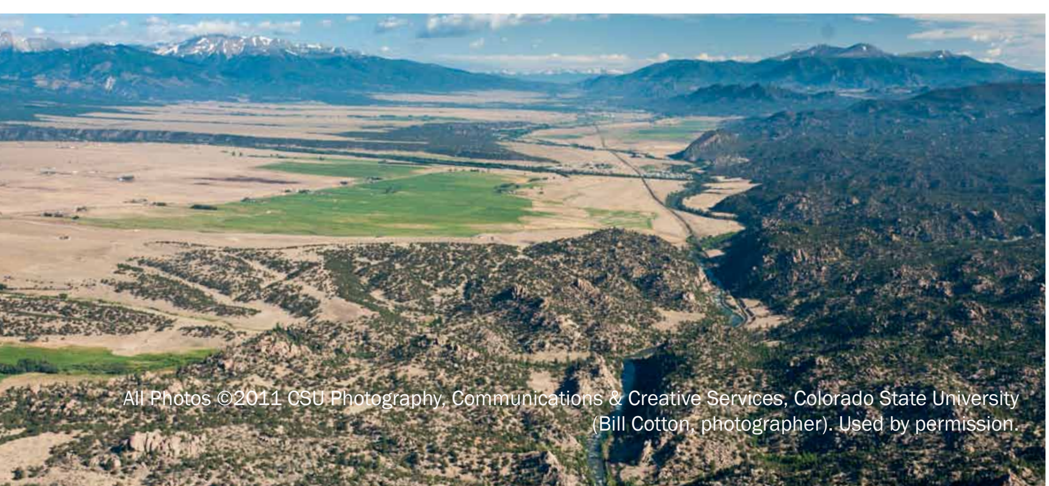
Prepared for the Colorado Water Conservation Board and Colorado Division of Water Resources

Arkansas River Decision Support System Feasibility Study

Brown AND Caldwell

December 2011 Report



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Feasibility Study for the Arkansas River Decision Support System

Prepared for
Colorado Water Conservation Board
and
Colorado Division of Water Resources
Denver, Colorado
December 2011

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List of Abbreviations

$0.00M	Millions of U.S. Dollars
AF	Acre-feet
AF/YR	Acre-feet per year
AHRA	Arkansas Headwaters Recreation Area
ArkDSS	Arkansas River Decision Support System
ASCE	American Society of Civil Engineers
BNDSS	Basin Needs Decision Support System
bgs	Below ground surface
CAS	Colorado agricultural statistics
CBM	Coalbed methane
CCM	Compressed county mosaics
CDL	Cropland data layer
CDOT	Colorado Department of Transportation
CDOW	Colorado Division of Wildlife
CDPHE	Colorado Department of Public Health and Environment
CDSS	Colorado's Decision Support Systems
cfs	Cubic feet per second
CFWE	Colorado Foundation for Water Education
CGS	Colorado Geological Survey
CIR	Crop irrigation requirement
CoAgMet	Colorado Agricultural Meteorological Network
CRDSS	Colorado River Decision Support System
CU	Consumptive use
CWCB	Colorado Water Conservation Board
DMI	Data management interface
DNR	Department of Natural Resources
DOLA	Department of Local Affairs
DOQ	Digital Orthophoto Quadrangle
DOQQ	Digital Orthophoto Quarter Quadrangle
DSS	Decision support system
DWR	Colorado Division of Water Resources
ET	Evapotranspiration
Fry-Ark	Fryingpan - Arkansas
GIS	Geographic Information System
gpm	Gallons per minute
GPS	Global positioning system
GUI	Graphical user interface
HB	House Bill
HEM	Heliborne electromagnetic
IBCC	Interbasin Compact Committee
KML	Keyhole markup language
LAVWCD	Lower Arkansas Valley Water Conservancy District
LCI	Land Cover Institute
LIRF	Lawn irrigation return flow
M&I	Municipal and Industrial
NAAP	National Aerial Photography Program
NAIP	National Agriculture Imagery Program
NHAP	National High Altitude Photography Program
NHD	National Hydrography Dataset
PET	Potential evapotranspiration
PRC	Peer Review Committee
PRWCD	Purgatoire River Water Conservancy District
PSOP	Preferred Storage Options Plan
QA/QC	Quality Assurance/Quality Control
RGDSS	Rio Grande Decision Support System
SB	Senate Bill
SDS	Southern Delivery System
SDF	Stream depletion factor
SECWCD	Southeastern Colorado Water Conservancy District
SNOTEL	Snowpack Telemetry
SPDSS	South Platte Decision Support System
SWSI	Statewide Water Supply Initiative
TDS	Total dissolved solids
UAWCD	Upper Arkansas Water Conservancy District
URF	Unit response function
USBR	Unites States Bureau of Reclamation
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WQCD	Water Quality Control Division

List of Models and Analytical Tools

ARAS – Arkansas River Accounting System: A tool developed by Division 2 that is used to track operational data for reservoir accounting and store historical accounting data

ArkRiver GeoDSS – A regional monitoring, modeling, and assessment program developed for the lower Arkansas River basin by researchers at Colorado State University

GWDMS – Groundwater Data Management System: Division 2 database for groundwater data, including pumping records, that is used in administration of the Compact

H-I Model - Hydrologic-Institutional Model: Model used to calculate annual depletions and accretions to Usable Stateline Flow by simulating the hydrologic and institutional systems that occur along the Arkansas River between Pueblo, Colorado and the Colorado-Kansas Stateline

HydroBase –SQL Server database that serves as the foundational water resources database for the State of Colorado, developed through CDSS and maintained by DWR

ISAM – Irrigation System Analysis Model: A planning and operations model that is used by Division 2 to determine the impact of a proposed irrigation system improvement for a farm and for estimating return flow maintenance requirements

MODFLOW – A three-dimensional finite-difference groundwater flow model developed by the USGS.

MODSIM – A generalized river basin management decision support system and network flow model developed by at Colorado State University

StateCU – The consumptive use analysis model developed for CDSS

StateDGI – CDSS data pre-processing tool developed to pre-process spatial data needed to prepare input files for MODFLOW

StateDMI – CDSS data pre-processing tool developed to process spatially distributed data (other than time-series data) for StateMod and StateCU

StateMod – The surface water planning model developed for CDSS

StatePP - CDSS data pre-processing tool developed to prepare input files for MODFLOW

StateWB – The water budget analysis model tool developed for CDSS

TSTool - CDSS tool developed for the data pre-processing and analysis of time-series data for StateMod and StateCU, with support for data files for other models, including MODSIM and RiverWare

Acknowledgments

The development and completion of the Feasibility Study for the Arkansas River Decision Support System was completed through a cooperative effort between the project consulting team, the Colorado Water Conservation Board and the Colorado Division of Water Resources. These efforts were greatly aided by the participation of the Arkansas Basin Roundtable and a technical subcommittee from the roundtable. The project team would like to expressly acknowledge and thank the subcommittee members for their volunteer efforts in reviewing interim work products and providing valuable feedback during the feasibility study process. The members of the subcommittee included Gary Barber, Leon Basdekas, Jim Broderick, Jeris Danielson, Pat Edelmann, Timothy Gates, Bob Hamilton, Heath Kuntz, Eve McDonald, Steve Miller, Ivan Walter, Alan Ward, and Ken Watts.

Additionally, as part of the needs assessment task of the feasibility study process, the project team engaged numerous stakeholders in the basin through both interviews and distribution of a survey. The project team is grateful to the time that each individual dedicated to answering our questions, providing their own unique perspectives on water issues and information needs in the Arkansas River Basin. A list of the participants in the user interviews and survey can be found in Appendix A.

Executive Summary

Beginning in 1992, the Colorado Water Conservation Board and Division of Water Resources embarked on an effort to establish a common and accepted framework of information and tools to help facilitate informed decision-making in water resources planning in the State of Colorado. The resulting Colorado's Decision Support Systems (CDSS) currently include three basin-specific subsystems (Colorado River Basin (CRDSS), Rio Grande Basin (RGDSS) and South Platte River Basin (SPDSS)) that share a central database. These data-centered systems integrate relational and spatial databases with analytical tools and models to assist water users and water managers in water resources planning and management.

The purpose of this study is to determine the feasibility of expanding CDSS to include the Arkansas River Basin in Colorado. This Arkansas River Decision Support System (ArkDSS) will build upon the structure, organization, and software developed previously for other basin subsystems; and address conditions and needs unique to this basin. Consequently, the ArkDSS Feasibility Study objectives are to:

- Determine the feasibility of developing a DSS for the Arkansas River Basin using standards similar to the decision support systems developed for the Colorado River and Rio Grande Basins and being developed for the South Platte River Basin.
- Identify the scope, functions, elements, data needs, costs and schedule to develop a DSS for the Arkansas River Basin.

In order to achieve the objectives of this study, the following tasks were addressed:

- Needs Assessment – Meet with stakeholders and identify needs to be met by ArkDSS
- Data Collection and Assessment – Assess the availability and quality of existing data and determine what new data are necessary or desirable to develop an ArkDSS that addresses the needs identified.
- ArkDSS Components – Review CRDSS, RGDSS and SPDSS, as well as existing efforts in the Arkansas Basin, and identify components that can be utilized in ArkDSS. Identify the components required to develop an ArkDSS that addresses the identified needs in a cost-effective manner.
- Options for Implementation – Develop options for implementation of the ArkDSS considering needs, data availability, costs, and other appropriate factors.
- Proposed Implementation - From the implementation options, formulate a recommended proposed implementation plan in consultation with the State and the ArkDSS Advisory Committee.

Based on the recommendations of data and components to address the needs of stakeholders in the basin, three levels of effort and cost, or tiers, were developed as options for implementation of an ArkDSS. These three tiers represent varying levels of data collection and analytical capability for the ArkDSS. Tier 1 provides a foundational DSS that meets many data needs, as well as some basic analytical needs. Tier 2 tasks, which can be developed subsequent to Tier 1 tasks in a cost-effective manner, meet a majority of the identified data and analytical component needs. Tier 3 tasks provide enhanced modeling capabilities at significant additional cost.

In considering the three levels of data collection and analytical capability, the tasks in Tier 1 and Tier 2 provide the most benefit to users at reasonable cost. Therefore, these tasks are recommended at this time for the implementation of the ArkDSS. Although Tier 3 tasks are not recommended at this time, elements at this level of analytical capability may be included in the ArkDSS in the future, if warranted by basin needs and if additional funding is available.

A phased approach for the proposed implementation will provide an efficient, step-wise process for completing tasks that build upon one another, and it will allow for periodic assessment of progress to date, potential for modifications to future implementation activities, and funding availability. Phases for ArkDSS implementation have been developed based on a data-centered approach for ArkDSS implementation, as well as the flow of information required between components.

The proposed ArkDSS implementation is divided into four major phases:

Phase 1: Initial Funding Tasks ($500,000)

- ArkDSS tasks approved for CWCB funding in November 2010:
  - Water resources data collection/analysis, including consumptive use data in the upper basin
  - Water rights and administration components development, including H-I Model process enhancements
  - Spatial data collection/analysis, including irrigated lands data collection and analysis in upper basin

Phase 2: Data Compilation and Collection ($3,810,000)

- Existing Data Compilation: Compile and review data for surface water, groundwater, consumptive use, and GIS components
- New Data Collection: Install gages and monitoring wells

Phase 3: Initial Components Development ($1,260,000)

- Consumptive Use Analysis: Enhance StateCU, develop basin-wide model and calculate basin CU
- Water Budget Analysis: Develop basin water budgets
- GIS and Irrigated Lands: Develop GIS component

Phase 4: Additional Components Development ($2,020,000)

- Surface Water Planning: Develop basin-wide model
- Groundwater Planning: Develop analytical tools for the upper and lower basin
- Water Quality Analysis: Develop conceptual model and make recommendations for further analysis

These four phases will allow the proposed data collection and components development tasks to be completed in a period of six to eight years. The combined cost for the four phases is estimated at $7,590,000. Note that this number is an incremental cost for expanding CDSS into the Arkansas Basin; the ArkDSS will benefit from nearly two decades of investment in CDSS components.

Section 1

Introduction

State of Colorado agencies, water providers and water users are constantly evaluating current water management practices and new and improved ways to manage water resources. Population and municipal demand increases, drought, agricultural water transfers, endangered species issues, meeting river compact obligations and reductions in Federal water program funding have focused the attention of water managers to find new ways to optimize and better manage water supplies.

As Colorado continues a new era of water management, cooperation among State agencies, water providers and water users is essential. To encourage continued cooperation, the State of Colorado, through the Department of Natural Resources (DNR), Colorado Water Conservation Board (CWCB) and Colorado Division of Water Resources (DWR) has developed Colorado's Decision Support Systems (CDSS). CDSS has been a key factor for enhancing cooperation by establishing a common and accepted framework of information and tools to facilitate informed decision-making. The decision support system (DSS) has been developed for use in the Colorado River and Rio Grande Basins and is being developed for the South Platte River Basin. State agencies, water users and managers in these basins increasingly rely on CDSS as a common and efficient means for organizing, accessing and evaluating a wide range of information and alternative strategies. This, in turn, has helped CDSS users make informed decisions regarding major water issues and policy positions.

The CWCB and the DWR have identified the need for a DSS in the Arkansas River Basin. As a result, and as the first step in establishing a DSS in the Arkansas River Basin, the CWCB funded the Arkansas River Decision Support System (ArkDSS) Feasibility Study. Funding for the ArkDSS Feasibility Study has been provided from the CWCB's Construction Fund under SB07-122, Section 7, as modified by HB08-1346.

The purpose of this study is to determine the feasibility of developing and implementing a DSS with appropriate data and analytical tools for making informed decisions regarding management of the water resources of the Arkansas River Basin in Colorado. The results of the ArkDSS Feasibility Study will be used by CWCB and DWR to recommend development of the ArkDSS to the Colorado General Assembly.

The ArkDSS is intended to support water management decision making for those concerned with Arkansas River Basin water resource issues. The ArkDSS must provide to State officials, water providers and water users an effective system with which to develop and manage the water resources of the basin. Consequently, the ArkDSS Feasibility Study objectives are to:

- Determine the feasibility of developing a DSS for the Arkansas River Basin using standards similar to the decision support systems that were developed for the Colorado River and Rio Grande Basins and that are being developed for the South Platte River Basin.
- Identify the scope, functions, elements, data needs, costs and schedule to develop a DSS for the Arkansas River Basin.

First and foremost, the ArkDSS must provide state officials and water users in the Arkansas Basin an effective system with which to plan, develop and manage their water resources. The ArkDSS will be an extension of and compatible with the existing CDSS components. Goals of the ArkDSS as contemplated by the CWCB and DWR include the following:

- Provide credible information on which to make informed decisions concerning the management of Arkansas Basin water resources.

- Expand the data available in DWR's water resources database, HydroBase, for the Arkansas Basin to assist in the administration and allocation of waters within the basin.
- Provide data and models to evaluate alternative water development and administration strategies, which can maximize utilization of available resources in various hydrologic conditions.
- Be a functional system that can be used by decision-makers and others, and be maintained and upgraded by the State.
- Represent current and potential Federal and State administrative and operational policies and laws, especially the Arkansas River Compact and Water Court Decrees.
- Promote information sharing among government agencies and water users.
- Use standards established under CDSS by CWCB and DWR.

The ArkDSS should consist of data and analytical tools that will provide the foundation for decision-making on many critical planning, administrative and operational issues in the Arkansas River Basin. The ArkDSS should contain historical and calculated information on streamflow, climate, and water use, as well as tabulations of water rights and water management operations. In addition to these parameters, water quality may also be included in the ArkDSS to address concerns of water users in the basin. Data should be keyed to locations in the basin using geographical information systems (GIS). The ArkDSS should use and enhance the existing CDSS tools as appropriate. The ArkDSS should allow decision-makers to efficiently access water resource data, simulate potential decisions and policies, and examine potential consequences related to various water resource planning and water rights administration scenarios. Towards this vision, the feasibility study assessed the quality of existing data, recommended quality assurance/quality control (QA/QC) as needed, and identified data gaps and recommended actions that could be taken to either correct or acquire the additional data needed.

1.1 Arkansas River Basin Overview

The Arkansas River Basin (Figure 1-1) is administered by the DWR as Water Division 2, and encompasses approximately the entire southeast quadrant of the State. The basin includes all or portions of 21 counties with a year 2000 population of 835,100. It is anticipated that the population in the Arkansas River Basin will grow by 55 percent, to nearly 1.3 million by 2030 (DOLA, 2001). The largest cities within the basin are Colorado Springs (population 400,411) and Pueblo (population 106,765) (DOLA, 2008), with other major population centers being the towns of Leadville, Salida, Fountain, Cañon City, Trinidad, La Junta, and Lamar.

Climate

The Arkansas River Basin has a continental-type climate, modified by topography, in which there are large temperature ranges and irregular seasonal and annual precipitation. In the higher elevations at the headwaters, the annual precipitation ranges from 25 to 60 inches per year, most of which occurs as snow. As the river flows from middle to lower elevations it transitions from forest to semi-desert climates. The warm, dry forests have average annual precipitation of 15 to 25 inches. The semi-desert region is only a few hundred feet lower in elevation; however, the average annual precipitation ranges from 8 to 12 inches. The High Plains in the eastern portion of the basin are also quite arid and generally receive less than 12 inches of precipitation per year. (CDPHE, 2002)

Surface Water Hydrology

The Arkansas River Basin is the largest river basin in Colorado with over 28,000 square miles of drainage area, encompassing both the Rocky Mountains in the western portion of the basin and the plains in the eastern side of the basin. The basin covers 27 percent of the surface area of the state (CWCB, 2006a). The headwaters of the Arkansas River begin near the Leadville area of the Rocky Mountains in central Colorado. The mainstem flows approximately 330 miles through Colorado in a generally south-southeasterly direction towards Coaldale. The river then turns more easterly, flowing through deep canyons west of Cañon City, Colorado, before exiting the mountains and flowing easterly across the plains to the Colorado-Kansas border. The river eventually flows a total of 1,469 miles into the Mississippi River. Average annual flow of the Arkansas River at the Stateline into Kansas is approximately 154,800 acre-feet per year (Figure 1-2).

Major tributaries of the Arkansas include: Cottonwood Creek, Chalk Creek, South Arkansas River, Grape Creek, Smith Canyon Creek, Rule Creek, Rush Creek, Adobe Creek, Timpas Creek, Cucharas River, Fountain Creek, St. Charles River, Huerfano River, Apishapa River, Horse Creek, Purgatoire River, Big Sandy Creek and Twin Buttes Creek. Pueblo and John Martin Reservoirs are the two major reservoirs located on the mainstem of the Arkansas River, with several large reservoirs located off of the mainstem, including Turquoise Lake, Twin Lakes Reservoir, Clear Creek Reservoir, DeWeese Reservoir, Trinidad Lake, Lake Meredith, Holbrook Reservoir, Adobe Creek Reservoir, Horse Creek Reservoir, and the Great Plains Reservoirs.

Although, by area, the Arkansas River Basin is the largest in the state, the mountainous areas comprise a relatively small portion of the basin, resulting in less snowpack being available to supply natural flows to the river (see Figure 1-2). Table 1-1 provides a summary of average annual flows for 1950 – 1985 on the mainstem at Pueblo and the Stateline, along with tributary flows in the Pueblo to Stateline reach. Average annual total diversions in the lower basin are also provided for this same period. Although the basin only provides approximately 540,000 acre-feet of water annually at Pueblo, total diversions below Pueblo are in excess of 880,000 acre-feet. These flow statistics illustrate the importance of upstream return flows to the water supply of downstream water users.

Table 1-1. Arkansas River and Tributary Flows from Pueblo to the Colorado-Kansas Stateline 1950-1985 Annual Averages in Acre-Feet

Locations/Types of Flows	Flow
Arkansas River at Pueblo (includes Bessemer Ditch Diversions)	539,876
Tributaries	
Fountain Creek at Pueblo	45,212
St. Charles River[a]	23,437
Huerfano River[a]	18,593
Apishapa River	17,924
Purgatoire River	61,659
Ungaged Tributaries	59,457[b]
Total Tributary Flows	226,282
Total Diversions	884,881
Stateline Flows	144,051

Source: Division 2, [a]Incomplete Record, [b]Estimated

Transmountain Diversions

Transmountain diversions provide an important supply of water to the Arkansas River Basin, and much of this water can be reused to extinction. There are eleven structures that import water into the Arkansas River Basin, providing approximately 130,000 acre-feet annually. These structures include imports from the Colorado River Basin, the Rio Grande Basin and the Gunnison River Basin. Table 1-2 summarizes recent average annual imports to the Arkansas River Basin through the transmountain diversion structures. In addition, there are two diversion structures that export water from the basin, the

Otero Pumping Station and the Homestake Pipeline, which both export water to the South Platte River Basin.

Table 1-2. Recent Average Annual Imports to the Arkansas River Basin 1996-2008 Transmountain Diversions (Acre-Feet)

Diversion Structure	Average Diversion, AF
Ewing& Wurtz	3,238
Columbine	1,514
Busk-Ivanhoe	4,545
Homestake	27,368
Twin Lakes Tunnel	41,998
Boustead Tunnel	52,523
Larkspur	132
Hudson & Medano	848
Blue River Project	9,874
Total	142,040

Source: SECWCD

Hydrogeologic Conditions in the Arkansas River Basin

Aquifer systems within the Arkansas River Basin include relatively shallow alluvial aquifers along the mainstem and several tributaries, mountain-valley basin-fill aquifers, and deeper bedrock aquifers. Figure 1-3 provides a general location map for the aquifers within the Arkansas River Basin. Notable alluvial aquifers include those along portions of the mainstem of the Arkansas River, Fountain Creek and Upper Big Squirrel and Upper Big Sandy Creeks. Basin-fill aquifers include those in the Wet Mountain Valley and in the upper Arkansas River Basin in the Buena Vista to Salida region. Bedrock aquifers include the Denver Basin, the Raton Basin, the Dakota-Cheyenne, and the High Plains. General descriptions of the aquifer systems in the basin given below are largely summarized from the Colorado Groundwater Atlas (CGS, 2003).

The alluvium along the mainstem downstream of Pueblo is the most significant alluvial aquifer in the basin. It extends about 150 miles along the mainstem from Pueblo to the Stateline, varying from approximately one to 14 miles in width. The thickness of the alluvium is typically less than 50 feet in depth, but it is greater than 200 feet in localized areas at the eastern end of its extent (USGS, 1989). Depth to water varies from about five to 30 feet below ground surface (CGS, 2003). Recharge is from canal leakage, losses from irrigation, precipitation, and seasonal losses from streamflow. The major use of the aquifer is for irrigation.

Alluvium is not present in significant amounts along many of the tributaries. Exceptions include Fountain Creek and the upper parts of Black Squirrel and Big Sandy Creeks, which also overlie the Denver Basin bedrock aquifers. These aquifers are important sources for irrigation and municipal supply. Recharge is from irrigation return flows, precipitation, and, along Fountain Creek, from seasonal losses from streamflow.

Alluvium and basin-fill aquifers in the upper basin (above Pueblo Reservoir) are not hydraulically connected to the alluvium in the lower basin except via the river itself. The alluvial aquifer system in the upper basin is typically less than 500 feet in thickness (USGS Fact Sheet 2005-3143). Depths to water range from 5 to 58 feet below ground surface (CGS, 2003). In many areas in the upper basin, the alluvium is absent where the river is actively eroding in bedrock canyons (CGS, 2003). The upper basin-fill aquifer is located beneath the alluvial aquifer system and consists of interbedded clays, silts, sands, and gravels up to 5,000 feet in thickness (USGS Fact Sheet 2005-3143). The upper basin-fill aquifer is typically less permeable than the overlying alluvial aquifer. The primary source of recharge to the alluvial and basin-fill aquifers in the upper basin is from leakage from streams and from surface water irrigation return flows. These aquifers are an important source for irrigation supply and public water supply in Chaffee and Lake Counties (CWCB, 2006b).

The basin-fill aquifer in the Wet Mountain Valley is bounded on the west by the Sangre de Cristo Mountains and on the east by the Wet Mountains. In the Wet Mountain Valley, depth to water is less than 10 feet below ground surface in the central part of the valley and less than 100 feet in most of the remainder of the valley. Groundwater from these aquifers is used for public supply, domestic use, irrigation and livestock watering. However, groundwater use is a small fraction of total water use in these areas.

The Denver Basin is located along the Front Range of the Rocky Mountains from Colorado Springs on the south to Greeley on the north, the foothills on the west, and Limon on the east. The majority of the Denver Basin lies under the South Platte River Basin; however, the southern portion lies under the north-central part of the Arkansas River Basin (Figure 1-3). The Denver Basin consists of several unconfined and confined aquifer layers with limited connection. The Denver Basin contains approximately 470 million acre-feet of water (Robson, 1987), with estimates of 200 to 300 million acre-feet of drainable storage (CWCB, 2006b). Natural recharge for these deep aquifers is minimal with the majority originating from outcrop areas. In the Arkansas Basin, the Denver Basin aquifers are important sources of supply for municipal and industrial purposes in the Colorado Springs and northern El Paso County areas. During the development of SPDSS, the hydrogeology (e.g., the aquifer configuration, properties and water levels) of the entire Denver Basin was extensively investigated.

The Dakota-Cheyenne aquifer consists of the Dakota Sandstone and the underlying Cheyenne Sandstone member of the Purgatoire Formation (CGS, 2003). The aquifer is present throughout most of Colorado and underlies most of the Arkansas River Basin below Pueblo, with the exception of those areas covered by the Denver Basin and High Plains aquifer. Well depths in the Arkansas River Basin vary from relatively shallow to approximately one-thousand feet (CGS, 2003). The aquifer provides water for irrigation and domestic water supply, but is a relatively small portion of overall water use within the basin (CDWR, 2010).

The High Plains aquifer is an extensive aquifer that underlies portions of eastern Colorado (CGS, 2003). Groundwater withdrawals from the High Plains aquifer have exceeded recharge since the early 1960's. Most wells in the High Plains aquifer are completed between 200 and 350 feet below ground surface (CGS, 2003). Recharge to the High Plains aquifer in Colorado is primarily from infiltration of precipitation, with lesser recharge from streambed infiltration and irrigation returns. The aquifer is heavily utilized for irrigation, livestock and industry in eastern Colorado.

The Raton Basin is located in Las Animas and Huerfano Counties and includes several aquifers: river valley alluvium; sandstones and siltstones of the Raton, Vermejo, and Trinidad Formations; and sandstones and siltstones of the Cuchara and Poison Canyon Formations (CGS, 2003). The Raton Basin receives recharge from the Sangre de Cristo mountain range, along with infiltration from precipitation, lakes and streams. The majority of the permitted wells in the Raton Basin are less than 150 feet deep (CGS, 2003). The Raton Basin is currently being developed by the energy industry for coalbed methane. Produced water resulting from the construction of coalbed methane wells is being evaluated by DWR to determine how much water pumped from the basin can be considered non-tributary to the surface stream system.

Designated basins have been established by the Colorado Ground Water Commission in accordance with Section 37-90-106 of the Colorado Revised Statutes. There are four designated basins in the Arkansas Basin, including Upper Big Sandy, Upper Black Squirrel Creek, the Northern High Plains and the Southern High Plains (Figure 1-3). Designated groundwater is defined in C.R.S. 37-90-103[6][a] as "that ground water which in its natural course would not be available to and required for the fulfillment of decreed surface rights or ground water in areas not adjacent to a continuously flowing natural stream wherein ground water withdrawals have constituted the principal water usage for at least fifteen years preceding the date of the first hearing on the proposed designation of basin, and which in both cases is within the geographic boundaries of a designated ground-water basin." Recharge for these basins comes from precipitation and from intermittent streams, as well as irrigation return flows. Since the 1960's, groundwater withdrawals in these basins have exceeded recharge (CWCB, 2006b), causing chronic reductions in the amount of stored groundwater.

Water Quality

The Colorado Department of Public Health and Environment (CDPHE) provides periodic assessments of the quality of the state's water resources. The following overview of water quality in the Arkansas Basin is taken from CDPHE's most recent comprehensive report on water quality, Status of Water Quality in Colorado: 2002 (CDPHE, 2002).

> "Water quality in the Arkansas River basin is generally good; portions of the headwaters have been designated as Outstanding Waters, and most waters fully support their designated uses. The Upper Arkansas is the most heavily used recreational river in the state, with many commercial rafting companies and individuals using it for rafting and kayaking. There are areas of the basin, however, where water quality concerns exist. The headwaters of the Arkansas River were subject to intensive mining activities in the late 1800's. These activities significantly degraded several tributaries to the river, as well as the mainstem itself. After the Arkansas leaves the mountains, it crosses geologic formations that are rich in soluble salts (iron, sulfate, and selenium). With the extensive irrigation in the lower basin, these naturally occurring constituents are concentrated in the soil and irrigation return flow. This high total dissolved solids (TDS) concentration lowers the water quality of the Arkansas River from La Junta to the Colorado/Kansas line."

Although water quality data and analysis tools have not historically been included in CDSS, the recognition that water quality and quantity are closely linked has prompted water users to communicate needs related to water quality. Addressing water quality issues through the ArkDSS is particularly important to water resource managers in the Arkansas Basin, as water resource management decisions increasingly are shaped by water quality degradation, particularly in the lower basin. Both the USGS and Colorado State University have been prominent in conducting water quality studies in the basin in order to better characterize water quality conditions and to understand the impacts of water quality management decisions.

1.2 Water Resources Demands in the Arkansas Basin

The settlement of the Arkansas River Basin through the 1800's revolved largely around the availability of water supplies. The development of agriculture from 1860 through 1890 was driven by the need to feed growing populations of miners in Leadville and Aspen (CFWE, 2004). A vast system of canals conveys water through the agricultural parts of the basin, most of which were developed by the end of the 1880's. Beginning in 1880, Arkansas River water was vital to the development of the steel industry in the Pueblo area, fueling an industrial boom (CFWE, 2004). Entering a wetter period after 1910, the need for flood controls and disputes over resources of the Arkansas River between Colorado and Kansas resulted in the federal authorization of John Martin Reservoir. Other reservoirs were developed in order to store surplus flows during the spring runoff, and when water was not needed for direct irrigation use, to allow the resource to be used later when river flows decreased. Although water quantity is highly managed in the basin, diversions from many second and third order streams for irrigation result in seasonal drying up of these smaller streams (CDPHE, 2002).

By the mid-20th century, increasing population and urbanization in the lower basin, particularly in the cities of Colorado Springs and Pueblo, prompted the need for additional water supplies. Several projects, the largest of which is the Fryingpan-Arkansas Project, were constructed to import water into the Arkansas Basin. These transbasin imports have increased long-term supply of water in the basin.

Current and Future Demand for Water Resources

The economy in the mountainous headwaters area of the Arkansas River Basin is based on tourism and recreation, much of which is dependent on surface water flows (i.e., rafting and fishing). The economy in the urbanized central region of the basin, which includes Colorado Springs and Pueblo, is related mostly to education, service and trade industries, and government services. The basin's surface water and groundwater resources are vitally important to the predominantly agricultural region east of Pueblo to the Colorado-Kansas Stateline.

Beginning in 2003, the CWCB implemented the Statewide Water Supply Initiative (SWSI), a comprehensive study of how Colorado will meet its future water needs. SWSI explored all aspects of Colorado's water use and development on both a statewide and individual basin basis. Findings from both SWSI 1 (2006) and the updated SWSI 2010 (2010) include the following:

- Annual water demand for municipal and industrial uses in the Arkansas Basin was approximately 257,000 acre-feet in 2000. This is anticipated to increase by 98,000 acre-feet for a total of 355,000 acre-feet per year by the year 2030.
- Annual water demand for agricultural uses in the Arkansas River Basin was estimated to be 1.77 million acre-feet of diversions in 2000. This annual demand is expected to decrease to between 1.46 million – 1.67 million acre-feet in gross diversions by 2030, mainly due to a reduction in irrigated agriculture to provide water for municipal uses.
- In addition to the diversion or gross water needs for consumptive uses listed above, nonconsumptive uses of water to serve recreational and environmental needs are expected to increase as well. These needs are currently being addressed through environmental and recreational flow management and enhancement programs.
- Arkansas River Compact requirements and existing uses and water rights result in little to no water availability for new uses.
- Growth in the headwaters region will present challenges in obtaining augmentation water for new junior water rights.
- Concerns over agricultural transfers and its impact on rural economies are significant in the lower portion of the basin downstream of Pueblo Reservoir.
- Concern over water quality and suitable drinking water are key concerns in the lower basin.
- The success of two major water projects (the Southern Delivery System and the Arkansas Valley Conduit) is the key to meeting future water needs.

1.3 Water Administration and Management

Colorado administers surface water and tributary ground water rights according to the prior appropriation doctrine (first in time, first in right). The decreed appropriation and adjudication dates are the basis for determining which users are entitled to river flow during periods when there is insufficient water for all appropriators. The Colorado State Engineer's Office and Division 2 staff administer water rights to both surface water and groundwater within the State and the Arkansas River Basin. Water rights in the Arkansas Basin are decreed by the Division 2 Water Court in Pueblo.

Water management and administration in the study area have become more challenging in the past few years, due to several factors:

- Compliance with the Arkansas River Compact and associated regulations regarding well pumping, replacement of depletions, and the proposed Irrigation Improvement Rules.
- Increased demand for municipal and industrial water supply in the urbanized areas. These demands have emphasized the need for efficient and effective management and administration on a real-time basis.
- Transfers of water from agriculture to municipal uses. These and other water rights transfers are becoming increasingly complex in order to fulfill the demand of growing urban areas and industry. Augmentation plans, water exchanges and substitutions have added to the complexity of administration.
- Recent years of drought have increased the competition for water supplies for both direct use and for augmentation purposes.

The increasing complexity of water administration requires efficient access to real-time diversion and streamflow data, and effective analytical and administrative tools.

Arkansas River Compact

Conflicts between Colorado and Kansas over the Arkansas River date back to the turn of the 20th century. In 1936, Congress authorized the John Martin Reservoir project to provide flood control and storage for Colorado and Kansas to facilitate sharing of the waters of the Arkansas River. The Arkansas River Compact of 1948 divides the waters of the Arkansas River primarily based on 1948 conditions. The Compact allocates only the “waters of the Arkansas River”, defined as the waters originating in the basin upstream from the Colorado-Kansas Stateline, excluding transbasin imports.

The Arkansas River Compact is unusual in that it does not apportion the waters of the river between the states in specific amounts or as a percentage of river flows. Instead, it includes language designed to protect the existing uses in both states from depletions due to future development – but without quantifying those uses. These future uses in both states are allowed only if the waters of the Arkansas River “shall not be materially depleted in usable quantity or availability for use to the water users in Colorado and Kansas” (CFWE, 2010).

The Supreme Court found Colorado in violation of this standard in Kansas v. Colorado because of post-Compact groundwater development in Colorado that had reduced flows at the border between the states. In 1996, the Division 2 Water Court approved rules promulgated by the State Engineer designed to address the well pumping concern through the Amended Rules and Regulations Governing the Diversion and Use of Tributary Ground Water in the Arkansas River Basin. Groundwater users in the Arkansas River Basin are required to provide replacement water for depletions to surface water rights in Colorado and to Kansas for depletions to usable Stateline flows. In addition, well measurement rules were adopted which require all tributary wells to be equipped with a totalizing flow meter, or rated to determine a power coefficient. Totalizing flow meters are required to be re-verified in the field every four years, while re-rating of power coefficients is required every two years.

The states finally brought the Kansas v. Colorado litigation to a close with an agreement on the final technical issues in mid-2009. Kansas and Colorado are now working closely together to monitor well pumping and replacement of well depletions, with frequent meetings and monthly exchanges of data. They have also agreed on an out-of-court dispute resolution procedure they hope will prevent future litigation (CFWE, 2010).

Recently, the Colorado State Engineer’s Office began developing another set of rules related to the Compact, this time designed to proactively address Kansas’ concern that the recent trend toward improved irrigation efficiency in surface water irrigation systems diverting from the Arkansas River will increase crop water consumption and reduce historical seepage and return flows owed to Kansas (CFWE, 2010). Rules have been developed that will evaluate the effects of proposed improvements of irrigation technology on return flows and provide irrigators with options for maintaining their historical seepage and return flows to the Arkansas River (SEO, 2009).

H-I Model

The final decree in Kansas v. Colorado prescribes that the determination of Compact compliance with respect to groundwater pumping "shall be determined using the results of the H-I Model over a moving 10-year period beginning with 1997" (Supreme Court of the United States, 2008). Therefore, tools developed under the ArkDSS cannot replace or supersede the H-I Model or its findings regarding Compact Compliance. The following description of the model is taken from the Fifth and Final Report of the Special Master in the Kansas v. Colorado Supreme Court Case (2008).

> "The Hydrologic-Institutional (H-I) Model is used to calculate annual depletions and accretions to Usable Stateline Flow by simulating the hydrologic and institutional systems that occur along the Arkansas River between Pueblo, Colorado and the Colorado-Kansas Stateline. The simulated surface water component of the H-I model includes native streamflows, transmountain deliveries, tributary inflows, reservoir operations and irrigation diversions. The simulated groundwater component includes the effects of well pumping and recharge in alluvial and surficial aquifers. The simulated institutional system includes rules that govern the diversion of surface water under the priority system in Colorado, the operation of John Martin Reservoir under the Arkansas River Compact and resolutions of the Arkansas River Compact Administration, and the operation of other, off-channel reservoirs and replacement, except for credit derived from operation of the Offset Account. The H-I Model predicts diversions, streamflows and storage of water in and releases of water from John Martin Reservoir and off-channel reservoirs. The H-I Model is currently calibrated over the period 1950 through 1994 to historical diversions and streamflows. The H-I Model simulates the period 1950 to the present. Additional years are added to the H-I Model by extending the input data sets.
>
> Historical groundwater pumping, transmountain deliveries and water supplies that are used to replace well depletions, except those for which the credit is derived from the operation of the Offset Account, are included in one H-I Model run to simulate actual historical conditions. This run is referred to as the "Historical" run. In a separate run of the H-I Model, post-compact groundwater pumping, transmountain deliveries and replacement water supplies are removed and groundwater pumping is limited to the pre-compact pumping allowance of 15,000 acre-feet per year to simulate diversions and Stateline flows that would have occurred under those conditions. This run is referred to as the "Compact" run. The difference in Stateline flows between the Historical run and the Compact run is considered to be a depletion or an accretion to Stateline flows with respect to Groundwater Pumping and credit for Replacement water supplies included in the H-I Model. The Durbin Usable Flow method with the Larson coefficients is used to determine whether depletions and accretions to Stateline flow determined using the H-I Model are depletions and accretions to Usable Stateline Flow."

1.4 Arkansas Basin Projects and Studies

Fryingpan-Arkansas Project

The Fryingpan-Arkansas Project (Fry-Ark Project) is the largest transmountain water diversion project in the Arkansas Basin. Approximately 69,000 acre-feet of water from the Fryingpan River and other tributaries are diverted each year to the eastern slope from the Rocky Mountains via a series of conduits and reservoirs, including Pueblo Reservoir, the terminal storage feature for the project. In addition to providing municipal, industrial and agricultural water supply to the Arkansas River Basin, the Fry-Ark Project also includes the 200 megawatt Mt. Elbert Power Plant (USBR, 2006).

The Fry-Ark Project was authorized by Congress in 1962. The Southeastern Colorado Water Conservancy District (SECWCD) was formed in 1958 for the purpose of developing and administering the Fry-Ark Project. Construction began with Ruedi Reservoir in 1964, and continued without interruption until September 28, 1990, when the project was declared completed with the dedication of the Fish Hatchery at Pueblo Reservoir. (SECWCD, 2010)

There are two distinct areas of the project: The western slope, located in the Hunter Creek and Fryingpan River watersheds, and the eastern slope in the Arkansas River Basin. These areas are separated by the Continental Divide. The project consists of diversion, conveyance, and storage facilities designed primarily to divert water from Colorado River tributaries on the western slope for use in the water-short areas in the Arkansas River on the eastern slope. The North and South Side Collection System and Ruedi Dam and Reservoir are located on the western slope in the Roaring Fork and Fryingpan River Basins. Sugar Loaf Dam and Turquoise Lake, Mt. Elbert Conduit, Halfmoon Diversion Dam, Mt. Elbert Forebay Dam and Reservoir, Twin Lakes Dam and Reservoir, and Pueblo Dam and Reservoir are all located on the eastern slope in the Arkansas River Basin. (SECWCD, 2010)

Transmountain diversions from the Fry-Ark Project (project water), along with water supplies in the Arkansas River Basin that are stored in project reservoirs, provide an average annual water supply of 80,400 acre-feet for both municipal and industrial use and the supplemental irrigation of 280,600 acres in the Arkansas Valley. Total project supplies may be further increased through use and reuse of project water. Project water is released from Pueblo Reservoir to the Arkansas River for irrigation and municipal use, to the Fountain Valley Conduit for municipal use by the members of the Fountain Valley Authority, City of Colorado Springs, City of Fountain, Security Water District, Stratmoor Hills Water District, and Widefield Water District; and to the Bessemer Ditch for irrigation use. (SECWCD, 2010)

Winter Water Storage Program

In parallel with the planning for the Fry-Ark Project, water users in the lower basin envisioned what became known as the Winter Water Storage Program (WWSP). Prior to construction of Pueblo Dam, the various irrigation entities would divert the flow of the Arkansas River when in priority outside of the normal irrigation season to maintain soil moisture levels in the fields where crops would be grown during the following season. Problems associated with winter operation of canal and lateral systems, labor, and related items were frequently experienced. As a result, the concept of a WWSP evolved with the objective of storing waters that otherwise would have been diverted to the fields downstream of Pueblo Reservoir. These stored waters would then be released during the following irrigation season. In 1974, the SECWCD, with the cooperation of various entities in the basin, promoted and operated a voluntary WWSP each year from 1975-76 through 1986-87, except 1977-78. With the experience and data gained each year, refinements and adjustments were made to the program with the goal of arriving at an equitable means of apportioning the stored water among the program participants and avoiding injury to nonparticipants. The WWSP was adjudicated by decree in 1987 (SECWCD, 2010).

Arkansas Valley Conduit

Poor quality of surface water and groundwater resources in the lower basin has affected not only irrigation uses, but municipal uses of water as well. The Environmental Impact Statement Analysis phase of the design of the Arkansas Valley Conduit has begun in earnest, following several feasibility studies over the past decade. The conduit will supply Fryingpan-Arkansas Project Water from Pueblo Reservoir eastward to municipalities and water providers along the Arkansas River from Pueblo to Lamar, Colorado. The need for the conduit is being driven by population growth, the economically-disadvantaged nature of the lower Arkansas River Basin, and increasingly expensive water treatment requirements being experienced by certain water providers in the lower basin. The increasing cost of water treatment is a result of poor quality of locally available groundwater and increasingly stringent requirements of the Safe Drinking Water Act. The local groundwater available from the alluvium has historically been high in TDS, sulfates, and calcium, and has concentrations of iron, manganese, and radionuclides that have exceeded drinking water standards. (GEI Consultants, 2003)

Southern Delivery System

The Southern Delivery System (SDS) is a regional water delivery system that intends to provide a cost-effective, environmentally responsible and dependable way to deliver water to Colorado Springs, Fountain, Security and Pueblo West into the future. The project will transport water from Pueblo Reservoir north through a 62-mile underground pipeline. The SDS partners own the rights to the water, which include Arkansas River water rights, and also receive annual allocations of Fry-Ark Project water. Components of initial phase of construction include the connection to Pueblo Dam, three pump stations, the pipeline, and a water treatment plant. Construction began in 2010 with water delivery scheduled to begin in 2016. (Colorado Springs Utilities, 2011)

Lower Arkansas Valley Super Ditch Company

The results of the SWSI study highlight the challenge of meeting ever-growing basin water demands, a reality that was made more apparent during the recent drought of 2002. In order to meet the needs of both irrigated agriculture and municipalities, maintain the viability of agriculture in the basin and provide an alternative to “buy-and-dry” transactions, shareholders in six major ditch companies in the lower basin recently formed the Lower Arkansas Valley Super Ditch Company.

The Super Ditch Company will facilitate temporary leases of water to municipalities and other water providers. By leasing water through leases negotiated by the Super Ditch Company, cities can obtain the water they need to serve their residents, while ownership of the water remains in the hands of local valley irrigators. Participating irrigators will forego irrigation of some of their lands, in some years, and at a pre-determined frequency. This will allow the water to be used by the cities, although most lands will remain in irrigation each year. It is expected that irrigators will forego irrigation of approximately 25 percent of their land and lease the water they do not use for municipal and other use. Feasibility studies show that 60,000 acre feet or more of water can be available for lease each year. (LAVWCD, 2010)

Colorado State University Research in the Lower Basin: ArkRiver GeoDSS

The water quality concerns in the lower basin identified by CDPHE and others have prompted a regional monitoring, modeling, and assessment program conducted by researchers at Colorado State University. The long-term goal of this research is to

> “provide water managers and users with information that will help them to enhance overall water utility and redress water quality degradation in the Lower Arkansas River Basin of Colorado. This is to be accomplished in dialogue with Valley farmers and agencies and through the discovery and the widespread adoption of water management practices that will (a) reduce detrimental waterlogging and salinity impacts to agriculture in the Arkansas River watershed, (b) enhance water quality in the Arkansas River by diminishing nonpoint source salinity and selenium loads, and (c) lead to real water conservation in the river by reducing nonbeneficial upflux from high water tables and extraction by invasive phreatophytes along the river corridor.” (Gates et al., 2006)

1.5 Decision Support Systems

The term Decision Support System (DSS) has become a common phrase used to describe integrated data management and analytical tools. A DSS is typically a group of databases and tools that help users make decisions, not by telling them what to do, but by providing data displays, analytical results, and model output that summarize information the user needs in order to make a decision.

Decision support systems and their use can be divided into three main classes.

1. Planning DSS
2. Administration DSS
3. Integrated planning and administration DSS

Most DSSs are implemented because there is a primary need to answer "what if" questions. The need for this capability is often related to management, environmental and legal issues (e.g., minimum flows for fish, interstate compact issues and water rights adjudication). A planning DSS is typically used where water resources development, management and protection are the central issues. Tools included in a planning DSS may be used in studies that involve reviewing long periods of historical data in order to validate a decision based on the long-term hydrologic characteristics of a basin. Studies may address issues such as ensuring minimum streamflows for fish or adequate reservoir storage to meet agricultural demands for irrigation water.

A DSS devoted to administration tasks is typically used by state water officials for administering water rights. The administrative component of a DSS relies on real-time data and information to help make daily decisions involving water rights administration. An administration tool must deal with the cumulative hydrometeorological and operational forces that affect a river basin. The increasing complexity of water administration requires access to real-time diversion and streamflow data together with effective analysis tools. An integrated planning and administration DSS provides tools for planning studies and water rights administration. For example, an administrative tool may rely on displays of historical data and the planning model results to indicate the reasonable bounds of a real-time decision. The ArkDSS is envisioned to be this type of DSS.

User-Friendly Interfaces for Decision Makers

DSSs are typically developed around a series of databases. The databases can be accessed directly to obtain raw data, or through graphical user interfaces (GUI) and analysis tools that are components of a DSS and that provide information to decision makers. This system structure and integration distinguishes a DSS by providing a framework with easy access to databases through user-friendly interfaces. CDSS utilizes this type of data-centered system, built around HydroBase (Figure 1-4). The data-centered approach emphasizes established, agreed-upon data on which CDSS tools operate using standard, accepted procedures. This approach also facilitates the updating of model datasets when necessary, such as the extension of a study period of a model after HydroBase has been updated.

These systems enable users to simply view the data or run complex analysis software without having extensive knowledge of input and output data structures. DSS linkages to the database allow users to display input and output data via a GUI and to perform data analyses with the visualization tools that are typically an integral part of the interface. The key element of a DSS is the integration of the data-centered system of models, databases, and interfaces to help the user analyze different scenarios. These combinations of data, model output, and data visualization were not previously possible without current computer capabilities. This integration of the components into a logical and easy-to-use framework is the core of the DSS.

ArkDSS Integration with Colorado's Decision Support Systems

As part of the ArkDSS Feasibility Study, the consultant team reviewed the CRDSS, RGDSS and SPDSS to determine the applicability of their components to the ArkDSS. This review was conducted to ensure that the tools developed for CRDSS, RGDSS and SPDSS are used to the greatest extent possible in ArkDSS in order to improve the cost-effectiveness of ArkDSS tool development and future CDSS maintenance.

The CRDSS, RGDSS and SPDSS are data-centered systems that integrate relational databases, analysis tools, and models. The relational database holds structure and station information, including streamflows, diversions, ground water levels, climate data, water rights, river calls, irrigated lands and geographic data. Key components of CRDSS, RGDSS and SPDSS are listed below:

- A centralized relational database (HydroBase)
- Associated spatial databases utilizing GIS data layers
- DSS computer infrastructure (e.g., a database server, a Web server)
- An intra-network to link the DWR's server in Denver with field offices throughout the basin and the CWCB
- The State of Colorado consumptive use model (StateCU)
- The State of Colorado water resources planning model (StateMod)
- The State of Colorado water budget tool (StateWB)
- Several data management interfaces (DMIs) to view and analyze data in the relational database
- Satellite connections to support real-time data collection
- A visual data browser to display GIS coverages
- A web-based database interface to allow Internet users access to the DSS database

The main components are supported by DMIs that process relational and spatial data using standard procedures and quality control to create input for models, and data products such as maps, graphs and reports to facilitate use by the water community. All CDSS products are documented and accessible via the Internet.

Potential Modifications for the ArkDSS

As indicated above, an objective of this Feasibility Study is to ensure that the tools developed for CRDSS, RGDSS and SPDSS are used to the extent possible in ArkDSS in the interest of cost-effectiveness of both development and future maintenance. This should be possible in large measure because the CRDSS, RGDSS and SPDSS were developed as data-centered decision support systems and, consequently, it should be possible with few or minimal changes to utilize many existing CDSS components in development of the ArkDSS.

Certain issues that are important in the Arkansas River Basin, however many require that some CDSS components be modified for ArkDSS. These issues include, but are not limited to:

- Compliance requirements of the Arkansas River Compact,
- Administration needs of the DWR Division 2 staff,
- Demand for real-time data, including "coloring" of the types of water at stream gages, and
- Water quality issues as related to water management.

1.6 Feasibility Study Organization

The State of Colorado, through the CWCB, contracted with Brown and Caldwell for project management of the Feasibility Study. Brown and Caldwell, in turn, subcontracted with Hemenway Groundwater Engineering, Inc.; TZA Water Engineers; Water Resources of the West; Merrick; Principia Mathematica; Don Ament; and Phyllis Thomas to assist in completing this Feasibility Study. The firms' respective responsibilities are:

- Brown and Caldwell – Project management and lead author, water rights and consumptive use assessments
- Hemenway Groundwater Engineering – Groundwater assessments
- TZA – Consumptive use assessments
- Water Resources of the West – Surface water assessments
- Merrick – GIS and irrigated land assessments
- Principia Mathematica – Groundwater assessments and H-I Model
- Don Ament – Arkansas Basin issues and user needs
- Phyllis Thomas – System integration and user needs

In addition to the project consulting team, staff from both CWCB and DWR participated in the feasibility study process and provided oversight for the development of the study report. Members of this State Management Team included Project Manager Andy Moore (CWCB), Ray Alvarado (CWCB), Mary Halstead (DWR), Dale Straw (DWR), Bill Tyner (DWR) and James Heath (DWR). Additionally, the Arkansas Basin Roundtable served as an advisory committee to the project team, and formed a technical subcommittee of Roundtable representatives who reviewed interim work products and provided feedback during the development of the feasibility study.

The feasibility study for the ArkDSS was conducted using a Business Case Evaluation (BCE) approach. A BCE is a structured and highly interactive economic analysis approach to making informed decisions. The goal of a BCE is to understand the problem to be solved, develop viable alternative solutions, and choose the best solution that is at an acceptable level of risk and has the lowest financial, social, and environmental costs (i.e., lowest triple bottom line cost). With respect to the Arkansas DSS Feasibility Study, a critical outcome will be to select a recommended ArkDSS implementation plan that is technically and economically defensible and that meets the needs of the various stakeholders in the basin. In order to achieve the objectives of this study, and following the steps of the BCE approach, the team performed tasks in order to write the following sections of the feasibility study:

- Introduction – Review available publications and provide an introduction to the Feasibility Study and the study area
- Needs Assessment – Meet with water users, water providers, and State officials, either independently or in groups, and identify needs to be met by ArkDSS
- Data Assessment – Assess the availability and quality of existing data and determine what new data are necessary or desirable to develop an ArkDSS that accurately and effectively addresses the needs identified in the previous task. Identify new data that must be obtained to fill gaps or increase ArkDSS accuracy. Prioritize new data collection based upon cost-effectiveness in meeting identified needs. This information is used to formulate the specifications of the proposed system.
- ArkDSS Components – Review the existing CRDSS, RGDSS and SPDSS systems and identify components that can be used in ArkDSS. Identify the components required to develop an ArkDSS that addresses the needs identified in the Needs Assessment in a cost-effective manner. Describe the functionality of each component and the data, hardware, and software requirements, as appropriate.

- Options for Implementation – Develop options for implementation of the ArkDSS considering needs, data availability, costs, and other appropriate factors.
- Proposed Implementation – From the implementation options, formulate a recommended proposed implementation plan in consultation with the State and the ArkDSS Advisory Committee.

Throughout the Feasibility Study, efforts were made to maximize the use of previous reports and existing data to help define the ArkDSS needs. A literature search was performed for publications and databases relevant to the study, including those available from the Colorado Water Conservation Board, Division of Water Resources, Colorado Department of Public Health and Environment, Colorado Geological Survey, Colorado State University, the United States Geological Survey, and others. The most relevant publications were obtained and reviewed and are included in later discussions in this report. A list of publications reviewed and referenced is presented at the end of this report.

Section 2

Needs Assessment

An important initial step in the feasibility study process is to conduct a needs assessment. Understanding the needs of potential system users will facilitate the eventual selection of the proposed implementation of the ArkDSS.

Needs Assessment Process

Information for assessing the needs was collected through interviews with State officials, water users, water managers and water suppliers in the basin. The consultant team interviewed 63 individuals representing 41 entities through meetings and telephone calls, in order to assess their needs for the ArkDSS. (See Appendix A-1 for list of interviewees.) Comments concerning ArkDSS needs were also collected using a comment sheet developed in coordination with the State. (See Appendix A-2 for a copy of the comment sheet.) The comment sheet was distributed to the membership of the Arkansas Basin Roundtable, to engineering consultants who work in the Arkansas Basin, and to each interviewee. Responses that were received were documented in a Comment Log to facilitate further analysis. Experience gained from the design, construction and use of the CRDSS, the RGDSS, and the SPDSS was also drawn upon during the needs assessment process.

The interview process revealed a wide variety of needs. Most needs fall into one of two basic types: data needs and application needs. Data needs are for specific data that are missing or incomplete and for which additional data collection is warranted. Application needs are those that can be fulfilled by a specific application or function of the ArkDSS. The numerous needs of potential ArkDSS users as expressed in the interviews were allocated to specific categories. These categories were created to facilitate translation of these needs into components and functionality of the ArkDSS, and include additional data that are called for to better support the application needs. These categories of needs include:

- Surface water planning
- Water rights administration and accounting
- Groundwater planning
- Consumptive use analysis
- Water budget analysis
- GIS and Irrigated lands analysis
- System Integration
- Water quality analysis

The needs presented in this section have been paraphrased and categorized but otherwise are presented as they were received in the original interviews. Some of the listed needs identify a system or application that is already in place. For completeness, these identified needs remain in this section even though their development costs, which are further discussed in Section 5, are insignificant.

Several of the expressed needs have been identified as being within the scope of other State or Federal agencies or replicating existing CDSS tools. Needs so identified are discussed in Section 2.11 and have been excluded from further consideration for the ArkDSS.

2.1 Surface Water Planning

Surface water planning is a primary function of the ArkDSS. The following needs, expressed by water users, water managers, State officials, and others involved in surface water planning, provide guidance for the data and tool development:

Surface Water Data Needs

- Need to accurately define native supplies versus transbasin supplies at stream gages on the mainstem, and provide better documentation of transbasin diversions in HydroBase, including coding of the recipient of the transbasin diversion (e.g., populate the “to” field)
- Review, assess and enhance the quality of historical records of calls, diversions, reservoir storage, and water rights, including checking records against non-HydroBase sources for the same data
- Data on historical reservoir operations and accounting should be incorporated into HydroBase
- Need to better understand bank storage and its effect on transit loss of reservoir releases
- Need additional data and analysis on historical river transit losses on both the mainstem and major tributaries to assist (1) the Division 2 Engineer in water rights administration, and (2) water users in operations and developing water management alternatives
- Compile output data from the daily Fountain Creek Transit Loss Model to facilitate analysis of historical operations on Fountain Creek
- For the voluntary flow management program above Pueblo Reservoir, the following data and information needs have been identified:
  - Public access to information on the releases from Twin Lakes and Turquoise Reservoirs, who is calling for the release, and how long the release will last
  - How much USBR water is available for the program each year, and how much will be exchanged from Pueblo Reservoir up to Twin Lakes during the spring and summer each year
  - What municipal exchanges are occurring in the reach during the summer months
  - What releases, timing and flow rate are being made from Clear Creek Reservoir by Pueblo Board of Water Works
  - What is the historical native flow rate at the Wellsville gage since 1980
  - What are the historical USBR releases from Twin Lakes Reservoir since 1980, and how many of the years was more than 10,000 AF released
  - Data on exchanges run from Pueblo Reservoir up to Twin Lakes Reservoir since 1980
  - Accurate spatial information for structures in the program

Modeling and Planning Efforts

- Assess effects of historical and future growth scenarios on water use and water supply sufficiency. Additionally, the tool should provide the ability to assess the influence of drought on historical use and water supply and be flexible enough for users to assess the impact of climate change on future water supply.
- Develop a publicly-available, basin-scale model that will allow for analysis of various water supply projects and processes that are being considered to meet the future water supply gap in the basin. This will aid the work of the IBCC and Arkansas Basin Roundtable, and others in water supply planning. Additionally, the tool should also have the flexibility to be able to assess water management impacts on a small-scale, not always at the basin-wide scale.

- Need to incorporate Arkansas Basin Roundtable non-consumptive flow needs into basin-planning model
- The tool should provide the ability to assess the following:
  - influence of drought on historical and future water use
  - re-use of fully consumable supplies
  - cumulative impacts of diverting water out of the basin
  - impacts of exchanges
  - impacts of operational changes by large water providers and users
- Need to investigate opportunities for, and the value of, water management strategies including:
  - alternatives to agricultural transfers (interruptible supply and rotational fallowing programs)
  - re-operation of existing storage for maximization of beneficial use
  - instream flow and recreational in-channel diversion appropriations
  - augmentation plans
  - exchanges
  - water availability for junior priority water rights
  - changed water rights
  - conjunctive use plans
  - changes in points of diversion and/or points of delivery
  - impacts of changes to and/or availability of transbasin supplies
  - opportunities for new storage reservoirs and expansion of existing reservoirs
- Assess effects of existing or potential instream flow requirements, flow management agreements and operations, and/or recreational in-channel diversions on water use and available supply. Additionally, there is a need to investigate effects of proposed water rights changes on instream flows and water supply.
- Need the ability to model or predict the USBR releases from Twin Lakes and Turquoise Reservoirs for the Voluntary Flow Management Program using snowpack and other relevant data.
- Need to assess the effect of unexercised conditional water rights on instream flows and water supply

Operations Assessments

- Assess effects of irrigation practices (e.g., center pivot sprinkler and drip irrigation development) on return flows over time in order to support decisions for the Irrigation Improvement Rules
- Evaluate effects of changes in lawn irrigation return flows and urban runoff on water supply
- Assess impacts of the Arkansas Valley Conduit to streamflows and water quality
- Track transmountain water from the sources to the beneficial use, including successive re-uses, and evaluate effects of changes and/or increases in transmountain imports and associated uses on water supplies
- Need for renovation and/or addition of stream gages, including the following locations:
  - Arkansas River at confluence with Chico Creek
  - Beaver Creek near Portland
  - Upper Purgatoire River Basin above Trinidad Reservoir at Stonewall, on the North Fork, South Fork, and Long Hollow

  - Huerfano River near Undercliffe
  - Ungaged tributaries in the upper basin
  - Fountain Creek between Pinon and Pueblo
  - Seasonal gages in upper basin need to be made year-round
  - Cucharas River near the confluence with the Huerfano River
- Need for satellite monitoring at the following locations:
  - Mt. Pisgah Reservoir
  - Collier Ditch
  - Excelsior Ditch
  - Otero Ditch
  - Water District 12 ditches
  - Off-channel reservoirs
  - Discharge from fish hatchery below Pueblo
  - Lake Minnequa
  - Historic Arkansas Riverwalk Park

2.2 Water Rights Administration and Accounting

Water rights administration is the responsibility of the Colorado Division of Water Resources, also known as the Office of the State Engineer, and specifically the Division 2 Engineer for the Arkansas River Basin. Water accounting is performed by water users and holders of water rights to demonstrate compliance with water right accounting requirements. Division 2 staff also performs water accounting for administration and enforcement purposes, as well as for Compact compliance purposes. Because the same data are used in many cases for water rights administration and water accounting, these needs are discussed together.

Water Rights Administration Needs

The Division 2 staff performs daily water rights administration, involving evaluation of past and current flow conditions, data communications, data entry, data storage, and visualization of results. Specific needs of the Division 2 Engineer and his staff to facilitate daily administration include:

- Enhancement to the Arkansas Daily Report tool to provide improved real-time information regarding available native flows, transbasin water, exchanges and augmentation releases (i.e., "color" of the water in the river). This tool would help provide more transparency for setting the call. Enhancements need to include expanding the Arkansas Daily Report to cover the entire basin.
- Need to incorporate data from Division 2 Ground Water Data Management System (GWDMS) into HydroBase
- Need to incorporate Division 2 Arkansas River Accounting System (ARAS) into ArkDSS and add automation and real-time functionality. This administrative/accounting tool is envisioned to account for a number of parameters, including:
  - diversions
  - reservoir storage and releases
  - exchanges
  - transmountain diversions

  - augmentation plans
  - instream flows
  - conjunctive use
  - municipal and industrial (M&I) and agricultural return flows
- Develop a reporting system for tracking and documenting exchanges
- Provide analysis tools which can perform water right curtailment analysis
- Provide ability to easily incorporate user-supplied data into daily accounting/administration tool
- Need for updated transit loss model along the entire mainstem that can be used by Division 2 staff to administer deliveries of water, including travel time estimates
- Need for a linked surface water/groundwater model capable of being used by water managers and administrators to manage the river on a daily basis
- Need capability to analyze exchange potential on a real-time basis

Interstate Needs

Interviews with State officials and water users identified several needs associated with data and analysis related to Compact compliance:

- Development of process/tools to facilitate compilation of data required for the annual run of the H-I Model, and make the H-I Model implementation more data-centered
- Assessment of the validity of certain assumptions used in the H-I Model, including ungaged tributary inflows, canal losses and farm efficiencies
- Acquire data and develop tools that will support improvements to the H-I Model
- Development of a groundwater model to support Compact compliance analysis
- Tools to help manage and apportion excess (i.e., flood) flows between Colorado and Kansas

Water Accounting Needs

The following additional needs have been identified to help water users and managers perform water accounting (items from above are not repeated below):

- Access to accounting data for various types of water (e.g., transmountain, native, storage releases, augmentation)
- Access to provisional data (e.g., real-time data before it becomes an official record) for reservoir accounting, transbasin deliveries and exchanges
- Ability to share data among various accounting/management tools used by the State and others
- Need for quicker turn-around on well plan accounting performed by Division 2 to help reduce the uncertainty associated with owed well depletions replacements and availability of replacement supplies
- Need the ability to ascertain from HydroBase the current total decreed diversion rate for a specific ditch. Also need to review administration numbers assigned in HydroBase to ditches in Water Districts 11 and 12 to ensure accuracy.
- Need for better public documentation of tributary/local calls in the basin

2.3 Groundwater Planning

Identified groundwater needs include:

- Ability to assess the effects and timing of stream depletions from alluvial well pumping

- Better quantification of the effects of recharge and augmentation plans on stream accretions in terms of both timing and location
- Ability to evaluate the effects of conjunctive use on streamflow
- Need to evaluate the effects on surface water appropriators of additional groundwater development to assure out-of-priority depletions are replaced
- Need to assess the effects of land use changes (e.g., urbanization, irrigation improvements), phreatophytes and changes in irrigation practices (e.g., flood to center pivot) on groundwater recharge and surface runoff
- Better estimates of canal losses to the alluvial aquifer, especially for areas outside the H-I Model domain
- Assess the validity of existing subsurface return flow factors, including the H-I Model URFs and the Fry-Ark lagging factors
- Increase understanding of trends in aquifer levels in the Denver Basin aquifers in the northern part of the Arkansas River Basin
- Identification of locations for groundwater storage
- Quantification of amount and timing of return flows from municipal lawn irrigation and septic systems
- A better understanding of stream-aquifer interactions in the basin, particularly along the mainstem and Fountain Creek
- Need to understand effects of extreme storm events on water levels in the alluvial aquifer
- Documentation on water produced from coalbed methane well production in the Raton Basin. This data should include what is pumped, what is put back into the system, and the quality of the water.
- Incorporation of all well pumping data recorded since 1994 into HydroBase, as well as estimated well pumping developed for H-I Model implementation
- Need better understanding of the groundwater system and overall water budget in the upper basin, especially in the deeper basin-fill aquifer system. This understanding is required before the need for a model in this region of the basin can be evaluated. Additionally, a better understanding of the groundwater system and overall water budgets along the tributaries away from the mainstem of the Arkansas River below Pueblo Reservoir to the Stateline is required.
- A better understanding of the vertical stratigraphy in the alluvial materials along the mainstem of the Arkansas River below Pueblo Reservoir and along the Fountain Creek drainage area
- Further definition and characterization of the deep bedrock aquifers (Dakota and the Northern and Southern High Plains) that are located beneath the shallow alluvial aquifer systems downstream of Pueblo Reservoir
- Need a better understanding of lateral and spatial distribution of groundwater quality and water level data throughout the lower basin alluvial aquifer systems
- Include the effect of industrial uses on groundwater levels, such as the Nestle Co. water bottling operation

2.4 Consumptive Use Analysis

Consumptive use analysis has been included in prior CDSS efforts in order to quantify basin water uses and losses. Similar analysis will likewise be important in the Arkansas River Basin. Consumptive use needs include:

- Quantification of both historical and current crop consumptive use in the upper basin to (1) support a water budget for the upper basin, and (2) provide data necessary for evaluating improvements to irrigation systems located outside of the H-I Model domain

- Quantification of non-crop consumptive uses and losses due to municipal use, industrial use, livestock use, wildlife use, and reservoir evaporation for current and historical periods, to understand how these have changed over time
- Estimation of water use for the following categories:
  - native vegetation
  - creation and maintenance of wildlife areas
  - municipal lawn irrigation
- In addition to crop consumptive use, investigation of the relationship between crop water use and crop yields
- Documentation of ditch water delivery schedules to better understand how crop irrigation water requirements are being met
- Include the following functionality in crop consumptive use calculations:
  - high-altitude crop coefficients and/or altitude adjustment for temperature and precipitation
  - calibrated crop coefficients based on the ACSE Standardized Method (Penman-Monteith)(where appropriate climate data are available) that can either be used with the Modified Blaney-Criddle or Modified Hargreaves (where the climate data record is not available to perform the Penman-Monteith calculation)
  - Calibration factors used by Division 2 in the H-I Model to adjust Modified Blaney-Criddle potential ET results to better approximate Penman-Monteith results
  - Calibrated crop coefficients based on Rocky Ford lysimeter studies
  - Adjustments for sub-irrigation from a high water table
- Develop a better understanding of water use efficiencies and how irrigation practices affect consumptive use and available return flows
- Provide monitoring of soil moisture to help farmers plan for upcoming irrigation season
- Quantification of current and historical consumptive use by phreatophytes
- Incorporation of remote-sensing determinations of ET for verification of modeled results
- Develop a tool for estimation of lake and pond evaporation based on nearby pan evaporation data. There is also the need to acquire additional pan evaporation locations, particularly in the upper basin. One suggestion is to include one at each CoAgMet station.
- Need CoAgMet stations to support more rigorous potential ET calculations in the following general locations:
  - Leadville
  - Purgatoire drainage/Trinidad Project Service Area
  - Wet Mountain Valley/Westcliffe
  - Colorado Springs
  - Buena Vista
  - Salida
  - Canon City
  - Penrose
  - Florence
  - Pikes Peak watershed

2.5 Water Budget Analysis

Water budget analysis was included in previous CDSS efforts in order to better understand the interactions of various water uses and the hydrologic cycle, as well as a first step to supporting more rigorous modeling efforts. These same functions will be useful to the ArkDSS. Specific needs for development of a water budget analysis in the Arkansas Basin include a need to provide historical basin-wide and sub-basin water budgets to understand the interactions among various water supplies and uses and how these interactions have changed over time. The water budget should include:

- Gaged and estimated surface and estimated groundwater inflows (including precipitation and basin imports)
- Gaged and estimated surface and estimated groundwater outflows
- Changes in surface and groundwater storage
- Crop consumptive use
- Other non-crop consumptive uses (e.g., M&I) and reservoir losses

2.6 GIS and Irrigated Lands Analysis

Spatially distributed data, such as the location of rivers, aquifers, diversion structures, reservoirs, wells and irrigated lands are an important component of performing water resources analyses. The following describes needs related to this type of spatially distributed data.

