
Kansas Geological Survey

Nitrate Contamination of Groundwater in the Vicinity of Haven, Kansas

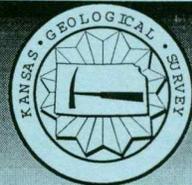
by

Margaret Townsend

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OPEN-FILE REPORT 97-79**

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Open File Report #97-79

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Nitrate Contamination of Groundwater in the Vicinity of Haven, Kansas

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Introduction

The city of Haven, Reno County, Kansas, contracted with the Kansas Geological Survey to identify potential sources of nitrate contamination in the wells that supply city water. One well had not been used for some time because of repeated high nitrate values. Another well had begun showing high nitrate-N values occasionally. The other two wells had nitrate values below the drinking water limit of 10 ppm but above the background level of 3 ppm. One of the wells is of low capacity and is unable to effectively meet the needs of the city.

In general a nitrate-N level in groundwater of greater than 3 ppm indicates an anthropogenic source such as fertilizer, septic tank waste, feedlot waste, or industrial waste (Madison and Brunet, 1985). Below this number the source of nitrate-N is considered to be a natural source such as soil organic matter. The national drinking water limit for nitrate-N set by the U. S. Environmental Protection Agency is 10 ppm. Values above this number are considered unsafe for drinking by infants or young livestock because of the potential for methoglobonemia (“blue baby syndrome”) to occur.

Some sources of nitrate (fertilizer and animal waste) are easily identified by using the natural concentration of nitrogen-15 isotope in measured nitrate. This method has been used successfully for over 20 years to identify both point and nonpoint sources of nitrate contamination.

Objectives of Study

The objectives of this study were: 1) identify areas of high and low nitrate-N concentration within and around the city of Haven in order to provide an indication of areas for future water development ; and 2) identify sources of nitrate using the nitrogen-15 isotope method and evaluation of general water chemistry.

Methods

Sampling of a total of 35 wells in and near the city of Haven was performed on June 25, 1997 and August 3-5, 1997. All sites were sampled for nitrate, 17 samples were collected for complete chemical analyses¹, and 26 samples analyzed for the nitrogen-15 isotope. Techniques used for sample preservation and analysis are presented in Appendix B.

Sites for water sampling were selected based on two criteria: 1) availability of stratigraphic well logs in the KGS data-library, and 2) necessity of sampling wells within the vicinity of Haven to determine the distribution of nitrate in and around the city. A few wells were sampled even though well log information was not available.

Sample collection points were selected to avoid pressure tanks and chemical treatment systems. In order to assure that the sampled water was representative of the aquifer and not the well bore or pressure tank, water samples were collected after several readings of specific conductance and temperature were constant. Results from all analyses were sent to well owners and to the City Administrator of the City of Haven.

Background

Haven, KS is located in Reno County (T25S-R4W-Sec 5) which is part of the Great Bend Prairie physiographic province (fig. 1). Soils in the area are predominantly of the Vanoss-Bethany association (NRCS, 1966). The Vanoss silt-loam series dominates with the Bethany series (silt-loam with more clay) occurring sporadically throughout the study area. The Vanoss series is a deep, well-drained, dark colored Reddish Prairie soil that occurs on the uplands and high stream terraces along the Arkansas River. The Bethany series is a deep, silt-loam, which occurs in the upland areas. The area around Haven is within 3 miles of the Arkansas River and is situated primarily on terrace material deposited by the river.

The major aquifer of the area is the Quaternary alluvial deposits of the Equus Beds. The sediments in this area range from 15 to 90 ft thick. The alluvial

¹ Complete chemical analyses include calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, nitrate, silica, specific conductance, and occasionally fluoride and boron.

sediments overlie the Permian Ninnescah shale bedrock. Most of the wells in the study area are sited within the alluvial aquifer.

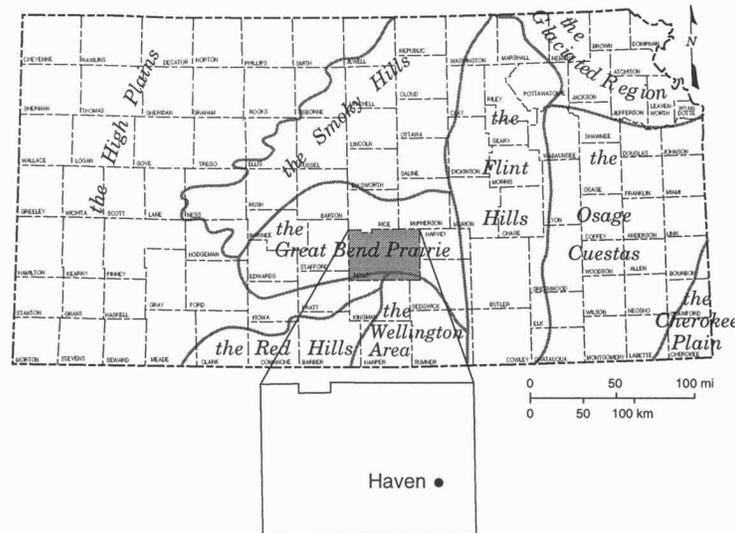


Figure 1. Location of Reno County, Kansas in Great Bend physiographic province.

Regional groundwater flow is generally from northwest to southeast, parallel to the Arkansas River (Myers et al., 1996) (fig. 2, arrow A). Depth to water in the Haven area is approximately 10 to 15 feet as per the 1997 water-level measurement survey (Woods et al., 1997). There is little irrigation in this portion of Reno County because of the presence of saline water from both the bedrock and the Arkansas River alluvium. In the area of Haven, groundwater flow is from southwest to northeast because of the rise in bedrock to the south and west of the Arkansas river (fig. 2, arrow B).

Several irrigation wells occur in the Haven area but farming is primarily dryland. The irrigated sites generally grow corn or sorghum. Haven has several small industries located outside the city limits including a steel products company, and a mattress products company. Most of the area around Haven is under cultivation.

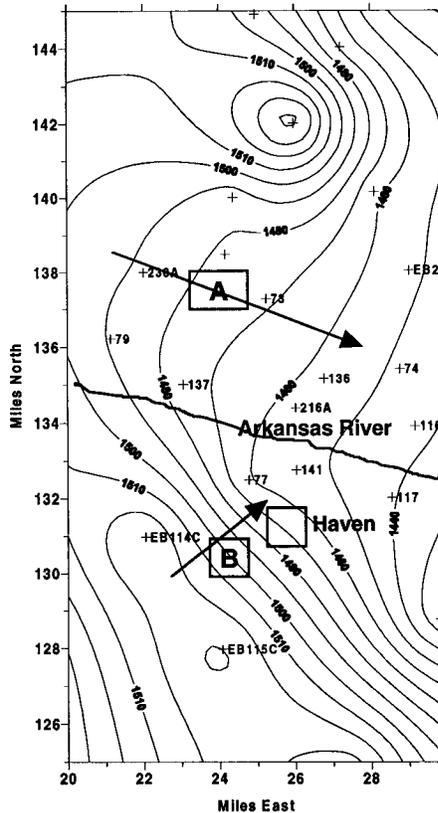


Figure 2. Generalized water-level map of portion of Reno County surrounding Haven, KS (box). Markers indicate wells used in water-level measurements. Approximate scale. Arrow A shows regional ground-water flow direction. Arrow B shows localized flow near Haven, KS.

General Water Chemistry

Water quality in the Equus Beds aquifer around Haven, Kansas is generally a calcium, sodium bicarbonate type water. This means that calcium, sodium and bicarbonate are the dominant ions in the water. Water chemistry analyses for the sampled wells are given in Appendix A.

All sampling points are shown in figure 3A. Sampling points for complete analyses are shown on figure 3B. Figure 4 shows a bar graph of the major water chemistry constituents for those samples where a complete analysis was performed. Values are presented in milliequivalent units to permit comparison of ions with different chemical charge. The samples in figure 4 are arranged in a west to east cross-section.

