PROTOCOL FOR A STATE-WIDE GROUND WATER QUALITY MONITORING PROGRAM AND ESTABLISHMENT OF A GROUND WATER QUALITY DATA CLEARING HOUSE

by

Nancy Ann O'Keeffe and Grant Cardon

Colorado Water
Resources Research Institute

Completion Report No. 199

Colorado State University

PROTOCOL FOR A STATE-WIDE GROUND WATER QUALITY MONITORING PROGRAM AND ESTABLISHMENT OF A GROUND WATER QUALITY DATA CLEARING HOUSE

by

Nancy Ann O'Keeffe and Grant Cardon
February, 2004

Completion Report No. 199

COLORADO WATER RESOURCES RESEARCH INSTITUTE
Colorado State University
Fort Collins, Colorado 80523

This report was financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Resources Research Institute and Grant No. 1434HQ96GR02660/04. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

ABSTRACT

In 1997, the Colorado Water Quality Control Commission concluded that a comprehensive state groundwater protection plan was needed for adequate groundwater quality protection. The study was conducted to identify aquifers that complied with the Domestic Use-Quality criteria, gather data on wellhead protection plans, and determine projected areas of state growth. Study results were obtained using existing government databases, reports, and records, and other data sources. Total dissolved solids (TDS) levels were the primary data filter used in the study. The TDS filtering limit for high quality drinking water was set at 0 to 500 ppm, with 0 to 100 ppm being pristine quality. The South Platte River alluvial aquifer, including Boulder Creek; Fountain Creek alluvial aquifer, including upper Black Squirrel Creek Basin; and Arkansas River Valley alluvial aquifer yielded high quality water. The Denver Basin; San Luis Basin, including Conejos River Subbasin; lower Gunnison River Basin; and West Slope fractured rock and alluvium also contained high quality water. The wells cited yielded TDS values mostly in the range of 200 ppm to 400ppm. Seventeen of the total 271 wells cited yielded pristine water quality and were located in the Winter Park area, Boulder Basin, San Luis Valley unconfined aquifer, and lower Gunnison River Basin. In 1998, the Colorado Wellhead Protection Program monitored 167 public water supply systems processing wellhead protection plans (WHPP), with four plans completed and approved. The approved WHP plans were located at Eads in Kiowa County, Karvel in Lincoln County, Vilas in Baca County, and Swink in Otero County. Overall, the Arkansas-Rio Grande and South Platte watershed regions were the most active in developing WHP plans, with 11 and 10 plans submitted, respectively. According to the 1998 Office of the State

Engineer well permit database, 294,878 wells were documented in the state, but an accurate count of active and inactive wells is not available. However, 1990 figures cited 91 percent of the state population receiving water from a public or private water supply system, 8 percent from individual wells, 7 percent from individually drilled wells, and less than 1 percent from individually dug well or other sources. The percent and type of well use has not significantly changed between 1970 and 1990 in Colorado. Based on 2000 U. S. Census counts, the total population in Colorado was 4,301,261, representing a 23 percent growth or an increase of 1,006,867 people since 1990. The metropolitan Front Range had a 77 percent growth rate, with the Eastern Mountains and West Slope at 4.2 percent and 3.2 percent, respectively. Eagle and Summit counties grew at an annual rate of 5.4 as a result of the tourist industry. A correlation between irrigated crop production, percent land use, dependency on public water supply systems for drinking water, and risk for groundwater contamination was suggested. In 1996, Weld and Otero counties demonstrated the greatest risk of TDS contamination to alluvial aquifer systems. Overall, public water supply systems and private domestic wells in the South Platte, Arkansas, Republic, and Rio Grande River Basins had comparatively higher risk. Based on irrigated land uses, the High Plains aquifer and the San Luis unconfined aquifer are also at risk of contamination. The lack of access to current groundwater quality data due to conflicting data storage and retrieval systems limited the scope of the study. The groundwater data available for review generated non-comparable data sets resulting from undocumented or unclear data analytical and reporting methods or missing numerical data and site information. The development of aquifer maps in an electronic format readily available to the public would create a useful research tool for future studies.

INTRODUCTION

High quality aquifers are extremely valuable water resources in Colorado. Today, however, these aquifers are vulnerable to degradation from urban and rural land use activities. The adverse activities that contribute to aquifer degradation include the inappropriate use, containment, or disposal of organic and inorganic products at industrial sites, municipal landfills, or agricultural businesses; abandoned or aging well structures; urban or rural runoff; and septic disposal systems. According to the Colorado Department of Health and Environment (1996), approximately 211 communities in Colorado use groundwater or a combination of surface and groundwater for public water supplies. Of the total 63 counties in Colorado, 59 and 29 counties, respectively, use and are solely reliant on groundwater for their drinking water supplies. Overall, 430,000 individuals in Colorado access public water supply systems using groundwater resources and 100,000 individuals are estimated to be accessing private wells (CDPHE 1996, 2002). A large number of private groundwater systems of unknown water quality are considered to be in use in mountainous and rural areas, but not permitted through the State Engineers Office. In general, the use of groundwater for drinking water supplies is correlated to geographic location, surface water quality, and community size (CDPHE, 1996).

Throughout time, the habits and social organizations of humans have been influenced more by water than the land. Human settlements near water thrived when the water was clean and accessible, but were nearly always abandoned once the water became scarce or contaminated. Today, the elimination of contaminates in water, especially in drinking water, is considered a priority (Rail, 1989). In response, the federal and state government promulgated numerous public laws and regulations to provide guidance in the management of our water resources. The laws and regulations highlighted below reflect the progression of societal goals in our country towards the protection and beneficial use of groundwater. The current legal framework also demonstrates the shift from federal control of water quality programs to state and community program development and implementation.

Directly relevant to the use of Colorado groundwater for domestic supplies is The Safe Drinking Water Act of 1974 and its Amendments. The Act guarantees the protection of the Domestic Use-Quality drinking water supply from public water systems through the use of maximum contaminant levels and variance limits. The Act also provides for state underground injection control, wellhead protection programs, and record-keeping requirements (Safe Drinking Water Act of 1974, 1976). The determination of critical aquifer protection areas through the Sole Source Aquifer Demonstration Program by any state or local government, municipality, or planning entity was provided in The Safe Drinking Water Act Amendments of 1986. The Amendment requires a comprehensive protection management plan to be submitted to the designated governing authority (Safe Drinking Water Act of 1986, 1989).

The Colorado Water Quality Control Act promulgates federal requirements set forth in the Federal Water Pollution Control Act of 1965 and its Amendments. Thus, state waters must be classified according to the origin and extent of existing pollution, present and future beneficial use goals, and the character and uses of the land bordering the water (CDPHE, 1998). In order to provide a monitoring and compliance framework for ensuring the protection of groundwater, 5 CCR 1002-41, or Regulation 41, was adopted by the Water Quality Control Commission in 1997. The Colorado Code of Regulations is commonly known as "The Basic Standards for Groundwater" and established statewide standards and a groundwater classification system to protect existing and potential beneficial uses (5 CCR 1002-41, 1997).

STUDY PURPOSE

In 1997, the Colorado Water Quality Control Commission conducted a triennial review of state groundwater quality regulations. The Commission determined that the site-specific water quality classifications and standards in use did not provide adequate groundwater quality protection. The discussion for a comprehensive state groundwater protection plan was stimulated by the development of large concentrated animal feeding operations, numerous federally mandated and voluntary clean-up sites, and conjunctive use issues in the state. The protection of sole-source aquifers near sites that were capable of generating mobile contaminants was of special concern to the Commission (CDPHE, 1997).

The study was initiated to assist the Colorado Water Quality Control Commission and the Water Quality Control Division comply with regulatory requirements for a comprehensive groundwater protection plan. The study goals were to develop background information on Colorado aquifers that meet Domestic Use-Quality criteria and identify the populations that were dependent on those high quality aquifers. The study objectives were to identify the aquifers that met the Domestic Use-Quality criteria provided in Regulation 41, identify the populations served by these high quality aquifers, and determine the status of wellhead protection plans and the projected areas of growth in the state using existing databases, records, and reports. Funding for the study was provided through an U. S. Environmental Protection Agency, Region VIII, grant under the direction of the Water Quality Control Division, Colorado Department of Public Health and Environment, and the Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado.

GROUNDWATER QUALITY

COLORADO AQUIFERS

In Colorado, shallow river alluvium and terrace aquifers occur along most of the large rivers and streams, with older, high-level terrace gravel being evident in the eastern plains. The intermontane basins and mountain valleys contain thick alluvial deposits that form the major aquifers. In the high mountains, the valley fill consists of till, glacial-fluvial, or glacial-lacustrine deposits, but can consist of talus, landslide, or slump deposits. The high eastern plains and western slope consists of bedrock aquifers formed from sedimentary rock, with the fractured igneous and metamorphic rock aquifers in the mountainous regions (CDPHE, 1996). Permeable formations like river alluvium, alluvial deposits, gravel, some tills, and sedimentary bedrock can yield large amounts of groundwater and are frequently classified as major aquifers. Fractured and weathered igneous and metamorphic rock, and some sedimentary rock, will generally contain localized pockets of groundwater that yield small amounts of well water (CDPHE, 1996). Overall, the network of groundwater deposits throughout Colorado is the result of complex, regional geology and climate. The general locations of the major alluvial and bedrock aquifers that have been identified in Colorado are listed in Table 1.

Groundwater in Colorado can exist as an artesian or a water table aquifer. An artesian aquifer occurs when an inclined and saturated, water-bearing formation is confined by an impermeable geologic layer. The groundwater will either flow to the surface or rise in a well bore when a well is drilled. A water table aquifer occurs in

Table 1. Colorado Alluvial and Bedrock Aquifers.

Major Bedrock Aquifers:	**Location:**
High Plains (Ogallala) Aquifer	Eastern Colorado
White River Aquifer	Northeastern Colorado
Dakota Aquifer	Southeastern Colorado
Denver Basin aquifer system	Denver area
San Luis Valley confined aquifer system	South central Colorado
Piceance Creek Basin aquifer system	Northwestern Colorado
Paleozoic aquifer system	Northwestern Colorado
Paradox-San Juan Basin aquifer system	Southwestern Colorado
Minor Bedrock Aquifers:	**Location:**
Dakota, Fountain, and Lyons Formations	Front Range area
Raton Formation	Trinidad area
Vermejo Formation	Walsenburg area
Troublesome and Browns Park Formations	Intermontane basins
Major Alluvial Aquifers:	**Location:**
South Platte River alluvial system	Northeastern Colorado
Arkansas River alluvial system	Southeastern Colorado
Yampa River Basin	Northwestern Colorado
White River Basin	Northwestern Colorado
Gunnison River Basin	Southwestern Colorado

(Hearne et al., 1987; CDPHE, 1996)

unconsolidated sands and gravel or in alluvium or terrace conditions and will only fill the well bore to the water level of the local aquifer (Pearl, 1979). Permeable aquifers are formed from interconnected porous rocks, like sedimentary bedrock, and are capable of transmitting groundwater at a very slow rate of several feet to one hundred feet per year. Aquifers of low permeability occur in igneous and metamorphic rocks, with groundwater collecting in fault and joint openings. The small pore size and low degree of pore interconnectivity found in crystalline bedrock accounts for the low permeability (Freeze and Cherry, 1979; Pearl, 1979). Dense, fine grained glacial-till and glacial-lacustrine silt and clay deposits are generally impermeable and are commonly distinguished as aquitards. The impermeable deposits contain a network of hairline, vertical fissures and joints formed from cycles of wetting and drying and freezing and thawing (Freeze and Cherry, 1979). In a region, a groundwater basin can consists of one or more aquifers that occur in vertical sequence with some overlap. The aquifers are usually contained by aquitards or an underground displacement of rock, such as a fault or divide (Bloomquist, 1992).

