Using GIS to Investigate Fine-scale Spatial Patterns in Historical American Indian Agriculture

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Agricultural land-use patterns in the landscape are a product of the complex interplay between social and biophysical systems. In agricultural fields, social organization, economics, and culture are tightly intertwined with soil, water sources, climate, and natural hazards.[1] While fields have clear spatial attributes, they also exist in time, and historical contingencies in both social and natural systems can leave a lasting imprint on the landscape. This article demonstrates how a geographical information system (GIS) based on historical maps contributes to visualizing and analyzing geographic patterns in American Indian irrigation agriculture along the Gila River.

In central Arizona, both prehistoric and historic irrigation agriculture have left their imprints along desert rivers.[2] Historic photos and documents illustrate agricultural practices and conditions, but can lack a clear spatial context. Fortunately, along the middle Gila River (Figure 1), a set of large-scale maps permits an unusually detailed view of the geography of Akimel O'odham (Pima) and Pee Posh (Maricopa) fields in the Gila River Indian Reservation in 1914. Perhaps the most conspicuous features displayed on the maps are the field clusters along the Gila River. Each cluster centers around a canal network, with individual fields keyed to crops planted in the winter and spring of 1914 (Figure 2). While some accounts treat the Gila River Indian Reservation as a generalized whole,[3] these maps suggest questions about finer-scale patterns and processes. Coupling these maps with the visual and analytical capabilities of GIS enables the investigation of previously unasked questions:

- How did varieties of crops grown differ within the reservation?
- Did the layout of fields vary between villages?
- How did field size vary across the reservation?

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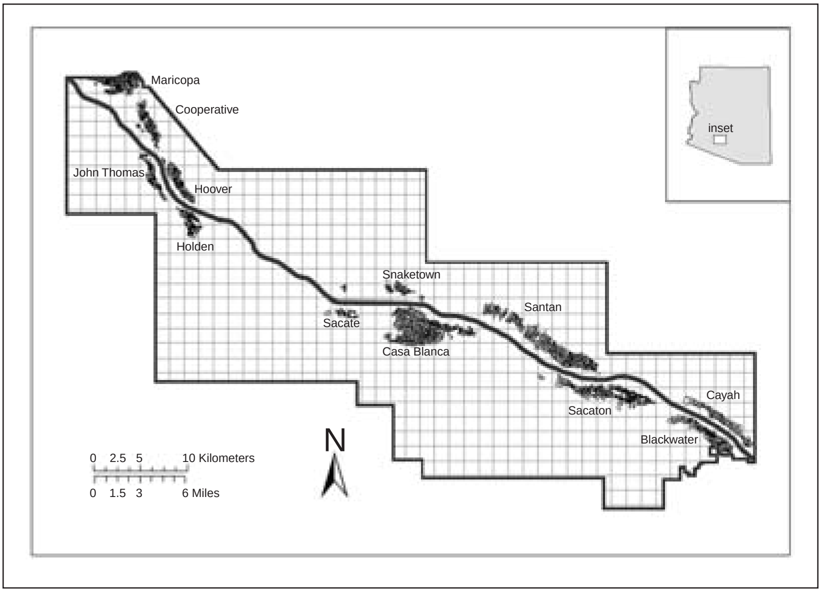

Figure 1. Location of agricultural field clusters and the Gila River within the Gila River Indian Reservation, 1914.

These questions could not be easily addressed by merely visually inspecting the set of 1914 maps. As with previous historical GIS scholarship,[4] this article illustrates how GIS enables the visualization and analysis of patterns not readily apparent in original paper maps. Pattern analysis of crop diversity, field arrangement, and field size, together with survey documentation, photographs, and other primary historical sources, make a new contribution to American Indian agriculture scholarship.

