

El Paso County Groundwater Quality Study Phase 1

PREPARED FOR:
El Paso County Groundwater
Quality Study Committee

For Presentation to
El Paso County Board of
County Commissioners



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Executive Summary

This report documents the work, findings, analysis, and recommendations of the Colorado Geological Survey (CGS) in executing the scope of work commissioned by El Paso County, through the Groundwater Study Committee, established in reference to Resolution No. 09-202. The subject of this report is the groundwater quality of the alluvial aquifer within the Upper Black Squirrel Creek (UBSC) basin (Figure 1.1). The Phase 1 study objectives are to characterize the current groundwater quality in the alluvial aquifer and determine whether there is a correlation between existing and future land uses and groundwater quality. The scope of work for Phase 1 was finalized in January 2010, and the County contracted with CGS to perform the work.

The current study is limited to evaluation of existing water quality data for groundwater in the alluvial aquifer system of the Upper Black Squirrel Creek Designated Groundwater basin (UBSC basin) of east-central El Paso County, Colorado. As part of the study a literature review identified 34 relevant publications and an annotated bibliography was prepared. Previous published studies indicated that the groundwater was of good quality, but identified nitrate as a contaminant of concern. Water quality data was acquired from a variety of public sources (county, state, and federal) and study cooperators. The data represent 150 samples collected from 72 different wells between 1954 and 2009. Samples collected for water quality analysis within the study area have a limited spatial and temporal distribution. Approximately 80% of the data were collected in the 1980s and 1990s, and the great majority of wells are within three miles of the Ellicott Highway. One of the most important characteristics of this data is the lack of multiple samples from individual locations. The northern and western portions of the UBSC basin where rapid development has occurred and is expected to continue are not represented in the data.

Groundwater chemical analysis data for inorganic compounds, total dissolved solids (TDS), nitrate, metals, organic compounds, and radionuclides were evaluated to characterize the UBSC basin alluvial aquifer's water quality. The groundwater sample data indicate that, where sampled, the water is generally acceptable with respect to drinking water standards; of moderate hardness; and free of pesticides, herbicides, and regulated organic contaminants. At certain times and locations, some water quality parameters were detected at concentrations in violation of primary and secondary drinking water standards including: arsenic, nitrate, pH, TDS, sulfate, and iron. Nitrate values greater than 5.0 mg/L are common in the basin, and suggest that the alluvial water quality has been influenced by sources of nutrient loading.

No clear relationship between land uses and groundwater quality was evident from the available data. Existing UBSC basin land uses evaluated include residential, agricultural, urban, commercial, industrial, military, and unregulated industrial waste disposal. Elevated nitrate concentrations are distributed over parcels associated with residential, dry land farming/grazing, and irrigated agriculture, suggesting localized sources rather than being impacted from categorical land use. Groundwater quality data are lacking in the northwest portion of the basin where the majority of the development is occurring. Consequently, information regarding nitrate concentrations in areas with higher density ISDSs is missing. Elevated TDS values are associated with both dryland farming/grazing land and rural residential land use. Potential contaminant sources associated with future land uses have been summarized in Table 5.1. Anticipated future land uses within the basin are a continuation and expansion of current land uses, primarily consisting of residential development in urban, rural residential and rural development densities with accompanying commercial development. Figure 5.2 summarizes activity nodes and transportation corridors where future development is expected to be concentrated.

Due to the spatial and temporal limitations of the compiled water quality data, this study was only partially successful in meeting the objectives established by the study committee. Unfortunately, there is no groundwater quality data available in the northwest portion of the basin, where urban land uses and ISDSs are concentrated and continued development is expected. Decision makers in El Paso County attempting to assess the vulnerability of the groundwater resource currently lack a complete understanding of the hydrogeology of the aquifer system and the associated anthropogenic effects controlling the source, transport, and fate of potential contaminants. To address this gap, we recommend implementing a Phase 2 investigation focusing on refining our understanding of the groundwater flow system and acquiring the water quality data needed to support and scientifically defend land use planning decisions.

1. Introduction

This report documents the work, findings, analysis, and recommendations of the Colorado Geological Survey in executing the Phase 1 scope of work commissioned by El Paso County, through the Board of County Commissioners, to study the groundwater quality of the alluvial aquifer within the Upper Black Squirrel Creek (UBSC) basin (Figure 1.1). The objectives of this initial phase were to document and characterize the historic and current groundwater quality in the alluvial aquifer and determine whether the water quality was influenced by existing land uses or may be influenced by future land uses. Depending upon the results of this phase of study, a Phase 2 may be necessary consisting of additional data collection and analysis. Phase 3, if warranted, would include additional land use analysis and development of land use regulations.

1.1. Background and Need

In early 2009, the El Paso County Board of County Commissioners held work sessions regarding potential changes to the El Paso County Land Development Code, including those related to groundwater protection. In May 2009, the Board adopted Resolution No. 09-202 which directed staff to initiate a groundwater contamination study, and provided for the formation of a groundwater quality study committee (Committee). A press release was issued on May 26, 2009, inviting participation on the Committee. The Committee consists of 14 voting members representing areas of the scientific community, developmental industry, building industry, agricultural community, and the community at-large. Additionally, the Committee includes 5 non-voting members from the El Paso County staff and the El Paso County Planning Commission. The study objective is to evaluate potential groundwater contamination issues to help participants make informed land use decisions.

Development Services Division staff were directed to report back to the Board with a stakeholder process and list of potential stakeholders. They also provided a study coordinator, Elaine Kleckner, to manage the process. Staff consulted with a number of individuals with technical knowledge of groundwater contamination issues including U.S. Geological Survey (USGS), Colorado Geological Survey (CGS), groundwater management districts, special districts, and governmental agencies and presented a preliminary work plan to the Board on July 9, 2009. The Committee met through the summer and fall of 2009 to refine the scope of work and identify funding partners. Pat Edelman of the USGS Colorado Water Science Center and Ralf Topper of CGS participated in a technical advisory role.

1.2. Scope of Work

The scope of work for Phase 1 was finalized in January 2010 and the Committee voted to recommend to the Board contracting with the Colorado Geological Survey (CGS) to perform the study. USGS personnel would continue to participate in the committee meetings and assist in a technical advisory capacity. Recognizing the diversity of groundwater resources in El Paso County, the Board's desire to obtain results quickly, and the limited funds available, the Committee and the Board of County Commissioners decided to focus the study on the alluvial aquifer of the Upper Black Squirrel Creek (UBSC) basin (Figure 1.2). The approved scope of work was divided into five tasks:

1. Project management, committee coordination and public participation
2. Literature review and data compilation/analysis
3. Identification of potential contaminant sources based on land use
4. Summary of results of Phase 1
5. Report compilation and presentation

In consultation with CGS, the Committee modified the scope of work by addendum; largely to clarify the providers and contractor deliverable requirements. In May 2010, El Paso County entered into agreement with CGS to conduct the study and executed a Memorandum of Understanding to identify the funding commitments for the study. In addition to the county and CGS's match of in-kind services, funding was provided by Cherokee Metropolitan District, Meridian Service Metropolitan District, Sunset Metropolitan District, Upper Black Squirrel Creek Ground Water Management District, and Accretive Investments, Inc. The El Paso County Development Services and Information Technologies departments were instrumental in providing data related to land use and the presence of individual sewage disposal systems (ISDSs).

1.3. Study Limitations

The current study is limited to evaluation of existing water quality data for groundwater in the alluvial aquifer system of the Upper Black Squirrel Creek (UBSC) Designated Groundwater basin of east-central El Paso County, Colorado. The study is intended to document and evaluate the current groundwater quality in the UBSC basin alluvial aquifer and assess the potential for groundwater contamination from existing and future land use. To accomplish this, the CGS has collected existing groundwater quality data from publicly available sources and from study cooperators. The CGS then

evaluated the data with respect to water quality and potential water quality impacts that current and future land uses have had, or are likely to have.

In addition to data provided by the study's utility cooperators, Cherokee Metropolitan District and Meridian Service Metropolitan District, CGS searched publicly available databases and reports for site-specific water quality information. Local, state, and U. S. government sources were queried for relevant data or information. Also, El Paso County issued a press release soliciting water quality data from private landowners and any other interested parties.

All public entities contacted agreed to share relevant groundwater quality data, if available, and the authors are not aware of any other sources of significant data relevant to the current study. No new water-quality sample collection and analysis was performed. CGS collected data from numerous sources, documenting some inconsistencies between data sources. Consequently, it is important to recognize that we discuss and evaluate the chemistry of common constituents in natural groundwater without the benefit of knowing or having documentation of the quality of the data presented. For example, original laboratory reports were seldom available. We compiled the data collected into an internally consistent data set for the analyses presented herein.

1.4. Understanding Water Quality Data

Laboratory analysis of chemical constituents in natural waters is commonly conducted on both the suspended and dissolved solids in the fluid. Suspended solids being insoluble particles remaining dispersed in a liquid. Suspended solids are common in surface water but not in groundwater, as subsurface materials (soil and rock) act as good filters. Consequently, analysis of groundwater and the water quality standards upon which those standards are based focus on concentrations of dissolved constituents. Most of the dissolved constituents in native groundwater are the result of chemical interactions between the water and the geologic materials with which groundwater has been in contact.

Dissolved solids in water come from a variety of sources including the atmosphere and earth materials. The chemical processes occurring between water and its contact environment can also be strongly influenced by biologic activity. In natural systems, precipitation is the source of groundwater. Rain or snow fall may pick up and incorporate atmospheric particles and gases. As the rain or snowmelt flow over the land and percolate into the soil, some of the soil minerals and surface materials, such as

decaying leaves or wood, dissolve into the water and become part of the water's chemistry. As the water percolates to the underlying water table, and moves through pores, within the soil or rock, the dissolved solids content will usually increase until, given enough time, the groundwater reaches a state of chemical equilibrium with the aquifer materials it flows through. The major dissolved constituents in groundwater include: calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, carbonate, and silica. Minor constituents may include: iron, manganese, fluoride, nitrate and other trace elements. Typically the dissolved solids content is relatively low in natural groundwater systems and the types and concentrations of dissolved solids reflect the dominant mineralogy of the aquifer through which the water has flowed. From a land use perspective, poor water quality is typically attributed to contamination from anthropogenic (man-made) sources such as road salt, excess fertilizer, storage tank leaks, or wastewater effluent.

Over the years, a wide variety of units have been used in reporting water analyses. Understanding the units and conventions used in the past is helpful when using the data available in the published literature. Because water is a liquid, concentrations are typically reported as the mass of a given solute per unit volume of water. For example, if one were to stir ten grams, or about 1 and 2/3 teaspoons, of table salt (sodium chloride), into one liter of pure water the mixture would have a salt concentration of "ten grams per liter." Since the concentration of dissolved constituents in most natural waters is generally low, the standard practice in water quality interpretation is to report units of one thousandths of a gram, or milligrams per liter (mg/L). These units can also be considered in terms of a weight basis to obtain "parts per million" values. Historically, the U.S. Geological Survey, and other labs throughout the U.S., reported concentrations in "parts per million (ppm)" (Hem, 1985). The assumption of equivalence between mg/L and ppm is based on unit density for water and is considered reasonable by hydrologists for waters with low dissolved mineral matter and ambient temperatures. For the purposes of this report, dissolved constituent concentrations are reported in the accepted convention of milligrams per liter.

