EVALUATION OF POSSIBLE CAUSES

OF

NITRATE CONTAMINATION IN GROUND WATER SOUTHEAST CARSON CITY

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1.0. INTRODUCTION

The consulting services of Vector Engineering, Inc., (Vector) have been retained by the Carson City Utilities Department to perform a third-party data review regarding the existence and potential causes of nitrate contamination of ground water reported in southeast Carson City, Nevada. The area under investigation comprises approximately 1.7 square miles in T.15N., R.20E., and covers parts of sections 28, 29, 32, and 33. The following streets roughly define the boundaries of the area:

Koontz and Damon on the north and northeast;

California and Silver Sage on west and northwest;

Synder on the south; and,

Conte on the east.

It is estimated that 440 residences are located within the area of concern. Drinking water is provided to 204 of these by the Carson City municipal water supply system; the remaining 236 residences rely on domestic wells. Nitrate contamination in these wells represents both a public health threat, and a threat to the municipal water supply of Carson City.

2.0. SCOPE OF WORK

Vector has reviewed existing data and work to date, and evaluated the existence and possible causes of elevated nitrate levels in the ground water which underlies parts of southeast Carson City. Information which was assembled for evaluation included the following items:

- hydrogeologic information defined in published reports and the Carson City Wellhead Protection Program;
- well logs recorded at the Nevada Division of Water Resources;
- soil information published by the U.S. Soil Conservation Service;
- historic and existing potential sources of nitrate;

- results of chemical analyses recorded at the Nevada Department of Human Resources, Division of Health Protection Services, since 1970;
- results of chemical analyses from 1992-1993 sampling events;
- historic land use issues; and,
- permitting practices for installation of septic systems.

Evaluation of the data listed above included an assessment of background chemistry and distribution of anomalous chemical values through time, consideration of hydrogeologic factors such as depth to ground water and rate and direction of flow, and correlation of anomalous chemical values to possible historic and modern sources.

3.0. PROBLEM VERIFICATION

The presence of nitrate contamination in ground water underlying areas of southeast Carson City has been firmly established and is documented in water quality reports for domestic wells in the area. This conclusion is based on review of reports provided by the Carson City Utilities Department for samples taken in 1992 and 1993 and submitted to multiple laboratories for analysis. It is supported by an examination of historical water quality reports available from the Nevada Department of Human Resources, Division of Health Protection Services.

3.1. Water Quality Data: Recent

Elevated levels of nitrate in ground water were initially reported by the Carson City Utilities Department in December, 1992. During this time, spot samples were taken from domestic wells as part of an aquifer testing program prior to the development of new municipal water supply wells. In response to these findings, the Utilities Department expanded the sampling program in March and April of 1993, and included 122 private wells in the area. Samples were analyzed in-house by the Utilities Department. Confirmation samples were taken in April and May of 1993 from twenty-three wells in which nitrate concentrations approached or exceeded the drinking water standard; these were sent to the State Health Laboratory for analysis. Finally, in November of 1993, all accessible domestic wells were resampled, and an independent laboratory (Sierra Environmental) was selected to perform the analyses.

Results of analyses performed on water samples by the three laboratories during 1992 and 1993 are closely correlated. A review of these results, which are on file with the Utilities Department, showed that only slight variations in nitrate concentrations (generally less than 5 mg/l) are present in samples from the same well submitted to different laboratories. However, larger variations (more than 5 mg/l) in the concentration of nitrate were detected in six wells. Of these wells, five showed an increase in concentration during the most recent sampling event, during which analyses were run by Sierra Environmental; a decrease in concentration was present in only one well.

Inter-laboratory analytical variations cannot be evaluated unless a comprehensive sampling program is done. For example, multiple samples would need to be drawn from each well, and submitted to the various laboratories simultaneously with a set of control samples. In lieu of such a program, and based on the correlation of analytical results, it seems statistically unlikely that the elevated levels of nitrate detected during recent sampling events are a product of analytical error. It is Vector's opinion that the data should be considered valid. It should be noted that 19 of the most recent samples exceed the maximum concentration limit of 45 mg/l nitrate, as defined by the Safe Drinking Water Act. An additional 16 samples returned values of 20-45 mg/l nitrate; water quality in these wells should be considered to be threatened.

3.2. Water Quality Data: Historical

Water quality data extending back to early 1970 was obtained from the Nevada Department of Human Resources, Division of Health Protection Services, for wells in the area of concern. Care must be taken in the interpretation of this data, as values are reported both as the complex ion (NO_3^-) and as molecular nitrogen (N). Maximum contaminant levels are defined as 45 mg/l for nitrate, and as 10 mg/l for molecular nitrogen. A multiplier of 4.5 is used to convert nitrogen concentrations to equivalent mg/l nitrate. Reports for 171 domestic wells were examined; a summary of the data available is given below.

Nitrate Concentration, mg/l	# Wells Sampled More Than Once	# Wells Sampled One Time	Total # Wells Reviewed
greater than 20.0	9	20	29
10.1 to 20.0	4	15	19
1.1 to 10.0	19	44	63
less than 1.0	21	39	60
Total	53	118	171

A review of this data indicates that background concentrations of nitrate during the period of record (approximately 1970-present) are generally less than 10 mg/l, and are commonly less than 1 mg/l. Seventy-two per cent of the wells reviewed report nitrate concentrations below 10 mg/l. Records indicating nitrate levels in excess of 10 mg/l generally date from the mid-1980's, although some examples of elevated levels prior to 1980 were noted. Where multiple analyses from different years exist for the same well, nitrate levels tend to either fluctuate within several mg/l, or increase over time; only occasional decreases in concentration through time are noted.

Nitrate is classified as a minor dissolved inorganic constituent of water (Driscoll), 1986) which naturally ranges in concentration from 0.1 mg/l to 10.0 mg/l. Therefore, concentrations in excess of 20 mg/l nitrate, which have been documented both in historic water quality records and in recent sampling events, are not an inherent product of the evolution of the local ground water system. Rather, the anomalous values reported from ground water in southeast Carson City are indicative of man's activities and represent an introduced contaminant.

