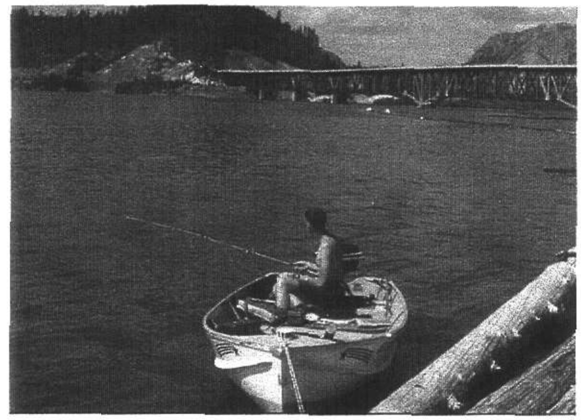
(3) Keswick Dam modifications,
(4) reservoir area saddle dike construction, and (5) power facility improvements and additions. Additional actions may also be required as a result of mitigation or operations requirements. The Low, Intermediate, and High Options are described in more detail below.

Low Option

The Low Option evaluates a dam raise with a new crest elevation at 1084 feet. The existing dam has a crest elevation at 1077.5 and an elevation of 1067 for the maximum water surface for joint-use storage space. The Low Option crest elevation of 1084 represents a structural raise of 6.5 feet to the crest height of the existing dam and has a new top of joint-use storage space at elevation 1075.5, an additional 8.5 feet of water in the reservoir. The total capacity of this new reservoir would be 4.84 million acre-feet, an increase of 290,000 acre-feet above the existing available storage.

The dam raise will be limited to the existing dam crest only, with mass concrete placed in blocks on the existing concrete gravity section and precast concrete panels used to retain compacted earthfill placed on the embankment sections. A new spillway crest section would be developed within the raised structure. Construction is assumed to require the removal of selected features from the existing dam crest, including the gantry crane and rails, the spillway bridge, the sidewalks and parapet walls, and miscellaneous concrete on both abutments.



Shasta Lake near its existing maximum water surface. Under a Low Option raise, the maximum water surface would be about 8-½ feet higher.

The spillway drum gates and control equipment and the concrete cantilever support walls would also be removed to accommodate the higher reservoir levels. Control features of the existing temperature control device would be extended up to the new crest elevation. The temperature control device itself would remain in place. It is assumed that personnel access can be provided to the existing elevator towers. Although the raised dam crest construction would remain above the new top of joint-use storage and provide for flood surcharge only, waterstops and other seepage control measures would be provided.

This option maximizes storage without replacing the Interstate Highway 5 and Union Pacific Railroad Pit River Bridge at Bridge Bay and minimizes any relocations of recreational facilities within the reservoir area. The option also avoids the construction of additional saddle dikes in the

