2.6 Kalihiwai Reservoir (KA-0024)

The SLRA workshop for Kalihiwai Reservoir was performed on March 22, 2023. The workshop included representatives from AECOM, DLNR, Kalihiwai Ridge Community Association (KRCA), and Porter Irrigation, comprised of experienced dam safety engineers with technical expertise in the geotechnical and general dam safety disciplines. Table 2-10 lists the participants in the SLRA workshop, which are referred to hereafter as the Team.

Table 2-10 – Kalihiwai Reservoir SLRA Participants (Team)

Name	Organization	Role
Jennifer Williams, PE	AECOM	Facilitator / Recorder / Geotechnical Subject Matter Expert
Christina Bennetts, PE	AECOM	Participant / Recorder / Geotechnical Subject Matter Expert
Noah Wong, PE	AECOM	Participant / Recorder / Civil Engineer
Gina Belleau, PE	DLNR	Participant / Dam Safety Engineer
Kristen Akamine	DLNR	Participant / Dam Safety Engineer
Tony Semedo	KRCA	Participant / Dam Owner's Representative
Elizabeth Letcher	KRCA	Participant / Dam Owner's Representative
Samuel Jones	KRCA	Participant / Dam Owner's Representative
John Donatani	KRCA	Participant / Dam Owner's Representative
Tripp McCallister	Porter Irrigation	Participant / Dam Operator's Representative

The Team identified and evaluated nine credible, risk-driving PFMs and screened several others from further evaluation. The SLRA results, including the failure likelihood category, consequence level, confidence rating, and total risk score for the evaluated PFMs are summarized in Table 2-11. The SLRA workbook detailing the results is provided in Appendix A-5. This workbook also provides a summary of the screened PFMs.

Of the nine evaluated PFMs, the Team judged one PFM to have a Remote failure likelihood (APF less than 10^{-6}) and eight PFMs to have a Low failure likelihood (APF of 10^{-5} to 10^{-6}). Four PFMs were associated with the normal loading condition, four PFMs were associated with the hydrologic loading condition, and one PFM was associated with the seismic loading condition. Overall, the confidence rating in the assigned failure likelihoods was Medium with one PFM having Poor confidence and one PFM having Strong confidence as there were several significant data gaps, which are summarized in Table 2-11. However, it is uncertain whether the data gaps would change the assigned failure likelihoods. No drawings were available, but a topographic survey of the dam site was available. Technical analyses were also available for review and used by the Team for evaluating PFMs. Available documents included the following:

- Phase I Visual Inspection Report, Kalihiwai Reservoir (Kleinfelder 2009)
- Individual Hazard Assessment Report, Kalihiwai Reservoir (Pacific Disaster Center 2016)
- Seepage and Slope Stability Analysis, Kalihiwai Dam and Reservoir (Meta Engineering 2017)
- 2019 Topographic Survey (Esaki Surveying and Mapping, Inc.)
- Kalihiwai Dam and Reservoir – Hydrologic and Hydraulic Analysis Technical Memorandum, (Gannett Fleming 2020)
- Draft Final Design Report, Kalihiwai Dam (Gannett Fleming 2021)
- Kalihiwai Dam Removal Final Design Report (Gannett Fleming 2022)
- Seismic Hazard Assessment, Kalihwai Reservoir (Gannett Fleming 2022)
- Phase I Inspection Report, Kalihwai Reservoir (AECOM 2023)

PAR was estimated as part of a 2016 individual hazard assessment based on census data within the floodplain. The hazard assessment modeled a reservoir storage volume of 428 acre-feet, which is significantly greater than the recently updated maximum reservoir storage volume of 242 acre-feet with a pool level at the dam crest (Gannett Fleming 2021). Therefore, the modeled inundation limits are considered significantly conservative, even for the hydrologic loading PFMs. The hazard assessment provided flood wave travel times and maximum flood depths and velocities and estimated a total PAR of 1. Upon review, there appeared to be a couple parcels in the inundation zone about 2 kilometers downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1 to 2 meters and 2 to 3 meters per second, respectively. The Team discussed that the inundation zone is not an area of heavy recreation use, so additional transient population that could increase the PAR is unlikely.

The Team also reviewed an additional *Dam Failure Inundation – Flow Simulation Study* performed in 2006 and considered two dam breach scenarios: a normal pool level breach and a dam crest pool level breach modeling 120 and 250 acre-feet, respectively. These release volumes are more consistent with the estimated reservoir storage capacity under a normal pool condition and for a pool level at the dam crest. There were no structures in the inundation zone for the normal pool level breach scenario and there were two structures in the inundation zone for the dam crest pool level breach scenario. The Team discussed the additional structure located in the zone identified in this 2006 study, and it was estimated that the structure is elevated 8 to 10 feet above the ground surface, so the flood severity would not be large at the location of the structure. Based on the two inundation studies available, a PAR of 1 was deemed reasonable by the Team, albeit uncertain.

The Team discussed the ability to warn and evacuate the PAR and used the *RCEM* [3] to estimate fatality rate. Life loss less than 1 was estimated using both the adequate and little to no warning fatality rate charts given the low PAR. Therefore, normal, hydrologic, and seismic loading PFMs were assigned Level 1 consequences (life loss less than 1). Overall, the confidence rating in the assigned consequence level was Medium given the uncertainties with the inundation zone for what was considered a normal pool condition and the actual PAR in the inundation zone. A more detailed consequences evaluation, including an incremental assessment (dam breach versus non-breach scenarios), considering the corresponding pool levels for the PFMs, would better inform the assignment.

Each evaluated PFM was plotted in the appropriate cell of the SLRA risk matrix based on the Team's selected failure likelihood category and consequence level, as shown on Figure 2-5. All nine PFMs plot within green cells, indicating "low risk" and a decreased justification to reduce risk. The total risk score for Kalihiwai Reservoir is 250.

Table 2-11 – Kalihiwai Reservoir SLRA Results

PFM Title	Failure Likelihood Category	Confidence Rating (Likelihood)	Consequence Level	Confidence Rating (Consequences)	Data Information Needs that May Impact Risk Category	Potential Risk Reduction Measures	Score	% Score Contribution
Normal PFMs								
Embankment								
PFM 1 – Internal Erosion through Embankment	Low	Medium	Level 1	Medium	• A more detailed consequences evaluation.	• More frequent inspections during normal operating conditions.	30	12.0%
PFM 2 – Internal Erosion through Foundation	Low	Medium	Level 1	Medium	• A more detailed consequences evaluation.	• More frequent inspections during normal operating conditions.	30	12.0%
PFM 3 – Internal Erosion along Low Level Outlet Conduit	Low	Medium	Level 1	Medium	• Design and construction details of the conduit. • A more detailed consequences evaluation.	• More frequent inspections during normal operating conditions. • Replacement of the conduit with a conduit that is fully encased in concrete with battered vertical walls, special compaction methods for backfilling, and filter diaphragm.	30	12.0%
PFM 4 - Internal Erosion due to Seepage out of Low Level Outlet Conduit	Low	Strong	Level 1	Medium	• Design and construction details of the conduit. • Information about the condition of conduit. • A more detailed consequences evaluation.	• More frequent inspections during normal operating conditions. • Slip-lining or replacing the conduit. This would require draining the reservoir prior to the conduit modifications or use of a small cofferdam.	30	12.0%
Hydrologic PFMs								
Spillway								
PFM 5 – Spillway Discharge Capacity is Reduced resulting in Dam Overtopping	Low	Poor	Level 1	Medium	• Flood frequency and hydraulic routing analyses using the existing mid-level outlet channel configuration including the access road and culverts that are in the channel to inform recurrence interval of flood that would overtop the embankment with existing configuration of spillways. • A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	• Replace spillway and/or mid-level outlet channel to increase discharge capacity.	30	12.0%
Embankment								
PFM 6 – Internal Erosion through Embankment during Flood	Low	Medium	Level 1	Medium	• A flood frequency analysis to inform reservoir pool level for various flood events. • A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	• Increase spillway capacity to limit pool rise during flood.	30	12.0%
PFM 7 – Internal Erosion through Foundation during Flood	Low	Medium	Level 1	Medium	• A flood frequency analysis to inform reservoir pool level for various flood events. • A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	• Increase spillway capacity to limit pool rise during flood.	30	12.0%
PFM 8 – Internal Erosion along Low Level Outlet Conduit during Flood	Low	Medium	Level 1	Medium	• A flood frequency analysis to inform reservoir pool level for various flood events. • A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	• Replacement of the conduit with a conduit that is fully encased in concrete with battered vertical walls and special compaction methods for backfilling and filter diaphragm. • Increase spillway capacity to limit pool rise during flood.	30	12.0%

PFM Title	Failure Likelihood Category	Confidence Rating (Likelihood)	Consequence Level	Confidence Rating (Consequences)	Data Information Needs that May Impact Risk Category	Potential Risk Reduction Measures	Score	% Score Contribution
Seismic PFMs								
Embankment								
PFM 9 – Seismic-Induced Differential Settlement resulting in Transverse Cracking and Internal Erosion	Remote	Medium	Level 1	Medium	• Evaluate the potential for strain-softening within the embankment and foundation soils. • A more detailed consequences evaluation.		10	4.0%
						Total Risk Score:	**250**	

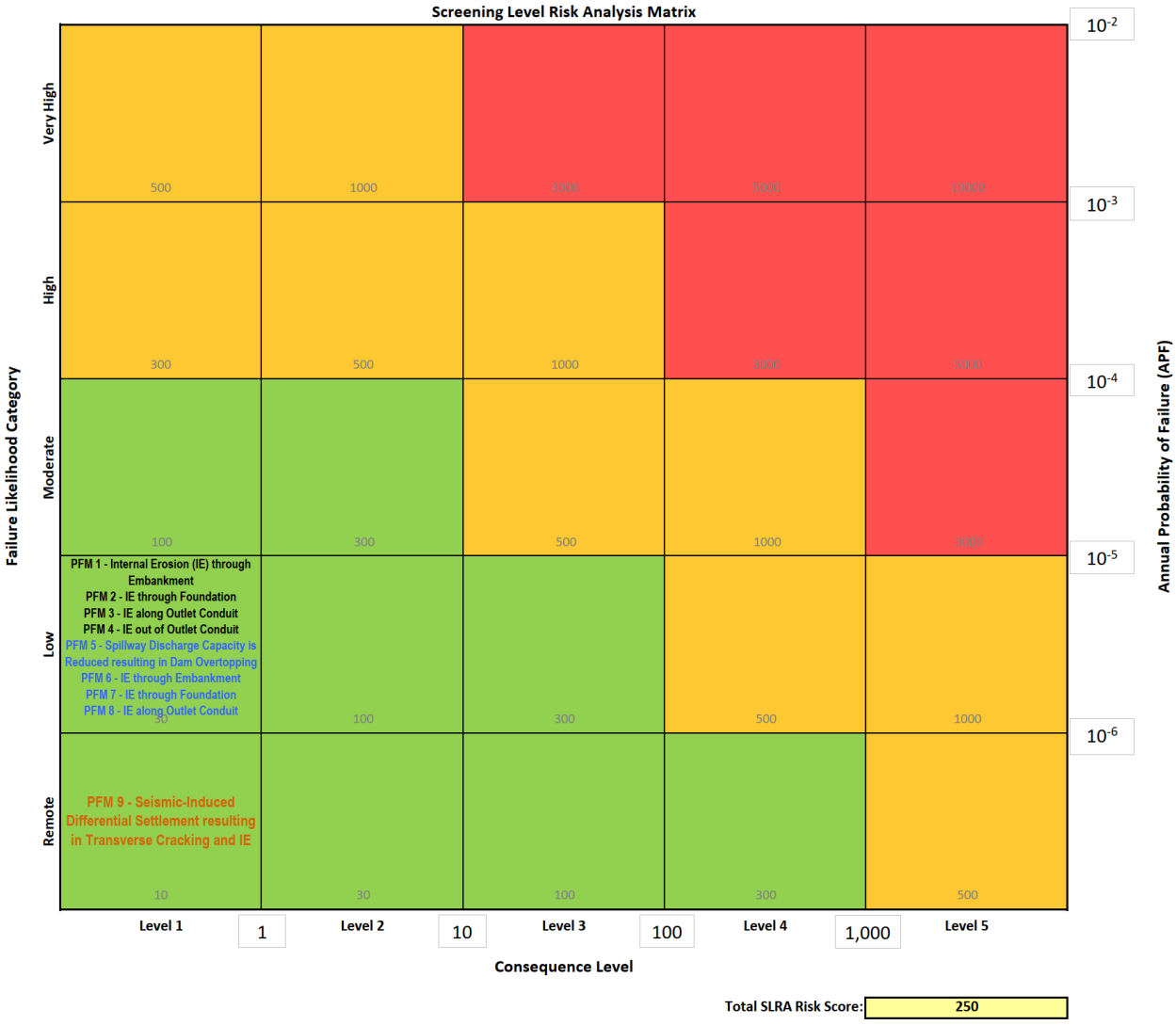


Figure 2-5 – Kalihiwai Reservoir SLRA Risk Matrix

Appendix A-5: Kalihiwai Reservoir (KA-0024)