3.3. Distribution of Contaminants

All samples with nitrate concentrations in excess of 20 mg/l were plotted on a map (1" = 200' scale) showing the size, location, and address of the parcel on which the well is located. The affected parcels were color-coded to discriminate those with wells whose water quality is considered to be threatened (20-45 mg/l nitrate) from those whose water quality has already exceeded the 45 mg/l nitrate concentration limit set by the Safe Drinking Water Act. It should be noted that a geographic continuity of data points is not possible because the 204 residences supplied by City water are randomly distributed among those supplied by domestic wells. In addition, water quality data is available for only 154 of the 236 lots in the area recorded as served by domestic water sources. Therefore, water quality information is available for only 35% of all developed parcels, and 65% of the lots served by domestic wells.

The distribution pattern of contaminated wells can be roughly delineated into three areas of concern.

- The most prevalent contamination occurs in a northeast-southwest trending zone. It is roughly bound by the intersection of Snyder and California on the southwest, and extends in a N45E direction across the area where Center and Ponderosa Drives cross Clearview Drive. It continues this trend approximately as far north as Alder Street, and as far east as Bigelow Drive. The linear extent of this zone covers approximately 4000 feet. Concentrations of nitrate exceed 45 mg/l in 17 wells in this zone, and range between 20-45 mg/l in 9 others.
- Two discrete areas of well contamination are delineated in the second area of concern; they straddle Koontz Lane and occur near Bigelow and Ponderosa Drives on the west and Sentinel on the east. It is possible that the contamination in the 11 wells in these two areas is related to the northeast-trending chemical anomalies described above. Continuity of data is insufficient for conclusive determination.
- The third area of concern is in the southeast portion of the study area, and straddles S. Edmonds and Conte Drives south of Clearview Drive. Two zones have been delineated; nitrate concentrations of 20-45 mg/l are reported from nine wells.

4.0. HYDROGEOLOGIC PARAMETERS

Information on the hydrogeologic setting of the Eagle Valley ground water basin has been presented by many authors. Comprehensive summaries reviewed for this study include those by Arteaga and Durbin (1978), Arteaga (1986), and Wateresource Consulting Engineers, Inc., (1993). Data presented below are summarized from those authors, and hydrologic parameters required to explain the observed nitrate contamination are outlined.

4.1. Hydrogeologic Setting

Eagle Valley is a north-trending, semi-arid ground water basin formed by sediment deposition in a down-faulted depression. The valley floor generally exhibits an eastward slope, and ranges in elevation from 4600 to 4800 feet. Quaternary alluvial deposits which cover the valley floor are unconsolidated to partially consolidated, and consist of variable proportions of coarse to fine sand, silt, and clay. The alluvium was deposited as discontinuous, alternating layers of sediment by streams carrying detritus derived from the nearby mountains. More permeable unconsolidated alluvium is dominated by sand and coarser materials and is found primarily south of Fairview Drive. The partially consolidated material, dominated by heterogeneous mixtures of sand, silt, and clay, is less permeable and is found mostly in areas north of Fairview Drive.

4.1.1. Recharge

Subsurface water occurs in two different zones (Heath, 1993). The upper zone, which occurs immediately under the land surface, is called the unsaturated zone. Pore spaces in the unsaturated zone are filled with both water and air. This is underlain by a deeper saturated zone, in which all interconnected openings are filled with water. Water in the saturated zone is the only water which is available to supply wells and can be correctly termed "ground water". By definition, an aquifer is a rock unit (bedrock or unconsolidated sediments) occurring in the saturated zone which is capable of yielding water in a usable quantity to a well or spring. A rock unit which has a low hydraulic conductivity and therefore restricts the flow of water either into or out of an aquifer is called a confining bed.

Water which is added to an aquifer is considered to be a source of ground water recharge. Natural recharge results from the infiltration of precipitation or surface water run-off, and seepage from streams.. Recharge to ground water may also be supplied by any of man's activities which result in the uncontained discharge of water to the land surface, such as irrigation for agricultural or municipal use, or sewage disposal (land application or septic systems).

Soil type greatly influences the rate and depth of infiltration through surface materials. Data from the Soil Conservation Service (1979) shows that most of the study area is underlain by soil described as deep and well-drained, with a moderately high permeability. The effective rooting depth in these soils is reported as 60 inches (SCS, 1979). There is a high correlation between the depth of the root zone and infiltration depths, especially in the Basin Big Sage Plant Community (Steve Walker, 1993, personal communication). Several different soil types are described in the east and southeast portions of the study area. Although most soil types exhibit moderately high permeabilities with effective rooting depths of 60 inches, soils are described as having a moderately low permeability with an effective rooting depth of 29 inches in the east-central part of the study area. These less permeable soils occupy an area roughly defined by Valley View on the north, Northview on the west, Bennett on the south, and Gentry on the east.

In Eagle Valley, natural recharge to the ground water system comes primarily from infiltration of rain or melting snow as it enters the alluvium at the base of the mountains near the periphery of the valley. Surface-water runoff from the small, peripheral drainage basins also infiltrates the upper part of the alluvial fans and percolates downward to the water table. The floor of Eagle Valley receives an average of 10 inches of precipitation annually. Most is consumed by vegetation and evaporation, and does not reach the water table to recharge ground water (Wateresource, 1993). This indicates that the bulk of the recharge which enters the ground water system from the valley floor is derived from discharge generated by the activities of man.

