PREHISTORIC WATER RESOURCE ADAPTATIONS IN THE AMERICAN SOUTHWEST: CASE STUDIES FROM TULAROSA, NEW MEXICO AND SAFFORD, ARIZONA

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ABSTRACT

The water resources and characteristics of two prehistoric canal systems, which are separated from one another by approximately 365 kilometers (227 miles) and about 500 years, are briefly described and discussed. In the process, similarities and differences are noted, adaptations to the arid environmental characteristics of the areas are evaluated, and the ingenuity and resourcefulness of the ancient engineers that conceived of, planned, and completed these canal systems are considered.

INTRODUCTION

Among other things, comparative case studies are a technique to determine and analyze variations in the manner in which cultures adapt to environmental conditions in which they live and develop. Case studies also provide insights into how cultures engineer infrastructure that allows them to develop economically and socio-politically.

This paper considers prehistoric efforts conducted to obtain water resources by two Southwestern groups a few centuries and a few hundred kilometers apart (Figure 1). Agriculture and water management were evidently important aspects and keys to meeting the subsistence needs for inhabitants of both of the areas discussed. These are illustrations of the ingenuity and sophisticated engineering skills of two different groups of peoples to adapt to the arid climes, as well as the differing hydrological regimes and varied landscape situations, in which they lived. They are described to emphasize the similarities and differences expressed considering the variations in the time, space, and cultural affiliations of the examples.

The case study from the eastern edge of the Tularosa Basin in south-central New Mexico is the earlier of the two cases by around 500 years. At the Creekside Village site (LA 146443) we see the employment of small-scale canal irrigation and development of planned fields to permit the apparent specialization and emphasis on corn cultivation that documents an early transition from small, more mobile communities with a semi-sedentary lifestyle based on a hunting and gathering economy into a large community with a sedentary lifestyle based on an agricultural economy.

Some 365 kilometers (227 miles) to the west, the bajada canals of the Safford Basin in southeastern Arizona represent a later, more sophisticated engineering adaptation that stretches

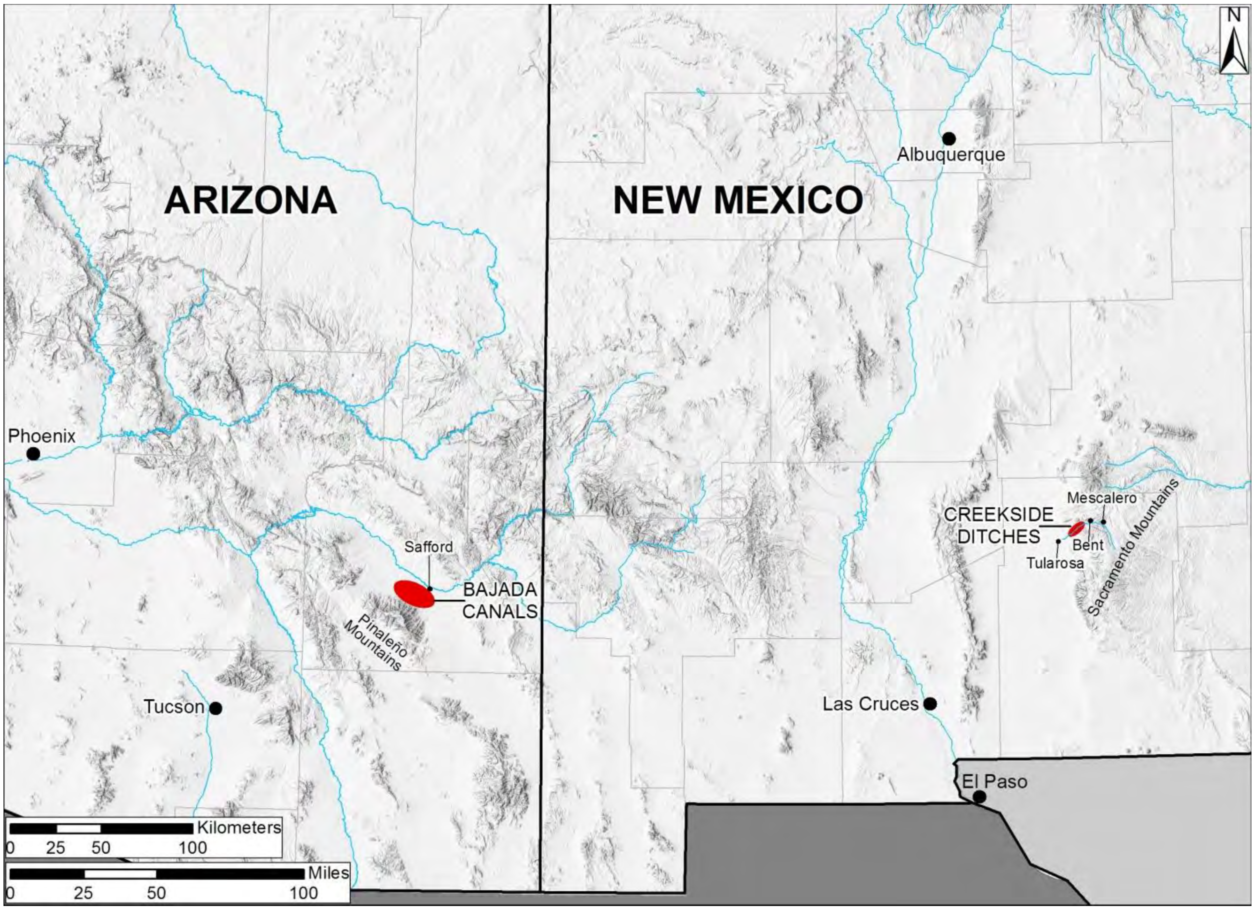

Figure 1. Maps showing the locations of the two case studies. (Illustration by Aaron Lovejoy).

the imagination as to how it was accomplished without surveying instruments and techniques, to increase productivity in locations otherwise of low agricultural value.

COMPARATIVE ENVIRONMENTAL CONTEXTS

Despite the distance separating the two case studies, the environmental contexts today are in many aspects quite similar. However, today's environmental contexts appear to be different in many ways from those of the past. Although paleo-environmental studies are lacking in both areas, historic records from the Safford area and some pollen studies from the Creekside Village indicate the vegetation of the past was characterized by lush grasslands with stands of oaks and junipers, as well as a cottonwood-dominant vegetation in riparian areas. This prehistoric vegetation, along with other forms of evidence, suggests both areas received greater amounts of precipitation in the past. Climatic change, as well as overgrazing by cattle, sheep, and goats, is largely responsible for the existing conditions in both areas today.

Topography

In both areas the surficial expression of clastic depositional and erosional features is typical of the semiarid Basin and Range Province (Lawton et al. 2000; Wikipedia 2018). The setting includes features such as multi-level piedmont slopes, and bolson floor and eolian deposits.

The canal system in the Tularosa area is situated on the westward sloping piedmont of the Sacramento Mountains in Otero County, in south-central New Mexico (Figure 1). It is located at the east-central edge of the Tularosa Basin, just northwest of U. S. Highway 70, approximately 11 kilometers (7 miles) northeast of the village of Tularosa. This piedmont is just south of the Sierra Blanca, which at 3,652 meters (11,981 feet) is the highest mountain in the southern part of the state. Today the area in the vicinity of the canal system is characterized by an over-steepened topography caused by down-cutting of some 10 to 15 meters (30 to 50 feet) of the Rio Tularosa channel since about 1935 (Charles Walker, personal communication 2000). The old valley flats are still in the process of being cut and the old piedmont surfaces are being eroded.

