PLAUSIBLE ETHNOGRAPHIC ANALOGIES FOR THE SOCIAL
ORGANIZATION OF HOHOKAM CANAL IRRIGATION

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This paper presents the results of a juxtaposition of archaeological findings on Hohokam irrigation and ethnographic research on the social organization of irrigation. There are no ethnographic or historic records pertaining to the Hohokam, so the comparative ethnographic approach is perhaps more productive than in other situations. Several forms of canal irrigation organization are considered, including politically centralized, acephalous, private, and several forms of communal. We find that politically centralized, acephalous, and private forms are implausible in the Hohokam context. Several of the communal forms are plausible. We find no ethnographic basis for positing a valley-wide management system.

Este trabajo presenta los resultados de una juxtaposición entre hallazgos arqueológicos sobre la irrigación Hohokam e investigación etnográfica sobre la organización social en sociedades agrícolas que emplean sistemas de irrigación. Puesto que no hay registros etnográficos o históricos sobre la cultura Hohokam, un enfoque etnográfico comparativo parece ser más productivo que en otras situaciones. Se consideran varias formas de organización de irrigación por medio de canales, incluyendo ejemplos de centralización política, de sociedades acefálas, de empresas privadas y de obras comunales. Concluimos que formas con centralización política, acefálas, y privadas son poco plausibles en el contexto Hohokam, pero varias formas de organización comunal sí son factibles. No encontramos ninguna base etnográfica para proponer la existencia de un sistema administrativo macro-regional.

Humans have occupied the northern Sonoran Desert for nearly ten millennia using a variety of subsistence strategies (Bayman 2001). Canal irrigation is attested by no later than 1200 B.C. in the Tucson area (Mabry 1999; Mabry et al. 1997; Muro 1998a, 1998b). "Hohokam" is the name applied to the culture in the area from sometime in the first millennium B.C. until disappearing shortly before the Spaniards arrived in the New World. The occupation of the Phoenix Basin between A.D. 500 and about A.D. 1400 was based upon the agricultural products of large expanses of land irrigated by the Salt and Gila Rivers. Around the present-day Phoenix metropolitan area they built and used four large (and more smaller) canal complexes (sets of main canals with proximate headgates that are known to Hohokam scholars as "canal systems," with more irrigated land (>20,000 ha.) than any other culture north of Mesoamerica until the sixteenth century A.D. (Doolittle 1990; Neely 2001).

Irrigated agriculture is a prominent feature of the Phoenix basin Hohokam, and irrigation features have received a great deal of attention (see Abbott 2000, 2003; Ackerly et al. 1987; Breternitz 1991; Graybill et al. 1989; Haury 1976; Howard 1993; Masse 1981). There has been interest in the amount of labor needed to build and maintain the canals, in the social organization that provides the authority structures for managing a canal, and in

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the nature of the management of the relations between canals.

Centralized political control became most pronounced during the Classic period (ca. A.D. 1150–1350+) when more than 100 platform mounds were built at the largest settlements. These monuments, which required the labor of supra-household groups to construct, served as elevated surfaces for public and private functions. In the intensely irrigated lowlands of the Phoenix basin, we find the highest density of platform mounds (more than 40) equally spaced (roughly 5 km apart) along the canal routes in the lower Salt and middle Gila River valleys. Among prehistorians, a consensus holds that the local Classic period leaders were associated with those monuments. Those same scholars, however, hotly debate how leadership authority was configured and what effect the irrigation economy had on leadership development.

Several analysts have theorized that social differentiation in the Phoenix basin was closely associated with vested authority for canal administration, which assured an equitable supply of irrigation water. The equal spacing of platform mounds along the canals may be the most salient evidence for coordinated leadership that oversaw the irrigation economy (Doyel 1981; Gregory 1991; Gregory and Nials 1985; Teague 1984; Wilcox 1987a, 1991).

Ideas about how Hohokam hydraulic management worked, however, are sketchy. Researchers agree that by the Classic period, the largest mound village in each canal system was differentiated from the others by some aspects of decision making, consumption, and conflict resolution (Crown 1987; Fish and Fish 1992:100; Gregory and Nials 1985; Upham and Rice 1980). Suzanne Fish (1996:112) inferred that the organized constituencies of different platform mound communities cooperated for canal operations, maintenance, and emergency repairs. As discussed elsewhere (Abbott 2000:41), this conceptualization logically implies a federation of sociopolitically separate communities negotiated by their leaders—an idea that suggests a more hierarchical political structure than if a single, large sociological community was coterminous with each irrigation cooperative.

Most investigators probably would agree with Gregory (1991:182; see also Abbott 2003) that social or political entities above the level of a canal system probably never existed, but Howard (1993:316–318) has proposed more complex administrative institutions during the Classic period (see also Wilcox 1988, 1999). In the lower Salt River valley, according to this view, conflicts over water flared as the irrigation infrastructure was expanded and overtaxed the limited stream flows, especially in dry years. Howard suggested that the many changes in Hohokam society that transpired at the beginning of the Classic period (including the platform mound constructions) possibly reflected a sociopolitical integration of neighboring canal systems to manage irrigation, perhaps at a valley-wide level. As Howard (1993:316) noted, if an intercanal-system political structure did evolve, “it would suggest the attainment of a level of complexity above simple rank or hierarchical societies and implies a range of complexity usually attributed to the formative states of Mesoamerica."

The Hohokam culture is known only from the archaeological record. Unfortunately, urban sprawl in the Phoenix basin through the last several decades has obliterated much of the evidence for Hohokam occupation there. Fortunately, during the last three decades there has been an enormous increase in the amount of archaeological excavation and survey of Hohokam sites, due mainly to cultural resource management work on infrastructure projects associated with urban expansion (see Gunerman 1991).

At first contact with Europeans (in the late seventeenth century) the Salt River area was unoccupied, and remained so until Anglo settlements in the mid-nineteenth century. The Gila River and its tributaries the Santa Cruz and San Pedro, on the other hand, were occupied by the Pima who had canal irrigation. The Pima are presumed by some to be descendants of the Hohokam.

Detailed observations of Pima agriculture start in the mid-nineteenth century, when the Pima were growing and selling large amounts of wheat to whites (many of whom were on their way to the California gold fields.) The Pima were more systematically investigated by Frank Russell in 1901–1902, and by Edward Castetter and Willis Bell in 1938, 1939, and 1940. By the time of Russell’s fieldwork at the turn of the century, upstream Anglos had already taken most of the water from the rivers, so Pima agriculture at the time was in
dire straits. By 1928 the Coolidge Dam had come on line, and there was more water for the Pima on the middle Gila.

Unfortunately the Pima ethnography is nearly silent on crucial questions of irrigation. The length of canals, the amount of land under a single canal, and the operation and maintenance of the canals are not addressed. Apparently there were village chiefs who had some responsibility for construction of new canals, but there is little more said.

In modern times as well as in the Pima ethnography, the size and scale of irrigation on the Middle Gila is less than on the Salt. While what little we know of Pima irrigation matters might well apply to the prehistoric irrigation, there seems to be no reason to use the Pima ethnography as a guide for interpreting the vastly larger systems the Hohokam built and operated on the Salt River. Doyel’s statement holds:

The Pima and Papago . . . did not build hundreds of miles of canals, 225 ballcourts, or over 60 platform mounds; neither did they maintain an economic system encompassing some 80,000 square kilometers in area. They possessed neither the population levels nor the complex settlement hierarchies documented for the prehistoric period [Doyel 1991:226].

The ethnographic record provides several models for the social organization of canal irrigation. The purpose of this paper is to apply the results of ethnographic research elsewhere to the evidence of Hohokam irrigation in the Phoenix Basin. Some of the ethnographic models we consider are more plausible in the Hohokam context than others. We conclude that we have been able to narrow the range of plausible organizational alternatives that the Hohokam may have employed in managing their irrigation agriculture.

Hohokam

The Hohokam culture should first be noted for what it did not have, given its Southwestern and Mesoamerican neighbors. There is no sign of cities, substantial division of labor, or writing. Among domestics we are missing the turkey, tomatoes, and chili peppers. Most scholars agree that even at its Classic period apogee there was no state (Crown 1991; Fish and Fish 2000).

