APPENDIX B PROPOSED SPILLWAY DESIGN

TETRA TECH

February 29, 2018

TECHNICAL MEMORANDUM

TO: Scituate Department of Public Works (DPW)
Mr. Kevin, Cafferty, Director Scituate DPW

CC: Mr. Dan Smith, Engineering Department, Scituate DPW
Mr. Sean McCarthy, Supervisor, Engineering Department, Scituate DPW
Mr. Sean Anderson, Supervisor Water Division, Scituate DPW

FROM: Mr. Thomas C. Cook, PE, Project Manager, Tetra Tech, Inc. (Tetra Tech)

SUBJECT: **DEIR Appendix B - Proposed Spillway Design**
Reservoir Dam – NID# MA 000478
Reservoir Dam Water Storage and Fish Passage Improvement Project

INTRODUCTION

The Certificate of the Secretary of Executive Office of Energy and Environmental Affairs (EOEEA #15711) for the Reservoir Dam Water Storage and Fish Passage Improvement Project (EOEEA 2017) includes a comment letter by the Department of Conservation and Recreation (DCR) Office of Dam Safety (ODS). The ODS requires a Dam Safety Chapter 253 permit for the Reservoir Dam Water Storage and Fish Passage Project and the project final design will have a spillway in compliant with the Spillway Design Flood (SDF) requirements of the dam safety regulations. This Technical Memorandum updates the Spillway Design Flood Analysis prepared in 2017 and presented in the 60 Percent Design and Permitting Final Report (Tetra Tech 2017) and provides the hydrologic and hydraulic analysis and design data for the project spillway. The 90 percent design drawings are provided in the Draft Environmental Report (DEIR) Appendix G.

Tetra Tech held an initial meeting with ODS on July 12, 2018 to discuss their comments provided with the EOEEA #15771 Certificate and obtain input for the final hydraulic modeling. The original U.S. Army Corp of Engineers' (USACE) Hydrologic Engineering Center (HEC) hydrologic modeling software (HMS) results were summarized and included in the Environmental Notification Form which was submitted to ODS for review. The original HEC-HMS model has been updated to incorporate the Hydrometeorological Report (HMR) No. 51 and No. 52 rainfall distribution for the project spillway design flood (SDF) equal to the one-half Probable Maximum Flood (1/2 PMF)] and analysis of potential dam failure scenarios to determine the extent of downstream flooding.

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Additional meetings will be held with ODS to review the spillway design and the hydrologic and hydraulic computations summarized in this Technical Memorandum after submittal of the DEIR. Final constructions drawings and specifications will be finalized in a future phase of the project to incorporate final permit conditions and will be transmitted to ODS as the last step in the Dam Safety Permit process. All ODS permit submittals will meet the requirements of 302 CMR 10 regulations and two sets of each submittal have been transmitted to ODS.

2017 Project design flood analysis

The sixty-percent design and permitting phase of the Reservoir Dam Water Storage and Fish Passage Improvement Project was completed in 2017 and included a Project Design Flood Analysis requested by ODS. The analysis updated the Spillway Design Flood (SDF) evaluation for Reservoir Dam and Old Oaken Bucket Pond Dam, both located in Scituate, Massachusetts. The analysis reflected current development that occurred in the Scituate Reservoir and Tack Factory Pond watershed tributary areas and utilized a HEC-HMS model to analyze the SDF for Reservoir Dam and Tack Factory Pond, which is the one-half Probable Maximum Flood (1/2 PMF).

The results of the Spillway Design Flood Analysis are summarized in Appendix D of the Sixty-Percent Design and Initial Permitting Final Report (Tetra Tech 2017). The Technical Memorandum was prepared to fulfill the ODS engineering requests from prior dam safety inspections and describe the proposed spillway modifications associated with the Reservoir Dam Water Storage and Fish Passage Improvement Project. The 2017 memorandum:

- Described the existing Reservoir Dam spillway design parameters;
- Determined the ½ PMF of the existing Reservoir Dam spillway design using HEC-HMS;
- Validated the HEC-HMS model parameters with a representative historic storm.
- Evaluated the existing spillway with the ½ PMF storm,
- Identified spillway modifications to increase capacity for ½ PMF with adequate freeboard on the results.
- Evaluated reservoir levels and spillway discharges with the proposed modifications for the ½ PMF, 100-year, and 50-year flood events; and,
- Recommended additional hydrologic and hydraulic analysis of Reservoir Dam and Old Oaken Bucket for the next ODS inspection report.

This Proposed Spillway Design Memorandum addresses the following recommendations provided in the 2017 Spillway Design Flood Analysis Technical Memorandum:

- Coordination with ODS to obtain approval of the SDF and proposed spillway modifications.
- Update of the HEC-HMS model to a multiple dam analysis incorporating Old Oaken Bucket Pond Dam. Since Old Oaken Bucket Pond is immediately downstream of

Reservoir Dam, Old Oaken Bucket has the same high hazard classification as Reservoir Dam.

- Update of the HEC-HMS model to include Chief Justice Cushing Highway (CJCH) as a control point with Tack Factory Pond and the watershed west of CJCH treated as a subbasin to the Reservoir Dam impoundment. This change defines flood levels in Tack Factory Pond which are known to be slightly higher than Reservoir Dam impoundment water levels.
- Conduct a multiple dam failure analyses for "sunny day" and ½ PMF initial conditions to verify the results presented in the 2017 Spillway Design Flood Analysis which indicated that peak flood levels with multiple dam failure were 1.9 ft. higher at Country Way and 0.5 ft. higher at Driftway Road than the peak flood levels with single dam failure.
- Incorporate the analysis results and a new inundation map into the Town's Emergency Action Plan (EAP) for the dams.

The results of the updated hydrologic and hydraulic as presented in the Technical Memorandum are the basis of the 90 percent design of the project features.

PROJECT FEATURES

TACK FACTORY POND

Tack Factory Pond Dam is located west of the Reservoir Dam impoundment and Chief Justice Cushing Highway (CJCH). First Herring Brook has a 4.5 ft high by 10.5 ft wide concrete box that is 75 ft long crossing CJCH. The invert of the culvert outlet into Reservoir Dam invert is at El. 32.8 ft North American Vertical Datum 1988 (NAVD88). All elevations in this Technical Memorandum refer to NAVD88.

Tack Factory Pond Dam is an earthen embankment with a concrete outlet structure located upstream of the First Herring Brook culvert under CJCH. The dam is an earthen embankment less than 5 ft high and approximately 250 ft long extending from CJCH on the left abutment (looking downstream) to natural ground on the right abutment. The embankment top is at El. 41.0 ft. First Herring Brook passes through a 5.25 ft high by 9.5 ft wide concrete box culvert approximately 13.25 ft long in the dam. The invert of the box culvert is at El. 34.6 ft with crown at El. 39.8 ft and top at El. 40.7 ft.

A concrete weir structure is located 6.75 ft upstream of dam and box culvert. The weir structure is approximately 18 ft wide with two 4.3 ft wide by 3 ft high slide gates. The slide gates have double operator stems for manual opening. The top of the weir and gates are at El. 39.3 ft. The gates are typically closed to retain storage in Tack Factory Pond for emergency water supply during droughts. Concrete side walls transition between the weir and culvert through the dam. The discharge rating data for the Tack Factory Pond weir with Reservoir Dam water levels lower than El. 39.3 is shown in Table C-1. The weir, embankment, and CJCH control Tack Factory

Pond water levels when Reservoir Dam levels are lower than the top of the Tack Factory Pond gate and weir. The CJCH roadway is overtopped at 1,800 cfs flow in First Herring Brook.

Table C-1. Tack Factory Pond Discharge Data (Reservoir Dam Water Levels Below El. 39.3 ft)

Tack Factory Pond Level (ft. NAVD88)	Weir Discharge (cfs)
39.3	0
40.0	30
40.7	86
41.0	139
41.5	441
42.0	1,143
42.3	1,803
43.0	4,166
43.3	5,574

Tack Factory Pond water levels are controlled by the CJCH culvert at Reservoir Dam water levels higher than the Tack Factory Pond weir. Table C-2 presents the discharge rating curve for CJCH with the Reservoir Dam proposed water level at El. 40.4 ft. The CJCH roadway is overtopped at 311 cfs.

Table C-2. Tack Factory Pond Discharge Data (Reservoir Dam Water Level at El. 40.4 ft)

Tack Factory Pond Level (ft. NAVD88)	CJCH Discharge (cfs)
40.4	0
40.5	71
41.0	175
42.0	283
42.3	311
43.0	687
43.5	1,398
44.0	2,578
44.5	4,303
45.0	6,639

The storage rating curve data for Tack Factory Pond are presented in Table C-3. The storage volumes are based on area measurements of the topographic contours obtained from MassGIS Lidar data for elevations above El. 40.0 ft and original design documents for lower elevations. Tack Factory Pond has 36.4 ac-ft. of useable storage between the existing normal pool (El. 39.3

ft. NAVD88) and the low level at which the current streamflow guidelines are discontinued (El. 30.9 ft. NAVD88). Tack Factory Pond has slide gates that are normally closed and maintain the water level at El. 39.3 ft NAVD88. Opening the gates provides an additional 5.6 ac-ft of useable storage between El. 39.3 ft and El. 38.9 ft NAVD88 water levels in Tack Factory Pond.

Table C-3. Tack Factory Pond Storage Data

Tack Factory Pond Level (ft. NAVD88)	Total Storage (Ac-ft.)
33.1	0.0
34.1	0.3
34.6	1.0
35.1	2.3
35.6	4.4
36.1	7.9
38.3	26.2
38.9	30.8
39.3	36.4
40.0	46.2
42.0	96.5
44.0	162.9
46.0	255.4
48.0	387.7

RESERVOIR DAM

Reservoir Dam is categorized as a High Hazard Potential dam in accordance with both Massachusetts General Law c.253, Section 46 and 301 Code of Massachusetts Regulations (CMR) 10.00. This classification applies to dam locations where failure will likely cause loss of life and serious damage to homes, businesses, public utilities, or highways. CMR 10.06 requires spillways for High Hazard Potential dams to have a discharge capacity at least equal to the One-half Probable Maximum Flood (½ PMF). Modifications to a High Hazard Potential dam, including the spillway and fishway, similarly must conform to the dam safety regulations, and must be approved by the Department of Conservation and Recreation (DCR) Office of Dam Safety (ODS).

Reservoir Dam is an earthen embankment with an ogee-shaped concrete spillway, a low-level outlet, and a pool and weir fishway. The low-level outlet is a 12-inch diameter pipe through the dam with an inlet structure at the bottom of the reservoir and a flow control valve on the downstream side of the dam. The low-level outlet flow control valve has an electric motor and is operated through a supervisory control and data acquisition (SCADA) system. The fishway has 21 weirs approximately 3 feet (ft.) wide creating pools that are approximately 3.5 ft. long.

The existing spillway has a 37.5 ft. minimum length with the crest at El. 38.9 ft. NAVD88 based the topographic survey conducted by Cavanaro Consulting in 2014. The discharge rating curve data for the surveyed spillway from the 2014 Preliminary Design Memorandum for the Reservoir Dam Fish Passage Project is presented in Table C-4. The rating curve is based on a conservative discharge coefficient value of 3.1, selected from Figure 249 in the Design of Small Dams (USDOI, 1973), over the entire range of flow for an ogee spillway. The existing spillway has a total discharge capacity of 1,751 cubic feet per second (cfs) at the top of dam El. 45.0 ft. NAVD88.

Table C-4. Reservoir Dam Existing Spillway Discharge Data

Reservoir Level (ft. NAVD88)	Spillway Discharge (cfs)
38.9	0
39.9	116
40.9	329
41.9	604
42.9	930
43.9	1,300
45.0	1,751
45.4	2,306
46.8	5,814
47.0	6,357

The storage rating curve data for the Reservoir Dam are presented in Table C-5. The storage volumes are based on data on area measurements of the topographic contours obtained from MassGIS Lidar data for elevations above El. 40.0 ft and original design documents in the 2014 Preliminary Design Memorandum for lower water elevations below El. 39.0 ft. The Reservoir Dam impoundment has 476.6 ac-ft. of useable storage between the existing normal pool (El. 38.9 ft. NAVD88) and the low level at which the current streamflow guidelines are discontinued (El. 30.9 ft. NAVD88).

Table C-5. Reservoir Dam Storage Data

Reservoir Level (ft. NAVD88)	Total Storage (Ac-ft.)	Reservoir Level (ft. NAVD88)	Total Storage (Ac-ft.)
25.9	0.0	38.9	476.6
28.9	4.5	40.0	549.3
30.9	54.5	42.0	700.9
32.9	134.3	44.0	872.8
34.9	231.9	46.0	1,071.5
36.9	348.6	48.0	1,286.2

Old Oaken Bucket Pond

Old Oaken Bucket Pond is the raw water supply for Scituate's water filtration plant located approximately 550 ft northwest of the intersection of Country Way and CJCH. Country Way is the dam. First Herring Brook connects the Reservoir Dam spillway to the north end of the Old Oaken Bucket Pond. Old Oaken Bucket is located dam is approximately 3,500 ft downstream from Reservoir Dam. Water Supply Well #17A is pumped to Old Oaken Bucket Pond through a transmission line as needed to meet demand.

The dam is an earthen embankment approximately 370 ft long and 35 ft wide. The low point in the road surface is El. 21.4 ft. NAVD88 (DPW 2013). The streambed at the toe of the dam is at El. 12.5 ft. NAVD88.The outlet structures include:

- a 2 ft wide concrete pool and weir fishway with exit channel bottom at El. 18.6 ft. NAVD88;
- a primary concrete overflow spillway with two broad crested weirs having a total length of 23 ft and crest at El. 18.8 ft NAVD88;
- a 10 ft. wide auxiliary concrete ogee-shaped spillway with a crest at El. 18.6 ft.;
- a 3 ft. wide concrete sluiceway with a manually operated aluminum low flow control gate; and,
- a concrete sluiceway with a manually operated gate to control flow to the Stockbridge Historic Grist Mill located east of the spillway.

A portion of the upstream face of the dam has stone rip-rap and the downstream face is partially developed and vegetated with grass and trees (DPW 2013).

Twin 36 ft. long stone arch culverts are located under Country Way downstream of the spillways. Each culvert is 5 ft. wide by 8 ft. high. A single 14 ft. wide by 8 ft. high concrete culvert extended the stone arch culverts by 54 ft. when Country Way was widened in 2000-2001.

The discharge rating data for Old Oaken Bucket Pond spillway and dam embankment are provided in Table C-6. The Old Oaken Bucket fixed crest spillways can pass 280 cfs with the Pond water level at 21.4 ft. At higher flows, the Country Way culverts and roadway restrict flow and submerge the spillways.

The storage rating curve data for the Old Oaken Bucket Pond are presented in Table C-7. The storage volumes are based on area measurements of the topographic contours obtained from MassGIS Lidar data for elevations above El. 18.6 ft and original design documents for lower water elevations. Old Oaken Bucket has no useable storage because water levels have to be held at spillway crest (El. 18.6 ft) to provide adequate submergence on the water treatment plant pumps.

Table C-6. Old Oaken Bucket Pond Spillway and Country Way Discharge Data

Pond Level (ft. NAVD88)	Spillway Discharge (cfs)
18.6	0
19.4	43
20.4	144
21.4	280
21.8	654
22.3	1,287
22.8	2,102
22.9	2.284
23.9	4,388
24.9	6,945

Table C-7. Old Oaken Bucket Pond Storage Capacity Data

Reservoir Level (ft. NAVD88)	Total Storage (Ac-ft.)
11.9	0.0
13.9	1.0
14.9	2.3
15.9	6.6
16.9	13.0
18.9	29.1
19.5	49.6
21.0	111.9
22.0	159.8
24.0	276.3
26.0	409.4

Methodology

The USACE's HEC-HMS was used to determine the probable maximum flood (PMF) for the First Herring Brook watershed at Tack Factory Pond, Reservoir Dam, and Old Oaken Bucket Pond. The software simulates the rainfall-runoff process resulting from Probable Maximum Precipitation (PMP) on the First Herring Brook watershed. The following describes the methodology behind selecting the model parameters necessary for the PMP simulation, as guided by the User's Manual (USACE, 2010). Supporting calculations for development of the model input parameters are provided in Attachment 1 to this memorandum.

Watershed Subbasins

The DPW Water Division's Dam Inspection/Evaluation Report dated April 2013 indicates the Reservoir Dam drainage area is 4.4 square miles of lightly developed land. Massachusetts Global Information System (GIS) Light Detection and Ranging (Lidar) topographic data (USGS 2011) was used to delineate the First Herring Brook watershed. This Computer Aided Design (CAD) delineation confirmed the Reservoir Dam watershed area at 4.3 square miles. This technique was used to further delineate the First Herring Brook watershed into three sub basins (Figure C-1). These sub-basins were measured at 3.5, 0.8, and 1.1 square miles for Tack Factory Pond (Sub-basin A), Reservoir Dam (Sub-basin B), and Old Oaken Bucket Pond (Sub-basin C) respectively.

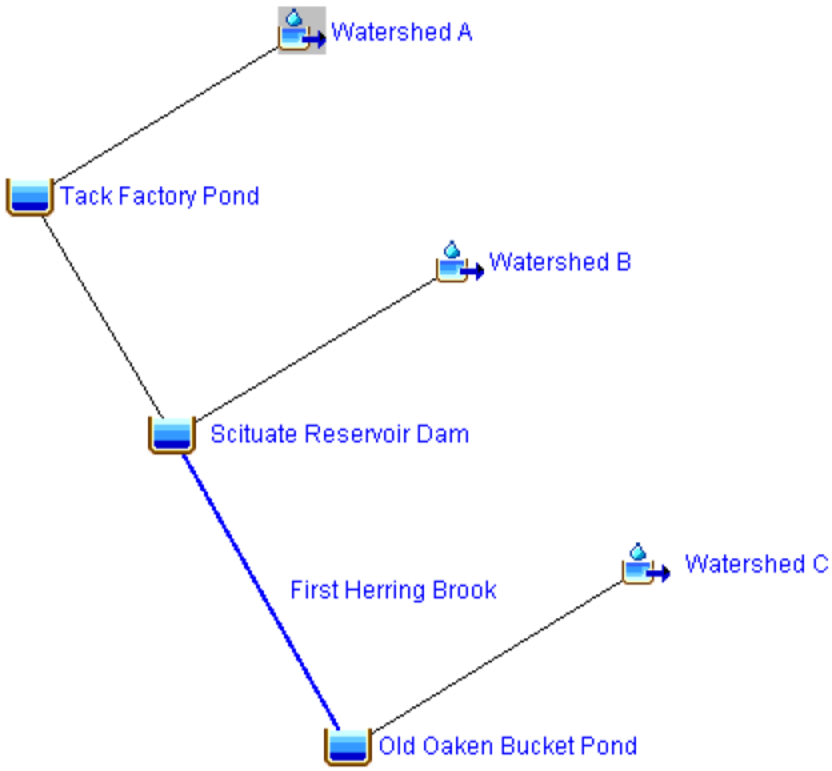

Figure C-1. Watershed Sub-basins

Infiltration Losses

Infiltration losses are the difference between rainfall and runoff volumes (HEC-HMS Technical Guide). The Soil Conservation Service (SCS) Curve Number method was selected for the watershed to represent all of the different soil group and land use combinations within the drainage basin. The Lidar data was used to calculate the percentage of impervious area within the each sub-basin using measurement of the total length of roads within each sub-basin and an average road width of 25 feet. The proportion of impervious surface over the three sub-basins was determined to be 1.67%, 3.06%, and 2.7% of each area, respectively.

An estimation of the curve number was determined for each sub-basin using the NRCS Web Soil Survey (NRCS USDA, 2017) with the watershed delineated as the area of interest. Each Sub-basin's soil map was downloaded and a curve number (CN) was then estimated for each soil group using methods described in TR-55 (USDA, 1986). The pervious CN was determined to be 70, 66, and 66 using Table 2-2a in TR-55. Since the percentage of impervious area within the watershed is less than 30% of unconnected impervious area, composite CNs needed to be calculated. Using Table 2-4 within TR-55, composite CNs for sub-basins A, B, and C were calculated to be 70.5, 70, and 68.5; assuming the ratio of unconnected impervious to total impervious was 1. Average watershed slopes were determined from the Scituate, MA and Cohasset, MA USGS topographic maps of the watershed area, using distances of the longest estimated flow path across each watershed and the elevations at the end points. This method resulted in slopes of 0.47%, 1.57%, and 1.55%; respectively.

The SCS unit hydrograph analysis was selected as the transform method for surface runoff calculations in the HEC-HMS model. This analysis is useful to develop flood hydrographs for ungaged watersheds in cases with extreme rainfall events. A unit hydrograph is the direct runoff from one unit of excess precipitation occurring uniformly and scaled by the time lag for the watershed.

Time lag may be calculated using several different methods. For this study, the Natural Resource Conservation Service (NRCS) watershed lag method described in the NRCS National Engineering Handbook (NEH) (NRCS USDA, 2010) was used. For the NRCS watershed lag method using curve numbers of 70.5, 70, and 68.5 (see above), the lag time or time between peak inflow and outflow (t_p), for each sub-basin was calculated to be 436.6, 70.6, and 100.6 minutes respectively, using equation 1 (Eq. 1).

$$t_p = \frac{L^{0.8}(S+1)^{0.7}}{1900\sqrt{y}} \qquad \text{(Eq. 1)}$$

where:		
	L= 22,123; 4,752; 6,969	Length to divide (ft.) or watershed length
	$S = \frac{1000}{CN} - 10 = 4.18; 4.29; 4.60$	Potential abstraction (in.)
	y = 0.47; 1.57; 1.55	Average watershed slope (%)

Baseflow

Baseflow is the amount of streamflow that exists regardless of excess rainfall from a storm event. The recession baseflow method was selected for the HEC-HMS simulations of the Scituate's Reservoir Dam since this method approximates typical behavior in watersheds when the channel flow exponentially declines after the peak discharge. The baseflow recession constant, k_{hr}, was calculated in the 2017 model with one basin using (Eq. 26) (USDOI 1973) to be 0.78 for a 24-hour storm. The constant describes the rate that baseflow recedes between storm events. The maximum PMP discharge was assumed to be 4,500 cfs with the discharge at the end of the storm receding to the initial discharge (12 cfs) (Tetra Tech 2017). While treating each sub-basin separately gave recession constant values of 0.78, 0.76, and 0.76 when a PMP storm was modeled (4,454 cfs, 1,815 cfs, and 2,533 cfs peak discharge for each sub-basin); a conservative recession constant of 0.78 was used for all sub-basins.

$$k_{hr} = \sqrt[t]{\frac{q_t}{q_o}} \qquad \text{(Eq. 2)}$$

where:	$t = 24$	Time interval between points 1 and 2 (hours)
	$q_t = 12$	Discharge at second point (cfs)
	$q_o = 4{,}500$	Discharge at first point (cfs)

Model Parameters

Four separate water-retaining elements were modeled in HEC-HMS to fully define the watershed (Figure C-1). Tack Factory Pond, downstream of Watershed A, was modeled as an orifice outlet with potential dam overtopping. Reservoir Dam, downstream of Watershed B and Tack Factory Pond, was modeled with an ogee spillway outlet with potential dam overtopping. A reach for First Herring Brook was modeled downstream of Scituate Reservoir Dam, and finally Old Oaken Bucket Pond; downstream of Watershed C and First Herring Brook, was modeled with an orifice outlet with potential dam overtopping.

Tack Factory Pond

Tack Factory Pond's outlet was modeled as a single-barrel orifice outlet, with parameters for center elevation, area, and discharge coefficient representative of the CJCH culvert with the dam and CJCH overtopping at flood flows. The dam overtopping model include parameters for elevation, length, and weir flow (spillway) coefficient as summarized in Table C-8.

An elevation-discharge curve for Tack Factory Pond (Table C-1) combined these two elements assuming that the culvert would always remain submerged and there was no overtopping flow over the culvert since the dam length included the culvert section. The tailwater elevation for the culvert was assumed to be held at 40.5 ft NAVD1988, the target level for Reservoir Dam. Tailwater would increase during a storm, which would decrease culvert flow resulting in an overestimation of CJCH overtopping conditions. The model results would be conservative and would be representative of the flood levels since the majority of flow occurs over CJCH at Tack Factory Pond El.43.0 ft.

Table C-8. Input parameters for Tack Factory Pond HEC-HMS hydrologic modeling

Subbasin	
Area (mi^2)	3.5380
Curve Number	70.5
Impervious (%)	1.67
Lag Time (min.)	436.6
Initial Discharge (cfs)	9.873
Recession Constant	0.78
Tack Factory Pond	
Initial Elevation (ft. NAVD1988): Existing	40.5
Main Tailwater: Downstream of Main Discharge (Rating Curves: Existing, Proposed)	Table C-4, Table C-10
Culvert	
Culvert Center Elevation (ft.)	34.65
Culvert Area (sq. ft.)	47
Coefficient	0.6
Dam Top (CJCH)	
Elevation (ft NAVD1988)	42.3
Length (ft)	160.6
Coefficient	2.6
Meteorological Model (PMP conditions)	
Probability (%)	2
Intensity Duration (hr.)	6
Storm Duration (hr.)	24
Intensity Position (%)	50
Storm Area (mi^2)	10
Total PMP / ½ PMF 6 Hours (in.)	23.5 / 13.2
Total PMP / ½ PMF 12 Hours (in.)	25.9 / 14.5
Total PMP / ½ PMF 24 Hours (in.)	28.2 / 15.8
Control Specifications	
Start Date	10 Mar
Start Time	00:00
End Date	20 Mar
End Time	00:00
Time Interval (minutes)	20

The HEC-HMS program uses frequency storms to develop a PMP distribution. For this study, a storm with a 2% probability of exceedance (50-year storm frequency) and a 24 hour duration was used as model input. Design of Small Dams (USDOI 1973) defines the PMP precipitation near Scituate, MA for the 6-hour storm event to be approximately 23.5 inches (DPW 2013). Precipitation values were adjusted for 12 and 24 hour storm durations using the appropriate figures in Design of Small Dams (*see Attachment 2 to this memorandum* Table 43).

Reservoir Dam

The model parameters for the existing ogee spillway, including the approach depth and head loss, crest elevation and length, apron elevation and length, and the design head, are consistent with the previous 2017 model as summarized in . The approach depth is the difference between the spillway crest and the bottom of the reservoir upstream of the spillway since there is no approach channel. Observations in 2016 and DPW water measurements indicate the approach depth is approximately 10 ft. The approach head loss would be approximately equal to one-half of the velocity head ($V^2/2g$) at the spillway crest. At a 2,000 cfs discharge and the existing spillway design head, the approach head loss would be less than one foot (Tetra Tech 2017). Crest length is the total width that water passes through the spillway. The apron elevation is the elevation at the bottom of the spillway (El. 25.0 ft. NAVD1988) and a 35 ft. length. The design head is the total energy head for which the spillway is designed, which appears to be approximately 5 ft. assuming a 1.5 ft. freeboard.