Aquifers formed from consolidated bedrock store water based on "the degree of cementation, bedding planes, fractures, joints, solution features, temperature, and pressure alterations, and characteristics of the particles themselves" (Krider, 1992). Geologic features, like folds and faults, also influence area drainage patterns, porosity, and permeability (Stone, 1999). The water storage ability of alluvial aquifers and sedimentary bedrock is dependent on the size and percent of pore space found in the sediment and rock materials present in the formations. Primary, or intergranular, porosity results from the way the bedrock was originally deposited or formed and may be altered by chemical reactions in the groundwater. Secondary, or fracture, porosity results from weathering, fracturing, and mechanical processes on the original bedrock formation. Overall, porosity is controlled by the uniformity of the particle size and shape, the degree of particle roundness and grading, and particle arrangement (Krider, 1992; Robson, 1989). The relationships between sediment and rock type, porosity, and permeability, as well as potential sources of groundwater supply, are shown in Table 2.

The specific yield and specific retention properties of the local material determine the volume of groundwater that can be removed from an aquifer. The amount of water yield to wells is greater from alluvium then bedrock aquifers due to differences in transmissivity, thickness of the formation, and the storage coefficient. The greater the pressure in an aquifer formation resulting from the potentiometric surface and elastic properties of the water and sediment, the less water that will flow to the well bore for

Table 2. Rock and Sediment Type and Groundwater Sources.

Major							
Sediment	Porosity	k (Darcy)	k (gal/day/ft^2)	**Rock**	Porosity	k (Darcy)	k (gal/day/ft^2)
Gravel	Pores	$10^{2} – 10^{5}$	10^{4} - 10^{7}	Basalt	Pores, Fractures	10^{-2} - 10^{3}	1 - 10^{5}
Sand – Silty Sand	Pores	10^{-2} - 10^{3}	1 – 10^{5}	Sandstone	Pores, Fractures	10^{-5} - 10^{-1}	10^{-3} - 10^{2}
Breccia	Pores	10^{-4} - 10^{-1}	10^{-2} – 10	Limestone, Dolomite	Pores, Fractures, Solutions	10^{-4} - 10^{-1}	10^{-2} - 10
Moderate to Small							
Sediment	Porosity	k (Darcy)	k (gal/day/ft^2)	**Rock**	Porosity	k (Darcy)	k (gal/day/ft^2)
Silt	Pores	10^{-4} - 1	10^{-2} – 10^{2}	Granite, Gneiss	Fractures	10^{-3} - 10	10^{-1} - 10^{2}
Siltstone	Pores	10^{-5} - 1	10^{-2} – 10^{2}	Quartzite, Schist, Marble	Fractures	10^{-9} - 10^{-5}	10^{-7} - 10^{-3}
Till	Pores	10^{-7} - 10^{-1}	10^{-5} – 10				
Functions as Confining Beds							
Sediment	Porosity	k (Darcy)	k (gal/day/ft^2)	**Rock**	Porosity	k (Darcy)	k (gal/day/ft^2)
Clay, Marl	Minimal	10^{-7}-10^{-2}	10^{-5} – 1	Shale	Minimal	10^{-9} - 10^{-4}	10^{-7} - 10^{-2}

(Kasenow, 2001; Stone, 1999)

pumping (Robson, 1989). The ease of accessing groundwater from alluvial aquifers over the deeper bedrock formations increases the likelihood of contamination from aquifer drawdowns, mining wastes, septic-disposal systems, and land uses such as improper landfill management or chemical use and storage. Likewise, deeper low water-yielding crystalline aquifers can be contaminated from surface activities as the contaminant passes through the fracture system of the bedrock. However, the mineral composition, structure, and fracture permeability of the bedrock will greatly slow the movement of contaminants into the localized pockets of groundwater to a period of decades.

LOCAL AND REGIONAL GROUNDWATER QUALITY

Groundwater quality is associated with topography and climate, recharge location, and the geochemical pathway of groundwater though the local soils and geologic materials. Precipitation infiltrating soils, colluvium, and rock in the vadose zone and freshwater inflow from surface water bodies form the bulk of the natural recharge of an aquifer. The physical movement of dissolved minerals, major ions, and contaminates are controlled, not only by hydrologic processes, but by soil texture and structures that create preferred pathways like macropores, root tubes, and pipes (Novotny and Olem, 1994; Stone, 1999). Overall, unsaturated soil and rock that have higher porosity and permeability values will transport non-adsorbed groundwater constituents over materials with lower permeability (Table 2). Thus, the movement of groundwater containing dissolved ions and contaminants occurs more commonly in alluvium, unconsolidated materials, and solution-weathered bedrock, like limestone and dolomite, than in clay, glacial till, shale, or dense bedrock (Kasenow, 2001; Palmer, 1992).

The geochemical evolution of groundwater is characterized by the Chebotarev sequence as a water aging process through time and space. The Chedotarev sequence is based on the anion-evolution sequence, $HCO_3^- \rightarrow SO_4^{2-} \rightarrow Cl^-$, in the groundwater solution as minerals are leached from the surrounding strata. The shift from one dominant anion to another is dependent on mineral abundance and solubility, with the level of dissolved solids increasing as the deeper groundwater becomes sluggish and saline (Freeze and Cherry, 1979). Mineral dissolution is considered to be the most important process in controlling groundwater quality. In general, the dissolution-precipitation reactions of carbonate, quartz, aluminosilicate, oxide, hydroxide, and sulfate minerals occurs in sedimentary and crystalline rock formations alike (Sposito, 1989).

The abundance of carbonate minerals in geologic materials influences the level of dissolved solids in groundwater by the leaching action of dissolved CO_2 or H_2CO_3. In recharge areas, HCO_3^- dominates as the most abundant anion and is formed from the dissolution of H_2CO_3 when in contact with CO_2 and calcite or dolomite. The dissolution of calcite, dolomite, gypsum, and other Ca-bearing minerals releases Ca^{2+}, Mg^{2+}, K^+, Na^+, HCO_3^-, SO_4^{2-}, F^-, and Cl^- ions into the groundwater solution (Freeze and Cherry, 1979). Solution-weathered crystalline aquifers containing quartz or aluminosilicate minerals, like feldspars and micas, react chemically to dissolved CO_2, releasing Na^+, K^+, Mg^{2+}, and Ca^{2+} into the groundwater. Associated with the leaching action, is a rise in groundwater pH, HCO_3^- concentrations, and an aluminosilicate residue that has a higher Al/Si ratio. The aluminosilicate residue is commonly in the form of the 1:1 and 2:1 clay minerals kaolinite, illite, or montmorillonite. The weathering sequence of clay minerals suggests that 2:1 clay minerals are replaced by 1:1 clay minerals, which are then replaced by metal hydrous oxides (Freeze and Cherry, 1979; Sposito, 1989).

Other influential factors that will alter mineral solubility include the P_{CO2}, ambient pH and temperature, solution ionic strength, and the common-ion effect. In heterogeneous formations, mineral solubility can be increased or decreased with the introduction of another mineral as the groundwater flows through the strata. For example, the solubility of calcite ($CaCO_3$) is noted to reprecipitate when gypsum ($CaSO_4 \cdot 2H_2O$) is introduced. The precipitation reaction occurs so that the solution equilibrium (K_{cal}) is maintained as a result of the common-ion effect. As SO_4^{2-} concentrations increase in the groundwater, the threshold between HCO_3^- and SO_4^{2-} is reached and SO_4^{2-} becomes the dominant anion in the solution. An increase in the concentration of a mineral not containing Ca^+, such as epsomite ($MgSO_4 \cdot 7H_2O$) or mirabillite ($Na_2SO_4 \cdot 10H_2O$) will increase calcite solubility from the ionic strength effect. Increased levels of dissolved salts in the groundwater will result in even greater mineral solubility. Halite (NaCl) and sylvite (KCl) are good examples of minerals that initiate dissolution reactions and increase the concentration of Cl^- anions known to be present in highly saline groundwater. Again, an anion threshold is reached in the solution between SO_4^{2-} and Cl^-, with Cl^- dominating as the overall level of dissolved solids increases significantly (Freeze and Cherry, 1979; Sposito, 1989). Mineral solubility is also influenced by the partial pressure of CO_2. For example, calcite solubility in groundwater at 25 °C, $K_{eq} = 10^{-8.4}$, and a pH of 7, varies from 100 mg/L at $P_{CO2} = 10^{-3}$ bar to 500 mg/L at $P_{CO2} = 10^{-1}$ bar (Freeze and Cherry, 1979).

Ion-exchange and adsorption-desorption reactions are additional processes that contribute to the geochemical evolution of groundwater. The ion-exchange process involves colloidal particles with an adsorbed ion in the crystal lattice that is readily replaced by another ion from the groundwater. A basic example of ion exchange is when a K^+ ion in a feldspar is replaced with a Na^+ ion and released into the groundwater as shown in the following equation: $KAlSi_3O_{8(s)} + Na^+_{(aq)} = NaAlSi_3O_{8(s)} + K^+_{(aq)}$ (Sposito, 1989). The colloidal surface charge is pH dependent and results from ionic substitution within the crystal lattice or by chemical dissolution reactions at the particle surface. Ionic substitution creates a net positive or negative charge on the surface of the particle that is compensated for by adsorbed and exchangeable counter ions. Montmorillonite, and to a lesser degree, vermiculite, are the primary colloidal particles predominately involved in ionic substitution. Montmorillonite-rich formations that undergo ionic substitution frequently demonstrate a decrease in permeability values as the crystal lattice dimension increases from the hydrated radii of two Na^+ ions at the Na^+-Ca^{2+} exchange site. In groundwater systems, the most important cation exchange reactions are Na^+-Ca^{2+}, Na^+-Mg^{2+}, K^+-Ca^{2+}, and K^+-Mg^{2+}. Of special concern is the increase in groundwater salinity by the replacement of Ca^{2+} and Mg^{2+} ions with Na^+ ions in aquifer rock formations dominated by calcite and dolomite (Freeze and Cherry, 1979; Sposito, 1989).

Complexation and oxidation-reduction reactions are geochemical processes that can also alter groundwater chemistry. Complexation reactions with inorganic and organic ligands or metals occur when a surface functional group of a mineral reacts with an ion or molecule in the groundwater solution to form a stable, less soluble molecular unit. An example of a complexation reaction is the dissolution of a mica, muscovite, by hydrolysis and the release of the anion $C_2O_4^{2-}$ into the solution to form a complex with Al^{3+} in the following equation: $K_2[Si_6Al_2]Al_4O_{20}(OH)_{4(s)} + 6C_2O_4H_{2(aq)} + 4H_2O = 2K^+_{(aq)} + 6C_2O_4Al^+_{(aq)} + 6Si(OH)_{4(aq)} + 8OH^-_{(aq)}$ (Sposito, 1989).

