TECHNICAL SERVICE CENTER
Denver, Colorado

Technical Memorandum No. BR-8130-RA-TM-00-2
Risk Based Evaluation

Modified Storm Operations - Bradbury Dam

Prepared by
Technical Service Center

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Technical Memorandum No. BR-8130-RA-TM-00-2

Region: Mid-Pacific

Project: Cachuma, California

Feature: Bradbury Dam

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Prepared:

Peer Review: ______________________________ ____________
Waterways and Concrete Dams Group, Date
Civil Engineer

REVISIONS

Date	Description	Prepared	Checked	Technical Approval	Peer Review

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I. INTRODUCTION

A. Background

This risk based evaluation was performed to evaluate the modified storm operations at Bradbury Dam that have been proposed by the Santa Barbara County, Public Works Department, Water Agency. The proposal is documented in Report of Modified Storm Operations, Bradbury Dam, Cachuma Project, Santa Barbara County, California [1]. The Bureau of Reclamation's Technical Service Center performed a technical evaluation of this proposal for Santa Barbara County. 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. This document only presents the results of the technical evaluation and is not a Reclamation decision document.

B. Risk Evaluation Participants

The following individuals participated in the study:

Jon Ahlroth - Santa Barbara County
Bill Fiedler - D-8130 (Waterways and Concrete Dams Group)
Dave Hinchliff - D-8130 (Waterways and Concrete Dams Group)
Bruce Muller - D-8130 (Waterways and Concrete Dams Group)
Connie Berte - D-8410 (Mechanical Equipment Group)
Pete Hoffmann - D-8420 (Hydraulic Equipment Group)

C. Description of Bradbury Dam

Bradbury Dam, formerly known as Cachuma Dam, and Cachuma Reservoir are located on the Santa Ynez River, approximately 18 miles northwest of Santa Barbara, California. Construction of Bradbury Dam began in 1950 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 (top of active conservation storage at El. 750.0). 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 and consists of a concrete inlet structure, a concrete overflow crest, regulated by four 50- by 30-foot radial gates, and a concrete spillway chute and stilling basin. Details of the existing dam and spillway structure can be found on Figures 1 and 2 (Drawings No. 368-D-94 and 368-D-534).

II. POTENTIAL FAILURE MODES

Several failure modes with the potential for an increased probability under the modified storm operations were identified. These included: seepage/piping failure of the dam embankment during high reservoir level; overtopping failure of the dam during extreme storm events; failure of the spillway hoist system if the spillway gates overtopped (possibly leading to a dam overtopping failure); and, failure of the spillway gates during overtopping. Descriptions are provided for each of the failure modes:

A. Seepage/Piping Failure - One of the elements of the modified storm operations is gate holding, where the maximum spillway releases during a storm runoff are reduced from the releases that would be made under current operations. Gate holding accomplishes this by limiting spillway gate openings. Since spillway releases are reduced, more of the storm inflow is stored within reservoir surcharge space and the result is a higher maximum water surface for a given storm.

Piping of the embankment or foundation materials would consist of the movement of fine materials in the impervious core of the dam or fine materials in the foundation into the coarser zones of the embankment or into openings within the foundation. If the piping progresses, conduits can be established through the embankment/foundation in which materials can more easily be transported and which could accelerate the piping process. If enough material is removed, the dam or the foundation could collapse and the dam could fail.

The higher maximum water surfaces that will result from the modified storm operations during storm inflows will increase the head on the dam (from levels that would occur under current spillway operations) and as a result could increase the probability of a seepage/piping failure.

B. Overtopping Failure of Dam - As discussed above, gate holding will likely increase the maximum water surface for a given storm. A higher maximum water surface increases the probability that the dam will overtop for large storms.

Bradbury Dam is a zoned embankment dam. Embankment dams typically can not withstand significant (over 1 foot) overtopping of significant duration (more than several hours) without causing erosion at the crest and on the downstream face that could eventually develop into a breach of the dam. While Bradbury Dam is a very well constructed embankment dam that would be more erosion resistant than most embankment dams, it is likely that it would fail under significant and sustained overtopping.

C. Failure of Spillway Gate Hoists - Under gate holding, the probability of the gates being overtopped will increase. Under current operations (during a large storm), the vertical spillway gate openings increase at a faster rate than the rate of reservoir rise. The freeboard on the gates increases as the storm inflow progresses (see Figure 3). Under gate holding, the vertical rise of the spillway gates will match the reservoir rise and a minimum freeboard on the gate (1 foot) will be maintained throughout the major portion of the storm inflow. Under current operations and a malfunction of the gates, hoists or power supply, there would be significant lead time to correct the malfunction and prevent overtopping of the gates. Under the modified storm operations and gate holding, there would be very little time before the gates overtopped if a malfunction of the gates, hoists or power supply occurred. If the gates overtop, and an attempt is made to open them, the load on the hoist system will increase.