Physical Context

The Gila River drains a 170,000 square-kilometer (65,620 square-mile) watershed stretching from western New Mexico and encompassing much of southern Arizona and the northern tip of Sonora. A bedrock channel for much of its upper portions, the Gila draws its flow from the Black Range, the Little Range, the Mogollon Range and the Diablo Range, each with elevations of 2,700-3,000 meters (8,800-9,800 feet). Near the Arizona/New Mexico line, the Gila flows through the Duncan Valley, receives the waters of the San Francisco River and flows through the Safford Valley. Past the constriction of a box canyon, the site of the Coolidge dam, the river receives the San Pedro River and flows into the basin and range province. Here it becomes an alluvial channel as it courses through thick unconsolidated mantels of sediment and losing much of its flow to infiltration. The Gila receives the Salt River just west of Phoenix, flows

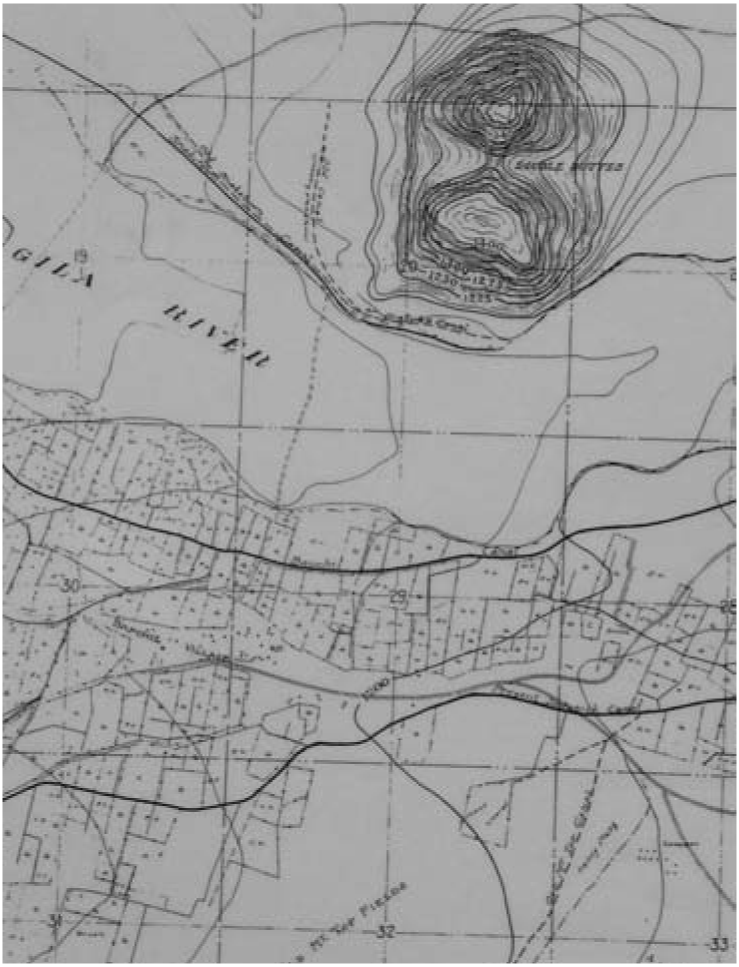

Figure 2. Detail of Casa Blanca Field near Double Buttes (known as Gila Butte today).

southwest across western Arizona and empties into the Colorado River near Yuma, just north of the Gulf of California.

Bisecting the Gila River Indian Reservation, the Middle Gila River is dynamic both in terms of flow quantity and the location of the channel itself.[5] Before the Gila was dammed in 1929, streamflow showed a clear seasonality corresponding to summer monsoons and winter precipitation originating in the Gulf of Mexico.[6] As with other large alluvial rivers flowing through deserts, major floods changed both the elevation of the bed and the lateral position of the channel.[7] This dynamism presented challenges to prehistoric and historic American Indian farmers trying to tap a reliable source of water for their fields.

Cultural-Historical Context

The Akimel O'odham (Pima) have farmed central Arizona for centuries, both dryland farming on *bajadas* skirting desert mountains and irrigation agriculture in the Salt and Gila River floodplain (see Figure 3). These agricultural traditions possibly originated with the prehistoric Hohokam culture.[8] In the late 1680s, Father Eusebio Kino and his fellow Jesuit missionaries provided the first documented European observations of what is now central Arizona. Kino, accompanied by a Spanish military officer Juan Mateo Manje, made several journeys to the Gila between 1694 and 1701, coming upon several groups of Piman Indians farming along the Gila, the San Pedro, and the Santa Cruz.[9] These settlements, located well beyond the territory administered by Spanish missions, did not experience intensive influence from the Spanish aside from the adoption of wheat and some metal tools.[10]

