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ARTICLE

# Early Canal Systems in the North American Southwest

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## Abstract

Current evidence suggests that Indigenous farmers in the North American Southwest began canal irrigation in the second millennium BC, marking an important change in food production technology. Early canal systems are preserved in alluvial floodplains of the US-Mexico Borderlands region, tend to be deeply buried, and can appear as natural fluvial features. Here I discuss some of the challenges in identifying early canals and associated fields and present case studies from the Santa Cruz River in southern Arizona where buried channels dating as early as 1600–1400 BC were likely human constructed. These small channels share several stratigraphic properties and are consistent with hypotheses of early canal irrigation practiced by small family groups reliant on mixed farming and foraging. Through time, irrigation canal systems expanded in size, resulting in increased labor investment, sedentism, and productivity and facilitating the development of larger irrigation communities. Stratigraphic and geomorphic properties of early canal systems thus far identified along the Santa Cruz River provide a framework for identifying potential early canal evidence in other fine-grained floodplains of the Southwest, thereby improving our understanding of Indigenous agricultural intensification.

## Resumen

La evidencia actual sugiere que los agricultores indígenas del suroeste de América del Norte comenzaron el riego por canales en el segundo milenio aC, lo que marcó un cambio importante en la tecnología de producción de alimentos. Los primeros sistemas de canales se conservan en llanuras aluviales de inundación en las zonas fronterizas de EE.UU.-México, tienden a estar profundamente enterrados, y puede aparecer como características fluviales naturales. Aquí discuto algunos de los desafíos en la identificación de los primeros canales y campos y presento estudios de caso del río Santa Cruz en el sur de Arizona, donde los canales enterrados que datan desde 1600–1400 aC probablemente fueron construidos por humanos. Estos pequeños canales comparten varias propiedades estratigráficas y son consistentes con las hipótesis de los primeros canales de riego practicados por pequeños grupos familiares que dependían de la agricultura mixta y la caza y la recolección. A lo largo del tiempo, los sistemas de canales de riego aumentaron de tamaño, lo que resultó en una mayor inversión laboral, sedentarismo y productividad, y facilitar el desarrollo de comunidades de regantes más grandes. Las propiedades estratigráficas y geomórficas de los primeros canales identificados hasta ahora a lo largo del río Santa Cruz brindan un marco para identificar posibles evidencias de las sistemas de canales tempranos en otras llanuras aluviales de grano fino del suroeste y mejorar nuestra comprensión de la intensificación agrícola indígena.

**Keywords:** irrigation canals; stratigraphy; early agriculture; Southwest

**Palabras clave:** canales de riego; estratigrafía; agricultura temprana; Suroeste

Early development of agriculture in the Americas remains a focus of archaeological research. Domestication of food crops possibly began more than 5,000 years ago in the North American Southwest by encouraging the growth of endemic grasses and weedy annuals, potentially involving the use of fire (Doolittle and Mabry 2006). With the arrival of Mesoamerican tropical domesticates such as maize and squash no later than 3000–2000 BC, food production increased, resulting in a shift in diet that eventually led to changes in health, fertility, mobility, social organization, demography, concepts of land ownership, and levels of conflict (Hard and Roney 2020; Lesure et al. 2021; Ortman et al. 2016; Philips et al. 2018). The speed and nature of how people incorporated agriculture into their lifeways varied geographically, depending on environmental and sociocultural circumstances (Kohler and Reese 2014); uncertainty still remains as to modes of cultigen dispersal and the influence of climate change.

Of the Mesoamerican crops adopted in the Southwest, maize became the most important and the most widely cultivated. Most of the region is too arid to successfully grow maize without increasing soil moisture through irrigation or conserving moisture with the use of mulches (Benson 2011; Lightfoot and Eddy 1995). Early maize appears to have been first cultivated in lowland river floodplains of the Sonoran Desert (Schroedl 2021; Vint 2018); cultivation later expanded to higher elevations and more northerly latitudes as cultigen varieties evolved that were adapted to fewer growing degree days. Early farmers took advantage of where water occurred naturally on the landscape but eventually sought ways to expand production and reduce the risk of crop failure by intervening in local hydrology. This likely began with the expedient construction of simple diversion structures made of earth, rock, and vegetation that deflected runoff toward field areas; these structures evolved into formalized canal channels that concentrated and directed flow farther from its natural pathway. Through time, irrigation canals increased in channel capacity and length. By the first millennium BC, Indigenous farmers were constructing canal systems more than 1 km long that comprised hierarchical channel networks and gridded fields in southern Arizona (Griset et al. 2018; Mabry et al. 2008; Vint 2015) and northwestern Sonora (Cajigas et al. 2020; Carpenter et al. 2015).

If the first irrigation canals evolved from simple diversions of natural runoff, then such evidence is likely to be buried in floodplains and have low archaeological visibility. Such evidence, defined by stratigraphy, is also likely to appear similar to natural floodplain features such as stream channels. The ability to distinguish a simple earth canal from a natural channel can be difficult depending on the geomorphic setting and how much of the stratigraphy is exposed and traceable downslope. To identify these early forms of hydraulic infrastructure, I discuss some of the differences and similarities between canals and natural channels and present three case studies from the Santa Cruz River of southern Arizona where channels dating to 1600–1400 BC have been interpreted as canals (Figure 1). These and other early canals identified in the Santa Cruz River floodplain share many stratigraphic and hydraulic properties and can serve as a reference for identifying similar evidence in other floodplains. I also review stratigraphic evidence of buried agricultural fields associated with early canals in the Santa Cruz River floodplain and the challenges faced in their identification. Recognizing early canal systems and other forms of water control is important for better understanding how Indigenous food production evolved and expanded in the Southwest.

## Canals versus Natural Channels

Historical sciences like geology and archaeology face the challenge of convergence or equifinality whereby different processes can produce similar if not identical phenomena (Glazner et al. 2022; Schumm 1991). For example, human and natural processes can produce similar material evidence such as modified stones or burned layers (e.g., Goldberg et al. 2001; Peacock 1991). This phenomenon also occurs in the study of canals. Early riverine canals in the Southwest were constructed of earth and used to divert water from its natural flow path in river floodplains. Each canal comprised a system with an intake at the water source, a delivery component comprising divergent channels, and a destination where the water was used, such as fields (Kelly 1983; Nials 2015a). With use, canals filled with sediment and were later buried by alluvium; they are thus analogous to alluvial channels, which are formed naturally into preexisting alluvium. Both human-constructed and natural channels are subject to physical laws of flow dynamics, stream energy, and sediment transport, and both have the ability to adjust channel geometry to best accommodate flow and sediment discharge (Leopold and Maddock 1953:43). Whereas initial canal channel cross sections formed by human excavation may be rectangular, trapezoidal, triangular, parabolic, or of intermediate shapes, canals and alluvial channels transecting