The bajada canals of the central Safford Basin are located south, southwest, and west of the city of Safford, Arizona, in Graham County, in southeastern Arizona (Figure 1). The Safford Basin is a trough-shaped depression formed by elongated mountain ranges oriented generally northwest by southeast, which rim a broad alluvial-filled valley. The area of the bajada canals is bounded by the Gila Mountains to the north and by the Pinaleño Mountains on the south (Houser et al. 1985), a distance of about 23.3 km (14.5 miles), and drains into the Gila River. The canals are situated on the northeastward sloping piedmont/bajada of the Pinaleño Mountains in Graham County, just north of Mount Graham, which at 3,267 meters (10,719 feet) is one of the highest mountains in southern Arizona.

Climate

The semi-arid Tularosa area is characterized by a hot, dry desert climate with most of the precipitation occurring in the summer months, with winters being relatively dry and warm. The average annual precipitation at Creekside Village is about 430 mm (17 inches), with the normal growing season precipitation (May through September) between 255 and 280 mm (10 to 11 inches) (U.S. Weather Bureau 1967). Interpolating between the values for Mescalero (6 km [3.8 miles] east, elevation 2068 m [6785 feet], enclosed by mountains) and Tularosa (9 km [5.6 miles] southwest, elevation 1354 m [4442 feet], at the edge of the Tularosa basin), the average annual temperature is about 13.2 degrees C (55.7 degrees F). January lows average about 3.5 degrees C (38.3 degrees F), and July highs about 23.0 degrees C (73.5 degrees F) (Gabin and Lesperance 1977). The frost-free season averages about 190 days each year (Tuan et al. 1973).

In the semi-arid Safford Basin, almost half of the total annual precipitation falls during July and August, and is from the North American Monsoon (Western Regional Climate Center 2017), and averages 22.7 cm (8.93 inches). Precipitation runoff and springs supply water to the bajada canals. Temperatures in the Safford Basin reach from 32º to over 38º C (90° to over 100º F) between May and September (Sellers and Hill 1974:422). Freezing temperatures occur on average from mid-November through early-March, allowing a “frost free” growing season that averages about 258 days in length (Weather Spark 2017). The relative humidity of the Safford Basin is low, with high and low averages ranging from between about 23% and 34% for the month of August, the month of greatest precipitation, to between about 11% and 18% for May and June, the driest months of the year. The evapotranspiration rate for this area is high - about nine times greater than the precipitation.

Native Plants

Relative to the native plants of the area, both systems of canals are located in ecotonal areas where the inhabitants could avail themselves of the varying plants from at least one other nearby differing life zone to augment and add variety to their diets. Such diversity of resources may have been essential to agriculturalists to guard against crop shortages or failure, as well as to acquire wild resources used for seasonings, dyes, foods, and in ceremonies or medicinally.

The canals in the Tularosa area are in the Lower Sonoran Life Zone, with the vegetation type mostly desert scrub. The canal system being considered is largely cut into the lower gravel terrace where the soil is much deeper and softer than on the hills above. The prehistoric Creekside Village site (LA 146443), the site most obviously associated with a canal, is near the northern tip of the gravel terrace where drainage is good. Dick-Peddie (1993:123–124) classifies the local vegetation as Montane Scrub, where the available moisture is less than might be expected considering the altitude, latitude, and/or surrounding vegetation.

At one time the valley bottom of the Rio Tularosa probably supported fairly rich riparian vegetation, but now that is also Montane Scrub due to entrenchment of the creek channel. Today, the 10 to 15 meter (30 to 50 feet) deep stream channel supports scattered cottonwoods, willow and the invasive tamarisk, with mixed mesquite, saltbush, creosote bush, and juniper across the floodplain. Beyond the floodplain margins, on the Pleistocene terraces, are stands of creosote bush and mesquite interlaced with yucca. Ocotillo thrives on the higher, rockier slopes.

In the Safford area, the canals descend northward from the rocky foothill/bajada of the Pinaleño Mountains, sometimes traversing the raised landforms of the ranges, to carry their loads to the rich, sandy soils of the basins and the Pleistocene terrace overlooking the Gila River floodplain. The biotic/vegetation community characterizing the area is a xeric shrubland of the Southwestern Desert Scrub type, with the creosote bush biotic community dominating (Figure 2) (Lowe 1964:20-24). Riparian woodland characterizes several of the drainages emanating from the Pinaleño Mountains, around artesian resources found on basin floors, and is also present on the floodplain of the Gila River (Lowe 1964:60-63).

Surface Water

Fed by runoff and numerous springs, the relatively small perennial Rio Tularosa flows southwestward through a steep-walled canyon from its headwaters in the Sacramento Mountains to cut through the rocky foothills/bajada in the area of the sites and canals in its course to the Tularosa Basin. Today the Rio Tularosa has an average annual runoff of about 13,666,958 m^3 (11,080 acre-feet), providing a daily average of about 19.7 to 30.1 million liters (5.2 to 8.0 million gallons) of water passing the Creekside Village! (Wiseman 2016:7). The largest springs

Figure 2. An example of the creosote and low mesquite vegetation characterizing the xeric shrubland of the Chihuahuan Desert subdivision of the Lower Sonoran life-zone found in the Safford Basin. This vegetation is present on the basin floors as well as on the Pleistocene terraces used for cultivation and is similar to that found around Creekside Village. (Photograph by James Neely).

in the Tularosa drainage basin are those at the head of the valley upstream from Mescalero, which supply much of the water to the stream. However, additional spring heads are found bordering the Rio Tularosa for its entire length. Large areas of the northern Tularosa Basin are underlain by gypsum. The gypsum accumulates primarily by the evaporation of brackish-to brine-saturated groundwater discharge. Gypsum build-up and erosion create surficial features that include gypsum spring mounds from 1 to 5 m (3.3 to 16.4 feet) high with basal areas from tens to hundreds of square meters. At least one of these gypsum spring mounds was modified and its water used by the prehistoric inhabitants of Creekside Village.

The surface water of the Safford area is characterized by both perennial and intermittent sources. The primary perennial stream of the area is the east-to-west flowing Gila River that lies a short distance north of the bajada canal terminations. South of the Gila River numerous drainages flow generally north as intermittent mountain-runoff and spring-fed streams that head in the Pinaleño Mountains. The canals were branched from the drainages that descend northward from the rocky foothill/bajada of the mountains, sometimes traversing the raised landforms of the ranges, to carry their loads to the rich, sandy soils of the basins and the Pleistocene terrace overlooking the Gila River floodplain. The watershed collection area is enormous, consisting of hundreds of square kilometers (USGS 2016). Marijilda Canyon, a major drainage supplying water for one of the bajada canal systems, was recorded in the 1970s as having an annual average of 3,314,361 m^3 (2,687 acre-feet) of water flow (ADWR 2014: Table 3.10-2). Today, the majority of the drainages in this area flow intermittently and for short periods of time, mostly just as direct runoff from recent rainfall.

THE CREEKSIDE VILLAGE CANALS: TULAROSA BASIN, SOUTH-CENTRAL NEW MEXICO

Background

During the ongoing study of the historic canals of the Tularosa Canyon area (Greenwald 2016), all of which took water from the Tularosa River prior to its channel incision that began around 1935, three prehistoric canal systems varying in length and complexity were recorded in the area between the village of Bent and Cottonwood Springs, northeast of the village of Tularosa (Figures 1 and 3). Survey and excavations have focused on Creekside Village (LA 146443), where a series of agricultural terraces with an associated small canal system have been confidently dated to the mid-Mesilla phase. Irrigation water was delivered to the terraced fields via a small canal and a series of shallow, smaller field canals. Earthen berms separate the terraces forming level field areas that were developed within Pleistocene loess sediments on the lower slope of the main ridge of Creekside Village. Additional water sources (upland runoff) and water management features (possible reservoirs and collection ditches) were employed to provide water for domestic uses and irrigation to a large permanent community.

