Chapter 8: Groundwater Quality and the Three-dimensional Groundwater and Nutrient Fate and Transport Model

The primary point of concern in the La Pine region is the long-term quality of the drinking water aquifer serving the residents of the sub-basin. As a result, the La Pine Project monitored the groundwater in order to characterize the resource in three ways:

- Background water quality (also described as existing conditions);
- The impacts of onsite wastewater treatment systems;
- The quality of the drinking water well network.

A small monitoring well network surrounds each onsite system monitored during the La Pine Project field test program. These wells consisted of an average of three background and down gradient wells and one well located in or immediately downgradient of the soil absorption unit. The best location for the drainfield wells was estimated given the best available knowledge of groundwater flow direction. As a result, the drainfield wells (identified as "MW Drain" in the statistics tables) occasionally missed the effluent plume or captured conditions at the edge of plume produced by the onsite system. The presence of chloride in groundwater indicates the influence of human wastewater sources, particularly when paired with elevate nitrogen concentrations. Background conditions are characterized by water with less than 1 mg/L TN and less than 2 mg/L chloride [Dunne and Leopold, 1978; Lazaro, 1990].

The data supporting the discussions in this chapter are provided in Appendix C, Table C-18. This dataset includes the field and lab water quality data collected from the shallow monitoring wells installed for the purposes of the field test program. Reference is made below to specific wells within the study area as examples of the point under discussion; an in-depth analysis of each site is not attempted here.

This data in addition to the data collected by the USGS for detailed groundwater investigations supported the development of the three dimensional groundwater and nutrient fate and transport simulation model of the La Pine sub-basin.

Background and/or network monitoring wells

The drinking water resource of the La Pine sub-basin is groundwater that is cold (average 9 ˚C/48˚F), oxygen rich (average dissolved oxygen (DO) = 5.1 mg/L) and shallow (average water table was 13 feet). (Table 8-1) Over all the shallow wells (141) monitored as part of the onsite system field test program that are not located within onsite system drainfields, most appeared to be showing the impacts of residential development in the area with overall average TN concentrations of 4.0 mg/L. The range of TN concentrations measured in the region varied between background levels (0.1 mg/L) and highly impacted (99 mg/L). Sixty percent of the network monitoring wells produced water with average TN concentrations greater than 1 mg/> and 88% produced water with chloride concentrations greater than 2 mg/L.

Background groundwater conditions were identified by wells that had little or no known impacts in the upgradient zone of influence to the well. For example, DEQ well 2052, as illustrated in Figure 8-1, was located far from the site's drainfield along a parallel flow path. The upgradient area, or zone of contribution, for this well consisted of publicly owned forest resource lands supporting second or third growth timber. Typical background conditions, as illustrated by well 2052, include TN concentrations of less than 1 mg/L and less than 2 mg/L chloride. Figure 8-1 also shows a well (DEQ 2054) downgradient of the drainfield monitoring well (DEQ 2045) that produced slightly elevated TN concentrations, which suggests the leading edge of the plume may have reached well 2054. In fact, when the concentrations of TN and chloride are plotted over time for this well (Figure 8-2), the increasing trend is illustrated.

This figure includes a plot of the electrical conductivity (EC) for the well over the same period to illustrate the potential value of this field measurement as a screening tool for water quality samples. The relationship between EC and nitrogen is not entirely reliable because the presence of other dissolved constituents can influence the EC result; however, in the La Pine Project the correlation between TN concentrations and EC is high (r = 0.82) and, therefore, EC field measurement could be used as an easily obtained indication of potential nitrogen impacts to oxic groundwater quality in the La Pine sub-basin.

Table 8-1. Network monitoring well summary statistics.

Mean of means - Network monitoring wells (MW)	BOD_5 (mg/L)	TSS (mg/L)	TN (mg/L)	Total Phosphorus (mg/L)	Total Alkalinity (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	pH	DO (mg/L)	EC (µmhos/cm)	Temp. (C)	Depth to Water Table (ft)
Mean	N/A	11	4.0	0.2	50	12	N/A	N/A	7.0	5.1	190	8.9	13.1
Geometric Mean	N/A	N/A	1.3	N/A	48	6.5	N/A	N/A	7.0	3.3	N/A	8.8	12.0
Median	ND	3.0	1.5	0.2	51	5.9	ND	ND	6.9	6.2	157	8.7	11.9
Standard Deviation	N/A	28	11	0.4	16	20	N/A	N/A	0.3	2.8	147	1.7	5.7
Minimum	ND	ND	0.1	ND	19	0.5	ND	ND	6.4	0.1	50	4.9	4.6
Maximum	39	170	99	3.8	88	139	41	41	8.3	8.3	1141	20	29.9
Count	47	46	141	105	46	141	139	139	141	141	141	141	141
95% Confidence Level	N/A	8.2	1.8	0.08	4.8	3.3	N/A	N/A	0.05	0.5	25	0.3	0.9
99% Confidence Level	N/A	11	2.4	0.10	6.4	4.3	N/A	N/A	0.07	0.6	32	0.4	1.2

Mean of means Network MW -anoxic water	BOD_5 (mg/L)	TSS (mg/L)	TN (mg/L)	Total Phosphorus (mg/L)	Total Alkalinity (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	pH	DO (mg/L)	EC (µmhos/cm)	Temp. (C)	Depth to Water Table (ft)
Mean	N/A	4	3.4	0.3	54	10	N/A	N/A	7.1	0.5	199	8.3	13.0
Geometric Mean	N/A	N/A	0.5	0.3	52	5.0	N/A	N/A	7.1	0.3	170	8.3	12.6
Median	ND	2.0	0.3	0.3	58	5.3	ND	ND	7.1	0.4	169	8.4	12.4
Standard Deviation	N/A	4	14	0.1	14	21	N/A	N/A	0.4	0.3	187	0.8	3.1
Minimum	ND	ND	0.1	0.1	30	0.5	ND	ND	6.5	0.1	67	7.1	5.5
Maximum	2	9	76	0.5	64	114	ND	ND	8.3	1.1	1141	10	19.6
Count	6	5	29	25	5	29	29	29	29	29	29	29	29
95% Confidence Level	N/A	5.2	5.3	0.05	17	7.8	N/A	N/A	0.15	0.1	71	0.3	1.2
99% Confidence Level	N/A	8.7	7.2	0.07	28	11	N/A	N/A	0.21	0.2	96	0.4	1.6

