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Ammonium Attenuation in Aquifer Material Impacted With High Levels of Organic Wastes

**Final Report
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**By:
Terry H. Brown**

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For
U.S. Department of Energy
Office of Fossil Energy
Federal Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

MASTER

not

By
Western Research Institute
365 North Ninth Street
Laramie, Wyoming 82071

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EXECUTIVE SUMMARY

Total concentrations of ammonium (NH_4^{+1}) have been found to exceed the State of Wyoming ground water quality standard for Class I aquifers near Torrington, Wyoming. The cause of the NH_4^{+1} contamination is thought to be associated with fertilizer use and/or the leaching of organics into the ground water from impoundments holding wastes from sugar beet processing. This type of contamination could be expected from other industrial processes, including those associated with the use of fossil fuels. In an initial step in understanding and solving the ground water contamination problem, Western Research Institute (WRI) conducted a laboratory investigation to understand the aquifer system as it relates to the chemistry of NH_4^{+1} as it moves through the aquifer material.

The data collected during the attenuation tests do provide an indication that the attenuation of NH_4^{+1} in the ground water system will occur. In addition, the results show the redox condition of the site and the possible chemical reactions that are influencing the ground water quality.

The tests completed with unimpacted aquifer material leached with NH_4^{+1} contaminated ground water show that dilution of NH_4^{+1} does occur at the front of the plume as it moves through the aquifer material. Apparently, the dilution is primarily a result of diffusion and hydrodynamic dispersion with some retardation due to electrostatic forces. In addition, the mixed system appears to have a redox condition that is poised at Eh values between +180 and +200mv and a pH value of about 7.9. This phenomenon is caused by some unknown redox couple.

The system of NH_4^{+1} contaminated aquifer material leached with uncontaminated ground water used to evaluate removal of NH_4^{+1} from the MW6 aquifer material had a poised redox condition of about +180mv to +200mv. In addition, the relatively high levels of NO_3^{-1} leached from the system could be due to either (1) the inadvertent incorporation of air into the system during sample setup, promoting nitrification or (2) the depletion of Fe^{+2} concentrations, allowing nitrification to occur. Additional studies would be required to determine the phenomena causing the formation of NO_3^{-1} in this system.

INTRODUCTION

Total concentrations of ammonium (NH_4^{+1}) have been found to exceed the State of Wyoming ground water quality standard for Class I aquifers near Torrington, Wyoming. The cause of the NH_4^{+1} contamination is thought to be associated with fertilizer use and/or the leaching of organics into the ground water from impoundments holding wastes from sugar beet processing. This type of contamination could be expected from other industrial processes, including those associated with the use of fossil fuels. In an initial step in understanding and solving the ground water contamination problem, Western Research Institute (WRI) conducted a laboratory investigation to understand the aquifer system as it relates to the chemistry of NH_4^{+1} as it moves through the aquifer material.

OBJECTIVE

The objective of this study was to estimate the attenuation of the NH_4^{+1} as it moves through the aquifer material. Attenuation of NH_4^{+1} was evaluated by studying the movement of contaminated ground water through nonimpacted aquifer material. In addition, nonimpacted ground water was leached through contaminated aquifer material to determine if the NH_4^{+1} present in the aquifer material could be readily mobilized and dispersed.

METHODS

The ground water and aquifer material (overburden) samples were to represent the ground water and aquifer material from NH_4^{+1} impacted and nonimpacted areas. Aquifer material and water samples were collected from, and adjacent to, well MW1, which represented a nonimpacted site, and Well MW6, which represented an impacted site. Samples of the aquifer material were collected using a backhoe. These samples were collected at levels below the capillary fringe of the aquifer. Ground water samples were collected from pre-existing monitoring wells MW1 and MW6, which are located adjacent to the backhoe pits. The water samples were collected using a small diameter submersible pump. The pump was lowered to midwater depth in each well. Approximately 4 well volumes were removed from each well prior to sample collection. During the collection of the ground water samples, field parameters such as pH, Eh and temperature (T) were determined using field meters. Ground water samples were submitted to Accu-Labs for analysis to establish baseline information.

The ground water and aquifer material collected for the attenuation tests were sampled and stored in a manner to help prevent the influence of air on the redox condition of the samples.