If the spillway gates were to be overtopped and the hoist motors burned out in an attempt to open the gates during this overtopping, the spillway capacity would be limited and the chance of the dam overtopping during a large storm would be increased. Overtopping of the dam could lead to the breaching and failure of the dam.

D. Failure of Spillway Gates - As discussed above, gate holding has the potential for increasing the probability of the gates being overtopped, especially if a malfunction of the gates, hoists or power supply occurred. If the gates overtop, water flowing over the top of the gates will result in additional load on the gate arms and will increase the probability of a gate failure.

A spillway gate failure could result in an uncontrolled release of the reservoir through the spillway gate(s) that failed.

III. FLOW CHART OF MODIFIED STORM OPERATIONS DECISION PROCESS

There are three components to the modified storm operations - precautionary releases, prereleases, and gateholding. Modified storm operations will not be implemented until after the watershed is saturated and the reservoir is filled to El. 750. Precautionary releases will not be made in advance of the storm season and will only be made if the watershed is generating runoff. The following is a description of each component of the modified storm operations:

<u>Precautionary releases</u> - These are releases made when the reservoir is within the active conservation storage pool prior to the onset of storm inflows. The purpose of these releases is to lower the reservoir level and create surcharge space for passing storm inflows. 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 counted on. 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..

Prereleases - These are releases of actual storm inflows at the beginning of the incoming flows. These releases are made to pass the early part of the storm inflows 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 hour's inflow, while not exceeding the maximum prerelease level. The maximum prerelease level will be reevaluated during operations and may be adjusted if warranted.

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.

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 and also identifying or clarifying steps in the overall process that were not clearly defined in the Report. The flow chart is provided in Figure 4. During the development of the flow chart, notes were kept to capture some of the key discussion points. The notes are included in the Appendix.

During the development of the flow chart, it became clear when the modified operations had the potential for increasing risk of failure of the dam from the risk under current SOP rule curve 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 is likely to 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 ensure that undue risk was not taken under gate holding. The first decision point is deciding whether or not to implement gate holding - if the storm is projected to be large and is projected to result in a maximum water surface of El. 760 or greater (approaching the dam crest of El. 766), gate holding will not be implemented because the risk of overtopping the dam is becoming significant. Secondly, if gate holding is implemented and the reservoir reaches El. 756, other decision points are implemented. If the storm is over and the maximum water surface is projected to be below 760, gate holding can continue. If the reservoir reaches El. 756, the storm is over, but the projected maximum water surface is above El. 760, releases must be immediately increased so inflow = outflow. Finally, if the reservoir reaches El. 756 and the storm is not over, operations must shift immediately to the rule curve (see Figure 5). While these restrictions will limit the use of gate holding for very large storms, it would allow the use of gate holding for all storms up to the storm of record at Bradbury Dam (recurrence interval of 1400 years, based on the storm inflow frequency curve [2]).

Previous risk analyses have concluded that the hydrologic risk under current operations is acceptable. The above 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 operations. The evaluation of risk under the modified storm operations is discussed further in Section IV.

The flow chart that was developed for this study is presented as a draft document that was intended to better define and clarify the Modified Storm Operations. If the Modified Storm Operations are incorporated into the Standing Operating Procedures (SOP), this flow chart should be reviewed and finalized.

IV. EVALUATION OF RISK

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. Risk (in terms of annualized Loss of Life) can be expressed by the following equation:

Annualized Loss of Life = (P_L) x (P_R) x Consequences

P_L = Probability of Loading
P_R = Probability of Adverse Response
Consequences = Loss of Life

The modified storm operations has the potential to affect only one of the components of the risk equation - P_R, Probability of Adverse Response. For a given storm, the probability of loading will be the same under both current and modified operations. The consequences of a failure should also be the same for a given failure mode. The only effect on risk will be the probability of an adverse response, which has the potential for increasing under modified storm operations.

The evaluation of any increased risk at Bradbury Dam will have two components. Is the risk under modified operations significantly increased from that of current SOP rule curve operations? And, is the risk under modified operations within Reclamations Guidelines [3], indicated by Annualized Loss of Life (Tier 1) and Annual Probability of Failure (Tier 2) (less than1 x 10^{-3} - Tier 1 and less than 1 x 10^{-4} - Tier 2)?

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, as measured at the downstream toe of the dam. 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 on the dam and the dam would only be exposed to this increased head for a short period of time.

The conclusion from this risk analysis was that the annual risk of failure of Bradbury Dam due to static seepage/piping failure modes was much less than that of the "average" embankment dam from historical failures. This was based on the fact that Bradbury Dam is very well constructed with a dense plastic zone 1 core of low permeability, contains a zone 2 material downstream of zone 1 capable of filtering zone 1, received good foundation treatment and grouting, and has had very little seepage historically. In addition, it now has a filter zone protecting the zone 1 core in the river channel alluvium.