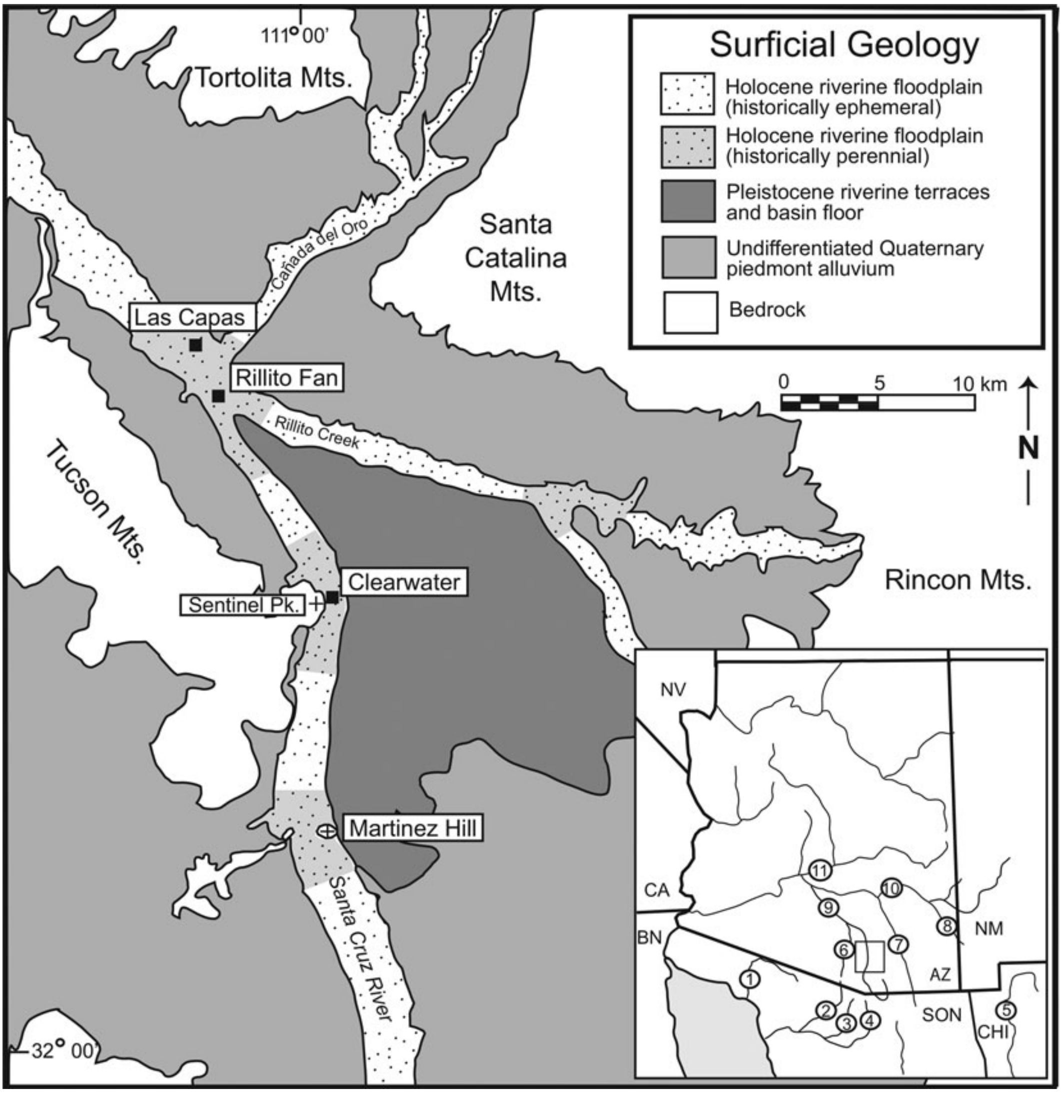

**Figure 1.** Simplified surficial geologic map of the Tucson Basin with locations of the Clearwater, Rillito Fan, and Las Capas sites (adapted from Huckleberry 2018a:Figure 16.1). Numbered drainages in inset map: (1) Río Sonoyta, (2) Río Altar, (3) Río Boquillas, (4) Río Magdalena, (5) Río Casas Grandes, (6) Brawley Wash, (7) San Pedro River, (8) San Simon Wash, (9) Santa Cruz River, (10) Gila River, and (11) Salt River.

unconsolidated materials tend to develop parabolic shapes through time via scour of the channel perimeter. Once filled with sediment and buried, both are defined stratigraphically by cut-and-fill unconformities that outline the former channel and contain waterlain deposits subject to postdepositional disturbances such as soil formation.

Canals and natural stream channels also display important differences. Stream channels develop naturally on terrestrial surfaces to efficiently convey runoff and sediment downslope, whereas canals are constructed by humans to divert water toward areas where it would otherwise not flow. In the absence of obstructions, natural streams follow maximum slope and develop channel dimensions that accommodate a wide range of discharge, often involving significant channel depths. Because gradient and flow depth strongly influence water velocity and total energy, natural streams have greater competence—the ability to transport large clasts—and greater overall sediment transport potential (Ackers 1983). Provided there are a wide variety of available grain sizes for transport, gravels and larger clasts are more likely to be present in natural channels, which tend to support higher water velocities than canals. When gravels are present in canals, it often implies uncontrolled flooding. Higher energy potential in natural alluvial channels allows for greater bank scour and channel mobility. As a result, natural channel width:depth ratios tend to be high, especially in coarse-textured floodplains (Leopold et al. 1964:198–202), whereas lower water velocities and scour potential in canals result in channel cross sections with relatively low width:depth ratios. Higher channel mobility in natural streams also results in greater sinuosity, whereas canals tend to have straight or arcuate alignments.

Other differences between canals and natural streams relate to channel network structure. With some exceptions such as deltas and alluvial fans, most natural stream networks are convergent: tributaries supply channels that increase downstream in cross-sectional area to accommodate larger flows. In contrast, irrigation canals are distributive systems where channel capacity decreases downstream as water is lost to infiltration and diverted from the main channel to branching channels and fields. This in turn affects the types of sediments observed within canals. As discharge and velocity decrease downstream, so does the canal's ability to transport sediment, resulting in an overall downstream decrease in alluvial grain size. In contrast, downstream changes in alluvial grain size can be much more variable in natural fluvial systems due to increasing peak discharge and stream competence potential.

With respect to channel patterns, natural braided and distributary streams commonly support divergent channels in a similar way to canal systems. However, natural stream channels diverge at bifurcation angles of less than 90°. In contrast, canals may support branching channels that are aligned perpendicular to each other, resulting in rectangular channel patterns that are unlikely to occur naturally. This becomes an important line of evidence in the identification of buried agricultural fields.

In sum, canals and alluvial channels are intrinsically different at a system scale and as such can be distinguished more easily when traced across the landscape. However, early canals are likely to be buried in floodplains—often deeply—and to be revealed at single localities through erosion or artificial excavations, precluding the ability to trace them downstream. When limited to only one or a few exposed channel cross sections, determination of natural versus human construction can be difficult. Because deep channels with multimeter dimensions make human construction unlikely, the challenge lies in distinguishing smaller natural channels and canals at a single location. Indeed, cross sections of small natural stream channels may look like canals, especially in fine-grained floodplains (e.g., Figure 2). Similarly, buried canals may be misidentified as natural channels, especially when the former were affected by uncontrolled flooding that scoured the channel perimeter and deposited coarse sediments.

In the end it may not be possible to unequivocally assign human agency to a buried channel feature. Instead, one can provide different lines of archaeological, geomorphic, and stratigraphic evidence to make a case for or against human construction. Three case studies are presented next from a fine-grained river floodplain in which multiple generations of canal systems have been confirmed through extensive archaeological investigations. Different lines of evidence are used to support interpretations of human construction of three small alluvial channels that likely represent some of the earliest canals in the Southwest. The approaches described here are offered as a template for identifying similar evidence in other floodplains.

## Three Case Studies

Evidence of early canal irrigation agriculture is common within the Santa Cruz River floodplain of southern Arizona's Tucson Basin (Figure 1). Historically, the watercourse supported alternating perennial and ephemeral reaches within an alluvial floodplain containing fertile soils and rich riparian ecosystems (Seymour 2020; Webb et al. 2014). Prior to historic groundwater pumping, perennial reaches occurred in areas of shallow bedrock, such as at Martinez Hill and Sentinel Peak, where lateral groundwater flow was deflected toward the surface, and at the mouths of large tributaries such as Rillito Creek and the Cañada del Oro (Nials et al. 2011). In the Tucson area, the Santa Cruz River floodplain contains a >5 m sequence of fine-grained alluvium formed through overbank flooding and sedimentation over the past approximately 5,000 years that preserves cultural deposits dating as early as the Middle Archaic (Gregory 1999; Huckell et al. 2021; Table 1). Hundreds of canal segments dating from the