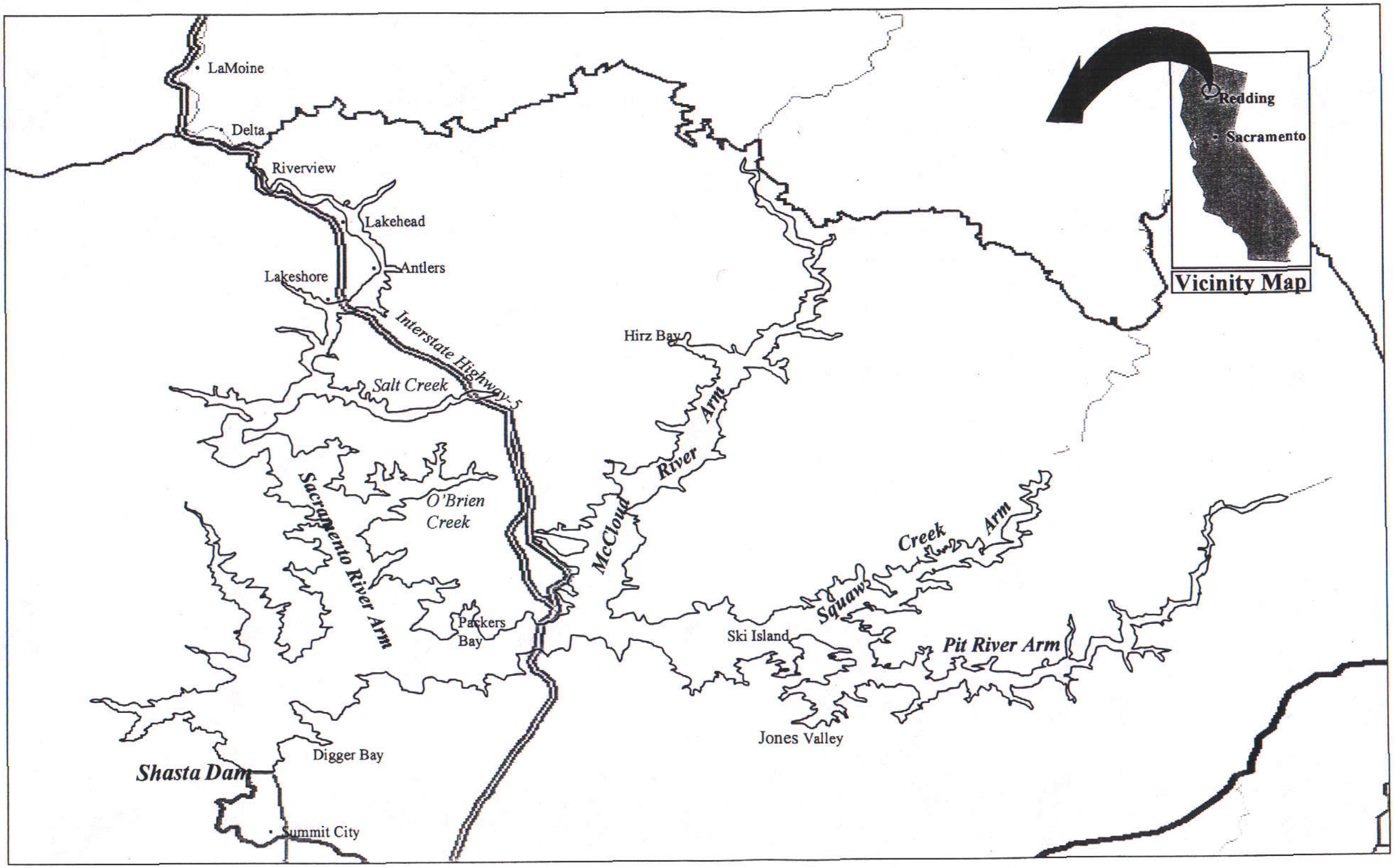


Figure 1 Shasta Dam and Reservoir

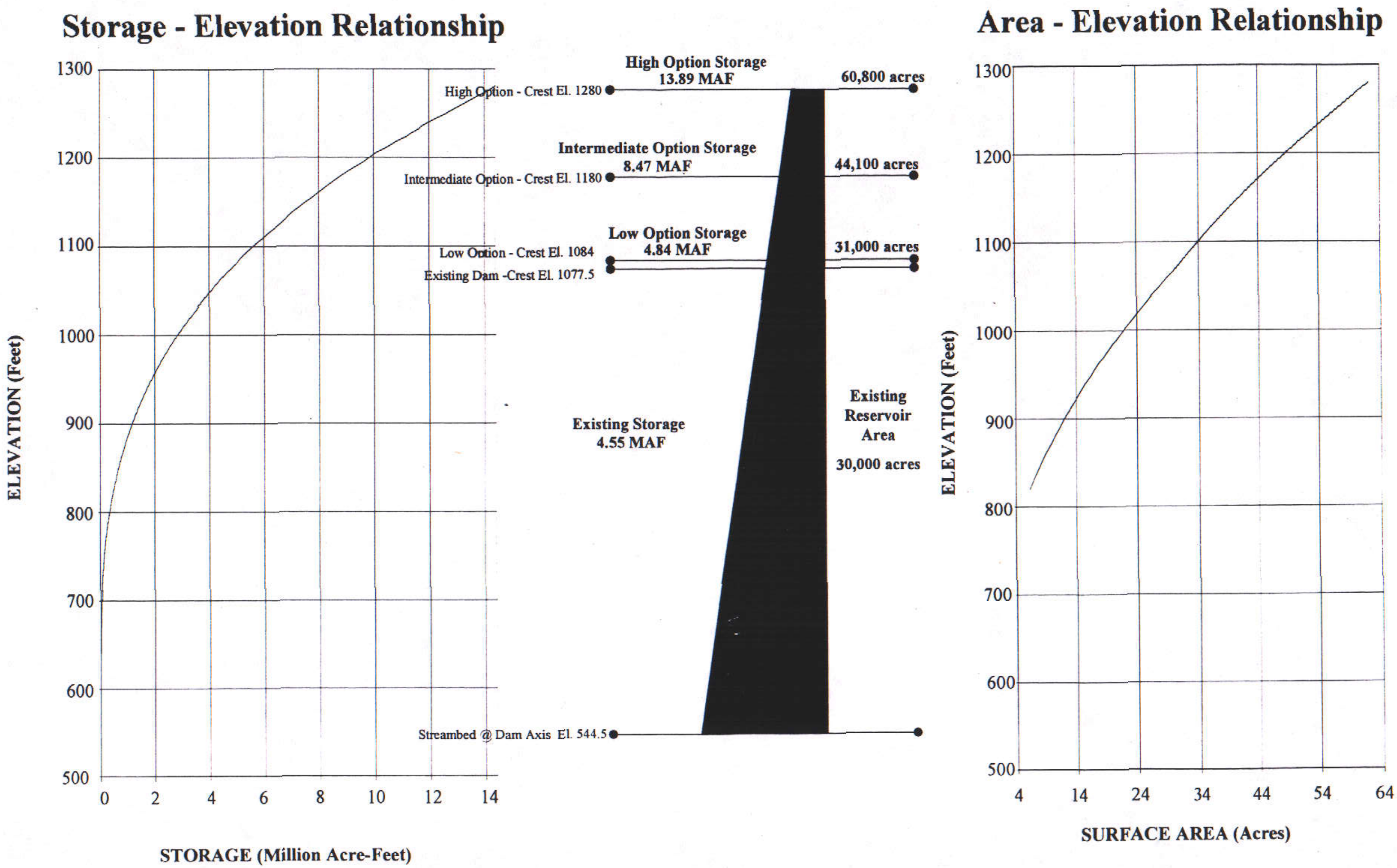


Figure 2 Storage - Area - Elevation Relationships of Shasta Reservoir

reservoir area. Modifications to the existing power facilities and Keswick Dam are not required, nor are any new power facilities developed under this option.

Intermediate Option

The Intermediate Option evaluates a dam raise with a new crest elevation at 1180 feet. This represents a structural raise of 102.5 feet to the height of the existing dam. The new top of joint-use storage space would be elevation 1171.5. This allows the storage of an additional 104.5 feet of water in the reservoir above the existing joint-use storage pool elevation. The total capacity of this new reservoir would be 8.47 million acre-feet, an increase of 3.92 million acre-feet above the existing available storage.

