STATE OF ARIZONA

THE IMPACTS OF SEPTIC SYSTEMS ON WATER QUALITY OF SHALLOW PERCHED AQUIFERS:

A CASE STUDY OF FORT VALLEY, ARIZONA

Prepared by

Hydrologic Support and Assessment Section

Water Quality Division

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The Impacts of Septic Systems on the Water Quality of Shallow Perched Aquifers:
A Case Study of Fort Valley, Arizona

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EXECUTIVE SUMMARY

Located five miles northwest of Flagstaff in Northern Arizona, Fort Valley is a small community whose residents utilize private wells for their domestic water supply and septic systems for wastewater disposal. With the regional aquifer located at depths 2,000 feet below land surface (bls), most water for domestic use in Fort Valley is supplied by groundwater pumped from small, perched aquifers, which are located at depths ranging from near surface to where an aquitard is encountered at approximately 175 feet bls. The discontinuous nature of these perched aquifers makes the occurrence and availability of shallow groundwater in Fort Valley extremely variable and unpredictable. The perched aquifers are also drought sensitive and groundwater elevations in Fort Valley fluctuate according to the amount of precipitation recharged by rapid snowmelt, high intensity rainfall, and lateral inflow from surrounding hills.

Fort Valley residents became concerned about possible health consequences of using untreated groundwater in early 1993, when privately-conducted bacteria sampling detected fecal coliform in approximately half of the 25 domestic water systems tested. Concerns over these detections provided the impetus for an Arizona Department of Environmental Quality study to assess the impact of septic systems on the groundwater quality in Fort Valley. Of particular concern was the effect a seasonally-fluctuating, shallow groundwater table had on the proper operation of the leach fields of septic systems. Seven wells scattered throughout Fort Valley were each sampled three times during periods characterized by varying precipitation levels, and thus, dissimilar groundwater conditions: Fall 1993, which followed a very wet spring, Spring 1994, which was abnormally dry; and Spring 1995, which was very wet. By sampling during three different seasons, each with dissimilar groundwater conditions, both permanent and temporary groundwater quality impacts from septic systems in Fort Valley would be assessed by the study.

Groundwater samples were analyzed for Safe Drinking Water (SDW) inorganic constituents, bacteria (total coliform, fecal coliform, and fecal streptococci), and SDW Volatile Organic Compounds (VOCs) by contract laboratories. The analytical results indicated that the majority of groundwater samples collected by ADEQ in Fort Valley were of good quality with few Primary or Secondary Maximum Contaminant Levels (MCLs) for inorganic constituents exceeded, and only minor bacteria or VOC contamination detected. Generally, only two extremely shallow wells contained groundwater with greatly-elevated levels of many constituents.

The results of this study did not indicate widespread groundwater contamination in Fort Valley caused by septic system effluent. However, comparing the major septage-indicator parameters in the groundwater sample collected at an upgradient control site to the corresponding Confidence Intervals established for the seven wells sampled in the study area, it was concluded that septic systems do affect groundwater quality in Fort Valley. In addition, levels of septage-indicator parameters, such as total nitrogen (NO_3/NO_2 as N), total dissolved solids (TDS), and chloride, were found to be significantly correlated among each other, providing further evidence that septic effluent has affected groundwater quality in Fort Valley.

The groundwater quality data was examined for correlations by comparing the levels of various parameters with indices such as sampling periods, well types, wells, and groundwater depth. Although statistically significant relationships were discovered with each factor, groundwater depth proved to be the best predictor of groundwater quality. A pattern emerged in which the level of many groundwater quality parameters decreased at an extreme rate with increasing depth bls until a certain depth - designated the "threshold" depth - was reached. Groundwater below the "threshold" depth exhibited a much smaller rate of change in the levels of the groundwater quality parameters. The "threshold" depth for total nitrogen, TDS, chloride, hardness, sulfate, alkalinity, calcium, magnesium, and sodium were found to be 12-15 feet bls, while "threshold" depths for total kjeldahl nitrogen and turbidity were 45 and 4.5 feet bls, respectively. For parameters having water quality standards, such as a Primary or Secondary MCL, a "critical" groundwater depth was also established. The "critical" depth is defined as the depth, above which water quality standards would be exceeded. In all cases, the "critical" depth was above the "threshold" depth and extremely shallow, never exceeding more than approximately one foot bls.

The study also confirmed that depth to groundwater in Fort Valley was significantly related to the corresponding local precipitation levels, with greater precipitation levels causing higher groundwater elevations. Therefore, with increasing precipitation, the odds of having the groundwater contaminated by septic systems in Fort Valley increases significantly. Along with physical indices such as fine-textured soils, steep slopes, and shallow soil overlying bedrock, shallow groundwater is a major limitation to the effective operation of septic system leach fields.

The extent of groundwater contamination by septage-indicator parameters observed in this study does not warrant recommending replacing currently-installed septic systems with alternative wastewater disposal systems at this time. However, caution should be exercised in both the operation of the septic systems currently in place as well as selecting appropriate locations and types of wastewater disposal systems for any future development in Fort Valley. Septic systems, including those with buried leach fields or trenches, appear adequate for wastewater disposal during much of the year in most areas in Fort Valley; however, during periods of heavy recharge when groundwater levels rise, it would be prudent to dispose of wastewater by pumping out these septic tanks rather than allowing the septic effluent to possibly be leached through saturated soil which would fail to provide proper clarification. It would also be prudent for home owners to subject their septic tanks to a tightness test to determine if their septic systems are operating properly.

It is not appropriate to install septic systems with leach fields or trenches in soil types the Soil Conservation Service has rated "unsuitable" for use as leach fields, in areas where there is not a five foot vertical separation between the bottom of the leach field or trench and groundwater, or in areas where there is shallow groundwater (< 15 feet bls) during any time of the year. In areas where the soil type is rated "unsuitable for use as a leach field" or groundwater does not meet the above depth requirement, alternative onsite wastewater treatment and disposal systems designed by an engineer should be used to provide denitrification and filtration of septic system effluent and thus, avoid contamination of groundwater. These alternative onsite wastewater treatment and disposal systems should conform to regulations promulgated in *Engineering Bulletin #12* (ADEQ, 1989) and be approved for use by the Coconino County Health Department.

Another important precautionary measure involves well use, location, and construction. Ideally, domestic wells in Fort Valley should produce water from deeper perching horizons. Shallow perched aquifers, such as those where the groundwater depth is < 15 feet bls, should be avoided as domestic water sources. If wells must be drilled in locations having shallow perched aquifers in order to tap deeper perched aquifers, care should be taken that the well is unscreened in the upper aquifer and, moreover, also properly constructed and sealed so as to exclude the entry of water from surface water and near-surface aquifers into the well. Finally, any older wells in Fort Valley not having proper surface seals should be retrofitted so as to provide additional groundwater protection against contamination from surface runoff.

INTRODUCTION

During the winter of 1993, residents of Fort Valley, Arizona became concerned about local groundwater quality after fecal coliform were detected in a number of domestic water systems during privately-conducted bacteriological sampling. Both Fort Valley residents and the Coconino County Health Department suspected that these potentially disease-producing microorganisms were the result of seasonally high groundwater levels intersecting the leach fields of septic systems, thus allowing partially-treated effluent to contaminate the shallow, perched aquifers underlying this area. Previous studies have established that fecal microorganisms present in septic effluents have the potential to penetrate saturated soil, and under certain conditions, to be transported various distances through the soils presumably via saturated flow (Bitton and Gerba, 1994) .

In response to these groups, as well as a request from the Northern Regional Office (NRO) of Arizona Department of Environmental Quality (ADEQ) seeking policy guidance in regard to wastewater disposal in the Fort Valley area, the ADEQ Groundwater Monitoring Unit (GMU) conducted a three-phase groundwater sampling study to assess the impacts of septic tank systems on groundwater quality at Fort Valley during various groundwater conditions. It was also envisioned that the information gained from this ADEQ study could be further utilized in reviewing permit applications for wastewater discharging facilities.

Geography/Geology

Fort Valley is an unincorporated, small though steadily-growing, community situated in Coconino County about five miles northwest of Flagstaff in Northern Arizona. Bisected by US Highway 180, this settlement consists of individual houses spread throughout a four square mile enclave of privately-owned land. The community is located in a grassy meadow surrounded by coniferous forest of the Coconino National Forest, specifically the San Francisco Mountains on the north and east, A-1 Mountain on the south, and Wing Mountain on the west. Due to its higher elevation, Fort Valley is generally slightly wetter and colder than Flagstaff, with a mean annual precipitation of 22 inches and mean temperature of 43 degrees Fahrenheit.

Fort Valley is not served by either a public water or wastewater system. The water supply of this community is provided by private domestic wells, while onsite septic systems treat the wastewater generated by households. During the time frame of this study, there were approximately 100 homes in the Fort Valley area that utilized both private wells and septic systems.

Fort Valley is located in the Colorado Plateau physiographic province, characterized by flat-lying units of sedimentary rocks cut by deep, narrow canyons. In the vicinity of Fort Valley, the Colorado Plateau is topped by volcanic flows and cinders of the San Francisco volcanic field. This area is characterized by three distinct geologic units: alluvial and colluvial units, volcanic flow rocks and cinders, and lithified sedimentary units.

Hydrogeology

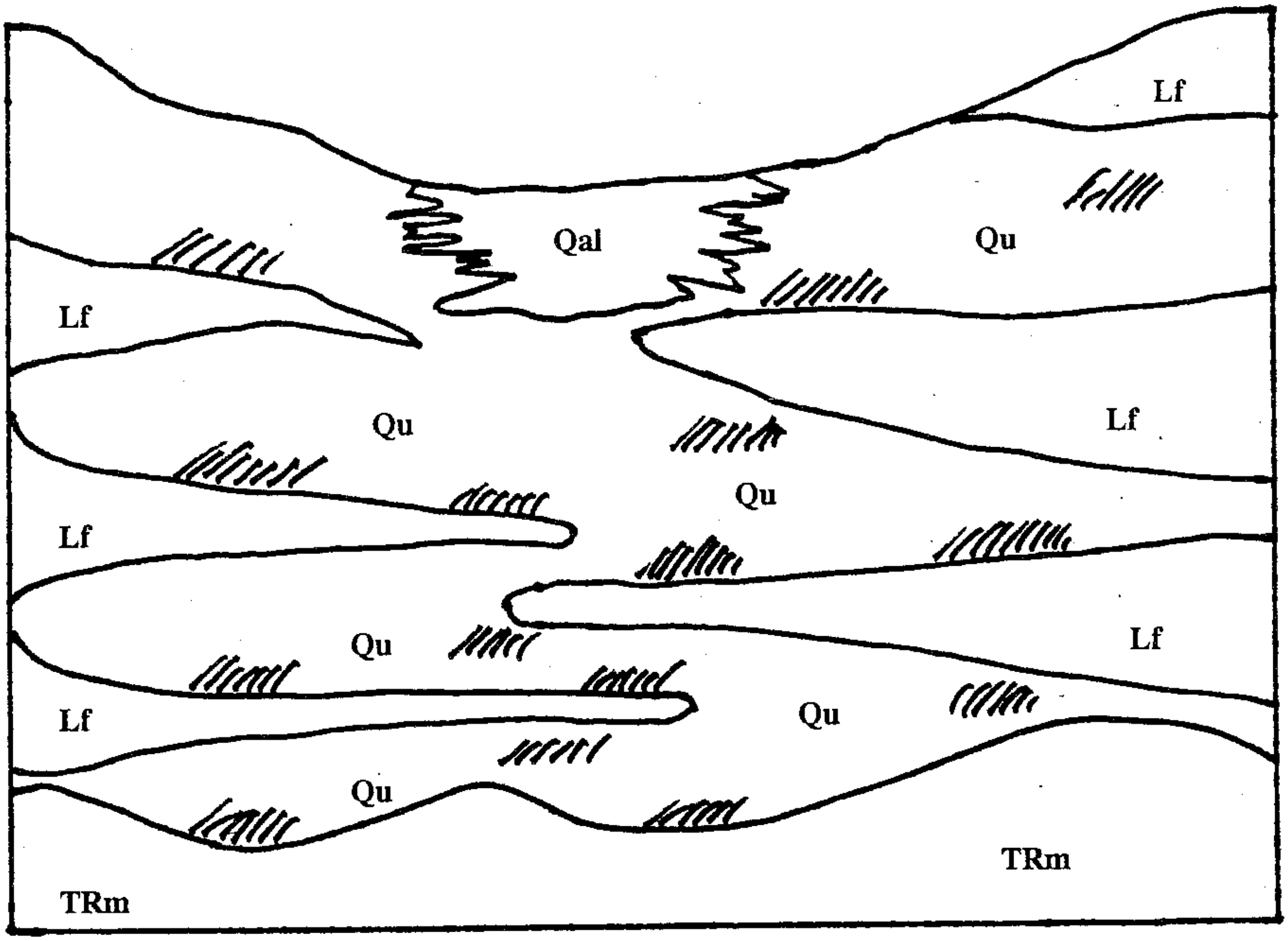
Located within the Flagstaff Area of the Little Colorado River Plateau Groundwater Basin (in regards to the hydrologic basins adopted by ADEQ and the Arizona Department of Water Resources (ADWR)), Fort Valley is drained by the Rio De Flag, a non-perennial water course having an average outflow of 375 acre/feet per year (ADWR, 1993). Groundwater constitutes the vast majority of water used in this small volcanic basin though this resource is available only in limited quantities due to both physical and economic constraints. Three geologic units underlying Fort Valley are used, to some degree, as sources of groundwater for the area:

1) Redwall Limestone - This is the regional aquifer, located at a depth of approximately 2,000 feet bls (ADWR, 1994). Since this is a depth uneconomic for withdrawing groundwater for most purposes (McGavock, et al., 1986) and water is generally available in overlying shallower units, few wells penetrate this limestone aquifer.

2) Moenkopi Formation - Encountered at depths approximately 175 feet bls, this geological unit provides only limited groundwater in the Fort Valley area. Consisting of medium to thin-bedded, reddish-brown shale and mudstone, with interbedded sandstone layers, this formation does not readily transmit water and its importance lies in its function as an aquitard (McGavock, et al., 1986). Its near impermeability results in water being perched in any alluvium, colluvium, or volcanic rocks which lie above it (Figure 1). Still, approximately a dozen wells in Fort Valley utilize the Moenkopi Formation as a groundwater source.

3) Perched Aquifers - Groundwater perched in alluvium, colluvium, volcanic cinders, and fractured lava-flow rocks above the Moenkopi Formation provides the majority of water used in Fort Valley. While located at an economically feasible depth for domestic wells, this perched groundwater has the physical drawback of being drought sensitive and does not provide a dependable supply for large water uses (ADWR, 1994). Most wells completed in Fort Valley draw water from these perched aquifers.

The perching layers in Fort Valley are limited in extent and the size of the aquifers depends on the dimensions of the perching layer and the saturated thickness of the aquifer. Volcanic flow rocks underlying Fort Valley have been reported to have a minimum and maximum thickness of 21 feet and 108 feet, respectively, while alluvial/colluvial deposits similarly have thicknesses of 7 feet and 84 feet, respectively. The saturated thickness, in turn, depends on the areal extent of the perching layer as well as the permeability of the aquifer material. Highly permeable aquifer material will result in a low mound of groundwater while more poorly permeable material results in a higher mound. Once an aquifer is recharged to capacity, any addition of water will result in "spillage" around the edges. Excess water will percolate down to a lower perching horizon or may drop all the way to the regional water table. In alluvium, the most common perching layers are impermeable clay lenses while lava-flow rocks perch a smaller amount of water. Water is perched in colluvial deposits by both clay layers and lava-flow rocks.



Qal	Alluvial deposits; clay, silt sand, gravel, cinders and lava flow rock, cobbles and boulders. Perched groundwater zones occur above clay and silt lenses and above unfractured lava-flow rocks.
Qu	Undifferentiated alluvial, colluvial and interflow deposits; clay, silt, sand, gravel, cinders and lava-flow rock cobbles and boulders. Perched groundwater zones occure above clay silt lenses, above unfractured lava-flow rocks, and above the Moenkopi formation
Lf	Undifferented lava-flow rocks; perched groundwater zones may occur in fractured lava-flow rocks.
TRm	Moenkopi Formation; alternating mudstone and poorly permeable sandstone strata. Perched groundwater zones may occur in sandstone strata.
////	Perched ground water zones.

Figure 1. Hydrogeologic Map of Fort Valley, Arizona.

Alluvial and colluvial deposits allow rapid infiltration of snowmelt, rainfall, and intermittent stream flow due to their high permeability, with recharge being greatest during summer thunderstorms and in times of rapid snowmelt. Significant amounts of water are recharged to perched aquifers by way of intermittent streamflow along the Rio de Flag and its larger tributaries. The alluvium found along these water courses is quite permeable and allows rapid infiltration to the aquifers beneath the channels. Another important source of recharge is lateral inflow from the hills surrounding Fort Valley, with water percolating rapidly through the alluvium and colluvium until it is intercepted by some sort of perching layer. Other precipitation events provide relatively little recharge, such as low intensity rainfall associated with wintertime cyclonic storms that is subject to high rates of evaporation and slow melting snowpack that results in moisture losses due to sublimation.

Groundwater levels fluctuate both spatially and seasonally throughout the Fort Valley area. The presence of numerous discontinuous perched aquifers spatially influences groundwater levels. With the majority of wells in Fort Valley obtaining groundwater from perched aquifers, even closely spaced wells may not be producing from the same aquifer. Two sets of wells sampled as part of this study are within 50 feet of each other, yet have water levels differing by over 75 feet. Seasonal differences in rates of recharge also affect groundwater levels, which typically decline from June through February when relatively little recharge from precipitation occurs, while rising from March through May (ADWR, 1992). A water level change of over 27 feet was recorded in a well sampled as part of this study. Depths to groundwater generally range from 20 to 170 feet below land surface (McGavock, et al., 1986). Well depths generally vary from 100 to 200 feet, with well yields ranging from 0.5 to 15 gallons per minute. Wells in the central and southwestern portions of the valley generally are shallower and have higher groundwater levels than the rest of Fort Valley.

Soils

Soils in the Fort Valley area generally consist of frigid subhumid soils of the Sponseller-Ess-Gordo Association. These soils are moderately deep, medium and moderately fine-textured, moderately sloping to very steep mountain soils. The soils were formed in residuum and colluvium weathered from basalt, rhyolite, andesite, cinders, ash-flow tuff, and related volcanic rocks (Hendricks, 1985).