Settlement Patterns Vis-À-Vis Canals

South of the village of Bent, a number of prehistoric sites, ranging in date from ca. A.D. 600 into the 1300s, parallel the Rio Tularosa. Of interest to us in this study are three, possibly four, prehistoric sites that appear in a rough alignment about 2.8 kilometers (1.75 miles) in length on the north side of the river that evidently had Rio Tularosa sourced canals in association (Figure 3).

The northernmost of these three sites is LA 166702. It is comprised of several pit house depressions and a very large great kiva depression, and has been recorded on BLM lands about 3.2 kilometers (2 miles) northeast of the Creekside Village. Surface finds suggest this village also dates earlier than A.D. 800, and may be contemporaneous with the Creekside Village. This village lies about 500 meters (1,640 feet) northwest of a canal (LA 169610) recorded by Greenwald et al. (2011). The waters from that canal may well have been used for that village's domestic purposes and field irrigation. This canal is about 2.1 miles in length, with its probable head just downstream of where Nogal Canyon joins the Rio Tularosa, a bit less than three-quarters of a mile downstream from the village of Bent. This canal is about the same width as the Creekside Village canal, and surface indications suggest that it has a slightly steeper, but still quite gentle, grade. As with the other Rio Tularosa canals in the vicinity, this canal was probably augmented with water from runoff and springs.

The next prehistoric community to the southwest is the Twin Kivas site (LA 6832), which also appears roughly contemporaneous with Creekside Village, consisting of pit house depressions and two kiva depressions, with a canal (LA 169610) coursing northeast to southwest just down slope of the site. The canal has been mapped from just west of Bent to the Twin Kivas site; to the southwest, the canal has been observed but not mapped. Its full extent currently remains unknown, but may extend as far as Creekside Village.

Creekside Village is the third prehistoric community in this rough alignment of sites. It has an estimated 65 pit houses and a great kiva (community structure) positioned at the highest point of the site on a ridge overlooking the village and the Rio Tularosa. Whereas the pit houses date between A.D. 650 and 825, the kiva has produced radiocarbon dates that indicate it was constructed about A.D. 700 (the early Mesilla Phase of the Pithouse or Formative Period).

Initially, the above mentioned canals were thought to be historic in origin; however, due to their proximity to the prehistoric sites and other factors, it is now thought that these canals have prehistoric origins and were subsequently refurbished by the historic occupants of the area. This historic refurbishment of an ancient canal is not unusual, as it has been noted in various locations throughout both the new and old world (e.g., Doolittle 2000; Gelles 1996; Haury 1976:122-123; Masse 1981; Neely 2014; Neely and Castellón Huerta 2014; Stanbury 1996; Woodbury and Neely 1972).

The Creekside Village Canal System

Although all three of the sites noted above appear to have been associated with canals branching from the Rio Tularosa, only Creekside Village has received extensive survey and excavations. The others have only received limited study because of land ownership access limitations.

Study was focused on two large canals just east of the Creekside Village, previously assigned New Mexico Laboratory of Anthropology site numbers LA 146442 and LA 146444 (Figure 3). These canals lie at the interface of the Rio Tularosa floodplain and the toe of the Pleistocene terraces, one on each side of the river's floodplain, and were designed to deliver water to floodplain fields. Efforts were expanded to the north side of the river to test other probable alignments in the area below the main ridge where the great kiva had been constructed. Two alignments representing small canals, Features 56 and 57, were discovered that seemingly originated north of the site (Figure 4). Along some segments, these canals had surface expressions that resembled cattle trails, but their locations and consistent near level appearance gave cause to consider them small canals. Testing by excavating short trenches across (perpendicular to) these alignments provided incontrovertible evidence of their function as water conveyance channels. These are small primary canals, only about 30 to 38 centimeters (12 to 15 inches) across at the present ground surface. They have an equally shallow depth, and a very gentle grade.

In tracing one of the Creekside Village canals (Feature 56) toward its head, an area of lush vegetation with sediments aberrant to the general area was noted (Figure 4). It is highly likely that at least Feature 56 extends from that location, which is now believed to represent a reservoir.

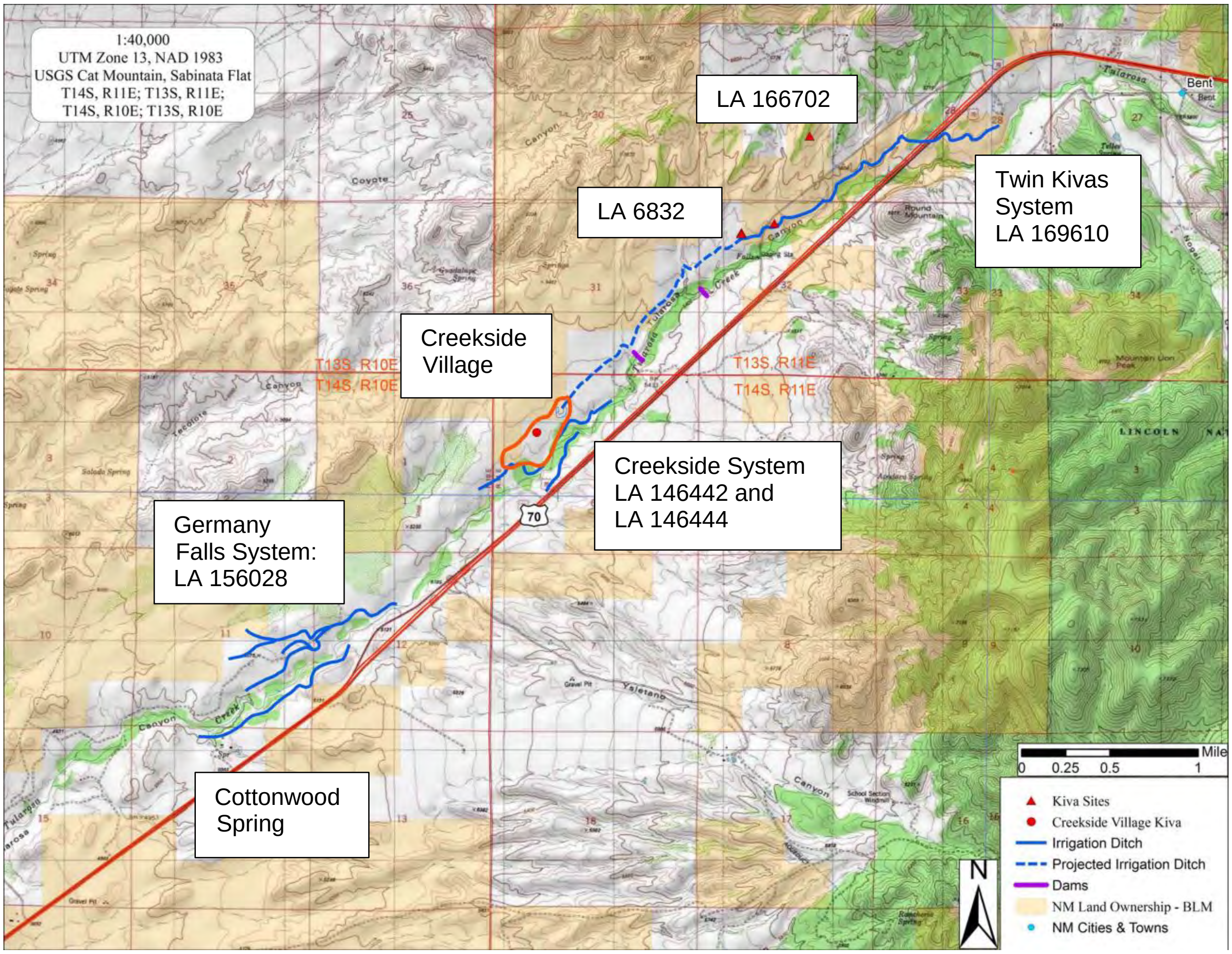

Figure 3. Topographic map showing the location of the sites and canals mentioned in the text.