Mean of means Network MW - oxic water	BOD_5 (mg/L)	TSS (mg/L)	TN (mg/L)	Total Phosphorus (mg/L)	Total Alkalinity (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	pH	DO (mg/L)	EC (µmhos/cm)	Temp. (C)	Depth to Water Table (ft)
Mean	1.2	12	4.6	0.2	50	13	N/A	N/A	6.9	6.2	188	9.1	13.2
Geometric Mean	N/A	N/A	2.1	N/A	47	7.0	N/A	N/A	6.9	5.9	162	8.9	11.8
Median	ND	3.0	2.2	0.2	46	7.2	ND	ND	6.9	6.8	156	8.7	11.5
Standard Deviation	6.2	30	11	0.5	17	19	N/A	N/A	0.3	1.8	140	2.0	6.5
Minimum	ND	ND	0.1	ND	19	0.7	ND	ND	6.4	1.4	50	4.9	4.6
Maximum	39	170	99	3.8	88	139	41	41	7.9	8.3	1131	20	29.9
Count	39	39	101	73	39	101	99	99	101	101	101	101	101
95% Confidence Level	2.0	9.7	2.1	0.11	5.5	3.8	N/A	N/A	0.06	0.3	28	0.4	1.3
99% Confidence Level	2.7	13	2.8	0.15	7.3	5.0	N/A	N/A	0.08	0.5	37	0.5	1.7

ND = Non detect; N/A = statistic not calculable

The shallow groundwater in the La Pine sub-basin is typically oxic although a significant proportion (40%) of the network monitoring wells produced water with low DO concentrations for at least a portion of the sampling period. The TN concentrations in the low DO wells is less than 1 mg/L in 75% of the anoxic wells with a corresponding average chloride concentration in that population of wells of 5.4 mg/L (minimum = 0.5 mg/L, maximum = 20 mg/L). The chloride concentrations indicate an impact on the groundwater from wastewater but the low nitrogen concentrations support the findings of the USGS (Hinkle *et al*, 2007) that there is some natural denitrification capacity with the anoxic portions of the aquifer that typically underlie the upper oxic layer near the water table.

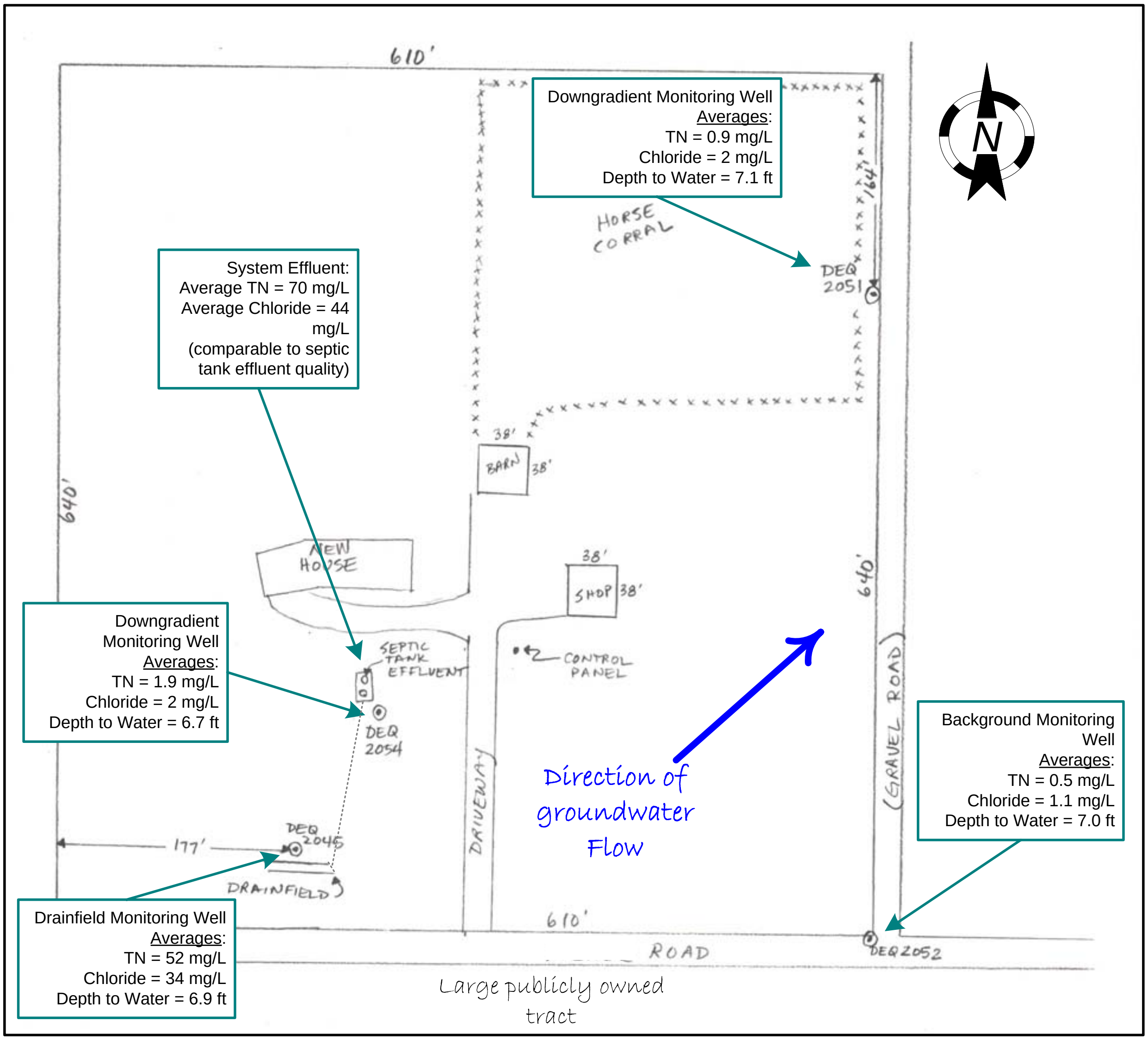

Figure 8-1. Background groundwater quality.

The anoxic groundwater conditions encountered during the field test appeared to be localized and were exhibited in a variety of manners. One well (Table 8-2) changed conditions over time during the sampling period; the remaining network wells on this site were consistently anoxic and the drainfield well DO ranges from 1.1 to 4.3 mg/L without a particular trend. Another field test site had one oxic well and 2 anoxic or suboxic wells with the drainfield well trending from anoxic to oxic. (Figure 8-3) A third example had one anoxic well and three oxic wells (Table 8-3). Therefore, it appears that DO concentrations near the water table can change within a relatively small area and can change in an area over time.