Some metals or organic compounds, such as arsenic or benzene, respectively, have been shown to impact human health at much lower concentrations than one milligram per liter. Such constituents are often measured in concentrations of micrograms per liter ($\mu\text{g/L}$), or the approximation "parts per billion" (ppb).

1.5. Evaluating Contaminant Concentrations

The quality of public drinking water is regulated by the US Environmental Protection Agency (US EPA) and enforced by the Colorado Department of Environmental Health and Environment (CDPHE). These agencies have developed rules and regulations intended to ensure the safety of drinking water supplies by setting numerical standards for the amount of certain constituents (bacteria, dissolved metals, organic chemicals and other compounds) considered harmful. When these constituents are found in water, at concentrations greater than the regulatory Maximum Contaminant Levels (MCLs), they are considered contaminants. MCLs are enforceable health based standards. The MCL is established to be protective of human health as determined by toxicological research.

Some dissolved constituents found in drinking water are not concerns with respect to health but rather produce nuisance issues such as poor taste, offensive odor, skin or tooth discoloration, or staining of laundry and plumbing fixtures. The EPA has set non-enforceable aesthetic guidelines regulating concentration of these contaminants, known as the Secondary Maximum Contaminant Levels (SMCLs). While contaminants have also been defined as an unwanted substance or a substance occurring in concentrations above background levels, the data presented herein are compared with the regulatory limits for both MCLs and SMCLs.

1.6. Sample Location (well) Identification System

Data tables presented in this report use a site identification numbering system based on the U.S. Bureau of Land Management system of land subdivision. The system identifies the survey meridian and the quadrant of the principal meridian in which the well is located, and then identifies the township, range, section and the well's location within the 160-acre quarter section, the 40 acre quarter-quarter section, and the 10 acre quarter- quarter- quarter section. As an example, the location of well SC01306230ACC1 can be determined by reading the identification number from left to right, the (S) indicates the Sixth Principal Meridian Survey, in the southwest quadrant (C), in Township 13 South (013) and Range 62 West (062) , section 30 (30). The last three letters of the well identification indicate the well is located in the southwest quarter (C) of the southwest (C) quarter of the northeast quarter (A). The last three letters of the well identification ("ACC") represent, from left to right, the largest to the smallest area. If more than one well is present in the 10-acre quarter-quarter-quarter section each well is given a numbered suffix. The well in this example is designated as the Number 1 well in the 10-acre

quarter-quarter-quarter section. A graphical depiction of the well identification system is shown in Appendix A.

2. Previous Studies and Literature Review

In the Committee's preliminary work plan a number of publications and data sources were identified for review. Task 2 of the scope of work included the compilation of an annotated bibliography. The annotation includes abstracts for publications, or a short paragraph summary if an abstract is not available. Our literature review identified 34 publications relevant to the current study and an annotated bibliography is presented in Appendix B. Table 2.1 presents a list of the publications and their relevance to this study. Both Table 2.1 and the annotated bibliography are presented in reverse chronological order, under the assumption that the more recent publications have greater relevancy to current land uses and water quality.

Documents reviewed were grouped into the following categories:

- 1) Studies containing data specifically from groundwater sampling performed in the UBSC basin,
- 2) Studies containing research relevant to physical, biological and chemical processes that may affect groundwater quality in the UBSC basin,
- 3) Studies containing research on the general relationship between land use and the potential for groundwater contamination, and
- 4) Studies containing data relevant to USBC basin groundwater quantity and supply.

Previous studies containing data, from groundwater sampling performed in the UBSC basin, were published between 1966 and 2009. These publications range from regional water- resource assessments, which include the UBSC basin, to research specifically focused on the water quality in the UBSC basin. To establish a foundation of previous work conducted specific to the UBSC basin, we provide a brief summary of the results and conclusions published by other investigators.

- The earliest study considered here was by McGovern and Jenkins (1966) who evaluated conditions in the alluvial aquifer in 1964 with respect to future groundwater development. Analyses from three groundwater samples were presented that included results for nitrate and other general chemistry parameters. McGovern and Jenkins predicted declines in water levels due to overdraft pumping of the aquifer and stated *the water quality as being generally good and of a mixed cation bicarbonate type*. The prediction of declining water levels has been validated historically and the water quality finding agrees with the current study.

- Bingham and Klein (1973) evaluated water level declines and groundwater quality in the UBSC basin and observed water level declines of 20 to 35 feet, in part of the UBSC basin, over a seven-year period between 1964 and 1971. They described *overall water quality as good and total dissolved solids (TDS) were observed to increase laterally from the main alluvial channel*. These results agree with what is known about the UBSC basin and what has been observed in the current study.
- Livingston, Klein and Bingham (1976) evaluated water resources of El Paso County including multiple watersheds and estimated the amount of available groundwater in the UBSC basin alluvial aquifer at 350,000 acre-feet. They found the TDS content of groundwater in the UBSC basin to be far lower than other alluvial aquifers in El Paso County. The storage estimate is conservative in comparison with a more recent study indicating approximately 475,000 acre-feet available in the alluvial aquifer (Topper, 2008). *Their conclusions with respect to water quality generally agree with the current study and other more recent studies*.
- Buckles and Watts (1988) evaluated water quality and performed preliminary groundwater flow modeling of the UBSC basin alluvial aquifer. They documented continuing decline of alluvial aquifer water levels and simulated the future effects of groundwater pumping. In 1984, they sampled 36 wells for water quality parameters including nitrate. The report documents that five wells, in the UBSC basin, had nitrate concentrations exceeding drinking water standards. However, at three of these wells, nitrate concentrations were interpreted to be anomalously high because the wells were located near local sources of nitrate loading. *The water quality results of Buckles and Watts (1988) are generally consistent with other studies and the current study*.
- Watts (1995) evaluated the hydraulic connection between the alluvial and bedrock aquifers, documented water level declines in the alluvial and underlying bedrock aquifers, and simulated the physical groundwater flow system. Watts (1995) considered water quality only as an indicator of flow between the two types of aquifers and did not focus on issues relevant to this study. His report, however, provides water quality data for a limited number of wells.

- Brendle (1997) compared nitrate concentrations from two time periods at specific wells to determine whether an observed increasing nitrate concentration trend was localized or typical of the UBSC basin alluvial aquifer in general. Brendle resampled 28 of the 36 wells sampled in 1984 by Buckles and Watts (1988) and performed statistical evaluation of changes in nitrate concentrations over the 12 years. *Brendle found nitrate concentrations to have decreased at eight wells and to have increased at 20 wells.* The average difference in nitrate concentrations over the 12-year period between the two sampling events was -0.18 mg/L. He documented anomalously high decreases in nitrate concentrations (-8 mg/L and -10 mg/L) in two wells. Removal of these two samples from the data set results in an average nitrate concentration difference among the remaining 26 wells of +0.55 mg/L over the 12-year period. *A statistical analysis using a paired t-test found there to be no significant difference in overall nitrate concentrations over the entire UBSC basin. However, if the geographic distribution is considered and the UBSC basin is divided into its northern one-third (10 wells in the north) and southern two-thirds (18 wells in the south), a statistically significant increase in the southern two-thirds of the UBSC Basin is indicated.*
- The Colorado Water Resources Research Institute (CWRRI, 2008) published generalized results of the Agricultural Chemicals and Groundwater Protection Program, a cooperative program between the Colorado Department of Agriculture (CDA), Colorado State University Extension Services (CSUES), and the Water Quality Control Division (WQCD). This program systematically monitored for the presence of agricultural related chemicals in vulnerable aquifers throughout Colorado. As part of the evaluation, the CDA sampled 49 wells in El Paso County, including seven alluvial wells in the UBSC basin, for a range of agricultural chemicals, metals, and general water quality parameters including nitrate. Data from the UBSC basin wells are not presented in the report; however, the data was provided to CGS for the current study by the CDA (Mauch, 2010). *A sample from one well yielded a nitrate concentration of 11.5 mg/L which exceeds the MCL for nitrate. Other than this single nitrate exceedance, sample results indicate generally good water quality for the aquifer at the locations sampled.* The analysis of the seven wells also reported concentrations below laboratory detection limits for 47 different pesticides and agricultural chemicals, and metals concentrations below primary (MCL) and secondary (SMCL) regulatory levels.

- The Colorado Geological Survey (Topper, 2008) performed a study of the UBSC basin alluvial aquifer to evaluate and refine the existing knowledge of the hydrogeology of the alluvial aquifer system for the purposes of assessing the potential for aquifer recharge and storage implementation. Water quality samples were obtained from new monitoring wells installed and hydrogeologic and geologic characterization was performed. The results indicate water from the alluvial aquifer in the UBSC basin is classified as either a sodium calcium-mixed anion or a sodium calcium bicarbonate type. *With few exceptions, the alluvial groundwater was determined to be of very good quality with total dissolved solids concentrations below 500 milligrams per liter.* In four samples cited from the literature, nitrogen compounds were observed to exceed the MCL. Subsequent reevaluation of the nitrate data indicates that data from the original source (McGovern and Jenkins 1966) were uncorrected with respect to reporting nitrate concentrations as nitrogen. This distinction is further discussed in Section 3.
- The Water Quality Control Division of the Colorado Department of Public Health and Environment publishes a status of water quality in Colorado (CDPHE, 2008) on a bi-annual basis. Groundwater monitoring results are collected through the Agricultural Chemicals and Groundwater Protection Program cited previously. The program collaborated with the CSU Cooperative Extension in eastern El Paso County to conduct a reconnaissance investigation of groundwater quality with respect to agricultural chemicals. CSU sampled forty-nine domestic, irrigation, stock watering, and municipal wells in El Paso County. These wells were completed in both the alluvial aquifer and the shallow portions of the Denver Basin bedrock aquifers. *The report concludes “that nitrate contamination does not appear to be a widespread problem based on the results of the reconnaissance investigation”.* However, the report warns against drawing site-specific conclusions due to a lack of sample distribution. *The program did not recommend a follow-up investigation and gave El Paso County a low priority with respect to vulnerability to agricultural chemicals and nitrate.*

Table 2.1
Literature Review Summary

Reference (by date) ¹	UBSC Basin Groundwater Studies	Processes Relevant to Groundwater Quality	Relationship Between Land Use and Groundwater Quality	UBSC Basin Groundwater Quantity and Supply
Rupert and Plummer, 2009		X	X	
CDPHE, 2008	X			
Topper, 2008	X			X
Conn, Segrist and Barber, 2007		X		
Paul, 2007		X		
Paul, Poeter, and Lewis, 2007		X		
Topper, 2007				X
Miller and Ortiz, 2007		X		
CWRRI 2008	X		X	
Dano, Poeter, and Thyne, 2006		X		
Wakida and Lerner, 2006		X		
Gardner and Vogel, 2005			X	
Heatwold, McCray, and Lowe, 2005		X		
Brendle, 2004		X		
Poeter and Thyne, 2004		X		
Ortiz, 2004		X		
Thyne, Guler and Poeter, 2004		X		
PPACG, 2003			X	
Poeter et al, 2003		X		
Trojan, et al., 2003			X	
Halapaska and Associates, 2002				X
Martin, Bassinger and Steele, 2002		X		
CWQCC, 2002		X		
Wakida and Lerner, 2002		X		
USGS, 2000		X		
Brendle, 1997	X			
Eckhardt and Strackleberg, 1995			X	
Watts, 1995	X			X
Buckles and Watts, 1988	X			X
Edlemann and Cain, 1985		X		
Livingston, Klein and Bingham, 1976	X			X
CDWR, 1974		X		
Bingham and Klein, 1973	X			X
McGovern and Jenkins, 1966	X			X

1. Full citations available in Reference Section

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3. Existing Water Quality Data

CGS acquired data from a variety of public sources, in both electronic and “hard copy” formats, compiled the data into an internally consistent database, and processed it for use in the analyses presented herein.

