

Five-Year Periodic Inflow Design Flood Control System Plan

Fly Ash Reservoir II Brilliant, Ohio

October 2021

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Prepared For:

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1.0 Introduction

The Cardinal Power Plant (Plant) is located in Wells Township, Jefferson County, near the town of Brilliant in eastern Ohio. The Plant is owned by Buckeye Power and AEP Generation Resources (GENCO). Cardinal Operating Company operates the Plant. The Plant utilizes the Fly Ash Reservoir II (FAR II) surface impoundment for storing coal combustion residuals (CCR). The FAR II is subject to the requirements of the United States Environmental Protection Agency's (USEPA) final CCR rule Title 40 Code of Federal Regulations (40 CFR) Part 257 Subpart D - "Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments." The Initial Inflow Design Flood Control System Plan was completed and placed into the Plant's operating record on October 9, 2016. A periodic Inflow Design Flood Control System Plan is required every 5 years pursuant to 40 CFR 257.82(c)(4).

The FAR II is impounded behind a dam that is approximately 250-feet high with a 30-foot-wide crest. The most recent dam modification was in 2013 where it was raised to its current height using back-to-back mechanically stabilized earth walls. The dam has had no major modifications since 2016, and conditions evaluated in the Initial Inflow Design Flood Control System Plan are representative of current conditions.

Federal Regulations

An owner or operator of an existing or new CCR surface impoundment or any lateral expansion must design, construct, operate, and maintain an inflow design flood control system for the CCR surface impoundment to:

- (1) adequately manage flow into the CCR surface impoundment during and following the peak discharge of the inflow design flood;
- (2) adequately manage flow from the CCR unit to collect and control the peak discharge resulting from the inflow design flood. The inflow design flood is based on the hazard potential classification of the unit as required by 40 CFR 257.73. The inflow design floods for specific hazard potential classifications are as follows:
 - i. The probable maximum flood for high hazard potential CCR surface impoundments,
 - ii. The 1,000-year flood for significant hazard potential CCR surface impoundments,
 - iii. The 100-year flood for low hazard potential CCR surface impoundments, or
 - iv. The 25-year flood for incised CCR surface impoundments; and
- (3) discharge from the CCR unit must be handled in accordance with the surface water requirements of 40 CFR 257.3-3.



2.0 Objective

This report was prepared by TRC Engineers, Inc. (TRC) to fulfill requirements for the periodic Inflow Design Flood Control System Plan documenting how the inflow design flood control system has been designed and constructed to meet the requirements of 40 CFR 257.82. This is the first 5-year periodic assessment as required per 40 CFR 257.82(c)(3).

To develop the periodic assessment TRC performed the following scope:

- Reviewed historical documents including:
 - Inflow Design Flood Control Plan, September 2016, prepared by AEP Geotechnical Engineering Services (refer to Attachment A)
 - Components of the FAR II Dam Permit Modification Application (S&ME, 2012)
 - Appendix C: Hydrologic and Hydraulic Analysis
 - 2016-2021 Annual FAR II Dam Inspection Reports
- Performed a site visit on September 1, 2021 to observe current conditions, and
- Developed a 5-year periodic Inflow Design Flood Control System Plan.

3.0 Design Storm

The FAR II is classified as a high hazard potential Dam (TRC, 2021); therefore, the FAR II must adequately manage peak discharges from the probable maximum flood (PMF). The FAR II dam was designed for a PMF event of 26.5 inches of precipitation for a 6-hour period based on Hydrometeorological Report 51 by the National Weather Service.

4.0 Inflow Design Flood Control System

4.1 Inflow Management

The FAR II dam acts as the primary inflow control by impounding the drainage area and regulating outflow through the service spillway. At the maximum design pool elevation, 974 feet National Geodetic Vertical Datum 1929 (NGVD 29), the impoundment has a surface area of approximately 161 acres. There is sufficient storage above the operating pool elevations to manage discharge though the service spillway during storm events up to the 24-hour, 50-year storm event without activating the emergency spillway.

4.2 Outflow Management

The FAR II has two designed outlets: the service spillway and the emergency spillway. The service spillway allows management of the operating pool elevation and allows discharge from the FAR II. The inlet to the service spillway is a rectangular weir with stoplogs that can be added or removed to control water elevations in FAR II. The rectangular weir connects to a sloping concrete shaft on the upstream dam face which discharges into a 54-inch diameter pre-stressed concrete cylinder pipe. The concrete pipe transitions to a steel pipe where it daylights on the



downstream face of the dam. Discharge from the service spillway occurs at an energy dissipator into Blockhouse Run.

The emergency spillway is an open channel spillway provided to manage flood events. The spillway has been designed to pass the PMF without overtopping the dam. Refer to Appendix A for additional detail on the outlet features.

4.3 Hydraulic Evaluation

FAR II was designed and constructed with a service spillway and an emergency spillway to control outflow.

Under the current conditions, the top of dam elevation is 983.0 feet (NGVD 29), and the maximum operating pool elevation is 974 feet NGVD 29. During the PMF, the estimated peak impounded water elevation is 981.9 feet NGVD 29. The existing configuration provides 1.1 ft of freeboard during the PMF. See Appendix A for more details. A summary of the hydraulic analysis of FAR II during the PMF is presented below:

Parameter	Current Conditions
Contributing Drainage Area	1,352 acres
Composite Runoff Curve Number, East Watershed	71
Composite Runoff Curve Number, West Watershed	75
Design Peak Inflow, Probable Maximum Flood	15,988 cubic feet per second (cfs)
Peak Discharge from Probable Maximum Flood	5,502 cfs
Top of Dam Elevation	983 feet NGVD 29
Pool Elevation, assuming probable maximum flood	981.9 feet NGVD 29

4.4 Discharge

Discharge from FAR II is regulated in accordance with an NPDES permit issued by the Ohio Environmental Protection Agency. The permit grants the Plant permission to discharge from the facility to Blockhouse Run in accordance with effluent limitations, monitoring requirements, and other conditions. The NPDES permit is issued in accordance with the provisions of the Federal Clean Water Act. Therefore, by complying with the NPDES permit, the discharge from FAR II is also being handled in accordance with the applicable surface water requirements.

5.0 Site Visit

TRC performed a site visit on September 1, 2021 to observe the current conditions of the FAR II. Based on the observations made during the site visit, the conditions modeled in Initial Inflow Design Flood Control Plan (AEP, 2016) accurately reflect the current conditions of the FAR II. The outlet features for the FAR II appeared to in good working order and functioning as designed.



6.0 Conclusions

The FAR II meets the requirements of 40 CFR 257.82 of adequately controlling the inflows and outflows of peak discharge for the following reasons:

- FAR II can adequately receive and store inflows for the PMF.
- The service spillway and emergency spillway were designed and constructed to collect and control peak outflow associated with the PMF in a controlled manner.
- The discharge from FAR II is permitted under a NPDES permit which was issued in accordance with the provisions of the Federal Clean Water Act.

This plan has been completed in compliance with the requirements set forth in 40 CFR 257.82. This document will be placed in the Plant's CCR operating record, and posted to the publicly accessible CCR website, and government notifications will be provided.

A periodic inflow design flood control system plan must be prepared every 5 years from the completion date of this Plan. The next Plan update is required by October 2026.

The Plan must be amended whenever the periodic review period is reached, or if changes in site conditions occur that will substantially affect the current written Plan.

7.0 Limitations

The observations, assessment, and recommendations presented in this Report are based on our limited scope of work and on information disclosed by our visual observations, the conditions of the site at the time of the September 1, 2021 inspection, the design information available at the time of this investigation, and only apply to the Cardinal FAR II Dam. This work has been performed in accordance with our authorized scope of work and is based on the level of effort and investigative techniques using that degree of care and skill ordinarily exercised under similar conditions by reputable members of the profession practicing in the same or similar locality at the time of service. No other warranties, expressed or implied, are made or intended by this Report. These services were intended to provide an indication of the current, observable conditions of the dam at the time of the visual observations on the date indicated in this Report. Such a limited visual review does not account for other non-visible, hidden, subsurface or material condition analyses, and the professional services rendered are not guaranteed to be a representation by TRC of inaccessible and unobservable site conditions or actual conditions subsequent to the date of TRC's site visit. Therefore, the evaluations, conclusions, recommendations and opinions provided in this Report are subject to change as a result of future natural or manmade processes and as a result of an additional comprehensive, intrusive investigation and engineering analyses beyond TRC's visual observations. TRC is not responsible for any conclusions or opinions drawn by others from the data included herein, nor are the recommendations specifically presented in this Report intended for use or reliance as construction specifications.



8.0 Certification

I, the undersigned Ohio Professional Engineer, hereby certify that I am familiar with the technical requirements of 40 CFR 257 Subpart D. I also certify that it is my professional opinion that, to the best of my knowledge, information, and belief, that the information in this demonstration is in accordance with current good and accepted engineering practice(s) and standard(s) and meets the requirements of 40 CFR 257.82(c).

For the purpose of this document, "certify" and "certification" shall be interpreted and construed to be a "statement of professional opinion." The certification is understood and intended to be an expression of my professional opinion as a Licensed Professional Engineer, based upon knowledge, information, and belief. The statement(s) of professional opinion are not and shall not be interpreted or construed to be a guarantee or a warranty of the analysis herein.

<u>Shawn D. McGee, P.E.</u> Name

Signature of Professional Engineer



PE.68761 Engineer License Number

10/8/2021

Date

Cardinal Operating Company – Fly Ash Reservoir II, Brilliant, OH Five-Year Periodic Inflow Design Flood Control System Plan



9.0 References

- American Electric Power Service Corporation (AEP). 2016. Inflow Design Flood Control Plan CFR 257.82: Fly Ash Reservoir II – Cardinal Plant, Brilliant, Ohio. Geotechnical Engineering Services. October 2016.
- S&ME. 2012. Permit Modification Application for the Fly Ash Reservoir II Dam at the Cardinal Power Plant. Brilliant, Ohio.
- Schreiner, L.C., and J.T. Riedel. 1978. Probable Maximum Precipitation Estimates, United States East of the 105th Meridian (HMR No. 51), National Weather Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, Washington, DC.
- TRC. 2021. CCR Surface Impoundment Hazard Potential Classification: Fly Ash Reservoir II. July 2021.



Appendix A: Initial Inflow Flood Control Plan

Cardinal Operating Company – Fly Ash Reservoir II, Brilliant, OH Five-Year Periodic Inflow Design Flood Control System Plan

INFLOW DESIGN FLOOD CONTROL PLAN CFR 257.82

Fly Ash Reservoir II

Cardinal Plant Brilliant, Ohio

September, 2016

Prepared for: Cardinal Operating Company - Cardinal Plant

Brilliant, Ohio

Prepared by: Geotechnical Engineering Services

American Electric Power Service Corporation

1 Riverside Plaza

Columbus, OH 43215



GERS-16-061

INFLOW DESIGN FLOOD CONTROL PLAN CFR 257.82 FLY ASH POND FAR II **CARDINAL PLANT**

GERS-16-061

8/26/2016 DATE PREPARED BY Ailouni, Ph.D., P.E. Mohammad A. **REVIEWED BY** DATE 1/12/2016 M Leilah Saad DATE **APPROVED BY** Gary F. Zych,

Manager - AEP Geotechnical Engineering



I certify to the best of my knowledge, information, and belief that the information contained in inflow design flood control plan meets the requirements of 40 CFR § 257.82

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1.0 OBJECTIVE

This report was prepared by AEP- Geotechnical Engineering Services (GES) section to fulfill requirements of CFR 257.82 for the hydrologic and hydraulic evaluation of CCR surface impoundments.

2.0 DESCRIPTION OF THE CCR UNIT

The Cardinal Power Plant in Wells Township, Jefferson County, near the town of Brilliant in eastern Ohio. It is owned by Buckeye Power and AEP Generation Resources (GENCO) and is operated by Cardinal Operating Company. The facility operates two surface impoundments for storing CCR; the Bottom Ash Complex and Cardinal Fly Ash Reservoir II (FAR II) Dam. This report deals with the hydrologic and hydraulic evaluation for the Fly Ash Pond FAR II.

The FAR II Dam is a valley filled dam with a unique structure whose current configuration is the result of the original earth fill dam and two separate raisings. The original earth fill dam (Stage 1) consisted of a 180 feet high arched earth embankment incorporating a zoned cross section. At 925 feet NGVD, the dam featured a 70-foot wide by 1,055-feet long crest. The maximum operating pool that could be achieved with the original configuration was El. 913. In 1997, the original dam was raised, referred to as Stage 2. Following this raising, the dam was 237 feet high with a 30-foot wide crest. In 2013, the dam was raised 13 feet using back-to-back MSE walls, bringing the dam into its current, Stage 3 configuration. The principal features of the typical section are the MSE wall themselves and a vinyl sheet pile wall extending from the existing clay core to the top of the PMF flood level for seepage cutoff purposes. The FAR II Dam received sluiced fly ash and waste water from the plant via the bottom ash pond.

3.0 INFLOW DESIGN FLOOD 257.82(a)(3)

The facility is classified as a High Hazard Potential Dam. The Inflow Design Flood is the Probable Maximum Flood (PMF).

4.0 FLOOD CONTROL PLAN 257.82(c)

All storm water runoff from the watershed drains into the reservoir created by the Fly Ash Pond Dam. The design spillway system has enough capacity to pass the probable maximum flood without overtopping the dam. The design is based on the normal pool being at maximum normal operating pool and utilizing only the emergency spillway to handle the PMF without overtopping the crest of the dam. The water discharged through the emergency spillway is directed away from the dam such that it causes no threat to the stability of the structure.

The analysis in Attachment A includes excerpts of the 2013 design report and the associated report Appendix C that provides the description of the spillway system, flood storage capacity, inflow peak discharge and volume, peak discharge from the facility and maximum pool elevation.

The calculations show that the facility has the capacity to manage the inflow design flood.

ATTACHMENT A

Attachment A-1

Excerpts from 2013 Design Report

Hydrology and Hydraulics

4. HYDROLOGIC AND HYDRAULIC ANALYSIS

4.1 Introduction

The existing hydrologic conditions at the proposed dam site are described herein. Blockhouse Run, the major drainage feature in the project area, drains directly into the Ohio River. Approximately one mile upstream of the Ohio River, Blockhouse Run splits into two branches, designated as the East Branch and the West Branch.

The East Branch drains the eastern watershed as delineated in the Watershed Map on Plate 2 of Appendix C. The active fly ash dam II inundates the East Branch. The West Branch has been dammed to form the old Fly Ash Reservoir I (FAR I).

The location of the dam is shown on the drawings. Extension of the dam will inundate approximately 161 acres, or 24 percent of the area in the eastern watershed. Since the location of the dam is situated downstream of the discharge points of the old dam, runoff from the western watershed drains into the existing reservoir. Therefore, the spillway system of the proposed dam raising has been designed to meet ODNR Class I design criteria based on the runoff from both watersheds. The following sections present the hydrologic considerations and analyses performed during the design phase of this project.

4.2 Basin Characteristics

Figure 3.1 shows the limits of the watershed boundary for the existing Fly Ash Reservoir II(FAR II). The total drainage area above the dam has been divided into two watersheds, East and West, for analysis of the storm runoff entering the reservoir, as shown on Plate 2 of Appendix C.

A review of available topographic maps and aerial photos was made to determine essential basin characteristics for each watershed. Such characteristics include the drainage boundaries, areas, slopes, soil types, ground cover, land use and the time of concentration. The time of concentration is defined as the elapsed time for runoff to travel from the hydraulically most distant part of the watershed to some reference point downstream.

The old fly ash dam is located in the western watershed. Present land use within the drainage area is limited to reclaimed strip mine areas, some woodlands, and the inactive FAR I. Reclamation of the reservoir area is actively in progress in the form of a residual waste landfill above the level of the ponded fly ash. A built-out landfill condition was also analyzed for the western watershed, using the 2005 FAR I PTI. The PTI listed a Curve Number (CN) of 74, therefore the composite CN of the current FAR I condition of 75 was used. See Plates 4 through 6 of Appendix C.

Woodlands and scattered reclaimed strip mines constitute the existing land use in the East watershed. Construction of the proposed fly ash dam raising will inundate approximately 161 acres at Elevation 974.0 feet NGVD, the maximum operating pool elevation.

Soil types in the areas have been identified by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture and classified into hydrologic soil groups. Within the study area, all soils fall under the hydrologic soil group B. Table 4.2.1, below, lists the basin characteristics for the Western and Eastern watersheds.

BASIN	WATERSHED						
CHARACTERISTICS	WF	CST	EAST				
	Woods	Landfill	Woods	Reservoir			
Drainage area (acres)	519	158	514	161			
Average land slope %	30	n/a	25	n/a			
Hydrologic soil group	С	С	С	n/a			
SCS curve number (CN)	70	91	70	100			
Composite CN	7	5	n/a				
Time of concentration (hours)	0.87		0.57 0.1				
TOTAL AREA (acres)	6	17	675				

Table 4.2.1 Basin Characteristics

4.3 Characteristics of Proposed Reservoir

A previously referenced, Drawing No. 2 shows the location of the existing dam. Based on this layout, the reservoir will have the following surface areas and storage capacities - as shown below in Table 4.3.1.

 Table 4.3.1 Surface Areas and Storage Capacities

ELEVATION	(Ft. NGVD)	AREA (AC)	STORAGE (AC-FT)
Maximum Pool	974.0	161	11,868
Emerg. Spillway	975.5	165	12,200
Top of Dam	983.0	184	13,500

The area-capacity-elevation curve developed for this dam is shown on Plate 3 of Appendix C.

4.4 Design and Assumptions

Rainfall - runoff data was not available for the site because the streams flow intermittently. Therefore, runoff hydrographs were generated using the U.S. Army Corps of Engineers HEC-1 computer program. The SCS dimensionless unit hydrograph method was employed in the calculation of the hydrographs. For each watershed, separate runoff hydrographs were computed and then later combined to form a single inflow hydrograph for the proposed reservoir.

Runoff from the West watershed was analyzed based on current landfill construction activity. The landfill area was assumed to be in a disturbed (unvegetated) condition. A composite curve number was used to represent the unvegetated landfill and surrounding wooded areas. This is shown on Plate 4 of Appendix C.

In the East watershed, the reservoir surface is modeled as a subbasin to convert direct rainfall into a runoff hydrograph. The ash sluice water of 13.3 mgd (20.6 cfs) is represented as a base flow in the East watershed.

Once computed, the runoff hydrographs from the three subbasin watersheds are combined and routed through the reservoir.

4.4.1 Service Spillway

According to OAC 1501:21-13-04, design of the principal (service) spillway for class I dams must be such that the average frequency use of the emergency spillway is predicted to be less than once in fifty years. The estimated precipitation for a 50-year storm was obtained from the NOAA Atlas 14. For a 6-hour storm, the precipitation is 3.43 inches, whereas the 24-hour storm amount is 4.51 inches, as shown on Plate 9 of Appendix C.

Both 6-hour and 24-hour storm durations with average soil moisture conditions were checked. The 24-hour storm resulted in a higher maximum water surface, therefore this storm duration was used for developing the 50-year storm inflow hydrograph.

4.4.2 Emergency Spillway

OAC 1501:21-13-02 specifies that for class I dams, the spillway system shall safely pass the design flood equal to the probable maximum flood (PMF) without any overtopping of the dam. The PMF is the result of the probable maximum precipitation (PMP), defined as the greatest depth of precipitation for a given duration that is meteorologically possible for a given basin at a particular time of year. Generalized estimates of the PMP have been published by the

Hydrometerological branch of the National Weather Service, as shown on Plates 11 and 12 of Appendix C. For the study area, a 6-hour PMP of 26.5 inches was used as the design rainfall event. The antecedent moisture conditions of the soil cover were assumed to be average.

The layout of the control section and outlet channel for the emergency spillway is shown on the Emergency Spillway Plan.

The emergency spillway control section will be a section of mass concrete at Elevation 975.5. It will have a bottom length of 108 feet and side slopes consisting of access ramps at 2 to 15% grades. Downstream of the access ramps and control section, vertical concrete retaining walls wrap into the spillway and guide flow down the channel. The width of the control section along the flow direction will be 15 feet. The downstream channel of the spillway will be stepped. Steps will be formed of the mass concrete beginning at the downstream end of the control section and tying-in to the existing RCC steps. The calculations show that flow downstream of the control section section becomes supercritical. The spillway channel transitions from an approximate 3.5H:2V slope along the proposed concrete steps to a 5H:2V slope along the existing RCC steps..

4.5 Analysis

All reservoir flood routings were conducted using the HEC-1 computer program. The program routes floods through the reservoir by the modified Puls method. In general, reservoir storage data and either spillway dimensions or discharge-rating curves are supplied by the user.

4.5.1 Service Spillway

Analysis of the service spillway system consisted of routing the 50-year storm to establish the invert of the emergency spillway. A design for the service spillway was determined and a stage-discharge curve was computed. A maximum operating level of elevation 974 was predetermined based on the projected life of the dam raising. Reservoir routings of the 50-year storm were performed using the maximum operating level of the reservoir.

Inflow was calculated as weir flow over the 4-foot stop log. Above Elevation 976, flow will enter through the top of the vertical service spillway structure. This flow was analyzed as both weir and orifice flow. Rating calculations for the service spillway are included on Plates 13 through 19 of Appendix C.

4.5.2 Emergency Spillway

Hydrologic reservoir routings were conducted to analyze the emergency spillway and its ability to pass the probable maximum flood without overtopping the dam. A flat rectangular control section was designed with a width of 15 feet and length of 108 feet. Discharge over the spillway was rated based on calculations of critical depth using the Corps of Engineers HEC-RAS computer program. Cross sections were taken at changes in geometry, slope or surface roughness. Manning's n roughness coefficients were input based on the expected channel surface conditions. Based on literature (see Plates 40 through 42 of Appendix C), a relatively high Manning's roughness coefficient of n=0.07 was used to model the stepped spillway surface. As shown on the drawings, proposed reinforced concrete training walls extend from the crest of the dam to a point approximately 3 feet beyond the proposed stepped channel transitions into the existing steps. Downstream from the training walls section, the spillway width becomes 110 feet, consistent with the current configuration.

The calculated relationship between stage and discharge was then used in the routing process to determine the maximum discharge and pool elevation. This information was used as the emergency spillway rating and input into HEC-1.

Discharges from the emergency spillway are routed away from the dam through an existing outlet channel.

4.6 Results

4.6.1 Service Spillway-Hydraulic Capacity

The proposed new principal spillway is a vertical concrete shaft structure with a 4-foot wide opening on one side. The spillway shaft will tie into the existing inclined spillway structure. The existing structure drains into a 54-inch diameter Prestressed Concrete Cylinder Pipe (P.C.C.P.), which then ties into a 42-inch steel pipe extending down the dam. The existing energy dissipator at the outlet of the steel pipe will be utilized. During most of the operating conditions, discharge through the service spillway will be controlled by weir flow over the stop logs in the opening of the shaft. The maximum operating level is set at elevation 974.0 feet. This corresponds to a maximum stop log elevation of 972.5 based on the base inflow of 20.6 cfs.

The peak inflow during the 50-year, 24-hour storm is 486 cfs, which results from 4.51 inches of rainfall according to NOAA Atlas 14. The reservoir level will rise to elevation 975.2 feet based

on an initial pool level of elevation 974. The peak outflow from the dam will be 58 cfs. The HEC-1 output for the reservoir routings are contained on Plates 44 through 75 of Appendix C.

4.6.2 Service Spillway-Structural Capacity

The 54-inch P.C.C.P. portion of the service spillway was also analyzed for additional internal and external pressures due to the 13-foot dam raising. The pipe is installed under the dam embankment and was trenched into bedrock. Pipe crushing calculations were performed to analyze the additional loading on the pipe from the raised dam. Previous calculations (see 2000 As-Built Drawing No. 13-30043-5) indicate that the pipe was designed to handle 80 feet of overburden material at 125 pcf. The proposed top of dam will be 74.6 feet above the pipe, therefore the existing concrete pipe will be suitable to handle the additional load. Additional information on as-built drawing 13-30043-5 also indicates that the pipe is capable of handling internal pressure up to 35 psi. It is possible that at high headwater elevations, the spillway pipe could become pressurized. Under the maximum pool elevation of 983.0, the maximum static head on the downstream portion of the pipe would be 80.5 feet, or 34.9 psi. As the water will be flowing through the pipe, the actual pressure on the pipe will be less than this value; therefore the pressure should not exceed the pipe rating of 36 psi. See Plates 20 and 21 of Appendix C.

4.6.3 Emergency Spillway

The development of the PMF hydrograph indicates a peak inflow to the reservoir equal to 16,329 cfs. This value represents the combined hydrographs from the West and East watersheds. Values of the runoff from each watershed and the combined runoff are shown in Appendix C.

Based on the flood routing, the calculated peak discharge from the dam is 5,409 cfs at a maximum pool elevation of 981.9 feet NGVD. The PMF routing was also checked with the service spillway blocked, which resulted in a maximum pool elevation of 982.8 and 0.2 feet of freeboard.

Both 6-hour and 24-hour storm durations were checked. The 6-hour storm resulted in a higher maximum water surface, therefore this storm duration was used for developing the PMF inflow hydrograph.

Depth of flow in the spillway was determined based on the HEC-RAS analysis. In the proposed spillway section, the training walls were kept a minimum of 1 foot above the critical water surface depth of 4.5 feet, as shown on Plates 23 and 32 of Appendix C. The training wall height downstream of the steps transition was kept to a minimum of 1 foot above the resultant water

surface depth during the PMF event (2 to 2.5 feet). The existing wall height of 4 feet meets this requirement. The HEC-RAS output is presented as Plates 25 through 36 of Appendix C. The structural analysis of the raised emergency spillway is presented elsewhere in this report.

