NVCA Groundwater Trend Analysis Using the Provincial Groundwater Monitoring Network

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1.0 Introduction

Groundwater (GW) monitoring provides an early warning system for changes in water levels caused by climatic conditions or in response to human activities such as water taking. It also provides an early warning system for changes in water quality from natural causes or anthropogenic impacts. An accurate assessment of current and emerging trends in ambient GW conditions allows for the development of scientifically based policy and associated GW management programs. Designed to gather long-term baseline data on GW quantity and quality in key aquifers across Ontario, the Provincial Groundwater Monitoring Network (PGMN) was established in the Nottawasaga Valley Conservation Authority (NVCA) in 2002. The NVCA in partnership with the Ministry of the Environment (MOE) maintains 16 PGMN wells at 13 locations (Figure 1).

A key consideration of the PGMN program is the detection of definable changes in the GW level over time. In GW monitoring applications, statistical trend tests and time series plots are often used to identify trends in water levels over a certain period of time (EPA, 2010). The Mann-Kendall and Thiel-Sen trend statistical tests are used to detect and estimate trends and magnitude, respectively, in the time series of the annual levels. Thus the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test; then the slope of a linear trend is estimated with the nonparametric Thiel-Sen method (Gilbert 1987). Both tests have no distributional assumptions and missing data or outliers are permitted (Gibbons, 1994).

Through the use of NVCA PGMN GW data, the objective of this report is to statistically determine: 1) what wells a trend analysis can be performed on and 2) if a time series of GW level observations is increasing or decreasing per well with time and by what amount.

1.1 NVCA PGMN data limitations

To conduct a statistical analysis, eight to 10 independent samples are required before a passable estimate of the standard deviation for populations having normal or lognormal (parametric) distributions can be generated (EPA, 2010). Also, trends are considered to be statistically significant if there is at least a 90% confidence level (i.e. that the trend is real). Note that 'statistically significant' indicates there is statistical evidence that a trend is present, but does not necessarily mean the trend is large (Nova Scotia Environment, 2012).

The NVCA has varying amounts of GW level data for the 16 PGMN wells for the period of 2003-2012 (Figure 1). The main limitation when conducting trend analysis on the GW level data was the low number of complete annual data sets (>75% of data per year) due to data logger issues that occurred between 2003 and 2006, and the fact that three NVCA PGMN wells are less than five years old. This resulted in a limited number of wells that provided sufficient data to generate results that could be considered statistically significant (95-90% confidence level). Due to the low number of qualifying wells, a minimum of seven years of data (with >75% of the calendar year total) was determined to be sufficient for developing a trend test and time series analysis methodology. Data sets that contained less than seven years would result in lower than a 0.05 significance level. Further, wells with fewer than seven years of data did not present normal distribution. The absence of a normal distribution would make it impossible for a *p*-value to be calculated and to identify the statistical significance of the trends (Helsel and Hirsch, 2002).