3.1 Water Quality Data Sources, Format and Limitations

CGS obtained site-specific information from publicly available databases, published reports, individuals, special and metropolitan districts, and government agencies at the local, regional, state, and federal level. We compiled all relevant and available data. Entities queried or providing data include:

- U.S. Environmental Protection Agency (STORET, SDWIS, UCMR, NCOD)
- U.S. Geological Survey (NWIS, CWQDR)
- Colorado Department of Public Health & Environment, Water Quality Control Division
- Colorado Department of Public Health & Environment, Solid Waste Unit
- Colorado Department of Public Health & Environment, Hazardous Waste Enforcement Unit
- Colorado Department of Agriculture
- Colorado Department of Labor & Employment, Division of Oil & Public Safety
- Colorado Department of Wildlife, Riverwatch Program
- Colorado State University Extension Service
- Pikes Peak Area Council of Governments
- El Paso County
- Cherokee and Meridian Metropolitan Districts
- Waste Management Inc.
- Scheiver Air Force Base
- Schubert Sod Farms
- Mr. Charles Barber

Publications with relevant water quality data include:

- McGovern and Jenkins, 1966
- Bingham and Klein, 1973
- Buckles and Watts, 1988
- Watts, 1995
- Brendle, 1997

- Topper, 2008

El Paso County also issued a press release calling for any data held by private well owners; no responses were received. The authors are not aware of any other sources of groundwater quality data relevant to the current study.

All data presented herein is preexisting and collected by others; as new water quality sampling and analysis was not included in the current study's scope. CGS created a master water-quality database that included chemical constituents, common to natural waters, and relevant to the use of the alluvial aquifer as a drinking and irrigation water source. CGS staff converted reported data into common units, manually entered data from paper documents, and combined all data into a master database. All values reported as either "parts per million" or in mass per volume units were converted to milligrams per liter (mg/L). CGS staff, other than those performing data entry, checked the accuracy of data entered into the master data set. The water-quality master database, organized into seven tables, is attached as Appendix C.

In some cases, different published and/or electronically available sources reported different sets of analytes for the same well and sampling event. We combined different data sets and removed duplicate records. In other cases, two different analytical results were available for the same parameter from the same sample. In these cases, the project team used the most recently published value, presuming newer data to have undergone additional quality assurance evaluation since publication of the older value.

We did not include or analyze all available water-quality data in this study. First, we believe that surface water samples collected from streams and lakes were not relevant to the current study's groundwater priority. These data, while representative of a portion of the water that percolates to the water table and recharges the aquifer, are not representative of water quality within the aquifer due to chemical and biological reactions occurring in the unsaturated zone, and dilution of the water once it reaches the aquifer. Secondly, most water supply analyses come from municipal water distribution systems. These samples are generally not representative of native groundwater quality because water providers treat the water and may blend it other water sources. Therefore, we did not use these sampling data, often provided to the public in Consumer Confidence Reports, in the current study. Any "new source" water quality data made available are representative of the groundwater quality and are included in the current report.

In general, the details of the sampling methods, laboratory analytical procedures and case narratives, well construction information, or other factors often indicative of sample bias were not available to the current study. The majority of the data was provided as summary data sheets from consultant reports or other secondary sources such as published reports or electronic databases.

Concentrations reported for many parameters were below the laboratory detection limits, but the detection limits were not quantified. Older data reports often used terms such as “BDL” (“below detection limit”) or “ND” (“not detected”) to describe parameters analyzed but not detected. We qualify these entries as “detection limit not quantified” (“DLNQ”) in the data tables provided.

The respective studies and sampling events from which the data are derived produce inconsistencies with regard to issues such as sampling protocol, the selection of analytes, methodologies and laboratories used, reporting criteria, and the design, construction, or original purpose of the well sampled. The lack of original laboratory reports and a consistent set of analytes precluded the ability to perform rigorous quality assurance and control. Despite these differences, CGS compiled the data into an internally consistent data set for the analyses presented.

3.2 Spatial and Temporal Characteristics of the Data

Samples collected for water quality analysis within the alluvial aquifer of the Upper Black Squirrel Creek basin have a limited areal distribution. Most sample locations are concentrated along the main alluvial channel, which follows a general north-south alignment within about three miles on either side of the Ellicott Highway. The locations of all 72-sample sites used in this study are displayed in Figure 3.1. To facilitate cross-referencing of the well locations with the well site identification numbers used in the subsequent data tables, a simplified reference table is presented in Appendix C, Table 1. No alluvial aquifer samples are available in the northwest portion of the basin that contains the urban corridor along US Highway 24. The limited spatial distribution of the data is portrayed as a histogram of water quality data by township and range. Figure 3.2 presents the number of available data points by township from north to south in the basin. Only 12 individual data points are available north of Judge Orr Road (township 12 south). The greatest number of data points, in township 13 south, is deceiving as 48 of the 61 reported are from a single sampling location.

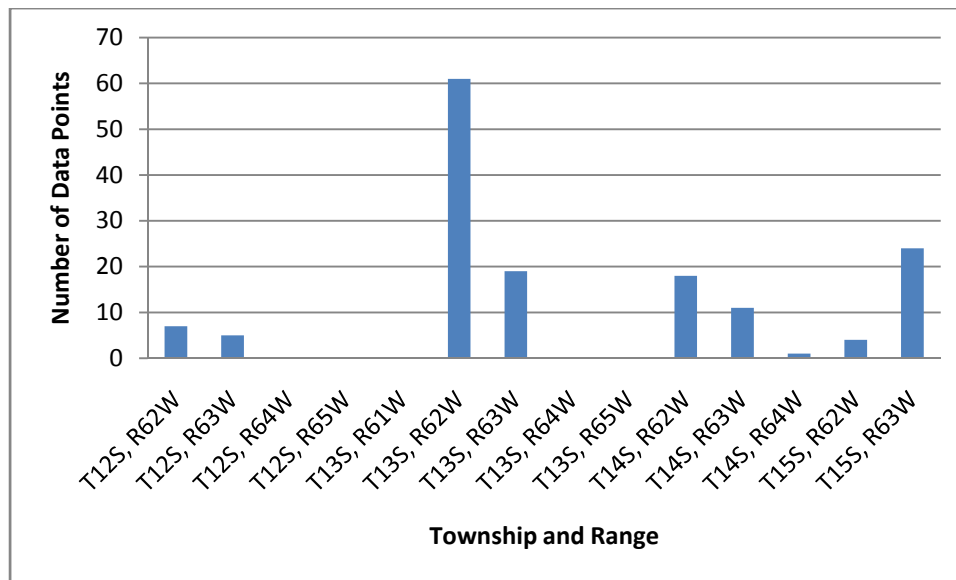


Figure 3.2 – Spatial distribution of water quality data

The groundwater quality data used in the current study consists of 150 samples collected from 72 wells between December 20, 1954 and Nov. 5, 2009. Table 3.1 present a summary of the data. The table provides statistics for the overall data set and in each of four periods: pre-1980, the 1980s, the 1990s, and the 2000s. Seventy-nine percent of the water quality data included in the current study was collected during the 1980s and 1990s. Data from prior to 1980 include only 11 samples and data from only 21 samples are available from the 2000s. One of the most important characteristics of this data is the lack of multiple samples from individual locations. Only four well sites have been sampled three or more times, with only one well reporting more than four sampling events. Consequently, the data’s temporal irregularity limit the evaluation of groundwater constituent trends to “snapshot” maps showing distribution of respective constituents during different decadal periods.

CGS used data from 72 wells in the current study area. Of these 72 wells, 25 wells were sampled twice, three wells were sampled three times and one well (SC01306230ACC1) was sampled 48 times. The resulting data set contains analytical results from a total of 150 samples collected from the 72 different wells (Table 3.1). Well SC01306230ACC1 provides almost one third of the nitrate concentration data available to the current study.

Table 3.1
Water Quality Data Summary Information

	Overall Data Set	Pre_1980	1980s	1990s	2000s
Number Records with Laboratory Parameters	150	11	65	53	21
Number of Wells Sampled	72 ¹	11	47	28	19
Earliest Record	12/21/1954				
Latest Record	11/5/2009				
Number of pH Data Values	121	10	63	27	21
Number of NO ₃ Data Values	142	10	65	53	14
Number of TDS Data Values	77	10	45	2	20
Number Pesticide Analyses	21	0	6	2	13
Number of VOC Analyses	3	0	0	0	3
Number of Inorganic Analyses (Cations) ²	51	9	22	2	18
Number of Inorganic Analyses (Anions) ³	37	10	19	2	6
Number of Metals Analyses ⁴	8	0	0	0	8
Number of Iron Analyses	43	7	22	2	12
Number of Radioactivity Analyses ⁵	12	0	2	2	8

Notes:

- 1 – Number of wells sampled in overall data set may be less than the sum of individual time periods due to multiple sampling events in the same well
- 2 - Analyses include Mg, Na, K, and Ca
- 3 - Analyses include HCO₃, SO₄, and Cl
- 4 - Metals included are Ba, Cd, Cr, Cu, Pb, and Zn
- 5 - Gross Alpha and Gross Beta Emitter Analyses

3.3. Data Analysis

The data have limitations described above in Section 3.1. We can only assume that the data have been collected by trained personnel using valid methods, subjected to quality assurance evaluation, evaluated by the original data users, and deemed representative of the alluvial groundwater quality at the wells sampled.

CGS compiled the data into a MS Excel spreadsheet. This format allowed for statistical analysis of the data, the creation of tables, and allowed us to utilize the chemical analysis tools in Rockware's® Aq•QA software to convert units, check for internal consistency, and create graphs and diagrams. We then imported information derived from our data analysis into GIS (ESRI ArcMap 9.3) software to allow display and presentation with respect to other geospatially referenced information and land use layers provided by

El Paso County. Project staff mapped wells or sample locations, lacking precise location coordinate data, at the center of the most refined public land survey system (PLSS) subdivision available.

As a method of evaluating the data set, CGS attempted a charge balance calculation for water samples for which major ion data were available; however, for many samples, the calculation indicates a charge balance discrepancy exceeding the standard analysis reliability criterion of 5% for chemical data. This discrepancy indicates several possibilities (Hounslow 1995), the most likely of which include:

- Inaccurate laboratory analyses
- Presence of ions not indicated in laboratory data sheets

Despite the potential for a discrepancy in the charge balance, sufficient data are present to characterize the overall water quality within the UBSC basin alluvial aquifer.

The spatial, temporal, and technical limitations of the available groundwater-quality data influence the objectives of the current study. Spatially, the data are unevenly distributed across the UBSC basin. There are no groundwater data available where dense residential development is a significant land use, primarily in the northwestern portion of the basin. Temporally the data cluster around particular time periods even though the data set spans more than five decades. Due to the chemical and physical changes that may occur in the groundwater environment over time, the age of much of the data precludes its application for characterizing the current groundwater quality in the study area. A number of technical aspects limit the usefulness of the data in the current study. Investigators typically sampled wells only once or twice; only one well was the subject of more than four sampling events during the period of record. Consequently, evaluation of water quality trends over the period of record is limited.