4.7 Summary and Conclusions

The hydrologic/hydraulic studies for the proposed dam raising included estimating the PMF and 50-year flood hydrographs and designing the emergency and service spillways. The U.S. Army Corps of Engineers computer programs HEC-1 and HEC-RAS were used in the analyses. The Hydrograph presented on Plate 43 of Appendix C displays the resultant inflow and outflow hydrographs from HEC-1 based on the PMF event. Table 4.7.1, gives a complete summary of the study.

The proposed spillway system has enough capacity to pass the probable maximum flood without overtopping the dam. The water discharged through the emergency spillway is directed away from the dam such that it causes no threat to the stability of the structure.

HYDRO	HYDROLOGIC AND HYDRAULIC SUMMARY						
Drainage Area	AREA (AC)	2.2 Sq. Mi.					
Design Floods (Inflow)							
	PMF Peak	16,329 cfs					
	50-Yr Peak	547 cfs					
Peak Discharge							
	PMF	5,409 cfs					
	50-Yr	58 cfs					
Maximum Pool Elevatio							
	PMF	981.9 ft					
	50-Yr	975.2 ft					
Emergency Spillway - O	verflow Control Section - Concrete						
	Crest Elevation, NGVD	975.5 ft					
	Bottom Width	105.0 ft					
	Side Slopes	Vertical					
Service Spillway - Size							
	Top of Vertical Concrete Structure	976.0 ft					
	Stop Log Width	4.0 ft					
	Conduit Size	54" & 42"					
	Maximum Operating Pool Level, NGVD	974.0 ft					

Table 4.7.1 Hydrologic/Hydraulic Summary for Proposed Raising Of Dam

Attachment A-2

2013 Report Appendix C

Hydrologic and Hydraulics Analysis

APPENDIX C HYDROLOGIC AND HYDRAULIC ANALYSIS



Appendix C calculations checked and reviewed by:

Ster

Stephen J. Loskota, P.E. S&ME, Inc.

Appendix C calculations prepared by:

A.J. Smith, P.E. S&ME, Inc.





Storage Volume Calc Cardinal Plant - Fly Ash Reservoir No. 2 Raising

						1 photo dated 0-0-2000			
	Elev	area (ft^2) (ft^2)	area (ac)	ave area (ft^2)	height (ft)	vol (ft^3) (ft^3)	Vol (ac-ft)	Cum Vol (ac-ft)	Total Vol (ac-ft)
		. ,	()	· · ·	()	(<i>)</i>	. ,	()	, ,
ex. pool	960	5,903,719	135.5					0	9,800
		/		5,973,619	2	11,947,238	274		
	962	6,043,519	138.7	0.444.007	~	10 000 705		274	10,074
	084	6 496 946	140.0	6,114,867	2	12,229,735	281	666	10 255
	904	0,100,210	142.0	6 259 072	2	12 518 1//	287	555	10,355
	966	6.331.928	145.4	0,200,072	2	12,010,144	207	842	10.642
		-,,		6,500,135	4	26,000,539	597		
ex. crest	970	6,668,342	153.1					1,439	11,239
				6,850,086	4	27,400,345	629		
prop. pool	974	7,031,831	161.4		_			2,068	11,868
F 0	075 F		405.0	7,109,159	2	14,218,319	326	0.005	10 105
prop. E.S.	975.5	7,186,488	165.0	7 010 064	05	3 606 430	02	2,395	12,195
	976	(interpolated) 7.238.040	166.2	7,212,204	0.5	3,000,132	00	2 478	12 278
	570	1,2.00,040	100.2	7.434.667	4	29.738.670	683	2,470	12,210
	980	7,631,295	175.2	.,,		,,,		3,160	12,960
				7,820,348	3	23,461,043	539		
prop. crest	983	8,009,400	183.9					3,699	13,499
		(interpolated)		8,198,450	3	24,595,349	565		
	986	8,387,500	192.6					4,263	14,063

Stage-storage for a dam raising design with a proposed crest at El. 983 Area calcuations above El. 970 (present crest) based on ground surface elevation contours Ground surface elevations taken from 2-foot contour interval base map from aerial photo dated 3-5-2009

Cardinal FAD 2 - Stage-Storage Curves



CARDINAL FAD 2

CALCULATE COMPOSITE CN - WEST WATERSHED

Based off of Worksheet 2 in Appendix D of 210-VI-TR-55, Second Ed., June 1986

Soil Name/	Cover Description	CN	Area	Product of CN x
Hydrologic Group			(ac)	Area
С	Newly graded areas	91	158.0	14,378
	(no vegetation)			
С	Woods, good	70	519.0	36,330

Totals	677.0

Composite CN 74.9

Use CN = 75

50,708

Check FAR 1 Landfill Post-Development conditions:

From 2005 FAR 1 PTI by GeoSyntec, Post-Development conditions for the final cover system is a CN of **74**. (see attached)

Therefore, use current landfill construction condition of CN = 75.

			(from FAR 1 PTI)
GEOSYNTEC	C CONSULTANTS		PAGE_2OF_14
Written by: <u>William Ste</u>	ier Date: 2 October 2005	Reviewed by: <u>Joo Chai Wong</u>	Date:
Client: AEP	Project: Cardinal Power Plant	Project/Proposal No.: <u>CHE8126</u>	Task No.:

• Hydrologic Soil Groups:

Interim Conditions – Interim site conditions will include exposed temporary waste slopes. FGD waste material is assumed to exhibit similar characteristics to soils of Hydrologic Soils Group C.

Post-Development - Soil used to construct the final cover system will consist of low permeability material, which will exhibit characteristics of Hydrologic Soils Group C.

• Curve Number (CN):

Interim Conditions – For interim slopes, a CN of 91 is selected, the value recommended by SCS for hydrologic soil group C for "newly graded areas".

Post-Development - For the final cover system, a curve number (CN) of 74 is used, the value recommended by SCS for hydrologic soil group C for "open spaces in good condition (grass cover > 75%)". A summary of runoff CN values provided by SCS [SCS, 1986] are provided in Table 2.

- Time of Concentration T_c : The T_c value represents the total time for stormwater runoff to travel from the hydraulically most distant point of a watershed or drainage area to a point of interest. Factors affecting T_c include surface roughness, channel shape and flow patterns, and slope. For this analysis the calculation of T_c evaluates the impact of three different types of stormwater runoff flow:
 - sheet flow flow over plane surfaces, which is limited to a maximum length of 150 ft.;
 - shallow concentrated flow after about 150 ft., sheet flow will begin to concentrate, but not necessarily defined in a specific channel; and
 - > **channel flow** flow that is confined to a defined channel section.

The T_c value for a drainage area is the sum of the individual various travel time (T_t) values of the above flow types. The equations for calculating the T_t are presented below

Sheet Flow:
$$T_{t} = \frac{0.007 (nL)^{0.8}}{(P_{2})^{0.5} s^{0.4}}$$
Shallow Concentrated Flow:
$$T_{t} = \frac{L}{3,600 V}$$



GEOSYNTEC CONSULTANTS				PAG	ГАК Е <u>7</u>
ritten by: <u>William Steier</u> Date: <u>2 October</u>	<u>2005</u> Reviewed by	: <u>Joo Cha</u>	i Wong		Dat
ient: <u>AEP</u> Project: <u>Cardinal Power Plant</u>	Project	/Proposal	No.: <u>CHE8</u>	126	Ta
	TABL	.Е 2			
Summary	y of Typical R	unoff	Curve	Numbe	rs
-					
Table 2-2a Runo	off curve numbers for u	ban areas ¹			
Cover description			Curve n hydrologic	umbers for soil group-	
Cover type and hydrologic condition	Average percent impervious area ²	A	в	С	D
Fully developed urban areas (vegetation established).	· · · · ·				-
Open space (lawns, parks, golf courses, cemeteries,			•		
Poor condition (grass cover < 50%)		68	79	86	8
Fair condition (grass cover 50% to 75%)		49	69	79	8
Good condition (grass cover > 75%)	•	39	61	74	80
Impervious areas:					
(avaluding right of man)					0333
Streets and roads:	• 10 0 - 11	98	98	98	98
Paved; curbs and storm sewers (excluding					
right-of-way)		98	98	98	05
Paved; open ditches (including right-of-way)		. 83	89	92	90
Gravel (including right-of-way)	•	76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas: Natural desert landscaping (pervious areas only) ⁴ (from FAR 1 PTI)	63	77	85	-
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand					00
or gravel mulch and basin borders) Urban districts:		96	96	96	96
Commercial and business	85	89	92	9.4	05
Industrial.	72	81	88	91	93
1/8 arre or less (town houses)					
1/4 some	. 65	77	85	90	92
1/8 acre	30	61	75	83	87
1/2 acre	25	5/	72	81	86
1 acre	20	51	69	80	85
2 acres	12	46	65	77	84 82
Developing urban areas					
Nuclear States and States an				1-	
Newly graded areas (pervious areas only,					

¹Average runoff condition, and $I_a = 0.2S$. ²The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas, are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4. ⁴CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type. ⁴Composite CN's for natural desert landscaping should be computed using figure 2-3 or 2-4. ⁴Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, ⁴Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, ⁴based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2-2a

Runoff curve numbers for urban areas 1/

Cover description			Curve n hvdrologia	umbers for soil group	
·	Average percent			BF	
Cover type and hydrologic condition	impervious area 2/	Α	В	С	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)	∛:				
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:		00	01	• •	00
Paved parking lots roofs driveways etc					
(excluding right-of-way)		98	98	98	98
Streets and roads	***************	50	00	00	00
Paved: curbs and storm sewers (excluding					
right_of_way)		<u>ġ</u> g	08	08	09
Payed: open ditches (including right of way)		83	90 90	02	03
Gravel (including right of way)		76	95	80 80	90 01
Dirt (including right of way)		70	00 00	09	81 80
Western degert urban areas		14	04	01	09
Netwol desort landscaping (nerviews proce only) 4/		69	777	0E	00
Artificial desert landscaping (pervious areas only)		60	((60	00
Artificial desert landscaping (impervious weed barrier	,				
desert shrub with 1- to 2-mch sand or gravel mulci	n	00	00	0.0	6.0
and basin borders)		96	96	96	96
Urban districts:	0.5			<u>.</u>	~ *
Commercial and business		89	92	94	95
Industrial		81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)		77	85	90	92
1/4 acre		61	75	83	87
1/3 acre		57	72	81	86
1/2 acre		54	70	80	85
1 acre		51	68	79	84
2 acres		46	65	77	82
Developing urban areas					
Newly graded areas				\sim	
(pervious areas only, no vegetation) ^{5/}		77	86	(91)	94
Idle lands (CN's are determined using cover types					

similar to those in table 2-2c). ¹ Average runoff condition, and $I_a = 0.2S$.

~

² The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

³ CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

⁴ Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

⁵ Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2-2c Runoff curve numbers for other agricultural lands 1/

Cover description		Curve numbers for 			
Cover type	Hydrologic condition	А	В	C	D
Pasture, grassland, or range—continuous forage for grazing. 2/	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Meadow—continuous grass, protected from grazing and generally mowed for hay.		30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. $\mathcal Y$	Poor Fair Good	48 35 30 4⁄	67 56 48	77 70 65	83 77 73
Woods—grass combination (orchard or tree farm). ⊭	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
→ Woods. [®] /	Poor Fair Good	45 36 30 ≰∕	66 60 55	77 73 70	83 79 77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

¹ Average runoff condition, and I_a = 0.2S.

2 Poor: <50%) ground cover or heavily grazed with no mulch. Fair: 50 to 75% ground cover and not heavily grazed.

Good: > 75% ground cover and lightly or only occasionally grazed.

³ Poor: <50% ground cover.

Fair: 50 to 75% ground cover.

Good: >75% ground cover.

⁴ Actual curve number is less than 30; use CN = 30 for runoff computations.

⁵ CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

⁶ *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.

Fair: Woods are grazed but not burned, and some forest litter covers the soil.

Good: Woods are protected from grazing, and litter and brush adequately cover the soil.



NOAA Atlas 14, Volume 2, Version 3 Location name: Mingo Junction, Ohio, US* Coordinates: 40.2666, -80.6517 Elevation: 1001ft* * source: Google Maps



POINT PRECIPITATION FREQUENCY ESTIMATES

G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

1

PF tabular 🗸 🗸 🗸 🗸 V												
PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches) ¹												
Duration		Average recurrence interval(years)										
Duration	1	2	5	10	25	50	100	200	500	1000		
5-min	0.320	0.383	0.463	0.524	0.603	0.663	0.720	0.780	0.859	0.916		
	(0.283-0.363)	(0.339-0.435)	(0.409-0.526)	(0.462-0.594)	(0.530-0.683)	(0.581-0.750)	(0.628-0.814)	(0.678–0.880)	(0.742-0.969)	(0.789–1.03)		
10-min	0.497	0.598	0.720	0.809	0.922	1.01	1.09	1.16	1.26	1.33		
	(0.440-0.565)	(0.529-0.680)	(0.636-0.817)	(0.713-0.916)	(0.811-1.04)	(0.881-1.14)	(0.946-1.23)	(1.01–1.31)	(1.09–1.42)	(1.15–1.50)		
15-min	0.610	0.731	0.883	0.995	1.14	1.24	1.35	1.45	1.58	1.67		
	(0.540-0.692)	(0.647–0.831)	(0.781-1.00)	(0.877-1.13)	(1.00-1.29)	(1.09-1.41)	(1.18-1.52)	(1.26–1.64)	(1.36–1.78)	(1.44–1.88)		
30-min	0.807	0.979	1.21	1.38	1.61	1.78	1.95	2.11	2.34	2.50		
	(0.714–0.916)	(0.866-1.11)	(1.07-1.37)	(1.22–1.57)	(1.41–1.82)	(1.56-2.01)	(1.70-2.20)	(1.84–2.39)	(2.02-2.63)	(2.15-2.82)		
60-min	0.985	1.20	1.52	1.76	2.09	2.34	2.60	2.87	3.23	3.51		
	(0.872-1.12)	(1.06–1.37)	(1.34–1.72)	(1.55–1.99)	(1.83-2.36)	(2.05–2.65)	(2.27-2.94)	(2.49–3.24)	(2.79–3.64)	(3.02–3.96)		
2-hr	1.13	1.37	1.74	2.02	2.41	2.72	3.05	3.39	3.85	4.22		
	(0.992–1.31)	(1.20–1.58)	(1.52–2.00)	(1.76–2.32)	(2.10-2.76)	(2.37–3.12)	(2.63-3.48)	(2.91–3.86)	(3.28–4.38)	(3.58–4.80)		
3-hr	1.21	1.46	1.84	2.14	2.56	2.90	3.26	3.63	4.15	4.56		
	(1.07-1.40)	(1.29-1.69)	(1.62-2.14)	(1.88-2.48)	(2.24-2.96)	(2.53-3.34)	(2.83-3.75)	(3.13–4.18)	(3.55-4.77)	(3.87–5.25)		
6-hr	1.44	1.73	2.17	2.52	3.02	(3.43	3.86	4.32	4.96	5.49		
	(1.28–1.65)	(1.54–1.98)	(1.93–2.47)	(2.24-2.87)	(2.67-3.43)	(3.01-3.88)	(3.37-4.37)	(3.75–4.87)	(4.26-5.59)	(4.67–6.17)		
12-hr	1.70	2.04	2.52	2.91	3.49	3.97	4.47	5.01	5.79	6.42		
	(1.53–1.90)	(1.83-2.28)	(2.26-2.82)	(2.61-3.25)	(3.11-3.88)	(3.52-4.39)	(3.94-4.93)	(4.39–5.51)	(5.01-6.35)	(5.51–7.01)		
24-hr	2.02	2.41	2.94	3.39	4.00	(4.51)	5.04	5.59	6.37	6.99		
	(1.87–2.18)	(2.24–2.61)	(2.74-3.18)	(3.14-3.65)	(3.70-4.31)	(4.15-4.85)	(4.62-5.40)	(5.10-5.98)	(5.77–6.81)	(6.30-7.46)		
2-day	2.37	2.82	3.42	3.90	4.57	5.11	5.67	6.24	7.04	7.66		
	(2.21–2.55)	(2.63-3.03)	(3.19-3.67)	(3.63-4.19)	(4.24-4.90)	(4.73-5.47)	(5.22-6.06)	(5.73-6.67)	(6.42-7.51)	(6.95–8.18)		
3-day	2.53	3.01	3.63	4.12	4.81	5.36	5.92	6.50	7.29	7.92		
	(2.38–2.71)	(2.83–3.22)	(3.40-3.88)	(3.86-4.41)	(4.49-5.13)	(4.98–5.71)	(5.49–6.31)	(6.00-6.92)	(6.69-7.76)	(7.22-8.42)		
4-day	2.70	3.21	3.84	4.35	5.05	5.61	6.18	6.76	7.55	8.17		
	(2.55–2.87)	(3.02–3.41)	(3.62-4.08)	(4.09-4.62)	(4.74–5.36)	(5.24-5.95)	(5.76-6.55)	(6.27–7.16)	(6.97–8.01)	(7.50-8.67)		
7-day	3.25	3.84	4.55	5.12	5.88	6.48	7.09	7.71	8.52	9.14		
	(3.08-3.44)	(3.63-4.06)	(4.31–4.82)	(4.83–5.41)	(5.54-6.22)	(6.09–6.85)	(6.65-7.49)	(7.20-8.14)	(7.92-9.00)	(8.45-9.67)		
10-day	3.74	4.41	5.18	5.78	6.59	7.22	7.85	8.47	9.29	9.91		
	(3.55–3.94)	(4.19–4.66)	(4.92–5.47)	(5.49-6.10)	(6.24–6.95)	(6.83–7.61)	(7.40-8.27)	(7.96-8.94)	(8.69-9.80)	(9.23–10.5)		
20-day	5.24 (5.00-5.51)	6.16 (5.87-6.48)	7.13 (6.79-7.50)	7.89 (7.51-8.29)	8.89 (8.45-9.33)	9.64 (9.15-10.1)	10.4 (9.83–10.9)	11.1 (10.5–11.7)	12.0 (11.3-12.7)	12.7 (11.9–13.4)		
30-day	6.58	7.70	8.83	9.72	10.9	11.7	12.6	13.4	14.4	15.2		
	(6.26–6.93)	(7.33-8.12)	(8.41-9.30)	(9.25-10.2)	(10.3-11.4)	(11.1–12.4)	(11.9-13.2)	(12.7–14.1)	(13.6–15.2)	(14.3-16.0)		
45-day	8.42 (8.04-8.81)	9.82 (9.38-10.3)	11.1 (10.6–11.7)	12.1 (11.6-12.7)	13.4 (12.8-14.0)	14.4 (13.7-15.0)	15.3 (14.5-16.0)	16.1 (15.3–16.9)	17.2 (16.2-18.0)	17.9 (16.9–18.8)		
60-day	10.1 (9.73-10.6)	11.8 (11.3–12.3)	13.3 (12.7–13.8)	14.4 (13.8-15.0)	15.8 (15.1–16.4)	16.8 (16.0-17.5)	17.7 (16.9–18.5)	18.6 (17.7–19.4)	19.6 (18.7–20.5)	20.3 (19.3–21.3)		

¹ Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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PF graphical

Precipitation Frequency Data Server



Large scale terrain



Large scale map



Large scale aerial



Figure 18.--All-season PMP (in.) for 6 hr 10 mi² (26 km²).

From HMR 51

PLATE 11

۰,



From HMR SI
		Control Type			Stop Log Weir Flow	Pressure Pipe Flow	Pressure Pipe Flow	Pressure Pipe Flow													
dth = 105'	Total	Outflow		0.0	4.7	13.3	24.5	37.7	52.7	69 <u>.</u> 2	299.5	660.8	1247.1	1776.0	2298.9	3334.3	4362.0	5364.5	5864.9	6365.2	
. 983, ES wi	E. Spillway	Flow	cfs	I	I	I	1	I	I	0'0	200.0	500.0	1000.0	1500.0	2000.0	3000.0	4000.0	5000.0	5500.0	6000.0	
p of Dam El	Control	Outflow	MGD	0.0	3.0	8.6	15.8	24.3	34.0	44.7	64.3	103.9	159.7	178.4	193.2	216.1	233.9	235.6	235.8	236.0	236.1
roposed To	Contro	Outflow	cfs	0"0	4.7	13.3	24.5	37.7	52.7	69.2	99.5	160.8	247.1	276.0	298.9	334.3	362.0	364.5	364.9	365.2	365.4
Capacity - P	Pressure	Pipe Flow	cfs	ı	357.8	358.2	358.6	358.9	359.3	359.7	360.3	360.8	361.4	361.9	362.3	363.2	363.9	364.5	364.9	365.2	365.4
g Spillway (Pipe Inlet	Flow	cfs	1	615.4	618.0	620.5	623.0	625.6	628.1	631.9	635.0	638.9	642.2	645.2	650.4	655.0	659.2	661.2	663.2	664.4
Dam Raisin	Structure	Outflow	cfs	0"0	4.7	13.3	24.5	37.7	52.7	69.2	99 - 5	160.8	247.1	276.0	298.9	334.3	362.0	385.1	395.5	405.4	411.7
linal FAD 2 I	Stop Log	Weir Flow	cfs	0.0	4.7	13.3	24.5	37.7	52.7	69.2	87.2	87.2	87.2	87.2	87.2	87.2	87.2	87.2	87.2	87.2	87.2
Carc	Duifing		cfs	ı	•	•		•	•		63.7	115.7	159.9	188.8	211.7	247.1	274.8	297.9	308.3	318.1	324.5
	01140 VDD	Moir Flow	cfs					ı			12.3	73.6	194.3	319.8	450.9	717.0	985.8	1256.1	1392.5	1530.2	1623.2
	Lake	Elevation	feet	972.50	973.00	973.50	974.00	974.50	975.00	975.50	976.27	976.89	977.70	978.37	978.98	90.080	981.02	981.90	982.32	982.73	983.00
				Top of Stop Log			Max Operating Pool			Emergency Spillway											Top of Dam = 983.0

Cardinal FAD 2 Stop Logs Weir Rating Weir Flow

$$Q = C_{SCW} L H^{\frac{3}{2}}$$
$$C_{SCW} = 3.27 + 0.4 \left(\frac{H}{H}\right)^{\frac{3}{2}}$$

for $H/H_c < 0.3$, C_{SCW} becomes 3.33

L= 4.00 *g*= 32.2 *Crest Elevation*= 972.5

Elevation	Η	Q
972.50	0.00	0.0
973.00	0.50	4.7
973.50	1.00	13.3
974.00	1.50	24.5
974.50	2.00	37.7
975.00	2.50	52.7
975.50	3.00	69.2
976.00	3.50	87.2



Cardinal FAD 2 Existing Spillway Pipe Rating Pipe Inlet Control

$$Q = CA\sqrt{2gh_1}$$

for C=0.62 orifice equation becomes:

$$Q = 3.91 D^2 \sqrt{h_1}$$

d= 54.000 INCHES

54" PCCP

Invert Elevation = 910.33

Headwater	Ori	fice
Elevation	Discharge	Velocity
(ft.)	(cfs)	(ft/s)
972.50	612.9	0.0
973.00	615.4	38.7
973.50	618.0	38.9
974.00	620.5	39.0
974.50	623.0	39.2
975.00	625.6	39.4
975.50	628.1	39.5
976.27	631.9	39.8
976.89	635.0	39.9
977.70	638.9	40.2
978.37	642.2	40.4
978.98	645.2	40.6
980.06	650.4	40.9
981.02	655.0	41.2
981.90	659.2	41.5
982.32	661.2	41.6
982.73	663.2	41.7
983.00	664.4	41.8

Cardinal FAD 2 Existing Spillway Pipe Rating Pressure Pipe Flow Computed with the Energy Equation (from inlet to outlet)

Manning's n= 0.015 Inlet Invert: 910 Outlet Invert (z_2): 736 Entrance Coefficent K_e= 0.9 Outlet Coefficent K_o= 1.0 MH Coefficent K_{MH}= 0.5 Bends Coefficent K_b= 0.8 Pipe Diameter in inches= 42 Pipe Diameter in feet (D)= 3.50 Pipe Eq. Length in feet (L)= 852 Darcy-Weisbach f= 0.027

Assuming Free Outlet (TW=EI. 739.5):

Headwater Elevation (z ₁)	Outlet Velocity	Outlet Flow Rate
(ft)	(ft/s)	(ft³/s)
972 50	37.1	357.4
973.00	37.2	357.8
973.50	37.2	358.2
974.00	37.3	358.6
974.50	37.3	358.9
975.00	37.3	359.3
975.50	37.4	359.7
976.27	37.4	360.3
976.89	37.5	360.8
977.70	37.6	361.4
978.37	37.6	361.9
978.98	37.7	362.3
980.06	37.7	363.2
981.02	37.8	363.9
981.90	37.9	364.5
982.32	37.9	364.9
982.73	38.0	365.2
983.00	38.0	365.4

The Darcy-Weisbach friction factor is related to Manning's n through the following equation:

$$f = \frac{185 \ n^2}{D^{\frac{1}{3}}}$$

The Energy Equation is:

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + \sum h_L$$

Where:

$$\sum h_L = \frac{v^2}{2g} \left(f \frac{L}{D} + K_e + K_o + K_b \right)$$

Because p_1 , v_1 and p_2 all are equal to 0 the energy equation becomes:

$$z_1 - z_2 = \frac{v^2}{2g} + \frac{v^2}{2g} \left(f \frac{L}{D} + K_e + K_o + K_b \right)$$

Solving for v gives:

$$v = \sqrt{\frac{2g(z_{1} - z_{2})}{\left(1 + \left(f\frac{L}{D} + K_{e} + K_{o} + K_{b}\right)\right)}}$$

Determine flow rate Q by:

Q = VA

Cardinal FAD 2 Vertical Box Structure Overflow Rating Weir Flow

$$Q = C_{SCW} L H^{\frac{3}{2}}$$

$$C_{SCW} = 3.27 + 0.4 \left(\frac{H}{H_c}\right)$$

for $H/H_c < 0.3$, C_{SCW} becomes 3.33



Elevation	Η	Q
976.00	0.00	0.0
976.27	0.27	12.3
976.89	0.89	73.6
977.70	1.70	194.3
978.37	2.37	319.8
978.98	2.98	450.9
980.06	4.06	717.0
981.02	5.02	985.8
981.90	5.90	1256.1
982.32	6.32	1392.5
982.73	6.73	1530.2
983.00	7.00	1623.2



Cardinal FAD 2 Vertical Box Structure Overflow Rating Orifice Flow

A= 42.5

$$Q=CA\sqrt{2gh_1}$$

Size= 5'-8" x 7'-6 " inside dimensions

S.F. %

Grating % Open Area 60 Orifice Centroid Elevation = 976.0

Headwater	Orifi	ce
Elevation	Discharge	Velocity
(ft.)	(cfs)	(ft/s)
976.00	0.0	
976.27	63.7	1.5
976.89	115.7	2.7
977.70	159.9	3.8
978.37	188.8	4.4
978.98	211.7	5.0
980.06	247.1	5.8
981.02	274.8	6.5
981.90	297.9	7.0
982.32	308.3	7.3
982.73	318.1	7.5
983.00	324.5	7.6

\$\$S&ME	Project/Proposal No		_ Calculated By <u>AJ</u>	Date
Cincinnati (513) 771-843	Project/Proposal Name	Cardinal Dam	_ Checked By	Date
Columbus (614) 793-22;	26 Subject <u>Pressure</u>	Pipe Flow	_ Sheet of	
Card	inal Dam - Ex	tended Service	Spillway	
EL, 976,0_	-EL. 983.0 -EL. 970		* *	
TI 9(0.33	Dam 21425 MH	, Ex. Se	ervice Spillmay	Pipe
<u>EL, 11-10-</u> 54	I" & PCCP.		- 4 " 	
	EL, 902.5	42" \$ 5	578	Ex. Energy
		teel Pin-		Dissipator
PCC.P Croncrete	Steel Diop			
n 0,015	0.015		EL, 73	6.0
D 54"	42			
f 0,025	0,027	5 = 1001/3		
L 214	795'	- V la -	- Al A reall	in the
Le 57'		Equivalent L	engin of 54	pipe to 4d.
		$Le = L\left(\frac{3}{3}e\right)$		$\frac{1}{f_0} = 0.93$
		= (214 f	+)(0.93)(3.5/4	,5) ⁵ =57′
Outlet	- Control - Full P	ipe Flow		
Head	water = Tailwater	$+\frac{\sqrt{2}}{2g}(1+ke+k$	MH + Kbends + K	; + k °)
	$k_e = 0, 9$ $k_o = 1.0$ $k_f = f\left(\frac{L}{b}\right) = 0$	0.027 (795+57)	= 6.6	
HW/=	$TW + \frac{\sqrt{2}}{2g} (1+0).$	9+0,5+4(0,2)	+ 6,6 + 1,0)	
				h h emu

 $HW - TW = \frac{\sqrt{2}}{2g} (10.8) \qquad \text{Let } TW = \text{Crown of pipe 2.739.5}$ $\therefore \left(\frac{(HW - 739.5)}{10.8} 2g \right)^{1/2} = V ; \quad V = 2.44 (HW - 739.5)^{1/2} \qquad A = 9.621 \text{ ft}^2$ Q = VA

-See spread sheet for HW vs. Q, stop log weir flow PLATE 1901s until ~ EL.982



Cleveland (216) 901-1000

Columbus (614) 793-2226

Project/Proposal No. 011-11497-042 Calculated By AJS Date 9-24-12 Cardinal Checked By SJL Date 9/20/12 Project/Proposal Name Subject Spillway Pipe Internal Pressure Sheet of



SS2ME

Project/Proposal No. 1176-12-004A Calculated By MRM Date 9/26/12 Project/Proposal Name CARDINAL FAD II RAISING Checked By 53 L Date 2/27 Cincinnati (513) 771-8471 Cleveland (216) 901-1000 Columbus (614) 793-2226 Subject PIPE STRENGTH CALCULATIONS Sheet of

TASK: DETERMINE SWITABILITY OF EXISTING 54" & P.C.C.P SPILLWAY PIPE UNDER ADDITIONAL PROPOSED LOADING CONDITIONS. RESULTS: COVER OVER SPILLINGY PIPE INCLUDING ADDITIONAL CONDR = 74.6 FT. BASED ON DRAWING 13-30043-5, THE 54" & SPILLWAY PIPE WAS DESIGNED TO HANDLE 80 FT SO OUR ADDITIONAL COVER STILL FALLS WITHIN THE PIPE STRENGTH CAPACITY. SKETCH OF EXISTING US PROPOSED (NOT TO SCALE) PROPOSED RAISING EL. 983.0 EL. 983.0 (PROP. TOD) EL. 908, 4 (INU. PIPS) 2 NO. 57 STONE ~2 13'-0" 74.6 FT COUER EXISTING TOP OF DAM EL. 970.0 V 50'-0" -RCC LIMITS OF RCC EL. 920.0 -CLAY CORE Z" NON-SHRINK GROUT 12'-7" -LEAN CONCRETE 54 0 P.C.C.P. N 1-0 EL. 908.4 -8-0"-TRENCH WID TH PLATE 21





From 2000 As-Built Dwg, No. 13-30041-6



PLATE 24

HEC-RAS PI	an: Plan 22 F	River: E. Spillway	Reach: 1									
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
-	140	PF 1	200.00	940.00	976.27	940.28	976.27	0.000000	0.03	8703.65	240.00	00.00
-	140	PF 2	500.00	940.00	976.89	940.51	976.89	0.000000	0.07	8853.88	240.00	00.0
~	140	PF 3	1000.00	940.00	977.70	940.81	977.70	0.00000	0.13	9047.40	240.00	00.0
-	140	PF 4	1500.00	940.00	978.37	941.07	978.37	0.000000	0.19	9209.44	240.00	0.01
-	140	PF 5	2000.00	940.00	978.98	941.29	978.98	0.000000	0.25	9354.95	240.00	0.01
-	140	PF 6	3000.00	940.00	980.06	941.69	980.06	0.000001	0.37	9613.49	240.00	0.01
-	140	PF 7	4000.00	940.00	981.02	942.04	981.02	0.000001	0.48	9844.20	240.00	0.01
-	140	PF 8	5000.00	940.00	981.90	942.37	981.90	0.000002	0.59	10056.02	240.00	0.02
-	140	PF 9	5500.00	940.00	982.32	942.54	982.32	0.000002	0.64	10156.63	240.00	0.02
7	140	PF 10	6000.00	940.00	982.73	942.69	982.73	0.000002	0.69	10254.30	240.00	0.02
-	115.1	PF 1	200.00	975.50	976.16		976.26	0.008703	2.61	81.00	142.14	0.57
1	115.1	PF 2	500.00	975.50	976.74		976.88	0.005540	3.18	173.06	175.04	0.50
-	115.1	PF 3	1000.00	975.50	977.52		977.68	0.003505	3.51	327.48	219.50	0.44
1	115.1	PF 4	1500.00	975.50	978.19		978.36	0.002549	3.63	488.12	255.18	0.39
-	115.1	PF 5	2000.00	975.50	978.80		978.96	0.001970	3.65	649.07	274.43	0.35
-	115.1	PF 6	3000.00	975.50	979.87		980.04	0.001413	3.73	962.46	308.48	0.31
-	115.1	PF 7	4000.00	975.50	980.83		981.00	0.001091	3.75	1267.33	323.63	0.29
1	115.1	PF 8	5000.00	975.50	981.71		981.89	0.000908	3.78	1557.18	335.36	0.27
-	115.1	PF 9	5500.00	975.50	982.13		982.31	0.000843	3.81	1698.33	340.92	0.26
1	115.1	PF 10	6000.00	975.50	982.54		982.71	0.000790	3.83	1837.51	346.32	0.25
1	115	PF 1	200.00	975.50	976.16		976.26	0.001226	2.62	80.95	142.13	0.57
-	115	PF 2	500.00	975.50	976.74		976.88	0.000780	3.19	173.02	175.02	0.50
-	115	PF 3	1000.00	975.50	977.52		977.68	0.000493	3.51	327.44	219.49	0.44
-	115	PF 4	1500.00	975.50	978.19		978.36	0.000359	3.63	488.11	255.18	0.39
7	115	PF 5	2000.00	975.50	978.80		978.96	0.000277	3.65	649.04	274.43	0.35
-	115	PF 6	3000.00	975.50	979.87		980.04	0.000199	3.73	962.44	308.48	0.31
-	115	PF 7	4000.00	975.50	980.83		981.00	0.000153	3.75	1267.31	323.63	0.29
-	115	PF 8	5000.00	975.50	981.71		981.89	0.000128	3.78	1557.18	335.36	0.27
1	115	PF 9	5500.00	975.50	982.13		982.31	0.000119	3.81	1698.33	340.92	0.26
1	115	PF 10	6000.00	975.50	982.54		982.71	0.000111	3.83	1837.51	346.32	0.25
-	100	PF 1	200.00	975.50	976.12		976.24	0.001460	2.76	76.48	140.33	0.62
1	100	PF 2	500.00	975.50	976.72		976.86	0.000820	3.24	170.09	174.07	0.52
1	100	PF 3	1000.00	975.50	977.51		977.67	0.000502	3.53	325.32	218.89	0.44
1	100	PF 4	1500.00	975.50	978.18		978.35	0.000362	3.64	486.46	254.98	0.39
-	100	PF 5	2000.00	975.50	978.79		978.96	0.000279	3.66	647.63	274.26	0.36
-	100	PF 6	3000.00	975.50	979.87		980.04	0.000199	3.74	961.40	308.37	0.32

HEC-RAS PI	an: Plan 22 F	River: E. Spillway	Reach: 1 (Co	ntinued)								
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	100	PF 7	4000.00	975.50	980.83		981.00	0.000154	3.75	1266.50	323.59	0.29
F	100	PF 8	5000.00	975.50	981.71		981.88	0.000128	3.79	1556.51	335.33	0.27
7	100	PF 9	5500.00	975.50	982.13		982.30	0.000119	3.81	1697.67	340.90	0.26
-	100	PF 10	6000 <u>.</u> 00	975.50	982.53		982.71	0.000111	3.84	1836.83	346.30	0.25
	000	DE 1		075 50	075 08	075 08	076 22	0.001785	3 05	50 60	105.01	1 00
	0.00		200.00	010.00	010.00	02.010	010.22	0.001100	0.00	0.00	105.00	
- -	6.66	L L L	00000	975.50	976.91	976.91	010 60 077 62	0.073231	77.9	93.00	105.04	1.01
- .	000	DE 7	1500.00	075 50	077 34	077 34	078.78	0.058886	7 75	103.68	105.05	101
- -	9 <u>9</u> 9	PF 5	2000.00	975.50	977.73	977.73	978.86	0.055267	8.53	234.60	105.06	1.01
	6.66	PF 6	3000.00	975.50	978.43	978.43	979.91	0.050473	9.76	307.49	105.08	1.01
1	<u>6.66</u>	PF 7	4000.00	975.50	979.05	979.05	980.84	0.047379	10.74	372.45	105.09	1.01
-	6.66	PF 8	5000.00	975.50	979.62	979.62	981.69	0.044943	11.56	432.64	105.11	1.00
F	6.66	PF 9	5500.00	975.50	979.89	979.89	982.10	0.044050	11.94	460.88	105.12	1.00
1	6.66	PF 10	6000.000	975.50	980.15	980.15	982.49	0.043279	12.30	488.18	105.12	1.01
1	96	PF 1	200.00	974.00	974.32	974.48	974.88	0.376398	6.04	33.13	105.01	1.89
1	96	PF 2	500.00	974.00	974.53	974.89	975.78	0.417760	8.99	55.65	105.01	2.18
1	96	PF 3	1000.00	974.00	974.86	975.41	976.78	0.338287	11.13	89.86	105.02	2.12
1	96	PF 4	1500.00	974.00	975.16	975.84	977.53	0.280174	12.37	121.29	105.03	2.03
1	96	PF 5	2000.00	974.00	975.43	976.23	978.18	0.242904	13.30	150.45	105.03	1.96
1	96	PF 6	3000.00	974.00	975.95	976.93	979.29	0.196469	14.67	204.51	105.04	1.85
7	96	PF 7	4000.00	974.00	976.43	977.55	980.26	0.167924	15.70	254.77	105.05	1.78
F	96	PF 8	5000.00	974.00	976.88	978.12	981.13	0.148546	16.55	302.19	105.06	1.72
-	96	PF 9	5500.00	974.00	60.776	978.39	981.55	0.141529	16.95	324.66	105.07	1.70
+	96	PF 10	6000.00	974.00	977.30	978.65	981.95	0.134987	17.30	346.96	105.07	1.68
7	93	PF 1	200.00	972.00	972.28	972.48	973.00	0.556401	6.79	29.47	105.01	2.26
1	93	PF 2	500.00	972.00	972.48	972.89	973.98	0.561951	9.82	50.91	105.01	2.49
1	93	PF 3	1000.00	972.00	972.76	973.41	975.21	0.508273	12.57	79.53	105.01	2.55
1	93	PF 4	1500.00	972.00	973.00	973.84	976.16	0.450602	14.26	105.17	105.02	2.51
1	93	PF 5	2000.00	972.00	973.23	974.23	976.95	0.402379	15.47	129.30	105.02	2.46
1	93	PF 6	3000.00	972.00	973.66	974.93	978.24	0.331961	17.17	174.72	105.03	2.35
1	93	PF 7	4000.00	972.00	974.07	975.55	979.32	0.283724	18.38	217.66	105.04	2.25
1	93	PF 8	5000.00	972.00	974.46	976.12	980.27	0.249809	19.34	258.54	105.04	2.17
-	93	PF 9	5500.00	972.00	974.65	976.39	980.72	0.237044	19.78	278.10	105.05	2.14
1	93	PF 10	6000.00	972.00	974.83	976.65	981.15	0.225141	20.17	297.57	105.05	2.11
1	85	PF 1	200.00	965.40	965.68	965.88	966.41	0.574097	6.85	29.19	105.01	2.29

HEC-RAS	Plan: Plan 22 F	River: E. Spillway	Reach: 1 (Cc	ontinued)								
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W S	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ff)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
-	85	PF 2	500.00	965.40	965.88	966.29	967.40	0.574378	9.89	50.58	105.02	2.51
-	85	PF 3	1000.00	965.40	966.13	966.81	968.77	0.573735	13.04	76.70	105.02	2.69
+	85	PF 4	1500.00	965.40	966.33	967.24	969.96	0.567474	15.29	98.14	105.03	2.79
-	85	PF 5	2000.00	965.40	966.52	967.63	971.03	0.556871	17.05	117.30	105.04	2.84
1	85	PF 6	3000.00	965.40	966.85	968.33	972.88	0.525993	19.72	152.20	105.05	2.89
-	85	PF 7	4000.00	965.40	967.16	968.95	974.45	0.491903	21.68	184.55	105.06	2.88
1	85	PF 8	5000.00	965.40	967.45	969.52	975.80	0.457272	23.19	215.67	105.07	2.85
+	85	PF 9	5500.00	965.40	967.60	969.79	976.42	0.441252	23.83	230.82	105.07	2.83
-	85	PF 10	6000.00	965.40	967.74	970.05	976.99	0.425444	24.41	245.88	105.08	2.81
1	80	PF 1	200.00	958.00	958.29	958.48	958.96	0.503104	6.59	30.37	105.01	2.16
-	80	PF 2	500.00	958.00	958.50	958.89	959.91	0.507624	9.53	52.49	105.02	2.37
1	80	PF 3	1000.00	958.00	958.76	959.41	961.21	0.507442	12.57	79.57	105.02	2.54
-	80	PF 4	1500.00	958.00	958.97	959.84	962.36	0.508227	14.79	101.45	105.03	2.65
1	80	PF 5	2000.00	958.00	959.15	960.23	963.42	0.508657	16.60	120.53	105.04	2.73
-	80	PF 6	3000.00	958.00	959.46	960.93	965.38	0.509361	19.53	153.67	105.05	2.84
1	80	PF 7	4000.00	958.00	959.74	961.55	967.15	0.504588	21.85	183.14	105.06	2.92
-	80	PF 8	5000.00	958.00	960.01	962.12	968.76	0.494769	23.74	210.63	105.06	2.95
-	80	PF 9	5500.00	958.00	960.13	962.39	969.50	0.488171	24.57	223.93	105.07	2.97
-	80	PF 10	6000.00	958.00	960.26	962.65	970.22	0.481204	25.33	236.95	105.07	2.97
-	77	PF 1	200.00	956.50	956.75	956.98	957.66	0.830089	7.65	26.14	105.01	2.70
-	77	PF 2	500.00	956.50	956.95	957.39	958.68	0.715384	10.56	47.36	105.01	2.77
-	77	PF 3	1000.00	956.50	957.20	957.91	960.04	0.646310	13.51	74.00	105.02	2.84
1	77	PF 4	1500.00	956.50	957.41	958.34	961.20	0.609956	15.62	96.04	105.03	2.88
-	77	PF 5	2000.00	956.50	957.60	958.73	962.29	0.594015	17.39	115.05	105.03	2.93
1	77	PF 6	3000.00	956.50	957.91	959.43	964.26	0.571945	20.22	148.42	105.04	3.00
+	77	PF 7	4000.00	956.50	958.19	960.05	966.05	0.555768	22.49	177.91	105.05	3.04
-	77	PF 8	5000.00	956.50	958.45	960.62	967.68	0.539953	24.38	205.17	105.06	3.07
-	77	PF 9	5500.00	956.50	958.58	960.89	968.44	0.531104	25.20	218.33	105.06	3.08
1	77	PF 10	6000.00	956.50	958.70	961.15	969.16	0.522282	25.96	231.19	105.06	3.08
-	70	PF 1	200.00	956.10	956.41	956.58	957.00	0.399350	6.14	32.55	105.01	1.94
-	20	PF 2	500.00	956.10	956.60	956.99	958.00	0.497833	9.47	52.80	105.01	2.35
1	70	PF 3	1000.00	956.10	956.85	957.51	959.36	0.527568	12.72	78.65	105.02	2.59
1	70	PF 4	1500.00	956.10	957.05	957.94	960.54	0.531031	14.98	100.12	105.03	2.70
1	70	PF 5	2000.00	956.10	957.23	958.33	961.64	0.535132	16.85	118.71	105.03	2.79
1	70	PF 6	3000.00	956.10	957.54	959.03	963.63	0.533230	19.80	151.57	105.04	2.90
Ţ	70	PF 7	4000.00	956.10	957.82	959.65	965.43	0.527691	22.14	180.70	105.05	2.97

HEC-RAS Pl	an: Plan 22 R	iver: E. Spillway	Reach: 1 (Co	ntinued)	-	-			-	-	-	
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
-	70	PF 8	5000.00	956.10	958.08	960.22	967.08	0.518801	24.08	207.65	105.06	3.02
-	70	PF 9	5500.00	956.10	958.20	960.49	967.84	0.511571	24.92	220.80	105.06	3.03
1	70	PF 10	6000.00	956.10	958.32	960.75	968.58	0.505503	25.71	233.47	105.06	3.04
1	6.69	PF 1	200.00	956.10	956.39	956.57	956.99	0.438962	6.20	32.24	110.01	2.02
-	6.69	PF 2	500.00	956.10	956.58	956.96	957.99	0.541413	9.53	52.45	110.02	2.43
-	6.69	PF 3	1000.00	956.10	956.81	957.47	959.35	0.571684	12.79	78.22	110.04	2.67
-	6.69	PF 4	1500.00	956.10	957.01	957.89	960.53	0.574944	15.06	09.66	110.05	2.79
-	6.69	PF 5	2000.00	956.10	957.17	958.27	961.63	0.578905	16.93	118.13	110.05	2.88
-	6.69	PF 6	3000.00	956.10	957.47	958.94	963.61	0.576374	19.89	150.87	110.07	2.99
-	6.69	PF 7	4000.00	956.10	957.73	959.54	965.42	0.570016	22.24	179.90	110.08	3.07
-	6.69	PF 8	5000.00	956.10	957.98	960.09	967.07	0.560262	24.19	206.75	110.09	3.11
-	6.69	PF 9	5500.00	956.10	958.10	960.37	967.82	0.552450	25.03	219.84	110.10	3.12
-	69.9	PF 10	6000.00	956.10	958.21	960.62	968.56	0.545879	25.82	232.47	110.11	3.13
1	60	PF 1	200.00	917.00	917.30	917 47	917.86	0.386204	5.97	33.50	110.02	1.91
1	60	PF 2	500.00	917.00	917.53	917.86	918.69	0.392246	8.65	57.78	110.03	2.10
1	60	PF 3	1000.00	917.00	917.79	918.37	919.83	0.395936	11.45	87.34	110.05	2.27
1	60	PF 4	1500.00	917.00	918.01	918.79	920.83	0.396575	13.47	111.35	110.06	2.36
1	60	PF 5	2000.00	917.00	918.20	919.16	921.75	0.396544	15.12	132.33	110.07	2.43
1	60	PF 6	3000.00	917.00	918.53	919.84	923.44	0.395788	17.77	168.89	110.09	2.53
-	60	PF 7	4000.00	917.00	918.82	920.44	925.00	0.396406	19.94	200.62	110.10	2.60
1	60	PF 8	5000.00	917.00	919.09	920.99	926.46	0.395771	21.80	229.49	110.12	2.66
-	60	PF 9	5500.00	917.00	919.21	921.27	927.16	0.395239	22.63	243.10	110.13	2.68
1	60	PF 10	6000.00	917.00	919.33	921.52	927.86	0.395732	23.44	256.04	110.13	2.71
-	53	PF 1	200.00	915.00	915.34	915.47	915.79	0.280219	5.42	36.88	110.02	1.65
-	53	PF 2	500.00	915.00	915.58	915.86	916.54	0.286142	7.87	63.51	110.03	1.83
1	53	PF 3	1000.00	915.00	915.88	916.37	917.55	0.285147	10.38	96.38	110.04	1.95
1	53	PF 4	1500.00	915.00	916.11	916.79	918.45	0.289592	12.26	122.36	110.06	2.05
1	53	PF 5	2000.00	915.00	916.31	917.17	919.29	0.295808	13.84	144.49	110.07	2.13
1	53	PF 6	3000.00	915.00	916.66	917.84	920.86	0.306301	16.45	182.38	110.08	2.25
1	53	PF 7	4000.00	915.00	916.95	918.44	922.34	0.315517	18.62	214.84	110.10	2.35
1	53	PF 8	5000.00	915.00	917.22	918.99	923.73	0.321483	20.48	244.25	110.11	2.42
1	53	PF 9	5500.00	915.00	917.34	919.27	924.41	0.324559	21.33	257.90	110.12	2.46
1	53	PF 10	6000.00	915.00	917.46	919.52	925.08	0.327665	22.15	270.95	110.12	2.49
-	52.9	PF 1	200.00	915.00	915.35	915.47	915.77	0.101776	5.22	38.34	110.02	1.56
1	52.9	PF 2	500.00	915.00	915.58	915.86	916.53	0.114142	7.79	64.19	110.03	1.80

						0.00.000	L L			L	T 142: -141-	
Keach	KIVER STA	Protile	Q lotal		W S Elev	Crit W. v.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	I op Width	Froude # Chi
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	52.9	PF 3	1000.00	915.00	915.88	916.37	917.53	0.115522	10.32	96.95	110.04	1.94
1	52.9	PF 4	1500.00	915.00	916.12	916.79	918.43	0.117970	12.21	122.89	110.06	2.04
, ,	52.9	PF 5	2000.00	915.00	916.32	917.17	919.27	0.120881	13.80	144.98	110.07	2.12
-	52.9	PF 6	3000.00	915.00	916.66	917.84	920.84	0.125556	16.41	182.83	110.08	2.24
-	52.9	PF 7	4000.00	915.00	916.96	918.44	922.32	0.129536	18.59	215.27	110.10	2.34
F	52.9	PF 8	5000.00	915.00	917.22	918.99	923.71	0.132129	20.44	244.66	110.11	2.42
1	52.9	PF 9	5500.00	915.00	917.35	919.27	924.39	0.133445	21.30	258.30	110.12	2.45
1	52.9	PF 10	6000.00	915.00	917.47	919.53	925.06	0.134768	22.12	271.35	110.12	2.48
-	50	PF 1	200.00	914.20	914.91		915.01	0.009510	2.56	78.07	110.03	0.54
1	50	PF 2	500.00	914.20	915.46		915.66	0.008811	3.61	138.44	110.05	0.57
F	50	PF 3	1000.00	914.20	916.17		916.50	0.007907	4.61	216.78	110.08	0.58
Ł	50	PF 4	1500.00	914.20	916.77		917.20	0.007375	5.31	282.36	110.11	0.58
F	50	PF 5	2000.00	914.20	917.28		917.82	0.007096	5.89	339.49	110.13	0.59
1	50	PF 6	3000.00	914.20	918.19		918.92	0.006743	6.83	439.76	110.17	09.0
+	50	PF 7	4000.00	914.20	918.99		919.89	0.006531	7.59	527.71	110.20	0.61
-	50	PF 8	5000.00	914.20	919.72		920.77	0.006356	8.22	609.31	113.67	0.62
F	50	PF 9	5500.00	914.20	920.06		921.18	0.006299	8.52	647.93	115.29	0.62
1	50	PF 10	6000.00	914.20	920.39		921.58	0.006233	8.79	685.98	116.86	0.62
1	49.9	PF 1	200.00	914.20	914.91		915.01	0.009218	2.52	78.78	112.38	0.53
1	49.9	PF 2	500.00	914.20	915.46		915.66	0.008274	3.50	141.01	114.22	0.55
1	49.9	PF 3	1000.00	914.20	916.17		916.50	0.007140	4.39	223.38	116.61	0.55
-	49.9	PF 4	1500.00	914.20	916.77		917.20	0.006450	4.98	293.73	118.62	0.55
1	49.9	PF 5	2000.00	914.20	917.29		917.82	0.006035	5.44	356.12	120.37	0.55
-	49.9	PF 6	3000.00	914.20	918.21		918.91	0.005460	6.16	468.14	123.45	0.54
1	49.9	PF 7	4000.00	914.20	919.02		919.87	0.005051	6.70	569.64	126.18	0.54
1	49.9	PF 8	5000.00	914.20	919.77		920.75	0.004734	7.14	664.25	128.67	0.53
1	49.9	PF 9	5500.00	914.20	920.11		921.16	0.004621	7.34	708.55	129.82	0.53
1	49.9	PF 10	6000.00	914.20	920.44		921.56	0.004516	7.52	751.83	130.93	0.53
-	30	PF 1	200.00	914.00	914.53	914.53	914.80	0.036552	4.15	48.50	92.33	1.00
1	30	PF 2	500.00	914.00	914.98	914.98	915.46	0.029619	5.60	90.14	94.28	1.00
-	30	PF 3	1000.00	914.00	915.55	915.55	916.30	0.025256	7.02	144.55	96.77	0.99
1	30	PF 4	1500.00	914.00	916.02	916.02	917.00	0.023257	8.04	190.31	98.82	1.00
1	30	PF 5	2000.00	914.00	916.44	916.44	917.62	0.021709	8.81	232.32	100.66	0.99
1	30	PF 6	3000.00	914.00	917.18	917.18	918.70	0.019651	10.02	308.60	103.92	0.99
1	30	PF 7	4000.00	914.00	917.83	917.83	919.64	0.018488	10.99	376.97	106.76	0.99
1	30	PF 8	5000.00	914.00	918.43	918.43	920.50	0.017510	11.79	441.74	109.39	0.99