Table C-9. Input parameters for Reservoir Dam HEC-HMS hydrologic modeling

Subbasin	
Area (mi^2)	0.7796
Curve Number	70
Impervious (%)	3.1
Lag Time (min.)	70.6
Initial Discharge (cfs)	2.176
Recession Constant	0.78
Reservoir Dam	
Initial Elevation (ft. NAVD1988): Existing / Proposed	38.9 / 40.4
Length (ft)	500
Coefficient	2.6
Dam elevation (ft. NAVD1988)	45.0
Ogee Spillway	
Approach Depth (ft.)	10
Approach Loss (ft.)	1
Crest Elevation (ft. NAVD1988): Existing / Proposed	38.9 / 40.4
Crest Length (ft.): Existing / Proposed	37.5 /36.5
Apron Elevation (ft.)	25.0
Apron Length (ft.)	35
Design Head (ft.)	5

Meteorological Model (PMP conditions)	
Probability (%)	2
Intensity Duration (hr.)	6
Storm Duration (hr.)	24
Intensity Position (%)	50
Storm Area (mi²)	10
Total PMP / ½ PMP 6 Hours (in.)	23.5 / 13.2
Total PMP / ½ PMP 12 Hours (in.)	25.9 / 14.5
Total PMP / ½ PMP 24 Hours (in.)	28.2 / 15.8
Control Specifications	
Start Date	10 Mar
Start Time	00:00
End Date	20 Mar
End Time	00:00
Time Interval (minutes)	20

For the current modeling effort, an elevation-discharge curve was calculated combining the spillway and entire dam overtopping flow (Table C-3). The model used a specified spillway for the existing fixed crest spillway with a discharge curve determined from the formula Q = CLH^3/2 with coefficient C = 3.1, L = 37.5 ft, and height H = the head above an initial elevation of 38.9 ft.

A discharge rating curve for the proposed spillway (Table C-10) was derived using coefficient C = 3.1, L = 36.5 ft, and height H = the head above an initial elevation of 36.5 ft. While the actual spillway gate would operate under a proportional or otherwise optimized controller that would have ; for this model the gate was assumed to be either fully closed or fully open. The entire dam above El. 45.0 ft was modeled as spillway with a coefficient of 2.6 and length of 500 ft.

Table C-10. Reservoir Dam Proposed Spillway Discharge Data

Reservoir Level (ft. NAVD88)	Spillway Discharge (cfs)	Reservoir Level (ft. NAVD88)	Spillway Discharge (cfs)
40.39	0	42.4	1,663
40.40	10	42.9	1,875
40.41	905	43.5	2,141
40.6	974	43.9	2,234
40.9	1,080	44.4	2,560
41.5	1,202	45.0	2,854
41.9	1,459	46.0	4,666

Derivation of the lag time for Tack Factory Pond using the NRCS methodology is discussed above in the Baseflow section. The PMP distribution is the same as discussed above for Tack Factory Pond.

Old Oaken Bucket Pond

Old Oaken Bucket Pond's culvert (two 3 ft x 4 ft stone culverts) was modeled as a single-barrel orifice outlet, with parameters for center elevation, area, and coefficient given below in Table C-11. The dam overtop model includes parameters for elevation, length, and a weir flow (spillway) coefficient. An elevation-discharge curve was calculated for Old Oaken Bucket Pond combining these two elements, assuming that the culvert would remain flooded and no weir flow through the culvert would occur (Table C-5). Orifice flow was calculated using the equation Q = CA(2gh)^0.5 with H = the head above an initial elevation of 15.2 ft; while weir flow over Country Way in the event of overtopping was modeled using Q = CLH^1.5 with H = the head above an initial elevation of 22.1 ft.

Table C-11. Input parameters for Old Oaken Bucket Pond HEC-HMS hydrologic modeling

Subbasin C	
Area (mi^2)	1.1228
Curve Number	68.5
Impervious (%)	2.7
Lag Time (min.)	100.6
Initial Discharge (cfs)	3.133
Recession Constant	0.78
Old Oaken Bucket Pond	
Initial Elevation (ft. NAVD1988):	18.9
Culvert	
Culvert Center Elevation (ft. NAVD1988)	15.2
Culvert Area (sq ft.)	24
Coefficient	0.6
Dam Top (CJCH)	
Elevation (ft NAVD19988)	22.1
Length (ft)	370
Coefficient	2.6
Meteorological Model (PMP conditions)	
Probability (%)	2
Intensity Duration (hr.)	6
Storm Duration (hr.)	24
Intensity Position (%)	50
Storm Area (mi^2)	10
Total PMP / ½ PMP 6 Hours (in.)	23.5 / 13.2

Total PMP / ½ PMP 12 Hours (in.)	25.9 / 14.5
Total PMP / ½ PMP 24 Hours (in.)	28.2 / 15.8
Control Specifications	
Start Date	10 Mar
Start Time	00:00
End Date	20 Mar
End Time	00:00
Time Interval (minutes)	20

ASSESSMENT OF EXISTING SPILLWAY DESIGN

The 60% HEC-HMS modeling simulated the PMF for the existing spillway with lag times of 620 minutes (NRCS TR-55 methodology) and 812 minutes (SCS Unitgraph methodology) using a 50% rainfall intensity position. A simulation time of three days was selected for the initial modeling to ensure that the runoff from the 24-hour storm was entirely depicted with 2-hour and 3-hour time intervals selected for the basin model set-up with 620- and 812- minute lag times, respectively. A section of the time series of the simulation for the 24-hour PMF storm duration is shown in Table C-12 for the 620 minute lag time and Table C-13 for the 812 minute lag time. The bolded row in both tables shows the point at which the dam is overtopped for the full PMF. The model indicates that the peak PMF outflow would be 3,680 cfs with a 620 minute lag time and 2,718 cfs with an 812 minute lag time. Table C-14 summarizes the 2017 PMF model results.

The 60% model indicated that the ½ PMF would be 1,840 cfs and 1,359 cfs with the 620 minute and 812 minute lag times, respectively. The maximum elevation of the Reservoir Dam impoundment during the ½ PMF would be El. 45.1 ft. NAVD88 at 1,840 cfs and El. 44.1 ft. NAVD88 at 1,359 cfs peak discharge as determined from the existing spillway discharge rating curve (Table C-4). The dam embankment is overtopped by approximately 0.1 ft. at 1,840 cfs. At 1,359 cfs, the dam embankment is not overtopped, but there is only 0.9 ft. of freeboard. A summary of the ½ PMF parameters is presented in Table C-15.

Table C-12. 2017 Existing Reservoir Dam Spillway PMF Time Series Results – 620 Minute Lag Time

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	8:00	14	484.1	39.0	3	38.9
10-Mar-17	10:00	23	486.6	39.0	4	38.9
10-Mar-17	12:00	122	497.2	39.2	13	39.0
10-Mar-17	14:00	423	536.2	39.7	64	39.5
10-Mar-17	16:00	1,052	631.7	40.9	255	40.6
10-Mar-17	18:00	1,959	801.0	42.6	693	42.2
10-Mar-17	20:00	2,901	1,027.4	44.5	1,382	44.1
10-Mar-17	**22:00**	**3,573**	**1,265.9**	**46.3**	**2,133**	**45.3**
11-Mar-17	00:00	3,782	1,468.1	47.6	2,719	45.6
11-Mar-17	02:00	3,705	1,568.3	49.4	3,576	45.9
11-Mar-17	04:00	3,629	1,574.8	49.6	3,680	46.0
11-Mar-17	06:00	3,555	1,568.6	49.4	3,580	45.9
11-Mar-17	08:00	3,482	1,564.2	49.2	3,510	45.9
11-Mar-17	10:00	3,410	1,559.7	49.1	3,438	45.9
11-Mar-17	12:00	3,340	1,555.2	48.9	3,368	45.9
11-Mar-17	14:00	3,272	1,550.8	48.8	3,299	45.8
11-Mar-17	16:00	3,205	1,546.5	48.7	3,231	45.8

Table C-13. 2017 Existing Reservoir Dam Spillway PMF Time Series Results – 812 Minute Lag Time

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10Mar2017	00:00	12.0	476.6	38.9	0.0	38.9
10Mar2017	03:00	11.8	479.5	38.9	0.7	38.9
10Mar2017	06:00	12.0	482.1	39.0	1.8	38.9
10Mar2017	09:00	15.0	484.8	39.0	3.3	38.9
10Mar2017	12:00	140.6	501.6	39.3	17.6	39.1
10Mar2017	15:00	551.7	570.1	40.1	124.5	39.9
10Mar2017	18:00	1312.2	724.0	41.8	481.7	41.5
10Mar2017	21:00	2214.9	951.9	43.9	1147.7	43.5
11Mar2017	**00:00**	**2800.9**	**1186.0**	**45.7**	**1890.3**	**45.1**
11Mar2017	03:00	2922.7	1355.6	46.9	2405.6	45.5
11Mar2017	06:00	2833.3	1440.4	47.4	2642.1	45.6
11Mar2017	09:00	2746.7	1467.7	47.6	2718.1	45.6
11Mar2017	12:00	2662.7	1465.2	47.5	2711.2	45.6

Table C-14. 2017 Existing Reservoir Dam Spillway PMF Summary

Lag Time (min.)	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in)	Total Outflow (in)	Peak Storage (ac-ft.)	Peak Elevation (ft.)
620	3,782	3,680	126.3	125.2	1,574.8	49.6
812	2,922.7	2,718.1	99.8	98.8	1,467.7	47.6

Table C-15. 2017 Existing Reservoir Dam Spillway ½ PMF Summary

Lag Time (min.)	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in)	Total Outflow (in)	Peak Storage (ac-ft.)	Peak Elevation (ft.)
620	1,891	1,840	63.2	62.6	1,098.1	45.1
812	1,461	1,359	49.9	49.4	975.6	44.1

The 2018 updated model simulated a 24-hour PMP storm model for the watershed subbasins with lag times of 437, 71, and 101 minutes (NRCS TR-55 methodology) using a 50% rainfall intensity position. A simulation time of ten days was selected to ensure that the runoff from the 24-hour storm was entirely depicted, with 20 minute time intervals. A section of the time series simulation for the 24-hour PMF storm duration is shown in Table C-16 for the Existing Reservoir Dam. The bolded row in both table shows the point at which the dam is overtopped for the full PMP storm. The model indicates that the peak PMF outflow for Reservoir Dam would be 4,931 cfs, 25% greater than the 2017 analysis.

Table C-16. 2018 Existing Reservoir Dam Spillway PMF Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	2	476.6	38.9	-	38.9
10-Mar-17	2:00	10	477.5	38.9	0	38.9
10-Mar-17	4:00	13	479.4	38.9	1	38.9
10-Mar-17	6:00	16	481.6	39.0	2	38.9
10-Mar-17	8:00	40	485.0	39.0	4	38.9
10-Mar-17	10:00	407	503.5	39.3	22	39.1
10-Mar-17	12:00	1,539	655.0	41.4	370	41.1
10-Mar-17	14:00	1,794	822.5	43.4	970	43.0
10-Mar-17	16:00	3,932	1,065.8	45.9	3,176	45.8
10-Mar-17	18:00	4,202	1,101.6	46.3	4,019	46.1
…						
10-Mar-17	20:00	4,903	1,131.7	46.6	4,796	46.4
10-Mar-17	**20:20**	**4,931**	**1,134.1**	**46.6**	**4,862**	**46.4**
10-Mar-17	20:40	4,930	1,135.5	46.6	4,899	46.5
10-Mar-17	**21:00**	**4,902**	**1,135.8**	**46.6**	**4,908**	**46.5**
10-Mar-17	21:20	4,848	1,135.2	46.6	4,890	46.5
10-Mar-17	21:40	4,771	1,133.5	46.6	4,846	46.4
10-Mar-17	22:00	4,674	1,131.1	46.6	4,779	46.4
…						
11-Mar-17	0:00	3,814	1,102.4	46.3	4,038	46.1
11-Mar-17	2:00	2,812	1,061.8	45.9	3,082	45.7

To model the effects of a ½ PMF storm for the entire watershed, the ½ PMF was calculated two separate ways. First, a ½ PMP storm was modeled using exactly half the rainfall of the PMP storm; i.e. a ½ PMP storm. This resulted in a ½ PMF at Reservoir dam of 2,136 cfs inflow. A section of the time series simulation for the 24-hour ½ PMP storm is shown in Table C-17 for Reservoir Dam. Secondly, rainfall values for a "½ PMF storm" were iterated such that the peak inflow for Reservoir Dam would be within 1 percent of half of the PMF inflow; i.e. 2,465 cfs. A section of the time series simulation for this 24-hour "½ PMF" storm is shown in Table C-18 for Reservoir Dam This resulted in a more conservative value for the ½ PMF. A summary of the ½ PMP storm and "½ PMF" storm results at Reservoir Dam is presented in Table C-19.

Table C-17. 2018 Existing Reservoir Dam Spillway ½ PMP Storm Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	2	476.6	38.9	-	38.9
10-Mar-17	2:00	9	477.5	38.9	0	38.9
10-Mar-17	4:00	12	479.2	38.9	1	38.9
10-Mar-17	6:00	13	481.2	39.0	2	38.9
10-Mar-17	8:00	14	483.1	39.0	3	38.9
10-Mar-17	10:00	104	487.1	39.1	5	38.9
10-Mar-17	12:00	605	542.8	39.9	88	39.7
10-Mar-17	14:00	805	630.8	41.1	298	40.8
10-Mar-17	16:00	1,370	726.8	42.3	611	41.9
10-Mar-17	18:00	1,637	838.9	43.6	1,038	43.2
…						
10-Mar-17	20:00	2,103	944.2	44.7	1,464	44.3
10-Mar-17	20:20	2,127	961.1	44.9	1,534	44.5
10-Mar-17	**20:40**	**2,136**	**976.5**	**45.0**	**1,611**	**44.7**
10-Mar-17	21:00	2,132	989.1	45.2	1,744	45.0
10-Mar-17	21:20	2,116	998.0	45.3	1,862	45.1
10-Mar-17	21:40	2,090	1,003.5	45.3	1,944	45.1
10-Mar-17	22:00	2,053	1,006.4	45.3	1,989	45.2
10-Mar-17	**22:20**	**2,009**	**1,007.3**	**45.4**	**2,004**	**45.2**
10-Mar-17	22:40	1,958	1,006.9	45.3	1,996	45.2
10-Mar-17	23:00	1,901	1,005.3	45.3	1,972	45.2

Table C-18. 2018 Existing Reservoir Dam Spillway "½ PMF" Storm Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	2	476.6	38.9	-	38.9
10-Mar-17	2:00	9	477.5	38.9	0	38.9
10-Mar-17	4:00	12	479.3	38.9	1	38.9
10-Mar-17	6:00	13	481.2	39.0	2	38.9
10-Mar-17	8:00	15	483.2	39.0	3	38.9
10-Mar-17	10:00	135	488.4	39.1	6	39.0
10-Mar-17	12:00	714	555.3	40.1	114	39.9
10-Mar-17	14:00	924	654.6	41.4	369	41.0
10-Mar-17	16:00	1,580	763.0	42.7	739	42.3
10-Mar-17	18:00	2,025	892.3	44.2	1,258	43.8
…						
10-Mar-17	20:00	2,462	1,009.9	45.4	2,045	45.2
10-Mar-17	**20:20**	**2,476**	**1,019.3**	**45.5**	**2,207**	**45.4**
10-Mar-17	20:40	2,475	1,025.2	45.5	2,315	45.4
10-Mar-17	21:00	2,460	1,028.6	45.6	2,378	45.5
10-Mar-17	21:20	2,432	1,030.0	45.6	2,407	45.5
10-Mar-17	**21:40**	**2,392**	**1,030.1**	**45.6**	**2,409**	**45.5**
10-Mar-17	22:00	2,342	1,029.2	45.6	2,391	45.5
…						
11-Mar-17	0:00	1,956	1,013.1	45.4	2,099	45.3
11-Mar-17	2:00	1,593	988.4	45.2	1,736	45.0

Table C-19. 2018 Existing Reservoir Dam ½ PMF Summary

Storm	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in)	Total Outflow (in)	Peak Storage (ac-ft.)	Peak Elevation (ft.)
½ PMP	2,136	2,004	30.7	30.4	1,007.3	45.4
"½ PMF"	2,476	2,409	35.3	35.1	1,030.1	45.6

Parameter Validation

Simulations with the HEC-HMS model were completed during the 2017 60% design to determine the sensitivity of the peak rainfall intensity position on peak discharge and to verify the watershed characteristic assumptions and lag time calculations using the NRCS T-55 and SCS Unitgraph methods using known floods.

Intensity Position Sensitivity

Three peak rainfall intensity positions (25%, 50%, and 75%) were evaluated to determine sensitivity of the position on maximum outflow. Additional HEC-HMS simulations for the PMF were completed with the 620 minute lag time for the existing spillway to compare 25% and 75% peak rainfall intensity positions to the 50% peak rainfall peak intensity results, as described below. Peak PMF outflow varied by about 270 cfs between 25% and 75% intensity positions (*see* Table C-20). Since peak outflows for the 25% and 75% intensity positions vary less than 5% of the 50% intensity position peak outflow, peak rainfall intensity position has minimal effect on peak PMF discharges and 50% storm intensity position was considered reasonable for the watershed.

Table C-20. PMF results with varying storm intensity positions.

Intensity Position	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in.)	Total Outflow (in.)	Peak Storage (ac-ft)	Peak Elevation (ft.)
25%	3,619	3,488	121.4	120.4	1,562.9	49.2
50%	3,782	3,680	126.3	125.2	1,574.8	49.6
75%	3,872	3,758	128.8	127.6	1,579.7	49.7

Watershed Characteristics Validation

Two actual storm events were evaluated with the 2014 HEC-HMS model to validate the HEC-HMS parameters and results were compared for the different lag times described above. Simulations were completed for the Mother's Day Storm that occurred in Scituate, MA on May 13, 2006 and the most recent storm on April 1, 2017.

The daily precipitation values for the Mother's Day Storm were measured by the Town's Water Department at the Water Treatment Plant and by the National Oceanic and Atmospheric Administration (NOAA) Plymouth Municipal Airport rain gage (NCDC, 2017). The precipitation values at the NOAA rain gage were significantly lower than the Water Department measurements (*see* Table C-21). This difference can be attributed to a dissimilar storm distribution pattern with the NOAA rain gage located approximately 19.3 miles south of Scituate.

Table C-21. Mother's Day Storm daily precipitation values

Date	Precipitation (in., 9am-8am)	
	Water Department	NOAA
5/12/2006	0.06	0.02
5/13/2006	0.90	0.81
5/14/2006	4.49	2.66
5/15/2006	3.15	0.22
5/16/2006	0.87	0.48
5/17/2006	0.22	0.59

The daily precipitation values recorded by the Water Department were distributed according to the hourly NOAA values to develop a reasonable approximation of the rainfall for the Mother's Day Storm. The ratios between the Water Department and NOAA daily rain precipitations were applied to the NOAA hourly data to form a realistic rain distribution at the Reservoir Dam (*see* Figure C-221). The timing of distribution was adjusted such that the calculated accumulated daily values matched the measured Water Department values at 8:00 AM each day.

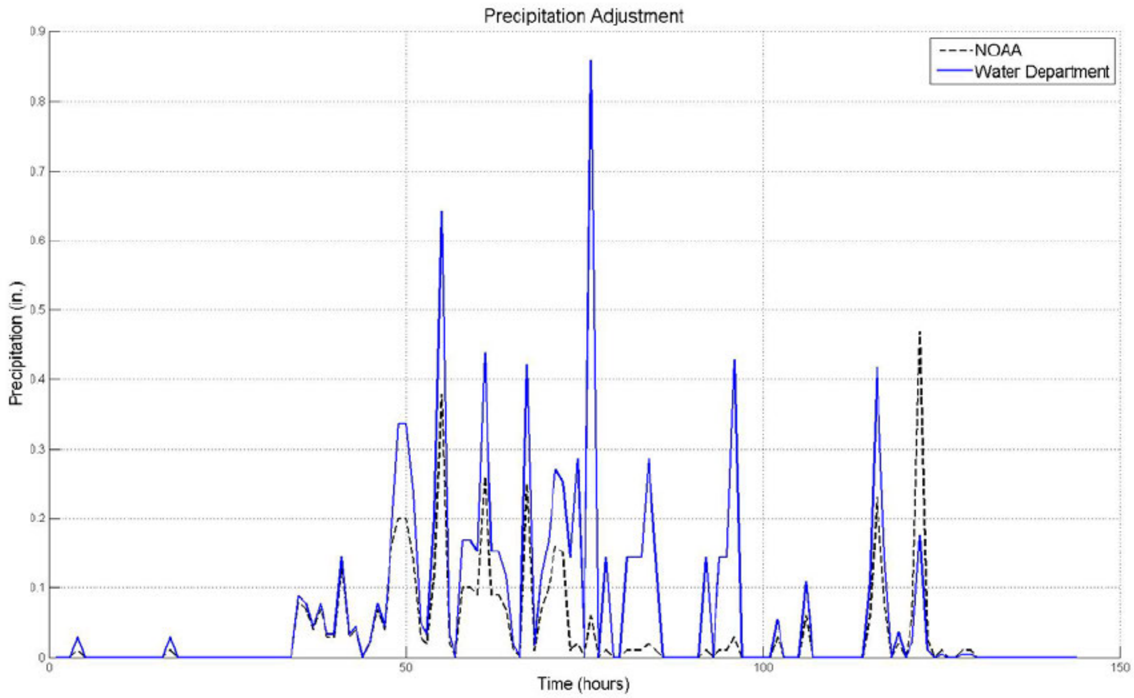

Figure C-2. Adjustment of Scituate Reservoir Dam Water Department precipitation values.

The Mother's Day Storm was a four-day storm beginning on May 12, 2006 around 7:00 PM and ending on May 16, 2006 around 5:00PM. Table C-22 shows the accumulated precipitation values, obtained from the adjusted rain distribution, starting from one hour after the beginning of the storm through the fourth day.

Table C-22. Accumulated Precipitation for the Mother's Day Storm at the Reservoir Dam.

Time	Precipitation (in.)
1 Hour	0.09
2 Hours	0.17
3 Hours	0.21
6 Hours	0.36
12 Hours	0.68
1 Day	2.94
2 Days	7.11
4 Days	9.63

The largest rainfall peaks for the Mother's Day Storm indicate that the intensity position occurred around 41% (*see* Figure C-332). The nearest intensity position of 50% was selected to simulate the frequency storm of 1%. A recession constant of 0.94 was calculated for a four-day storm using (Eq. 26) (see Methodology Section).

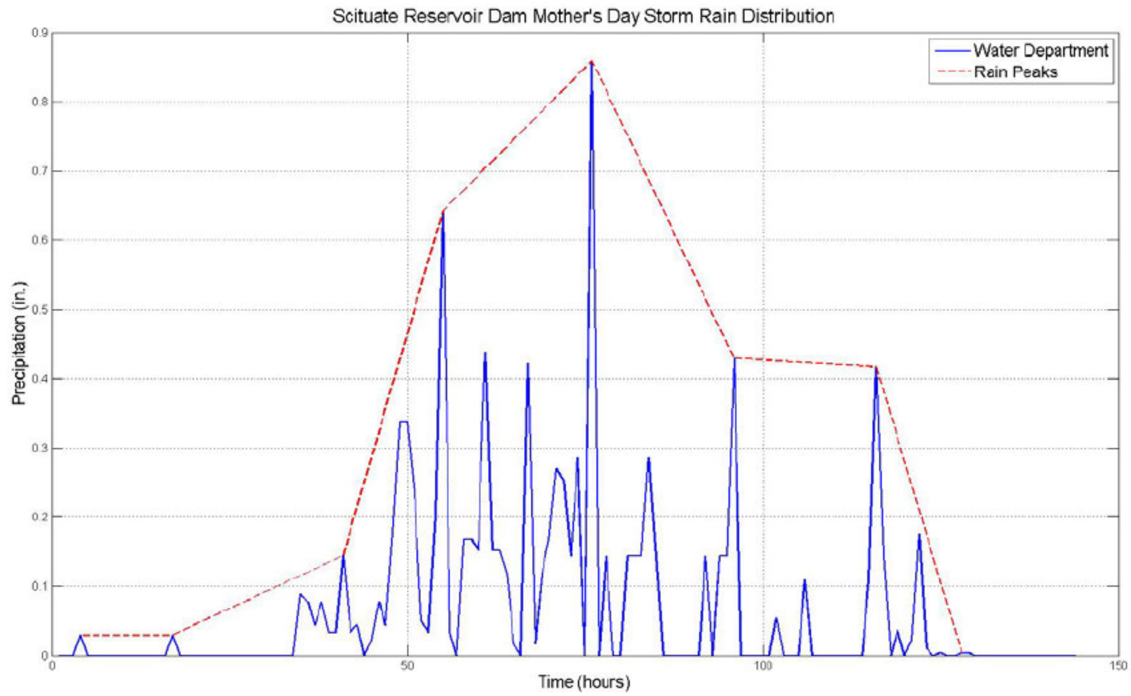

Figure C-3. Mother's Day Storm Dam Peak Rain Distribution at Reservoir Dam

The results of Mother's Day Storm simulations are presented in Table C-23 for the 620 minute and 812 minute lag times evaluated for the watershed. Peak outflow was 371 cfs for the 620 minute lag time and 310 cfs with the 812 minute lag time. The model results indicate the Reservoir Dam impoundment levels were El. 41.4 ft. NAVD88 and El. 41.1 ft. NAVD88 for the 620 and 812 minute lag times, or 2.5 ft. and 2.2 ft., respectively, above the spillway crest.

Table C-23. Results of Mother's Day Storm simulations.

Lag Time (min.)	Storm	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in.)	Total Outflow (in.)	Peak Storage (ac-ft)	Peak Elevation (ft.)
812	200-yr	808.6	781	44.1	42.9	831.3	42.9
812	100-yr	652.4	629.1	35.6	34.6	778.2	42.4
812	50-yr	524.2	506.6	28.7	27.8	733.3	41.9
812	Mother's Day	319	309.5	18.3	17.7	655.6	41.1
620	200-yr	1,003	968	54.9	53.6	894.9	43.4
620	100-yr	810	781	44.3	43.2	831.2	42.9
620	50-yr	652	627	35.6	34.7	777.5	42.4
620	Mother's Day	382	371	22.0	21.3	680.7	41.4

Water Department personnel have indicated that the water levels in Tack Factory Pond were almost up to the low point in Chief Justice Cushing Highway (CJCH) (El. 42.4 ft. NAVD88). This level is approximately 3.5 ft. above the spillway crest. The impoundment water levels simulated with HEC-HMS model are consistent with the observed water levels. Assuming the CJCH has a flow area of 50 ft.^{2}, water levels on the Tack Factory Pond would be expected to be 0.8-1.2 ft. higher than the Reservoir Dam Impoundment.