The Hohokam occupied a large territory ca. 80,000 square kilometers (Doyel 1991) and a wide variety of habitats, including the valleys of large rivers, smaller stream basins, and uplands (Figure 1). They utilized wild game, fish, agave, saguaro cactus, mesquite, and other wild plants. Their crops included maize, beans, squash, pumpkin, cotton, tobacco, and a diverse array of annual and perennial native plants. They lived in small settlements all over their territory. Even in the Phoenix basin, with elaborate irrigation facilities, the largest settlements contained fewer than 2,000 people. The total population at any given point in time is a matter of debate, although approximately 50 villages were probably contemporaneously occupied during the Classic period in the lower Salt River Valley.

Irrigation in the Phoenix basin grew during the Pioneer period (ca. A.D. 1–500) (Howard 1993), and lasted for several hundred years until the end of the Classic Period, some time after A.D. 1350 (Abbott 2003). During the Classic Period, there were many canals drawing water from the Salt around contemporary Phoenix, and most archaeologists recognize four large complexes among them: “Canal System 1” and the “Lehi System” on the left bank, “Canal System 2” and the “Scottsdale System” on the right bank. Figure 2 depicts some of the major ones and gives some indication of the very large scale of Hohokam irrigation features.

Although the end of the Hohokam occupation of the Phoenix Basin some time after A.D. 1350 is under investigation, there is little agreement among scholars on a more precise date for the Hohokam collapse (Bayman 2001:290–293).

The Phoenix area is watered primarily by the Salt River. The fluvial regime of the Salt is of considerable importance in a discussion of irrigation. There are two primary sources of water: winter precipitation in the headwaters that provide a spring flood of snowmelt, and summer rainstorms that supply less water but result in a marked increase in river flow during August and September. The geologically young riverbed of the Salt River is flat and shallow, rather than deep and well incised. Aside from annual flooding, catastrophic floods with flow volumes several magnitudes above the annual average are also known to have occurred (Graybill et al. 2004; Nials et al. 1989:65, 68, 69). Even with storage dams on both the Salt and Gila Rivers, there
were downstream floods in 1980 on the Salt (Masse 1981:409), and in 1983 and 1993 on the Gila (Darling et al. 2004:286).²

The agricultural regime is equally important. The reader should be aware throughout the following discussion that a very important component of the agricultural regime—the agricultural calendar—is not available. An agricultural calendar depicts the timing of field preparation, planting, competitor control, and harvesting, along with the crops grown, and environmental variables (such as frost, rainy season, floods, etc.) The combination of the agricultural calendar and the fluvial calendar (with annual and decadal variation) shows how variations in river flows correlate with stages of agricultural production, labor demands, and crop vulnerabilities in the fields. Floods, water scarcity, and system maintenance are major phenomena to be dealt with by an irrigation organization. Without the agricultural calendar we are much more ignorant about timing and about threats to the systems than is desirable.

Hohokam settlements are relatively well understood. The social and territorial organization has the characteristic feature of modularity. Beginning in early Hohokam villages, two to six pit houses opening onto a common courtyard are considered residential aggregates linked by kinship (e.g. Henderson 1987; Howard 1985; Wilcox et al. 1981). These courtyard groups are the building blocks for all higher levels of organization. Larger residential groupings with several house clusters are designated suprahousehold units or village segments (Doelle et al. 1987; Henderson 1987; Howard 1985; Wilcox 1987b). During the Classic period, pit houses were largely replaced by above-
ground adobe rooms, but the modular arrangement persists (Sires 1987). Adobe room clusters, especially in larger sites, were enclosed into walled compounds. Large compounds, including several room clusters, recall the higher-order suprathousehold units or village segments.

The Hohokam trajectory is marked by changing territorial institutions that parallel developments in residential and kinship organization. These institutions are subsumed under the concept of a "community," a territorial entity with archaeological expression in spatial patterns and symbols (e.g., Adler 1994; Doyel and Lekson 1993; Fish and Fish 1994; Wilcox and Sternberg 1983). According to this view a Hohokam community consists of a set of interrelated settlements within a bounded territory and contains a center with public architecture not duplicated in farmsteads, hamlets, and smaller villages within the community. Integration of the population of multiple settlements is symbolically embodied by ballcourts and plazas prior to A.D. 1150 and by platform mounds after that time. (But see Abbott 2000 for an alternative perspective on community organization in the lower Salt River valley.)

It seems reasonable to infer that at least one office would have been connected with each community. Activities that might be associated with the office include defense, ritual, long-distance trade, regulation of marketplaces, external and internal conflict resolution, craft production, agricultural production, and irrigation, in various combinations. The office could be a coordinator for a council of elders, or could have more power associated with it. There could be a small hierarchy of offices involved.

It is evident that there is considerable spatial variation in the Hohokam area (Fish and Fish 1994) over time. This paper concentrates on the largest and best-known set of Hohokam canals during the Classic period and does not attempt to incorporate the temporal and spatial variations.

Review of Archaeological Literature

A number of archaeologists have proposed inter-
pretations for the social organization that managed Hohokam canals. Here, we will focus on those dealing with the largest canals. As we will see, there are several positions in the literature.

There are a number of issues. Everybody agrees that cooperation and competition are major dilemmas for canal irrigation. The social organization has to deal with how to achieve cooperation, and how to manage competition. Another issue is the control of the labor needed to construct and maintain the canals. Water scarcity is recognized by everybody as posing problems, and the solutions (if any are found) are mostly in the social organization. Finally, there is the issue of the effect of scale on the organization. There is a general presumption that as the scale of the irrigation facility increases the need for controls increases as well.

Woodbury (1961) is the main exponent of small-scale social systems. Woodbury excavated a number of trenches across canals at Pueblo Grande (on Canal System 2). He responded to Wittfogel’s Oriental Despotism (1957) in his interpretation. Woodbury argued that Hohokam canals could have been built by accretion, digging a small canal in one agricultural season. As Howard (1990) and Doolittle (1991) have argued, a canal can be widened by accretion but it cannot be significantly lengthened in the same way. The purpose for lengthening is to increase command area (the area of fields irrigated by the system), which requires that more water be provided. The standard way to accomplish this is to dig a deeper canal as well as a wider one. But deepening a canal in place will not permit water to flow to fields at the tail, as there is insufficient head for the water. To deepen a canal means moving at least the upper reaches of the canal upslope, and thus digging a new canal.

Turning to operation of the canals, Woodbury (1961:557) was of the opinion that “simple traditional agreements” would have been sufficient for cooperation. And, he continued, “a more formal legal alliance of two or three villages for the purpose of managing mutual water problems would still fall far short of strong central authority that the theory of ‘hydraulic society’ proposes” (Woodbury 1961:557). Woodbury proposed that a local control system was plausible.

Masse (1981) argued for larger and more centralized control systems. Masse (1981:412) estimated command areas for main canals at 1,000–10,000 ha and noted that the Salt River canals were much larger than those along the Gila River at Snaketown. He concludes: “On the basis of Pueblo Grande data [Canal System 2], I suggest that some form of coordination or control was necessary not only with single irrigation systems, but among all the systems in the Salt River Valley” (Masse 1981:414). The characteristics of these control systems spanning different canal systems were not identified.

Nicholas and Neitzel (1984) contrast the “egalitarian” view of canal management of Woodbury and Haury with their view that a complex or centralized system was needed. Nicholas and Neitzel discussed several tasks (construction, maintenance, distribution) and review the growth of canal systems on part of the left bank of the Salt River. Rejecting the egalitarian model, they conclude that the scale of the left bank systems was large enough to require administrative hierarchies for each canal system (Nicholas and Neitzel 1984:174). They also are of the opinion that the administrative hierarchies became more complex as the canal systems grew (Nicholas and Neitzel 1984:174).

Nicholas and Feinman (1989) consider the entirety of the Salt River middle basin based primarily on aerial photographs. They distinguish between “horizontal organizational structures” (apparently kinship or territorial groups) and “hierarchical organizational structure” (Nicholas and Feinman 1989:217, 220). They are of the opinion that there was no basin-level management system (Nicholas and Feinman 1989:225).

Jerry Howard (1993) has presented one of the most detailed archaeological accounts of canal irrigation for the Hohokam. Howard has a detailed reconstruction of the sequence of changes in Canal System 2 and provided many calculations of volume of water, potential acreage irrigated from the canals, and labor needed for construction.