HEC-RAS	Plan: Plan 22 F	River: E. Spillway	y Reach: 1 (Co	ontinued)								
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
-	30	PF 9	5500.00	914.00	918.73	918.73	920.91	0.016968	12.11	474.09	110.67	0.98
-	30	PF 10	6000.00	914.00	919.00	919.00	921.30	0.016592	12.44	504.77	111.88	0.98
-	Ø	PF 1	200.00	904.00	904.67	904.63	904.94	0.027464	4.20	48.00	72.75	06.0
+	8	PF 2	500.00	904.00	905.04	905.15	905.74	0.040065	6.77	74.76	74.23	1.17
1	8	PF 3	1000.00	904.00	905.57	905.82	906.77	0.039315	8.85	115.07	76.42	1.24
1	ω	PF 4	1500.00	904.00	90 0 .00	906.37	907.63	0.039161	10.37	148.05	78.16	1.29
-	8	PF 5	2000.00	904.00	906.39	906.86	908.38	0.037780	11.48	179.08	79.77	1.31
-	ω	PF 6	3000.00	904.00	907.04	907.72	909.74	0.037500	13.41	231.48	82.40	1.36
-	8	PF 7	4000.00	904.00	908.40	908.49	910.56	0.018523	12.07	347.73	87.98	1.01
-	8	PF 8	5000.00	904.00	60 ⁻ 606	909.19	911.54	0.017473	12.91	409.07	90.78	1.01
-	8	PF 9	5500.00	904.00	909 [.] 39	909.50	912.00	0.017277	13.34	436.71	92.01	1.01
+	8	PF 10	6000.00	904.00	909.71	909.82	912.44	0.016859	13.69	465.80	93.30	1.01
1	S	PF 1	200.00	898.00	898 <u>.</u> 66	898.63	898.94	0.029687	4.30	46.83	72.47	0.93
-	5	PF 2	500.00	898.00	90 [.] 06	899.15	899.73	0.037008	6.61	76.49	73.98	1.13
+	5	PF 3	1000.00	898.00	899.67	899.82	900.73	0.032456	8.36	121.81	76.25	1.14
-	ۍ ا	PF 4	1500.00	898.00	900.34	900.38	901.52	0.022966	8.83	174.27	78.78	1.02
-	5	PF 5	2000.00	898.00	900.84	900.87	902.24	0.021127	9.63	214.07	80.66	1.01
-	5	PF 6	3000.00	898.00	901.26	901.73	903.61	0.029568	12.50	248.50	82.24	1.22
-	5	PF 7	4000.00	898.00	902.35	902.50	904.60	0.019600	12.31	339.75	86.30	1.04
-	S	PF 8	5000.00	898.00	903.03	903.21	905.59	0.018457	13.17	399 <u>.</u> 59	88.86	1.03
-	S	PF 9	5500.00	898.00	903.33	903.52	900.00	0.018223	13.61	426.65	00.00	1.04
1	5	PF 10	6000.00	898.00	903.65	903.84	906.51	0.017721	13.95	455.43	91.19	1.03
1	3	PF 1	200.00	878.00	878.68	878.66	878.98	0.030014	4.41	46.07	70.91	0.94
1	e	PF 2	500.00	878.00	879.12	879.19	879.77	0.034177	6.58	78.12	74.75	1.10
-	ო	PF 3	1000.00	878.00	879.73	879.87	880.76	0.030618	8.32	125.22	80.06	1.12
-	e	PF 4	1500.00	878.00	880.34	880.42	881.53	0.023880	8.99	175.92	85.40	1.04
-	e	PF 5	2000.00	878.00	880.77	880.91	882.21	0.023299	9.95	213.82	89.19	1.05
1	3	PF 6	3000.00	878.00	881.56	881.75	883.38	0.021500	11.29	286.81	90.96	1.05
-	e	PF 7	4000.00	878.00	882.38	882.48	884.37	0.018037	11.88	368.74	103.24	1.00
1	3	PF 8	5000.00	878.00	883.14	883.15	885.25	0.015782	12.35	448.84	109.79	0.96
-	e	PF 9	5500.00	878.00	883.17	883.44	885.68	0.018586	13.47	453.01	110.12	1.04
-	e	PF 10	6000.00	878.00	883.60	883.73	886.05	0.016496	13.38	500.82	113.85	1.00

PLATE 30



PLATE 31











Table 3-1 (Continued) Manning's 'n' Values

<u></u>	Type of Channel and Description	Minimum	Normal	Maximum
C. Exca	vated or Dredged Channels			
1. Eartl	h, straight and uniform			
a. (Clean, recently completed	0.016	0.018	0.020
b. 4	Clean, after weathering	0.018	0.022	0.025
c. (Gravel, uniform section, clean	0.022	0.025	0.030
d.	With short grass, few weeds	0.022	0.027	0.033
2. Eartl	h, winding and sluggish			
a.	No vegetation	0.023	0.025	0.030
b.	Grass, some weeds	0.025	0.030	0.033
с.	Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d.	Earth bottom and rubble side	0.028	0.030	0.035
e.	Stony bottom and weedy banks	0.025	0.035	0.040
f.	Cobble bottom and clean sides	0.030	0.040	0.050
3. Drag	line-excavated or dredged			
a.	No vegetation	0.025	0.028	0.033
b.	Light brush on banks	0.035	0.050	0.060
4. Rock	cuts			
a.	Smooth and uniform	0.025	0.035	0.040
<u>b.</u>	Jagged and irregular	0.035	0.040	0.050
5 Chan	inels not maintained, weeds and brush			
J. Chan	Clean hottom brush on sides	0.040	0.050	0.080
h.	Same as above highest stage of flow	0.045	0.070	0.110
с. С	Dense weeds high as flow denth	0.050	0.080	0.120
с. Л	Dense brush high stage	0.050	0.000	0.120
u.	1.01100 010011, 111511 34460	0.000	0.100	V.1TV

Other sources that include pictures of selected streams as a guide to n value determination are available (Fasken, 1963; Barnes, 1967; and Hicks and Mason, 1991). In general, these references provide color photos with tables of calibrated n values for a range of flows.

Although there are many factors that affect the selection of the n value for the channel, some of the most important factors are the type and size of materials that compose the bed and banks of a channel, and the shape of the channel. Cowan (1956) developed a procedure for estimating the effects of these factors to determine the value of Manning's n of a channel. In Cowan's procedure, the value of n is computed by the following equation:

Table 3-1	(Continued)	Manning's	'n' Values
-----------	-------------	-----------	------------

Type of Channel and Description	Minimum	Normal	Maximum
B. Lined or Built-Up Channels			
1. Concrete		and the second	
> a. Trowel finish	0.011	(0.013)	0.015
b. Float Finish	0.013	0.015	0.016
c. Finished, with gravel bottom	0.015	0.017	0.020
d. Unfinished	0.014	0.017	0.020
e. Gunite, good section	0.016	0.019	0.023
f. Gunite, wavy section	0.018	0.022	0.025
g. On good excavated rock	0.017	0.020	
h. On irregular excavated rock	0.022	0.027	
2. Concrete bottom float finished with sides of:			
a. Dressed stone in mortar	0.015	0.017	0.020
b. Random stone in mortar	0.017	0.020	0.024
c. Cement rubble masonry, plastered	0.016	0.020	0.024
d. Cement rubble masonry	0.020	0.025	0.030
e. Dry rubble on riprap	0.020	0.030	0.035
3. Gravel bottom with sides of:			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036
4. Brick			
a. Glazed	0.011	0.013	0.015
b. In cement mortar	0.012	0.015	0.018
5. Metal			
a. Smooth steel surfaces	0.011	0.012	0.014
b. Corrugated metal	0.021	0.025	0.030
6. Asphalt			
a. Smooth	0.013	0.013	
b. Rough	0.016	0.016	
7. Vegetal lining	0.030		0.500

11497-042 Calculated By A = 5 Date 9 - 14 - 12Project/Proposal No. Checked By Sub Date Cincinnati (513) Cardinal Project/Proposal Name Cleveland (216) 901-1000 Stepped Spillway Subject _ 'n Sheet _ Columbus (614) 793-2226 Determine Manning's "n" for stepped spilling model in HEC-RAS References : Boes, R.M., and Hager, W.H. (2003), "Hydraulic Design of Stepped Spillways," J. Hydraul. Eng. 129(9), Ghare, A.D., Porey P.O., and Ingle, R.N. (2005), "Discussion of "Hydraulic Design of stepped Spillways" by Boes Hager". J. Hydraul, Eng. 131. p. 524. Eig. 1 of Discussion plots Manning's n vs. Yo for different H* Ye = he normalized critical depth he = critical depth hu = uniform flow depth H = spillway height = 60' H = spillway height 60' = 30 cton hoight 2' step height from HEC-RAS, $h_c = \frac{4.5'}{2} = 2.35$ (for n=0.07) $\frac{Y_c}{H} = \frac{2.25}{60} = 0.03.75$ From Fig. 1, n=0.017 for Y. 0.0375, H* = 30 EL. 975.5 Proposed 60 EL. 915-916 PLATE 39

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Discussion of "Hydraulic Design of Stepped Spillways" by Robert M. Boes and Willi H. Hager

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The authors are to be complimented for presenting extensive experimental data on characteristics of aerated skimming flow over stepped spillways along with hydraulic design aspects of stepped spillways. The authors have focused their attention on various aspects, including onset of skimming flow, aeration characteristics, residual energy, and training wall design.

Considering the applicability of the design guidelines, the discussers would like to know the height of stepped spillway in the experimental setup for all 3 cases. Further, the authors may clarify regarding the limiting height of prototype stepped spillways up to which the design guidelines presented in this paper could be applied.



The discussers would also like to know the number of steps provided in each case and the location of first step along the spillway profile. Can the authors suggest any readily usable explicit guidelines from hydraulic considerations for deciding on the step height, apart from the given RCC lift thickness? Some other investigators, including Rice and Kadavy (1996), Yildiz and Kas (1998), Chamani and Rajaratnam (1999) have indicated that the step height *s* affects the energy dissipation over stepped spillway.

Eq. (24) includes K, the roughness height perpendicular to the pseudobottom, which can be considered to be a representative term for step height s. In the last paragraph on energy dissipation, it is mentioned that Fig. 12 gives an idea of main parameters involved in the expression of relative residual energy. However, Fig. 12 does not indicate effect of any step height parameter on relative residual energy head ratio $[H_{\rm res}/H_{\rm max}]$. Fig. (1) shows a plot compiled by discussers based on experimental data obtained by Ghare (2003) and Yildiz and Kas (1998), which show the effect of step height on Manning's equivalent n for a stepped spillway. In this plot H^* is considered a ratio of spillway height to step height. Can authors provide any other dimensionless plot that covers all the main parameters including step height s affecting the performance of the stepped spillway under skimming flow regime?

Proposed Eq. (24) is based on the results obtained from Eqs. (20) and (21). Hence the use of Eq. (24) appears to be a tedious process. As indicated by the authors in Fig. (12), the variation in relative residual energy head ratio for Φ =40° and 50° is not appreciable; hence a simpler relationship for relative residual energy can be presented eliminating Φ as a variable. The resulting relationship would be applicable for Φ greater than 40°. Without a properly designed energy dissipation system on the downstream side, the hydraulic design of a stepped spillway system would be incomplete. The discussers would like to know the opinion of the authors regarding the applicability of the conventional conjugate depth relationship for stilling basin design in case of a stepped spillway where highly aerated flow near the toe of the spillway is encountered.

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Chamani, M. R., and Rajaratnam, N. (1999). "Characteristics of skimming flows over stepped spillways." J. Hydr. Engrg. 125(4), 361–367. $=(h_{w,e1}+h_{w,e2})/2=0.87$ m in the continuity equation yields a terminal velocity of $v_{w,e} = q_d / h_{w,e} = 20/0.87 \approx 23$ m/s.

If the chute was long enough for the attainment of uniform flow, i.e., $H_{dam} = H_{dam,u} \approx 70 \text{ m}$, the normalized residual head would read $H_{\rm res}/H_{\rm max}=0.36$ according to Eq. (24b), with f_b =0.067 from Eq. (21), $D_{h,w,u} \approx 4h_{w,u} = 4 \cdot 0.80 = 3.20$ m and 0.1 $< K/D_{h,w,u} = 0.23 < 1.0$. In this case, 64% of the flow energy of $H_{\rm max} \approx 75.2$ m would be dissipated on the spillway, and the terminal velocity would amount to $v_{we} \approx 20/0.80 = 25$ m/s.

Training Wall Design

With $\eta = 1.2$ for concrete dams, the required sidewall height from Eq. (25) is $h_d = 2.09$ m, with $h_{90,u} = 1.74$ m from Eq. (5). A sidewall height of 2.1 m is proposed. If the downstream dam face were prone to erosion, and if it were essential to avoid overtopping of the training walls, distinction should be made about whether the crest profile above the point of tangency is smooth or stepped. In the latter case, the required wall height should be at least $h_d = 1.5 h_{90,u} = 2.61$ m, whereas for a smooth crest profile, the wall height should be $h_d = h_{spray} = 4s = 4 \times 1.2 = 4.8 \text{ m over}$ about $L = 25s = 25 \times 1.2 = 30$ m from the crest to allow for the spray resulting from nappe impact on the first steps below the smooth crest (Boes and Minor 2002).

Conclusions

The following findings of the present experimental study apply:

- 1. The onset of skimming flow is expressed by the ratio of critical depth to step height and follows a linear function as expressed in Eq. (1).
- 2. The uniform equivalent clear water depth $h_{w,u}$ on stepped spillways depends on the chute angle and unit discharge only, as given in Eq. (4).
- 3. The characteristic uniform mixture depth $h_{90,u}$ according to Eq. (5) is a function of step height, unit discharge and chute angle.
- 4. The drawdown length to the approximate location of uniform flow attainment as given in Eq. (13) depends on chute angle and unit discharge only.
- 5 The bottom roughness friction factor is approximated for a wide range of spillway angles and relative roughness by Eq. (20) or (21).
- 6. The significant effect of aeration on the reduction of friction factors is illustrated by the ratio f_w/f_m as function of the mean air concentration, Eq. (22), where f_w and f_m are friction factors with and without consideration of flow aeration, respectively.
- 7. A general expression of residual energy head along stepped chutes is given in Eq. (24), with distinction between developing and uniform flow regions.
- 8. Stepped spillway training walls should be designed according to Eq. (25), taking into account the erosion potential of the downstream dam face.

These conclusions in conjunction with the results of Boes and Hager (2003) allow for the hydraulic design of stepped spillways for a wide range of boundary conditions including typical applications both for embankment and gravity dams.

Acknowledgment

The present project was financed by the Swiss National Science Foundation, Grant No. 21-45424.95. The assistance of Professor Y. Yasuda, Nihon University, Tokyo, in providing experimental data is also gratefully acknowledged.

Notation

The following symbols are used in this paper:

- b = spillway or river width;
- C = depth-averaged air concentration;
- C_i = depth-averaged air concentration at inception point;
- $\overline{C_u}$ = uniform depth-averaged air concentration;
- C(y) =local air concentration;
- $D_{h,w} = 4R_{h,w}$ hydraulic diameter;
- $D_{h,\text{eff}}^{n,\text{eff}} = w D_{h,w}$ effective hydraulic diameter; $F = u/(gh)^{1/2}$ local Froude number;

- $F_0 = q_w / (gh_0^3)^{1/2}$ approach Froude number at jetbox;
- $F_* = q_w / (g \sin \phi s^3)^{1/2}$ roughness Froude number;
- f = Darcy–Weisbach friction factor of unaerated flow;
- f_{h} = friction factor of bottom roughness;
- = Darcy–Weisbach friction factor in two-phase flow f_m without consideration of aeration;
- f_s = skin friction factor of sidewall roughness;
- f_w = Darcy–Weisbach friction factor in two-phase flow with consideration of aeration;
- g = gravitational acceleration;
- $H_{\rm dam}$ = vertical spillway or dam height;
- $H_{\text{dam},u}$ = vertical distance from spillway crest to close uniform equivalent clear water flow;
- $H_{\rm max}$ = maximum reservoir energy head;
- $H_{\rm res}$ = residual energy head;
 - h = local flow depth;
- h_c = critical depth;
- h_d = training wall design height;
- h_m = mixture depth;
- $h_{m,i}$ = mixture depth at inception point;
- $h_{\rm spray}$ = spray height resulting from nappe impact on steps; h_u = uniform flow depth;
 - $h_w = (1-C)h_{90}$ equivalent clear water depth;
- $h_{w,e}$ = clear water depth at chute end;
- $h_{w,i}$ = clear water depth at inception point;
- $h_{w,u}$ = uniform equivalent clear water depth;
- $h_{90} = h(C=0.90)$ characteristic mixture depth with local air concentration of C = 0.90;
- h_0 = approach flow depth at jetbox;
- $h_{90,u}$ = uniform characteristic mixture depth;
 - $K = s \cdot \cos \phi$ roughness height perpendicular to pseudobottom;
 - L_i = black water length from spillway crest to inception point;
 - $L_s = s/\sin \phi = K/(\sin \phi \cos \phi) = 2K/\sin(2\phi)$ distance between step edges, roughness spacing;
- Q_d = design discharge;
- Q_w = water discharge;
- q_d = design discharge per unit width;
- q_w = water discharge per unit width;
- $R = uD_{h,w}/\nu$ Reynolds number;
- $R_{h,w}$ = hydraulic radius;
 - S_f = friction slope;
 - s = step height;
 - u = flow velocity in x direction;
- $v_{m,i}$ = mixture velocity at inception point;
- $v_{w,e}$ = clear water velocity at chute end;

- $v_{w,i}$ = clear water velocity at inception point;
 - w = shape correction coefficient;
 - x = streamwise coordinate originating at spillway crest;
- $x_s = h_c^3 / (h_{w,u}^2 \sin \phi)$ scaling length;
- x_u = drawdown length from spillway crest to close uniform equivalent clear water flow;
- $Y = h/h_{\mu}$ normalized local flow depth;
- $Y_c = h_c / h_u$ normalized critical depth;
- y = transverse coordinate originating at pseudobottom;
- z_i = vertical black water length from spillway crest to inception point;
- α = energy correction coefficient;
- η = safety factor;
- ν = kinematic viscosity of water
- $\Pi_1 = 0.5 0.42 \sin(2\phi)$ function taking into account roughness spacing;
- $\Pi_2 = (K/D_{h,w})^{0.2}$ function taking into account relative chute roughness;
- σ = factor originating from
 - Gauckler-Manning-Strickler formula;
- ϕ = chute angle from horizontal; and
- $\chi = x/x_s$ normalized streamwise coordinate.

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1	0000	2	.00	.00	-00	ů.	*	1	1212	62	.00	- 00	.00	0.
1	0024	2	27	37	.00	0.	*	1	1224	63	.00	.00	.00	ο.
, ±	0029	/	40	- 36	.00	10	*	1	1236	64	.00	.00	.00	Ο.
1	0030 004P	5	.90	21	14	57	*	1	1248	65	.00	.00	.00	Ο.
1	0100	5	50	28	22	167	*	1	1300	66	.00	.00	.00	С,
1	0112	7	.56	25	31	343.	*	1	1312	67	.00	.00	.00	0.
1	01124	Ŕ	61	.20	.39	566.	*	ĩ	1324	68	,00	.00	.00	0.
1	0136	å	66	19	.47	815.	*	1	1336	69	.00	.00	.00	0.
Ť	0149	10	.00	.20	. 68	1100.	*	1	1348	70	.00	.00	.00	ο.
1	0200	11	1 32	.23	1.10	1504.	*	1	1400	71	.00	.00	,00	0.
1	0212	12	3.97	.40	3.58	2516.	*	1	1412	72	.00	.00	.00	0.
1	0224	13	3.97	.21	3.77	4635.	*	1	1424	73	.00	.00	.00	С.
1	0236	14	2,52	.09	2.43	7603.	*	1	1436	74	.00	.00	.00	с.
1	0248	15	1.19	.03	1.16	8174.	*	1	1448	75	.00	.00	.00	0.
1	0300	16	.93	,02	.90	7671.	*	1	1500	76	.00	.00	.00	0.
1	0312	17	.82	,02	.80	6310.	*	1	1512	77	,00	.00	.00	0.
1	0324	18	.74	.02	.73	5000.	*	1	1524	78	.00	.00	.00	0.
1	0336	19	.69	.01	.67	4045.	*	1	1536	79	.00	.00	.00	0.
1	0348	20	.64	.01	.62	3386.	*	1	1548	80	.00	.00	.00	Ο.
1	0400	21	.58	.01	.57	2915.	*	1	1600	81	.00	.00	.00	Ο.
1	0412	22	.53	.01	,52	2566.	*	1	1612	92	.00	.00	.00	0.
1	0424	23	.50	.01	.49	2292.	*	1	1624	83	.00	.00	.00	0.
1	0436	24	.48	.01	.47	2077.	*	1	1636	84	.00	.00	.00	0.
l	0448	25	.46	.01	.45	1908.	*	1	1648	85	00	.00	.00	0.
1	0500	26	.43	.01	.43	1771.	*	1	1700	86	.00	,00	.00	0.
1	0512	27	.41	.01	.41	1657.	*	1	1712	87	.00	.00	.00	ο.
1	0524	28	.40	.01	.39	1562.	*	1	1724	88	.00	.00	.00	υ.
1	0536	29	.39	.01	.38	1484.	*	1	1736	89	,00	.00	.00	υ.
1	0548	30	.38	,01	.37	1419.	*	1	1748	90	.00	.00	.00	0.
1	0600	31	. 37	.00	.36	1366,	*	1	1800	91	.00	.00	.00	0.
1	0612	32	.00	.00	.00	1258.	*	1	1812	92	.00	.00	.00	υ.
1	0624	33	.00	.00	.00	1007.	*	1	1824	93	.00	.00	.00	υ.
1	C636	34	.00	.00	.00	686.	×	1	1836	94	.00	.00	.00	υ.
1	0648	35	.00	.00	,00	413.	*	1	1848	95	.00	.00	.00	U. 0
1	0700	36	.00	.00	.00	241.	*	1	1900	96	.00	.00	.00	0.
1	0712	37	.00	,00	.00	143.	*	i	1912	97	.00	.00	.00	0.
1	0724	38	.00	.00	.00	83.	*	1	1924	98	.00	.00	.00	0.
1	0736	39	.00	.00	.00	49.		1	1930	100	.00	.00	.00	0.
1	0748	40	.00	.00	.00	28.	*	1	1948	101	.00	.00	.00	0.
1	0800	41	.00	.00	.00	16. 0	*	1	2000	102	.00	.00	.00	0.
1	C812	42	.00	.00	.00	у.	*	1	2012	102	.00	.00	.00	с. С
1	0824	43	.00	.00	.00	5.	*	1	2024	103	.00	.00	.00	0.
1	0836	44	.00	.00	.00	2.	*	1	2030	105	.00	.00	.00	Ŭ.
1	0348	45	.00	.00	.00	υ.	*	1,	2048	105	.00	.00	.00	v. 0
1	0900	46	.00	.00	.00	G.	*	1	2100	106	.00	.00	.00	υ.