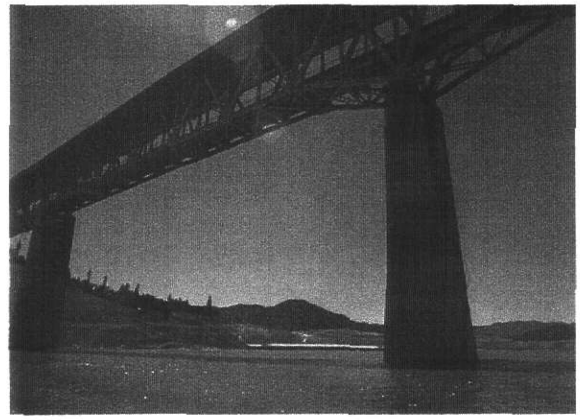
For the intermediate dam raise, the existing concrete gravity dam section would be raised using a mass concrete overlay on the main section of the dam with roller-compacted concrete wing dams constructed on both abutments. The left wing dam would extend approximately 1,380 feet, and the right wing dam would extend approximately 420 feet. The mass concrete overlay on the downstream face of the existing dam in the main section would extend from elevation 1180 down to the foundation contact at the downstream toe on a 0.7:1 slope. The overflow (or spillway) section will be made thicker to accommodate the gated spillway crest. The mass concrete overlay for the intermediate dam raise option will be significantly thinner than for the high dam raise option.

