Implementation of regulatory directives for a water supply reservoir - a case history of Crystal Springs Dam in San Francisco Peninsula, California, U.S.A.

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Abstract

This paper provides a historical summary of the Crystal Springs Reservoir's purpose, design and development, physical changes and modifications, operational changes, and regulatory issues that have collectively contributed to the reservoir's current challenges. It touches upon the current operation of the reservoir and its hydraulic interrelationship with the surrounding water bodies. This paper also presents the explanation of the various operation scenarios that could be associated with the dam modifications proposed for construction and how the various operating scenarios might impact the environment.

1 Introduction

The State of California, Division of Safety of Dams (DSOD) has regulatory authority over the Crystal Springs Dam. In 1983, the DSOD classified dams based on the potential for loss of life and property damage should the dam fail. Because outflows from the dam pass through the highly urbanized City of San Mateo before reaching the San Francisco Bay, the dam was classified as a high hazard dam. The
requirements of a high hazard dam were: (1) it must pass the full probable maximum flood (PMF) discharge without overtopping the dam, or (2) flows over the dam must not erode the downstream abutments of the dam causing structural failure. DSOD required the owner, San Francisco Public Utilities Commission (SFPUC) to either demonstrate that the dam could safely pass the PMF or develop structural modification and/or operational procedures for regulating the outflow such that the dam could safely pass the PMF. In the interim, the DSOD ordered that the historical maximum storage elevation be lowered by 8 feet until such time that the SFPUC could demonstrate that a higher storage level would be safe.

2 Description of the project

The construction of the Lower Crystal Springs Dam began in 1887 and was completed in 1890. The dam is located on the San Mateo Creek. It is 175 feet (53.4 m.) high and is a double curvature concrete arch gravity dam. The dam has a parapet wall, which was raised by 4 feet (1.22 m.) in 1911 to present Elevation 292.8 feet. In cross-section, the dam increases from a 43-foot (13 m.) crest width to a base width of 176 feet (53.7 m.). The upstream slope has a 1H: 4V batter and the downstream slope varies from 1H:2V at the top to 1H:1V at the toe. The overflow spillway is located in the center of the dam structure. The spillway crest is at Elevation 283.8 feet resulting in a maximum reservoir storage capacity of 58,300 acre-feet (72 mcm). It has 8 spillway openings, which are controlled manually with timber stop logs. Prior to 1983 the reservoir was operated with eight feet of stop-log barriers in each of the spillway bays to increase the storage to elevation 291.8 feet with a corresponding maximum capacity of 69,300 acre-feet (85.5 mcm). The dam has two outlet structures with capacities of 106 and 760 cubic feet per second (3 and 21.5 cms), respectively. The dam also has a stilling basin at the toe.

The SFPUC manages a complex water supply system that provides water to over 2.3 million customers within the City and County of San Francisco, the San Francisco peninsula and in portions of San Mateo, Santa Clara and Alameda Counties. The system water supply comes primarily from two sources: the Tuolumne River, through the Hetch Hetchy Water and Power Project (Hetch Hetchy System); and local runoff into reservoirs in Bay Area watersheds—Calaveras and San Antonio Reservoirs in Alameda County (Alameda System) and Crystal Springs, San Andreas and Pilarcitos Reservoirs (Peninsula System) in San Mateo County. The Peninsula System includes facilities connecting the Bay Division Pipelines to San Francisco's In-City distribution system and to other SFPUC customers on the Peninsula. Two reservoirs, Crystal Springs and San Andreas, collect runoff from the San Mateo Creek watershed. Water from Pilarcitos Reservoirs on Pilarcitos Creek can also deliver water to Crystal Springs and San Andreas Reservoirs. Water delivered from
the Bay Division Pipelines in excess of demand spills into Crystal Springs and can be pumped into San Andreas Reservoir. The total average demand for water was 325 mgd (9 cms), with a minimum of 200 mgd (6 cms) in the winter and a maximum of 420 mgd (12 cms) in the summer. The total system capacity was rated at 494 mgd (14 cms).