4. Alluvial Groundwater Quality in the Upper Black Squirrel Creek Basin

Groundwater chemical analysis data for inorganic compounds, total dissolved solids, nitrates, metals, volatile organic compounds, and radionuclides were evaluated to characterize the UBSC basin alluvial aquifer water quality. Natural waters obtain a chemical signature as a result of weathering, a process whereby water in the form of precipitation dissolves atmospheric gases and reacts with minerals on the surface of the earth. The interaction of geologic materials with the atmosphere and hydrosphere determines the native chemical signature of the groundwater. This chemical signature can be further modified by human activities and the release of chemicals into the environment. Regulatory agencies such as the US EPA have established numerical standards for drinking water supplies that are protective of human health. We evaluate the water quality of the alluvial aquifer of the UBSC basin with respect to naturally occurring compounds and chemicals that may be introduced by various land uses. A copy of all the groundwater chemical analysis data utilized in this study is attached as Appendix C. Illustration of water quality analyses is used to plot the geographic distribution of the parameter of interest and evaluate the presence of chemical trends.

4.1 Total Dissolved Solids Concentrations

The most common indicator of water quality is the determination of the total dissolved solids (TDS) content. This analysis quantifies the amount of major ions in solution. Pure waters have very low TDS concentrations while brines have extremely high concentrations. The US EPA established a Secondary Maximum Contaminant Level (SMCL) of 500 milligrams/liter (mg/L) for drinking water. Seventy-seven TDS values were available to us from 72 wells.

Concentrations ranged from a low of 165 mg/L to a high of 842 mg/L (Table 4.1). The distribution of TDS values by number of wells sampled is presented in Figure 4.1.

For presentation, we averaged values collected from the same well over the period of record. As can be seen in the TDS histogram (Fig. 4.1), 51 of the 72 wells sampled for TDS have values of less than

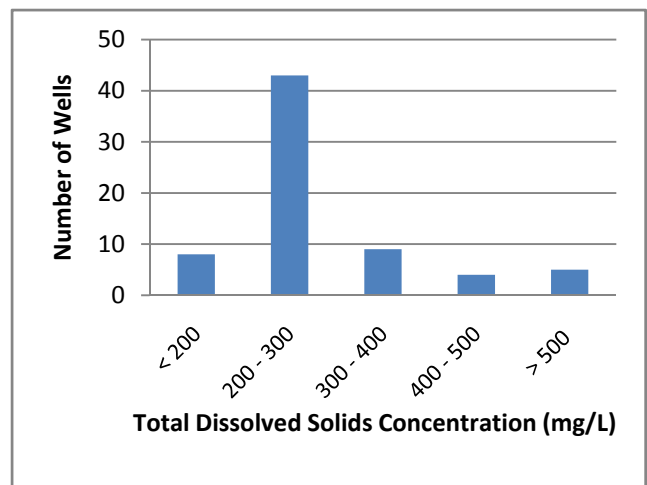


Figure 4.1 – Distribution of TDS

300 mg/L; indicating groundwater is generally of good quality. Six wells reported concentrations exceeding the SMCL of 500 mg/L.

The locations of the sampling points for these data are presented in Figure 4.2. Generally, lower TDS values are present along and to the west of the main alluvial channel of Black Squirrel and Brackett Creeks in areas of the thickest saturated alluvium. Samples with higher TDS values were collected from wells generally to the east of Black Squirrel and Brackett Creeks and in areas of thinner alluvium such as the northern and eastern portions of the UBSC basin alluvial aquifer. The TDS values compiled for this study indicate that in the majority of the areas where sample data are available, TDS values are typically less than 300 mg/L.

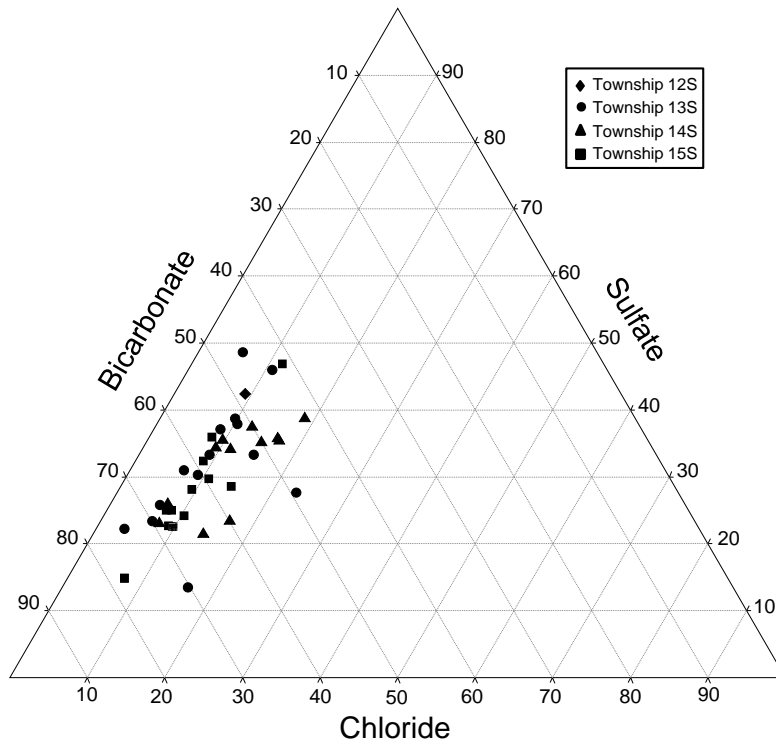
In some cases, higher TDS values are reported adjacent to wells with low values (e.g. southern portion of the basin). The reason for the increased TDS concentrations in areas of thinner saturated alluvium is unknown. Possible sources of higher TDS concentrations include runoff, irrigation return flow, and discharge of underlying bedrock aquifers.

4.2 Major Ion Ratios

The total dissolved solids concentration in a water sample can be divided into the individual constituents present. These constituents are usually referred to as the major ions and their ratios can be used to classify the water by general chemical type. These constituents usually include the positively charged ions (cations) calcium, magnesium, sodium and potassium, and the negatively charged ions (anions) chloride, sulfate, and bicarbonate. Commonly, in natural waters, the electrical charge associated with the combined cations will be equal to the combined charge of the anions resulting in a charge balance. As water migrates through an aquifer, the chemistry can evolve along the flow path from one water type to another due to dissolution of minerals within the aquifer, infiltration of water from other sources, upward migration of water from underlying aquifers (Watts, 1995) or reactions resulting from changes in the aquifer mineralogy (Hounslow, 1995).

The major ion ratios for all water samples, with sufficient data, are presented in Figure 4.3. Due to the weathering process, major ion chemistry may vary between different aquifers. Watts (1995) used major ion ratios as an indication of how water was flowing between the alluvial aquifer and underlying bedrock aquifers in the UBSC basin. The percentages of the different ions are plotted on triangular or

Anions



Cations

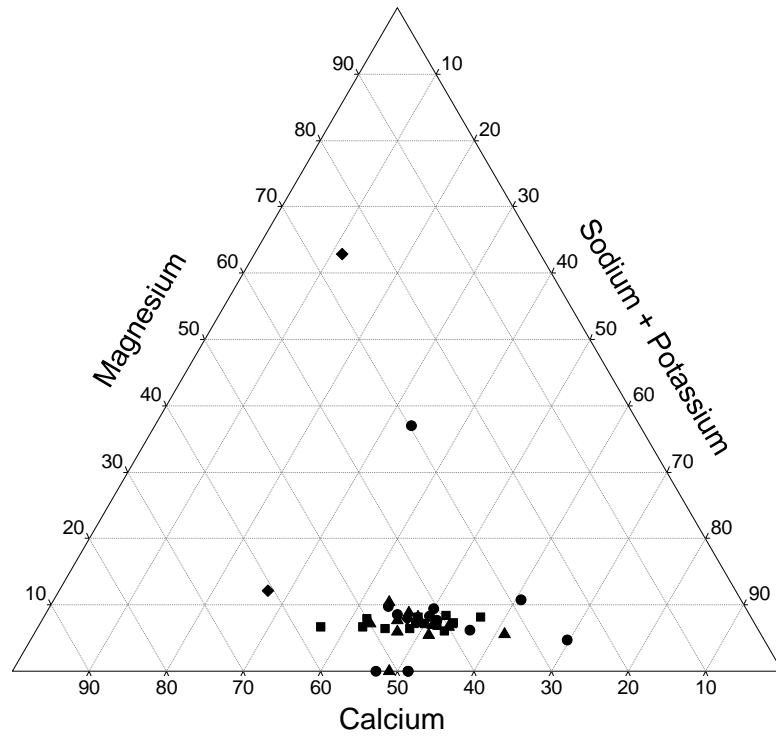


Figure 4.3 - Relative proportions of dissolved anions and cations in water from the alluvial aquifer in the Upper Black Squirrel Creek Basin.
(Units along axes are percentage of total milliequivalents per liter)

Ternary diagrams to evaluate water chemistry trends and sources. Overall, in charge balanced units of milliequivalents per liter, the proportions of cations generally range from approximately 35% - 55% calcium, 35% - 55% sodium and 5% - 10% magnesium, while anions generally fall within ranges of 20% - 50% sulfate, 55% to 70% bicarbonate and 5% - 15% chloride. These analyses indicate that the alluvial groundwater within the study area is a mixed cation bicarbonate water, containing a mixture of the cations calcium and sodium, with an anion content consisting predominantly of bicarbonate. The use of different symbols, in Figure 4.3, for each of the different townships in the study area allows for evaluation of geographic trends in the major ion proportions. No significant geographic zonation in water chemistry is evident from this analysis.

Two outliers are evident in the cation ratio ternary plot of Figure 4.3, samples SC01306230ACC3 and SC01306219CDB. These samples are skewed by relatively high magnesium concentrations of 12 and 54 mg/L, respectively. The water supply wells from which the samples were collected are within one mile of each other and both draw water from the bottom portion of the alluvial aquifer in a location underlain by the Denver aquifer which may contribute to water captured by the two wells and explain the different water chemistry.

4.3 Hardness

Water hardness is a measure of the dissolved metallic ions in water that can react with soaps to produce a residual scum (bath tub ring), result in plumbing fixture scaling, and hamper the efficiency of detergents. The calcium and magnesium constituents represented by hardness values also react with other dissolved constituents in water to form mineral scale in boilers and other appliances using hot water. Eventually, mineral scale is capable of rendering boilers inefficient and fouling appliances that heat water. Hardness data represent a combination of dissolved constituents and for simplicity are generally expressed as “mg/L as CaCO₃” or “mg/L equivalent calcium carbonate” (Freeze and Cherry, 1979). Soft water has concentrations less than 60 mg/L, while very hard water is classified by values greater than 150 mg/L.

Available hardness data are mapped in Figure 4.4. The data indicate that groundwater in the UBSC basin alluvial aquifer is generally classified as “moderately hard” with isolated areas containing water classified as “hard” or “very hard.” Locations with hard and very hard water coincide with locations containing the highest TDS values, and are generally in the shallower portions of the aquifer outside of the main alluvial channel. This indicates that water hardness is associated with the TDS concentrations.