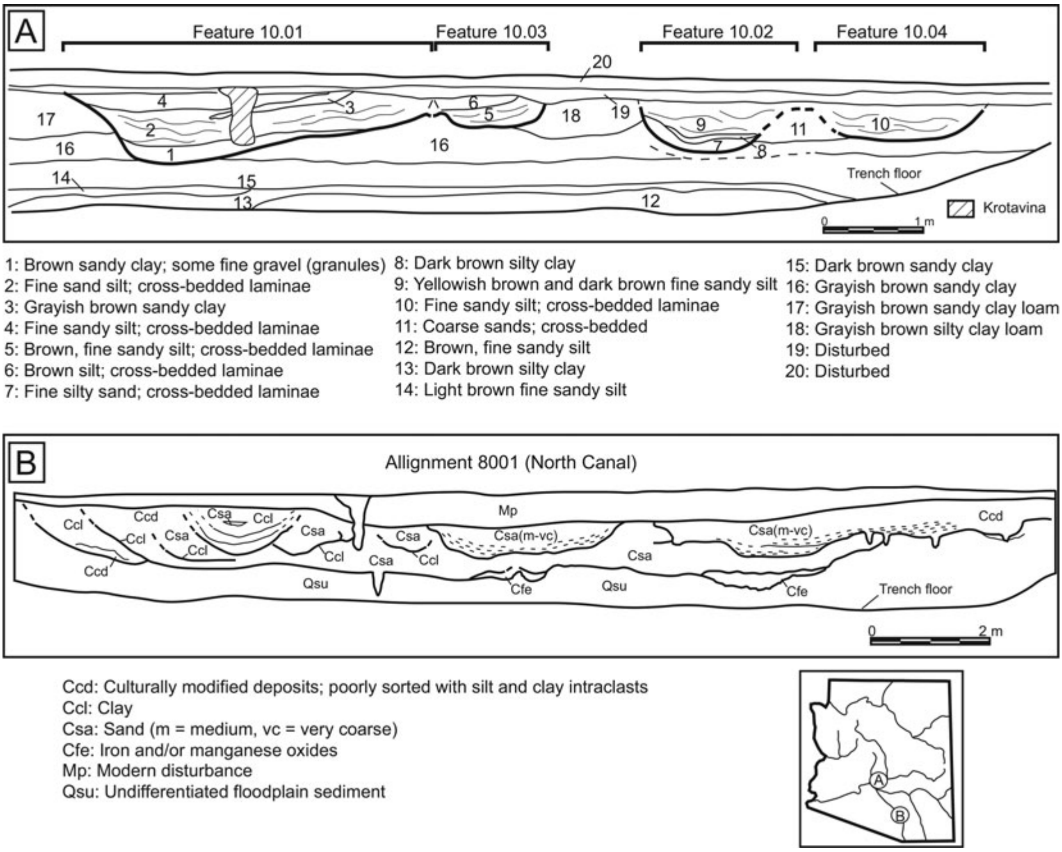

**Figure 2.** Example showing stratigraphic similarities between canals and natural channels: (A) Natural channels in the Santa Cruz River floodplain, Tucson (Huckleberry 2022a); (B) Hohokam canal alignment within Salt River floodplain (Phoenix) containing multiple inset parabolic channels (Anderson et al. 1994).

Early Agricultural to the Historic era have been identified within the floodplain in association with agricultural settlements (Huckleberry 2009, 2018b; Nials 2008, 2015a).

Confirmed ancient canals in the Santa Cruz River floodplain tend to have parabolic cross sections with width:depth ratios less than 5 (Figure 3). Channel deposits are usually stratified with boundaries that roughly conform to the channel shape. Evidence of canal berms may or may not be preserved (e.g., Whitney 2023:Figure 4.11) or visible because the upper stratigraphy is commonly bioturbated. Where preserved, berms may contain poorly sorted sediments that represent clean-out deposits associated with canal maintenance (Nials 2008). Santa Cruz River canals demonstrate an overall increase in cross-sectional area through time (Figure 3), indicating increased flow capacity in response to the growing population and food demand (Mabry et al. 2008). Canal channel fills contain mainly fine sand, silt, and clay, reflecting low-energy streamflow during canal use and subsequent post-use sedimentation from slopewash. Some canals contain coarse sandy deposits, with rip-up clasts of silt and clay suggesting uncontrolled flooding. Although also found in natural stream channels, canals commonly contain orange (iron) and black (manganese) reduction-oxidation (redox) mottles along the base of the channel (see Figure 2B for an example in a Hohokam canal), a product of past wetting and drying. Artifacts such as fire-cracked rock and flaked stone may be present within the channel fill but are usually rare. Fluvially redeposited pieces of fine (less than 4 mm diameter) charcoal are also common in canal fill, possibly reflecting the dumping of trash or burning of weeds as part of channel maintenance.

Dozens of archaeological excavations within the Santa Cruz River floodplain over the past 30 years have resulted in one of the most robust alluvial chronologies in the Southwest: it is anchored by more

**Table 1.** Tucson Basin Cultural Chronology.

| Era/Period | Phase | Date Range |
|---|---|---|
| Historic era | | AD 1694–present |
| Protohistoric era | | AD 1450–1694 |
| Hohokam Classic | | AD 1150–1450 |
| Hohokam Sedentary | | AD 950–1150 |
| Hohokam Colonial | | AD 750–950 |
| Hohokam Pioneer | | AD 500–750 |
| Early Ceramic | | AD 50–500 |
| Late Archaic / Early Agricultural | | |
| | Cienega | 800 BC–AD 50 |
| | San Pedro | 1200–800 BC |
| | Silverbell Interval | 2100–1200 BC |
| Middle Archaic | Chiricahua | 3700–1200 BC |
| Early Archaic | Sulphur Springs | 6500–3700 BC |
| Paleoindian | | 11,000?–6500 BC |

*Sources:* Lindeman and Wallace 2004; Vint 2018.

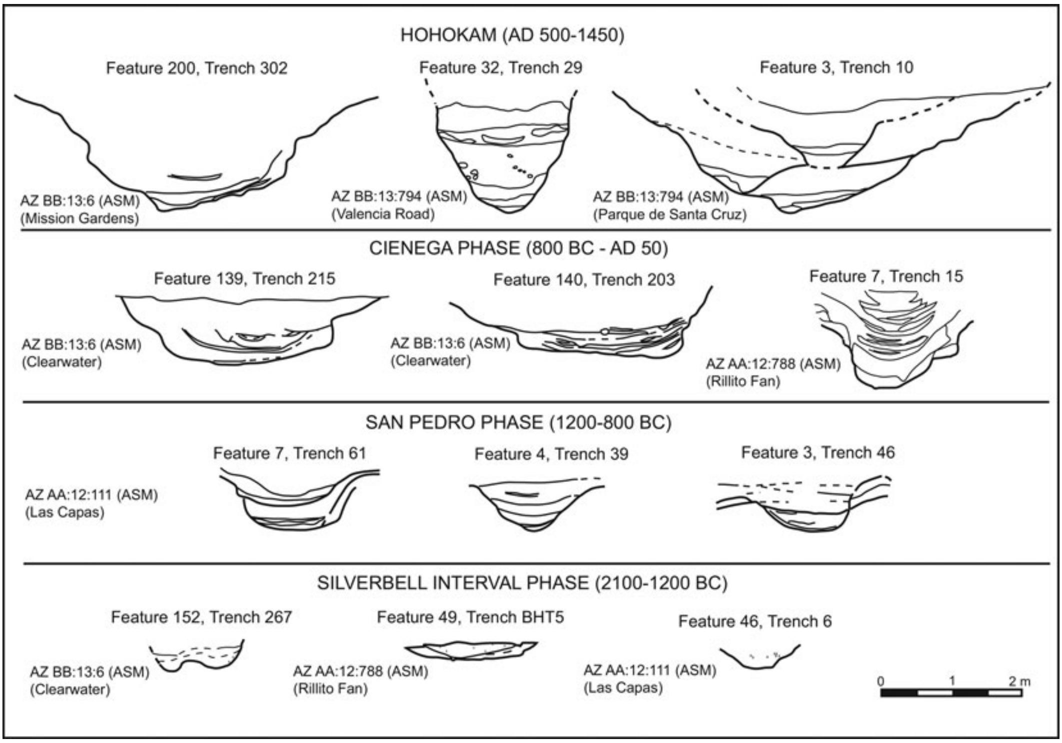

**Figure 3.** Time series of San Pedro, Cienega, Hohokam, and Silverbell canal cross sections documented along the Santa Cruz River in the Tucson area. Primary sources: Clearwater (Klimas et al. 2006); Las Capas (Huckleberry 2022b; Mabry et al. 2008); Parque de Santa Cruz (Huckleberry 2009); Rillito Fan (Huckleberry and Rittenour 2014); Valencia Road (Huckleberry and Lindeman 2016). Layout adapted from Mabry and colleagues (2008:Figure 10.3).