.05 .02 .01 .00 .00 .00 .00

.00 .00 .CC

1	0912	47	.00	.00	.00	ο.	*	1	2112	107	.00	.00	.00	Ο.
1	0924	48	.co	.00	.00	ο.	*	1	2124	108	.00	.00	.00	0.
1	0936	49	.00	.00	,00	0.	*	1	2136	109	.00	.00	.00	Ο.
1	0948	50	.00	.00	.00	0.	*	I	2148	110	.00	.00	.00	ο.
1	1000	51	.00	.00	.00	0.	*	1	2200	111	.00	.00	.00	0.
1	1012	52	.00	.00	.00	Ο.	*	1	2212	112	.00	.00	.00	0.
1	1024	53	.00	.00	.00	с.	*	1	2224	113	.00	.00	.00	С.
1	1036	54	.00	.00	.00	с.	*	1	2236	114	.00	.00	.00	с.
1	1048	55	.00	.00	.00	Ο.	*	1	2248	115	.00	.00	.00	0.
1	1100	56	.00	.00	.00	Ο.	×	1	2300	116	.00	.00	.00	0.
1	1112	57	.00	.00	.00	0.	*	1	2312	117	.00	.00	.00	ο.
1	1124	58	.00	.00	.00	Ο.	sk:	l	2324	118	.00	.00	.00	ο.
1	1136	59	.00	.00	,00	0.	*	1	2336	119	.00	.00	.00	ο.
1	1148	60	.00	.00	.00	0.	*	1	2348	120	.00	.00	.00	0.
							*							

* * *

	TOTAL RAIN	FALL =	26.50, TOTA	LL LOSS =	3.62, TOTAL	EXCESS =	22.88
	PEAK FLOW	TIME			MAXIMUM AVER	AGE FLOW	
				6-HR	24-HR	72-HR	23.80-HR
+	(CFS)	(HR)					
			(CFS)				
+	8174.	2.80		2588.	658.	658.	658.
			(INCHES)	22.704	22,881	22.881	22.881
			(AC-FT)	1284.	1294.	1294.	1294.
			CUMULATIV	S AREA =	1.06 SQ MI		

*	÷	÷	

		* *
20	KK	* EAST * RUNOFF FROM EAST WATERSHED
		* *

		WOODS ONLY
		SUBBASIN RUNOFF DATA
22	BA	SUBBASIN CHARACTERISTICS
22	Las	TAREA .75 SUBBASIN AREA
		PRECIPITATION DATA
26	Ъщ	TOTAL STORM STATIONS 10
õ	PN	WEIGHTS 1.00
· ·	1.0	
24	PR	RECORDING STATIONS 10
25	PW	WEIGHTS 1.00
23	LS	SCS LOSS RATE
		STRTL .86 INITIAL ABSTRACTION
		CRVNBR 70.00 CURVE NUMBER
		RTIMP .00 PERCENT IMPERVIOUS AREA

27 UD SCS DIMENSIONLESS UNITGRAPH TLAG .34 LAG

PRECIPITATION STATION DATA

STATION	TOTAL	AVG. ANNUAL	WEIGHT
10	26.50	.00	1.00

TEMPORAL DISTRIBUTIONS

STATION	10, WEIG	GHT = 1.0	00						
.01	.01	.01	.02	.02	.02	.02	.02	.03	.05
.15	,15	.10	.05	.03	.03	.03	.03	.02	.02
.02	,02	.02	.02	.02	.02	,01	.01	.01	.01
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	,00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	,00	.00	.00	.00	.00	.00	,00
.00	.00	.00	.00	.00	.00	.00	.00	.00	,00
.00	.00	.00	.00	.00	.00	.00	.00	.00	

WARNING *** TIME INTERVAL IS GREATER THAN .29*LAG

UNIT HYDROGRAPH 10 END-OF-PERIOD ORDINATES

				10 END-OF	-PERIOD ORI	JINATES			
329.	820.	669.	314.	153.	73.	34.	16,	8.	4.

							1	*								COHP Q
	1	0000	1	.00	.00	.00	ο.	*	1	12	00	61	.00	.00	.00	0.
	1	C012	2	.34	.34	.00	0.	*	1	12	12 54	62 62	.00	.00	.00	U. C
	1	0024	.5	. 57	.3/	.00	U.	÷	1	12	24	61	.00	00.	.00	0.
	1	0036	4	.40	. 20	.01	J. 40	*	1	12	28 28	65	.00	.00	.00	0.
	1	0100	6	.50	.34	.17	134.	÷	ī	13	00	66	.00	.00	.00	ŏ.
	1	0112	7	.56	.31	.25	280.	*	1	13	12	67	.00	.00	.00	ο.
	1	0124	8	.61	.28	,33	454.	*	1	13	24	68	.00	.00	.00	ο.
	1	0136	9	.66	.25	.41	641.	*	1	13	36	69	.00	.00	.00	0.
	1	0148	10	.87	.27	.61	871.	*	1	13	48	70	.00	.00	,00	0.
	1	0200	11	1.32	.31	1.01	1265.	*	1	14	00	71	.00	.00	,00	0.
	1	0212	12	3,97	.57	3.41	2563.	*	1	14	12	72	.00	.00	.00	0.
	1	0224	13	3.97	.31	3.67	4960.	*	1	14.	44 36	22	.00	.00	.00	0.
	1. 1	0230	16	1 10	.1.0	2.39	6076	*	1	14	48	75	00	00	.00	n.
		0240	16	. 93	.03	. 69	4601.	*	1	15	cc	76	.00	.00	.00	č.
	1	0312	17	.82	.03	.79	3361.	*	1	15	12	77	.00	.00	.00	c,
	1	0324	18	74	.03	.72	2611.	*	1	15	24	78	.00	.00	.00	Ο.
	1	0336	19	.69	.02	.67	2157.	*	1	15	36	79	.00	,00	.00	0.
	1	0348	20	.64	.02	. 62	1871,	×	1	15	48	80	.00	.00	.00	0.
	1	0400	21	.58	.02	.57	1670.	*	1	16	00	81	.00	.00	.00	0.
	1	0412	22	.53	.01	.52	1506.		1	16	12	82	.00	.00	.00	υ.
	1	0424	23	.50	.01	.49	13/1.	*	1	16	24	83	.00	.00	.00	0,
	1	0436	24	,48	.01	- 4 /	1270.	*	1	10	20 49	85	00.	.00	00.	0.
	1	0448	25	.40	.01	.44	1132.	*	1	17	40 00	86	.00	.00	,00	0.
	1	0500	27	.45	.01	. 40	1075.	*	1	17	12	87	.00	.00	.00	0.
	ĩ	0524	28	.40	.01	,39	1024.	*	ĩ	17	24	88	.00	.00	.00	0.
	1	0536	29	.39	.01	.38	981.	*	1	17	36	89	.00	.00	.00	Ο.
	1	0548	30	.38	.01	.37	946.	*	1	17	48	90	.00	.00	.00	с.
	1	0600	31	.37	.01	.36	917.	*	1	18	00	91	.00	.00	.00	С.
	1	0612	32	.00	.00	.00	777.	*	1	18	12	92	.00	.00	.00	ο.
	1	0624	33	.00	.00	.00	469.	*	1	18	24	93	.00	.00	.00	0.
	1	0636	34	.00	.00	.00	222.	* ~	1	10	30 10	94	.00	.00	.00	0.
	1	0548	30	.00	.00		50	÷	1	10	40 00	96	-00	.00	00	0.
	1	0700	30	.00	.00	00,	23	*	1	19	12	97	.00	.00	.00	0.
	1	0724	38	.00	.00	.00	10.	*	ĩ	19	24	98	.00	.00	.00	0.
	ī	0736	39	.00	.00	.00	4.	*	1	19	36	99	.00	.00	.00	0.
	l	0749	40	.00	.00	.00	1.	*	1	19	48	100	.00	.00	.00	Ο.
	1	0800	41	.00	.00	.00	С.	*	1	20	00	101	.00	,00	.00	0.
	1	0812	42	.00	.00	.00	Ο.	*	1	20	12	102	.00	.00	.00	0.
	1	0824	43	.00	.00	.00	0.	*	1	20	24	103	.00	.00	.00	0.
	1	0836	44	.00	.00	.00	0.	*	1	20	36	104	.00	.00	.00	υ.
	1	0848	45	.00	.00	.00	0.	*	1	20	48	106	.00	.00	.00	0.
	1	0900	40	.00	.00	.00	0.	*	1	21	12	107	.00	.00	.00	o. D
	1	0912	48	00	00		0.	*	1	21	2.4	108	.00	.00	.00	ŏ.
	1	0936	49	.00	.00	.00	0.	×	1	21	36	109	.00	.00	.00	ο.
	1	0948	50	.00	.00	.00	0.	*	1	21	48	110	.00	.00	.00	0.
	1	1000	51	.00	.00	.00	0.	*	1	22	00	111	.00	.00	.00	ο.
	1	1012	52	,00	.00	.00	0.	*	1	22	12	112	.00	.00	.00	ο.
	1	1024	53	,00	.00	.00	Ο.	*	1	22	24	113	.00	.00	.00	0.
	1	1036	54	.00	.00	.00	Ο.	*	1	22	36	114	.00	.00	.00	0.
	1	1049	55	.00	.00	.00	υ.	*	1	22	48	110	.00	.00	.00	0.
	1	1100	50	.00	.00	.00	0.	*	1	23	12	117	00	.00	.00	0. 0
	1	1124	59	.00	.00	.00	0.	*	1	23	24	118	00	.00	.00	с. С.
	1	1136	59	.00	.00	.00	ő.	*	1	23	36	119	.00	.00	.00	0.
	1	1148	60	.00	.00	.00	ō.	*	1	23	48	120	,00	.00	.00	ο.
	-							*								
*** ****	*****	*****	****	******	******	* * * * * * * * *	* * * * * * * * *	******	******	*****	* * *	****	******	******	*******	*******
	TOTAL R	AINFALL	= 2	5.50, TOT	TAL LOSS	= 4.5	3, TOTAL	EXCESS =	21.97							
PE.	AK FLOW	TIME	3		6-H	MAXI R 2	MUM AVERA 4-HR	GE FLOW 72-HR	23.80-H	łR						
+	(CFS)	(HR)														
				(CFS)			4.47	447								
+	6527,	2.60	1 (3	INCHES) (AC-FT)	1767 21.90 876	2 21	447. .971 879.	447. 21.971 879,	44 21,9 879	/. 71 9.						

HYDROGRAPH AT STATION EAST
	**	****	******											
28 KI	К *		LAKE *	J	INSTANTA	NEOUS RUNG	OFF FROM LAP	Œ SURFACE						
	*	*****	* *****											
			1	LAKE (NLY									
		SUBB	ASIN RUN	OFF DZ	ATA									
30 B.	<u>A</u>	SU	BBASIN CI TAREA	HARAC' A	FERISTIC: .30	SUBBASII	N AREA							
31 B	F	BA.	SE FLON (STRT) QRCS RTIO	CHARAO 2 N R	CTERISTI: 20.00 .00 1.00000	CS INITIAL BEGIN BA RECESSIO	FLOW ASE FLOW REC ON CONSTANT	CESSION						
		PR	ECIPITAT	ION DA	ATA									
35 P 0 P	T' W	Т	OTAL STO	RM ST) WI	ATIONS EIGHTS	10 1.00								
33 P. 34 P	R		RECORDI	NG STA	ATIONS EIGHTS	10 1.00								
32 L	s	sc	S LOSS R STRT CRVNB RTIM	ATE L R P	.CO. 100.CO .OC	INITIAL CURVE N PERCENT	ABSTRACTION UMBER IMPERVIOUS	AREA						
36 U	D	sc	S DIMENS	IONLE:	SS UNITG	RAPH								
			TLA	6	.10	LAG								
		PREC	IPITATIO	N STA	TION DAT.	Ą		***						
			STA	TION 10	TOTAL 26.50	AVG.	ANNUAL WH	EIGHT 1.00						
		TE	MPORAL D	ISTRI	BUTIONS									
		ST	ATION	1	0, WEIG	HT = 1.	00							
			.01 .15 .02 .00		.01 .15 .02 .00	.01 .10 .02 .00	.02 .05 .02 .00	.02 .03 .02 .00	.02 .03 .02 .00	.02 .03 .01 .00	.02 .03 .01 .00	.03 .02 .01 .00	.02 .02 .01 .01	5 2 1 1
			.00		.00	.00	.00	.00	.00	.00	.00	.00	.00))
			.00		.00	.00	.00	.00	.00	.00	.00	.00	.00)
			.00		.00	.00	.00	.00	.00	.00 .00	.00	.00	.00)
			.00		.00 .00	.00 .00	.00	.00 .00	.00	.00	.00	.00 .00	.00)
WARNIN	(G *** T)	IME IN	TERVAL I	S GRE	ATER THA	N .29*LAG								
							UN	IT HYDROGE	APH					
		719.	20	1.	40.	в.	5 END	OF-PERIOD	ORDINATES					
******	******	*****	******	****	*****	*******	*******	********	*******	********	**********	*******	******	********
							HYDROGRAPH	AT STATI	on Lak	E				
******	******	******	****	****	******	*******	*********	*****	*******	*******	**********	*******	******	******
	DA MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	* *	DA MON	HRMN OF	RD RAIN	LOSS E	XCESS	COMP Q
	1 1	0000	1	.00	.00 .00	.00	20. 268	*	1	1200 e	51 .00 52 .00	.00	.00	20. 20.
	1	0024	3	.37	.00	.37	356.	*	1	1224	53 .00	.00	.00	20.
	1 1	0036 0048	4 5	,40 .45	.00	.40	394. 441.	*	1 1	1236 (54 .00 55 .00	.00	.00	20.
	1	0100	6	.50	.00	.50	491	*	1	1300 (56 00	.00	.00	20.
	1.	0112	7	.56 61	.00	.56	543. 594	*	3.	1312 (1324 (57 .00 58 .00	.00	.00	20. 20.
	۰. ۱	0124	9 9	.66	.00	.66	645.	*	1	1336 (59 .00	.00	, co	20.
	1	0148	10	.87	.00	.87	811.	vir 	1	1348	70 .00	.00	.00	20.
	1	0200 0212	11 12	1.32	.00	1.32 3.97	1180. 3185.	*	1	1400 1412 ·	72 ,00	.00	.00	20.
	ĩ	0224	13	3.97	.00	3.97	3738,	*	1	1424	73 .00	.00	.00	20.
	1	0236	14	2.52	.00	2.52	2799.	*	1	1436 '	74 .00 75 00	.00	.00	20.
	ı. L	0248 0300	15 16	1.19 .93	.00	1.19 .93	1058.	*	1	1500 '	76 .00	.00	.00	20.
	1	0312	17	.82	.00	.82	865.	*	1	1512	77 .00	.00	.00	20.
	1	0324	18	.74	.00 იი	.74 KG	765.	*	ב ז	1524 · 1536 ·	79 .00	.00	,00 ,00	20. 20.
	1	0348	20	.64	.00	.64	652.	*	ĩ	1548 (30 .00	.00	.00	20.

1	0400	21	5.8	on	58	600	*	1	1600	81	.00	.00	.00	20.
1	0412	22	.53	.00	- 53	549	*	1	1612	82	.00	.00	.00	20.
1	0424	23	.50	.00	- 50	517.	*	1	1624	83	.00	.00	.00	20.
ĩ	0436	24	48	00	48	492.	*	1	1636	84	.00	.00	00	20.
1	n448	25	- 46	.00	- 46	468.	*	1	1648	85	.00	.00	.00	20.
î	0500	26	.43	.00	. 43	447.	*	1	1700	86	.00	.00	.00	20.
1	0512	27	41	. ñõ	. 41	427.	*	1	1712	87	.00	.00	.00	20.
1	0524	28	.40	.00	.40	410.	*	1	1724	88	.00	.00	.00	20.
1	0536	2.9	.39	.00	.39	398.	*	1	1736	89	.00	.00	.00	20.
1	0548	30	.38	.00	.38	388.	×	1	1748	90	.00	.00	.00	20.
ī	0600	31	.37	.00	.37	379.	*	1	1600	91	.00	.00	.00	20.
1	0612	32	.00	.00	.00	112.	*	1	1812	92	.00	.00	.00	20.
ĩ	0624	33	.00	.00	.00	38.	×	1	1824	93	.00	.00	.00	20.
1	0636	34	.00	.00	.00	23.	×	1	1836	94	.00	.00	.00	20,
1	0648	35	.00	.00	.00	20.	*	1	1848	95	.00	.00	.00	20,
1	0700	36	.00	.00	.00	20.	*	1	1900	96	.00	.00	.00	20,
1	0712	37	.00	.00	.00	20.	*	1	1912	97	.00	.00	.00	20.
1	0724	38	.00	.00	.00	20.	*	1	1924	98	.00	.00	.00	20.
1	0736	39	.00	.00	.00	20.	*	1	1936	99	.00	.00	.00	20.
1	0748	40	.00	.00	.00	20.	*	1	1948	100	.00	.00	.00	20.
1	0600	41	.00	.00	.00	20.	*	1	2000	101	.00	.00	.00	20,
1	0812	42	.00	.00	.00	20.	*	1	2012	102	.00	.00	.00	20.
1	0824	43	.00	.00	.00	20.	*	1	2024	103	.00	.00	.00	20.
1	0836	44	.00	.00	.00	20.	*	1	2036	104	.00	.00	.00	20.
1	0848	45	.00	.00	.00	20.	*	1	2049	105	.00	.00	.00	20.
1	0900	46	.00	.00	.00	20.	*	1	2100	106	.00	.00	.00	20.
1	0912	47	.00	.00	.00	20.	*	1	2112	107	.00	.00	.00	20.
1	0924	4 B	.00	.00	.00	20.	×	1	2124	108	.00	.00	.00	20.
1	0936	49	.00	.00	.00	20.	×	1	2136	109	.00	.00	.00	20.
1	0948	50	.00	.00	.00	20.	*	1	2148	110	.00	.00	.00	20,
1	1000	51	.00	.00	.00	20.	*	1	2200	111	.00	.00	.00	20.
1	1012	52	,00	.00	.00	20.	*	1	2212	112	.00	.00	.00	20.
1	1024	53	,00	.00	.CO	20.	*	1	2224	113	.00	.00	.00	20.
1	1036	54	.00	.00	.00	20.	*	1	2236	114	.00	.00	.00	20.
1	1048	55	.00	.00	.00	20,	*	1	2248	115	.00	.00	.00	20,
1	1100	56	.00	.00	.00	20.	*	1	2300	116	,00	.00	.00	20.
1	1112	57	.00	.00	.00	20.	*	1	2312	117	.00	.00	.00	20.
1	1124	58	.00	.00	.00	20.	*	1	2324	118	.00	.00	.00	20.
1	1136	59	.00	.00	.00	20.	*	1	2336	119	.00	.00	.00	20.
1	1148	60	.00	.00	.00	20.	*	1	2348	120	.00	.00	.00	20.

	TOTAL RA	INFALL =	26.50, TOI	AL LOSS =	.00, TOTAL	L EXCESS =	26,50
	PEAK FLOW	TIME			MAXIMUM AVE	RAGE FLOW	
				6-HR	24-HR	72-HR	23.80-HR
+	(CFS)	(HR)					
			(CFS)				
+	3738.	2.40		869.	236.	236.	236.
			(INCHES)	26.923	28.959	28,959	28,959
			(AC-FT)	431.	463.	463.	463.
			CUMULATIN	Æ AREA =	.30 SQ MI		

* * *

4

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* * * * * * * * * * * * * * * IN * * * COMBINE INFLOWS FROM WEST AND EAST WATERSHEDS AND LAKE SURFACE 37 KK

******* HYDROGRAPH COMBINATION ICOMP 3 NUMBER OF HYDROGRAPHS TO COMBINE 38 HC

HYDROGRAPH AT STATION IN SUM OF 3 HYDROGRAPHS

| **** | ***** | ****** | ****** | * * * * * * * * * | * * * * | **** | ***** | ******* | ****** | **** | ****** | ***** | * * * * * * * | **** | **** | ***** | ***** | ***** | **** |
|-------|--------|--------|--------|-------------------|---------|--------|-------|---------|--------|------|--------|-------|---------------|------|------|--------|-------|-------|------|
| *** | | | | | | | | | | | | | | | | | | | |
| FLON | DA MON | HRMN | ORD | FLOW | * | DA MON | HRMN | ORD | FLOW | × | DA MON | HRMN | ORD | FLOW | * | da mon | HRMN | ORD | |
| L TOM | | | | | * | | | | | * | | | | | * | | | | |
| 20 | 1 | 0000 | 1 | 20. | * | 1 | 0600 | 31 | 2663. | * | 1 | 1200 | 61 | 20. | * | 1 . | 1800 | 91 | |
| 20. | 1 | 0012 | 2 | 268. | * | 1 | 0612 | 32 | 2148. | * | 1 | 1212 | 62 | 20. | * | I | 1812 | 92 | |
| 20. | 1 | 0024 | 3 | 356. | × | 1 | C624 | 33 | 1513. | * | 1 | 1224 | 63 | 20. | × | 1 | 1824 | 93 | |

| | 1 | 0036 | 4 | 409. | * | 1 | 0636 | 34 | 931. | * | 1 | 1236 | 64 | 20. | * | 1 | 1836 | 94 |
|-----|---------|-------------|--------|---------------|-----------|--------------------|------------------|--------------------|-------------------|-------|-------|---------|-----------|---------|--------|--------|--------|---------------|
| 20. | 1 | 0048 | 5 | 538. | * | 1 | 0648 | 35 | 539. | × | 1 | 1248 | 65 | 20. | * | 1 | 1848 | 95 |
| 20. | 1 | 0100 | 6 | 793. | * | 1 | 0700 | 36 | 311. | * | 1 | 1300 | 66 | 20. | * | 1 | 1900 | 96 |
| 20. | 1 | 0112 | 7 | 1165. | × | i | 0712 | 37 | 186. | * | 1 | 1312 | 67 | 20. | * | 1 | 1912 | 97 |
| 20. | 1 | 0124 | 8 | 1613. | * | 1 | 0724 | 38 | 114. | * | 1 | 1324 | 68 | 20. | * | 1 | 1924 | 98 |
| 20. | - | 0124 | 0 | 2102 | * | 1 | 0736 | 30 | 73 | × | 1 | 1336 | 69 | 20 | * | 1 | 1936 | 99 |
| 20. | 1 | 0130 | 20 | 2102. | - | - | 0746 | 40 | 40 | * | - | 1249 | 70 | 20 | * | 1 | 1948 | 100 |
| 20. | T | 0148 | 10 | 2781. | Ŷ | 1 | 0746 | 40 | 42. | | - | 1.040 | 70 | 20. | ىلە | - | 2000 | 101 |
| 20. | 1 | 0200 | 11 | 3949. | * | 1 | 0800 | 41 | 36. | * | 1 | 1400 | /1 | 20. | | 1 | 2000 | 101 |
| 20. | 1 | 0212 | 12 | 8264. | ÷ | 1 | 0812 | 42 | 29. | * | 1 | 1412 | 72 | 20, | × | 1 | 2012 | 1.02 |
| 20. | 1 | 0224 | 13 | 13339. | * | 1 | 0824 | 43 | 25. | * | 1 | 1424 | 73 | 20. | * | 1 | 2024 | 103 |
| 20 | 1 | 0236 | 14 | 16329. | * | 1 | 0836 | 44 | 22. | * | 1 | 1436 | 74 | 20. | * | 1 | 2036 | 104 |
| 20 | 1 | 0248 | 15 | 15821. | * | 1 | 0848 | 45 | 20. | * | 1 | 1448 | 75 | 20. | * | 1 | 2048 | 105 |
| 20. | 1 | 0300 | 16 | 13330. | * | 1 | 0900 | 46 | 20. | × | I | 1500 | 76 | 20. | × | 1 | 2100 | 106 |
| 20. | 1 | 0312 | 17 | 10536. | * | 1 | 0912 | 47 | 20. | * | 1 | 1512 | 77 | 20. | * | 1 | 2112 | 107 |
| 20. | 1 | 0324 | 18 | 8376. | * | 1 | 0924 | 48 | 20. | × | 1 | 1524 | 78 | 20. | * | 1 | 2124 | 108 |
| 20. | 1 | 0336 | 19 | 6907. | * | 1 | 0936 | 49 | 20. | * | 1 | 1536 | 79 | 20, | * | 1 | 2136 | 109 |
| 20. | 1 | 0348 | 20 | 5909. | * | 1 | 0948 | 50 | 20. | * | 1 | 1548 | 80 | 20, | * | 1 | 2148 | 110 |
| 20. | 1 | 0400 | 21 | 5186. | × | 1 | 1000 | 51 | 20. | * | 1 | 1600 | 81 | 20. | ÷ | 1 | 2200 | 111 |
| 20. | 1 | 0412 | 22 | 4621. | * | 1 | 1012 | 52 | 20. | * | 1 | 1612 | 82 | 20. | * | 1 | 2212 | 112 |
| 20. | 1 | N424 | 23 | 4179. | * | 1 | 1024 | 53 | 20. | ÷ | 1 | 1624 | 83 | 20. | * | 1 | 2224 | 113 |
| 20. | 1 | 0436 | 24 | 2939 | * | T | 1036 | 54 | 20. | * | 1 | 1636 | 84 | 20. | * | 1 | 2236 | 114 |
| 20. | 1 | 0430 | 21 | 2671 | ÷ | 1 | 1020 | 55 | 20 | * | - | 1648 | 85 | 20. | × | 1 | 2248 | 115 |
| 20, | 1 | 0440 | 25 | 3371. | | | 1010 | 50 | 20. | ÷ | 1 | 1700 | 30 | 20 | * | 1 | 2300 | 116 |
| 20. | 1 | 0500 | 26 | 3350. | Ĵ | 1 | 1100 | 50 | 20. | | | 1710 | 00
07 | 20. | + | 1 | 2300 | 117 |
| 20. | 1 | 0512 | 27 | 3158. | * | T | 1112 | 57 | 20. | | 1 | 1712 | 37 | 20. | | 1 | 2012 | 110 |
| 20. | 1 | 0524 | 28 | 2996. | * | 1 | 1124 | 58 | 20. | * | T | 1/24 | 88 | 20. | | 1 | 2324 | 110 |
| 20. | 1 | 0536 | 29 | 2863. | × | 1 | 1136 | 59 | 20. | * | 1 | 1736 | 89 | 20. | * | 1 | 2336 | 119 |
| 20. | 1 | 0548 | 30 | 2753. | * | 1 | 1148 | 60 | 20. | * | 1 | 1748 | 90 | 20, | * | 1 | 2348 | 1.20 |
| | | | | | * | | | | | * | | | | | * | | | |
| *** | ****** | * * * * * * | ****** | ******** | **** | ***** | ***** | ****** | ******* | **** | **** | | ******* | ***** | ***** | ***** | ***** | ********** |
| P | EAK FLO | W | TIME | | | | MAX | IMUM AVI | ERAGE FLOW | 7 | | | | | | | | |
| | | | 1001 | | | 6-HR | | 24-HR | 72-HI | 3 | 23.80 |)-HR | | | | | | |
| Ţ | (013) | | 0.00 | (CFS) | | 5104 | | 1240 | 1240 | | 1. | 840 | | | | | | |
| + | 16329. | | 2.60 | (INCHES) | | 22.843 | 2 | 3.422 | 23.422 | 2 | 23 | .422 | | | | | | |
| | | | | (AC-FT) | | 2571. | | 2635. | 2636. | • | 21 | 0.00. | | | | | | |
| | | | | CUMULAT | IVE | AREA = | 2.1 | 1 SQ MI | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| * * | * *** * | ** *** | *** * | ** *** *** | **: | * *** ** | * *** | *** *** | *** *** | *** * | ** ** | * *** * | ** *** ** | * *** > | *** ** | ** *** | *** ** | * *** *** *** |
| *** | | | | | | | | | | | | | | | | | | |
| | | * + * | ***** | **** | | | | | | | | | | | | | | |
| | 39 KK | * | Di | *
AM * | RO | JTE FLOC | D HYDR | OGRAPHS | THRU FAD | #2 | | | | | | | | |
| | | *
* * * | ***** | * | | | | | | | | | | | | | | |
| | | | | STAR
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MM | S POOL I
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72.5 | VEL | | | | | | | | |
| | | | | STOP | P LO | G WIDTH | IS 4 F | T | | | | | | | | | | |
| | | | HYDROG | RAPH ROUTI | NG | DATA | | | | | | | | | | | | |
| | 43 RS | | STOR | AGE ROUTIN | IG | ч | NT THAT ANY | | DEACHES | | | | | | | | | |
| | | | | NSTPS
ITYP | | T
TLOW | TYPE O | F INITI | AL CONDIT | ĨON | | | | | | | | |
| | | | | RSVRIC
X | | 20.60
.00 W | INITIA
ORKING | L CONDI
R AND | TION
D COEFFIC | IENT | | | | | | | | |
| | 44 SA | | | AREA | 1 | 35.5 | 138.7 | 14 | 2.0 1 | 45.4 | 1 | 53.1 | 161.4 | 166 | .2 | 175.3 | 2 1 | 192.6 |
| | | | | | | | | | | | | | | | | | | |