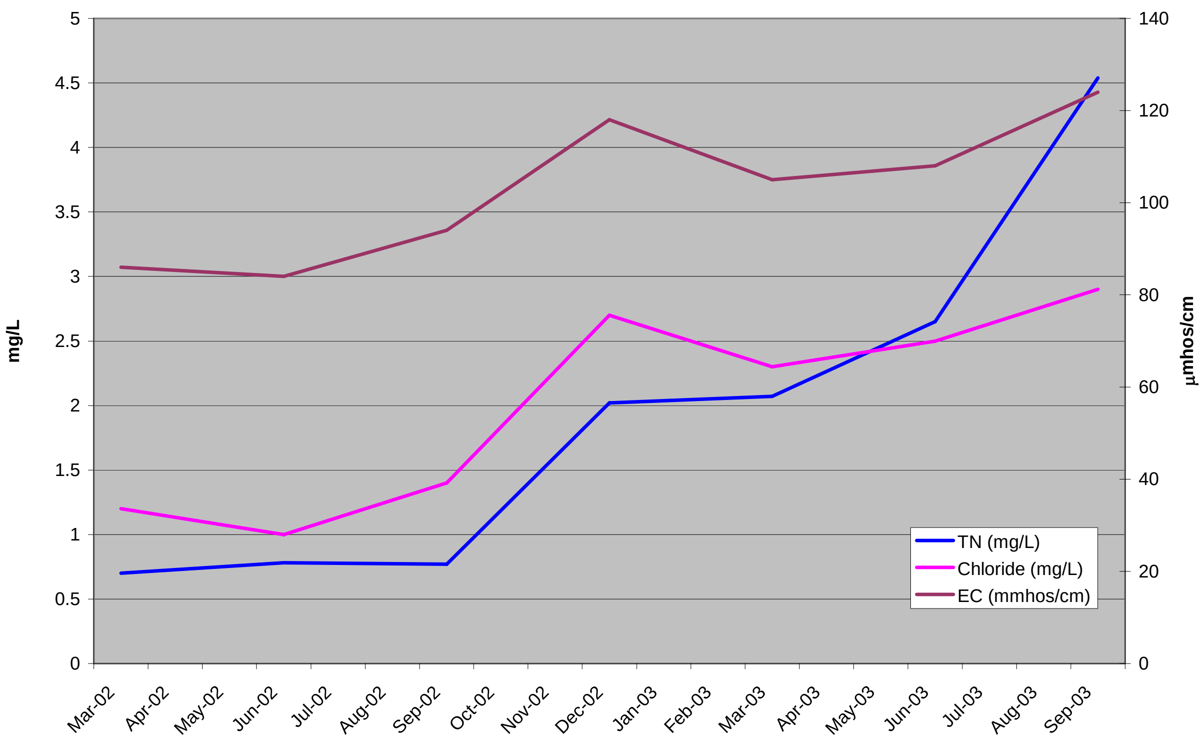

Figure 8-2. TN and chloride concentrations over time in Well 2054.

The other factor which may contribute to the persistence of DO concentrations near the water table is the period of lower than normal precipitation that coincided with the sampling period for the La Pine Project. The USGS (Morgan et al, *in press*) found that only 1-2 inches of the average annual 13 inches per year of precipitation reaches the aquifer. If the recharge rates are lower than the rate at which oxic water moves down through the aquifer and is depleted of oxygen, then it is possible that the oxic portions of the aquifer could thin.

Table 8-2. Changing DO conditions from anoxic to oxic in a monitoring well.

Site ID	Point ID	DEQ Well ID	Sample Date	NH_4 as N (mg/L)	Nitrate-Nitrite as N (mg/L)	TKN (mg/L)	TN (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	Dissolved Oxygen (mg/L)	Depth to Water Table (ft)
51309-N	MW	2093	5/29/01	0.01	1.3			3.5			0.2	7.37
51309-N	MW	2093	2/19/02	0.00	2.6	0.1	2.7	2.7	ND	ND	0.1	12.61
51309-N	MW	2093	5/13/02	0.01	9.6	0.3	9.9	7.7	ND	ND	0.5	12.51
51309-N	MW	2093	8/19/02	0.01	5.9	0.1	6.0	4.6	ND	ND	0.4	12.6
51309-N	MW	2093	11/4/02	0.05	2.8	0.1	2.9	3.0	ND	ND	0.5	12.57
51309-N	MW	2093	2/18/03	0.03	2.5	0.2	2.7	3.4	ND	ND	1.2	12.63
51309-N	MW	2093	5/12/03	0.01	4.3	0.1	4.4	3.8	ND	ND	1.6	13.21
51309-N	MW	2093	8/18/03	0.01	2.1	0.1	2.2	2.9	ND	ND	1.7	12.62
51309-N	MW	2093	11/18/03	0.01	1.6	0.1	1.7	2.6	ND	ND	1.6	12.59
51309-N	MW	2093	12/6/04	0.01	2.3	0.1	2.4	3.6	ND	ND	2.6	12.64

ND = non detect

Other data suggests that the denitrification capacity of the anoxic portions of the aquifer may be limited. The 25% of the anoxic wells with TN concentrations of 1 mg/L or greater included wells with elevated levels of TN and chloride where it appeared the denitrification capacity was limited. Two of the wells, 2183 and 2184, located on the same property, contained TN concentrations that are predominantly TKN. This results in conditions where the nitrogen cannot be reduced to nitrogen gas because there is no oxygen, in the form of NO_3, being carried into the anoxic portion of aquifer for use in microbial metabolic processes. Of the remaining anoxic wells with elevated TN concentrations, however, the nitrogen was predominantly in the NO_3 form. One well in particular, well 2140 (Table 8-4), produced water with average concentrations of nitrogen of 76 mg/L and chloride of 113 mg/L. The DO concentrations in this well ranged from 0.1 mg/L to 2.6 mg/L with an average of 0.7 mg/L. The sampling record included two events where the DO is elevated at 2.5 and 2.6 mg/L. Often this type of high value in an otherwise anoxic record was the result of air introduced to the sample during well pumping. These measurements, however, appear to be actual high concentrations in the aquifer because the sampling team did not report any difficulties with obtaining a sample and the nitrogen concentrations in the nutrient sample increased during these periods, which implies that some denitrification did occur at this location when the groundwater was anoxic. It should be noted that the extremely high TN concentrations in this well were due to the presence of a horse corral with an associated unlined manure storage area. Farm uses in the study area, as evidenced by this site, can significantly impact the aquifer; the proportion of land devoted to farm use in the area, however, is only 1.1% (Tim Berg, Deschutes County Community Development Department, *written communication*) of the study area and nitrogen loading from the much larger area and more numerous sites devoted to residential uses is the dominant source of nitrogen in the sub-basin.

The actual mechanisms driving the appearance of anoxic water near the water table would need to be further investigated to define the spatial and temporal persistence of the anoxic conditions if the denitrification capability of the aquifer were to be exploited for nitrogen attenuation.