For social organization, he starts at the bottom of the system with a Unit Command Area, “the group of farmers who formed a cooperative productive unit along a single distribution canal.” Members would have to “cooperate in water allocation, water scheduling, and local ditch maintenance and construction” (Howard 1993:309). He does not discuss the principles of organization of the Unit Command Area. The next unit up is the users of a distribution canal, which includes sev-
eral Unit Command Areas. Next above comes the branch canal, and both levels would have to coordinate water distribution. Individual canals (presumably, what we are calling main canals within the canal system) are the next level of organization (Howard 1993:309). The village is the next level up. When there are multiple villages on a canal system, “the village near the canal head takes the lead in organizing the system as a whole” (Howard 1993:310). It should be noted that Howard has shifted from hydraulic features to settlement features.

Howard sees a need for a “complex, centralized administration on an intrasystem level” (1993:315) to handle the amount of water and the amount of labor mobilized. Above the Unit Command Area, Howard locates officers in villages, with a hierarchy of such offices (Howard 1993:315).

David Abbott (2000, 2003) has traced the robust exchange of utilitarian pottery over short distances in order to outline the social networks and community boundaries within the lower Salt River valley. The ceramic evidence has led him to characterize Canal System 2 during the early Classic period as a single integrated irrigation community. In contrast to the arguments for a multi-tiered and politically centralized administration, Abbott suggests that a less complex and situational decision-making body, organized communally in Canal System 2, probably managed irrigation during the early Classic period and before. Political elites, however, may have taken control of the hydraulic works during the late Classic period when environmental and social conditions were probably on the decline. Abbott also interpreted the ceramic patterns to suggest that Canal Systems 1 and 2, the Lehi System, and the Scottsdale System followed different trajectories of social development, thereby contradicting the idea that they were ever administratively united for irrigation purposes.

Glen Rice (1998) presents segmentary opposition as another possible model for organizing Hohokam canals. Basing his model on Sahlins’s (1961) argument about segmentary lineages and warfare, Rice proposes that settlements on long canal systems could relate to each other on the basis of force and cooperation. Segments would oppose each other at one level, but cooperate with each other in opposition to other segments at a different level. Rice doubts the validity of the horizontal model for the larger canals (Rice 1998:292–293).

In summary, we have several proposals in the archaeological literature for organizing Hohokam canal irrigation at the systemic and intersystemic levels: (1) at the system level the organization can be egalitarian, have two kinds of administrative centralization (tight or loose), or be segmentary; (2) at the intersystem level some find no administrative centralization, and some think there was some.

In what follows we explicitly range over the ethnographic literature. There are three main topics to be considered: (1) how each main canal and canal system were managed, (2) whether or how relations between canal systems were managed, and (3) how irrigation system management might connect with institutions apart from the canal, such as offices of polities, or elites.

Social Organization of Irrigation—Concepts

At the time that Wittfogel (1957) was writing Oriental Despotism there were only historical accounts of canal irrigation, and few of those accounts were available to the general reader. Since 1957 a substantial literature has accumulated. Many projects of field and archival work on irrigated zones have been conducted, written up, and published. In addition, there has been systematic comparison of the ethnographies. In what follows, we apply findings from both the field studies and from the comparative efforts. We are inferring Hohokam irrigation organization principally from the ethnographic data, rather than from the archaeological data.

It should be noted that we are dealing with two moving targets. Knowledge of irrigation features in the northern Sonoran desert increases with each year. It is likewise with our knowledge of the social organization of irrigation. New cases appear every year, and the comparative and conceptual work is only slightly behind. This article is an attempt to capture much of what is known of Hohokam irrigation features in 2003, much of what is known of the social organization of irrigation (from historic, ethnographic and ethnological sources) in the same year, and to apply the latter to the former as an example of ethnographic analogy. Hopefully neither branch of knowledge has reached the end of its road. If this exercise is fruitful, it will need to be repeated in the future as knowledge from both sides grows.5
Hunt has noted (Hunt 2003) that virtually all of our ethnographic cases derive from irrigation systems found in states. The exceptions are the Sonjo, Mount Kilimanjaro, and the Tanala. As the Hohokam (by most accounts) did not have a state, the question of the impact of the state on irrigation is an important consideration. Over the last several millennia, states have varied enormously in how effective they were in managing local agriculture, and in how interested they were in doing so. One is likely to assume that any state is a strong state and effectively manages the rural areas. The thrust of Wittfogel’s Oriental Despotism thesis (1957) was that one kind of strong state took considerable interest in irrigated agriculture. But we have many examples of states that were either too weak to intervene, or chose not to. Among them can be included Valencia (Glick 1970), Mexico, highland Peru, the Philippines for centuries under Spanish rule, Japan, and many others. The existence of a state does not automatically produce regular and systematic state intervention in local affairs, especially in irrigation affairs. In the industrial era the state has organized construction of water control features (including irrigation) and has a strong interest in conflict resolution in cases involving death. No other intervention in irrigation is always or even routinely associated with states. We therefore conclude, until persuasive arguments to the contrary are forthcoming, that the existence of a state in the vast majority of ethnographic examples does not affect our argument.

Following Kelly (1983) and Hunt (1988), we distinguish between two foci of organization for canal irrigation in general, the management internal to a main canal, and how that canal management is connected to other features of the society (such as political offices, elites, etc.) Hunt conceptualized the internal structure as unified or acausal and then discussed the various charters of authority for the officers of unified systems, as discussed below.

**Canal System: Definition and Size**

Care is needed when applying the word “system” to canal irrigation. The term “system” has been applied with varying degrees of precision in the literature on irrigation by both the Hohokam archaeological community and the ethnographers. The entirety of the Phoenix Basin irrigation has been called an irrigation system, and each of the four major complexes of canals with proximate headgates is called a canal system. Two of the four major Salt River Hohokam canal sets have “system” in their names (Canal System 1, Canal System 2). Ethnographers are equally quick to apply the term “system.”

This article concentrates on Canal System 2 during the Classic Period, and, as we will see, there is considerable uncertainty about what “system” means in this context.

Hunt proposed a definition of a canal irrigation system in 1988:

A canal irrigation system is composed of (1) a facility (gate, offtake) which takes water from a natural channel and moves it away from its natural downhill course and (2) the subsequent control works (canals, gates, fields) that guide the water flowing on the surface to the agricultural plants until that water either soaks into the earth or flows on the surface out of the control works [Hunt 1988:339–340].

Hunt notes at least two problems with this definition, systems with more than one headgate, and uncertain boundaries between systems (Hunt 1988:351). It should be noted that this is a physical, not a social, definition, and a social system would have to be defined differently. Hunt (1988) in the same article discusses the structure of authority associated with the physical “systems.” The only explicit link between the two is that the authority structure is associated with operation of the main gate, or intake.

Given that we have evidence for physical systems in the Hohokam case, and are trying to infer social systems, the physical definition seems an appropriate one. For considerations of the relationship of size to social organization, it will eventually be necessary to establish what we mean when we call something “an irrigation system” from the social point of view. For the moment we assume that the discussions of roles, tasks, and rules in the social organization of irrigation is firmly connected to the management of the physical manifestations of irrigation (intakes, canals, gates, and fields). There is no doubt that it is connected, but a systematic discussion of the variations in these connections has not been done.

Following the Hohokam irrigation literature we
use “canal system” to refer to a complex of main canals with proximate headgates, along with their distribution and drainage facilities as discovered and documented by historians and archaeologists in the Phoenix area. A “physical irrigation system” is the headgate, main canal, and subsequent works as defined by Hunt in 1988. “Irrigation social organization” will be used to refer to the roles and tasks associated with the construction and operation of “physical irrigation systems.”

Size of a canal irrigation system is always of interest. Large-scale systems are widely (if erroneously) thought to require certain kinds of management. Hunt (1988) refutes this idea using ethnographic data. How we measure size is important. The archaeological literature on Hohokam provides measurements of the length of some main canals, sometimes is able to measure their cross-sections, and then estimates the amount of water that could have flowed in that canal. The engineering and ethnographic literature measures command area, the area of fields irrigated by the (physical) system. Command areas for Hohokam canals have apparently never been measured. Rather, they have been estimated from measurements of main canals. All such measures and estimates are problematic. (See Hunt [1988:343–345] for an extended discussion of the principles and problems, and Doolittle [1991:149–144] for a detailed discussion of field and tail-end features.)