Through the 1700s, Jesuit and Franciscan missions made sporadic inroads into Arizona, but their influence was limited to southern Arizona.[11] For the Akimel O'odham along the Gila River, the next Euro-Americans to enter their valley were trappers in the 1820s and two military expeditions in the 1840s. When the treaty of Guadalupe Hidalgo was signed in 1848, the Gila River became the international boundary between the United States and Mexico. Seven years later, through the Gadsden Purchase, the United States acquired lands south of the Gila to

Figure 3. Akimel O'odham farmer planting fields at Santan c. 1905.

the present day Arizona/Mexico border. During this time period, the Akimel O'odham aided travelers, including the stream of Forty-niners seeking California gold. Congress established the reservation in 1859, the first reservation in what would become Arizona Territory. Originally consisting of 25,900 hectares (64,000 acres), the reservation was expanded through several acts of Congress, bringing the total area to 149,000 hectares (369,000 acres).

The Akimel O'odham, a self-sufficient tribe, became quite prosperous supplying travelers, United States military personnel, and early settlers with food and other supplies. In his 1859 report, Silas St. John, special agent for the reservation, observed this economic prosperity:

> They have under fence and in cultivation Fifteen thousand acres of land this year, an increase of one third over last year. During 1858 they produced and sold One hundred and ten thousand pounds of wheat, Thirty thousand pounds of corn and Five thousand pounds of beans at an average price of one and one half cents per pound, beside a large amount sold to emigrants, and itinerant traders of which I have no means of ascertaining the quantity . . . From the preparations now making, by the extension of irrigation ditches &c, the increase for the ensuing year will be still larger, for all of which they will have a ready market at home.[12]

Central to their ability to produce a food surplus was a free-flowing Gila River, a fact which did not escape the special Indian agent. In his report the following year, St. John portends the fate of water on the Gila River Reservation:

> Should the land immediately above them [upstream] be occupied it would be necessary to procure water from the river Gila for . . . cultivation; at a low stage of the river this would deprive the Pimos, which would undoubtedly be a fruitful source of contention and difficulty unless some law be made for the use of water as in all sections of the country where water is used for irrigation purposes.[13]

The Akimel O'odham's lack of access to Gila River water was a point of controversy from the earliest days of the reservation, and continues today.[14]

Political Context of the Southworth Maps

Ironically, it was a man charged with protecting the concerns of the Indians, the first designated Indian Agent Ammi M. White, who instigated the first non-Indian irrigation directly upstream of the reservation. Subsequent settlers of Adamsville and Florence constructed the Florence canal and attempted to irrigate 6,100-8,100 hectares (15,000-20,000 acres), more than what had been irrigated on the reservation by the Indians.[15] Further up river, Mexican and American settlers used Gila water to irrigate rich land in the Safford and Duncan valleys, creating additional demands on the scarce water. Vincent Colyer, a member of the Board of Indian Commissioners working to ease tensions between settlers and Indians, wrote: "Four or five hundred settlers above them, on the Gila River, have built *acequias* and diverted the water from the Pima Reservation, instead of returning it to the river as they should. The Pimas and Maricopas assert very justly that in a dry season their crops will be ruined in consequence of this action of the settlers, and so an unfriendly feeling has sprung up."[16]

Combined with drought conditions, the upstream diversion of the Gila River created a crisis for those downstream. A council of fourteen Akimel O'odham and Pee Posh chiefs convened to meet with Special Indian Agent John H. Stout May 11, 1872. They reported on increasingly dire conditions on the reservation in a statement.

> We have always raised two crops a year, one of wheat and one of corn. Now, since the Americans and Mexicans have moved on the land above us and taken the water from our river to water their grain, we never raise but one crop. Some of us who live on the lower part of the land which you say is ours [the reservation] do not get even enough water to water our wheat, and much of it is now lying down on the ground, dead. We cannot raise any beans or pumpkins or melons or corn down there any more because there is no water. Some of our families there will suffer this year if your captain does not give us something to eat.[17]

Prompted by a growing crisis on the Gila River Indian Reservation, the Federal government began investigating options to increase the availability of Gila River water as early as 1896.[18] A properly placed dam would store excess water collected during high flows, and control the water's release during low-flow periods when water was most needed. While the project promised to relieve some of the water stresses, such an undertaking would require the adjudication of Indian and non-Indian water rights, a quagmire of legal and political entanglements.[19]

A Pima Agency photograph (Figure 4), documents a greatly diminished Gila River. Agency reports and photographs spurred government action. In 1913, the 63rd Congress appropriated $50,000 for a feasibility study of the proposed San Carlos Irrigation Project. Much of the middle and lower Gila River would be surveyed to quantify the amount of currently and previously farmed land. To ascertain the water rights of Gila River Valley farmers, including the Akimel O'odham, part of the investigation included mapping reservation crop land and summarizing the history of irrigation along the Middle Gila.