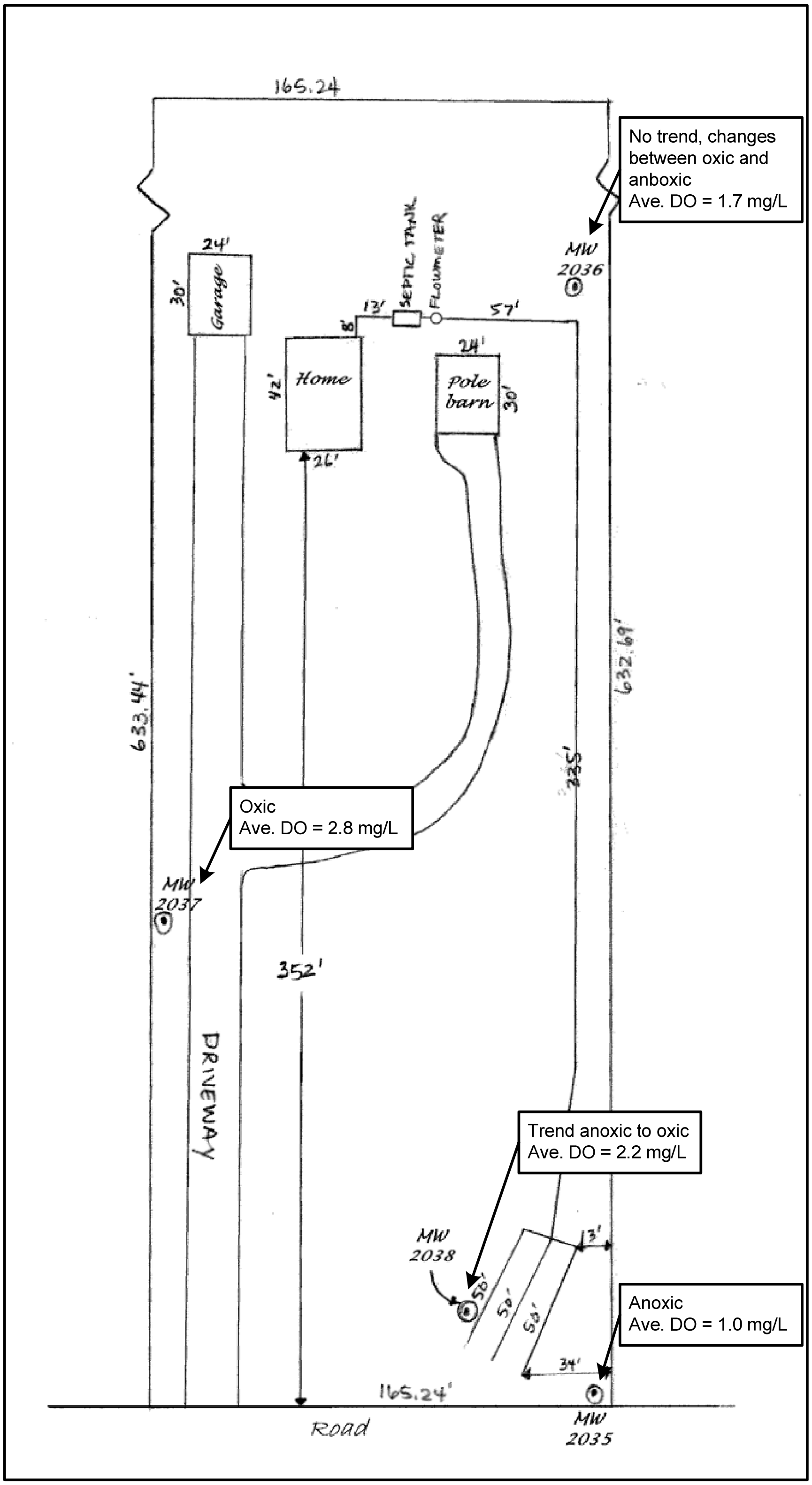

Figure 8-3. Spatial changes in DO concentrations on a site.

Table 8-3. Variable oxic conditions in monitoring wells on a single property.

NiteLess-T MW 2138	TN (mg/L)	Total Phosphorus (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	Dissolved Oxygen (mg/L)	Depth to Water Table (ft)
Mean	25	1.6	139	N/A	N/A	7.5	7.0
Geometric Mean	20	1.6	87	N/A	N/A	7.4	7.0
Median	22	1.6	109	ND	ND	7.4	6.8
Standard Deviation	19	N/A	140	N/A	N/A	1.0	0.5
Minimum	5.8	1.6	20	ND	ND	5.7	6.4
Maximum	57	1.6	400	ND	ND	9.2	7.9
Count	6	1	6	6	6	7	13
95% Confidence Level	20	N/A	147	N/A	N/A	1.0	0.3
99% Confidence Level	31	N/A	230	N/A	N/A	1.5	0.4

NiteLess-T MW 2139	TN (mg/L)	Total Phosphorus (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	Dissolved Oxygen (mg/L)	Depth to Water Table (ft)
Mean	27	0.1	38	N/A	N/A	7.3	6.9
Geometric Mean	26	0.1	37	N/A	N/A	6.7	6.8
Median	28	0.1	37	ND	ND	7.8	6.6
Standard Deviation	7.1	N/A	8.5	N/A	N/A	2.5	0.9
Minimum	14	0.1	29	ND	ND	2.1	6.0
Maximum	36	0.1	57	ND	ND	9.7	8.8
Count	8	1	9	8	8	9	12
95% Confidence Level	5.9	N/A	6.5	N/A	N/A	1.9	0.5
99% Confidence Level	8.8	N/A	9.5	N/A	N/A	2.7	0.8

NiteLess-T MW 2140	TN (mg/L)	Total Phosphorus (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	Dissolved Oxygen (mg/L)	Depth to Water Table (ft)
Mean	76	0.2	114	N/A	N/A	0.7	7.1
Geometric Mean	49	0.2	89	N/A	N/A	0.3	7.1
Median	70	0.2	110	ND	ND	0.3	7.0
Standard Deviation	63	N/A	76	N/A	N/A	1.0	0.6
Minimum	7.4	0.2	23	ND	ND	0.05	6.2
Maximum	209	0.2	280	ND	ND	2.6	8.3
Count	8	1	10	8	8	10	13
95% Confidence Level	53	N/A	55	N/A	N/A	0.7	0.4
99% Confidence Level	78	N/A	79	N/A	N/A	1.0	0.5

NiteLess-T MW Drain	TN (mg/L)	WTS TN (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	Dissolved Oxygen (mg/L)	Depth to Water Table (ft)
Mean	41	63	28	N/A	N/A	6.8	6.5
Geometric Mean	40	62	27	N/A	N/A	6.7	6.4
Median	40	61	27	ND	ND	7.0	6.4
Standard Deviation	7.4	16	3.5	N/A	N/A	1.2	0.7
Minimum	29	47	23	ND	ND	4.5	5.2
Maximum	61	120	34	ND	ND	9.4	7.9
Count	20	23	20	20	20	22	21
95% Confidence Level	3.4	7.0	1.6	N/A	N/A	0.5	0.3
99% Confidence Level	4.7	9.5	2.2	N/A	N/A	0.7	0.4

ND = non detect   N/A = statistic not calculable   WTS = wastewater treatment system

Table 8-4. Well 2140 concentrations over time.

