

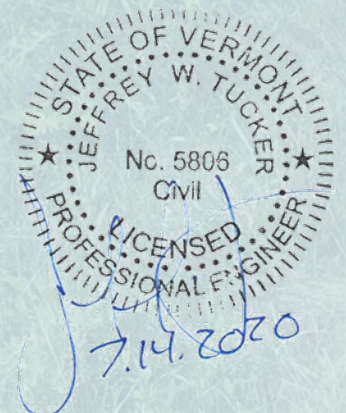


# SHADOW LAKE DAM

HYDROLOGIC & HYDRAULIC STUDY; JULY 14, 2020

**DuBois  
& King** inc.

SUBMITTED TO:  
SELECTBOARD, TOWN OF GLOVER  
51 BEAN HILL RD., GLOVER, VT 05839



## Technical Memorandum

To: Town of Glover Selectboard  
From: Andrew Sampsell, EI (DuBois & King)  
Cc: Jeffrey Tucker, PE (DuBois & King)  
Benjamin Green, PE (VT DEC)

Date: July 14, 2020

Re: Shadow Lake Dam Hydrologic and Hydraulic Study  
VT Dam No. 81.02 – Glover, Orleans County, Vermont

### I. Background:

Shadow Lake Dam impounds the upper 13.6-ft (approx.) of Shadow Lake, which is located in the Town of Glover, VT. The dam is owned and operated by the Town and is identified by the Vermont Department of Environmental Conservation, Dam Safety Section as No. 81.02.

The VT Dam Safety Section has regulatory jurisdiction over this dam and, currently conducts 3-5 year periodic inspections. The Dam Safety Section issued their most recent inspection report to the Town dated February 10, 2018. This inspection report concludes the dam is considered to be in FAIR condition and identifies several specific elements that define the basis for the condition assessment.

The State's inspection report provided long term remedial recommendations for the Owner. These recommendations included conducting an updated hydrologic and hydraulic (H&H) analysis using modern engineering models and current climatology data to determine the adequacy of the spillway and, depending on the results, identify and implement improvements to the dam to bring it into compliance with current dam safety hydraulic criteria.

The last H&H analysis for the dam was conducted in 1991 by DuBois & King, Inc. (D&K) on behalf of the US Army Corps of Engineers and the VT Dam Safety Section. The 1991 study concluded the dam has adequate freeboard during the 100-year storm but is subject to overtopping by 4-ft during the 1/2 probable maximum flood (PMF).

The dam has a current VT Hazard Classification of SIGNIFICANT, which is based largely on its potential to cause loss of life and economic damages in the event of a hypothetical dam failure. The dam has a current US Army Corps of Engineers (USACE) size classification of INTERMEDIATE, which is based on the storage volume and height of the dam. The hazard and size classification in turn defines the minimum hydraulic criteria that the dam and its spillway is required to meet. In the case of Shadow Lake Dam, the hydraulic criteria is the Spillway Design Flood (SDF). Vermont's dam statutes (10 V.S.A. Chapter 43) which apply to jurisdictional dams do not define a specific SDF for any of the hazard classifications. Following state policy:

*SDF and outlet works capacities should be consistent with guidelines or service criteria established by Federal agencies such as the Corps of Engineers, Soil Conservation Service and the Bureau of Reclamation for a given size and hazard classification, with the following additional requirements:*

- *SDF, as appropriate, but in no case less than a routed Q100 (one hundred-year frequency) inflow (Ref: FERC Engineering Guidelines..., October 1993, Paragraph 2-3.3).*
- *Freeboard, as appropriate, but not less than 1.5 feet with routed Q100 inflows, and not less than 3.0 feet from principal spillway crest (usually NWL). Applies to all embankment dams and other dams where appropriate.*

Currently the information provided by VT Dam Safety for selecting design criteria such as spillway design floods and required freeboard is best characterized guidance. The language is intentionally vague to allow for the use of professional judgement since there are often times site specific considerations that are not accounted for in the three hazard classifications. Also not all SIGNIFICANT hazard dams possess the exact same hazard potential (there is a range of hazard potential within each category).

It is worth noting that the design standards (currently provided as guidance) are currently under review and are expected to be updated in July of 2022. Additionally the administrative rules which pertain to things such as hazard classifications, inspection schedules, exemptions from registration and inspection are also currently under review and are expected to be updated in July of 2020. More information about the review processes currently underway is available on the Dam Safety page of the Vermont Department of Environmental Conservation's (VT DEC) website.

## II. Purpose of Hydrologic & Hydraulic Study:

The purpose of this H&H study is to:

1. Conduct an updated assessment of the hydraulic capacity of the dam and its spillway using modern hydrologic and hydraulic modeling techniques and current climatology data,
2. Provide suitable technical information for use in a subsequent dam breach analysis and inundation mapping project pending anticipated grant funding.

## III. Shadow Lake Dam & Watershed Description:

D&K conducted a site visit on August 21, 2019 to measure key hydraulic features and to obtain limited geometric data of the dam using a GPS survey unit. A detailed field survey was not included in this scope of work. The elevation data from the GPS unit was determined to reasonably correspond with the LIDAR digital elevation model (DEM) data on the North American Vertical Datum of 1988 (NAVD88-feet). The GPS survey data was used to support the hydraulic analysis. The table below references measurements obtained from the 8-21-2019 site visit and also measurements included in a VT DEC Dam Safety Inspection memorandum dated February 2<sup>nd</sup>, 2018.

Table 1: Shadow Lake Dam & Watershed Description

Physical Characteristics	
Type	Earth fill with masonry walls
Length	130 feet
Structural Height	11.5 feet (1,399.8' – 1,388.3')
Impoundment Height	13.6 feet (1,399.8' – 1,386.2')

Top Width	Varies 7 to 8 feet
Side Slopes	Upstream face approx. 3H:1V, Downstream face approx. 3H:1V
Primary Spillway	
Description	Cast in place concrete drop inlet with gate controlled 36" diameter outlet. Lake water level controlled by stop logs.
Auxiliary Spillway	
Description	15 foot wide broad crested weir with concrete chute
Discharge at Dam Crest Elevation	276 cfs
Impoundment (Surface Area)	
Principal Spillway Crest	217.3 acres
Auxiliary Spillway Crest	221.5 acres
Top of Dam	225.9 acres
Impoundment (Volume)	
Principal Spillway Crest	1,708.8 acre-ft
Auxiliary Spillway Crest	2,061.1 acre-ft
Top of Dam	2,866.2 acre-ft
Key Elevations (NAVD88 ft)	
Top of Dam	1,399.8'
Auxiliary Spillway	1,396.2'
Principal Spillway / Normal Pool	1,394.6'
Toe of Embankment	1,388.3'
Streambed at Toe of Embankment	1,386.2'
Watershed	
Size	5.3 square miles (3,392 acres)
Type	Primarily forest with some residential development and fields.

Photographs of the dam taken during the 8-21-2019 site visit are included in Attachment A.

#### IV. Watershed Hydrology:

Table 2 below summarizes hydrologic and hydraulic inputs used to characterize and evaluate the Shadow Lake Dam watershed. Applicable inputs defined below were estimated based on methodology contained in the NRCS National Engineering Handbook (NEH), Part 630 Hydrology.

Table 2: D&K 2019 H&H Analysis Input Data Sources

Rainfall Data	NOAA ATLAS-14 PFDS, NOAA HMR-51 & HMR-52
Land Cover Data	Site Observations, Orthophotos, 2016 National Land Cover Database Raster

Soils Data	USDA National Resources Conservation Service Web Soil Survey (SSURGO/STATSGO2 Database)
Time of Concentration	NRCS Watershed Lag Method
Pond / Lake Storage	LIDAR Digital Elevation Model, VT DEC Bathymetry Maps
Number of Watershed Subcatchments	2
Hydrograph Method	NRCS Unit Hydrograph
Rainfall Distribution (Probable Maximum Precipitation)	24-hr NOAA HMR-51, 52 NRCS 5-pt Distribution
Rainfall Distribution (Recurrence Interval Storms, i.e. 100-yr)	24-Hour Center Weighted Frequency Distribution Generated from NOAA ATLAS-14 Data
Elevation & Geometry Data	Abbreviated Field Survey 2014 (0.7 m) Hydroflattened LIDAR Digital Elevation Model
Elevation Datum	NAVD88 Feet

Drainage Area:

The drainage area of the Shadow Lake Dam watershed was delineated using the United States Geological Survey's (USGS) StreamStats web application. The StreamStats drainage area was cross-checked with contours generated from the 2014 0.7m Hydroflattened LIDAR DEM and overlaid on top of a recent orthophoto to assess accuracy and adjust as necessary. The drainage area at the dam was measured to be 5.3 square miles. A map depicting the watershed is included in Attachment B.

The drainage area was divided into two subcatchments, one which corresponds to the upstream Daniels Pond (1.43 sq. mi.) and one which corresponds to Shadow Lake (3.86 sq. mi.). The drainage area was divided to represent attenuation of flood discharges by the storage volume in Daniels Pond as controlled by the pond's outlet structure (70"x 42" corrugate metal pipe arch, and roadway overtopping).

Times of Concentration:

The time of concentration for each subcatchment was determined using the NRCS Watershed Lag Method, as defined in the above referenced NEH Part 630 Hydrology, Chapter 15, Time of Concentration. This method requires data defining the longest flow path within the subcatchment such starting elevation, ending elevation, and flow length. Each subcatchments time of concentration data is input into an equation provided in NEH 630 Chapter 15 to approximate the travel time.

### Antecedent Moisture Condition:

An antecedent moisture condition of 2 was used in the hydrologic modeling. This condition represents partially saturated soils before rainfall and is considered in the field of hydrology appropriate for initial starting conditions for watershed evaluations and thus used for this study. An antecedent moisture condition of 3 would represent very saturated soils prior to the rainfall occurring and an antecedent moisture condition of 1 would represent nearly unsaturated soils prior to rainfall occurring.