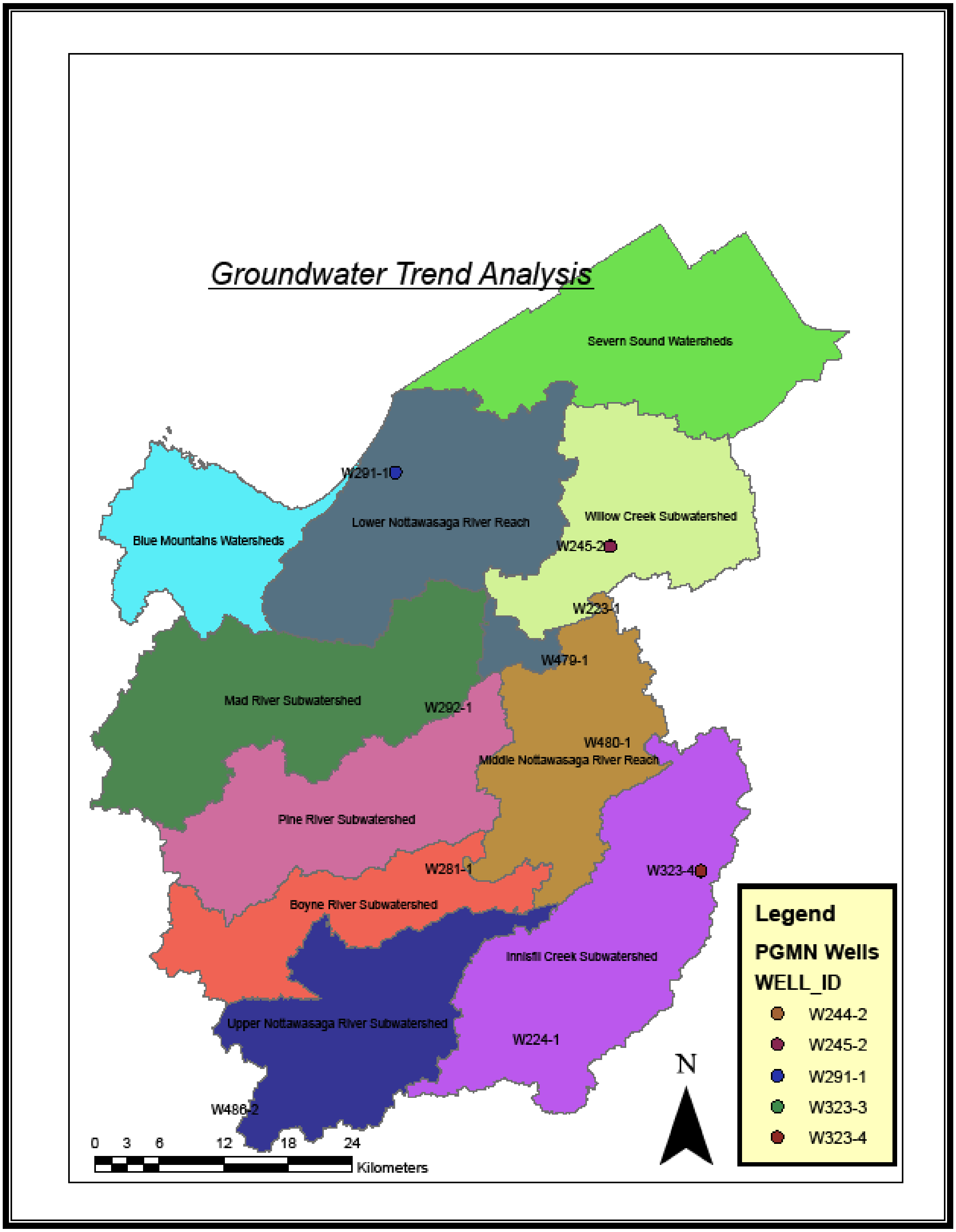

Figure 1: NVCA PGMN well locations

1.2 Software

ProUCL version 4.1 was selected because it: 1) is user friendly, 2) works with the most commonly used statistical methods to evaluate trends in environmental data and 3) is free. It can be obtained from the U.S. Environmental Protection Agency (http://www.epa.gov/osp/hstl/tsc/software.htm). The Trend Tests module within ProUCL version 4.1 has the Mann-Kendall and Theil-Sen trend tests, and time series plots as described in the Unified RCRA Guidance Document (EPA, 2010).

2.0 Methodology

The following methodology was used for the statistical trend analysis:

1. NVCA GW level data was obtained from the MOE-maintained PGMIS.
2. This PGMIS data set was filtered through the identification and removal of time series errors, including but not limited to outliers and logger failures resulting in slips or data gaps.
3. Using the filtered data sets, the average daily GW levels were calculated by utilizing pivot tables in MS Excel and the time series length per year/per well was determined.
4. The individual well time series were calculated to determine if enough data was present to provide statistical value for trend analysis. For this project it was determined that any well with a minimum of seven years of data with >272 daily averages per year (75% completeness) would be used.
5. The resulting data set was then checked for the presence of secular (long-term) temporal trends. Since all wells presented seasonal trends, it was determined that the recommended methods for testing for temporal stationarity were the nonparametric Mann-Kendall and Theil-Sen trend tests .

3.0 Results

A summary of the NVCA well time series, useable years and overall percent completion is listed in Table 1. It is noted that the time series length is reflective of the available PGMN data on PGMIS as of December 31, 2012. Currently there are three wells (W244-2, W245-2 and W291-1) that possess the sample size of more than eight years recommended by the EPA (2010) for trend analysis, or 19% of the NVCA PGMN network; however, W323-3 and W323-4 had seven years of usable data and were included. Therefore, five NVCA PGMN wells had sufficient data to complete the trend analysis. Water level hydrographs for the five wells are presented in Figures 2 through 6.

It is noted that with time, the values for percent completion and usable years in Table 1 will increase the number of wells that would meet the requirements of seven years of data with a minimum of 272 data points for trend analysis.

A summary of the GW trend analysis results completed on five of the NVCA's 16 monitoring wells is presented in Table 2. All Mann-Kendall tests were conducted with a 95% confidence coefficient.

Table 1: Computation of well summary illustrating number of viable wells for trend analysis (well depths: shallow - <20 metres below top of casing (mbtoc); intermediate - between 21 and 60 mbtoc; deep - >61 mbtoc). Italics indicate wells with suitable data time series for trend analysis.

PGMN Well Number	Time Series		Usable Years	Percent Complete	Wells Depth
	Start	current			
W223-1	Sep-03	Jul-12	5	86	Deep
W224-1	Dec-02	Jul-12	4	61	Deep
W230-1	Mar-03	Jun-12	6	84	Intermediate
W231-1	Feb-03	Jun-12	5	60	Intermediate
W232-2	Jun-03	Nov-10	6	78	Deep
W244-2	*Feb-02*	*Jun-12*	*9*	*88*	*Intermediate*
W245-2	*Feb-03*	*Jun-12*	*9*	*96*	*Deep*
W281-1	Mar-03	Jun-12	4	67	Shallow
W291-1	*Mar-03*	*Jun-12*	*8*	*89*	*Shallow*
W292-1	Mar-03	Jul-11	5	63	Shallow
W323-2	May-03	Aug-12	6	87	Shallow
W323-3	*May-03*	*Aug-12*	*7*	*96*	*Intermediate*
W323-4	*May-03*	*Aug-12*	*7*	*95*	*Deep*
W479-1	Dec-08	Jun-12	3	77	Deep
W480-1	Mar-09	Jul-11	1	93	Intermediate
W486-1	Mar-10	Jun-12	2	100	Intermediate

