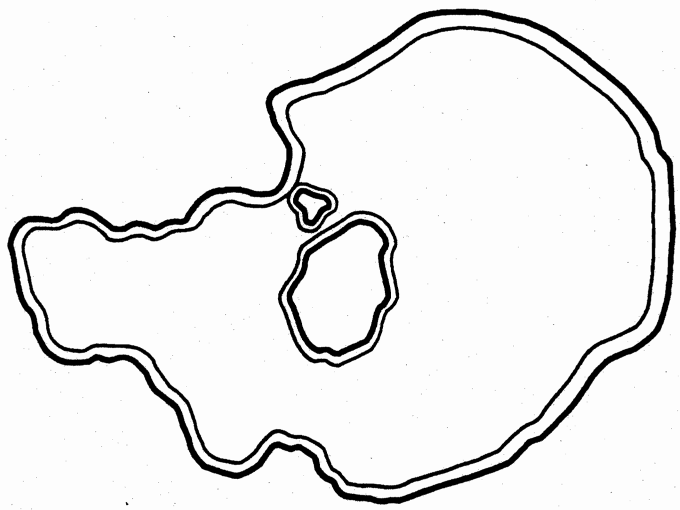
An Auxiliary Report
Prepared for the

MONO BASIN WATER RIGHTS EIR

Past and Future Toppling of Tufa Towers and Sand Tufa at Mono Lake, California



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Mono Basin EIR Auxiliary Report No. 9

**An Auxiliary Report
Prepared for the
Mono Basin Water Rights EIR Project**

This auxiliary report was prepared to support the environmental impact report (EIR) on the amendment of appropriative water rights for water diversions by the City of Los Angeles Department of Water and Power (LADWP) in the Mono Lake Basin. Jones & Stokes Associates is preparing the EIR under the technical direction of the California State Water Resources Control Board (SWRCB). EIR preparation is funded by LADWP.

SWRCB is considering revisions to LADWP's appropriative water rights on four streams tributary to Mono Lake, Lee Vining Creek, Rush Creek, Parker Creek, and Walker Creek. LADWP has diverted water from these creeks since 1941 for power generation and municipal water supply. Since the diversions began, the water level in Mono Lake has fallen by 40 feet.

The Mono Basin water rights EIR examines the environmental effects of maintaining Mono Lake at various elevations and the effects of possible reduced diversions of water from Mono Basin to Owens Valley and the City of Los Angeles. Flows in the four tributary creeks to Mono Lake and water levels in Mono Lake are interrelated. SWRCB's decision on amendments to LADWP's water rights will consider both minimum streamflows to maintain fish populations in good condition and minimum lake levels to protect public trust values.

This report is one of a series of auxiliary reports for the EIR prepared by subcontractors to Jones & Stokes Associates, the EIR consultant, and contractors to LADWP. Information and data presented in these auxiliary reports are used by Jones & Stokes Associates and SWRCB, the EIR lead agency, in describing environmental conditions and conducting the impact analyses for the EIR. Information from these reports used in the EIR is subject to interpretation and integration with other information by Jones & Stokes Associates and SWRCB in preparing the EIR.

The information and conclusions presented in this auxiliary report are solely the responsibility of the author.

Copies of this auxiliary report may be obtained at the cost of reproduction by writing to Jim Canaday, Environmental Specialist, State Water Resources Control Board, Division of Water Rights, P.O. Box 2000, Sacramento, CA 95810.

Past and Future Toppling of Tufa Towers and Sand Tufa at Mono Lake, California

A report to
Jones and Stokes, Associates, Inc.
Sacramento, CA

April, 1992

Prepared by:
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A copy of this report has been placed in the Water Resources Center Archives, U.C. Berkeley.

