4-4-2010

Urbanization of Seven Springs, New Mexico: An Evaluation of Current and Projected Impacts on Ground- and Surface-Water Resources

William S. McDonald

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by

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A Professional Project Report prepared in partial fulfillment of the requirements
For the Degree of

Master of Water Resources Administration

Water Resources Program
The University of New Mexico
Albuquerque, New Mexico

June 2000

Committee Approval

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ABSTRACT

The village of Seven Springs, New Mexico, lies north of Fenton Lake in the valley of the Rio Cebolla in the Jemez Mountains of northern New Mexico. The valley is funnel shaped -- narrowest downstream -- with homes most densely packed at the bottom of the funnel. It is typical of many small communities scattered throughout the state in that residents rely on private wells for drinking water and on individual septic systems for disposal of household waste. The current population in the village and the valley is light -- about 50 permanent residents swelling to about 100 during the summer months. However, increased development of the valley is likely resulting in more permanent and seasonal residents.

Ground water in the valley is shallow, ranging in depth from five to forty feet, and the threat to ground-water quality from increased development is high. To assess current and projected impacts to ground water from septic systems, water was sampled from wells at eleven homes, from two springs from which people obtain water, and from the Rio Cebolla above and below the village. Ground and surface waters were analyzed for major ions, metals, nutrients, volatile organic compounds, and coliforms.

Coliform bacteria were found in Cebolla Spring, Hatchery Spring, and the Rio Cebolla. Water from Cebolla Spring tested positive for total coliform bacteria and water from the Hatchery Spring and the Rio Cebolla tested positive for both fecal and total coliforms. Residents who participated in the study were cautioned to avoid drinking water from the springs and the river.

The ground water in the valley is of good quality with hardness under 37 mg/L (2.2 grains), total dissolved solids content less than 200 mg/L, nitrate at 0.2 mg/L or less and no coliforms or elevated metals. No detectable impact was found from the old gas station located in the village. There are some areas where anoxic conditions exist and at least one resident complained of rusty water with an odor of rotten-eggs. However, it was not determined if these conditions are the direct result of septic system discharge.

Increased development may, however, adversely impact ground-water quality in the valley. Construction of a simple hydrogeologic model shows that the septic discharge from only 46 homes with 127 year-round residents in the valley may be enough to increase nitrate levels in shallow ground water at the bottom of the valley to 5 mg/L -- half of the ground-water standard. Runoff from farming and grazing operations has likely contaminated the river and Fenton Lake with excessive nutrients. Additionally, an increase in population may bring more people into contact with spring and river water, which were been found to be contaminated with coliform bacteria.

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ACKNOWLEDGEMENTS

I wish to thank my committee – Michael E. Campana, Clifford N. Dahm, Bruce M.Thomson, and Dennis M. McQuillan – for their review and comments on drafts of this report. Incorporation of their suggestions will benefit the reader as it has benefited me.

I especially wish to thank the New Mexico Environment Department Ground Water Quality Bureau and Dennis McQuillan for the use of instrumentation and the funding for laboratory analyses. No less thanks go to Dr. Michael Campana who was instrumental in obtaining said funding.

1.0 INTRODUCTION

As the populations of western states are increasing, so is the demand for water for industry, agriculture, and human consumption. Potable water that has naturally low mineral content, good taste, no odor, and crystal clarity, is sought by many and obtained by few. It is important that we protect high-quality water supplies from activities that would impair its quality.

As of 1992, approximately 170,000 New Mexicans relied on septic systems to dispose of their household wastewater. This included not only rural dwellers, but also suburbs of major population centers such as Albuquerque, Santa Fe, and Las Cruces (McQuillan and Keller, 1992). Small communities are especially at risk because of the lack of wastewater treatment facilities, shallow ground water, and small lot sizes. The inner valley of the middle Rio Grande is an example where on-site wastewater disposal has contaminated shallow ground water with nitrate and caused taste and odor problems. Additionally, petroleum products (gasoline, diesel and jet fuel) from leaking pipelines, gas station underground storage tanks, and bulk storage terminals and extraordinarily high nitrate from fertilizers used for farming operations have contaminated shallow ground water (Gallaher et al, 1987; Space, McQuillan, and McDonald, 1993). Development in other small communities in New poses a threat of similar ground-water contamination problems.

Seven Springs is one of many small communities located in the northern mountainous areas of New Mexico that are without a community waste-water treatment system. Some of these have small public water supplies while others (e.g., Seven Springs) rely entirely on private wells. The Safe Drinking Water Act establishes stringent regulations regarding operation and testing of public water supplies, but communities that rely on private wells receive no such protection. Private well owners often have no information on the quality of their water and of the threats to their water supply that may be present.

1.1 Purpose and Objectives

This report focuses on the canyon of the Rio Cebolla in which the village of Seven Springs, New Mexico, is located. The proposed improvement of NM 126 from Fenton Lake, through Seven Springs, to Cuba, primarily by paving the existing dirt road, will likely result in increased tourism and recreational use at Fenton Lake. Also, the improved access to Seven Springs, the upper canyon of the Rio Cebolla, and to Cuba and Farmington may result in more homes being built in the Seven Springs area. The people living in Seven Springs depend on septic systems for disposal of household wastewater and on private wells for drinking water. Future development will also use septic systems and private wells. Thus, it is important to understand the potential health and ecological threats related to future development (number of homes/systems per unit area), especially to the downstream residents (i.e., those living in the southern extent of Seven Springs).

The current health of the watershed and a management plan that will "stabilize the health of watershed natural systems by preventing further degradation from human use and by rehabilitating damaged areas...." was previously described by Breeding (1995). While her focus was on the effects that development has on the health of the watershed, the purpose of this report is to evaluate the potential threat of development to public health. The objectives of this report are twofold:

1. Furnish citizens of Seven Springs with an understanding of the hydrogeology of the watershed in which they live.

2. Determine potential health threats from future development, which relies on on-site water supply and wastewater disposal systems.

1.2 Organization of the Report

First, the hydrogeologic setting of the watershed will be described including geography and geology, climate, and soils. Next, the operation of a 'conventional' septic system, the

governing regulatory guidelines, and the threats to human health posed by improperly designed and/or operating systems and high septic system density are discussed. A conceptual hydrogeologic model of the Seven Springs area is presented wherein the relationships between climate, geology, soils, vegetation, and surface and ground waters are explained. Then, the methods used in acquiring surface- and ground-water information are described and the information/data obtained are discussed. (An excellent discussion of other watershed descriptors -- vegetation, natural resources and land use including an examination of the effects of grazing, logging, and recreational uses -- was provided by Breeding [1995]).

Concluding is a discussion of the potential effects on human health and the environment of uncontrolled development resulting in 'maximum' lot density -- the result of subdividing all of the lots into the minimum allowable size. Projected increases in numbers of year round residents, seasonal residents, and recreational use along the upper Rio Cebolla are discussed. The effects of these increases on ground- and surface-water quality will be estimated. Estimates of minimum lot sizes for the area are offered based upon soil and ground-water information that is available, assumptions made regarding soil and ground-water parameters, and comparison to models constructed by CH2M HILL for the City of Albuquerque.

2.0 SETTING

Residents of the canyon of the Rio Cebolla are concentrated in the community of Seven Springs, which lies at an elevation of 7,795 feet (2,375 meters) in a narrow corridor along the river, in Sandoval County, New Mexico (Figure 1). The 1995 year round population of Seven Springs was approximately 10 residents (Duemler, 1997). The year round population in the canyon is estimated at about 50 residents -- swelling to about 100 residents in summer (Breeding, 1995). Private wells and septic systems serve all of the homes in the Seven Springs area.

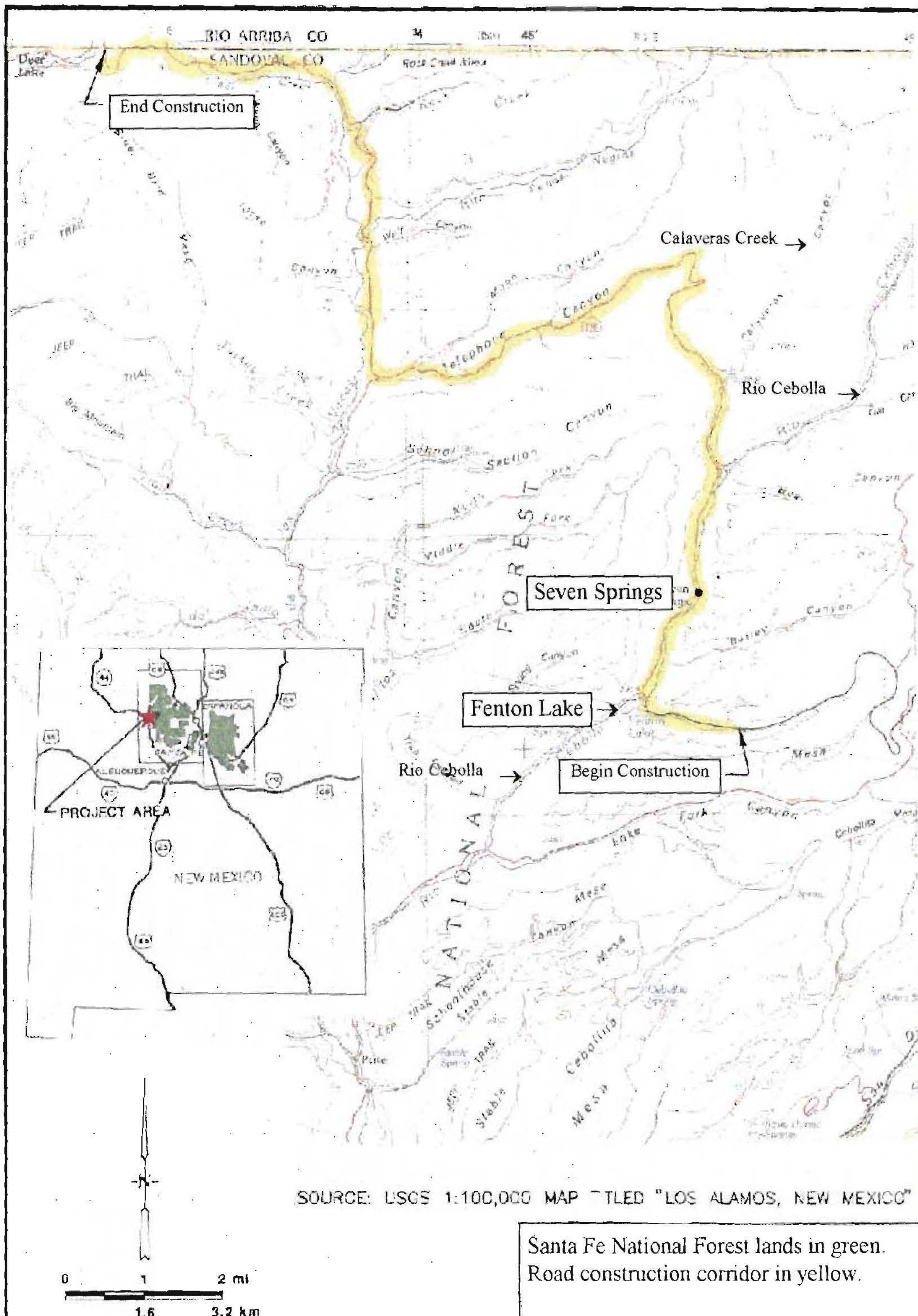


Figure 1. Location map: Santa Fe National Forest; project area; Seven Springs, New Mexico; and proposed road construction corridor (modified from Anonymous, 1996).

2.1 Geography and Geology

The Rio Cebolla is a perennial stream of which the upper 16.8 miles from Fenton Lake to its headwaters, drains 47 square miles of the Santa Fe National Forest in the Jemez Mountains (Figure 2). The majority of the Rio Cebolla watershed comprises mountainous terrain above elevation 8,400 ft (2,560 m). The head of the river (upper limit of the watershed) lies at 9,820 ft (2,993 m). Fenton Lake is a 35-acre reservoir lying 1.5 miles downstream of Seven Springs at an elevation of approximately 7,440 ft (2,268 m). The average grade of the river from the headwaters to Fenton Lake is 2.4 percent (Breeding, 1995). The river drops 2,025 ft (617 m) over the 15.3 miles (24.6 kilometers) from its headwaters to Seven Springs for an average grade of 2.5 percent.

The Jemez Mountains were formed as the result of volcanic and tectonic events occurring over the last 16.5 million years. Present surface and bedrock geology in the area resulted from the violent eruptions that deposited the Bandelier Tuff and created the famous Valles Caldera. The Bandelier Tuff comprises two rhyolite ash-flow units -- the Otowi Member and the Tschirege member – erupted from the Toledo and Valles volcanic centers, 1.61, and 1.22 million years ago, respectively. The eruption of the Otowi Member yielded 95 cubic miles (mi^3) of rhyolite ignimbrite. The eruption of the Tschirege Member, which was a catastrophic Mount St. Helens style event, yielded 70 mi^3 of high-silica rhyolite ignimbrite (Mount St. Helens erupted only 0.5 mi^3) resulting in the Valles Caldera (Gardner et al., 1996, and Gardner and Goff, 1996).

The canyon of the Rio Cebolla is located approximately 12 miles (19.3 kilometers) east of the Valles Caldera and is incised into the Otowi Member of the Bandelier Tuff. In the vicinity of Seven Springs, the Otowi consists of up to 600 ft (183 m) of "nonwelded to densely welded ash-flow deposits, characteristically containing abundant accidental lithic inclusions". The Otowi makes lesser slopes and elevations in the area -- surface rocks, alluvium, and bedrock. Cliffs and higher elevations outside of the study area are composed of the Tschirege Member (Smith et al., 1970).

