Papillion Creek and Tributaries Lakes, Nebraska

General Reevaluation Report

Appendix A-2. Dam Site 19 Hydrology

June 2021

Omaha District
Northwestern Division
Hydrologic Engineering Branch
Engineering Division

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Executive Summary

This Hydrology Appendix for the Papillion general reevaluation report (GRR) study documents the National Economic Development (NED) plan for Dam Site 19 (DS19) as well as other designs leading to the NED used to screen for and justify federal interest. It also incorporates input from the Tentatively Selected Plan (TSP) and the Agency Decision Milestone (ADM) meetings. Design criteria were generally consistent with the four existing Papillion Creek dams but updated to current USACE standards including Engineering Regulation 1110-8-2(FR), *Inflow Design Floods for Dams and Reservoirs* (USACE, 1991). The DS19 NED design has a permanent multipurpose pool ("wet" dam).

This report refers to the designs listed below:

- <u>Original Design</u> – USACE 1975 design.
- <u>NRD Design</u> – the Papio Natural Resources District (NRD) (Sponsor) design developed by HDR (HDR, 2018) building off a model from FYRA (FYRA, 2018).
- <u>TSP Design</u> – design presented at the Tentatively Selected Plan (TSP) milestone meeting. Dam design was built on the NRD Design incorporating some preliminary updates in USACE guidance. Appendix A described this design.
- <u>ADM Design</u> – design presented at the ADM meeting and used to determine federal interest. Included both wet and dry dam designs. The dam design was updated to ER 1110-8-2(FR) and the spillway design flood was updated to HMR 51&52 with optimization. Future land use conditions were used. Spillway cut and embankment fill balance were not yet considered in design selection. A conservative flowage easement pool was assumed. A dry dam paper exercise was used to determine if the dam is justified just on flood risk management (FRM) benefits alone.
- <u>After ADM (Balanced) Design</u> – design leading up to the National Economic Development (NED) plan design. Best balance of spillway cut and embankment fill (cut-and-fill). Future land use conditions used in design. Included a dry dam paper exercise with approximate benefits of the wet dam for cost optimization. Note this design was modified slightly after optimization with the final design presented in Section 19 NED Plan of this document.
- <u>After ADM (NRD) Design</u> – refinement of the USACE ADM Design (wet dam only). Flowage easement pool lowered to NRD top of dam. Used to match real estate takings of NRD Design. This design was considered a candidate for NED but it was found to impact the same amount of real estate as the After ADM (Balanced) Design and was therefore not adopted.
- <u>NED Design</u> – National Economic Development (NED) plan design. This design added a slight modification to the outlet works of the After ADM (Balanced) Design in response to Project Development Team (PDT) review. The conduit outlet invert was raised from 1126 ft to 1139.46 ft NAVD88 to elevate the outlet into more stable geology (glacial till). However, the results presented were not significantly sensitive to this change. See Section 19 and Appendix A-2A of this document for a discussion of these results.

The After ADM (Balanced) Design is the focus of this report. This design led to the NED Plan design presented in Section 19. Other important designs are the ADM wet and dry dams. The ADM Design of the dry dam was used to determine federal interest in DS19.

The NED design presented is still tentative and includes only a simplified hydrologic loading curve and not a risk-based design, which will be completed in a later phase of the study. Refer to the Risk to Life Safety Appendix (Appendix L) for the simplified hydrologic loading curve.

While the nonfederal sponsor, the Papio-Missouri River Natural Resources District (NRD), was primarily interested in building a dam with a permanent pool at this site ("wet" dam), a dry dam paper exercise was considered based on guidance and feedback at the TSP and ADM milestones in order to determine if a dam could be justified just on Flood Risk Management (FRM) costs and benefits. The dry dam design was not optimized to balance cut-and-fill and was completed as only a paper exercise for FRM benefits.

The dry dam paper exercise at the time of the ADM meeting (ADM Design dry dam) had the same spillway invert elevation criteria (at top of flood control pool) and width (400 ft) as the wet dam. This wet dam design had been used to determine justification on FRM costs and benefits and was selected based on spillway cut and embankment fill balance. it's the dry dam outlet was also sized to approximate the outflow of the wet dam design for the 0.2 percent annual exceedance probability (AEP) to provide consistency between the two designs for large events.

In the case of the wet dam designs, the elevation of the multipurpose pool and the flood pool were determined based on design principles used for the four existing Papillion Creek Dams in the Papillion Creek basin (Cunningham Lake, Standing Bear Lake, Zorinsky Lake, and Wehrspann Lake). This maintains consistency to the existing Papillion Creek Dams. The top of the multipurpose pool and the outlet invert were set based on the 100-year sediment pool.

The minimum spillway crest elevation and top of flood control pool were determined by routing a reservoir a design flood (RDF) over the full multipurpose pool for the wet dam alternatives and an empty pool for the dry dam alternatives. The wet dams assumed 97 percent of the standard project flood (SPF) as the RDF to avoid inundating Highway 6. The probable maximum flood (PMF) was then routed through the reservoir with antecedent pools required by ER 1110-8-2(FR), *Inflow Design Floods for Reservoirs* (USACE, 1991), to compute the maximum PMF pool.

The probable maximum precipitation (PMP) was determined through optimization in HEC-HMS version 4.4beta using HMR52 Storm. Optimization considered maximization of peak flow, inflow volume, and pool elevation.

Unit hydrographs were determined from the existing FYRA 2018 (FYRA, 2018) models which were calibrated to three recent events with radar precipitation data. These unit hydrographs were then peaked at the dam by 125, 150 and 175 percent. The 125 percent peaking was used for the RDF modeling and the 150 and 175 percent peaking was used for the spillway design flood routing and sensitivity. Note that 175 percent is outside the typical peaking range required, but it was determined more in line with assumptions from past studies and leveraged for sensitivity analysis. Frequency events were modeled without unit hydrograph peaking.

Both a Most Reasonable PMF (MR PMF) and a Reasonable High PMF (RH PMF) were considered in the spillway optimization. A Reasonable Low will be determined in another phase of the project. A family of spillway crest elevation and width combinations were used to help optimize the cut-and-fill to reduce the costs at the site.

The top of dam elevation was determined by routing the MR PMF over the antecedent pool set to the top of flood control (FC) with three feet of freeboard added. This was more critical than the RH PMF max pool without freeboard.

Frequency event modeling for all the wet dam designs after ADM (except the NED Plan design) are the same because they have the same outlet and their spillway elevations are higher than the 0.2 percent AEP event pool elevation. The outlet was modified for the NED Plan but the change increases the benefits of the project because flows out of the dam decreased.

Note that the spillway optimization with cut-and-fill was not available at the time a pool was needed by the Omaha District Real Estate section before the ADM milestone so a pool of 1192.4 feet-NAVD88 was provided. This was the pool presented at the ADM meeting in June 2020. It was the elevation of the maximum of the range of PMF pools considered at the time. Adopted results for real estate flowage easement ideally would have been the max pool of the Reasonable High PMF of the dam design with the best balance of cut and fill. This was an elevation of 1186.6 ft-NAVD88 for the ADM design and 1185.4 ft-NAVD88 for the After ADM (Balanced) Design. This means real estate costs for the ADM might have been overestimated for the wet dam scenario at the time of the ADM milestone.

Figure E1 shows the NED plan design. Table E1 and E2 list pertinent information for the NED design. Figure E2 shows the NED dam location and design pools.

Figure E3 and E4 show the wet dam and dry dam paper exercise at the time of ADM. Figure E5 compares the pool elevations of these dry and wet dam designs. The dry dam design shown was used to determine federal interest based on only FRM benefits.

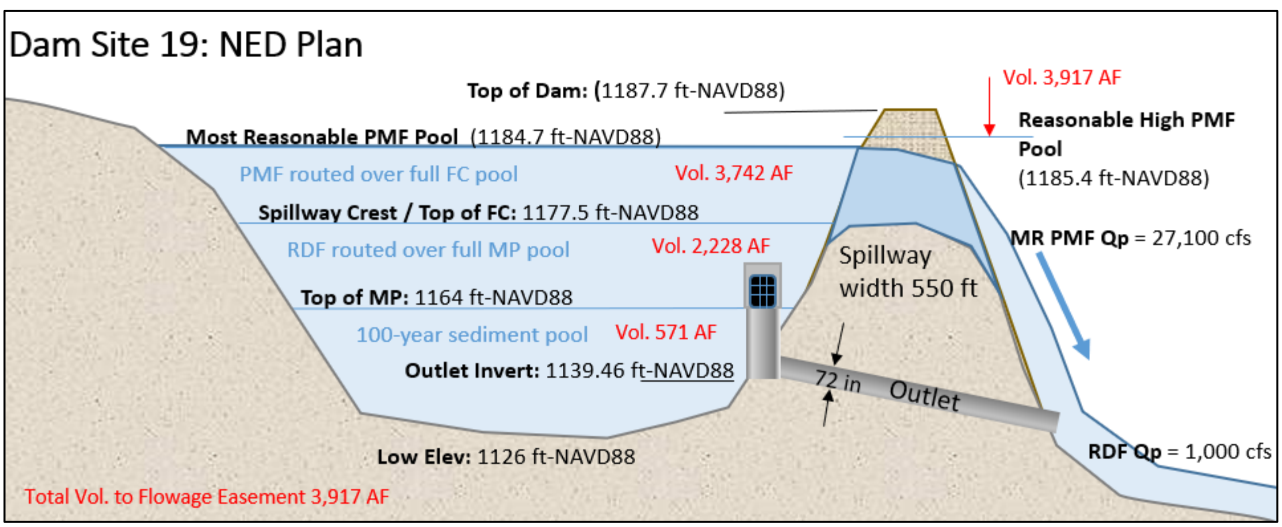

Figure E1. NED Design.

Table E1. Design Pertinent Information (Precipitation)

Precipitation	
Reasonable High Probable Maximum Precipitation (RH PMP) - 1.05*MR PMP	
72-hour total depth (in)	39.2
1-hour max depth (in)	15.4
5-min max depth (in)	1.68
Most Reasonable Probable Maximum Precipitation (MR PMP)	
72-hour total depth (in)	37.4
1-hour max depth (in)	14.6
5-min max depth (in)	1.6
Reservoir Design Flood (Wet Dam Design) - 0.96*SPS	
96-hour total depth (in)	15.17
1-hour maximum depth (in)	3.60
5-min max depth (in)	0.3

Table E2. NED Plan Pertinent Information

	NED Plan Design
Spillway Design Flood - RH PMF	
Peak inflow (cfs)	41,300
Peak outflow (cfs)	32,000
Inflow volume (AF)	7438
Spillway Design Flood - MR PMF	
Peak inflow (cfs)	34,500
Peak outflow (cfs)	25,100
Inflow volume (AF)	6868
Reservoir Design Flood	
Peak inflow (cfs)	7,100
Peak outflow (cfs)	930
Inflow volume (AF)	2286
Top of Dam (ft)	1187.7
RH PMF Pool (ft) – Flowage Easement	1185.4
MR PMF Pool (ft)	1184.7
Spillway Crest (ft)	1177.5
Top of Flood Control Pool (ft)	1177.5
Top of Multipurpose Pool (ft)	1164.0
Outlet Invert Elevation (ft)	1164.0
Outlet Culvert Invert (ft)	1139.46
Min Pool Elevation (ft)	1126.0

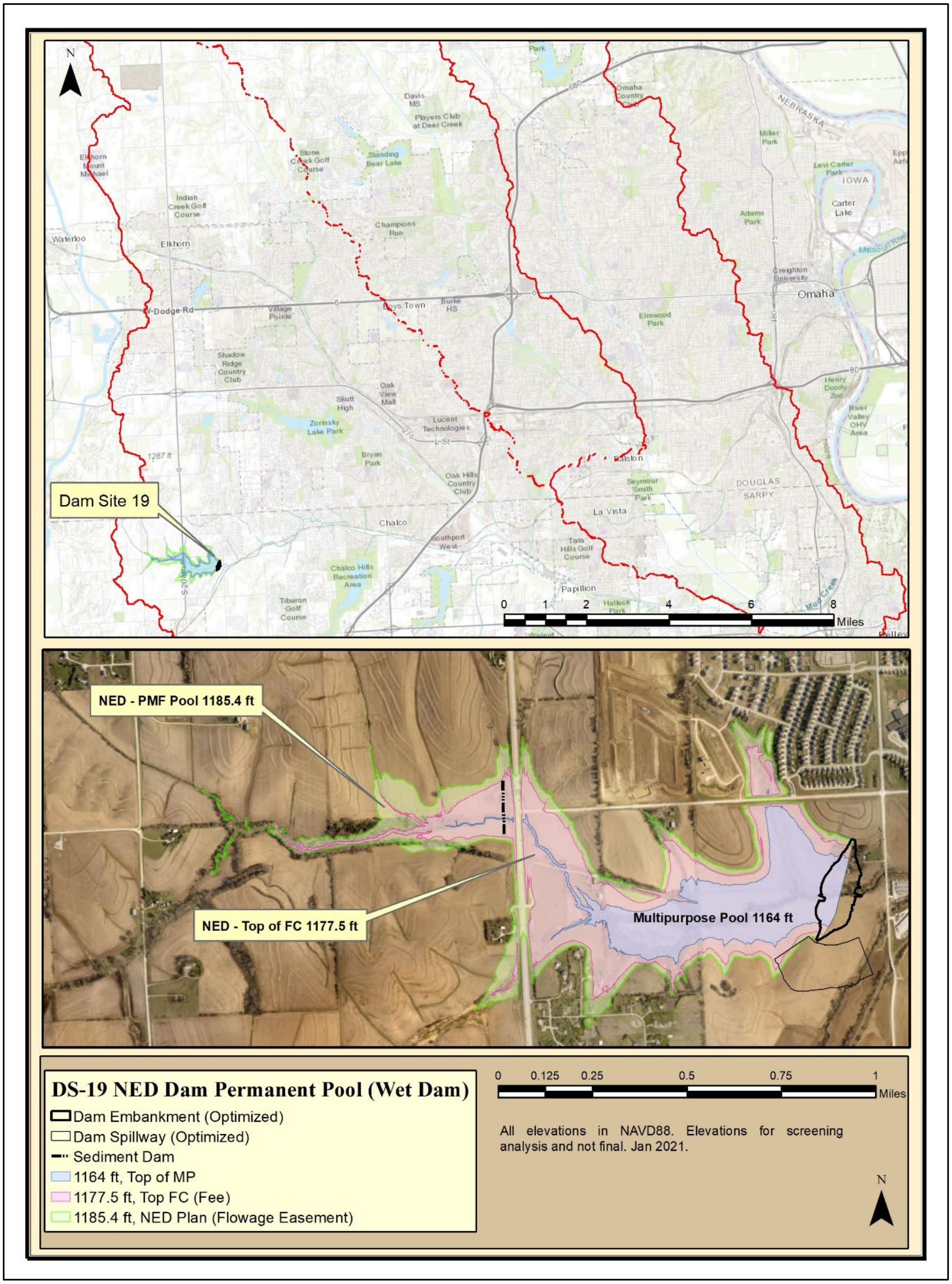

Figure E2. Project Location and Pools

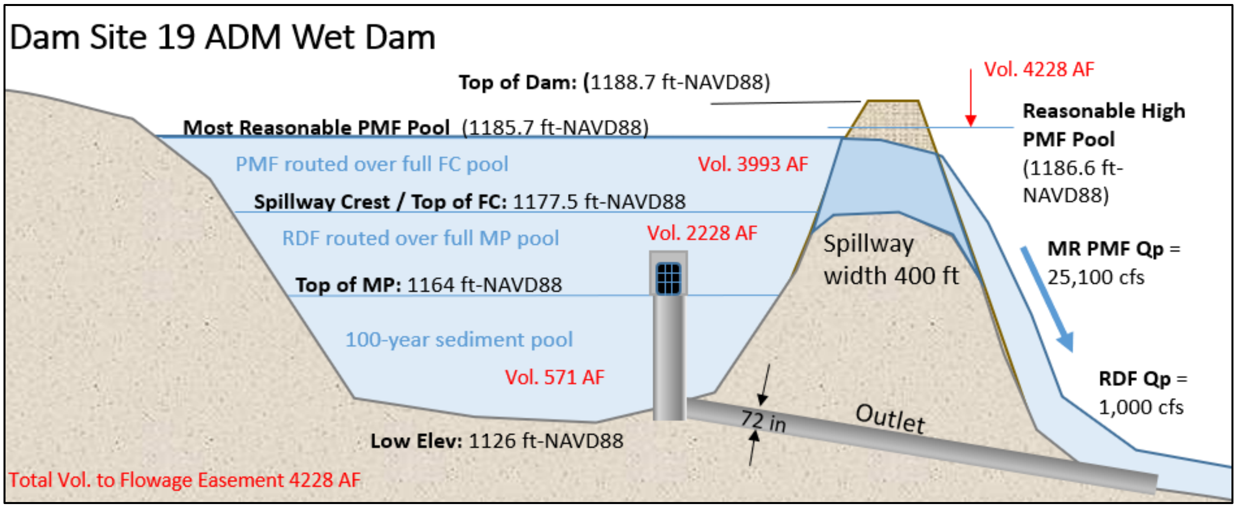

Figure E3. ADM wet dam design

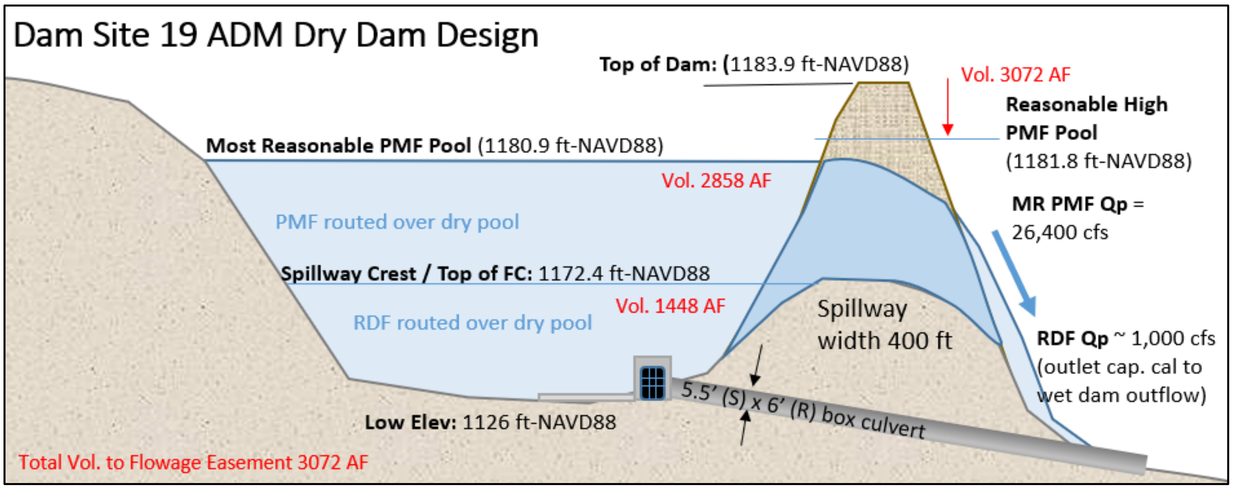

Figure E4. ADM dry dam paper exercise design

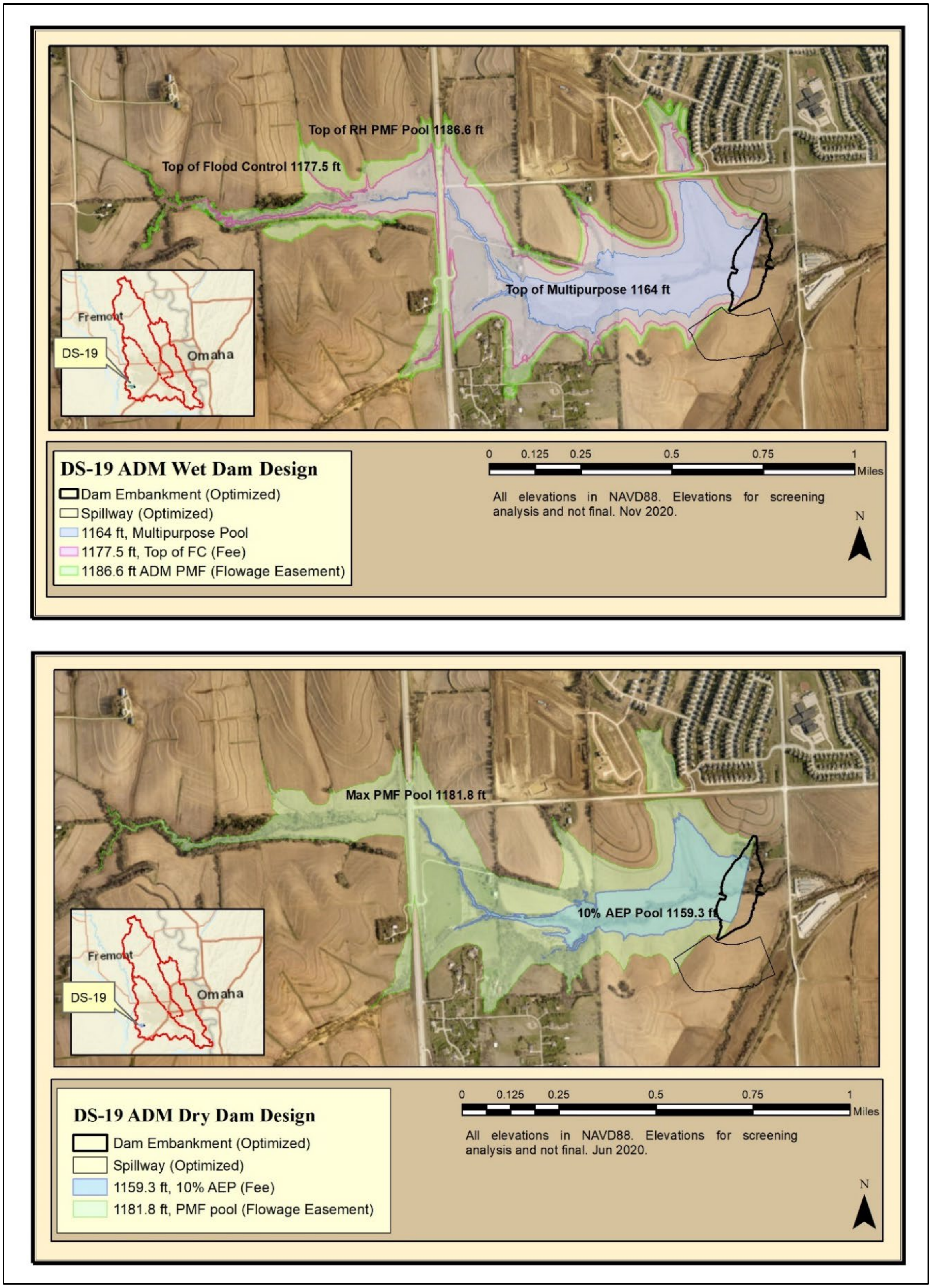

Figure E5. ADM dry and wet dam pool comparison

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1 Purpose

The purpose of this general reevaluation report (GRR) study was to model flood risk management (FRM) alternatives in the Papillion Creek watershed. This Hydrology Appendix documents the DS19 NED Plan design as well as portions of other designs considered. The NED incorporates input from the Tentatively Selected Plan (TSP) and Agency Decision Milestone (ADM) meetings. An array of designs is presented that lead up to the determination of the NED plan design. Current USACE standards were used including Engineering Regulation 1110-8-2(FR), *Inflow Design Floods for Dams and Reservoirs* (USACE, 1991). The design presented is still tentative and includes only a simplified hydrologic loading curve and not a risk-based design, which will be completed in a later phase of the study.

Design criteria were generally consistent with the four existing Papillion Creek dams but updated to current USACE standards including Engineering Regulation 1110-8-2(FR). DS19 was designed as a dam with a permanent multipurpose pool ("wet" dam). However, two dry-dam paper-exercise designs were also included in this document to determine whether there is federal interest in the FRM portion of the design and optimize costs. Both dry dam paper exercises are presented in this report, but the focus is on the design used for FRM benefits. The dry dam alternative is only presented in the Cost Optimization section.

The nonfederal project sponsor was the Papio-Missouri River Natural Resources District (NRD).

Refer to the Risk to Life Safety Appendix (Appendix L) for the simplified hydrologic loading curve.

2 Dam Site

DS19 is located on South Papillion Creek near Gretna, Nebraska in Sarpy County. South Papillion Creek is a tributary to West Papillion Creek. The contributing drainage area to the site is 4.3 square miles and the area is largely rural in land use. The project location is shown in Figure 1.

3 Vertical Datum

Table 1 shows the vertical datum conversions used in this study. Conversions from project datum (PD), National Geodetic Vertical Datum 1929 (NGVD29), and North American Vertical Datum 1988 (NAVD88) are not consistent between all the Papillion Creek sites. The Omaha Dam Safety section noted that PD does not equal NGVD29 for these sites.

To remain consistent with the NRD Design (HDR, 2018) study for DS19 and the LiDAR elevation data, the NAVD88 datum was used for all elevations unless otherwise stated. The Wehrspann Lake conversion were used for DS19 where needed because it is the closest existing Papillion Creek dam to DS19.

Table 1. Vertical Datum Conversions

Site	Papio No.	Conversion
Cunningham Lake	11	NAVD88 = PD + 0.243 ft
Standing Bear Lake	16	NAVD88 = PD - 0.371 ft
Zorinsky Dam	18	NAVD88 = PD + 0.487 ft
Wehrspann Lake	***20***	***NAVD88 = PD + 0.525 ft***
Cunningham Lake	11	NGVD29 = NAVD88 - 0.404 ft
Standing Bear Lake	16	NGVD29 = NAVD88 - 0.404 ft
Zorinsky Dam	18	NGVD29 = NAVD88 - 0.358 ft
Wehrspann Lake	***20***	***NGVD29 = NAVD88 - 0.344 ft***

4 Dam Designs Overview

The following lists the dam designs considered in the Papillion Creek GRR study. These names are used throughout this report.

- Original Design – USACE 1975 design.
- NRD Design – Sponsor's design developed by HDR (HDR, 2018) building off a model from FYRA (FYRA, 2018).
- TSP Design – design presented at the Tentatively Selected Plan (TSP) milestone meeting. Dam design was built on the Papio Natural Resources District (NRD) 2018 (HDR, 2018) design incorporating some preliminary updates to USACE guidance. The previous TSP report (USACE, 2020) describes this design.
- ADM Design – design presented at the ADM meeting and used to determine federal interest. Included both wet and dry dam designs. The dam design was updated to ER 1110-8-2(FR) and the spillway design flood was updated to HMR 51&52 with optimization. Future land use conditions were used in design. Spillway cut and embankment fill balance were not yet considered in design selection. A conservative flowage easement pool was assumed. The dry dam paper exercise was used to determine if the dam is justified just on flood risk management (FRM) benefits alone.
- After ADM (Balanced) Design – National Economic Development (NED) plan design. Best balance of spillway cut and embankment fill (cut-and-fill). Future land use conditions used in design. Included a dry dam paper exercise with approximate benefits of the wet dam for cost optimization.
- After ADM (NRD) Design – refinement of the USACE ADM Design (wet dam only). Flowage easement pool lowered to NRD top of dam. Used to match real estate takings of NRD Design. This design was considered a candidate for NED but it was found to impact the same amount of real estate as the After ADM (Balanced) Design and was therefore not adopted.
- NED Design – National Economic Development (NED) plan design. This design added a slight modification to the outlet works of the After ADM (Balanced) Design in response to Project Development Team (PDT) review. The conduit outlet invert was raised from 1126 ft to 1139.46 ft NAVD88 to elevate the outlet into more stable geology (glacial till). However, the results presented were not significantly sensitive to this change. See Section 19 and Appendix A-2A of this document for a discussion of these results.

The After ADM (Balanced) design was determined to be the NED plan and is therefore the focus of this report. Other designs where specifics are presented included the ADM dry and wet designs used to justify DS19 solely by FRM benefits and costs.

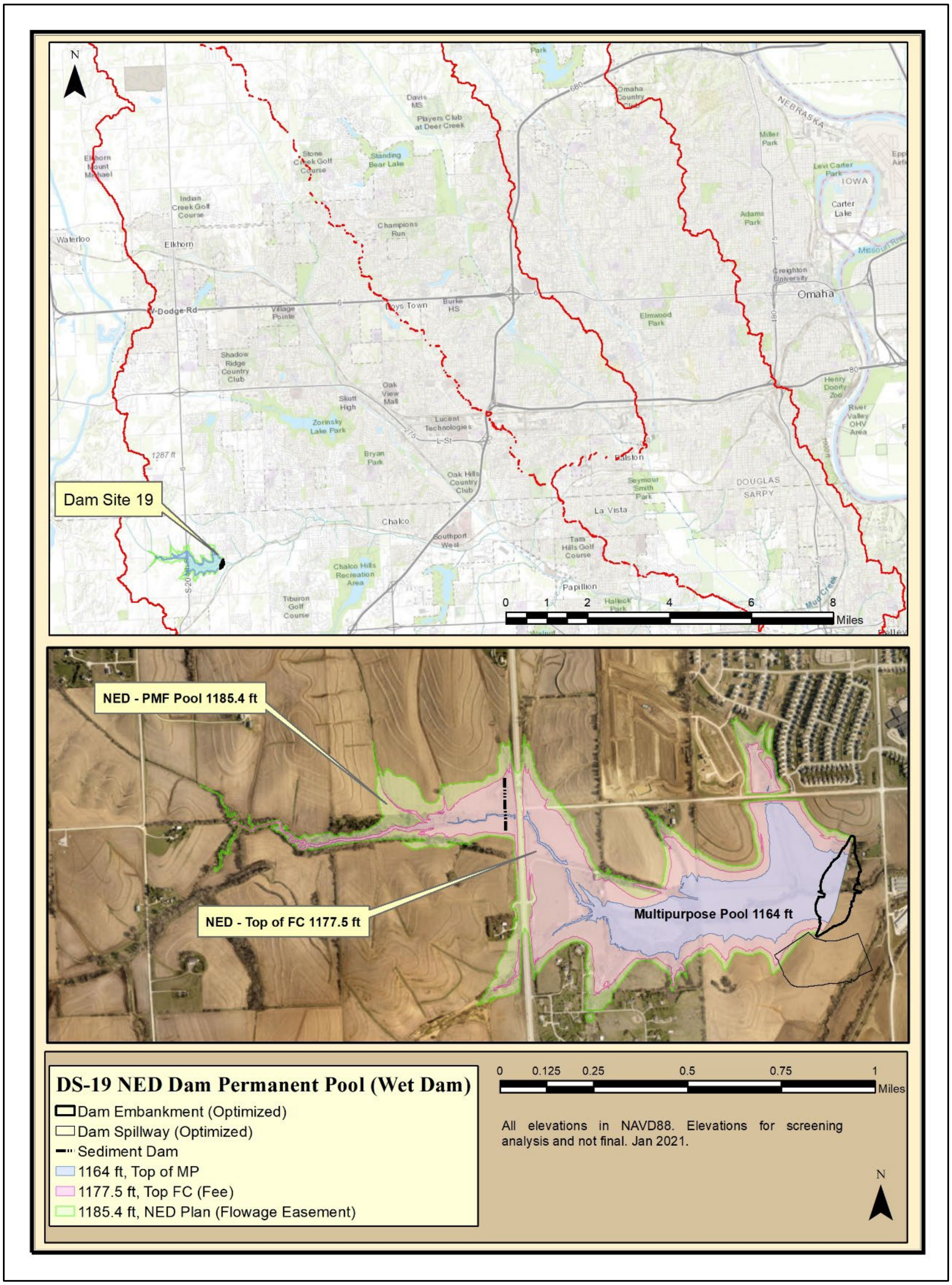


Figure 1. DS19 Location (Wet Dam Shown)

5 NED Design Compared to Past Designs

Table 2 compares the NED plan design [After ADM (Balanced)] with the USACE 1970s Original Design and the 2018 NRD Design (HDR, 2018). All designs shown are for dams with permanent pools (wet dams). The Original Design incorporated USACE standards from the 1970s while the NRD Design was produced to NRCS standards. The NRD design was tentatively updated to current USACE standards before the TSP milestone (USACE, 2020).

