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The Tides of History: Modeling Native American Use of Recessional Shorelines

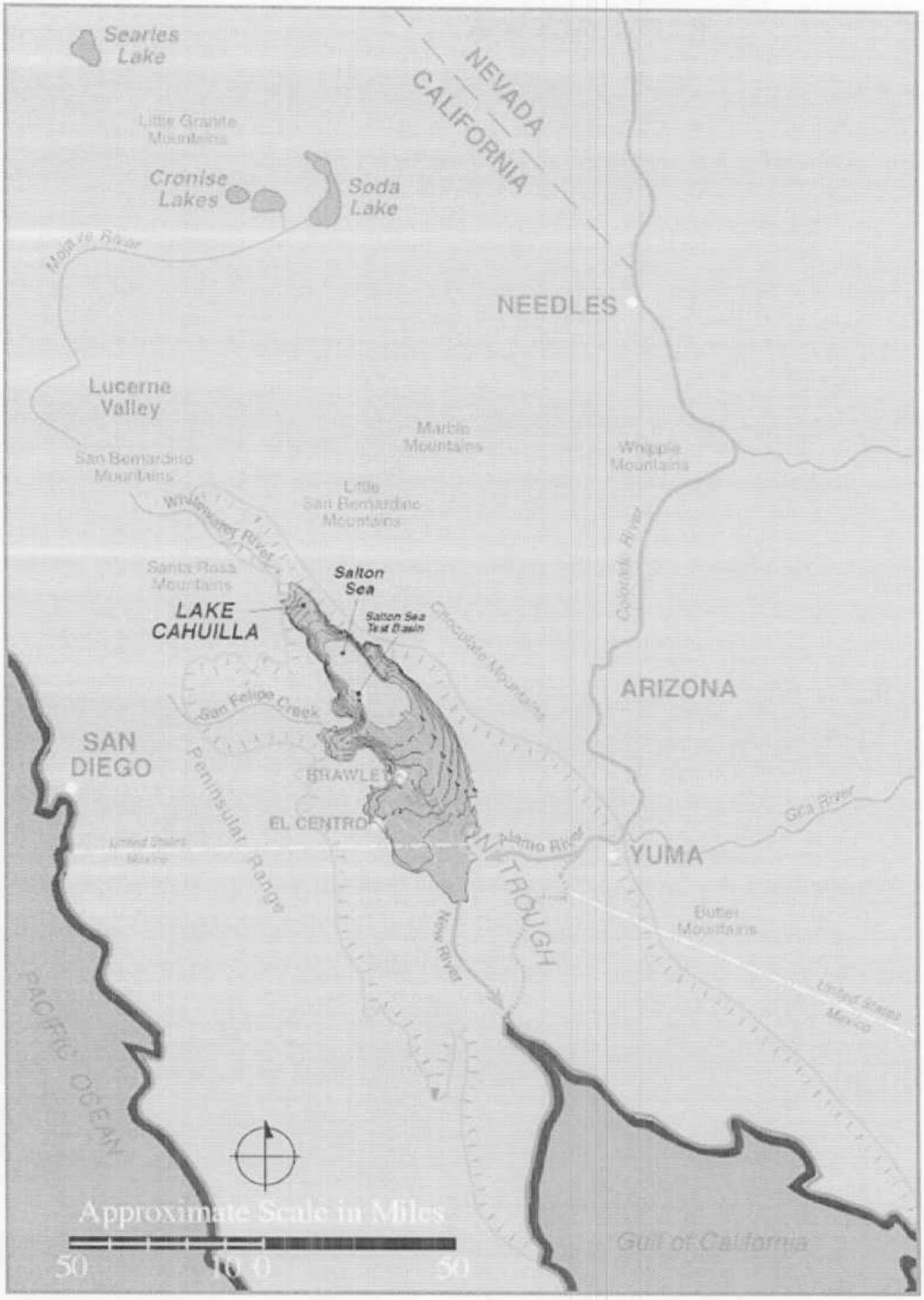
Abstract: KEA Environmental employs GIS technology to analyze a variety of environmental data, including geology, hydrology, biology and archaeology. This paper shows how KEA applied ArcView and 3-D Analyst to model a 700 year record of changing lakeshore configurations. The results helped describe the prehistoric environment and explain Native American settlement patterns. GIS simulations allowed the analyst to visualize the rising and falling levels of Lake Cahuilla, which formed at times when the Colorado River flowed west into the desert rather than into the Gulf of California. In addition, volume calculations can be useful in describing water quality.

Problem Statement

Archaeologists working in California (and many other places as well) have a problem. They want to study patterns of human behavior that occur in seasonal or yearly cycles, but they typically do not have chronological controls that allow them to sort their data to such a fine scale. Prehistoric archaeology in California is heavily reliant on radiocarbon dating to provide a chronological framework. Unfortunately, radiocarbon dating is not precise, typically yielding an uncertainty factor that far exceeds a prehistoric person's life expectancy. It is as if a cabinet-maker attempted to measure a board with his car's odometer. All too often the archaeologist is like the unfortunate craftsman: his tools for measuring time are not equal to the task. Occasionally, however, circumstances do occur that yield clearer snapshots in time.