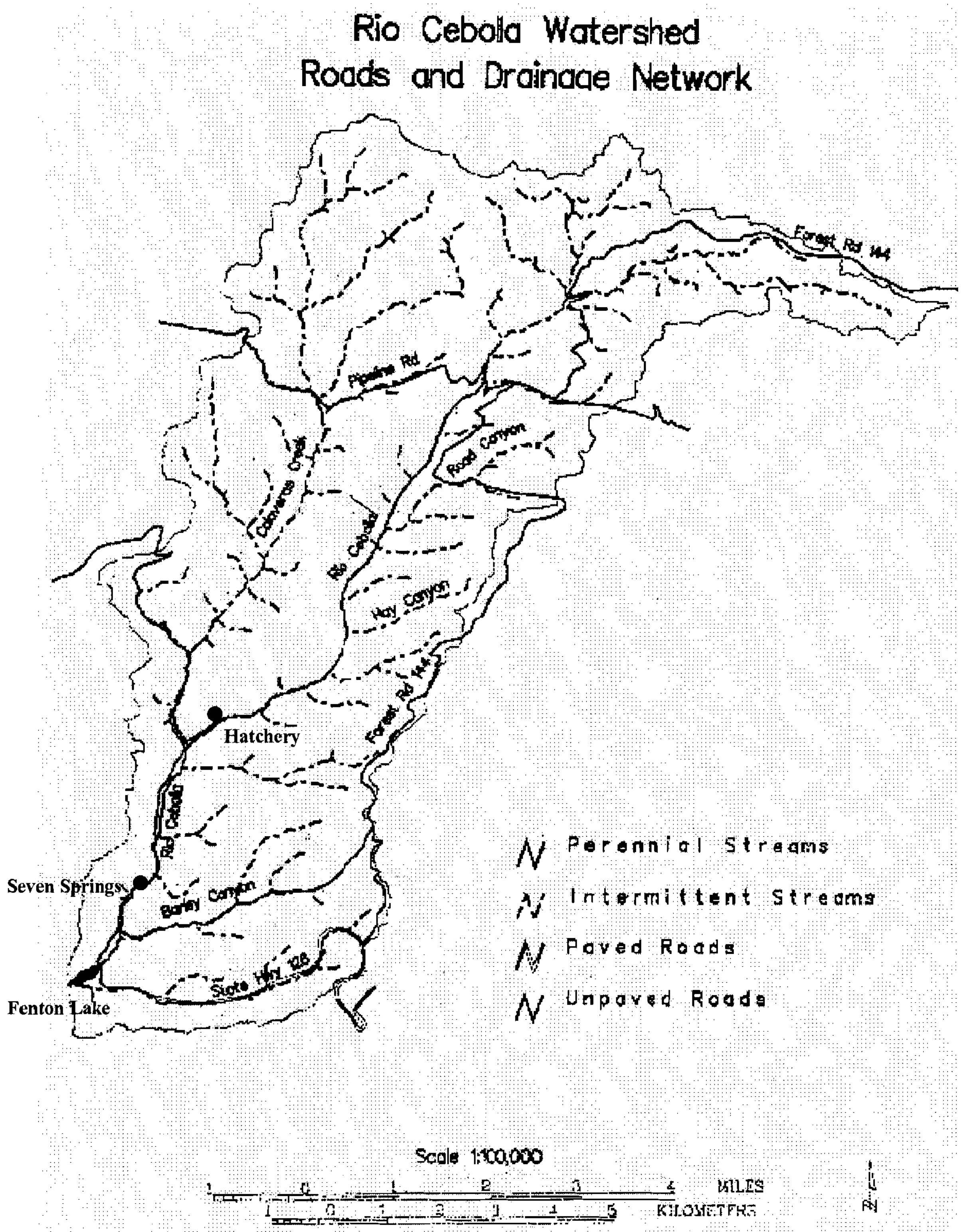


Figure 2. Watershed of the Rio Cebolla above Fenton Lake (from Breeding, 1995)

2.2 Climate

Breeding (1995) describes the climate in the Jemez Mountain region as varying from semi-arid in the lower elevations to sub-humid and continental in the higher elevations. Annual rainfall varies from 16 inches (40.6 centimeters) to 20 inches (50.8 centimeters) -- increasing with altitude. Most of the Rio Cebolla watershed lies above 8,400 ft (2,560 m), and probably receives 20 inches (50.8 centimeters) or more annual precipitation. Approximately half of the annual precipitation falls as summer thundershowers and the other half as snowfall. Roughly 75 percent of all precipitation is lost to evapotranspiration, 20 percent leaves the watershed as streamflow, and 5 percent infiltrates to groundwater. At Seven Springs the elevation is 7,795 ft (2,375 m) and annual rainfall is probably slightly less than 20 inches (Breeding, 1995).

Average annual temperature is approximately 40°F (4.4°C) with extremes recorded nearby ranging from 99°F (37.2°C) to -41°F (-40.5°C). Large seasonal and large daily fluctuations in temperature are typical of this latitude in New Mexico (Breeding, 1995).

2.3 Soils

Soils in the study area are generally evolved from eroded volcanic tuff. On the valley slopes, soils are 10 to 24 inches (25.4 to 61 cm) thick. In the alluvium of the valley bottom, total soil depth ranges from 30 to 40 in (76.2 to 101.6 cm) although topsoil is less than 7 in (17.8 cm). These soils are highly permeable and would make poor material for road construction purposes (Anonymous, 1996). Bedrock under the valley alluvium is highly fractured volcanic tuff allowing ground water to reach the surface in the form of springs (Breeding, 1995).

2.4 Water Quality

Depending upon the source of data cited, New Mexico has 6,000 to 8,682 miles of perennial (flowing year-round) rivers and streams (Anonymous, 1998). The designated uses for 3,432 river miles are threatened or impaired predominantly by "...toxic metals,

temperature, plant nutrients, bottom deposits, and other causes." In New Mexico over 91 percent of water quality impairment (contamination) in rivers and all lake water quality impairment are due to nonpoint (or diffuse) source pollution. Sources of nonpoint pollution in surface waters are agriculture, recreation, hydromodification, and mineral extraction. Over half of all identified cases of ground water contamination in New Mexico are from nonpoint source pollution predominantly from clustered (small communities or subdivisions) household septic systems and cesspools (Anonymous, 1998).

Under authority of the New Mexico Water Quality Act, the New Mexico Water Quality Control Commission (WQCC) has adopted regulations specifying water quality standards and designated uses for the Jemez River and all of its tributaries in *State of New Mexico Standards for Interstate and Intrastate Streams* (Anonymous, 1994). The Rio Cebolla is tributary to the Jemez River, which is the second largest tributary to the Rio Grande. Section 2106A of the WQCC water-quality standards lists designated uses for the Jemez River and all of its tributaries as domestic water supply, fish culture, high quality cold water fishery, irrigation, livestock watering, wildlife habitat, and secondary contact.

Water quality parameters for any single surface-water sample and use-specific standards for the segment of the Rio Cebolla from Fenton Lake to its headwaters are found are listed in Section 2106b and Section 3101 of the WQCC water-quality standards, respectively. The designated uses of this segment or reach of the Rio Cebolla are domestic water are the same as those described above for the Jemez River.

The New Mexico Environment Department Surface Water Quality Bureau identified exceedances of temperature, total phosphorus, and stream bottom of the river and Fenton Lake as the primary water quality problems in the watershed. Therefore, the designated use as a HQCWF is not fully supported in the segment of the Rio Cebolla from Fenton Lake to its headwaters. Livestock, farming and septic systems are known sources of the nutrients (nitrogen and phosphorus) which cause eutrophication (excessive growth of

algae) in rivers and lakes. The accumulation of sediments in the stream and lake most likely stems from road and streambank erosion (Anonymous, 1998).

2.4.1 Ground Water

Water quality is evaluated through field and laboratory analyses of physical, chemical, and biologic characteristics. Variation in concentrations of naturally occurring constituents (e.g., sulfate, chloride, TDS, and nitrate) or any detection of VOCs in ground or surface waters may indicate the impact of septic systems. Discussed below are the parameters that comprise "general water chemistry" and the effects they have on water quality.

Water-quality standards or Maximum Contaminant Levels (MCLs) for public water supply systems have been established by the federal Safe Drinking Water Act (SDWA). The SDWA also establishes schedules by which operators of public supply systems must collect samples for laboratory analysis. Although owners of private wells are not bound by these requirements, the SDWA MCLs are used for comparative purposes in this report. Public drinking water standards can be found at the New Mexico Environment Department website (www.nmenv.state.nm.us/gwb/gwstds.html).

Consumers of water judge its quality by subjective standards of color, clarity, taste, and odor; sensory inputs related to the underlying physical, chemical, and biological characteristics (including pollution) of water. The important physical characteristics of water are defined by its total suspended sediments (TSS) or turbidity (important for surface water), total dissolved solids (TDS – important for ground water), temperature, dissolved oxygen (DO), acidity (pH), alkalinity, and specific conductance. Various concentrations of sulfate, nutrients and metals dissolved into water create chemical conditions affecting hardness, taste and odor. Biological hazards are indicated by the presence of coliform and fecal coliform bacteria although parasites and viruses are also transmitted in surface and ground waters.

Effluent from a properly operating septic system contains high concentrations of ammonia, sulfate, chloride, total dissolved solids, nutrients, and, potentially, volatile organic compounds (VOCs) and metals. Nitrification occurs when the nitrogen in ammonia combines with the dissolved oxygen (DO) in ground water to form nitrate. This oxidation (i.e., addition of oxygen, removal of hydrogen, or removal of electrons) of the nitrogen removes DO from the ground water.

Microbes also use DO for respiration. If DO is absent or is being used faster than it is supplied, oxygen depleted (anoxic) conditions result and microbes must then resort to other sources of energy for respiration. In decreasing order of energy yielded for respiration, microbes will reduce oxygen (aerobic respiration), nitrate (denitrification), manganese (reduction), iron, (reduction), sulfate (reduction), and carbon (methanogenesis -- McQuillan, 1989). Therefore, under reducing conditions (i.e., removal of oxygen, addition of hydrogen, or addition of electrons) first oxygen then nitrate are removed from ground water. When the source of nitrate is depleted, sulfate reduction may then occur, releasing hydrogen sulfide (H_2S) gas. And/or, iron and manganese in the soil (and/or well casing) may be reduced making them mobile in ground water. When water leaving the faucet is aerated, H_2S is released and the iron and manganese are re-oxidized and precipitate out of solution creating smelly, bad tasting water and red and black staining on sinks and toilette bowls.

Oxidation/reduction or redox conditions can be evaluated through observation of odor or precipitation of iron and manganese oxides and by wet chemistry methods (i.e., laboratory analysis). Also, direct measurement of the redox potential, or Eh, can be made in the field.

Acidity and alkalinity are measured in terms of pH – the negative logarithm of the effective hydrogen ion concentration in gram equivalents per liter – with values from 0 to 14. On the pH scale, 7.0 indicates "neutral" conditions (neither acidic or alkaline), less than 7.0 increasing acidity, and values greater than 7.0 increasing alkalinity. Generally, water is

toxic to aquatic organisms at pH values below 4.8 and above 9.2 although most freshwater fish can only tolerate pH ranging from 6.5 to 8.4 (Brooks et al., 1997).

Thermal pollution of surface waters is not just a problem in industrial settings. Deforestation of riparian areas (the banks of streams and rivers) results in more solar radiation reaching the water and increasing water temperature from 4-14 degrees (Centigrade). With increasing temperature the ability of oxygen to dissolve into water drops and biologic activity rises adding to the demand on dissolved oxygen (DO).

The TDS concentration in ground water represents the amount of dissolved salts and is used as a general indicator of ground-water quality. Water hardness is indicated by the concentrations of calcium and magnesium ions (other ions -- iron, manganese, strontium, and aluminum -- also produce hardness, but are rarely present in significant quantities). Hardness is the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations expressed in mg/L as calcium carbonate ($CaCO_3$). Hardness is sometimes measured in grains per gallon (gpg) where 1.0 gpg equals 17.1 mg/L.

Individual tolerance to hardness is relative to the degree of exposure – we can become acclimated to very hard water. However, most people prefer hardness under 150 mg/L (8.8 gpg) and 300-500 mg/L (17.5-29.2 gpg) is considered excessively hard for public water supplies. Hardness in the range of 60-120 mg/L (3.5-7.0 gpg) is considered moderate (Viessman and Hammer, 1993).

TDS is often expressed in units of specific conductance or micromhos per centimeter (mmho/cm); higher specific conductance equates as higher TDS. While there are no health standards for TDS levels in ground water in New Mexico, ground water with 10,000 mg/L of TDS or less is protected under state regulations and there is a secondary (aesthetic) standard for TDS in ground water of 1,000 mg/l (Anonymous, 1995a).

Eight ions make up more than 90% of TDS in most natural ground waters: sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}). Other ions commonly present at concentrations of 0.10 to 10 mg/L are iron ($Fe^{2+,3+}$) and nitrate (NO_3^-). Less common are ions of fluoride (F^-), strontium (Sr^{2+}), and boron (B^{3+} -- Fetter, 1994). Like TDS there are no state health standards for SO_4^{2-} and Cl^-, but there are secondary standards: 600 mg/L and 250 mg/L, respectively.

Consumption of the NO_3^- ion has been determined to have adverse health effects for young children; intake of excessive concentrations can lead to the rare but potentially fatal condition of methemoglobinemia (Anonymous, 1998). State health standards for nitrate in ground water have been set at 10 mg/L. High Cl^- levels indicate saline conditions (salty taste), and SO_4^{2-} in excess of 600 mg/L in drinking water can have a laxative effect for individuals not acclimated.

Coliform bacteria are ubiquitous in the environment. Fecal coliforms in water result only from the feces of people or animals coming into contact with the water and may indicate a health threat to humans. Any detection of coliforms is treated as an indicator that the water is contaminated and unsafe to drink.

Other chemicals discharged into ground water from septic systems are volatile organic compounds (VOCs), such as cleaning solvents and paint thinners, and heavy metals (e.g., lead, mercury and cadmium).

Thus, discharge from a properly operating septic system will negatively affect the physical and chemical characteristics of ground water. Improperly operating or leaking systems may exacerbate the impact to ground water and provide a direct connection between raw effluent and surface water providing a pathway for pathogens. The basic components of the conventional septic system and human and ecological concerns are discussed below.

3.0 SEPTIC SYSTEM DESIGN

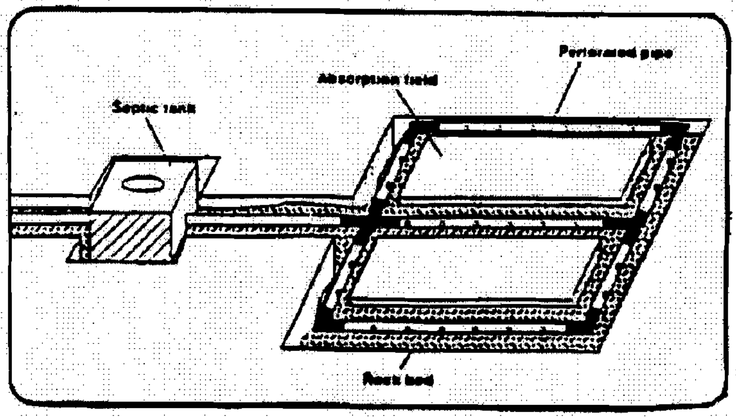
Figure 3 illustrates the three main components of a conventional tank and absorption field septic system; other types of septic systems are also available. These components work together to remove solids and organic matter from household effluent by settling and by biodegradation, respectively, in a three-part/three-step process:

1. The septic tank: scum and settleable solids are removed and initial anoxic (without oxygen) bacterial action partially consumes the organic material in the wastewater. The partially treated wastewater, or effluent, exiting through the outlet still contains various contaminants and requires further treatment.

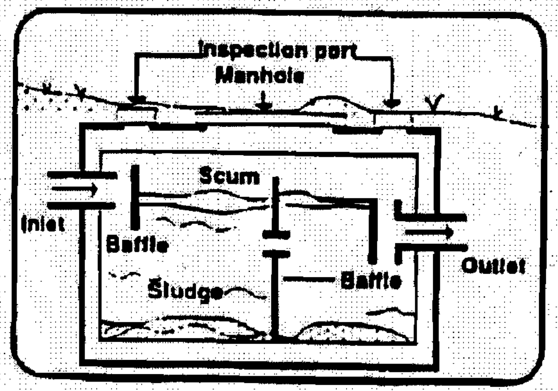
2. The absorption (drain) field: effluent from the septic tank is evenly distributed throughout a system of perforated pipes connected to a manifold. These pipes are laid side by side on gravel beds in trenches several ft below grade.