The NOAA Atlas 14 precipitation distributions for 50-, 100-, and 200- year storms for Scituate, MA (NOAA NWS, 2014) were also simulated with the HEC-HMS model with the two lag times. Peak discharges ranged from 507 cfs for the 50-year storm and 812 minute lag up to 968 cfs for the 200-year storm and 620 minute lag time. The simulations indicate that flood flows would not overtop the dam embankment for any of the storm events with both lag times, as shown in Table C-23.

April 1, 2017 Storm

A rainstorm that occurred on April 1, 2017 was also evaluated with the HEC-HMS model with a time lag of 620 minutes. Rainfall amounts and Reservoir levels were obtained for this storm (*see* Table C-24). The March 31, 2017 5:00 PM to April 1, 2017 4:00 PM NOAA hourly precipitation data from the NOAA Blue Hill Local Climatological Data (LCD), MA rain gage was used to model the one-day storm precipitation distribution at Reservoir Dam (NCDC, 2017). The rain gage is located about 18.2 miles west of the Scituate Reservoir Dam and measured an accumulation of 2.57 in. of rain by 4:00 PM on April 1, 2017 (*see* Table C-25). The NOAA data and the measurements obtained at the reservoir were very similar. Due to their similarities, the simulated peak elevation should theoretically be near the measured El. 40.2 ft. at 4:00 PM.

Table C-24. Measured precipitation and reservoir levels.

Date	Time	Rain (in.)	Reservoir Level (ft.)
3/31/17	8:00 AM	0	38.9
4/1/17	8:00 AM	2.15	39.8
4/1/17	4:00 PM	-	40.2

Table C-25. Gaged precipitation from NOAA Blue Hill LCD.

Time	Precipitation (in.)
1 Hour	0.05
2 Hours	0.08
3 Hours	0.15
6 Hours	0.48
12 Hours	1.11
1 Day	2.57

The total inflow was calculated to be 2.13 inches, which is slightly lower than the actual 4:00 PM accumulated precipitation at the reservoir (*see* Table C-26). This slight difference can be attributed to differences in the storm distribution patterns at the rain gage and Reservoir Dam. A peak elevation was calculated to be about 0.2 ft. lower than the measured elevation, which confirms that the HEC-HMS model input parameters are reasonable and representative of the watershed characteristics.

Table C-26. April 1, 2017 rainstorm simulation results.

Storm	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in.)	Total Outflow (in.)	Peak Storage (ac-ft)	Peak Elevation (ft.)
1-Apr-17	60.7	51	2.13	2.06	527.6	39.6

Assessment Of Proposed Spillway Modifications

Reservoir Dam

The 2017 60-percent HEC-HMS simulations for the existing spillway indicated that the watershed has lag times between 620 and 812 minutes corresponding to ½ PMF peak discharges of 1,840 and 1,359 cfs, respectively. The ½ PMF discharge of 1,840 cfs was selected as a conservative SDF peak discharge for Reservoir Dam since the shorter lag time results in a higher peak discharge. Spillway modifications were evaluated to increase the spillway discharge capacity for the SDF with adequate freeboard to prevent overtopping of the earthen embankment.

The proposed spillway modifications require lowering of the ogee-shaped crest to El. 36.5 ft. NAVD88. The new ogee shape would have a similar shape as the existing spillway but would have a bottom-hinged crest gate to maintain the maximum normal pool at El. 40.4 ft. NAVD88. The new crest would have a 3.1 discharge coefficient similar to the existing spillway.

The spillway section would be extended upstream to provide a concrete approach apron and downstream to support the crest gate. The new concrete ogee section would be anchored by dowels drilled into the existing spillway mass concrete ogee section. The new ogee crest length would be 36.5 ft. long to allow the gate to fit inside the existing abutment walls.

The discharge rating curve data for the proposed spillway is presented in Table C-10. The proposed spillway would have a total discharge capacity of 2,854 cfs with the Reservoir Dam impoundment level at the top of dam (El. 45.0 ft. NAVD88). The 2017 model indicated that the reservoir level would be approximately El. 42.8 ft. NAVD88 at the ½ PMF (1,840 cfs) peak flow with the proposed spillway gate full open. At the ½ PMF peak reservoir level, there would be about 2.2 ft. of freeboard with no wave action.

Potential wave heights at the Reservoir Dam embankment were determined to be as high as 2.5 ft. based on the 2,000 ft maximum open water fetch distance from the north and a 74 mile per hour (mph) Category 1 hurricane minimum wind speed. The proposed spillway provides 1.0 ft. of freeboard with a wave equal to one-half of a Category 1 hurricane wave (1.2 ft) that could be expected to hit the dam during the ½ PMF event.

The 2017 HEC-HMS model with Tack Factory Pond and Reservoir Dam combined as a single basin was used to evaluate the PMF conditions with the modified spillway similar to the existing spillway simulations. These simulations assume a starting reservoir level at maximum normal pool El. 40.4 ft. NAVD88 and initiation of the gate opening at the beginning of the storm with the gate fully open prior to the peak rainfall intensity. Table C-27 and Table C-28 present a section of the time series for the PMP simulation for the 24-hour storm duration with watershed lag times of 620 minutes and 812 minutes, respectively.

Table C-29 summarizes the 2017 PMF results for the proposed spillway design. The full PMF peak discharge was calculated to be 3,506 cfs with a 620 minute lag time and 2,763.5 cfs with an 812 minute lag time.

The ½ PMF would be 1,753 cfs and 1,382 cfs with the 620 minute and 812 minute lag times, respectively, as shown in Table C-30 for the 2017 HEC-HMS simulations. The proposed spillway modifications result in an 88 cfs reduction in the ½ PMF SDF for the existing spillway with a 620 minute watershed lag time because of the additional spillway capacity. The maximum elevation of the Reservoir Dam impoundment during the ½ PMF would be El. 42.6 ft. NAVD88 at 1,753 cfs and El. 41.7 ft. NAVD88 at 1,382 cfs peak discharge as determined from the existing spillway discharge rating curve (Table C-4). Maximum water levels in the impoundment are 2.4-3.3 ft. for both of these scenarios. At 1,753 cfs, the dam embankment is not overtopped and there is 0.9 ft. of freeboard above the crest of a 1.5 ft. wave.

Table C-27. 2017 Proposed Spillway Modification PMF Time Series Results – 620 Minute Lag Time

Date	Time	Inflow (cfs)	Storage (ac-ft)	Elevation (ft)	Outflow (cfs)	Stage (ft)
10Mar2017	00:00	12	590.3	40.4	774	40.0
10Mar2017	02:00	12	496.1	39.2	427	38.8
10Mar2017	04:00	12	443.5	38.4	250	37.8
10Mar2017	06:00	12	412.3	37.9	160	37.3
10Mar2017	08:00	15	392.4	37.6	111	37.0
10Mar2017	10:00	23	379.6	37.4	83	36.9
10Mar2017	12:00	123	378.1	37.4	80	36.8
10Mar2017	14:00	424	404.8	37.8	141	37.2
10Mar2017	16:00	1,052	482.9	39.0	382	38.5
10Mar2017	18:00	1,959	622.6	40.8	895	40.4
10Mar2017	20:00	2,901	811.5	42.7	1,608	42.3
10Mar2017	22:00	3,574	1,013.2	44.4	2,349	44.0
11Mar2017	**00:00**	**3,783**	**1,180.6**	**45.7**	**2,924**	**45.1**
11Mar2017	02:00	3,705	1,285.6	46.4	3,262	45.8
11Mar2017	04:00	3,629	1,338.0	46.8	3,429	46.1
11Mar2017	06:00	3,555	1,359.3	46.9	3,498	46.2
11Mar2017	08:00	3,482	1,362.0	46.9	3,506	46.2
11Mar2017	10:00	3,411	1,354.2	46.9	3,482	46.2
11Mar2017	12:00	3,341	1,340.4	46.8	3,437	46.1
11Mar2017	14:00	3,272	1,323.4	46.7	3,382	46.0

Table C-28. 2017 Proposed Spillway Modification PMF Time Series Results – 812 Minute Lag Time

Date	Time	Inflow (cfs)	Storage (ac-ft)	Elevation (ft)	Outflow (cfs)	Stage (ft)
10Mar2017	00:00	12.0	590.3	40.4	774.2	40.0
10Mar2017	03:00	11.8	466.1	38.7	324.6	38.2
10Mar2017	06:00	12.0	412.3	37.9	160.1	37.3
10Mar2017	09:00	15.0	384.9	37.5	94.6	36.9
10Mar2017	12:00	140.6	381.6	37.4	87.6	36.9
10Mar2017	15:00	551.7	429.9	38.2	208.8	37.6
10Mar2017	18:00	1312.2	551.5	39.9	628.5	39.5
10Mar2017	21:00	2214.9	734.7	41.9	1317.6	41.5
11Mar2017	00:00	2800.9	927.1	43.7	2036.0	43.3
11Mar2017	03:00	2922.7	1062.4	44.8	2524.6	44.3
11Mar2017	**06:00**	**2833.3**	**1122.1**	**45.2**	**2725.7**	**44.7**
11Mar2017	09:00	2746.7	1133.3	45.3	2763.5	44.8
11Mar2017	12:00	2662.7	1123.0	45.3	2729.0	44.7
11Mar2017	15:00	2581.3	1104.3	45.1	2666.4	44.6
11Mar2017	18:00	2502.3	1082.4	45.0	2593.9	44.5

Table C-29. 2017 Proposed Spillway Modifications PMF Summary

Lag Time (min.)	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in)	Total Outflow (in)	Peak Storage (ac-ft)	Peak Elevation (ft)
620	3,783	3,506	126.3	125.4	1,361.8	46.9
812	2,922.7	2,763.5	99.8	100.1	1,133.3	45.3

Table C-30. 2017 Proposed Spillway Modifications ½ PMF Summary

Lag Time (min.)	Peak Inflow (cfs)	Peak Outflow (cfs)	Total Inflow (in)	Total Outflow (in)	Peak Storage (ac-ft)	Peak Elevation (ft)
620	1,891	1,753	63.2	62.6	803.7	42.6
812	1,461	1,382	49.9	50.1	633.9	41.7

The 2018 HEC-HMS simulations modeled Tack Factory Pond and Reservoir Dam as a separate subbasins to evaluate the PMF conditions with the modified spillway. These simulations also assume a starting reservoir level at maximum normal pool El. 40.4 ft. NAVD88 and that the gate fully opens for reservoir levels above the maximum normal pool and fully closes for levels below, i.e. on-off control only, no control loop. Table C-31 presents a section of the time series for the ½ PMF simulation. The ½ PMF storm has been used for 2018 modeling of the proposed spillway and dam failure analysis since this approach was found to be more conservative than the ½ PMP approach as discussed above for simulating the existing spillway configuration. The 2018 model uses a total lag time of 437 minutes watershed upstream of Reservoir Dam for the 24-hour storm duration since the Tack Factory Pond subbasin discharges directly into the Reservoir Dam impoundment.

The 2018 model simulations resulted in a 1/2 PMF peak discharge of 2,247 cfs. The 2018 analysis results in slightly higher peak discharge and reservoir level than the 2017 analysis. The 2018 model results with separate subbasins are more conservative than the 2017 model with Tack Factory Pond and Reservoir Dam combined into a single basin. The 2018 modeling determined that the maximum elevation of the Reservoir Dam impoundment during the ½ PMF would be El. 43.7 ft. NAVD88. The model results indicate that the dam embankment would not overtopped and would have 1.3 ft of freeboard without wave action. This freeboard would be adequate to prevent overtopping of the dam with a wave height associated with approximately one-half of a Category 1 hurricane minimum wind speed.

Table C-31. 2018 Proposed Spillway ½ PMF Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	9	579.6	40.4	10	40.4
10-Mar-17	2:00	13	579.6	40.4	13	40.4
10-Mar-17	4:00	13	579.6	40.4	13	40.4
10-Mar-17	6:00	14	579.6	40.4	14	40.4
10-Mar-17	8:00	17	579.6	40.4	17	40.4
10-Mar-17	10:00	151	579.7	40.4	113	40.4
10-Mar-17	12:00	794	580.2	40.4	745	40.4
10-Mar-17	14:00	1,109	590.1	40.5	952	40.5
10-Mar-17	16:00	1,709	645.3	41.3	1,216	41.3
10-Mar-17	18:00	1,956	708.7	42.1	1,537	42.1
…						
10-Mar-17	20:00	2,419	790.4	43.0	1,937	43.0
10-Mar-17	20:20	2,446	803.1	43.2	2,003	43.2
10-Mar-17	20:40	2,458	814.6	43.3	2,063	43.3
10-Mar-17	21:00	2,456	824.8	43.4	2,115	43.4
10-Mar-17	21:20	2,440	833.3	43.5	2,160	43.5
10-Mar-17	21:40	2,411	840.2	43.6	2,196	43.6

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	22:00	2,371	845.2	43.7	2,223	43.7
10-Mar-17	22:20	2,322	848.4	43.7	2,240	43.7
10-Mar-17	**22:40**	**2,266**	**849.8**	**43.7**	**2,247**	**43.7**
10-Mar-17	23:00	2,203	849.4	43.7	2,245	43.7

Tack Factory Pond

The results of the 2018 HEC-HMS simulations of ½ PMF conditions at Tack Factory Pond are presented in Table C-32 and Table C-33 for the existing Reservoir Dam spillway and the proposed spillway, respectively. The sections of the time series at Tack Factory Pond for the ½ PMP simulations indicate that the peak discharge at Tack Factory Pond would be 2,227 cfs for the existing conditions and 2,228 cfs for the proposed conditions. The maximum elevation of the Tack Factory Pond during the ½ PMF would be El. 44.8 ft. NAVD88 with the existing Reservoir Dam spillway and El. 44.9 ft. NAVD88 with the proposed Reservoir Dam spillway. The model results indicate that CJCH would be overtopped during the ½ PMF with both the existing and proposed Reservoir Dam spillway configurations

Table C-32. Tack Factory Pond Existing Conditions ½ PMF Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	10	30.8	38.9	-	39.5
10-Mar-17	2:00	10	31.9	39.0	6	39.6
10-Mar-17	4:00	10	32.3	39.0	9	39.6
10-Mar-17	6:00	10	32.4	39.0	9	39.7
10-Mar-17	8:00	11	32.6	39.0	9	39.7
10-Mar-17	10:00	20	34.1	39.1	-	39.5
10-Mar-17	12:00	133	44.3	39.9	-	39.5
10-Mar-17	14:00	518	93.2	41.9	-	39.5
10-Mar-17	16:00	1,221	191.6	44.6	814	41.8
10-Mar-17	18:00	1,926	225.7	45.4	1,782	42.4
…						
10-Mar-17	20:00	2,245	241.1	45.7	2,224	42.5
10-Mar-17	20:20	2,245	241.5	45.7	2,239	42.5
10-Mar-17	**20:40**	**2,231**	**241.5**	**45.7**	**2,239**	**42.5**
10-Mar-17	21:00	2,204	241.1	45.7	2,224	42.5
10-Mar-17	21:20	2,166	240.4	45.7	2,197	42.5
10-Mar-17	21:40	2,116	239.4	45.7	2,158	42.5

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	22:00	2,059	238.1	45.6	2,109	42.5
…						
11-Mar-17	0:00	1,612	223.1	45.3	1,728	42.4
11-Mar-17	2:00	1,149	197.7	44.8	1,369	42.2

Table C-33. Tack Factory Pond Proposed Conditions ½ PMF Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	10	56.3	40.4	7	40.4
10-Mar-17	2:00	10	56.3	40.4	10	40.4
10-Mar-17	4:00	10	56.3	40.4	10	40.4
10-Mar-17	6:00	10	56.3	40.4	10	40.4
10-Mar-17	8:00	11	56.3	40.4	11	40.4
10-Mar-17	10:00	20	56.4	40.4	17	40.4
10-Mar-17	12:00	133	59.6	40.5	80	40.5
10-Mar-17	14:00	518	87.6	41.6	185	41.1
10-Mar-17	16:00	1,221	153.1	43.7	943	43.2
10-Mar-17	18:00	1,926	189.6	44.6	1,712	43.6
…						
10-Mar-17	20:00	2,245	213.7	45.1	2,181	43.8
10-Mar-17	20:20	2,245	215.1	45.1	2,209	43.8
10-Mar-17	**20:40**	**2,231**	**215.7**	**45.1**	**2,222**	**43.8**
10-Mar-17	21:00	2,204	215.6	45.1	2,220	43.8
10-Mar-17	21:20	2,166	214.9	45.1	2,205	43.8
10-Mar-17	21:40	2,116	213.5	45.1	2,177	43.8
10-Mar-17	22:00	2,059	211.5	45.1	2,138	43.8
…						
11-Mar-17	0:00	1,612	191.9	44.6	1,758	43.7
11-Mar-17	2:00	1,149	166.3	44.1	1,306	43.4

Old Oaken Bucket Pond

The results of the 2018 HEC-HMS simulations of ½ PMF conditions at Old Oaken Bucket are presented in Table C-34 and Table C-35 for the existing Reservoir Dam spillway and the proposed spillway, respectively. The sections of the time series at Old Oaken Bucket for the ½ PMF simulations indicate that the peak discharge at Old Oaken Bucket would be 2,717 cfs for the existing conditions and 2,560 cfs for the proposed conditions. The maximum elevation of the Old Oaken Bucket Pond during the ½ PMF would be El. 23.9 ft. NAVD88 with the existing Reservoir Dam spillway and El. 23.8 ft. NAVD88 with the proposed Reservoir Dam spillway. The model results indicate that Country Way would be overtopped during the ½ PMF with the existing and proposed Reservoir Dam spillway configurations.

Table C-34. Old Oaken Bucket Pond Existing Conditions ½ PMF Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	3	29.1	18.9	222	21.0
10-Mar-17	2:00	4	4.8	15.5	61	19.6
10-Mar-17	4:00	5	3.6	15.2	5	18.7
10-Mar-17	6:00	7	3.6	15.2	7	18.7
10-Mar-17	8:00	9	3.6	15.2	9	18.8
10-Mar-17	10:00	90	4.5	15.4	53	19.5
10-Mar-17	12:00	855	49.8	19.5	240	21.1
10-Mar-17	14:00	1,528	198.4	22.7	721	21.9
10-Mar-17	16:00	1,897	244.8	23.5	1,857	22.6
10-Mar-17	18:00	1,598	236.8	23.3	1,629	22.5
10-Mar-17	20:00	2,154	248.2	23.5	1,956	22.7
…						
10-Mar-17	22:00	2,731	271.8	23.9	2,709	23.1
10-Mar-17	**22:20**	**2,713**	**272.1**	**23.9**	**2,717**	**23.1**
10-Mar-17	22:40	2,682	271.7	23.9	2,705	23.1
10-Mar-17	23:00	2,642	270.9	23.9	2,677	23.1
10-Mar-17	23:20	2,595	269.8	23.9	2,640	23.1
10-Mar-17	23:40	2,542	268.4	23.9	2,595	23.0
11-Mar-17	0:00	2,482	266.8	23.8	2,543	23.0
…						
11-Mar-17	2:00	2,096	254.9	23.6	2,162	22.8

Table C-35. Old Oaken Bucket Pond Proposed Conditions ½ PMF Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	13	29.1	18.9	222	21.0

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	2:00	17	5.7	15.7	81	19.8
10-Mar-17	4:00	18	3.7	15.2	18	18.9
10-Mar-17	6:00	19	3.7	15.2	19	19.0
10-Mar-17	8:00	22	3.7	15.2	22	19.0
10-Mar-17	10:00	141	5.5	15.6	76	19.7
10-Mar-17	12:00	1,432	95.0	20.6	268	21.3
10-Mar-17	14:00	2,142	247.8	23.5	1,944	22.7
10-Mar-17	16:00	2,389	261.8	23.8	2,379	22.9
10-Mar-17	18:00	1,906	248.9	23.5	1,979	22.7
10-Mar-17	20:00	2,193	253.4	23.6	2,113	22.8
…						
10-Mar-17	22:00	2,517	264.7	23.8	2,471	23.0
10-Mar-17	22:20	2,543	265.8	23.8	2,508	23.0
10-Mar-17	22:40	2,559	266.6	23.8	2,535	23.0
10-Mar-17	23:00	2,566	267.1	23.8	2,552	23.0
10-Mar-17	**23:20**	**2,563**	**267.4**	**23.8**	**2,560**	**23.0**
10-Mar-17	23:40	2,552	267.3	23.8	2,559	23.0
11-Mar-17	0:00	2,533	267.0	23.8	2,549	23.0
…						
11-Mar-17	2:00	2,288	260.7	23.7	2,344	22.9

100-Year Flood

The 100-year flood was modeled using NOAA Atlas 14 point precipitation data for the Hingham, MA station; up to a 4-day event. Peak intensity was 5 minutes in duration at a position of 50 percent.

Tack Factory Pond

The results of the 2018 HEC-HMS simulations of 100-year flood conditions at Tack Factory Pond are presented in Table C-36 and Table C-37 for the existing Reservoir Dam spillway and the proposed spillway, respectively. The sections of the time series at Tack Factory Pond for the 100-year flood simulations indicate that the peak discharge at Tack Factory Pond would be 1,023 cfs for the existing conditions and 1,023 cfs for the proposed conditions. The maximum elevation of the Tack Factory Pond during the 100-year flood would be El. 44 ft. NAVD88 with the existing Reservoir Dam spillway and El. 43.7 ft. NAVD88 with the proposed Reservoir Dam spillway. The model results indicate that CJCH would be overtopped during the 100-year flood with the existing and proposed Reservoir Dam spillway configurations. The FEMA 100-year flood level upstream of Tack Factory Pond is El. 44.0 ft NAVD88.

Table C-36. Tack Factory Pond Existing Conditions 100-year Flood Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	10	30.8	38.9	-	39.5
10-Mar-17	6:00	10	32.2	39.0	9	39.7
10-Mar-17	12:00	9	32.3	39.0	10	39.7
10-Mar-17	18:00	9	32.2	39.0	9	39.7
11-Mar-17	0:00	9	32.2	39.0	9	39.6
11-Mar-17	6:00	9	32.3	39.0	8	39.6
11-Mar-17	12:00	18	33.7	39.1	12	39.7
11-Mar-17	18:00	48	38.5	39.4	33	40.0
12-Mar-17	0:00	137	56.0	40.4	24	39.9
12-Mar-17	6:00	937	151.9	43.7	835	41.8
…						
12-Mar-17	7:00	1,012	158.2	43.9	958	41.9
12-Mar-17	7:20	1,024	159.5	43.9	984	41.9
12-Mar-17	7:40	1,032	160.5	43.9	1,002	41.9
12-Mar-17	8:00	1,034	161.2	43.9	1,014	41.9
12-Mar-17	8:20	1,030	161.6	44.0	1,021	41.9
12-Mar-17	**8:40**	**1,019**	**161.6**	**44.0**	**1,023**	**41.9**
12-Mar-17	9:00	1,005	161.4	44.0	1,019	41.9
…						
12-Mar-17	12:00	750	150.7	43.6	815	41.8
12-Mar-17	18:00	366	124.7	42.8	407	41.4

Table C-37. Tack Factory Pond Proposed Conditions 100-Year Flood Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	10	56.3	40.4	7	40.4
10-Mar-17	6:00	10	56.3	40.4	10	40.4
10-Mar-17	12:00	9	56.3	40.4	9	40.4
10-Mar-17	18:00	9	56.3	40.4	9	40.4
11-Mar-17	0:00	9	56.3	40.4	9	40.4
11-Mar-17	6:00	9	56.3	40.4	9	40.4
11-Mar-17	12:00	18	56.4	40.4	17	40.4
11-Mar-17	18:00	48	57.2	40.4	44	40.5
12-Mar-17	0:00	137	62.2	40.6	110	40.7
12-Mar-17	6:00	937	141.4	43.4	822	43.1
…						
12-Mar-17	7:00	1,012	148.5	43.6	954	43.2
12-Mar-17	7:20	1,024	149.9	43.6	982	43.2
12-Mar-17	7:40	1,032	150.9	43.6	1,002	43.2
12-Mar-17	8:00	1,034	151.5	43.7	1,015	43.2
12-Mar-17	**8:20**	**1,030**	**151.9**	**43.7**	**1,023**	**43.2**
12-Mar-17	8:40	1,019	151.9	43.7	1,023	43.2
12-Mar-17	9:00	1,005	151.7	43.7	1,019	43.2
…						
12-Mar-17	12:00	750	141.1	43.3	817	43.1
12-Mar-17	18:00	366	116.5	42.6	405	42.6

RESERVOIR DAM

The results of the 2018 HEC-HMS simulations of 100-year flood conditions at Reservoir Dam are presented in Table C-38 and Table C-39 for the existing Reservoir Dam spillway and the proposed spillway, respectively. The sections of the time series for the 100-year flood simulations indicate that the peak discharge at the Reservoir Dam spillway would be 1,031 cfs for the existing conditions and 1,115 cfs for the proposed conditions. The maximum elevation of the Reservoir Dam impoundment during the 100-year flood would be El. 43.6 ft. NAVD88 with the existing Reservoir Dam spillway and El. 41.0 ft. NAVD88 with the proposed Reservoir Dam spillway. The model results indicate that Reservoir Dam would not be overtopped during the 100-year flood with either the existing or proposed spillway. The 100-year flood level with proposed spillway would be El. 41.0 ft. NAVD88 with 4 ft of freeboard on the Dam embankment. The FEMA 100-year flood level upstream of the Reservoir Dam spillway is El. 42.0 ft NAVD88.