The number of persons at risk downstream of Bradbury Dam is significant. However, the actual number of estimated lives lost as a result of a seepage/piping failure was thought to be small due to the slow development time for a static piping failure and the subsequent warning time. In addition, a Safety of Dams funded early warning system is planned for Bradbury Dam to improve warning capability over and above that presently existing. The low probability of a static seepage/piping related failure, multiplied by a low loss of life estimate would result in a low annualized loss of life value, well below that of Reclamation's guideline value of 1x 10^{-3}.

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 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.

Storm inflow frequency curves were developed as part of a paleoflood study for Bradbury Dam. The best fit curve from the study indicated that an event with a recurrence interval of 10,000 years would have a peak of 93,000 ft^3/s [2]. This peak inflow is less than the spillway capacity at the crest of the dam (160,000 ft^3/s), indicating it would take an event larger than a 10,000 year event to initiate overtopping of the dam. The paleoflood study also estimated the return period of a flood having a peak of 160,000 ft^3/s to exceed 6 million years.

The population at risk downstream of Bradbury Dam is about 40,000 people (including people in the towns of Solvang, Santa Ynez, Lompoc and Buellton). Assuming a minimum warning time of 90 minutes, a fatality rate range of 0.0002 to 0.002 was used, resulting in loss of life from 8 to 80 people. The fatality rates were estimated from a publication by Graham [4], which provides a method for estimating loss of life, considering flood severity, warning time and flood severity understanding. The flood severity was considered as low to medium and more likely to be low. The assumption of 90 minutes warning time is believed to be very reasonable.

Assuming that there is no chance of the dam failure for floods with peak discharges less than 160,000 ft^3/s, and certain failure for floods with peaks above 160,000 ft^3/s

$$\text{Annualized Loss of Life} = 1.6 \times 10^{-7} (8 - 80) = 1 \times 10^{-6} \text{ to } 1 \times 10^{-5} \text{ (Tier 1)}$$
$$\text{Annual Probability of Failure} = 1.6 \times 10^{-7} (1) = 1.6 \times 10^{-7} \text{ (Tier 2)}$$

Both of these values are within Reclamation guidelines.

C. 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 existing hoist system [5] was conducted as part of the overall evaluation of the modified storm operations evaluation. This analysis indicated that the gates could be overtopped by 5 to 10 feet and the spillway gate hoists would still have adequate capacity to raise the gates. This will significantly reduce the probability of a dam failure/gate failure triggered by a gate hoist failure.

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. This would include diligently performing maintenance of the gates, hoists and power supply; performing a test of the complete system (gates, hoists and power supplies) prior to the start of each storm flow season; and, making provisions for a second backup power supply for the gates (plans have been made for allowing operation of the spillway gate hoist system with an available portable engine-generator).

D. Failure of Spillway Gates - This failure mode would only become possible if the gates overtopped and then additional loads on the spillway gate arms caused a failure of the gate arms and a loss of the gate. 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 existing gates during overtopping [6] was conducted as part of the overall evaluation of the modified storm operations evaluation. This analysis indicated that the gates could be overtopped by up to 5 feet without failure. The probability of a storm that would cause the top of the gates to be overtopped by 5 feet (even assuming that the spillway gates remained closed during the entire storm inflow) would be very remote.

Attempting to quantify the probability of a malfunction of the gates/hoists/power supply and the subsequent failure of the spillway gates would be difficult. As discussed above, the focus should be on maintenance and other preventative measures to insure the gates/hoists can be operated when needed.

V. CONCLUSIONS

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 4). 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.

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.

The recommendations included in Section VI should be considered if the modified storm operations are adopted.

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

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

4. Conduct yearly table top exercises, in which simulated decisions are made regarding modified storm operations.

5. 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.

6. 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.

7. Exercise the spillway gates/hoists and back-up power supplies prior to each storm flow season.

Figures

* Subsequently changed to Bradbury Dam

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. Ostenaa, D.A., Levish. D.R., O'Connell, D.R.H., Paleoflood Study for Bradbury Dam, Seismotectonic Report 96-3, Seismotectonic and Geophysics Section, Technical Service Center, Bureau of Reclamation, Denver, CO, April 1996.

3. Bureau of Reclamation, Interim Guidelines For Achieving Public Protection in Dam Safety Decision Making, Technical Service Center, Denver Colorado, April 4, 1997.

4. Graham, W.J., Procedures for Estimating Loss of Life Caused by Dam Failure, DSO-99-06, Bureau of Reclamation, Denver, Colorado, September 1999.

5. 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, December 1999.

6. Bureau of Reclamation, Technical Memorandum No. BD-8420-SS-TM-00-1, "Evaluation of Spillway Gates Under Modified Storm Operations, Arm Buckling and Stress Analysis," Technical Service Center, Denver, Colorado, July 2001.