Soils in the Fort Valley area could provide problems to the efficient operation of septic systems if their leach fields are constructed without regard to fine-textured soils, steep slopes, soil depth to bedrock, and high groundwater tables (USDA, 1975). Excessive vegetational growth, seepage and/or odor are indications that leach fields are not working properly. Soils commonly encountered in the developed portions of Fort Valley include:

1) Well drained soils on alluvial fills: Valle cindery loam, 0-2% slopes
Valle cindery loam, 2-8% slopes

2) Soils with restricted drainage: Siesta loam seeped variant, 0-2% slopes
Siesta loam, seeped variant, 2-8% slopes
Luth clay loam, seeped variant, 0-2% slopes

Important facts in determining the suitability of a soil for leach fields include (USDA, 1975):

1) permeability and percolation rates of the soil;
2) depth to seasonal watertable;
3) depth to bedrock or other impervious layers;
4) flooding potential, and;
5) soil slope

Soils in Fort Valley area vary widely in their suitability for leach fields, though all have some limitations. Specifically, the soil types and their suitability as septic leach fields are:

1) Valle cindery loam, 2-8% slopes - slight to moderate limitations, because of gentle to strong slopes.
2) Siesta loam, seeped variant, 2-8% slopes - moderate limitations, because of some strong slopes and slow permeability.
3) Valle cindery loam, 0-2% slopes - severe limitations, because of a seasonally high groundwater table averaging 5.5-7 feet bls.
4) Luth clay loam, seeped variant, 0-2% slopes - unsuitable, subject to seasonal overflow and has seasonably high groundwater averaging 2-5 feet bls.
5) Siesta loam, seeped variant, 0-2% slopes - unsuitable, subject to occasional overflow, slow permeability and has a seasonally high groundwater table averaging 3 feet bls.

Septic Systems Operation

Septic systems are a widely used method of disposing of residential or other domestic wastewater and sewage. Those systems are composed of two individual units, the septic tank which functions under anaerobic conditions and the percolation or leach field which operates aerobically under unsaturated flow. The septic tank is designed to slow down the movement of raw sewage and to promote the removal of solids either by settling or liquification. Thus, the septic tank reduces the organic load only to a limited extent; therefore, the distribution of the septic tank effluents into unsaturated soil is necessary to complete the treatment process (Bitton & Gerba, 1994). The leach fields for septic tanks typically consist of 500 to 600 square feet of drain field located at 18 to 24 inches below land surface, thus distributing the effluent over a wide area. The shallow depth of the field permits some evaporation as well as uptake of contaminants by plants. Because it is near the surface, the leach field operates under aerobic conditions, thus recharging the aquifer with fairly good quality water under normal circumstances. In order to accomplish this, a zone of unsaturated soil must occur between the leach field and the groundwater table so that the effluent from the septic tank is not discharged directly into the aquifer. Thus, the unsaturated soil must furnish the bulk of wastewater treatment by the processes of physical filtration, chemical reaction, and biological transformations. When operating correctly, septic systems efficiently renovate wastewater.

Properly designed, constructed, maintained, and located septic systems are efficient and economical alternatives to public sewage disposal systems, particularly in sparsely populated areas. However, septic systems have become a common source of groundwater pollution in the United States for several reasons (Canter and Knox, 1985):

1) Larger scale septic systems, with a greater potential for pollution, are being designed and used;
2) Septic systems often reach densities of 40 per square mile, a threshold above which is considered to have strong potential for groundwater contamination;
3) Septic systems routinely exceed their design life several-fold; and
4) Locational factors such as soil depth, soil percolation rates, slope, groundwater levels, and flooding potential are not always considered in selecting a septic system site. Sites having even periodically high groundwater levels are not suitable for the disposal of wastewater using conventional septic systems.

Another major problem with septic systems are improper installation and poor maintenance, which dramatically increases their failure rate (Bitton and Gerba, 1994). For instance, a Mohave County, Arizona study of 500 septic tanks found 22% of newly-installed septic tanks failed water tightness testing (Bishop, 1996).

Therefore, although septic systems can provide efficient and economical wastewater disposal, declines in groundwater quality due to indiscriminate use of septic systems in soils unsuited for adequate domestic waste purification has been documented by a number of studies (Bitton & Gerba, 1994).

Septic Systems Impact on Groundwater Quality

While the efficiency of constituent removal in the soil underlying the leach field affects the potential for groundwater pollution, the quality of the effluent from the septic tank portion of the system is also important. Constituents and their concentrations in domestic sewage are provided in Table 1. Alhajjar, et al. (1990), observed that nitrogen was very prevalent in septic tank effluent, ranging from 20 - 130 mg/l with an average of about 40 mg/l and existed primarily in ammonia (75%) and organic (25%) forms. Low nitrate concentrations are typically present in the effluent within the septic tank due to the associated anaerobic conditions. Phosphorus is also common in septic tank effluent, averaging 25 mg/l in single-household systems.

Table 1. Characteristics of Domestic Sewage

Constituent	Level
Total Suspended Solids	200 mg/l
Conductivity	700 umhos/cm
Chemical Oxygen Demand (COD)	500 mg/l
Biochemical Oxygen Demand (5-day BOD)	200 mg/l
Total Organic Carbon	200 mg/l
pH	8.0 mg/l
Alkalinity (as $CaCO_3$)	100 mg/l
Acidity (as $CaCO_3$)	20 mg/l
Total Phosphorus	10 mg/l
Total Nitrogen	40 mg/l
Chloride	50 mg/l
Calcium	50 mg/l
Magnesium	30 mg/l
Iron	0.1 mg/l
Manganese	0.1 mg/l

Source: Pye, 1983 from U.S. EPA, 1973.

Primary groundwater pollutants from septic systems are those associated with domestic wastewater, such as nitrate, chloride, TDS, phosphate, bacteria, and viruses, though synthetic organic chemicals such as trichloroethylene (TCE), benzene, and methylene chloride originating from system cleaning may also be present (Bedient, et al., 1994). On the other hand, as potential septic-indicator constituents, Pye, et al. (1983) listed nitrates, phosphates, heavy metals, inorganic ions such as sodium, chloride, sulfate, potassium, calcium, magnesium, pathogenic organisms, and toxic synthetic organic chemicals. Some of these parameters are examined in greater detail below:

1) Nitrate analysis is considered the most valuable septage indicator since septic systems are ineffective in reducing the concentration of this constituent. The fate of the introduced nitrogen is dependent upon its initial form as well as biological conversions in the soil and groundwater. Nitrates (NO_3^-) can be formed by the nitrification process involving the conversion of ammonium ion (NH_4^+) to nitrite (NO_2^-) and subsequently to nitrate (NO_3^-). This process is quicker and more complete when the septic systems are located in well-drained soils, such as the Sponseller-Ess-Gordo Association found in the Fort Valley area (Hendricks, 1985). Nitrogen, in the form of nitrate, is not normally appreciably attenuated in the vadose zone and therefore, often reaches the groundwater. Once in the aquifer, nitrate is very mobile because of its solubility.

2) Ammonium ions (NH_4^+) are another form of nitrogen which can affect groundwater quality. Ammonia may be discharged from the septic leach field or generated in the soil from the ammonification process, involving the conversion of organic nitrogen to ammoniacal nitrogen. Canter and Knox (1985) attributed adsorption, cation exchange, incorporation into microbial biomass, or release to the atmosphere in the gaseous form as processes which could affect the transport and fate of ammonium ions. Because there is no volatilization and less adsorption in the soil, nitrate is a better septage indicator than ammonia in groundwater. Ammonia concentration is generally low in groundwater because it absorbs to soil particles and clays and is not readily leached from soils (Fransoma, 1989).

3) Another valuable indicator of septic pollution of groundwater are bacteria and viruses. Although bacteria has been found to move only a few dozen centimeters with percolating waters in unsaturated soil layers, much greater distances are possible under saturated flow conditions (Bitten & Gerba, 1994). Pathogenic bacteria, viruses, and other microorganisms not native to the subsurface environment generally do not multiply underground and eventually die. However, they can move considerable distances and survive for a long enough time be a health concern (Bitton and Gerba, 1994). Typically, bacteriological testing is given preference over virological testing because it is easier and less expensive (Canter and Knox, 1985). Since it isn't possible to monitor for all possible pathogens, indicator microorganisms are used to indicate the possible presence of pathogens. Among the various species of bacteria, total coliform, fecal coliform, and fecal streptococci are commonly used indicators of biological contamination of groundwater by septic effluent. Coliform bacteria are excreted in large numbers in the fecal wastes of people and other warm-blooded animals and thus, can be used to monitor

the movement of septic and sewage wastes in groundwater and can be easily differentiated from common soil micro flora by their ability to grow on solution media at elevated temperatures (Bitton and Gerba, 1994).

4) Although phosphorus is a major constituent of septic effluent, it is not a good indicator of contamination associated with partially-treated septic tank effluent. Canter and Knox (1985) observed that while phosphorus could move through soils and reach groundwater, this nutrient was typically retained in soil due to chemical changes and adsorption by soil underlying the leach field of the septic tank. This is particularly true in the Fort Valley area, where the soil (Sponseller-Ess-Gordo Association) was formed from weathered volcanic rocks (Hendricks, 1985). Soils derived from volcanic rocks usually have extremely high phosphorus fixation (Fox and Kamprath, 1970; Young and Plunkett, 1966); therefore, only very low concentrations of phosphorus would be expected to be introduced into the groundwater.

5) Other inorganic contaminants, metals, and synthetic organic chemicals have also been identified as potential contaminants by other studies. Among these contaminants, chloride and total dissolved solids (TDS) are potentially valuable indicators of more noxious pollution from septic systems, particularly if background levels for these constituents are low (Alhajjar, et al., 1990). Chloride concentration is higher in wastewater than natural water because sodium-chloride (NaCl) is a common component of diet and passes unchanged through the human digestive system (Fransom, 1989). Septic systems are ineffective in the removal of chloride which, because of its solubility, is very mobile in groundwater. TDS is an important septage indicator because water that passes through a septic system may experience a 100-300 mg/l increase in the TDS level.

Canter and Knox (1985) concluded that groundwater monitoring for only nitrate, fecal coliform, and fecal streptococci would be sufficient in most potential septic contamination studies.

Background

The widespread presence of bacteria in Fort Valley domestic water systems was discovered during a study conducted in the spring of 1985. Water samples from 29 households in the Fort Valley area were collected by the Arizona Department of Health Services (ADHS) to test for bacteria. While some water samples were collected from faucets near wellheads that would be good indicators of bacteria aquifer contamination, the majority of samples were obtained from household faucets. Of the 29 samples, 19 did not show the presence of either total coliform bacteria or fecal coliform bacteria, five samples had an acceptable total coliform bacteria level of <4 cfu/100 ml and no detection of fecal coliform bacteria, and five samples had total coliform bacteria counts >4 cfu/100 ml, including a single sample which indicated the presence of fecal coliform bacteria and a total coliform bacteria count of >200 cfu/100 ml. The groundwater conditions at the time of the ADHS sampling were not mentioned (ADHS, 1985).

Many domestic water systems in the Fort Valley area were again found to be contaminated with bacteria in 1993. The initial detection of bacteria was as a result of privately conducted sampling of a domestic water supply in February 1993. Other residents of Fort Valley were informed of the detection, which resulted in additional testing of other domestic water systems. The water samples were typically collected from an indoor faucet prior to being analyzed by Western Technologies, Inc., in Flagstaff. The results indicated that of the 25 domestic water systems sampled, 21 were contaminated with total coliform bacteria, whereas 13 showed the presence of fecal coliform bacteria.

Concern was expressed by Fort Valley residents and local government officials that the presence of bacteria in these domestic water systems might have originated from septic tank effluent. In Fort Valley, there are typically three types of septic systems (Olberding, 1997):

1) Septic tank leach field systems - consisting of a buried leach field, installed up until approximately the mid-1970s;

2) Septic tank leach trench systems - 10-12 foot deep trenches, installed from approximately the mid-1970s to the mid-1980s; and

3) Septic tank mound systems - consisting of an elevated leach field, installed since the mid-1980s.

During times of high groundwater levels, typically in the spring, the saturation of buried septic leach fields or trenches might occur, thus exceeding the ADEQ five-foot vertical separation requirement between the bottom of the subsurface disposal field or trench and groundwater. The septic tank effluent, deprived of unsaturated soil for drainage and clarification, could potentially become a source of pollution. Some areas of Fort Valley also have a high density of housing on small real estate parcels which ensures that wells are in close proximity to septic tanks, a situation which may magnify the pollution problem these systems pose to the groundwater underneath.

Record snowfalls in the winter of 1992/93 caused extremely high rates of recharge resulting in total saturation of Fort Valley perched aquifers. The degree of saturation was so extreme that water was seen pooling above ground in a number of places. After a dry winter of 1993/94, these saturated groundwater conditions were again evident two years later during the winter of 1994/95. Thus, the combination of periodic high groundwater levels, high densities of septic tank systems, soils which are unsuitable for use as septic system leach fields, the close proximity of septic systems and domestic water wells, and a history of bacteria detections in domestic water systems, makes the potential contamination of groundwater in the Fort Valley area by septic system effluent a worthy topic of study by ADEQ.

Methods and Materials

Well Selection

In evaluating the effects of septic systems upon groundwater quality, the most logical sampling location to determine the contaminant input to the aquifer is in the upper portion of the saturated zone, directly beneath the septic leach fields. Lacking monitoring wells located in these areas, groundwater samples collected from shallow wells should typically first exhibit any contaminants resulting from partially treated septic effluent. Samples collected from wells pumping groundwater from deeper perched aquifers might contain only highly diluted levels of potential contaminants from septic system effluent.

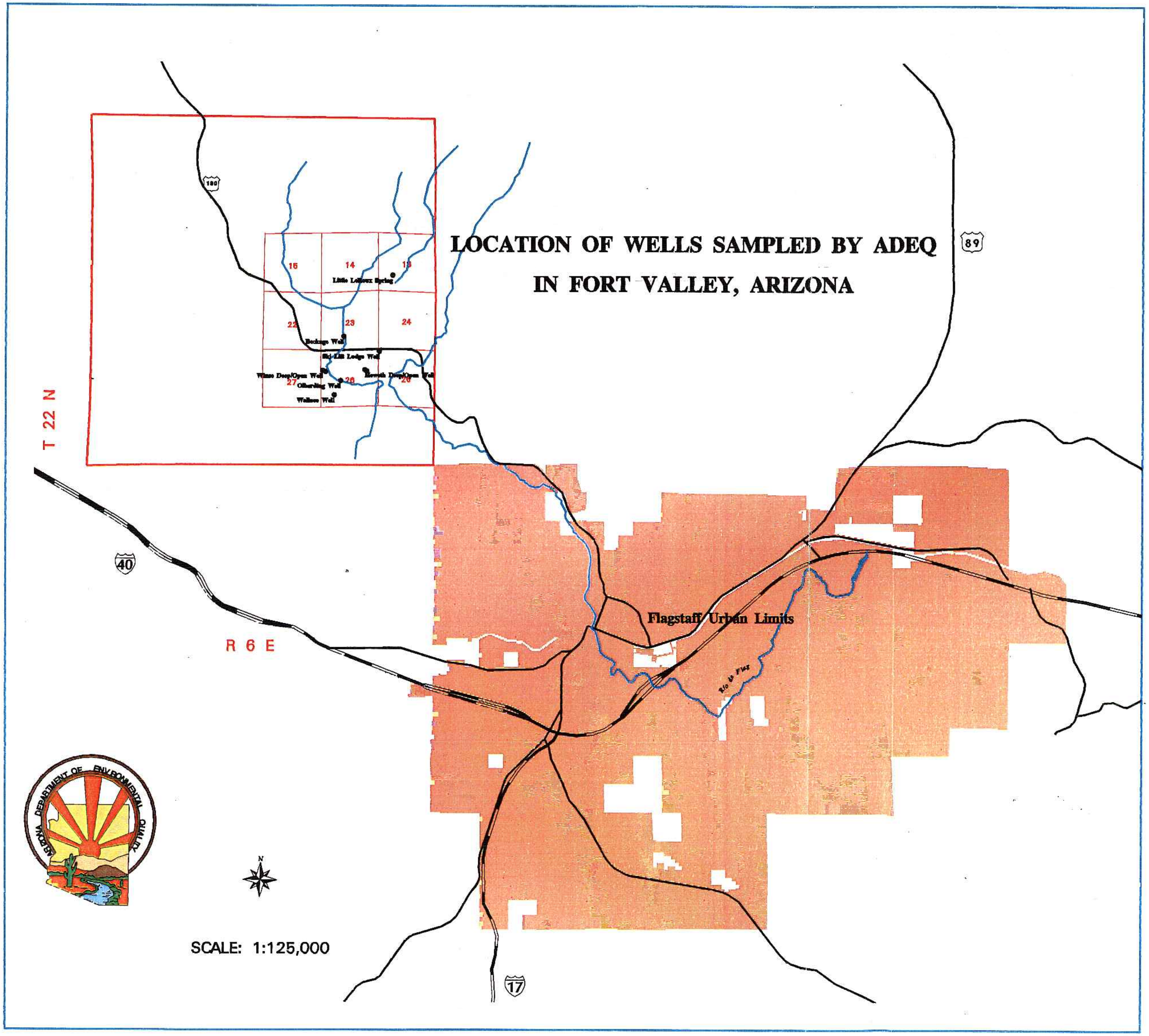
The number of wells necessary to adequately determine the impact of septic systems on an aquifer is dependent upon the homogeneity of both the soil and the aquifer, as well as the uniformity of effluent distribution (Canter and Knox, 1985). With a series of perched aquifers, several soil types, and nonuniform effluent distribution in the Fort Valley area, greater numbers of sampled wells are necessary to estimate broad impacts of septic systems on groundwater quality.

Locating suitable wells for groundwater quality sampling in Fort Valley was undertaken with the assistance of Mr. Drew Swieczkowski of the Arizona Department of Water Resources (ADWR), who was involved in monitoring groundwater levels in the area. After being informed of the objective of ADEQ's groundwater quality study, Mr. Sweiczkowski canvassed well owners on the availability of their wells for sampling. It was emphasized that wells for sampling should be equipped with sample ports or taps at the wellhead. Due to extremely cold winters in Fort Valley, most wells in this area lead directly into large underground cisterns and sampling such wells often requires draining 2000 to 5000 gallon cisterns in order to get the pump to turn on to meet purging requirements. Therefore, the vast majority of the estimated 100 wells in Fort Valley were not considered adequate for sampling.

ADEQ conducted a reconnaissance trip to Fort Valley in November 1993 to examine wells which might meet ADEQ's sampling requirements. Only eight wells were identified in the Fort Valley area that met these standards for sampling. Five of these wells are located in the center of the community in the Fort Valley Trails area and a single well was located in each of the following outlying areas: Fort Valley Ranch, Fort Valley Estates, and North of Highway 180 areas (Figure 2). The number of wells sampled represents an attempt to sample all Fort Valley wells with proper wellhead sampling ports.

While no monitoring wells were in existence that could be used to sample the upper portion of the aquifer in the Fort Valley area, three of the wells selected for sampling were relatively shallow and could be expected to dramatically show the impacts of any partially treated septic system effluent input to the groundwater. These shallow wells, which are not used for domestic drinking water purposes, were as follows: Howeth Open Well - an ADWR water-level index well, Olberding Well - used for irrigation and stock purposes, and Winse Open Well - an unused well. Howeth Open and Olberding Wells, which are both located in close proximity to corrals

LOCATION OF WELLS SAMPLED BY ADEQ IN FORT VALLEY, ARIZONA



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holding livestock, had potential water quality impacts from animal waste as well as septic systems. The five deeper wells in the Fort Valley study were sampled in order to determine the vertical migration of any potential septic effluent contamination. Beckage, Howeth, Ski Lift Lodge, Wallace, and Winse Wells all supply groundwater for private domestic use. Little Leroux Spring, a perennial spring issuing from the flanks of the San Francisco Peaks and upgradient of Fort Valley, was also sampled to provide benchmark groundwater quality information for the area. Little Leroux Spring should be representative of the perched aquifer conditions, since both water sources are recharged by lateral inflow from the San Francisco Mountains. Well construction standards for these eight wells selected for sampling appeared adequate: most wells were enclosed within a well house and looked to possess acceptable surface seals.