Table C-38. Reservoir Dam Existing Conditions 100-Year Flood Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	2	476.6	38.9	-	38.9
11-Mar-17	0:00	11	490.5	39.1	8	39.0
12-Mar-17	0:00	218	538.6	39.8	80	39.6
12-Mar-17	6:00	1,012	712.1	42.1	562	41.7
12-Mar-17	7:00	1,133	749.5	42.6	690	42.2
…						
12-Mar-17	8:00	1,187	783.5	43.0	816	42.5
12-Mar-17	8:20	1,194	793.3	43.1	854	42.7
12-Mar-17	8:40	1,195	802.2	43.2	889	42.8
12-Mar-17	9:00	1,190	810.1	43.3	920	42.9
12-Mar-17	9:20	1,181	817.0	43.4	948	42.9
12-Mar-17	9:40	1,168	822.9	43.4	972	43.0
12-Mar-17	10:00	1,150	827.8	43.5	992	43.1
12-Mar-17	10:20	1,128	831.6	43.5	1,008	43.1
12-Mar-17	10:40	1,104	834.5	43.6	1,020	43.1
12-Mar-17	11:00	1,077	836.3	43.6	1,027	43.2
12-Mar-17	**11:20**	**1,048**	**837.2**	**43.6**	**1,031**	**43.2**
12-Mar-17	11:40	1,015	837.2	43.6	1,031	43.2
12-Mar-17	12:00	982	836.4	43.6	1,028	43.2
…						
12-Mar-17	18:00	563	760.9	42.7	731	42.3

Table C-39. Reservoir Dam Proposed Conditions 100-year Flood Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	9	579.6	40.4	10	40.4
11-Mar-17	0:00	11	579.6	40.4	11	40.4
12-Mar-17	0:00	304	579.8	40.4	277	40.4
12-Mar-17	6:00	999	582.4	40.4	915	40.4
12-Mar-17	7:00	1,130	593.2	40.6	967	40.6
…						
12-Mar-17	8:00	1,189	606.9	40.8	1,030	40.8
12-Mar-17	8:20	1,195	611.0	40.8	1,050	40.8
12-Mar-17	8:40	1,196	614.8	40.9	1,067	40.9
12-Mar-17	9:00	1,190	618.1	40.9	1,083	40.9
12-Mar-17	9:20	1,180	620.7	40.9	1,096	40.9
12-Mar-17	9:40	1,166	622.7	41.0	1,105	41.0
12-Mar-17	10:00	1,148	624.0	41.0	1,112	41.0
12-Mar-17	**10:20**	**1,127**	**624.7**	**41.0**	**1,115**	**41.0**
12-Mar-17	10:40	1,103	624.7	41.0	1,115	41.0
12-Mar-17	11:00	1,077	624.0	41.0	1,112	41.0
12-Mar-17	11:20	1,048	622.8	41.0	1,106	41.0
12-Mar-17	11:40	1,016	620.9	40.9	1,096	40.9
12-Mar-17	12:00	983	618.4	40.9	1,084	40.9
…						
12-Mar-17	18:00	561	580.1	40.4	560	40.4

Old Oaken Bucket Pond

The results of the 2018 HEC-HMS simulations of 100-year flood conditions at Old Oaken Bucket are presented in Table C-40 and

Table C-41 for the existing Reservoir Dam spillway and the proposed spillway, respectively. The sections of the time series at Old Oaken Bucket for the 100-year flood simulations indicate that the peak discharge at Old Oaken Bucket would be 1,222 cfs for the existing conditions and 1,308 cfs for the proposed conditions. The maximum elevation of the Old Oaken Bucket Pond during the 100-year flood would be El. 23.1 ft. NAVD88 with the existing Reservoir Dam spillway and with the proposed Reservoir Dam spillway. Country Way with the minimum road surface at El. 22.1 ft would be overtopped during the 100-year flood with the existing and proposed Reservoir Dam spillway configurations. The FEMA 100-year flood level upstream of the Old Oaken Bucket Pond dam is El. 17.5 ft NAVD88.

Table C-40. Old Oaken Bucket Pond Existing Conditions 100-year Flood Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	3	29.1	18.9	222	21.0
11-Mar-17	0:00	11	3.6	15.2	11	18.8
12-Mar-17	0:00	267	15.2	17.2	162	20.5
…						
12-Mar-17	6:00	727	195.8	22.6	673	21.8
12-Mar-17	7:00	849	201.2	22.7	775	21.9
12-Mar-17	8:00	975	207.3	22.8	902	22.0
12-Mar-17	9:00	1,087	213.0	22.9	1,026	22.1
12-Mar-17	10:00	1,169	217.3	23.0	1,126	22.2
…						
12-Mar-17	11:00	1,215	220.0	23.0	1,192	22.2
12-Mar-17	11:20	1,222	220.6	23.0	1,205	22.2
12-Mar-17	11:40	1,226	221.0	23.1	1,215	22.2
12-Mar-17	12:00	1,225	221.2	23.1	1,220	22.2
12-Mar-17	**12:20**	**1,221**	**221.3**	**23.1**	**1,222**	**22.2**
12-Mar-17	12:40	1,214	221.2	23.1	1,219	22.2
12-Mar-17	13:00	1,203	220.9	23.0	1,214	22.2
12-Mar-17	13:20	1,191	220.6	23.0	1,205	22.2
12-Mar-17	13:40	1,176	220.1	23.0	1,194	22.2
…						
12-Mar-17	18:00	931	210.1	22.9	962	22.0

Table C-41. Old Oaken Bucket Pond Proposed Conditions 100-year Flood Time Series Results

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
10-Mar-17	0:00	13	29.1	18.9	222	21.0
11-Mar-17	0:00	14	3.7	15.2	14	18.9
…						
12-Mar-17	0:00	427	31.5	19.0	224	21.0
12-Mar-17	0:20	552	38.8	19.2	231	21.0
12-Mar-17	0:40	762	50.4	19.5	240	21.1
12-Mar-17	1:00	1,072	68.8	20.0	252	21.2
12-Mar-17	1:20	1,412	95.9	20.6	269	21.3
12-Mar-17	1:40	1,635	130.2	21.4	287	21.4
12-Mar-17	2:00	1,721	168.2	22.1	314	21.4
12-Mar-17	2:20	1,612	199.9	22.7	750	21.9
12-Mar-17	2:40	1,443	216.2	23.0	1,100	22.2
…						
12-Mar-17	11:00	1,311	224.7	23.1	1,307	22.3
12-Mar-17	**11:20**	**1,307**	**224.7**	**23.1**	**1,308**	**22.3**
12-Mar-17	11:40	1,301	224.6	23.1	1,306	22.3
12-Mar-17	12:00	1,291	224.4	23.1	1,301	22.3
12-Mar-17	12:20	1,278	224.1	23.1	1,292	22.3
12-Mar-17	12:40	1,263	223.6	23.1	1,281	22.3
…						
12-Mar-17	18:00	760	201.9	22.7	790	21.9

2014 Dam Failure Analysis

The Town's Emergency Action Plan (EAP) dated January 2014 considered failure of Reservoir Dam. However, ODS requested the Town to consider a multiple dam failure scenario with Old Oaken Bucket Dam failing subsequently to Reservoir Dam and incorporate the analysis results and a new inundation map into the EAP for the dams. The preliminary design completed in 2014 included a multiple dam failure analyses for "sunny day" and ½ PMF initial conditions and the results were included in the Preliminary Design Memorandum for the Reservoir Dam Fish Passage Project (Tetra Tech 2014). The analysis was a simplified analysis of multiple dam failure using the EAP analysis for Reservoir Dam and conservative assumptions for failure of Old Oaken Bucket Dam. Assumptions for the 2014 analysis were:

1. There are no changes to EAP flood levels and breach flows at Old Oaken Bucket Dam and upstream of Country Way for both the Sunny Day and ½ PMF failure scenarios.

2. Country Way is an integral part of Old Oaken Bucket Dam and the twin stone culverts are the primary outlet. The culverts have a discharge capacity of approximately 300 cfs without overtopping Country Way.
3. Instantaneous failure of a 14 ft wide by 12 ft deep section of Country Way at the twin stone culverts. This breach represents the width and depth of the culverts and is the weakest point where a sudden failure could occur in the dam. Failure of Old Oaken Bucket Dam/Country Way occurs when the flood wave (peak breach flow and maximum water elevation) resulting from failure Reservoir Dam arrive at Old Oaken Bucket Dam/Country Way.
4. Culverts under Driftway have minimal discharge capacity and flood levels at Drift Way are controlled by the highway profile.
5. No attenuation of the peak breach flow downstream of Old Oaken Bucket Dam/Country Way to the limits of the analysis at the North River, i.e., peak breach flow at the North River is the same as peak breach flow at Old Oaken Bucket/Country Way.

The analysis indicated that peak flood levels with multiple dam failure would be 1.9 ft. higher at Country Way and 0.5 ft. higher at Driftway Road than the peak flood levels with single dam failure. The results of the multiple failure analysis are presented in Table C-42. The river mile references in the table are relative to the distance downstream from Reservoir Dam.

Peak flood levels at Country Way for the multiple dam failure analysis would be higher than single failure of Reservoir Dam because of the assumption that Country Way controls water levels in Old Oaken Bucket and that Country Way would be overtopped at river flows greater than 300 cfs. Downstream at Driftway Road and the North River, flood levels with multiple dam failure would be less than 0.5 ft higher than single dam failure.

An inundation map for First Herring Brook reflecting the 2014 simplified multiple dam failure analysis is provided in Appendix E of the 2014 Preliminary Design Report.

Table C-42. 2014 Reservoir Dam Failure Analysis

	Sunny Day Failure		½ PMF Failure	
	Single Dam	Multiple Dam	Single Dam	Multiple Dam
Reservoir Dam (River Mile 0.0)				
Maximum Breach Flow (cfs)	3,950	3,950	9,250	9,250
Peak Flood Level (ft NAVD88)	38.9	38.9	42.9	42.9
Toe of Dam (River Mile 0.01)				
Maximum Breach Flow (cfs)	3,950	3,950	9,250	9,250
Peak Flood Level (ft NAVD88)	32.4	32.4	34.8	34.8
First Herring Brook (River Mile 0.36)				
Maximum Breach Flow (cfs)	3,350	3,350	7,900	7,900
Peak Flood Level (ft NAVD88)	23.3	23.3	25.3	25.3
Country Way (River Mile 0.69)				
Maximum Breach Flow (cfs)	2,725	3,700	6,830	8,405
Peak Flood Level (ft NAVD88)	22.4	23.7	23.7	25.6
Driftway Road (River Mile 0.81)				
Maximum Breach Flow (cfs)	2,230	3,700	6,825	8,405
Peak Flood Level (ft NAVD88)	13.0	13.4	15.0	15.2
Downstream Flood Plain (River Mile 1.16)				
Maximum Breach Flow (cfs)	2,190	3,700	6,825	8,405
Peak Flood Level (ft NAVD88)	0.0	2.8	9.1	9.4
North River (River Mile 1.8)				
Maximum Breach Flow (cfs)	2,100	3,700	6,825	8,405
Peak Flood Level (ft NAVD88)	0.0	2.7	9.1	9.3

HEC-HMS Dam Failure Analysis

The HEC-HMS model was used to conduct a multiple dam failure analyses for "sunny day" and ½ PMF initial conditions to verify the results of the simplified analysis presented in the 2014 Preliminary Design Report. A summary of the assumptions and results of the analysis are presented in the following sections.

Failure Scenarios

Ten scenarios were investigated, seven with single failure of Reservoir Dam and three with multiple failures of Reservoir Dam and Tack Factory Pond. The Reservoir Dam single failure analysis included five scenarios for the ½ PMF flood condition, three with an overtopping breach and two with a piping breach. The analysis included two "sunny day" scenarios with single failure of Reservoir Dam, one with an overtopping breach and one with a piping breach.

A summary of the model input parameters for the single failure analysis of the existing Reservoir Dam is presented in Table C-43 for the ½ PMF flood conditions. Scenarios 1A, 1B, and 1C investigates the effects of the breach development time (2 hours, 6 hours, 0.25 hours, respectively) on peak failure discharge with an overtopping breach of Reservoir Dam. Scenario 2 investigates the effects of the breach bottom width (100 ft versus 200 ft) on peak discharge with an overtopping breach. The breach bottom El. 43.9 ft is the top elevation of the existing concrete core wall. Scenarios 3 simulates embankment piping breaches with a breach bottom elevation at the approximate elevation of erodible material (El. 41.5 ft) in the dam abutments at the end of the concrete core wall.

Model input parameters for the single failure of the proposed Reservoir Dam modifications for the ½ PMF flood and Sunny Day conditions are summarized in Table C-44. Scenario 4 simulates an embankment piping breach above the Reservoir Dam concrete core wall (El. 43.9 ft). Scenarios 5 and 6 simulate failure of the proposed spillway gate during ½ PMF flood and Sunny Day conditions, respectively. Scenario 7 simulates a Sunny Day piping failure of the Reservoir Dam abutment to the bottom of the concrete core wall (El. 36.1 ft).

Model input parameters for the multiple dam failure scenarios with proposed spillway and the ½ PMF flood and Sunny Day conditions are summarized in Table C-45. Scenario 8 models overtopping of the Reservoir Dam with the proposed modifications during a ½ PMF event followed by overtopping failure of Old Oaken Bucket Pond Dam. Scenario 9 simulates failure of the proposed Reservoir Dam spillway gate during the ½ PMF flood followed by overtopping failure Old Oaken Bucket Pond Dam. Scenario 10 represents a Sunny Day failure of the proposed Reservoir Dam spillway gate followed by overtopping failure Old Oaken Bucket Pond Dam. The Reservoir Dam failure parameters are the same as Scenarios 4, 5, and 6 for the multiple dam failure Scenarios 8, 9, and 10, respectively.

Table C-43. Existing Reservoir Dam Failure Assumptions with ½ PMF Flood Conditions (Scenarios 1-3)

Parameter	Scenario 1A	Scenario 1B	Scenario 1C	Scenario 2	Scenario 3
Failure Description	Single Reservoir Dam Embankment Overtopping Erosion	Single Reservoir Dam Embankment Overtopping Erosion	Single Reservoir Dam Embankment Overtopping Erosion	Single Reservoir Dam Embankment Overtopping Erosion	Single Reservoir Dam Abutment Piping Erosion
Rainfall Event	1/2 PMF	1/2 PMF	1/2 PMF	1/2 PMF	1/2 PMF
Basin Name	**Existing Scenario 1A**	**Existing Scenario 1B**	**Existing Scenario 1C**	**Existing Scenario 2**	**Existing Scenario 3**
Element Name	Reservoir Dam	Reservoir Dam	Reservoir Dam	Reservoir Dam	Reservoir Dam
Method of Failure	Overtop Breach	Overtop Breach	Overtop Breach	Overtop Breach	Piping Breach
Direction	Main	Main	Main	Main	Main
Top Elevation (ft NAVD88)	45.0	45.0	45.0	45.0	45.0
Bottom Elevation (ft NAVD88)	43.9	43.9	43.9	43.9	41.5
Bottom Width (ft)	200	200	200	100	25
Left Slope (xH:1V)	1	1	1	1	1
Right Slope (xH:1V)	1	1	1	1	1
Piping Elevation (ft NAVD88)	n/a	n/a	n/a	n/a	43.5
Piping Coefficient	n/a	n/a	n/a	n/a	0.8
Development Time (HR)	2	6	0.25	2	0.25
Trigger Method	Elevation	Elevation	Elevation	Elevation	Elevation
Trigger Elevation (ft NAVD88)	45.0	45.0	45.0	45.0	45.0
Trigger Duration (HR)	n/a	n/a	n/a	n/a	n/a
Progression Method	linear	linear	linear	linear	linear

Table C-44. Proposed Reservoir Dam Failure Assumptions with ½ PMF Flood and Sunny Day Conditions (Scenarios 4-7)

Parameter	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Failure Description	Single Reservoir Dam Abutment Piping Erosion	Single Reservoir Dam Spillway Gate Failure	Single Reservoir Dam Spillway Gate Failure	Single Reservoir Dam Abutment Piping Erosion
Rainfall Event	1/2 PMF	1/2 PMF	Sunny Day	Sunny Day
Basin Name	**Proposed Scenario 4**	**Proposed Scenario 5**	**Proposed Scenario 6**	**Proposed Scenario 7**
Element Name	Reservoir Dam	Reservoir Dam	Reservoir Dam	Reservoir Dam
Method of Failure	Piping Breach	Overtop Breach	Overtop Breach	Piping Breach
Direction	Main	Main	Main	Main
Top Elevation (ft NAVD88)	45.0	40.4	40.4	40.4
Bottom Elevation (ft NAVD88)	43.9	36.4	36.4	36.4
Bottom Width (ft)	25	36.6	36.6	36.6
Left Slope (xH:1V)	1	0.1	0.1	0.1
Right Slope (xH:1V)	1	0.1	0.1	0.1
Piping Elevation (ft NAVD88)	39.1	n/a	n/a	39.1
Piping Coefficient	0.8	n/a	n/a	0.8
Development Time (HR)	0.25	0.08	0.08	0.25
Trigger Method	Elevation	Elevation	Elevation	Elevation
Trigger Elevation (ft NAVD88)	43.5 (just below Peak Elevation 1/2 PMF no failure)	43.5 (just below Peak Elevation 1/2 PMF no failure)	40.40	40.39
Trigger Duration (HR)	n/a	n/a	n/a	n/a
Progression Method	linear	linear	linear	linear

Table C-45. Existing and Proposed Multiple Dam Failure Assumptions with ½ PMF Flood and Sunny Day Conditions (Scenarios 8-10)

Parameter	Scenario 8	Scenario 9	Scenario 10
Reservoir Dam Failure Description	Scenario 4	Scenario 5	Scenario 6
Old Oaken Bucket Failure Description	Multiple Dam Embankment Overtopping Erosion	Multiple Dam Spillway Gate Failure	Multiple Dam Spillway Gate Failure
Rainfall Event	1/2 PMF	1/2 PMF	Sunny Day
Basin Name	**Existing Scenario 8**	**Proposed Scenario 9**	**Proposed Scenario 10**
Element Name	Reservoir Dam	Reservoir Dam	Reservoir Dam
Method of Failure	Overtop Breach	Overtop Breach	Piping Breach
Direction	Main	Main	Main
Top Elevation (ft NAVD88)	21.3	21.3	21.3
Bottom Elevation (ft NAVD88)	12.45 (streambed at toe of dam per dam safety inspection report	12.45	12.45
Bottom Width (ft)	200	200	200
Left Slope (xH:1V)	1	1	1
Right Slope (xH:1V)	1	1	1
Piping Elevation (ft NAVD88)	n/a	n/a	n/a
Piping Coefficient	n/a	n/a	n/a
Development Time (HR)	2	2	2
Trigger Method	Elevation	Elevation	Elevation
Trigger Elevation (ft NAVD88)	22.6	22.6	22.6
Trigger Duration (HR)	n/a	n/a	n/a
Progression Method	linear	linear	linear

The ½ PMF scenarios simulate failure with the ½ PMP rainfall as described above. The “Sunny Day” failure scenarios assume no rainfall with a base flow of 12 cfs discharged through the Reservoir Dam low-level outlet.

Overtopping breach scenarios for the existing Reservoir Dam spillway assume the breach is initiated when water levels reach the top of the embankment. Bottom of breach at top of core wall. A two hour breach development time were selected as reasonable approximation of the embankment erosion of the stone armored upstream slope and grass covered downstream slope to reach the concrete core wall at Reservoir Dam and extend over a 200 ft breach width (1.6 minute per lineal ft of breach). To verify that this approximation is conservative, breach development times of 6 hours and 15 minutes (0.6 linear ft and 13.3 linear ft per minute, respectively) for a 200 ft breach.

The abutment piping breach assumes the breach is initiated Abutment piping breach development time of 15 minutes was selected as a conservative failure time for a breach to form. The abutments at the end of the embankment concrete core wall have a upward slope (10% or flatter) and an abutment piping breach would be at least 30 ft long. A faster breach development time would be unlikely in the vegetated abutment and glacial till material.

Single Dam Failure

The results of the single failure scenarios for the existing Reservoir Dam during the ½ PMF event are summarized in Table C-46. Time series results are presented in Table C-47, Table C-48, Table C-49, Table C-50, and Table C-51. A comparison of the Scenarios 1A, 1B, and 1C indicates that a 2 hour development time of a 200 ft breach of the Reservoir Dam embankment provides a conservative simulation of peak flood discharge (2,838 cfs) for a 1/2 PMF single dam failure. The Reservoir Dam embankment would be overtopped with all three scenarios with peak flood levels at El. 45.5 ft. The 0.25 and 6 hour breach development times both result is slightly lower peak discharges from Reservoir Dam than the 2 hour breach because of the offset between the peak inflow time and the full breach time. When the full breach occurs prior to the peak inflow, the breach releases storage lowering water level resulting in a reduced peak discharge. With the longer 6 hours breach development time, the peak inflow occurs prior to the full breach and the full breach occurs when inflow is decreasing, which also reduces the peak discharge.

The results for Scenarios 1A and 2 indicate that a longer breach results in a slightly more conservative peak discharge. The Scenario 3 gate failure has lower peak outflow form Reservoir Dam and with slightly lower peak reservoir levels than the 200 ft long embankment breach (Scenario 1A).

All single Reservoir Dam failure scenarios result in peak discharge at Old Oaken Bucket Pond greater than 2,750 cfs with peak ½ PMF levels at least 2.7 ff higher than Country Way. Flood levels over County Way would be 0.7 ft higher with a Reservoir Dam failure than the no failure scenarios for the existing dam.

Table C-46. Existing Reservoir Dam Failure Results during ½ PMF Flood Conditions (Scenarios 1-3)

Parameter	Single Dam Failure Existing Scenario 1A 1/2 PMF Overtop Erosion	Single Dam Failure Existing Scenario 1B 1/2 PMF Overtop Erosion	Single Dam Failure Existing Scenario 1C 1/2 PMF Overtop Erosion	Single Dam Failure Existing Scenario 2 1/2 PMF Overtop Erosion	Single Dam Failure Existing Scenario 3 1/2 PMF Piping Erosion
Tack Factory Pond					
Peak elevation (ft. NAVD88)	45.7	45.7	45.7	45.7	45.7
Peak Outflow (cfs)	2,239	2,239	2,239	2,239	2,239
Reservoir Dam a/					
Peak elevation (ft. NAVD88)	45.4	45.5	45.2	45.5	45.2
Peak Outflow (cfs)	2,838	2,485	2,464	2,658	2,439
Old Oaken Bucket					
Peak elevation (ft. NAVD88)	24.1	24.0	24.0	24.0	23.9
Peak Outflow (cfs)	3,038	2,792	2,777	2,902	2,754

Notes:
a/ In general peak elevations occurred either 20-40 minutes prior to peak outflows (breach), or at the same time (gate failure)

Table C-47. Dam Failure Scenario 1A Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	20:00	2,462	1,008.0	45.4	2,143	45.3
10-Mar-17	20:20	2,476	1,013.4	45.4	2,398	45.5
10-Mar-17	20:40	2,475	1,012.8	45.4	2,598	45.5
10-Mar-17	21:00	2,460	1,007.2	45.4	2,741	45.6
10-Mar-17	21:20	2,432	997.7	45.3	2,838	45.6
10-Mar-17	21:40	2,392	988.9	45.2	2,626	45.6
10-Mar-17	22:00	2,342	983.4	45.1	2,505	45.5
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	21:00	2,914	270.2	23.9	2,654	23.1
10-Mar-17	21:20	3,058	276.4	24.0	2,866	23.2
10-Mar-17	21:40	3,157	281.1	24.1	3,009	23.2
10-Mar-17	22:00	2,959	282.1	24.1	3,038	23.3
10-Mar-17	22:20	2,833	279.3	24.0	2,954	23.2
10-Mar-17	22:40	2,746	276.1	24.0	2,856	23.2
10-Mar-17	23:00	2,679	273.4	24.0	2,764	23.1

Table C-48. Dam Failure Scenario 1B Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	20:00	2,462	1,009.5	45.4	2,064	45.2
10-Mar-17	20:20	2,476	1,018.2	45.5	2,242	45.4
10-Mar-17	20:40	2,475	1,023.0	45.5	2,365	45.5
10-Mar-17	21:00	2,460	1,024.8	45.5	2,439	45.5
10-Mar-17	21:20	2,432	1,024.5	45.5	2,476	45.5
10-Mar-17	21:40	2,392	1,022.6	45.5	2,485	45.5
10-Mar-17	22:00	2,342	1,019.5	45.5	2,472	45.5
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	21:00	2,684	266.0	23.8	2,514	23.0
10-Mar-17	21:20	2,760	269.9	23.9	2,645	23.1
10-Mar-17	21:40	2,798	272.4	23.9	2,730	23.1
10-Mar-17	22:00	2,807	273.8	24.0	2,776	23.1
10-Mar-17	22:20	2,794	274.2	24.0	2,792	23.1
10-Mar-17	22:40	2,767	274.0	24.0	2,784	23.1
10-Mar-17	23:00	2,732	273.4	23.9	2,762	23.1

Table C-49. Dam Failure Scenario 1C Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	20:00	2,462	979.6	45.1	2,427	45.5
10-Mar-17	20:20	2,476	980.5	45.1	2,445	45.5
10-Mar-17	20:40	2,475	981.2	45.1	2,458	45.5
10-Mar-17	21:00	2,460	981.4	45.1	2,462	45.5
10-Mar-17	21:20	2,432	981.0	45.1	2,455	45.5
10-Mar-17	21:40	2,392	980.1	45.1	2,436	45.5
10-Mar-17	22:00	2,342	978.6	45.1	2,407	45.5
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	21:00	2,784	272.5	23.9	2,732	23.1
10-Mar-17	21:20	2,787	273.5	24.0	2,766	23.1
10-Mar-17	21:40	2,779	273.8	24.0	2,777	23.1
10-Mar-17	22:00	2,760	273.7	24.0	2,772	23.1
10-Mar-17	22:20	2,729	273.2	23.9	2,754	23.1
10-Mar-17	22:40	2,691	272.3	23.9	2,726	23.1
10-Mar-17	23:00	2,649	271.3	23.9	2,691	23.1

Table C-50. Dam Failure Scenario 2 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	20:00	2,462	1,008.9	45.4	2,096	45.3
10-Mar-17	20:20	2,476	1,016.2	45.4	2,307	45.4
10-Mar-17	20:40	2,475	1,018.6	45.5	2,469	45.5
10-Mar-17	21:00	2,460	1,017.0	45.5	2,583	45.5
10-Mar-17	21:20	2,432	1,012.2	45.4	2,658	45.6
10-Mar-17	21:40	2,392	1,007.0	45.4	2,543	45.5
10-Mar-17	22:00	2,342	1,003.3	45.3	2,463	45.5
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	21:00	2,787	267.9	23.9	2,577	23.0
10-Mar-17	21:20	2,902	272.9	23.9	2,746	23.1
10-Mar-17	21:40	2,978	276.5	24.0	2,869	23.2
10-Mar-17	22:00	2,871	277.6	24.0	2,902	23.2
10-Mar-17	22:20	2,789	276.2	24.0	2,859	23.2
10-Mar-17	22:40	2,722	274.3	24.0	2,792	23.1
10-Mar-17	23:00	2,663	272.4	23.9	2,728	23.1

Table C-51. Dam Failure Scenario 3 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	20:00	2,462	985.6	45.1	2,351	45.4
10-Mar-17	20:20	2,476	988.3	45.2	2,389	45.5
10-Mar-17	20:40	2,475	990.3	45.2	2,419	45.5
10-Mar-17	21:00	2,460	991.4	45.2	2,436	45.5
10-Mar-17	21:20	2,432	991.6	45.2	2,439	45.5
10-Mar-17	21:40	2,392	991.0	45.2	2,430	45.5
10-Mar-17	22:00	2,342	989.6	45.2	2,408	45.5
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	21:00	2,743	270.8	23.9	2,676	23.1
10-Mar-17	21:20	2,759	272.3	23.9	2,724	23.1
10-Mar-17	21:40	2,762	272.9	23.9	2,747	23.1
10-Mar-17	22:00	2,753	273.1	23.9	2,754	23.1
10-Mar-17	22:20	2,730	272.9	23.9	2,746	23.1
10-Mar-17	22:40	2,699	272.3	23.9	2,726	23.1
10-Mar-17	23:00	2,662	271.5	23.9	2,697	23.1

Table C-52 shows that the Reservoir Dam peak discharge and elevation for the single failure Scenarios 4 and 5 during the ½ PMF are lower than the existing Reservoir Dam non-failure Scenario 1. Both the piping and gate failure scenarios would have approximately 2,220 cfs peak outflow from Reservoir Dam with a peak flood level at El. 43.7 ft, both less than the existing spillway simulations. Peak outflow at Old Oaken Bucket Pond would be approximately 2,569 cfs for a single Reservoir Dam failure with a peak flood level at El. 23.8 ft (2.6 ft above the low point in Country Way). Time series results for these simulations are presented in Table C-53, Table C-54, Table C-55, and Table C-56.