The Indian Irrigation Service put a young engineer, Clay H. Southworth, in charge of these tasks for the reservation. With supervising engineers N.W. Irsfeld and W.M. Reed, Southworth created a set of detailed topographic maps. Southworth hired and trained a crew of Akimel

Figure 4. The Gila River in the Gila River Indian Reservation c. 1905.

O'odham men to survey the reservation. Drawn at a scale of 1:12,000 with a 5 ft contour interval, these maps provide a detailed picture of Akimel O'odham farming during a time of environmental and social change.[20]

In his report to Congress,[21] Reed describes the survey methods and the maps. He states that, "advantage was taken of existing maps, and when these were found sufficiently accurate, they were incorporated in this work." The surveyors used a triangulation system tied into the U.S. Geological Survey triangulation system. Two to three field parties worked simultaneously to map 549 square miles, including the reservation. As Reed wrote:

> These maps show in detail the land at present irrigated, that previously irrigated, and that susceptible of irrigation from the present canal systems. They show also the complete canal systems including field laterals. The various kinds of crops to which the land was planted during the seasons 1913-1914 are designated. All roads, land fenced, and land lines are shown with sufficient accuracy to determine individual ownerships.[22]

In addition to producing the maps, Southworth also interviewed tribal elders as sources of historical farming information. Thirty-four men from districts across the reservation gave details of canal construction, changing technology, and the effects of the Florence Canal Diversion on their water supply. Published as an appendix to his report, these statements provide extensive descriptions of irrigation agriculture from the perspective of the Indian farmers themselves and help clarify the geography and history of fields shown on the Southworth maps.[23]

The land-tenure system underpinned the spatial characteristics of fields. Each field cluster coincided with at least one village. Villages consisted of family groups receiving their water from a common canal, with houses (*kis)* spread throughout the field cluster (note the small black squares representing *kis* on the map in Figure 2). From interviews with tribal members, Southworth reports:

> Villages and agricultural communities were usually made up of a number of relatives, who, having been brought together by some headman, or perhaps a committee of men, cooperated to build their ditch and establish their settlement. After the establishment of a village, the land under the ditch was allotted by the headman or committee, the size of the allotments being governed largely by those in charge of this work, the headmen, of course, always choosing the best and largest tracts.[24]

Most of the reservation acreage away from the river was treated as a commons where anyone could gather wild produce or hunt game. In contrast, major agricultural works such as dams, canals, and fences were treated as communal property; created and maintained through the efforts of the people who would benefit from them. However, individuals made decisions concerning the management of their specific fields.[25] Anthropologist Willard W. Hill stated "The responsibility for the development of the assigned plot was purely individual....The use of the land was under the direction of the patriarchal head of the family....He chose the type of crop, decided upon the time of planting and harvesting, and directed the irrigation and cultivation."[26] Fields were demarcated by lateral canals and fences of brush or barbed wire.[27] Agriculture along the Gila River took form from this patchwork of privately owned individual tracts connected by communally owned and maintained canals.

Methods

The 13 Southworth maps, each nearly 60 cm (2 feet) on a side, span an unwieldy 5 meters east-west by 2.5 meters north-south when placed side by side. Crop and village annotations appear at a very fine scale making discerning crop patterns challenging. To more easily visualize possible spatial patterns, I created a GIS using ESRI ArcMap software. I scanned sections of second-generation copies of the maps at a resolution of 600 dpi. The Southworth maps are based on the township/range cadastral survey, so I was able to register them to a modern coverage I obtained from the Arizona State Land Department.

Using the scanned image of the map as a visual guide, I digitized each of the approximately 3,300 fields represented on the 13 paper maps. While digitizing was straightforward for field clusters contained within a single paper map, for those spanning two or more maps, imperfect edge matching made determining the dimensions and area of approximately fifty fields impossible, and I eliminated them from the analysis.

