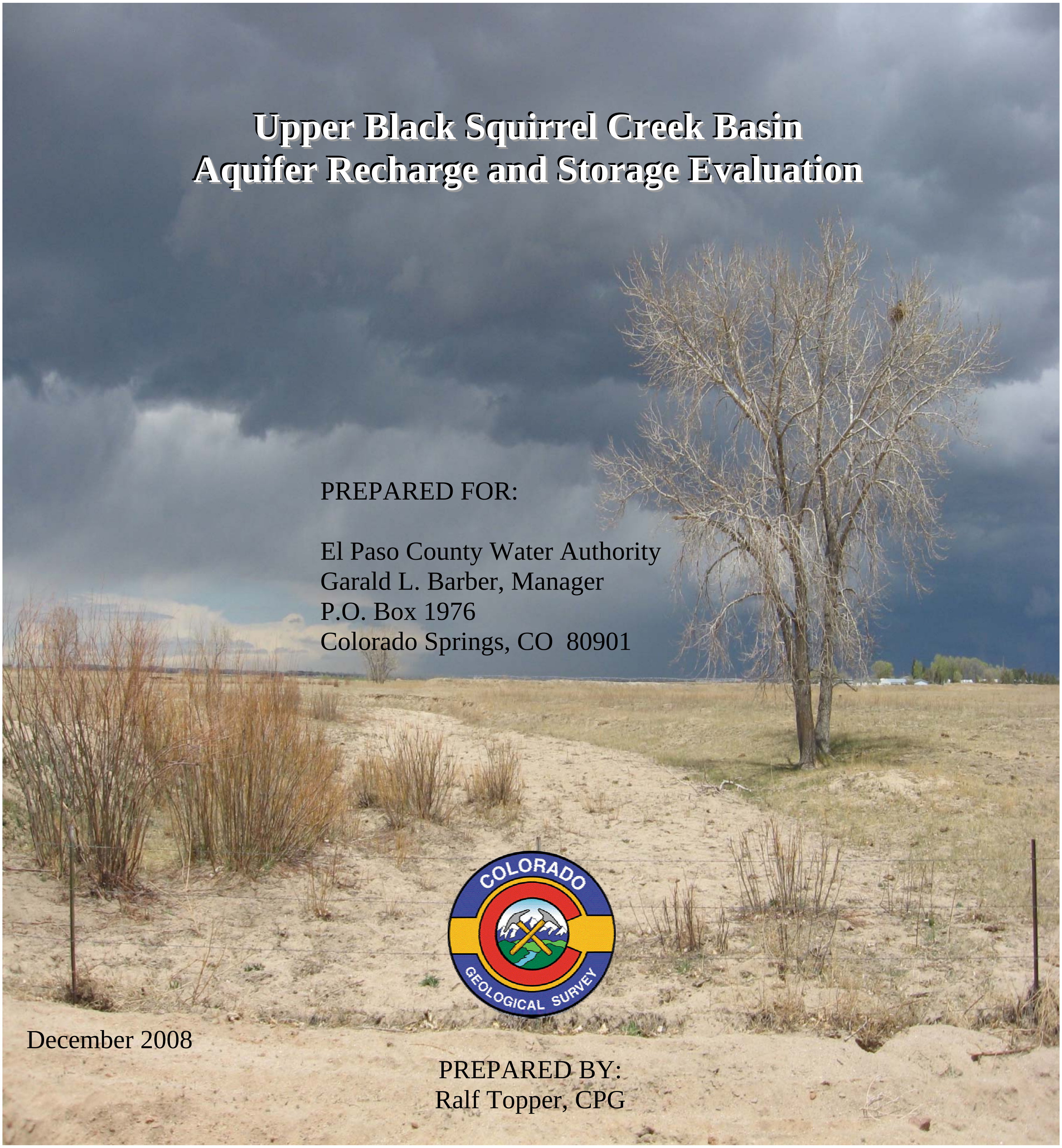
Upper Black Squirrel Creek Basin Aquifer Recharge and Storage Evaluation



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The objective of this project is to evaluate and refine the existing knowledge of the hydrogeology of the alluvial aquifer system in the Upper Black Squirrel Creek basin for the purposes of assessing the potential for aquifer recharge and storage implementation. Geographic, geologic, hydrologic and water quality data were collected and analyzed to evaluate the recharge potential, storage capacity, and ambient water quality in the study area. The study area encompasses the entire Upper Black Squirrel Creek drainage basin and coincides with the designated ground water basin boundary (Figure 1). The analysis and display of data collected or acquired for this study was accomplished through application of Geographic Information System (GIS) software, specifically ESRI ArcGIS v.9.3. The results and findings of this study are being conveyed through production of a series of map plates and this accompanying report. The associated GIS files and tabular data used in the generation of the maps will also be made available to the project participants.

In January 2006 the El Paso County Water Authority (EPCWA) submitted a grant application to the Severance Tax Trust Fund Operational Account administered by the Colorado Water Conservation Board. That grant application requested funding in the amount of $50,000 to be used towards funding an investigation of recharge capacity and potential in the Upper Black Squirrel Creek Basin in conjunction with matching funds provided by El Paso County Water Authority. The idea of recharging water into the alluvium of Upper Black Squirrel Creek came in part from Colorado Water Resources Circular #32, published by the Colorado Water Conservation Board in 1976. That circular documents declining water levels and a loss of water in storage of approximately 50,000 acre-feet between 1964 and 1974. That loss afforded an opportunity to recharge that portion of the alluvium that once stored water.

The Colorado Geological Survey (CGS) was identified as the contractor to perform the study, and submitted a scope of work and final cost estimate to the EPCWA on November 27, 2006. The Water Authority sought and acquired additional funding for the project through a Water Supply Reserve Account grant application that was approved by the Arkansas River Basin Roundtable established under the Colorado Water for the 21st Century Act. Individual project cooperators including: Cherokee Metro District, Colorado Springs Utilities, Meridian Ranch Metro District, Paintbrush Hills Metro District, Sunset Metro District, Upper Black Squirrel Creek Ground Water Management District, and Woodmen Hills Metro District provided the balance of the project funding. The final contract between the EPCWA and CGS was executed on May 2, 2007.

ACKNOWLEDGMENTS

This project was conceived and made possible by the vision, preliminary funding request, and ongoing management of Mr. Garald Barber of the El Paso County Water Authority. The board of directors of the EPCWA have been strong supporters of underground storage, and their interest in this area provided the organizational structure and funding to move the concept forward.

The Colorado Geological Survey is very grateful for the input, support, and data-sharing contributions of the cooperating partners. This project benefitted significantly from the cooperative environment established between the various utilities involved in this project. We would like to specifically acknowledge several organizations and key personnel for providing engineering infrastructure files, well production information, and hydrologic data. The level of cooperation and data-sharing by Mr. Kip Petersen and the Cherokee Metropolitan District was unparalleled in a basin renowned for its legal conflicts. Mr. Sean Chambers of Sunset Metropolitan District and Mr. Patrick Wells of Colorado Springs Utilities were most helpful in providing service area and infrastructure information for their respective utilities and in sharing their knowledge of water development in the basin. A wealth of information on land use, land ownership, special districts, infrastructure, and geology was made available by El Paso County, through the dedicated efforts of Mr. Carl Schueler, former Long Range Planning Manager with the county.

The Upper Black Squirrel Creek Ground Water Management District, through its former president Kathy Hare and current president Dave Doran, provided critical information on water development in the basin and coordinated a most beneficial reconnaissance tour of the basin. The district also provided access to their consulting geologist, Mr. John Himmelreich, who provided valuable geologic maps and reports and facilitated a geologic fieldtrip of the basin. The previous published studies and ongoing hydrogeologic work in the basin by the U.S. Geological Survey were very valuable to this study. The cooperation and information provided by Mr. Ken Watts and his associates in the USGS Southeast Colorado Water Science Center is very much appreciated.

We would also like to acknowledge the cooperation of the Colorado State Board of Land Commissioners and their managers, Mr. John Valentine and Matt Pollart, for providing historical hydrologic reports and documents for the basin and access to state parcels for installation of new monitoring wells. We gratefully appreciate the cooperation of local land owners who have participated in the state's monitoring well program, and extend particular thanks to Mr. Dean Goss and Mr. George Schubert for access to their wells.

This study kicked off with an absolutely delightful and most beneficial aerial reconnaissance tour of the basin coordinated by Mr. Sean Chambers and provided by Mr. Rodney Preisser. The ability to view and photograph the Upper Black Squirrel Creek basin from the cockpit of a small airplane was of tremendous benefit in understanding the geography and geometry of the basin as well as visualizing the geomorphic and geologic features. The generosity of Mr. Preisser in providing this opportunity and the experience it offered is very much appreciated. Lastly, I would like to recognize the contributions of Colorado Geological Survey temporary employee Kevin Donegan whose assistance with the fieldwork and GIS skills contributed greatly to this final product.