Sample Date	NH_4 as N (mg/L)	Nitrate-Nitrite as N (mg/L)	TKN (mg/L)	TN (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	pH	Dissolved Oxygen (mg/L)	EC (umhos/ cm)	Temp. (C)	Depth to Water Table (ft)
9/27/01	0.04	27			70			6.6	0.05	768	10.2	7.7
2/26/02	0.05	207	1.5	209	280	ND	ND	6.4	2.6	2445	7.0	6.6
5/22/02	0.04	7.1	0.3	7.4	23	ND	ND	6.8	0.3	390	7.2	6.2
8/26/02	0.09	88	1.6	89	160	ND	ND	6.5	0.1	1476	10.3	7.0
11/12/02	0.08	94	1.3	96	160	ND	ND	6.5	2.5	1422	9.8	8.3
2/25/03	0.08	68	0.1	68	100	ND	ND	6.7	0.3	1168	6.8	6.9
5/19/03	0.04	8.1	0.1	8.2	24	ND	ND	6.7	0.5	406	7.4	6.6
8/27/03	0.09	72	1.4	73	130	ND	ND	6.6	0.1	1353	9.5	7.2
11/5/03	0.04	59	0.1	60	120	ND	ND	6.6	0.2	1217	9.9	8.1

ND = Non detect

Drainfield Monitoring wells

The sampling team monitored the drainfield wells on the same schedule as the onsite system in order to pair the final discharge samples with drainfield well data. These wells were also monitored each quarter at the same time as the surrounding network wells. This approach caused the drainfield monitoring wells to be the most intensively monitored locations in the field test program because the onsite system and network well monitoring events were on different schedules (monthly/bimonthly vs. quarterly).

The performance statistics for each drainfield monitoring well are provided in Appendix C. The statistics provided in the tables include the TN concentrations measured directly from the samples and the TN concentrations discharged by the onsite wastewater treatment system discharging to the related drainfield. The tables are numbered for reference during the following discussion. Each well will not be discussed in detail, rather, particular wells will be identified as examples of specific discussion points.

Table 8-5 contains the overall statistics representing the average water quality underlying the drainfields in the field test. The statistics were generated by producing the mean values for individual wells and then averaging the means. In general, the BOD_5 concentrations recorded for these wells are very low. The higher TSS concentrations typically indicated well development and/or the difficulty obtaining samples from very deep wells using a peristaltic pump. For example, the highest concentrations reported for TSS samples primarily came from one well that produced an average value of 146 mg/L. The average water table depth for this monitoring well was 29 feet, which is essentially the maximum depth from which a peristaltic pump can elevate water at the altitude of the La Pine study area. As a result, the flow from these deeper wells was erratic and disturbed the sediments surrounding the well screens. The number of non-detects for BOD_5 concentrations and the difficulties associated with obtaining representative TSS samples suggest that these parameters could be omitted from a sampling plan for groundwater monitoring wells. As a result, the La Pine project eliminated BOD_5 and TSS sampling from the network monitoring wells and took these parameters only from the drainfield wells. The data, even from the drainfield wells, suggests that these parameters may be of limited utility in groundwater investigations because the data obtained from 47 wells produced non-detects for BOD_5 on average with one well producing the highest value (BOD_5 = 26 mg/L) during well purging; this well produced the highest individual average concentration of 1.8 mg/L. The TSS data, while producing higher overall average concentrations, is largely suspect because of the low mean and median values, which indicate that the mean is skewed by high concentrations which tended to come from the deepest wells.

Two wells produced individual positive results for fecal coliform and E. coli bacteria but these results were not duplicated at later sampling events. During the project nearly 1,080 samples from 48 drainfield wells were analyzed for bacteria in the La Pine Project and the positive results comprised only 0.2 % of the total. Given that it was not clear whether the positive counts indicated actual bacteria contamination in the aquifer or if they were a result of contamination introduced during sampling it appears that, overall, the vertical separation between the point at which effluent is dispersed into the environment and the water table provides significant protection from bacterial contamination.

The field parameters indicated some differences between the drainfield wells and the network wells. Particularly, the conductivity measurements were significantly higher (99% confidence level) on average than the network monitoring wells, which could be related to the higher average chloride and total nitrogen values found in the drainfield monitoring wells. The depth to water table appeared to be less in the drainfield monitoring wells than the network wells on average and the average water table elevation (mean elevation = 4195.2 feet above mean sea level) is higher for the drainfield monitoring wells than the network wells (95% confidence level); however, confirmation of any potential groundwater mounding inferred by this difference would require site by site analyses of water table gradients.

The average TN concentrations from drainfield monitoring wells were significantly higher (99% confidence level) than that produced from the network monitoring wells. The difference between the mean TN and chloride concentrations suggests the presence of anoxic water in some of the drainfield wells. Indeed, Table C-2, AX20-M, and Table C-8, IDEA-H, (Appendix C) provide examples of drainfield monitoring wells tapping anoxic water. The anoxic water present in these and other locations may have facilitated denitrification that caused the mean concentrations of TN to decline in comparison to mean chloride concentrations. When the anoxic well data is removed from the statistics, average TN concentrations increase (Table 8-6).

The drainfield wells did not consistently illustrate the effects of the onsite system on the aquifer because of difficulties experienced in placing the well in the effluent plume. For example, the wells monitoring the bottomless sand filters, Systems-H3 and –B, were located in the upgradient end of the sand filter. The third bottomless sand filter's monitoring well was placed in the downgradient end of the sand filter and showed impacts that correlated better with the effluent quality discharged from the sand filter. (Appendix C, Table C-4) Due to the placement of several drainfield wells, the statistics reported in Tables 8-5 and 8-6 may not accurately represent the conditions at the water table below drainfields.

Several drainfield monitoring wells illustrated the adverse impacts that conventional onsite wastewater treatment systems have on the aquifer. For example, the bottomless sand filter mentioned above, (Appendix C, Table C-4, System-A) discharged 81 mg/L on average and the well monitoring the top of the aquifer below the sand filter (depth to water table averaged 15.7 feet) discharged water with average TN concentrations of 50 mg/L. At another site, the septic tank serving a standard system discharged 56 mg/L TN on average (Appendix C, Table C-17, System-PE) and the well monitoring the top of the aquifer underlying the drainfield discharged water with average TN concentrations of 36 mg/L.

State rules specified, at the time of the La Pine Project and under current regulations, that a failing system is "any system that discharges untreated or incompletely treated sewage or septic tank effluent directly or indirectly onto the ground surface or into public waters." The definition of public waters includes "lakes, bays, ponds, … and all other bodies of surface or underground waters, natural or artificial… which are wholly or partially within or bordering the state or within its jurisdiction." Treatment is defined as "the alteration of the quality of wastewaters by physical, chemical, or biological means or combination thereof such that tendency of said wastes to cause degradation in water quality, risk to public health or degradation of environmental conditions is reduced." "Pollution" or "Water Pollution" means any alteration of the physical, chemical, or biological properties of any waters of the state, or any discharge of any liquid … or other substance into any waters of the state that … threatens to create a public nuisance or render such waters harmful, detrimental, or injurious to public health safety, or welfare or to domestic, commercial, industrial, agricultural, recreational or other legitimate beneficial uses or to livestock, wildlife, fish, or other aquatic life or the habitat thereof." The La Pine Project demonstrated, by monitoring onsite systems and the groundwater below the soil absorption units, that onsite wastewater treatment systems degraded water quality by discharging nitrogen and other wastewater constituents to the groundwater environment. The degradation of water quality by onsite system discharges implies that the wastewater was incompletely treated and, therefore, onsite systems failed and caused water pollution even when constructed according to prescriptive standard. Research results reported by Weyer, et al (2001) indicate that public health is threatened by chronic exposure to low levels of nitrate (> 2.5 mg/L) in drinking water.

Table 8-5. Overall water quality statistics for drainfield monitoring wells.