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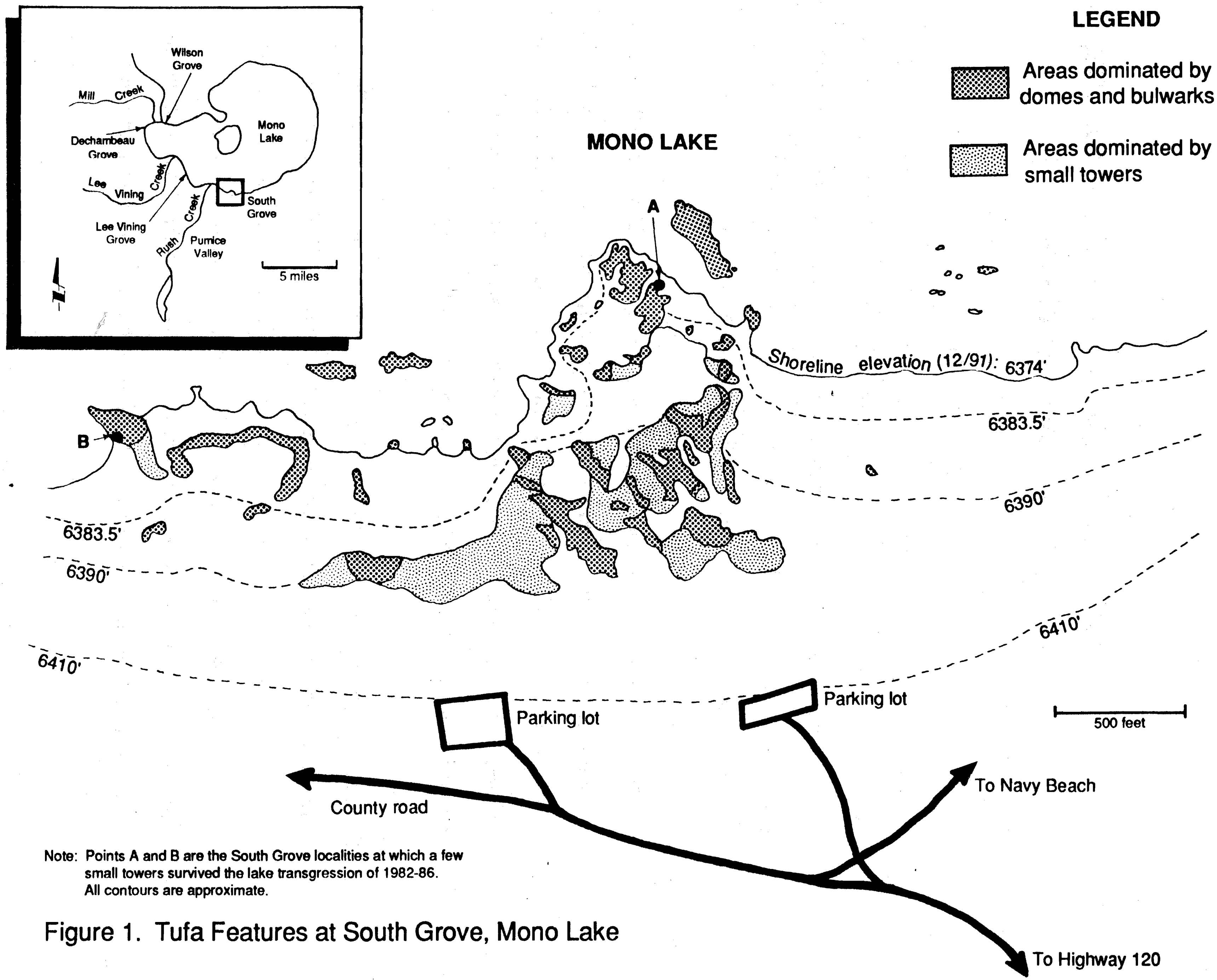
PAST AND FUTURE TOPPLING OF TUFA TOWERS AND SAND TUFA AT MONO LAKE, CALIFORNIA

Introduction

Mono Lake, a high-alkaline water body in east-central California, is renowned for its deposits of tufa. While these calcium carbonate deposits take many forms, they occur most conspicuously as pinnacles, domes and spires (collectively, "tufa towers"), and as a cement matrix within littoral sands ("calcite-impregnated defluidization structures", or "sand tufa").

Since 1940 the Los Angeles Department of Water and Power has been diverting the streams that feed Mono Lake. In response to these diversions, the lake has fallen 45 vertical feet, reaching a low stand elevation of 6372 feet in 1982. This artificially induced recession has exposed several large concentrations of tufa towers, as well as several acres of sand tufa.

Several years of abnormally high Sierran snowpack beginning in 1982 produced more runoff than could be diverted by the LADWP system. As a result, the lake rose 9 feet from its historic low stand, reaching an elevation of 6381 feet in 1986. The tufa towers at most of the major groves withstood the geomorphic alteration of the shorelands that accompanied this 9-foot rise in lake level. At the South Tufa Grove (Figure 1), however, the transgression



Note: Points A and B are the South Grove localities at which a few small towers survived the lake transgression of 1982-86. All contours are approximate.