4.1.2. Depth to Groundwater and Degree of Aquifer Confinement

Water level elevations vary throughout the area of concern, and published data indicates that mean sea levels range from approximately 4690' in the west, to 4660' in the east. Static water levels in domestic wells are commonly reported to range from 30-70' below the surface, although depths of 85-105' are also noted. A review of domestic well logs indicates that static water levels are not reflective of depths to the uppermost aquifer; water-bearing horizons are located deeper in the subsurface. Static water levels are interpreted to represent the potentiometric head of a confined or partially confined aquifer. This indicates that the ground water basin consists of interlayered aquifers which are variably confined and are to some extent hydraulically connected.

Domestic wells commonly tap aquifer horizons which are 20-40' thick and located within 150' of the land surface. It is noted that several wells were drilled as deep as 225'. In general, wells in the east half of the study area are deeper than those to the west. Data for municipal water supply wells adjacent to the study area indicate that these higher volume wells are deeper (greater than 400') than the domestic wells, and are drawing water from a longer screened interval (several hundred feet). The municipal wells are recorded (Wateresource, 1993) as tapping an unconfined aquifer, although it is possible that they intersect multiple water-bearing horizons which exhibit variable degrees of confinement. It is likely that the water source for the municipal wells is hydraulically connected to the aquifers tapped by domestic wells. It is therefore reasonable to expect that cross-contamination of water sources may occur.

4.1.3. *Direction of Ground Water Flow*

Studies which define the altitude and configuration of the pre-development water table are documented by Arteaga (1986). Water level contour maps were developed from 28 water-level measurements taken in 1964, and 37 measurements available for the period of 1949-1966. Because ground water moves from areas of high water levels to areas of low water levels, this information can be used to determine the rate and direction of ground water flow.

The direction of ground water flow through the majority of the area of concern in this review is shown to be from southwest to northeast, toward the north end of Prison Hill. In the vicinity of Clear Creek, south of this study area, ground water flows to the southeast, parallel to Clear Creek and toward the Carson River at the south end of Prison Hill. Ground water flow directions may be locally variable in the southeast, where consolidated rock underlies part of the study area at shallow depths. East of Bobby Sox Fields, ground water movement is likely to parallel topography. It would therefore have a component of flow directed to the west-northwest toward Muldoon Street, which is roughly located in the topographically lowest part of the valley. At the null point of the west-trending gradient, the flow would again be dominated by north-northeast vectors. In the area described by S. Edmonds and Conte Drives, south of Clearview Drive, ground water may also be expected to exhibit a component of flow which is generally coincident with topography. In this instance, however, it is likely to be east-northeast. Ground water movement in this area is complicated by the presence of a fault to the east of Conte Drive, which may act as a barrier on the flow regime.

4.1.4. *Rate of Ground Water Flow*

Ground water flow velocities can be calculated if data for the gradient, hydraulic conductivity, and permeability are available. Wateresource Consultants, Inc. (1993), presented these data for municipal supply wells as part of a data base compiled for Carson City's Wellhead Protection Program. Information available from Arteaga (1986) was used to calculate these parameters for non-municipal supply wells in the areas of concern. Hydraulic conductivities generally range from 4-10 ft/day, gradients are generally very flat and average 0.006, and the accepted default value for porosity is 0.25. Based on this range of values, velocity of ground water flow may be expected to vary between 0.096 ft/day and 0.24 ft/day. These numbers are equivalent to approximately 35 ft/yr and 88 ft/yr, respectively. Hydraulic conductivities estimated from well pump-test data and presented by Arteaga (1986) indicate that lower conductivities are more prevalent in the study area. Therefore, flow velocities are more likely to be reflected by the low end of the range of values presented above.

4.2. *Hydrogeologic Qualifications for Contaminant Sources*

In order to properly explain the presence of a contaminant in ground water, the contaminant in question must be evaluated in the context of the hydrogeologic environment and the observed chemical distribution. Based on the review of hydrogeologic and water quality data presented above, several conditions can be defined which any proposed item must meet in order to be considered as a viable contaminant source. These conditions are outlined below.

- There must be a universal aspect of the source which makes it equally applicable to all defined areas of contamination. It is unlikely that the chemical anomalies in southeast Carson City are caused by multiple, isolated point sources of different origin.

- The proposed source must be accountable for the observed distribution pattern of contaminants. If a single intermittent source or multiple point sources are involved, the expected pattern would be spotty and periodic, with concentration spikes occurring in both time and space. If a source is continuous, the distribution of contaminants would approach that of a plume, although concentrations may be expected to vary with those of the source output.

- The position of the source must be hydraulically up-gradient from or coincident with the contaminated wells. The direction of ground water flow must be accounted for when considering movement of the contaminant in the subsurface.

- Existence of the source in time and space must allow for contaminant transport in time-frames dictated by the velocities of ground water flow as defined above. For example, if the source was historical, contaminated ground water may have moved through and out of the area before contaminants were detected. In this case, the historical source cannot be used to explain present-day nitrate levels. Alternatively, if the source was recent, ground water carrying the contaminants may not yet have reached the area of concern.

- Surface sources must be accounted for in terms of ground water recharge. A transport mechanism (aqueous) must be available to explain movement of the contaminant through the unsaturated zone in spite of the documented low precipitation recharge and shallow infiltration depths.

5.0. EVALUATION OF POTENTIAL SOURCES OF NITRATE

Dissolved nitrogen in the form of nitrate (NO_3^-) is the most common contaminant identified in ground water (Freeze and Cherry, 1979). Dissolved nitrogen also occurs in the form of ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-), nitrogen (N_2), nitrous oxide (N_2O), and organic nitrogen. Organic nitrogen is nitrogen that is incorporated in organic substances. Nitrate in ground water generally originates from nitrate sources at the land surface, in the soil zone, or in shallow subsoil zones where nitrogen-rich wastes are buried (Freeze and Cherry, 1979).

Nitrate may enter the soil as a result of a variety of man's activities on or near the ground surface. Once in the ground, it may be transported in solution by downward-percolating soil water, and eventually enter the ground water flow regime. Potential sources of soil nitrogen are decomposing plant debris, animal waste, nitrate-rich fertilizers, and sewage disposal on or beneath the land surface. Contamination in a well may result from direct discharge of contaminated surface water into the well, or by natural infiltration of the contaminated surface water to the zone of ground water production.

