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# Bajada "Hanging" Canals of the Safford Basin, Southeastern Arizona: Excellence in Prehistoric Engineering

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## abstract

A large network of exceptionally well-engineered prehistoric canals has now been discovered near Safford, Arizona. Within an area of roughly 450 km$^2$, 12 distinct canal systems, comprised of 41 canals, have been identified originating from the bajada of the Pinaleño Mountains. Conveying water from runoff and springs, the longest canal is about 13 km, and the total length of all systems exceeds 125 km.

While a few canals may date to ca. a.d. 1100, the vast majority date to between ca. a.d. 1250 and 1450 and appear to have been constructed by migrants from northeastern Arizona. These features now represent the second largest network of canal systems in the American Southwest, and, while smaller in size and in total length than the canal systems of the Phoenix Basin, they do exhibit engineering sophistication not found in those systems.

These canals have expanded the knowledge of prehistoric water management engineering and agricultural intensification in the American Southwest.

## introduction

The study of prehistoric subsistence systems is one of several ways archaeologists may gain insights into the past lifeways of prehistoric peoples. This study not only tells us what plants and animals comprised the diets of ancient peoples, but also documents how well they understood and adapted to their environment and their ability to plan and carry out strategies to survive under adverse conditions. While giving us some idea of their technological and engineering capabilities.

As agriculture was the foundation of the subsistence system of the late prehistoric populations in the U.S. Southwest, we search for evidence of the plants that they cultivated and the means by which the cultivation was conducted. Due to arid climatic constraints, the people of the Southwest searched for means of securing reliable water sources in order to ensure dependable annual crop yields that at times had to be increased due to population growth, the establishment of trade networks, etc. Canal irrigation was a prime technology they developed to achieve that goal, particularly in Arizona's semiarid basin and range country.

This is the initial report covering the discovery of a series of unusual canal systems near the city of Safford, in Graham County, southeastern Arizona **[figure 1]**…

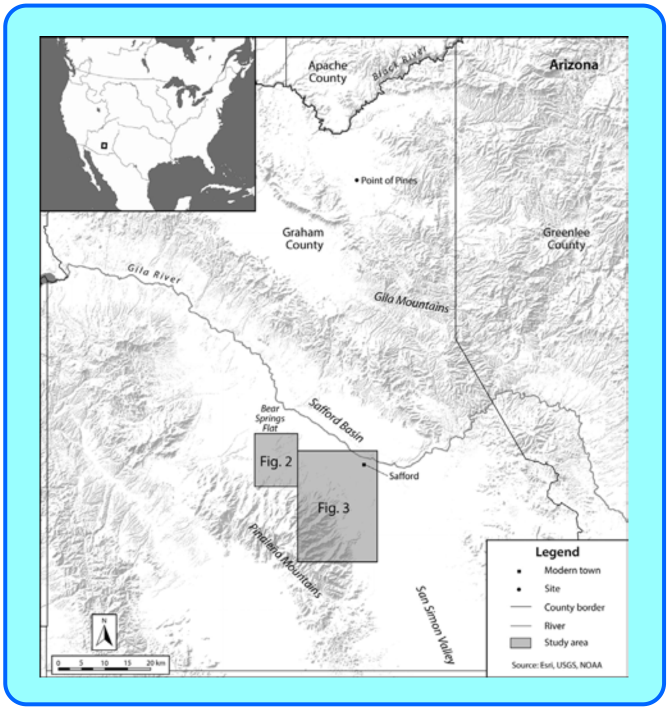


**FIGURE 1 – A Map showing the locations of the bajada canal survey areas, as well as other locations mentioned in the text. This map was prepared by Steven Burges.**

These canal systems can be located in the central portion of the Safford Basin, specifically in the region extending from the northern foothills of the Pinaleño Mountains on the south to the southern boundary of the Gila River floodplain to the north, and from U.S. Highway 191 in the east to Bear Springs Flat in the west, an area of roughly 450 km$^2$ (174 square miles)

Twelve systems of canals, comprised of at least 41 small individual canals in total, have been recorded **[figures 2, 3]**…

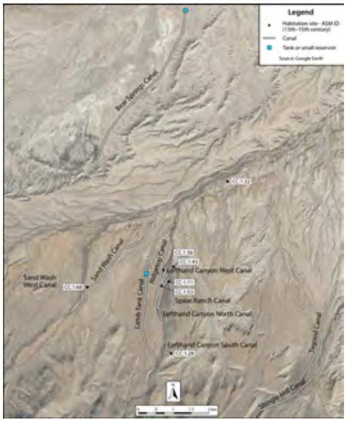


**FIGURE 2 – Map showing the bajada canals and Arizona State Museum registered 13th to 15th century habitation sites found in the northwest portion of our survey area. Canal flow is northward. Maps by Sam Lewis and James Neely, modified by Steven Burges.**

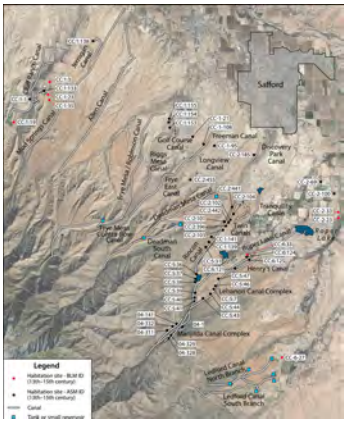


**FIGURE 3 – Map showing the bajada canals, as well as Bureau of Land Management and Arizona State Museum registered 13th 15th century habitation sites, in the southeast portion of the survey area. Habitation sites shown are all well above the Gila River floodplain. Canal flow is toward the north.**

The vast majority of the bajada (foothill/piedmont) canals recorded are located on Coronado National Forest, Arizona State, and Bureau of Land Management lands, although a few extend onto private property.

Interest in these systems was piqued by the sophisticated engineering involved in their construction, their amazing preservation, and the canal-serviced agricultural fields found in association. In several ways these canals do surpass the well-known canal engineering skills of the Hohokam of the Phoenix Basin.

**FIGURE 4 – An Oblique aerial photo of Basin and Range topography. Portions of the Bajada Canals were constructed as perched or hanging canals cut into the sides of some of the elevated ranges in order to reach field areas in the basins and on the Pleistocene terrace located several kilometers north of the canal heads.**

**FIGURE 5 – Creosote and low Mesquite vegetation characterizing the xeric shrubland of the Chihuahuan Desert subdivision of the Lower Sonoran Life-Zone. This vegetation is present on the basin floors and on the Pleistocene terrace used for cultivation. Photograph by James Neely.**

This documentation has primarily been accomplished through the use of the **Google Earth** and **ACME Mapper** satellite imagery websites.

Pedestrian archaeological surveys in Lefthand and Marijilda Canyons by Neely **[Neely, J. A. 2005 145-169]**, **[Neely, J. A. 2014 401-432]**, **[Neely, J. A. 2017 ]**, and additional surveys by Neely and Lancaster **[Neely, J. A. and D Lancaster, 2013a part1 3-10]** and **[Neely, J. A. and D. Lancaster, 2013b part2 8-9]** and **[Neely, J. A. and D Lancaster, 2015 5-6]** have verified and provided details as to the canal's geographic contexts, construction, cultural affiliations, and ages.

Some of these canals are documented historically, and a few are presently operational. However, ground-truth observations, including study of the canals found on the floodplain of the Gila River. Neely and Murphy **[Neely, J. A. and E. J. Murphy. 2008 61-101]** have indicated that most, if not all, of these canals are refurbishments of earlier prehistoric canals. It should seem obvious that it is usually easier to historically "dig out an old ditch" than to engineer a new canal from scratch.

It must be noted that our recording of these bajada systems is not the initial discovery of these features, as a literature search has revealed that Bandelier **[Bandelier, A. F. 1892 410-411]** as well as Sauer and Brand **[Sauer, C., and D. D. Brand 1930 415-458]** had previously briefly noted their existence.

Additional bajada hanging canal references should be available on **Wikipedia**, an **author's website**, this **web directory**, this **.PDF directory**, and and ongoing **news blogs**. Plus **google scholar**, **researchgate**, **arXiv**, **academia**, and **wesrch**.

## environmental contexts

The bajada canals are located south, southwest, and west of the city of **Safford**, Arizona **[figures 2, 3]**. They are situated in the central portion of the Safford Basin, a trough-shaped depression as formed by elongated mountain ranges that are oriented generally northwest-southeast, which rim a broad alluvial-filled valley.

The area of the bajada canals is bounded by the southern edge of the Gila River floodplain to the north and by the Pinaleño Mountains on the south **[Houser et al. 1985]**, a distance of about 21 km (13 mi), and is drained by the **Gila River**.

The arid environment of the central portion of the Safford Basin may be briefly summarized as follows: The basin and range topography **[Wilson 1962]** extends from the bajadas at the northern foot of the **Pinaleño Mountains** on the south down to interface with the remnant Pleistocene terrace north to the floodplain of the Gila River, and generally determines the usual orientation of the bajada canal systems **[figures 2, 3]**.

The Pinaleños have an exceptionally high peak-to-base ratio combined with a substantial number of northeast trending perennial streams. These factors might partially explain the apparently unique location choices for the bajada canals.