The oxidation of organic matter, in the presence of O_2 and aerobic micro-organisms, is a primary source of CO_2 and H^+ ions in groundwater. Hydrogen ions are then consumed by reduction reactions with minerals present in the soil and rock formations. Thus, oxidation-reduction reactions initiate electrochemical changes in groundwater, where large pE values favor the existence of oxidized species and small pE values favor reduced species (Freeze and Cherry, 1979). In general, the sequence of reduction reactions at a pH of 7 in soil-water shows a chemical transformation according to oxygen availability. The reduction sequence of minerals is described as the following: NO_2^- and NO_3^- (3.4 to 8.5 pE) → MnO_2 (3.4 to 6.8 pE) → $Fe(OH)_3$ and FeOOH (1.7 to 5.0 pE) → SO_4^{2-} (-2.5 to -0.0 pE) (Sposito, 1989). As the groundwater moves from an oxic to an anoxic state, NO_2^-, N_2, NH_4^+, Mn_2^+, Fe_2^+, HS^-, $S_2O_3^-$, and H_2S are released. The redox potential (Eh) is dependent on matrix structure, porosity, and permeability; temperature and pH; type and distribution of organic matter; and recharge activity (Freeze and Cherry, 1979). The oxidation of NH_4^+ forms NO_3^-, a highly mobile compound in oxidized groundwater because of its anionic and soluble characteristics. As the redox potential is lowered, NO_3^- is reduced to N_2O and then to N_2 (Freeze and Cherry, 1979). Nitrate contaminates are seen in both shallow, highly permeable aquifers and fractured rocks at varying rates. For example, wells sampled for nitrate exceeded the primary drinking water standard of 10 mg/L by 35 percent in the South Platte River alluvial aquifer and 14 percent in the Lower Arkansas River alluvial aquifer and San Luis Valley unconfined aquifer. The High Plains aquifer and Western Slope shallow aquifers exceeded the nitrate drinking water standard by 6 percent and 1 percent, respectively. The groundwater analyses were conducted on domestic wells in locations influenced by irrigation agriculture in a series of studies by the Colorado Water Quality Control Division (Austin 1993a, 1993b, 1995, 1998; CDPHE, 2002). The oxidation of organic matter in anaerobic environments is accomplished through SO_4^{2-} reduction. The sulfate reduction reaction is catalyzed by anaerobic, sulfate-reducing microorganisms and produces hydrogen sulfide (H_2S) gas. Methane (CH_4) is a common constituent of deep groundwater in sedimentary basins, but the gas has been found in shallow groundwater (Freeze & Cheery, 1979). An example of reducing conditions in deep aquifers is the production of hydrogen sulfide and methane gas in the Laramie-Fox Hills aquifer in the Denver Basin system. The Laramie-Fox Hills layers are composed of silty shale, clay, sandstone, and gravel; with sodium bicarbonate, sodium sulfate, sulfate, and iron commonly found in the layers (CDPHE, 2002; Hearne et al., 1987).

GROUNDWATER CONTAMINATES

The transport and fate of dissolved ions and contaminates in groundwater is dependent on the physicochemical nature of the contaminants, aquifer stratigraphy, and advection and diffusion processes (Palmer, 1992). A majority of contaminants in Colorado groundwater are considered to be local in their distribution at a limited number of small sites in the state. The local contaminants occur primarily in agricultural, mining, and Superfund sites; municipal and on-site industrial landfills; storage tanks, septic tanks or leach fields; or they naturally occur in the bedrock. Locally found substances include volatile and synthetic organic chemicals, petroleum products, sodium, chloride, arsenic, copper, lead, iron, manganese, and zinc. Regional contaminants include radium, radon, uranium, and gross alpha and beta substances. Contaminates that are widespread in the state are selenium, iron, fluoride, total dissolved solids, sulfate, and nitrate (CDPHE 1996, 2002). Many of the constituents found naturally in groundwater occur at levels that exceed drinking water standards as a result of the local hydrogeology and are categorized as contaminants. The naturally occurring contaminants include sodium, manganese, fluoride, selenium, iron, arsenic, uranium, sulfate, and radium (CDPHE, 1996).

MATERIALS AND METHODS

A comprehensive review of existing databases, records, and reports was conducted for aquifer water quality data that meets the Domestic Use-Quality criteria during the spring and summer of 1998. The research for groundwater quality data was completed using U. S. Environmental Protection Agency and U. S. Geological Survey technical reports and Web pages, the STORET database, and the NWIS database. Colorado Geological Survey technical reports, Water Quality Control Division technical reports and Web page, and the Colorado Water Resources Research Institute at Colorado State University was also thoroughly researched. Minor groundwater quality data and aquifer information was obtained from water conservancy district documents and other technical journal articles and records.

The groundwater quality data was reviewed and categorized by watershed, structural basin, aquifer, and then geological unit when groundwater sample depths were provided. Documentation on groundwater sample collection and handling and laboratory analysis procedures and protocols, data handling and analysis techniques, data record attributes, and reporting methods was obtained as much as possible. Additional documentation on well location coordinates, total depth and depth to water, sample collection level, pumping rate per valve aperture, and field conditions was also sought. Aquifer descriptions that included lithology, transmissivity measurements, depth, basin slope, water volume and total area, recharge location and rate, flow direction, and associated surface water bodies were beneficial in anticipating nature of the constituents in the groundwater.

The Domestic Use-Quality classification for groundwater is partially defined as groundwater used for domestic purposes within a specified area or when available information regarding background levels demonstrates future domestic use of water within the specified area is reasonably probable. The background levels must be generally adequate to comply with Human Health Standards and total dissolved solids levels are less than 10,000 mg/L (5 CCR 1002-41, 1997). The secondary maximum contaminant level for total dissolved solids is cited at 500 mg/L in the National Secondary Drinking Water Regulations, which addresses the aesthetic qualities of drinking water from public water systems (40 CFR 143.3, 2001).

The first data filter used to identify aquifers in the state that meet the Domestic Use-Quality criteria was total dissolved solids (TDS). The TDS filtering limits for drinking water quality were further defined as: 0 to 100 ppm, pristine quality; 100 to 500 ppm, high quality; 500 to 750 ppm, questionable quality; and 750 ppm and higher, poor quality (Moravec, 1998). Therefore, all of the aquifers that complied with the Domestic Use-Quality criteria and produced TDS values in the range of 0 to 500 ppm were determined to be of high quality. The TDS limit used to define high quality drinking water was the primary method for categorizing water quality data in the study. Additional filtering of water quality data using nutrient, metal, pesticide, and volatile organic carbon values did not further eliminate aquifers according to the Domestic Use-Quality criteria. Since there has been significant changes in land use activities and population density in the state, water quality data published before 1980 was not considered in the study to ensure an assessment of current groundwater quality.

RESULTS AND DISCUSSION

In the survey of domestic wells yielding high quality groundwater in Colorado, locations in the South Platte River alluvial aquifer, including Boulder Creek; Fountain Creek alluvial aquifer and tributary alluvium, including the upper Black Squirrel Creek Basin; and the Arkansas River Valley alluvial aquifer were cited. The Denver Basin system; San Luis Basin, including the Conejos River Subbasin; the lower Gunnison River Basin; and West Slope fractured rock and alluvium also yielded well water samples consistent with Domestic Use-Quality standards and TDS limits for high quality drinking water. The general locations of the study areas in the state with wells that yielded high quality water can be found in Figure 1. The 1998 Water Quality Control Division study was not included on the map since it encompassed the entire western slope (Figure 1). The domestic wells cited in the study yielded TDS values primarily in the range of 200 ppm to 400 ppm. Seventeen of the total 271 wells cited yielded pristine quality water in the range of 0 to 100 ppm. The domestic wells with pristine quality water were located in the Winter Park area, the Boulder Basin, the San Luis Valley unconfined aquifer, and the lower Gunnison River Basin. The wells yielding pristine quality water were separated from the other water quality values for special consideration and were noted as red dots on the map (Figure 1).

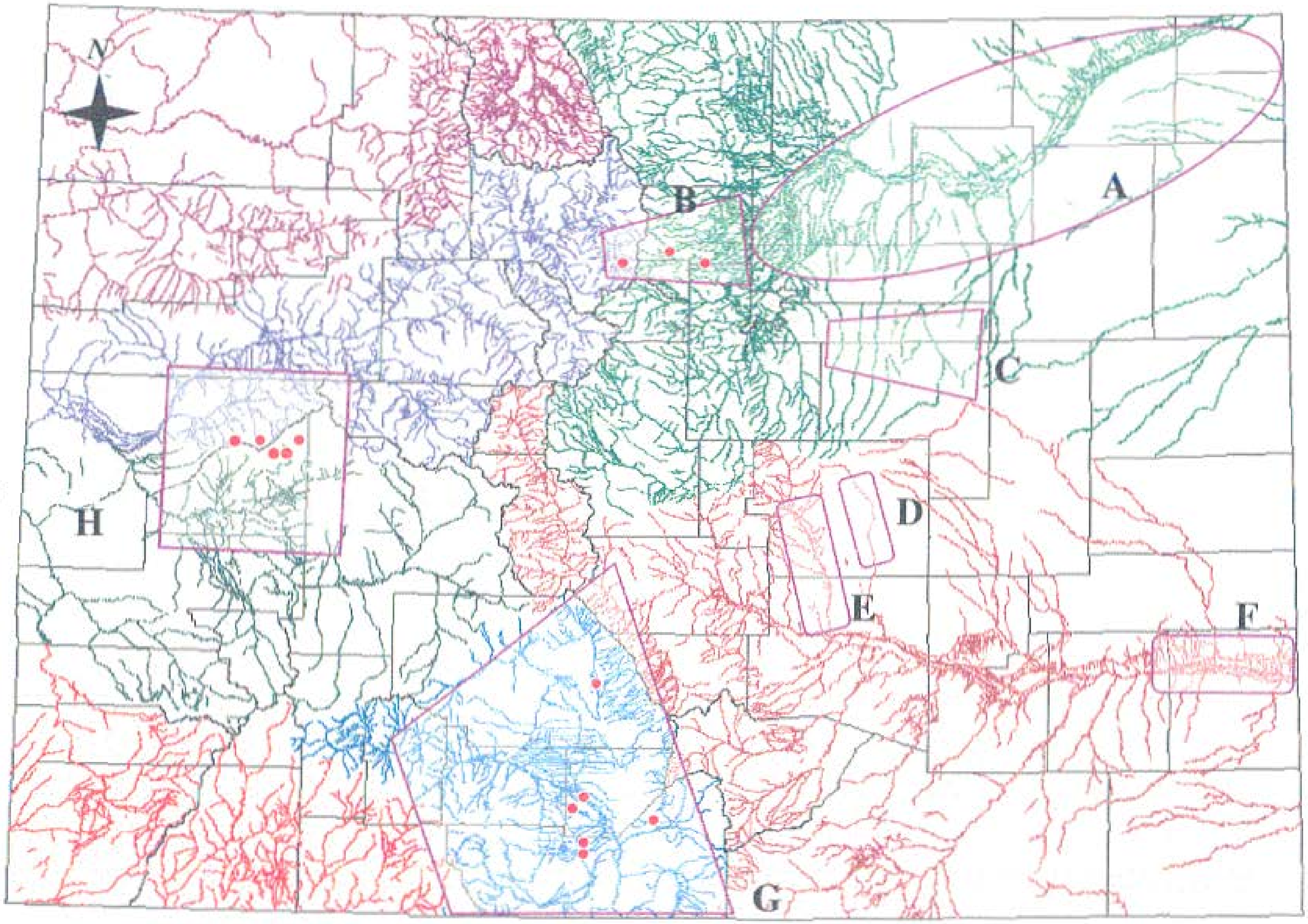

Figure 1. General study areas, major river basins, and pristine water quality well sites.
* WQCD West Slope study area encompasses the entire western slope and is not on the map.
(Map Legend on page 18)

Map Legend:

General study areas, major river basins, and pristine water quality well sites.

General Study Areas:

A. WQCD Monitoring Activities: South Platte River Alluvial Aquifer, 1992 - 1993;
U. S. Geological Survey NWIS Database, 1992 - 1997.

B. U. S. Geological Survey Water-Resources Investigations Report 97-4091;
U. S. Geological Survey NWIS Database, 1992 - 1997 (West Slope Pristine Well Site On Map Only).

C. U. S. Environment Protection Agency STORET Database, 1990 - 1998.

D. U. S. Geological Survey Water Resources Investigations Report 88-4017.

E. U. S. Geological Survey Water-Supply Paper 2381-D, 1988 - 1989;
U. S. Geological Survey Water Resources Investigations Report 94-4118.