Geographic Information System Needs

One of the primary objectives of the ArkDSS is to facilitate ease of use and greater understanding of model output by the users. Based on the interviews and Comment Sheet responses, the following visualization, presentation and common data needs, categorized as Geographic Information System (GIS) needs were identified:

- Provide visualization tools for all components, including data, maps and graphs. This includes tools to help visually display data from satellite monitoring systems, and modeling output
- Provide a comprehensive, easy-to-use GIS database that incorporates existing spatial data for Division 2, as well as spatial data that will be developed for the ArkDSS and that is available via the CDSS website or DWR's AquaMap. GPS locations for all structures, diversion headgates, trace of ditch systems and well locations will be necessary. Incorporate interactive mapping that allows access to structure data by clicking on the structure location.
- Need GIS coverage depicting accurate locations of wells, including coalbed methane wells
- Conduct a thorough quality review of the locational attributes of structures, including documentation of how the locations (e.g., latitude/longitude coordinates) were determined
- Further the incorporation of the National Hydrography Dataset (NHD) into the ArkDSS GIS
- Develop a virtual "Bulletin Board" to post upcoming planned operations (i.e., reservoir releases and exchanges)
- The same type and quality of data developed from 1986 to 2009 for the H-I model area needs to be acquired for the remainder of the basin so that better decisions and management capabilities can be made basin-wide.
- Make data more "visible" so that users can help report errors, and have process by which documentation of error-correction is made available.
- Expand web services so that TSTool and StateDMI can access HydroBase via the Internet
- Utilize more open and publicly-accessible formats for spatial data products (i.e., KML or Google map, map window, ODM tools, CUAHSI products)

- Integrate mapping work done for CWCB's Flood DSS and H-I Model spatial data into ArkDSS GIS (i.e. URF reaches)
- Publish straight-line diagrams for the Arkansas Basin on the CDSS website
- Provide as much real-time data as possible via the Internet, and provide linkages to websites that are relied upon by others, such as the AHRA WaterFlow website

Irrigated Lands Analysis Needs

Major changes in land use and irrigation practices in the Arkansas River Basin have affected the availability of water supply. Because of the litigation between Colorado and Kansas and subsequent Compact requirements, an analysis of current irrigation water use, and changes in irrigation water use since 1950, is conducted annually by the Division 2 Engineer and his staff. However, this analysis is only for the H-I Model domain (irrigated areas along the mainstem below Pueblo Reservoir). To better understand land use and irrigation practice changes in the upper basin, as well as further refine the irrigated lands analyses in the lower basin, the following are needed:

- Mapping of current and historical (i.e., snapshots over time) land use and irrigated lands by crop type above Pueblo Reservoir, in and Fountain Creek drainage and designated basins to match the irrigated land analyses developed by Division 2 in the lower basin. This mapping is a high priority to Division 2, as it will provide needed data to
  - evaluate improvements to irrigation systems as required under the proposed irrigation improvement rules;
  - estimate historical natural flow for surface water modeling;
  - support historical consumptive use analyses, on either a regional or farm scale

  This mapping should be made available through the ArkDSS GIS.
- Performing a QA/QC review of the current assignments of irrigated parcels with their sources of water supply in the lower basin, as well as creating a linkage between irrigated parcels and their sources of supply in the upper basin. This will require mapping of ditch systems and well locations with their respective service areas.
- Documentation of major changes in land use and irrigation practices (i.e., changes in irrigated areas, transition to center pivot irrigation methods, and conversion of irrigation to municipal and industrial water use)
- Mapping of native vegetation and phreatophytes
- Maps from the Arkansas River Tamarisk Coalition should be included in the ArkDSS GIS

2.7 System Integration

System integration needs are those that cover the presentation and visualization aspects of the ArkDSS package; needs common to a number of users and information categories, including surface water planning, water rights administration and accounting, groundwater planning and water budgets; and standards that evolved as decision support systems for the Colorado River, Rio Grande and South Platte River were developed. The system needs indicate that the ArkDSS should focus on data access and quality, technologies and training, and scenario modeling and planning efforts further described below:

Data Access and Quality Needs

- Be a data-centered system based on data that has undergone thorough QA/QC review, fully accessible to both State and wide base of water users
- Be based on proven and accepted concepts
- Make maximum use of existing data and tools

- Continue to incorporate processes by which to flag data of questionable quality
- Ensure coordination of the ArkDSS with agencies that collect and analyze data, to promote data sharing and reduce duplication of effort. Agencies include USGS, Colorado State University, DWR and others

Technology and Training Needs

- Have an open architecture that promotes expandability and versatility
- Use state-of-the-art technology
- Conform to existing hardware and software standards adopted by the State
- Do not duplicate efforts or products of other State and Federal agencies
- Provide complete documentation
- Provide training and public information dissemination
- Identify requirements for using the models, including any limitations that would impact who uses the models
- Provide easy-to-use interfaces
- Provide a maintenance/updating program including upgrades to current system technology
- Include an automated way to submit information, including error-reporting, for incorporation into HydroBase
- Provide a consistent starting point for ArkDSS tools by closing out development that has been occurring for other CDSS projects and publish a milestone release of tools
- Provide functionality to allow translations of model input/output from one model to another (i.e., H-I Model to StateMod, MODSIM to StateMod, etc.)
- Provide documentation of open test cases to demonstrate the abilities and purposes of the ArkDSS as compared to other models in the basin. This documentation should include model “testing” to demonstrate the validity and/or limitations of the model for the intended purpose
- Develop a public education program on CDSS databases and tools, particularly the new functionality of TSTool and StateDMI
- Provide easy access to documentation, data, and products on the CDSS web site, while adhering to the State's website standards

Scenario Modeling and Planning Needs

- Analyze water supply scenarios in various hydrologic settings
- Support development of creative solutions to water resources management issues and support of analysis of exchanges, instream flow and environmental issues
- Characterize water supplies and uses in the study area
- Characterize types or “colors” of water available at specific locations
- Provide enhanced visualization of data, analysis and model results
- Assist in the planning process for State initiatives, such as The Colorado Water for the 21st Century Act

2.8 Water Quality Analysis

Recognition that water quality and quantity are closely linked has prompted water users to communicate needs related to water quality, which is not currently addressed by CDSS. These needs are particularly important to water resource managers in the Arkansas River Basin, as water resource management decisions are becoming increasingly shaped by water quality degradation, particularly in the lower basin. These needs include:

- Provide way to include water quality databases or provide linkage to other water quality databases, most notably USGS's Colorado Water Quality Data Repository
- Tools to help analyze water quality management scenarios in the basin
- Tools to assess the impacts of water resource management decisions on water quality
- Ability to include water quality data collected on produced water from CBM wells

2.9 Needs Identified But Provided By Others

A few of the needs expressed by water users are within the services and products provided by other stakeholders in the basin, including State and Federal agencies, water conservancy districts, and research institutions. In order to avoid duplication of effort and to maximize efficient use of resources, these needs may not be included in a future ArkDSS. However, there may be opportunities for coordination and support of these activities. These needs have been described below, along with the group or agency primarily responsible for addressing the need.

- Need for streamflow forecasting data and tools
  - Streamflow forecasts are provided cooperatively by the National Weather Service and the Natural Resources Conservation Service. The needs that have been expressed by water users for forecast information can be addressed through a combination of coordination with responsible agencies and through tools provided in the ArkDSS to efficiently access forecast information provided by these agencies. It is not anticipated that a component that performs streamflow forecasting will be included in the ArkDSS.
- Need to understand socioeconomic impacts of water resources management decisions
  - The outcomes of certain large water transfers in the Arkansas Basin have resulted in the recognition that water resources management decisions can have socioeconomic impacts to communities in the basin. However, predicting these effects through analytical tools can be challenging. Recent collaborative work between Colorado State University and the Massachusetts Institute of Technology focused on developing a model to predict economic impacts from specific water resources management scenarios implemented in order to reduce salinity in the lower basin. This work resulted in the development of ArkAgent, an agent-based model that simulates a water quality trading market, the water use and interactions of basin stakeholders, and basin hydrology by incorporating Colorado State University's ArkRiver GeoDSS (Kock, 2010). The ArkAgent modeling approach has potential benefit to stakeholders in the basin, but the implementation of the model is considered preliminary, with no current plans by Colorado State University or MIT to expand their work. Incorporating the ArkAgent model, which utilizes proprietary software, into the CDSS would be expensive and challenging, though further evaluation should be considered during ArkDSS implementation.
- Need to incorporate water quality analysis and modeling into the ArkDSS
  - As noted in the previous section, water quality data and analysis tools have not been included in CDSS components in other basins. Water quality issues are typically handled by the Water Quality Control Division (WQCD) in the Colorado Department of Public Health and Environment. The USGS has also performed decades of scientific research and data collection for water quality issues in the Arkansas Basin. Their Colorado Water Quality Data Repository is the most comprehensive database of water quality data available in the basin. Additionally, Colorado State University has invested over a decade of research in the basin to assess water quality impacts of irrigation management practices. This feasibility study examined how to best utilize these existing

resources to address the water quality needs discussed above in order to avoid duplication of effort.

2.10 Summary

Water users and State officials who will utilize the data and tools of the ArkDSS communicated each of the needs outlined in the above sections. These needs require that the ArkDSS have both data and analysis components. The data required to fulfill both the direct data needs of the users, as well as the data required for analytical tools, are discussed in Section 3. The components required to interface with the user, display data, perform analyses and present results are presented in Section 4. Options for ArkDSS implementation, incorporating different combinations of data and components, are presented in Section 5.

Table 2-1 indicates where to find in Section 3 (Data Assessment) and Section 4 (DSS Components) the responses to the expressed needs detailed in this section.

Table 2-1. Needs Summary and Relation to Data and Components

Needs Category	Data and Components	Appropriate Section of Discussion
Surface water planning	Surface water data collection	3.1-3.4
	Surface water resources planning components	4.2
Water rights administration and accounting	Water rights data collection	3.5, 3.6
	Water rights administration and accounting components	4.3
Groundwater planning	Groundwater data collection	3.6-3.9
	Groundwater resources planning components	4.4
Consumptive use analysis	Consumptive use data collection	3.10
	Consumptive use analysis components	4.5
Water budget analysis	Water budget data collection	3.11
	Water budget analysis components	4.6
GIS and Irrigated lands analysis	GIS and land use and irrigation service areas data collection	3.14 - 3.15
	System integration components	4.9
System integration	System integration components	4.9
Water quality analysis	Water quality data	3.16
	Water quality analysis components	4.12

Section 3

Data Collection and Assessment

As described in Section 1, the ArkDSS is envisioned to consist of a central database and models that will provide the foundation for decision-making on many critical planning, administrative and operational issues in the Arkansas River Basin. The ArkDSS will be a data-centered system containing historical and calculated information for a variety of water resources data types. It will allow decision-makers to efficiently access water resource data, simulate the potential impacts of decisions and policies, and examine potential consequences related to various water resource planning and water right administration scenarios. Towards this vision, this section of the feasibility study focuses on assessing the quality of existing data, recommending quality assurance/quality control (QA/QC) as needed, and identifying data gaps and recommended actions that could be taken to either correct or acquire the additional data needed.

The purpose of this section is to:

- Inventory data sets that pertain to the groundwater and surface water resources of the Arkansas River Basin in Colorado
- Assess the adequacy of these data sets with respect to their spatial coverage, period of record, completeness and quality
- Determine what additional data need to be obtained to implement the necessary ArkDSS data sets

This inventory, analysis and determination of additional required data were conducted for the following categories of data under the major categories described in Section 2:

Surface Water

- Streamflow (including transit losses)
- Surface water diversions
- Transbasin diversions and return flows
- Reservoirs (physical data and use)
- Snow survey

Water Rights Administration and Accounting

- Surface water rights (including replacement/augmentation plan operations)
- Wells (location and physical data)

Groundwater

- Groundwater pumping
- Aquifer configuration and properties
- Groundwater levels

Consumptive Use

- Consumptive use estimates
- Climate

GIS And Irrigated Lands Analysis

- Land use and irrigation service areas
- Geographic information system containing general spatial information relevant to water resources

Water Quality

- Water quality

Each section presented below provides a detailed discussion of each data category, including the inventory, assessment and recommendations for further data collection. The inventory and assessment of existing data for the Arkansas River Basin focuses largely on data that are readily available through the DWR's water resources database, HydroBase.

HydroBase is the foundational water resources database for the State that has been developed through CDSS for the entire state of Colorado. HydroBase is a SQL Server database that includes streamflow, diversion, well pumping, climate, water rights and other records; these data are available through the CDSS website and are also updated annually and published on DVD for purchase through the DWR. The DVD version of HydroBase used in this assessment includes records for Division 2 through 2008, while the version available on the CDSS website is updated more frequently. In addition to HydroBase, the DWR maintains a real-time Surface Water Conditions web page that provides real-time data at various locations for streamflow, diversions, and reservoir levels. Real-time data for many of the stream gages and diversion structures in Division 2 are available through this website. Most data are relayed by satellite or other telemetry and are considered provisional. The data on this website are ultimately reviewed and adjusted as necessary and are incorporated into HydroBase during the annual July update. Thus, the Surface Water Conditions web page is not a source of additional data beyond HydroBase, but provides access to some provisional data on a daily basis.

Table 3-1 summarizes the recommendations for new data that should be collected to support the ArkDSS, including the priority and relative cost level for these new data collection activities. Table 3-2 describes data compilation activities for existing data sets that will be needed as part of the ArkDSS implementation process. These two tables reflect all the data needs identified in stakeholder interviews, plus additional needs identified as part of this research. The priorities provided in these tables for ArkDSS development are based on the following criteria:

- Data needed to meet water rights administration needs
- Data needed to fill spatial data gaps in order to meet multiple water resources analysis/modeling needs
- Data needed to fill data quality gaps in order to meet multiple water resources analysis/modeling needs

It should be noted that the recommendations for additional data collection include those that would provide the highest level of data necessary for rigorous water resources analysis and modeling in the Arkansas River Basin. Section 5 will further refine these recommendations according to priority, costs, and ability to meet the user needs described in Section 2.

3.1 Streamflow

Streamflow data are important as a basic water resource need and for water rights administration and modeling requirements. Streamflows throughout Division 2 vary due to:

- precipitation and run-off
- transbasin diversions into and out of the basin
- interaction with groundwater as reaches gain or lose water with the aquifer system

- direct diversions removing water from the system
- reservoir releases
- return flows to the system from irrigation, municipal and other uses

Given the relatively large size of the Arkansas River Basin, time of travel can significantly influence streamflows throughout the basin, particularly for reservoir releases and flood events.

Historical streamflow data are fundamental to an understanding of surface and groundwater resources. Specifically they may be used to (1) establish the baseline hydrology of the basin, (2) define the available surface water supply under a range of hydrological conditions and flood/drought cycles, (3) provide boundary conditions for groundwater modeling, and (4) calibrate water resources models.

Real-time streamflow data with satellite telemetry are used by the Division 2 Engineer to quantify the flows at specific locations throughout the basin at any given time to aid in water rights administration.

The greater the coverage of streamflow data available, in terms of space and time, the greater the understanding of the hydrologic system.

Description and Assessment of Available Data

Stream gages are operated and maintained in Division 2 by two agencies, the USGS and DWR. Historical data from both agencies' gages are available through HydroBase. Real-time streamflow for all gages with satellite-based data transmission are available through the DWR's Surface Water Conditions website.

Table B-1 in Appendix B presents a summary of information for stream gages in the Arkansas River Basin, sorted first by water district and second by station name. The streamflow data in HydroBase are available on a daily basis. It should be noted that some of the gages listed in Table B-1 are measuring flow in canals, seeps and outfall structures.

Streamflow data were reviewed and assessed to determine if the data are adequate to meet the needs for streamflow information in the basin, based on the needs assessment discussed in Section 2. The streamflow records were reviewed for spatial coverage, period of record, completeness of record, and reliability of record.

There are 219 stream gages with historical streamflow data in the basin. As shown on Figure 3-1, the measuring stations are located on the river mainstem and tributaries throughout Division 2.

As shown in Table B-1, 111 streamflow gages have records extending to 2008, indicating the gages are currently active. Approximately 30 streamflow gages have periods of record that end prior to 1950, limiting their use for modeling purposes. There are 76 gages with periods of record in excess of 50 years, while many of the gages on small tributaries have relatively short periods of record. Only 32 active gages have a start year prior to 1950.

For the period of record at each gage, Table B-1 lists the percentage of daily data that are missing. Approximately 33 streamflow gages have less than 30 percent missing records for the period of 1950 through 2008, while 19 streamflow gages have less than 10 percent missing records for the same period.

The USGS classifies accuracy of their records as "poor," "fair," "good," and "excellent." Each qualitative description relates to a statistical degree of accuracy for a specific stream gage which can be reviewed prior to inclusion of the data in further analysis. This qualitative type of information is not included in the HydroBase streamflow records. However, the measurement procedures and preparation of the records for stream gages for both the USGS and DWR are established and accepted in the water community. Reliability of the streamflow data is considered adequate for modeling purposes, though a more thorough quality assessment would be warranted in order to document the reliability of individual records as part of the development of the surface water components of the ArkDSS.

The Upper Arkansas Water Conservancy District (UAWCD) is in the process of installing a network of streamflow gages that will also be fitted with satellite telemetry for real-time flow data access. This monitoring network, designed in coordination with the CWCB, the USGS and DWR, has been designed to fill a large portion of the data gap in the upper basin and to support a sub-basin water balance effort. Figure 3-2 shows the location of the UAWCD stream gaging network.

Additional Data Required

As discussed in the needs assessment in Section 2, additional streamflow information would be useful in several parts of the basin to support modeling and administrative purposes. Tables 3-1 and 3-2 summarize the additional streamflow data required, which are discussed in further detail below. Additional data needs were divided into three categories: 1) stream gages, 2) transit loss data and 3) components of streamflow.

Stream Gages

Effort should be spent on identifying key streamflow stations and determining if gages can be combined (replacement gage, moved gage, etc.) in order to fill missing data or extend the period of record. Missing streamflow records may not need to be filled for the surface water modeling component, as techniques currently used in the CRDSS and SPDSS to estimate natural flows can be utilized rather than estimating streamflow at specific gages. However, missing streamflow records for groundwater modeling may need to be filled, as this is an important boundary condition. Techniques used previously in the CDSS should be utilized for this purpose. (See SPDSS Surface Water Memorandum for Task 2, revised February 10, 2007)

The coverage of stream gages is considered sufficient for water resources planning purposes. However, additional gages on tributaries would enhance modeling and administration by providing more points of known flow for modeling calibration, to provide data to document inflows from smaller watersheds, and to better estimate travel times and gains and losses. Additional streamflow information for modeling and administration would be useful at certain locations in addition to the gages being installed in the upper basin by UAWCD. The Division 2 Office has identified the following based on their administration needs:

- Stream gages or stream gage improvements needed at the following locations:
  - Fountain Creek between Piñon and Pueblo
  - Beaver Creek near Portland
  - Huerfano near Undercliffe

The following locations were identified by water users as needing stream gages to improve understanding of flows in these areas:

- Arkansas River below confluence with Chico Creek
- Purgatoire River Basin above Trinidad Reservoir
  - Purgatoire River near Stonewall
  - South Fork of the Purgatoire
  - North Fork of the Purgatoire
  - Long Hollow
- Cucharas River near the confluence with the Huerfano River

Additionally, the Arkansas Basin Non-Consumptive Needs Assessment identified several watersheds in the basin where multiple environmental and recreational attributes warrant a high prioritization for collecting additional information. The highest priority watersheds include small, ungaged tributary systems in: (1) the upper basin, (2) around Pueblo Reservoir, (3) around John Martin Reservoir, and (4) around the Great Plains Reservoirs. Additional investigation is needed to determine the need and location for stream gaging to support further analysis of the non-consumptive water supply needs of these highest priority areas.

DWR staff is responsible for the general maintenance and operation of many of the existing streamflow gages and diversion satellite monitoring systems in Division 2. This responsibility would grow with the addition of new gages proposed in this feasibility study. The Division 2 office was previously understaffed but was approved to hire a fourth staff hydrographer in 2010. It is unclear at this time if Division 2 staff will be able to maintain any of the additional new streamflow gages. The additional new streamflow gages can potentially be rated, operated and maintained under the ArkDSS for the duration of the ArkDSS implementation program.

The new data collection recommendations described above are summarized in Table 3-1.

Transit Loss Data

A point flow or gain/loss analysis tool would be an integral part of the surface water planning component. Travel time and transit loss information is important for administering reservoir releases, transbasin and other fully consumable return flows, and augmentation plans. The information from these studies can also be used in the calibration and/or verification of an alluvial groundwater model.

Division 2 assesses transit losses for the mainstem of the Arkansas River based on the following:

- Upper basin – constant transit loss factor
- Lower basin between Pueblo Reservoir and John Martin Reservoir – results from Russ Livingston's 1976 transit loss study (Livingston updated this study in 2011 and the results are anticipated to be implemented by Division 2.)
- Lower basin between John Martin Reservoir and the Stateline – results from recently completed transit loss study by Russ Livingston to support Compact compliance analysis
- For the ArkDSS, the current transit loss studies on the mainstem below Pueblo Reservoir need to be reviewed and incorporated. Using data collected through the new UAWCD stream gages in the upper basin, a transit loss study could be completed for the upper basin. The DWR operates the existing Fountain Creek Transit Loss model, which is a near real-time model that allows users to track reusable and native water return flows. The daily data associated with the Fountain Creek Transit Loss model needs to be compiled and further analyzed to understand the long-term transit losses on Fountain Creek.

Components of Streamflow

Operations in the Arkansas River Basin are complex due to the movement of water through the basin from transbasin diversions, reservoir releases, native inflows and exchanges. A majority of these operations occur above the confluence with Fountain Creek. Division 2 staff and numerous water users have expressed a need for the various components of streamflow (i.e., "colors" of the water) to be identified at stream gage locations in order to properly administer the river and to coordinate operations. Information useful to identifying the colors of water is often located in individual water user's accounting and is not centrally located or publicly available.

HydroBase currently is not capable of storing the color of water flowing past a stream gage. The ArkDSS should analyze the availability and quality of information needed to identify the components of streamflow and make recommendations on how this information may be recorded or estimated and made available to water users. Previous CDSS efforts in developing the Water Information Sheet tool could be applied to a new tool specific to Arkansas Basin needs for identifying and tracking components of streamflow.

The data compilation activities described for transit loss data and components of streamflow are summarized in Table 3-2.

3.2 Surface Water Diversions

Historical daily diversion records for existing water rights in Division 2 will be used in water resources planning models for many purposes, including: (1) to estimate natural flows (pre-development streamflows) (2) to define water demands under future conditions or planning scenarios, (3) to perform historical use analyses, and (4) to analyze exchange potential. Records of historical diversions are collected by Division 2 and incorporated into HydroBase, and are updated on an annual basis.

DWR also maintains and operates a number of real-time satellite-monitoring gages on major diversions in the Arkansas River Basin. These diversion gages are used in conjunction with the streamflow gages to more accurately administer water rights. Based on both the flows and the priority of diverting rights, the Division 2 Engineer administers the water rights by identifying those rights that are junior in priority that must be curtailed in order to satisfy rights more senior. Understanding the relationships between flows at various locations along the river and the effect of curtailing water rights diversions on downstream water rights is critical to the administration decision-making process.

Description and Assessment of Available Data

HydroBase includes daily diversion records (in cfs) for structures diverting in Division 2. Table B-2 in Appendix B provides an estimate of the number of direct surface water diversions, categorized by total decreed diversion volumes, in each water district. The values in Table B-2 are based on a simple query of the July 2009 HydroBase (HydroBase_CO_20090701) for Division 2. The diversion record query to create Table B-2 was not reviewed in-depth to account for data outliers such as: (1) diversion structures that have diverted historically, but no longer divert, (2) diversion structures that exist but the water rights are diverted at other locations, (3) missing diversion structures, or (4) other reasons for erroneous data.

The available diversion records were reviewed for spatial coverage throughout Division 2, period of available records, completeness of available records, and overall reliability of the data. Table 3-3 is a general summary of the diversion record adequacy by water district. Table 3-3 is based on discussions with the staff of the Division 2 Engineer's office and from observation and use of the diversion records. It should be noted that assessment of diversion records for any given structure in a water district could vary significantly from the general assessment presented in Table 3-3 and the discussion below, which analyzes the diversion records for a water district and summarizes the quality of these records for the entire district.

HydroBase indicates that there are approximately 7,031 surface water diversion structures in Division 2. Only 2,567 of these structures have measured diversion records included in HydroBase, providing an indication that not all structures are used for stream diversions. Satellite monitoring has been installed on 50 of the major ditches in the basin to provide real-time diversion data. Historically, this real-time provisional data has not been provided in HydroBase. However, DWR is currently updating HydroBase to include access to more real-time data, with cautions regarding the provisional nature of the data. Figure 3-3 shows the location of structures, both stream gages and diversions, which are included in the satellite monitoring system.

Electronic records for some diversions date back as far as the late 1800s. The structures that make up a majority of the annual diversions within the basin have reliable records starting in the late 1930s. As indicated in Table 3-3, the record lengths vary by water district. The periods of record of diversions as a whole should be adequate for water resources planning purposes.

HydroBase contains records for 2,567 diversion structures with an aggregate average annual diversion of 3,065,886 acre-feet for the Arkansas River Basin. Note that this value is likely higher than current annual aggregate diversions because it does not reflect changes in water rights and includes structures that have historical records but are no longer diverting.

The following summarizes the nature and extent of the diversion records in HydroBase:

- 48 structures have average annual diversions greater than 10,000 ac-ft which represents 65 percent of the diversions in the basin
- 92 structures have average annual diversions greater than 5,000 ac-ft which represents 75 percent of the diversions in the basin
- 154 structures have average annual diversions greater than 2,000 ac-ft which represents 81 percent of the diversions in the basin
- 270 structures have average annual diversions greater than 1,000 ac-ft which represents 87 percent of the gaged diversions in the basin
- HydroBase contains 4,076 diversion structures without any diversion records, and 388 structures with only infrequent diversion records
- As shown in Table 3-3, many of the incomplete diversion records exist in the upper basin

Many of the major ditches in the basin have been equipped with Parshall flumes and continuous recording devices since the 1930s, with the major mainstem ditches equipped with satellite monitoring in the 1980s. In recent years, Division 2 has made an intense effort to require reliable measuring devices on all diversion structures. The accuracy of most permanently installed measurement devices is considered good. The accuracy of records for structures without recording equipment depends on the number and timing of spot observations by the water commissioner.

For structures without continuous recorders, the DWR's policy is to record changes in flow only. For example, if a diversion of 5 cfs was recorded on June 10th and the next change in diversion magnitude was to 3 cfs on June 20th, the DWR enters data on June 10th and June 20th. To interpret the diversion record from June 11th through June 19th, the June 10th value of 5 cfs is carried forward. This "carry forward "procedure is an efficient database practice that has been accepted in numerous Water Court cases. The water community generally acknowledges it as a reasonable procedure for developing a complete diversion record.

It is assumed that the diversion records have undergone the normal quality control review by the DWR during the process of transcribing records from water commissioner field books to the electronic database and are considered sufficiently accurate for water resources planning purposes. It is our understanding that historical diversion records used in the H-I Model for compact compliance purposes underwent an additional QA/QC review prior to use for calibration of the model.

On the basis of this review, data for the total water diverted through a given structure are considered reliable. Data for diversions to specific water use types are also reasonably reliable. The primary exception is a release from off-stream storage for municipal or irrigation purposes. Data for diversions to storage are usually available because they are administered as part of the river. Measurements of off-channel reservoir releases are typically an owner's decision that are not administered and therefore often go unrecorded. Therefore, the total water supply for a given structure may not be known because the diversion records do not reflect the water supplied by an off-channel reservoir. In addition, coding of the types of water diverted by a given structure, such as reservoir water or water taken by exchange, has not been consistent over the years. Finally, there also exist situations involving the movement of water in the basin that are so complex that they cannot be described adequately with existing diversion coding, such as exchanges to facilitate out-of-basin diversions. The updated HydroBase water class coding scheme, to be implemented in 2011, should address most of these complex situations and may be further enhanced to capture complex situations that arise in the future.

Additional Data Required

Additional real-time information for modeling and administration would be useful at certain surface diversion locations (See Table 3-1). The Division 2 Office has identified the following:

- Satellite monitoring on mainstem ditches: Collier, Excelsior and Otero ditches.
- Satellite monitoring on major ditches in Water District 12 (Mainstem from Salida to Portland)

Additionally, water users have identified the following diversion locations for satellite monitoring (See Table 3-1):

- Flows through the fish hatchery below Pueblo Reservoir
- Historic Arkansas Riverwalk Park

Highlights of the additional data compilation required for surface water diversions are (See Table 3-2):

- Diversion data in the H-I Model should be compared with diversion data in HydroBase. It is unclear if the diversion data that were subjected to the QA/QC review for incorporation into the H-I model were ever updated back into HydroBase. A process to document how these diversion records were compared and where differences in records exist should be completed.
- For the water resources planning model and the consumptive use model, a complete record of diversions for the study period of record is needed for major structures in Division 2. In the Colorado River and Rio Grande DSS models, major structures comprising 75 to 85 percent of the total diversion in the basin are modeled individually or “explicitly”, while minor structures representing the remaining 15 to 25 percent are spatially aggregated into “aggregate structures”. A similar approach should be adequate for ArkDSS purposes. Therefore, major diversion structures with average diversions greater than 1,000 acre-feet/year (representing approximately 87 percent of the diversions in the basin as calculated from the data shown in Table B-2) will be explicitly modeled. It is anticipated that diversion structures with average annual diversions below 1,000 acre-feet per year, including structures reporting infrequent diversion data, will be combined into aggregate structures for modeling purposes. Therefore, it is not necessary to estimate the missing diversions at these smaller diversion structures.
- Data collection for the diversion data should concentrate on identifying the major diversion structures in the basin with missing data and developing estimates for the missing records at these key structures. Table B-2 shows 270 diversions with average annual diversions greater than 1,000 acre-feet/year. Approximately 25 percent of these diversion structures have some missing diversion records based on the information reviewed in the creation of Table 3-3 and Table B-2 and spot inspection of the diversion records. Diversion records will therefore need to be filled for approximately 68 major diversion structures with average annual diversions greater than 1,000 acre-feet/year.

3.3 Transbasin Diversions and Return Flows

Transbasin diversions, which include the Frying pan-Arkansas (Fry-Ark) Project and other diversions as shown in Table 1-2, represent a major inflow component to the Arkansas River. As with surface water diversion records, transbasin diversion records will be used in the development of natural flows and will also be used to define inflows to the basin for modeling of future conditions. Transbasin diversion records are maintained by DWR, as well as independently by owners/operators of the diversions.

Return flows generated from the use of transbasin water is another category of information that is critical to water use and administration in the Arkansas River Basin. These data, although estimated and tracked by Division 2 and others, are only recently beginning to be included as monthly time series in HydroBase

Description and Assessment of Available Data

Table B-3 in Appendix B summarizes the 14 transbasin diversion structures located in Division 2. Of these, 13 structures deliver water into the Arkansas Basin, and only one structure exports Arkansas River water out of the basin. Transbasin diversion records were reviewed for spatial coverage throughout Division 2, period of available records, completeness of available records and overall reliability of the data.

Transbasin diversions import water into the Arkansas River Basin from the Colorado, South Platte, Gunnison, and Rio Grande Basins. Water is also exported from the Arkansas Basin into the South Platte Basin. Figure 3-4 shows the locations of the transbasin diversion structures in Division 2. All transbasin structures have at least some records of diversions.

The periods of record for the transbasin diversions that are monitored by streamflow stations are consistent with the lifespan of the projects. These include all transbasin diversion structures except the Hudson and Medano transbasin ditches, which have only partial records. It will be necessary to rely upon owners' records for filling the missing data for these structures.

From inspection of the period of record and the data contained in HydroBase, records are not complete for many of the structures. As shown in Table B-3, some transbasin diversion records are missing for most of the structures; however, the records for 11 of the 14 structures are at least 80 percent complete.

The major transbasin diversions are currently equipped with Parshall flumes or similar devices that accurately measure the flow. The available records identify the point where the imports reach the stream but in many cases do not identify the end user or the delivery point. Overall, the quality of the transbasin diversion data will only be adequate after this missing information has been filled or estimated.

Transbasin Return Flows

Transbasin water can be used to extinction in the basin of import. For this reason, careful accounting of return flows generated from the use of transbasin water supplies is performed by Division 2 in order to determine the availability of water for secondary uses, including replacement, augmentation and exchange. Accounting procedures used to estimate the amount and timing of return flows of transbasin supplies are based on various methodologies, depending on the source of supply, and range from factors developed many years ago to track return flows of Fry-Ark water, to the sophisticated Fountain Creek Transit Loss Accounting Tool, used to track non-native supplies from Colorado Spring Utilities down Fountain Creek. The data developed through these accounting procedures, while used for administration purposes, have not been included in HydroBase to date.

Additional Data Required

For water resources planning, a complete record of diversions for the study period of record is needed for transbasin diversion structures in Division 2. The HydroBase records should, therefore, be supplemented with historical data available from (1) owners of transbasin diversions, (2) DWR hard copies of transbasin data, and (3) paper copies of the USGS Water Resources Data reports. For example, missing records for Homestake deliveries from the Arkansas Basin to the South Platte Basin from 1982-1998 could be filled from the owners' records and from USGS records where needed. If these sources are incomplete, the missing records should be estimated.

Another effort for this task will involve resolving operationally complex records. For example, diversions through the Homestake Tunnel are brought into the headwaters of the Arkansas River and then re-diverted for delivery via pipelines to the City of Aurora in the South Platte Basin and to Colorado Springs Utilities in the Arkansas Basin. Accurate and complete records of the transbasin diversions are important because the deliveries represent foreign water, which in most cases can be fully consumed by first or secondary uses. The information shown in Table B-3 indicates that most transbasin structures have some periods with incomplete records. These missing data need to be filled and daily records need to be obtained if available.

Transbasin Return Flows

To facilitate analysis of return flows available from transbasin water use, it is recommended that estimates of historical transbasin return flows derived from accounting performed by Division 2 be recorded in HydroBase, and coded by transbasin diversion structure. In this way, transbasin water use can be tracked to extinction.

Table 3-2 summarizes the additional transbasin data compilation required.

3.4 Reservoirs

Reservoirs regulate streamflows and are an important component of the river system in the Arkansas River Basin. Reliable reservoir physical and operational data (e.g., storage, stage and releases) are required to accurately develop natural flow estimates and to conduct realistic simulations of the historical and future operations of the facilities.

Description and Assessment of Available Data

Table B-4 in Appendix B summarizes reservoir storage information taken from HydroBase. The values in Table B-4 are based on estimates developed from the July 2009 HydroBase database (HydroBase_CO_20090701).

Another source of reservoir data is the reservoir accounting that either Division 2, the reservoir owner/operator, or both performs. For example, the USBR performs accounting of the contents and various storage accounts in Twin Lakes, Turquoise Lake, and Pueblo Reservoir as part of its operation of the Fryingpan-Arkansas Project. This accounting is performed internally and in coordination with the entities with contracts for project water. The accounting is made available to both SECWCD and Division 2, and could be uploaded to HydroBase to better understand Fry-Ark Project reservoir operations. Other sources of reservoir accounting in the basin include Division 2 (John Martin Reservoir), PRWCD (Trinidad Reservoir), and irrigation companies operating smaller irrigation reservoirs. For cases in which multiple entities perform accounting for the same reservoir, review of the accounting is needed to reconcile any discrepancies in the data.

The available reservoir records were reviewed for spatial coverage throughout Division 2, the period of record available, the completeness of available records, and the overall reliability of the data.

In Division 2 there are 1,720 reservoir structures representing more than 1.5 million acre-feet of potential storage volume. Adequate data describing the physical location and decreed water rights for these structures is available in HydroBase.

From inspection of the data in HydroBase, the majority of the reservoirs have very limited historical storage records available. Table B-4 breaks down the number of reservoirs by size and identifies peak storage volumes for the period of record. Only 16 percent of the reservoirs in the basin have storage records. A summary of the reservoirs by peak storage volume follows:

- 56 reservoirs have peak storage that exceeds 1,000 acre-feet

- 18 reservoirs have peak storage that exceeds 10,000 acre-feet
- Only 6 reservoirs have peak storage that exceeds 50,000 acre-feet

For the Arkansas River Basin, HydroBase does not include elevation-area-capacity information, operating rules for the facilities, or identify the end user of the reservoir releases. Storage deliveries to specific users in many cases are coded in the diversion records only if the storage releases are conveyed to the user via a stream. This information is needed to support adequate modeling of the surface water system. Of the data sources required for the surface water component of the ArkDSS, the reservoir data are the least complete.

HydroBase has very limited information concerning historical storage records, reservoir inflows, reservoir releases, maximum storage capacity, dead storage and stage area-capacity information. No information is available to identify the ownership of the various accounts in a reservoir, or the use of water by account. Currently, the operating principles of each reservoir are not available in HydroBase. The reservoir data in HydroBase are currently inadequate for ArkDSS purposes.

Additional Data Required

Additional real-time information for modeling and administration would be useful at certain off-channel reservoir locations. The Division 2 Office has identified the following (See Table 3-1):

- Holbrook Reservoir
- Mt. Pisgah Reservoir
- Brush Hollow Reservoir

For water resources planning, a complete record of physical and operational data for the study period is needed for major storage facilities in Division 2. The data collection should focus on reservoirs greater than 1,000 acre-feet in capacity. Then, DWR personnel and the owners of the selected key reservoirs would be interviewed to collect available hydrologic data and reservoir accounting, document use of the reservoirs and operating rules. Non-numerical data (e.g. operational descriptions) collected through these efforts would be documented in memoranda. The numerical hydrologic data collected would be digitized and incorporated into HydroBase and missing historical storage records estimated. Table 3-2 summarizes the additional reservoir data compilation required.

3.5 Snow Survey

Historical snow course data can be used to develop and evaluate the accuracy of forecasting spring runoff quantities and patterns. Real-time snow course data can be used to assist with water management if an accurate forecast method is available. This information is often used by reservoir owners in Division 2 to determine their release and fill operations for the year.

Description and Assessment of Available Data

In the Arkansas Basin, there are 10 SNOTEL (snow telemetry) stations managed by the Natural Resources Conservation Service (NRCS). For these sites, snow water equivalent (SWE) data are available in HydroBase on a monthly basis. More detailed information (e.g., daily data, monthly summaries, averages, and basin update reports) is available directly through the NRCS Colorado Snow Survey Program. Table B-11 provides a summary of the data available from NRCS SNOTEL sites.

Snow data were reviewed to determine if they are adequate for use in forecasting runoff quantities and patterns and for estimating historical reservoir operations, by assessing the spatial coverage, length of records, completeness of records, and reliability of records.

The snow survey sites are all located in the upper areas of the basin and have good coverage for the Arkansas River mainstem and its major tributaries. Table B-11 provides the location of each SNOTEL site.

Many of the SNOTEL sites have been in place since the early 1980s, providing nearly 30 years of records. The length of record is generally adequate to support forecasting and analysis of reservoir operations.

Based on information provided from the Western Regional Climate Center, the SNOTEL sites are continuously recorded and relatively complete. Existing SNOTEL stations and their ongoing data collection should be adequate for forecasting spring runoff and estimating historical reservoir operations.

Additional Data Required

Given the amount of historical snow survey data available, its spatial distribution and its reliability, no additional snow survey data sites are recommended for use in the ArkDSS.

3.6 Surface Water Rights

Surface water rights records contain the key physical and legal attributes of each decreed surface water right in Division 2. This information is necessary to both administer water rights and simulate water allocation under historical and future conditions. River call records indicate historical administration and are valuable for understanding both historical and future water right settings.

Description and Assessment of Available Data

Table B-5 in Appendix B is a summary of the decreed water rights in the Arkansas River Basin. As with the other information extracted from HydroBase, the reported information is based on the July 2009 update of HydroBase (HydroBase_CO_20090701) for Division 2.

River call records maintained by Division 2 indicate for a given time period the most senior water right in a given river reach whose demand is not satisfied. Some historical call records for Division 2 are included in HydroBase, but they date back only to 2002. Division 2 has maintained a more complete call record database separate from the records in HydroBase. Additionally, the Arkansas Daily Report, published daily by Division 2 staff to the DWR website, includes the river call in effect at the time of publication.

The available water rights records were reviewed for spatial coverage in Division 2, the period of record available, the completeness of available records, and the overall reliability of the data. The HydroBase water rights tabulation for Division 2 contains records for decreed water rights in the Arkansas River Basin, providing sufficient coverage for ArkDSS purposes. The electronic water rights tabulation includes water rights decreed since the first adjudications in the individual water districts within Division 2. Therefore, the period of record of this data type is sufficient.

Call records typically exist for the mainstem of the Arkansas River in both hard copy and electronic format since approximately 1953, but only in hard copy format for the Arkansas tributaries. The Arkansas Daily Reports date back to September 1, 1999, and contain the mainstem call at the time of day that the report was published.

Information in HydroBase indicates what water rights at a given structure have been transferred to other uses but does not provide sufficient detail to describe the terms and conditions of these transfers. For example, many water rights throughout the Arkansas River Basin were originally decreed for irrigation, but were transferred to municipal purposes in the 1980s and 1990s. HydroBase indicates that these water rights have been transferred to municipal uses but the database does not describe the terms and conditions associated with these transfers. For this level of detail, the appropriate decrees can be viewed at the CDSS website.

Similarly, the current HydroBase is not designed to include details of augmentation plans and substitute supply plans on a consistent basis for the entire state. However, considerable effort is undertaken each month by Division 2 to collect the necessary data, estimate out-of-priority depletions, and determine if sufficient replacement of those depletions has been made. The data from these replacement/augmentation plan accounting efforts have not been included in HydroBase.

CWCB instream flow appropriations are inventoried in HydroBase, and are included in the “other” category of water rights. Priority call records in electronic and paper form are maintained by Division 2 for the mainstem of the Arkansas, but few records are available for the tributary watersheds. Reports for the South Arkansas and Cottonwood tributaries are available through links on the Arkansas Daily Report. These reports contain the local call for those tributaries; however, these reports are only for the current conditions and historical call information is not available online. The call records in HydroBase for Division 2 are not considered as complete as the call records maintained by the Division 2 office.

Water rights data in HydroBase provide an accurate summary of the water rights originally decreed for a given structure, and also provide documentation of water rights transfers for the given structure, including changes in use and point of diversion. The water rights tabulation is considered sufficiently accurate for the purposes of the ArkDSS, with the exception of Water District 11. In this district, the administration number assigned to certain water rights incorrectly reflects the administration of these water rights by Division 2. Although call records have been maintained by Division 2 for the mainstem of the Arkansas, procedures for recording calls and dry river conditions were inconsistent in the early records. Also, the availability of call records for tributary watersheds is inadequate.

Based upon an initial review, a few structures have annual volume water rights that are possibly misclassified as “Other” and have been excluded from the net amounts shown in Table B-5.

These structures and a possible appropriate classification include:

- 1000972 – Cherokee Metro WWTP, 1.06 ac-ft (storage)
- 1003695 – Chapel Hills East Det Pd, 47.3 ac-ft (storage)
- 1005795 – Rawhide Ent Dawson Right, 69.66 ac-ft (groundwater)
- 1007104 – Church of Christ, 1590 ac-ft (groundwater)
- 1105769 – Indian Spgs Well Field, 24.37 ac-ft (groundwater)
- 1403570 – Antelope Pit Tank #1, 0.125 ac-ft (storage)
- 1603516 – Bear Lake Minimum Level, 21 ac-ft (storage)

Additional Data Required

A complete record of the physical and legal attributes of major operating water rights in Division 2 would be necessary for developing a complete and accurate water resources model. Although the water rights tabulation in HydroBase accurately defines original water rights, and denotes transfers, it needs to be supplemented with additional transfer decree, augmentation plan, substitute supply plan, and priority call data.

Additional information regarding the use and operation of key diversion, reservoir and transbasin structures in the basin is needed to accurately incorporate these structures into the CDSS models. Previous CDSS efforts have collected this information through interviews, and documented the information in memoranda during the data collection phase. This operational data is closely related to water rights and administration, and so these efforts are included in the data collection for surface water rights. Additional water rights data compilation required to meet the needs detailed in Section 2 are presented in Table 3-2.

Data collection and assessment of terms and conditions for water rights transfers, replacement/augmentation plans and substitute supply plans could be a relatively expensive effort. The level of effort for this task is dependent upon the level of detail that would be incorporated into the surface water model. For purposes of this feasibility study, it is assumed that detailed information would be collected and summarized for all of the Rule 14 well replacement plans, and for up to 30 of the largest water rights transfers and other augmentation plans (in terms of annual diversions) in Division 2.

Augmentation plans are not physical structures; however, in HydroBase direct flow and storage water rights are being assigned to these plans. Discussions are underway at DWR on how to consistently include information from these plans in HydroBase. It is recommended that further discussions occur to determine the best way to represent augmentation plans within HydroBase and that a common practice be implemented throughout the State. This will be necessary for developing a complete and accurate water resources model that can be created through a data-centered approach.

Priority call data would be valuable to an understanding of historical and existing water rights administration. Existing call records for the mainstem of the Arkansas River interpreted and digitized by the Division 2 office should be reviewed and validated prior to placement in HydroBase. Other existing call records should also be interpreted and digitized. As part of this effort, various issues concerning the quality of the call records would have to be addressed. This effort does not address the development of call records where no records exist.

The water rights tabulation for District 11 should also be reviewed and possibly revised to match current Division 2 administration and in context with the postponement doctrine.

3.7 Wells

Well data are required to identify the location and determine the ownership, capacity and historical use of wells in the basin. In addition, the well data can be used to establish a tie to groundwater rights.

Description and Assessment of Available Data

Publicly recorded well information for the Arkansas River Basin is available primarily from the DWR and the Colorado Oil and Gas Conservation Commission. These data vary greatly in content and quality. Much of this information is static, describing location and construction, and does not include either pumping or water level data.

The well data available from the DWR are contained primarily in three datasets which have been incorporated into HydroBase. The first is the water rights tables in HydroBase, which includes information on well owner, location, use and adjudication information, including decreed pumping rate and priority date. Nearly 10,000 well records consisting of absolute rights and conditional rights are maintained in the water rights tabulation for Division 2. Table B-6 in Appendix B provides a summary of the number of wells by flow rate in each water district in Division 2.

The second dataset included in HydroBase, the well permit data for Division 2, is larger and includes information on (1) wells that may or may not be listed in the water rights database (e.g., exempt wells, designated basin wells), (2) wells that are for non-production purposes (e.g., monitoring), (3) wells that have been abandoned, and (4) wells that have yet to be installed. This dataset also contains information on owner, location and use. Many of the well permits contain geologic information from the well driller, including a log of geologic materials encountered during drilling, initial water levels, well yield and well completion information such as well depth, well construction and screened or open borehole intervals.

There may be some wells listed in one database and not the other, so it will be necessary to combine the datasets during ArkDSS implementation to obtain a more comprehensive State listing of wells.

The third dataset in HydroBase is of geophysical well logs. This dataset is maintained by the SEO Geotechnical Services Branch. It includes information on well permit number, location and owner, formation boundaries, sand thickness, water level and types of logs available, but mainly covers wells located in the Denver Basin.

Additional records are maintained by (1) water user groups within Water Division 2 including, but not limited to, agricultural user groups such as Southeastern Colorado Water Conservancy District, Upper Arkansas Valley Water Conservancy District, and Lower Arkansas Valley Water Conservancy District, and (2) municipal user groups such as Colorado Springs Utilities, City of La Junta, and Pueblo Board of Water Works.

Data available from the Colorado Oil and Gas Conservation Commission are primarily on oil and gas test wells that were drilled during limited development efforts in the basin. Data collected on these wells include geophysical logs, drillstem tests and geologic descriptions of formations encountered.

Well data in HydroBase were reviewed in terms of spatial coverage, length or period of record, completeness and reliability. Location information for wells has been provided by DWR as a GIS shapefile that contains all of the decreed wells in Division 2 (see Figure 3-5). Division 2 performed a GPS survey to verify the location of all high production wells (pumping rate > 50 gpm) in the basin, providing more accurate information than has historically been recorded in well permits and decrees. However, this survey did not include measuring accurate elevations of these wells.

Well structural and location data are not time series, so the period of record does not directly apply. However, the date the well was completed provides information on the development of the groundwater over time within an area, and possibly the reliability of the well for current and future uses (monitoring, pumping tests, etc.).

Well data vary greatly in content and quality. The location information provided in HydroBase is the primary source of information for well locations. Experience with well data and groundwater modeling in other basins has shown that interpretation of location information when GPS coordinates are not provided can be difficult. The difficulties lie in the fact that original well locations are approximate and many wells have been moved or replaced. Additionally, very few wells in the basin have been surveyed for accurate elevation. Also, these records have been collected over a long period where recording procedures have changed. A well permit may contain coarse geologic and hydrologic information in the form of driller’s descriptions of formations encountered, casing and screen schedule, well depth, water level and well yield. However, the amount, type, and quality of the information provided on each individual well permit may vary significantly from permit to permit. Therefore, the well data summarized in HydroBase can vary greatly from well to well.

Additional Data Required

Additional wells that are completed by individuals, municipalities, USGS, Colorado State University, and other entities, including monitoring wells, should be added to the database as they are developed to expand the information available for future modeling. All monitoring wells should be surveyed for accurate elevation data, as well as a subset of high capacity wells. Accurate elevations of wells are critical to interpreting the data collected from the well, and in groundwater modeling. Table 3-1 summarizes the additional data collection identified for well data.

3.8 Groundwater Pumping

This section discusses existing information and data needs relating to groundwater pumping from wells. Pumping data are important in (1) characterizing historical water usage, (2) evaluating the location and timing of stream depletions, (3) assessing future water supply options, (4) in some instances evaluating aquifer properties, and (5) groundwater model input or calibration. Pumping information is an important parameter in groundwater modeling efforts to simulate aquifer responses such as groundwater levels, stream depletions and aquifer yields.

Description and Assessment of Available Data

HydroBase contains records of well pumping for all tributary wells in Division 2. Well pumping has been measured and reported to Division 2 since 1994 as required by the Arkansas Amended Well Measurement Rules; however, only well pumping since 1998 has been populated into HydroBase. These records are listed as diversion records for the well structure type. Although not directly measured, well pumping has been estimated back to 1950 for tributary, high capacity wells that are located below Pueblo Reservoir. This effort was part of the H-I Model analysis to assess Compact compliance.

Division 2 has gathered and maintained additional groundwater data, including periodic metering tests, which include pumping water levels, and groundwater level data collected at various sites throughout the lower basin over the last decade. It is anticipated that this data will be populated into HydroBase in the future. In addition, limited pumping water level data are available from the DWR well database from information submitted with well permits. Well permit data include a pumping rate and the associated pumping water level at the time the well was drilled and completed. Additional groundwater pumping data are currently being collected by CGS in the Raton Basin as part of the coalbed methane (CBM) well water quality and quantity studies.

The available data were reviewed in terms of spatial coverage, length of period of record, completeness and reliability. Well pumping data are provided in HydroBase for all tributary wells that pump at a rate of at least 50 gpm in the basin within Division 2. The large majority of these higher-capacity wells are located in the lower basin below Pueblo Reservoir. All other wells below 50 gpm capacities are included in the DWR's WellView database; however, the data from these wells are very limited with respect to groundwater pumping, with only the initial tested pumping rate identified. The spatial distribution of all decreed wells (not all have pumping information) within Division 2 is shown on Figure 3-5.

Measurement of tributary well pumping in Division 2 was initiated on a basin-wide scale due to the litigation between Colorado and Kansas and Compact compliance issues and a need to better understand groundwater pumping in the Arkansas River Basin. Division 2 enacted the Well Measurement Rules in 1994, requiring actual measurement of pumping with a totalizing flow meter, or using a method to estimate pumping with a power coefficient applied to power consumption for the well pump. Both methods have contributed to a high-quality dataset for well pumping for tributary, high capacity wells since the late 1990's.

Wells that pump less than 50 gpm and that are part of a plan for augmentation are not subject to the Well Measurement Rules, and therefore pumping from these wells has not historically been reported or available in HydroBase. Pumping data from these wells will be added to HydroBase in the future. However, as shown in Table B-6, wells which have a pumping capacity of less than 50 gpm comprise less than 2 percent of the groundwater pumping capacity in the basin. Additionally, well pumping in designated basins and non-tributary aquifers such as the Dakota aquifer is not reported or available in HydroBase.

Additional Data Required

For water resources planning and groundwater modeling purposes, additional pumping data are needed in the designated basin areas (Upper Big Sandy, Upper Black Squirrel Creek, Northern and Southern High Plains) and the bedrock aquifer systems (Dakota and Denver Basin). In addition, following the review of the CGS studies on CBM well production and stream depletions, additional pumping information may need to be collected in the Raton Basin.

Also, additional pumping data may need to be collected in the upper basin following the review of the studies and data collection efforts by the USGS and Colorado State University. Table 3-1 summarizes the additional groundwater pumping data required.

3.9 Aquifer Configuration and Properties

Aquifer configuration includes the horizontal and vertical extent of the aquifers in the study area. Aquifer properties describe the groundwater flow rate and yield and include parameters such as hydraulic conductivity, specific yield and storage coefficient, transmissivity, streambed conductance (used to simulate stream-aquifer interactions) and saturated thickness. The aquifer configuration and properties are necessary inputs in groundwater models.

Description and Assessment of Available Data

The USGS is the primary source for geologic structure data in the Arkansas River Basin. The data are primarily contained in reports and publications which can be obtained directly from the USGS website.

Another source of aquifer data is the Colorado Geological Survey's (CGS) Ground Water Atlas of Colorado (CGS, 2003). The atlas is "intended to be a comprehensive reference of the state's ground-water resources: summarizing the location, geography, geology, water quality and hydrologic characteristics of its major aquifers" and is tailored for use by "decision-makers, planners, developers, ground-water professionals, and the public". The atlas is available in hard-copy format, and relies in part on information contained in the USGS investigations described above.

In 2008, CGS prepared a geographic and digital bibliography for the alluvial and bedrock aquifers within the Arkansas River Basin in Colorado (CGS, 2008). The bibliography identifies literature that addresses the aquifer configuration, aquifer hydraulic properties, water levels and/or water quality of the alluvial and bedrock aquifers in the basin. The study areas and content for the bibliographic database were geo-referenced within a GIS platform to provide a searchable mapping tool. This tool allows the end-user to identify studies and data by geographic reference and specific content for the alluvial aquifer, bedrock aquifers, or both. The bibliography represents a substantially complete compilation of publications related to the alluvial and bedrock aquifer systems in the Arkansas River Basin.

Table B-7 in Appendix B lists references included in the Arkansas Groundwater Bibliography. The volume of information on Arkansas Basin groundwater is evident in this list of publications, which number 334. Additionally, a product of the bibliography is a series of maps depicting the spatial coverage of the investigations involving aquifer property and aquifer configuration information, provided as Figures C-1 through C-4 in Appendix C. Review of this geo-referenced bibliography provides an understanding of the availability and scope of geologic structure and aquifer property data in the Arkansas Basin, summarized below. However, a more thorough review of the referenced investigations will be required to fully understand the completeness and reliability of the data themselves to support groundwater modeling in the basin.

Figures C-1 through C-4 show that there has been a relatively complete series of studies defining the aquifer properties in the alluvial aquifers along the mainstem of the Arkansas River below Pueblo, and along the Fountain and Black Squirrel Creek drainages. There is moderate to little information in tributary basins and in the upper basin of the Arkansas River.

The spatial distribution of geologic and aquifer property information is much less for the bedrock aquifers and designated basins within the entire Arkansas River Basin. Figures C-3 and C-4 show that much of the information in these areas is from medium- to large-scale studies with limited site-specific details on geology and aquifer properties.

The period of record of groundwater and aquifer studies within the Arkansas Basin (see Appendix B, Table B-7) dates back to 1896 (Gilbert, 1896). However, the vast majority of the geologic and aquifer properties studies are from the 1950s and 1960s through the present. Continuing studies by the USGS, Colorado State University, and CGS are extending the period of record with ongoing studies in the upper and lower Arkansas River Basins and in the Raton Basin.

Colorado State University, as part of its regional monitoring, modeling, and assessment program in the Arkansas Valley, has collected information from a network of groundwater monitoring wells in two regional study areas located above and below John Martin Reservoir. The routine monitoring data collected include water levels, water quality, soil stratification, aquifer thickness of the alluvial aquifer, and hydraulic conductivity. These data will be available for import into HydroBase under current funding from the CWCB. Starting in 2009, Colorado State University researchers embarked on a similar monitoring effort in the upper basin. Data collected under this upper basin monitoring program will be used in coordination with other monitoring in the upper basin to support better characterization of the alluvial aquifer in this region. Table 3-4 at the end of this section summarizes the data collection program for Colorado State University's research in the Arkansas Valley.

As noted in the spatial distribution of the information, although there have been significant studies and data collection along the mainstem of the Arkansas River and the Fountain and Upper Black Squirrel Creek drainages, the completeness of the data sets as they relate to geologic structure and aquifer properties has not been fully assessed. Upon review of the over 300 referenced studies in these areas, the completeness and reliability of the information should be determined for these areas. What is known from preliminary review of the data sources and the interviews with stakeholders within the Arkansas River Basin is that there are insufficient data regarding: (1) water quality in all of the aquifer systems, (2) the vertical stratification within the aquifer systems, (3) impact of the vadose zone, (4) definition and quantification of aquifer/stream interactions, and (5) characterization (properties, quantification) of the bedrock aquifer systems.

Additional Data Required

Full review of the published references is anticipated to reveal that additional data will be needed to better characterize the geologic and aquifer properties of all the alluvial and bedrock aquifer systems. Based on a general understanding from ongoing studies and interviews with staff from CGS, USGS, Colorado State University, and other stakeholders, additional data will need to be developed: (1) in the upper basin, (2) along the tributaries in the lower basin, and (3) in the bedrock aquifers.

Current plans by the USGS and Colorado State University are to install additional monitoring wells in the upper basin. However, the exact number, location, and construction details for these wells are not known at this point. As these programs proceed, additional wells may be necessary to fully define the aquifers in the upper basin. In particular, the deeper basin-fill deposits need to be characterized and evaluated with respect to interflow between the upper shallow alluvial aquifer and the basin-fill aquifer system.

Monitoring wells will be needed in the upper and lower basins of the Arkansas River for defining and characterizing aquifer properties and configuration within the alluvial aquifer systems. The majority of the wells completed in the alluvial aquifers do not fully penetrate the alluvial deposits to bedrock.

Therefore, the vertical stratification and the associated impacts with respect to flow within and between layers in the aquifers and the stream systems are not well known. The lack of aquifer configuration information within the alluvial aquifers may also impact the ability to evaluate water quality issues, water rights implications, and vadose zone issues.

Additional research of existing bedrock wells needs to be conducted to fully evaluate the quantity and quality of the groundwater in the bedrock aquifers (Dakota-Cheyenne, Denver Basin, and Northern and Southern High Plains) as well as the interconnection of these aquifers with the shallow alluvial aquifers underlying the Arkansas River and its tributaries. Following the review of existing bedrock well data, additional monitoring wells may need to be installed to verify existing data and to be spatially distributed to supplement the information in each of the bedrock aquifers.

Further review of existing groundwater studies is needed before a final recommendation of the number and location of new monitoring wells can be made. It is recommended that the first phase of groundwater data collection for the ArkDSS include a comprehensive review of existing studies and data, including digitizing and mapping of historical data that are not available in this format. From the findings of this review, a recommended field plan for additional groundwater data collection can be developed. The new wells installed under the ArkDSS can be used to supplement the characterization of the geology, the estimation of aquifer properties through pumping tests and the monitoring of water levels and water quality.

An additional option that shows promise for characterizing the geologic and aquifer properties of the basin is to perform a high resolution airborne magnetic survey of the basin. This technique has been used by the USGS to perform geophysical surveys. The objective of the surveys is to map aquifers and bedrock topography over large areas to help improve the understanding of groundwater–surface-water systems. Frequency-domain heliborne electromagnetic (HEM) surveys collect resistivity data that can be related to lithologic information for refinement of groundwater model inputs. In conjunction with sensitivity analyses, actual borehole data, and geological interpretation, the HEM survey data can be used to characterize hydrogeologic features at a very high resolution. The two- and three- dimensional interpretation of the HEM data provide groundwater modelers with a high-resolution hydrogeologic framework to develop accurate groundwater computer models while minimizing geologic uncertainties. Information collected from HEM surveys would enable the definition of the actual hydrogeology at a level of accuracy not achievable using previous data sets. However, more information will need to be acquired to determine the cost-effectiveness of using this type of technology for aquifer mapping.

If, after review the existing groundwater studies, very little data are available in terms of spatial coverage completeness and adequacy of the data described therein, then the recommended program outlined in Table 3-1 provides a comprehensive data acquisition program that would support groundwater modeling efforts throughout the basin. This data acquisition program can be scaled down according to the findings of the review of the groundwater studies. Section 5 will provide options to further refine the scope and scale of this effort. Table 3-2 itemizes the data compilation requirements for groundwater.

3.10 Groundwater Levels

Measuring groundwater levels is relevant to many aspects of the ArkDSS. These include (1) understanding changes in aquifer water levels due to pumping, (2) quantifying the amount, timing and location of stream depletions resulting from groundwater pumping, (3) assisting in calibration of groundwater models, and (4) forecasting when and where critical water use scenarios are developing.

Description and Assessment of Available Data

Water level data collected in the Arkansas River Basin by DWR and the USGS is available in HydroBase. HydroBase contains water level records for over 6,000 individual wells dating back to the early 1900s. These data are summarized in Table B-8 by water district.

Data maintained by the USGS can also be accessed directly through the USGS website, as part of their Ground Water Watch active water level monitoring network, as well as locations with historical water level data. Most of the data can be downloaded directly, while additional data can be found in the form of reports and publications.

The Arkansas Groundwater Bibliography (CGS, 2008) described in Section 3.9 provides references of publications and investigations with water level information (see Table B-7 and Figures C-5 and C-6).