### Stream Baseflow:

The baseflow discharge values used in the hydrologic model were obtained from a Journal of Hydrology report titled "Regional estimation of base flow for the conterminous United States by hydrologic landscape regions" (2007, by C. Santhi et. Al). Using Figure 5 in the report (see Attachment B), the project site is located within a region with an estimated baseflow volume range of 400 to 700 mm. The upper limit (700 mm) was selected and a cubic feet per second (cfs) discharge was obtained through unit conversion, multiplication by drainage area, and division by the number of seconds within a year. The baseflow for the Daniels Pond subcatchment was calculated to be 2.71 cfs. The base flow for the Shadow Lake subcatchment was calculated to be 7.84 cfs.

### Land Cover, Soils, and SCS Curve Numbers:

The SCS curve numbers used to calculate watershed runoff were determined using standard NRCS (formerly the Soil Conservation Service) reference values based on land cover and hydrologic soil group classification. Using GIS software the land cover data and soils data were paired together and tabulated to allow for SCS curve number determination. Land cover type was based on observations made during a site visit and interpretation of recent ortho-imagery. Approximately 76% of the watershed is forested, 8% of the watershed is residential development, 7% of the watershed is field/open land, and 9% of the watershed is either a waterbody or soils most often completely saturated with water. An orthophoto map of the watershed is included in Attachment B. The hydrologic soil groups (HSG) were based on NRCS digital soil maps. Approximately 5% of the watershed is comprised of relatively well drained HSG B soils, 37% are HSG C soils, and the remaining 58% are HSG D soils. A map of the hydrologic soil groups is included in Attachment B.

### Rainfall:

The depth-duration rainfall values used to define the recurrence interval storms (50-yr, 100-yr, 200-yr, 500-yr, and 1000-yr) were obtained from the US National Oceanic and Atmospheric Administration's (NOAA) ALTAS-14 Precipitation Frequency Data Server (PFDS). The depth-duration rainfall value used to define the probable maximum precipitation (PMP) was obtained from the NOAA's Hydrometeorological Reports No. 51 and No. 52. The rainfall values were used in the hydrologic modeling in combination with the other inputs described above to generate inflow hydrographs used in evaluating the hydraulic performance and adequacy of the Shadow Lake Dam.

## V. Hydrologic Modeling:

The rainfall events modeled as part of this analysis included the following: 50-yr, 100-yr, 200-yr, 500-yr, 1000-yr, and the PMP. Typical storm durations for evaluating design events range from 6 to 72 hours based on location and other climatic factors. Based upon conversations with a NRCS hydrologist, sound engineering practice, and review of NRCS (federal) reference materials, both the recurrence interval storms (50-yr through 1000-yr) and the PMP were modeled as 24-hr storms.

The recurrence interval & PMP storms were analyzed using US Army Corps of Engineers HEC-HMS hydrologic modeling software (version 4.3). HEC-HMS includes the NRCS rainfall losses and unit hydrograph transformation method which are used to calculate stormwater runoff from a watershed. These calculations yield runoff discharge rates (i.e. inflow flood hydrograph into Shadow Lake Dam) for a given drainage area over a specified duration of time.

### Recurrence Interval Storm Events:

A regionally specific 24-hour storm distribution of the rainfall was created from the NOAA ATLAS-14 rainfall data within HEC-HMS for each recurrence interval storm event. The storm distributions were created using the frequency method within HEC-HMS. The storm distributions were selected to be center weighted. A center weighted storm distribution means that the peak rainfall intensity duration occurs approximately half way through the storm. This methodology aligns with federal NRCS guidance included in NEH 630 CH 4 Storm Rainfall Depth and Distribution. The rainfall depths for the recurrence interval storms are tabulated in Attachment B and Table 3 below. Application of the recurrence interval storm rainfall is detailed in Attachment C.

### Probable Maximum Flood Storm Event:

The PMP is the rainfall depth-duration which generates the probable maximum flood (PMF). The PMP rainfall value was used in the analysis to produce a corresponding probable maximum flood (PMF) inflow hydrograph. The PMF hydrograph was then fractionalized to produce the 1/4 PMF, 1/2 PMF, and 3/4 PMF inflow hydrographs.

NOAA's HMR-52 report provides guidance on how to spatially distribute and orient the PMP storm using isohyet ellipses which represent a typical spatial distribution of rainfall based on historic storms they studied around the time the report was produced (1982). The most intense rainfall occurs within the smallest center isohyet ellipse. For this analysis the smallest isohyet (10 sq. mi.) was centered over the approximate centroid of the 5.3 sq. mi. drainage area with a corresponding storm orientation of 270 degrees (clockwise from North). It was found that the 10 sq. mi. isohyet ellipse encompassed the 5.3 sq. mi. drainage area. Since the smallest isohyet ellipse encompassed the drainage area, the rainfall distribution was not spatially varied and area reductions were not applied.

A center weighted 24-hour storm distribution was developed using PMP rainfall depth duration values and was transformed into a hyetograph using the NRCS 5-pt distribution which is derived from guidance included in HRM-52. The rainfall depth value for the PMP storm is tabulated in Attachment B and Table 3 below. Application of the PMP rainfall is detailed in Attachment C.

## VI. Hydrologic Modeling Results:

Table 3: 2020 Hydrologic Analysis Recurrence Interval Storm Results

Event	24-hour Rainfall Depth (in)	Peak Runoff (cfs)	Unit Discharge (cfs/sq mi)
Shadow Lake Dam Subcatchment (3.86 sq. mi.)			
50-year	4.82	1,989	515
100-year	5.40	2,365	612
200-year	6.88	2,969	769
500-year	7.08	3,373	873
1000-year	7.92	3,839	994
Daniels Pond Subcatchment (1.43 sq. mi.)			
50-year	4.82	708	494
100-year	5.40	849	593
200-year	6.88	1,084	757
500-year	7.08	1,231	860
1000-year	7.92	1,409	984

Table 4: 2020 Hydrologic Analysis PMP Storm Results

Event	24-hour Rainfall Depth (in)	Peak Runoff (cfs)	Unit Discharge (cfs/sq mi)
Shadow Lake Dam Subcatchment (3.86 sq. mi.)			
1/4 PMF	-	1,039	269
1/2 PMF	-	4,157	1,076
3/4 PMF	-	6,236	1,614
PMF	26.00	8,314	2,152
Daniels Pond Subcatchment (1.43 sq. mi.)			
1/4 PMF	-	767	536
1/2 PMF	-	1,534	1,072
3/4 PMF	-	2,301	1,607
PMF	26.00	3,068	2,143

## VII. Hydraulic Modeling:

The hydraulic analysis was performed using US Army Corps of Engineers HEC-RAS (2D) flood modeling software version 5.0.7. Using detailed terrain data (i.e. LIDAR DEM and/or survey) HEC-RAS 2D enables the user to create a computational mesh which divides the model area into a series of cells which capture the elevation data of the terrain surface and roughness values of the land cover. HEC-RAS employs an implicit finite difference method to determine flow characteristics such as flow direction, velocity and depth at each cell within the computational mesh. The 2D model will route flow through the computation mesh using a physically derived equation selected by the user (diffusion wave or full momentum). For this analysis the more detailed full momentum equation was selected for model accuracy and stability.

The Shadow Lake Dam 2D HEC-RAS model was built to encompass the storage of Daniels Pond, flow from Daniels Pond to Shadow Lake, storage of Shadow Lake, and outflow from the dam to a point approximately 2,150 feet (stream centerline distance) downstream of the dam. The terrain surface of

the 2D HEC-RAS model was based off of a 2014 Hydroflattened LIDAR DEM with a corresponding 0.7 m x 0.7 m resolution. The LIDAR DEM was manually edited to reflect conditions observed and/or surveyed during the 8-21-2019 site visit.

Surface roughness was estimated using the 2016 National Land Cover Database (NLCD) raster data set which is publicly available from the Multi-Resolution Land Characteristics Consortium (MRLC). The land cover classifications part of the dataset correspond to a Manning's n value which represents degree of surface roughness and is used to calculate energy losses within the hydraulic model. The NLCD land cover data is obtained via satellite survey. The NLCD raster has a resolution of 15 m x 15 m which with respect to the 2D HEC-RAS models cells size (which varies from 100 ft x 100 ft to 5 ft x 5 ft) is relatively coarse. The computational cell size within the 2D HEC-RAS model is selected based on desired level of detail, computational stability, and a reasonable simulation run time. In areas of the 2D HEC-RAS model in which increased detail was desired i.e. in the vicinity of the Shadow Lake Dam and within stream channels, the NLCD land cover data was manually overridden to use more representative Manning's n-values based upon site observations and recent ortho-imagery.

The 2D HEC-RAS model is comprised of two upstream boundary conditions which include the inflow hydrograph for Daniels Pond, and the inflow hydrograph for Shadow Lake. The inflow hydrographs were referenced from the HEC-HMS hydrologic model of the Daniels Pond and Shadow Lake Subcatchments. The downstream boundary condition of the model is normal depth. The normal depth boundary condition is established using normal flow depth in the stream channel, as defined by its slope at the downstream end of the model ( $s = 0.049 \text{ ft / ft}$ ).

Daniels Pond Road controls the flow of water out of Daniels Pond via a 70" x 42" CMP arch and if the storm is large enough, roadway overtopping. The Daniels Pond outlet structure was modeled using a hydraulic structure in the 2D HEC-RAS model which included the centerline roadway profile as the controlling roadway overtopping elevation and modeled flow over the roadway as broad crested weir flow. The culvert geometry, elevations, and location were approximated based on observations and measurements made during the 8-21-2019 site visit. The normal water surface elevation of Daniels Pond was taken to be the invert of the CMP arch culvert (approx. 1630.2' NAVD88). The invert of the culvert was obtained by measuring down from the top of Daniels Pond Road and referencing the LIDAR DEM top of road elevation above the culvert.