APPENDIX

NOTES FROM RISK ANALYSIS MEETING

NOTES - RISK ANALYSIS MEETING

1. Monitor Pacific Storms

   Santa Barbara County, NWS, Reclamation, Others already doing this. Backup process already exists. Numerous communication channels exist.

   * Need to insure decision makers have access to same data and make uniform consistent decisions.

2. Large Storm Predicted (> 20,000 ft^3/s)

   Santa Barbara County, NWS, Reclamation have models that predict large rainfall (Quantitative Precipitation Forecast (QPF))

   * Need to insure trained qualified staff is always available to run model and that computer systems are running.

   Emergency Operations Center is in place at Santa Barbara County Offices (includes backup generator).

3. Discuss w/USBR Remaining Water in Watershed

   Informal communication process now used between County, USBR, Water Users, etc.

   * Consider developing a written communication plan (with decision makers and backups identified) for those times it is known a large storm is approaching.

   Precautionary drawdown is not more than 50 percent of estimated runoff remaining in the watershed. This should reduce the risks of dumping water that won't be replaced. Also runoff from approaching storm is not included in this estimation of the expected inflow.

4. Decision - Make Precautionary Releases?

   50 percent rule to be applied.
   Decision makers are County and USBR.

   * USBR needs to insure "political" issues of the decision are covered (i.e. water users are aware their water supply could be affected). This will require continual communication and cooperation.

5. Need amount and rate to lower reservoir.

   Need to know inflow, expected drawdown, time available for drawdown, downstream limitations and releases (i.e. don't exceed downstream channel capacity)

   * Need to know downstream flow conditions.

6. Downstream Notification

   Part of EAP (or at least it should be)

7. Issue Order to Open Gates

   Analyses show gates and hoists are fully capable of reliable operation.

   * Gates and hoists require regular O & M.

8. Await Storm

9. Perform Sensitivity Analysis with QPF estimates.

   Follows continuously after step 2.
   Done by Santa Barbara County, with communications to USBR.
   (Repeat issue from 2).

10. Decide Initial Max Pre Release

   Need input from step 2 and step 9 for this decision
   Decision makers are Santa Barbara County and Reclamation
   * Need to know downstream flow conditions

11. Perform Real Time Watershed Monitoring

   Rainfall/runoff in watershed now occurring
   Rain and stream gage data collected throughout watershed by Santa Barbara County (Gibraltar gage is critical (has backup).
   Watershed conditions modeled continuously.
   * Need well maintained calibrated gages and communication links to insure reliable operation during storm
   * Need to have operations defined should the gage be lost (some or all) or model can't be run - e.g. go to rule curve if data is lost and model can not be run.

12. Reevaluate pre-release flows

    Santa Barbara County and Reclamation
    Monitor lower and upper watershed responses to storm and continuously reevaluate pre-release discharge.

13. Issue Order to Open or Change Gates for Discharge

    Decided upon by Santa Barbara County and Reclamation.
    Match outflow to previous hours inflow until pre-release max is reached.

14. Does Inflow Exceed Maximum Pre-Release?

15. Is Inflow Increasing?

16. Is Reservoir Above El. 750?

    If yes, use rule curve to get back down to El. 750, if inflow is decreasing.
    If no, fill reservoir to El. 750.

17. Let Reservoir Rise to El. 750.

18. Is the Reservoir Forecasted to Exceed El. 760 with Gate Holding (at Current Gate Setting)?

    Yes - use standard rule curve (monitor next hours rainfall and got back to step 18).
    See right most side of flow chart for more detail.
    * Dam safety concerns (i.e. overtopping of the dam) are now an important part of the decision making process.
    * For this and all following steps - Need to maintain EAP processes and communications.
    * This needs to be part of a regular EAP table top exercise.
    * In an actual storm, Reclamation needs to perform an independent review of the modeling to insure correct decision on gate holding.
    * If data or communications break down anywhere, staff at dam are to implement rule curve process immediately.