Table 2: Results from Mann-Kendall trend test on five PGMN wells

	Well Number				
Results	**W244-2**	**W245-2**	**W291-1**	**W323-3**	**W323-4**
Confidence Coefficient	0.95	0.95	0.95	0.95	0.95
Level of Significance	0.05	0.05	0.05	0.05	0.05
Number of Events (n)	9	9	8	7	7
Minimum (masl)	229.7	226.1	184.5	254.5	230.4
Maximum (masl)	231.2	227.5	185.3	256.1	231.8
Mean	230.4	226.6	185	255.5	231.1
Median	230.5	226.6	185	255.5	230.9
Standard Deviation	0.523	0.456	0.245	0.58	0.611
SEM	0.174	0.152	0.0867	0.219	0.231
Test Value (S)	26	24	2	11	15
Tabulated *p*-value	0.003	0.006	0.452	0.068	0.015
Standard Deviation of S	9.592	9.592	8.083	6.658	6.658
Standardized Value of S	2.606	2.398	0.124	1.502	2.103
Approximate *p*-value	0.00457	0.00824	0.451	0.0666	0.0177
Theil-Sen slope (m/yr)	0.1441	0.1324	n/a	n/a	0.2283

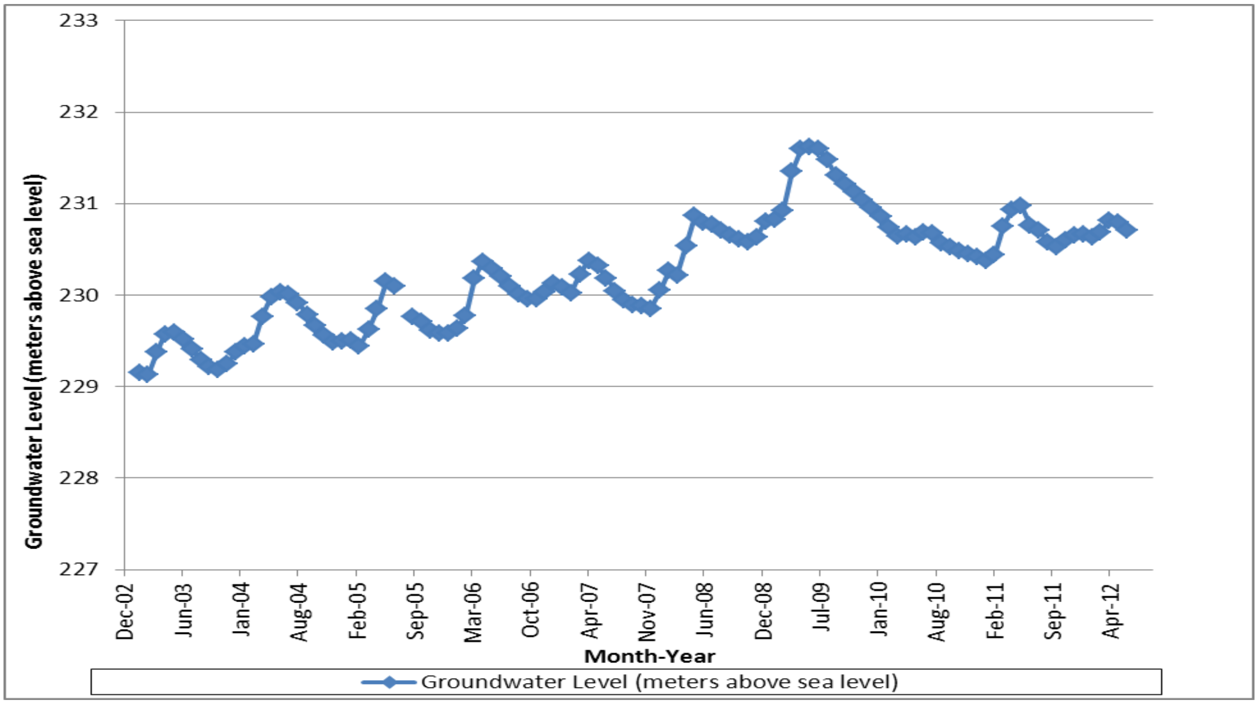

Figure 2: W244-2 Monthly Groundwater Level - February 2003 to June 2012

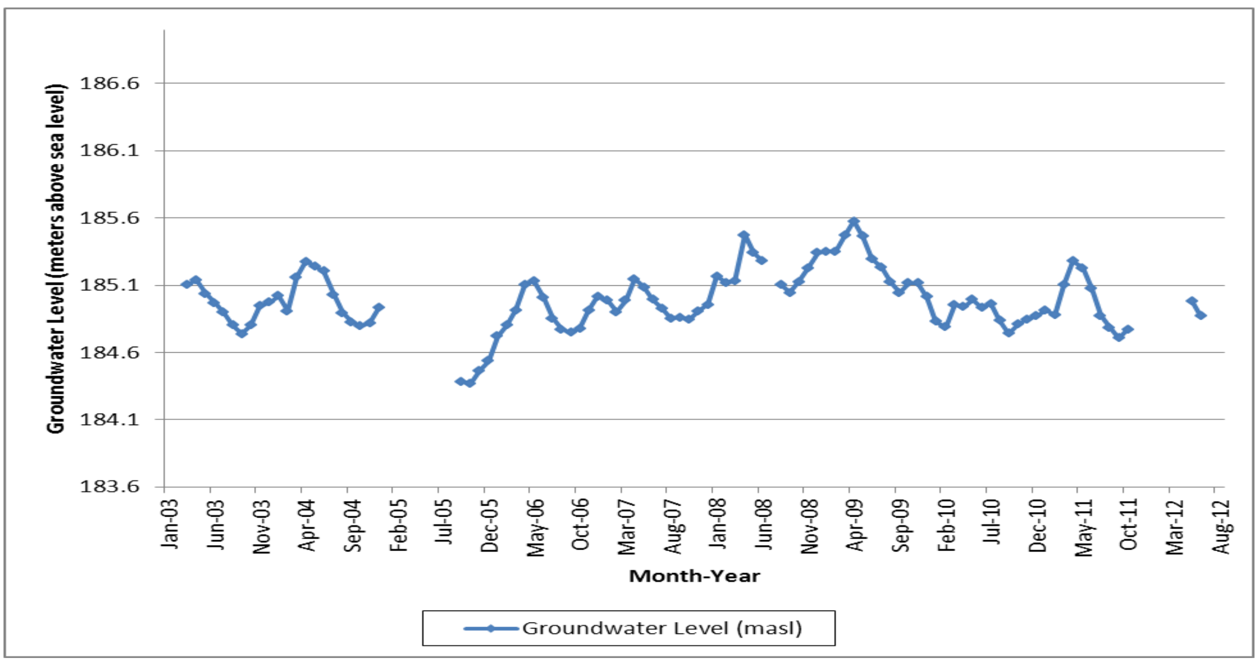

Figure 3: W245-2 Monthly Groundwater Level - March 2003 to June 2012

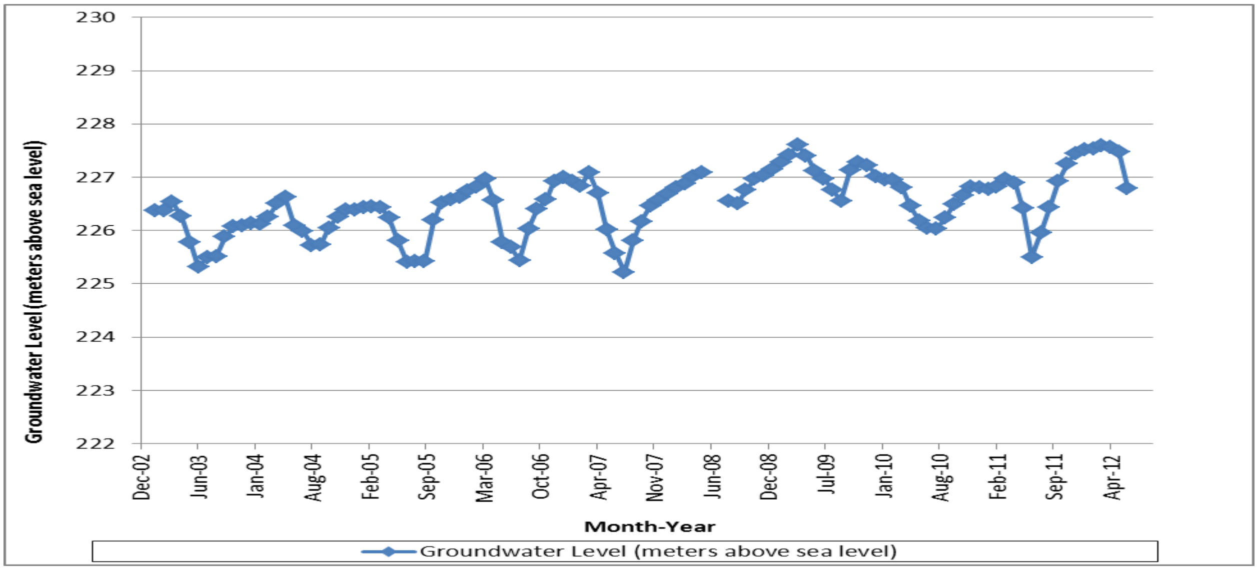

Figure 4: W291-1 Monthly Groundwater Level - February 2003 to June 2012

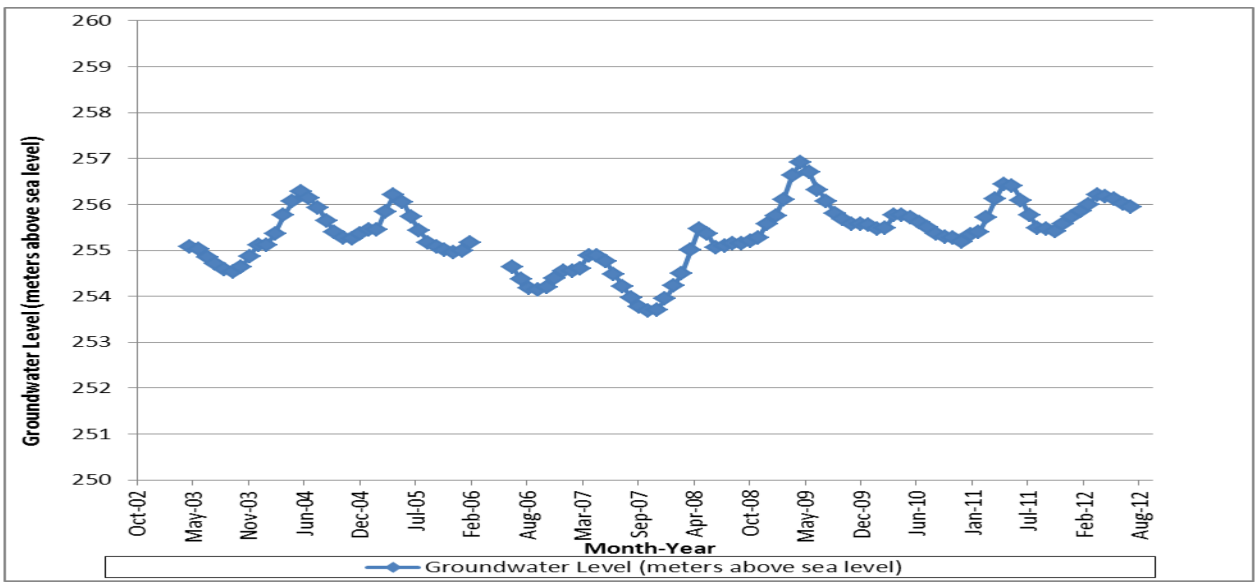

Figure 5: W323-3 Monthly Groundwater Level - May 2003 to July 2012

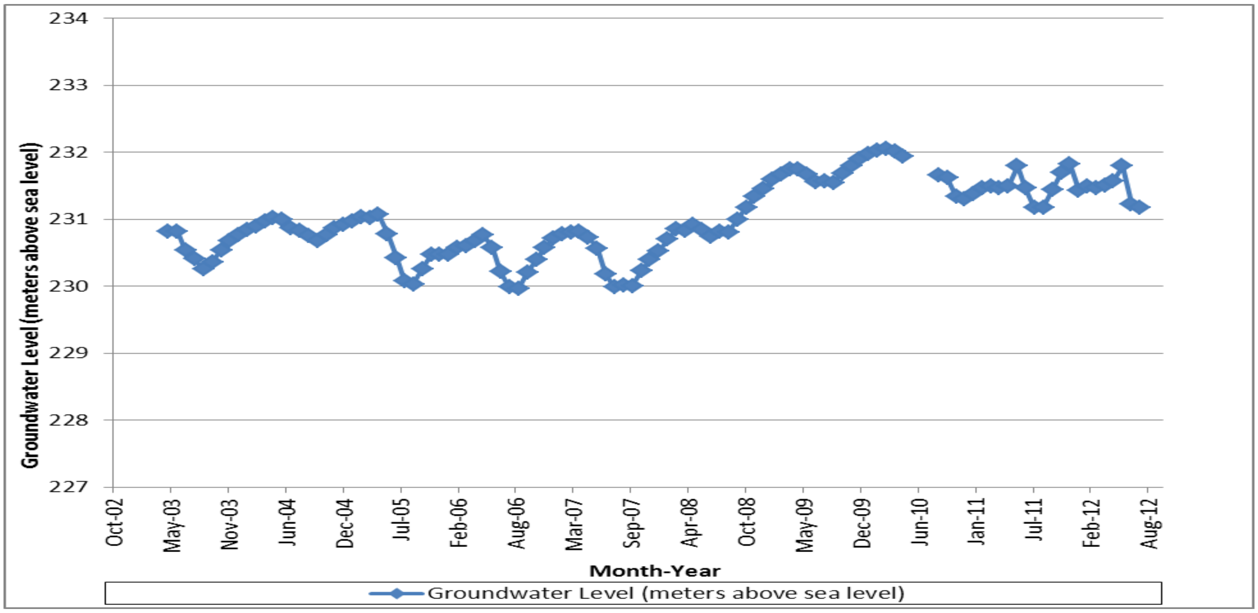

Figure 6: W323-4 Monthly Groundwater Level - May 2003 to July 2012

4.0 Discussion

The Mann-Kendall test computes the Kendall's tau nonparametric correlation coefficient (Test Value (S)) and its test of significance for any pair of X,Y data (Helsel & Hirsch, 2002). If X is time, the test is for a trend in the Y variable (Mann, 1945). Further, the Test Value is the sum of the signs of the slopes of all possible pairs in the dataset and determines the presence of a trend and in which direction (Kendall & Gibbons, 1990). When the Test Value is closer to zero, it indicates that there is insufficient data to suggest the presence of a trend. If the tabulated *p*-value is greater than the level of significance, then the null hypotheses of no trend is rejected.