Located on BLM lands, the reservoir covers an area in excess of 50 m (164 feet) in diameter. Recognizable in aerial images (Figures 4 and 5), the sediments are posited to represent both reservoir fill and overbank deposits, the latter having been deposited downslope once the reservoir had completely in-filled. Testing is proposed within the area of the reservoir in the near future. The terminus of Feature 56 has not been determined at this time, but it likely to terminate within the site boundary of Creekside Village. The head and tail of Feature 57 have yet to be located. The canal has been cut by an abraded channel downslope of the reservoir area and has not been identified in that location. Its terminus probably occurs within the site boundary of Creekside Village.

The tail (end point) of the lower floodplain canal on the north side of the creek (LA 146444) has not yet been determined, and may no longer be visible. However, the broad alluvial area, located about ¾ of a mile to the southwest of Creekside Village appears to be a reasonable endpoint. It has an area of approximately 647,497 m^2 (one-quarter square mile), and appears to have fairly rich alluvial soils for cultivation.

As noted, Tularosa Canyon contains numerous relict or fossil springs, most recognizable as low mounds of gypsum or travertine deposits. One such spring mound is located on the main ridge up slope of the kiva about 100 m and about 150 m southwest of the reservoir (Figure 4). The opening of the spring was apparently modified during the prehistoric occupation of the site when the spring was active. Gypsum materials were removed from the mound around the spring opening and possibly used in the construction of the adobe upper walls of the kiva and for other architectural elements. A drainage channel that leads from this spring mound to Feature 56 may have delivered into this small canal, although this has not been demonstrated. The prehistoric use of a natural drainage in conjunction with canals to convey water to a desired location has been documented in the Safford area (Neely 2017; Neely and Lancaster In Press).

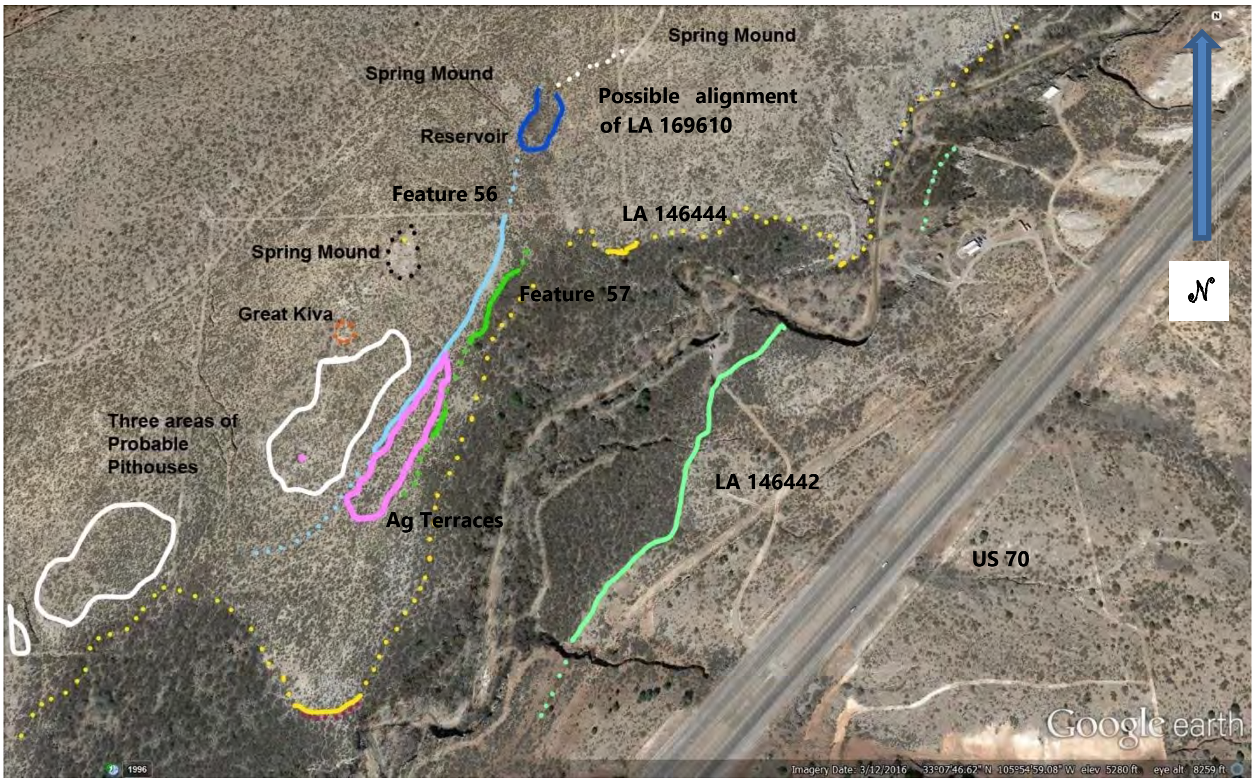

Figure 4. Satellite image with the features associated with the Creekside Village outlined. (Modified from a Google Earth image by David Greenwald).

A trench dug into the opening of that spring mound indicates the presence of thermally altered rock, deposits of ash and charcoal, and possible pits with indications of burning. Fire-altered rock is common across the surface of the spring mound as if it was a favored area for conducting roasting, perhaps using spring water to elevate the moisture level within roasting pits. The water, however, contained extremely high levels of gypsum; few plant taxa grow on gypsiferous spring mounds (typically dominated by snakeweed). The mineral content of the water would have been detrimental to agricultural plants and even dwarfs creosote bush and mesquite that grows on these mineral-rich features today.

However, the incorporation of a reservoir (Figure 5) within the water management strategies at Creekside Village may have served to increase water quality. The water toxicity within the reservoir may have been ameliorated with the augmentation of fresher waters from the Rio Tularosa conveyed to the reservoir by the prehistoric canal (LA 169610), heading up-stream about 2.7 kilometers (1.7 miles) northeast of Creekside Village (Figure 3), and apparently also serving the Twin Kiva site (LA 6832). Water quality of the lacustrine environment created within the reservoir may have been as important to residents as having the capability to store a supply of water for domestic and irrigation purposes.

Creekside Village Fields

While defining the canals, indications of broad, level areas were noted lower, east of canal Feature 56, on the slope of the main ridge of the site (Figure 4). These level areas seemed to form a pattern, although very subtle, of a series of level areas occurring in a step-like surface expression extending down the slope. Posited as terraced fields associated with Feature 56, a shovel trench (48 m in length) was initiated at Feature 56 and extended eastward down the slope. A series of earthen terrace berms spaced between 2.5 and 5.0 m appear to be separating small field areas. Shallow field ditches were discovered while excavating this trench. The sediments exposed in the trench were anthropogenic, and contained elevated amounts of organic matter, charcoal, artifacts, and fire-cracked rock. A sharp boundary exists between the Anthrosol sediments and the underlying culturally sterile loess silts.

Observations

The Creekside Village canal was not a haphazard venture; to the contrary, it was well planned! Primary in the planning was to know where the endpoint or "tail" was to be. In this case it apparently was the postulated field area to the southwest of Creekside Village. Therefore, we may assume that the occupants of Creekside Village had already planned and started the canal prior to or during the village construction. Canal and tail placement would serve two primary purposes: (1) to supply water for domestic uses at Creekside Village and (2) to irrigate the fields along its route and at its tail.

The discovery of these small canals and related fields is of crucial importance in reconstructing the subsistence system of the Creekside Village inhabitants. This is due to the recovery of large quantities of *Zia mays* remains and pollen, and a very low frequency of faunal remains from the pit house tests that have been conducted, suggesting the inhabitants of Creekside Village were largely dependent on agriculture.

