TECHNICAL SERVICE CENTER
Denver, Colorado

Report of Findings

Evaluation of Modified Storm Operations
Bradbury Dam
Cachuma Project, California

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Report of Findings
Evaluation of Modified Storm Operations Proposal

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I. Scope and Objective

This Report of Findings is intended to provide a summary of the studies performed by the Bureau of Reclamation Technical Service Center to evaluate the proposed Modified Storm Operations for Bradbury Dam. The studies included: flood routings, a structural evaluation of the spillway gates considering overtopping of the spillway gates, an evaluation of the spillway gate hoists considering overtopping of the spillway gates and a risk analysis. The individual studies are documented in more detail in separate reports. This report summarizes the individual studies and the risk analysis that were performed and includes recommendations regarding the Modified Storm Operations.

II. Description of Dam

Bradbury Dam, formerly known as Cachuma Dam, and reservoir are located on the Santa Ynez River, approximately 18 miles northwest of Santa Barbara, California. Construction of Bradbury Dam began in 1949 and was completed in 1953.

The dam is a zoned, rolled earthfill structure with a crest length of 3350 feet, a crest width of 40 feet, a structural height of 279 feet, and a hydraulic height of 198 feet. The crest of the dam is at elevation 766.0. Cachuma Lake has an active conservation storage capacity of 172,360 acre-feet. It is the main storage feature in the Cachuma Project, which provides water for irrigation and municipal use.

The spillway is located on the left abutment of the dam and consists of a concrete lined overflow crest, four 50- by 30-foot radial gates, a concrete-lined spillway chute, and a stilling basin. The spillway walls are a combination of cantilevered retaining walls and counterforted retaining walls. The spillway crest is at elevation 720.00 and the top of active conservation is at elevation 750.0.

III. Summary of Proposed Modified Storm Operations

The modified storm operations proposed by the Santa Barbara County, Public Works Department, Water Agency would provide an alternate means of making flood releases for storms that meet certain criteria. The main benefit under modified storm operations is that peak flood releases would be reduced from what would occur under standard operations. There are three components to the modified storm operations - precautionary releases, prereleases, and gateholding as described in a report by Santa Barbara County [1]. The following is a description of each:

> Precautionary releases - These are releases made within the active conservation storage pool prior to the onset of a flood. The purposes of these releases is to lower the reservoir level and create surcharge space for passing floods. Precautionary releases will only evacuate a volume of conservation storage equal to or less than 50 percent of remaining runoff already in the watershed. Inflows from the incoming storm are not considered in the determination of precautionary releases. Precautionary releases would typically be made 24-36 hours in advance of inflows reaching the reservoir, and would typically result in a 1 to 6 foot lowering of the reservoir.
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> Prereleases - These are releases of actual flood inflows at the beginning of a flood. These releases are made to pass the early part of the flood while maintaining as much of the surcharge space in the reservoir as possible (including that created from precautionary releases). A maximum prerelease level is determined in advance of initiating prereleases which considers downstream flows in the Santa Ynez River and attempts to limit total flows downstream to the safe channel capacity. Prereleases are set to match the previous hours inflow, while not exceeding the maximum prerelease level.
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> Gateholding - Gateholding is a method of operating the spillway gates in which the gates are opened in response to a rise in the reservoir, with the intent of maintaining a minimum freeboard (1 foot) on the gate.

The decision process for implementing modified storm operations are provided in Figure 1. This includes criteria identified in the report prepared by Santa Barbara County [1], as well as refinements that were added in the risk analysis meeting [2].

One of the critical tools necessary for the implementation of modified storm operations is the ability is to monitor and forecast rainfall and streamflows. The National Weather Service (NWS) and private consultants are used to provide weather forecasts, including quantitative precipitation forecasts (QPF) for each significant storm which is projected to result in reservoir inflow. The Santa Barbara County Flood Control and Water Conservation District also maintains a system of rainfall gages throughout Santa Barbara County and in adjacent contributing watersheds. Santa

Barbara County Flood Control, Santa Barbara County Water Agency, the city of Santa Barbara, the Montecito Water District, and the USGS operate and maintain a system of stream gaging stations in the Santa Ynez River watershed. Several of the stream gaging stations as well as the rainfall gages are connected to the ALERT System (automated local evaluation in real time). Data from the stream gages and rainfall gages are transmitted by remote radio communication devices to Santa Barbara Flood Control and the NWS.