Human behavior always has a spatial dimension, and sometimes the spatial dimension is chronologically organized. In such a case spatial analysis using GIS can provide improved chronological control - a better measuring rod. And, sometimes, this control is of sufficient precision to allow the prehistorian to see time on a truly human scale. Rapidly changing recessional shorelines along Lake Cahuilla in California's hyper-arid Colorado Desert provide such an opportunity. At various times in prehistory, much of the Imperial Valley was covered by the waters of Lake Cahuilla, a huge lake that advanced and receded in response to the changing course of the Colorado River (Figure 1). When the lake receded, prehistoric people followed the shrinking shoreline, leaving traces of their camps as they went. Investigating these camps, we found that GIS can be extremely useful in modeling the complex relationships between humans and this rapidly changing environment.

Figure 1. Regional Map

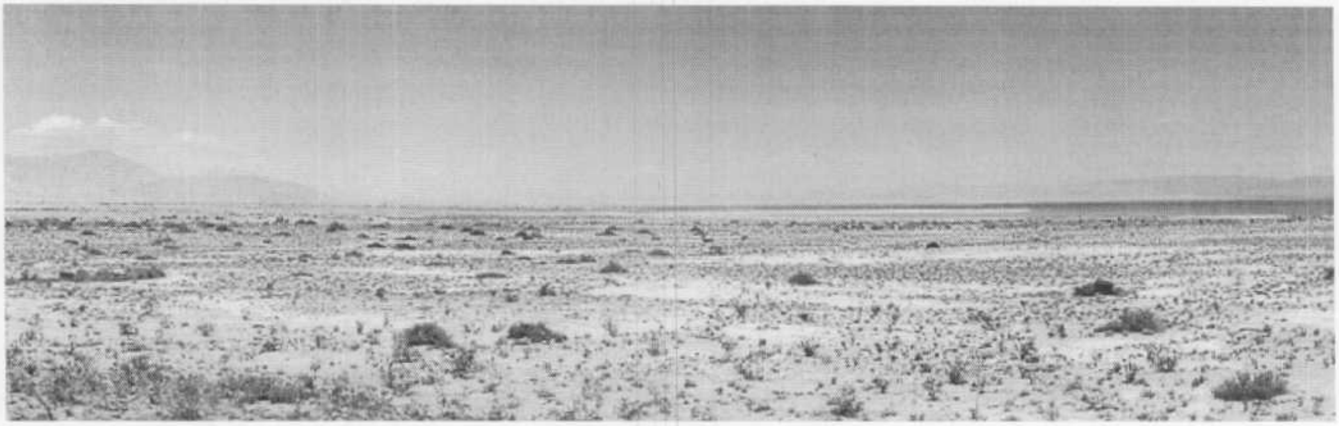


History of Lake Cahuilla

Our study area lies in the northwestern portion of the Colorado Desert, a subdivision of the Sonoran Desert which occupies large portions of southeastern California, southwestern Arizona, and much of northern Mexico. The dominant physiographic feature of the Colorado Desert is the Salton Trough, a roughly 130 mile long, 70 mile wide desert basin that forms the landward extent of the Gulf of California. The bottom of the trough, now occupied by the Salton Sea, is at more than 250 feet below sea level exceeded only by Death Valley as the lowest and most arid region in the United States. Clearly, the periodic appearance of a huge body of fresh water in such a rigorous environment (Figure

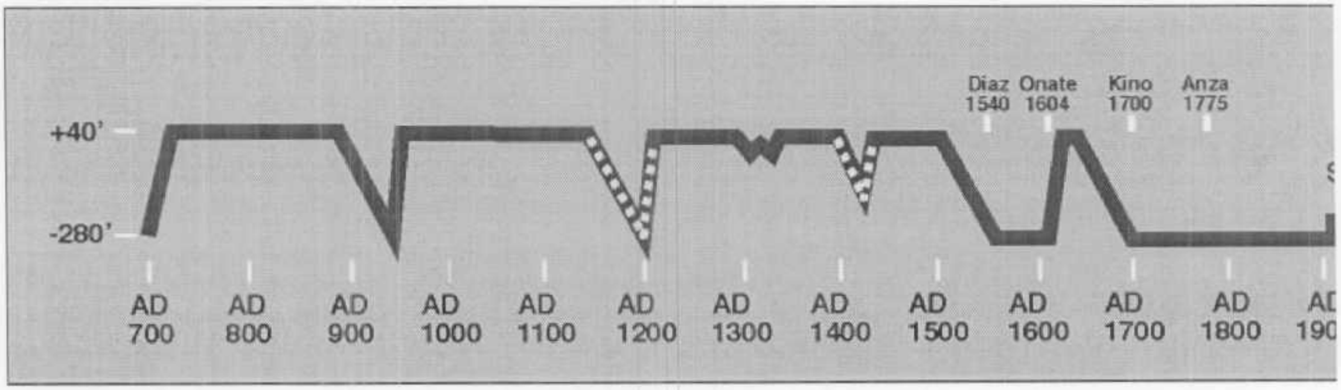
Clearly, the periodic appearance of a huge body of fresh water in such a rigorous environment (Figure 2) would cause radical changes in the resource base for humans throughout the region. At its maximum stand of 5,700 square kilometers and 96 meters deep, this lake would not only have provided a source of fresh water in one of the world's most arid regions, but would also have supported a wide variety of plant and animal resources as well.