Designs before TSP had a 48-inch outlet. The wet dam ADM and After ADM Designs had 72-inch outlets to drop the flood control pool to avoid inundating Highway 6 during the reservoir design flood (RDF). All designs are fill-and-spill dams.

Figure 2 summarizes the general USACE design used for the After ADM dams. Note that two PMFs, Reasonable High (RH) and Most Reasonable (MR), were evaluated per current dam safety best practices in spillway optimization.

Note that the m.s.l. datum is a project datum and not equal to NGVD29 for DS19. Assuming the datum calculations of Wehrspann Lake, the conversion to NAVD88 is NAVD88 = PD + 0.525 ft.

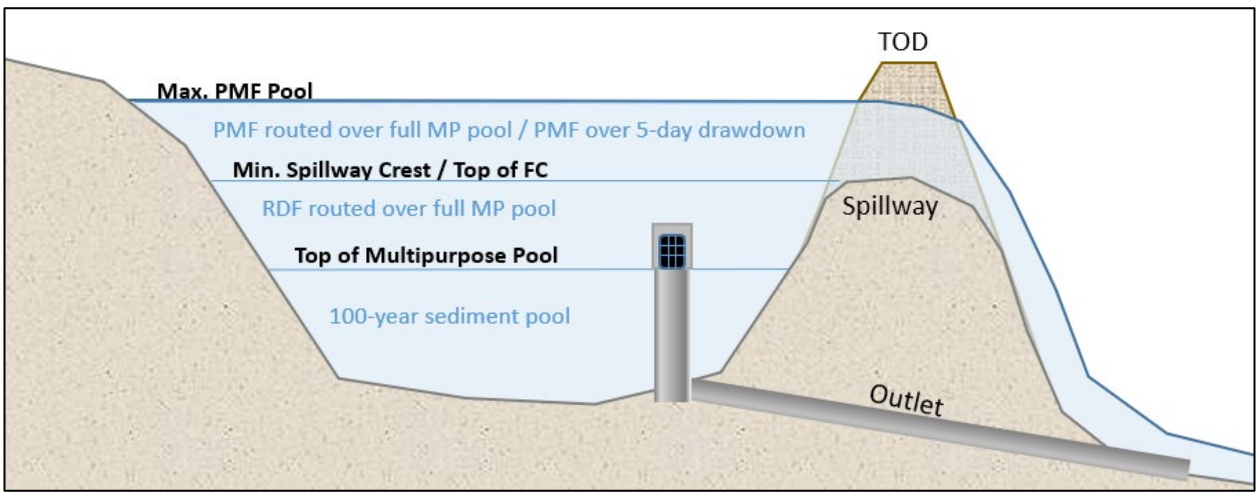


Figure 2. General Wet Dam Design

6 Reservoir Capacity Curve

The reservoir pool capacity curve was determined from 2016 LiDAR data using the Surface Volume tool in ArcMap version 10.2.2 in Batch mode. One-foot increments were used. Figure 3 shows the updated capacity curve. Figure 4 shows this updated curve compared with that used in the NRD Design (HDR, 2018).

Table 2. Wet Dam Design Comparisons

Pool Elevations	Original Design (1970s)	NRD Design (2018)	TSP Design (2020)	NED Plan Design (2020)
Criteria and Guidance:	HMR NO. 33	NRCS TR-60 NOAA Atlas 14 Site-Specific PMP	ER 1110-8-2(FR) HMR 51&52	ER 1110-8-2(FR) HMR 51&52
Top of Multipurpose Pool (MP)	Top of 100-year sediment pool with additional storage for low flow releases for environmental and aesthetic reasons.	Normal pool set to 1164 ft-NAVD88. Has sustainability ratio of ~ 2.5 percent. (Forecasted 100-year sediment volume up to 1153.0 ft, 74.6 AF.)	Same as NRD design.	Same as NRD design. Compared to 100-year sediment pools with observed rates and found to be realistic.
	1171.0 ft-msl ~ 1171.5 ft-NAVD88	1164 ft-NAVD88	1164 ft-NAVD88	1164 ft-NAVD88
Top of Flood Control	Reservoir Design Flood (RDF) routed over full MP pool with 25% UH peaking and outlet operational. RDF was the standard project flood (SPF) (USACE, 1971).	Principle Spillway Hydrograph (PSH) produced by 500-year event routed over top of full MP pool.	Same as NRD design.	RDF routed over full MP pool with 25% UH peaking and outlet operational. RDF was 96% of the standard project flood (SPF). SPF decreased to avoid HWY 6 becoming real estate fee acquisition.
	1182.0 ft-msl ~ 1182.5 ft-NAVD88	1177.0 ft-NAVD88	1177.0 ft-NAVD88	1177.5 ft-NAVD88
Spillway Crest	Minimum at top of RDF/SPF pool.	Top of PSH event routing (500-year event) rounded up to nearest foot.	Same as NRD design.	Top of flood control.
	1183.0 ft-msl ~ 1183.5 ft-NAVD88	1177.0 ft-NAVD88	1177.0 ft-NAVD88	1177.5 ft-NAVD88
Top of Surcharge (Max Pool)	Probable maximum flood (PMF) routed over: (1) flood control pool ½ full, (2) full flood control pool	Auxiliary Spillway Hydrograph (ASH) produced by combined 100-year and PMP rainfall: $P_{100} + 0.26(PMP\text{-}P_{100})$.	PMF determined from PMP from HMR 51&52 PMP routed over full flood control pool.	Reasonable High PMF routed over full flood control pool.
	1188.0 ft-msl ~ 1188.5 ft-NAVD88	1178.1 ft-NAVD88	1186.34 ft-NAVD88	1185.4 ft-NAVD88
Top of Dam	Max pool plus 3 feet of freeboard.	Freeboard Hydrograph (FBH) produced by site-specific PMP.	Max pool plus 3 feet of freeboard.	Most Reasonable PMF plus 3 feet freeboard
	1191.0 ft-msl ~ 1191.5 ft-NAVD88	1184.0 ft-NAVD88	1189.4 ft-NAVD88	1187.7 ft-NAVD88

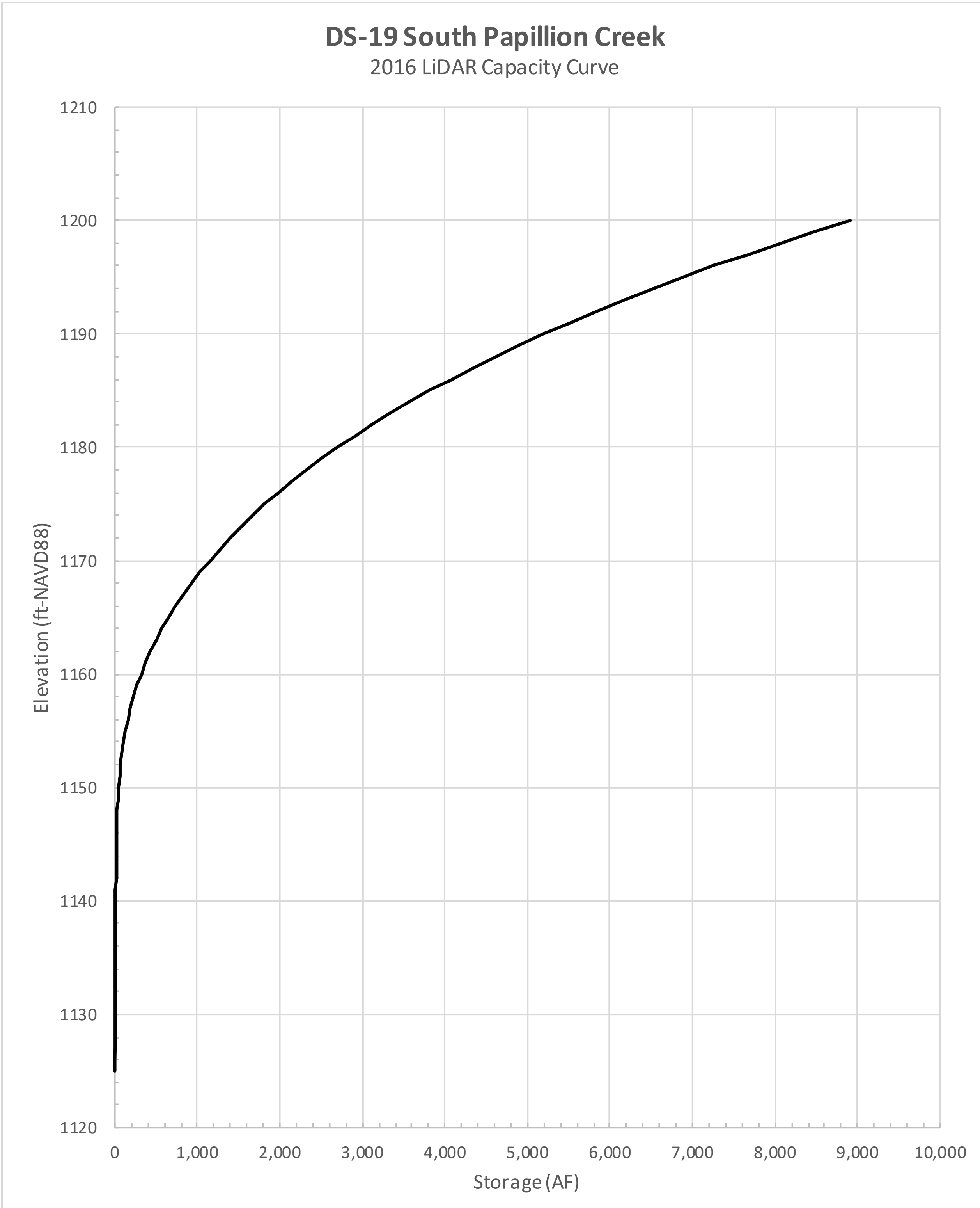


Figure 3. Updated DS19 Capacity Curve (datum NAVD88)

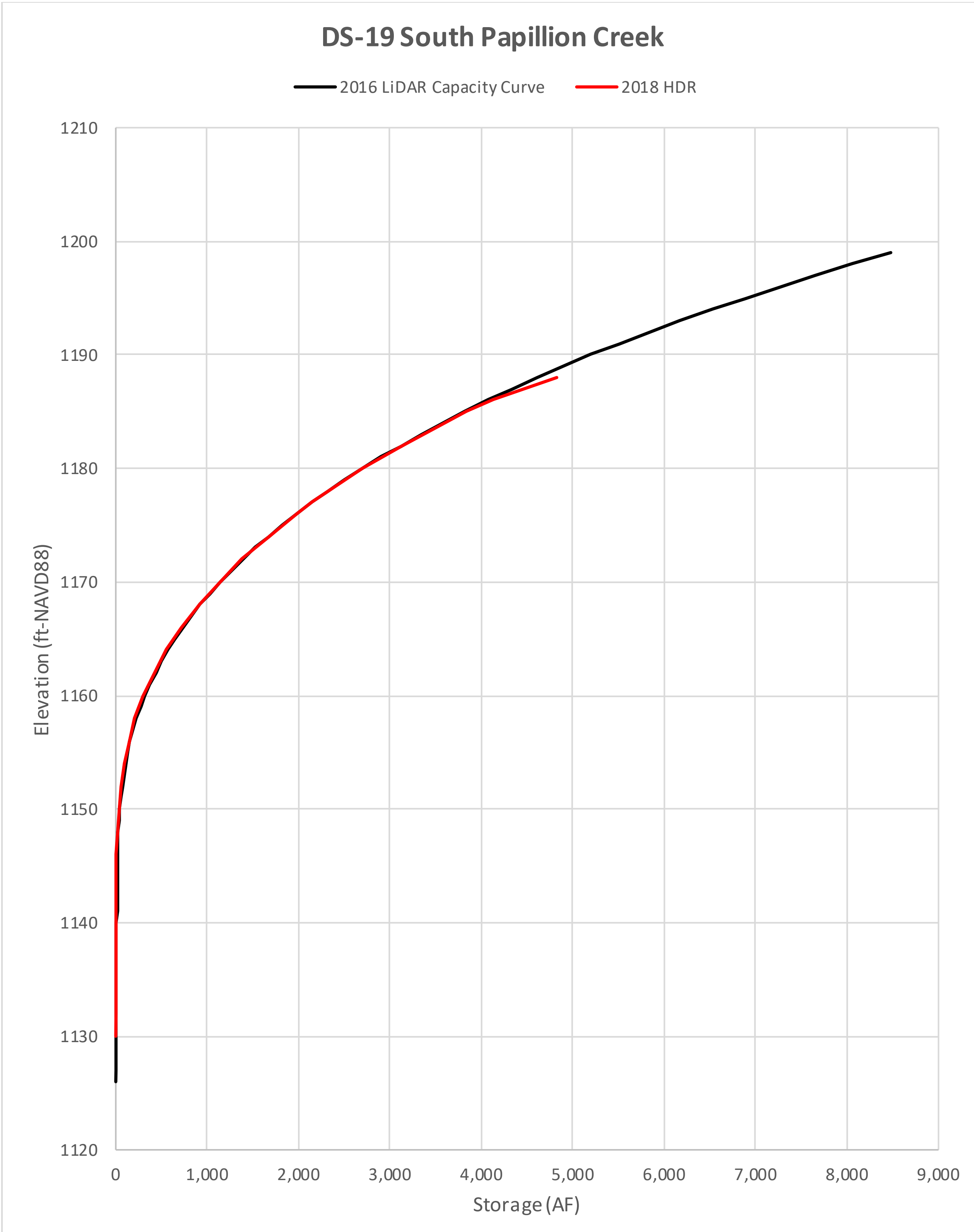


Figure 4. Comparison with Past Capacity Curve

7 Sediment Storage Depletion Rates

Sediment storage depletion rates were important in the design of DS19. Depletion of storage was important because the outlet structure invert elevation in past designs of the Papillion Creek Dams was set at or above the elevation of a sediment pool accumulation over a certain design life. This sediment accumulation is based on the paradigm that sediment deposits at the lowest pool elevations and builds upward.

This paradigm was maintained for the DS19 wet dam design in order to remain consistent with how the existing Papillion Creek Dams' multipurpose pools were determined. In the case of DS19, this results in a riser height of 44 feet based on the updated 2016 LiDAR elevation-storage curve and a 100-year sediment volume from the 1970s design memorandums [1,100 AF of sediment storage (USACE, 1971); -2.6 AF/year/square mile rate]. However, when additional analysis was undertaken based on observed sediment rates at the existing Papillion Creek Dams (WEST, 2013), a riser height between 35.5 and 29.5 feet was realistic.

Wehrspann Lake is the closest to the proposed DS19 location and its rate of sediment accumulation ranged from 0.7 AF/year/square mile of drainage area from 1984-1994 to 0.3 AF/year/square mile drainage area from 1994-2009. The total loss of storage over the period of record of surveys (1984-2009) was -0.5 AF/year/square mile of drainage area. These rates are also similar with those for Zorinsky Lake to the north.

Communication with the Omaha District River and Reservoir Engineering Section revealed that many dams in the District have overdesigned sediment pools based on the paradigm of sediment deposition in the lowest portions of the reservoir. Observations through time have found that sediment deposition is largest near the tailwaters but depends on the pool duration and extent.

The riser height used in the NDR Design (HDR, 2018) was 1164 ft-NAVD88 with a sediment pool of 560 AF. This is a riser height of about 38 feet. This is a loss of storage of -1.3 AF/year/square mile of drainage area. While this rate was high compared with Lake Wehrspann and Zorinsky, it falls within range for the other built Papillion Creek Dams. Figure 5 and Table 3 show these rates of storage loss for the four existing Papillion Creek Dams. These were calculated from pool survey data from WEST (2013).

The riser height of 38 ft (1164 ft-NAVD88) was adopted for this study. This is consistent with the 2018 NRD design and the USACE TSP design (USACE, 2020).

Table 3. Observed loss of gross storage for existing Papillion Dams

Observed Loss In Gross Storage				
Project	High (AF/yr/sq mi)	Low (AF/yr/sq mi)	Average (AF/yr/sq mi)	Years of Data
Cunningham Lake (Papio No. 11)	-6.4	-1.6	-4	34
Standing Bear (Papio No. 16)	-9	-1.4	-5.6	34
Zorinsky Lake (Papio No. 18)	-0.9	-0.9	-0.9	23
Wehrspann Lake (Papio No. 20)	-0.7	-0.3	-0.5	26

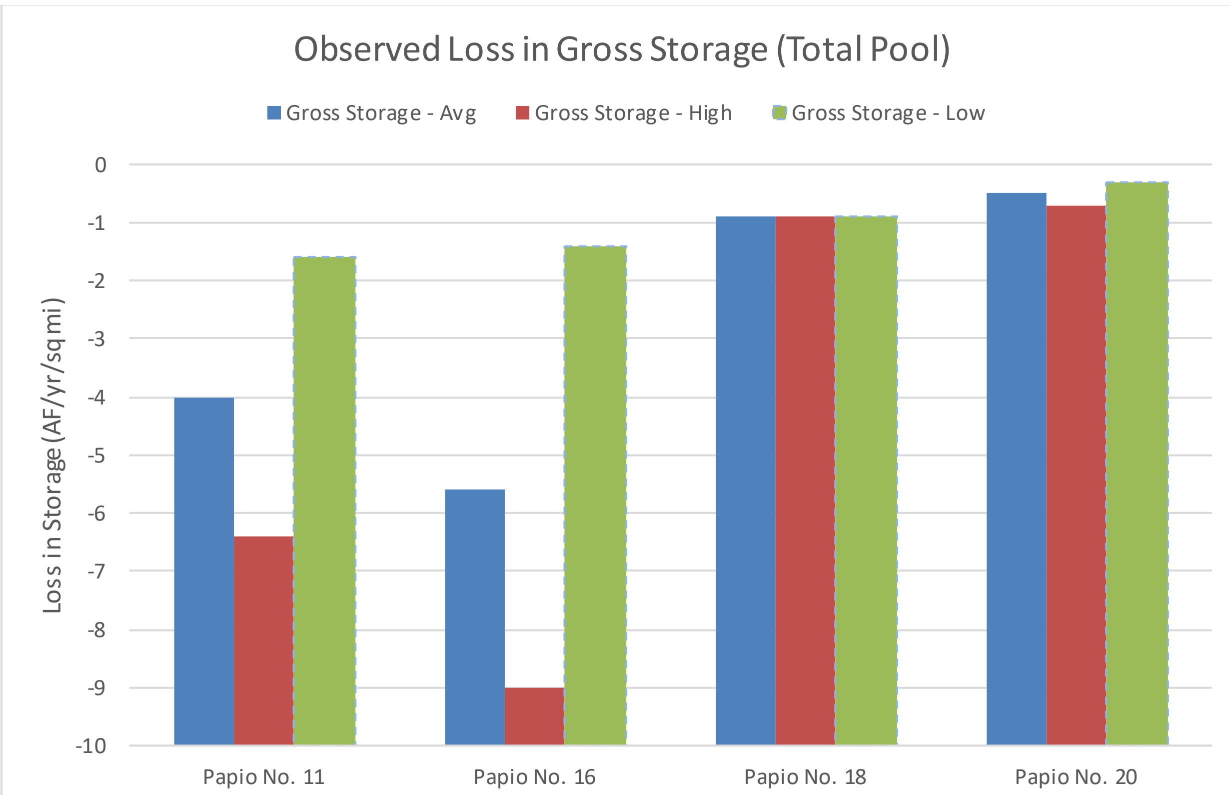


Figure 5. Observed loss of gross storage to sediment for existing Papillion Dams. A loss rate of -1.3 AF/year/square mile was assumed for DS19 wet dam design.

8 Dam Outlet Structures

8.1 Wet Dam Outlet Structure

In the case of the wet dam design, the multipurpose pool was set to the invert elevation of the outlet structure riser which rests at the top of the 100-year sediment pool. This is consistent with how the existing four Papillion Creek Dams were designed.

Figure 6 and Table 4 show the outlet rating curve for the wet dam structure. The updated DS19 designs (USACE ADM and After ADM designs) have a 72-inch diameter outlet opposed to the 48-inch diameter outlet of the HDR and USACE TSP designs. This change was made to help lower the top of flood control pool to 1177.5 ft-NAVD88 to avoid impacting Highway 6 while still reducing downstream flood risk. Note that this curve was updated later in the study to account for a raise in the outlet culvert invert. The curve shown was used through most of the study so it is provided here in place of the NED design plan curve. The NED outlet rating curve is documented in Section 19.

Table 5 summarizes the outlet designs of the existing Papillion Creek Dams referenced; all these dams are 'wet' dams with permanent pools and have their outlet structure inverts set to an elevation above the 100-year sediment accumulation in the pool. The additional storage is for environmental and aesthetic releases to the downstream channel.

It was determined based on sediment accumulation rates at observed Papillion Creek sites that the outlet structure invert elevation used in the HDR and TSP designs was reasonable and was retained in this study.

This feasibility-level design did not include design of a low-level outlet to meet USACE drawdown requirements. This analysis is deferred to a later design phase.

The downstream channel capacity for DS19 is 4,550 cfs based on information from the Omaha District Hydraulics section.

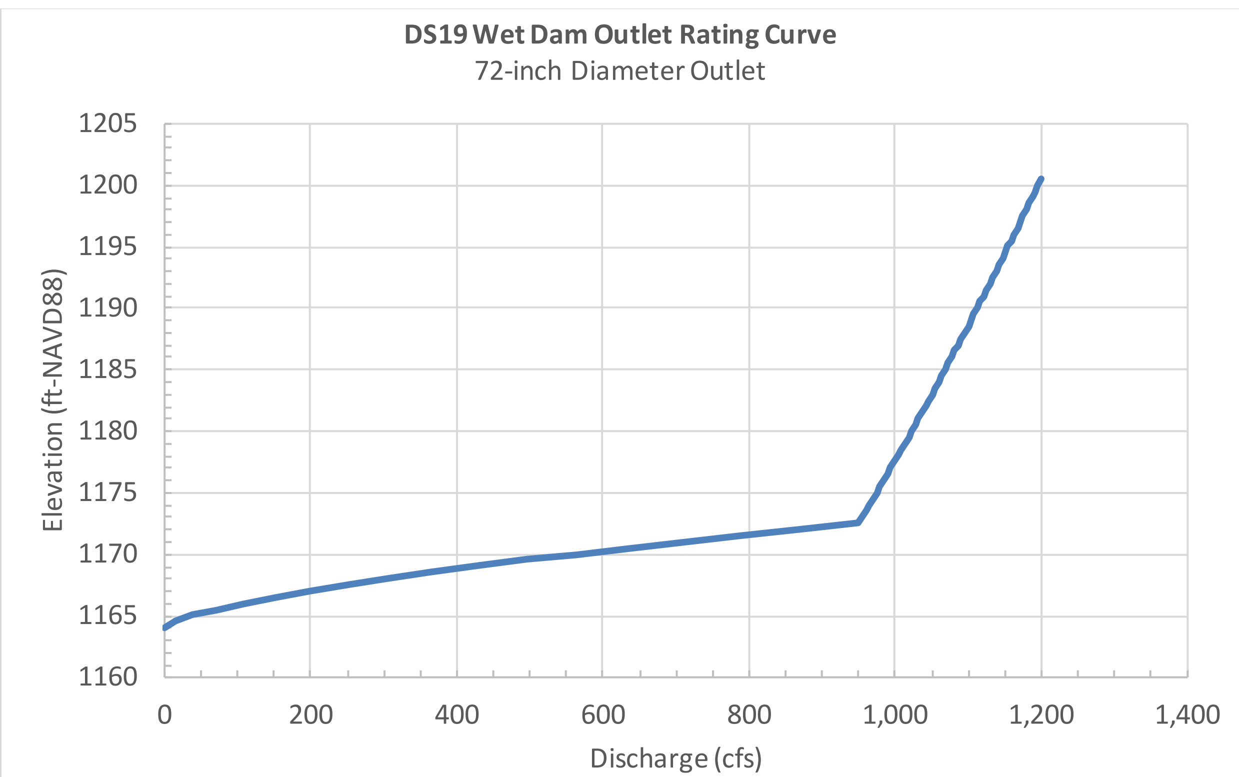


Figure 6. Wet dam lower-level service outlet rating curve

Table 4. Wet Dam Lower-level Outlet Rating Curve (72-inch Outlet)

Pool (ft)	Discharge (cfs)	Pool (ft)	Discharge (cfs)	Pool (ft)	Discharge (cfs)
1164.03	0.0	1176.53	989	1189.03	1104
1164.53	13.6	1177.03	994	1189.53	1108
1165.03	38.4	1177.53	999	1190.03	1112
1165.53	70.5	1178.03	1004	1190.53	1117
1166.03	109	1178.53	1008	1191.03	1121
1166.53	152	1179.03	1013	1191.53	1125
1167.03	200	1179.53	1018	1192.03	1129
1167.53	251	1180.03	1022	1192.53	1134
1168.03	307	1180.53	1027	1193.03	1138
1168.53	367	1181.03	1032	1193.53	1142
1169.03	429	1181.53	1036	1194.03	1146
1169.53	495	1182.03	1041	1194.53	1150
1170.03	564	1182.53	1046	1195.03	1155
1170.53	636	1183.03	1050	1195.53	1159
1171.03	711	1183.53	1055	1196.03	1163
1171.53	789	1184.03	1059	1196.53	1167
1172.03	869	1184.53	1064	1197.03	1171
1172.53	950	1185.03	1068	1197.53	1175
1173.03	955	1185.53	1073	1198.03	1179
1173.53	960	1186.03	1077	1198.53	1183
1174.03	965	1186.53	1082	1199.03	1187
1174.53	969	1187.03	1086	1199.53	1191
1175.03	974	1187.53	1091	1200.03	1195
1175.53	979	1188.03	1095	1200.53	1199
1176.03	984	1188.53	1099		

Table 5. Existing Papillion Dam Outlet Structures

Project	DA (sq mi)	Outlet Invert Design	Height of Intake Invert above Zero Storage (ft)
Cunningham Lake (Papio No. 11)	17.8	Top of 100-yr sed pool & low flow storage	36
Standing Bear Lake (Papio No. 16)	6	Top of 100-yr sed pool & low flow storage	44
Zorinsky Lake (Papio No. 18)	16.4	Top of 100-yr sed pool & low flow storage	49.5
Wehrspann Lake (Papio No. 20)	13.1	Top of 100-yr sed pool & low flow storage	26.8

8.2 Dry Dam Outlet Structure

The outlet structure design for the DS19 dry dam was determined through the investigation of outlets for existing dry dams in the Omaha District and consultation with the Omaha District River and Reservoir Engineering section. The downstream capacity of the channel was referenced to make sure the flow is contained in the channel.

The design is a 5.5-ft (Span) x 6-ft (Rise) box culvert sized to approximate the outflow of the wet dam for the 0.2-percent AEP event to provide consistency at large events between the two designs and allow the passage of a skid loader for clean out between large events. This outlet design passes sediment more efficiently to better maintain flood storage, allows for easier cleanout of the outlet works, and reduces downstream erosion.

Based on input from the Omaha District River and Reservoir Engineering section, the proposed design with the 5.5-ft (Span) x 6-ft (Rise) outlet would be largely self-cleaning in that the more frequent events would pass through with minor detention and carry sediment that would have otherwise been entrained behind the dam. This has the added benefit of decreasing stream degradation downstream in that the water maintains its sediment load instead of becoming "hungry" at the dam outlet and degradating the downstream channel, exposing utilities and eroding into property.

If the outlet structure invert elevation for the DS19 wet dam was set to the top of the 100-year sediment pool elevation calculated from the 1975 DM 100-year sediment load of 1100 AF, the height of the riser would be 44 feet based on the updated elevation storage curve (2016 LiDAR data curve). If this was used in the dry dam design and assumed to be full for the reservoir design flood routing to set the minimum spillway elevation, then the dry dam design for DS19 would be equivalent to the wet dam design.

Figure 7 shows the outlet works for Kelly Road Dry Dam in Aurora, Colorado. This design includes a riser as well as a lower level outlet with a trash rack. This design was presented to the chiefs of Hydrology and the River and Reservoir Engineering sections in the Omaha District and it was decided to remove the riser from design and increase the size of the lower level outlet. As noted previously, this design passes sediment more efficiently to better maintain flood storage, allows for easier cleanout of the outlet works, and reduces downstream erosion.

Other dry dams investigated were Bull Hook Dam and Scott Coulee Dam near Havre, Montana and Cedar Canyon Dam near Rapid City, South Dakota. The drainage area of these dams varied significantly ranging from 54 to 0.71 square miles. All were closed in the 1950s. Reservoir Design Floods varied and included the 1% AEP, the Standard Project Flood (SPF) and a hypothetical event twice the size of the flood of record. Spillway design floods were either the PMF or ten times the flood of record. Sediment pools were designed to contain either 100 years or 50 years of sediment deposition or sediment deposition was not considered due to small sediment loads. The discharge from the lower-level outlet works varied from 49 to 570 cfs and their diameters ranged from 24 to 48 inches. Some of these dams had outlet inverts at the bottom of the pool and others were raised to accommodate sediment storage. Cedar Canyon Dam's outlet invert was set at the top of the 50-year sediment pool which is the design life of the structure.

The 50-percent AEP flow immediately below the dam from HEC-HMS modeling is 1,540 cfs. The downstream capacity of the channel immediately below the dam is 4,550 cfs based on information from the hydraulics model.

Figure 8 and Table 6 show the outlet rating curve for the dry dam structure. The outlet is a 5.5 ft (Span) x 6 ft (Rise) box culvert.