A predictive tool has been developed by Santa Barbara County Flood Control for forecasting flood flows on the Santa Ynez River. The FCRIVER Model utilizes QPF for approaching storms as an early predictive tool and actual rain gage data is substituted into the model as this information is generated. Santa Barbara Flood Control has used the FCRIVER model to predict flood inflows since 1979. A comparison of model results against actual (measured) streamflow suggests that the model is accurate to within 10 percent in its prediction of peak flows for a wide range of large and moderate storms. In smaller storm events, or in events where a significant amount of upper watershed precipitation occurs as snow, the predicted peak flow may vary from the actual flow by significantly more than 10 percent. In addition, under some rainfall distribution conditions, the model gives results which indicate a slightly longer peak flow (duration) with lower amplitude (maximum) but with the same volume as the peak period of flow as compared to the measured flow [1].

IV. Flood Routing Studies

The Modified Storm Operations would change the way the spillway gates are operated during a flood. Flood routings were performed to evaluate the difference in flood routing results for the modified storm operations as compared to that required in the existing Standard Operating Procedures (SOP) for Bradbury Dam [3]. Also, since the spillway gates would be more vulnerable to overtopping under Modified Storm Operations, this condition was evaluated with flood routings. The results of the flood routings are provided in Technical Memorandum (TM) No. BR-8130-SS-TM-01-1 [4].

Four different floods were used in the flood routing studies - the April 15 PMF, the 10,000 year regional flood, the 10,000 year balanced flood and the January 1969 flood. The April 15 PMF, and the 10,000 year floods are floods that could occur after April 15 of each year (at the end of the runoff season). The January 1969 flood is a historical flood that occurred at Bradbury Dam. The floods used in this study were chosen because they represent a good cross section of floods that would be candidates for modified storm operations and because were readily available from previous studies [5]. These floods were not specifically developed for this study.

The results of the flood routings are summarized in Table 1 and Table 2. Table 1 provides the maximum water surface resulting from five different operational scenarios during the routing of the four hydrographs. Table 2 provides information on the time it would take for the spillway gates to overtop by 5 feet if they became stuck or inoperable at a point during the routing. The time shown is from the time the gates became stuck or inoperable to the time the gates were overtopped by 5 feet. This represents the time available for intervention to make the gates operable. Intervention could consist of making repairs to the hoist systems, recovering from human error in gate operation, providing an alternate means of opening the gates or implementing an alternate power supply system.

The routings indicated that operating under modified storm operations will result in a higher maximum water surface than what would occur under standard operations. The increased in the maximum water surface ranged from 1.4 to 4.4 feet, for the floods evaluated. Of the four floods routed, only the April 15 PMF resulted in the dam overtopping and it would overtop under both standard operations and modified storm operations. For all floods but the April 15 PMF, the peak discharge from Bradbury Dam was reduced. The reduction ranged from 22 to 26 percent for these three floods. The April 15 PMF resulted in a 10 percent increase in the peak outflow with Modified Storm Operations. This is due to the fact that the gates were nearly full open at the peak outflow, making the discharge close to what would occur under standard operations (for the same water surface elevation) and the fact that the maximum water surface was higher by 2 feet under Modified Storm Operations.

Another factor evaluated as part of the flood routing studies was the risk of the spillway gates overtopping during modified storm operations. Under gate holding, the reservoir water surface will be about 1 foot below the top of the spillway gates throughout the routing as compared to increasing amounts of freeboard under standard operations. A malfunction of the gates or the power supply (that would result in the inability to open the gates at some point during a flood) would be equally likely to occur under either mode of operation. The reaction time for intervention to correct a problem before the gates overtopped would be less, however, under modified storm operations.