Finally, Colorado State University, as part of its Lower Arkansas Valley Research Project, has collected water levels from over 200 wells in the lower basin on a routine basis (see Table 3-4). In 2009, Colorado State University researchers embarked on a similar monitoring effort to collect water level data in the upper basin. This water level data will be available for import into HydroBase under current funding from the CWCB.

Table B-8 in Appendix B summarizes the availability of groundwater level data in HydroBase by water districts within the Arkansas River Basin. Of the over 6,000 wells with water level information, over half of the wells (3,119) are located within Water Districts 10 (Fountain Creek) and 67 (Arkansas mainstem from Las Animas to the Stateline). Of the remaining wells, one-third are located in Water Districts 14 (Arkansas mainstem from Portland to Fowler), 17 (Arkansas mainstem from Fowler to Las Animas), and 66 (Cimarron River Basin). The vast majority of the wells with water level data are located along the mainstems of the Arkansas River and Fountain Creek (4,927) and evenly distributed within the Northern and Southern High Plains Designated Basins. In contrast, there is very little water level data in other tributaries to the Arkansas River, within the deeper aquifers, or in the upper basin. In addition, there is limited published water level data in the Raton Basin. Further review of the data collection procedures and reliability of the wells for monitoring purposes needs to be conducted to fully assess the adequacy of the water level data.

Water level data date as far back as 1917, and include wells with a single water level reading as well as others with continuous records from the early 1900s to the present. Wells that have extended continuous water level data are in the minority, typically beginning in the late 1950s to 1970s and running to the present.

Water level data for certain areas of the basin are extensive. However, as noted above, other areas have very little water level data, either single-point or continuous. Specifically, there is very little water level data for the deep bedrock aquifers, the deep basin-fill aquifer in the upper basin, and for wells completed in the Raton Basin.

Additional Data Required

Additional water level measurements will need to be collected throughout the Arkansas River Basin to provide the level of data required to assess the water resources of the basin and for future planning efforts. Additional wells will need to be installed to collect water level data in areas that currently have no monitoring wells. In addition, some monitoring wells should be constructed to evaluate the impacts of vertical stratification on water levels.

Continuous water level data should be collected at strategic locations to identify the time varying aspect of the groundwater systems. Single-point water level data are less valuable in assessing current and future water resource needs. If continuous recorders are not installed, quarterly water level measurements, at a minimum, should be maintained in the wells. If wells have a pump installed, the rate, volume and duration of pumping should be recorded to properly evaluate the water level information.

As noted previously, the reliability of the water level data needs to be assessed. The data needs to be reviewed with concern for the data collection procedures and for the ability of pumping wells to produce accurate water level information.

Table 3-1 provides a list of components for a comprehensive groundwater level collection program for the Arkansas River Basin. Section 5 will further refine the scope and scale of this proposed effort. Table 3-2 itemizes requirements for groundwater level data compilation.

3.11 Consumptive Use

Consumptive Use (CU) data include both direct measurements of consumptive water losses, and data that are used to support modeled estimates of consumptive losses. The CU component of the ArkDSS relies upon and will be an important part of an integrated system which includes surface water and groundwater models, irrigated lands analysis information, climate data and water supply information (diversions and groundwater pumping).

Development of a consumptive use component for the ArkDSS will include the following:

- Agricultural (crop) consumptive use
- Municipal and domestic consumptive use
- Native and non-native vegetation consumptive use
- Other consumptive use (industrial, livestock, lake evaporation)

Required input data for consumptive use analysis and the relationship to other components are shown in Table 3-5. Many of the data required to estimate consumptive use are discussed in following sections.

Description and Assessment of Available Data

Agricultural Consumptive Use Data

Estimates of historical agricultural consumptive use for the lower basin have been produced as part of the H-I Model analysis to assess Compact compliance from 1950 to present. The process of running the H-I Model includes pre-processing climate data from CoAgMet stations to generate estimates of potential evapotranspiration (PET). The estimates of PET for various crop types are generated using the ASCE Standardized Penman-Monteith equation at each CoAgMet climate station in the lower Arkansas Valley for years since 1998. For years prior to 1998, the Modified Blaney-Criddle equation is used with crop coefficients that have been calibrated to the Penman-Monteith estimates. The monthly PET estimates are then distributed to each ditch system in the H-I Model according to county agricultural statistics indicating the various crop mixes grown in each county. Additional data such as irrigated acres, crop types, irrigation practices, water source (surface water or groundwater) and supplied amount are used to determine the actual consumptive use as a result of irrigated agriculture within the H-I Model domain on a monthly and annual basis.

Other estimates of agricultural consumptive use can be found in engineering reports prepared to support changes of water rights from irrigation to other uses.

At their research center near Rocky Ford, Colorado State University has conducted two lysimeter studies to improve estimates of agricultural consumptive use. Data regarding actual measured evapotranspiration from the lysimeters will be used to develop locally-calibrated ET estimates for crops grown in the Arkansas River Basin using the ASCE Standardized Penman-Monteith equation. Additionally, Colorado State University has refined a remote-sensing technique to estimate actual daily

ET estimates from irrigated areas using infrared satellite imagery. These ET estimates are then used in Colorado State University's Lower Arkansas Valley Research Project for calibration of their groundwater models.

The Statewide Water Supply Initiative (SWSI) for the Arkansas River Basin quantified both recent (2003) and future agricultural water demand and consumptive use. Updates to this analysis are underway which will provide additional estimates of current and future agricultural consumptive use in the basin.

Additional information obtained through user interviews and reports prepared to support water rights change cases have not been completely assessed at this time, but should be considered in the ArkDSS development. The ArkDSS will contain components for estimating agricultural consumptive use based on various other data inputs, as shown in Table 3-5. Information required for agricultural consumptive use estimates, including crop patterns, crop acreage, climate data, water supplies, and irrigation methods, are discussed in following sections.

Municipal and Domestic Consumptive Use

Estimates of both current and future municipal water demand and consumptive use have been developed as part of SWSI and are readily available. The information is presented at both the municipal and the county level. An update to these estimates is currently underway and is expected to be available during ArkDSS implementation.

Data regarding historical municipal and domestic consumptive use are less readily available. Following the methodology used in SWSI, population data will likely be used to estimate historical municipal and domestic consumptive use where other data do not exist. In addition, per capita withdrawal and use rates will need to be determined to estimate consumptive use based on population data. The following data types would be useful in determining municipal and domestic consumptive use:

- Population data: County and municipal population estimates are available from the Colorado Department of Local Affairs. Data include population estimates every 10 years, plus annual estimates for the years 2000 through 2008.
- Indoor municipal and domestic per capita supply and use rates: Information from SWSI can be used to determine a per capita consumptive use factor that can be applied to municipal areas where data on historical per capita use and consumption are not available. These data can also be used to estimate domestic consumptive use factors.

Outdoor municipal and domestic water use rates: Information from SWSI can be used to estimate historical municipal outdoor consumptive use Municipal and domestic water consumptive use data developed by SWSI in the Arkansas Basin were reviewed to understand current water demand. SWSI estimated current and future municipal water demand and consumptive use for every county in the basin, based primarily on population census data. Since census data are collected or estimated for every county and most towns (generally over a few hundred residents) in Colorado, the approach provides good spatial coverage for current and future consumptive use estimates. Population census data are generally believed to be reliable for this purpose. Additional information regarding both future and historical municipal and domestic water demand is planned to be collected and documented through the Basin Needs Decision Support System (BNDSS). This effort will improve estimates of this type of water use and will allow the ArkDSS to utilize a more comprehensive water demand dataset than was used in SWSI.

Historical municipal consumptive use data are not readily available and will need to be either collected through user interviews, published reports, and utility records -- or estimated. The first type of information was not assessed at this time, but generally, larger muncipalities along the Front Range have diversion and WWTP discharge records. As mentioned above, some historical use data may be collected from municipalities and compiled into the BNDSS. These sources should be considered in the

ArkDSS development. Where provider records are not available, municipal use will need to be estimated from population data. Annual population estimates are available for municipalities in Colorado from the State Demography Office back to 1990, and for counties annually back to 1985.

Lawn irrigation return flow (LIRF) studies are helpful in providing a basis for estimating outdoor consumptive use. Both Colorado Springs Utilities and Pueblo Board of Water Works have developed LIRF studies specific to their municipalities which are used in water accounting of return flows from outdoor irrigation. These studies could be used to estimate outdoor consumptive use for other municipalities in the basin.

Non-beneficial Vegetation Consumptive Use

Non-beneficial vegetation consumptive use refers to consumption by non-cultivated plants. Data for this consumption are not readily available for the Arkansas River Basin. The H-I Model analysis includes a calibration factor, termed secondary evapotranspiration, which attempts to capture the aggregated effects of non-beneficial vegetation consumptive use of return flows from agricultural irrigation.

Although non-beneficial vegetation consumptive use estimates are envisioned to be outputs of the water budget analysis, published reports and estimates should be collected and summarized to provide verification of the water budget results. In addition, published reports and studies should be reviewed to estimate the amount of groundwater use by non-beneficial vegetation as a function of depth to groundwater and should be prepared for use in groundwater area budget analyses.

Some studies have focused on estimating non-beneficial vegetative consumptive use from phreatophytes in riparian areas in the lower basin. Led by the SECWCD, the Tamarisk Coalition has been formed and a report published that provides maps and inventories of tamarisk areas, including estimates of consumptive use of this non-native species. This report is available through SECWCD's "Arkansas River Watershed Invasive Plant Plan" website (http://arkwipp.org).

Published reports and estimates of water use associated with the creation and maintenance of vegetation associated with wildlife and wetland areas in the basin should also be collected and reviewed. User interviews should be held with managers of wildlife areas to understand water application methods and water use practices over time. Information obtained through user interviews and published reports have not been fully assessed at this time but should be considered during ArkDSS development.

Other Consumptive Use Data

Other consumptive uses in the basin include use by livestock, reservoir and pond evaporation and industrial water uses. Livestock counts published as part of annual county agricultural statistics should be collected to estimate livestock water use. Livestock count data are published by year, by county. Data can be obtained in non-digital form back to the early 1900s. Livestock count data are believed to be reliable for estimating livestock water use. HydroBase includes consumptive use estimates for several livestock types.

Reservoir and stock pond evaporation losses will be based on either maximum surface area or reservoir end-of-month contents. The data required to estimate reservoir and stock pond evaporation is assessed in Sections 3.4 and 3.11.

Estimates of both current and future (2050) self-supplied industrial water demand and consumptive use have been developed as part of SWSI and are readily available. The information is presented at the county level, on an annual basis. Current estimates of industrial water use as developed for SWSI are adequate for CDSS purposes and are considered the best available. Historical industrial consumptive use estimates should be based on user-supplied information gathered through interviews.

Additional Data Required

Agricultural consumptive use estimates that have been developed in Division 2 and are described above, should be collected, reviewed, and assessed during ArkDSS implementation for inclusion in the consumptive use and water budget models of the ArkDSS. Table 3-2 summarizes the additional consumptive use data compilation required, discussed in further detail below.

Additional data required to estimate agricultural consumptive use, as discussed in other sections, include information such as historical irrigated acreage and cropping estimates, soils information, surface and groundwater sources tied to historical acreage, and irrigation methods and efficiencies tied to historical acreage (sprinkler versus flood irrigation). A need has been expressed for developing a better understanding of consumptive use by meadow grass at the higher elevations in the upper part of the basin. Research performed by Dan Smith in the Gunnison Basin (Smith and Brummer, 2004) should be investigated to evaluate its applicability in the Arkansas Basin. Consideration should also be given to performing a lysimeter study in the upper basin, as well as other methods to develop locally-calibrated crop coefficients in this area.

The amount and quality of municipal and domestic use data in the Arkansas Basin generally exceed that which is available in the Colorado and Rio Grande Basins, and is similar to that available for the South Platte Basin. Because the municipal and domestic use data were found to be adequate for development of decision support systems in those basins, no additional municipal and domestic data beyond that discussed above are expected to be required for ArkDSS.

As discussed above, available information regarding non-beneficial vegetation consumptive use will need to be assembled and reviewed before it can be determined if additional data collection is warranted. No additional data beyond that discussed above are required to estimate other consumptive uses.

3.12 Climate

Climate records are important for calculating the precipitation term of the basin's water balance, as well as for estimating consumptive losses and evaporation out of the basin. Climate data are currently available in HydroBase at numerous stations throughout the Arkansas Basin. The Modified Blaney-Criddle evapotranspiration method, the standard method used in the CDSS consumptive use model StateCU, requires monthly temperature and precipitation data. Other methods included in StateCU, such as the Penman-Monteith method, require more detailed climate information such as wind speed, solar radiation, and vapor pressure. Snow data and evaporation data are also available at a number of stations throughout the basin.

Description and Assessment of Available Data

Approximately 170 Arkansas River Basin climate stations are in HydroBase, providing temperature, precipitation, snow, and evaporation data. Most of the stations, approximately 150, are operated by the National Oceanic and Atmospheric Administration (NOAA). These stations generally provide temperature and precipitation data, and some of the stations also provide snow and/or evaporation data. Of these NOAA stations, approximately 60 stations are currently active, whereas the other stations provide historical data. A summary of the NOAA stations is included in Table B-9.

Colorado State University collects climate information from 17 CoAgMet (Colorado Agricultural Meteorological Network) stations that provide daily temperature, precipitation, vapor pressure, solar radiation, wind speed, and soil temperature data. Four of these stations are no longer active, but historical data are available. One of the inactive stations, Stonington, has not been included in HydroBase and must be accessed through the CoAgMet website. Data from the remaining 16 sites can be accessed either directly through the CoAgMet website or in HydroBase. A summary of the CoAgMet station data is included in Table B-10.

Historical climate data were reviewed to determine if these data are adequate for estimating basin crop consumptive use, by assessing the spatial coverage, length of records, and completeness and reliability of records. In addition, it is recognized that the location and elevation of climate stations needs to be reviewed to determine the applicability of data from a specific station for use in crop consumptive use estimates during ArkDSS implementation.

Figure 3-6 shows the spatial extent of the NOAA climate stations. Coverage appears to be adequate to represent the historical temperature and precipitation throughout the Arkansas Basin, especially in agricultural areas along the Arkansas River mainstem. Figure 3-6 also shows the location of the CoAgMet climate stations. The CoAgMet climate stations have relatively good spatial coverage for the lower portion of the Arkansas Basin (east of Pueblo), which is an area of high agricultural use. There are no CoAgMet stations located in the upper part of the Arkansas Basin. However, the Upper Arkansas Water Conservancy District has plans to install CoAgMet stations at the following locations in the Upper Valley: Salida, Buena Vista, and the Wet Mountain Valley.

Existing evaporation stations are primarily located at major reservoirs within the Arkansas Basin, extending from Turquoise Lake near the upper end of the basin to John Martin Reservoir near the lower end of the basin. As described below, it is believed that additional evaporation station data would be helpful for estimating evaporation throughout the basin.

There are 32 NOAA stations that have continuous temperature and precipitation records beginning around 1950 and continuing through 2008. These stations, highlighted in Table B-9, are dispersed relatively well throughout the Arkansas Basin. Five long-term stations have records prior to 1947. If the historical crop consumptive use analysis were to start in 1950, there is sufficient long-term climate data to represent historical climate throughout the basin. There are, however, insufficient data for an analysis period beginning prior to 1950 in many parts of the basin.

Climate data from CoAgMet, including wind speed, solar radiation, and vapor pressure, have a relatively short length of record, generally 10 years or less. The use of these data to directly estimate crop requirements for a long historical period is limited. These data can be extremely useful, however, for calibrating crop coefficients for the less data-intensive Modified Blaney-Criddle method, to results from more data-intensive Penman-Monteith method.

The percent completeness of records for the NOAA climate stations for the period of record is indicated in Table B-9. These percentages are based on the data stored in HydroBase. The amount of missing data for the long-term stations is relatively low. Precipitation data are more than 90 percent complete for most stations. The percent complete for temperature data is also high in many cases. As part of the South Platte DSS (Task 76.8-2), a filled climate dataset was developed for 26 “key” climate stations in the Arkansas Basin. The filled dataset extends back to at least 1950 for each of the 26 key stations, and ends in 2003, which is reflected in the percent complete calculations shown in Table B-9. The methodology used to fill the data in the South Platte DSS through 2003 could be used to extend the dataset to the present time for these key climate stations. It is believed that this extended dataset for the key Arkansas Basin climate stations will be sufficient for use in computing historical crop consumptive use.

The relatively low percent complete for evaporation stations reflects winter months when most evaporation stations are not in service. Because most of the evaporation in the basin occurs during the warmer months, the percent complete is misleading. Generally the evaporation data percent complete for the non-winter months is closer to 90 percent at the listed stations. Therefore, there are adequate evaporation data for use in the ArkDSS.

Based on data in HydroBase, the percent complete for the CoAgMet climate stations is very high, above 90 percent for the period of record.

NOAA and CoAgMet climate station data are generally considered to be of good quality. The extent of records and excellent spatial coverage will provide sufficient climate data to be used to estimate crop consumptive requirements throughout the basin. As part of the process of determining crop consumptive demands, a more detailed assessment should be made for the appropriate use of each climate station.

Colorado DWR staff has been conducting QA/QC investigations of the CoAgMet stations used for computing potential evapotranspiration input data for the H-I Model. The CoAgMet data that has been subjected to the QA/QC process should be used in the ArkDSS and made available in HydroBase.

Additional Data Required

Additional climate data stations that collect precipitation and temperature data are not needed for historical consumptive use estimates throughout the Arkansas River Basin. The lower basin is sufficiently covered for recent measurements of wind speed, vapor pressure, and solar radiation. These data should provide an adequate basis for use in a consumptive use analysis in recent years and for calibration purposes in a longer historical period. Stations measuring these factors are near the major agricultural areas in the lower basin. Additional CoAgMet climate stations in the upper basin would be useful for future consumptive use estimates and calibration of different methods for calculating evapotranspiration. Installation of new CoAgMet stations near Salida, near Buena Vista, and in the Wet Mountain Valley by the UAWCD should meet this need. It is also recommended that evaporation pans be installed at these same locations.

As with other data sources that will be used to support models and other DSS components, a thorough review and QA/QC verification of the data should be part of the ArkDSS implementation process.

Table 3-2 summarizes the additional climate data compilation required.

3.13 Land Use and Irrigated Lands Analysis

Mapping of land use, including irrigated lands analysis, is essential for understanding current water use, estimating historical water use, analyzing trends, and other planning functions. In the ArkDSS, current and historical land use maps will serve other elements of the ArkDSS including surface water, groundwater, and especially the consumptive use/water budget component. Historical data on land use will enable the quantification of changes in water use including, for example, changes from agriculture to municipal use, or conversion of lands from flood irrigation to more efficient sprinkler irrigation. Locating and mapping irrigation service areas will provide essential spatial data for linking consumptive use and water delivery and allocation systems for both surface water and groundwater.

Data collection for land use and irrigation service area data consists of three main activities:

- Classification and mapping of current land use/land cover with emphasis on irrigated lands
- Classification of historical land use and change analysis
- Identification of the source of irrigation water, irrigation method and mapping of service areas for both ground and surface water

These activities will rely on both attribute and spatial (GIS) data. The attribute, or tabular, data includes agricultural statistics, diversion locations, etc. Some of these data are presently available in HydroBase and others will be collected or generated by other ArkDSS activities (e.g., consumptive use, surface water, and groundwater analyses). The spatial data, such as the digital elevation model, hydrography, soils, etc., also will be assimilated under ArkDSS and are described in Section 3.14 below. The results from these data collection activities will be mapping of historical land use, current land use and irrigation service areas for both groundwater and surface water. These results will be utilized as inputs for ArkDSS models, including consumptive use, groundwater and surface water models.

This section first examines the available data and assesses its utility, then describes the need for additional information. For organization, each section is structured according to the main products: current land use, historical land use, agricultural statistics, and irrigation source and service areas.

Description and Assessment of Available Data

Current Land Use

Data applicable for mapping current land use primarily consists of irrigated lands maps developed by Division 2 as part of the H-I Model analysis used to assess Compact compliance. This analysis covers lands irrigated off the Arkansas River mainstem below Pueblo Reservoir. The Division 2 irrigated lands analysis was performed using satellite imagery and aerial photography in 2003, and again in 2008, and includes assignments of crop type to irrigated parcels.

The Purgatoire River Water Conservancy District (PRWCD), along with Division 2, has performed a similar irrigated lands analysis in order to track changes in irrigated parcels and crop type in order to make annual allocations of Trinidad Reservoir project water. Data regarding irrigated parcels and crop type are available in GIS format on an annual basis starting in 2002.

A current analysis of irrigated lands outside of the H-I Model domain and PRWCD (i.e., the upper basin and lands irrigated off lower tributaries) was undertaken as part of the SWSI update for estimating agricultural water demand. This analysis utilizes Landsat satellite imagery from 2009 and remote-sensing analysis to map irrigated lands and identify crop types.

Beginning in 2010, the GIS Section of the DWR will include Division 2 in its statewide irrigated parcel update. The current extent of irrigated parcels in Division 2 (The H-I Model domain and PRWCD) will be included in the update. Additionally, DWR plans to include as many irrigated parcels for the remainder of Division 2 as possible. The statewide irrigated parcel update is a 2 to 3 year process that will include ground-truthing information obtained from water commissioners.

Another source of data for current and historical land use mapping is the Farm Service Agency's National Agriculture Imagery Program (NAIP). This program acquires aerial imagery during the agricultural growing season for the continental U.S. and makes the imagery available as either digital orthophoto quarter quad tiles (DOQQ) or as compressed county mosaics (CCM). NAIP imagery is available for Colorado for several years from 2004 through 2009.

In addition to using remote sensing/satellite imagery data to determine extent of irrigated areas and crop type, these data can be used to estimate actual ET. Currently, Colorado State University is using techniques to estimate daily ET from irrigated lands, as described in Section 3.10 above. The CWCB and DWR have also explored techniques estimating ET directly via remote sensing. These techniques could also be applied to estimate ET for phreatophytes in the basin, which is currently based on a linear-growth assumption in the H-I Model.

Historical Land Use

Annual updates of irrigated lands data have been developed by Division 2 for years between the satellite imagery assessments and going back to 1980 using a process in which a selection of farmers were interviewed each year to track changes in irrigated areas, crop type, and source of supply. Data from these assessments support consumptive use modeling for the lower basin using the H-I Model. GIS coverages of irrigated lands exist for 1980, 1985, 1998, and 2000 – 2009. The GIS data includes delineated irrigated areas and the GIS data beginning in 2002 includes crop types for each field. The Division 2 office also has some hard-copy mapping showing irrigated lands for 1947 and 1962; however this data has not been digitized into GIS. Figures D-1 and D-2 in Appendix D provide illustrations of the coverage of the irrigated lands analysis data available from Division 2.

In addition to irrigated lands analyses described in the above section, there are other historical land use data that could be useful. These include the USGS Land Cover Institute (LCI) which provides numerous United States based Land Cover Data Links (http://landcover.usgs.gov/landcoverdata.php#na/). For the most part, these maps contain state-wide coverages. Another source of digital land cover maps is the Colorado Gap Analysis Project, containing land cover, habitat and species maps at a scale of 1:100,000 (http://ndis1.nrel.colostate.edu/cogap/). Additional sources include delineations of irrigated lands performed by engineering consultants to support water rights transfers.

Aerial photography has been used by Division 2 and other water users in the basin to delineate historically irrigated areas. Aerial photography is typically available from the following sources:

- Aerial Photography flown by counties and cities located in Division 2
- U.S. Geological Survey
  - National Aerial Photography Program (NAAP)
  - National High altitude Photography (NHAP)
  - Digital Orthophoto Quadrangles and Quarter Quadrangles (DOQ, DOQQ)
  - Historical Aerial Photography (1939 – present) from various sources.
  - Satellite Imagery: Landsat ETM – TM and MSS programs
  - SRTM: Shuttle Imaging Radar Topographic Mission

Agricultural Statistics

Agricultural statistics should be collected for use in estimating historical irrigated lands and corresponding crop types for periods when a more detailed irrigated lands analysis is not practical or not cost-effective. In addition, agricultural statistics provide information on crop yields that may be useful in determining variations in crop water use over time. The H-I Model analysis of historical consumptive use relies on county agricultural statistics to estimate cropping patterns within the H-I Model domain for years not included in the Division 2 irrigated lands analysis.

The Colorado Agricultural Statistics (CAS) report annual acreages and yields by crop, which are provided by the agricultural producer. The USDA's National Agricultural Statistics Surveys (NASS) have historically reported acreage and yield by crop every five years. Recently, NASS has developed a digital Cropland Data Layer (CDL) which has been published for 2008 -2009 and will continue to be published yearly and is available for free in the Internet. The CDL provides a coded raster graphic with crop types, to the level needed to perform CU analysis. Both CAS and NASS statistics are available for each county in Colorado from prior to 1950 to the present. Historical data can be ordered, but it is likely that early years may not be available digitally. Previous experience with agricultural statistics data during RGDSS and SPDSS development indicate that these data sets will need to be assessed for reliability prior to use in basin consumptive use analyses.

Irrigation Source and Service Areas

The primary source of data regarding irrigation source and service areas is the irrigated lands analysis data described above for the H-I Model. In order to accurately model supply-limited consumptive use from surface water and groundwater sources, irrigated parcels have been tied to ditch service areas and/or wells. As part of its annual update of its irrigated lands analysis, each year Division 2 conducts field verification of 20 percent of the mainstem farms with wells in order to verify source of irrigation and irrigation status. A similar verification of irrigation source and service area is conducted by the PRWCD as part of its annual irrigated lands mapping. The field verification programs also include verification of dry-up, which is recorded by Division 2 in a geodatabase of dried-up acres.

Outside of the H-I Model domain and PRWCD, there are some existing data available that could be used to depict irrigation canals and ditches and their service areas. One source is the National Hydrography Dataset (NHD) that is under stewardship of the GIS section of the DWR. These digital maps were created from the 1:24,000-scale, 7.5-minute topographic quadrangles of the USGS. All the hydrographic features depicted on the USGS quads are digitized, including rivers, streams, canals, major ditches and drains. DWR plans to maintain the NHD to fulfill the needs of the CDSS, including an assessment and mapping of all the surface water structures and conveyances in Division 2.

In addition to the NHD maps, many irrigation ditch companies have maps of some type describing their irrigation delivery systems. These maps are in a variety of formats and degrees of completeness.

Locating wells and mapping their associated irrigation service areas in the lower basin has largely been completed as part of the H-I Model effort. For areas outside the H-I Model domain, Division 2 collects information on well locations and their associated service area as part of its Well Measurement Program.

Additional Data Required

Existing sources of current land use, irrigated lands, and dried-up lands (Division 2, PRWCD, DWR GIS Section and SWSI) provide coverage of the entire Arkansas River Basin. The statewide irrigated parcels update for 2010 being performed by CWCB and DWR should satisfy many of the irrigated lands needs. However, continued maintenance of DWR's irrigated parcels updates for Division 2 may need funding through the ArkDSS. FSA's NAIP latest imagery and the NASS CDL should be collected to provide the most recent status of agricultural land use in the basin.

To construct information regarding historical land use, irrigated lands, and irrigation source and service areas, the following data should be collected:

- Up to five snapshots (one per decade starting in the 1950s) of satellite imagery and/or aerial photography covering the entire basin. This can include aerial photography already obtained by the Division 2 office for 1947 and 1962.
- USGS's National Land Cover Dataset to help classify irrigated lands and other vegetated areas
- Reports and engineering assessments of historically irrigated lands completed as part of decreed water rights transfers
- NHD maps being developed by DWR for Division 2
- Both CAS and NASS data should be collected for each county in the basin beginning in 1950. This information could be used when verified along with other sources of data described above in order to assign crop types to historically irrigated lands.
- Irrigation systems maps available from Division 2, water conservancy districts and/or irrigation companies

These data compilation activities are further summarized in Table 3-2.

3.14 Geographic Information System

Spatial (or GIS) data provided through geo-referenced maps in GIS are important for data visualization and spatial analysis. The goal of this component is to construct a comprehensive and consistent GIS for use in the development of the ArkDSS. Some GIS coverage already exists for Division 2 in CDSS. For example, the H-I Model implementation for Compact compliance in the basin has generated some GIS data, and requires continued GIS data input. The ArkDSS will expand on the amount of GIS data available to facilitate data visualization and water rights administration and water resources modeling.

The focus of this section is on (1) acquiring currently available GIS data that can be assimilated with minimal processing and made usable during ArkDSS development in consistent formats, projections, etc., and (2) identifying critical GIS data that will be required in the early stages of ArkDSS development. This GIS data should be developed early because the products will be useful to all other components of the ArkDSS.

Description and Assessment of Available Data

Several GIS databases exist within the Arkansas River Basin at different levels of spatial accuracy and composed of different thematic data layers. These include:

- HydroBase GIS database
- Colorado Division of Water Resources data – Denver office
- Colorado Division of Water Resources data - Division 2 office
- U.S. Geological Survey databases
- Colorado State University Lower Arkansas Valley Research Project GIS database

The HydroBase GIS for the Arkansas River Basin is composed of the following spatial data layers (see Figure D-3 in Appendix D):

- Colorado Water Division Boundaries (polygon)
- Division 2: Water District Boundaries (polygon)
- Division 2: Lakes, Ponds and Rivers (polygons)
- Division 2: River and Streams (lines)
- Division 2: Reservoirs (points)
- Division 2: Wells – Decreed (points)
- Division 2: Wells – Other
- Division 2 Temperature Stations (points)
- Division 2: Precipitation Stations (points)
- Division 2: Flow Stations (points)
- Division 2: Climate Stations (points)
- Division 2: Evapotranspiration Stations (points)
- Division 2: Evapotranspiration (isolines)
- Division 2: Precipitation (isolines)
- Division 2: Highways (lines)
- Division 2: Cities (points)
- Division 2: Irrigated Lands 2003 (polygons)
- Division 2: Irrigated Lands 2003

Several major layers are missing for Division 2 when compared to other Colorado water divisions within the HydroBase (examples: land use, ditch systems, soils). The above-mentioned datasets are comparable in scope, resolution and spatial and attribution detail to files found in HydroBase for the other Colorado water divisions.

DWR has the following available data layers in its inventory:

- Rivers and Streams (lines)
- Lakes and Ponds (polygon)
- Aquifers (polygons)

- Basins (polygons)

These layers are comparable in resolution to those currently in HydroBase and can supplement them with minimal integration effort.

Colorado State University has developed GIS layers to support modeling, data analysis and data presentation for its Lower Arkansas Valley Research Project (http://www.csuarkriver.colostate.edu). Interactive, web-based maps are available via the project's website, and include the following attributes: project groundwater and surface water data collection locations, streams, lakes, highways, irrigation canals (below Pueblo), cities, counties, and irrigated fields (below Pueblo).

Other sources of useful GIS data include cities, counties and water conservancy districts. For example, the UAWCD has GIS mapping of their district boundaries and augmentation plan coverage areas, as well as their newly installed stream and reservoir gaging network. SECWCD has mapping of their district boundaries, Fry-Ark Project facilities, and has recently completed mapping of tamarisk extent in riparian areas.

Federal and State agencies involved in water management also rely on GIS to support their purposes and functions in the basin. The USGS has interactive, web-based displays showing locations of active and inactive stream gages, reservoir sites, groundwater monitoring wells, and water quality sampling locations throughout the basin. By clicking on individual sites, the user can access historical data collected at that specific location. The USGS also has digital raster graphics (DRGs) providing base layer mapping available for the entire State of Colorado.

Other agencies with useful GIS data in the basin include the U.S. Bureau of Land Management (BLM), U.S. Department of Agriculture (USDA), Colorado Department of Transportation (CDOT), Colorado Department of Local Affairs (DOLA), Colorado Geological Survey (CGS), and Colorado Division of Wildlife (CDOW). The previously mentioned NHD, which is maintained in Colorado by DWR, provides a repository for hydrographic mapping components that may be available from Colorado State University, water conservancy districts and the other State and Federal agencies listed above.

Additional Data Required

CDSS strives for each water division to have certain base components for GIS, along with certain specific components related only to that division. These base components include irrigated parcels, hydrography, structures (surface water and ground water) and landuse/ground cover. In order to have base component GIS data layers comparable to those for other water divisions in HydroBase, the following layers need to be added for Division 2:

- Public land survey system (PLSS) data (i.e., township, range and section mapping) (polygon)
- County boundaries (polygon)
- Soils (polygons)
- Land use (polygons)
- Drains (lines)
- Irrigation canals (lines)
- Ditch service areas (polygons)
- Solar Radiation (isolines)
- Historically irrigated lands
- Wetland mapping, native and non-native vegetation mapping

Several basinwide datasets can be found in the public domain or obtained for relatively low cost. These data layers can serve as both cartographic and topographic base maps, and can be used for land cover-land use classifications and water-use analysis. It is recommended that the following datasets be used to supplement the spatial data in HydroBase for the Arkansas Basin:

- USGS Landsat ETM and Landsat TM imagery inventory
- USGS ASTER satellite imagery inventory
- USGS 1.0-meter digital orthophoto quarter quadrangles (DOQQ)
- USGS Digital Elevation Data: NED 1/3" (10.0-meter) and NED 1" (30-meter)
- Available county and cities aerial photography taken over the Arkansas Basin

These data compilation activities are summarized in Table 3-2.

3.15 Water Quality

Water users in the basin have identified water quality as an important issue that should be integrated into water resources management and decision-making. Colorado State University, USGS, and the Colorado Department of Public Health and Environment (CDPHE) are potential sources of water quality data related to both surface water and groundwater.

Description and Assessment of Available Data

The USGS's extensive data regarding the Arkansas River Basin are available in an online database, the Colorado Water-Quality Data Repository. This database combines water quality data from the USGS National Water Information System (NWIS) and US EPA STORET databases, plus additional relevant datasets from a variety of other sources. This database is presented as an interactive map where the user can query for sites of interest and search for numerous water quality parameters, including biological, inorganic, nutrient, organic, physical, and sediment data.

The USGS also has real-time water quality data available through their Water Quality Watch online database that provides real-time water quality data at several sites in the Arkansas River Basin; data include temperature, specific conductance, pH, dissolved oxygen, turbidity, and discharge/flow rate. Both real-time and historical data are also available at several sites within the basin through the USGS NWIS water quality database.

The CDPHE provides a list of Section 303(d) water quality limited stream segments requiring Total Maximum Daily Loads (TMDLs). The list provides information on the constituent for which each stream segment is impaired.

Colorado State University has been collecting water quality and water resources data in the Arkansas River Basin since 1999 (see Table 3-4). The main focus of this water quality data has been to investigate the increased loads of salinity and selenium through the lower basin to the Stateline. Recently, their research has expanded into the upper basin in order to collect comparable water quality data above Pueblo Reservoir.

Water quality data available from the USGS website (Water Quality Watch and Colorado Water Quality Data Repository) was initially reviewed to determine if it is adequate for use in water quality characterization and analysis by assessing the spatial coverage, length of records, completeness of records, and reliability of records.

With 15 real-time water quality stations operated by the USGS in the Arkansas Basin, instantaneous water quality information for certain constituents (temperature, specific conductance, pH, DO) is available along the entire mainstem of the Arkansas River, as well as along Fountain Creek. Most of these stations have been collecting real-time water quality data since the early 1990s. Many of these stations also have historical discrete water quality sampling data for a larger number of constituents, some available back to the 1960s. Additionally, historical water quality samples have been collected at hundreds of other locations in the basin, in surface water, groundwater, springs and reservoirs. These discrete water quality sampling results are available through the Colorado Water Quality Data Repository.

Although Colorado State University's water quality data were not available for direct assessment, information about the data collection program and Colorado State University's use of their data in groundwater and water quality models provides an indication of the suitability of the data for water resources analysis purposes. Data available from Colorado State University's research program provide water quality information for the constituents of interest within the research study areas above and below John Martin Reservoir since 1999, as well as for several study sites in the upper basin since 2009.

Water quality data are most often collected for investigative purposes to better understand a particular water quality issue. For this reason, the period of record at some water quality sampling locations is one day (one sampling event), and at other locations can span several decades. For water resources management purposes, data from long-term monitoring programs is most useful in order to characterize large-scale temporal trends in water quality. Data from the USGS's Water Quality Watch website provides over a decade of continuously monitored surface water quality for sites along the entire Arkansas mainstem, which could be very helpful in assessing changes in water quality as a result of more recent hydrologic and water management changes in the basin. Water quality data from Colorado State University's research program in the lower valley have been collected since 1999, and therefore provide at least 10 years of record. Further review of the water quality datasets available through the USGS Colorado Water Quality Data Repository is needed to determine if other long-term water quality datasets exist.

Many water quality datasets in the Colorado Water Quality Data Repository include only one constituent, and third-party data often lack the descriptions of sampling and analysis methodology necessary to rely on them. Water quality datasets available through the Repository should be reviewed more thoroughly to determine if the longer-period water quality datasets provide completeness for constituents of concern.

Water quality data from Colorado State University's research program have been developed as part of a documented monitoring program designed to provide data appropriate for further analysis and modeling purposes. This data should be adequate for its intended research purposes to characterize water quality in the lower basin. However, further review may be needed during ArkDSS development to determine its applicability to ArkDSS needs.

Additional Data Required

Based on the availability of water quality data from the USGS's continuous monitoring program along the mainstem, and Colorado State University's research efforts in both the upper and lower basin, no additional water quality monitoring locations are recommended for the initial phase of the ArkDSS development. However, support of ongoing monitoring efforts in the basin would benefit both the current monitoring agencies and potentially future incorporation of water quality into the ArkDSS. If water quality modeling is recommended as a high priority component of the ArkDSS, the integration of water quality information and analysis into the DSS will require a careful review of the available longer-term water quality datasets to determine their applicability to the DSS and the need for additional data will be further assessed.

3.16 ArkDSS Study Period

One goal of the ArkDSS is to provide baseline datasets for modeling each of the various components (i.e., surface water, groundwater, consumptive use) with a common study period. These baseline datasets should be available digitally on the CDSS website and complete for the selected study period. The data described in the above sections have varying temporal coverage. Table 3-1 summarizes the major categories of hydrological and land use data and the period of record currently available in HydroBase.

Based on data availability, the variations in the hydrologic record, and the history of water management and water development in the Arkansas Basin, as well as experience in other basins, a study period of 1950 to present is recommended for the ArkDSS. Generally, the data should be complete for daily records where daily data are collected (e.g., flow data) and complete for monthly records where monthly records are collected (e.g., reservoir content and well pumping,). Development of baseline data sets for this study period will require additional data collection and data-filling activities, which have been described in the sections above and are summarized in Tables 3-1 and 3-2.

3.17 Summary

The ArkDSS will be a data-centered system that will provide a comprehensive database of pertinent water resource data for the Arkansas River Basin in Colorado. The data will be available as (1) existing gaged datasets that require no further modification, (2) existing datasets that have had missing data filled in or have been subjected to additional QA/QC, and (3) where needed, additional data that will be collected during the first few years of DSS implementation. These additional data are required to improve the spatial and temporal coverage, completeness and reliability of data from which the ArkDSS will derive calculations and results.

A summary of (1) existing data to be used for the ArkDSS, (2) necessary QA/QC and data filling required, and (3) additional data required for the ArkDSS are presented in Tables 3-1 and 3-2. The data sets listed in Tables 3-1 and 3-2 would be required to meet the expressed data needs of water users and State agencies and support the analysis and modeling needs identified in Section 2. Estimated costs for obtaining these datasets and priorities for collection of these data are further defined in Section 5.

Table 3-1. Summary of Identified New Data Required for ArkDSS

Data Type	Description	Priority[1]			Cost Level[2]
		Admin Need	Spatial Data Need	Data Quality Need	
Surface Water Data					
Install/Repair real-time streamflow gages	Beaver Creek below Skaguay Reservoir – Install new flume	High	Low	High	Low
	Beaver Creek near Portland – Install new gage and satellite equipment	High	High	Low	Low
	Huerfano River near Undercliffe – Replace gage	High	Low	High	Low
	Purgatoire River at Stonewall - Install new gage and satellite equipment	Medium	High	Low	Low
	Long Hollow Creek (Purgatoire Basin)– Install new gage and satellite equipment	Medium	High	Low	Low
	Fountain Creek between Pinon and Pueblo – Install new gage and satellite equipment	High	High	Medium	Low
	Cucharas River near confluence with Huerfano River – Install new gage and satellite equipment	Low	Low	High	Low
	Arkansas River below confluence with Chico Creek – Install new gage and satellite equipment	Low	Low	High	Low
	South Fork of the Purgatoire River above Trinidad Reservoir – Install new gage and satellite equipment	Low	Medium	Low	Low
	North Fork of the Purgatoire River above Trinidad Reservoir – Install new gage and satellite equipment	Low	Medium	Low	Low
Investigation of Stream Gages needed for Non-consumptive High Priority Watersheds	Interview stakeholders, coordinate with other gaging entities (USGS, UAWCD, Colorado State University), develop recommendations for	Low	High	Low	Low
Real-time diversion gages	Excelsior Ditch – Install satellite equipment	High	High	High	Low
	Collier Ditch – Install satellite equipment	High	High	High	Low
	Fish hatchery below Pueblo Reservoir – Install satellite equipment	Low	High	High	Low
	Historic Arkansas Riverwalk Park – Install diversion gage and satellite equipment	Low	High	High	Low
Maintenance of new gages	Division 2 may operate and maintain all new diversion gages and new streamflow gages under existing Division 2 program if new hydrographer position allows.	High	Low	High	Medium

Table 3-1. Summary of Identified New Data Required for ArkDSS (Continued)					
Data Type	Description	Priority[1]			Cost Level[2]
		Admin Need	Spatial Data Need	Data Quality Need	
Real-time gages on reservoirs	Mt. Pisgah Reservoir – Install satellite equipment	Medium	High	Low	Low
	Holbrook Reservoir – Install satellite equipment	Medium	High	Low	Low
	Brush Hollow Reservoir – Install satellite equipment	Medium	High	Low	Low
	Lake Minnequa – Install satellite equipment	Medium	High	Low	Low
Groundwater Data					
Conduct streambed conductance tests at up to 70 sites, (10 sites in the upper basin area, 60 sites in the lower basin and all tributaries).	Evaluating the streambed conductance will enhance future modeling efforts to quantify aquifer/stream interactions.	Low	Medium	High	Medium
Drill/install up to 200 alluvial aquifer monitoring wells, (30 wells in the upper basin, 40 wells in the lower basin mainstem area, 40 in the Fountain and Upper Black Squirrel Creek drainages, and 90 in the tributaries in the lower basin area).	The alluvial wells will be drilled to bedrock to fully characterize the vertical stratification of the alluvial aquifer systems. These wells will also provide information on the impacts of the vadose zone on water budgets and water quality. The wells will also be used for future water level monitoring.	Low	High	High	Medium
Install a sufficient number (10 to 15) of deep monitoring wells in the upper basin	The deep wells will be used to fully characterize the deep basin-fill aquifer system and the interconnection between the aquifer and the shallow alluvial system and the Arkansas River.	Low	High	High	
Drill and install up to 40 bedrock monitoring wells in the Denver, Dakota, Northern and Southern High Plains aquifers to characterize the quantity, quality, and interconnection to the shallow alluvial aquifer systems.	Based on existing data, additional wells need to be drilled and tested in the bedrock aquifers to better understand how these aquifers will be used in future water resources planning and how they impact the shallow alluvial aquifer systems and the Arkansas River and tributaries.	Low	High	High	High
Survey elevations of all newly installed monitoring wells, and subset of existing wells in the basin that may be used for groundwater analysis and modeling.	Need accurate elevations of monitoring wells for data interpretation, modeling and calibration purposes.	Low	Low	High	Medium
Conduct pumping tests in up to 20 of the new alluvial wells to evaluate the impacts of vertical stratification within the aquifers and the hydraulic connection to the bedrock and shallow aquifer systems.	Information from the pumping tests will be used in future modeling efforts evaluating the interaction between the alluvial aquifers and the surface water stream systems. In addition, water quality samples will be collected to further characterize the water quality aspects of the alluvial aquifers	Low	High	High	Medium

Table 3-1. Summary of Identified New Data Required for ArkDSS (Continued)

Data Type	Description	Priority[1]			Cost Level[2]
		Admin Need	Spatial Data Need	Data Quality Need	
Conduct pumping tests in up to 20 of the new deep bedrock wells.	The pumping tests will evaluate the hydraulic connection between the bedrock aquifers and the shallow aquifer systems and surface water streams. In addition, the pumping tests will quantify the water resources aspects of the bedrock aquifers and evaluate water quality issues that impact the deep bedrock aquifers and the shallow alluvial aquifers (uranium and other radiochemistry concerns).	Low	High	High	Medium
Collect future water level data on a monthly basis for up to 200 existing, up to 100 new, and up to 20 converted wells (abandoned wells converted to monitoring wells) in the bedrock aquifers (Denver and Dakota), designated basins, and the alluvial aquifers of the upper and lower basins.	Required for calibration and refinement of groundwater models.	Low	High	High	Medium
Perform frequency-domain heliborne electromagnetic (HEM) surveys of the basin.	Information collected from HEM surveys would enable the definition of the actual hydrogeology at a level of accuracy not achievable using previous data sets. However, more information will need to be acquired to determine the cost-effectiveness of using this type of technology for aquifer mapping.	Low	High	High	High

[1]Priorties are divided into three categories:

Data needed for water administration

Data needed to fill spatial data gaps for modeling

Data needed to improve data quality for modeling

[2]Cost Level categories:

Low = less than $50,000

Medium = $50,000 - $250,000

High = more than $250,000

Table 3-2. Summary of Existing Data Compilation Required for ArkDSS

Data Type	Description
Surface Water Data	
Missing streamflow records	Identify key streamflow gages in Arkansas River Basin and fill missing records using CRDSS and SPDSS-developed techniques, or other technique as appropriate.
Transit Losses	Review currently updated transit loss studies by Livingston on mainstem below Pueblo Reservoir. Develop transit loss study in upper basin when data are available. Compile output from Fountain Creek Transit Loss Model into database for further analysis.
Streamflow Component Identification	Analyze the availability and quality of information needed to identify the components of streamflow and make recommendations on how this information may be recorded or estimated and made available to water users
QA/QC of diversion records	Compare diversions in HydroBase with diversion records that were QA'd for HI Model
Identify Key Diversion Structures based on discussions with the Division Engineers, water users and historical diversion records for Division 2	Review HydroBase records, interview water users and Division 2 Engineers, and do analysis of historical diversion and streamflow records.
Estimate missing daily diversions records in Division 2	Fill data for 68 diversions (25 percent of approximately 270 major diversions).
Estimate missing daily transbasin diversion data in Division 2	For 14 transbasin diversions obtain available data, resolve differences in various sources of digitized data, contact structure owner to obtain any additional data and estimate any missing data.
Identify key reservoir structures in Division 2	Review HydroBase records, interview water users and the Division Engineers to identify the major reservoir structures that should be included in the initial surface water modeling effort. Effort will include collecting reservoir accounting records, documenting operations, and estimating missing data.
Gather, digitize and incorporate major water rights transfers and augmentation plan data in Division 2	Gather available data for up to 30 augmentation plans, Rule 14 Plans, and/or transfer decrees and determine how best to represent information in HydroBase
Gather, digitize and incorporate river call data into HydroBase for mainstem and major tributaries in Division 2	Collect, interpret, and digitize data
Groundwater Data	
Review and summarize all of the data and literature catalogued by CGS on the Arkansas River Basin.	Following the review, areas in which the data needs to be supplemented can be fully defined.
Review ongoing studies by CGS within the Raton Basin to determine what additional studies/investigations will be required to fully evaluate the water resources impacts by development of CBM wells.	CGS is currently conducting extensive studies on the impacts of groundwater production during the development of CBM. As ArkDSS development progresses, supplemental studies may be required to meet the needs of ArkDSS.
Collect additional pumping data to assist in identifying existing aquifer configuration and characteristics data for the upper basin aquifers.	Additional pumping data needs to be collected throughout the upper and lower Arkansas River Basin. Pumping data would include well pumping rates, volumes, timing, and any corresponding water level information.
Consumptive Use Data	
Agricultural CU/Crop characteristics/crop coefficients	Collect, review and assess estimates of ET for irrigated areas developed by Colorado State University, SWSI and others. Review investigations of ET for meadow grass in higher elevations in Gunnison Basin. May need lysimeter study in upper basin for locally-calibrated crop coefficients.
Native and non-native vegetation estimates/reports for Arkansas River Basin	Existing estimates used to compare with results of water budget analysis. Gather existing data.
Population data for cities, towns and counties in study area	Used in conjunction with per capita use data to estimate municipal and domestic water supply. Gather existing data.
Municipal consumptive use per capita estimates for cities,	Used in conjunction with population data to estimate municipal and domestic

Table 3-2. Summary of Existing Data Compilation Required for ArkDSS (Continued)

Data Type	Description
towns and counties in study area	water supply. Gather existing data.
Municipal indoor use return flows	Used in conjunction with municipal and domestic supply estimates to determine municipal and domestic consumptive use. Gather existing data.
Municipal outdoor use return flows	Used in conjunction with municipal and domestic supply estimates to determine municipal and domestic consumptive use. Gather existing data.
Climate data	Review and QA/QC climate station data sets.
Land Use, Irrigation Service Areas and Geospatial Data	
Mapping of current land use and irrigated lands	Use existing data sources - irrigated lands analysis based on satellite imagery from DWR updates, Division 2, PRWCD and SWSI. Gather imagery from FSA's NAIP dataset for Colorado, and NASS CDL for each upcoming year.
Mapping of historical land use and irrigated lands	Process to create maps includes data purchase, processing and analysis for up to 5 snapshots (1950's through 2000's). Existing data sources include current land use map (described above), historic satellite images, land use and land cover classifications (MRLC, USGS), aerial photographs, and agricultural statistics data.
Water source and service area data (location of structures, water service areas, irrigated parcels, etc.)	Existing data sources needed for irrigated service map coverages includes information from HydroBase, Division 2, NHD, Water Conservancy Districts, Irrigation Companies
Agricultural statistics (annual acreage and yield by crop)	All available CAS and NASS data will be gathered for every county in the study area from 1950 to the present. Use existing data.
GIS Database for support to overall ArkDSS activities (includes all spatial data discussed above and below)	Creation of database Includes data purchase, processing and results. Use existing data.
River system and water distribution data (names, locations, structures)	Use existing data from sources, including USGS, Colorado State University, NHD
Spatial data from local government entities	Collect existing data deemed useful.
Other relevant GIS data including highways, PLSS, soils and wetlands	Existing data available from U.S. government sources in vector format.

Table 3-3. Summary of Diversion Records by Water District

Water District	Period of Record Data is Generally Available in HydroBase	Reliability of Records	Comments
10,12,14,15,17, 18,19, and 67 (Middle and Lower Arkansas River and larger tributaries)	1950-Present	Good	Most structures are equipped with Parshall flumes and continuous recording devices. Installation of continuous recorders on major ditches occurred in 1930s, with satellite monitoring of major ditches installed in the 1980s.
11,13,16, and 79 (Upper Arkansas River and upper tributaries)	1970-Present	Poor to Average	Many ditches have incomplete and infrequent diversion records. It has been a historic and ongoing practice for the Water Commissioners to work on a one-on-one basis with the ditch company/owner to install better equipment to allow for the collection of better records for the user and Division.
66 (Cimarron River Basin)	N/A	Poor	No meaningful data available for the structures within this district.

Table 3-4. Summary of Colorado State University's Data Collection in Arkansas River Basin

Study Area	Site Type	Total Number of Sites	Data Collected	Period of Record
Upper Arkansas River Basin	Groundwater	17 wells	Water levels, water quality, soil stratification, hydraulic conductivity	2009 - Present
	Surface Water	19 stream sites, 3 canals	Flow rates, water quality, canal seepage	2009 - Present
	Groundwater	Compiled existing data from: Nestle, Dean Roberts Ranch, DOW	Water levels	2001 - Present
Lower Arkansas River Basin - Upstream of John Martin Reservoir	Groundwater	100 wells	Water levels, water quality, soil stratification, aquifer thickness, hydraulic conductivity	1999 - Present
	Surface Water	6 tributary sites	Synoptic stream gaging	2010
	Surface Water	150 stream and canal sites	Water quality	1999 - Present
	Surface Water	4 canals	Canal seepage	2001 - 2007
	Irrigation	11 surface supply, 7 sprinkler supply	Water applied, tailwater runoff, groundwater levels, salinity, crop yields	2004 - 2006, 2008
	Crop Surveys		Crop type	1999 - 2007
	Soils	60 fields	Soil salinity and water content	1999 - 2005
	Other		Precipitation using NEXRAD, remote-sensing estimates of ET, stream and canal water levels, canal hydraulic geometry, bedrock shale chemistry	
Lower Arkansas River Basin - Downstream of John Martin Reservoir	Groundwater	110 wells	Water levels, water quality, soil stratification, aquifer thickness, hydraulic conductivity	2002 - Present
	Surface Water	120 stream and canal sites	Water quality	2002 - Present
	Surface Water	4 canals	Canal seepage	2003 - 2007
	Irrigation	24 surface supply, 10 sprinkler supply	Water applied, tailwater runoff, groundwater levels, salinity, crop yields	2004 - 2008
	Crop Surveys		Crop type	2002 - 2007
	Soils	60 fields	Soil salinity and water content	2002 - 2005
	Other		Precipitation using NEXRAD, remote-sensing estimates of ET, stream and canal water levels, canal hydraulic geometry, bedrock shale chemistry	

Table 3-5. Consumptive Use Component Required Data

Type of Data	Description	Municipal/ Crop	Data Source	Data Acquired By:
Time Series	Climate	Crop	Historical Records	CU
	Ditch Diversions	Crop/Municipal	Historical Records	SW
	Irrigated Land/Cropping	Crop	Analysis/Historical Records	GIS
	Agricultural Statistics	Crop	Historical Records	CU
	Groundwater Pumping	Crop/ Municipal	Analysis/Historical Records	GW or CU
	Crop Yields	Crop	Historical Records/ Interviews	CU
	Population	Municipal	User Interviews/ Historical Records	CU
Factor	Municipal CU/capita	Municipal	User Interviews/Studies/SWSI	SW, GW, CU
	Crop Characteristics	Crop	Local Calibration/ Lysimeters	CU
	Crop Coefficients			
	Ditch Conveyance Loss	Crop	User Interviews/ Studies	CU
	Farm/Well Headgate Loss	Crop	User Interviews/ Studies	CU
	Municipal Indoor Use Return Flows	Municipal	User Interviews/ Studies	CU
	Municipal Lawn Irrigation Return Flows	Municipal	User Interviews/ Studies	CU

GW=Groundwater Component, SW=Surface Water Component, CU=Consumptive Use Component

Table 3-6. Summary of Major Hydrological and Land Use Data and Period of Record

Data Set Category	Period of Record Available
Streamflow records	Period of record varies. Many gages have been discontinued. Of 219 historical stream gages, only 32 gages are currently active and have records extending back to at least 1950.
Surface water diversion records	Records for some diversions date back to late 1800s. Structures that make up a majority of the annual diversions within the basin (middle and lower mainstem and larger tributaries) have reliable records starting in the late 1930s. Records for smaller tributaries and upper mainstem are generally not as complete prior to 1970.
Transbasin diversion records	Records are consistent with the lifespan of the project to present (most transbasin diversions constructed between 1940 and 1970). Most records are missing some data.
Reservoir content and operational information	Only 16 percent of reservoirs have storage data available in HydroBase with varying periods of record. No operational information is currently included in HydroBase.
Well pumping data	Records for well pumping currently begin in 1998. Well pumping has only been measured since 1994.
Groundwater level data	Most records are single measurement for a well. Some extended continuous water level records extend from late 1950s to present.
Climate data	Approximately 20 stations have climate data (temperature and precipitation) extending from 1950 to the present. CoAgMet data is only available since the mid-1990s for some stations.
Irrigated lands and land use data	GIS layers of irrigated lands for the H-I Model domain are available for certain years back to 1980. Other land use classifications in Division 2 (e.g., forest, municipal) has not been included in HydroBase.
Water Quality	Long-term water quality sampling data available for the mainstem and Fountain Creek available since the early 1990s, with more targeted data available in Colorado State University's lower basin research areas since 1999.

Section 4

DSS Components

4.1 Introduction

Decision support system (DSS) components include tools, models, data management systems and the interfaces between them. The objective of this section is to identify DSS components that will meet the needs identified in Section 2, Needs Assessment. The needs assessment identified application needs that components of the ArkDSS should address. These needs have been consolidated under the following DSS component categories:

- Surface Water Planning
- Water Rights Administration and Accounting
- Groundwater Planning
- Consumptive Use Analysis
- Water Budget Analysis
- GIS and Irrigated Lands Analysis
- System Integration
- Water Quality Analysis

Each of the listed component categories are described in detail in the following sections. Each section 1) addresses the need for and purpose of the specified component, 2) describes the existing applicable components, and 3) provides options for developing, adding to, or enhancing ArkDSS components.

Components developed within CDSS in other basins should be applicable to the Arkansas River Basin. To respond to the needs expressed in Section 2, however, new components and modifications to the existing components will be required.

In addition to CDSS, other entities such as Colorado State University, municipalities and water conservancy districts in the Arkansas Basin have developed tools that may be appropriate for use by the ArkDSS. Several of these existing components are described and a preliminary assessment is made regarding the ability of these components to meet the basin's system and application needs.

4.2 Surface Water Planning

The surface water planning component of the ArkDSS should address many of the surface water planning needs and several of the groundwater planning needs identified in Section 2. Many of the surface water needs presented in Section 2.1 relate to understanding the impacts of changes in hydrology and management decisions on water resources of the Arkansas Basin within Colorado. This includes an understanding of how the supply, demand, and utilization of these resources have changed over time. Furthermore, users want to be able to evaluate the future use and management of these resources on a scale ranging from the examination of individual water rights transfers to complex reservoir re-operations or multiple ditch rotational fallowing programs covering a larger portion of the basin. A basin-wide model of the surface water system of the Arkansas Basin that integrates with groundwater information will best meet the myriad of planning needs expressed during the needs assessment. Properly designed and developed, this model can be used to (1) simulate the operation and interaction of surface water supplies and uses, and (2) account for the physical, legal and institutional constraints of the system.

Existing Component Description

CDSS Components

StateMod is the CDSS water resources planning model. It was originally developed for the State of Colorado as part of the Joint-Use Reservoir and Green Mountain Exchange Projects (Boyle Engineering Corporation, 1987). The model has been supported and enhanced by the State of Colorado since 1994. StateMod is a monthly or daily water allocation and accounting model capable of making comparative analyses for the assessment of various historical and future water management policies in a river basin. StateMod's operation, like the stream itself, is governed by hydrology, water rights, and the associated structures and operating rules, defined in the StateMod data set.

StateMod recognizes five (5) types of water rights: direct flow rights, instream flow rights, reservoir storage rights, well rights, and operational rights. Each of the water rights is given an administration number (priority) and location in the stream system. The model then sorts the water rights by priority and simulates their operation by the assigned priority, thus replicating the Prior Appropriation Doctrine (first in time, first in right). The water right categories are mostly self-explanatory; operational rights generally pertain to reservoir operating policies, exchanges, carrier ditch systems, and terms and conditions associated with a water rights' operation. Water quantity accounting is performed on a water right/structure basis while reporting is performed for both structure and river node.

A unique feature of StateMod is its baseflow estimation module, which calculates historical hydrology absent modeled uses and operations. By adding historical diversions and losses back into historical gaged streamflows, and subtracting historical return flows, imports, and reservoir releases, the module automatically generates undepleted flow time series, which are required input for the water allocation module. The water allocation module simulates the water rights described above against these baseflows.

StateMod is designed to be applied to any river basin through appropriate input data preparation and can be configured for the Arkansas Basin and implemented in the ArkDSS. StateMod has been successfully used by public and private entities as a planning tool in other basins within Colorado and Wyoming to evaluate basin depletions, climate change effects, proposed reservoir operations, proposed new water resources projects, river flows for ecological purposes, water resources project yield analyses, and other evaluations.

StateMod is maintained by the State of Colorado and is enhanced in response to requirements for modeling in different DSS basins. Software updates support CDSS activities; thus major updates have been released every one to five years, while minor changes are made more often on an as-needed basis. Key characteristics of StateMod include adherence to the doctrine of prior appropriation, the data-centered approach through data management interfaces (DMIs) with HydroBase, and compatibility with other CDSS products. Other features of StateMod v.12 (the current version as of 2011) are listed in Table 4-1.

Non-CDSS Components

Several surface water modeling and analysis applications currently exist for the Arkansas Basin. These applications have been developed by various entities for project-specific purposes and water resource management needs. Several of these regional and basin-scale surface water models utilize the MODSIM platform.

MODSIM is a generalized river basin management decision support system and network flow model originally conceived in 1978 at Colorado State University. MODSIM is used by Colorado Springs Utilities and Colorado State University in the Arkansas Basin and has been implemented throughout the western U.S. and locations abroad. MODSIM is similar to StateMod in its capabilities and has been updated repeatedly by Colorado State University through releases of new versions. Features of MODSIM include network flow optimization, support of streamflow routing and lagging, and the ability for the user to add to MODSIM's basic functionality through custom coding. Other specific components of MODSIM 8.1, the current version, are listed in Table 4-1.

MODSIM is maintained by staff and faculty at Colorado State University. Additional information and documentation regarding MODSIM can be found on Colorado State University's Department of Civil and Environmental Engineering website.

Colorado Springs Utilities has utilized the MODSIM platform both as a monthly operations and planning model and as a daily exchange model for their water resources planning in the Arkansas Basin. Versions of Colorado Springs Utilities' surface water models were used in the analysis of both the Preferred Storage Options project (PSOP) and the Southern Delivery System (SDS). A version of the model is also currently being used in the EIS process for the proposed Arkansas Valley Conduit. Although their models are currently proprietary, there is a willingness to share these models. Benefits could be gained by coordinating with their staff and consultants to assess and possibly incorporate unique modeling methodologies, particularly from their complex daily exchange operations model, as well as information from their extensive data-gathering efforts on historical exchanges operated in the Arkansas Basin.

Colorado State University has used MODSIM as part of a basin-scale surface water model (Pueblo Reservoir to the Colorado-Kansas Stateline) that includes a water quality module. The surface water model is integrated through an artificial neural network with regional-scale groundwater models; all components are contained within a spatial decision support system (ArkRiver GeoDSS), for the purposes of assessing water management options and impacts to water quality across the lower Arkansas Basin (Triana et al., 2010a, 2010b, 2010c).

This effort encompasses refinements to MODSIM to allow for modeling stream-aquifer interactions, with the additional complexities of water rights and water quality. The ArkRiver GeoDSS methodology trains the artificial neural networks to find relationships between spatially distributed system state variables (i.e., canal lengths, irrigated areas, water body areas and elevations) that can be measured or estimated at the basin scale, and the spatially distributed aquifer response to stresses as represented in the regional-scale groundwater models. The use of the artificial neural network provides a more dynamic linkage for predicting return flow patterns needed by the basin-scale surface water model than the more traditional reliance on URFs. However, potential issues with the artificial neural network methodology include: (1) utilizing the right explanatory variables, (2) adequate training of the neural network, (3) avoiding use of the neural network to extrapolate beyond the values used during training, and (4) ensuring conservation of mass.

In addition to the efforts described above, other studies in the basin have relied on other tools for modeling and analysis. For example, an exchange analysis tool has been developed by the Lower Arkansas Valley Water Conservancy District (LAVWCD) as part of a larger project funded in part through the CWCB and the Water Supply Reserve Account. This Microsoft Access database tool models historical river flows, diversions and operations from Pueblo Reservoir to John Martin Reservoir. The tool was initially developed to analyze if exchange potential exists on the Arkansas River between Pueblo Reservoir and downstream ditches participating in the Super Ditch project. The next phase of the project is to further analyze how much water can be exchanged under different hydrologies and system operations. Because of limitations of the Access model, LAVWCD is planning to incorporate the Access model data into a StateMod model for the next phase of the project.

The Joint Front Range Climate Change Vulnerability Study (Water Research Foundation 2009) utilized several analysis tools and models to better understand the potential impact of climate change on Front

Range water supplies. In this study, selected datasets were used to drive hydrologic models that were applied to assess the sensitivity of streamflow to changes in climate, including watersheds in the upper Colorado, South Platte, and Arkansas basins. Two hydrologic models were applied independently, including the National Weather Service models that are currently used by the National Weather Service River Forecast Centers, and the WEAP (Water Evaluation and Planning) model (developed by the Stockholm Environment Institute).

The models and tools described above may provide useful information or methodologies that could be incorporated into the ArkDSS for tracking exchanges and determining exchange capacity for both analysis and administration purposes. These products may also provide insights on how to model the exchange operations within the surface water model.

ArkDSS Component Options

The components described above offer alternatives for surface water planning analysis in the Arkansas Basin. Two modeling platforms, StateMod and MODSIM, provide the water allocation and accounting capability required for an Arkansas Basin surface water planning tool. These options were compared through the development of a matrix, shown in Table 4-1 below, which details the capabilities of each modeling platform. Both modeling platforms have their strengths and provide a viable surface water planning tool for the Arkansas Basin.

Although there is currently no StateMod model in the Arkansas Basin, the tools, procedures and data structures that have been set up in other basins for CDSS can be used to facilitate the development of an Arkansas Basin model. Also, a StateMod model is being developed by LAVWCD to analyze exchanges on the river reach between Pueblo Reservoir and John Martin Reservoir; this could potentially benefit the ArkDSS, whether StateMod or MODSIM is utilized.