* possible recommendations

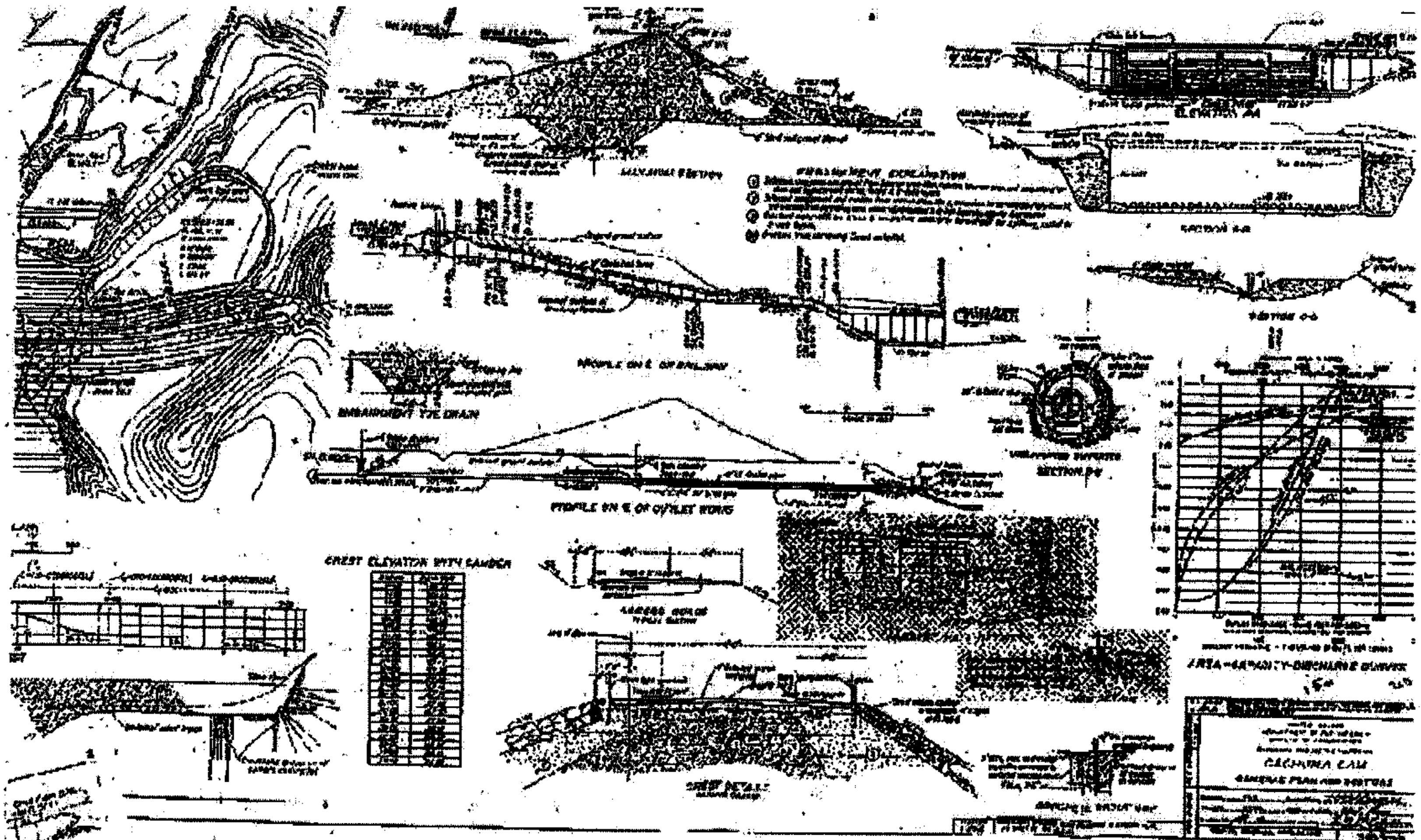
MAXIMUM SECTION
PROFILE ON ℄ OF SPILLWAY
EMBANKMENT TOE DRAIN
PROFILE ON ℄ OF OUTLET WORKS
CREST ELEVATION WITH CAMBER
CREST DETAIL
ELEVATION A-A
SECTION C-C
AREA-CAPACITY-DISCHARGE CURVES
CACHUMA DAM
GENERAL PLAN AND SECTIONS