Figure 2. Panorama of Colorado Desert along Lake Cahuilla Recessional Shorelines



Prior to modern flood control measures, Lake Cahuilla would form when the Colorado River diverted its flow into the Salton Trough from its normal course into the Gulf of California. This occurred when the meandering channels along the north side of the river's delta occasionally cut through their natural levees and flowed down the steeper gradient to the northwest toward the Salton Trough instead of the Gulf. This caused rapid head-cutting and enlargement of the channel, and eventually captured the entire flow of the river. Once it began, there was little to stop this flow until the entire basin filled to a point 40 feet above sea level. At this point the lake stabilized by flowing back into the Gulf through an outlet channel near Cerro Prieto, Mexico. Eventually, the channels at the delta would meander back to the southeast and the lake would begin to evaporate.

Figure 3. Chronology of Late Prehistoric Lake Cahuilla



The most widely accepted chronology for the stands of Lake Cahuilla (Waters 1983) identifies a series of four lakestands occurring over the past 1,500 years (Figure 3). The first is thought to have begun at about A.D. 700 and ended around A.D. 940, with full desiccation. The second interval is not directly dated but based on estimated sedimentation and evaporation rates is inferred to have occurred sometime between A.D. 940 and 1210, again with complete desiccation. The third interval is thought to have begun around A.D. 1210, with a partial recession to about -130 feet below sea level at about A.D. 1430. At this time the lake began to fill again, initiating the fourth interval; this interval is estimated to have terminated around A.D. 1540 based on sedimentation and evaporation rates, as well as the lack of any direct observation of the lake by Spanish explorers traveling through the area after that time. More recently, a fifth interval has been proposed based on archaeological data from a site on a recessional shoreline. This is believed to have been a partial infilling occurring sometime between A.D. 1516 and 1659 (Schaefer 1994).

The Salton Sea Test Base Data

Our work on the recessional shorelines of Lake Cahuilla was related to the upcoming closure of the U.S. Navy's Salton Sea Test Base, a roughly 10-square mile facility located on the lake's southwest shore (Apple, et al. 1994). As part of the closure, the Navy was required to fund a complete inventory of the facility for cultural resources, as well as a subsurface testing program to determine which sites are eligible for the National Register of Historic Places. The archaeological inventory of the base revealed a surprising number of prehistoric cultural sites, some 166 in all. Of these, nearly half contained hearths, rock enclosures, and artifact assemblages that suggested that they were the remains of temporary camps, indicating this area to have been fairly heavily occupied during certain periods of prehistory. An extensive suite of radiocarbon dates indicated that nearly all of this occupation took place between the AD 1640 and AD 1740 (Cleland 1999).

Figure 4. A Rock Enclosure at Salton Sea Test Base

The most prominent features of the habitation sites are the rock enclosures (Figure 4); we found nearly 200 of these on the base, occurring singly or in clusters of up to a dozen or so. Typically, these features circular or semi-circular in shape, and are constructed of forty or fifty sandstone slabs stacked one to three courses high, with a well-defined opening on the east side, away from the prevailing winds. Excavations at more than 100 of these enclosures indicated them to be the centers of domestic activity at the camps: most contained charcoal and fish bone, and were generally surrounded by small scatters of artifacts. Also of interest in the investigations were sandstone features thought to have been used as fish traps (Figure 5). These are "v" or "u" shaped arrangements of sandstone, usually several meters long and always oriented with the narrow end downslope. It is believed that fish were driven into them, or went in to spawn, and were caught using nets and baskets. Unlike the rock enclosures, the fish traps must have been directly associated with the shoreline at the time they were used.