3. The soil: the effluent enters the gravel bed of the trenches through the distribution pipe perforations and percolates into the soil column. The soil column filters the effluent and aerobic (using oxygen) chemical and bacteria processes further treat the effluent before ground water or low permeability geologic materials (e.g., bedrock and calcrete) are encountered. The end product of a properly designed and well-maintained septic system is water, increased TDS, and increased nitrogen as nitrite (NO_2^{2-}) or nitrate (NO_3^-).

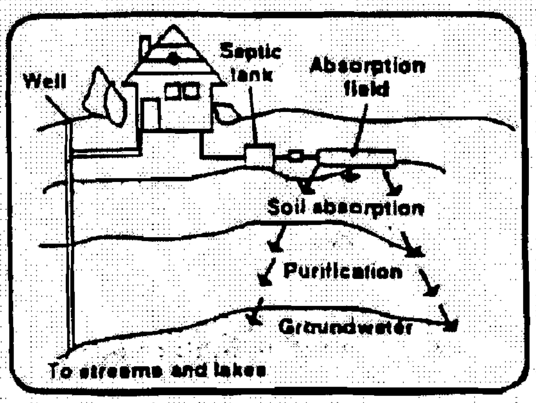
Septic systems that are not only undesirable but also illegal are those where household wastewater is discharged to a cesspool (pit) or to the surface. These types of systems do not provide efficient biodegradation of organic matter. Surface discharges and overflowing cesspools -- common problems -- provide pathogens the opportunity to contact humans and animals directly and through surface-water transport.



The septic tank and drainfield.



The septic tank.



The soil column.

Figure 3. Components of the "conventional" septic system (source: New Mexico Environment Department, District 1).

3.1 Regulatory Requirements

Prior to adoption of New Mexico Environmental Improvement Board (NMEIB) Liquid Waste Disposal System Regulations (LWDR) in November 1973, septic systems were often installed with little or no planning. Insufficient capacity and improper siting, emplacement depth, and construction of cesspools were common problems resulting in surfacing sewage, contaminated wells, and contamination of ground water by untreated sewage. Also, in populated areas (e.g., the Albuquerque South Valley), small lot sizes and high septic system density have resulted in degraded ground-water quality (Anonymous, 1998).

Prior to January 1, 1960 lot sizes and septic systems were unregulated by the state. From January 1, 1960 to November 1, 1973, lots in subdivisions with supplied water could be as small as 0.25 acres (ac) with septic-system discharge rates potentially as high as 1,000 gallons per day (gpd). Lot sizes and septic systems located outside of subdivisions were unregulated. From 1960 to 1973, the NMEIB LWDR allowed minimum lot sizes of 0.50 acres (ac) for lots with private wells. Design requirements from November 1, 1973 until November 9, 1985 allowed a discharge rate of 1,000 gpd per 0.75 ac for lots with private wells. This decreased to 375 gpd for 0.75 ac lots by 1990, which is the maximum discharge rate and minimum lot size under current LWDR. Conversations with some year-round and part-time residents of Seven Springs indicate that most septic systems there were constructed prior to 1960 (Duemler, 1997, and Davis, 1997).

3.2 Human Health Concerns

Indicators of septic system contamination that are also health threats for people drinking from contaminated wells are described by Gallaher et al. (1987):

1. Elevated nitrate which may cause methemoglobinemia ("blue baby" syndrome -- reduction of the blood's ability to carry oxygen to the body).

2. Water borne diseases, i.e., bacteria (e.g., salmonella, shigella and cholera), viruses (e.g., hepatitis), and protozoa parasites (e.g., *E. histolitica*, *E. coli* and giardia). These organisms can migrate in excess of 100 ft in the subsurface.

3. High concentrations of chemicals, pesticides, and metals. Degreasing solvents such as tetrachloroethylene (PCE) and trichloroethylene (TCE) are often poured down the drain as "treatment additives" for the septic tank. Phenols, toluene, and naphthalene are released from soaps and detergents; benzene from deodorants; and para-dichlorobenzene from block or cake toilet deodorizers. Pesticides are washed from fruits and vegetables, and toxic metals come from ointments, shampoos, and cosmetics.

Of these health threats, water-borne infectious diseases are the most immediate in most rural communities. However, pathogens in ground water are filtered out after a short distance (typically 100 ft) and usually represent only a local threat. But, pathogens that find their way to surface water, for example, from surfacing sewage or illegal septage dumping, can travel much greater distances (Brooks et al., 1997).

Nitrate in ground water, on the other hand, represents a health threat to distant down-gradient ground-water users. Nitrogen present in wastewater is steadily supplied through the system and converts readily to nitrate (unless denitrifying conditions are present, i.e., chemically reducing conditions in ground water). Nitrate dissolves into and flows easily with ground and surface waters and is cumulative.

The presence of anoxic conditions is often evidenced by taste and odor problems associated with hydrogen sulfide gas and iron and manganese precipitates resulting from decomposition of large amounts of organic material. These are aesthetic (non-health threatening) indicators of septic system contamination. Hydrogen sulfide production will

give an unpleasant rotten egg odor and production of large quantities of iron and manganese imparts a metallic taste and stains porcelain and laundry.

Ecological Concerns

In addition to the human-health threat, septic systems potentially present a threat to the ecology of surface waters. Nutrients (i.e., nitrate, phosphorus) from surfacing sewage or from treated water can reach surface water as runoff, through ground water recharge to gaining reaches of streams, or as "springs". This can cause growth of algae leading to reduced stream quality and lake eutrophication. Also, influx of low-DO ground water can reduce DO levels in surface water; cold-water fish species need 6 mg/L DO to maintain diversity and 7 mg/L during spawning (Brooks et al., 1997).

4.0 METHODS AND RESULTS

The author completed two investigations of the study area: one in 1997 (McDonald and Najmi, 1997) and the last in the spring and summer of 1999. The methods and results of these two investigations are discussed below.

4.1 Phase 1 -- Preliminary Reconnaissance Results, Summer 1997

This was a preliminary reconnaissance, which was limited primarily to literature research and phone interviews. Some field data were gathered on a single field trip to Seven Springs.

4.11 Literature Search and Interviews

A literature search of UNM libraries, Sandoval County offices, and offices of the New Mexico Environment Department (Santa Fe, District 1, and Bernalillo Field Office) was made for surface- and ground-water quality information gathered in the Seven Springs area. Appendix A contains tables and location maps for surface-water quality data collected by others. The NMED Surface Water Quality Bureau collected water-quality

data from below Fenton Lake, from three locations on the Rio Cebolla above the lake, and from one location on Calaveras Creek in 1989 (Anonymous, 1990).

The University of New Mexico collected data from three locations on the Rio Cebolla, one from Calaveras Creek, and one from Fenton Lake in 1994. Breeding (1995) collected data at four locations above and below Seven Springs and one from Fenton Lake, near the UNM locations, over a period of one year from September 1994 to August 1995 (White, 1994).

Also, an attempt was made to locate non-resident homeowners in Seven Springs by cross-referencing the water rights owners registered with the Office of the State Engineer with the Albuquerque area phone book. The results are sparse; only nine names could be cross-referenced, and of these, only three owners could be contacted. Information on ground-water quality obtained from those contacted was limited. Of the three owners who were contacted at their homes in Albuquerque, none either knew or remembered much about their wells except that from their own laboratory analyses the water was good enough to drink and did not contain nitrate. Some were sure that tests for fecal coliforms had been conducted and that the results were negative. One remarked that her water turned black in mixed drinks.

4.12 Field Reconnaissance of Ground- and Surface-Water Conditions

An attempt was made to gather field data on ground- and surface-water quality in and surrounding Seven Springs. Limitations on available equipment, money, and time allowed for gathering only nitrate (as nitrogen), specific conductance, and temperature data from ground and surface waters at limited locations. Furthermore, only one data collection trip was possible. Analyses for nitrate were performed using a HACH DRL 2000 spectrophotometer. Specific conductance, pH, and temperature were taken using a Yellow Springs Instruments (YSI) 3500. Field data were gathered in late July 1997 are found in Table 1. Sample locations are shown on Figure 4.

Table 1. Summer 1997 field reconnaissance: ground- and surface-water quality data for the Rio Cebolla and Seven Springs area.

Location	Temp °C	pH	Specific Conductance (m-mho/cm)	Nitrate (mg/L)
Tr. 3	9.4	7.15	102	0.25
Middle Part, Tr. 2	16.6	6.40	260	Tr[1]
Lands of B.W. Argo , Lot B	9.4	7.12	74	0.50
Lower Spring	12.6	7.68	89	0.0
SW1	14.7	7.46	84	Tr

[1] Trace

Simple percolation-rate tests were performed at two sites by digging an approximately 1-ft-by-1-ft-by-1-ft hole, pouring it full of water, and noting the time it took for the water level in the hole to drop one inch. New Mexico Environment Department (NMED) Liquid Waste Treatment and Disposal regulations require percolation tests before drainfield construction. "Percolation test holes shall be dug vertically and shall be four (4) to twelve (12) inches in diameter and as deep as the proposed drainfield bottom"...with "...Two (2) inches of gravel or sand"..."placed in the bottom of each test hole. Each test hole shall be saturated with a minimum of twelve (12) inches of water for at least four (4) hours prior to performance of the test (Anonymous, 1995b)." The author's percolation tests do not meet the NMED criteria and are qualitative only.

4.13 Discussion of Findings

Table 2, compiled from State Engineer drilling records, indicates that the deepest well on record in Seven Springs is 100 ft deep; the shallowest, a driven well, is 28 ft. Depth to ground water varies from approximately 5 to 35 ft in Seven Springs. Additionally, discussions with residents suggest that most wells in the canyon are likely less than 100 ft

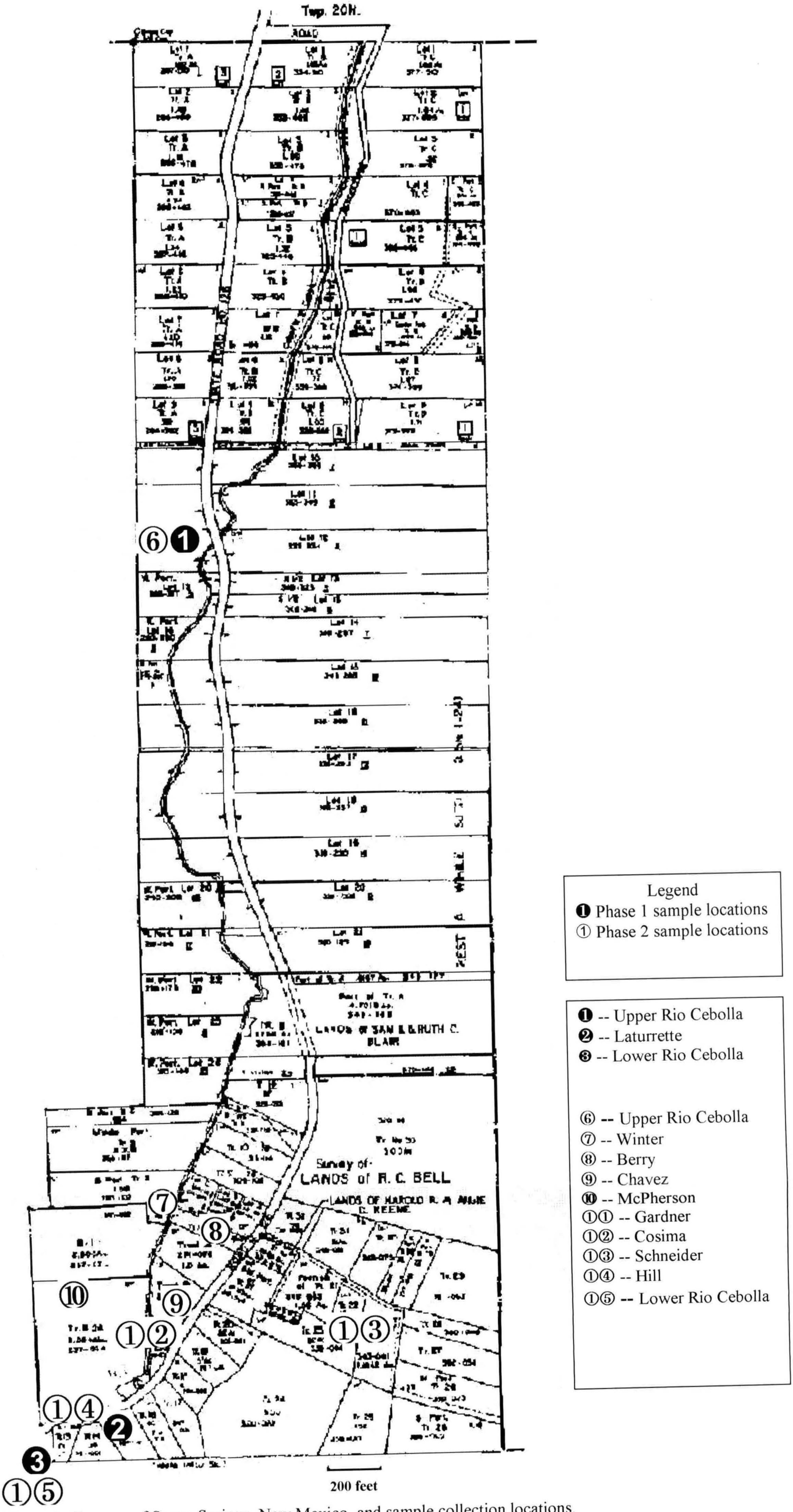


Figure 4. Plat map of Seven Springs, New Mexico, and sample collection locations. Vertical distance is one mile (source: Sandoval County).

Table 2. Well record for private wells in T19N R2E S3 (compiled from drilling reports filed with Office of the State Engineer – see Figure 4 for approximate locations).

Lot[1]	Total Depth (ft)	Screen Interval (ft)	Depth to Water[2] (ft)	Production Rate (gpm)	Driller's Comments[3] (aquifer rock)
na[4]	33	na[4]	7	Na	na
Na	100	95-100	na	10	'crevice'
Tr. 31	80	60-80	30	15	'white limestone'
Tr. B	40	20-40	20	14	'white pumice sand'
Na	100	60-100	30	15	'white/brn shale'
Na	90	50-90	30	10	'white limestone'
Tr. 25	75	30-74	31	15	Pumice sand/gravel
Tr. 90	90	1-20	5	10-15	gravel
Tr. 21 NW Part	48	35-45	35	15	sand and conglomerate
Tr. 33	50	30-50	30	24	white pumice gravel
Na	28	na	5	Na	Hand pounded

[1] Some lot descriptions were not given and owner's name could not be cross referenced with water-rights records -- lot may have changed owners.
[2] Driller's measurement, probably to the nearest foot.
[3] Driller's description: "limestone" is probably a welded tuff.
[4] Information is not available

deep. However, not enough surface-elevation and water-level data are available to determine ground-water gradient and flow direction.