| 45 SE | Ŧ | LEVATION | 960.00 | 962. | 00 964. | .00 | 966.00 | 970.00 | 974.00 | 976.00 | 980.00 | 986.00 |
|--|--|--|--|--|---|---|---|---|---|---|--|--|
| 46 SQ | Г | DISCHARGE | 0. | 1 | 5. 5 | ι3. | 25. | 38. | 53. | 69. | 300. | 661. |
| 1247. | | | 1776. | 229 | 9. 333 | 34. | 4362. | 5365. | 5865. | 6365. | | |
| 48 SE | E | LEVATION | 972.50 | 973. | 00 973 | .50 | 974.00 | 974.50 | 975.00 | 975.50 | 976.27 | 976.89 |
| 977.70 | | | 978.37 | 978. | 98 980 | .06 | 981.02 | 981.90 | 982.32 | 982.73 | | |
| 50 SS | ţ | SPILLWAY
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| 51 ST | : | FOP OF DAM
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. COEFFICI
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ENT
EAD | DAM | | | | | |
| | | | | | | | *** | | | | | |
| | | | | | COMPUT | ED STO | RAGE-ELEVA | TION DATA | | | | |
| | STORA | GE
ON 960 | .00 274.19 | 55
96 | 4.89 8 | 42.28
66.00 | 1439.21
970.00 | 2068.14
974.00 | 2395.73
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980.00 | 4181.44
986.00 | |
| | DESTREE | | | c | OMPUTED S | TORAGE | -OUTFLOW-E | LEVATION I | DATA | | | |
| | | | | | (INC | LUDING | FLOW OVER | DAM) | | | | |
| | STORA | GE | .00 274.19 | 55 | i4.89 8 | 42.28 | 1439.21 | 1828.40 | 1907.79 | 1987.70 | 2068.14 | 2149.14 |
| | OUTFL
ELEVATI | 0W
ON 960 | .00 .00
.00 962.00 | 96 | .00
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970.00 | 00.
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974.00 | 37.70
974.50 |
| | STORA | GE 2230 | .74 2312.93 | 239 | 5.73 24 | 40.69 | 2544.53 | 2681.49 | 2795.89 | 2900.93 | 3078.45 | 3088.97 |
| | OUTFL
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ON 975 | .70 69.20
.00 975.50 | 21
97 | .8.74 2
76.00 9 | 99.50
76.27 | 660.80
976.89 | 977.70 | 978.37 | 978.90 | 990.00 | 980.06 |
| | STORA
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OW 4362
ON 991 | .64 3416.47
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586
98 | 92.58 35
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| | | | | | | | | | | | | |
| **** | ******* | ***** | ******* | ***** | ******* | ***** | ********* | ******** | ********* | | | |
| | | | | | HYDRC | GRAPH | AT STATIO | n dam | | | | |
| | | | | | **** | ***** | | | | | | |
| ******* | * * * * * * * * * * * | ***** | ***** | ***** | | | ****** | ****** | ***** | ******** | ********* | *************** |
| *** | ****** | **** | ******* | ***** | | | ******* | ******* | *********** | ***** | ***** | ******** |
| DA MON | HRMN ORD | ***********
OUTFLOW | ****************
STORAGE STA | ******
*
.GE * I | or mon hrm | IN ORD | OUTFLOW | ************************************** | ************************************** | 4 MON HRMN | ORD OUTFI | LOW STORAGE |
| DA MON
STAGE | HRMAN ORD
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21. | ************************************** | ******
#
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| DA MON HRM | IN ORD | | ***********
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GE * I
*
•.8 * | DA MON HRM
1 080
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1966.
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2803.2 | ************************************** | 4 MON HRMN
1 1600
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82 2: | LOW STORAGE
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| DA MON
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OUTFLOW
21.
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GE * I
8 *
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1 080
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10 41
.2 42
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L 1600
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| DA MON
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2046.9 97:
2052.8 97:
2060.2 97:
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| 1 | 0336 | 19 | 5280. | 3403.1 | 981.8 * | 1 | 1136 | 59 | 563. | 2516.4 | 976.7 * | 1 | 1936 99 | 140. | 2351.9 |
|-----------------|--------|--------|---------|---------|---------|-------|---------|-------|--------|---------|---------|-------|------------|--------|--------|
| 975.7
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| 975.7
1 | 0436 | 24 | 5139. | 3380.8 | 981.7 × | 1 | 1236 | 64 | 427. | 2477.3 | 976.5 * | 1 | 2036 104 | 123. | 2342.7 |
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1 | 0448 | 25 | 4997. | 3358.4 | 981.6 * | 1 | 1248 | 65 | 405, | 2470.8 | 976.5 * | 1 | 2048 105 | 120. | 2341.1 |
| 975.7
1 | 0500 | 26 | 4845. | 3334.4 | 981.4 * | 1 | 1300 | 66 | 383. | 2464.6 | 976.4 * | 1 | 2100 106 | 117, | 2339.4 |
| 975.7
1 | 0512 | 27 | 4687. | 3309.5 | 981.3 * | 1 | 1312 | 67 | 363. | 2458.8 | 976.4 * | 1 | 2112 107 | 114. | 2337.9 |
| 975.7
1 | 0524 | 28 | 4527. | 3284.4 | 981.2 * | 1 | 1324 | 68 | 343. | 2453.3 | 976.3 * | l | 2124 108 | 112. | 2336,3 |
| 975.6 | 0536 | 29 | 4367. | 3259.4 | 981.0 * | 1 | 1336 | 69 | 325. | 2449.1 | 976.3 * | 1 | 2136 109 | 109. | 2334.8 |
| 975.6 | 0548 | 30 | 4220 | 3235 1 | 980.9 * | 1 | 1348 | 70 | 308. | 2443.2 | 976.3 × | 1 | 2148 110 | 106. | 2333.4 |
| 975.6 | 0540 | 31 | 4078 | 3231 4 | 980.8 * | 1 | 1400 | 71 | 296. | 2438.5 | 976.3 * | 1 | 2200 111 | 104. | 2332.0 |
| 975.6 | 0600 | 32 | 3020 | 3195 3 | 980 6 * | 1 | 1412 | 72 | 288. | 2434.0 | 976.2 * | 1 | 2212 112 | 101. | 2330.6 |
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975.6 | 0624 | 33 | 3720. | 3152.4 | 980.4 * | 1 | 1424 | 13 | 200. | 2425.7 | 370.2 | 1 | 2223 113 | 07 | 222310 |
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975.6 | 0636 | 34 | 3481. | 3113.1 | 980.2 * | 1 | 1436 | 74 | 272. | 2425.4 | 976.2 × | T | 2235 114 | 97. | 2320.0 |
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975.6 | 0648 | 35 | 3229. | 3069.8 | 980.0 * | 1 | 1448 | 75 | 265. | 2421.3 | 976.2 * | 1 | 2248 115 | 94. | 2326.8 |
| 1 | 0700 | 36 | 2986. | 3025.4 | 979.7 * | 1 | 1500 | 76 | 258. | 2417.3 | 976.1 * | 1 | 2300 116 | 92. | 2325.6 |
| 1 | 0712 | 37 | 2748. | 2982.1 | 979.4 * | 1 | 1512 | 77 | 251. | 2413.5 | 976.1 * | 1 | 2312 117 | 90. | 2324.4 |
| 975.0
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1 | 0748 | 40 | 2131. | 2867.0 | 978.8 * | 1 | 1548 | 80 | 231. | 2402.5 | 976.0 - | 1 | 2348 120 | 84. | 2321.1 |
| 975.5 | | | | | * | | | | | | * | | | | |
| * * * * * * * * | ****** | ****** | ******* | ******* | ****** | ***** | ***** | ***** | ****** | ******* | ****** | ***** | ********** | ****** | ***** |
| * * * | | | | | | | | | | | | | | | |

PEAK OUTFLOW IS 5409. AT TIME 4.00 HOURS

| PEAK FLOW | TIME | | c III | MAXIMUM AVEP | AGE FLOW | 23 8 0-H R |
|--------------------|--------------|---------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| + (CFS) | (HR) | (078) | 0-HK | 24 110 | 72 100 | 25,00 110 |
| ÷ 5409. | 4.00 | (INCHES)
(AC-FT) | 3785.
16.677
1877. | 1198.
20,947
2357. | 1198.
20.947
2357. | 1198.
20.947
2357. |
| PEAK STORAGE | TIME | | | MAXIMUM AVER | GE STORAGE | 07 66 IF |
| ሐ (ስር-ምግ) | (HR) | | 6-HR | 24-HR | /2-HR | 23.80-HK |
| 3423. | 4.00 | | 3153. | 2585. | 2585. | 2585. |
| PEAK STAGE | TIME | | | MAXIMUM AVER | AGE STAGE | |
| 10101 011100 | | | 6-HR | 24-HR | 72-HR | 23.80-HR |
| + (FEET)
981.94 | (HR)
4.00 | | 980.41 | 977.10 | 977.10 | 977.10 |
| | | CUMULATI | /E AREA = | 2.11 SQ MI | | |

1

RUNOFF SUMMARY FLOW IN CUBIC FEET PER SECOND TIME IN HOURS, AREA IN SQUARE MILES

| | | | PEAK | TIME OF | AVERAGE FL | OW FOR MAXIM | UM PERIOD | BASIN | MAXIMUM | TIME OF | |
|---------|---------------|---------|--------|---------|------------|--------------|-----------|-------|---------|-----------|--|
| ÷ | OPERATION | STATION | F.POM | PEAK | 6-HOUR | 24-HOUR | 72-HOUR | ANEA | STAGE | THA STROM | |
| + | HYDROGRAPH AT | WEST | 8174. | 2.80 | 2589. | 658. | 658. | 1.06 | | | |
| + | HYDROGRAPH AT | EAST | 6527. | 2.60 | 1767. | 447. | 447. | .75 | | | |
| + | HYDROGRAPH AT | LAKE | 3738. | 2.40 | 869. | 236. | 236. | .30 | | | |
| + | 3 COMBINED AT | IN | 16329. | 2,60 | 5184. | 1340. | 1340. | 2.11 | | | |
| <u></u> | ROUTED TO | DAM | 5409, | 4.00 | 3785. | 1198. | 1198, | 2.11 | | | |

4.00

981.94

SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION DAM (PEAKS SHOWN ARE FOR INTERNAL TIME STEP USED DURING BREACH FORMATION)

| PLAN | 1 | ELEVATION
STORAGE
OUTFLOW | INITIAL
973
20 | VALUE
.83
440.
21. | SPILLWAY CR
975.50
2313.
69. | est top | OF DAM
983.00
3617.
6695. | |
|------|--------------------|----------------------------------|------------------------------|-----------------------------|---------------------------------------|-------------------------------|------------------------------------|-----------------------------|
| | RATIO
OF
PMF | MAXIMUM
RESERVOIR
W.S.ELEV | MAXIMUM
DEFTH
OVER DAM | MAXIMUM
STORAGE
AC-FT | MAX IMUM
OUT FLOW
CFS | DURATION
OVER TOP
HOURS | TIME OF
MAX OUTFLOW
HOURS | TIME OF
FAILURE
HOURS |
| | I.00 | 981.94 | .00 | 3423. | 5409. | .00 | 4.00 | .00 |

*** NORMAL END OF HEC-1 ***

981,94 6 983.0 /

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i.

| 1 * * * * * * * * * * * * * * * * * * * | ! * * |
|---|-------|
| ******* | |
| ÷ | × |
| * FLOOD HYDROGRAPH PACKAGE (HEC-1) | * |
| * JUN 1998 | * |
| * VERSION 4.1 | * |
| * * | * |
| * RUN DATE 22SEP12 TIME 16:46:48 | * |
| * | * |
| * ************************************* | *** |
| **** | |

PMF, assume "U.S. ARMY CORPS OF ENGINEERS HYDROLOGIC ENGINEERING CENTER Service spillway "609 SECOND STREET is blocked, "916) 756-1104

- * HYDROLOGIC ENGINEERING CENTER

*

| х | Х | XXXXXXX | XX | XXX | | х |
|------|-----|---------|----|-----|-------|-----|
| Х | х | Х | х | Х | | XX |
| Х | х | Х | х | | | Х |
| XXXX | XXX | XXXX | х | | XXXXX | Х |
| х | Х | х | Х | | | Х |
| Х | Х | Х | х | Х | | х |
| Х | Х | XXXXXXX | XX | XXX | | XXX |

THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE. THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE, SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY, DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL LOSS RATE:GREEN AND AMPT INFILTRATION VINCHMARK WAVE, NEW FINITE DIFFERENCE ASCOUNTS. KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

| 1 | HEC-1 INPUT PAG | 3E 1 |
|--------------|---|------|
| LINE I | D1 | |
| *** FREE *** | | |
| 1 I | D CARDINAL FLY ASH DAM #2 | |
| 2 I | D THIRD RAISING - CREST OF 983 FT | |
| з І | D DESIGN FLOOD PMP, 6-HR | |
| 4 T | D FILE: FAD2-PMP-105FT-noPS | |
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5 T | | |
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| 7 1 | - 10 26 5 | |
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9 D | | |
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| 9 P | ~ 000 0EC 071 000 000 000 000 000 000 000 000 000 | |
| 10 P | 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | |
| II P | ι <u>Ι</u> ,υ | |
| 12 K | K WEST RUNOFF FROM FAD#1 WATERSHED | |
| 13 K | M RECLAIMED POND AND LANDFILL | |
| 14 P | A 1.06 . | |
| 15 I | s 0 75 | |
| 16 F | R 10 | |
| 1'7 F | W 1 | |
| 18 F | T 10 | |
| 19 U | D 0.52 | |
| 20 K | K FAST RINOFF FROM KAST WATERSHED | |
| 20 1 | | |
| 21 1 | | |
| 22 1 | A 0.75 | |
| 23 1 | | |
| 24 F | | |
| 25 E | | |
| 26 E | T IC | |
| 27 1 | D 0.34 | |
| 28 F | K LAKE INSTANTANEOUS RUNOFF FROM LAKE SURFACE | |
| 29 F | M LAKE ONLY | |
| 30 E | A C.30 | |
| 31 E | ۶° 20 | |
| 32 1 | S 0 100 | |
| 33 E | R 10 | |
| 34 F | M 1 | |
| 35 1 | | |
| 36 0 | D 0.1 | |
| 37 1 | V IN COMPTNE THEFORS FROM WEST AND FAST WATERSHEDS AND LAKE SUDFACT | |
| 20 1 | A | |
| 28 F | | |
| 39 F | K DAM ROUTE FLOOD HYDROGRAPHS THRU FAD#2 | |
| 40 F | M STARTING POOL IS MAXIMUM OPERATING LEVEL | |
| 41 F | M ASSUME PRINCIPAL SPILLWAY IS BLOCKED | |
| 42 F | S 1 FLOW 20.6 | |

| 22 30 12 30 0 0 2 20 0.04 1000 4 0 0.05 2.05 0.05< | | 43 S.
44 S | A 135.5
E 960 | 138.7
962 | 142.0
964 | 145.4
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|--|------------|---------------------------|-------------------|-----------------|---------------------|------------------|--------------|--------------|--------------|--------------|--------------|-----------|---------------------|
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| <pre>LINE II</pre> | 1 | 49 S | S 975.5 | | | HEC~1 | INPUT | | | | | | PAGE 2 |
| LING WILLING ALL DESCRIPTION AND AND AND AND AND AND AND AND AND AN | ÷ - | | р 1 | 2 | 2 | | 5 | 6 | 7 | g | 9 | 1.0 | |
| 1 DOUD ETRODUCTION THE ADDRESS OF TH | L.: | .AE 1 | L | | | | | | | | •••••••• | | |
| THONO HYDROTEADE EXCERCE (EEC-1) CON 1998 CON 1998 VEDICO 4.1 CON 1998 VEDICO 4.1 CON 2007 FILE (446.44 CON 1007 FILE (446 | | 50 S | T 983 | | | | | | | | | | |
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| JUN 1996 JUN 1996 VELATION 4.1 SOU SECOND CHEMICAN AND AND AND AND AND AND AND AND AND A | * FLOOD HT | DROGRAPH PACKA | .GE (HEC-1 |) * | | | | | | | * 0.5 | 5. ARMY C | ORPS OF ENGINEERS |
| VERTOR 4.1 * 00 BECOD STREET
OWIS, CALIFORNIA 55615
WIN DATE 225ED12 THE 16:46:48
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| LINE DATE: 2245212 THE 16:46:48
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| INN DATE 2238FP12 THE 16:46:49 CARDDUAL FLY AN DAY #2
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| CARDEDAL FUX AND DAM #2
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| CARDENNEL FLY AND DAM 42
THERD RAISING - CREET OF 99 ST FT
DEGION HOLDS - LONG
THERD RAISING - CREET OF 99 ST FT
DEGION HOLDS - LONG
FLY CONTROL VALIABLES
6 10 OUTPUT CONTROL VALIABLES
FLY INFORMATION DATA
IECOT 0 FLY CONTROL
(geold 0, HINGORATH HOLDS CALE
IT INFORMATION DATA
IECOT 1 0 STARTING DATE
IECOT 1 | * | | | * | | | | | | | * | | |
| CANDENAL FLY ASH DAM #2
THEND RAISING - CR83 OF 983 ST
ENGLAND MAD. DAM, 6-HR
FILS: FROM- WALLASS
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| CANODINL FLY ACH DAW 42
THISD BALADNE - COMBY 07 93 ST
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FILE: FAC2-RMFAC2
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| CANDIDAL FLY ASK DAM 42
THEND PAISING - CRUSH 0 - 913 ST
THEND PAISING - CRUSH 0 - 913
FILLE FD22-MR-JOSET-D078
FILLE FD23-MR-JOSET-D078
FILLE FD23-MR-JOSET-FD23
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FILLE FD23-MR-JOSET-FD23
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FEMT 1 PRINT 0 PENT CONFEGL
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17 HYDROGRAPH TIME DATA
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TOTAL TIME AC | | | CARDINAL | FLY ASH | DAM #2 | | | | | | | | |
| <pre>FILE: PROFILEME 1098T -noPS 5 10 OUTPUT CONTROL VARIABLES LIPOT 0 PLOT CONTROL LIPOT 1 0 PLOT CONTROL LIPOT 0 PLOT PLOT PLOT PLOT PLOT PLOT PLOT LIPOT 0 PLOT PLOT PLOT PLOT PLOT PLOT PLOT PLOT</pre> | | | DESIGN FI | SING - | CREST OF
PMP. 6- | 983 FT
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| IRNET I PELINT CONFIDENCE
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NQ 120 NUMBER OF FUNCEBARD ORDINATES
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PROFILITION DEPTH SUCKES
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14 BA
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12 KK WEST * RUNOFF FROM FAD#1 WATERSHED