Several items have been presented as possible sources of the nitrate contamination reported in southeast Carson City. The specific areas of concern are outlined below:

- historic timber-related activities;
- fowl habitat/Ross Gold Park;
- prison farm/land application of septage;
- wastewater treatment plant/distribution lines;
- agricultural land use/fertilizer application;
- livestock; and,
- septic systems.

Vector has investigated each of the above items in terms of its viability as a potential cause of nitrate contamination. Where appropriate, potential contaminant sources are evaluated in the context of the hydrogeologic environment. Results are discussed in the subsequent sections.

5.1. *Historic Timber-Related Activities*

Concern has been expressed by members of the community that historic lumber operations may have been the source of nitrate contamination. Information about the Carson-Tahoe Lumber and Fluming Company was obtained by personal communication with Chris Dewitt, Supervisor, State of Nevada Railroad Restoration, Bob Nylen, Curator of History, Nevada State Museum, and Kyle Wyatt, Assistant Curator, Nevada State Railroad Museum. Documents at the Nevada Historical Society were also examined. From this research, it has been determined that the flume line, V & T rail spur, the lumber yard, and the company's planing mill and box factory were not located within or up-gradient of the area of concern. The Carson-Tahoe Lumber and Fluming Company, which ceased operations in 1898, was located close to what is now Curry Street, west of U.S. Highway 395. The area of operations, including the flume, lumber yard, and some of the rail spurs, was roughly bound by Fairview Ave. on the north, and extended no further south than Koontz. The company's planing mill and box factory was located on Stewart Street, 1/2 mile north of the Ranger Station.

Given ground water flow velocities of 35 to 88 ft/yr, as derived in Section 4.1.4., ground water underlying the operations would have moved between 3325 feet and 8360 feet from the point of origin in the 95 years since the cessation of timber-related activities. However, because all of the historic lumber operations were located north and northwest of the study area, and because the direction of ground water flow in the study area is from southwest to northeast, ground water could not have moved from the operations area into the area of concern. Comparison of geographic relationships, ground water flow direction, and flow velocities proves that historic timber operations could not have caused the elevated levels of nitrate observed in southeast Carson City.

5.2. *Fowl Habitat/Ross Gold Park*

No evidence was found to support the suggestion that the pond at Ross Gold Park, which hosts a large waterfowl population, may be a source of nitrate contamination. The pond, approximately ¼ acre in size, is located in the north-central part of Ross Gold Park adjacent to Overland Drive, between Oak and California Streets. According to information obtained from the Carson City Parks Department (Steve Kastens, personal communication), the pond was constructed in May, 1973, and was lined during construction with a 6" layer of soil having a 4% bentonite mix. The Parks Department has not noted fluctuating water levels or other evidence of liner failure; no leakage from the pond to the ground water system has been documented.

A chemical analysis of water from the pond was performed in December, 1993, by the Carson City Wastewater/Water Laboratory. Results showed a concentration of 0.03 mg/l nitrogen, which is equivalent to 0.135 mg/l nitrate. Assuming that this water could have leaked from the pond, it is not reasonable to expect that nitrate concentrations of less than 1 mg/l could be responsible for the degree of contamination observed in adjacent parts of the study area.

5.3. Prison Farm/Land Application of Septage

Water quality samples from piezometers surrounding the area of land application of septage, south of the prison compound at the Nevada State Prison Ranch/Dairy, were taken quarterly since January, 1991. Elevated nitrate levels are reported for May (18.6 mg/l), June (42.5 mg/l), and August (48.0 mg/l) of 1993 in piezometer #2. This monitoring well is located on the west-central boundary of the application area, adjacent to the southerly realignment channel for Clear Creek. Nitrate levels in this well had shown a substantial decrease by November, 1993, with a concentration of 6.06 mg/l.

Information on collar elevations of the monitoring wells is not detailed enough to allow the precise determination of the direction of ground water flow in the immediate vicinity of the wells. As documented by Arteaga (1986), regional-scale flow is to the southeast, parallel to the Clear Creek drainage and toward the south end of Prison Hill. It is unlikely that ground water underlying the area south of the prison compound is moving toward the north, crossing the Clear Creek drainage, and continuing to move north toward the southern part of the study area.

It should be noted that if contamination was derived from farming practices, a relatively continuous supply of water (irrigation), and consequently of leachate, would be generated. In this case, the contaminants might be expected to move as a front/plume, and be relatively continuous in an up-gradient direction toward the source. If the contaminants were moving north toward the south end of the study area, anomalous nitrate concentrations would be expected in monitoring wells to the north of piezometer #2. No data exists to support this contention, and the presence of clean wells between the prison farm and the southern occurrences of nitrate on S. Edmonds Drive argues against this alternative.

Consideration of flow velocities also supports the conclusion that land application of septage south of the prison compound is not responsible for the contamination in the study area. Given a rate of ground water movement of 35-88 ft/yr, the contamination documented in piezometer #2 would have moved a maximum of 15-55 feet since it was detected (May, 1993). Additionally, the short duration of the contamination episode (6 months) would allow for substantial down-gradient dilution, possibly to non-anomalous levels over relatively short distances.

5.4. Wastewater Treatment Plant/Distribution Lines

The distribution system which transports waste and treated effluent between the wastewater treatment plant and the prison farm has been considered as a potential source of nitrate contamination. The system enters the study area from the north and parallels Hillview Drive to the south until it meets Clearview Drive. At the intersection of Hillview and Clearview, it takes a turn to the west until it intersects Muldoon Street. The distribution lines parallel Muldoon to the south, and cross Snyder before reaching the prison farm.