Figure 7. Kelly Road Dry Dam Outlet Structure Aurora, Colorado

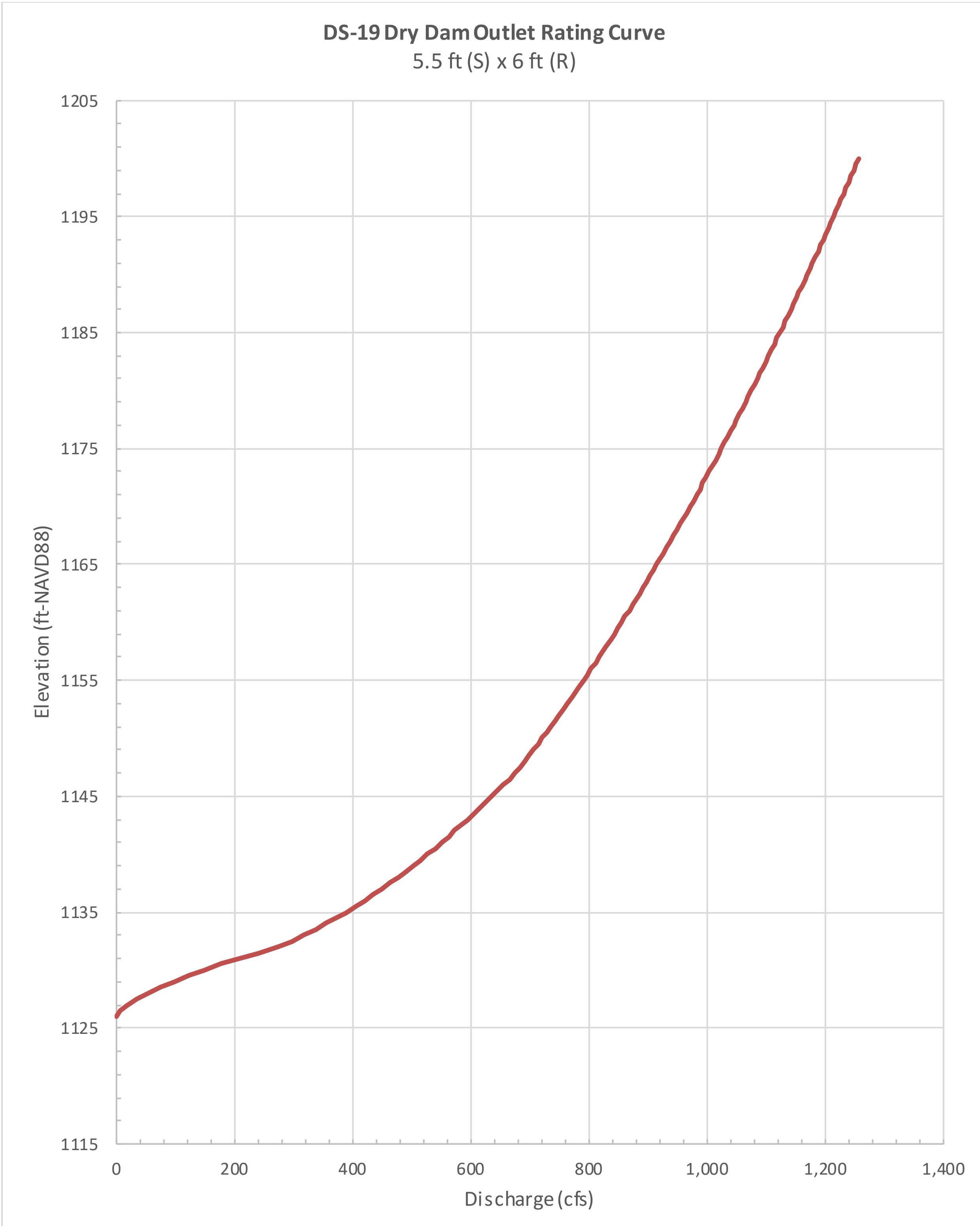


Figure 8. Dry Dam Lower-level Outlet

Table 6. Dry Dam Lower Level Outlet

Elev (ft-NAVD88)	Discharge (cfs)	Elev (ft-NAVD88)	Discharge (cfs)	Elev (ft-NAVD88)	Discharge (cfs)	Elev (ft-NAVD88)	Discharge (cfs)
1126	0	1146	655	1166	927	1186	1132
1126.5	6.6	1146.5	665	1166.5	932	1186.5	1137
1127	18.7	1147	674	1167	938	1187	1142
1127.5	34.4	1147.5	683	1167.5	944	1187.5	1146
1128	53	1148	691	1168	949	1188	1151
1128.5	74	1148.5	698	1168.5	955	1188.5	1156
1129	97.3	1149	706	1169	960	1189	1160
1129.5	123	1149.5	713	1169.5	966	1189.5	1165
1130	150	1150	721	1170	971	1190	1169
1130.5	179	1150.5	728	1170.5	977	1190.5	1174
1131	209	1151	735	1171	982	1191	1178
1131.5	242	1151.5	742	1171.5	987	1191.5	1183
1132	275	1152	749	1172	993	1192	1187
1132.5	297	1152.5	757	1172.5	998	1192.5	1192
1133	318	1153	763	1173	1003	1193	1196
1133.5	337	1153.5	770	1173.5	1009	1193.5	1201
1134	355	1154	777	1174	1014	1194	1205
1134.5	373	1154.5	784	1174.5	1019	1194.5	1209
1135	389	1155	791	1175	1024	1195	1214
1135.5	405	1155.5	797	1175.5	1029	1195.5	1218
1136	420	1156	804	1176	1035	1196	1222
1136.5	435	1156.5	811	1176.5	1040	1196.5	1227
1137	449	1157	817	1177	1045	1197	1231
1137.5	463	1157.5	824	1177.5	1050	1197.5	1235
1138	477	1158	830	1178	1055	1198	1240
1138.5	490	1158.5	836	1178.5	1060	1198.5	1244
1139	502	1159	843	1179	1065	1199	1248
1139.5	515	1159.5	849	1179.5	1070	1199.5	1252
1140	527	1160	855	1180	1075	1200	1257
1140.5	539	1160.5	861	1180.5	1080		
1141	550	1161	867	1181	1085		
1141.5	562	1161.5	874	1181.5	1090		
1142	573	1162	880	1182	1094		
1142.5	584	1162.5	886	1182.5	1099		
1143	595	1163	892	1183	1104		
1143.5	605	1163.5	897	1183.5	1109		
1144	615	1164	903	1184	1114		
1144.5	626	1164.5	909	1184.5	1118		
1145	636	1165	915	1185	1123		
1145.5	645	1165.5	921	1185.5	1128		

8.3 Comparison of Wet Dam and Dry Dam Rating Curves

Figure 9 compares the outlet rating curves of the wet and dry dams for DS19. Elevation 1164.0 ft-NAVD88 is the top of multipurpose pool for the wet dam. Elevation 1126.0 ft-NAVD88 is the lowest elevation of the dry dam with an empty pool.

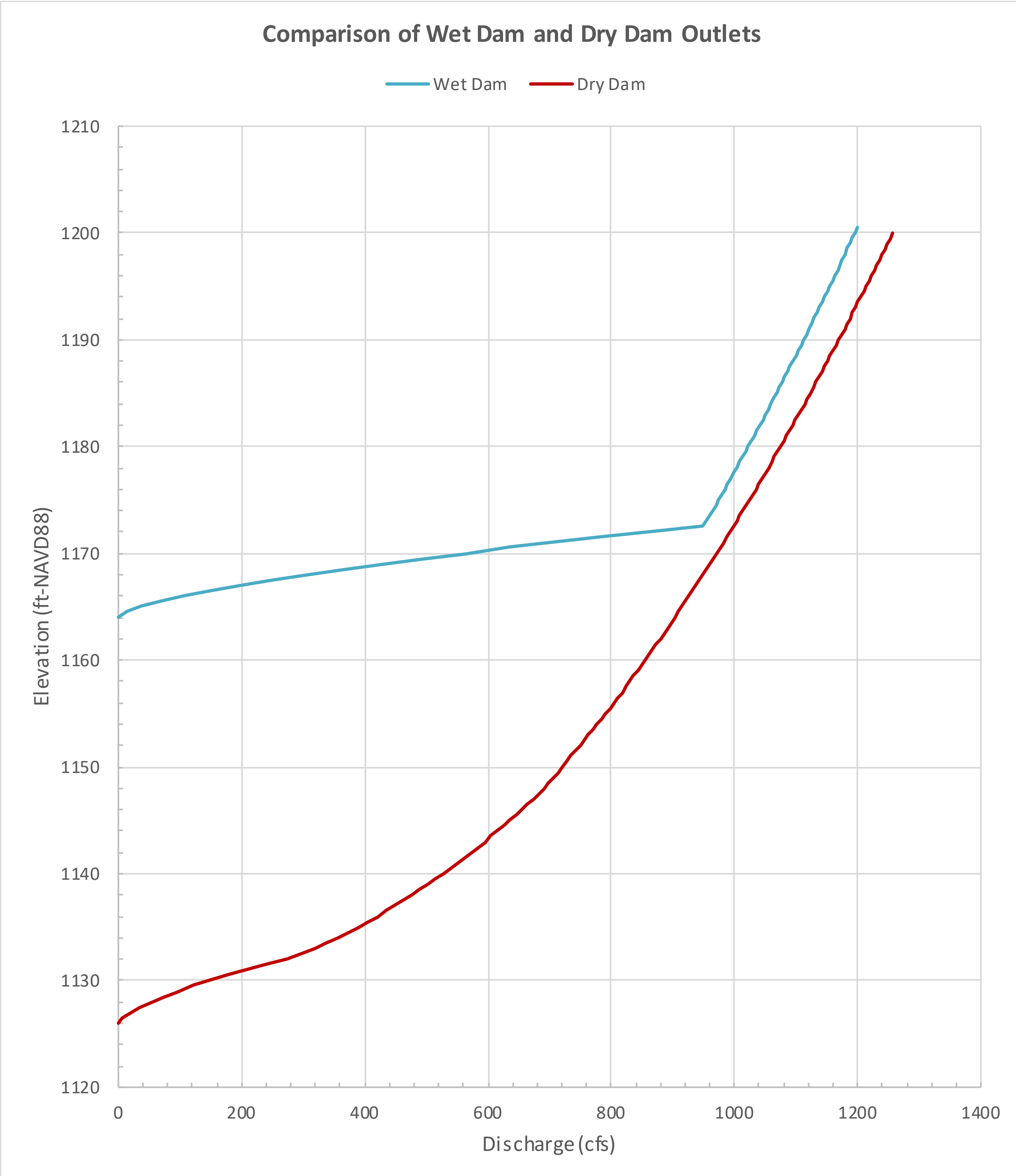


Figure 9. Comparison of Wet and Dry Dam Outlet Rating Curves

9 Standard Project Storm

The reservoir design flood (RDF) for DS19 was used to set the minimum spillway elevation and was assumed to be the standard project flood (SPF) produced by the standard project storm (SPS) determined in the 1970s design of the dam. However, the design memorandum related specifically to this storm could not be found in the USACE archive. Due to this, a forensic analysis of the existing dams' SPSs was conducted to determine a reasonable SPS to be used in DS19 preliminary design.

Table 7 summaries the drainage areas, SPS total depths, SPS maximum one-hour depths, and SPS durations. All SPSs were 96 hours in duration and had the same hyetograph pattern as shown in Figure 10.

The SPS total depth and maximum 1-hour depths were plotted for the sites to look for overall patterns. It was determined that SPS total 96-hour depths and 1-hour maximums decreased as expected with increases in drainage area. Figure 11 shows these comparisons.

Since DS10 and DS19 have the same area (4.3 square miles) and all the SPSs sampled in the watershed are very similar, even though they are spatially spread out, the SPS for DS10 was adopted for analysis of DS19.

The adopted SPS for both sites is shown in Table 8, Table 9, and Figure 12.

Table 7. Referenced SPSs from Other Papillion Sites

Site	Drainage Area (sq mi)	SPS Total (in)	Max 1 Hr Depth (in)	SPS Duration (hrs)
Cunningham (Papio No. 11)	17.8	15.68	3.70	96
Standing Bear (Papio No. 16)	6	15.82	3.75	96
Zorinsky (Papio No. 18)	16.4	15.68	3.70	96
Wehrspann (Papio No. 20)	13.2	15.75	3.73	96
DS10 (Papio No. 10)	4.3	15.81	3.75	96
DS19 (Papio No. 19)	*No Document*	*No Document*	*No Document*	*No Document*

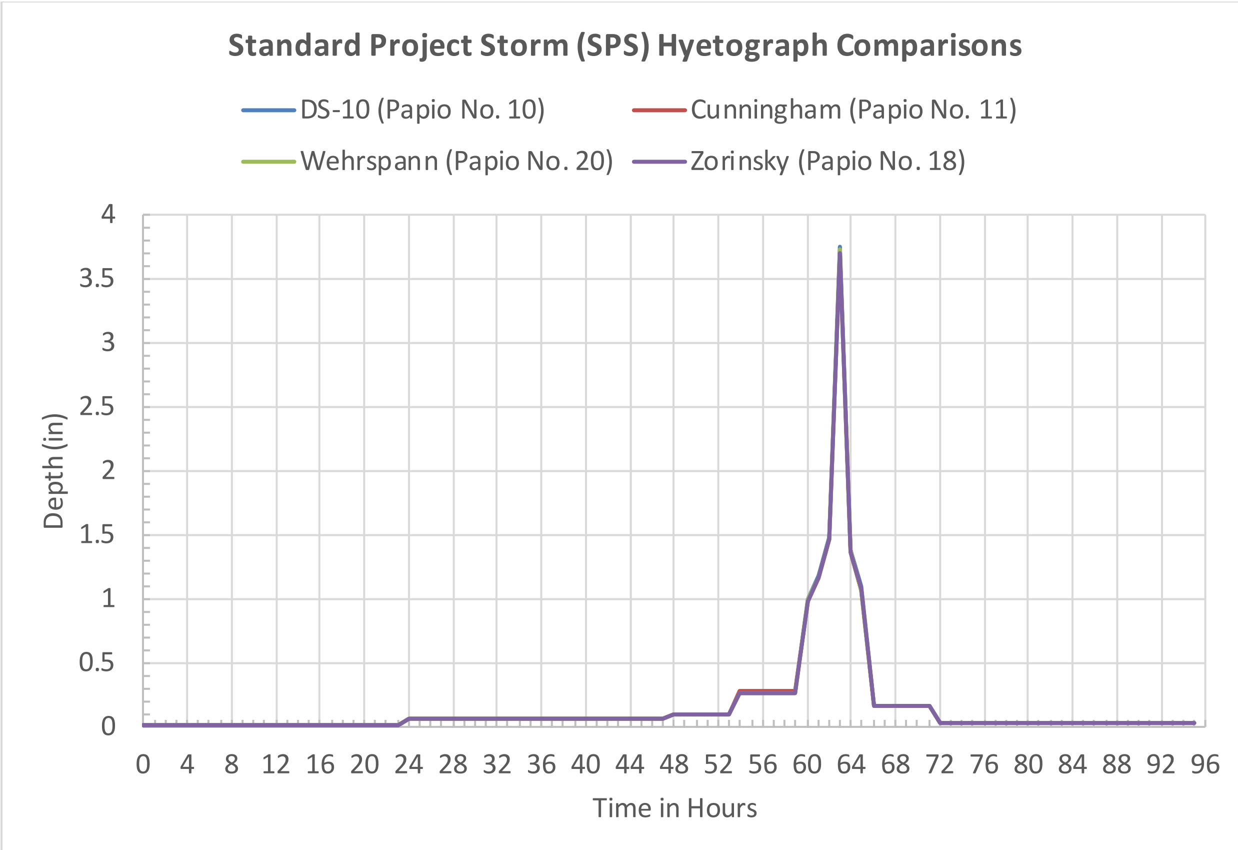
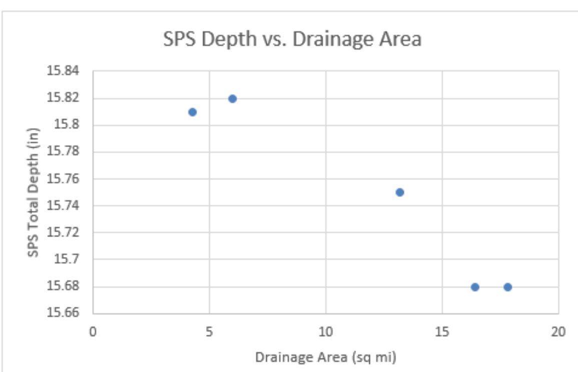


Figure 10. Standard Project Flood Hyetograph Patterns



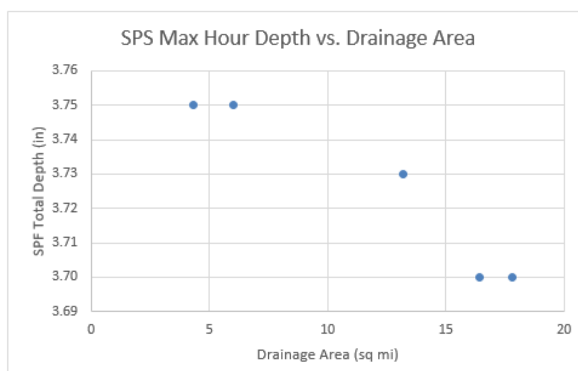


Figure 11. Standard Project Flood comparisons by drainage area

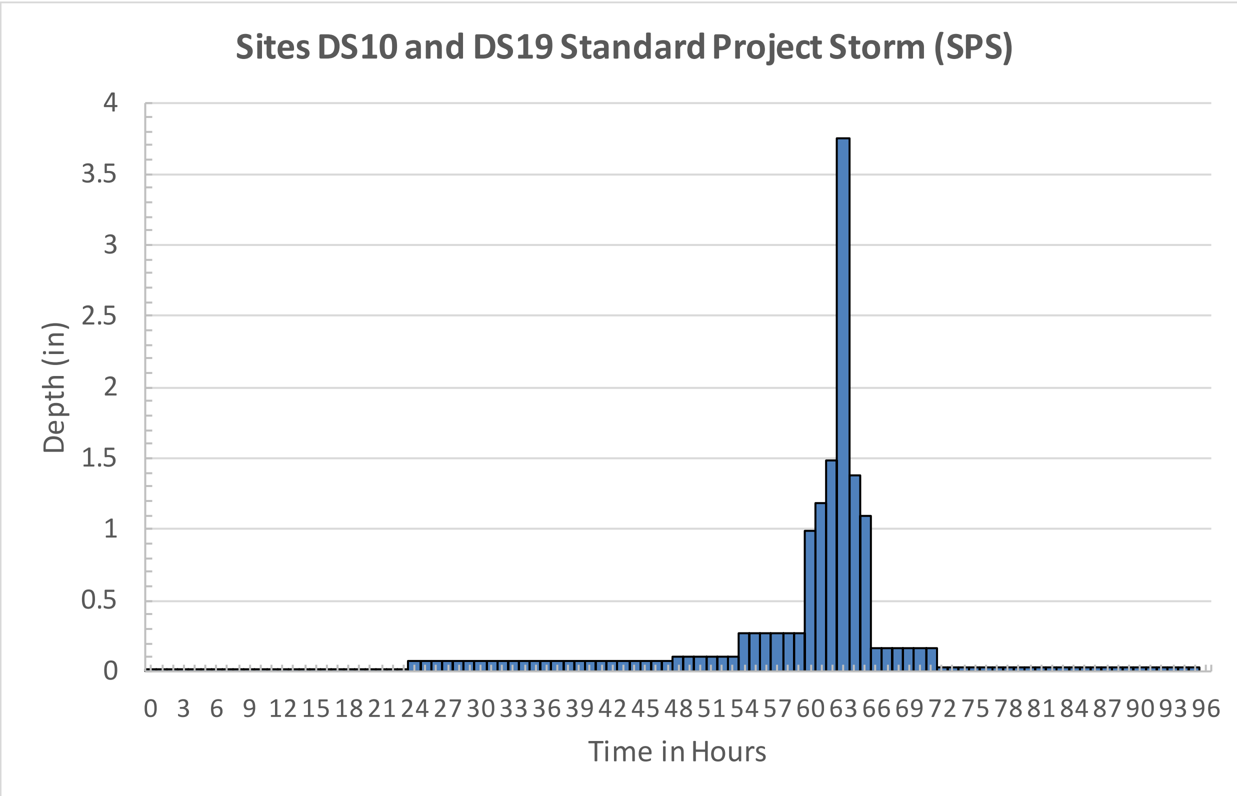


Figure 12. Adopted reservoir design storm for DS10 and DS19 (wet dams)

Table 8. Reservoir Design Flood for DS10 and DS19

Time (Hours)	SPF Depth (in)
0-24	0.31
24-48	1.71
48-54	0.61
54-60	1.62
60-61	0.99
61-62	1.18
62-63	1.48
63-64	3.75
64-65	1.38
65-66	1.09
66-72	1.01
72-96	0.68
Total:	**15.81**

Table 9. Standard Project Flood for HEC-HMS Model (DS10 and DS19)

Time (hrs)	Rainfall (in)	Time (hrs)	Rainfall (in)	Time (hrs)	Rainfall (in)	Time (hrs)	Rainfall (in)
0	0.013	24	0.071	48	0.102	72	0.028
1	0.013	25	0.071	49	0.102	73	0.028
2	0.013	26	0.071	50	0.102	74	0.028
3	0.013	27	0.071	51	0.102	75	0.028
4	0.013	28	0.071	52	0.102	76	0.028
5	0.013	29	0.071	53	0.102	77	0.028
6	0.013	30	0.071	54	0.27	78	0.028
7	0.013	31	0.071	55	0.27	79	0.028
8	0.013	32	0.071	56	0.27	80	0.028
9	0.013	33	0.071	57	0.27	81	0.028
10	0.013	34	0.071	58	0.27	82	0.028
11	0.013	35	0.071	59	0.27	83	0.028
12	0.013	36	0.071	60	0.99	84	0.028
13	0.013	37	0.071	61	1.18	85	0.028
14	0.013	38	0.071	62	1.48	86	0.028
15	0.013	39	0.071	63	3.75	87	0.028
16	0.013	40	0.071	64	1.38	88	0.028
17	0.013	41	0.071	65	1.09	89	0.028
18	0.013	42	0.071	66	0.168	90	0.028
19	0.013	43	0.071	67	0.168	91	0.028
20	0.013	44	0.071	68	0.168	92	0.028
21	0.013	45	0.071	69	0.168	93	0.028
22	0.013	46	0.071	70	0.168	94	0.028
23	0.013	47	0.071	71	0.168	95	0.028

10 Probable Maximum Precipitation

DS19 is a Standard 1 Dam and is required by ER 1110-8-2(FR) (USACE, 1991) to have an inflow design flood (IDF) equal to the PMF. The PMF is determined by applying the PMP to the drainage area upstream of the dam.

Hydrometeorological Reports 51 and 52 (HMR 51&52) were used to determine the PMP for the watershed. The MMC Precip Tool version 1.2.0 was used to determine PMP depths and other inputs and the HEC-HMS version 4.4beta model was used to optimize the PMP event over the watershed. The MMC Precip tool is a GIS extension within ArcMap that uses a georeferenced shapefile of the watershed along with HMR 51 gridded depth-area-duration values to produce a watershed average depth-area-duration table. The HMR 51 depths are shown in Table 10.

Although the MMC Precip Tool generates a PMP storm following standard procedures outlined in HMR 52, HEC-HMS 4.4beta has the functionality to maximize a desired parameter. The benefit to optimizing the PMP storm in HEC-HMS is that it takes channels, subbasins, and reservoir routing into account.

The optimization trials performed in HEC-HMS altered the PMP storm area, orientation, and center coordinates to maximize either the peak inflow, storm volume, or reservoir pool elevation. Storm peak intensity period was altered through the Meteorological model to test sensitivity to the hyetograph pattern. Optimization initial values for all these parameters were set so they were not near the values determined by the MMC Precip tool that were initially input into the Meteorological Model. Two to three hundred iterations resulted in convergence.

Table 11 shows the results of the three optimization trials to peak inflow, storm volume, and reservoir pool elevation. Optimization trials were run, their optimized parameters determined, and then these were entered into the HMR52 meterological model and a simulation run to check results. Additional optimization trials were completed with different initial values when convergence results were questionable. Optimization to peak flow, storm volume, and reservoir pool elevations produced similar results. Optimization based on the maximum peak inflow was adopted.

Figure 13 shows the PMP over the watershed upstream of DS19 using optimization results from the HEC-HMS HMR52 Tool in the MMC Precip Tool interface. Table 12 compares the PMP used in this analysis with the site-specific PMP used in the 2018 HDR analysis.

Figure 14 through Figure 16 show the optimized PMP adopted for this study over the three subbasins of the watershed.

Table 10. HMR 51 PMP Depths (MMC, 2017)

Storm Area (sq mi)	PMP Precipitation Depths (in)				
	6 hour	**12 hour**	**24 hour**	**48 hour**	**72 hour**
10	26.1	30.7	32.4	35.9	37.6
200	19.1	22.6	24.4	27.6	29.2
1000	13.9	17	18.7	21.8	23.6
5000	8.4	10.9	12.8	16	17.5
10000	6.4	8.7	10.4	13.6	15
20000	4.6	6.7	8.3	11.4	12.8

Table 11. Sample PMP Optimization Trials

Storm Parameter	Meteorological Model Initial Value*	Optimization Initial Value	Optimization Trial Statistical Results		
			(ADOPTED) Peak Flow (cfs)	Max Storm Volume (AF)	Max Pool Elevation (ft-NAVD88)
Area (sq mi)	10	15	10	9.91	10
Preferred Orientation (degrees)	244	-	-	-	-
Actual Orientation (degrees)	280	210	284.19	284.58	276.48
Peak Intensity Period	Hours 36-42	Hours 36-42	Does not matter	Does not matter	Does not matter
1 to 6 ratio	0.306	0.306	-	-	-
x-coordinate	-66699.23	-69301	-68577	-68556	-71816
y-coordinate	6623055.74	6622989	6623048	6623073	6623517
Reservoir Optimization Results					
Peak Inflow (cfs)			34,453	34,453	34,362
Peak Discharge (cfs)			459	459	458
Inflow Volume (AF)			6,868	6,868	6,858
Peak Storage (AF)			6,840	6,840	6,831
Peak Elevation (ft)			1194.9	1194.9	1194.84

*Estimated from MMC Precip Tool (2017).

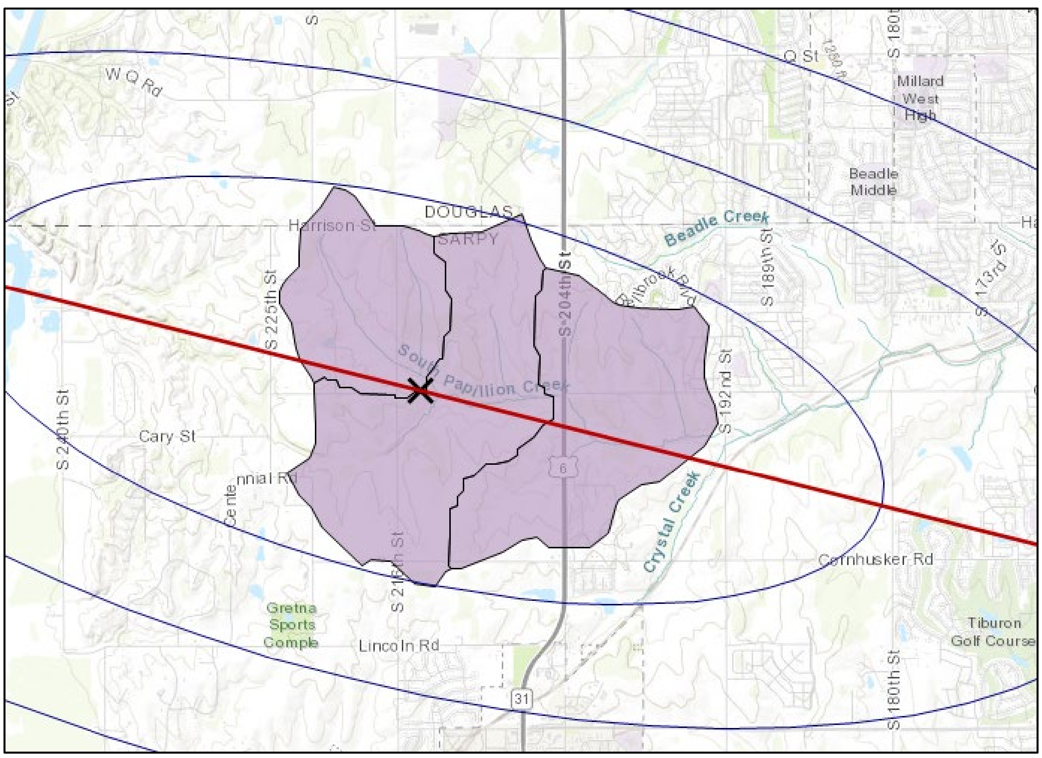


Figure 13. PMP orientation over watershed (MMC Precip Tool with results from HMS HMR 52 Storm Tool)

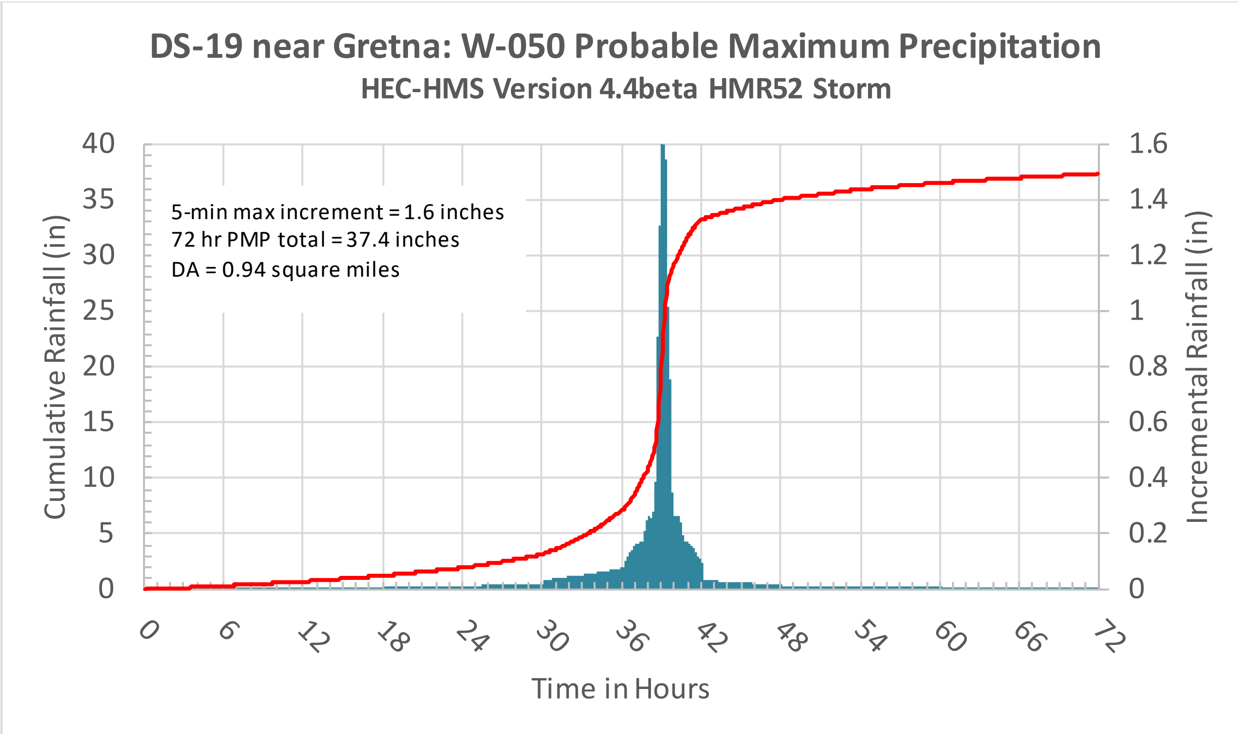


Figure 14. Subbasin W-050 HMR 51&52 PMP (5-minute interval)

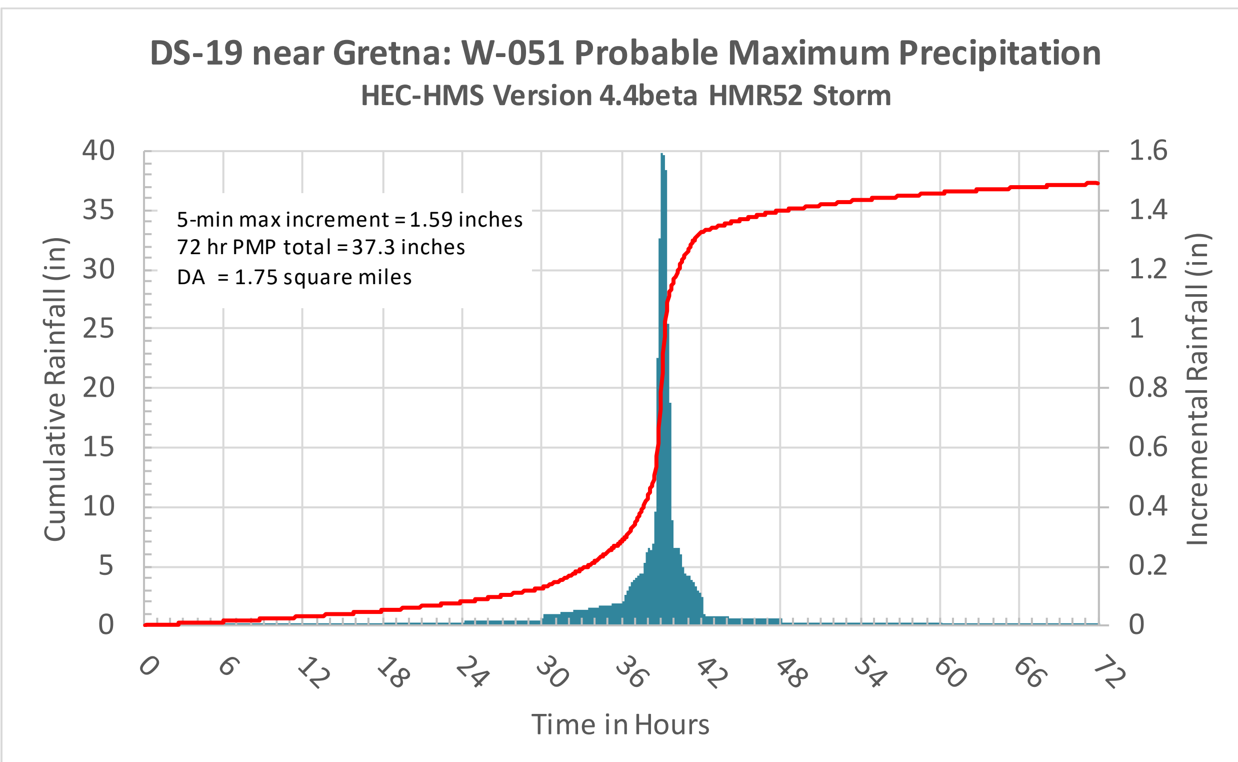


Figure 15. Subbasin W-051 HMR 51&52 PMP (5-minute interval)

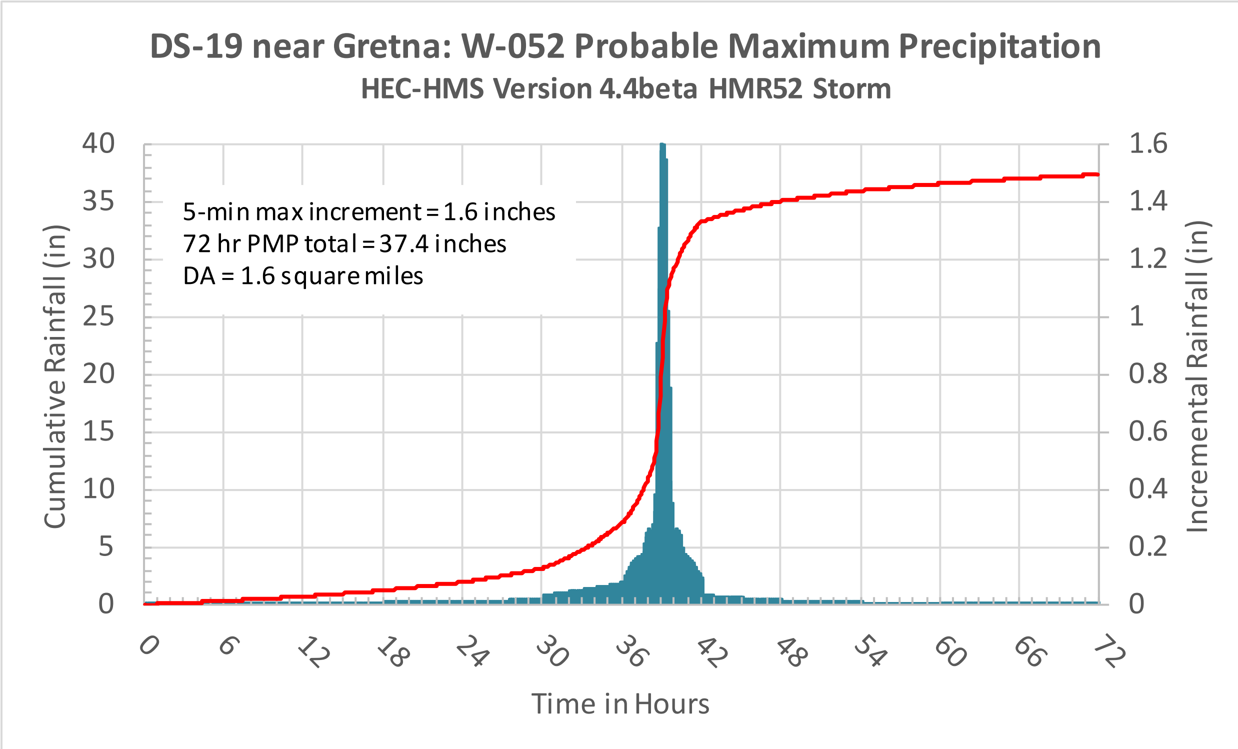


Figure 16. Subbain W-052 HMR 51&52 PMP (5-minute interval)

Table 12. Comparison of PMPs Depths for Various Durations

	12-hour	24-hour	72-hour
Site Specific PMP (HDR, 2018)	22.5	24	25.5
HMR 51&52	30.1	33.1	37.4

11 Hydrologic Model

Figure 17 shows the HEC-HMS version 4.4beta hydrologic model used to determine inflows into DS19. Subbasin delineations and subbasin and channel properties were adopted from the calibrated FYRA future conditions model. The FYRA model was the model used by HDR to develop a dam design for the NRD. The HEC-HMS version 4.4beta model (HMS, 2020) was used in order to include the most up-to-date HMR52 Storm modeling for PMP optimization.