than 400 $^{14}$C dates (Ballenger and Mabry 2011; Waters and Haynes 2001). These dates have helped identify early canals by focusing on age-appropriate deposits. Hundreds of canals dating to the Early Agricultural period have been identified, of which there are currently three candidates for the earliest constructions. All three are located in formerly perennial reaches of the Santa Cruz River: the Clearwater site, or AZ BB:13:6(ASM); the Rillito Fan site, or AZ AA:12:788(ASM); and the Las Capas site, or AZ AA:12:111(ASM; Figure 1).

### Clearwater Site

AZ BB:13:6(ASM) is located at the base of Sentinel Peak (Figure 1) near downtown Tucson and contains buried canals ranging in age from Early Agricultural to Historic (Thiel and Mabry 2006). Canal preservation/visibility is variable, with some features limited to single exposures and others traceable over several tens of meters through excavation. One of the canals, Feature 152, contains a small channel approximately 1.3 m below the modern surface and 400 m west of the modern Santa Cruz River channel. The canal was traced approximately 30 m through a combination of backhoe trenching and horizontal stripping (Klimas et al. 2006). The canal's northeastern alignment is straight and displays a uniform channel width and cross-sectional area of approximately 0.3 m$^2$ (Figures 4 and 5). Channel fill consists of stratified fine sand and silt (Supplemental Table 1) inset into a natural floodplain stratum dated by two nearby pit features, which provide a correlated age for the canal (Mabry 2006). Roasting pit Feature 572 contained mesquite charcoal dated 3280 ± 40 $^{14}$C yr BP or a 2σ calibrated age of 1628–1446 BC ($p = 1.000$; Table 2). Pit feature 630 contained unidentified annual plant remains that dated to 3220 ± 40 $^{14}$C yr BP or a 2σ calibrated age of 1544–1413 BC ($p = 0.968$). The calibrated median probability ages for features 572 and 630 are 1550 BC and 1480 BC, respectively.

### Rillito Fan

AZ AA:12:788(ASM) is located immediately upstream of the Rillito Creek and Santa Cruz River confluence (Figure 1) where the former has constructed a large tributary alluvial fan. Excavations resulted in the identification of several Early Agricultural canals and fields, some with preserved human footprints (Griset et al. 2018). Feature 49 is a small parabolic channel identified approximately 3.0 m below the modern surface in a single deep stratigraphic excavation, approximately 150 m east of the modern river channel (Huckleberry 2018b; Figures 5 and 6). The channel has a cross-sectional area of approximately 0.3 m$^2$ with a sandy fill containing subangular silt intraclasts suggestive of an uncontrolled flood. Due to the channel's deep burial and project area constraints, it was not feasible to trace the channel downslope to the north or northwest.

With only a single exposure, it is difficult to determine whether Feature 49 is a canal or natural channel. However, sand mineralogy within Feature 49 contrasts with that of the surrounding matrix comprising the Rillito tributary fan. Whereas the site comprises Rillito Creek alluvium dominated by quartz and feldspar derived from granites within its catchment, sands within Feature 49 are mineralogically diverse with abundant volcanic fragments, a mineral assemblage consistent with the Santa Cruz River (Miksa 2008). Thus, Feature 49 conveyed Santa Cruz River water onto the Rillito Creek fan, an alignment that deviates from the natural slope. A concentration of detrital charcoal fragments within Feature 49 yielded an age of 3230 ± 30 $^{14}$C yr BP or a 2σ calibrated age of 1539–1425 BC ($p = 0.997$; Table 2) and a calibrated median age of 1485 BC. Because the charcoal is detrital in a secondary context, there is the potential for fluvial reworking resulting in a measured age that predates deposition within the canal (Huckleberry and Rittenour 2014). However, the alluvial sequence at the Rillito Fan site is well dated with $^{14}$C ages from firm stratigraphic contexts, allowing for the construction of an age-depth model that suggests that the Feature 49 charcoal age is consistent with the floodplain depth (Huckleberry 2018b).

### Las Capas

AZ AA:12:111(ASM) is located at the confluence of the Cañada del Oro and Santa Cruz Rivers (Figure 1), approximately 1 km downstream from the Rillito Fan site. Recent excavations near the western edge of the site resulted in the exposure of a small parabolic canal 2.8 m below the modern surface

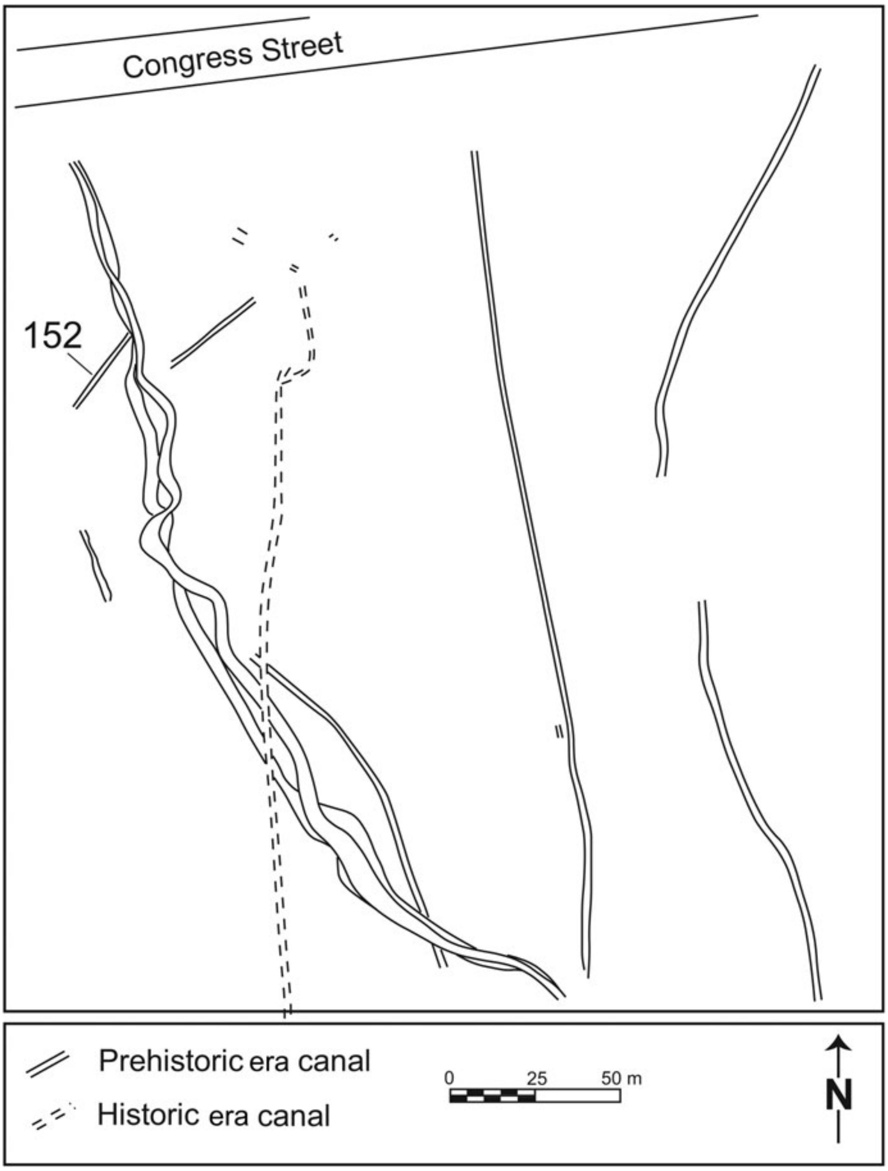

**Figure 4.** Map showing location of Feature 151 in relation to younger canals in the western part of the Congress Street Locus at AZ BB:13:481 (adapted from Klimas et al. 2006:Figure 4.97).