Shadow Lake Dam controls the flow of water out of Shadow Lake via primary spillway gate house structure, and the concrete chute auxiliary spillway. For the purposes of this analysis the primary spillway structure was represented by a rating curve which incorporates weir and orifice flow (see Attachment E). The discharge capacity of the primary spillway is limited by the 36" diameter concrete orifice at higher heads. The primary spillway outlet discharges 64.5 cfs when the water surface is at the top of dam elevation. The primary spillway does have a gate which is manually operated but according to the dam owner/operator the gate is left in the fully open position. The primary spillway was represented as being fully open in the hydraulic model. The LIDAR DEM surface was adjusted such that the Shadow Lake water surface started at the normal pool elevation (approx. 1394.6' NAVD88). The LIDAR DEM surface was also adjusted in the vicinity of the dam to reflect a controlling top of dam elevation of 1399.8' NAVD88, a controlling auxiliary spillway invert of 1396.2' NAVD88, a controlling auxiliary spillway width of 15 feet, and to reflect the approximate footprint and height of the primary spillway gatehouse structure.

Shadow Lake Dam was modeled with a combination of 2D flow area and hydraulic structures. The hydraulic structures were used to represent the auxiliary spillway, primary spillway, and portion of the dam with a relatively consistent dam crest (elevation 1399.8' NAVD88 FT). HEC-RAS has the ability to calculate discharge over dam structures (such as the Shadow Lake Dam auxiliary spillway and dam crest) based on headwater and tailwater elevations and can vary the discharge coefficient accordingly. The discharge coefficient is initially defined by the user based on the type of spillway. Both the auxiliary spillway and dam crest overtopping flow were represented with discharge coefficients corresponding to broad crested weir flow. The auxiliary spillway was represented with a discharge coefficient of 2.70, the dam crest was represented with a weir coefficient of 2.63. Discharge coefficient selection was based on observations made during a site visit and general guidance provided in the US Bureau of Reclamation's "Design of Small Dams – third edition" technical publication (1987).

Downstream of Shadow Lake Dam (approx. 220 ft) is Stone Shore Road. The Stone Shore Road Bridge deck was not included in the HEC-RAS model due to the relatively insignificant effects on any attenuation or influence on the estimated water surface during the scenarios analyzed. The river hydraulics of this crossing and its potential tailwater effects on the dam was included in the HEC-RAS model by including the channel constriction created by the bridge abutments at the crossing. The LIDAR DEM surface was edited to remove the bridge deck such that a channel width corresponding to the approximate width of the opening was created. The invert elevation of the opening was set the approximate upstream channel invert based on the LIDAR DEM. A map depicting the 2D HEC-RAS model geometry is included in Attachment D.

#### VIII. Hydraulic Modeling Results:

Table 5: Composite Inflow<sup>1</sup> vs Composite Outflow<sup>2</sup> at Shadow Lake Dam

Event	Shadow Lake Dam Composite Peak Inflow <sup>1</sup> (cfs)	Shadow Lake Dam Composite Routed Peak Outflow <sup>2</sup> (cfs)	Shadow Lake "Level Pool" Peak Water Surface Elevation <sup>3</sup> (NAVD88 ft)	Shadow Lake Peak Water Surface Elevation at Dam <sup>4</sup> (NAVD88 ft)	Available Freeboard (+) or Overtopping Depth (-) <sup>5</sup> (feet)
50-yr (24-hr)	1,791	96 <sup>6</sup>	1397.3	1397.2	2.6
100-yr (24-hr)	2,142	144 <sup>6</sup>	1397.7	1397.6	2.2
200-yr (24-hr)	2,670	278 <sup>6</sup>	1398.7	1398.6	1.3
500-yr (24-hr)	3,055	294 <sup>6</sup>	1398.8	1398.7	1.1
1000-yr (24-hr)	3,420	378 <sup>6</sup>	1399.3	1399.2	0.6
1/4 PMF (24-hr)	1,836	474 <sup>6</sup>	1399.9	1399.7	0.1
1/2 PMF (24-hr)	4,243	2,801 <sup>7</sup>	1403.5	1403.1	-3.3
3/4 PMF (24-hr)	7,541	6,098 <sup>7</sup>	1406.0	1405.4	-5.6
PMF (24-hr)	10,699	9,661 <sup>7</sup>	1407.7	1407.0	-7.2

1 - Composite inflow represents the combined inflow of the Daniels Pond Subcatchment and Shadow Lake Subcatchment. Values are measured at the upper end of Shadow Lake.

2 - Composite outflow represents the combined outflow of flow from the auxiliary spillway, dam overtopping flow, and flow around the left and right abutments. Values are measured at the downstream end of the dam (approx. toe of slope).

3 - Water surface elevation is measured within the lake's "level pool" before influence from dam flow.

4 - Water surface elevation is measured at upstream face of auxiliary spillway.

5 - Freeboard and overtopping depths are measured using the water surface elevation at the dam in reference to top of dam elevation 1399.8' (NAVD 88).

6 - Flow does not overtop the dam and is conveyed by principal and auxiliary spillways only.

7 - Flow overtops the dam and is a combination of auxiliary spillway flow, dam overtopping flow, and flow around the left and right abutments.

Additional model results and velocity / inundation mapping in the vicinity of the Shadow Lake Dam can be found in Attachment D.

IX. Comparison of Results with 1991 H&H Study:

As previously described in Section I of this memo, the last H&H analysis for the dam was conducted in 1991 by D&K. The 1991 analysis produced different inflow hydrographs, outflow hydrographs, peak water surface elevations, and overtopping depths. A difference in results is to be expected because the methods, input data (such as rainfall depths and durations), and hydrologic and hydraulic models used differ between the 2020 and 1991 analyses.

Generally, the results of the 2020 analysis indicate lower peak water surface elevations (less overtopping / more freeboard) compared to the 1991 analysis. A few key differences are summarized below.

1. The 2020 analysis uses two subcatchments (one which drains to Daniels Pond and one which drains directly to Shadow Lake) to more accurately account for attenuation of flow provided by storage in Daniels Pond.
2. The 1991 analysis confined 100% of the routed outflow discharge to the 130 foot long section of dam and did not allow overbank flow to occur, which produced conservative, higher peak lake levels. During the full PMF the 2020 analysis indicates the width of flow at the dam is approximately 380 feet when the water surface elevation is at its maximum. This means that water is flowing around the left and right abutments of the dam instead of all of the water across the top of the dam.
3. The 2020 analysis was performed using HEC-RAS (2D), which utilizes an implicit finite difference method to analyze flow through a computational mesh. The 1991 analysis was performed using HEC-1, which utilizes a step-backwater routine which interpolates a single water surface elevation between user defined cross-sections.

Table 6: Comparison of Freeboard (+) / Overtopping (-) Depths (feet)

Storm Event	D&K 1991 Analysis	D&K 2020 Analysis
50-yr (24-hr)	N/A	2.6
100-yr (24-hr)	2.6	2.2
200-yr (24-hr)	N/A	1.3
500-yr (24-hr)	N/A	1.1
1000-yr (24-hr)	N/A	0.6
1/4 PMF (48-hr)	0.4	0.1
1/2 PMF (48-hr)	-4.0	-3.3
3/4 PMF (48-hr)	-6.9	-5.6
PMF (48-hr)	-9.2	-7.2

## X. Vermont Dam Safety Regulations:

The following is a summary of the Vermont Dam Safety regulations as it relates to the hydraulic evaluation and adequacy of Shadow Lake Dam.

1. Current Vermont Dam Safety regulations are administrated under 10 V.S.A. Chapter 43: Dams. The Vermont Dam Safety program is currently developing new dam safety regulations, the technical standards are expected to be adopted and in place in 2022.
2. The technical evaluation of dams and spillways (H&H, stability, etc) portion of the current dam safety guidelines are based on performance guidance from the U.S. Army Corps of Engineers. Vermont dam safety guidelines encourage professional engineering judgement to be applied when interpreting and applying the guidelines.
3. The dam and spillway performance guidelines utilize the U.S. Army Corps of Engineer's Structure classifications (hazard and size). The hazard classification of Shadow Lake Dam is SIGNIFICANT and the size classification is INTERMEDIATE.
4. The guidelines indicate a spillway design flood (SDF) is to be used to evaluate the hydraulic adequacy of spillways. The guidelines do not provide a specific frequency for the SDF, but provide a general frequency range, with the low end being in excess of the 100-yr event and typical values between the 40% and 60% PMF. For a SIGNIFICANT hazard classification and INTERMEDIATE size dam, the guidance recommends the SDF be between the 1/2 PMF and full PMF.
5. Typical Vermont Dam Safety engineering practice over the past 30-plus years has been to utilize the 1/2 PMF as the SDF for the evaluation of existing dams and spillways having a SIGNIFICANT hazard classification, (regardless of size). This practice includes providing 1.5 feet of freeboard from the peak reservoir water surface elevation to the top of dam during the routing of the SDF.

## XI. Summary and Conclusions:

Based upon the results of the 2020 H&H analysis, the following summary and conclusions are provided:

1. Inflow runoff hydrographs for storm event frequencies identified above were developed for the Shadow Lake Dam watershed and routed through the lake following the NRCS Unit Hydrograph methodology. Current rainfall-duration values were used as part of the hydrograph development.
2. Routed outflow hydrographs were generated and peak rate of discharge and associated peak lake levels at Shadow Lake Dam were computed. Storage and attenuation provided by the lake as well as by Daniels Pond were accounted for. Freeboard associated with each hydrograph was computed, measured as the vertical distance from the peak lake level to the top of the dam (El. 1399.8).

