Tara Seely
14/6/11

Impact of the September 4, 2010 Canterbury Earthquake on Nitrogen and Chloride Concentrations in Groundwater

Abstract

On September 4, 2010, the Canterbury region of New Zealand was hit by a magnitude 7.1 earthquake. The earthquake threatened the quality of groundwater with its potential to cause mixing between Canterbury's layered aquifers. Groundwater quality is important to monitor because Canterbury residents rely on this resource for clean drinking water. This study examined chloride and nitrogen concentration in wells in the Canterbury region as potential indicators of groundwater mixing and contamination. Average and quartile statistical results show some increases in both chloride and nitrogen concentrations after the earthquake, but not enough to fully support the theory of seismic-induced aquifer mixing. Spatial analysis of the wells that displayed increases in chloride suggest seismic activity was concentrated in the north-western region of Canterbury. Spatial analysis of the wells with increases in nitrogen was inconclusive. Land use data needs to be analyzed for pre-existing spatial patterns of contaminant concentrations, and groundwater level should be studied as an additional indication of the earthquake's impact. Current nitrogen and chloride concentrations are not a threat to the health of Canterbury residents.

Introduction

On September 4, 2010, the New Zealand region of Canterbury experienced a magnitude 7.1 earthquake. The earthquake caused no fatalities, but significantly damaged homes and buildings. In addition to structural damage, the earthquake also posed other threats to the safety of Canterbury residents. Groundwater quality in particular, a feature closely tied to the health of Canterbury residents, was threatened by the seismic activity.

The groundwater hydrology of the Canterbury region exists in a series of horizontal aquifers separated by less-permeable bedrock (Hanson, 2009). Groundwater is extracted from the deepest aquifers where an extensive residence time has allowed aqueous bacteria and viruses to decay. This water is therefore uncontaminated and ready for potable use without any processing (Stewart, 2002). However, extension and compression of bedrock as a result from earthquakes may cause vertical mixing between aquifers (Rojstaczer, 1995). Mixing leads to geochemical contamination of deep aquifers by contaminated shallow aquifers, threatening the quality of drinking water. This study addressed the geochemical changes in water quality resulting from the physical hydrologic response to the September 4, 2010 Canterbury earthquake.

Assessing geochemical changes in water quality is not only relevant to the scientific understanding of the impacts of earthquakes, but it is also extremely important for the health and safety of Canterbury residents. The potential aquifer mixing that may occur as a result of seismic activity could contaminate Canterbury drinking water (Hanson, 2009). The goal of this study was to use contaminant data before and after the September 4, 2010 earthquake as an indication of aquifer mixing that may have occurred from the earthquake. By analyzing nitrogen and chloride sample data from wells across the Canterbury region, this study produced a spatial and temporal analysis of geochemical changes to groundwater resulting from the September 4, 2010 earthquake. The analysis concluded that the increases in chloride and nitrogen concentration displayed by some wells after September 4, 2010 supports the theory of aquifer mixing but does not decisively prove it. Further study must be conducted for more conclusive results.

Background

The study site is the Canterbury region and its underlying aquifer system. The groundwater of the Central Canterbury Plains exists within a sequence of gravel alluvial fans deposited in the Quaternary period (Hanson, 2009). Source of groundwater recharge varies spatially across the plain and is either from land surface or alpine river (Hanson, 2009). Figure 1 shows the hydrology of the Canterbury plains. A series of wells part of the Environmental Canterbury project were used as sample sites for this study. Figure 2 is an image generated in ArcMAP showing the location of the ECAN wells in the Canterbury region used for this study.