Ground water samples were pumped from the well into preconditioned 5-gallon sealable containers. The containers were prepared by thorough rinsing with the ground water and then were purged with argon to remove the air (oxygen) from the container. The containers were filled, leaving zero head space, and capped to help eliminate changes in redox conditions. The aquifer material samples were placed in preconditioned 5-gallon plastic buckets. The buckets were initially purged with argon and filled about half full with ground water collected from the respective well. The aquifer materials were placed in the buckets directly from the backhoe. The buckets were sealed with plastic and duct taped. Following the collection of the samples, the samples were agitated by shaking to remove air trapped in the sample during removal from the aquifer. The air was removed from the container by purging the system with argon through a hole in the plastic sheet. The buckets were then resealed by taping the hole made for argon purging and taping another layer of plastic over the bucket. The ground water and aquifer material samples were shipped immediately after sampling to WRI's facilities and stored at about 4°C.

In-place material densities were determined at the sampling locations to provide an approximate density to be used for the laboratory testing. Due to the sandy nature of the aquifer material and the resulting instability, these tests were conducted on materials at depths of about 4 feet that were very similar to the deeper aquifer materials. The field densities were determined with a sand cone apparatus in pits constructed using a front-end loader. Small excavations were made at two sites in each pit located near ground water wells MW1 and MW6. The excavated materials were collected and placed in plastic bags for wet and dry weight measurements. The amount of sand (by weight) required to fill the excavations was determined. The field bulk densities were calculated knowing the weight/volume relationship for the sand used and the dry weight of the material removed from the excavation.

The pore volume of the aquifer materials was determined using the method described in *Methods of Soil Analysis – Part 1 (1982)*. The following equation is used to calculate the pore volume:

$$S_t = (1 - \rho_b / \rho_p)$$

where S_t = total porosity, ρ_p = particle density, and ρ_b = dry bulk density

The weighted average particle density was determined using the method described in *Methods of Soil Analysis – Part 1 (1982)*. The following equation was used:

$$G_{avg} = 1/((R_1 / 100G_1) + (P_1 / 100G_2))$$

where G_{avg} = weighted average particle density, R_1 = % of material >4 mesh sieve size, P_1 = % of material <4 mesh sieve size, G_1 = particle density of material >4 mesh sieve size, G_2 = particle density of material <4 mesh sieve size

The particle density of each size fraction was determined using the following equation, discussed in the above-noted reference:

$$\rho_p = \rho_w(W_s - W_a) / ((W_s - W_a) - (W_{sw} - W_w))$$

where ρ_p = particle density, ρ_w = density of water, W_s = weight of container plus oven dry soil, W_a = weight of container, W_{sw} = weight of container plus soil, W_w = weight of container plus water

Water samples removed from the storage containers for use in the permeameter were taken in a manner to reduce the influence of air on the redox condition of the samples. Ground water samples were removed from the sample containers very slowly and placed in plastic containers that had previously been purged with argon. The containers were filled, maintaining zero head space, subsequent to capping. Following the removal of the ground water sample from the storage container, the head space was purged with argon, and the container was capped and sealed.

Soil materials were removed from the sample buckets and compacted in the argon-conditioned specimen tubes using a hand wand vibrating massager. The densities of the materials were approximately equal to the in-place densities of the materials tested using the sand cone apparatus. However, the compaction of the test columns was done using wet material to prevent the influence of air on the redox status of the samples. As a result, variation in water content between samples could cause the calculated dry densities to differ. However, an attempt was made to take water content into account during sample compaction.

After the samples were removed from the storage containers, the head space of the sample bucket was purged with argon gas to remove any oxygen present. The bulk density of the specimens closely resembled the field densities of in-place materials determined using sand cone density measurements (previously discussed). The samples were compacted in the specimen tubes after purging the tubes with argon gas. During the setup of each permeameter run, the permeameter was purged with argon, and during runs 5 through 8, argon was allowed to bleed into the bubble tube to help reduce the amount of oxygen invading the system. Total porosity of the compacted materials was determined using methods described in *Methods of Soil Analysis—Part 1* (1982). The total porosity was used to determine the pore volume of the specimens.