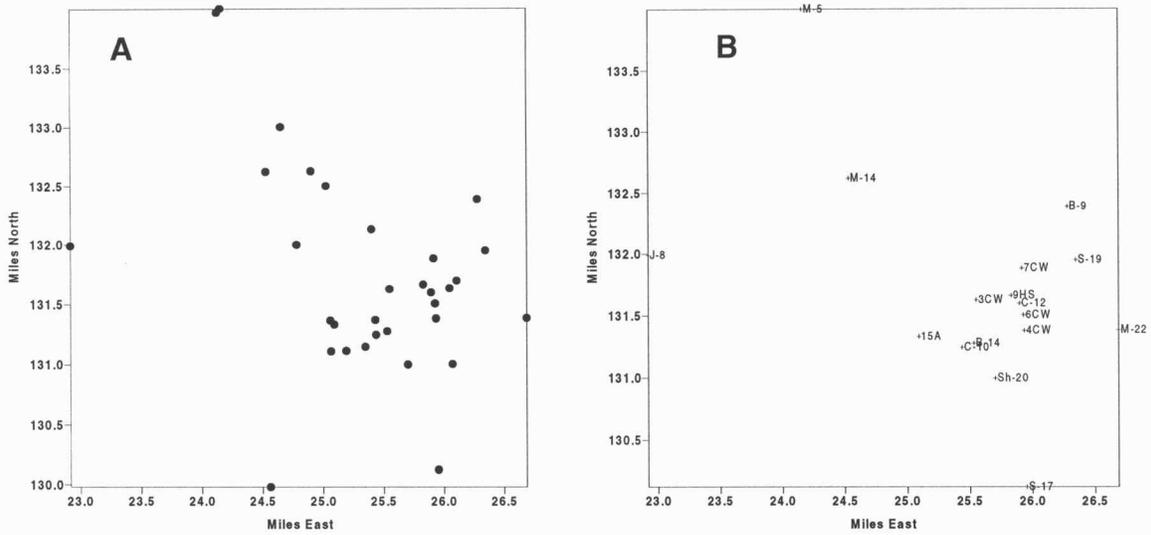


Figure 3 A, B. Figure 3A shows all sampling points from study area. Figure 3B shows sampling points for complete chemical analyses illustrated in figure 4.

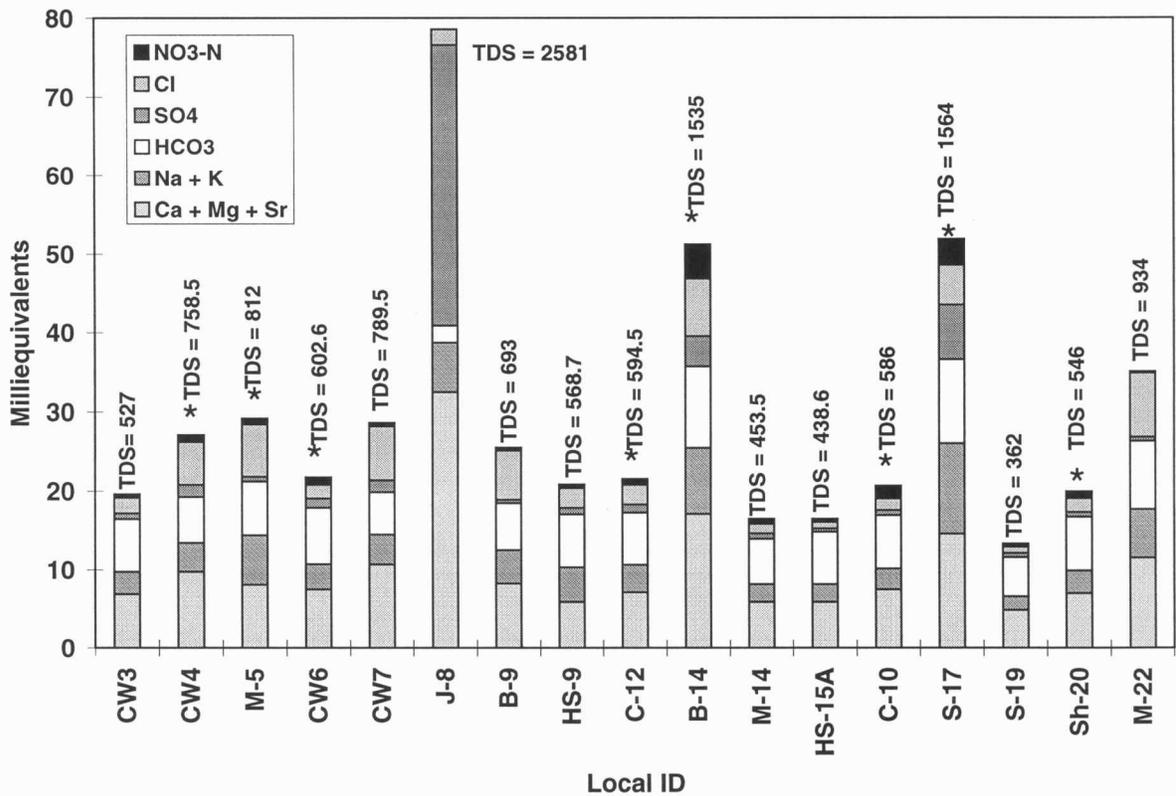


Figure 4. Bar graph shows comparison of water chemistry for various sampling points in and around the city of Haven. Stars mark wells with nitrate-N near or above drinking water limit of 10 ppm.

Most of the samples (excluding J-8 which is a bedrock well west of Haven) have calcium + magnesium and bicarbonate as the major constituents. In general the wells that have the nitrate-N near or above the drinking water limit of 10 ppm (stars on figure 4) also have higher concentrations of chloride, sulfate, and total dissolved solids. Points B-14 and S-17 have the highest total dissolved solids (TDS) values and nitrate-N concentrations (Appendix A) for the shallow wells in the area. The S-17 well is a known septic tank contamination site. The similarity between this well and the B-14 well in town suggests the possibility that leakage from a sewer line may be the cause of the contamination. Site S-19 has the lowest TDS of all samples and is considered background ground-water quality for the area (Appendix A).

Domestic Wastewater Chemistry

One of the suspected sources for contamination of the city water supply at Haven is the north-south sewer line that runs along the western edge of the town (fig. 5). In addition, the city administrator of Haven reported that the lift station in north-east Haven overflowed during the major rain events in the summer of 1993. This may be another possible source for the high values found in 6CW and 4CW.

At the time of sample collection a sample of the municipal wastewater was not collected. As a substitute, a range of values for typical domestic wastewater adapted from Tchobanoglous and Burton (1991) is presented in table 1.