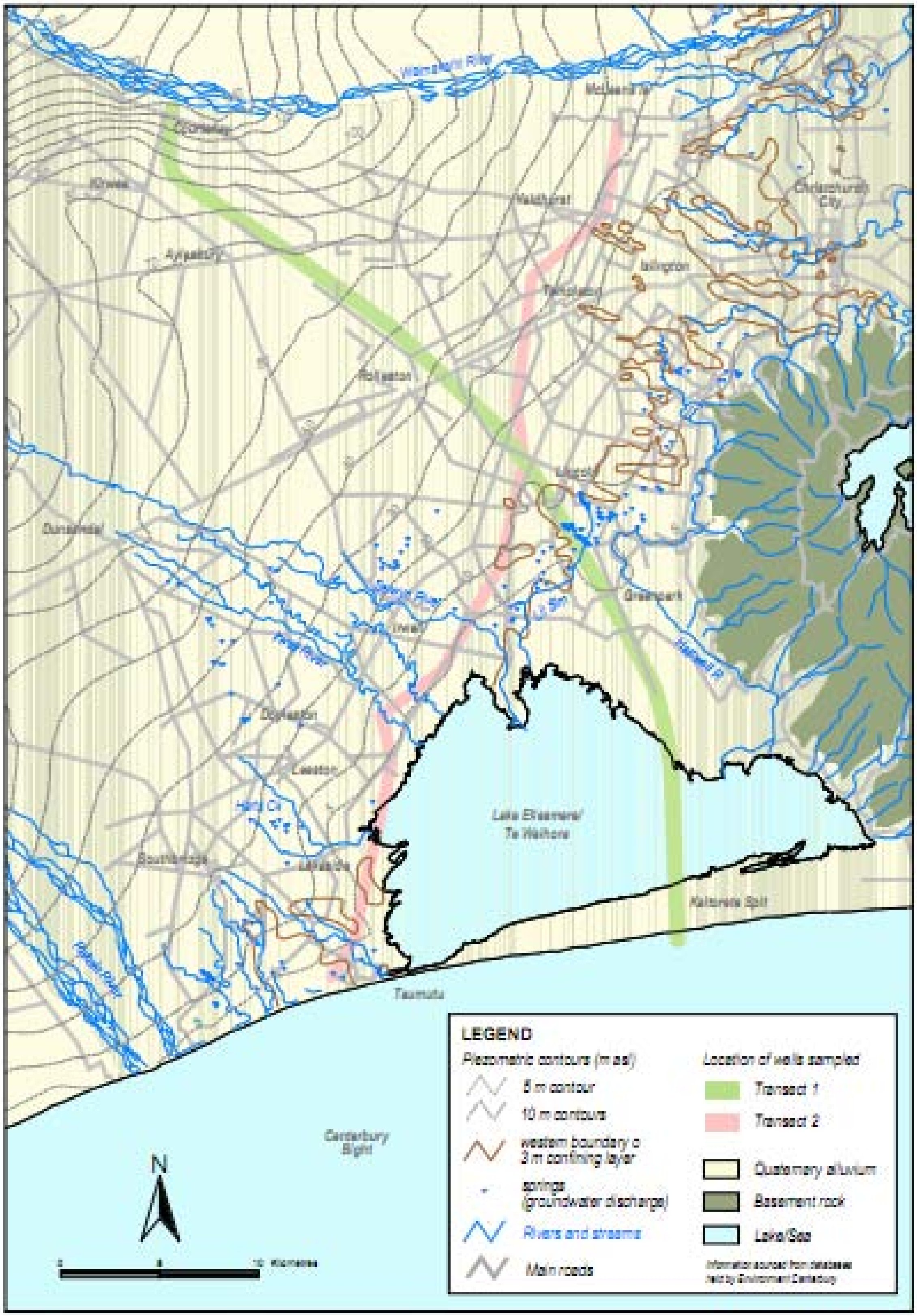

Figure 1: Hydrology of the Canterbury Plains including Environmental Canterbury sample transects (Hanson, 2009) Groundwater level gradually decreases towards bodies of water, and most of Canterbury's bedrock is Quaternary alluvium.

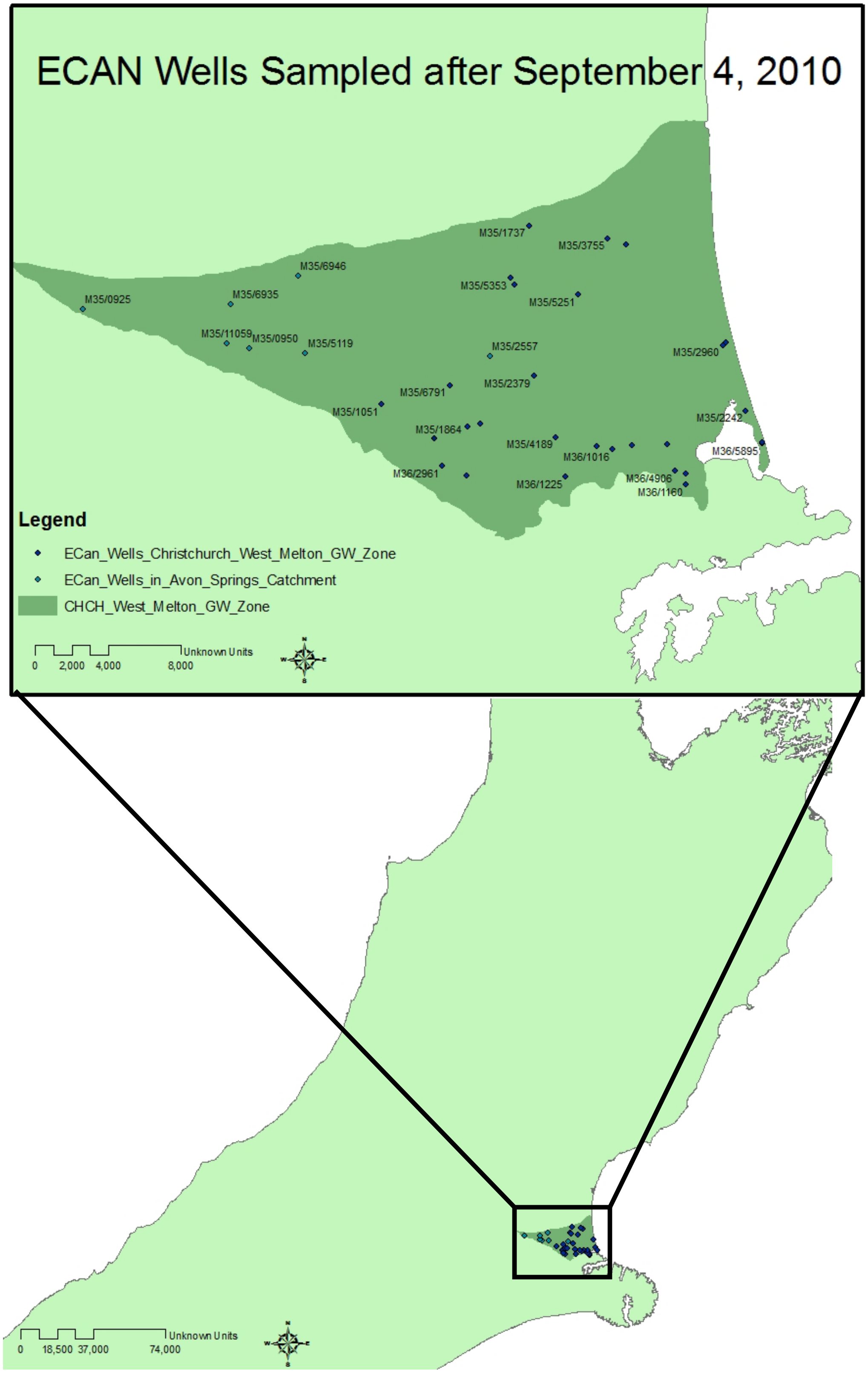

Figure 2: Map showing the location of ECAN wells with samples after September 4, 2010 used for this study. Wells come from the Avon Springs and Christchurch West Melton datasets and are scattered around the Canterbury region.