INTRODUCTION

The Upper Black Squirrel Creek drainage basin is located in the southern part of the structural Denver Basin. This basin encompasses an area of approximately 350 square miles and is entirely within east-central El Paso County, Colorado. The northern portion of Black Squirrel Creek and its associated tributaries, of which Brackett and Big Springs Creek are the only two commonly named, form a drainage basin known as Upper Black Squirrel Creek basin (Fig.1). All the streams in the basin are ephemeral, have dry sandy streambeds, and flow only in direct response to thunderstorms, spring snowmelt, or prolonged periods of rainfall. Consequently, these streams are not a reliable water source. Water supply over much of the basin comes from the alluvial aquifer and the underlying Denver Basin bedrock aquifers. As surface water is scarce and ground water has been the dominant water source since the late 1800's, the Colorado Ground Water Commission established the Upper Black Squirrel Creek designated ground water basin in May 1968 (Plate 1). The drainage basin very nearly coincides with the boundaries of the designated ground water basin of the same name to the southern edge of the designated basin. The mainstem of Black Squirrel Creek lies approximately 18 miles east of Colorado Springs Municipal Airport. The headwaters of Black Squirrel Creek are in the Black Forest region in the northwest corner of the basin at an elevation of approximately 7,400 feet. The southern edge of the designated ground water basin was taken as the south line of township 15 south, that being Squirrel Creek Road (Erker and Romero, 1967). This boundary also approximates the southern edge of the administrative portion of the Denver Basin being the outcrop area for the Fox Hills Sandstone. The elevation at the southern boundary is approximately 5,600 feet, which produces a total relief in the basin of about 1,800 feet.

The basin is characterized by gently rolling to flat topography. Prairie grasses dominate the native vegetation. The area is rural with the principle industries related to agricultural products and livestock. The town of Ellicott, along State Highway 94, in the south-central portion of the basin is the focus of the agricultural activity. Development pressures are being felt along the western and northwestern portions of the basin as growth expands from Colorado Springs to Falcon. The towns of Falcon and Peyton lie along U.S. Highway 24 which traverses the basin in its northern portion.

Water from the alluvial aquifer is used for domestic, agricultural, and municipal uses. Metropolitan districts that have developed water supply infrastructure in the basin include Cherokee, Woodmen Hills, and Meridian. Exportation of alluvial ground water for municipal purposes in conjunction with extensive development for irrigation and other agricultural purposes since the mid 1950's has resulted in large declines of the water table (Buckles and Watts, 1988). These declines and the resultant loss of water in storage from the aquifer have been documented in numerous studies (Erker and Romero, 1967; Bingham and Klein, 1973 and 1974; Livingston, Klein, and Bingham, 1976; Watts, 1995). This loss presented an opportunity to store water in this newly unsaturated portion of the alluvial aquifer utilizing aquifer recharge technologies. This study integrates new field data collection with information from previous studies and cooperating partners to refine our knowledge of the hydrogeology of the alluvial aquifer system in the Upper Black Squirrel Creek basin for the purposes of identifying potential sites for aquifer recharge and storage implementation. The study area encompasses the entire designated ground water basin within the Upper Black Squirrel Creek basin (Plate 1).

Climatic Considerations

Precipitation is the dominant source of natural ground water recharge. The climate of the Upper Black Squirrel Creek Basin is semi-arid. Precipitation varies in the basin due to elevation differences and orographic effects of topography. Precipitation data has been collected at several locations within and near the basin, e.g. Big Springs Ranch, Yoder, Rush, Calhan, Ellicott, Fountain, and Colorado Springs, however the longevity and continuity of data varies significantly. The more complete period of record for precipitation data correlates to two stations on the west and east sides of the basin respectively, Colorado Springs Municipal Airport and Rush.

Monthly precipitation data at Colorado Springs Municipal Airport is available from 1963-2005. Average annual precipitation for the period of record is 16.7 inches (Fig. 2-A). Mean monthly precipitation ranges seasonally from 0.3 – 3.2 inches (Fig. 2-B). Eighty-one percent of the average annual precipitation (13.5 inches) was recorded between April and September, whereas 19% of the average annual precipitation (3.2 inches) was recorded between October and March.

Monthly precipitation data at Rush is also available from 1963-2005 (excluding 1972, 1973, 1974, 1996). Average annual precipitation for the period of record was 14.3 inches (Fig. 3-A). Mean monthly precipitation ranges seasonally from 0.2 – 2.7 inches (Fig. 3-A). Eighty-three percent of the average annual precipitation (11.9 inches) was recorded between April and September, whereas 17% of the average annual precipitation (2.5 inches) was recorded between October and March.

GEOLOGY OF THE BASIN

The geology of the Upper Black Squirrel Creek basin consists of unconsolidated, Quaternary age alluvial and eolian deposits overlying a sequence of slightly dipping sedimentary rocks of Tertiary and Cretaceous age representing the southern edge of the Denver Basin bedrock aquifers. Understanding the geologic framework of the basin is critical as these rock units form the aquifers that supply ground water to wells. The alluvial deposits consist of gravel, sand, and silt deposited by rivers and streams that were eroding the adjacent bedrock. Consequently the composition of the alluvial deposits mimics the bedrock from which it was derived. Granite, quartz, and feldspar pebbles predominate, and the Dawson Arkose is considered to be the likely source. Erker and Romero (1967) and Goeke (1970) describe the alluvium as consisting of light-yellowish-gray to grayish-orange gravelly sand with thin discontinuous layers of silt and clay and minor amounts of reworked shale.

The geology of the basin has been mapped by several investigators at various scales (Soister, 1968; Schwochow and others, 1974; Scott, 1974; Scott and others, 1978; and Byant and others, 1981). Unfortunately over time, authors have used different means to classify and portray the alluvial deposits. The classifications usually being a combination of place of emplacement like valley-fill, floodplain, or terrace, and age such as the last 5,000 years (e.g. Piney Creek). All of the alluvial deposits in the basin are of Pleistocene age (1.8 million years ago) or younger. They represent sediments that were carried in the outwash or melt-waters of several periods of glaciation. We have compiled the geologic mapping available in the literature to produce a composite geologic map of the Upper Black Squirrel Creek basin (Plate 2). This map follows the naming convention of Scott (1974) using type locality names to depict the glaciation events that produced the deposit. Six mappable sequences of alluvium have been deposited in the basin. The Nussbaum alluvium being the oldest is restricted to the area of the Holcolm Hills in the northeast portion of the basin. The slightly younger Rocky Flats alluvium is located in the area just southeast of Falcon. A remnant of the younger still Verdos alluvium is located in the area near Rattlesnake Butte north of Peyton. Only a sliver of the younger Slocum alluvium remains along the East Branch Brackett Creek. The majority of the alluvium in the basin consists of the youngest of the Pleistocene aged glaciation deposits the Louviers alluvium, referred to as valley fill by others, and the recent aged Piney Creek alluvium that occupies current stream channels. The geometry of the alluvial deposits are masked by an eolian (wind blown) deposit composed of silt and fine to coarse grained sand that blankets a major portion of the basin. The thickness of the eolian deposits varies between 0 and 40 feet (Watts, 1995). The eolian deposits have also been referred to as dune sand deposits (Erker and Romero, 1967). A description of the alluvial and eolian unconsolidated deposits and underlying bedrock formations is included in Table 1.

The contact between the alluvial deposits and underlying northward dipping sedimentary formations of the Denver Basin is erosional. Plate 2 includes the axis of the Denver Basin based on Soister's (1968) structural interpretation of the base of the Pierre Shale. The Cretaceous Pierre Shale subcrops beneath the alluvium in the extreme southern edge of the designated basin, i.e. at Squirrel Creek Road. The Fox Hills Sandstone and Laramie Formation outcrop along the Crow's Roost hillside in the southeastern part of the basin. Conforming with the nomenclature used by Scott (1974), the Tertiary and Upper Cretaceous aged Dawson Formation overlies the Laramie Formation. The Dawson Formation is exposed at the surface over most of the northern portion of the basin. In this terminology, the Dawson Formation includes the Arapahoe and Denver Formations and Dawson Arkose that other investigators often reference. An erosional remnant of the Tertiary age Castle Rock Conglomerate, the youngest of the bedrock units, is exposed in the northernmost portion of the study area at Rattlesnake Butte. Maximum thickness of these bedrock formations is about 1,700 in the northern portion of the basin (Major and others, 1983). This study is only concerned with the hydrogeology of the unconsolidated alluvial deposits not the underlying bedrock formations.