A seasonal groundwater monitoring sampling strategy was used in Fort Valley to detect both permanent and temporary concentrations of pollutants in the groundwater. Wells were sampled in the fall when the threat from septic system contamination was at a minimum because of the relatively deep groundwater levels as well as during the spring when higher groundwater levels were more likely to interfere with the septic leach fields as a result of increased precipitation, thus leading to groundwater contamination.

Sample Parameters and Collection

Prior to sampling a well, three bore volumes of its water were purged to assure that stagnant water in the well casing had been removed and the groundwater sample collected was representative of the associated aquifer. Physical parameters of the groundwater, including temperature, pH, and electrical conductivity (EC), were monitored during purging as a matter of standard practice to assess the adequacy of the purging and to serve as a quality assurance/quality control check. The following groups of parameters were selected as potential septic system contamination indicators for the Fort Valley groundwater quality study:

1. Safe Drinking Water (SDW) Inorganic Compounds
2. Bacteria (total coliform, fecal coliform, and fecal streptococci)
3. Safe Drinking Water (SDW) Volatile Organic Compounds (VOCs)

All groundwater samples collected in Fort Valley were tested for the above-listed groups of parameters. Sampling procedures associated with this investigation met the quality assurance requirements and protocols listed in ADEQ's *Quality Assurance Project Plan* (ADEQ, 1991). The SDW inorganic samples were collected in three, one-liter high-density, polyethylene bottles; one bottle contained nitric acid used as a preservative for dissolved metals, one bottle contained sulfuric acid used as a preservative for nutrients, while respectively, the third bottle did not contain any acid preservative and was for physical parameters. Bacteria samples were collected in three, pre-sterilized, 100-ml Whirl-Pak bags which contained a pre-added dechlorinating agent, sodium thiosulfate. VOC samples were collected in two 40-ml amber glass vials with Teflon septums and preservative provided by the laboratory. All samples were kept at 4^0 C by packing on ice in an insulated picnic cooler immediately after collection until transferred to laboratory personnel. SDW inorganic samples were delivered to the ADHS laboratory in

Phoenix for analysis within the recommended EPA holding time, while VOC samples were delivered to McKenzie Laboratories and/or the ADHS laboratory, both in Phoenix, in the same manner. Samples taken for bacteria were either submitted to the ADHS laboratory in Flagstaff within the required six-hour holding time or incubated and counted in the field using procedures developed by ADEQ's Surface Water Monitoring Program (ADEQ, 1995).

A total of 23 groundwater samples were collected for the Fort Valley study by ADEQ on three different sampling trips (fall 1993, spring 1994, and spring 1995). Twenty-one of these groundwater samples were collected from seven wells, each sampled on three occasions. Of the remaining two groundwater samples, one was collected from Wallace Well (which was unable to be resampled because of plumbing problems) and one groundwater sample was collected from the Little Leroux Spring above Fort Valley to establish upgradient groundwater quality (which was unable to be resampled because it was frozen during subsequent sampling trips). For quality assurance/quality control purposes, four duplicates, four field blanks, and four travel blanks were also collected as part of the Fort Valley study. Well characteristics and sampling summaries are presented in Table 2. Each of the 23 samples collected by ADEQ from the eight wells and one spring were analyzed for SDW volatile organic compounds (VOCs), bacteria (total coliform, fecal coliform, and fecal streptococci), and SDW inorganic constituents.

Statistical Analysis

The impacts of wells, well types (open or deep wells), sampling periods, and groundwater depths on various groundwater quality parameters were assessed by the Analysis of Variance (ANOVA), whereas the differentiation among means of these parameters were determined by Least Significant Difference (LSD). Linear Regression Analysis and curve-fitting techniques were used to assess the degree of correlation and establish mathematical relationships between each pair of parameters, respectively. All statistical analysis was conducted by personal computer using the statistical package, SYSTAT. The Piper Trilinear Diagram, which graphically displays as composition percentages the cations and anions of groundwater samples permitting empirical examination of data trends, was generated using HC-GRAM.

Table 2. Characteristics of Wells Sampled in Fort Valley.

Well Name	Well Location	Well Registry Number	Sample Date	Well Depth & (Perfer-ations)	Depth to Water	Gallons Purged Prior to Sampling	Quality Control
Beckage Well	(A-22-06)23cda	649987	11/19/93	120'	89.2'	132	
"	"	"	04/08/94	(N/A)	91.7'	120	Duplicate = A(6-22)32ACD
"	"	"	03/28/95		89.5'	133	
Howeth Deep Well	(A-22-06)26bdb	608396	11/20/93	150'	64'	452	
"	"	"	04/08/94	(110'-150')	91.7'	120	
"	"	"	03/27/95		64'	800	
Howeth Open Well	(A-22-06)26bdb	608397	12/1/93	50'	15.5'	150	VOC Duplicate = Clover Well
"	"	"	04/09/94	(0-50')	16.2'	88	Field Blank = Allen Well
"	"	"	03/27/95		12.8'	102	
Little Leroux Spr.	(A-22-06)13cac		11/20/93				Ambient Sample
Olberding Well	(A-22-06)26cab	514115	11/20/93	14'	6'	452	
"	"	"	04/10/94	(5-14)'	3.5'	612	Field Blank = Corey Well
"	"	"	03/27/95		1.3'	1400	Duplicate=FV-03
Ski Lift Lodge	(A-22-06)25bbb	601851	12/02/93	200'	160'	180	
"	"	"	04/11/94	(150-200')	172.7'	123.4	
"	"	"	03/27/95		167'	180	
Wallace Well	(A-22-06)26cca	647302	04/08/94	210' (79-98 & 138-198)	148'	275	
Winse Deep Well	(A-22-06)26bc	517151	11/19/93	178'	69.8'	468	Field Blank = Bog Well
"	"	"	04/09/94	(95-170')	79.7'	433	
"	"	"	03/28/95		58.4'	900	
Winse Open Well	(A-22-06)26bc	620413	12/01/93	30'	5.5'	105	Field Blank = Corey Well
"	"	"	04/09/94	(N/A)	5.4'	108	Duplicate = Winse Cold
"	"	"	03/28/95		2.2'	125	

RESULTS AND DISCUSSION

Evaluation of Analytical Data

Examining the data collected in this study, it was observed that among the vast majority of measured inorganic groundwater quality parameters, the duplicate samples and the original samples were always within 10% of each other. At the same time, field blanks prepared for inorganic parameters also indicated excellent quality control with respect to the corresponding non-detection of the analyzed parameters.

However, field blanks prepared for VOCs during the sampling trip in the Fall 1993 and Spring 1994 exhibited some contamination problems. For example, the field blank intended for the Fall 1993 sampling had a mean chloroform and bromodichloromethane detection of 29 µg/l and 0.6 µg/l, respectively. Moreover, the two field blanks associated with the Spring 1994 sampling had detections of chloroform at 9.5 and 7.6 µg/l and m,p-xylene at 1.8 and 1.6 µg/l, respectively. With the exception of the chloroform, none of the VOCs detected in the early Fall 1993 sampling were also detected in the groundwater sample collected; therefore, it appeared that the deionized water used by the contract laboratory to prepare the field blanks was contaminated with the detected VOCs. The chloroform detected in the groundwater sample collected from Little Leroux Spring during the early Fall 1993 was lower than that of the corresponding field blank (31 µg/l vs. 34 µg/l). Therefore, it is concluded by ADEQ that the contamination problem encountered in the study with respect to VOCs had not impacted the integrity of this study.

The comparison of total N (NO_3+NO_2 as N) associated with ADEQ's groundwater sampling on March 27-28, 1995, with results of five wells sampled earlier (March 8, 1995) by scientists from Northern Arizona University (NAU), also supports the high quality assurance of the study. The ADEQ and NAU total N levels were highly correlated at P=0.01 with each other as indicated by the extremely significant correlation coefficient (Fig. 3).

Cation-anion balances were made for all inorganic analyses with the exception of the sampling conducted in the Spring of 1994 where the samples were not analyzed for the full range of ions (Fig. 4). Figure 4 reflects that the cation-anion balance variations for the other two rounds of sampling were within 3%. In addition, the electrical conductivity measurement (EC) obtained in the field also correlated significantly at P=0.01 with the total dissolved solids (TDS) level determined by the contract laboratory (Fig. 5).

Thus, all quality assurance controls indicate the analytical work conducted under the auspices of this study was valid.

Groundwater Chemistry

Groundwater samples collected in the study area were plotted on Piper trilinear diagrams (Fig. 6) to illustrate their ionic chemical composition. These trilinear diagrams show that the groundwater samples collected in each of the three sampling periods had calcium and bicarbonate as the dominate cation and anion tending slightly towards magnesium and chloride,

Figure 3. ADEQ - NAU GW Sampling

Total Nitrogen (NO3/NO2) Correlation

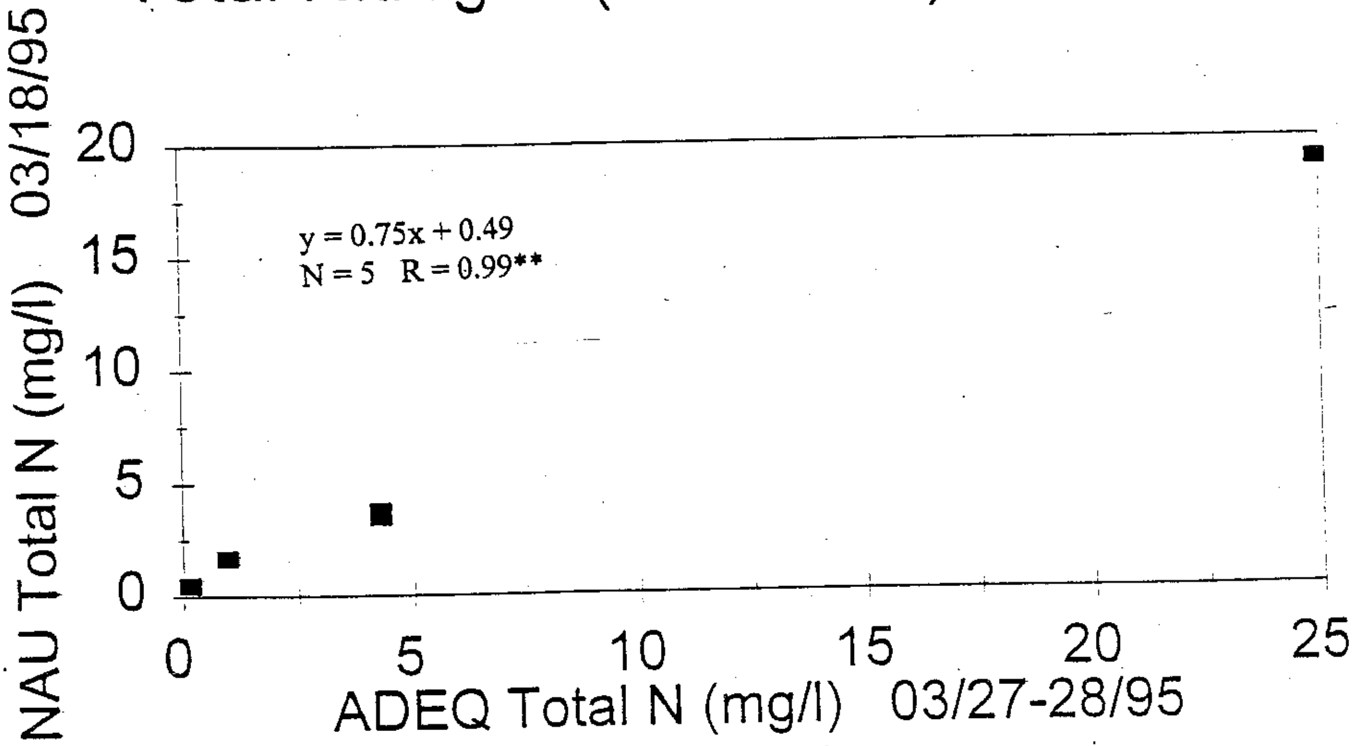


Figure 4. Cation/Anion Balances of Fort Valley Groundwater Samples

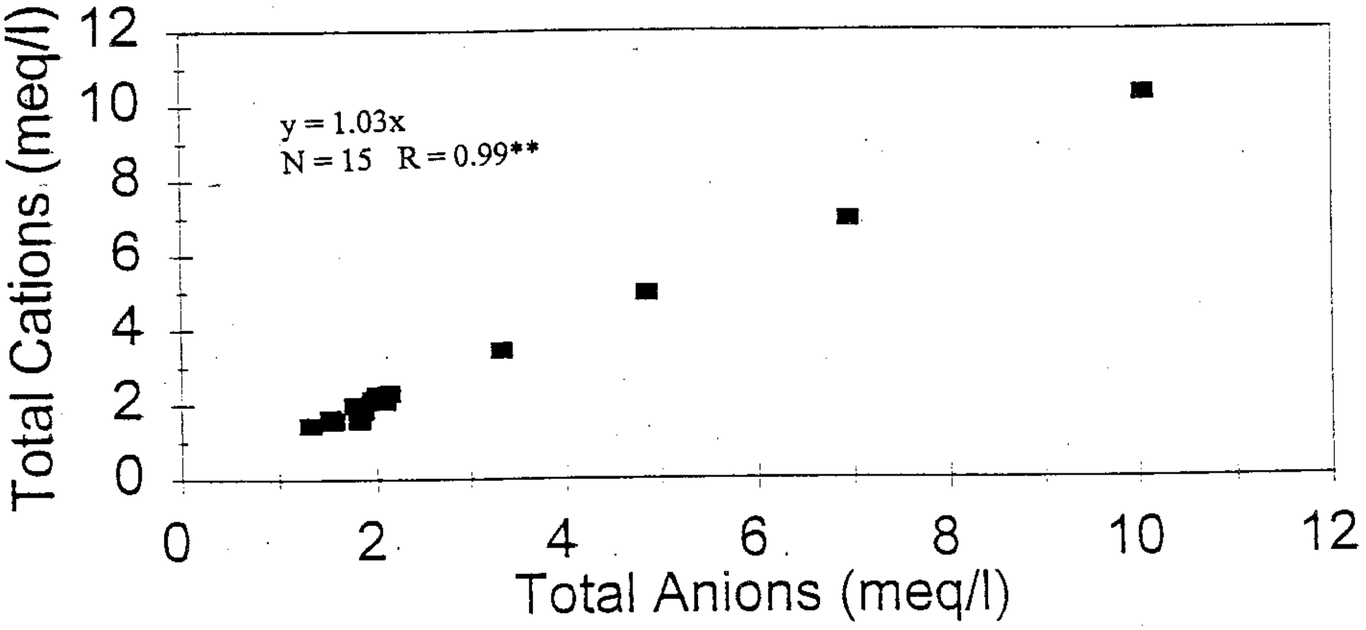


Figure 5. EC/TDS Balances of
Fort Valley Groundwater Samples

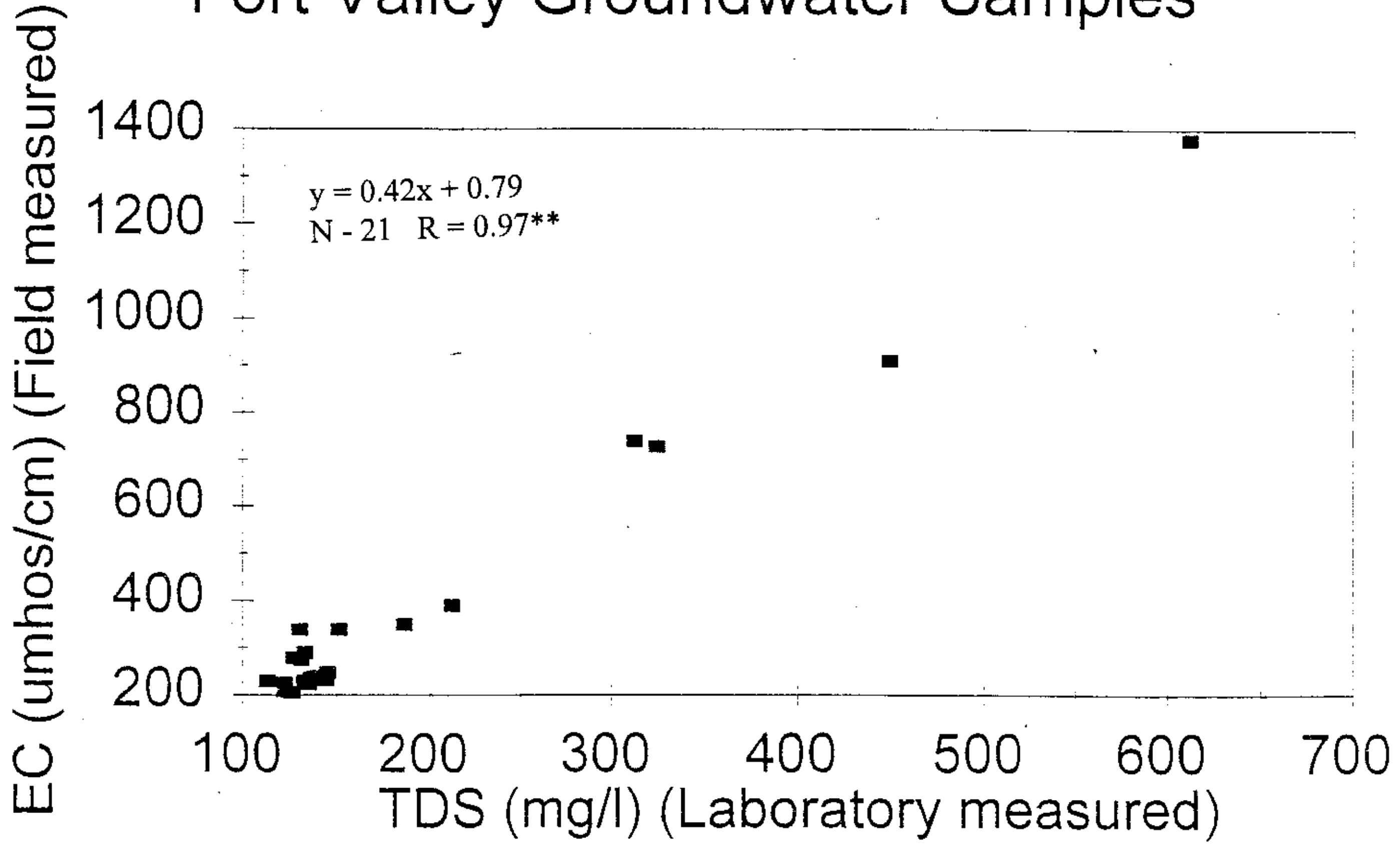
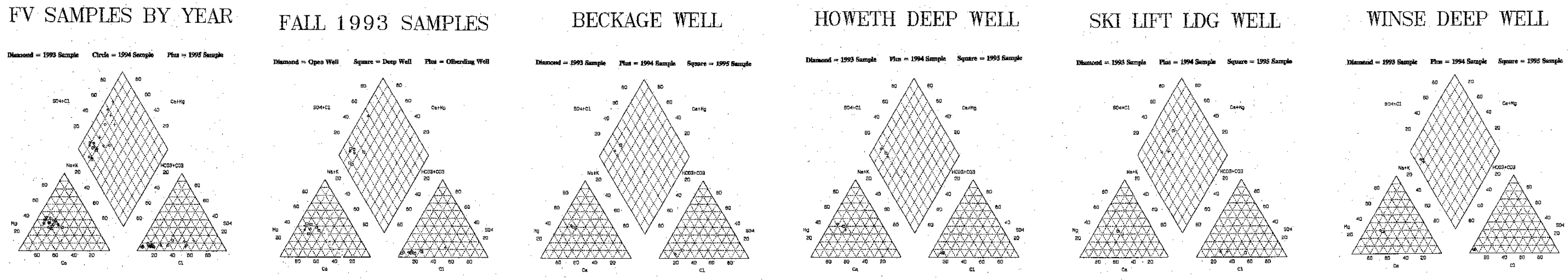
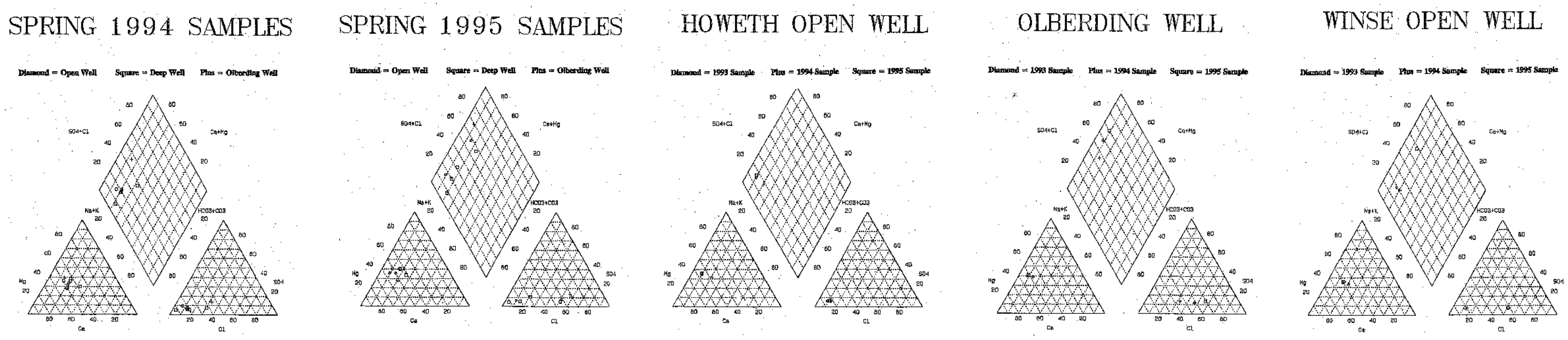