Figure 1. Tufa Features at South Grove, Mono Lake

resulted in the toppling of several hundred towers.

The purpose of this report is 4-fold: 1) to examine the pattern, degree, and causation of tufa-tower toppling that accompanied this recent lake transgression; 2) to examine the factors that made the towers at South Grove susceptible to toppling; 3) to predict, using the 1982-1986 transgression as a model, the pattern and degree of tower toppling that would result from any future rises of the lake (specifically, to the elevations being considered by the California State Water Resources Control Board as "alternative lake levels", i.e. 6377 feet, 6383.5 feet, 6390 feet, and 6410 feet); and 4) to predict, based on past behavior of littoral geomorphic processes at Mono Lake, the effect of these possible future rises in lake level on the sand tufa deposits along the south shore of the lake.

Background to Tufa Tower Toppling

Tufa tower formation--general. Tufa towers form at sublacustrine spring sites where calcium-bearing spring water mingles with the carbonate-rich water of the lake. Where sublacustrine springs issue from distinct, solitary point sources, the result is an isolated tower. These lone-standing individuals can occur in densities of hundreds per acre. At other sites, in contrast, the spring water may emanate from a more complex and areally extensive vent, or from linear ground-breaks associated with faults. In such instances individual towers may coalesce to form large, complex, dome-like agglomerations 50 feet or more in basal diameter, or linear bulwarks of tufa up to nearly a thousand feet in length and over 15 feet in width.

Cross sections through broken towers found at the Lee Vining, Wilson, Dechambeau, Old Marina, and South groves reveal that the towers typically are composed of a core of highly porous tufa that can be crushed with the fingers. This soft core material is encased in one to several rinds of relatively dense, durable tufa that is difficult to break without the aid of a hammer. Early workers proposed that the hard, outer material forms first, conveying water upwards as a pipe that subsequently fills with the porous tufa. More recent evidence points to the opposite sequence of events: the punky inner material forms initially, through the rapid physicochemical precipitation of calcium carbonate. Only later is this material sheathed in the harder, denser tufa, formation of which may be related to the action of algae. Examples of yet-unsheathed columns of the porous tufa are found today on the lake floor immediately off the Lee Vining Grove (Dr. D. Herbst, pers. comm., 1990).

Excavations of the tower bases reveal that they are "rooted" in littoral, lacustrine, and tephratic sediments to a depths ranging from a few inches (at South Grove) to at least two, and often more than three feet (at the Lee Vining and Dechambeau groves). A large portion of this "rooting" is clearly related to burial of the bases following tower formation. It is the shallow rooting at South Grove that makes the towers there particularly susceptible to toppling (see below).

Radiocarbon assays on tufa towers at Mono Lake yield aberrantly old ^{14}C ages, apparently because a large amount of the carbon incorporated into the lake's carbonate deposits is derived from the ancient limestones of the eastern Sierran front. This precludes direct radiometric dating of the towers. Realistic dates can be derived by analyzing the shrub branches that are occasionally incorporated into the towers at the time of their formation. Radiocarbon assays on these wood inclusions at the Lee Vining and Dechambeau groves indicate that the towers there formed between about 900 and 600 years ago.[1]

Age and formation of the South Grove. South Grove is peculiar among the tufa groves of the Mono shorelands in that its towers apparently contain no wood. The timing of tower formation therefore cannot be dated through radiocarbon analysis. But the towers can be dated, or at least constrained between dates, based on sedimentary evidence. As noted above, the towers at South Grove are shallowly rooted, extending into the shoreland sediment only a few inches. Excavations, as well as surface exposures, reveal that the bases not only stand well above the buried tephra associated with the Mono Craters eruption of ~AD 1345, but also above the tephra associated with the Paoha Island eruption of ~AD 1675. Indeed, application of sedimentation rates to the dating problem leads to the conclusion that the towers formed within the early decades of this century.

Another peculiarity of South Grove is that springs and seeps are relatively scarce. Whereas water continues to issue from the bases of many (perhaps most) of the towers at the other groves, springs (more typically, low-flow seeps) are common only at and immediately above the shoreline at South Grove. The huge bulk of towers at South Grove lack basal springs.

These peculiarities raise the following questions: Why are the towers at South Grove so young? What was the source of the spring water that allowed so much tufa to form so recently and so rapidly at South Grove? Why were the springs that gave rise to the towers suddenly "turned on" during the early decades of this century? And why have the springs "turned off" in more recent time?