Flood routings were performed to evaluate the time for the gates to be overtopped by 5 feet if they became inoperable during a flood. For all four floods routed, the gates would overtop if they became stuck at the start of the flood and this would be independent of the operation method since the gates were never operated. The gates were also assumed to become stuck at 5 foot openings and 10 foot openings. For these cases, the gates would not overtop for the 10,000 year balanced flood or the January 1969 flood, under both operation methods standard and modified storm operations). For the case of the gates becoming stuck at 5 foot openings, the gates would overtop by 5 feet in 18 hours under standard operations and in 11 hours under modified storm operations during the April 15 PMF. During the 10,000 year regional flood, the gates would overtop by 5 feet in 13 hours under standard operations and in 6 hours under modified storm operations. While the reaction time is reduced under modified storm operations, there would still be substantial time to correct whatever problem occurred.

Since a gate malfunction could occur under either operation method, it is important that the gates and backup power supply be well maintained and exercised to insure their reliability.

V. Structural Analysis of Spillway Gates

The spillway gates were evaluated for a scenario where the gates would be overtopped and the gates would be operated to continue to raise the gates while the overtopping occurred. Since the Modified Storm Operations would operate the gates with only 1 foot of freeboard throughout a flood as compared to a steadily increasing amount of freeboard under standard operations, if the gates malfunctioned during operation and could not be opened temporarily, the probability of the gates being overtopped would be increased. The hoists were evaluated for this overtopping condition and the results of the evaluation are documented in Technical Memorandum No. BD-8420-SS-TM-00-1 [6].

The likely mode of failure for any radial gate which leads to catastrophic gate failure is an arm buckling failure, similar to the Folsom Dam radial gate failure. In the case of Bradbury it is not the buckling strength of the arms which is critical but the strength of other structural components of the gate, including; the vertical faceplate supports, the webs of the horizontal girders, and most importantly, the strength of the cantilevered trunnion pin, and the embedded anchor bolts for the anchor girder.

The deep, tapered-web arms of the Bradbury radial gate provides a large cross-sectional capacity for axial arm loads, and bending resistance against moments. For either loading scenario (described as a. and b. below), the arm loadings are substantially below the critical loading required for arm buckling failure. However, as the loads on the gates increase, structural elements other than the arms become over-stressed.

a. Gateholding operation - The arms have ample strength against an arm buckling failure during a gateholding operation. The hydrostatic loading on the radial gates remains relatively constant as the gate is raised throughout its travel, and therefore the stress levels in the arms remains relatively constant throughout the full 30-foot operational range of the reservoir on the gate.

b. Gate overtopping operation - Overtopping of the closed radial gates at any reservoir elevation **is not recommended** as a standard operating procedure. However, the gate's structural integrity was checked for catastrophic failure due to an overtopping scenario during emergency flooding in the event the gates can not be raised for the gate holding operation. The following conclusions can be made:

i. Allowable overtopping of the radial gates depends on the height of reservoir overtopping. For the existing Bradbury Dam Spillway radial gates, and a reservoir water surface elevation resulting in up to 5 feet of overtopping, the radial gate arms have sufficient strength against arm buckling failure. The plate elements comprising the horizontal girder, and the vertical faceplate vertical girders are stressed below the yield strength. The downstream faceplate contributes to an overall stiffer faceplate assembly and helps to accommodate shedding of the overtopping flow off the faceplate assembly. As the reservoir continues to rise and overtopping of the gates increases by more 5 feet, various plate elements of the radial gate begin to overstress beyond the yield strength.

ii. With 20 feet of overtopping, many of the gate structural plate elements comprising the horizontal girder, and the vertical faceplate rib girders are stressed above the yield strength, which will lead to gate faceplate yielding and to a lesser extent, possible failure. However, this does not include the elements comprising the radial gate arms. The radial gate arms have sufficient strength against buckling for reservoir overtopping up to 20 feet.

iii. With minor reinforcement the gates could structurally withstand up to 20 feet of reservoir overtopping (reservoir at El. 770 feet). The following two gate areas in particular will require reinforcement:

a. Minor reinforcement in the area of the upper corners of the arm-to-faceplate connections.
b. Minor reinforcement of the webs near each end of the upper horizontal girder.
c. Reinforcement of the web elements around the trunnion pin hub.

