERISTICS

The Sydney Wellfield production wells have depths greater than 124 m with casing length over 12.2 m. Based on blow tests that were conducted following production well installation, the groundwater yield from 6 production wells was above 4500 L/m (1000 igpm); 3 production wells were over 2700 L/m (600 igpm) and 2 production wells were over 1800 L/m (400 igpm). The pump settings in the production wells range between 60 m (200 feet) and 73 m (240 feet). Each production well is equipped with a digital water level recorder (transducer) and a magnetic flow meter located at the wellhead.

Observation wells are distributed at different locations throughout the area/communities surrounding the Sydney Wellfield and vary in depth to gather data from different aquifer depths (shallow, intermediate and deep). According to groundwater response to withdrawal from the wellfield, the twenty-four observation wells are grouped as follows: observation wells within the deep aquifer are located in the vicinity of wellfield; observation wells are at shallow depth; and observation wells are located outside the wellfield (Dillon 2006b).

5 WATER LEVEL MEASUREMENTS

The water level and pumpage of each production well have been recorded on a daily basis since operation began. The monitoring program for the observation well network of the wellfield includes the collection of water level measurements both manually and automatically. During the initial three months of wellfield operation, from April to August 1996, the water level monitoring for the observation wells was recorded on a daily basis. Following that period and to present, manual water level measurements are recorded on a weekly basis. In addition, automatic water level measurements are recorded on an hourly basis via transducers located in seven observation wells since September 2004.

During the start-up stage of wellfield operation, the water levels in most of the observation wells (intermediate and deep) dropped in response to the initial withdrawal. Following the immediate drawdown induced by groundwater withdrawal, the wellfield reached its dynamic equilibrium and since that time water levels respond to seasonal variations. As well, monitoring data also indicated that the water level variations from the observation wells at shallow depths had no detectable effect from the water withdrawal of the wellfield, as shown in Figure 3.

6 GROUNDWATER CHEMISTRY

The pre-production water chemistry sampled from production wells in 1993/1994 is referenced as background groundwater chemistry for the Sydney

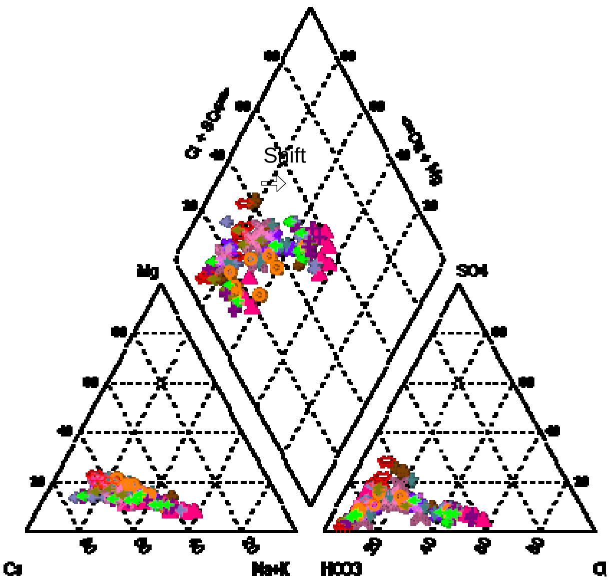

Figure 4. Hydrogeochemistry of Groundwater from Production Wells (1994-2008)

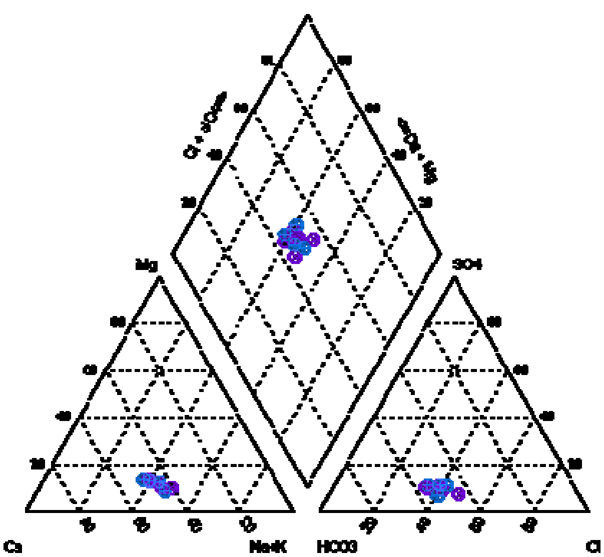

Figure 5. Hydrogeochemistry of the Mixed Raw Water from Water Treatment Plant (1999-2006)

Wellfield. The analysis identified that the groundwater from each production well was calcium-bicarbonate (Ca-HCO_3) type water. Tritium and Carbon Dating identified the age of the groundwater at greater than 13,000 years. The chemistry of groundwater sampled since 1997 generally tended to be calcium/sodium-bicarbonate (Ca•Na-HCO_3) and calcium/sodium-bicarbonate/chloride (Ca•Na-HCO_3•Cl) type water, as presented in Figure 4. The small increase in the concentrations of sodium and chloride are attributed to the induced recharge within the drawdown cone of depression. Analytical results of the mixed raw water from production wells showed no changes in water chemistry, as presented in Figure 5. The