3 Purpose of project evaluation

The purpose of the current project evaluation is to develop and evaluate alternate operation plans for the reservoir under the modified dam condition. Specifically, the study evaluated the potential trade-off between water supply and flood storage benefits associated with the additional storage volume created with restoration of the historical storage levels of the reservoir. It was also anticipated that the results of this study would be used to evaluate the potential environmental impacts and mitigation requirements associated with a change to the current operation of the reservoir.

4 Understanding of the project—its purpose and constraints

Since 1983, the environmental setting has been significantly altered due to the reduction of reservoir level by eight feet. The environmental impact study of the reservoir operation alternatives would have to be based on a new ecosystem surrounding the reservoir in order to fully address the DSOD’s concerns, being the direct and indirect impacts from the construction and the reservoir operation alternatives to the present conditions.

SFPUC has been keeping hydrologic data for the entire water system dating back to 1901. The hydrologic information includes storage level in the reservoir and rainfall in the various watersheds. After 1997 the SFPUC started maintaining electronic records of hydrologic events within the watershed, including the inflows from the Pilarcitos and San Andreas Reservoirs, and outflows to San Mateo Creek. Because of the cyclical supply, demand trends and operating practices within the SFPUC water system, the water levels in the Crystal Springs Reservoir followed a fairly uniform cyclical pattern. Although the storage level peaks and valleys occurred around the same time each year, the magnitudes of the peaks and valleys varied significantly from year-to-year. Thus, SFPUC resorted to using the end-of-month storage levels to evaluate the reservoir operations. To minimize the computation effort and to evaluate storage data from when the demands were most likely similar, average end-of-month storage data between 1960 and 2000 was used to represent the pre- and post-lowering conditions.
5 Operational history and its deficiency

It is the policy of the SFPUC to operate the water system "in a prudent manner that maximizes the reliability and quality of water deliveries". System operations were based on the following rules: (1) numerous specific requirements described in several legal agreements, authorizing legislation, and regulatory requirements, (2) physical capabilities and constraints of the system, (3) the unknown, unpredictable, day-to-day realities of the system. Operations are also guided by staff judgment, strategies and historical experience. Both formal and informal "rules" were used to operate each component of the SFPUC's water system.

The SFPUC water system is operated to generally balance water demands, local watershed runoff and imported water from Hetch Hetchy. Water system operations has divided water demands into three geographical areas: (1) East of Crystal Springs, which represents East Bay, South Bay, and South Peninsula water demand and is served with waters from Hetch Hetchy and East Bay Reservoirs, (2) Crystal Springs Gradient "low" zone, which include North Peninsula and In-City water demands and are also served with waters from Hetch Hetchy and the Peninsula reservoirs, and (3) San Andreas Gradient "High" zone water demands, which are generally north peninsula and In-City demands served from the Tracy Water Treatment Plant, Peninsula reservoirs and Hetch Hetchy.

The Crystal Springs Reservoirs provided balancing storage between water transfers from the Hetch Hetchy and East Bay systems and water demands on the North Peninsula and in the City. Water flows into the Upper Crystal Springs Reservoir when water demands are less than water transfers. Lower Crystal Springs Reservoir and Pump Station also provided conveyance of waters from Hetch Hetchy and the East Bay reservoirs to San Andreas Reservoir and ultimately to the Harry Tracy Treatment Plant, which serves the "high" zone and in San Francisco.

Although there aren’t stringent "rules" that dictated certain water levels be maintained at specific times of the year, there were goals that the SFPUC Operations Management followed to regulate inflows and outflows for the various reservoirs. For Crystal Springs Reservoir, the "normal year" goal was to achieve maximum storage levels on or about May 1st of each year and a minimum storage level by November 1st. The maximum storage level by May 1st was needed to insure adequate water supply for the peak summer demands, which also corresponded to the typically dry time of the year when storm water runoff is minimal. The minimum storage level by November 1st was needed to provide adequate storage for storm water runoff during the wet winter months, when the water demands decreased significantly due to reduction in landscape irrigation and cool weather. With the current Lower Crystal Springs Dam spillway configuration, the maximum and
minimum storage levels were set at elevation 283.8, or 58,600 acre-feet (19,000 mgal, or 72.2 mcm) and 273.3 or 46,000 acre-feet (14,900 mgal or 56.7 mcm), respectively. With eight feet of additional storage capacity prior to 1983, the maximum storage levels would be higher.