F. WQCD Monitoring Activities: Arkansas River Valley Alluvial Aquifer, 1994 - 1995.

G. WQCD Monitoring Activities: San Luis Valley Unconfined Aquifer, 1993;
U. S. Geological Survey Water-Resources Investigations Report 96-4144;
U. S. Geological Survey Water-Resources Investigations Report 89-4040.

H. U. S. Geological Survey Water-Resources Investigations Report 84-4185.

- Pristine Water Quality Well Sites

Major River Basins:

- South Platte River Basin
- Arkansas River Basin
- Rio Grande River Basin
- San Juan River Basin
- Lower Colorado River Basin
- Upper Colorado River Basin
- Green River Basin

The TDS values cited in the study were obtained from the U. S. Environmental Protection Agency STORET database, the U. S. Geological Survey NWIS database and technical reports, and Water Quality Control Division technical reports. The TDS values, organized by watershed and research report, can be found in Appendix A. The watershed basin and aquifer name, county, well location, well depth, and water sample reference number were provided with the TDS values when they were available. The TDS values provided in Appendix A represent the general locations and range of water quality values published after 1980 that meet the Domestic Use-Quality criteria and filtering limits for high quality drinking water.

Overall, there was a significant lack of current groundwater quality data and aquifer descriptions published or readily accessible for review during the study. The groundwater quality data available lacked a uniform format and was scattered between multiple small-scale sources, decreasing the comparability of the data from different water resource agencies. Data record attributes like non-detects, missing values, duplicate values or observations, seasonality, and non-normality were frequently not available with the data set. Data collection methods and laboratory and data analysis protocols were also difficult to obtain.

Total dissolved solids are defined as the total amount of dissolved solids, or ions, that dissolve into the water body as the water flows over and through the rock structure. The mineral ions and gas constituents commonly found in the groundwater are Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, HCO_3^{-}, SO_4^{2-}, F^{-}, and Cl^{-} (Novotny and Olem, 1994). The concentration of dissolved solids in an aquifer can be used as a general indicator of inorganic water quality at a specific sampling level. Once the predominate anions and cations are determined, the dissolved solids concentration will identify recharge sources and act as an indicator of groundwater flow direction.

In a confined aquifer, the concentration of dissolved solids increases in a downward gradient due to redox and dissolution processes. In an unconfined aquifer, the concentration of dissolved solids changes as groundwater moves according to the flow path and encounters biotic and abiotic materials (Lewis, 1995; Williams and Hammond, 1989). Shallow alluvial aquifers hydraulically connected to major rivers have shown a significant change in dissolved solids levels and the dominant ions present in the groundwater as the flow path moves downstream. The South Platte and Arkansas River alluvium are good examples of the major alterations in ion composition and concentration from upstream reaches to downstream. In general, the groundwater moves from a less mineralized state dominated by calcium and bicarbonate compounds to a highly mineralized water dominated by sodium and sulfate compounds (Robson, 1989; Williams and Hammond, 1989).

Specific conductance is associated with TDS levels in water and varies directly with the ionic strength; as ions or dissolved solids increase, specific conductance also increases in fresh water at 25 °C. However, since groundwater contains both ionic and uncharged species at varying amounts throughout time, it can be argued that accurate estimates of ion concentrations by conductance determinations are of questionable value (Lewis, 1995; Freeze and Cherry, 1979). In addition, the ionic mobility of a solute ion is reduced by increased concentrations of dissolved solids, variations in temperature, and interactions with the solvent and other ions (Hem, 1992). Specific conductance measurements can be broadly descriptive of dissolved solids levels by assuming that dissolved solids values (mg/L) will be from 0.55 to 0.75 times that of the conductance value (μ/cm). Therefore, the alluvium in the upper reaches of the South Platte River will contain groundwater composed primarily of bicarbonate compounds with a factor near the lower end of the range and downstream alluvium groundwater containing sulfate compounds will reach or exceed the upper end (Hem, 1992).

Total dissolved solids are considered a widespread groundwater contaminate that degrades public drinking water supplies throughout the state of Colorado. As noted, much of the increased concentrations of dissolved solids are a results of surface evapotranspiration and higher water tables, irrigation return flows, use and reuse of surface waters, and natural soil and rock composition (Dennehy et al., 1993; Hearne et al., 1987). Since total dissolved solids measurements are considered to be a quick and inexpensive method of determining inorganic water quality (Palmer, 1992) and there is statewide occurrence of dissolved solids in shallow and deep aquifers, the use of TDS values as a method to identify high quality aquifers is justified.

WELLHEAD PROTECTION AND DEMOGRAPHICS

Community water systems account for 46 percent of the total 1,781 public water supply systems in Colorado, with 44 percent of the total representing non-transient non-community water systems. Throughout the state, 170 communities use groundwater as their main public water supply source and 29 of the 63 counties rely solely on groundwater supplies (CDPHE, 2002). A primary responsibility of public water supply systems is the provision of safe drinking water through on-going water quality monitoring and contaminate vulnerability analyses. In rural locations, domestic water supplies are commonly obtained from groundwater, with private, potable-wells servicing small towns and subdivisions not connected to a public water system (CDPHE, 2002). The protection of groundwater drinking water supplies is closely tied to the identification of critical aquifer protection areas and wellhead protection activities.

The identification of critical aquifer protection areas through the Sole Source Aquifer Demonstration Program by local, municipal, or state entities was provided in the Safe Drinking Water Act Amendments of 1986. Directly relevant to this study is the selection of aquifer protection areas based on the vulnerability of an aquifer to contamination. Aquifer vulnerability is based on the hydrogeologic characteristics of the aquifer and the number of persons, or the proportion of the population, using the groundwater as a drinking water source (Safe Drinking Water Act of 1986, 1989). An aquifer vulnerability analysis determines how sensitive the aquifer is to being adversely affected by a contaminate load. Accordingly, the accessibility of the saturated zone and the attenuation capacity of the geologic materials present in the aquifer will indicate the vulnerability of the groundwater to contamination. A primary goal of the vulnerability assessment is to obtain contaminate dispersion rates through the soil and water solution using designated hydrogeologic parameters. The parameters include the identification of the unsaturated and saturated media, hydraulic conductivity, flow velocity, depth to water, recharge, degree of confinement, and land-slope surface (Hearne et al., 1995).

Groundwater vulnerability assessments are key components in the development of Wellhead Protection Plans (WHPP) for public water supply wells in the state. The Colorado Wellhead Protection Plan program is operated by the Ground-Water Unit of the Water Quality Control Division and represents a preventive and educational approach in the protection of groundwater supplies at the local level. The basic goal of the protection plan is to establish a wellhead protection area (WHPA) around a public water supply source. Public water systems in fractured bedrock and shallow and unconfined aquifers are considered the most vulnerable to contamination. Within the WHPA, chemical and physical factors that influence the likelihood of a contaminate reaching a well, such as the time-of-travel (TOT) criterion, are delineated. Applied to the delineation criteria is a numerical threshold value. A threshold value of five years is recommended for unconfined aquifers given continuous pumping, with the contaminate moving at the speed of groundwater flow. In a confined aquifer, the TOT from the surface moving vertically downwards through the confining layers is forty years. The threshold value represents the length of time required for contaminates to migrate from the WHPA boundary to the well (CDPHE, 1994). Groundwater contamination, particularly in confined aquifers, results from poor well construction and maintenance, old wells and well casings, abandoned wells without adequate seals, uncapped wells, waste disposal wells, oil and gas wells, and test holes. In addition to the delineation criteria, public water suppliers are required to inventory and map contaminates and land use activities that pose a threat to the groundwater supply and develop a mitigating management strategy (CDPHE, 1994).

MATERIALS AND METHODS

Extensive research was conducted for background data and information on state aquifers that met the Domestic Use-Quality criteria and the populations served by the high quality aquifers. The status of wellhead protection plans, the projected areas of growth in the state, and the potential impact of land use activities around high quality aquifers were also obtained. The research was conducted using Water Quality Control Division technical reports, maps, and Web page; Colorado Wellhead Protection Program manual and database; Office of the State Engineer well permit database; Colorado Demography Section of the Colorado Department of Local Affairs Web pages; and the University of Colorado at Boulder, University Libraries Web page. Additional information was gathered from U. S. Geological Survey technical reports and Web page, U. S. Environment Protection Agency technical reports and Web page, and other reports and records.

RESULTS AND DISCUSSION

In 1998, the Colorado Wellhead Protection Program monitored 167 public water supply systems in the process of establishing a WHPP, representing the main six watersheds in the state. At the time of the study, a completed and approved WHPP had been established for four of the 167 public water supply systems in the database. An overview of the WHP plans in progress by watershed, as documented by the Water Quality Control Division WHPP database, is provided in Table 3. The approved WHP plans were located at Eads in Kiowa County, Arkansas-Rio Grande watershed; Karval in Lincoln County, Arkansas-Rio Grande watershed; Vilas in Baca County, Arkansas-Rio Grande watershed; and Swink in Otero County, Arkansas River watershed. Overall, the Arkansas-Rio Grande and South Platte watershed regions were the most active in developing WHP plans, with 11 and 10 plans submitted, respectively (CDPHE, 1998).

Table 3. Colorado Wellhead Protection Plans.

Watershed	WHPA Delineation	Inventory	Management Application	Submitted	Reviewed	Approved
South Platte	61	22	11	10	6	-
Arkansas River	4	3	-	-	-	1
Arkansas-Rio Grande	47	25	20	11	2	3
Lower Colorado	14	4	2	-	-	-
Western Colorado	1	-	-	1	-	-
Upper Colorado	9	2	-	-	-	-

(CDPHE, 1998)

According to the 2000 U. S. Census, the total population in Colorado was 4,301,261, representing a 23 percent growth, or an increase by 1,006,867 people, since the 1990 census (http://www.dlg.oem2.state.co.us/demog). The major area of population growth in the state from 1990 to 1999 was the metropolitan Front Range, with the Eastern Mountains and the Western Slope following in population increases. The Front Range experienced a 77 percent increase in population numbers between 1990 and 1999. The fastest rate of growth in the state occurred in the Eastern Mountains and on the Western Slope at an annual growth rate of 4.2 percent and 3.2 percent, respectively. Eagle and Summit counties grew at an annual rate of 5.4 percent as a result of the tourist industry (http://www.dlg.oem2.state.co.us/demog). The counties in the state that have experienced the greatest population increases between 1990 and 1999 have been summarized by the Colorado Department of Local Affairs and provided in Table 4.

Projected population growth by region between 1990 and 2025 (Table 4), and expressed as an average annual percent change in five or ten year increments, is also provided.

Table 4. Colorado Percent Population Change by County and Region.

Region:	1990-1995	1995-2000	2000-2005	2005-2015	2015-2020
Colorado	2.9	2.6	1.8	1.7	1.5
Front Range	2.8	2.6	1.7	1.6	1.4
Western Slope	3.6	3.0	2.5	2.2	1.8
Eastern Mtns.	4.2	2.9	3.0	3.0	3.4
Park and Teller Counties	6.9	5.1	6.2	5.9	6.1
Park Co.	7.8	6.7	10.1	9.1	8.0
Teller Co.	6.3	4.0	3.1	1.5	1.1
San Luis Valley					
Eastern Plains	2.0	1.6	1.6	1.6	1.4
County:	1990 Population	1999 Population	Percent Change		
Douglas	60,391	164,495	172.4		
Elbert	9,646	19,810	105.4		
Park	7,174	14,218	98.2		
Custer	1,926	3,596	86.7		
Archuleta	5,345	9,581	79.3		
Teller	12,468	21,303	70.9		
San Miguel	3,653	6,003	64.3		
Eagle	21,928	35,522	62.0		
Hinsdale	467	750	60.6		
Summit	12,881	20,435	58.6		

(http://www.dlg.oem2.state.co.us/demog)

The numeric and percent changes in population numbers reflect potential areas within the state where current and future water and land use needs may detrimentally impact groundwater availability and Domestic Use-Quality. Significant increases in land development and groundwater use within the boundaries of identified aquifer systems may suggest the need to apply greater groundwater protection measures beyond what is currently in place.