SLRA Results
Kalihiwai Reservoir

Dam Name: Kalihiwai Reservoir
State Dam ID No. / NID No.: KA-0024 / HI00024
Owner: Kalihiwai Ridge Community Association
County: Kauai
Year Constructed: 1920
SLRA Date: 3/22/2023

Hazard Classification: High
Dam Type: Earthfill Embankment
Dam Height: 20 ft
Reservoir Storage: Approx. 30 (GH 7) / 242 (crest) ac-ft per Gannett Fleming 2021
Purpose: Irrigation and Recreation

Total SLRA Risk Score: 250

Potential Failure Modes (PFMs):

PFM Title	Failure Likelihood Category	Confidence Rating (Likelihood)	Consequence Level	Confidence Rating (Consequences)	Data Information Needs that May Impact Risk Category	Potential Risk Reduction Measures	Score	% Score Contribution
Normal PFMs								
Embankment								
PFM 1 - Internal Erosion through Embankment	Low	Medium	Level 1	Medium	A more detailed consequences evaluation.	More frequent inspections during normal operating conditions.	30	12.0%
PFM 2 - Internal Erosion through Foundation	Low	Medium	Level 1	Medium	A more detailed consequences evaluation.	More frequent inspections during normal operating conditions.	30	12.0%
PFM 3 - Internal Erosion along Low Level Outlet Conduit	Low	Medium	Level 1	Medium	Design and construction details of the conduit. A more detailed consequences evaluation.	More frequent inspections during normal operating conditions. Replacement of the conduit with a conduit that is fully encased in concrete with battered vertical walls, special compaction methods for backfilling, and filter diaphragm.	30	12.0%
PFM 4 - Internal Erosion due to Seepage out of Low Level Outlet Conduit	Low	Strong	Level 1	Medium	Design and construction details of the conduit. Information about the condition of conduit. A more detailed consequences evaluation.	More frequent inspections during normal operating conditions. Slip-lining or replacing the conduit. This would require draining the reservoir prior to the conduit modifications or use of a small cofferdam.	30	12.0%
Hydrologic PFMs								
Spillway								
PFM 5 - Spillway Discharge Capacity is Reduced resulting in Dam Overtopping	Low	Poor	Level 1	Medium	Flood frequency and hydraulic routing analyses using the existing mid-level outlet channel configuration including the access road and culverts that are in the channel to inform recurrence interval of flood that would overtop the embankment with existing configuration of spillways. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	Replace spillway and/or mid-level outlet channel to increase discharge capacity.	30	12.0%
Embankment								
PFM 6 - Internal Erosion through Embankment during Flood	Low	Medium	Level 1	Medium	A flood frequency analysis to inform reservoir pool level for various flood events. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	Increase spillway capacity to limit pool rise during flood.	30	12.0%
PFM 7 - Internal Erosion through Foundation during Flood	Low	Medium	Level 1	Medium	A flood frequency analysis to inform reservoir pool level for various flood events. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	Increase spillway capacity to limit pool rise during flood.	30	12.0%
PFM 8 - Internal Erosion along Low Level Outlet Conduit during Flood	Low	Medium	Level 1	Medium	A flood frequency analysis to inform reservoir pool level for various flood events. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).	Replacement of the conduit with a conduit that is fully encased in concrete with battered vertical walls and special compaction methods for backfilling and filter diaphragm. Increase spillway capacity to limit pool rise during flood.	30	12.0%
Seismic PFMs								
Embankment								
PFM 9 - Seismic-Induced Differential Settlement resulting in Transverse Cracking and Internal Erosion	Remote	Medium	Level 1	Medium	Evaluate the potential for strain-softening within the embankment and foundation soils. A more detailed consequences evaluation.	-	10	4.0%

SLRA Results
Kalihiwai Reservoir

Dam Name:	Kalihiwai Reservoir	Hazard Classification:	High		
State Dam ID No. / NID No.:	KA-0024 / HI00024	Dam Type:	Earthfill Embankment		
Owner:	Kalihiwai Ridge Community Association	Dam Height:	20	ft	
County:	Kauai	Reservoir Storage:	Approx. 30 (GH 7) / 242 (crest)	ac-ft	
Year Constructed:	1920	Purpose:	Irrigation and Recreation		
SLRA Date:	3/22/2023				

LEGEND: Normal Loading PFMs (Black)
Hydrologic Loading PFMs (Blue)
Seismic Loading PFMs (Burnt Orange)

Screening Level Risk Analysis Matrix

Failure Likelihood Category	Level 1 (1)	Level 2 (10)	Level 3 (100)	Level 4 (1,000)	Level 5
Very High	500	1000	3000	5000	10000
High	300	500	1000	3000	5000
Moderate	100	300	500	1000	3000
Low	PFM 1 - Internal Erosion (IE) through Embankment PFM 2 - IE through Foundation PFM 3 - IE along Outlet Conduit PFM 4 - IE out of Outlet Conduit PFM 5 - Spillway Discharge Capacity is Reduced resulting in Dam Overtopping PFM 6 - IE through Embankment PFM 7 - IE through Foundation PFM 8 - IE along Outlet Conduit 30	100	300	500	1000
Remote	PFM 9 - Seismic-Induced Differential Settlement resulting in Transverse Cracking and IE 10	30	100	300	500

Annual Probability of Failure (APF): 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}

Consequence Level

Total SLRA Risk Score: 250

PERTINENT DATA

Dam Name:	Kalihiwai Reservoir	
State Dam ID No. / NID No.:	KA-0024 / HI00024	
Owner:	Kalihiwai Ridge Community Association	
County:	Kauai	
Year Constructed:	1920	
Hazard Classification:	High	
Dam Type:	Earthfill Embankment	
Dam Height:	20	ft
Reservoir Storage:	Approx. 30 (GH 7) / 242 (crest)	ac-ft
Purpose:	Irrigation and Recreation	

Maximum storage of 428 acre-feet that is in DLNRs records seems to be an erroneous legacy value.

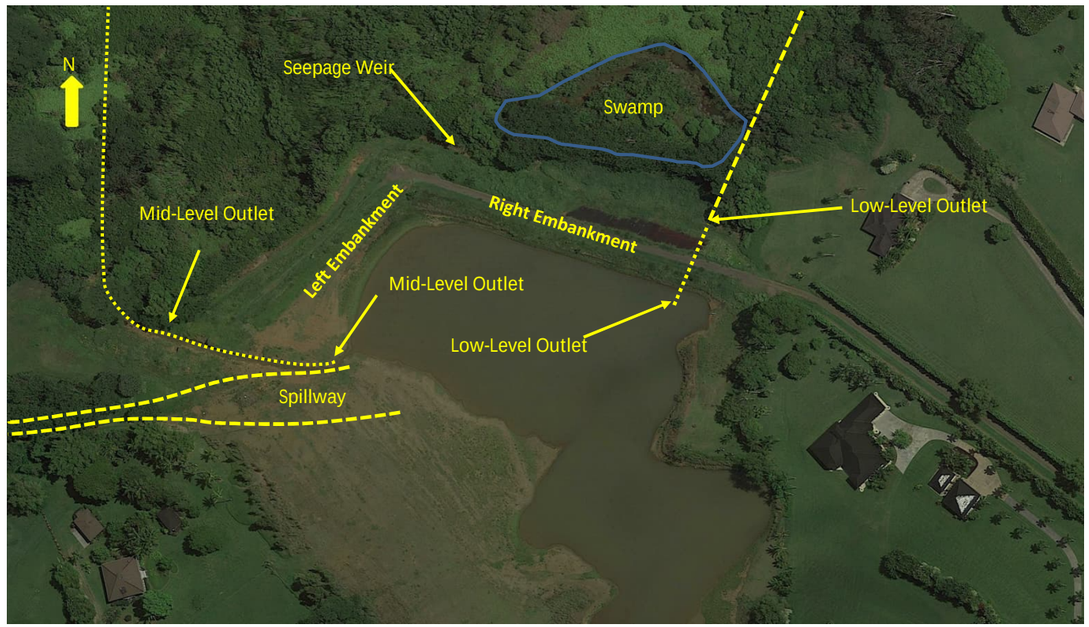
242 ac-ft max storage (dam crest) per 2021 Gannett Fleming design report

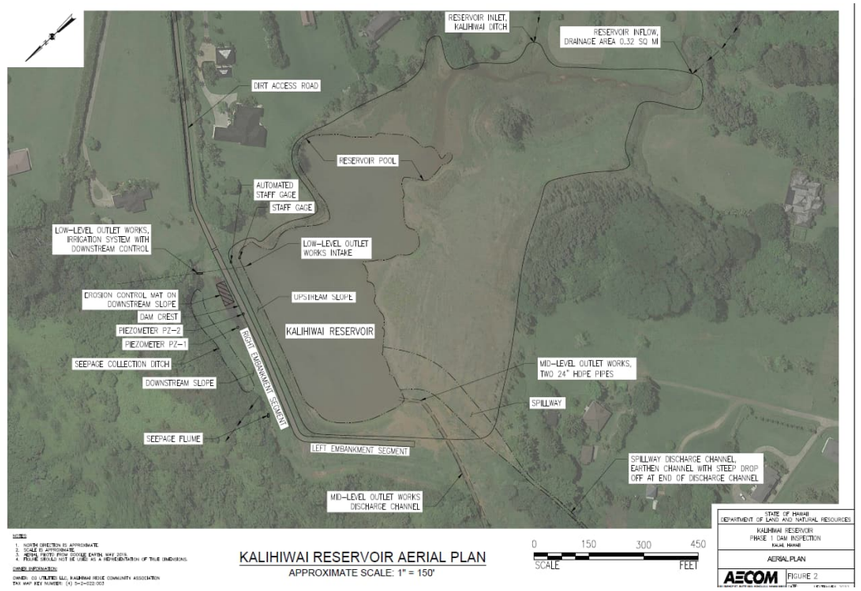
Typical Normal Pool = gage height 7 (invert of mid-level outlet)

Storage at gage height 7 is possibly 20-30 acre feet

Restricted Pool = gage height 10.2 ft

DATA CHECKLIST		NOTES
DESIGN		
ORIGINAL DESIGN DRAWINGS	No	limited photos of construction reportedly available but were not available for review
ORIGINAL AS-BUILT DRAWINGS	No	
ORIGINAL SPECIFICATIONS	No	
MODIFICATION DRAWINGS	No	
MODIFICATION SPECIFICATIONS	No	
SURVEY DATA		
TOPOGRAPHIC SURVEY	Yes	
LIDAR SURVEY	No	
BATHYMETRY SURVEY	Yes	
GEOTECHNICAL DATA		
BORINGS/CPTS	Yes	4 borings drilled in January 2020 by Geolabs
BLOW COUNT	Yes	
LAB DATA	Yes	
ANALYSES		
INFLOW HYDROLOGY	Yes	2020 Gannett Fleming Hydrologic and Hydraulic Analysis Technical Memo
FLOOD ROUTING (IDF, SPILLWAY CAPACITY)	Yes	2020 Gannett Fleming Hydrologic and Hydraulic Analysis TM (not of current mid level outlet channel configuration)
FREQUENCY FLOODS	Yes	100-year frequency flood evaluated during 2020 study
STABILITY ANALYSIS (STATIC)	Yes	2021 Gannett Fleming Draft Final Dam Rehab Design Report
SEISMIC ANALYSIS	Yes	Triggering Assessment Completed as part of 2021 study but existing dam configuration not evaluated for post-earthquake loading.
CONSEQUENCES		
BREACH INUNDATION	Yes	2009 Data used in 2016 Individual Assessment Report (Pacific Disaster Center). Top-of-dam breach only
PAR	Yes	2009 Data used in 2016 Individual Assessment Report (Pacific Disaster Center)
LOSS OF LIFE	No	