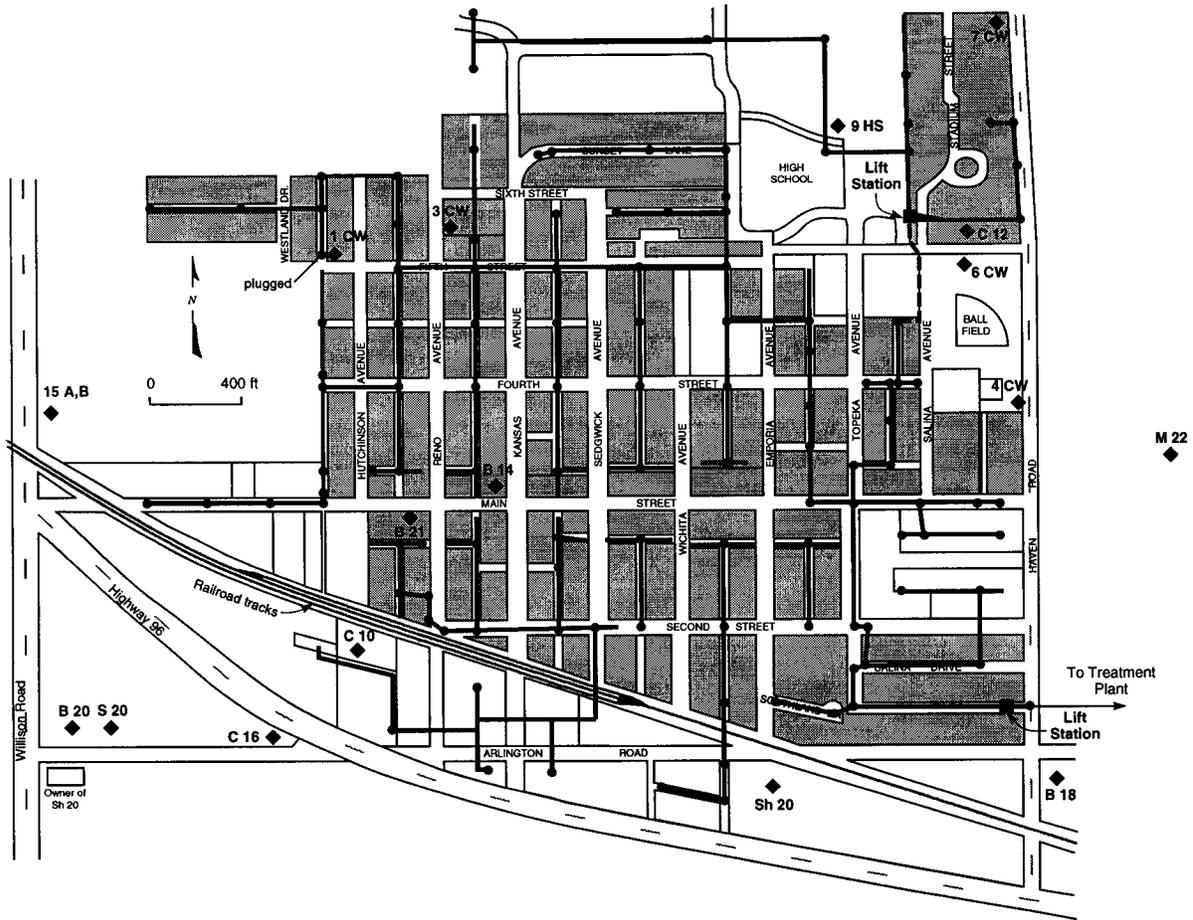


Figure 5. Location of sewer lines within the city of Haven (dark lines). Sampling points indicated by diamonds.

Table 1. Range of values for untreated domestic wastewater *.

Contaminant (ppm)	Domestic Wastewater Chemistry			Background Chemistry (Well S-19, Appendix A)		
	Weak	Medium	Strong	Weak	Medium	Strong
Total Dissolved Solids	250	500	850	610	860	1210
Specific Conductance (mmhos/cm)	420	830	1415	1010	1430	2015
Total Nitrogen as N (organic + ammonia)	20	40	85			
Chloride	30	50	100	60	80	130
Sulfate	20	30	50	50	60	110
Alkalinity as bicarbonate	50	100	200	350	400	500

* Adapted from Tchobanoglous and Burton (1991)

These numbers were increased by the quantity of these parameters present in the background groundwater quality. If the analysis for S-19 (Appendix A) is considered background for the area then the TDS values increase by approximately 360, chloride and sulfate increase by approximately 30, and alkalinity expressed as bicarbonate increases by about 300 ppm. These values are included in table 1. The nitrogen values are not included in the background columns because the transformation of wastewater nitrogen to nitrate over time results in variable concentrations. However, comparison of the estimated ranges of wastewater concentrations with samples collected in the Haven area (Appendix A: 4CW, 6CW, 7CW, B-14, B-21) suggests a strong possibility of leaky sewer lines or spills from sewer junction points as possible sources for the observed nitrate.

Water Chemistry and Depth of Well

Figure 5 shows a bar graph of the depth of wells with nitrate-N concentration. This figure shows that the majority of the nitrate-N contamination (> 10 ppm) occurs in wells of less than 100 feet deep. The samples with nitrate-N between 3 and 10 ppm also occur predominantly in wells of less than 100 feet depth. This suggests

that the shallower portion of the Equus Beds aquifer is very vulnerable to potential nitrate contamination in this area.

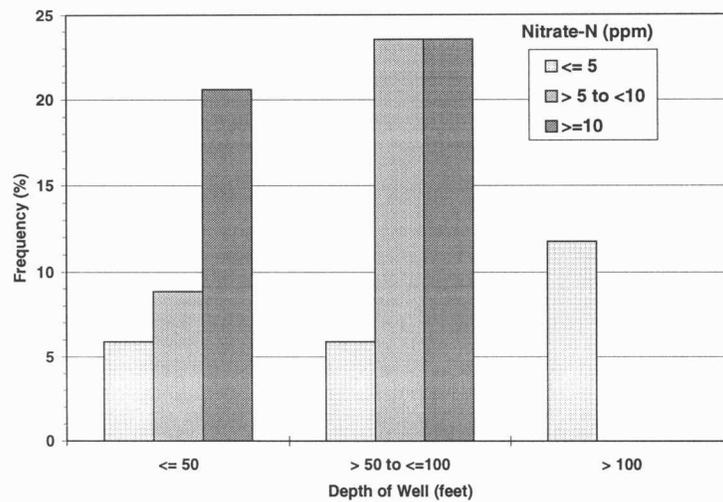


Figure 6. Distribution of nitrate-N with depth of well in study area. Note majority of samples with nitrate-N ≥ 10 ppm are in wells of less than or equal to 100 foot depth.

Figure 7 illustrates that the majority of the wells in the Haven area are below 60 foot depth and that the number of wells with nitrate-N above the drinking water limit of 10 ppm increases as well depth decreases. Also, the deepest wells have the lowest nitrate-N values. The occurrence of high nitrate in shallow wells and low nitrate in deeper wells is a common observation in many studies (Spalding and Exner, 1993).

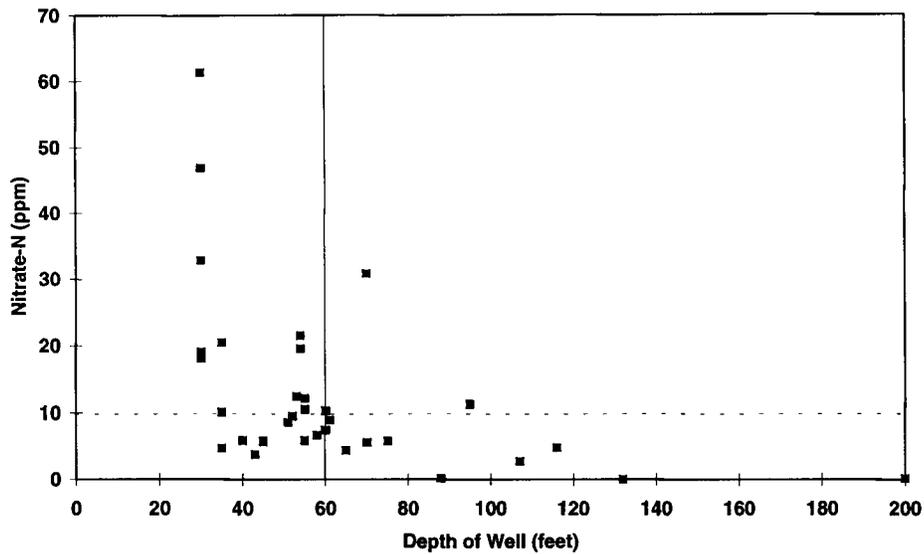


Figure 7. Increased nitrate-N concentration with decreasing well depth and decreased nitrate-N values with increased well depth. Note majority of wells are less than 60 feet deep (solid line). Dashed line is 10 ppm drinking water limit for nitrate.

Distribution of Nitrate-N

The major contaminant observed in groundwater near Haven was nitrate. Seventeen of the 34 wells sampled had nitrate-N above or near the drinking water limit of 10 ppm. Figure 8 shows a contour map of the distribution of nitrate-N within the immediate area of Haven. Also on the map are groundwater-elevation contours and flow directions for the area immediate to Haven.