According to the 1998 Well Permit Database from the Office of the State Engineer, there was 294,878 wells in Colorado (CDWR, 1998). The lack of complete information from the Well Permit Database on active and inactive wells in the state limits an accurate count of well permits. In 1990, however, approximately 91 percent of the state population received water from a public or private water supply system, 8 percent from individual wells, 7 percent from individually drilled wells, and less than 1 percent from individually dug wells or other sources. The percent and type of well use in Colorado has not significantly changed between 1970 and 1990 (http://www.colorado. edu/ libraries/govpubs/colonumb/watersrc.htm).

Many shallow, alluvial aquifers in the state are hydraulically connected to major rivers and their tributaries. Therefore, impacts to alluvium water quality from non-point source pollution, municipal and industrial wastewater, irrigation agriculture, and livestock feeding operations are commonly cited. Crop irrigation production accounts for 96 percent of the groundwater consumed in Colorado and 20 percent or more of the irrigated acreage is dependent on groundwater sources. Surface irrigation practices such as spray irrigation systems, ditches, canals, and diversions from rivers, streams, and reservoirs can result in the irrigation water becoming a recharge source to shallow aquifers (CDPHE, 1996). Thus, an increase in alluvium and shallow bedrock TDS, nitrate, and pesticide levels in agricultural areas can be directly connected to irrigation water leaching through the soil and porous rock, irrigation return flows, and surface evapotranspiration processes. The counties that rely in part on irrigated crops for economic stability lie mostly in the eastern plains of Colorado. A correlation between irrigated crop production, percent land use per county or river basin, and the level of dependency on public water supply systems for drinking water is shown in Table 5.

Table 5. Irrigated Acreage and Public Water Supply Systems,1996.

County	Irrigated Acreage	County Area (percent)	Major River Basin	Number of PWS Systems	Population Served
Weld	332,230	13.55	South Platte	18	11,865
Yuma	181,300	12.20	Republican	3	5,232
Prowers	175,300	16.91	Arkansas	9	11,633
Otero	154,500	19.17	Arkansas	25	14,594
Morgan	144,780	17.66	South Platte	9	18,898
Bent	115,300	11.83	Arkansas	5	3,609
Logan	113,680	9.67	North/South Platte	9	13,820
Pueblo	113,500	7.49	Arkansas	8	3,051
Kit Carson	91,300	6.67	Republican	6	4,807
Alamosa	60,600	13.25	Rio Grande	7	10,005

(CDPHE, 1996)

In 1996, Weld County in the South Platte River Basin and Otero County in the Arkansas River Basin showed the greatest risk of TDS contamination to alluvial aquifer systems. An increased risk of alluvium contamination increases the potential for public water supplies that serve a notable proportion of the county population to be degraded. Overall, the South Platte River and Arkansas River Basins, Republican River Basin, and Rio Grande River Basin demonstrate a comparatively higher risk for damage to public water supplies and private domestic wells as a result of irrigated crop production. Other agricultural activities that impact groundwater quality, like concentrated animal feedlots, also occur in locations that rely on shallow aquifers for drinking water. The potential movement of contaminates into deep bedrock aquifers, that provide domestic water supplies, is important to note. Since the High Plains (Ogallala) aquifer underlies 12,000 square miles of eastern Colorado and is a primary source of water in the region, the downward movement of contaminates represents a potentially significant risk to drinking water quality (CDPHE, 2002). There is also a risk of groundwater contamination from agricultural practices in the south-central region of the state. The San Luis Valley is intensely irrigated using a combination of surface and groundwater sources and the San Luis unconfined aquifer underlying the valley serves as a major source of domestic water in the region (CDPHE, 2002).

CONCLUSION

A significant segment of the Colorado population relies in part or solely on groundwater resources for domestic use purposes through public supply systems or private wells. In general, the use of groundwater for drinking water supplies is correlated to geographic location, surface water quality, and community size. Population pressures on water resources are projected to continue for at least the next twenty years, with a great deal of growth continuing on the West Slope, central mountains, and along the Front Range. The identification and protection of aquifers of high quality is critical to ensuring economic stability for the communities at greatest risk to land use activities that lead to groundwater contamination. Research has demonstrated that total dissolved solids measurements are a quick and inexpensive method to determine aquifer hydrogeologic characteristics and the impact of surface inputs into the groundwater system.

When researching for Domestic Use-Quality data and associated aquifer information several issues arose that limited an accurate and comprehensive review of aquifers in the state. A primary problem encountered was the lack of coordination between federal and state groundwater agencies, water municipalities, and water management districts. The lack of coordination between water resource entities frequently results in non-comparable data sets, incomplete and non-uniform data, and missing numerical data and site information. The resulting database available to researchers, therefore, contains irrelevant or outdated information on an aquifer's water condition and use, with the valuable information often being obscured. The inability to clearly understand water quality issues in the state results in improper manage of groundwater and fiscal resources. A full attempt was made to locate GIS maps on state aquifers from federal and state agencies. The development of GIS maps applicable to the groundwater study was considered overly time consuming for the scope of the study, although several agencies are currently in the design process and maps will be available in the near future.

With increasing population pressures and water demands in Colorado, protection of high quality aquifers and the public drinking water supply is essential. The future of groundwater management depends on further research and development of interactive GIS technology, data access, and public educational strategies that will be of benefit to professionals and the public alike.

REFERENCES

Anderholm, S. K. 1996. Water-quality assessment of the Rio Grande Valley, Colorado, New Mexico, and Texas-Shallow ground-water quality of a land-use area in the San Luis Valley South-Central Colorado, 1993. U.S. Geol. Surv. Water-Resour. Invest. Rep. 96-4144. U.S. Gov. Print. Office, Washington, DC.

Austin, B. 1998. Ground water monitoring activities: West slope of Colorado, 1998. Agric. Chem. Prog., WQCD, CDPHE, Denver, CO.

Austin, B. 1995. Ground water monitoring activities: Arkansas River Valley alluvial aquifer, 1994-1995. Agric. Chem. Prog., WQCD, CDPHE, Denver, CO.

Austin, B. 1993a. Ground water monitoring activities: San Luis Valley unconfined aquifer, 1993. Agric. Chem. Prog., WQCD, CDPHE, Denver, CO.

Austin, B. 1993b. Ground water monitoring activities: South Platte River alluvial aquifer, 1992-1993. Agric. Chem. Prog., WQCD, CDPHE, Denver, CO.

Bloomquist, W. 1992. Dividing the Waters. ICS Press, San Francisco, CA.

Brooks, T. and D. J. Ackerman. 1985. Reconnaissance of ground-water resources in the Lower Gunnison River Basin, southwestern, Colorado. U.S. Geol. Surv. Water-Resour. Invest. Rep. 84-4185. U.S. Gov. Print. Office, Washington, DC.

Bruce, B.W. and C. O'Riley. 1997. Comparative study of ground-water quality, 1976 and 1996, and initial gain-and-loss assessment of Boulder Creek, Boulder County, Colorado. U.S. Geol. Surv. Water-Resour. Invest. Rep. 97-4091. U.S. Gov. Print. Office, Washington, DC.

Buckles, D. R. and K. R. Watts. 1988. Geohydrology, water quality, and preliminary simulations of ground-water flow of the alluvial aquifer in the Upper Black Squirrel Creek Basin, El Paso County, Colorado. U.S. Geol. Surv. Water-Resour. Invest. Rep. 88-4017. U.S. Gov. Print. Office, Washington, DC.

Chafin, D. T. 1996. Effects of land use on water quality of the Fountain Creek alluvial aquifer, East-Central Colorado. U.S. Geol. Surv. Water-Supply Pap. 2381-D. U.S. Gov. Print. Office, Washington, DC.

Colorado Department of Local Affairs. 2002. Preliminary population projections for Colorado counties and regions, 1990-2025. Colorado Demography Section, Denver. (Available online at http://www.dlg.oem2.state.co.us.demog.) (Verified 29 Apr. 2002.)

Colorado Department of Local Affairs. 2002. Population estimates for Colorado counties. Colorado Demography Section, Denver. (Available online at http://www.dlg.oem2.state.co.us.demog.) (Verified 29 Apr. 2002.)

Colorado Department of Public Health and Environment. 2002. Status of water quality in Colorado, 2002. WQCD, Denver. (Available online at http://www.cdphe.state.co.us/wq/wqhom.asp.) (Verified 24 Apr. 2002.)

Colorado Water Quality Control Act of 1998. Title 25, Article 8. Water Quality Control. (1998). CDPHE, Denver, CO.

Colorado Department of Public Health and Environment. 1998. Colorado Wellhead Protection Program Database. WQCD, Denver.

Colorado Department of Public Health and Environment. 1997. Colorado ground water quality protection policy options, Memorandum (Aug. 27, 1997), WQCD, Denver.

Colorado Department of Public Health and Environment. 1996. Status of water quality in Colorado, 1996. WQCD, Denver.

Colorado Department of Public Health and Environment. 1994. Colorado Wellhead Protection Program. WQCD, Denver.

Colorado Division of Water Resources. 1998. Well Permit Database. Off. of the State Eng., Denver.

5 CCR 1002-41. The basic standards for ground water, Regulation No. 41. WQCD, CDPHE (1997). Denver, CO.

40 CFR 143.3. National Secondary Drinking Water Regulations, Secondary Maximum Contaminant Levels. Title 40, Vol. 19, July 1, 2001. U. S. Fed. Reg., Gov. Print. Office, Washington, DC

Dennehy, K. F., D. W. Litke, C. M. Tate, and J. S. Heiny. 1993. South Platte River Basin-Colorado, Nebraska, and Wyoming. Water Resour. Bull. 29(4):647-683.

Freeze, R. A. and J. A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Lewis, M. 1995. Quality of water in the alluvial aquifer and tributary alluvium of the Fountain Creek Valley, southwestern El Paso County, Colorado, 1991-92. U.S. Geol. Surv. Water-Resour. Invest. Rep. 94-4118. U.S. Gov. Print. Office, Washington, DC.

Hearne, G. A., M. Wireman, A. Campbell, S. Turner, and G. P. Ingersoll. 1995. Vulnerability of the uppermost ground water to contamination in the greater Denver area. U.S. Geol. Surv. Water-Resour. Invest. Rep. 92-4143. U.S. Gov. Print. Office, Washington, DC.

Hearne, G. A., J. Lindner-Lunsford, D. Cain, K. R. Watts, S. G. Robson, R. L. Tobin, R. W. Teller, P. A. Schneider, Jr., and M. J. Gearhart. 1987. Colorado ground-water quality. U.S. Geol. Surv. Open-File Rep. 87-0716. U.S. Gov. Print. Office, Washington, DC.

Hem, J. D. 1992. Study and interpretation of the chemical characteristics of natural water. 3rd ed. U.S. Geol. Surv. Water-Supply Pap. 2254. U.S. Gov. Print. Office, Washington, DC.

Kasenow, M. 2001. Applied groundwater hydrology and well hydraulics. 2nd ed. Water Resources Publications, LLC, Highlands Ranch, CO.

Krider, James H. (ed.) 1992. Agricultural waste management field handbook. USDA-SCS Nat. Eng. Handb. 210-AWMFH, 4/92. U.S. Gov. Print Office, Washington, DC.