KALIHIWAI RESERVOIR AERIAL PLAN
APPROXIMATE SCALE: 1" = 150'

General (2022 Phase I Inspection Report)				
Dam Crest El.:	396	ft	Gage Height 19	Elevations are presented in mean sea level (MSL). Gannett 2021 states 394.8 to 397.2
Spillway Crest El.:	391.5	ft	Gage Height 14.2 ft	2022 EAP
Restricted Pool El.:	387.6	ft	Gage Height 10.2 ft	
Invert of Mid-Level Outlet:			Gage Height 7 ft	

Construction History (2022 Phase I Inspection Report)

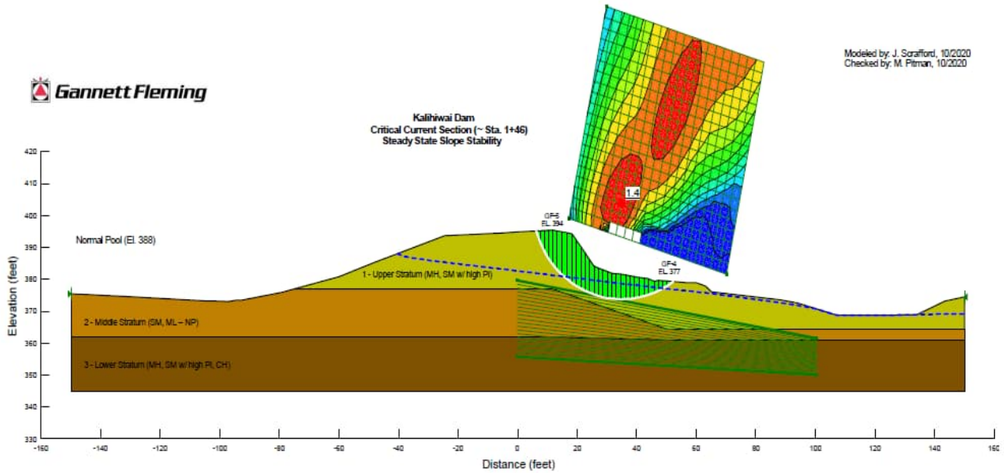
1920 - Original construction for providing irrigation water
2013 - DLNR issued Notice of Deficiency (NOD) related to condition of the mid-level outlet works
2017 - DLNR issued follow up to 2013 NOD
2018 - embankment overtopped following major storm event that resulted in emergency removal of the mid-level outlet gate. Overtopping also prompted repairs of the embankment crest and downstream slope along the right embankment segment.
2020 - two ungated 24-inch HDPE pipes installed at the location of the mid-level outlet.

Embankment Dam (HI DLNR Data Sheet, 2022 Phase I Inspection Report, 2021 Slope Stability)			
Type:	Homogenous earthfill embankment.		
Crest El.:	396	ft	394.8 to 397.2 per Gannett Fleming 2021
Crest Length:	950	ft	
Crest Width:	15	ft	
Maximum Height:	20	ft	
Upstream Slope:	2H:1V		
Downstream Slope:	0.6H:1V 2H:1V		varies 0.6H:1V to 2H:1V
Base Width:	~130	ft	Based on steady state slope stability embankment cross-section.
Embankment Material:	High plasticity clayey silt (PIs of 24 to 37).		
Slope Stability:	2021 Gannett Fleming		

Table 2-5: Existing Dam Embankment Slope Stability

Analysis Conditions	Factor of Safety	
	Required Minimum[1]	STA 1+46 Section
Long Term Steady State - Downstream	1.5	Global: 1.4 Upper slope: 1.0
Rapid Drawdown - Upstream	1.3	1.6

1. U.S. Army Corps of Engineers (USACE). Slope Stability, EM 1110-2-1902. 2003 as referenced in HAR §13-190.



Spillway (HI DLNR Data Sheet, 2020 Gannett Fleming, 2021 Gannett Fleming, 2022 Phase I Inspection Report)

Type:	Uncontrolled, unlined earthen spillway channel with trapezoidal control section and earthen discharge channel.		
Control Section Crest El.:	391.5	ft	Gage Height 59.5 ft.
Control Section Length:	180	ft	
Control Section Width:	55	ft	
Channel Length:	332	ft	
Minimum Channel Width:	14	ft	Narrows to 14ft wide channel
Discharge Capacity:	1975	cfs	with reservoir at elevation 395.5 - approx. dam crest elevation (Gannett Fleming 2020)

Note: The existing spillway channel flows due west out of the reservoir, into what appears to be historic irrigation ditches and ultimately into the Kalihiwai River Gulch approximately 600 feet downstream.

Outlet Works Low-Level (2022 Phase I Inspection Report)

Type:	Low-level outlet consists of a 24-inch metal pipe through the right embankment and is used to distribute water to the downstream irrigation system. It is controlled downstream, located near the right abutment.		
Conduit Diameter:	2	ft	
Conduit Length:	~121	ft	Gannet Fleming existing plan
Conduit Invert El.:	375.1	ft	2022 EAP (unknown source), outlet invert 374.5
Discharge Capacity:	Unknown	cfs	

Note: 24-inch line through the embankment into an 18-inch line that tees to two 12-inch lines which flow through filters and back to an 18-inch line. Controlled downstream at Plantation.

Outlet Works Mid-Level (2022 Phase I Inspection Report, 2020 Gannett Fleming)

Type:	Mid-level outlet consists of a 2 24-inch HDPE pipes at the left abutment that empty into an excavated outlet channel that was excavated as emergency intervention during the 2018 flood event.		
Conduit Diameter:	2 (ea)	ft	
Conduit Length:	~25	ft	
Conduit Invert El.:	387.6	ft	2022 EAP (unknown source, estimated based on reference to old outlet structure)
Discharge Capacity:	1660	cfs	2020)

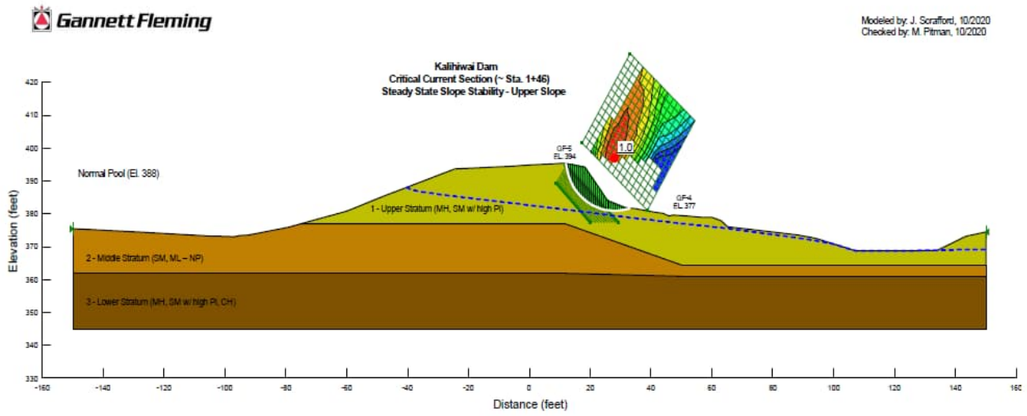
Note: Mid-Level Outlet gate structure was removed in 2018. The uncontrolled mid-level outlet now serves as the primary spillway controlling normal reservoir level.

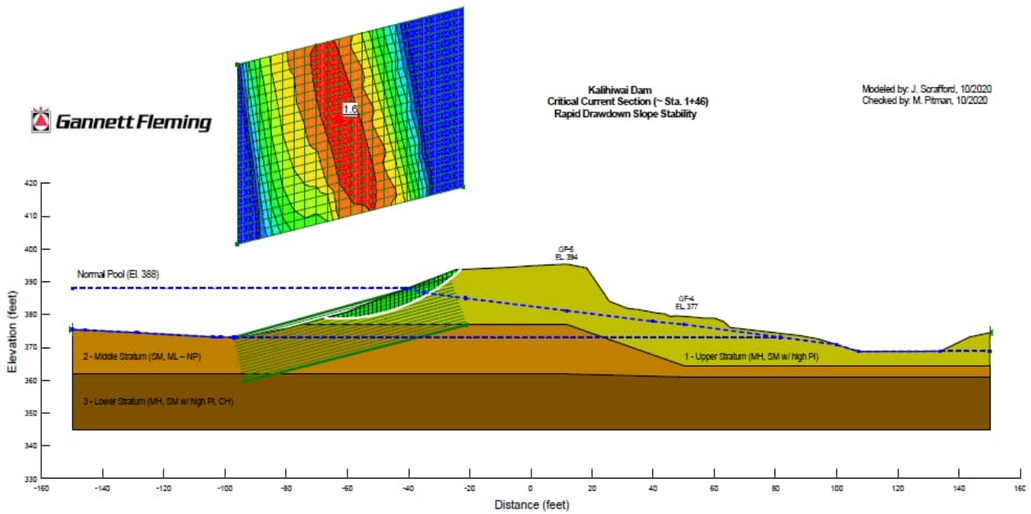
Geology and Foundation (2020 borings)

General Site Geology: The upper stratum includes the top portion of the existing dam embankment materials. This stratum is comprised by elastic silt (MH) and silty sand (SM) of high plasticity, with varying gravel content. The Plasticity Index (PI) of the soils ranged from 24 to 37. The SPT N-values ranged from 0 (weight of hammer) to 4 blows per foot (bpf), with an average of 2 bpf indicating that the material is very soft to soft.

The middle layer is comprised by non-plastic sandy silt (ML) and non-plastic fine silty sand (SM) with gravel, occasionally weathered. The SPT N-values varied from 1 to 8 bpf, with an average of 4 bpf indicating that material is soft to medium stiff or very loose to loose. It was judged that the embankment-foundation contact is at an indeterminate elevation within this zone.

The bottom foundation layer investigated was comprised by elastic silt (MH) and fat clay (CH) with little to no sand. One sample of silty sand (SM) with a PI of 30 was identified in GF-5. In general, the PI of the soils ranged from 9 to 56, and the SPT N-values ranged from 3 to 20 bpf, with an average of 10 bpf. The SPT N-values indicate the materials range from soft to very stiff. Dispersion tests indicate that these soils are non-dispersive.





Embankment Foundation: No bedrock was encountered to the depths investigated during the geotechnical investigations (down to elevation 346).

Soil samples indicate the embankment and foundation soils are similar in color and texture making it difficult to identify the embankment-foundation contact.

Spillway Foundation: Similar to embankment.

Hydrology (2020 Gannett Fleming H&H Analysis Report)

Drainage Area:	0.32	mi^2	
PMF Inflow:	3624	cfs	Used HMR No. 39. PMP 49.9 inches
PMF Outflow:	2412	cfs	
PMF Pool El.:	393.9	ft	
Residual Freeboard:	1.1	ft	This did not take into account the current, existing configuration of the mid-level outlet works channel and is also less than the 2.52 calculated wave runup and wind setup .