3. The Shadow Lake dam spillway provides freeboard during the 50-yr, 100-yr, 200-yr, 500-yr, 1000-yr, and 1/4 PMF storm events. The dam is overtopped at the 1/2 PMF, 3/4 PMF, and full PMF storm events. Specific freeboard values are listed in Table 5 above.
4. The minimum desired freeboard of 1.5-ft is achieved at the 100-year and less storm events. The freeboard is less than 1.5-ft for the 200-year and greater storm events.
5. In the absence of an incremental flood impact analysis to properly define the SDF, D&K recommends the 1/2 PMF be used as the storm event to evaluate the hydraulic adequacy of the dam and its spillway.
6. The hydraulic capacity of the dam and its spillway, based on the dam's INTERMEDIATE size and current SIGNIFICANT hazard classification does not meet the intended performance of the Vermont Dam Safety regulations and its referenced US Army Corps of Engineers guidelines for the following reasons:
  - a. The dam does not meet the desired 1.5-ft of freeboard for the 200-year and greater storm events and is well under 1-ft for the 1,000 year storm event.
  - b. The dam is subjected to 3.3-ft of overtopping for the 1/2 PMF event for a significant duration (several hours). The earthen portion of the dam is not protected for overtopping and is therefore has an increased potential for breach and failure from erosion and scour at the predicted depths and velocities.
  - c. The abutting flanks of the dam are not protected from erosion and scour and at the predicted depths and velocities, dam failure could likely occur through the abutment areas.
7. A stability analysis of the dam was not included in this 2020 study so the stability of the dam during the various storm events is unknown. While there are no known concerns with the dam's stability, the lack of data prevents an evaluation of the dam's adequacy.
8. The hydraulic performance of the dam and spillway as compared between the 2020 and 1991 analyses are similar. Both analyses indicate the spillway can pass the 1/4 PMF with freeboard and overtop the dam at the 1/2 PMF and greater events. This 2020 analysis considers overtopping discharge that flanks the left and right abutments of the dam (whereas the 1991 study did not).

## XII. Recommendations:

1. Review and discuss the results of this study with the Vermont Dam Safety office.
2. Utilize the results of the study to re-evaluate the dam's hazard classification with a subsequent dam breach analysis.
3. Conduct an incremental flood damage analysis as part of the dam breach and hazard classification analysis to select a specific spillway design flood (SDF).

4. Identify feasible measures or combinations of measures to bring the dam into compliance with current dam safety regulations while maintaining the lake at its current level, such as (not limited to):
  - a. Increase the auxiliary spillway hydraulic capacity to lower the peak water level during the SDF,
  - b. Raise the dam to achieve required freeboard,
  - c. Improve primary spillway,
  - d. Install overtopping protection to protect the earthen portions of the dam and abutments from erosion and scour during an overtopping event,
  - e. A combination of the above.

Regarding measure 4.a above, D&K estimated the increased hydraulic capacity of a widened spillway from its current 15-ft to 150-ft would be approx. 1,232.5 cfs at 1.5-ft of freeboard. For reference leaving 1.5 feet of freeboard from the top of dam provides 2.1 ft of head on the auxiliary spillway. For context, the peak inflow of the 1/2 PMF is approximately 4,243 cfs. As such, lowering the peak lake level during the SDF by increasing spillway capacity as a sole measure is not considered practical and would likely not achieve the needed results.

Similarly, raising the top of the dam to achieve the desired freeboard during the 1/2 PMF would result in an approx. 4.8-ft of dam height increase. This significant increase may not be practical as a sole measure based on topographic restrictions and additional impacts to shoreline properties as a result of increased storage and water levels in the lake.

Improving the primary spillway (i.e. removing the operated gate and improving discharge capacity would provide increases in freeboard available to lessor storms which currently (based on this analysis) do not overtop the dam. It is not anticipated that this option would significantly alter the results of the events which currently (based on this analysis) do overtop the dam. Additionally the original primary spillway was designed to support historical functions of the dam which no longer exist. The primary spillway could be redesigned to increase performance and reliability for in reference to the dam's current purpose (recreation).

Armoring the dam and abutments to prevent erosion and scour during overtopping is considered to be a practical solution to achieve the desired dam safety criteria. Based on an initial review of practical alternatives, an armoring / overtopping protection combined with some increase in the top of dam is likely the most cost-effective alternative.

It is important to note any measure aimed at bringing the dam into compliance will involve balancing flowage rights and inundation upstream of the dam vs impacts of additional discharge downstream of the dam.

# Attachment A

## Photo Log

**Project Name:**  
Shadow Lake Dam H&H Analysis

**Site Location:**  
Glover, Vermont

**Project No.:**  
925163

<b>Photo No.:</b> 1	<b>Date:</b> 8-21-2019
<b>Photo Orientation:</b> North West	
<b>Description:</b> Daniels Pond	



<b>Photo No.:</b> 2	<b>Date:</b> 8-21-2019
<b>Photo Orientation:</b> East	
<b>Description:</b> Daniels Pond ~ 70" x 42" arch culvert outlet under Daniels Pond Road.	



<b>Project Name:</b> Shadow Lake Dam H&H Analysis	<b>Site Location:</b> Glover, Vermont	<b>Project No.:</b> 925163
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<b>Photo No.:</b> 3	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> North		
<b>Description:</b> Daniels Pond Road		

<b>Photo No.:</b> 4	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> North West		
<b>Description:</b> Daniels Pond Road culvert outlet.		

<b>Project Name:</b> Shadow Lake Dam H&H Analysis	<b>Site Location:</b> Glover, Vermont	<b>Project No.:</b> 925163
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<b>Photo No.:</b> 5	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> West		
<b>Description:</b> Shadow Lake		

<b>Photo No.:</b> 6	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> South East		
<b>Description:</b> Shadow Lake Dam		

<b>Project Name:</b> Shadow Lake Dam H&H Analysis	<b>Site Location:</b> Glover, Vermont	<b>Project No.:</b> 925163
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<b>Photo No.:</b> 7	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> East		
<b>Description:</b> Shadow Lake Dam auxiliary spillway (chute)		

<b>Photo No.:</b> 8	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> West		
<b>Description:</b> Shadow Lake Dam auxiliary spillway inlet condition.		

<b>Project Name:</b> Shadow Lake Dam H&H Analysis	<b>Site Location:</b> Glover, Vermont	<b>Project No.:</b> 925163
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<b>Photo No.:</b> 9	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> South		
<b>Description:</b> Shadow Lake Dam center section and primary spillway gatehouse.		

<b>Photo No.:</b> 10	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> South		
<b>Description:</b> Shadow Lake Dam primary spillway gatehouse structure inlet and southern end of dam.		

<b>Project Name:</b> Shadow Lake Dam H&H Analysis	<b>Site Location:</b> Glover, Vermont	<b>Project No.:</b> 925163
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<b>Photo No.:</b> 11	<b>Date:</b> 8-21-2019
<b>Photo Orientation:</b> North	
<b>Description:</b> Shadow Lake Dam northern end of dam (upstream face).	



<b>Photo No.:</b> 12	<b>Date:</b> 8-21-2019
<b>Photo Orientation:</b> North West	
<b>Description:</b> Shadow Lake Dam primary spillway gatehouse outlet (36" dia.).	



<b>Project Name:</b> Shadow Lake Dam H&H Analysis	<b>Site Location:</b> Glover, Vermont	<b>Project No.:</b> 925163
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<b>Photo No.:</b> 13	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> North		
<b>Description:</b> Shadow Lake Dam downstream toe.		

<b>Photo No.:</b> 14	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> West		
<b>Description:</b> Shadow Lake Dam downstream toe.		

<b>Project Name:</b> Shadow Lake Dam H&H Analysis	<b>Site Location:</b> Glover, Vermont	<b>Project No.:</b> 925163
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<b>Photo No.:</b> 15	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> East		
<b>Description:</b> Shadow Lake Dam downstream reach.		

<b>Photo No.:</b> 16	<b>Date:</b> 8-21-2019	
<b>Photo Orientation:</b> South		
<b>Description:</b> Stone Shore Road stream crossing downstream of Shadow Lake Dam.		

# Attachment B

## Watershed Mapping & Input Data







Soil Map—Orleans County, Vermont  
(Shadow Lake Drainage Area)


### MAP LEGEND

**Area of Interest (AOI)**

 Area of Interest (AOI)




















**Soils**







 Soil Map Unit Polygons

 Soil Map Unit Lines


 Soil Map Unit Points

**Special Point Features**






-  Blowout
-  Borrow Pit
-  Clay Spot
-  Closed Depression
-  Gravel Pit
-  Gravelly Spot
-  Landfill
-  Lava Flow
-  Marsh or swamp
-  Mine or Quarry
-  Miscellaneous Water
-  Perennial Water
-  Rock Outcrop
-  Saline Spot
-  Sandy Spot
-  Severely Eroded Spot
-  Sinkhole
-  Slide or Slip
-  Sodic Spot

-  Spoil Area
-  Stony Spot
-  Very Stony Spot
-  Wet Spot
-  Other
-  Special Line Features


**Water Features**

 Streams and Canals

**Transportation**

-  Rails
-  Interstate Highways
-  US Routes
-  Major Roads
-  Local Roads

**Background**

 Aerial Photography

### MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service  
Web Soil Survey URL:  
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Orleans County, Vermont  
Survey Area Data: Version 27, Sep 16, 2019

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: May 1, 2011—Sep 26, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

## Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
2A	Peacham mucky peat, 0 to 8 percent slopes, very stony	27.8	0.8%
3B	Vershire-Lombard complex, 3 to 8 percent slopes, rocky	0.8	0.0%
3C	Vershire-Lombard complex, 8 to 15 percent slopes, rocky	14.6	0.4%
3D	Vershire-Lombard complex, 15 to 25 percent slopes, rocky	8.3	0.2%
6C	Vershire-Lombard complex, 8 to 15 percent slopes, very stony	10.8	0.3%
12C	Tunbridge-Lyman complex, 8 to 15 percent slopes, very rocky	66.1	2.0%
12D	Tunbridge-Lyman complex, 15 to 35 percent slopes, very rocky	211.8	6.3%
12E	Tunbridge-Lyman complex, 35 to 60 percent slopes, very rocky	198.6	5.9%
17B	Buckland loam, 3 to 8 percent slopes	148.3	4.4%
17C	Buckland loam, 8 to 15 percent slopes	198.0	5.9%
17D	Buckland loam, 15 to 25 percent slopes	19.3	0.6%
18C	Buckland loam, 8 to 15 percent slopes, very stony	635.0	18.8%
18D	Buckland loam, 15 to 35 percent slopes, very stony	264.1	7.8%
47B	Cabot silt loam, 3 to 8 percent slopes	49.9	1.5%
47C	Cabot silt loam, 8 to 15 percent slopes	30.2	0.9%
59B	Cabot silt loam, 0 to 8 percent slopes, very stony	211.2	6.2%
59C	Cabot silt loam, 8 to 15 percent slopes, very stony	503.5	14.9%
83A	Wonsqueak and Pondicherry mucks, 0 to 2 percent slopes	154.8	4.6%
93C	Monadnock fine sandy loam, 8 to 15 percent slopes, very stony	4.7	0.1%
94D	Vershire-Glover complex, 15 to 35 percent slopes, very rocky	46.0	1.4%