The attenuation tests were conducted using a constant head permeameter constructed by Trautwein Soil Testing Equipment. The flow rate of solution through the test specimens was approximately 1.6 ft/day (5.65×10^{-4} cm/sec), which is the approximate flow rate in the aquifer as determined by TriHydro Corporation. Flow rates in the constant head permeameter were controlled by varying the head difference across the specimens using the elevation differences between a bubble tube located in the solution reservoir and the outflow from the base of the permeameter. Five permeameter runs were conducted for the contaminated ground water/uncontaminated aquifer material tests, and three runs were conducted for the uncontaminated ground water/contaminated aquifer material tests. Each test consisted of collecting 5 pore volumes of ground water from the specimen. After about 0.5 pore volume of ground water had exited the permeameter, a sample of the effluent water was collected every 15 ml until 2 pore volumes of solution had been collected. A single sample of the effluent was collected following the permeation of the third, fourth, and fifth pore volumes. The samples were tested for pH, EC, and Eh soon after collection. The head space of each sample was purged with argon, and a portion of each sample was acidified and refrigerated for NH_4^{+1} and nitrate (NO_3^{-1}) analysis.

The attenuation tests were conducted using two scenarios. In the first scenario, the uncontaminated aquifer material (MW1) was placed in the sample container using the procedure explained previously. Following compaction, the material was saturated with water from the MW1 ground water sample. The saturated sample was then leached with the contaminated water collected from well MW6. As noted previously, 5 pore volumes of water were collected from the outflow. In the second scenario, the tests were conducted using the same conditions except the contaminated aquifer material (MW6) was leached with the uncontaminated water (MW1).

The analytical work was conducted by an experienced analyst using formal procedures for analytical quality control. The quality control system included: the use of tuning and calibration checks on equipment, duplicate analysis every 10 samples, spiked and blank sample analysis every 10 samples, the use of standard checks, the use of certified standards, limited-access laboratories, and complete documentation of every aspect of the work in notebooks.

RESULTS AND DISCUSSION

Tests – Uncontaminated Aquifer Material and Ammonium Contaminated Ground Water

The pore volume associated with the aquifer was estimated using the particle density calculated in the laboratory and the bulk density determined in the field using sand cone testing equipment. The particle densities for samples MW1 and MW6 were 2.65 g/cm^3 and 2.63 g/cm^3 , respectively. A particle density of 2.65 g/cm^3 and a field bulk density of 2.0 g/cm^3 were used to calculate the pore volume of about 27% that was used to determine the amount of solution needed to flow through the aquifer materials during each run.

A series of five runs were conducted with very similar results from each. In these tests, MW6 water, which contains high levels of NH_4^{+1} , was used as a permeate for the MW1 aquifer material, which was not previously influenced by the NH_4^{+1} contaminated ground water. The data collected during these tests are shown in Figures 1 through 5.

The nitrate levels of solutions exiting the aquifer material were relatively constant at low concentrations throughout the 5 pore volume flow period. Therefore, it appears that very little NH_4^{+1} is converted to NO_3^{-1} during the leaching process. The gradual increase in NH_4^{+1} levels in the effluent as the high NH_4^{+1} ground water is leached through the aquifer material probably results from the diffusion, hydrodynamic dispersion, and soil sorption processes taking place in the system. The cation exchange capacity of the MW1 material is low at about 4 meq/100g of soil. As a result, the aquifer material is able to hold only small amounts of NH_4^{+1} . Therefore, diffusion and dispersion are thought to be the most important contributors to the noted dilution.

The NH_4^{+1} level of the MW6 water was initially 40.7 mg/L, and at the end of the run the MW6 water from the same container had 34.4 mg/L of NH_4^{+1} . The change is suspected to be associated with sorption of NH_4^{+1} to Fe-precipitates or other amorphous materials. Therefore, as the NH_4^{+1} contaminated ground water moves through the uncontaminated zone, a gradual decline in the levels of NH_4^{+1} found in solution would be expected. However, this assumption does not give consideration to the conversion of NH_4^{+1} to NO_3^{-1} due to the nitrification processes that may occur at some point in the ground water system.