The maximum contaminant levels occur at site B-14 in the center of town and the two adjacent site B-21 and C-10. On the east of town, 4CW, 6CW, and C12 have the highest concentrations. There is a possibility of a plume moving in the direction of groundwater flow to the northeast but no wells were available to sample between the two sides of town. The chloride (fig. 10), specific conductance (fig. 12), and nitrogen-15 isotope (next section, fig. 16) contour maps all show a similar trend of higher values within the city boundaries and lower values outside of the city. ▾

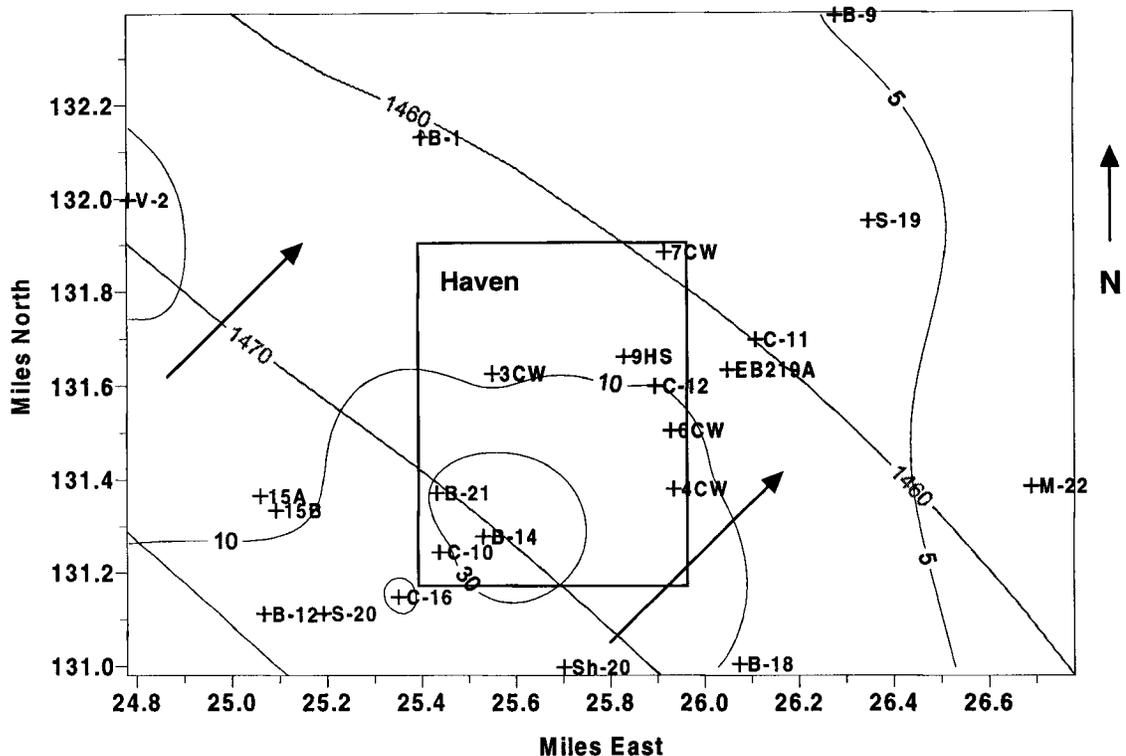


Figure 8. Contour map of nitrate-N distribution in and around the city of Haven (box). Ground-water elevation lines shown in feet (gray lines). Ground-water flow direction shown by arrows.

The drinking water limit for chloride and sulfate is 250 ppm. Figures 9 and 11 show that the concentration for these two constituents is less than 100 ppm for all depths in the majority of the samples. The occurrence of the chloride may be related to the use of water softeners, possibly deicing salt, the depth of well in relation to Permian bedrock, or the location of the well in relation to the Arkansas River alluvium which is known to have increased salinity. The values measured for chloride are similar to the results of Myers et al. (1996). The wells that have measured elevated chloride, above 100 ppm, (B-14, 4CW, 7CW, B-9, C-11, C-12, S-17, M-22, S-20, and EB219A; Appendix A) may have chloride sources such as water softeners, saline water from the Arkansas River alluvium, or a septic source such as a leaky sewer line or septic system.

Figure 10 shows chloride contours for the area immediately around Haven. The contour map is similar in configuration to the nitrate distribution map. Higher

concentrations occur to the east particularly in the area of two irrigation wells (B-9 and M-22). The occurrence of the highest levels within the city limits of Haven again indicates the possibility of wastewater contamination (table 1).

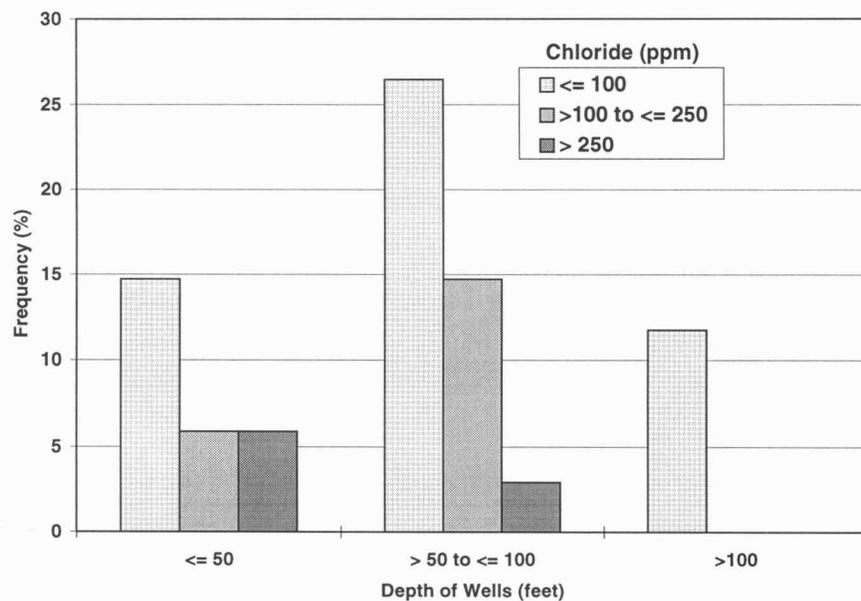


Figure 9. Distribution of chloride concentration with depth of well. Majority of the samples have chloride of less than 100 ppm.

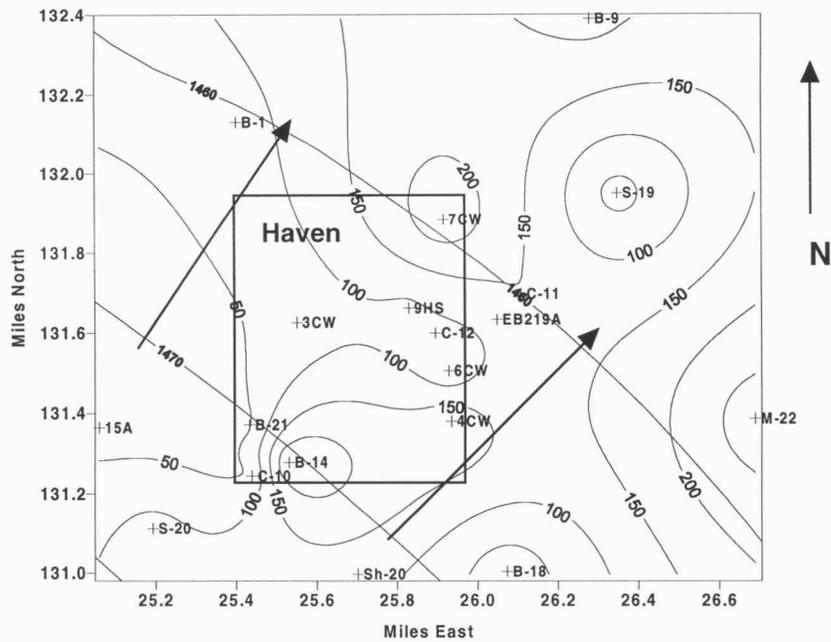


Figure 10. Contour of chloride concentration of area immediate to city of Haven (box). Groundwater-elevation contours (feet) superimposed on map. Groundwater-flow direction shown by arrows.

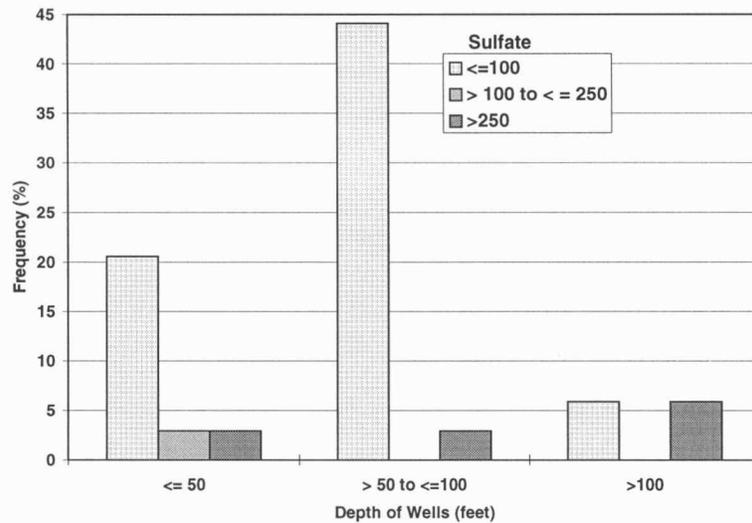


Figure 11. Distribution of sulfate with depth of well. Most samples have less than 100 ppm.