It is necessary to consider the direction of ground water movement in the evaluation of the distribution lines which transport waste and effluent between the prison farm and the wastewater treatment plant. In order for the distribution lines to have caused the observed contamination, any leakage present must have occurred up-gradient from the affected wells. It should be noted that the distribution lines were designed to cross the study area at the topographically lowest part of the basin (Turner, 1993). The return line, which carries untreated sewage from the prison to the wastewater treatment plant, is designed as a gravity-flow system through the study area, and therefore contains unpressurized flow in a northerly, down-gradient direction. The sewage is carried from a lift at the prison by a pressure main north to Snyder; at Snyder, it is carried by gravity flow north to the wastewater treatment plant. In December, 1993, flow at the pressure main at Snyder was recorded at 0.5 CFS. At the same time, flow was recorded at the interceptor at Koontz Lane at 0.49 CFS. It is likely that the slight reduction in values is either a discrepancy in the precision of measurements, or reflective of friction losses in flow. There is no indication of leakage from the sewage line.

For the distribution lines to cause the contamination, it is necessary for the leakage responsible to flow up-gradient in order to explain the geographic pattern of the anomalous well samples. Based on these relations, and on the negative results of the leakage tests, it is determined that contamination both to the west and east of the lines could not have been caused by the distribution system.

5.5. *Agricultural Land Use/Fertilizer Application*

Nitrate contamination in ground water may result from agricultural land uses. Bacteria living on the roots of certain plants, such as alfalfa and legumes, convert atmospheric nitrogen to nitrate and transfer it to the soil, where it is used by the plants. Excess nitrate may also be released to soils through the application of nitrate-rich fertilizers to irrigated farm land. Some of the surplus nitrogen, generated by plants or derived from fertilizers, may be transported in solution by downward-percolating water and may eventually reach ground water. In order for these to be feasible sources, however, it is necessary to identify a transport mechanism with which to carry nitrates from the base of the root zone (limit of infiltration of natural recharge precipitation) to ground water. Continuous surface application of water through irrigation is the most plausible mechanism.

Evidence of intense agricultural use of the land area under study was not uncovered during the course of this investigation. Residential development has dominated land use since the 1950's in the west-northwest portion of the study area, and since the mid-1970's in the southwest part. It is Vector's understanding that the study area was under control of the U.S. Bureau of Land Management (BLM) prior to mid-1950. Although BLM ground may be used as pasture, widespread farming is not one of the land uses commonly noted. Arteaga (1986) and Arteaga and Durbin (1978) refer to the existence of irrigated pasture land, and not of crop land. They state that irrigation wells do not constitute a major source of ground water withdrawal. From this, it can be inferred that water applied to the land surface during irrigation was relatively minor. Because successful crop growth in this area is dependent on irrigation, it is concluded that agricultural use was not prevalent either prior to or during private residential development. By analogy, crops likely to produce excess soil nitrate or require widespread application of nitrate-rich fertilizers are not considered to be prevalent either historically or presently. They are therefore not considered a viable source of nitrate contamination in the area.

Residential application of fertilizers may produce localized occurrences of excess nitrate in soils or in run-off water. If a household is supplied by a domestic well which does not have a sanitary seal, or which is improperly sealed, it is possible that the well could become contaminated by direct entry of nitrate-bearing run-off water from a fertilized plot of ground. However, such point sources do not account for the distribution of recently documented contaminants. If unsealed, private wells and locally applied fertilizers were responsible, geochemical highs would appear almost instantaneously as contaminated surface water travels down the well. Similarly, the source of contamination (surface water) would cease coincidentally with the end of irrigation. Any nitrates that reach the ground water would move away from the well at a rate of 35-88 ft/yr. Repeated measurements of elevated nitrates would not be expected unless the well was sampled at the same time each year, and contaminated surface water run-off was coincidentally generated at the same time each year. The regularity of these events is considered unlikely. In addition, this proposed point source does not adequately address the increases in concentration over time documented in historical water quality data. A steady discharge by a point source would be required to explain the continuity of observed values in time and space, as well as the trends toward increasing concentrations over time. In short, down-hole movement of nitrate-rich fertilizers in unsealed private wells cannot uniformly explain the presence and distribution of the area-wide contamination.

5.6. Livestock

The presence of livestock has been presented as a possible source of nitrate contamination. Livestock as a contaminant source is reported in the literature in the context of animal feedlots, which concentrate a large volume of waste in a relatively small acreage (U.S. EPA, 1990). It should be noted that no feedlots are present in the study area. In the publications reviewed for this study, ground water contamination by livestock on pasture land is not documented. Where animal wastes are widely scattered on the land surface, a concentration of source material sufficient to generate contaminated leachate is unlikely. Fetter (1993) reports a study which showed that ground water from a shallow unconsolidated sand aquifer beneath permanent pasture has less than 1.0 mg/l of nitrate as nitrogen. Note that this study took place in Ontario, Canada, which has a higher quantity of annual precipitation than Carson City. It therefore also has a higher potential for the generation of leachate from animal wastes, with subsequent infiltration to ground water through natural recharge. In spite of these factors, the Canadian study did not show contamination in the ground water.

Vector does not consider livestock on pasture land in the Eagle Valley to be a viable source of ground water contamination in the area of concern. This conclusion is based on the following:

- precipitation on the floor of Eagle Valley does not recharge ground water (Wateresource, 1993);
- infiltration depths of natural recharge water is estimated as five feet (SCS, 1979; Walker, 1993);

- as stated in the preceding section, water use for the irrigation of pasture land in the area of concern has been minor over time, indicating that artificial recharge is also minor;

- cumulative concentrations of animal wastes likely to be found on pasture land is minimal and therefore concentrations of nitrate in leachate, if generated, would be negligible;

- urine would evaporate before infiltrating to the water table; and,

- documentation of nitrate contamination under permanent pasture land was not found in the Canadian study described above.