By building a master attribute table for the GIS, I was able to code each field to its cluster, and designate the crop or land use marked on the paper maps. In most cases this step was straightforward, however in less than 14 percent of the fields either the code was missing or multiple codes were present. I used ArcMap scripts to calculate the area for each field, a simple way to extract quantitative data to describe and analyze patterns in agricultural fields. Table 1 summarizes the number of fields of each crop- or land-use type at each cluster and Table 2 reports the descriptive statistics for each cluster's mean field size.

Patterns in Fields Revealed Through GIS

Crop Diversity

Two caveats should be considered when using the Southworth maps as a statement of crop diversity. First, Akimel O'odham agriculture followed seasonal patterns, as noted by Reed: "It has long been a custom among the Pimas to plant their first crop to grain, which was harvested in June or July; the next or second crop to corn or beans."[28] Castetter and Bell describe in great detail the seasonality and methods used to cultivate certain key crops on the Gila Reservation.[29] The maps must be considered within the context of seasonality. The survey took place from January to June, with the month or months noted on eleven of the thirteen sheets. The two undated maps are similar to adjacent maps in terms of predominant crops, which indicates they were likely drawn in the same season. From the Southworth maps, grains (wheat and barley) clearly dominate in the cooler months (50 percent of all fields), while corn, the major warm-weather crop, is much less abundant (5 percent).

A second caveat relates to the scale of the maps. While entire fields are marked as consisting of a single crop, some crops were likely grown in smaller quantities. For example, squash and melons were staples of the Akimel O'odham diet, probably grown in household gardens and small portions of fields that would have been marked with the predominant crop. Reed states: "Annually a portion of each field would be planted to pumpkins, squash, and melons." He goes on to mention that "many kinds of semitropical fruits, such as dates, pomegranates, and olives, have been successfully grown in this valley [Gila River], as well as the more common fruits—plums, prunes, cherries, pears, etc. however, fruit raising has been confined to small orchards in connection with individual farms."[30] This statement may help explain the scarcity of orchards on the maps (only 11 of 3,301 fields). While the scale of the paper maps permits a tremendous amount of detail, showing a few fields smaller than 0.5 ha, the scale would miss smaller gardens and would tend to homogenize fields that may have been planted with small quantities of different crops.

Within these constraints, the maps do reveal variations in crop diversity between clusters, easily quantified using GIS. Table 1 shows the num-

Table 1. 1914 Gila River Indian Reservation crop diversity by cluster, west to east.

Field Cluster	G	A	C	CT	B	GD	O	NC	PC	No ID	Diversity	Total Fields
Maricopa	147	14	9	19	1		2	21	32	36	6	281
Cooperative	76	27	4			1	3	40	42	32	5	225
John Thomas	127	18	3			1	2	33	40	9	5	233
Hoover	166	54	1				1	9	8	23	4	262
Holden	123	49				1		29	15	30	3	247
Sacate	25							5	2	12	1	44
Snaketown	33		10		1			2	21	14	3	81
Casa Blanca	332		48			2		22	117	67	3	588
Santan	289	34	42	18			2	25	77	51	5	538
Sacaton	126	57	47	9	3	3	1	20	28	122	7	416
Cayah	94	6	1					45	3		3	149
Blackwater	121	11	2	4		1		34	6	58	5	237
Totals	**1659**	**270**	**167**	**50**	**5**	**9**	**11**	**285**	**391**	**454**		**3301**

Key: G (grain), A (alfalfa), C (corn), CT (cotton), B (beans), GD (garden), O (orchard), NC (not cultivated), PC (cultivated by previous culture), No ID (not identified), Diversity (number of different crop types).

Source: Data from *Gila River Survey* maps, U.S. Indian Service 1914

Table 2. Number of fields per length of lateral canal.

Cluster	Number of Fields	Lateral canal length (km)	Number of Fields/ length of lateral
Santan	538	96	5.6
Casa Blanca	588	67	8.8
Hoover	262	26	10.1
Cooperative	225	22	10.2
John Thomas	236	21	11.2
Holden	251	21	11.9
Maricopa	281	21	12.7

Source: Data from *Gila River Survey* maps, U.S. Indian Service 1914.

ber of fields of each crop by cluster. What explains the variation in crop diversity? The higher diversity near the center of the reservation (Sacaton and Santan) and in Maricopa may reflect the presence of experimental farms. The U.S. Field Station, established in 1907 through the U.S. Department of Agriculture and the Bureau of Indian Affairs, supervised the experimental planting of new crop varieties.[31] Farmers at these locations, marked "U.S. Farm" on the paper maps, may have had easier access to markets and experimental seed than farmers in villages lacking such farms.