VI. Evaluation of Spillway Gate Hoists

The spillway gate hoists were evaluated for a scenario where the gates would be overtopped and the hoists would be operated to continue to raise the gates while the overtopping occurred. Since the Modified Storm Operations would operate the gates with only 1 foot of freeboard throughout a flood as compared to a steadily increasing amount of freeboard under standard operations, if the gates malfunctioned during operation and could not be opened temporarily, the probability of the gates being overtopped would be increased. The hoists were evaluated for this overtopping condition and the results of the evaluation are documented in Technical Memorandum No. BR-RA-TM-99-1 [7].

Two cases were evaluated - overtopping the gates by 5 feet and 10 feet. The study concluded that the hoists could continue to lift the gates, without problems, up to a 10-foot overtopping of the gates.

VII. Risk Analysis

A risk based evaluation was performed to evaluate the modified storm operations at Bradbury Dam. This evaluation is documented in Technical Memorandum No. BR-8130-RA-TM-00-2

[2]. The purpose of the risk evaluation was to assess the incremental impact to the dam safety risk at Bradbury Dam with the modified storm operations in place.

As part of the evaluation, a flow chart was developed, which identifies the flow of events and decisions that would be made in implementing the modified storm operations. The flow chart was established using decision making processes identified in the Modified Storm Operations Report [1] and also by identifying or clarifying steps in the overall process that were not clearly defined in the report.

During the development of the flow chart, it became clear at what points the modified operations had the potential for increasing risk at the dam beyond the risk under current operations. The implementation of precautionary releases and prereleases will reduce the risk of various failure modes at Bradbury Dam, by lowering the reservoir water surface and reducing the loading on the dam and the spillway gates during the early portions of storm inflows. Gate holding is the only component of the modified operations that will increase the risk at the dam. It will increase the maximum reservoir water surface for a given storm (thus increasing the loading on the dam) and will increase the probability of the dam overtopping. The probability of the gates being overtopped during gate holding is also increased, since the reservoir will be allowed to stay only a minimal distance (1 foot) from the top of the gates. This increases the probability of a gate failure or a failure of the gate hoists. Criteria were added at several points in the process to insure that undue risk was not taken under gate holding. Previous risk analyses have concluded that the hydrologic risk under current operations is acceptable. Decision points were added to the overall process as safeguards to insure that the modified operations (specifically the gate holding component) would not significantly increase the risk above the current operating conditions.

The Modified Storm Operations were evaluated for the potential to increase the dam safety risk at Bradbury Dam when compared to the existing SOP operations [3]. The following conclusions were reached relative to each of the failure modes:

A. Seepage/Piping Failure - For this failure mode, it was concluded that the modified storm operations would have negligible effect. The hydraulic head on the dam with the reservoir at the top of active conservation, elevation 750, is approximately 260 feet. The modified storm operations has the potential to increase the maximum water surface for large storms from 1 to 5 feet. This is a small percentage of the static hydraulic head and the dam would only be exposed to this increased head for a short period of time.

B. Overtopping Failure of Dam - The modified storm operations will increase the maximum water surface for a given storm when gate holding is used. In general, this will increase the probability of the dam being overtopped during large storms. Safeguards have been built into the decision making process that will not allow use of gate holding for storms that would result in a maximum water surface near the dam crest with gate holding. Also if gate holding is being used, constant checks will be made to insure adequate dam freeboard under gate holding. If dam freeboard is encroached on, operations will be changed back to the rule curve or to the more stringent outflow = inflow scenario. Because of this, the increased probability of this failure mode is judged to be minimal.

C. Failure of Spillway Gates - This failure mode would only become possible if the gates overtopped and then additional loads caused a failure of the gates. In order for the gates to overtop during a storm there would have to be some sort of malfunction of the spillway gates, the spillway gate hoists or the power supply (or operator error). The probability of a malfunction would be independent of the storm operations method. If a malfunction occurred, however, the chance of an adverse response (P_R, Probability of Adverse Response) would be greater under modified storm operations, since there would be less time to react and fix the problem before the gates overtopped. Analyses of the spillway gates indicates that the gates could withstand 5 feet of overtopping without any overstressing [6]. Attempting to quantify the probability of a malfunction of the gates/hoists/power supply and the subsequent failure of the spillway gate hoist system would be difficult. A reasonable approach would be to recognize the importance of thorough maintenance of the gate system and take measures that reduce the probability of a malfunction.