Figure 6. Piper Trilinear Diagrams of Groundwater Samples Collected in Fort Valley





respectively.

With the exception of the Olberding Well, there was little variability in the groundwater chemistry between Fall 1993 and Spring 1994 in wells sampled in the study area (Fig. 6); however, the groundwater chemistry of Ski Lift Lodge Well and Winse Open Well exhibited dramatic changes during the Spring 1995 sampling as compared to the previous two periods (Fig. 6). A constant change in the groundwater chemistry among the three sampling periods was also observed in the Olberding Well (Fig. 6).

In addition to these empirical observations, a more precise and quantitative comparison of each groundwater quality parameter among these wells during these sampling periods was conducted using ANOVA and LSD and the results are presented later in this report.

Inorganic Parameters

The groundwater samples collected in this study were analyzed for various inorganic parameters including those on the SDW list. Appendices A, B, and C provide the analytical inorganic and bacteria results for all the groundwater samples collected in Fort Valley while Appendix D provides the EPA methods for each analysis. The analytical results associated with these parameters for the 23 samples indicated that the groundwater in the study area was generally of acceptable quality. Only six samples of the 23 collected had at least one parameter level exceeding a Primary or Secondary MCL. All together, only three Primary MCLs and six Secondary MCLs were exceeded by these 23 samples. Overall, six wells had groundwater samples collected from them which had at least one parameter exceeding the Primary or Secondary MCL. The analytical results for most of the SDW inorganic parameters is summarized as follows, whereas those related to septic systems are separately discussed in the Section of Major Septage-Indicator Parameters:

Alkalinity - While Phenolphthalein Alkalinity was not detected in any of the groundwater samples collected in the study area, total alkalinity among the 15 samples collected from seven wells and one spring ranged from 41.7 mg/l to 155.5 mg/l, with a mean of 89.4 mg/l and a median of 80.7 mg/l. There is no Primary or Secondary MCL for alkalinity.

Aluminum (Al) - Of the 23 groundwater samples collected in the study area, only three of these collected from three different wells had a detection of Al and each of these detections exceeded the Secondary MCL of 0.05 mg/l (Howeth Open Well at 0.82 mg/l in the Fall, 1993; Beckage Well at 0.17 mg/l in the Spring, 1995, and Howeth Deep Well at 0.11 mg/l in the Spring, 1995).

Arsenic (As) - Arsenic was not detected in any of the 23 groundwater samples collected in the study area.

Barium (Ba) - Barium was not detected in any of the 23 groundwater samples collected in the study area.

Boron (B) - Boron was not detected in any of the 23 groundwater samples collected in the study area.

Cadmium (Cd) - Of the 23 groundwater samples collected in the study area, Cd was only detected in the Olberding Well at 0.003 mg/l during the Fall 1993 sample. This detection was below the Primary MCL of 0.005 mg/l.

Calcium (Ca) - Calcium was detected in all 23 groundwater samples collected in the study area. Levels of detection ranged from 11.7 mg/l to 104 mg/l, with a mean of 28.1 mg/l and a median of 19.3 mg/l. There is no Primary or Secondary MCL for Ca.

Chromium (Cr) - Chromium was not detected in any of the 23 groundwater samples collected in the study area.

Copper (Cu) - Copper was detected in six of the 23 groundwater samples collected in the study area. None of the detected levels exceeded the SDW Action Level of 1.3 mg/l.

Fluoride (F) - Of the 23 groundwater samples collected in the study area, F was only detected at a concentration of 0.22 mg/l in the sample collected from the Wallace Well during the Spring 1994 sampling. The detected level was well below the Primary and Secondary MCLs of 4.0 mg/l and 2.0 mg/l, respectively.

Hardness - Of the 23 samples collected in the study area, hardness levels ranged from 53 mg/l to 451 mg/l, with a mean and median of 120 mg/l and 84 mg/l, respectively. Though there are no Primary or Secondary MCLs for hardness, a hardness rating system devised by Crockett (1995) is customarily used as a water quality standard. Of the 23 samples collected, seven samples were within the soft category (< 75 mg/l), 12 samples had a hardness level within the moderately hard category (75 - 150 mg/l), two samples were within the hard category (150 - 300 mg/l), and two samples are within the very hard category (> 300 mg/l).

Iron (Fe) - Iron was detected in four of the 23 groundwater samples collected in the study area. Of these four detections, only the one associated with the Fall 1993 sampling at the Howeth Open Well contained an Fe level (1.63 mg/l) exceeded the Secondary MCL of 0.3 mg/l. The Fe levels detected ranged from non-detect to 1.63 mg/l.

Lead (Pb) - Lead was not detected in any of the 23 groundwater samples collected in the study area.

Magnesium (Mg) - Magnesium was detection in all 23 samples collected in the study area. Levels of detection ranged from 5.7 mg/l to 51.2 mg/l, with a mean of 13.1 mg/l and a median of 9.7 mg/l. There is no Primary or Secondary MCL for Mg.

Manganese (Mn) - Only the groundwater sample collected from the Howeth Open Well during the Fall 1995 sampling had a detection of Mn at 0.22 mg/l, a level above the Secondary MCL of 0.05 mg/l.

Mercury (Hg) - Only the groundwater sample collected from the Winse Deep Well during the Fall, 1993 sampling had a detection of Hg at 0.0017 mg/l. This detected Hg level was below the Primary MCL of 0.002 mg/l

pH - The 15 groundwater samples collected in the study area had laboratory-analyzed pH levels varying from 7.23 to 8.05 with a mean of 7.72. None of the groundwater samples collected contained a pH level that was an outlier of the Secondary MCL range of 6.5-8.5.

Of the 22 groundwater samples collected in the study area, field-analyzed pH levels varied from 5.48 - 8.04 with a mean of 7.01. Four of the samples had pH levels that were outliers of the Secondary MCL range of 6.5-8.5.

Potassium (K) - Potassium was detected in all but one of the 23 groundwater samples collected in the study area. Levels of K ranged from non-detect to 6.06 mg/l, with a mean of 2.49 mg/l. There is no Primary or Secondary MCL for K.

Selenium (Se) - Selenium was not detected in any of the 23 groundwater samples collected in this study.

Silver (Ag) - Silver was not detected in any of the 23 groundwater samples collected in this study.

Sodium (Na) - Sodium was detected in all but two of the 23 groundwater samples collected in the study area. Levels of Na detection ranged from non-detect to 20.6 mg/l, with a mean and median of 8.6 mg/l and 8.0 mg/l, respectively. There is no Primary or Secondary MCL for Na.

Sulfate (SO_4) - Of the 23 groundwater samples collected in the study area, only 9 groundwater samples collected from five wells had any detection of SO_4. Levels of SO_4 detection were far below the Secondary MCL of 250 mg/l, ranging from non-detect to 64.5 mg/l, with a mean of 12.4 mg/l.

Total Kjeldahl Nitrogen (TKN) - Total Kjeldahl Nitrogen levels among the 23 groundwater samples collected in the study area ranged from non-detect to 0.47 mg/l, with a mean and median of 0.13 mg/l and 0.10 mg/l, respectively. There is no Primary or Secondary MCL for TKN.

Turbidity - Turbidity levels among the 15 groundwater samples collected in the study ranged from 0.09 NTU to 48 NTU with a mean of 4.86 NTU. The turbidity standard, which applies only to water systems using surface water, is < 1 NTU as a monthly average or 5 NTU as an average of two consecutive days.

Zinc (Zn) - Zinc was detected in six of the 23 groundwater samples collected in the study area. Levels of detection ranged from nondetect to 0.19 mg/l, far below the Secondary MCL of 5.0 mg/l.

Major Septage-Indicator Parameters

Total N (Nitrate/Nitrite as N) - Total N was detected in all but one of the 23 groundwater samples collected in this study area. Levels of Total N detection ranged from non-detect to 27.6 mg/l, with a mean of 4.8 mg/l and a median of 2.4 mg/l. As such, groundwater in the study area was generally of good quality with respect to this parameter. Only three samples from two wells contained a total N level exceeding the Primary MCL of 10 mg/l.

Chloride (Cl) - Chloride was detected in all 23 groundwater samples collected in the study area, though none exceeded the Secondary MCL of 250 mg/l. Levels of Cl detection ranged from 1.0 mg/l to 135 mg/l, with a mean and median of 16.1 mg/l and 4.6 mg/l, respectively. As such, groundwater in the study area was generally of good quality with respect to this parameter.

Total Dissolved Solids (TDS) - TDS levels in the groundwater samples collected in the study area ranged from 113 mg/l to 611 mg/l, with a mean and median of 191 mg/l and 138 mg/l, respectively. As such, groundwater in the study area was generally of good quality with respect to this parameter since only one sample collected from the Olberding Well (611 mg/l) exceeded the Secondary MCL of 500 mg/l.

Total Phosphorus (P) - Of the 23 groundwater samples collected in the study area, only 16 of these collected from eight wells showed any detection of P. P levels ranged from non-detect to 0.40 mg/l, with 0.17 mg/l both the mean and median. There is no Primary or Secondary MCL for P. The rather low P level in the groundwater might be associated with the extremely high phosphorus fixation capacity of the volcanic ash soil commonly found in the Fort Valley area (Young and Plunket, 1966; Fox and Kamprath, 1970). Most of the free P from septic systems might have been adsorbed by the soil prior to entering into the groundwater.

Ammonia (NH_3) - Ammonia was not detected in any of the 23 groundwater samples collected in the study area, which might be due to the extremely high volatility exhibited by NH_3. Prior to entering into the groundwater, most of the NH_3 could have been volatilized.

SDW Volatile Organic Compounds (VOCs)

Among the 23 groundwater samples collected in the study area, only four samples from two wells and one spring showed any detection of at least one of the 56 SDW VOCs analyzed for, all of which compounds are listed in Appendix E. None of the detected VOCs exceeded the respective MCLs and most of these detections occurred at or near the Minimum Report Level (MRL) of 0.5 µg/l.

The sampling conducted in Fall, 1993 revealed a detection of chloroform at 31 µg/l in the groundwater sample collected from the Little Leroux Spring with the corresponding MCL of 100 µg/l; however, the corresponding field blank was found to have chloroform at 34 µg/l. Therefore, the validity of such detection was not confirmed.

Tetrachloroethane (TCA) was detected at the MRL of 0.5 µg/l in the groundwater sample collected from the Howeth Open Well during the Spring 1994 sampling. The groundwater samples associated with the Howeth Open Well and Winse Open Well during the Spring 1995 sampling was also found to contain TCA at 0.7 μg/l and 0.5 μg/l, respectively. All these detections of TCA were well below the corresponding MCL of 200 μg/l.

While there is not a readily identifiable source for TCA in the study area, it was suggested by Bedient, et al. (1994) that some synthetic organic chemicals used as septic tank cleaning fluids might be discharged to surface soil and eventually groundwater by septic systems. Since the TCA detection was obtained from the groundwater samples collected from the extremely shallow Howeth Open and Winse Open Well, this might be an indication of a slight contamination of the upper portion of the aquifer by effluent from the associated septic systems.

Bacteria

Of the 23 groundwater samples collected in the study area during the three sampling periods, only five had bacteria detections. These detections were as follows:

1. Winse Open Well, Fall, 1993 - total coliform
2. Ski Lift Lodge Well, Spring, 1994 - total and fecal coliform
3. Winse Open Well, Spring, 1995 - total coliform, fecal coliform, and fecal streptococci
4. Beckage Well, Spring, 1995 - fecal coliform
5. Olberding Well, Spring, 1995 - fecal streptococci

Except in the groundwater sample collected from the Winse Open Well during the Spring 1995 sampling where the total coliform bacteria counts were found to be 4 cfu/100 ml, all bacteria detections mentioned above had counts < 2 cfu/100 ml.

Several well owners in the study area indicated to ADEQ staff that chlorine, in the form of bleach, was routinely applied to wells to prevent bacteria growth since the bacteria contamination problem was first identified by local residents during a private sampling in early 1993. The impact of chlorination by these bleach applications on the bacteria counts in the groundwater samples collected can be demonstrated by the following examples during the course of the study:

Several days prior to sampling by ADEQ scientists, a small amount of bleach was poured into the casing of the Howeth Deep Well by the well owner and the subsequent groundwater sample collected by ADEQ did not show any detection of bacteria as compared to an earlier sampling of the same well by scientists from NAU where the associated groundwater sample was found to have fecal coliform bacteria at 5 cfu/100 ml. A very similar phenomenon was observed in the Beckage Well in which the groundwater sample collected by ADEQ was found to contain fecal coliform bacteria at 1 cfu/100 ml as compared to the reading of 6 cfu/100 ml associated with the sampling conducted by NAU scientists earlier.

While bacteria counts in groundwater samples are an important indicator of septic system contamination, easy and cheap chlorination methods may alter their counts, making other physio-chemical parameters a more reliable index of contamination stemming from septic systems. It also appears that, based on the low bacteria counts found in this ADEQ study, the bacteria counts observed in previous studies undertaken by local residents might have been the result of contamination within domestic water systems rather than the aquifer itself. Other studies have demonstrated that the surfaces of drinking water distribution systems are colonized by bacteria support this assertion (Ridgeway and Olson, 1981).

Impacts of Septic Systems On the Groundwater Quality

A good starting point in determining whether septic systems have degraded groundwater quality is to compare an aquifer's septage-indicator parameters with those associated with a control. For this purpose, an ambient groundwater sample was collected during Fall 1993 sampling from the Little Leroux Spring, located in a relatively pristine location upgradient of the study area. The levels of this spring's various septic-indication parameters would then be compared with those associated with other groundwater samples collected in the Fort Valley area. Because the water in the Little Leroux Spring was frozen during the second and third round of sampling in the Spring of 1994 and 1995, respectively, it was not subsequently sampled as in the case of the study area wells.

In general, the level of septage-indicator parameters such as total N, Cl, TDS, SO_4, TKN, and total P was lower in the Little Leroux Spring groundwater as compared to those collected in other wells during the same sampling period. This observation was further analyzed statistically by determining whether each of these parameters for the spring was within the corresponding Confident Intervals ($CI_{0.95}$) established for the sampled wells (Table 3). $CI_{0.95}$ indicates that 95% of the population lies within the stated interval. The results revealed that levels of total N, total P, SO_4, and TKN in the Little Leroux Spring were below the lower limit of the corresponding $CI_{0.95}$ established from the data of the well samples, whereas TDS and Cl were not.

Another important consideration in determining whether septic systems have degraded groundwater quality is to assess the simultaneous presence of the septic-indicator parameters in the groundwater. Therefore, linear regression analysis was used to assess the relationship among several septage-indicator parameters detected in the groundwater samples collected in the study areas. The results indicated that levels of total N and Cl were significantly correlated with each other at P=0.01, while total N and TDS were also significantly correlated with each other at P=0.05 (Table 4). If the data associated with the Olberding Well is included, all the septage-indicator constituents: total N - TDS, total N - Cl, and TDS - Cl, were also significantly correlated at P=0.01 (Table 4).

Based on the detection of TCA from the extremely shallow Winse Open Well and Howeth Open Well, the bacteria detections described earlier, and the above findings, it appears that the groundwater quality in the study area has been degraded by septic systems. The latter part of this report will further demonstrate that this contamination problem in the study area is largely groundwater depth dependent and becomes elevated when the groundwater level is high as a result of heavy precipitation and subsequent groundwater recharge.