Nitrate in surface and ground water is very low -- less than 0.5 mg/L. The range of specific conductance was low indicating that the water tested was low in total dissolved solids. The measured pH (an indicator of acidity if less than 5) was in the 'normal' range for surface and ground water. The nitrate results agree with those collected by Breeding where, generally, nitrate in samples was below 0.10 mg/L and phosphorus was below 0.20 mg/L (Appendix A).

The homeowner in the Middle Portion of Tr. 2 had the lowest pH and highest specific conductance and also complained of rusty water. This may be due to rusting well casing and screen or iron precipitate due to anoxic (low oxygen) conditions. The owner also noted that his first well, which was closer to the river, was abandoned because of the odor and black color of the water. He also remarked that his neighbors to the south (S part of TR. 2?) who are closer to the river have 'smelly' water. Some or all of the people at all three sample sites brought in their drinking water -- two used water from Cebolla Spring and one -- from the Middle Portion of Tr. 2 -- brought water from Albuquerque because her well water and the spring water upset her stomach.

Pit Test 1 was conducted on the building pad of the house constructed on the Middle Portion of Tr. 2; the percolation rate was approximately 10 minutes per inch. Pit Test 2 was done in an undisturbed area west of NM 126 immediately south of Seven Springs; the percolation rate was 2 minutes per inch. Though these simple tests were crude, they suggest that the disturbed and undisturbed soils in which leachfields may be installed may be at the fast end of the allowable range of percolation rates. State of New Mexico guidelines define suitable soils for a leachfield as those that "...are minimally characterized by percolation rates between one (1) and one hundred twenty (120) minutes per inch..." (Anonymous, 1995b). This indicates that effluent travel times from leachfield to ground

water may be rapid, filtration of solids may be reduced and effluent contact with soil microorganisms may be shortened.

4.2 Phase 2 -- Spring and Summer of 1999

Phase 2 began in August 1998 with an attempt to hand deliver letters to each residence inviting the homeowner to participate in a ground-water investigation. Hydrochemical data from their well would be used to:

1. Determine whether wells are currently impacted by septic-system discharge.

2. Create a ground-water model for the purpose of evaluating the [maximum] number of septic systems that the ground-water system lying under Seven Springs can support before water is degraded to an unsafe condition with contaminants.

Because most residences are for seasonal use, few people were home. Residences with locked gates or fences were not approached, but letters were left on the gates.

Respondents to the August 1998 letter were mailed a letter in December 1998 requesting their participation in an epidemiological survey. Included with the letter was a simple health-survey form asking residents whether they used well water for drinking, cooking, or bathing and whether they experienced any gastrointestinal illness when visiting Seven Springs. Residents who experienced any gastrointestinal illness during their stay in Seven Springs were encouraged to contact their physician for a stool analysis. Stool analyses would be used to identify particular pathogens causing the illness and would be paid for by the NMED (McQuillan, 1998). Three objectives were envisioned for Phase 2:

1. Develop a more refined conceptual hydrogeologic model.

2. Assess the current hydrochemistry of surface water and ground water.

3. Evaluate the current and potential threats to water resources and human health.

Objective one was to be accomplished by gathering water-level data, surveying wellhead elevations, and conducting a simple pumping test. In the end, none of these were accomplished because the private wells could not be accessed for water-level measurements. Additional pit-infiltration tests were also planned but discarded for lack of time and utility.

The second objective was accomplished satisfactorily. Fourteen people responded positively to the August 1998 letter and ultimately, eleven private wells, two springs, and the Rio Cebolla above and below Seven Springs were sampled. The results of this effort are discussed below.

The third objective entails the synthesis of information obtained in Phase 1 and Phase 2. Although the conceptual hydrogeologic model was not refined, significant hydrochemical data were collected. Therefore, as discussed below, it was possible to refine our understanding of the potential threat to public health from current and potential development.

4.21 Results of Epidemiological Survey

Fourteen residents responded to the health survey form. There were a few complaints of prior gastrointestinal problems but none during the study and no one requested a stool analysis.

4.22 Results of Ground- and Surface-Water Sampling

Because most homes in Seven Springs are used seasonally, it was anticipated that the heaviest use would occur during the summer. Therefore, it was expected that septic-system-discharge indicators (SO_4^{2-}, Cl^-, and nutrients -- nitrate, phosphorus, and total

Kjeldahl nitrogen [TKN – includes ammonia, ammonium, and organic nitrogen]) would be lowest before the summer season. To determine baseline conditions, before any potential impact from the summer season, two surface-water samples and one ground-water sample were collected in May 1999. These samples were analyzed for major ions and nutrients. Results are shown in Table 3 and sample locations are shown on Figure 4.

More extensive sampling was conducted at the end of the summer season in August and October 1999. Ground- and surface-water samples were collected from eleven wells, two springs, and two river locations and analyzed for major ions, metals, nutrients, and coliforms. Table 4 is a tabulation of the analytes and analytical methods. Sample IDs and laboratory analytical results are shown in Tables 5-7. Sample locations are shown on Figure 4 and field photos are in Appendix B.

From the results of analyses of ground water and surface water samples collected from locations in lower Seven Springs up to Cebolla Spring (Tables 3, 5, and 7), some general observations about ground- and surface-water quality in the canyon of the Rio Cebolla can be made:

1. Analyses for hardness (Ca^{2+} + Mg^{2+} as $CaCO_3$) resulted in all well water, the river, and the springs falling under 37 mg/L hardness. This is within the range of soft to slightly hard water: 0.0 to 60 mg/L. The EPA recommended maximum for hardness in drinking water is 120 mg/L.

2. The dissolved mineral quality of ground and surface water in the Seven Springs area is good. Total dissolved solids (TDS -- the total of dissolved constituents) ranged from a low of 128 mg/L to a high of only 214 mg/L. In fact, only one well was over 200 mg/L TDS. The recommended aesthetic limit for TDS in drinking water is 1,000 mg/L.

Table 3. Spring 1999 baseline sampling results.

	Parameter (mg/L)											
Location/Sample ID[1]	NO_3+NO_2	TKN	Total P	K	Na	Ca	Mg	Hardness	HCO_3	Cl	SO_4	TDS
Upper Rio Cebolla/❶	<0.1	0.46	0.11	<5	8.65	11.2	1.74	35.1	49.8	<10	<10	164
Todd Laturrette/❷	0.55	<0.1	0.08	<5	5.99	9.1	1.59	29.3	28.3	<10	13.6	172
Lower Rio Cebolla/❸	<0.1	0.37	0.1	<5	8.71	10.6	1.55	32.8	51.7	<10	<10	158

[1] Sample locations on Figure 4 and in Figure 5.

Table 4. Laboratory parameters for general water chemistry and nutrients analyses.

Analyte	Units	Lab Method (EPA no.)	Detection Limit[1] (mg/L)	Dilution Factor
Potassium (K)	mg/L	200.7	1.0	1
Sodium (Na)	mg/L	200.7	1.0	1
Calcium (Ca)	mg/L	200.7	1.0	1
Magnesium (Mg)	mg/L	200.7	1.0	1
Hardness (Ca + Mg) as Calcium Carbonate ($CaCO_3$)	mg/L	200.7	6.6	1
Bicarbonate (HCO_3)	mg/L	310.1	3.0	1
Chloride (Cl)	mg/L	9252	10.0	1
Sulfate (SO_4)	mg/L	300	10.0	1
Nitrate+Nitrite (NO_3+NO_2)	mg/L	353.2	0.1	1
Ammonia (NH_4)	mg/L	Na	0.1	1
Total Kjeldahl Nitrogen (TKN)	mg/L	351.2	0.1	1
Total Phosphorus (P)	mg/L	365.4	0.05	1
Total Dissolved Solids (TDS)	mg/L	160.1	10.0	1
Total Suspended Solids (TSS)	mg/L	160.2	3.0	1

[1] Detection Limit – the smallest amount or concentration of a chemical that can be reliably determined (i.e., is statistically present).

3. In only a few wells was arsenic (As) found at the detection limit of 0.001 mg/L – far below the new EPA limit of 0.05 mg/L for public water systems. No other detectable levels of heavy metals were found in ground water in the Seven Springs area.

4. Volatile organic compounds (VOCs) were undetected with the exceptions of one spurious detection of methylene chloride in a well and the detection of benzene and MEK in a field blank (deionized water obtained from the lab). Although methylene chloride is found in paint strippers, it is also a common laboratory chemical and occasionally finds its way into sample analyses.

5. Septic-system indicator parameters are low. Chloride (Cl) is non-detect in all samples, total dissolved solids (TDS) varies only from 128 to 214 mg/L, sulfate (SO_4) results are generally less than 10 mg/L -- its detection limit -- rising to a high of only 26.2 mg/L in the lower part of Seven Springs, and nitrate (NO_3) is just above its detection limit (0.1 mg/L).

6. Other nutrients are also low. Total phosphorus (P) is generally at or below the detection limit except for the Rio Cebolla below Seven Springs where total P is 0.21, above the O.20 MCL for this segment of the river. The data indicate that the river gains 0.16 mg/L in total P in its trip through Seven Springs. Ammonia (NH_4) is at or less than 0.10 mg/L, and Total Kjeldahl Nitrogen (TKN -- organically bound nitrogen including ammonia) is low, under 1 mg/L.

7. Coliform bacteria were found in all river and spring samples. Cebolla Spring, from which many residents and tourists get drinking water, tested positive for total coliforms, but fecal coliforms were not present.

Table 5. Summer 1999: field parameters and general water chemistry analytical results.

	Analyte (mg/L)									Field Parameters			
Location/Sample ID[1]	K	Na	Ca	Mg	Hardness (as $CaCO_3$)	HCO_3	Cl	SO_4	TDS	pH	DO (mg/L)	Conductance (μmhos)	temp (°C)
Cebolla Spring USFS/ ①	<5	14.9	8.12	1.75	27.5	58.8	<10	<10	164	6.9	5.45	78	8.8
Johnson (Hatchery)/ ③	<5	7.12	12.0	1.64	36.8	53.4	<10	<10	128	6.88	5.48	75	14.5 (kitchen)
Brasier/ ④	<5	14.2	7.98	1.65	26.7	60.3	<10	<10	166	6.78	3.54	82	11.6
Fenton Ranch/ ⑤	<5	14.3	9.76	1.87	32.1	70.3	<10	<10	172	6.85	2.51	90	11.3 (hose bib)
Upper Rio Cebolla/ ⑥	<5	9.2	10.9	1.6	33.8	53.9	<10	<10	172	7.49	5.29	80	15.1
Winter/ ⑦	<5	9.05	8.13	1.49	26.4	45.1	<10	11.5	178	6.18	2.25	80	12.1 (kitchen)
Berry/ ⑧	<5	11.3	8.57	1.52	27.7	39.0	<10	17.7	162	5.9	4.52	80	8.5
Chavez/ ⑨	<5	10.6	9.99	1.51	31.2	42.2	<10	17.2	178	na	2.64	80	9.9
McPherson/ ⑩	<5	11.7	8.69	1.51	27.9	57.6	<10	<10	196	7.0	1.26	98	8.7 (bathroom)
Gardner/ ①①	<5	11.1	10.8	1.74	34.1	44.9	<10	19.2	194	na	3.21	85	8.8
Cosima/ ①②	<5	10.6	10.8	1.62	33.6	48.6	<10	11.8	180	6.13	7.0	90	8.0
Schneider/ ①③	5.38	12.6	8.21	1.28	25.8	28.5	<10	26.2	214	5.37	3.03	80	7.0
Hill/ ①④	<5	10.1	11.7	1.75	36.5	55.6	<10	<10	166	6.13	0.63	90	8.1
Lower Rio Cebolla/ ①⑤	<5	9.46	11	1.64	34.3	56.6	<10	<10	162	7.75	5.48	83	15.1

[1] Sample locations showed on Figure 4 and Figure 5.

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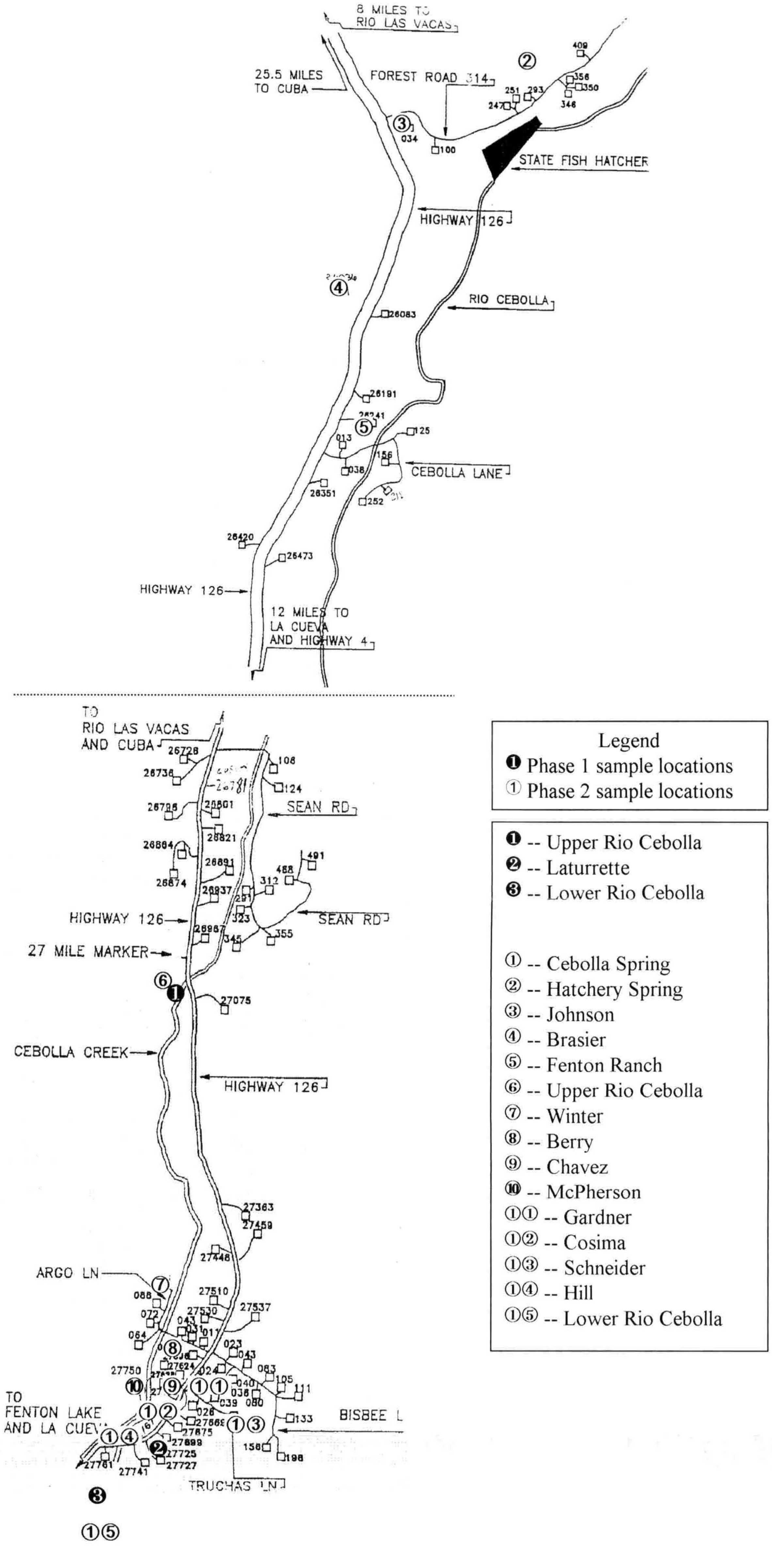


Figure 5. Sample location map for Spring and Summer 1999.
(Composite of two maps joined at dashed line -- source Seven Springs Homeowner Association).
Note that the Hatchery has moved east of the map location,
Cebolla Spring is east of Hatchery on south side of Forest Road 314.