An interesting aspect of the chemistry of this system is that the pH and Eh of the effluent from the column are relatively constant throughout the run. The pH ranged from about 8.14 to 7.82, and the Eh varied from about +224 mv to +180 mv. The pH of the inflow appeared to be similar to the pH of the outflow. However, the Eh of the inflow appeared to be poised by the aquifer material to a higher level. For example, the Eh of the inflow for Test 5 was -152 mv and

Figure 1. The Levels of Ammonium and Nitrate in Leachate from MW1 Aquifer Material Leached with MW6 Ground Water for Run 1

Figure 2. The Levels of Ammonium and Nitrate in Leachate from MW1 Aquifer Material Leached with MW6 Ground Water for Run 2

Figure 3. The Levels of Ammonium and Nitrate in Leachate from MW1 Aquifer Material Leached with MW6 Ground Water for Run 3

Figure 4. The Levels of Ammonium and Nitrate in Leachate from MW1 Aquifer Material Leached with MW6 Ground Water for Run 4

Figure 5. The Levels of Ammonium and Nitrate in Leachate from MW1 Aquifer Material Leached with MW6 Ground Water for Run 5

the effluent had Eh values of about +190mv. The Eh values of all the effluent samples from all runs using MW6 water with MW1 aquifer material were comparable at the +224mv to +180 mv levels. This was true even with substantial efforts to keep air from influencing the system.

A possible cause of this phenomenon may be associated with the redox couple $\text{Fe}^{+2} \rightleftharpoons \text{Fe}^{+3} + e^{-1}$, which is thought to be important in this ground water system since with time Fe-oxides precipitate from the contaminated ground water when exposed to air. Fe^{+2} is thought to be in the ground water at rather high levels due to the incorporation of the sugar beet sludge into the aquifer, causing reducing conditions with measured Eh values of about -200mv. As a result, the sludge material undergoes anaerobic decomposition, causing the release of nitrogen in the form of NH_4^{+1} . At the same time, iron compounds present in the sugar beet sludge or resulting from the breakdown of minerals present in the aquifer are becoming soluble as Fe^{+2} .

As stated previously, measured Eh values of the uncontaminated ground water are poised at about +200mv and at a pH near 8. Under these conditions, the Fe^{+2} tends to oxidize, forming Fe^{+3} compounds. In comparison, the oxidation potential of the Fe couple is about -200mv at pH 8 (This will vary, however, depending on the complexity of the system), and the oxidation potential of the NH_4^{+1} couple is +260mv at pH 8. Therefore, the oxidation of Fe^{+2} may tend to promote the reduction of nitrogen. If a considerable amount of Fe^{+2} exists in the system, the tendency may be to maintain nitrogen in the NH_4^{+1} form and to poise the system at a specific Eh

value until the Fe^{+2} becomes oxidized. After Fe^{+2} is depleted from solution, NH_4^{+1} will begin to convert to NO_3^{-1} . However, this system may have much more complexity, as other redox couples are probably involved. The Eh continued to increase with time for the MW6 water stored under argon and at about 4°C . However, several runs were conducted with MW6 water having Eh values of about +150mv without showing any differences in results compared to water with initial Eh values of -150mv. Regardless of the redox condition of the leaching solution, the Eh of the outflow seemed to be poised at about +180 to +200mv. Additional work would have to be done to thoroughly understand the chemistry of this system.

Tests – Ammonium Contaminated Aquifer Material and Uncontaminated Ground Water

The concentrations of NH_4^{+1} and NO_3^{-1} leached from the contaminated aquifer materials (MW6) using MW1 ground water as the leaching solution are shown in Figures 6 through 8. The data shown in Figure 6 indicate that much of the NH_4^{+1} present in the aquifer material was converted to NO_3^{-1} either prior to or during the run. Similar results were obtained for Runs 7 and 8, which were done using a different sample of contaminated material (Figures 7 and 8). The only difference observed between Runs 7 and 8 and the data shown in Figure 6 for Run 6 was that NH_4^{+1} levels were in the range of 5 mg/L, compared to about 1.5 mg/L found in Run 6. The differences found in NH_4^{+1} could be associated with sorption on Fe-compounds. Initially it was thought that the NH_4^{+1} was converted to NO_3^{-1} in the contaminated aquifer materials (MW6) during sample storage or during sample setup. The rapid breakthrough of the NO_3^{-1} in the leachate would definitely support this conclusion. However, a solution sample collected from the original sample of MW6 indicated that the NH_4^{+1} did not convert to NO_3^{-1} during storage but was converted either during the setup of the sample as a result of contamination of air into the system followed by nitrification or during permeation of the uncontaminated aquifer material from the promotion of nitrification by a process operating under the conditions of the system. Additional testing would have to be done to determine how the NO_3^{-1} is formed in this system.