Scenario 6 sunny day embankment erosion failure and Scenario 7 sunny day gate failure of Reservoir Dam result in peak discharges from Reservoir that raise Old Oaken Bucket Pond to levels that are 2.6 ft and 1.8 ft above the spillway crest (EL. 18.6 ft NAVD88, respectively. Maximum peak flood level with a sunny date failure of the proposed Reservoir Dam spillway gate would result in a maximum Old Oaken Bucket Pond level equal to the low point in Country Way (El. 21.2 ft).

Table C-52. Proposed Reservoir Dam Failure Results with ½ PMF Flood and Sunny Day Conditions (scenarios 4-7)

Parameter	Single Dam Failure	Single Dam Failure	Single Dam Failure	Single Dam Failure
	Proposed	Proposed	Proposed	Proposed
	Scenario 4	Scenario 5	Scenario 6	Scenario 7
	1/2 PMF Piping Erosion	1/2 PMF Gate Failure	Sunny Day Gate Failure	Sunny Day Piping Erosion
Tack Factory Pond				
Peak elevation (ft. NAVD88)	45.1	45.1	40.4	40.4
Peak Outflow (cfs)	2,222	2,222	10	10
Reservoir Dam a/				
Peak elevation (ft. NAVD88)	43.7 b/	43.7	40.4	40.4
Peak Outflow (cfs)	2247 b/	2,235	905	801
Old Oaken Bucket				
Peak elevation (ft. NAVD88)	23.8	23.8	21.2	20.4
Peak Outflow (cfs)	2,560	2,548	283	263

Notes:
a/ In general peak elevations occurred either 20-40 minutes prior to peak outflows (breach), or at the same time (gate failure)
b/ b/ no breach occurred (Peak elevation did not reach the modeled breach threshold)

Table C-53. Dam Failure Scenario 4 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	21:00	2,456	824.8	43.4	2,115	43.4
10-Mar-17	21:20	2,440	833.3	43.5	2,160	43.5
10-Mar-17	21:40	2,411	840.2	43.6	2,196	43.6
10-Mar-17	22:00	2,371	845.2	43.7	2,223	43.7
10-Mar-17	22:20	2,322	848.4	43.7	2,240	43.7
10-Mar-17	22:40	2,266	849.8	43.7	2,247	43.7
10-Mar-17	23:00	2,203	849.4	43.7	2,245	43.7
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	22:00	2,517	264.7	23.8	2,471	23.0
10-Mar-17	22:20	2,543	265.8	23.8	2,508	23.0
10-Mar-17	22:40	2,559	266.6	23.8	2,535	23.0
10-Mar-17	23:00	2,566	267.1	23.8	2,552	23.0
10-Mar-17	23:20	2,563	267.4	23.8	2,560	23.0
10-Mar-17	23:40	2,552	267.3	23.8	2,559	23.0
11-Mar-17	0:00	2,533	267.0	23.8	2,549	23.0

Table C-54. Dam Failure Scenario 5 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	22:00	2,371	842.2	43.6	2,207	43.6
10-Mar-17	22:20	2,322	845.8	43.7	2,226	43.7
10-Mar-17	22:40	2,266	847.5	43.7	2,235	43.7
10-Mar-17	23:00	2,203	847.5	43.7	2,235	43.7
10-Mar-17	23:20	2,134	845.8	43.7	2,226	43.7
10-Mar-17	23:40	2,061	842.5	43.6	2,208	43.6
11-Mar-17	0:00	1,986	837.7	43.6	2,183	43.6
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	22:00	2,498	264.0	23.8	2,449	23.0
10-Mar-17	22:20	2,527	265.2	23.8	2,488	23.0
10-Mar-17	22:40	2,545	266.1	23.8	2,518	23.0
10-Mar-17	23:00	2,554	266.7	23.8	2,538	23.0
10-Mar-17	23:20	2,553	267.0	23.8	2,547	23.0
10-Mar-17	23:40	2,543	267.0	23.8	2,548	23.0
11-Mar-17	0:00	2,525	266.7	23.8	2,539	23.0

Table C-55. Dam Failure Scenario 6 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	0:00	9	579.6	40.4	905	40.4
10-Mar-17	0:20	12	556.4	40.1	804	40.1
10-Mar-17	0:40	12	535.9	39.8	711	39.8
10-Mar-17	1:00	12	517.7	39.5	630	39.5
10-Mar-17	1:20	12	501.7	39.3	559	39.3
10-Mar-17	1:40	12	487.5	39.1	496	39.1
10-Mar-17	2:00	12	475.0	38.9	441	38.9
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	3:00	370	119.1	21.2	282	21.4
10-Mar-17	3:20	337	121.1	21.2	283	21.4
10-Mar-17	3:40	307	122.2	21.2	283	21.4
10-Mar-17	4:00	280	122.5	21.2	283	21.4
10-Mar-17	4:20	256	122.0	21.2	283	21.4
10-Mar-17	4:40	233	121.0	21.2	283	21.4
10-Mar-17	5:00	213	119.3	21.2	282	21.4

Table C-56. Dam Failure Scenario 7 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	0:00	9	579.6	40.4	10	40.4
10-Mar-17	0:20	12	579.6	40.4	10	40.4
10-Mar-17	0:40	12	556.5	40.1	801	40.4
10-Mar-17	1:00	12	536.1	39.8	707	40.4
10-Mar-17	1:20	12	518.1	39.5	624	40.4
10-Mar-17	1:40	12	502.3	39.3	553	40.4
10-Mar-17	2:00	12	488.2	39.1	493	40.4
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	3:00	401	78.6	20.2	258	21.2
10-Mar-17	3:20	361	81.9	20.3	260	21.3
10-Mar-17	3:40	327	84.2	20.3	262	21.3
10-Mar-17	4:00	296	85.6	20.4	263	21.3
10-Mar-17	4:20	270	86.1	20.4	263	21.3
10-Mar-17	4:40	247	86.0	20.4	263	21.3
10-Mar-17	5:00	226	85.3	20.4	262	21.3

Multiple Dam Failure

The results of the multiple dam failure scenarios for the existing and proposed Reservoir Dam spillway configuration with the ½ PMF event and Sunny Day conditions are summarized in Table C-57. Time series results for the multiple dam failure analyses are presented in Table C-58, Table C-59, and Table C-60.

Multiple dam failure Scenario 8 with failure of Reservoir Dam and Old Oaken Bucket during the ½ PMF indicates that the peak discharge at Old Oaken Bucket would be 4,847 cfs assuming a 200 ft long breach Country Way. This peak flow occurred 6 hours prior to the embankment breach of the Reservoir Dam. Failure of Country Way would result in peak Old Oaken Bucket Pond flood levels approximately 1 ft lower than the single failure of Reservoir Dam and both failure scenarios would overtop Country Way.

Table C-57. Existing and Proposed Multiple Dam Failure Results with ½ PMF Flood and Sunny Day Conditions (Scenarios 8-10)

Parameter	Multiple Dam Failure Existing Scenario 8 1/2 PMF Overtop Erosion, Overtop Erosion	Multiple Dam Failure Proposed Scenario 9 1/2 PMF Gate Failure, Overtop Erosion	Multiple Dam Failure Proposed Scenario 10 Sunny Day Gate Failure, Overtop Erosion
Tack Factory Pond			
Peak elevation (ft. NAVD88)	45.7	45.1	40.4
Peak Outflow (cfs)	2,239	2,222	10
Reservoir Dam a/			
Peak elevation (ft. NAVD88)	45.4	43.7	40.4
Peak Outflow (cfs)	2,838	2,235	905
Old Oaken Bucket			
Peak elevation (ft. NAVD88)	22.9	22.8	21.2 b/
Peak Outflow (cfs)	4,847 c/	4,974 d/	283.4 b/

Notes:
a/ In general peak elevations occurred either 20-40 minutes prior to peak outflows (breach), or at the same time (gate failure)
b/ no breach occurred (Peak elevation did not reach the modeled breach threshold)
c/ Not a cascading event. Old Oaken Bucket Pond experienced peak outflow at 15:20 due an overtopping breach caused by rainfall and normal Reservoir Dam outflow. This was prior to Reservoir Dam's peak outflow (21:20).
d/ Not a cascading event. Old Oaken Bucket Pond experienced peak outflow at 14:40 due an overtopping breach caused by rainfall and normal Reservoir Dam outflow. This was prior to Reservoir Dam's peak outflow (22:40).

Table C-58. Dam Failure Scenario 8 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	20:00	2,462	1,008.0	45.4	2,143	45.3
10-Mar-17	20:20	2,476	1,013.4	45.4	2,398	45.5
10-Mar-17	20:40	2,475	1,012.8	45.4	2,598	45.5
10-Mar-17	21:00	2,460	1,007.2	45.4	2,741	45.6
10-Mar-17	21:20	2,432	997.7	45.3	2,838	45.6
10-Mar-17	21:40	2,392	988.9	45.2	2,626	45.6
10-Mar-17	22:00	2,342	983.4	45.1	2,505	45.5
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	14:00	1,528	198.4	22.7	721	21.9
10-Mar-17	14:20	1,619	211.0	22.9	1,569	22.5
10-Mar-17	14:40	1,706	198.6	22.7	2,660	23.1
10-Mar-17	15:00	1,787	156.8	21.9	3,947	23.7
10-Mar-17	15:20	1,855	82.9	20.3	4,847	24.1
10-Mar-17	15:40	1,897	13.0	16.9	2,829	23.2
10-Mar-17	16:00	1,897	1.9	14.6	1,990	22.7

Table C-59. Dam Failure Scenario 9 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	22:00	2,371	842.2	43.6	2,207	43.6
10-Mar-17	22:20	2,322	845.8	43.7	2,226	43.7
10-Mar-17	22:40	2,266	847.5	43.7	2,235	43.7
10-Mar-17	23:00	2,203	847.5	43.7	2,235	43.7
10-Mar-17	23:20	2,134	845.8	43.7	2,226	43.7
10-Mar-17	23:40	2,061	842.5	43.6	2,208	43.6
11-Mar-17	0:00	1,986	837.7	43.6	2,183	43.6
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	14:00	1,745	185.1	22.4	3,101	23.3
10-Mar-17	14:20	1,851	130.3	21.4	4,449	23.9
10-Mar-17	14:40	1,951	50.4	19.5	4,974	24.1
10-Mar-17	15:00	2,045	6.8	15.9	2,454	23.0
10-Mar-17	15:20	2,127	2.0	14.7	2,085	22.8
10-Mar-17	15:40	2,179	2.1	14.7	2,150	22.8
10-Mar-17	16:00	2,188	2.1	14.8	2,213	22.9

Table C-60. Dam Failure Scenario 10 Peak Elevation and Discharges for Reservoir Dam and Old Oaken Bucket Pond

Date	Time	Inflow (cfs)	Storage (ac-ft.)	Elevation (ft.)	Outflow (cfs)	Stage (ft.)
Reservoir Dam - Peak Elevation and Discharge						
10-Mar-17	0:00	9	579.6	40.4	905	40.4
10-Mar-17	0:20	12	556.4	40.1	804	40.1
10-Mar-17	0:40	12	535.9	39.8	711	39.8
10-Mar-17	1:00	12	517.7	39.5	630	39.5
10-Mar-17	1:20	12	501.7	39.3	559	39.3
10-Mar-17	1:40	12	487.5	39.1	496	39.1
10-Mar-17	2:00	12	475.0	38.9	441	38.9
Old Oaken Bucket Pond - Peak Elevation and Discharge						
10-Mar-17	3:00	370	119.1	21.2	282	21.4
10-Mar-17	3:20	337	121.1	21.2	283	21.4
10-Mar-17	3:40	307	122.2	21.2	283	21.4
10-Mar-17	4:00	280	122.5	21.2	283	21.4
10-Mar-17	4:20	256	122.0	21.2	283	21.4
10-Mar-17	4:40	233	121.0	21.2	283	21.4
10-Mar-17	5:00	213	119.3	21.2	282	21.4

Multiple failure of the proposed Reservoir Dam gates and the Old Oaken Bucket embankment (Scenario 9) results in a peak discharge from Old Oaken Bucket, and a peak Old Oaken Bucket flood level, similar to Reservoir Dam embankment failure Scenario 8.

The sunny day failure of the proposed Reservoir Dam spillway gate (Scenario 10) analysis indicates that the peak flood elevation in Old Oaken Bucket would only reach the low point in Country Way and the Old Oaken Bucket Pond could store the peak outflow from Reservoir Dam.

Summary and Conclusions

Spillway Standard Design Flood

The HEC-HMS modeling conducted in 2018 with the First Herring Brook divided into subbasins evaluated the SDF using two approaches. The first method used rainfall intensities equal to one-half of the PMF rainfall intensities. The second more conservation method used a rainfall intensity that resulted in a ½ PMF peak inflow into Reservoir Dam equal to one-half of the peak PMF inflow. The model simulations indicated that the existing spillway does not have sufficient capacity to pass the SDF and the Reservoir Dam embankment would be overtopped 0.6 ft during ½ PMF SDF and that the maximum peak discharge would be 2,476 cfs.

The 2018 HEC-HMS modeling indicates that a conservative value for the Reservoir Dam ½ PMF Standard Design Flood (SDF) is 2,247 cfs. The spillway modifications should include reconstruction of the spillway to lower the crest El. 36.5 ft. NAVD88 and installation of a 36.5 ft. wide bottom-hinged gate to allow a maximum normal pool El. 40.4 ft. NAVD88 with the gate fully closed. This proposed spillway configuration increases the existing spillway capacity with the proposed gate fully opened lowering the peak discharge water level to El. 43.7 ft. NAVD88, 1.3 ft. below the top of the Reservoir Dam embankment. The proposed spillway would prevent overtopping of the embankment during the SDF with a wave height equal to one-half of a wave height that could be expected at the dam with the 2,000 ft. open water fetch and a 74 mph Category 1 minimum wind speed.

The Tack Factory Pond weir structure and CJCH, and Old Oaken Bucket Pond dam and Country Way, would be overtopped during the ½ PMF with the existing Reservoir Dam spillway.

100-year Flood

The FEMA Flood Map currently shows the 100-year flood level at El. 42.0 ft. NAVD88 around Reservoir Dam and El. 44.0 ft. NAVD88 around Tack Factory Pond. The analysis conducted to date indicates the Reservoir Dam impoundment 100-year flood level would be El. 43.6 ft. NAVD88 with the existing spillway. Operation of the proposed spillway would reduce the peak 100-year flood discharge to El. 41.0 ft NAVD88.

The HEC-HMS model simulations indicate that the Tack Factory Pond maximum levels during the 100-year flood would be El, 44.0 ft NAVD88 with the existing Reservoir Dam spillway with the proposed Reservoir Dam spillway reducing the peak levels to El, 43.7 ft NAVD88.

Maximum 100-year flood levels at Old Oaken Bucket El. 23.1 ft NAVD88 with the existing and proposed Reservoir Dam spillway. Country Way would be overtopped during the 100-year storm with the existing and proposed Reservoir Dam spillway.

Reservoir Dam Failure

The 2018 HEC-HMS model was used to simulate Reservoir Dam failure via embankment overtopping and piping and failure of the proposed spillway gate. All Reservoir Dam failure scenarios during ½ PMF event indicate that Country Way at Old Oaken Bucket will be overtopped by several feet for both the existing Reservoir Dam spillway and proposed gated spillway. The proposed spillway for Reservoir Dam reduces the flood level at Old Oaken Bucket by several inches during the ½ PMF storm. Sunny Dam failure of the Reservoir Dam embankment results in a peak flood El. 20.4 ft NAVD88 at Old Oaken Bucket without overtopping of Country Way. Failure of the proposed Reservoir Dam spillway gate would result in a peak flood El. 21.2 ft NAVD88 in Old Oaken Bucket with the water level at the same elevation as the low point in Country Way.

Multiple Dam HEC-HMS Analysis

The results of multiple dam failure analysis with the HEC-HMS indicate that peak flood levels in Old Oaken Bucket Pond during the ½ PMF event with failure of the proposed spillway gate or embankment with proposed operations to the existing conditions. The results of Sunny Day multiple dam failure scenario are similar to the single Reservoir Dam failure scenario.

FEMA Flood Map Update

The FEMA flood level maps currently indicate that the 100-year flood levels are El. 44.0 ft NAVD88 upstream of Tack Factory Pond, El. 42.0 ft NAVD88 between Tack Factory Pond and Reservoir Dam, and El. 17.5 ft NAVD88 upstream of Old Oaken Bucket. Since the 100-year flood levels upstream of the proposed Reservoir Dam are 3-4 inches lower than the current FEMA 100-year flood, revision of the FEMA flood map would not be necessary for the Reservoir Dam Water Storage and Fish Passage Improvement Project. However, the DPW should consider submittal of a flood level change request to FEMA for the 100-year flood level at Old Oaken Bucket Pond based on the HEC-HMS modeling since the predicted level is 5.6 ft higher than current FEMA level. This change request should be filed after the construction documents are complete.

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List of Attachments

Attachment 1 Supporting Calculations
Attachment 2 HMR-51 PMP Intensity Calculations

ATTACHMENT 1 SUPPORTING CALCULATIONS

KEN'S CALCS TCC 1-23-19
ROAD % IMPERVIOUS

		A			B			C
Count	Name	Length	Count	Name	Length	Count	Name	Length
1.00	Polyline	668.3838	1.00	Polyline	124.7091	1.00	Polyline	393.5074
1.00	Polyline	378.6257	1.00	Polyline	604.8636	1.00	Polyline	365.5797
1.00	Polyline	559.468	1.00	Polyline	236.766	1.00	Polyline	6210.703
1.00	Polyline	442.5204	1.00	Polyline	1323.833	1.00	Polyline	892.0563
1.00	Polyline	597.8842	1.00	Polyline	3419.93	1.00	Polyline	717.4073
1.00	Polyline	4748.699	1.00	Polyline	413.1017	1.00	Polyline	923.5461
1.00	Polyline	157.7494	1.00	Polyline	5356.806	1.00	Polyline	932.2923
1.00	Polyline	2300.713	1.00	Polyline	536.7361	1.00	Polyline	2860.831
1.00	Polyline	164.3264	1.00	Polyline	443.9207	1.00	Polyline	395.6704
1.00	Polyline	345.5928	1.00	Polyline	446.2662	1.00	Polyline	1089.295
1.00	Polyline	86.9883	1.00	Polyline	4114.55	1.00	Polyline	155.8168
1.00	Polyline	494.9812	1.00	Polyline	262.4961	1.00	Polyline	424.4475
1.00	Polyline	250.8527	1.00	Polyline	114.4708	1.00	Polyline	842.434
1.00	Polyline	1953.629	1.00	Polyline	170.6771	1.00	Polyline	341.7765
1.00	Polyline	426.8222	1.00	Polyline	164.3452	1.00	Polyline	376.6479
1.00	Polyline	748.8962	1.00	Polyline	253.7271	1.00	Polyline	524.7238
1.00	Polyline	2467.614	1.00	Polyline	620.4761	1.00	Polyline	949.554
1.00	Polyline	403.8334	1.00	Polyline	614.9638	1.00	Polyline	1017.623
1.00	Polyline	1772.7	1.00	Polyline	551.931	1.00	Polyline	195.9212
1.00	Polyline	4302.939	1.00	Polyline	361.548	1.00	Polyline	1292.308
1.00	Polyline	1008.921	1.00	Polyline	1081.937	1.00	Polyline	586.1839
1.00	Polyline	4474.544	1.00	Polyline	622.092	1.00	Polyline	3515.492
1.00	Polyline	2314.62	1.00	Polyline	83.4441	1.00	Polyline	658.4745
1.00	Polyline	1676.735	1.00	Polyline	576.1628	1.00	Polyline	472.8203
1.00	Polyline	701.6682	1.00	Polyline	659.5505	1.00	Polyline	1260.564
1.00	Polyline	2746.499	1.00	Polyline	644.6925	1.00	Polyline	1224.843
1.00	Polyline	2243.476	1.00	Polyline	601.8282	1.00	Polyline	1171.565
1.00	Polyline	1373.966	1.00	Polyline	108.7992	1.00	Polyline	3165.987
1.00	Polyline	1908.203	1.00	Polyline	255.5466	1.00	Polyline	934.3455
1.00	Polyline	1272.687	1.00	Polyline	322.5112	1.00	Polyline	1273.97
1.00	Polyline	192.6188	1.00	Polyline	743.384	1.00	Polyline	89.1097
1.00	Polyline	4393.069	1.00	Polyline	761.3827	1.00	Polyline	2014.097
1.00	Polyline	2605.802	1.00	Polyline	310.0314	1.00	Polyline	758.1497
1.00	Polyline	3372.991	1.00	Polyline	1212.889	1.00	Polyline	206.0966
1.00	Polyline	11125.79	1.00	Polyline	625.6632	1.00	Polyline	2277.568
1.00	Polyline	415.2938	1.00	Polyline	201.4917	1.00	Polyline	1347.044
1.00	Polyline	1224.837	1.00	Polyline	765.333	1.00	Polyline	391.3342

KEN'S CALCS JCC 1-23-19
ROAD 2 IMPERVIOUS

1.00	Polyline	10468.3	
1.00	Polyline	298.773	
1.00	Polyline	83.1913	
1.00	Polyline	802.4078	
1.00	Polyline	250.1428	
1.00	Polyline	1107.579	
1.00	Polyline	487.1621	
1.00	Polyline	1016.354	
1.00	Polyline	581.6674	
1.00	Polyline	269.2538	
1.00	Polyline	83.5582	
1.00	Polyline	570.7103	

1.00	Polyline	1728.43
1.00	Polyline	1812.53

Road width 20 ft

	A		B	B	C		check A+B - matches @ 25' wide 60% calc
	sq ft	sq mi	sq ft	sq mi	sq ft	sq mi	sq ft
Impervious Area	1646881	0.059074	665076.3	0.023856331	844995.7	0.03031	2311957.122
Total Area	98634358	3.538021	21734654	0.779623436	31300927	1.122766	120369012
% Impervious	1.670%		3.060%		2.700%		1.921%

Ken's Calcs TCC 1-23-19

Watershed A CN

Map unit symbol	Map unit name	Rating
1	Water	
6A	Scarboro muck, coastal lowland, 0 to 3 percent slopes	A/D
30A	Raynham silt loam, 0 to 3 percent slopes	C/D
37A	Massasoit - Mashpee complex, 0 to 3 percent slopes	D
47A	Brockton sandy loam, 0 to 3 percent slopes	C/D
48A	Brockton sandy loam, 0 to 3 percent slopes, extremely stony	C/D
49A	Norwell mucky fine sandy loam, 0 to 3 percent slopes, extremely stony	D
49B	Norwell mucky fine sandy loam, 3 to 8 percent slopes, extremely stony	D
51A	Swansea muck, 0 to 1 percent slopes	B/D
52A	Freetown muck, 0 to 1 percent slopes	B/D
53A	Freetown muck, ponded, 0 to 1 percent slopes	B/D
69A	Mattapoisett loamy sand, 0 to 3 percent slopes, extremely stony	D
71A	Ridgebury fine sandy loam, 0 to 3 percent slopes, extremely stony	D
71B	Ridgebury fine sandy loam, 3 to 8 percent slopes, extremely stony	D
110B	Canton-Chatfield-Rock outcrop complex, 0 to 8 percent slopes, very stony	B
111C	Chatfield-Rock outcrop-Canton complex, 8 to 15 percent slopes, very stony	B
223B	Scio very fine sandy loam, 3 to 8 percent slopes	C
253B	Hinckley loamy sand, 3 to 8 percent slopes	A
256B	Deerfield fine sand, 3 to 8 percent slopes	A
260A	Sudbury fine sandy loam, 0 to 3 percent slopes	A/D
262A	Quonset sandy loam, 0 to 3 percent slopes	A
289B	Hinckley gravelly sandy loam, 3 to 8 percent slopes, bouldery	A
289C	Hinckley gravelly sandy loam, 8 to 15 percent slopes, bouldery	A
300B	Montauk fine sandy loam, 3 to 8 percent slopes	C
301B	Montauk fine sandy loam, 0 to 8 percent slopes, very stony	C
301C	Montauk fine sandy loam, 8 to 15 percent slopes, very stony	C
301E	Montauk fine sandy loam, 15 to 35 percent slopes, very stony	C
305B	Paxton fine sandy loam, 3 to 8 percent slopes	C
306C	Paxton fine sandy loam, 8 to 15 percent slopes, very stony	C
310A	Woodbridge fine sandy loam, 0 to 3 percent slopes	C/D
310B	Woodbridge fine sandy loam, 3 to 8 percent slopes	C/D
311A	Woodbridge fine sandy loam, 0 to 3 percent slopes, very stony	C/D

KIEN'S CALCS TCC 1-23-19
WATERSHED A CN

311B	Woodbridge fine sandy loam, 3 to 8 percent slopes, very stony	C/D
315A	Scituate gravelly sandy loam, 0 to 3 percent slopes	C/D
315B	Scituate gravelly sandy loam, 3 to 8 percent slopes	C/D
316A	Scituate gravelly sandy loam, 0 to 3 percent slopes, very stony	C/D
316B	Scituate gravelly sandy loam, 3 to 8 percent slopes, very stony	C/D
316C	Scituate gravelly sandy loam, 8 to 15 percent slopes, very stony	C/D
321A	Birchwood sand, 0 to 3 percent slopes, very stony	B/D
321B	Birchwood sand, 3 to 8 percent slopes, very stony	B/D
322A	Poquonock sand, 0 to 3 percent slopes	A
323B	Poquonock sand, 3 to 8 percent slopes, very stony	A
323C	Poquonock sand, 8 to 15 percent slopes, very stony	A
341B	Broadbrook very fine sandy loam, 3 to 8 percent slopes, very stony	C
421B	Canton fine sandy loam, 0 to 8 percent slopes, very stony	B
421C	Canton fine sandy loam, 8 to 15 percent slopes, very stony	B
426A	Newfields fine sandy loam, 0 to 3 percent slopes	B
426B	Newfields fine sandy loam, 3 to 8 percent slopes	B
427A	Newfields fine sandy loam, 0 to 3 percent slopes, extremely stony	B
427B	Newfields fine sandy loam, 3 to 8 percent slopes, extremely stony	B
453B	Gloucester - Canton complex, 3 to 8 percent slopes, extremely bouldery	A
453C	Gloucester - Canton complex, 8 to 15 percent slopes, extremely bouldery	A
478C	Plymouth - Poquonock complex, 8 to 15 percent slopes, bouldery	A
602B	Urban land, 0 to 8 percent slopes	
654B	Udorthents, loamy, 0 to 8 percent slopes	B
659B	Udorthents, 0 to 8 percent slopes, gravelly	B
700A	Udipsamments, wet substratum, 0 to 3 percent slopes	A/D
Totals for Area of Interest		