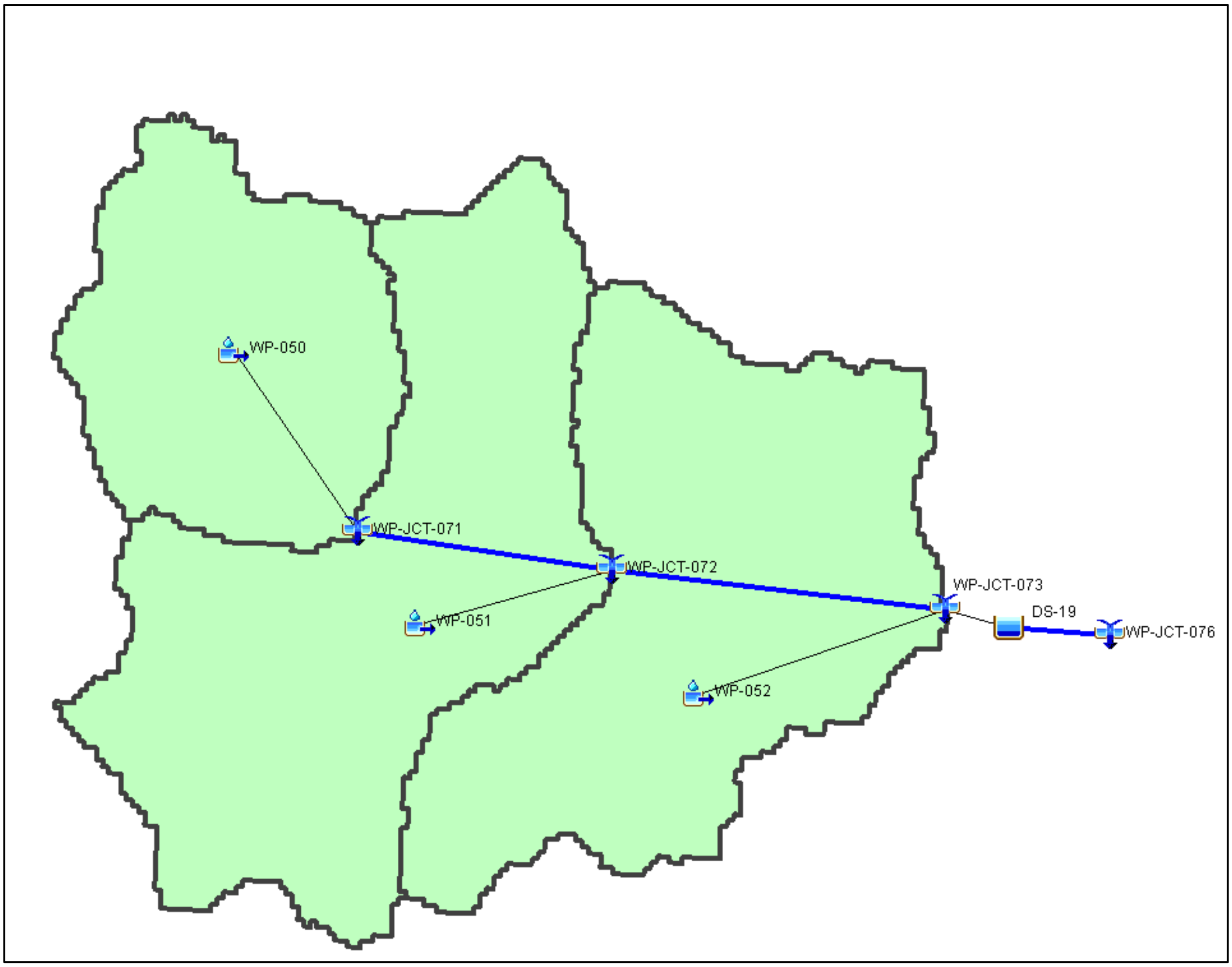


Figure 17. HEC-HMS model

12 Watershed Parameters

The following sections describe the watershed parameters input into the HEC-HMS model.

12.1 Drainage Area

The drainage area contributing to DS19 is 4.3 square miles. The drainage area for DS19 was re-delineated in this study with 10-meter DEM data and ArcHydro tools and found to match the drainage area determined in the NRD design. While the updated drainage areas of the subbasins varied slightly from those in the FYRA model and HDR report, the FYRA model parameters were adopted because they belong to the calibrated model. Drainage areas are shown in Table 13.

Table 13. Drainage Areas

Subbasin	ADOPTED - NRD/FYRA/HDR Model Drainage Area (sq mi)	Delineated Drainage Area (sq mi)
WP-050	0.94	1
WP-051	1.75	1.71
WP-052	1.63	1.59
Total	**4.3**	**4.3**

12.2 Unit Hydrographs

Unit hydrographs used in this study are shown in Figure 18. Their parameters are listed in Table 14. The 1-hr unit hydrographs without peaking were adopted from the calibrated FYRA model. The unit hydrographs for each subbasin were peaked to to produce 125, 150 and 175-percent peaked unit hydrographs at the dam.

While a detailed design memorandum (DM) specific to DS19 was never created historically, the detailed report for DS10 could be referenced for unit hydrograph information. The original (USACE, 1975) design peaked the unit hydrograph at DS10 more than 150 percent based on the unit hydrograph plates in the DM. The unit hydrograph peaking for the MR PMF was 150 percent at the dam while the RH PMF used the 175 percent peaked unit hydrograph. The 175 percent was based on information from the original Papillion design memorandums and the peaking was retained for consistency to existing dam designs, even though it is outside the recommended peaking percentages in ER 1110-8-2(FR).

One-hour unit hydrograph peaking was determined using an HMS model without soil losses, 1 inch of rainfall over 1 hour, and a spreadsheet tool provided by the Hydrologic Engineering Center. A single adjustment factor is applied to each subbasin parameter until the peak flow at the dam site is peaked the required amount.

Note that the 150-percent unit hydrograph peaking in this investigation is different from that in the TSP Design (USACE, 2020). In that study, the unit hydrographs of the separate subbasins were peaked 150 percent which produced a peaking of only 143 percent at the dam. Peaking at the dam is now exactly 125, 150 and 175 percent.

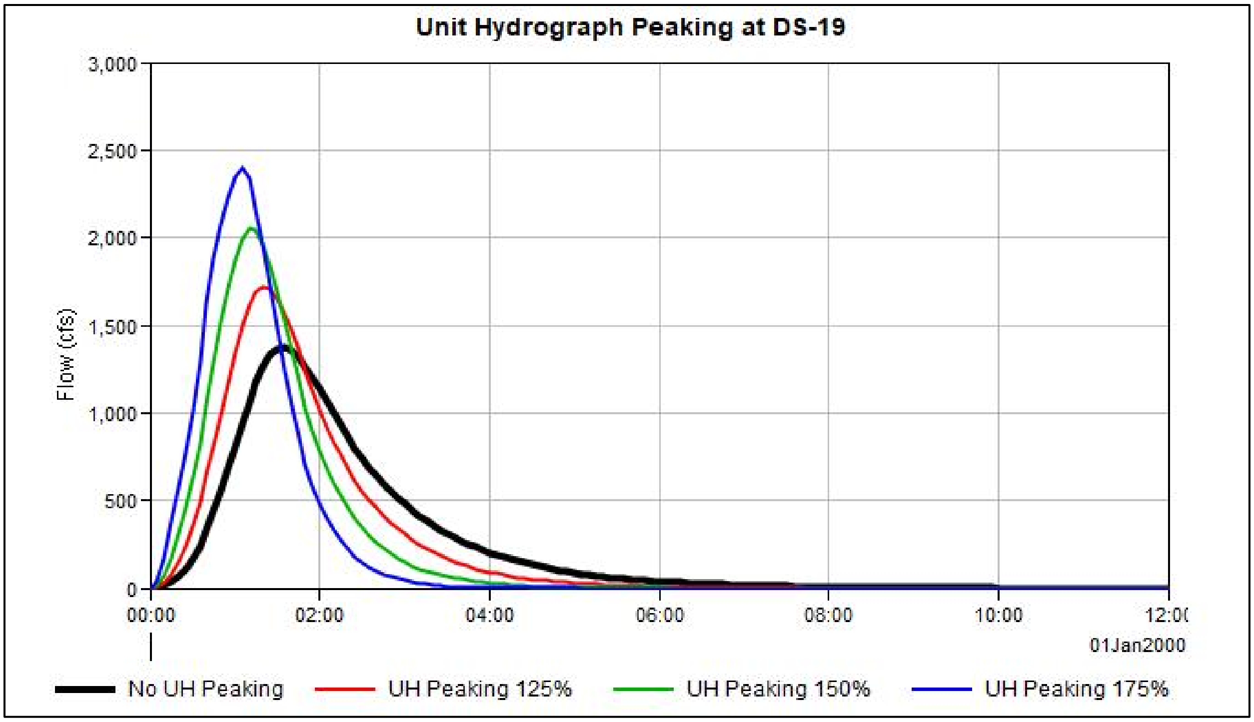


Figure 18. Unit Hydrograph Peaking at the Dam

Table 14. 1-hour unit hydrographs and peaking

	UH Peaked 0%			
	WP-050	**WP-051**	**WP-052**	**DS19**
Peak Discharge (cfs)	279	548	657	1371
Tc (hrs)	0.91	0.93	0.8	-
R (hrs)	1.34	1.22	0.8	-
Percent Peaked	0	0	0	0
	UH Peaked 25%			
	WP-050	**WP-051**	**WP-052**	**DS19**
Peak Discharge (cfs)	361	707	809	1719
Tc (hrs)	0.631	0.645	0.554	-
R (hrs)	0.923	0.845	0.554	-
Percent Peaked	129	129	123	125
	UH Peaked 50%			
	WP-050	**WP-051**	**WP-052**	**DS19**
Peak Discharge (cfs)	446	862	934	2053
Tc (hrs)	0.44	0.449	0.386	-
R (hrs)	0.647	0.589	0.386	-
Percent Peaked	160	157	142	150
	UH Peaked 75%			
	WP-050	**WP-051**	**WP-052**	**DS19**
Peak Discharge (cfs)	527	1007	1021	2397
Tc (hrs)	0.291	0.298	0.256	-
R (hrs)	0.429	0.39	0.256	-
Percent Peaked	189	184	155	175

12.3 Soil Losses

Table 15 shows the soil losses from the calibrated FYRA model for both existing and future conditions. A constant loss rate of 0.3 inches per hour is consistent with older USACE models. Future soil losses could change this loss rate. However, it was assumed as part of the study that future development would be represented by an increase in percent impervious only as the specific affects of urbanization on soil losses is not well defined.

Table 15. Soil Losses

	Calibrated Existing Model Loss Rates		
	WP-050	**WP-051**	**WP-052**
Initial Loss (in)	0.8	0.8	0.8
Constant Loss (in/hr)	0.3	0.3	0.3
Existing Condition Imperviousness (%)	2	2	6
	Future Model Loss Rates		
	WP-050	**WP-051**	**WP-052**
Initial Loss (in)	0.8	0.8	0.8
Constant Loss (in/hr)	0.3	0.3	0.3
Future Condition Imperviousness (%)	30	30	30

12.4 Baseflow

Baseflow was not modeled in the FYRA model and is not modeled in this investigation for DS19.

13 Reservoir Design Flood (RDF) Routing

The reservoir design flood (RDF) was used to determine the minimum spillway elevation for DS19. The RDF for the wet dam and dry dam differ. The RDF was originally assumed to be the standard project flood (SPF) determined by routing the standard project storm (SPS) over the watershed upstream of the dam for both the wet and dry designs. However, in the case of the wet dam design, this resulted in the flood control pool inundating Highway 6. To avoid this impact to Highway 6, the wet dam's RDF was modified to a 0.965 * SPF to lower the resulting routed pool to 1177.5 ft-NAVD88. The dry dam's RDF was the SPF.

Future conditions and the 125 percent unit hydrograph peaking at the dam were used. The model computation time steps were 5 minutes and the precipitation for the SPF was in 1 hour increments from the Design Memorandum (DM). The lower level service outlet was operational as was the case in the design of the existing Papillion Creek Dams based on the 1970s DM documentation.

Figure 19 and Figure 20 show the routing of the RDF for the wet and dry dams, respectively. Note that the SPF precipitation is shown in 5-minute increments.

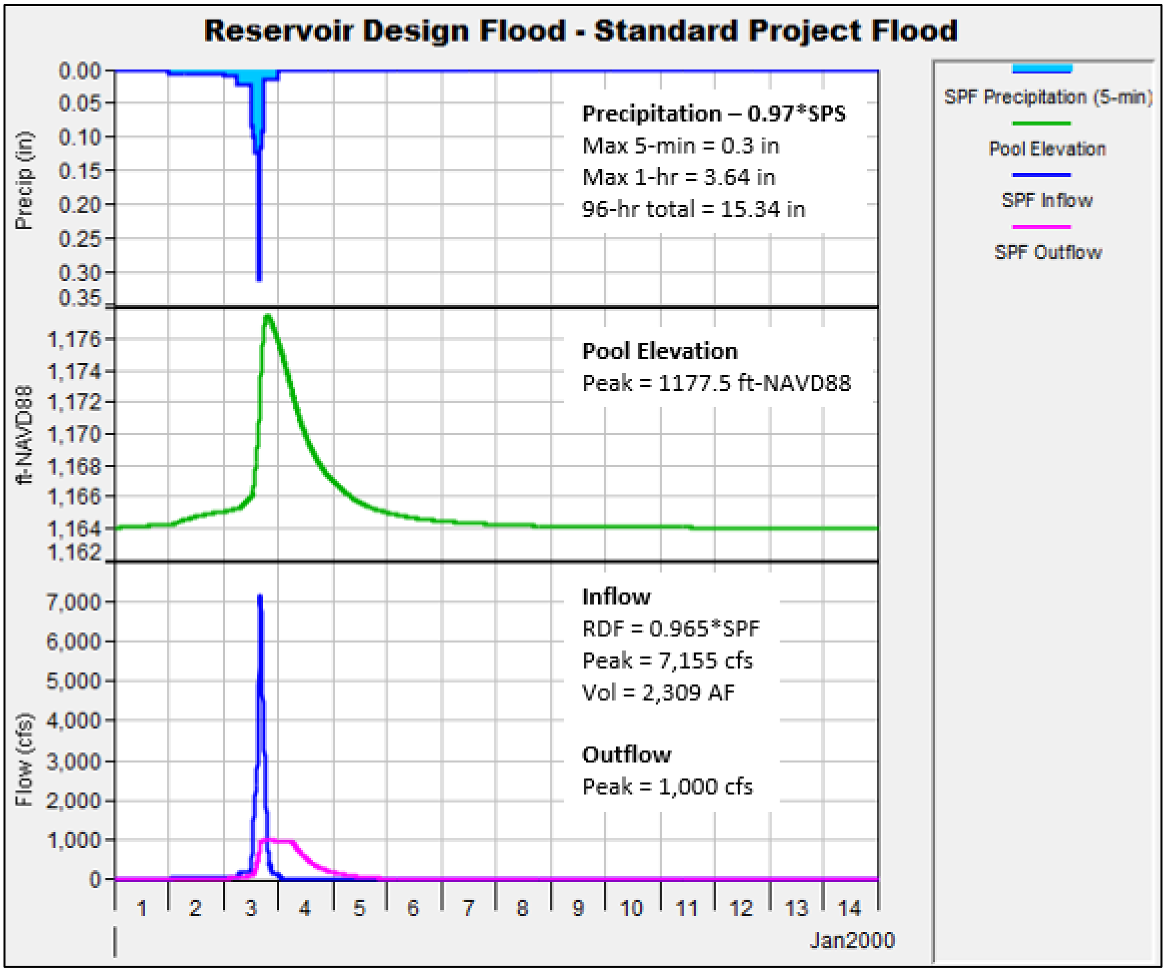


Figure 19. Wet Dam Reservoir Design Flood (97% SPF) Routing

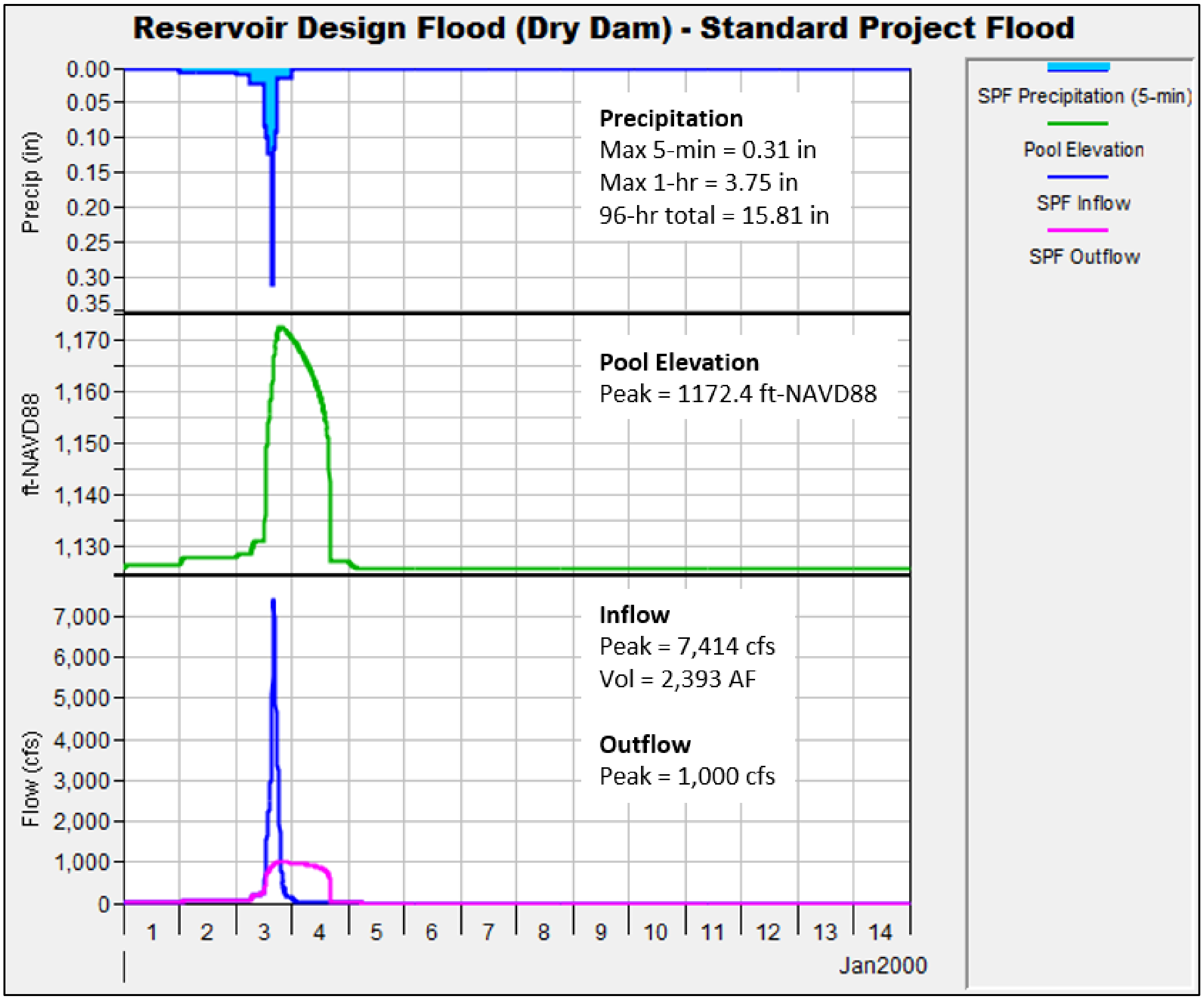


Figure 20. Dry Dam Reservoir Design Flood (SPF)

14 Spillway Design Flood Optimization

Spillway design flood routing included the Most Reasonable Probable Maximum Flood (MR PMF) and the Reasonable High PMF (RH PMF) with future-condition land use. The MR PMF and the RH PMF differed in their PMP depths, soil losses and unit hydrograph peaking. These differences are summarized below.

- Most Reasonable PMF (Best Estimate)
    - Soil loss rates = calibration values (0.8 in initial deficit and 0.3 in/hr infiltration)
    - Transform = calibrated values, unit hydrograph peaked 150%
    - PMP = PMP determined from HMR 51&52 optimization
- Reasonable High PMF (Reasonable Worst Case)
    - Soil loss rates = -25% calibration values (0.6 in initial deficit and 0.23 in/hr infiltration)
    - Transform = calibrated values, unit hydrograph peaked 175%
    - PMP = base PMP with ordinates increased 5%

Different spillway crest elevation and width combinations were used to help optimize the spillway and dam embankment height cut-and-fill to reduce costs at the site.

The two antecedent pool conditions required by ER 1110-8-2(FR), *Inflow Design Floods for Dams and Reservoirs* (USACE, 1991), were considered: (1) over the full flood control pool and (2) over the 5-day drawdown pool. The 5-day drawdown pool elevation was determined by routing the ½ PMF over the full multipurpose pool with outlets operational followed by the PMF five days later with outlets blocked. The five-day spacing was determined from the peak of the ½PMF and the peak of the PMF following.

Table 16 and Table 17 show the spillway crest and width combinations for the wet and dry dams, respectively. Figure 21 compares the Most Reasonable and Reasonable High PMFs.

Table 18 shows the PMF and starting pool combinations. Table 19 through 22 show the results of the simulations.

Table 16. Wet dam spillway crest elevations and width combinations

Simulation ID	Spillway Crest Elev (ft-NAVD88)	Spillway Width (ft)
FC250	1177.5	250
FC400	1177.5	400
FC550	1177.5	550
FC750	1177.5	750
FC850	1177.5	850
L250	1179.6	250
L400	1179.6	400
L550	1179.6	550
M250	1181.6	250
M400	1181.6	400
M550	1181.6	550
H250	1183.6	250
H400	1183.6	400
H550	1183.6	550

Table 17. Dry dam spillway crest elevation and width combinations

Simulation ID	Spillway Crest Elev (ft-NAVD88)	Spillway Width (ft)
FC250	1172.4	250
FC400	1172.4	400
FC550	1172.4	550
L250	1177.5	250
L400	1177.5	400
L550	1177.5	550
M250	1179.6	250
M400	1179.6	400
M550	1179.6	550
H250	1181.6	250
H400	1181.6	400
H550	1181.6	550

Table 18. Probable Maximum Flood combinations

Simulation ID	Description
P50	Most Reasonable PMF - 150% UH peaking
P75	Reasonable High PMF - 175% UH peaking
Fc	Starting pool top of flood control
5d	Starting pool top of 5-day drawdown pool

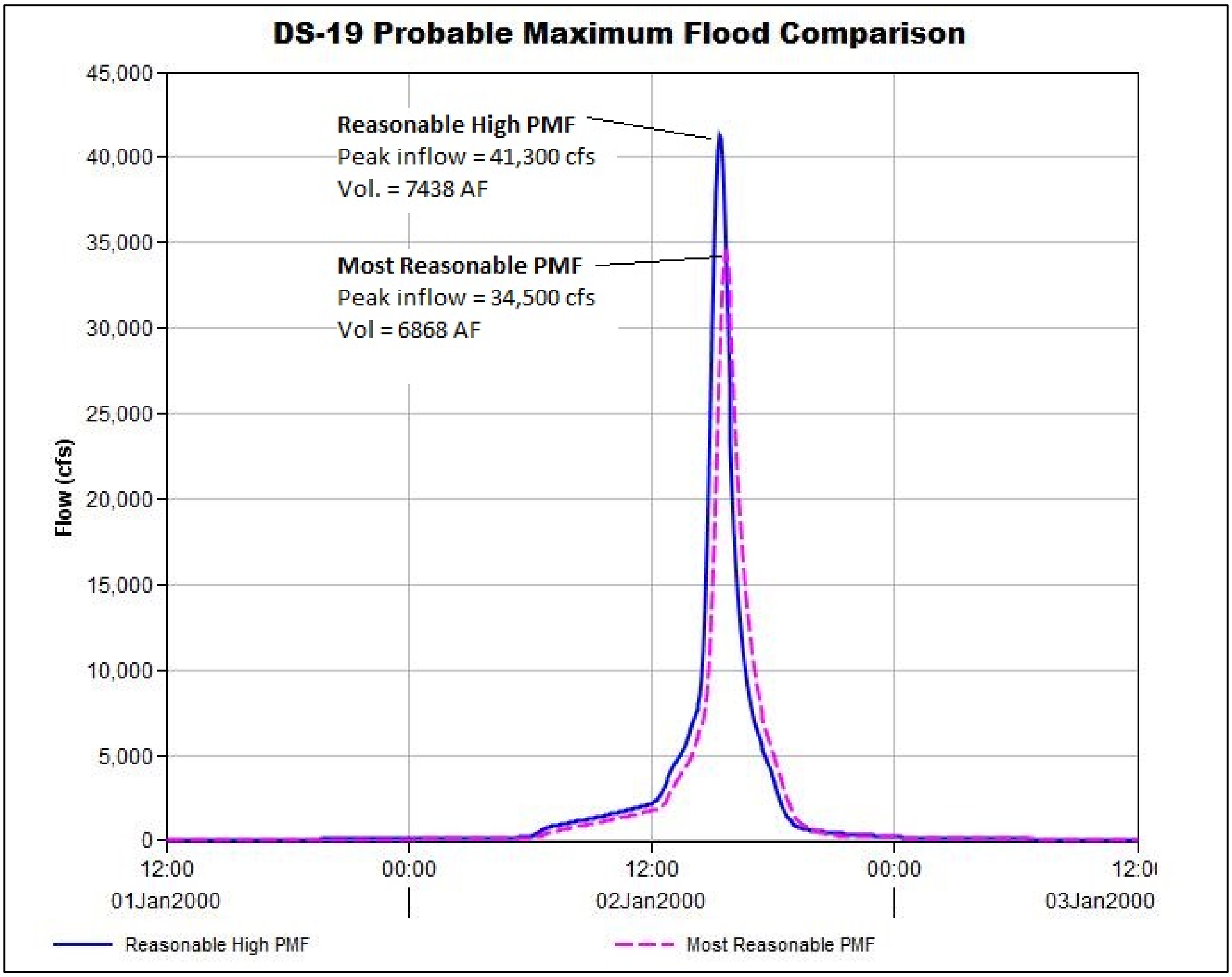


Figure 21. PMF Comparison

Table 19. Wet Dam Most Reasonable PMF Spillway Optimization Results. Used to Set Top of Dam.