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
94E	Vershire-Glover complex, 35 to 60 percent slopes, very rocky	65.2	1.9%
100B	Tunbridge-Peru complex, 3 to 8 percent slopes, rocky	8.9	0.3%
100C	Tunbridge-Peru complex, 8 to 15 percent slopes, rocky	9.2	0.3%
101C	Tunbridge-Peru complex, 8 to 15 percent slopes, very stony	121.3	3.6%
101D	Tunbridge-Peru complex, 15 to 35 percent slopes, very stony	45.5	1.3%
101E	Tunbridge-Peru complex, 35 to 60 percent slopes, very stony	48.4	1.4%
W	Water	282.7	8.4%
<b>Totals for Area of Interest</b>		<b>3,385.0</b>	<b>100.0%</b>



**NOAA Atlas 14, Volume 10, Version 3**  
**Location name: Glover, Vermont, USA\***  
**Latitude: 44.6666°, Longitude: -72.2165°**  
**Elevation: 1394.36 ft\*\***  
 \* source: ESRI Maps  
 \*\* source: USGS



**POINT PRECIPITATION FREQUENCY ESTIMATES**

Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite

NOAA, National Weather Service, Silver Spring, Maryland

[PF\\_tabular](#) | [PF\\_graphical](#) | [Maps & aerials](#)

**PF tabular**

<b>PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)<sup>1</sup></b>										
<b>Duration</b>	<b>Average recurrence interval (years)</b>									
	<b>1</b>	<b>2</b>	<b>5</b>	<b>10</b>	<b>25</b>	<b>50</b>	<b>100</b>	<b>200</b>	<b>500</b>	<b>1000</b>
<b>5-min</b>	<b>0.304</b> (0.238-0.386)	<b>0.351</b> (0.274-0.446)	<b>0.428</b> (0.332-0.545)	<b>0.491</b> (0.380-0.630)	<b>0.578</b> (0.432-0.768)	<b>0.645</b> (0.471-0.873)	<b>0.712</b> (0.503-0.996)	<b>0.783</b> (0.529-1.13)	<b>0.879</b> (0.571-1.31)	<b>0.954</b> (0.604-1.45)
<b>10-min</b>	<b>0.431</b> (0.337-0.547)	<b>0.497</b> (0.388-0.631)	<b>0.605</b> (0.471-0.771)	<b>0.695</b> (0.537-0.889)	<b>0.818</b> (0.611-1.09)	<b>0.913</b> (0.668-1.24)	<b>1.01</b> (0.713-1.41)	<b>1.11</b> (0.749-1.60)	<b>1.25</b> (0.808-1.86)	<b>1.35</b> (0.856-2.06)
<b>15-min</b>	<b>0.507</b> (0.396-0.643)	<b>0.584</b> (0.456-0.743)	<b>0.711</b> (0.553-0.906)	<b>0.817</b> (0.632-1.05)	<b>0.963</b> (0.719-1.28)	<b>1.07</b> (0.784-1.46)	<b>1.19</b> (0.839-1.66)	<b>1.31</b> (0.881-1.88)	<b>1.47</b> (0.952-2.18)	<b>1.59</b> (1.01-2.42)
<b>30-min</b>	<b>0.666</b> (0.521-0.845)	<b>0.768</b> (0.600-0.976)	<b>0.935</b> (0.728-1.19)	<b>1.08</b> (0.831-1.38)	<b>1.27</b> (0.945-1.68)	<b>1.41</b> (1.03-1.91)	<b>1.56</b> (1.10-2.18)	<b>1.71</b> (1.16-2.47)	<b>1.92</b> (1.24-2.85)	<b>2.07</b> (1.31-3.15)
<b>60-min</b>	<b>0.826</b> (0.645-1.05)	<b>0.952</b> (0.744-1.21)	<b>1.16</b> (0.901-1.48)	<b>1.33</b> (1.03-1.71)	<b>1.57</b> (1.17-2.08)	<b>1.75</b> (1.28-2.37)	<b>1.93</b> (1.36-2.70)	<b>2.12</b> (1.43-3.05)	<b>2.37</b> (1.54-3.52)	<b>2.55</b> (1.61-3.88)
<b>2-hr</b>	<b>1.03</b> (0.811-1.30)	<b>1.20</b> (0.946-1.52)	<b>1.49</b> (1.17-1.88)	<b>1.72</b> (1.34-2.19)	<b>2.05</b> (1.54-2.71)	<b>2.29</b> (1.69-3.10)	<b>2.55</b> (1.81-3.56)	<b>2.82</b> (1.91-4.04)	<b>3.20</b> (2.08-4.75)	<b>3.51</b> (2.23-5.30)
<b>3-hr</b>	<b>1.16</b> (0.918-1.46)	<b>1.37</b> (1.08-1.72)	<b>1.71</b> (1.34-2.15)	<b>1.99</b> (1.55-2.52)	<b>2.37</b> (1.79-3.13)	<b>2.66</b> (1.97-3.59)	<b>2.96</b> (2.12-4.14)	<b>3.30</b> (2.24-4.72)	<b>3.78</b> (2.46-5.59)	<b>4.17</b> (2.65-6.29)
<b>6-hr</b>	<b>1.41</b> (1.12-1.76)	<b>1.68</b> (1.33-2.10)	<b>2.11</b> (1.67-2.65)	<b>2.48</b> (1.95-3.12)	<b>2.98</b> (2.26-3.92)	<b>3.35</b> (2.49-4.50)	<b>3.74</b> (2.71-5.23)	<b>4.20</b> (2.86-5.97)	<b>4.87</b> (3.18-7.16)	<b>5.43</b> (3.46-8.14)
<b>12-hr</b>	<b>1.68</b> (1.35-2.09)	<b>2.02</b> (1.61-2.50)	<b>2.56</b> (2.04-3.19)	<b>3.01</b> (2.38-3.77)	<b>3.63</b> (2.78-4.75)	<b>4.09</b> (3.07-5.48)	<b>4.58</b> (3.34-6.38)	<b>5.16</b> (3.53-7.30)	<b>6.03</b> (3.95-8.82)	<b>6.75</b> (4.32-10.1)
<b>24-hr</b>	<b>1.99</b> (1.61-2.46)	<b>2.38</b> (1.92-2.94)	<b>3.02</b> (2.42-3.74)	<b>3.55</b> (2.83-4.42)	<b>4.28</b> (3.29-5.57)	<b>4.82</b> (3.63-6.42)	<b>5.40</b> (3.95-7.47)	<b>6.08</b> (4.17-8.55)	<b>7.08</b> (4.66-10.3)	<b>7.92</b> (5.08-11.8)
<b>2-day</b>	<b>2.37</b> (1.92-2.90)	<b>2.81</b> (2.27-3.44)	<b>3.51</b> (2.83-4.31)	<b>4.10</b> (3.28-5.06)	<b>4.91</b> (3.79-6.33)	<b>5.51</b> (4.17-7.26)	<b>6.15</b> (4.50-8.41)	<b>6.88</b> (4.74-9.61)	<b>7.93</b> (5.24-11.5)	<b>8.81</b> (5.67-13.0)
<b>3-day</b>	<b>2.67</b> (2.17-3.25)	<b>3.12</b> (2.53-3.80)	<b>3.85</b> (3.12-4.71)	<b>4.46</b> (3.59-5.49)	<b>5.30</b> (4.11-6.81)	<b>5.93</b> (4.50-7.78)	<b>6.60</b> (4.84-8.98)	<b>7.35</b> (5.08-10.2)	<b>8.43</b> (5.59-12.2)	<b>9.33</b> (6.02-13.7)
<b>4-day</b>	<b>2.93</b> (2.39-3.55)	<b>3.39</b> (2.76-4.12)	<b>4.14</b> (3.36-5.06)	<b>4.77</b> (3.85-5.85)	<b>5.64</b> (4.38-7.21)	<b>6.28</b> (4.78-8.22)	<b>6.97</b> (5.12-9.46)	<b>7.74</b> (5.36-10.7)	<b>8.86</b> (5.88-12.7)	<b>9.78</b> (6.32-14.4)
<b>7-day</b>	<b>3.61</b> (2.96-4.36)	<b>4.11</b> (3.37-4.97)	<b>4.93</b> (4.02-5.98)	<b>5.61</b> (4.55-6.84)	<b>6.54</b> (5.12-8.32)	<b>7.25</b> (5.53-9.42)	<b>7.99</b> (5.89-10.8)	<b>8.82</b> (6.14-12.2)	<b>10.0</b> (6.68-14.4)	<b>11.0</b> (7.15-16.1)
<b>10-day</b>	<b>4.26</b> (3.51-5.13)	<b>4.80</b> (3.94-5.78)	<b>5.68</b> (4.65-6.87)	<b>6.41</b> (5.21-7.79)	<b>7.42</b> (5.82-9.39)	<b>8.18</b> (6.26-10.6)	<b>8.97</b> (6.62-12.0)	<b>9.85</b> (6.87-13.6)	<b>11.1</b> (7.41-15.8)	<b>12.1</b> (7.86-17.7)
<b>20-day</b>	<b>6.24</b> (5.17-7.45)	<b>6.89</b> (5.70-8.24)	<b>7.96</b> (6.56-9.55)	<b>8.84</b> (7.24-10.7)	<b>10.1</b> (7.92-12.6)	<b>11.0</b> (8.43-14.0)	<b>11.9</b> (8.79-15.7)	<b>12.9</b> (9.03-17.6)	<b>14.1</b> (9.46-20.0)	<b>15.0</b> (9.78-21.8)
<b>30-day</b>	<b>7.89</b> (6.57-9.39)	<b>8.64</b> (7.18-10.3)	<b>9.86</b> (8.16-11.8)	<b>10.9</b> (8.93-13.1)	<b>12.3</b> (9.68-15.3)	<b>13.4</b> (10.3-16.9)	<b>14.4</b> (10.6-18.8)	<b>15.4</b> (10.8-20.9)	<b>16.6</b> (11.2-23.5)	<b>17.5</b> (11.4-25.2)
<b>45-day</b>	<b>9.96</b> (8.32-11.8)	<b>10.8</b> (9.02-12.8)	<b>12.2</b> (10.2-14.6)	<b>13.4</b> (11.0-16.0)	<b>15.0</b> (11.9-18.5)	<b>16.3</b> (12.5-20.5)	<b>17.5</b> (12.8-22.6)	<b>18.5</b> (13.1-25.1)	<b>19.8</b> (13.4-27.9)	<b>20.7</b> (13.5-29.8)
<b>60-day</b>	<b>11.7</b> (9.80-13.8)	<b>12.7</b> (10.6-15.0)	<b>14.2</b> (11.8-16.9)	<b>15.5</b> (12.8-18.5)	<b>17.3</b> (13.7-21.3)	<b>18.7</b> (14.4-23.5)	<b>20.0</b> (14.7-25.8)	<b>21.2</b> (15.0-28.6)	<b>22.6</b> (15.3-31.7)	<b>23.5</b> (15.4-33.7)