KEN'S CALC TCC 1-23-19

WATERSHED A CN

Acres in AOI	Percent of AOI	cover type (estimate)	Curve #	Pervious CN	mpervious (use figure 2-4 if	
12.2	0.50%	water	0	0	0	0
2.5	0.10%	woods/marsh	30	75	0	0
4.4	0.20%		77	338.8	0	0
5.6	0.20%		82	459.2	0	0
41.5	1.80%	woods/marsh	70	2905	0	0
104.9	4.60%	residential	77	8077.3	12	969.276
142.7	6.30%	woods/marsh	77	10987.9	0	0
15.8	0.70%		82	1295.6	0	0
89.1	3.90%	woods/marsh	55	4900.5	0	0
257.4	11.40%	woods/marsh	55	14157	0	0
5.8	0.30%	woods/marsh	55	319	0	0
3	0.10%		82	246	0	0
3.4	0.20%		82	278.8	0	0
15.5	0.70%	woods/marsh	77	1193.5	0	0
4.4	0.20%		65	286	0	0
2	0.10%	woods/marsh	77	154	0	0
4.4	0.20%		77	338.8	0	0
44.7	2.00%	res, res wide	46	2056.2	12	246.744
7.8	0.30%	woods/marsh	30	234	0	0
0.6	0.00%		46	27.6	0	0
4.1	0.20%	res	54	221.4	25	55.35
2.6	0.10%		46	119.6	0	0
29.3	1.30%	residential	54	1582.2	25	395.55
2.5	0.10%	woods/marsh	70	175	0	0
90.1	4.00%	residential	80	7208	25	1802
15.5	0.70%	res	80	1240	25	310
9.8	0.40%	woods/marsh	70	686	0	0
37	1.60%	residential	80	2960	25	740
3.8	0.20%	res	80	304	25	76
5.5	0.20%	field	74	407	0	0
25.3	1.10%	res	80	2024	25	506
152	6.70%	residential	80	12160	25	3040

KEN'S CALCS TCC 1-23-19

WATERSHED A CN

304.1	13.40%	residential, woods/marsh	77	23415.7	12	2809.884
43.4	1.90%	res wide	77	3341.8	12	401.016
3.5	0.20%	residential	80	280	25	70
84.5	3.70%	residential	80	6760	25	1690
195.5	8.60%	residential	80	15640	25	3910
13.8	0.60%	woods/marsh	70	966	0	0
24.3	1.10%	residential, woods/marsh	55	1336.5	12	160.38
59.4	2.60%	residential	70	4158	25	1039.5
3	0.10%	residential	54	162	25	40.5
64.2	2.80%	residential	54	3466.8	25	866.7
54.8	2.40%	residential	54	2959.2	25	739.8
10.9	0.50%		77	839.3	0	0
33.7	1.50%	residential	70	2359	25	589.75
6.1	0.30%	res	65	396.5	25	99.125
2.9	0.10%	residential	70	203	25	50.75
14.6	0.60%	residential	70	1022	25	255.5
73.6	3.30%	res wide	65	4784	12	574.08
61.8	2.70%	residential	70	4326	25	1081.5
3	0.10%	res	54	162	25	40.5
19.8	0.90%		46	910.8	0	0
2.3	0.10%		46	105.8	0	0
16.2	0.70%	big urban	89	1441.8	80	1153.44
2	0.10%	res	70	140	25	35
16.7	0.70%	res	70	1169	25	292.25
5.3	0.20%	res	54	286.2	25	71.55
2,264.50	**100.00%**		pervious CN	69.79104478		15%
			composite CN from figure 2-4:	70.5		

KEN'S CALCS TCC 1-23-19

WATERSHED A CN

' < 30%)

CN numbers used to estimate composite CN

	A	B	C	D	% imperv
Agricultural	67	78	85	89	
Urban	89	92	94	95	85
1/2 acre	54	70	80	85	25
2 acre	46	65	77	82	12
parks	39	61	74	80	
woods	30	55	70	77	

WATERSHED 13 CN

(3)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
1	Water		63.3	12.70%
48A	Brockton sandy loam, 0 to 3 percent slopes, extremely stony	C/D	41.6	8.30%
49B	Norwell mucky fine sandy loam, 3 to 8 percent slopes, extremely stony	D	17	3.40%
51A	Swansea muck, 0 to 1 percent slopes	B/D	9.1	1.80%
53A	Freetown muck, ponded, 0 to 1 percent slopes	B/D	1.6	0.30%
69A	Mattapoisett loamy sand, 0 to 3 percent slopes, extremely stony	D	0	0.00%
71A	Ridgebury fine sandy loam, 0 to 3 percent slopes, extremely stony	D	1.4	0.30%
301B	Montauk fine sandy loam, 0 to 8 percent slopes, very stony	C	24.4	4.90%
301C	Montauk fine sandy loam, 8 to 15 percent slopes, very stony	C	1.2	0.20%
310B	Woodbridge fine sandy loam, 3 to 8 percent slopes	C/D	2.8	0.60%
311A	Woodbridge fine sandy loam, 0 to 3 percent slopes, very stony	C/D	73.5	14.70%
311B	Woodbridge fine sandy loam, 3 to 8 percent slopes, very stony	C/D	218	43.70%
311C	Woodbridge fine sandy loam, 8 to 15 percent slopes, very stony	C/D	1.6	0.30%
321B	Birchwood sand, 3 to 8 percent slopes, very stony	B/D	14.3	2.90%
322B	Poquonock sand, 3 to 8 percent slopes	A	0	0.00%
322C	9	A	3.5	0.70%
323C	Poquonock sand, 8 to 15 percent slopes, very stony	A	4.5	0.90%
427A	Newfields fine sandy loam, 0 to 3 percent slopes, extremely stony	B	0.3	0.10%
427B	Newfields fine sandy loam, 3 to 8 percent slopes, extremely stony	B	0.2	0.00%
602B	Urban land, 0 to 8 percent slopes		7	1.40%
659B	Udorthents, 0 to 8 percent slopes, gravelly	B	13.4	2.70%
700A	Udipsamments, wet substratum, 0 to 3 percent slopes	A/D	0.4	0.10%
Totals for Area of Interest			**499**	**100.00%**

over type (estimat	Curve #			Impervious	vious (use figure
water		0	0	0	0
water		0	0	0	0
woods		70	2912	0	0
woods		77	1309	0	0
woods/marsh		55	500.5	0	0
woods/marsh		55	88	0	0
road		0	0	80	0
res edge		82	114.8	12	13.776
res 75%		77	1878.8	12	225.456
res		80	96	25	24
res		80	224	25	56
residential denser		80	5880	80	4704
woods/development (v		77	16786	12	2014.32
res		80	128	25	32
res wide		65	929.5	12	111.54
res		0	0	25	0
woods		30	105	0	0
res wide		46	207	12	24.84
res		70	21	25	5.25
res		70	14	25	3.5
school		95	665	80	532
park/track/road		70	938	12	112.56
dam		30	12	0	0
	pervious CN		65.7355		24%
	composite CN from figure 2-4:		70		

KEN'S CALCS TCC 1-23-19
WATERSHED C CN

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI	cover type (estimate)	Curve #		Impervious	percent impervious (use figure 2-4 if < 30%)
1	Water		10.4	1.40%	water	0	0	0	0
23A	Tihonet coarse sand, 0 to 3 percent slopes	A/D	8.1	1.10%	agricult	67	542.7	0	0
37A	Massasoit - Mashpee complex, 0 to 3 percent slopes	D	7.3	1.00%	res	85	620.5	25	155.125
47A	Brockton sandy loam, 0 to 3 percent slopes	C/D	2.1	0.30%	woods	70	147	0	0
48A	Brockton sandy loam, 0 to 3 percent slopes, extremely stony	C/D	66.5	9.30%	res/woods	77	5120.5	12	614.46
49A	Norwell mucky fine sandy loam, 0 to 3 percent slopes, extremely stony	D	9.8	1.40%	woods	77	754.6	0	0
49B	Norwell mucky fine sandy loam, 3 to 8 percent slopes, extremely stony	D	28.7	4.00%	res wide, woods	82	2353.4	12	282.408
51A	Swansea muck, 0 to 1 percent slopes	B/D	20	2.80%	woods	55	1100	0	0
52A	Freetown muck, 0 to 1 percent slopes	B/D	61.7	8.60%	woods	55	3393.5	0	0
53A	Freetown muck, ponded, 0 to 1 percent slopes	B/D	25.6	3.60%	marsh	55	1408	0	0
55A	Freetown coarse sand, 0 to 3 percent slopes, sanded surface	B/D	16.4	2.30%	cranberry bog	78	1279.2	0	0
60A	Swansea coarse sand, 0 to 2 percent slopes	B/D	5.3	0.70%	cranberry bog	78	413.4	0	0
71A	Ridgebury fine sandy loam, 0 to 3 percent slopes, extremely stony	D	0.7	0.10%	woods	77	53.9	0	0
221A	Eldridge fine sandy loam, 0 to 3 percent slopes	C/D	3.7	0.50%	res	80	296	25	74
221B	Eldridge fine sandy loam, 3 to 8 percent slopes	C/D	8.8	1.20%	res	80	704	25	176
253B	Hinckley loamy sand, 3 to 8 percent slopes	A	2.8	0.40%	woods	30	84	0	0
255C	Windsor loamy sand, 8 to 15 percent slopes	A	2.8	0.40%		30	84	0	0
256A	Deerfield fine sand, 0 to 3 percent slopes	A	2.5	0.30%	woods	30	75	0	0
260A	Sudbury fine sandy loam, 0 to 3 percent slopes	A/D	59.6	8.30%	res	54	3218.4	25	804.6
289B	Hinckley gravelly sandy loam, 3 to 8 percent slopes, bouldery	A	13.8	1.90%	res	54	745.2	25	186.3
289C	Hinckley gravelly sandy loam, 8 to 15 percent slopes, bouldery	A	36.3	5.00%	woods, res	46	1669.8	12	200.376
300B	Montauk fine sandy loam, 3 to 8 percent slopes	C	8	1.10%	res	80	640	25	160
300C	Montauk fine sandy loam, 8 to 15 percent slopes	C	18.4	2.60%	res	80	1472	25	368
310B	Woodbridge fine sandy loam, 3 to 8 percent slopes	C/D	13.2	1.80%	res	80	1056	25	264

KEN'S CALCS TCC 1-23-19
WATERSHED < CN

311A	Woodbridge fine sandy loam, 0 to 3 percent slopes, very stony	C/D	34.2	4.80%	woods	70	2394	0	0
311B	Woodbridge fine sandy loam, 3 to 8 percent slopes, very stony	C/D	70.6	9.80%	res	80	5648	25	1412
311C	Woodbridge fine sandy loam, 8 to 15 percent slopes, very stony	C/D	26.2	3.60%	res	80	2096	25	524
321B	Birchwood sand, 3 to 8 percent slopes, very stony	B/D	36.3	5.10%	res/woods	65	2359.5	12	283.14
322A	Poquonock sand, 0 to 3 percent slopes	A	1.3	0.20%	woods	30	39	0	0
322B	Poquonock sand, 3 to 8 percent slopes	A	4.5	0.60%	res	54	243	25	60.75
322C	Poquonock sand, 8 to 15 percent slopes	A	0	0.00%		0	0	0	0
341B	Broadbrook very fine sandy loam, 3 to 8 percent slopes, very stony	C	2.2	0.30%	woods	70	154	0	0
341C	Broadbrook very fine sandy loam, 8 to 15 percent slopes, very stony	C	6.3	0.90%	res/woods	77	485.1	12	58.212
421B	Canton fine sandy loam, 0 to 8 percent slopes, very stony	B	3.4	0.50%	res	70	238	25	59.5
426A	Newfields fine sandy loam, 0 to 3 percent slopes	B	5.7	0.80%	res	70	399	25	99.75
427A	Newfields fine sandy loam, 0 to 3 percent slopes, extremely stony	B	10.5	1.50%	res wide, woods	60	630	12	75.6
427B	Newfields fine sandy loam, 3 to 8 percent slopes, extremely stony	B	19	2.60%	res wide, woods	60	1140	12	136.8
478B	Plymouth - Poquonock complex, 3 to 8 percent slopes, bouldery	A	5.8	0.80%	res	54	313.2	25	78.3
478C	Plymouth - Poquonock complex, 8 to 15 percent slopes, bouldery	A	15.5	2.20%	res	54	837	25	209.25
623B	Woodbridge-Scituate-Urban land complex, 0 to 8 percent slopes	C/D	11	1.50%	res, heavy dev, park	80	880	80	704
652E	Udorthents, refuse substratum, 8 to 35 percent slopes	B	9.2	1.30%	woods	55	506	0	0
656B	Udorthents - Urban land complex, 0 to 8 percent slopes	B	15.3	2.10%	heavy urban	92	1407.6	80	1126.08
700A	Udipsamments, wet substratum, 0 to 3 percent slopes	A/D	9.5	1.30%	dam	30	285	0	0
Totals for Area of Interest			**718.6**	**100.00%**		pervious CN	65.76565		17%
					composite CN from figure 2-4		68.5		

KEN'S CALCS TCC 1-23-19
WATERSHED LAG

NRCS Watershed Lag (SCS Lag) Method
t(p) =(L^0.8(S+1)^0.7)/(1900*(y)^0.5)
where L = Length to divide (ft)
S = potential abstraction (inches)
S = (1000/CN) - 10
y = average watershed slope (%)

SCS unit graph method
tc = Tca + Tcb + Tcc, Tca = travel time subbasin A
Tc = ((11.9*L^3)/H)^0.385 ?? - not sure where this equation comes from - just a check against Lag method
Lt = 0.6t ??
Tp = D/2 + Lt ??
where L = length to divide (mi)
H = elevation difference (ft)
d= storm duration (hours)

	A	B	C	60% example check
L (miles)	4.19	0.9	1.32	4.346591
L (ft)	22123.2	4752	6969.6	22950
H (lowest)	42.3	42.3	16	42.3
H (highest	146	117	124	100
H	103.7	74.7	108	57.7
y (%)	0.469%	1.572%	1.550%	0.28%
CN	70.5	70	68.5	64
S	4.184397	4.285714	4.59854	5.625
Lag method (hours)	7.276929	1.176787	1.676321	11.51128
Lag method (minutes)	436.6157	70.60725	100.5792	690.6769
unit graph method	12.4526	12.28405	12.28562	12.57527
unit graph method (minutes)	747.156	737.0429	737.1372	754.5162

KEN'S CALCS TCC 1-23-19

WATERSHED BASEFLOW

⑥

Initial Discharge	12 cfs			
Area A+B (60%)	4.3 sq mi			
ratio	2.790698 cfs/sq mi			
			check	
Area A	3.538 sq mi		area A+B	4.3176 sq mi
Area B	0.7796 sq mi			
Area C	1.1228 sq mi			
Discharge A	9.873 cfs			
Discharge B	2.176 cfs			
Discharge C	3.133 cfs			

KEN'S CALCS TCC 1-23-19
STORAGE CAP CURVES – EXISTING

Reservoir

Sources:

2001 CEI Bathymetry

2011 LiDaR (2018 analysis)

Elevation		Area			Incremental Storage Volume		Total Storage Volume	
1988 Datum	1929 Datum	Sq ft	acres	sq mi	gal	acre-ft	acre-ft	million gal
48	49.1	4677660	107.38	0.16779	69982654	214.77	1286.24	419.13
46	47.1	4326469	99.32	0.15519	64728471	198.64	1071.47	349.14
44	45.1	3744050	85.95	0.13430	56014878	171.90	872.83	284.41
42	43.1	3303061	75.83	0.11848	49417224	151.66	700.93	228.40
40	41.1	2876324	66.03	0.10317	23668037	72.63	549.27	178.98
38.9	40	2788778	64.02	0.10003	41723016	128.04	476.64	155.31
36.9	38	2542576	58.37	0.09120	38039579	116.74	348.60	113.59
34.9	36	2124551	48.77	0.07621	31785490	97.55	231.86	75.55
32.9	34	1737654	39.89	0.06233	25997109	79.78	134.31	43.77
30.9	32	1090069	25.02	0.03910	16308565	50.05	54.53	17.77
28.9	30	97600	2.24	0.00350	1460197	4.48	4.48	1.46
26.9	28							

Tack Factory Pond

Sources:

2001 CEI Bathymetry

2011 LiDaR (2018 analysis)

Elevation		Area			Incremental Storage Volume		Total Storage Volume	
1988 Datum	1929 Datum	Sq ft	acres	sq mi	gal	acre-ft	acre-ft	million gal
48	49.1	2880898	66.14	0.10334	43101227	132.27	387.66	126.32
46	47.1	2014300	46.24	0.07225	30136021	92.48	255.39	83.22
44	45.1	1445557	33.19	0.05185	21627035	66.37	162.91	53.08
42	43.1	1095430	25.15	0.03929	16388771	50.30	96.54	31.46
40	41.1	612454	14.06	0.02197	5039621	15.47	46.24	15.07
38.9	40	330153	7.58	0.01184	1481830	4.55	30.78	10.03
38.3	39.4	354767	8.14	0.01273	5971143	18.32	26.23	8.55
36.05	37.15	301168	6.91	0.01080	1126447	3.46	7.90	2.58
35.55	36.65	186498	4.28	0.00669	697551	2.14	4.45	1.45
35.05	36.15	113700	2.61	0.00408	425268	1.31	2.31	0.75
34.55	35.65	58866	1.35	0.00211	220174	0.68	1.00	0.33
34.05	35.15	20003	0.46	0.00072	74816	0.23	0.33	0.11
33.55	34.65	6934	0.16	0.00025	25935	0.08	0.10	0.03
33.05	34.15	1408	0.03	0.00005	5266	0.02	0.02	0.01

KEN'S CALCS TCC 1-23-19
STORAGE CAP CURVES - EXISTING

Old Oaken Bucket

Sources:

2001 CEI Bathymetry

2011 LiDaR (2018 analysis)

Elevation		Area			Incremental Storage Volume		Total Storage Volume	
1988 Datum	1929 Datum	Sq ft	acres	sq mi	gal	acre-ft	acre-ft	million gal
26	27.1	2899423	66.56	0.10400	43378380	133.12	409.39	133.40
24	25.1	2536967	58.24	0.09100	37955662	116.48	276.27	90.02
22	23.1	2085872	47.88	0.07482	15603406	47.88	159.79	52.07
21	22.1	1809461	41.54	0.06491	20303562	62.31	111.90	36.46
19.5	20.6	1487453	34.15	0.05336	6676153	20.49	49.59	16.16
18.9	20	351682	8.07	0.01261	5261528	16.15	29.10	9.48
16.9	18	278075	6.38	0.00997	2080145	6.38	12.96	4.22
15.9	17	184781	4.24	0.00663	1382258	4.24	6.57	2.14
14.9	16	59916	1.38	0.00215	448203	1.38	2.33	0.76
13.9	15	20818	0.48	0.00075	311459	0.96	0.96	0.31
11.9	13							

KEN'S CALCS TCC 1-23-19
STORAGE CAPACITY CURVES

Reservoir

Sources:

2001 CEI Bathymetry

2011 LiDaR (2018 analysis)

Elevation	Weap	Area			Incremental Storage Volume	
1988 Datum	1929 Datum	Sq ft	acres	sq mi	gal	acre-ft
48	49.1	4677660	107.38	0.16779	69982654	214.77
46	47.1	4326469	99.32	0.15519	64728471	198.64
44	45.1	3744050	85.95	0.13430	56014878	171.90
42	43.1	3303061	75.83	0.11848	49417224	151.66
40	41.1	2876324	66.03	0.10317	23668037	72.63
38.9	40	2788778	64.02	0.10003	41723016	128.04
36.9	38	2542576	58.37	0.09120	38039579	116.74
34.9	36	2124551	48.77	0.07621	31785490	97.55
32.9	34	1737654	39.89	0.06233	25997109	79.78
30.9	32	1090069	25.02	0.03910	16308565	50.05
28.9	30	97600	2.24	0.00350	1460197	4.48
26.9	28					

KEN'S CALCS TCC 1-23-19

STORAGE CAPACITY CURVES

Tack Factory Pond

Sources: NAVD88 + 0.8 ft = NGVD 1929

2001 CEI Bathymetry — per Tom Cook 1/24/19

2011 LiDaR (2018 analysis)

Elevation		Area			Incremental Storage Volume		Total Storage Volume	
1988 Datum	1929 Datum	Sq ft	acres	sq mi	gal	acre-ft	acre-ft	million gal
48	49.1	2880898	66.14	0.10334	43101227	132.27	387.66	126.32
46	47.1	2014300	46.24	0.07225	30136021	92.48	255.39	83.22
44	45.1	1445557	33.19	0.05185	21627035	66.37	162.91	53.08
42	43.1	1095430	25.15	0.03929	16388771	50.30	96.54	31.46
40	41.1	612454	14.06	0.02197	3207032	9.84	46.24	15.07
39.3	40.4	612461	14.06	0.02197	1832610	5.62	36.40	11.86
38.9	40	330153	7.58	0.01184	1481830	4.55	30.78	10.03
38.3	39.4	354767	8.14	0.01273	5971143	18.32	26.23	8.55
36.05	37.15	301168	6.91	0.01080	1126447	3.46	7.90	2.58
35.55	36.65	186498	4.28	0.00669	697551	2.14	4.45	1.45
35.05	36.15	113700	2.61	0.00408	425268	1.31	2.31	0.75
34.55	35.65	58866	1.35	0.00211	220174	0.68	1.00	0.33
34.05	35.15	20003	0.46	0.00072	74816	0.23	0.33	0.11
33.55	34.65	6934	0.16	0.00025	25935	0.08	0.10	0.03
33.05	34.15	1408	0.03	0.00005	5266	0.02	0.02	0.01
32.55	33.65							
39.3	40.4						36.4	

Old Oaken Bucket

Sources:

2001 CEI Bathymetry

2011 LiDaR (2018 analysis)

Elevation		Area			Incremental Storage Volume		Total Storage Volume	
1988 Datum	1929 Datum	Sq ft	acres	sq mi	gal	acre-ft	acre-ft	million gal
26	27.1	2899423	66.56	0.10400	43378380	133.12	409.39	133.40
24	25.1	2536967	58.24	0.09100	37955662	116.48	276.27	90.02
22	23.1	2085872	47.88	0.07482	15603406	47.88	159.79	52.07
21	22.1	1809461	41.54	0.06491	20303562	62.31	111.90	36.46
19.5	20.6	1487453	34.15	0.05336	6676153	20.49	49.59	16.16
18.9	20	351682	8.07	0.01261	5261528	16.15	29.10	9.48
16.9	18	278075	6.38	0.00997	2080145	6.38	12.96	4.22
15.9	17	184781	4.24	0.00663	1382258	4.24	6.57	2.14
14.9	16	59916	1.38	0.00215	448203	1.38	2.33	0.76
13.9	15	20818	0.48	0.00075	311459	0.96	0.96	0.31
11.9	13							

PS-8-2

KEN'S CALCS TCC 1-23-19
BLV-DISCHARGE CURVES-EXISTING

CJCH Culvert Rating Curve - Minimum Reservoir Pool El. 36.5 ft
First Herring Brook - CJCH

1) Weir flow up to HW El. 37.3 ft; Q = C L H^1.5 ; C = 2.6 (broad crested weir); L = 10.5 ft;
C = 2.6 H = HW - Reservoir Level
L = 10.5
2) Orifice flow above HW El. 37.3 ft; Q = C A (2 g Ho)^1/2
C = 0.6 H = HW - Reservoir Level
A = 47
3) Weir flow over CJCH above El. 42.3 ft; Q = C L H^1.5;
C = 2.6 H = HW - Reservoir Level
L = 100 + (160.6 x (HW - 42.3))

	Reservoir Level		Culvert		Roadway			
	El. (ft)	HW EL. (ft)	H (ft)	Q (cfs)	EL.	H (ft)	Q (cfs)	Total Q (cfs)
Invert Culvert	32.8	32.8	0.00	0.0				0
Low Reservoir	32.8	33.0	0.20	2.4				2
	32.8	33.5	0.70	16.0				16
	32.8	34.0	1.20	35.9				36
	32.8	34.5	1.70	60.5				61
	32.8	35.0	2.20	89.1				89
	32.8	36.0	3.20	156.3				156
	32.8	36.5	3.70	194.3				194
Crown Culvert	32.8	37.3	4.50	260.6				261
Minimim Fishway Operation	36.5	36.6	0.10	0.9				1
	36.5	36.8	0.30	4.5				4
	36.5	37.0	0.50	9.7				10
Crown Culvert	36.5	37.3	0.80	19.5				20
begin orifice flow	36.5	37.3	0.80	202.4				202
	36.5	37.5	1.00	226.3				226
	36.5	38.5	2.00	320.0				320
	36.5	39.5	3.00	392.0				392
	36.5	40.5	4.00	452.6				453
	36.5	41.5	5.00	506.0				506

KEN'S CALCS + CC 1-23-19
ELV - DISCHARGE CURVES - EXISTING

	36.5	42.3	5.80	545.0				545
	36.5	43.0	6.50	577.0				577
	36.5	38.5	2.00	39.9				40
High Reservoir (existing)	38.9	38.9	0.00	0.0				0
Tom - Top of Weir corrected	39.3	39.3	0.00	0.0				0
	39.3	39.5	0.20	100.9				101
	40.4	40.4	0.00	0.0				0
	40.4	40.5	0.10	71.3				71
	40.4	41.0	0.60	174.7				175
	40.4	41.5	1.10	236.6				237
	40.4	42.0	1.60	285.4				285
	40.4	42.3	1.90	311.0	42.3	0.0	0	311
	40.4	42.5	2.10	326.9	42.3	0.2	31	358
	40.4	43.0	2.60	363.8	42.3	0.7	323	687
	40.4	43.5	3.10	397.2	42.3	1.2	1000	1,398
	40.4	44.0	3.60	428.0	42.3	1.7	2150	2,578
	40.4	44.5	4.10	456.8	42.3	2.2	3846	4,303
	40.4	45.0	4.60	483.9	42.3	2.7	6155	6,639
	40.4	45.5	5.10	509.5	42.3	3.2	9137	9,647
	40.4	46.0	5.60	533.9	42.3	3.7	12846	13,380
	40.4	47.0	6.60	579.6	42.3	4.7	22646	23,226
	40.4	48.0	7.60	621.9	42.3	5.7	35928	36,550

KEN'S CALCS TCC 1-23-19
BL - DISCHARGE CURVES - EXISTIN

KEN TOM

yellow - used in HEC-HMS model. K.S, combined Culvert and Overtop values with Res held @ 40.5 ft

Elevation (	Discharge	Discharge	Elevation (Ft)	
38.9	0			
39.0	71			
39.5	175			
40.0	237	0	40.4	0
40.5	285	71	40.5	71.34098
41.0	327	175	41.0	174.749
41.5	364	237	41.5	236.6113
42.0	397	285	42.0	285.3639
42.3	416	311	42.3	310.9681
42.5	459	358	42.5	357.6501
43.0	780	687	43.0	687.2255
43.5	1,484	1,398	43.5	1397.665
44.0	2,659	2,578	44.0	2577.751
44.5	4,380	4,303	44.5	4302.831
45.0	6,713	6,639	45.0	6639.185
45.5	9,717	9,647	45.5	9646.613
46.0	13,447	13,380	46.0	13380.02
47.0	23,288	23,226	47.0	23225.75
48.0	36,608	36,550	48.0	36549.8

Ken - USE THIS RATING CURVE FOR TFP EXISTING

Tom Corrected to eliminate culvert flow - All flow over TFP dam and CJCH

TFP Dam Discharge Rating Curve - Minimum Pool El. 39.3 ft

First Herring Brook - TFP

Pg 15 of ____
Reservoir Dam
TICP No.________
Tack Factory Pond
Discharge Rating Curve
by: TCC; Ch'd: NM
10/10/2017

1) Weir flow over TFP gates above El. 39.3 ft; Q = C L H^1.5;

C = 2.6 H = HW - 40.7

L = 20

2) Weir flow over embankment above El. 40.7 ft; Q = C L Hb^1.5;

C = 2.6 Hb = HW - 40.7

L = 182 x (HW - 40.7)

	TFP Level	Gates Full Closed			Embankment			
	El. (ft)	HW EL. (ft)	H (ft)	Q (cfs)	HW EL.	H (ft)	Q (cfs)	Total Q (cfs)
top of gates	39.3	39.3	0.00	0				0
		40.0	0.70	30				30
top of bridge	40.7	40.7	1.40	86	40.7	0.00	0	86
		41.0	1.70	115	41.0	0.30	23	139
		41.5	2.20	170	41.5	0.80	271	441
		42.0	2.70	231	42.0	1.30	912	1143
CJCH low poiint	42.3	42.3	3.00	270	42.3	1.60	1,532	1803
		43.0	3.70	370	43.0	2.30	3,796	4166
		43.3	4.00	416	43.3	2.60	5,158	5574
		44.0	4.70	530	44.0	3.30	9,361	9891

KHN's CALCS TCC 1-23-19
BLV – DISCHARGE CURVES-EXIST.