Most Reasonable Probable Maximum Flood (Wet Dam - 72-in Outlet)									
Simulation	**UH Peaking (%)**	**Starting Pool (ft)**	**Spillway Crest Elev (ft)**	**Spillway Width (ft)**	**Peak Inflow (cfs)**	**Inflow Vol (AF)**	**Peak Discharge (cfs)**	**Peak Elevation (ft)**	**TOD (ft-NAVD88)**
Starting Pool at Top of FC									
PMF_MR_fc_FC250	150	1177.5	1177.5	250	34,453	6867.9	22,004	1187.3	**1190.3**
PMF_MR_fc_FC400	150	1177.5	1177.5	400	34,453	6867.9	25,126	1185.7	**1188.7**
PMF_MR_fc_FC550	150	1177.5	1177.5	550	34,453	6867.9	27,115	1184.7	**1187.7**
PMF_MR_fc_FC750	150	1177.5	1177.5	750	34,453	6867.9	28,796	1183.8	**1186.8**
PMF_MR_fc_FC850	150	1177.5	1177.5	850	34,453	6867.9	29,399	1183.3	**1186.3**
PMF_MR_fc_L250	150	1177.5	1179.6	250	34,453	6867.9	21,103	1189.1	**1192.1**
PMF_MR_fc_L400	150	1177.5	1179.6	400	34,453	6867.9	24,358	1187.6	**1190.6**
PMF_MR_fc_L550	150	1177.5	1179.6	550	34,453	6867.9	26,464	1186.6	**1189.6**
PMF_MR_fc_M250	150	1177.5	1181.6	250	34,453	6867.9	19,817	1190.7	**1193.7**
PMF_MR_fc_M400	150	1177.5	1181.6	400	34,453	6867.9	23,385	1189.3	**1192.3**
PMF_MR_fc_M550	150	1177.5	1181.6	550	34,453	6867.9	25,592	1188.4	**1191.4**
PMF_MR_fc_H250	150	1177.5	1183.6	250	34,453	6867.9	17,958	1192.1	**1195.1**
PMF_MR_fc_H400	150	1177.5	1183.6	400	34,453	6867.9	21,665	1190.9	**1193.9**
PMF_MR_fc_H550	150	1177.5	1183.6	550	34,453	6867.9	24,112	1190.1	**1193.1**
PMF_MR_fc_C550	150	1175.6	1175.6	550	34,453	6867.9	27,819	1182.9	**1185.9**
PMF_MR_fc_C850	150	1175.6	1175.6	850	34,453	6867.9	29,964	1181.5	**1184.5**
Starting Pool at Top of 5-Day Drawdown Pool									
PMF_MR_5d_FC400	150	1164.2	1177.5	400	34,453	6867.9	23,080	1185.3	**1188.3**
PMF_MR_5d_FC550	150	1164.2	1177.5	550	34,453	6867.9	25,500	1184.4	**1187.4**
PMF_MR_5d_FC850	150	1164.2	1177.5	850	34,453	6867.9	28,474	1183.2	**1186.2**
PMF_MR_5d_L250	150	1164.2	1179.6	250	34,453	6867.9	16,941	1187.9	**1190.9**
PMF_MR_5d_L400	150	1164.2	1179.6	400	34,453	6867.9	20,457	1186.8	**1189.8**
PMF_MR_5d_L550	150	1164.2	1179.6	550	34,453	6867.9	22,979	1186.0	**1189.0**
PMF_MR_5d_M250	150	1164.2	1181.6	250	34,453	6867.9	14,225	1189.1	**1192.1**
PMF_MR_5d_M400	150	1164.2	1181.6	400	34,453	6867.9	17,599	1188.1	**1191.1**
PMF_MR_5d_M550	150	1164.2	1181.6	550	34,453	6867.9	19,895	1187.4	**1190.4**
PMF_MR_5d_H250	150	1164.2	1183.6	250	34,453	6867.9	11,769	1190.2	**1193.2**
PMF_MR_5d_H400	150	1164.2	1183.6	400	34,453	6867.9	14,564	1189.4	**1192.4**
PMF_MR_5d_H550	150	1164.2	1183.6	550	34,453	6867.9	16,664	1188.8	**1191.8**

Orange = ADM design
Dark Blue = NED design
Green = After ADM (NRD) design
Blue = Highest PMF pool
Purple = For dam optimization (spillway crest at 0.2% AEP flood pool)
Top of Dam determined as MR PMF max pool plus assumed 3 feet of freeboard at this point in analysis
Top of Dam for RH PMF was assumed to be max pool

Table 20. Wet Dam Reasonable High PMF Spillway Optimization Results. Used to Determine Flowage Easement Pool.

Reasonable High Probable Maximum Flood (Wet Dam - 72-in Outlet)									
Simulation	**UH Peaking (%)**	**Starting Pool (ft)**	**Spillway Crest Elev (ft)**	**Spillway Width (ft)**	**Peak Inflow (cfs)**	**Inflow Vol (AF)**	**Peak Discharge (cfs)**	**Peak Elevation (ft)**	**TOD (ft-NAVD88)**
Starting Pool at Top of FC									
PMF_RH_fc_FC250	175	1177.5	1177.5	250	41,343	7438	25,530	1188.2	**1188.2**
PMF_RH_fc_FC400	175	1177.5	1177.5	400	41,343	7438	29,487	1186.6	**1186.6**
PMF_RH_fc_FC550	175	1177.5	1177.5	550	41,343	7438	31,980	1185.4	**1185.4**
PMF_RH_fc_FC750	175	1177.5	1177.5	750	41,343	7438	34,141	1184.4	**1184.4**
PMF_RH_ft_FC800	175	1177.5	1177.5	800	41,343	7438	34,622	1184.2	**1184.2**
PMF_RH_fc_FC850	175	1177.5	1177.5	850	41,343	7438	34,930	1184.0	**1184.0**
PMF_RH_fc_FC900	175	1177.5	1177.5	900	41,343	7438	35,269	1183.8	**1183.8**
PMF_RH_fc_L250	175	1177.5	1179.6	250	41,343	7438	24,479	1190.0	**1190.0**
PMF_RH_fc_L400	175	1177.5	1179.6	400	41,343	7438	28,513	1188.4	**1188.4**
PMF_RH_fc_L550	175	1177.5	1179.6	550	41,343	7438	31,160	1187.3	**1187.3**
PMF_RH_fc_M250	175	1179.6	1181.6	250	41,343	7438	23,184	1191.6	**1191.6**
PMF_RH_fc_M400	175	1179.6	1181.6	400	41,343	7438	27,514	1190.1	**1190.1**
PMF_RH_fc_M550	175	1179.6	1181.6	550	41,343	7438	30,237	1189.1	**1189.1**
PMF_RH_fc_H250	175	1179.6	1183.6	250	41,343	7438	21,253	1193.0	**1193.0**
PMF_RH_fc_H400	175	1179.6	1183.6	400	41,343	7438	25,785	1191.7	**1191.7**
PMF_RH_fc_H550	175	1179.6	1183.6	550	41,343	7438	28,797	1190.8	**1190.8**
PMF_RH_fc_H550	175	1175.6	1175.6	550	41,343	7438	32,850	1183.7	**1183.7**
PMF_RH_fc_C850	175	1175.6	1175.6	850	41,343	7438	35,625	1182.2	**1182.2**
Starting Pool at Top of 5-Day Drawdown Pool									
PMF_RH_5d_FC400	175	1164.2	1177.5	400	41,343	7438	27,968	1186.3	**1186.3**
PMF_RH_5d_FC550	175	1164.2	1177.5	550	41,343	7438	30,965	1185.3	**1185.3**
PMF_RH_5d_FC850	175	1164.2	1177.5	850	41,343	7438	34,447	1183.9	**1183.9**
PMF_RH_5d_L250	175	1164.2	1179.6	250	41,343	7438	20,654	1189.0	**1189.0**
PMF_RH_5d_L400	175	1164.2	1179.6	400	41,343	7438	25,223	1187.7	**1187.7**
PMF_RH_5d_L550	175	1164.2	1179.6	550	41,342	7438	28,419	1186.9	**1186.9**
PMF_RH_5d_M250	175	1164.2	1181.6	250	41,343	7438	17,695	1190.1	**1190.1**
PMF_RH_5d_M400	175	1164.2	1181.6	400	41,343	7438	22,019	1189.0	**1189.0**
PMF_RH_5d_M550	175	1164.2	1181.6	550	41,343	7438	25,072	1188.3	**1188.3**
PMF_RH_5d_H250	175	1164.2	1183.6	250	41,343	7438	14,618	1191.1	**1191.1**
PMF_RH_5d_H400	175	1164.2	1183.6	400	41,343	7438	18,460	1190.2	**1190.2**
PMF_RH_5d_H550	175	1164.2	1183.6	550	41,343	7438	21,297	1189.6	**1189.6**

Orange = ADM design
Dark Blue = NED design
Green = After ADM (NRD) design
Blue = Highest PMF pool
Purple = For dam optimization (spillway crest at 0.2% AEP flood pool)
Top of Dam determined as MR PMF max pool plus assumed 3 feet of freeboard at this point in analysis
Top of Dam for RH PMF was assumed to be max pool

Table 21. Dry Dam ADM Paper Exercise - Most Reasonable Probable Maximum Flood

Most Reasonable Probable Maximum Flood (Dry Dam)									
Simulation	**UH Peaking (%)**	**Starting Pool (ft)**	**Spillway Crest Elev (ft)**	**Spillway Width (ft)**	**Peak Inflow (cfs)**	**Inflow Vol (AF)**	**Peak Discharge (cfs)**	**Peak Elevation (ft)**	**TOD (ft-NAVD88)**
Starting Pool at Top of FC									
PMF_P50_fc_FC250_DryBox	150	1172.4	1172.4	250	34,453	6868	24,315	1182.6	**1185.6**
PMF_P50_fc_FC400_DryBox	150	1172.4	1172.4	400	34,453	6868	27,166	1181	**1184.0**
PMF_P50_fc_FC550_DryBox	150	1172.4	1172.4	550	34,453	6868	28,969	1179.9	**1182.9**
PMF_P50_fc_L250_DryBox	150	1172.4	1177.5	250	34,453	6868	21,647	1187.2	**1190.2**
PMF_P50_fc_L400_DryBox	150	1172.4	1177.5	400	34,453	6868	24,952	1185.7	**1188.7**
PMF_P50_fc_L550_DryBox	150	1172.4	1177.5	550	34,453	6868	27,046	1184.7	**1187.7**
PMF_P50_fc_M250_DryBox	150	1172.4	1179.6	250	34,453	6868	19,936	1188.8	**1191.8**
PMF_P50_fc_M400_DryBox	150	1172.4	1179.6	400	34,453	6868	23,611	1187.4	**1190.4**
PMF_P50_fc_M550_DryBox	150	1172.4	1179.6	550	34,453	6868	25,944	1186.5	**1189.5**
PMF_P50_fc_H250_DryBox	150	1172.4	1181.6	250	34,453	6868	17,774	1190.1	**1193.1**
PMF_P50_fc_H400_DryBox	150	1172.4	1181.6	400	34,453	6868	21,497	1188.9	**1191.9**
PMF_P50_fc_H550_DryBox	150	1172.4	1181.6	550	34,453	6868	23,989	1188.1	**1191.1**
Starting Pool at Top of 5-Day Drawdown Pool (ADOPTED)									
PMF_P50_5d_FC250_DryBox	150	1126	1172.4	250	34,453	6868	23,024	1182.3	**1185.3**
PMF_P50_5d_FC400_DryBox	150	1126	1172.4	400	34,453	6868	26,324	1180.9	**1183.9**
PMF_P50_5d_FC400_DryBoxR	150	1126	1172.4	400	34,453	6868	26,324	1180.9	**1183.9**
PMF_P50_5d_FC550_DryBox	150	1126	1172.4	550	34,453	6868	28,444	1179.8	**1182.8**
PMF_P50_5d_L250_DryBox	150	1126	1177.5	250	34,453	6868	16,952	1185.9	**1188.9**
PMF_P50_5d_L400_DryBox	150	1126	1177.5	400	34,453	6868	20,401	1184.8	**1187.8**
PMF_P50_5d_L550_DryBox	150	1126	1177.5	550	34,453	6868	22,851	1184.0	**1187.0**
PMF_P50_5d_M250_DryBox	150	1126	1179.6	250	34,453	6868	14,391	1187.1	**1190.1**
PMF_P50_5d_M400_DryBox	150	1126	1179.6	400	34,453	6868	17,559	1186.1	**1189.1**
PMF_P50_5d_M550_DryBox	150	1126	1179.6	550	34,453	6868	19,797	1185.5	**1188.5**
PMF_P50_5d_H250_DryBox	150	1126	1181.6	250	34,453	6868	11,887	1188.3	**1191.3**
PMF_P50_5d_H400_DryBox	150	1126	1181.6	400	34,453	6868	14,604	1187.4	**1190.4**
PMF_P50_5d_H550_DryBox	150	1126	1181.6	550	34,453	6868	16,671	1186.8	**1189.8**

Orange = ADM paper exercise

Table 22. Dry Dam Reasonable High Probable Maximum Flood

Reasonable High Probable Maximum Flood (Dry Dam)									
Simulation	UH Peaking (%)	Starting Pool (ft)	Spillway Crest Elev (ft)	Spillway Width (ft)	Peak Inflow (cfs)	Inflow Vol (AF)	Peak Discharge (cfs)	Peak Elevation (ft)	TOD (ft-NAVD88)
Starting Pool at Top of FC									
PMF_P75_fc_FC400_DryBox	175	1172.4	1172.4	400	41342	7438	31923	1181.9	1181.9
Starting Pool at Top of 5-Day Drawdown Pool									
PMF_P75_5d_L400_DryBox	175	1126	1172.4	400	41343	7438	31435	1181.8	1181.8

Orange = ADM paper exercise

15 Dam Designs Leading to the NED Plan

15.1 Wet Dam Designs

Figure 22 shows the After ADM (Balanced) Design. The final NED plan optimized design is similar but has the invert elevation of the outlet culvert raised. The NED plan is presented in Section 19 of this document.

These routings are the same for this design and the NED Design presented in Section 19. Figure 23 and 24 show the spillway design flood routings for the design. Required starting pool elevations were the top of flood control and the 5-day drawdown pool as required by ER 1110-8-2(FR). In the case of the 5-day drawdown pool simulations, the ½ PMF was routed with the service outlets operational while the PMF following five days later was routed with the outlets blocked.

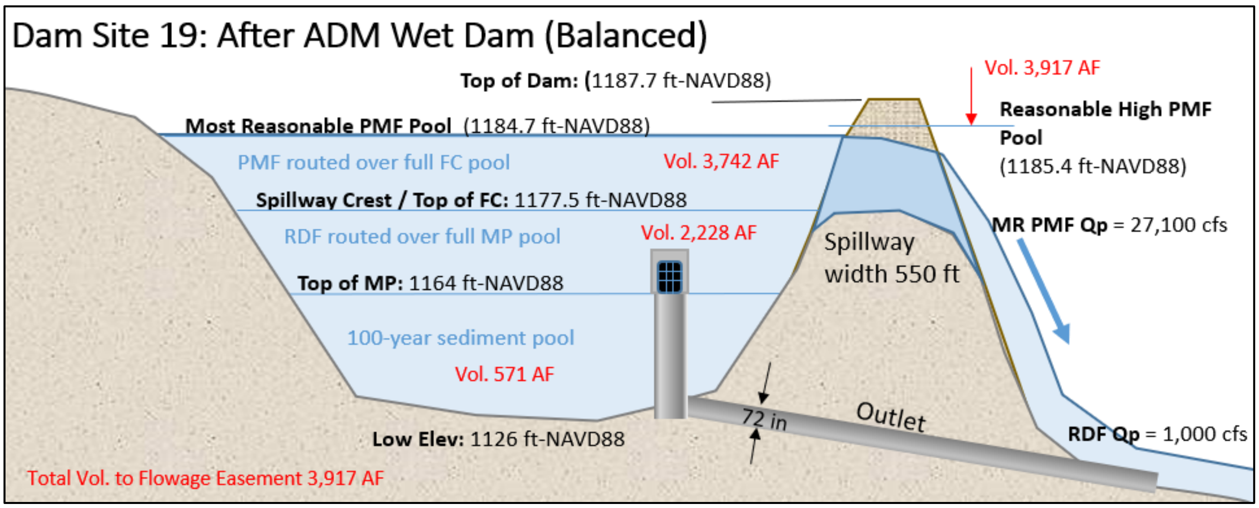


Figure 22. Wet dam After ADM (Balanced) Design. Best balance of cut and fill.

Figure 25 and 26 show other wet dam designs considered in this study. Figure 25 shows the ADM wet dam. This design was used at ADM because it had one of the best balances of spillway cut and embankment fill at the site at the time of ADM and because it produced the lowest maximum PMF pool to avoid taking more real estate in comparison to the other alternative with a good balance of cut and fill. Figure 26 shows the After ADM (NRD) design that drops the Reasonable High PMF pool to the NRD dam top of dam elevation (1184.0 ft-NAVD88) by increasing the spillway width. It was thought at the time this design would reduce real estate takings as it would be comparable to the land acquisitions of the NRD in their design (HDR, 2018).

Refer to the NED Design section for information on the selected design.

15.2 Dry Dam FRM Paper Exercise

Figure 27 shows the ADM dry dam paper exercise. This dry dam paper exercise was completed to determine if flood risk management (FRM) benefits would result in a project of federal interest (benefit-cost ratio of unity or higher). A dry dam with similar design assumptions as the wet dam at the time of ADM was selected (same spillway width and flood control pool at spillway crest opposed to a perched spillway crest). This dry dam did not consider a balance of cut-and-fill.

For this study comparison, the box-culvert outlet size was selected to approximate the outflow of the wet dam design for the 0.2 percent AEP event to provide consistency at larger events between the two designs (wet and dry). The larger outlet size at the bottom of the reservoir also increases the ability to mechanically remove debris in the outlet. See the "Hypothetical Design Storm Modeling" section for comparison of wet dam and dry dam peak discharges for the frequency events.

Figure 28 and 29 show the spillway design flood routings for the wet dam design. Starting pool elevations were the top of flood control and the 5-day drawdown pool as required by ER 1110-8-2(FR). In the case of the 5-day drawdown pool simulations, the ½ PMF was routed with the service outlets operational while the PMF following five days later was routed with the outlets blocked.

15.3 Comparison of Wet Dam and Dry Dam Pools

Figure 30 compares the wet dam and dry dam pools.

In the case of the wet dam, a high PMF pool (1192.4 ft-NAVD88) was provided to the Omaha District Real Estate section to provide a flowage easement pool before a design based on a balance of cut-and-fill was completed. This pool was used for the calculation of real estate for the ADM. The wet dam design that produced the lowest PMF pool with one of the best balances of cut-and-fill at the site had a PMF pool of 1185.4 ft-NAVD88. This is lower than what was used at ADM and may increase the benefit-cost-ratio of the wet dam compared with what was presented.

The dry dam design was a paper exercise to see if the dry dam design would be of federal interest based of FRM benefits. The design presented is one of many and does not include a balance of cut and fill.

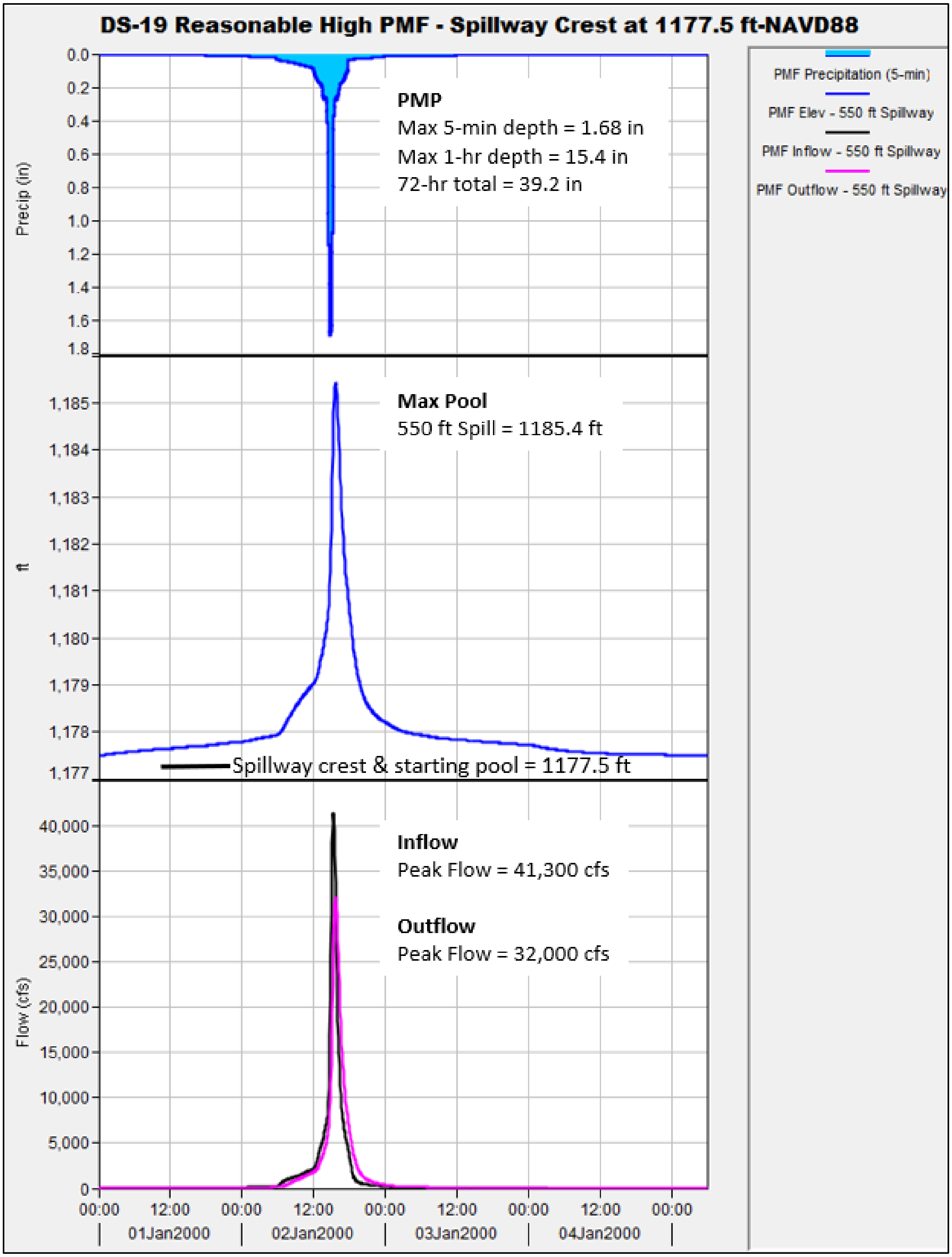


Figure 23. After ADM (Balanced) Design RH PMF Routing. Starting Pool Top of Flood Control.

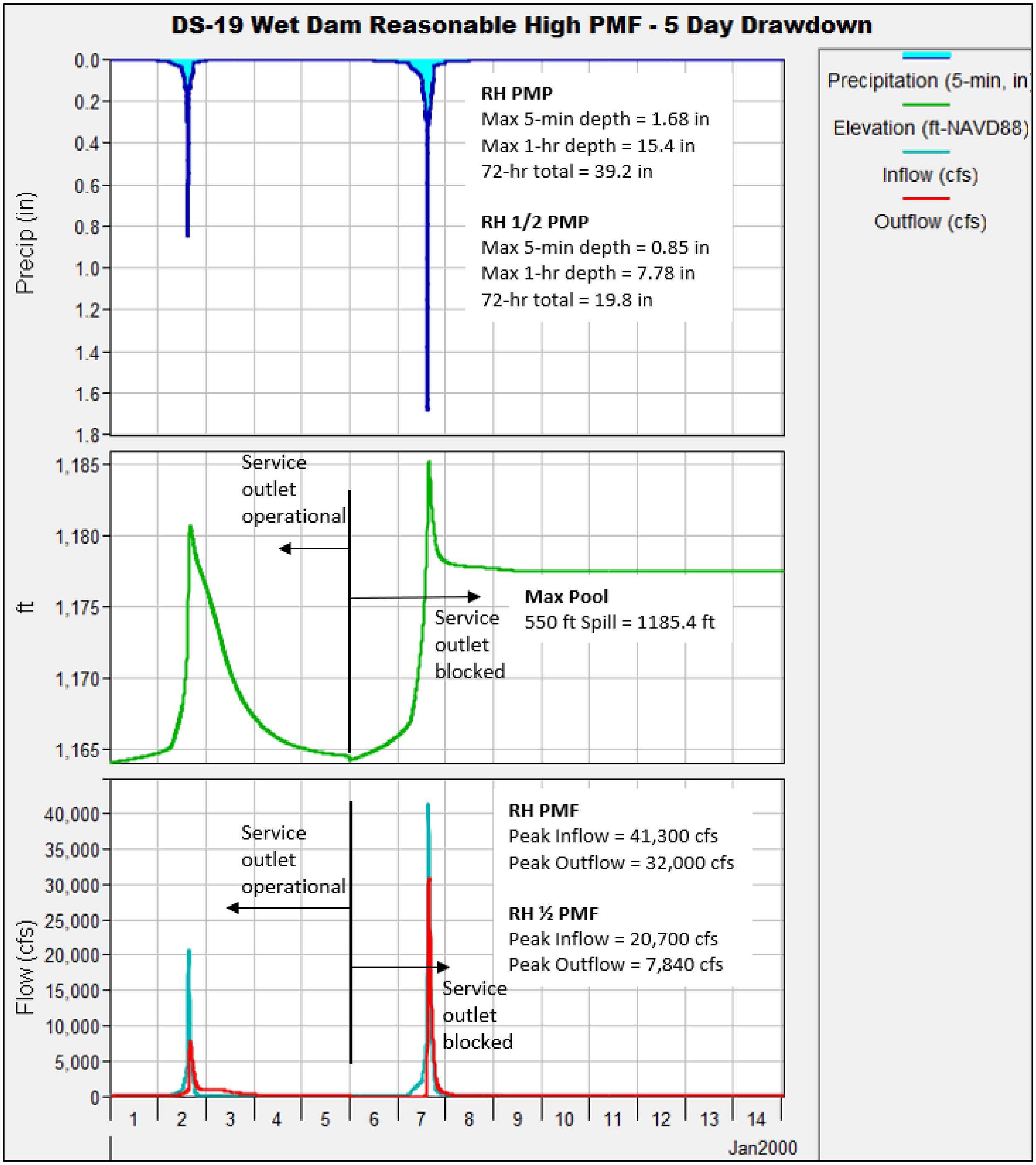


Figure 24. After ADM (Balanced) Design RH PMF Routing. Starting Pool 5-Day Drawdown.

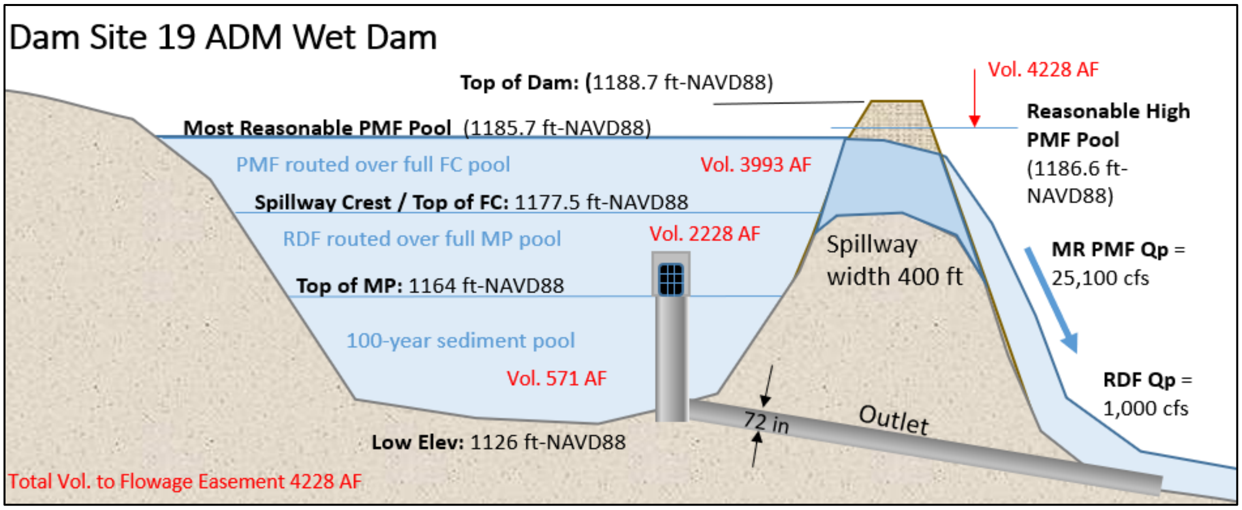


Figure 25. ADM Wet Dam Design

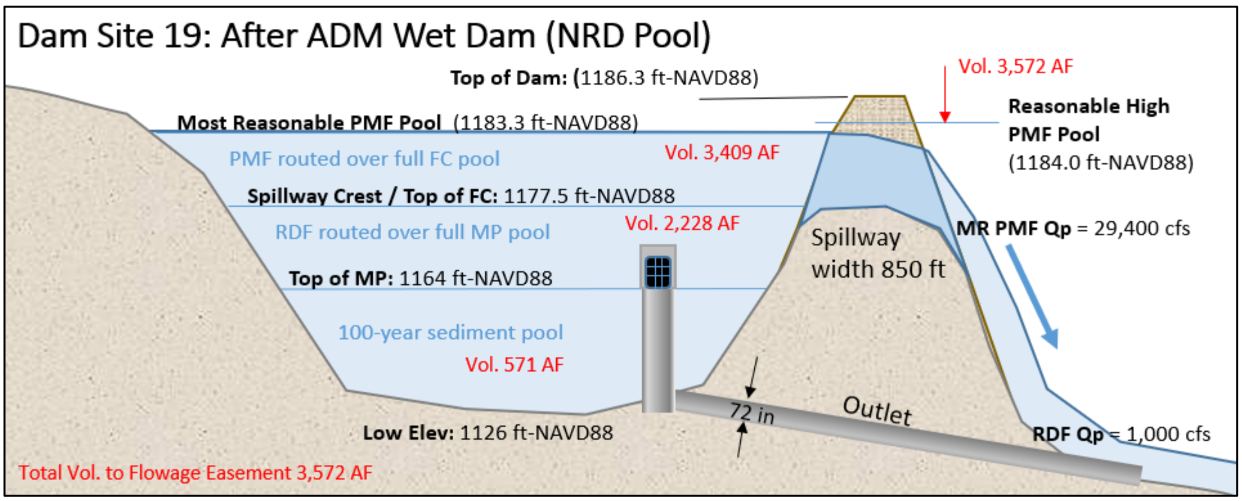


Figure 26. After ADM (NRD) Wet Dam Design; RH PMF/flowage easement pool dropped to 1184.0 ft-NAVD88.