A new crest roadway and spillway bridge would be constructed. In addition, new elevators and gantry crane would be required, along with all the associated mechanical equipment required for operating the various outlet gates, temperature control device, and other features.

This option halves the number of saddle dikes required within the reservoir area to close off the gaps between mountain peaks in the upper basin watershed, allowing storage without spilling into adjacent watersheds. Two saddle dikes, at Jones Valley and Clickipudi Creek, are required in this option, but these are half the number needed in the High Option.

Replacement of the Pit River Bridge at Bridge Bay is required in this alternative. In addition, most recreational facilities require relocation. New power facilities are also developed in this alternative. These power facilities include a new powerplant below the left abutment, improvements to the existing penstocks, and a new switchyard. New facilities (raised dam and modified power facilities) at Keswick would also be required.

While the existing powerplant would continue to be operated within its operating range under this enlargement option, no new upgrading modifications to the existing powerplant were considered in this appraisal-level study (ongoing generator rewind uprating programs were assumed to occur). Given the increased reservoir elevations in this alternative, and in the High Option, there may be a potential requirement for major modifications to the existing structure to accommodate new units and overhead cranes. Evaluation of these requirements was beyond the scope of this appraisal study. In addition, major modifications may be required for the temperature control device to accommodate higher design discharges. Further studies are needed to evaluate alternatives to modifying the existing powerplant and to determine the most economic way of optimizing its generating capacity under any potential enlargement.



The Pit River Bridge carries traffic of Interstate Highway 5 on its upper deck and railroad traffic on its lower deck. Replacement of this bridge represents a major undertaking under the Intermediate and High Options.

High Option

The High Option evaluates a dam raise with a new crest elevation at 1280 feet. This represents a structural raise of 202.5 feet to the height of the existing dam. The new top of joint-use storage space would be elevation 1271.5. This allows the storage of an additional 204.5 feet of water in the reservoir. The total capacity of this new reservoir would be 13.89 million acre-feet, an increase of 9.34 million acre-feet above the existing available storage.

The High Option represents the highest raise of Shasta Dam possible before experiencing significant additional constraints. Enlargements beyond this point begin to experience significant geological foundation problems and relocation requirements of upstream Pacific Gas & Electric reservoirs and powerplants.

The existing concrete gravity dam section will be raised using a mass concrete overlay on the existing dam crest and downstream face. The upstream face within the curved nonoverflow sections will extend vertically to the new dam crest at elevation 1280, and the downstream face will have a 0.7:1 slope to the downstream toe. The dam crest will be completed with a crest cantilever for the roadway surface, sidewalks, and parapet walls. The existing elevator shafts will be extended to the new dam crest, and new elevator towers will be provided. The overflow (or spillway) section will require a thicker section to accommodate the gated spillway crest (similar to the profile for the existing spillway).

The new dam crest would include a crest roadway and spillway bridge, passenger and freight elevators, and three gantry cranes. The gantry cranes would be sized to handle mechanical equipment located at the upstream face for the river outlets in the spillway section (60-ton capacity) and for the penstocks for both the existing powerplant (125-ton capacity) and the new powerplant (175-ton capacity). The proposed configuration of the dam modifications would permit retention of the Upper Vista House and parking lots.

This option requires four saddle dikes to close off the gaps between mountain peaks in the upper watershed. A new powerplant and associated switchyard facilities are included on the left abutment. The existing powerplant would continue to be operated within its operating range. The existing penstocks on the right abutment would also be upgraded. New facilities at Keswick (raised dam and modified power facilities at Keswick) would also be required to accommodate the new powerplant.

Engineering and Other Technical Considerations

Shasta Lake at low storage.

This chapter documents the current technical engineering studies based on dam crests at elevation 1280 (high), elevation 1180 (intermediate), and elevation 1084 (low), using mass concrete gravity sections with roller-compacted concrete (RCC) gravity wing dams, where required. The current appraisal-level designs for enlargement of Shasta Dam address new spillways, river outlets, reservoir dikes, and hydropower features. These features are discussed below, along with a brief discussion of diversion features and associated Keswick Dam modifications.