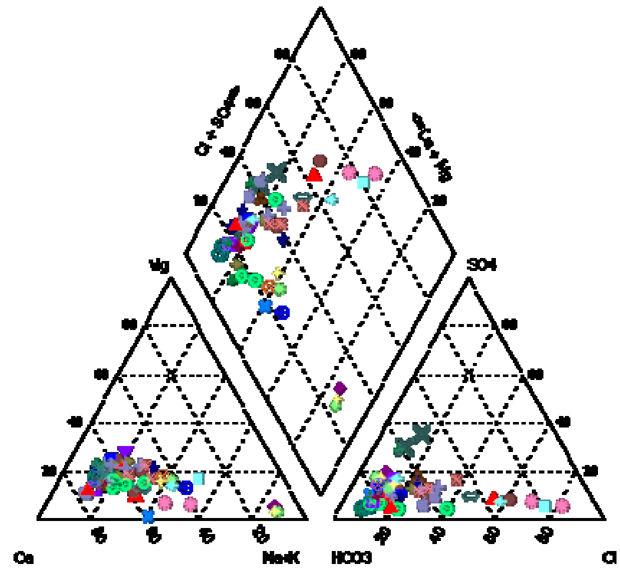

Figure 6. Hydrogeochemistry of Groundwater from the Observation Well Network (1994-2007)

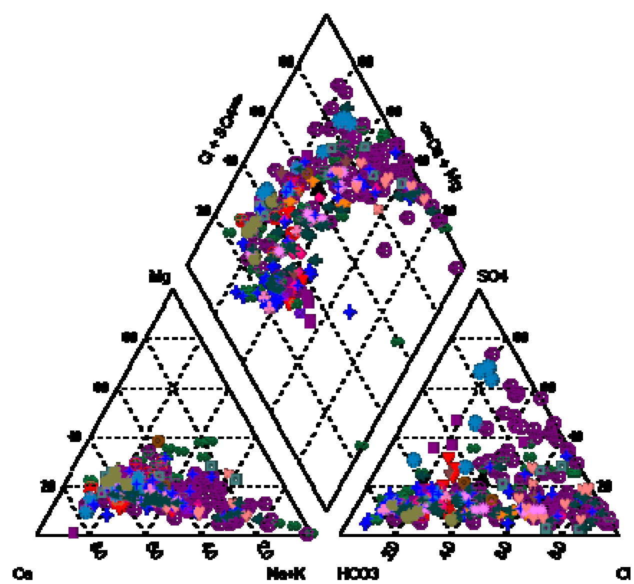

Figure 7. Hydrogeochemistry of Groundwater from Domestic Wells

stable water chemistry specifies that the groundwater system is in a state of equilibrium.

Two observation wells, OBS#3 and OBS#24, located in the wellfield, with similar well construction characteristics to the production wells, showed a slight drift in water chemistry as a response to the initial extraction of groundwater. Water chemistry of groundwater from observation wells at shallow depth remained consistently calcium-bicarbonate/chloride (Ca-HCO3-Cl) type water since pre-production in 1994. Additional observations within the area around the wellfield showed the distinct chemical diversity of groundwater with no transient changes in water chemistry, as shown in Figure 6. As well, groundwater samples collected from the domestic well network outside the wellfield indicated that the groundwater chemistry demonstrated significant range of variation. Water types included sodium-chloride (Na-Cl), calcium-sulphate (Ca-SO_4), and calcium-bicarbonate (Ca-HCO_3) as well as the mixed patterns of the three water types, as shown in Figure 7. The varieties in domestic well water chemistry at shallow depth indicated that localized hydraulic exchange is the control factor for domestic well water quality in the area. These variations in hydrogeochemistry between the wellfield and domestic wells imply different sources of groundwater supply.

7 CONCLUSIONS

The groundwater system of the Sydney Wellfield achieved dynamic equilibrium in the first three months of production. The status of the wellfield has been acknowledged by long-term monitoring which has demonstrated the stability of groundwater levels and groundwater chemistry from both the production and observation wells. This equilibrium response indicated that the massive fractured sandstone aquifer in the study area has sufficient storage and recharge mechanisms to meet the demand of this supply.

Groundwater levels in the deep aquifer within the vicinity of the wellfield vary under an integrated influence related to pumping volume, production well pumping sequence and recharge from precipitation. Groundwater levels in the shallow aquifer close to the wellfield and groundwater levels outside the wellfield predominately fluctuate in response to seasonally variations in precipitation. Spatial and temporal pattern of groundwater chemistry has been consistent and stable over the last thirteen years. The groundwater chemistry outside the Sydney Wellfield is dominated by localized exchange and showed distinct water types without transient changes. Under the appropriate protection and management, the Sydney Wellfield can deliver a safe and secure sustainable groundwater supply for future use and with the potential for demand expansion.

ACKNOWLEDGEMENTS

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