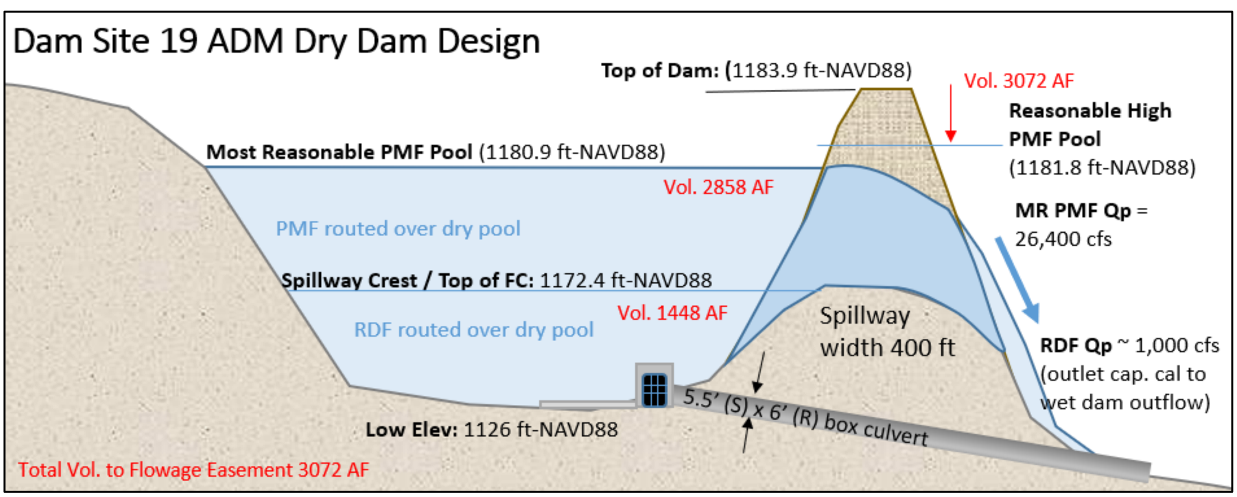


Figure 27. ADM Dry Dam Paper Exercise

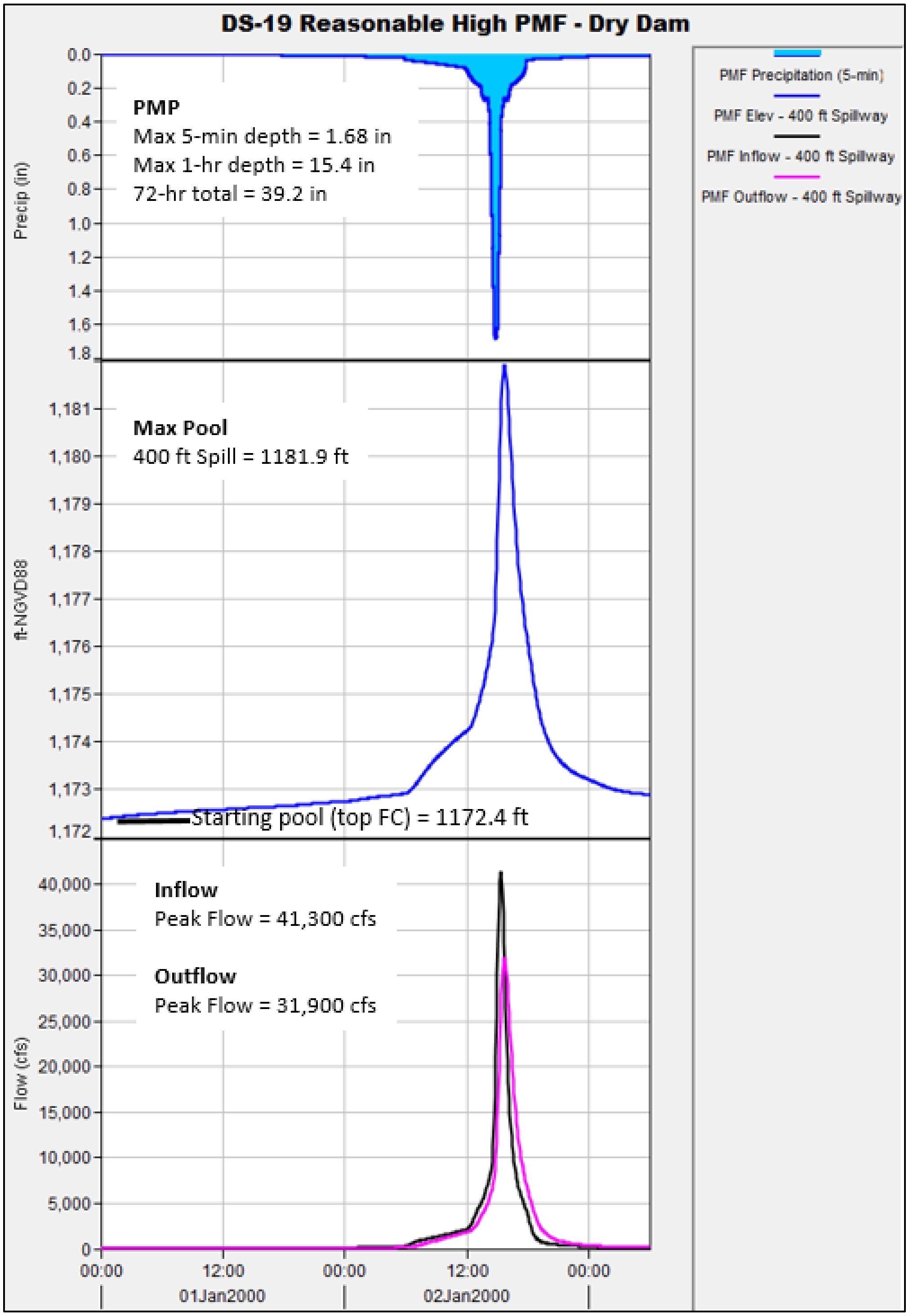


Figure 28. ADM Dry Dam Design Routing - Starting Pool Top of Flood Control (Spillway Width 400 ft)

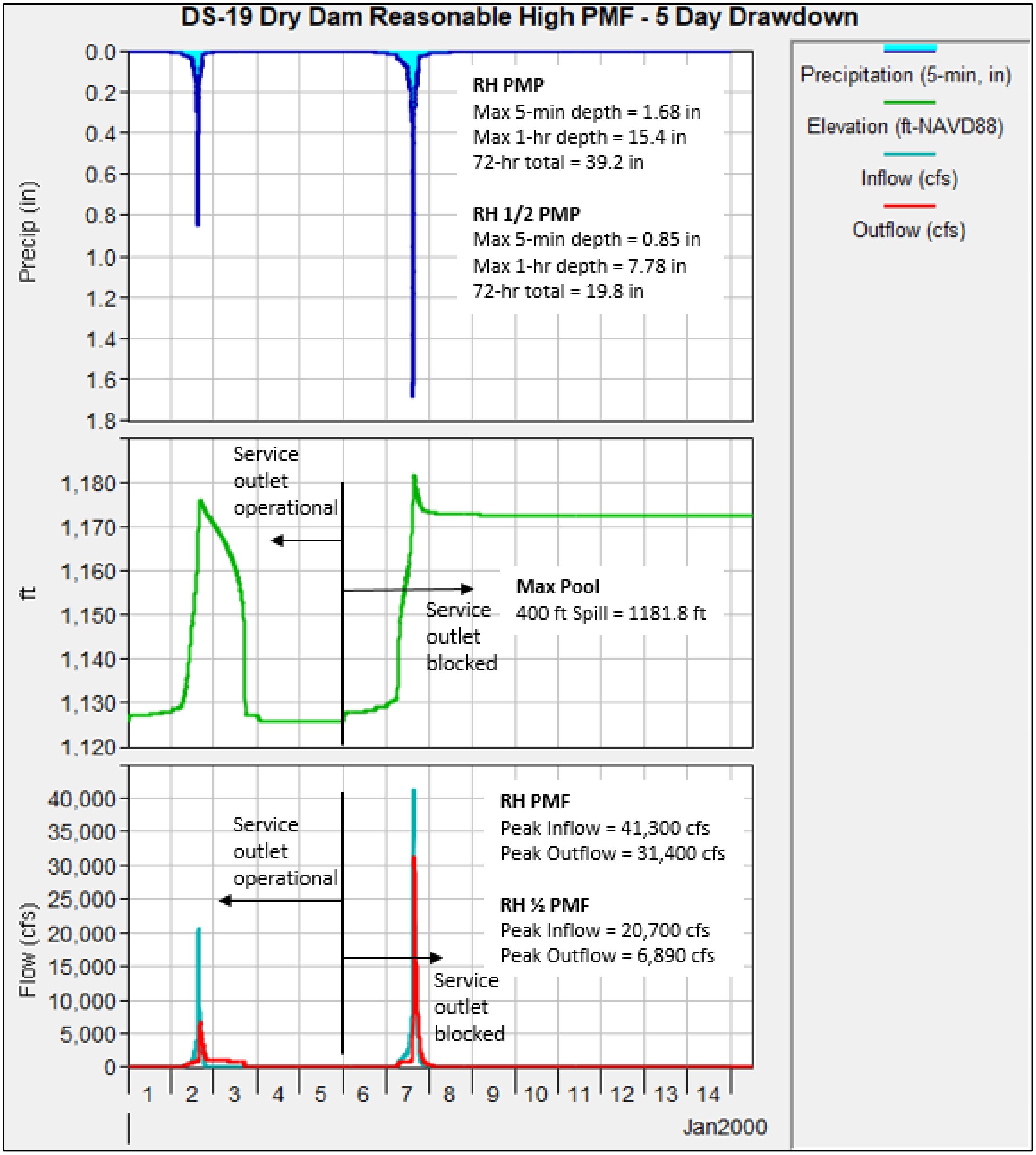


Figure 29. ADM Dry Dam Design Routing - Starting Pool 5-Day Drawdown (Spillway Width 400 ft)

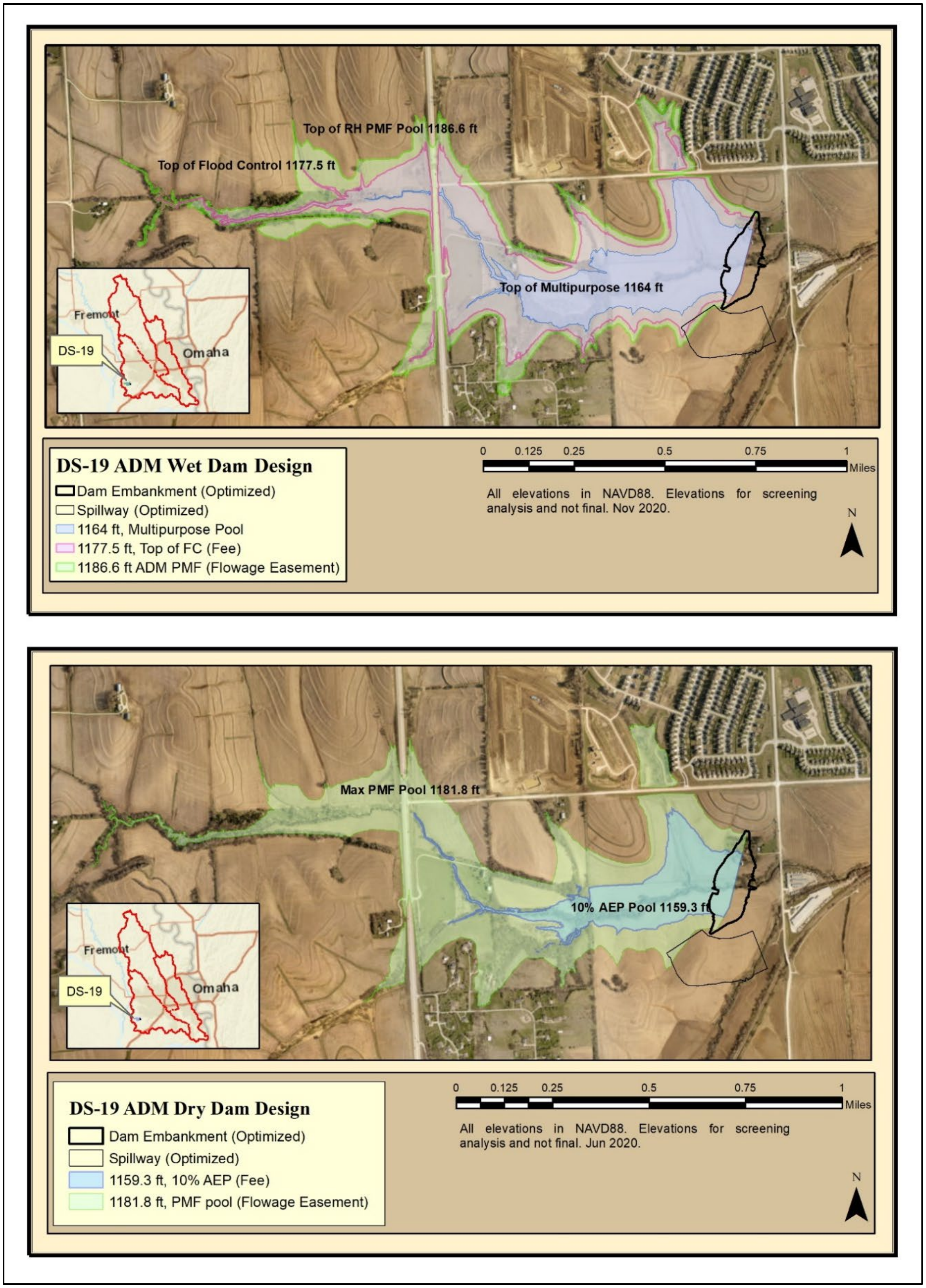


Figure 30. Pool Comparison – ADM Wet and Dry Dams

16 Hypothetical Design Storm Modeling

Four hypothetical scenarios were modeled:

1. Wet dam future conditions
2. Wet dam existing conditions
3. Dry dam future conditions
4. Dry dam existing conditions

Hypothetical frequency events included the 0.2-, 0.5-, 1-, 2-, 4-, 10-, 20-, 50- and 99.9-percent annual exceedance probability (AEP) events (500-, 200-, 100-, 50-, 25-, 10-, 5- and 2-year events). Results shown are for existing and future conditions. Both sets of hydrographs were provided to the Omaha District Hydraulics section for use in unsteady flow modeling.

For the wet dam scenarios, the hypothetical design storms were routed through the reservoir with the antecedent pool set to the top of the permanent pool (1164 ft-NAVD88). For the dry dam scenarios, the hypothetical design storms were routed into an empty reservoir because the dam has no permanent pool. All results were provided to the Omaha District Hydraulics section for use in unsteady flow modeling.

The hypothetical precipitation were NOAA Atlas 14 12-hour depths with temporal patterns and areal reductions from the Applied Weather Associates (AWA) study documented in Appendix J of the FYRA 2018 report (FYRA, 2018). Temporal pattern calculations are shown in Appendix H of the FYRA report. These are the same events used in the project before TSP.

Table 23 shows the 12-hour NOAA Atlas 14 precipitation depths used for the frequency events. Appendix A-2B shows temporal patterns for those events not determined by FYRA. The FYRA report shows the other temporal events.

Table 24 through 27 and Figure 31 through 34 show the frequency event results.

Figure 35 shows the difference in frequency event peak flows between the wet dam and the comparable dry dam designs. While the dry dam outlet was sized by approximating the 0.2 percent AEP peak outflow of the wet dam to maintain consistency between the largest events, there are differences in peak flows for the more frequent events which resulted in a loss of FRM benefits for the dry dam compared to the wet dam design. Differences in peak outflows are due to the outlet effective area and the location of the dry dam outlet works at the bottom of the reservoir where head increases are greater for equivalent increases in storage volume.

Table 23. NOAA Atlas 14 12-hour Depths

	NOAA Atlas 14 Precipitation Depth								
Duration	**99.9% AEP**	**50% AEP**	**20% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.5% AEP**	**0.2% AEP**
12-hr	1.88	2.64	3.33	3.96	4.94	5.77	6.67	7.65	9.06

Table 24. Wet Dam Existing Conditions Frequency Event Inflows, Outflows and Peak Pool Elevations (Same for Both ADM and After ADM Designs)

Event (AEP%)	Return Period (YR)	Peak Inflow (cfs)	Peak Outflow (cfs)	Starting Pool Elevation (ft)	Peak Elevation (ft)	Rise in Pool (ft)
0.2	500	6,782	974	1164	1174.9	10.9
0.5	200	5,499	954	1164	1173	9
1	100	4,773	859	1164	1172	8
2	50	4,010	687	1164	1170.9	6.9
4	25	3,302	534	1164	1169.8	5.8
10	10	2,470	363	1164	1168.5	4.5
20	5	1,880	250	1164	1167.5	3.5
50	2	1,304	150	1164	1166.5	2.5
99.9	1	672	57	1164	1165.3	1.3

Table 25. Wet Dam Future Conditions Frequency Events. The primary change is an increase in percent imperviousness from existing conditions.

Event (AEP%)	Return Period (YR)	Peak Inflow (cfs)	Peak Outflow (cfs)	Starting Pool Elevation (ft)	Peak Elevation (ft)	Rise in Pool (ft)
0.2	500	7,006	980	1164	1175.6	11.6
0.5	200	5,712	961	1164	1173.7	9.7
1	100	5,003	950	1164	1172.6	8.6
2	50	4,241	789	1164	1171.5	7.5
4	25	3,534	630	1164	1170.5	6.5
10	10	2,703	452	1164	1169.2	5.2
20	5	2,114	331	1164	1168.2	4.2
50	2	1,540	221	1164	1167.2	3.2
99.9	1	908	113	1164	1166.1	2.1

Table 26. Dry Dam Existing Conditions Frequency Events

Event (AEP%)	Return Period (YR)	Peak Inflow (cfs)	Peak Outflow (cfs)	Starting Pool Elevation (ft)	Peak Elevation (ft)	Rise in Pool (ft)
0.2	500	6,782	978	1126	1169.7	43.7
0.5	200	5,500	956	1126	1166.9	40.9
1	100	4,773	940	1126	1165.2	39.2
2	50	4,010	917	1126	1163.1	37.1
4	25	3,302	892	1126	1161	35
10	10	2,470	855	1126	1158	32
20	5	1,880	813	1126	1155.2	29.2
50	2	1,304	753	1126	1151.5	25.5
99.9	1	672	570	1126	1141.9	15.9

Table 27. Dry Dam Future Conditions Frequency Events

Event (AEP%)	Return Period (YR)	Peak Inflow (cfs)	Peak Outflow (cfs)	Starting Pool Elevation (ft)	Peak Elevation (ft)	Rise in Pool (ft)
0.2	500	7,006	985	1126	1170.4	44.4
0.5	200	5,712	963	1126	1167.7	41.7
1	100	5,003	950	1126	1166.1	40.1
2	50	4,241	928	1126	1164.1	38.1
4	25	3,534	904	1126	1162.1	36.1
10	10	2,703	871	1126	1159.3	33.3
20	5	2,114	837	1126	1156.7	30.7
50	2	1,540	786	1126	1153.5	27.5
99.9	1	908	692	1126	1148	22

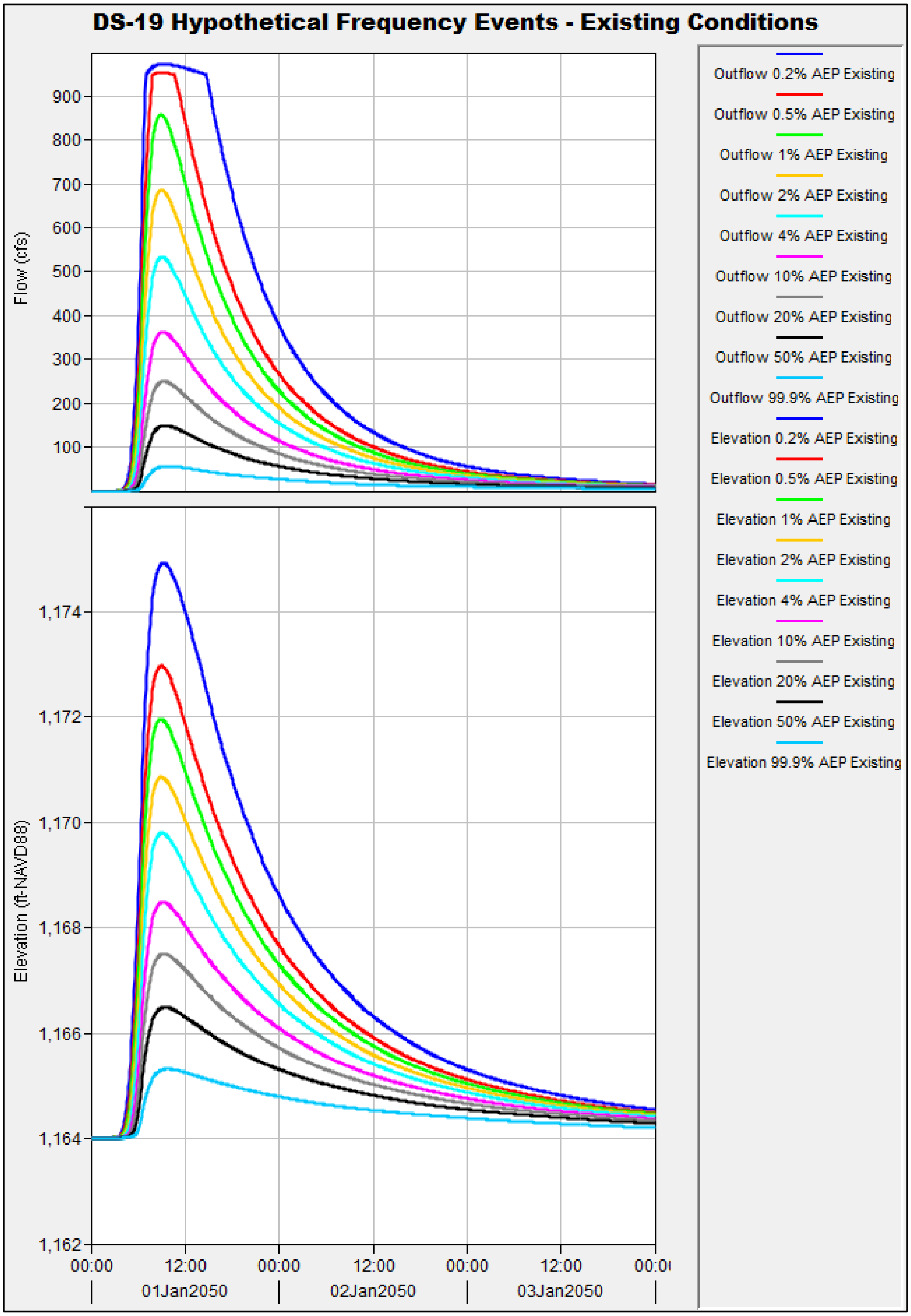


Figure 31. Wet Dam Existing Conditions Frequency Event Outflows and Pool Elevations

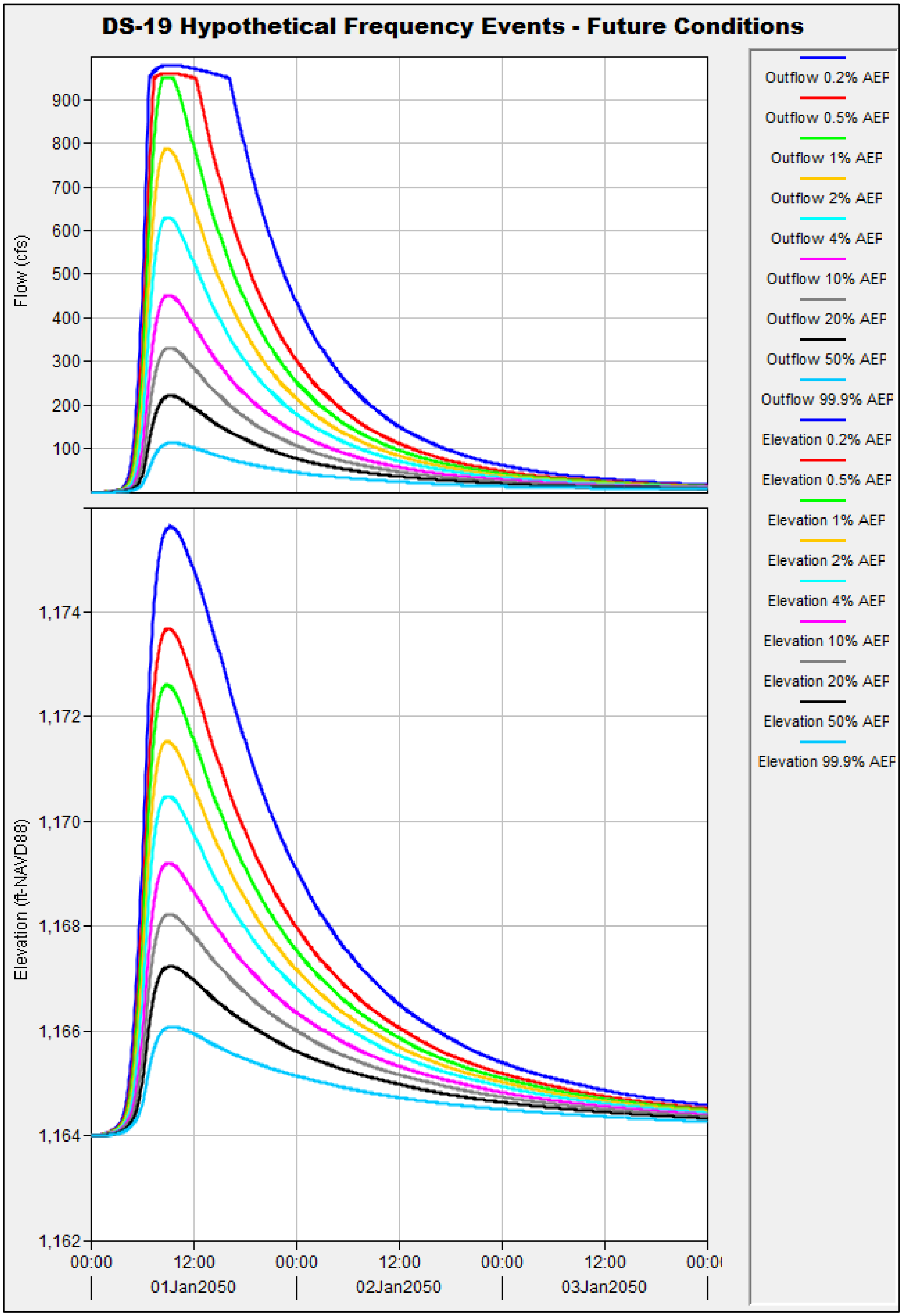


Figure 32. Wet Dam Future Conditions Frequency Event Outflows and Pool Elevations

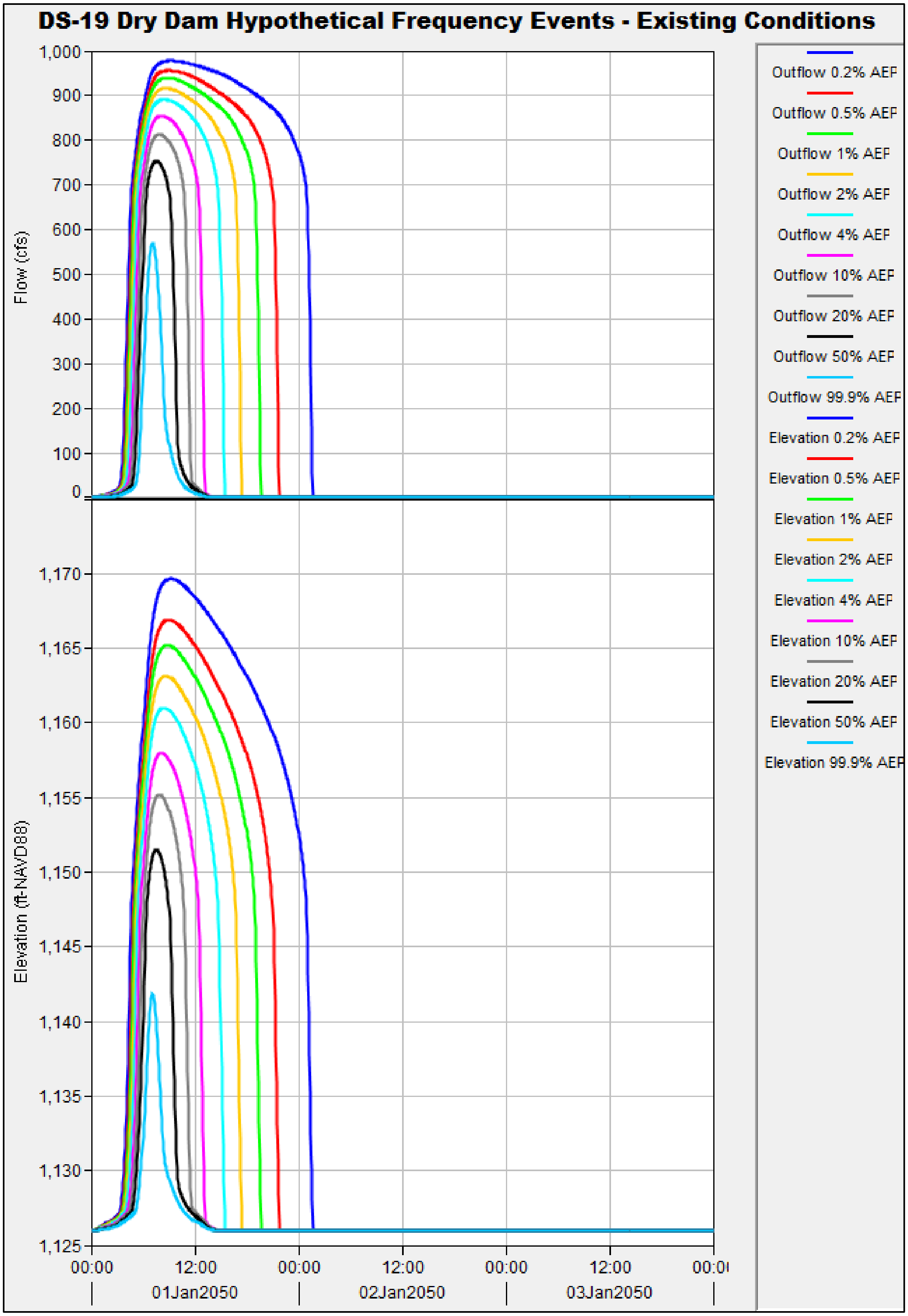


Figure 33. Dry Dam Existing Conditions Frequency Event Outflows and Pool Elevations

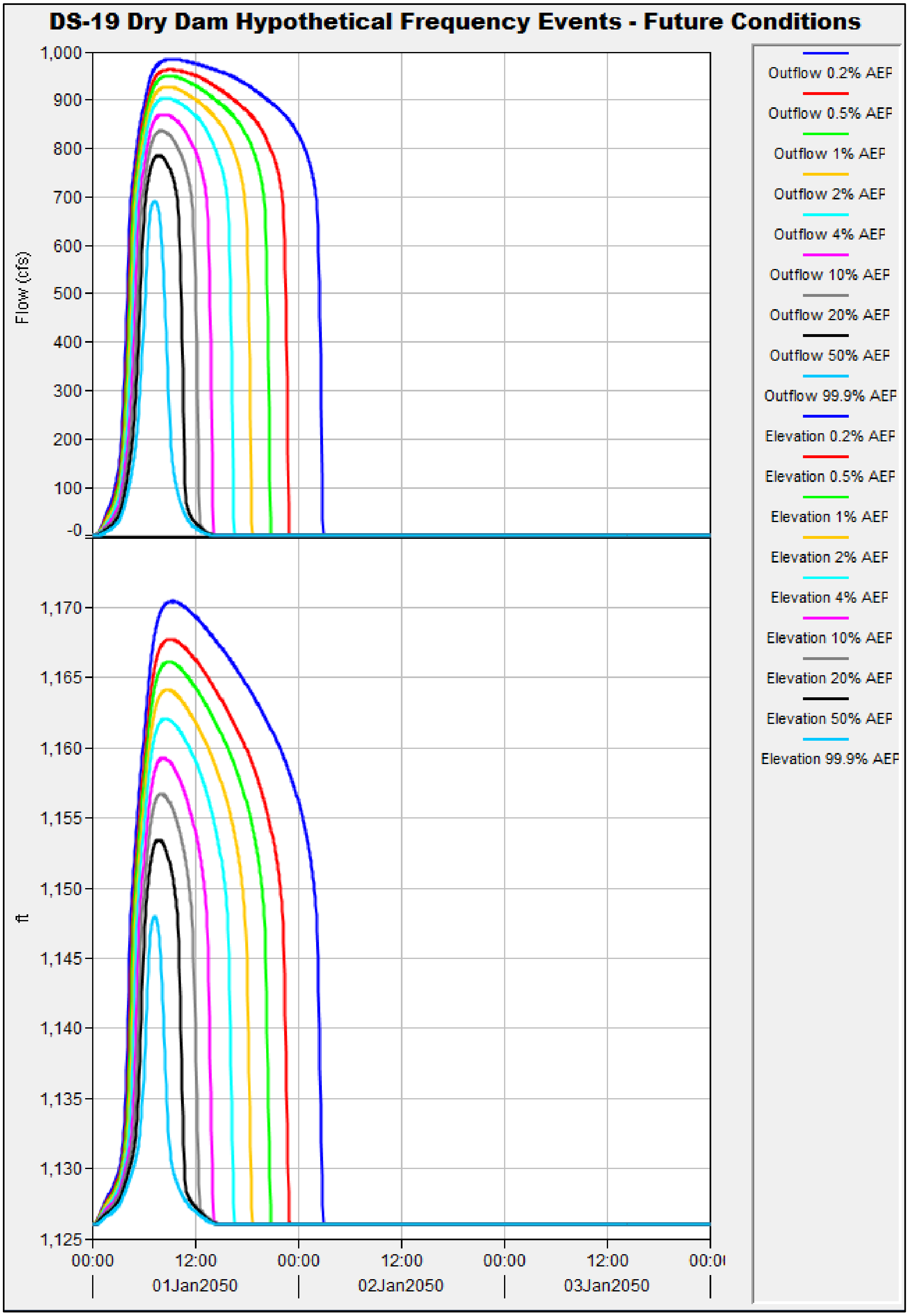


Figure 34. Dry Dam Future Conditions Frequency Event Outflows and Pool Elevations

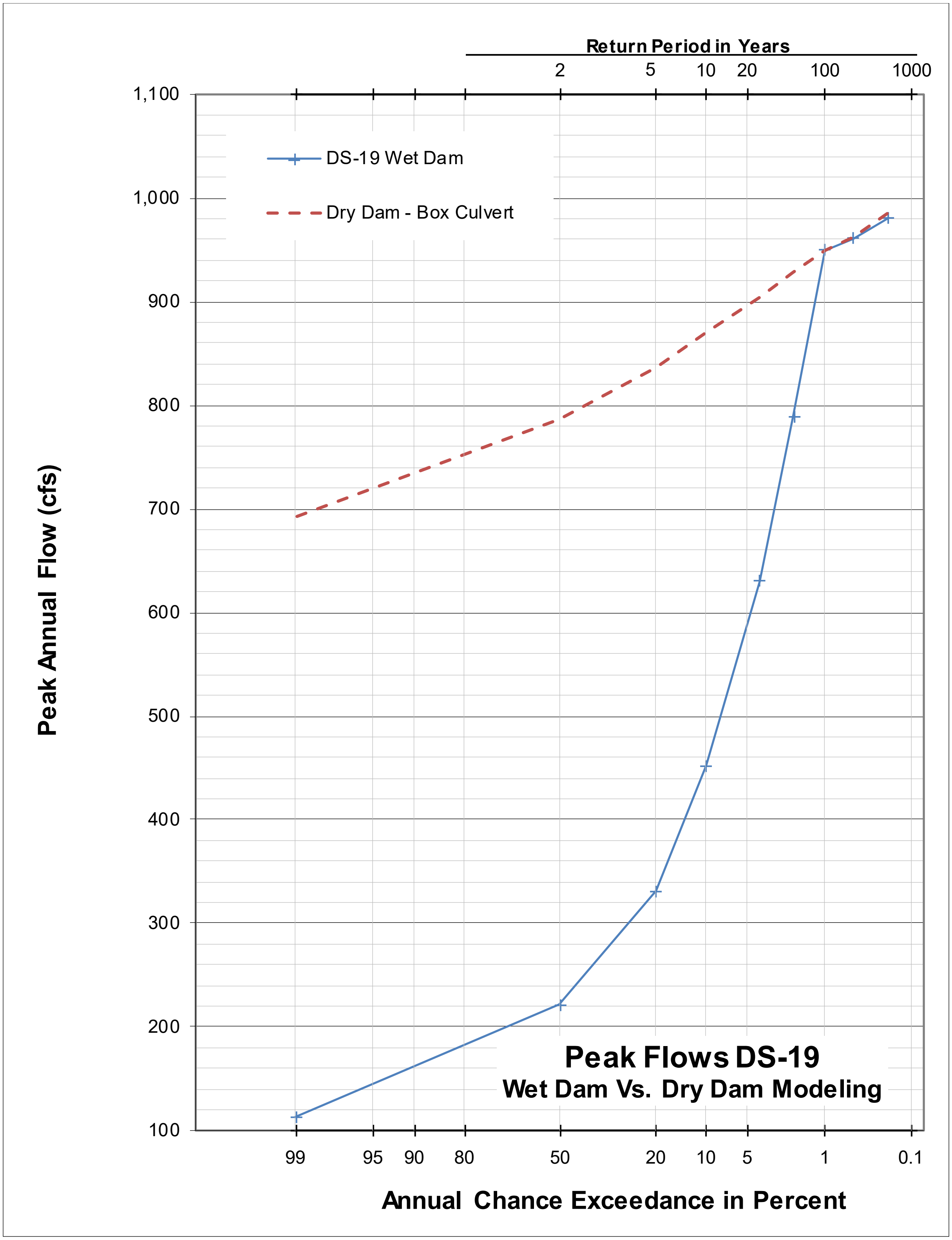


Figure 35. Peak Flow Comparison - Wet and Dry Dams

17 Cost Optimization

Cost optimization was undertaken to determine if DS10 could produce the same benefits of the current design (NED Plan) at a lower cost. The additional costs of the excavation of the spillway and the addition of a spillway sill resulted in higher costs than the design with the spillway crest at the top of the RDF.