Moravec, G. F. 1998. Personal Communication. WQCD, CDPHE, Denver, CO.

Novotny, Vladimir and Harvey Olem. 1994. Water quality: prevention, identification, and management of diffuse pollution. Van Nostrand Reinhold, New York.

Palmer, C. M. 1992. Principles of contaminant hydrogeology. Lewis Publishers, Inc., Chelsea, MI.

Pearl, Richard Howard. 1974. Geology of ground water resources in Colorado. Spec. Publ. 4, Colo. Geol. Surv., Dep. of Nat. Resour., Denver, CO.

Rail, C. D. 1989. Groundwater contamination: Sources, control, and preventive measures. Technomic Publishing Co., Inc., Lancaster, PA.

Robson, S. G. 1989. Alluvial and bedrock aquifers of the Denver Basin – eastern Colorado's dual ground-water resource. U.S. Geol. Surv. Water-Supply Pap. 2302. U.S. Gov. Print. Office, Washington, DC.

Safe Drinking Water Act of 1986. Statutes at Large. C. PL 99-339 (1989).

Safe Drinking Water Act of 1974. Statutes at Large. LXXXVIII. PL 93-523 (1976).

Stone, W. J. 1999. Hydrogeology in practice: A guide to characterizing groundwater systems. Prentice Hall, Upper Saddle River, NJ.

Sposito, G. 1989. The chemistry of soils. Oxford University Press, New York.

University of Colorado at Boulder. 2002. Sources of water. University Libraries. (Available online at http://www.colorado.edu/libraries/govpubs/colonumb/watersrc.htm.) (Verified 29 Apr. 2002.)

U. S. Geological Survey. 1998. NWIS Database: 1990-98. Denver, CO.

U. S. Environmental Protection Agency. 1998. STORET Database: 1990-98. Denver, CO.

Williams, Jr., R. S. and S. E. Hammond. 1989. Selected water-quality characteristics and flow of ground water in the San Luis Basin, including the Conejos River Subbasin, Colorado and New Mexico. U.S. Geol. Surv. Water-Resour. Invest. Rep. 89-4040. U.S. Gov. Print. Office, Washington, DC.

APPENDIX A

SOUTH PLATTE RIVER BASIN

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Unknown)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U. S. ENVIRONMENTAL PROTECTION AGENCY STORET DATABASE, 1990-1998							
SP/STOR-01	3.937260E+14	122K/RKDL	178	39.623892	103.881948	ARAPAHOE	*
SP/STOR-02	3.939580E+14	124E/OCN	267	39.666115	104.673059	ARAPAHOE	*
SP/STOR-03	3.938430E+14	111V/LFL	332	39.645281	104.673338	ARAPAHOE	*
SP/STOR-04	3.93207E+14(a)	*	207	39.553059	103.905004	ELBERT	*
SP/STOR-05	3.93207E+14(b)	*	283	39.557504	103.903338	ELBERT	*

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Sum of Constituents, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U.S. GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATIONS REPORT 97-4091							
Site C01(13-Aug-96)	SC00173233BCBC	*	33	In Report	In Report	BOULDER	*
Site C79(15-Aug-96)	SC00107125DACAU	*	89	In Report	In Report	BOULDER	*
Site C07(13-Aug-96)	SC00107213CBBA	*	155	In Report	In Report	BOULDER	*
Site C09(13-Aug-96)	SC00107320ADBB	*	147	In Report	In Report	BOULDER	*
Site C31(21-Aug-96)	SB00107015BBCB	*	379	In Report	In Report	BOULDER	*
Site C41(8-Aug-96)	SB00207020DCCC	*	361	In Report	In Report	BOULDER	*
Site C46(5-Aug-96)	SC00107001 3CDAA	*	176	In Report	In Report	BOULDER	*
Site C52(14-Aug-96)	SB00207134DCCC	*	264	In Report	In Report	BOULDER	*
Site C55(21-Aug-96)	SB00107127DBCD	*	237	In Report	In Report	BOULDER	*
Site C58(3-Sep-96)	SB00107111AADA	*	252	In Report	In Report	BOULDER	*
Site C70(19-Aug-96)	SC00107012ACCC	*	269	In Report	In Report	BOULDER	*
Site C77(7-Aug-96)	SB00106916BCBC	*	209	In Report	In Report	BOULDER	*
Site C89(3-Sep-96)	SC00107021BDAB	*	179	In Report	In Report	BOULDER	*

SOUTH PLATTE RIVER BASIN, cont.

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Residue at 180 °C, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U.S. GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATIONS REPORT 97-4091							
Site C01(13-Aug-96)	SC0017323BCBC	*	44	In Report	In Report	BOULDER	*
Site C79(15-Aug-96)	SC00107125DACAU	*	90	In Report	In Report	BOULDER	*
Site C07(13-Aug-96)	SC00107213CBBA	*	149	In Report	In Report	BOULDER	*
Site C09(13-Aug-96)	SC00107320ADBB	*	150	In Report	In Report	BOULDER	*
Site C31(21-Aug-96)	SB00107015BBCB	*	391	In Report	In Report	BOULDER	*
Site C41(8-Aug-96)	SB00207020DCCC	*	367	In Report	In Report	BOULDER	*
Site C46(5-Aug-96)	SC001070013CDAA	*	175	In Report	In Report	BOULDER	*
Site C52(14-Aug-96)	SB00207134DCCC	*	302	In Report	In Report	BOULDER	*
Site C55(21-Aug-96)	SB00107127DBCD	*	238	In Report	In Report	BOULDER	*
Site C58(3-Sep-96)	SB00107111AADA	*	275	In Report	In Report	BOULDER	*
Site C70(19-Aug-96)	SC00107012ACCC	*	273	In Report	In Report	BOULDER	*
Site C77(7-Aug-96)	SB00106916BCBC	*	220	In Report	In Report	BOULDER	*
Site C89(3-Sep-96)	SC00107021BDAB	*	178	In Report	In Report	BOULDER	*

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Gravimetric)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
WQCD MONITORING ACTIVITIES: SOUTH PLATTE RIVER ALLUVIAL AQUIFER, 1992-1993							
SP92-06A	*	ALLUVIAL	370	*	*	ADAMS	*
SP92-76	*	ALLUVIAL	150	*	*	WASHINGTON	*
SP92-84	*	ALLUVIAL	230	*	*	LOGAN	*
SP92-94A	*	ALLUVIAL	300	*	*	SEDWICK	*

SOUTH PLATTE RIVER BASIN, cont.							
REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Unknown)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U. S. GEOLOGICAL SURVEY NWIS DATABASE, 1992-1997							
17-Aug-95	XLN-18	*	209	40.0324	105.201201	BOULDER	*
25-Jul-95	XLN-4	CRYSTALLINE	403	39.5314	105.281001	GILPIN	180.00
11-Sep-95	XLN-27	CRYSTALLINE	141	39.3245	105.155000	JEFFERSON	125.00
8-Dec-92	DUBOIS-8	*	143	40.1841	104.432301	WELD	*

ARKANSAS RIVER BASIN							
REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Sum of Constituents, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet) (depth to bottom of sampling level)
U. S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2381-D, 1988-1989							
U01(18-Jul-88)	SC01406619DBC1	ALLUVIAL	323	In Report	In Report	*	15.30
U01(27-Jul-89)	SC01406619DBC1	ALLUVIAL	249	In Report	In Report	*	15.30
U03(21-Jul-88)	SC01406632AAA1	ALLUVIAL	366	In Report	In Report	*	57.50
U03(13-Feb-89)	SC01406632AAA1	ALLUVIAL	363	In Report	In Report	*	57.50
U09(20-Jul-88)	SC01506602CCC1	ALLUVIAL	284	In Report	In Report	*	39.80
U09(30-Jan-89)	SC01506602CCC1	ALLUVIAL	297	In Report	In Report	*	39.80
U09D(20-Jul-88)	SC01506602CCC2	ALLUVIAL	275	In Report	In Report	*	53.20
U11(5-Aug-88)	SC01506611BDC2	ALLUVIAL	318	In Report	In Report	*	54.20

ARKANSAS RIVER BASIN, cont.

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Sum of Constituents, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet) (depth to bottom of sampling level)
U. S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2381-D, 1988-1989, cont.							
U11(24-Feb-89)	SC01506611BDC2	ALLUVIAL	300	In Report	In Report	*	54.20
U11D(5-Aug-88)	SC01506611BDC3	ALLUVIAL	317	In Report	In Report	*	67.00
U12(8-Aug-88)	SC01506611CDD1	ALLUVIAL	363	In Report	In Report	*	44.00
U12(15-Feb-89)	SC01506611CDD1	ALLUVIAL	492	In Report	In Report	*	44.00
U12D(8-Aug-88)	SC01506611CDD2	ALLUVIAL	417	In Report	In Report	*	56.70
U14(9-Aug-88)	SC01506613CBD1	ALLUVIAL	462	In Report	In Report	*	45.50
U14(23-Feb-89)	SC01506613CBD1	ALLUVIAL	446	In Report	In Report	*	45.50
U14D(9-Aug-88)	SC01506613CBD2	ALLUVIAL	421	In Report	In Report	*	71.60
U19D(21-Jul-88)	SC01506624DBD3	ALLUVIAL	392	In Report	In Report	*	47.70

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Gravimetric)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
WQCD MONITORING ACTIVITIES: ARKANSAS RIVER VALLEY ALLUVIAL AQUIFER, 1994-1995							
AK94-005	*	ALLUVIAL	365	*	*	*	*
AK94-058	*	ALLUVIAL	460	*	*	*	*

ARKANSAS RIVER BASIN, cont.							
REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Sum of Constituents, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U. S. GEOLOGICAL SURVEY WATER-INVESTIGATIONS REPORT 88-4017							
8-Aug-84	SC-12-63-36ACC	ALLUVIAL	230	*	*	EL PASO	*
7-Aug-84	SC-13-62-19CDB	ALLUVIAL	230	*	*	EL PASO	*
7-Aug-84	SC-13-62-30ACC1	ALLUVIAL	250	*	*	EL PASO	*
7-Aug-84	SC-13-62-31ACC	ALLUVIAL	220	*	*	EL PASO	*
10-Aug-84	SC-13-63-34ABB	ALLUVIAL	220	*	*	EL PASO	*
7-Aug-84	SC-14-62-05BBB	ALLUVIAL	230	*	*	EL PASO	*
7-Aug-84	SC-14-62-05CAA	ALLUVIAL	230	*	*	EL PASO	*
10-Aug-84	SC-14-62-31BAA	ALLUVIAL	180	*	*	EL PASO	*
8-Aug-84	SC-15-62-18ACB	ALLUVIAL	320	*	*	EL PASO	*
7-Aug-84	SC-15-63-10DCC	ALLUVIAL	180	*	*	EL PASO	*
8-Aug-84	SC-12-62-30BDB	ALLUVIAL	244	*	*	EL PASO	*
8-Aug-84	SC-12-62-30CDC	ALLUVIAL	237	*	*	EL PASO	*
9-Aug-84	SC-12-63-22BBB	ALLUVIAL	316	*	*	EL PASO	*
10-Aug-84	SC-13-62-16AAB	ALLUVIAL	401	*	*	EL PASO	*
10-Aug-84	SC-13-62-21BDD	ALLUVIAL	210	*	*	EL PASO	*
16-Aug-84	SC-13-63-01CCC	ALLUVIAL	171	*	*	EL PASO	*
9-Aug-84	SC-13-63-06DAA	ALLUVIAL	321	*	*	EL PASO	*
9-Aug-84	SC-13-63-12CDB	ALLUVIAL	195	*	*	EL PASO	*
13-Aug-84	SC-13-63-14ABB	ALLUVIAL	257	*	*	EL PASO	*
10-Aug-84	SC-13-63-22ADB	ALLUVIAL	353	*	*	EL PASO	*
16-Aug-84	SC-14-62-05ACD	ALLUVIAL	233	*	*	EL PASO	*
10-Aug-84	SC-14-62-08CCB	ALLUVIAL	193	*	*	EL PASO	*
7-Aug-84	SC-14-62-32BBA	ALLUVIAL	220	*	*	EL PASO	*
9-Aug-84	SC-14-63-03-DDC	ALLUVIAL	179	*	*	EL PASO	*
10-Aug-84	SC-14-63-12DCD	ALLUVIAL	200	*	*	EL PASO	*
10-Aug-84	SC-14-63-13-DAA2	ALLUVIAL	196	*	*	EL PASO	*
7-Aug-84	SC-14-63-36AAB	ALLUVIAL	222	*	*	EL PASO	*
7-Aug-84	SC-15-63-01AAA	ALLUVIAL	204	*	*	EL PASO	*
7-Aug-84	SC-15-63-12DCC	ALLUVIAL	199	*	*	EL PASO	*
24-Jul-84	SC-15-63-24DAB	ALLUVIAL	349	*	*	EL PASO	*
24-Jul-84	SC-15-63-25BBA	ALLUVIAL	223	*	*	EL PASO	*
8-Aug-84	SC-15-63-26BAB	ALLUVIAL	235	*	*	EL PASO	*