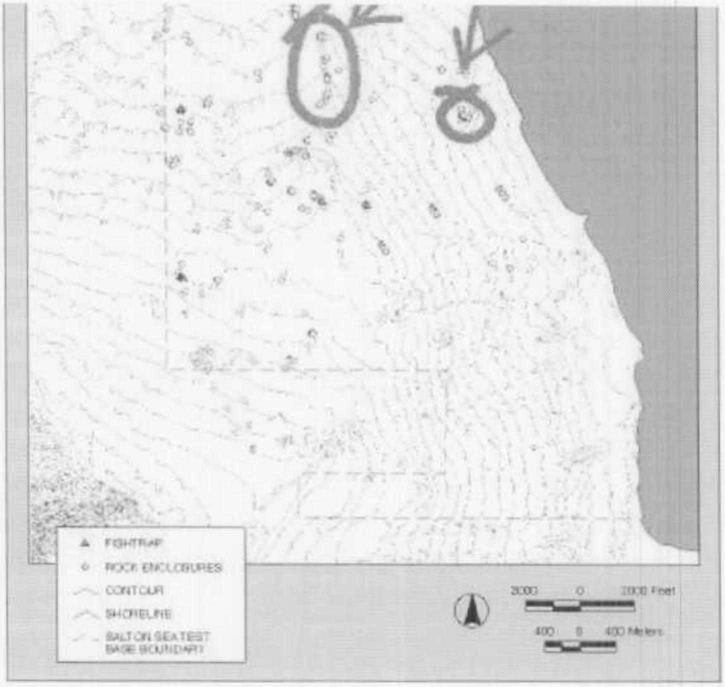
Figure 5. A Probable Fish Trap at Salton Sea Test Base

The archaeological data from the SSTB indicated pretty clearly that the occupations of the sites within the project area were fairly short in duration, and focused directly on the use of the receding shorelines. With the help of GIS, patterns in the distributions of the habitation areas and fish traps begin to emerge, and their relationships with the receding shorelines in this area can be seen more clearly.

GIS Analysis of Shoreline Sites

While in the field, KEA's archaeologists used a Sokkia submeter GPS instrument to map the precise location of each site. After completion of the survey, each rock ring and fish trap was plotted using ArcView. As can be seen in Figure 6, some clustering of locations is immediately apparent. A linear configuation and a small cluster are indicated as examples. But overall, it is not easy to determine which sites were utilized contemporaneously and which represent a time series of occupations. We wanted to know: were all sites used at the same time, or were only a few used each year?

Figure 6. Distribution of Archaeological Features at Salton Sea Test Base



The archaeological evidence was pretty clear on some things. Sourcing of raw materials used in the manufacture of pottery and flaked stone tools indicated that Native American groups with access to the peninsular ranges to the west occupied the Salton Sea sites; the low quantity and diversity of the artifact assemblages indicated that occupation was typically brief. Groups came down from the mountains or mountain canyons seasonally to fish and to process their catch for transport and storage. After a very brief stay, they would move on to other subsistence resource patches (Apple, et al. 1997).

We hoped that radiocarbon dating would help sort out our sites chronologically. And, it did to a limited degree. We were able to identify three distinct periods of Late Prehistoric occupation, contemporaneous with the recession of periodic stands of Lake Cahuilla. One site dated to a recessional interval between the second and third lakestands about AD 1200 and two sites dated to the recessional interval between the third and fourth stand probably around AD 1460. But, the vast majority of the sites dated to very late fifth infilling that has only recently been identified, probably after AD 1640 when the first Spanish explorers passed through the area.

Dated sites from the last lakestand range in elevation from 90 feet below sea level down to 190 feet. But site distributions suggest a broader range in our area from -50 to -210 feet. Radiocarbon dating could not sort these sites into a dated sequence, so we wondered whether spatial analysis could. All indications suggest that this final lakestand was quite short-lived. A previous investigator calculated that, without replenishment from the Colorado, the lake level would recede due to evaporation at 5 to 6 feet per year (Laylander 1994). If so, our final period sites might cover a span of only thirty to forty years.

Spatial or locational analysis in archaeology generally assumes that archaeological site locations were originally selected on the basis such important variables as ease of access to resources, shelter, defendability, and length of occupation. Fish trap features obviously must be located in shallow water. The rock enclosures, which were used as temporary shelter and for drying fish, are not as constrained with regard to location. Since we have good reason to believe that the rock enclosures were utilized over relatively short periods of time, perhaps only a few days to a few weeks, they would be considered expedient features and would most probably have been sited primarily on the basis of access to resources. Three resources appear to have been most critical - access to fish, access to fuel for smoking the fish, and access to sandstone slabs for fish traps and rock enclosures. Fuel would have been available most abundantly in desert washes; however, there is no apparent clustering of fish processing features along washes, so we can discount this factor. Sandstone is relatively abundant, and it does appear that low sandstone ridges were preferred locations of fish processing camps. Finally, we come to access to fish - the shoreline. Given that sandstone ridges are relatively ubiquitous, it seems reasonable to assume that access to the shoreline was the driving force in site selection. Thus, seasonal camps were located on or adjacent to sandstone ridges in close proximity to fishing locations along the shoreline. Each year as the lake shrank the distance to the shoreline would increase unless fish camps were moved downslope. At some point it would be most economic for returning fishing groups to occupy a new site rather than reuse the previous one. We don't know if this happened yearly or every few years. But the point is that sites lying at the same elevation may well have been utilized contemporaneously, while those at substantially higher or lower elevation would probably have been older or younger respectively.