The predominance of wheat and barley across all of the clusters would be expected based on the seasonality of the crops. Reed notes a second explanation for the preponderance of grain fields along the Gila River: "Wheat and barley are the staple crops…. alfalfa, corn, and vegetables are also raised. While the grains are the least profitable, yet they require the least water for irrigation, and this consideration is responsible for the selection of these particular crops."[32] Thus, ubiquitous grain fields may reflect a widespread water shortage.

GIS allows the quantification of crop diversity in each cluster, data that are difficult to glean from visually inspecting the thirteen paper maps. These quantitative summaries taken together with the crop maps allow straightforward data exploration and analysis.

Field Shape and Orientation

Among the field clusters, Santan's pattern of field shape and orientation stand out. While other field clusters are made up of irregular polygons situated along crooked canals, Santan is comprised of regularly shaped fields connected to the straight backbone of the Santan Canal. Figure 5 shows the distinctive pattern of the Santan fields.

This difference in pattern may be attributed to the unique conditions surrounding the formation of this canal system. In 1877, Reverend Charles Cook spearheaded the surveying of this canal and fields. A statement made to Clay Southworth in 1914 by Akimel O'odham farmer John Manual revealed that the construction process lasted years and was subject to re-engineering following a flood. Tor White, another Akimel O'odham farmer, recalled how dimensions of the canal changed as more people moved to the district:

> The reason why we came to Santan District was because our water supply got short on the Island and Sweetwater District. Mr. Cook surveyed the land for the Santan Ditch. The mouth of the ditch was about nine feet bottom running to about five feet at the end. The ditch extended to about 5-1/2 miles in length. More people came under this ditch to farm and the ditch was enlarged and extended to its present size and length.[33]

Using the tools and customs of Anglo farmers, Reverend Cook created an agricultural landscape that differed sharply from the other, native-designed field clusters. Did this difference in pattern potentially reflect a difference in canal management? Since the landowners served by a given canal cooperated to maintain it,[34] a canal efficient to maintain would serve relatively fewer fields and involve less extensive cooperation per unit length than canals serving more fields. To see if the efficiency of maintaining the Cook-designed Santan system differed from traditionally designed systems, I measured the length of lateral canals (branches of the larger main

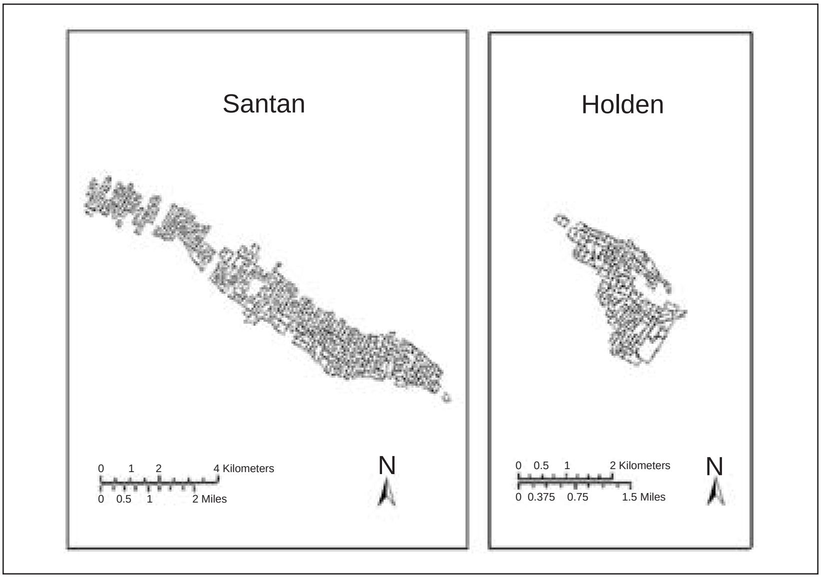

Figure 5. Field orientation in Santan and Holden.

stem canal central to a field cluster) in clusters where they were clearly shown on the map. To quantify and compare canal efficiency, I calculated ratios of lateral-canal length to the number of fields served (Table 2). The ratio of number of fields to length of canals in Santan is roughly half that of other clusters. This ratio may indicate that Santan canals constituted a more efficient maintenance system, and presumably fewer landowners would be involved in maintaining a given length of canal. If this relative decrease in cooperative labor was in fact the case, social structure and relationships may have shifted as well. While speculative, these results suggest that the changing physical landscape of agricultural fields and canals may have changed the way the canal systems were maintained.