Alternative 8A - Proposed Spillway Replacement w/ Low - Normal Gate Operation
Spillway Rating Curve - Existing Crest with New Gate Crest (Ogee Discharge Coefficient) and additional Gated spillway
First Herring Brook - Reservoir Dam

$Q = CLH^{3/2}$

	NAVD 1988		**Lower Existing Spilway Crest = El. 36.4 ft**	Existing Ogee-shaped Spillway Crest	36.4 ft
New Crest El. =	**36.4 ft**				
L	0 ft		**L**	36.5 ft per survey minus 6" gate guides	
C	3.1		C	3.1	
Dam -			**L**	500 ft (dam width)	
			C	2.6	

	Spillway			Dam			
	EL.	H (ft)	Q (cfs)	EL.	H (ft)	Q (cfs)	Total Q (cfs)
	36.4	0.00	0				0
	37.5	1.10	131				131
	38.9	2.50	447				447
	39.9	3.50	741				741
	40.4	4.00	905				905
	40.6	4.20	974				974
	40.9	4.50	1080				1080
	41.5	5.10	1303				1303
	41.9	5.50	1459				1459
	42.4	6.00	1663				1663
	42.9	6.50	1875				1875
1/2 PMF	43.5	7.10	2141				2141
	43.9	7.50	2324				2324
	44.4	8.00	2560				2560
op of dam	44.9	8.50	2804				2804
	45.00	8.60	2854				2854
	45.33	8.93	3019	45.33	0.33	246	3266
	45.67	9.27	3194	45.67	0.67	713	3906
	46	9.60	3366	46	1	1300	4666
	47	10.60	3905	47	2	3677	7582
	48	11.60	4470	48	3	6755	11225
	49	12.60	5061	49	4	10400	15461

Use El. 42.0 ft as maximum water level to provide 0.5 ft freeboad with 2.5 ft wave for 50 mph wind; 0.2 ft freeboard with 2.8 ft wave for 100 mph wind.

KHN's CALCS TCC 1-23-19

ELV - DISCHARGE CURVES - EXISTING

yellow - used in HEC-HMS model for existing dam. Identical to discharge curve modeled in 60% design K.S.

38.9	0
39.9	116
40.9	329
41.9	604
42.9	930
43.9	1300
45	1751
45.43	2306
46.83	5814
47	6357
47.25	7192
48	9946
49	14131

36.4	0
37.5	0
38.9	0
39.9	0
40.39	0
40.4	10
40.41	905
40.6	974
40.9	1080
41.5	1303
41.9	1459
42.4	1663
42.9	1875
43.5	2141
43.9	2324
44.4	2560
44.9	2804
45.00	2854
45.33	3266
45.67	3906
46	4666
47	7582
48	11225
49	15461

in actuality it would control to maintain 40.4 but for flood simulate full on/off (i.e. max Q for values > 40.4, zero for values < 40.4)

pg 9-5

KBW'S CALCS TCC 1-23-19
BLV - DISCHARGE CURVES - EXISTING

Discharge Rating Curve

First Herring Brook - Country Way / Old Oaken Bucket Dam

Q = 0.6 A (2gh)^0.5

A = 24 sq ft (2, 3 x 4 ft stone culverts)

crown culverts = 17.2 ft

h = El. Water -15.2

$Q = CLH^{3/2}$

Country Way El. = 22.1 ft

L 370 ft

C 2.6

NAVD88 + 0.8 ft = NGVD1929

		Culvert			Dam (Country Way)			
Water El. NAVD88		Water EL. NGVD 1929	H (ft)	Q (cfs)	Water El.	H (ft)	Q (cfs)	Total Q (cfs)
14.4		15.2	0	0				0
15.4		16.2	1	116				116
16.4	crown culv	17.2	2	163				163
17.4		18.2	3	200				200
18.6		19.4	4.2	237				237
19.4		20.2	5	258				258
20.4		21.2	6	283				283
21.4	ave crown	22.2	7	306	22.2	0.1	30	336
21.8		22.6	7.4	314	22.6	0.5	340	654
22.3		23.1	7.9	325	23.1	1.0	962	1287
22.8		23.6	8.4	335	23.6	1.5	1767	2102
22.9		23.7	8.5	337	23.7	1.6	1947	2284
23.9		24.7	9.5	356	24.7	2.6	4033	4389
24.9		25.7	10.5	374	25.7	3.6	6571	6945
25.9		26.7	11.5	392	26.7	4.6	9491	9883

KEN'S CALCS TCC 1-23-19
ELV - DISCHARGE CURVES - EXISTING

Discharge Rating Curve

First Herring Brook - Old Oaken Bucket Dam Spillway

From Reference 1): Old Oaken Bucket Dam Phase I Inspection Report,

Spillway and outlet works flow capacity with pond at El. 21.4 ft, which is approximately 1 ft freeboard on Country Way.

Check datum

ogee - weir 113 cfs

gate abutments 38 cfs

Spillway crest @ El. 18.6 NGVD

gate 24 cfs

fish ladder 24 cfs

Total flow with 1 ft freeboard on Country Way 199 cfs

Country Way controls water levels at Flow greater than approximately 300 cfs.

10-yr storm = 405 cfs

yellow - used in HEC-HMS model. K.S.

NAVD88	NGVD	Country Way	Spillway
14.4	15.2	0	0
15.4	16.2	116	0
16.4	17.2	163	0
17.4	18.2	200	0
18.6	19.4	237	0
19.4	20.2	258	43
20.4	21.2	283	144
21.4	22.2	336	280
21.8	22.6	654	654
22.3	23.1	1287	1287
22.8	23.6	2102	2102
22.9	23.7	2284	2284
23.9	24.7	4389	4389
24.9	25.7	6945	6945
25.9	26.7	9883	9883

KEN'S CALCS TCC 1-23-19
ELV-DISCHARGE CURVES-EXISTING

Discharge Rating Curve

First Herring Brook - Country Way / Old Oaken Bucket Dam

$Q = CLH^{3/2}$

Spillway crest 19.4 ft

L 23 ft

C 2.6

NAVD88 + 0.8 ft = NGVD1929

Dam (Country Way)

Water El. NAVD88		Water EL. NGVD 1929	H (ft)	Q (cfs)	Water El.	H (ft)	Q (cfs)	Total Q (cfs)
14.4		15.2	0	0				0
15.4		16.2	0	0				0
16.4	crown culv	17.2	0	0				0
17.4		18.2	0	0				0
18.6		19.4	0	0				0
19.4		20.2	0.8	43				43
20.4		21.2	1.8	144				144
21.4		22.2	2.8	280				280

pg. 9-8

KEN'S CALCS JCC 1-23-19
ELV - DISCHARGE CURVES

Reservoir

CJCH Culvert Rating Curve - Minimum Reservoir Pool El. 36.5 ft
First Herring Brook - CJCH

1) Weir flow up to HW El. 37.3 ft; Q = C L H^1.5 ; C = 2.6 (broad crested weir); L = 10.5 ft;
C = 2.6 H = HW - Reservoir Level
L = 10.5
2) Orifice flow above HW El. 37.3 ft; Q = C A (2 g Ho)^1/2
C = 0.6 H = HW - Reservoir Level
A = 47
3) Weir flow over CJCH above El. 42.3 ft; Q = C L H^1.5;
C = 2.6 H = HW - Reservoir Level
L = 60.6 x (HW - 42.3))

	Reservoir Level		Culvert		Roadway			
	El. (ft)	HW EL. (ft)	H (ft)	Q (cfs)	EL.	H (ft)	Q (cfs)	Total Q (cfs)
Invert Culvert	32.8	32.8	0.00	0.0				0
Low Reservoir	32.8	33.0	0.20	2.4				2
	32.8	33.5	0.70	16.0				16
	32.8	34.0	1.20	35.9				36
	32.8	34.5	1.70	60.5				61
	32.8	35.0	2.20	89.1				89
	32.8	36.0	3.20	156.3				156
	32.8	36.5	3.70	194.3				194
Crown Culvert	32.8	37.3	4.50	260.6				261
Minimim Fishway Operation	36.5	36.6	0.10	0.9				1
	36.5	36.8	0.30	4.5				4
	36.5	37.0	0.50	9.7				10
Crown Culvert	36.5	37.3	0.80	19.5				20
begin orifice flow	36.5	37.3	0.80	202.4				202
	36.5	37.5	1.00	226.3				226
	36.5	38.5	2.00	320.0				320
	36.5	39.5	3.00	392.0				392
	36.5	40.5	4.00	452.6				453
	36.5	41.5	5.00	506.0				506
	36.5	42.3	5.80	545.0				545
	36.5	43.0	6.50	577.0				577
	36.5	38.5	2.00	39.9				40
High Reservoir	40.5	40.5	0.00	0.0				0
	40.5	41.0	0.50	159.5				160
	40.5	41.5	1.00	225.6				226
	40.5	42.0	1.50	276.3				276
	40.5	42.3	1.80	302.7	42.3	0.0	0	303
	40.5	42.5	2.00	319.0	42.3	0.2	31	350
	40.5	43.0	2.50	356.7	42.3	0.7	323	680
	40.5	43.5	3.00	390.8	42.3	1.2	1000	1,391
	40.5	44.0	3.50	422.1	42.3	1.7	2150	2,572
	40.5	44.5	4.00	451.2	42.3	2.2	3846	4,297
	40.5	45.0	4.50	478.6	42.3	2.7	6155	6,634
	40.5	45.5	5.00	504.5	42.3	3.2	9137	9,642
	40.5	46.0	5.50	529.1	42.3	3.7	12846	13,375
	40.5	47.0	6.50	575.2	42.3	4.7	22646	23,221
	40.5	48.0	7.50	617.8	42.3	5.7	35928	36,546

yellow - used in HEC-HMS model. K.5, combined Culvert and Overtop values with Res held @ 40.5 ft

Elevation	Discharge (CFS)
40.5	0.00
41.0	159.52
41.5	225.60
42.0	276.30
42.3	302.67
42.5	349.77
43.0	680.16
43.5	1391.21
44.0	2571.76
44.5	4297.23
45.0	6633.90
45.5	9641.59
46.0	13375.23
47.0	23221.34
48.0	36545.69

KBN'S CALCS TCC 1-23-19
ELV - DISCHARGE CURVES

Alternative 8A - Proposed Spillway Replacement w/ 1 - Normal Gate Operation
Spillway Rating Curve - Existing Crest with New Gate Crest (Ogee Discharge Coefficient) and additional Gated spillway
First Herring Brook - Reservoir Dam

$Q = CLH^{3/2}$ — Existing Ogee-shaped Spillway Crest

NAVD 1988 Lower Existing Spilway Crest = El. 36.4 ft — 36.4 ft

New Crest El. = 36.4 ft

L	0 ft		L	36.5 ft per survey minus 6" gate guides
C	3.1		C	3.1
Dam -			L	500 ft (dam width)
			C	2.6

	Spillway			Dam				
	EL	H (ft)	Q (cfs)	EL	H (ft)	Q (cfs)	Total Q (cfs)	
	36.4	0.00	0				0	
	37.5	1.10	131				131	
	38.9	2.50	447				447	
	39.9	3.50	741				741	
	40.4	4.00	905				905	
	40.6	4.20	974				974	
	40.9	4.50	1080				1080	
	41.5	5.10	1303				1303	
	41.9	5.50	1459				1459	
	42.4	6.00	1663				1663	
	42.9	6.50	1875				1875	
1/2 PMF	43.5	7.10	2141				2141	Use El. 42.0 ft as maximum water level
	43.9	7.50	2324				2324	to provide 0.5 ft freeboad with 2.5 ft wave
	44.4	8.00	2560				2560	for 50 mph wind; 0.2 ft freeboard with 2.8 ft
top of dam	44.9	8.50	2804				2804	wave for 100 mph wind.
	45.00	8.60	2854				2854	
	45.33	8.93	3019	45.33	0.33	246	3266	
	45.67	9.27	3194	45.67	0.67	713	3906	
	46	9.60	3366	46	1	1300	4666	
	47	10.60	3905	47	2	3677	7582	
	48	11.60	4470	48	3	6755	11225	
	49	12.60	5061	49	4	10400	15461	

yellow - used in HEC-HMS model. K.S.

36.4	0	
37.5	0	
38.9	0	
39.9	0	
40.39	0	in actuality it would control to maintain 40.4 but for flc
40.4	10	
40.41	905	
40.6	974	
40.9	1080	
41.5	1303	
41.9	1459	
42.4	1663	
42.9	1875	
43.5	2141	
43.9	2324	
44.4	2560	
44.9	2804	
45.00	2854	
45.33	3266	
45.67	3906	
46	4666	
47	7582	
48	11225	
49	15461	

KEN'S CALCS TCC 1-23-19
BLV - DISCHARGE CURVES

Discharge Rating Curve

First Herring Brook - Country Way / Old Oaken Bucket Dam

Q = 0.6 A (2gh)^0.5

A = 24 sq ft (2, 3 x 4 ft stone culverts)

crown culverts = 17.2 ft

h = El. Water -15.2

$Q = CLH^{3/2}$

Country Way El. = 22.1 ft

L 370 ft

C 2.6

	Culvert			Dam (Country Way)			
	Water EL.	H (ft)	Q (cfs)	Water El.	H (ft)	Q (cfs)	Total Q (cfs)
	15.2	0	0				0
	16.2	1	116				116
crown cul	17.2	2	163				163
	18.2	3	200				200
	19.2	4	231				231
	20.2	5	258				258
	21.2	6	283				283
ave crown	22.1	6.9	304	22.1	0	0	304
	22.6	7.4	314	22.6	0.5	340	654
	23.1	7.9	325	23.1	1.0	962	1287
	23.6	8.4	335	23.6	1.5	1767	2102
	23.7	8.5	337	23.7	1.6	1947	2284
	24.7	9.5	356	24.7	2.6	4033	4389
	25.7	10.5	374	25.7	3.6	6571	6945
	26.7	11.5	392	26.7	4.6	9491	9883

Discharge Rating Curve

First Herring Brook - Old Oaken Bucket Dam Spillway

From Reference 1): Old Oaken Bucket Dam Phase I Inspection Report,

Spillway and outlet works flow capacity with pond at El. 21.4 ft,
which is approximately 1 ft freeboard on Country Way.

ogee - weir	113 cfs
gate abutments	38 cfs
gate	24 cfs
fish ladder	24 cfs
Total flow with 1 ft freeboard on Country Way	199 cfs

Country Way controls water levels at Flow greater than approximately 300 cfs.

10-yr storm = 405 cfs

yellow - used in HEC-HMS model. K.S.

15.2	0
16.2	116
17.2	163
18.2	200
19.2	231
20.2	258
21.2	283
22.1	304
22.6	654
23.1	1287
23.6	2102
23.7	2284
24.7	4389
25.7	6945
26.7	9883

KEN'S CALCS TCC 1-23-19
DAM BREAK INPUT

Reservoir Dam
HEC-HMS
Dam Failure Analysis heters

T. Cook 5-Nov-18

Failure D	Single Dam Reservoir Dam Embankment Overtopping Erosion	Single Dam Reservoir Dam Embankment Overtopping Erosion	Single Dam Reservoir Dam Embankment Overtopping Erosion
Rair	1/2 PMF	1/2 PMF	1/2 PMF
Ba	**Existing Scenario 1A**	**Existing Scenario 1B**	**Existing Scenario 1C**
Elem	Reservoir Dam	Reservoir Dam	Reservoir Dam
	Overtop Breach	Overtop Breach	Overtop Breach
	Main	Main	Main
*Top Elevation (ft	45.0	45.0	45.0
*Bottom Elevation (ft	43.9	43.9	43.9
*Bottom	200	200	200
*Left Slop	1	1	1
*Right Slop	1	1	1
* Piping Elevation (ft	n/a	n/a	n/a
*Piping C	n/a	n/a	n/a
*Development	2	6	0.25
Trigge	Elevation	Elevation	Elevation
*Trigger Elevation (ft	45.0	45.0	45.0
*Trigger Dur	n/a	n/a	n/a
Progressio	linear	linear	linear

OK OK

KEN'S CALCS TCC 1-23-19
DAM BREAK INPUT

Reservoir Dam
HEC-HMS
Dam Failure Analysis I

T. Cook 5-Nov-18	To Be Verified		
	Single Dam Reservoir Dam	Single Dam Reservoir Dam	Single Dam Reservoir Dam
Failure D	Embankment Overtopping Erosion	Abutment Piping Erosion	Abutment Piping Erosion
Rair	1/2 PMF	1/2 PMF	1/2 PMF
Ba	**Existing Scenario 2**	**Existing Scenario 3**	**Proposed Scenario 4**
Elem	Reservoir Dam	Reservoir Dam	Reservoir Dam
	Overtop Breach	Piping Breach	Piping Breach
	Main	Main	Main
*Top Elevation (ft	45.0	45.0	45.0
*Bottom Elevation (ft	43.9	41.5	43.9
*Bottom	100	25	25
*Left Slop	1	1	1
*Right Slop	1	1	1
* Piping Elevation (ft	n/a	43.5	39.1
*Piping C	n/a	0.8	0.8
*Development	2	0.25	0.25
Trigge	Elevation	Elevation	Elevation
*Trigger Elevation (ft	45.0	45.0	43.5 (just below Peak Elevation 1/2 PMF no failure)
*Trigger Dur	n/a	n/a	n/a
Progressio	linear	linear	linear

OK OK did not breach

KEN'S CALCS TCC 1-23-19

DAM BREAK INPUT

Reservoir Dam
HEC-HMS
Dam Failure Analysis I

T. Cook 5-Nov-18

	Single Dam Reservoir Dam	Single Dam Reservoir Dam	Single Dam Reservoir Dam
Failure D	Spillway Gate Failure	Spillway Gate Failure	Abutment Piping Erosion
Rair	1/2 PMF	Sunny Day (low flow normal pond)	Sunny Day (low flow normal pond)
Ba	**Proposed Scenario 5**	**Proposed Scenario 6**	**Proposed Scenario 7**
Elem	Reservoir Dam	Reservoir Dam	Reservoir Dam
	Overtop Breach (use adjusted spillway rating curve without HMS failure routine)	Overtop Breach (use adjusted spillway rating curve without HMS failure routine)	Piping Breach - Adjusted initial elevation of dam to 40.3998 ft (1/10,000 of an inch below trigger elevation, 2/10,000ths below gate open/close
	Main	Main	Main
*Top Elevation (ft	40.4	40.4	40.4
*Bottom Elevation (ft	36.4	36.4	36.4
*Bottom	36.6	36.6	36.6
*Left Slop	0.1	0.1	0.1
*Right Slop	0.1	0.1	0.1
* Piping Elevation (ft	n/a	n/a	39.1
*Piping C	n/a	n/a	0.8
*Development	0.08	0.08	0.25
Trigge	Elevation	Elevation	Elevation
*Trigger Elevation (ft	43.5 (just below Peak Elevation 1/2 PMF no failure)	40.4025	40.3999
*Trigger Dur	n/a	n/a	n/a
Progressio	linear	linear	linear

combined spillway and dam br Tack Factory Pond seems to dr Tack Factory Pond seems to

KBN'S CALCS TCC 1-23-19
DAM BREAK INPUT

Reservoir Dam
HEC-HMS
Dam Failure Analysis I

T. Cook 5-Nov-18	Added Multiple Dam Reservoir Dam	Added Multiple Dam Reservoir Dam	Added Multiple Dam Reservoir Dam
Failure D	Embankment Overtopping Erosion	Spillway Gate Failure	Spillway Gate Failure
Rair	1/2 PMF	1/2 PMF	Sunny Day (low flow normal pond)
Ba	**Existing Scenario 8**	**Proposed Scenario 9**	**Proposed Scenario 10**
Elem	Reservoir Dam	Reservoir Dam	Reservoir Dam
	Overtop Breach	Overtop Breach (use adjusted spillway rating curve without HMS failure routine)	Overtop Breach (use adjusted spillway rating curve without HMS failure routine)
	Main	Main	Main
*Top Elevation (ft	45.0	40.4	40.4
*Bottom Elevation (ft	43.9	36.4	36.4
*Bottom	200	36.6	36.6
*Left Slop	1	0.1	0.1
*Right Slop	1	0.1	0.1
* Piping Elevation (ft	n/a	n/a	n/a
*Piping C	n/a	n/a	n/a
*Development	2	0.08	0.08
Trigge	Elevation	Elevation	Elevation
*Trigger Elevation (ft	45.0	43.5 (just below Peak Elevation 1/2 PMF no failure)	40.4025
*Trigger Dur.	n/a	n/a	n/a
Progressio	linear	linear	linear

drain too far down (below res dam levels)

KEN'S CALLS TCC 1-23-19
DAM BREAK INPUT

	Old Oaken Bucket	Old Oaken Bucket	Old Oaken Bucket
Failure D	Embankment Overtopping Erosion	Embankment Overtopping Erosion	Embankment Overtopping Erosion
Rain	1/2 PMF	1/2 PMF	Sunny Day (low flow normal pond)
Ba	**Existing Scenario 8**	**Proposed Scenario 9**	**Proposed Scenario 10**
Elem	Old Oaken Bucket	Old Oaken Bucket	Old Oaken Bucket
	Overtop Breach	Overtop Breach	Overtop Breach
	Main	Main	Main
*Top Elevation (ft NAVD88 = NGVD1	21.3	21.3	21.3
*Bottom Elevation (ft	12.45 (streambed at toe of dam per dam safety inspection report	12.45	12.45
*Bottom	200	200	200
*Left Slop	1	1	1
*Right Slop	1	1	1
* Piping Elevation (ft	n/a	n/a	n/a
*Piping C	n/a	n/a	n/a
*Development	2	2	2
Trigge	Elevation	Elevation	Elevation
*Trigger Elevation (ft	22.6	22.6	22.6
*Trigger Dur	n/a	n/a	n/a
Progressio	linear	linear	linear

KEN'S CALCS TCC 1-23-19
DAM BREAK INPUT

Adjusted spillway curve for gate failure

Spillway Rating Curve - Existing Crest with New Gate Crest (Ogee Discharge Coefficient) and additional Gated spillway
First Herring Brook - Reservoir Dam

$Q = CLH^{3/2}$

	NAVD 1988	
New Crest El. =	36.4	ft
L	0	ft
C	3.1	

Dam -

Spillway

EL.	H (ft)	Q (cfs)
36.4	0.00	0
37.5	1.10	131
38.9	2.50	447
39.9	3.50	741
40.4	4.00	905
40.6	4.20	974
40.9	4.50	1080
41.5	5.10	1303
41.9	5.50	1459
42.4	6.00	1663
42.9	6.50	1875
43.5	7.10	2141
43.9	7.50	2324
44.4	8.00	2560
44.9	8.50	2804
45.00	8.60	2854
45.33	8.93	3019
45.67	9.27	3194
46	9.60	3366
47	10.60	3905
48	11.60	4470
49	12.60	5061

KEN'S CALCS TCC 1-23-19
DAM BREAK INPUT

Existing Ogee-shaped Spillway Crest

Lower Existing Spilway Crest = El. 36.4 ft

L	36.5 ft per survey minus 6" gate gui
C	3.1
L	500 ft (dam width)
C	2.6

EL.	Dam H (ft)	Q (cfs)
45.33	0.33	246
45.67	0.67	713
46	1	1300
47	2	3677
48	3	6755
49	4	10400

KEN'S CALCS TCC 1-23-19
DAM BREAK INPUT

36.4 ft

ides

Total Q (cfs)
0
131
447
741
905
974
1080
1303
1459
1663
1875
2141
2324
2560
2804
2854
3266
3906
4666
7582
11225
15461

Use El. 42.0 ft as maximum water level to provide 0.5 ft freeboad with 2.5 ft wave for 50 mph wind; 0.2 ft freeboard with 2.8 ft wave for 100 mph wind.

used in HEC-HMS for spillway gate failure (full open)

36.4	0
37.5	131
38.9	447
39.9	741
40.4	905
40.6	974
40.9	1080
41.5	1303
41.9	1459
42.4	1663
42.9	1875
43.5	2141
43.9	2324
44.4	2560
44.9	2804
45.00	2854
45.33	3266
45.67	3906
46	4666
47	7582
48	11225
49	15461

ATTACHMENT 2 HMR-51 PMP INTENSITY CALCULATIONS

TETRA TECH	SUBJECT PMP INTENSITY RESERVOIR DAM	PROJECT RESERVOIR DAM
	ORIGINATOR TCC CHECKED NM	TC/P NO. 194-5938
		DATE 6/26/17 PAGE 1 OF 1 PAGES

HMR-51 FIGURE 18 (SEE ATTACHED EXCERPTS)

PMP 6HR 10 mi^2 = 25.3 in

FIGURE 19

PMP 12hr 10 mi^2 = 29.0 in

FIGURE 20

PMP 12hr. 10 mi^2 = 31.9 in.

