GEOLOGIC AND HYDROLOGIC CHARACTERIZATION OF THE DAKOTA-BURRO CANYON AQUIFER NEAR BLANDING, SAN JUAN COUNTY, UTAH

by
Stefan Kirby

SPECIAL STUDY 123
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Cover photo: View across City of Blanding Starvation Reservoir of the Abajo Mountains, north of Blanding. Water filling this and other City of Blanding reservoirs is diverted from streams that drain the Abajo Mountains.

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CONTENTS

FIGURES

TABLES

PLATES

GEOLOGIC AND HYDROLOGIC CHARACTERIZATION OF THE DAKOTA-BURRO CANYON AQUIFER NEAR BLANDING, SAN JUAN COUNTY, UTAH

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ABSTRACT

The principal aquifer in the Blanding area is made up of geographically isolated bedrock of the Dakota and Burro Canyon Formations. These units are largely structurally intact and composed primarily of sandstone and lesser, laterally discontinuous mudstone, claystone, and shale. Ground water flows generally to the south or southeast across the study area. The total amount of water in transient storage in the principal aquifer is estimated at 156,000 acre-feet (192 hm^3). Recharge to the principal aquifer occurs from direct precipitation and infiltration of surface water transported onto Blanding-White Mesa via canals and pipelines and stored in reservoirs along the northern portion of the study area. Water levels in the principal aquifer have fluctuated through time, generally increasing prior to 1989 and decreasing since then. Fluctuations in water level are primarily the result of changes in the rate of artificial recharge, due to replacement of canals with pipelines, lining of reservoirs, and land-use changes. Based on chlorofluorocarbon apparent-age-of-recharge data, most ground water was recharged prior to 1980, and ground water generally increases in age to the south-southeast, parallel to the potentiometric slope. Stable isotope ratios from ground and surface water suggest a significant component of water in the principal aquifer is the result of artificial recharge from a variety of sources. Discharge of the Dakota-Burro Canyon aquifer occurs primarily by seepage and springs along the margins of the study area and along drainages including Lems Draw, Browns Canyon, and Corral Creek, and by subsurface outflow along the southern margin of the study area. Withdrawal from wells is a significant source of discharge locally. Future changes in water delivery, storage, and land use across Blanding-White Mesa will further alter the balance between recharge and discharge and the amount of water in the principal aquifer.

INTRODUCTION

Recent residential growth in unincorporated portions of San Juan County north and east of Blanding utilizes ground water derived primarily from sandstone of the undivided Dakota and Burro Canyon Formations for culinary water. The primary source of recharge to the bedrock aquifer may be seepage from unlined irrigation canals and reservoirs along the northern extent of the study area, but the relative contribution of seepage to total recharge is unknown. Potential installation of a pipe system for water delivery along the northern canal could decrease recharge from seepage and adversely affect ground-water availability at culinary wells near Blanding. Ground-water budgets, subsurface geometry, extent, sources, and amounts of recharge for this aquifer have not been assessed prior to this study and are of concern to local water managers.

The goal of this study is to characterize the geologic framework of the Dakota-Burro Canyon aquifer and adjacent units and estimate the relative amounts of artificial and natural recharge for this aquifer. The scope of work for this project included new geologic mapping based on color air photos and extensive fieldwork, new measured stratigraphic sections of the principal aquifer, and well-log analysis. These data are used to constrain the extent and geologic characteristics of the principal aquifer. To estimate sources of recharge and discharge and the amount of water in the principal aquifer, new and compiled water-level, and new geochemical, isotopic, and dissolved gas data from ground- and surface-water were collected and analyzed. Hydrologic and geologic framework data presented in this report will support informed resource management decisions and provide basic data necessary for future numerical modeling of ground-water flow in the principal aquifer.

GEOGRAPHIC SETTING

Geography

Blanding is located in the Colorado Plateau physiographic province of southeastern Utah (Stokes, 1977). The study area, referred to in this report as Blanding-White Mesa, consists of the Blanding bench including the municipality of Blanding and the surrounding farm and residential lands which grade southward into White Mesa (figure 1). The study area is characterized by a series of south sloping mesas bounded by Recapture Creek along the north and east and Brushy Basin Wash to the west. To the south the study area is arbitrarily bounded by farmlands along White Mesa.

Along the western portion of the study area, several south-draining canyons begin along the northern reaches of Blanding-White Mesa, including Westwater Creek and Big Canyon. To the east, Lems Draw, Browns Canyon, and several other smaller drainage systems cut the central and eastern portions of Blanding-White Mesa (figure 1). Many smaller stream courses on White Mesa are intermittent, flowing only during runoff events, including snowmelt or peri-

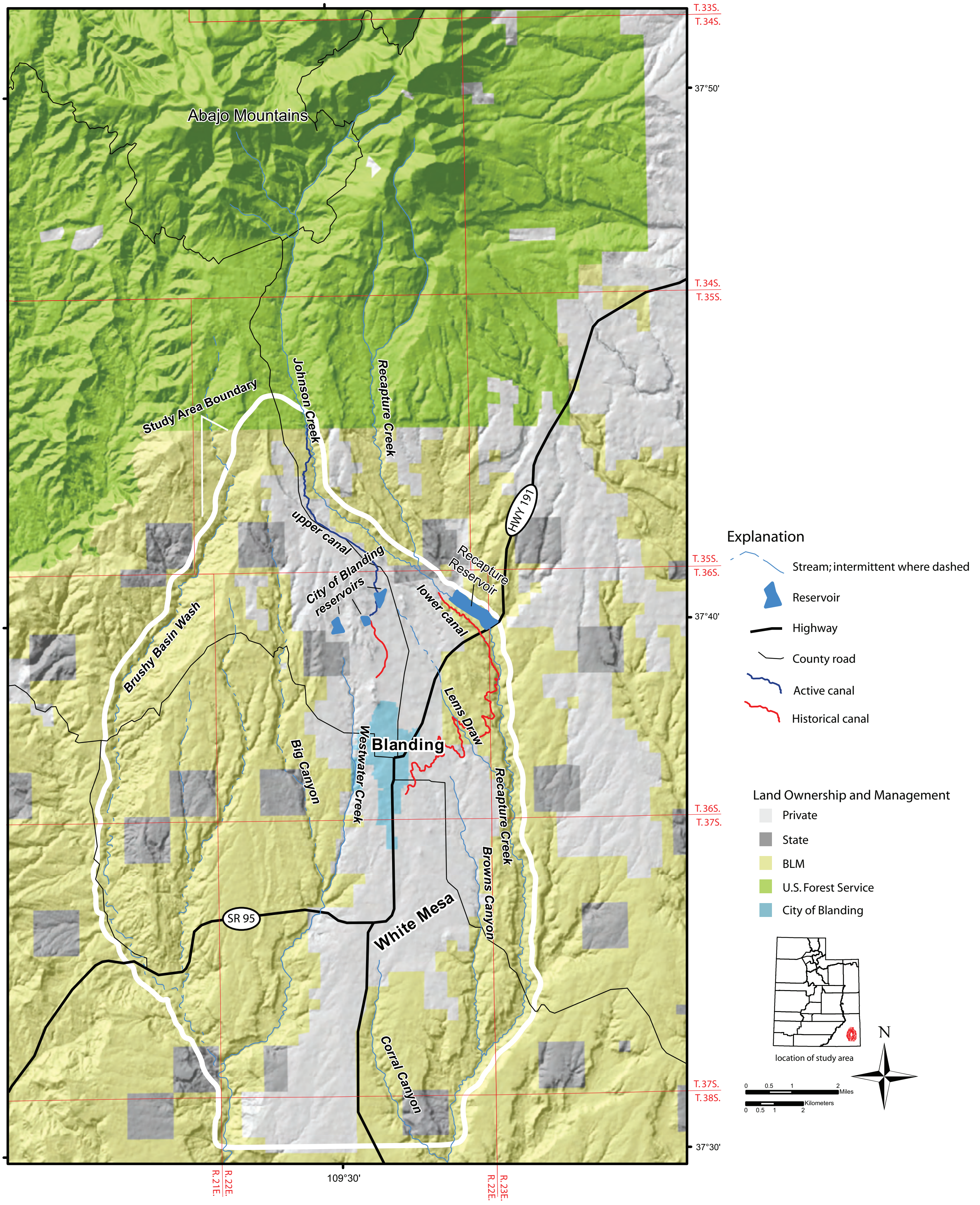

Figure 1. Geographic overview of the Blanding-White Mesa area.

odic intense rainfall (figure 1). Larger drainages along the margins of Blanding-White Mesa, including Johnson, Recapture, and Cottonwood Creeks, are perennial, with much of their yearly flow derived from spring and summer snowmelt in the Abajo Mountains north of the study area. Westwater Creek and the lower portions of Lems Draw, Browns Canyon, and Corral Canyon also are perennial (figures 1 and 2).

History of Water Use

Since the earliest twentieth century, surface water has been imported and stored on Blanding-White Mesa for both agricultural and municipal uses (Danny Fleming, city of Blanding, verbal communication, 2005). The primary source of regional surface water is the upland areas of the Abajo Mountains north of the study area. Early water delivery consisted of two water-diversion ditches, one in the northern portion (upper canal) and one in the southern portion (lower canal) of the study area, that brought water from Johnson and Recapture Creeks onto Blanding-White Mesa (figures 1 and 2). The upper canal was completed in 1900 and the lower canal was completed several years later. The two canals supplied water for irrigation, domestic, and municipal use across Blanding-White Mesa. The first in a series of five reservoirs were constructed in 1916 and filled with water from the northern canal (Danny Fleming, verbal communication, 2005). All of these reservoirs were initially filled directly over unconsolidated deposits and Dakota-Burro Canyon bedrock. Of the five initial reservoirs three are still in use: Starvation Reservoir and City of Blanding Reservoirs 3 and 4 (figure 2). City of Blanding Reservoirs 3 and 4 were upgraded and at least partially lined with impermeable clay during the summer of 1990, and similar work is pending for Starvation Reservoir (Jeff Black, city of Blanding, verbal communication, 2006). The lower canal was replaced with a closed pipe in the early 1980s, and portions of the upper canal have been replaced with closed pipe since 1990 (Jeff Black, verbal communication, 2006).

Surface water currently used in the Blanding area is conveyed via canals and pipelines from Johnson Creek and Recapture Reservoir (Utah Division of Water Resources, 1996, 2000). Areas outside of the city of Blanding rely on ground water pumped from the Dakota-Burro Canyon aquifer for culinary water (figure 2). Irrigation water is either from piped surface water sources or ground water (Utah Division of Water Resources, 1996). Nearly all of the 856 wells within the study area are less than 150 feet (46 m) deep and completed in the Dakota and Burro Canyon aquifer (figure 2) (Utah Division of Water Rights, 2006). Most of these wells are used for domestic supply and small-scale irrigation of gardens, landscaping, and stock. Within the city of Blanding municipal boundaries, private water wells are commonly used in conjunction with municipal water to irrigate landscaping and gardens (Jeff Black, verbal communication, 2006).

Climate

The climate of the study area is semiarid, with hot summers with occasional high-intensity rainfall events and cool winters with periodic snow and rain (figure 3). Mean annual precipitation at Blanding is 13 inches (33 cm), but actual yearly precipitation is highly variable (figure 4) (Western Regional Climate Center, 2006). To the north of the study area, upland portions of the Abajo Mountains receive considerably more precipitation. At the Camp Jackson snotel site, along the upper reaches of Johnson Creek on the south flank of the Abajo Mountains, average annual precipitation is 29 inches (74 cm) (Western Regional Climate Center, 2006). Water derived from the Abajo Mountains supplies most of the surface water used across the Blanding-White Mesa. From the months of April thru October estimated average monthly potential evapotranspiration greatly exceeds precipitation. Total annual potential evapotranspiration, calculated using the Hargreaves equation, is 47 inches (120 cm) at Blanding (figure 3) (Ashcroft and others, 1992). Actual evapotranspiration is dependent on many localized meteorological and geographic parameters and likely varies from the potential evapotranspiration shown in figure 3. Annual precipitation measured at Blanding has a slightly decreasing trend for much of the period of record (1900-2006) (figure 4). Mean annual temperature at Blanding is 50ºF (10ºC) (Western Regional Climate Center, 2006).

GEOLOGIC AND HYDROLOGIC SETTING

Regional Geologic Background

The study area is characterized by flat or gently south-sloping mesas separated by canyon systems incised in Upper Jurassic and Cretaceous rocks (Hintze and Stokes, 1963; Haynes and others, 1972). Resistant Cretaceous sandstone forms caprocks that underlie mesa tops and form cliffs along adjoining canyons that expose Upper Jurassic units across the study area (Haynes and others, 1972). Thin mantles of Quaternary-age unconsolidated deposits cover most of the mesa tops and parts of the intervening canyons (Haynes and others, 1972; Biggar and others, 1981). Rocks older than Late Jurassic lie beneath the study area but are not exposed at the surface (plate 1) (Haynes and others, 1972). Several rock units older than those exposed at the surface are intercepted by deep wells and may become increasingly important aquifers in the near future (Gaeaorama Inc., 2004). Detailed discussion of potential aquifers beneath the Burro Canyon Formation is beyond the scope of this report, but generally the Early Jurassic Navajo Sandstone may contain usable quantities of ground water beneath the study area (Gaeaorama Inc., 2004).

The study area is located in the Blanding sub-basin of the larger Paradox Basin, characterized by thick sequences of anhydrite, carbonate, and organic-rich shale of the Paradox Formation (figure 5). The Paradox Formation is part of the Hermosa Group, which, together with the overlying Cutler Group, were deposited during Pennsylvanian and Permian transgressions and regressions (Condon, 1995; Nuccio and Condon, 1996). The Paradox Basin covers much of southeastern Utah and adjoining portions of Colorado, Arizona, and New Mexico (figure 5). The Blanding sub-basin occupies the southwestern corner of the Paradox Basin; it is bounded to the west by the Comb Ridge monocline, to the north and northeast by the Abajo Mountains and Paradox fold and fault belt, and to the southeast by the four corners platform (Nuccio and Condon, 1996) (figure 5).

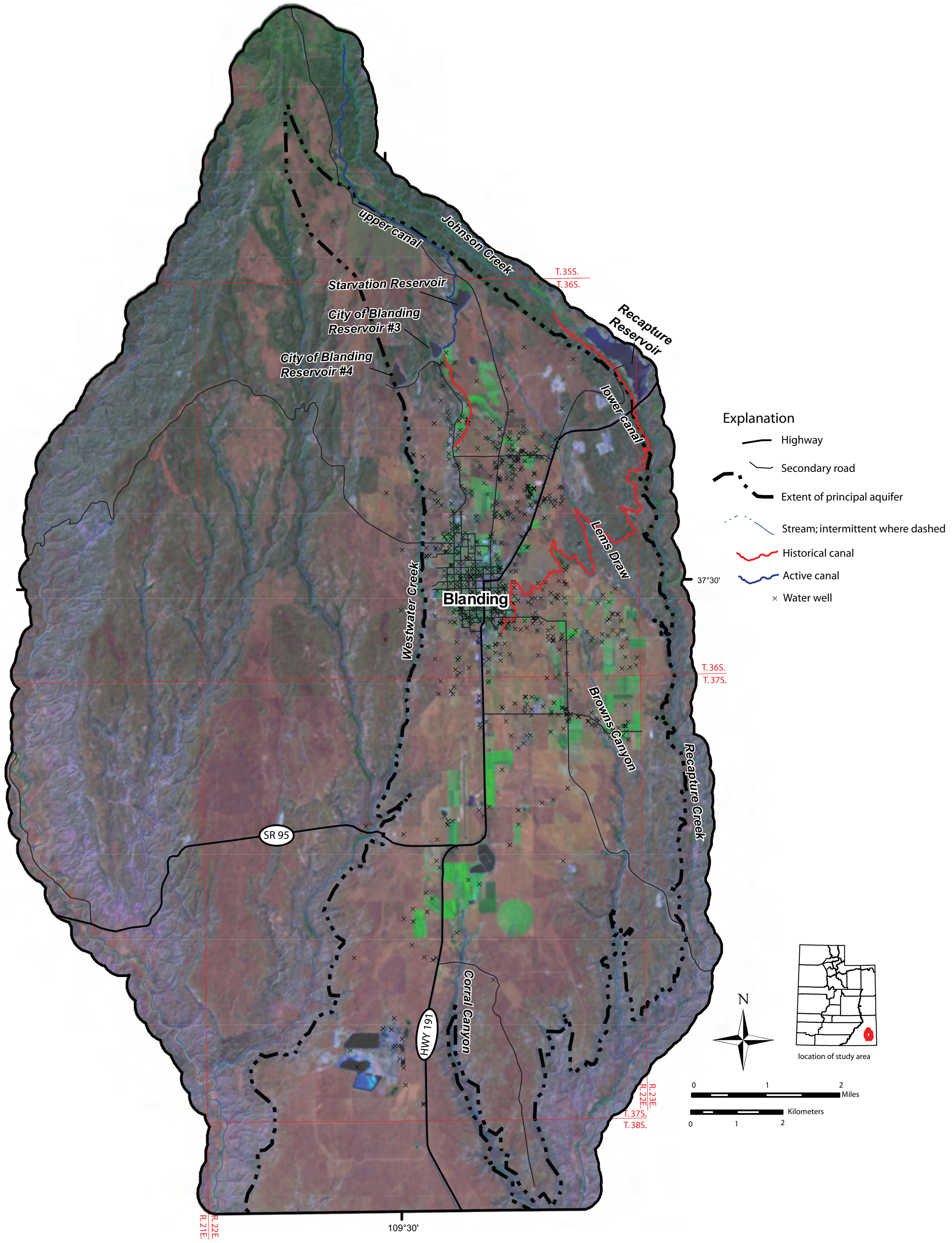

Figure 2. False color Landsat image of the Blanding area. Areas of active irrigation are green. Surface water including City of Blanding reservoirs and Recapture Reservoir are dark blue. Image date is 6/15/2000, data available from Intermountain Region Digital Archive Center (2006). Water wells from the Utah Division of Water Rights (2006).

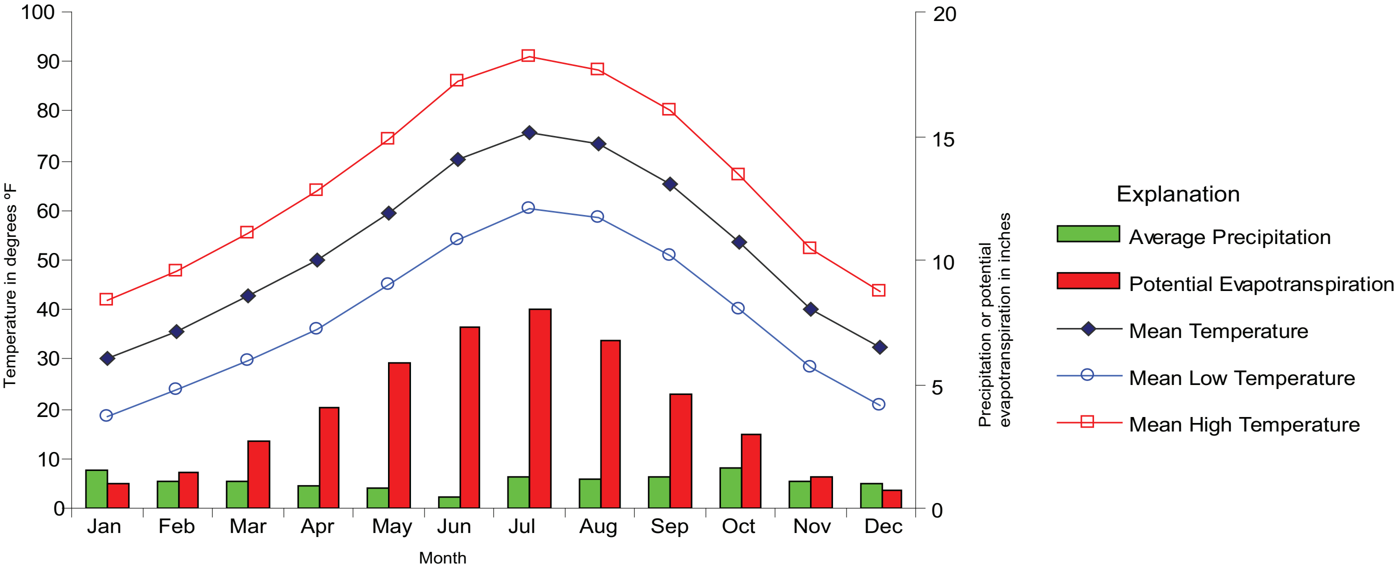

Figure 3. *Climate data for Blanding. Potential evapotranspiration exceeds average precipitation nearly every month. Climate data are for the 1904 to 2005 period, and are compiled from Ashcroft and others (1992) and Western Regional Climate Center (2006).*

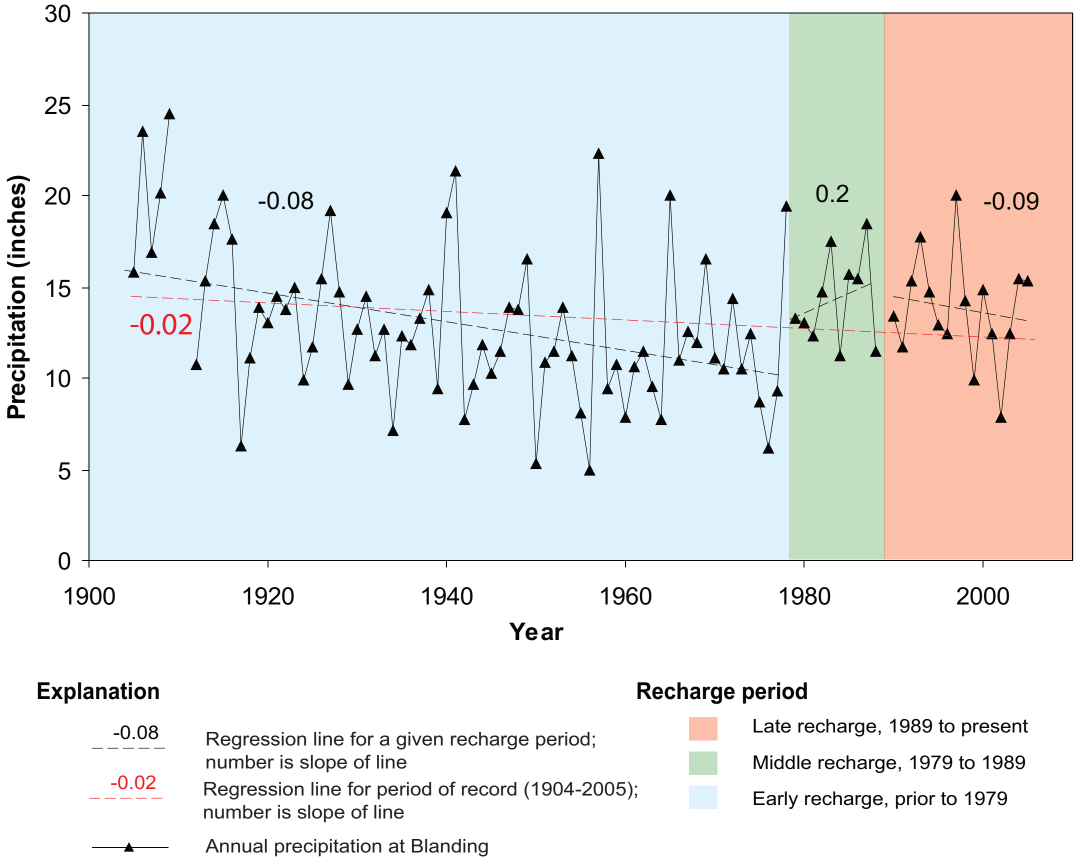

Figure 4. *Annual precipitation at Blanding with linear least squares regression lines and slope of line for selected time periods. Regression lines and slopes represent secular change in precipitation for each recharge period. Precipitation data from the Western Regional Climate Center (2006).*

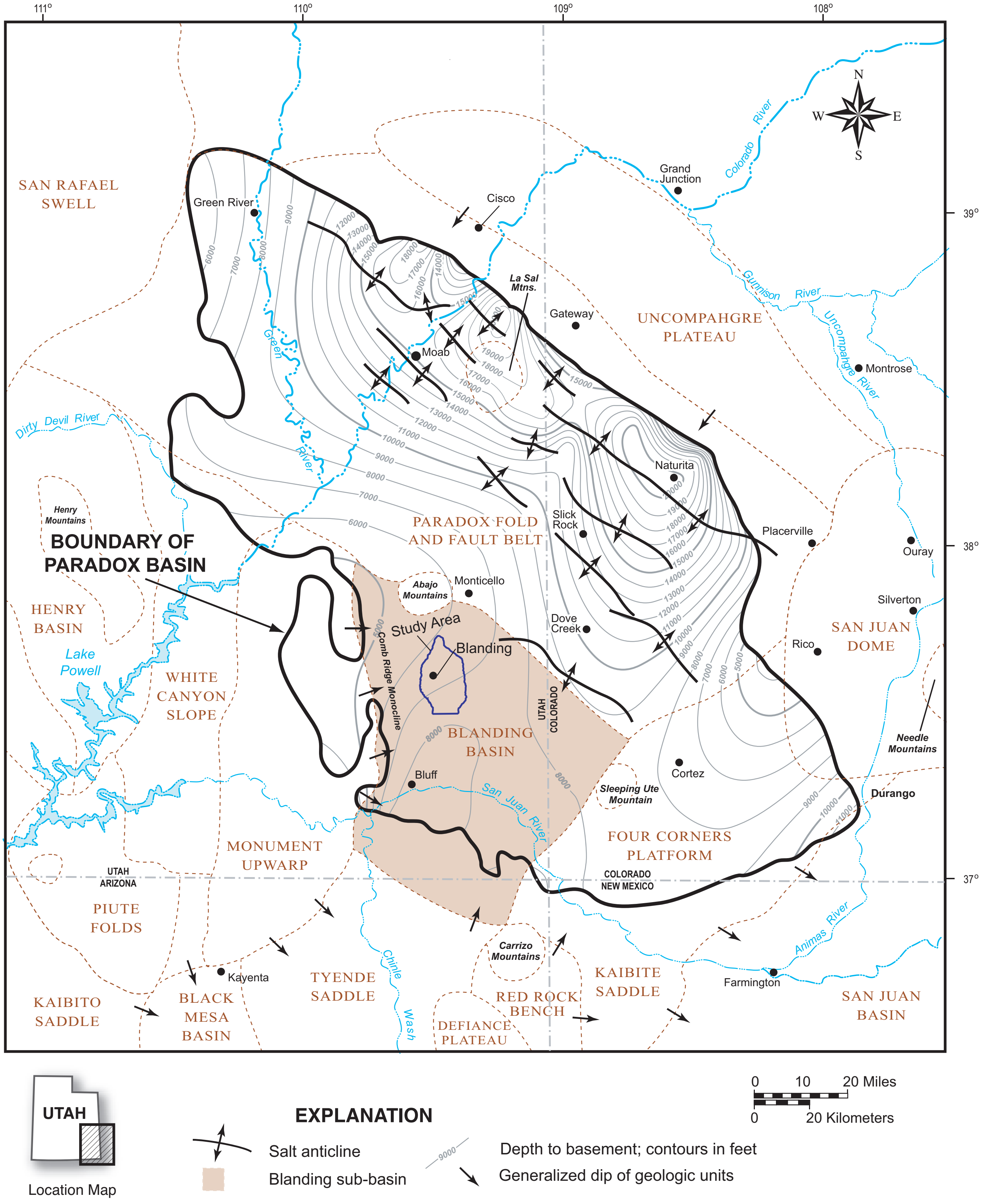

Figure 5. Regional tectonic setting of the Blanding area, showing the extent of the Paradox Basin, major sub-basins, and geographic provinces (modified from Nuccio and Condon, 1996). Depth to basement from Condon (1995).

Deposition of the sedimentary section in the Paradox Basin was episodic and included a variety of rock types ranging from marine carbonate, sandstone, organic-rich shale, and salts to foreland continental deposits of sandstone, mudstone, and claystone (Hintze and Stokes, 1963; Haynes and others, 1972; Craig, 1981; Molenaar, 1981, 1987; Condon, 1995; Nuccio and Condon, 1996). Deposition, burial, and subsequent exhumation of these rocks occurred in response to regional and local tectonic and eustatic events ranging from the early Paleozoic to Tertiary (Nuccio and Condon, 1996). Late Cretaceous through early Tertiary Laramide reverse faulting produced major structures, including the Comb Ridge monocline west of the study area (Sears, 1956; Lewis and Campbell, 1965; Nuccio and Condon, 1996) (figure 5).

During the mid-Tertiary, emplacement of the igneous laccoliths of the Abajo Mountains north of the study area locally deformed and uplifted the sedimentary sequence of the Paradox Basin (Witkind, 1964; Friedman and Huffman, 1998). Faulting and folding occurred near igneous intrusions, and bedrock in the Blanding area was tilted gently to the south and southeast away from intrusions in the Abajo Mountains (Witkind, 1964).