6 Operational plans under modified dam condition

As can be seen in Figure 1, the end-of-month storage level in the Reservoir exceeded the maximum level of 283.3 feet four times in the last seventeen years. Additionally, the storage level in the Reservoir never reached within 1 foot of the maximum storage level of 291.8 feet for the pre-1983 condition. It appears that the operation scheme employed by the SFPUC governs the maximum storage levels achieved at the Reservoir. In light of the operational data, there is still room for improving the reservoir operation.

The proposed modifications to the Crystal Springs Reservoir Dam include (1) Raising the height of the existing parapet wall by six feet from elevation 292.6 to 298.6, (2) modifying the existing spillway to safely pass the PMF, and (3) modifying the stilling basin at the toe of the dam. Thus, the maximum allowable storage level would be restored to the historic elevation of 291.8 feet, and the reservoir surface would be at elevation 298.0 feet during a PMF event.
In consideration of the use of the additional storage, varying the assumed minimum and maximum storage levels for each alternative could make the trade-off between water supply and floodwater storage. Assuming a lower elevation in November would leave more storage for the winter rains, it would also result in a lower residual storage level in late spring, which could reduce the available water supply storage for the peak summer demands. The converse would also be true. Maintaining a higher elevation during the winter months would leave more residual storage for summer water demands (especially during drought conditions when the reservoir would more likely be drawn down below design levels), but would limit the floodwater storage capacity. The following assumptions were made in the development and evaluation of the alternatives.

1. The minimum "design" operating level of the reservoir is elevation 273.3 and occurs on or about November 1st.
2. The maximum "design" operating level of the reservoir can range from the current limit of 283.3 to the future raised limit of 291.8 and occurs on or about May 1st.
3. Precipitation is based on average monthly rainfall.
4. Inflow is defined as the contribution to the reservoir due to runoff from the local watershed and is computed assuming a calibrated yield of 40-per cent over the 24.81 square mile tributary watershed.
5. Input is defined as the contribution to the reservoir from Hetch Hetchy.
6. Drafts are defined as exports from Lower Crystal Springs Reservoir to San Andreas Reservoir.
7. Evaporation losses are based on an assumed evaporation rate of 4 to 8 inches per month.
8. Net change in reservoir volume thus obtained by substracting drafts and Evaporation from Inflow plus Input.
9. Residual storage volume to be used for floodwater storage; i.e., the available volume between maximum-modeled water level and modified spillway elevation of 291.8.
10. Protection levels corresponding to available floodwater storage are based on the minimum residual storage volume during the year on or about May 1st. Actual storage volume would likely be greater during the "rainy season" from November through March when the greater floodwater storage would be needed.

Two models were used to evaluate the storage levels in the Crystal Springs Reservoir under the alternative operational scenarios: "Tt" Model and Water Supply Operations Model. The Tt Model was developed specifically for this project by Tetra Tech, Inc., while the Water Supply Operations Model by SFPUC for evaluating impacts of changes within the local Bay Area water system facilities. The Tt model utilized simple conservation of volume principles to compute changes in reservoir storage.
elevation. Though the Water Supply Operations Model used the same principle as the Tt Model, it executed water allocation policies among the various reservoirs for the entire SFPUC water supply domain, including those set at the Crystal Springs Reservoir and Calaveras Reservoir. Thus, Water Supply Operations Model was run by iteration with the allocations of water use in the Crystal Springs Reservoir to verify the results from the Tt Model for any operations alternative to be considered. The procedure used was as follows: (1) assume a starting storage level corresponding to November 1st, (2) assume average input and draft values for each month, (3) using the Tt Model, compute the beginning of the month storage elevations for subsequent months, (4) determine if beginning of the month levels balance and meet goals of alternative, (5) adjust starting storage level and/or input and draft assumptions accordingly, (6) determine available residual storage volume and approximate flood water protection level, and (7) verifying model results and determine impacts on local Bay Area facilities using the Water Supply Operations Model.