Creekside Village, with a great kiva and an estimated 65 pit houses, was more than a transient camp — it is clearly a large prehistoric village in size and complexity. The discovery of a permanent, large village with a canal system and other water management infrastructure, well planned agricultural fields, a very heavy frequency of corn/maize remains, and a notable absence of faunal remains alters the mindset that at around A.D. 650 to 700 the occupants of the Tularosa Basin were more focused on hunting and gathering and practiced a semi-sedentary settlement system. Rather than small agricultural plots, planted with little or no further attention until harvested as an annual round was completed, sizeable field areas had been delineated. The size and care in field preparation, as well as the time and effort of engineering and constructing a canal system for their irrigation, suggests that a change had taken place in the settlement and subsistence systems, and quite likely the sociopolitical organization, of these people. It probably

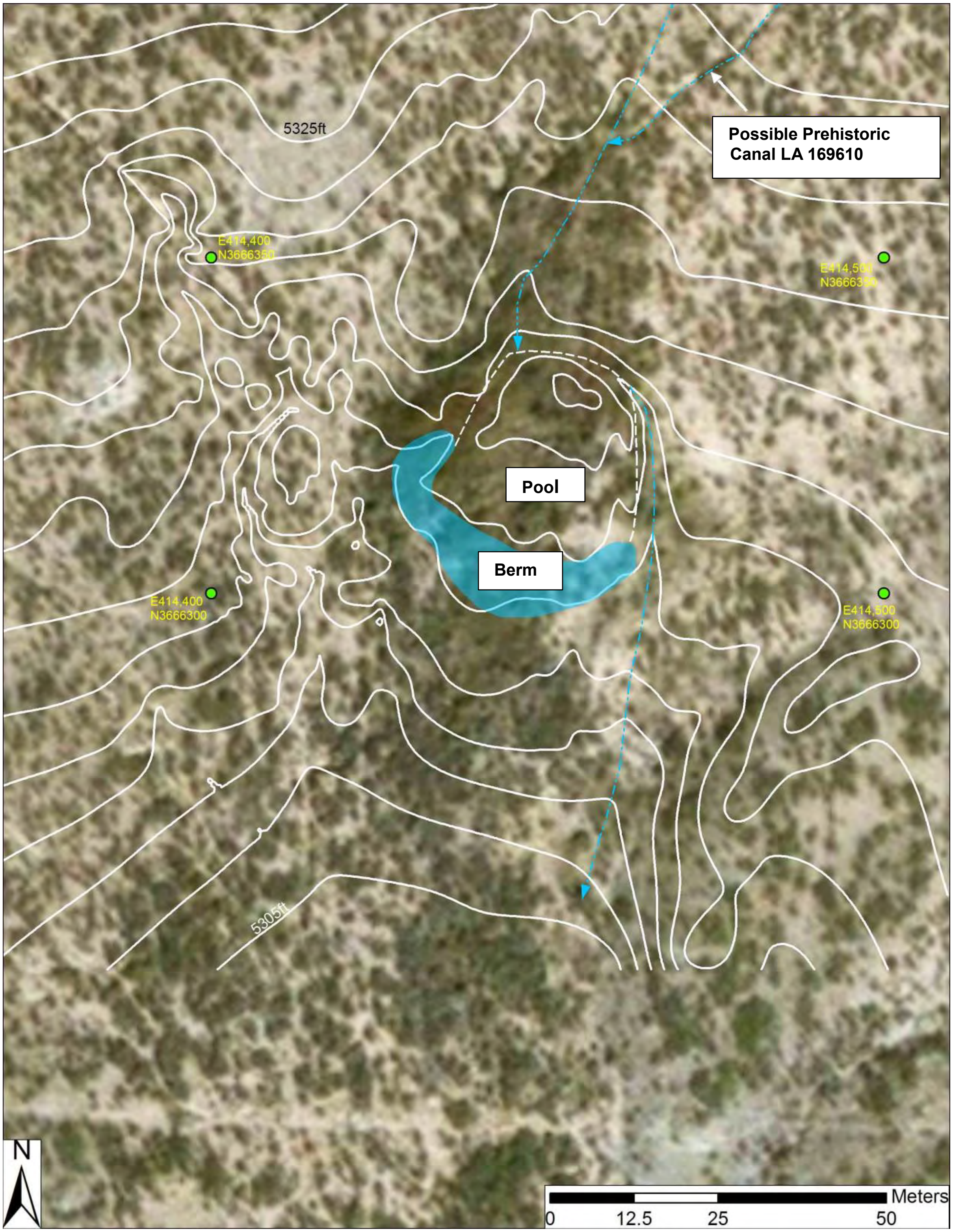

Figure 5. Satellite image showing the Creekside Village reservoir with topographic lines added. (Modified from a Google Earth image by David Greenwald).

represented a community with multiple households that worked together to build and maintain the irrigation canals and cultivate nearby fields. The occupants probably had become fully sedentary, and their subsistence was now apparently nearly totally dependent on agriculture. In fact, the very large amount of *Zea mays* remains and pollen from the excavated pit houses makes one wonder if they might have focused on its cultivation for both domestic use and as a trade item.

THE BAJADA CANALS OF THE CENTRAL SAFFORD BASIN, SOUTHEASTERN ARIZONA

Background

The initial discovery of the bajada canals in the arid central Safford Basin of southeastern Arizona may be attributed to Bandelier (1892), with additional verification by Sauer and Brand (1930). Neely (1997, 2005) augmented the early brief reports during his survey and test excavations in Lefthand Canyon, southwest of Safford. Subsequent research and surveys by Neely and Lancaster, a retired engineer living in the village of Thatcher, have more fully investigated their nature (Neely 2014, 2017; Neely and Lancaster In Press).

The use of satellite imagery and ongoing archaeological survey has greatly augmented the brief early notes mentioning these canals, found in an area where other older and contemporaneous water management schemes are also present, including conventional lowland riverine canals, extensive non-irrigated terraced and gridded agricultural fields, numerous check-dams, and grouped arrays of agricultural mulch rings and rockpiles (Neely 2014). This area may now be seen to rival the prehistoric agricultural intensification of the Salt River Valley (Masse 1981; Midvale 1968) when these canal systems are added to the great variety of agricultural strategies and density of agricultural infrastructure recorded in this portion of the Safford Basin.

Settlement Patterns Vis-À-Vis Canals

In the Safford area, surveys in Lefthand Canyon (near the west boundary of our survey), the Cluff Ranch area (near the center of our survey area), and Marijilda Canyon (near the east boundary of our survey) have recorded a rather heavy population scattered along the canals, but the sites are nearly all small. To date, survey along the other canals has recorded only a few small scattered sites, with the vast majority of the apparently associated sites located near the tails of the canals and related fields on the Pleistocene terrace overlooking the Gila River floodplain.

The Canal Systems

Twelve systems of canals, comprised of at least 41 individual canals, have been identified to date, most of which are shown in Figure 6. Survey continues and more systems are likely to be found. Whereas some exceptions occur, most systems appear to be an independent entity dedicated to a single major drainage and set of agricultural fields. The canals appear as single channels, with few branch canals or enroute agricultural fields, that terminate in fields situated on basin floors or the Pleistocene terrace overlooking the Gila River floodplain. The longest of the 41 canals is about 9.7 kilometers (6 miles) in length, and the total length of all systems exceeds 121 kilometers (75 miles).

These canal systems differ from the prehistoric canal systems found in the Salt River Valley in the vicinity of Phoenix and elsewhere in the Southwest in that they channeled water from the Pinaleño Mountain bajada (foothill) drainages fed by runoff, springs, and artesian sources, rather than from rivers. Some carry their water load from over 1646 meters (5,400 feet) down to just above the floodplain of the Gila River at about 884 meters (2,900 feet). They are also unusual in that they traverse the vertically undulating uplands of basin and range topography rather than being restricted to a nearly level riverine floodplain. The difficulty in the original excavation of these systems was further intensified by the very rocky nature of much of the terrain that they traverse.