D. Failure of Spillway Gate Hoists - This failure mode would only become possible if the gates overtopped and then an attempt was made to open the gates. In order for the gates to overtop during a storm there would have to be some sort of malfunction of the spillway gates, the spillway gate hoists or the power supply (or operator error). The probability of a malfunction would be independent of the storm operations method. If a malfunction occurred, however, the chance of an adverse response (P_R, Probability of Adverse Response) would be greater under modified storm operations, since there would be less time to react and fix the problem before the gates overtopped. An analysis of the spillway gates hoists indicates that the hoists would still be within their capacity for overtopping depths of 10 feet [7]. Attempting to quantify the probability of a malfunction of the gates/hoists/power supply and the subsequent failure of the spillway gate hoist system would be difficult. A reasonable approach would be to recognize the importance of thorough maintenance of the gate system and take measures that reduce the probability of a malfunction.

VIII. Conclusions

The proposed modified storm operations has the potential to reduce peak flood outflows from Bradbury Dam for storms that meet certain criteria. This is accomplished through three components of the modified operations - precautionary releases, prereleases and gateholding.

Operation of the spillway gates under modified storm operations will increase the maximum reservoir water surface during a flood. Four floods were routed with and without modified storm operations - the April 15 PMF, the 10,000 year regional flood, the 10,000 year balanced flood and the January 1969 flood. The first three floods represent floods that would occur after April 15 of each year (at the end of the runoff season). These floods were developed from previous studies for Bradbury Dam. The January 1969 is a historical flood that occurred at Bradbury Dam. Of the four floods routed only the April 15 flood would overtop the dam, even under modified storm operations. The April 15 PMF overtopped under both operational methods. The maximum water surface increased from 1.4 to 4.4 feet under modified storm operations.

The proposed modified storm operations will change the way the spillway gates are operated during a flood. Gates will be operated with a constant minimum freeboard of 1-foot under gate holding, as opposed to the gates being operated with a gradually increasing amount of freeboard under standard operations. For a gate holding operation, it is imperative that the gate operability is dependable at the time of a storm event. A good maintenance and exercise program is essential to the reliability of the gates.

The gates can tolerate 5-feet of overtopping without overstressing members of the gates. Beyond 5-feet of overtopping, the bending stresses on the cantilevered trunnion pin rise above the AISC allowable. Without additional localized structural reinforcement, overtopping beyond 5-feet begins to overstress the web plate elements of the horizontal girders and the vertical faceplate ribs beyond their yield strength, and plate deformation is likely.

Arm buckling failure is the mode of failure of most concern in that in would result in uncontrolled releases through the gates. It is not believed that plate yielding of the horizontal girder webs and ribs would lead to the same catastrophic failure. However, if overtopping of the gates beyond 5-feet can reasonably be expected, then additional steel reinforcement of horizontal webs, vertical ribs and the corner area around the arms should be designed and installed.

The radial gate hoists can continue to lift the spillway radial gates up to an overtopping of the gates of 10 feet without problems. If more than 10 feet of overtopping occurs, the loading begins to effect the safety factor of the hoists. The hoists should continue to operate under more overtopping until a hoist load of 170,000 lb is reached.

The modified storm operations results in reduced out of channel flows downstream of Bradbury Dam, as evidenced by actual implementation of the modified operations for the February 23-24, 1998 event and from computer simulated operations with and without the modified operations for other historical spills at Bradbury Dam [1].

The process for implementing the modified storm operations was defined in a flow chart (see Figure 1). The flow chart incorporates procedures defined in the Modified Storm Operations Report [1] as well as additional steps and procedures added during the risk evaluation. The additional steps and procedures were added for clarification and to provide safeguards against increasing the dam safety risk at Bradbury Dam. The safeguards are required for the implementation of gate holding, the only component of the three modified storm operations components which has the potential to increase hydrologic risk at the dam.