Field Size

GIS permits the rapid calculation of area of each of the fields. Statistical software permits the analysis of differences in area between clusters, and reveals that the difference in mean are between field clusters is significant.[35] Table 3 shows these differences in field size for each cluster. Inspection of this table in conjunction with the map shown in Figure 1 reveals that larger fields are generally located near the center of the reservation, with smaller fields located upstream and downstream.

Since water was a limiting factor in agricultural production at the time of the maps, it would be reasonable to assume that the larger fields (perhaps producing a surplus) would have been located where water was most abundant. However, at the time of these field surveys, alluvial springs or *shon* still yielded some water precisely in those areas where the fields are the smallest, and the river was dry near some of the largest fields at Casa Blanca and Santan.[36] The large fields at Maricopa derived their water from the Salt River just upstream of its confluence with the Gila River, and were not subject to the depletion of the Gila River's flow.

Lee's 1904 U.S. Geological Survey study notes the marked difference in water resources at Gila Crossing (Hoover field cluster) in the west and Sacaton in the center of the reservation. He quotes a resident as stating that while the Indians inhabiting the six villages near Gila Crossing cultivate only 1,500 acres, "they have always had an ample water supply for from 4,000-6,000 acres." In Sacaton, Lee describes a different situation: "These Indians have had little water since 1890. Many farms which were productive before that time have lain idle for the past 13 years. Occasionally enough water is obtained from a flood or from a shower to raise a scanty crop if the land happens to be ready at the right time. This, however, is so uncertain that most of the Indians have long since ceased to prepare their fields for the possibility."[37] If early 1900s water resources fail to correlate with field-size observations, what then explains the distribution of field sizes across the reservation?

Table 3. Cluster field characteristics by age of canal construction.

Cluster	Number of Fields	Total Area	Mean Area/Field	Standard Deviation	Age of Construction
Casa Blanca	588	1745	3.0	2.4	Ancient
Sacate	44	150	3.4	3.4	Ancient
Snaketown	81	200	2.5	1.5	Ancient
Blackwater	237	637	2.7	2.8	1866
Cayah	149	561	3.8	4.4	1869
Sacaton	416	973	2.3	2.8	1872
Hoover	262	415	1.6	1.0	1873
Holden	247	321	1.3	1.5	1877
John Thomas	233	285	1.2	1.0	1877
Santan	538	1484	2.8	1.9	1877
Cooperative	225	433	1.9	1.7	1900
Maricopa	281	652	2.3	1.8	unknown

Source: Data from *Gila River Survey Maps*, U.S. Indian Service, 1914. Canal ages from Clay H. Southworth, "History of Irrigation on the Gila River," *Appendix A—Hearings Before the Committee on Indian Affairs*. House of Representatives 66th Congress 1st Session June 30, 1919.

These differences in field size did not go unnoticed by early observers. Taking a historical look at possible changes in field size may provide clues to the uneven distribution of field sizes observed in 1914. Early sources indicate varying estimates of field acreage. Garces states in his 1775 manuscript "Their sowings of wheat [are] very large, well set off and fenced, and although it seems that all join to make the fences they have their lands within divided."[38] Russell estimates that "Each family cultivates from 1-5 acres. With an abundance of water and the new needs of the tribe it is probable that the size of the individual holdings will rapidly increase."[39] Castetter and Bell echo this estimate: "It is our own judgment that in early historic times the cultivated acreage per Pima family varied from two to five acres. More-over [sic] it is certain that the average size of the Pima farm anciently was much smaller than at present."[40] Agency Superintendent J.B. Alexander summarized populations and acreages for several villages in January 1903 (Table 4).[41] Interestingly, these patterns persist through the next decade.

Table 4. Gila River Indian Reservation Village Population and Land Cultivation, 1903.