Beginning during the late Tertiary, between 4 and 8 Ma, and continuing through the Quaternary, uplift and drainage integration across the Colorado Plateau removed several thousand feet of overlying Tertiary and Cretaceous sedimentary rocks from the Blanding area, exposing the bedrock that comprises the principal aquifer (Pederson and others, 2002; McMillan and others, 2006). Episodic deposition of Quaternary unconsolidated sediment has occurred as stream incision and uplift have continued into the present (Biggar and others, 1981).

Based on well logs, current total thickness of sedimentary rocks beneath the study area is approximately 7000 feet (2100 m), and includes Paleozoic through Mesozoic strata that rest on Precambrian basement (figure 5) (Condon, 1995). Detailed discussion of the stratigraphy underlying the Upper Jurassic and Cretaceous bedrock exposed in the study area is beyond the scope of this report, but is included in recent work to the north by Doelling (2004).

Bedrock across the Blanding sub-basin is shallowly dipping and generally structurally intact except for a series of gentle southeast- and south-trending folds and the basin-scale north-south trending Comb Ridge monocline. Several east-west striking graben systems along the southern margin of the Abajo Mountains cut rocks north of the study area (Witkind, 1964; Haynes and others, 1972).

Local Geologic Background

Bedrock units exposed in the study area include Upper Jurassic through Cretaceous sedimentary rocks (plate 1) (Hintze and Stokes, 1963; Haynes and others, 1972). The stratigraphy of these units is the primary geologic control on ground-water movement and availability beneath the study area and will therefore be discussed in greater detail. The oldest unit exposed in the study area, the Upper Jurassic Brushy Basin Member of the Morrison Formation, is overlain by Cretaceous rocks including the Lower Cretaceous Burro Canyon Formation, and the Upper Cretaceous Dakota Sandstone and Mancos Shale.

Brushy Basin Member of the Morrison Formation

The Brushy Basin Member of the Morrison Formation crops out along canyons that bound and cut Blanding-White Mesa, immediately below the cliff-forming sandstone of the Burro Canyon Formation (plate 2) (Haynes and others, 1972; Montgomery, 1980). Natural exposure of the Brushy Basin Member is generally poor, and characterized by small landslide complexes and areas of intact bedrock that are generally overgrown with piñon, juniper, and oak brush scrub (Montgomery, 1980).

Locally the Brushy Basin Member of the Morrison Formation consists of interbedded mudstone, claystone, shale, and sandstone. Much of the uppermost Brushy Basin Member consists of variegated red to green mudstone, siltstone, or claystone (Huff and Lesure, 1965). Medium- to coarse-grained sandstone and minor conglomerate interbeds, lithologically similar to overlying Burro Canyon sandstone, are less common and generally less than 10 to 15 feet thick (3-4 m), lenticular in geometry, and laterally discontinuous (figure 6). The Brushy Basin Member was deposited in a mixed lacustrine and fluvial environment (Currie, 1997; Aubrey, 1998); south of the study area, the age of deposition of the Brushy Basin Member is approximately 148 Ma (Late Jurassic) (Kowalis and others, 1998).

The top of the Brushy Basin Member of the Morrison Formation commonly consists of an altered, abrupt, disconformable surface separating red or greenish mottled mudstones or rare sandstone beds of the uppermost Brushy Basin Member from the trough cross-bedded sandstone, pebbly sandstone, and conglomerate of the overlying Burro Canyon Formation (plate 2; figure 6) (Huff and Leisure, 1965; Craig, 1981; Currie, 2002). Local erosional relief of several feet is apparent along exposures of the upper contact, which may represent a depositional hiatus of up to 30 Ma north of the study area (Craig, 1981; Doelling, 2004) (figure 6). The contact is mapped as the base of cliff-forming sandstones that ring Blanding-White Mesa and form nearby canyon rims (Haynes and others, 1972; Montgomery, 1980).

Mudstone and claystone of the upper Brushy Basin Member likely represent a low permeability hydrologic barrier that forms the lower boundary of the Dakota-Burro Canyon aquifer (Avery, 1986). Where sandstone of the Brushy Basin Member directly underlies the upper contact, water may move vertically between the Brushy Basin Member and Burro Canyon Formation but is unlikely to move laterally due to the discontinuous nature of the sandstone beds (figure 6). These factors also suggest that any significant recharge and ground-water flow from upland exposures of the Brushy Basin Member north of the study area are unlikely, and further supports the hydrologically isolated nature of the overlying Dakota-Burro Canyon aquifer.

Burro Canyon Formation

The Burro Canyon Formation crops out as a yellow to white sandstone (Haynes and others, 1972; Craig, 1981) forming a generally unbroken vertical cliff typically between 40 and 60 feet (12-18 m) and up to 80 to 100 feet (24-31 m) high along the margin of Blanding-White Mesa and adjoining canyon rims (Montgomery, 1980) (figure 7). Fine-grained mudstone, claystone, and interbedded sandstone, in upper portions of the Burro Canyon Formation, form slopes and

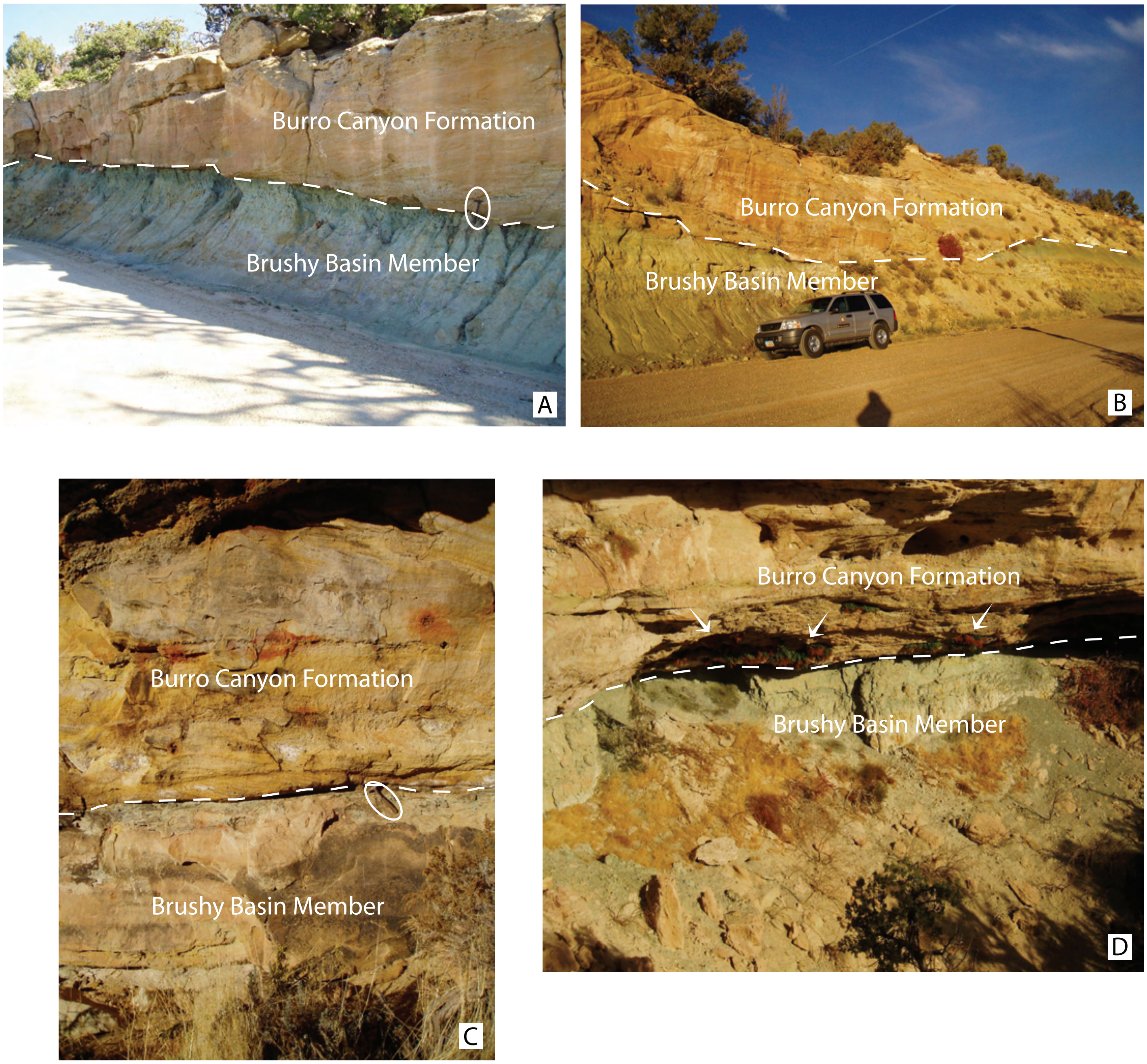

Figure 6. *Contacts of the Burro Canyon Formation and the Brushy Basin Member of the Morrison Formation. A) Typical contact of Burro Canyon Formation sandstone with underlying impermeable variegated mudstone of the Brushy Basin Member; circled rock hammer for scale. B) Base of the Burro Canyon Formation southeast of Blanding showing several feet of erosional relief. C) Base of the Burro Canyon Formation sandstone resting directly on sandstone of the Brushy Basin Member; circled rock hammer for scale. Contacts like this may facilitate vertical leakage between the Brushy Basin Member and the Burro Canyon Formation, but are generally laterally discontinuous. D) Shows the same contact 15 feet from C) where the Burro Canyon Formation rests on siltstone and mudstone of the Brushy Basin Member. Arrows show small seeps typical of the base of the Burro Canyon Formation along the margins of Blanding-White Mesa.*

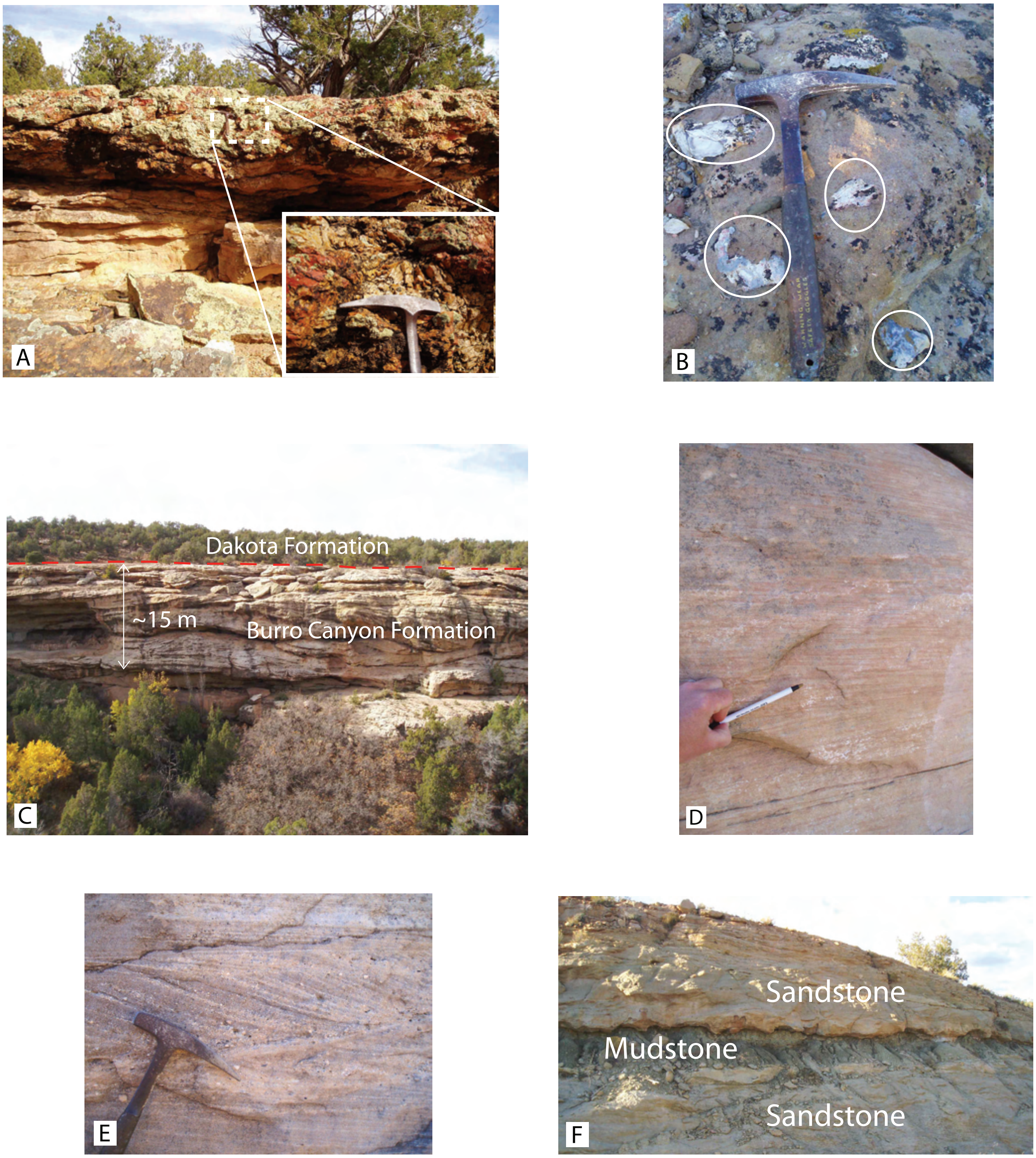

Figure 7. *Contact between the Dakota and Burro Canyon Formations and stratigraphy of the Burro Canyon Formation. (A) Photo of resistant authigenic chert layer locally marking the top of the Burro Canyon Formation. Inset box shows close up of chert layer, overlying sandstone of the Burro Canyon Formation. B) Angular chert rip-up clasts in lower bioturbated sandstone of the Dakota Formation just stratigraphically above chert layer. C) Cliff-forming sandstone of the Burro Canyon Formation along Westwater Creek. Most of the ground-water in the Dakota-Burro Canyon Aquifer in the Blanding area resides in similar sandstone. D) Close up of low-angle cross-stratification in medium-grained Burro Canyon sandstone along measured section 1. E) Trough cross-bedding in coarse-grained Burro Canyon sandstone along measured section 1. F) Mudstone interbed in the upper Burro Canyon Formation south of Blanding. Similar interbeds, while generally laterally discontinuous, may form important local impermeable layers.*

ledges along canyon rims in the study area. Burro Canyon bedrock is not contiguous across the region; instead, it forms caprock on spatially isolated mesas and cuestas separated by intervening canyons (plate 1) (Avery, 1986; Lowe, 1996).

The Burro Canyon Formation is about 100 feet (31 m) thick in the study area, consisting of medium- to coarse-grained sandstone, conglomerate, and pebbly sandstone, with interbeds of green mudstone, sandy mudstone, and claystone (Stokes, 1952; Huff and Lesure, 1965; Craig, 1981; Currie, 1997) (plate 2; figure 7). Cross-bedded channel sandstone, conglomerate, and scattered thin interbeds, less than 3 feet (1 m) thick, of blue to green claystone or mudstone dominate much of the lower Burro Canyon Formation (plate 2) (Craig, 1981). Claystone interbeds are laterally discontinuous, particularly in the lower Burro Canyon Formation; laterally continuous scour surfaces are apparent in many outcrops. Mudstone, claystone, and interbedded sandstone are more common in upper portions of the Burro Canyon Formation (plate 2). The Burro Canyon Formation was deposited under fluvial conditions associated with regional flexure and uplift produced by the Sevier fold and thrust belt located to the west and southwest (Craig, 1981; Currie, 1997, 2002). Local age constraint on deposition of the Burro Canyon Formation is lacking; palynomorphs north of the study area, collected near the top of the formation, indicate an Early Cretaceous age of deposition (Tschudy and others, 1984).

Sandstone of the Burro Canyon Formation commonly comprises most or all of the saturated part of the Dakota-Burro Canyon aquifer in the study area. These sandstones are laterally continuous beneath the Blanding-White Mesa area and, where exposed or thinly mantled with unconsolidated deposits, may provide direct recharge pathways to the principal aquifer. Mudstone and claystone interbeds are generally laterally discontinuous but may form impermeable layers locally.

Dakota Formation

Outcrop of the Dakota Formation is less extensive and more variable in character than Burro Canyon Formation (plate 1) (Haynes and others, 1972). Commonly, outcrops of the Dakota Formation form small slopes and “slickrock” sandstone benches above Burro Canyon cliffs along the margins of Blanding-White Mesa. Outcrops of Dakota Formation sandstone occur sporadically across Blanding-White Mesa, usually along small drainages (plate 1). City of Blanding Reservoirs 3 and 4 and Starvation Reservoir lie directly on sandstone and mudstone of the Dakota Formation.

The Dakota Formation locally consists of a variety of lithologies including sandstone, mudstone, siltstone, shale, and local beds of low-rank coal and carbonaceous shale (Plate 2) (Young, 1960; Huff and Lesure, 1965). Woody trace fossils, extensive bioturbation, low-rank coal, and carbonaceous shales and mudstones are characteristic of the Dakota Formation across the study area (Young, 1960; Haynes and others, 1972; Doelling, 2004) (figure 8). The base of the Dakota Formation represents an erosional surface developed in the Burro Canyon Formation (Huff and Leisure, 1965), and rip-up clasts of the uppermost Burro Canyon Formation are found in some of the lower sandstone of the Dakota Formation (Huff and Leisure, 1965) (figure 7).

The Dakota Formation, where measured along the north-

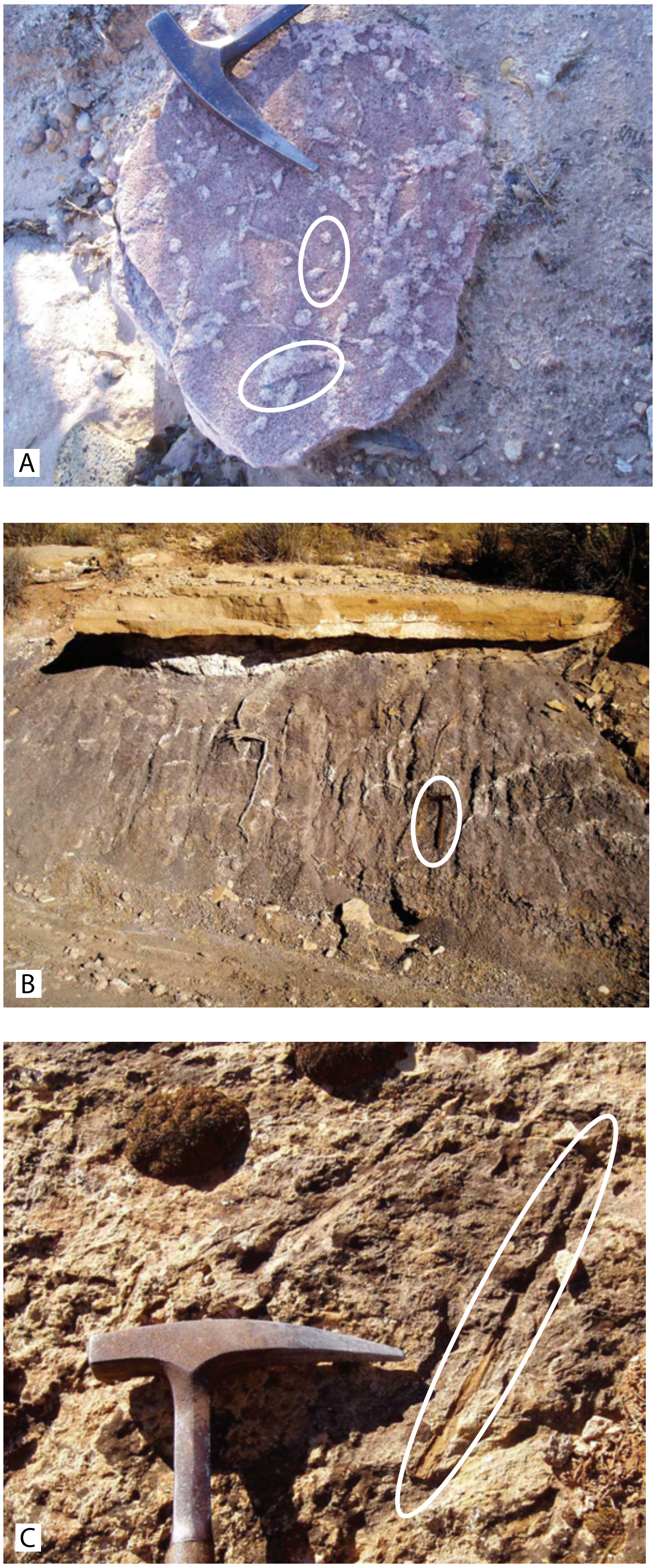

Figure 8. *Photographs of the Dakota Formation A) Burrow trace fossils (circled) typical of fine-grained sandstone in the Dakota Formation near Blanding. B) Carbonaceous mudstone interbedded with thin sandstone in the Dakota Formation; circled rock hammer for scale. C) Wood trace fossils (circled) typical of Dakota Formation sandstone.*

ern margin of Blanding-White Mesa, is at least 30 to 40 feet (9-12 m) thick, consisting of interbedded sandstone, siltstone, mudstone and shale (plate 2). Sandstone is laterally variable, commonly interfingering or pinching out into mudstone or shale within several hundred feet. Sandstone beds up to 20 feet (6 m) thick are common in the lower Dakota Formation, consisting of medium-grained trough and planar cross-bedded quartz arenite and fine- to medium-grained sandstone that are commonly massively bedded or bioturbated. The upper portion of the Dakota Formation is characterized by carbonaceous mudstone, siltstone, and sandstone beds less than 10 feet (3 m) thick. The Mancos Shale conformably overlies the Dakota Formation, where it has not been removed by subsequent erosion (Haynes and others, 1972; Molenaar, 1981; Doelling, 2004). The Dakota Formation was deposited in fluvial and marginal marine conditions produced by southwestward transgression of the Cretaceous Interior Seaway (Molenaar, 1981; Elder and Kirkland, 1994). The Dakota Formation is Late Cretaceous in age (Molenaar, 1981); more detailed local age constraints for the Dakota Formation are lacking (Huff and Lesure, 1965; Haynes and others, 1972).

The relatively complex distribution of permeable sandstone and impermeable mudstone and shale within the Dakota Formation may place important spatial controls on recharge to the principal aquifer. Areas where Dakota Formation sandstone is exposed or thinly mantled by unconsolidated deposits and in direct contact with underlying sandstone of the Burro Canyon Formation, such as near city of Blanding Reservoirs 3 and 4 prior to relining, and along drainages across much of Blanding-White Mesa, may be important recharge areas. Where the Burro Canyon Formation is completely saturated, lower sandstone of the Dakota Formation may also harbor and produce water.

Mancos Shale

Outcrops of the Upper Cretaceous Mancos Shale occur as hills and slopes generally near or directly beneath overlying Quaternary pediment remnants across portions of the study area. Mancos Shale is absent in most of the study area where rocks of the Dakota Sandstone and Burro Canyon Formation are either exposed or directly mantled by thin unconsolidated deposits.

The Mancos Shale in the study area consists of marine shale and interbeds of thin (less than 2 feet [0.7 m] thick) sandstone and siltstone beds. Various pelecypod fossils are common in Mancos Shale outcrop areas (Huff and Lesure, 1965; Haynes and others, 1972) (figure 9). Total thickness is estimated at 30 to 40 feet (9-12 m), but is generally 0 to 20 feet (0-6 m). The Mancos Shale was deposited during transgression and highstand of the Cretaceous Interior Seaway during the Late Cretaceous (Elder and Kirkland, 1994).

Areas where the Mancos Shale is either mapped or present in the subsurface are shown in figure 10. Where present, the Mancos Shale may act as an important impermeable layer reducing the amount of potential infiltration and recharge to the underlying Dakota-Burro Canyon aquifer (Avery, 1986; Goodknight and Smith, 1996). Local perched water tables may exist in unconsolidated deposits above Mancos Shale beds but are likely to be limited in extent (Goodknight and Smith, 1996).

Quaternary Deposits

Unconsolidated deposits of Quaternary age cover most of the Blanding-White Mesa area (plate 1). Locally these deposits include (1) alluvium, consisting of sand and gravel lining active stream channels, (2) loess that covers much of the mesa tops, and (3) erosional remnants of pediment surfaces, characterized by clast-supported gravel and cobbles and thick layers of pedogenic calcite (figure 9).

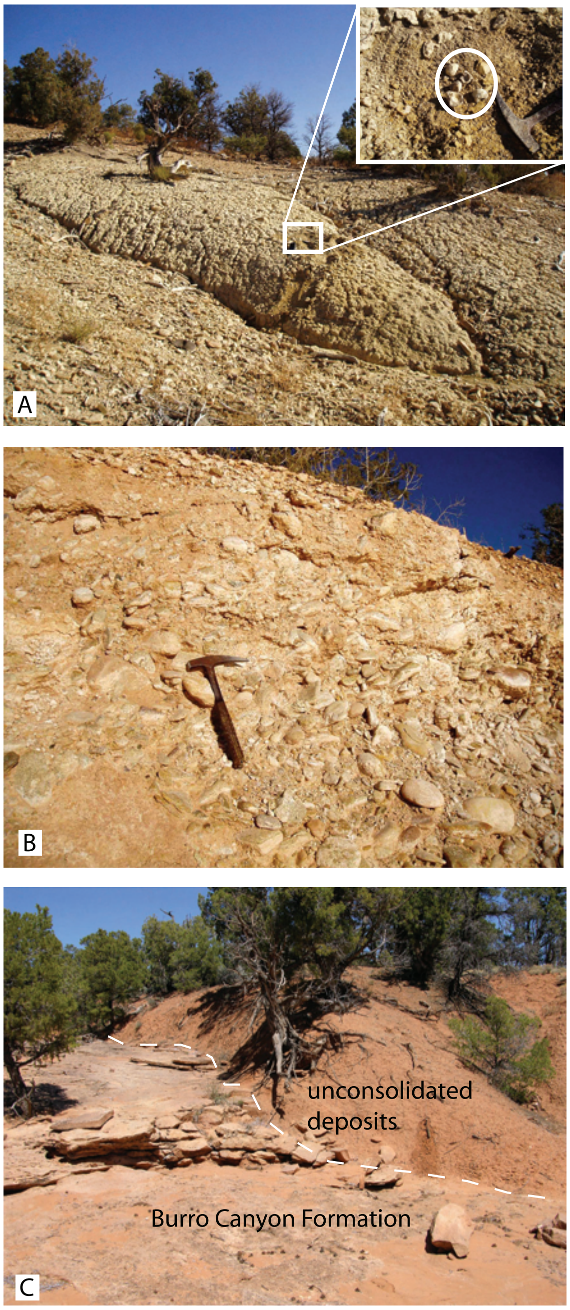

Figure 9. Mancos Shale and unconsolidated deposits. A) Weathered slope of Mancos Shale southeast of Blanding. Inset shows various pelecypod fossils (circled) indicative of Mancos Shale outcrops. Little recharge of the principal aquifer is likely where outcrops such as these occur. B) Quaternary clast- and matrix-supported unconsolidated cobble deposits that cap small hills on Blanding-White Mesa. These deposits and C) unconsolidated fine-grained sand and silt deposits where they directly overlie sandstone of the Dakota or Burro Canyon Formations likely facilitate recharge of the principal aquifer.