Utilizing excels pivot tables and ProUCL version 4.1, the Mann-Kendall test for trend was conducted on five NVCA PGMN wells. The results presented in Table 2 indicate three out of the five wells (W244-2, W245-2, and W323-4) exhibit statistically significant trends. A positive value of Test Value (S) indicates an upward trend, which is the case for W244-2, W245-2 and W323-4. For this report, the Mann-Kendall was used to determine whether a trend was statistically significant at a 0.05 significance level, corresponding to a confidence level of 95% for a two-sided probability. Therefore, if the tabulated *p*-values was >0.05 the null hypothesis was accepted. The null hypothesis indicates no presence of a trend, as was the case for wells W291-1 and W323-3. It is noted that the Mann-Kendall is ideal for determining the probability of a trend being present; however, it does not indicate the magnitude of the trend.

The Theil-Sen test is also nonparametric and provides a more robust slope estimate than the least-squares method because outliers or extreme values in the time series affect it less (Sen, 1968). Therefore, this test provides an estimate of the true slope of an existing trend (as change per year) (Amnell et al., 2002). This test was conducted on wells that presented statistically significant evidence of a trend when run through ProUCL's Mann-Kendall test to estimate the magnitude of trend in metres per year (m/yr). The Theil-Sen slope is presented in Table 2 and in Figures 7 through 9.

From the linear regression analysis, the water level has increased in well 244-2 approximately 1.2 m and 245-2 approximately 0.95 m over the nine-year period, whereas well 323-4 has increased in water level roughly 1.55 m over the past seven years. It is noted that wells W244-2 and W245-2 are in the same location (Midhurst), with W244-2 being of intermediate well depth and W245-2 identified as a deep well, indicating that there is a statistically definable, localized increase in the GW levels, which is possibly related to locale change in aquifer pumping conditions.   Conversely, wells W323-4 (deep) and W323-3 (intermediate) are also at the same location (12th Line, Bradford West Gwillimbury) but, unlike W244-2 and W245-2, do not both statistically exhibit common increasing/decreasing trends. The reason for the increase in this unit at this location is unclear given the local rural land use with limited proximal water takings. Finally, the limited number of collectively analyzed wells prevents broad interpretation of regional aquifer trend analysis.

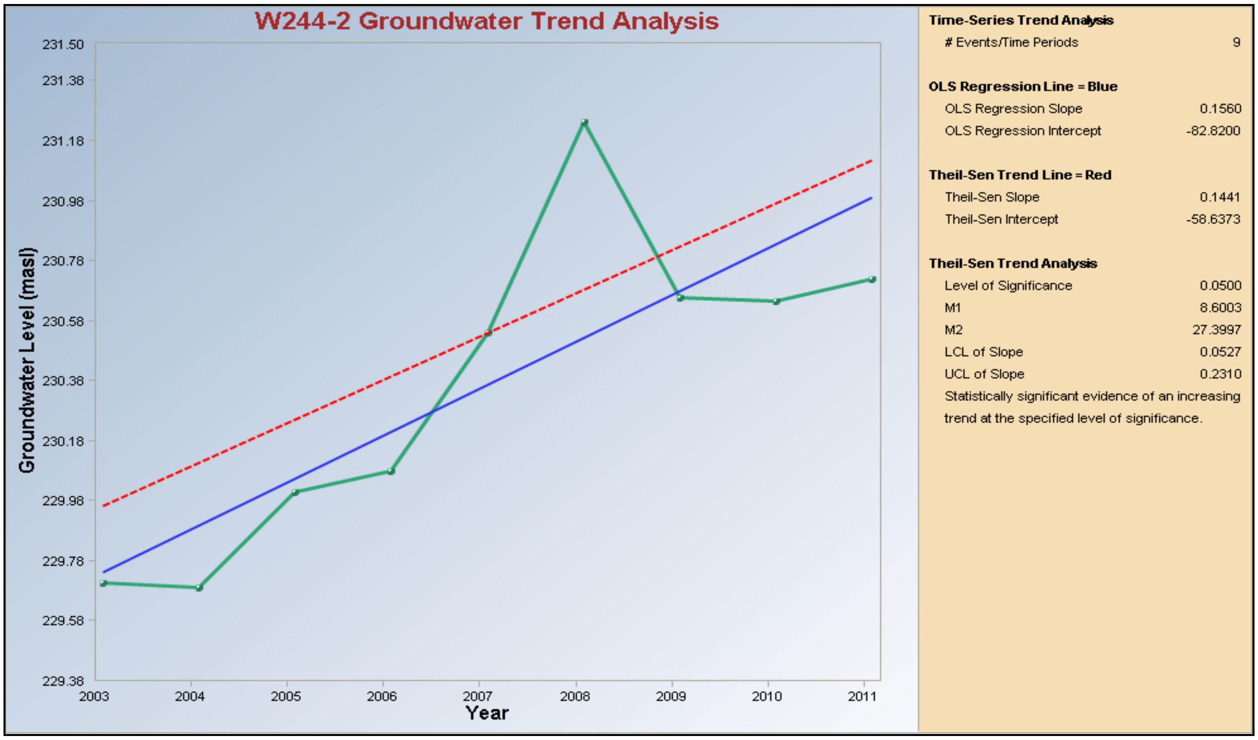

Figure 7: Illustration of results from Theil-Sen trend test for groundwater level data for W244-2 at 95% confidence coefficient.