Table 3. **Comparison of Groundwater Quality Parameters of Various Wells and the Little Leroux Spring Control.**

Parameters	**$CI_{0.95}$ mg/l**	**Control mg/l**
Total N	0.95-3.71	ND*
Cl	1.1-4.3	1.5
TDS	113-182	138
Total P	0.11 - 0.39	ND*
Hardness	57-117	62
SO_4	3.4-8.8	ND*
TKN	0.01-0.21	ND*
Alkalinity	55.4-117.1	73.5
pH	7.63-7.98	7.23*
Turbidity	-10.63-29.32	1.9
Ca	13.3-28.2	13.5
K	1.36-3-70	3.21
Mg	6.0-13.0	7.7
Na	2.2-9.4	6.1

* Below the lower limit of $CI_{0.95}$

Table 4. Linear Regression Analysis on Septage-Indicator Parameters

Parameters	Correlation Coefficient Without Olberding Well	 With Olberding Well
Total N vs. Cl	0.59**	0.70**
Total N vs TDS	0.88*	0.82**
TDS vs. Cl	ns	0.95**

ns	Not Significant
*	Significant at P = 0.05
**	Significant at P = 0.01

Impacts of Sampling Periods, Wells, Well Types, and Groundwater Depths On The Groundwater Quality Parameters

Sampling Periods

One of the objectives of this study was to assess the impacts of seasonal changes as reflected in the groundwater level on the groundwater quality in the study area. Therefore, two rounds of groundwater sampling were initially planned, with one round preceding a dry period (Fall, 1993) and the other round preceding a wet period (Spring, 1994). However, an abnormally dry season preceding Spring 1994 in the study area necessitated an additional round of groundwater sampling in Spring 1995, in order to obtain a more accurate assessment on the impact of high groundwater levels on groundwater quality. The impacts of sampling periods on the groundwater quality in the study area were assessed using ANOVA (Table 5).

The results shown in Table 5 indicate, with the exception of Cl, total P, K, and Na, levels of most groundwater quality parameters were not significantly different among the three sampling periods in this study. In addition to the above results, other findings was also established (Table 6):

1. The mean Cl level was significantly higher at P=0.05 in the Spring 1995 sampling than that of the other two sampling periods;
2. The mean total P level associated with the Spring 1995 sampling was significantly lower at P=0.05 than that of the other two sampling periods;
3. The mean K level associated with the Spring 1994 sampling was the highest among the three sampling periods implemented; and
4. The mean Na level resulting from the Fall 1993 sampling was the lowest among the three sampling periods.

When the data associated with the Olberding Well, a well where groundwater quality is potentially impacted by both animal wastes and septic systems, was included in the statistical analysis, only the total P, K, and Na levels were significantly impacted by sampling periods (Table 5); however, the following trends were also observed (Table 7):

1. The mean total P and K levels were the highest during Spring 1995 sampling.
2. The mean Na levels associated with Spring 1994 and Spring 1995 sampling were higher than that of Fall 1993.

Table 5. **ANOVA on the Effect of Sampling Periods on Various Groundwater Quality Parameter Levels**

Parameter	Significance	
	Without Olberding Well	With Olberding Well
Total N	ns	ns
Cl	*	ns
TDS	ns	ns
Total P	**	**
Hardness	ns	ns
SO_4	ns	ns
TKN	ns	ns
Alkalinity	ns	ns
pH	ns	ns
Turbidity	ns	ns
Ca	ns	ns
K	**	**
Mg	ns	ns
Na	**	**

ns	Not Significant
*	Significant at P = 0.05
**	Significant at P = 0.01

Table 6. Comparison of Mean Levels of Groundwater Quality Parameters Among the Three Sampling Periods

	Total N	Cl	TDS	Total P	Hard	SO_4	TKN	Alk	pH	Turb	Ca	K	Mg	Na
Fall 1993	2.33	2.73b	148	0.25a	86.8	6.1	0.11	86.2	7.80	9.34	20.7	2.53b	9.48	5.80b
Spring 1994	2.10	4.42b	141	0.19a	84.2	6.9	0.10	N/A	N/A	N/A	19.2	3.73a	8.67	8.77a
Spring 1995	6.39	10.58a	161	0.07b	85.0	8.0	0.11	75.1	7.78	2.16	23.5	1.87c	10.63	9.07a
Significance	ns	*	ns	**	ns	ns	ns	ns	ns	ns	ns	**	ns	**
$LSD_{0.95}$		5.54		0.089								0.49		1.78
$CI_{0.95}$	-1.62 to 8.84	1.99 to 9.83	124.2 to 175.4	0.10 to 0.23	74.00 to 103.9	4.80 to 9.13	0.069 to 0.150	72.10 to 89.22	7.75 to 7.84	-7.9 to 19.4	17.15 to 23.15	2.37 to 3.06	9.95 to 11.24	6.28 to 8.80

ns	Not Significant
*	Significant at P = 0.05
**	Significant at P = 0.01
$LSD_{0.95}$	Least Significant Difference
$CI_{0.95}$	Confidence Interval

Row values followed by the same letter are not significantly different at P = 0.05 as determined by LSD

Table 7. Comparison of Mean Levels of Groundwater Quality Parameters Among the Three Sampling Periods Including the Olberding Well.

	Total N	CI	TDS	Total P	Hard	SO_4	TKN	Alk	pH	Turb	Ca	K	Mg	Na
Fall 1993	4.50	12.3	191	0.24a	118.4	11.0	0.13	94.5	7.75	8.25	28.1	2.36b	12.98	6.62b
Spring 1994	2.15	11.9	167	0.18a	105.2	11.1	0.09	N/A	N/A	N/A	23.5	3.48a	10.91	9.70a
Spring 1995	9.03	28.5	225	0.07b	146.0	16.0	0.16	86.7	7.76	1.88	35.0	1.73c	16.43	9.86a
Significance	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	**	ns	*
LSD$_{0.95}$				0.075								0.44		2.19
CI$_{0.95}$	-0.034 to 10.49	5.13 to 30.02	147.6 to 240.9	0.11 to 0.22	87.78 to 158.62	7.82 to 17.54	0.06 to 0.21	81.62 to 99.52	7.68 to 7.83	-6.0 to 16.1	20.35 to 37.41	2.21 to 2.83	9.30 to 17.59	7.18 to 10.28

ns	Not Significant
*	Significant at P = 0.05
**	Significant at P = 0.01
LSD$_{0.95}$	Least Significant Difference
CI$_{0.95}$	Confidence Interval

Row values followed by the same letter are not significantly different at P = 0.05 as determined by LSD

Wells

The variation of different groundwater quality parameter levels among the groundwater samples collected in the study area was assessed using ANOVA and the results are shown in Table 8. The results of the analysis indicated, with the exception of total N, Cl, total P, and turbidity, the levels of most groundwater quality parameters were well dependent. When the data associated with the Olberding Well was included in the statistical analysis, a phenomenon fairly similar to the above one was observed; however, instead of the chloride level, only the TKN level along with those of total N, total P, and turbidity was not significantly different between wells (Table 8). The variation of each of these parameters among the wells sampled during the three sampling periods with and without the Olberding Well is shown in Table 9 and Table 10, respectively.

An examination of the results in Table 9 and Table 10 reveal that, with the exception of pH and K, the highest concentration of these well dependent groundwater quality parameters was associated with the shallowest well. Therefore, it appears that much of the variation of the levels of these groundwater quality parameters in the study area among wells was related to the groundwater depth. The effect of groundwater depth on these parameters will be discussed later in this report.

Unlike other wells sampled in the study area (with the exception of Howeth Open Well), the extremely shallow Olberding Well is situated near a corral where the underlying groundwater quality is potentially influenced by both animal activities and septic systems. The statistical impacts of incorporating the groundwater data of the Olberding Well on the overall picture of statistical analysis was assessed by plotting the Coefficient of Variation (CV) of various groundwater quality parameters based on the database associated with all the wells sampled (7 wells) in this study to the database where the Olberding Well was excluded (6 wells). The linear regression analysis conducted on the data presented in Fig. 7 indicated the overall variability of the database increased with the incorporation of the data of the Olberding Well. As a result of this, the Least Significant Difference (LSD) for various groundwater quality parameters was found higher when the Olberding Well was included in the mean differentiation analysis as compared to when it was excluded (Tables 9 and 10, respectively).

Well Types

In general, there were two well types among the wells sampled in this study: open wells and deep wells. Open wells are shallow and not typically used for the withdraw of groundwater (Howeth Open and Winse Open) whereas the deep wells extend far below the surface and are used by residents for private domestic consumption (Beckage, Howeth Deep, Ski Lift Lodge, and Winse Deep). ANOVA was used to determine if there were any significant impacts of well types on levels of various groundwater quality parameters over the three sampling periods.

Table 8. **ANOVA on the Effect of Wells on Various Ground Water Quality Parameter Levels.**

Parameters	Correlation Coefficient Without Olberding Well	 With Olberding Well
Total N	ns	ns
C1	ns	*
TDS	**	ns
Total P	ns	ns
Hardness	**	**
SO_4	ns	**
TKN	*	ns
Alkalinity	**	**
pH	**	**
Turbidity	ns	ns
CA	**	**
K	**	**
Mg	**	**
Na	**	**

ns	Not Significant
*	Significant at $P = 0.05$
**	Significant at $P = 0.01$

Table 9. Comparison of Mean Levels of Groundwater Quality Parameters Among Various Wells Including the Olberding Well

	Total N	Cl	TDS	Total P	Hard	SO_4	TKN	Alk	pH	Turb	Ca	K	Mg	Na
Beckage	3.15	4.6b	144c	0.14	89.2bc	6.9b	0.10	76.8c	7.87ab	2.53	19.3bc	1.51e	10.8bc	7.3bc
Howeth Op	1.78	4.2b	136c	0.15	81.4bc	5.0b	0.05	76.0cd	7.87ab	1.56	18.3c	2.60bc	9.7bc	5.7bc
Howeth Dp	1.40	3.1b	119c	0.22	71.0c	6.9b	0.19	66.8cde	7.65c	26.0	17.8c	2.41cd	7.0c	3.9c
Ski L Ldg	3.88	10.9b	129c	0.08	53.0c	5.0b	0.08	45.7e	7.66c	0.18	12.2c	4.75a	6.1c	7.0bc
Winse Dp	0.10	2.8b	135c	0.15	83.0bc	5.0b	0.07	100.8b	8.05a	1.72	22.2bc	3.25b	7.5bc	7.7b
Winse Op	11.35	9.8b	237b	0.25	155.0b	13.0b	0.19	118.0b	7.69bc	2.61	37.1b	1.76de	16.5b	13.7a
Olberding	14.96	87.6a	461a	0.14	330.0a	47.0a	0.27	150.0a	7.52c	0.97	75.3a	1.39e	36.5a	15.8a
Significance	ns	*	*	ns	**	**	ns	**	**	ns	**	**	**	**
$LSD_{0.95}$		26.89	65.69		76.51	10.50		23.66	0.19		18.42	0.67	8.96	3.35
$CI_{0.95}$	-2.81 to 13.27	-1.44 to 36.59	123.0 to 265.5	0.081 to 0.240	69.10 to 177.30	5.26 to 20.11	-0.02 to 0.25	73.73 to 107.29	7.48 to 8.03	-15. to 25.7	15.85 to 41.91	2.05 to 3.00	7.11 to 19.78	6.36 to 11.10

ns	Not Significant
*	Significant at P = 0.05
**	Significant at P = 0.01
$LSD_{0.95}$	Least Significant Difference
$CI_{0.95}$	Confidence Interval

Row values followed by the same letter are not significantly different at P = 0.05 as determined by LSD

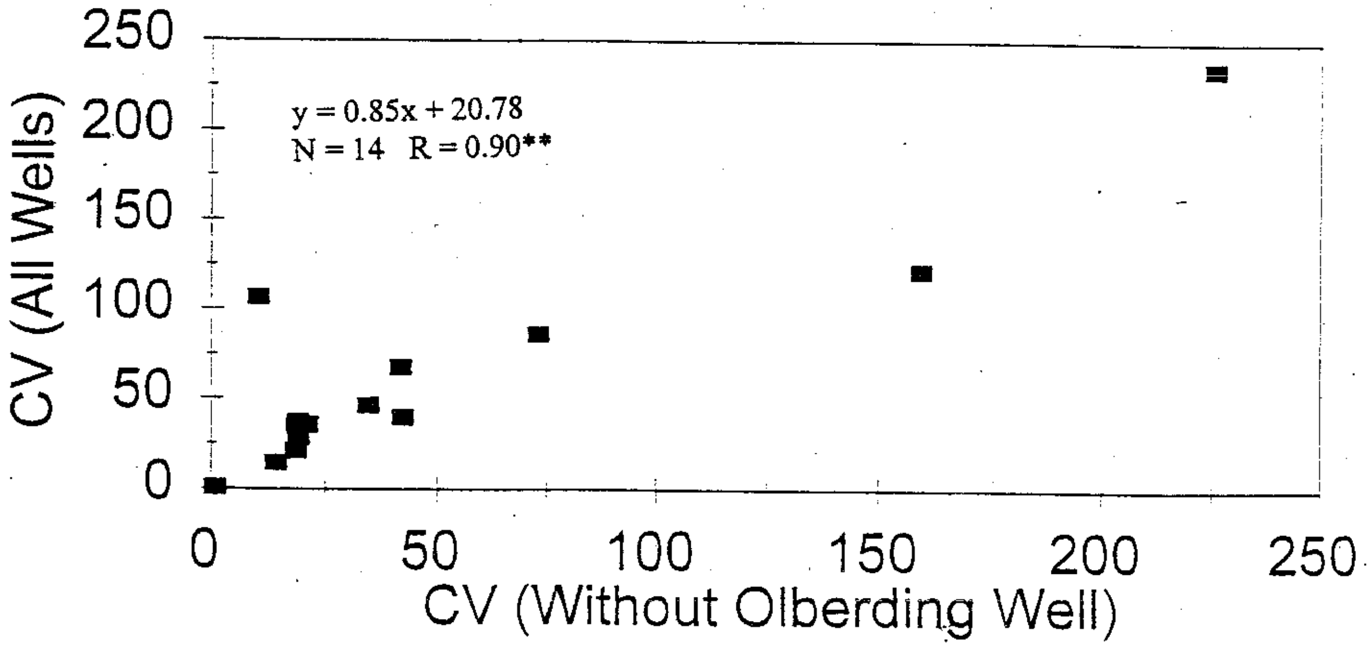
Table 10. Comparison of Mean Levels of Groundwater Quality Parameters Among Various Wells

	Total N	Cl	TDS	Phos	Hard	SO_4	TKN	Alk	pH	Turb	Ca	K	Mg	Na
Beckage	3.15	4.6	144b	0.14	89.2b	6.9b	0.10b	76.8c	7.87b	2.53	19.3bc	1.51e	10.8b	7.3bc
Howeth Op	1.78	4.2	136b	0.15	81.bcd	5.0b	0.05b	76.0c	7.87b	1.56	18.3bc	2.60bc	9.7bc	5.7bcde
Howeth Dp	1.40	3.1	119b	0.22	71.bcd	6.9b	0.19a	66.8c	7.65c	26.0	17.8bc	2.41cd	7.0cd	3.9e
Ski L Ldg	3.88	10.9	129b	0.08	53.0d	5.0b	0.08b	45.7d	7.66c	0.18	12.2c	4.75a	6.1d	7.0bcd
Winse Dp	0.10	2.8	135b	0.15	83.0bc	5.0b	0.07b	100.8b	8.05a	1.72	22.2b	3.25b	7.5cd	7.7b
Winse Op	11.35	9.8	237a	0.25	155.0a	13.0a	0.19a	118.0a	7.69c	2.61	37.1a	1.76de	16.5a	13.7a
Significance	ns	ns	**	ns	**	*	*	**	**	ns	**	**	**	**
LSD $_{0.95}$			51.18		29.99	4.33	0.083	12.11	0.096		7.99	0.69	3.28	2.52
CI $_{0.95}$	-3.79 to 11.00	0.37 to 11.45	113.6 to 186.0	0.076 to 0.25	67.47 to 109.88	3.90 to 10.03	0.052 to 0.17	65.83 to 95.49	7.71 to 7.88	-18. to 29.3	15.40 to 26.80	2.23 to 3.20	7.27 to 11.91	5.76 to 9.32

ns	Not Significant
*	Significant at P = 0.05
**	Significant at P = 0.01
LSD$_{0.95}$	Least Significant Difference
CI$_{0.95}$	Confidence Interval

Row values followed by the same letter are not significantly different at P = 0.05 as determined by LSD

Figure 7. Coefficient of Variations
With and Without Olberding Well



Between the two open wells, only the Na concentration in the groundwater was found to be well dependent (Table 11). However, among the four deep wells sampled during the same sampling periods in the study area, mean levels of groundwater quality parameters of total N, hardness, alkalinity, pH, Ca, K, and Mg were significantly affected by wells (Table 11). The differentiation for the mean parameter levels among the deep wells is shown in Table 12. Based on the above observations, it is concluded that there are more well dependent groundwater parameters among deep wells than open wells in the study area.

Between the two open wells, mean levels of groundwater quality parameters of total P and K were affected significantly by sampling periods; among the four deep wells, the same phenomenon was observed in the alkalinity and K levels in the groundwater (Table 13). The differentiation for these mean parameter levels among the three sampling periods is shown in Table 14. Finally, the level of total phosphorus, SO_4, TKN, and Ca in the groundwater in the study area was significantly affected by well types over the three sampling periods (Table 15).

In order to assess which well type resulted in a more overall variation in levels of the different groundwater quality parameters tested during the three sampling periods, the CV was determined for each of these parameters for both open and deep wells and were plotted against each other (Fig. 8). The linear regression analysis conducted for the data shown in Fig. 8 indicated the overall variation in levels of in the groundwater quality parameter tested in this study was higher in the open wells than in deep wells.

Groundwater Depths

In order to assess the impacts of groundwater depth on the levels of groundwater quality parameters in the study area, the level of each of these parameters was plotted against the corresponding groundwater depth determined in the field using a sounder (Fig. 9). In general, each of these graphs exhibited a biphasic pattern in which the concentration of a groundwater quality parameter would decrease at an extremely high rate with increasing groundwater depth until a certain groundwater depth was reached. Further increasing the groundwater depth resulted in a much lower rate of decrease in the level of the parameter. This biphasic trend exhibited by these parameters was adequately described by the following general equation established by the curve-fitting technique:

$$[\text{Parameter}] = a(D)^{-b}$$

where [Parameter] is the level of a groundwater quality parameter in mg/l; a and -b the integers, and D the groundwater depth in feet below land surface as measured by the sounder in the field. The equation for each of these parameters is presented in Table 16.