Depending on their source of recharge, shallow aquifers vary in their amount of nitrogen and chloride contaminants. Higher levels of nitrogen are typically found in groundwater recharged by land surface infiltration while lower levels are found in groundwater recharged by alpine rivers (Hanson, 2009). Sources of Nitrogen include the natural oxidation of organic soil matter, cropping, inorganic fertilizers, and manure (Stewart, 2002). Shallower wells are generally shown to have higher concentrations of chloride. Runoff from urbanized areas contributes more chloride to groundwater than forested areas, and runoff from agricultural land yields intermediate chloride concentrations. The increase in chloride concentration in urbanized areas is attributed to sewage-systems and landfills (Mullaney, 2009). Land use and land cover correlates with certain levels of chloride and nitrogen in underlying groundwater. Therefore, spatial variation exists for both chloride and nitrogen contamination, and any changes in contaminants resulting from the earthquake must be compared to the site's pre-existing contaminant levels (Scanlon, 2005).

Environmental Canterbury dates groundwater using the CFC dating method which measures concentrations of Chlorofluorocarbons in groundwater to determine age. Because the amount of CFCs used during past decades is roughly known, the age of groundwater can be estimated based on its CFC concentration. For example, the highest levels of CFCs are found in the shallowest aquifers. This correlates to the spike in CFC use in recent years from agricultural intensification suggesting the shallow aquifer water is very young (Stewart, 2002). Lower to nearly zero levels of CFCs in deeper aquifers indicate that this water is much older, and the aquifers are horizontally stratified (Stewart, 2001). However, Hanson recently collected geochemical data that demonstrates vertical mixing between aquifers for at least 150-200m of depth across the inland region of the plains (2009). Despite existing vertical mixing, the seismic activity of magnitude 7 earthquakes has the potential to either greatly increase the permeability of aquatards, the impermeable bedrock between confined aquifers, or to force water upwards through bedrock by elastic compression (Rojstaczer, 1995). According to Rojstaczer, if an earthquake primarily increased aquatard permeability, lower groundwater levels would result. However, if elastic compression was the dominant process, groundwater levels would rise (2005). Each process increases vertical mixing between aquifers, but the dominant process will depend on the specific characteristics of an earthquake.

In a study of the effects of the Kobe Earthquake on hydrology, Tokunaga found that the earthquake increased horizontal aquifer permeability, and it was determined that hydrologic effects of an earthquake are most prominent immediately after the earthquake (Tokunaga, 1999). The temporal component of this study is thus very important. If the earthquake is found to significantly alter the geochemistry of deep aquifers, it is important to monitor contaminant levels immediately after the earthquake and over time, as the system may continue to fluctuate.

Methods

Data was acquired from the University of Canterbury and the Regional Council Environmental Canterbury (ECAN). Data was provided in the format of excel files and included geochemical samples from a series of wells located in the Canterbury plains. Refer to figure 2 for the location of the wells. For each well, data included the geochemical sample parameter, the value of the sample, sample units, and the date the sample was taken. For this study, nitrate nitrogen and chloride concentration were the geochemical parameters analyzed for each well. Each well varied in the number of samples recorded, but sample dates generally ranged from 1960 to 2010.

All statistical work was conducted using various functions in the Microsoft Office Excel software. Wells with sample data after September 4, 2010 were first isolated. Wells with less than 10 samples taken before the cut-off date were eliminated from statistical analyses since they did not have enough data to draw statistical conclusions. The goal of the analyses was to evaluate each well's post-earthquake nitrogen and chloride concentrations in relation to its pre-earthquake concentrations. This strategy allowed the focus to be only on the impact of the earthquake and ignored pre-existing variability of nitrogen and chloride concentrations between different wells. Quartile data and averages were taken from the nitrogen levels prior to September 4, 2010 for each well. Nitrogen levels after September 4, 2010 were then analyzed to see how they fit in with the pre- September 4, 2010 quartiles and averages. Additionally, R-squared and slope data were taken from the data before September 4, 2010 using dates as the x-axis values and nitrogen levels as the y-axis values. The purpose of this was to determine if there was any temporal trend in nitrogen values already occurring before the September 4 earthquake. This process was repeated with Chloride data for the same set of wells.

Because the levels of nitrogen and chloride may have monthly variation, contaminant levels were also plotted against sample month. Pre-September 4, 2010 data was compared to post-September 4, 2010 data in a scatter plot format to analyze how the concentrations post-earthquake compared to the concentrations pre-earthquake around the same month. Because most data after September 4, 2010 was sampled in the month of October, the range of

September to November was generally evaluated for each graph. Graphs were graded using a scale of 'low', 'mid', and 'high'. 'Low' described graphs whose post-September 4, 2010 samples were in the lower range of pre-September 4, 2010 samples around the same month. An example of such a graph is shown in figure 3. 'Mid' described graphs whose post- September 4, 2010 samples were in the middle of the pre-September 4, 2010 samples taken around the same month. Figure 4 is an example of a 'mid' graph. An example of a 'high' graph is shown in figure 5. The 'high' graph has post-September 4, 2010 either in the high range or exceeding pre-September 4, 2010 values around the same month.

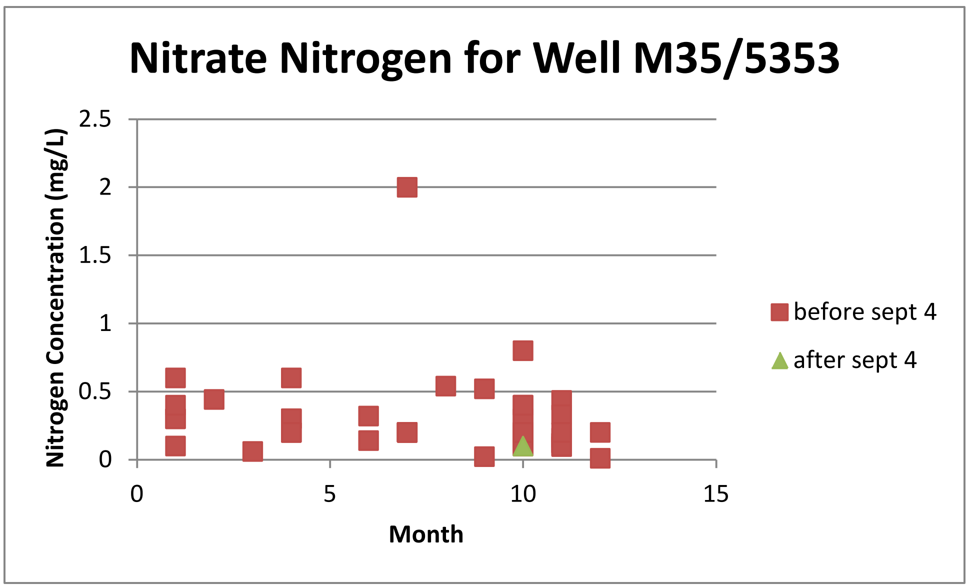

Figure 3: Example of a graph graded 'low'. The post-September 4, 2010 value is among the lowest of the pre-September 4, 2010 values within the September-November range.