The southwest to northeast juxtaposed elevated ranges and depressed basins of **[figure 4]**, descend from elevations of about 1675 m (5500 ft) to approximately 925 m (3035 ft). 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 5]** though this is undoubtedly changed from prehistoric times. **[Lowe 1964 20-24]**

A riparian woodland characterizes several of the drainages emanating from the Pinaleño Mountains, and is also present around basin floor artesian resources. **[Lowe, C.H. 1964 p60-63 ]** Temperatures in this part of the Safford Basin reach to beyond 38 C (100 F) between May and September **[Sellers and Hill 1974 p422]** Freezing temperatures occur on average from mid-November through early March, allowing a frost-free growing season that averages 258 days **[Weather Spark 2017]**

Summer rain is from the **North American Monsoon Western Regional Climate Center**, and often averages 22.7 cm (8.93 in). Almost half of the total annual precipitation for the Safford Basin falls during July and August. 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 high evapotranspiration rate for this area is about nine times greater than the precipitation. The hydrology of the area is characterized by both perennial and intermittent sources. There are also significant artesian resources present.

The primary perennial stream of the area is the **Gila River**, which 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 originate in the Pinaleño Mountains. The watershed collection area is enormous, consisting of hundreds of square kilometers **[United States Geological Survey 2016]**. Today, the majority of the drainages in this area flow intermittently and for short periods of time, mostly as runoff from recent rainfall or snowmelt.

## background

Archaeological investigation within this portion of the Safford Basin has a relatively long and uneven history characterized by little research when compared with other areas of the Southwest.

The earliest mention comes from the report outlining the 1846 passage of the "Army of the West" commanded by Kearny Emory **[Emory, W. H. 1848]** that mentions numerous antiquities at the northern base of the Pinaleño Mountains and along the Gila River. Later, Bandelier **[Bandelier, A.F. 1892]** published his "**Investigations Among the Indians of the Southwestern United States**".

Fewkes **[Fewkes, J. W. 1898]** published "**A Preliminary Account of Archaeological Field Work in Arizona 1897.**" and **{Fewkes, J. W. 1904]** "**Two Summer's Work in Pueblo Ruins.**" While **[Hough, W. 1907]** published "**Antiquities of the Upper Gila and Salt River Valleys in Arizona and New Mexico**" and conducted the earliest, albeit brief, archaeological work in the Safford area.

In the following years only a few projects have been conducted. See, for example, Brown **[1973 Brown, J.L. 1973]**. "**Salado Evidence from the Safford Valley, Arizona.**" Or Doolittle and Neely **[Doolittle, W.E. and J.A. Neely 2004]** "**The Safford Valley Grids: Prehistoric Cultivation in the Southern Arizona Desert**".

Or Neely **[Neely, J. A. 2005]** "**Prehistoric Agricultural and Settlement Systems in Lefthand Canyon, Safford Valley, Southeastern Arizona.** Or Neely, **[Neely J.A. 2014]** "**Prehistoric Agricultural Strategies in the Safford Basin, Southeastern Arizona.**" And Neely, **[Neely J.A. 2014]** "**Prehistoric Agricultural Strategies in the Safford Basin, Southeastern Arizona.**"

And Neely and Murphy **[Neely, J.A., and E.J. Murphy. 2008]** "**Prehistoric Gila River Canals of the Safford Basin, Southeastern Arizona**". Or Neuzil **[Neuzil, A.A. 2005]** "**In the Aftermath of Migration: Assessing the Social Consequences of Late 13th and 14th Century Population Movements into Southeastern Arizona.**"

Continuing our summary of Gila Valley research, Rinker **[Rinker, J. R. 1998]** **The Bryce-Smith Project: Irrigated Agriculture and Habitation from A.D. 1000 to 1450, Lefthand Canyon, Safford Valley, Arizona.**" And Rule **[1993 Rule 1993]**. "**The Owens-Colvin Site of the Safford Valley**". Plus Tyberg **[Tyberg, J.J. 2000]** "**Influences, Occupation, and Salado Development at the Solomonsville Site.**"

**FIGURE 6 – A hanging portion of the central branch of canal AZ CC:5:28 (ASM) coursing around a lobe of the long, narrow mesa landform it traverses [figure 7]. At this point the canal is about 40 m above the adjacent basin to the west. Looking east. Photo by James Neely.**

And Woodson [Woodson M. K. 1995]. "The Goat Hill Site: A Western Anasazi Pueblo in the Safford Valley of Southeastern Arizona." Or Woodson's [Woodson, M.K. 1999 63-84]. "Migration in Late Anasazi Prehistory: The Evidence from the Goat Hill Site." Much of which has been done in the immediate vicinity of the Bajada Canals.

Several recent projects involve compliance work conducted by government agencies and cultural resource management companies, including those by Clark [Clark, J.J. 2004]. "Ancient Farmers of the Safford Basin: Archaeology of the U.S. 70 Safford-to-Thatcher Project."

Farrell and Spoerl [Farrell, M.M., and P. M. Spoerl 1988] published "The Marijilda Canyon Prehistoric Archaeological District. . While Farrell and colleagues Farrell, M.M., P.M. Taylor, and W.B. Gillespie. 2002] were involved in An Archaeological Investigation of the Proposed Maintenance of the Graham County Electrical Cooperative Power Line". Both are Safford Ranger District, unpublished docs.

Much of the above work has been done in the vicinity of the Bajada Canals, although few seemed to recognize the canals' existence, let alone their scope and engineering significance.

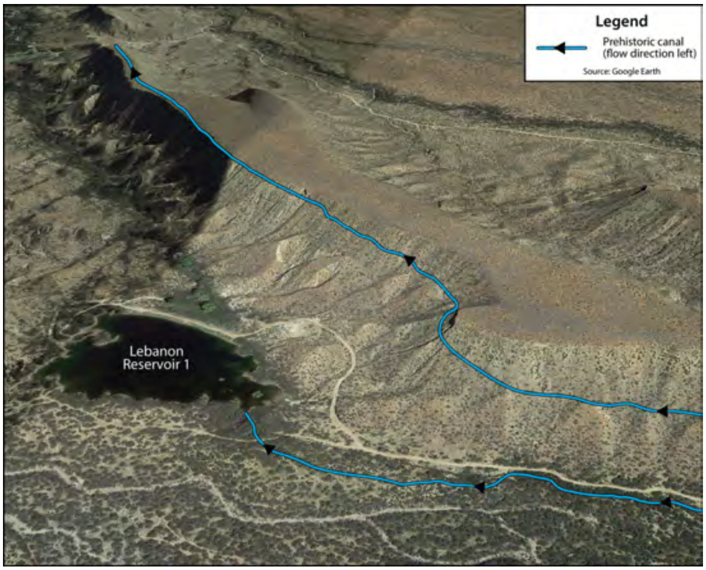


FIGURE 7 – Highlighted course of the central branch of canal AZ CC:5:28 (ASM), flowing from right to left as it routes to the top of the mesa. The canal drops off the nose of the mesa into a French Drain in the upper left of the figure. The historic Lebanon Reservoir #1 is situated about 60 m below the canal on the basin floor. This reservoir appears to be an enlargement of a prehistoric reservoir as the west branch of canal AZ CC:5:28 (ASM) emptied into it. Looking northeast. Modified from a Google Earth image by James Neely and Steven Burges.

In addition to the bajada canals, there are numerous other prehistoric Safford Basin constructs which remain largely understudied. There are many larger Gila River fed riverine canals which formed the basis for historic ag redevelopment. In general, these are clearly simpler to engineer and construct than the hanging bajada canals. There are tens of thousands of gridded fields and many similar rock alignments. There are circular mulch rings that had been apparently intended to prolong evaporation.

There are many check dams on secondary drainages, some of which feature aprons for distribution or erosional control. Combined with rock structures ranging from simple field houses to elaborate pueblo style structures. Potsherds remain in many areas, some of which include tradeware of a surprisingly wide range. Of earlier interest, there are numerous trincheras and petroglyphs.

Confusing the issue are many thousands of **CCC** era diversional water spreading rock constructs. Some of which were placed on **top** of prehistoric counterparts. These date from the 1930's and are often far more obvious. In general, prehistoric projects are usually run **along** a drainage, while CCC versions go **across**.

One of the most significant local prehistoric finds was Haury and Huckell's **[Haury, E.W., and L.W. Huckell. 1993 Kiva 95-145]**. **"A Prehistoric Cotton Cache from the Pinaleño Mountains, Arizona."**

**FIGURE 8 – Deadman East forms a still unvisited stunning hanging canal example. It features a near optimal slope nearest to the highest of available terrain, several defining pinch points that force demand a particular route, and a possible French Drain in the region of mesa dropoff. Image by Don Lancaster.**

Additional studies include Johnson and Wasley **[Johnson, A.E. and W.W. Wasley. 1966 Kiva 205-253]** **"Archaeological Excavations near Bylas, Arizona"**, or Lascaux and Huckleberry's **[Lascaux, A., and G. Huckleberry. 2005 Archaeology Southwest 20:15]** **"Epley s Ruin"**.