The answers may lie in yet another heretofore unresolved hydrological matter of modern Mono Basin history. Beginning around 1920, thousands of acre feet of Rush Creek water were annually diverted eastward from the stream and spread onto Pumice Valley for irrigation. A small portion of that water was undoubtedly lost to evapotranspiration. Some of the water is known to have seeped back into Rush Creek as groundwater. But flow records for Rush Creek reveal that the amount of Pumice Valley irrigation water that found its way back into Rush Creek was small.

What was the fate of the remainder of the Pumice Valley irrigation water? Confined by the Mono Craters on the east, and flowing within northwardly-dipping alluvial and lacustrine sediments, the groundwater from this irrigation had available to it only one other path: northeastward through the gap that lies between Panum Crater and the main range of Mono Craters. This pathway funnels water directly to the Mono shorelands at South Grove. It is hypothesized that the irrigation of Pumice Valley during the first half of this century provided the groundwater responsible for the formation of South Grove. Irrigation of Pumice Valley was dramatically curtailed beginning in the mid- to late 1940s, presumably putting an end to the spring activity that gave rise to the towers at South Grove.[2]

Littoral processes and tower undercutting. Erosion along a shoreline typically creates a "wave-cut platform"--a low-gradient surface that terminates landward at a cliff, and lakeward at a nickpoint (a level at which gradient abruptly increases in the downslope direction). A lake surface that is either receding or holding stable against steeply inclined shorelands is capable of eroding only a narrow wave-cut platform. Width of the platform is limited because waves moving across it toward shore expend their energy as frictional drag on its surface. Once the platform reaches some critical width, insufficient wave energy remains at shoreline to accomplish further backwearing of the cliff, and widening of the platform ceases. During a rise in lake level, in contrast, wave bases are elevated above any existing platform, allowing the waves to batter and wear back the cliff, thereby widening the platform. The waves of a rising lake thus create a relatively broad platform that, depending on the erodibility of the substrate, may widen until the transgression ceases.

This very sequence of events characterized South Grove during the decades prior to 1986. The early years were characterized by generally declining lake levels, when the regressing lake margin cut a series of small, subdued platforms with head-cliffs seldom more than a few inches in height. The 9-foot lake transgression that characterized the years 1982-1986, in contrast, cut a wide and prominent terrace into the shorelands at South Grove. The lake has now retreated from this highstand, exposing a head-cliff that ranges from 1 to 3 feet in height (this variation is a function of the pre-transgression topography). It was this transgression that caused the towers at South Grove to topple.

Nature and Extent of Tower Toppling

Toppling of tufa during the transgression of 1982-86 was almost entirely confined to the South Grove. Only at Lee Vining Grove could other toppled towers be found. There, toppling was limited to only ~18 towers.

The loss of hundreds of towers at South Grove was clearly a direct result of the shallow rooting (and thus ultimately the youth) of the towers. It is emphasized that these towers did not fall due to the battering of their flanks by waves. Indeed, the tower flanks were subjected to wave-battering for decades as they emerged from the falling lake. The very existence of upright towers on lands exposed by the lake recession of the last several decades (and the near-absence of toppled towers on exposed lands unaffected by lake transgressions) testifies to the ability of towers to withstand pounding by waves. Rather, the towers were undercut during the lake transgression of 1982-86, as waves eroded the sediment in which they were rooted.

Observations related to toppled towers at South Grove were made in the field during December, 1991. Estimating the number of towers toppled between 1982 and 1986 was hindered by many complexities, including, *a) ambiguity over what constitutes a single tower.* So complex and bizarre are the forms taken by the towers, and so often are towers agglomerated rather than lone-standing, that all attempts at accurate field counts ended in vexed frustration; and *b) questions as to how many toppled towers remain submerged in the lake and thus beyond view.* After many hours of counts and recounts, it was estimated that approximately 300 towers were toppled by the transgression. Because of the problem of submergence noted above, this is necessarily an extrapolation.

In the course of these field surveys particular attention was paid to the nature (including the size and grouping) of the toppled vs. the non-toppled towers, and to the locations of the toppled vs. non-toppled towers. Two clear patterns emerged:

<u>Nature and diameter of the tower bases</u>. Basal diameters of individual tufa towers at South Grove vary greatly, from less than a foot, to more than 30 feet. For simplicity's sake, towers less than 4 feet in basal diameter are referred to in discussions below as "small-diameter towers", or simply "small towers".