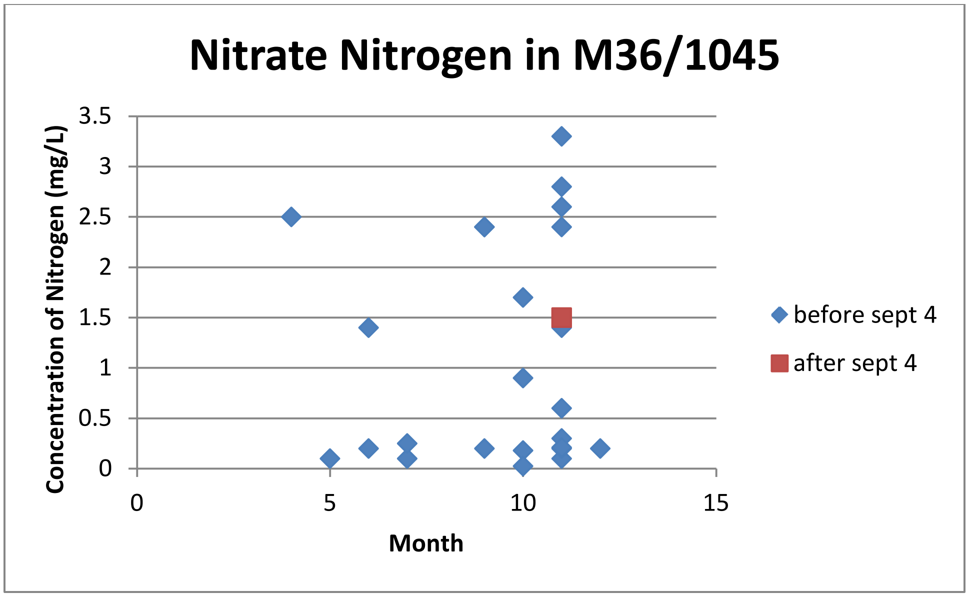

Figure 4: Example of a graph graded 'mid'. The post-September 4, 2010 value is around the mid range of the pre-September 4, 2010 values within the September-November period.

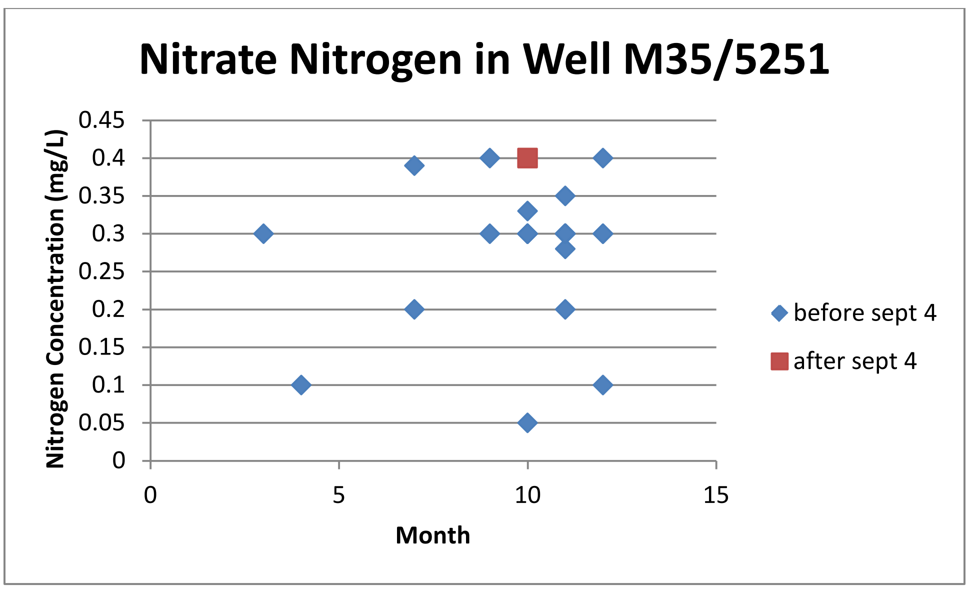

Figure 5: Example of a graph graded 'high'. The post-September 4, 2010 value is among the highest of the pre-September 4, 2010 values within the September-November range.

ArcMAP, a spatial analysis program part of ArcGIS software, was used to plot the locations of the wells analyzed. Each well was then color-coded based on its graph categorization of 'high', 'mid', or 'low' for both nitrogen and chloride. Spatial patterns of post-quake contamination values were then analyzed using both of these maps.

Results

Thirty seven wells from the ECAN data were sampled after September 4, 2010. Two wells had less than ten samples and were therefore eliminated from statistical analysis. For the nitrogen data, eighteen wells had post-September 4, 2010 sample values above the average pre-September 4, 2010 sample values. For the chloride data, twenty-one wells had post-September 4, 2010 values above the average pre-September 4, 2010 sample values.

For nitrogen, eleven wells had post- September 4, 2010 samples above the third quartile, and one above the maximum. Nine wells had post-September 4, 2010 data between the second and third quartile, seven between the first and second, and seven below the first quartile. Four wells had post-September 4, 2010 data that did not fit within the listed quartile categories (i.e. fit between first and third quartile or second and fourth quartile) and are not included in the results. For the chloride data, five wells had post September 4, 2010 values below the first quartile, two between first and second quartile, eleven between second and third quartiles, and ten between third and fourth quartile. Three wells had post-September 4, 2010 values as maxima. Quartile data is summarized in table 1.