ARKANSAS RIVER BASIN, cont.							
REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Sum of Constituents, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U. S. GEOLOGICAL SURVEY WATER-INVESTIGATIONS REPORT 94-4118							
01-Aug-91	SC01506614BBA	ALLUVIAL	498	38 45 03N	104 45 16W	EL PASO	*
31-Jul-91	SC01506610ADB1	ALLUVIAL	333	38 45 40N	104 45 38W	EL PASO	*
30-Jul-91	SC01506624DBD2	ALLUVIAL	342	38 43 39N	104 43 35W	EL PASO	*
18-Aug--92	SC01506624DBD2	ALLUVIAL	372	38 43 39N	104 43 35W	EL PASO	*
09-Aug-91	SC01506624BAD1	ALLUVIAL	418	38 44 07N	104 43 48W	EL PASO	*
26-Aug-92	SC01506624BAD1	ALLUVIAL	396	38 44 07N	104 43 48W	EL PASO	*
08-Aug-91	SC01506613CDA	ALLUVIAL	318	38 44 22N	104 43 52W	EL PASO	*
25-Aug-92	SC01506613CDA	ALLUVIAL	335	38 44 22N	104 43 52W	EL PASO	*
14-Aug-91	SC01506613CBD2	ALLUVIAL	388	38 44 33N	104 44 07W	EL PASO	*
20-Aug-92	SC01506613CBD2	ALLUVIAL	381	38 44 33N	104 44 07W	EL PASO	*
8-Aug-91	SC01506614AAD	ALLUVIAL	277	38 44 58N	104 44 26W	EL PASO	*
25-Aug-92	SC01506614AAD	ALLUVIAL	312	38 44 58N	104 44 26W	EL PASO	*
1-Aug-91	SC01506611CDD2	ALLUVIAL	360	38 45 13N	104 44 53W	EL PASO	*
19-Aug-92	SC01506611CDD2	ALLUVIAL	381	38 45 13N	104 44 53W	EL PASO	*
8-Aug-91	SC01506611CaD	ALLUVIAL	239	38 45 24N	104 44 51W	EL PASO	*
25-Aug-92	SC01506611CaD	ALLUVIAL	285	38 45 24N	104 44 51W	EL PASO	*
2-Aug-91	SC01506611BDC3	ALLUVIAL	252	38 45 34N	104 45 03W	EL PASO	*
21-Aug-92	SC01506611BDC3	ALLUVIAL	276	38 45 34N	104 45 03W	EL PASO	*
6-Aug-91	SC01506611BCD2	ALLUVIAL	217	38 45 35N	104 45 08W	EL PASO	*
21-Aug-92	SC01506611BCD2	ALLUVIAL	270	38 45 35N	104 45 08W	EL PASO	*
8-Aug-91	SC01506611BCB	ALLUVIAL	252	38 45 43N	104 45 18W	EL PASO	*
8-Aug-91	SC01506611BBB2	ALLUVIAL	243	38 45 53N	104 45 18W	EL PASO	*
25-Aug-92	SC01506611BBB2	ALLUVIAL	263	38 45 53N	104 45 18W	EL PASO	*
8-Aug-91	SC01506610AAB2	ALLUVIAL	365	38 45 58N	104 45 39W	EL PASO	*
19-Aug-92	SC01506610AAB2	ALLUVIAL	374	38 45 58N	104 45 39W	EL PASO	*
9-Aug-91	SC01506602CCC2	ALLUVIAL	237	38 46 04N	104 45 15W	EL PASO	*
21-Aug-92	SC01506602CCC2	ALLUVIAL	277	38 46 04N	104 45 15W	EL PASO	*
8-Aug-91	SC01506603DDB	ALLUVIAL	372	38 46 10N	104 45 35W	EL PASO	*
25-Aug-92	SC01506603DDB	ALLUVIAL	405	38 46 10N	104 45 35W	EL PASO	*
7-Aug-91	SC01506604AAA	ALLUVIAL	427	38 46 53N	104 46 36W	EL PASO	*
14-Aug-91	SC01406633DBB1	ALLUVIAL	469	38 47 18N	104 46 58W	EL PASO	*
20-Aug-92	SC01406633DBB1	ALLUVIAL	477	38 47 18N	104 46 58W	EL PASO	*
13-Aug-91	SC01406632AAA1	ALLUVIAL	292	38 47 43N	104 47 45W	EL PASO	*

ARKANSAS RIVER BASIN, cont.

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Sum of Constituents, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U. S. GEOLOGICAL SURVEY WATER-INVESTIGATIONS REPORT 94-4118, cont.							
20-Aug-92	SC01406632AAA1	ALLUVIAL	390	38 47 43N	104 47 45W	EL PASO	*
18-Nov-91	SC01506612CDC	ALLUVIAL	453	38 45 09N	104 43 59W	EL PASO	*
21-Aug-92	SC01506612CDC	ALLUVIAL	431	38 45 09N	104 43 59W	EL PASO	*
9-Aug-91	SC01506612ABA	ALLUVIAL	283	38 45 53	104 43 29W	EL PASO	*
9-Aug-91	SC01506610DDB	ALLUVIAL	287	38 46 10N	104 43 24W	EL PASO	*
26-Aug-92	SC01506610DDB	ALLUVIAL	335	38 46 10N	104 43 24W	EL PASO	*
12-Aug-91	SC01506602BDC	ALLUVIAL	379	38 46 28N	104 45 08W	EL PASO	*
27-Aug-92	SC01506602BDC	ALLUVIAL	383	38 46 28N	104 45 08W	EL PASO	*
13-Aug-91	SC01506603AAD	ALLUVIAL	392	38 46 39N	104 45 28W	EL PASO	*
13-Aug-91	SC01506601BBD	ALLUVIAL	280	38 46 42N	104 44 01W	EL PASO	*
26-Aug-92	SC01506601BBD	ALLUVIAL	309	38 46 42N	104 44 01W	EL PASO	*
13-Aug-91	SC01506603ABA	ALLUVIAL	331	38 46 48N	104 45 45W	EL PASO	*
20-Aug-92	SC01506603ABA	ALLUVIAL	360	38 46 48N	104 45 45W	EL PASO	*
12-Aug-91	SC01506602BBB	ALLUVIAL	285	38 46 53N	104 45 19W	EL PASO	*
28-Aug-92	SC01506602BBB	ALLUVIAL	345	38 46 53N	104 45 19W	EL PASO	*
25-Nov-91	SC01406635CaA	ALLUVIAL	340	38 47 19N	104 44 47W	EL PASO	*
25-Nov-91	SC01406635CaA	ALLUVIAL	341	38 47 19N	104 44 47W	EL PASO	*
26-Aug-92	SC01406635CaA	ALLUVIAL	284	38 47 19N	104 44 47W	EL PASO	*

RIO GRAND RIVER BASIN							
REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Gravimetric)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
WQCD MONITORING ACTIVITIES: SAN LUIS VALLEY UNCONFINED AQUIFER, 1993							
		SAN LUIS VALLEY:					
21-Jun-93	SL93-1	UNCONFINED	402	*	*	SAGUACHE	*
21-Jun-93	SL93-2	UNCONFINED	287	*	*	SAGUACHE	101.00
14-Jun-93	SL93-4	UNCONFINED	256	*	*	SAGUACHE	100.00
14-Jun-93	SL93-4A	UNCONFINED	312	*	*	SAGUACHE	100.00
14-Jun-93	SL93-5	UNCONFINED	252	*	*	SAGUACHE	40.00
14-Jun-93	SL93-6	UNCONFINED	372	*	*	SAGUACHE	79.00
14-Jun-93	SL93-7	UNCONFINED	347	*	*	SAGUACHE	75.00
15-Jun-93	SL93-8	UNCONFINED	203	*	*	SAGUACHE	*
15-Jun-93	SL93-9	UNCONFINED	129	*	*	SAGUACHE	100.00
15-Jun-93	SL93-10	UNCONFINED	191	*	*	SAGUACHE	*
23-Jun-93	SL93-11	UNCONFINED	123	*	*	SAGUACHE	90.00
22-Jun-93	SL93-12	UNCONFINED	252	*	*	SAGUACHE	100.00
2-Aug-93	SL93-13	UNCONFINED	255	*	*	SAGUACHE	79.00
22-Jun-93	SL93-14	UNCONFINED	346	*	*	SAGUACHE	100.00
15-Jun-93	SL93-18	UNCONFINED	460	*	*	SAGUACHE	*
15-Jun-93	SL93-21	UNCONFINED	322	*	*	SAGUACHE	40.00
22-Jun-93	SL93-22	UNCONFINED	111	*	*	RIO GRANDE	*
28-Jun-93	SL93-23	UNCONFINED	137	*	*	RIO GRANDE	100.00
28-Jun-93	SL93-24	UNCONFINED	163	*	*	RIO GRANDE	60.00
3-Aug-93	SL93-25	UNCONFINED	172	*	*	RIO GRANDE	96.00
30-Jun-93	SL93-26	UNCONFINED	189	*	*	RIO GRANDE	81.00
3-Aug-93	SL93-29	UNCONFINED	156	*	*	RIO GRANDE	52.00
22-Jun-93	SL93-30	UNCONFINED	420	*	*	RIO GRANDE	*
10-Aug-93	SL93-31	UNCONFINED	292	*	*	RIO GRANDE	100.00
3-Aug-93	SL93-32	UNCONFINED	155	*	*	RIO GRANDE	100.00
3-Aug-93	SL93-32A	UNCONFINED	221	*	*	RIO GRANDE	70.00
28-Jun-93	SL93-33	UNCONFINED	265	*	*	RIO GRANDE	53.00
29-Jun-93	SL93-34	UNCONFINED	329	*	*	RIO GRANDE	79.00
10-Aug-93	SL93-36	UNCONFINED	289	*	*	RIO GRANDE	55.00
30-Jun-93	SL93-37	UNCONFINED	485	*	*	RIO GRANDE	44.00
3-Aug-93	SL93-40	UNCONFINED	296	*	*	RIO GRANDE	40.00
3-Aug-93	SL93-42	UNCONFINED	184	*	*	RIO GRANDE	30.00

RIO GRAND RIVER BASIN, cont.