(The small-diameter towers are also relatively short, rarely exceeding a height of 10 feet.) Towers with basal diameters greater than 4 feet are referred to below as "domes", a term that includes both individual towers and agglomerations of towers. A further distinction is drawn between domes and the "linear bulwarks" of tufa that have formed on elongate fractures in the ground.

With only two observed exceptions, toppling at South Grove was limited to small-diameter towers. Well over 90% of the toppled towers have basal diameters of less than 2 feet. This is not to say that domes were unaffected by the lake rise. Indeed, nearly all presently-standing domes that lie between 6372 feet and 6381 feet exhibit some degree of wave-induced erosion at their bases, with several domes overhanging the ground on their lakeward side. Small-diameter towers protruding from the linear bulwarks were typically toppled by the lake rise, but the bulwarks themselves survived the transgression with little modification. This appears to be due, at least in part, to the fact that the sediments from which the bulwarks protrude are themselves thoroughly cemented with tufa.

<u>Tower location</u>. The linear bulwarks constitute breakwaters against which waves crash. As a point of departure for the study, it was hypothesized that the fields of small-diameter towers protected from waves by a bulwark to their lakeward should have experienced a lower incidence of toppling than tower fields unprotected by a breakwater. Only in two small areas (Figure 1, Points A

and B) did the observations confirm this hypothesis. Elsewhere, the incidence of toppling among small-diameter towers was virtually 100% on both "protected" and "unprotected" shorelands. In most areas, even those small, lone-standing towers lying in the immediate lee of a bulwark were toppled by wave induced undercutting. This suggests that even small, refracted waves are capable of eroding the sediments that support the towers.

Predicting the Extent of Future Tower Toppling

Background. With the exception of South Grove, all the major concentrations of tufa towers at Mono Lake (including the Dechambeau, Wilson, Lee Vining, and Old Marina groves) are composed of deeply rooted towers. This, and the fact that these other groves occupy shorelands with gradients that are in equilibrium with the littoral geomorphic processes, explain why tower toppling during the transgression of 1982-86 was limited to South Grove. For these same reasons, it is highly likely that tower toppling in response to any future rises in lake level will be restricted to South Grove.

Field observations on the nature and degree of geomorphic alteration of the shorelands at South Grove lead to the following conclusions:

--Because they are readily undermined by waves, small-diameter towers are clearly susceptible to toppling during lake transgressions. With the exception of the two small areas noted above, toppling of small towers was effectively 100% on lands inundated by the lake transgression of 1982-1986.

--The tufa domes survived the transgression, though not without undergoing some erosion of the supporting sediments at their bases.

--Toppling along the linear bulwarks of tufa was limited to the small towers on the bulwark flanks.

It is important to understand that the transgression of 1982-86 was exceptional for its rapidity. At the time the transgression commenced the lake was low (6372 feet), and was therefore particularly susceptible to a rapid rise (the lake stood "low in its cone", and therefore required relatively little inflow per foot of rise). Runoff during water year 1982 was the third highest on record. This was followed by even higher runoff in 1983--the highest runoff on record. By April of 1984 the lake had risen 8.9 of the 9 feet that would constitute the modern transgression (the final 0.1 foot of rise did not occur until 1986). Given the extreme speed of this transgression, it would be unrealistic to hypothesize a more rapid lake rise for any time in the future.

The speed of the transgression is important because it bears on the susceptibility of tufa domes to future toppling. Had the lake risen more slowly between 1982 and 1986, or had it lingered at one or more intermediate elevations for some period of time, erosion at the bases of the domes almost certainly would have been more extensive, and dome toppling might well have occurred. It is also conceivable that a slower rise could have undermined the linear bulwarks, though their susceptibility to toppling seems low due to the thorough cementation of their basal sediments.

Future management of the lake will likely result in the shoreline spending long periods of time within a relatively narrow elevational band (ranging from 5.5 feet to 7 feet, depending on which EIR management alternative is selected--Mr. Ken Casaday, pers. comm., 1992). The initial rise to the high stand of this management band can be expected to topple virtually all small towers on the inundated lands at South Grove. As the lake lingers within the band, many of the domes whose bases stand within that elevation interval may ultimately topple. The domes that lie below the management band, and that survive the initial transgression into that band, are not likely to be undermined and toppled. Whether or not they survive the initial transgression depends on, among other things, the speed of that rise.

For reasons given above, it is difficult to make numerical estimates of future tower toppling. Given the experience of 1982-86, certain qualitative statements about future toppling can be made with a reasonable degree of confidence. All numerical estimates given below should be taken only as order-of-magnitude approximations.