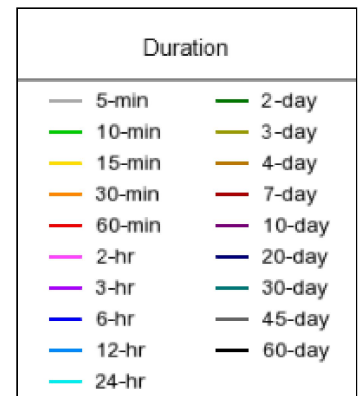
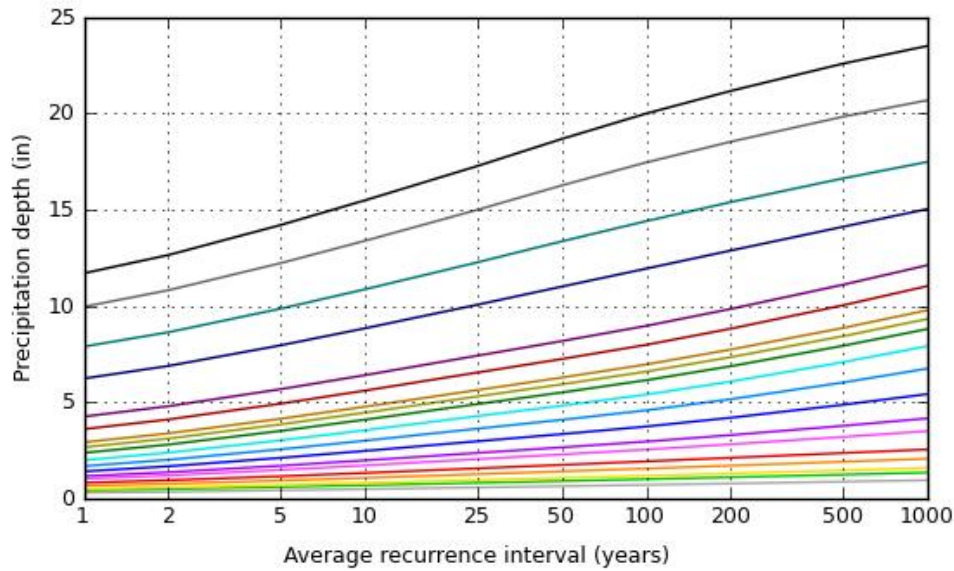
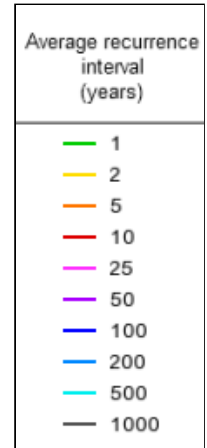
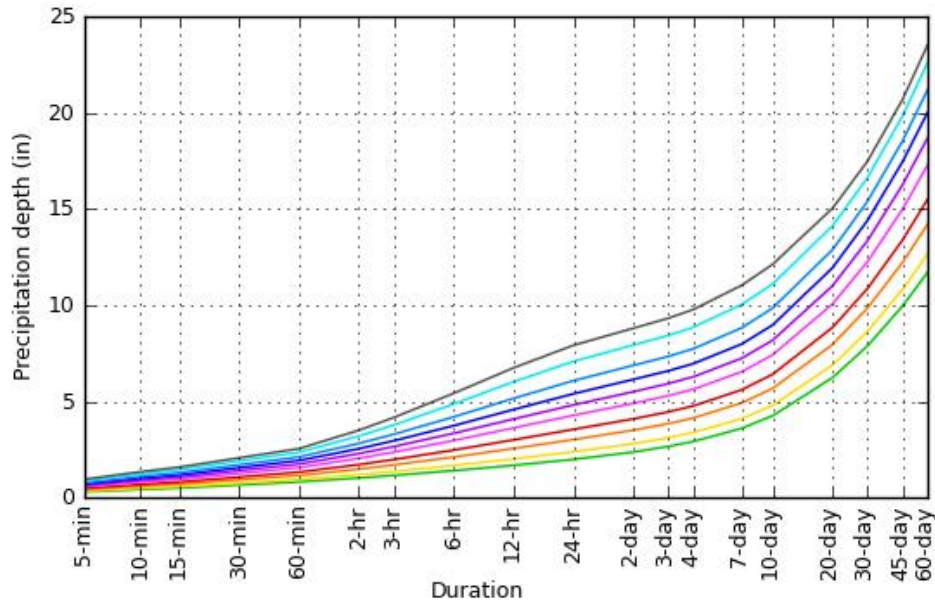
<sup>1</sup> Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS). Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values. Please refer to NOAA Atlas 14 document for more information.

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**PF graphical**

PDS-based depth-duration-frequency (DDF) curves

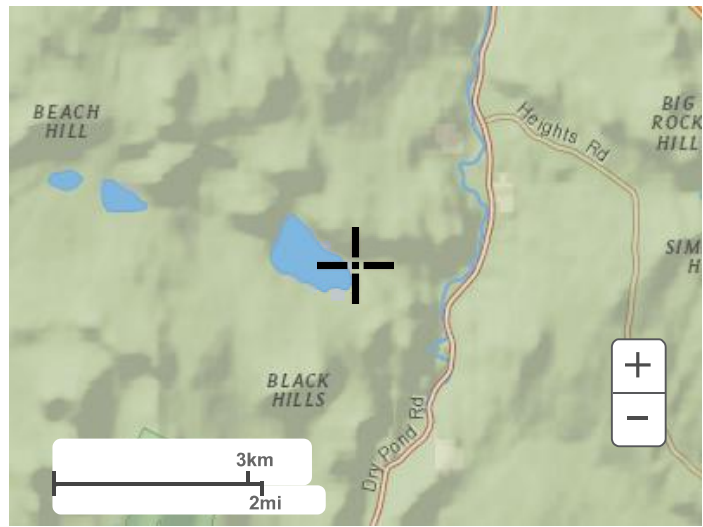
Latitude: 44.6666°, Longitude: -72.2165°



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**Maps & aerials**

**Small scale terrain**



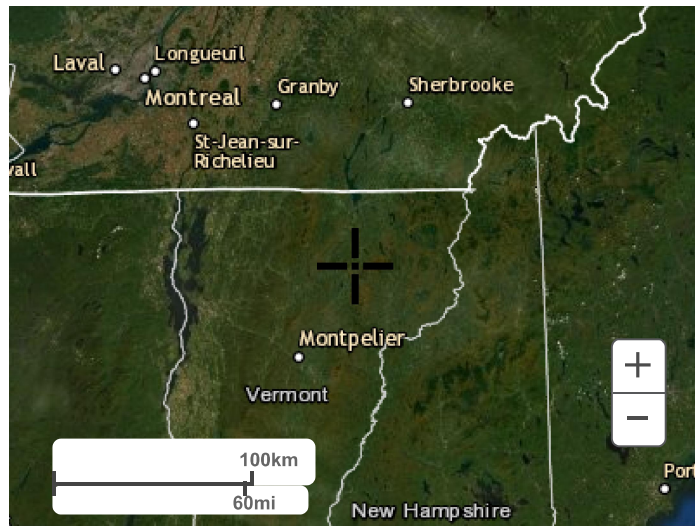
Large scale terrain



Large scale map



Large scale aerial



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[National Weather Service](#)  
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1325 East West Highway  
Silver Spring, MD 20910  
Questions?: [HDSC.Questions@noaa.gov](mailto:HDSC.Questions@noaa.gov)

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JOB 925163 - Shadow Lake Dam

SHEET NO. \_\_\_\_\_ OF \_\_\_\_\_

CALCULATED BY: AJS DATE: 10/3/19

CHECKED BY: \_\_\_\_\_ DATE: \_\_\_\_\_

SCALE: \_\_\_\_\_

### PMP Precipitation Estimate (10 sq. mi.)

Duration	Factor	Rainfall (inches)	Data Source
5-min	0.34	4.16	The Mult. factor is found in HMR52 pg 94
15-min	0.539	6.52	The Mult. factor is found in HMR52 pg 95
60-min	1.0	12.10	Value is from HMR52 pg 87
6-hr	1.0	20.50	The PMP value is taken from HMR51 pg 48
12-hr	1.0	23.50	The PMP value is taken from HMR51 pg 49
24-hr	1.0	26.00	The PMP value is taken from HMR51 pg 50
48-hr	1.0	29.00	The PMP value is taken from HMR51 pg 51
72-hr	1.0	30.00	The PMP value is taken from HMR51 pg 52

Time (min)	1/4 PMP precip *	1/2 PMP precip *	3/4 PMP precip *	Full PMP precip
5	1.04	2.08	3.12	4.16
15	1.63	3.26	4.89	6.52
60	3.03	6.05	9.08	12.10
360	5.13	10.25	15.38	20.50
720	5.88	11.75	17.63	23.50
1440	6.50	13.00	19.50	26.00
2880	7.25	14.50	21.75	29.00
4320	7.50	15.00	22.50	30.00

\* Fractions of PMP NOT USED in analysis shown for illustrative purposes only.