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Gravimetric)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
WQCD MONITORING ACTIVITIES: SAN LUIS VALLEY UNCONFINED AQUIFER, 1993 (cont.)							
6-Jul-93	SL93-67	UNCONFINED	303	*	*	ALAMOSA	31.00
7-Jun-93	SL93-71	UNCONFINED	231	*	*	CONEJOS	40.00
7-Jun-93	SL93-74	UNCONFINED	127	*	*	CONEJOS	20.00
6-Jul-93	SL93-77	UNCONFINED	183	*	*	CONEJOS	104.00
8-Jun-93	SL93-79	UNCONFINED	138	*	*	CONEJOS	26.00
8-Jun-93	SL93-80	UNCONFINED	214	*	*	CONEJOS	30.00
8-Jun-93	SL93-81	UNCONFINED	119	*	*	CONEJOS	*
1-Jun-93	SL93-82	UNCONFINED	269	*	*	COSTILLA	*
1-Jun-93	SL93-83	UNCONFINED	285	*	*	COSTILLA	108.00
6-Jul-93	SL93-85	UNCONFINED	451	*	*	COSTILLA	*
1-Jun-93	SL93-86	UNCONFINED	211	*	*	COSTILLA	*
1-Jun-93	SL93-87	UNCONFINED	443	*	*	COSTILLA	100.00
1-Jun-93	SL93-88	UNCONFINED	226	*	*	COSTILLA	4.00
1-Jun-93	SL93-89	UNCONFINED	373	*	*	COSTILLA	79.00
1-Jun-93	SL93-90	UNCONFINED	273	*	*	COSTILLA	60.00

REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Residue at 180 °C, Dissolved)	LATITUDE	LONGITUDE	COUNTY	Total WELL DEPTH (feet)
U. S. GEOLOGICAL SURVEY WATER-INVESTIGATIONS REPORT 96-4144							
13-Sep-93	MAP REFERENCE 4	UNCONFINED	77	374307	1061350	*	40.00
10-Sep-93	MAP REFERENCE 5	UNCONFINED	92	374515	1061921	*	44.80
9-Sep-93	MAP REFERENCE 6	UNCONFINED	75	375037	1061234	*	19.50
12-Sep-93	MAP REFERENCE 13	UNCONFINED	86	370936	1060105	*	24.90
1-Sep-93	MAP REFERENCE 29	UNCONFINED	88	370936	1060007	*	18.30

RIO GRAND RIVER BASIN, cont.							
REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Solids, Residue at 180 °C, Dissolved)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
U. S. GEOLOGICAL SURVEY WATER-INVESTIGATIONS REPORT 96-4144, cont.							
8-Sep-93	MAP REFERENCE 1	UNCONFINED	294	372849	1060902	*	15.00
7-Sep-93	MAP REFERENCE 2	UNCONFINED	102	373849	1061245	*	28.56
15-Sep-93	MAP REFERENCE 3	UNCONFINED	141	374153	1061532	*	34.50
9-Sep-93	MAP REFERENCE 7	UNCONFINED	387	374757	1060853	*	17.60
13-Sep-93	MAP REFERENCE 8	UNCONFINED	292	374359	1060855	*	24.20
10-Sep-93	MAP REFERENCE 9	UNCONFINED	376	374217	1060825	*	24.75
7-Sep-93	MAP REFERENCE 10	UNCONFINED	354	373849	1060743	*	24.80
16-Sep-93	MAP REFERENCE 12	UNCONFINED	175	371914	1060429	*	44.63
8-Sep-93	MAP REFERENCE 14	UNCONFINED	198	372311	1060325	*	19.35
26-Aug-93	MAP REFERENCE 15	UNCONFINED	375	373323	1060250	*	19.85
2-Sep-93	MAP REFERENCE 16	UNCONFINED	282	374101	1060356	*	19.36
30-Aug-93	MAP REFERENCE 17	UNCONFINED	151	374423	1060428	*	15.89
31-Aug-93	MAP REFERENCE 18	UNCONFINED	257	375154	1060211	*	14.65
31-Aug-93	MAP REFERENCE 19	UNCONFINED	142	374825	1060213	*	19.70
30-Aug-93	MAP REFERENCE 20	UNCONFINED	144	374310	1060324	*	14.90
29-Aug-93	MAP REFERENCE 21	UNCONFINED	364	373916	1060217	*	19.70
27-Aug-93	MAP REFERENCE 22	UNCONFINED	113	373611	1060145	*	24.23
27-Aug-93	MAP REFERENCE 25	UNCONFINED	423	373527	1055542	*	28.56
31-Aug-93	MAP REFERENCE 30	UNCONFINED	238	375054	1060134	*	14.40
24-Aug-93	MAP REFERENCE 34	UNCONFINED	154	373732	1055256	*	18.50
12-Sep-93	MAP REFERENCE 35	UNCONFINED	262	372233	1053511	*	19.90

RIO GRAND RIVER BASIN, cont.							
REFERENCE ID	**REFERENCE ID**	**AQUIFER**	**total diss. solids TDS (mg/L) (Lab Method: Solids, Sum of Constituents, Dissolved)**	**LATITUDE**	**LONGITUDE**	**COUNTY**	**WELL DEPTH (feet) (Depth to Water)**
U. S. GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATION REPORT 89-4040							
RG-120(30-Jul-80)	NA04301109BBA	*	97	38 00 02	105 46 23	SAGUACHE	180.00
RG-14(4-Jun-82)	NA03300935DBB	*	130	37 02 57	105 55 39	CONEJOS	225.00
RG-15(4-Jun-82)	NA03300936DBB	*	140	37 03 24	105 56 12	CONEJOS	223.00
RG-17(4-Jun-82)	NA03300933CAB2	*	170	37 03 26	105 59 43	CONEJOS	235.00
RG-30(23-Jul-80)	CC03207404AAA	*	290	37 17 58	105 39 20	COSTILLA	392.00
RG35(22-Jul-80)	SC3007436BDD	*	220	37 23 45	105 36 37	COSTILLA	340.00
RG-38(22-Jul-80)	SC3007327ABA	*	170	37 24 17	105 31 26	COSTILLA	240.00
RG-49(31-Jul-80)	NA03801134DDA1	*	440	37 29 29	105 44 54	RIO GRANDE	29.50
RG-86(25-Mar-81)	NA04000931CCC	*	200	37 39 44	106 02 20	ALAMOSA	28.00
RG-88(8-May-80)	NA03901106BBB	*	460	37 39 47	105 49 07	ALAMOSA	27.00
RG-89(31-Jul-80)	NA04000932DAA	*	430	37 39 51	106 00 20	ALAMOSA	77.00
RG-90(8-May-80)	NA04001232BAA	*	270	37 40 12	105 41 04	ALAMOSA	30.00
RG-117(30-Jul-80)	NA04301114DAD	*	180	37 58 41	105 43 35	SAGUACHE	250.00
RG-119(31-Jul-80)	NA04300907BBB2	*	320	37 59 39	106 02 01	SAGUACHE	27.00
RG-130(29-Jul-80)	NA04700926CCB	*	160	38 17 42	105 57 18	SAGUACHE	99.00

WEST SLOPE: COLORADO							
REFERENCE ID	**REFERENCE ID**	**REFERENCE ID**	**total diss. solids TDS (mg/L) (Lab Method: 70301)**	**LATITUDE**	**LONGITUDE**	**COUNTY**	**WELL DEPTH (feet)**
U. S. GEOLOGICAL SURVEY NWIS DATABASE, 1992-1997							
29-Sep-97	WINTER PARK-	VISTOR CENTER	61	39.5507	105.470200	GRAND	*
5-May-97	STEPHENS PARK	*	199	39.3718	106.253000	EAGLE	*
4-Sep-97	SC00608934BAB00	FARNUM	387	39.2850	107.184900	GARFIELD	*
2-Sep-97	SC00107519AAC00-	FRASER MUN	118	39.5658	105.485400	GRAND	*
21-May-97	TABERNASH,	CNTY ROAD 522	181	39.5929	105.510300	GRAND	*
17-Sep-97	UCOL NAWQA SUS-	CEBOLLA CRE	168	38.1804	107.061000	GUNNISON	*
28-Aug-97	NB04900109CA00-	SPANN	164	38.3121	106.583000	GUNNISON	*
13-May-97	SKYLAND RANCH	*	114	38.5124	106.562200	GUNNISON	*

REFERENCE ID	**REFERENCE ID**	**AQUIFER**	**total diss. solids TDS (mg/L) (Lab Method: Unknown)**	**LATITUDE**	**LONGITUDE**	**COUNTY**	**WELL DEPTH (feet) (Depth to Water)**
U.S. GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATIONS REPORT 84-4185							
9-Sep-81	SC01209515ACC1	GLACIAL DEPOSITS	79	*	*	DELTA	*
9-Sep-81	SC1209503DBD1	GLACIAL DEPOSITS	46	*	*	DELTA	*
10-Sep-80	SC01209509AAB1	ALLUVIUM	62	*	*	DELTA	112.10
22-Aug-81	SC01209607CBC1	*	49	*	*	MESA	*
24-Aug-81	SC01209710DAB1	ALLUVIUM	85	*	*	MESA	*
11-Sep-80	SC01109431CDC1	GREEN RIVER FORM.	240	*	*	DELTA	49.40
10-Sep-80	SC01109431DCC1	GREEN RIVER FORM.	120	*	*	DELTA	7.00
26-Aug-81	SC01309406BAC1	MESAVERDE FORM.	200	*	*	DELTA	26.00
14-Aug-81	SC01309415AAB1	MESAVERDE FORM.	470	*	*	DELTA	236.45
26-Aug-81	SC01309418DBA1	MESAVERDE FORM.	180	*	*	DELTA	31.00
30-Jul-81	SC01309512ACC1	MESAVERDE FORM.	380	*	*	DELTA	36.77
16-Jul-81	SC01309512BDC1	MESAVERDE FORM.	440	*	*	DELTA	20.17
29-Aug-81	NB05101618DBD1	MORRISON FORM.	240	*	*	MESA	*
29-Aug-81	NB05101629DBD1	MORRISON FORM.	240	*	*	MESA	*
24-Aug-81	SC1310123ACD1	DAKOTA SANDSTONE	280	*	*	MESA	*
24-Aug-81	SC01310124BBC1	ALLUVIUM	300	*	*	MESA	*
2-Jul-81	UC00100126BBD1	*	340	*		MESA	

WEST SLOPE: COLORADO							
REFERENCE ID	REFERENCE ID	AQUIFER	total diss. solids TDS (mg/L) (Lab Method: Gravimetric)	LATITUDE	LONGITUDE	COUNTY	WELL DEPTH (feet)
WQCD MONITORING ACTIVITIES: WEST SLOPE OF COLORADO, 1998							
WS98-033	*	*	89	*	*	ROUTT	*
WS98-027	*	*	401	*	*	ROUTT	*
WS98-029	*	*	248	*	*	ROUTT	*
WS98-034	*	*	349	*	*	ROUTT	*
WS98-039	*	*	180	*	*	MOFFAT	*
WS98-045	*	*	478	*	*	EAGLE	*
WS98-046	*	*	331	*	*	EAGLE	*
WS98-049	*	*	444	*	*	GARFIELD	*
WS98-053	*	*	372	*	*	PITKIN	*
WS98-061	*	*	312	*	*	DELTA	*
WS98-063	*	*	298	*	*	DELTA	*
WS98-071	*	*	409	*	*	MONTROSE	*
WS98-081	*	*	449	*	*	DOLORES	*
WS98-084	*	*	142	*	*	MONTEZUMA	*
WS98-085	*	*	356	*	*	LA PLATA	*
WS98-086	*	*	457	*	*	LA PLATA	*
WS98-087	*	*	369	*	*	MONTEZUMA	*