Howard’s primary concern is with the canals included in Canal System 2. He suggests that it had a total Classic Period command area of approximately 7,600 hectares (Howard 1993:294–295). The complex had 9 “main canals” in use at the same time, and a single canal could have a command area as large as 1,800 ha. We argue that it is useful to consider each separate main canal to represent a different physical irrigation system with its own management institutions. It is conceivable that two or more of the simultaneous main canals were managed as a unit (with integrated headworks). It is even conceivable that all nine were part of an organizationally integrated canal system. The differences may not make a difference. From the comparative literature it is fairly clear that the change in size from 1,800 ha command area for a single canal to 7,600 ha command area for all nine main canals does not make a difference in management requirements. Ethnographically, no single-village irrigation systems are as large as 1,800 ha. All systems of this size involve several villages, so intervillage management must be developed. Eventually we might be able to determine how the multiple main canals of Canal System 2 relate to each other in terms of simultaneity and organization.

Tasks, Roles, Charter of Authority

In the ethnographic record some universal tasks have been identified including construction, distribution, maintenance, accounting, and conflict resolution. Ritual was probably widespread before the industrial revolution, but is now rather infrequent. Allocation, the dividing of available water by rights, is widespread but not demonstrably universal. Roles (to perform the tasks) include farmer/user, worker, and officer (Hunt 1988).

If the social organization is unified there is a chief administrative officer (CAO). Charter of authority refers to the source of authority for the CAO: so far we have identified several kinds of communal charter, two kinds of political centralization, and a private charter (Hunt 1988, 2001). There are several kinds of communal charter: Irrigation Community, a corporate group of all and only the users; Municipality, the local territorial unit; and District, a territorial unit larger than a village created by a state, which is granted management authority over the irrigation facilities. Political Centralization can be located in the State, or in a Province of a state. A private charter occurs when a wealthy person (or joint-stock partnership) builds and owns the system and runs it (Hunt 1988).

There are, in addition, a few cases of irrigation community consortia. A number of contiguous irrigation systems organized as irrigation communities combine in a consortium to manage some of their affairs. In every case known to Hunt the systems draw water from at least one common source. Valencia is the best known of these (see Glick 1970; Maass and Anderson 1978 for accessible accounts). The King’s River Water Association based in Fresno California is another case (see Hunt 1988, 1994; Maass and Anderson 1978). These consortia occur in states, but seem to be run in a bottom-up way. State control of them seems to be minimal.

There are a handful of ethnographic systems that are acephalous, in the sense that there is no role with authority to manage the system. They are all
quite small, none irrigating more than 20–30 hectares (Hunt 1988).

Community(ies)

Community and village are often used to describe the locus of irrigation management. It is possible (but not always necessary) to separate the roles of irrigator from village member. We have a number of ethnographic irrigation systems where the village administration is responsible for, among other duties, managing the irrigation system. The village administration usually has responsibility for a number of activities, including roads, bridges, ritual spaces, conflict resolution of many sorts, and relationships with members of other settlements, and with other settlements. In states these settlements are always arranged in a hierarchy. Village officers may well have permanent physical offices, and irrigation affairs may well take place there.

We have a number of ethnographic irrigation systems where membership is composed of the users of irrigation water, and it is explicitly separated from membership in settlements. One of the first cases described in the literature was Bali (Geertz 1967). There, the irrigation unit is the subak, which is made up of landowners who receive water from a common outlet. The subak has an organization, officers, membership, a treasury, etc. Villages are based on residence, not land-owning, and they also have an organization, officers, membership, etc. A natural person is a member of only one village, but they are members of each subak within which they have water rights.

Recently it has become clear that all irrigation communities based purely on water rights are also separated from village administrations. This is as true of Valencia (Glick 1970; Maass and Anderson 1978) as it is of the King’s River Water Association in Fresno California (Hunt 1994). Thus, while it is tempting to connect a physical settlement with an irrigation system, there is no necessary connection between the two.

Canal System 2 Social Organization

Among the many canals that took water from the Salt River in the Phoenix Basin (see Nicholas and Feinman 1989 for maps) there are four large sets that have been bundled together by archaeologists (Canal System 1 and Lehi on the left bank and Canal System 2 and Scottsdale on the right bank.) Determining the size of these sets of canal systems is problematic. Archaeologists have tended to measure them by the length of the main canals. Nials and Gregory (1989:55) stated a range of length of main canals of 5–24 km, with Canal Grande in Canal System 2 at 24 km. Howard (1993:296) presents lengths for Canal System 2 canals: Grand Canal (? Canal Grande) is 20 km, and both Woodbury North and East Papago are given as 34 km in length.

Command area is the dimension of size most used by geographers and anthropologists, and is of course hard to measure archaeologically. Nials et al. (1989:70) calculate the land area that could potentially be irrigated from the Salt River. They use the annual Salt River discharge (estimated from tree ring data from the upper watershed), irrigation duty assumptions of 5, 6, 7, 8, and 9 acre feet of water/acre, and three different conveyance efficiencies (20, 30, and 40 percent). The range of land area that could be irrigated by the Salt ranged from 2,652 ha in the worst drought years to 84,134 ha in maximum flood years.

Howard (1993) calculates the land area that Canal System 2 could irrigate, based on measurements of canal cross sections. He calculates canal capacity, assumes a duty of 1 cusec (one cubic foot per second) for 40 acres (16 ha), and assumes the total should be divided by 4 to account for a 25 percent delivery efficiency. Using these assumptions, he arrives at figures of 8,473 ha in the Colonial period, 6,709 ha in the Sedentary period, and 7,614 ha in the Classic period. Focusing now on the three long canals in the Classic period Canal System 2, Grand Canal could have irrigated 1,023 ha, Woodbury North 1,814 ha, and East Papago 1,307 ha. In contrast, Howard’s estimate for Canal System 2 is near the upper end of the range Suzanne Fish (2000:257) reports for the total irrigated area for the Phoenix basin, 4,900–9,800 ha.

The measurements of length of canal seem to be reasonably stable, although it would be good to know more about the observations of the tail ends of these long canals. The estimations of command area are based on large numbers of assumptions that vary from study to study and would appear to be highly variable. Nevertheless, we are almost certainly talking about sets of canals with command areas in the thousands of hectares, and individual
canals with command areas in a few cases of more than a thousand hectares. This gives an approximation of the size of the command area of the facilities.

Canal System 2 is apparently the largest of the four main sets of canals on the Salt River in the Phoenix Basin, and of the four, it has received the greatest amount of research and publication. Most of what we have to say in the paper is focused on Canal System 2 during the Classic Period.

As can be seen in Figure 2, there are many canals shown. The precise dating of canal construction and use is notoriously difficult; it is not currently possible to demonstrate, nor is it even probable, that all primary canals and all parts of Canal System 2 were functioning contemporaneously at any point in time (Howard 1993:291–293). However, canal networks by their very nature are hydrological systems (Figure 3), and it is likely that a majority of trunk-line canal routes in Canal System 2 were in operation at the same time during the Sedentary and Classic periods (circa, A.D. 1000–1350+). The chronological profile of settlement patterns encompassing this network strongly suggest a largely coeval system (e.g., Howard 1993:293–304; Nicholas and Feinman 1989:199–236; Nicholas and Neitzel 1984: 161–168; Upaham and Rice 1980:78–105). Excavations in the vicinity of many major Phoenix basin canals also document dynamic sequences of rebuilding and reengineering of over long temporal intervals (for example, Figure 4) in response to changes such as system expansion and relocation of headgates (e.g., Ackerly et al. 1987:113–114; Doolittle 1991:144–148; Haury 1976:139–140; Masse 1976:13).

In what follows, we start at the bottom with the field, proceed to a set of fields drawing water from the same lateral canal, to all the fields drawing water from the distributary canal, on up to the main canal, and the intake from the natural source of water.

The Irrigated Field

The irrigated field is the smallest physically bounded territorial unit of a canal irrigation system. It will receive water from either a canal or from another field. Water will flow out of a field either into another field or into a ditch of some sort (water supply, drainage). Both inflow and outflow must be constructed, operated, and maintained. These tasks are almost everywhere the job of the farmer. It is usually the responsibility of the farmer to let water into the field, let water out of the field, and to manage the surface of the field so that water flows to the right places at the right times and at the right speed. The surface of the field must be sculpted to achieve this result, and it is the farmer’s responsibility to see that it is done (see Doolittle 1991).