and approximately 600 m east of the current Santa Cruz River channel (Huckleberry 2022b). The small parabolic channel has a cross-sectional area of approximately 0.2 $m^2$, is filled with stratified silt loam and clay loam, and contains black and orange redox mottles along its base (Figure 5; Supplemental Table 1). Given the confined width of the project corridor, it was not possible to trace the northwest-aligned channel downstream. Much like Feature 49 at the Rillito Fan site, Feature 46 contains a concentration of detrital charcoal within its channel. Charred annual nonwood tissue submitted for dating yielded an age of 3200 ± 30 $^{14}$C yr BP or a 2σ calibrated age of 1510–1417 BC ($p = 1.000$; Table 2) and a median age of 1469 BC.

As with Feature 49 at the Rillito Fan site, confirmation of human construction for Feature 46 is hindered by there being only a single stratigraphic exposure. However, Feature 46 displays stratigraphic properties, such as charcoal and redox features, consistent with other canals at Las Capas (Nials 2008).

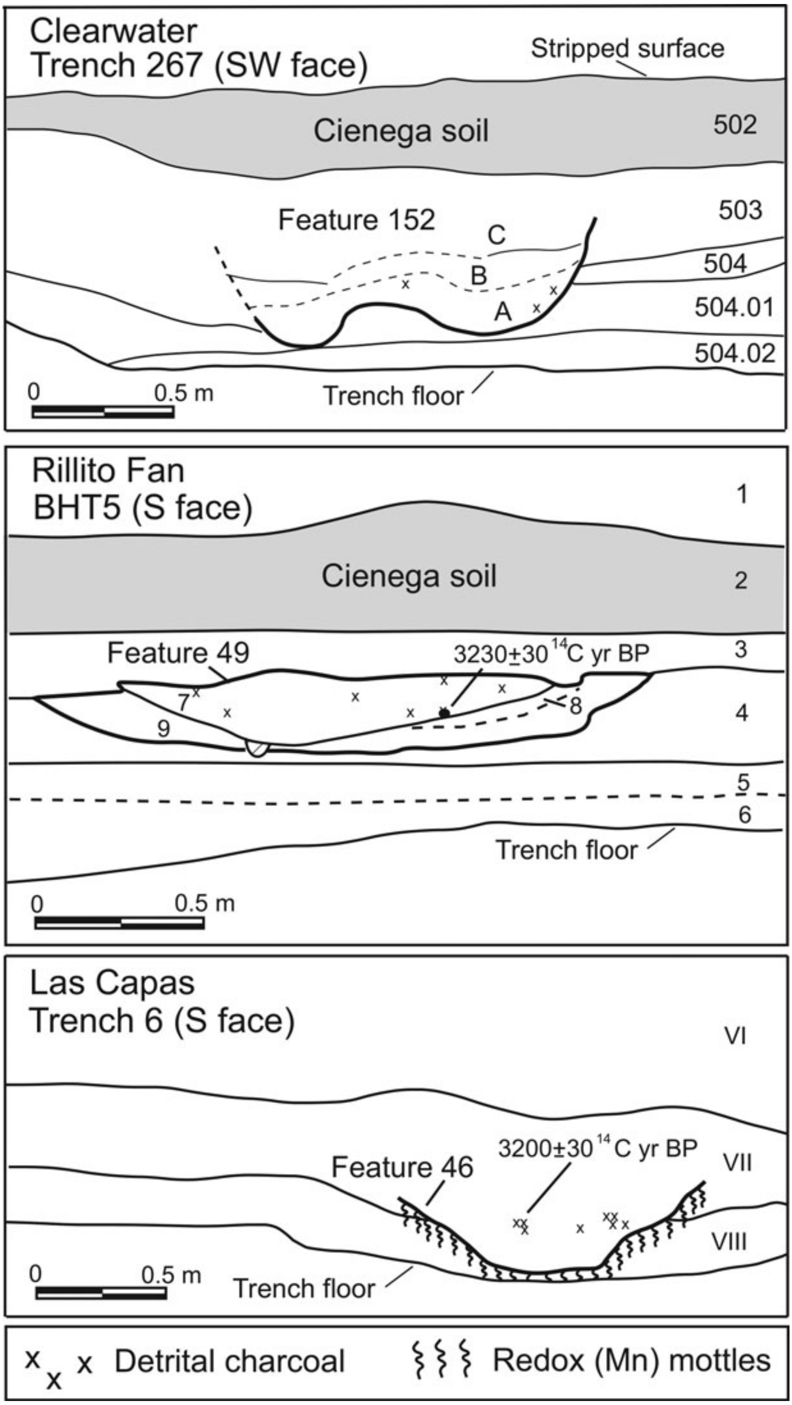

**Figure 5.** Stratigraphic profiles of case study canals at the Clearwater (Klimas et al. 2006), Rillito Fan (Huckleberry 2018a), and Las Capas (Huckleberry 2022b) sites. See Supplemental Table 1 for stratigraphic descriptions.

Also similar to Feature 49 is the possibility that detrital charcoal from Feature 46 is older than the associated depositional event. Although Feature 46 could not be stratigraphically traced to independently dated features, it is approximately at the same elevation as a buried occupation surface approximately 120 m to the northeast that dates to 1630–1555 BC (stratigraphic Unit 508.01 in Whitney [2023]); this

**Table 2.** Radiocarbon Ages and Context.

| Site / Canal Feature | Beta Lab # | Age $^{14}$C yr BP | $\delta^{13}$C (‰) | 2σ Calibrated Age (Probability)[a] | Median Probability | Material | Context |
|---|---|---|---|---|---|---|---|
| Clearwater/152 | 190713 | 3280 ± 40 | −24.5 | 1628–1446 BC ($p = 1.000$) | 1550 BC | Mesquite charcoal | Pit Feature 572 from top of stratum containing canal (Mabry 2006) |
| Clearwater/152 | 193150 | 3220 ± 40 | −8.3 | 1608–1604 BC ($p = 0.003$)<br>1602–1583 BC ($p = 0.025$)<br>1559–1556 BC ($p = 0.004$)<br>1544–1413 BC ($p = 0.968$) | 1480 BC | Annual plant | Pit Feature 630 from top of stratum containing canal (Mabry 2006) |
| Rillito Fan/49 | 453369 | 3230 ± 30 | −23.8 | 1596–1594 BC ($p = 0.003$)<br>1539–1425 BC ($p = 0.997$) | 1485 BC | Unidentified charred wood tissue | Concentration of detrital charcoal in canal channel fill (Huckleberry 2018b) |
| Las Capas/46 | 613537 | 3200 ± 30 | −22.0 | 1510–1417 BC ($p = 1.000$) | 1469 BC | Charred annual nonwood tissue (parenchyma) | Concentration of detrital charcoal in canal channel fill (Huckleberry 2022b) |

[a] Calibrated with Calib v. 8.2 and IntCal20 database (Reimer et al. 2020).

**Figure 6.** Oblique photograph of Feature 49 exposed through excavation at the Rillito Fan site (photograph by Gary Huckleberry).

suggests that Feature 46's charcoal age is consistent with its depth. In this same area within Unit 508.01, a straight, narrow parabolic channel was identified and traced 5 m. Although possibly a canal, the feature lacked waterlain sediments or redox mottles, and its function remains uncertain.