Or Lascaux and Montgomery **[Lascaux, A., and B.K. Montgomery 2005]** paper of **"Archaeological Investigations along US 70 and State Route 75 from Solomon to Apache Grove"**

Purcell **[Purcell, D.E. 2004]** has published **"Formative Settlements on the Pinaleño Mountains Bajada"** Along with Purcell and Clark **[Purcell, D.E., and J.J. Clark. 2008]** **"Multi-Cultural Communities in the Safford Basin."** While Seymour and colleagues **[Seymour, G.R., R.V.N. Ahlstrom, and D.P. Doak, 1997]**. **"The Sanchez Copper Project: Vol. 1. Archaeological Investigations in the Safford Valley of Graham County, Arizona."**

Taylor and colleagues authored **[Taylor, P., Mary F., W. Gillespie, and C. LeBlanc 2002].** **"Heritage Resource Report: Gillespie III Prescribed Burn"**, Safford Ranger District, Coronado National Forest.

And Tuohy **[Tuohy, D.R. 1960]** **"Archaeological Survey and Excavation in the Gila River Channel Between Earven Dam Site and Buttes Reservoir Site, Arizona."** On file Arizona State Museum Library, Tucson, AZ.

**FIGURE 9 – Photograph of a portion of the Allen Canal. Clearly defined and slightly raised spoil banks paralleling the canal channel are often present. Looking northeast. Photograph by James Neely.**

**FIGURE 10 – A Typical poorly-defined canal coursing through dense mesquite and acacia vegetation. This canal is 40 cm wide and has been filled with alluvial soils to a level where the channel and spoil banks are difficult to discern. Looking north-northeast. Photo by James Neely.**

## cultural-historical setting

The current model of cultural development for the Safford Basin is divided into five broad chronological periods based on developments in the settlement and subsistence systems, artifact types, and inferred sociopolitical characteristics.

The three earliest cultural/temporal periods of **Paleoindian**, **Archaic**, and the **Early Formative** **[ca. 8,000 b.c. to a.d. 800]** evidently precede the construction of the bajada canal systems and they will not be considered here. However, the later two cultural/temporal periods are relevant to this study.

The Late Formative **Pre-Classic** period **[ca. a.d. 800-1200]**, saw the area populated by the long resident San Simon **Mogollon** as well as groups showing **Hohokam** and **Mimbres** affiliations.

The period was characterized by an increasing focus on agriculture and the development of more complex agricultural systems that incorporated more varied water-management and irrigation technology, a limited occupation and utilization of marginal areas, some population aggregation, regional differentiation, and apparent increasing cultural system complexity.

The Classic period from **[ca. a.d. 1200-1450]** was characterized by the influx of substantial numbers of immigrants from Kayenta and Point of Pines areas, about 435 km (270 mi) and 60 km (37 mi) to the north, respectively **[figure 1]**. Cultural interaction between local and migrant groups resulted in an inclusive ideology referred to as **Salado** by Clark and Huntley **[Clark, J.J., and D.L. Huntley 2012] "Who or What was Salado?"**

The period also saw agricultural intensification with complex systems of irrigation and field technology, increasing population aggregation, the formation of substantial sub-regional centers, emerging complexity of the religious and social systems, the development of new exchange-alliance networks, and, finally, system collapse and abandonment.

## method and approach

We have found that the high-precision general purpose computer mapping and satellite image applications **Google Earth** and **ACME Mapper** are effective in discovering and recording the bajada canals. However, we have employed pedestrian surveys, limited to the course of the canals, to verify our findings and to provide information on the presence and nature of some associated habitation sites and agricultural fields.

Google Earth has allowed us to view the topography at different angles, and through its perspective, elevation, and elevation profile functions make initial determinations that a linear feature could be a canal. The ability to toggle between satellite imagery and USGS topographic maps in ACME Mapper has facilitated recording feature locations and permitted a better understanding of a canal's relationships to the topography and historical features.

**FIGURE 11 – Segment of a canal with boulders bordering the channel. Canals constructed thusly are present mostly on the bajadas of the Pinaleño Mountains, closer to the canal heads. Note the 20 cm scale on the boulder just right of the canal channel. Looking south. Photograph by James Neely.**

Using both the satellite imagery and topographic mapping modes, screenshots of the marked canal routes were taken and saved for reference. Canal routes were subsequently transferred to USGS 7.5 minute topographic maps to obtain a more complete picture of the canal distributions relative to the topography and human-made features.

About 25% of the canal systems, including those in Lefthand and Marijilda Canyons, have been fully verified by pedestrian survey. Other canals have been verified in the field from 25-50% of their lengths, with the remaining canals strongly supported by satellite image research. In general, the preservation of canal evidence ranges from good to exceptional.

While natural erosional cuts through the canals have been examined to observe canal cross-sections in profile, no excavations have been conducted due to permit regulations. Although we believe that we have a good idea of the distribution and range of variation of these systems, we do not claim to have found them all. Recent new evidence shows them extending farther east and west, and are possibly present on the south side of the Pinaleño Mountains as well.

## the canal systems

Due to the unique aspects of their construction, their good preservation, and the potential for expanding our knowledge of Southwestern canal engineering and agricultural intensification techniques, the bajada canal systems are the most outstanding of the many prehistoric human landscape modifications that characterize the central Safford Basin.

The juxtaposition of the bajada canals with canals on the Gila River floodplain and large tracts of dry-farming cultivation mark an important multi-component ecotonal relationship that greatly amplified the subsistence base of the prehistoric inhabitants.

See Neely **2014 [Neely, J. A. 2014] Prehistoric Agricultural Strategies in the Safford Basin, Southeastern Arizona. Exploring the Archaeology and History of Southeastern Arizona**.

The bajada canal systems are important because they differ significantly from the prehistoric canal systems found in the vicinity of Phoenix and elsewhere in the Southwest, and augment our knowledge of the methods employed by the prehistoric inhabitants of the region to adapt to a challenging environment in which precipitation is deficient and unpredictable.

They differ from the Hohokam canal systems in several ways, perhaps the most evident being that they obtained water directly from the Pinaleño Mountain bajada drainages fed by runoff and springs, rather than from rivers. They are also unusual in that they traverse the vertically erratic landscape of the basin and range topography rather than being restricted to a nearly level riverine floodplain.

The construction of these systems was made even more difficult by the very rocky nature of much of the terrain they traverse. Some carry their water load distances about 13 km (8.1 mi), from elevations over 1675 m (5500 ft) down to the rich soils of the Pleistocene terrace overlooking the floodplain of the Gila River, at about 925 m (3035 ft).

In more level terrain, the canals are of the traditional type: linear excavations into the ground that obliquely transect the natural contours of the landscape. In topographically variable areas within the same system, the canals appear to be "perched" or "hanging" as they traverse the sheer sides of mesas, with some coursing about 60 m (197 ft) above the adjacent basin floor **[figures 6, 7]**.

The construction of these canal segments was a cut and fill process, with a notch being cut into the mesa side, a canal channel excavated into the notched area, and the removed soil redeposited immediately downslope to create a supporting embankment for the canal.

The engineering of the hanging segments was evidently designed to permit the canals to follow the most direct route from origin to destination regardless 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 river floodplain canals.

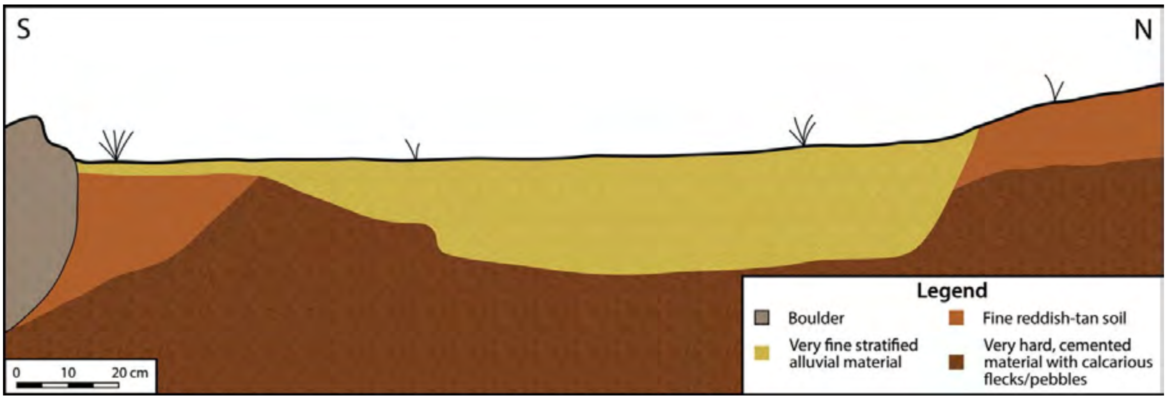


**FIGURE 12 – Cross-section profile drawing of the central branch of canal AZ CC:5:28 (ASM). This profile was drawn using a cleaned face of an erosional cut bisecting the canal. Drawing by James Neely and William Doolittle, modified in collaboration with Steven Burges.**

This area may now be seen to rival the Phoenix Basin 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.

After discovery, the initial task was to determine if the linear features we saw in the satellite imagery were human-excavated canals rather than natural erosional features. Augmented by pedestrian ground verification, we have determined beyond a doubt that the linear features were human-made canals rather than natural drainages.

Supporting evidence includes 14 observations. **The foremost of which is a nearly absolute and unvaryingly uniform optimal canal slope.**

Four other compelling factors include: excavation spoil banks were frequently present paralleling the channel; hanging canal segments were present; the channels varied little in their width and depth throughout their course; and the channels followed higher terrain and the toes of raised landforms rather than the lowest part of a basin or terrace.