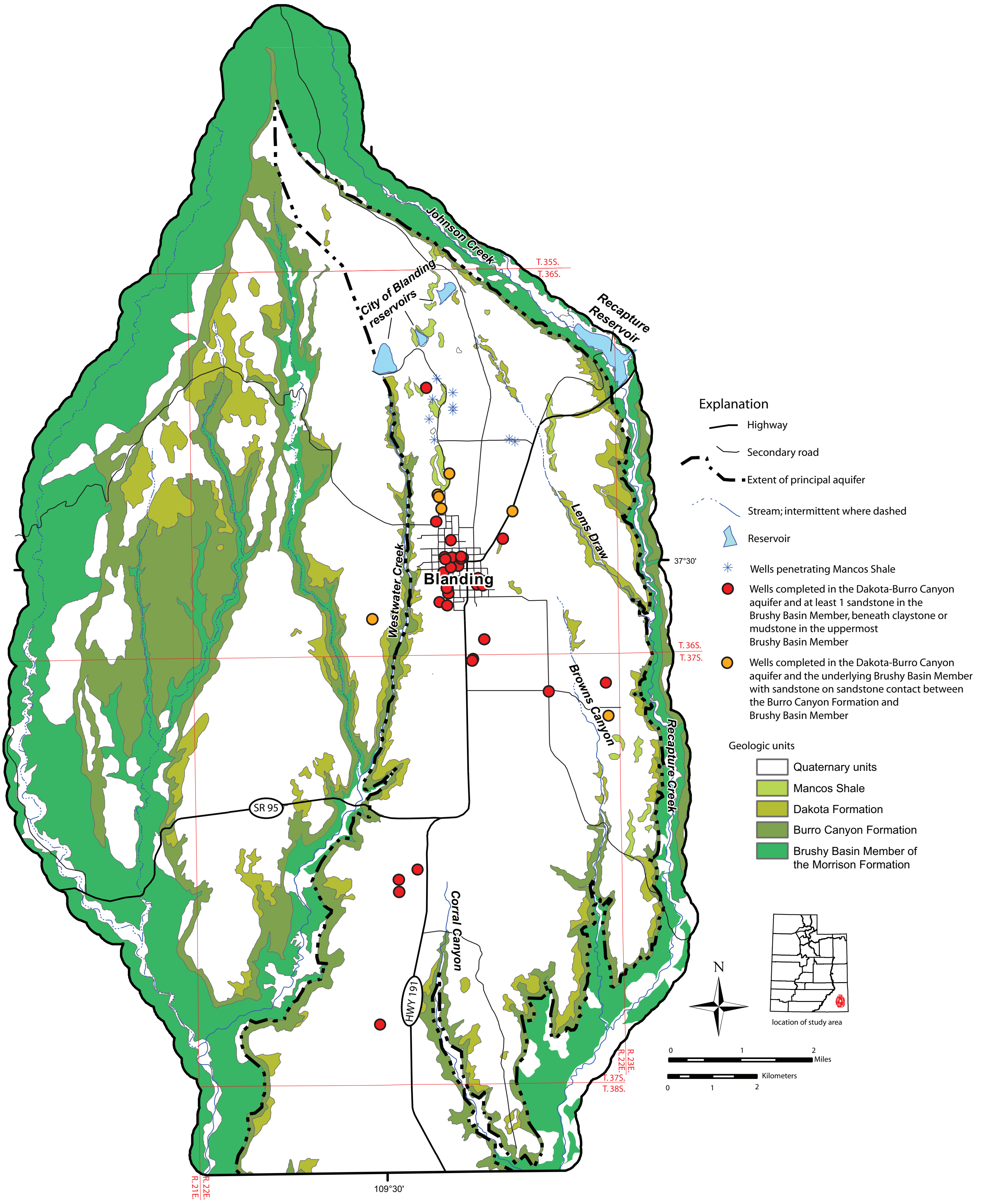

Figure 10. Well log summary and outcrop of Creteaceous and Jurassic rocks in the Blanding area.

Previous workers and I mapped active alluvial deposits along many of the stream courses that bound and drain Blanding-White Mesa (Haynes and others, 1972; Montgomery, 1980) (Plate 1). These deposits typically consist of sand and gravel in active stream channels and dissected stream terraces along channel margins (Biggar and others, 1981). Typical thickness is less than 20 feet (6 m) along many of the drainages in the study area.

Loess deposits of red to brown, finely bedded silt, sand, and lesser clay rest directly on Cretaceous and Upper Jurassic bedrock across much of the study area (Haynes and others, 1972; Biggar and others, 1981). Loess thickness in the Blanding area averages 10 feet (3 m) based on available wells logs (table A.1). In exposures south of Blanding, a series of buried calcareous soils indicates periodic deposition of loess during the Holocene (Biggar and others, 1981).

Pediment remnants form conspicuous higher surfaces and hills across the northern and southeastern portions of the study area (plate 1; figure 9b). Clast-supported, intermixed gravel and cobbles are derived from rocks exposed in and near the Abajo Mountains. Samples from sand lenses in pediment remnants are reversely magnetized, implying that they were deposited during the Matayama reverse chron, between 700,000 and 2.4 Ma years ago (Biggar and others, 1981).

Due to their relatively high permeability (Goodknight and Smith, 1996), unconsolidated deposits, particularly where less than 30 feet (9 m) thick, likely facilitate recharge of the principal aquifer by infiltration of precipitation and various types of artificial recharge. In areas where these deposits overlie Mancos Shale or fine-grained deposits of the upper Dakota Formation, significant recharge of the principal aquifer is unlikely and localized perched water tables may exist within the unconsolidated deposits.

Local Structure

Bedrock dips shallowly 2 to 5 degrees to the south-southeast, away from the Abajo Mountains (plate 1) (Haynes and others, 1972; Gaeaorama Inc., 2004). No faults have been mapped in the study area (plate 1) (Haynes and others, 1972). Joints were found to be uncommon across exposures of the Dakota and Burro Canyon Formations. Where present, primary joints are nearly vertical and north striking, and commonly several meters in length; secondary joint sets are oriented east-west and commonly terminate at the longer primary joint surfaces. Where present, joints may facilitate general north to south movement of ground water. Structural control of ground water is likely limited due to the relative absence of faults and the apparent low frequency of joints.

Subsurface Data

Water-Well Logs

To constrain the subsurface extent and geometry of the Dakota-Burro Canyon aquifer, I examined available water-well logs for the study area (Utah Division of Water Rights, 2006) (table A.1). I noted lithologic contacts between the Brushy Basin Member of the Morrison Formation, Burro Canyon Formation, Dakota Sandstone, and overlying unconsolidated deposits where appropriate. I also noted basic well completion data including screen interval and static water level (table A.1).

The contact between the Burro Canyon Formation and the Brushy Basin Member is apparent in most well logs and is most commonly defined by a vertical transition from continuous white sandstone of the overlying Burro Canyon Formation to red or less commonly green shale or claystone interbedded with sandstone (< 10 feet thick) of the Brushy Basin Member. In the absence of red clay or shale in the uppermost Brushy Basin Member, I placed the contact at the transition from thick (> 20 feet) sandstone commonly noted as white to a thin (< 10 feet thick) sandstone noted as brown or tan in color. The contact between the Burro Canyon and overlying Dakota Formation is more variable, and I noted it only where evidence is strong for its position. In areas where Dakota Formation sandstone rests directly on sandstone of the upper Burro Canyon Formation, the base of the Dakota Formation may not be recognizable based on driller logs.

Most wells in the Blanding-White Mesa area are completed in the basal Burro Canyon Formation and the uppermost portion of the Brushy Basin Member of the Morrison Formation. Few wells are entirely completed in the Brushy Basin Member of the Morrison Formation. Several deep wells penetrate units below these formations, however significant production from these deeper aquifers has not yet occurred.

The lithology of the uppermost Brushy Basin Member varies across the Blanding-White Mesa area. Figure 10 shows the locations of wells where sandstone of the Brushy Basin Member directly underlies Burro Canyon Formation sandstone. Permeable sandstone beds in the upper Brushy Basin Member, where laterally continuous, may facilitate downward leakage from the principal aquifer. Hydraulic continuity between sandstones in the uppermost Brushy Basin Member and the Burro Canyon Formation may increase the saturated thickness and volume of ground water in transient storage.

Open intervals and screened intervals are not always noted on well logs. Open intervals or screened zones commonly include at least the lower half of the hole. Wells that are completed across the base of the Burro Canyon Formation provide local hydrologic continuity between the Burro Canyon sandstones and thin sandstones in the uppermost Brushy Basin Member (figure 10).

Logged wells north of Blanding show Mancos Shale overlying rocks of the principal aquifer near areas where Mancos Shale is mapped at the surface (plate 1, figure 10). The thickness of Mancos Shale where present is up to 40 feet (12 m); average thickness is approximately 15 feet (5 m). Infiltration to the principal aquifer may be reduced where impermeable Mancos Shale overlies the principal aquifer. Local perched water tables may be developed in and above areas where Mancos Shale is present in the subsurface (Goodknight and Smith, 1996).

Structure Contours

Structure contours of the base of the Burro Canyon Formation based on well logs and geologic mapping are presented in plate 3. The base of the Burro Canyon Formation slopes gently southeast and south at an average of 116 feet per mile (22 m per km) across the study area. North of Blanding the Burro Canyon Formation dips to the southeast, and east of Lems Draw and south of Blanding the Burro Canyon Formation dips south (plate 3); this change in orientation possibly defines a subtle south plunging syncline parallel to Lems Draw (Gaeaorama Inc., 2004). However, surficial strike and dip data are ambiguous (plate 1), suggesting that changes in dip direction apparent on plate 3 are related to paleotopography prior to deposition of the Burro Canyon Formation. Where well log data points are dense, small-scale changes up to 20 to 30 feet (6-9 m) in contact elevation over short lateral distances are apparent (plate 3). Small-scale changes at the base of the Burro Canyon may represent paleotopography developed prior to deposition of the Burro Canyon and Dakota formations.

HYDROGEOLOGIC SETTING

Aquifer Characteristics

The principal aquifer extends between Recapture and Westwater Canyons across contiguous portions of Dakota and Burro Canyon Formation bedrock from an arbitrary east-west boundary in the south, northward beneath Blanding-White Mesa (plate 4; figure 2). Total land area above the principal aquifer is 30,800 acres (125 km^2). The Cretaceous and Upper Jurassic rocks, including the Mancos, Dakota, and Burro Canyon Formations and the upper part of the Brushy Basin Member of the Morrison Formation, comprise the principal aquifer and aquicludes in the Blanding-White Mesa area. The principal aquifer includes the Dakota and Burro Canyon Formations, bounded below by the Brushy Basin Member aquiclude and, locally, above by erosional remnants of the Mancos Shale aquiclude.

The principal aquifer is largely unconfined. Confining conditions may exist where the Mancos Shale is mapped at the surface and/or noted on well logs, and the principal aquifer is completely saturated near the City of Blanding Reservoirs (figure 10). The possible extent of confined conditions is only a small fraction (less than 5 percent) of the total area of the principal aquifer (figure 10) and evidence for confining conditions in the principal aquifer away from outcrops of the Mancos Shale exists only at a single flowing well near the intersection of Lem's Draw and Highway 191. The principal aquifer is therefore assumed to be entirely unconfined for all subsequent water level and water volume calculations.

Ground-water movement through rocks is controlled by basic geologic properties that include porosity and permeability. Porosity is a measure in percent of the open intergranular void space in a rock mass. Because pores that are not connected are unable to convey fluids and therefore unlikely to directly control water movement, a measure of effective porosity or interconnected pore space is commonly presented as a measure of usable pore space. Hydraulic conductivity is the velocity at which water moves through a saturated porous medium.

Freethey and Cordy (1991) presented regional porosity and permeability data for the Dakota and Burro Canyon Formations based on drill-stem, aquifer, and laboratory tests. Data for the Dakota and Burro Canyon Formations are undifferentiated and represent composite regional hydrologic properties of the two units. Based on 39 measurements, effective porosity ranged from 2 to 22 percent with a mean value of 10 percent (Freethey and Cordy, 1991). Values in the study area may be higher than the mean due to the high local ratio of sandstone to mudstone and claystone, and the near-surface condition of the aquifer. Regional transmissivity values calculated from aquifer tests and estimated from saturated thickness and hydraulic conductivity are greater than 100 ft2/day (9 m^2/day) (Freethey and Cordy, 1991). Hydraulic conductivity based on laboratory measurements of the Dakota and Burro Canyon Formation had a mean of 0.32 feet per day (1.14 x 10^{-4} cm/sec) and a range of 0.11 to 0.52 feet per day (0.39-1.83 x 10^{-4} cm/sec) (Freethey and Cordy, 1991). Single slug tests north of the study area, near Monticello, gave lower hydraulic conductivities, 0.06 feet per day (2 x 10^{-5} cm/sec) for the Dakota and Burro Canyon Formations (Goodknight and Smith, 1996) in geologic conditions similar to those across Blanding-White Mesa.

Ground Water Levels and Movement

Contours of ground-water elevation in the principal aquifer are based on existing springs and seeps, U.S. Geological Survey long-term monitoring wells (2006a), and new water level measurements (plate 4, table 1). Ground-water levels were contoured using ArcGIS, and then modified in areas of poor fit from water level and spring location and elevation data (table 1) taken during March and April of 2006. Dashed lines on plate 4 show areas of estimated ground-water elevation. In these areas either well or spring data is lacking and ground-water elevations are assumed based on nearby measured values and geology (i.e., the structure contour on the base of the principal aquifer). Error in areas of estimated ground-water elevation may be significant and is likely compounded by subsequent calculations based on the potentiometric surface (plate 4, figures 11 and 12).

Ground-water elevations for the Dakota-Burro Canyon aquifer decrease to the south and southeast across the study area (plate 4). The hydraulic gradient is steepest along the northern portion of the study area just south of the City of Blanding Reservoirs and the upper canal (plate 4). To the south the hydraulic gradient decreases and is nearly equal to the topographic slope. Previous work by Avery (1986) estimated the gradient at approximately 100 feet per mile (19 m/km) to the south. The average hydraulic gradient based on plate 4 is 104 feet per mile (20 m/km) to the south.

Depth to ground water for the study area is the difference between land surface elevation, taken from a 10-meter Digital Elevation Model (U.S. Geological Survey, 2006b), and the ground-water surface derived from plate 4 using ArcGIS (figure 11). Depth to water varies from 0 to 200 feet (0-60 m) across the study area; average depth to water is 90 feet (27 m) (figure 11). Areas of relatively shallow ground water, within 20 feet (6 m) of the land surface, line many of the drainages including Lems Draw and Browns Canyon (figure 11).

Water in Transient Storage

The total amount of ground water in the principal aquifer is the product of the saturated volume of rock and effective porosity of the principal aquifer. The saturated volume of rock in the principal aquifer is the difference between the potentiometric surface (plate 4) and the structure contour on

Table 1. *Water-level sites used to construct potentiometric surface shown on plate 4 and location of additional long-term monitoring wells.*

Id	East[1]	North[1]	Water Elevation[2]	Date	Description
1	634295	4162449	5846	3/28/2006	USGS 1 long term well
2	633753	4164444	5948	3/28/2006	USGS 2 long term well
3	634896	4164550	5933	3/28/2006	USGS 3 long term well
4	634495	4166953	6114	3/28/2006	USGS 4 long term well
5	634299	4164939	—	—	USGS 5 long term well
6	634250	4164939	—	—	USGS 6 long term well
7	634704	4160174	—	—	USGS 7 long term well
8	635947	4168261	6180	4/10/2006	well
9	633528	4170032	6430	4/11/2006	well
10	634677	4166792	6100	4/10/2006	well
11	633230	4167096	6148	4/10/2006	well
12	634326	4164228	5939	4/12/2006	well
13	633658	4168363	6248	4/13/2006	well
14	637869	4166286	5960	4/13/2006	spring/seep
15	637842	4166343	5980	4/13/2006	spring/seep
16	636179	4165527	6020	4/14/2006	spring/seep
17	636664	4166190	6020	4/14/2006	spring/seep
18	637603	4168819	6120	4/13/2006	spring/seep
19	637628	4168771	6120	4/14/2006	spring/seep
20	637725	4168514	6100	4/13/2006	spring/seep
21	635778	4168382	6190	4/14/2006	spring/seep
22	637132	4161506	5735	4/14/2006	spring/seep
23	633909	4156875	5600	4/13/2006	spring/seep
24	632648	4168551	6300	4/14/2006	spring/seep
25	635034	4164655	5941	6/7/2005	well log
26	634714	4167355	6154	5/5/2005	well log
27	632531	4154992	5575	4/21/2005	well log
28	632255	4154363	5531	4/9/2005	well log
29	632148	4155323	5575	4/29/2005	well log
30	631927	4154694	5515	4/22/2005	well log
31	631767	4154967	5510	4/21/2005	well log
32	631647	4154767	5502	4/22/2005	well log
33	631372	4154984	5496	4/21/2005	well log
34	631119	4154584	5485	4/21/2005	well log

(1)=easting, northing coordinates are in NAD 27 UTM zone 12 N

(2)=Water elevation in feet above sea level

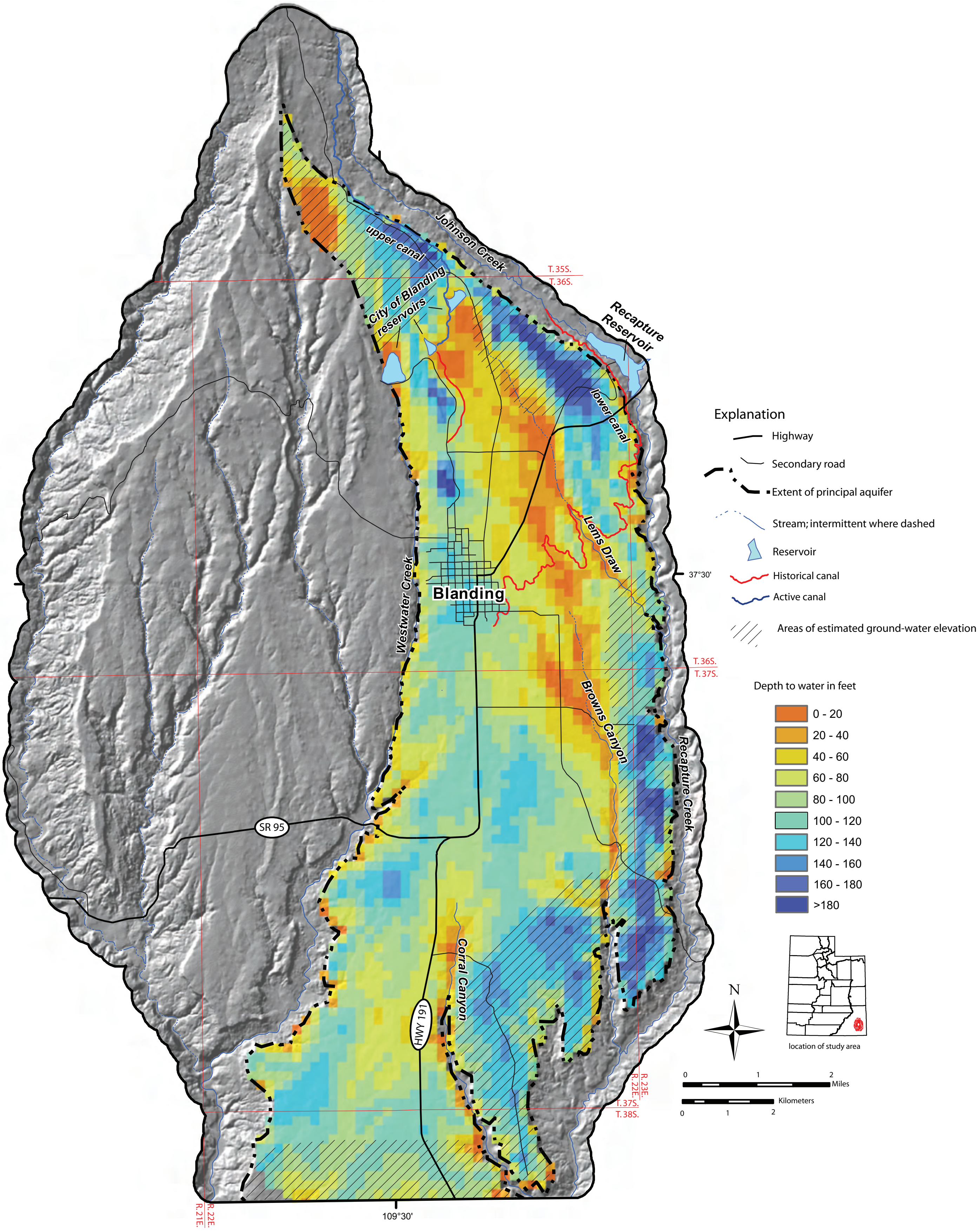

Figure 11. Depth to water, in spring 2006, in the Dakota-Burro Canyon aquifer beneath the Blanding area. Values are the difference between the potentiometric surface in Plate 4 and 10-meter digital elevation model available from the U.S. Geological Survey (2006b). Areas of estimated ground-water elevation have greater potential for error than other parts of the study area. Pixels are 200 x 200 meters (660 x 660 ft).

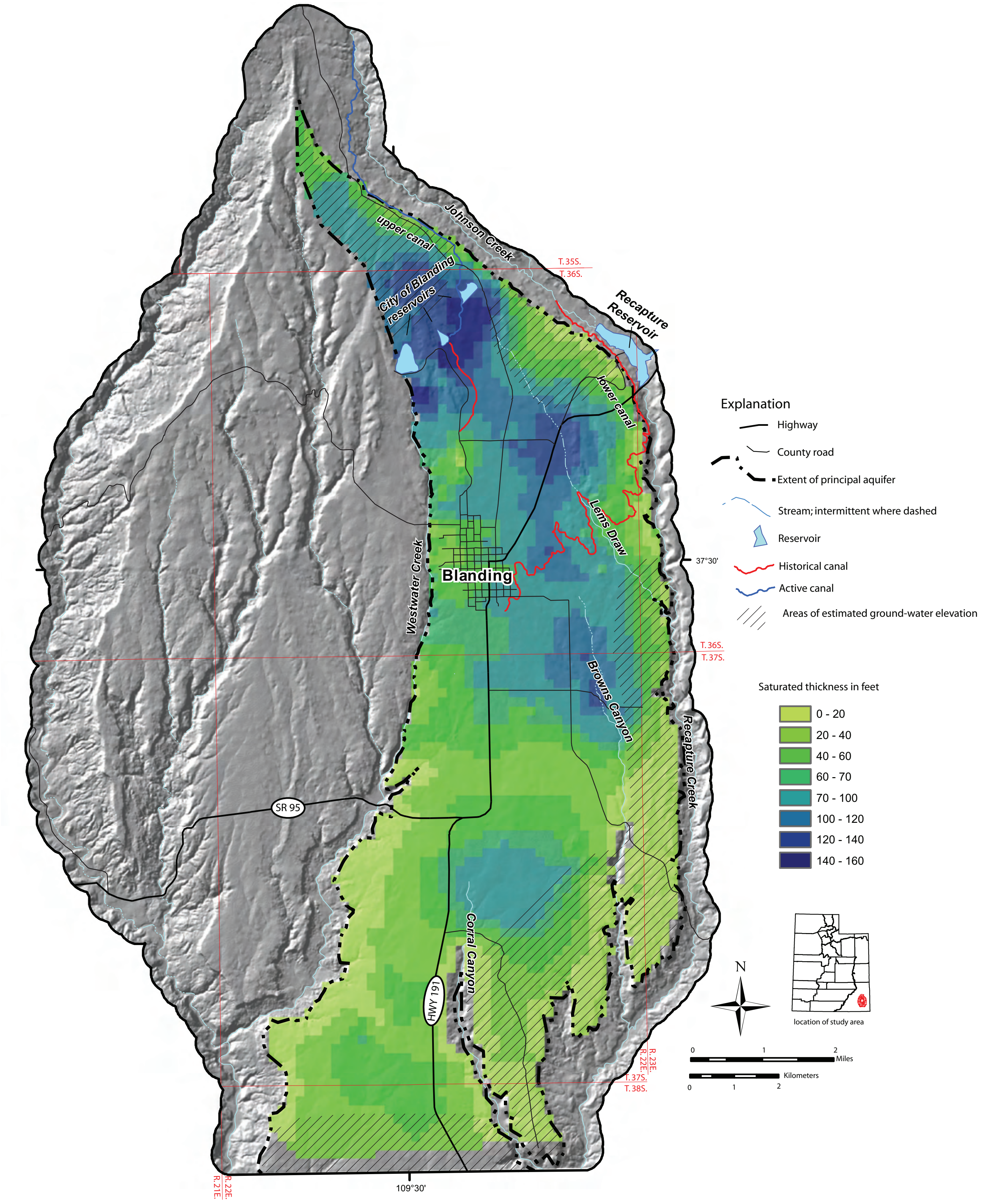

Figure 12. *Saturated thickness, in spring 2006, for the Dakota-Burro Canyon aquifer. Thickness is difference between the potentiometric surface (plate 4) and the base of the Burro Canyon structure contour (plate 2). Areas of estimated ground-water elevation have greater potential for error than other parts of the study area. Pixels are 200 x 200 meters (660 x 660 ft).*

the base of the Burro Canyon Formation (plate 3). Grid surfaces for both plate 3 and plate 4 were generated using a natural neighbor interpolation technique in ArcGIS. The structure contour grid was then subtracted from the potentiometric grid to produce a saturated thickness grid (figure 12). Total volume of saturated rock is 1,560,000 acre-feet (1920 hm^3), estimated by summing the saturated volume of each square 200 x 200 meters (660 x 660 ft) pixel in figure 12 across the entire aquifer.

A zone of high-saturated thickness extends south and southeast of City of Blanding Reservoirs and the upper canal, along Lems Draw in the north and roughly parallel to the mesa axis to the south (figure 12). Saturated thickness decreases to zero along exposed portions of the base of the Burro Canyon Formation along the margin of Blanding-White Mesa (figure 12). Multiplying the saturated rock volume by mean effective porosity (interconnected pore space through which water may move) of ten percent (Freethey and Cordy, 1991) yields 156,000 acre-feet (192 hm^3) of water in transient storage. Actual effective porosity of the principal aquifer may vary between at least 2 and 22 percent (Freethey and Cordy, 1991), and estimates of transient storage may vary accordingly from 31,000 acre-feet (38 hm^3) and 343,000 acre-feet (423 hm^3).

Long-Term Water Levels

Since 1942, the U.S. Geological Survey has periodically measured water levels at wells near Blanding. Seven wells having the longest period of record were analyzed in greater detail (figure 13, table 2) (U.S. Geological Survey, 2006a). U.S. Geological Survey wells 5, 6, and 7 provide water-level data for the area beginning in 1942, and monitoring of U.S. Geological Survey wells 1, 2, 3, and 4 began later, and continues to the present.

Rates of water-level change, taken as the linear least squares regression line for a given well and time period, are shown in table 2. Statistical data for regressions and water-level data is shown in table A.2. Most regressions (table A.2) have statistically valid trends and are therefore useful in predicting water-level changes through time. Data sets with poor regression trends are also included in subsequent calculations because of the limited amount of water-level measurements for the study area. This may ultimately increase error in calculation of mean values but does provide needed spatial and temporal coverage of water-level change in the principal aquifer.

Water levels in monitoring wells show at least three distinct periods of water-level change. An early period of increasing water levels is apparent in all seven monitoring wells with periods of record ranging from 1942 to 1979 (figure 13, table 2). Water-level fluctuation and decline in the late 1970s and early 1980s followed by steadily increasing water levels define a middle period from 1979 to 1989. Since 1989 water levels have slowly declined at all sites (figure 13, table 2). Mean rate of ground-water level increase for all monitoring wells is 6.7 inches (16.9 cm) per year prior to 1979 and 7.3 inches (18.5 cm) per year between 1979 and 1989. Since 1989 ground-water levels have declined by a mean rate of 5.3 inches (13.4 cm) per year.

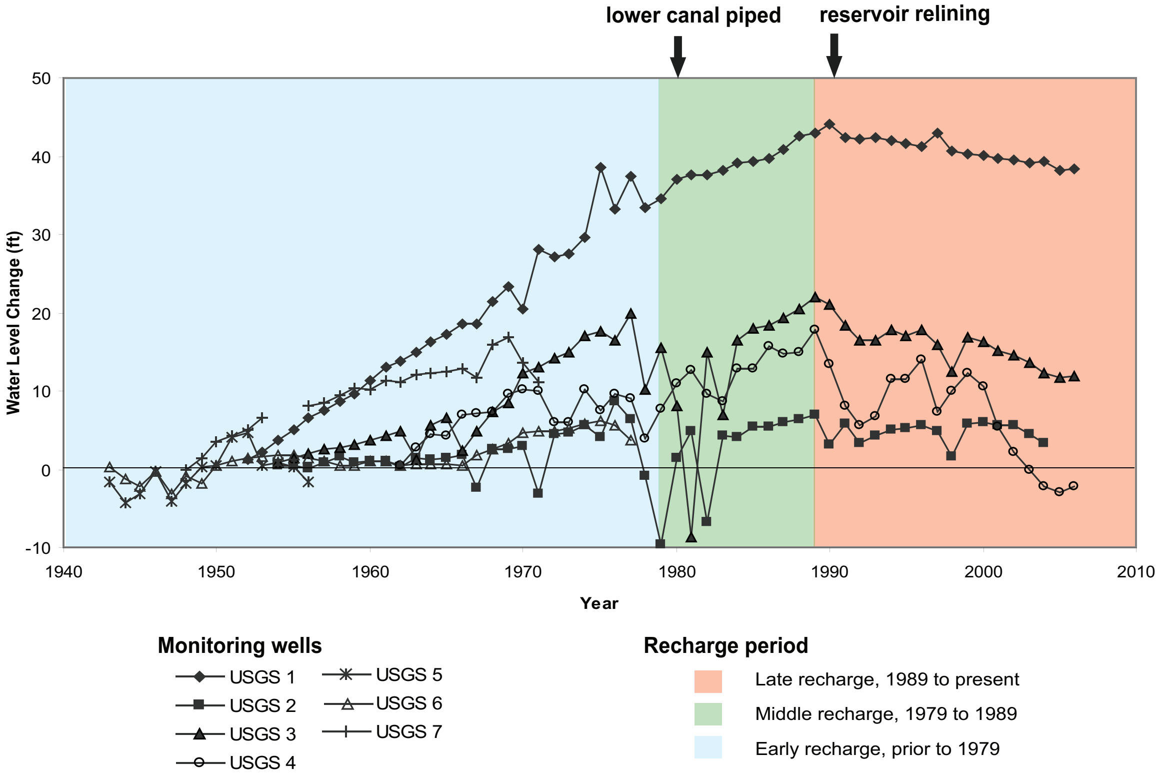

Figure 13. Cumulative annual water-level change at selected U.S. Geological Survey monitoring wells in the Blanding area. Water levels increase across all wells prior to 1989; since 1989 water levels have declined. Rate of water-level change for each well and recharge period are shown in table 2. Statistical summary of trends is presented in table A.2. Location of monitoring wells is shown on plate 4.