Table 11. **ANOVA on the Effect of Open and Deep Wells on Various Groundwater Quality Parameter Levels**

Parameter	Significance	
	Open Wells	Deep Wells
Total N	ns	*
C1	ns	ns
TDS	ns	ns
Total P	ns	ns
Hardness	ns	**
SO_4	ns	ns
TKN	ns	ns
Alkalinity	ns	**
pH	ns	**
Turbidity	ns	ns
Ca	ns	**
K	ns	**
Mg	ns	**
Na	*	ns

ns	Not Significant
*	Significant at $P = 0.05$
**	Significant at $P = 0.01$

Table 12. Comparison of Mean Levels of Various Groundwater Levels of Various Groundwater Quality Parameters Among Deep Wells

	Total N	Cl	TDS	Total P	Hard	SO_4	TKN	Alk	pH	Turb	Ca	K	Mg	Na
Beckage	3.15ab	4.6	144	0.14	89.2a	6.9	0.10	76.8b	7.87b	2.53	19.3b	1.51c	10.8a	7.3
Howeth Dp	1.40c	3.1	119	0.22	71.0c	6.9	0.19	66.8c	7.65c	26.0	17.8bc	2.41bc	7.0bc	3.9
Ski L Ldg	3.88a	10.9	129	0.08	53.0d	5.0	0.08	45.7d	7.66c	0.18	12.2c	4.75a	6.1d	7.0
Winse Dp	0.10c	2.8	135	0.15	83.0b	5.0	0.07	100.8a	8.05a	1.72	22.2a	3.25b	7.5b	7.7
Significance	*	ns	ns	ns	**	ns	ns	**	**	ns	**	**	**	ns
$LSD_{0.95}$	1.61				5.08			6.99	0.09		1.73	0.93	0.76	
$CI_{0.95}$	1.09 to 13.27	1.54 to 12.82	124.4 to 145.1	0.06 to 0.20	73.05 to 80.25	3.18 to 7.75	0.04 to 0.12	69.86 to 79.74	7.79 to 7.92	-1.60 to 4.59	16.77 to 19.23	2.37 to 3.68	8.07 to 9.13	5.27 to 8.34

ns Not Significant
* Significant at P = 0.05
** Significant at P = 0.01
$LSD_{0.95}$ Least Significant Difference
$CI_{0.95}$ Confidence Interval
Row values followed by the same letter are not significantly different at P = 0.05 as determined by LSD

Table 13. **ANOVA on the Effect of Sampling Periods Among Open and Deep Wells on Various Groundwater Quality Parameter Levels**

Parameter	Significance	
	Open Wells	Deep Wells
Total N	ns	ns
C1	ns	ns
TDS	ns	ns
Total P	*	ns
Hardness	ns	ns
SO_4	ns	ns
TKN	ns	ns
Alkalinity	ns	*
pH	ns	ns
Turbidity	ns	ns
Ca	ns	ns
K	*	**
Mg	ns	ns
Na	ns	ns

ns	Not Significant
*	Significant at P = 0.05
**	Significant at P = 0.01

Table 14. Comparison of Mean Levels of Groundwater Quality Parameters in Deep Wells Among the Three Sampling Periods

	Total N	Cl	TDS	Total P	Hard	SO_4	TKN	Alk	pH	Turb	Ca	K	Mg	Na
Fall 1993	2.23	2.6	138.3	0.17	77.3	5.0	0.05	78.3	7.87	0.74	18.2	2.89	8.70	5.12
Spring 1994	2.06	4.2	133.8	0.17	76.5	5.0	0.07	N/A	N/A	N/A	17.3	4.00	8.05	8.25
Spring 1995	2.40	9.5	135.3	0.05	76.0	6.4	0.07	71.3	7.85	2.24	18.6	2.20	8.85	7.43
Significance	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	**	ns	ns
LSD $_{0.95}$								4.94				0.80		
CI $_{0.95}$	1.24 to 3.21	-0.58 to 11.86	127.6 to 143.8	0.07 to 0.19	73.54 to 79.76	3.49 to 7.44	0.04 to 0.11	71.31 to 78.29	7.81 to 7.90	-0.70 to 3.68	16.94 to 19.06	2.46 to 3.60	8.14 to 9.06	5.50 to 8.16

NS Not Significant
* Significant at P = 0.05
** Significant at P = 0.01
$LSD_{0.95}$ Least Significant Difference
$CI_{0.95}$ Confidence Interval
Row values followed by the same letter are not significantly different at P = 0.05 as determined by LSD

Table 15. **ANOVA on the Effect of Well Types (Open vs. Deep) on Various Groundwater Quality Parameters Levels.**

Parameters	Significant
Total N	ns
C1	ns
TDS	ns
Total P	*
Hardness	ns
SO_4	*
TKN	**
Alkalinity	ns
pH	ns
Turbidity	ns
Ca	*
K	ns
Mg	ns
Na	ns

ns Not Significant
* Significant at P = 0.05
** Significant at P = 0.01

Figure 8. Coefficient of Variations

Comparison Between Open and Deep Wells

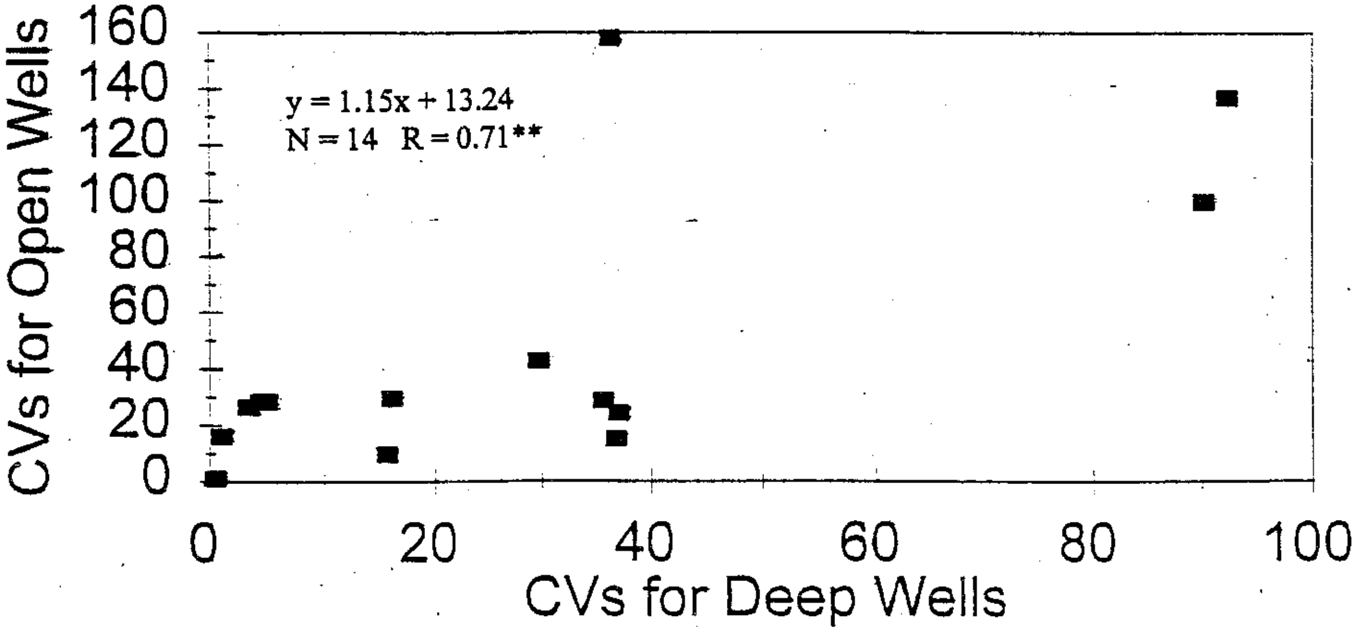
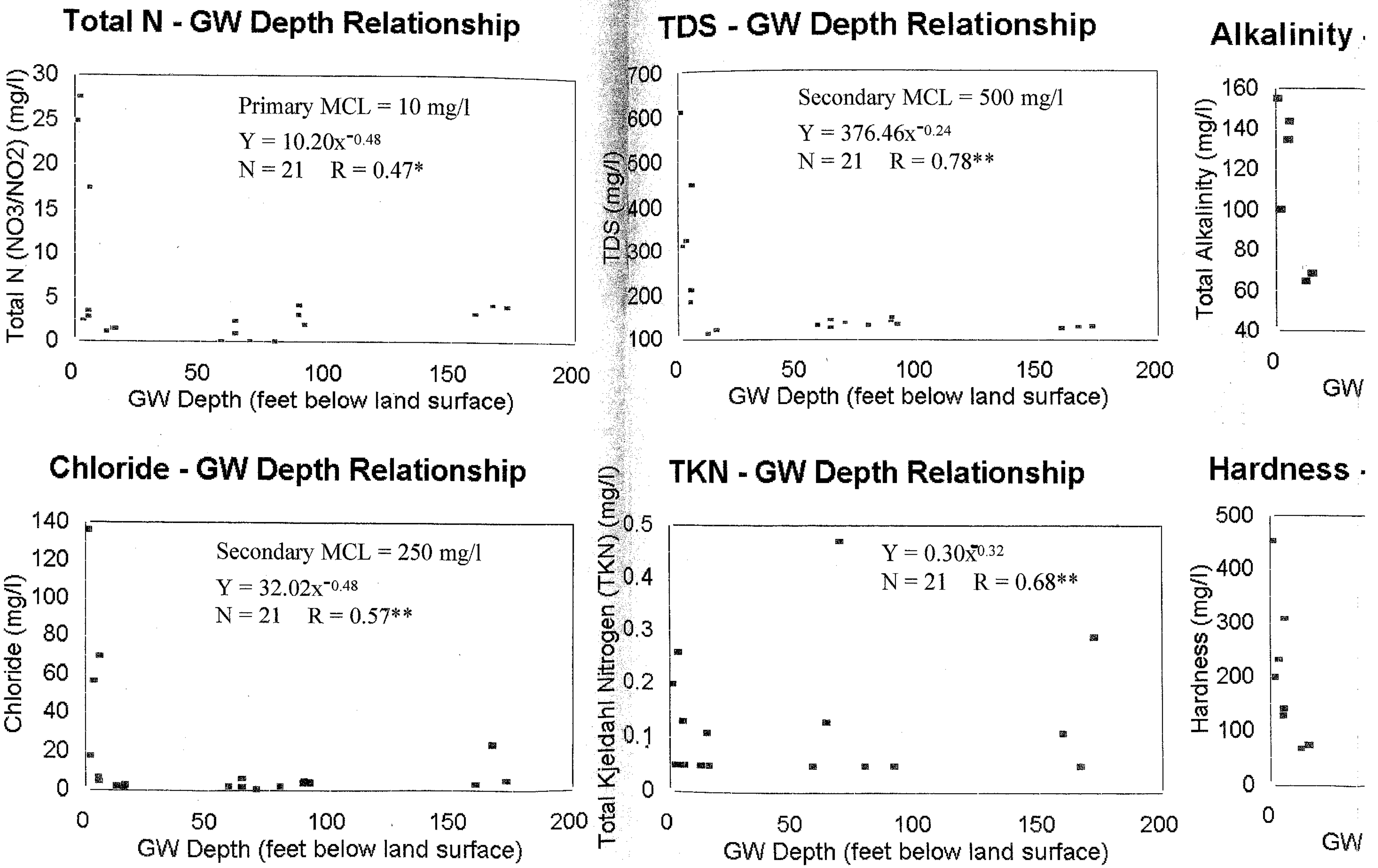