## Identifying Buried Agricultural Fields

As a general rule, smaller canals such as field laterals are more difficult to see stratigraphically because they tend to have less distinct boundaries and so blend into the surrounding sedimentary matrix. Thus, buried canals located near the intakes and distal ends of a canal system are easier and difficult to identify, respectively. For decades, archaeologists working in alluvial floodplains in Arizona were unable to identify buried prehistoric field lateral canals using conventional backhoe trenching. Given that field laterals help define the size and location of agricultural fields, a critical part of prehistoric canal systems remained poorly defined. Based on archaeological and ethnographic evidence (Doolittle 2000; Masse 1991; Nials and Gregory 1989), Indigenous canal-fed and flood-irrigated fields clearly vary in size, shape, or form due to local environmental and cultural factors. Nevertheless, the expectation is that those constructed in fine-grained alluvial floodplains are likely to consist of shallow basins bordered by low earth mounds to help regulate the flow of water. If so, how might such agricultural infrastructure appear stratigraphically?

In the early 2000s, archaeologists investigating Early Agricultural sites in the Santa Cruz River floodplain increasingly incorporated mechanical horizontal stripping in site excavations where backhoes carefully removed thin (<5 cm) layers of sediment resulting in large (e.g., >500 $m^2$) plan view exposures of buried floodplain surfaces. At the Las Capas site, such excavations conducted by skilled backhoe operators revealed geometric soil patterns caused by slight differences in sedimentary texture and moisture content. This patterning, often in the form of perpendicular lineations and irregular polygons, occurred in multiple stratigraphic levels containing nearby San Pedro phase main and distribution canals. When seen outside periglacial environments, such patterned ground is unlikely to have a natural explanation. Lineations representing natural channels are common in floodplains, but they do not bifurcate at right angles. As more areas were exposed, it became clear that these geometric soil patterns represented field lateral canals and gridded agricultural fields (Herr 2009; Figure 7A).

More than 1,000 discrete agricultural field cells dating to the Early Agricultural period have been identified at Las Capas (Nials 2015a, 2015b). Individual cells consist of shallow basins, most ranging from 10 to 30 $m^2$ in area, that are bordered by low earth berms that were formed through shallow excavation on either side of the intended berm location and piling of sediment (Figure 7B). A similar excavation procedure was used to construct field lateral canals: sediment was piled into berms producing a slightly elevated channel. In places the berms also served as field borders. Field shapes vary depending on local slope, topography, and canal system layout. Water was applied from either side of the field lateral by breaching the berms and then refilling with mud to close. Similar breaks in field borders were used to direct water downslope between cells. Natural floods often penetrated the systems and inundated these fields, depositing layers of sediment across fields and their borders. Individual canal systems at Las Capas were rebuilt multiple times with shifting canals and field borders within an aggrading floodplain that spanned several human generations.

In cross section, this agricultural infrastructure commonly appears as thinly layered alluvial deposits with wavy boundaries (Figure 8), a stratigraphic sequence that could easily be produced through natural fluvial processes. As noted by Nials (2015a:444), field laterals and borders were generally not

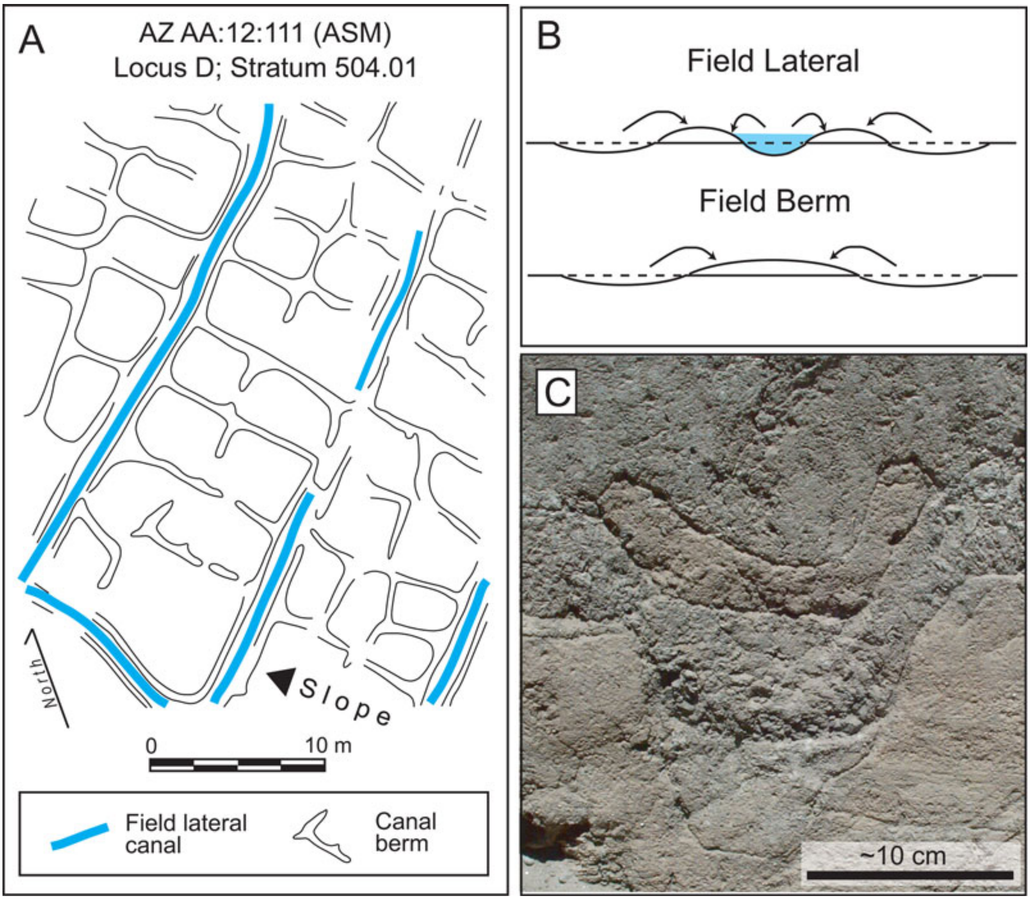

**Figure 7.** (A) Bordered agricultural fields at Las Capas (adapted from Nials 2015a:Figure 11.7); (B) schematic cross section showing construction of canal field lateral and field berm (adapted from Huckleberry 2018b:Figure 15.3); (C) photo of planting hole in profile (Brack and Ruble 2013:Figure 2.3; photo reproduced by permission of Desert Archaeology, Inc.).

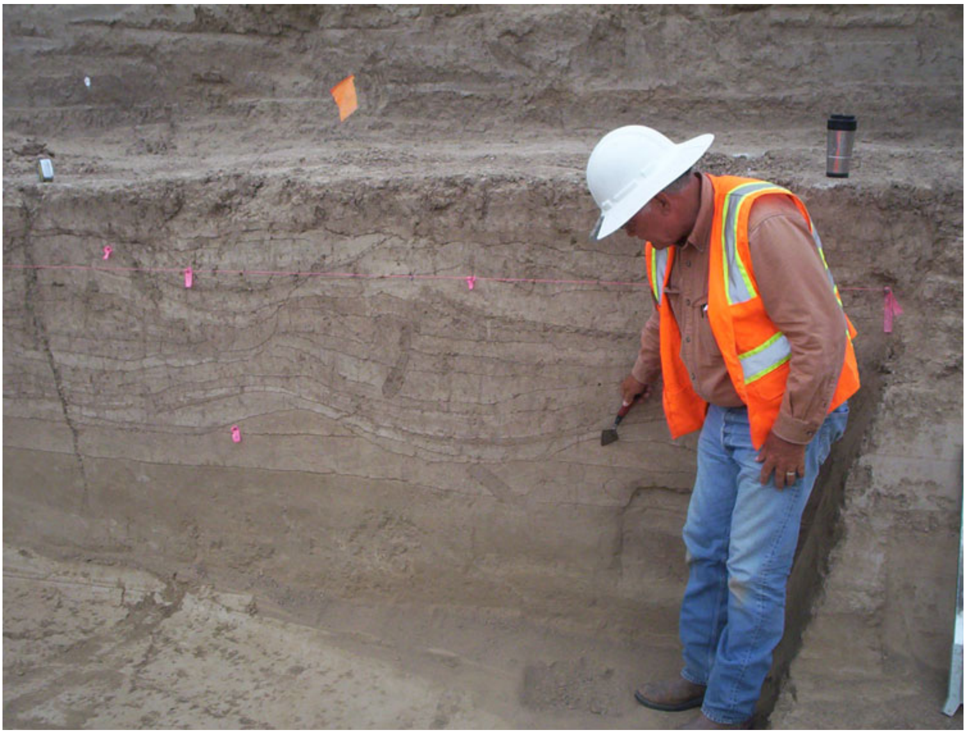

**Figure 8.** Stratigraphic exposure of San Pedro phase agricultural field at the Las Capas site (photograph by Gary Huckleberry).