Figure 11 shows the distribution of sulfate with depth of well. The majority of these samples have sulfate concentration of less than 100 ppm. The source of

excess sulfate in a few of the wells may be related to domestic wastewater or possibly to a fertilizer source.

GMD2 Monitoring Wells

Groundwater Management District #2 has several monitoring wells in the area. One of the nest of wells is east of Haven (EB219A shown figs. 8 and 10; Appendix A). These wells show a decrease in nitrate-N ($\text{NO}_3\text{-N}$) and chloride (Cl) concentration with depth (5.7 ppm ($\text{NO}_3\text{-N}$) and 119 ppm Cl at 45 feet (EB219A); 0.2 ppm $\text{NO}_3\text{-N}$ and 18.8 ppm Cl at 88 feet (EB219B), and <0.1 ppm $\text{NO}_3\text{-N}$ and 13.1 ppm Cl at 132 feet, EB219C) and an increase of sulfate with depth (52.1 at 45 feet, 287 ppm at 88 feet, and 607 ppm at 132 feet) suggesting that the shallow aquifer is possibly contaminated with wastewater or irrigation water that has been concentrated by evaporation, and the deeper wells are reflecting water seepage either from underlying bedrock or from Arkansas River alluvium. The analysis for site C-11 (Appendix A) which is nearby shows similar results at a depth of 60 feet.

Specific Conductance Values

Specific conductance values given in table 1 represent estimates based on the presented total dissolved solids values. The estimates for the background chemistry are within the observed range for the samples collected in the Haven area. Figure 12 shows specific conductance contour lines for the area immediately surrounding Haven. The maximum conductance values are near point B-14 but there is a general increase in values from west to east across the city and in the surrounding area as previously noted for the nitrate and chloride maps.

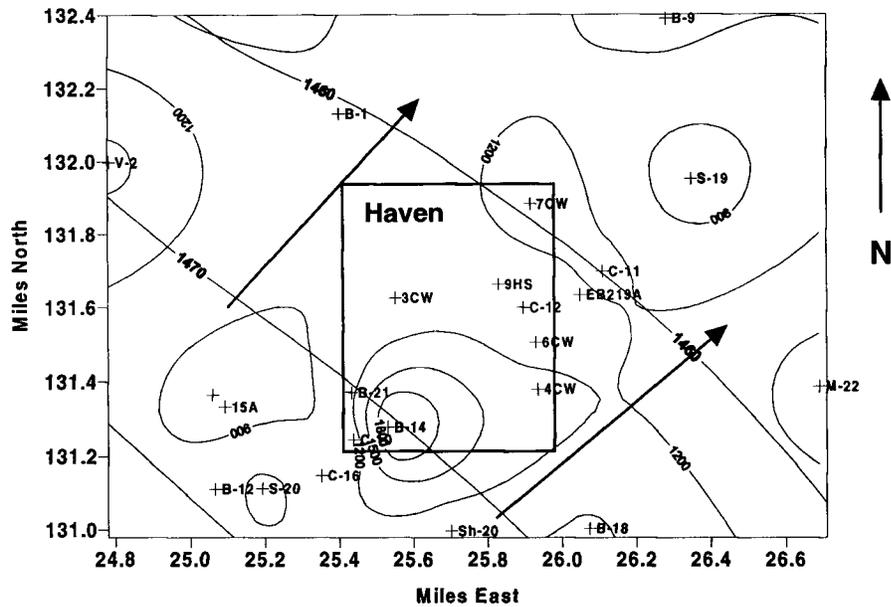


Figure 12. Specific conductance values (mmhos/cm) for the immediate Haven area. Haven shown by box. Contour interval 300 mmhos/cm. Groundwater-elevation shown in feet. Groundwater-flow direction shown by arrows.

Figure 13 shows specific conductance values for all of the sampling points except for the bedrock well (J-8) and site S-17 (Appendix A). This figure shows a similar trend to figure 12. However, when points outside the city area are included the results show increased values to the northeast. The values within Haven suggest a similar source.

The values outside of the city of Haven reflect the varied sources of the water and the depth of wells. Higher conductivity values reflect the impacts of point source contamination from septic systems, recharge by evaporative concentration of irrigation water, possible leakage from underlying portions of the Equus Beds aquifer that may be in contact with Permian bedrock, or the influence of water from the Arkansas River alluvium to the north which may be migrating toward higher capacity irrigation wells.

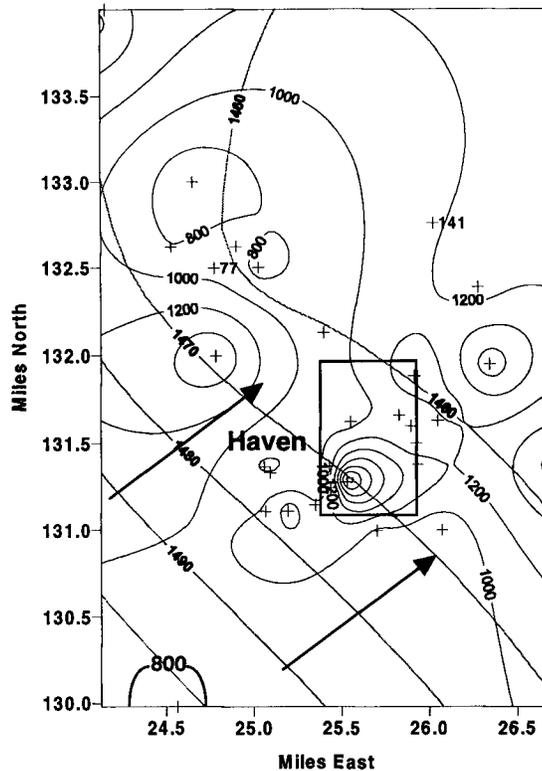


Figure 13. Specific conductance values (mmhos/cm) for all points except for J-8 and S-17 (Appendix A). Haven shown by box. Contour interval 200 mmhos/cm. Ground-water flow direction shown by arrows.

Nitrogen-15 Isotope Background

Nitrogen-15 isotope analysis is a method to assist in determining sources of nitrogen in groundwater. The isotope analysis evaluates the ratio of nitrogen-14 (what is present in the air) to the amount of nitrogen-15 present in the water or other compound which is being analyzed. This ratio is compared to a standard based on the ratio of N^{14}/N^{15} (represented by $\delta^{15}N$) present in air. Comparisons of these values indicates if there is more (a positive value +) or less (negative value -) than the standard. The plus or minus sign indicates whether the sample is enriched (+) or depleted (-) in relation to the standard. Work by many researchers have found that sources of nitrogen in groundwater fall into various categories. These are illustrated in figure 14.