Individual animals may produce localized occurrences of excess nitrate in a manner similar to that discussed in the preceding section on residential application of fertilizers. As with any local point source, it is possible that water could become contaminated if a household is supplied by a domestic well which is improperly sealed. The cause would be direct introduction of either source material or nitrate-bearing water into the well. This means that a waste pile must be located close enough to and up-gradient from the wellhead so that either the waste itself is carried into the well, or water which percolates through the waste pile and generates leachate enters the well.

In order to evaluate the presence of such multiple point sources, the Carson City Utilities Department surveyed the area and plotted the presence of 96 horses and 1 llama in the 1.7 square miles of concern. The distribution of these animals relative to the location of elevated nitrate levels was examined to determine if they could uniformly account for the observed water chemistry. A total of six horses at three locations were documented at residences from which elevated nitrate was reported. The remaining animals reside on property which is served either by municipal water supplies, or by domestic wells which do not show elevated nitrate levels.

Vector does not believe that the contaminant source is domestic livestock, based on the following:

- there is no correlation between the presence of animals and anomalous wells;

- there is a lack of source material geographically positioned to provide contamination to most of the wells of concern;

- it is reasonable to assume that household waste management practices would assure adequate separation of manure piles from wellheads;
- animals as point sources cannot account for the distribution of recently documented contaminants; and,
- individual animals as a source cannot adequately account for the increase in concentration over time observed in historical water quality data.

5.7. Septic Systems

The introduction of nitrates to ground water from septic systems has been widely documented (Driscoll, 1986; Freeze and Cherry, 1979; Fetter, 1993; U.S. EPA, 1990). The viability of septic systems as the source of the observed contamination is discussed in subsequent sections.

5.7.1. NDEP Policy Statement

The Nevada Division of Environmental Protection (NDEP) has generated an internal policy which defines a conservative maximum number of residences which may be permitted on septic systems. Before this number may be exceeded, NDEP requires that a ground water study be performed, and a determination made that continued installation of septic systems will not adversely affect ground water. The "trigger" number defined by NDEP for Eagle Valley is 105 residences per square mile. Approximately 400 homes in the 1.7 square mile study area use septic systems for domestic waste disposal, which is more than twice the number recommended as a conservative level.

5.7.1.A. Technical Justification

The premise used by NDEP in determining the number of residences which will trigger the requirement for a ground water study is based on the following two-part governing equation:

- total contamination = contamination contributed to the total aquifer recharge + contamination contributed to the ground water in storage.

Terms are defined as follows:

- total contamination is proportional to total # residences on septics;

- ground water in storage = ground water stored in upper 100' of saturated alluvium;
- the volume available for assimilating (diluting) septage is the volume of the total aquifer recharge plus groundwater in storage; and,
- total # septics = # septics affecting recharge volume + # septics affecting storage volume.

Based on the above premise and on the assumptions and calculations outlined below, the governing equation is defined as follows:

$$\# \text{ septics} = \frac{(0.2)(\text{ppt recharge AF}) + (.02)(\text{storage AF})}{.392 \text{ AF}}$$

Values for precipitation recharge, ground water in storage, and area of basin were obtained from Nevada Department of Conservation and Natural Resources, Division of Water Resources, Water Planning Report No. 3 (1971).

5.7.1.B. General Assumptions

Assumptions inherent in the premise used to develop the governing equation are listed below.

- All contamination being considered is derived from septic systems; therefore, total contamination is related to the total # of residences on septic systems.
- Total nitrogen has been selected as the constituent of primary concern with respect to impacts on ground water quality from septic systems.
- An estimate of maximum residential flow is 350 gallons per day, which is equivalent to 0.392 acre-ft/year/residence.
- Based on the EPA Design Manual for Onsite Wastewater Treatment and Disposal Systems, the concentration of total nitrogen which enters a leach field varies from 35 to 100 mg/l. As a conservative approach to ground water protection, 100 mg/l total nitrogen was chosen as input to the leach field.

- As a conservative estimate for use in the governing equation, the accepted limit of total nitrogen in ground water used for drinking water is 10 mg/l.
- All of the 100 mg/l of total nitrogen is available to be converted to nitrogen as nitrate.

5.7.1.C. *Assumptions and Calculations Related to Recharge Considerations (The First Factor in the Governing Equation)*

Assumptions relating to recharge considerations are listed below.

- A 50% decrease in concentration of septic effluent in the unsaturated zone was assumed (e.g., plant uptake, possible dilution, etc.). Therefore the possible concentration of the discharge from a septic system which could reach the ground water was assumed to be 50 mg/l.
- Precipitation recharge has a total nitrogen content of zero.
- If precipitation recharge is assumed to have a nitrogen content of zero, then all nitrogen in recharge to ground water must come from septics. If a septic system has an output of 50 mg/l, but 10 mg/l is the acceptable limit, then the ratio of permissible septic recharge to precipitation recharge must be 1:5, or 0.20. Therefore, septic recharge = (0.20)(precipitation recharge).

In the determination of the first factor in the governing equation, which addresses the relationship of the total # of residences on septics to the contamination in the total recharge to the aquifer, the following relationships were employed:

- septic recharge = (# septics)(output/septic)
  = (# septics)(0.392 AFY);
- septic recharge/precipitation recharge = 1/5 = 0.20; and,
- septic recharge = (0.20)(precipitation recharge).

Consequently,

$$\text{\# septics} = \frac{(0.20)(\text{ppt recharge AFY})}{0.392 \text{ AFY}} .$$

5.7.1.D. *Assumptions and Calculations Related to Aquifer Storage Considerations (The Second Factor in the Governing Equation)*

Assumptions relating to recharge considerations are listed below.