Seismic (2022 Site Specific Hazard Assessment)

2,500-year PGA:	0.07	g
5,000-year PGA:	0.10	g
10,000-year PGA:	0.14	g

Performance (2022 Phase I Inspection Report)

Overall POOR rating. The POOR rating was selected because there are identified existing dam safety deficiencies which have been documented for loading conditions expected during the life of the structure. Embankment stability evaluations (ARCADIS 2015; Meta Engineering 2017; Gannett Fleming 2021) indicate computed Factors of Safety (FOS) below accepted standards. In addition, the hydraulic capacity of the existing spillway is unknown, but unlikely to convey the probable maximum flood (PMF) event. Consideration was also made to the current Notice of Deficiency (NOD) dated August 24, 2017 related to the condition of the mid-level outlet. The NOD restricts the reservoir pool to an elevation of 10.2 feet and that the pool be maintained at or below the invert of the mid-level outlet. The discharge capacity of the modified configuration of the mid-level outlet is unknown.

The reservoir has a reported history of storm events that have exceeded the spillway capacity leading to overtopping of the embankment, including once in the 1970's and again in April 2018 during record setting rainfall.
Owner is currently developing design plans to improve and rehabilitate the embankment, spillway, and outlet works.

Based on past performance, seepage is judged to be a concern when the reservoir is operating with a full normal storage. Existing seepage areas at the toe of the right embankment should be monitored regularly for changing conditions such as increase in flows, muddy flows, and turbidity or sediment in the discharge.

Instrumentation (2022 Phase I Inspection Report)

Embankment: Reservoir staff gage, automated digital staff gage (18 inches lower than staff gage), two piezometers, two open standpipe monitoring wells, and seepage monitoring flume located at downstream toe of right embankment segment (left end of right embankment section).

Spillway: None.

Inlet: Flume located at reservoir inlet (not inspected)

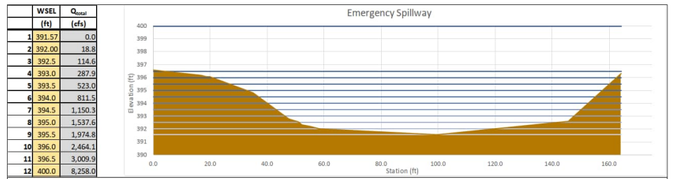
Consequences (2016 Individual Assessment Report)

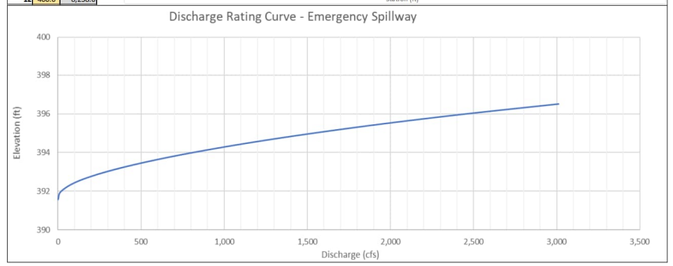
PAR: 1

Routed 428 acre-feet which corresponds to the maximum (dam crest) storage capacity of the reservoir based on DLNR records.

Assumed cross-section and discharge curve of spillway for 2020 H&H analyses

	WSEL (ft)	Q_{total} (cfs)
1	391.57	0.0
2	392.00	18.8
3	392.5	114.6
4	393.0	287.9
5	393.5	523.0
6	394.0	811.5
7	394.5	1,150.3
8	395.0	1,537.6
9	395.5	1,974.8
10	396.0	2,464.1
11	396.5	3,009.9
12	400.0	8,258.0

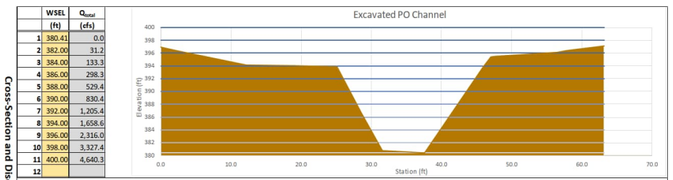


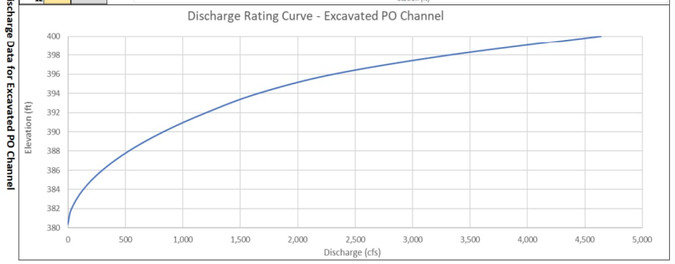


Assumed cross-section and discharge curve of mid-level outlet works channel for 2020 H&H analyses

Cross-Section and Discharge Data for Excavated PO Channel

	WSEL (ft)	Q_{total} (cfs)
1	380.41	0.0
2	382.00	31.2
3	384.00	133.3
4	386.00	298.3
5	388.00	529.4
6	390.00	830.4
7	392.00	1,205.4
8	394.00	1,658.6
9	396.00	2,316.0
10	398.00	3,327.4
11	400.00	4,640.3
12		





POTENTIAL FAILURE MODE (PFM) BRAINSTORM LIST

During the workshop, Team developed PFMs 4, 6, 7, 8 and briefly discussed PFM 5. Following the workshop, AECOM finished developing PFMs 1, 2, 3, and 9.

Loading Conditions

Normal Operation: Historically, the reservoir had a normal operating pool level at gage height 14.2 ft, which corresponds to the spillway crest elevation. Reservoir is restricted to a pool level at gage height 10.2 ft and the mid level conduits were installed in 2020 that now act as a primary spillway controlling reservoir levels at gage height 7. Since there are plans to decommission the facility, the Team considered the normal operating pool level to be the level of the primary spillway at gage height 7 ft.

Hydrologic: Pool levels above the normal operating pool level of gage height 7 ft up to the PMF pool level elevation of 393.9 feet (1.1 feet below the dam crest).

Seismic: Normal operating pool level of gage height 7 ft and earthquakes up to an event with a 10,000-year recurrence period (PGA of 0.14g based on the 2022 site-specific seismic hazard assessment).

PFM Title	Potential Defects	PFM Screening Notes
	Normal Potential Failure Modes	
Internal Erosion through Embankment	Concentrated Leak: A crack above an abrupt change in rock slope on an abutment, a hydraulic fracture crack in a low stress zone in the core, a desiccation crack, differential settlement cracking, a frost damaged layer at a winter shutdown level, the boundary in the embankment created by a closure section, defects due to animal burrows or roots. Backward Erosion Piping (BEP): A low plasticity (PI<7) layer or zone through the core under a roof-forming layer, dispersive soil. Global BEP (Internal Migration): Erodible material susceptible to unraveling or stoping (Global BEP or Internal Migration) without a roof-layer. Contact Erosion: Pervious zone above the core. Suffusion/Suffosion: Presence of internally unstable soil (gap graded or broadly graded), dispersive soil.	CARRIED FORWARD - PFM 1 *Team considered Concentrated Leak Erosion to be the most likely mechanism.*
Internal Erosion through Foundation	Concentrated Leak Erosion: A crack above an abrupt change in rock slope, a hydraulic fracture crack in a low stress zone, differential settlement cracking, crack due to collapsible soil, karstic features, open or erodible bedrock discontinuities. Backward Erosion Piping (BEP): A continuous pervious, low plasticity (PI<7) layer through the foundation, direct entrance into pervious layer, open exit or heave/blowout, dispersive soil. Contact Erosion: Flow through pervious foundation layer underlying fine-grained confining layer. Foundation seepage path consisting of a system of high-porosity interconnected and open rock fractures, solution cavities, open coarse material, or a fault system. Suffusion/Suffosion: Presence of internally unstable soil (gap graded or broadly graded).	CARRY FORWARD - PFM 2 *Team considered Concentrated Leak Erosion to be the most likely mechanism.*

PFM Title	Potential Defects	PFM Screening Notes
Internal Erosion of Embankment into Foundation	Concentrated Leak Erosion: Coarse open-work foundation soils (gravels/cobbles), voids, karstic features, untreated open rock fracture. Backward Erosion Piping (BEP): A low plasticity (PI<7) layer near the core base, filter incompatibility between embankment and foundation soils, dispersive soil. Contact Erosion: Flow through pervious foundation layer in contact with and scouring overlying embankment.	SCREENED - JUDGED TO NOT BE A RISK DRIVER Based on test holes through the embankment and foundation, the embankment materials consist of low permeable, high plasticity silt (MH) and silty sand (SM). The foundation soils encountered in the test holes were very similar to the embankment such that the embankment and foundation materials are likely filter compatible. There is no indication of open-work gravel or high transmissive open rock fractures/joints.
Internal Erosion of Embankment along Structural Contact	Hydraulic fracture occurs along low stress zones (along a steep wall or low compaction zones) or gap developing due to settlement of dam fill adjacent to rigid structure (concrete section, spillway or retaining wall, etc.).	SCREENED - JUDGED TO NOT BE CREDIBLE No rigid structural contact identified within the embankment that extends continuously from upstream to downstream. Outlet conduit is considered in another PFM.
Internal Erosion *along* Low Level Outlet Conduit	A crack, void, or zone of low compaction density due to shape of conduit or presence and configuration of seepage collars.	CARRIED FORWARD - PFM 3
Internal Erosion *into* Low Level Outlet Conduit	A crack, hole, open pipe joint, slots/perforations cut too large for surrounding soil, or other opening that is in a strategic part of the embankment and below the phreatic surface. This hole may be in alignment with an existing flaw in the embankment along the conduit that connects to the reservoir.	SCREENED - JUDGED TO NOT BE CREDIBLE The outlet is pressurized with downstream control. A defect in the conduit would result in seepage out of the conduit versus into the conduit.
Internal Erosion due to Seepage *out of* Low Level Outlet Conduit	Pressurized conduit with a crack, hole, open pipe joint, or other opening that is in a portion of the embankment susceptible to hydraulic fracture and/or erosion. Conduits with upstream control can readily be closed to intervene, while conduits with only downstream control induce a pressurized condition.	CARRIED FORWARD - PFM 4
Slope Instability resulting in Deformations Greater than Freeboard	Phreatic level (pore pressures) rises due to filter or toe drain clogging, saturation of slope from surface run-on or precipitation infiltration, progressive shallow failure.	SCREENED - JUDGED TO NOT BE A RISK DRIVER A stability analysis was recently performed under steady-state loading condition with a restricted pool level of gage height 10.5 (Gannett 2021). Minimum factor of safety of 1.4 was calculated for a global shear surface that does not intercept the reservoir pool. A stability analysis using the lower pool level of gage height 7 considered for normal loading would show a higher factor of safety. Additionally, a shear surface that intercepts the reservoir pool will have a higher factor of safety than the 1.4 indicated. The minimum factor of safety calculated of 1.4 is above a factor of safety of 1.0. A change in condition from the steady-state loading would need to be postulated to cause embankment failure.