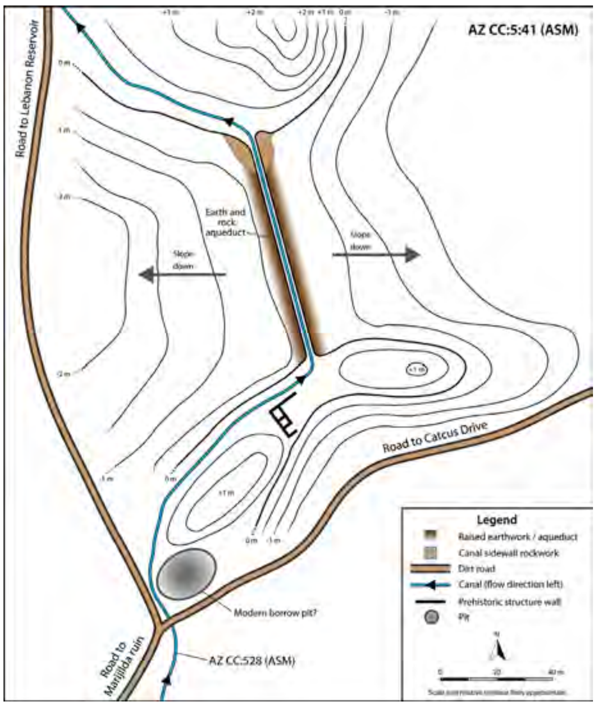


**FIGURE 13 – Sketch map shows the relationship of the central branch of the prehistoric Lebanon Canal [AZ CC:5:28 [ASM]] and a raised aqueduct to a small 3-4 room structure at site AZ CC:5:41 (ASM). See Figure 14. Map by Joseph Crary, as modified by James Neely in collaboration with Steven Burges.**

Once convinced that these linear features were canals, the next question to address was whether they were prehistoric or historical in origin.

Ground verification of a number of canals has indicated that they are prehistoric. Supporting this premise were 13 observations; four are especially compelling.

First is the close association between canals and prehistoric habitation sites, as well as several canals terminating into prehistoric fields (discussed below).

Second is the presence of prehistoric sherds and digging tools adjacent to the channels. Third is documentation that early Hispanic and Anglo farmers had refurbished prehistoric canals.

Such as Colvin and Cook **[Colvin, V.R., and P.A. Cook. 2006] Historic Canals of the Safford Basin.** Archaeology Southwest 20. Or Fewkes **[Fewkes, J. W. 1898] A Preliminary Account of Archaeological Field Work in Arizona 1897.**

Last is the absence of historical documentation (either in writing or in response to oral inquiries) of the planning and excavation of canals in the bajada area by a predominantly Mormon agricultural community, where nearly every extended family has a long regional history and a considerable interest in combined with documentation of that history.

All of these factors would be acceptable as validation no matter where they were observed, and while any of the preceding may be contestable, the large number of such factors presents a strong case for canal antiquity.

Prehistoric non-riverine, piedmont-associated canals have also been recorded in the Tucson Basin by Huckleberry **[Huckleberry 2013] A Non-Riverine Prehistoric Canal System on the Tortolita Mountain Piedmont, Southern Arizona.** Kiva 78.

Or Mabry and Archer **[Mabry, J.B., and G.H. Archer 1997] The Santa Cruz Bend Site, AZAA: 12:746 (ASM)**. And also found in the Papagueria area of southern Arizona by Masse **[Masse, B. 1980] Excavations at Gu Achi: A Reappraisal of Hohokam Settlement and Subsistence in the Arizona Papagueria**.

Or Raab **[Raab, L.M. 1975] A Prehistoric Water Reservoir from Santa Rosa Wash, Southern Arizona** Kiva 40: 295 308. And by Withers **[Withers, A.M. 1973] Excavations at Valshni Village, Arizona** Arizona Archaeologist Number 7.

However, these canals are quite different from the Safford bajada canals as they parallel the piedmont/bajada face and receive water as runoff from the upper slopes of the landforms, rather than directly tapping bajada drainages by canals.

In addition, all of these canal systems are smaller and do not traverse any topographically challenging landscapes such as those spanned by the Safford bajada canals.

The 12 well-defined canal systems found to issue from different drainages emanating from the Pinaleño Mountains are comprised of from one to at least eight small canals each. The majority appear to be main (or primary ) canals, and were excavated to carry water from a drainage/spring resource directly to a field area with very few or no branching canals.

A few canals have recognizable distribution (or secondary ) branches, but it is only in Lefthand and Marijilda Canyons, as well as the Cluff Ranch area, (figures 2, 3) that lateral (or field ) canals have been recognized. Canals within the same system terminate in different field locations, thus maximizing production and/or permitting a rotation of fields to allow fallowing.

While the catchment areas for most of the canal systems have not yet been studied, that for the Marijilda area has been initially estimated to cover an area of about 43.7 $km^2$ (16.9 mi2) **[United States Geological Survey 2016] United States Geological Survey. Hydrologic Data - Arizona NWIS-W**.

The Safford bajada canal systems appear in two formats. In Lefthand and Marijilda Canyons and the Cluff Ranch area, where habitation sites and field areas are present in large numbers along the canal route, canals supplied water for domestic use and irrigation to locations nearer the water sources **[figures 2, 3]**.

**FIGURE 14 – Photograph of the canal AZ CC:5:28 (ASM) aqueduct, looking south. Note the canal sidewall rockwork in the foreground and the person standing at the south end the of the aqueduct. The scale is 20 cm in length. See Figure 12. Photograph by James Neely.**

The relatively high habitation site density in these three locales suggests that water was available for the entire year. In other areas, the canals were apparently engineered to carry water from a distant resource directly to the fields and a few habitation sites located on the nearly level Pleistocene terrace overlooking the southern floodplain of the Gila River.

The near absence of habitations sites in proximity to these canals perhaps indicates that water was available only during part of the year.

## the canals

Remnant bajada canals vary in appearance, ranging from clearly visible channels to segments that are imperceptible due to erosion or alluviation. Some of the areas in which the channels are no longer visible appear to have been severely scoured, perhaps as a result of tropical storms occurring over the last 500 years.

For example, tropical storm Octave **[Smith, W. 1986]**. **The Effects of Eastern North Pacific Tropical Cyclones on the Southwestern United States**. NOAA Technical Memo, NWS-WR0-197, which dropped twelve inches of rain on the Pinaleño Mountains in 1983, doubled the maximum rainfall record recorded during the previous 65 years, and caused significant erosion and soil transport.

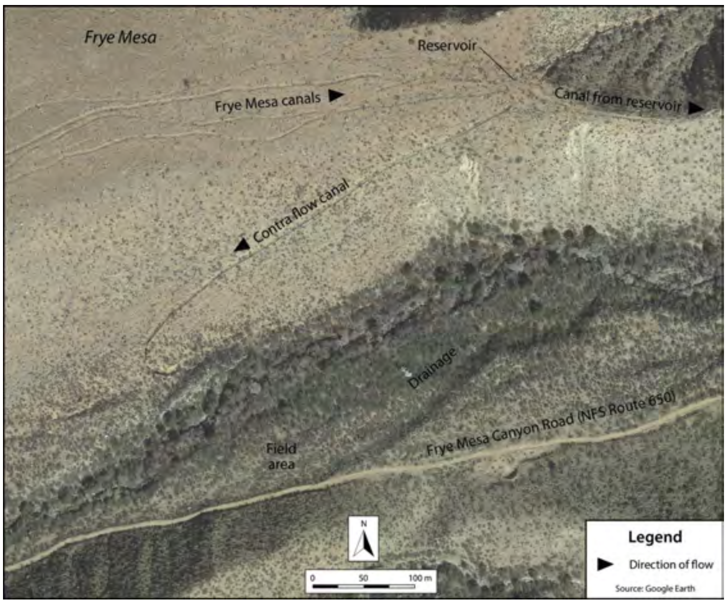


**FIGURE 15 – Satellite image showing the contra-flow canal on Frye Mesa. Several braided channels of the Frye Mesa canal flow left to right atop the mesa to empty into a small reservoir. The contra-flow canal flows from the reservoir 40 m downward from right to left, possibly (but still unproven) to service downcanyon canals. Modified from a Google Earth image by James Neely in collaboration with Steven Burges.**

The channels are often no more than narrow, shallow, linear, sand-filled features that cut through the natural vegetation and topography **[figure 8]**. The channels are sometimes bordered with low "spoil banks" representing the earth and rock excavated from the canal channel **[figure 9]**.

In some locations the channels are bordered on the up-slope side or on both sides with rocks that vary in size from small cobbles to medium size boulders that clearly have been placed along the canal edges **[figure 10]**. In some areas, such as the hanging segments, this rock bordering serves to support the down-slope wall, and upslope to protect the canal from alluvium being washed into the channel and protect the channel from being cut through by runoff.

These bajada primary canals are considerably smaller than those found in the Hohokam region. The visible channels varied greatly, from about 40 cm in width from the tops of the spoil banks and 1-2 cm in depth, to about 6 m in width and 1.5 m in maximum preserved channel depth.