***Table 2**. Trends in annual water-level change at U.S. Geological Survey monitoring wells in the Blanding area. Rate of change taken from slope of best fit linear regression line for each data period. Statistical summary of trends is presented in table A.2. Water levels increased in all wells prior to 1989; since 1989 water levels have declined. Location of monitoring wells is shown on plate 4.*

	Average change in water level in inches (cm) per year for each time period				
Monitoring well	**Prior to 1979**	**1979-1989**	**After 1990**	**Average depth to water (ft)**	**Period of record**
USGS 1	16.2 (41.1)	7.9 (20.1)	-3.7 (-9.3)	84.1	1951-2006
USGS 2	2.5 (6.3)	4.6 (11.7)	-0.7 (-1.9)	122.9	1953-2006
USGS 3	9.0 (22.9)	7.9 (20.1)	-5.8 (-14.7)	97.6	1953-2006
USGS 4	6.5 (16.5)	8.8 (22.4)	-10.8 (-27.4)	47.6	1961-2006
USGS 5	3.2 (8.1)	NA	NA	18.3	1942-1956
USGS 6	2.3 (5.8)	NA	NA	49.7	1942-1977
USGS 7	7.1 (18.0)	NA	NA	79.5	1947-1971
Mean	6.7 (16.9)	7.3 (18.5)	-5.3 (-13.4)		

Long-term precipitation trends at Blanding show little correlation with water-level trends (figures 4 and 13). The precipitation trend, taken as the slope of the least squares regression line prior to 1979, shows slightly decreasing yearly precipitation, during a period of ground-water level increase. Prior to 1989, ground-water level increases measured at all seven long-term monitoring wells are therefore likely due to unintended artificial recharge from any or all of the potential artificial recharge sources discussed in the water budget section below. After 1989, water levels in monitoring wells have declined slowly and water-level fluctuations may at least partially correlate with annual precipitation measured at Blanding (figures 4 and 13).

WATER-BUDGET COMPONENTS

Introduction

The annual water budget is the balance of water added to (recharge) and removed from (discharge) and the change in storage in the principal aquifer (Fetter, 1980). Assuming steady state conditions, the sum of all components of recharge should equal the sum of all components of discharge and the change in storage over the same period (Freeze and Cherry, 1979).

Changes in the water budget components through time have resulted in continuous change in measured water levels in the principal aquifer (figure 13). Because of this, and the potential for future changes in recharge and discharge, water budget components are estimated for distinct time periods that include 1) a period of water level increase prior to 1990, 2) a period of water level decrease since then, and 3) an assumed future state based on planned changes to water delivery and storage across the study area (figure 14, table 3). Numerical modeling of transient water-level conditions in the Dakota-Burro Canyon aquifer is required to accurately constrain all water-budget components and is beyond the scope of this report.

I based ground-water budget components presented in this report on estimated inputs and outputs to the Dakota and Burro Canyon aquifer in the study area. The estimates of water-budget components listed below each have inherent error that is relative to a given component. Water-budget components with relatively small inputs or outputs are in many cases less than the possible error associated with many of the larger water-budget components.

Recharge

Recharge to the principal aquifer occurs naturally through direct infiltration of rain and snow, and artificially from seepage of unlined reservoirs, ponds, and canals, unconsumed irrigation water, and septic systems. Subsurface input from underlying units is unlikely because of (1) downward ground-water gradients between the Dakota and Burro Canyon aquifer and the Brushy Basin Member, (2) the relatively impermeable underlying Brushy Basin Member, and (3) the apparent lack of significant geologic structures that could facilitate hydrologic communication between the principal aquifer and underlying units. Recharge varies both temporally and spatially across the study area; detailed discussion of the various components of recharge is presented below.

Precipitation

Recharge by direct infiltration of precipitation in arid areas likely occurs from only a small fraction of total annual precipitation (Scanlon, 2004). Previous empirical estimates of recharge as a percentage of annual precipitation range from 2 to 7 percent for areas with precipitation and evapotranspiration ranges similar to that at Blanding (Price and Arnow, 1974; Flint and others, 2002; Scanlon, 2004). Price and Arnow (1974) estimated recharge for shallow aquifers across the Colorado Plateau at 4 percent of annual precipitation. Local recharge of 1370 acre-feet (2 hm^3) per year is calculated based on 4 percent of 13 inches (33 cm) average

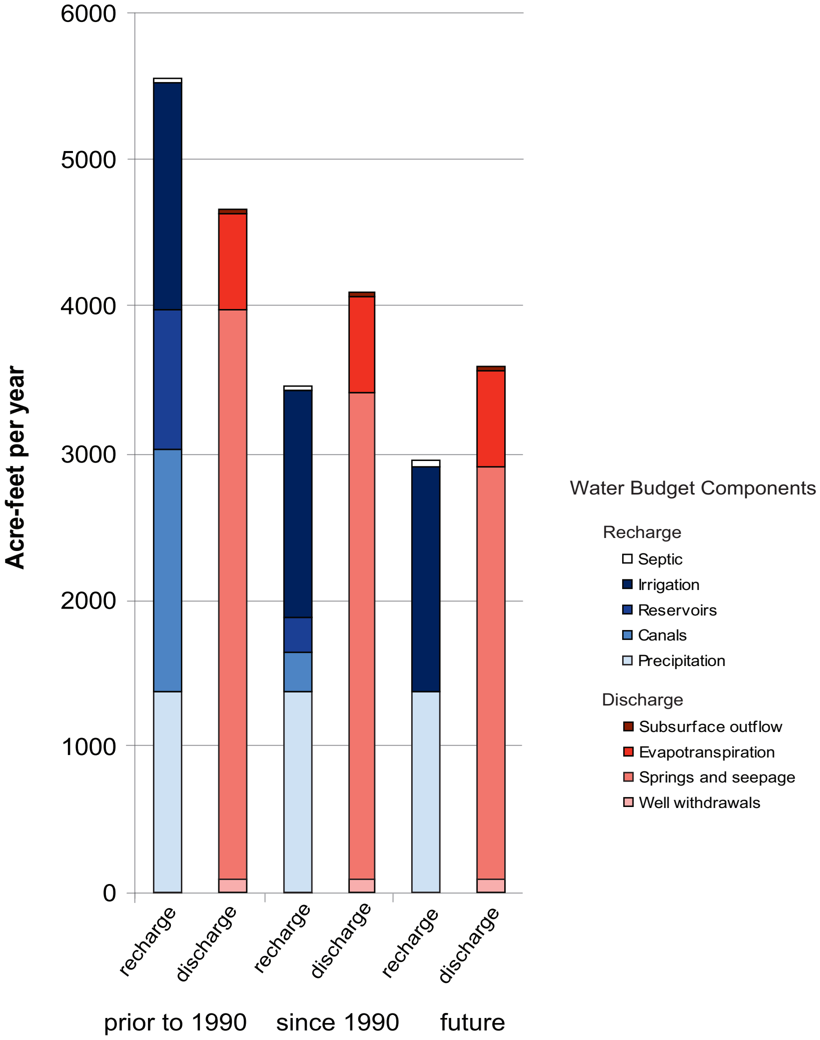

Figure 14. *Graph of annual water budget components for the Dakota and Burro Canyon aquifer near Blanding, Utah. Imbalance between recharge and discharge is assumed to be change in storage for a given period. Prior to 1990 change in storage is estimated as an increase of 900 acre-feet. Since 1990 and in the future, change in storage is estimated as a decrease of 640 acre-feet. For further description see text and table 3.*

Table 3. *Water budget components for the Dakota-Burro Canyon aquifer in the study area. All values are in acre-feet per year. Loss of recharge represents the reduction of artificial recharge compared to pre-1990 conditions. Negative values for change in storage represent a cumulative loss of water from the principal aquifer. See text for further explanation.*

	Prior to 1990		**Since 1990**		**Future**	
Component	**Recharge**	**Discharge**	**Recharge**	**Discharge**	**Recharge**	**Discharge**
Precipitation	1370		1370		1370	
Canal seepage	1650		270		0	
Reservoir seepage	970		240		0	
Excess irrigation	1540		1540		1540	
Septic Seepage	30		30		30	
Total recharge	5560		3450		2940	
Reduction of recharge			2110		2620	
Well withdrawal		90		90		90
Subsurface outflow		25		25		25
Evapotranspiration		650		650		650
Springs and seepage		3900		3330		2820
Total discharge		5560		3450		2940
Change in storage		900		-640		-640

annual precipitation (for the period 1904 to 2006) measured at Blanding and the total surface area (30,800 acres) above the principal aquifer on which infiltration and recharge can occur (table 3). Recharge calculated for 2 and 7 percent of annual precipitation is 680 acre-feet (1 hm3) and 2390 acre-feet (3 hm3) per year, respectively.

Artificial Recharge

Various types of artificial recharge likely contribute water to the Dakota-Burro Canyon aquifer. Since the Blanding area was settled in the early part of the twentieth century, water has been brought onto the Blanding-White Mesa for irrigation and culinary purposes along upper and lower canal systems (figure 2), and stored in a series of reservoirs along the northern portion of Blanding-White Mesa. The primary source of this water is the perennial Johnson Creek drainage, which drains upland portions of the Abajo Mountains (figure 2). The annual amount of artificial recharge from varying sources has changed as the extent and characteristics of these sources have changed.

Canals: Initially two water-diversion ditches, one in the northern (upper canal) and one in the southern (lower canal) portion of the study area, delivered surface water to the Blanding-White Mesa area from Johnson Creek (figure 2). The upper (now partially enclosed) and lower (now completely enclosed pipeline) canals deliver 2390 and 2410 acre-feet (~ 3 hm^3) per year, respectively (Utah Division of Water Resources, 2001). Seepage from the lower canal, prior to installation of a closed pipe system in the 1980s, was estimated at 800 acre-feet per year for a 4.7-mile (7.6-km) stretch along the east portion of the study area (Utah Division of Water Resources, 1973), or a seepage rate of 0.07 acre-foot per mile per acre-foot of delivered water. Applying this seepage rate over the 6.8-mile (11 km) length of the lower canal above the principal aquifer gives estimated seepage of 1150 acre-feet (1.4 hm^3) per year prior to installation of a closed pipe system in the early 1980s. Similar seepage was assumed for the upper canal (Utah Division of Water Resources, 1973), and applying these seepage rates over the 3-mile (4.9 km) historical length of the upper canal above the principal aquifer gives an estimated seepage of 500 acre-feet (0.6 hm^3) per year for the upper canal. Actual seepage may be less than this value due to the presence of impermeable Mancos Shale beneath portions of the upper canal. Prior to replacement of the lower canal and portions of the upper canal with closed pipe, total canal seepage is estimated at up to 1650 acre-feet (2 hm^3) per year for the period prior to 1990 (table 3, figure 14).

Seepage from the remaining 1.6-mile (2.7 km) unpiped section of the upper canal may still account for some artificial recharge since 1990. Assuming similar seepage rates, current estimated seepage from the upper canal is 270 acre-ft (0.3 hm^3) per year since 1990 (table 3, figure 14). The entire upper canal will be replaced with closed pipe in coming years (Jeff Black, verbal communication, 2006), eliminating this component of recharge in the near future (table 3, figure 14).

City of Blanding Reservoirs: Early in the previous century, the city of Blanding constructed reservoirs that store water diverted from Johnson Creek (figure 2). Currently three reservoirs are actively used, including City of Blanding Reservoirs 3 and 4 and Starvation Reservoir. Reservoirs are filled as fluctuating stream flows allow and municipal demand dictates (Danny Fleming, verbal communication, 2005).

City of Blanding Reservoirs 4, 3, and Starvation Reservoir, were all initially unlined, and rested directly on bedrock of the Dakota Formation (Danny Fleming, verbal communication, 2005). The reservoirs are generally only partially full (perhaps 60 percent full) much of the year due to fluctuating demand and changes in water supply (Danny Fleming, verbal communication, 2005). There is no existing data on potential seepage of these reservoirs into the bedrock aquifer (Danny Fleming, verbal communication, 2006) and quantitative methods, including monitoring wells and seepage and tracer studies, are beyond the scope of this report. Instead, I made crude estimates of seepage using the area of contact between the reservoirs and the underlying aquifer rocks and the estimated hydraulic conductivity of rocks underlying the reservoirs. I calculated contact areas of the reservoirs using air photos and ArcGIS and assumed the reservoirs are 60 percent full for the entire year. The contact areas of the City of Blanding Reservoirs 3 and 4 and Starvation Reservoir are estimated at 6.6, 26.4, and 10.8 acres (2.7, 10.7, and 4.4 hectares), respectively. Estimated potential seepage assuming hydraulic conductivity of 0.06 feet per day (2×10^{-5} cm/s) (Goodknight and Smith, 1996) for aquifer rocks immediately underlying the reservoirs yields 150, 580, and 240 acre-feet (0.2, 0.7, and 0.3 hm^3) per year for city of Blanding reservoirs 3, 4, and Starvation reservoir respectively for the period prior to 1990. Seepage prior to 1990 is therefore estimated at 970 acre-feet (1.2 hm^3) per year (table 3, figure 14).

Beginning in 1990, both City of Blanding Reservoirs 3 and 4 were at least partially lined by impermeable clay, and similar clay lining is planned for Starvation Reservoir in the next few years (Jeff Black, verbal communication, 2006). Current and future seepage rates therefore are likely only a small fraction of the seepage rates prior to relining. Current seepage for the period since 1990 is assumed to be just that of unlined Starvation Reservoir or 240 acre-feet (0.29 hm^3) per year (table 3, figure 14). Future relining of Starvation Reservoir could reduce total seepage to zero (table 3).

Excess irrigation: Nearly all of the water from the lower canal is used to irrigate various crops during the summer months. Irrigation is common on agricultural lands that cover portions of the northern and much of the southern portion of Blanding-White Mesa (figure 2). Common crops include alfalfa, pasture, and grains; irrigation techniques include various types of sprinkler and flood irrigation (Utah Division of Water Resources, 1996). Excess irrigation water that is not lost to evapotranspiration infiltrates and recharges the principal aquifer. Loss of irrigation water to ground water depends on many variables including climate, irrigation, and crop type, as well as soil type and substrate characteristics (Susong, 1995; Plummer and others, 2000). Previous work has shown sprinkler irrigation of alfalfa in similar soil types in other portions of Utah results in minor or no recharge of the underlying aquifer, whereas flood irrigation recharges approximately 50 percent of the total water applied—between 30 and 36 inches (76-91cm) of recharge over the area of irrigation per irrigation season (Susong, 1995). Total flood-irrigated acreage was estimated from Utah Division of Water Resources (1996) land-use data and 2004 aerial photography at 615 acres (249 ha) (figure 2). The crop type for nearly all of the flood-irrigated acreage is alfalfa. Assuming recharge from flood irrigation equal to 30 inches (76 cm) (Susong, 1995), total potential recharge from irrigation is 1540 acre-feet (1.9 hm3) per year across the study area (table 3, figure 14). Actual recharge from irrigation may be much less than this value, and depends on yearly changes in crop and irrigation type and climate. Because of a lack of detailed yearly crop and water application data, yearly infiltration of unconsumed irrigation is assumed to be constant for all water budget time periods considered.

Infiltration of residential irrigation for lawns and landscaping may contribute significant recharge in and around the city of Blanding. No data are available for this type of recharge in the study area.

Septic systems: Seepage from septic systems in portions of Blanding-White Mesa not serviced by the city of Blanding municipal sewer system contributes to recharge of the Dakota and Burro Canyon aquifer. Total potential septic recharge was estimated from daily per capita indoor use of 70 gallons (265 L) (Utah Division of Water Resources, 2001, pg. 33) multiplied by approximately 400 citizens (U.S. Census Bureau, 2006) in outlying portions of the study area not served by the city of Blanding water and sewer system. Total potential yearly recharge from septic systems is 30 acre-feet (0.04 hm^3) per year (table 3). Actual recharge amount is likely less than this amount due to evapotranspiration of at least a portion of septic water before it can reach the water table. Determination of the amount of septic seepage lost to evapotranspiration is beyond the scope of this study.

Change in Storage

Change in total storage is estimated as the product of measured water level change, effective porosity (assumed to be 10 percent), and area over which water level change likely occurs. Water level change is taken from mean rates of water level change (figure 13). Water levels are assumed to have increased 7 inches (18 cm) per year prior to 1989, and to have decreased 5 inches (13 cm) per year since then. It is assumed that most of the change in storage occurs in portions of the aquifer near Blanding where most of the artificial recharge likely occurs, over an estimated area of 15,400 acres (6230 hectares). Change in storage is therefore estimated as a yearly increase of 900 acre-feet (1.1 hm^3) prior to 1990 and yearly decrease of 640 acre-feet (0.8 hm^3) since 1990 (table 3). Future reduction in storage is assumed to equal that of the period since 1990. Reduction in storage may increase as future artificial recharge is reduced and domestic withdrawals increase. Therefore future annual reduction in storage, of 640 acre-feet (0.8 hm^3) (table 3), is a minimum.

Discharge

Total discharge from the Dakota-Burro Canyon aquifer is the sum of water withdrawn from wells, surficial discharge by springs and seeps along the margin of Blanding-White Mesa and along creeks and drainages, evapotranspiration in areas where the water table is near the land surface, subsurface outflow along the southern margin of the study area, and seepage to the underlying Brushy Basin Member.

Well Withdrawals

I estimated total discharge from private wells from average per capita water use and the number of citizens using private wells as their principal source of culinary water. Average water use for the Blanding area is 200 gallons per capita per day (770 L) or 0.22 acre-feet per capita per year (Utah Division of Water Resources, 1996). The total population relying on domestic wells is estimated from recent census data at approximately 400 persons within the study area (U.S. Census Bureau, 2006). Based on these estimates, total yearly withdrawal from domestic wells is 90 acre-feet (0.1 hm^3) per year for all time periods (table 3). Future domestic well withdrawal will increase as population in areas reliant on ground water increases. Because of uncertainty in future population growth no attempt is made to estimate corresponding increases in domestic well withdrawal. A portion of the water withdrawn from wells is returned to the aquifer via seepage from septic systems, which is estimated above, and infiltration of domestic irrigation water, which is beyond the scope of this study.

Springs and Seepage

Water discharges from the principal aquifer at various springs, as seepage along drainages and canyons cut into the principal aquifer, and as seepage downward into the underlying Brushy Basin Member. Because data accounting for springs and seepage is lacking, this water budget component is calculated as the residual when all other terms are estimated. For these calculations it is assumed that changes in storage and artificial recharge previously estimated are reflected in either increases or decreases in total spring flow and seepage for a given water budget period.

Springs and seeps in the Dakota-Burro Canyon aquifer exist along several drainages on Blanding-White Mesa, along the margin of the mesa near the base of the Burro Canyon Formation, and at other locations where the potentiometric surface intersects the land surface. Major springs and points of seepage recorded by this study are shown on plate 4. Along drainages, springs commonly issue along bedding planes in sandstone of the Burro Canyon Formation or along the contact of the Burro Canyon Formation and the underlying Brushy Basin Member. Major areas of seepage from the principal aquifer occur along the lower sections of Lems Draw (Gaeaorama Inc., 2004), Browns Canyon, Corral Creek, and Westwater Canyon. Major springs and seeps exist along canyon walls bounding the principal aquifer, near the base of the Dakota-Burro Canyon aquifer along Recapture Canyon and Westwater Canyon. Total discharge from the various springs and seeps is not estimated separately from leakage to the underlying Brushy Basin Member, but likely represents the single largest component of discharge from the principal aquifer.

Downward seepage from the base of the Burro Canyon Formation into the underlying Brushy Basin Member is likely minor across much of the study area where the uppermost Brushy Basin is characterized by low permeability mudstone and claystone. However, in other areas sandstone of the basal Burro Canyon Formation rests directly on discontinuous sandstone of the Brushy Basin Member (figures 6 and 10). In these areas seepage from the overlying Burro Canyon Formation into the underlying Brushy Basin may be significant. Figure 10 shows two areas, north of Blanding and in Browns Canyon, where well logs do not indicate confining beds between the Brushy Basin Member and Burro Canyon Formation. Much of the study area lacks well control, however, so the actual amount of discharge from this type of seepage is unknown.

Many well logs record the presence of thin sandstone beds below the fine-grained mudstone and claystone that typify the uppermost Brushy Basin Member (Utah Division of Water Rights, 2006). Wells with open completions or continuously screened intervals across the contact of the Burro Canyon Formation and the Brushy Basin Member including at least one Brushy Basin sandstone are common. Wells such as these may be points of downward leakage of ground water into permeable sandstone of the Brushy Basin Member. The total amount of leakage is unknown and likely dependent on site-specific borehole and lithologic characteristics.

Total estimated discharge from springs and seepage is 3900 acre-feet (5 hm^3) per year for the period before 1990 (table 3, figure 14). After 1990, reductions in water levels and storage are assumed to decrease discharge to springs and seepage to 3330 acre-feet (4 hm^3) per year. Potential future reductions in artificial recharge and subsequent reductions in storage yield 2820 acre-feet (3 hm^3) per year of discharge to springs, seeps, and vertical leakage (table 3, figure 14).

Subsurface Outflow

Along the southern edge of the study area, a southward sloping potentiometric surface implies ground water is leaving the study area in the principal aquifer. Total amount of southward seepage is estimated using the cross sectional area of the saturated portion of the Dakota Burro Canyon aquifer, effective porosity, and estimated permeability of the aquifer. Based on saturated thickness data shown in figure 12, the total cross sectional area through which ground water leaves the study area is 12 acres (48,600 m^2). Assuming hydraulic conductivity of 0.06 ft/day (2 x 10^{-5} cm/s) (Goodknight and Smith, 1996) for aquifer rocks and an effective porosity of ten percent (Freethey and Cordy, 1991) yields a total subsurface outflow of 25 acre-feet per year (0.03 hm^3) (table 3).

Evapotranspiration

Evapotranspiration likely occurs in areas of shallow ground water where phreatophytes can actively withdraw water from the principal aquifer. In the study area the principal phreatophyte community consists of mixed cottonwood and willow stands that line drainages with perennial flow and areas of shallow ground water within 10 feet (3 m) of the surface (Avery, 1986; USGS National Gap Analysis Program, 2004). Total yearly evapotranspiration for cottonwood and willow communities in climates similar to Blanding is approximately 3 feet (1 m) (Bewazir, 2000; Leenhouts and others, 2006). Total area of evapotranspiration from ground water is taken from the depth to ground water grid shown in figure 11. Across the study area, 217 acres (89 ha) have ground water at less than 10 feet (3 m) below the land surface. Total evapotranspiration is estimated as the product of the vegetated area with shallow ground water (217 acres [87.8 ha]) and the yearly rate of evapotranspiration (3 feet [1 m]). Total annual evapotranspiration is estimated at 650 acre-feet (0.8 hm^3) (table 3, figure 14).

The area covered by phreatophyte communities may change through time as land use and ground-water levels fluctuate (Bewazir, 2000). A comparison of available land-cover data from 1995 (Homer, 1995) and 2004 (U.S. Geological Survey National Gap Analysis Program, 2004) shows little change in area of mapped phreatophyte communities in the study area. Field investigation of phreatophyte communities, and discussions with local landowners, also found no evidence of recent changes in phreatophyte extent. Therefore evapotranspiration from ground water is considered steady through time. However, continued ground-water level declines may reduce the extent of phreatophyte communities in the study area, possibly reducing this form of discharge in the future.

WATER CHEMISTRY AND ISOTOPE SAMPLING

Introduction

Ground and surface waters contain chemical and isotopic constituents that can provide important constraints on certain aspects of the hydrogeologic system (Freeze and Cherry, 1979; Fetter, 1980; Domineco and Schwartz, 1997; Clark and Fritz, 1997). To constrain ground-water flow paths and the timing and sources of recharge for the principal aquifer, samples were collected during April 2006 using standard collection methods (Wilde and others, 1998). Samples were analyzed for general solute chemistry and stable and unstable isotopes at the Brigham Young University (BYU) hydrogeology laboratory, and dissolved chlorofluorocarbon (CFC) concentrations were analyzed at the University of Utah Dissolved Gas Laboratory.

Solute Chemistry

Ground water within an aquifer aquires a distinct chemical composition based on the chemical composition of the water that recharges the aquifer and its interaction with the geologic framework (Fetter, 1980; Domenico and Schwartz, 1997). Ground and surface waters were sampled for major dissolved cations and anions at selected sites in the study area (figure 15, table A.3). The relative concentrations of the principle anions and cations are plotted on a trilinear diagram shown in figure 16. Surface waters from the upper canal, City of Blanding Reservoirs 3 and 4, Recapture Reservoir, and Johnson Creek form end members on the trilinear diagram (figure 16) and are of calcium-magensium-bicarbonate type. Ground-water and surface-water from other streams across the study area plot along a trend of increasing sodium, chloride, and sulfate concentration relative to city of Blanding reservoirs, the upper canal, and Johnson Creek (figure 16). Major ion chemistry of ground water from wells and springs is primarily calcium-magnesium-sodium- and either bicarbonate or sulfate type.