Structure of Bedrock Surface

The buried bedrock surface provides the foundation from which to discuss and analyze the overlying alluvial aquifer. Prior to and concurrent with the deposition of the alluvial sediments, the exposed bedrock surface was subjected to erosion. Streams were actively downcutting and creating channels in the bedrock surface. Erker and Romero (1967) published the first bedrock contour map in the basin based on well and test hole data obtained from the State Engineer's Office, the U.S. Geological Survey, and their own subsurface investigations. Their mapping indicated that deep buried stream channels were incised into the bedrock, which depending upon the stratigraphic position within a formation or the formation itself would be impermeable units such as clays and shales or low permeability units such as siltstone, sandstone, or conglomerate. They also found that the main buried channel of the paleo-Black Squirrel Creek trended north-south and was joined by numerous, small buried-tributary channels emanating from the headwaters areas.

We have digitized Erker and Romero's (1967) bedrock contour map and modified the geometry of that surface based on additional well control information available from the State Engineer's Office, surface topography, and bedrock outcrop areas documented on the available geologic mapping. Plate 3 represents the modified bedrock-contour “structure” map in the Upper Black Squirrel Creek basin using a 20-foot contour interval. The contours in the eastern portion of the basin are not well constrained by well control points. The buried bedrock topographic surface exhibits approximately 1,600 vertical feet of relief between the northern and southern portions of the basin. The surface slopes to the south at approximately 70-80 feet per mile. The inset map on Plate 3 is a hillshade representation of the bedrock topography to aid in visualizing the geometry of this surface. Plate 3 clearly shows the numerous buried tributary channels that originate in the higher elevation headwater areas in the northwest, north, and northeast portions of the basin. The buried tributary stream channels nearly parallel the surface streams. In the northern portion of the basin, a north-south trending deep main channel roughly parallels the Ellicott Highway from the intersection with Highway 94 north to Scott Road. This buried main channel lies approximately ½ to 1 mile east of Brackett Creek. This channel contains numerous irrigation wells and is the location of Cherokee’s northern wellfield. Another large erosional channel is located just west of the town of Ellicott. This channel trends north-south, south of Highway 94 and curves to the northwest, north of the highway. In its northern portion, this channel underlies an unnamed tributary of Black Squirrel Creek. In the southern portion of the basin, south of Highway 94, the erosional buried channels coalesce, and become much broader and deeper. The buried erosional channels in the central and southern portions of the basin tend to be sub-parallel to the current course of Black Squirrel Creek with offsets from 1-2 miles to the east. The best yielding wells and greatest saturated thickness will be found within these buried channels as they are filled with permeable sand and gravel with minor interbedded lenses of silt and clay. This channelized system represents areas of rapid precipitation infiltration, enhanced irrigation return flows, and a large ground water storage capacity.

GROUND WATER

Alluvial Aquifer

The alluvial aquifer consists of the saturated interval of all of the alluvial deposits depicted on the geologic map (Plate 2). This is the principle aquifer in the basin and provides water to supply domestic, stock, irrigation, and municipal wells. It is important to note that though alluvial sequences can be mapped as separate deposits, the composition and physical characteristics of these deposits are quite similar. That is, the alluvium generally consists of unconsolidated gravely sand with intervals of silt and clay that were deposited in paleo stream channels and hence form a continuous aquifer. Alluvial materials have a much greater ability to transmit significant quantities of water than the underlying bedrock aquifers. The presence of finer material, particularly thin, discontinuous beds of clay and silt may influence ground water recharge and flow. The eolian deposits (dune sands) generally lie above the water table and are not a significant aquifer. They are, however, an important catchment area for recharge of precipitation to the underlying alluvium.

As part of El Paso County's HB1041 (1974) mapping, the county contracted with Wm. Curtis Wells and Company to produce a geologic map with aquifer delineations. In our review, we determined that the Curtis Wells map was the best depiction of the alluvium available. Using this map and other published geologic maps as a basis to refine the geometry of the alluvium, we incorporated water well completion information from the Colorado Division of Water Resources well permit database to verify, exclude, or augment previously mapped alluvium. The resultant product from this process is the alluvial coverage map presented as Plate 4. The alluvial aquifer covers approximately 167 mi^2.

Plate 4 also portrays the spatial relationship of the alluvium with the underlying Denver Basin formations that contain the bedrock aquifers administered by the Office of the State Engineer. It should be noted by the reader that the geometry of the Denver Basin aquifers as depicted in the maps associated with the Denver Basin Rules, does not strictly coincide with the geologic formations of the same name. The bedrock geology information displayed on Plate 4 is predominantly compiled from the Curtis Wells mapping produced for the county (unpublished). Rather than the nomenclature used by Scott (1974) as depicted in Plate 2, Curtis Wells has differentiated the Dawson Formation into the Arapahoe and Denver formations and Dawson Arkose. This classification more closely coincides with the Denver Basin bedrock aquifer designations used by the Office of the State Engineer which includes a sequence of permeable and relatively impermeable rocks. Within the permeable intervals of the underlying bedrock formations, there is hydraulic connection with the overlying alluvial aquifer. Watts (1995) suggests that in the northern portion of the basin where the alluvial aquifer overlies the Denver and Arapahoe aquifers ground water flow is upward into the alluvium. In the southern portion of the basin where the alluvial aquifer overlies the Laramie confining unit and Laramie-Fox Hills aquifer ground water flow is downward into the bedrock. Based on modeling simulations, Watts (1995) estimated that the simulated net flow into the alluvial aquifer from the underlying bedrock was 0.50 ft^3/s (approx. 360 acre-feet/year) at the end of the 1990 irrigation season.

The alluvium varies in thickness from a few feet to an estimated maximum of approximately 215 feet. The thickest alluvial sequence encountered in the well database, used in this study, was 205 feet. That well is located in the southern part of the basin near Drennan Road. Utilizing the GIS software allows for analysis beyond the existing control areas. Plate 5 represents the thickness of alluvium, with a 20-foot color gradation interval, within the entire coverage area included in Plate 4. This information was derived through a mathematical calculation of the digital elevation model (topography) and bedrock topography (structure) raster (gridded) surfaces. Subtracting the bedrock contours from the surface topography produces a value in each grid cell of the interval thickness between those two surfaces. We have limited that analysis to the alluvial coverage, and hence the interval thickness represents the thickness of alluvium (or alluvium plus eolian deposits). We acknowledge that this process may be capturing some eolian deposits also, but since the physical characteristics of eolian sands are similar to the alluvial deposits and the eolian deposits are recharge areas we feel justified in their inclusion for the purposes of this study. The interpretation generated from this analysis was corroborated with the well control included on the map. The alluvium thickness in the tributary channels extending to the Falcon and Peyton areas is generally less than 20 feet. The buried channels discussed in the bedrock structure section become very pronounced in this display. The channel in the northern portion of the basin along Ellicott Road may reach a maximum thickness of approximately 180 feet. The larger well defined channel south of Ellicott contains alluvium of approximately 200 feet thickness. The user of this information must keep in mind that alluvium thickness is not only related to buried, incised channels in the bedrock, but is also dependent upon topography. That is, a topographically high area will produce a thick alluvium result in this type of analysis. Fortunately, the central portion of the basin does not contain large topographic variability. Thick regions of alluvium have the ability to store larger volumes of water and are more attractive for high-capacity well production.

As the purposes of this study are to identify areas suitable for aquifer recharge and storage implementation, we have eliminated the thinner (<20 feet) alluvium areas from further consideration. In doing so, a primary alluvium coverage area has been defined that excludes the upper reaches of the tributary arms extending to the western and northwest portion of the basin. This primary alluvium covers an area of approximately 120 mi^2, and will be used for subsequent displays in this report.

Ground Water Withdrawals

Information from the well permit database of the Colorado Division of Water Resources, State Engineer's Office, indicates that as of May 2007 there were 3,947 permitted wells of record within the designated basin. The database was qualified to include only those entries with drilling and/or completion information, i.e. an actual hole in the ground. The distribution of those wells is presented in Plate 6. These wells include all use categories (e.g. domestic, livestock, irrigation, etc.) and both alluvial and bedrock wells.

Utilizing the distribution of alluvium presented as Plate 4 and applying depth of completion criteria, we estimate that as of May 2007 there are a maximum of 1,227 water supply wells potentially completed in the alluvium within the designated basin. The distribution of potential alluvial wells in the basin is presented as Plate 7. Since many of the well permit records are incomplete with respect to well depth, water level, or perforated interval, the number of alluvial wells cited (1,227) is probably an over-estimation. To be included in this accounting, the well location must be within the alluvial coverage, the well depth must be less than 200 feet or not recorded, and the water level must be less than 180 feet or not recorded. For the area north of Highway 24 and west of range 63 west, a stricter criterion was applied as we have determined the alluvium to be much thinner. In this region, a maximum well depth and/or water level of 100 and 80 feet, respectively were used. Again, this estimate of slightly over 1,200 wells completed in the alluvial aquifer is probably an over-estimation, but provides some basis upon which to evaluate ground water withdrawals.