Mean of means MW Drain	BOD_5 (mg/L)	TSS (mg/L)	TN (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	pH	Dissolved Oxygen (mg/L)	EC (umhos/cm)	Temp. (C)	Depth to Water Table (ft)
Mean	N/A	6.6	9.2	17	33	47	6.9	5.3	261	8.8	12.6
Geometric Mean	N/A	2.9	3.6	12	N/A	N/A	6.9	3.7	230	8.8	11.6
Median	ND	2.8	4.2	11	ND	ND	6.9	6.4	228	8.6	11.1
Standard Deviation	N/A	21	13	15	N/A	N/A	0.3	2.6	138	1.0	5.6
Minimum	ND	0.4	0.1	0.7	ND	ND	6.5	0.1	94	7.3	4.9
Maximum	1.8	146	52	72	1500	2190	8.1	8.5	651	12.0	29.0
Count	47	47	48	48	48	48	48	48	48	48	48
95% Confidence Level	N/A	6.2	3.8	4.3	N/A	N/A	0.08	0.8	40	0.3	1.6
99% Confidence Level	N/A	8.2	5.0	5.8	N/A	N/A	0.11	1.0	54	0.4	2.2

ND = non detect N/A = statistic not calculable

Table 8-6. Water quality statistics for drainfield monitoring wells located in the oxic portion of the aquifer.

Mean of means MW Drain- oxic water	BOD_5 (mg/L)	TSS (mg/L)	TN (mg/L)	Chloride (mg/L)	Fecal Coliform	E. coli	pH	Dissolved Oxygen (mg/L)	EC (umhos/cm)	Temp. (C)	Depth to Water Table (ft)
Mean	N/A	7.7	11	19	N/A	N/A	6.9	6.2	273	8.9	12.8
Geometric Mean	N/A	3.3	5.9	14	N/A	N/A	6.9	6.0	240	8.9	11.7
Median	ND	3.0	6.7	16	ND	ND	6.9	6.7	247	8.8	10.9
Standard Deviation	N/A	23	14	16	N/A	N/A	0.2	1.6	146	1.1	6.0
Minimum	ND	0.4	0.5	2.0	ND	ND	6.5	2.1	106	7.5	6.2
Maximum	1.8	146	52	72	ND	ND	7.3	8.5	651	12.0	29.0
Count	38	38	39	39	39	39	39	39	39	39	39
95% Confidence Level	N/A	7.6	4.4	5.1	N/A	N/A	0.06	0.5	47	0.3	1.9
99% Confidence Level	N/A	10	5.9	6.8	N/A	N/A	0.09	0.7	63	0.5	2.6

ND = non detect N/A = statistic not calculable

Drinking water wells

The La Pine Project team completed four synoptic sampling events at the beginning of the project between 1999 and 2001. These synoptic, or snapshot, events focused on private drinking water wells to define drinking water quality of the region and to identify any developing areas of concern. An early hypothesis of the project was a relatively rapid travel time of groundwater through the aquifer and therefore a rapid change in the groundwater quality due to wastewater discharges. Based on this hypothesis, the Project team scheduled all the synoptic sampling events at the beginning of the project. Once the USGS completed a portion of the groundwater investigation, particularly the part dealing with chlorofluorocarbon sampling for age dating, the findings indicated that the water is moving more slowly than expected. The study found that, while recharge could move rapidly through the unsaturated soils above the water table, groundwater velocities are slow because of the small percentage of the annual recharge that reaches the aquifer. Given this information, scheduling the drinking water well sampling throughout the study may have had greater utility in illustrating the changes in the aquifer quality over the project period. However, the data was essential to the timely development of the 3-D model and, given the groundwater velocities found by the USGS investigations and the ages found in the aquifer, the period for repeating the synoptic events is on the order of 7 to 10 years, which is a longer period than planned for the La Pine Project.

Another source of data available for characterizing the drinking water quality was the results from samples taken during real estate transactions. This dataset was large (1,466 reported results between 1989 and 2003); however, the results could not be incorporated into the 3-D model because of the lack of any quality assurance or control on how and where the samples were taken. This data (summarized in Figure 8-4) indicated that there have been a significant number of samples (18%) taken at the time of sale that contained elevated levels of nitrate. Of these, 17% represent concentrations between 3 and 9.9 mg/L. Some of these represent properties that were sampled repeatedly because of the high property turnover rate in the area.

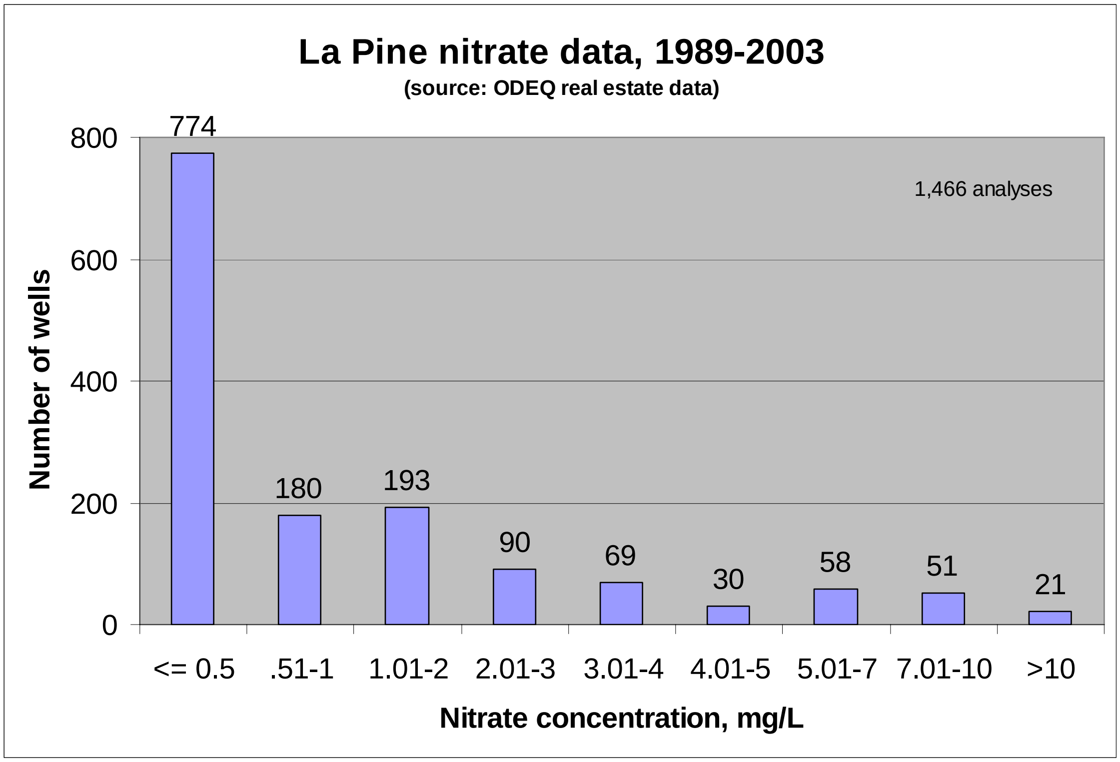

Figure 8-4. La Pine area nitrate data from real estate transactions, 1989-2003.