Even smaller, ca. 25 cm wide, lateral/field canals were found in Marijilda Canyon that led to small agricultural plots sometimes no more than 25 $m^2$ in area. A cross-section profile of an exposed face of an erosional cut through a small canal is shown in **[Figure 11]**.

Note the shallow depth of the channel relative to its width. As our survey undertook no excavations, it is unknown if this is a typical canal cross-section. However, other erosional cross-cutting exposures of canals have exhibited generally the same profile.

Many of the prehistoric channels were excavated at the toes of large topographic landforms that paralleled the slope of the basins they border. This was apparently done to maximize the amount of irrigated land while not encroaching on cultivated lands down slope of the canals.

Habitation sites were usually situated a short distance up-slope of the canals, probably to provide easy access and to prevent canal breaks from flooding the structures. Another apparent canal use was to supply water for the processing of edible plants, probably agave, in the many 1-3 m diameter roasting pits that were frequently found paralleling the canals.

## canal-associated fields and gardens

Most of the the fields associated with bajada canals are of two types: unimproved (those lacking any water and soil management rock constructions) and improved (those with rock features to collect and retain water and soil).

Unimproved fields are quite difficult to discern as they retain few indications of having been cultivated except for their proximity to canals. Most examples of this type appear at the terminus of the canals, where evidence of their existence has often been largely obscured by historic fields or constructions.

For example, the fields probably associated with the Mud Springs Canal appear to be under the main cemetery for the village of Central, Arizona; those associated with the Allen Canal are probably under the historic Central Dam and reservoir, as well as a smaller Central village cemetery where members of another extended Mormon family are interred.

Also, in a few cases the fields were identified by the presence of scattered lithic tools, as well as ceramics and fragments of burned bone probably representing prehistoric midden trash used as mulch and fertilizer. Improved fields/gardens, characterized by the presence of rock constructions, are clearly visible.

Plots range in size from about 25 $m^2$ to large fields several hundred square meters in area. A variety of rock improvements were seen, including linear contour borders, low terraces, grid field/garden quadrangles, rock piles, and check dams. See Neely **[Neely, J.A. 2014] Prehistoric Agricultural Strategies in the Safford Basin, Southeastern Arizona**.

Another type of cultivated plot was found situated in the bottom of shallow relict drainages and is frequently associated with habitation sites. These are similar to gardens found in the Tarahumara and Pima Bajo areas of northern Mexico. Per **[Doolittle, W E. 1992] House-Lot Gardens in the Gran Chichimeca: Ethnographic Cause for Archaeological Concern**.

In preparation for use, the floors of the drainages were cleared of rocks that subsequently were reused to reinforce the sides of the drainage and for the construction of field borders and low terraces constructed perpendicular to the channel that define each cultivated plot.

One of these fields/gardens in a channel was quite well defined in Lefthand Canyon per **[Neely, J. A. 2005] Prehistoric Agricultural and Settlement Systems in Lefthand Canyon, Safford Valley, Southeastern Arizona. [figure 6]**.

This field extended about 473 m in length, was subdivided by low walls of cobbles into 22 terraced cultivation plots that ranged from about 12 $m^2$ to nearly 124 $m^2$. It provided a total cultivable area of about 1200 $m^2$ (about 0.3 acres).

Although grid quadrangle fields and gardens are usually attributed to agave dry farming, **[Doolittle and Neely 2004] The Safford Valley Grids: Prehistoric Cultivation in the Southern Arizona Desert** there appear to be several associated with canals. These may represent irrigated plots like those reported by Fish and Fish **[Fish, S.K., and P.R. Fish 1984] Agricultural Maximization in the Sacred Mountain Basin** that contained evidence for the cultivation of maize.

It is also conceivable that irrigated grid quadrangles may have served as seedbeds for transplantable cultigens, or were used in the cultivation of medicinal plants, specialty plants (e.g., tobacco), and as gardens to grow a variety of vegetables. Per **[Doolittle, W. E. 2000] Cultivated Landscapes of Native North America**.

An irrigated rock-bordered garden complex was found in Lefthand Canyon by Neely **[Neely, J.A. 2005] Prehistoric Agricultural and Settlement Systems found in Lefthand Canyon, Safford Valley, Southeastern Arizona** at the foot of the landform upon which the Goat Hill site was constructed. See also Woodson's paper **[Woodson, M.K. 1999] Migration in Late Anasazi Prehistory: The Evidence from the Goat Hill Site.** Kiva 65: 63 84.

A small bajada canal passed through this complex, but it is likely that judicious hand-watering was done using a gourd or ceramic vessel. A complex of small, morphologically different, rock-bordered plots that may have served as seedbeds or gardens was also found at the foot of the French Drain-like feature (described below) located near the north central end of of canal AZ CC:5:28 (ASM).

While primarily designed to supply water for domestic uses and irrigation, it should be recognized that canals also generated an adjacent linear natural micro-environment that permitted the growth of useful plants and attracted animals that augmented the diet and provided materials (e.g., reeds and skins) for various other uses.

## canal-related water management features

This study has documented what may be considered to be ingenious solutions to topographic challenges that the prehistoric canal engineers faced in planning and executing canal systems. Most of these features have not been reported from elsewhere in the American Southwest, further illustrating the adaptive genius of the Safford bajada canal engineers.

### • mesa edge hanging

Foremost would be the hanging of canals on sheer mesa edges to make their slope largely independent of local terrain. Thus significantly reducing the total construction energy required. And making much more of the construction effort across rather than along the canal routes.

### • french drains

A nearly vertical French Drain-like trench filled with pebbles and cobbles to redirect surface water was constructed to drop water from one canal to another in an innovative, but labor intensive, water-saving topographic problem solution.

A feature of this type was found associated with the central branch of canal AZ CC:5:28 (ASM) **[figure 7]**, where canal waters were dropped approximately 37 m (120 ft) from the northern nose of the mesa to another canal that led to a nearby reservoir. Candidate French Drains seem to exist on several of the other bajada canals where a sudden off-mesa drop was needed. These remain unstudied and are the only construction of this type yet reported in the American Southwest.

### • aqueducts

Aqueducts a few meters in length were recorded close to the mouth of Marijilda Canyon, where canals transition from the bajada of the Pinaleño Mountains to the nearly level basin lying to the northeast. This transitional area has a number of natural finger-like ridge projections extending from the bajada that blend into the basin surface and the ancient fields thereon.

Small branching secondary canals appear to have been taken off a primary canal and were carried down the tops of these finger-like landforms. Where the ridges have low areas along their top surfaces, small aqueducts were constructed to bridge the gaps.

As these small canals coursed down the ridges they apparently irrigated linear fields/gardens constructed in the low areas between the ridges. To the northeast in this same system, a few small aqueducts were also constructed in the more level basin field areas to bridge erosional low points that could not be efficiently circumvented by following the contours.

One much larger aqueduct was constructed as part of the central branch of canal **AZ CC:5:28 (ASM) [figures 12, 13]**. It was constructed across a saddle-like depression in the landscape that seemed difficult to circumvent by following the natural land contours. This aqueduct was approximately 80 m long and was constructed atop a human-made earthen and rock embankment that was trapezoidal in cross-section.

The base of the approximately 1 m high feature was about 3 m wide and its top was about 1.5 m wide. Although the central portion of the aqueduct's top surface has been damaged due to cattle and ATV activity, the north end of the feature is relatively well preserved, presenting rockwork that indicates the sidewalls of the canal were constructed of, or bordered by, rock slabs and small boulders. Such construction may have been improved with a clay lining to reduce water seepage.

This aqueduct is only the second large-scale prehistoric aqueduct documented in the state of Arizona, being generally similar to that found in the Lower Verde River area **[Doolittle, W.E. 2000]**. **Cultivated Landscapes of Native North America.** Or **[Midvale, F. 1946] Map of Prehistoric Horseshoe Reservoir Ruins and Irrigation Features**. Also reported in the **[Van West, C., and J.H. Altschul. 1997]** paper on **Environmental Variability and Agricultural Economics along the Lower Verde**.

The Marijilda aqueduct rested on a trapezoidal earth and rock base and apparently had a rock, or rock bordered, channel. The Verde valley aqueduct had a base of unmodified rocks and apparently had a channel made of split and hollowed-out logs placed end to end.

The use of split and hollowed-out logs to form smaller aqueducts has been proposed for other prehistoric canals in the Verde valley **[Kearnes, T.M., M.R. Polk, and L.S. Teague. 1973]**. **Archaeological Resources, Orme Reservoir, Phase II**.

As well as one of the Safford Gila River-sourced canals **[Neely, J.A., and E.J. Murphy 2008] Prehistoric Gila River Canals of the Safford Basin, Southeastern Arizona: An Initial Consideration.**

## • use of natural drainages

The resourcefulness of the agriculturalists was again exemplified where natural drainages were incorporated into canal systems. Purposefully diverting water flow from a canal into a natural drainage, and then back into a canal, represents a major understanding and exploitation of topography and hydraulics, as well as attention to energy and design efficiency.

For example, where one of the canals in Marijilda Canyon was approaching a field of large boulders, a rectangular pile of boulders was constructed to act as a dam to assist in the diversion of the waters into an abrupt turn of the canal channel leading to a natural drainage. In turn, about 150 m down slope, the drainage was tapped by a canal that conveyed its load to a field area. We have seen this practice in several locations within the central Safford Basin.