Stiff diagram plots of ground- and surface-water chemistry (figure 15) show minor down gradient evolution of ground-water solute chemistry in the Dakota-Burro Canyon aquifer. This implies ground water is quickly chemically equilibrated after recharge and only slightly altered along its

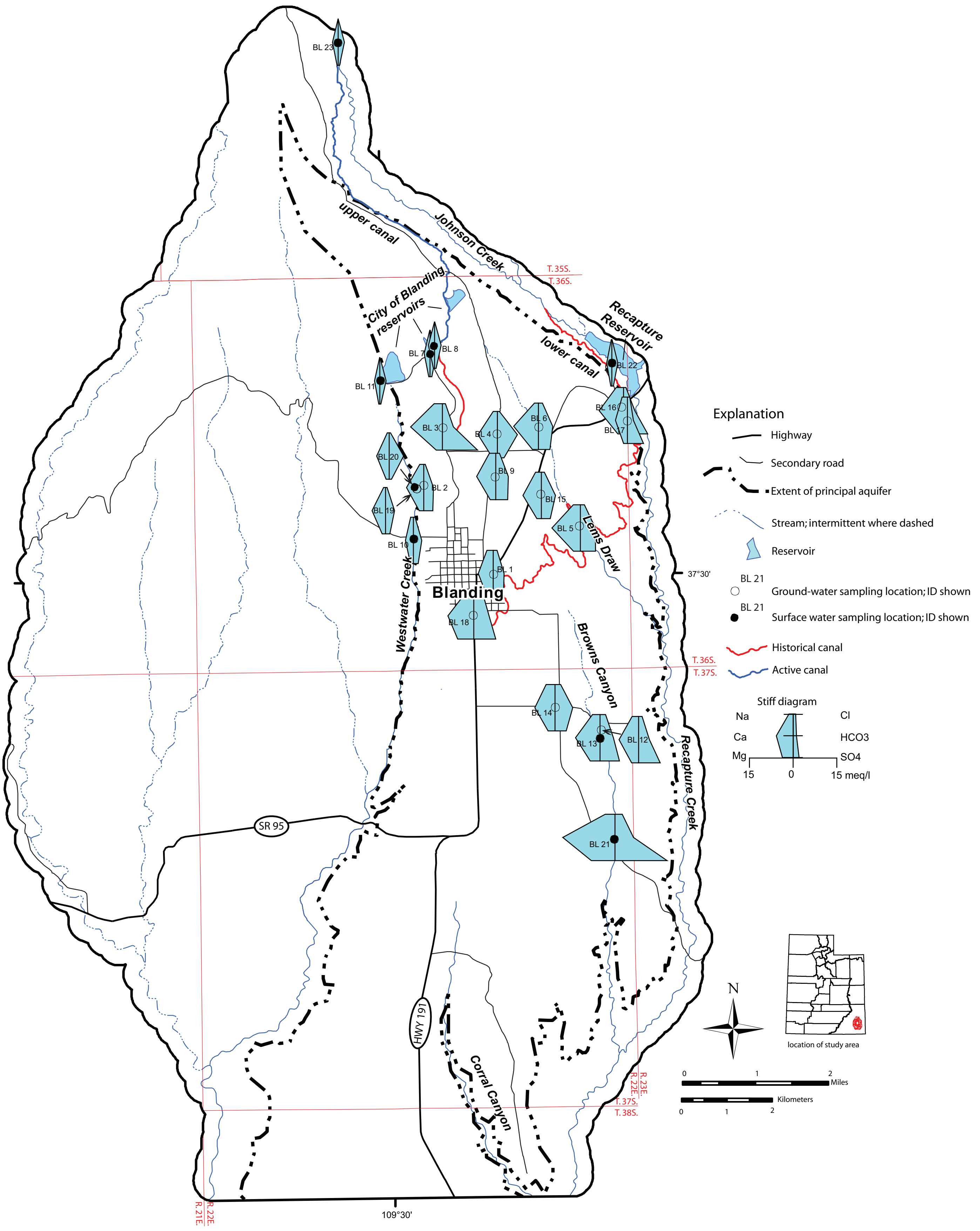

Figure 15*. Summary of surface- and ground-water solute chemistry in the Blanding area.*

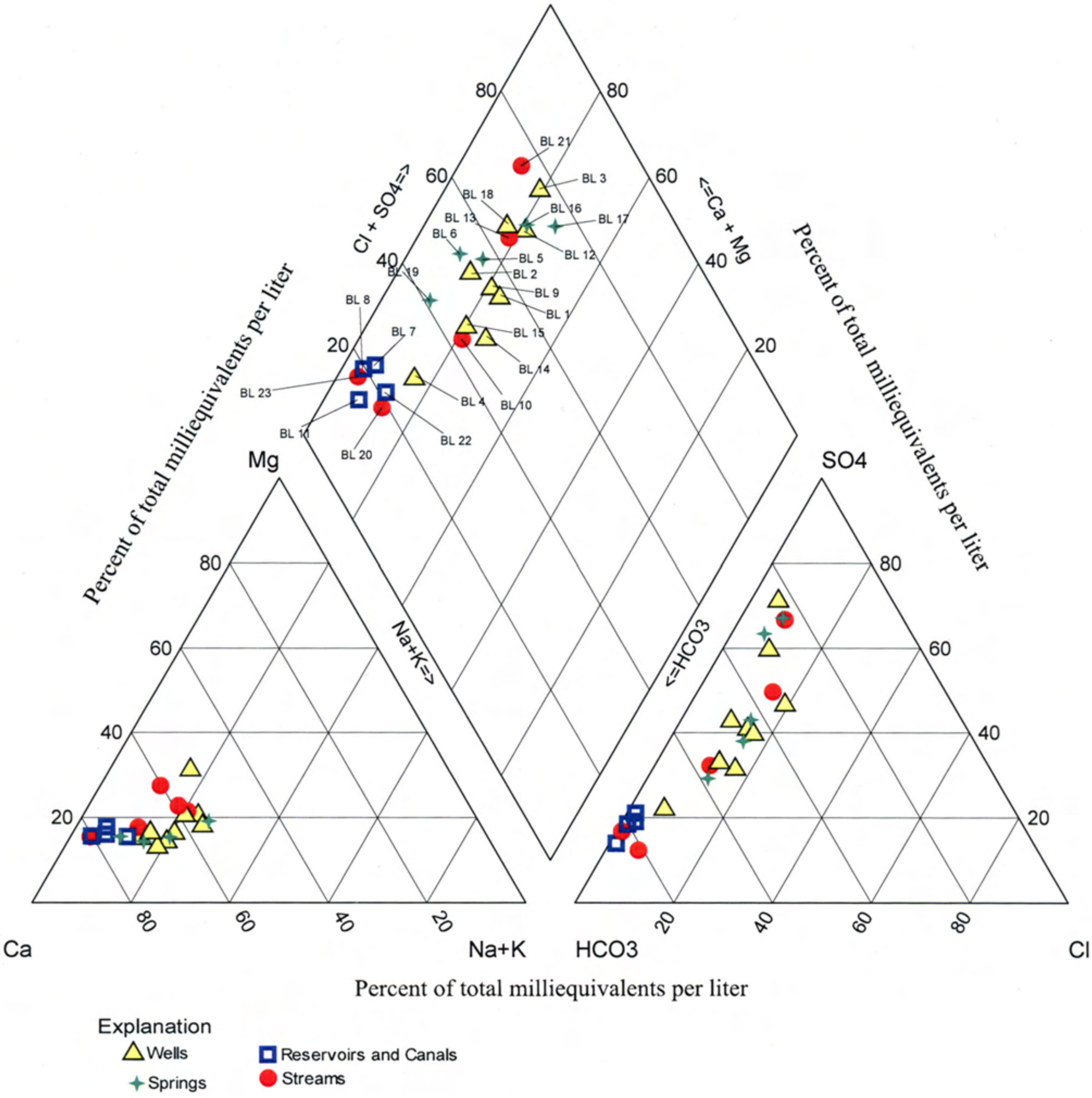

Figure 16. *Trilinear diagram of surface- and ground-water samples for the Blanding-White Mesa area.*

flow path. The chemical composition of surface water sampled in Browns Canyon and Lems Draw resembles that of ground water sampled across the study area (figure 15), implying that stream flow at these locations is primarily the result of seepage from the principal aquifer. Springs and seeps sampled along the margin of Blanding-White Mesa south of Recapture Reservoir also closely resemble ground water from wells, and therefore represent direct seepage from the principal aquifer. Water sampled along Westwater Creek west of Blanding appears closely related to water sampled to the north in City of Blanding Reservoir 4, implying that much of the water in Westwater Creek at this location is not derived from ground water that has spent any appreciable time in the principal aquifer.

Stable Isotopes

Sources of recharge to an aquifer and the source and history of surface water may be determined by analyzing the composition of stable isotopes of oxygen (^{16}O and ^{18}O) and hydrogen (^{1}H and ^{2}H). Isotopic ratios of these constituents in precipitation vary systematically with topography, temperature, and distance from the ocean (Clark and Fritz, 1997). Stable isotopic ratios in surface waters in arid areas are strongly affected by evaporation, preferentially enriching the isotopic ratios of these waters. Conversely, stable isotope ratios are generally conservative in ground water and therefore record the isotopic signature of meteoric or surface waters at the time of recharge (Clark and Fritz, 1997).

Isotopic ratios of hydrogen ($^{2}H/^{1}H$) and oxygen ($^{18}O/^{16}O$) are calculated in delta (δ) units per mil or parts per thousand relative to a reference standard (Standard Mean Ocean Water) (Craig, 1961) via the following equation:

$$\delta x = \frac{Rsample - Rstandard}{Rstandard} .1000$$

where:

$\delta x = {}^{18}O$ or ^{2}H

Rsample = $^{18}O/^{16}O$ or $^{2}H/^{1}H$ in the sampled water

Rstandard = $^{18}O/^{16}O$ or $^{2}H/^{1}H$ in the reference standard

Meteoric waters from many parts of the world generally plot along a meteoric water line (Craig, 1961) (figure 17); waters from arid areas where evaporation is significant may follow slightly different trends (Clark and Fritz, 1997). Stable-isotope ratios for samples from the study area are plotted along with the meteoric water line (Craig, 1961) in figure 17. Two composite snow samples from the Abajo Mountains (Spangler and others, 1996) represent baseline precipitation data for upland areas that supply much of the water to canals and reservoirs on the Blanding-White Mesa. No other samples of precipitation exist for the study area, but modeled values of $\delta^{2}H$ in precipitation (Meehan and others, 2004) are shown both for areas above 7000 ft (2100 m) in the Abajo Mountains and for Blanding-White Mesa (figure 17).

Stable-isotope data for wells and springs in the study area lie primarily between the isotopic composition of surface water in Johnson Creek and the upper canal, and samples of the city of Blanding and Recapture reservoirs (figure 17). The isotopic composition of Johnson Creek and the upper canal are enriched compared with the $\delta^{2}H$ field (Meehan and others, 2004) for the Abajo Mountains and composite snow samples (Spangler and others, 1996); these samples, however, form depleted end members of ground-water samples in figure 17. Surface water samples taken from City of Blanding Reservoirs 3 and 4 and Recapture Reservoir represent the enriched end member of the ground and surface waters sampled (figure 17). Most of the water filling these reservoirs is assumed to be from isotopically depleted water delivered via the upper canal from Johnson Creek. Enrichment of water in these reservoirs is most likely related to sur-

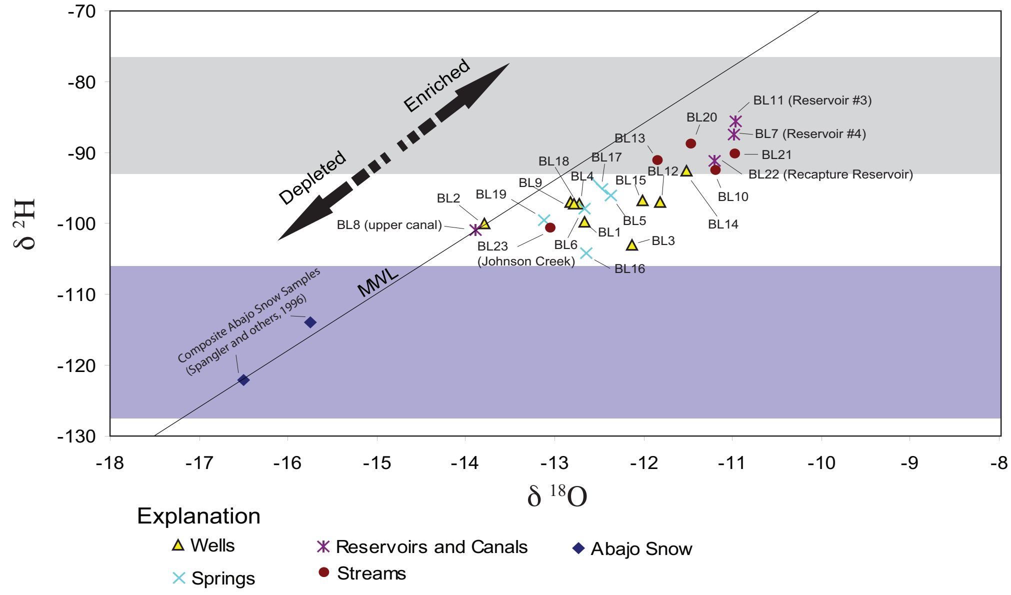

Figure 17. *Stable isotopic composition of waters near Blanding. MWL is the meteoric water line of Craig (1961). Gray shading represents the modeled $\delta^{2}H$ range of annual mean precipitation across the Blanding-White Mesa (Meehan and others, 2004). Blue shading represents the modeled $\delta^{2}H$ range of annual mean precipitation for the south flank of the Abajo Mountains above about 7000 feet elevation (Meehan and others, 2004). Most ground-water samples likely represent a mix of water naturally recharged from local precipitation on the Blanding-White Mesa and artificially recharged from imported water derived from upland portions of the Abajo Mountains.*

ficial evaporative fractionation that is a common process in surface water in arid areas (Clark and Fritz, 1997). Isotopic enrichment in similar reservoirs decreases with depth (Clark and Fritz, 1997), suggesting water recharged from the city of Blanding reservoirs is likely more depleted than the sampled values. Surface water in streams draining Blanding-White Mesa (samples BL10, 13, 20, 21) plot in the δ^{2}H field (Meehan and others, 2004) for Blanding-White Mesa precipitation and on the enriched end of the ground water field. These waters may be at least partially sourced from ground water and then enriched via evaporation along the stream course and addition of local precipitation (figure 17 and 18).

Mixing of recharge between two isotopically distinct end members, in this case assumed to be the relatively depleted upper canal and the enriched lower Browns Canyon creek (assumed to be similar to local precipitation on Blanding-White Mesa), can be quantified using δ^{18}O and the following linear algebra (Clark and Fritz, 1997):

$$\delta\text{sample} = \chi\delta A + (1-\chi)\delta B$$

where:

δsample = δ^{18}O in the sampled water

δA= δ^{18}O of the upper canal (-13.89)

δB= δ^{18}O of lower Browns Canyon (-10.96)

χ = fractional amount of δA relative to δB

This mixing equation assumes all variance in δ^{18}O is the result of mixing of waters with different δ^{18}O, and is not the result of dispersion or other processes that may occur below the water table. Mixing ratios are calculated for all groundwater samples (table 4). Values of χ (ratio of depleted to enriched recharge) for samples from wells and springs range from 0.96 to 0.18 with a mean of 0.53 (table 4, figure 18). Most samples north of the lower canal commonly have ratios implying at least half of these waters were initially from depleted canal sources. Samples BL 12 and 14 south of the lower canal have lower ratios implying a greater component of recharge from enriched sources, likely infiltration of unconsumed irrigation. Some of the variation in mixing ratios may also be the result of variable amounts of precipitation with location.

Table 4. *Summary of stable isotopic sampling results and ^{18}O mixing ratio for sites in the Blanding area. See text for discussion of mixing ratios.*

Site ID	Sampling Date	Sample type	δ^{2}H	δ^{18}O	δ^{18}O mixing ratio
BL 1	4/10/2006	well	-99.7	-12.66	0.58
BL 2	4/11/2006	well	-100.0	-13.78	0.96
BL 3	4/11/2006	well	-103.0	-12.13	0.40
BL 4	4/11/2006	well	-97.3	-12.73	0.60
BL 5	4/11/2006	spring	-96.1	-12.37	0.48
BL 6	4/11/2006	spring	-97.9	-12.66	0.58
BL 7	4/11/2006	reservoir	-87.4	-10.99	NA
BL 8	4/11/2006	canal	-101.0	-13.89	NA
BL 9	4/11/2006	well	-96.9	-12.82	0.63
BL 10	4/12/2006	stream	-92.5	-11.18	NA
BL 11	4/12/2006	reservoir	-85.5	-10.97	NA
BL 12	4/12/2006	well	-97.1	-11.82	0.29
BL 13	4/12/2006	stream	-91.2	-11.84	NA
BL 14	4/12/2006	well	-92.6	-11.51	0.18
BL 15	4/12/2006	well	-96.9	-12.01	0.36
BL 16	4/12/2006	spring	-104.2	-12.65	0.58
BL 17	4/12/2006	spring	-95.1	-12.47	0.52
BL 18	4/13/2006	well	-97.2	-12.78	0.62
BL 19	4/13/2006	spring	-99.6	-13.12	0.74
BL 20	4/13/2006	stream	-88.9	-11.46	NA
BL 21	4/13/2006	stream	-90.2	-10.96	NA
BL 22	4/13/2006	reservoir	-91.1	-11.20	NA
BL 23	4/13/2006	stream	-100.6	-13.03	NA

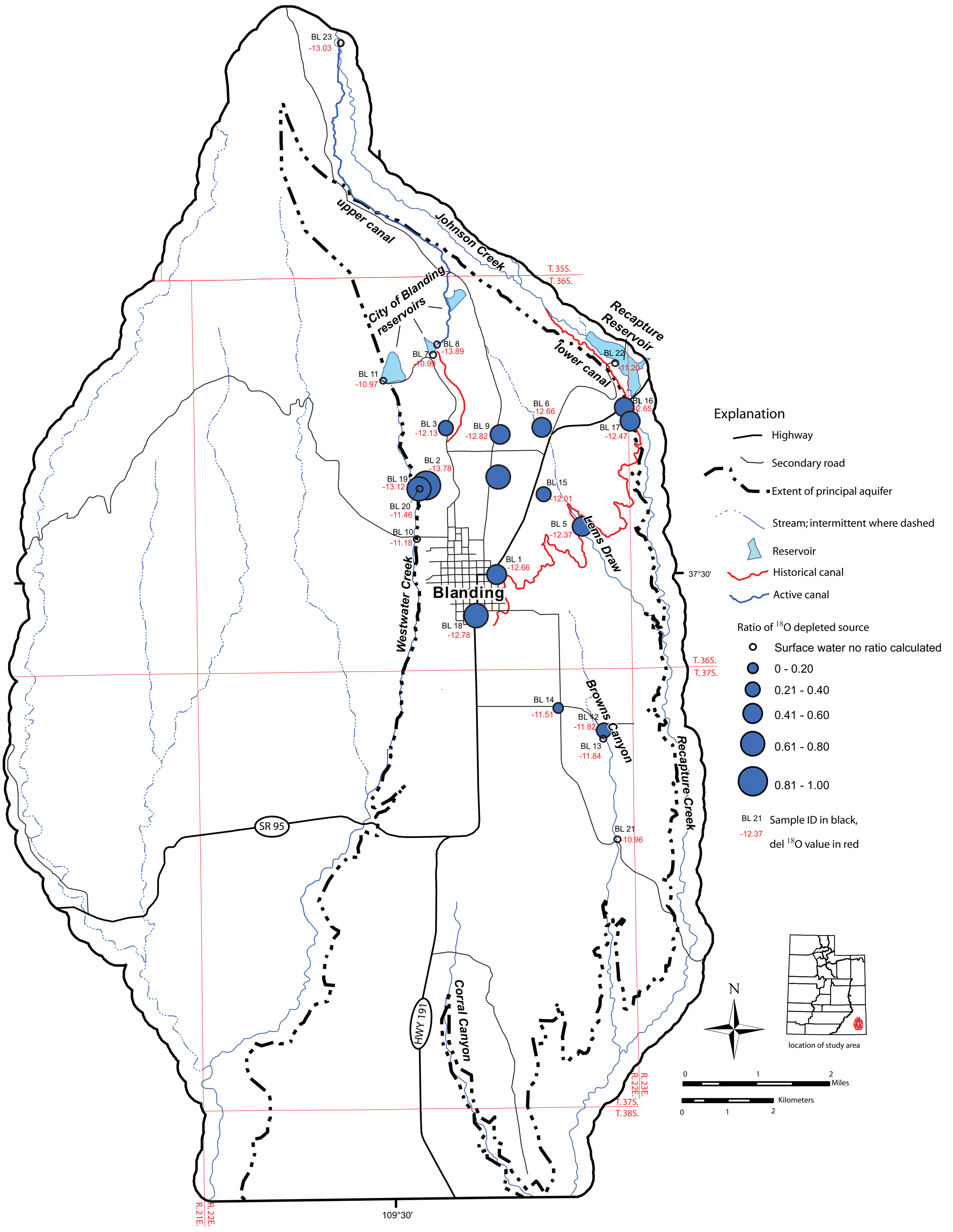

Figure 18. *^{18}O stable isotopic data and mixing ratios in the Blanding area.*

Overall these mixing ratios imply that generally half of all ground water sampled was initially recharged from isotopically depleted water imported onto Blanding-White Mesa. Because the enriched component of recharge may represent infiltration of precipitation and/or water recharged from evaporatively enriched sources, including city of Blanding Reservoirs and unconsumed irrigation water, the actual components of these sources of artificial recharge cannot be directly constrained but is at least 50 percent.

Chlorofluorocarbons

Chlorofluorocarbons (CFC or Freon) are a family of refrigerant gases widely used since the 1930s. Atmospheric concentration of these gases has varied as the compounds were manufactured and released, increasing in concentration from the 1950s to the 1990s and slowly decreasing subsequently (Busenberg and Plummer, 1992; Plummer and others, 1993) (figure 19). CFC concentration in surface water and precipitation is a function of the atmospheric concentration and solubility. As precipitation or surface water infiltrates to the water table it is assumed that the atmospheric equilibrated CFC concentration for a given temperature and elevation is preserved (Plummer and others, 1993). Therefore by assuming values for temperature and elevation of recharge and known solubility constants, measured CFC concentrations in ground water represent atmospheric concentrations at the time of recharge. By comparing measured CFC concentrations in ground water with known atmospheric concentrations of these gases through time, an apparent age of recharge can be calculated (Plummer and others, 1993) (table 5, figure 20).

Samples for this study were collected in April 2006 in triplicate glass bottles sealed under flowing water to avoid direct atmospheric contact. Sampling methods follow those presented by the U.S. Geological Survey (at<http://water.usgs.gov/lab/>). Samples were analyzed at the University of Utah Dissolved Gas Laboratory and apparent age estimates were computed from measured CFC concentrations using standard spreadsheets available from the U.S. Geological Survey (at <http://water.usgs.gov/lab/>) and the University of Utah Dissolved Gas Laboratory. Elevation of recharge was assumed equal to that of City of Blanding Reservoir 3 for samples north of the southern canal and an approximate elevation of the southern canal for samples to the south. The sensitivity of age calculations to variation of recharge elevations possible across the Blanding-White Mesa was low, with computed ages varying by a year or less for elevation var-

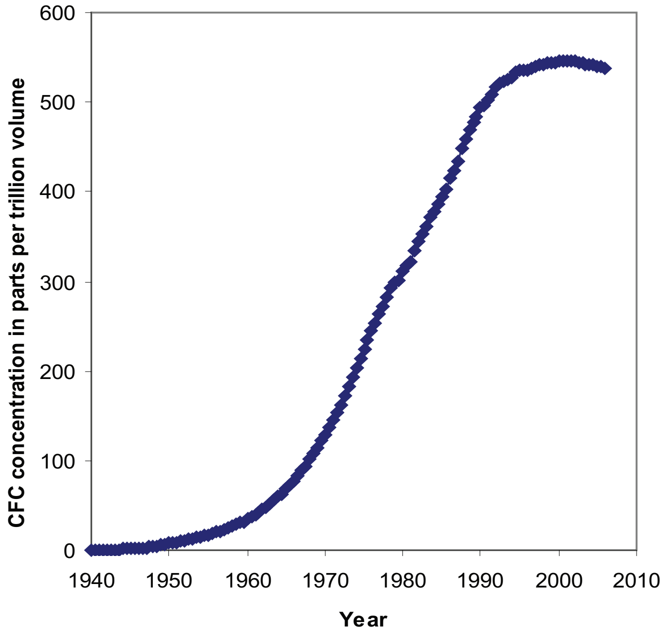

Figure 19. *Atmospheric concentration of CFC-12 in the northern hemisphere since 1940. Composite data used to construct curve available at http://water.usgs.gov/lab/software/air_curve/.*

Table 5. *Summary of CFC and tritium sampling results for selected sites in the Blanding area. Distance to upgradient artificial-recharge source is estimated distance to the upper canal and city of Blanding Reservoirs for samples north of the lower canal and the lower canal and major irrigated areas for samples south of the lower canal.*

Site ID	Depth to water (ft)	Total depth of well (ft)	Sampling Date	CFC-12 concentration, standard deviation (pmoles/kg)	CFC-12 air equivalent concentration, standard deviation (ppt)	CFC-12 estimated recharge year, standard deviation	Tritium (TU), + error	Distance to upgradient artificial recharge source (m)
BL 2	95	140	4/11/2006	1.08, 0.20	254.5, 47.9	1977, 3	6.0, 0.4	2380
BL 3	118	180	4/11/2006	0.86, 0.23	202.7, 54.81	1974, 3	9.1, 0.4	1700
BL 4	65	190	4/11/2006	0.72, 0.01	170.4, 3.3	1972, 0	9.9, 0.3	2350
BL 9	50	140	4/11/2006	0.20, 0.02	47.4, 3.5	1962, 1	5.5, 0.3	3100
BL 12	30	140	4/12/2006	0.28, 0.05	63.7, 11.5	1965, 1	1.9, 0.2	3900
BL 14	40	140	4/12/2006	1.51, 0.18	349.2, 41.0	1983, 2	5.0, 0.4	1300
BL 15	60	160	4/12/2006	0.05, 0.02	11.4, 5.8	1952, 3	3.5, 0.3	4090
BL 19	Spring	Spring	4/13/2006	0.61, 0.01	144.3, 1.5	1971, 0	3.3, 0.3	2490

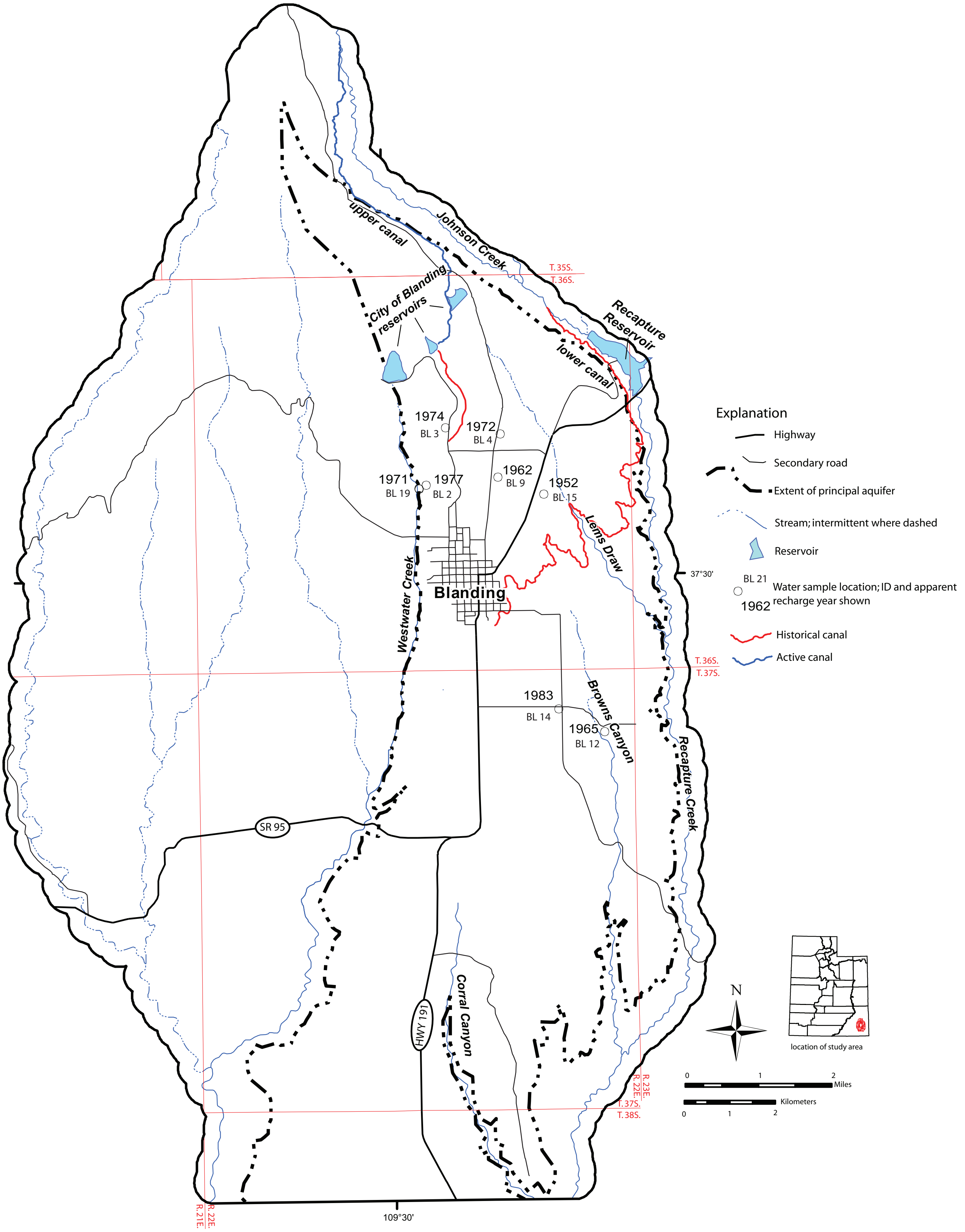

Figure 20. Apparent CFC-12 recharge year for selected sites in the Blanding area.

iance of hundreds of feet, roughly equivalent to the topographic slope across Blanding-White Mesa. Temperature of recharge across a shallow water table is commonly assumed to be nearly equal to the mean annual temperature (Cook and others, 1995) or 50º F (10º C) for the Blanding area.

Several factors may contribute error and unknowns to CFC age estimation, including different transport properties of the various CFC constituents, potential biodegradation of CFC compounds, contamination from CFC point sources or certain well components, and improper sampling techniques (Cook and others, 1995; Busenberg and others, 1993; Plummer and others, 2000). Ground water typically consists of water with a range of recharge ages due to diffusion and dispersion (Clark and Fritz, 1997; Bethke and Johnson, 2002; Weissman and others, 2002). Because ground water is generally age stratified with depth, samples near the upper portion of the water column yield the youngest apparent ages. Samples taken from wells with lengthy screened or open intervals record an aggregate age of water recharged at various times; apparent CFC ages are, therefore, mixed-age values for ground water that include water both older and younger than the apparent age (Bethke and Johnson, 2002).

Measurable concentrations of CFC were found at all sample sites (analyzed for CFC) implying at least a component of modern water, recharged since 1950, at each site. Apparent ages calculated from CFC-12 yielded recharge dates ranging from 1952 to 1983 (figure 20; table 5). Apparent age of recharge increases to the south-southeast (down gradient) for a series of wells (sites BL 3, 4, 9 and 15) across the northern portion of the study area. This suggests most of the ground water at these sample sites was recharged at discrete sites to the north, likely as seepage from the unlined upper canal and/or city of Blanding reservoirs. South of the former lower canal, apparent CFC age distribution is possibly controlled by more localized recharge of unconsumed irrigation water north of sampling site BL 14. To the southwest ground water at site BL 12 is older and may be derived from historical seepage from the lower canal and recharge of unconsumed irrigation water.