Several implementations of MODSIM have been developed within the Arkansas Basin utilizing MODSIM versions 7.x, 8.x, and ArkRiver GeoDSS. There may be potential benefits to ArkDSS in building from established models. However, these models were developed for specific user needs, such as water utility planning and irrigation management and water quality impact analyses; these models would need to be reviewed in depth before being incorporated into the CDSS. Any existing model data sets would need to be significantly enhanced to meet the objectives of the ArkDSS. These potential enhancements include the following:

- Expand the model area to encompass the entire Arkansas Basin within the State of Colorado and modify existing modeled areas to represent structures as identified through the ArkDSS process;
- Expand the model study period to include 1950 through the present ;
- Modify any custom coding to be consistently implemented throughout the model;
- Modify custom coding to correctly operate in the MODSIM version utilized;
- Modify/develop custom coding to represent complex operations in the basin as identified through the ArkDSS process.

If an existing model on the MODSIM platform is utilized for CDSS, CDSS utilities such as TSTool and StateDMI may also need to be modified to ensure compatibility. Another compatibility issue concerns the linkage of multiple basin models. In StateMod, models from different basins (e.g., the Colorado and South Platte) can be linked and run as one model. The ability to add the Arkansas Basin model would be an important factor. These linked-basin models would aid in broader analyses involving multiple basins, such as modeling for coordinated East Slope – West Slope operations, compact compliance, new multi-basin water projects, projected population growth effects statewide, and climate change effects statewide.

Table 4-1. Surface Water Planning Model Platform Capability Matrix

Capability	StateMod	MODSIM/River GeoDSS
Basic Structure	Node-based model	Link-based model
Proprietary Nature	Not open source as of this writing; executable available without cost.	Not open source as of this writing; executable available without cost. Custom coding may or may not be proprietary.
Graphical User Interface/GIS linkage	Has GUI interface; GIS interface not available.	For River GeoDSS: GIS is used as GUI; everything is done in ArcMap interface; no other routines needed; ArcView license required to develop in ArcMap.
Implementation programming language	GUI: Java StateMod: FORTRAN	GUI: Visual Basic.net Main platform: Visual C++. Net GIS Interfaces: ESRI ArcObjects
River system simulation	Modified Direct Solution Algorithm: Model operates as river is administered. Handles large networks.	Network Solver: Network flow optimization algorithm. Good for large networks; uses fastest optimization algorithms available.
Data integration/data management interfaces	HydroBase data-centered. StateDMI, formatted data files with a high degree of transparency and easily reproducible. Data source overwrites, and filling are stamped on each input file. DMIs assure that file formats are correct.	Imports data from HydroBase into an ACCESS object-oriented database. Because it is a relational database, interconnections are flexible allowing automatic updates. Does not use formatted data files.
Model time step	Annual, monthly, daily	Monthly, weekly, daily, 10-day time step
Incorporation of water rights/prior appropriation doctrine	Direct Solution Algorithm (DSA) based on priority (administration number). Can color water as reusable, nonreusable, from storage, from carrier, etc.	Administration numbers transformed into cost basis structure. Water is colored as natural flow or storage.
Incorporation of return flow accounting, efficiencies and soil moisture accounting	Solution algorithm automatically handles return flows. Variable irrigation efficiency approach added to mimic historical CU analysis. Can model soil moisture accounting, same as StateCU. Variety of outside methods can be used to estimate return flow parameters and CIR.	Variety of methods built in to estimate return flow parameters: SDF, URF, Glover analytical, linkage to GEOMODFLOW, and artificial neural network training. Soil moisture reservoir not automatically considered, but could be coded. Variable efficiency not built in but could be coded.
Simulation of water transfers, reusable water supply, augmentation plans or out-of-priority well pumping	Yes. Uses the concept of a "plan" structure.	Yes. Mostly done without custom code.
Simulation of operating agreements, subordination agreements and exchanges	Yes, via operating rule code and input-defined parameters No lagging on exchanges; may be added in the future.	Yes, via custom .NET coding. Can lag for exchanges
Simulation of wells as a sole source or supplemental to surface water	Yes	Yes

Table 4-1. Surface Water Planning Model Platform Capability Matrix (Continued)

Capability	StateMod	MODSIM/River GeoDSS
Simulation of instream flows	Handled as a regular water right by reach or point	Handled as a flow though demand. Similar to StateMod.
Estimation of natural streamflows	Natural (Base) flow generator	Not a standard report, but can be estimated from calibration mode results.
Call reporting	Yes. Every time step at every node can look at report to find out if it was shorted and what water right called it out. Reporting of available flow at each node at each time step.	No formal call reporting but all of the information is available and can be extracted. Report capabilities could be added.
Compatibility with other CDSS products	Yes	Yes with TSTool (limited to text input versions of MODSIM), StateCU, and HydroBase
Extensive automatic error-checking of input data	Yes. Several automatic checks for formats, demands exceed capacity, etc. by StateMod; extensive checking by StateDMI and TSTool	No, but not as necessary because no formatted files used; other checks are not automatic.
Partitioning of reservoir storage	Yes	Yes
Modeling of hydropower generation	Yes, but weak. Can put in a demand but not many capabilities.	Yes, strong capacity. On peak, off-peak, pump-storage, nonlinear head flow, tail water conditions, run of river projects, hydraulic capacity constraints (max discharge based on head).
Flow-routing/stream flow lagging	Does not support at this time.	Does support Muskingum flow routing and stream flow lagging. Back-routing capabilities for reservoir releases.
Stochastic modeling	Can use any flow as natural flow. Done outside of model. Statistical analysis of output done through DMIs.	Can use any flow as natural flow. Done outside of model. Built in statistical analysis of output
Output formats	Some standard output reports. All data is put into a binary file for analysis.	Some standard output reports, but not as extensive node by node as StateMod. User can add coding to extract data. Scenario comparative analysis tool. Animated display of simulation with color or size variation with flow and storage. All data is put into a database file for analysis
Capability of linking with StateMod models in other basins	Yes. Basin linkage tool works with all models running together as one linked model. Requires all models to be operated on the same time step.	No. Could develop tool to exchange data and information between MODSIM and StateMod
Identification of types of water at specific locations and within reservoirs	Yes. Ability to identify priority, type, account, reusable/usable, carryover. Cannot specifically identify the year water was stored.	Yes. Ability to identify priority, type, account, reusable/usable, carryover. Cannot specifically identify the year water was stored.

Table 4-1. Surface Water Planning Model Platform Capability Matrix (Continued)

Capability	StateMod	MODSIM/River GeoDSS
Reservoir ops and accounting rules (e.g., evap, spill, seepage, right to store, release priorities)	Extensive existing operating rules. State documents, reviews and executes new rules per public request	Custom coding and routines as needed. Does not require rewriting source code. Custom coding compiled into source code.
Stream transit losses and travel times	Yes: Transit losses No: Travel times	Yes: Transit losses and travel times
Analysis scale (e.g., basin, sub-basin)	Partial or full basin analysis capabilities	Partial or full basin analysis capabilities
Cost of model implementation in Arkansas Basin	See cost tables.	There may be potential benefits because of existing MODSIM models in basin, but there would be a need to review models, create new rules, incorporate linking capability to other basin models and support O&M for additional platform.
Water Quality (General Capability)	No, but simple mass balance could be added to StateMod	Water quality module available for non-reactive, conservative transport (salinity).
Calibration process	Process similar for both models.	Process similar for both models. Current models are calibrated as follows: Colo. Spgs. Util. -- Leadville to Las Animas gage (mainstem and Fountain Creek): 1982-2004; Colo. St. Univ. -- Pueblo Res. to Stateline (mainstem): 1975 to 2001.

Regardless of the platform adopted for the surface water planning component of the ArkDSS, these enhancements will be needed to create a more rigorous surface water planning tool:

- There is a need to better understand the timing of water flow through the basin, especially when associated with reservoir releases. A daily operational model with streamflow routing would allow water users to evaluate the timing of water through the basin; both StateMod and MODSIM are capable of operating on a daily time step.
  - StateMod would require enhancements to include lagging/routing functionality, including demand forecasting related to reservoir releases and routing these releases over time through the river network to make it more robust for operational modeling.
  - MODSIM has the ability to operate routing links within a simulation; however, it is anticipated that a significant number of routing links and custom coding would be required to simulate observed river flow timing.
  - These enhancements to either modeling platform may also allow for additional analyses regarding daily exchange capacity in the basin. Coordination with the existing exchange models developed by Colorado Springs Utilities (using MODSIM) and by the Lower Arkansas Valley Water Conservancy District (Access and StateMod) may provide information on how to enhance the ArkDSS surface water model to provide this additional functionality.
- Another need is for a better understanding of water quality and constituent transport. Currently StateMod does not have the ability to model water quality directly and enhancements to the code would be required to allow for this capability. Incorporation of water quality analysis into the ArkDSS is discussed further in Section 4.9.

- A significant potential enhancement is for the development of an "interactive linkage" between the surface water and groundwater planning models. Previously in CDSS, unit response functions (URFs), which are generated in MODFLOW, have been implemented in StateMod to lag irrigation return flows and the effects of well pumping on a monthly basis for pre-defined reaches of the river. The URFs offer a static linkage between the surface water and groundwater components, which can be a reasonable representation for planning purposes. Multiple options exist to more dynamically represent groundwater interactions within the surface water model, including the following:
    1. Implement an iterative process of running the surface water and groundwater models. First, the groundwater model would be run to generate average URFs for use in the surface water model. Second, the surface water model would be run with the average URFs. Third, results from the surface water model run (i.e., river flows, diversion through canals, water applied to irrigated lands, well pumping, etc.) would be passed back to the groundwater model as inputs and the groundwater model would be re-run. Fourth, the surface water model would be run with monthly URFs generated from the groundwater model. Fifth, steps three and four would repeat until results are sufficiently similar to the previous iterative run. This would be a time-intensive process during calibration and model simulation.
    2. Utilize a "model interpolator" process. This process would utilize a database that is populated with results from iterative groundwater model runs based on multiple pumping and hydrologic conditions. Once the database is populated, the model interpolator allows the computer model to interpolate between or outside of populated solutions based on the given parameters of the current simulation. This allows the return flow timing and pattern to vary more realistically with the parameters of the current simulation (as opposed to using static URFs) but without the complexity and cumbersome nature of a fully linked surface water/groundwater model. Colorado State University has implemented the model interpolator approach with MODSIM using an artificial neural network. Another option for the model interpolator is kriging. Further investigation of the model interpolator methodology is warranted to determine if this would be a compromise solution that allows for faster processing without fully linking the surface water and groundwater models, and which interpolator provides the most accurate and robust linkage.
    3. Fully incorporate the groundwater model into the surface water model, similar to the incorporation of StateCU operations into StateMod, or build significant custom coding into MODSIM to interact with the MODFLOW model. This concept will need to be explored in much greater detail to determine if portions of the groundwater model program can be incorporated or if the entire code would need to be included in StateMod, or the level of effort needed for the MODSIM custom coding.
- The following basin operations should be reviewed in both MODSIM and StateMod to determine if refinements to the code or operating rules are required:
    - Operating rules for the reservoirs comprising the Fry-Ark Project
    - Rules regarding the operation of the major tributary well replacement plans (Rule 14 Plans)
    - Operating rules for non-consumptive uses of water, including the voluntary flow management programs above and below Pueblo Reservoir
    - Operating rules for the Winter Water Storage Program
    - Operating rules to represent the operational, legal and institutional constraints of the Arkansas River Compact and the associated operations of John Martin Reservoir; this should also include coordination and comparison with the H-I Model methodology as performed annually by DWR.

Another consideration relates to surface water/groundwater interactions in the upper basin. The lack of data and understanding of the hydrogeology in the upper basin may preclude development of a detailed groundwater model. As a result, return flow patterns and lagging of well pumping may need to be estimated in a separate analysis. In particular, there are anticipated to be significant flow contributions from the groundwater system to the surface water system near Salida that may need to be estimated from existing data without the knowledge gleaned from a detailed groundwater model of the region.

4.3 Water Rights Administration and Accounting

The needs identified for water rights administration and accounting fall into two main categories:

- Needs regarding daily water rights administration (including Compact compliance) by the Division 2 Engineer and his staff.
- Needs regarding the accessibility and transfer of water accounting data.

Both categories of needs involve streamlining data collection and reporting to facilitate a more data-centered approach, including data transfer between State and non-State entities. Included in this is the need for a tool to aid in the compilation of data each year for the H-I Model simulation that is used to determine Compact compliance. Some of these needs may be met by current CDSS data components with enhancements, and some will require new components specific to the needs of this basin.

The CDSS relational database management system, HydroBase, and enhancements to this system are described further in Section 4.8. Tools that could be used to aid the analysis of data to support water rights administration and accounting are described below.

Existing Component Description

HydroBase is the CDSS component that provides storage of and access to water resources data, and is described further in Section 4.8. Data that are frequently relied upon for water rights administration and accounting include diversions, river calls, and reservoir operations, all which must be available within 1 to 2 days of occurrence to be useful for administration. HydroBase does not currently include recently recorded (i.e., provisional data), or operational data such as reservoir releases from specific storage accounts, which limits its use for water rights administration and accounting purposes. Planned enhancements to HydroBase by DWR will provide more access to provisional diversion data in the future.

Division 2, as part of its administration duties, has developed the following databases and accounting systems to support daily administration. These data are not currently included in HydroBase.

- The Arkansas Daily Report, a data reporting tool that provides daily information on Arkansas River conditions (flows, diversions, exchanges) at key locations in the basin and is published online.
- A database of well pumping data, called Ledger, is used to calculate depletions to the Arkansas River from well pumping on a monthly basis. These data, along with data from various other sources are compiled and input into Excel spreadsheets to account for replacement of well pumping depletions.
- A tool that is currently under development, the Arkansas River Accounting System (ARAS), will be used to track operational data for reservoir accounting and store historical accounting data. ARAS will incorporate the current accounting systems for Pueblo Reservoir, John Martin Reservoir and Trinidad Reservoir.
- The Fountain Creek Transit Loss Accounting Program, developed by the USGS, tracks delivery and use of transmountain water in Fountain Creek on a daily basis to facilitate the exchange of this water into Pueblo Reservoir.

In addition to these accounting systems and databases developed by Division 2, entities within the basin have developed user-specific water accounting tools to:

- determine compliance with well augmentation plans and conditions of water rights transfers

- facilitate reservoir operations, such as tracking stored water by water type and water owner
- help with visualization of river conditions, such as SECWCD's daily river flow schematics

At the time of publication of this report, an accounting and administration tool for lease-fallowing operations such as Super Ditch is being proposed by the Upper Arkansas Water Conservancy District. The goals for the tool are to quantify the transferrable consumptive use and associated changes in the amount, timing, and location of return flows; to support the development of plans to maintain historical return flows and quantify transferrable consumptive use in a manner consistent with Colorado water law and the Arkansas River Compact; and to develop interfaces that will complement ArkDSS and build a common technical platform for the transfer of data to and from HydroBase.

H-I Model

The H-I Model has been mandated by the U.S. Supreme Court as the tool to determine compliance with the Arkansas River Compact. Section 1.3 provides a description of the H-I Model and its intended purpose. The model is not intended to be used for planning purposes, and the tools and components developed under the ArkDSS cannot replace or supersede the H-I Model or its findings regarding Compact compliance. However, both Division 2 and the SEO have described areas in which the ArkDSS can improve the H-I Modeling process. These needs were described in Section 2, and the improvements include the following:

- Facilitate compilation of data required for the annual run of the H-I Model, and make the H-I Model implementation more data-centered
- Validate certain assumptions used in the H-I Model, including ungaged tributary inflows, canal losses and farm efficiencies
- Aid in acquiring data and developing tools that will help support improvements to the H-I Model
- Develop a groundwater model to support Compact compliance analysis. The model will not replace or add to the H-I Model, but instead will provide more accurate information used by the H-I Model regarding return flows
- Develop tools to help manage excess (i.e., flood) flows

ArkDSS Component Options

The following components are recommended for the ArkDSS to support water rights administration and accounting:

- Straight-line diagrams should be created under the guidance of Division 2 for each water district and made available on the CDSS website to aid in visualization and understanding of the river and priority system.
- A tool that tracks different colors of water (e.g., transmountain, native, reservoir, and augmentation - both consumptive use and return flow portions) in real time at a given location could enhance the ability Division 2's ability to administer the river and would provide more timely information to water users. Including functionality to help Division 2 with short-term forecasting (i.e. reservoir spills) would provide additional benefit for administration purposes. This tool is envisioned to interface with both HydroBase and the real-time satellite monitoring system data. Planned updates to diversion coding and more access to provisional diversion data by DWR will help in determining the color of water at specific stream gages.
- If operational and accounting data are incorporated into the online version of HydroBase, then there is a need to update TSTool's and/or StateDMI's web services components to access these data. If operational and accounting data are incorporated into the desktop version of HydroBase, updates will also be needed to access, manipulate and output this information into *.stm, H-I Model, and other file formats as appropriate.

H-I Model

Development of a surface water planning model and a groundwater planning model in the lower basin through the ArkDSS could support improvements to the assumptions and methods employed by the H-I Model. Recommendations for the development of these models are included in Sections 4.2 and 4.4.

In the shorter term, efficiency of gathering and assembling H-I Model input could be improved under the ArkDSS. Although much of the data required for the annual simulation of the H-I Model is included in HydroBase, the preceding year's data are not updated to HydroBase in a timely manner to meet the schedule for the initial model run (by March 31st of each year). Consequently, data must be manually compiled from various sources. Additionally, accounting data that is developed by Division 2 is available only through spreadsheets, and so must be manually transferred into the formats needed for the H-I Model. Recommendations to allow a more data-centered approach to the annual H-I Model simulation include:

- Start DWR's HydroBase update with Division 2 and specifically with the datasets needed to generate the input files for the H-I Model. Make the data available either through the CDSS online database or through a DVD release that is available by January 15th of each year.
- Ensure that the NOAA and CoAgMet climate data currently being used by Division 2 can be made available in the January 15th HydroBase release. Also ensure that these data can be extracted from HydroBase in the format needed for the H-I Model input files.
- Ensure that groundwater pumping records from Division 2 from the previous irrigation season are included in the January 15th HydroBase release.
- Set up a StateCU dataset that is specific to the H-I model's requirements to calculate potential evapotranspiration at Division 2 CoAgMet stations using the ASCE Standardized Penman-Monteith equation, as required by the H-I Model.
- Ensure that functionality is included in ARAS (including use of proper diversion and water use data coding that follows HydroBase standards) that will allow export of reservoir accounting and well plan accounting data that is needed by the H-I Model. The ArkDSS should also explore the option of including operational and accounting data in HydroBase, which has historically not stored this type of information. If data from ARAS are determined to be useful for storage in HydroBase, statewide standardization of reservoir and augmentation plan accounting is recommended.
- Update TSTool /StateDMI to query HydroBase and create H-I Model input files in the appropriate format.

4.4 Groundwater Planning

The groundwater resources planning component of the ArkDSS addresses those needs identified in Section 2 that relate to groundwater data analysis and modeling. The groundwater resources planning component of the ArkDSS should have the capability to:

- Evaluate and quantify the hydraulic connection between the aquifers (shallow and deep) and the Arkansas River and associated tributaries.
- Characterize the shallow and deep aquifer systems in the upper basin (shallow alluvial and deep basin-fill aquifers) and in the lower basin (shallow alluvial and deep Dakota/Cheyenne/Raton Basin/Denver Basin aquifers) and the hydraulic interaction between the two types of aquifers.
- Provide information on the location and timing of groundwater return flows to the Arkansas River and tributaries.
- Characterize groundwater flow and yields of various aquifer systems and provide information on the water budget elements (e.g., evapotranspiration, recharge, and pumping) for each aquifer system.

- Provide maps and tools to show historical and predicted groundwater levels.

Additional data that could be collected to help address many of the individual groundwater planning needs listed in Section 2.5 are described in Section 3. Evaluating effects of pumping (and recharge) on streamflow and aquifer yield may require development of detailed groundwater flow models and other related tools. These tools and models are discussed below.

Existing Component Description

Groundwater analysis models have been developed through CDSS efforts in other parts of the State, including MODFLOW models in the Rio Grande and South Platte Basins. These models are site-specific and would not transfer to the Arkansas Basin. However, the modeling platform, MODFLOW, is considered the best state-of-the-science for basin-scale groundwater modeling.

The following is taken from a USGS summary of MODFLOW (2010a):

> "MODFLOW is a three-dimensional finite-difference groundwater model that was first published in 1984. It has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model. OFR 00-92 documents a general update to MODFLOW, which is called MODFLOW-2000 in order to distinguish it from earlier versions.
>
> MODFLOW-2000 simulates steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal directions aligned with the grid axes), and the storage coefficient may be heterogeneous. Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modeled area at a rate proportional to the current head difference between a "source" of water outside the modeled area and the boundary block. MODFLOW is currently the most used numerical model in the U.S. Geological Survey for ground-water flow problems.
>
> In addition to simulating ground-water flow, the scope of MODFLOW-2000 has been expanded to incorporate related capabilities such as solute transport and parameter estimation."

Groundwater analysis tools have been developed on regional scales in the Arkansas Basin for specific projects and analysis needs. For Compact compliance purposes, a set of unit response functions (URFs) was developed to estimate the timing of well depletions to the Arkansas River mainstem below Pueblo Reservoir. These URFs are used in the H-I Model to lag both well depletions and return flows from irrigation. The URFs have also been adopted in numerous water rights transfers in the lower basin to model historical groundwater return flows from irrigation. Despite the use of these URFs for Compact compliance analyses, DWR staff and others have questioned how accurately the URFs represent the timing of groundwater return flows in the lower basin alluvium; furthermore, the basis for the URFs is not well-documented.

Colorado State University, as part of its Lower Arkansas Valley research, has developed two regional-scale groundwater models to analyze the alluvial aquifer, water quality and stream-aquifer interactions in two study areas in the lower basin. The MODFLOW groundwater flow models are linked with the MT3DMS contaminant transport model to solve finite-difference approximations of flow and salt transport equations. Colorado State University has enhanced the modeling to include analysis of soil water content and salinity and subsurface drainage (Gates et al., 2002, Burkhalter and Gates 2005, 2006; Gates et al., 2006). Two regional-scale models have been developed, one to cover intense research efforts in an area upstream of John Martin Reservoir (from approximately Manzanola to Las Animas), and the other for an area downstream of John Martin Reservoir (Lamar to the Stateline). The regional-scale groundwater models are currently being used to evaluate the effects of irrigation management practices on groundwater and surface water quality. Colorado State University is in the process of significantly revising and expanding these calibrated regional-scale models.

Finally, a MODFLOW model of the Raton Basin was developed by consultants for energy production companies interested in developing coalbed methane (CBM) wells in the Raton Basin. The purpose of this model was to determine the impacts of CBM wells on the surface water system and the tributary status of groundwater pumped from this aquifer. The scope and spatial coverage of this model is limited for ArkDSS purposes.

ArkDSS Component Options

This section discusses existing and potential new components for ArkDSS groundwater resources planning that meet user needs in the basin.

Existing Components

The following enhancements to existing groundwater resource planning components should be considered for inclusion in the ArkDSS. For the existing CDSS components, enhancements include:

- Evaluate and compare the H-I Model URFs with results of existing regional groundwater models (Colorado State University's two lower basin MODFLOW models)
- Analyze existing and new alluvial aquifer data to better characterize aquifer properties and configuration.

New Components

The following list of new components would provide the necessary tools for analyzing the most widely-used groundwater systems in the Arkansas Basin, providing the full analysis capabilities that were listed at the beginning of this section.

- Utilizing data from Colorado State University's regional groundwater models develop a regional MODFLOW model of the lower basin alluvium (Pueblo Reservoir to the Stateline, including major tributaries).
- If sufficient data are collected, develop a regional MODFLOW model for the upper basin that incorporates the shallow alluvial aquifer and deep basin-fill aquifer.
- Enhance CDSS DMI's to support groundwater model development and linkage with other CDSS components in the Arkansas Basin.
- Using StateWB, develop water budgets for the upper and lower basins that incorporate flow from deep and shallow aquifers and all tributaries (see Section 4.6 below).
- Develop a method to dynamically link the groundwater and surface water models. This may require enhancements to the surface water planning model or require a different modeling approach than the methodology used in previous CDSS efforts. In either case, the approach would use URFs developed from groundwater simulations. Further investigation of Colorado State University's artificial neural network methodology, kriging, or other similar methodology may provide a solution that allows for faster processing without fully linking the surface water and groundwater models (see discussion in Section 4.2 above).

4.5 Consumptive Use Analysis

The consumptive use component of the ArkDSS addresses the expressed user need to quantify historical consumptive use in the Arkansas River Basin and to estimate future consumptive use. User needs that will be met by the consumptive use component are presented in the following sections.

Existing Component Description

StateCU is the CDSS Consumptive Use Model, which the State of Colorado developed to estimate and report crop consumptive use within the state. It consists of a FORTRAN-based computer program and an associated graphical user interface (GUI). The crop consumptive use methods employed in the program are the modified Blaney-Criddle, original Blaney-Criddle, and the Pochop (for bluegrass only) methods with calculations on a monthly basis; and the ASCE Standardized Penman-Monteith method with calculations on a daily basis. Other crop consumptive use methods available outside the GUI include the Penman-Monteith and modified Hargreaves methods, which operate on a daily time step.

StateCU allows several types of analysis including:

- Crop irrigation water requirement by CU Location
- Water supply limited crop consumptive use by structure
- Water supply limited crop consumptive use by structure considering groundwater
- Water supply limited crop consumptive use by structure and priority

StateCU determines crop consumptive use by “CU Location”, which can be a climate station, a specific diversion structure, a combination of diversion structures, or a specific area of land. A CU Location is defined by latitude, associated climate stations, crop types, and acreage.

StateCU features a HydroBase Wizard, which allows the user to interactively build a dataset to estimate potential consumptive use or water supply limited consumptive use at a user-defined location. The HydroBase Wizard allows the user to extract the required input data (e.g., climate data, diversion records, and crop coefficients) directly from HydroBase via an Internet connection. A number of base datasets are available through the CDSS website to allow the user to input data into the StateCU analysis.

After the required input data are entered into StateCU and the model is run, results can be evaluated by generating graphs and tables available through the GUI, or reviewing output reports generated by the StateCU FORTRAN program operated outside of the GUI.

ArkDSS Component Options

In order to respond to the expressed needs detailed in Section 2, several general enhancements regarding the “usability” of StateCU have been identified. These enhancements include, but are not limited to:

- Improve program documentation to provide more “how-to” instruction. This could include example scenarios available through the quick-start guide, in addition to more detailed documentation.
- Review the selected monthly Blaney-Criddle crop coefficients and allow the user to enter higher resolution interpolation for crop coefficients, with less than a 15-day time step for perennial crops and less than a 5-percent time step for annual crops.
- Expand help menu files to provide additional explanation of options within the StateCU program.
- Improve error messages to be more meaningful and provide more troubleshooting information.
- Investigate emerging methodologies for determining actual CU using remote-sensing techniques, and determine if an appropriate methodology should be incorporated into StateCU.

In order to respond to the expressed needs detailed in Section 2, the following enhancements to the StateCU GUI should also be considered:

- Incorporate the Modified Hargreaves method into the StateCU GUI.
- Streamline the GUI to separate standard from more complex consumptive use analyses.
- Improve the existing GUI to reduce inconsistencies between window behaviors.
- Include a function for estimating crop consumptive use met by subirrigation on a parcel-specific basis.
- Provide interface to use CoAgMet station data in monthly and daily analyses with automated data processing. Although this can be done using TSTool or StateDMI, a direct interface through the Wizard and GUI would be more user-friendly.
- Add the daily crop consumptive use equations (ASCE Standardized Penman and Modified Hargreaves) to the scenario development process through the StateCU Wizard.
- Provide a function to allow the user to perform additional QA/QC on input and output data, and provide user documentation within the scenario.
- Develop locally-calibrated crop coefficients for use in the Modified Blaney-Criddle and Modified Hargreaves method using information obtained from the Rocky Ford lysimeter study and the ASCE Standardized Penman method.
- Research and recommend a methodology to incorporate remote-sensing determinations of ET, to verify modeled results.

As Section 2 describes, users have indicated a need to estimate non-crop consumptive uses in the Arkansas Basin. StateCU could be enhanced to allow for computation of these non-crop consumptive uses, such as:

- Automated estimations of lake evaporation based on site-specific or regional pan evaporation data
- Development of methodology or coefficients for determining ET from native vegetation, phreatophytes, and municipal/residential landscaped areas

4.6 Water Budget Analysis

The water budget component describes the major inflow, outflow and storage terms in the Arkansas River Basin. It can be used to understand the interaction among different water uses and how they may have changed over time.

In addition, the water budget component will meet an important internal need during the ArkDSS development by providing a preliminary estimate of a basin's or sub-basin's water balance. It can be used during project development to quantify major water budget components and evaluate preliminary consumptive use, surface water, and groundwater modeling results for reasonableness. Upon project completion, it will combine the final results of other ArkDSS data and modeling components to provide overall basin and sub-basin water budgets.

Existing Component Description

The State of Colorado's Water Budget and Consumptive Uses and Losses Reporting Tool (StateWB) was developed to calculate a basin-wide water balance and to summarize consumptive uses and losses on a basin-wide basis. These functions were combined into the same tool because they rely upon similar data. StateWB is based on a Microsoft Access database that uses data entry, queries and codes to calculate the water budget and generate consumptive uses and losses. It is a simple mass balance tool that accounts for surface and groundwater components of inflow and outflow, consumptive use and losses, and changes in storage for a specific area.

StateWB performs the following simple water mass balance equation to calculate a water balance:

Inflows – Outflows = Changes in Storage

The components of the water balance equation include:

- Inflows: gaged surface water inflows, groundwater budget inflow, imports, precipitation, and ungaged surface water inflow
- Outflows: crop consumptive use, exports, gaged surface water outflow, groundwater outflow, livestock consumptive use, municipal and industrial consumptive use, native vegetation consumptive use, and reservoir evaporation
- Changes in Storage: change in groundwater storage and change in surface water storage

When StateWB calculates a water balance, one of the inflow, outflow, or change in storage components is designated as the residual, calculated as the inflows minus the outflows plus/minus any change in storage:

Residual = Inflows – Outflows +/- Change in Storage

The residual can be used to estimate an unknown water budget component or group of components. It can also be used to determine the sensitivity of the water budget relative to a specific water budget component or group of components.

StateWB can also be used to generate a Consumptive Uses and Losses Summary, which summarizes the consumptive uses associated with agriculture, livestock, reservoir and stockpond evaporation, municipal use, mineral use, thermal electric power generation, and exported water for a specific user-defined basin.

ArkDSS Component Options

It is recommended that StateWB be utilized for the entire Arkansas Basin, as well as the sub-basin water budgets for the upper and lower basin (divided at Pueblo Reservoir). Preliminary basin and sub-basin water budgets should be developed using readily available information to provide initial estimates to be used as checks for other modeling efforts. These preliminary estimates should be regularly updated and used as an accounting check throughout the ArkDSS process to assure that the same base data are used in consumptive use, surface water and groundwater modeling efforts. The final water budgets could be used to estimate water budget parameters that could not be determined directly (e.g., consumptive use from native vegetation).

Consideration should also be given to whether the components of StateWB should be more readily-accessed from the StateCU program.

4.7 GIS and Irrigated Lands Analysis

Spatial data management involves the construction and use of GIS databases for reference, analysis and presentation of results. The spatial data management components will address the data visualization and GIS needs identified in Section 2.

Existing Component Description

CDSS spatial data in the Arkansas Basin currently includes only basic GIS water resource and mapping features, which are described in more detail in Section 3, as well as the irrigated lands analysis mapping completed in 2003. Section 3 provides more detail on the data assembly needed to build an Arkansas Basin spatial database and GIS that adheres to CDSS standards developed in other basins.

ArkDSS Component Options

The ArkDSS needs a comprehensive, user-friendly GIS database that is available via the CDSS website, similar to the GIS systems developed for other basins in the State. The following are recommendations for development of the Arkansas Basin's GIS to aid in spatial analysis and presentation and visualization of data and modeling results:

- To improve accuracy of structure mapping, a GPS location is needed for all structures that currently do not have a GPS coordinate location.
- Provide interactive mapping that allows access to structure data (i.e., water rights and diversions) by clicking on the structure location, similar to the interactive GIS mapping available in other basins.
- Provide any needed support to further incorporate the National Hydrography Dataset (NHD) into the ArkDSS GIS to support analysis functions.
- Provide additional enhancements to model GUIs to facilitate georeferencing of spatially dependent modeling inputs and outputs to support visualization of results using GIS mapping and visualization tools.
- Develop stream network data to allow display of priority call features and visualization of the physical system to aid in modeling and analysis.

As described in Section 3, several additional data layers would make the ArkDSS spatial database compatible with the spatial databases in other basins. These recommended data layers, which were also described in Section 3.14, include the following basin-wide image datasets:

- USGS Landsat Enhanced Thematic Mapper (ETM) and Landsat Thematic Mapper (TM) imagery inventory
- USGS Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite imagery inventory
- USGS 1.0-meter digital orthophoto quarter quadrangles (DOQQ)
- USGS digital elevation model (DEM) data: NED 1/3" (10.0-meter) and NED 1" (30-meter)

The above data should be incorporated into the ArkDSS GIS using methodologies and techniques that have been followed in other basins. Adding these datasets will provide the following functionality to the ArkDSS:

- A historical image archive can be built using USGS Landsat ETM and TM imagery, as well as by acquiring USGS ASTER satellite imagery for those years where images are available for the entire basin. This historical image database can be established at the 15.0-meter to 30-meter pixel ground sample distance (gsd) resolution and can serve as a database that provides snapshots extending back to the early 1980s to establish the following data layers using remote-sensing, digital image processing techniques:
  - Irrigation use and mapping, as a function of time
  - Land use and land cover mapping, as a function of time
  - Change detection analysis (i.e., comparative agricultural land use)
  - Historical mapping of agricultural lands on a tract-by-tract basis
  - Mapping of large structures within the basin.
  - Mapping and monitoring of wetlands within the basin
- The USGS 1.0-meter DOQQ will provide the DSS full orthophotographic coverage of the basin and will provide a 1.0-meter ground sample distance cartographic base from which all other GIS layers and imagery can be georeferenced. In lieu of high-resolution aerial orthophotography (1.0-meter or less), this dataset can initially serve as the base map for the ArkDSS GIS. This cartographic base can allow

GIS users to build 1.0-meter resolution GIS layers of irrigation structures, drains, surface hydrology, and other infrastructure using digitizing techniques.

- Establishment of DEM data over the entire basin by acquiring USGS NED 1/3 arc second (10.0-meter point spacing) digital elevation data and NED 1 arc second (30-meter point spacing) digital elevation data. This will allow the ArkDSS to retain a digital terrain model of the entire basin that will serve as the digital topographic base map. This will allow GIS database users to perform basin-wide topographic analysis, generate digital elevation models, 3-D perspective using GIS and image overlays, and generate medium-resolution contours.

It should be noted that the datasets mentioned above are generally mid-resolution (DEM and satellite data, 10.0-meter to 30-meter resolutions), while the DOQQ is at 1.0-meter resolution. The advantage of using the mid-resolution imagery is that these datasets are immediately available to the ArkDSS at basin-wide coverage, at minimal cost and can serve as the base maps (image and topographic) in the interim while higher resolution datasets (airborne digital orthophotography, high resolution lidar and or satellite imagery) are acquired through time.

4.8 System Integration

System integration tools consist of four parts:

- System linkages, which are utilities that help with data viewing, formatting and processing, as well as provide linkages between DSS components. They are generally applied to one or more applications and are therefore described as a group. Each application category described above has common data needs and linkages with other application categories. For example, the surface water model requires the consumptive use model's estimates of irrigation water requirement.
- A relational database system, HydroBase, which serves as the repository and master copy of observed data. HydroBase is what makes the DSS data-centered and ensures data consistency.
- A maintenance program is needed to ensure that the CDSS components continue to function as designed and can be enhanced in response to changes in the operating environment and new requirements.
- Stakeholder education and involvement, which provides information and education to stakeholders and solicits input from stakeholders, for DSS improvements. ArkDSS stakeholders are defined as water managers, water users, and water providers in the Arkansas Basin.

Each of these four parts is discussed in the following sections.

System Linkages

Existing Component Description

Various elements for system integration have been developed through CDSS efforts in other basins. The following summarizes these system integration elements:

- Data management interface (DMI) utilities facilitate querying the database, viewing data, and formatting results for modeling to achieve a data-centered approach for modeling and analysis purposes.
- Models and DMIs use command files that allow reproduction of an analysis. DMIs print standard information at the top of model files, including information about the version of HydroBase that was used, a list of the commands used to run the program, the location where it was run, the date, and the model version. This allows results to be reproduced and helps users learn how to use the system.
- Common file formats have been adopted to facilitate reuse of tools. For example, time series files for the surface water and consumptive use models typically use the StateMod convention.

- A standard directory structure for modeling has been implemented in which preliminary input, active model files, and model output are stored. This provides structure to the modeling environment.
- Standard file and data set names have been devised in CDSS. Applied rigorously, naming standards clarify the organization and content of the file and allow the use of wildcards and relative references in command files, making them transferable to different applications.
- GIS files used for displays and analysis use ESRI shapefiles, which have attributes that allow linking to HydroBase and model files.

As summarized above, the State has developed tools to access HydroBase and prepare input data for CDSS models. TSTool is also compatible with MODSIM and other water resources software. These data pre-processing tools, referred to as DMIs, convert spatially distributed data such as stream gage data and water right locations into point data to define items such as the model network configuration. They also process diversion and demand time series and efficiencies required by the model.

Several of the DMIs have been refined and consolidated into two primary applications, TSTool and StateDMI. TSTool is used to process and analyze time-series data, while StateDMI is used to process other data, including spatially distributed data. Both StateDMI and TSTool were developed to provide greater consistency in modeling when using StateMod and StateCU. StateDMI and TSTool provide a common set of input file types and facilitate interoperability between StateMod and StateCU. Additional information and documentation regarding StateCU, StateMod, StateDMI, and TSTool can be found on the CDSS website.

For groundwater applications in the RGDSS and SPDSS, StatePP and StateDGI have been developed. These DMIs prepare input files to MODFLOW using information from HydroBase and StateCU regarding wells, irrigated parcels, recharge areas, and evapotranspiration.

ArkDSS Component Options

ArkDSS will utilize the system integration and linkages that have been developed for CDSS components in other basins. For example, for the SPDSS, consistent formats for data and interfaces used for similar features of StateMod and StateCU were developed. Additional enhancements to system integration are expected to be needed only for new components that do not currently exist in other basins. For example, if MODSIM is adopted as the surface water modeling platform, modifications to the existing linkages between StateMod and other CDSS components (StateDMI, TSTool) will be required

Through the needs assessment process, many users expressed a need for access to more real-time surface water data (including provisional diversion records) and the ability to perform analyses utilizing the real-time data that are currently available online from the satellite monitoring system and the Arkansas Daily Report. Some improvements are currently being made to TSTool to allow for assessment of real-time data. Enhancements should be made to TSTool and StateDMI allowing their full suite of analysis tools when accessing the online version of HydroBase. This would allow more users to utilize TSTool and StateDMI and has the potential to make these software packages developed by the State more widely used. The following should also be considered:

- Continued enhancements to the web services packages within TSTool and StateDMI.
- Addition of web service interfaces for the collection and presentation of real-time data.

Relational Database Management System

Colorado’s DSS’s have been developed as data-centered systems. In these systems the database, HydroBase, serves as the repository and master copy of observed data. This approach ensures that CDSS tools use the same database and, therefore, the same data. This philosophy promotes data consistency, requires development of fewer tools for data entry and visualization, and allows analysis results to be duplicated. It also encourages other entities to interact with and build on CDSS.

Many of the needs identified for ArkDSS involve data. Some of these data needs are for additional or more accurate data. Other data needs result from the tools that facilitate more efficient access to data. Direct data needs are presented in Section 3. This section describes database requirements and tools to make data access more efficient.

Existing Component Description

HydroBase is maintained by DWR and is accessed online through the CDSS website. Additionally, HydroBase is published on an annual basis in July, with updates through the previous water year. Data for structures in HydroBase are keyed according to structure ID numbers, which allows for interface with the spatial database system (GIS), described in Section 4.7 above. Documentation for HydroBase is available on the CDSS website.

DWR currently plans to change the way that diversion data are coded in HydroBase to allow for a more clear connection between the source of water for diversion and the use to which the water is placed. Additionally, DWR plans to allow provisional diversion data to be stored in HydroBase and uploaded on a more frequent basis. These planned changes to HydroBase will allow for more access to data and provide further understanding of water use on the basin.

ArkDSS Component Options

HydroBase currently works well for both raw data access and data pre-processing for CDSS components by TSTool, StateDMI, the StateCU Wizard, and StateView. However, specific data access needs of Division 2 for water administration purposes may require modifications to HydroBase or development of new tools to interface with HydroBase, described below.

Enhancements needed to improve the timeliness of observed data available in HydroBase to support the annual run of the H-I Model are described in Section 4.3 above.

Additional enhancements to HydroBase may make these data more readily accessible and improve data transfer between entities. To accomplish these objectives, the following actions are recommended:

- Because real-time data by nature has not gone through a rigorous QA/QC process, data presentation should be updated to indicate if data are provisional.
- Statistical procedures, such as Bayesian network analysis, could be applied to real-time data to provide level of confidence information for real-time data.

Update/Upgrade Existing CDSS Tools

Because CDSS is a large system with multiple ongoing applications, it is important that every component be maintained and that linkages between components are functional. The maintenance activities should consider not only the needs of the ArkDSS but also those of existing CDSS components.

Existing Component Description

Outside of DWR's maintenance of HydroBase, minimal funding is available for ongoing maintenance of CDSS components. CDSS components that require maintenance include:

- HydroBase (Local and online database)
- StateView
- TSTool
- StateDMI
- StateMod (FORTRAN and GUI)
- StateCU (FORTRAN, GUI and Wizard)
- StateWB

- StateDGI
- StatePP
- Map Viewer
- Other GIS interfaces and datasets

ArkDSS Component Options

The following elements of an enhanced maintenance plan have been identified to meet the needs of the ArkDSS:

- Provide resources to update system components due to operating system and commercial software updates.
- Provide resources to maintain data collection systems implemented for CDSS. This includes collecting water levels from wells. In addition, wells scheduled for abandonment should be reviewed quarterly to identify candidates for conversion to monitoring wells.
- Provide resources for maintenance of all the CDSS components. Activities that are envisioned include (1) maintenance enhancements and troubleshooting of the database and tools; (2) updating databases with new information from ongoing data collection activities, analyzing the data for relevant trends and relationships, and updating mapping of the information; and (3) updating the models (most likely through DMIs from HydroBase) to reflect the new and/or more detailed information that has become available. Combination of some of these tools will provide a more streamlined suite of tools. A similar task was completed under SPDSS which combined programs and created StateDMI.
- Provide resources to upgrade system components in response to technology changes. Further, web-based applications and data dissemination is becoming more common practice. Enhancement to the DMIs may be needed to access updated versions of HydroBase provided through the CDSS website.
- The online operation of the CDSS is hampered by data access limitations designed to limit the quantity of data served at a given time. This is due to the potential of huge spikes in usage, such as during a model run. Moving HydroBase, the associated web services, and related tools to an on-demand, cloud-based environment would provide additional capacity when needed without requiring a large capital outlay to fund rarely used capacity.

Stakeholder Education and Involvement

Stakeholder education and involvement consists of providing information and education to stakeholders and soliciting input from stakeholders for DSS improvements. ArkDSS stakeholders are defined as water managers, water users, and water providers.

Investing in stakeholder education and involvement is critical to the successful development and ongoing use of ArkDSS. The system is complex and use of many features requires a high level of technical expertise. Stakeholder involvement provides education and a forum for stakeholders to voice approval or concern in the development process, and increases the chances of future use of the data and tools.

Existing Component Description

Stakeholder education and outreach have evolved and improved with the development of each DSS. These outreach and involvement tools are either in place or are being developed:

- Advisory committee – three meetings during the development of the ArkDSS feasibility study
- Peer Review Committees (PRCs)
- Newsletters – hard copy and email (sign up for email via CWCB Insider on CWCB website)

- Presentations at ArkDSS Roundtable Meetings
- Outreach meetings with other subcontractors to learn about tools and develop articles for the newsletter
- Website improvements to increase understanding of the CDSS website and tools and provide more “layman” information (more informational/intro pages)
- Self-paced training materials and sample data for CDSS software

ArkDSS Component Options

The outreach and involvement tools listed above will be applied to the Arkansas Basin to increase access and visibility of CDSS in the basin, and to provide education to potential system users. Table 4-2 summarizes the needs expressed by ArkDSS users during the interview process, and the outreach and involvement steps that will address these needs during development of ArkDSS.

Table 4-2. Options for Stakeholder Outreach and Involvement

ArkDSS User Needs	Implementation
Data-centered system based on data that has undergone thorough QA/QC review	Document a QA/QC process that is transparent and have available for distribution – identify when peer review is appropriate, conduct PRCs
Development of creative solutions to water resources management issues	Engage Arkansas Roundtable during alternatives development of feasibility study and during implementation
Accessible to both the State and water users	CDSS website, newsletters (email)
Enhanced visualization of data, analysis and model results	CDSS website
Complete documentation	CDSS website
Expanded communication with user base	CWCB Insider – anyone can sign up to receive newsletters
Training and public information dissemination	PRCs, Roundtable presentations, newsletters (with “how to” sections on using tools)
User-friendly interfaces	CDSS website, online interfaces for tools, more comprehensive technical documentation and training manuals that are accessible via the CDSS website, as well as through model GUIs
Documentation of open test cases to demonstrate the abilities and purposes of the ArkDSS components as compared to other models in the basin. This documentation should include model testing to demonstrate the validity and/or limitations of the model for the intended purpose.	Develop online FAQs and list of Proven Successes that are readily accessible

4.9 Water Quality Analysis

A need identified by water resource managers in the Arkansas Basin is the ability to assess water quality impacts from water resource management decisions, particularly in the lower basin. DSS component needs described in Section 2 include data collection and tools to help analyze water quality management scenarios and assess water quality impacts from water resource management decisions.

Existing Component Description

Water quality data and analysis have not previously been included in CDSS, partly because they have not been within the statutory purview of CWCB and DWR. However, recent changes to Colorado water law require that water quality impacts be considered for water rights transfers. Collection and compilation of water quality data, and water quality assessments to determine compliance with water quality standards, are performed by the Water Quality Control Division (WQCD) in the Colorado Department of Public Health and Environment. The WQCD has done numerous water quality assessments in the Arkansas Basin, as part of their 305(b) and 303(d) reporting requirements under the Clean Water Act. These assessments are performed for stream segments and are based on available historical data. At this time, the WQCD has not performed a basin-wide analysis or developed a model to predict water quality impacts from water resource management decisions.

The USGS has also performed decades of scientific research and data collection for water quality issues in the Arkansas Basin. Both site-specific and regional water quality assessments have been performed, as evidenced by several publications and water quality projects described on the USGS website. Several studies that could provide information or methodologies for incorporation into a basin-wide water quality assessment tool include the following:

- *Occurrence and Distribution of Dissolved Solids, Selenium, and Uranium in Groundwater and Surface Water in the Arkansas River Basin from the Headwaters to Coolidge, Kansas, 1970–2000 (USGS, 2010b)*
- *Lower Arkansas River Comprehensive Data Base and Data Assessment (USGS, 2002).*
- *Identifying Changes in Background Water-Quality Conditions Using Dissolved-Solids Concentrations and Loads as Indicators, Arkansas River and Fountain Creek, in the Vicinity of Pueblo, Colorado (USGS, 2004).*

These studies and others are expected to provide data and information regarding current and historical water quality conditions in the basin. However, no basin-scale model has been developed to facilitate analysis of impacts to water quality resulting from changes in water resources management and administration.

Colorado State University has invested over a decade of research in the Arkansas Basin to assess water quality impacts of irrigation management practices. As described above in sections 4.2 and 4.4, and further in: Gates et al., 2002; Burkhalter and Gates 2005, 2006; and Gates et al., 2006, Colorado State University has designed a spatial decision support system (ArkRiver GeoDSS) to assist with the assessment of irrigation water management options and water quality impacts in the lower basin. The ArkRiver GeoDSS integrates GIS and surface and groundwater quantity and quality models into a tool for conjunctive surface and groundwater quality modeling. The ArkRiver GeoDSS has been developed using artificial neural networks to fully integrate surface and groundwater models. The consultant team has interviewed Colorado State University staff and reviewed publications describing the research and model development.

ArkDSS Component Options

Inclusion of a water quality analysis component in the ArkDSS would require an extensive development effort, as this type of component has not previously been included in the CDSS. Integrating water quality into basin-scale groundwater and surface water planning models is an extremely complex process that requires appropriate use of scale, adequate spatial and temporal coverage of the underlying data used for calibration and verification of the models, appropriate mathematical solutions for the underlying modeling equations at the appropriate resolution, and appropriate application of modeling assumptions and modeling result interpretations. This type of integration has not been attempted in any other river basin in Colorado, and would require extensive development of new components for the ArkDSS.

As discussed above, Colorado State University has over the last ten years been collecting data and developing an integrated surface water/groundwater quality model of the Arkansas Basin below Pueblo Reservoir. This existing model provides a potential alternative for a decision support system tool that can assess water quality impacts from water resource management strategies in the lower basin. Coordinating with Colorado State University and supporting their continued data collection and model refinement efforts would reduce duplication and maximize funding efficiency for a water quality analysis component. However, further review of Colorado State University's models, data, assumptions, and calibration techniques is required. Further investigation of the use of artificial neural networks to estimate basin-scale solutions where basin-wide groundwater models do not exist is also needed.

Additionally, investigation of the capability of Colorado State University's ArkRiver GeoDSS to provide similar flow solutions to the ArkDSS surface water planning component may be needed in order to verify that the CDSS components that will be used for water resources planning throughout the Arkansas Basin can be paired with the ArkRiver GeoDSS to answer regionally-specific water quality impact questions.

For the ArkDSS, it is recommended that implementation efforts concentrate on developing sound surface water and groundwater flow models to meet the majority of the needs expressed in Section 2; valid surface water and groundwater flow models provide the basis for further water quality analyses. Section 3 provides recommendations for more data collection that is needed to support basin-wide water quality analyses. Additionally, further investigation of Colorado State University's ArkRiver GeoDSS for water quality analysis purposes should be performed during ArkDSS development, with consideration for coordination with and support for their ongoing efforts.

4.10 Summary

The existing CDSS has many of the functions and tools that are needed in the ArkDSS to meet the needs identified in Section 2. To fulfill many of the expressed user needs, however, modifications to some existing components and development of new components would be required. These modifications and new tools are described in the preceding sections, and summarized in Table 4-3. Options for implementation of new DSS components, along with modifications to existing DSS components for inclusion in the ArkDSS are discussed in Section 5.

Table 4-3. Summary of DSS Component Options

Component Option/Enhancement	Description
Surface Water Planning	
a. Develop model for the Arkansas Basin	Develop a monthly and daily time-step model - modeling platform to be determined during implementation
b. Model enhancements : Flow routing	Enhancements may be needed to facilitate daily routing and flow forecasting
c. Model enhancements: Groundwater model linkage	Linkage between surface and groundwater model using URFs or a robust interpolator
d. Model enhancements: Arkansas River Compact Operating Rules	Development and application of the water resources planning model to the constraints of the Compact and the associated operations of John Martin Reservoir
e. Model enhancements: Arkansas Basin operations	Review basin operations to determine if refinements to the StateMod code are required
f. Model enhancements: Statewide model linkages	Enhancements needed for Statewide model linkages
Water Rights Administration and Accounting	
a. Develop straight-line diagrams	Created for each water district
b. Develop water-type tracking tool	Develop a tool that tracks transmountain, native, augmentation and reservoir water
c. Improve the efficiency of H-I Model input data collection: Early data release	DWR start the HydroBase update with Division 2 and specifically with the datasets needed to generate the input files for the H-I model. Publish this information either through the CDSS online database or through a DVD release that is available by January 15th of each year
d. Improve the efficiency of H-I Model input data collection: Create StateCU dataset	Setup a StateCU dataset that is specific to the H-I model's requirements to calculate potential evapotranspiration at Division 2 CoAgMet stations using the ASCE Standardized Penman-Monteith equation
e. Improve the efficiency of H-I Model input data collection: ARAS well accounting output enhancements	Ensure that functionality is included in ARAS which will allow for data export of reservoir accounting and well plan accounting data that is needed by the H-I Model
f. Improve the efficiency of H-I Model input data collection: Update TSTool/StateDMI	Update TSTool/StateDMI to create H-I Model data input files

Table 4-3. Summary of DSS Component Options (Continued)

Component Option/Enhancement	Description
Groundwater Planning	
a. Evaluate existing basin URFs	Evaluate and compare the H-I Model URFs with existing regional groundwater models (Colorado State University's two lower basin MODFLOW models)
b. Incorporate URFs from existing models into ArkDSS	Incorporate URFs from Colorado State University's groundwater modeling efforts into HydroBase and ArkDSS surface water model
c. Improve the representation and understanding of the vertical stratification within the alluvial aquifers	Use results of Colorado State University's data and MODFLOW models, and supplement with data from alluvial aquifer data collection program
d. Improve the user interface to existing models	Develop links through the ArkDSS to access the existing groundwater analysis tools in the basin, including the H-I Model URFs, Colorado State University's regional MODFLOW models, and the Raton Basin MODFLOW model
e. Develop regional model for lower basin alluvium	Utilizing data from Colorado State University's regional groundwater models, develop regional MODFLOW model of the lower basin (below Pueblo Reservoir) of the Arkansas River mainstem and the major tributaries
f. Develop a regional model for the upper basin	Develop a MODFLOW model for the upper basin that incorporates the shallow alluvial aquifer and deep basin-fill aquifer if sufficient data are collected
g. Enhancements to groundwater model DMIs as needed	Effort commensurate with modeling effort described above
Consumptive Use Analysis	
a. StateCU Enhancements: Model documentation	Improved program documentation to provide more "how-to" instruction. This could include a separate quick start guide, with expanded documentation following in more detail
b. StateCU Enhancements: Higher resolution crop coefficients	Allow higher resolution interpolation for crop coefficients less than 15 day time step for perennial crops and less than 5-percent time step for annual crops
c. StateCU Enhancements: Help files	Expand help files to provide additional explanation of options within the StateCU program
d. StateCU Enhancements: Troubleshooting	Improve error messages to be more meaningful and provide more troubleshooting information
e. StateCU Enhancements: ET estimates for non-crop vegetation	Development of methodology for determining ET from native vegetation, phreatophytes, and municipal/residential landscaped areas
f. Enhancements to StateCU GUI: Add Modified-Hargreaves method	Incorporate the Modified-Hargreaves method into the StateCU GUI
g. Enhancements to StateCU GUI: streamline and categorize options	Streamline the GUI to separate standard from more complex consumptive use analyses
h. Enhancements to StateCU GUI: improve window behavior	Improve existing GUI to reduce inconsistencies between window behavior
i. Enhancements to StateCU GUI: subirrigation method	Include function for estimating crop consumptive use met by subirrigation
j. Enhancements to StateCU GUI: direct interface with CoAgMet station data	Provide interface to use CoAgMet station data in monthly analyses with automated data processing
k. Enhancements to StateCU GUI: add daily equations	Add the daily crop consumptive use equations to StateCU Wizard
l. Enhancements to StateCU GUI: additional QA/QC of data	Provide a function to allow the user to perform additional QA/QC on input and output data, and provide user documentation within the scenario
m. Method for determining ET using Remote-Sensing data	Incorporation of remote-sensing determinations of ET for verification of modeled results
Water Budget Analysis	
a. Develop water budgets for Arkansas Basin	Develop basin-wide and sub-basin water budget using StateWB
b. StateWB Enhancements: Lake evaporation	Automated estimations of lake evaporation based on site-specific or regional pan evaporation data
GIS and Irrigated Lands Analysis	
a. Develop GIS Database to support overall ArkDSS activities (includes all data collection or purchase, processing, and publishing results).	Creation of database Includes data purchase, processing and results. GIS will include functionality for display, viewing and editing capability, database query functions, import and export functions, ability to change projections, and plotting functions. Utilize the GIS template used in other CDSS GIS efforts

Table 4-3. Summary of DSS Component Options (Continued)

Component Option/Enhancement	Description
b. Further the incorporation of the National Hydrography Dataset (NHD) into the ArkDSS GIS to support analysis functions	Provide support to DWR efforts
c. Georeference spatially dependent modeling inputs and output to support visualization of results using GIS mapping and visualization tools.	Effort is commensurate with modeling recommendations
d. Develop stream network data to allow display of priority call features and visualization of the physical stream system.	Effort is commensurate with modeling recommendations
System Integration	
1. Relational Database Management System	
a. Data access needs of Division 2 for water administration purposes (described in surface water alternatives) may require modifications to HydroBase or development of new tools to interface with HydroBase	When real-time data are uploaded to HydroBase, update data presentation to indicate if data are provisional, and include statistical procedures to provide confidence level of data.
2. System Linkages	
a. Enhancements to TSTool and StateDMI to work with on-line HydroBase	Support ongoing real-time data enhancements, including the addition of web-services interfaces for the collection and presentation of real-time data.
3. Update/Upgrade Existing CDSS Tools	
a. Provide resources to update system components due to operating system and commercial software updates	Provide necessary resources as needed
b. Provide resources to maintain data collection systems implemented for CDSS	Provide necessary resources as needed
c. Provide resources to upgrade system components in response to technology changes	Provide necessary resources as needed
d. Move HydroBase, the associated web services, and related tools to an on-demand, cloud-based environment	Not included
4. Stakeholder Education and Involvement	
a. Engage Arkansas Basin Roundtable	Develop communication plan for roundtable and utilize meetings as forum for public dissemination of information on ArkDSS development
b. Enhance CDSS website to aid in communication of DSS efforts, expand access to users, and provide documentation	Provide online interfaces for tools, more comprehensive technical documentation and training manuals that are accessible via the CDSS website, as well as through model GUIs
c. Document a QA/QC process that is transparent and have available for distribution	Expand on SPDSS QA/QC documentation
d. Identify when peer review is appropriate and conduct PRCs	Conduct targeted PRC meeting during critical data and component development stages of the ArkDSS
e. Develop online FAQs and list of Proven Successes that are readily accessible	Documentation of open test cases to demonstrate the abilities and purposes of the ArkDSS components as compared to other models in the basin. This documentation should include model testing to demonstrate the validity and/or limitations of the model for the intended purpose
Water Quality Analysis	
a. Investigate Colorado State University's ArkRiver GeoDSS for application to water quality analysis throughout the Arkansas Basin.	Provide linkages between CDSS and Colorado State University's ArkRiver GeoDSS if models are found to be compatible and sufficient for DSS purposes.

Section 5

Options for ArkDSS Implementation

The goal of this feasibility study is to propose a recommendation for implementation of an ArkDSS that meets the needs of the various stakeholders in the basin and is technically and economically feasible. The purpose of this section is to present the analysis of options for ArkDSS implementation involving data collection and DSS components that have been presented in previous sections. Chapter 6 will then discuss the recommended elements that have been selected for proposed implementation.

Options for ArkDSS implementation were identified by evaluating the various recommendations included in Sections 3 and 4 in regard to how well the recommendations met the needs of the users described in Section 2. Recommendations were also screened for reasons for exclusion from the ArkDSS implementation, because of issues such as duplication of effort with another entity, being outside the scope or vision of the CDSS, and others. Finally, analysis of the present value costs of the various recommendations was used to further refine the recommendations into three categories, or levels of effort and cost. These three categories represent three “tiers” of analytical capability, or options for ArkDSS implementation, along with the data required to support that capability. These tiers are summarized below:

- Tier 1 gives the water users, CWCB, and DWR a foundational DSS that meets many of the needs of the users and adheres to the standards for CDSS efforts developed in other basins. Tier 1 recommendations include those for data collection and development of analytical tools to support basic administration and planning tools.
- Tier 2 provides an enhanced level of analysis that meets a majority of the needs and gives the water users, CWCB, and DWR a cost-effective DSS that collects necessary data and develops appropriate tools for administration and planning. Tier 2 builds on the activities listed under Tier 1, and provides additional data collection and analytical components. The surface and groundwater planning tools will be developed at an appropriate level to enable water users, the CWCB, and DWR to address present and future water policy, development, and administration issues in a timely, efficient, and cost-effective manner.
- Tier 3 provides a "full-featured" level of analysis that gives water users, the CWCB, and DWR a DSS that collects data and develops tools for administration and planning at a detailed, but expensive level. Tier 3 options include everything from Tier 1 and Tier 2, plus additional data collection and functional components. This option would meet nearly all of the stakeholders’ expressed needs listed in Section 2 – Needs Assessment, at a higher cost than either Tier 1 or Tier 2.

The following sections describe the three tiers of ArkDSS development in detail. Each tier begins with a discussion of the recommended data collection activities that are envisioned to take place to support the implementation of that tier and possibly continue throughout implementation of ArkDSS in specific cases. The data collection section is followed by a discussion of the recommended DSS components for that tier. Under a phased approach to the ArkDSS development, these components would be developed and implemented primarily after completion of data collection. Note that the tiers do not indicate potential phases in the ArkDSS implementation but options for implementation for different levels of effort and analytical capability. Section 6 provides the proposed plan and phasing for implementation of the ArkDSS, and the development and analysis of the tiers in this section will help in framing the phasing for the proposed implementation.

Estimated present value capital costs for the three tiers are presented in Tables E-1 through E-8 in Appendix E and are also summarized in Table 5-1 at the end of this section. Consistent with previous DSS developments, the estimated operation and maintenance costs during the ArkDSS development period are included in Table E-7, System Integration.

5.1 ArkDSS Tier 1

Surface Water Planning

Data collection and development of DSS components included under Tier 1 for the surface water category are intended to support and enhance basic basin-wide planning and administration functions. Please refer to Table E-1.

Data Collection

Tier 1 surface water data collection activities include addition of stream gages for administration purposes, and recommendations that focus on the review, compilation, and filling in of missing records of existing data sets in order to support surface water planning tools. These data collection activities include the following:

- Install a high priority administrative streamflow gage with satellite equipment: Fountain Creek between Pinon and Pueblo
- Identify key streamflow gages in the Arkansas Basin and fill in missing records using CDSS-developed techniques
- Compare diversions in HydroBase with diversion records that were inspected for quality for the H-I Model, and make corrections to the HydroBase records as necessary
- Review HydroBase records for diversion structures representing 85% of the total annual diversion in the Arkansas Basin, interview water users and the Division 2 office, and do analysis of historical diversion and streamflow records for monthly and daily diversion data. Fill missing data for 68 diversions (25% of approximately 270 key diversions), and all transbasin diversions, using CDSS established standards
- Review HydroBase reservoir storage records and interview water users and the Division Engineer to identify the major reservoir structures (defined as those approximately greater than 1,000 acre-feet) that should be included in the initial surface water modeling effort. The effort will include collecting daily and monthly reservoir accounting records and performing QA/QC reviews, documenting operations, and estimating missing data

DSS Components

The DSS components included in Tier 1 provide analytical tools that would support daily and monthly, basin-wide surface water planning. Section 4 discussed the applicability of StateMod and MODSIM to the surface water planning tool, concluding that either could provide the functionality needed for the ArkDSS.

A final selection of the modeling platform for the surface water planning component will not be determined for purposes of this feasibility study. As described in Section 4, there are numerous ongoing efforts in the basin involving surface water modeling. It was decided that selecting a CDSS modeling platform during the feasibility study might be a complicating factor for some of the other modeling efforts. Furthermore, the development and implementation of the ArkDSS surface water planning component is several years away, and making the selection at this time is not a necessity. Additionally, model selection in the future could benefit from the latest technology changes and evolution of the StateMod and MODSIM modeling platforms, as they have been refined in the Arkansas Basin and throughout the State for specific user needs. It is anticipated that much of the current surface water modeling work in the basin will be completed in the next few years and that these modeling efforts will benefit the eventual development of the ArkDSS surface water planning component.

Regardless of the final model selection, specific recommendations regarding the development of the surface water planning component include the following:

- Select the ArkDSS surface water modeling platform and develop a monthly time-step model for the entire Arkansas Basin
- Enhance the model to allow application of the constraints of the Arkansas River Compact and the associated operations of John Martin Reservoir
- Enhance the model GUI to match the revised capabilities of the model, and develop enhancements as appropriate

Water Rights Administration and Accounting

Tier 1 recommendations for the water rights administration and accounting component include improved data access and tools to aid in the administration duties of Division 2. Please refer to Table E-2.

Data Collection

Data collection recommendations for water rights administration and accounting under Tier 1 will provide users access to administration and accounting data that have previously not been included in HydroBase. These data collection recommendations include:

- Gather available data for all Rule 14 Plans and high-priority augmentation plans and transfers and determine how to best represent the information in HydroBase
- Collect, interpret, and digitize river call data for mainstream and major tributaries in Division 2. This task will require input from Division 2 to adequately capture historical administration practices throughout the basin
- Review Water District 11 water rights tabulation and make corrections to administration numbers as needed

DSS Components

Tier 1 recommendations will allow the development of tools to better understand the source and use of water as it moves through the basin and will facilitate easier data compilation for the annual H-I Model simulations required for Compact compliance. These recommendations specifically include:

- Develop straight-line diagrams for each water district
- Develop a tool that tracks transmountain, native, augmentation, and reservoir water and exchanges or incorporate these capabilities into the Division 2 Arkansas River Accounting System (ARAS). Include short-term forecasting capability. This tool is envisioned to be an enhancement to ARAS that will benefit administration efforts of Division 2, and also benefit water users through enhancements to the Arkansas River Daily Reports.
- Improve the efficiency of H-I Model input data collection through the following:
  - Start the annual DWR HydroBase update with Division 2 data and specifically with the datasets needed to generate the input files for the H-I Model. Publish this information either through the CDSS online database or through a DVD release that provides data for the previous water year by the following January 15th.
  - Set up a StateCU dataset that fulfills the H-I Model's requirements to calculate potential evapotranspiration at Division 2 CoAgMet stations using the ASCE Standardized Penman-Monteith

equation. Development of this dataset will include quality review of the CoAgMet station data and filling of missing data as needed using CDSS techniques.