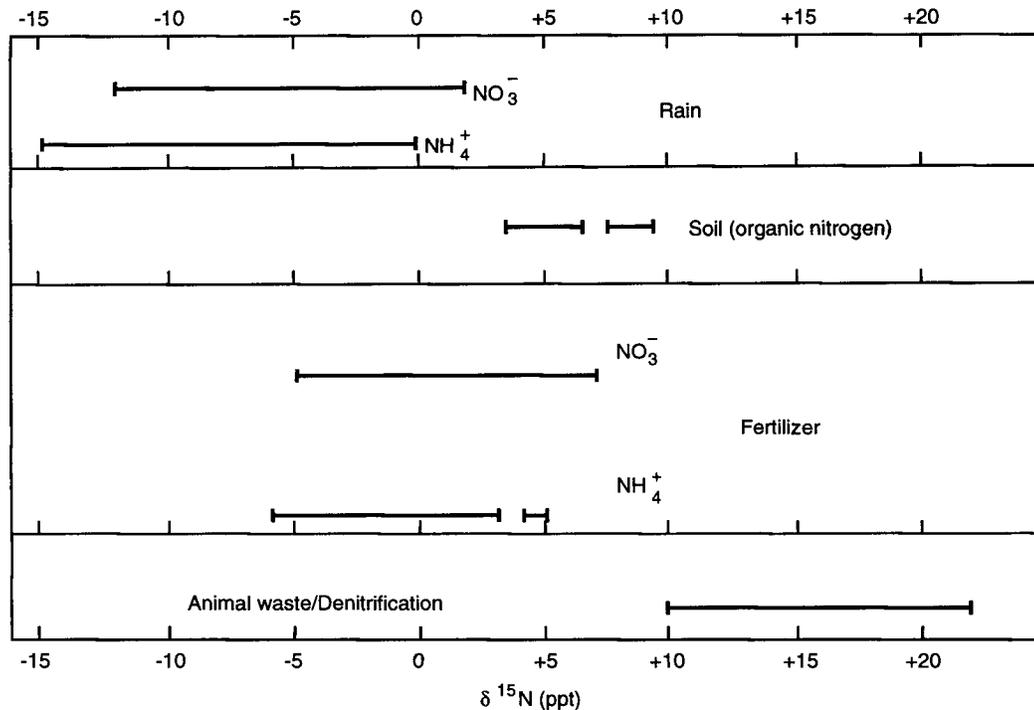


Figure 14. Range of $\delta^{15}\text{N}$ for different sources of nitrogen reported from the literature. Rain, soil nitrogen, fertilizer, and animal waste or denitrification are the major sources of nitrogen. The nitrogen can be measured as either ammonium (NH_4^+) or nitrate (NO_3^-) (after Heaton, 1986).

Values that range from negative -5 ppt up to +7 or +8 ppt generally indicate a source from atmospheric nitrogen (rain), fertilizer, or soil organic nitrogen. The quantity of nitrate measured in the sample also helps to indicate the possible sources.

Rainwater has very low nitrogen content as nitrate (NO_3^-) or ammonium (NH_4^+), usually less than 1 or 2 ppm. Fertilizer and soil organic nitrogen samples are frequently above 3 ppm which is considered a background level found everywhere, based on the work of many researchers over the years. Generally if fertilizer is a source, the nitrate-N concentration is above 3 ppm and often over 10 ppm (drinking water limit) and the N-15 signature is between +2 and +8 (Herbell and Spalding, 1993; Heaton, 1986).

Animal waste sources have a signature which is generally greater than +10. Nitrate-nitrogen concentrations are often above the drinking water limit of 10 ppm. Volatilization (changing of a liquid to a gas) of ammonium (NH_4^+), from anhydrous

ammonia, to ammonia gas (NH_3) may also result in enriched nitrogen-15 values but with nitrate concentrations between 3 and 10 ppm.

Another possibility for an enriched value (greater than +10) is called denitrification. This occurs when bacteria break down nitrate-N to nitrogen gas. This process usually results in nitrate-N concentration of below 2 ppm along with a high N-15 value (greater than +10).

Sources of nitrogen are often hard to identify for samples with nitrogen-15 values between +7 and +10. Nitrate-nitrogen values and other major chemistry ions may help to determine the possible source of the nitrogen. The isotope signature alone is not well enough defined to determine a definitive source.

Table 2. Nitrate-N and Nitrogen-15 Values for Haven Well sites.

ID	Nitrate-N (ppm)	Nitrogen 15 (ppt)
C-16	5.8	2.3
M-22	3.0	3.2
B-9	4.9	6.2
B-18	9.5	6.7
S-19	6	6.9
15A	5.6	7.1
EB219A	5.7	7.1
B-21	33	7.6
V-13	8.7	7.8
C-18	21.6	8.6
H-7	3.9	8.7
B-4	2.8	8.9
4CW	12.1	9
B-14	61.4	9.2
Sh-20	11.3	9.2
B-12	20.6	9.3
B-1	10.1	9.4
M-14	9.0	9.6
7CW	6.7	10
S-20	30.9	10.0
HS-9	5.8	10.1
C-11	7.4	10.5
S-17	47	10.5
6CW	12.5	10.8
V-2	4.4	11.5
3CW	5.87	12.9

Figure 16 shows the distribution of nitrogen-15 values in relation to ground-water flow lines. The highest values are, as mentioned above, generally within the center of town and the city wells.

Wells located outside the city boundaries that show high values above +10 ppt (B-20, S-20) are probably indicative of point sources from septic tanks. The occurrence of values relatively close to +10 at most points except for C-10 and B-21 (southwest corner of town) helps to support the idea that a sewer leak may be the source of the nitrate. The points C-10 and B-21 have signatures more closely associated with fertilizer as a possible source of contamination. Other sites that also show fertilizer as a possible source are C-16, B-18, M-22, and B-9 (table 2). Point

Nitrogen-15 Results for City of Haven

Figure 15 shows the range of nitrogen-15 and nitrate-N values for the majority of the samples collected during this study. Values for all of the samples are given in table 2. The city wells are identified by CW. These wells are within the range of +9 to +12.9 ppt for nitrogen-15 values. These are generally within the range of animal waste as a potential source for the nitrate. The location of well 3CW (+12.9 ppt) is at the northwestern edge of town but to the east of the main sewer line for the city (fig. 16). The area to the north of this well is dryland farm and this well is surrounded by houses. It is possible that the high N-15 value is related to an abandoned septic system or to a leak in the sewer line.

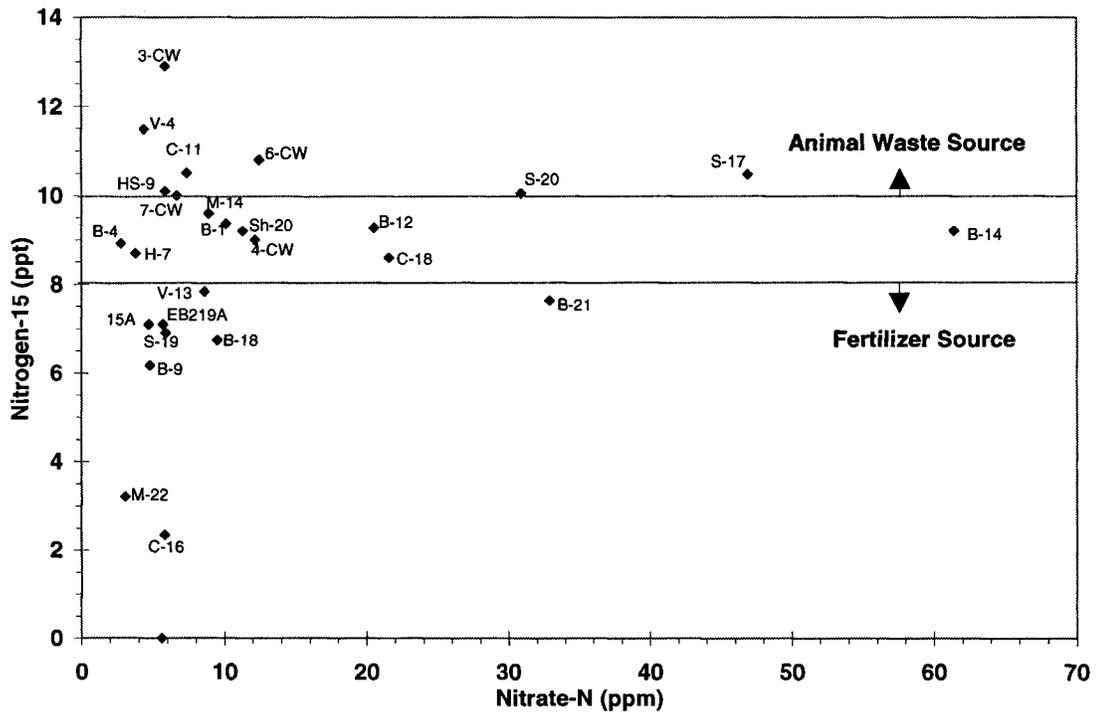


Figure 15. Nitrogen-15 isotope values for city of Haven and vicinity. Highest nitrate-N and N-15 values appear related to animal waste or mixed sources.

C-11 to the east of town may reflect the presence of plume from the west or possibly represents volatilization of the fertilizer stored at the site.