	Number of wells with post-earthquake data within given quartile range					
Contaminant	<0	0-1	1-2	2-3	3-4	>4
Chloride	1	6	7	9	11	1
Nitrogen	2	3	2	11	10	3

Table 1: This table summarizes the number of wells within each quartile range for both chloride and nitrogen contaminants. Most wells had post-quake chloride and nitrogen values above the median (quartile 2).

For Nitrogen data, only one R-squared value, using sample dates as the x-values and nitrogen concentrations as the y-values, was above the cut-off value of .7, and it correlated to a slope of -0.00039. For Chloride data, only two R-squared values were above .7. These two R-squared values correlated to slopes of -.00112 and -.05485. R-squared and slope data are summarized in table 2.

Contaminant	Well ID	RSQ	Slope
Chloride	M36/1016	0.887914	-0.001124
Chloride	M36/4906	0.843917	-0.054851
Nitrogen	M36/1016	0.871725	-0.000393

Table 2: This table displays the only wells with R-squared values above the cut-off of .7 and their corresponding slope values. Only two wells out of thirty-five displayed any linear trend between sample date and sample value.

Scatter plots showing sample month against nitrogen concentration were evaluated using a scale consisting of 'low', 'mid' and 'high', previously explained in methods section. For nitrogen, twelve wells had 'high' results, fourteen had 'mid' and eight had 'low'. For Chloride data, fourteen were ranked as 'high', fifteen as 'mid' and six as 'low'. Table 3 summarizes these results.

	Number of wells classified as:		
Contaminant	Low	Medium	High
Chloride	8	14	12
Nitrogen	6	15	14

Table 3: This table summarizes the classification of the month vs. Concentration graphs detailed in the methods section. Most wells had post-September 4, 2010 values in the mid-range of pre-September 4, 2010 values around the same month.

Figure 6 shows the map generated in ArcMAP with wells color-coded based on their graph classifications of ‘high’, ‘mid’, or ‘low’ for nitrogen concentrations. With a few exceptions, the wells that showed ‘high’ relative chloride concentrations after September 4, 2010 to pre-September 4, 2010 values around the same month are in the north-western region of Canterbury. The south-eastern region has a mix of both ‘mid’ and ‘low’ relative concentrations of chloride after September 4, 2010.

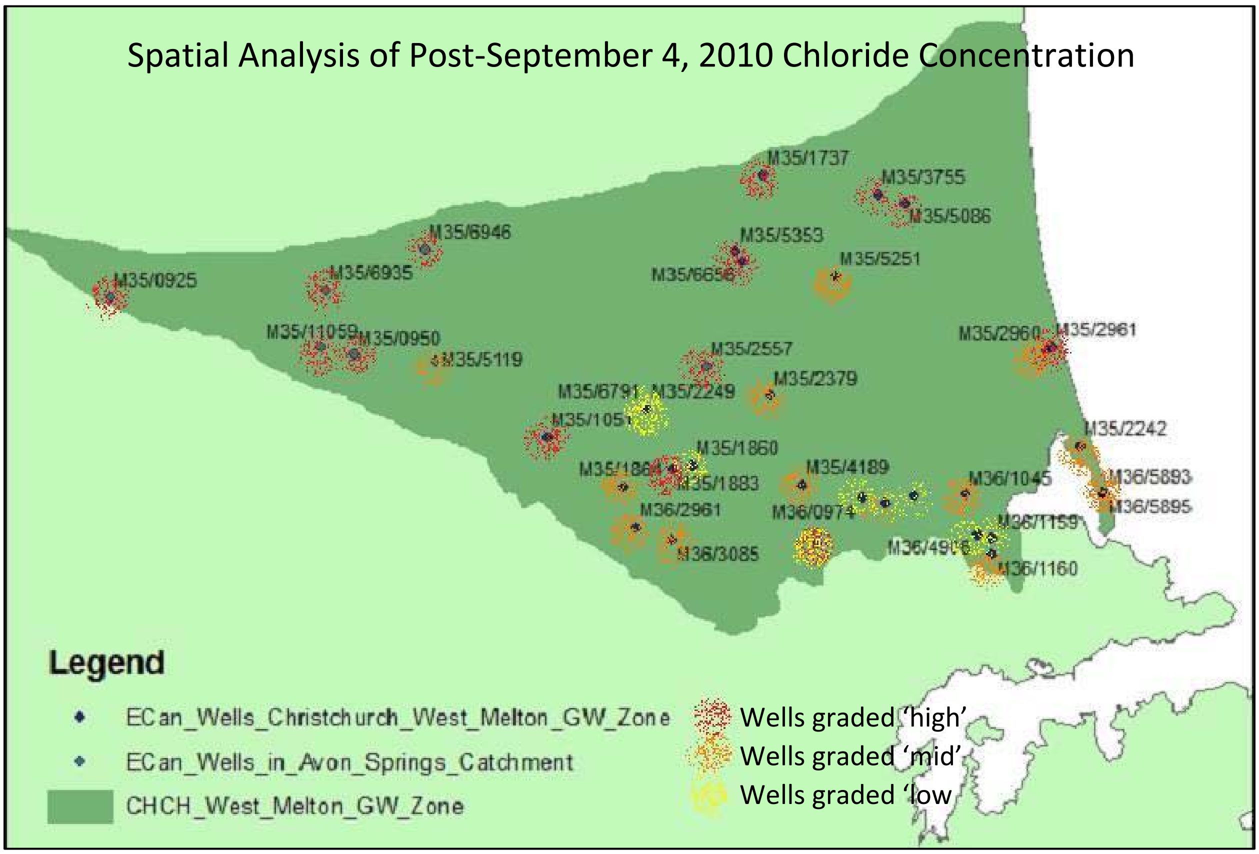

Figure 6: This map generated in ArcMAP summarizes the spatial relationship of the wells with 'high', 'mid', and 'low' classifications for chloride values. The northwest region of Canterbury contains wells mostly classified as ‘high’ while the southeast region contains wells mostly classified as ‘mid’ and ‘low’.