A plot of apparent year of recharge versus distance to upgradient artificial recharge source (figure 21) shows a similar trend of increasing distance from potential recharge sources with increasing apparent age. For samples north of the lower canal, upgradient recharge was assumed to occur at the upper canal and city of Blanding Reservoir 3. For samples south of the lower canal, recharge was assumed to occur at the lower canal for BL 12 and along irrigated fields north of sample site BL 14.

Tritium

Radiogenic or unstable isotopes such as tritium (^{3}H) may be used to qualitatively constrain apparent ground-water age (Clark and Fritz, 1997). Tritium is a radioactive isotope of hydrogen produced in high concentrations during above-ground testing of thermonuclear devices after 1950, and its occurrence in ground water has been used to make relative age determinations based on relative concentration of tritium in ground water. Tritium concentrations in the atmosphere peaked in 1963 and have declined since (Clark and Fritz, 1997). Samples for tritium were collected using standard U.S. Geological Survey sampling techniques (Wilde and others, 1998) and analyzed via tritium enrichment and scintillation counting at Brigham Young University (David Tingey, Brigham Young University, verbal communication, 2006).

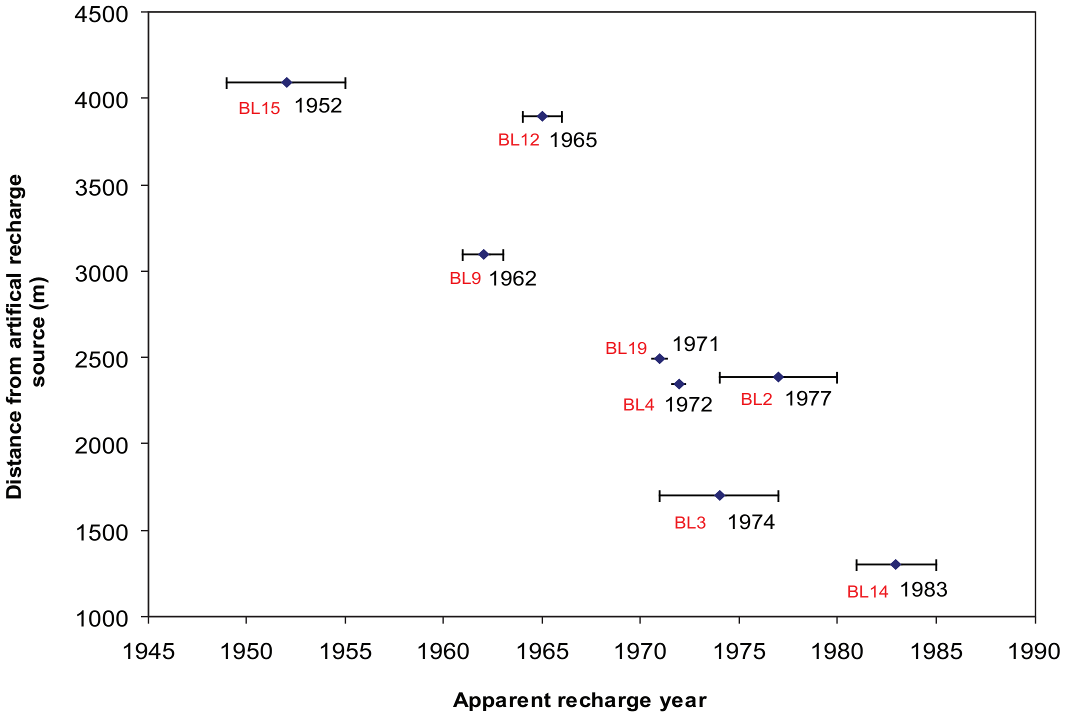

Figure 21. *Apparent CFC-12 recharge year versus distance to potential upgradient artificial recharge sources. Sample ID is red, age is black, error bars represent one standard deviation.*

Tritium count results show measurable concentrations of tritium for all samples analyzed, indicating at least a portion of the ground-water sampled was recharged after 1950 (table 5). These data qualitatively support apparent CFC age data presented above that indicate significant recharge since 1950. Assuming tritium loading to the principal aquifer peaked during the early 1960s, samples with apparent age of recharge during this same period should show the highest values of tritium. Direct comparison of the tritium count data and CFC apparent age data is more complex and does not indicate a pronounced peak in tritium concentration for samples with CFC apparent age dates near the 1963 peak atmospheric tritium levels. Similar discrepancies between tritium concentrations and apparent CFC age have been noted by previous workers and may be caused by variance in solubility, diffusion, and concentration of CFC compounds at time of recharge, and processes including concentration of initial tritium loading at a given site, relatively short half life of tritium, and measurement errors associated with small concentrations of tritium (Plummer and others, 1993; Cook and Solomon, 1995; Plummer and others, 2000).

DISCUSSION

Ground water in the principal aquifer beneath Blanding-White Mesa is controlled by a combination of geologic, geographic, climatic, and land-use characteristics. The stratigraphy and outcrop pattern of the Upper Jurassic through Upper Cretaceous rocks, which make up the principal aquifer and aquiclude, place fundamental controls on ground-water availability. The isolated spatial extent of the Dakota and Burro Canyon Formations does not allow for regional recharge of the principal aquifer. Instead ground-water recharge in the Dakota-Burro Canyon aquifer is from local infiltration of precipitation and various sources of artificial recharge across Blanding-White Mesa. The ground-water levels and water quality in the principal aquifer are therefore highly susceptible to changes in land and water use.

The balance of recharge and discharge to the principal aquifer has changed with time as evidenced by long-term ground-water level trends. Ground-water levels increased prior to 1989 and have declined since then. Early increase in ground-water levels is due to unintended artificial recharge of the principal aquifer. Subsequent declines in water levels may be the result of reductions in yearly artificial recharge. The relative timing and magnitude of reductions in artificial recharge is difficult to constrain. Instead, changes in ground-water level are assumed to represent the aggregate of changes that include replacement of unlined canals with closed pipe, the lining of city of Blanding Reservoirs with impermeable clay, and changes in the type and amount of irrigation across the study area. A general increase in discharge from pumping wells in the principal aquifer with time may also be responsible for a lesser but locally important component of ground-water level decline.

Ground-water budgets based on past, current, and future states of recharge and discharge indicate annual reduction in artificial recharge of up to 2100 acre-feet (2.6 hm^3) since changes in water delivery and storage began in the late 1970s. Planned future changes in water delivery and storage may further reduce the annual amount of artificial recharge by up to 500 acre-feet (0.6 hm^3). Decreasing artificial recharge has thus far driven a reduction of ground water in storage and consequent decline in ground-water levels across the study area. Reduction of ground water in transient storage in the principal aquifer will likely continue and may ultimately reduce water availability and water quality in the prinicipal aquifer.

Base flow in Lems Draw, Browns Canyon, and Corral Creek, and seepage from springs along Recapture Canyon is ultimately sourced from ground water in the principal aquifer and is therefore directly tied to fluctuations in the ground-water budget of the study area. Continued future reductions in artificial recharge and consequent ground-water level decline may also lead to reductions in baseflow along these drainages.

Ground-water chemistry, stable isotope composition, and CFC-based apparent age calculations provide support for recent artificial recharge of the principal aquifer. Stable isotope ratios suggest that water imported to Blanding-White Mesa and artificially recharged to the principal aquifer comprises at least 50 percent of the total ground water at many sites. Comparison of CFC apparent age data and concentration of major anions shows little correlation, suggesting that chemical composition is controlled by local stratigraphic and mineralogic variation and not residence time in the principal aquifer. Based on apparent CFC age data much of the ground water beneath the study area was recharged before 1980. Most ground water, therefore, was recharged prior to structural changes in water delivery and storage, begun in the late 1970s; these changes have likely vastly reduced the amount of artificial recharge to the principal aquifer. Therefore, measurable changes within the principal aquifer may occur years after any changes of artificial or natural recharge to the principal aquifer on Blanding-White Mesa.

SUMMARY AND CONCLUSIONS

The principal aquifer beneath the Blanding-White Mesa area consists of the sandstone and less abundant fine-grained deposits of the Dakota and Burro Canyon Formations. These units form hydrologically isolated caprock, separated from upland areas to the north and adjoining mesas to the east and west by intervening canyons incised into the underlying Brushy Basin Member. The Brushy Basin Member is dominated by impermeable mudstone and lesser, laterally discontinuous sandstone. Downward hydraulic gradients in the principal aquifer and the impermeable nature of the Brushy Basin Member preclude recharge of the principal aquifer from underlying units.

Ground water flows generally to the south or southeast across the study area. The total amount of water in transient storage in the principal aquifer is estimated at 156,000 acre-feet (192 hm^3). Long term ground-water level monitoring indicates recharge averaging 6 to 7 inches (15-18 cm) per year more than discharge prior to 1989. Since 1989, ground-water levels have generally declined by a mean of 5 inches (13 cm) per year at long-term monitoring sites.

Recharge of the principal aquifer occurs from both direct precipitation and artificial sources including canal and reservoir seepage, infiltration of excess irrigation, and minor septic seepage. Springs and seepage are the primary source of discharge from the principal aquifer; other sources of discharge include pumping of irrigation and domestic wells, evapotranspiration where ground water is shallow, and subsurface outflow along the southern portion of the study area. Yearly change in storage in the principal aquifer is largely the result of either an excess or reduction of artificial recharge from seepage of canals and reservoirs across the study area. Based on water level data, storage in the principal aquifer increased by 900 acre-feet per year prior to 1990 and has decreased by 640 acre-feet per year since 1990. Reductions in spring flow and seepage from the principal aquifer have likely followed reduced artificial recharge, reductions in storage in the principal aquifer and water level decline since 1990. Because all water budget components are estimated, numerical modeling of the transient conditions within the prinicipal aquifer in conjunction with additional seepage studies will be required to accurately constrain all components of recharge and discharge for the principal aquifer.

Apparent CFC ages indicate that most ground water in the Dakota-Burro Canyon aquifer was recharged prior to 1980, and that ground water generally increases in age to the south-southeast, parallel to the potentiometric slope. Stable isotope ratios from ground and surface water support the hypothesis that a significant component of water in the principal aquifer is the result of artificial recharge of waters imported to Blanding-White Mesa. Solute chemistry indicates ground water is a significant component of stream flow in several drainages, including Lems Draw and Browns Canyon.

Changes in water delivery, storage, and use across Blanding-White Mesa have altered the water budget of the Dakota-Burro Canyon aquifer. Future changes in both water delivery and storage will further alter this balance, potentially leading to a continued decline in ground-water levels across the Blanding-White Mesa.

Based on the data presented above the primary conclusions of this report are as follows:

1) The principal aquifer, within the study area, consisting of the Dakota and Burro Canyon Formations is hydrologically isolated and receives recharge only from direct precipitation and various artificial sources, including seepage from city of Blanding reservoirs, unlined portions of the upper canal, and infiltration of unconsumed irrigation water.

2) Water levels in the principal aquifer along the western portion of Blanding-White Mesa increased by 6 to 7 inches per year, prior to 1989 (15-18 cm per year). Since 1989 water levels have decreased by 5 inches per year (13 cm per year).

3) Estimated yearly water budgets for the principal aquifer reflect changes in water level, and include a increase in storage of 898 acre-feet prior to 1990 and decrease in storage of 642 acre-feet since 1990. Changes in storage are driven by reductions in artificial recharge from canal and reservoir seepage occurring since the 1980s.

4) A significant amount of ground water in the principal aquifer was artificially recharged after 1950 and prior to 1980. Most artificial recharge is likely derived from canal and reservoir seepage and to a lesser degree from excess irrigation water.

5) Past changes in water delivery, storage, and use across Blanding-White Mesa have altered the water budget of the Dakota-Burro Canyon aquifer. Future changes in both water delivery and storage will further alter this balance, potentially leading to a continued decline in ground-water levels across the Blanding-White Mesa.

6) Detailed quantitative constraints on recharge and discharge to the principal aquifer should be estimated using numerical modeling techniques and tracer/seepage studies of the city of Blanding reservoirs and remaining unlined portions of the northern canal.

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APPENDIX

Table A.1. *Summary of water-well logs used to construct structure contours on plate 3. Abbreviations used below are: Q = Quaternary deposits, Km = Mancos Shale, Kd = Dakota Formation, Kbc = Burro Canyon Formation, Jmbb = Brushy Basin Member of the Morrison Formation. Dashed fields indicate no data.*

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
1	632386	4154106	S3460 W2160 NE 33 37S 22E SL	5580	5475	—	10	—	—	—	70-110	5481	12/19/2001
2	632411	4154368	S2600 W2080 NE 33 37S 22E SL	5580	5490	—	10	—	—	—	55-95	5527	12/19/2001
3	632661	4155313	N500 W1260 SE 28 37S 22E SL	5625	5545	—	10	—	—	x	40-80	5552	12/18/2001
4	632719	4156045	N2900 W1070 SE 28 37S 22E SL	5650	5550	—	10	—	—	x	70-110	5542	12/17/2001
5	632746	4155630	N1540 W980 SE 28 37S 22E SL	5630	5535	—	10	—	—	—	60-100	5613	12/18/2001
6	632472	4165989	S1448 W1273 NE 28 36S 22E SL	6170	6040	6142	5	102	—	—	—	6050	03/17/2001
7	632552	4166009	S1382 W1010 NE 28 36S 22E SL	6160	6040	—	4	—	—	—	85-125	6064	03/05/2001
8	633447	4168565	S950 E2050 W4 15 36S 22E SL	6370	6200	—	15	—	—	—	—	6256	02/13/2002
9	633462	4168672	S600 E2100 W4 15 36S 22E SL	6395	6200	—	50	—	—	—	—	6259	02/12/2002
10	635952	4162417	S100 W650 E4 02 37S 22E SL	5870	5740	—	10	—	—	—	—	5823	11/24/2001
11	632361	4154775	S1265 W2245 NE 33 37S 22E SL	5620	5495	5575	5	80	—	—	81-131	5504	07/10/2002
12	632364	4155065	S315 W2235 NE 33 37S 22E SL	5615	5535	5585	15	50	—	—	62-122	5564	07/09/2002
13	632366	4154926	S770 W2228 NE 33 37S 22E SL	5625	5515	5585	10	70	—	x	85-145	5527	07/10/2002
14	632390	4155197	N118 W2150 SE 28 37S 22E SL	5630	5510	—	10	—	—	—	55-125	5578	07/09/2002
15	632528	4155202	N135 W1695 SE 28 37S 22E SL	5640	5505	5600	10	95	—	—	60-140	5577	07/08/2002
16	632702	4154730	S1415 W1125 NE 33 37S 22E SL	5610	5520	—	10	—	—	x	53-93	—	07/02/2002
17	632703	4154934	S745 W1120 NE 33 37S 22E SL	5610	5510	—	10	—	—	—	63-103	—	07/01/2002
18	632720	4155073	S290 W1065 NE 33 37S 22E SL	5615	5510	5585	10	75	—	—	42-102	5564	07/01/2002
19	634009	4167143	S400 W1489 E4 22 36S 22E SL	6260	6080	6165	30	85	—	—	—	6173	04/22/2002
20	634221	4164097	N174 W931 E4 34 36S 22E SL	6020	5860	—	15	—	—	—	—	5928	04/27/2002
21	635542	4166992	S970 W1720 E4 23 36S 22E SL	6130	6000	—	5	—	—	—	—	6074	06/26/2002
22	634983	4165801	S2140 E1652 NW 26 36S 22E SL	6080	5965	—	1	—	—	—	—	6022	08/05/2002
23	634482	4167609	S1535 E115 NW 23 36S 22E SL	6220	6090	—	5	—	—	—	—	6162	11/12/2002
24	636409	4166143	S1100 E1100 NE 26 36S 22E SL	6120	5979	—	1	—	—	—	—	6081	05/07/2003
25	635186	4162619	N628 E2125 W4 02 37S 22E SL	5985	5852	5951	7	99	—	—	—	5943	02/20/2003
26	634371	4164519	S1080 W403 NE 34 36S 22E SL	6050	5875	—	10	—	—	—	—	5948	03/14/2003
27	634732	4164770	S257 E780 NW 35 36S 22E SL	6050	5903	—	6	—	—	—	—	5956	04/21/2003
28	633885	4164627	S724 W2000 NE 34 36S 22E SL	6080	5919	6035	11	116	—	x	—	5954	05/19/2003
29	634575	4165097	N818 E264 SW 26 36S 22E SL	6070	5932	6031	4	99	—	—	—	5974	06/04/2003
30	634070	4165554	S316 W1366 E4 27 36S 22E SL	6115	5954	6070	4	116	—	—	—	6012	08/13/2003
31	633781	4163726	N1629 E217 S4 34 36S 22E SL	6000	5842	—	3	—	—	—	—	5898	11/10/2003
32	633812	4163652	N1388 E317 S4 34 36S 22E SL	5995	5832	—	3	—	—	—	—	5897	12/27/2003

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
33	635369	4162406	N2565 E2680 SW 02 37S 22E SL	5885	5745	—	10	—	—	—	—	5845	06/04/2004
34	631584	4154971	S590 E480 NW 33 37S 22E SL	5605	5480	5570	15	90	—	—	—	5502	04/22/2005
35	631704	4155170	N65 E875 SW 28 37S 22E SL	5610	5505	—	15	—	—	—	70-110	5510	04/21/2005
36	632191	4154567	S1950 W2800 NE 33 37S 22E SL	5610	5500	—	10	—	—	—	—	5531	04/09/2005
37	634651	4167559	S1700 E670 NW 23 36S 22E SL	6205	6085	6190	10	105	—	—	—	6154	05/05/2005
38	631407	4154632	S1700 W100 NE 32 37S 22E SL	5580	5432	5525	10	93	—	—	—	5446	08/17/1994
39	631452	4154407	N200 0 W4 33 37S 22E SL	5570	5422	—	14	—	—	—	—	—	08/20/1994
40	633854	4164752	S275 E550 N4 34 36S 22E SL	6080	5905	6045	10	140	—	x	—	5930	03/19/1996
41	634191	4166610	N513 W946 SE 22 36S 22E SL	6195	6035	6160	7	125	—	—	—	—	10/28/1996
42	633159	4167295	N170 E1025 W4 22 36S 22E SL	6245	6110	—	10	—	—	—	—	6155	09/07/1996
43	633243	4167246	N10 E1300 W4 22 36S 22E SL	6230	6110	—	5	—	—	—	—	6170	09/17/1996
44	632790	4157912	N1095 W725 E4 21 37S 22E SL	5710	5590	5685	5	95	—	x	—	5660	05/12/1997
45	633320	4167021	N1938 E1510 SW 22 36S 22E SL	6220	6075	—	15	—	—	—	—	6165	05/02/1998
46	632783	4158184	S660 W700 NE 21 37S 22E SL	5720	5580	5680	10	100	—	x	—	5662	07/22/1998
47	633618	4169470	S651 W13 N4 15 36S 22E SL	6440	6235	—	20	—	—	—	—	—	01/08/1999
48	632412	4155146	S50 W2075 NE 33 37S 22E SL	5625	5520	—	15	—	—	—	—	5562	12/15/1999
49	632420	4154856	S1000 W2050 NE 33 37S 22E SL	5620	5515	5595	5	80	—	—	—	5555	12/15/1999
50	632428	4155051	S360 W2025 NE 33 37S 22E SL	5625	5515	—	10	—	—	—	90-130	5559	12/15/1999
51	632435	4154817	S1130 W2000 NE 33 37S 22E SL	5615	5520	—	10	—	—	—	70-110	5543	12/05/1999
52	632435	4154894	S875 W2000 NE 33 37S 22E SL	5620	5510	—	10	—	—	—	80-120	5551	12/15/1999
53	632450	4154856	S1000 W1950 NE 33 37S 22E SL	5615	5525	—	10	—	—	—	—	5544	11/17/1999
54	637327	4164256	N600 W1300 E4 36 36S 22E SL	5965	5820	5931	10	111	—	—	105-145	5881	11/28/03
55	634217	4160338	N1050 W1195 SE 10 37S 22E SL	5810	5660	—	5	—	—	—	—	—	09/23/1980
56	633792	4167774	S960 E500 N4 22 36S 22E SL	6310	6133	—	0	—	—	—	—	6180	04/14/1978
57	637428	4162174	N1580 W1040 SE 01 37S 22E SL	5830	5655	—	12	—	—	—	—	5742	07/09/1978
58	634761	4164906	N190 E875 SW 26 36S 22E SL	6045	5920	5988	6	68	—	—	—	5982	07/03/1978
59	635706	4163222	S100 W1400 NE 02 37S 22E SL	5905	5780	—	5	—	—	—	—	5830	10/29/1982
60	633647	4166487	N150 W75 S4 22 36S 22E SL	6200	6050	—	10	—	—	—	120-180	6120	09/07/1979
61	634679	4165575	S250 E630 W4 26 36S 22E SL	6080	5960	6040	15	80	—	—	—	6013	09/22/1980
62	634590	4166729	N905 E363 SW 23 36S 22E SL	6165	6010	—	0	—	—	—	—	6080	11/25/1978
63	635673	4165304	N1430 W1410 SE 26 36S 22E SL	6030	5870	—	5	—	—	—	—	5987	11/19/1980
64	635349	4161968	N1090 W20 S4 02 37S 22E SL	5900	5735	—	15	—	—	—	—	5848	01/02/1982
65	634913	4167827	S820 E1530 NW 23 36S 22E SL	6225	6045	—	5	—	—	—	—	6185	09/25/1979
66	633607	4168501	N1425 W110 S4 15 36S 22E SL	6355	6170	6270	20	100	—	—	—	6170	06/24/1981

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
67	635798	4168256	N520 W855 SE 14 36S 22E SL	6175	6032	—	5	—	—	—	—	6140	06/04/1980
68	637440	4162049	N1170 W1000 SE 01 37S 22E SL	5820	5656	—	5	—	—	—	—	5700	11/08/1979
69	634708	4166170	S932 E750 NW 26 36S 22E SL	6120	5990	—	3	—	—	—	—	6060	04/24/1980
70	633395	4166984	N1780 W900 S4 22 36S 22E SL	6240	6095	6167	15	72	—	—	—	6140	04/05/1980
71	634750	4165217	N1210 E840 SW 26 36S 22E SL	6055	5875	—	5	—	—	—	—	6007	04/19/1980
72	633252	4167079	N2090 W1370 S4 22 36S 22E SL	6210	6100	6140	4	40	—	—	—	—	06/12/1980
73	635475	4168042	S150 E730 N4 23 36S 22E SL	6205	6055	6165	10	110	—	—	—	6165	10/30/1980
74	635006	4167767	S1050 W810 N4 23 36S 22E SL	6220	6065	—	10	—	—	—	—	6155	07/01/1980
75	635515	4168040	S155 E860 N4 23 36S 22E SL	6200	6060	—	10	—	—	—	—	6145	10/31/1980
76	635247	4168118	N100 W20 S4 14 36S 22E SL	6220	6073	—	10	—	—	—	—	6180	06/04/1980
77	635925	4168448	N1150 W440 SE 14 36S 22E SL	6180	6075	—	26	—	—	—	—	6165	06/13/1980
78	634515	4165611	S129 E91 W4 26 36S 22E SL	6085	5975	—	10	—	—	—	—	6005	03/31/1981
79	636671	4162456	N2580 W921 S4 01 37S 22E SL	5815	5700	—	15	—	—	—	—	5780	10/15/1980
80	635071	4168114	N88 W597 S4 14 36S 22E SL	6240	6093	—	10	—	—	—	—	6200	01/31/1981
81	633552	4171490	S1358 W48 N4 03 36S 22E SL	6550	6390	—	12	—	—	—	—	—	09/14/1946
82	633621	4166247	S640 W160 N4 27 36S 22E SL	6180	6053	6152	4	99	—	x	—	6100	05/13/1977
83	633752	4166421	S69 E270 N4 27 36S 22E SL	6190	6045	—	5	—	—	—	open below 110	6140	04/07/1981
84	635329	4166481	N8 W2445 SE 23 36S 22E SL	6115	5975	—	7	—	—	x	—	6045	04/16/1981
85	634526	4165530	S395 E130 W4 26 36S 22E SL	6085	5953	—	17	—	—	—	—	5965	03/05/1991
86	634672	4168324	N810 E740 SW 14 36S 22E SL	6260	6130	6225	5	95	—	—	—	6215	04/08/1981
87	634847	4168975	N312 E1335 W4 14 36S 22E SL	6270	6156	—	15	—	—	—	—	—	01/13/1947
88	634752	4168516	N1440 E1000 SW 14 36S 22E SL	6285	6120	6245	5	125	—	—	—	6230	05/31/1981
89	634675	4168485	N1340 E750 SW 14 36S 22E SL	6275	6125	6185	15	60	—	—	—	6220	06/10/1981
90	634428	4168430	N1160 W60 SE 15 36S 22E SL	6285	6145	—	10	—	—	—	—	6244	06/28/1982
91	634945	4167757	S1085 W1010 N4 23 36S 22E SL	6220	6060	6175	5	115	—	—	—	6165	10/13/1981
92	635006	4162659	N760 E1532 W4 02 37S 22E SL	5915	5772	—	15	—	—	—	—	—	02/05/1982
93	633057	4158537	N500 E200 SW 15 37S 22E SL	5735	5615	5710	5	95	—	—	—	—	09/05/1947
94	636765	4162170	S910 E2020 W4 01 37S 22E SL	5805	5655	—	25	—	—	—	—	5755	11/24/1981
95	636967	4162066	N1300 E50 S4 01 37S 22E SL	5800	5635	5735	5	100	—	—	—	5740	08/07/1982
96	635445	4168113	N50 W2013 SE 14 36S 22E SL	6205	6070	6175	10	105	—	—	—	6165	06/01/1982
97	633651	4166850	N1340 W60 S4 22 36S 22E SL	6235	6085	—	7	—	—	x	—	—	05/20/1977
98	633248	4168756	S325 E1400 W4 15 36S 22E SL	6375	6165	6250	5	85	—	—	—	6245	01/06/1983
99	637258	4164604	S870 E1155 N4 36 36S 22E SL	5980	5830	5940	15	110	—	—	—	5910	08/27/1984
100	635382	4164947	N290 E275 S4 26 36S 22E SL	5910	5745	—	5	—	—	—	—	5820	07/02/1983

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
101	634858	4168470	N1255 W1295 S4 14 36S 22E SL	6275	6110	—	15	—	—	—	—	6210	06/01/1986
102	635372	4168058	S95 E390 N4 23 36S 22E SL	6210	6075	6175	20	100	x	—	—	6170	04/15/1986
103	637080	4161921	N750 W2180 SE 01 37S 22E SL	5785	5655	—	10	—	—	—	—	5755	10/22/1986
104	633676	4166800	N1175 E20 S4 22 36S 22E SL	6230	6030	—	3	—	—	x	—	6116	08/10/1977
105	634357	4165138	N950 W450 SE 27 36S 22E SL	6095	5923	6033	15	110	—	—	—	5995	09/29/1977
106	633661	4167844	S730 E70 N4 22 36S 22E SL	6370	6147	—	0	—	—	—	—	6195	03/14/1979
107	635663	4167134	S506 W1325 E4 23 36S 22E SL	6135	5990	6107	2	117	—	—	—	—	08/16/1977
108	634674	4164906	N190 E590 SW 26 36S 22E SL	6060	5918	6028	3	110	—	x	—	5970	09/09/1977
109	633407	4169790	N400 W705 S4 10 36S 22E SL	6460	6270	—	45	—	—	—	—	6362	—
110	633566	4166042	S1310 W340 N4 27 36S 22E SL	6165	6010	—	5	—	—	—	—	6115	10/19/1977
111	634721	4167894	S600 E900 NW 23 36S 22E SL	6230	6088	6186	7	98	—	—	—	6199	09/29/1977
112	634216	4165432	N1917 W912 SE 27 36S 22E SL	6105	5957	—	6	—	—	x	—	6000	12/02/1977
113	633983	4168834	S150 W1500 E4 15 36S 22E SL	6350	6186	6276	13	90	x	—	—	6260	07/28/1977
114	634385	4162261	S545 W505 E4 03 37S 22E SL	5905	5733	—	8	—	—	—	—	5793	10/26/1977
115	636051	4167079	S685 W50 E4 23 36S 22E SL	6120	5965	—	9	—	—	—	—	6071	11/05/1977
116	636044	4169088	N265 W15 E4 14 36S 22E SL	6295	6114	6178	20	64	—	—	—	6245	06/09/1989
117	634890	4168416	N1080 W1190 S4 14 36S 22E SL	6270	6120	6180	15	60	—	—	—	6216	01/22/1990
118	633740	4166477	N115 E230 S4 22 36S 22E SL	6200	6040	—	5	—	—	—	—	6138	11/10/1989
119	634473	4164990	N465 W70 SE 27 36S 22E SL	6075	5915	—	10	—	—	—	—	5955	11/24/1989
120	634043	4165425	S740 W1455 E4 27 36S 22E SL	6115	5960	6055	5	95	—	x	—	6060	08/31/1989
121	633911	4165437	S700 W1890 E4 27 36S 22E SL	6115	5965	6055	10	90	—	—	—	6000	04/16/1990
122	634686	4164750	S320 E630 NW 35 36S 22E SL	6050	5885	—	15	—	—	—	—	5920	11/08/1989
123	633746	4165224	N1272 E195 S4 27 36S 22E SL	6110	5960	—	25	—	—	—	100-160	6005	08/14/1989
124	636193	4162339	S3000 E200 NW 01 37S 22E SL	5860	5705	5825	5	120	—	—	60-160	5765	05/16/1990
125	634784	4165170	N1055 E950 SW 26 36S 22E SL	6050	5900	6000	15	100	—	—	115-160	5925	05/02/1990
126	633514	4166216	S740 W510 N4 27 36S 22E SL	6180	6070	—	10	—	—	x	50-120	6135	04/20/1990
127	635530	4166965	S1060 W1760 E4 23 36S 22E SL	6125	5985	—	10	—	—	—	80-160	6040	04/19/1999
128	634611	4166992	N1765 E432 SW 23 36S 22E SL	6185	6030	—	10	—	—	—	—	6122	08/27/1990
129	634557	4166170	S930 E255 NW 26 36S 22E SL	6130	6005	—	15	—	—	—	—	6037	04/25/1990
130	635319	4166429	S120 E140 N4 26 36S 22E SL	6110	5932	—	12	—	—	—	—	—	08/23/1953
131	634680	4168644	N1860 E765 SW 14 36S 22E SL	6305	6145	6245	25	100	—	—	—	6245	04/08/1991
132	635327	4166481	N8 W2450 SE 23 36S 22E SL	6115	5965	—	15	—	—	—	—	6095	07/09/1991
133	634470	4164491	S1170 W80 NE 34 36S 22E SL	6035	5855	—	5	—	—	—	open below 40	5955	05/07/1992
134	635125	4167752	S1100 W420 N4 23 36S 22E SL	6215	6040	6180	5	140	—	—	—	6142	07/09/1996