- A constant volume of aquifer storage is assumed, with negligible interbasin flow.
- Ground water in storage may have a background value of total nitrogen of 0-5 mg/l.
- Because 10 mg/l is the "trigger" limit of nitrogen in ground water used for drinking, and water in storage may have up to 5 mg/l background concentration, the maximum concentration of nitrogen which could be added to water in storage is 5 mg/l. Therefore, some number less than 5 mg/l must be used in the calculations to provide an adequate means of pollution prevention. In this instance, 2 mg/l was chosen as a limit for nitrogen added to ground water in storage.
- When calculating the effect of nitrogen from septic systems on the ground water in aquifer storage, no decrease in concentration of septic effluent in an unsaturated zone was assumed.
- If a septic system has an output of 100 mg/l, but 2 mg/l is the acceptable concentration to be added to ground water in storage, then the ratio of permissible septic nitrogen to aquifer storage nitrogen must be 2:100, or 0.02. Therefore, septic nitrogen contributed to ground water in storage = (0.02)(ground water in storage).

In the determination of the second factor in the governing equation, which addresses the relationship of the total # of residences on septics to the contamination ground water in storage in the aquifer, the following relationships were employed:

- total nitrogen of ground water in storage = nitrogen contributed from septics + background nitrogen of ground water in storage;
- concentrations of nitrogen from septics and background nitrogen concentrations are proportional to the respective associated fluid volumes;

- nitrogen contributed from septics = (# of septics)(output from septics) = (# of septics)(.392 AF);
- concentration of septic nitrogen/background concentration of ground water in storage = 1/50 = 0.02; and,
- septic nitrogen contributed to ground water in storage = (.02)(ground water in storage).

Consequently,

$$\# \text{ septics} = \frac{(0.02)(\text{AF storage})}{0.392 \text{ AF}} .$$

5.7.1.E. Conclusions: Validity of Policy

As a conservative approach to ground water protection, the assumptions, parameters, and calculations presented above provide an appropriate guideline to the point at which the density of septic systems may begin to adversely affect the quality of ground water. A comparison of NDEP's guidelines to the density of septic systems existing in the study area shows that the ground water is at risk of nitrate contamination. The parameters outlined by NDEP support the conclusion that additional septic systems in the study area should not be permitted.

5.7.2. Suitability of Soils

As described in Section 4.1.1. above, data from the Soil Conservation Service (1979) shows that almost two-thirds of the study area is mapped as Surprise soils, which are described as deep and well-drained with a moderately high permeability. Several other soil types are described in the east and southeast portions of the study area. Although most of these soils (Haybourne map units, subdivided according to per cent slope) are also characterized by moderately high permeabilities with effective rooting depths of 60 inches, other soils are described as having a moderately slow permeability with an effective rooting depth of 29 inches. The less permeable soils are named Indiano Variant, and are exposed in the east-central part of the study area. They occupy an area roughly described by Valley View on the north, Northview on the west, Bennett on the south, and Gentry on the east.

5.7.2.A. *Permeable Soils*

The Soil Conservation Service has described each of the soil units in terms of its potential to support various uses (SCS, 1979). The Surprise and Haybourne soils, which have been shown to be moderately to highly permeable, are described as fair to poor for community development and sanitary facilities. In all cases, SCS suggests that if the density of housing is moderate or high, community sewage systems are needed. SCS states that septic tank absorption fields on the Surprise soils are a hazard to health because of seepage. This implies that contaminant-bearing water is likely to seep from leach fields, infiltrate through the permeable soils, and enter the ground water to become available to domestic water supplies.

It is reasonable to conclude that where a large number of septic systems, with an average output of 350 gal/day/system (127,750 gallons/year/household), are installed on highly permeable soils, a semi-continuous fluid flow in the unsaturated zone may be generated. This quantity of fluid could create a saturated front beneath and adjacent to the leach field. Saturation would encourage leakage through the subsurface and downward percolation of water. If that percolation is fast, in situ treatment of the septage may not occur prior to fluid intersection with the relatively shallow ground water. It is recognized that rapid percolation is desirable for effective operation of leach fields, because a septic system is considered to have failed if it does not drain properly. However, it is reasonable to expect that, from the perspective of ground water protection, percolation can be too rapid and allow contaminants to reach ground water at shallow levels. Data supplied by the SCS (1979) indicates that this may be the case for the Surprise and Haybourne soils.

5.7.2.B. *Impermeable Soils*

The Soil Conservation Service has described the Indiano Variant soils as exhibiting a moderately slow permeability and an effective rooting depth of 29 inches (SCS, 1979). Depth to bedrock is also reported as 29 inches. The potential is described as fair to poor for community development and sanitary facilities. SCS (1979) comments that if density of housing is moderate to high, community sewage systems are needed. Uses are limited by slope and shallow depth; houses and access roads need to be designed so that bedrock is not exposed during excavation. In soils which exhibit low permeability and shallow depth to bedrock, septic system failures are possible. Percolation tests are recommended and modified construction may be required. Water quality reports from Consumer Health Services record contamination from a septic system failure on S. Edmonds. The system had been constructed on or immediately adjacent to the Indiano Variant soils.

5.7.3. *Design and Installation*

An investigation into the design and installation of septic systems was undertaken in order to determine whether modified designs were utilized in the study area. Modified designs are recommended by the State of Nevada Department of Human Resources under the following circumstances:

- if the required percolation tests show excessively high rates, soil amendment to impede the flow of water is required as a ground water protection mechanism; and,
- if the required percolation tests indicate that the soils are not sufficiently permeable, soil amendment to increase permeability is required to prevent system failure.

Carson City began supervising the permitting and installation of septic systems in 1973. Prior to this time, permitting was done by the State of Nevada Department of Human Resources. Information obtained from the Carson City Health District indicates that septic system designs required by the City have been similar to those required by the State. However, it is acknowledged that the Carson City Health District did not require percolation tests of the soils prior to January, 1993. Design modifications were determined on-site in response to a visual inspection by the City Health District, and implemented according to verbal agreement between the Health District representative and the builder.

Files at the Carson City Health District offices were inspected for records of septic system designs, in an effort to correlate system design and well failures. No files were discovered which recorded either proposed or "as-built" designs submitted for review and approval. There were some notations by Health District representatives concerning field inspections and system installation; however, design data was generally lacking. In short, it was not possible to verify actual construction design, or the existence or need for modifications of standard designs.