<u>The future of South Grove at a Management Alternative Lake Level of 6377 feet</u>. (According to computations by Jones and Stokes Associates, Mono Lake, managed at an elevation of 6377 feet, will occasionally reach a level as high as 6382.9 feet--Mr. Ken Casaday, pers. comm., 1992.) With virtually all small towers between elevations of 6372 feet and 6381 feet having been toppled during the lake transgression of 1982-1986, a rise in lake level from the

present-day elevation (6374 feet) to 6381 feet will have no further effect on towers less than 4 feet in diameter. Perhaps 3 dozen more small towers can be expected to topple as the lake rises from 6381 feet to 6382.9 feet. For the sake of a rough quantitative comparison, the number of small towers that would be toppled in this process is on the order of perhaps 10% of the number toppled by the modern transgression, and perhaps 1% to 2% of the small towers that currently stand at South Grove.

The future of South Grove at a Management Alternative Lake Level of 6383.5 feet. (According to computations by Jones and Stokes Associates, Mono Lake, managed at an elevation of 6383.5 feet, will occasionally reach a level as high as 6389.5 feet--Mr. Ken Casaday, pers. comm., 1992.) Because virtually all small towers between elevations of 6372 feet and 6381 feet were toppled during the lake transgression of 1982-1986, a rise in lake level from the present-day elevation (6374 feet) to 6381 feet will have no further effect on towers less than 4 feet in diameter. Perhaps 200 more small towers can be expected to topple as the lake rises from 6381 feet to 6389.5 feet. For the sake of a rough quantitative comparison, the number of small towers that would be toppled in this process is on the order of perhaps two-thirds of the number toppled by the modern transgression, and perhaps 3% to 5% of the small towers that currently stand at South Grove. Tufa domes might also be toppled by a transgression to a level of 6389.5 feet, though the modern transgression does not provide a clear enough pattern of dome toppling to make any realistic numerical predictions.

The future of South Grove at a Management Alternative Lake Level of 6390 feet. (According to computations by Jones and Stokes Associates, Mono Lake, managed at an elevation of 6390 feet, will occasionally reach a level as high as 6395.1 feet--Mr. Ken Casaday, pers. comm., 1992.) Assuming that the pattern of geomorphic alteration that characterized the modern transgression continues as the lake rises to a level of 6395.1 feet, perhaps 50% of the small towers currently standing at South Grove will topple. Note that most of the small towers lying below an elevation of 6395.1 feet (and, indeed, below 6388.5 feet, the level to which the lake would occasionally drop when managed at the 6390-foot lake level alternative--Mr. Ken Casaday, pers. comm., 1992) would be under water and out of sight at this lake level regardless of whether or not they toppled. Depending on the rate of rise and the manner in which the lake is managed, a transgression to 6395.1 feet could possibly result in the toppling of tufa domes at South Grove, though the modern transgression does not provide a clear enough pattern of dome toppling to make any realsitic numerical predictions. If the past pattern prevails, the linear bulwarks will survive the management of the lake at this level.

The future of South Grove at a Management Alternative Lake Level of 6410 feet. (According to computations by Jones and Stokes Associates, Mono Lake, managed at an elevation of 6410 feet, will occasionally reach a level as high as 6414.7 feet--Mr. Ken Casaday, pers. comm., 1992.) Assuming again that future transgressions are characterized by the same geomorphic consequences that accompanied the modern transgression, a lake rise to a management level of

6414.7 feet would be expected to topple virtually 100% of the small towers at South Grove. Some unknown number of tufa domes could also be toppled, depending on the rate of the lake transgression, but the modern transgression does not provide a clear enough pattern of dome toppling to make any realsitic numerical predictions. If the past pattern prevails, the linear bulwarks will survive the management of the lake at this level. Note that at an elevation of 6414.7 feet (and even at an elevation of 6407.1 feet, the level to which the lake would occasionally drop when managed at the 6410-foot lake level alternative--Mr. Ken Casaday, pers. comm., 1992), virtually all towers at South Grove, standing or toppled, would be under water and out of sight.

The extent to which inundation alone would efface tufa towers both standing and toppled) from the view at South Grove is estimated in Table 1.

Table 1

Inundation of South Grove tufa towers (standing and toppled) per given Management Alternative Lake Level. Expressed as the percentage of total towers that were exposed at the time of the Historic Low Stand (= 6372 feet). All percentages are approximations made from analyses of aerial photos.