DESIGN SMALL DAMS. (SEE ATTACHED EXCERPTS)

FIGURE 15 Scituate in Zone 1

PMP 6hr 10 mi^2 = 23.5 in

FIGURE 16, RATIO FOR LONGER STORMS

12hr. 10 mi^2 RATIO = 1.10

PMP 12 hr, 10 mi^2 = 1.1 (23.5) = 25.8 in

24hr 10 mi^2 RATIO = 1.20

PMP 24hr 10 mi^2 = 28.2 in

HYDROMETEOROLOGICAL REPORT NO. 51

Probable Maximum Precipitation Estimates, United States East of the 105th Meridian

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Washington, D C
June 1978

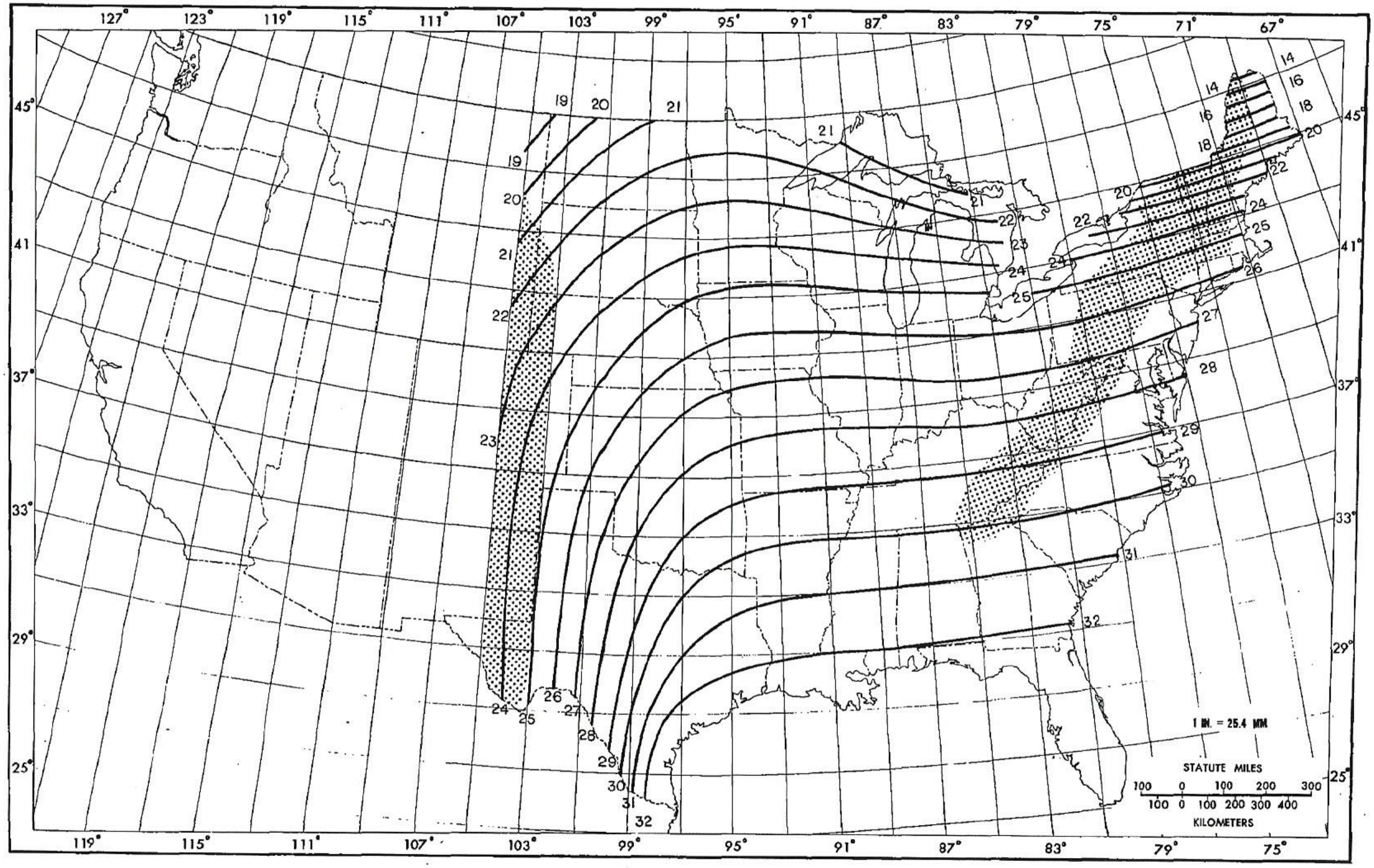

Figure 18.--All-season PMP (in.) for 6 hr 10 mi² (26 km²).

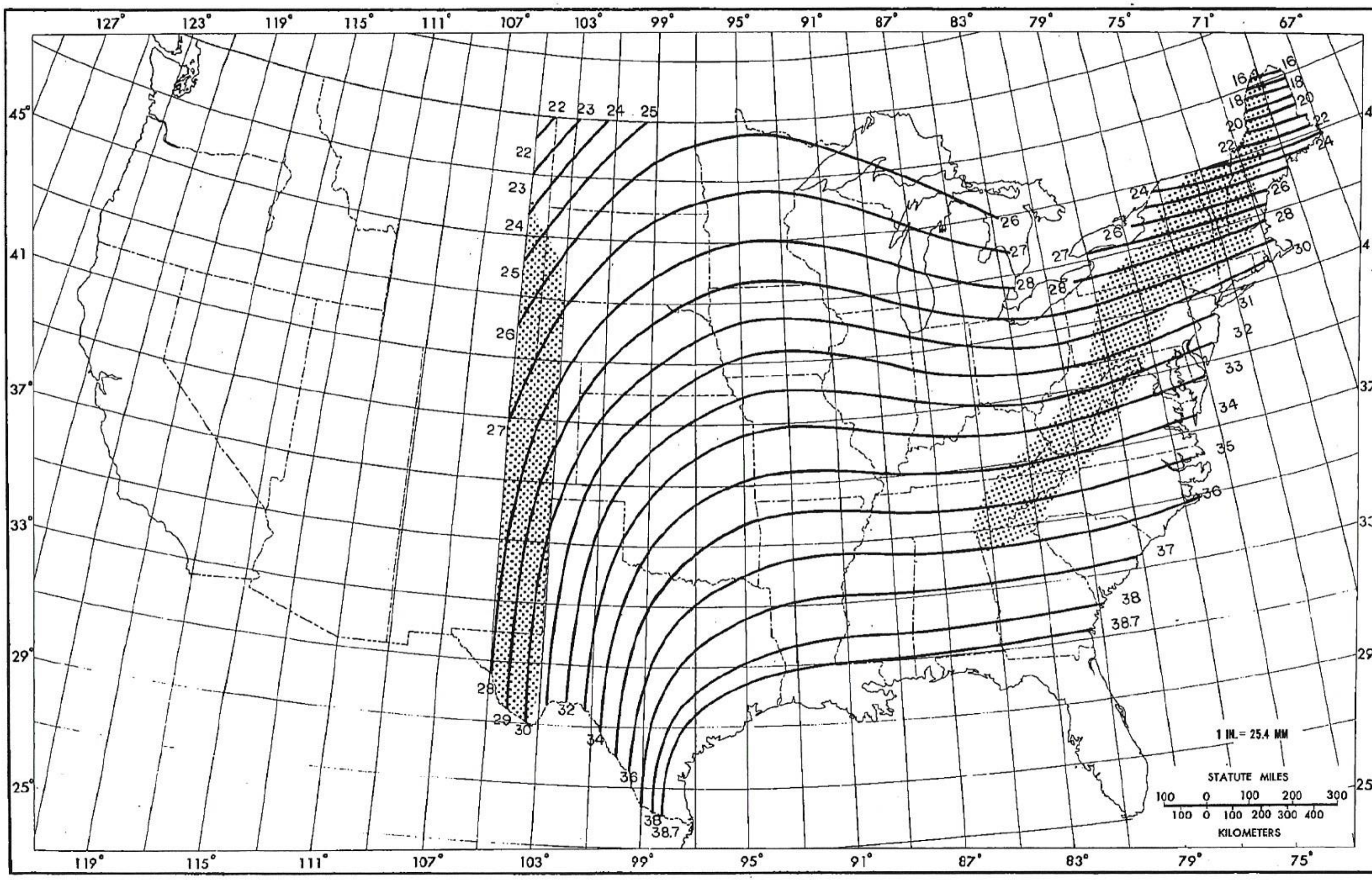

Figure 19.--All-season PMP (in.) for 12 hr 10 mi^2 (26 km^2).

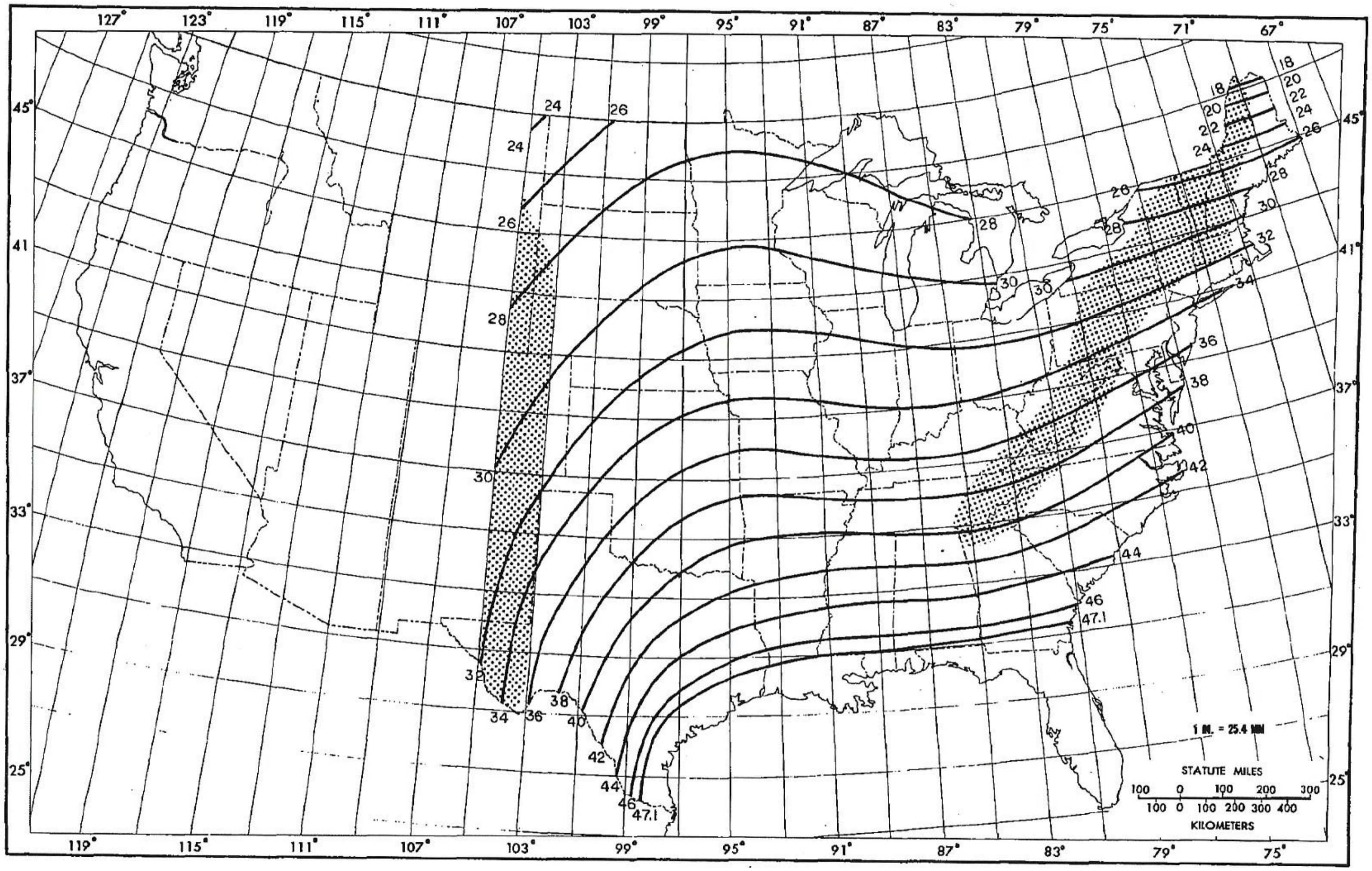

Figure 20.--All-season PMP (in.) for 24 hr 10 mi^2 (26 km^2).

APPENDIX A
PROBABLE MAXIMUM FLOOD COMPUTATION

Methodology

The probable maximum flood (PMF) for a watershed is defined as the flood which occurs during the probable maximum precipitation (PMP) event. "Design of Small Dams", published by U.S. Department of the Interior, Bureau of Reclamation, defines this precipitation amount to be approximately 23.5 inches near Scituate, MA for the 6-hour storm event. Precipitation values can be adjusted for longer storm durations (12-hour, 24-hour, etc.) using appropriate figures in Design of Small Dams.

The Natural Resources Conservation Service (NRCS) hydrologic curve number (CN) method, as outlined in Technical Release 55 (TR-55), and Hydrology and Floodplain Analysis (Bedient 2013) was used to calculate the PMF given the PMP.

The peak flow for 1 inch of rainfall excess is defined as:

$$Q_p = \frac{484A_m}{T_R}$$

where A_m = area of the watershed (sq mi)
T_R = time of rise (hr)

The time of rise is calculated with the following equation:

$$T_R = \frac{D}{2} + t_p$$

where: D = storm duration (hr)
t_p = lag time from centroid of rainfall to Q_p (hr)

The lag time is computed with the following equation:

$$t_p = \frac{L^{0.8}(S+1)^{0.7}}{1900\sqrt{y}}$$

where: L = length to divide (ft) or watershed length
y = average watershed slope (in percent)
S = potential abstraction (inches)

The potential abstraction is based on the weighted curve number of the watershed:

$$S = \frac{1000}{CN} - 10$$

The curve number for the watershed was calculated using NRCS TR-55, aerial maps, and the NRCS web soil survey (U.S. Department of Agriculture) to derive the following assumptions:

- Approximately 60% of the watershed is wooded. Half of these soils are Hydrologic Soil Group C, and half are Hydrologic Soil Group D.
- About 40% of the watershed consists of ½-ac residential neighborhoods. Twenty percent of these soils are Hydrologic Soil Group B and 80% are Hydrologic Soil Group C.

The length and slope of the watershed were estimated with topographic maps. The watershed area was assumed to be 4.4 square miles (DPW 2013).

Once the peak flow Q_p was obtained, this flow is computed to a unit peak discharge by dividing by the watershed area.

$$q_u = \frac{Q_p}{A_m}$$

The unit peak discharge was then used as an input to the TR-55 equation for peak flow, or in this case, the probable maximum flood. This equation can be used for any rainfall amount, whereas the original peak flow (Q_p) is defined for 1 inch of rainfall.

$$PMF = q_u A_m Q F_p$$

where q_u = unit peak discharge (cfs/sq mi/inch)
A_m = area of the watershed (sq mi)
Q = direct runoff (inches)
F_p = adjustment factor for pond and swamp areas

The direct runoff is calculated with the following equation:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$$

where P = probable maximum precipitation (inches)
S = potential abstraction (inches)

EA conservatively assumed that 1% of the watershed consists of ponded/swampy areas, which according to the TR-55 produces an adjustment factor F_p of 0.87.

Input parameters for the PMF calculation are presented in Table A-1.

Table A-1 Input Parameters for Probable Maximum Flood Analysis

Runoff CN	Watershed Length, L (ft)	Watershed slope, y (%)	Watershed Area, A_m (sq. mi.)	Ponding Adjustment Factor, F_p
77	17,200	0.29	4.4	0.87

Results

Estimates of the PMF peak discharge for 6-hr, 12-hr, and 24-hr precipitation duration are summarized in Table A-2. The Spillway Design Flood (SDF) for Reservoir Dam is the ½ PMF flow which is also shown in Table A-2.

Table A-2 Probable Maximum Flood for 6-hr, 12-hr, and 24-hr Precipitation Events

Storm Duration, D (hr)	Probable Maximum Rainfall, P (in)	PMF (cfs)	½ PMF (cfs)
6	23.5	4,042	2,021
12	25.9	3,405	1,703
24	28.2	2,524	1,262

Reservoir Dam would have approximately 0.5 ft of freeboard and would not be overtopped during a 6-hour ½ PMF SDF. Longer duration storms would have lower peak discharges and more freeboard.

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be equal to the rainfall Therefore, the overall retention loss for rainfall on a partially snow-covered watershed during the melting season will be less than that for the same watershed when bare of snow.

It should be kept in mind that, although a usual sequence of events may produce floods, it is generally the unusual event or series of events that produce the great floods. The occurrence of two hurricane storms a few days apart following the same path over a large area in the northeastern States in August of 1955 is a prime example. Hasty conclusions as to flood potential should not be made on the basis of a long period of streamflow record. For example, although the recorded maximum peak discharge on the Pecos River near Comstock, Tex., was 116,000 second-feet for the period of years 1900 through 1953, a discharge of 948,000 second-feet occurred on June 28, 1954.

B. PROCEDURES

49. *Introduction*.—The selection of an appropriate inflow design flood is an essential part of the engineering studies for a project. The words "selection" and "appropriate" are used advisedly because a considerable amount of engineering judgment must be exercised in any hydrologic study of flood potential. It might be presumed that the problems of determining an inflow design flood would decrease in direct ratio to the size of the drainage areas involved and that such problems for drainage areas above small dams could be resolved quite easily. Such is not the case. In many instances, the hydrologic problems for small drainage areas are less easily resolved than those for large areas because relevant data for small natural watersheds are extremely meager.

It is believed that those using the material in this text most often will be concerned with projects for which little direct hydrologic data are available. Therefore, material and procedures presented herein have been selected with a view to assisting in solution of flood estimating problems for such projects. However, all available recorded streamflow and precipitation data should be utilized to the fullest extent possible, and outlines for methods of analyzing these data are included in this text. Discussions of procedural developments have been omitted or condensed, and discussions of applications of automatic data processing programs which have been developed for utilization in flood estimates are not included. The engineer so interested may obtain them from references cited in the bibliography, section 60. Discussions of the following subjects are presented:

Subject:	*Section*
Estimating storm potential	50
Estimating runoff from rainfall	51
Unitgraph principles	52
Hydrograph analysis	53
Unitgraph derivation for ungaged areas	54
Triangular hydrograph analysis	55
Estimating time of concentration	56
Application of triangular hydrographs	57
Estimating inflow design flood	58
Frequency curve computations	59

50. *Estimating Storm Potential*.—(a) *General.*—An estimate of storm potential is an integral part of the hydrometeorological approach to computation of inflow design floods. The term "storm potential" is all-inclusive, embracing factors such as rainfall intensity, duration and areal extent. Meteorologists are able to establish estimates of maximum values for these factors which, judged by present knowledge, appear to be the limit of nature's capabilities. These maximum values differ throughout the United States (and the world). Knowledge of such limits, and the resulting probable maximum precipitation, provides the hydrologist with a good starting point for his estimate of a maximum probable flood as well as for floods less than the maximum probable. The precipitation values adopted for computing the selected inflow design flood are usually referred to as design storm values.

(b) *Definitions.*—For the purposes of this text, the following terminology is used:

(1) *Probable maximum precipitation.*—Probable maximum precipitation values represent an envelopment of maximized intensity-

duration values obtained from all types of storms. It is recognized that probable maximum precipitation values for all durations and for all areas will not occur from any one type of storm. For example, a maximized thunderstorm is very likely to provide probable maximum precipitation over an area of 50 square miles for a duration of 6 hours or less, but the controlling values for longer durations or for larger areas will almost invariably be obtained from general storms.

(2) *Probable maximum storm.*—The probable maximum storm values represent an envelopment of maximized intensity-duration values obtained from one type of storm only. Consideration is given to storm type and variations of precipitation with respect to location, areal coverage, and duration.

(c) *Probable Maximum Storm Considerations.*—Estimates of probable maximum storms are based on analyses which consist of three steps: (1) determining the areal and time distribution of the larger storms of record in the general area; (2) maximizing these observed storms by increasing their values to their physical upper limit as determined from a consideration of their observed moisture content in relation to the probable maximum moisture content that could be associated with a similar storm condition; and (3) considering transposition of these storms. The results of the first step will indicate which storms are best suited for further analysis and can also be used in the hydrograph analyses to estimate average retention loss rates and hydrograph lag times.

In the second step, the relation between maximum moisture potential and the moisture charge of the inflowing airmass is considered. Other factors that are effective in determining the efficiency of a storm in converting atmospheric moisture into precipitation have not been defined sufficiently at the present time to enable their use for making estimates of storm efficiency.

Storm transposition considered in the third step is based on the assumption that the location of a particular storm depended upon meteorological factors that could just as easily occur over other locations within given regions. Transposition, in the case of general-type storms, is limited to regions subject to similar types of storms and not separated by major orographic features. Thunderstorms are more widely transposed than general-type storms. Because the period of record for any particular drainage basin is generally quite short, the transposition of other storms within the same homogeneous meteorological and orographic area has the advantage of combining regional experience of a large number of storms.

(d) *Generalized Precipitation Charts.*—An engineer encountering a design flood estimating problem needs information regarding storm potential. Since such information pertains to magnitudes of storms which could occur from a more severe combination of meteorological events that has yet been observed, the engineer cannot make his estimate directly from recorded storm data. It is impossible to show all the refinements and variations that can influence the magnitude of design storm values for all individual locations within the United States on a generalized chart. However, broad areas do have like storm potential. Generalized charts have been prepared for this text to provide one means of rapidly determining design storm values for any specific area. The design storm values obtained from the generalized charts represent a reasonable upper limit and in most cases will exceed the values obtained for a specific watershed by a detailed hydrometeorological study. If such a study is desired because of the importance or size of the project, the services of a consulting hydrometeorologist should be secured.

(1) *Generalized chart for the United States east of 105° meridian.*—Figure 15 shows probable maximum 6-hour precipitation values for 10-square-mile areas of the United States east of the 105° meridian. This chart is based on one presented in Hydrometeorological Report No. 33, prepared by the Hydrometeorological Branch of the National Weather Service in collaboration with the U.S. Corps of Engineers (see bibliography, sec. 60). These 6-hour values for 10-square-mile areas can be modified for durations in excess of 6 hours and for larger areas up to 1,000 square miles by use of figure 16. No variation is assumed between point and 10-square-mile precipitation. For

*

Figure 15. **Probable maximum precipitation (inches) east of the 105° meridian for an area of 10 square miles and 6 hours' duration. 288–D–2449A, 288–D–2754, 288–D–2755.**

durations shorter than 6 hours, the time distribution of precipitation can be obtained from curve C, figure 18. After the publication of Hydrometeorological Report No. 33, the Corps of Engineers recommended [12] that the following reductions be applied to the report values in order to provide for the imperfect "fit" of storm isohyetal patterns to the shape of a particular basin.

Drainage area (square miles)	*Reduction factor applicable to H.R. 33 rainfall values (percent)*
1,000	10.0
500	10.0
200	11.0
100	13.0
50	15.0
10	20.0

[12] Engineer Circular No. 1110–2–27, dated August 1, 1966, "Policies and Procedures Pertaining to Determination of Spillway Capacities and Freeboard Allowances for Dams."

*The NWS (National Weather Service) periodically updates these maps. Therefore, it is suggested that the user utilize the latest map of the NWS.

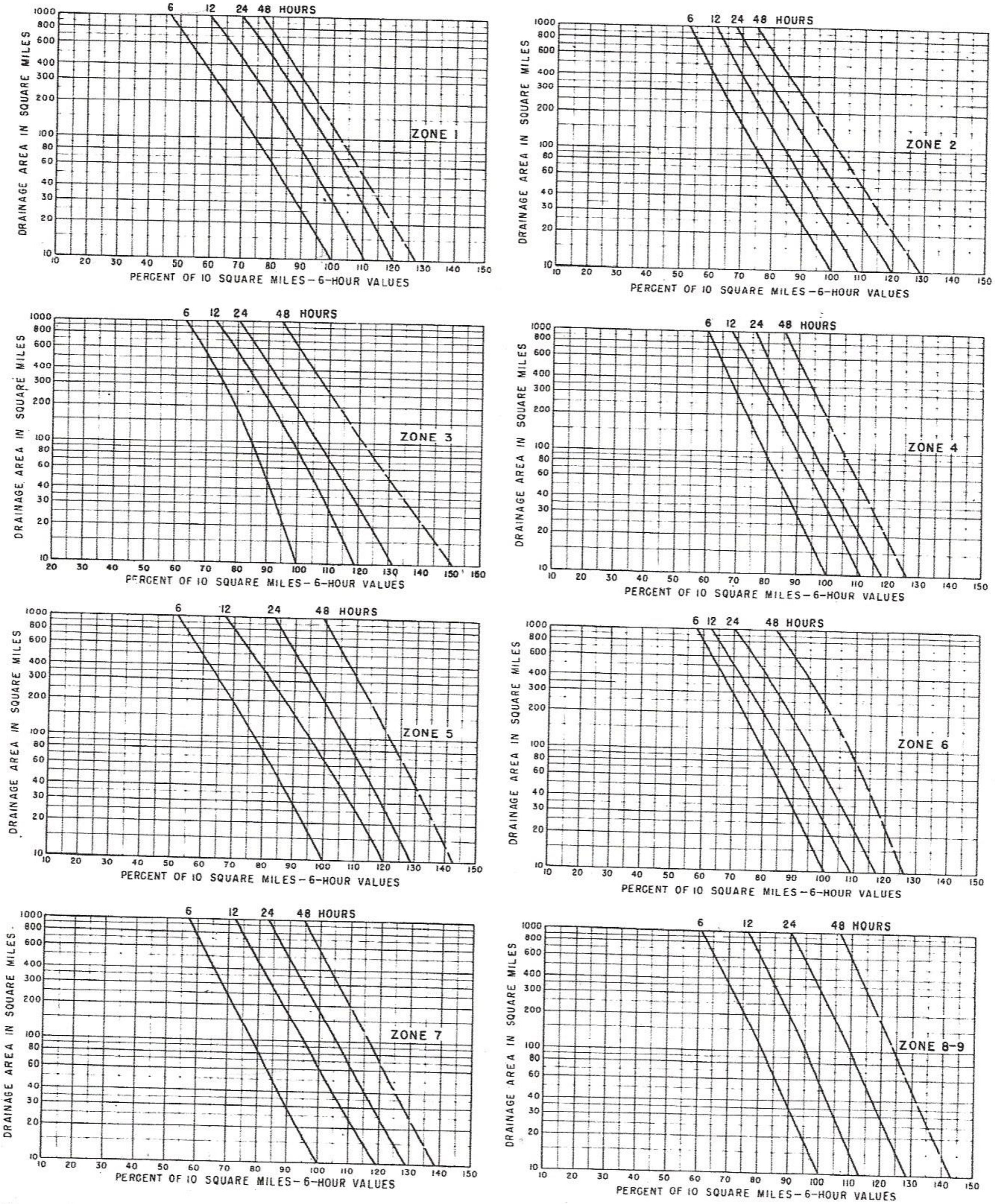

Figure 16. **Depth-area-duration relationships. Percentage to be applied to 10 square miles, 6-hour probable maximum precipitation values. 288–D–2450.**