PFM Title	Potential Defects	PFM Screening Notes
Rapid Drawdown Upstream Slope Instability	The reservoir is lowered faster than pore pressures can dissipate in upstream materials. Consider that freeboard is very large once reservoir is drawdown, and thus deformations would need to be great to lead to loss of reservoir.	SCREENED - JUDGED TO NOT BE A RISK DRIVER A slump in the embankment is conceivable, but a slope stability failure progressing through the embankment crest to the point of reservoir release is remote, particularly under the increased freeboard and need for a subsequent flood event to elevate the reservoir level above the deformed embankment. Furthermore, the rapid drawdown loading condition was evaluated for the upstream slope and indicated a factor of safety of 1.6.
Landslide / Mudslide into Reservoir resulting in Dam Overtopping	Steep reservoir rim, reservoir rim materials prone to landslide.	SCREENED - JUDGED TO NOT BE CREDIBLE The topography immediately adjacent to the reservoir is gentle. The Team judged the topography was not conducive to producing a large enough slide mass into the reservoir to cause dam overtopping.
Collapse Failure of Outlet Conduit	Structural failure of the outlet conduit.	SCREENED - JUDGED TO NOT BE A RISK DRIVER The Team judged that collapse of the outlet conduit sufficient to cause a breach and reservoir release to be very unlikely due to the relatively small diameter (24-inch) steel conduit under a moderate height embankment.
Failure of Outlet Works Intake Structure	Structural failure of the intake structure.	SCREENED - JUDGED TO NOT BE CREDIBLE The Team could not identify an initiator to fail the outlet works intake structure. Even if the intake structure were to fail, the outlet works flow can be shut off at the downstream Plantation (downstream control) to prevent reservoir release.
Hydrologic Potential Failure Modes		
Spillway Discharge Capacity Less than IDF resulting in Dam Overtopping	Insufficient spillway size, localized low areas on crest (ATV or animal traffic, runoff, rutting), high tailwater, downstream constrictions, etc.	SCREENED - JUDGED TO NOT BE A RISK DRIVER Based on the recent H&H evaluation, the spillway and mid-level outlet channel can convey flows associated with the PMF event without overtopping the embankment crest so this failure mode was judged to not be a risk driver. However, these analyses did not model the existing configuration of the access road and culverts across the mid-level outlet channel which would effectively decrease the capacity of the channel. Therefore, Team carried forward the PFM below regarding the reduction of spillway discharge capacity results in dam overtopping.
Spillway Discharge Capacity is Reduced resulting in Dam Overtopping	Debris, trash racks, fish screens.	CARRY FORWARD - PFM 5

PFM Title	Potential Defects	PFM Screening Notes
Erosion of Unlined Spillway Channel	Headcutting progressing to breach through spillway or toe scour, erodible spillway foundation, lack of armoring, spillway cutoff failure. Consider erosion progressing through spillway channel or lateral erosion that may scour the embankment toe.	SCREENED - JUDGED TO NOT BE A RISK DRIVER Adverse: Spillway channel primarily consists of bare soil with no erosion protection. Positive: Spillway operated satisfactorily without observation of significant erosion during the 2018 inflow event. Based on the H&H evaluation, there is greater flow through the mid level outlet channel than the spillway, so Team thought the more critical channel is the mid level outlet channel (discussed in row below). While the spillway channel grade increases significantly at a steep drop off location where head-cutting erosion could initiate, this steep drop off is estimated to be at least 100 yards downstream of the spillway control section. Upstream of this drop-off the spillway discharge channel slope is gradual at about 1%. In the recent H&H evaluation, durations of peak outflows during the PMF event were estimated to be less than 4 hours for the pre-existing configuration which is considered a short duration to progress head-cutting to the reservoir. The spillway control section is 55 feet wide and narrows to a 14 feet wide discharge channel. The width change is gradual which is favorable for spillway hydraulics.
Erosion of Mid Level Outlet Channel	Headcutting progressing to breach through spillway or toe scour, erodible spillway foundation, lack of armoring, spillway cutoff failure. Consider erosion progressing through spillway channel or lateral erosion that may scour the embankment toe.	SCREENED - JUDGED TO NOT BE A RISK DRIVER Adverse: Based on the H&H evaluation, there is greater flow through the mid level outlet channel than the spillway. The channel is unlined and was cut as an emergency intervention in 2018 to increase outflow capacity. Positive: While the channel grade increases significantly at a steep drop off location where head-cutting erosion could initiate, this steep drop off is estimated to be at least 100 yards downstream of the channel control section. Upstream of this drop-off the channel slope is gradual at about 1%. In the recent H&H evaluation, durations of peak outflows through the original spillway during the PMF event were estimated to be less than 4 hours for the pre-existing configuration which is considered a short duration to progress head-cutting to the reservoir. The channel has a bottom and top width of about 8 and 20 feet, respectively, and the channel width is similar along its length until the steep drop off to the river below which is favorable for spillway hydraulics.
Erosion of Lined Spillway Channel	Hydraulic jacking of liner leading to headcutting progressing to breach through spillway.	N/A
Internal Erosion through Embankment during Flood	Same as normal.	CARRY FORWARD - PFM 6

PFM Title	Potential Defects	PFM Screening Notes
Internal Erosion through Foundation during Flood	Same as normal.	CARRY FORWARD - PFM 7
Internal Erosion of Embankment into Foundation during Flood	Same as normal.	SCREENED - JUDGED TO NOT BE A RISK DRIVER
Internal Erosion *along* Low Level Outlet Conduit during Flood	Same as normal.	CARRY FORWARD - PFM 8
Internal Erosion *into* Low Level Conduit during Flood	Same as normal.	SCREENED - JUDGED TO NOT BE A RISK DRIVER The conduit is pressurized
Slope Instability during Flood resulting in Deformations Greater than Freeboard	Pore pressures within saturated portions of embankment rise due to hydrologic loading.	SCREENED - JUDGED TO NOT BE A RISK DRIVER The Team judged that the increased probability of global slope instability would not statistically overcome the infrequent probability of a flood. Therefore, the failure likelihood of slope instability under normal pool would control. Furthermore, during the 2018 inflow event, a slump on the downstream slope developed but not a global failure of the embankment. Also based on the recent H&H evaluation, the duration of the elevated flood pool is estimated to be less than one day. There was a steady-state loading condition analyzed with a pool at gage height 10.5 (which is about 3.5 feet over the normal pool level being considered of gage height 7) which resulted in a factor of safety of 1.4. It is recognized though that drained material properties were used for this analysis. The flood loading condition should consider undrained properties. The Team thought a seepage related PFM would control versus stability under the flood loading.
Landslide / Mudslide into Reservoir during Flood resulting in Dam Overtopping	Same as normal.	SCREENED - JUDGED TO NOT BE CREDIBLE Same justification for normal loading.

PFM Title	Potential Defects	PFM Screening Notes
Seismic Potential Failure Modes		
Seismic Deformation Greater than Freeboard resulting in Dam Overtopping	Significant reduction in foundation strength due to liquefaction of low plasticity and cohesionless soils. Also consider cohesive, plastic soils susceptible to significant strength loss due to strain-softening.	SCREENED - JUDGED TO NOT BE A RISK DRIVER Positive: Based on the 2022 Site-Specific Seismic Hazard Assessment, bedrock PGAs range from 0.10g for the 5,000-year seismic event to 0.14g for the 10,000-year seismic event. It would take a rare earthquake to induce low to moderate ground motions. Minimum normal freeboard on the embankment is about 12 feet with the reservoir at the restricted pool level/normal operating level. Embankment instability would need to deform the crest by more than 12 feet (about 60% of the maximum embankment height) for reservoir release to occur. Earthquake-induced crest settlement was estimated by Gannett during the 2021 study and ranged from1 to 2.7 feet based on the simplified deformation analysis using methodology by Makdisi and Seed (1977). The soils in the upper strata (existing embankment materials) and lower strata are primarily elastic silts (MH) and fat clays (CH) with PI ranging from 9 to 56 so were not considered susceptible to liquefaction based on their plasticity (Gannett 2021). While the non plastic soils of the middle foundation stratum were found susceptible to liquefaction triggering, this foundation unit appears to thin out under the downstream slope of the embankment and downstream of the toe, indicating susceptible soils may not extend continuously upstream to downstream which is necessary to cause global slope stability failure. Additionally, these soils were found susceptible to triggering at PGAs higher than the 10,000-year event based on the 2022 PSHA. They may not be susceptible to triggering under the lower seismic hazard. Adverse: As part of the 2021 Gannett study, the saturated, silty sand (SM) layers within the middle foundation stratum were found to be susceptible to liquefaction triggering using a M6.5 and PGAs ranging from 0.16g to 0.47g. A post-earthquake loading condition was not evaluated for the existing embankment configuration as part of the 2021 study so stability factors of safety are uncertain. High plasticity silt (MH) and fat clays (CH) embankment fill and foundation soils may be susceptible to strain-softening which was not considered or evaluated during Gannett's 2021 study.
Seismic-Induced Differential Settlement resulting in Transverse Cracking and Internal Erosion	Differential settlement (less than freeboard) caused by foundation and embankment irregularities including abrupt change in foundation depth or density, abrupt change in embankment height due to valley shape, collapsible soils.	CARRY FORWARD - PFM 9
Seismic-Induced Separation at Structural Contact leading to Internal Erosion	Separation at contact between embankment and rigid structure (concrete section, spillway or retaining wall, etc.) due to differential dynamic response.	SCREENED - JUDGED TO NOT BE CREDIBLE No rigid structural contact identified within the embankment that extends continuously from upstream to downstream.

2023 Kalihiwai Reservoir SLRA
March 22, 2023

PFM No.:	1
PFM Title:	Internal Erosion through Embankment
PFM Loading:	Normal
PFM Description:	» Reservoir is at normal operating level (GH 7 ft).
	» A flaw or defect exists within the embankment.
	» A concentrated seepage path develops through the flaw in the embankment with seepage velocities sufficient to initiate erosion of the embankment materials.
	» Seepage and eroding material exit, unfiltered, at the downstream embankment slope or toe.
	» Erosion progresses as embankment materials are capable of holding a void along the flaw.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Upstream materials fail to self-heal (clog) the void.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Seepage through the pipe increases and the pipe enlarges.
	» The pipe collapses, resulting in embankment crest deformations that exceed available freeboard.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	Embankment is homogenous and, based on samples collected from test holes in the embankment, consists of low permeable, high plasticity silt (MH) and silty sand (SM). This high plasticity silt (MH) would provide some erosion resistance.
	Maximum hydraulic head on the embankment is approximately 5 to 7 feet at gage height 7 considered for this failure mode, which is low. Therefore, seepage velocities through a flaw within the embankment is not likely to be sufficient to initiate erosion of the high plasticity silt (MH) embankment fill.
	While there is historic seepage on the downstream face and at the toe, the seepage is clear and observed when the reservoir reaches gage height 12 and above which is above the normal operating level considered under this failure mode. Seepage has not been observed on the embankment toe when the reservoir is below gage height 12 feet.
	There was a tree root in the embankment that was removed including the root ball and the hole backfilled.
	Storage capacity at the normal operating pool level of gage height 7 may not be sufficient to progress this failure mode to breach.
	Embankment is visited by dam operator after rain events, allowing opportunity for detection of unusual seepage at the downstream end.
	The outlet works can be used to lower the reservoir level for emergency intervention.
	Material is stockpiled near the site and equipment could be mobilized to the site within 10 minutes that could be used for emergency intervention.

Adverse Factors:	SPT N-values performed in the embankment ranged from 0 to 4 blows per foot indicating the material is very soft to soft which could make it more susceptible to erosion.
	Construction records detailing embankment compaction procedures are not available. Poor/low compaction could result in low stress zones (e.g., higher compressibility zones) that may lead to cracking and concentrated leak erosion within the embankment.
	There is likely no engineered filter within the embankment (typical of era) to arrest progression of erosion through a flaw in the embankment.
	Based on materials encountered in test hole GF-5, there is a 2.5-ft layer of non-plastic silty sand (SM) at a depth of about 8 feet and then the bottom portion of the embankment was logged as silty sand (SM). This material is considered more susceptible to erosion.
Failure Likelihood Category:	Low
	See bolded factors.
Confidence Rating (Likelihood):	Medium
	See data information needs below.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	A more detailed consequences evaluation.
Potential Risk Reduction Measures:	More frequent inspections during normal operating conditions.

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). This inundation study is therefore considered overly conservative for this failure mode that is considering the reservoir at gage height 7 feet. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that considered two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed no structures are inundated for the normal pool level breach. Based on the 2006 study and the conservative 2016 inundation study, a PAR of 1 or less was considered by the Team for the normal operating pool level failure modes. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone and the ability to warn those within the inundation zone.