Alternative	**At lowstand of alt.**	**At highstand of alt.**	**At average stand of alt.**
6372.7'	6372.2' 100% exposure	6378.8' 3-5% inundation	6375.1' 1-3% inundation
6377'	6376.6' 1-3% inundation	6382.9' 4-8% inundation	6379.3' 3-5% inundation
6383.5	6383' 4-8% inundation	6389.5' 7-14% inundation	6386' 6-12% inundation
6390'	6388.5' 7-14% inundation	6395.1' ~50% inundation	6391.5' ~20% inundation
6410'	6407.1' 100% inundation	6414.7' 100% inundation	6410.3' 100% inundation

Inundation of the Wilson, Dechambeau, and Lee Vining Groves

As previously stated, management of Mono Lake at the various alternative levels being considered in the EIR process will likely not result in significant toppling of towers at any of the other tufa groves. Each of the Management Alternative Lake Levels, however, will result in a greater or lesser amount of inundation of these other groves (including Lee Vining Grove, Dechambeau Grove, and Wilson Creek Grove). The effect of the various management scenarios on these other groves is summarized below in Table 2.

Background to Sand Tufa Destruction

Sand tufa occurs locally along the south shore of Mono Lake, most notably in the vicinity of Navy Beach. These carbonate-cemented beach sands form intricate, tubular structures. In some localities these castellated formations protrude above the ground surface; elsewhere they can be seen in section along the head cliffs of wave-cut terraces, most notably in the head-cliff that intersects the terrace at ~6390 feet immediately below the Navy Beach parking lot.

The same geomorphic processes that result in shoreland truncation at South Grove are active along Navy Beach. Because the largest and best exposed deposits of sand tufa (indeed, virtually all of the classic sand tufa sites) lie above an elevation of 6390 feet, this resource would be negatively affected only by management at the 6390-foot Management Alternative Lake Level (which,

Table 2

Partial and complete inundation of tufa towers per given Management Alternative Lake Level at the Wilson, Dechambeau, and Lee Vining groves, expressed as the percentage of total towers that were exposed at the time of the Historic Low Stand (=6372 feet). All percentages are approximations made from analysis of aerial photos. (Note that figures for basal inundation at 6372.2 feet refer to those towers that were characterized by basal inundation at the time of the Historic Low Stand.)

Grove	**Alternative**	**At lowstand of alt.**	**At highstand of alt.**	**At average stand of alt.**
Wilson Grove	6372.7'	6372.2' 100% exposure	6378.8' 100% exposure	6375.1' 100% exposure
	6377'	6376.6' 100% exposure	6382.9' 100% exposure	6379.3' 100% exposure
	6383.5	6383' 100% exposure	6389.5' basal inundation, 40%	6386' basal inundation, 30%
	6390'	6388.5' basal inundation, 40%	6395.1' total inundation, 10% basal inundation, 50%	6391.5' basal inundation, 40%
	6410'	6407.1' total inundation, 20% basal inundation, 60%	6414.7' total inundation, 40% basal inundation, 40%	6410.3' total inundation, 30% basal inundation, 35%
Grove	**Alternative**	**At lowstand of alt.**	**At highstand of alt.**	**At average stand of alt.**
Dechambeau Grove	6372.7'	6372.2' basal inundation, 5%	6378.8' basal inundation, 5%	6375.1' basal inundation, 5%
	6377'	6376.6' basal inundation, 5%	6382.9' basal inundation, 10%	6379.3' basal inundation, 10%
	6383.5	6383' basal inundation, 10%	6389.5' total inundation, 5% basal inundation, 40%	6386' total inundation, 5% basal inundation, 30%
	6390'	6388.5' total inundation, 5% basal inundation, 40%	6395.1' total inundation, 5% basal inundation, 50%	6391.5' total inundation, 5% basal inundation, 40%
	6410'	6407.1' total inundation, 90% basal inundation, 10%	6414.7' total inundation, 100%	6410.3' total inundation, 90% basal inundation, 10%
Grove	**Alternative**	**At lowstand of alt.**	**At highstand of alt.**	**At average stand of alt.**
Lee Vining Grove	6372.7'	6372.2' basal inundation, 10%	6378.8' basal inundation, 15%	6375.1' basal inundation, 12%
	6377'	6376.6' basal inundation, 15%	6382.9' basal inundation, 20%	6379.3' basal inundation, 18%
	6383.5	6383' basal inundation, 20%	6389.5' total inundation, 15% basal inundation, 55%	6386' total inundation, 10% basal inundation, 55%
	6390'	6388.5' total inundation, 15% basal inundation, 55%	6395.1' total inundation, 25% basal inundation, 50%	6391.5' total inundation, 18% basal inundation, 55%
	6410'	6407.1' total inundation, 95% basal inundation, 5%	6414.7' total inundation, 100%	6410.3' total inundation, 100%