## • reservoirs

It appears likely that Lebanon Reservoirs #1 and #2 are historically refurbished prehistoric reservoirs as the west and central branch of canal **AZ CC:5:28 (ASM)**, respectively, emptied into them **[figures 3, 7]**.

## • contra-flow canals

Branches of the northern part of the primary Frye Mesa Canal empty into a small reservoir, near the top edge of the mesa. A branching contra-flow canal was excavated from this reservoir, and extended some 330 m down the mesa slope at an acute angle. Possibly used to service the needs of down-canyon canals or to irrigate fields lying 40 m below and behind the point of branching **[figure 14]**.

**Contra flowing can take place when the downslope aspect of the canal routes itself into generally rising terrain.** Other more minor instances of counterflowing apparently occur during several well executed wash crossings.

## • artesian integration

There are a significant number of artesian spring resources in the area, generally located between the bajada canals and the riverine ones. Many of these appear to have been exploited as part of an apparently integrated water delivery system.

Of these, the **Tranquility Canal**, the **Bigler Canal**, and the **Bandolier Canal** are the best studied examples to date. The artesian resources can generally be classified as flatter and shorter and of somewhat simplified engineering compared to the bajada hanging canals. Interpretation can be difficult owing to ongoing continued historic and modern use.

### • watershed crossings or Inter-drainage Connections

Reminiscent of the inter-valley Peruvian canals **[Huckleberry, G.F., Hayashida, and J. Johnson. 2012]**. **New Insights into the Evolution of an Intervalley Prehistoric Irrigation Canal System, North Costal Peru.**Or **[Ortloff, C.R., M.E. Moseley, and R.A. Feldman, 1983]**. **The Chicama-Moche Intervalley Canal: Social Explanations and Physical Paradigms.** is an inter-drainage canal joining Ash Creek and Mud Springs Canyons. The 1 m wide canal is centered upon and traverses a rather narrow watershed saddle to join the two drainages. By this means, the agriculturalists could divert a portion of the better-watered Ash Creek drainage to flow into the Mud Springs drainage.

**Watershed crossings can represent a level of engineering sophistication well beyond that involved in conventional riverine canal design**. In that a downward canal slope must be maintained at a near constant rate within the bounds of continuing reasonable flow and non-excessive erosion.

A watershed crossing has been tentatively identified where at least part of the Frye Canyon drainage flow could have been diverted into the Spring Canyon drainage. And another mid-route on the Tripp Canal. These apparently are the only instances of this engineering feat yet recorded in the American Southwest.

## associated habitation sites and artifacts

### • habitation sites

We have found clusters of habitation sites in proximity to canal systems in three east to west areas: Marijilda Canyon, the Cluff Ranch area, and Lefthand Canyon.

Numerous other canal systems appear likely to have one or more associated destination fields. A sampling of these do include, from east to west: Jennings canal, Veech canal, Ledford canal, Tranquility canal, TB Ponding canals, Discovery Park canal, Deadman group, Lower Frye complex, Freeman canal, Robinson canal, Golf Course canal, Allen canal, Mud Springs canal, Jernigan canal, Shingle Mill canal, Tugood canal, Sand Wash canal, Bear Springs canal group, the Tripp Canal, and the Bandolier complex. A current directory of the known canal sites along with many of their field notes and images can be found **here**.

With a few exceptions, the vast majority of these sites have components dating to the 13th, 14th, and/or 15th centuries, and appear to be the habitations of peoples participating in Salado ideology. Per **[Clark, J.J., and D.L. Huntley 2012]** **Who or What was Salado?** Or see **[Clark, J.J., A. A. Neuzil, and P.D. Lyons 2004]**. **Safford Basin Past and Present**.

While the association of these habitation sites has provided circumstantial evidence for the Classic Period dating and origins of most of the bajada canals, it will remain for future work to produce more secure dating through radiocarbon and photonic luminescence analyses (see below).

### • lithic tools

Stone hoes per **[Neely, J.A. 1995]**. **Mogollon/Western Pueblo Soil and Water Control Systems of the Reserve Phase** and mattocks (also called picks ) by **[Haury, E.W. 1945]**. **The Excavation of Los Muertos and Neighboring Ruins in the Salt River Valley**., fashioned from basalt and schist, are found throughout the central Safford Basin. Per **[Neely, J.A. 2004a] Archaeological Perspective**. Or **[Neely, J.A. 2004b]**. **Paleoclimatic and Archaeological Contexts.**

Their digging function is inferred based on their shapes, details of manufacture, use wear, and the contexts in which they were found. These tools were mostly found in canal and field associations. However, they have also been found in a well-dated (ca. a.d. 1275-1325) habitation room and in kiva ceremonial or communal structure floor contexts at the Goat Hill site that has been interpreted as a Kayenta immigrant enclave.

See **[Woodson, M K. 1995]**. **The Goat Hill Site: A Western Anasazi Pueblo in the Safford Valley of Southeastern Arizona.** Or **[Woodson, M.K. 1999]**. **Migration in Late Anasazi Prehistory: The Evidence from the Goat Hill Site** This strongly suggest that they were a valued part of the inhabitant s tool-kit, and had ritual significance. These tools support our cultural affiliation for the bajada canals.

### • possible surveying techniques

The engineering involved in the planning and construction of these canals seems phenomenal considering the lack of leveling instruments.

It would appear possible that as the canals were being excavated, in spite of the tedious and time-consuming application involved, pilot extensions of the canals themselves could have served as static water levels.

There are also many local prominences which could give an "aerial perspective" to portions of the canal routings. Virtually all of the Mud Springs canal can be viewed from one point or another. Which suggests it might have served as an initial earlier prototype.

## observations

### • chronological placement and cultural relationships

While some of the bajada canals may have been engineered and excavated by the San Simon Mogollon, probably during the Eden Phase of the Formative Period (ca. a.d. 1100 1200), our hypothesis is that the more complex and extensive canal systems were constructed during the Bylas through Safford Phases of the Classic Period (ca. a.d. 1200 1450) by migrant populations from the Kayenta or Point of Pines areas. These lie 435 km (270 mi) and 60 km (37 mi) to the north.

See **[Lindsay, A.J., Jr. 1987]**. **Anasazi Population Movements to Southeastern Arizona**. Or see **[Haury, E.W. 1958**. **Evidence at Point of Pines for a Prehistoric Migration from Northern Arizona.**

Paradoxically, although we hypothesize bajada canal construction by migrants from the north, water management features reported from the Kayenta and Point of Pines areas are small and relatively simple.

As per **[Lindsay, A.J., Jr. 1961]**. **The Beaver Creek Agricultural Community on the San Juan River, Utah.** Or **[Sharrock, F.D., D.S. Dibble, and K M. Anderson 1961]**. **The Creeping Dune Irrigation Site in Glen Canyon, Utah.** Or **[Woodbury, R.B. 1961] Prehistoric Agriculture at Point of Pines, Arizona**. But none of these even remotely approach the engineering sophistication and larger scale of the bajada canal systems.

The hypothesis we propose is based on excavation findings at Goat Hill **[Woodson, M.K. 1999]**. **Migration in Late Anasazi Prehistory: The Evidence from the Goat Hill Site.** and other sites such as **[Rinker, J.R. 1998]**. **The Bryce-Smith Project: Irrigated Agriculture and Habitation from A.D. 1000 to 1450, Lefthand Canyon, Safford Valley, Arizona.** As well as survey in the Lefthand Canyon **[Neely, J. A. 2005]**. **Prehistoric Agricultural and Settlement Systems in Lefthand Canyon, Safford Valley, Southeastern Arizona.**

The Goat Hill site is particularly important due to the presence of well-dated evidence of its occupation by migrants originating from the Kayenta area. **[Figures 2 and 3]** show 13th, 14th, and 15th century sites associated with bajada canals.

**FIGURE 16 – Although not yet convincingly connected, this spectacular hanging Lower Frye Complex appears to be a portion of a "supercanal" involving the Frye Watershed Crossing, Upper Frye Mesa, the HS Canal, the Blue Ponds canal and the Freeman canal. Photo by Henry Schneiker.**

It seems unlikely that we will be able to determine whether the bajada canals were a result of independent invention or of emulation. The uniqueness of Mount Graham's elevation differential and its numerous reliable perennial northeast streams may seem to be compelling factors for in-place canal system evolution.

It is entirely possible that the earlier canals in the Tucson **[Mabry, J.B., ed. 2008]**. **Las Capas: Early Irrigation and Sedentism in a Southwestern Floodplain**. or Phoenix **[Haury, E.W. 1976]**. **The Hohokam: Desert Farmers and Craftsmen** areas may have provided models for the bajada canals.

However, canals dating as early as ca. 190 b.c. have been found on the floodplain of the Gila River very near Safford. Per **[Clark, J.J., A.A. Neuzil, and P.D. Lyons 2004] Safford Basin Past and Present.** Or **[Lascaux, A., and B.K. Montgomery 2005] Archaeological Investigations along US 70 and State Route 75 from Solomon to Apache Grove, Graham and Greenlee Counties**.