**Reference:** HydroMeteorological Report No. 51 and 52

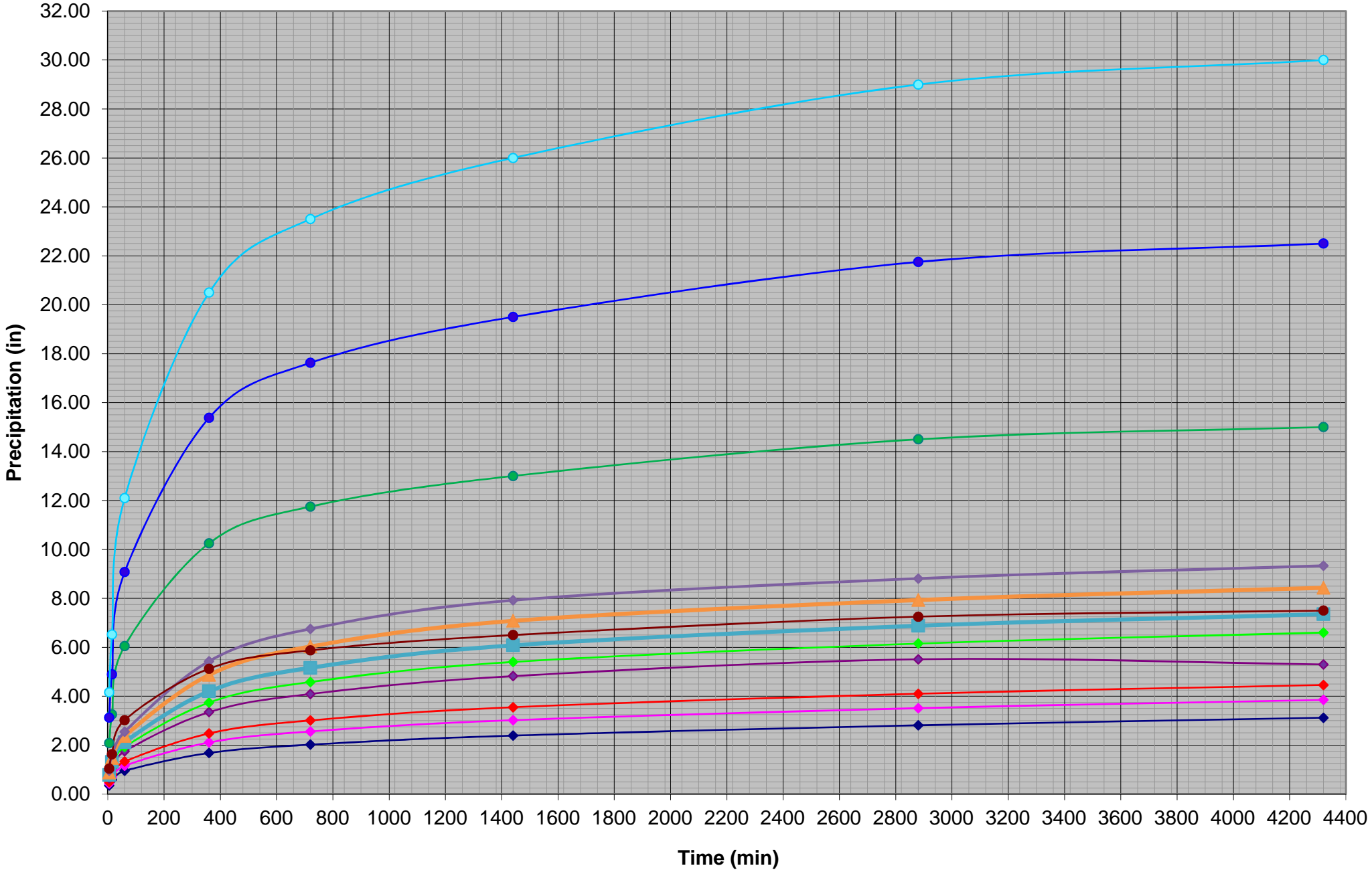
Probable Maximum Precipitation Estimates, US East of the 105th Meridian

NOAA -- US ACOE, 1986



# Precipitation Estimates for Shadow Lake Dam H&H Analysis

- 2 YR Precip
- 5 YR Precip
- 10 YR Precip
- 50 YR Precip
- 100 YR Precip
- 200 YR Precip
- 500 YR Precip
- 1000 YR Precip
- 1/4 PMP precip
- 1/2 PMP precip
- 3/4 PMP precip
- Full PMP precip





JOB: 925163 - Shadow Lake Dam

SHEET NO. \_\_\_\_\_ OF \_\_\_\_\_

CALCULATED BY: A. Sampsell DATE: 7/13/2020

CHECKED BY: \_\_\_\_\_ DATE: \_\_\_\_\_

SCALE: \_\_\_\_\_

## NRCS 5-pt Critically Stacked PMP Rainfall Distribution

**Notes:** Obtain the 6, 12, and 24-hour PMP rainfall values from HMR-51.

Distribute the rainfall values in 6-hour increments.

- a.) First 6-hour block is half of the difference between the 12-hour and 24-hour PMP.
- b.) Second 6-hour block is the 6 hour PMP.
- c.) Third 6-hour block is the difference between the 12-hour and 6-hour PMP.
- d.) Fourth 6-hour block is half of the difference between the 12-hour and 24-hour PMP.

Rainfall Duration (hours)	HMR-51 Depth (inches)
0	0
6	20.50
12	23.50
24	26.00

Rainfall Duration (hours)	6-hour block	Incremental Depth (Inches)	Cumulative Depth (Inches)
0	---	---	---
6	a	1.25	1.25
12	b	20.50	21.75
18	c	3.00	24.75
24	d	1.25	26.00

**Reference:** National Engineering Handbook Part 630 Hydrology

Chapter 21 - Design Hydrographs

USDA NRCS, 1987, Amended May 2019



JOB: 925163 - Shadow Lake Dam

SHEET NO. \_\_\_\_\_ OF \_\_\_\_\_

CALCULATED BY: A. Sampsell DATE: 7/13/2020

CHECKED BY: \_\_\_\_\_ DATE: \_\_\_\_\_

SCALE: \_\_\_\_\_

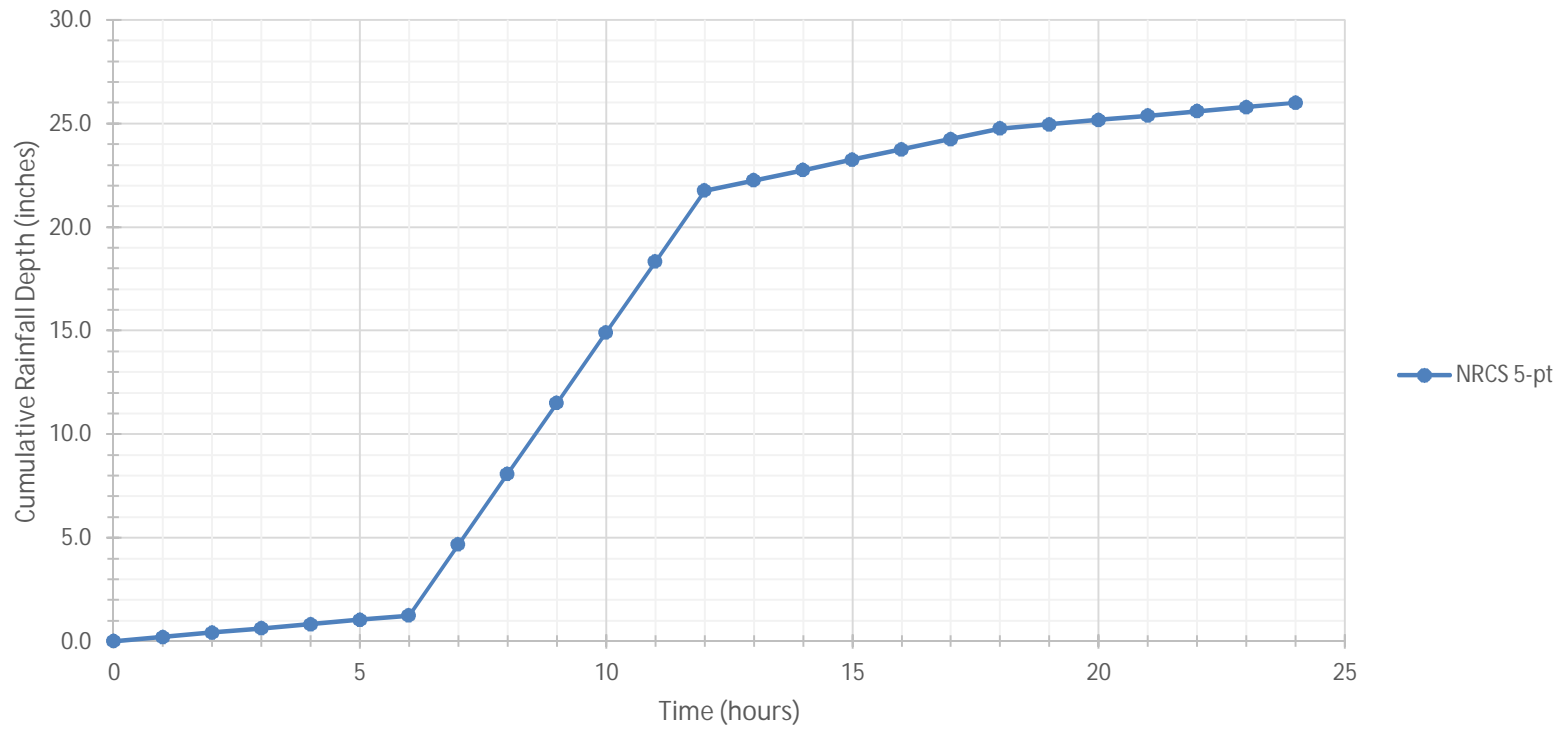
### NRCS 5-pt Critically Stacked PMP Rainfall Distribution