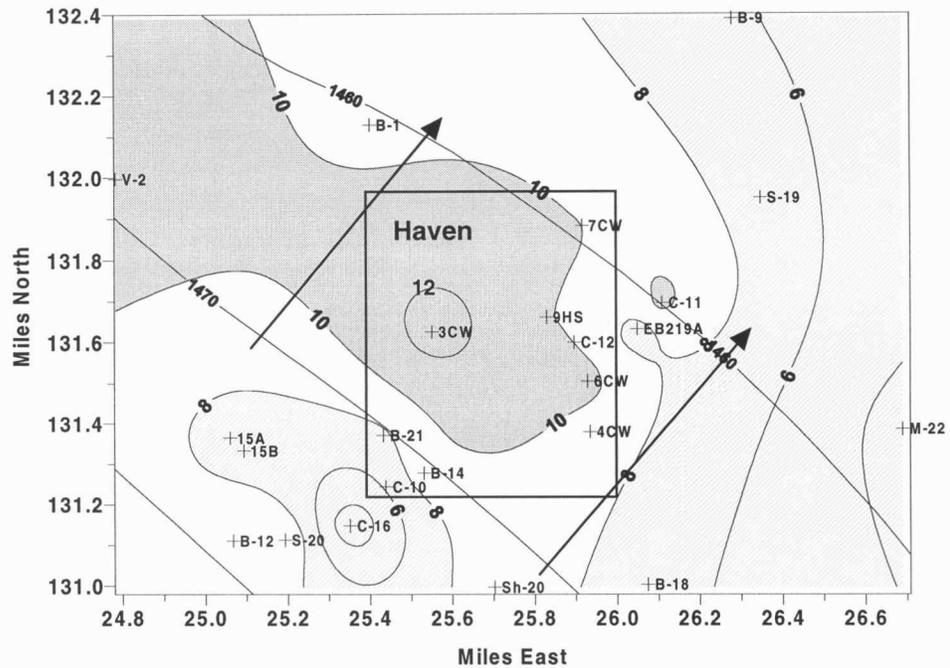


Figure 16. Contour map of nitrogen-15 values and groundwater-elevation contours around city of Haven (box). Groundwater flow direction shown by arrows. Dark shaded areas have $\delta^{15}\text{N}$ values greater than +10 ppt indicative of animal waste. Light shaded areas have $\delta^{15}\text{N}$ values between +2 and +8 ppt indicative of fertilizer.

Figure 17 shows contours of nitrogen-15 values for all of the sampled wells for this study. The highest isotope value is at well 3CW in the northeast part of the city. This well has slightly elevated chloride (71.5 ppm) and nitrate-N concentration of 5.9 ppm. The presence of the higher nitrogen-15 value (+12.5 ppt) and the lower nitrogen value suggests the possibility that denitrification is occurring because the well has not been pumped much because of low capacity, or there is a small leak in the sewer line or there are abandoned septic tank(s) in the area that are contributing small amounts of nitrate that is indicative of animal waste. Usually when there is a high nitrogen-15 value there is either a large nitrate-N value (indicating an obvious source) or a very small nitrate-N value indicative of denitrification (breakdown of the nitrate by bacteria and subsequent enrichment of the remaining nitrogen with the

heavier isotope). Because the chloride is slightly elevated (fig. 18; Appendix A; table 1) relative to the assumed background value, this might indicated some sewer effluent has affected the well.

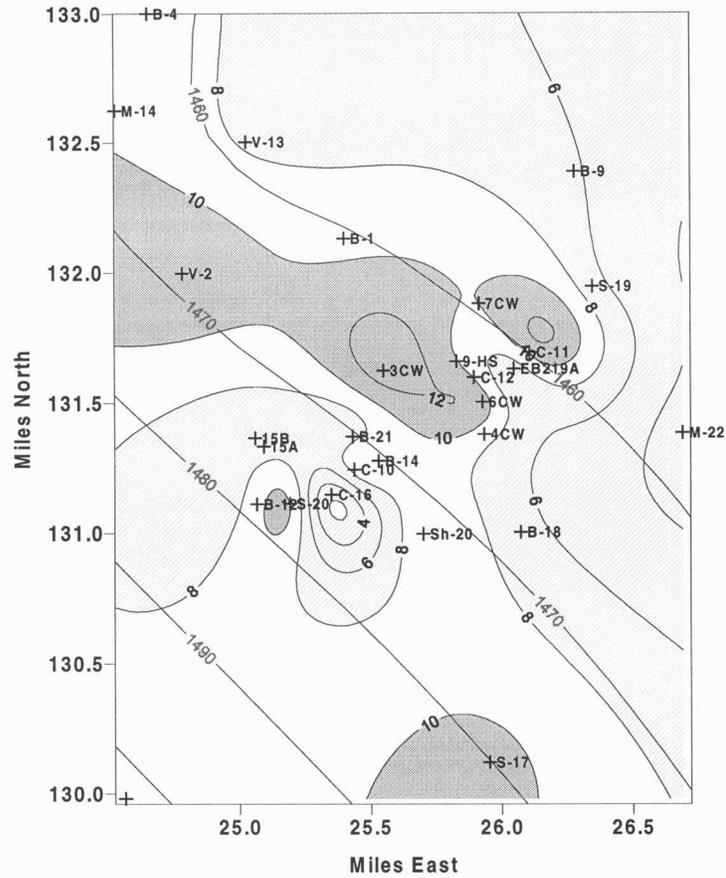


Figure 17. Contour map of nitrogen-15 values for sample points in area of Haven. Values range from +2.8 to +12.9 indicating a variety of sources for the nitrate observed in the groundwater. Light shaded areas are +2 to +8 for fertilizer. Dark shaded areas are +10 and above indicating animal waste. Groundwater elevation shown by gray lines. Groundwater flow direction shown by arrows.

The relationships between nitrate-N concentration, nitrogen-15 values, and chloride concentration are shown in figure 18. This figure is for samples with nitrate-N concentration above 10 ppm. The graph illustrates the relationship between possible wastewater sources (S-20 and S-17 as examples) and the occurrence of the highest concentrations at B-14 in Haven. Points M-6 and M-5 northwest of Haven (fig. 17) also are indicative of possible point source from septic system or animal waste sources because of the high nitrate and chloride concentrations. Note the similarity between point 4CW and these two points. The clustering of Sh-20, 6CW, B-1, and C-12 also suggests a relationship between animal waste and nitrate-N, chloride, and N-15 values.

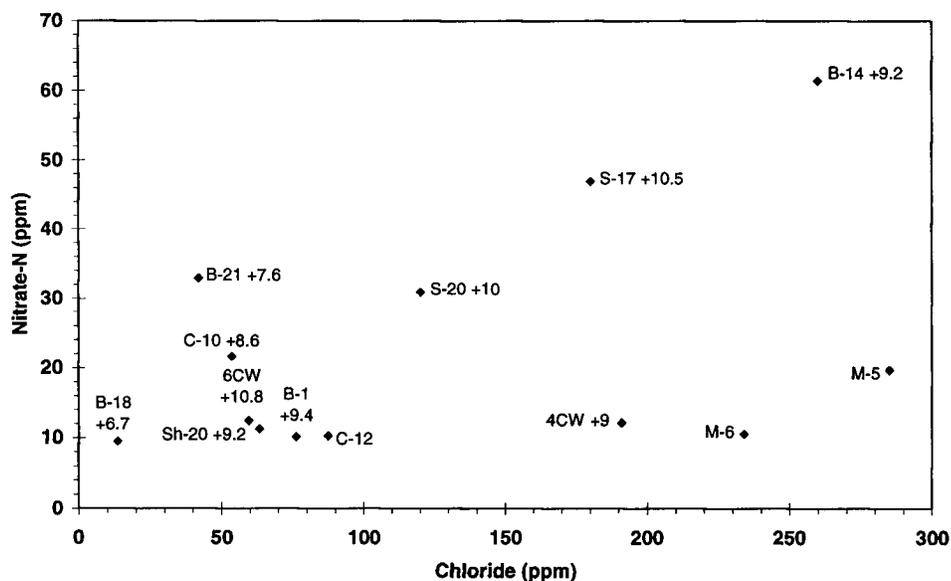


Figure 18. Wells with nitrate-N greater than 10 ppm frequently have chloride greater than 50 ppm and N-15 values greater than +9 ppt. Sample numbers show values as reported in Appendix A. Nitrogen-15 values, where measured, are posted by sample point number.