visible in backhoe trench profiles and required plan view exposures to be identified. Field lateral canals exposed in cross section display broad and shallow parabolic channel shapes with deposits that are commonly bioturbated, as evidenced by root and insect channels and gradual stratigraphic boundaries. Other stratigraphic features identified within fields include small circular pits interpreted as planting holes for seeding. Previously identified elsewhere in the Santa Cruz River floodplain (Brack and Ruble 2013), these features generally range from 10 to 50 cm in diameter, extend more than 30 cm deep, and have conical to basinal shapes (Figure 7C). In cross section, planting holes commonly contain poorly sorted sediments suggestive of the manual removal of plants, including rootstocks, and infilling with disturbed soil. Although natural biotic processes may create similar stratigraphic features in floodplain deposits, the systematic layout, density, and stratigraphic context of these pits in relation to field laterals and borders strongly support an interpretation of intentional human activities related to cultivation.

Buried agricultural fields at Las Capas have served as a template for subsequent canal investigations elsewhere in the region. Since these discoveries, similar excavation strategies have been successfully used to identify buried prehistoric agricultural fields and field laterals at other sites in the Santa Cruz River floodplain (Griset et al. 2018) and along the lower Salt River in Phoenix (Schaafsma 2015), providing a more holistic picture of prehistoric canal system construction and operation.

## Discussion

Our understanding of the timing and spread of early agriculture into the Southwest has changed considerably over the past several decades, with new discoveries increasingly pushing the shift from foraging to farming further back in time (see Hard and Roney 2020; Plog et al. 2015). Maize evidence from good stratigraphic contexts confirms its presence in the Sonoran Desert and on the Colorado Plateau no later than 2100 BC, and recent $^{14}$C dates on maize remains at Las Capas suggest cultivation as early as 3700 BC (Vint 2018). Of interest is when and how water-control technology developed in support of food production. Unequivocal canals date as early as 3400 BC in the Zaña Valley of north coastal Peru (Dillehay et al. 2005), and intriguingly earlier $^{14}$C dates have recently been obtained on spring-fed, travertine-lined canals in the Tehuacán Valley of southern Mexico, suggesting canal technology as early as 6000–4000 BC (Neely et al. 2022); however, more work is needed to confirm these dates. Canal irrigation in the prehistoric Southwest was long believed to have been a relatively recent technology introduced by migrants from Mesoamerica around 300 BC (e.g., Haury 1976:150). However, the large scale and complexity of Hohokam canals relative to their Mesoamerican counterparts challenged that hypothesis (Doolittle 1990:79–81); subsequent discoveries of Early Agricultural canal systems in the Tucson area and in northwestern Sonora (Cajigas et al. 2020; Carpenter et al. 2015) have confirmed that water management in support of agriculture has a much deeper history in this region. Evidence of early canal irrigation is likely preserved in multiple Southwest alluvial floodplains, but the challenge is how to find and recognize it.

The three case study canals from the Santa Cruz River floodplain described here come from well-defined stratigraphic and archaeological contexts indicating an age of 1600–1400 BC. With respect to whether these are truly canals, it must be recognized that none of their features contain unequivocal evidence of human construction, such as stone slab linings or water-regulating features like headgates and tapons. Moreover, we do not know the location of these channel segments within their larger networks. Nonetheless, several lines of evidence are consistent with a canal interpretation. In the case of Feature 152, the straight and uniform channel was traced over 30 m and is stratigraphically similar to younger confirmed canal segments at the Clearwater Site (Figure 8). Features 46 and 49 were defined by single stratigraphic exposures and thus little can be said regarding their alignment or downslope change in cross-sectional area. However, alluvial mineralogy indicating a water diversion from the Santa Cruz River onto the Rillito Creek fan makes it unlikely that Feature 46 is natural. Feature 49 does not display anomalous channel fill mineralogy but does have stratigraphic elements consistent with younger confirmed canals at Las Capas.

If these are indeed canals, what common properties might help guide the identification of similar features in other floodplains, and what do their characteristics tell us about early irrigation farming? First, all three channels display small parabolic cross sections less than 0.4 $m^2$ and two have width:depth ratios less than 5 (Table 3). The high apparent width:depth ratio for Feature 49 is likely due to an oblique exposure. All three contain channel fills consisting of thinly bedded, waterlain fine sand, silt, and clay suggestive of controlled low-velocity flow. An exception is the upper fill of

**Table 3.** Stratigraphic and Hydraulic Properties Associated with Buried Irrigation Canals in the Santa Cruz River Floodplain.

| **Single Stratigraphic Exposure Evidence** |
|---|
| Parabolic channel morphology with width:depth ratios <5 |
| Artifacts in channel fill |
| Charcoal in channel fill |
| Large rocks inconsistent with mean alluvial grain sizes (manuports) |
| Agricultural plant remains (macro, pollen, phytoliths) |
| Iron and manganese redox mottles along or below channel base |
| Proximity and morphological/stratigraphic similarity to other confirmed buried canals |
| Channel-fill mineralogy inconsistent with water sources in natural catchment |
| **Multiple Stratigraphic Exposure Evidence Allowing Definition of Alignments** |
| Deviation from natural slope |
| Straight to arcuate alignment; overall low sinuosity |
| Downstream uniformity in channel morphology |
| Downstream uniformity or slight reduction in cross-sectional area |
| Branching channels at angles >45° |
| Discontinuous concentrations of large rocks inconsistent with mean alluvial grain sizes |

Feature 49, which contains medium sand and matrix-supported silt intraclasts suggestive of uncontrolled flooding in canals (e.g., Huckleberry et al. 2018). These canals originated from perennial segments of the Santa Cruz River, which allowed farmers to control when and how much water to divert at different times of the year. The three channels lacked obvious berms, and rock material for regulation of flow or bank stabilization was absent. In terms of position within their respective networks, all three features are located within 600 m of the modern Santa Cruz River channel. At the Rillito Fan and Las Capas sites, the river's channel has remained relatively fixed along the western edge of the floodplain for the past several thousand years (Nials et al. 2011), suggesting that Features 46 and 49 are several hundred meters from their intakes and perhaps are in the middle portions of their systems. At the Clearwater Site, the historic Santa Cruz River below Sentinel Peak prior to arroyo cutting consisted of multiple small channels (Thiel and Mabry 2006), and it is difficult to know the location of the original intake and length of the system associated with Feature 152.

Criteria discussed earlier emphasize two-dimensional exposures of stratigraphy that are likely to be insufficient for identifying buried field laterals and bordered fields. The identification of buried Early Agricultural fields at Las Capas is due in part to geological serendipity: depositional conditions favored preservation and visibility. However, the identification of similar phenomena at other sites in the Santa Cruz River and Salt River floodplains that have different depositional regimes suggest that combined vertical trenching and mechanical stripping are essential to finding buried fields. Two-dimensional exposures in arroyo walls and backhoe trenches may be insufficient to confirm human-constructed features. Unfortunately, mechanical stripping generally requires the movement of large volumes of sediment, especially in deeply buried sites, and is therefore costly and highly disruptive to potential overlying cultural deposits. Such strategies are likely to be used only where impact to cultural resources due to development is imminent, such as the case of these recent discoveries in modern urban settings.