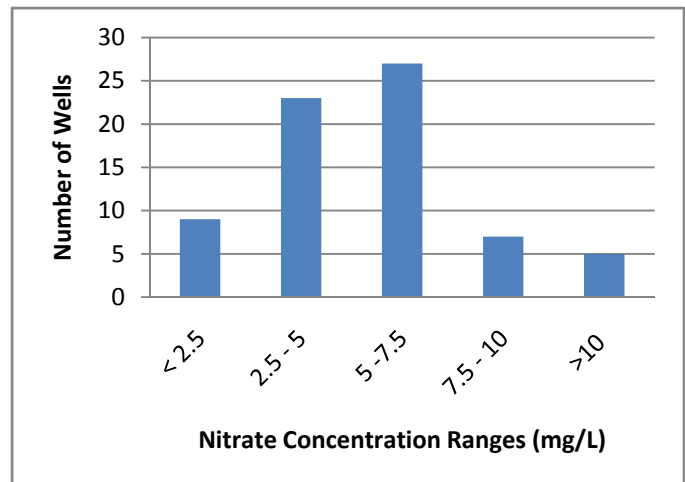
4.4 Flouride

Flouride is found naturally in low concentrations in groundwater. Flouride compounds are salts that form when the element fluorine combines with minerals in soils and rocks. Flourine is derived from the weathering of flouride minerals, such as flourite. Many water suppliers add flouride to their drinking water to promote dental health. The US EPA has established an SMCL for flouride at 2.0 mg/L. Fourteen samples contained an analysis for flouride. Flouride concentrations in groundwater, for the data available, ranged from 0.3-1.0 mg/L, with the majority of values ranging from 0.4-0.5 mg/L.

4.5 Nitrate Concentrations

The Committee has identified nitrate as a contaminant of concern in the UBSC basin. Common sources of nitrate in groundwater include: runoff from improper application of fertilizer or manure spreading, leaching from septic tanks, sewage and weathering of geologic units. Nitrate concentration values in the basin at individual sample locations were

averaged and a histogram prepared to show a frequency distribution of nitrate values (Figure 4.5). The majority of nitrate concentrations range between 2.5-7.5 mg/L. The MCL for nitrate is 10 mg/L. For the current study, all nitrate values are expressed in terms of nitrate as nitrogen. For graphical presentation of nitrate data, we assumed concentration values were less than 2.5 mg/L for samples in which nitrate was not detected, regardless of the laboratory detection limits.



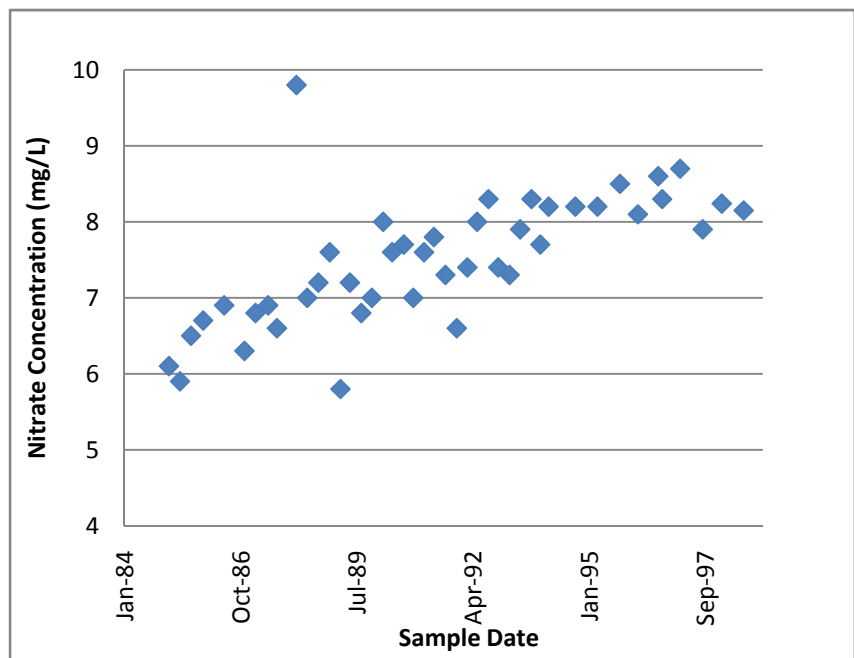
4.5 - Frequency Distribution of Nitrate Values

Nitrate values represent one of the largest data sets in our database, 142 samples with detectable values. The availability of this data allowed us to analyze the potential changes in nitrate concentrations over time. Four decadal time periods, pre-1980, the 1980s, the 1990s, and the 2000s were evaluated using average decadal nitrate concentrations at individual sampling sites and mapped to display potential changes over time (Figures 4.6 through 4.9). Information on nitrate concentrations in the alluvial aquifer pre-1980 is sparse.

Figure 4.6 shows two locations with elevated concentrations associated with irrigated agriculture along the mainstem of Black Squirrel Creek in the southern portion of the basin. The sampling data for nitrate increased significantly in the 1980s with five locations exceeding the MCL (Fig. 4.7). Four of these locations are in the upper reaches of Brackett Creek. Groundwater in the main alluvial channel was characterized by nitrate concentrations of 7.5 mg/L or less. Less sampling occurred in the 1990s, but available data indicate similar concentrations as observed in the 1980s with portions of Brackett Creek experiencing higher values (Fig. 4.8). The 2000s data suggest that the area around Brackett Creek continues to experience elevated nitrate concentrations in groundwater (Fig. 4.9). It should be recognized, however, that most of these data represent different well/sample locations for the periods evaluated. These conclusions generally support those of Brendle (1997) who resampled 28 wells throughout the UBSC Basin that had been sampled in August 1984 by Buckles and Watts (1988). However, as Brendle (1997) states, "...two samples from each of the 28 wells are not sufficient to definitively determine trends in nitrate concentrations..."

The geographic distribution of nitrate data in the UBSC Basin is greatly skewed toward the main alluvial paleochannel, which follows a general north-south alignment along the Ellicott Highway (Topper, 2008). Groundwater has historically been sampled from locations in the mainly agricultural portion of the UBSC Basin. Data are not available to determine whether ISDS's associated with large residential developments in the northwestern portion of the UBSC Basin have impacted groundwater quality.

We previously mentioned in Section 3 that few wells have multiple sampling events associated with them. The exception being well SC01306230ACC1, a monitoring well associated with Cherokee Metropolitan District production well #4. At that location, a series (from February 1985 through August 1998) of nitrate concentration data has been reported (Fig. 4.10). The well



4.10 - Nitrate Concentrations with Time at Well SC01306230ACC1

shows an increasing trend in nitrate concentrations, from the mid 1980s to the mid 1990s. This trend was the impetus for Brendle's (1997) study.

Elevated nitrate (>10 mg/L) in drinking water is a significant health issue for infants below the age of six months. The risk known as methemoglobinemia is commonly referred to as "blue baby syndrome" due to the afflicted baby's bluish skin color, particularly around the eyes and mouth (Jennings and Sneed, 1996).

Nitrate is often naturally present in groundwater at concentrations of less than 2-3 mg/L due to decomposition of proteins and other organic nitrogen compounds present in vegetation and animal wastes. Nitrate contamination from wastewater effluent has been observed to persist for decades in groundwater and can travel from its source for miles through an aquifer (LeBlanc, 2006).

4.6 Metals

Dissolved metals can be derived from weathering of natural deposits, from waste, or chemical spills. These include common elements like iron, lead, copper, and zinc, and less familiar elements like selenium, barium, arsenic, and beryllium. Drinking water containing high dissolved metal concentrations can be harmful to human health and the EPA has established various numeric standards for different metals. The data summary table 3.1 indicates that we acquired 43 samples with iron analysis and 8 samples with results of other metals. The dissolved metals concentrations indicate that only one detection of a regulated metal has been at, or greater than, that metal's respective MCL. During January of 1987, arsenic was detected at a concentration of 0.01 mg/L, equal to the recently established arsenic MCL, in a sample from well SC01306301DCB.

Iron has been detected in three samples at concentrations exceeding the SMCL (0.3 mg/L). In September 1980, iron was detected at a concentration of 1 mg/L in a sample from well SC01306219CDB and in March 2006; iron was detected at concentrations of 2.8 and 0.48 mg/L in samples from well SC01206219CC and SC01206230BB, respectively. The limited and/or inconsistent values for dissolved metals do not lend itself to meaningful graphical presentation.

4.7 Organic Chemicals

Organic chemicals include a wide range of petroleum products, solvents, pesticides, herbicides, and other carbon containing compounds. These chemicals are often associated with internal organ damage and

consequently have very low MCLs. We acquired data for 21 independent samples with pesticide analyses and 3 samples with analyses of volatile organic compounds. All reported concentrations of volatile organic compounds were below the laboratory detection limits. The pesticides and herbicides are common agricultural chemicals used on crops and pastures to control weeds and other threats to crops. The concentrations for these chemicals were also below the laboratory's detection limit.

4.8 Radioactivity

Water quality sampling requirements for municipal water providers includes analysis of radioactivity. This typically includes quantification of radioactive particle (gross alpha and beta) activity as a trigger for additional analysis of radioactive elements such as radon and uranium. The US EPA has established action levels of 15 picocuries per liter (pCi/L) for gross alpha emitters and a gross beta particle dose of 4 millirems per year. The beta emitter concentration, expressed in millirems per year, is calculated from a detailed laboratory analysis that is generally not performed on routine water samples and only required when gross beta radioactivity exceeds 50 pCi/L (U. S. EPA, 2001). Thirteen data points were acquired with gross alpha and beta analyses. Radioactivity, in the context of the UBSC basin alluvial aquifer, is an indicator of naturally occurring dissolved constituents that emit alpha and beta particles. Low levels of alpha and beta particle activity were detected in groundwater sample analysis presented in the current study. The highest detections of both alpha and beta particle activity were 3.6 and 6.0, respectively, well below the regulatory action levels.

4.9 Summary of Groundwater Quality Standard Exceedences

Exceedence of Maximum contaminant levels (MCL) or Secondary maximum contaminant levels (SMCL) are presented in bold text in data tables herein. Table 4.1 summarizes the samples from which the reported values exceed those standards. A total of 22 groundwater quality values reported concentrations that equal or exceed the regulatory standards. MCL or SMCL exceedences were observed for arsenic, nitrate, pH, sulfate, and iron:

- Only one sample, collected in 1987, reported an elevated arsenic concentration of 0.01 mg/L, which is the MCL.
- Nine samples, with collection dates from 1971 to 2006, reported nitrate concentrations in excess of the 10 mg/L MCL. Most of these samples reported concentrations of 11 mg/L, with three having significantly higher concentrations. The two well sites with the highest nitrate concentrations were documented as being near likely nitrate point source (Buckles and Watts, 1988).

- Two samples collected in 1984, reported pH values below (6.3) and above (9.2) the SMCL standard range of 6.5-8.5.
- The SMCL (500 mg/L) for total dissolved solids was exceeded in six samples, collected in 1971 and 1984, with a maximum concentration of 842 mg/L reported.
- One sample, collected in 1971, reported a sulfate concentration at the SMCL of 250 mg/L.
- Three samples, from municipal production wells, exceeded the SMCL (0.3 mg/L) for iron

The locations of these samples are illustrated in Figure 4.11. Three wells in particular, SC01206314DDC, SC01306209BBB and SC01506325ABA, provided samples where multiple parameters exceeded MCLs or SMCLs. A sample collected from well SC01206314DDC in August of 1984 was observed to have 72 mg/L nitrate and 650 mg/L TDS. The nitrate concentration reported is the highest groundwater nitrate concentration available to the current study and is consequently suspect. The water sample also contained relatively high concentrations of other dissolved solids and yielded the highest value for hardness (510 mg/L as CaCO₃) observed in the current study. More recent groundwater sample data are not available for this well, described by Buckles and Watts (1988) as being at a point source of nitrate contamination. This information, combined with a comparison of TDS, hardness, and all other nitrate concentration observed indicates the groundwater quality observed at well SC01206314DDC represents localized groundwater conditions and is not representative of the aquifer as a whole.