RECLAIMED FOND AND LANDFILL
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14 BA SUBBASIN CHARACTERISTICS
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PRECIPITATION DATA
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| 1 | 1024 | 53 .00 | .00 | ,00 | ο. | * | 1 | 2224 | 113 | .00 | .00 | .00 | 0. |
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55 00 | .00 | .00 | 0. | * | 1 | 2236 | 114 | .00 | .00 | .00 | 0. |
| 1 | 1100 | 56 .00 | .00 | .00 | ŏ. | * | 1 | 2300 | 116 | .00 | .00 | .00 | ο. |
| 1 | 1112 | 57 .00 | .00 | .00 | 0. | * | 1 | 2312 | 117 | .00 | .00 | .00 | 0. |
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| 1 | 1148 | 60 .00 | .00 | .00 | с. | *
* | 1 | 2348 | 120 | .00 | .00 | .00 | Ο. |
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| TOTAL R | AINFALL = | 26.50, TC | TAL LOSS = | = 3.62, T | OTAL EXC | CESS = | 22.88 | | | | | | |
| PEAK FLOW | TIME | | 6-HR | MAX IMUM .
24-HR | AVERAGE | FLOW
72-HR | 23.00-AR | | | | | | |
| + (CFS) | (HR) | (CES) | | | | | | | | | | | |
| + 8174. | 2,80 | (010) | 2588. | 658. | | 658. | 658. | | | | | | |
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(AC-FT) | 22.704
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1294. | 22 | 2,881
1294, | 22.881
1294. | | | | | | |
| | | CUMULATI | VE AREA = | 1,06 SQ 1 | MI | | | | | | | | |
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| 22 BA | SUBE | ASIN CHARAC | TERISTICS | | | | | | | | | | |
| | | TAREA | .75 | SUBBASIN AR | EA | | | | | | | | |
| | PREC | CIPITATION I | ATA | | | | | | | | | | |
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| | DA MON | HRMN | ORD | RAIN | LOSS | EXCESS | COMP Q | * | DA MON | HRMN | ORD | RAIN | LOSS | EXCESS | COMP Q |
| | 1 | 0000 | 1 | .00 | .00 | .00 | ο. | * | 1 | 1200 | 61 | .00 | .00 | .00 | Ο. |
| | 1 | 0012 | 2 | .34 | .34 | .00 | 0. | * | 1. | 1212 | 62 | .00 | .00 | .00 | 0. |
| | 1 | 0024 | 3 | .37 | .37 | .00 | 0. | * | 1 | 1224 | 63 | .00 | .00 | .00 | 0. |
| | 1 | 0036 | 4 | .40 | ,38 | .01 | 5. | * | 1 | 1236 | 64 | 00. | .00 | .00 | U.
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| | 1 | 0112 | 7 | .56 | .31 | .25 | 280. | * | ī | 1312 | 67 | .00 | .00 | .00 | Ο. |
| | 1 | 0124 | 8 | .61 | .28 | .33 | 454. | * | 1 | 1324 | 68 | .00 | .00 | .00 | Ο. |
| | 1 | 0136 | 9 | .66 | .25 | .41 | 641. | × | 1 | 1336 | 69 | ,00 | .00 | .00 | 0. |
| | 1 | 0148 | 10 | .87 | .27 | .61 | 871. | * | 1 | 1348 | 70 | .00 | .00 | .00 | υ. |
| | 1 | 0200 | 12 | 1.32 | .31 | 3 41 | 1200. | * | 1 | 1412 | 72 | .00 | .00 | .00 | 0. |
| | 1 | 0212 | 13 | 3.97 | .31 | 3.67 | 4966. | * | 1 | 1424 | 73 | .00 | .00 | .00 | ο. |
| | 1 | 0236 | 14 | 2.52 | .13 | 2.39 | 6527, | * | 1 | 1436 | 74 | .00 | .00 | .00 | Ο. |
| | 1 | 0248 | 15 | 1.19 | .05 | 1.14 | 6074. | * | 1 | 1448 | 75 | .00 | .00 | .00 | 0. |
| | 1 | 0300 | 16 | .93 | .04 | .89 | 4601. | * | 1 | 1500 | 76 | .00 | .00 | .00 | 0. |
| | 1 | 0312 | 1.9 | .82 | .03 | .79 | 2611 | * | 1 | 1512 | 78 | .00 | .00 | .00 | 0. |
| | 1 | 0324 | 19 | . 69 | .02 | .67 | 2157. | * | 1 | 1536 | 79 | .00 | .00 | ,00 | ċ, |
| | 1 | 0348 | 20 | .64 | .02 | .62 | 1871. | * | 1 | 1549 | 80 | .00 | .00 | .00 | с. |
| | 1 | 0400 | 21 | .58 | .02 | .57 | 1670. | * | 1 | 1600 | 81 | .00 | .00 | .00 | с. |
| | 1 | 0412 | 22 | .53 | .01 | .52 | 1506. | * | 1 | 1612 | 82 | .00 | .00 | .00 | 0. |
| | 1 | 0424 | 23 | .50 | .01 | .49 | 1371. | * | 1 | 1624 | 83 | 00. | 00. | .00 | 0. |
| | 1 | 0448 | 25 | .46 | .01 | .44 | 1195. | * | 1 | 1648 | 85 | .00 | .00 | .00 | ο. |
| | 1 | 0500 | 26 | .43 | .01 | .42 | 1132. | * | 1 | 1700 | 86 | .00 | .00 | .00 | ο. |
| | 1 | 0512 | 27 | .41 | .01 | .40 | 1075. | × | 1 | 1712 | 87 | .00 | .00 | .00 | 0. |
| | 1 | 0524 | 28 | .40 | .01 | .39 | 1024. | * | 1 | 1724 | 88 | .00 | .00 | .00 | 0. |
| | 1 | 0536 | 29 | .39 | .01 | .38 | 981. | * | 1 | 1748 | 60
89 | .00 | .00 | .00 | 0. |
| | 1 | 0548 | 31 | .37 | .01 | .36 | 917. | * | 1 | 1800 | 91 | .00 | .00 | .00 | ŏ. |
| | ī | 0612 | 32 | .00 | .00 | .00 | 777. | * | 1 | 1812 | 92 | .00 | .00 | .00 | 0. |
| | 1 | 0624 | 33 | .00 | .00 | .00 | 469. | * | 1 | 1824 | 93 | .00 | .00 | .00 | Ο, |
| | 1 | 0636 | 34 | .00 | .00 | .00 | 222. | * | 1 | 1836 | 94 | .00 | .00 | ,00 | 0. |
| | 1 | 0648 | 35 | .00 | .00 | ,00 | 106. | * | 1 | 1848 | 95 | .00 | -00 | .00 | U.
G |
| | 1 | 0712 | 37 | .00 | .00 | .00 | 23. | * | 1 | 1912 | 97 | .00 | .00 | .00 | ö. |
| | 1 | 0724 | 38 | .00 | .00 | .00 | 10. | * | 1 | 1924 | 98 | .00 | .00 | .00 | ο. |
| | l | 0736 | 39 | .00 | .00 | .00 | 4. | * | 1 | 1936 | 99 | .00 | .00 | .00 | 0. |
| | 1 | 0748 | 4 C | .00 | .00 | .00 | 1. | * | 1 | 1948 | 100 | .00 | .00 | .00 | 0. |
| | 1 | 0800 | 41 | .00 | .00 | .00 | U.
0 | ,
, | 1 | 2000 | 101 | .00 | .00 | .00 | 0. |
| | 1. | 0812 | 42
/3 | .00 | .00 | .00 | U.
N | * | 1 | 2012 | 102 | .00 | .00 | .00 | o.
0 |
| | 1 | 0836 | 44 | .00 | .00 | .00 | ů. | * | 1 | 2036 | 104 | .00 | .00 | .00 | ō. |
| | 1 | 0848 | 45 | .00 | .00 | ,00 | с. | * | 1 | 2048 | 105 | .00 | .00 | .00 | 0. |
| | 1 | 0900 | 46 | .00 | .00 | .00 | С. | × | 1 | 2100 | 106 | .00 | .00 | .00 | 0. |
| | 1 | 0912 | 47 | .00 | .00 | .00 | 0. | * | 1 | 2112 | 107 | .00 | .00 | .00 | 0. |
| | 1 | 0924 | 48 | .00 | .00 | .00 | 0. | + | 1 | 2136 | 100 | .00 | .00 | .00 | 0. |
| | 1 | 0948 | 50 | .00 | .00 | .00 | 0. | * | 1 | 2148 | 110 | .00 | .00 | .00 | ů. |
| | 1 | 1000 | 51 | .00 | .00 | .00 | ο. | * | 1 | 2200 | 111 | .00 | .00 | .00 | C. |
| | 1 | 1012 | 52 | .00 | .00 | .00 | 0. | * | 1 | 2212 | 112 | .00 | .00 | .00 | 0. |
| | 1 | 1024 | 53 | .00 | .00 | .00 | o. | * | 1 | 2224 | 113 | .00 | .00 | .00 | 0. |
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C | * | 1 | 2236 | 115 | .00 | .00 | .00 | υ. |
| | 1 | 11040 | 56 | .00 | .00 | .00 | 0. | * | 1 | 2300 | 116 | .00 | .00 | .00 | 0. |
| | 1 | 1112 | 57 | .00 | .00 | .00 | Ο. | × | 1 | 2312 | 117 | .00 | .00 | .00 | 0. |
| | 1 | 1124 | 58 | .00 | .00 | .00 | 0. | * | 1 | 2324 | 118 | .00 | .00 | .00 | 0. |
| | 1 | 1136 | 59 | .00 | .00 | .00 | 0. | * | 1 | 2336 | 119 | .00 | .00 | .00 | 0. |
| | 1 | 1148 | 60 | .00 | .00 | .00 | υ. | * | 1 | 2348 | 120 | .00 | .00 | .00 | υ. |
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| | TOTAL RAD | INFALL • | = 2 | 6,50, TOI | AL LOSS | = 4.5 | 3, TOTAL E | XCESS = | 21.97 | | | | | | |
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R 2 | MUM AVERAG
4-HR | SE FLOW
72-HR | 23.80-HR | | | | | | |
| + | (CFS) | (HR) | | 1 | | | | | | | | | | | |
| т. | 6527 | 2 60 | | (CFS) | ראדו | | 447 | 667 | 447 | | | | | | |
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| | | | , | (AC-FT) | 876 | | 879. | 879, | 879. | | | | | | |

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| 20. | 1 | 0100 | 6 | 793. | * | 1 | 0700 | 36 | 311. | * | 1 | 1300 | 66 | 20. | * | 1 | 1900 | 96 |
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| 20. | 1 | 0124 | 8 | 1613. | * | 1 | 0724 | 38 | 114. | * | 1 | 1324 | 68 | 20. | * | 1 | 1924 | 98 |
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| 20. | 1 | 0148 | 10 | 2781, | * | 1 | 0748 | 40 | 49. | * | 1 | 1348 | 70 | 20. | * | 1 | 1948 | 100 |
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| 20. | 1 | 0212 | 12 | 8264. | * | 1 | 0812 | 42 | 29. | * | 1 | 1412 | 72 | 20. | * | 1 | 2012 | 102 |
| 20, | ī | 0224 | 13 | 13330 | * | 1 | 0824 | 43 | 25 | * | 1 | 1424 | 73 | 20. | * | 1 | 2024 | 103 |
| 20. | 1 | 0224 | 1.4 | 10000 | + | - | 0024 | | 22 | * | 1 | 1436 | 74 | 20 | * | - | 2036 | 104 |
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| 20. | 1 | 0248 | 15 | 15821. | * | 1 | 0848 | 45 | 20. | * | 1 | 1448 | 15 | 20. | | 1 | 2048 | 105 |
| 20. | 1 | 0300 | 16 | 13330. | * | 1 | 0900 | 46 | 20. | × | 1 | 1500 | 76 | 20, | * | 1 | 2100 | 105 |
| 20. | 1 | 0312 | 17 | 10536. | * | 1 | 0912 | 47 | 20. | * | 1 | 1512 | 77 | 20. | * | 1 | 2112 | 1.07 |
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| 20 | 1 | 0348 | 20 | 5909. | * | 1 | 0948 | 50 | 20. | * | 1 | 1548 | 80 | 20. | * | I | 2148 | 110 |
| 20. | 1 | 0400 | 21 | 5186. | * | 1 | 1000 | 51 | 20. | * | 1 | 1600 | 81 | 20. | * | 1 | 2200 | 111 |
| 20. | 1 | 0412 | 22 | 4621. | * | 1 | 1012 | 52 | 20. | * | 1 | 1612 | 82 | 20. | * | 1 | 2212 | 112 |
| 20. | 1 | 0424 | 23 | 4179. | × | l | 1024 | 53 | 20. | * | 1 | 1624 | 83 | 20. | * | 1 | 2224 | 113 |
| 20. | 1 | 0436 | 24 | 3839. | * | 1 | 1036 | 54 | 20. | * | 1 | 1636 | 84 | 20. | * | 1 | 2236 | 114 |
| 20. | 1 | 0448 | 25 | 3571. | * | 1 | 1048 | 55 | 20. | * | 1 | 1648 | 85 | 20. | * | 1 | 2248 | 115 |
| 20. | 1 | 0500 | 26 | 3350. | * | 1 | 1100 | 56 | 20. | * | 1 | 1700 | 86 | 20. | * | 1 | 2300 | 116 |
| 20. | 1 | 0512 | 27 | 3158. | * | 1 | 1112 | 57 | 20. | * | 1 | 1712 | 87 | 20. | × | 1 | 2312 | 117 |
| 20. | 1 | 0524 | 28 | 2996. | * | 1 | 1124 | 58 | 20. | ¥ | 1 | 1724 | 88 | 20. | * | 1 | 2324 | 118 |
| 20. | - | 0536 | 29 | 2863 | × | 1 | 1136 | 59 | 20. | * | 1 | 1736 | 89 | 20. | * | 1 | 2336 | 119 |
| 20. | 1 | 0548 | 30 | 2753 | * | 1 | 1148 | 60 | 20. | * | 1 | 1748 | 90 | 20. | * | 1 | 2349 | 120 |
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| 1 | 0348 | 20 | 6059. | 3576.2 | 982.8 * | 1 | 1148 | 60 | 572. | 2564.2 | 977.0 * | 1 | 1948 100 | 136. | 2399.4 |
|------------|--------|----|-------|--------|----------|---|------|-----|------|--------|---------|---|----------|------|--------|
| 976.C
1 | 0400 | 21 | 6005. | 3568.2 | 982.7 × | 1 | 1200 | 61 | 54C, | 2555.4 | 977.0 * | 1 | 2000 101 | 133. | 2397.5 |
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1 | 0412 | 22 | 5891. | 3551.0 | 982.6 * | 1 | 1212 | 62 | 509. | 2547.0 | 976.9 * | 1 | 2012 102 | 130. | 2395.7 |
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1 | ñ424 | 23 | 5736. | 3527.8 | 982.5 * | 1 | 1224 | 63 | 484. | 2539.1 | 976.9 * | 1 | 2024 103 | 127. | 2393.9 |
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1 | 0524 | 28 | 4788. | 3382.9 | 981.7 * | 1 | 1324 | 68 | 386. | 2505.C | 976.7 * | 1 | 2124 108 | 114. | 2385.6 |
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1 | 0536 | 29 | 4605. | 3353.9 | 981.6 * | 1 | 1336 | 69 | 369. | 2499.1 | 976.6 * | 1 | 2136 109 | 112. | 2384.1 |
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1 | 0548 | 30 | 4427. | 3325.8 | 981.4 * | 1 | 1348 | 70 | 353. | 2493.4 | 976.6 * | 1 | 2148 110 | 109. | 2382.6 |
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1 | 0600 | 31 | 4257 | 3298 9 | 981.2 * | 1 | 1400 | 71 | 337. | 2488.1 | 976.6 * | 1 | 2200 111 | 107. | 2381.1 |
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975.9 | 0624 | 33 | 3860. | 3234.7 | 980.9 * | 1 | 1424 | 73 | 308. | 2478.1 | 978.5 * | 7 | 2224 113 | 103. | 2318.3 |
| 1 | 0636 | 34 | 3616. | 3193.1 | 980.7 * | 1 | 1436 | 74 | 295. | 2473.4 | 976.5 * | 1 | 2236 114 | 101. | 2377.0 |
| 1 | 0648 | 35 | 3348. | 3147.7 | 980.4 * | 1 | 1448 | 75 | 282. | 2469.0 | 976.4 * | l | 2248 115 | 99. | 2375.7 |
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1 | 0724 | 38 | 2606. | 3014.5 | 979.6 * | 1 | 1524 | 78 | 247. | 2456.9 | 976.4 * | 1 | 2324 118 | 93. | 2371.9 |
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| | | | | | J. | | | | | | * | | | | |

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PEAK OUTFLOW IS 6059. AT TIME 3.80 HOURS

| PEAK FLOW | TIME | | 6_up | MAXIMUM AVER | AGE FLOW | 23 B0-HB |
|--------------------|--------------|---------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| + (CFS) | (HR) | (277) | 0-nK | 24-110 | 72 111 | 20,000 mit |
| + €059. | 3.80 | (INCHES)
(AC-FT) | 4139.
18.238
2052. | 1319.
23.055
2594. | 1319.
23.055
2594. | 1319.
23.055
2594. |
| PEAK STORAGE | TIME | | | MAXIMUM AVER | GE STORAGE | |
| | ((10)) | | 6-HR | 24-HR | 72-HR | 23.80-HR |
| + (AC-FT)
3576. | 3.80 | | 3268. | 2678. | 2678. | 2678. |
| PEAK STAGE | TIME | | | MAXIMUM AVE | RAGE STAGE | |
| | | | 6-HR | 24-HR | 72-HR | 23.80-MR |
| + (FEET)
982.78 | (HR)
3.80 | | 981.06 | 977.64 | 977.64 | 977.64 |
| | | CUMULATIV | /E AREA = | 2.11 SQ MI | | |

RUNOFF SUMMARY FLOW IN CUBIC FEET PER SECOND TIME IN HOURS, AREA IN SQUARE MILES

| | | | PEAK | TIME OF | AVERAGE | FLOW FOR MAX | IMUM PERIOD | BASIN | MAXIMUM | TIME OF |
|---|---------------|---------|------------|----------|-------------|--------------|-------------|-------|---------|-----------|
| + | OPERATION | STATION | FLOW | PEAK | 6-HOUR | 24-HOUR | 72-hour | ARLA | SINCE | MAA SIAGE |
| + | HYDROGRAPH AT | WEST | 8174. | 2.90 | 2588. | 658. | 658. | 1.06 | | |
| ÷ | HYDROGRAPH AT | EAST | 6527. | 2.60 | 1767. | 447. | 447. | .75 | | |
| + | HYDROGRAPH AT | LAKE | 3738. | 2.40 | 869. | 236. | 236. | .30 | | |
| ÷ | 3 COMBINED AT | IN | 16329. | 2.60 | 5184. | 1340. | 1340. | 2.11 | | |
| + | ROUTED TO | DAM | 6059. | 3.80 | 4139. | 1319. | 1319. | 2.11 | 982.78 | 3.80 |
| 1 | | | SUMMARY OF | DAM OVER | POPPING/BRE | ACH ANALYSIS | FOR STATION | DAM | | |

(PEAKS SHOWN ARE FOR INTERNAL TIME STEP USED DURING BREACH FORMATION)

| plan | 1 | ELEVATION
STORAGE
OUTFLOW | INITIAL
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21. | SPILLWAY CRE
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0. | ST TOP | OF DAM
983.00
3617.
6329. | |
|------|--------------------|----------------------------------|------------------------------|------------------------------|---------------------------------------|-------------------------------|------------------------------------|-----------------------------|
| | RATIO
OF
PMF | MAXIMUM
RESERVOIR
W.S.ELEV | MAXIMUM
DEPTH
OVER DAM | MAX IMUM
STORAGE
AC-FT | MAX IMUM
OUT FLOW
CFS | DURATION
OVER TOP
HOURS | TIME OF
MAX OUTFLOW
HOURS | TIME OF
FAILURE
HOURS |
| | 1.00 | 982.78 | .00 | 3576. | 6059. | .00 | 3.80 | .00 |

*** NORMAL END OF HEC-1 ***

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- * U.S. ARMY CORPS OF ENGINEERS
- * HYDROLOGIC ENGINEERING CENTER
- * 609 SECOND STREET
- * DAVIS, CALIFORNIA 95616
 - (916) 756-1104

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THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HECIGS, HECIDB, AND HECIKW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE. THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE, SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY, DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL LOSS RATE:GREEN AND AMPT INFILTRATION KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

| 1 | | HEC-1 INPUT PA | AGE 1 |
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| LINE | ID | 1 | |
| *** FREE *** | | | |
| 1 | ID | ARDINAL FLY ASH DAM #2 | |
| 2 | ID | HIRD RAISING - CREST OF 983 FT | |
| 3 | ID | ESIGN FLOOD 50 YR, 24-HR | |
| 4 | TD | TTE: FAD2-50YB | |
| 5 | тт | 49 0 0 100 | |
| 6 | то | | |
| -7 | PG | 10 4.51 | |
| 8 | PC | | |
| 9 | PC | 23 38 53 625 67 705 736 764 79 814 | |
| 10 | PC | .836 .856 .875 .8931 .9103 .9267 .9423 .9573 .9719 .9861 | |
| 11 | PC | 1.0 | |
| 12 | кк | WEST RUNOFF FROM FAD#1 WATERSHED | |
| | KM | ECLAIMED POND AND LANDEILI. | |
| 14 | BA | | |
| 15 | LS | 0 75 | |
| 16 | DD | | |
| 17 | E R. | 10 | |
| 17 | PW
DF | | |
| 10 | P1 | 10 | |
| 19 | 00 | 0.52 | |
| 20 | KK | EAST RUNOFF FROM EAST WATERSHED | |
| 21 | КM | OODS ONLY | |
| 22 | BA | 0.75 | |
| 23 | LS | 0 70 | |
| 24 | PR | 10 | |
| 25 | PW | 1 | |
| 26 | PT | 10 | |
| 27 | UD | 0.34 | |
| 28 | KK | LAKE INSTANTANEOUS RUNOFF FROM LAKE SURFACE | |
| 29 | KM. | AKE ONLY | |
| 30 | BA | 0.30 | |
| 31 | BF | 20 | |
| 32 | LS | C 100 | |
| 33 | PR | 10 | |
| 34 | PW | 1 | |
| 35 | PT | 10 | |
| 36 | UD | 0.1 | |
| 37 | KK | IN COMBINE INFLOWS FROM WEST AND EAST WATERSHEDS AND LAKE SURFACE | |
| 38 | HC | 3 | |
| 39 | KK | DAM ROUTE FLOOD HYDROGRAPHS THRU FAD#2 | |
| 40 | KM | TARTING POOL IS MAXIMUM OPERATING LEVEL | |
| 41 | KM | AXIMUM TOP OF STOP LOG IS 972.5 | |
| 42 | KM | TOP LOG WIDTH IS 4 FT | |

| | 43 RS
44 SA | 1
135.5 1 | FLOW 20.
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| | 5 | UBBASIN | RUN | OFF DATA | | | |

| 22 | BA | SUBBASIN CHARACTERISTICS | |
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| | | TAREA .75 | SUBBASIN AREA |
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PRECIPITATION DATA

| 26 | PT | TOTAL STORM STATIONS 10 |
|----|----|--|
| 0 | PW | WEIGHTS 1.00 |
| 24 | PR | RECORDING STATIONS 10 |
| 25 | PW | WEIGHTS 1.00 |
| 23 | LS | SCS LOSS RATE
STRTL .86 INITIAL ABSTRACTION
CRVNBR 70.00 CURVE NUMBER
RTIMP .00 PERCENT IMPERVIOUS AREA |
| 27 | סט | SCS DIMENSIONLESS UNITGRAPH
TLAG .34 LAG |

PRECIPITATION STATION DATA

| STATION | TOTAL | AVG. ANNUAL | WEIGHT |
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TEMPORAL DISTRIBUTIONS

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WARNING *** TIME INTERVAL IS GREATER THAN .29*LAG

UNIT HYDROGRAPH 5 END-OF-PERIOD ORDINATES 449. 126. 25. 5. 0.

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| 2 | 1248 | .00 | .00 | .00 | 0. * | 4 | 0448 | 97 .00 | 0.00 | .00 | 0. |
| 2 | 1336 4
1424 4 | 19 .00
19 .00 | .00 | .00 | U. *
D. * | 4 | 0624 | 98 .04
99 .01 | 00.00 | .00 | 0. |
| 2 | 1512 | .00 | .00 | .00 | C. * | 4 | 0712 1 | 0. 00 | c .00 | .00 | Ο. |
| ***** | **** | ******* | ***** | ***** | ***** | ******** | ****** | ******** | **** | ****** | * * * * * * * * * * * * * |
| *** | | | | | | | | | | | |
| TOTAL R | AINFALL = | 4.51, TOT | PAL LOSS - | 2.83, TOT | AL EXCESS = | 1.68 | | | | | |
| PEAK FLOW | TIME | | 6-HR | MAXIMUM AV
24-HR | ERAGE FLOW
72-HR | 79.20-HR | | | | | |
| + (CFS) | (HR) | (CFS) | | | | | | | | | |
| + 135. | 9.60 | | 80. | 34. | 11. | 10. | | | | | |
| | | (INCHES)
(AC-FT) | 37. | 67, | 67. | 67. | | | | | |
| | | CIMULATIN | VE AREA = | .75 SO MI | : | | | | | | |
| | | 0011011111 | | | | | | | | | |
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* LA | *
* | INSTANTANE | OUS RUNOFF FF | OM LAKE SUR | FACE | | | | | |
| 28 KK | * LA
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KE * :
* | INSTANTANE | OUS RUNOFF FF | OM LAKE SUR | FACE | | | | | |
| 28 KK | * LA
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LAKE (| INSTANTANE
ONLY | OUS RUNOFF FF | ROM LAKE SUR | FACE | | | | | |
| 28 KK | + LA
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31 BF | * LA
* LA
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33 PR 34 PW RECORDING STATIONS WEIGHTS

10 1.00

32 LS SCS LOSS RATE

| | STRTL .00 INITIAL ABSTRACTION
CRVNBR 100.00 CURVE NUMBER
RTIMP .00 PERCENT IMPERVIOUS AREA |
|-------|--|
| 36 UD | SCS DIMENSIONLESS UNITGRAPH
TLAG .10 LAG |
| | *** |

PRECIPITATION STATION DATA

| STATION | TOTAL | AVG. ANNUAL | WEIGHT |
|---------|-------|-------------|--------|
| 10 | 4.51 | .00 | 1.00 |

TEMPORAL DISTRIBUTIONS

| STATION | 10, WEIG | SHT = 1.0 | 00 | | | | | | |
|---------|----------|-----------|------|-----|-----|-----|-----|-----|-----|
| .01 | .01 | .01 | ,02 | .02 | .02 | .02 | .02 | .03 | .05 |
| .15 | .15 | .10 | ,05 | .03 | .03 | .03 | .03 | .02 | .02 |
| .02 | .02 | .02 | .02 | .02 | .02 | .01 | .01 | .01 | .01 |
| .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 00 | . 00 | .00 | . 00 | .00 | .00 | .00 | .00 | .00 | ,00 |
| .00 | . 00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| .00 | .00 | . 00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | |

WARNING *** TIME INTERVAL IS GREATER THAN .29*LAG

UNIT HYDROGRAPH 5 END-OF-PERIOD ORDINATES 180. 50. 10. 2. 0.