Figure 7 shows a similar map color-coded with relative values of nitrogen after September 4, 2010. Unlike the chloride map, no clear pattern can be seen with the relative nitrogen values post-quake, although ‘high’ and ‘mid’ predominates over ‘low’.

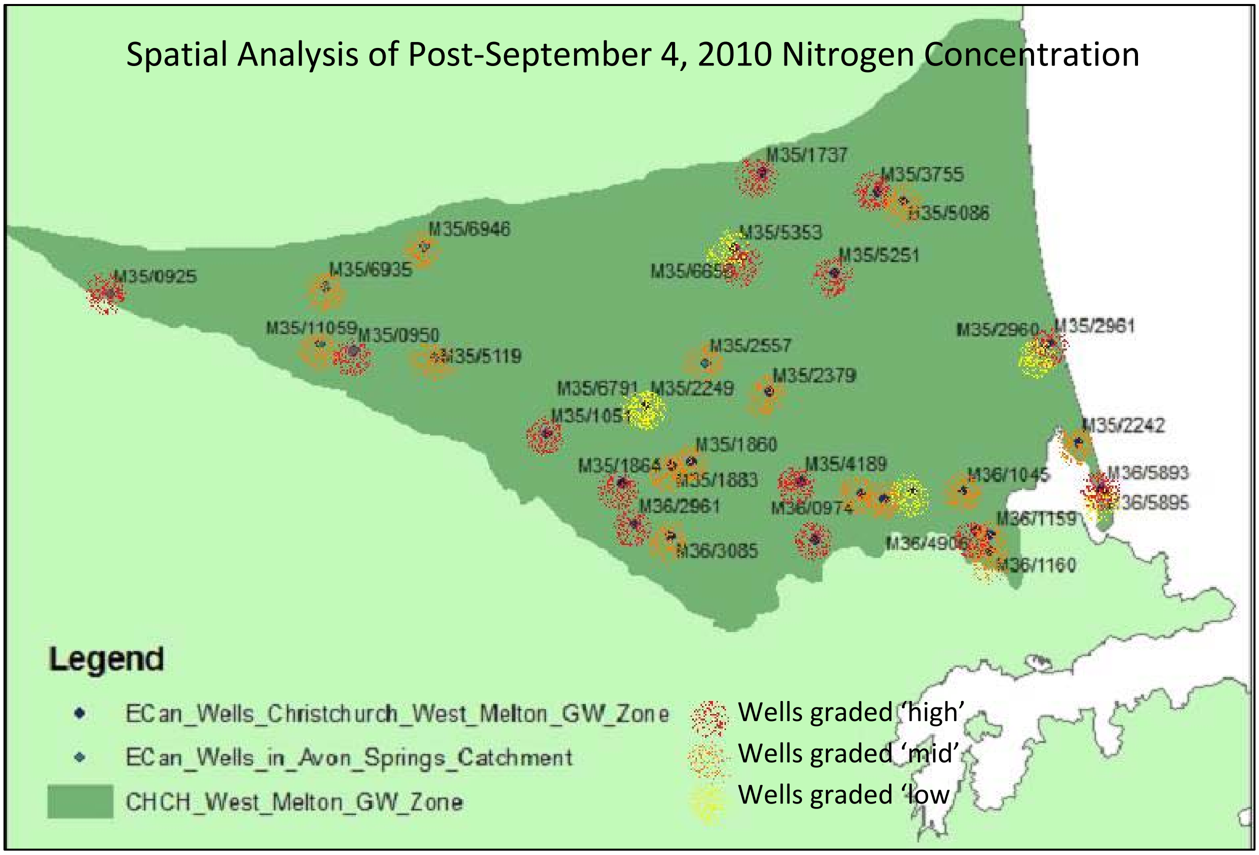

Figure 7: This map generated in ArcMAP displays the spatial relationship of wells classified as 'high', 'mid', and 'low' for nitrogen values. No clear pattern is determined, but 'high' and 'mid' classifications predominate.

Discussion

The number of wells with post-September 4, 2010 values greater than the pre-September 4, 2010 average was over half for both nitrogen and chloride. This could indicate earthquake-induced groundwater mixing but does not confirm it. For Nitrogen concentrations, the majority of the wells had post-September 4, 2010 samples above the second quartile. This pattern was also found in the Chloride concentrations. Again, these results support groundwater mixing but are not able to decisively prove it. Between both Nitrogen and Chloride data, only three full date and sample value R-squared values were above the cut-off value .7. This indicates that there has not been a natural increase or decrease in contaminants over the years prior to the earthquake. The three wells that did show a correlation had negative slopes, meaning that nitrogen and chloride concentrations decreased in the years prior to the earthquake. While this does not agree with initial expectations of a steady increase in nitrogen and chloride values, it does suggest that an increase in contaminants resulting from the earthquake would be easily distinguished from any pre-existing decreasing trends in contaminant concentration.

The scatter plots of sample month against sample concentration did not demonstrate any clear or consistent monthly patterns. For both nitrogen and chloride, most of the graphs were categorized in the ‘mid’ range, but out of the remaining wells, more were considered ‘high’ than ‘low’. This is similar to the quartile and average data in that these results could fit a scenario in which the earthquake caused increased contamination, but is not strong enough to prove the elevated levels of nitrogen and chloride result from the earthquake alone. The spatial analysis of the post-earthquake values relative to pre-earthquake values shows the north-western region of Canterbury having higher levels of chloride after the earthquake. This may indicate that the northern region experienced more aquifer mixing due to more concentrated seismic activity. However, no such pattern was displayed with the nitrogen data. Evaluating land use may help account for the difference between nitrogen and chloride. Additionally, it is important to note that elevated contaminant concentrations may result from increased development of land rather than seismic-induced changes.