The data collected during the synoptic events indicated that the quality of the region's drinking water supply was good on average (Table 8-7). In October 1999, about 90% of the wells discharged water with less than 2 mg/L of nitrogen in any form. Ten percent of the wells discharged water with elevated ammonium levels, which in conjunction with a deep well depth and anoxic water, indicates that the water was drawn for a portion of the aquifer with buried organic material. Data from the synoptic events in 2000 and 2001 indicated that a large proportion of the wells were screened in the anoxic portion of the aquifer; the synoptic events in the fall of 2000 and the spring of 2001 had smaller proportions of the wells located in the anoxic part of the aquifer in order to devote more effort to characterizing the oxic, and nitrate vulnerable portion.

Nine percent of the samples in the drinking wells sampled in October 1999 showed elevated nitrate concentrations. This proportion changed to 12% for the two synoptic sampling events completed in 2000 and to 15% in the 2001 synoptic. The elevated concentrations occurred primarily in the 3.0 – 9.9 mg/L range, which is less than the 10 mg/L maximum contaminant level for drinking water. However this level of contamination warrants investigation because of the increase in nitrate concentrations predicted for the region and because research has indicated a correlation between chronic ingestion of nitrate concentrations as low as 2.5 mg/L and certain types of cancer. [Weyer et al, 2001]

Table 8-7. Summary of synoptic drinking water well sampling, 1999-2001.

October 1999	Ammonia	TKN	Nitrate	Chloride	Percent	Ammonia	TKN	Nitrate	Chloride
ND	64	82	46	3	ND	48%	62%	34%	2%
ND-0.9	45	26	65	27	ND-0.9	34%	20%	48%	20%
1.0-2.9	10	9	12	71	1.0-2.9	8%	7%	9%	53%
3.0-4.9	5	8	5	13	3.0-4.9	4%	6%	4%	10%
5.0-6.9	1	2	2	7	5.0-6.9	1%	2%	1%	5%
7.0-9.9	0	0	4	5	7.0-9.9	0%	0%	3%	4%
10.0-14.9	3	3	1	4	10.0-14.9	2%	2%	1%	3%
15.0-19.9	1	1	0	3	15.0-19.9	1%	1%	0%	2%
>20.0	3	2	0	0	>20.0	2%	2%	0%	0%
Totals	132	133	135	133					

June 2000	Ammonia	TKN	Nitrate	Chloride	Percent	Ammonia	TKN	Nitrate	Chloride	DO	#	%
ND	65	129	62		ND	34%	67%	32%	0%	0.0-1.5	88	47%
ND-0.9	95	30	88	43	ND-0.9	49%	16%	46%	23%	1.6-2.0	6	3%
1.0-2.9	10	10	23	90	1.0-2.9	5%	5%	12%	47%	>2.0	94	50%
3.0-4.9	9	10	9	25	3.0-4.9	5%	5%	5%	13%	total	188	
5.0-6.9	2	2	3	9	5.0-6.9	1%	1%	2%	5%			
7.0-9.9	3	3	5	12	7.0-9.9	2%	2%	3%	6%			
10.0-14.9	6	5	0	6	10.0-14.9	3%	3%	0%	3%			
15.0-19.9	0	1	1	3	15.0-19.9	0%	1%	1%	2%			
>20.0	2	2	1	3	>20.0	1%	1%	1%	2%			
Totals	192	192	192	191								

October 2000	Ammonia	TKN	Nitrate	Chloride	Percent	Ammonia	TKN	Nitrate	Chloride	DO	#	%
ND	49	71	17	0	ND	49%	80%	17%	0%	0.0-1.5	36	36%
ND-0.9	43	10	55	25	ND-0.9	43%	11%	55%	26%	1.6-2.0	3	3%
1.0-2.9	2	3	16	42	1.0-2.9	2%	3%	16%	43%	>2.0	62	61%
3.0-4.9	2	3	5	8	3.0-4.9	2%	3%	5%	8%	total	101	
5.0-6.9	1	0	2	6	5.0-6.9	1%	0%	2%	6%			
7.0-9.9	1	1	4	5	7.0-9.9	1%	1%	4%	5%			
10.0-14.9	0	0	0	6	10.0-14.9	0%	0%	0%	6%			
15.0-19.9	0	0	0	3	15.0-19.9	0%	0%	0%	3%			
>20.0	2	1	1	1	>20.0	2%	1%	1%	1%			
Totals	100	89	100	96								

June 2001	Ammonia	TKN	Nitrate	Chloride	Percent	Ammonia	TKN	Nitrate	Chloride	DO	#	%
ND	57	102	24	1	ND	46%	82%	19%	1%	0.0-1.5	43	34%
ND-0.9	59	15	59	26	ND-0.9	48%	12%	47%	21%	1.6-2.0	6	5%
1.0-2.9	2	2	23	53	1.0-2.9	2%	2%	18%	43%	>2.0	76	61%
3.0-4.9	3	3	8	10	3.0-4.9	2%	2%	6%	8%	total	125	
5.0-6.9	0	0	3	6	5.0-6.9	0%	0%	2%	5%			
7.0-9.9	2	2	6	12	7.0-9.9	2%	2%	5%	10%			
10.0-14.9	0		1	9	10.0-14.9	0%	0%	1%	7%			
15.0-19.9	0	0	0	4	15.0-19.9	0%	0%	0%	3%			
>20.0	1	1	1	3	>20.0	1%	1%	1%	2%			
Totals	124	125	125	123								

ND = Non detect

USGS Groundwater Investigations and the Three-Dimensional Groundwater and Nutrient Fate and Transport Model

The USGS was an integral partner during the entire La Pine Project. The work undertaken and completed is documented in a series of reports published under separate cover and includes the geochemical investigations, groundwater study and the 3-D model. The abstracts for these reports follow:

Aquifer-scale controls on the distribution of nitrate and ammonium in ground water near La Pine, Oregon