Crop discipline is another matter. Crop discipline refers to the locus of decision making about what to plant, and when to plant it (Hunt 1992). Some systems are so designed that some group or set of persons decides these matters. In the Gezira Scheme in the Sudan, for example, it was the Scheme Authority that decided what got planted in a particular field, when it was planted, and how much water was to be applied when. Farmers had nothing to say about those decisions (Dishoni 1966; Farbrother 1973). In Bali (and in general in wet rice systems), when wet rice is to be planted all farmers within a set of fields have a planting date, all must plant wet rice at that time, and there are no other options. If water flows from field to field there is not even the option of not operating your field in a given year (Jha 2002).

At the other extreme, each farmer decides not only what to plant, but when to plant (and therefore harvest). There are constraints on this freedom. If water is available only during part of the year, then crops must be sown according to that schedule. But where the growing season is year-long, and water is available year-round, systems might allow individual fields to follow their own schedules. Most systems in arid zones without water storage have a standard yearly rhythm to water availability, and so at least the approximate timing of planting is dictated by water availability. The crops to be planted may not be.

Crop discipline is affected by water availability, by the farmer, and can be affected by a suprafarmer organization. Water supply in the Phoenix basin varied from month to month, and must have been at least somewhat predictable. It must have been integrated with cropping patterns and with the organization of work on the irrigation facilities.

Excavation of Hobokam fields might reveal how the water was managed within the field. If there was flooding of the field, then banks (raised field borders that keep water inside) would have been pre-
Figure 3. A 7.5" map corresponding to the U.S.G.S. Phoenix Quadrangle that depicts the scale, complexity, and systemic character of Canal System 2. This map is adapted from one of six similar quadrangle maps prepared by Jerry Howard (1991) displaying the entirety of known Hohokam canals along the Salt River in the Phoenix Basin. Courtesy of Paul Fish.
sent. The absence of bunds likely indicates that flooded fields were not the norm. Pollen analysis might reveal variability of crops in fields. The shape and size of the fields would also be interesting.

**Field Cluster**

Ethnographically, in the vast majority of canal irrigation systems each field is closely associated with a small number of other fields which share an outlet from the same lateral canal (similar if not identical to Howard’s Unit Command Area). The command area is often less than 10 ha.

**Lateral Canal**

Each field or field cluster draws water from a lateral canal. The lateral is usually less than 1 km in length, and its command area is rarely larger than 100 ha.

The tasks to be done include construction of the lateral, maintenance of that lateral, distribution of water from the lateral, accounting of water and work, conflict resolution, and ritual if there is a ritual component of the canal management. The lateral needs to be repaired when necessary and cleaned on a regular schedule. In some systems, each farmer maintains the section of the lateral that borders on their field. This requires little “overhead” other than monitoring and sanction for noncompliance. In others, maintenance requires shutting down the lateral and assembling the group of farmers who share water from the lateral to do the work. Stopping flow through the lateral is not to be taken lightly; nobody can irrigate and all labor must be directed to maintenance. The lateral needs to be cleaned from the tail to the junction with the distributary canal, and other structures such as gates, drop boxes, and settling basins need attention and work.

Usually, each field has a right to water, and the duties of farmers are normally proportional to the amount of water right. Each farmer then has to provide labor, materials, and money proportionate to the water right. Another task is to deal with the users of other, adjacent laterals over water. Issues include maintenance upstream on the canal system, and water supply to their lateral. The roles include farmer, and worker, and usually it is the same natural person who does both. Usually each lateral has a CAO with several responsibilities: distribution in times of shortage, organizing maintenance, accounting (who does not show up for work, or does not pay), conflict resolution, and representing the cluster to the rest of the system. This CAO can be formally elected or be the senior member of the group.

**Distributary Canal**

Between the main canal and the laterals there can be one or more levels of distributary canals (Howard’s distribution and branch canals). The lev-
els can vary in number from just one to many. There appear to be two focal templates for layout of a whole system, a long thin “linear” one with few branchings and few levels, and a dendritic one, with many branchings and levels. This is determined largely by the dimensions of the irrigable land, and also by population pressure. For present purposes, we will assume there is only one level of distributary canal, but the reader should keep in mind that there can be several levels. All pose the same kinds of problems, which is why we have lumped them together.

The distributary canal will provide water to 2 or more laterals. Distributary canals are usually 1–10 km in length. Usually the land operators are the actors on the canal. The command area for a distributary is often in the 50 to 200 ha range. The tasks to be done on this canal include construction, distribution, maintenance, accounting, and conflict resolution, with ritual being a possibility. The roles include some sort of office (these canals are never acahpalous), farmers, and workers. The duties of the farmers include maintaining the distributary, and providing materials and cash as needed. Annual cleaning of the distributary may well proceed from the tail to the head, encouraging all to participate and discouraging free riders.

Distribution in times of generous supply of water can be done with very little management attention. With the canal full of water each farmer can take as much water as desired when desired. The officer can be virtually invisible at this time. As water supplies shrink (relative to demand), the management load increases, and the officers and the rules become much more visible. Scheduling and even rationing of the water supply for a group of this size requires some office, and that officer will be busier as the scarcity increases. Scarcity can lead to trouble, so everybody is more concerned and involved.

As water supply increases, excess water must be prevented if possible, and drained if not. Canal banks must be watched for overtopping. Leaks must be found and fixed quickly before the canal bank gives way and floods arable land, houses, roads, etc. At some point the flood becomes unmanageable, and flight may be the only option. Management ceases at that point, but returns to action once the flood recedes. After the flood there may be a great deal of work to do, in the extreme case construct-

ing the canal and field system anew. Sediments have to be removed from canals, canal banks may have to be rebuilt, the grade may have to be re-established, and gates and other control features renewed. Presumably all of the farmers participate. If these events are frequent enough, then large numbers of farmers know what needs to be done, and how to do it. Experienced hands will know how to organize the sequences of tasks.

The irrigation systems of the Orbigo Ribera in the upper watershed of the Duero basin in northwestern Spain bear on the problem of understanding Hohokam irrigation. These systems originated in the colonization of the area in the mid-ninth through the eleventh centuries following the expulsion of the Muslims. The case is unusually well documented ethnohistorically as well as ethnographically (see Guillet 1998). The region was depopulated as a “buffer zone” between the Christians in the north and Muslims in the south. In the subsequent Reconquest irrigation systems were developed in a “pioneer” setting. The state had little if any impact other than to recognize the institutions developed by the settlers. There was a major impact of the state with the marriage of Ferdinand and Isabella in 1492 and the series of institutional reforms they undertook to centralize state authority, but this occurs centuries after the irrigation systems were developed.

Like the Salt River, farmers were confronted with a fast-flowing river, seasonally high and low river flows, and a wide and flat flood plain. And, as with the Salt River, a number of main canals took water from the river. On the Orbigo river, 16 separate main canals irrigated a total of 9,400 ha.

In the Orbigo case, once water entered the main canal at the beginning of the irrigation season, it flowed continuously until late September. Along its course, distributary canals took off water for delivery to towns and villages. A variety of techniques were used to allocate water to distributary canals. One was to divide up the water of the main canal into proportionate shares. In the Presa de la Felgeresia, the largest of the Orbigo systems in canal length and irrigated area, water was transported 12 km from the river to lower villages and towns. At approximately 3 km, a measuring device, or modulo, divided the water into ten equal portions, called lanzas; one lanza of water was diverted into the Reguero de Matilla canal to be shared by Matilla.
and San Roman and nine _lanzas_ flowed downstream to other villages.

Proportionate distribution devices required no operation and little maintenance effort in comparison with a system of gates, which must be lowered and raised, monitored for sabotage, and maintained. Proportionate division was often combined with the distribution of water to villages and towns by time, usually a fixed day of the week taken in turn. The villages of Villares and Villarejo carefully scheduled their joint use of the two thirds portion of water allocated to them by the Presa de la Tierra on the basis of days of the week.