**Table 4.1
Samples Exceeding Regulatory Standards**

Site ID	Sample Date	Local Well Name	Reported Value	Data Source	Comments
Arsenic (As), MCL = 0.01 mg/L					
SC01306301DCB	1/1/1987	CMD-08	0.01	3	Reported as 0.01 in data summary sheet ³
Nitrate (NO₃), MCL = 10 mg/L					
SC01206314DDC	8/9/1984		72	2	TDS exceedence also, well at nitrate point source ²
SC01306209BBB	8/10/1984		33	5	Well at nitrate point source ² , TDS exceedence also
SC01306209BBB	8/22/1996		25	5	Well at nitrate point source ²
SC01306229DAC	11/30/06	PP-D-039	11.5	4	Farm animals watered by well, turf farms in area
SC01206230CDC	8/8/1984		11	5	Resampled in 1996, nitrate below MCL
SC01206230BDB	8/9/1984		11	5	Resampled in 1996, nitrate below MCL
SC01306334ABB	8/10/1984		11	5	Resampled in 1996, well nitrate point source ²
SC01306334ABB	8/21/1996		11	5	Sampled in 1984, well at nitrate point source ²
SC01506325ABA	9/8/1971		11	5	Sulfate and TDS exceedences also
pH, SMCL defined as outside range between 6.5 and 8.5					
SC01306221BDD	8/10/1984		9.2	5	NA
SC01206336ACC	8/8/1984		6.3	5	NA
Total Dissolved Solids (TDS), SMCL = 500 mg/L					
SC01306209BBB	8/10/1984		842	5	Nitrate exceedence also, well at nitrate point source ²
SC01506325ABA	9/8/1971		767	1	NA
SC01206314DDC	8/9/1984		650	2	Nitrate exceedence also
SC01406228CCB	9/8/1971		596	1	NA
SC01406220DBC	8/10/1984		548	2	NA
SC01406216CCC	8/10/1984		546	5	NA
Sulfate (SO₄), SMCL = 250 mg/L					
SC01506325ABA	9/8/1971		250	1	Nitrate exceedence also
Iron (Fe), SMCL = 0.3 mg/L					
SC01206219CC	March 2006	Guthrie Well #2	2.8	6	NA
SC01206230BB	March 2006	Guthrie Well #1	0.48	6	NA
SC01306219CDB	9/10/1980	CMD-05	1.0	3	NA

Notes: MCL= Maximum Contaminant Level; SMCL= Secondary Maximum Contaminant Level

Data Source: 1 – Bingham and Klein, 1973
4 – CO Dept. of Agriculture

2 - Buckles and Watts, 1988
5 – USGS NWIS/WQR database

3 – CMD, Curt Well's Reports
6 – Woodman Hills Metro

5. Potential Land Use Impacts on Groundwater Quality

As discussed in Section 1, the objective of this study is to evaluate groundwater contamination issues to help participants make informed land use decisions. The El Paso County Board of County Commissioners is considering potential changes to the El Paso County Land Development Code, including those related to groundwater protection. The El Paso County Development Services Division and Information Technology Division have provided GIS analysis and mapping services to portray existing and future land uses within the study area. The County also provided parcel-based well and septic data derived from the Assessor's database. Existing land use was integrated with the groundwater quality data to identify potential sources of contamination associated with land uses that may negatively influence groundwater quality. Future land use scenarios were also considered to focus efforts of any proposed Phase 2 investigations.

The existing land uses within the study area are presented as Figure 5.1. Land uses are classified as industrial, commercial, urban residential, rural residential, vacant land, irrigated and dry land agricultural and other (forest land, parks, federal and institutional properties). The vast majority of land uses, within the UBSC basin, are agricultural and rural residential. Urban residential is concentrated within and north of Falcon, in Peyton, and at several isolated small developments throughout the basin. Only two industrial parcels exist within the study area and these are located north of Highway 24 in the Falcon area. A number of commercial land uses exist largely along the Highway 24 corridor near Ellicott.

5.1 Potential Contamination Sources Related to Land Use.

Groundwater quality can be degraded by a variety of naturally occurring and anthropogenic (man-made) processes. Groundwater quality changes can also result from materials in the aquifer matrix such as organic matter, minerals, salts or metals that leach into groundwater as it flows through the aquifer. Examples of anthropogenic groundwater contaminant sources include: fuel or chemical spills, stormwater runoff from roads and parking areas, road deicing, or improper application of pesticides, herbicides or fertilizers. Other potential sources include improper disposal of industrial wastes, landfill leakage, wastewater treatment plant effluent, feedlot waste, and improperly designed or maintained individual sewage disposal systems (ISDS).

The relationship between land use and groundwater quality has been documented in a variety of settings (Eckhard and Strackleberg, 1995, USGS, 1999, Gardner and Vogel, 2005, Dano and Poeter, 2004,

Dano, et al., 2006, Brendle 1997). Land use has been referred to as the dominant factor affecting shallow groundwater quality by Trojan, et al. (2003). Since high-density urban and industrial land uses are limited in the UBSC basin; commercial, agricultural, and residential activities present the greatest potential to impact groundwater quality.

Table 5.1 provides a summary of common types of groundwater contaminants and land uses often associated with them. Land uses present in the UBSC Basin having the potential to contaminate groundwater include retail fuel distribution, agricultural operations, automotive salvage yards, residential ISDSs, feedlots, landfills, military facilities, and industrial waste/wastewater disposal. Potential sources of groundwater contamination related to existing and future land uses in the UBSC basin are discussed in detail below.

**Table 5.1
Groundwater Contaminants Commonly Associated with Various Land Uses**

Groundwater Quality Constituents	Total Dissolved Solids	pH	Major Ions	Nutrients (nitrate / phosphate)	Pathogens	Pesticides / Herbicides	Semi-Volatile Organic Compounds	Volatile Organic Compounds	Petroleum Hydrocarbons	Heavy Metals	Radioactivity
Land Use											
Agriculture / Cultivation	X	X	X	X	X	X					
Animal Feedlot	X	X	X	X	X						
Residential	X	X	X	X	X	X					
Industrial / Commercial	X	X	X	X		X	X	X	X	X	
Fuel Distribution	X	X	X				X	X	X	X	
Industrial Waste Disposal	X	X	X	X	X	X	X	X	X	X	X
Landfill	X	X	X	X		X	X	X	X	X	X
Military	X	X	X	X	X	X	X	X	X	X	X
Mining	X	X	X							X	X
Metal Plating	X	X	X					X		X	
Commercial Property	X	X	X	X		X					
Automotive Salvage	X	X	X				X	X	X	X	

After USGS (1997) and CDPHE (2006).

Residential: Typical groundwater contaminants from residential land use are primarily associated with ISDSs and lawn care chemicals such as pesticides, herbicides and fertilizers. Contaminants from ISDSs generally include nutrients such as nitrates and phosphorus, and bacteria such as fecal coliform (Fetter 1994, Brendle 1997). Other contaminants that may result from residential ISDSs are personal care products and medications that are not metabolized. Pesticides, herbicides and fertilizers, used in lawn and garden applications, can be a potential contaminant when improperly used or disposed. Excess irrigation can cause these products to leach to the water table and impact groundwater quality. Common brand name pesticides often contain organophosphates, carbamates, and organochlorines. Commonly available herbicides may contain metolachlor glyphosate, and atrazine. Fertilizers often contain concentrated nitrogen and phosphorous.

Agricultural Activities: Improper storage and/or application of agricultural pesticides and herbicides can result in groundwater being contaminated by organic chemicals and their breakdown products. Common agricultural pesticides contain lindane and endrin. Chemicals, such as toxaphane and methoxychlor, which have been banned, may persist in the environment. Agricultural herbicides include such chemicals as 2,4-Dichlorophenoxyacetic acid (2,4-D), glyphosate (Roundup[®]), and atrazine. The herbicide 2 (2,4,5-Trichlorophenoxy) propionic acid (2,4,5-TP or Silvex) has been banned but may persist in the environment.

Improper storage and application of agricultural fertilizers can result in nutrient loading to the aquifer. Nutrient loading to groundwater can also result where manure is spread or is concentrated such as in fields, feedlots, and corrals, respectively (Brendle 1997).

Leaks from fuels or fluids used in agricultural machinery may pose a threat to groundwater resources depending upon the volume spilled and surface conditions. Typically, fuel storage tanks for agricultural activities are often smaller than those used in retail fueling facilities and installed aboveground where leakage can be observed and quickly mitigated.

Unregulated Industrial Waste Disposal: Improper disposal of industrial wastes can result in a wide variety of contaminants being introduced to the groundwater. Common groundwater contaminants include heavy metals, volatile and semi-volatile organic compounds, highly acidic or basic solutions, solvents and nutrients.

Urban and Commercial: As an area is urbanized, the amount of paved and impermeable surfaces increases and so does the volume of stormwater runoff. Stormwater can pick up chemicals from spills, leaks, or those inherent in the surface materials over which it passes. Stormwater runoff is often contained and conveyed from streets, parking lots, rooftops, and other impervious surfaces to detention basins or discharged to streams and other surface water bodies. These engineered features represent areas in which chemical contaminants may be concentrated. If stormwater is released to ephemeral drainages or allowed to infiltrate, the dissolved chemicals can impact groundwater quality. Runoff percolating into the subsurface from dry or low-flow stream channels can carry dissolved and microscopic contaminants to the water table. Contaminants present in stormwater runoff that degrade groundwater quality include pathogens, metals, nutrients, PCBs, pesticides, road de-icing solutions, and volatile- and semi-volatile organic compounds (US EPA, 1994).

In addition to potential contaminants in stormwater, urban and commercial land uses may involve industrial processes or other activities using chemicals that can directly contaminate groundwater if spilled or disposed of improperly. ISDSs associated with commercial, industrial and manufacturing facilities may impact groundwater with a variety of chemicals used at the facility that cannot be degraded by the septic system.

Older or improperly designed municipal solid waste landfills have been known as sources for a wide variety of groundwater contaminants including nutrients, volatile and semi-volatile organic compounds, heavy metals, pesticides, herbicides, and PCBs.

Retail fueling facilities (gas stations) carry petroleum fuels, oils, and lubricants that can migrate to the water table through leaks or spills. Gasoline contains volatile organic compounds such as benzene, ethylbenzene, toluene and xylenes, while diesel fuels contain naphthalene and a variety of semi-volatile hydrocarbons. These common groundwater contaminants are typically released to the environment by leaking underground storage tanks (USTs) and piping. Spills from fueling facilities can have a significant impact on groundwater quality in the immediate vicinity of the retail fueling facility.

Automotive salvage yards may also result in contamination of soil and groundwater. Commonly observed contaminants include petroleum fuels, oils, lubricants, heavy metals including mercury, antifreeze, lead, battery acid, plasticizers, and solvents (CDPHE, 2006).

Military: Facilities associated with military activities have been the source of a wide variety of groundwater contaminants due to the improper storage and disposal of wastes from diverse activities ranging from vehicle fueling and maintenance to ordnance training and chemical weapon storage. Groundwater contaminants historically associated with military bases include pathogens, petroleum fuels, heavy metals, radioactive materials, explosives, chemical weapons, and PCBs.