GIS helps us visualize (or model) the project area as the water slowly receded exposing more and more dry land for human utilization. One cluster of rock enclosures occurs between -30 and -50 feet on a relatively regular, northeast facing shoreline (Figure 7). For our purposes, we'll call this Year One because this is probably the first fishing camp in the survey area associated with the final lakestand, but undoubtedly similar camps occur at this elevation in unsurveyed areas to the northwest and southeast. Four to five years later, the first fish traps appear along the -70 foot lakeshore (Figure 8). These traps are located just below several rock enclosures, indicating a fishing/fish processing camp. Another probable fishing camp is indicated by a rock enclosure a little over a mile to the southeast. The shoreline at this time is still relatively regular and northeast facing.

Figure 7. Modeled -50 Foot Shoreline with Archaeological Features

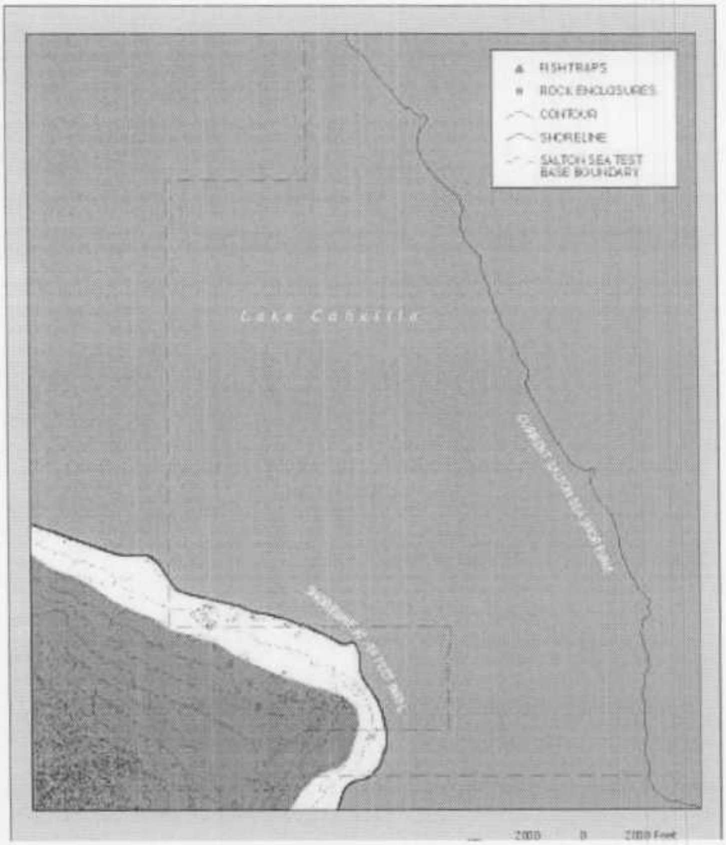
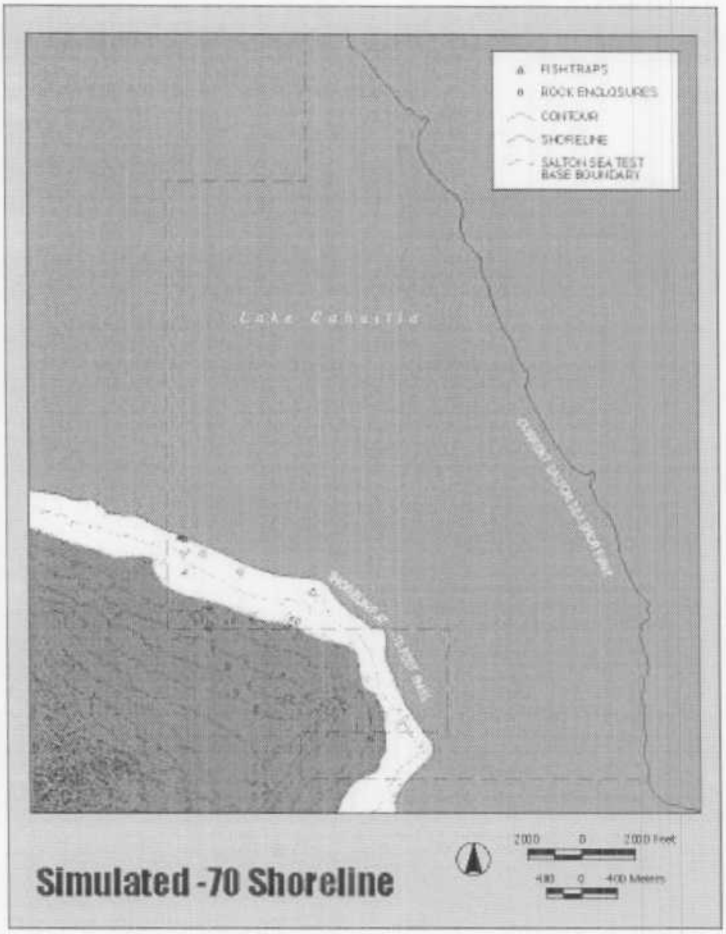