Table 6. Summer 1999: laboratory parameters for metals analyses.

Element	Units	EPA Method	PQL[1]	Dilution Factor	Sample Detection Limit[2]
Antimony	Mg/L	200.8	0.001	1	0.001
Arsenic	Mg/L	200.8	0.001	1	0.001
Barium	Mg/L	200.8	0.1	1	0.1
Beryllium	Mg/L	200.8	0.001	1	0.001
Cadmium	Mg/L	200.8	0.001	1	0.001
Chromium	Mg/L	200.8	0.001	1	0.001
Mercury	Mg/L	245.1	0.0002	1	0.0002
Nickel	Mg/L	200.8	0.01	1	0.01
Selenium	Mg/L	200.9	0.005	1	0.005
Thallium	Mg/L	200.8	0.001	1	0.001

[1] Practical Quantitation Limit – the smallest amount of an analyte that can be reliably measured (quantitated).
[2] Detection Limit -- the smallest amount or concentration of a chemical that can be reliably determined (i.e., is statistically present).

Table 7. Summer 1999: results of analyses for coliforms and nutrients.

Location	**Parameter**					
Sample Location[1]	Coliforms (Total/Fecal) Algae	VOCs (ug/L)	Nitrate (NO_2+NO_3) (mg/L)	NH_4 (mg/L)	TKN (mg/L)	Total P (mg/L)
Cebolla Spring USFS/ ①	Total – present Fecal – absent	nd[2]	0.194	<0.1	0.4	0.05
Hatchery Spring/ ②	Total – present Fecal – present	na[2]	na	na	na	na
Hatchery Spring duplicate	Total – present Fecal – present	Na	na	na	na	na
Johnson (Hatchery Spring) / ③	Total – present Fecal – absent Algae – absent	Nd	0.207	<0.1	0.32	<0.05
Brasier/ ④	Na	Nd	0.194	<0.1	0.4	0.05
Fenton Ranch/ ⑤	Total – absent	Nd	0.213	<0.1	0.32	0.05
Upper Rio Cebolla/ ⑥	na[3]	Nd	<0.1	0.05	0.21	<0.1
Penny Winter/ ⑦	Na	3.7[4]	<0.1	<0.1	0.66	<0.03
Berry/ ⑧	Na	Nd	0.101	<0.1	0.37	<0.05
Chavez/ ⑨	Na	Nd	0.111	<0.1	0.11	<0.03
Chavez – duplicate	Na	Nd				
David McPherson/ ⑩	Na	Nd	<0.1	<0.1	0.18	0.06
Gardner/ ①①	Na	Nd	0.115	<0.1	<0.1	0.05
Cosima/ ①②	Total – absent	Nd	<0.1	<0.1	0.48	0.06
Schneider/ ①③	Na	Nd	0.104	0.1	0.34	0.05
Hill/ ①④	Total – absent	Nd	0.213	<0.1	0.53	0.08
Lower Rio Cebolla/ ①⑤	Total – present Fecal – present	Nd	<0.1	0.05	0.21	0.21

[1] See Table 4 sample location map. [2] Not detected. [3] Not analyzed. [4] methylene chloride: a common laboratory contaminant.

Well, spring, and river waters in Seven Springs, the Rio Cebolla canyon, and up to the Hatchery are of similar chemical composition with only small variations in major-ion concentrations. Slightly elevated levels of SO_4 and TDS and areas of low DO in ground water in Seven Springs indicate a minimal impact of septic-system discharge to ground water in the village but with no elevated levels of NO_3 or detections of coliforms.

As a result, it was determined that there is no present danger from wells tested. However, springs and especially the river should be avoided; spring water is not better in chemical quality than ground water but is potentially contaminated with coliform bacteria. Examination of the conceptual hydrogeologic model of the canyon of the Rio Cebolla will aid residents' understanding as to why increased development may increase their risk.

5.0 CONCEPTUAL HYDROGEOLOGIC MODEL

A conceptual hydrogeologic model is one view of the relationship between the hydrology (surface and ground water) and the geology (alluvium and rock of the canyon). Discussions with Stone (1997) indicate that the conceptual models shown in Figure 6 may be representative of conditions in the Rio Cebolla canyon in the Seven Springs area. These conceptual models are thought to represent various ground-water conditions that may exist in Mortandad Canyon near Los Alamos (Anonymous, 1997), which also is incised into Bandelier Tuff. In the author's opinion, the "bathtub" model best represents the relationship between the alluvium that fills the canyon bottom and the part of the alluvium that is saturated. The following conceptual hydrogeologic model was constructed from limited hydrological, geological, and hydrochemical information collected by the author and others.

Ground water occurs in the thin alluvium filling the floor of the canyon of the Rio Cebolla and in weathered bedrock, but probably occurs only in fractures in the much less permeable underlying bedrock. For the alluvium of the Rio Calaveras, an upstream

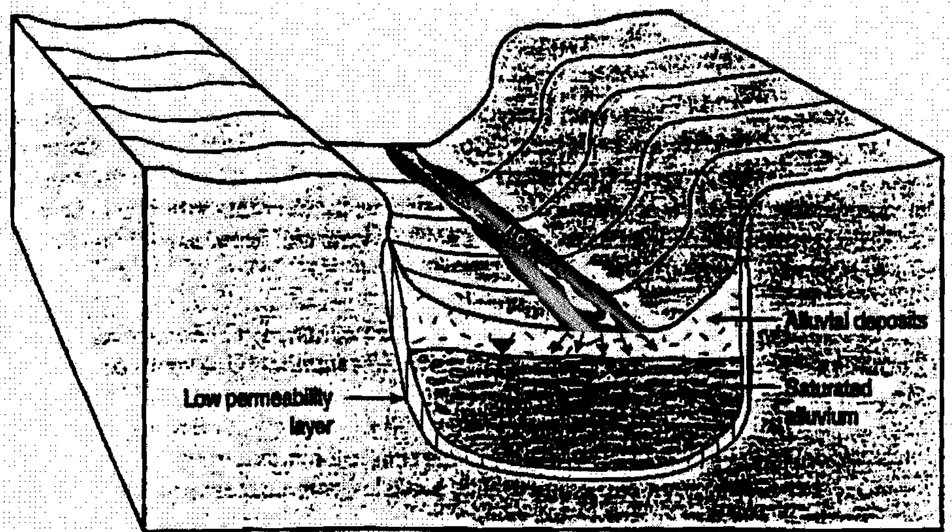


Illustration of the "Bathtub" Model for the occurrence of alluvial groundwater in the Mortandad Canyon system.

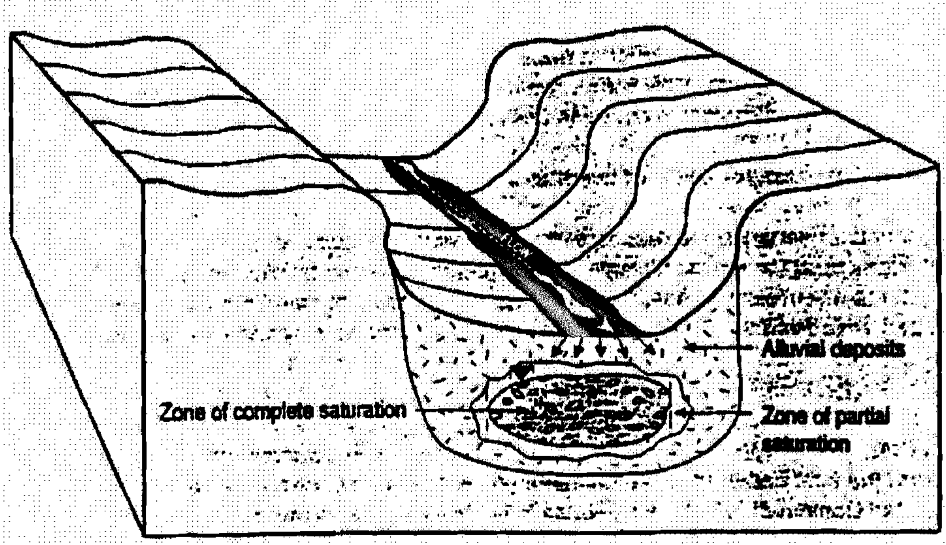


Illustration of the "Sausage" or Linear-Nephrod Model for the occurrence of alluvial groundwater in the Mortandad Canyon system.

Figure 6. Conceptual hydrogeologic models that may represent conditions in the canyon of the Rio Cebolla (from Anonymous, 1997)

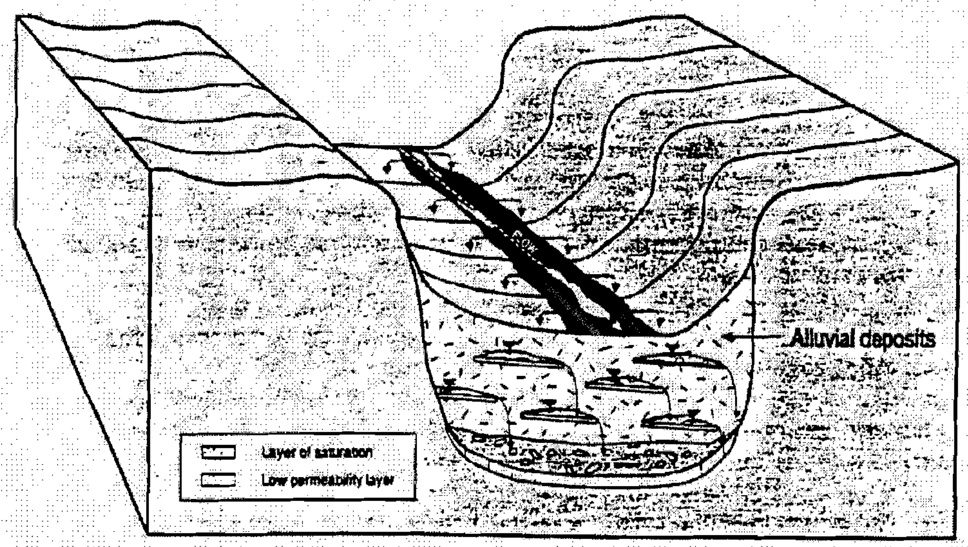


Illustration of the "Interleaved Card" or Layer Model for the occurrence of alluvial groundwater in the Mortandad Canyon system.

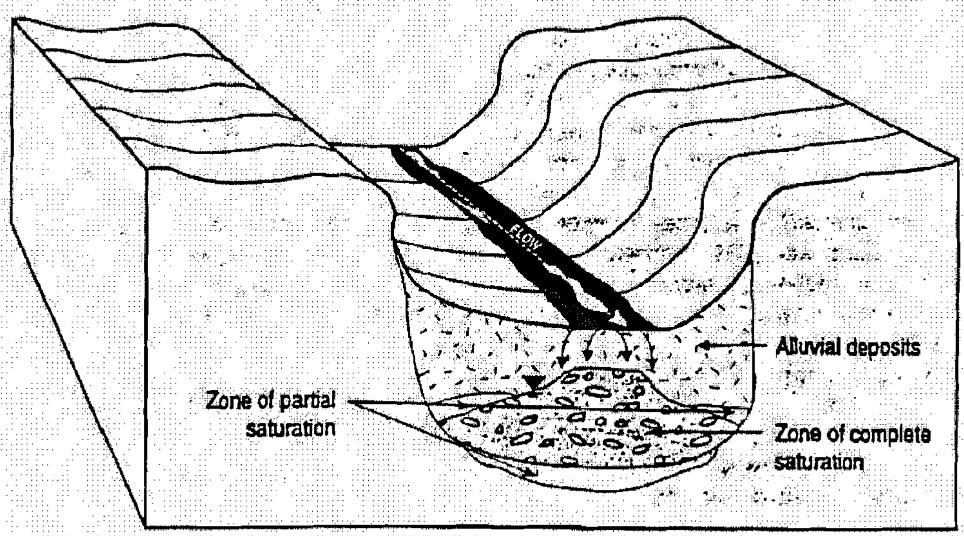


Illustration of the "Saturated Mound" Model for the occurrence of alluvial groundwater in the Mortandad Canyon system.

Figure 6. (Continued)

tributary of the Rio Cebolla, Morrice et al. (1997) calculated the mean particle size as: 36% gravel, 53% sand, 9% silt, 2% clay. Henry et al. (1994) calculated hydraulic conductivity as 1.2×10^{-3} cm/s (25.4 gal/day/ft^2); conditions are probably similar in the alluvium of Cebolla canyon. The average slope of the canyon floor of the Rio Cebolla can be used as an approximation of the gradient of the water table; this was previously calculated as 2.5%.

Seven Springs sits astride the Rio Cebolla above Fenton Lake in northern New Mexico. Its location in a high mountain watershed where abundant winter snow and summer rain (up to 50 inches of precipitation annually) would seem to preclude water shortages. But, in recent conversations with Mr. Bill Burnett, Seven Springs resident, the author has learned that water levels are falling in some residents' wells -- most likely as a result of the current drought. This suggests that the canyon's alluvial aquifer is small -- the result of a narrow canyon and thin alluvium -- and may not transport that much ground water. Depth-to-bedrock information found in Table 1 and well-depth information obtained from residents provide support for this assumption.

Future development in the Rio Cebolla canyon can only occur upstream from Seven Springs. A thin and narrow alluvial aquifer may only be capable of supplying a limited amount of ground water, limiting the number of wells in the shallow alluvium. Additionally, a thin and narrow alluvial aquifer may not be able to dilute domestic wastewater from new residents' septic systems; literally, some residents are potentially at risk of drinking upstream residents' diluted sewage.

6.0 LOT SIZES AND SEPTIC SYSTEM DENSITY

The New Mexico Water Quality Control Commission notes that developers generally seek to subdivide properties into the smallest lots possible. Unfortunately, this can result in septic systems contaminating drinkable water supplies and expensive alternate treatment

systems for homeowners. Careful planning of lot sizes is needed to control septic system density and to avoid locating septic systems where they will not function properly (Anonymous, 1995b).