- Ensure that functionality is included in ARAS which will allow for data export of reservoir accounting and well plan accounting data that is needed by the H-I Model
- Update TSTool/StateDMI to create H-I Model data input files and to post-process output

Groundwater Planning

The groundwater data collection and DSS component development activities under Tier 1 will focus on supporting the development of a basic groundwater model for the lower basin alluvium. Please refer to Table E-3.

Data Collection

The collection of groundwater data under Tier 1 is driven by the data needed to support groundwater modeling at the Tier 1 level. It should be noted that the level of effort for groundwater data collection listed below is approximate and will be refined into a full groundwater field work plan once a thorough review of the existing published data can be conducted during the first phase of the ArkDSS implementation. These data collection activities are anticipated to include the following:

- Review and summarize all data and literature catalogued by CGS on the Arkansas Basin
- Rely on existing pumping data sources, primarily in the lower basin; no additional pumping data are to be collected
- Rely on existing streambed conductance test data; no additional conductance data are to be collected
- Drill/install up to eighteen alluvial aquifer monitoring wells: up to five wells in the upper basin, up to five wells in the lower Arkansas River mainstream area, up to three wells in the Fountain Creek drainage, and up to five wells in the other major tributaries in the lower basin. Note that the density of monitoring wells in each sub-basin will be refined upon further review of existing data
- Conduct pumping tests in up to eighteen of the new alluvial wells to evaluate the impacts of vertical stratification within the aquifers and the hydraulic connection to the bedrock and shallow aquifer systems
- Use existing published aquifer data for the deep aquifers in both the upper and lower basins
- Survey elevations of all newly installed monitoring wells and subsets of existing wells in the basin that may be used for groundwater analysis and modeling
- Collect water level data using continuous data loggers for four years for up to 50 wells (30 existing, up to 10 new, and up to 10 converted abandoned wells) in the upper and lower basins and tributaries to support modeling efforts. This effort will be coordinated with other water level monitoring programs in the basin (e.g., USGS and Colorado State University)

DSS Components

Tier 1 efforts for the groundwater component are focused on data collection and analysis of existing models, with minimal work on developing new groundwater models in the basin. Specific component development includes the following:

- Analyze existing and new alluvial aquifer data to better characterize aquifer properties and configuration. Identify data gaps for future data collection efforts
- If necessary, develop URFs from Colorado State University's regional groundwater models to show surface water and groundwater model linkages

- Evaluate and compare the H-I Model URFs with existing regional groundwater models (Colorado State University's two lower basin MODFLOW models)
- Develop a simplified analytical model for the upper basin in conjunction with the data collection program described above

Consumptive Use Analysis

Estimating crop and non-crop consumptive use provides foundational information to all other aspects of the ArkDSS, including surface water planning, groundwater planning, and water budget analysis tools. Therefore, many of the data collection and DSS component development activities to support consumptive use analysis are included under Tier 1. Please refer to Table E-4.

Data Collection

Recommended Tier 1 data collection activities include:

- Collect, review, and assess estimates of ET for irrigated areas in the Arkansas Basin developed by DWR, Colorado State University, SWSI, and others
- Coordinate with other ArkDSS component categories (i.e. surface water planning component and Irrigated Lands/GIS component) to collect the information necessary for consumptive use calculations in the upper basin. This data includes: canal and lateral losses, tailwater run-off, secondary ET losses, soil moisture accounting, and irrigation efficiencies, many of which are important for consumptive use analyses performed by Division 2 using the ISAM model.
- Gather existing population data, municipal consumptive use per capita and municipal indoor and outdoor use return flow for cities, towns, and counties in the study area to estimate municipal and domestic water consumptive use. Data collected through SWSI should provide the bulk of the needed information as well as any Arkansas Basin Roundtable data that may be appropriate.
- Collect data on other consumptive uses in the basin (e.g., industrial, mining, power, livestock and stockpond evaporation)
- Gather existing data on native and non-native vegetation estimates/reports for the Arkansas Basin
- Review climate station data in HydroBase and inspect them for quality, making corrections as needed

DSS Components

Similar to the data collection activities described above, enhancements to the CDSS tool for estimating basin consumptive use, StateCU, are mainly recommended under Tier 1 in order to meet the need for consumptive uses and losses data by other CDSS components. Several of the enhancements to StateCU are driven by the need for StateCU to be more user-friendly and to appeal to a wider user audience.

Enhancements to the StateCU model structure itself include the following:

- Develop locally-calibrated crop coefficients for use in the Modified Blaney-Criddle and Modified Hargreaves method using information obtained from the Rocky Ford lysimeter study in the lower basin
- Develop locally-calibrated crop coefficients for use in the Modified Blaney-Criddle and Modified Hargreaves method using the ASCE Standardized Penman equation in conjunction with available CoAgMet data throughout the entire basin
- Improve program documentation to provide more "how-to" instruction. This could include example scenarios through the quick-start guide, with expanded documentation following in more detail

- Review the selected monthly Blaney-Criddle crop coefficients for use in the basin and allow the user to enter higher resolution interpolation for crop coefficients, with less than a 15-day time step for perennial crops and less than a 5-percent time step for annual crops
- Expand help files to provide additional explanation of options within the StateCU program
- Improve error messages to be more meaningful and provide more troubleshooting information

Enhancements to the StateCU GUI include:

- Incorporation of the Modified-Hargreaves method into the StateCU GUI
- Streamline the GUI to separate standard and more complex consumptive use analyses
- Improve existing GUI to reduce inconsistencies and streamline window behavior
- Include function for estimating crop consumptive use met by subirrigation
- Add the daily crop consumptive use equations (ASCE Standardized Penman and Modified Hargreaves) to the scenario development process through the StateCU Wizard
- Provide interface to use CoAgMet station data in monthly analyses with automated data processing. Although this can be done using TSTool or StateDMI, a direct interface through the Wizard and GUI would be preferable
- Provide a function to allow the user to perform additional quality inspections on input and output data, and provide user documentation within the scenario

Once enhancements to StateCU are completed, the model will be used to prepare the consumptive uses and losses summary and documentation for the Arkansas Basin. Activities needed to estimate the basin's consumptive use and losses include the following:

- Fill missing daily and monthly climate data at key climate stations in the basin
- Develop historical consumptive use estimates for the key basin structures (as determined in the surface water data collection effort) plus aggregate structures using the existing monthly Blaney-Criddle technique available in StateCU in order to estimate historical crop consumptive use for the entire Arkansas Basin. This analysis will utilize pumping data collected by Division 2 and reported in HydroBase for all large capacity irrigation wells. For those wells where pumping data are not available, StateCU will be used to estimate groundwater pumping and groundwater consumption as a function of the irrigation water requirement not met by surface water, acres served by wells, acres served by sprinklers, and well capacities.
- Estimate recharge from precipitation over the groundwater model areas based on published information and previous studies
- Estimate native vegetation consumptive use rates from groundwater based on published information and previous studies
- Prepare estimates of municipal and domestic consumptive use (indoor and outdoor) using data from SWSI 2010 and other published information and previous studies
- Prepare estimates of industrial consumptive uses in the basin (e.g., mining, power)
- Prepare estimates of reservoir and stock pond evaporation from historical end-of-month contents and evaporation rates, or available reservoir evaporation studies
- Prepare estimates of livestock use based on per capita use and livestock counts
- Prepare estimates of consumptive use to create and maintain wildlife areas based on Division of Wildlife regarding water application methods and uses and published report

Water Budget Analysis

The water budget DSS component development will provide a tool that can be used to describe the major inflow, outflow and storage terms in the Arkansas River Basin. Water budget information can be used to understand the interaction among different water uses and how they may have changed over time. Please refer to Table E-5.

Data Collection

The data relied upon for the water budget analysis tool, StateWB, is included in other application categories of the ArkDSS.

DSS Components

No enhancements to the StateWB analysis component are recommended at the Tier 1 level for the ArkDSS. Activities needed to prepare the basin water budgets include the following:

- Develop three basin water budgets using StateWB and published water budget estimates for the Arkansas Basin. These three water budgets, which include an initial, intermediate and final water budget, will be prepared using an annual time step. The initial and intermediate water budgets are expected to provide guidance for contractors responsible for the detailed estimates of consumptive use, surface water flows, and groundwater flows used in the final water budget and other modeling efforts.
- Compare and document the native vegetation consumptive use estimates with previously published estimates, as this is the closure term in the basin water budget calculation.

GIS and Irrigated Lands Analysis

Spatial data collection and compilation into a geographic information system will provide important data for understanding water use in the Arkansas Basin. The majority of data collection activities and DSS component development are recommended under Tier 1. Please refer to Table E-6.

Data Collection

Data from existing sources will be acquired and used for developing a foundational spatial database to cover the entire Arkansas Basin in Tier 1. Data will be acquired and developed for mapping and classifying land use, irrigated parcels, and irrigation service areas for both ground and surface water sources in order to support other ArkDSS components, including the consumptive use, surface water planning, and groundwater planning components. These data collection activities include:

- Use existing data to map current irrigated lands from existing data sources, including irrigated lands analyses based on satellite imagery from DWR updates, Division 2, PRWCD, and SWSI. Gather additional existing data useful for classifying land use, including: USGS Survey Landsat ETM and Landsat TM imagery inventory; USGS ASTER satellite imagery inventory; USGS 1.0-meter digital orthophoto quarter quadrangles (DOQQ); USGS digital elevation data: NED 1/3” (10-meter) and NED 1” (30-meter). Also gather imagery from FSA's NAIP dataset for Colorado and NASS CDL for each year up to 5 years of ArkDSS implementation.
- Develop maps of historically irrigated lands. The process to create maps includes data purchase, processing, and analysis for up to five snapshots (1950s through 2000s). Gather data from existing sources, including current land use maps (described above), historical satellite images, land use and land cover classifications (MRLC, USGS), aerial photographs, and agricultural statistics data
- Gather existing data sources needed to map water source and service area for irrigation service map coverages. Data needed includes information from HydroBase, Division 2, NHD, water conservancy districts, and irrigation companies.

- Assign irrigated parcels with source of supply in the upper basin
- Develop maps to delineate native and non-native vegetated areas using data gathered for current land use analysis described above
- Check completeness of CAS and NASS agricultural statistics data (annual acreage and yield by crop) in HydroBase. Data should include annual cropping statistics for every county in the study area from 1950 to the present
- Gather existing data to map the river system and water distribution features (names, locations, structures) from sources such as the USGS, Colorado State University, and NHD
- Improve locational information for all administered structures that currently do not have a recorded GPS location by providing funding for Division 2 to perform GPS survey of key administered structures in the basin (i.e., headgates and wells)
- Collect existing GIS data from local government entities deemed useful for developing the ArkDSS GIS database

DSS Components

The following activities for the ArkDSS GIS component development are recommended for Tier 1:

- Focus efforts for developing the ArkDSS GIS database on gathering the base data layers, described above, including incorporation of the spatial data from the H-I Model
- Provide support to DWR to further incorporate the National Hydrography Dataset (NHD) into the ArkDSS GIS to support analysis functions of other ArkDSS components)
- Georeference spatially dependent modeling inputs and output to support visualization of results using GIS mapping and visualization tools

System Integration

System Integration refers to a number of DSS elements, including utilities that help with data viewing, formatting and processing (the relational database management system), providing linkages between DSS components, DSS maintenance, and stakeholder education and involvement. Development of the system integration components are a foundational part of the DSS and many activities are recommended at the Tier 1 level. Please refer to Table E-7.

DSS Components

Unique data and analysis needs of the Arkansas Basin will likely require enhancements to the CDSS system to accommodate the new data or analysis functions. System integration components have been categorized into the following areas: relational database management system, system linkages, maintenance, and stakeholder education and involvement.

<u>Relational database management:</u> The following enhancements are recommended for Tier 1:

- The need for more access to real-time data will require enhancements to the data presentation in HydroBase to indicate when data are provisional. Include automated QA/QC of station data (streamflow, climate) before data are posted to HydroBase.

<u>System Linkages:</u> Tier 1 enhancements for system linkages include:

- Support of ongoing enhancements to TSTool and StateDMI to work with the on-line version of HydroBase so that key analysis features can be used for both real-time (provisional) and historical data.

Update/Upgrade Existing CDSS Tools: Tier 1 recommendations for ArkDSS maintenance include:

- Provide resources to update ArkDSS components, when needed, as updates are made to the operating system and commercial software components
- Provide resources to maintain data collection systems implemented for CDSS
- Provide resources to upgrade system components in response to technology changes

Stakeholder Education and Involvement: Tier 1 recommendations for stakeholder education and involvement include:

- Establish and engage Peer Review Committees (PRCs) during critical model development phases of ArkDSS implementation to discuss surface water, groundwater and consumptive use model development. It is estimated that five to eight meetings will be required.
- Publish a biannual newsletter via hard copy and email (sign up for email via CWCB Insider on CWCB website) to update stakeholders on the five-year ArkDSS implementation progress
- Engage stakeholders on a regular basis by giving at least two presentations at Arkansas Basin Roundtable meetings per year
- Hold at least three outreach meetings per year during the implementation with other subcontractors to learn about tools and develop articles for the newsletter
- Consider CDSS website improvements to increase understanding of the website and tools and provide more "layman" information through more informational/education pages

Water Quality Analysis

Water quality data and analysis tools have not previously been included in the CDSS. Although water quality issues are important to water resources management in the Arkansas Basin, the inclusion of water quality data collection and analysis components is considered duplicative of other efforts in the basin and is not recommended at the Tier 1 level for the ArkDSS. Please refer to Table E-8.

Data Collection

No water quality data collection is included in Tier 1

DSS Components

No components are proposed to be developed for water quality analysis purposes under Tier 1

5.2 ArkDSS Tier 2

The data collection activities and components described in Tier 2 are in addition to those detailed in Tier 1. Consequently those data collection activities and components included under Tier 1 are not repeated below. The additional data and components proposed to be included under Tier 2 will enhance the ArkDSS and fulfill the majority of expressed needs in Section 2 – Needs Assessment. The major additions in Tier 2 are highlighted below:

Additional data collection includes:

- Install two additional administrative stream gages, four additional diversion gages, and three additional reservoir gages with associated maintenance support
- Conduct streambed conductance tests at up to twenty sites
- Install seventeen additional alluvial monitoring wells, (five more in the upper basin, five more on the lower mainstream, two more in the Fountain Creek drainage and five more in other tributaries)
- Conduct pumping tests and collect water level data on the additional monitoring wells
- Support ongoing basin water quality data collection activities

Additional component development includes:

- Enhance the surface and groundwater planning tools to enable water users, the CWCB, and DWR to address present and future water policy, development, and administration issues in a timely, efficient, and cost effective manner
- Prepare a MODFLOW groundwater model for the lower basin that uses the expanded groundwater data collection

Surface Water Planning

Tier 2 recommendations for surface water planning include data collection activities to support additional administration needs, and more detailed surface water modeling efforts. Please refer to Table E-1.

Data Collection

Tier 2 data collection activities for surface water data include the installation or repair of several measuring devices in the basin, including installation of satellite equipment to facilitate access to real-time data. Specific recommendations include:

- Install two additional high priority administrative streamflow gages with satellite equipment: Beaver Creek near Portland and Huerfano River near Undercliffe
- Install four real-time diversion gages with satellite equipment: Excelsior Ditch, Collier Ditch, Otero Ditch, and Fish Hatchery below Pueblo Reservoir
- Install three real-time gages on reservoirs with satellite equipment: Mt. Pisgah Reservoir, Holbrook Reservoir and Brush Hollow Reservoir
- To ensure maintenance of new gages, ArkDSS funding may be used to support Division 2 operation and maintenance of recommended diversion gages during ArkDSS implementation

Other data collection activities recommended at the Tier 2 level include:

- Review currently updated transit loss studies by Livingston on Arkansas River mainstream below Pueblo Reservoir
- Compile output from Fountain Creek Transit Loss Model into a database to facilitate further analysis of historical operations on Fountain Creek and understand long-term transit losses on Fountain Creek
- Analyze the availability and quality of information needed to identify the components ("colors" of water) of streamflow and make recommendations on how this information may be recorded or estimated and made available to water users

DSS Components

The Tier 2 recommendations for developing surface water planning tools include added functionality to allow analysis on a daily time-step and additional model enhancements. These are described below:

- Building on the monthly time-step model from Tier 1, develop a daily time-step surface water planning model
- Review basin operations to determine if refinements to the surface water model code are required and make necessary changes

Water Rights Administration and Accounting

The majority of data collection and DSS component development activities for water rights administration and accounting were determined to be a high priority for the ArkDSS, and so were included under Tier 1. Please refer to Table E-2.

Data Collection

No new data collection for water rights administration purposes is included in Tier 2.

DSS Components

No new components are proposed to be developed for water rights administration and accounting purposes under ArkDSS Tier 2.

Groundwater Planning

Data collection activities to support more detailed modeling of the lower basin alluvium have been included in the Tier 2 recommendations for groundwater planning. Please refer to Table E-3.

Data Collection

The Tier 2 level of data collection activities for groundwater data is increased from Tier 1 to provide additional data where gaps exist and to expand data collection into more areas of the basin. As previously discussed, the groundwater data collection activities will be refined upon completion of review of the published data and literature available for the basin. The following level of effort is expected to provide the needed data to support development of groundwater analysis tools:

- Collect additional pumping data at sites beyond previous data collection efforts to assist in identifying existing aquifer configuration and characteristics data for the upper basin aquifers
- Conduct streambed conductance tests or gain/loss studies at up to twenty sites: five sites in the upper basin and fifteen sites in the lower basin and major tributaries
- Drill and install up to thirty-five alluvial aquifer monitoring wells: up to ten wells in the upper basin, up to ten wells in the lower basin mainstream area, up to five wells in the Fountain Creek drainage, and ten wells in other tributaries in the lower basin area. Note that the density of monitoring will be refined upon review of existing data and ongoing data collection programs
- Conduct pumping tests in up to thirty-five new alluvial wells, described above
- Survey elevations of all newly installed monitoring wells, plus up to forty additional existing wells in the basin
- Collect water level data on continuous basis using data loggers for four years for up to seventy new wells (forty existing, up to fifteen new, and up to fifteen converted wells) in the upper and lower basins and tributaries

DSS Components

Additional model and analysis tool development is recommended at the Tier 2 level in order to increase the level of understanding of the groundwater systems of the most widely used aquifers in the Arkansas Basin. These recommendations include:

- Analyze existing and new alluvial aquifer data from data collection activities described above to better characterize aquifer properties and configuration
- Develop a MODFLOW groundwater planning model for the lower basin. This model will utilize the data collected and compiled at the Tier 1 and Tier 2 levels, and will provide resolution appropriate to support groundwater resource analysis in the lower basin
- Enhance CDSS DMIs as needed to support groundwater modeling efforts

Consumptive Use Analysis

The high priority of data and analysis needs for consumptive use, including the necessary integration of consumptive use information into other DSS components (e.g., surface water planning model and groundwater model), results in the majority of recommendations being included at the Tier 1 level. Additional items for Tier 2 are described below. Please refer to Table E-4.

Data Collection

No additional data collection is recommended at the Tier 2 level.

DSS Components

The majority of the consumptive use components development activities are recommended at the Tier 1 level. However, additional efforts include:

- Perform an investigation of the various techniques used to estimate ET using remote-sensing data and make a recommendation of methodologies appropriate for use in the Arkansas Basin. Incorporate the recommended methodologies into StateCU as appropriate
- From existing methods select an appropriate methodology for estimating ET from native vegetation, phreatophytes, and municipal/residential landscaped areas
- Add functionality to StateCU to automate estimations of lake evaporation based on site-specific or regional pan evaporation data

Water Budget Analysis

The Tier 2 contains no additional recommendations for the water budget analysis. Please refer to Table E-5.

Data Collection

No water budget data collection activities are recommended under Tier 2. This is because the data relied upon for the water budget analysis tool, StateWB, are included in other application categories of the ArkDSS.

DSS Components

No enhancements to StateWB are recommended at the Tier 2 level for the ArkDSS.

GIS and Irrigated Lands Assessment

Data collection and DSS component activities for land use, irrigated lands, and GIS include additional historical land use data collection and more rigorous analysis of existing data sources. Please refer to Table E-6.

Data Collection

Tier 2 recommendations for data collection specifically include:

- In coordination with DWR efforts, perform a quality assessment of the current assignments of irrigated parcels with their sources of water supply in the lower basin
- Conduct a thorough quality assessment of the locational attributes of structures, including documentation of how the locations (e.g., lat/long coordinates) were determined

DSS Components

Additional features will be incorporated into the ArkDSS GIS at the Tier 2 level. These include:

- Creation of a full-featured GIS database utilizing the GIS template used in other CDSS GIS efforts and spatial data collected as described above. This effort includes data purchase, processing, and results. The ArkDSS GIS will include functionality for display, viewing and editing capability, database query functions, import and export functions, ability to change projections, and plotting functions.

- Develop stream network data to allow display of priority call features and visualization of the physical stream system that is commensurate with the model development described above

System Integration

System Integration activities at the Tier 2 level will provide users better access to CDSS tools through the Internet. Please refer to Table E-7.

DSS Components

Additional system integration recommendations include:

- Develop enhancements to TSTool and StateDMI to work with on-line HydroBase and allow key analysis components for both real-time and historical data

Water Quality Analysis

Tier 2 recommendations for water quality analysis recognize the importance of water quality data collection efforts, and are focused towards characterizing water quality issues in the basin. Please refer to Table E-8.

Data Collection

Tier 2 includes support of ongoing water quality field data collection activities in the basin, which are focused primarily on total dissolved solids, metals, and radiologicals as constituents of concern. This support will build upon established water quality monitoring programs, and enhance existing water quality databases, notably the USGS water quality data repository for the Arkansas Basin.

DSS Components

Tier 2 includes the development of a conceptual water quality model, using existing data collected throughout the basin, which will include qualitative descriptions, based on current understanding, of water quality constituent sources, fate and transport. The objective of the model will be to identify areas of regional and local water quality concerns, and develop recommendations for analysis tools that could be integrated with the ArkDSS. The water quality conceptual model will include a thorough review of Colorado State University's ArkRiver GeoDSS water quality models for the lower basin. This review will determine if the ArkRiver GeoDSS can serve ArkDSS purposes for water quality analysis for basin planning in the lower basin, and if expansion of the ArkRiver GeoDSS into other parts of the basin is warranted.

5.3 ArkDSS Tier 3

In order to fulfill most of the user needs described in Section 2 – Needs Assessment, Tier 3 includes additional data collection activities and components development. Tier 3 major additions over the Tier 2 level are highlighted below.

Additional data collection includes:

- Install six additional administrative stream gages and two additional diversion gages with associated maintenance support
- Install four additional gages needed for non-consumptive use areas
- Conduct streambed conductance tests at up to twenty more sites (total of forty sites)
- Install sixty-five additional alluvial monitoring wells for a total of one hundred alluvial wells
- Conduct pumping tests and collect water level data on the additional monitoring wells

- Install seven bedrock monitor wells in the Dakota aquifer and conduct associated pumping tests and survey locations
- Revise HydroBase to include water quality data, gather water quality data, QA/QC data and provide linkage to input data into HydroBase

Additional component development includes:

- Enhance surface water model to incorporate water quality analysis for major constituents of concern
- Develop a multi-layer MODFLOW model that supports water quality modeling efforts
- Evaluate impact of coalbed methane (CBM) well development
- Create a Bayesian network analysis tool to improve confidence in provisional data

Surface Water Planning

Additional activities under Tier 3 for surface water planning are intended to meet the full range of data and analysis needs expressed by users in the basin. Some of these recommendations may be more user-specific, rather than regional in nature. Please refer to Table E-1.

Data Collection

The following additional surface water data collection activities will meet additional data needs expressed by basin stakeholders:

- Install an additional six stream gages with satellite equipment: Purgatoire River at Stonewall, Long Hollow Creek, Cucharas River near confluence with Huerfano, Arkansas River below Chico Creek, South Fork of Purgatoire above Trinidad Reservoir, and North Fork of Purgatoire above Trinidad Reservoir
- Involve stakeholders to coordinate and develop recommendations for additional gauging and install up to four new gages
- Install additional real-time diversion gage at the power plant that feeds the Historic Arkansas Riverwalk Park
- Provide additional funding for maintenance of new gages described above
- Develop a transit loss study in upper basin when data become available from recently initiated monitoring programs

DSS Components

The following enhancements to the surface water planning component are recommended at the Tier 3 level:

- Develop the enhancements needed to provide linkage for a statewide surface water planning model
- Develop additional enhancements for the surface water model GUI
- If StateMod is the surface water platform, add daily routing and flow forecasting
- Additional enhancements needed to incorporate water quality analysis for major constituents of concern

Water Rights Administration and Accounting

Additional data collection to better understand basin water rights transfers and augmentation plans are included under Tier 3 for water rights administration and accounting. Please refer to Table E-2.

Data Collection

The following data collection activity is recommended at the Tier 3 level:

- Gather available data for all augmentation plans and transfers greater than 100 acre-feet and incorporate the data into HydroBase

DSS Components

No additional component development is recommended at the Tier 3 level for water rights administration and accounting.

Groundwater Planning

Data collection and DSS component development to support very detailed modeling of the groundwater resources in both the upper and lower basin have been included in Tier 3. Please refer to Table E-3.

Data Collection

The following data collection activities are recommended at the Tier 3 level that would support rigorous groundwater modeling efforts throughout the basin:

- Review ongoing studies by CGS within the Raton Basin to determine what additional studies/investigations will be required to fully evaluate the water resources impacts by development of CBM wells and perform additional investigations of the impact of CBM well development on the Raton Basin aquifer as required
- Perform a review and verification of existing pumping data programs
- Conduct streambed conductance tests or gain/loss studies at up to forty sites: ten sites in the upper basin and thirty sites in the lower basin and all tributaries
- Drill and install up to one hundred alluvial aquifer monitoring wells: up to twenty wells in the upper basin, up to forty wells in the lower basin mainstream area, up to ten wells in the Fountain Creek drainage, and up to thirty wells in the tributaries in the lower basin
- Conduct pumping tests at up to one hundred new alluvial wells
- Install up to four deep aquifer monitoring wells in the upper basin to better understand the connection between the deep and shallow aquifer systems in this area
- Drill and install up to seven bedrock monitoring wells in the Dakota and Northern and Southern High Plains aquifers in order to better understand the connection between the deep and shallow aquifer systems in the lower basin. Data collection from these wells will include water quality samples to determine if the deep aquifers are a possible source of radiological contamination
- Conduct pumping tests for up to eleven new deep aquifer wells
- Survey elevations of all newly installed monitoring wells, and up to eighty additional existing wells

DSS Components

Groundwater planning components development at the Tier 3 level will provide additional modeling and analysis tools covering the majority of the major aquifers in the basin. These recommendations include the following:

- Improve the characterization of aquifer properties and configuration within the alluvial aquifers through analysis of the additional data collected under Tier 3
- Develop a multi-layer MODFLOW model for the lower basin that incorporates additional data collected under Tier 3 and provides a level of detail necessary to support water quality modeling within the groundwater system in the lower basin. (See water quality subsection below)
- Develop either full linkage or the use of a robust interpolator to provide more dynamic linkage between the surface water and groundwater models

- Develop a regional MODFLOW model for the upper basin that incorporates the shallow alluvial aquifer and deep basin-fill aquifer using data from the expanded data collection program described above
- Enhance the CDSS DMIs as needed to support the groundwater modeling efforts described above

Consumptive Use Analysis

The majority of consumptive use data collection and DSS component development activities were recommended under Tier 1 and Tier 2, with one additional data collection recommendation included below. Please refer to Table E-4.

Data Collection

An additional recommendation to meet the need for more specific ET data in the basin includes:

- Develop a lysimeter study in the upper basin to support the development of locally-calibrated crop coefficients

DSS Components

No additional components are recommended at the Tier 3 level.

Water Budget Analysis

The majority of water budget data collection and DSS component development activities were recommended under Tier 1 and Tier 2, with one additional component recommendation included below. Please refer to Table E-5.

Data Collection

No additional data collection is recommended at the Tier 3 level.

DSS Components

The following additional component is recommended at the Tier 3 level:

- Provide access to StateWB and StateCU functions from a common platform

GIS and Irrigated Lands Analysis

The collection and analysis of spatial data needed for the ArkDSS has largely been included in Tier 1 and 2. Tier 3 includes additional data collection and component development to support better spatial data visualization and presentation. Please refer to Table E-6.

Data Collection

The following additional data collection activity is recommended at the Tier 3 level:

- Collect and incorporate phreatophyte mapping from the Arkansas River Tamarisk Coalition into the ArkDSS GIS

DSS Components

Tier 3 for the ArkDSS GIS development includes the following:

- Provide additional enhancements for georeferencing spatially dependent modeling inputs and output to support visualization of results using GIS mapping and visualization tools
- Enhance the development stream network data to allow display of priority call features and visualization of the physical stream system commensurate with the model development described above

System Integration

Recommendations under Tier 3 for system integration include those associated with better data and tool access through the Internet, and more efficient accommodation of on-line DSS users. Please refer to Table E-7.

DSS Components

The following recommendations are included under Tier 3:

- Create a Bayesian network analysis tool and use it to provide level of confidence information for data that is listed as provisional in HydroBase
- Allow the full suite of analysis components from TSTool and StateDMI to work with the on-line version of HydroBase
- Move HydroBase, the associated web services, and related tools to an on-demand, cloud-based environment

Water Quality Analysis

Tier 3 provides for eventual integration of water quality data and analysis into the ArkDSS. The format of this integration is yet to be determined, but will rely on the ability of the water quality analysis models developed by Colorado State University to meet the needs of the users in the basin. Please refer to Table E-8.

Data Collection

Tier 3 contains the data compilation and data processing efforts necessary to incorporate water quality data into HydroBase. This effort includes compilation of existing water quality data for the major constituents of concern (total dissolved solids, metals, and radiologicals), as well as other commonly monitored water quality constituents (e.g., temperature, pH, dissolved oxygen, electrical conductivity). The data compilation will rely heavily on the Water Quality Data Repository developed for the Arkansas Basin by the USGS. Additional efforts include data QA/QC and software development to facilitate import of the existing data into HydroBase, as well as import of future data collected in the basin.

DSS Components

Tier 2 efforts will provide a conceptual water quality model that will identify areas and constituents of concern in the Arkansas Basin, and will identify appropriate analysis tools that could be used in concert with ArkDSS flow models to answer questions about water quality impacts. Based on the review of the ArkRiver GeoDSS under Tier 2, further development of a water quality component at the Tier 3 level could include the incorporation of components of the ArkRiver GeoDSS into the ArkDSS as appropriate. Alternately, it may be determined that it would be more appropriate to develop water quality analysis components using existing data and Tier 3 ArkDSS surface and groundwater models.

5.4 Recommendations

Three tiers, representing three levels of effort and cost, for developing and implementing the ArkDSS are described in this section. Estimated capital costs and operations and maintenance costs during the ArkDSS development and implementation phase are included in the tables in Appendix E and summarized below in Table 5-1.

Table 5-1. Summary of Estimated Costs for ArkDSS Implementation Options

Application Category	Tier 1	Tier 2	Tier 3
Surface Water Planning	$1,020,000	$610,000	$1,550,000
Water Rights Administration and Accounting	$240,000	$0	$30,000
Groundwater Planning	$1,160,000	$2,060,000	$7,430,000
Consumptive Use Analysis	$960,000	$230,000	$180,000
Water Budget Analysis	$100,000	$0	$60,000
GIS and Irrigated Lands Analysis	$350,000	$110,000	$50,000
System Integration	$490,000	$70,000	$410,000
Water Quality Analysis	$0	$200,000	$680,000
Tier Total	$4,320,000	$3,270,000	$10,390,000
Cumulative Total	$4,320,000	$7,590,000	$17,980,000

Note: All costs in 2010 dollars

Table 5-1 summarizes the costs associated with the tasks described under each tier. Tier 1 was developed to address many of the needs for water resources planning in the basin. Tier 2 builds upon the efforts of Tier 1, particularly in regard to increased data collection and modeling capability for the surface water and groundwater planning components. Tier 3 adds significantly enhanced modeling capability (and associated data collection) to support potential water quality analysis needs, as well as enhancements to other components to address all the expressed needs of the users in the basin.

In considering the three levels of data collection and analytical capability of each tier, the tasks in Tier 1 and Tier 2 provide the most benefit to users at reasonable cost. Therefore, these tasks are recommended at this time for the implementation of the ArkDSS. Tier 1 provides a foundational DSS that meets many data needs, as well as some basic analytical needs. Tier 2 tasks, which can be developed subsequent to Tier 1 tasks in a cost-effective manner, meet a majority of the identified data and analytical component needs. Although Tier 3 tasks are not recommended at this time, elements at this level of analytical capability may be included in the ArkDSS in the future, if warranted by basin needs and additional funding becomes available.

Further discussion of the proposed plan and phasing for the ArkDSS implementation is included in the following section. It should be noted that the phasing of the implementation tasks over several years will allow flexibility to evaluate changing needs of the users in the basin and funding availability. These reviews should be performed periodically to identify necessary changes to the recommended implementation activities to better meet user needs.

Section 6

Proposed Implementation

This final section of the feasibility study presents the recommended elements for implementation of the ArkDSS. This proposed ArkDSS implementation will provide a DSS that builds upon the DSS efforts in other river basins, while addressing the specific needs of the users in the Arkansas Basin. The proposed plan for implementation includes a phased approach that allows for periodic review and assessment of work to date, upcoming tasks, and future scheduling and budgetary considerations.

As described at the end of Section 5, tasks from the Tier 1 and Tier 2 levels have been recommended at this time for implementation of the ArkDSS. In considering the three tiers of data collection and analytical capability described in Section 5, the tasks in Tier 1 and Tier 2 provide the most benefit to users at reasonable cost. Tier 1 provides a foundational DSS that meets many data needs, while Tier 2 tasks, which can be developed subsequent to Tier 1 tasks in a cost-effective manner, meet a majority of the identified data and analytical component needs. Although Tier 3 has not been included in the recommended implementation, elements at this level of analytical capability may be included in the ArkDSS in the future, if warranted by basin needs and additional funding becomes available.

Summary of Phased Approach for Implementation

Phasing the tasks for implementation of the ArkDSS provides a process by which elements of the ArkDSS can be developed in an efficient manner. Phasing allows for the following:

- Basic data compilation and collection up front to support development of analytical components
- Development of analytical components according to implementation priorities and basin needs
- Periodic assessment of work to date and evolving needs of the basin to determine necessity for additional enhancements
- Assessment of funding availability and exploration of opportunities for cooperative partnerships

The ArkDSS implementation is divided into four major phases:

Phase 1: Initial Funding Tasks ($500,000)

- ArkDSS tasks approved for CWCB funding in November 2010, includes:
  - Water resources data collection/analysis, including key consumptive use data in the upper basin
  - Water rights and administration components development, including H-I Model process enhancements
  - Spatial data collection/analysis, including irrigated lands data collection and analysis in upper basin

Phase 2: Data Compilation and Collection ($3,810,000)

- Existing Data Compilation
- New Data Collection

Phase 3: Initial Components Development ($1,260,000)

- Consumptive Use Analysis
- Water Budget Analysis

- Land Use, Irrigated Lands, and GIS

Phase 4: Additional Components Development ($2,020,000)

- Surface Water Planning
- Groundwater Planning
- Water Quality Analysis

Tables 6-1 through 6-4 provide a descriptive and cost summary of the phases proposed for the recommended ArkDSS implementation. Phases have been developed based on the data-centered approach for ArkDSS implementation, as well as the flow of information required between components. Although numerous tasks may be shown in the same phase, many tasks will need to be completed in a step-wise fashion, as certain data and components are needed before others can be developed. Figures 6-1 and 6-2 provide a flow-chart and phasing diagram summarizing this step-wise process for implementation. The following sections provide a more detailed discussion of each phase and considerations for future ArkDSS enhancements.

6.1 Phase 1 - Initial Funding Tasks

Phase 1 includes high-priority data collection and tool development that were approved for funding by the CWCB in November 2010. These tasks were identified during the feasibility study as critical for completion early in the ArkDSS implementation process. Assuming that funding is available from the State, the work for Phase 1 could begin in late 2011. Phase 1 tasks are shown in Table 6-1. The estimated costs for these tasks total $500,000. Tasks in Phase 1 include the following:

- Collect water resources data needed for improved administration in Division 2, including installation of key stream gage and compiling key consumptive use data to support use of the ISAM model in the upper basin
- Perform components development tasks to support ArkDSS water rights administration and accounting functions, including improving the efficiency of H-I Model input data collection
- Collect satellite and aerial photography data and delineate irrigated lands both for current and historical conditions. Also gather information to assign source of water supply to irrigated parcels, focusing on the upper basin

6.2 Phase 2 – Data Compilation and Collection

Phase 2 consists primarily of data compilation and collection tasks. This phase is expected to take two years to complete, with some continuous monitoring tasks lasting up to five years. It is envisioned that initial efforts of this phase will focus on compilation of existing data, while the collection of new data will begin after assessment of existing data is complete. Table 6-2 summarizes the data compilation and collection tasks included in Phase 2, which were also discussed in Section 5 as part of the Tier 1 and Tier 2 implementation recommendations.

Existing Data Compilation

Data collection activities under this phase include compilation of previously identified existing sources for surface water, groundwater, consumptive use, water budget, and GIS and irrigated lands data. The compiled data will be reviewed and assessed and work plans will be developed for: (1) integrating the existing data, as necessary, into HydroBase; and (2) collecting additional data, as needed, to fill identified data gaps, and incorporating new data into HydroBase . Included in this effort will be the development of a field program for the groundwater monitoring well installations and continuous monitoring activities planned throughout the ArkDSS implementation period.

A discussion of the recommended data compilation tasks is included in the text of Section 3, summarized in Table 3-2, and summarized with costs in the tables in Appendix E. The existing data compilation effort under each data category is also summarized below. Data compilation tasks are shown in Table 6-2. The estimated costs for these tasks total $1,010,000.

Surface Water Data

Compilation efforts for existing surface water data include:

- Fill missing daily streamflow data at key streamflow gages throughout the basin
- Review transit loss studies/models in the basin and understand how they may apply to the ArkDSS, including compilation of output from Fountain Creek Transit Loss Model
- Review available data needed to identify the components (i.e. colors) of streamflow
- Review, QA/QC, and fill diversion record data for diversions representing 85% of the basin demand
- Collect and review daily reservoir accounting records, including QA/QC review, documentation of operations, and filling of missing records at key reservoirs in the basin

Groundwater Data

Compilation efforts for groundwater data include:

- Review all data and literature catalogued by the CGS for the Arkansas Basin, including data on geologic structure, aquifer configuration and properties, and water levels; and provide summaries of the existing data
- Compile pumping data that is currently collected by Division 2 but has not been incorporated into HydroBase

Consumptive Use Data

Compilation efforts for existing consumptive use data include:

- Collect and review municipal water use data, including population estimates, per capita water use, estimates of indoor and outdoor consumptive uses, and municipal use return flows
- Collect existing data on other consumptive uses (e.g., industrial, minerals, power, livestock and stockpond evaporation) in the basin
- Review climate station data in HydroBase and inspect them for quality, making corrections as needed, and fill missing daily and monthly climate data at key climate stations
- Collect existing data or literature on native and non-native vegetation ET

GIS and Irrigated Lands Data

Compilation efforts for existing GIS data include:

- Collect available CAS and NASS data regarding annual cropping statistics throughout the basin from 1950 to the present
- Collect existing GIS data on stream systems and water distribution
- QA/QC the location attributes of structures not completed in Phase 1
- Collect spatial data from local government sources

New Data Collection

This work includes collecting new surface and groundwater data to fill gaps and support model development and analysis needs in the basin, as well as support for ongoing water data collection. The new data collection tasks are described in Section 3 and summarized in Table 3-1 and the tables in Appendix E. New data collection tasks are shown in Table 6-2. The estimated costs for these tasks total

$2,420,000. It is important to highlight that the installation of new monitoring stations will also require continued maintenance beyond the ArkDSS implementation time period. Periodic assessment of ArkDSS progress between phases should include review of potential funding sources, including partnership opportunities, for maintenance of monitoring stations.

Surface Water Data

The new surface water data collection tasks will include installation of two additional streamflow gages, four new diversion gages, and three new reservoir gages, as well as support of Division 2 operation and maintenance of the recommended diversion gages during ArkDSS implementation.

Groundwater Data

The recommended new groundwater data collection tasks will be refined during Phase 2, after a thorough review of the existing groundwater data in the basin and development of the groundwater monitoring field work plan. Based on initial review of groundwater data sources during this feasibility study, the following list of expected new groundwater data collection tasks was developed. These activities will fill data gaps and support the development of the ArkDSS groundwater analysis tools.

- Conduct streambed conductance tests at up to twenty sites throughout the basin
- Drill/install up to thirty-five new alluvial aquifer monitoring wells and conduct pumping tests at new wells
- Survey elevations of all new wells plus subset of existing wells
- Collect continuous water level data using dataloggers at up to seventy wells

Water Quality Data

Finally, this work includes ArkDSS support of ongoing water quality data collection activities in the basin. Proposed periodic evaluation of ArkDSS implementation will include a review of current water quality data collection programs in the basin and recommendations for partnering to support further data collection efforts for future water quality analyses in the basin. This effort is closely tied to the water quality conceptual model described in Phase 3.

System Integration

This subsection includes system integration tasks that will support the incorporation of new data into HydroBase, as well as enhancements to online CDSS data access and analysis functions. Additionally, updates and upgrades of CDSS system components, as part of the ongoing maintenance needs of the CDSS, are included in system integration. These tasks can be completed concurrently with the data compilation and collection efforts in previous Phase 2 subsections above. Stakeholder education and involvement tasks will occur throughout ArkDSS development and these efforts are included in this phase for the first two years of ArkDSS development.

System integration tasks included in Phase 2 are shown in Table 6-2. The estimated costs for these tasks total $380,000.

6.3 Phase 3 – Initial Components Development

Phase 3 begins the development of the ArkDSS components - the tools necessary to analyze water use and water management scenarios in the basin. This phase is expected to take approximately two to three years to complete. The ArkDSS components slated for development during Phase 3 include the GIS, the consumptive use, and the water budget components. The development of these components precedes the surface water and the groundwater components, because these three components rely on existing data in the basin, and will, after development, provide information needed for the surface water and groundwater models.

Specific tasks recommended for development of the GIS, consumptive use, and water budget components of the ArkDSS were first described in Section 4 and summarized in Table 4-3. The development tasks included in Phase 2 are those that support analysis at both the Tier 1 and Tier 2 levels, as described in Section 5 and summarized below. Phase 3 tasks are shown in Table 6-3. The estimated costs for these tasks total $1,260,000. Note that during Phase 3, stakeholder outreach and involvement activities will continue; therefore, a portion of the system integration costs associated with these tasks is included in this phase.

Consumptive Use Analysis

One focus of the ArkDSS consumptive use (CU) component is to enhance the CDSS consumptive use model, StateCU, in order to provide improved analysis functions needed by users in the Arkansas Basin. In addition to StateCU model enhancements, the consumptive use component will include analysis and documentation of historical crop consumptive use for the entire basin through the use of the monthly Modified Blaney-Criddle method.

Proposed enhancements to broaden the analysis functions in StateCU include:

- Develop locally-calibrated crop coefficients for use in the Modified Blaney-Criddle and Modified Hargreaves method for use in historical CU analyses
- Incorporate Modified Hargreaves into StateDMI as well as the StateCU GUI; determine whether changes to HydroBase are required and if so, implement them
- Include functionality to estimate crop CU met by subirrigation
- Add daily ET methods (ASCE Standardized Penman-Monteith) to the StateCU Wizard
- Add the ability to access CoAgMet station data through the StateCU Wizard for use in daily and monthly analyses with automated data processing
- Investigate various techniques to estimate ET using remote-sensing data and incorporate recommended techniques into StateCU as appropriate
- Add a function to allow automated estimations of lake evaporation based on site-specific or regional pan evaporation data
- Develop a methodology for determining ET from native vegetation, phreatophytes, and municipal/residential landscaped areas
  - Additional enhancements are also recommended to make the StateCU program more user-friendly, including:
  - Improving documentation to include more "how-to" instruction, and
  - Structural improvements to the GUI

Water Budget Analysis

The development of the water budget component for the ArkDSS will utilize StateWB, the state's water budget analysis tool. No enhancements to the StateWB tool are recommended, however, recommended analysis includes developing an initial, intermediate, and final water budget (as data and models are refined during implementation) for the Arkansas Basin.

GIS and Irrigated Lands Analysis

Developing the ArkDSS spatial database, or GIS, will include of the following tasks:

- Integrate Arkansas Basin spatial data into a basin-wide GIS
- Further incorporate the National Hydrography Dataset (NHD) into the ArkDSS GIS to support analysis functions

- Georeference spatially dependent modeling inputs and outputs to support visualization of results using GIS mapping and visualization tools
- Develop stream network data to allow display of priority call features and visualization of the physical stream system

6.4 Phase 4 – Additional Components Development

The scope of work for Phase 4 includes the development of the surface water and groundwater components of the ArkDSS. Development of a surface water and groundwater model for the Arkansas Basin will build upon the data compilation and collection efforts in Phase 1, and the consumptive use, water budget, and GIS components developed in Phase 3. Phase 4 is expected to last two to three years.

Specific tasks recommended for development of the surface water and groundwater components of the ArkDSS were first described in Section 4 and summarized in Table 4-3. The development tasks included in Phase 3 are those that support analysis at both the Tier 1 and Tier 2 levels, as described in Section 5 and summarized below. Phase 4 tasks are shown in Table 6-4. The estimated costs for these tasks total $2,020,000. Note that, as in prior phases, stakeholder outreach and involvement activities will continue; therefore, a portion of the system integration costs associated with these tasks is included in this phase.

Surface Water Planning

The development activities proposed for the ArkDSS surface water component include the following:

- Review the surface water models developed for water management purposes in the Arkansas Basin to date. Select the most appropriate surface water model platform for the needs of the ArkDSS and develop a monthly and daily time-step model for the entire Arkansas Basin to be used for planning purposes. This development will be broken into sub-phases, beginning with the development and calibration of the monthly surface water model, followed by refinement into a daily model.
- Enhance the selected surface water model by developing model operations that apply the constraints of the Arkansas River Compact and the associated operations of John Martin Reservoir
- Provide recommendations for surface water model GUI enhancements and develop as needed
- Review Arkansas Basin operations to determine if refinements to the model code are required and make necessary changes

All of the above tasks will utilize existing basin surface water model elements, as appropriate, in an effort to increase efficiency in developing the ArkDSS surface water component, and to promote opportunities for partnerships with stakeholders who have invested in surface water modeling in the basin.

Groundwater Planning

The proposed development of the groundwater component includes the following:

- Analyze existing and new alluvial aquifer data to better characterize aquifer properties and configuration
- Develop a simplified analytical model for the upper basin that can be used to estimate groundwater return flows and natural flows for the surface water model
- Develop a MODFLOW model of the lower basin alluvial aquifer that utilizes data from data collection efforts described in Phase 2
- Develop URFs from the ArkDSS MODFLOW model described above

- Document, evaluate and compare URFs from the H-I Model with URFs from existing regional groundwater models (Colorado State University's two lower basin MODFLOW models) and the ArkDSS MODFLOW model to provide guidance for URF selection by users
- Enhance/update groundwater model DMIs and related modeling software as needed

As with the surface water model development above, development of the lower basin alluvial groundwater model will, as appropriate, build upon existing regional groundwater models that have been built in the basin.

Water Quality Analysis

Phase 4 includes the development of a conceptual water quality model that can interface with existing water quality data sources and be used to identify regional and basin-wide water quality issues. This conceptual water quality model will include the following:

- Develop qualitative descriptions, based on current understanding, of water quality constituent sources, fate and transport in the basin, identify areas of regional and local water quality concerns and develop recommendations for water quality analysis tools that could be integrated with the other ArkDSS components (e.g., GIS, surface water model, or groundwater model)
- Perform a thorough review of Colorado State University's ArkRiver GeoDSS water quality models for the lower basin. This review will determine if the ArkRiver GeoDSS can serve ArkDSS water quality analysis needs for basin planning in the lower basin and if expansion of the ArkRiver GeoDSS into other parts of the basin is warranted

6.5 Consideration of Future ArkDSS Enhancements

As discussed at the beginning of the section, each phase of the ArkDSS implementation will begin with an assessment of the progress to date, evolving needs of the basin, necessity for modification or enhancements to the ArkDSS that are not included in the proposed phases described above, and availability of funding to complete the next phase. Tasks that were described in Section 5 to support a Tier 3 level of analysis have not been included in the proposed ArkDSS implementation described above, but may be needed to meet evolving needs of the basin in the future. If adequate funding is available to include these enhancements, some of the tasks may be included in the ArkDSS implementation. Items from the Tier 3 level include the following potential additional data collection activities:

- Install six additional administrative stream gages and one additional diversion gage with associated maintenance support
- Install four additional gages needed for non-consumptive use areas
- Gather and incorporate additional water rights transfers and augmentation plan data into HydroBase
- Conduct streambed conductance tests at up to twenty more sites
- Install up to sixty-five additional alluvial monitoring wells
- Install four deep wells in the upper basin and seven bedrock monitoring wells in the Dakota aquifer and conduct associated pumping tests and survey locations
- Conduct pumping tests and collect water level data on the additional monitoring wells
- Revise HydroBase to include water quality data, compile water quality data, QA/QC data, and provide linkage to input data into HydroBase

Potential additional component development includes the following:

- Enhance surface water model to support water quality analysis, daily routing, and statewide model linkages

- Develop a multi-layer MODFLOW model expanded through the entire basin that supports water quality modeling efforts
- Incorporate components of the ArkRiver GeoDSS into the ArkDSS as appropriate OR develop water quality analysis components using existing data and enhanced surface and groundwater models
- Evaluate potential impacts of coalbed methane well development on basin water resources
- Enhance system integration tools, including improved access to provisional and real-time data, improved web-based analysis tools and migration of HydroBase and related tools to an on-demand, cloud-based environment
- Develop transit loss model in upper basin when data are available, and compile output from Fountain Creek transit loss model for analysis
- Develop a lysimeter study in the upper basin for locally-calibrated crop coefficients

These items are best evaluated after significant progress of the ArkDSS implementation has been made and a clearer understanding of future funding is available.

6.6 Summary

The preceding sections describe the proposed plan for implementation of the ArkDSS. Four phases, spanning a total of six to eight years, will be required to complete the proposed data collection and components development tasks. A phased approach for proposed implementation provides an efficient, step-wise process for completing tasks that build upon one another, and allows for periodic assessment of progress to date, potential modifications to future implementation activities, and funding availability. The total cost for the proposed ArkDSS implementation is estimated at $7,590,000.

Table 6-1. Phase 1 – Initial Funding Tasks

Summary of Phase	
Implementation Schedule:	1 to 2 years
Estimated Cost:	$500,000

Surface Water	
Install a high-priority administrative gage at Fountain Creek between Pinion and Pueblo	$50,000

Water Rights and Administration	
Gather available data for all Rule 14 Plans and high-priority augmentation plans and transfers and determine how best to represent information in HydroBase.	$40,000
Gather, digitize and incorporate river call data into HydroBase for mainstem and major tributaries in Division 2	$50,000
Perform review and make corrections to Water District 11 administration numbers as needed.	$5,000
Create straightline diagrams for each water district.	$25,000
Develop a tool that tracks transmountain native, augmentation and reservoir water - integration with ARAS	$20,000
Improve the efficiency of H-I Model input data collection: Early data release	$12,000
Improve the efficiency of H-I Model input data collection: Create StateCU dataset	$6,000
Improve the efficiency of H-I Model input data collection: ARAS well accounting output enhancements	$6,000
Improve the efficiency of H-I Model input data collection: Update TSTool/StateDMI	$75,000
SUM	$239,000

Consumptive Use	
Collect, review and assess estimates of ET for irrigated areas developed by Colorado State University, SWSI and others. Includes compilation of necessary CU data for ISAM: canal and lateral losses, tailwater run-off, secondary ET losses, soil moisture accounting, and irrigation efficiencies.	$75,000

GIS and Irrigated Lands Analysis	
Gather data to map current land use and irrigated lands.	$58,000
In coordination with DWR efforts, create a linkage between irrigated parcels and their sources of supply in the upper basin.	$30,000
Conduct a thorough quality review of the locational attributes of structures in the upper basin, including documentation of how the locations (e.g. lat/long coordinate) were determined and GPS survey of structures are needed.	$48,000
SUM	$136,000

Table 6-2. Phase 2 – Data Compilation and Collection

Summary of Phase			
Implementation Schedule:	2 to 3 years	Data Compilation Tasks	(shaded)
Estimated Cost	$3,811,000	Data Collection Tasks	(unshaded)
Cumulative Cost	$4,311,000		

Surface Water	
Identify key streamflow gages in Arkansas Basin and fill missing records using CRDSS and SPDSS-developed techniques	$35,000
Review currently updated transit loss studies by Livingston on mainstem below Pueblo Reservoir. Compile output from Fountain Creek Transit Loss Model into database for further analysis.	$58,000
Analyze the availability and quality of information needed to identify the components of streamflow and make recommendations on how this information may be recorded or estimated and made available to water users.	$25,000
Compare diversions in HydroBase with diversion records that were QA'd for the HI Model. Review diversion records at 85% basin wide demand level and do analysis of historical diversions and streamflow records for daily diversion data. Fill daily data for 68 diversions (25 percent of approximately 270 key diversions).	$266,000
Review HydroBase records, interview water users and the Division Engineer to identify the major reservoir structures that should be included in the initial surface water modeling effort. Effort will include collecting DAILY reservoir accounting records and performing QA/QC review, documenting operations, and estimating missing data.	$147,000
Install 2 high-priority administrative gages: Beaver Creek near Portland; Huerfano River near Undercliffe	$85,000
Install 4 diversion gages: Excelsior Ditch, Collier Ditch, Otero Ditch, Fish Hatchery below Pueblo Res.	$60,000
Install 3 reservoir gages: Mt. Pisgah Res., Holbrook Res., Brush Hollow Res.	$45,000
Support Division 2 operation and maintenance of recommended diversion gages during ArkDSS implementation	$180,000
SUM	$901,000

Groundwater	
Review and summarize all data and literature catalogued by CGS on the Arkansas Basin.	$35,000
Collect additional pumping data to assist in identifying aquifer configuration and characteristics data for the upper basin aquifers.	$75,000
Conduct streambed conductance tests at up to 20 sites (5 sites in the upper basin, 15 sites in the lower basin and all tributaries).	$475,000
Drill/install up to 35 alluvial aquifer monitoring wells (10 wells in the upper basin, 10 wells in the lower basin mainstem area, 5 in the Fountain Creek drainage, and 10 in other tributaries in the lower basin).	$375,000
Conduct pumping tests up to 35 new alluvial wells.	$500,000
Survey well elevations. Surveying effort is commensurate with number of new wells installed, plus additional existing wells.	$70,000
Collect future water level data on a daily basis using dataloggers for 4 years for up to 70 wells (40 existing, 15 new, and 15 converted wells) in the upper and lower basins and tributaries.	$525,000
SUM	$2,055,000

Consumptive Use	
Gather existing population data for cities, towns and counties and use in conjunction with per capita use data to estimate municipal and domestic water supply.	$15,000
Gather existing municipal CU data and use in conjunction with population data to estimate municipal and domestic water supply.	$15,000
Gather existing data on municipal indoor use return flows and use in conjunction with municipal and domestic supply estimates to determine municipal and domestic consumptive use.	$20,000
Gather existing data on municipal use outdoor return flows and use in conjunction with municipal and domestic supply estimates to determine municipal and domestic consumptive use.	$20,000
Gather existing data on other consumptive uses (e.g., industrial, minerals and power).	$20,000
Review and QA/QC climate station datasets in HydroBase.	$50,000
Gather existing data on native and non-native vegetation ET and use to compare with results of Water Budget Analysis.	$40,000
SUM	$180,000

Water Quality	
Support on-going basin water quality data collection activities.	$100,000

GIS and Irrigated Lands Analysis	
Gather data to map historical land use and irrigated areas. Create maps for up to 5 snapshots (1950's through 2000's); includes data purchase, processing and analysis.	$86,000
In coordination with DWR efforts, perform a QA/QC review of the current assignments of irrigated parcels with their sources of water supply in the lower basin.	$35,000
Use data gathered for current land use analysis described above to delineate non-crop areas and develop maps of native and non-native vegetation.	$8,000
All available CAS and NASS data regarding annual cropping statistics will be gathered for every county in the study area from 1950 to the present.	$15,000
Gather existing data on river systems and water distribution from existing sources, including USGS, Colorado State University, and NHD.	$15,000
Continue quality review of the locational attributes of structures.	$17,000
Collect existing spatial data from government sources that are deemed useful.	$15,000
SUM	$191,000

System Integration	
DWR is planning an update to HydroBase to include access to provisional diversion data. When real-time data are uploaded to HydroBase, update data presentation to indicate if data are provisional. Also include automated QA/QC of station data before posting.	$50,000
Enhance TSTool and StateDMI to interface with on-line HydroBase.	$140,000
Provide resources to update system components due to operating system and commercial software updates.	$60,000
Provide resources to maintain data collection systems implemented for CDSS.	$80,000
Provide resources to upgrade system components in response to technology changes.	$20,000
Publish bi-annual newsletter to update stakeholders on ArkDSS implementation progress (2 yrs).	$20,000
Presentations at Arkansas Basin Roundtable Meetings (2 yrs).	$2,000
Hold outreach meetings with other subcontractors (2 yrs)	12,000
SUM	$384,000

Table 6-3. Phase 3 - Initial Components Development

Summary of Phase	
Implementation Schedule:	2 to 3 years
Estimated Cost	$1,260,000
Cumulative Cost	$5,571,000

Consumptive Use	
Fill missing daily and monthly climate data at key climate stations in the basin.	$10,000
Develop locally-calibrated crop coefficients for use in the Modified Blaney-Criddle and Modified Hargreaves method using information obtained from the Rocky Ford lysimeter study and the ASCE Standardized Penman equation.	$30,000
Improve program documentation to provide more "how-to" instruction. This could include example scenarios through the quick-start guide, with expanded documentation following in more detail.	$20,000
Allow user to enter higher resolution interpolation for crop coefficients (less than 15-day time step for perennial crops and less than 5-percent time step for annual crops).	$15,000
Expand help files to provide additional explanation of options within the StateCU program.	$10,000
Improve error messages and provide more troubleshooting information.	$15,000
Incorporate the Modified Hargreaves method into the StateCU GUI.	$10,000
Streamline the GUI to separate standard from more complex consumptive use analyses.	$60,000
Improve existing GUI to reduce inconsistencies in behavior of windows.	$50,000
Include function for estimating crop consumptive use met by subirrigation.	$15,000
$15,000	
Provide interface to use CoAgMet station data in monthly analyses with automated data processing.	$35,000
Provide a function to allow the user to perform additional QA/QC on input and output data, and provide user documentation within the scenario.	$20,000
Automate estimations of lake evaporation based on site-specific or regional pan evaporation data.	$30,000
Develop methodology for determining ET from native vegetation, phreatophytes, and municipal/residential landscaped areas.	$50,000
Use monthly Modified Blaney-Criddle for historical CU estimates for approx 270 key structures plus aggregates.	$450,000
Investigate various techniques to estimate ET using remote-sensing data and incorporate best techniques into StateCU.	$100,000
SUM	$935,000

Water Budget	
Develop basin water budgets using StateWB: Include initial, intermediate and final water budgets, and native vegetation CU comparison.	$100,000
SUM	$100,000

GIS and Irrigated Lands Analysis	
Develop GIS database to support overall ArkDSS activities.	$58,000
Further the incorporation of the National Hydrography Dataset (NHD) into the ArkDSS GIS to support analysis functions.	$15,000
Georeference spatially dependent modeling inputs and output to support visualization of results using GIS mapping and visualization tools.	$29,000
Develop stream network data to allow display of priority call features and visualization of the physical stream system.	$29,000
SUM	$131,000

System Integration	
Hold 3 meetings for GIS and CU model development.	$30,000
Publish bi-annual newsletter to update stakeholders on ArkDSS implementation progress (2 yrs).	$20,000
Presentations at Arkansas Basin Roundtable Meetings (2 yrs).	$2,000
Hold outreach meetings with other subcontractors (2 yrs).	$12,000
Moderate enhancements to CDSS website to include more informational/educational pages.	$30,000
SUM	$94,000

Table 6-4. Phase 4 - Additional Components Development

Summary of Phase	
Implementation Schedule:	2 to 3 years
Estimated Cost	$2,019,000
Cumulative Cost	$7,590,000

Surface Water		Groundwater		Water Quality		System Integration	
Select surface water model platform and develop a monthly and daily time-step model for entire Arkansas River Basin.	$550,000	Analyze existing and new alluvial aquifer data and develop report to improve the representation and understanding of alluvial aquifer properties.	$120,000	Develop conceptual model, review ArkRiver GeoDSS and make recommendations for further analysis	$100,000	Hold 4 meetings for SW, GW model development.	$45,000
Model Enhancements: Development and application of the constraints of the Compact and the associated operations of John Martin Reservoir.	$65,000	Develop a robust MODFLOW model of the lower basin that utilizes data from expanded data collection efforts described above.	$600,000			Publish bi-annual newsletter to update stakeholders on ArkDSS implementation progress (2 yrs).	$20,000
Provide recommendations for surface water model GUI enhancements and develop as needed.	$35,000	Develop URFs from the ArkDSS MODFLOW model described above.	$20,000			Presentations at Arkansas Basin Roundtable Meetings (2 yrs).	$2,000
Review basin operations to determine if refinements to the model code are required and make necessary changes.	$30,000	Evaluate and compare URFs from the H-I Model with URFs from existing regional groundwater models (Colorado State University's two lower basin MODFLOW models) and the ArkDSS MODFLOW model.	$45,000			Hold outreach meetings with other subcontractors (2 yrs).	$12,000
SUM	$680,000	Develop a simplified analytical model for the upper basin	$200,000			SUM	$79,000
		Enhance/update groundwater model DMIs and related modeling software as needed.	$175,000				
		SUM	$1,160,000				

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Appendix A-1: List of Interviewees

Appendix A-1

List of Interviews for ArkDSS Feasibility Study

Entity/Interest	Person
Personal and Group Interviews	
Colorado Springs Utilities	Leon Basdekas, Kalsoun Abassi, Kevin Lusk
Pueblo Board of Water Works	Alan Hamel, Alan Ward
Rocky Ford	Dan Hyatt
Canon City	Bob Hartzman
El Paso County Water Authority	Gary Barber
St. Charles Mesa Water District	David Simpson
Westcliffe/Round Mountain Water District	Chris Haga
Beaver Park Irrigation	Debra Dunfee
City of Fountain	Curtis Mitchell
Aurora	Rick Kienitz
Agriculture	Reeves Brown
Agriculture	Jonathan Fox
Agriculture	Dan Henrichs
Agriculture	John Schweizer
Arkansas Groundwater Users Assn	Scott Lorenz
Lower Arkansas Water Management Association	Don Higbee
Colorado Water Protection and Development Association	Ann Lopkoff
Upper Black Squirrel Designated Basin	Peter Nichols
Division 2	Steve Witte, Bill Tyner, Joe Flory, Tom Ley
State Engineer's Office	Dick Wolfe, Dale Straw, Heidi Frey, Doug Stenzel, Scott Cuthbertson, Pat Chase
Compact Issues	Dennis Montgomery
Arkansas River Compact Administration	Colin Thompson
Colorado Attorney General's Office	Eve McDonald
Southeastern Colorado WCD	Jim Broderick, Bob Hamilton
Upper Arkansas WCD	Terry Scanga, Ivan Walter, Ken Baker
Lower Arkansas Valley WCD	Jay Winner, Peter Nichols, Heath Kunz
Purgatoire WCD	Jeris Danielson
Recreation/Rafting	Reed Dils
CDPHE - Water Quality Control Division	Dick Parachini
Arkansas Valley Audobon Society	SeEtta Moss
USGS	Pat Edelmann, Ken Watts
Colorado Geological Survey	Ralph Topper
US Bureau of Reclamation	Linda Hopkins
Tri-State	Kelly Cummins
Comanche	Don Halffield
Rocky Mountain Steel Mills	Pete Tanburg, Brad Zerfias
Colorado State University	Dr. Tim Gates
Colorado Water Conservation Board	Ray Alvarado, Andy Moore, Steve Miller
Comment Sheets	
Bishop Brogden	Mike Sayler
Arkansas Basin Rountable Rep	Jane Rawlins
Statewide perspective	Hal Simpson
Applegate Group	Bill Warmack
Riverside Technologies	Steve Malers
Headwaters	Beorn Courtney
Leonard Rice Engineers	Erin Wilson
Penrose	Lisa Pinello
Groundwater issues	Bob Longebaugh
Arkansas Headwaters Recreation Area	Rob White

Appendix A-2: Comment Sheet

Appendix A-2
Arkansas River Decision Support System Feasibility Study
Water User Comment Sheet

Name:	
Date:	
Organization/Position:	
Phone#/email:	

Colorado's Decision Support Systems (CDSS) is a water management system including data and modeling tools being developed by the Colorado Water Conservation Board and the Colorado Division of Water Resources. The goal of CDSS is to assist in making informed decisions regarding historical and future use of water. Currently there are DSSs in place for the Colorado River and Rio Grande Basins, and the development of the South Platte DSS is underway.