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
135	634522	4168794	S283 E267 W4 14 36S 22E SL	6320	6150	6275	10	125	—	—	—	6277	—
136	635634	4167393	N343 W1420 E4 23 36S 22E SL	6165	6015	6135	10	120	—	—	—	6105	05/12/1994
137	634945	4167665	S1385 W1010 N4 23 36S 22E SL	6210	6045	6180	5	135	—	—	—	6165	05/29/1994
138	633525	4169015	S2094 E2346 NW 15 36S 22E SL	6460	6225	6310	30	85	x	—	—	6270	09/24/1994
139	635308	4167397	S2266 E180 N4 23 36S 22E SL	6180	6045	6145	10	100	—	—	—	6118	02/28/1995
140	634694	4166758	N1000 E705 SW 23 36S 22E SL	6170	6010	6116	11	106	—	—	—	6082	—
141	634646	4167600	N1100 E600 W4 23 36S 22E SL	6210	6090	—	7	—	—	—	—	6168	04/03/1976
142	634677	4167556	N955 E703 W4 23 36S 22E SL	6205	6098	—	5	—	—	—	—	6172	04/02/1976
143	635208	4170416	N2020 W90 S4 11 36S 22E SL	6375	6219	6329	3	110	—	—	—	6301	11/20/1974
144	635433	4167682	S1330 E590 N4 23 36S 22E SL	6195	6030	6135	5	105	—	—	—	6135	04/28/1983
145	636043	4162570	N400 W350 E4 02 37S 22E SL	5865	5734	5820	7	86	—	—	—	5805	11/05/1977
146	637422	4162623	N3055 W1059 SE 01 37S 22E SL	5840	5679	—	19	—	—	x	150-160, 170-179	5753	10/29/1997
147	635219	4167301	S2580 W110 N4 23 36S 22E SL	6160	6005	6131	16	126	—	—	—	—	08/24/1977
148	633697	4166347	S310 E90 N4 27 36S 22E SL	6190	6020	6108	7	88	—	—	—	6100	08/29/1977
149	633463	4165443	N1990 W735 S4 27 36S 22E SL	6115	5968	—	12	—	—	—	—	6003	08/29/1977
150	635368	4167213	N2450 E300 S4 23 36S 22E SL	6165	6015	6126	10	111	—	—	—	—	08/25/1977
151	633945	4165832	S2000 E905 N4 27 36S 22E SL	6135	6005	6106	8	101	—	x	—	6030	08/03/1996
152	636142	4162425	S75 W25 E4 02 37S 22E SL	5865	5740	5830	6	90	—	x	—	5825	10/27/1977
153	637361	4161957	N868 W1260 SE 01 37S 22E SL	5805	5665	5750	5	85	—	—	—	5753	08/15/1995
154	634982	4167957	S429 W889 N4 23 36S 22E SL	6245	6110	—	5	—	—	—	—	6180	09/13/1995
155	633596	4164439	S1303 W299 N4 34 36S 22E SL	6065	5900	—	18	—	—	—	open below 117	5930	11/27/1995
156	635484	4168243	N510 E760 S4 14 36S 22E SL	6190	6070	6150	25	80	—	—	—	6148	12/21/1995
157	633692	4164434	S1321 E17 N4 34 36S 22E SL	6065	5885	—	17	—	—	x	—	5955	12/31/1995
158	633985	4169157	N910 W1493 E4 15 36S 22E SL	6380	6205	—	10	—	x	—	—	6300	06/12/1996
159	635164	4166285	S593 W371 N4 26 36S 22E SL	6125	5975	—	5	—	—	—	—	6090	05/23/1996
160	633862	4164354	S1621 W2073 NE 34 36S 22E SL	6060	5910	—	10	—	—	x	—	5940	05/31/1996
161	633810	4168617	N1804 E558 S4 15 36S 22E SL	6360	6165	—	15	—	—	—	—	—	09/09/1996
162	635338	4167283	N2680 E200 S4 23 36S 22E SL	6170	6015	—	5	—	—	—	—	6105	06/18/1996
163	635148	4167802	S900 E2300 NW 23 36S 22E SL	6215	6070	6160	7	90	—	—	—	—	11/04/1996
164	635198	4168162	N245 W180 S4 14 36S 22E SL	6225	6075	—	10	—	—	—	—	6190	09/23/1996
165	636753	4162224	N1816 W651 S4 01 37S 22E SL	5810	5675	5775	15	100	—	—	—	5775	09/06/1996
166	635642	4168540	N1449 W1369 SE 14 36S 22E SL	6205	6080	6170	5	90	—	—	—	6177	04/19/1997
167	635366	4168107	N30 W2273 SE 14 36S 22E SL	6210	6055	—	10	—	—	—	—	6165	06/28/1997
168	635451	4164950	N300 E500 S4 26 36S 22E SL	5910	5755	—	5	—	—	—	—	5860	09/04/1997

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
169	637477	4161875	N600 W880 SE 01 37S 22E SL	5780	5620	5745	15	125	—	x	—	5726	03/09/1999
170	632769	4166868	S1230 W255 E4 21 36S 22E SL	6195	6063	6162	0	99	—	—	88-130	6115	12/13/1997
171	632184	4164054	N110 W2339 W4 34 36S 22E SL	6020	5850	—	5	—	—	x	—	5875	06/06/1998
172	633522	4166346	S313 W484 N4 27 36S 22E SL	6190	6020	—	5	—	—	—	—	6141	07/06/1998
173	637473	4162255	N1847 W893 SE 01 37S 22E SL	5835	5662	5775	19	113	—	x	—	5710	12/08/1998
174	633264	4170055	N1270 W1174 S4 10 36S 22E SL	6515	6330	—	35	—	—	—	—	6383	—
175	637016	4164455	S1360 E360 N4 36 36S 22E SL	5960	5822	5926	13	104	—	—	—	5895	01/28/1999
176	633092	4158123	S860 E315 NW 22 37S 22E SL	5710	5560	—	10	—	—	—	—	5650	02/22/2000
177	633558	4168934	N258 E2414 W4 15 36S 22E SL	6445	6210	—	0	—	—	—	—	—	02/10/1999
178	635276	4167395	S2270 E77 N4 23 36S 22E SL	6180	6090	6155	10	65	—	—	—	6120	04/30/1999
179	635792	4167050	S780 W900 E4 23 36S 22E SL	6125	5990	6085	10	95	—	—	—	6064	05/27/1999
180	633779	4167841	S775 W2192 NE 22 36S 22E SL	6320	6155	6275	0	120	—	—	—	6215	05/11/1999
181	633889	4165715	N210 W1960 E4 27 36S 22E SL	6130	5985	—	5	—	—	—	—	5990	05/12/1999
182	634648	4163968	S250 E470 W4 35 36S 22E SL	5980	5830	—	5	—	—	—	—	5890	11/18/1999
183	637196	4165161	N950 W1685 SE 25 36S 22E SL	6020	5860	5930	40	70	—	x	—	5912	—
184	634692	4163592	N1151 E577 SW 35 36S 22E SL	5975	5840	—	5	—	—	x	—	5933	05/27/2000
185	635109	4165866	S1968 W550 N4 26 36S 22E SL	6120	5985	—	10	—	—	x	—	6036	07/12/2000
186	633397	4169257	S1300 E1924 NW 15 36S 22E SL	6525	6288	—	17	—	—	x	—	6295	10/14/2000
187	635927	4164944	N250 W575 SE 26 36S 22E SL	5995	5850	—	10	—	—	—	—	5932	06/06/2001
188	635579	4168028	S230 W1575 NE 23 36S 22E SL	6190	6055	—	10	—	—	—	—	6137	06/25/2002
189	635904	4163232	S70 W750 NE 02 37S 22E SL	5885	5760	—	8	—	—	—	—	5865	02/28/2002
190	636065	4162109	S1110 W277 E4 02 37S 22E SL	5845	5715	5805	0	90	—	—	100-140	5805	03/27/2002
191	636385	4162368	S2904 E830 NW 01 37S 22E SL	5840	5742	—	6	—	—	—	85-105	—	05/06/2002
192	637140	4164258	S2010 W1870 NE 36 36S 22E SL	5950	5800	5905	5	105	—	—	—	5887	08/14/2002
193	634588	4167064	N2004 E356 SW 23 36S 22E SL	6190	6035	—	4	—	—	—	—	6140	07/24/2002
194	634744	4162542	N375 E675 W4 02 37S 22E SL	5905	5740	—	8	—	—	—	—	5853	10/08/2002
195	634912	4167372	S2312 E1525 NW 23 36S 22E SL	6180	6065	—	5	—	—	—	—	6134	08/03/2002
196	635826	4164316	N831 W945 E4 35 36S 22E SL	5970	5813	5909	10	96	—	—	—	5895	04/14/2003
197	636924	4165022	N500 E60 S4 25 36S 22E SL	6030	5895	—	1	—	—	—	—	5942	03/06/2003
198	633760	4168507	N1443 E392 S4 15 36S 22E SL	6345	6186	—	0	—	—	—	—	6260	—
199	634938	4169032	N498 E1634 W4 14 36S 22E SL	6290	6157	6225	1	68	—	—	—	6230	06/15/2001
200	634971	4164859	N35 E1565 SW 26 36S 22E SL	6030	5900	—	10	—	—	—	—	5941	06/07/2005
201	637067	4164874	N10 W2110 SE 25 36S 22E SL	5995	5845	5935	10	90	—	—	—	5938	11/20/2004
202	635977	4167366	S2400 W270 NE 23 36S 22E SL	6110	5981	6094	3	113	—	—	—	6061	11/24/2002

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
203	635344	4166991	S976 W2370 E4 23 36S 22E SL	6125	6005	—	2	—	—	—	—	6100	01/20/1975
204	636005	4167014	S900 W200 E4 23 36S 22E SL	6125	5975	—	15	—	—	—	—	6035	01/19/1978
205	633762	4168219	N500 E400 S4 15 36S 22E SL	6305	6169	—	13	—	—	—	—	6215	04/20/1974
206	633680	4163026	S619 W135 N4 03 37S 22E SL	5965	5815	—	5	—	—	—	—	5879	07/02/1974
207	633564	4168097	N100 W250 S4 15 36S 22E SL	6325	6187	—	6	—	x	—	—	6245	02/20/1975
208	634671	4165102	N835 E580 SW 26 36S 22E SL	6065	5905	—	7	—	—	—	—	5995	03/24/1975
209	634531	4164833	S50 E120 NW 35 36S 22E SL	6070	5933	6020	7	87	—	x	—	5966	05/09/1977
210	633964	4165305	N1500 W1740 SE 27 36S 22E SL	6015	5860	5968	10	108	—	—	—	5928	04/07/1977
211	634510	4166355	S325 E100 NW 26 36S 22E SL	6155	6010	—	5	—	—	—	—	6060	04/08/1977
212	635652	4166699	N725 W1385 SE 23 36S 22E SL	6095	5954	6055	13	101	—	—	—	6043	04/09/1977
213	634081	4165361	S950 W1330 E4 27 36S 22E SL	6110	5962	—	8	—	—	x	—	6015	04/12/1977
214	633553	4165447	N2005 W440 S4 27 36S 22E SL	6125	5955	—	10	—	—	—	—	6055	05/21/1996
215	633806	4165446	N2000 E390 S4 27 36S 22E SL	6125	5978	—	14	—	—	x	—	6009	04/26/1977
216	634419	4163119	S360 W350 NE 03 37S 22E SL	5960	5813	—	14	—	—	x	—	5888	05/09/1977
217	633781	4165105	N880 E310 S4 27 36S 22E SL	6095	5954	—	17	—	—	x	—	5987	05/12/1977
218	633784	4166129	S1025 E375 N4 27 36S 22E SL	6165	6019	6119	10	100	—	—	—	6100	04/28/1977
219	634112	4165242	S1340 W1230 E4 27 36S 22E SL	6110	5964	—	13	—	—	x	—	5994	04/27/1977
220	633975	4165440	S690 W1680 E4 27 36S 22E SL	6115	5969	6069	5	100	—	x	—	6025	04/28/1977
221	634696	4165567	S275 E685 W4 26 36S 22E SL	6080	5955	—	10	—	—	—	—	6009	10/28/1984
222	634622	4165067	N720 E420 SW 26 36S 22E SL	6065	5919	6011	8	92	—	—	—	5980	04/20/1977
223	634654	4165526	S410 E550 W4 26 36S 22E SL	6075	5958	6047	4	89	—	—	—	6011	05/12/1977
224	634565	4166801	N1140 E280 SW 23 36S 22E SL	6170	6008	6137	5	129	—	—	—	6085	05/18/1977
225	634113	4165285	S1200 W1225 E4 27 36S 22E SL	6110	5928	6038	8	110	—	x	—	5990	05/17/1977
226	634177	4165406	N1830 W1040 SE 27 36S 22E SL	6110	5963	6064	9	101	—	x	—	6075	05/06/1977
227	633949	4165213	N1235 E860 S4 27 36S 22E SL	6095	5948	—	4	—	—	x	—	5989	05/12/1977
228	634639	4168200	N405 E630 SW 14 36S 22E SL	6245	6085	—	25	—	—	—	—	6165	01/12/1978
229	633639	4166308	S440 W100 N4 27 36S 22E SL	6190	6030	—	8	—	—	x	—	6121	06/18/1977
230	634814	4165144	N970 E1050 SW 26 36S 22E SL	6050	5911	—	12	—	—	—	—	5985	06/27/1977
231	633940	4165373	N1760 E830 S4 27 36S 22E SL	6110	5962	6062	5	100	—	—	—	6000	05/31/1977
232	633801	4166533	N300 E430 S4 22 36S 22E SL	6215	6043	—	4	—	—	—	open >103	6145	05/28/1977
233	634703	4165623	S90 E710 W4 26 36S 22E SL	6085	5953	6049	13	96	—	—	—	6005	05/27/1977
234	633923	4166381	S200 E830 N4 27 36S 22E SL	6180	6025	6131	7	106	—	—	—	6115	05/28/1977
235	633821	4165394	N1830 E440 S4 27 36S 22E SL	6125	5978	—	9	—	—	x	—	6090	05/06/1977
236	634409	4165584	S220 W255 E4 27 36S 22E SL	6100	5930	—	11	—	—	—	—	6053	12/11/1979

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
237	634478	4166295	S520 W5 NE 27 36S 22E SL	6150	6005	—	8	—	—	—	—	6065	06/16/1977
238	634689	4165205	N1170 E640 SW 26 36S 22E SL	6065	5905	—	10	—	—	—	—	5979	06/18/1977
239	636217	4162423	S80 E220 W4 01 37S 22E SL	5860	5722	—	8	—	—	—	—	5785	05/20/1977
240	634173	4165453	S650 W1030 E4 27 36S 22E SL	6110	5955	6053	6	98	—	x	—	6000	07/05/1977
241	633760	4165306	N1540 E240 S4 27 36S 22E SL	6120	5954	—	15	—	—	—	—	5997	07/08/1977
242	634517	4165462	S620 E100 W4 26 36S 22E SL	6085	5945	6043	5	98	—	—	—	5993	07/11/1977
243	634664	4165620	S100 E580 W4 26 36S 22E SL	6085	5957	6053	9	96	—	—	—	5995	08/03/1977
244	634634	4167815	S860 E615 NW 23 36S 22E SL	6220	6069	—	5	—	—	—	—	6178	10/07/1977
245	634458	4166029	N1240 W95 E4 27 36S 22E SL	6120	6003	—	4	—	—	—	—	6042	05/24/1977
246	634597	4165902	N825 E360 W4 26 36S 22E SL	6110	5978	—	6	—	—	—	—	6044	05/26/1977
247	634302	4165403	N1820 W630 SE 27 36S 22E SL	6100	5947	6058	6	111	—	—	—	6030	06/23/1977
248	635094	4166061	S1330 W600 N4 26 36S 22E SL	6115	5987	—	12	—	—	—	—	6049	05/26/1977
249	633841	4167408	S2160 E660 N4 22 36S 22E SL	6290	6155	—	10	—	—	—	—	6210	07/08/1977
250	633608	4165274	N1435 W260 S4 27 36S 22E SL	6115	5960	—	11	—	—	—	—	6000	06/28/1977
251	634656	4164810	S125 E530 NW 35 36S 22E SL	6055	5921	—	8	—	—	x	—	5959	07/05/1977
252	634433	4165156	N1010 W200 SE 27 36S 22E SL	6090	5910	—	7	—	—	—	—	6005	07/23/1977
253	635306	4166079	S1310 W2520 NE 26 36S 22E SL	6100	5950	6070	7	120	—	—	—	6038	08/05/1977
254	633797	4165205	N1210 E360 S4 27 36S 22E SL	6105	5955	—	7	—	—	—	—	5985	07/07/1977
255	634448	4165122	N900 W150 SE 27 36S 22E SL	6085	5938	6042	10	104	—	—	—	5979	07/08/1977
256	634558	4164976	N420 E210 SW 26 36S 22E SL	6070	5943	—	10	—	—	x	—	5972	07/06/1977
257	634566	4167915	S530 E390 NW 23 36S 22E SL	6235	6098	—	4	—	—	—	—	6193	07/15/1977
258	633980	4168761	S390 W1510 E4 15 36S 22E SL	6350	6182	6254	14	72	x	—	—	6261	07/29/1977
259	636680	4162195	S830 E1740 W4 01 37S 22E SL	5790	5655	5715	6	60	—	x	—	5746	07/20/1977
260	633581	4165969	S1550 W290 N4 27 36S 22E SL	6165	6005	—	10	—	—	—	—	6116	07/12/1977
261	633465	4166291	S495 W670 N4 27 36S 22E SL	6180	6020	6130	5	110	—	—	—	6121	07/12/1977
262	637370	4162171	N1570 W1230 SE 01 37S 22E SL	5830	5676	5773	4	97	—	—	—	5774	08/10/1977
263	637141	4162079	N1270 W1980 SE 01 37S 22E SL	5805	5688	5791	4	103	—	x	—	5749	08/10/1977
264	635010	4165692	S2540 W875 N4 26 36S 22E SL	6070	5956	—	8	—	—	—	—	6008	07/18/1977
265	633326	4167073	N2110 E1530 SW 22 36S 22E SL	6220	6082	6166	0	84	—	—	—	6130	04/23/1979
266	634607	4164910	N205 E370 SW 26 36S 22E SL	6065	5910	—	8	—	—	—	—	5980	07/19/1977
267	634730	4161225	S1310 E585 NW 11 37S 22E SL	5840	5689	—	4	—	—	—	—	5783	08/25/1977
268	633452	4165278	N1450 W770 S4 27 36S 22E SL	6110	5976	—	9	—	—	—	—	5995	07/28/1977
269	633590	4166125	S1040 W260 N4 27 36S 22E SL	6170	6015	—	8	—	—	—	—	6118	07/19/1977
270	634808	4165229	N1250 E1030 SW 26 36S 22E SL	6050	5898	—	8	—	—	—	—	6003	08/18/1977

ID[1]	East[2]	North[2]	PLS Location[3]	Elevation[4]	Kbc base[5]	Kd base[5]	Q thickness[6]	Kbc thickness[6]	Km[7]	Jmbb ss[7]	Screen Interval[8]	Water elevation[9]	Date
271	633433	4166369	S240 W775 N4 27 36S 22E SL	6180	6035	6122	2	87	—	—	—	6135	08/25/1977
272	633203	4158415	N100 E680 SW 15 37S 22E SL	5725	5561	—	16	—	—	x	—	5675	11/07/1977
273	634701	4164903	N180 E680 SW 26 36S 22E SL	6055	5928	6024	8	96	—	—	—	5970	08/06/1977

[1] ID corresponds those on plate 3
[2] Easting and northing coordinates are in NAD 27 UTM zone 12 N
[3] PLS location from Utah Division of Water Rights database
[4] Land surface elevation, in feet, at well site
[5] Base of formation in feet above sea level
[6] Thickness of unit in feet
[7] x indicates the presence of Mancos Shale or sandstone beds in the Brushy Basin Member
[8] Screen interval is in feet below land surface
[9] Water elevation in feet above sea level at time of completion

Table A.2. *Statistical summary of trends in water levels for selected U.S. Geological Survey monitoring wells in the Blanding area. All data used in regressions are from the U.S. Geological Survey (2006a). Standard equations used to calculate the following statistics are presented in Ott (1977) and Bhattacharyya and Johnson (1987). Location of monitoring wells is shown on plate 4. See text for further discussion.*

Monitoring well	Time period[1]	Number of measurements	Slope in feet per year[2]	R2[3]	F-statistic[4]	Df[5]	F-critical[6]	F-test[7]
USGS 1	A	29	1.34	0.97	948	27	4	Pass
	B	11	0.66	0.86	154	9	5	Pass
	C	18	-0.31	0.90	140	16	5	Pass
USGS 2	A	27	0.21	0.34	12	22	4	Pass
	B	11	0.38	0.09	10	9	5	Pass
	C	18	-0.06	0.05	2	16	5	Fail
USGS 3	A	27	0.75	0.85	112	25	4	Pass
	B	11	0.66	0.12	6	9	5	Pass
	C	18	-0.48	0.77	54	16	5	Pass
USGS 4	A	19	0.54	0.61	10	17	5	Pass
	B	11	0.73	0.69	25	9	5	Pass
	C	18	-0.90	0.61	25	16	5	Pass
USGS 5	A	15	0.26	0.21	4	13	5	Fail
USGS 6	A	36	0.19	0.69	77	34	4	Pass
USGS 7	A	25	0.59	0.88	171	23	4	Pass

[1] *A = prior to 1979; B =1979 to 1989; C =1989 to 2006*
[2] *Slope of least squares linear regression for each data period; negative represents water-level decline*
[3] *Coefficient of determination for a given regression, values closer to 1 indicate a better fit between regression-predicted values and measured values*
[4] *F observed value, see Ott (1977) and Bhattacharyya and Johnson (1987) for complete description*
[5] *Degrees of freedom taken as the difference between the total number of measurements and the number of variables plus 1*
[6] *F-critical values for given degrees of freedom and number of variables at a 5 percent significance level*
[7] *Pass indicates F-statistic value is greater than F-critical for a given regression and indicates that the trend is valid within the specified limits; Fail indicates F-statistic value is less than F-critical for a given regression and indicates that the trend is invalid within the specified limits*

Table A.3. *Summary of dissolved chemistry of ground and surface waters in the Blanding area. See text for Piper and Stiff diagrams of the data and discussion of trends. Locations are in meters NAD 27 UTM zone 12; all laboratory results are in mg/L. Gray shade shows surface water samples. All analyses were preformed at the Brigham Young University hydrogeology laboratory.*

ID	Site	East	North	Sample Date	Ca	Mg	Na	K	HCO_3	F	Cl	NO_2	NO_3	Br	HPO_4	SO_4
BL 1	COB visitor center	634777	4165134	4/10/2006	94.14	21.64	43.68	0.98	222	0.38	48.86	< 0.01	3.66	0.0068	< 0.01	3.42
BL 2	Curtis Perkins Well	633230	4167096	4/11/2006	106.38	14.48	23.68	1.04	205	0.14	26.42	< 0.01	1.22	0.0054	< 0.01	3.18
BL 3	COB treatment plant	633658	4168363	4/11/2006	208.40	25.61	63.80	1.29	211	0.12	30.81	1.70	1.31	0.0038	< 0.01	11.26
BL 4	Clark Well	634855	4168225	4/11/2006	126.00	19.35	32.06	0.75	393	0.25	22.94	< 0.01	1.59	0.0042	< 0.01	2.09
BL 5	Lems Draw Spring	636670	4166194	4/11/2006	176.13	21.67	42.03	1.24	322	0.14	62.71	< 0.01	1.67	0.0115	< 0.01	5.35
BL 6	Upper Lems Draw Spring	635778	4168382	4/11/2006	153.63	19.31	22.35	0.84	303	0.40	57.37	< 0.01	3.74	0.0104	< 0.01	4.05
BL 7	Blanding Res 3	633377	4169982	4/11/2006	38.36	5.41	2.84	0.58	126	0.17	1.48	< 0.01	0.01	0.0000	< 0.01	0.57
BL 8	Canal inflow Blanding Res 3	633464	4170209	4/11/2006	40.43	4.76	1.82	0.36	129	0.08	1.15	< 0.01	0.11	0.0000	< 0.01	0.49
BL 9	McPherson Well	634808	4167280	4/11/2006	119.07	19.56	43.02	1.53	260	0.26	50.61	< 0.01	0.45	0.0094	< 0.01	4.06
BL 10	Westwater Creek near Blanding	633013	4165912	4/12/2006	51.95	11.68	20.12	0.97	164	0.09	19.04	< 0.01	0.26	0.0036	< 0.01	1.54
BL 11	Blanding Res 4	632276	4169406	4/12/2006	34.64	4.35	2.94	0.47	123	0.07	0.96	< 0.01	0.00	0.0008	< 0.01	0.33
BL 12	Watkins Well	637153	4161690	4/12/2006	127.80	28.07	49.80	1.46	208	0.20	38.26	< 0.01	0.20	0.0088	< 0.01	6.90
BL 13	Upper Browns Canyon	637132	4161506	4/12/2006	155.70	36.32	52.24	1.65	273	0.28	69.78	< 0.01	2.13	0.0150	< 0.01	6.42
BL 14	McDonald Well	636142	4162190	4/12/2006	129.15	26.03	64.82	1.82	354	0.27	67.92	< 0.01	2.87	0.0106	< 0.01	3.67
BL 15	Wojtz Well	635818	4166901	4/12/2006	116.82	16.28	39.58	0.92	288	0.21	39.91	< 0.01	3.08	0.0057	< 0.01	2.99
BL 16	Recapture Dam Spring	637600	4168820	4/12/2006	157.50	22.60	54.63	1.36	221	0.18	28.96	< 0.01	0.85	0.0031	< 0.01	7.79

Table A.3. *(continued)*

ID	Site	East	North	Sample Date	Ca	Mg	Na	K	HCO$_3$	F	Cl	NO$_2$	NO$_3$	Br	HPO$_4$	SO$_4$
BL 17	KBC seep along Recapture Canyon	637726	4168517	4/12/2006	80.17	16.94	42.20	1.57	110	0.09	22.70	< 0.01	0.57	0.0066	< 0.01	5.08
BL 18	COB Park Well	634326	4164228	4/13/2006	165.24	61.57	56.66	1.97	308	0.53	104.14	< 0.01	9.52	0.0205	< 0.01	7.22
BL 19	Perkin's Spring	633070	4167019	4/13/2006	84.32	11.61	11.39	1.01	188	0.14	23.32	< 0.01	1.52	0.0077	< 0.01	1.55
BL 20	Upper Westwater Canyon	633080	4167018	4/13/2006	82.71	12.71	15.71	1.06	281	0.25	13.45	< 0.01	0.03	0.0022	< 0.01	0.70
BL 21	Lower Browns Canyon	637442	4159278	4/13/2006	338.30	93.23	72.95	3.53	364	0.57	81.56	< 0.01	0.13	0.0123	< 0.01	16.85
BL 22	Recapture Reservoir	637393	4169794	4/13/2006	33.61	4.29	5.28	0.75	117	0.15	2.13	< 0.01	0.01	0.0000	< 0.01	0.47
BL 23	Johnson Creek above diversion	631338	4176866	4/13/2006	36.97	4.29	1.68	0.26	121	0.09	0.88	< 0.01	0.01	0.0000	< 0.01	0.41