Perhaps it is more appropriate and productive to attribute the development of this technology to the advantageous combined mountain-bajada runoff and springs and limitation deficient, variable, and unpredictable precipitation of the environment of the region, as well as local group necessities, rather than resulting from direct contact with, or influence from, any exterior source. This approach is supported by the apparent absence of bajada canals elsewhere in the Southwest.

**FIGURE 17 – This "Culebra Cut" found below Allen Dam is one of several examples of extensive earthmoving that appear bajada canal involved. Other examples include the H.S. Canal, the Lower Frye Complex, and the Marijilda Aqueduct. Photo by Don Lancaster.**

## thirteenth century bajada occupation and canal development

The fundamental reason for the surge in population and development of the bajada area beginning in the 13th century is unknown.

A reasonable hypothesis is that immigrants from the Kayenta and Point of Pines areas chose the available bajada lands because of a lack of space on the already occupied and cultivated Gila River floodplain, possible social tensions with the floodplain residents, and recognition of the bajada's potential considering their reliance on dry-farming in their former homeland.

The migrants  choice to occupy the bajada might be more plausible than an occupation that was forced by the local residents of the Gila River floodplain. This hypothesis is supported by limited excavations that have shown that migrants from the north had access to, and at least temporary floodplain habitations.

See **[Clark, J.J., A.A. Neuzil, and P.D. Lyons 2004] Safford Basin Past and Present** Or **[Lascaux, A., and B.K. Montgomery 2005] Archaeological Investigations along US 70 and State Route 75 from Solomon to Apache Grove**. It is further bolstered by the relatively small earlier Formative Period occupation of the bajada, which presented a largely unpopulated and unused niche to settle and cultivate.

The underlying reasons why the bajada canals were engineered and constructed are also still unknown. The planning and effort that went into the engineering, design, and excavation of the canals, as well as their subsequent maintenance, was impressive, and suggests that demand for greater agricultural production by means of irrigated cultivation was high.

While a number of 13-15th century archaeological sites have been recorded associated with the canals, it is only in Lefthand Canyon, and the Cluff Ranch and Marijilda areas, that the number and size of sites would suggest a demand sufficient for such efforts.

The otherwise sparse population of the area between the Pinaleño Mountains and the floodplain of the Gila River does not appear to have required these canals.

We offer two hypotheses: first, the development of the canals and fields were necessary to sustain the migrants and an expanding population on the Gila River floodplain; and/or, second, the participation of the area in a large-scale trade network in which foodstuffs, and perhaps cotton, were major trade items.

Supporting the latter hypothesis are recent Social Network Analyses that indicate increasing ceramic consumption network ties for the Safford area with much of the southeastern quadrant of what is now Arizona and the southwestern part of New Mexico during the period of ca. a.d. 1300-1400.

Per **[Mills, B.J., J.J. Clark, et al. 2013]**. **The Transformation of Social Networks in the Late Pre-Hispanic U.S. Southwest.**

## labor estimates

While it is not possible to determine the amount of time it took to plan and engineer a bajada canal, we can make a rough estimate of the number of person days it took to excavate one.

Calculating the amount of earth a person can excavate in a day depends on several variables: the length of the work day, the topography, the nature of the soil, the implement(s) used for excavation, the strength and stamina of the excavators, etc. Of these variables, only the sandy soils and rocky substrate, the topography, and the limited stone hoe and mattock technology are known.

Estimates of how much soil a person can excavate in one day vary. See **[Erasmus, C.J. 1965] Monument Building: Some Field Experiments**. Or view **[Mabry et al. 2008] Modeling Canal Characteristics and Trends**. Or see **[Wilkinson, T.J. 2003] Archaeological Landscapes of the Near East.**

We have found Southworth's **[Southworth, C.H. 1931] Gila River Survey Report, Vol. 1, Supplemental Exhibits** figure of 1.6 $m^3$ appears to be the best to use because it reflects the labor invested by Pima Indians in the rocky, sandy soil of the nearby Salt River Valley at a time using manual labor with a minimum of modern equipment.

As an example, we provide an estimate based on a known bajada canal width and depth exposed by an erosional cut and a hypothetical canal 12 km in length excavated into terrain with a gentle slope and a minimum of topographic variation. We use this partially hypothetical example because, with the exception of a few unconnected canal segments, all of the bajada canals we have recorded have hanging portions.

We find it difficult to calculate the person-days it would take to construct those portions, especially on the high sheer sides of some mesas. The example is 12 km in length, with a channel cross-section averaging about 1.28 m wide, and 22 cm deep. Using a formula to calculate the volume of parabolic cross-section canals by Chow in **[1959 Chow, V.T. 1959] Open-Channel Hydraulics**. the total amount of earth removed from this canal was about 2264.1 $m^3$.

Divided by a figure of 1.6 $m^3$ of soil excavated per person per day, results in about 1415 person-days to excavate the canal. If 25 laborers worked on this canal, it could conceivably have been excavated in about 57 days. This simplified example provides a rough idea of the time and effort to excavate a canal, but should be considered conservative due to the exclusion of the time expended in engineering the canals and constructing the hanging portions.

An alternate approach to construction time estimates that one foot of routine canal could possibly be built in one hour. Which translates to fifteen feet per man day or one mile per man year. Thus 150 man-years for the project. Excluded factors would likely raise this figure to 250 man years total.

## sociopolitical implications

Sociopolitical organization must be considered in the light of the extensive human modifications of the landscape, for it was probably through the organized efforts of a sizeable workforce that the bajada canal systems were accomplished.

Surveys have disclosed only two large habitation sites in the bajada area, with smaller hamlets of less than 10 rooms being prevalent. These findings do not indicate the presence of a hierarchical or stratified sociopolitical organization.

With the exception of the Lefthand, Cluff Ranch, and Marijilda communities where the grouping of habitation sites around the canals probably supplied sufficient labor to excavate and maintain the canals, it seems that the labor was supplied by separate autonomous households working for mutual benefit.

The bajada canals are herein modeled as products of individuals from several sites operating on an egalitarian kin-based or household level of organization that comprised an informal irrigation community. As addressed by **[Hunt. R.C. 1989]**. **Appropriate Social Organization? Water Users Associations in Bureaucratic Canal Irrigation Systems.** Or **[Mabry, J.B. 1996]**. **Ethnology of Local Irrigation.**

Integration may well have been strengthened by the cross-cutting or overarching ideological and religious affiliations attributed to the Salado **[Clark, J J., and D.L. Huntley 2012]** **Who or What was Salado?** The mutually benefitting systems would, in turn, serve to reinforce the community identity and solidarity.

This would indicate a society based on collaborative/consensual forms of decision making based on frequent face-to-face contact that preempted the development of a hierarchical or stratified socio-political organization. Per **[Feinman, G. M. 2013]** **The Emergence of Social Complexity: Why More than Population Size Matters**. Or **[Johnson, G.A. 1982]** **Organizational Structure and Scalar Stress.**

Such an organizational model has received support from a recent study **[Hunt et al. 2005]** **Plausible ethnographic analogies for the social organization of Hohokam canal irrigation** Also see **[Abbott D.R. 2000]** **Ceramics and Community Organization among the Hohokam.**

Also see **[Abbott, D.R., S.E. Ingram, and B G. Kober 2006]** **Hohokam Exchange and Early Classic Period Organization in Central Arizona: Focal Villages or Linear Communities?**

In either of the two hypotheses posed above, it is possible that groups living on the Gila River floodplain may have cooperated with the newly arrived migrants in the construction of the bajada canals. In addition to economic reasons, it seems conceivable that cooperative ventures may also have been instituted to ameliorate socio-political, and perhaps ceremonial or religious, conflicts. Which might arise from an increasing population of local as well as ethnically and linguistically diverse immigrant peoples.

This cooperation may have been roughly similar to the infield-outfield practice of cultivation described by **[Wolf, E.R. 1966] Peasants**, with the Gila floodplain being an example of an infield and the bajada area being an outfield area example.

This practice has been documented for both prehistoric and historic agricultural groups in Europe **[Grigg, D.B. 1974] The Agricultural Systems of the World: An Evolutionary Approach**. Or by **[Kirkby, A.V.T. 1973]. The Use of Land and Water Resources in the Past and Present, Valley of Oaxaca, Mexico**. Also see **[Palerm, A. and E.R. Wolf 1961] La Agricultura y el Desarrollo de la Civilizaci n en Mesoamerica**. And **[Santley, R. S. 2007] The Prehistory of the Tuxtlas**.

The construction of all of the bajada canals may not necessarily have been done with the cooperation of the same informal corporate irrigation communities. This would permit the operation of a bajada canals system and its fields, as well as a plot of farmland on the floodplain, by a few of many kin-based communities, thereby not exceeding the perceived 100 ha upper limit between democratic and bureaucratic management capacities **[Tang, S.Y. 1992] Institutions for Collective Action: Self-Governance in Irrigation**.

## canal refurbishments in the Safford basin and elsewhere

As far as we have been able to tell to date, no other prehistoric hanging canal bajada examples of similar size and complexity comparable to those of Mount Graham are known in the American Southwest. One curious **historic** oddity does appear as the **Levadas** of the Canary Islands, dating from the 1400's. These also used "hanging" to make their slopes largely independent of terrain.