There appears to be a logical means for the conversion of NH_4^{+1} to NO_3^{-1} in the sample core during the leaching process. As discussed previously, if Fe^{+2} is present in the system with NH_4^{+1} , it will oxidize before the oxidation of NH_4^{+1} , preventing or retarding the oxidation of NH_4^{+1} to NO_3^{-1} . However, once the Fe^{+2} has been depleted, the NH_4^{+1} present in the system is allowed to convert to NO_3^{-1} . The depletion of the Fe^{+2} in the system can be caused by oxidation and possibly by dilution resulting from the addition of MW1 ground water, which contains very low levels of Fe^{+2} , to the MW6 aquifer material.

The data presented in Figures 6 through 8 also show that the nitrogen present in the aquifer material is removed as leaching progresses. Initial NH_4^{+1} plus NO_3^{-1} levels of about 20 mg/L are reduced to less than 2 mg/L after 5 pore volumes of leaching. This supports the contention that the aquifer will become less contaminated with time following the removal or elimination of the source of contamination.

Figure 6. The Levels of Ammonium and Nitrate in Leachate from MW6 Aquifer Material Leached with MW1 Ground Water for Run 6

Figure 7. The Levels of Ammonium and Nitrate in Leachate from MW6 Aquifer Material Leached with MW1 Ground Water for Run 7

Figure 8. The Levels of Ammonium and Nitrate in Leachate from MW6 Aquifer Material Leached with MW1 Ground Water for Run 8

CONCLUSIONS

The data collected during the attenuation tests do provide an indication that the attenuation of NH_4^{+1} in the ground water system will occur. In addition, the results show the redox condition of the site and the possible chemical reactions that are influencing the ground water quality.

The tests completed with MW1 aquifer material leached with MW6 ground water show that dilution of NH_4^{+1} does occur at the front of the plume as it moves through the aquifer material (Figures 1 through 5). Apparently, the dilution is primarily a result of diffusion and hydrodynamic dispersion with some retardation due to electrostatic forces. In addition, the mixed system appears to have a redox condition poised at Eh values between +180 and +200mv and pH values of about 7.9. This phenomenon may be caused by the $\text{Fe}^{+2} \rightleftharpoons \text{Fe}^{+3} + e^{-1}$ couple. It is possible that this redox condition occurs at the fringes of the contamination plume.

The system of MW6 aquifer material leached with MW1 ground water used to evaluate removal of NH_4^{+1} from the MW6 aquifer material had a poised redox condition of about +180mv to +200mv. In addition, the relatively high levels of NO_3^{-1} leached from the system could be due to either (1) the inadvertent incorporation of air into the system during sample setup, promoting

nitrification, or (2) the depletion of Fe^{+2} concentrations, allowing nitrification to occur. Additional studies would be required to determine the phenomenon causing the formation of NO_3^{-1} in this system.

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APPENDIX A

TABLES

Table 1. Run 1 (5/4/95) - MW6 Ground Water with MW1 Aquifer Material					
Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1-A	7.94		142	1.64	0.6
1-B	7.94		150	2.73	0.59
1-C	7.97		146	4.01	0.66
2-1	7.85		124	5.05	0.54
2	7.94		146	6.12	0.74
3	7.9		152	8.29	0.51
4	7.89		158	8.78	0.73
5	7.92		164	10.6	0.48
6	7.91		160	12.7	0.53
7	7.89		150	12.9	0.5
8	7.89		164	13.3	0.53
9	7.87		163	15.3	0.48
10	7.86		165	15.3	0.47
11	7.87		160	15.8	0.48
12	7.89		162	17.5	0.52
13	7.85		165	18.5	0.53
14	7.89		165	19.2	0.46
15	7.87		162	21	0.47
16	7.88		163	20.2	0.45
17	7.85		173	19.1	0.9
18	7.87		172	20.9	0.6
3PV	7.84		205	34.2	0.48
4PV	-		-	36.4	0.48
5PV	-		-	37.2	0.6