The modified storm operations and the proposed flow chart that would provide a decision process for implementing components of this operation (see Figure 1) calls for the decision to not implement modified storm operations or to suspend operation under modified storm operations, if the projected maximum reservoir water surface is El. 760 or above. This is 6 feet below the crest of the dam, El. 766. Based on this, the probability of creating a dam overtopping situation at Bradbury Dam under modified storm operations that would not have occurred under standard operations is very unlikely.

A key component of the modified storm operations is the ability to forecast and monitor rainfall and streamflows. A comprehensive system of rainfall and streamflow gages are in place that transmit data directly on a real time basis to Santa Barbara Flood Control. A model has been set up that can predict flood inflows into Bradbury Dam which has a proven track record. This forecasting and monitoring capability is critical to be able to implement modified storm operations at Bradbury Dam.

Under modified storm operations and especially during gate holding operations, there would be an increased risk of the gates overtopping since there will be less reaction time if something goes wrong and the gates can not continue to be opened. While the reaction time is reduced, there will still be substantial time to correct the problem. Since a malfunction could occur and the gates could be overtopped under either gate operation method, the gates and power supplies need to be well maintained and exercised.

With the modified storm operations (as defined by the flow chart) the incremental increased dam safety risk at Bradbury Dam is small and risks from the various failure modes appear to be well within Reclamation criteria.

Precautionary releases result in evacuating conservation storage in anticipation that the storage will be recovered when runoff enters the reservoir. The precautionary releases are conservatively based on 50 percent of runoff that is already projected to exist in the drainage basin but that has not yet reached Cachuma Reservoir. Inflows from the incoming storm are not considered in the determination of precautionary releases. While the basis for determining precautionary releases is conservative there is a small risk that the conservation storage evacuated may not be recovered.

In summary, Modified Storm Operations will provide substantial reduction in downstream flows during large flood events and will reduce impacts to downstream populations. There will be a small increase in risk of dam and spillway gate failure under Modified Storm Operations. The recommendations included in Section IX should be considered if the modified storm operations are adopted.

IX. Recommendations

The following recommendations are made as suggested improvements to the modified storm operations and as measures to be considered if the modified storm operations process is adopted:

1. Include Modified Storm Operations in the Standing Operating Procedures (SOP) as an alternate method for passing storm runoff. The current procedure (using the rule curve provided as Figure 5) should remain in the SOP as the primary method of operation.

2. Prior to implementing Modified Storm Operations as an alternate method of flood operations at Bradbury Dam, develop an agreement as to who assumes responsibility if precautionary releases are made and the conservation storage can not be recovered.

3. Provide Training for South Central California Area Office on the storm inflow forecasting computer model used by Santa Barbara County, with the intent of providing adequately trained Reclamation staff to independently run the forecasting model during storm inflow events.

4. In an actual flood, the South-Central California Area Office should perform an independent review of the flood forecast modeling to insure correct decisions are made on gate holding.

5. Conduct yearly table top exercises, in which simulated decisions are made regarding modified storm operations. This will ensure that any new personnel who will be running the computer models as well as those making decisions during a flood event have a good understanding of storm operations.

6. Develop and implement a written communication plan (with decision makers and backups identified) for the table top exercises and those times when it is known a large storm is approaching.

7. Prepare written operations for conditions where communications between personnel or instrumentation is lost, or model can't be run - e.g. go to rule curve if data is lost and model can not be run.

8. Exercise the spillway gates/hoists and back-up power supplies to the extent reasonably possible, prior to each storm flow season.

9. Inspect and maintain the wire ropes and wire rope connections on a regular basis to ensure their integrity.

X. References

1. Santa Barbara County, Public Works Department, Water Agency, "Report of Modified Storm Operations, Bradbury Dam, Cachuma Project, Santa Barbara County, California," December 29, 1998.

2. Bureau of Reclamation, Technical Memorandum No. BR-8130-RA-TM-00-2, "Risk Based Evaluation, Modified Storm Operations - Bradbury Dam," Technical Service Center, Denver, Colorado, February 2000.