Significant development of the basin's ground-water resources did not occur until the 1950's when many irrigation wells were drilled (Buckles and Watts, 1988). Ground water development for irrigation and municipal demands represent the largest discharge from the alluvial aquifer. Early irrigation was mostly used to grow alfalfa and pasture grass (Buckles and Watts, 1988). McGovern and Jenkins (1966) reported that in 1964 irrigation pumpage from 95 wells and sumps, calculated from fuel and electric power records, was 8,000 acre-feet. In March 1964, Cherokee Water District began providing municipal water to customers located in an enclave of Colorado Springs from eight large-capacity wells (CMD-1 thru -8) with an annual appropriation of 5,260 acre-feet (CMD, 2005). McGovern and Jenkins (1966) estimated that the amount of water in storage in the main channels of the alluvial aquifer was approximately 400,000 acre-feet.

Given the availability of water level data and the initiation of municipal withdrawals, 1964 is the starting year for our analysis of water level declines and loss of ground water in storage in the alluvial aquifer. As part of this study, we analyzed the magnitude and distribution of changes in water levels, in ten year increments, from 1964 to 2004. Water level information in specific wells was obtained from the USGS Active Water-Level Network database and the Colorado Division of Water Resources monitoring database. Where ever possible, we attempted to use water level information from the same wells throughout the study period. Plate 8 shows the change in water levels from 1964-1974 as a response to pumping in the basin. This map shows the wells in which water level measurements were taken as well as the magnitude of decline during that decade. Water levels declined in all of the wells in which measurements were available, and the amount of decline varied from -1 to -42 feet. Since hydrographs vary with pumping cycles and seasonally, we elected to measure and compare water levels with a least-squares fit linear trendline to the actual data. This produced a straight line and eliminated the variability in the hydrograph. Hydrographs for selected wells, for the period of analysis, are also displayed on Plate 8 along with the trendline. The maximum area of decline parallels Black Squirrel Creek in the vicinity of Ellicott. The water level decline information portrayed on this map compares favorably with the map produced by Bingham and Klein (1974). The differences in the maximum decline and area geometry between the Bingham and Klein map and ours are the result of the trendline analysis approach and interpretive license. Using a specific yield of 0.18 for the alluvial aquifer, consistent with Buckles and Watts (1988), the amount of water removed from storage during the period 1964-1974 was approximately 45,300 acre-feet. This calculated value should be considered a minimum as the area in which water levels changed less than five feet were not included in the computation. This loss of water in storage compares to 50,000 acre-feet cited by Livingston and others (1976). Table 2 presents a summary of the amount of water lost or gained from storage in the alluvial aquifer for the four decade periods analyzed.

The loss of water in storage in an aquifer from pumping can be exacerbated by a reduction in natural recharge from precipitation and streamflow infiltration. To assess the potential impacts of climate, we compared the mean annual precipitation values at Rush and Colorado Springs for the period 1963-2005 with the decade periods analyzed in this report. The results of that comparison are displayed as Figure 4. For the 1964-1974 decade, the mean precipitation at both stations was substantially less than the long-term average, thus indicating that the decade as a whole was a period of drought for the region. A reduction of natural recharge would also contribute to water table declines.

For the period 1974-1984, the rate of water level decline decreased dramatically from the previous decade. This is surprising as the Pikes Peak Water Company initiated pumping for municipal use outside of the basin in 1975. The reported changes in water levels varied from -2 to -25 feet. The reduction in the rate and magnitude of decline was likely due to the loss of pump production resulting from the declines of the previous decade. Water level declines for this period are presented as Plate 9. The same analysis methodology and display discussed previously is utilized for all decade water level change maps. We note for this period, the maximum areas of decline remain relatively consistent with that of the previous decade for the area to the southeast of Ellicott. North of Ellicott, the maximum area of decline has elongated parallel to the Ellicott Highway within township 13 south. The loss of water stored in the aquifer for the period 1974-1984 was determined to be approximately 7,800 acre-feet based on the volume of the impacted areas in the aquifer. Buckles and Watts (1988) reported that the amount of ground water exported out of the basin by the Cherokee Water District and the Pikes Peak Water Company for municipal use during this period was 22,370 acre-feet. Consumptive use from irrigation pumping would add another 20-30 percent to the municipal use value. The large discrepancy between the calculated storage loss value and the consumptive use values may be due to (1) the portions of the aquifer that are not included in the calculation (i.e. area with changes in water level of less than five feet), (2) errors in the reported municipal pumping amounts, (3) the impact of natural recharge, or (4) any combination of these. In comparing the precipitation data for this period, it appears that the 1974-1984 decade was a normal period relative to the long-term average (Fig. 4).

Buckles and Watts (1988) suggest that between1964-1984 about 100,000 acre-feet of water had been removed from storage. Our calculations based on ArcGIS analysis indicates that their value may be overestimated, with at least 53,000 acre-feet of water in storage removed.

The rate of water level decline decreased further in the 1984-1994 decade. Reported water level changes varied from -2 to -19 feet. For this period, three separate areas of decline are delineated on Plate 10. The northernmost area still parallels the Ellicott Highway, but has expanded further north beyond Judge Orr Road. The middle area remains just east of Ellicott, but has contracted in size from the previous decade. A new southern area of declining water levels has developed in the vicinity of the Pikes Peak wellfield, just west of the Ellicott Highway and south of Drennan Road. Analysis of the change in ground-water storage during this period indicates that a minimum of about 9,400 acre-feet was lost.

1994-2004 represents the last decade we analyzed for basin-wide water level changes. Surprisingly, this decade produced both regions of recovery and decline (Plate 11). The decline rates remained similar to that of the previous decade with water level declines of -2 to -19. The volumetric calculations produce a minimum 2,460 acre feet of water removed from storage. The areas still experiencing water level declines have constricted significantly. The northern area has constricted to a portion along the Ellicott Highway between Jones Road and the Falcon Highway. The southern area in the paleo-channel near Drennan Road has expanded slightly to the north towards Black Squirrel Creek. Areas which experienced rises in the water table saw increases of 1 to 14 feet. Volumetric calculations indicate that a minimum of 4,360 acre feet of water has been restored to the aquifer. These include the northernmost portion of the basin along the Ellicott Highway in the vicinity of Judge Orr Road and a large area just north of Ellicott spanning both Black Squirrel and Brackett Creek. Personal communication with local irrigation well owners has confirmed that well production capacities have fallen off dramatically since the 1960's as a result of declining water tables.

Rising water tables implies that natural recharge rates exceed ground-water withdrawal rates. Municipal water providers exporting water out of the basin have had to expand their well fields as individual well production has declined in order to meet production demands. The larger distribution of these municipal wells in conjunction with changes in operating schedules may be reducing the localized impact seen in the previous decades. Natural recharge from precipitation certainly played a role during this decade. Flood events were recorded in 1995, 1996, 1997, 1998, and 1999. The Gazette reported that rainfall totals made 1999 the wettest in 100 years. Eight to thirteen inches of rain fell in late April 1999 producing an estimated $30 million in damages in El Paso County (The Colorado Springs Gazette). Average precipitation values for the period 1994-2004 at both Rush and Colorado Springs were significantly higher than the long term average (Fig. 4). It appears that the above average precipitation during this decade has resulted in partial replenishment of lost storage in the basin. Based on the volumetric calculations conducted using ArcGIS, the net increase of water in storage in the aquifer was at least 1,900 acre feet.

Table 2

Historic Changes in Ground Water Storage

Decade	**Maximum Change in Water Level (ft)**	**Area of Water Table Change > 5ft (acres)** (Determined from ArcGIS)	**Change in Ground Water Storage* (acre-feet)** (Determined from ArcGIS)
1964-1974	-42	19,300	-45,272
1974-1984	-25	13,519	-7,841
1984-1994	-19	12,908	-9,445
1994-2004	-19	5,137	-2,461
1994-2004	14	5,679	4,356
1994-2004 Net			1,895
Cum 1964-2004	-42		**-60,664**

* Using a storage capacity per unit volume (specific yield) of 0.18

Ground Water Recharge

The dominant source of recharge to the alluvial aquifer is infiltration of precipitation and surface water. As all of the stream drainages within the basin only flow in response to large precipitation events or spring snowmelt, precipitation is the key resource for ground water recharge. Watts (1995) indicated that this source represented about 93 percent of total recharge. Irrigation return flow and upward flow from the underlying bedrock aquifers represent the remainder of the total recharge component. Long term precipitation data is available from the National Climatic Data Center stations at Colorado Springs Municipal Airport and in Rush. Average annual precipitation for a 42-year period of record (1963-2005) at Colorado Springs Municipal Airport is 16.7 inches. The average annual precipitation for approximately the same period at Rush is 14.3 inches. Larger amounts of precipitation can be expected in the upland areas in the northern portion of the basin, and the value represented by Colorado Springs Municipal Airport is likely more representative of this region. The central and southern portions of the basin likely receive precipitation amounts more similar to those at Rush.