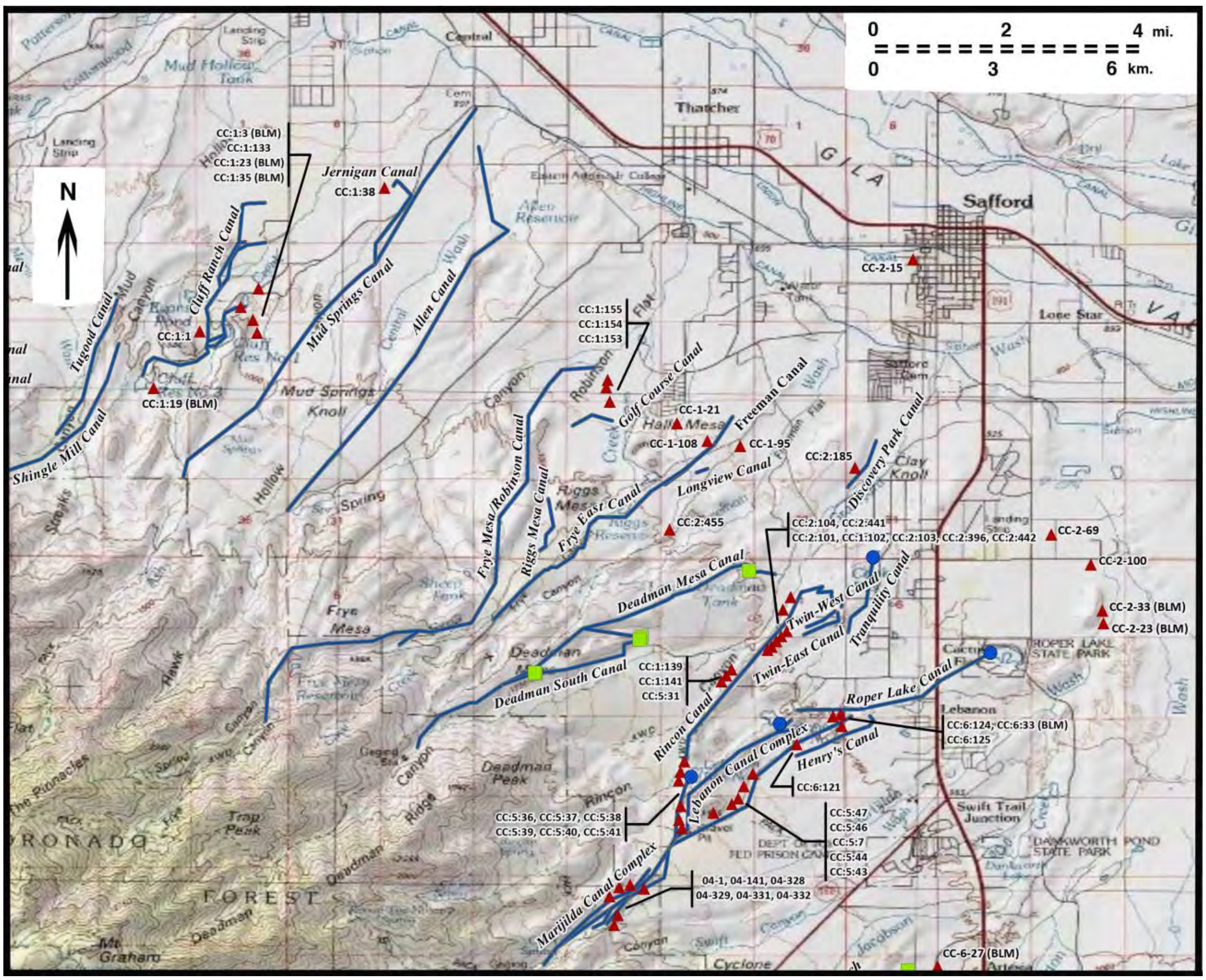

Figure 6. Topographic map showing the locations of the majority of Bajada Canals and recorded 13th to 15th century habitation sites. Additional canals and sites to the east and west are not shown to permit readability of the large map. Lefthand Canyon is off the map to the northeast. The blue linear features are canals, the small red triangles are 13th to 15th century habitation sites recorded above the Gila River floodplain, the green squares are tanks and small reservoirs, and the blue circles are large reservoirs. The numbers associated with the habitation sites have been assigned by the Arizona State Museum and the Bureau of Land Management. (Map by Sam Lewis and James Neely).

In more level terrain, the canals are of the traditional type – narrow, linear excavations into the ground that obliquely transect the natural contours of the landscape (Figure 7). In other locations within the same canal system, they appear as "perched" or "hanging" canals traversing the sheer sides of mesas (Figure 8), with some traversing over 60 meters (200 feet) above the adjacent basin floor (Figure 9). The engineering of the "perched" or "hanging" segments was evidently designed to permit the canals to follow the most direct route from origin to destination, with those segments being essentially independent of their surrounding terrain. This would reduce the energy input needed to excavate additional canal length to follow the irregularities of the topography and would also reduce water loss through seepage and evapotranspiration. The engineering involved in the planning and excavation of such canals was indeed sophisticated and presented challenges not faced in the engineering of canals located on the nearly level floodplains of rivers.

Figure 7. Photograph of a portion of the Allen Canal. Note the clearly defined, slightly raised spoil banks paralleling the canal channel. A 20-cm scale is present in the channel foreground. Looking northeast. (Photograph by Don Lancaster).

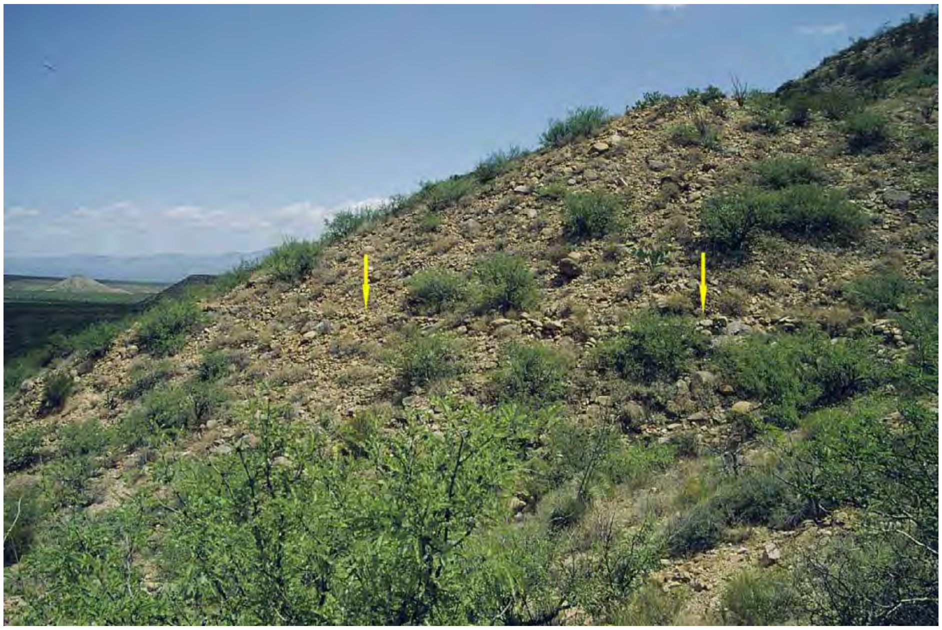

Figure 8. A "hanging" portion of the central branch of the prehistoric Lebanon Canal coursing around a lobe of the long, narrow mesa landform it traverses (see Figure 9). At this point the canal is about 40 meters above the adjacent basin to the west. Looking northwest. (Photograph by James Neely).

Figure 9. Highlighted course of the central branch of the prehistoric Lebanon Canal, flowing from right to left as it courses to the top of the mesa. The historic Lebanon Reservoir #1 is situated about 60 meters below the canal on the basin floor. This reservoir appears to be an enlargement of a prehistoric reservoir as another branch of the prehistoric Lebanon Canal emptied into it. Looking northeast. (Modified from a Google Earth image by James Neely).