The objectives of the ArkDSS feasibility study are to:

1. *Determine the feasibility of developing a Decision Support System for the Arkansas River Basin using standards similar to the Decision Support Systems (DSS) developed for the Colorado River and Rio Grande Basins and being developed for the South Platte River Basin.*

2. *Identify the scope, functions, elements, data needs, costs and schedule to develop a decision support system for the Arkansas River Basin that will allow state officials and water users in the Arkansas Basin an effective system with which to plan, develop and manage their water resources.*

GENERAL QUESTIONS:
As a water user and/or manager in the Arkansas Basin, please answer the following questions regarding your needs for data and tools to facilitate better planning and management of your water resources. For questions with a numeric response, use the following: 1-Very Important, 2-Somewhat Important, 3-Not Important

Response	Question
Yes No	1. Are you familiar with Colorado's Decision Support Systems (CDSS) for water resources planning?
Yes No	2. Have you ever used data or tools available through CDSS? (Examples: HydroBase, TSTools, StateCU, CDSS Website, etc…)
	3. If YES to Question 2, for what purposes have you used CDSS data or tools?
Yes No	4. Is it important to your water management needs for the ArkDSS to provide data or information currently not available to you now?
	5. If YES to Question 4, what data or information do you need provided?

Yes No	6. Are you familiar with the State's water resources database, HydroBase, and the types of data available in HydroBase for the Arkansas River Basin?
	7. If YES to Question 6, what additional data types would you need to be included in HydroBase (examples: diversion structure locations, maps of irrigated areas, groundwater pumping) AND for what purposes?
	8. If NO to Question 6, what types of data (including spatial coverage and period of record) do you or your organization need to facilitate better water resources planning and/or management?
Yes No	9. Are there data sets, in HydroBase or in general, that you have used of which you question the reliability or quality?
	10. If YES to Question 9, what was the data quality issue?
1 2 3	11. How would you rate current communication and transfer of data among water users in the Arkansas River Basin?
	12. What suggestion would you have to improve communication and information transfer among water user on the Arkansas River?
1 2 3	13. How important is it to have access to CDSS data and products via the Internet?
1 2 3	14. Are map-based spatial data products (geographic information systems) useful to you (examples, maps of rivers, lakes, roads, river headgates, irrigated areas)?
	15. What specific spatial data products do you need for your specific water management purposes? (Examples: historical irrigated areas, locations of river headgates, locations of wells, etc…)

Yes No	16. Have you used any of the CDSS modeling components (StateMod, StateCU)?
	17. If YES to Question 16, which ones?
Yes No	18. Are enhancements needed to the CDSS modeling components for your specific analyses?
	19. If YES to Question 18, what enhancements are needed for your purposes?
	20. What analytical tools do you need in order to help you or your organization better evaluate strategies for water planning and/or management purposes? If you are unsure of the tools needed, please describe the type of analysis required for your evaluation purposes.
	21. From your perspective, as a person familiar with the Arkansas River Basin, what are the most pressing issues that will need to be addressed in the near term <u>and</u> long term to meet the water needs of the basin and the State?

TECHNICAL QUESTIONS:

The following questions solicit your input on the technical aspects of specific water resources issues in the basin. If you are unfamiliar with a particular issue or subject area, please do not feel obligated to answer.) To the left of each question, please rank each issue according to the following: 1-Not Important, 2-Somewhat Important, 3-Very Important

SURFACE WATER

Rank	Question
1 2 3	1. What is your best source of information to obtain reservoir elevations and/or stream gauge readings?
1 2 3	2. Are you or your organizations more interested in reservoir operations, river administration, or both?
1 2 3	3. Is streamflow (flow rates) during specific times of the year an issue for your organization? If yes, what reach of river (nearest gage) has the most importance to your operations?
1 2 3	4. Would a historical diversion record quality control review assist in developing an ArkDSS? What about the same for reservoir records and water rights?
1 2 3	5. Can hydrologic data and maps be made more accessible to the general public via the Web? Would they be of value?
1 2 3	6. Are additional stream gages required in the basin? If so, how many, and where should they be located? Do you have an estimate of the cost to install these gages and how it might be funded?
1 2 3	7. Are there locations (i.e. streamgages, diversion structures, reservoirs) where satellite monitoring is needed? Where?
1 2 3	8. Is it important to provide data on the relative amounts of water (native versus transmountain or native versus reservoir released water) at any existing or new stream gages or points on the river system? If so, please describe what types of information would be useful.
1 2	9. A. Would a surface water planning model be a valuable tool to assist decision-makers in evaluating water resource issues?

3	B. What enhancements, if any, would be required to the models developed for CRDSS, RGDSS and SPDSS? C. How might it interact with a groundwater model? D. Should exchanges and transbasin deliveries into and out of the Arkansas Basin be incorporated into the surface water planning model?
1 2 3	10. What is the relationship of water use (from surface water, groundwater, transmountain diversions, etc.) in the upper basin to inflows into Pueblo Reservoir?
1 2 3	11. A. Is the current return flow availability sufficient for your operations? (Please specify your source of return flow) B. How important is return flow identification? Please explain.
1 2 3	11. Is there a need for a comprehensive water budget for the basin?

GROUNDWATER

Rank	Question
1 2 3	12. A. Well measurement rules have been in place in the Arkansas River Basin since 1994 and most high capacity wells are subject to these rules. Reporting under these rules and the Amended Use Rules adopted in 1996 has provided a good body of well pumping data. Where groundwater pumping data is incomplete or for periods prior to 1994, should groundwater pumping be estimated by assuming a full water supply to crops or are other techniques (e.g., power records) required? B. Can the range of error associated with assuming a full water supply be quantified?

	C. Can the analysis accommodate the fact that many wells may have been constructed but not used for one reason or another, particularly in the past?
1 2 3	13. What is the relationship of water use (surface, groundwater, transmountain, etc.) to water levels in aquifers in your region?
1 2 3	14. Is water mining of the aquifers in your region occurring? Please explain.
1 2 3	15. Would groundwater models be valuable tools to assist decision-makers in evaluating water resource problems in the Arkansas River Basin? Please explain.

CONSUMPTIVE USE

Rank	Question
1 2 3	16. Is a comprehensive assessment of irrigated acreage, similar to that developed for SPDSS, required for the ArkDSS? Is one year adequate or should a history of irrigated acreage be developed?
1 2 3	17. A. Crop yields have improved over the last 50 years. How significant is crop yield to water use? B. How can the ArkDSS provide critical information to assist in making decisions related to farm management practices and decisions about surface water system improvements while maintaining compliance with the Arkansas River Compact by ensuring return flow reductions do not materially deplete the flows of the Arkansas River?
1 2 3	18. Are additional climate stations needed in the basin? If so, how many, and where should they be located? Do you have an estimate of the cost to install these gages and how it might be funded?

1 2 3	19. Would a consumptive use model that could accommodate various geographical units (e.g., a climate station, an individual field, a ditch system, or a basin) be a valuable tool to assist decision-makers in evaluating water resource issues?

EXISTING MODELS

Rank	Question
1 2 3	20. A. How should the proposed ArkDSS interact with the existing modeling efforts (e.g., the H-I Model and ongoing Colo. St. Univ. modeling) of the Arkansas River Basin? B. How can duplication of effort be minimized? C. What existing models should be incorporated into an ArkDSS?
1 2 3	21. Should the H-I Model from the Kansas v. Colorado decree be incorporated into an ArkDSS with a data centered approach? Can the H-I Model be utilized as a planning tool for purposes of the ArkDSS? Please explain.
1 2 3	22. A. What modeling and planning tools can be developed and utilized in the lower basin without negatively affecting the H-I Model and the Kansas v. Colorado decree? B. If certain modeling tools are found to be problematic in the lower basin, can they be developed for the upper basin without negative impacts? C. How would you recommend the DSS proceed forward while minimizing negative impacts?

ENVIRONMENTAL ISSUES

Rank	Question
1 2 3	23. Should a tool be included in the ArkDSS to help manage the Arkansas River Voluntary Flow Program?
1 2 3	24. Should data or tools be included in the ArkDSS to help manage recreational uses of water resources in the Basin? If yes, what type of data or tools would be most helpful?
1 2 3	25. Are wildlife and wetland issues significant? Please explain.
1 2 3	26. Are there endangered species issues that might impact future water use in the basin? Please explain.
1 2 3	27. Invasive plants (e.g., tamarisk) are a serious issue in the Arkansas Basin. How should their impacts be addressed in an ArkDSS?
1 2 3	28. A. Is water quality an issue for your organization? If so, what aspect of water quality is important? (examples: Salinity, heavy metals, and/or turbidity) B. Should water quality data and/or modeling be incorporated into an ArkDSS? Please explain.

OTHER

Rank	Question
1 2	29. What geographic coverages and data viewing systems would be useful to assist decision-makers in evaluating water resource problems?

3	
1 2 3	30. Is historical data sufficient to perform planning studies or should stochastic (i.e., statistically derived) data be developed?
1 2 3	31. What operational agreements, outside the priority system, need to be included in an ArkDSS?
1 2 3	32. Should socioeconomic effects of water resource activities be incorporated into an ArkDSS? Please explain.
1 2 3	33. Is there a need for accessible and consistent data regarding climate change and future drought planning?

ADDITIONAL COMMENTS:

We know that your time is valuable and we appreciate you taking your time to fill out this survey. Your feedback will directly influence the Arkansas DSS and will enhance the Statewide DSS system. Thank you for your time and feedback – we greatly appreciate it!

Please return to:
Lindsay Griffith, Brown and Caldwell
1697 Cole Blvd., Suite 200
Golden, CO 80401
Ph: 303-239-5400, Email: lgriffith@brwncald.com

Appendix B: Summary of Available Data

Table B-1. Summary of Arkansas River Basin Stream Gage Data in HydroBase

STATION ID	STATION NAME	Source	Lat	Long	USGS Hydrologic Unit	Water District	Elevation (feet)	Drainage (sq. mi.)	Period of Record		# of Years	Percent Missing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)		(11)	(12)
07099400	ARKANSAS RIVER ABOVE PUEBLO, CO	DWR	38.27	-104.72	11020002	10	4,740	4,670.00	1965	2008	44	0.00%
07105780	B DITCH DRAIN NEAR SECURITY, CO.	USGS	38.75	-104.76	11020003	10	5,724	0.00	1981	1988	8	4.45%
07105000	BEAR CREEK NEAR COLORADO SPRINGS, CO	USGS	38.82	-104.89	11020003	10	6,520	6.93	1992	2008	17	0.09%
07103703	CAMP CREEK AT GARDEN OF THE GODS, CO	USGS	38.88	-104.87	11020003	10	6,310	9.45	1992	2008	17	0.45%
07105490	CHEYENNE CREEK AT EVANS AVE AT COLORADO SPRINGS,CO	USGS	38.79	-104.86	11020003	10	6,280	21.70	1992	2008	17	0.34%
07105820	CLOVER DITCH DRAIN NEAR WIDEFIELD, CO.	USGS	38.72	-104.73	11020003	10	5,620	0.00	1981	1988	8	3.94%
07103977	COTTONWOOD CR AT COWPOKE RD. AT COLO SPRINGS, CO	USGS	38.95	-104.71	11020003	10	6,875	5.93	1998	2008	11	57.66%
07103985	COTTONWOOD CR TRIB AB RANGEWOOD DR AT CO SPRGS, CO	USGS	38.93	-104.75	11020003	10	6,630	2.81	1998	2002	5	35.68%
07103990	COTTONWOOD CREEK AT MOUTH, AT PIKEVIEW, CO.	USGS	38.93	-104.81	11020003	10	6,265	18.70	1985	2008	24	0.34%
07103980	COTTONWOOD CREEK AT WOODMEN RD NR COLO SPRINGS, CO	USGS	38.94	-104.74	11020003	10	6,680	10.30	1992	2008	17	0.17%
07103785	DEADMANS CR ABV DEADMANS LAKE AT USAF ACADEMY, CO	USGS	39.02	-104.90	11020003	10	7,220	1.55	2000	2003	4	1.83%
07105530	FOUNTAIN CR BLW JANITELL RD BLW COLO. SPRINGS, CO	USGS	38.80	-104.80	11020003	10	5,840	413.00	1989	2008	20	0.36%
07105500	FOUNTAIN CREEK AT COLORADO SPRINGS, CO	USGS	38.82	-104.82	11020003	10	5,900	392.00	1976	2008	33	0.15%
07099990	FOUNTAIN CREEK AT GREEN MOUNTAIN FALLS, CO	USGS	38.94	-105.02	11020003	10	7,740	16.60	2001	2005	5	0.00%
07106500	FOUNTAIN CREEK AT PUEBLO, CO.	USGS	38.29	-104.60	11020003	10	4,705	926.00	1922	2008	87	23.18%
07105800	FOUNTAIN CREEK AT SECURITY, CO.	USGS	38.73	-104.73	11020003	10	5,640	495.00	1964	2008	45	0.00%
07103700	FOUNTAIN CREEK NEAR COLORADO SPRINGS, CO.	USGS	38.85	-104.88	11020003	10	6,110	103.00	1958	2008	51	0.00%
07106000	FOUNTAIN CREEK NEAR FOUNTAIN, CO.	USGS	38.60	-104.67	11020003	10	5,355	681.00	1938	2008	71	43.31%
07106300	FOUNTAIN CREEK NEAR PINON, CO	USGS	38.43	-104.60	11020003	10	4,990	865.00	1973	2008	36	0.00%
384220104503701	GALE DITCH FROM ROCK CR NR FORT CARSON, CO	USGS	38.71	-104.84	11020003	10	6,380	0.00	2003	2008	6	3.64%
07105900	JIMMY CAMP CREEK AT FOUNTAIN, CO.	USGS	38.68	-104.69	11020003	10	5,530	65.60	1976	2008	33	0.12%
07103960	KETTLE CREEK ABOVE USAF ACADEMY, CO	USGS	38.98	-104.80	11020003	10	6,620	16.10	2000	2008	9	52.21%
07103950	KETTLE CREEK NEAR BLACK FOREST, CO.	USGS	39.00	-104.74	11020003	10	6,980	9.01	1976	1986	11	0.65%
07105920	L FOUNTAIN C AB KEATON RE, NR FORT CARSON, CO.	USGS	38.68	-104.86	11020003	10	6,430	11.00	1978	1998	21	34.08%
07105928	LITTLE FOUNTAIN CREEK NEAR FORT CARSON, CO.	USGS	38.68	-104.85	11020003	10	6,360	11.80	1978	1998	21	26.16%
07105940	LITTLE FOUNTAIN CREEK NEAR FOUNTAIN, CO.	USGS	38.64	-104.75	11020003	10	5,560	26.90	1978	1988	11	3.94%
07099220	LITTLE TURKEY CREEK NEAR FOUNTAIN, CO.	USGS	38.63	-104.87	11020002	10	6,395	9.59	1978	1988	11	3.81%
383619104520401	LYTLE DITCH AT FT. CARSON, CO	USGS	38.61	-104.87	11020002	10	6,270	0.00	2003	2008	6	0.00%
383944104474201	MERRIAMS L. FOUNTAIN DITCH AT FT. CARSON, CO	USGS	38.66	-104.80	11020003	10	5,770	0.00	2003	2008	6	5.63%
384037104472001	MERRIAMS ROCK CREEK DITCH AT FT. CARSON, CO	USGS	38.68	-104.79	11020003	10	5,830	0.00	2003	2008	6	3.87%
07103780	MONUMENT C AB N.GATE BLVD AT USAF ACADEMY, CO.	USGS	39.03	-104.85	11020003	10	6,640	81.70	1985	2008	24	5.06%
07103970	MONUMENT CR ABV WOODMEN RD AT COLORADO SPRINGS, CO	USGS	38.93	-104.82	11020003	10	6,270	181.00	1996	2008	13	0.00%
07103940	MONUMENT CR AT SOUTH BOUNDARY USAF ACADEMY, CO	USGS	38.95	-104.83	11020003	10	6,350	150.00	2000	2003	4	1.22%
07103790	MONUMENT CR BEL SEWAGE TR PLANT AT USAF ACADEMY,CO	USGS	38.98	-104.83	11020003	10	6,420	122.00	2000	2003	4	28.40%
07104905	MONUMENT CREEK AT BIJOU ST. AT COLO. SPRINGS, CO	USGS	38.84	-104.83	11020003	10	5,980	235.00	2003	2008	6	0.00%
07103750	MONUMENT CREEK AT MONUMENT, CO.	USGS	39.10	-104.89	11020003	10	6,925	28.50	1976	1977	2	2.59%
07103747	MONUMENT CREEK AT PALMER LAKE, CO	USGS	39.10	-104.89	11020003	10	6,950	25.80	1977	2008	32	45.14%
07104000	MONUMENT CREEK AT PIKEVIEW, CO.	USGS	38.92	-104.82	11020003	10	6,203	204.00	1938	2008	71	37.03%
07103755	MONUMENT CREEK BELOW MONUMENT LAKE NR MONUMENT, CO	USGS	39.09	-104.88	11020003	10	6,885	30.30	2005	2008	4	1.00%
07103740	NORTH MONUMENT CR. AT SPRING ST. AT PALMER LAKE	USGS	39.12	-104.91	11020003	10	7,120	16.00	2002	2004	3	39.62%
384047104510301	RIPLEY DITCH FROM L. FOUNTAIN CR AT FT. CARSON, CO	USGS	38.68	-104.85	11020003	10	6,340	0.00	2003	2008	6	0.00%
07105945	ROCK CREEK ABOVE FORT CARSON RESERVATION, CO.	USGS	38.71	-104.85	11020003	10	6,390	6.79	1978	2008	31	0.16%
07105950	ROCK CREEK NEAR FORT CARSON, CO.	USGS	38.70	-104.83	11020003	10	6,150	7.79	1978	1998	21	0.24%
07105960	ROCK CREEK NEAR FOUNTAIN, CO.	USGS	38.65	-104.75	11020003	10	5,600	16.90	1978	1988	11	4.15%

Table B-1. Summary of Arkansas River Basin Stream Gage Data in HydroBase

STATION ID	STATION NAME	Source	Lat	Long	USGS Hydrologic Unit	Water District	Elevation (feet)	Drainage (sq. mi.)	Period of Record		# of Years	Percent Missing
07105600	SAND CREEK ABOVE MOUTH AT COLORADO SPRINGS, CO	USGS	38.79	-104.77	11020003	10	5,837	52.50	2003	2008	6	46.06%
383637104531301	STROBEL DITCH FROM TURKEY CR AT FT. CARSON, CO	USGS	38.61	-104.89	11020002	10	6,370	0.00	2002	2008	7	12.71%
07099238	TELLER RESERVOIR SPILLWAY NEAR STONE CITY, CO	USGS	38.44	-104.82	11020002	10	5,480	71.50	2000	2008	9	23.49%
07104500	TEMPLETON GAP FLOODWAY AT COLORADO SPRINGS, CO.	USGS	38.89	-104.82	11020003	10	6,200	8.73	1951	1981	31	0.00%
382629104493000	TURKEY C EAST SEEP BL TELLER RES NR STONE CITY, CO	USGS	38.44	-104.83	11020002	10	5,420	0.00	2001	2008	8	0.00%
382628104493700	TURKEY CR WEST SEEP BL TELLER RES NR STONE CITY,CO	USGS	38.44	-104.83	11020002	10	5,420	0.00	2001	2008	8	0.00%
07099230	TURKEY CREEK AB TELLER RES NEAR STONE CITY, CO.	USGS	38.47	-104.83	11020002	10	5,520	62.30	1978	2008	31	5.25%
07099215	TURKEY CREEK NEAR FOUNTAIN, CO	USGS	38.61	-104.89	11020002	10	6,420	13.00	1978	2008	31	34.30%
07099235	TURKEY CREEK NR STONE CITY, CO	USGS	38.43	-104.83	11020002	10	5,350	72.40	1978	2008	31	17.19%
07103930	WEST MONUMENT CR AT MOUTH AT USAF ACADEMY, CO	USGS	38.96	-104.84	11020003	10	6,380	23.50	2000	2003	4	1.22%
07103800	WEST MONUMENT CREEK AT U.S. AIR FORCE ACADEMY, CO	USGS	38.97	-104.90	11020003	10	7,180	14.90	1970	2008	39	0.00%
07103797	WEST MONUMENT CREEK BELOW RAMPART RESERVOIR, CO	USGS	38.97	-104.96	11020003	10	8,710	7.29	1993	2008	16	0.31%
07103900	WEST MONUMENT CREEK NEAR PIKEVIEW, CO.	USGS	38.97	-104.90	11020003	10	7,081	15.40	1957	1970	14	0.00%
384048104504901	WOMACK DITCH FROM L. FOUNTAIN CR NR FT. CARSON, CO	USGS	38.68	-104.85	11020003	10	6,370	0.00	2003	2008	6	3.52%
07105924	WOMACK DITCH NEAR FORT CARSON, CO.	USGS	38.68	-104.86	11020003	10	5,620	0.00	1978	1991	14	0.60%
07087200	ARKANSAS RIVER AT BUENA VISTA, CO.	USGS	38.85	-106.12	11020001	11	7,920	611.00	1964	1993	30	20.69%
07086000	ARKANSAS RIVER AT GRANITE, CO.	DWR	39.04	-106.27	11020001	11	8,915	427.00	1910	2008	99	0.00%
07091500	ARKANSAS RIVER AT SALIDA, CO.	DWR	38.55	-106.01	11020001	11	7,051	1,218.00	1909	2008	100	0.00%
07083710	ARKANSAS RIVER BELOW EMPIRE GULCH NEAR MALTA, CO	USGS	39.16	-106.32	11020001	11	9,280	237.00	1990	2008	19	70.72%
07087050	ARKANSAS RIVER BELOW GRANITE, CO	USGS	38.99	-106.22	11020001	11	8,620	546.00	1999	2008	10	47.14%
07081200	ARKANSAS RIVER NEAR LEADVILLE, CO.	USGS	39.26	-106.34	11020001	11	9,730	98.80	1967	2008	42	15.60%
07083700	ARKANSAS RIVER NEAR MALTA, CO.	USGS	39.17	-106.32	11020001	11	9,300	228.00	1964	1984	21	35.00%
07091200	ARKANSAS RIVER NEAR NATHROP, CO.	USGS	38.65	-106.05	11020001	11	7,350	1,060.00	1964	2008	45	31.14%
07093700	ARKANSAS RIVER NEAR WELLSVILLE, CO.	DWR	38.50	-105.94	11020001	11	6,883	1,485.00	1961	2008	48	0.01%
391517106223801	BARTLETT MINE DRAINAGE TUNNEL BLW TURQ LAKE NR L	USGS	39.25	-106.38	11020001	11	9,800	0.00	2005	2007	3	1.13%
07081800	CALIFORNIA GULCH AT MALTA, CO.	USGS	39.22	-106.36	11020001	11		0.00	1991	1992	2	2.62%
07090000	CHALK CREEK (UPPER STATION) NEAR ST. ELMO, CO.	USGS	38.71	-106.32	11020001	11	9,670	48.00	1913	1919	7	0.00%
07091000	CHALK CREEK NEAR NATHROP, CO.	DWR	38.73	-106.16	11020001	11	8,113	97.00	1949	2008	60	23.98%
07090500	CHALK CREEK NEAR ST. ELMO, CO.	USGS	38.71	-106.24	11020001	11	9,000	83.00	1911	1916	6	0.00%
07086500	CLEAR CREEK ABOVE CLEAR CREEK RESERVOIR, CO.	DWR	39.02	-106.28	11020001	11	8,885	67.10	1946	2008	63	0.00%
CCBCCRCO	CLEAR CREEK BELOW CLEAR CREEK RESERVOIR	DWR	39.02	-106.24	11020001	11			1953	2008	56	36.61%
07089000	COTTONWOOD C BL HOT SPRINGS, NR BUENA VISTA, CO.	USGS	38.81	-106.22	11020001	11	8,532	65.00	1911	1986	76	34.22%
07089250	COTTONWOOD CREEK NEAR BUENA VISTA	DWR	38.84	-106.12	11020001	11			1970	2008	39	16.02%
391504106225200	DINERO MINE DRAINAGE TUNNEL BLW TURQUOISE LK NR	USGS	39.25	-106.38	11020001	11	9,800	0.00	2003	2007	5	9.37%
07079500	EAST FORK ARKANSAS RIVER NEAR LEADVILLE, CO.	USGS	39.26	-106.34	11020001	11	9,700	50.00	1913	1924	12	0.00%
07079300	EF ARKANSAS R AT US HIWAY 24, NR LEADVILLE, CO.	USGS	39.27	-106.31	11020001	11	9,900	49.90	1990	2008	19	0.16%
07083500	HALFMOON CREEK NEAR LEADVILLE, CO.	USGS	39.20	-106.37	11020001	11	9,510	25.20	1911	1914	4	0.00%
07083000	HALFMOON CREEK NEAR MALTA, CO.	USGS	39.17	-106.39	11020001	11	9,830	23.60	1946	2008	63	0.00%
07084500	LAKE CREEK ABOVE TWIN LAKES RESERVOIR, CO.	DWR	39.06	-106.41	11020001	11	9,310	75.00	1946	2008	63	3.20%
LAKBTLCO	LAKE CREEK BELOW TWIN LAKES RESERVOIR	DWR	39.08	-106.31	11020001	11			1953	2008	56	32.27%
07082000	LAKE FORK ABOVE SUGAR LOAF RESERVOIR, CO.	USGS	39.27	-106.40	11020001	11	9,800	23.90	1946	1967	22	0.09%
LKCTURCO	LAKE FORK CREEK ABOVE TURQUOISE	DWR	39.28	-106.44	11020001	11			1984	1987	4	0.00%
07082500	LAKE FORK CREEK BELOW SUGAR LOAF DAM NEAR LEADVILLE	DWR	39.25	-106.37	11020001	11			1969	2008	40	2.56%
07079200	LEADVILLE MINE DRAINAGE TUNNEL AT LEADVILLE, CO	USGS	39.27	-106.29	11020001	11		0.00	1990	1993	4	0.32%
07093000	PONCHA CREEK AT PONCHA, CO.	USGS	38.51	-106.08	11020001	11	7,000	56.00	1911	1918	8	0.00%

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STATION ID	STATION NAME	Source	Lat	Long	USGS Hydrologic Unit	Water District	Elevation (feet)	Drainage (sq. mi.)	Period of Record		# of Years	Percent Missing
SARKMOCO	SOUTH ARKANSAS RIVER AT MOUTH AT SALIDA,	DWR	38.52	-105.99	11020001	11			1970	1976	7	0.00%
07093500	SOUTH ARKANSAS RIVER NEAR SALIDA, CO.	USGS	38.52	-105.99	11020001	11	7,040	208.00	1922	1940	19	29.27%
07092000	SOUTH FORK ARKANSAS RIVER AT PONCHA, CO.	USGS	38.51	-106.08	11020001	11	7,470	140.00	1911	1973	63	81.95%
07080980	ST. KEVIN GULCH ABV TEMPLE GULCH NR LEADVILLE, CO	USGS	39.29	-106.37	11020001	11		1.84	1993	1996	4	46.91%
07081000	TENNESSEE CREEK NEAR LEADVILLE, CO.	USGS	39.26	-106.34	11020001	11	9,760	48.00	1913	1924	12	0.00%
07096000	ARKANSAS RIVER AT CANON CITY, CO.	DWR	38.43	-105.26	11020002	12	5,342	3,117.00	1888	2008	121	1.03%
07094500	ARKANSAS RIVER AT PARKDALE, CO.	USGS	38.49	-105.37	11020001	12	5,720	2,548.00	1945	2008	64	25.21%
07097000	ARKANSAS RIVER AT PORTLAND, CO.	DWR	38.39	-105.02	11020002	12	5,022	4,024.00	1939	2008	70	31.73%
07093775	BADGER CREEK, LOWER STATION, NEAR HOWARD, CO.	USGS	38.47	-105.86	11020001	12	6,780	211.00	1980	2003	24	12.58%
07093740	BADGER CREEK, UPPER STATION, NEAR HOWARD, CO.	USGS	38.66	-105.81	11020001	12	8,790	106.00	1980	2003	24	31.39%
07099050	BEAVER CR ABV UPPER BEAVER CEMETERY NR PENROSE, CO	USGS	38.56	-105.02	11020002	12	6,020	122.00	1991	2005	15	26.03%
07099060	BEAVER CREEK ABOVE HIGHWAY 115 NEAR PENROSE, CO	USGS	38.49	-105.00	11020002	12	5,660	138.00	1991	2008	18	25.48%
07099100	BEAVER CREEK NEAR PORTLAND, CO.	DWR	38.37	-104.96	11020002	12	4,993	214.00	1970	1983	14	0.00%
07096250	FOURMILE CREEK BELOW CRIPPLE CREEK NEAR VICTOR, CO	USGS	38.66	-105.23	11020002	12	6,870	272.00	1992	2008	17	4.40%
07096500	FOURMILE CREEK NEAR CANON CITY, CO.	USGS	38.44	-105.19	11020002	12	5,254	434.00	1948	1997	50	34.89%
OILCANCO	OIL CREEK NEAR CANON CITY, CO	DWR				12			1949	1953	5	0.00%
07095000	GRAPE CREEK NEAR WESTCLIFFE, CO.	DWR	38.19	-105.48	11020001	13	7,690	320.00	1925	2008	84	3.25%
07094900	MIDDLE TAYLOR CREEK NEAR WESTCLIFFE, CO.	USGS	38.11	-105.60	11020001	13	9,950	3.19	1974	1985	12	48.00%
07094600	SOUTH COLONY CREEK NEAR WESTCLIFFE, CO.	USGS	38.00	-105.49	11020001	13	8,930	6.03	1974	1978	5	0.75%
07099970	ARKANSAS RIVER AT MOFFAT STREET AT PUEBLO, CO	USGS	38.25	-104.61	11020002	14	4,653	4,778.00	1988	2008	21	0.00%
ARKNECCO	ARKANSAS RIVER AT NEPESTA ROAD BRIDGE NEAR NEPESTA	DWR	38.18	-104.14		14			2000	2008	9	0.00%
07117500	ARKANSAS RIVER AT NEPESTA, CO.	USGS	38.18	-104.14	11020005	14	4,370	9,460.00	1914	1936	23	4.84%
07109500	ARKANSAS RIVER NEAR AVONDALE, CO.	USGS	38.25	-104.40	11020002	14	4,510	6,327.00	1939	2008	70	18.94%
07117000	ARKANSAS RIVER NEAR NEPESTA, CO.	DWR	38.18	-104.17	11020005	14	4,385	9,345.00	1935	2008	74	0.00%
07099200	ARKANSAS RIVER NEAR PORTLAND, CO.	USGS	38.34	-104.94	11020002	14	4,940	4,280.00	1964	1974	11	0.00%
07099500	ARKANSAS RIVER NEAR PUEBLO, CO.	USGS	38.27	-104.66	11020002	14	4,690	4,686.00	1894	1975	82	0.00%
07099973	ARKANSAS RIVER TRIBUTARY ABOVE HWY 227 AT PUEBLO	USGS	38.25	-104.60	11020002	14	4,640	0.00	2004	2008	5	1.48%
07110400	CHICO CR NEAR PUEBLO CHEMICAL DEPOT, CO	USGS	38.36	-104.39	11020004	14	4,982	672.00	1997	1999	3	0.11%
07110500	CHICO CREEK NEAR NORTH AVONDALE, CO.	USGS	38.27	-104.37	11020004	14	4,520	864.00	1941	1946	6	11.86%
07117600	CHICOSA CREEK NEAR FOWLER, CO.	USGS	38.15	-104.08	11020005	14	4,335	109.00	1968	1974	7	1.31%
07116000	HUERFANO R BL HUERF VALY DAM NR UNDERCLIFFE, CO.	USGS	38.00	-104.47	11020006	14	4,886	1,673.00	1939	1967	29	0.00%
07116500	HUERFANO RIVER NEAR BOONE, CO.	USGS	38.23	-104.26	11020006	14	4,444	1,875.00	1922	2008	87	61.54%
OXFDITCO	OXFORD FARMERS DITCH COMPANY	DWR	38.18	-104.14	11020005	14			2000	2008	9	0.00%
07110000	SIXMILE CREEK NEAR AVONDALE, CO.	USGS	38.25	-104.39	11020002	14	4,520	45.00	1941	1946	6	0.00%
07109000	ST. CHARLES RIVER AT MOUTH, NEAR PUEBLO, CO.	USGS	38.26	-104.47	11020002	14	4,560	475.00	1922	1925	4	0.00%
07108900	ST. CHARLES RIVER AT VINELAND, CO.	USGS	38.25	-104.49	11020002	14	4,582	474.00	1978	2008	31	0.00%
07108100	GRANEROS CREEK NEAR RYE, CO	USGS	37.91	-104.93	11020002	15	6,770	4.32	1998	2001	4	0.00%
07108050	GREENHORN CREEK NEAR COLORADO CITY, CO.	USGS	37.95	-104.80	11020002	15	5,630	29.60	1974	1979	6	1.50%
07107900	GREENHORN CREEK NEAR RYE, CO.	USGS	37.92	-104.96	11020002	15	7,220	9.56	1973	2001	29	67.76%
07107500	ST. CHARLES RIVER AT BURNT MILL, CO.	USGS	38.05	-104.79	11020002	15	5,350	172.00	1923	1934	12	2.17%
07107000	ST. CHARLES RIVER AT SAN ISABEL, CO.	USGS	37.98	-105.06	11020002	15	8,590	16.00	1937	1941	5	0.00%
07108500	ST. CHARLES RIVER NEAR PUEBLO, CO.	USGS	38.21	-104.53	11020002	15	4,690	467.00	1941	1953	13	3.91%
07108800	ST. CHARLES RIVER NEAR VINELAND, CO.	USGS	38.23	-104.50	11020002	15	4,619	473.00	1968	1974	7	1.19%
07114000	CUCHARAS RIVER AT BOYD RANCH, NEAR LA VETA, CO.	DWR	37.42	-105.05	11020006	16	7,781	56.00	1934	2008	75	9.46%
CRHBLVCO	CUCHARAS RIVER AT HARRISON BRIDGE NEAR LA VETA, CO	DWR	37.55	-104.94		16	6,654		2000	2008	9	0.00%

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07114500	CUCHARAS RIVER NEAR LA VETA, CO.	USGS	37.45	-105.04	11020006	16	7,500	75.00	1923	1934	12	28.20%
07119500	APISHAPA RIVER NEAR FOWLER, CO.	USGS	38.09	-103.98	11020007	17	4,317	1,125.00	1922	2008	87	15.60%
07119000	APISHAPA RIVER NEAR WHITEROCK, CO.	USGS	37.77	-104.13	11020007	17	4,790	737.00	1942	1947	6	0.00%
ARKCACCO	ARKANSAS RIVER AND CATLIN CANAL (COMBINED)	DWR	38.13	-103.91	11020005	17			1990	2008	19	0.00%
07119700	ARKANSAS RIVER AT CATLIN DAM, NEAR FOWLER, CO.	DWR	38.13	-103.91	11020005	17	4,246	10,901.00	1964	2008	45	0.00%
07123000	ARKANSAS RIVER AT LA JUNTA, CO	DWR	37.99	-103.53	11020005	17	4,041	12,210.00	1912	2008	97	0.00%
07124000	ARKANSAS RIVER AT LAS ANIMAS, CO.	USGS	38.08	-103.22	11020009	17	3,884	14,417.00	1939	2008	70	0.00%
ARKROCCO	ARKANSAS RIVER NEAR ROCKY FORD	DWR	38.06	-103.69	11020005	17			1999	2008	10	0.00%
07120620	BIG ARROYO NEAR THATCHER, CO	USGS	37.55	-104.02	11020005	17	5,288	15.50	1983	1990	8	0.51%
07119705	CATLIN CANAL AT CATLIN DAM NEAR FOWLER	DWR	38.12	-103.94	11020005	17	4,268		1979	2008	30	0.00%
07122500	CROOKED ARROYO NEAR LA JUNTA, CO.	USGS	38.00	-103.59	11020005	17		0.00	1922	1925	4	0.00%
07122400	CROOKED ARROYO NEAR SWINK, CO.	DWR	37.98	-103.60	11020005	17	4,100	108.00	1968	2008	41	4.92%
07122060	FORT LYON CANAL NEAR CASA, CO	USGS	38.04	-103.47	11020005	17	4,060	0.00	1988	1990	3	2.86%
07122105	FORT LYON CANAL NEAR CORNELIA, CO	USGS	38.11	-103.25	11020009	17		0.00	1988	1990	3	3.71%
HILCANCO	HIGHLAND CANAL	DWR	37.90	-103.30		17			2000	2008	9	0.00%
HRC194CO	HORSE CREEK AT HIGHWAY 194	DWR	38.09	-103.35	11020008	17			1998	2008	11	0.00%
07123675	HORSE CREEK NEAR LAS ANIMAS, CO	USGS	38.09	-103.35	11020008	17	3,975	1,403.00	1979	1993	15	0.00%
07123500	HORSE CREEK NEAR SUGAR CITY, CO.	USGS	38.24	-103.63	11020008	17	4,271	1,080.00	1940	1947	8	0.44%
NMCHIGCO	NINEMILE CANAL AT NINEMILE DAM NEAR HIGBEE	DWR	37.71	-103.51	11020010	17			1979	2008	30	0.00%
07128000	PURGATOIRE R AT HIGHLAND DAM, NR LAS ANIMAS, CO.	USGS	37.90	-103.30	11020010	17	3,980	3,203.00	1931	1955	25	0.00%
PURNICCO	PURGATOIRE RIVER AT NINEMILE DAM, NEAR HIGBEE (C	DWR	37.71	-103.51	11020010	17			1990	2008	19	0.00%
07126500	PURGATOIRE RIVER AT NINEMILE DAM, NR HIGBEE, CO.	DWR	37.71	-103.51	11020010	17	4,241	2,752.00	1924	2008	85	0.00%
PURHICCO	PURGATOIRE RIVER BELOW HIGHLAND DAM NEAR LAS ANIMA	DWR	37.90	-103.30		17			2000	2008	9	0.00%
PURHILCO	PURGATOIRE RIVER BLW HIGHLAND DAM NR LAS ANIMAS	DWR	37.90	-103.30		17			2000	2008	9	0.00%
07128500	PURGATOIRE RIVER NEAR LAS ANIMAS, CO.	USGS	38.03	-103.20	11020010	17	3,878	3,318.00	1922	2008	87	19.16%
07121500	TIMPAS CREEK AT MOUTH NEAR SWINK, CO.	USGS	38.00	-103.66	11020005	17	4,120	496.00	1922	2008	87	48.34%
07121000	TIMPAS CREEK NEAR ROCKY FORD, CO.	USGS	37.95	-103.72	11020005	17	4,220	451.00	1923	1949	27	53.85%
07118500	APISHAPA RIVER AT AGUILAR, CO.	USGS	37.40	-104.64	11020007	18	6,335	149.00	1938	1981	44	88.76%
07118000	APISHAPA RIVER NEAR AGUILAR, CO.	USGS	37.39	-104.67	11020007	18	6,408	126.00	1939	1950	12	0.00%
07126480	BENT CANYON CREEK AT MOUTH NEAR TIMPAS, CO	USGS	37.59	-103.65	11020010	19	4,402	56.20	1983	2008	26	55.76%
07126320	BURKE ARROYO TRIBUTARY NEAR THATCHER, CO.	USGS	37.43	-103.97	11020010	19	5,108	0.00	1984	1986	3	0.00%
07124350	CARPIOS CANYON NEAR JANSEN, CO.	USGS	37.15	-104.57	11020010	19	6,250	0.00	1978	1981	4	45.24%
07126470	CHACUACO CREEK AT MOUTH NEAR TIMPAS, CO	USGS	37.54	-103.63	11020010	19	4,410	424.00	1983	1992	10	0.03%
07125100	FRIJOLE CREEK NEAR ALFALFA, CO.	USGS	37.20	-104.19	11020010	19	5,400	80.00	1957	1968	12	0.00%
07126390	LOCKWOOD CANYON CREEK NEAR THATCHER, CO.	USGS	37.49	-103.83	11020010	19	4,785	48.80	1983	2008	26	42.77%
07124300	LONG CANYON CREEK NEAR MADRID, CO.	USGS	37.11	-104.61	11020010	19	6,259	100.00	1972	1989	18	0.34%
07126100	LUNING ARROYO NEAR MODEL, CO.	DWR	37.30	-104.02	11020010	19	5,150	86.00	1966	1984	19	0.00%
07124050	MIDDLE FORK PURGATOIRE RIVER AT STONEWALL, CO.	USGS	37.15	-105.01	11020010	19	7,690	0.00	1978	1981	4	0.64%
07124100	MOLINO CANYON NEAR WESTON, CO.	USGS	37.13	-104.81	11020010	19	6,730	0.00	1978	1981	4	47.98%
07124210	MULLIGAN CANYON NEAR BONCARBO, CO.	USGS	37.21	-104.66	11020010	19	6,765	0.00	1978	1981	4	42.45%
07124200	PURGATOIRE RIVER AT MADRID, CO.	USGS	37.13	-104.64	11020010	19	6,262	505.00	1972	2008	37	0.00%
07126485	PURGATOIRE RIVER AT ROCK CROSSING NR TIMPAS, CO.	USGS	37.62	-103.59	11020010	19	4,350	2,635.00	1983	2008	26	7.86%
07124500	PURGATOIRE RIVER AT TRINIDAD	DWR	37.17	-104.51	11020010	19	5,980	795.00	1896	2008	113	17.04%
07124410	PURGATOIRE RIVER BELOW TRINIDAD LAKE, CO.	USGS	37.14	-104.55	11020010	19	6,074	672.00	1976	2008	33	0.13%
07126000	PURGATOIRE RIVER NEAR ALFALFA, CO.	USGS	37.19	-104.13	11020010	19	5,280	1,320.00	1905	1968	64	62.07%

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07125000	PURGATOIRE RIVER NEAR HOEHNE, CO.	USGS	37.25	-104.40	11020010	19	5,733	857.00	1954	1968	15	0.00%
07126300	PURGATOIRE RIVER NEAR THATCHER, CO.	USGS	37.36	-103.90	11020010	19	4,790	1,791.00	1966	2008	43	0.00%
RACRSTCO	RATON CREEK ABOVE STARKVILLE, CO	DWR	37.13	-104.52		19	6,280		2002	2008	7	0.00%
07126415	RED ROCK CANYON CREEK AT MOUTH NR THATCHER, CO.	USGS	37.52	-103.73	11020010	19	4,510	48.90	1983	2008	26	50.94%
07124220	REILLY CANYON AT COKEDALE, CO.	USGS	37.15	-104.62	11020010	19	6,290	0.00	1978	1981	4	46.72%
07125500	SAN FRANCISCO CREEK NEAR ALFALFA, CO.	USGS	37.17	-104.14	11020010	19	5,320	160.00	1954	1968	15	0.00%
07124120	SARCILLO CANYON NEAR SEGUNDO, CO.	USGS	37.12	-104.76	11020010	19	6,565	0.00	1978	1981	4	29.23%
07126325	TAYLOR ARROYO BL ROCK CROSSING, NR THATCHER, CO.	USGS	37.42	-103.92	11020010	19	4,982	48.40	1983	2008	26	18.07%
07126200	VAN BREMER ARROYO NEAR MODEL, CO.	USGS	37.35	-103.96	11020010	19	4,960	175.00	1966	2008	43	0.00%
07126140	VAN BREMER ARROYO NEAR TYRONE, CO	USGS	37.40	-104.12	11020010	19	5,310	132.00	1985	2004	20	14.34%
07099080	RED CREEK BELOW SULLIVAN PARK AT FORT CARSON, CO	USGS	38.50	-104.91	11020002	21	5,783	26.60	2000	2003	4	38.10%
07139000	ARKANSAS RIVER AT GARDEN CITY, KS	USGS	37.96	-100.88	11030001	67	2,815	27,071.00	1922	2008	87	18.67%
07135500	ARKANSAS RIVER AT HOLLY, CO.	USGS	38.04	-102.12	11020009	67	3,378	25,073.00	1910	1953	44	1.15%
07133000	ARKANSAS RIVER AT LAMAR, CO.	USGS	38.11	-102.62	11020009	67	3,597	19,780.00	1913	2008	96	3.63%
07138000	ARKANSAS RIVER AT SYRACUSE, KS	USGS	37.97	-101.76	11030001	67	3,209	25,763.00	1902	2008	107	14.71%
ARKCARCO	ARKANSAS RIVER BELOW X-Y CANAL DAM NEAR CARLTON, CO	DWR	38.10	-102.43	11020009	67			1999	2005	7	0.00%
07130500	ARKANSAS RIVER BELOW JOHN MARTIN RESERVOIR, CO.	USGS	38.07	-102.93	11020009	67	3,737	18,915.00	1938	2008	71	0.70%
07137500	ARKANSAS RIVER NEAR COOLIDGE, KS	USGS	38.03	-102.01	11030001	67	3,331	25,410.00	1950	2008	59	0.00%
07134180	ARKANSAS RIVER NEAR GRANADA, CO.	USGS	38.10	-102.31	11020009	67	3,480	23,707.00	1980	2008	29	0.04%
07134000	BIG SANDY CR ABV AMITY CNL DIVERSN, NR KORNMAN, CO	USGS	38.21	-102.48	11020011	67	3,650	3,136.00	1941	1946	6	0.00%
07134100	BIG SANDY CREEK NEAR LAMAR, CO.	USGS	38.11	-102.48	11020011	67	3,545	3,248.00	1968	2008	41	30.77%
07131000	CADDOA CREEK AT CADDOA, CO.	USGS	38.06	-102.92	11020009	67	3,740	131.00	1941	1946	6	19.99%
07122350	FORT LYON CANAL NEAR BIG BEND, CO	USGS	38.26	-102.78	11020009	67	3,900	0.00	1988	1990	3	3.71%
07122200	FORT LYON CANAL NEAR HASTY, CO.	USGS	38.14	-102.96	11020009	67		0.00	1968	1990	23	55.95%
07137000	FRONTIER DITCH, KS	USGS	38.04	-102.04	11030001	67	3,343		1950	2008	59	0.01%
07122390	FT LYON CANAL WASTE TO AMITY CANAL NR. KORNMAN, CO	USGS	38.14	-102.59	11020009	67	3,705	0.00	1989	1990	2	6.81%
07136500	HOLLY DRAIN NEAR HOLLY, CO.	USGS	38.05	-102.05	11020009	67	3,352	0.00	1924	1950	27	0.00%
MUDTOOCO	MUDDY CREEK BELOW MUDDY CR DAM NR TOONERVILLE, CO	DWR	37.76	-103.24		67			2004	2008	5	0.00%
RULTOOCO	RULE CREEK AT HWY 101 NEAR TOONERVILLE, CO	DWR	37.82	-103.18		67			2004	2008	5	18.14%
07129500	RULE CREEK NEAR CADDOA, CO.	USGS	38.00	-103.08	11020009	67	3,890	435.00	1941	1946	6	0.00%
07135000	TWO BUTTE CREEK NEAR HOLLY, CO.	USGS	38.03	-102.14	11020013	67	3,415	817.00	1942	1999	58	87.09%
07134990	WILD HORSE CREEK ABOVE HOLLY, CO	USGS	38.06	-102.14	11020009	67	3,405	270.00	1995	2008	14	34.63%
07136000	WILD HORSE CREEK AT HOLLY, CO.	USGS	38.05	-102.12	11020009	67	3,380	270.00	1922	1950	29	14.84%
07133050	WILLOW CREEK NEAR LAMAR, CO.	USGS	38.04	-102.61	11020009	67	3,685	42.00	1974	1977	4	1.80%
07111000	HUERFANO R AT MANZANARES XING, NR REDWING, CO.	DWR	37.73	-105.35	11020006	79	8,270	73.00	1923	2008	86	9.78%
07112500	HUERFANO RIVER AT BADITO, CO.	DWR	37.73	-105.01	11020006	79	6,415	532.00	1923	2008	86	78.74%
07113000	HUERFANO RIVER AT HUERFANO, CO.	USGS	37.81	-104.74	11020006	79	5,650	717.00	1924	1928	5	0.00%
07111500	HUERFANO RIVER AT MALACHITE, CO.	USGS	37.74	-105.25	11020006	79	7,450	107.00	1923	1925	3	0.00%
07112000	HUERFANO RIVER NEAR BADITO, CO.	USGS	37.73	-105.02	11020006	79	6,500	499.00	1941	1946	6	0.00%
07113500	HUERFANO RIVER NEAR MUSTANG, CO.	USGS	37.85	-104.70	11020006	79	5,500	803.00	1942	1947	6	0.00%

Table B-2. Summary of Surface Water Diversion Records in HydroBase

Water District	Approximate Number of Structures with Average Annual Diversions (acre-ft) as Categorized							
	No data	Infrequent Data	0 - 999	1,000 - 1,999	2,000 - 4,999	5,000 - 9,999	Greater than 10,000	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
10	450	57	117	23	12	3	4	666
11	431	129	278	43	27	9	8	925
12	999	24	325	14	5	14	10	1,391
13	246	22	586	2	1	0	0	857
14	143	22	25	2	5	4	7	208
15	169	14	168	3	3	1	1	359
16	382	23	186	3	2	0	0	596
17	159	21	53	6	2	6	11	258
18	182	4	42	2	0	0	0	230
19	254	0	228	6	2	4	2	496
66	81	10	5	0	0	0	0	96
67	174	54	55	6	3	3	5	300
79	406	8	229	6	0	0	0	649
Total	4076	388	2,297	116	62	44	48	7,031
Total of Average Annual Diversions (ac-ft/yr)	N/A	N/A	408,270	161,142	190,187	312,384	1,993,902	3,065,886

Notes:

1) Structures for the purpose of this table were identified as headgates within the structure table and have surface water sources in HydroBase
2) Average calculated from the available data within HydroBase (DivTotal).
3) Infrequent data represents structures with only infrequent data within HydroBase (IDivTotal).
4) No data represents structures that do not have diversion records within HydroBase.
5) There are 1773 structures with diversion records (DivTotal), which also have infrequent data (IDivTotal). The infrequent data is not represented in the total average diversions (ac-ft/yr).

Table B-3. Summary of Transbasin Diversion Structures in Division 2

Station ID	Station Name	Source	Owner	Basin Diverted From	Basin Diverted To	Period of Record	# of Years	Percent Missing	Related Structure WDIDs
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
07086300 (AHOMPLCO) HOMSPICO HOMOTECO	AURORA HOMESTAKE PIPELINE AB. 11-MILE RE AURORA HOMESTAKE PIPELINE TO SPINNEY RESERVOIR HOMESTAKE-OTERO PUMPS NEAR GRANITE, CO	DWR	City of Aurora and Colorado Springs Utilities	Arkansas	South Platte / Arkansas	1980-1982 1998-2008 1970-1982	3 21 13	0.00% 0.00% 18.18%	2304490, 0804490, 1100529, 1004615
09063700 (HOMTUNCO)	HOMESTAKE TUNNEL	DWR	City of Aurora and Colorado Springs Utilities	Colorado	Arkansas	1966-2008	43	0.20%	3704614, 1104613, 1104614
09061500 (COLDITCO)	COLUMBINE DITCH NEAR FREMONT PASS	DWR	Pueblo Board of Water Works	Colorado	Arkansas	1947-2008	62	12.39%	3704641, 1104616
09062000 (EWIDITCO)	EWING DITCH AT TENNESSEE PASS	DWR	Pueblo Board of Water Works	Colorado	Arkansas	1947-2008	62	24.82%	3704642, 1100500
09062500 (WURDTCO)	WURTZ DITCH NEAR TENNESSEE PASS	DWR	Pueblo Board of Water Works	Colorado	Arkansas	1947-2008	62	17.02%	3704648, 1100501
WUREXDCO WUREXTCO	WURTZ EXTENSION	DWR	Pueblo Board of Water Works	Colorado	Arkansas	1967-1991 1991-2008	25 18	4.16% 0.02%	3701290
09077160 (BOUTUNCO)	CHARLES H. BOUSTEAD TUNNEL	DWR	Southeastern Colorado Water Conservancy District	Colorado	Arkansas	1971-2008	38	0.04%	3804625, 1104615
09077500 (BUSTUNCO)	BUSK-IVANHOE TUNNEL	DWR	City of Aurora and Pueblo Board of Water Works	Colorado	Arkansas	1947-2008	62	15.59%	3804613
09073000 (TWITUNCO)	TWIN LAKES TUNNEL	DWR	Twin Lakes Reservoir and Canal Company	Colorado	Arkansas	1934-2008	75	1.12%	3804617, 1104617
09042000 (HSPATHCO)	HOOSIER PASS TUNNEL AT HOOSIER PASS, CO.	USGS	Colorado Springs	Colorado	South Platte	1956-1967	12	0.00%	3604683, 2304688, 2304612
HSPTUNCO	HOOSIER PASS TUNNEL AT MONTGOMERY RESERVOIR NEAR ALMA	DWR	Colorado Springs	South Platte	Arkansas	1952-2008	57	8.89%	1004676
LARDITCO	LARKSPUR DITCH AT MARSHALL PASS	DWR	Catlin Canal Company	Gunnison	Arkansas	1948-2008	61	22.89%	2804655, 1104618
N/A	HUDSON BRANCH XMTN DITCH	N/A	Wolf Springs Ranch Incorporated	Rio Grande	Arkansas	N/A	N/A	N/A	3500657, 7900851
N/A	MEDANO DITCH	N/A	Wolf Springs Ranch Incorporated	Rio Grande	Arkansas	N/A	N/A	N/A	3500658, 7900968

Table B-4. Summary of Reservoir Structures in Division 2

Water District	Approximate Number of Structures with Maximum Storage (acre-ft) as Categorized							
	No Storage Record	0 - 999	1,000 - 4,999	5,000 - 9,999	10,000 - 19,999	20,000 - 49,999	Greater than 50,000	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
10	148	64	2	2	3	1	0	220
11	183	2	0	0	1	0	1	187
12	185	9	9	0	0	0	0	203
13	94	1	1	0	0	0	0	96
14	83	8	3	1	0	1	1	97
15	59	3	4	1	0	0	0	67
16	30	46	6	0	0	1	0	83
17	229	16	1	2	0	2	1	251
18	15	1	1	0	0	0	0	17
19	37	22	2	1	0	0	1	63
66	108	0	0	0	0	0	0	108
67	209	10	1	0	0	3	2	225
79	70	32	1	0	0	0	0	103
Total	1,450	214	31	7	4	8	6	1,720

Table B-5. Summary of Water Rights Data in HydroBase

Water District	Ground Water				Direct Flow				Storage				Other				Total No. of Entries
	Absolute		Other / Conditional		Absolute		Other / Conditional		Absolute		Other / Conditional		Absolute		Other / Conditional		
	No. of Entries	Net Amounts (cfs)	No. of Entries	Net Amounts (cfs)	No. of Entries	Net Amounts (cfs)	No. of Entries	Net Amounts (cfs)	No. of Entries	Net Amounts (acre-ft/yr)	No. of Entries	Net Amounts (acre-ft/yr)	No. of Entries	Net Amounts (cfs)	No. of Entries	Net Amounts (cfs)	
10	1,943	1,646	114	158	184	1,498	5	26	308	169,252	11	3,658	156	1,428	3	17	2,724
11	632	89	21	7	599	2,456	16	6,524	184	184,729	18	162,996	151	856	2	350	1,623
12	1,097	104	35	3	560	1,682	4	2,008	156	23,175	16	3,926	95	247	1	104	1,964
13	380	34	7	2	739	895	2	1	78	10,119	11	225	31	74	0	0	1,248
14	1,229	677	16	19	107	5,890	1	7	53	352,756	6	428,895	3	45	1	166	1,416
15	506	61	13	2	251	1,512	3	10	36	22,459	8	3,004	30	32	0	0	847
16	691	46	23	1	243	433	3	10	64	46,538	14	42,721	13	16	4	8	1,055
17	1,665	1,272	9	6	104	36,043	0	0	202	424,541	5	27,610	7	17	2	1	1,994
18	303	14	0	0	45	440	0	0	15	4,824	0	0	6	31	0	0	369
19	441	31	6	107	272	2,699	1	51	33	80,122	5	27,199	16	29	0	0	774
66	100	7	0	0	22	162	0	0	107	793	0	0	6	0	0	0	235
67	1,803	2,253	20	22	136	5,750	1	6	200	401,653	0	0	30	77	2	43	2,192
79	589	42	37	3	309	676	3	21	79	13,606	7	31	8	10	1	1	1,033
Total	11,379	6,275	301	329	3,571	60,136	39	8,664	1,515	1,734,568	101	700,265	552	2,862	16	690	17,474

Notes:

1) Ground Water includes structure type classifications of well, spring, seep, AQ, and WF.
2) Well rights that are recorded as a volume were primarily associated with Denver Basin wells. These volumes were converted from 100 year acre-feet appropriations to cfs.
3) Water rights recorded for Agmentation Plan structures are included as Direct Flow for "Rate" rights and included as Storage for "Volume" rights.
4) Other includes structure type classifications of other, mine, pipeline, pump, power plant, and EP.
5) Alternate points are not included in the totals above because the primary right is already accounted for.
6) This table references water rights rather than structures. Many structures have multiple water rights and each of the rights are represented in this table.