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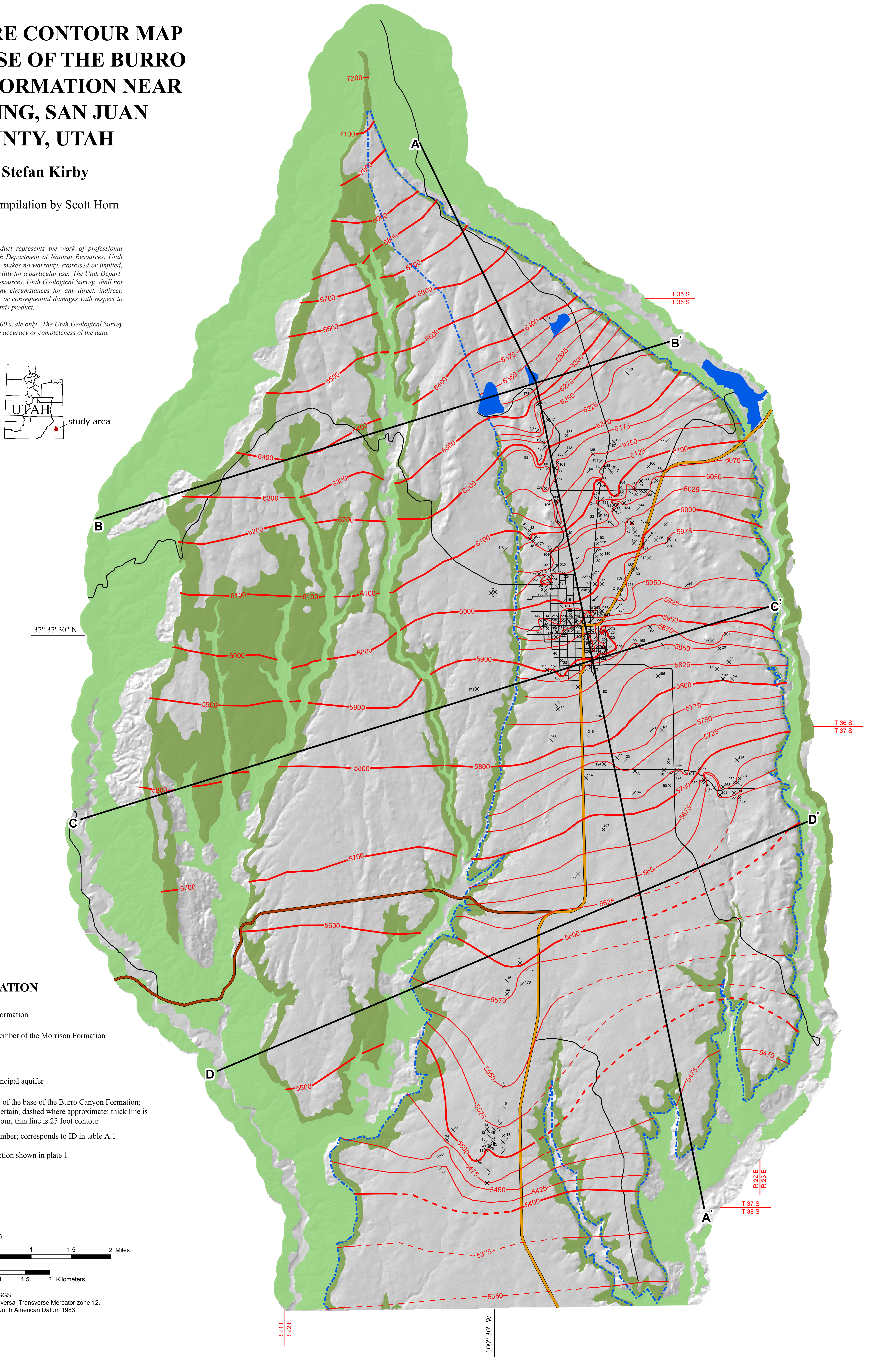
Plate 3
Special Study 123
Geologic and Hydrologic Characterization of the
Dakota-Burro Canyon Aquifer near Blanding, San Juan County, Utah

STRUCTURE CONTOUR MAP OF THE BASE OF THE BURRO CANYON FORMATION NEAR BLANDING, SAN JUAN COUNTY, UTAH

by Stefan Kirby

Digital compilation by Scott Horn



EXPLANATION

🟩	Burro Canyon Formation
🟩	Brushy Basin member of the Morrison Formation
🟦	Water body
▭	Extent of the principal aquifer
6400	Elevation in feet of the base of the Burro Canyon Formation; solid where certain, dashed where approximate; thick line is 100 foot contour, thin line is 25 foot contour
123 ×	Drillers' logs number; corresponds to ID in table A.1
A——A'	Line of cross section shown in plate 1
	Secondary road
	State road 95
	US highway 191

SCALE 1:50,000

0 0.5 1 1.5 2 Miles

0 0.5 1 1.5 2 Kilometers

DEM base from USGS.
Map projection Universal Transverse Mercator zone 12.
Horizontal datum North American Datum 1983.

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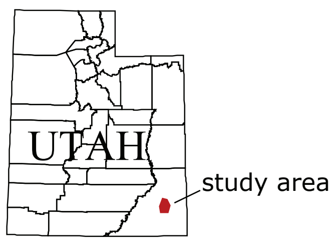
Plate 2
Special Study 123
Geologic and Hydrologic Characterization of the
Dakota-Burro Canyon Aquifer near Blanding, San Juan County, Utah

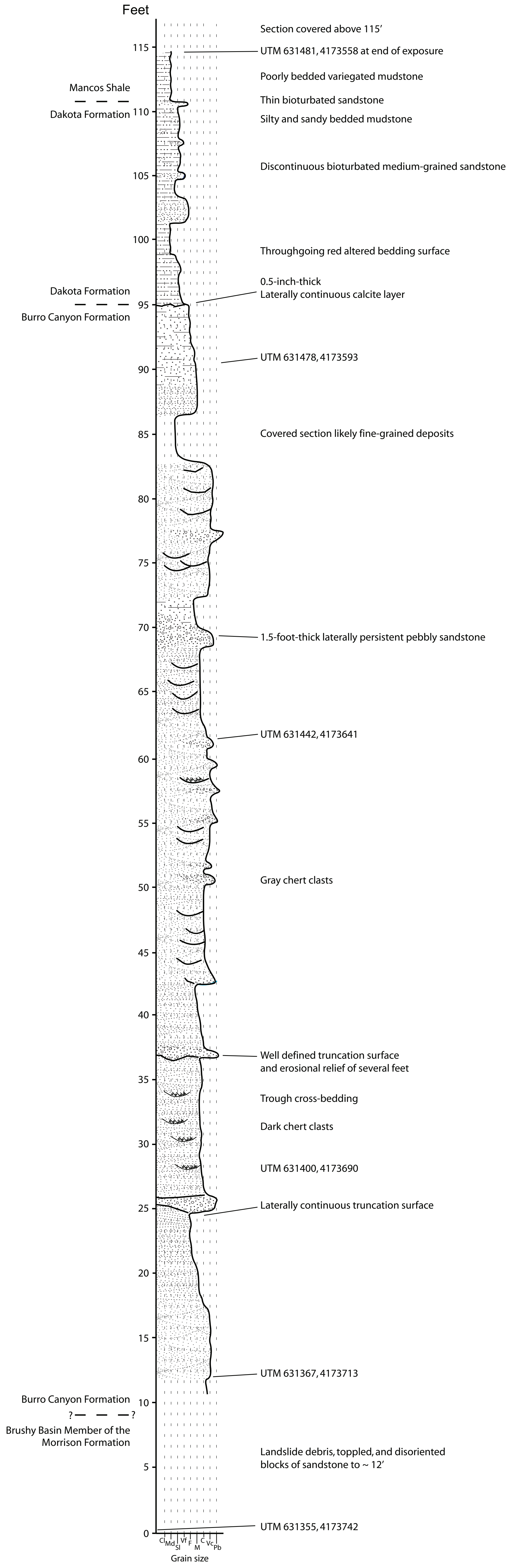
MEASURED SECTIONS OF THE DAKOTA AND BURRO CANYON FORMATIONS NEAR BLANDING, UTAH

by Stefan Kirby

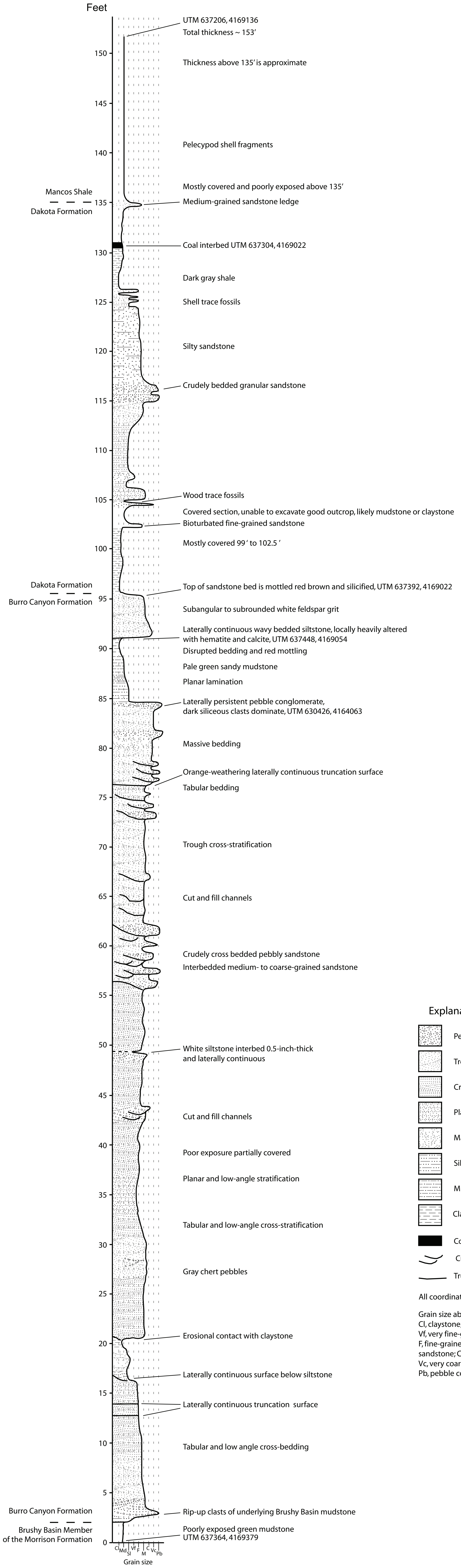
See plate 1 for section locations



Blanding Measured Section 1



Blanding Measured Section 2



Explanation

- ⁘ Pebble conglomerate
- ░ Trough cross-bedded sandstone
- ░ Cross-stratified sandstone
- ░ Planar-bedded sandstone
- ░ Massively bedded sandstone
- ▤ Siltstone
- ▤ Mudstone
- ▤ Claystone or shale
- ■ Coal
- ⌣ Cut and fill channel structures
- — Truncation surface

All coordinates are in NAD 27 UTM zone 12

Grain size abbreviations:
Cl, claystone; Md, mudstone; Sl, siltstone; Vf, very fine-grained sandstone; F, fine-grained sandstone; M, medium-grained sandstone; C, coarse-grained sandstone; Vc, very coarse-grained sandstone; Pb, pebble conglomerate

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GEOLOGIC MAP OF THE BLANDING AREA, SAN JUAN COUNTY, UTAH

by Stefan Kirby

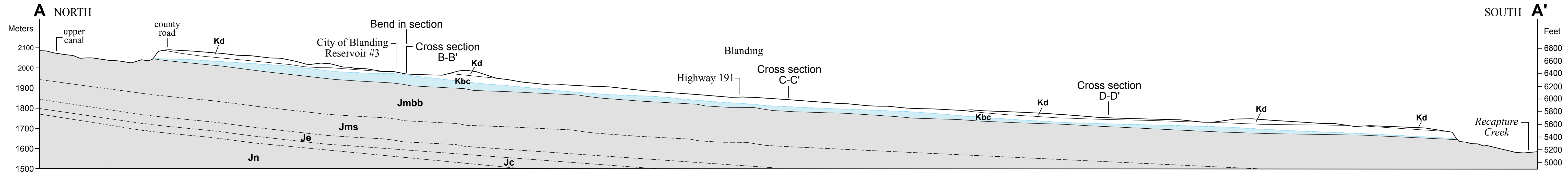
Digital compilation by Scott Horn

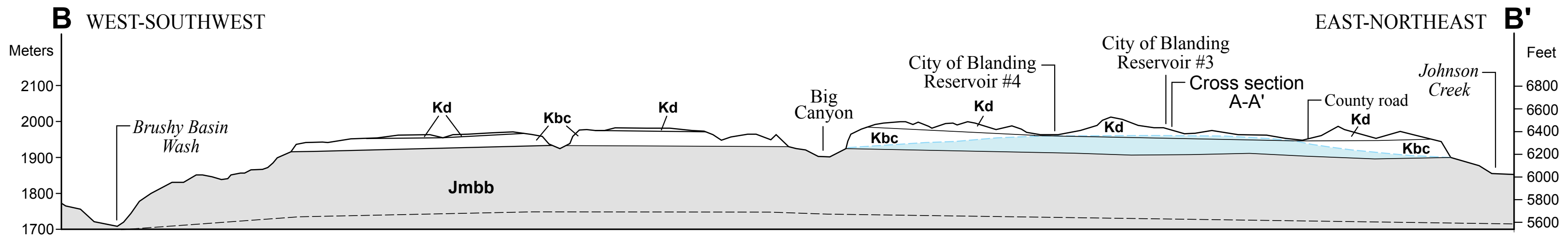
SCALE 1:50,000

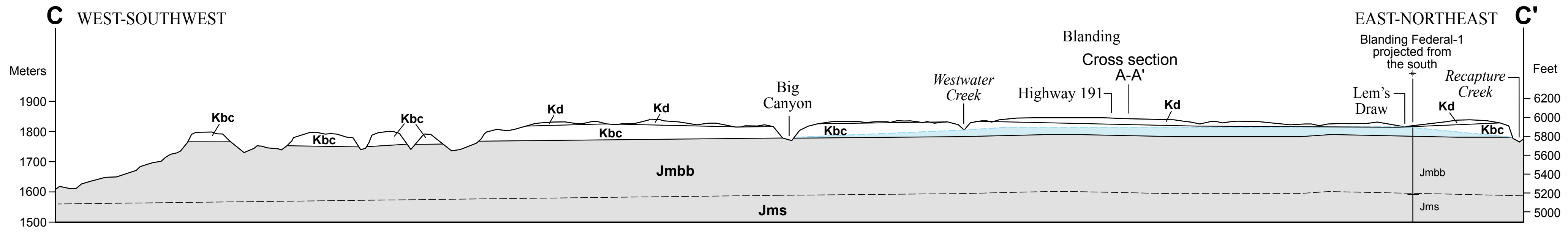
Contour interval 50 meters

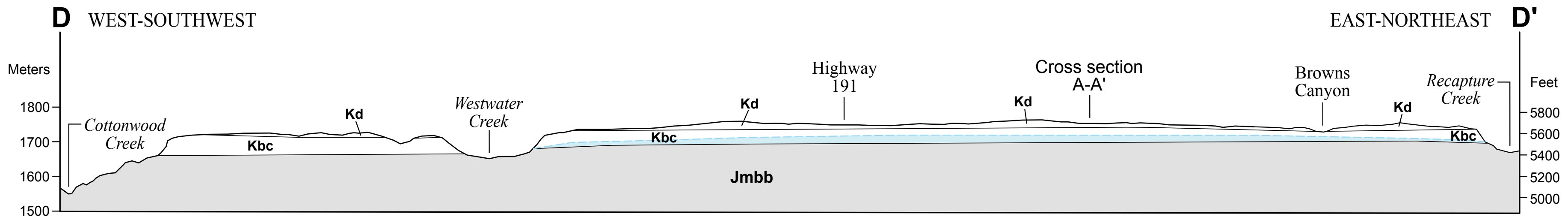
Topographic base from USGS Blanding 30' x 60' map. Map projection Universal Transverse Mercator zone 12. Horizontal datum North American Datum 1983.

Previous mapping includes 1:250,000 scale mapping by Hintze and Stokes (1963) and Haynes and others (1972) that covers the entire study area.









☐ Rocks of the principal aquifer

▨ Units below the principal aquifer

▨ Saturated area of the principal aquifer based on potentiometric surface in plate 4

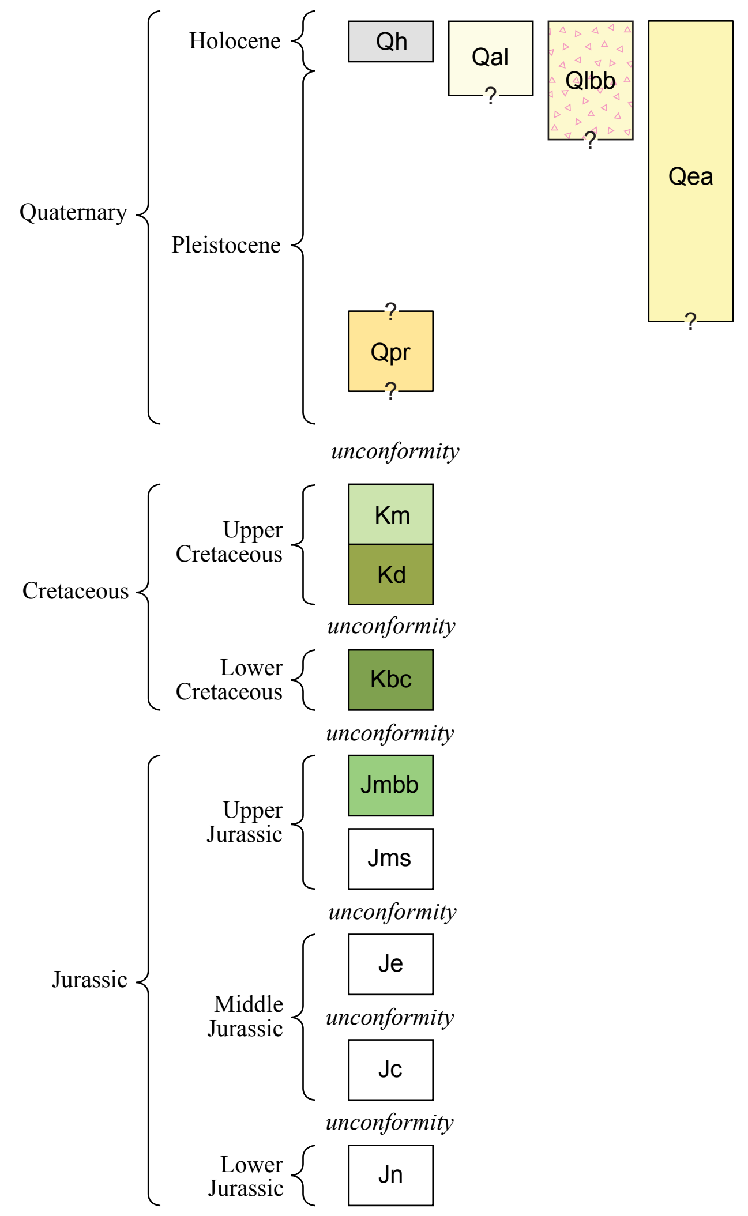
3X vertical exaggeration on all cross sections

Thin unconsolidated Quaternary units and the Mancos Shale not shown

Units below the Brushy Basin Member include: Jms, Salt Wash Member of the Morrison Formation; Je, Entrada Sandstone; Jc, Carmel Formation; Jn, Navajo Sandstone

For description of units below the Brushy Basin Member see Hintze and Stokes (1963), Haynes and others (1972), and Doelling (2004)

CORRELATION OF MAP UNITS



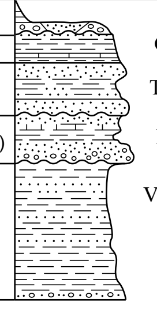
DESCRIPTION OF MAP UNITS

Qh	Artificial cut and fill – Clay to boulder-size material; variable thickness; latest Holocene.
Qal	Stream alluvium – Sand, silt, clay, and gravel; thickness varies but commonly less than 9 m (30 ft); Holocene.
Qlbb	Slumps and landslides – Hummocky deposits and slumped material; most common on slopes of the Brushy Basin Member of the Jurassic Morrison Formation; variable thickness; Holocene to upper Pleistocene.
Qea	Mixed eolian and alluvial deposits – Eolian sand deposits with interspersed alluvial gravels, sands, and silts; variable thickness usually less than 6 m (20 ft); Holocene to middle Pleistocene.
Qpr	Pediment remnant deposits – Alluvial gravel, cobbles, and boulders; deposited as alluvial fans on flanks of the Abajo Mountains; up to 12 m (40 ft) thick; lower Pleistocene.
Km	Mancos Shale – Marine shale, lesser siltstone, and sandstone. Within the study area only the base of the Mancos Shale is present, up to 9 m (30 ft) thick; Upper Cretaceous.
Kd	Dakota Sandstone – Sandstone, conglomerate, and interbedded mudstone and shale; thickness varies from 5 to 15 m (15-50 ft); Upper Cretaceous.
Kbc	Burro Canyon Formation – Sandstone, conglomerate, and mudstone; thickness averages 29 m (95 ft); Lower Cretaceous.
Jmbb	Brushy Basin Member of the Morrison Formation – Siltstone, mudstone, lesser sandstone and conglomerate, and minor limestone. Within the study area only the upper 60 m (200 ft) are exposed; Upper Jurassic.
Jms	Salt Wash Member of the Morrison Formation – Interbedded sandstone and siltstone and mudstone. Not exposed in the study area. Thickness is estimated from borehole data and Haynes and others (1972) at ~ 110 m (360 ft). Shown only on cross sections.
Je	Entrada Sandstone – Crossbedded sandstone. Not exposed in the study area. Thickness is estimated from borehole data and Haynes and others (1972) at ~ 50 m (160 ft). Shown only on cross sections.
Jc	Carmel Formation – Silty shale, siltstone, and sandstone. Not exposed in the study area. Thickness is estimated from borehole data and Haynes and others (1972) at ~ 30 m (100 ft). Shown only on cross sections.
Jn	Navajo Sandstone – Crossbedded sandstone. Not exposed in the study area. Thickness is estimated from borehole data and Haynes and others (1972) at least 120 m (400 ft). Shown only on cross sections.

LITHOLOGIC COLUMN

SYSTEM	SERIES		FORMATION AND MEMBERS	SYMBOL	THICKNESS Meters (Feet)
QUAT.			Surficial deposits	Q	<12 (<40)
CRET.	Upper		Mancos Shale	Km	0-9 (0-30)
			Dakota Sandstone	Kd	5-15 (15-50)
	L.		Burro Canyon Formation	Kbc	24-36 (80-120)
JURASSIC	Upper	Morrison Fm.	Brushy Basin Member	Jmbb	>60 (>200)

LITHOLOGY



Gray marine shale

Thin discontinuous coal beds

Pebble conglomerate and sandstone

Variegated mudstone, claystone, and sandstone

Commonly covered by landslides beneath canyon rims

Modified from Doelling (2004).

MAP SYMBOLS

———— – – – –	Contact – Solid where definitely located; dashed where gradational
A——A'	Line of cross section
	Location of measured section shown on plate 2
4	Strike and dip of bedding
🟦	Water body

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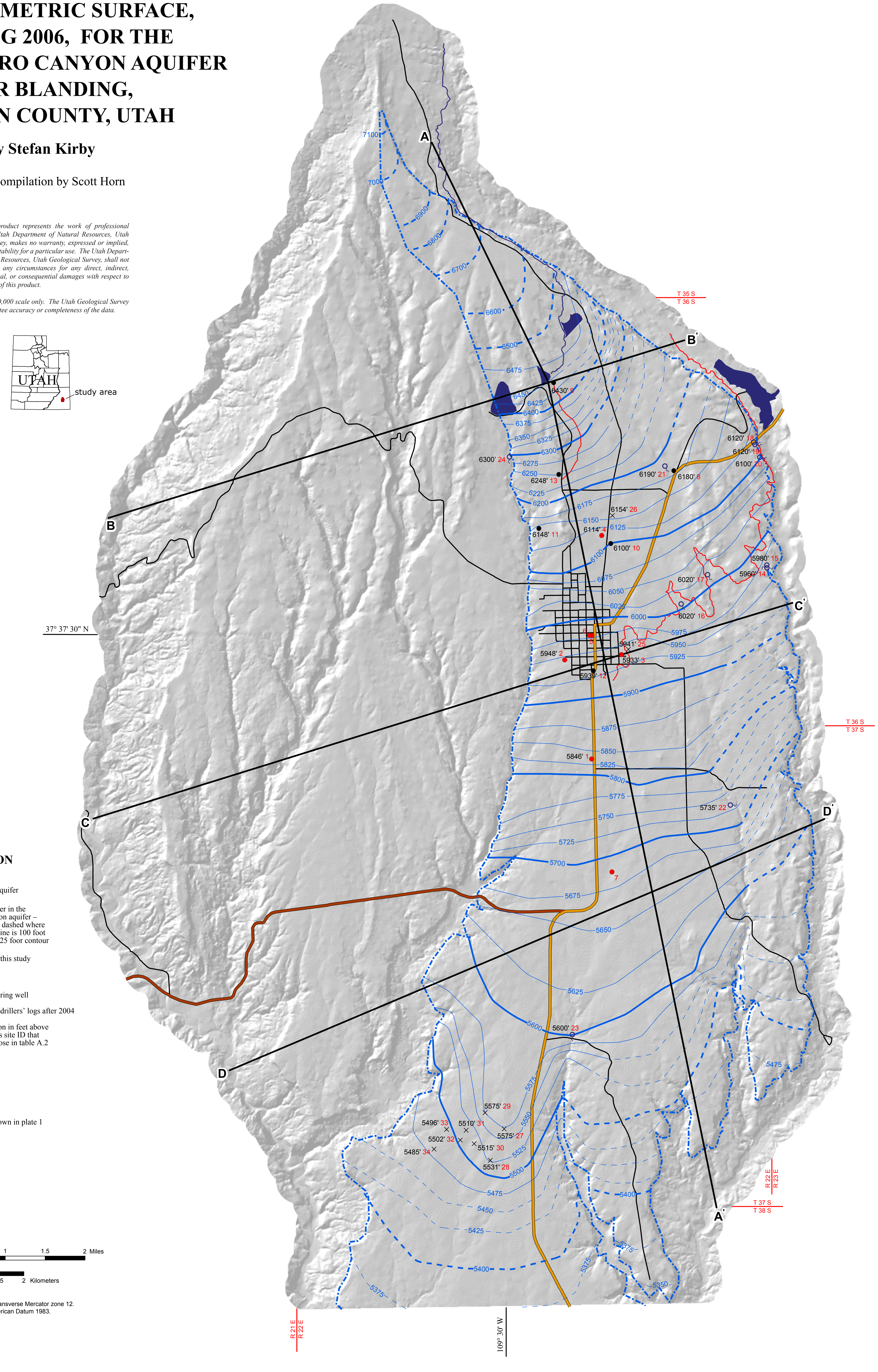
POTENTIOMETRIC SURFACE, IN SPRING 2006, FOR THE DAKOTA-BURRO CANYON AQUIFER NEAR BLANDING, SAN JUAN COUNTY, UTAH

by Stefan Kirby

Digital compilation by Scott Horn



EXPLANATION

- Extent of the principal aquifer
- 5400 Elevation of ground water in the Dakota-Burro Canyon aquifer – Solid where certain, dashed where approximate; thick line is 100 foot contour, thin line is 25 foor contour
- ● Static water levels from this study
- ○ Spring
- ● USGS long term monitoring well
- × Static water levels from drillers' logs after 2004
- 5846' 1 Black number is elevation in feet above MSL; red number is site ID that corresponds with those in table A.2
- ■ Water body
- Historical canal
- Active canal
- A——A' Line of cross section shown in plate 1
- Secondary road
- State road 95
- US highway 191

SCALE 1:50,000

0 0.5 1 1.5 2 Miles

0 0.5 1 1.5 2 Kilometers

DEM base from USGS.
Map projection Universal Transverse Mercator zone 12.
Horizontal datum North American Datum 1983.