Further investigation of this issue should include analyzing changes in groundwater level for each well. This information could indicate what areas experienced bedrock compression or extension and consequently aquifer mixing. Additionally, each well should be continually monitored. Most of the wells analyzed in this study only had one sample after September 4, 2010. More samples are necessary to determine if groundwater contamination is sustained.

Conclusion

A series of wells in the Canterbury region have been analyzed for geochemical changes to groundwater as a result of the September 4, 2010 earthquake. The results have been used as an indication of aquifer mixing. From the analysis of geochemical contaminants, chloride and nitrogen levels show more increases than decreases after the September4, 2010 earthquake based on average and quartile data. However, the results are not strong enough to conclude that the earthquake did cause aquifer mixing. Spatial analysis of chloride levels post-earthquake show most increases in chloride occurred in the north-western region of Canterbury, possibly indicating more concentrated seismic activity in this region. No such pattern could be drawn from the spatial analysis of nitrogen levels. Land use should be evaluated in order to account for the spatial differences between nitrogen and chloride levels. While the health of Canterbury residents drinking groundwater does not appear to be threatened, continuous monitoring of wells will be necessary to fully understand the sustained impact of the earthquake.

References

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Appendix

Well	Parameter	Minimum	25p	Median	75p	Maximum	post s-4	post s-4	Count	Average	rsq	Slope	Graph
M35/2557	chloride	2.8	4	4.5	6.075	12	9.2		26	5.4111	0.0251	1.3756E-04	high
M35/0925	chloride	1	1.675	1.85	2	2.5	2.3		24	1.7833	0.3047	5.4528E-05	high
M35/11059	chloride	3.8	4.7	4.9	7.3	8.8	7.2		5	5.9000	0.0036	2.1288E-04	high
M35/5119	chloride	4	4.625	6.55	9.275	16	10		14	7.6500	0.1466	1.0049E-03	mid
M35/6935	chloride	1.4	1.7	1.9	2.075	2.8	2.4	2.2	18	1.9167	0.0533	5.8924E-05	high
M35/6946	chloride	0.4	1	1.1	1.6	2	1.5		13	1.2231	0.2586	1.4105E-04	high
M35/0950	chloride	5.3	5.7	6.1	10.55	15	16		3	10.6000	0.4488	2.5827E-03	high
M35/5353	chloride	3.1	5.85	7.2	12	39	18		47	9.7511	0.1098	-7.7369E-04	high
M35/1051	chloride	6	10	11	13	23	19		256	11.8785	0.1211	4.1284E-04	high
M35/2960	chloride	4.4	5	5.4	5.9	6.4	5.5		23	5.4391	0.0477	-4.8880E-05	mid
M35/2961	chloride	5.4	5.95	6.3	6.55	7	6.5		23	6.2783	0.0194	2.4919E-05	high
M36/5893	chloride	39	43	43.5	44.25	47	43		16	43.5000	0.0003	3.0949E-05	mid
M36/5894	chloride	3.5	4.6	4.7	4.8	4.9	4.4		13	4.5923	0.0180	4.5564E-05	mid
M36/5895	chloride	3.7	4.65	4.9	5.05	5.4	4.7		14	4.8071	0.0224	5.6451E-05	mid
M35/1737	chloride	1.2	1.7	1.8	2	2.5	2.4		19	1.8737	0.0081	-1.1171E-05	high
M35/2249	chloride	4	5.9	7.6	9	14	5.3		31	7.9742	0.0614	2.8319E-04	low
M35/3755	chloride	4.5	4.9	5.7	6	7	5.8		25	5.5080	0.0426	-4.8617E-05	high
M35/5086	chloride	7	7.7	8	8	9.5	8.8		24	7.9542	0.0186	3.0619E-05	high
M35/5251	chloride	1.7	2	2.1	3	4	2.7		29	2.4207	0.2416	-1.1795E-04	mid
M35/6656	chloride	1.5	2.3	2.5	3	4	4.1	4	22	2.6409	0.0116	-3.0236E-05	high
M35/6791	chloride	4.7	5	5.1	5.3	7	5.1		71	5.1718	0.0312	-3.3546E-05	low
M35/1860	chloride	2.2	4	5	6	14	3.8		53	5.1472	0.3235	-3.0556E-04	low
M35/1864	chloride	3.2	4	4.65	5	7	4.1		38	4.6842	0.3889	-1.4520E-04	mid
M35/1883	chloride	11	12	13	15	19	15	15	27	13.7037	0.3748	-6.4020E-04	high
M36/0974	chloride	16	20	22	24	26	18		35	21.7143	0.1043	-2.2050E-04	low
M36/1016	chloride	17	21.75	22.5	25	27	16		16	22.7500	0.8879	-1.1243E-03	low
M36/1225	chloride	2	13	16	18	37	15		38	15.4737	0.0028	-8.7134E-05	mid
M36/2961	chloride	10	14	17	20	38	17		102	17.5539	0.1628	-7.5074E-04	mid
M36/3085	chloride	15	37	80	153.75	190	57		30	89.9667	0.5318	-1.5047E-02	mid
M36/4906	chloride	50	75.5	120	285	360	53		34	171.1765	0.8439	-5.4851E-02	low
M35/2379	chloride	3	4.8	5	6	9.3	6.4		29	5.4690	0.0729	8.0370E-05	mid
M35/4189	chloride	2.8	4.075	4.3	4.85	8.7	4.1		12	4.8000	0.1269	-4.7061E-04	mid
M36/1045	chloride	4.3	5	6	10	12	8.4		24	7.3042	0.3412	4.3492E-04	mid
M36/1057	chloride	10	14	16	17	18	13		36	15.5972	0.0069	-3.8637E-	low