Figure 9. Relationship Between Various Groundwater



Total N - GW Depth Relationship

TDS - GW Depth Relationship

Alkalinity

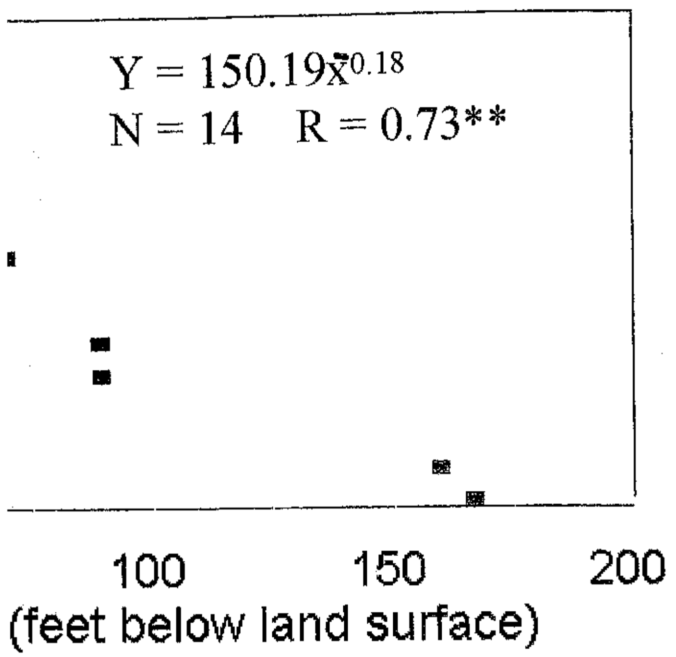
Chloride - GW Depth Relationship

TKN - GW Depth Relationship

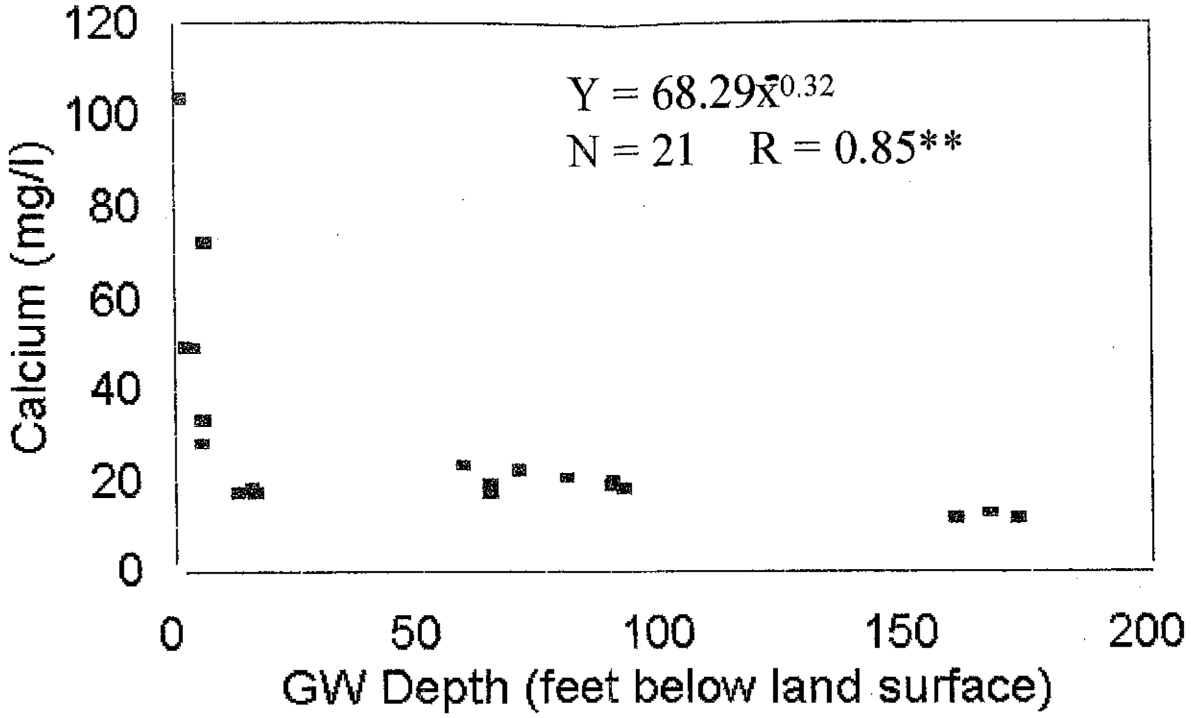
Hardness

ality Parameters and Groundwater Depth

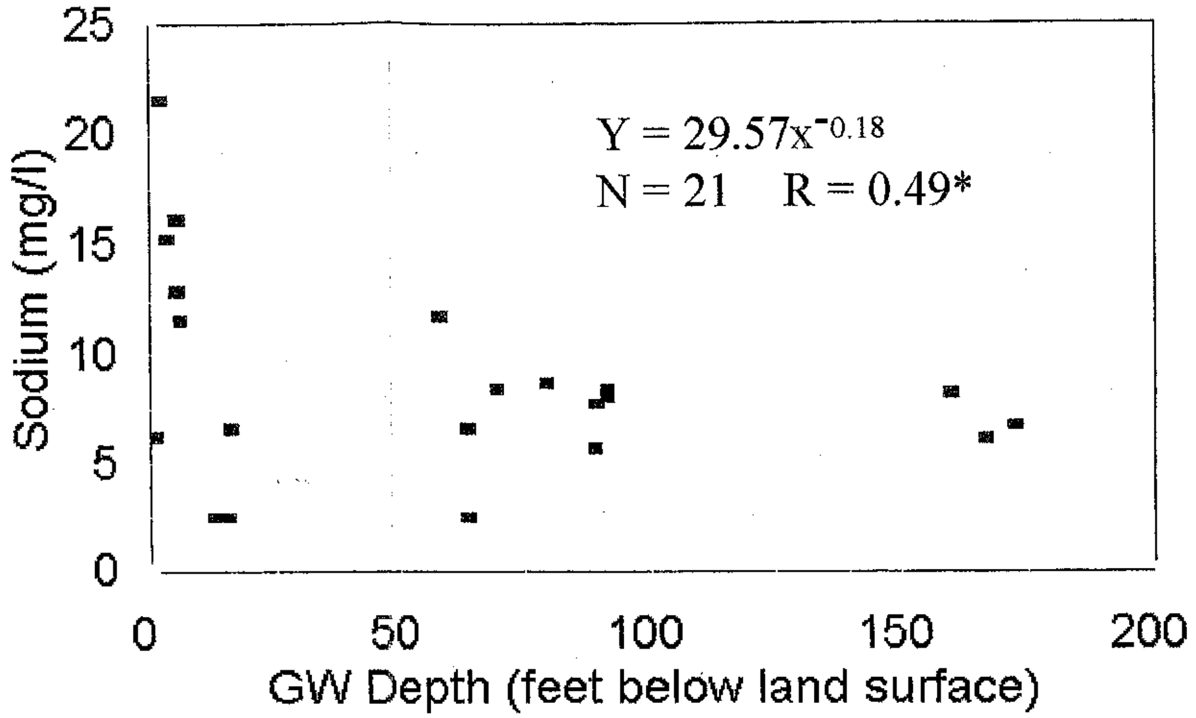
Depth Relationship



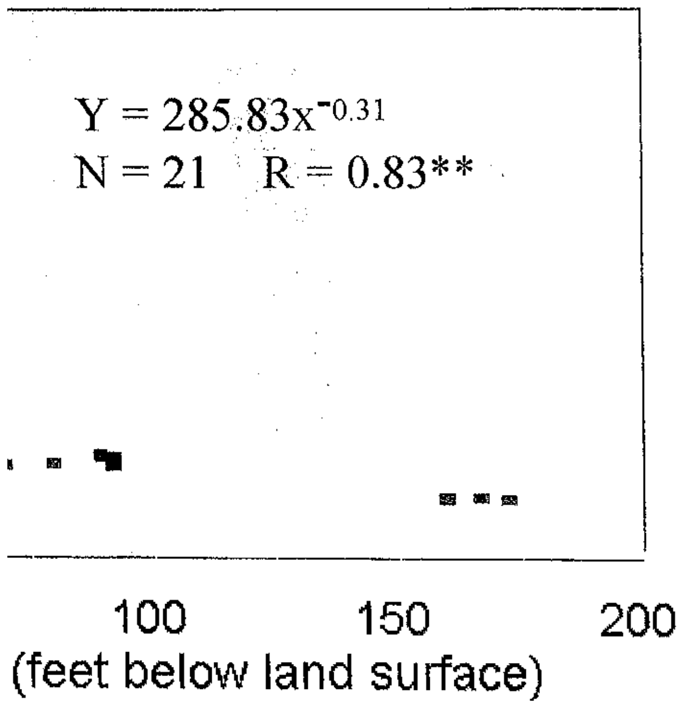
Calcium - GW Depth Relationship



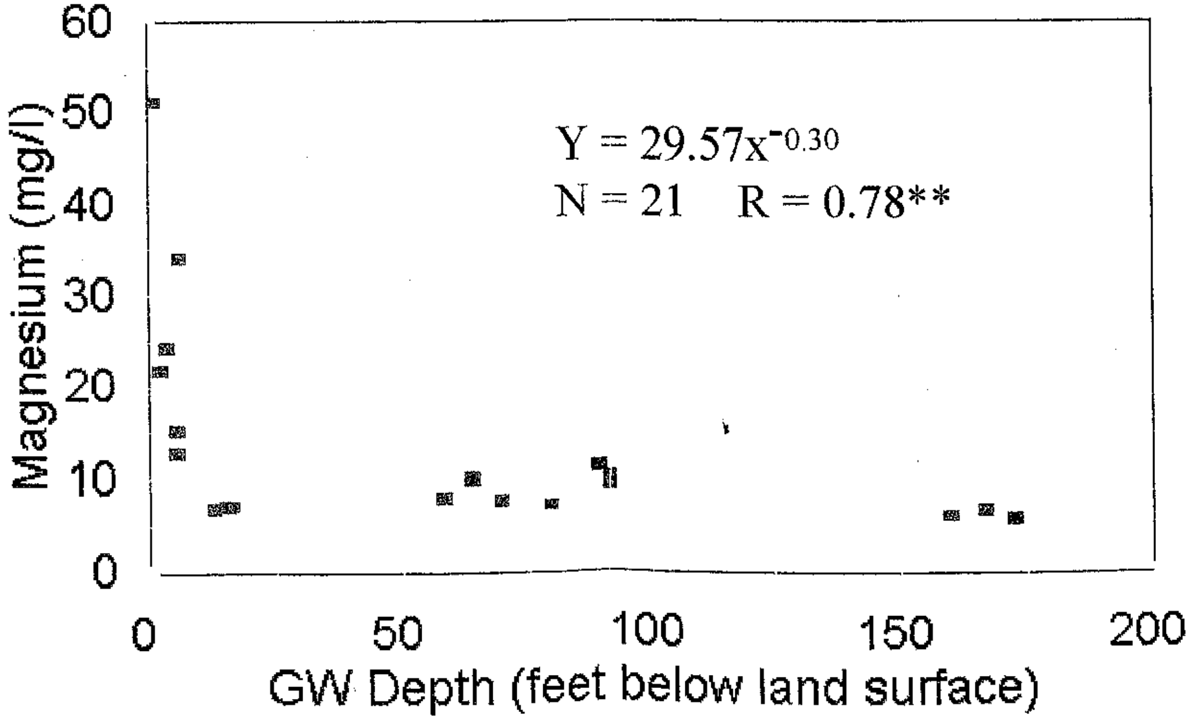
Sodium - GW Depth Relationship



Depth Relationship



Magnesium - GW Depth Relationship



Sulfate - GW Depth Relationship

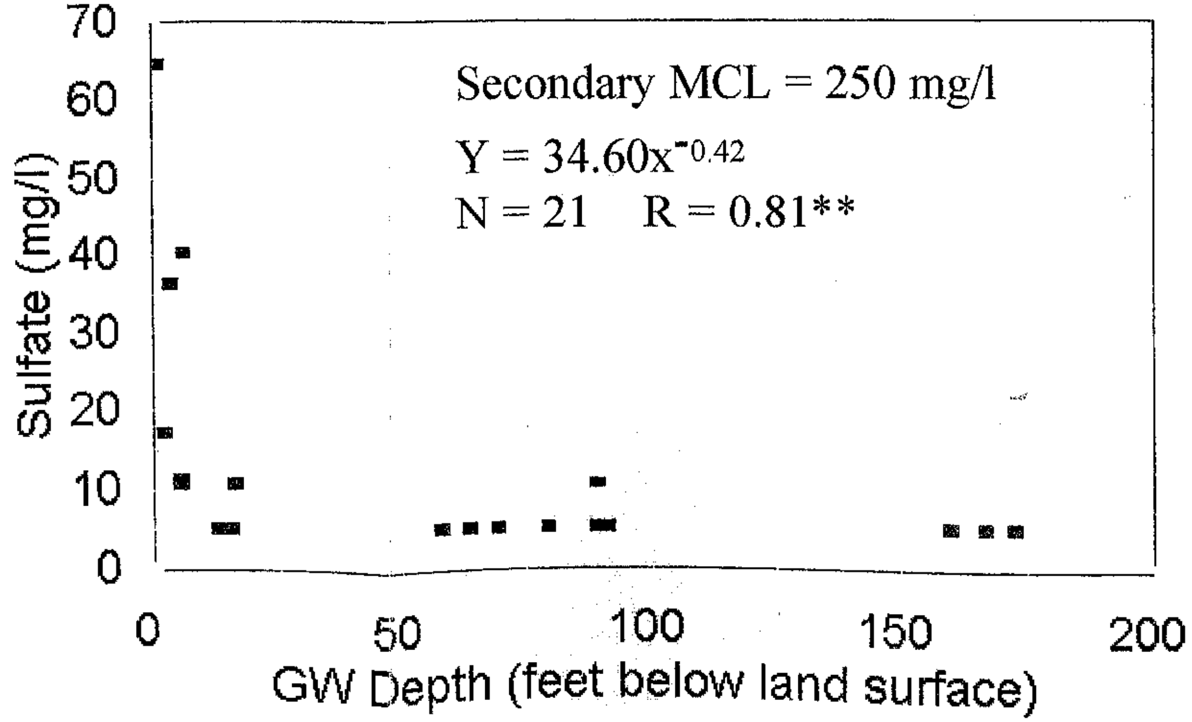


Table 16. Mathematical Equations Reflecting Various Groundwater Quality Parameter Levels to Groundwater Depth (bls)

Parameter	Equation	N	R
Total N	$y = 10.20x^{-0.48}$	21	0.47 *
Cl	$y = 32.01x^{-0.48}$	21	0.57 **
TDS	$y = 376.46x^{-0.24}$	21	0.78 **
Hardness	$y = 285.83x^{-0.31}$	21	0.83 **
SO_4	$y = 34.60x^{-0.42}$	21	0.82 **
TKN	$y = 0.30x^{-0.32}$	21	0.88 **
Alkalinity	$y = 150.19x^{-0.18}$	14	0.73 **
Ca	$y = 68.29x^{-0.32}$	21	0.85 **
Mg	$y = 29.57x^{-0.30}$	21	0.78 **
Na	$y = 13.80x^{-0.18}$	21	0.73 **

bls	Below land surface
N	Number of groundwater samples
R	Correlation coefficient
*	Significant at $P = 0.05$
**	Significant at $P = 0.01$

Further examining the graphs shown in Fig. 9 revealed there existed a groundwater depth above which the level of total N, Cl, TDS, hardness, SO_4, TKN, Ca, Mg, Na, and alkalinity would began to rise drastically even exceeding the Primary or Secondary MCL in some cases. This groundwater depth was defined as the "threshold" groundwater depth in this report. The "threshold" groundwater depth for the groundwater quality parameters was determined by simultaneously solving the two linear equations generated by the linear regression analysis for the two phases of the biphasic trend and the results are shown in Table 17. The groundwater depth ranged from 12 to 15 feet for the parameters of total N, Cl, TDS, hardness, SO_4, Ca, Mg, Na, and alkalinity; only the parameter of TKN at 44.9 feet differs greatly from this group of parameters.

The validity of the "threshold" groundwater depth established above for the groundwater quality parameters was further evaluated by the following procedures:

The groundwater samples collected in the study area were initially divided into two groups for each of the groundwater quality parameters based on the criteria whether the groundwater depth at the time of sampling was above or below the "threshold" groundwater depth established earlier; ANOVA was subsequently used to determine if there was a significant difference between these two groups of groundwater samples with respect to the various groundwater quality parameters. The results, shown in Table 18, reflected that these two groups of groundwater samples were significantly different from each other with respect to the concentration of total N, Cl, TDS, hardness, SO_4, TKN, Ca, Mg, Na, and alkalinity. Therefore, the validity of the "threshold" groundwater depth established previously for these parameters was substantiated.

In addition, the "critical" groundwater depth above which the Primary or Secondary MCL would be exceeded for these groundwater quality parameters was also calculated based on the respective mathematical equations determined earlier. The results are shown in Table 17.

The "threshold" as well as the "critical" depth determined for the various groundwater quality parameters can be used in land use and water use planning. For instance, septic systems should not be installed in areas where groundwater depth would rise to the level that would fail the "threshold" depth requirement for septage-indicator parameters such as total N, Cl, and TDS (15.2, 14.5, and 13.4 bls, respectively) during any period of time in a year or the underneath groundwater quality would be significantly deteriorated. Moreover, domestic water supplies should not be used from wells without treatment when the groundwater depth in the well would rise to the level that would fail the "critical" depth requirement determined for the various groundwater quality parameters. Care should be taken to properly construct the well so as to exclude the entry of any groundwater from shallow depths from entering the well, although placement of domestic wells in areas of shallow groundwater should also be avoided when possible.

Table 17. Threshold and Critical Depths for Various Groundwater Quality Parameters

Parameters	Threshold Depth in Feet (bls)	Critical Depth in Feet (bls)
Total N	15.09	1.04 #
Cl	14.67	0.01 $$
TDS	13.42	0.31 $$
Hardness	12.46	-
SO_4	14.79	0.01 $$
TKN	44.85	-
Alkalinity	15.43	-
Turbidity	4.41	-
Ca	12.35	-
Mg	12.18	-
Na	12.26	-

#	Primary MCL
$$	Secondary MCL
bls	Below land surface

Table 18. ANOVA on the Validity of the "Threshold" Depth Established for Some Groundwater Quality Parameters

Parameter	Significance
Total N	*
Cl	**
TDS	**
Hardness	**
SO_4	**
TKN	**
Alkalinity	**
Ca	**
Mg	**
Na	**

* Significant at P = 0.05

** Significant at P = 0.01

Given that the impacts of wells and sampling periods on groundwater depths in the study area were found to be significant as reflected by the results of ANOVA (Table 19), the existence of discontinuous and perched aquifers underlying the study area as reported by many investigators is therefore confirmed (McGavock and others, 1986).

Since the impacts of groundwater depths on levels of some groundwater quality parameters in the study area have been established, factors such as precipitation potentially affecting groundwater depths were subsequently examined. Precipitation data from the U.S. Forest Service's Fort Valley weather station was plotted against corresponding groundwater depths recorded during the three sampling periods in the study area. The resulting graph indicated that the depth to groundwater decreased with increasing precipitation (Fig. 10); this relationship was found to be significant at P=0.01 by ANOVA (Table 20).

During heavy precipitation, the groundwater depth would rise to such an extent that the potential of groundwater intersecting the leach fields of septic systems would increase significantly. During the period of intersection, all groundwater quality parameters including those associated with septic systems would diffuse into the groundwater body until an equilibrium was reached. When the dry season comes, the groundwater depth would subside, thus carrying the pollutants into the underlying aquifer.

Table 19. ANOVA on the Impact of Wells and Sampling Periods on Groundwater Depth (bls)

Source	DF	MS
Well	6	245.87**
Sampling Period	2	4.00*
Error	12	

*	Significant at P = 0.05
**	Significant at P = 0.01
bls	Below land surface

Figure 10. Relationship Between Precipitation and Groundwater Levels

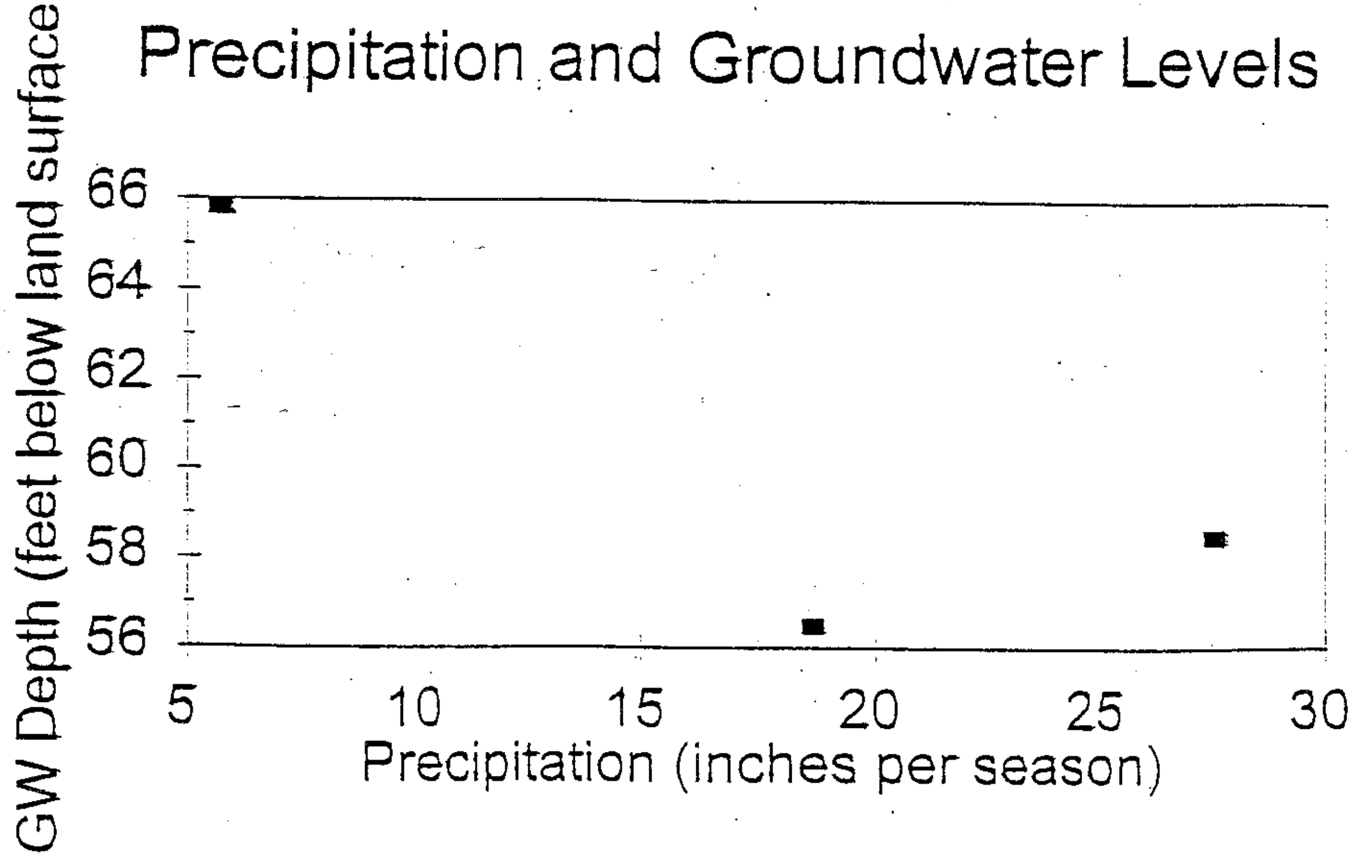


Table 20. ANOVA on the Effects of Precipitation and Wells on Groundwater Depth (bls)

Source	DF	MS
Precipitation	2	169.67 *
Wells	6	10,420.77 **
Error	12	

*	Significant at P = 0.05
**	Significant at P = 0.01
bls	Below land surface

Conclusion

This three-phase study to assess the impacts of septic systems on the groundwater quality at Fort Valley was conducted by ADEQ during 1993-1995. The study was designed to evaluate groundwater quality during times when the water table was high and during times when the water table was low. The results of the study indicated the following key findings:

1) The very significant variation in groundwater depths as affected by wells and sampling periods established by this study confirms the existence of discontinuous, perched aquifers underlying Fort Valley.

2) Groundwater depths in Fort Valley vary over time as precipitation levels vary. This statement confirms the findings of an ADWR (1993) study which indicated groundwater level fluctuations are correlatable with precipitation amounts and recharge to perched aquifers.

3) Widespread groundwater contamination by septic system effluent in Fort Valley was not observed based on the results of this study. However, the groundwater quality at depths < 15 feet bls had been significantly impacted by some groundwater quality parameters associated with septic systems. This statement agrees with the assertion that impacts from septic system effluent are generally first observed in the upper portion of the aquifer; therefore, shallow wells will most likely exhibit high septage-indicator parameter levels before other wells in the area (Darr, 1989).

4) The relationship of groundwater depths and levels of septage-indicator parameters established in this study supports the assertion by Kaplan (1987) that vertical separation was far more important than horizontal separations between leach field and groundwater. ADEQ's findings also support the statement made by the American Water Works Association (1973) that in unconsolidated materials such as those found in Fort Valley, water obtained from depths of 25-30 feet or more is reasonably well protected from surface contamination, while more shallow groundwater might have water quality problems.

5) The level of some groundwater quality parameters is dependent on wells, well types, and sampling periods. Therefore, the level of these groundwater quality parameters obtained from a well of a particular type during a particular season does not reflect the general condition of the groundwater quality in Fort Valley. Moreover, this study also indicated that a much higher variation was obtained for open wells than deep wells in Fort Valley, with respect to the distribution of some groundwater quality parameters.

6) With groundwater depths significantly related to precipitation levels, the odds of having the groundwater impacted by septic systems in Fort Valley increases significantly with increasing precipitation and snowmelt, factors that also provide important recharge to the underlying aquifer. Other studies have noted that rainfall mobilizes bacteria previously retained in the soil and greatly promotes their transport to groundwater.

Furthermore, the greatest degree of drinking water well contamination occurs after periods of heavy rainfall (Bitton and Gerba, 1994).

7) Since chlorination methods have been routinely used by residents in Fort Valley to kill bacteria in their water systems, bacteria counts associated with water samples directly obtained from water systems may not be a valid indicator to determine whether the groundwater quality has been adversely affected by septic systems.

Recommendations

Care should be taken in both the operation of the existing septic systems and domestic wells in Fort Valley as well as in selecting appropriate locations and types of both wastewater disposal systems and well characteristics for any future development in Fort Valley. These precautions are to prevent further deterioration of the groundwater quality in Fort Valley, even with continued population growth.

In order to better manage the impacts of septic systems on the groundwater quality in Fort Valley, the following actions are recommended with septic systems currently in use:

1) The extent of groundwater contamination with respect to septage-indicator parameters observed in this study does not warrant recommending replacing septic systems having buried leach fields or trenches with alternative wastewater disposal systems at this time. Septic systems with buried leach fields or trenches appear adequate for wastewater disposal during much of the year in most areas in Fort Valley.

2) Caution should be exercised in making sure existing septic systems are properly installed and adequately maintained. Tests to check the tightness of septic tanks will provide assurance the effluent passes through leach fields or trenches rather than leaking directly from the septic tank.

3) Many of the older septic systems with buried leach fields or trenches were approved and constructed during the summer and may not provide adequate clarification for effluent during high spring groundwater levels. Thus, during periods of heavy recharge when groundwater levels rise, it would be prudent to dispose of wastewater by other means, such as pumping out septic tanks rather than allowing the septic effluent to possibly be leached through saturated soil which would fail to provide proper clarification.