Prehistoric canals were constantly in states of modification and maintenance, refurbishments being required by fluctuations in water flow, the accumulation of sediments in channels, wash outs, etc. See **[Haury, E. W. 1976] The Hohokam: Desert Farmers and Craftsmen**. Or view **[Huckleberry, G. 2013]**. **A Non-Riverine Prehistoric Canal System on the Tortolita Mountain Piedmont.**

Refurbishments of ancient river-sourced canal systems on the Gila River floodplain by the 19th and 20th century farmers in the vicinity of Safford have been well documented historically. Per **[Colvin, V.R., and P.A. Cook 2006] Historic Canals of the Safford Basin.** Along with **[Fewkes, J.W.1898] A Preliminary Account of Archaeological Field Work in Arizona 1897**. Or per **[Fewkes, J.W. 1904] Two Summer's Work in Pueblo Ruins.**

Continuing, **[Hodge, F.W. 1893] Prehistoric Irrigation in Arizona**. And **[Neely, J.A., and E.J. Murphy 2008]**. **The Prehistoric Gila River Canals of the Safford Basin, Southeastern Arizona: An Initial Consideration**

Several of these earthen canals are still in use. Most of the bajada canals we have recorded are prehistoric in origin; however, about one-third of these canals have been historically refurbished, and a very few still remain in use. Portions of some have been repurposed to serve cattle tanks.

It should seem fairly obvious that "digging out an old ditch", "stealing the plans", or "borrowing the blueprints" would seem preferable to historically engineering a new canal system in horribly complex terrain from scratch. Especially if all the good locations were already in earlier use.

The refurbishments of ancient canals should not be considered unusual or isolated events. The recognition of a prehistoric canal, and the desire to avoid the necessary engineering and labor in the excavation of a new canal, makes their reuse a logical decision and appears to be rather commonplace.

See **[Doolittle, W.E. 2000]** **Cultivated Landscapes of Native North America** Or **[Haury, E.W. 1976]**. **The Hohokam: Desert Farmers and Craftsmen**. Or **[Masse, B. 1981]** **Prehistoric Irrigation Systems in the Salt River Valley, Arizona.**

Worldwide examples include **[Gelles 1996 Gelles, P.H. 1996]**. **The Political Ecology of Irrigation in an Andean Peasant Community.** Or **[Stanbury, P. C. 1996]** **The Utility of Tradition in Sri Lankan Bureaucratic Irrigation.** Or **[Doolittle, W.E. 1988]** **Pre-Hispanic Occupance in the Valley of Sonora, Mexico: Archaeological Confirmation of Early Spanish Reports**. Also **[Neely, J.A., and B.R. Castell n Huerta. 2014]** **Una S ntesis de Mananejo de Agua de la Prehistoria en el Valle de Tehuacan de Puebla, Mexico.** And **[Woodbury, R.B., and J.A. Neely 1972]**. **Water Control Systems of the Tehuacan Valley.**

A very few of the prehistoric bajada canals still may flow to this day. These do include the Marijilda Canal, Deadman West Canal, Goat Canal, Ledford Canal, Cottonwood Canal, Bigler Canal, Hog Canyon Canal, Aravaiipa Canal, Grant Creek Canal, Artesian#1 Canal, and the Artesian#2 Canals.

## future work

Unlike the detailed study by Huckleberry **[Huckleberry, G. 2013]**. **A Non-Riverine Prehistoric Canal System on the Tortolita Mountain Piedmont,** our findings are based solely on surface survey and a few canal cross-sections exposed by erosion.

It is our intention to continue work on the canals, as well as their associated fields and habitation sites, implementing a multidisciplinary study that includes more archaeological, as well as soil, hydrological, geological, geomorphological, and archaeobotanical investigations. A number of specialists have already visited the area, and most have expressed interest in participating in such a project.

Efforts will be made to more accurately date the canals by collecting soils from the canal channels for both radiocarbon and photonic **[Berger, G.W., et. al. 2004]** **Photonic Dating of Prehistoric Irrigation Canals at Phoenix, Arizona, U.S.A.**

Single-grain luminescence analysis has been found to provide accurate dating for ancient water-control systems **[Huckleberry, G., and T. Rittenour 2014]** **Combining Radiocarbon and Single-Grain Optically Stimulated Luminescence Methods to Accurately Date Pre-Ceramic Irrigation Canals**.

Further covered by **{Huckleberry et al. 2012 Huckleberry, G., F. Hayashida, and J. Johnson. 2012] New Insights into the Evolution of an Intervalley Prehistoric Irrigation Canal System, North Costal Peru.** Single grain luminescence appears particularly useful, especially in sandy soils such as those bajada present.

Some of the environmental characteristics noted earlier may well not be indicative of environmental conditions in the prehistoric past. Future studies will include a detailed study of the prehistoric environment, as knowledge of the conditions in which the agriculturalists worked, and to which they had to adapt, is crucial.

Work is intended to continue on expanding and upgrading the preliminary field notes, and continuing the exploration of presently unaccounted for canal segments. It is our intent to make as much of this **Creative Commons** available as possible. Such as **this example**. Better use of drones is also anticipated.

A number of second order questions need to be addressed. How did the environmental context affect the prehistoric settlement and subsistence strategies found in this part of the Safford Basin? More precisely, when, and by whom, were the bajada canal systems engineered and excavated?

What was the scale of occupation in the bajada, and how many and which sites were contemporaneous? What was the relationship between the bajada and floodplain settlement and subsistence systems? How did the cultural milieu affect the historical trajectory of this area? Were ceremonial/religious entities involved in the planning and maintenance of the bajada canal systems?

## summary and conclusions

Survey has revealed that ancient agriculturalists greatly modified the landscape of the central portion of the Safford Basin by using a broad array of infrastructure implementing their agricultural strategies. Per **[Neely, J.A. 2014] Prehistoric Agricultural Strategies in the Safford Basin, Southeastern Arizona**.

Of these modifications, the bajada hanging canal systems were clearly the most sophisticated and difficult to construct. They were a labor-intensive adaptive approach undertaken to reduce subsistence risks resulting from highly variable and unpredictable water resources.

These canals, hypothesized as being a technology developed by migrants from the north during the 13th through 15th centuries, greatly expanded the zone of habitation and permitted irrigated agriculture to be practiced on the arid northern Pinaleño Mountain bajada, its adjacent basins, and the Pleistocene terrace overlooking the Gila River floodplain.

This approach has been further hypothesized as the product of migrant and floodplain inhabitants cooperating to intensify agricultural production to supply a burgeoning local population and/or to permit greater participation in a southern Southwestern trade network.

Engineering has been defined as a "sense of the fitness of things" **[Eddington A. S. 1930]**. Aptly meeting this definition, the prehistoric bajada canal systems are a highly-sophisticated innovation, and a very remarkable adaptation to an arid environment that superbly optimizes energy and represents a brilliant engineering solution for water transport and delivery from distant water sources over the basin and range topography to agricultural fields.

The discovery of these canal systems has expanded our knowledge of prehistoric agricultural strategies as well as revealing the problem solving capabilities and engineering skills of the late occupants of the central Safford Basin. With the exception of the Hohokam canals of the Phoenix area, the degree of planning and engineering involved in these canals is unparalleled in the American Southwest.

While some aspects of the prehistoric agricultural strategies of the Safford Basin are at least partially known, future work is clearly needed to provide additional information to better understand the interrelationships of the agricultural system with the economic, sociopolitical, and ceremonial systems.

The study of cultural continuity, change, and process involve the recovery and utilization of good qualifiable and quantifiable data through excavation. Although the present study is limited, it has provided evidence that additional informative data will be available with excavation.

This paper constitutes an initial attempt to study one aspect of agricultural intensification, as achieved through the development of an unusual form of canal irrigation. Although it is only one aspect in the study of agriculture as process, it is important for understanding the development of, and regional variations in, prehistoric subsistence strategies throughout the American Southwest.

## some resource notes

### • tools

Both **Google Earth** and **Acme Mapper** have served as major research tools, while **Ockham's Razor** has proven most useful for "filling in the blanks" of missing or absent canal sections.

Frustratingly, satellite image resolutions have often been inadequate. Additional future use of drones is expected to ease some these problems. Also now under investigation is video mapping and **Lidar**.

### • geolocation information

This canal study area is located in the central portion of the Safford Basin in Southeastern Arizona. The approximate central GPS coordinates for this area are **N 32.82107 W 109.82145**.

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## • dedication

This paper is dedicated to Dr. Raymond H. Thompson, who as the senior author's major professor at the University of Arizona shared his vast knowledge of the Southwest, provided wise advice and support on many fronts, and introduced him to the Safford Basin during a 1959 field trip as part of his Southwestern Archaeology course.

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## • disclosure statement

No potential conflict of interest was reported by the authors.

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## • blogs

Temporal records of much of the bajada hanging canal discovery work appears in **this series of record**.

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Directories to the bajada hanging canal field notes, images, maps, and similar resources can be found **here** in Acrobat **[.PDF]** format and **here** in web **[.SHTML]** format. Wikipedia coverage can be found **here** with additional web access on **ResearchGate**, **WeSrch**, and elsewhere. Authors can be contacted **here** and **here**. The main **JFA** paper doi is **https://doi.org/10.1080/00934690.2018.1557029**.

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