Three alternatives have been developed. The first two alternatives maintained the baseline condition in input and draft values, but assume different starting storage elevations corresponding to the post- and pre-1983 design conditions. The third alternative assumed revised input and draft values to maximize summer storage for water supply needs and winter storage for floodwater needs. Following are the three operations alternatives:

Alternative 1--Current Post-1983 Condition: Maintain existing reservoir levels by using the minimum design starting level (elevation 273.3) and adjusted values for input and draft adjustment to the Water Supply Model. This would maximize the flood retention benefits of the additional storage created with the raising of the spillway.

Alternative 2--Maximize reservoir levels by raising assumed starting water surface and maintaining the same adjusted input and draft as Alternative 1. This would increase the available water supply storage portion and decrease the flood retention portion of the additional storage created with the raising of the spillway.

Alternative 3--Revise spring input and summer drafts to maximize the water supply storage in the summer months and the flood retention capacity in the winter months, and minimize impact to habitat during critical spawning and growth periods in spring and early summer.
7 Environmental impact from the operational plans and mitigation

Two types of impacts of the modifications were identified. Direct impacts were those that would result directly from construction of new facilities. New facilities will also include renewing the bridge on the top of the dam. Indirect impacts were reductions in vegetation and habitat that would result from the changes in reservoir storage level due to restoring the historical heights of operation.

The construction activities will potentially have direct impacts on habitat and animal species. Impacts include construction of new stilling basin and riprap installation downstream, and modification to the dam structure itself. These impacts will be mitigated through the creation and enhancement of freshwater marsh habitat suitable for the California Red Legged Frog and the San Francisco Garter Snake at various sites in the vicinity of the reservoir. Both species are endangered and habitats favorable to the species were chosen. In the implementation of the mitigation plan, it has been noted that the garter snakes actually feed upon the frogs. This has created an unfortunate environmental consequence of construction that is difficult to mend, since laws protect the endangered snakes eating the endangered frogs. These direct impacts from construction are the same for the three operational alternatives.

Indirect impacts on sensitive plants and habitats include those that may result from restoring the existing maximum storage elevation of 283.8 feet to the historic, or pre-1983 elevation of 291.8 feet. Adverse impacts on vegetation could result from prolonged inundation into this area during the summer growing season.

Indirect impacts to the California Red Legged Frog occurred as a result of seasonal loss of wetland habitat due to prolonged inundation of emergent marsh and increased access for predatory fish. The life stages of the frog and corresponding months are as follows: Breeding in December and January, hatching in February, and rearing from three to five month in the months of March through August each year. The Operational Alternative 3 imposes the least impact to the frog population.

8 Public involvement

Any construction must comply with local and federal regulations, and this project is no exception. The design and environmental documents will be completed and approved by agencies having jurisdiction over the project. It should be noted that the affected communities are involved in the study and planning stages.
9 Economic justification for the operational plans

The benefit from regaining the once lost reservoir storage provides ample evidence that the project is a worthwhile undertaking. It is evident that the benefit of the project far exceeds the cost of making changes to the dam, its abutment structures and other necessary remediation work. Much attention was paid to the intangible benefits to be yielded from the project, even though they could not be translated into monetary terms. No considerations were given to the flood control benefits, although there is no question that there will be benefits from the reduction of the peak flows in the wealthy communities in San Mateo Creek, below the Dam.

10 Conclusions

The restoration of the reservoir storage elevation to the historical level can be a success to all interested parties involved in the project. This includes the water customers, the owner, the regulators, the funding agencies, and engineering and environmental establishment. Through construction of new spillway and related work, the SFPUC will provide a 20% to 25% improvement in the capacity of a major reservoir serving San Francisco and Peninsula customers, while mitigating the effects on endangered species and meeting requirements of the Division of Dam Safety. Upon the completion of the enhancement of the dam structures, the properties below the dam would enjoy additional protection from the floods. The leadership that SFPUC assumed over a period of two decades will strengthen its service by fully utilizing the water in the Crystal Springs Reservoir. Irrespective of the final selection of the operational alternatives, the environmental assets will be enhanced and impact mitigated, while further improvements could still be realized by constantly monitoring the California Red Legged Frog population in the habitat within the reservoir proper and at the mitigation sites. With this additional eight feet of reservoir storage, SFPUC will have, by implementing the technology of automatic hydrologic data collection and processing, an opportunity to refine their reservoir operating rule curves, thus maximizing its use of water for water supply and power generation for years to come.

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