6.1 Current Septic System Density

Most of Seven Springs is located in Section 3 of T19N, R2E; the densest population area is the R.C. Bell Subdivision. The plat map of this part of Seven Springs, shown in Figure 4, indicates that, at that time, there were 100 lots totaling approximately 173 acres (includes road right-of-way and river bottom). The smallest lot is 0.162 acres (Tr. 1, R.C. Bell Subdivision) and the largest lots are 5 acre undeveloped lots in the center of Seven Springs. Homes are dispersed along the Rio Cebolla up to the fish hatchery. From records of the Rio Jemez Adjudication (United States District Court, CIV. NO. 823-1041 SC), there are 50 individuals with ground-water rights in the Seven Springs community, and therefore, the total number of homes in the Seven Springs community is about 50. This results in an average lot size per septic system of 3.5 acres (173 acres / 50 systems) Potentially, the 173 acres comprising the Seven Springs community could be subdivided into the minimum allowable lot sizes of 0.75 acres. This would yield 230 lots of 0.75 acres each.

6.2 Calculating a Maximum Allowable Density

The rate at which nitrate enters the ground from a septic system is the nitrate loading rate. Bitner and Graves (1992) describe the nitrate loading rates for the average septic system as ranging from 6 to 17 grams per person per day. This report will use 12.75 grams per person per day and a loading rate for an average household of 2.75 people of 34 grams per day. These are the rates used by CH2M Hill in its numerical model of the Albuquerque South Valley (Bitner and Graves, 1992). For the purposes of this report, it is assumed that this entire nitrate load ends up in ground water. Also, although the drinking-water maximum contaminant level (MCL) for nitrate in ground water is 10 mg/L, 5 mg/L will be used as the highest level of nitrate that should be allowed in ground water at Seven Springs.

The health threat from the cumulative impacts of upstream discharges is to the people living in the southern part of Seven Springs. There must be a sufficient volume of ground water flowing through the saturated alluvium of the canyon to dilute chemical contaminants, such as nitrate, in order that they not present a health threat. If a cross section is made across the canyon, the volume of ground water that moves through the saturated alluvium per unit time is the *volumetric flow rate*. This volumetric flow rate must equal or exceed the volume of water needed to dilute the nitrate loading rate to 5 mg/L or less.

The width of the canyon varies from approximately 1,700 ft (518 m) to 1,300 ft (396 m). The alluvium filling the canyon is probably lens shaped -- thin on the canyon sides and thickest in the center. The thickness of the alluvium in the center of the canyon is unknown, but is probably 100 ft (30 m) or less (Figure 6). A simple cross-sectional model of the saturated alluvium can be constructed wherein the thickness is represented by “b”, an unknown, and the width, "w", which is 1,300 ft (396 m). The thickness of the alluvium (“b”) will be treated as uniform across the canyon even though much of the property on the sides of the canyon is steep, and probably has a thin soil cover unsuitable for septic systems. (People are, however, building homes up on the sides of the canyon walls).

The area of the watershed above Seven Springs is approximately 35 square miles (90.3 square kilometers). Using 20 inches (50.8 centimeters) as the average annual precipitation, total water available in the watershed above Seven Springs is approximately 3.73×10^4 acre-feet (4.59×10^7 cubic meters). Breeding (1995) estimated twenty percent of total precipitation leaves the watershed as streamflow. For the watershed above Seven Springs, the annual runoff rate is calculated as 7.47×10^3 acre-feet (9.17×10^6 cubic meters) or 10.3 cubic feet per second (cfs) -- within the range of monthly averages calculated from Breeding's data. If evapotranspiration (water lost to plant uptake and atmospheric evaporation) is 75 percent, as Breeding calculates, then five percent of the total water, or 1.86×10^3 acre-feet (2.29×10^6 cubic meters), infiltrates the soil column annually to become

ground water. The daily rate of infiltration is 5.1 acre-feet/day or 1.66×10^6 gpd. Figure 7 illustrates a simplified conceptual model of ground-water flow in the saturated alluvium of the canyon. The volumetric flow rate of water moving through the saturated alluvium is expressed by the formula Q = (K)(I)(w)(b). Earlier in this report, Henry et al. (1994) provided K and I as 25.4 gal/day/ft^2 and 2.5%, respectively. We have assumed that the width of the saturated alluvium is 1,300 ft; Q has been previously calculated as 1.66×10^6 gpd. Therefore, we can estimate b:

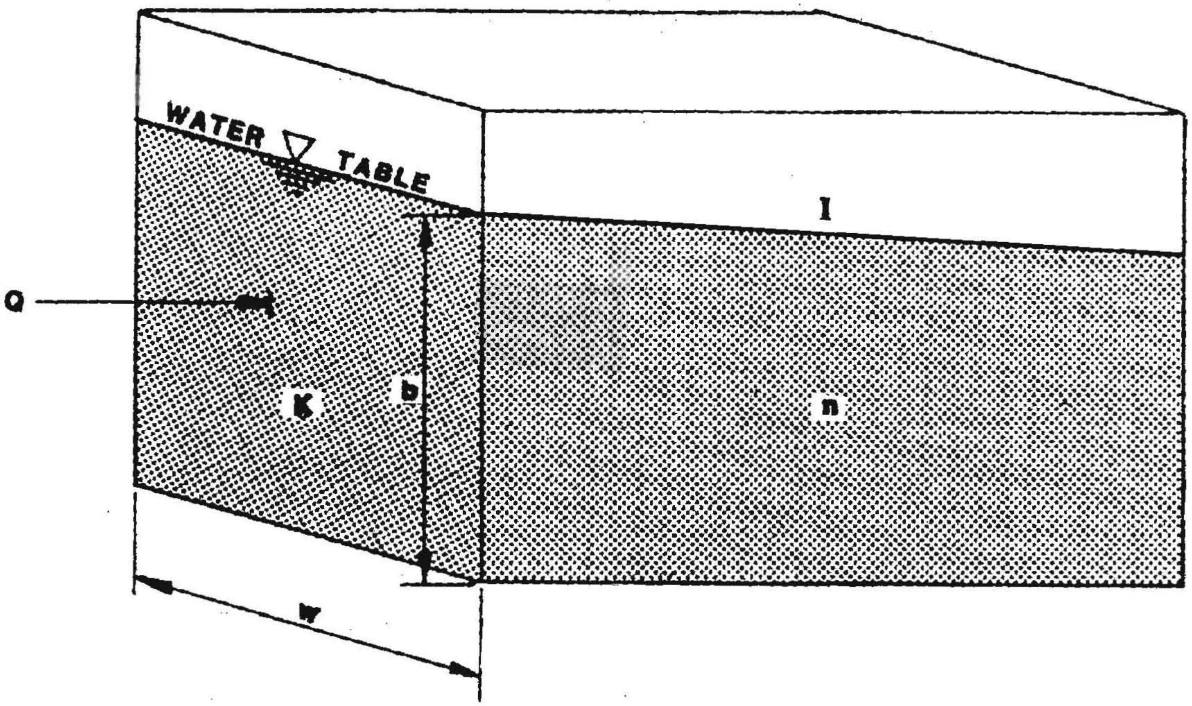
$$Q = 1.66 \times 10^6 \text{ gpd} = (25.4 \text{ gal/day/ft}^2) \times (0.025) \times (1{,}300 \text{ ft}) \times (b) = 825.5 \times (b)$$

$$b = 2{,}010 \text{ ft}$$

It is extremely doubtful that the saturated alluvium is 2,010 ft thick; bedrock fractures probably account for much of the transportation of ground water. The valley alluvial fill is probably no more than 100 ft thick as indicated by the data in Table 1. Although some wells were completed near 100 ft total depth in alluvium (e.g., the Jean Davis well, drilled 90 ft into gravel), most wells drilled beyond 80 ft reached total depth in bedrock ('limestone' or 'shale'). One, the Richard Duemler well, was completed at 100 ft in what may be fractured bedrock ('crevice'). If the average saturated thickness of the alluvium is assumed to be 100 ft, then Q can be calculated:

$$Q = (25.4 \text{ gal/day/ft}^2) \times (0.025) \times (1{,}300 \text{ ft}) \times (100 \text{ ft}) = 82{,}550 \text{ gpd}$$

With a MCL of 5 mg/L, the maximum daily nitrate load for 82,550 gpd would be [3.7854 L/gal x 82,550 gpd] x [5 mg of nitrate/L x 1 gram/1,000 mg] = 1,562 grams/day -- the average daily nitrate loading of 46 households. This means that ground water downstream of 46 homes with year-round residents, for the cross sectional model described above, would be contaminated to the level of 5 mg/L -- assuming total mixing and that the entire nitrate load was discharged to ground water. But what if homes were built on the current



Q = (K)(I)(w)(b) = GROUND-WATER FLOW RATE

K = 25.4 gal/day/ft^2 = HYDRAULIC CONDUCTIVITY (n = 0.25 = porosity)

I = 0.025 ft/ft = HYDRAULIC GRADIENT (SLOPE OF THE WATER TABLE)

b = 100 ft = SATURATED THICKNESS

w = 1,300 ft = WIDTH OF MODELED AREA

Figure 7. Parameters affecting ground-water flow (from Anonymous, 1997).

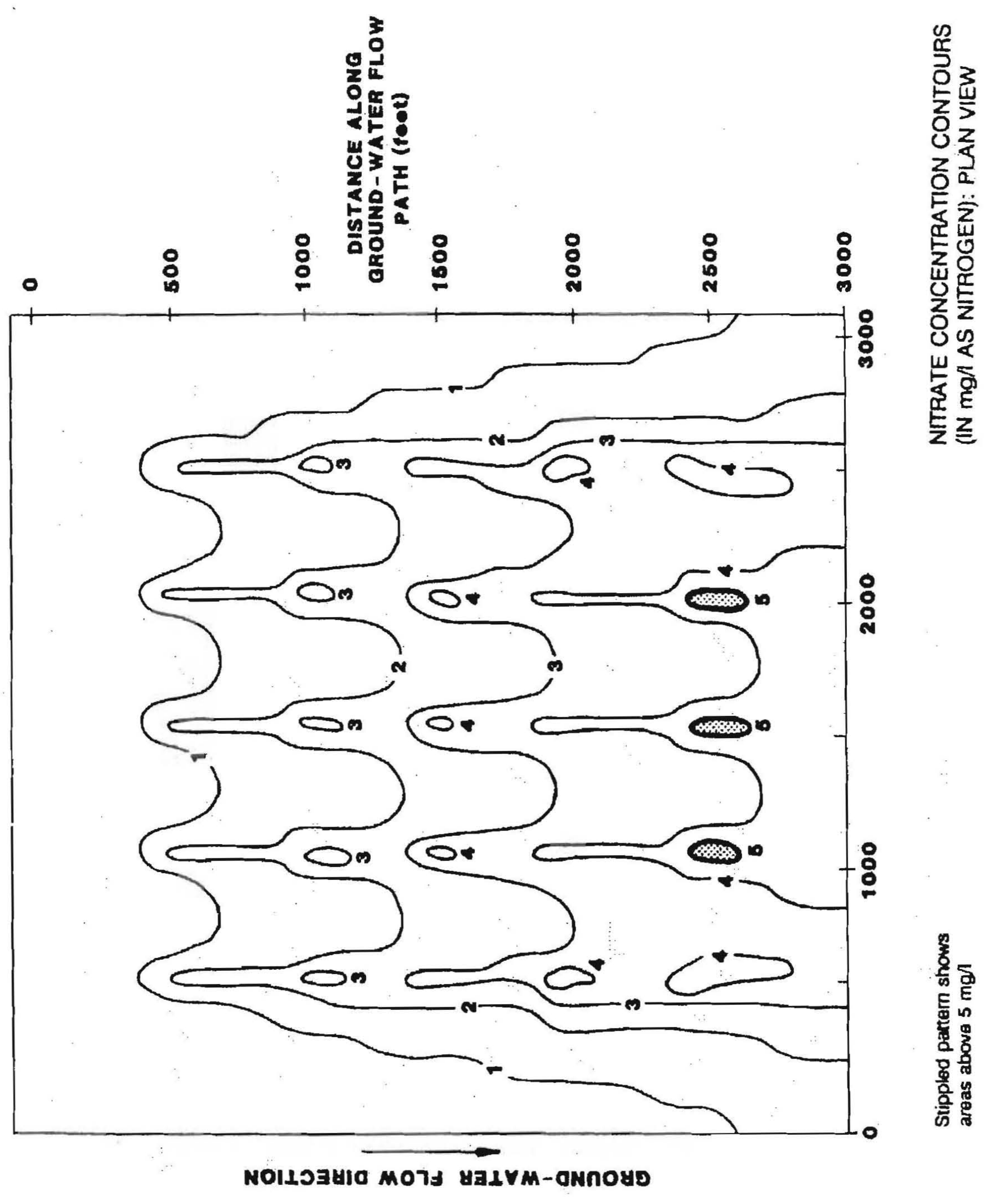


Figure 8. CH2M Hill nitrate concentration model of the Albuquerque South Valley (direction of flow in the canyon of the Rio Cebolla would be south); individual sources (homes) located at nodes, (from Bitner and Graves, 1992).

1. A positive correlation between increases in nitrate and increases in conductivity and chloride.

2. The highest nitrate levels were found hydraulically downgradient of the mobile-home parks (average lot size < 1/10 acre) and the oldest subdivisions with the smallest average lot sizes (1/4 to 1/2 acre).

3. Nitrate levels in wells is inversely proportional to well depth -- depths of wells producing water with nitrate in excess of 10 mg/L ranged from 40 to 160 ft.

4. Many older shallow wells had to be replaced with deeper wells because of "sanding" (falling water levels) and/or nitrate encroachment.

7.0 CONCLUSIONS AND SUMMARY

Analyses of samples collected for this study indicate that present development in the Seven Springs area has not yet resulted in contamination of ground water with nitrate, volatile organic compounds, heavy metals, or coliform bacteria. However, SO_4 and TDS data indicate potential septic-system impact to ground water in the village. Additionally, from conversations with residents whose water was not sampled, the author was made aware of potential areas of anoxic contamination. The residents described conditions of bad odor (from sulfur reduction) and bad taste and staining (from iron and manganese precipitation).

Currently, average lot sizes in the study area are large -- 3.5 acres. However, the potential exists for subdividing the 173 acres comprising Seven Springs into 230 lots of 3/4 acre each. Construction of a simple hydrogeologic model suggests that ground water occurring in a thin (less than 100 ft) alluvial aquifer could become contaminated with 5 mg/L of nitrate by 46 homes occupied by year-round residents. 100 homes would raise the level of

nitrate in the model to greater than 10 mg/L. The availability of deeper water in the bedrock is unknown. However, drilling records indicate that the bedrock is fractured and the simple hydrogeologic model indicates that the shallow alluvium may be incapable of transporting all of the predicted ground-water flow. Also, communications from one resident suggests that at least one resident's shallow well has gone dry in the current drought (Burnett, 2000).

This information suggests that ground water availability in the shallow alluvial aquifer is mostly dependent on snowpack and rain in the upper watershed rather than interbasin flow. Residents should be cautioned against drinking from any of the springs in the Seven Springs area. They are all surface-water sources -- open to the air and to animal entry even though they appear sealed. For example, careful examination of Cebolla Spring revealed holes in the mortar joints of the rock enclosure through which dirt and animals have access to the water. Also, the author has repeatedly removed trash and fish entrails from around the outlet pipe.

The construction of new homes in the Seven Springs area is already in progress – population and septic system density are increasing. However, there is little hydrogeologic and water quality information; the availability of ground-water resources and the current threat and potential increase in threat to public health from increasing home construction should be properly evaluated. The following additional information is needed.