5.2 Anticipated Future Land Use

El Paso County Development Services Division provided GIS layers representing future land use or build out. The Falcon/Peyton Small Area Master Plan, Black Forest Preservation Plan, Highway 94 Comprehensive Plan, and Ellicott Valley Comprehensive Plan were the basis for future land uses. The result of that synthesis is presented in Figure 5.2. The future land uses anticipated within the UBSC basin are a continuation and expansion of current land uses, primarily consisting of residential development in urban, rural residential and rural development densities corresponding to lot sizes of less than 2.5 acres, 2.5 to 5 acres, and greater than 5 acres, respectively. Commercial development is expected to accompany residential development and is identified as activity nodes (Fig. 5.2).

Future development is expected to occur primarily in the northern and western portions of the UBSC basin along major transportation corridors and where infrastructure is expected to be concentrated. Specifically, these areas include corridors along Highway 24, Judge Orr Road, the Peyton Highway and Curtis Road. Additionally, activity node development is expected to occur at locations such as at the intersection of Highway 94 and the Ellicott Highway, Peyton Highway, Curtis Road, Enoch Road, and at locations where Enoch and Blue Roads enter Schriever Air Force Base. The future land use plans do not propose significant industrial development; however, some industrial uses are expected to develop in areas proposed for urban density. Conversion of agricultural land to urban use is expected to occur.

The potential impacts to groundwater quality associated with expected future land uses primarily consist of contaminants associated with stormwater runoff and wastewater disposal facilities. Currently only a small portion of urban and rural residential development in the UBSC basin is served by sanitary sewers and municipal wastewater facilities. If future development continues to rely on ISDSs then the potential contaminants associated with these systems could negatively impact groundwater quality. Impacts to groundwater are expected to be more pronounced in areas with higher density of ISDSs and in particular, where lot size is less than one acre (WQCD 2008). Currently, county regulations and

development codes require central sewer service for urban development, commercial and industrial development, and residential lots less than 2.5 acres.

6. Results Summary

This section summarizes the results of the current study and addresses specific questions presented in the Scope of Work. The Colorado Geological Survey has attempted to compile all publicly available water quality data associated with the alluvial aquifer of the UBSC basin. These data were analyzed in conjunction with current land uses in the basin to meet the objectives for the groundwater quality study. Thirty-four relevant publications were identified and reviewed, some of which contained water quality data incorporated into this study. In addition to data compiled from the published literature, information was acquired from public water providers, regional and local government agencies, and state and federal regulatory and scientific agencies. A total of 150 records with laboratory analysis were collected from 72 wells.

Most of the sampling locations are concentrated along the Black Squirrel Creek and Brackett Creek alluvial valleys (Fig. 1.1). The data are limited in its spatial distribution with no groundwater quality data available in the northwest portion of the basin where the majority of development is occurring. The sampling frequency or temporal distribution of the data is also limited with the majority of samples collected in the 1980s and 1990s. Only four sampling locations have been sampled more than three times. Consequently, continuous water quality trends are discernible at only one location. The data could not be subjected to rigorous quality control or analysis reliability due to absence of comprehensive laboratory analyses, lack of sampling method details, laboratory analytical procedures and case narratives, well construction information, or other factors often indicative of potential sample bias.

Groundwater chemical analysis data for inorganic compounds, total dissolved solids, nitrate, metals, organic compounds, and radionuclides were evaluated to characterize the UBSC basin alluvial aquifer's water quality. Based on major ion ratios, the alluvial groundwater within the study area is a calcium/sodium bicarbonate water type. The groundwater is generally classified as moderately hard with isolated areas of harder water. Total dissolved solids concentrations, being an overall indicator of water quality, are generally at 300 mg/L or less indicating good water quality. Fluoride concentrations are well below the EPA's SMCL. Nitrate has been identified as a contaminant of concern in the UBSC basin due to the predominance of individual sewage disposal systems associated with residential development. Nitrate values greater than 5.0 mg/L are common in the basin, and suggest that the alluvial water quality has been influenced by sources of nutrient loading. Limited analyses of dissolved metals indicate concentrations below regulatory levels with three locations reporting higher iron values. Organic chemical analyses were available for a few source

water supply wells. We focused on the more common compounds in this group of chemicals representing volatile and semi-volatile compounds, i.e. pesticides and herbicides. No concentrations above the laboratory's detection limit were reported for these chemicals. Available analysis of radioactivity indicated particle activity counts well below the regulatory action levels also.

The data were compared with regulatory drinking water standards established by the US EPA. A total of 22 groundwater quality exceedences were observed in data from 18 samples collected from 16 different wells. MCL or SMCL exceedences were reported for arsenic, nitrate, pH, sulfate, TDS and iron. Nine samples, with collection dates from 1971 to 2006, reported nitrate concentrations in excess of the 10 mg/L MCL, with most reporting concentrations of 11 mg/L.

6.1 Relationship between Land Use and Water Quality

To assess the relationship of current land uses to nitrate concentrations in the UBSC basin, we present nitrate analyses from the past two decades (1990-2009) on a map of current land use (Fig. 6.1). The resulting data set contains 47 groundwater nitrate data values. Analyses from wells at which nitrate was detected more than once during the evaluation period were averaged. As presented in Figure 6.1, the data are distributed along the central portion of the basin where rural residential, dry land farming/grazing, and irrigated agriculture are the dominant the land uses. Elevated nitrate concentrations are distributed over all three of these land uses. In general, however, where data are associated with parcels classified as irrigated agriculture, nitrate concentrations exceed 5.0 mg/L. Sample locations with the highest nitrate concentrations are not associated with irrigated agriculture and suggest a local source such as cattle pens. Additionally, some locations with elevated concentrations are in close proximity to locations with low concentrations. This may be an artifact of the longer period of evaluation, localized sources of nutrient loading or sampling bias. While it appears that the alluvial aquifer has historically been impacted by nitrate loading, the data is insufficient to determine whether the impact is regional.

To further assess the relationship between nitrate concentration in the basin and land use, we have plotted these same nitrate values (Fig. 6.1) with land parcels listed as having ISDSs in the El Paso County assessor's database. This relationship is presented as Figure 6.2 which portrays the locations of the 4,887 parcels listed as having ISDSs by El Paso County. This analysis does not indicate a direct correlation with elevated nitrate concentrations, where data are present. However, most of the locations where groundwater data are available have residential developments with lots greater than 35 acres and thus a low ISDS density. Elevated nitrate concentrations also occur in areas with no septic systems. It is unlikely

that low-density residential septic systems are contributing significantly to the nitrate loading as the subsurface materials act as sand filters. Areas of higher density residential septic systems lack water quality monitoring information.

A similar analysis was conducted to assess total dissolved solids concentrations with respect to current land use. Twenty-one TDS values are available; 2 values from the 1990s and 19 values from between 2000 and 2010. This relationship is presented as Figure 6.3. TDS concentrations are classified into three categories. Of the 21 values presented in Figure 6.3, all but 5 are in the lowest category of 200-300 mg/L. Elevated TDS values are associated with both dryland farming/grazing land and rural residential land use. As with nitrate, the limited data indicate there is no regional trend in the aquifer that may be associated with particular land uses.

Table 5.1 listed common groundwater contaminants that were associated with certain land uses. During this investigation, we were made aware of operations and facilities within the UBSC basin that could pose a greater potential for impacts to groundwater quality. These include animal feedlots, retail fueling facilities, unpermitted industrial waste treatment/disposal, a permitted landfill and a military base. Where known, the locations of these facilities are shown on Figure 6.4.

- A former animal feedlot has been reported south of Judge Orr Road and west of the Ellicott Highway (Kleckner, 2010). Details regarding the exact location, size and period(s) of operation are unavailable to the current study.
- Five retail-fueling facilities with registered underground storage tanks (USTs) are present in the UBSC basin. According to the Colorado Division of Oil and Public Safety, there are currently no sites with documented groundwater contamination within the study area (Noel 2010). Fuel components have also not been observed in groundwater sample data evaluated for the current study.
- Improper industrial waste treatment has been documented in the UBSC basin. This unpermitted operation occurred at a location (the Cordova property) where metal wastes were discharged into an unregulated waste evaporation pond for the stated purpose of concentrating the waste for metals recovery. The primary contaminants identified in the waste are nickel, copper, cadmium and zinc. Currently, the Colorado Department of Public Health and Environment is overseeing assessment and cleanup activities and monitoring results have not been made available (Henderson, 2010). Indications of elevated metal concentrations have not been observed in groundwater sample data evaluated for the current study.

- The Colorado Springs Landfill is the only regulated landfill known to exist within the current study area and straddles the southwestern boundary of the UBSC basin. This facility accepts municipal solid waste and conducts regular groundwater monitoring for a wide range of groundwater contaminants including metals, organic compounds, and major ions. Groundwater monitoring at well MWG-15 does not indicate elevated concentrations of these constituents.
- The southwest boundary of the UBSC basin is straddled by Schriever Air Force Base (Schriever). This military facility was constructed in the 1980s and known operations at this facility have little potential impact to groundwater quality. Interviews with environmental management staff (Olsen et. al., 2010) and review of documents provided to the CGS by Schriever AFB environmental staff indicate that only minor spills have occurred and have been appropriately mitigated (Schriever AFB, 2007).

Due to the predominance of water supply wells, residents using groundwater may be the first to be influenced by impacts to groundwater quality associated with various land use activities and operations. El Paso County provided information on water supply wells in the basin from the assessor's database. Figure 6.5 presents the 4,955 parcels listed by El Paso County as containing water supply wells in comparison with the location of potential alluvial wells registered with the Office of the State Engineer as determined the CGS study (Topper, 2008). This figure indicates that groundwater is used extensively throughout the basin. The difference between these data is that the county assessor's database data does not differentiate the well depths or aquifer supply water to individual parcels. This information is presented so that stakeholders may assess specific parcel/well locations with respect to the water quality data presented herein.

6.2 Questions from Scope of Work

The Scope of Work for the current study includes a list of specific questions that the Committee wanted to address. These are answered below and expanded upon as needed.

Substantive Scope

- **What is the status of existing groundwater quality, focusing initially on the alluvium of the Upper Black Squirrel Creek Basin?** Overall the groundwater quality is good and the groundwater is suitable for existing beneficial uses. Historically, elevated nitrate concentrations have been observed with some samples exceeding drinking water standards. Water quality data is lacking in those portions of the basin experiencing the most development pressure. The Colorado Department of Public Health and Environment (CDPHE, 2008) gave El Paso County a low priority with respect to vulnerability to agricultural chemicals and nitrate.
- **What groundwater pathways exist? (Understanding how the groundwater system functions is important in determining groundwater contamination migration potential, impacts and solutions.)** The dominant surficial geologic deposits in the UBSC basin are unconsolidated aeolian and alluvial materials that are more vulnerable to contamination than the underlying Denver Basin bedrock aquifers. In general, the UBSC basin alluvial aquifer is characterized by ancient channels carved into the underlying bedrock into which clay, silt, sand and gravel have been deposited. These channels generally follow streambeds currently present in the UBSC basin, but may diverge from the main channels of modern-day streams. Figure 1.2 displays the thickness and distribution of the alluvial deposits and the locations of modern streams. Areas with thicker alluvium, indicated by the cooler colors on the map, are generally the main groundwater pathways. The direction of groundwater flow is from the edges of the basin towards the central main alluvial channel and from north to south. Groundwater flow velocity is estimated by Topper (2008) as 3.1 feet per day resulting in approximately two miles of travel per decade.
- **What is the groundwater age? (Groundwater age can help determine contamination potential according to published reports.)** No age-dating has been reported for the alluvial aquifer within the basin. Water table aquifers such as those present in the UBSC basin are influenced and replenished by precipitation, and the correlation of water levels with precipitation indicate the qualitative age of the water is more modern than “fossil” waters found in the Denver Basin bedrock aquifers.