Erker and Romero (1967) estimated that only 4 percent of actual precipitation is infiltrated to recharge ground water. Colorado Springs Utilities conducted a thorough lysimeter study during the late 1980s and early 1990s and found that natural ground water recharge varies between 7.69 and 3.42 percent of precipitation on irrigated and non-irrigated land, respectively (P. Wells, personal comm.). The majority of precipitation is lost to evapotranspiration. Using a 4 percent estimate, annual recharge to the alluvial aquifer ranges from 0.67 to 0.57 inches per year. The alluvial aquifer as depicted on Plate 4 covers an area of approximately 167 mi^2. If we ignore the contribution of runoff from bedrock surfaces and deep percolation of infiltration through the eolian deposits, the volume of annual recharge to the alluvial aquifer ranges from approximately 5,080 to 5,970 acre-feet per year. This annual amount of ground water recharge compares to approximately 8,670 acre-feet per year estimated by modeling by Watts (1995) and 11,500 acre-feet per year estimated by Erker and Romero (1967).

Ground Water Levels

Erker and Romero (1967) produced a water table contour map of the Upper Black Squirrel Creek basin from 111 observation points during the spring 1966. We digitized the Erker and Romero map on a 50-foot contour interval and displayed those contours with our primary alluvium coverage as Plate 12. This map forms a basis upon which to compare later water level measurements. The spring 1966 water table is characterized as a broad north-south trending trough with several small troughs that coincide with buried channel systems. The water table varies from 6,600 feet above mean sea level in the northernmost part of the primary alluvium to 5,550 feet at the southern designated basin boundary. This produces a gradient of 1,050 feet over 23 miles or 0.0086, which is 45 feet per mile. Water flows downgradient and at right angles to the water table contours. In the northern portion of the basin, ground water flows from the upland areas receiving recharge towards the center main buried channel. In the central portion of the basin around Ellicott, there is a steeper gradient of approximately 80 feet per mile along the western edge of the primary alluvium. This steepening in the hydraulic gradient may be the result of recharge from the overlying eolian deposits and the influence of the vertical flow component. The flow east of Ellicott is predominantly southward. In the southern portion of the basin, ground water again flows from the flanking upland areas towards the center of the buried channel.

This project included measurement of water levels in wells for a 6-month period. Water level measurements were obtained from 88 wells in a network established by CGS that included wells monitored annually by the Colorado Division of Water Resources (DWR), a water level monitoring network established by Cherokee Metropolitan District, and a long-term network established by the USGS (Plate 13). The water level measurements and associated graphs are attached as Appendix A. Water levels were measured by CGS staff in 26 existing wells (designated BS-xx to correspond to the DWR designation), most of which were active irrigation wells. Water levels were measured with a steel tape or electronic water level meter monthly beginning in mid-December 2007 and ending at the end of May 2008. This time frame should encompass the seasonal low water table, spring recharge cycle, and impact from irrigation wells. The USGS site identification convention (public land grid survey system) is used for the well location information field. In general, for the period of record water levels varied from approximately 9 feet below ground surface at well BS-22A to approximately 123 feet below ground surface at well BS-29. Water levels in most wells exhibited a slight increase (a few feet) in the water table in response to spring recharge. The water levels in wells in the northern-most and southern-most portion of the basin remained relatively stable for the period of monitoring. Water levels in wells that were actively pumping were not recorded. Most irrigation wells started pumping in March or April, and water levels in wells near pumping irrigation wells started declining. Surprisingly, the maximum change in water levels in wells measured for this study was generally less than 10 feet.

Under a cooperative agreement with the USGS, Cherokee Metropolitan District measures water levels on a bimonthly basis from their production wells #1 through #17 and their associated monitoring wells, as well as 13 dedicated monitoring wells not associated with their production wells. These measurements are forwarded to the USGS Pueblo office for inclusion in their National Water Information System (NWIS) database accessible through the web. The water level measurements collected from these wells from December 2007 through June 2008 are included in Appendix A along with their associated hydrographs. For the monitoring period of this study, water levels within the CMD network varied from 17 feet below ground surface in well 11/24 to approximately 125 feet below ground at production well 11. Under non-pumping conditions, the water levels during the 6-month monitoring period were relatively stable. Water levels in most wells exhibited a 1-4 feet rise, depending upon location, in response to spring recharge. The response of the water table to CMD production well pumping produced drawdowns of approximately 18-40 feet.

The USGS actively monitors water levels in 8 alluvial wells every other month. Water levels were reported for the months of January, March, and May 2008. Four of those wells correspond to wells within the CGS monitoring network. The water level measurements and associated hydrographs for the other four, identified as Salay wells, are included in Appendix A. The water levels in these wells varied from 73 to 98 feet below ground level. For the short period of record, wells 1 through 3 experienced an approximate one foot rise in the water table while well 4 reported a one foot decline.

The 6-month monitoring period of this study was an attempt to quantify the seasonal variability of the water table. This variability is dependent upon natural recharge. Precipitation during the winter 2007 and spring 2008 was significantly below the long-term average for the basin. Our monitoring did not record large variations in the water table. In general, the water table only rose 2-4 feet in response to spring recharge. Water level information maintained by the USGS as part of the NWIS program contains information in the basin with periods of record exceeding 30 years.

The altitude of the water table was remapped using data collected from the monitoring well network in January 2008. This recent water table contour map, on a 50-feet contour interval, is presented as Plate 14. It should be noted that in the northeast portion of the basin, the water table contours have been extended into the area dominated by bedrock. We do not intend to imply that this map represents bedrock water levels. Extension of the contours was necessary to avoid edge effects in the computational processes. These contours were not trimmed back prior to printing the map plates, but are correct in the digital files.

The January 2008 water table contour map portrays the response of the water table to ground-water withdrawals. In comparison to the map produced from the 1966 data (Plate 12) we notice:

- The head differential between the northern-most primary alluvial coverage and the southern boundary of the designated basin is 1,100 feet. This produces a gradient only slightly larger than observed in 1966 of 0.0091, which is 48 feet per mile versus 45 feet per mile in 1966.
- The water table has become much more sculpted in response to pumping with narrower and deeper troughs coinciding with buried alluvial channels.
- Flow throughout the basin is towards the main buried channel of Black Squirrel Creek from the surrounding upland areas and south out of the study area
- Gradients from the flanking upland areas towards the center of the buried channel have increased significantly over that observed in 1966, ranging from 0.015 to 0.025 or 80 to130 feet per mile.

While the general ground water flow direction remains similar to 1966, i.e. towards the center main buried channel and south, locally the direction of ground water flow has deviated by up to 45^{o}.

Ground water flow velocity is a function of the aquifer's hydraulic conductivity, the aquifer's effective porosity, and the slope or gradient of the water table. In summarizing the available pump test data, discussed in the next section, the average horizontal hydraulic conductivity of the alluvial aquifer was determined to be 87 ft/day. The effective porosity of the alluvium is generally cited to be 25-35 percent (Watts, personal comm.). Effective porosity being the interconnected pore space through which water can flow. We use an effective porosity value of 25 percent, consistent with Buckles and Watts (1988) and the value determined by a tracer test in the southern portion of the basin (URS, 2004). Applying a basin-wide gradient of 0.009, produces an average flow velocity of 31 ft/day or 1,143 ft/yr. Under this scenario, ground water is expected to move approximately 2 miles in 10 years. The range in calculated hydraulic conductivity values produces ground water flow velocities slower or faster than the average value, i.e. 631 ft/yr or 1,767 ft/yr, respectively. This calculation assumes uniform aquifer conditions and produces average velocity and travel times. Actual conditions can vary considerably as the lithology of the alluvium changes. In addition, local flow velocities may be greater due to variations in the gradient and aquifer hydraulic conductivity.

ALLUVIAL AQUIFER PROPERTIES

The variability of the physical characteristics of the alluvium is a critical consideration for aquifer recharge and storage as this variability would considerably influence the hydraulic properties of the aquifer. The alluvial deposits predominantly consist of gravelly-sand deposited by rivers and streams that were eroding the adjacent bedrock. Overbank or off-channel deposits of the alluvium also contain a finer grained fraction as layers of silt and clay. The presence and thickness of this finer material, particularly continuous beds of clay and silt can significantly influence ground water recharge and flow (Emmons, 1977). Several investigators (McGovern and Jenkins, 1966; Erker and Romero, 1967; Goeke, 1970; Emmons, 1977; Buckles and Watts, 1988; and URS, 2004) have cited the presence of lenses of silt and clay within the predominantly gravelly-sand alluvial aquifer. A layered alluvial system will significantly impact the vertical hydraulic conductivity and thus the infiltration rate if recharge is implemented through spreading basins/surface lagoons

As part of this project, we installed six new monitoring wells on State Land Board parcels. These wells, completed for potential stock water use, will be accessible for future monitoring activities. The new wells designated SLB-1 through -6 were drilled by Can-America Drilling, Inc. of Simla, Colorado using a mud rotary drill rig. The locations of wells SLB-1 through -6 are shown on figure 5. CGS personnel supervised the drilling activities, logged and classified the geologic materials circulated up the borehole, ran geophysical logs in the open borehole, designed and supervised the well completion details, and observed the well development activities. At the request of the State Land Board, these wells were designed for stock watering application with the installation of 4-1/2 inch Schedule 40 PVC casing. The geophysical logging suite included spontaneous potential, single-point resistance, and natural gamma. A diagram for each well including a geologic description log, the geophysical tool responses, and a well completion diagram are attached as Appendix B.