Cost optimization was carried out by lowering the level of protection to the 0.2 percent AEP. The spillway crest was lowered to the pool created by the ten square mile 0.2 percent AEP storm used in the analysis of the alternatives. A dam with this level of protection has the following:

- Top of dam = 1185.9 ft NAVD88
- Spillway crest = 1175.6 ft NAVD88
- Spillway width = 550 ft
- Flowage easement pool or RH PMF pool = 1183.7 NAVD88

An increase in the level of protection was not considered because it does not result in higher benefits and only raises the costs.

18 Cost Allocation

The design of Dam Site 19 (DS19) included both FRM and recreation benefits. This section documents the hydrology used to separate out the FRM and recreation benefits. This analysis was requested by reviewers after the ADM.

18.1 Recreation Only Scenario

The recreation only scenario was conceptualized by lowering the spillway crest to the top of the multipurpose/recreation pool elevation (1164.0 ft NAVD88). This means the spillway will flow for all events and will require armoring on the spillway embankment. Armoring and the spillway cut involved is discussed in other disciplines' Appendices.

At this point in the analysis, only the costs of the additional cut required to lower the spillway elevation were considered. Peak flows and outflow hydrographs were not determined.

18.2 FRM Benefits Only Scenario

A dry dam scenario with a conceptual outlet design that approximates the benefits of the After ADM Design (Balanced Pool) wet dam was used to determined costs and benefits for a dam that provides only FRM benefits. This modified hypothetical design was developed to better compare the wet and dry dam designs based on reviewer feedback at ADM.

Table 22 shows the rating curve for the modified outlet and Figure 24 shows a comparison of the dry dam peak outflows to the wet dam design [After ADM Wet Dam (Balanced)]. Outflows could not be matched exactly between this dry dam and the wet dam design. This is because the dry dam outlet has a riser with slots beginning at the bottom of the reservoir where storage is smaller than at the top of the multipurpose pool elevation where inflows for the wet dam would enter. This means the dry dam will have a higher stage and head over the outlet compared to a wet dam with an identical flood event.

The dry dam for the FRM Benefits only scenario has the same spillway crest elevation, top of dam and future Reasonable High PMF pool elevation (flowage easement pool) as the NED wet dam because it will eventually fill with sediment up to the top of multipurpose pool elevation.

Table 28. Outlet Rating Curve for Dry Dam Slotted Riser/Outlet (72 Inch Diameter)

Elevation (ft NAVD88)	Discharge (cfs)	Elevation (ft NAVD88)	Discharge (cfs)	Elevation (ft NAVD88)	Discharge (cfs)	Elevation (ft NAVD88)	Discharge (cfs)
1126	0	1145	101.2	1164	584	1183	1050.2
1126.5	0.3	1145.5	105.7	1164.5	623.9	1183.5	1054.8
1127	0.8	1146	110.3	1165	672.6	1184	1059.4
1127.5	1.4	1146.5	115	1165.5	727.1	1184.5	1063.9
1128	2.1	1147	119.7	1166	786.2	1185	1068.3
1128.5	2.9	1147.5	124.5	1166.5	849.4	1185.5	1072.8
1129	3.8	1148	129.3	1167	892.2	1186	1077.3
1129.5	4.7	1148.5	134.3	1167.5	897.6	1186.5	1081.8
1130	5.7	1149	139.2	1168	902.9	1187	1086.2
1130.5	6.7	1149.5	144.3	1168.5	908.2	1187.5	1090.6
1131	8.2	1150	149.4	1169	913.5	1188	1095
1131.5	10	1150.5	154.5	1169.5	918.7	1188.5	1099.4
1132	11.9	1151	159.8	1170	923.9	1189	1103.7
1132.5	14	1151.5	165	1170.5	929.1	1189.5	1108
1133	16.3	1152	170.4	1171	934.2	1190	1112.3
1133.5	18.7	1152.5	175.7	1171.5	939.4	1190.5	1116.7
1134	21.2	1153	181.2	1172	944.5	1191	1121
1134.5	23.9	1153.5	189	1172.5	949.5	1191.5	1125.2
1135	26.7	1154	197.9	1173	954.6	1192	1129.4
1135.5	29.5	1154.5	207.6	1173.5	959.6	1192.5	1133.7
1136	32.5	1155	217.9	1174	964.6	1193	1137.9
1136.5	35.6	1155.5	228.9	1174.5	969.5	1193.5	1142.1
1137	38.8	1156	240.4	1175	974.4	1194	1146.3
1137.5	42.1	1156.5	252.4	1175.5	979.4	1194.5	1150.5
1138	45.4	1157	264.9	1176	984.2	1195	1154.7
1138.5	48.9	1157.5	277.8	1176.5	989.1	1195.5	1158.8
1139	52.4	1158	291.2	1177	993.9	1196	1162.9
1139.5	56.1	1158.5	305	1177.5	998.8	1196.5	1167
1140	59.8	1159	319.2	1178	1003.5	1197	1171.1
1140.5	63.6	1159.5	333.8	1178.5	1008.3	1197.5	1175.2
1141	67.5	1160	354.1	1179	1013	1198	1179.3
1141.5	71.4	1160.5	377	1179.5	1017.8	1198.5	1183.4
1142	75.5	1161	401.9	1180	1022.5	1199	1187.4
1142.5	79.6	1161.5	428.6	1180.5	1027.1	1199.5	1191.4
1143	83.7	1162	456.9	1181	1031.8	1200	1195.5
1143.5	88	1162.5	486.7	1181.5	1036.5	1200.5	1199.5
1144	92.3	1163	517.9	1182	1041.1		
1144.5	96.7	1163.5	550.3	1182.5	1045.7		

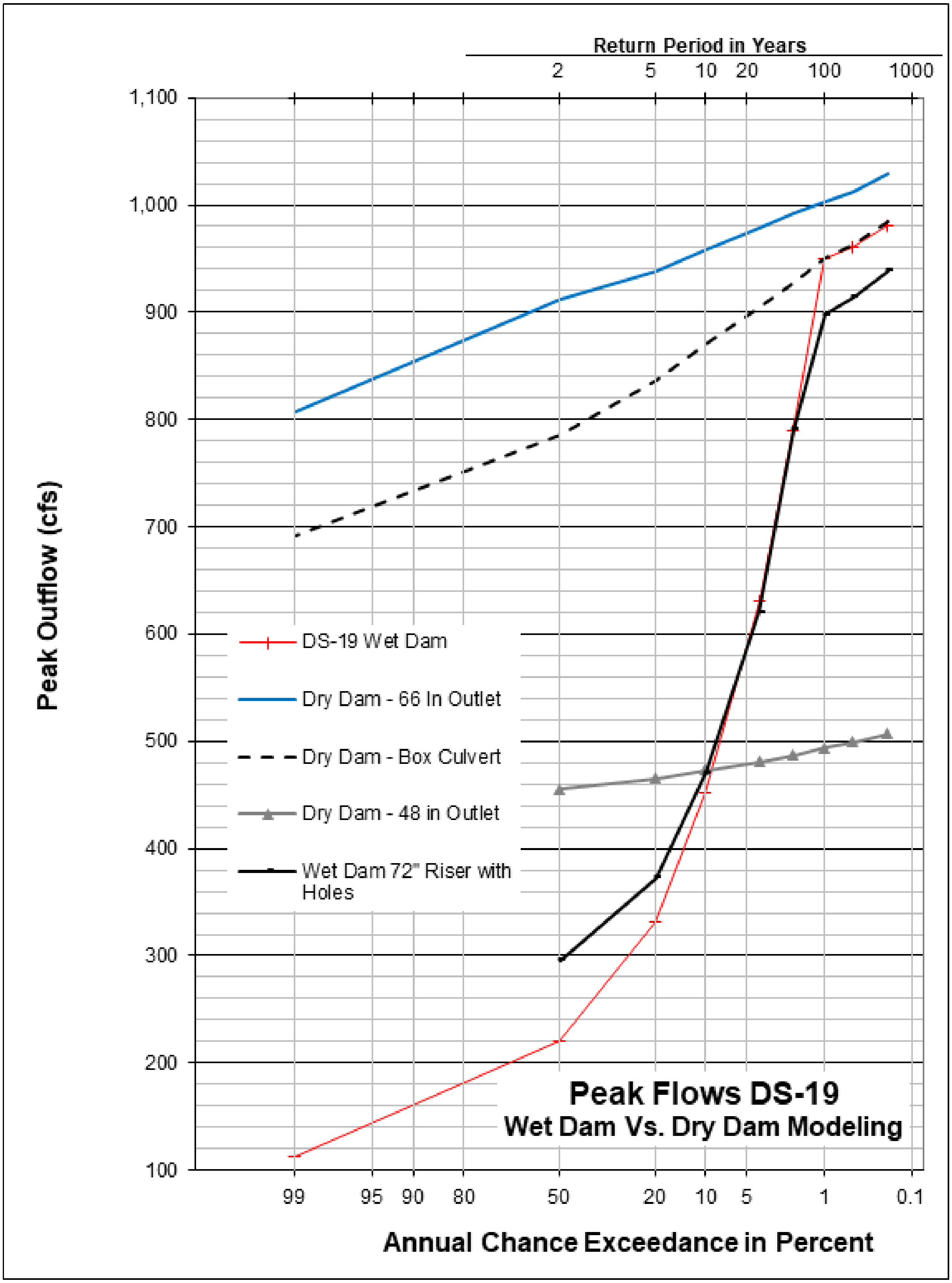


Figure 36. Peak outflow frequency comparisons (Wet Dam 72" Riser with Holes option adopted)

19 NED Design

Figure 37 shows the design of DS19 adopted as the NED after optimization and incorporating input from other disciplines. The conduit outlet invert was raised from 1126 ft to 1139.46 ft NAVD88 to elevate the outlet into more stable geology (glacial till). Results developed up to this point in the study were not negatively impacted by this change. See Appendix A-2A of this document for more information on sensitivity testing.

Figure 38 and Table 29 show the outlet rating curve used for this design. Capacity and spillway curves remain the same as documented previously. The volume of the RDF was reduced to 0.96*SPF to maintain the same top of flood pool and spillway crest elevation.

Figure 39 shows the spillway design flood routing and Figure 40 shows the RDF routing.

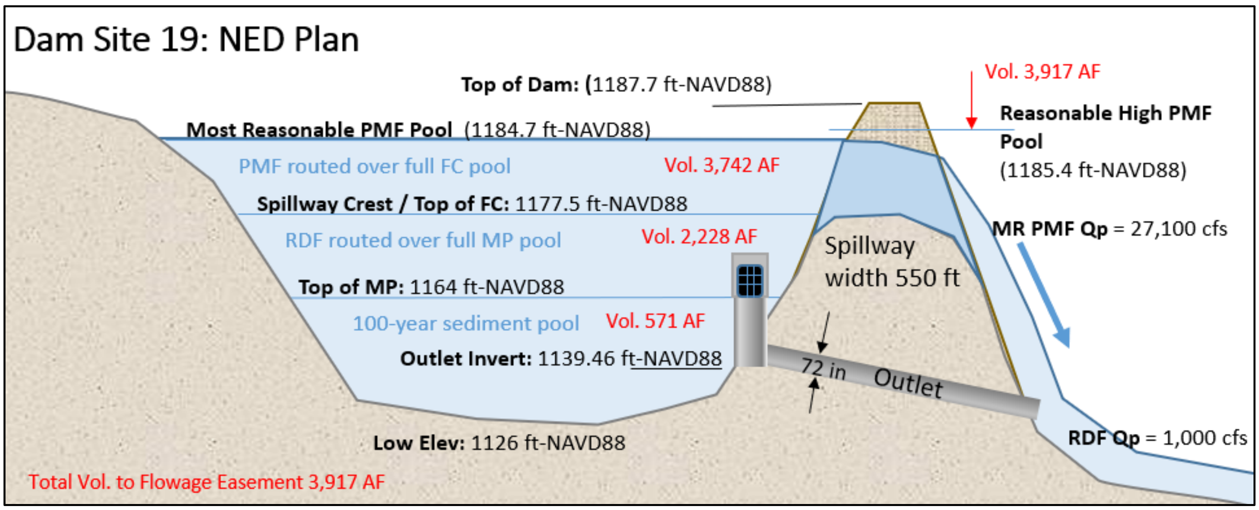


Figure 37. NED Optimized Plan

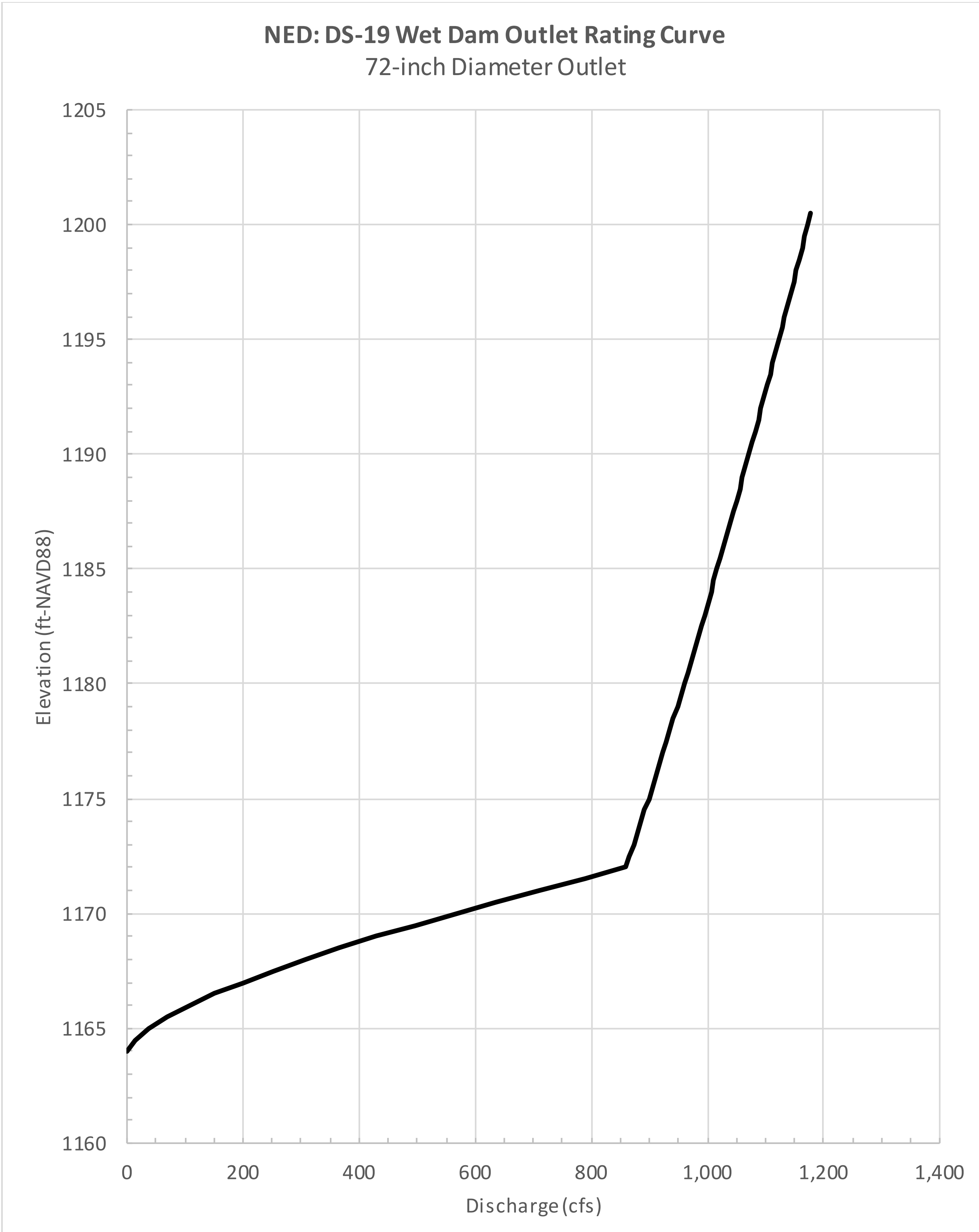


Figure 38. NED Outlet Rating Curve

Table 29. NED Outlet Rating Curve

Pool (ft)	Discharge (cfs)	Pool (ft)	Discharge (cfs)	Pool (ft)	Discharge (cfs)
1164.00	0.0	1176.5	917.2	1189	1060.8
1164.50	13.6	1177	923.4	1189.5	1066.1
1165.00	38.4	1177.5	929.5	1190	1071.4
1165.50	70.5	1178	935.6	1190.5	1076.7
1166.00	109	1178.5	941.6	1191	1081.9
1166.50	152	1179	947.6	1191.5	1087.2
1167.00	200	1179.5	953.6	1192	1092.4
1167.50	251	1180	959.6	1192.5	1097.6
1168.00	307	1180.5	965.4	1193	1102.7
1168.50	367	1181	971.3	1193.5	1107.9
1169.00	429	1181.5	977.2	1194	1113
1169.50	495	1182	982.9	1194.5	1118.1
1170.00	564	1182.5	988.7	1195	1123.1
1170.50	636	1183	994.4	1195.5	1128.2
1171.00	711	1183.5	1000.1	1196	1133.2
1171.50	789	1184	1005.8	1196.5	1138.2
1172.00	860	1184.5	1011.4	1197	1143.2
1172.50	866	1185	1017	1197.5	1148.1
1173.00	873	1185.5	1022.6	1198	1153.1
1173.50	879	1186	1028.1	1198.5	1158
1174.00	886	1186.5	1033.6	1199	1162.9
1174.50	892	1187	1039.1	1199.5	1167.7
1175.00	898	1187.5	1044.5	1200	1172.6
1175.50	905	1188	1050	1200.5	1177.4
1176.00	911	1188.5	1055.4		

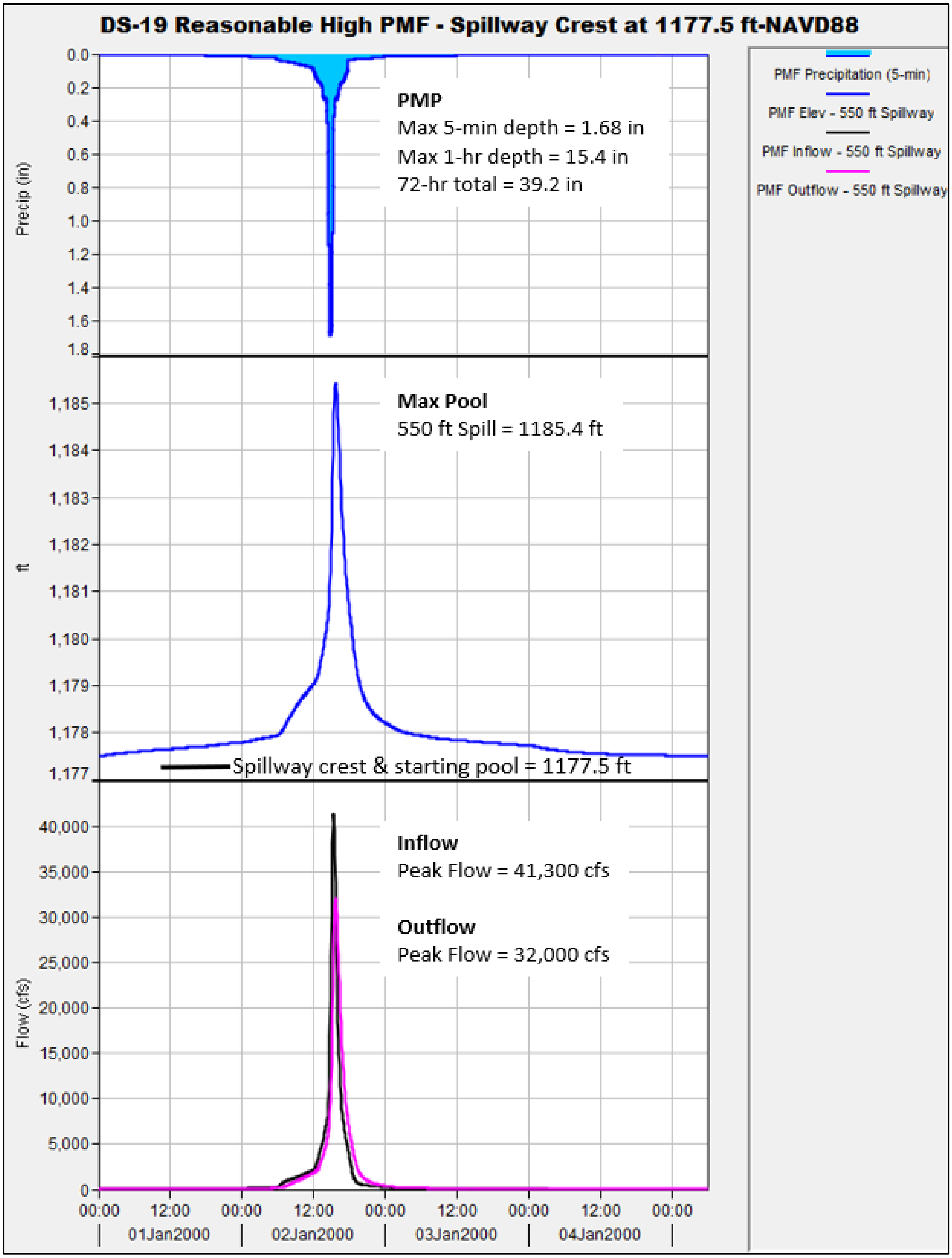


Figure 39. NED Spillway Design Flood -- PMF Routed Over Full Flood Control Pool (Outlet Blocked)

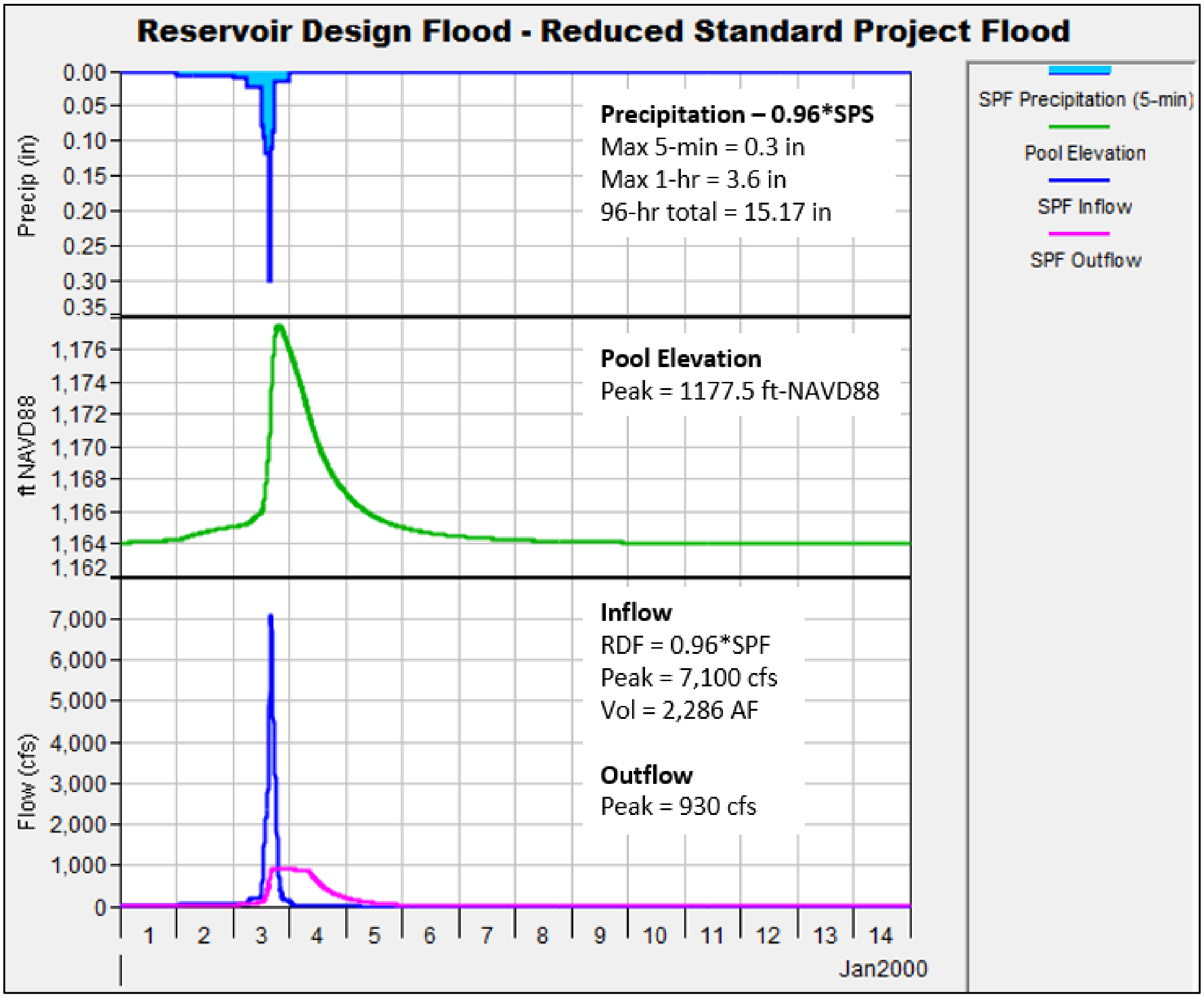


Figure 40. NED Reservoir Design Flood --0.96*SPF Routed Over Full Multipurpose Flood (Outlet Functional)

20 Study Risks

Identified study risks related to modeling of DS19 outlined below.

20.1 Model Calibration Events

The Papillion Creek watershed does not have a long history of gauge data to which to calibrate the model. The three events used to calibrate the FYRA model were all recent events and all occurred in the month of June.

20.2 Highway 6 Impacts

It was assumed that dropping the RDF to 1177.5 ft-NAVD88 would negate effects of the flood event on Highway 6. Additional hydraulic modeling determined that the existing 8 ft x 8 ft box culverts on HWY 6 look to be appropriately sized. The resulting water surface from the 14 ft x

14 ft triple box culvert on HWY 6 does look to encroach slightly into the outer drive lane during the RDF. Raising the roadway by 0.6 ft for about 500 feet of roadway length would take the place of resizing the culverts. This may be small enough for an asphalt overlay.

20.3 Dam Safety Risk Analysis

The feasibility analysis to TSP included very limited dam safety risk analysis and has not compared risk across alternatives. An Abbreviated Semi-Quantitative Risk Assessment (SQRA) was developed for DS10 and DS19 after TSP with the NED plan designs. These are documented in the Risk to Life Safety Appendix (Appendix L).

20.4 Affects of Sediment on Storage Capacity

While a 100-year sediment pool was considered in the placement of the outlet invert of the riser, the loss of storage within the different zones of the reservoir was not considered at this point in the analysis.

21 Equivalent Period of Record

Based on reference to Table 4-5 in EM 1110-2-1619, the equivalent years of record for a rainfall-runoff model calibrated to several events recorded at a short-interval gauge in the watershed is somewhere between 20-30 years.

The recommended equivalent years of record for the Papillion Creek GRR project is 23 years. Several locations were used in the calibration of the model, but the events used were small in comparison with the historic and moderate events of record (except in the Papillion Creek at Fort Crook location). However, the watershed has changed significantly since these historic events (like the 1964 flood) so calibration to these larger events would not reflect current conditions.