In lieu of hard data, Vector interviewed two local home builders. Results of the interviews indicate that the City Health Department utilized a standard septic system design. Mr. Pete Ranser, a local builder, indicated that the standard design was to construct one trench with the following dimensions: 60 feet in length, 15 feet in depth, and 2 feet in width. Mr. Rasner indicated that the City Health Department would verify the design in the field, and approval would be essentially automatic if the design met the above specifications. He stated that of the six homes he built in the area, none have experienced septic system failure. Neither builder recalled being asked to amend soils in order to either impede the percolation rate in permeable soils, or increase it in less permeable soils. However, the required size of the leach fields and lengths of the leach lines were occasionally modified according to the perceived permeability of the soil. Vector was unable to document these modifications.

It is possible that the apparent lack of modified designs used in the installation of septic systems may have increased the possibility of ground water contamination. Although, as previously stated, high percolation rates in soils ensure that a septic system does not fail, in some cases percolation can be too rapid and allow contaminants to reach shallow levels of ground water. This may have been the case in portions of the study area; data are not available to confirm or deny this hypothesis.

5.7.4. *Assessment of Source Characteristics*

Section 4.2 of this report described five conditions which a proposed contaminant must satisfy in order to be considered as a viable source. These conditions are used to explain the presence of a contaminant in ground water in the context of the hydrogeologic environment and the observed chemical distribution. It is shown below that septic systems fit the parameters described by those conditions, and are therefore a likely source of nitrate contamination in ground water.

- *There must be a universal aspect of the source which makes it equally applicable to all defined areas of contamination.*

It is Vector's understanding that there are approximately 440 residences in the study area, and that domestic waste from most of them is disposed of by individual septic systems. Septic systems are a widespread and uniformly applicable source of nitrate in the area.

- *The proposed source must be accountable for the observed distribution pattern of contaminants.*

Septic systems provide an array of multiple point sources which discharge high volumes of water at a fairly constant rate. Potential point sources are distributed throughout all areas experiencing elevated nitrate levels. Concentrations of contaminants from septic systems are expected to rise slowly over time, as nitrate loading occurs; however, concentration spikes may be seen if source systems operate intermittently. In general, continuous use of multiple point source systems would cause a contaminant distribution that would approach that of a plume, although concentrations may be expected to vary with those of the source output. The distribution pattern would eventually create a trend of contamination which generally parallels the direction of ground water flow.

- *The position of the source must be up-gradient from or coincident with the contaminated wells.*

This condition is satisfied if septic systems are considered the source of contaminant movement in the subsurface. The universal presence of septic systems accounts for point sources in all direction surrounding a contaminated well. Elevated nitrate levels may be caused by a septic system on the same property as the contaminated well, or by one or more septic systems located on adjacent up-gradient properties. The widespread use of septic systems puts a potential source in a position which will satisfy any geographic requirement.

- *Existence of the source in time and space must allow for contaminant transport in time-frames dictated by the defined velocities of ground water flow.*

Septic systems have been used in the study area since the mid-1950's. Residence time of nitrates in the study area, when evaluated in terms of ground water flow velocity, will depend on continuity of source discharge and location. However, the continuous use of septic systems through time allows for the presence of multiple point sources in any time-frame chosen for discussion.

- *Surface sources must be accounted for in terms of ground water recharge.*

A transport mechanism (aqueous) must be available to explain movement of the contaminant through the unsaturated zone in spite of the documented low precipitation recharge and shallow infiltration depths. The average output of a domestic septic system is estimated to be 350 gallons per day. This translates to 127,750 gallons per year per household. A relatively continuous output of this volume could create a saturated front beneath and adjacent to the leach field. Saturation would encourage leakage through the subsurface, and downward percolation of water. Therefore, the aqueous transport mechanism for the contaminant is provided with the source.

6.0 SUMMARY AND CONCLUSIONS

Vector has compiled and reviewed available information concerning the hydrogeologic setting of part of the Eagle Valley in southeast Carson City, and evaluated the existence and possible sources of nitrate contamination documented in domestic wells. It has been determined that previous interpretations of the hydrogeologic setting are sound, and the existence of nitrate contamination has been firmly established by water quality studies.

A set of parameters was defined and used to evaluate proposed contaminant sources as the causes of observed elevated nitrate levels. The conditions are two-fold: first, the existence of a proposed source must be appropriately documented in time and space; second, it must be adequately explained in the context of the hydrogeologic environment.

Each of the following items was investigated and assessed in terms of its viability as a potential source of nitrate contamination:

- historic timber-related activities;
- fowl habitat/Ross Gold Park;
- prison farm/land application of septage;
- wastewater treatment plant/distribution lines;
- agricultural land use/fertilizer application;
- livestock; and,
- septic systems.

It has been determined that, of the seven items investigated, the widespread use of septic systems is the only proposed source of nitrates which can explain the observed water quality data, and can be adequately interpreted in the context of the hydrogeologic setting. Because the source for Carson City's municipal water supply is to some degree hydraulically connected to aquifers tapped by domestic wells, cross-contamination of water sources may occur. Accordingly, it would be prudent to eliminate the source of nitrate prior to widespread decrease in the quality of water provided by both domestic and municipal supply wells.

7.0 *LIMITATIONS*

This report was prepared in accordance with generally accepted hydrogeologic practices applicable at the time of preparation. The findings and conclusions presented in this report are based on review of appropriate available literature, data provided by the Carson City Utilities Department, and on information gathered verbally from interviews with representatives of appropriate public and private agencies. New technical information was not generated during the course of this review.

Conclusions presented in this report are specific for this site and this client, and may not be expanded to include areas beyond this site. Vector Engineering, Inc., makes no other warranties, express or implied, as to the professional advice provided in this report.

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