according to computations by Jones and Stokes Associates, will include occasional transgressions to elevations as high as 6395.1 feet--Mr. Ken Casaday, pers. comm., 1992), and the 6410-foot Management Alternative Lake Level (which, according to computations by Jones and Stokes Associates, will include occasional transgressions to elevations as high as 6414.7 feet--Mr. Ken Casaday, pers. comm., 1992).

Presently the "equilibrium shoreland gradient" (the gradient to which waves will bevel the shorelands during a lake transgression) is approximately 1 per 80 along that portion of Navy Beach characterized by large deposits of sand tufa. The shorelands rise at this gradient until they encounter the steep cliff at an elevation of approximately 6390 feet. Should the lake rise above 6390 feet, the shoreline will not simply "climb" this cliff; rather, it will beat the cliff-base landward, effectively widening the existing wave-cut platform. There is no apparent reason why this process should halt as long as the lake continues to rise. If the lake were to rise to 6395.1 feet--the high stand computed for the 6390-foot Management Alternative Lake Level--the cliff will retrograde approximately 400 feet. This would destroy virtually all of the existing "classic" sand tufa that protrudes above the ground surface. It would also obliterate all the sand tufa that is currently exposed in section in the cliff, though it is possible, and perhaps even likely, that new in-section exposures would become visible as the cliff continued to wear back. Were the lake to rise to 6414.7 feet--the high stand computed for the 6410-foot Management Alternative Lake Level--the cliff could retrograde as much as 2000 feet. This, too, would obliterate all existing sand tufa, perhaps exposing more in section in the newly created cliff face.

Footnotes

1 One other aspect of tower morphology at South Grove may point to relative youth. Whereas the towers at all the other groves are encased in at least 2, and up to 4, relatively thick (typically >4 mm) sheaths of dense tufa, the towers at South Grove are encased in only one, relatively thin (typically <2 mm-thick), sheath.

2 Through an earlier analysis of streamflow records* it was determined that springs issuing from the margins of the Rush Creek canyon immediately above and below "the narrows" contributed from 18 to 52 cfs to the stream (with an annual average of roughly 34 cfs, = 24,616 acre feet). The bulk of this water issued from springs along the western side of the canyon (this west-side water was fed by irrigation of the Parker Creek and Walker Creek lands). A lesser amount entered the creek from its eastern side (this east-side water originated from the irrigation of Pumice Valley via "A-ditch" and "B-ditch" off Rush Creek). Between 1920 and 1947, an average of 24,944 acre feet of Rush Creek water was applied to ~600 acres of highly permeable land east of Rush Creek. An accounting of this water (based on collaboration with Mr. P.T. Vorster) follows:

<u>Input</u>

1. Water applied from A and B ditches: 24,944 acre feet

<u>Outputs</u>

1. ET loss: At 2 feet per year, on 600 acres, = 1200 acre feet (Vorster, 1985).
2. Seepage back into Rush Creek along the eastern canyon wall: Assuming that 25 percent of the springwater input to Rush Creek was from the east, total return seepage averages 6029 acre feet.

<u>Total known input</u>	24,944 acre feet
<u>Total assumed output</u>	7,229 acre feet
<u>Water unaccounted</u>	17,715 acre feet

These figures suggest that an annual average of roughly 17,700 acre feet of Pumice Valley irrigation water flowed to Mono Lake as groundwater from Pumice Valley. (If it is assumed that 50% of the springwater input to Rush Creek came from the east side, the amount of unaccounted water is still substantial--an average of 11,686 acre feet annually. The higher figure for unaccounted water is favored, however, since aerial photos, as well as written and spoken accounts, indicate that substantially more water came in from the west than from the east.) It is suggested that this unaccounted water flowed subsurface through the gap in the Mono Craters (south of Panum Crater), entering Mono Lake at the present site of the South Tufa Grove.

*Stine, S.W., 1990. Extent of riparian vegetation on streams tributary to Mono Lake, 1930-1940: An assessment of the streamside woodlands and wetlands, and the environmental conditions that supported them. Report to the California State Water Resources Control Board, and Jones and Stokes, Associates, Sacramento, 73 pp. plus appendices.