Each of the new monitoring wells was drilled to the top of bedrock, which consisted of either gray sandstone/siltstone or gray shale. A few clay intervals were encountered in select wells with thickness varying from a few inches to approximately four feet. More often, clayey mixtures were encountered. Based on our drilling activities, we did not observe any thick clay intervals, and the clays we encountered were not laterally extensive. Consequently, we do not believe that vertical migration of infiltrated water will be significantly impeded. Locally, perched ground water tables may exist, but due to the limited lateral distribution of these more impermeable layers perched ground water will spill at the edges of these layers and continue a downward migration to the water table.

Aquifer Hydraulic Properties

A number of aquifer pump tests have been conducted in alluvial wells within the basin. Unfortunately, some of the data we anticipated would be available to us was withheld due to legal conflicts. We have compiled aquifer hydraulic property information from public USGS reports, information contained in the Cherokee and Meridian Service Metropolitan District's Southern Well Field Alluvial Aquifer Replacement Plan, Cherokee metropolitan District's consultant reports, and information provided in water court hearings. The available data has been tabulated and is attached as Appendix C.

Appendix C contains information on specific capacity, transmissivity, and hydraulic conductivity. Specific capacity is a measure of well yield (gpm) per foot of drawdown. This well property is dependent upon the amount of drawdown and reflects the efficiency of the well. It is included as a guide to compare aquifer property data from other wells. Transmissivity is the rate at which water is transmitted through a unit width of the entire saturated aquifer under a unit gradient. Transmissivity values range from approximately 22,000 to 73,000 gallons per day per foot. An aquifer's hydraulic conductivity is the volume of water that will move through a unit area of porous media under a unit gradient. Hydraulic conductivity values cited in this report represent the horizontal component and range from approximately 300 to 1,100 gallons per day per square foot. To determine the average hydraulic conductivity value, we have eliminated the highest and lowest values from consideration to remove the extremes. The remaining data produce an average hydraulic conductivity of 649 gallons per day per square foot, which equates to 87 feet per day. This value is slightly higher than the 64 ft/day estimated by Buckles and Watts (1988) based on ground water modeling, and slightly lower than the 115 ft/day computed from tracer tests conducted by URS for pilot recharge studies in the basin (URS, 2004). In consistent units, the hydraulic conductivity values range from a low of 48 ft/day to a high of 134 ft/day.

A value for the vertical hydraulic conductivity of the alluvial aquifer has only been reported in two locations. In September 1989, Ken Watts (1995) of the USGS conducted a 3 day aquifer test on Cherokee's production well No. 6 in section 7 of township 13 south, range 62 west. Water levels were measured in four observation wells completed in the alluvial aquifer. Type curve matching analysis produced a vertical hydraulic conductivity of 3 ft/day. As part of the pilot study for the southern well field replacement water infiltration basin conducted for Cherokee Metropolitan District, URS Corporation (2004) conducted a 4-month pilot infiltration study that produced a stabilized infiltration rate of 2.8 ft/day. Earlier work on aquifer recharge tests in the Upper Black Squirrel Creek basin conducted by

Emmons (1977) of the USGS produced average rates of infiltration from 1.0-1.7 ft/day. Infiltration rates were dependent upon the water level (stage) in the excavated pits with an adjusted infiltration rate of 1.8 ft/day for a constant stage of 2.5 feet (Emmons, 1977).

Water Quality

Water quality is an environmental consideration that will influence the feasibility and operation of an aquifer recharge/storage project. Knowledge of the ambient water quality of the alluvial aquifer is useful in determining potential geochemical reactions that may occur in the aquifer when chemically different source waters are used for recharge. It also provides information to address potential treatment requirements of recharge or extracted water. We also need to consider the potential leaching of minerals found in the soil or unsaturated zones and impacts to aquifer water quality. In this study, water-quality data for 123 wells was compiled from five existing literature sources (McGovern and Jenkins, 1966; Bingham and Klein, 1973; Buckles and Watts, 1988; Cherokee Metro District - Curt Wells' Reports (unpublished)), as well as five water samples from wells drilled for this study. Of these 123 wells, only 40 had data from laboratory analysis of select chemical constituents. The remaining wells had some data for the water quality physical characteristics of specific conductance, temperature, and pH. These data are summarized in two separate tables (Physical Characteristics and Chemical Analysis) attached as Appendix D.

Specific conductance is an electrical measurement related to the amount and mobility of dissolved ions in the water. Four wells listed in the physical characteristics table had specific conductance values greater than 1,000 micro-Siemens per centimeter. Watts (1995) has used differences in water quality as an indicator of flow between the alluvial and bedrock aquifers. High specific conductance is not a characteristic of the bedrock aquifers in this area, so these wells represent local anomalies. One well (SC12-63-14DDC) highlighted in the chemical analysis table has constituents that are nearly always the highest across the dataset. The elevated nitrite plus nitrate levels in this well indicate it is being influenced by a near surface source, and is not representative of the alluvial aquifer water quality. We note that many alluvial wells are generally drilled to the top of the “grey” or “blue” shale as an indicator of bedrock. At many locations, however, bedrock is a siltstone or sandstone and if penetrated may contribute water to the well, producing a mixed chemical signature.

Based on the analytical data, water from the alluvial aquifer in the basin is classified as either a sodium calcium-mixed anion or a sodium calcium bicarbonate type of water (Figure 6). Samples in figure 6 are annotated with respect to township, and no discernable geographic trends were evident in this water quality data. The concentrations of dissolved calcium plus magnesium approximately equal the concentrations of sodium plus potassium for the alluvial aquifer. Denver Basin bedrock aquifers in the study area are classified as either sodium bicarbonate or sodium-mixed ion type of water (Watts, 1995).

The physical characteristics of the water samples compiled for this study are presented as histograms in Figure 7. Water temperatures ranged from 10–19.5°C with the majority of samples between 11-15°C. The pH of the water samples ranged from 6.3–9.2 with the majority of samples in the neutral range between 6.5–7.9. Specific conductance values ranged from 250–1430 μS/cm with 80% of the samples having a value less than 500 μS/cm.

With a few exceptions, the alluvial ground water is of very good quality with total dissolved solids concentrations below 500 milligrams per liter (mg/L). In four well locations nitrogen compounds exceeded the state drinking water standard. Hardness values ranged from 55 – 511 mg/L $CaCO_3$, with values over 200 mg/L $CaCO_3$ associated with the anomalous wells discussed earlier. In general, these waters are classified as moderately hard to very hard. Sodium absorption ratio (SAR) values for 37 samples ranged from ranged from 0 – 5.3, which in combination with the electrical conductivity data categorizes this water as a low sodium hazard.

ALLUVIAL STORAGE CAPACITY

Amount of Water in Storage

The capacity of an aquifer to store water is quantified by its storage coefficient. For unconfined aquifers like alluvium, the storage coefficient is the specific yield which quantifies the pore space that is drainable by gravity. Some water will be left behind within the pores of the aquifer and this is termed specific retention. The effective porosity represents the summation of the specific yield and the specific retention. The amount of recoverable water in storage is then calculated as the aquifer volume (thickness x extent) multiplied by its specific yield. We can determine the saturated thickness of the alluvial aquifer utilizing the current water level information. Applying the computational functionality of ArcGIS, we have subtracted the bedrock structure (Plate 3) from the January 2008 water table surface (Plate 14) to produce a saturated thickness map. The current saturated thickness of the alluvial aquifer is displayed as Plate 15. The saturated thickness varies from less than one foot to a maximum of 109 feet. Saturated thickness is displayed using a color gradation scheme on Plate 15 with a 20-foot interval with dark blue and purple being the area of maximum saturated thickness. Areas of thicker saturated intervals include (1) an area northwest of the Ellicott Highway between Judge Orr Road and the Falcon Highway, (2) an area directly around Ellicott, (3) an area paralleling the Ellicott Highway between Sanborn and Drennan Road, and (4) an area in the southwest corner of the southern portion of the basin. To estimate the amount of water in storage in the alluvial aquifer, we utilize the specific yield cited by Buckles and Watts (1988) determined from model calibration of 18 percent. This value of specific yield is consistent with previous investigations and represents a conservative value for storage estimates (Emmons, 1977). The total area of primary alluvium used in this calculation is 78,850 acres. The volume of water in storage in the saturated portion of the primary alluvial coverage depicted on Plate 15 is approximately 474,640 acre-feet.