Municipalities, in turn, distributed water to end-users via lateral canals. Farmers obtained water as a right of their ownership of land in a municipality, not as a right of membership in an irrigation system. Municipalities also attached conditions to its access. Landowners were expected to keep lateral canals bordering their fields clean and to contribute toward the labor and material costs of rebuilding and maintaining irrigation infrastructure. Villages and towns distributed water to farmers by using simple queuing mechanisms when water was ample and a system of turns, combined with a lottery in some instances, when water was scarce.

**Main Canal**

The intake acquires water from a natural source (a large river in the case of the Salt), directs it into a main canal and from there into the system of distributaries and laterals. At its fullest extent Canal System 2 irrigated a command area of >8,400 ha through at least nine separate main canals. Some of these main canals were quite long (> 30 km) and had command areas in the range of 1,000 to 2,000 ha. The scale of the intake and main canal will be quite large. The force exerted by the water flow in the main canal is quite substantial and must have a competent engineering solution (Freeman 1988). The amount of earth to be moved during construction and maintenance is large and considerable labor will need to be mobilized for those tasks.

The manner in which water is diverted to distributary canals depends upon the choice of technology. Two common technological solutions are proportional dividers and sliding gates. Gates permit precise measurement and flexibility. Gates are the technique of choice in modern canal systems and are usually constructed of iron and cement. They require someone (often an officer) to operate them and must be monitored regularly. Proportional dividers are often made of wood and are in operation as long as they are in place. A wooden structure is built such that the water flow over it is divided into two or more streams. The area of each opening is proportional to the water designated to flow through that opening. Often the proportional dividers are simply wooden beams with two or more notches cut in them. Proportional dividers require no operators and infrequent maintenance. They adjust automatically and equitably to increases or declines in the flow of water.

Cleaning and maintenance of the main canal is essential to the successful operation of this system. All those downstream, and that means every farmer, are impacted by failures. The main canal will have to be cleaned when needed. If it is large enough, and the flow rate fast enough, there may well be little sediment or weeds to clean out of the head reaches of the main canal. The canal banks have to be watched very carefully and kept in good condition, for a break could be catastrophic given the amount of water, and force, involved. Responsibility for cleaning and maintaining the main canal can rotate among subgroups, usually irrigators from the same distributary canal, but a CAO of the main canal system may have a major authority role.

Between-distributary management is necessary, and there will be officers responsible for this. There must also be a set of rules for these distribution decisions.

Should there be a major flood, the main canal will need to be cleaned or reconstructed. In this case there will be massive amounts of dirt to be moved. Labor and tools have to be motivated, assembled, and directed. The CAO for the whole main canal irrigation system is almost certainly responsible, although delegation of some decisions to specialists is frequently found.

Labor and time for construction of canals has been a concern since at least Woodbury’s (1961) investigations. Ethnography contributes here as well. Given paleotechnic methods, it is interesting to contemplate the amount of dirt that a worker could move in a day. There are remarkably few measurements of this. Erasmus (1965) has addressed the issue with respect to monuments.
The Hohokam literature has assumptions of 1 and 3 m³ of dirt moved per day (Howard 1993; Woodbury 1961). Fernea (1970:130) reports that Iraqi workers were expected to remove 1.9 m³ per day. One can plausibly assume that the dirt is moved in baskets, for this is widespread in the modern world. How the dirt is loosened and lifted into the baskets is the unanswered question. Wooden spades or shovels are widespread. Hafted stone could be used to loosen the earth, but so could digging sticks. Some archaeological attention to this problem might be productive.

We assume that, initially, farmers would have had minimal engineering skills and limited labor. Materials could have presented a problem if, for example, a scarce material such as wood was used extensively in construction. Given these constraints, an early canal system was most likely to have been constructed on the lowest alluvial terrace closest to the river, consistent with a small irrigation channel near the floodplain in the Price Road project area (Ackerly and Henderson 1988) dated to A.D. 50 and the appearance of large-scale canals on the first and second terraces of the Salt River in the Snake-town phase (circa A.D. 500–700). As they acquired engineering experience and additional labor (growing population) and materials, they would have expanded, building a new main canal away from the river, on successively higher alluvial terraces. Thus, by the end of the Colonial period, early canals close to the floodplain were abandoned and new ones constructed higher on the contour, away from the river (Howard 1993). With each expansion, engineering skills and costs in material and labor would have increased.

The construction of a new main canal would not necessarily have entailed any requirements for coordination with existing, lower, canals. At some point, however, expanding from one to two or more main canals drawing water from the same source would produce problems. A new main canal with unrestricted volume constructed upstream of the intake of an existing main canal would quite possibly lower flow to the latter. One of the most common principles for settling such disputes is “first in time, first in right.” This principle can be incorporated into customary law and rationalized, for example, in terms of moral economy. In state-organized societies, it can be codified into state law and enforced through a system of courts.

Intake and Main Gate

Given the Salt River fluvial regime, water would most likely have been obtained through a series of dams diverting water from the river into each of the main canals. Along the canal, just downstream from the intake, it would have been highly advantageous to install a gate. In the event of a flood, closing the gate would protect all the works down-canal. Each dam could be dismantled and the intake closed at the end of the harvest, and the dam rebuilt and the intake reopened when spring flooding receded. Closing off the opening of a main canal intake would have avoided damage to the interior infrastructure of the canal system and nearby fields and villages. Once returned to operation, water would flow continuously through the main canal, subject to diversion to distributary canals.

On the Orbigo in Spain, villages and towns joined ranks to build canal systems, called presas, to divert water from the river to irrigate their fields. Diversion dams were carefully constructed on a firm, packed, foundation, capable of withstanding strong river currents. A stockade of tree trunks was set into the foundation and interlaced with loose flexible branches of willow to hold sod cut from nearby meadows and other loose material necessary to render the dam impermeable. The water was diverted across the flood plain of the riverbed and from there into the intake of the main canal. The width and depth of the main canal intake had to be carefully adjusted to ensure the entry of sufficient water to flow with enough pressure to move rapidly through the network of main and distributary canals.

The Orbigo fell only five meters over its course of 41 kilometers. Such a slight fall forced diversion dams to be located far upstream to ensure that enough water would be diverted from the river into the canal and flow downstream with sufficient force to quickly irrigate the field area of a settlement. Even then, complicated techniques of damming main and secondary canals were necessary to raise a water head sufficient for entering field intakes.

Seasonal flooding jeopardized the entire waterworks. Late winter snowmelt in the mountains increased flow from 30–35 m³/second at the upstream town of Carrizo to over 1,500 m³/second. An increase of this magnitude on the flat and shallow river bed quickly swelled the river into a wide,
impassable expanse. To keep the swollen river from inundating towns and villages, settlers dismantled diversion dams and closed the main canal with large stones every year in late September. In April, the stones were removed and the dam reconstructed, shunting water into the main canal for the irrigation season. The annual reconstruction consumed large amounts of labor and materials. On this occasion a representative from the most important of the villages or towns, usually the one that took the lead in the construction of the system, would assume charge, working with representatives from the other villages and towns and perhaps a local expert engineer to organize the operation.

The social organization of this command area of 9,400 hectares was fragmented at the higher levels. No valley-wide consortium on the model of the Valencia systems integrated Orbigo presas into a wider system. Each presa was a unified system, taking water directly from the river. The CAO is from the “founder” town, village or monastery, but is not one of the general village offices (like mayor). The main canal conveys water to a number of downstream settlements, each of which names a juez de la presa for its own territory. All member towns and villages of the Presa de la Tierra usually assembled in Villares, the “village with the greater legal rights,” and the irrigation judge of that village would run the meeting. The special position of Villares, the founder village of the presa is noted in archival sources: “el pueblo de Villares, que siempre ha sido el que forma cabeza en la mancomunidad o alarcaría.” This pattern is found with minor variations throughout the Orbigo main canal irrigation systems.

Towns and villages, in turn, managed the water to which they had access either in an open meeting, the concejo abierto, usually held after Sunday mass or, more commonly, through a special-purpose body, the Junta de Regantes or Junta de Riegos. When managed through a concejo abierto, a vigilante would often be hired for 3 or 4 months during the irrigation season to report infractions and collect fines. The irrigation junta met independently of local government and reported to local authorities. Irrigation juntas were commonly organized with a president and a set of representative (vocales) from lateral canals. In recent decades a secretary would be added to keep the minutes of meetings and handle paperwork. Decision making in the concejo abierto and in the juntas was along the lines of one man, one vote.