Table 2. Run 2 (5/95) - MW6 Ground Water with MW1 Aquifer Material					
Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1A	-	-	-	-	0.8
1B	8.02	1.3	224	2.38	0.84
1C	8.04	1.36	194	3.42	0.64
1D	8.07	1.42	194	4.32	0.63
1E	7.99	1.36	4.9	4.9	0.7
1F	8.05	1.58	183	6.14	0.62
2-1	8.14	1.56	187	6.55	0.88
2	8.13	1.51	190	8.32	0.67
3	7.96	1.29	178	8.02	0.56
4	8.03	1.31	184	8.2	0.52
5	8.06	1.31	180	8.76	0.69
6	7.98	1.29	214	9.51	0.55
7	7.98	1.3	214	8.62	0.48
8	7.97	1.36	214	9.2	0.87
9	8.04	1.33	213	9.66	0.41
10	8.05	1.37	204	10.75	0.48
11	7.96	1.3	212	11	0.69
12	7.93	1.28	204	11.9	0.42
13	7.97	1.3	200	10.8	0.31
14	7.95	1.32	214	12.3	0.5
15	8.01	1.34	212	13.4	0.38
16	7.94	1.33	214	7.1	0.69
17	8.01	1.33	213	15.9	0.32
18	7.92	1.38	214	15.5	0.47
PV-3	7.82	1.52	180	31.5	0.72
PV-4	7.84	1.56	207	35.1	0.61
PV-5	7.84	1.56	208	34.3	0.78

Table 3. Run 3 (5/11/95) - MW6 Ground Water with MW1 Aquifer Material					
Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1-A	8.02	1.29	186	1.99	0.51
1-B	7.95	1.31	178	2.38	0.78
1-C	7.84	1.29	182	3.42	0.5
1-D	7.83	1.31	183	4.32	0.53
1-E	7.81	1.33	189	4.9	0.51
1-F	7.85	1.33	188	6.14	0.44
2-1	7.85	1.32	180	6.55	0.5
2	7.89	1.35	189	8.32	0.44
3	7.96	1.33	179	8.02	0.48
4	8	1.35	177	8.2	0.43
5	7.85	1.35	180	8.76	0.43
6	7.87	1.35	184	9.51	0.41
7	7.92	1.36	184	8.62	0.39
8	7.9	1.38	184	9.2	0.31
9	7.95	1.37	186	9.66	0.45
10	7.95	1.37	182	10.75	0.37
11	7.84	1.38	183	11	0.39
12	7.82	1.38	183	11.9	0.38
13	7.88	1.43	180	10.8	0.4
14	7.87	1.4	184	12.3	0.38
15	7.86	1.42	175	13.4	0.38
16	7.83	1.44	178	7.1	0.48
17	7.89	1.41	181	15.9	0.44
PV-3	7.95	1.5	201	31.5	0.41
PV-4	7.77	1.48	199	35.1	0.67
PV-5	7.94	1.5	192	34.3	0.85

Table 4. Run 4 (5/16/95) - MW6 Ground Water with MW1 Aquifer Material					
Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1A	7.95	1.4	210	4.03	0.56
1B	7.89	1.36	207	4.82	0.49
1C	7.88	1.34	207	6.48	0.46
1D	7.84	1.37	201	7.38	0.37
1E	7.87	1.38	193	8.77	0.49
1F	7.85	1.39	193	9.83	0.42
2-1	7.88	1.43	195	11.7	0.4
2	7.95	1.44	195	11.3	0.44
3	7.88	1.37	200	11.9	0.38
4	7.88	1.37	201	11.7	0.49
5	7.86	1.37	202	14.1	0.38
6	7.9	1.41	195	14.1	0.34
7	7.86	1.42	199	15.4	0.42
8	7.89	1.4	195	15.9	0.37
9	7.84	1.42	199	16.7	0.32
10	7.89	1.43	199	17.5	0.35
11	7.9	1.39	204	19.3	0.38
12	7.87	1.41	204	19.2	0.34
13	7.84	1.42	206	18.9	0.4
14	7.82	1.47	206	20.6	0.4
15	7.81	1.4	204	19	0.46
16	7.84	1.45	199	19.9	0.44
17	7.82	1.44	192	19.9	0.4
18	7.83	1.43	195	20.2	0.78
PV-3	7.84	1.54	198	30.6	0.44
PV-4	7.83	1.55	212	34.8	0.33
PV-5	7.79	1.56	215	36.2	0.36
MW6	7.61	1.42	151	39.2	0.41
MW6-Post				39.6	0.59
MW1				<0.2	