Figure 8. Modeled -70 Foot Shoreline with Archaeological Features



As time goes on the number of rock enclosures increases, suggesting that Native Americans were intensifying their fish procurement activities. By about Year 12, we find three distinct clusters of rock enclosures and associated fish traps along the -110 foot shoreline (Figure 9). Interestingly, at this time we have two sets of fish traps in the same vicinity that appear to have been only one year apart in that they are separated by 5 feet in elevation, the estimated yearly recession of the lake. It is also noteworthy that a north-facing embayment is beginning to become apparent. This embayment appears to have created an especially good fishing location for several years inasmuch as at three or four possible time-seriated camps appear along a peninula that juts northward into the receding lake. This embayment continues to be a prominent feature in the vicinity through -160 feet, suggesting a ten to twelve year period during which the embayment was a favored fishing area (Figure 10).

Figure 9. Modeled -110 Foot Shoreline with Archaeological Features

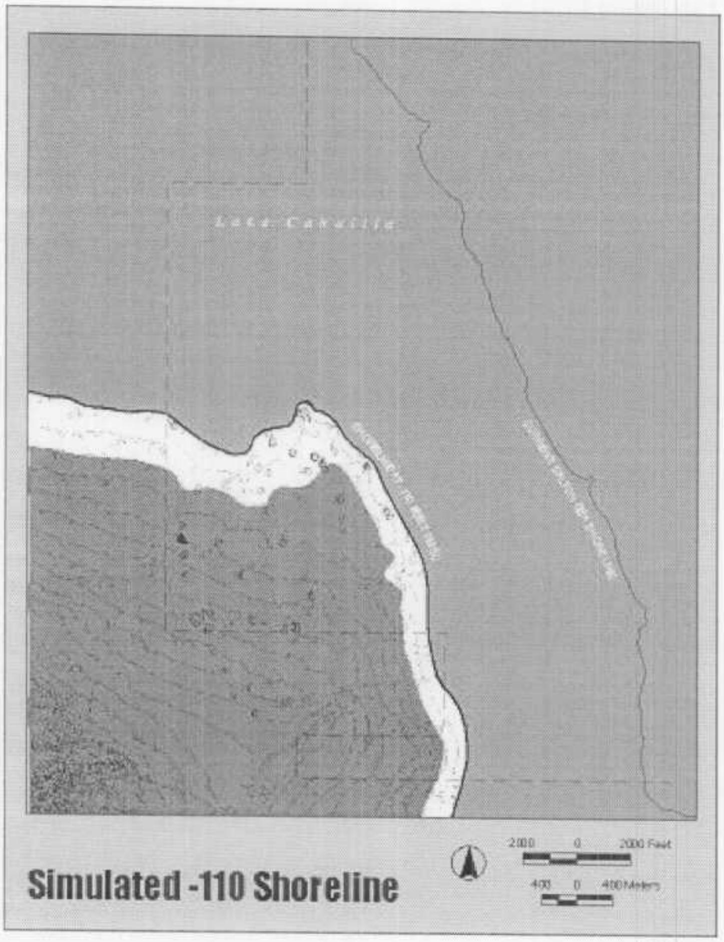
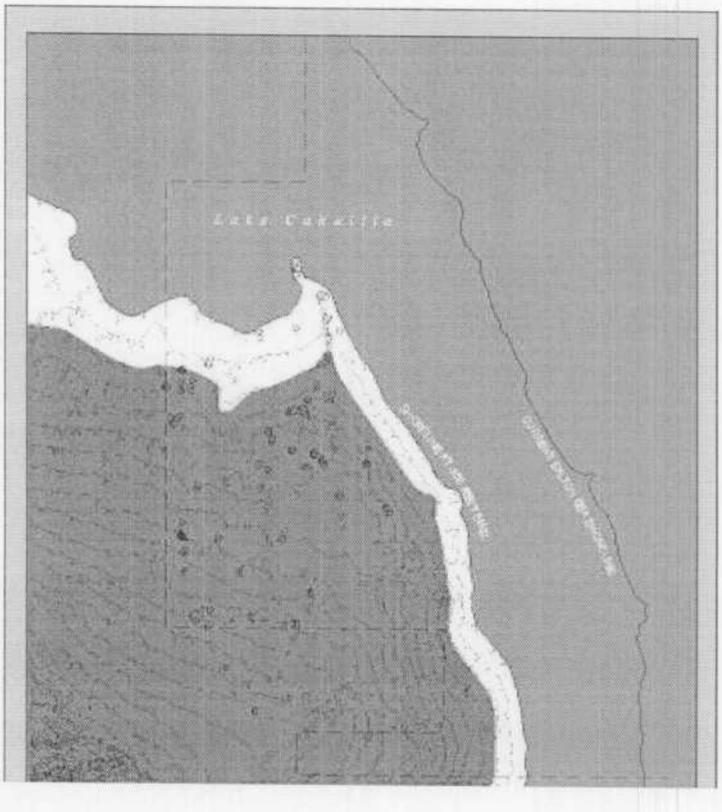
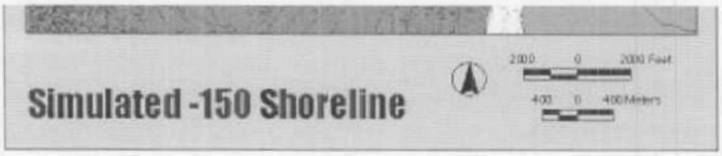