The Orbigo case suggests a plausible social organization and management model for Hohokam irrigation on the Salt River. Some or all of these elements would have worked for the Hohokam. Early settlers claimed squatter’s rights to water and these rights were respected by later claimants under a system of prior appropriation. Each of the main canals was operated as a separate irrigation system. Dams were dismantled and rebuilt annually to avoid damage from flooding. Water flowed continuously through the main canal and was distributed via distributaries to towns and villages on a proportional basis and/or by time and crop. Villages and towns, in turn, distributed water to landowners via lateral canals on a queuing basis when water was abundant or by turns/lotteries when water was scarce. Whenever a main canal system had to act jointly, e.g., to maintain canal infrastructure or to renegotiate right of way with an upper main canal system, irrigation officials from founder villages or towns stepped in to coordinate efforts of the constituent towns. And, each main canal system could operate independently of the others without the need for coordination.14

In the Orbigo, conflicts were not uncommon. They would occur between irrigation presas when a catastrophic flood forced the relocation of the dam and upper stretch of the main canal. The upstream presa would attempt to extract unreasonable compensation from the downstream presa for relocating the dam and main canal within its territory. These conflicts were resolved either through the system of state law and courts in operation at the end of the Reconquest in the twelfth century or more commonly through locally negotiated agreements. The state’s role in the management of the 16 main canal systems on the Orbigo river was limited basically to codifying customary law into state law and providing a system of courts to help in the resolution of conflicts.

Organization of a Phoenix Basin Hohokam Irrigation System

We have argued from the ethnographic record that canal systems of 1,000 ha command area and scores of kilometers of canal are not acephalous. They must have some sort of office that unified man-
agement within the physical canal system. We have considered three major kinds of charter of authority: private, state, and communal.

The number of private systems in the ethnographic record is quite small. Often the outcome of a colonizing effort, they are subsidized byimporting capital to construct an irrigation system. This happened often on the front range in Colorado and in the Central Valley in California in the nineteenth-century U.S. and territories (Maass and Anderson 1978). But in every case the developers wanted out of operating a canal system as soon as possible, and at least in the U.S. communally run systems took over from the private management.

If there is a land market, then wealthy people (often merchants) are able to accumulate large amounts of it. This happened in Japan over at least the last 400 years. Land reform was instituted several times. But at no time was the management of the irrigation system in the hands of the landlords. Rather, it was in the hands of locals who operated the fields (Beardsley et al. 1959). Private capitalists also built irrigation systems for sugar mills in Mexico in the late nineteenth century (Barkin and King 1970; Rofeldt 1973).

Our few cases of private charter occur in monetized economies where it is easy to convert assets into money, move the money to other places, and convert that money back into labor and materials. They also involve substantial economic stratification. As neither a money economy nor substantial economic stratification seem to be characteristic of Hohokam social organization, it follows that, at least given what we know now, a private charter for irrigation seems implausible.

Political centralization of irrigation (by state or province) is certainly present in this world and is found in Egypt, Sudan, Iraq, India, Pakistan, Indonesia, and Mali. In these cases the state provides the charter of authority for the CAO, hires management and workers, and sets the rules (see Mollinga 1998; Wade 1988 for examples from India). It is not even clear that there are water rights held by farmers in these systems. This form of organization is dependent upon the existence of a state, and a fairly strong state at that. As there is no evidence that the Hohokam had a state (Crown 1991; Fish and Fish 2000), this form of irrigation organization would seem to be implausible.

That leaves the several forms of communal man-
agement. Many Hohokam specialists (Crown 1987; Fish and Fish 1991; Fish 1996; Gregory 1987; Gregory and Nials 1985; Masse 1991; Wilcox and Sternberg 1983) have related territorial communities and their regular spacing within irrigation systems to the administrative requirements of irrigation, including recruitment of labor, water allocation and adjudication, and intercommunity communication.

This spatial organization occurs throughout the Hohokam region, including areas like the Tucson basin that are unsuited for large-scale irrigation (e.g., Downum 1993; Fish et al. 1992). Furthermore, hierarchy and power relationships associated with centralized ritual at community centers do not appear to be uniquely tied to irrigation or necessarily to long-standing land tenure in the best agricultural locations. For example, in the Tucson basin, locational change from Preclassic ballcourt centers to Classic platform mound centers involved shifts of more than several miles and to locations with lesser agricultural potential (see Doelle and Wallace 1991; Fish et al. 1992). This suggests multiple management functions for the ballcourt centers and platform mounds.

Several forms of communal organization have been proposed. We are dealing with unified systems ranging up to nearly 9,000 ha (given the uncertainties surrounding a single "physical irrigation system"). In our ethnographic samples a single "village" complex can manage a 1,000 ha system. With an 1,800 ha command area, however, it is more problematic, for the scale of the system must cover several villages. At this size, farmers along the canal were living in several settlements, and likely had divided loyalties. Organizing the farmers as an irrigation community (all, and only, farmers are members) is certainly plausible. Another possibility is that the several settlements in the canal system had one administrative system that unified them for at least the purposes of irrigation tasks. Some sort of district organization based on ritual/shrines (see Lansing 1987, 1991) is also plausible. A challenge for the future is to identify archaeological signatures of the several possibilities and test them in the field to see if we can narrow the options.

Rice (1998) has proposed a segmentary model in which territorial units are the segments. Fernea (1970) presents the major ethnographic account of
irrigation in a sociocultural system with segmentary lineages. Fernea attempts to probe the organization of irrigation in Iraq prior to the establishment of state control by the British in the early twentieth century. The situation there was characterized by frequent violence and by groups expanding at the expense of other groups. An individual’s plot of land was held only under the condition that their segment of the lineage was militarily strong enough to hold the territory and the canal. The canals that were built and maintained were rather short, on the order of 1–2 km at most. It would seem that a segmentary lineage organization is a poor candidate for centuries-long operation of long (20 km) main canals. Whether a segmentary organization by territory would be plausible is another question.

On the question of unified management for each Hohokam main canal, we agree with Masse, Nicholas and Neitzel, Nicholas and Feinman, Howard, Rice, and Abbott. Acephalous organization is implausible. Given the absence of a state we propose that the politically centralized form of unified canal management is implausible. Some forms of communal charter seem plausible for organizing each main canal. It is not clear that the entirety of Canal System 2 was a single irrigation system, rather than a space containing a number of canal systems. Even if it was a single system, its size alone does not rule out some sort of communal management.

Inter-System Management

In the Howard model of Canal System 2, by the Classic period at least nine major canals were drawing water from one river. As demand increased more than supply, by increasing the number of main canals, the probability of scarcity of river water increased. When there is surplus or sufficient water, no river management is necessary or desirable. When scarcity occurs, there are likely to be problems.

Some solutions for management across main canal irrigation systems found in the ethnographic literature seem less than plausible. In the western U.S., for example, each river has been adjudicated, in the sense that there is specification of a large number of water rights, to whom they belong is settled, and this leads to an orderly partitioning of the available river water. But the sophisticated engineering and transaction costs of adjudication have been substantial for this state-level society and are likely beyond the capabilities of Hohokam. The management of the Salt and the Gila rivers was fairly chaotic during Anglo historic times (1866 onwards). The impact of storage dams on the allocation of water from the Salt (the Roosevelt Dam in 1911) and the Gila (the Coolidge Dam in 1928) is unknown.

The 12-Go system in Japan, another state organized society, had a number of communally managed canal systems on the same river (Beardsley et al. 1959). Intakes were subject to being washed away by floods, and each system was responsible for rebuilding its own dam. Each system was tempted to increase the size of the intake, thus decreasing the amount of water available downstream. Disputes between systems are reported. The Japanese State refused to even discuss the matter, throwing it back into the laps of the several systems. How it was resolved was not reported.

Masse (1981) was the only archaeologist to argue for the need for intercanal system, or even basin-scale, management institutions. It is plausible to visualize an opportunity for such institutions, but they rarely occur even in the context of a state. Consortia of communal systems are found in the modern world and are effective. They are a plausible form of organization for large complexes like Canal System 2. The two cases we know well, Valencia and Kings River Water Association, have physical headquarters that are almost invisible, although they are located in the major settlement of the area (Valencia; Fresno, California). Furthermore, they are not part of the territorial political administration. Archaeological signatures might be very hard to find.