Table 5. Run 5 (5/19/95) - MW6 Ground Water with MW1 Aquifer Material					
Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1A	?	1.32	212	1.69	0.88
1B	7.96	1.32	201	2.21	0.63
1C	7.83	1.34	209	3.1	0.87
1D	7.82	1.33	200	4.32	0.91
1E	7.84	1.37	192	5.82	0.89
1F	7.83	1.37	192	6.79	0.83
1G	7.79	1.4	193	7.72	0.78
1H	7.85	1.41	199	8.67	0.86
1I	7.8	1.37	200	9.68	0.88
2-1	7.76	1.39	200	10.3	0.76
2	7.82	1.41	199		0.71
3	7.83	1.37	197	12.3	
4	7.81	1.4	198	11.8	0.63
5	7.79	1.43	200	12.4	0.7
6	7.77	1.4	199	13.6	0.61
7	7.75	1.44	197	12.7	0.86
8	7.75	1.42	194	14.5	0.74
9	7.75	1.48	180	16.2	0.75
10	7.79	1.4	193	15.4	0.59
11	7.71	1.44	187	16.9	0.76
12	7.77	1.42	194	18.1	0.72
13	7.73	1.46	195	18.3	0.55
14	7.72	1.44	197	19.9	0.29
15	7.74	1.47	181	18.6	0.76
16	7.72	1.45	189	19	0.48
17	7.73	1.44	191	20	0.52
18	7.75	1.48	192	19.6	0.51
PV-3	7.62	1.53	198	35.1	0.53
PV-4	7.72	1.5	200	35.2	0.67
PV-5	7.69	1.63	190	36.1	0.48
(fresh water)	7.45	1.66	-151.7		
(within the first 30 minutes the sample turned orange)					
MW6 Pre	7.45	1.66	-151.7	45.2	
MW1-Pre	7.42	1.1	239.5	<0.2	
MW6-Post					0.35
MW1-Post					0.52
Res - Post				45	0.54

Table 6. Run 6 (5/23/95) - MW6 Aquifer Material and MW1 Ground Water					
Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1A	7.95	1.35	172	0.28	15
1B	7.95	1.36	164	0.35	15.4
1C	7.94	1.44	166	0.41	16.7
1D	7.94	1.37	170	0.52	16.3
1E	7.88	1.35	170	0.65	15.7
1F	7.9	1.35	173	0.94	15.1
1G	7.89	1.36	178	1.12	11.9
1H	7.87	1.32	182	1.22	13.4
1I	7.91	1.35	174	1.34	12.5
2-1	7.93	1.28	177	1.35	11.65
2	7.9	1.29	183	1.28	11.7
3	7.9	1.28	175	1.24	10.1
4	7.92	1.27	164	1.35	9.87
5	7.91	1.31	169	1.4	9.52
6	7.95	1.23	174	1.17	8.66
7	7.9	1.22	171	1.33	8.62
8	7.95	1.25	177	1.28	8.34
9	7.9	1.25	179	1.25	8.37
10	7.92	1.22	182	1.07	7.32
11	7.91	1.19	185	1.1	9.28
12	7.92	1.2	186	1.02	6.73
13	7.91	1.23	182	0.88	6.29
14	7.95	1.22	186	0.87	5.8
15	7.91	1.19	186	0.83	5.49
16	7.95	1.19	189	0.84	6.83
17	7.9	1.18	193	0.8	4.85
18	7.92	1.17	190	0.78	5.69
3PV	7.84	1.17	208	<0.2	0.95
4PV	7.71	1.09	217	<0.2	0.55
5PV	7.71	1.13	214	<0.2	0.79
MW1 water	7.53	1.08	229	<0.2	0.12
MW1-Post				<0.2	0.4
MW6 water/sand	7.76	1.55	-96		
MW1 Sample	7.82	1.13	214	<0.2	