Figure 1

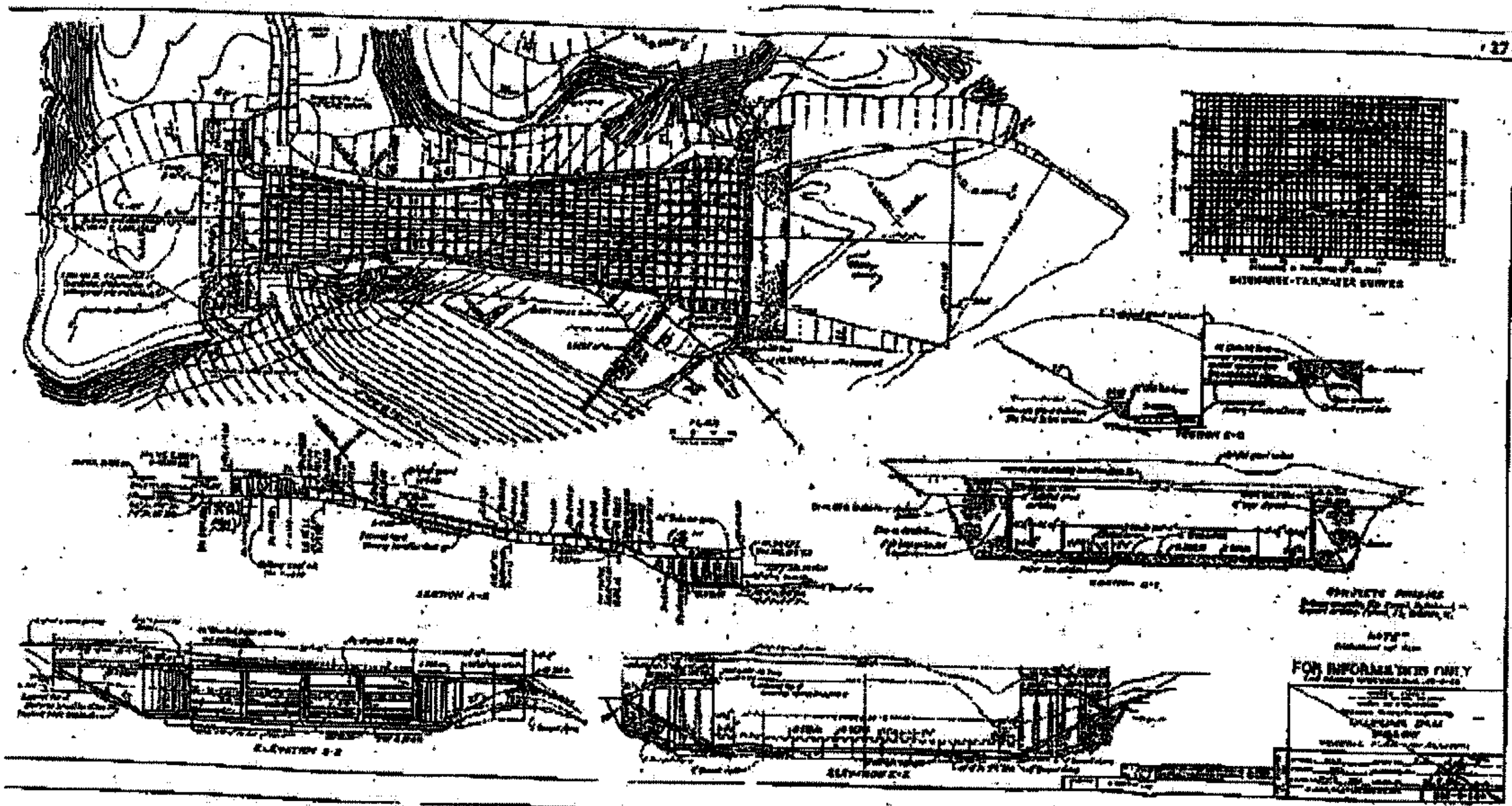
FOR INFORMATION ONLY
DISCHARGE-TAILWATER CURVES
ELEVATION 3-3

Figure 2

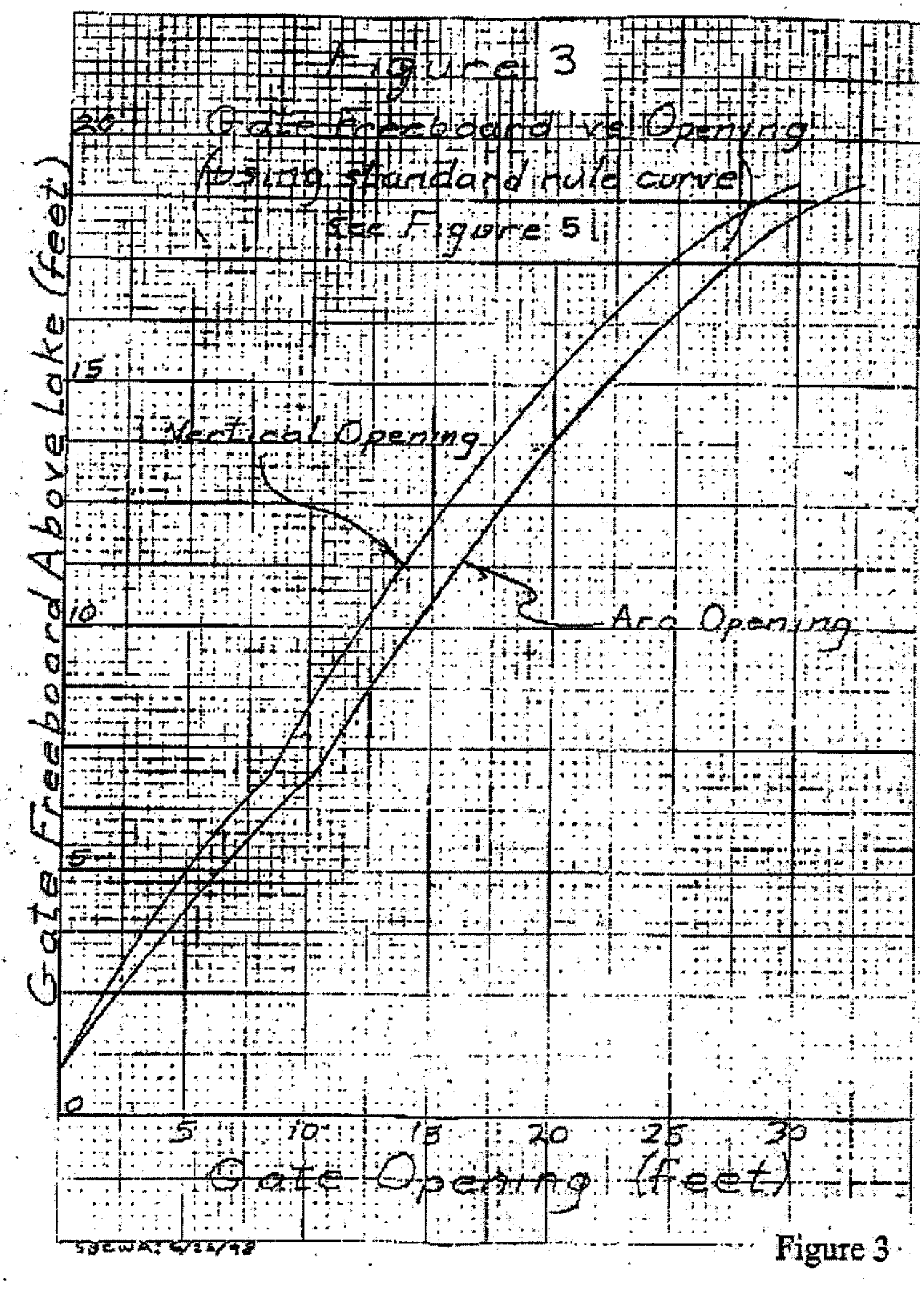
Figure 3
Gate Freeboard vs Opening
(using standard rule curve)
See Figure 5
Vertical Opening
Arc Opening
Gate Freeboard Above Lake (feet)
Gate Opening (feet)
0
5
10
15
20
25
30