The relationship between canal layout, settlement patterns, and the social organization of the canals is not highly determined, it would appear. Irrigators can be organized in terms of settlements, or in terms of canals. It follows that without other evidence it is hazardous to infer the organization of irrigators from either canal or settlement data.

Canal Management and Other Institutions

Although it is frequently asserted that large systems must be politically centralized, Hunt (1988) has demonstrated that size alone does not determine
charter of authority, especially not at the 1000 ha., nor even at the 10,000 ha. size. There is no sign of a state for the Hohokam, and therefore political centralization (in the sense of a state or provincial charter of authority for the CAO) of the canal systems appears implausible.

Another issue altogether is the relationship of elites to the canal system management. Where there is social stratification, an agrarian society is very likely to have elites based on agricultural production, trade, ritual, political office, and warfare. Especially if these elites are drawing wealth or power from agriculture, one can expect them to be involved in irrigation matters (see Hunt 1986; Hunt and Hunt 1974). Elites with status based on ritual, political office, and war may also have considerable influence on irrigation matters. The ethnographic record is nearly silent on these matters, so little more can be said. Of interest in the Hohokam case would be archaeological evidence of elites, and particularly of elites with different sources of influence, power or wealth.

Summary

In this paper, we have addressed the social organization and management of Hohokam canal irrigation systems. We have concentrated on the largest of the Hohokam canal sets, Canal System 2, on the right bank of the Salt River in the Phoenix basin during the Classic period. Because of its relative size it would have posed the most serious organizational challenges. There are two arenas for thinking about “centralized” management for canals, one internal to the canal system, and another linking the canal system’s management to other institutions, usually the state.

We have argued that it is implausible that an 8,000+ ha command area with at least nine major canals was acephalous. A command area this large clearly had an internal management system, and it was most likely operative at the level of a single main canal. The charter for the authority of the CAO is almost certainly not private or state. There is no evidence for, and no claim of, the state being present in Hohokam society. Given the scarcity of private charters in the ethnographic record, and the apparent lack of economic elites in the archaeological record, a private charter for Hohokam canal authority seems highly unlikely.

We are left, then, with the various communal forms of charter of authority as the more plausible alternatives. Ethnographically each seems viable. The major question is whether that organization is single purpose (irrigation alone, as in the irrigation communities), or multiple purpose.

Inter-system, or river, management almost everywhere presents a set of problems to be solved, but they are not always solved. It may be that lack of a solution to the intersystem problems is more tolerated than in the intrasystem case.

An effort should be made to design archaeological research that would narrow the alternatives even further. As Rice (1998) has argued, the function of the platform mounds with respect to canal irrigation is intriguing. Establishing the agricultural calendar is crucial for more detailed work on canal (and agricultural) management. Establishing whether the nine or more main canals of Canal System 2 were in operation at the same time would be a useful addition to the evidence. Where it is still possible, doing additional survey work addressing command area would be productive.

Our strategy with respect to ethnographic analogy has been to list the possible interpretations, and then to try and narrow the field. We have concluded that an 8,000 ha command area displays internal centralization. But it should be clear that we have not arrived at unique or single solutions. There are still uncertainties. We regard this as progress.

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Notes

1. Ackerly (1991) suggested that early Anglo experiences with canals taking water from the Salt River and the Gila River might well be analogs for what happened during Hohokam times. He was referring almost entirely to floods, silt, and channel shifting as they affected canals. The idea can be extended. During the second half of the nineteenth century Anglo development of irrigated agriculture proceeded very rapidly. And for several decades there was little control by any state. We might be able to reconstruct how these Anglos organized canal irrigation. A close look at the abundant record of that half-century might be very productive. (RCH is grateful to William E. Doolittle for pointing him in this direction.)

2. There are only two rivers in the world for which we have measures of yearly flows over centuries: the Nile and the Salt/Gila system. For the Nile, the Egyptians built two Nilometers to measure the height of the water surface, observed the heights, and wrote them down (see Butzer 1976 for an account of the Nile, a river that has much in common with the Salt/Gila river regimes). For the Salt/Gila system we have the results of tree-ring analysis in the headwaters, which when correlated with stream flows accounts for 80 percent of the variance in the yearly river flow. There are data and analysis for the Salt River (A.D. 572 to 1988) and for the Gila River (A.D. 534 to 1988) (Graybill et al. 2004; Nials et al. 1989). To our knowledge there is no other record like it in the world.

3. Here we review some of the archaeological literature on the social organization of Hohokam canals. So far as we are aware there has been no mention of the Hohokam systems in the ethnohistoric literature. Pima and Anglo irrigated agriculture of the nineteenth century have also been ignored in that literature.

4. Woodbury calculated that 25 men, each moving 1 cubic meter of dirt per day, could construct a canal 2–3 miles long and 2 meters wide between planting and harvest (Woodbury 1961:556). His calculations are in error. A 2 mile canal is 3.2 km. Assume that the canal is only 1 meter deep. 3.2 x 1 x 2 = 6,400 m³, which requires 6,400 person-days. Dividing 6,400 by 25 (persons) yields 256 days of work per worker. Assuming each person works every day, this will not fit into the period between planting and harvesting. The three-mile-long canal (4.8 km) requires 384 days of labor/person. Woodbury was also assuming that the 25 persons were not doing any agricultural labor, such as weed control. Even if we assume 2 m³ of earth moved per day (Fernéa 1970:166), a two-mile canal will require 128 days of work for 25 persons, and a three-mile canal would need 192 days of work, all without a day’s rest or other work. It does not seem to be a viable proposition.

5. Hunt conducted ethnographic fieldwork on irrigation in Mexico, Colorado, and California, and Guillet has done years of fieldwork on irrigation in Peru and Spain. Hunt has spent the last 30 years studying the social organization of irrigation by conducting systematic comparisons, using the ethnographic and historical literature.

6. Hunt (1988) called this office the chief executive officer (CEO). Nobody liked the phrase. Hunt and Guillet now propose a new name. We want to retain “officer,” signaling that there is a role in a system of roles. We want to retain “chief,” signaling that it is the highest office in a hierarchy of roles. “Executive,” the previous name, implies a degree of autonomous power which is often not the case. The office more often is called upon to carry out decisions made by others. “Administrative” seems to capture this reality better than “executive.”

7. It would be useful to ground-truth the claims about the tail ends of the long canals. It would also be useful to do a detailed survey of the command area of at least one prehistoric canal, to try to establish fields, and command area.

8. Attaching water rights to land is a common solution to the unique physical features of water and the high transaction costs of assigning property rights to it. See Guillet (1997).

9. One suspects that the degree of formal organization of the lateral would correlate with, among other variables, the incidence of scarcity in the water supply.

10. In this and following sections we present data from the Orbigo River in Spain collected and analyzed by David Guillet.

11. Figures are for 1913 and are taken from the Proyecto de ordenamiento y modulación de Las zonas de regadío del rio Orbigo. Sección comprendida entre el origen del río y La Bañeza 1918/20 Archivo General de la Administracion, Alacala de Henares, GA Caja 18.314 Topogr. 24/50, Appendix 1. For material on the Orbigo systems, see Guillet (1998).

12. Mass and Anderson (1978:3) suggest an ethnographic alternative to prior appropriation rights: “In the Berber areas of Morocco the principle for settling water disputes between irrigation communities is one of location rather than prior occupancy. The upstream users always have preference over those below them on the water course.”

13. Expediente de testimonio sobre un litigio entre Hospital de Orbigo y los pueblos de Villares, Villarejo, y Moral. 1870–1872 Archivo de la Comunidad de Regantes de Hospital de Orbigo, CRHO 8v/.

14. This changed in the 1930s when the Barrios de Luna dam on the Luna River upstream of the Orbigo River came on line and a regional watershed authority stepped in to coordinate releases of water.

15. Hunt argued in 1988 that the large (>40,000 ha) U.S. systems were managed communally. Price (1994) disagreed arguing that they were politically centralized. Hunt (1994) rebutted Price.

16. Balinese irrigation occurs in the presence of states, but is widely thought to be organized by the temples, not by the state. Recently, Hauser-Schaublin (2003) has argued that the precolonial Balinese states were deeply involved in irrigation. Whatever the results turn out to be for the precolonial situation, there is no sign of doubt that the complex Balinese irrigation systems have been organized and run (in the twentieth century) by the farmers and priests, and not by the state.

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