Table 7. Run 7 (5/31/95) - MW6 Aquifer Material and MW1 Ground Water

Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1A	7.96	1.28	199	4.98	17.5
1B	7.97	1.25	172	4.66	14.3
1C	7.97	1.25	177	4.63	12.9
1D	7.95	1.24	180	4.69	11.7
1E	7.97	1.26	183	4.52	11.3
1F	7.97	1.24	182	4.62	10.4
1G	7.94	1.25	177	4.65	10.4
1H	7.93	1.22	180	4.55	9.48
1I	7.93	1.33	181	4.12	9.19
2-1	7.95	1.25	181	4.42	9.83
2	7.95	1.27	180	4.57	8.42
3	7.92	1.3	185	4.26	8.76
4	7.91	1.23	183	4.48	7.48
5	7.84	1.2	182	4.31	9.16
6	7.86	1.19	182	4.31	7.02
7	7.85	1.2	177	4.27	8.42
8	7.86	1.19	178	4.14	10.3
9	7.83	1.19	181	4.14	8.92
10	7.85	1.19	182	4.06	7.9
11	7.84	1.17	180	3.96	9.41
12	7.85	1.17	179	3.92	7.89
13	7.81	1.17	180	3.9	6.29
14	7.85	1.17	186	3.73	5.96
15	7.85	1.17	186	3.69	5.86
16	7.85	1.16	186	3.57	5.44
17	7.88	1.15	185	3.41	5.15
18	7.86	1.16	182	3.36	5.53
3PV	7.7	1.11	206	1.09	2.24
4PV	7.77	1.12	215	0.27	0.69
5PV	7.76	1.13	213	<0.2	1.1
MW1-initial	7.57	0.99	198	<0.2	0.23
MW6-initial	7.55	1.39	142	40.3	<0.1
MW1-Post	7.91	1.13	210	<0.2	0.78
Post-Water Below	7.63	1.26	184	7.44	1.65

Table 8. Run 8 (6/7/95) - MW6 Aquifer Material and MW1 Ground Water					
Sample	pH	EC	Eh	NH ₄ ⁺	NO ₃ ⁻
	su	mS/cm	mv	ppm	ppm
1A	7.98	1.24	191	5.14	13.2
1B	7.98	1.2	187	5.18	12.8
1C	7.98	1.2	184	5.07	8.64
1D	7.97	1.18	183	4.95	10.5
1E	7.97	1.18	184	5.07	9.86
1F	7.98	1.19	177	5.03	8.87
1G	7.97	1.18	178	5.09	8.8
1H	7.96	1.17	175	5.01	8.75
1I	7.95	1.16	177	5.01	8.38
2-1	7.95	1.16	178	4.98	8.24
2	7.94	1.16	181	4.96	9.45
3	8.01	1.19	178	4.94	7.36
4	7.99	1.18	178	4.87	7.23
5	7.98	1.22	174	4.78	6.9
6	7.95	1.2	174	4.76	6.6
7	7.95	1.2	178	4.55	6.39
8	7.95	1.19	174	4.4	6.03
9	7.92	1.21	176	4.34	5.67
10	7.94	1.18	174	4.45	8.77
11	7.92	1.18	174	4.34	4.89
12	7.95	1.17	172	4.24	4.47
13	7.94	1.18	176	4.31	4.19
14	7.9	1.14	174	4.11	3.94
15	7.9	1.16	174	4.01	4.61
16	7.94	1.14	133	3.76	3.77
17	7.92	1.15	155	3.94	2.91
18	7.93	1.17	160	3.86	2.7
3PV	7.74	1.1	197	1.29	1.12
4PV	7.8	1.07	210	0.39	0.66
5PV	7.67	-	201	0.2	0.68
MW1	7.62	1.02	207		0.3
MW6	7.75	1.43	182		<0.1