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HYDROGRAPH AT STATION LAKE

| | | | | | | | * | | | | | | | |
|--------|-------|-----|------|------|--------|--------|---|------|-----------|-----|------|------|--------|--------|
| DA MON | HRMN | ORD | RAIN | LOSS | EXCESS | COMP Q | * | da M | ION HRMAN | ORD | RAIN | LOSS | EXCESS | COMP Q |
| 1 | 0000 | 1 | .00 | .00 | .00 | 20. | * | 2 | 1600 | 51 | .00 | .00 | .00 | 20. |
| 1 | 0048 | 2 | .06 | .00 | .06 | 31. | * | 2 | 1648 | 52 | .00 | .00 | .00 | 20. |
| 1 | 0136 | 3 | .06 | .00 | .06 | 34. | * | 2 | 1736 | 53 | .00 | .00 | .00 | 20. |
| ī | 0224 | 4 | .07 | .00 | .07 | 36. | * | 2 | 1824 | 54 | .00 | .00 | .00 | 20. |
| ī | 0312 | 5 | . 08 | .00 | . 0 B | 38. | * | 2 | 1912 | 55 | .00 | .00 | .00 | 20. |
| 1 | 0400 | 6 | 09 | .00 | .09 | 40. | * | 2 | 2000 | 56 | .00 | .00 | .00 | 20. |
| 1 | 0448 | 7 | . 09 | .00 | .09 | 42. | * | 2 | 2048 | 57 | .00 | .00 | .00 | 20. |
| 1 | 0536 | ß | .10 | .00 | .10 | 44. | * | 2 | 2136 | 58 | .00 | .00 | .00 | 20. |
| 1 | 0624 | ů, | .11 | .00 | .11 | 47. | × | 2 | 2224 | 59 | .00 | .00 | .00 | 20. |
| 1 | 0712 | 10 | .15 | .00 | .15 | 54. | * | 2 | 2312 | 60 | .00 | .00 | .00 | 20. |
| 1 | 0800 | 11 | - 23 | .00 | .23 | 69. | * | 3 | 0000 | 61 | .00 | .00 | .00 | 20. |
| 1 | 0848 | 12 | . 63 | . 00 | . 68 | 155. | * | 3 | 0048 | 62 | .00 | .00 | .00 | 20. |
| 1 | 0936 | 13 | - 68 | .00 | . 68 | 178. | * | з | 0136 | 63 | .00 | .00 | ,00 | 20. |
| 1 | 1024 | 14 | . 43 | .00 | .43 | 138. | * | 3 | 0224 | 64 | .00 | .00 | .00 | 20. |
| 1 | 1112 | 15 | .20 | .00 | .20 | 86. | × | 3 | 0312 | 65 | .00 | .00 | .00 | 20. |
| î | 1200 | 16 | .16 | .00 | .16 | 64. | * | 3 | 0400 | 66 | .00 | .00 | .00 | 20. |
| 1 | 1248 | 17 | .14 | .00 | .14 | 56. | * | Э | 0448 | 67 | .00 | .00 | .00 | 20. |
| Ť | 1336 | 18 | .13 | .00 | .13 | 52. | * | 3 | 0536 | 68 | .00 | .00 | .00 | 20. |
| 1 | 1424 | 19 | .12 | .00 | .12 | 49. | * | 3 | 0624 | 69 | .00 | .00 | .00 | 20. |
| ī | 1512 | 20 | .11 | .00 | .11 | 47. | * | 3 | 0712 | 70 | .00 | .00 | .00 | 20. |
| 1 | 1600 | 21 | .10 | .00 | .10 | 45. | * | 3 | 0800 | 71 | .00 | .00 | .00 | 20. |
| 1 | 1648 | 22 | .09 | .00 | .09 | 43. | * | 3 | C848 | 72 | .00 | .00 | .00 | 20. |
| 1 | 17.36 | 23 | .09 | .00 | .09 | 41, | * | 3 | 0936 | 73 | .00 | .00 | .00 | 20. |
| î | 1824 | 24 | .08 | .00 | .08 | 40, | * | 3 | 1024 | 74 | .00 | .00 | .00 | 20. |
| 1 | 1912 | 25 | .08 | .00 | .08 | 39, | * | 3 | 1112 | 75 | .00 | .00 | .00 | 20. |
| 1 | 2000 | 26 | .07 | .00 | .07 | 38. | * | 3 | 1200 | 76 | .00 | .00 | .00 | 20. |
| 1 | 2048 | 27 | .07 | .00 | .07 | 37. | * | 3 | 1248 | 77 | .00 | .00 | .00 | 20. |
| 1 | 2136 | 28 | .07 | .00 | .07 | 37. | * | 3 | 1336 | 78 | .00 | .00 | .00 | 20. |
| 1 | 2224 | 29 | .07 | .00 | .07 | 36. | * | 3 | 1424 | 79 | .00 | .00 | .00 | 20. |
| 1 | 2312 | 30 | .06 | .00 | .06 | 36. | * | 3 | 1512 | 80 | .00 | ,00 | .00 | 20. |
| 2 | 0000 | 31 | .06 | .00 | ,06 | 35. | * | 3 | 1600 | 81 | .00 | .00 | .00 | 20. |
| 2 | 0048 | 32 | .00 | .00 | .00 | 24. | * | з | 1648 | 82 | .00 | .00 | .00 | 20. |
| 2 | 0136 | 33 | .00 | .00 | .00 | 21. | * | 3 | 1736 | 83 | .00 | .00 | .00 | 20. |
| 2 | 0224 | 34 | .00 | .00 | .00 | 20, | * | 3 | 1824 | 84 | .00 | .00 | .00 | 20. |
| 2 | 0312 | 35 | .00 | .00 | .00 | 20. | * | 3 | 1912 | 85 | .00 | .00 | .00 | 20. |
| 2 | 0400 | 36 | .00 | .00 | .00 | 20. | * | 3 | 2000 | 86 | .00 | .00 | .00 | 20. |
| 2 | C448 | 37 | .00 | .00 | .00 | 20. | * | 3 | 2048 | 87 | .00 | .00 | .00 | 20. |
| 2 | 0536 | 38 | .00 | ,00 | .00 | 20. | * | 3 | 2136 | 88 | .00 | .00 | .00 | 20. |
| 2 | 0624 | 39 | .00 | .00 | .00 | 20. | * | 3 | 2224 | 89 | .00 | .00 | .00 | 20. |
| 2 | 0712 | 40 | .00 | .00 | .00 | 20. | * | 3 | 2312 | 90 | .00 | .00 | .00 | 20. |
| 2 | 0800 | 41 | .00 | .00 | .00 | 20. | * | 4 | 0000 | 91 | .00 | .00 | .00 | 20. |
| 2 | 0848 | 42 | .00 | .00 | .00 | 20. | * | 4 | 0048 | 92 | .00 | .00 | .00 | 20. |
| 2 | 0936 | 43 | .00 | .00 | .00 | 20. | * | 4 | 0136 | 93 | .00 | .00 | .00 | 20. |
| 2 | 1024 | 44 | .00 | .00 | .00 | 20. | * | 4 | 0224 | 94 | .00 | .00 | .00 | 20. |
| 2 | 1112 | 45 | ,00 | .00 | .00 | 20. | * | 4 | 0312 | 95 | .00 | ,00 | .00 | 20. |
| 2 | 1200 | 46 | .00 | .00 | .00 | 20. | * | 4 | 0400 | 96 | .00 | .00 | .00 | 20. |
| 2 | 1248 | 47 | .00 | ,00 | .00 | 20. | * | 4 | 0448 | 97 | .00 | .00 | .00 | 20. |
| 2 | 1336 | 48 | .00 | .00 | .00 | 20. | * | 4 | 0536 | 98 | ,00 | .00 | .00 | 20. |
| 2 | 1424 | 49 | .00 | .00 | .00 | 20. | * | 4 | 0624 | 99 | .00 | .00 | .00 | 20. |

× 0712 100 20. 1512 50 .00 .00 .00 20. 4 .00 .00 .00 2 *** 4.51, TOTAL LOSS = .CO, TOTAL EXCESS = 4.51 TOTAL BAINFALL = PEAK FLOW TTME. MAXIMUM AVERAGE FLOW 6-HR 79.20-HR 72-HR 24-HR (CFS) (HR) ÷ (CFS) 178. 9.60 107. 56. 32 31. 6.956 11.948 12.692 (INCHES) 3.091 (AC~FT) 49. 111. 191. 203. CUMULATIVE AREA = .30 SQ MI *** * * * ****** IN * COMBINE INFLOWS FROM WEST AND EAST WATERSHEDS AND LAKE SURFACE 37 KK *********** 38 HC HYDROGRAPH COMBINATION " . NUMBER OF HYDROGRAPHS TO COMBINE TCOMP *** ***** *** HYDROGRAPH AT STATION IN SUM OF 3 HYDROGRAPHS + + + DA MON HEMN ORD FLOW DA MON HRMN ORD FLOW * DA MON HRMN ORD FT OW * DA MON HRMAN ORD × FT ON 1200 76 3 0000 1 20. 1 2000 26 118. * 2 1600 51 20. 1 20. 77 1248 1 0048 2 31. * 1 2048 27 114. * 2 1648 52 20. 3 20. 28 111. * 2 1736 53 20. × З 1336 7.9 0136 3 34. * 1 2136 1 20, 2224 29 108. * 2 1824 54 20. З 1424 79 1 0224 4 36. × 1 20. 1512 80 * 106. × 2 1912 55 20. ÷ 3 38. 1 2312 30 0312 1 5 20. 1600 0000 105. 2 2000 56 20. ÷ З 81 1 0400 6 40. 2 31 20. . 82 2 57 з 1648 2 46. 2048 20. 1 0448 $\overline{7}$ 42 × 0048 32 20. 83 * 2 3 1736 1 0536 8 44. * 2 0136 33 26. 2136 58 20. 20. + 84 1 0624 9 47. * 2 0224 34 21. 2 2224 59 20. З 1824 20. 2 0312 35 20. × 2 2312 60 20. * 3 1912 85 10 57. * 1 0712 20. × 2 C400 36 20. * 3 0000 61 20, * 3 2000 86 91. l 0800 11 20. * ÷ 2048 87 * 20. 3 0048 62 20. 3 339. 2 0446 37 1 0848 12 20. 2 20. * З 0136 63 20. * з 2136 88 547. * 0536 38 1 0936 13 20. * . 2 20. З б4 20. 3 2224 89 1 1024 14 502. × 0624 39 0224 20. π * 3 2312 90 1112 15 324. * 2 0712 40 20. 3 0312 65 20. 1 20. ÷ 91 234. * 2 0800 41 20. 3 0400 66 20. × 4 0000 1 1200 16 20. 1248 17 197. * 2 0848 42 20. * 3 0448 67 20. × 4 0048 92 1 20, * 0536 68 20. * 4 0136 93 ÷ 2 0936 43 20. 3 178. 1 1336 18

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138. * 2

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95

96

97

| | 1 | 1736 | 23 | 132. | * | 2 | 1336 | 48 | 20. | * | 3 | 0936 | 73 | 20. | * | 4 | 0536 | 98 | |
|-------------|-------|--------|--------|--------|------|-------|--------|-------|---------|------|-------|-------|--------|--------|------|-------|--------|--------|-------|
| 20. | 1 | 1824 | 24 | 127. | × | 2 | 1424 | 49 | 20. | ÷ | 3 | 1024 | 74 | 20. | * | 4 | 0624 | 99 | |
| 20. | 1 | 1912 | 25 | 122. | * | 2 | 1512 | 50 | 20. | * | 3 | 1112 | 75 | 20. | * | 4 | 0712 | 100 | |
| 20. | | | | | * | | | | | × | | | | | * | | | | |
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*** | ***** | ****** | ****** | ****** | **** | ***** | ****** | ***** | ******* | **** | ***** | ***** | ****** | ****** | **** | ***** | ****** | ****** | ***** |

| | PEAK FLOW | TIME | | | MAXIMUM AVERJ | AGE FLOW | |
|---|-----------|------|-----------|----------|---------------|----------|----------|
| | | | | 6-HR | 24-HR | 72-HR | 79,2C∽HR |
| ÷ | (CFS) | (BR) | | | | | |
| | | | (CFS) | | | | |
| + | 547. | 9,60 | | 325. | 148. | 63. | 59. |
| | | | (INCHES) | 1.339 | 2.612 | 3.330 | 3.436 |
| | | | (AC-FT) | 151. | 294. | 375. | 387. |
| | | | CUMULATIV | E AREA = | 2.11 SQ MI | | |

| | **** | ***** | * * | |
|-------|------|---------------|-----|--|
| | × | | × | |
| 39 KK | * | DAM | * | ROUTE FLOOD HYDROGRAPHS THRU FAD#2 |
| | * | | * | |
| | **** | * * * * * * * | * * | |
| | | | | STARTING POOL IS MAXIMUM OPERATING LEVEL |
| | | | 3 | MAXIMUM TOP OF STOP LOG IS 972.5 |
| | | | | STOP LOG WIDTH IS 4 FT |

HYDROGRAPH ROUTING DATA

| 43 RS | STOP | RAGE ROUTIN
NSTPS
ITYP
RSVRIC
X | G
FLOW
20.60
.00 | NUMBER 05
TYPE OF I
INITIAL C
WORKING R | SUBREACHE
NITIAL CON
CONDITION
AND D COEF | 5
DITION
FICIENT | | | | | |
|-------|---------------------------------|---|---|--|--|-----------------------------|--------------------------|---------------------------|----------------------------|----------------------------|----------------------------|
| 44 SA | | AREA | 135.5 | 138.7 | 142.0 | 145.4 | 153.1 | 161.4 | 166.2 | 175.2 | 192.6 |
| 45 SE | ELE | ATION | 960.00 | 962.00 | 964.00 | 966.00 | 970.00 | 974.00 | 976.00 | 980.00 | 986.00 |
| 46 SQ | DISC | CHARGE | ο. | 5. | 13. | 25. | 38. | 53. | 69. | | |
| 47 SE | ELE | ATION | 972.50 | 973.00 | 973.50 | 974.00 | 974.50 | 975.00 | 975.50 | | |
| 48 SS | SPI | 975.50
,00
,00
1,50 | SPILLWAY
SPILLWAY
WEIR COE)
EXPONENT | CREST ELEV
WIDTH
FFICIENT
OF HEAD | ATION | | | | | | |
| 49 ST | TOP | OF DAM
TOPEL
DAMWID
COQD
EXPD | 983.00
.00
.00
.00 | ELEVATIO
DAM WIDT
WEIR COE
EXPONENT | N AT TOP OB
H
FFICIENT
OF HEAD | f DAM | | | | | |
| | | | | | | * * * | | | | | |
| | | | | C | MPUTED STO | RAGE-ELEVA | ATAC NOITA | | | | |
| | STORAGE
ELEVATION | .00
960.00 | 274.19
962.00 | 554.89
964.00 | 842.28
966.00 | 1439.21
970.00 | 2068.14
974.00 | 2395.73
976.00 | 3078.45
980.00 | 4181.44
986.00 | |
| | | | | COMPU | IED STORAGE | E-OUTFLOW-H | LEVATION I | ATA | | | |
| | | | | | (INCLUDING | G FLOW OVER | R DAM) | | | | |
| | STORAGE
OUTFLOW
ELEVATION | 00.
00.
960.00 | 274.19
.00
962.00 | 554.89
.00
964.00 | 842.28
.00
966.00 | 1439,21
.00
970.00 | 1828.40
.00
972.50 | 1907.79
4.70
973.00 | 1987.70
13.30
973.50 | 2068.14
24.50
974.00 | 2149.14
37.70
974.50 |
| | STORAGE
OUTFLOW
ELEVATION | 2230.74
52.70
975.00 | 2312.93
69.20
975.50 | 2395.73
85.70
976.00 | 3078.45
217.70
980.00 | 4181.44
415.70
986.00 | | | | | |
| **** | ****** | ******* | ******* | ***** | * * * * * * * * * * * | ***** | * * * * * * * * * * * * | ********* | * * * * * * * * * * | ******* | ***** |
| | | | | | HYDROGRAPH | AT STATIO | n dam | | | | |
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| DA MON
STAGE | HRMN | ORÐ | OUTFLOW | STORAGE | STAGE * | DA MON | HRMN (| JRD | OUTFLOW | STORAGE | STAGE * | DA MON | HRMN (| ORD | OUTFLOW | STORAGE | |
|--------------------------|-------|--------|---------|---------|--------------|--------|--------|------|----------|---------|--------------|--------|--------|------|---------|---------|---|
| 1 | 0000 | 1 | 21 | 2040-1 | *
973.8 * | 2 | 0312 | 35 | 57. | 2249.9 | *
975.1 * | 3 | 0624 | 69 | 44. | 2183.3 | |
| 974.7 | 0069 | 2 | 21 | 2040 4 | 0738* | 2 | 0400 | 36 | 56 | 2247 6 | 975 1 × | ٦ | 0712 | 70 | 44. | 2381.8 | |
| 974.7 | 0126 | 2 | 21. | 2040.4 | 072 0 * | 2 | 0449 | 37 | 56 | 2245.2 | 975 1 * | 3 | 0800 | 71 | 43 | 2180 2 | |
| 974.7 | 0100 | د
• | £4. | 2041.1 | 973.0 | 2 | 0500 | 50 | 50. | 2213.2 | 075 1 + | ~ | 0000 | 75 | 40. | 2170 7 | |
| 974.7 | 0224 | 4 | 21. | 2042.1 | 973.8 * | 2 | 0536 | 36 | 55. | 2242.9 | 9/5.1 * | 2 | 0040 | 72 | 43. | 21/0./ | |
| 1
974.7 | 0312 | 5 | 21. | 2043.1 | 973.8 × | 2 | 0624 | 39 | | 2240.6 | 975.1 * | 3 | 0936 | 73 | 42. | 2177.2 | |
| 1
974.7 | 0400 | 6 | 21. | 2044.3 | 973.9 * | 2 | 0712 | 40 | 54. | 2238.3 | 975.0 * | 3 | 1024 | 74 | 43. | 2175.7 | |
| 1
974.7 | 0448 | 7 | 21. | 2045.6 | 973,9 * | 2 | 0800 | 41 | 54. | 2236.1 | 975.0 * | 3 | 1112 | 75 | 42. | 2174.2 | |
| 1
974.6 | 0536 | 8 | 22. | 2047.1 | 973.9 * | 2 | C848 | 42 | 53. | 2233.8 | 975.0 * | 3 | 1200 | 76 | 42. | 2172.7 | |
| 1
974.6 | 0624 | 9 | 22. | 2048.6 | 973.9 * | 2 | 0936 | 43 | 53. | 2231,7 | 975.0 * | 3 | 1248 | 77 | 42. | 2171.3 | |
| 1 974 6 | 0712 | 10 | 22. | 2050,6 | 973.9 * | 2 | 1024 | 44 | 52. | 2229.5 | 975.0 * | 3 | 1336 | 78 | 42. | 2169.9 | |
| 1 | 0800 | 11 | 23. | 2054.0 | 973.9 * | 2 | 1112 | 45 | 52. | 2227.4 | 975.0 * | 3 | 1424 | 79 | 41. | 2168.5 | |
| 1 | 0848 | 12 | 24. | 2066.6 | 974.0 * | 2 | 1200 | 46 | 52. | 2225.3 | 975.0 * | З | 1512 | 80 | 41. | 2167.1 | |
| 1 | 0936 | 13 | 29. | 2094.1 | 974.2 * | 2 | 1248 | 47 | 51. | 2223.2 | 975.0 * | 3 | 1600 | 81 | 41, | 2165.7 | |
| 1 | 1024 | 14 | 34. | 2126.6 | 974.4 * | 2 | 1336 | 48 | 51. | 2221.2 | 974.9 - | 3 | 1648 | 82 | 41. | 2164.3 | |
| 974.0 | 1112 | 1,5 | 38. | 2151.5 | 974.5 * | 2 | 1424 | 49 | 51. | 2219.1 | 974.9 * | З | 1736 | 83 | 40. | 2163.0 | |
| 9/4.6
1 | 1200 | 16 | 41. | 2167.3 | 974.6 * | 2 | 1512 | 50 | 50. | 2217,1 | 974.9 * | 3 | 1824 | 84 | 40. | 2161.7 | |
| 974.6
1 | 1248 | 17 | 43, | 2178.7 | 974.7 * | 2 | 1600 | 51 | 50. | 2215.2 | 974.9 * | 3 | 1912 | 85 | 40. | 2160.4 | |
| 974.6
I | 1336 | 18 | 45. | 2188.2 | 974.7 * | 2 | 1648 | 52 | 49. | 2213.2 | 974.9 * | З | 2000 | 86 | 40. | 2159.1 | |
| 974.6
1 | 1424 | 19 | 46. | 2196.5 | 974.8 * | 2 | 1736 | 53 | 49. | 2211.3 | 974.9 * | 3 | 2048 | 87 | 39. | 2157.8 | |
| 974.6
1 | 1512 | 20 | 48. | 2204.1 | 974.8 * | 2 | 1824 | 54 | 49. | 2209.4 | 974.9 * | 3 | 2136 | 88 | 39, | 2156.5 | |
| 974.5
1 | 1600 | 21. | 49. | 2211.0 | 974.9 * | 2 | 1912 | 55 | 48. | 2207.5 | 974.9 * | 3 | 2224 | 89 | 39. | 2155.3 | |
| 974.5
1 | 1648 | 22 | 50. | 2217.2 | 974.9 * | 2 | 2000 | 56 | 48. | 2205.6 | 974.8 * | з | 2312 | 90 | 39. | 2154.0 | |
| 974.5
1 | 1736 | 23 | 51. | 2222.7 | 975.0 * | 2 | 2048 | 57 | 48. | 2203.8 | 974.8 * | 4 | 0000 | 91 | 38. | 2152.8 | |
| 974.5
1 | 1824 | 24 | 52. | 2227.8 | 975.0 × | 2 | 2136 | 58 | 47. | 2202.0 | 974.8 * | 4 | 0048 | 92 | 38. | 2151.6 | |
| 974.5
1 | 1912 | 25 | 53. | 2232,5 | 975.0 * | 2 | 2224 | 59 | 47. | 2200.2 | 974.8 * | 4 | 0136 | 93 | 38. | 2150.4 | |
| 974.5
1 | 2000 | 26 | 54. | 2236.9 | 975.0 * | 2 | 2312 | 60 | 47. | 2198.4 | 974.8 * | ٤ | 0224 | 94 | 39. | 2149.3 | |
| 974.5
1 | 2048 | 27 | 55. | 2241.0 | 975.1 * | 3 | 0000 | 61 | 46. | 2196.6 | 974.6 * | 4 | 0312 | 95 | 38. | 2148.1 | |
| 974.5
1 | 2136 | 28 | 56. | 2244.8 | 975.1 * | 3 | 0048 | 62 | 46. | 2194.9 | 974.8 * | 4 | C400 | 96 | 37. | 2146.9 | |
| 974.5
1 | 2224 | 29 | 56. | 2248.3 | 975.1 * | 3 | 0136 | 63 | 46. | 2193.2 | 974.8 * | 4 | 0448 | 97 | 37. | 2145.8 | |
| 974.5
1 | 2312 | 30 | 57. | 2251.6 | 975.1 × | 3 | 0224 | 64 | 46. | 2191.5 | 974.8 * | 4 | 0536 | 98 | 37. | 2144.7 | |
| 974.5
2 | 0000 | 31 | 58. | 2254,8 | 975.1 * | 3 | 0312 | 65 | 45. | 2189.8 | 974.7 * | 4 | 0624 | 99 | 37. | 2143.6 | |
| 974.5
2 | 0048 | 32 | 58. | 2256.0 | 975.2 * | 3 | 0400 | 66 | 45. | 2188.2 | 974.7 × | 4 | 0712 | 100 | 37. | 2142.5 | |
| 974.5
2 | 0136 | 33 | 57 | 2254.5 | 975.1 * | 3 | C448 | 67 | 45. | 2186.5 | 974.7 * | | | | | | |
| 2 | 0224 | 34 | 57. | 2252.3 | 975.1 * | 3 | 0536 | 68 | 44. | 2184.9 | 974.7 *
* | | | | | | |
| * * * * * * * *
* * * | ***** | **** | ******* | ****** | ******* | ****** | ***** | **** | ******** | ****** | ***** | ***** | ***** | **** | ****** | ***** | k |

PEAK OUTFLOW IS 58. AT TIME 24.80 HOURS

| | PEAK FLOW | TIME | | 6→HB | MAXIMUM AVEF | AGE FLOW | 79.20-HR |
|---|--------------|-------|----------|--------|---------------|------------|----------|
| ÷ | (CFS) | (HR) | | | | | |
| | | | (CFS) | | | | |
| ÷ | 58. | 24.80 | | 57. | 54. | 46. | 43. |
| | | | (INCHES) | .235 | ,949 | 2.412 | 2.524 |
| | | | (AC-FT) | 26, | 107. | 271. | 284. |
| J | PEAK STORAGE | TIME | | | MAXIMUM AVERA | GE STORAGE | |
| | | | | 6-HR | 24-HR | 72-HR | 79.20-HR |
| + | (AC+FT) | (HR) | | | | | |
| | 2256. | 24,8C | | 2252. | 2236. | 2191. | 2178. |
| | | | | | | | |
| | PEAK STAGE | TIME | | | MAXIMUM AVEF | AGE STAGE | |
| | | | | 6-HR | 24-HR | 72-HR | 79.20-HR |
| ÷ | (FEET) | (HR) | | | | | |
| | 975.15 | 24.80 | | 975.13 | 975.03 | 974.76 | 974.68 |

CUMULATIVE AREA = 2.11 SQ MI

RUNOFF SUMMARY FLOW IN CUBIC FEET PER SECOND TIME IN HOURS, AREA IN SQUARE MILES

| | | 0.000 | PEAK | TIME OF | AVERAGE F | LOW FOR MAXIM | BASIN | MAXIMUM | TIME OF | |
|---|---|---------|------|---------|-----------|---------------|---------|---------|---------|-----------|
| ÷ | OPERATION | STATION | FLOW | PEAK | 6-HOUR | 24-HOUR | 72-HOUR | ANLA | SINGE | MAA SINGA |
| + | HYDROGRAPH AT | WEST | 235. | 9.60 | 142. | 59. | 20. | 1.06 | | |
| + | HYDROGRAPH AT | EAST | 135. | 9.60 | 80. | 34. | 11. | .75 | | |
| + | HYDROGRAPH AT | LAKE | 178. | 9,60 | 107. | 56. | 32, | .30 | | |
| ÷ | 3 COMBINED AT | IN | 547. | 9.60 | 325. | 148. | 63. | 2.11 | | |
| + | ROUTED TO | DAM | 58. | 24.80 | 57. | 54. | 46. | 2.11 | 975.15 | 24.80 |
| 1 | SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION DAM
(PEAKS SHOWN ARE FOR INTERNAL TIME STEP USED DURING BREACH FORMATION) | | | | | | | | | |

| PLAN | 1 | ELEVATION
STORAGE
OUTFLOW | INITIAI
973
20 | VALUE
.83
40.
21. | SPILLWAY CRE
975.50
2313.
69. | ST TOP | OF DAM
983.00
3617.
317. | | |
|------|--------------------|----------------------------------|------------------------------|-----------------------------|--|-------------------------------|-----------------------------------|-----------------------------|--|
| | RATIO
OF
PMF | MAXIMUM
RESERVOIR
W.S.ELEV | MAXIMUM
DEPTH
OVER DAM | MAXIMUM
STORAGE
AC-FT | MAXIMUM
OUTFLOW
CFS | DURATION
OVER TOP
HOURS | TIME OF
MAX OUTFLOW
HOURS | TIME OF
FAILURE
HOURS | |
| | 1.00 | 975,15 | .00 | 2256. | 58. | .00 | 24.80 | .00 | |

*** NORMAL END OF HEC-1 ***

975,15 6 975.5 V