Village	Population	Families	Acres Cultivated	Average Acres/ Family
Blackwater	490	100	705	7
Sacaton Flats	312	70	520	7.5
Sacaton	275	60	not reported	
Casa Blanca	918	210	2000	10
Santan	322	80	900	11
Gila Crossing	1195	280	1035	4
Maricopa	350	190	900	13

Source: J.B. Alexander to W. Code, 1/28/1903, National Archives RG75 BIA, Irrigation Division, General Correspondence, 1901-31, District 4. Gila River.

Hill was less specific in his estimate, but provides hints about how field size was determined:

> Agricultural plots were of no particular size. The ends of the farms bordering on the ditch were measured off in "so many ropes," and each family received a section of land of the same width. (this width might and did vary in different villages.) The length of the farm was determined by the needs of the owner and by the feasibility of conveying water to the far end of the field. If the family outgrew the assignment, more land was given to them. The number of acres in each plot varied.[42]

The size of the fields may have changed with changing economies. Prior to the arrival of military, clergy and settlers the Indians grew enough food for their families and for small-scale trade with surrounding tribes. In the mid-1800s, they became players in an expanded economy as they supplied the U.S. Army with wheat and alfalfa, both new crops to the Pima.[43] New settlers and the onslaught of miners headed for California provided ever-increasing demands for their produce. Farmers increased the amount of land under cultivation and prospered while there was sufficient water to irrigate their land.[44]

This increase in cultivated land may be reflected in larger fields, as noted by Indian Agent Roswell Wheeler in 1884.[45] Providing possible evidence in this vein, Russell relates: "…an ancient measurement…hUmakâ kUirspa, "one step"—that is, one step with the same foot, equal to about

5 feet. Land is divided into plots 100 or 200 "steps" in width, according to the size of the family."[46] If this dimension is used for both width and length, the resulting plots would be two to nine hectares (five to twenty-three acres).

Table 3 shows mean field size in each cluster in relative order of canal construction. In general, older fields are larger. This temporal trend in field size may be explained through changing water availability. Older, larger fields were established during times of dependable streamflow, while the smaller fields were established as the depleted streamflow forced the gradual abandonment of the larger fields.[47] From Southworth's interviews of tribal elders, it is clear that the construction of many of the canals upstream and downstream was sparked by environmental crisis. Many Indians moved from the dry central reservation to the comparatively wetter regions upstream and downstream. These moves were made in desperation. With little time to establish new canals and fields, they may have established their field size based on the amount of land they could optimistically bring into production with a limited amount of water in a short time period. The smaller field size may reflect field establishment during a time of limited water resources and severe economic pressure.

Seen through this broader perspective, the Southworth maps become more than a mere static snapshot of a reservation at a particular point in time. Rather, the maps provide critical observations that aid in creating a dynamic view of a place undergoing a tremendous amount of social and environmental change.

Conclusion

Geographical information systems serve as useful tools to explore and analyze historical maps, permitting analyses previously difficult if not impossible. This fresh perspective generates new insights as well as new questions. In this study, GIS provided the means to consolidate, organize, and analyze large quantities of qualitative and quantitative data. Because the maps themselves provide only part of the story, augmenting the GIS data with primary sources contextualizes and helps explain patterns. New, fine-scale patterns not readily apparent on paper maps emerge, presenting additional questions.

This study addressed three patterns: crop diversity, field shape, and field size. Crop diversity was simply quantified, and GIS-produced maps allowed the visual exploration of patterns in diversity. Areas central to reservation administration and crop experimentation displayed higher levels of diversity that may reflect greater availability of agency resources and transportation networks for marketing the variety of crops. The orientation and shape of the fields is a manifestation of different cultural practices, as seen in the example of the Santan field cluster. While the pattern is apparent through a casual inspection of the digitized maps, first-person accounts of the missionary's development explain the pattern. Differences in field size are not immediately apparent until quantified and statistically described, tasks requiring GIS. The differences reflect the dynamism of Akimel O'odham settlement in a time of tremendous social and environmental change.

Exploration and analysis of Southworth's exquisitely detailed historical maps provides insights impossible to be gained through other historical documents alone. GIS permits clearer visualization and novel analyses of agricultural patterns. In this study, these results help illustrate and reconstruct a highly dynamic period in Akimel O'odham history. GIS facilitates the investigation of fine-scale patterns, suggesting new questions. Instead of a static landscape, a complex environment in social and ecological flux emerges. GIS offers fresh ways of visualizing and analyzing historical maps, stimulating new lines of inquiry.

Notes

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