The canals often create the illusion of water flowing uphill in that the mesa top slope is usually somewhat steeper than the rate of fall of the canal itself. After reaching a mesa top through a long, gentle, and an evidently carefully calculated optimal grade, and then continuing as far as possible along the usually flat but gently sloping ground surface, the canals will typically "fall off" the far end of the mesa in steep but apparently highly controlled and nondestructive cascade descending in nearly vertical constructions similar to French drains (a trench filled with pebbles and cobbles).

Canal cross-sections are small, varying from about 30 to 90 centimeters (12 to 35 inches) in width and about 20.5 to 41.0 cm (8 to 16 inches) in depth. Atypical examples may range up to as much as 178 to 280 cm (70 to 110 inches) in width. Portions of most of the systems remain almost pristine and are currently filled with fine-grained sediments.

These systems are located mostly on Arizona State and Coronado National Forest lands that fortunately remain largely undeveloped. While often of difficult access, as there are few roads and fewer mesa top trails, major canal portions are usually easily traced on foot and by satellite imagery such as those provided by the high-precision general purpose computer mapping and satellite image applications Acme Mapper and Google Earth. Unfortunately, both historic and modern constructions and land modifications, nearly all in the vicinity of the terminus of the canals, have negatively affected these systems and largely obliterated the associated fields.

A number of unusual constructions were incorporated into some of these canal systems; three notable examples are an aqueduct, about 1.5 meters (5 feet) in height and a bit over 80 meters (265 feet) long, was constructed to bridge a “saddle” in the topography (Figure 10). The second example is a “contra flow” canal located at a point where a primary canal is situated near the top edge of the mesa. This branching “contra flow” canal was excavated down the mesa slope at an acute angle apparently to irrigate fields lying below and behind the point of branching (Figure 11). The third example is represented as portions of several canal systems that illustrate the purposeful switching of the watercourses from canals to natural drainages, and then back to canals. In sum, these constructions appear to represent a major understanding and very careful exploitation of the topography and hydraulic fundamentals, as well as attention to extreme energy and use efficiency.

The Bajada Canal Fields

As noted, the canals appear as single channels, with few branch canals or enroute agricultural fields, which terminate in fields situated on basin floors or the Pleistocene terrace overlooking the Gila River floodplain. Notable exceptions are the Lefthand, Marijilda, and Cluff Ranch systems that have several branching canals servicing multiple fields along their routes (Neely 2017). While many fields are unimproved and difficult to define in area, others, especially in Lefthand and Marijilda Canyons and the Cluff Ranch area, are well-defined by rock infrastructure. These latter fields have been leveled by the installation of linear contour borders and terracing. These fields have also been modified through the construction of rock gridded quadrangles, rock piles, and check dams. Fields generally range from about 650 m^2 (¼ acre) to around 10,000 m^2 (2.6 acres). Some of the fields have been subdivided by rock borders into small plots ranging from about 25 m^2 (269 ft^2) to around 100 m^2 (1076 ft^2).

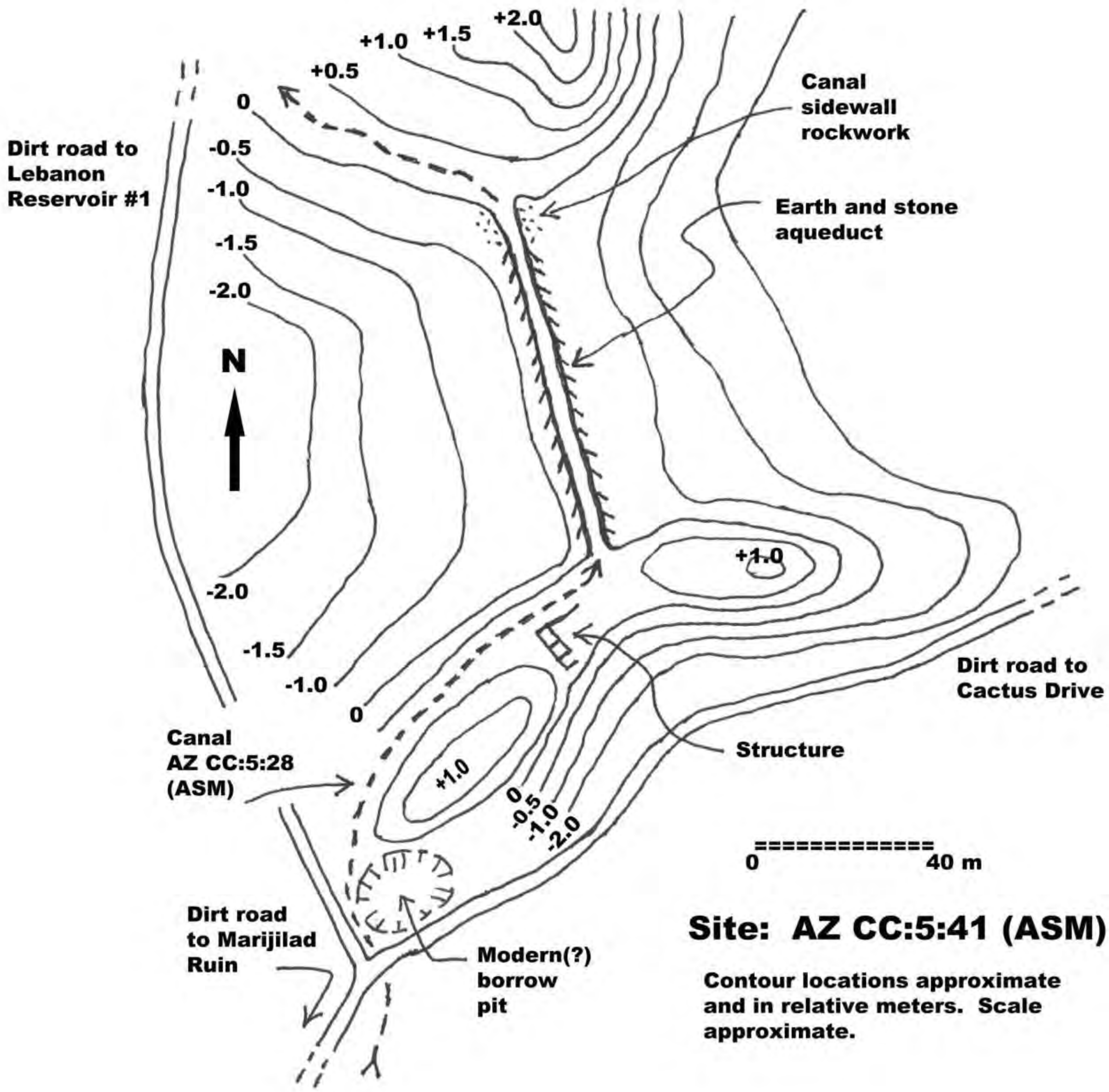

Figure 10. Sketch map showing the relationship of the central branch of the prehistoric Lebanon Canal (AZ CC:5:28 [ASM]) and its raised aqueduct to the small 3-4-room structure at site AZ C:5:41 (ASM). (Sketch map by Joseph Crary, modified by James Neely).