In order to better manage the impacts of septic systems on the groundwater quality, the following actions are recommended for future residential development in Fort Valley:

1) Septic tanks using buried leach fields and/or trenches should not only not be used in areas where there is not the minimum five foot vertical separation between the bottom of the leach field and groundwater according to *Engineering Bulletin #12* (ADEQ, 1989); they should not be used in areas of Fort Valley with shallow groundwater levels (<15 feet

bls) during any portion of the year;

2) Septic tanks using buried leach fields and/or trenches should not be used in areas of Fort Valley with soils rated by the Soil Conservation Service as "unsuitable" for use as leach fields or trenches, as several studies have attributed decline in groundwater quality to indescriminant use of septic systems in soils unsuited for adequate domestic wastewater purification (Bitton and Gerba, 1994);

3) In areas of Fort Valley with seasonal high groundwater (<15 feet bls) and/or soils rated by the Soil Conservation Service as "unsuitable" for use as leach fields or trenches, alternative on-site wastewater treatment and disposal systems should be designed by an engineer to conform to *Engineering Bulletin #12* (ADEQ, 1989), avoid contamination of groundwater or surface water, as well as being approved by the Coconino County Health Department.

In order to better manage the impacts of septic systems on the groundwater quality, the following actions are recommended for wells in Fort Valley:

1) The "critical" depth generated in this study should also be used as general criterion for managing domestic use water quality in Fort Valley. If water is retrieved for domestic uses from wells with groundwater depths < 1 feet below land surface during any time of the year, it is recommended that a treatment process must be in place to improve the water quality by lowering the level of various water quality parameters below the corresponding Primary or Secondary MCL.

2) The "threshold" depth generated by this study may also be used as a general criterion for managing domestic water quality in Fort Valley. It is recommended that all domestic wells be cased at least through 15 feet bls, where elevated septage-indicator parameter levels are likely to be encountered. Domestic wells should be screened only at depths > 15 bls, although a greater margin of safety might be desired, especially in areas where septic tanks are prevalent and domestic animals are billeted.

3) Well construction could potentially be an important factor in groundwater quality. Residents of Fort Valley should check their wells to determine if the annular space outside the casing is grouted with an impervious material to prevent water movement and contamination between aquifers and/or the surface. Impervious grouting of wells is a major cause of contamination of groundwater as other studies (Bitton and Gerba, 1994) have attributed the presence of coliform bacteria to several factors including poor construction of wells. New domestic well construction should also conform to a 100 foot setback from septic tanks and disposal fields (ADWR, 1989).

4) Wells, especially with historical shallow groundwater depths < 15 feet bls during any time of the year, should be monitored for SDW parameters at regular intervals by local residents, especially following heavy winter precipitation in order to obtain information on levels of septage-indication parameters in groundwater.

Additional studies investigating septic system impacts on groundwater quality would benefit from the following actions:

1) Tracers such as bromide, stable isotopes, fluorescent dyes, and /or halogen salts can be placed in septic systems situated in vulnerable areas with respect to groundwater contamination; wells in the vicinity of these systems would then be monitored for these tracers to determine the flowpaths and precise impacts of the septic systems on the underlying aquifer.

2) ADWR (1993) indicated that groundwater levels typically decline in Fort Valley from June through February and increase from March through mid-April. With these seasonal variations in groundwater elevations, groundwater quality parameter levels also vary. As such, several rounds of sampling may be necessary following a wet spring to determine peak concentrations of septage-indicator parameters. Lag times may occur between the appearance of high total N, Cl, and TDS levels in groundwater and the peak levels represented by the equilibrium (full impact) condition (Darr, 1989). As a consequence, septage-indicator parameter levels measured by ADEQ may have been higher if measured at regular intervals during high groundwater level periods in the spring.

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Appendix A. Septage-Indicator Constituent Levels in Fort Valley Samples

Well Name	Well Registry Number	Sample Date	Total Coliform /100 mls	Fecal Coliform /100 mls	Fecal Strep /100 mls	Total N mg/l	Cl mg/l	TDS mg/l	Total P mg/l	NH$_3$-N mg/l	B mg/l
Minimum Reporting Levels (MRLs)			1	1	1	0.10	1.0	10	0.10	0.10	0.10
Maximum Contaminant Levels (MCLs)			1	1	1	10.0	(250)	(500)			0.63*
Beckage Well	649987	11/19/93	ND	ND	ND	3.10	3.9	144	0.23	ND	ND
"	"	04/08/94	ND	ND	ND	2.09	4.9	136	0.14	ND	ND
"	"	03/28/95	ND	1	ND	4.25	5.1	151	ND	ND	ND
Howeth Deep Well	608396	11/20/93	ND	ND	ND	2.44	2.2	145	0.20	ND	ND
"	"	04/08/94	ND	ND	ND	1.98	4.1	135	0.20	ND	ND
"	"	03/27/95	ND	ND	ND	0.93	*6.3*	127	ND	*ND*	ND
Howeth Open Well	608397	12/01/93	ND	ND	ND	1.51	1.2	122	0.40	ND	ND
"	"	04/09/94	ND	ND	ND	1.51	3.1	122	0.21	ND	ND
"	"	03/27/95	ND	ND	ND	1.17	*< 5.0*	113	ND	*ND*	ND
Olberding Well	514115	11/20/95	ND	ND	ND	17.5	69.9	449	0.18	ND	ND
"	"	04/10/95	ND	ND	ND	2.48	56.8	324	0.17	ND	ND
"	"	03/27/95	ND	ND	1	24.9	*136*	611	0.11	*ND*	ND

ND = None Detected at Lab Minimum Reporting Level (MRL)
* = Human Health-Based Guideline (HBGL)
Shadow # = Spike Recovery Not Between 90 - 110%

( ) = Secondary SDW Maximum Contaminant Level (MCL) Standard
Italics # = Exceeded Recommended Holding Time
N/A = Constituent Not Analyzed For

Appendix A. Septage-Indicator Constituent Levels in Fort Valley Samples--Continued

Well Name	Well Registry Number	Sample Date	Total Coliform /100 mls	Fecal Coliform /100 mls	Fecal Strep /100 mls	Total N mg/l	Cl mg/l	TDS mg/l	Total P mg/l	NH_3-N mg/l	B mg/l
Minimum Reporting Levels (MRLs)			1	1	1	0.10	1.0	10	0.10	0.10	0.10
Maximum Contaminant Levels (MCLs)			1	1	1	10.0	(250)	(500)			0.63*
Little Leroux Spring	None	11/20/93	N/A	N/A	N/A	ND	1.5	138	ND	ND	ND
Ski Lift Lodge Well	601851	12/02/93	ND	ND	ND	3.27	3.3	126	ND	ND	ND
"	"	04/11/94	< 2	< 2	N/A	4.10	5.3	131	0.15	ND	ND
"	"	03/28/95	ND	ND	ND	4.27	24.1	130	ND	ND	ND
Wallace Well	647302	04/08/94	ND	ND	ND	0.85	4.6	167	0.32	ND	ND
Winse Deep Well	517151	11/19/93	ND	ND	ND	0.11	1.0	138	0.20	ND	ND
"	"	04/09/94	ND	ND	ND	< 0.10	2.5	133	0.20	ND	ND
"	"	03/28/95	ND	ND	ND	0.13	< 5.0	133	ND	ND	ND
Winse Open Well	620413	12/01/93	1	ND	ND	3.57	4.8	212	0.40	ND	ND
"	"	04/09/94	ND	ND	ND	2.88	6.6	186	0.21	ND	ND
"	"	03/28/95	4	1	2	27.6	18.0	312	0.14	ND	ND

ND = None Detected at Lab Minimum Reporting Level (MRL)
* = Human Health-Based Guideline (HBGL)
Shadow # = Spike Recovery Not Between 90 - 110%

( ) = Secondary SDW Maximum Contaminant Level (MCL) Standard
Italics # = Exceeded Recommended Holding Time
N/A = Constituent Not Analyzed For

Appendix B. Other Inorganic Constituent Levels in Fort Valley Samples

Well Name	ADEQ Well ID Number	Sample Date	Alkalinity, Phenol. mg/l	Alkalinity, Total mg/l	Fluoride mg/l	Hardness $CaCo_3$ mg/l	pH SU	Sulfate SO_4 mg/l	TKN mg/l	Turbidity NTU
Minimum Reporting Levels (MRLs)			2.0	2.0	0.20	10	0.1	10	0.10	0.01
Maximum Contaminant Levels (MCLs)					4.0 & (2.0)		(6.5 to 8.5)	(250)		
Beckage Well	46489	11/19/93	ND	80.9	ND	90	7.90	ND	ND	0.65
"	"	04/08/94	N/A	N/A	ND	88.6	N/A	ND	0.13	N/A
"	"	03/28/95	ND	72.7	ND	89	7.82	10.6	0.11	4.4
Howeth Deep Well	15795	11/20/93	ND	80.7	ND	85	7.86	ND	ND	0.30
"	"	04/08/94	N/A	N/A	ND	82.2	N/A	ND	ND	N/A
"	"	03/27/95	ND	71.2	*ND*	77	7.87	ND	ND	*2.8*
Howeth Open Well	15796	12/01/93	ND	68.9	ND	73	7.61	ND	*0.26*	48.
"	"	04/09/94	N/A	N/A	ND	73	N/A	10.7	0.20	N/A
"	"	03/27/95	ND	64.6	*ND*	67	7.68	ND	0.11	*3.9*
Little Leroux Spring	15725	11/20/93	ND	73.8	ND	62	7.23	ND	ND	1.90
Olberding Well	15802	11/20/93	ND	144	ND	308	7.40	40.1	0.29	1.74
"	"	04/10/94	ND	N/A	ND	231	N/A	36.3	ND	N/A
"	"	03/27/95	ND	155	*ND*	452	7.63	64.5	0.47	*0.19*

ND = None Detected at Lab Minimum Reporting Level (MRL)
Italics # = Exceeded Recommended Holding Time

( ) = Secondary SDW Maximum Contaminant Level (MCL) Standard

Appendix B. Other Inorganic Constituent Levels in Fort Valley Samples--Continued

Well Name	ADEQ Well ID Number	Sample Date	Alkalinity, Phenol. mg/l	Alkalinity, Total mg/l	Fluoride mg/l	Hardness CaCO$_3$ mg/l	pH SU	Sulfate SO$_4$ mg/l	TKN mg/l	Turbidity NTU
Minimum Reporting Levels (MRLs)			2.0	2.0	0.20	10	0.1	10	0.10	0.01
Maximum Contaminant Levels (MCLs)					4.0 & (2.0)		(6.5 to 8.5)	(250)		
Ski Lift Lodge Well	15759	12/02/93	ND	49.7	ND	53	7.66	ND	*ND*	0.16
"	"	04/11/94	N/A	N/A	ND	52.0	N/A	ND	ND	N/A
"	"	03/28/95	ND	41.7	ND	54	7.65	ND	0.13	0.19
Wallace Well	15806	04/08/94	N/A	N/A	0.22	114	N/A	13.3	ND	N/A
Winse Deep Well	46488	11/19/93	ND	102	ND	81	8.05	ND	ND	1.85
"	"	04/09/94	N/A	N/A	ND	83.4	N/A	ND	ND	N/A
"	"	03/28/95	ND	99.5	ND	84	8.05	ND	0.10	1.58
Winse Open Well	51465	12/01/93	ND	135	ND	139	7.74	11.3	*0.19*	5.1
"	"	04/09/94	N/A	N/A	ND	126	N/A	10.7	0.20	N/A
"	"	03/28/95	ND	101	ND	199	7.63	17.1	0.17	0.09

ND = Non-detected at Minimum Reporting Level (MRL)

( ) = Secondary SDW Maximum Contaminant Level (MCL) Standard

Appendix C. Metal Constituent Levels in Fort Valley Samples

Well Name	Sample Date	Ag mg/l	Al mg/l	As mg/l	Ba mg/l	Cd mg/l	Ca mg/l	Cr mg/l	Cu mg/l	Fe mg/l	K mg/l	Hg mg/l	Mg mg/l	Mn mg/l	Na mg/l	Pb mg/l	Se mg/l	Zn mg/l
Minimum Reporting Levels (MRLs)		0.001	0.50	0.01	0.10	.001	1.0	0.01	0.01	0.1	0.5	.0005	1.0	0.05	5.0	0.005	0.005	0.05
Maximum Contaminant Levels (MCLs)		(0.1)	(0.05 to 0.20)	0.05	2.0	.005		0.1	{1.3}	(0.3)		0.002		(0.05)		{.015}	0.05	(5.0)
Beckage	11/19/93	ND	ND	ND	ND	ND	19.3	ND	ND	ND	1.50	ND	11.0	ND	5.67	ND	ND	0.06
"	04/08/94	ND	ND	ND	ND	ND	18.4	ND	0.025	ND	2.79	ND	10.2	ND	8.4	ND	ND	ND
"	03/28/95	ND	0.17	ND	ND	ND	20.2	ND	ND	0.10	ND	ND	11.3	ND	7.7	ND	ND	ND
Howeth Dp	11/20/93	ND	ND	ND	ND	ND	19.2	ND	ND	ND	2.45	ND	10.2	ND	ND	ND	ND	0.06
"	04/08/94	ND	ND	ND	ND	ND	18.3	ND	0.012	0.12	3.61	ND	9.2	ND	8.0	ND	ND	0.19
"	03/27/95	ND	0.11	ND	ND	ND	17.5	ND	ND	ND	1.74	ND	9.7	ND	6.6	ND	ND	ND
Howeth Op	12/01/93	ND	0.82	ND	ND	ND	18.4	ND	ND	1.63	2.31	ND	7.0	0.22	ND	ND	ND	ND
"	04/09/94	ND	ND	ND	ND	ND	17.5	ND	ND	ND	3.46	ND	7.1	ND	6.6	ND	ND	ND
"	03/27/95	ND	ND	ND	ND	ND	17.5	ND	ND	ND	1.45	ND	6.8	ND	ND	ND	ND	ND
Ltl Lrx Spr	11/20/93	ND	ND	ND	ND	ND	13.5	ND	ND	ND	3.21	ND	7.7	ND	6.1	ND	ND	0.08
Olberding	11/20/93	ND	ND	ND	ND	.003	72.5	ND	ND	ND	1.35	ND	34.0	ND	11.6	ND	ND	ND
"	04/10/94	ND	ND	ND	ND	ND	49.3	ND	0.011	ND	1.96	ND	24.4	ND	15.3	ND	ND	ND
"	03/27/95	ND	ND	ND	ND	ND	104	ND	ND	ND	0.87	ND	51.2	ND	20.6	ND	ND	ND

ND = None Detected at Lab Minimum Reporting Level (MRL)
Italics # = Exceeded Recommended Holding Time

( ) = Secondary SDW Maximum Contaminant Level (MCL) Standard
Shadow # = Spike Recovery Not Between 90 - 110%

{ } = SDW Action Levels for Copper and Lead

Appendix C. Metal Constituent Levels in Fort Valley Samples--Continued

Well Name	Sample Date	Ag mg/l	Al mg/l	As mg/l	Ba mg/l	Cd mg/l	Ca mg/l	Cr mg/l	Cu mg/l	Fe mg/l	K mg/l	Hg mg/l	Mg mg/l	Mn mg/l	Na mg/l	Pb mg/l	Se mg/l	Zn mg/l
Minimum Reporting Levels (MRLs)		0.001	0.50	0.01	0.10	.001	1.0	0.01	0.01	0.1	0.5	.0005	1.0	0.05	5.0	0.005	0.005	0.05
Maximum Contaminant Levels (MCLs)		(0.1)	(0.05 to 0.20)	0.05	2.0	.005		0.1	{1.3}	(0.3)		0.002		(0.05)		{.015}	0.05	(5.0)
Ski L Lodge	12/02/93	ND	ND	ND	ND	ND	11.8	ND	ND	ND	4.26	ND	6.0	ND	6.2	ND	ND	ND
"	04/11/94	ND	ND	ND	ND	ND	11.7	ND	0.017	ND	6.06	ND	5.7	ND	8.2	ND	ND	ND
"	03/28/95	ND	ND	ND	ND	ND	13.0	ND	ND	ND	3.92	ND	6.5	ND	6.7	ND	ND	ND
Wallace	04/08/94	ND	ND	ND	ND	ND	25.8	ND	ND	ND	1.06	ND	11.2	ND	8.3	ND	ND	0.11
Winse Deep	11/19/93	ND	ND	ND	ND	ND	22.3	ND	ND	ND	3.33	.0017	7.6	ND	6.1	ND	ND	0.06
"	04/09/94	ND	ND	ND	ND	ND	20.8	ND	0.033	0.11	3.52	ND	7.1	ND	8.4	ND	ND	ND
"	03/28/95	ND	ND	ND	ND	ND	23.5	ND	ND	ND	2.89	ND	7.9	ND	8.7	ND	ND	ND
Winse Open	12/01/93	ND	ND	ND	ND	ND	33.4	ND	ND	ND	1.33	ND	15.1	ND	11.8	ND	ND	ND
"	04/09/94	ND	ND	ND	ND	ND	28.4	ND	0.010	ND	2.94	ND	12.7	ND	13.0	ND	ND	ND
"	03/28/95	ND	ND	ND	ND	ND	49.5	ND	ND	ND	1.01	ND	21.6	ND	16.2	ND	ND	ND

ND = None Detected at Lab Minimum Reporting Level (MRL)
Italics # = Exceeded Recommended Holding Time
( ) = Secondary SDW Maximum Contaminant Level (MCL) Standard
Shadow # = Spike Recovery Not Between 90 - 110%
{ } = SDW Action Levels for Copper and Lead

Appendix D. EPA Methods Used to Determine Inorganic Constituent Concentration Levels In Fort Valley Groundwater Samples.

Parameter	EPA Method	Parameter	EPA Method
Alkalinity, Total	310.1	B	200.7
Alkalinity, Phenol	310.1	Ba	200.7
Ammonia-Nitrogen	350.1	Cd	213.2
Chloride	SM 4500 Cl D	Ca	200.7
Fluoride	340.2	Cr	218.2
Hardness	130.2	Cu	220.2
Nitrite-Nitrate Total N	353.2	Fe	200.7
Nitrite	353.2	K	258.1
Phosphorous	365.4	Hg	245.1
TKN	351.2	Mg	200.7
pH	150.1	Mn	200.7
Sulfate	375.2	Na	200.7
TDS	160.1	Pb	239.2
Turbidity	180.1	Se	200.9
Ag	272.2	Zn	200.7
As	200.9		

Appendix E. SDW Volatile Organic Compounds (VOCs) by EPA Method 601/602 Sampled for in Fort Valley.

Benzene
Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
n-Butylbenzene
sec-Butylbenzene
tert-Butylbenzene
Carbon Tetrachlride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
2-Chlorotoluene
4-Chlorotoluene
Dibromochloromethane
Bibromomethane
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorodifluromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,1-Dichloropropene
c-1,3-Dichloropropene
t-1,3-Dichloropropene
Ethylbenzene
Hexachlorobutadiene
Isopropylbenzene
p-Isopropytoluene
Methylene Chloride
Naphthalene
n-Propylbenzene
Styrene
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
1,2,3-Trichlorobenzene
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
1,2,3-Trichloropropane
1,2,4 Trimethylbenzene
1,3,5-Trimethylbenzene
Vinyl Chloride
Total Xylenes
Chlorofluorobenzene (EICD)
Chlorofluorobenzene (PID)