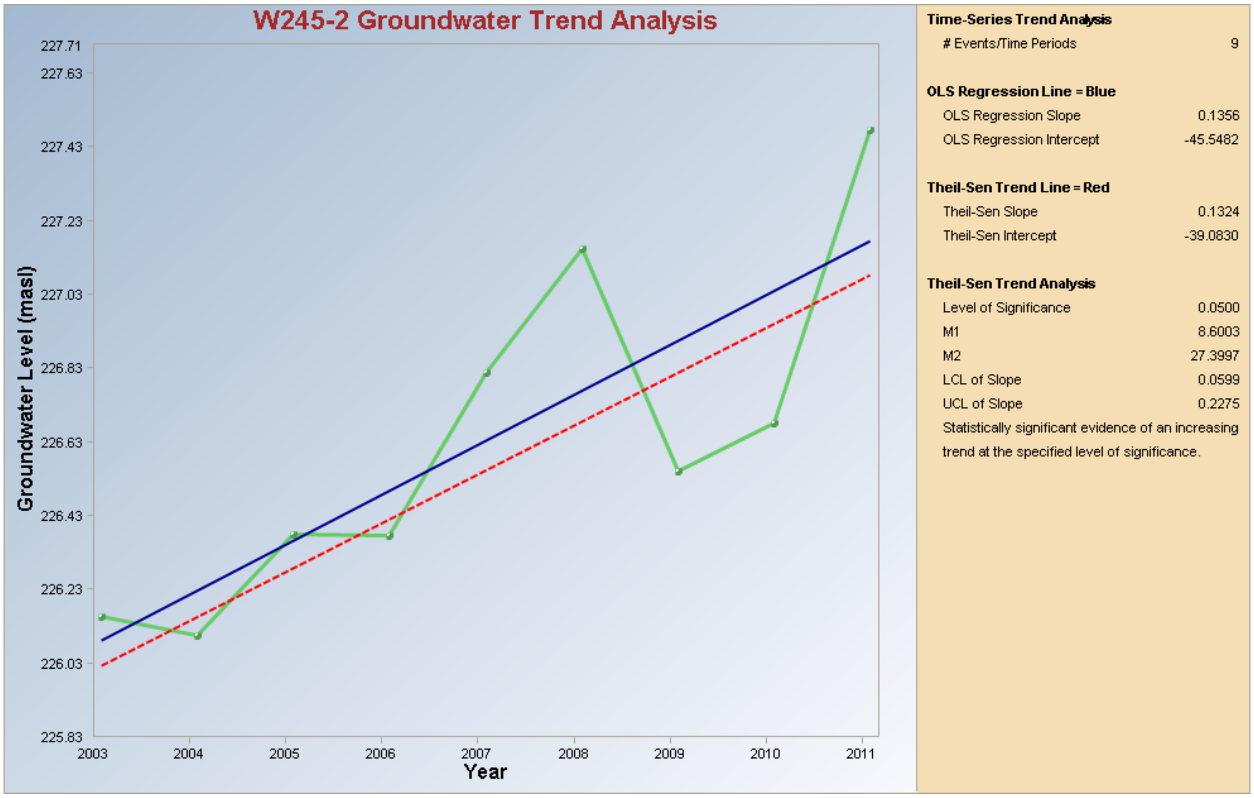

Figure 8: Illustration of results from Theil-Sen trend test for groundwater level data for W245-2 at 95% confidence coefficient.