3. Bureau of Reclamation, Standard Operating Procedures, Bradbury Dam, Cachuma Project, California, Dated July 1980.

4. Bureau of Reclamation, Technical Memorandum No. BR- 8130-SS-TM-01-1, "Flood Routing Studies, Evaluation of Proposed Modified Storm Operations, Bradbury Dam, California, " Technical Service Center, Denver, Colorado, Dated June, 2001.

5. Memorandum to Bill Fiedler, Team Leader, D-8130 from Kenneth Bullard, Hydraulic Engineer, Flood Hydrology Group, Subject: Lake Cachuma - Bradbury Dam April 15 Hydrographs for Evaluating the Proposed Surcharge Conditions, Bureau of Reclamation, Technical Service Center, Denver, Colorado, Dated March 23, 1998.

6. Bureau of Reclamation, Technical Memorandum No. BD- 8420-SS-TM-00-1, "Bradbury Dam, California, 50' x 30' Spillway Radial Gates, Arm Buckling and Stress Analysis," Technical Service Center, Denver, Colorado, Dated September 27, 2000.

7. Bureau of Reclamation, Technical Memorandum No. BR-8-RA-TM-99-1, "Evaluation of Spillway Gate Hoists Under Modified Storm Operations," Technical Service Center, Denver, Colorado, Dated December 10, 1999.

Table 1 - MODIFIED STORM OPERATIONS
FLOOD ROUTING RESULTS - MAXIMUM WATER SURFACE ELEVATION, FT.

Flood	Standard Operations	Gateholding	Gateholding Gates Stuck at 5' Open	Gateholding Gates Stuck at 10' Open	Gates Closed
April 15 PMF (initial res. at El. 750)	771.07	773.16	774.80	774.38	775.34
April 15 PMF (initial res. at El. 745)		773.16	774.80	774.38	
10,000 Yr, - Regional (initial res. at El. 750)	755.08	759.51	761.91	759.51	767.63
10,000 Yr, - Regional (initial res. at El. 745)		759.51	761.91	759.51	
10,000 Yr, - Balanced (initial res. at El. 750)	751.88	753.27	753.27	753.27	760.23
January 1969 Flood (initial res. at El. 750)	755.02	758.95	762.31	758.95	767.29
January 1969 Flood (initial res. at El. 745)		758.87	762.02	758.87	

Note: Dam Crest at El. 766

Table 2 - MODIFIED STORM OPERATIONS
FLOOD ROUTING RESULTS - TIME FOR GATES TO BE OVERTOPPED BY 5 FEET, HOURS

Flood	Standard Operations Gates Stuck at 5' Open*	Gateholding Gates Stuck at 5' Open	Gateholding Gates Stuck at 10' Open	Gates Closed
April 15 PMF (initial res. at El. 750)	18.1 (25.8 to 43.9)	11.2 (31.7 to 42.9)	95 (44.6 to 139.5)	20.7 (0 to 20.7)
April 15 PMF (initial res. at El. 745)		10.8 (32.1 to 42.9)	95 (44.4 to 139.5)	
10,000 Yr, - Regional (initial res. at El. 750)	12.9 (136.9 to 149.8)	5.7 (141.4 to 147.1)	Gates don't overtop	40.5 (0 to 40.5)
10,000 Yr, - Regional (initial res. at El. 745)		5.7 (141.4 to 147.1)	Gates don't overtop	
10,000 Yr, - Balanced (initial res. at El. 750)	N/A	Gates don't overtop	Gates don't overtop	29.9 (0 to 29.9)
10,000 Yr, - Balanced (initial res. at El. 745)		Gates don't overtop	Gates don't overtop	
January 1969 Flood (initial res. at El. 750)	12.3 (28.0 to 40.3)	7.1 (31.6 to 38.7)	Gates don't overtop	28.8 (0 to 28.8)
January 1969 Flood (initial res. at El. 745)		7.5 (32.1 to 39.6)	Gates don't overtop	

* These routings were all started at reservoir water surface El. 752.25. Based on the rule curve provided on Dwg. 368-D-910, the gate opening will be 5 feet at this reservoir water surface elevation. The starting hour for these flood routings were obtained by using the output from previous routings where the gates did not become stuck and determining the hour during the routings where the reservoir

water surface reached El. 752.25.