Table B-6. Summary of Well Records in HydroBase

Water District	Number of Wells by Decreed Maximum Flow Rate (gpm)								Number of Wells in Water District	Percentage of Total Wells	Total of Maximum Flow (gpm)	Percentage of Total Flow
	<15	15-50	50-100	100-200	200-500	500-1,000	1,000-2,000	>2,000				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
10	501	316	164	198	331	268	174	157	2,109	23%	1,839,646	29%
11	351	164	26	10	13	9	3	3	579	6%	39,371	1%
12	321	121	11	18	26	10	3	2	512	6%	38,511	1%
13	163	55	5	5	14	8	1	0	251	3%	16,883	0%
14	232	219	94	168	308	136	38	2	1,197	13%	308,155	5%
15	229	95	24	47	28	5	0	0	428	5%	27,265	0%
16	269	73	17	6	19	2	1	0	387	4%	17,118	0%
17	317	221	77	150	416	331	103	6	1,621	18%	576,949	9%
18[a]	0	0	0	0	0	0	0	0	0	0%	0	0%
19[a]	0	0	0	0	0	0	0	0	0	0%	0	0%
66	36	5	0	4	1	0	0	0	46	0%	1,466	0%
67	485	228	47	90	285	311	257	192	1,895	20%	3,402,856	54%
79	170	44	4	3	9	1	0	1	232	3%	10,714	0%
Total # of Wells	3,074	1,541	469	699	1,450	1,081	580	363	9,257	100%		
Percentage	33%	17%	5%	8%	16%	12%	6%	4%	100%			
Total Flow	30,868	54,592	38,359	109,513	510,219	805,545	829,939	3,934,546			6,278,935	100%
Percentage	0%	1%	1%	2%	8%	13%	13%	63%			100%	

[a]Note that Coalbed Methane Wells in WD 18 and 19 are not reflected in this summary of well records

Table B-7. Bibliography of Groundwater Investigations in the Arkansas River Basin (From CGS, 2008)

REF NO	TITLE OF PUBLICATION	YEAR	AUTHOR(S)	PUBLISHER	PUBLICATION TYPE	REPORT COMMENTS AND DATA INFO
1	Underground waters of the Arkansas Valley in eastern Colorado	1896	Gilbert, G.K.	US Geological Survey	Annual Report	general config, properties
2	Geology and underground waters of the Arkansas Valley in eastern Colorado	1906	Darton, N.H.	US Geological Survey	Professional Paper	only very general alluvial config info
3	Underground waters of a part of southeastern Colorado	1921	Coffin, R.C., Tieje, A.J.	Colorado Geological Survey	Bulletin	very minor configuration information
4	Geology of parts of Las Animas, Otero, and Bent Counties	1924	Duce, J.T.	Colorado Geological Survey	Bulletin	very minor configuration information
5	Underground water possibilities for stock and domestic purposes in the La Junta area, Colorado	1924	Patton, H.B.	Colorado Geological Survey	Bulletin	configuration, water quality
6	Underground water resources of parts of Crowley and Otero Counties	1924	Toepelman, W.C.	Colorado Geological Survey	Bulletin	configuration, small amount general WQ inform
7	Report on ground water for irrigation of Big Sandy Valley, Colorado	1945	Code, W.E.	Colorado State University Agricultural Experiment S	Miscellaneous Series Paper	alluv cnfg, wl, wq
8	Geology and ground-water resources of parts of Lincoln, Elbert, and El Paso Counties, Colorado with special reference to Big Sandy Creek Valley above Limon	1946	McLaughlin, T.G.	Colorado Water Conservation Board; US Geologica	Ground Water Series Bulletin	prop, config, wls, wq
9	Selected well logs of Colorado	1946	Barb, C.F.	Colorado School of Mines	Quaterly Report	alluv and bdrk config
10	Temperature and heat flow in a well near Colorado Springs; colorado	1947	Birch, A.F.	Kline Geology Laboratory	American Journal of Science.	bdrk wq only
11	Ground water in the vicinity of Trinidad, Colorado	1952	Powell, W.J.	US Geological Survey	Ground-Water Series Circular	config, prop, wls, wq
12	General availability of ground water and depth to water level in the Arkansas, White, and Red River basins	1953	Lohman, S.W., Burtis, V.M.	US Geological Survey	Hydrologic Investigations Atlas	general config, prop
13	Geology and ground-water resources of Baca County, Colorado	1954	McLaughlin, T.G.	US Geological Survey	Water-Supply Paper	config, wls, wq, minor prop (also published as CWCB Ground-Water Series Bulletin 2)
14	Ground water in Colorado and the status of investigations	1956	McLaughlin, T. G.	Colorado Water Conservation Board	Ground Water Series, Circular	alluv confg, wl
15	Report on an Aquifer test at Monument, Colorado	1956	Cardwell, W.D.E.	US Geological Survey	Open-File Report	bdrk prop only, one well
16	Water table fluctuations in eastern Colorado	1958	Code, W.E.	Colorado State University	Experimental Station Bulletin	wls w/location, no well depths or names
17	Ground water in the Ogallala and several consolidated formations in Colorado	1960	Moulder, E.A.	US Geological Survey	Ground Water Series Circular	bdrk config only
18	Records and logs of selected wells and test holes, and chemical and radiometric analyses of ground water, Prowers County, Colorado	1960	Voegeli, P.T., Hershey, L.A.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	wls, general well data, lith log, wq
19	Uranium content of ground and surface waters in a part of the Central Great Plains	1960	Landis, E.R.	US Geological Survey	Bulletin	bdrk wq
20	Effects and benefits of artificial recharge in Fountain Creek Valley, Colorado	1961	Trelease, F.J.	Colorado State Universitiy	Master's Thesis	alluv - config, prop, wl
21	Radiochemical analyses of ground and surface water in Colorado, 1954-1961	1961	Scott, R.C., Voegeli, P.T.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	only 3 alluvial data wq points
22	Records and logs of selected wells and test holes, and chemical analyses of ground water from wells and mines, Huerfano County, Colorado	1961	McLaughlin, T.G., Burtis, V.M., Wilson, W.W.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	wls, general well data, lith log, wq
23	Records and logs of selected wells and test holes, and chemical analyses of ground water from wells and mines, Huerfano County, Colorado	1961	McLaughlin, T. G., Burtis, V.M., Wilson, W. W.	Colorado Water Conservation Board	Ground-water series basic-data release	alluv & bdrk confg, wl, wq
24	Records, logs, and water-level measurements of selected wells and test holes, and chemical analyses of ground water in Fountain, Jimmy Camp, and Black Squirrel Valleys, El Paso County, Colorado	1961	Jenkins, E.D.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	wls, general well data, lith log, wq
25	Colorado ground-water levels, spring 1962	1962	Skinner, M.M.	Colorado State University	Experimental Station Report	wls w/location, no well depths or names
26	Records, logs, and water-level measurements of selected wells and test holes, and chemical analyses of ground water in eastern Cheyenne and Kiowa Counties, Colorado	1962	Boettcher, A.J.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	wls, general well data, lith log, wq
27	Records, logs, and water-level measurements of selected wells and test holes, and chemical analyses of ground water in Otero and the southern part of Crowley Counties, Colorado	1962	Weist, W.G.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	wls, general well data, lith log, wq data
28	Use of inflatable packers in multiple-zone testing of water wells	1962	Koopman, F.C., Irwin, J.H., Jenkins, E.D.	US Geological Survey	Professional Paper	bedrock only -aqprop, wl,
29	Colorado ground-water levels, spring 1963	1963	Skinner, M.M.	Colorado State University	Experimental Station Report	wls w/location, no well depths or names
30	Effects of water management on a reach of the Arkansas Valley, La Junta to Las Animas, Colorado	1963	Moulder, E.A., Jenkins, C.T., Moore, J.E., Coffin, D	Colorado Water Conservation Board	Colorado Ground Water Circular	minor config, prop, wl, wq data
31	Potential ground-water development in the northern part of the Colorado High Plains	1963	McGovern, H.E., Coffin, D.L.	Colorado Water Conservation Board	Ground Water Series Circular	alluv & bedrk - config, prop, wl
32	Prospects for Irrigation in Eastern Cheyenne and Kiowa Counties, Colorado	1963	Boettcher, A.J.	Colorado Water Conservation Board	Colorado Ground Water Series Circular	bdrk only, cnfg, wq
33	Radium in natural waters in the United States	1963	Scott, R.C.	Colorado State University	Publication of the National Symposium on Radioecology	bdrk - wq
34	Records, logs, and water-level measurements of selected wells and test holes, and chemical analyses of ground water in Bent County, Colorado	1963	Broom, M.E., Irwin, J.H.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	wls, general well data, lith log, wq
35	The role of ground water in the national water situation	1963	McGuinness, C.L.	US Geological Survey	Water-Supply Paper	alluv & bdrk prop, wl, wq
36	Water in the Dakota and Purgatoire Formations in Otero County and the Southern Part of Crowley County, Colorado	1963	Weist, W.G. Jr.	US Geological Survey	Water-Supply Paper	all bedrock categories
37	Colorado ground-water levels, spring 1964	1964	Skinner, M.M., Thomas, J.L.	Colorado State University	Experimental Station Report	wls w/location, no well depths or names
38	Geology and ground-water resources in eastern Cheyenne and Kiowa Counties, Colorado	1964	Boettcher, A.J., Horr, C.A.	US Geological Survey	Water-Supply Paper	minor configuration and properties informatio
39	Ground water in Fountain and Jimmy Camp Valleys, El Paso County, Colorado	1964	Jenkins, E.D.	US Geological Survey	Water-Supply Paper	alluv - config, prop, wl
40	Ground water in Fountain and Jimmy Camp Valleys, El Paso County, Colorado	1964	Jenkins, E.D.	US Geological Survey	Water-Supply Paper	config, prop, wl, wq
41	Hydrogeologic data of the alluvial deposits in Pueblo and Fremont Counties, Colorado	1964	McGovern, H.E., Gregg, D.O., Brennan, R.	Colorado Water Conservation Board	Colorado Ground Water Basic Data Report	aquifer config, wls, wq, properties
42	Methods for controlling the ground-water regime exploitation and conservation	1964	Moulder, E. A., Jenkins, C.T.	International Association of Scientific Hydrology	Serial; Report	alluv confg, wl
43	Records of wells in Colorado	1964	McConaghy, J.A.	Colorado Water Conservation Board	Colorado Ground Water Basic-Data Release	prop, wls
44	Colorado ground-water levels, spring 1965	1965	Duke, H.R., Skinner, M.M.	Colorado State University	Experimental Station Report	wls w/location, no well depths or names
45	Geology and ground-water resources of Prowers County, Colorado	1965	Voegeli, P.T., Hershey, L.A.	US Geological Survey	Water-Supply Paper	alluv & bedrk - config, prop, wl
46	Geology and ground-water resources of Prowers County, Colorado	1965	Voegeli, P.T., Hershey, L.A.	US Geological Survey	Water-Supply Paper	config, prop, wls, wq
47	Geology and occurrence of ground water in Otero County and the southern part of Crowley County, Colorado	1965	Weist, W.G.Jr., Jenkins, E.D., Horr, C.A.	US Geologcal Survey	Water-Supply Paper	alluv & bedrk - config, prop, wl
48	Geology and occurrence of ground water in Otero County, and the southern part of Crowley County, Colorado	1965	Weist, W.G., Jr., Jenkins, E.D.; Horr, C.A.	US Geological Survey	Water-Supply Paper	config, prop, wls, wq
49	Pumping tests in Colorado	1965	Wilson, W.W.	Colorado Water Conservation Board	Colorado Ground Water Circular	general hydrogeologic data, well test data
50	The water utilization study, Arkansas Valley region	1965	Planning and Community Development Section	Colorado Division of Commerce and Development	Working Paper	very general prop, config, wq

REF NO	TITLE OF PUBLICATION	YEAR	AUTHOR(S)	PUBLISHER	PUBLICATION TYPE	REPORT COMMENTS AND DATA INFO
51	Water utilization study, Project No. Colorado P-30/Arkansas Valley region	1965	Skinner, M.M.	Colorado State University	Engineering Research Center Report	wls, no well depth or aq data
52	A new approach for estimating transmissibility from specific capacity	1966	Hurr, R.T.	American Geophysical Union	Water Resources Research	alluv only, aqcng, wl
53	An evaluation of the effect of groundwater pumpage on the infiltration rate of a semipervious steambed	1966	Moore, J.E., Jenkings, C.T.	American Geophysical Union	Water Resources Research	alluv only, aqcng, wl
54	Contour of bedrock surface, Boone to Fowler, Colorado	1966	Hurr, R.T., Moore, J.E., Richards, D.B.	US Geological Survey	Open-File Report	config
55	Ground water in Black Squirrel Creek Valley, El Paso County, Colorado	1966	McGovern, H.E., Jenkins, E.D.	US Geological Survey	Hydrologic Investigations Atlas	config, prop, wls, wq
56	Ground water in Huerfano County, Colorado	1966	McLaughlin, T.G.	US Geological Survey	Water-Supply Paper	general config, prop, wls, wq
57	Ground-water development in the High Plains of Colorado	1966	Boettcher, A.J.	US Geological Survey	Water-Supply Paper	all bedrock categories
58	Transmissibility of valley-fill aquifer, Boone to Fowler, Colorado	1966	Hurr, R.T., Moore, J.E.	U.S. Geological Survey	Open File Report	alluv aqprop only
59	Watertable contour map, Boone to Fowler, Colorado, March 15 to 30, 1966	1966	Moore, J.E., Hurr, R.T.	US Geological Survey	Open-File Report	config, wls, prop
60	Data requirements and preliminary results of an analog-model evaluation--Arkansas River Valley in eastern Colorado	1967	Moore, J.E., Wood, L.A.	Ground Water	Journal Article	general config, prop, wl data
61	Geology and ground-water resources of the Big Sandy creek valley, Lincoln, Cheyenne, and Kiowa counties, Colorado; with a section on chemical quality of the ground water	1967	Coffin, D.L., Horr, C.A.	US Geological Survey	Water Supply Paper	alluv & bedrk - config, prop, wl, wq
62	Ground water in the high plains of eastern Colorado	1967	Duke, H.R.	Colorado State University Agricultural Experiment S	General Series	bdrk cnfg only
63	Ground water resources study relating to portions of Prowers, Baca, and Las Animas counties, Colorado	1967	Beck, R.W. and Associates	R.W. Beck and Associates	Consultant Report	bdrk prop, confg
64	Ground-water resources of the upper Black Squirrel Creek basin, El Paso County, Colorado	1967	Erker, H.W., Romero, J.C.	Colorado Division of Water Resources	Division of Water Resources Report	config, prop, wls
65	Geology of the Manitou Springs-Cascade area, El Paso County, Colorado with a study of the permeability of its crystalline rocks	1968	Bianchi, L.	Colorado School of Mines	Master's Thesis	bedrk - config, prop
66	Hydrogeologic data for Baca and southern Prowers Counties, Colorado	1968	Richards, D.B., Hershey, L.A., Glanzman, R.K.	Colorado Water Conservation Board	Colorado Ground Water Basic-Data Release	wls, aq prop, minor wq and config information
67	Relation of channel width to vertical permeability of streambed, Big Sandy Creek, Colorado	1968	Coffin, D.L.	US Geological Survey	Professional Paper	alluv aqcnfg only
68	Water legislation investigations for the Arkansas River basin in Colorado	1968	W.W. Wheeler and Assoc.; Woodward-Cyde & Ass	W.W. Wheeler and Assoc.; Woodward-Clyde & As	Consultant Report	config, prop
69	Analog-digital models of stream-aquifer systems	1969	Moulder, E.A., Jenkins, C.T.	Robert S. Storm	Ground Water journal of the Technical Division National Water Well Association	alluv wl only
70	Colorado ground-water levels, spring, 1969	1969	Brookman, J.A.	Colorado State University Experiment Station	CSU Map Publication	alluv & bdrk wl
71	Water-level records for the northern High Plains of Colorado	1969	Boettcher, A.J., Hofstra; W.E., Major, T.J.	Colorado Water Conservation Board	Ground-water series basic-data release	alluv & bdrk wl
72	Hydrogeologic data for the lower Arkansas Valley, Colorado	1970	Major, T.J., Hurr, R.T., Moore, J.E.	Colorado Water Conservation Board	Colorado Ground Water Basic-Data Release	wls, wq, config, prop
73	The hydrogeology of Black Squirrel creek basin, El Paso County, Colorado	1970	Goeke, J.W.	Colorado State University	Master's Thesis	alluv & bdrk prop, confg, wl
74	Ground water resources of the Big Sandy Creek drainage area, southeastern Colorado	1971	Willard Owens Associates	Willard Owens Associates	Consultant Report	config, prop, wls, very general wq
75	Hydrogeologic characteristics of the valley-fill aquifer in the Arkansas River valley, Bent County, Colorado	1971	Hurr, R.T., Moore, J.E.	US Geological Survey	Hydrologic Atlas	alluv - config, prop, WL
76	Test of the Stroebel Spring, a supplementary study of the Fort Carson Expansion Project, Civic Action No. 9820, Track No. 202, El Paso County, Colorado	1971	Jenkins, E.D.	US Geological Survey	Open-File Report	alluv prop only
77	A new technique for estimating recharge using a digital model	1972	Taylor, O.J., Luckey, R.R.	National Water Well Association	Ground Water	alluv & bedrk - config, prop, wl
78	Appraisal of shallow ground-water resources, Pueblo Army Depot, Colorado	1972	Welder, F.A., Hurr, R.T.	US Geological Survey	Open-File Report	alluv- cnfg, prop, wl, wq
79	Brief description as of April, 1968, of the geology and hydrology of the Lake Minnequa area, Pueblo, Colorado, and suggested solutions for trouble caused by a high water table	1972	Scott, G.R.	US Geological Survey	Open-File Report	general config and wl information
80	Geohydraulics at the unconformity between bedrock and alluvial aquifers	1972	Waltz, J.P., Sunada, D.K.	U.S. Geological Survey	Completion Report	alluv & bdrk prop, confg, wl
81	Ground-water levels in the lower Arkansas River Valley of Colorado, 1968-1972	1972	Taylor, O.J., Luckey, R.R.	Colorado Water Conservation Board	Colorado Water Resources Basic-Data Release	wls, well depths and aq
82	Ground-water levels in the lower Arkansas River valley of Colorado, 1968-72	1972	Colorado Water Conservation Board	Colorado Water Conservation Board	Ground-water series basic-data release	alluv wl only
83	Hydrogeologic characteristics of the valley-fill aquifer in the Arkansas River Valley, Bent County, Colorado	1972	Hurr, R.T., Moore, J.E.	US Geological Survey	Hydrologic Investigations Atlas	config, prop, wls
84	Hydrogeologic data for the northern High Plains of Colorado	1972	Hofstra, W.E., Major, T.J., Luckey, R.R.	Colorado Water Conservation Board	Ground-water series basic-data release	bdrk prop config wl
85	Maps showing the approximate configuration and depth to the top of the Laramie-Fox Hills Aquifer, Denver Basin, Colorado	1972	Romero, J.C., Hampton, E.R.	US Geological Survey	Miscellaneous Investigations Series Map	bdrk cnfg
86	Stream depletion factors, Arkansas River Valley, southeastern Colorado; A basis for evaluating plans for conjunctive use of ground and surface water	1972	Jenkins, C.T., Taylor, O.J.	US Geological Survey	Open-File Report	config, properties
87	Water-level changes 1964-71, Northern High Plains of Colorado	1972	Hofstra, W.E., Klein, J.M., Major, T.J. Jr.	US Geological Survey	Open-File Report	alluv & bdrk wl
88	Water-level records for the northern High Plains of Colorado, 1968-72	1972	Hofstra, W.E., Luckey, R.R.	US Geological Survey	Water Resources Basic-Data Release	alluv & bdrk wl
89	Chemical and spectrochemical analyses of selected ground water in Colorado	1973	Mallory, E.C., Barnett, P.R.	US Geological Survey	Open-File Report	WQ, mainly springs, few wells w/unknown dpth
90	Colorado ground-water trends	1973	Bookman, J.A.	Colorado State University	Engineering Research Center Report	alluv & bdrk wl
91	Digital model of the hydrologic system, northern High Plains of Colorado; A preliminary report	1973	Luckey, R.R., Hofstra, W.E.	US Geological Survey	Ground Water Series Circular	bdrk- config, wl
92	Extent of development and hydrologic conditions of the alluvial aquifer, Fountain and Jimmy Camp Valleys, Colorado, 1972	1973	Bingham, D.L., Klein, J.M.	Colorado Water Conservation Board	Colorado Water Resources Circular	wls, wq, config - aq extent
93	Ground-water levels in the lower Arkansas River Valley of Colorado, 1969-1973	1973	Taylor, O.J., Luckey, R.R.	Colorado Water Conservation Board	Colorado Water Resources Basic-Data Release	wls, well depths and aq
94	Ground-water levels in the lower Arkansas River valley of Colorado, 1969-73	1973	Taylor, O.J., Luckey, R.R.	Colorado Water Conservation Board	Ground-water series basic-data release	alluv wl only
95	Simulation of hydrologic and chemical quality variations in an irrigated stream-aquifer system, Arkansas River valley, Colorado	1973	Konikow, L.F.	Pennsylvania State University	Doctoral Thesis	alluv prop, wl, wq
96	Simulation of hydrologic and chemical-quality variations in an irrigated stream-aquifer system - A preliminary report	1973	Konikow, L.F., Bredehoeft, J.D.	Colorado Water Conservation Board	Colorado Water Resources Circular	general hydrogeologic data
97	Simulation of hydrologic and chemical-quality variations in an irrigated stream-aquifer system, Arkansas River Valley, Colorado	1973	Konikow, L.F.	Pennsylvania State University	Doctoral Thesis	config, prop, wls, wq
98	Use of finite-difference arrays of observation wells to estimate evapotranspiration from ground water in the Arkansas River Valley, Colorado	1973	Weeks, E.P., Sorey, M.L.	US Geological Survey	Water-Supply Paper	config, prop, wls

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99	Water-level declines and ground-water quality, upper Black Squirrel Creek basin, Colorado	1973	Bingham, D.L., Klein, J.M.	Colorado Water Conservation Board	Colorado Water Resources Circular	wls, wq, minor config- aq extent
100	Water-level records, 1969-73, and hydrogeologic data for the northern High Plains of Colorado	1973	Hofstra, W.E., Major, T.J.	Colorado Water Conservation Board	Ground-water series basic-data release	bdrk prop, config, wl
101	Bibliography and index of geology and hydrology, Front Range urban corridor, Colorado	1974	Chronic, F., Chronic, J.	US Geological Survey	Bulletin	index of sources
102	Colorado ground water levels, spring 1974	1974	Brookman, J.	Colorado State University	Experimental Station Report	wls w/location and aquifer
103	Geology of ground water resources in Colorado; an introduction	1974	Pearl, R.H.	Colorado Geological Survey	Special Publication	alluv & bdrk cnfg, wq
104	Modeling flow and chemical quality changes in an irrigated stream-aquifer system	1974	Konikow, L.F., Bredehoeft, J.D.	American Geophysical Union	Water Resources Research	alluv wl, wq
105	Selected water-level records for Colorado, 1970-1974	1974	Major, T.J., Kerbs, L., Penley, R.D.	Colorado Water Conservation Board	Colorado Water Resources Basic-Data Release	wls, well depths with aq designation
106	Water-level decline, spring 1964 to spring 1974, upper Black Squirrel Creek basin, Colorado	1974	Bingham, D.L., Klein, J.M.	US Geological Survey	Open-File Report	config, wls
107	Water-level records for the northern High Plains of Colorado, 1970-74	1974	Hofstra, W.E., Major, T.J.	Colorado Water Conservation Board	Ground-water series basic-data release	alluv & bdrk wl
108	Water-management studies of a stream-aquifer system, Arkansas River Valley, Colorado	1974	Taylor, O.J., Luckey, R.R.	Ground Water	Journal Article	very general and minor config and prop info
109	Appraisal of water resources of northwestern El Paso County, Colorado	1975	Livingston, R.K., Bingham, D.L., Klein, J.M.	Colorado Water Conservation Board	Colorado Water Resources Circular	minor alluvial aq config, wq, wls, prop info
110	Artificial recharge experiments in the alluvial aquifer south of Fountain, El Paso County, Colorado	1975	Taylor, O.J.	Colorado Water Conservation Board	Colorado Water Resources Circular	properties, config, wls
111	Geohydrology of Baca and southern Prowers Counties, southeastern Colorado	1975	Hershey, L.A., Hampton, E.R.	US Geological Survey	Water-Resources Investigations Report	minor config, prop, wq, primarily bedrock aq
112	Hydrogeology of St. Charles Mesa, Pueblo County, Colorado	1975	Dumeyer, J.M.	Colorado Geological Survey	Map Series	configuration, wq, wls, some aq properties
113	Map showing availability of hydrologic data published as of 1974 by the U. S. Environmental Data Service and by the U. S. Geological Survey and cooperating agencies, Colorado Springs-Castle Rock area, Front Range urban corridor, Colorado	1975	Anna, L.O.	U. S. Geological Survey	Miscellaneous Investigations Series	alluv & bdrk all categores
114	Numerical model of flow in a stream-aquifer system	1975	Rovey, C.E.K.	Colorado State University	Doctoral Thesis	alluv prop & wl
115	Water quality, Fountain and Jimmy Camp Valleys, Colorado, 1973	1975	Klein, J.M., Bingham, D.L.	Colorado Water Conservation Board	Colorado Water Resources Circular	water quality, aq config (extent)
116	Water resources data, Colorado, water year 1975. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1975	USGS	US Geological Survey	Water-Data Report	wls, multiple wells
117	Water resources study for western Las Animas County, Colorado	1975	Rocky Mountain Consultants, Inc.	Rocky Mountain Consultants, Inc.	Consultant Report	config, prop, wls
118	Water-level records for Colorado, 1971-75	1975	Major, T.J., Kerbs, L., Penley, R.D.	Colorado Water Conservation Board	Colorado Water Resources Basic-Data Release	water levels
119	Appraisal of water resources of southwestern El Paso County, Colorado	1976	Livingston, R.K., Klein, J.M., Bingham, D.L.	Colorado Water Conservation Board	Colorado Water Resources Circular	config, prop, wls
120	Geothermal resources of the upper San Luis and Arkansas valleys, Colorado	1976	Pearl, R.H., Barrett, J.K.	Colorado School of Mines	Professional Contributions of Colorado School of Mines	alluv & bedrk - wq
121	Ground water resources of the bedrock aquifers of the Denver Basin, Colorado	1976	Romero, J.C.	State of Colorado Department of Natural Resource	Division of Water Resources Report	bedrock only, all categories
122	Ground water resources of the bedrock aquifers of the Denver Basin, Colorado	1976	Colorado Division of Water Resources	Colorado Division of Water Resources	Report	bdrk confg, wl, wq
123	Hydrogeoligical data of thermal springs and wells in Colorado	1976	Barrett, J.K., Pearl, R.H.	Colorado Geological Survey	Information Series	bdrk only, wq
124	Summary appraisals of the Nation's ground-water resources	1976	Bedinger, M.S., Sniegocki, R.T.	US Geological Survey	Professional Paper	Very general, large area, entire Ark basin
125	Water resources data, Colorado, water year 1976. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1976	USGS	US Geological Survey	Water-Data Report	wls, multiple wells
126	Water resources of El Paso County, Colorado	1976	Livingston, R.K., Klein, J.M., Bingham, D.L.	Colorado Water Conservation Board	Colorado Water Resources Circular	aquifer config, wls, wq, minor prop. info
127	Waterlogging in an alluvial aquifer near Lake Minnequa, Pueblo, Colorado	1976	Emmons, P.J.	US Geological Survey	Water-Resources Investigations Report	config, prop, wls, wq
128	Artificial-recharge tests in upper Black Squirrel Creek basin, Jimmy Camp Valley, and Fountain Valley, El Paso County, Colorado	1977	Emmons, P.J.	US Geological Survey	Water-Resources Investigations Report	config, prop, wls, wq
129	Digital ground-water model of the Ogallala Aquifer in parts of Cheyenne and Kiowa Counties, northern High Plains of Colorado	1977	Kapple, G.W., Luckey, R.R., Hofstra, W.E.	US Geological Survey	Ground Water Series Circular	alluv & bedrk - config, prop, wl
130	Environmental baseline descriptions for use in the management of Fort Carson natural resources; Report 2, water-quality, meteorologic, and hydrologic data collected with automated field stations	1977	West, H.W., Floyd, H.M.	U. S. Army Corps of Engineers, Waterways Experi	Technical Report	unable to review
131	Geohydrologic setting of the environment near Cotter Mill, Canon City, Colorado	1977	Alther, G.R.	Rocky Mountain Association of Geologists	The Mountain Geologist	alluv-config, wl, prop, bdrk-config, prop, wq
132	Water resources data, Colorado, water year 1977. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1977	USGS	US Geological Survey	Water-Data Report	wls, multiple wells
133	Water-level changes in northern High Plains of colorado, 1964 to 1976 and 1972 to 1976	1977	Borman, R.G., Major, T.J.	US Geological Survey	Open-File Report	alluv & bdrk wl
134	Water-level records for the lower Arkansas River Valley of Colorado, 1973-77	1977	Penley, R.D.	US Geological Survey	Open-File Report	wls
135	Water-level records for the northern High Plains of colorado, 1973-77	1977	Major, T.J., Borman, R.G., Vaught, K.D.	US Geological Survey	Open-File Report	alluv & bdrk wl
136	Appraisal of the water resources of Park and Teller counties, Colorado	1978	Klein, J.M., Goddard, K.E., Livingston, R.K.	Colorado Water Conservation Board	Water Resources Circular	alluv & bdrk config, wq
137	Geothermal resources of South central Colorado and their relationship to ground and surface waters	1978	Romero, J.C., Fawcett, D.	Colorado Division of Water Resources	Water Resources Investigations	alluv & bdrk wq
138	Hydrologic data for water-table aquifers in the Colorado Springs-Castle Rock area, Front Range Urban Corridor, Colorado	1978	Hutchinson, E.C., Hillier, D.E.	US Geological Survey	Open-File Report	alluv & bedrk - config, prop, wl, wq
139	Plan of study for the High Plains regional aquifer-system analysis in parts of Colorad, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1978	Weeks, J.B.	US Geological Survey	Water-Resources Investigations Report	bdrk prop, cnfg, wl, wq
140	Uranium hydrogeochemical and stream sediment reconnaissance of the Pueblo NTMS Quadrangle, Colorado, including concentrations of forty-three additional elements	1978	Shannon, S.S.	Los Alamos Scientific Laboratory	Informal Report	alluv wq only
141	Water resources data, Colorado, water year 1978. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1978	USGS	US Geological Survey	Water-Data Report	wls, multiple wells
142	Waterl-level records for the northern High Plains of colorado, 1975-78	1978	Borman, R.G.	US Geological Survey	Open-File Report	alluv & bdrk wl
143	Water-resources appraisal of the Wet Mountain Valley, in parts of Custer and Fremont Counties, Colorado	1978	Londquist, C.J., Livingston, R.K.	US Geolgocial Survey	Water-Resources Investigations Report	alluv & bedrk - config, prop, wl, wq
144	Altitude and configuration of the water table and depth to water in the northern High Plains of Colorado, January 1987	1979	Borman, R.G.	US Geological Survey	Water-Resources Investigations Report	bdrk wl only
145	Appraisal of ground water in the vicinity of the Leadville Drainage Tunnel, Lake County, Colorado	1979	Turk, J.T., Taylor, O.J.	US Geological Survey	Open-File Report	alluv & bedrk - config, wl, wq

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146	Dawson Aquifer model converted	1979	Emmons, P.J., Livingstong R.K., Klein, J.M., Bingh	US Geological Survey	Professional Paper	bdrk only-aq prop
147	Detailed uranium hydrogeochemical and stream sediment reconnaissance of the Tallahassee Creek, Badger Creek, Castle Rock Gulch, and Buffalo Gulch areas in the northwestern part of the Pueblo NTMS Quadrangle, Colorado	1979	Shannon, S.S.	Los Alamos Scientific Laboratory	Informal Report	alluv wq only
148	Ground-water resources of Crowley County	1979	Ryan, B.J., Cain, D.L., Emmons, P.J.	US Geoogical Survey	Professional Paper	bdrk-prop, alluv-aqprop, wq
149	Six-state High Plains-Ogallala aquifer area study	1979	High Plains Associates	High Plains Associates	Interim report	unable to review
150	Uranium hydrogeochemical and stream sediment reconnaissance of the La Junta NTMS Quadrangle, Colorado, including concentrations of forty-three additional elements	1979	Purson, J. D., Warren, R. G.	Los Alamos Scientific Laboratory	Informal Report	alluv wq only
151	Uranium hydrogeochemical and stream sediment reconnaissance of the Lamar NTMS Quadrangle, Colorado, including concentrations of forty-three additional elements	1979	Shannon, S.S.	Los Alamos Scientific Laboratory	Informal Report	alluv wq only
152	Water resources data, Colorado, water year 1979. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1979	USGS	US Geological Survey	Water-Data Report	wls, multiple wells
153	Water-level records for the northern High Plains of colorado, 1975-79	1979	Borman, R.G.	US Geological Survey	Open-File Report	alluv & bdrk wl
154	Depth to the water table (1976-77) in the Colorado Springs-Castle Rock area, Front Range urban corridor, Colorado	1980	Hillier, D.E., Hutchinson, E.C.	U. S. Geological Survey	Miscellaneous Investigations Series	bdrk wl
155	Hydrology and chemical quality of ground water in Crowley County, Colorado	1980	Cain, D., Ryan, B.J., Emmons, P.J.	US Geological Survey	Open-File Report	wq, wls
156	Radioactivity in water wells, Pueblo County, Colorado	1980	Felmlee, J.K., Cadigan, R.A.	US Geological Survey	Professional Paper	bdrk only-wq
157	Uranium hydrogeochemical and stream sediment reconnaissance of the Trinidad NTMS Quadrangle, Colorado, including concentrations of forty-two additional elements	1980	Shannon, S.S., Simi, O.R., Martell, C.J., Hensley,	Los Alamos Scientific Laboratory	Informal Report	alluv wq only
158	Water resources data, Colorado, water year 1980. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1980	USGS	US Geological Survey	Water-Data Report	wls, multiple wells
159	Water table in the High Plains aquifer in 1978 in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1980	Gutentag, E.D., Weeks, J. B.	US Geological Survey	Hyrdologic Atlas	alluv & bedrk - config, wl
160	Water-level records for the northern High Plains of Colorado, 1976-80	1980	Borman, R. G.	US Geological Survey	Open-File Report	alluv & bdrk wl
161	Well yields and chemical quality of water from water-table aquifers in the Colorado Springs-Castle Rock area, Front Range urban corridor, Colorado	1980	Hillier, D.E., Hutchinson, E.C.	U. S. Geological Survey	Miscellaneous Investigations Series	bdrk wl, wq
162	Alluvial and bedrock aquifers of the Denver Basin - Eastern Colorado's dual ground-water resource	1981	Robson, S.G.	US Geological Survey	Water-Supply Paper	alluv & bedrk - config, prop, wl, wq
163	Atlas of ground water quality in Colorado	1981	Repplier, F.N., Healy, F.C., Collins, D.B., Longmire	Colorado Geological Survey	Map Series	bdrk & alluvium aqprop, wq
164	Bedrock geology, altitude of base, and 1980 saturated thickness of the high plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1981	Weeks, J. B., Gutentag, E.D.	US Geological Survey	Hydrologic Atlas	alluv & bedrk - config, prop, wl
165	Geologic structure, hydrology and water quality of the Dawson Aquifer in the Denver Basin, Colorado	1981	Robson, S.G., Romero, J.C.	US Geological Survey	Hydrologic Atlas	alluv config, bdrk config, wl, wq
166	Geologic structure, hydrology, and water quality of the Arapahoe Aquifer in the Denver Basin, Colorado	1981	Robson, S.G., Wacinski, A., Zawistowski, S., Rome	US Geological Survey	Hydrologic Atlas	bedrock only, prop, config, quality
167	Geologic structure, hydrology, and water quality of the Denver Aquifer in the Denver Basin, Colorado	1981	Robson, S.G., Romero, J.C.	US Geological Survey	Hydrologic Atlas	alluv config, bdrk config, wl, wq
168	Geologic structure, hydrology, and water quality of the Laramie-Fox Hills Aquifer in the Denver Basin, Colorado	1981	Robson, S.G., Wacisnki, A., Zawistowski, S., Rome	US Geological Survey	Hydrologic Atlas	bedrock only, prop, config, quality
169	Hydrology and chemical quality of ground water in Kiowa County, Colorado	1981	Mustard, M.H., Cain, D.	US Geological Survey	Open-File Report	alluv and bdrk - confg, wl, wq
170	Role of solute-transport models in the analysis of groundwater salinity problems in agricultural areas	1981	Konikow, L.F.	Elsevier	Developments in Agricultural Engineering. Land and Stream Salinity	alluv wl, wq
171	Water resources data, Colorado, water year 1981. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1981	USGS	US Geological Survey	Water-Data Report	wq and wls, multiple wells
172	Water-level and saturated-thickness changes, predevelopment to 1980, in the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1981	Luckey, R.R., Gutentag, E.D., Weeks, J.B.	US Geological Survey	Hyrdologic Atlas	alluv & bedrk - prop, wl
173	Water-level records for the northern High Plains of Colorado, 1977-81	1981	Borman, R. G.	US Geological Survey	Open-File Report	alluv & bdrk wl
174	Dissolved solids and sodium in water from the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1982	Krothe, N.C., Oliver, J.W., Weeks, J.B.	US Geological Survey	Hyrdologic Atlas	alluv & bdrk wq
175	Ground water in Raton Basin, Las Animas County	1982	Geldon, A.L.	US Geological Survey	Professional Paper	alluv-prop, wl bdrk-aqprop, wq
176	Hydrogeology of the Dakota Group aquifer with emphasis on the radium-226 content of its contained ground water, Canon City Embayment, Fremont and Pueblo counties, Colorado	1982	Vinckier, T.A.	Colorado Geological Survey	Open-File Report	bdrk all categories
177	The hydrogeology of the Raton basin, southcentral Colorado	1982	Howard, W.B.	Indiana University	Master's Thesis	bdrk - config, wq
178	Water resources data, Colorado, water year 1982. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1982	USGS	US Geological Survey	Water-Data Report	wq and wls, multiple wells
179	Water-level records for the northern High Plains of colorado, 1978-82	1982	Blattner, J.L., Rasmuson, B.D.	US Geological Survey	Open-File Report	alluv & bdrk wl
180	Estimating 1980 ground-water pumpage for irrigation on the High Plains in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1983	Heimes, F.J., Luckey, R.R.	US Geological Survey	Water-Resources Investigations Report	alluv & bedrk - config, prop, wl
181	Groundwater flow patterns in the Dakota Group Aquifer in an area near Pueblo, Colorado	1983	Banta, E.R.	Colorado State University	Master's Thesis	bdrk- cnfg, prop, wq
182	Hydraulic characteristics of the Principal bedrock aquifers in the Denver Basin, Colorado	1983	Robson, S.G.	US Geological Survey	Hydrologic Atlas	bedrk - config, prop
183	Hydrogeologic data from parts of the Denver Basin, Colorado	1983	Major, T.J., Robson, S.G., Romero, J.C., Zawistow	US Geological Survey	Open-File Report	alluv & bedrk - config, prop, wl, wq
184	Hydrology of Area 61, northern Great Plains and Rocky Mountain coal provinces, Colorado and New Mexico	1983	Abbott, P.O., Geldon, A.L., Cain, D.L., Hall, A.P., E	US Geological Survey	Water-Resources Investigations Report	alluv & bedrk - config, wl, wq
185	The Ogallala aquifer in the northern High Plains of Colorado- saturated thickness in 1980; saturated-thickness changes, predevelopment to 1980; hydraulic conductivity; specific yield; and predevelopment and 1980 probable well yields	1983	Borman, R.G.	US Geological Survey	Hydrologic Investigations Atlas	bdrk - config, prop,wl
186	Water resources data, Colorado, water year 1983. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1983	USGS	US Geological Survey	Water-Data Report	wq and wls, multiple wells

REF NO	TITLE OF PUBLICATION	YEAR	AUTHOR(S)	PUBLISHER	PUBLICATION TYPE	REPORT COMMENTS AND DATA INFO
187	Water-level records for the northern High Plains of colorado, 1979-83	1983	Blattner, J.L., Rasmuson, B.D.	US Geological Survey	Open-File Report	alluv & bdrk wl
188	Artificial aquifer recharge in the Colorado portion of the Ogallala Aquifer	1984	Longenbaugh, R., Miles, D., Hess, E., Rubingh, J.	Colorado State University, Environmental Resourc	Information Series	bdrk prop, confg
189	Assessment of water resources at Fort Carson Military Reservation near Colorado Springs, CO	1984	Leonard, G.J.	US Geological Survey	Water-Resources Investigations Report	alluv & bedrk - config, prop, wl, wq
190	Determination and distribution of the hydraulic conductivity and specific yield of the Ogallala Aquifer in the northern High Plains of Colorado	1984	Bryn, S.M.	Colorado School of Mines	Master's Thesis	bedrk - config, prop, wl
191	Effects of irrigating with wastewater on ground-water quality at Fort Carson Military Reservation golf course near Colorado Springs, Colorado	1984	Edelmann, P.	US Geological Survey	Water-Resources Investigations Report	alluv - config, wl, wq
192	Geohydrology of the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1984	Gutentag, E.D., Heimes, F.J., Krothe, N. C., Lucke	US Geological Survey	Professional Paper	alluv & bedrk - config, prop, wl, wq
193	Geology, altitude, and depth of the bedrock surface; altitude of the water table in 1980; and saturated thickness of the Ogallala Aquifer in 1980 in the southern High Plains of Colorado	1984	Borman, R.G., Meredith, T.S., Bryn, S.M.	U. S. Geological Survey	Hydrologic Investigations Atlas	bdrk confg, wl
194	Locations of irrigation wells and application rates for irrigated cropland during 1980 in the Northern High Plains of Colorado	1984	Borman, R.G.	US Geological Survey	Hydrologic Investigations Atlas	wl
195	Quality of the Arkansas River and irrigation-return flows in the lower Arkansas River Valley, Colorado	1984	Cain, D.	US Geological Survey	Water-Resources Investigations Report	wq, wls, prop (pump) - detailed in Holly area
196	Specific yield by geophysical logging potential for the Denver Basin	1984	McWhorter, D. B.	Colorado State University, Colorado Water Resour	Completion Report	bdrk prop only
197	Water resources data, Colorado, water year 1984. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1984	USGS	US Geological Survey	Water-Data Report	wq and wls, multiple wells
198	Water-resources appraisal of the upper Arkansas River Basin from Leadville to Pueblo, Colorado	1984	Crouch, T.M., Cain, D., Abbott, P.O., Penley, R.D.,	US Geological Survey	Water-Resources Investigations Report	alluv & bedrk - config, prop, wl, wq
199	Assessment of long-term salinity changes in an irrigated stream-aquifer system	1985	Konikow, L.F., Person, M.A.	American Geophysical Union	Water Resources Research	alluv - config, prop, wl, wq
200	Colorado ground-water resources	1985	Hurr, R.T., Hearne, G.A.	US Geological Survey	Water-Supply Paper	alluv-cnfg,wl,prop bdrk-confg,wl,prop
201	Elevated nitrate concentrations in the Widefield Aquifer south of Colorado Springs, Colorado	1985	Cain, D.L.	US Geological Survey	Professional Paper	alluvial wq only
202	Gechemical interactions between uranium tailings fluids and subjacent bedrock, Canon City, Colorado; use of the computer model MINTEQ	1985	Davis, A.O.	University of Colorado	Doctoral Thesis	bdrk - config, prop, wq
203	Maps showing water geochemistry of the Buffalo Peaks Wilderness Study Area, Lake, Park, and Chaffee counties, Colorado	1985	Nowlan, G.A., Ficklin, W. H., Dover, R.A.	U.S. Geological Survey	Miscellaneous Field Studies Map	alluv & bdrk wq
204	Potential well yields from the Ogallala Aquifer in the northern High Plains of Colorado	1985	Lunsford, J.B.L., Borman, R.G.	US Geological Survey	Hydrologic Atlas	alluv & bedrk - config, prop, wl
205	Proposed work plan for the study of hydrologic effects of ground-water development in the Wet Mountain Valley, Colorado	1985	Robson, S.G.	US Geolgocial Survey	Open-File Report	alluv & bedrk - config
206	Selected climatological and hydrologic data, Raton Basin, Huerfano and Las Animas counties, Colorado, and Colfax County, New Mexico	1985	Geldon, A.L., Abbott, P.O.	US Geological Survey	Open-File Report	alluv & bedrk - config, prop, wl, wq
207	Selected hydrographs and statistical analyses characterizing the water resources of the Arkansas River basin, Colorado	1985	Burns, A.W.	US Geological Survey	Water-Resources Investigations Report	wls
208	Sources of water and nitrogen to the Widefield aquifer, southwestern El Paso County, Colorado	1985	Edelmann, P., Cain, D.	US Geological Survey	Water-Resources Investigations Report	config, prop, wq
209	The Dakota Aquifer near Pueblo, Colorado; faults and flow patters	1985	Banta, E.R.	US Geological Survey	Water-Resources Investigations Report	bedrk - config, prop, wl, wq
210	Water resources data, Colorado, water year 1985. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1985	USGS	US Geological Survey	Water-Data Report	wq and wls, multiple wells
211	A reconnaissance water-quality appraisal of the Fountain Creek alluvial aquifer between Colorado Springs and Pueblo, Colorado, including trace elements and organic constituents	1986	Cain, D., Edelmann, P.	US Geological Survey	Water-Resources Investigations Report	config, wls, wq, minor prop
212	Digital simulation of ground-water flow in the High Plains Aquifer in parts of Colorado, Kansas, nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming	1986	Luckey, R.R., Gutentag, E.D., Heimes, F.J., Weeks	US Geological Survey	Professional Paper	alluv & bedrk - config, prop, wl
213	High Plains regional aquifer-system study	1986	Weeks, J. B.	US Geological Survey	Circular	all bedrock categories
214	Influence of irrigation on salinity and nitrate changes in a stream-aquifer system	1986	Konikow, L.F., Person, M.A.	International Association of Hydrological Sciences	Conference-Document	alluv wq only
215	Recalibration and predictive reliability of a solute-transport model of an irrigated stream-aquifer system	1986	Person, M. A., Konikow, L. F.	Elsevier	Journal of Hydrology	alluv wq only
216	Water resources data, Colorado, water year 1986. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1986	USGS	US Geological Survey	Water-Data Report	wq and wls, multiple wells
217	Bedrock qquifers in the Denver Basin, Colorado; a quantitative water-resource appraisal	1987	Robson, S.G., Malcolm, R.L.	US Geological Survey	Professional Paper	bedrk - config, prop, wl, wq
218	Geochemical interactions between acidic tailings fluid and bedrock; use of the computer model MINTEQ	1987	Davis, A.O., Runnells, D.D.	Pergamon Press	Applied Geochemistry	bdrk wp only, 2 wells
219	Ground-water contamination near a uranium tailings disposal site in Colorado	1987	Goode, D.J., Wilder, R.J.	National Water Well Association	Ground Water	alluv & bedrk - config, prop, wl, wq
220	Ground-water flow and quality near Canon City, Colorado	1987	Hearne, G.A., Litke, D.W.	US Geological Survey	Water-Resources Investigations Report	alluv & bedrk - config, prop, wl, wq
221	Ground-water resources of the Denver Basin	1987	Robson, S.G., Malcolm, R.L.	US Geological Survey	Professional Paper	very general bedrk props only
222	Hydrology of the US Army Pinon Canyon Maneuver Site, Las Animas County, Colorado	1987	von Guerard, P., Abbott, P.O., Nickless, R.C.	US Geological Survey	Water-Resources Investigations Report	minor wl, PRIMARILY BEDROCK AQUIFER DATA
223	Relations of specific conductance to streamflow and selected water-quality characteristics of the Arkansas River basin, Colorado	1987	Cain, D.	US Geological Survey	Water-Resources Investigations Report	config, prop, wq,
224	Water resources data, Colorado, water year 1987. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1987	Ugland, R.C., Ebling, J.L., Steger, R.D.	US Geological Survey	Water-Data Report	wq, multiple wells
225	Water-bearing characteristics of geologic formations in northeastern New Mexico-southeastern Colorado	1987	Kilmer, C.L.	New Mexico Geological Society, Thirty-eighth annu	Conference-Document	bdrk confg, prop, wq
226	Water-level records for the northern High Plains of Colorado, 1970-86	1987	Reed, R	US Geological Survey	Open-File Report	alluv & bdrk wl
227	Geohydrology, water quality, and preliminary simulations of ground-water flow of the alluvial aquifer in the upper Black Squirrel Creek basin, El Paso County, Colorado	1988	Buckles, D.R., Watts, K.R.	US Geological Survey	Water-Resources Investigations Report	config, prop, wq, wls
228	Summary of the High Plains regional aquifer-system analysis in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming	1988	Weeks, J.B., Gutentag, E.D., Heimes, F.J., Luckey	US Geological Survey	Professional Paper	alluv & bedrk - config, prop, wl

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229	Water resources beneath State lands in part of T16S, R63W, Black Squirrel Creek basin, El Paso County, Colorado	1988	Kirkham, R.M., Cannon, S.H., Rogers, W.P., Stove	Colorado Geological Survey	Proprietary Report	config, prop, wls
230	Water resources data, Colorado, water year 1988. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1988	Ugland, R.C., Cochran, B.J., Ebling, J.L., Steger, R	US Geological Survey	Water-Data Report	wq, multiple wells
231	Ground water resources of the bedrock aquifers of the Denver Basin, Colorado	1989	Romero, J.C.	Colorado Division of Water Resources	Report	bdrk - config, wl, wq
232	Ground-water hydrology of the central Raton Basin, Colorado and New Mexico	1989	Geldon, A.L.	US Geological Survey	Water Supply Paper	alluv & bedrk - config, prop, wl, wq
233	Hydrogeologic characteristics of the valley-fill aquifer in the Arkansas River Valley, Crowley and Otero Counties, Colorado	1989	Nelson, G.A., Hurr, R.T., Moore, J.E.	US Geological Survey	Open-File Report	config, wls
234	Hydrogeologic characteristics of the valley-fill aquifer in the Arkansas River Valley, Prowers County, Colorado	1989	Nelson, G.A., Hurr, R.T., Moore, J.E.	US Geological Survey	Open-File Report	config, wls
235	Hydrogeologic characteristics of the valley-fill aquifer in the Arkansas River Valley, Pueblo County, Colorado	1989	Nelson, G.A., Hurr, R.T., Moore, J.E.	US Geological Survey	Open-File Report	config, wls
236	Hydrologic effects of pumpage from the Denver Basin bedrock aquifers of northern El Paso County, Colorado	1989	Banta, E.R.	US Geological Survey	Water-Resources Investigations Report	bedrk - config, prop, wl
237	Preliminary Assessment of the effects of acid mine drainage on ground water beneath a wetland near Leadville, Colorado	1989	Walton, K.D., Briggs, P.H.	US Geological Survey	Water-Resources Investigations Report	alluv wq
238	Water resources data, Colorado, water year 1989. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1989	Ugland, R.C., Cochran, B.J., Ebling, J.L., Steger, R	US Geological Survey	Water-Data Report	wq, multiple wells
239	Geohydrology and ground-water quality at the Pueblo Depot Activity landfill near Pueblo, Colorado	1990	Watts, K.R., Ortiz, R.F.	US Geological Survey	Water-Resources Investigations Report	config, prop, wls, wq
240	Impacts of wastewater discharge to Fountain Creek on nitrate contamination in the Widefield Aquifer	1990	Loomis, K.S., Warner, J.W.	Colorado State University, Colorado Water Resour	Completion Report	alluv wq only
241	The Widefield Aquifer Management Program	1990	Thompson, G.B.	Conference proceedings on Groundwater engineer	Conference-Document	alluv prop, confg, wl
242	Water resources data, Colorado, water year 1990. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1990	Ugland, R.C., Cochran, B.J., Hiner, M.M., Steger, F	US Geological Survey	Water-Data Report	wq, multiple wells
243	Water-level changes in the High Plains Aquifer underlying parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas; predevelopment through nonirrigation season 1988-89	1990	Dugan, J.T.,Schild, D.E., Kastner W.M.	US Geological Survey	Water-Resources Investigations Report	alluv & bdrk wl
244	Ground water levels in the Upper Black Squirrel Creek Designated Ground Water Basin	1991	Colorado Division of Water Resources	Colorado Division of Water Resources	Report	alluv wl only
245	Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the middle Arkansas River basin, Colorado and Kansas, 1988-89	1991	Mueller, D.K., DeWeese, L.R., Garner, A.J., Spruill	US Geological Survey	Water-Resources Investigations Report	general config, only 2 gw wq points
246	Water resources data, Colorado, water year 1991. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1991	Ugland, R.C., Cochran, B.J., Hiner, M.M., Steger, F	US Geological Survey	Water-Data Report	wq, multiple wells
247	Evaluating the hydrogeology of the Pleistocene Nussbaum Alluvium, Colorado, using vertical variability analysis and numerical modeling	1992	Paschke, S.S.	Colorado School of Mines	Master's Thesis	alluv- config, prop, wl
248	Evaluation of proposed water-management alternative to lower the high water table in the Arkansas River Valley near La Junta, Colorado	1992	Watts, K.R., Lindner-Lunsford, J.B.	US Geological Survey	Water-Resources Investigations Report	config, prop, wls
249	Quantification of reusable subsurface irrigation return flows in Colorado Springs (1987-1990)	1992	Kaufman, J.M.	Proceedings of the 28th symposium on Engineerin	Conference-Document	alluv & bdrk wl
250	Water resources data, Colorado, water year 1992. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1992	Ugland, R.C., Cochran, B.J., Hiner, M.M., Steger, F	US Geological Survey	Water-Data Report	wq, multiple wells
251	Water-level changes in the High Plains Aquifer, predevelopment to 1990	1992	Dugan, J.T., Schild, D. E.	US Geological Survey	Water-Resources Investigations Report	alluv & bdrk wl
252	Hydrology of the Great Plains aquifer system in Nebraska, Colorado, Kansas and adjacent areas	1993	Helgesen, J.O., Leonard, R.B., Wolf, R.J.	US Geological Survey	Professional Paper	bedrk - config, prop, wl, wq
253	The effect of streambed topography on surface-subsurface water exchange in mountain catchments	1993	Harvey, J.W., Bencala, K.E.	American Geophysical Union	Water Resources Research	alluv prop, wl
254	Water resources data, Colorado, water year 1993. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1993	Ugland, R.C., Cochran, B.J., Hiner, M.M., Steger, F	US Geological Survey	Water-Data Report	wq, multiple wells
255	A modern, refined application of a ground water flow model to the Arkansas River Basin	1994	Cole, S.E., Sharma, D., Schreuder, W.A.	Colorado State University	Publication of the 1994 Groundwater Modeling Conference	alluv & bedrk - config, prop, wl
256	Irrigation leaches uranium from soils and shales and concentrates it in Arkansas Valley waters of southeastern Colorado	1994	Bolinder, S.A., Zielinski, R.A.	US Geological Survey	Open-File Report	alluv - wq
257	Statistical analysis of uranium-mill raffinate contamination in water wells in Lincoln Park, south-central Colorado	1994	Banta, E. R.	US Geological Survey	Water-Resources Investigations Report	alluv wq
258	Water resources data, Colorado, water year 1994. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1994	Ugland, R.C., Maura, W.S., Steger, R.D., O'Neill, G	US Geological Survey	Water-Data Report	wq, multiple wells
259	Water-level changes in the High Plains Aquifer, predevelopment to 1992	1994	Dugan, J.T., Mcgrath, T., Zelt, R.B.	US Geological Survey	Water-Resources Investigations Report	alluv & bdrk wl
260	Water-level changes in the High Plains Aquifer, predevelopment to 1993	1994	Dugan, J.T., Cox, D. A.	US Geological Survey	Water-Resources Investigations Report	alluv & bdrk wl
261	Bibliography of selected water-resources information for the Arkansas River Basin in Colorado through 1985	1995	Kuzmiak, J.M., Strickland, H.H.	US Geological Survey	Open-File Report	config, prop, wls, wq
262	Ground water atlas of the United States; Segment 2, Arizona, Colorado, New Mexico, and Utah	1995	Robson, S.G., Banta, E.R.	US Geological Survey	Hydrologic Atlas	bdrk config, prop, wl, wq
263	Hydrogeologic characteristics of the alluvial aquifer and adjacent deposits of the Fountain Creek Valley, El Paso	1995	Radell, M.J., Lewis, M.E., Watts, K.R.	US Geological Survey	Water-Resources Investigations Report	config, prop, wls
264	Hydrogeology and simulation of flow between the alluvial and bedrock aquifers in the upper Black Squirrel basin, El Paso County, Colorado	1995	Watts, K.R.	US Geological Survey	Water-Resources Investigations Report	config, prop, wq, wls
265	Interpretation of ground-water and geologic data as part of the investigation of metals loading into Chalk Creek, Mary Murphy Mine site, Chaffee County, Colorado	1995	Wireman, M., Anctil, R.J.	American Institute of Professional Geologists, Pros	Conference-Document	alluv & bdrk wq
266	Irrigation water for the Fort Lyon Canal, southeastern Colorado, 1989-90	1995	Dash, R.G.	US Geological Survey	Water-Resources Investigations Report	prop

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267	Nitrogen isotopes in nitrate from surface water and shallow ground water at Sixmile Creek, southeastern Colorado	1995	Johnson, C.A., Zielinski, R.A., Asher-Bolinder, S.	US Geological Survey	Open-File Report	minor wq data
268	Quality of water in the alluvial aquifer and tributary alluvium of the Fountain Creek Valley, southwestern El Paso County, Colorado, 1991-92	1995	Lewis, M.E.	US Geological Survey	Water-Resources Investigations Report	water quality, minor config
269	The effect of river valleys and the Upper Cretaceous aquitard on regional flow in the Dakota Aquifer in the Central Great Plains and southeastern Colorado	1995	Macfarlane, P.A.	Kansas Geological Survey	Bulletin	Bdrk config, prop, wl
270	Uraniferous waters of the Arkansas River valley, Colorado, U.S.A.; a function of geology and land use	1995	Zielinski, R.A., Asher, B.S., Meier, A.L.	Pergamon Press	Applied Geochemistry	alluv & bdrk wq only
271	Water resources data, Colorado, water year 1995. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1995	Crowfoot, R.M. and others	US Geological Survey	Water-Data Report	wq, multiple wells
272	Effects of land use on water quality of the Fountain Creek alluvial aquifer, East-Central Colorado	1996	Chafin, D.T.	US Geological Survey	Water-Supply Paper	alluv wq
273	Hydrogeology of the alluvial aquifers at the Pueblo Depot Activity near Pueblo, Colorado	1996	Chafin, D.T.	US Geological Survey	Water-Resources Investigations Report	config, prop, wls, wq
274	Water resources data, Colorado, water year 1996. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1996	Crowfoot, R.M. and others	US Geological Survey	Water-Data Report	wq, multiple wells
275	Water-level changes in the High Plains Aquifer, predevelopment to 1994	1996	Dugan, J.T., Sharpe, J.B.	US Geological Survey	Water-Resources Investigations Report	alluv & bdrk wl
276	Ground water monitoring activities, Arkansas River Valley alluvial aquifer, 1994-1995	1997	Austin, B.	Colorado Department of Public Health and Environ	Report to the Commissioner of Agriculture	wq, very minor prop & config
277	Ground water monitoring in the Arkansas Valley	1997	Yergert, M., Austin, B., Waskom, R.	Colo. Dept. of Agriculture; Colo. Dept. of Public He	Arkansas River Valley Monitoring Fact Sheet	wq
278	Have nitrate concentrations changed in water in the alluvial aquifer of the Upper Black Squirrel Creek Basin since 1984?	1997	Brendle, D.	US Geological Survey	Fact Sheet	alluv wq
279	Low temperature diagenetic-metamorphic and magmatic contributions of external CO2 gas to a shallow ground water system	1997	Mayo, A. L., Muller, A.B.	Elsevier	Journal of Hydrology	bdrk wq only
280	Water resources data, Colorado, water year 1997. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1997	Crowfoot, R.M. and others	US Geological Survey	Water-Data Report	wq, multiple wells
281	Development of an object-oriented reaction transport computer code and simulation of acid mine drainage impacts to groundwater at the St. Kevin Gulch site, Leadville, Colorado	1998	Paschke, S.S.	Colorado School of Mines	Doctoral Thesis	alluv & bedrk - config, prop, wl, wq
282	Environmental isotopic investigation of ground-water movement and surface-water interactions, Royal Gorge Arch, Colorado	1998	Clarey, T.L., Krishnamurthy, R.V., Chase, R.B.	Rocky Mountain Association of Geologists	The Mountain Geologist	bdrk wq only
283	Noble gases, stable isotopes, and radiocarbon as tracers of flow in the Dakota Aquifer, Colorado and Kansas	1998	Clark, J.F., Davisson, L.M., Hudson, B.G., Macfarla	Elsevier	Journal of Hydrology	bdrk prop only
284	Sensitivity of Colorado aquifers to pesticide contamination: A regional-scale hydrogeologic analysis	1998	Hall, M.D.	Colorado Department of Agriculture; Colo Dept. of	State Management Plan Report	very general prop, config, wl data
285	Simulated effects of irrigation on salinity in the Arkansas River valley in Colorado	1998	Goff, K., Lewis, M.E., Person, M.A., Konikow, L.F.	National Water Well Association	Ground Water	alluv - config, prop, wl, wq
286	Water resources data, Colorado, water year 1998. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1998	Crowfoot, R.M. and others	US Geological Survey	Water-Data Report	wq, multiple wells
287	A Groundwater mass loading balance for the Apache tailings area, Leadville, Colorado	1999	Davis, G.S., Foulk, C.L., Close, B.V.	Colorado State University	Publication of the International Conference on Tailings and Mine Waste	alluv & bedrk - config, prop, wq
288	Comparison of two approaches for determining ground-water discharge and pumpage in the lower Arkansas River basin, Colorado, 1997-98	1999	Dash, R.G., Troutman, B.M., Edelmann, P.	US Geological Survey	Water-Resources Investigations Report	Mainly PUMPAGE DATA ONLY
289	Digital map of changes in water levels from predevelpment to 1980 for the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming	1999	Cederstrand, J.R., Becker, M.F.	US Geological Survey	Open-File Report	alluv & bdrk wl
290	Digital map of water-level changes in the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, 1980 to 1994	1999	Fischer, B.C., McGuire, V.L.	US Geological Survey	Open-File Report	alluv & bdrk wl
291	Digital map of water-level changes in the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, 1980 to 1995	1999	Fischer, B.C., McGuire, V.L.	US Geological Survey	Open-File Report	alluv & bdrk wl
292	Digital map of water-level changes in the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, 1980 to 1996	1999	Fischer, B.C., McGuire, V.L.	US Geological Survey	Open-File Report	alluv & bdrk wl
293	Evaluation of possible human-induced effects on ground-water quality, St. Charles Mesa, Colorado, 1997	1999	Brendle, D.L.	US Geological Survey	Water-Resources Investigations Report	wls, wq
294	Extent of the high water table and water-table fluctuations, St. Charles Mesa, Colorado, April 1997 to October 1998	1999	Brendle, D.L.	US Geological Survey	Fact Sheet	wls
295	Ground-water hydrology and simulation of five remediation alternatives for an area affected by uranium-mill effluent near Canon City, Colorado	1999	Banta, E.R., Chafin, D.T.	US Geological Survey	Water-Resources Investigations Report	wq, minor alluv config, minor alluv prop
296	Migration of geochemical evolution of ground water affected by uranium-mill effluent near Canon City, Colorado	1999	Chafin, D.T., Banta, E.R.	US Geological Survey	Water-Resources Investigations Report	alluv & bdkj wq
297	Water resources data, Colorado, water wear 1999. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	1999	Crowfoot, R.M. and others	US Geological Survey	Water-Data Report	wq, multiple wells
298	Analysis of hydrologic factors that affect ground-water levels in the Arkansas River alluvial aquifer near La Junta, Colorado, 1959-99	2000	Bossong, C.R.	US Geological Survey	Water-Resources Investigations Report	wls
299	Digital map of water-level changes in the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, 1980 to 1997	2000	Fischer, B.C., McGuire, V.L., Kollasch, K.M.	US Geological Survey	Open-File Report	alluv & bdrk wl
300	Effects of fluvial tailings deposits on soils and surface-and ground-water quality, and implications for remediation-upper Arkansas River, Colorado 1992-96	2000	Walton-Day, K. Ross, F.J., Gerner, L.J., Evans, J.E	US Geological Survey	Water-Resources Investigations Report	alluv wl, wq
301	Late-Quaternary recharge determined from chloride in shallow groundwater in the central Great Plains	2000	Macfarlane, P. A., Clark, J.F., Davisson, L.M., Hud	Academic Press	Quaternary Research	bdrk prop only
302	Mechanisms of groundwater contamination at a fluvial tailings site, Leadville, Colorado	2000	Peebles, T.H.	Colorado School of Mines	Master's Thesis	alluv & bedrk - config, prop, wl, wq
303	Water levels in the Denver Basin bedrock aquifers	2000	Colorado Division of Water Resources	Colorado Division of Water Resources	Report	bdrk wl
304	Water levels in the southern High Plains Designated Groundwater Basin, May 2000	2000	Colorado Division of Water Resources	Colorado Division of Water Resources	Report	alluv & bdrk wl

REF NO	TITLE OF PUBLICATION	YEAR	AUTHOR(S)	PUBLISHER	PUBLICATION TYPE	REPORT COMMENTS AND DATA INFO
305	Water resources data, Colorado, water year 2000. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	2000	Crowfoot, R.M., Unruh, J.W., Steger, R.D., O'Neill,	US Geological Survey	Water-Data Report	wq and wls, multiple wells
306	Water resources data, Colorado, water year 2001. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	2001	Crowfoot, R.M., Steger, R.D., Payne, W.F., O'Neill,	US Geological Survey	Water-Data Report	wq and wls, multiple wells
307	Changes in ground-water levels in selected wells in the Arkansas River alluvial aquifer downstream from Pueblo Reservoir, Southeastern Colorado, 1965-2001	2002	Steger, R.D.	US Geological Survey	Fact Sheet	wls
308	Evaluation of possible alternatives to lower the high water table of St. Charles Mesa, Pueblo County, Colorado	2002	Brendle, D.L.	US Geological Survey	Water-Resources Investigations Report	config, prop, wls,
309	Water resources data, Colorado, water year 2002. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	2002	Crowfoot, R.M., Payne, W.F., O'Neill, G.B.	US Geological Survey	Water-Data Report	wq, multiple wells
310	Particle and particle-facilitated contaminant transport in the vadose zone	2003	DeNovio, N.M.	University of Colorado	Doctoral Thesis	alluv - wq
311	Probability of detecting atrazine/desethyl-atrazine and elevated concentrations of nitrate in ground water in Colorado	2003	Rupert, M.G.	US Geological Survey	Water-Resources Investigations Report	wq
312	Water resources data, Colorado, water year 2003. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	2003	Crowfoot, R.M., Payne, W.F., O'Neill, G.B.	US Geological Survey	Water-Data Report	wq and wls, multiple wells
313	Aquifers of the Denver Basin, Colorado	2004	Topper, R.	Rocky Mountain Association of Geologists	The Mountain Geologist	bedrk - config, prop, wl
314	Assessing irrigation-induced selenium and iron in the stream-aquifer system of the lower Arkansas River Valley, Colorado	2004	Donnelly, J.P., Gates, T.K.	Colorado State University	Hydrology Days 2004 Proceedings	wq
315	Bedrock aquifers of the Denver Basin	2004	Raynolds, R.G., Reynolds, M.L.	Rocky Mountain Association of Geologists	The Mountain Geologist	bdrk-prop,confg,wl,wq
316	Ground water levels in the Denver Basin bedrock aquifers, October 2004	2004	VanSlyke, G.	Colorado Division of Water Resources	Report	bdrk wl
317	Ground water levels in the northern High Plains Designated Groundwater Basin, October 2004	2004	VanSlyke, G.	Colorado Division of Water Resources	Report	alluv & bdrk wl
318	Ground water levels in the southern High Plains Designated Groundwater Basin, October 2004	2004	Vanslyke, G	Colorado Division of Water Resources	Report	alluv & bdrk wl
319	Groundwater mining of bedrock aquifers in the Denver Basin; past, present, and future	2004	Moore, J. E., Raynolds, R. G., Barkmann, P. E.	Springer International	Environmental Geology	bdrk confg
320	Ground-water quality of granitic- and volcanic-rock aquifers in southeastern Park County, Colorado, July-August 2003	2004	Ortiz, R.F.	US Geological Survey	Fact Sheet	wq only
321	Water resources data, Colorado, water year 2004. Volume 1. Missouri River basin; Arkansas River basin; and Rio Grande basin	2004	Crowfoot, R.M., Payne, W.F., O'Neill, G.B., Boulge	US Geological Survey	Water-Data Report	wq and wls, multiple wells
322	Water-level changes in the High Plains Aquifer, predevelopment to 2002, 1980 to 2002, and 2001 to 2002	2004	McGuire, V.L.	US Geological Survey	Fact Sheet	alluv & bdrk wl
323	Hydrogeology and quality of ground water in the upper Arkansas River Basin from Buena Vista to Salida, Colorado, 2000-2003	2005	Watts, K. R.	US Geological Survey	Scientific Investigations Report	alluv & bedrk - config, prop, wl, wq
324	Sustainability of ground-water resources in the upper Arkansas River Basin between Buena Vista and Salida, Colorado, 2000-2003	2005	Watts, K. R.	US Geological Survey	Fact Sheet	config. Only
325	Variability of differences between two approaches for determining ground-water discharge and pumpage, including effects of time trends, lower Arkansas River basin, southeastern Colorado, 1998-2002	2005	Troutman, B.M., Edelmann, P., Dash, R.G.	US Geological Survey	Scientific Investigations Report	Mainly PUMPAGE DATA ONLY
326	A preliminary evaluation of vertical separation between production intervals of coalbed-methane wells and water-supply wells in the Raton Basin, Huerfano and Las Animas Counties, Colorado, 1999-2004	2006	Watts, K.R.	US Geological Survey	Scientific Investigations Report	bdrk config, wl
327	Application of a stream-aquifer model to Monument Creek for development of a method to estimate transit losses for reusable water, El Paso County, Colorado	2006	Kuhn, G., Arnold, R. L.	US Geological Survey	USGS Scientific Investigations Report	alluv - config, prop, wl
328	Assessing and modeling irrigation-induced selenium in the stream-aquifer system of the lower Arkansas River Valley, Colorado	2006	Herting, A.W., Gates, T.K.	Colorado State University	Hydrology Days 2006 Proceedings	wq
329	Ground water levels in the Upper Black Squirrel Creek Designated Ground Water Basin, March 2006	2006	Schaubs, M.P.	Colorado Division of Water Resources	Water Level Measurements	wls
330	Ground water levels, Upper Big Sandy Designated Ground Water Basin, March 2006	2006	Schaubs, M.P.	Colorado Division of Water Resources	Water Level Measurements	wls
331	Hydrostratigraphic framework of the Raton, Vermejo, and Trinidad Aquifers in the Raton Basin, Las Animas County, Colorado	2006	Watts, K.R	US Geological Survey	Scientific Investigations Report	bdrk config, wl
332	Toward optimal water management in Colorado's lower Arkansas River Valley: monitoring and modeling to enhance agriculture and environment	2006	Gates, T.K., Garcia, L.A., Labadie, J.W.	Colorado State University	Colorado Water Resources Research Institute Completion Report	wls, wq (also published as Colorado Ag. Experiment Station Technical Report TR06-10)
333	Water-quality assessment of the High Plains Aquifer, 1999-2004	2007	Mcmahon, P.B., Dennehy, K.F., Breton, B.W., Gur	US Geological Survey	Professional Paper	alluv & bedrk - config, wl, wq
334	Analyzing the effects of high water tables on evapotranspiration from uncultivated land in Colorado's lower Arkansas River Valley	2008	Hallberg, N.U., Niemann, J.D., Gates, T.K.	Colorado State University	Hydrology Days	alluv wl only

Table B-8. Summary of Water Level Data in HydroBase

Water District	Number of Wells with Water Level Data	Period of Record	
10	1,056	1920	2009
11	191	1959	2009
12	169	1903	2009
13	194	1964	2009
14	490	1922	2009
15	74	1960	2009
16	86	1949	1986
17	958	1952	2009
18	39	1978	1978
19	255	1937	1997
66	466	1917	2009
67	2,063	1920	2009
79	14	1950	2008
Total	6,055		

Table B-9. Climate Data Summary
Based on data from HydroBase, summarized
NOAA stations