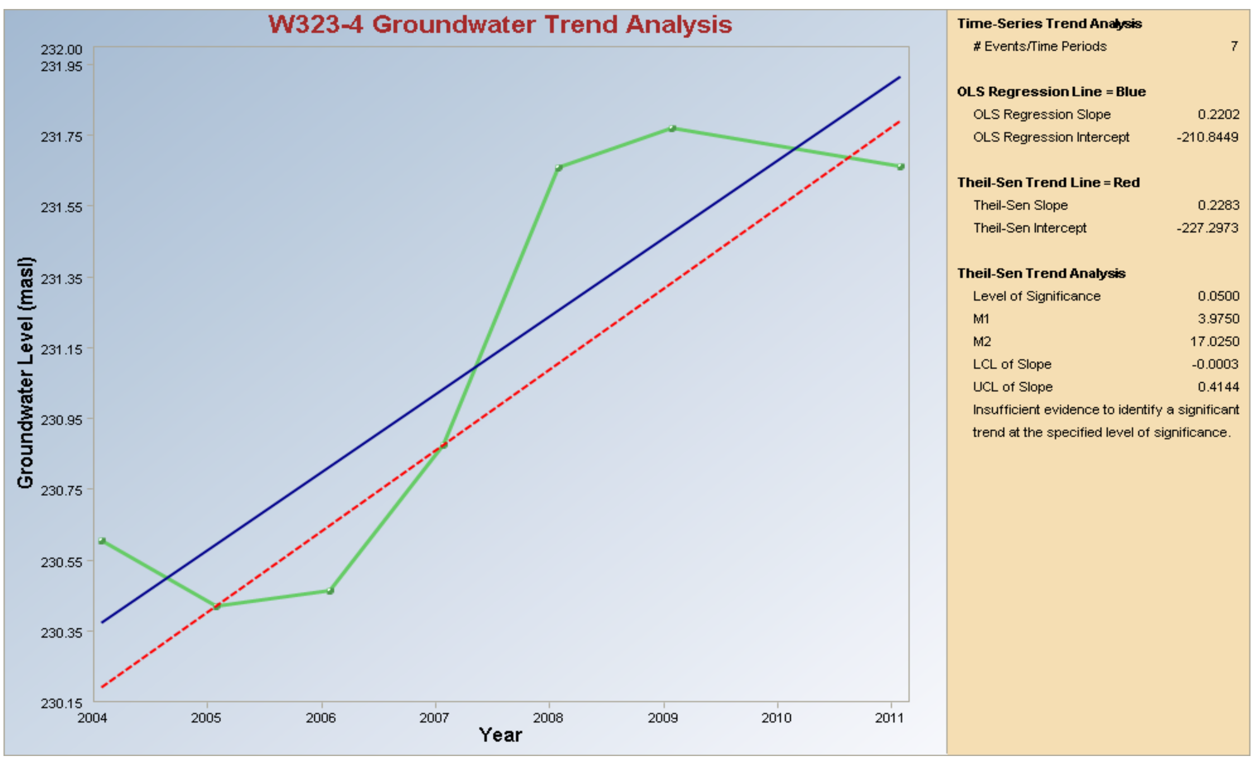

Figure 9: Illustration of results from Theil-Sen trend test for groundwater level data for W323-4 at 95% confidence coefficient.

5.0 Conclusion and recommendations

This is the first attempt by the NVCA to statistically interpret trend analysis of PGMN GW levels. It is recognized that statistically definable results can be utilized to manage GW resources, assess drought conditions, evaluate the impact of human activities on GW and evaluate long-term GW trends (Nova Scotia Environment, 2012).

Five of the 16 NVCA PGMN wells had time series data that was long and complete enough (>75% per year for a minimum seven year period) to calculate trend analysis. It is noted that with time, the values for percent completion and usable years will increase the number of wells that would meet the requirements of seven years of data with a minimum of 272 data points for trend analysis. A statistically significant trend was observed in three of the five wells based on the Mann-Kendall test. These three wells demonstrated an upward trend based on the results generated from the Theil-Sen slope, indicating a positive increase in GW levels. From the linear regression analysis, the water level has increased in well 244-2 approximately 1.2 m and in 245-2 approximately 0.95 m over a nine-year period, whereas well 323-4 has increased in water level roughly 1.55 m over the past seven years. It is suggested that localized increases in the GW levels in well 244-2 and 245-2 are possibly related to locale change in aquifer pumping conditions however, the reason for the water level increase at location 323-4 is unclear, given that the other wells in the well nest - notably 323-4 - did not exhibit any significant trend and the associated local land use is rural with limited proximal water takings and no large-scale takings.

It is recommended that annual updates on the Mann-Kendall and Theil-Sen trend analysis be completed for all NVCA PGMN wells where sufficient data permits for updates, and communicated through an annual summary GW characterization document.

For wells that have been analyzed and experience a trend, further analysis should be completed using Seasonal Kendall in order to test for the presence of seasonal trends within the data set. The Seasonal Kendall analysis requires a minimum of three years of monthly data, or 36 data points (Gilbert, 1987), which would allow more NVCA wells to be analyzed. It is unlikely that serial correlation (independence) can be quantified in quarterly ground water data without at least 10 years of quarterly data, or 40 data points (Gilbert, 1987). Therefore, three to five NVCA wells should have enough data to satisfy these parameters by the end of 2013. Another test that can be done for data sets that have a minimum three years of quarterly data for the same months is the Kruskal-Wallis Test.

As a long-term goal, it is recommended that a regional Mann-Kendall trend analysis be completed for wells situated in similar hydrostratigraphic horizons to determine regional aquifer level characterization.

It is recommended that water quality of pertinent parameters, either exceedances and/or parameters related to the watershed report card (e.g. nitrate + nitrite and chloride), be similarly statistically analyzed to determine trend analysis. It is noted that eight to 10 independent samples are needed to conduct a statistical analysis and generate a passable estimate of the population standard deviation for populations having normal or lognormal (parametric) distributions (EPA, 2010).

6.0 References

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