The recognition of Features 46, 49, and 152 as possible canals was facilitated by their location in areas of previously confirmed buried canal networks with firm alluvial chronologies. Identifying such features in floodplains that have not been as intensively investigated is likely to be challenging, and there may be logistical impediments and environmental concerns regarding deep mechanical excavations. Nevertheless, early canal systems are likely preserved in several fine-grained floodplains of the Borderlands region along reaches that historically supported dependable streamflow. Candidates include the Río Altar, Río Boquillas, Río Magdalena, and Río Sonoyta in northern Sonora and the Río Casas Grandes in northwestern Chihuahua (Figure 1). In the United States, candidates include Brawley Wash and the San Pedro, San Simon, and upper Gila Rivers. Several reaches of these rivers and streams are entrenched, creating opportunities for natural exposures of early canals in arroyo walls (Anyon et al. 2015:149–150). Alluvial reach boundaries supporting perennial flow are particularly ideal locations for containing such evidence (Nials et al. 2011). Distinguishing natural and cultural channels in these floodplains will require multiple lines of evidence similar to those associated with Early Agricultural canals along the Santa Cruz River (Table 3). When limited to single stratigraphic exposures or short segments, channel morphology and stratigraphy may be insufficient to confidently ascribe human construction, especially in fine-grained floodplains where natural channels can look like canals (Figure 2). In such cases, interpretations may remain as working hypotheses pending further supporting evidence.

Given an approximately 5,000-year time depth for agriculture in the Southwest based on recent early $^{14}$C dates on maize, it is not unreasonable that canal irrigation began considerably before 1600–1400 BC. The ability to find older canals hinges in part on the presence of alluvial deposits of commensurate age conducive for preserving earthen agricultural features. Many Southwest floodplains experienced erosive flow regimes during the middle Holocene (Copeland et al. 2012; Huckell 1996; Nordt 2003; Waters and Haynes 2001), likely caused by climatic changes that affected flood frequency and magnitude. For some of the larger rivers like the Salt and Gila, such conditions extended into the late Holocene and may explain the paucity of preceramic agricultural evidence in those floodplains (Huckleberry et al. 2013; Waters 2008). Most fine-grained deposits in alluvial floodplains of the Borderlands region date to the past approximately 4,000 years; earlier deposits tend to be absent or associated with higher-energy streamflow. It is worth noting that maize remains predating 2500 BC from the Santa Cruz River floodplain were all recovered in secondary contexts in younger strata

(Vint 2018). Hence, the potential to find canals older than 1600–1400 BC exists, but alluvium favorable for the preservation of agricultural infrastructure older than 2000 BC is commonly absent, creating another challenge to finding early canals.

Recognizing that older canals may have been constructed in the Southwest and farther south in Mexico and have yet to be identified, what can be said about the earliest canals thus far identified? Assuming that Features 46, 49, and 152 are not located in the distal ends of their respective systems, their small channel cross-sectional areas are consistent with expectations that early canal systems consisted of simple diversions that supplied water to localized areas close to their intakes. Building and maintaining canal systems of this scale unlikely required cooperative organization beyond a single or few family-related household groups. Nonetheless, such infrastructure required more labor effort throughout the year compared to floodwater or water-table farming strategies (Mabry 2005), favoring reduced mobility at a time when early farmers were still heavily reliant on foraging (Diehl and Davis 2016; Hard and Roney 2020; Minnis 1992). These early canal systems were precursors to later, larger, and better-defined San Pedro phase canal networks. By 1200 BC, farmers at Las Capas were constructing 1–2 km long canal systems comprising multiple branching channels that irrigated 20–50 ha and supported a community of approximately 50–100 people (Mabry et al. 2008; Vint 2015). Around the same time, canal systems of possibly larger scale may have been present along the Río Casas Grandes at the terraced hilltop settlement Cerro Juanaqueña, supporting a community of 200–250 people (Hard and Roney 2020). Through time, canals at Las Capas increased in size (Figure 3) with subsequent Cienega-phase systems supporting more regulated flow (Palacios-Fest and Davis 2008) and a greater diversity of crops for larger irrigation communities. Similarly, Cienega-phase canal systems up to 2 km in length were constructed along the Río Boquillas and supported multiple generations of farmers at La Playa (Cajigas et al. 2020; Carpenter et al. 2015). In Las Capas and La Playa, canal system size was likely constrained more by available river discharge than the amount of irrigable land, labor, and technological skill. Several centuries later, the largest irrigation canal systems north of Peru prior to European contact were along the Salt and Gila Rivers (Doolittle 1990; Fish and Fish 2007; Figure 1), supporting villages of more than a thousand people and playing a key role in Hohokam food production and settlement patterns.

Through time, Indigenous Southwest canal systems also expanded geographically into diverse geomorphic settings. Selective pressures favoring successful maturation with fewer growing degree days facilitated maize expansion onto the Colorado Plateau by at least 2000 BC (Merrill et al. 2009; Schroedl 2021), and canal irrigation in the upland Southwest appears to have been established no later than the first millennium BC (Damp et al. 2002). Whereas Indigenous canals on the Colorado Plateau did not reach the scale of those in the river valleys of the Sonoran Desert, hydraulic engineering skills required to divert and store water in complex canyon and mesa topography was no less impressive (Vivian 1974; Wilshusen et al. 1997; Wright 2006). By the time of the Spanish *entrada*, the Southwest had witnessed more than 3,000 years of canal irrigation history. How this extended period of water management affected the biophysical and cultural landscape and the legacies it left behind are still being discovered.

## Summary and Conclusions

The ability to capture, divert, and store water had important social and environmental consequences that helped shape human history. Early human interventions in surface hydrology mainly involved canal building in support of agriculture. In the desert Southwest, supplemental water was essential for successfully growing the primary crop, maize. However, the impact of early irrigation farming on regional subsistence, sedentism, demography, and social organization remains poorly understood. Identifying the earliest canals and understanding how they functioned are hindered by the fact that they tend to be found in geomorphically dynamic settings prone to erosion and burial. If preserved, they are likely to have low archaeological visibility. Early Indigenous canals are commonly buried in floodplains and can be difficult to distinguish from natural fluvial features. At present, three small alluvial channels identified within the Santa Cruz River floodplain of southern Arizona, interpreted as probable canals and dated 1600–1400 BC, represent some of the earliest evidence of water management (excluding wells) in the Southwest. Consisting of small parabolic earth channels, these canals had limited discharge capacities and were built primarily to support maize irrigation for household groups who mixed farming with foraging. Through time, canal systems increased in size, supporting larger irrigation communities that required higher levels of social organization for coordinating canal construction, maintenance, and water allocation.

Early canal systems in the Santa Cruz River floodplain confirm that Indigenous knowledge of hydrology and hydraulic engineering extends more than 2,000 years before construction of the large, monumental canal earthworks associated with the Hohokam. Hydraulically sophisticated channel networks constructed during the Early Agricultural period served as a template for subsequent larger canal systems. Evidence of second millennium BC canal irrigation in the US-Mexico Borderlands is consistent with the notion that the technology originated locally through a process of experimentation with surface runoff, but this hypothesis requires further testing. Much of the Southwest and areas farther south in Mexico remain unsampled. More research is needed to refine our understanding of when and where canal irrigation began in the Americas and subsequently expanded in support of food production. Such evidence is likely to be differentially preserved in Southwest floodplains due to a period of widespread erosion that overlaps with early maize cultivation. Alluvial floodplains with middle-to-late Holocene fine-grained deposits are most likely to preserve evidence of early irrigation infrastructure. Identification of such features will be favored by an understanding of local geomorphology, hydrology, and multiple lines of evidence consistent with human construction. Identification of buried agricultural fields will also be facilitated by mechanical excavations that provide plan view exposures of former floodplain surfaces. Determining the age and geography of early canal systems will in turn provide clarity and context to the many sociocultural and environmental changes associated with agricultural intensification in the Southwest and beyond.

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Supplemental Table 1. Stratigraphic Descriptions for Canal Profiles in Figure 5.

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