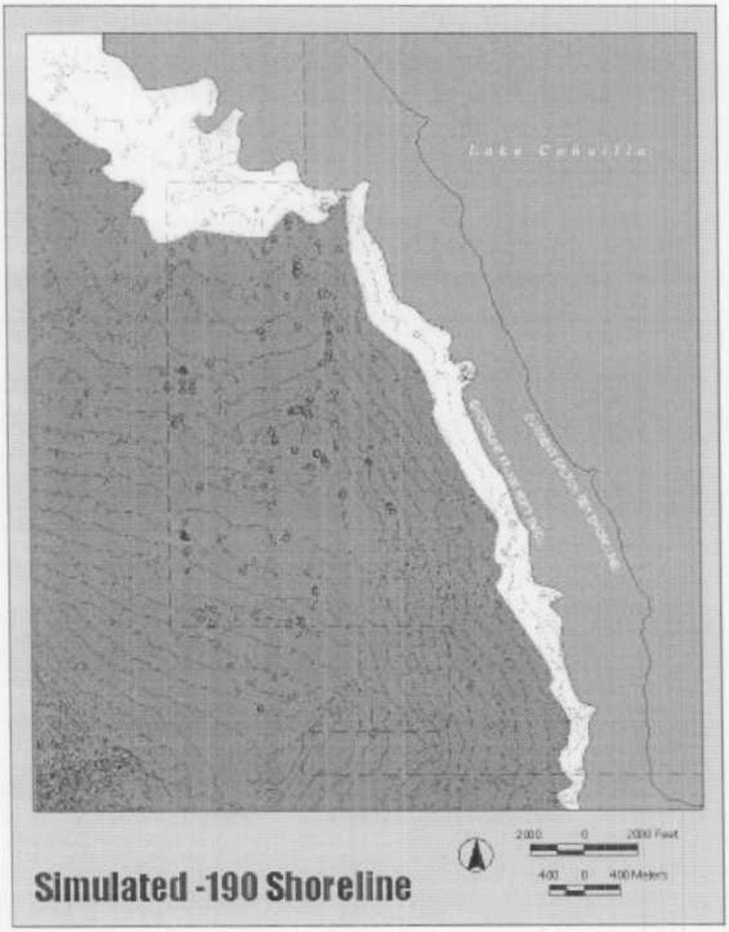
Figure 10. Modeled -150 Foot Shoreline with Archaeological Features





During the life of this embayment, the use of fish-traps appears to have been abandoned in our project area. It is not clear at present whether this is due to declining fish yields, or perhaps to the introduction of a new fish-procurement technology/strategy. Or, perhaps it is due to changing shoreline characteristics that made fish traps less productive (Figure 11). It is true, however, that as the use of fish traps was given up, the overall intensity of occupation of the project area appears to have declined. To demonstrate this, we used the analytic capabilities of GIS to generate counts of fish traps, rock enclosures, and other Late period features in twenty foot elevational intervals, and then divided these counts by the length of shoreline exposed in the survey area. This gave us the frequency of each feature type per km of shore.

Figure 11. Modeled -190 Foot Shoreline with Archaeological Features



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Analyzing our point data in this manner proved to be a challenge for our GIS operator. She imported USGS Digital Elevation Model files for two quads into ArcView and converted each file into a Grid, using applications within the Spatial Analyst extension. She then created a mosaic of the Grids using an ESRI extension called Transform Grid and recreated the topographic contours using Spatial Analyst. A major challenge was imposed by the fact that the contours are line layers, but point data such as our sites can only be clipped to polygons. ArcView and Spatial Analyst enabled her to avoid the 20 hours or more of work that it would have taken to redraw polygon shapes along the contour lines; AVENUE expressions were used to select contour intervals in 20-meter swaths. Each selection was then converted into a shapefile. Twelve separate shapefiles were created in this manner, and the site data were clipped to each using the Geoprocessing Extension. The compiled data were then exported to dBase IV and Excel for further analysis.