Available Storage Capacity

The unsaturated portion of the alluvium provides the reservoir in which additional water can be stored. The unsaturated portion of the alluvium can be calculated as the interval between the land surface and the water table. Using the raster calculation functionality of ArcGIS, we have subtracted the January 2008 water table surface from the surface topography to produce an unsaturated thickness map. The primary alluvium covers a total area of 78,850 acres. To exclude the negative impacts of shallow ground water, we have applied a 10-foot buffer zone by producing a pseudo-topographic surface that is 10-feet below the actual ground surface. The current unsaturated thickness of alluvium is displayed as Plate 16. The unsaturated thickness varies from less than one foot to a maximum of 174 feet. The thickness information is displayed using a color gradation scheme, with a 10-foot interval, from dark green to dark red for the thickest unsaturated areas. Thick areas of unsaturated materials include (1) an area paralleling the Ellicott Highway between Jones Road and the Falcon Highway, (2) a large area straddling the Ellicott Highway extending for four miles directly south of Ellicott, and (3) an area west of the Ellicott Highway in the vicinity of Drennan Road. Again utilizing a specific yield of 18 percent, i.e. at least 18 percent of the volume is represented by air-filled voids that could be filled with water, we estimate that 605,850 acre-feet of additional storage is available within the unsaturated portion of the alluvium in the basin excluding the uppermost 10-feet. This compares to 510,000 acre-feet estimated in the SB06-193 Underground Water Storage Study. Practically, however, the alluvium could not be filled uniformly to this level without increasing subsurface flow out of the basin and into underlying bedrock aquifers. To identify areas for potential aquifer recharge/storage implementation, we have sliced the unsaturated volume horizontally by depth to quantify the storage capacity for different intervals. For example, if we were only to consider that volume at a depth greater than 50 feet below ground surface, the area available for recharge is reduced to approximately 38,000 acres and the approximate unsaturated storage capacity is 218,330 acre-feet (inset A of Plate 16). Similarly, at 75 feet below ground surface the area available for recharge is reduced to approximately 20,250 acres producing approximately 88,160 acre-feet of storage (inset B of Plate 16). Finally, if we only consider that area greater than 100 feet below ground surface, three distinct areas are delineated with a cumulative area of 8,540 acres and an associated unsaturated alluvium storage capacity of 26,000 acre-feet (inset C of Plate 16). The available storage capacity displayed on Plate 16 is summarized on Table 3 below.

Table 3

Storage Capacity in the Upper Black Squirrel Creek Basin

Alluvium Description	**Area (acres)** (Determined from ArcGIS)	**Total Volume (cubic meters)** (Determined from ArcGIS)	**Storage Capacity* (acre-feet)**
Total saturated primary alluvium	78,850	3.255×10^9	474,640
Total unsaturated primary alluvium (10 ft. buffer)	78,850	4.155×10^9	605,860
Unsaturated alluvium greater than 50 feet deep	38,000	1.497×10^9	218,330
Unsaturated alluvium greater than 75 feet deep	20,250	6.047×10^8	88,160
Unsaturated alluvium greater than 100 feet deep	8,540	1.783×10^8	26,000

* Using a storage coefficient (specific yield) of 0.18

LAND USE/OWNERSHIP AND AVAILABLE INFRASTRUCTURE

Land use/ownership and proximity to existing infrastructure are two of the most important concerns in evaluating the relative ease or difficulty of implementing an aquifer recharge project. We assume that recharge projects are more easily sited on public lands not zoned for development. Considerations include the location of urban, commercial and industrial, planned development, residential, open-space, or agricultural zoning designations. Knowledge of whether the lands are public versus privately held and the locations of inaccessible lands (such as military bases and reserves) is also valuable. El Paso County provided the zoning designation of lands within the Upper Black Squirrel Creek basin as of November 2007. This information is compiled as Plate 17. In the central portion of the basin, encompassing the primary storage areas, the majority of land is zoned agricultural with some residential in the western portions. Information on publicly-owned federal, state, and county land was acquired from the Colorado Department of Transportation (published Dec. 2005) and El Paso County (published Nov. 2007). Information on privately held land was acquired from El Paso County (published Nov. 2007). The land ownership information is compiled as Plate 18. The information is displayed as publicly or privately-owned and the private land holdings are further categorized by the size of the parcel and name of the property owner. Properties smaller than 160 acres are not displayed on Plate 18. The three primary storage areas, outlined on Plate 16, are also displayed on this map. Most of the land within these areas is privately-owned with parcel sizes from less than 160 acres to 1280 acres. Some state-owned land exists within the storage areas in the southern portion of the basin.

The presence of existing utility infrastructure, particularly water conveyance features, is an important consideration influencing the cost and overall feasibility of an aquifer recharge/storage project. The sources of water available for storage are not considered in this study. It is assumed, however, that the existence of canals, ditches, pipelines, and other water delivery/storage structures presents an opportunity to convey water to a potential recharge location. Utility infrastructure information was provided by all of the water and water and sanitation districts in the basin. These included Colorado Springs Utilities, Cherokee, Sunset Metro, Woodmen Hills, and Meridian Metropolitan Districts. This information is compiled as Plate 19. Included on Plate 19 are the existing and proposed service areas for these utilities. The service areas represent larger established or proposed suburban developments.

Though outside of the designated basin, water delivery pipelines with a diameter greater than 24-inches are displayed for Colorado Springs Utilities as their proximity to the western portion of the basin affords a cooperative venture opportunity. Also displayed on Plate 19 is the proposed Jimmy Camp Creek Reservoir, a potential component of the Southern Delivery System. The Upper Williams Creek Reservoir located approximately 6-7 miles south of the proposed Jimmy Camp Creek Reservoir is another proposed alternative for terminal storage in the Southern Delivery System. If constructed, either of these reservoirs offers temporary storage that might be used as an exchange mechanism for ground water stored or recovered from the basin.

Plate 19 contains locations and information on water supply wells, water and wastewater distribution lines, storage tanks, and lift stations for each of the utilities operating in the basin. Also included are existing and proposed wastewater treatment plants. Key components of the Southern Well Field Alluvial Aquifer Replacement Plan submitted by Cherokee Metropolitan District and Meridian Service Metropolitan District are also displayed on this map. These include a new wastewater treatment plant currently in construction southeast of Schreiver Air Force Base, the location of the ground water recharge infiltration basins, and the locations of the current wells within the Southern Well Field. Advanced treated effluent will be released to the infiltration basins to augment out-of-priority pumping.

The three primary storage areas are also overlaid on Plate 19. Cherokee's water transmission distribution system traverses the majority of these potential storage areas. Meridian/Woodmen Hills water main along Judge Orr Road traverses the northern portion of the 50 and 75 feet storage area. A proposed water supply line by Sunset Metropolitan District would also be located in this area. Sunset also has an existing and proposed wastewater main west of Ellicott that traverses a number of potential storage areas. Plate 19 demonstrates that water conveyance infrastructure currently exists and more is proposed that could be used to convey water to potential recharge locations.

SUMMARY AND CONCLUSIONS

This study integrates new field data with information from previous studies and cooperating partners to refine our knowledge of the hydrogeology of the alluvial aquifer system in the Upper Black Squirrel Creek basin for the purposes of identifying potential sites for aquifer recharge and storage implementation. The analysis and display of data collected or acquired for this study was accomplished through application of Geographic Information System (GIS) software, specifically ESRI ArcGIS v.9.3. The results and findings of this study are being conveyed through production of a series of map plates and this accompanying report.

The study area encompasses the entire Upper Black Squirrel Creek drainage basin and coincides with the designated ground water basin boundary (Fig.1). This basin encompasses an area of approximately 350 square miles and is entirely within east-central El Paso County, Colorado. All the streams in the basin are ephemeral, have dry sandy streambeds, and flow only in direct response to thunderstorms, spring snowmelt, or prolonged periods of rainfall. Consequently, these streams are not a reliable water source. Ground water from the alluvial aquifer has been the dominant water source since the late 1800's.

Water from the alluvial aquifer is used for domestic, agricultural, and municipal uses. Cherokee, Woodmen Hills, and Meridian metropolitan districts have developed water supply infrastructure in the basin to service their customers. Exportation of alluvial ground water for municipal supply in conjunction with extensive development for irrigation and other agricultural purposes, since the mid 1950's, has resulted in large declines of the water table.