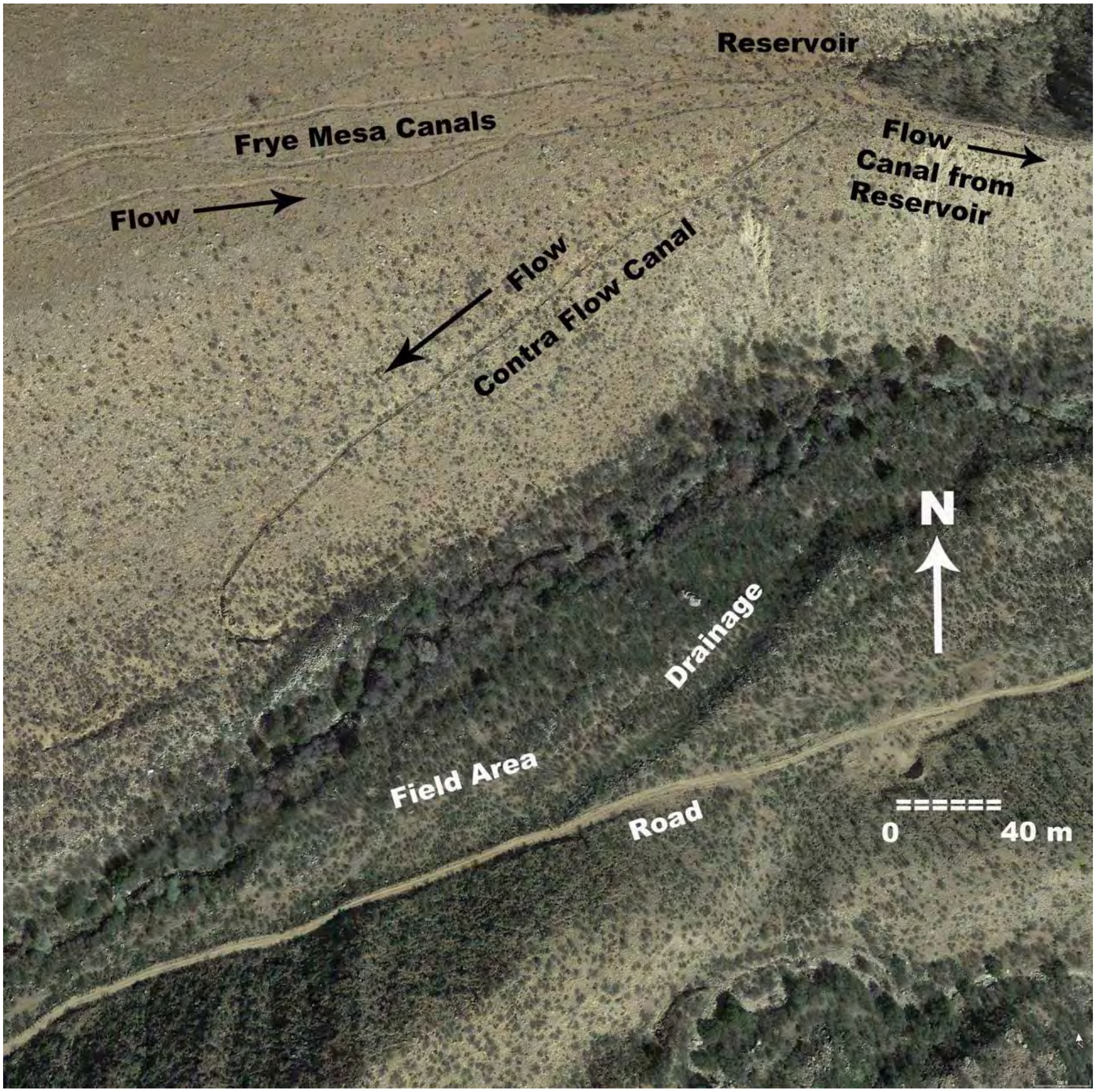

Figure 11. Satellite image showing the "contra-flow" canal on Frye Mesa. Several channels of the Frye Mesa canal flow left to right atop the mesa to join at a small reservoir. The contra-flow canal flows from the reservoir from right to left down a steep slope to fields on the drainage floodplain, about 40 meters below. (Modified from a Google Earth image by James Neely).

Observations

These canals have been difficult to date since our study has been based solely on surface survey. We have depended on stratigraphy, surface artifact finds, and associated prehistoric sites to provide temporal parameters. Although a few canals may date as early as A.D. 1100, the vast majority appear to originate after A.D. 1250 with some persisting until ca. A.D. 1450. It is not possible at this time to determine if the canal systems were functioning contemporaneously.

It is our hypothesis that the majority, if not all of the bajada canal systems were engineered and excavated by migrant populations from the Kayenta and Point of Pines areas to the north (Lindsay 1987; Haury 1958). This hypothesis is based on survey and excavation findings at the Goat Hill site (Woodson 1999**)** and other sites **(**Rinker 1998**)** in Lefthand Canyon, as well as survey in the Marijilda area **(**Neely 2017**)**. The Goat Hill site (AZ CC:1:28 [ASM]) is particularly important due to the presence of well-dated evidence of its occupation by migrants originating from the Kayenta area. There, specific types of digging tools frequently found on the canal banks and in canal associated fields were found on the floors of rooms and a kiva (a communal meeting structure) radiocarbon dated to ca. A.D. 1275-1325, thus lending credence to the dating and cultural affiliation of the canals. Figure 6 shows recorded 13th, 14th, and 15th century sites associations with the bajada canals.

CONCLUSIONS

As noted, these case studies are of contrasting scale. The Tularosa area canals under consideration, the full extent of which are still being traced, descend from an elevation of about 1,756 meters (5,760 feet) to approximately 1,695 meters (5,560 feet) over a distance of about 6.4 airline kilometers (4 airline miles). Whereas, currently, the 12 systems, comprised of 41 individual canals, that have been recorded in the Safford area descend from elevations of about 1,675 meters (5,500 feet) to approximately 925 meters (3,035 feet), with the most extensive about 9.7 kilometers (6 miles) in length, and the total length of all systems exceeding 121 kilometers (75 miles).

The Creekside Village canal represents a relatively small effort to provide irrigated cultivation for an early prehistoric community, whereas the Safford bajada canals represent a much greater effort to intensify an already developed agricultural area for later prehistoric communities. Especially considering the dates of the canals, in both areas the engineering involved in the planning and construction of these canals seems phenomenal considering the lack of leveling instruments and metal tools. It would appear possible that pilot extensions of the canals themselves could have served as water levels in spite of the tedious and time-consuming application involved.

Engineering has been defined as a “sense of the fitness of things” (Eddington 1930:337), with both case studies aptly meeting this criterion. Each case study documents a ground breaking discovery of apparently successful attempts to adapt to less than ideal environments to enhance agricultural productivity. The Creekside Village canal is to date the earliest documented example of an effort to provide irrigated agriculture to a large permanent community in an area where settlements of this time frame were thought to still be established primarily on a shifting settlement pattern based on a hunting and gathering subsistence base. In addition, current evidence points to those efforts allowing the Creekside Village occupants to be very strongly agriculturally dependent. The Safford bajada canals represent a form of irrigation as yet found nowhere else in the American Southwest. It represents an unparalleled engineering effort to provide water to locations not accessible to conventional riverine canals, thereby substantially increasing the agricultural productivity of the area. The “hanging” form of canal technology was superbly adapted to the basin and range topography of the Safford area. It developed in a relatively short period of time apparently representing the ingenuity and engineering of a group of migrants who evidently had not applied this technology in their former homeland of the Four Corners area of northeastern Arizona.

Although the nature of both canal systems may be considered in this comparative study, they should not be ranked as to the superiority of one over the other. The fact is that each system successfully adapted to their respective arid environments to apparently accomplish their respective goals. Interestingly, the engineering they exhibit appears not to have been previously accomplished in their respective areas — and, thus, at least for the present, they may represent two cases of pure adaptive innovation! Furthermore, efforts to define water management strategies in the Tularosa Basin and adjacent areas are really in their infancy with regard to searching for similar systems as now recognized in Tularosa Canyon. The west bajada slopes of the Sacramento Mountains potentially possess various examples of water control and management features, whose presence and extent remain to be identified. Just as with the bajada systems in the Safford area, use of both "on-the-ground" and aerial imagery may prove beneficial in further delineating prehistoric systems and subsistence strategies.

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