The results of these efforts are summarized in Table 1. First, looking at the middle column we see that the frequency of Late period features per unit of shoreline increases steadily until it reaches a peak along the -110 and -130 foot shorelines and then declines fairly rapidly. Importantly, during the four intervals where fish traps were present, we also find our highest frequencies of rock enclosures. These data indicate first that fishing was probably best in the project area during the time that the lake surface was between -70 and -130 feet. This period may have only lasted a decade or a decade and a half. We do not know if the decline was due to declining productivity of the fishery or simply the shifting of procurement activities to new favorable places located elsewhere along the shoreline. Studies similar to this one of additional areas along the recessional shores of Lake Cahuilla would be necessary to answer this question. We do know that a relatively intensively used Late period camp was located five miles south at the Elmore Site, excavated by Caltrans archaeologists (Laylander 1994). This site is located at -180 feet and thus would have been under-water during the height of utilization of the Salton Sea Test Base. The Elmore site is adjacent to San Felipe Creek a potential source of freshwater. This makes us wonder: was water quality within the lake declining so as to encourage the creation of a larger encampment near a water source? More research would be necessary to answer this question, but GIS can also help in addressing changes in water quality by allowing us to calculate lake volumes with a high degree of accuracy.

Table 1
Density of Late Prehistoric Features along Lake Cahuilla Shorelines

Shoreline Elevation (ft. amsl)	# Late features	Late features per km	Fish traps per km	Rock Enclosures per km
-30	1	1.4	0.0	1.4
-50	7	2.2	0.0	2.2
-70	20	6.6	2.6	4.0
-90	19	3.8	0.6	3.2
-110	41	10.7	1.3	9.4
-130	33	7.1	1.3	5.8
-150	32	3.7	0.0	3.7
-170	30	2.2	0.0	2.0
-190	22	2.0	0.0	1.9
-210	5	0.6	0.0	0.6

Lake Volume

In modeling human use of the shorelines of Lake Cahuilla, it is useful to accurately calculate the lake's volume at different levels. One way in which accurate volumetric estimates are useful is that they allow us to calculate the rate at which the lake filled, by using known values for evaporation, precipitation, and Colorado River flow. This in turn will help us to model the settlement of the submaximum lakeshore during transgressions, and to help establish the timing of lakestands, particularly the hypothesized fifth last infilling during the fifteenth century.

More importantly, good volumetric estimates will eventually allow us to more accurately model a number of important parameters of the lake's recession. Since the lake's recession is controlled mainly by evaporation, this will be a more linear progression with respect to elevation, and has been estimated at about 5 to 6 feet per year on average. However, the lake's salinity during recessions is controlled by changes in the volume of the water in the lake. As the lake volume is reduced by evaporation, dissolved salts, which do not evaporate, are increasingly concentrated in the remaining water. At a certain point, the water becomes too salty to drink, restricting the occupation of the shorelines. Later on, the lake will not support the freshwater mussels that are so common in sites along the maximum shorelines. Eventually, the lake's abundant fish resources decline and eventually disappear entirely. Since increasing salinity during recessional episodes is controlled by the reduced amount of water in the lake, estimates of volume at specific points is critical to modeling salinity and its effect on human use of the shorelines.

Previous calculations of the lake's area and volume have been based on counting the number of square miles covered by the lake at various contour intervals (Laylander 1994). While careful application of this method has provided fairly good "ballpark" estimates, the use of GIS for these estimates is clearly much more accurate and less cumbersome. Calculation of the lake's volume at specific contours is a fairly straightforward procedure using GIS derived values for the area of the Salton Basin at specified contour intervals. For example, at its maximum extent at the 40-foot contour, these calculations show the lake surface encompassed 1,279,363 acres and that it contained some 191,462,187 acre feet. Halfway through its recession, at the -150 foot contour, it encompassed 436,170 acres and contained 37.066,095 acre feet.

The values of the lake's volume can then be used to estimate infilling times employing (1) known values for the flow of the Colorado River during the 19th and early 20th centuries; (2) values for average yearly precipitation in the Salton Basin; and (3) values for yearly evaporation in inches (Laylander 1994). Assuming full capture of the Colorado River's flow, these values may be used to arrive at a filling time of 17.5 years for the lake. The volumetric values can then be applied to Laylander's (1994) volume-based salinity curve for the lake's recession. Although subject to a variety of complicating factors, this simplified model suggests that beginning with a salinity at the maximum stand equal to that of the historic Colorado River (322 ppm), the water would become distinctly salty to the taste by the 21st year of the recession, and the salinity of seawater would be reached by the 49th year.

Conclusions

The rapidity of Lake Cahuilla's recession after the Colorado River was rediverted to the Gulf of

California offers a unique opportunity to study a prehistoric culture with a fine-toothed chronological comb. The analytical capabilities of GIS are critical to this endeavor in that they allow us to develop models of how archaeological sites might relate to each other in time as well as facilitating the study archaeological sites in relationship to landscape variables. Also of value is the ability to model transgressions and recessions volumetrically, yielding a better understanding of water quality and suitability for human occupation. Now that we have our data in GIS we will be able to use modeling approaches to evaluate alternative scenarios of the interrelationships of archaeological sites and the environment over time.

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