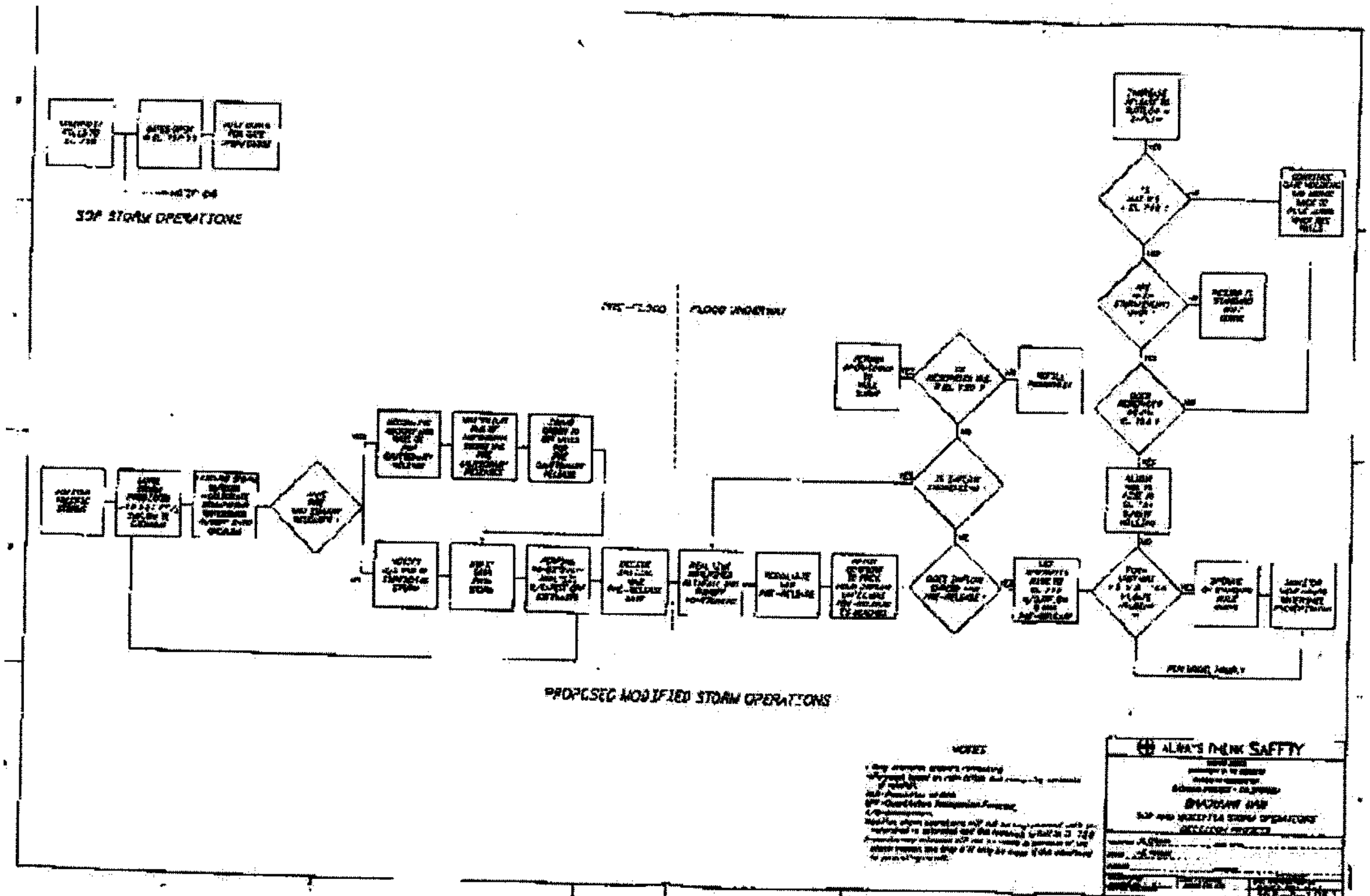
SOP STORM OPERATIONS
PRE-FLOOD
FLOOD UNDERWAY
PROPOSED MODIFIED STORM OPERATIONS
NOTES
ALWAYS THINK SAFETY

Figure 1