1. The availability of ground water in the canyon is poorly understood. The conceptual hydrogeologic model must be refined; additional hydrogeologic information is needed for the canyon of the Rio Cebolla:

   - Water-level elevations should be determined so that gradient and flow directions can be calculated (installation of surveyed piezometers for precise water-level measurements).

- Aquifer tests should be conducted to determine aquifer parameters such as hydraulic conductivity (K), transmissivity (T), porosity (n), etc.

- The interactions between the river, the alluvial aquifer, and a potential deeper aquifer should be evaluated.

2. The following information is needed so that the public health threat from current and future septic systems can be evaluated.

   - Seasonal ground- and surface-water sampling for major ions, nutrients, coliforms, and indicators of reducing or oxidizing (redox) conditions.

   - Survey of septic system and well locations for compliance with minimum lot sizes and offset requirements of leachfields from wells and rivers.

   - Survey of 'grandfathered' septic systems to evaluate operational condition and construction -- old systems may be near the end of their useful lives or may be nothing more than cesspools.

   - Survey of home-use patterns so that the spatial and temporal patterns of nitrate loading rates can be determined.

3. Little is known about the availability of ground water in the canyon of the Rio Cebolla. However, from information obtained from residents in the summer of 2000 indicates that some wells are drying up. Therefore, it is prudent to assume that ground-water resources are limited and should be protected:

- At the minimum, existing on-site wastewater regulations controlling minimum lot size, well/leachfield offset, and septic system construction should be rigorously enforced.

- The effects of additional wells on current users should be evaluated. If shallow ground water is limited and subject to depletion during drought or increased pumping, then new wells could be installed in a deeper aquifer to limit impact on the shallow alluvial aquifer.

- Watershed protection measures should be implemented to increase infiltration of precipitation and reduce runoff. Reductions in roads and trails, logging, piñon and juniper encroachment, and grazing should be evaluated.

Action now may save the village of Seven Springs from a fate like that of the Albuquerque South Valley where shallow ground water is unfit for human consumption. The old axiom "an ounce of prevention is worth a pound of cure" is never more self-evident than when protecting our ground-water resources. Also, implementation of a watershed management plan, such as that described by Breeding, is a first step that residents can take that will give them control and direction over development and use of their watershed.

REFERENCES

Anonymous, 1998, Water quality and water pollution control in New Mexico, 1998: prepared for the New Mexico Water Quality Control Commission by the New Mexico Environment Department, report no. NMED/SWQ-98/4, variously paged.

Anonymous, 1997, Work plan for Mortandad Canyon: Los Alamos National Laboratory, variously paged.

Anonymous, 1996, Preliminary draft environmental impact statement, New Mexico Forest Highway 12, Cuba -- La Cueva Road, State Highway 126: Federal Highway Administration, report no. FHWA-FPNM-EIS-96- 1 -D, variously paged.

Anonymous, 1995a, Ground and surface water protection: New Mexico Water Quality Control Commission, report no. 20 NMAC 6.2, 85 p.

Anonymous, 1995b, Liquid waste disposal system regulations: New Mexico Environmental Improvement Board, report no. 20 NMAC 7.3, 27 p.

Anonymous, 1994, State of New Mexico standards for interstate and intrastate streams: New Mexico Water Quality Control Commission, report no. 20 NMAC 6.1, 51 p.

Anonymous, 1990, Rio de las Vacas, Clear Creek and Rio Cebolla, *in* Intensive water quality stream surveys and lake water quality assessment surveys 1989: Surveillance and Standards Section, Surface Water Quality Bureau, Environmental Improvement Division, New Mexico Health Department, pp 72-84.

REFERENCES (continued)

Bitner, M.S., Graves, T., 1992, Effect of lot sizes on potential ground-water contamination from conventional septic systems: Numerical modeling: CH2M HILL, Albuquerque, 47 p.

Breeding, N.A., 1995, Management plan for the Rio Cebolla watershed, Santa Fe National Forest, New Mexico: Master's Thesis, University of New Mexico, 71 p.

Brooks, K.N., Ffolliott, P.F., Gregersen, H.M., and DeBano, L.F., 1997, Hydrology and management of watersheds (2nd ed.): Iowa State University Press, Ames, Iowa, 502 p.

Burnett, Bill, 2000, Secretary/Treasurer of the Seven Springs Association and Telephone Company personal communication to William McDonald.

Davis, Jean, 1997, Seven Springs, New Mexico homeowner, personal communication to William McDonald.

Duemler, Richard R., 1997, Seven Springs, New Mexico homeowner, personal communication to William McDonald.

Fetter, C.W., 1994, Applied hydrogeology (3rd ed.): Prentice Hall, Englewood Cliffs, NJ, 691 p.

Gallaher, B.M., McQuillan, D.M., Chavez, L.D., Huu, H.F., and Eidson, M., 1987, Ground-water quality and public health, Albuquerque south valley: New Mexico Environmental Improvement Division, Report no. EID/GWH/-87/1, 239 p.

REFERENCES (continued)

Gardner, J.N., Goff, F., 1996, Geology of the northern Valles Caldera and Toledo Embayment, New Mexico: New Mexico Geological Society 47th Field Conference, Jemez Mountain Region, pp 41-58.

Gardner, J.N., Goff, F., and Rogers, M.A., 1996, Second-day road log, from Los Alamos through Valles Caldera and return: New Mexico Geological Society 47th Field Conference, Jemez Mountain Region, 1996, pp 225-230.

Henry, K.S., Valett, H.M., Morrice, J.A., Dahm, C.N., Wroblicky, G.J., Santistevan, M.A., and Campana, M.E., 1994, Ground water-surface water exchange in two headwater streams: Second International Conference on Ground Water Ecology, 1994, pp 319-328.

McDonald, W.S., Najmi, Y., 1997, Current and projected impacts of septic systems on surface-and ground-water quality in Seven Springs, NM: a preliminary assessment: class project prepared for Public Administration 573, Water Resources Program, UNM, variously paged.

McQuillan, D.M., 1998, Program Manager for the NMED Ground Water Quality Bureau, personal communication.

McQuillan, D.M. and Keller, N., 1992, Ground-water contamination and remediation in New Mexico: 1927-1992: Proceedings, New Mexico Conference on the Environment, September 13-15, 1992, Albuquerque, N.M., pp 44-53.

McQuillan, D.M., 1989, Ground-water quality impacts of septic-tank use. New Mexico Health and Environment Department, Environmental Improvement Division, Report no. EID/GWB/-89/1, 10 p.

REFERENCES (continued)

McQuillan, D.M., Jasper, M.J., and Swanson, B.H., 1989, Ground-water contamination by septic-tank use: New Mexico Health Department Environmental Improvement Division, Ground Water Bureau, report no. EID/GWB-89/2, 37 p.

Morrice, J.A., Valett, H.M., Dahm, C.N., and Campana, M.E., 1997, Alluvial characteristics, groundwater -- surface water exchange and hydrological retention in headwater streams: Hydrological Processes Vol. II, pp. 253-267.

Smith, R.L., Bailey, R.A., and Ross, C.S., 1970, Geologic map of the Jemez Mountains, New Mexico: US Geological Survey Map 1-571.

Space, M.L., McQuillan, D.M., and McDonald, W.S., 1993, Possible sources of nitrate contamination along Tijeras and Hell Canyon Arroyos and the Mountainview Subdivision, New Mexico: abstract presented at the American Water Resource Association 6th Annual Conference, New Mexico Section

Stone, W.J., 1997, Senior Hydrogeologist, New Mexico Environment Department, personal communication to William McDonald.

Viessman, W. and Hammer, M.J., 1993, Water supply and pollution control: third edition, HarperCollins College Publishers, New York, N.Y., 860 p.

White, C.S., 1994, Final report, study of the effect on water quality of Forest Highway 12 (State Highway 126): Department of Biology, University of New Mexico, variously paged.

APPENDIX A

Historic Water-Quality Data

Water-quality data collected by Breeding (1995)
(Location map attached)

Table 1: Site 1

Date	Flow Rate (cfs)	Nitrate Nitrogen (mg/l)	Phosphorus (mg/l)
9/30/94	1.75	.02	.07
10/30/94	3.00	.02	.17
12/04/94	3.50	.03	.07
1/07/95	frozen	.05	.09
2/05/95	3.54	.07	.19
3/04/95	4.6	.06	.13
4/09/95	12.7	.07	.07
5/14/95	22.1	.04	.13
6/18/95	6.7	.07	.10
8/13/95	3.9	.08	.11

Table 2: Site 2

Date	Flow Rate (cfs)	Nitrate Nitrogen (mg/l)	Phosphorus (mg/l)
9/30/94	1.6	.70 (?)	.33
10/30/94	3.8	.02	.17
12/04/94	3.4	.04	.08
1/07/95	frozen	.04	.11
2/05/95	frozen	.05	.15
3/04/95	4.5	.05	.10
4/09/95	14.9	.04	.09
5/14/95	23.4	.06	.11
6/18/95	8.2	.04	.11
8/13/95	4.4	.07	.11

Notes:
On 9/30/94 electronic device used to measure nitrogen gave questionable reading

Table 3: Site 3

Date	Flow Rate (cfs)	Nitrate Nitrogen (mg/l)	Phosphorus (mg/l)
10/01/94	4.11	.08	.13
10/30/94	5.0	.04	.13
12/04/94	5.6	.07	.07
1/07/95	5.7	.08	.11
2/05/95	6.29	.07	.14
3/04/95	8.2	.07	.12
4/09/95	18.6	.06	.09
5/14/95	32.8	.04	.08
6/18/95	11.9	.05	.13
8/13/95	7.8	.06	.13

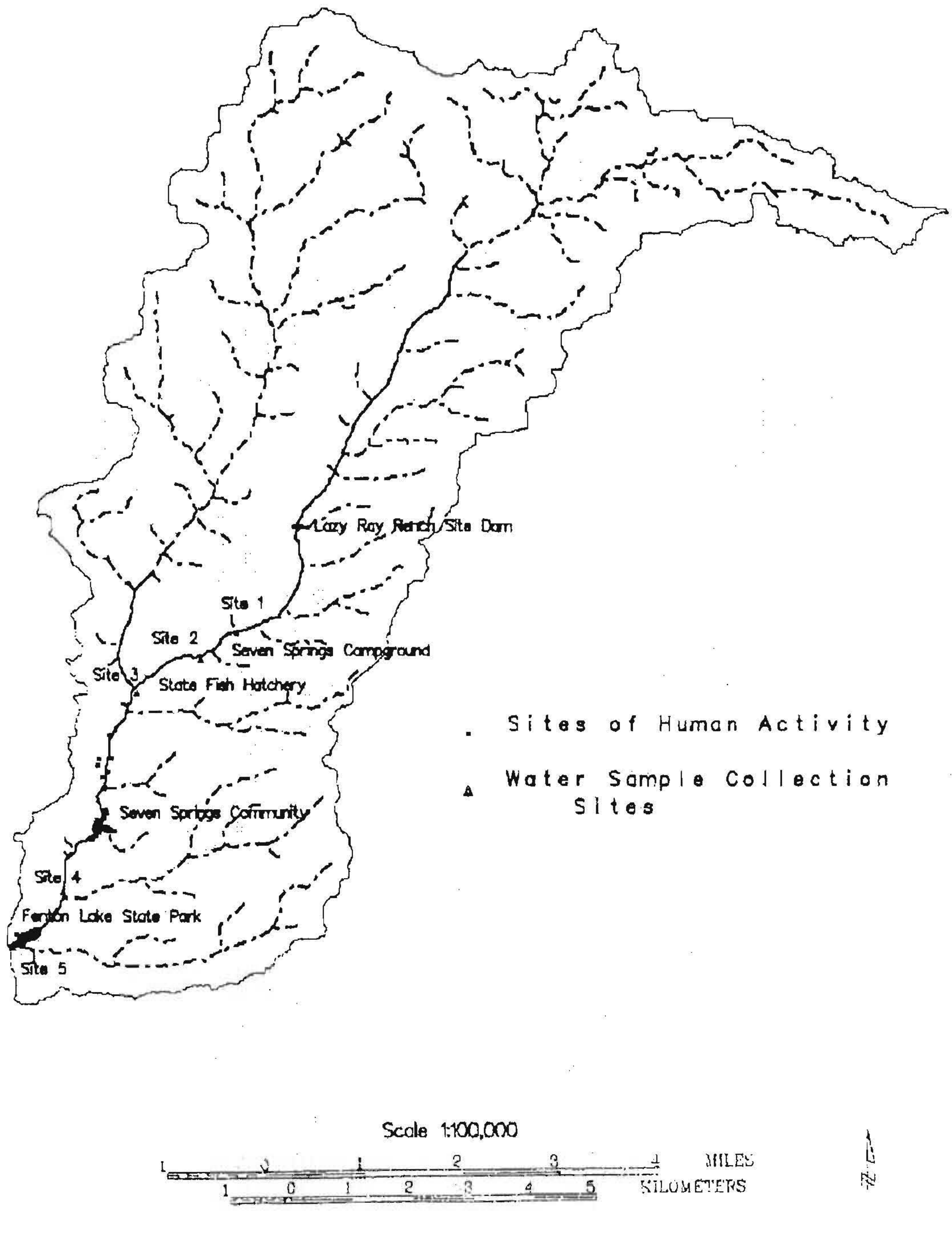
Table 4: Site 4

Date	Flow Rate (cfs)	Nitrate Nitrogen (mg/l)	Phosphorus (mg/l)
10/01/94	5.4	.03	.10
10/30/94	6.3	.06	.15
12/04/94	6.6	.06	.07
1/07/95	frozen	.07	.10
2/05/95	9.5	.07	.12
3/04/95	13.0	.08	.11
4/09/95	25.0	.04	.12
5/14/95	46.6	.06	.08
6/18/95	17.8	.07	.12
8/13/95	9.4	.10	.14

Table 5: Site 5

Date	Flow Rate (cfs)	Nitrate Nitrogen (mg/l)	Phosphorus (mg/l)
10/01/94	–	.03	.13
10/30/94	–	.03	.08
12/04/94	–	.04	.09
1/07/95	–	.05	.10
2/05/95	–	.04	.13
3/04/95	–	.07	.09
4/09/95	–	.08	.09
5/14/95	–	.06	.15
6/18/95	–	.05	.10
8/13/95	–	.05	.13

Rio Cebolla Watershed
Location Map for samples collected by Breeding.