2023 Kalihiwai Reservoir SLRA
March 22, 2023

PFM No.:	2
PFM Title:	Internal Erosion through Foundation
PFM Loading:	Normal
PFM Description:	» Reservoir is at normal operating level (GH 7 ft).
	» A flaw or defect exists within the foundation.
	» A concentrated seepage path develops through the flaw in the foundation with seepage velocities sufficient to initiate erosion of the embankment materials.
	» Seepage and eroding material exit, unfiltered, downstream of the embankment toe.
	» Erosion progresses as foundation materials are capable of holding a void along the flaw.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Upstream materials fail to self-heal (clog) the void.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Seepage through the pipe increases and the pipe enlarges.
	» The pipe collapses, resulting in embankment crest deformations that exceed available freeboard.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	Based on test holes in foundation, some of the foundation materials consist of low permeable, high plasticity silt (MH), which would provide some erosion resistance.
	While non-plastic silty sand (SM) materials were encountered in the borings, there is a cap of high plasticity silt (MH). Seepage gradients would need to be sufficient to cause blowout of this cap.
	Maximum hydraulic head on the embankment is approximately 5 to 7 feet at gage height 7 considered for this failure mode, which is low. Therefore, seepage velocities through a flaw within the foundation may not be sufficient to initiate erosion of the high plasticity silt (MH) foundation zones.
	Seepage that has been observed has been clear and seepage observed close to the foundation contact does not appear until the reservoir reaches gage height 12 feet, 5 feet above the level considered in this failure mode.
	Seepage observed at the downstream toe and downstream of the toe in the swampy area dries up during drought when the reservoir remains at the same level suggesting that seepage is from precipitation versus through the foundation.
	Storage capacity at the normal operating pool level of gage height 7 may not be sufficient to progress this failure mode to breach.
	Embankment is visited by dam operator after rain events, allowing opportunity for detection of unusual seepage downstream of the dam.
	Material is stockpiled near the site and equipment could be mobilized to the site within 10 minutes that could be used for emergency intervention.
	The outlet works can be used to lower the reservoir level for emergency intervention.

Adverse Factors:	There are some zones within the foundation that are comprised of non-plastic sandy silt (ML) and non-plastic fine silty sand (SM) with gravel with SPT N-values varying from 1 to 8 bpf, with an average of 4 bpf indicating that material is very loose to loose. These materials could be more susceptible to erosion.
	There is likely no engineered filter within the foundation (typical of era) to arrest progression of erosion through a flaw.
	Foundation preparation during original construction is unknown and may have resulted in a layer of topsoil or organic soil which could be more susceptible to erosion.
Failure Likelihood Category:	Low
	See bolded factors.
Confidence Rating (Likelihood):	Medium
	See data information needs below.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	A more detailed consequences evaluation.
Potential Risk Reduction Measures:	More frequent inspections during normal operating conditions.

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). This inundation study is therefore considered overly conservative for this failure mode that is considering the reservoir at gage height 7 feet. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that considered two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed no structures are inundated for the normal pool level breach. Based on the 2006 study and the conservative 2016 inundation study, a PAR of 1 or less was considered by the Team for the normal operating pool level failure modes. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone and the ability to warn those within the inundation zone.

PFM No.:	3
PFM Title:	Internal Erosion along Low Level Outlet Conduit
PFM Loading:	Normal
PFM Description:	» Reservoir is at normal operating level (GH 7 ft).
	» The initial construction of the dam resulted in a continuous zone of low compaction density backfill along the contact with the outlet conduit.
	» A concentrated seepage path develops through the zone of low compaction density backfill along the outlet conduit with seepage velocities sufficient to initiate erosion of the embankment materials along the conduit.
	» Seepage and eroding material exit, unfiltered, at the outlet conduit discharge portal.
	» Erosion progresses as overlying embankment materials are capable of holding a void.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Upstream materials fail to self-heal (clog) the void.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Seepage through the erosion pipe increases and the erosion pipe enlarges.
	» The erosion pipe collapses, resulting in embankment crest deformations that exceed available freeboard.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	Based on test holes through the embankment and foundation, the embankment materials consist of low permeable, high plasticity silt (MH) and silty sand (SM). The high plasticity silt would provide some erosion resistance.
	Maximum hydraulic head on the embankment is approximately 5 to 7 feet at gage height 7 considered for this failure mode, which is low. Therefore, seepage velocities through a flaw within the embankment may not be sufficient to initiate erosion of the high plasticity silt (MH) embankment fill.
	There is no historic seepage that has been observed exiting near the valves on the downstream side of the conduit.
	Seepage observed at the downstream end of the conduit dries up during drought when the reservoir remains at the same level suggesting that seepage is from precipitation versus along the conduit.
	Embankment is visited by dam operator after rain events, allowing opportunity for detection of unusual seepage at the downstream end.
	Storage capacity at the normal operating pool level of gage height 7 may not be sufficient to progress this failure mode to breach.
	The outlet works can be used to lower the reservoir level for emergency intervention.
	Material is stockpiled near the site and equipment could be mobilized to the site within 10 minutes that could be used for emergency intervention.

Adverse Factors:	The outlet conduit extends through the embankment.
	SPT N-values performed in the embankment ranged from 0 to 4 blows per foot indicating the material is very soft to soft which could make it more susceptible to erosion.
	Construction records detailing embankment compaction procedures are not available. Poor/low compaction around the circular conduit could result in a low density zone along its length.
	There is likely no engineered filter around the conduit (typical of era) to arrest progression of erosion through a flaw in the embankment.
	of the embankment fill material. This material is considered more susceptible to erosion.
Failure Likelihood Category:	Low
	See bolded factors.
Confidence Rating (Likelihood):	Medium
	See data information needs below. While there are uncertainties about the design and construction details of the conduit, this additional detail may or may not change the risk assignment to the point the decision to take or not to take action changes.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	Design and construction details of the conduit. A more detailed consequences evaluation.
Potential Risk Reduction Measures:	More frequent inspections during normal operating conditions. Replacement of the conduit with a conduit that is fully encased in concrete with battered vertical walls, special compaction methods for backfilling, and filter diaphragm.

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). This inundation study is therefore considered overly conservative for this failure mode that is considering the reservoir at gage height 7 feet. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that considered two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed no structures are inundated for the normal pool level breach. Based on the 2006 study and the conservative 2016 inundation study, a PAR of 1 or less was considered by the Team for the normal operating pool level failure modes. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone and the ability to warn those within the inundation zone.

PFM No.:	4
PFM Title:	Internal Erosion due to Seepage out of Low Level Outlet Conduit
PFM Loading:	Normal
PFM Description:	» Reservoir is at normal operating level (GH 7 ft).
	» A defect develops in the pressurized outlet conduit.
	» Seepage out of the defect in the outlet conduit occurs with sufficient pressure to cause hydraulic fracturing of the adjacent embankment materials.
	» Seepage velocities are sufficient to initiate erosion of the surrounding embankment materials.
	» Seepage and eroding material exit, unfiltered, at the outlet conduit discharge portal.
	» Erosion progresses as overlying embankment materials are capable of holding a void.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Seepage through the erosion pipe increases and the erosion pipe enlarges.
	» The erosion pipe collapses, resulting in embankment crest deformations that exceed available freeboard.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	Based on test holes through the embankment and foundation, the embankment materials consist of low permeable, high plasticity silt (MH) and silty sand (SM), which would provide some erosion resistance.
	Maximum hydraulic head on the embankment is 5 to 7 feet with the reservoir at the normal pool level considered for this failure mode, which is low. Therefore, pressure through a defect in the outlet conduit may not be sufficient to cause hydraulic fracturing of the high plasticity silt (MH) embankment fill. Embankment fill height is about 20 feet which would counteract hydraulic pressure out of the conduit.
	Based on observation of the valve components downstream of the dam and era of construction, the conduit is either steel or cast iron so the defect would be corrosion related which would likely be a pinhole-size and would serve as a flow limiter, limiting seepage out of the conduit.
	Seepage observed at the downstream end of the conduit dries up during drought when the reservoir remains at the same level suggesting that seepage is from precipitation versus out of the conduit that remains pressurized.
	Embankment is visited by dam operator after rain events, allowing opportunity for detection of unusual seepage at the downstream end.
	Storage capacity at the normal operating pool level of gage height 7 may not be sufficient to progress this failure mode to breach.

Adverse Factors:	The outlet conduit extends through the embankment.
	The outlet conduit is pressurized with downstream control.
	An internal camera inspection of the outlet conduit has not been performed, and thus, the condition of the conduit is unknown.
	There is likely no engineered filter within the embankment around the outlet conduit (typical of era) to arrest progression of erosion along the conduit.
	The conduit is constructed of either steel or cast iron and given its age is susceptible to corrosion.
Failure Likelihood Category:	Low
	See bolded factors. A defect in the conduit is not known to exist but given the age of the conduit, potential defects or developing a defect cannot be ruled out. The Team thought hydraulic fracturing or seepage velocity sufficient to erode the embankment materials is unlikely given the low hydraulic head and 20 feet of overlying embankment over the pipe.
Confidence Rating (Likelihood):	Strong
	Even though there are uncertainties about the condition of the outlet pipe and design and construction details, the Team discussed that given the low Consequence level, it is unlikely that additional information will change the likelihood assignment by an order of magnitude to the point where decision to take action would change. Team would need to assign a High likelihood to move to the higher risk level.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	Design and construction details of the conduit. Information about the condition of conduit. A more detailed consequences evaluation.
Potential Risk Reduction Measures:	More frequent inspections during normal operating conditions. Slip-lining or replacing the conduit. This would require draining the reservoir prior to the conduit modifications or use of a small cofferdam.

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). This inundation study is therefore considered overly conservative for this failure mode that is considering the reservoir at gage height 7 feet. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that considered two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed no structures are inundated for the normal pool level breach. Based on the 2006 study and the conservative 2016 inundation study, a PAR of 1 or less was considered by the Team for the normal operating pool level failure modes. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone and the ability to warn those within the inundation zone.

PFM No.:	5
PFM Title:	Spillway Discharge Capacity is Reduced resulting in Dam Overtopping
PFM Loading:	Hydrologic
PFM Description:	» Debris clogs the spillway discharge channel and/or natural stream channel.
	» Flood occurs with an inflow greater than the reduced spillway discharge capacity.
	» Reservoir level rises above the effective dam crest, and the overflow duration, depth, and velocity initiate erosion of the downstream embankment slope/toe.
	» No structural element is present within the embankment to limit upstream progression of the headcut/erosion.
	» Duration of the overtopping flow is long enough to permit the erosion to progress upstream, eventually eroding the embankment crest.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Downcutting of the embankment crest leads to breach by widening and deepening of the headcut.
Positive Factors:	Based on the recent H&H evaluation, the spillway and mid-level outlet channel can convey flows associated with the PMF event without overtopping the embankment crest. The PMF event results in a reservoir level 1.1 feet below the dam crest. However, the existing condition of the access road and culverts in the mid-level discharge channel was not modeled in the analyses (see countering adverse factor).
	The embankment was overtopped recently in 2018 by several inches. Depth of overtopping, locations, etc. are not documented in an incident report. A slump on the downstream face developed but the embankment was not breached.
	Overtopping from wave erosion is considered very unlikely due to the orientation of the reservoir compared to prevalent wind direction and the unlikely event that a very large wind event would occur concurrently with the PMF event.
Adverse Factors:	Existing condition of the access road and culverts in the mid-level discharge channel has not been analyzed in the recent H&H evaluation and this would effectively decrease the discharge capacity of the mid-level discharge channel. The capacity may decrease enough to overtop the embankment.
	The uncontrolled mid-level outlet that now acts as a primary spillway controlling reservoir levels was installed following emergency intervention measures during the 2018 overtopping event. This outlet channel, albeit not designed as a permanent structure, was considered during the recent H&H evaluation. The 2022 Phase I inspection report recommends modifying this structure to be a more permanent and robust structure or incorporated as part of a spillway modification.

Failure Likelihood Category:	Low
	See bolded factors.
Confidence Rating (Likelihood):	Poor
	See data information needs below.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	Flood frequency and hydraulic routing analyses using the existing mid-level outlet channel configuration including the access road and culverts that are in the channel to inform recurrence interval of flood that would overtop the embankment with existing configuration of spillways. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).
Potential Risk Reduction Measures:	Replace spillway and/or mid-level outlet channel to increase discharge capacity.
Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). Therefore, this inundation study is considered conservative for this flood loading failure mode. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that looked at two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed two structures are inundated under a dam crest reservoir failure. The additional structure located within the inundation zone identified in this 2006 study was discussed by the Team in detail and it was estimated that it is elevated approximately 8-10 feet above the ground. Based on the 2006 and 2016 inundation studies, a PAR of 1 seemed reasonable to Team. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone, the ability to warn those within the inundation zone, and incremental consequences.