Figure 3

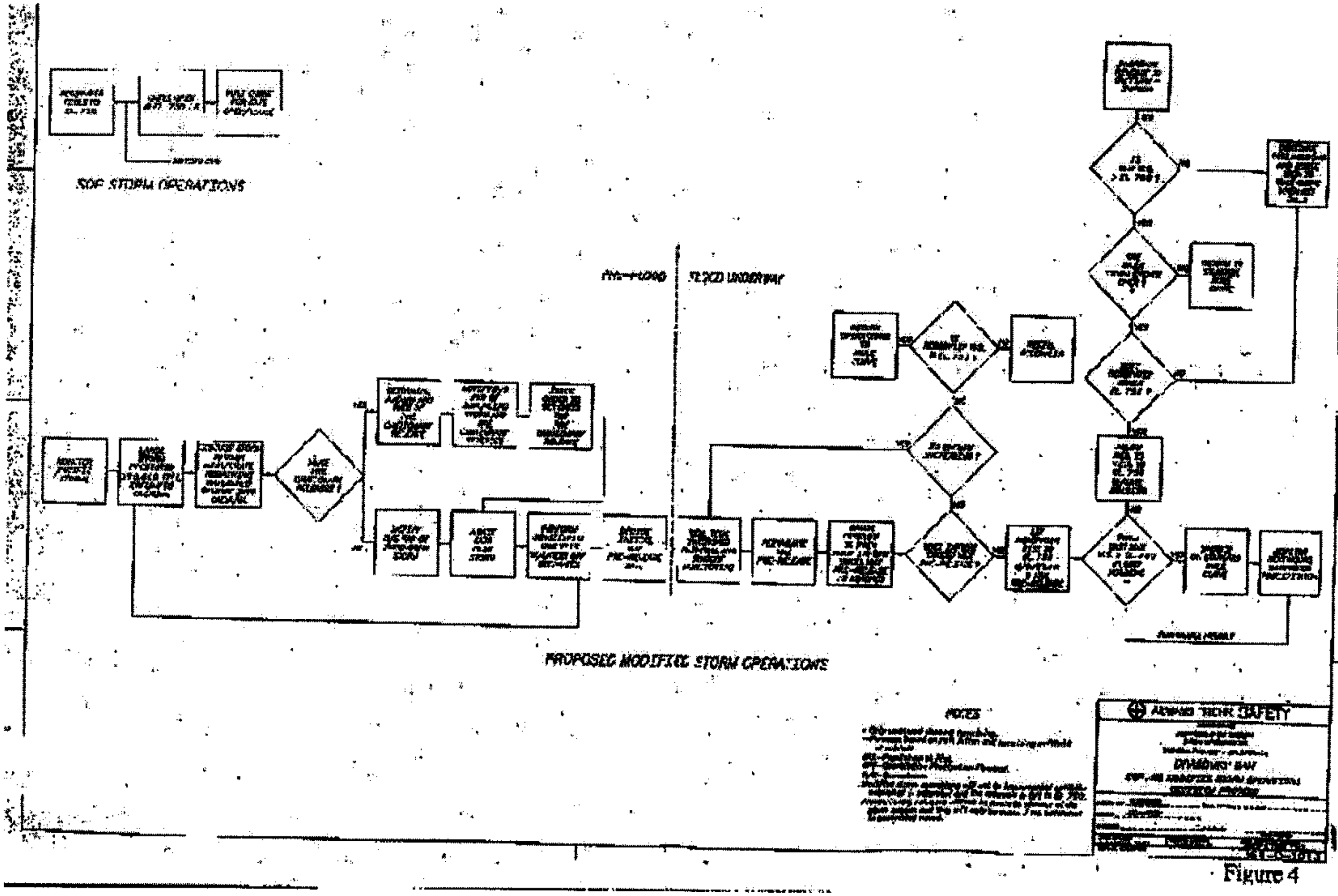
SOP STORM OPERATIONS
PROPOSED MODIFIED STORM OPERATIONS
NOTES

Figure 4

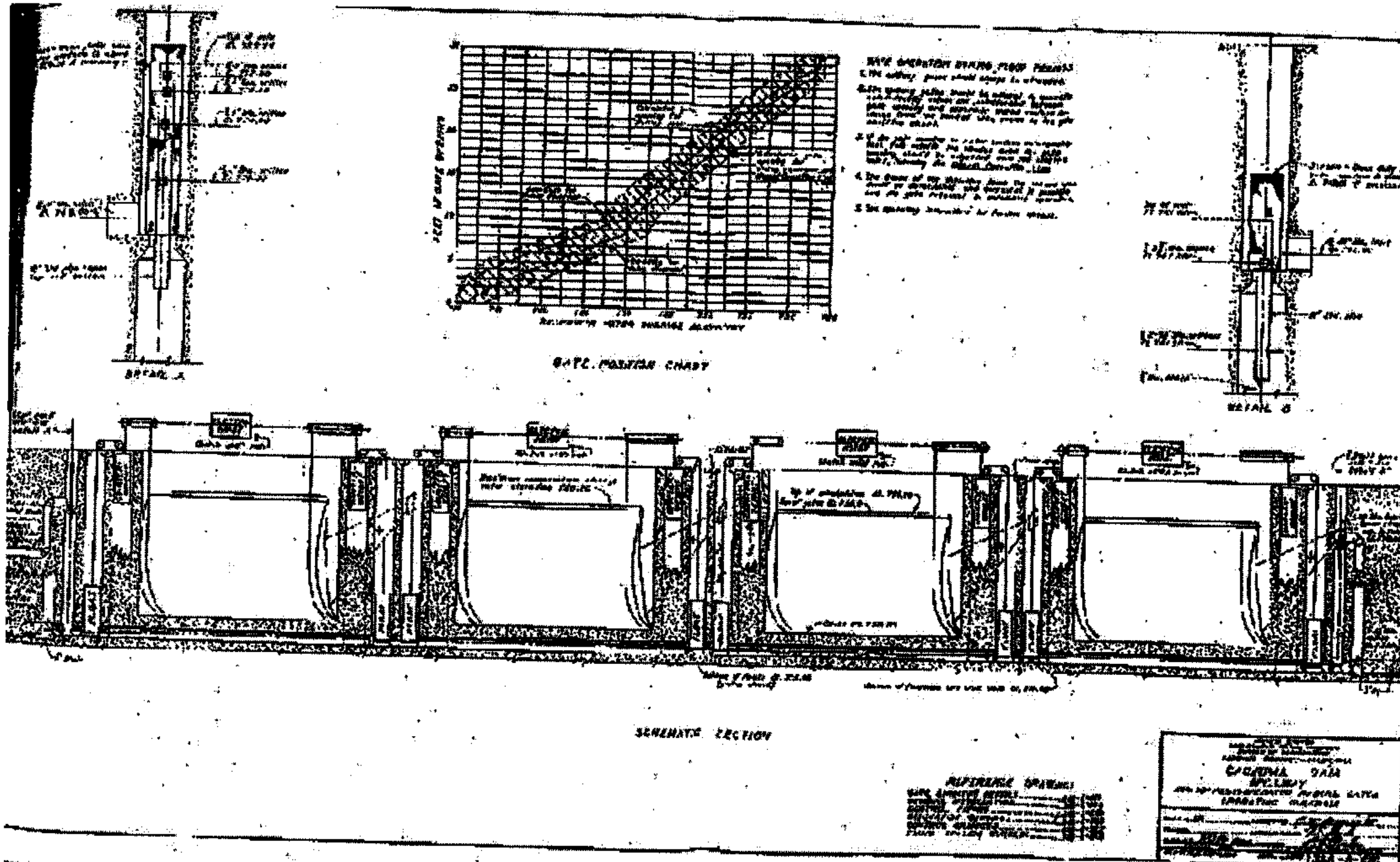
DETAIL A
GATE POSITION CHART
DETAIL B
SCHEMATIC SECTION
REFERENCE DRAWINGS

Figure 5