- What are potential sources of contamination now and in the future (per drinking water and agricultural standards), relating contaminants to land uses and land use patterns, specifically addressing septic systems and other nitrate sources?** Table 5.1 lists common groundwater contaminants that are associated with certain land uses. Land uses present in the UBSC Basin having the potential to contaminate groundwater include retail fuel distribution, agricultural operations, automotive salvage yards, residential ISDSs, feedlots, landfills, military facilities, and industrial waste/wastewater disposal. Analysis of the 4,887 parcels listed as having ISDSs by El Paso County does not indicate a direct correlation with elevated nitrate concentrations, where data are present. However, most of the locations where groundwater quality data are available have residential developments with lots greater than 35 acres and thus a low ISDS density. Elevated nitrate concentrations also occur in areas with no septic systems. The temporal and spatial limitations of the data available for this study precluded identification of potential sources for the elevated concentrations observed.
- What is the probability of groundwater contamination (now and in the future)?** The water quality data collected for this study indicate that some parameters (arsenic, nitrate, pH, sulfate, TDS and iron) have exceeded regulatory drinking water standards at certain locations and times. The data available to this study are not sufficient to indicate whether regional impact to water quality from existing land uses or operations have occurred. However, over half of the samples analyzed for nitrate exceeded 5 mg/L suggesting that historic land uses or operations have likely increased nitrate concentrations in the alluvial aquifer. This also indicates groundwater quality is susceptible to future land use activities. An assessment of the vulnerability of the groundwater resource to contamination depends both on the physical and chemical factors influencing the aquifer as well as the associated anthropogenic effects.

The probability of groundwater contamination in the future is dependent upon the type of development anticipated and occurrence of unpermitted or illegal activities. High density ISDS development, improper disposal of commercial and industrial wastes, focused discharge of stormwater runoff, and discharge of wastewater treatment plant effluent all have the potential to negatively impact groundwater quality in the future.

- What and where are the data gaps?** Significant geographic and temporal limitations of existing water quality data have been identified. There has been no consistent basin-wide, long-term groundwater monitoring program and the available data are insufficient to reliably evaluate specific land use impacts on groundwater quality. There are no data indicative of groundwater age which

could then be used to determine whether contamination is the result of historic, recent or ongoing activities. The most significant geographic data gap is in the northern and western portion of the UBSC basin where the more intensive current development is occurring. The most significant temporal data gap is the lack of regularly-acquired groundwater quality data from a consistent set of wells that would allow determination of trends throughout the UBSC basin.

- **What are appropriate constituents and locations for further testing in Phase 2 to support development of recommendations in Phase 3?** Recommendations for a Phase 2 study are presented in Section 7. The Committee should consider incorporating a vulnerability index assessment tool and defining clear water-resource management objectives before committing to more comprehensive and contaminant specific studies.

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7. Phase 2 Study Recommendations

The Phase 1 study objectives were to characterize the current UBSC basin alluvial aquifer groundwater quality and determine whether there is a correlation between existing and future land uses and groundwater quality. This study was only partially successful in meeting those objectives. The data collected indicates that groundwater is generally of good quality. The study Committee identified nitrate as a contaminant of concern and concentrations exceeding the regulatory drinking water standards have been documented in the basin. Unfortunately, there is no groundwater quality data available in the northwest portion of the basin, where urban land uses and ISDSs are concentrated and continued development is expected. Therefore, we could not correlate groundwater quality with land use and land use patterns.

The vulnerability of the groundwater resource to contamination depends not only on the properties of the groundwater flow system but also on the locations and types of sources of naturally occurring and anthropogenic contaminants, physical and chemical characteristics of the contaminant, and locations of sensitive receptors. Decision makers in El Paso County attempting to assess the vulnerability of the groundwater resource currently lack a complete understanding of the hydrogeology of the aquifer system and the associated anthropogenic effects controlling the source, transport, and fate of potential contaminants. The lack of comprehensive knowledge founded on scientifically defensible data often leads to a choice of deciding whether to manage the groundwater resource based on existing knowledge of the groundwater flow system and the known associations of water quality and land use or to commission more comprehensive and contaminant specific assessments.

The path forward and components of a Phase 2 investigation are very dependent upon the water-resource/land use management objectives to be met. This Phase 1 investigation addressed the concerns about water quality impacts and land use by compiling and quantifying potential contaminants to provide an assessment of current and historic groundwater quality. It did not further our understanding of the groundwater flow system or the geochemical system that determines fate and transport of contaminants. A determination of land use impacts on water quality necessitates a scientific assessment of groundwater vulnerability that can assess both the groundwater flow system and geochemical system. To provide a balance between management and scientific objectives, in addressing the county's concerns, we recommend that a Phase 2 study be implemented focusing on the following primary goals:

1. Further refine our understanding of the groundwater flow system by mapping the geometry and extent of the alluvial aquifer, in the northern and western portions of the basin, and the shallow bedrock aquifers most vulnerable to contamination from surficial sources, investigate interactions with surface water, well pumping and other stresses that influence advective transport of contaminants; and
2. Acquire the data needed to support land-use planning decisions by establishing a long-term groundwater monitoring program throughout the basin.

Groundwater monitoring is a critical component of water-resource management. Specifics of the groundwater monitoring program will be dependent upon the objectives to be achieved and need to be determined in the scoping process of the Phase 2 program. With respect to addressing the county's concerns, the monitoring program should focus on assessing the impact from contaminant sources that are related to specific land uses.

7.1 Further Refine the Hydrogeology of Vulnerable Alluvial and Shallow Bedrock Aquifers

The water resources in the UBSC basin alluvial sediments and the shallow portions of the Denver Basin bedrock aquifers are both vulnerable to contamination from surface activities. The current study has documented the water quality of the alluvial aquifer in the UBSC basin based on limited data availability. Due to the distribution of the available data, our results are limited to the central and southern portions of the basin where the alluvium is thicker. Mapping by the Colorado Geological Survey (Topper, 2008) indicates that thinner alluvial deposits extend into the northern and western portions of the UBSC basin as tributary channels. The degree of saturation in these thinner exterior portions of alluvium is unknown as is their usefulness for water supply. However, these thinner portions of the alluvium are pathways for potential contaminant migration to the greater aquifer. In the northern portions of the basin the Denver Basin bedrock aquifers are also present either at the surface or overlain by relatively thin alluvial or aeolian deposits.

A Phase 2 investigation should include additional hydrogeologic characterization of the alluvial and aeolian sediments in the northern and western portions of the UBSC basin, as well as the shallow portions of Denver Basin bedrock aquifers. Characterization of these aquifers can be performed by evaluating both subsurface and surface geologic information through available geologic mapping, drill logs, and geotechnical reports. Incorporation of current geologic mapping of the Falcon Quadrangle by the CGS would benefit this

effort. In addition to refining the geology, the Phase 2 investigation should also study hydraulic stresses that could influence groundwater flow and surface water interactions. This additional information would provide a better characterization of the hydrogeology in the areas of the basin where the majority of development is occurring or being planned. Details of the Phase 2 Investigation are expected to be refined in Phase 2 Scoping activities.

7.2 Basin-Wide Long-Term Groundwater Monitoring Program

The current data set is highly inconsistent and hampers any analysis to understand potential land use impacts on alluvial aquifer groundwater quality. A long-term groundwater monitoring program will help planners, developers and water suppliers better understand natural and anthropogenic factors affecting groundwater quality throughout the UBSC basin alluvial aquifer. The new data will also provide a scientific basis to support regulators and policy makers regarding potential policy and / or regulatory changes that may result from Phase 3 activities or provide input for statistical and process-based methods used in groundwater vulnerability assessments.

The proposed long-term, groundwater monitoring program will fill data gaps in the current study and help evaluate impacts related to specific land uses. Objectives and specific details (well locations, monitoring parameters, monitoring frequency, etc.) of the monitoring program should be determined as part of the Phase 2 scoping process. In designing a monitoring program or sampling strategy, it is important to have specific goals/objective in mind. Depending on the ultimate study objectives other alternate approaches to long-term monitoring may be appropriate.

For guidance, and assuming a long-term, groundwater monitoring program is the preferred approach, we provide a general framework and considerations for implementing such a program. The Phase 2 groundwater monitoring program should incorporate select sampling locations (wells) previously sampled by the USGS (e.g. Brendle, 1997) and CGS (e.g. Topper, 2008) to provide continuity and repeatability of long-term concentration trends. To assess trends and determine current water quality, wells from which samples have exceeded water quality standards should be resampled during the first two years for the respective parameter(s) that have exceeded standards. Existing wells considered for inclusion in a monitoring network should be assessed and construction details evaluated to determine the suitability for meeting the programs objective.

Based on the finding of the Phase 1 study, we offer suggested locations for groundwater quality monitoring that fill data gaps and provide for assessment of potential contaminant sources. The general locations of proposed monitoring wells are presented in Figure 7.1. While generalized, these proposed locations address spatial data gaps, consider surface water interactions and flow pathways, are downgradient of potential nitrate sources, and include areas where new development is anticipated. These locations are predominantly along stream channels and at the confluence of alluvial channels. Figure 7.1 also shows those wells that have been included in previous USGS and CGS monitoring well sampling programs with existing water quality data.

Design of the monitoring plan will be dependent upon the objectives and scope of the project. Considerations include: hydrogeologic units to be monitored; analytes of concern; well types and sampling intervals; land use; timeframe for the program; financial, personnel, and analytical considerations; and data management considerations. We suggest semi-annual monitoring for the first two years of the program with a focus on contaminants of concern and those commonly associated with existing and future land uses. The following general groups of indicator parameters should be considered for inclusion in the groundwater monitoring program:

- Field measurements (water level, pH, specific conductance, temperature, dissolved oxygen)
- Total dissolved solids (TDS)
- Major Inorganic Ions (calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate)
- Nitrate and Phosphate
- Coliform bacteria
- Total petroleum hydrocarbons (gasoline and diesel range)
- Total organic carbon (TOC)

The above parameters are either contaminants of concern previously identified in the UBSC basin alluvial aquifer or indicators of potential groundwater quality impacts associated with current and expected land uses in the UBSC basin. The use of indicator parameters establishes baseline water quality at each sample location and an early warning system of potential contamination can guide the selection of additional, more specific sampling parameters to monitor for potential contaminants. Following establishment of baseline conditions, the monitoring program may be revised as needed to change sampling frequency and/or list of parameters either for the entire program or at individual wells.

The Committee may desire to design a specific stratified network based on land use and other important variables that could impact groundwater quality, and sample that network for specific constituents needed for data analysis. It may also consider adding emerging contaminants such as pharmaceuticals and personal care products. Conn, Siegrist and Barber (2007) have identified such compounds in residential and commercial wastewater and describe negligible removal of these compounds by ISDS treatment alone. Should more quantitative groundwater age data than the estimates provided herein be desired, Rupert and Plummer (2009) provide a template for age determination sampling and analysis. Details of the Phase 2 program are dependent upon the ultimate study objectives, which are expected to be clarified in the Phase 2 scoping activities.

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