PFM No.:	6
PFM Title:	Internal Erosion through Embankment during Flood
PFM Loading:	Hydrologic
PFM Description:	» Flood occurs and reservoir level rises up to the dam crest elevation.
	» A flaw or defect exists within the embankment.
	» A concentrated seepage path develops through the flaw in the embankment with seepage velocities sufficient to initiate erosion of the embankment materials.
	» Seepage and eroding material exit, unfiltered, at the downstream embankment slope or toe.
	» Erosion progresses as embankment materials are capable of holding a void along the flaw.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Upstream materials fail to self-heal (clog) the void.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Seepage through the pipe increases and the pipe enlarges.
	» The pipe collapses, resulting in embankment crest deformations that exceed available freeboard.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	This embankment has been tested under flood loading (the dam has overtopped once and the reservoir level reached the dam crest at least one other time in documented history) and performed relatively well without any observed signs of erosion.
	Embankment is homogenous and, based on samples collected from test holes in the embankment, consists of low permeable, high plasticity silt (MH) and silty sand (SM). This high plasticity silt (MH) would provide some erosion resistance.
	Maximum hydraulic head on the embankment is approximately 20 feet with the reservoir at the dam crest, which is relatively low. Therefore, seepage velocities through a flaw within the embankment may not be sufficient to initiate erosion of the high plasticity silt (MH) embankment fill.
	Seepage that has been observed has been clear and there is no trend of increased seepage with increased pool level, at least up to gage height 17 feet.
	Seepage has not been observed on the embankment toe when the reservoir is below gage height 12 feet.
	There was a tree root in the embankment that was removed including the root ball and the hole backfilled.
	Based on recent H&H evaluation, the estimated duration of an elevated flood pool during a PMF event under the pre 2018 configuration was about 20 hours. Maximum average horizontal gradient through the embankment is estimated to be 0.15 which is considered low to initiate erosion of the SM embankment materials under the limited duration of the elevated pool level.
	The outlet works can be used to lower the reservoir level for emergency intervention after the flood recedes.
	During significant flood events the dam is observed on a regular basis.
	Material is stockpiled near the site and equipment could be mobilized to the site within 10 minutes that could be used for emergency intervention.

Adverse Factors:	Based on recent H&H evaluation, the 100 year flood event raises the reservoir level to about gage height 12, which is 5 feet above the considered normal pool level. Based on a rough estimate of inflow volume and reservoir storage, a 1,000 year flood event would raise the pool to gage height 14, corresponding the spillway crest elevation. An elevated pool level could intersect defects higher in the embankment.
	SPT N-values performed in the embankment ranged from 0 to 4 blows per foot indicating the material is very soft to soft which could make it more susceptible to erosion.
	Construction records detailing embankment compaction procedures are not available. Poor/low compaction could result in low stress zones (e.g., higher compressibility zones) that may lead to cracking and concentrated leak erosion within the embankment.
	There is likely no engineered filter within the embankment (typical of era) to arrest progression of erosion through a flaw in the embankment.
	Based on materials encountered in test hole GF-5, there is a 2.5-ft layer of non-plastic silty sand (SM) at a depth of about 8 feet and then the bottom portion of the embankment was logged as silty sand (SM). This material is considered more susceptible to erosion.
	Seepage is observed on the downstream face and toe when the reservoir reaches gage height 12 feet.
Failure Likelihood Category:	Low
	See bolded factors. Team estimated nodal probabilities for two flood events: the 1,000-year and the PMF event. Nodal probabilities suggested a likelihood category of Remote to Low. The Team assigned Low, even though the Team thought that progression of erosion would be unlikely given the limited duration of the elevated pool level.
Confidence Rating (Likelihood):	Medium
	See data information needs below. Team recognized there are uncertainties regarding the recurrence interval of the PMF event (i.e., the event that raises the reservoir pool within about 1 foot of the dam crest). However, Team thought this information would likely not change the order of magnitude estimate that would change the decision to take or not take action.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	A flood frequency analysis to inform reservoir pool level for various flood events. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).
Potential Risk Reduction Measures:	Increase spillway capacity to limit pool rise during flood.

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). Therefore, this inundation study is considered conservative for this flood loading failure mode. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that looked at two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed two structures are inundated under a dam crest reservoir failure. The additional structure located within the inundation zone identified in this 2006 study was discussed by the Team in detail and it was estimated that it is elevated approximately 8-10 feet above the ground. Based on the 2006 and 2016 inundation studies, a PAR of 1 seemed reasonable to Team. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone, the ability to warn those within the inundation zone, and incremental consequences.

2023 Kalihiwai Reservoir SLRA
March 22, 2023

PFM No.:	7
PFM Title:	Internal Erosion through Foundation during Flood
PFM Loading:	Hydrologic
PFM Description:	» Flood occurs and reservoir level rises up to the dam crest elevation.
	» A flaw or defect exists within the foundation.
	» A concentrated seepage path develops through the flaw in the foundation with seepage velocities sufficient to initiate erosion of the embankment materials.
	» Seepage and eroding material exit, unfiltered, downstream of the embankment toe.
	» Erosion progresses as foundation materials are capable of holding a void along the flaw.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Upstream materials fail to self-heal (clog) the void.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Seepage through the pipe increases and the pipe enlarges.
	» The pipe collapses, resulting in embankment crest deformations that exceed available freeboard.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	This embankment has been tested under flood loading (the dam has overtopped once and the reservoir level reached the dam crest at least one other time in documented history) and performed relatively well without any observed signs of erosion.
	Based on test holes in foundation, some of the foundation materials consist of low permeable, high plasticity silt (MH), which would provide some erosion resistance.
	While non-plastic silty sand (SM) materials were encountered in the borings, there is a cap of high plasticity silt (MH). Seepage gradients would need to be sufficient to cause blowout of this cap.
	Maximum hydraulic head on the embankment is approximately 20 feet with the reservoir at the dam crest, which is relatively low. Therefore, seepage velocities through a flaw within the foundation may not be sufficient to initiate erosion of the high plasticity silt (MH).
	Based on recent H&H evaluation, the estimated duration of an elevated flood pool during a PMF event under the pre 2018 configuration was about 20 hours. Maximum average horizontal gradient through the foundation is estimated to be lower than 0.15 (lower than through the embankment due to the longer seepage pathway) which is considered low to initiate erosion of the SM and MH foundation materials under the limited duration of the elevated pool level.
	Seepage that has been observed has been clear and there is no trend of increased seepage with increased pool level, at least up to gage height 17 feet.

	Seepage observed at the downstream toe and downstream of the toe in the swampy area dries up during drought when the reservoir remains at the same level suggesting that seepage is from precipitation versus through the foundation.
	Embankment is visited by dam operator after rain events, allowing opportunity for detection of unusual seepage at the downstream end.
	Material is stockpiled near the site and equipment could be mobilized to the site within 10 minutes that could be used for emergency intervention.
	The outlet works can be used to lower the reservoir level for emergency intervention after the flood recedes.
Adverse Factors:	Based on recent H&H evaluation, the 100 year flood event raises the reservoir level to about gage height 12, which is 5 feet above the considered normal pool level. Based on a rough estimate of inflow volume and reservoir storage, a 1,000 year flood event would raise the pool to gage height 14, corresponding the spillway crest elevation.
	There are some zones within the foundation that are comprised of non-plastic sandy silt (ML) and non-plastic fine silty sand (SM) with gravel with SPT N-values varying from 1 to 8 bpf, with an average of 4 bpf indicating that material is very loose to loose. These materials could be more susceptible to erosion.
	There is likely no engineered filter within the foundation (typical of era) to arrest progression of erosion through a flaw.
	Seepage is observed close to the foundation contact when the reservoir reaches gage height 12 feet.
	Foundation preparation during original construction is unknown and may have resulted in a layer of topsoil or organic soil which could be more susceptible to erosion.
Failure Likelihood Category:	Low
	Team thought about this PFM comparatively with PFM 6 - Internal Erosion through the Embankment under Flood and did recognize that the likelihood of this failure mode is less than PFM 6 but did not think it should be reduced by an order of magnitude.
Confidence Rating (Likelihood):	Medium
	Team recognized there are uncertainties regarding the recurrence interval of the PMF event (i.e., the event that raises the reservoir pool within about 1 foot of the dam crest). However, Team thought this information would likely not change the order of magnitude estimate that would change the decision to take or not take action.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	A flood frequency analysis to inform reservoir pool level for various flood events. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).
Potential Risk Reduction Measures:	Increase spillway capacity to limit pool rise during flood.

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). Therefore, this inundation study is considered conservative for this flood loading failure mode. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that looked at two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed two structures are inundated under a dam crest reservoir failure. The additional structure located within the inundation zone identified in this 2006 study was discussed by the Team in detail and it was estimated that it is elevated approximately 8-10 feet above the ground. Based on the 2006 and 2016 inundation studies, a PAR of 1 seemed reasonable to Team. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone, the ability to warn those within the inundation zone, and incremental consequences.

PFM No.:	8
PFM Title:	Internal Erosion along Low Level Outlet Conduit during Flood
PFM Loading:	Hydrologic
PFM Description:	» Flood occurs and reservoir level rises up to the dam crest elevation.
	» The initial construction of the dam resulted in a continuous zone of low compaction density backfill along the contact with the outlet conduit.
	» A concentrated seepage path develops through the zone of low compaction density backfill along the outlet conduit with seepage velocities sufficient to initiate erosion of the embankment materials along the conduit.
	» Seepage and eroding material exit, unfiltered, at the outlet conduit discharge portal.
	» Erosion progresses as overlying embankment materials are capable of holding a void.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Upstream materials fail to self-heal (clog) the void.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Seepage through the erosion pipe increases and the erosion pipe enlarges.
	» The erosion pipe collapses, resulting in embankment crest deformations that exceed available freeboard.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	This embankment has been tested under flood loading (the dam has overtopped once and the reservoir level reached the dam crest at least one other time in documented history) and performed relatively well without any observed signs of erosion.
	Based on test holes through the embankment and foundation, the embankment materials consist of low permeable, high plasticity silt (MH) and silty sand (SM). The high plasticity silt would provide some erosion resistance.
	Maximum hydraulic head on the embankment is approximately 18 to 20 feet with the reservoir at the dam crest, which is relatively low. Therefore, seepage velocities along the conduit may not be sufficient to initiate erosion of the high plasticity silt (MH) embankment fill.
	There is no historic seepage that has been observed exiting near the valves on the downstream side of the conduit.
	Seepage observed at the downstream end of the conduit dries up during drought when the reservoir remains at the same level suggesting that seepage is from precipitation versus along the conduit .
	Embankment is visited by dam operator after rain events, allowing opportunity for detection of unusual seepage at the downstream end.

	Based on recent H&H evaluation, the estimated duration of an elevated flood pool during a PMF event under the pre 2018 configuration was about 20 hours. Maximum average horizontal gradient through the embankment is estimated to be 0.14 (slightly less than through the embankment) which is considered low to initiate erosion of the SM embankment materials under the limited duration of the elevated pool level.
	The outlet works can be used to lower the reservoir level for emergency intervention after the flood recedes.
	Material is stockpiled near the site and equipment could be mobilized to the site within 10 minutes that could be used for emergency intervention.
Adverse Factors:	The outlet conduit extends through the embankment.
	Based on recent H&H evaluation, the 100 year flood event raises the reservoir level to about gage height 12, which is 5 feet above the considered normal pool level. Based on a rough estimate of inflow volume and reservoir storage, a 1,000 year flood event would raise the pool to gage height 14, corresponding the spillway crest elevation.
	SPT N-values performed in the embankment ranged from 0 to 4 blows per foot indicating the material is very soft to soft which could make it more susceptible to erosion.
	Construction records detailing embankment compaction procedures are not available. Poor/low compaction around the circular conduit could result in a low density zone along its length.
	There is likely no engineered filter around the conduit (typical of era) to arrest progression of erosion through a flaw in the embankment.
	Borings in the area have logged the presence of silty sand (SM) that were used as part of the embankment fill material. This material is considered more susceptible to erosion.
Failure Likelihood Category:	Low
	Team discussed this PFM comparatively with PFM 6 - Internal Erosion through the Embankment under Flood loading and thought the likelihood of this PFM to be similar.
Confidence Rating (Likelihood):	Medium
	Team recognized there are uncertainties regarding design and construction details of the conduit and the recurrence interval of the PMF event (i.e., the event that raises the reservoir pool within about 1 foot of the dam crest). However, Team thought this information would likely not change the order of magnitude estimate that would change the decision to take or not take action.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category	A flood frequency analysis to inform reservoir pool level for various flood events. A more detailed consequences evaluation including an incremental assessment under the flood case (breach versus non breach scenarios).
Potential Risk Reduction Measures:	Replacement of the conduit with a conduit that is fully encased in concrete with battered vertical walls and special compaction methods for backfilling and filter diaphragm. Increase spillway capacity to limit pool rise during flood.