Conclusions

1. General groundwater chemistry and nitrogen-15 isotope values for groundwater around Haven, Kansas indicate several possible sources: areas to the east of town have values in the fertilizer range (+3 to +8); within the city the isotope values range between +9 to +12.9 suggesting an animal waste source; the southwest edge of town has isotope values in the fertilizer range of +7 to +8.6 possibly indicating the local cooperative as a source or spills along the railway associated with transporting fertilizer.
2. Chloride levels in the town are generally within the range of medium to strong untreated domestic wastewater indicating that sewage waste is a strong possible source for the nitrate observed in the groundwater.
3. Several point sources of nitrate contamination from septic systems were observed in the area. Comparison of these analyses with those observed at the city wells show some similarities helping to support the hypothesis that leaky sewer lines may be at least one source affecting the water supply.
4. All of the wells with high nitrate concentrations are less than 60 feet deep. The presence of chloride and sulfate at higher than background levels (site S-19 assumed to be background level) helps to support the contention of sewage as a source of contamination.

Recommendations

1. The city is rehabilitating site 3CW as an additional source of water. It would be useful to collect additional samples during a pumping development test to determine if the nitrate-N and chloride levels fluctuates with time. Also, an additional N-15 test might help to determine if the source is due to denitrification or a possible point source.

2. Water to the east and northeast of town is lower in nitrate-N but is higher in total dissolved solids and chloride. The source of the chloride may be from the underlying Permian formations, from evapoconcentration of irrigation water, or from the Arkansas River alluvium. Chemical tests are available to determine possible sources of water by use of bromide and iodide.
3. Several point sources of potential nitrate contamination exist upgradient from the city. It may be advisable to have those locations evaluated and determine if the localized septic systems pose an additional threat to the future city water supply.
4. Caffeine has been used a tracer to determine industrial versus municipal waste sources in surface water studies (USGS, 1995). It is possible that this compound would also work as a tracer for contaminated groundwater. If the source of nitrate contamination is from the sewer line it is possible that caffeine could be used as an indicator of municipal wastewater as the source of contamination. The Kansas Department of Agriculture is able to analyze for caffeine down to several parts per thousand concentration which means if the compound is diluted in the groundwater it may still be detected.
5. Assuming that the sewer lines may be the point source it is possible that the remediation section of KDHE might be able to do a larger scale evaluation of the problem and assist in clean-up and establishing a more reliable water source for the city.
6. Although the shallow portion of the aquifer is contaminated going deeper may not be a solution because of observed higher chloride, sulfate, and total dissolved solids in the groundwater. It may be that a source can be found to the north, northeast, or east that would provide lower nitrate water. However, with the groundwater flow being generally to the northeast in the area care must be taken to not cause increased movement of water from the shallow aquifer to the new well. Proper grouting and casing needs to be carefully observed to prevent mixing of contaminated water with water at somewhat greater depths.
7. The city of Haven should begin the process of well-head protection planning in order to eliminate as many surface point sources as possible. During this investigation several open well bores were discovered as well as poorly packed

casings around existing wells currently being used. Reference was made to several abandoned septic systems that were discovered over the years as well as a sewer junction box that overflowed during an unusual rainfall event. The junction point now has a backup generator to prevent future problems.

8. Installation of a monitoring well(s) within the city limits between points B-14 and city well #4 might help to determine if there is a plume that is migrating from west to east.

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Appendix A. Chemical Analyses for Haven Water Samples (1997)

ID	SPCD	Ca	Mg	Na	K	Sr	HCO3	SO4	Cl	NO3-N	TDS	N-15	F	B	Depth	LOCATION
	mmhos	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppt	ppm	ppb	ft	T-R-Sec
B-1	920							36.8	76.1	10.1		9.4			35	24-04W-32CDD
V-2	1610									4.4		11.5			65	25-04W-06AAB
CW-3	917	109	16.7	66.9	1.8	0.45	408	34.2	71.5	5.9	527.2	12.9			55	25S-04W-5ACC
M-3	910									18.3					30	24-04W-31ADD
B-4	645							19.4	25.9	2.8		8.9			107	24-04W-31ABA
4CW	1330	157	23.2	83.6	2.5	0.7	354	72.6	191	12.1	758.5	9.0			55	25S-04W-05DAD
M-5	1445	137	14.8	145	2.7	0.52	412	28.4	234	10.5	811.9		0.22	43	55	24-04W-30BAA
6CW	1005	120	17.6	74.3	1.8	0.55	436	59.2	59.6	12.5	602.6	10.8			53	25S-04W-05DAA
M-6	1705							39.0	285	19.6					30	24-04W-30BBA
7CW	1395	172	25.1	87.2	2.8	0.77	325	72.3	240	6.7	789.5	10.0			58	25S-04W-05AAD
H-7	800							13.6	50.1	3.9		8.7			43	25-04W-18ABB
J-8	2965	462	112	141	3.4	7.63	132	1718	70.7	0.2	2581.1		0.70	767	200	25-05W-02AAA
B-9	1310	130	20.8	97.2	2.9	0.80	364	22.1	218	4.9	692.7	6.2	0.25	<47	116	25-04W-33CAC
HS-9	988	93.7	14.3	101	2.6	0.41	411	40.3	88.4	5.8	568.7	10.1			45	25S-04W-05ADCA
C-10	980	124	15.4	60.6	2.1	0.52	415	30.1	53.6	21.6	586.0	8.6			54	25-04W-05CDA
C-10 dup	945									19.7					54	25-04W-05CDA
C-11	1280							57.8	150	7.4		10.5			60	25-04W-04BC
B-12	1050									20.6		9.3			35	25-04W-05CCC
C-12	1020	113	17.7	80.1	1.7	0.51	405	49.4	87.4	10.3	594.6				60	25S-04W-05ADDC
V-13	720							24.5	34.7	8.7		7.9			51	24-04W-32BBC
B-14	2360	284	35.8	187	4.4	0.91	626	183	260	61.4	1534.9	9.2			30	25S-04W-05DCBB
M-14	800	95.8	13.2	50.7	2.3	0.45	354	33.8	43.4	9.0	453.6	9.6	0.20	<38	61	24-04W-31
15A	780	98.0	12.2	50.2	1.5	0.39	412	20.0	28.8	5.6	438.7	7.1	0.22	<38	35	24-04W-05CBC
15B	770									4.7					70	25-04W-05CBCD
C-16	1030									5.8		2.3			75	25-04W-05CDCA
B-18	840							25.8	13.5	9.5		6.7			52	25-04W-09BBB
S-17	2260	219	44.8	259	2.3	0.84	647	332	180	47.0	1564.3	10.5	0.21	<83	30	25-04W-08DDD
S-19	650	78.9	11.5	37.6	1.8	0.38	307	26.9	27.5	6.0	362.3	6.9	0.22	28	40	25-04W-04BA
S-20	1320							36.3	120	30.9		10.0			70	25-04W-05CCD
Sh-20	938	114	15.4	66.4	1.6	0.5	418	29.2	63.3	11.3	545.8	9.2			95	25S-04W-058ABA
B-21	1090							47.5	41.9	33.0		7.6			30	25-04W-05CAD
EB219A	1140							52.1	119	5.7					45	25-04W-04BCC
EB219B	945							287	18.8	0.2					88	25-04W-04BCC
EB219C	1370							607	13.1	<0.1					132	25-04W-04BCC
M-22	1675	179	31.6	140	3.4	0.64	519	25.9	285	3.0	934.3	3.2	0.27	221	60	25-04W-04DBD

Appendix B

Sample Handling

Samples for nitrate analysis were collected in a 200-ml acidified bottle with 2 ml HCl for preservation. Samples for complete analyses were collected in 500-ml unacidified and 200-ml acidified bottles. Samples for nitrogen-15 isotope analyses were collected in 125-ml unacidified bottles. All samples were kept on ice until returned to the laboratory. The nitrogen-15 samples were frozen until analyses were done by Dr. Stephen Macko, University of Virginia, Department of Environmental Sciences.