In addition, the model was calibrated to events and not peak flow frequencies. Calibration or verification to a peak flow frequency at a gauge would have decreased uncertainty in model results and resulted in a longer equivalent record. Twenty-three years opposed to 20 was selected to include the higher confidence due to the availability of higher-quality calibration data like radar rainfall.

The estimate of 23 year of equivalent years of record was used for both the existing and future conditions. Future conditions (2040) are not that far in the future so an assumption of 23 years (the same uncertainty in data) was considered reasonable.

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Appendix A-2A. Sensitivity Analysis: Increase in Outlet Conduit Invert

Increase in Outlet Conduit Invert

This appendix summarized impacts to the results after the outlet invert of the dam was raised from 1126 ft to 1139.46 ft NAVD88. Results presented previously were not significantly sensitive to this change. Figure A1 shows the conceptual design of the dam after the outlet invert of the 72-inch diameter culvert is raised over ten feet. Note that the elevation of the riser invert stays the same at 1177.5 ft NAVD88.

Results that differed from those presented in this Addendum included:

- An additional decrease in the standard project flood (SPF) used in the reservoir design flood (RDF) design. Originally 0.97*SPF was used. With the raise of the outlet conduit invert 0.96*SPF was used for the reservoir design flood. There was no increase in the starting pool of the inflow design flood (IDF) so routings presented early in these report are unchanged.
- A decrease in peak outflows for the frequency events (0.2 to 50 percent annual exceedance probabilities (AEP)) from 70 to 80 cfs. This increases the benefits of the project and would not negatively affect the benefit cost ratio. Table A1 shows the updated results.
- An increase in the peak pool elevations created by the frequency events. These were not significant increases, 0.1 ft or less. Table A1 shows the updated results.

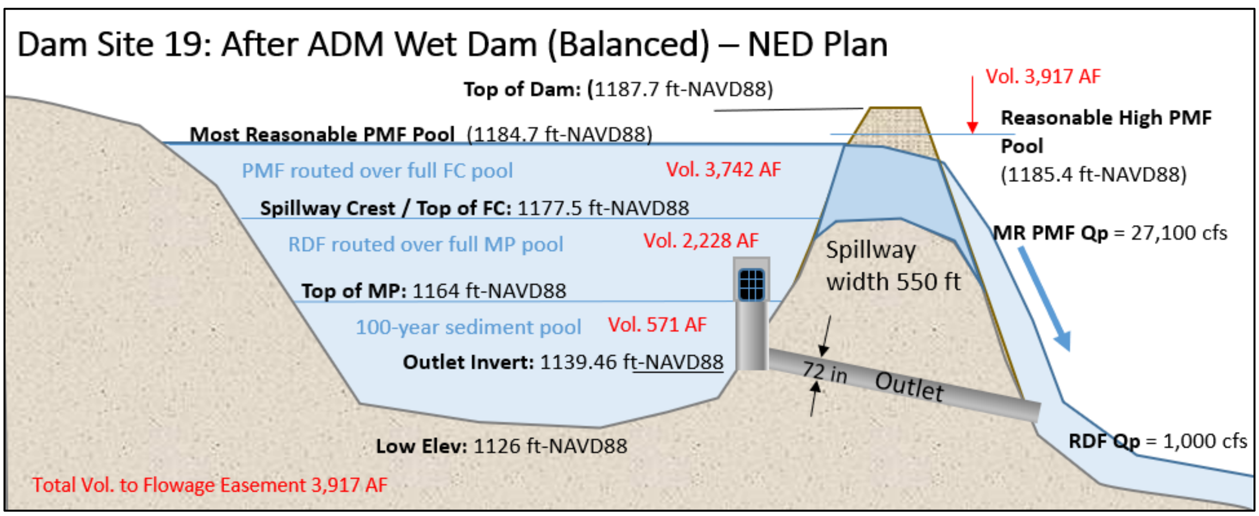

Figure A1. DS19 NED Plan with Raised Conduit Outlet Invert

Table A1. Frequency event results with raised outlet

Event (AEP%)	Event (YR)	Peak Inflow (cfs)	Peak Outflow (cfs)	Starting Pool Elevation (ft)	Peak Elevation (ft)	Rise in Pool (ft)	Change in Flow with Raise (cfs)	Change in Elev with Raise (ft)
0.2	500	7,006	908	1164	1175.7	11.7	72	0.1
0.5	200	5,712	883	1164	1173.8	9.8	78	0.1
1	100	5,003	868	1164	1172.7	8.7	82	0.1
2	50	4,241	791	1164	1171.5	7.5	~0	0
4	25	3,534	633	1164	1170.5	6.5	~0	0
10	10	2,703	454	1164	1169.2	5.2	~0	0
20	5	2,114	333	1164	1168.2	4.2	~0	0
50	2	1,540	223	1164	1167.2	3.2	~0	0
99.9	1	908	114	1164	1166.1	2.1	~0	0

Appendix A-2B. Rainfall Hyetographs

1-Year Local Storm													
12 Hour Rainfall Depth (in)		**1.88**	Atlas 14, 2 Year (lower bound of 90% confidence limit)										
Storm Size (sq mi)		10	20	30	50	70	95	120	150	200	250	300	400
ARF %		98	96.1	94.4	91.1	88.4	85	82.4	79.4	75.6	72.8	70.7	68
Rainfall Depth (in)		1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
Storm Time (hours)	Cumulative %												
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.17	0.1	0	0	0	0	0	0	0	0	0	0	0	0
0.33	0.2	0	0	0	0	0	0	0	0	0	0	0	0
0.50	0.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.67	0.6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.83	0.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1.00	1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
1.17	1.3	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1.33	1.5	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1.50	1.7	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
1.67	1.9	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
1.83	2.2	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
2.00	2.6	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03
2.17	3.1	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04
2.33	3.6	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05
2.50	4.2	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.05
2.67	5	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06
2.83	6	0.11	0.11	0.11	0.1	0.1	0.1	0.09	0.09	0.09	0.08	0.08	0.08
3.00	7.5	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.1	0.1	0.1
3.17	9	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.12
3.33	10.5	0.19	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.14	0.14	0.13
3.50	12.5	0.23	0.23	0.22	0.21	0.21	0.2	0.19	0.19	0.18	0.17	0.17	0.16
3.67	14.5	0.27	0.26	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.2	0.19	0.19
3.83	17	0.31	0.31	0.3	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.23	0.22
4.00	19.5	0.36	0.35	0.35	0.33	0.32	0.31	0.3	0.29	0.28	0.27	0.26	0.25
4.17	22.5	0.41	0.41	0.4	0.38	0.37	0.36	0.35	0.34	0.32	0.31	0.3	0.29
4.33	25.5	0.47	0.46	0.45	0.44	0.42	0.41	0.4	0.38	0.36	0.35	0.34	0.33
4.50	29.5	0.54	0.53	0.52	0.5	0.49	0.47	0.46	0.44	0.42	0.4	0.39	0.38
4.67	33.5	0.62	0.61	0.59	0.57	0.56	0.54	0.52	0.5	0.48	0.46	0.45	0.43
4.83	38.5	0.71	0.7	0.68	0.66	0.64	0.62	0.6	0.57	0.55	0.53	0.51	0.49
5.00	43.5	0.8	0.79	0.77	0.74	0.72	0.7	0.67	0.65	0.62	0.6	0.58	0.56
5.17	49.5	0.91	0.9	0.88	0.85	0.82	0.79	0.77	0.74	0.7	0.68	0.66	0.63
5.33	55.5	1.02	1	0.98	0.95	0.92	0.89	0.86	0.83	0.79	0.76	0.74	0.71
5.50	62.5	1.15	1.13	1.11	1.07	1.04	1	0.97	0.93	0.89	0.86	0.83	0.8
5.67	70.5	1.3	1.28	1.25	1.21	1.17	1.13	1.09	1.05	1	0.97	0.94	0.9
5.83	77.5	1.43	1.4	1.37	1.33	1.29	1.24	1.2	1.15	1.1	1.06	1.03	0.99
6.00	83.5	1.54	1.51	1.48	1.43	1.39	1.34	1.29	1.24	1.19	1.14	1.11	1.07
6.17	88.5	1.63	1.6	1.57	1.51	1.47	1.42	1.37	1.32	1.26	1.21	1.18	1.13
6.33	91.5	1.68	1.66	1.62	1.56	1.52	1.46	1.42	1.36	1.3	1.25	1.22	1.17
6.50	93.5	1.72	1.69	1.65	1.6	1.55	1.5	1.45	1.39	1.33	1.28	1.24	1.2
6.67	94.5	1.74	1.71	1.67	1.62	1.57	1.51	1.46	1.41	1.34	1.29	1.26	1.21
6.83	95.5	1.76	1.73	1.69	1.63	1.59	1.53	1.48	1.42	1.36	1.31	1.27	1.22
7.00	96.3	1.77	1.74	1.7	1.65	1.6	1.54	1.49	1.43	1.37	1.32	1.28	1.23
7.17	97	1.78	1.76	1.72	1.66	1.61	1.55	1.5	1.45	1.38	1.33	1.29	1.24
7.33	97.5	1.79	1.76	1.73	1.67	1.62	1.56	1.51	1.45	1.38	1.34	1.3	1.25
7.50	97.9	1.8	1.77	1.73	1.67	1.63	1.57	1.52	1.46	1.39	1.34	1.3	1.25
7.67	98.2	1.81	1.78	1.74	1.68	1.63	1.57	1.52	1.46	1.39	1.35	1.31	1.26
7.83	98.5	1.81	1.78	1.74	1.68	1.64	1.58	1.53	1.47	1.4	1.35	1.31	1.26
8.00	98.7	1.82	1.79	1.75	1.69	1.64	1.58	1.53	1.47	1.4	1.35	1.31	1.26
8.17	98.9	1.82	1.79	1.75	1.69	1.64	1.58	1.53	1.47	1.4	1.35	1.32	1.27
8.33	99	1.82	1.79	1.75	1.69	1.64	1.58	1.53	1.48	1.41	1.36	1.32	1.27
8.50	99.1	1.82	1.79	1.75	1.69	1.65	1.59	1.54	1.48	1.41	1.36	1.32	1.27
8.67	99.2	1.83	1.8	1.76	1.7	1.65	1.59	1.54	1.48	1.41	1.36	1.32	1.27
8.83	99.3	1.83	1.8	1.76	1.7	1.65	1.59	1.54	1.48	1.41	1.36	1.32	1.27
9.00	99.4	1.83	1.8	1.76	1.7	1.65	1.59	1.54	1.48	1.41	1.36	1.32	1.27
9.17	99.5	1.83	1.8	1.76	1.7	1.65	1.59	1.54	1.48	1.41	1.36	1.32	1.27
9.33	99.6	1.83	1.8	1.76	1.7	1.65	1.59	1.54	1.48	1.41	1.36	1.32	1.27
9.50	99.7	1.83	1.8	1.76	1.7	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
9.67	99.8	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
9.83	99.9	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
10.00	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
10.17	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
10.33	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
10.50	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
10.67	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
10.83	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
11.00	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
11.17	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
11.33	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
11.50	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
11.67	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
11.83	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28
12.00	100	1.84	1.81	1.77	1.71	1.66	1.6	1.55	1.49	1.42	1.37	1.33	1.28

2-Year Local Storm													
12 Hour Rainfall Depth (in)		**2.64**	Atlas 14, 2 Year										
Storm Size (sq mi)		10	20	30	50	70	95	120	150	200	250	300	400
ARF %		98	96.1	94.4	91.1	88.4	85	82.4	79.4	75.6	72.8	70.7	68
Rainfall Depth (in)		2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
Storm Time (hours)	Cumulative %												
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.17	0.1	0	0	0	0	0	0	0	0	0	0	0	0
0.33	0.2	0.01	0.01	0	0	0	0	0	0	0	0	0	0
0.50	0.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.67	0.6	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.83	0.8	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
1.00	1	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1.17	1.3	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
1.33	1.5	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1.50	1.7	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
1.67	1.9	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03
1.83	2.2	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04
2.00	2.6	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05
2.17	3.1	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
2.33	3.6	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.06
2.50	4.2	0.11	0.11	0.1	0.1	0.1	0.09	0.09	0.09	0.08	0.08	0.08	0.08
2.67	5	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.1	0.1	0.09	0.09
2.83	6	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.11	0.11
3.00	7.5	0.19	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.14	0.14	0.14
3.17	9	0.23	0.23	0.22	0.22	0.21	0.2	0.2	0.19	0.18	0.17	0.17	0.16
3.33	10.5	0.27	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.21	0.2	0.2	0.19
3.50	12.5	0.32	0.32	0.31	0.3	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.23
3.67	14.5	0.38	0.37	0.36	0.35	0.34	0.32	0.32	0.3	0.29	0.28	0.27	0.26
3.83	17	0.44	0.43	0.42	0.41	0.4	0.38	0.37	0.36	0.34	0.33	0.32	0.31
4.00	19.5	0.51	0.5	0.49	0.47	0.45	0.44	0.43	0.41	0.39	0.37	0.36	0.35
4.17	22.5	0.58	0.57	0.56	0.54	0.52	0.5	0.49	0.47	0.45	0.43	0.42	0.41
4.33	25.5	0.66	0.65	0.63	0.61	0.59	0.57	0.56	0.54	0.51	0.49	0.48	0.46
4.50	29.5	0.76	0.75	0.73	0.71	0.69	0.66	0.64	0.62	0.59	0.57	0.55	0.53
4.67	33.5	0.87	0.85	0.83	0.81	0.78	0.75	0.73	0.7	0.67	0.64	0.63	0.6
4.83	38.5	1	0.98	0.96	0.93	0.9	0.86	0.84	0.81	0.77	0.74	0.72	0.69
5.00	43.5	1.13	1.1	1.08	1.05	1.01	0.97	0.95	0.91	0.87	0.84	0.81	0.78
5.17	49.5	1.28	1.26	1.23	1.19	1.15	1.11	1.08	1.04	0.99	0.95	0.93	0.89
5.33	55.5	1.44	1.41	1.38	1.34	1.29	1.24	1.21	1.17	1.11	1.07	1.04	1
5.50	62.5	1.62	1.59	1.56	1.51	1.46	1.4	1.36	1.31	1.25	1.2	1.17	1.13
5.67	70.5	1.83	1.79	1.76	1.7	1.64	1.58	1.54	1.48	1.41	1.35	1.32	1.27
5.83	77.5	2.01	1.97	1.93	1.87	1.81	1.74	1.69	1.63	1.55	1.49	1.45	1.4
6.00	83.5	2.16	2.12	2.08	2.01	1.95	1.87	1.82	1.75	1.67	1.6	1.56	1.5
6.17	88.5	2.29	2.25	2.2	2.13	2.06	1.98	1.93	1.86	1.77	1.7	1.65	1.59
6.33	91.5	2.37	2.32	2.28	2.21	2.13	2.05	1.99	1.92	1.83	1.76	1.71	1.65
6.50	93.5	2.42	2.37	2.33	2.25	2.18	2.09	2.04	1.96	1.87	1.8	1.75	1.68
6.67	94.5	2.45	2.4	2.35	2.28	2.2	2.12	2.06	1.98	1.89	1.81	1.77	1.7
6.83	95.5	2.47	2.43	2.38	2.3	2.23	2.14	2.08	2.01	1.91	1.83	1.79	1.72
7.00	96.3	2.49	2.45	2.4	2.32	2.24	2.16	2.1	2.02	1.93	1.85	1.8	1.73
7.17	97	2.51	2.46	2.42	2.34	2.26	2.17	2.11	2.04	1.94	1.86	1.81	1.75
7.33	97.5	2.53	2.48	2.43	2.35	2.27	2.18	2.13	2.05	1.95	1.87	1.82	1.76
7.50	97.9	2.54	2.49	2.44	2.36	2.28	2.19	2.13	2.06	1.96	1.88	1.83	1.76
7.67	98.2	2.54	2.49	2.45	2.37	2.29	2.2	2.14	2.06	1.96	1.89	1.84	1.77
7.83	98.5	2.55	2.5	2.45	2.37	2.3	2.21	2.15	2.07	1.97	1.89	1.84	1.77
8.00	98.7	2.56	2.51	2.46	2.38	2.3	2.21	2.15	2.07	1.97	1.9	1.85	1.78
8.17	98.9	2.56	2.51	2.46	2.38	2.3	2.22	2.16	2.08	1.98	1.9	1.85	1.78
8.33	99	2.56	2.51	2.47	2.39	2.31	2.22	2.16	2.08	1.98	1.9	1.85	1.78
8.50	99.1	2.57	2.52	2.47	2.39	2.31	2.22	2.16	2.08	1.98	1.9	1.85	1.78
8.67	99.2	2.57	2.52	2.47	2.39	2.31	2.22	2.16	2.08	1.98	1.9	1.86	1.79
8.83	99.3	2.57	2.52	2.47	2.39	2.31	2.22	2.16	2.09	1.99	1.91	1.86	1.79
9.00	99.4	2.57	2.52	2.48	2.4	2.32	2.23	2.17	2.09	1.99	1.91	1.86	1.79
9.17	99.5	2.58	2.53	2.48	2.4	2.32	2.23	2.17	2.09	1.99	1.91	1.86	1.79
9.33	99.6	2.58	2.53	2.48	2.4	2.32	2.23	2.17	2.09	1.99	1.91	1.86	1.79
9.50	99.7	2.58	2.53	2.48	2.4	2.32	2.23	2.17	2.09	1.99	1.91	1.86	1.79
9.67	99.8	2.58	2.53	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
9.83	99.9	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
10.00	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
10.17	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
10.33	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
10.50	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
10.67	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
10.83	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
11.00	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
11.17	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
11.33	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
11.50	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
11.67	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
11.83	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8
12.00	100	2.59	2.54	2.49	2.41	2.33	2.24	2.18	2.1	2	1.92	1.87	1.8

					5-Year Local Storm								
12 Hour Rainfall Depth (in)		**3.33**	Atlas 14, 5 Year										
Storm Size (sq mi)		10	20	30	50	70	95	120	150	200	250	300	400
ARF %		98	96.1	94.4	91.1	88.4	85	82.4	79.4	75.6	72.8	70.7	68
Rainfall Depth (in)		3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
Storm Time (hours)	Cumulative %												
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.17	0.1	0	0	0	0	0	0	0	0	0	0	0	0
0.33	0.2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0
0.50	0.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.67	0.6	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
0.83	0.8	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1.00	1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
1.17	1.3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03
1.33	1.5	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03
1.50	1.7	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04
1.67	1.9	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.04	0.04
1.83	2.2	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05
2.00	2.6	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06
2.17	3.1	0.1	0.1	0.1	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.07
2.33	3.6	0.12	0.12	0.11	0.11	0.11	0.1	0.1	0.1	0.09	0.09	0.08	0.08
2.50	4.2	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.1	0.1	0.09
2.67	5	0.16	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11
2.83	6	0.2	0.19	0.19	0.18	0.18	0.17	0.16	0.16	0.15	0.15	0.14	0.14
3.00	7.5	0.24	0.24	0.24	0.23	0.22	0.21	0.21	0.2	0.19	0.18	0.18	0.17
3.17	9	0.29	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.21	0.2
3.33	10.5	0.34	0.34	0.33	0.32	0.31	0.3	0.29	0.28	0.26	0.25	0.25	0.24
3.50	12.5	0.41	0.4	0.39	0.38	0.37	0.35	0.34	0.33	0.32	0.3	0.29	0.28
3.67	14.5	0.47	0.46	0.46	0.44	0.43	0.41	0.4	0.38	0.37	0.35	0.34	0.33
3.83	17	0.55	0.54	0.53	0.52	0.5	0.48	0.47	0.45	0.43	0.41	0.4	0.38
4.00	19.5	0.64	0.62	0.61	0.59	0.57	0.55	0.53	0.51	0.49	0.47	0.46	0.44
4.17	22.5	0.73	0.72	0.71	0.68	0.66	0.64	0.62	0.59	0.57	0.54	0.53	0.51
4.33	25.5	0.83	0.82	0.8	0.77	0.75	0.72	0.7	0.67	0.64	0.62	0.6	0.58
4.50	29.5	0.96	0.94	0.93	0.89	0.87	0.83	0.81	0.78	0.74	0.71	0.69	0.67
4.67	33.5	1.09	1.07	1.05	1.02	0.98	0.95	0.92	0.88	0.84	0.81	0.79	0.76
4.83	38.5	1.26	1.23	1.21	1.17	1.13	1.09	1.05	1.02	0.97	0.93	0.9	0.87
5.00	43.5	1.42	1.39	1.37	1.32	1.28	1.23	1.19	1.15	1.1	1.05	1.02	0.98
5.17	49.5	1.61	1.58	1.55	1.5	1.46	1.4	1.36	1.31	1.25	1.2	1.16	1.12
5.33	55.5	1.81	1.78	1.74	1.68	1.63	1.57	1.52	1.47	1.4	1.34	1.3	1.25
5.50	62.5	2.04	2	1.96	1.89	1.84	1.77	1.71	1.65	1.58	1.51	1.47	1.41
5.67	70.5	2.3	2.26	2.21	2.14	2.07	2	1.93	1.86	1.78	1.71	1.66	1.59
5.83	77.5	2.53	2.48	2.43	2.35	2.28	2.19	2.12	2.05	1.95	1.88	1.82	1.75
6.00	83.5	2.72	2.67	2.62	2.53	2.45	2.36	2.29	2.2	2.1	2.02	1.96	1.89
6.17	88.5	2.89	2.83	2.78	2.68	2.6	2.5	2.42	2.34	2.23	2.14	2.08	2
6.33	91.5	2.98	2.93	2.87	2.77	2.69	2.59	2.51	2.42	2.31	2.21	2.15	2.07
6.50	93.5	3.05	2.99	2.94	2.83	2.75	2.65	2.56	2.47	2.36	2.26	2.2	2.11
6.67	94.5	3.08	3.02	2.97	2.86	2.78	2.67	2.59	2.49	2.38	2.29	2.22	2.14
6.83	95.5	3.11	3.06	3	2.89	2.81	2.7	2.62	2.52	2.41	2.31	2.24	2.16
7.00	96.3	3.14	3.08	3.02	2.92	2.83	2.73	2.64	2.54	2.43	2.33	2.26	2.18
7.17	97	3.16	3.1	3.05	2.94	2.85	2.75	2.66	2.56	2.44	2.35	2.28	2.19
7.33	97.5	3.18	3.12	3.06	2.95	2.87	2.76	2.67	2.57	2.46	2.36	2.29	2.2
7.50	97.9	3.19	3.13	3.07	2.97	2.88	2.77	2.68	2.58	2.47	2.37	2.3	2.21
7.67	98.2	3.2	3.14	3.08	2.98	2.89	2.78	2.69	2.59	2.47	2.38	2.31	2.22
7.83	98.5	3.21	3.15	3.09	2.98	2.9	2.79	2.7	2.6	2.48	2.38	2.31	2.23
8.00	98.7	3.22	3.16	3.1	2.99	2.9	2.79	2.7	2.61	2.49	2.39	2.32	2.23
8.17	98.9	3.22	3.16	3.11	3	2.91	2.8	2.71	2.61	2.49	2.39	2.32	2.24
8.33	99	3.23	3.17	3.11	3	2.91	2.8	2.71	2.61	2.49	2.4	2.33	2.24
8.50	99.1	3.23	3.17	3.11	3	2.91	2.8	2.72	2.62	2.5	2.4	2.33	2.24
8.67	99.2	3.23	3.17	3.11	3.01	2.92	2.81	2.72	2.62	2.5	2.4	2.33	2.24
8.83	99.3	3.24	3.18	3.12	3.01	2.92	2.81	2.72	2.62	2.5	2.4	2.33	2.24
9.00	99.4	3.24	3.18	3.12	3.01	2.92	2.81	2.72	2.62	2.5	2.41	2.34	2.25
9.17	99.5	3.24	3.18	3.12	3.01	2.93	2.82	2.73	2.63	2.51	2.41	2.34	2.25
9.33	99.6	3.25	3.19	3.13	3.02	2.93	2.82	2.73	2.63	2.51	2.41	2.34	2.25
9.50	99.7	3.25	3.19	3.13	3.02	2.93	2.82	2.73	2.63	2.51	2.41	2.34	2.25
9.67	99.8	3.25	3.19	3.13	3.02	2.93	2.82	2.73	2.63	2.51	2.42	2.35	2.26
9.83	99.9	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
10.00	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
10.17	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
10.33	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
10.50	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
10.67	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
10.83	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
11.00	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
11.17	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
11.33	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
11.50	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
11.67	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
11.83	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26
12.00	100	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.52	2.42	2.35	2.26

200-Year Local Storm													
12 Hour Rainfall Depth (in)		**7.65**	Atlas 14, 200 Year										
Storm Size (sq mi)		10	20	30	50	70	95	120	150	200	250	300	400
ARF %		98	96.1	94.4	91.1	88.4	85	82.4	79.4	75.6	72.8	70.7	68
Rainfall Depth (in)		7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
Storm Time (hours)	Cumulative %												
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.17	0.1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.33	0.2	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.50	0.4	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
0.67	0.6	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
0.83	0.8	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04
1.00	1	0.08	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.05	0.05
1.17	1.3	0.1	0.1	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.07	0.07
1.33	1.5	0.11	0.11	0.11	0.1	0.1	0.1	0.09	0.09	0.09	0.08	0.08	0.08
1.50	1.7	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.1	0.1	0.09	0.09	0.09
1.67	1.9	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.1	0.1
1.83	2.2	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11
2.00	2.6	0.2	0.19	0.19	0.18	0.18	0.17	0.16	0.16	0.15	0.14	0.14	0.14
2.17	3.1	0.23	0.23	0.22	0.22	0.21	0.2	0.2	0.19	0.18	0.17	0.17	0.16
2.33	3.6	0.27	0.26	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.2	0.19	0.19
2.50	4.2	0.32	0.31	0.3	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.23	0.22
2.67	5	0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.3	0.29	0.28	0.27	0.26
2.83	6	0.45	0.44	0.43	0.42	0.41	0.39	0.38	0.36	0.35	0.33	0.32	0.31
3.00	7.5	0.56	0.55	0.54	0.52	0.51	0.49	0.47	0.46	0.43	0.42	0.41	0.39
3.17	9	0.68	0.66	0.65	0.63	0.61	0.59	0.57	0.55	0.52	0.5	0.49	0.47
3.33	10.5	0.79	0.77	0.76	0.73	0.71	0.68	0.66	0.64	0.61	0.58	0.57	0.55
3.50	12.5	0.94	0.92	0.9	0.87	0.85	0.81	0.79	0.76	0.72	0.7	0.68	0.65
3.67	14.5	1.09	1.07	1.05	1.01	0.98	0.94	0.91	0.88	0.84	0.81	0.78	0.75
3.83	17	1.28	1.25	1.23	1.18	1.15	1.11	1.07	1.03	0.98	0.95	0.92	0.88
4.00	19.5	1.46	1.43	1.41	1.36	1.32	1.27	1.23	1.18	1.13	1.09	1.05	1.01
4.17	22.5	1.69	1.65	1.62	1.57	1.52	1.46	1.42	1.37	1.3	1.25	1.22	1.17
4.33	25.5	1.91	1.87	1.84	1.78	1.72	1.66	1.61	1.55	1.47	1.42	1.38	1.33
4.50	29.5	2.21	2.17	2.13	2.06	1.99	1.92	1.86	1.79	1.71	1.64	1.6	1.53
4.67	33.5	2.51	2.46	2.42	2.33	2.26	2.18	2.11	2.03	1.94	1.87	1.81	1.74
4.83	38.5	2.89	2.83	2.78	2.68	2.6	2.5	2.43	2.34	2.23	2.14	2.08	2
5.00	43.5	3.26	3.2	3.14	3.03	2.94	2.83	2.74	2.64	2.51	2.42	2.35	2.26
5.17	49.5	3.71	3.64	3.57	3.45	3.35	3.22	3.12	3	2.86	2.76	2.68	2.57
5.33	55.5	4.16	4.08	4.01	3.87	3.75	3.61	3.5	3.37	3.21	3.09	3	2.89
5.50	62.5	4.69	4.59	4.51	4.36	4.23	4.06	3.94	3.79	3.61	3.48	3.38	3.25
5.67	70.5	5.29	5.18	5.09	4.91	4.77	4.58	4.44	4.28	4.07	3.93	3.81	3.67
5.83	77.5	5.81	5.7	5.6	5.4	5.24	5.04	4.88	4.7	4.48	4.32	4.19	4.03
6.00	83.5	6.26	6.14	6.03	5.82	5.64	5.43	5.26	5.07	4.83	4.65	4.52	4.34
6.17	88.5	6.64	6.5	6.39	6.17	5.98	5.75	5.58	5.37	5.12	4.93	4.79	4.6
6.33	91.5	6.86	6.73	6.61	6.38	6.19	5.95	5.76	5.55	5.29	5.1	4.95	4.76
6.50	93.5	7.01	6.87	6.75	6.52	6.32	6.08	5.89	5.68	5.4	5.21	5.06	4.86
6.67	94.5	7.09	6.95	6.82	6.59	6.39	6.14	5.95	5.74	5.46	5.26	5.11	4.91
6.83	95.5	7.16	7.02	6.9	6.66	6.46	6.21	6.02	5.8	5.52	5.32	5.17	4.97
7.00	96.3	7.22	7.08	6.95	6.71	6.51	6.26	6.07	5.85	5.57	5.36	5.21	5.01
7.17	97	7.28	7.13	7	6.76	6.56	6.31	6.11	5.89	5.61	5.4	5.25	5.04
7.33	97.5	7.31	7.17	7.04	6.8	6.59	6.34	6.14	5.92	5.64	5.43	5.27	5.07
7.50	97.9	7.34	7.2	7.07	6.82	6.62	6.36	6.17	5.94	5.66	5.45	5.3	5.09
7.67	98.2	7.37	7.22	7.09	6.84	6.64	6.38	6.19	5.96	5.68	5.47	5.31	5.11
7.83	98.5	7.39	7.24	7.11	6.87	6.66	6.4	6.21	5.98	5.69	5.49	5.33	5.12
8.00	98.7	7.4	7.25	7.13	6.88	6.67	6.42	6.22	5.99	5.7	5.5	5.34	5.13
8.17	98.9	7.42	7.27	7.14	6.89	6.69	6.43	6.23	6	5.72	5.51	5.35	5.14
8.33	99	7.43	7.28	7.15	6.9	6.69	6.44	6.24	6.01	5.72	5.51	5.36	5.15
8.50	99.1	7.43	7.28	7.16	6.91	6.7	6.44	6.24	6.02	5.73	5.52	5.36	5.15
8.67	99.2	7.44	7.29	7.16	6.91	6.71	6.45	6.25	6.02	5.73	5.53	5.37	5.16
8.83	99.3	7.45	7.3	7.17	6.92	6.71	6.45	6.26	6.03	5.74	5.53	5.37	5.16
9.00	99.4	7.46	7.31	7.18	6.93	6.72	6.46	6.26	6.03	5.75	5.54	5.38	5.17
9.17	99.5	7.46	7.31	7.18	6.94	6.73	6.47	6.27	6.04	5.75	5.54	5.38	5.17
9.33	99.6	7.47	7.32	7.19	6.94	6.73	6.47	6.27	6.05	5.76	5.55	5.39	5.18
9.50	99.7	7.48	7.33	7.2	6.95	6.74	6.48	6.28	6.05	5.76	5.55	5.39	5.18
9.67	99.8	7.49	7.34	7.21	6.96	6.75	6.49	6.29	6.06	5.77	5.56	5.4	5.19
9.83	99.9	7.49	7.34	7.21	6.96	6.75	6.49	6.29	6.06	5.77	5.56	5.4	5.19
10.00	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
10.17	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
10.33	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
10.50	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
10.67	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
10.83	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
11.00	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
11.17	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
11.33	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
11.50	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
11.67	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
11.83	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2
12.00	100	7.5	7.35	7.22	6.97	6.76	6.5	6.3	6.07	5.78	5.57	5.41	5.2