												05	
M36/1159	chloride	166	1050	1700	1850	2300	680		39	1506.3077	0.0056	1.5895E-02	low
M35/2242	chloride	2.6	4	4.3	5	6	4.8		36	4.4111	0.2047	-8.2900E-05	mid
M36/1160	chloride	134	190	210	240	380	200		17	221.4118	0.0060	9.0855E-04	mid
M35/2557	nitrate nitrogen	0.2	0.765	1	1.9	5.7	1.7		27	1.4719	0.0612	-1.0972E-04	mid
M35/0925	nitrate nitrogen	0.2	0.5	0.5	0.5625	0.7	0.7		26	0.5077	0.3825	1.6464E-05	high
M35/11059	nitrate nitrogen	1.4	1.9	2.1	3.4	3.8	3		5	2.5200	0.0258	2.8285E-04	mid
M35/5119	nitrate nitrogen	0.88	1.725	2.6	3.35	6.9	3.9		14	2.9414	0.1900	5.4342E-04	mid
M35/6935	nitrate nitrogen	0.2	0.2	0.23	0.3	0.4	0.3	0.3	18	0.2706	0.2912	3.2068E-05	mid
M35/6946	nitrate nitrogen	0.025	0.09	0.09	0.1	0.13	0.1		13	0.0913	0.0038	-9.7512E-07	mid
M35/0950	nitrate nitrogen	1.5	1.9	2.3	3.35	4.4	3.7		3	2.7333	0.6426	8.5977E-04	high
M35/5353	nitrate nitrogen	0.01	0.14	0.2	0.32	2	0.1		49	0.2914	0.0267	1.7433E-05	low
M35/1051	nitrate nitrogen	3.2	5.2	5.6	6.7	16.7	9.7		256	6.0581	0.0669	1.7067E-04	high
M35/2960	nitrate nitrogen	0.01	0.1	0.1	0.195	0.49	0.05		23	0.1327	0.0526	-8.6869E-06	low
M35/2961	nitrate nitrogen	0.009	0.075	0.1	0.1	0.39	0.1		23	0.0935	0.0783	-7.7785E-06	high
M36/5893	nitrate nitrogen	0.025	0.1	0.1	0.1	0.1	0.1		16	0.0875	0.5527	1.7659E-05	high
M36/5894	nitrate nitrogen	0.025	0.1	0.1	0.1	0.1	0.1		13	0.0904	0.4496	1.4401E-05	high
M36/5895	nitrate nitrogen	0.1	0.1	0.1	0.13	0.2	0.1		14	0.1243	0.0005	-8.5780E-07	low
M35/1737	nitrate nitrogen	0.01	0.315	0.4	0.5	0.7	0.7		19	0.4011	0.1364	2.2432E-05	high
M35/2249	nitrate nitrogen	1	1.55	1.7	2.5	4.8	0.3		31	2.2000	0.1601	1.7316E-04	low
M35/3755	nitrate nitrogen	0.5	0.64	0.7	0.8	1.4	1		25	0.7452	0.2551	3.3959E-05	high
M35/5086	nitrate nitrogen	0.025	0.4	0.5	0.5325	1.5	0.5		24	0.4977	0.0064	-8.8130E-06	mid
M35/5251	nitrate nitrogen	0.05	0.3	0.3	0.3	0.4	0.4		29	0.2828	0.0071	2.6754E-06	high
M35/6656	nitrate nitrogen	0.05	0.15	0.2	0.2	0.44	0.3	0.2	23	0.1813	0.0214	-5.2646E-06	high
M35/6791	nitrate nitrogen	0.1	0.2	0.23	0.3	0.8	0.2		71	0.2836	0.1398	4.6527E+03	low
M35/1860	nitrate nitrogen	0.1	0.41	0.6	0.9	6.4	0.6		53	0.8292	0.0804	-7.2533E-05	mid
M35/1864	nitrate nitrogen	0.2	0.4	0.545	0.625	1	0.8		32	0.5438	0.2725	2.3347E-05	high
M35/1883	nitrate nitrogen	5.3	5.75	6.2	8.25	13	7.5	7.5	27	7.1481	0.3746	-5.4453E-04	mid
M36/0974	nitrate nitrogen	0.48	5.05	6.05	7.35	8	5		34	5.8935	0.0007	1.1277E-05	mid
M36/1016	nitrate nitrogen	4.7	5.925	6.2	7.35	7.6	4.6		18	6.3556	0.8717	-3.9327E-04	low
M36/1225	nitrate nitrogen	0.2	2.6	2.75	3.1	4.7	3.7		38	2.5421	0.2869	1.5371E-04	high
M36/2961	nitrate nitrogen	2.3	3.9	4.8	5.4	10	7.4		103	4.8155	0.1853	2.1033E-04	high
M36/3085	nitrate nitrogen	15	37	80	153.75	190	57		30	89.9667	0.5318	-1.5047E-02	mid

M36/4906	nitrate nitrogen	0.025	0.0675	0.1	0.1425	0.3	0.2		28	0.1139	0.0895	1.0971E-05	high
M35/2379	nitrate nitrogen	0.2	0.8	1.1	1.3	2.8	1.1		29	1.1159	0.0212	1.6460E-05	mid
M35/4189	nitrate nitrogen	0.06	0.09	0.2	0.2	0.21	0.2		12	0.1575	0.0183	-7.6768E-06	high
M36/1045	nitrate nitrogen	0.025	0.2	0.45	2.4	3.3	1.5		24	1.1027	0.2546	1.5374E-04	mid
M36/1057	nitrate nitrogen	1.1	4.175	5.4	5.725	6	4		36	4.9333	0.1842	1.1530E-04	mid
M36/1159	nitrate nitrogen	0	0.064	0.1	0.1	1.4	0.1		34	0.1511	0.1001	2.7768E-05	mid
M35/2242	nitrate nitrogen	0	0.072	0.1	0.1	0.56	0.1		36	0.1083	0.0013	9.7029E-07	mid
M36/1160	nitrate nitrogen	0.05	0.3	1.2	1.7	3.4	1		17	1.1479	0.2826	1.0588E-04	mid

Appendix Table 1: This table summarizes all the statistical data for each well for both chloride and nitrate nitrogen concentrations. Wells highlighted in red had fewer than ten samples and were eliminated from statistical analyses. R-squared values highlighted in blue were above the cut-off value of .7.