The geology of the alluvium consists of six sequences of gravel, sand, and silt deposited by rivers and streams that were eroding the adjacent bedrock. These alluvial deposits overlie slightly dipping sedimentary rocks of Tertiary and Cretaceous age representing the southern edge of the Denver Basin bedrock aquifers. The geometry of the alluvial deposits are masked by an eolian (wind blown) deposit composed of silt and fine to coarse grained sand that blankets a major portion of the basin. Prior to and concurrent with the deposition of the alluvial sediments, the exposed bedrock surface was subjected to erosion. A buried structure map of the bedrock topographic surface depicting the incised erosional channels is presented as Plate 3, and forms the foundation of the alluvial aquifer system.

The alluvium varies in thickness from a few feet to an estimated maximum of approximately 215 feet (Plate 5) and covers approximately 167 mi^2. The alluvial aquifer consists of the saturated portion of all of the alluvial deposits. Mapping provided to El Paso County by Curtis Wells and other published geologic maps were used as a basis to refine the geometry of the alluvium. Well completion data from the Colorado Division of Water Resources was incorporated to verify, exclude, or augment previously mapped alluvium. Thick alluvium exists within the buried, incised bedrock channels. The alluvium thickness in the tributary channels, extending to the Falcon and Peyton areas, is generally less than 20 feet. To meet the objectives of this study, a primary alluvium coverage area of approximately 120 mi^2 has been defined that excludes these thinner tributary arms.

Information from the well permit database of the Colorado Division of Water Resources, State Engineer's Office, indicates that as of May 2007 there were 3,947 permitted wells of record (bedrock and alluvial) within the designated basin. Utilizing the new alluvial coverage map as a template and applying depth of completion criteria, we estimate that up to 1,227 of the total water supply wells may potentially be completed in the alluvium. Since many of the well permit records are incomplete with respect to well depth, water level, or perforated interval, the number of alluvial wells cited (1,227) is probably an over-estimation. Ground water development for irrigation and municipal demands represent the largest discharge from the alluvial aquifer and was initiated in the 1950's.

Significant water level declines and loss of water from storage in the basin have been documented by previous investigators. As part of this study, we analyzed the magnitude and distribution of changes in water levels, in ten year increments, from 1964 to 2004. The majority of water was removed from storage prior to 1974 (Table 2). Using a specific yield of 0.18 for the alluvial aquifer, the amount of water removed from storage during the period 1964-1974 was at least 45,300 acre-feet and water levels declined as much as 42 feet. The rate of decline for the subsequent decades analyzed slowed, as well production decreased, with an additional 17,290 acre-feet removed from storage through 1994. In the final decade analyzed, 1994-2004, recharge exceeded losses with a net gain to the aquifer of at least 1,900 acre-feet. This recharge was most likely the result of the above average precipitation that fell during this decade. The cumulative loss of ground water in storage in the alluvial aquifer of Upper Black Squirrel Creek basin was at least 60,700 acre-feet. These loss estimates represent minimum volumes as we are unable to quantify the thinner portions of alluvium. This loss of water from storage represents an opportunity for aquifer recharge.

Precipitation is the key resource for ground water recharge. Irrigation return flow and upward flow from the underlying bedrock aquifers represent the remainder of the total recharge component. Current studies suggest that approximately 4 percent of actual precipitation reaches the water table. Using this value, the average annual recharge to the alluvial aquifer ranges from 0.7 to 0.6 inches per year. Based on our mapped alluvial coverage, we estimate that the volume of annual recharge to the alluvial aquifer ranges from approximately 5,000 to 6,000 acre-feet per year.

This project included monthly measurement of water levels in wells for a 6-month period from December 2007 through May 2008. This time period should have captured the spring recharge event and the influence of irrigation pumping. Water level measurements were obtained from 88 wells in a network established by CGS that included wells monitored annually by the Colorado Division of Water Resources (DWR), a water level monitoring network established by Cherokee Metropolitan District, and a long-term network established by the USGS (Plate 13). Water levels varied from approximately 9 feet below ground surface in the northern portion of the basin to approximately 123 feet below ground surface in the vicinity of Drennan Road near the southern end. The water levels in wells in both the northern-most and southern-most portion of the basin remained relatively stable for the period of monitoring. The maximum change in water levels in wells measured for this study was generally less than 10 feet.

A water table contour map of the January 2008 water levels is presented as Plate 14. This map portrays the response of the water table to ground-water withdrawals. Approximately 1,100 feet of head differential exists between the northern and southern portions of the basin, with an average gradient of 48 feet per mile (0.009 ft/ft). Flow throughout the basin is towards the main buried channel of Upper Black Squirrel Creek from the surrounding upland areas and south out of the study area. Applying the average aquifer hydraulic conductivity (87 ft/day) and effective porosity (25%), produces an average flow velocity of 31 ft/day or 1,143 ft/yr. Under this scenario, ground water is expected to move approximately 2 miles in 10 years.

The variability of the physical characteristics of the alluvium is a critical consideration for aquifer recharge and storage. This includes changes in lithology, aquifer hydraulic properties, and water quality. The presence and thickness of finer geologic materials, particularly continuous beds of clay and silt can significantly influence ground water recharge and flow. Six new water supply wells on state land were drilled to the top of bedrock as part of this study. To evaluate the lithologic changes of the alluvium, CGS personnel supervised the drilling activities, logged and classified the geologic materials circulated up the borehole, and ran geophysical logs in the open borehole. A few clay intervals were encountered at some well locations with thickness varying from a few inches to approximately four feet. More often, clayey sediment mixtures were encountered. Based on our drilling activities, we did not observe any thick or laterally extensive clay intervals that would significantly impede the vertical migration of infiltrated water.

A number of aquifer pump tests have been conducted in alluvial wells within the basin by previous investigators and the current operators. The available data produce an average horizontal hydraulic conductivity of 87 feet per day with reported values ranging from a low of 48 ft/day to a high of 134 ft/day. Only a few references for vertical hydraulic conductivity or infiltration rate have been reported with values of 2-3 feet per day.

Water quality information was compiled and collected to ascertain the ambient quality and chemistry of the alluvial groundwater, and to access potential chemical equilibrium issues or need for treatment of source waters used for recharge. The data included field measurements of physical characteristics as well as laboratory analysis. Based on the analytical data, water from the alluvial aquifer in the basin is classified as either a sodium calcium-mixed anion or a sodium calcium bicarbonate type of water. With a few exceptions, the alluvial ground water is of very good quality. This ambient water quality is not problematic to recharge operations.

The capacity of the alluvial aquifer to store water is determined by its storage coefficient or specific yield which quantifies the pore space that is drainable by gravity. The amount of recoverable water in storage is calculated as the aquifer volume (thickness x extent) multiplied by its specific yield. The saturated thickness varies from less than one foot to a maximum of 109 feet (Plate 15). Utilizing the GIS functionality of this project and a specific yield value of 0.18, we estimate that approximately 475,000 acre-feet of water remains in storage within the basin. The unsaturated portion of the alluvium provides the reservoir in which additional water can be stored. The computed unsaturated thickness varies from less than one foot to a maximum of 174 feet (Plate 16). The primary alluvium, as delineated in this report, covers a total area of 78,850 acres. The unsaturated portion of that alluvium could hold an additional 605,000 acre-feet of water if it were filled to within 10-feet of the surface. Practically, however, the alluvium could not be filled uniformly to this level without increasing subsurface flow out of the basin and into underlying bedrock aquifers.

To achieve the objectives of this study and identify areas for potential aquifer recharge/storage implementation, we have isolated sections of the unsaturated portion of the alluvium by depth and calculated the available storage capacity. These areas can be visualized as zones where the water table is recharged to depths of 100, 75, and 50 feet below ground surface (Plate 16). The available storage capacity in each of these depth limited zones across the basin is 26,000, 88,000, and 218,000 acre-feet, respectively. That is, an additional 26,000 acre-feet of water can be stored in the basin if recharge water filled the aquifer from its current water level to within 100 feet below ground surface. This study outlines areas that identify the locations of these depth limited zones.

Land use/ownership and proximity to existing infrastructure are two of the most important concerns in evaluating the relative ease or difficulty of implementing an aquifer recharge project. This study produces maps that depict land use zoning and land ownership, as publicly or privately-owned classified by the size of the parcel and name of the property owner. The sources of water available for storage are not considered in this study. It is assumed, however, that the existence of canals, ditches, pipelines, and other water delivery/storage structures presents an opportunity to convey water to a potential recharge location. Utility infrastructure information was provided by all of the water and water and sanitation districts in the basin and compiled on a single map (Plate 19). This map demonstrates that water conveyance infrastructure currently exists and more is proposed that could be used to convey water to the potential recharge areas identified in this study. The information provided in this report significantly enhances our knowledge of the hydrogeology of the Upper Black Squirrel Creek basin, establishes a framework of the aquifer's physical characteristics, and provides specific locations for future implementation of aquifer recharge/storage projects.

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