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A shallow, sandy sole-source aquifer receives septic tank effluent from most residents in the vicinity of La Pine, Oregon. High concentrations of NO_3^- (>10 mg NO_3^--N/L) have been observed in study area ground water since the early 1980s. Thus, a framework for understanding NO_3^- dynamics, and a conceptual model in support of a numerical NO_3^- transport model, are needed. Geochemical and hydrologic data were collected at multiple scales to develop an aquifer scale (640 km^2 area, 37-m thickness) understanding of NO_3^- source, transport, and fate. A network of 193 existing (primarily domestic) wells, transects of monitoring wells installed along ground-water flowpaths, an array of direct-push wells installed perpendicular to one of the transects, and three wells installed in plumes of septic tank effluent were sampled and analyzed for major ions, nutrients, dissolved organic carbon, field parameters, dissolved gases, isotopes of water and nitrogen, and age-dating tracers (CFCs, ^3H, $^3H/^3He$). Nitrogen isotopes, N/Cl^- relationships, age gradients, and hydraulic data indicate that septic tank effluent is the predominant source of NO_3^- in the aquifer. Most NO_3^- currently resides in shallow plumes near the water table, due to low recharge rates and low hydraulic gradients that limit advection. High concentrations of NH_4^+ (>10 mg NH_4^+-N/L) were observed in deep ground water that, for the most part, resides beneath the primary aquifer. Nitrogen isotopes, N/Cl^- and N/C relationships, ^3H data, and hydraulic data are consistent with a natural, sedimentary organic matter source for most NH_4^+, and contraindicate an origin from septic tanks. Relationships between NO_3^-, Cl^-, and geochemical indicators of redox conditions, and relationships between concentrations and isotopes of N_2, indicate that denitrification is extensive in the study area. Denitrification occurs near the boundary between oxic and suboxic portions of the aquifer. Laboratory denitrification experiments with aquifer sediments demonstrate a denitrification capacity in sediments currently exposed to NO_3^-, and also demonstrate denitrification capacity in sediments collected from what is currently NO_3^--free ground water. Our data were used to develop a framework and conceptual model for a NO_3^- transport model. Septic tank effluent is the dominant NO_3^- source. Census data were combined with study area septic tank effluent data to estimate NO_3^- loading. Concentration data from the direct-push array allowed estimation of dispersion. Advection of NO_3^- occurs until NO_3^- reaches the oxic/suboxic boundary, at which point denitrification converts NO_3^- to N_2. To account for aquifer-scale denitrification in the La Pine aquifer, a redox-boundary approach that implicitly captures spatial variability in the distribution of electron donors is proposed. An early version of these results were presented at the American Geophysical Union Meeting as Hinkle, S.R., Böhlke, J.K., Duff, J.H., Morgan, D.S., Weick, R.J., 2002, Nitrate source, transport and fate in ground water near La Pine, Oregon [abs.], Eos, Transactions of the American Geophysical Union, v. 83, fall meeting supplement. (Hinkle et al, 2007)

Evaluation of approaches for managing nitrate loading from on-site wastewater systems near La Pine, Oregon

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The central Oregon community of La Pine is a rapidly growing rural-residential area without centralized wastewater disposal or drinking water systems. Most homes rely on individual septic systems for wastewater disposal and wells for water supply. Wells are typically shallow (less than 50 feet) to tap permeable sands and gravels and to avoid more mineralized ground water found in deeper aquifers. The water table is also shallow (less than 10 feet) and thin volcanic soils provide little opportunity for removal of nitrogen before septic effluent recharges the aquifer. Centralized sewer or water systems have been determined to be economically infeasible in the area and, with a large number of lots still available, planners and regulators are concerned that future growth will render the ground-water resource unusable.

The purpose of the U.S. Geological Survey (USGS) investigation was to evaluate existing water quality conditions and to develop an understanding of ground-water flow and geochemical dynamics that would provide a framework for a numerical simulation model that could be used to evaluate the effects of alternative land-use and wastewater management strategies on ground-water quality.

An important finding of this investigation is that ground-water velocities are low and much of the nitrate in the aquifer is concentrated near the water table. Ground water flows downward and toward the rivers that drain the area, however, nitrate has not moved very far either laterally or vertically since development began in the 1960s. This finding has helped the public and regulators understand why, at present, relatively few wells have nitrate concentrations above the drinking water standard of 10 mg/L. Simulations using a ground-water flow and nitrate transport model show, however, that even if nitrogen loading to the aquifer remained at present levels, peak nitrate concentrations in the aquifer would not occur for 30 years. Simulations show that doubling of nitrate loading, as is forecast to occur at buildout in 2020, will result in nitrate concentrations above the drinking water standard over large areas.

Deschutes County is pursuing two primary options to manage ground-water quality in the area: reduction of housing density and reduction of nitrate loading using innovative septic-system technology. Innovative septic systems have been field tested in the La Pine area as part of the National Demonstration Project (NDP). The USGS simulation model was used to predict the effects of implementing these options and showed that innovative septic systems could effectively reduce nitrate loading and improve ground-water quality. As a result of the study, the Oregon Department of Environmental Quality has revised rules regarding septic systems to allow the use of the innovative systems in Oregon. These results will also have national implications as more rural communities face the issue of ground-water quality protection under the pressures of population growth.

The simulation model developed under the NDP was enhanced by adding optimization capability. This work was funded jointly by the USGS and Deschutes County under a grant from the National Decentralized Wastewater Capacity Development Project. The objective of this project was to develop and demonstrate a method to estimate the optimal loading of nitrate from decentralized wastewater treatment systems to an aquifer. The method utilizes a simulation-optimization approach in which a nitrate fate and transport simulation model is linked to an optimization model. Using this method, maximum (optimal) sustainable loading rates that meet constraints on ground-water quality and nitrate loading to streams via ground-water discharge can be determined. This method enhances the value of a simulation model as a decision-support tool in developing performance-based standards for on-site systems that will protect the quality of ground-water resources.

The La Pine nitrate loading management model (NLMM) was developed by linking the La Pine simulation model to an optimization model using the response-matrix technique. The NLMM was used to determine the minimum nitrate loading reductions that would be required in 97 management areas to meet specified water-quality constraints. Constraints can be set on ground-water nitrate concentration, discharge of nitrate to streams, and maximum or minimum loading reductions in management areas. Minimum loading reductions are determined for existing and future on-site systems. Cost factors can be applied to the optimization if the cost of reducing loading favors reductions for existing or future homes. The NLMM was used to perform trade-off analyses on the cost in terms of increased loading reductions required to meet more stringent water quality criteria.

The USGS Scientific Investigations Report describes the hydrogeologic framework of the La Pine aquifer system and documents the development and use of the NLMM and underlying simulation model. The potential uses of the NLMM in long-term resource management planning processes for La Pine, Oregon, as well as considerations for application of the optimization method to other areas are also described. (Morgan, et al, 2007)

Conclusion

The aquifer underlying the La Pine sub-basin is a high quality water resource threatened by the effects of development, particularly the installation of conventional onsite wastewater treatment systems. The drinking water well network currently produces water that meets drinking water standards; however, some wells are showing indications of nitrate contamination. The shallow monitoring well networks installed for the onsite system field test program indicate that nitrate contamination of the aquifer is more prevalent near the water table. Additionally, the drainfield monitoring wells illustrate the significant impacts that conventional onsite systems have on the aquifer. In the rapidly draining soils of the La Pine sub-basin, the conventional onsite systems prescribed in rule are not protecting the drinking water resource of the region.

Predictions of future impacts to the aquifer, as produced by the USGS three-dimensional nutrient fate and transport model, indicate that the quality of the aquifer will continue to decline with increased development using conventional onsite wastewater systems. The model also predicts that the use of innovative onsite technologies to reduce the nitrogen content of residential wastewater can be effective. The resource protection professionals of the region have the opportunity to define the desired outcome for the groundwater resource and use the optimization model developed subsequent to the 3-model to develop the management approaches necessary to meet the goal.

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