Site Geology

Shasta Dam is located in the foothills near the northern end of the Sacramento Valley, in the southern Klamath Mountain Geomorphic Province. Tectonic activity associated with the interactions between the North American, Pacific, and Gorda crustal plates (Mendocino triple junction), where they join about 100 miles west of the dam, has influenced regional geomorphic features. Eruptions at Mt. Shasta, a dormant volcano located about 56 miles northeast of the dam, and at Mt. Lassen, a dormant volcano about 50 miles to the southeast, are attributed to heat developed near the interface between the Gorda and the overriding North American plate. Forces generated by the impact and jostling of these plates are believed largely responsible for the faults and the jointed, crushed, and sheared zones that are common to this region.

Shasta Dam is in an area of historically low-level seismicity in which no Quaternary faults are known (USBR, July 1986). Activity increases to the east in the Lassen Peak area, and to the west in the area of the Mendocino triple junction. The dam may be subjected to the effects of moderate to large earthquakes that might originate in these adjacent, more seismically active regions to the west and east. Most recently (1991-92), earthquakes with magnitudes between M 6.0 and 7.1 were located near the Mendocino triple junction (CDMG, March/April 1992). These earthquakes were felt throughout much of northern California and southern Oregon. Earthquakes of magnitude 6.0, 6.5, and 7.1 occurred on April 25 and 26, 1992.

Studies performed by University of California Seismograph Station personnel indicate that the rate of local seismicity that occurred during the initial filling of Shasta Lake in 1943 was not significantly different from that documented during the 1953-64 period. In addition, an annual periodicity correlating to seasonal changes in reservoir levels was not evident in the seismicity data for that period. Therefore, future reservoir-induced seismicity does not appear to be likely at the existing Shasta Lake. Further review of the potential for reservoir induced seismicity would be conducted in feasibility studies for any potential enlargement project.

The foundation of Shasta Dam consists of the Copley Formation, a sequence of volcanic rocks which has been metamorphosed to produce a rock type more commonly called greenstone. In the foundation, this rock is fresh and hard where unbroken; however, its integrity has been disturbed by numerous seams consisting of weathered joints and shears and zones of crushed rock.

All rock on the left abutment is a metavolcanic greenstone of the Copley Formation. Drill hole investigations conducted in 1984 for previous dam enlargement studies confirmed variably porphyritic to fine-grained meta-andesite flows with occasional medium- to coarse-grained pyroclastic layers with subordinate brecciated lenses. Weathering effects were found to decrease with depth in all seven drill holes, and the weathering boundaries encountered were generally consistent with the results of a geophysical survey performed in 1982. Eighty-four percent of the rock core recovered was very intensely fractured. Rock strength tests ranged from average to hard rock (unconfined compressive strengths from 5,000 to 16,000 pounds per square inch [lb/in^2]), and permeability was considered low (K from zero to 350 feet per year).

Rock on the right abutment is of similar origin and exhibits similar weathering conditions. Most of the rock recovered in drill holes is moderately to slightly fractured and hard (unconfined compressive strengths from 8,000 to 16,000 lb/in^2) and has a low permeability (less than 100 feet per year).

Original construction documentation states that the existing dam foundation was explored meticulously, and zones of weakness were effectively treated. In general, the quality of the foundation improves with depth and, despite the surface fracturing, the individual pieces or blocks are sound and fit together tightly.

Removal of Existing Structures

Enlargement of Shasta Dam will require the removal of existing structures on the dam crest, including the parapet walls and crest cantilever, sidewalks, curbing, crane rails, and spillway bridge. The existing elevator towers are assumed to be retained for the low dam raise option only. The spillway drum gates and frames, cantilever support walls, control equipment, and bridge piers must be removed for all dam raise options to accommodate the new spillway gates. The high and intermediate dam raise options will require minor excavation of the stilling basin floor at the downstream toe contact and the complete removal of the spillway training walls. The existing concrete surfaces will be prepared for new concrete placement by the application of high-pressure water jets (over 6,000 lb/in^2), consistent with normal practice for preparing construction joints, rather than the bushhammering or sandblasting assumed in previous studies. This method of surface preparation was used successfully for the modifications to Theodore Roosevelt Dam in Arizona, which were designed by the Bureau of Reclamation (Reclamation) with construction being completed in 1996.

The existing 125-ton gantry crane will likely be replaced with new equipment, due to its age (over 50 years old). Other mechanical equipment to be removed includes various river outlet gates and valves, steel piping, and operating equipment.