STATION ID	STATION NAME	WATER DISTRICT	COUNTY	LATITUDE	LONGITUDE	ELEVATION	TEMP	PRECIP	EVAP	SNOW	START YEAR	END YEAR	SOURCE	TEMP % COMPLETE[1]	PRECIP % COMPLETE	EVAP % COMPLETE[2]	SNOW % COMPLETE
102	AGUILAR 1 SE	18	LAS ANIMAS	37.4	-104.65	6399.9		X		X	1980	2005	NOAA		97%		97%
105	AGUILAR 18 WSW	19	LAS ANIMAS	37.316666	-104.949997	8644		X		X	1998	2009	NOAA		98%		98%
242	AMY	67	LINCOLN	38.883322	-103.650513	5243		X		X	1948	1973	NOAA		97%		95%
343	AROYA 6 NE	67	CHEYENNE	38.916666	-103.083832	4793.5	X	X		X	1948	1972	NOAA	0%	99%		97%
437	AYER RANCH	10	EL PASO	39.016657	-104.600533	7234.6	X	X		X	1948	1970	NOAA	0%	100%		99%
712	BIG SPRINGS RANCH	10	EL PASO	38.866653	-104.317194	6043.6		X			1948	1951	NOAA		97%		
784	BLOOM	17	OTERO	37.683347	-103.950512	4472		X		X	1949	1954	NOAA		100%		100%
840	BOONE 2 SE	14	PUEBLO	38.216663	-104.233853	4434.9		X		X	1980	1986	NOAA		81%		76%
837	BOONE 6 SSW	14	PUEBLO	38.166668	-104.316666	4596.1		X		X	2002	2007	NOAA		98%		98%
839	BOONE 9NNW	14	PUEBLO	38.366665	-104.300003	4790		X		X	2002	2009	NOAA		97%		98%
873	BOX RANCH	19	LAS ANIMAS	37.233352	-103.800522	5604	X	X		X	1948	1950	NOAA	71%	76%		76%
884	BOYERO 1 WSW	67	LINCOLN	38.91666	-103.283826	4741	X	X		X	1981	1981	NOAA	75%	95%		100%
895	BRANDON	67	KIOWA	38.45001	-102.450474	3925.1		X		X	1955	1999	NOAA		89%		80%
898	BRANSON	19	LAS ANIMAS	37.016681	-103.883853	6293	X	X		X	1948	1974	NOAA	88%	90%		89%
1071	BUENA VISTA	11	CHAFFEE	38.816666	-106.133331	7945.9	X	X		X	1948	2009	NOAA	94%	95%		91%
1157	BUTLER RANCH	14	PUEBLO	38.03334	-104.467199	4852.6		X		X	1951	1977	NOAA		95%		94%
1268	CAMPO 7 S	66	BACA	37.016666	-102.550003	4118.1	X	X		X	1954	2009	NOAA	78%	94%		92%
1294	CANON CITY	12	FREMONT	38.466667	-105.23333	5366.1	X	X		X	1948	2009	NOAA	93%	93%		91%
1539	CHERAW 1 N	17	OTERO	38.116665	-103.51667	4147	X	X		X	1948	2009	NOAA	100%	30%		98%
1586	CHIVINGTON	67	KIOWA	38.43334	-102.533812	3904.4		X		X	1953	1954	NOAA		100%		99%
1660	CLIMAX	11	LAKE	39.383335	-106.199997	11319.9	X	X	X	X	1958	2009	NOAA	99%	99%	25%	99%
1693	COALDALE	12	FREMONT	38.383332	-105.783903	6535.8		X			1948	1951	NOAA		99%		
1698	COALDALE 2 SW	12	FREMONT	38.349995	-105.783899	6906.5	X	X		X	1963	1964	NOAA	93%	89%		86%
1780	COLORADO SPRINGS FIRE DEPARTM	10	EL PASO	38.816666	-104.783333	19862.2		X		X	2008	2009	NOAA		100%		93%
1781	COLORADO SPRINGS FS 18	10	EL PASO	38.916668	-104.849998	21761.8		X		X	2008	2009	NOAA		90%		93%
1782	COLORADO SPRINGS FS 19	10	EL PASO	38.950001	-104.76667	22224.4		X		X	2007	2009	NOAA		100%		93%
1784	COLORADO SPRINGS FS 20	10	EL PASO	38.916668	-104.75	22040.7		X		X	2007	2009	NOAA		99%		81%
1778	COLORADO SPRINGS MUNI AP	10	EL PASO	38.816666	-104.683334	6181.1	X	X		X	1948	2009	NOAA	100%	100%		99%
1973	CRIPPLE CREEK	12	TELLER	38.75	-105.183334	9549.9	X	X		X	1948	2003	NOAA	10%	10%		10%
1977	CRIPPLE CREEK 3NNW	12	TELLER	38.783333	-105.199997	30298.6	X	X		X	2005	2009	NOAA	83%	90%		94%
2000	CROWDER RANCH	19	LAS ANIMAS	37.38335	-103.883856	5131.5	X	X		X	1980	1983	NOAA	100%	100%		92%
2040	CUCHARAS DAM	16	HUERFANO	37.750004	-104.600543	5845.4		X			1948	1951	NOAA		96%		
2178	DELHI	17	LAS ANIMAS	37.633348	-104.017188	5092.1	X	X		X	1954	1980	NOAA	93%	96%		94%
2312	DOHERTY RANCH	19	LAS ANIMAS	37.38335	-103.883856	5134.8		X		X	1948	1980	NOAA		99%		93%
2446	EADS	67	KIOWA	38.483334	-102.783333	4214.9	X	X		X	1918	2009	NOAA	90%	93%		91%
2501	EASTONVILLE 6 WSW	10	EL PASO	39.033321	-104.667197	7605.4		X		X	1956	1966	NOAA		98%		97%
2803	EVERSOLL RANCH	66	BACA	37.03335	-102.067122	3582.9	X	X		X	1948	1966	NOAA	81%	97%		96%
2955	FLORENCE	12	FREMONT	38.383334	-105.133883	5193.8	X	X		X	1948	1950	NOAA	100%	100%		100%
1978	FLORISSANT FOSSL BED	12	TELLER	38.866651	-105.300557	8507.6		X			1948	1951	NOAA		95%		
2997	FORDER 8 S	17	LINCOLN	38.549997	-103.683838	4783.7	X	X		X	1948	1979	NOAA	89%	91%		91%
3002	FORT CARSON BUTTS AAF	10	EL PASO	38.683334	-104.76667	5841.9	X	X		X	1981	2003	NOAA	64%	89%		93%
3063	FOUNTAIN	10	EL PASO	38.683328	-104.700534	5560.3		X		X	1948	1997	NOAA		96%		91%
3068	FOUNTAIN 6 NNE	10	EL PASO	38.783324	-104.617196	5964.9		X		X	1948	1959	NOAA		99%		98%
3079	FOWLER 1 SE	17	OTERO	38.116665	-104	4330		X		X	1948	2009	NOAA		100%		99%
3138	FROZE CREEK	13	CUSTER	38.000004	-105.333894	8205.8		X			1948	1948	NOAA		83%		
3222	GARDNER	79	HUERFANO	37.766669	-105.183894	6965.6		X		X	1948	1971	NOAA		96%		92%
3463	GRAFT 2NNE	67	BACA	37.45001	-102.883811	4954.3		X		X	1948	1949	NOAA		83%		83%
3477	GRANADA	67	PROWERS	38.066674	-102.317143	3483.1		X		X	1948	1951	NOAA		91%		100%
3654	GUFFEY	12	PARK	38.749992	-105.533888	8606.1		X		X	1948	1950	NOAA		100%		100%
3656	GUFFEY 10 SE	12	FREMONT	38.683334	-105.400002	8595.1		X		X	1950	2006	NOAA		97%		97%
3655	GUFFEY 5 N	12	PARK	38.816652	-105.53389	9006.3		X		X	1950	1950	NOAA		100%		100%

STATION ID	STATION NAME	WATER DISTRICT	COUNTY	LATITUDE	LONGITUDE	ELEVATION	TEMP	PRECIP	EVAP	SNOW	START YEAR	END YEAR	SOURCE	TEMP % COMPLETE[1]	PRECIP % COMPLETE	EVAP % COMPLETE[2]	SNOW % COMPLETE
3652	GUFFEY 9SE	12	FREMONT	38.683334	-105.383331	29248.7		X		X	2007	2009	NOAA		100%		100%
3783	HARMON RANCH	67	BACA	37.483341	-102.683813	4462.2		X		X	1948	1959	NOAA		100%		100%
3828	HASWELL	17	KIOWA	38.450001	-103.166664	4524.9	X	X		X	1922	2009	NOAA	0%	96%		96%
3982	HIGBEE 2 SW	17	OTERO	37.750009	-103.467171	4252.2		X		X	1948	1980	NOAA		26%		24%
4076	HOLLY	67	PROWERS	38.049999	-102.116669	3390.1	X	X		X	1918	2009	NOAA	94%	95%		94%
4172	HUGO 1 NW	67	LINCOLN	39.150002	-103.48333	5024.9	X	X		X	1948	2009	NOAA	94%	34%		91%
4388	JOHN MARTIN DAM	67	BENT	38.066666	-102.933334	3814	X	X	X	X	1948	2009	NOAA	88%	96%	34%	91%
4444	KARVAL	17	LINCOLN	38.733334	-103.550003	5075.1	X	X		X	1948	2009	NOAA	92%	98%		96%
4546	KIM 10 SSE	66	LAS ANIMAS	37.116665	-103.300003	5299.9	X	X		X	1988	2009	NOAA	100%	100%		100%
4538	KIM 15 NNE	67	LAS ANIMAS	37.450001	-103.316666	5149.9	X	X		X	1948	2009	NOAA	70%	37%		70%
4542	KIM 5 SW	19	LAS ANIMAS	37.200019	-103.483836	5810.6	X	X		X	1980	1983	NOAA	96%	95%		96%
4603	KIT CARSON	67	CHEYENNE	38.766666	-102.800003	4319.9	X	X		X	1948	2009	NOAA	92%	94%		93%
4606	KIT CARSON 9 NNE	67	CHEYENNE	38.883335	-102.716667	4609.9	X	X		X	1996	2009	NOAA	100%	99%		99%
4684	KUTCH	67	ELBERT	38.91666	-103.867177	5653.2		X			1948	1951	NOAA		80%		
4686	KUTCH 6 SSE	17	LINCOLN	38.833321	-103.833844	5364.4	X	X		X	1980	1985	NOAA	97%	98%		94%
4724	LA JUNTA 1 S	17	OTERO	37.983334	-103.533333	4191.9	X	X		X	1995	2009	NOAA	94%	96%		96%
4726	LA JUNTA 20 S	17	OTERO	37.716667	-103.5	4240.2	X	X		X	1982	2009	NOAA	99%	99%		99%
4720	LA JUNTA MUNICIPAL AP	17	OTERO	38.049999	-103.51667	4193.9	X	X		X	1945	2009	NOAA	94%	94%		93%
4865	LA VETA	16	HUERFANO	37.500013	-105.000552	7034.5	X	X		X	1963	1971	NOAA	93%	97%		97%
4870	LA VETA PASS	16	HUERFANO	37.466677	-105.16723	9245.9		X		X	1948	1954	NOAA		93%		88%
4750	LAKE MORAINE	10	EL PASO	38.816647	-104.983864	10263	X	X		X	1948	1963	NOAA	95%	96%		78%
4770	LAMAR	67	PROWERS	38.099998	-102.633331	3627	X	X		X	1918	2009	NOAA	99%	99%		98%
4834	LAS ANIMAS	17	BENT	38.066666	-103.216667	3890.1	X	X		X	1930	2009	NOAA	96%	98%		97%
4884	LEADVILLE	11	LAKE	39.216653	-106.30059	9941.4	X	X		X	1948	1982	NOAA	79%	81%		57%
4885	LEADVILLE LAKE COUNTY AP	11	LAKE	39.233334	-106.316666	9938	X	X		X	1976	2008	NOAA	89%	87%		91%
5001	LIME 3 SE	15	PUEBLO	38.116666	-104.583877	4905.1		X		X	1948	1968	NOAA		90%		90%
5017	LIMON	67	LINCOLN	39.266652	-103.683842	5371	X	X		X	1948	1971	NOAA	98%	99%		98%
5018	LIMON	67	LINCOLN	39.18332	-103.700507	5562.3	X	X		X	1971	1999	NOAA	84%	84%		97%
5015	LIMON 10 SSW	67	ELBERT	39.149984	-103.767187	5564.6	X	X		X	1918	1971	NOAA	93%	94%		93%
5020	LIMON HASS RANCH	67	ELBERT	39	-103.73333	5503.9		X		X	1956	2009	NOAA		23%		23%
6438	LIMON HASS RANCH	67	ELBERT	38.999984	-103.733845	5453		X		X	1948	1955	NOAA		100%		100%
5352	MANITOU SPRINGS	10	EL PASO	38.849984	-104.933866	6630.2		X		X	1948	1992	NOAA		8%		100%
5427	MATHESON 8 SE	67	ELBERT	39.133335	-103.849998	5830	X	X		X	1995	2009	NOAA	97%	97%		96%
5564	MIDWAY 4 N	10	EL PASO	38.616658	-104.667192	5354.6		X			1948	1951	NOAA		78%		
1278	MITCHELL 22 E	66	BACA	37.066679	-102.233795	4383.4		X		X	1951	1954	NOAA		93%		93%
5667	MITCHELL 22 E	66	BACA	37.066679	-102.233795	4383.4		X		X	1948	1951	NOAA		100%		100%
5734	MONUMENT	10	EL PASO	39.099998	-104.866669	7080	X	X		X	1988	2003	NOAA	98%	98%		98%
5732	MONUMENT 1SSE	10	EL PASO	39.066666	-104.849998	22752.6	X	X		X	2004	2009	NOAA	93%	97%		98%
5730	MONUMENT 2 WSW	10	EL PASO	39.083321	-104.917211	7346.2	X	X		X	1948	1964	NOAA	92%	94%		93%
5819	MULE SHOE LODGE 1 SS	16	HUERFANO	37.583334	-105.183899	8870.2		X			1948	1951	NOAA		83%		
5890	NEPESTA 2 NW	14	PUEBLO	38.183331	-104.16719	4403.1		X		X	1978	1979	NOAA		100%		76%
5990	NORTH LAKE	19	LAS ANIMAS	37.216676	-105.050567	8806.2	X	X		X	1948	1980	NOAA	96%	97%		74%
6131	ORDWAY 2 ENE	17	CROWLEY	38.216667	-103.716667	4315	X	X		X	1939	2009	NOAA	87%	95%		94%
6136	ORDWAY 21 N	17	LINCOLN	38.533333	-103.699997	4767.1	X	X		X	1980	2009	NOAA	99%	99%		97%
6280	PALMER LAKE	10	EL PASO	39.116665	-104.916664	7220.1	X	X		X	1965	2009	NOAA	91%	45%		44%
6410	PENROSE 3 NNW	12	FREMONT	38.450001	-105.067215	5413.6		X		X	1948	1973	NOAA		97%		92%
6710	PRITCHETT 16 SW	66	BACA	37.233345	-103.083827	5180.7	X	X		X	1980	1982	NOAA	100%	86%		92%
6767	PUEBLO 6 SSW	15	PUEBLO	38.183334	-104.650534	4914.9	X	X	X	X	1971	1985	NOAA	95%	99%	45%	79%
6763	PUEBLO ARMY DEPOT	14	PUEBLO	38.316665	-104.350531	4734.5		X		X	1957	1977	NOAA		94%		82%
6743	PUEBLO CITY RESERVOIR	10	PUEBLO	38.283328	-104.650534	4691.8	X	X	X	X	1948	1970	NOAA	94%	98%	61%	89%
6748	PUEBLO FIRE STN #2	10	PUEBLO	38.266667	-104.600533	4705		X		X	1948	1954	NOAA		99%		97%
6753	PUEBLO FIRE STN #5	10	PUEBLO	38.283332	-104.617203	4803.4		X		X	1948	1950	NOAA		100%		97%
6740	PUEBLO MEMORIAL AP	14	PUEBLO	38.283333	-104.5	4720.1	X	X	X	X	1971	2009	NOAA	100%	99%	39%	97%
6765	PUEBLO RESERVOIR	14	PUEBLO	38.266666	-104.716667	4855	X	X	X	X	1975	2009	NOAA	94%	99%	53%	94%

STATION ID	STATION NAME	WATER DISTRICT	COUNTY	LATITUDE	LONGITUDE	ELEVATION	TEMP	PRECIP	EVAP	SNOW	START YEAR	END YEAR	SOURCE	TEMP % COMPLETE[1]	PRECIP % COMPLETE	EVAP % COMPLETE[2]	SNOW % COMPLETE
6738	PUEBLO WB AIRPORT	14	PUEBLO	38.23333	-104.633863	4806.7	X	X		X	1948	1954	NOAA	100%	100%		100%
6977	RED WING 1 WSW	79	HUERFANO	37.716666	-105.317228	7900.3	X	X		X	1982	1995	NOAA	96%	99%		99%
7167	ROCKY FORD 2 SE	17	OTERO	38.033333	-103.699997	4170	X	X		X	1918	2009	NOAA	100%	100%		100%
7287	RUSH 1 N	17	EL PASO	38.866665	-104.099998	6054.1	X	X		X	1924	2009	NOAA	90%	93%		88%
7309	RUXTON PARK	10	EL PASO	38.849998	-104.966667	9049.9	X	X		X	1959	2009	NOAA	99%	99%		99%
7315	RYE	15	PUEBLO	37.916677	-104.933888	6848.4	X	X		X	1948	1992	NOAA	92%	93%		79%
7317	RYE 1 SW	15	PUEBLO	37.916668	-104.949997	7141.1	X	X		X	1997	2009	NOAA	100%	100%		100%
7370	SALIDA	11	CHAFFEE	38.533333	-106.01667	7160.1	X	X		X	1948	2009	NOAA	75%	75%		75%
7371	SALIDA 3 W	11	CHAFFEE	38.533324	-106.050581	7488.2	X	X		X	1970	1984	NOAA	83%	83%		82%
7572	SHEEP MOUNTAIN	79	HUERFANO	37.716667	-105.23333	7753.9	X	X		X	1988	2009	NOAA	97%	96%		97%
7582	SHERIDAN LAKE	67	KIOWA	38.466667	-102.300003	4071.9	X	X		X	2000	2008	NOAA	92%	93%		95%
7664	SIMLA	67	ELBERT	39.149986	-104.083855	5980.3		X			1948	1951	NOAA		95%		
7862	SPRINGFIELD	67	BACA	37.400016	-102.617149	4411.3		X		X	1918	1985	NOAA		87%		86%
7866	SPRINGFIELD 7 WSW	66	BACA	37.366665	-102.75	4622	X	X	X	X	1956	2002	NOAA	98%	99%	57%	100%
7867	SPRINGFIELD 8 S	66	BACA	37.283348	-102.617148	4504.8	X	X		X	1948	1964	NOAA	86%	97%		94%
6705	SPRINGFIELD 8 SW	66	BACA	37.316683	-102.71715	4393.3		X		X	1948	1951	NOAA		97%		100%
7871	SPRINGFIELD 8 SW	66	BACA	37.316683	-102.71715	4393.3		X		X	1951	1956	NOAA		100%		100%
7345	ST ELMO	11	CHAFFEE	38.699994	-106.36725	10016.9		X		X	1950	1953	NOAA		100%		100%
7992	STONINGTON	66	BACA	37.300012	-102.183801	3802.4		X		X	1948	1999	NOAA		96%		94%
8064	SUGARLOAF RESERVOIR	11	LAKE	39.25	-106.366669	9737.9	X	X	X	X	1948	2009	NOAA	91%	90%	30%	81%
8157	TACONY 10 SE	14	PUEBLO	38.400002	-104.066666	4960	X	X		X	1955	2009	NOAA	93%	95%		95%
8212	TENNESSEE PASS	11	LAKE	39.333322	-106.333925	10256.4	X	X		X	1948	1953	NOAA	100%	100%		100%
8220	TERCIO 4 NW	19	LAS ANIMAS	37.083348	-105.050567	8270.4		X		X	1948	1951	NOAA		100%		100%
8290	TIMPAS 13 SW	17	OTERO	37.666677	-103.917185	4830.3	X	X		X	1978	1993	NOAA	98%	99%		99%
8429	TRINIDAD	19	LAS ANIMAS	37.183334	-104.48333	6029.9	X	X		X	1948	2009	NOAA	92%	91%		87%
8436	TRINIDAD LAKE	19	LAS ANIMAS	37.15	-104.55	6310	X	X	X	X	1989	2009	NOAA	100%	99%	62%	95%
8434	TRINIDAD LAS ANIMAS COUNTY AP	19	LAS ANIMAS	37.266666	-104.333336	5741.1	X	X		X	1948	2009	NOAA	99%	99%		99%
8431	TRINIDAD RIVER	19	LAS ANIMAS	37.18335	-104.517216	6050.2	X	X		X	1978	1993	NOAA	100%	97%		80%
8468	TROY 1 SE	66	LAS ANIMAS	37.133355	-103.300499	5607.2	X	X		X	1948	1987	NOAA	0%	98%		95%
8496	TWIN LAKES EVAPORATION	11	LAKE	39.083322	-106.30059	9177	X	X	X	X	1965	1967	NOAA	33%	28%	25%	29%
8501	TWIN LAKES RES	11	LAKE	39.099998	-106.349998	9205	X	X	X	X	1949	2009	NOAA	83%	91%	22%	84%
8510	TWO BUTTES	67	BACA	37.566672	-102.400476	4134.1	X	X		X	1918	1972	NOAA	79%	80%		80%
8516	TWO BUTTES RESERVOIR	67	PROWERS	37.650007	-102.53381	4252.2		X		X	1953	1955	NOAA		99%		98%
8574	UTLEYVILLE	66	BACA	37.266683	-103.033827	5003.5	X	X		X	1948	1956	NOAA	68%	93%		92%
8649	VICTOR	12	TELLER	38.716657	-105.150539	9708.5	X	X		X	1966	1976	NOAA	73%	73%		67%
8781	WALSENBURG	16	HUERFANO	37.633335	-104.76667	6149.9	X	X		X	1948	2009	NOAA	99%	99%		99%
8793	WALSH 1 W	67	BACA	37.383335	-102.300003	3978	X	X	X	X	1951	2009	NOAA	97%	71%	48%	70%
8931	WESTCLIFFE	13	CUSTER	38.133335	-105.466667	7859.9	X	X		X	1948	2009	NOAA	98%	99%		99%
8986	WETMORE 2 S	12	CUSTER	38.216664	-105.100544	6585	X	X		X	1948	1968	NOAA	92%	93%		85%
8988	WETMORE 8 SW	12	CUSTER	38.133338	-105.200548	7605.4		X		X	1949	1953	NOAA		100%		95%
8990	WETMORE 9 S	12	CUSTER	38.133336	-105.083886	7365.9	X	X		X	1968	1976	NOAA	95%	80%		80%
8997	WHITE ROCK	17	PUEBLO	37.866668	-104.117188	4729.9		X			1948	1951	NOAA		97%		
9060	WILD HORSE 11SSE	67	CHEYENNE	38.650002	-102.98333	14386.5	X	X		X	2004	2009	NOAA	93%	97%		96%
9058	WILD HORSE 6N	67	CHEYENNE	38.900002	-103.01667	4720.1	X	X		X	2004	2009	NOAA	97%	97%		97%
9216	WOOTTON RANCH	19	LAS ANIMAS	37.016666	-104.48333	7580		X		X	1978	2001	NOAA		100%		95%

n/a - Data not available

[1] Temperature data availability based on mean monthly temperature. Additional data available for daily, minimum and maximum temperatures.

[2] Evaporation data percent complete does not account for the fact that during winter months there is no evaporation data because no evaporation is occurring.

Table B-10. Climate Data Summary
Based on data from HydroBase, summarized
COAGMET stations

STATION ID	STATION NAME	WATER DISTRICT	COUNTY	LATITUDE	LONGITUDE	ELEVATION (FEET)	TEMP	PRECIP	VAPOR PRESSURE	SOLAR	WIND	SOIL TEMP	START YEAR	END YEAR	SOURCE	TEMP % COMPLETE[1]	PRECIP % COMPLETE	VAPOR PRESSURE % COMPLETE	SOLAR % COMPLETE	WIND % COMPLETE
AVN01	AVONDALE, 1 MI SE AVONDALE	14	PUEBLO	38.216599	-104.341003	4580	X	X	X	X	X	X	1992	CURRENT	COAGMET		98%	97%	97%	98%
RFD02	CSU EXPT STN ROCKY FORD NRCS, MOVED TO HLY01	17	OTERO	38.038502	-103.695	4180	X	X	X	X	X	X	1999	2005	COAGMET		79%	55%	46%	63%
RFD01	CSU EXPT STN ROCKY FORD, 2.5 MI SE ROCKY FORD	17	OTERO	38.038502	-103.695	4180	X	X	X	X	X	X	1992	CURRENT	COAGMET		95%	95%	95%	95%
FWL01	FOWLER, FOWLER GOLF COURSE	17	OTERO	38.135101	104.031998	4335	X	X	X	X	X	X	2005	CURRENT	COAGMET		100%	100%	100%	100%
HNE01	HOEHNE, NE TRINIDAD	19	LAS ANIMAS	37.289299	-104.313004	5625	X	X	X	X	X	X	2000	CURRENT	COAGMET		99%	99%	99%	99%
HLY02	HOLLY #2, 8.5 MI NW HOLLY	67	PROWERS	38.136101	102.240997	3570	X	X	X	X	X	X	2005	CURRENT	COAGMET		93%	90%	89%	92%
HLY01	HOLLY, 5 MI NW HOLLY	67	PROWERS	38.07	-102.089996	3636	X	X	X	X	X	X	2001	CURRENT	COAGMET		99%	99%	99%	97%
LJT01	LAJUNTA, 11 MI NE LAJUNTA	17	BENT	38.077801	103.365997	3960	X	X	X	X	X	X	2005	CURRENT	COAGMET		100%	100%	100%	100%
LAM01	LAMAR #1, 4.5 MI S LAMAR	67	PROWERS	37.980701	-102.596001	3776	X	X	X	X	X	X	1996	CURRENT	COAGMET		86%	89%	85%	84%
LAM02	LAMAR #2, 7 MI NNE LAMAR	67	PROWERS	38.173401	-102.558998	3736	X	X	X	X	X	X	2002	2005	COAGMET		83%	99%	99%	99%
LAM03	LAMAR #3, 10 MI SW LAMAR	67	BACA	37.979801	-102.712997	3918	X	X	X	X	X	X	2002	CURRENT	COAGMET		90%	98%	95%	98%
LAM04	LAMAR #4, 4.5 MI NNE LAMAR	67	PROWERS	38.1539	102.598999	3705	X	X	X	X	X	X	2005	CURRENT	COAGMET		99%	99%	99%	99%
LMS01	LAS ANIMAS, 1 MI NW MCCLAVE	67	BENT	38.1478	102.859001	3895	X	X	X	X	X	X	2005	CURRENT	COAGMET		100%	100%	100%	99%
PBL01	PUEBLO (DEFUNCT), PUEBLO	14	PUEBLO	38.231701	-104.467003	4710	X	X	X	X	X	X	1993	1995	COAGMET		95%	95%	95%	95%
SCM01	SAND CREEK MASSACRE HS, 7.5 MI NNE OF CHIVINGTON	67	KIOWA	38.5439	102.502998	3963	X	X	X	X	X	X	2008	CURRENT	COAGMET		100%	100%	100%	100%
VLD01	VINELAND, 13 MI SE PUEBLO	14	PUEBLO	38.223499	-104.460999	4420	X	X	X	X	X	X	1993	CURRENT	COAGMET		98%	98%	98%	98%

[1] Percent complete calculations for temperature were based on mean monthly temperature data availble in HydroBase (for NOAA stations). Temperature data for CoAgMet stations only available on a daily basis.

Additional COAGMET Station not included in HydroBase:

STT01	STONINGTON	66	BACA	37.1613	102.122	3841	X	X	X	X	X	X	2006	2008	COAGMET

Table B-11. Summary of SNOTEL Sites in Division 2

NWS ID	NRCS ID	Site Name	Lat	Long	Elev	Start	End	Tributary
APSC2	05M07S	APISHAPA	37.20	-105.04	10,000	1980	Active	Apishapa
BRMC2	06K40S	BRUMLEY	39.05	-106.32	10,600	1980	Active	Arkansas
FMTC2	06K08S	FREMONT PASS	39.23	-106.12	11,400	1980	Active	Blue
GLNC2	05L11S	GLEN COVE	38.53	-105.06	11,460	2004	Active	Fountain
HPAC2	05L12S	HAYDEN PASS	38.16	-105.51	10,720	2007	Active	San Luis
MDPC2	05M16S	MEDANO PASS	37.50	-105.26	9,620	1978	Active	San Luis
PRPC2	06L03S	PORPHYRY CREEK	38.29	-106.20	10,760	1978	Active	Tomichi
CTEC2	06L05S	SAINT ELMO	38.42	-106.22	10,540	2007	Active	Arkansas
SCYC2	05M13S	SOUTH COLONY	37.58	-105.32	10,800	1991	Active	Arkansas
WSKC2	05M14S	WHISKEY CK	37.13	-105.07	10,220	1980	Active	Purgatoire

Source: NWS and NRCS Records

Appendix C: Maps of Aquifer Property and Aquifer Configuration Information

Aquifer Studies in the Arkansas River Basin - *A Digital Geographic Bibliography*

Ralf Topper, Colorado Geological Survey, October 2008

Studies with Alluvial Aquifer Property Information

Basemap data sources:
Colorado Department of Local Affairs
Colorado Department of Transportation

Figure C-1 Studies with Alluvial Aquifer Property Information

Basemap data sources:
Colorado Department of Local Affairs
Colorado Department of Transportation

Figure C-2 Studies with Alluvial Aquifer Configuration Information

Aquifer Studies in the Arkansas River Basin - *A Digital Geographic Bibliography*

Ralf Topper, Colorado Geological Survey, October 2008

Studies with Bedrock Aquifer Property Information

Figure C-3 Studies with Bedrock Aquifer Property Information

Basemap data sources:
Colorado Department of Local Affairs
Colorado Department of Transportation

Basemap data sources:
Colorado Department of Local Affairs
Colorado Department of Transportation

Figure C-4 Studies with Bedrock Aquifer Configuration Information

Figure C-5 Studies with Alluvial Aquifer Water Level Information

Basemap data sources:
Colorado Department of Local Affairs
Colorado Department of Transportation

Basemap data sources:
Colorado Department of Local Affairs
Colorado Department of Transportation

Figure C-6 Studies with Bedrock Aquifer Water Level Information

Appendix D: Division 2 Available Data

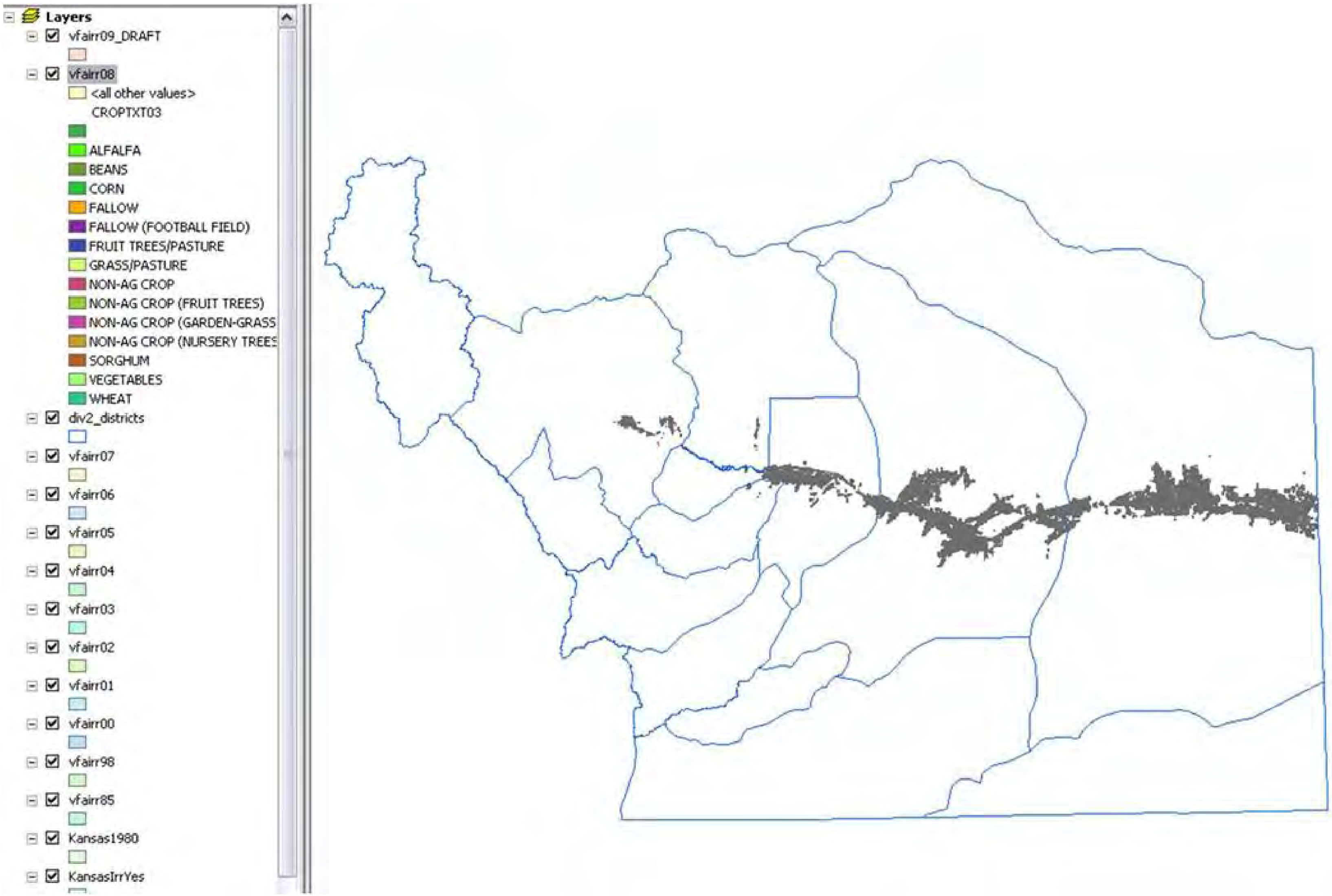

Figure D-1. List of Irrigated Crop shape files between 1980 and 2009 from Division 2

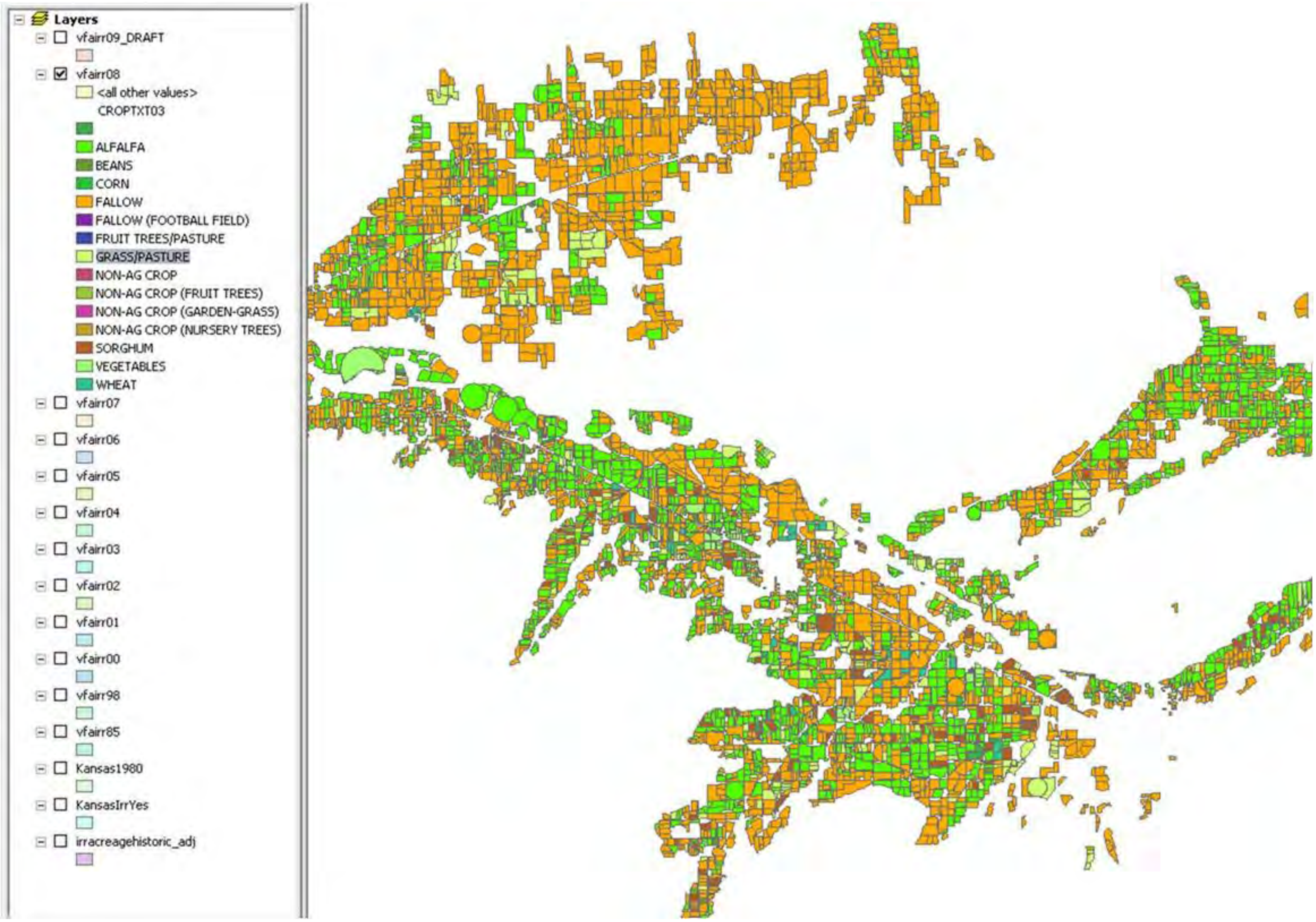

Figure D-2. Display of 2008 Irrigated Crop coverage by Crop Type

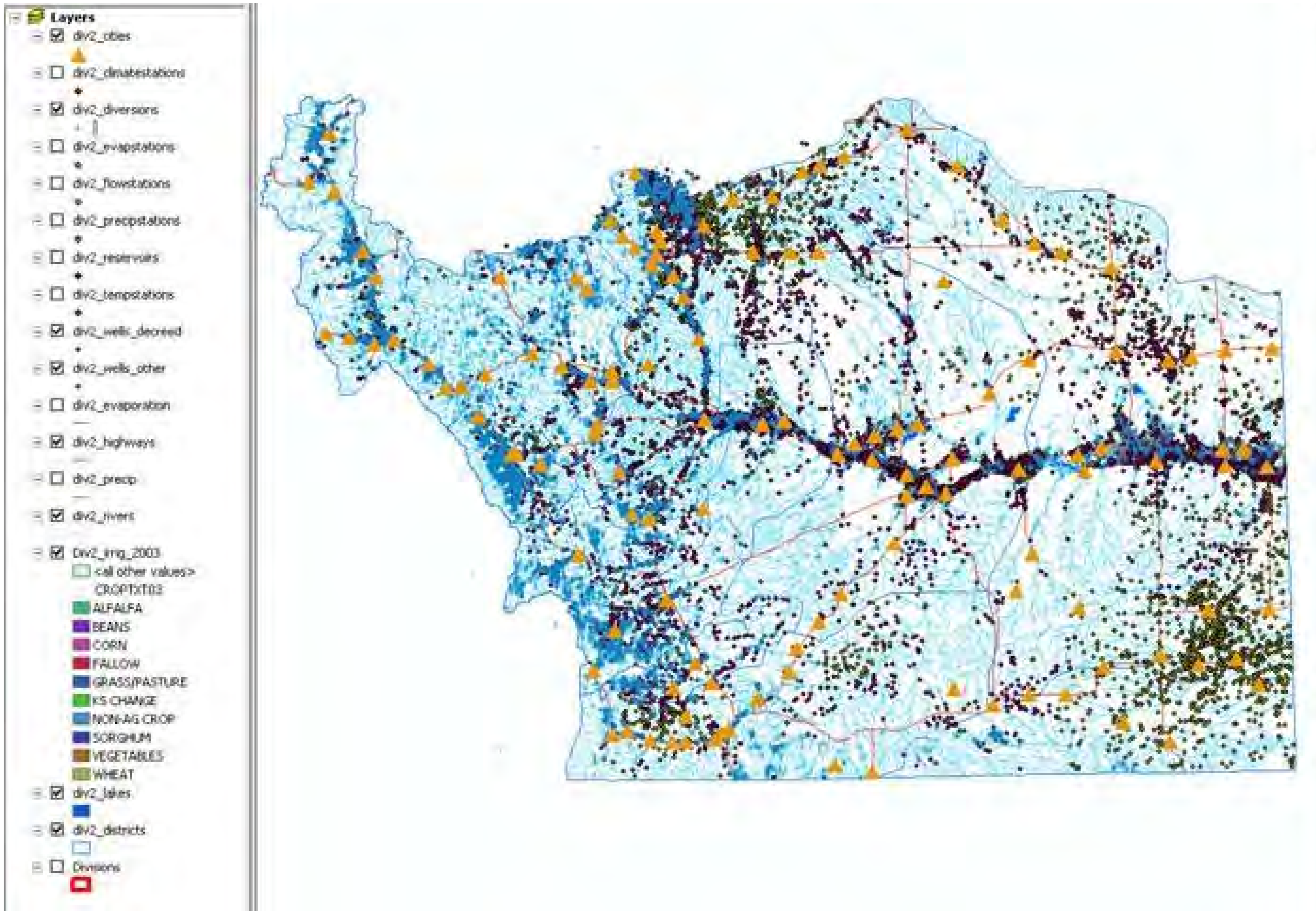

Figure D-3. Available HydroBase data layers for Division 2

Appendix E: Options for Implementation Cost Tables

Table E-1. Surface Water Planning - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Install/repair real-time streamflow gages with satellite equipment	Install a high-priority administrative gage: Fountain Creek between Pinon and Pueblo	$50,000	Install 2 additional administrative gages: Beaver Creek near Portland; Huerfano River near Undercliffe	$135,000	Install 6 additional gages: Purgatoire River at Stonewall, Long Hollow Creek, Cucharas River near confluence with Huerfano, Arkansas River below Chico Creek, South Fork of Purgatoire above Trinidad Res., North Fork of Purgatoire above Trinidad Res.	$410,000
Investigation of stream gages needed for non-consumptive priority areas	Not included	$0	Not included	$0	Interview stakeholders, coordinate with other gaging entities (USGS, UAWCD, Colorado State University), develop recommendations for additional gaging, and install up to 4 gages.	$144,000
Install real-time diversion gages with satellite equipment	Not included	$0	Install 4 gages: Excelsior Ditch, Collier Ditch, Otero Ditch, Fish Hatchery below Pueblo Res.	$60,000	Install additional gage at powerplant that feeds the Historic Arkansas Riverwalk Park	$95,000
Install real-time gages on reservoirs with satellite equipment	Not included	$0	Install 3 gages: Mt. Pisgah Res., Holbrook Res., Brush Hollow Res.	$45,000	Nothing added	$45,000
Maintenance of new gages	Not included	$0	Support Division 2 operation and maintenance of recommended diversion gages during ArkDSS implementation	$180,000	Funding to increase commensurate with additional recommended gages.	$285,000
Missing streamflow records	Identify key streamflow gages in Arkansas Basin and fill missing records using CRDSS and SPDSS-developed techniques	$35,000	Nothing added	$35,000	Nothing added	$35,000
Transit losses	Not included	$0	Review currently updated transit loss studies by Livingston on mainstem below Pueblo Reservoir. Compile output from Fountain Creek Transit Loss Model into database for further analysis.	$58,000	Develop transit loss study in upper basin when data are available.	$208,000
Streamflow component identification	Not included	$0	Analyze the availability and quality of information needed to identify the components of streamflow and make recommendations on how this information may be recorded or estimated and made available to water users.	$25,000	Nothing added	$25,000

Table E-1. Surface Water Planning - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Diversion records review: Identify key diversion structures, QA/QC diversion data and fill missing records	Compare diversions in HydroBase with diversion records that were QA'd for the HI Model. Review diversion records at 85% basin wide demand level and do analysis of historical diversions and streamflow records for daily diversion data. Fill daily data for 68 diversions (25 percent of approximately 270 key diversions).	$266,000	Nothing added	$266,000	Nothing added	$266,000
Reservoir records review: Identify key reservoirs, QA/QC data and fill missing records	Review HydroBase records, interview water users and the Division Engineer to identify the major reservoir structures that should be included in the initial surface water modeling effort. Effort will include collecting monthly and daily reservoir accounting records and performing QA/QC review, documenting operations, and estimating missing data.	$147,000	Nothing added	$147,000	Nothing added	$147,000
Components Recommendations						
Develop surface water model for the Arkansas Basin	Develop a monthly time-step model.	$420,000	Incorporate a daily time-step into model.	$550,000	Additional enhancements needed to incorporate water quality.	$600,000
Model enhancements: Arkansas River Compact Operations	Development and application of the constraints of the Compact and the associated operations of John Martin Reservoir.	$65,000	Nothing added	$65,000	Nothing added	$65,000
Model enhancements: Arkansas Basin operations	Not included	$0	Review basin operations to determine if refinements to the model code are required and make necessary changes.	$30,000	Nothing added	$30,000
Model enhancements : Flow routing	Not included	$0	Not included	$0	Addition of daily routing and flow forecasting.	$625,000
Model enhancements: Statewide model linkages	Not included	$0	Not included	$0	Enhancements needed for Statewide model linkages.	$129,000
Model GUI enhancements	Provide recommendations for GUI enhancements and develop as needed.	$35,000	Nothing added	$35,000	Develop more enhanced features.	$75,000
TOTAL	Tier 1	$1,018,000	Tier 2	$1,631,000	Tier 3	$3,184,000

Table E-2. Water Rights Administration and Accounting - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Gather, digitize and incorporate major water rights transfers and augmentation plan data in Division 2	Gather available data for all Rule 14 Plans and high-priority augmentation plans and transfers and determine how best to represent information in HydroBase.	$40,000	Nothing added	$40,000	Gather available data for all aug plans and transfers greater than 100 acre-feet.	$70,000
Gather, digitize and incorporate river call data into HydroBase for mainstem and major tributaries in Division 2	Collect, interpret, and digitize data.	$50,000	Nothing added	$50,000	Nothing added	$50,000
Water District 11 water rights tabulation review	Perform review and make corrections to administration numbers as needed.	$5,000	Nothing added	$5,000	Nothing added	$5,000
Components Recommendations						
Develop straight-line diagrams	Create for each water district.	$25,000	Nothing added	$25,000	Nothing added	$25,000
Develop a tool that tracks transmountain, native, augmentation and reservoir water	Develop tool or incorporate into ARAS.	$20,000	Nothing added	$20,000	Nothing added	$20,000
Improve the efficiency of H-I Model input data collection: Early data release	Start DWR HydroBase update with Division 2 and specifically with the datasets needed to generate the input files for the H-I Model. Publish this information either through the CDSS online database or through a DVD release that is available by January 15th of each year.	$12,000	Nothing added	$12,000	Nothing added	$12,000
Improve the efficiency of H-I Model input data collection: Create StateCU dataset	Set up a StateCU dataset specific to the H-I Model's requirements to calculate potential evapotranspiration at Division 2 CoAgMet stations using the ASCE Standardized Penman-Monteith equation.	$6,000	Nothing added	$6,000	Nothing added	$6,000
Improve the efficiency of H-I Model input data collection: ARAS well accounting output enhancements	Ensure that functionality is included in ARAS which will allow for data export of reservoir accounting and well plan accounting data that is needed by the H-I Model.	$6,000	Nothing added	$6,000	Nothing added	$6,000
Improve the efficiency of H-I Model input data collection: Update TSTool/StateDMI	Update TSTool/StateDMI to create H-I Model data input files and post-process output.	$75,000	Nothing added	$75,000	Nothing added	$75,000
TOTAL	Tier 1	$239,000	Tier 2	$239,000	Tier 3	$269,000

Table E-3. Groundwater Planning - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Review published studies and data in basin.	Review and summarize all data and literature catalogued by CGS on the Arkansas Basin.	$35,000	Nothing added	$35,000	Nothing added	$35,000
Evaluate impact of CBM well development.	Not included	$0	Not included	$0	Review ongoing studies by CGS within the Raton Basin to determine what additional studies/investigations will be required to fully evaluate the water resources impacts by development of CBM wells and perform investigations as required.	$100,000
Collect pumping data.	Rely on existing pumping data sources, primarily in the lower basin. No additional pumping data to be collected.	$0	Collect additional pumping data to assist in identifying aquifer configuration and characteristics data for the upper basin aquifers.	$75,000	Collect additional pumping data as in Alternative 2, and perform verification of existing pumping data collection programs used in the lower basin.	$100,000
Conduct streambed conductance tests and gain loss studies.	Rely on existing streambed conductance test data. No additional data to be collected.	$0	Conduct streambed conductance tests at up to 20 sites (5 sites in the upper basin, 15 sites in the lower basin and all tributaries).	$475,000	Conduct streambed conductance tests at up to 40 sites (10 sites in upper basin, 30 sites in lower basin and all tributaries).	$950,000
Install alluvial aquifer monitoring wells.	Drill/install up to 18 alluvial aquifer monitoring wells, (5 wells in the upper basin, 5 wells in lower basin mainstem area, 3 in the Fountain Creek drainage, and 5 in other tributaries in lower basin).	$175,000	Drill/install up to 35 alluvial aquifer monitoring wells (10 wells in the upper basin, 10 wells in the lower basin mainstem area, 5 in the Fountain Creek drainage, and 10 in other tributaries in the lower basin).	$375,000	Drill/install up to 100 alluvial aquifer monitoring wells (20 wells in upper basin, 40 wells in lower basin mainstem area, 10 in the Fountain Creek drainage, and 30 in other tributaries in the lower basin).	$800,000
Conduct alluvial pumping tests.	Conduct pumping tests up to 18 new alluvial wells to evaluate the impacts of vertical stratification within the aquifers and the hydraulic connection to the bedrock and shallow aquifer systems.	$215,000	Conduct pumping tests up to 35 new alluvial wells.	$500,000	Conduct pumping tests up to 100 new alluvial wells	$1,250,000
Install deep aquifer monitoring wells in upper basin.	Use existing aquifer data from published sources.	$0	Nothing added	$0	Install 4 deep monitoring wells	$550,000
Install deep aquifer monitoring wells in lower basin.	Use existing aquifer data from published sources.	$0	Nothing added	$0	Drill and install up to 7 bedrock monitoring wells in the Dakota aquifer to characterize the quantity, quality, and interconnection to the shallow alluvial aquifer systems.	$2,750,000

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Conduct deep aquifer pumping tests.	Not included	$0	Not included	$0	Conduct pumping tests up to 11 new deep aquifer wells	$650,000
Survey well elevations.	Survey elevations of all newly installed monitoring wells, and subset of existing wells in the basin that may be used for groundwater analysis and modeling	$35,000	Surveying effort is commensurate with number of new wells installed, plus additional existing wells.	$70,000	Surveying effort is commensurate with number of new wells installed, plus additional existing wells.	$180,000
Collect water level data.	Collect future water level data on a daily basis using dataloggers for 4 years for up to 50 wells (30 existing, 10 new, and 10 converted wells) in the upper and lower basins and tributaries.	$370,000	Collect future water level data on a daily basis using dataloggers for 4 years for up to 70 wells (40 existing, 15 new, and 15 converted wells) in the upper and lower basins and tributaries.	$525,000	Nothing added	$525,000
Components Recommendations						
Analyze existing and new alluvial aquifer data to better characterize aquifer properties and configuration. Identify data gaps for future data collection efforts.	Effort commensurate with alluvial aquifer data collection program described above.	$90,000	Effort commensurate with alluvial aquifer data collection program described above.	$120,000	Effort commensurate with alluvial aquifer data collection program described above.	$150,000
Develop regional model for lower basin alluvium.	Not included	$0	Develop a MODFLOW model of the lower basin that utilizes data from expanded data collection efforts described above.	$600,000	Develop a multi-layer MODFLOW model that will support water quality modeling efforts.	$1,500,000
Develop surface water model/groundwater model linkage.	If necessary, develop URFs from CSU's regional groundwater models.	$10,000	Develop URFs from the ArkDSS MODFLOW model described above.	$20,000	Develop full linkage or a robust interpolator to provide more dynamic linkage between the surface and groundwater models.	$310,000
Evaluate existing basin URFs.	Evaluate and compare URFs from the H-I Model with URFs from existing regional groundwater models (Colorado State University's two lower basin MODFLOW models)	$30,000	Compare URFs from ArkDSS MODFLOW model described above.	$45,000	Nothing added	$45,000

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Develop a regional model for the upper basin.	Develop a simplified analytical model in conjunction with the data collection program described above.	$200,000	Nothing added	$200,000	Develop a regional MODFLOW model for the Upper Basin that incorporates the shallow alluvial aquifer and deep basin-fill aquifer using data from the expanded data collection program described above.	$500,000
Enhance/update groundwater model DMIs and related modeling software as needed.	Not included	$0	Effort commensurate with modeling effort decribed above.	$175,000	Effort commensurate with modeling effort decribed above.	$250,000
TOTAL	Tier 1	$1,160,000	Tier 2	$3,215,000	Tier 3	$10,645,000

Table E-4. Consumptive Use - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Collect data on agricultural CU/crop characteristics/crop coefficients.	Collect, review and assess estimates of ET for irrigated areas developed by Colorado State University, SWSI and others. Includes compilation of necessary CU data for ISAM in upper basin: canal and lateral losses, tailwater run-off, secondary ET losses, soil moisture accounting, and irrigation efficiencies.	$75,000	Nothing added	$75,000	Develop lysimeter study in upper basin for locally-calibrated crop coefficients.	$250,000
Collect population data for cities, towns and counties in study area.	Gather existing data and use in conjunction with per capita use data to estimate municipal and domestic water supply.	$15,000	Nothing added	$15,000	Nothing added	$15,000
Gather municipal consumptive use per capita estimates for cities, towns and counties in study area.	Gather existing data and use in conjunction with population data to estimate municipal and domestic water supply.	$15,000	Nothing added	$15,000	Nothing added	$15,000
Collect data on municipal indoor use return flows.	Gather existing data and use in conjunction with municipal and domestic supply estimates to determine municipal and domestic consumptive use.	$20,000	Nothing added	$20,000	Nothing added	$20,000
Collect data on municipal outdoor use return flows.	Gather existing data and use in conjunction with municipal and domestic supply estimates to determine municipal and domestic consumptive use.	$20,000	Nothing added	$20,000	Nothing added	$20,000
Collect data on other consumptive uses (e.g., industrial, minerals, and power) and return flows in the basin.	Gather existing data.	$20,000	Nothing added	$20,000	Nothing added	$20,000
Review climate data.	Review and QA/QC climate station datasets in HydroBase.	$50,000	Nothing added	$50,000	Nothing added	$50,000
Components Recommendations						
Fill missing climate data at key climate stations	Fill missing daily and monthly data at key climate stations	$10,000	Nothing added	$10,000	Nothing added	$10,000
StateCU enhancements: Develop calibrated crop coefficients.	Develop locally-calibrated crop coefficients for use in the Modified Blaney-Criddle and Modified Hargreaves method using information obtained from the Rocky Ford lysimeter study and the ASCE Standardized Penman equation.	$30,000	Nothing added	$30,000	Nothing added	$30,000

Table E-4. Consumptive Use - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
StateCU enhancements: Model documentation.	Improve program documentation to provide more "how-to" instruction. This could include example scenarios through the quick-start guide, with expanded documentation following in more detail.	$20,000	Nothing added	$20,000	Nothing added	$20,000
StateCU enhancements: Higher resolution crop coefficients.	Allow user to enter higher resolution interpolation for crop coefficients (less than 15-day time step for perennial crops and less than 5-percent time step for annual crops).	$15,000	Nothing added	$15,000	Nothing added	$15,000
StateCU enhancements: Help files.	Expand help files to provide additional explanation of options within the StateCU program.	$10,000	Nothing added	$10,000	Nothing added	$10,000
StateCU enhancements: Troubleshooting.	Improve error messages and provide more troubleshooting information.	$15,000	Nothing added	$15,000	Nothing added	$15,000
Enhancements to StateCU GUI: Add Modified Hargreaves method.	Incorporate the Modified Hargreaves method into the StateCU GUI.	$10,000	Nothing added	$10,000	Nothing added	$10,000
Enhancements to StateCU GUI: Streamline and categorize options.	Streamline the GUI to separate standard from more complex consumptive use analyses.	$60,000	Nothing added	$60,000	Nothing added	$60,000
Enhancements to StateCU GUI: Improve window behavior.	Improve existing GUI to reduce inconsistencies in behavior of windows.	$50,000	Nothing added	$50,000	Nothing added	$50,000
Enhancements to StateCU GUI: Subirrigation method.	Include function for estimating crop consumptive use met by subirrigation.	$15,000	Nothing added	$15,000	Nothing added	$15,000
Enhancements to StateCU GUI: Add daily equations.	Add the daily crop consumptive use equations.	$15,000	Nothing added	$15,000	Nothing added	$15,000
Enhancements to StateCU GUI: Direct interface with CoAgMet station data.	Provide interface to use CoAgMet station data in monthly analyses with automated data processing. Although this can be done using TSTool or StateDMI, a direct interface through the GUI would be preferable.	$35,000	Nothing added	$35,000	Nothing added	$35,000
Enhancements to StateCU GUI: additional QA/QC of data	Provide a function to allow the user to perform additional QA/QC on input and output data, and provide user documentation within the scenario.	$20,000	Nothing added	$20,000	Nothing added	$20,000

Table E-4. Consumptive Use - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Method for determining ET using remote-sensing data.	Not included	$0	Investigate various techniques to estimate ET using remote-sensing data and incorporate best techniques into StateCU.	$100,000	Nothing added	$100,000
Additions to StateCU: Lake evaporation.	Not included	$0	Automate estimations of lake evaporation based on site-specific or regional pan evaporation data.	$30,000	Nothing added	$30,000
Additions to StateCU: non-crop ET.	Not included	$0	Develop methodology for determining ET from native vegetation, phreatophytes, and municipal/residential landscaped areas.	$50,000	Nothing added	$50,000
Develop StateCU analysis for basin and prepare historical consumptive uses and losses summary report.	Use monthly Modified Blaney-Criddle for historical CU estimates for approx 270 key structues plus aggregates. Analysis of basin summary report includes estimation of CU from irrigation, native vegetation, muncipal, livestock, wildlife and industrial uses, as well as recharge from precipitation and evaporation from ponds and reservoirs.	$400,000	Model historical CU for approx 270 key structures plus aggregates.	$450,000	Nothing added	$450,000
TOTAL	Tier 1	$920,000	Tier 2	$1,150,000	Tier 3	$1,325,000

Table E-5. Water Budget - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Collect data on native and non-native vegetation estimates/reports forArkansas River basin	Gather existing data and use to compare with results of Water Budget Analysis.	$40,000	Nothing added	$40,000	Nothing added	$40,000
Components Recommendations						
Develop basin water budgets using StateWB.	Include initial, intermediate and final water budgets, and native vegetation CU comparison.	$100,000	Nothing added	$100,000	Provide access to StateWB functions and StateCu from a common platform	$160,000
TOTAL	Tier 1	$140,000	Tier 2	$140,000	Tier 3	$200,000

Table E-6. GIS and Irrigated Acreage Assessment - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Develop mapping of current land use and irrigated lands.	Use existing data from irrigated lands assessments based on satellite imagery from DWR updates, Division 2, PRWCD and SWSI. Gather additional existing data including: USGS Landsat ETM and Landsat TM imagery inventory; USGS ASTER satellite imagery inventory; USGS 1.0-meter digital orthoimagery quarter quadrangles (DOQQ); USGS Digital Elevation Data: NED 1/3" (10.0-meter) and NED 1" (30-meter). Also gather imagery from FSA's NAIP dataset for Colorado and NASS CDL for each year during implementation.	$58,000	Nothing added	$58,000	Nothing added	$58,000
Develop mapping of historical land use and irrigated lands.	Create maps for up to 5 snapshots (1950's through 2000's);includes data purchase, processing and analysis. Existing data sources include current land use map (described above), historical satellite images, land use and land cover classifications (MRLC, USGS), aerial photographs, and agricultural statistics data.	$86,000	Nothing added	$86,000	Nothing added	$86,000
Develop mapping of water source and service area data (location of structures, water service areas, irrigated parcels, etc.).	Gather existing data sources needed for irrigated service map coverages; includes information from HydroBase, Division 2, NHD, water conservancy districts, and irrigation companies. Support DWR's effort to tie water source to irrigated lands in the upper basin.	$43,000	In coordination with DWR efforts, perform a QA/QC review of the current assignments of irrigated parcels with their sources of water supply in the lower basin, as well as creating a linkage between irrigated parcels and their sources of supply in the upper basin.	$65,000	Nothing added	$65,000
Develop mapping of native and non-native vegetation.	Use data gathered for current land use assessment described above to delineate non-crop areas.	$8,000	Nothing added	$8,000	Incorporate maps from the Arkansas River Tamarisk Coalition.	$23,000
Collect agricultural statistics data (annual acreage and yield by crop).	All available CAS and NASS data regarding annual cropping statistics will be gathered for every county in the study area from 1950 to the present.	$15,000	Nothing added	$15,000	Nothing added	$15,000
River system and water distribution data (names, locations, structures)	Gather existing data from sources, including USGS, Colorado State University, and NHD.	$15,000	Nothing added	$15,000	Nothing added	$15,000
Improve locational information for all structures that currently do not have a recorded GPS location	Provide funding to perform GPS survey of key structures.	$43,000	Conduct a thorough quality review of the locational attributes of structures, including documentation of how the locations (e.g., lat/long coordinates) were determined	$65,000	Nothing added	$65,000
Gather spatial data from local government entities.	Collect existing data deemed useful.	$15,000	Nothing added	$15,000	Nothing added	$15,000

Table E-6. GIS and Irrigated Acreage Assessment - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Components Recommendations						
Develop GIS database to support overall ArkDSS activities (including all spatial data discussed above).	Focus efforts on gathering base data layers, described above. Incorporate spatial data from H-I Model (i.e., URF reaches).	$20,000	Create database (includes data purchase, processing and results). GIS will include functionality for display, viewing and editing capability, database query functions, import and export functions, ability to change projections, and plotting functions. Utilize the GIS template used in other CDSS GIS efforts.	$58,000	Nothing added	$58,000
Further the incorporate of the National Hydrography Dataset (NHD) into the ArkDSS GIS to support analysis functions.	Provide support to DWR efforts.	$15,000	Nothing added	$15,000	Nothing added	$15,000
Georeference spatially dependent modeling inputs and output to support visualization of results using GIS mapping and visualization tools.	Effort is commensurate with modeling recommendations.	$29,000	Effort is commensurate with modeling recommendations.	$29,000	Effort is commensurate with modeling recommendations.	$51,000
Develop stream network data to allow display of priority call features and visualization of the physical stream system.	Not included	$0	Effort is commensurate with modeling recommendations.	$29,000	Effort is commensurate with modeling recommendations.	$44,000
TOTAL	Tier 1	$347,000	Tier 2	$458,000	Tier 3	$510,000

Table E-7. System Integration - Estimated Costs During ArkDSS Implementation

Components Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Relational Database Management System						
Provisional data access needs for water administration purposes may require modifications to HydroBase or development of new tools to interface with HydroBase.	DWR is planning an update to HydroBase to include access to provisional diversion data. When real-time data are uploaded to HydroBase, update data presentation to indicate if data are provisional. Also include automated QA/QC of station data before posting.	$50,000	Nothing added	$50,000	Create a Bayesian network analysis tool and use it to provide level of confidence information for data that is listed as provisional.	$300,000
System Linkages						
Enhance TSTool and StateDMI to interface with on-line HydroBase.	Support ongoing real-time data enhancements, including the addition of web-services interfaces for the collection and presentation of real-time data.	$75,000	Include key analysis components for both real-time and historical data.	$140,000	Allow full suite of analysis components	$200,000
Maintenance						
Provide resources to update system components due to operating system and commercial software updates.	Provide necessary resources as needed.	$60,000	Nothing added	$60,000	Nothing added	$60,000
Provide resources to maintain data collection systems implemented for CDSS.	Provide necessary resources as needed.	$80,000	Nothing added	$80,000	Nothing added	$80,000
Provide resources to upgrade system components in response to technology changes.	Provide necessary resources as needed.	$20,000	Nothing added	$20,000	Nothing added	$20,000
Move HydroBase, the associated web services, and related tools to an on-demand, cloud-based environment.	Not included	$0	Not included	$0	Perform full effort.	$100,000
Stakeholder Education and Involvement						
Establish and engage Peer Review Committees (PRCs) during critical model development phases of ArkDSS implementation.	Hold 5 to 8 meetings for SW, GW, GIS and CU model development.	$75,000	Nothing added	$75,000	Nothing added	$75,000
Publish newsletters via hard copy and email (sign up for email via CWCB Insider on CWCB website) to update stakeholders on ArkDSS implementation progress.	Publish biannual newletter during 6-year implementation.	$60,000	Nothing added	$60,000	Nothing added	$60,000
Engage stakeholders on a regular basis by giving presentations at Arkansas Basin Roundtable Meetings.	Make 2 presentations per year.	$6,000	Nothing added	$6,000	Nothing added	$6,000

Hold outreach meetings with other subcontractors to learn about tools and develop articles for the newsletter.	Hold 3 meetings per year for 6 years.	$36,000	Nothing added	$36,000	Nothing added	$36,000
Consider CDSS website improvements to increase understanding of the CDSS website and tools and provide more "layman" information.	Moderate enhancements to include more informational/educational pages.	$30,000	Nothing added	$30,000	Nothing added	$30,000
TOTAL	Tier 1	$492,000	Tier 2	$557,000	Tier 3	$967,000

Table E-8. Water Quality - Estimated Costs During ArkDSS Implementation

Recommendations	Tier 1 Description	Estimated Cost	Tier 2 Description	Estimated Cost	Tier 3 Description	Estimated Cost
Data Collection Recommendations						
Collect data on constituents of concern in the basin	Not included	$0	Support on-going basin water quality data collection activities.	$100,000	Gather existing water quality data, perform QA/QC and provide system linkage for future data collection to be imported into HydroBase	$300,000
Components Recommendations						
Develop Water Quality Conceptual Model	Not included	$0	Develop conceptual model using existing data to identify areas of regional and local water quality concerns. Include review of Colorado State University's Arkriver GeoDSS and see if all or portions can serve CDSS purposes for water quality analysis for basin planning.	$100,000	Nothing added	$100,000
Develop water quality analysis component for ArkDSS	Not included	$0	Nothing added	$0	Incorporate components of the ArkRiver GeoDSS into the CDSS as appropriate OR develop water quality analysis components using existing data and Alternative 3 ArkDSS surface and groundwater models.	$500,000
TOTAL	Tier 1	$0	Tier 2	$200,000	Tier 3	$875,000[a]

[a]Note that the additonal costs of modifying the surface water and groundwater models to incorporate water quality are included in the respective component tables.

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