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). Therefore, this inundation study is considered conservative for this flood loading failure mode. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that looked at two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed two structures are inundated under a dam crest reservoir failure. The additional structure located within the inundation zone identified in this 2006 study was discussed by the Team in detail and it was estimated that it is elevated approximately 8-10 feet above the ground. Based on the 2006 and 2016 inundation studies, a PAR of 1 seemed reasonable to Team. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone, the ability to warn those within the inundation zone, and incremental consequences.

PFM No.:	9
PFM Title:	Seismic-Induced Differential Settlement resulting in Transverse Cracking and Internal Erosion
PFM Loading:	Seismic
PFM Description:	» Reservoir is at normal operating level (GH 7 ft).
	» Earthquake occurs.
	» Dynamic loading causes differential settlement of the embankment, leading to transverse cracking that intercepts the phreatic surface.
	» A concentrated seepage path develops through the crack in the embankment with seepage velocities sufficient to initiate erosion of the embankment materials.
	» Seepage and eroding material exit, unfiltered, at the downstream embankment slope.
	» Erosion progresses as embankment materials are capable of holding a void along the crack.
	» There is no effective flow limiter along the seepage path to restrict flow through the void and erosion pipe enlarges.
	» Upstream materials fail to self-heal (clog) the void.
	» Developing failure mode is not detected, or if detected, intervention is unsuccessful.
	» Flow through the crack increases as the crack enlarges.
	» Downcutting and scour of the embankment occurs through the crack.
	» Flows erode the embankment, leading to a full dam breach and uncontrolled release of the reservoir.
Positive Factors:	Based on the 2022 Site-Specific Seismic Hazard Assessment, bedrock PGAs range from 0.10g for the 5,000-year seismic event to 0.14g for the 10,000-year seismic event. It would take a rare earthquake to induce low to moderate ground motions.
	Minimum normal freeboard on the embankment is about 12 feet with the reservoir at the restricted pool level/normal operating level. A transverse crack would need to extend by more than 12 feet (about 60% of the maximum embankment height) to intersect the reservoir pool.
	A transverse crack that extends below the reservoir level would be exposed to a low head seepage velocity condition.
	Embankment is homogenous and, based on samples collected from test holes in the embankment, consists of low permeable, high plasticity silt (MH) and silty sand (SM). This high plasticity silt (MH) would provide some erosion resistance.
	Maximum hydraulic head on the embankment is approximately 5 to 7 feet at gage height 7 considered for this failure mode, which is relatively low. Therefore, seepage velocities through a crack within the embankment may not be sufficient to initiate erosion of the high plasticity silt (MH) embankment fill.
	Storage capacity at the normal operating pool level of gage height 7 may not be sufficient to progress this failure mode to breach.
	The outlet works can be used to lower the reservoir level for emergency intervention.
	The embankment would likely be inspected following a large earthquake event.

Adverse Factors:	As part of the 2021 Gannett study, the saturated, silty sand (SM) layers within the middle foundation stratum were found to be susceptible to liquefaction triggering using a M6.5 and PGAs ranging from 0.16g to 0.47g.
	High plasticity silt (MH) and fat clays (CH) embankment fill and foundation soils may be susceptible to strain-softening which was not evaluated.
	High plasticity silt (MH) embankment fill could hold open a crack and allow erosion to progress.
	There is likely no engineered filter within the embankment (typical of era) to arrest progression of erosion through a crack in the embankment.
	SPT N-values performed in the embankment ranged from 0 to 4 blows per foot indicating the material is very soft to soft which could make it more susceptible to erosion.
	Based on materials encountered in test hole GF-5, there is a 2.5-ft layer of non-plastic silty sand (SM) at a depth of about 8 feet and then the bottom portion of the embankment was logged as silty sand (SM). This material is considered more susceptible to erosion.
Failure Likelihood Category:	Remote
	See bolded factors.
Confidence Rating (Likelihood):	Medium
	See data information needs.
Consequence Level:	Level 1
Confidence Rating (Consequences):	Medium
Data Information Needs that May Impact Risk Category:	Evaluate the potential for strain-softening within the embankment and foundation soils. A more detailed consequences evaluation.
Potential Risk Reduction Measures:	-

Consequence Considerations:	Team discussed the 2016 Pacific Disaster Study (PDC) study that modeled a dam breach with the reservoir level at the dam crest and indicated a Population at Risk (PAR) of 1. This inundation study routed 428 acre-feet. The Team discussed how this storage volume is significantly greater than the maximum (dam crest) storage estimated for the reservoir today (242 acre-feet reported in Gannett Fleming 2021 design report). This inundation study is therefore considered overly conservative for this failure mode that is considering the reservoir at gage height 7 feet. The Team reviewed the depth and velocity values from the 2016 study in ArcGIS. There appeared to be a couple parcels in the inundation zone about 2 km downstream of the embankment, immediately upstream of the highway. There is uncertainty in the number of structures in this specific zone and therefore the actual PAR as it appeared there was some construction occurring based on 2023 imagery. Flood depths and velocities in this zone were approximately 1-2 meters and 2-3 meters/second. Some additional uncertainties with the 2016 inundation study stem from the study not showing inundated structures immediately downstream of the highway while the FEMA flood maps shows some of these structures flooding during a 100-year storm event. Team discussed how we can never completely preclude that someone is going to be in this inundation zone as transient population and if someone where there, they would be difficult to warn. However, the inundation area is not an area of heavy recreation use that would significantly increase the PAR. An additional 2006 Dam Failure Inundation - Flow Simulation was reviewed by the Team that considered two scenarios: a normal pool level breach and a dam crest level breach at 40 MG and 80 MG, respectively (120 and 250 acre-feet). These reservoir volumes are considered more representative of the current reservoir than the 2016 PDC study that used 428 acre-feet. The 2006 study showed no structures are inundated for the normal pool level breach. Based on the 2006 study and the conservative 2016 inundation study, a PAR of 1 or less was considered by the Team for the normal operating pool level failure modes. The Team reviewed the RCEM fatality charts for little to no warning and landed on a Level 1 consequences assignment (life loss less than 1) based on the very little PAR resulting from both the 2006 and 2016 inundation study. Team assigned Medium confidence to reflect the uncertainties with the actual PAR in the inundation zone and the ability to warn those within the inundation zone.

DEFINITIONS

Event Probabilities

Verbal Descriptors

Descriptor	Probability
Virtually Certain	0.999
Very Likely	0.99
Likely	0.9
Neutral	0.5
Unlikely	0.1
Very Unlikely	0.01
Virtually Impossible	0.001

Event Probability Guidelines

Description of Condition or Event	Order of Magnitude of Probability Assigned
Occurrence is virtually certain	1
Occurrence of the condition or event are observed in the available database.	10^{-1}
The occurrence of the condition or event is not observed, or is observed in one isolated instance, in the available database; several potential failure scenarios can be identified.	10^{-2}
The occurrence of the condition or event is not observed in the available database. It is difficult to think about any plausible failure scenario; however, a single scenario could be identified after considerable effort.	10^{-3}
The condition or event has not been observed, and no plausible scenario could be identified, even after considerable effort.	10^{-4}

Failure Likelihood Categories (Reclamation and USACE 2019)		
Remote	More remote (less frequent) than 1/1,000,000	Several events must occur concurrently or in series to cause failure, and most, if not all, have negligible likelihood such that the failure likelihood is negligible. Roughly compares with an estimated annual probability of failure greater than 1E-6 based on historic failure rates.
Low	Between 1/100,000 and 1/1,000,000	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to its initiation. Roughly compares with an estimated annual probability of failure between 1E-6 and 1E-5 based on historic failure rates.
Moderate	Between 1/100,000 and 1/10,000	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward “less likely” than “more likely." Roughly compares with an estimated annual probability of failure between 1E-5 and 1E-4 based on historic failure rates.
High	Between 1/10,000 and 1/1,000	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward “more likely” than “less likely.” Roughly compares with an estimated annual probability of failure between 1E-4 and 1E-3 based on historic failure rates.
Very High	More frequent (greater) than 1/1,000	There is direct evidence or substantial indirect evidence to suggest it has initiated or is likely to occur in near future. Roughly compares with an estimated annual probability of failure greater than 1E-3 based on historic failure rates.
N/A		Not applicable considering the physical features and configuration of the dam.

Consequence Levels (Reclamation and USACE 2019)		
Level 1	Average life loss is less than 1. Although life-threatening flooding occurs, direct loss of life is unlikely due to severity or location of the flooding or effective warning and evacuation.	Average economic loss is less than $10 million. Limited property and/or environmental damage is likely.
Level 2	Average life loss is in the range of 1 to 10. Some direct loss of life is likely, related primarily to difficulties in warning and evacuating small population centers.	Average economic loss is in the range of $10 million to $100 million. Moderate property and/or environmental damage is likely.
Level 3	Average life loss is in the range of 10 to 100. Large direct loss of life is likely, related primarily to difficulties in warning and evacuating small population centers or difficulties evacuating large population centers with significant warning time.	Average economic loss is in the range of $100 million to $1 billion. Significant property and/or environmental damage is likely.
Level 4	Average life loss is in the range of 100 to 1,000. Extensive direct loss of life can be expected due to limited warning for large population centers and/or limited evacuation routes.	Average economic loss is in the range of $1 billion to $10 billion. Extensive property and/or environmental damage is likely.
Level 5	Average life loss is greater than 1,000. Extremely high direct loss of life can be expected due to limited warning for very large population centers and/or limited evacuation routes.	Average economic loss is greater than $10 billion. Extremely high property and/or environmental damage is likely.

Consequence Levels Related to Population at Risk (PAR) and Flood Severity (Reclamation 2009)			
PAR Description	Flood Severity		
	Low (No buildings are likely to be washed off their foundations.)	Moderate (Homes are likely to be destroyed and moved, but trees and mangled homes remain for refuge.)	High (Flood is likely to sweep area clean.)
Metropolitan area or large town	Level 3	Level 4	Level 4
One or more small towns	Level 3	Level 3	Level 4
Scattered residences and farms/ranches	Level 2	Level 3	Level 3
One or two residences and/or recreation activity	Level 2	Level 2	Level 3
Minor recreation or no exposure	Level 1	Level 2	Level 2

Confidence Ratings (Reclamation and USACE 2019)	
Strong	The team is confident in the risk characterization, and it is unlikely that additional information would change the order-of-magnitude of the assigned category to the point where the decision to take (or not take) action to reduce risk or reduce uncertainty would change.
Medium	The team is relatively confident in the risk characterization, but key additional information might possibly change the order-of-magnitude of the assigned category to the point where the decision to take (or not take) action to reduce risk or reduce uncertainty may change.
Poor	The team is not confident in the risk characterization, and it is entirely possible that additional information would change the order-of-magnitude of the assigned category to the point where the decision to take (or not take) action to reduce risk or reduce uncertainty could change.

SLRA Scoring System

	Level 1	Level 2	Level 3	Level 4	Level 5
Very High	500	1000	3000	5000	10000
High	300	500	1000	3000	5000
Moderate	100	300	500	1000	3000
Low	30	100	300	500	1000
Remote	10	30	100	300	500