Concrete Dam Main Section and Abutments

High Option - Crest Elevation 1280.—As described previously, a mass concrete overlay on the existing dam crest and downstream face is required. The upstream face within the curved nonoverflow sections will extend vertically to the new dam crest at elevation 1280, and the downstream face will have a 0.7:1 slope. The mass concrete will be placed in alternating high-low blocks, with 10-foot lift heights and keyed contraction joints, similar to the recent dam raise modifications to Theodore Roosevelt Dam in Arizona.

Due to the thickness of the concrete overlay, a longitudinal contraction joint may be required, which would also be keyed and grouted. The dam crest will be completed with a crest cantilever for the roadway surface, sidewalks, and parapet walls. The existing elevator shafts will be extended to the new dam crest, and new elevator towers will be provided.

The overflow (or spillway) section will require a thicker section to accommodate the gated spillway crest (similar to the profile for the existing spillway).

The left and right abutments will be excavated to the top of moderately weathered rock to provide foundations for RCC wing dams. Assumed excavation depths average 70 feet on the left abutment and 60 feet on the right abutment. This excavation will be performed following the construction of the upstream cellular cofferdams and will include the removal of embankment materials and concrete core walls.

Extensive dental concrete treatment may be required for expected shear zones within the excavated foundation surface, and shaping concrete will be required to provide a suitable surface for RCC placement. The RCC will be rolled and compacted in 1- to 2-foot lifts between slip-formed concrete facing elements at the upstream and downstream faces, similar to Upper Stillwater Dam in Utah. The facing elements were designed by Reclamation, and construction was completed in 1988. This will provide a similar appearance to the mass concrete dam section.

For crest elevation 1280, the left abutment wing dam will extend approximately 1,500 feet, and the right abutment wing dam will extend approximately 570 feet. The existing grout and drainage curtains for Shasta Dam will be made deeper for the higher reservoir pressures and will be extended on both abutments. Extensive instrumentation will be required for the dam raise construction, including new thermistors and joint meters throughout the mass concrete blocks. The existing instruments will be extended or replaced. Specific instrumentation monitoring requirements will be developed in future studies.

The new dam crest will include a crest roadway and spillway bridge, passenger and freight elevators, and a total of three gantry cranes sized to handle mechanical equipment. One crane will be located at the upstream face for the river outlets in the spillway section (60-ton capacity), one for the penstocks for the existing powerplant (125-ton capacity), and one for the new powerplant (175-ton capacity). A modern lighting system will be provided for the dam crest, and lighting and ventilation will be provided for the new galleries. The proposed configuration of the dam modifications will permit retention of the Upper Vista House and parking lots.

Figure 3 shows a plan, profile, and section drawing of the proposed High Option.

Intermediate Option - Crest Elevation 1180.—The appraisal-level designs for the intermediate dam raise option are very similar to those for the high dam raise option. The left wing dam will extend approximately 1,380 feet, and the right wing dam will extend approximately 420 feet. The overflow (or spillway) section will be made thicker to accommodate the gated spillway crest. The mass concrete overlay for the intermediate dam raise option will be significantly thinner than for the high dam raise option and may not require a longitudinal contraction joint or an extension of the stilling basin.

Low Option - Crest Elevation 1084.—The dam raise in this option will be limited to the existing dam crest only, with mass concrete placed in blocks on the existing concrete gravity section, including the new spillway crest section, and with precast concrete panels used to retain compacted earthfill placed on the embankment sections (assuming reinforced-earth methods as used for Lake Sherburne Dam in Montana). No additional material is needed on the face of the existing dam.

Construction is assumed to require the removal of selected features from the existing dam crest, including the gantry crane and rails, the spillway bridge, the sidewalks and parapet walls, and miscellaneous concrete on both abutments. The spillway drum gates and control equipment and the concrete cantilever support walls would also be removed to accommodate the higher reservoir levels. It is assumed that personnel access can be provided to the existing elevator towers in order to retain them.

Spillway and Outlet Works (All Options)

The spillway structure layouts for all three dam raise options are basically the same. The existing spillway crest length of 330 feet is retained but is divided into six 55-foot-long gated sections, rather than the