Water-quality data collected by UNM (White, 1994)
(location map attached)

SUMMARY OF WATER QUALITY ANALYSES

Sample Location	Turbidity (NTU[1]) Range	Turbidity No. Exceedances[2]	Total Phosphorous (mg/L) Range	Total Phosphorous No. Exceedances[3]	Total Nitrogen (mg/L) Range	Total Nitrogen No. Exceedances[4]	Total Suspended Solids (mg/L)
Clear Creek above FH12	1.4 - 104.9	1	0.02 - 0.2	1	0.25 - 0.78	0	<3 - 170
Clear Creek below FH12	5 - 170.7	2	0.02 - 0.4	3	0.21 - 0.32	0	<3 - 275
Rio de las Vacas above FH12	0.9 - 88.3	1	<0.05 - 0.1	0	0.07 - 0.22	0	1.25 - 124
Rio de las Vacas below FH12	1.3 - >200	2	0.04 - 0.6	1	0.14 - 0.21	0	1.0 - 520
American Creek above FH12	2.1 - 166.7	1	0.05 - 0.2	1	0.12 - 0.21	0	3.0 - 360
American Creek below FH12	3.9 - 192.3	2	0.05 - 0.3	1	<0.05 - 0.3	0	1.3 - 611
Rock Creek above FH12	3.7 - >200	2	0.03 - 0.5	2	<0.05 - 0.15	0	1.3 - 785
Rock Creek below FH12	ND - >200	3	0.03 - 0.6	2	0.1 - 0.39	0	<3 - 805
Rito Peñas Negras above FH12	ND - 143	5	<0.05 - 0.23	1	0.1 - 0.35	0	<3 - 325
Rito Peñas Negras below FH12	ND - 117.3	5	0.04 - 0.09	0	0.09 - 0.27	0	<3 - 225
Calaveras Canyon above FH12	3.6 - 4.0	0	<0.05	0	0.04 - 1.97	1	2.0 - 4.4
Calaveras Canyon below FH12	4.2 - 14	0	<0.05	0	0.07 - 1.42	1	3.0 - 38.5
Rio Cebolla above Hatchery	7.9 - 8.6	0	<0.05 - 0.05	0	0.09 - 0.21	0	19.5 - 22
Rio Cebolla at Barley Canyon	6.4 - 9.6	0	0.05	0	0.2 - 0.28	0	16 - 21
Rio Cebolla above Fenton Lake	8.1 - 15	0	<0.05 - 0.08	0	0.19 - 0.37	0	9.6 - 35
Fenton Lake	7.8 - 12	0	0.08 - 0.09	0	0.31 - 0.5	0	10 - 40.5

Source: White 1994.

mg/L = milligrams per liter
ND = Not Detected

[1] Nephelometric Turbidity Units
[2] Number of samples exceeding the New Mexico Water Quality standard of 25 NTU
[3] Number of samples exceeding the New Mexico Water Quality standard of 0.1 mg/L
[4] Number of samples exceeding the New Mexico Water Quality standard of 1.0 mg/L

Water-quality data collected by UNM (continued)

(location map attached)

SUMMARY OF WATER QUALITY ANALYSES

(Concluded)

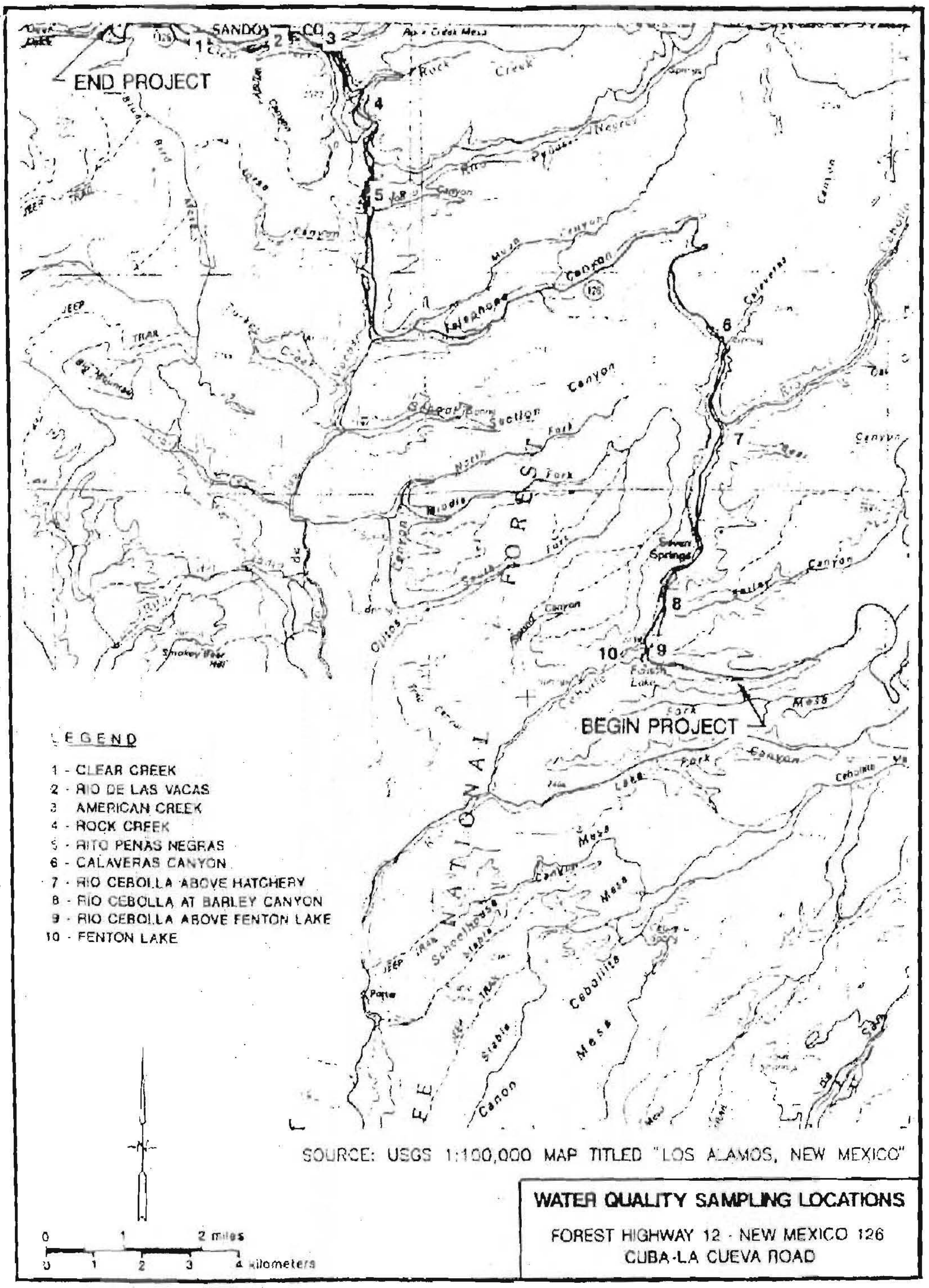
Sample Location	Chloride (mg/L)	Bromide (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
Clear Creek above FH12	<0.5 - 1.25	<0.03 - 0.11	<0.05 - 0.01	<0.05	<1 - 3.54	7.9 - 46.5	1.1 - 3.05	1.5 - 6.7	0.56 - 1.65
Clear Creek below FH12	0.55 - 1.81	<0.03 - 0.11	0.01 - 0.06	<0.05	2.93 - 3.50	6.6 - 45.9	0.8 - 3.11	0.9 - 6.8	0.45 - 1.81
Rio de las Vacas above FH12	0.47 - 1.07	<0.03 - 0.03	<0.05 - 0.01	<0.05	2.52 - 3.05	1.8 - 6.9	0.27 - 1.01	0.4 - 2.7	0.1 - 0.8
Rio de las Vacas below FH12	0.49 - 0.75	<0.03 - 0.11	<0.05- 0.01	<0.05	2.45 - 3.07	2.8 - 14.4	0.43 - 1.53	1.4 - 2.9	0.25 - 0.84
American Creek above FH12	1.05 - 1.46	0.03 - 0.11	<0.05 - 0.01	<0.05	3.77 - 4.86	22.9 - 32.7	3.0 - 4.16	3.6 - 6.6	0.99 - 1.53
American Creek below FH12	1.04 - 1.48	0.03 - 0.11	<0.05 - 0.02	<0.05	3.33 - 4.84	25.4 - 33.2	2.79 - 4.07	4.3 - 7.4	0.89 - 1.62
Rock Creek above FH12	<0.5 - 1.68	0.03 - 0.11	<0.05 - 0.01	<0.05	3.87 - 4.77	27.2 - 60.3	2.82 - 5.37	2.4 - 9.8	0.3 - 1.31
Rock Creek below FH12	<0.5 - 1.42	0.03 - 0.11	<0.05 - 0.01	<0.05	3.88 - 4.75	19.6 - 50.4	3.02 - 6.09	3.4 - 9.7	0.4 - 1.38
Rito Peñas Negras above FH12	1.3 - 1.46	0.03 - 0.11	<0.05 - 0.01	<0.05	4.07 - 4.37	14.3 - 32.7	2.24 - 2.99	2.9 - 6.5	0.67 - 1.86
Rito Peñas Negras below FH12	1.01 - 1.8	0.03 - 0.19	<0.05 - 0.01	<0.05	4.01 - 4.48	28.6 - 33.7	2.52 - 3.15	2.7 - 7.1	1.0 - 1.8
Calaveras Canyon above FH12	1.75 - 2.17	<0.03 - 0.12	0.06 - 0.12	<0.05	3.68 - 3.87	8.4 - 11.0	1.22 - 1.85	3.1 - 7.1	1.71 - 2.07
Calaveras Canyon below FH12	1.91 - 2.38	0.04 - 0.12	0.09 - 0.10	<0.05	3.16 - 3.50	5.1 - 9.3	0.74 - 1.79	2.6 - 7.7	0.63 - 2.42
Rio Cebolla above Hatchery	1.94 - 2.33	0.04 - 0.05	0.08 - 0.10	<0.05	2.95 - 3.36	8.0 - 9.0	1.54 - 1.76	7.8 - 10.6	2.47 - 2.59
Rio Cebolla at Barley Canyon	1.98 - 2.01	0.03 - 0.04	0.1	<0.05	3.17 - 3.36	9.2 - 9.8	1.77 - 1.85	7.9 - 8.5	2.65 - 2.80
Rio Cebolla above Fenton Lake	1.73 - 2.39	0.04 - 0.11	0.03 - 0.08	<0.05	3.36 - 4.26	5.6 - 10.2	1.0 - 2.67	4.2 - 9.2	1.34 - 2.87
Fenton Lake	2.14	0.03 - 0.05	<0.05 - 0.07	<0.05	2.85 - 3.64	9.5 - 9.9	1.84 - 1.96	8.7 - 9.0	2.95 - 3.08

Source: White 1994.

mg/L = milligrams per liter
ND = Not Detected

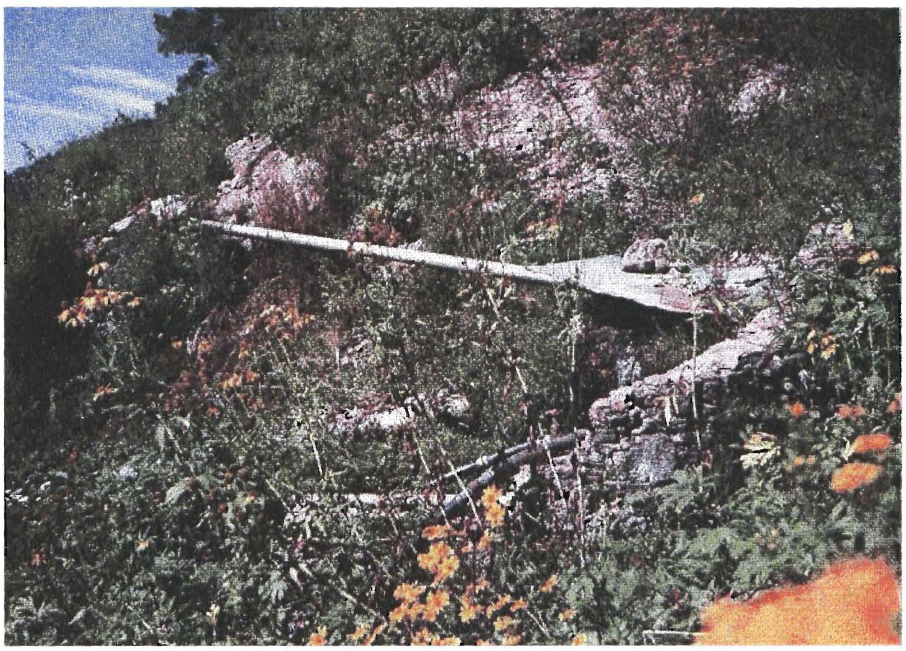
[1] Nephelometric Turbidity Units
[2] Number of samples exceeding the New Mexico Water Quality standard of 25 NTU
[3] Number of samples exceeding the New Mexico Water Quality standard of 0.1 mg/L
[4] Number of samples exceeding the New Mexico Water Quality standard of 1.0 mg/L

Location map for water-quality samples collected by UNM (White, 1994)



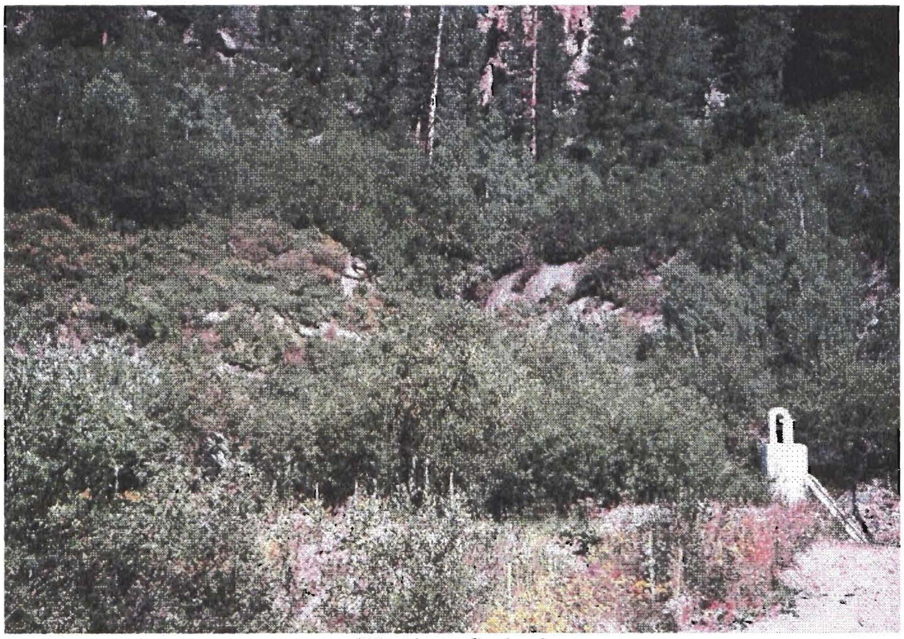
APPENDIX B
Field Photos of Cebolla Spring and the Hatchery Spring

'Hatchery Spring' -- upper pool
Note sandbag dam used to create pool. Pipe runs from upper pool to lower pool as shown in photo below.



'Hatchery Spring' -- lower pool
Pipe runs from upper pool (upper left corner of photo) to lower pool (also an open-air pool) where a distribution pipe (lower left corner of photo) carries spring water to Hatchery residences by gravity flow.

'Cebolla Spring'
Located west of the Hatchery. Residents and tourists fill water containers from discharge pipe. Note hinged steel cover on top of collection box allowing access to the spring.



'Hatchery Spring'
View north from road at the Hatchery. Spring is in the left-center of photograph.