Time (hours)	6-hour Block Distribution	Incremental Depth (inches)	Total Depth (inches)	Percent Accumulation
0		0.0000	0.0000	0.0000
1		0.2083	0.2083	0.0080
2		0.2083	0.4167	0.0160
3	1.25	0.2083	0.6250	0.0240
4		0.2083	0.8333	0.0321
5		0.2083	1.0417	0.0401
6		0.2083	1.2500	0.0481
7		3.4167	4.6667	0.1795
8		3.4167	8.0833	0.3109
9	20.50	3.4167	11.5000	0.4423
10		3.4167	14.9167	0.5737
11		3.4167	18.3333	0.7051
12		3.4167	21.7500	0.8365
13		0.5000	22.2500	0.8558
14		0.5000	22.7500	0.8750
15	3.00	0.5000	23.2500	0.8942
16		0.5000	23.7500	0.9135
17		0.5000	24.2500	0.9327
18		0.5000	24.7500	0.9519
19		0.2083	24.9583	0.9599
20		0.2083	25.1667	0.9679
21	1.25	0.2083	25.3750	0.9760
22		0.2083	25.5833	0.9840
23		0.2083	25.7917	0.9920
24		0.2083	26.0000	1.0000

**Reference:** National Engineering Handbook Part 630 Hydrology  
 Chapter 21 - Design Hydrographs  
 USDA NRCS, 1987, Amended May 2019



Shadow Lake Dam  
Glover, VT  
NRCS 5-pt Critically Stacked PMP Rainfall Distribution





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# Regional estimation of base flow for the conterminous United States by hydrologic landscape regions

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Received 8 June 2007; received in revised form 2 December 2007; accepted 4 December 2007

## KEYWORDS

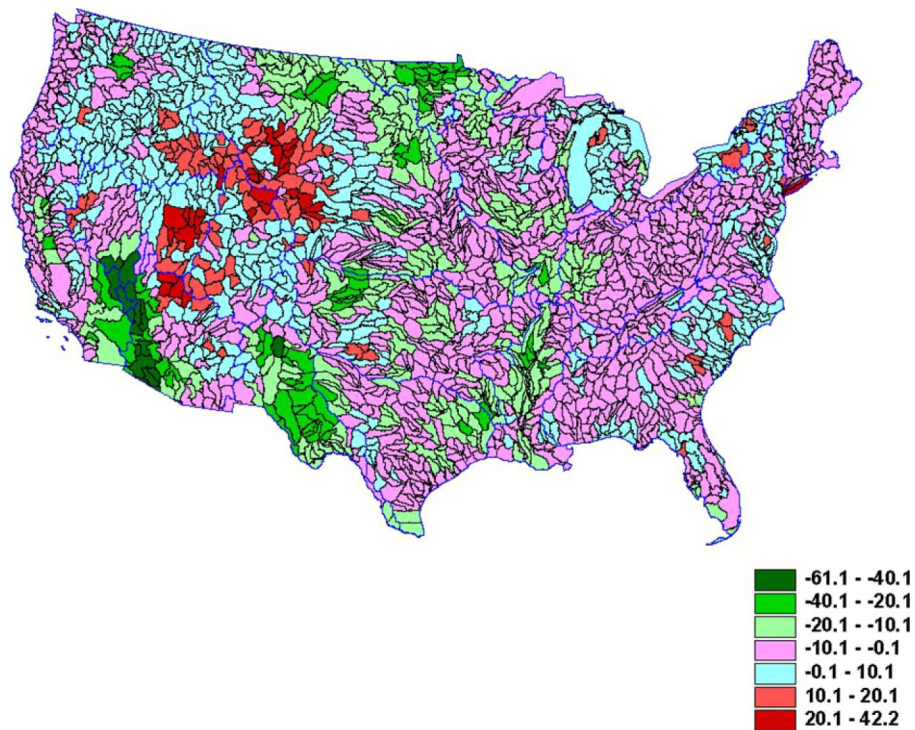
Base flow;  
Recursive digital filter  
method;  
Landscape regions;  
Regression;  
Regionalization;  
Continental

**Summary** Information on base flow availability and/or contributions is needed to develop water quantity and water quality management strategies. Base flow availability varies over space and time in a region due to climate, topography, landscape, and geological characteristics. In this study, base flow index (BFI) (base flow/total stream flow) was estimated from daily streamflow records using a recursive digital filter method and interpolated to produce a raster grid map for the conterminous United States. When compared for validation, BFI estimated by recursive digital filter method showed good agreement overall with the USGS smoothed minima BFI method. Estimated base flow index and volume were analyzed, with Hydrological Landscape Regions (HLRs) developed for the United States to identify the mean hydrologic flow response within HLR. They were also used to determine relationships with hydro-geologic descriptive variables and used for defining the HLRs based on Pearson's correlation table and a stepwise multiple regression. These descriptive variables used in defining the HLRs include relief, effective rainfall, potential evapotranspiration and percentage of sand. The regression results indicated that relief and percentage of sand were highly correlated to base flow index, and the amount of base flow volume can be related to gradient and the amount of effective rainfall. The regression results also suggested that the descriptive variables used in constructing the HLR can be used to define mean values of shallow ground water flow within the regions. Further testing is needed to ascertain if such relationships could be used to define flow within an HLR.

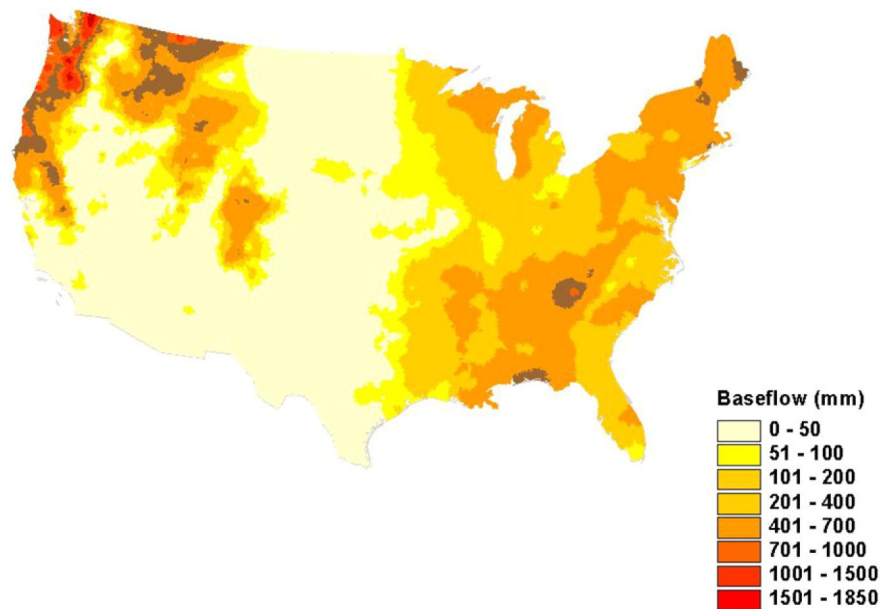
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**Figure 4** Residuals (in %) of base flow index at 8-digit HUCs between the USGS base flow index and recursive digital filter methods.



**Figure 5** Base flow volume estimated for the hydrologic landscape regions from filter base flow index and USGS total flow.

### Hydrological landscape regions

In the present study, the concept of hydrologic landscape regions developed by Wolock et al. (2004) is used for analysis. According to Wolock et al. (2004), the hydrologic system of a fundamental hydrologic landscape unit consists of: (a) the movement of surface water, which is controlled by the slopes and permeability of the landscape; (b) the movement of ground water, which is controlled by the hydraulic

characteristics of the geologic framework; and (c) atmosphere-water exchange, which is controlled by climate (Fig. 6). All hydrologic units are variations of fundamental hydrologic landscape units that can be used to define general landscape types. Also, the movement of water over the surface and through the subsurface of generalized landscapes is controlled by common physical principles regardless of the geographic location of the landscapes. The authors suggest that for example, in a landscape with low

# Attachment C

HEC-HMS

# HEC-HMS Model Input & Output

## Daniels Pond Subcatchment Input

Basin Model

**Name: Daniels Pond Subcatchment**

Description:

Unit System: U.S. Customary

Sediment: No

Replace Missing: No

Local Flow: No

Flow Ratios: No

Default Grid Region: --None--

Subbasin Loss Transform Baseflow Options

**Basin Name: Daniels Pond Subcatchment**

**Element Name: 1**

Description:

Downstream: --None--

\*Area (MI<sup>2</sup>): 1.4312

Latitude Degrees:

Longitude Degrees:

Canopy Method: --None--

Surface Method: --None--

Loss Method: SCS Curve Number

Transform Method: SCS Unit Hydrograph

Baseflow Method: Constant Monthly

Subbasin Loss Transform Baseflow Options

**Basin Name: Daniels Pond Subcatchment**

**Element Name: 1**

Initial Abstraction (IN): 0.667

\*Curve Number: 75

\*Impervious (%): 0.0

Subbasin Loss Transform Baseflow Options

**Basin Name: Daniels Pond Subcatchment**

**Element Name: 1**

Graph Type: Standard (PRF 484)

\*Lag Time (MIN): 57.54

Subbasin Loss Transform Baseflow Options

**Basin Name: Daniels Pond Subcatchment**

**Element Name: 1**

*January (CFS)	2.91
*February (CFS)	2.91
*March (CFS)	2.91
*April (CFS)	2.91
*May (CFS)	2.91
*June (CFS)	2.91
*July (CFS)	2.91
*August (CFS)	2.91
*September (CFS)	2.91
*October (CFS)	2.91
*November (CFS)	2.91
*December (CFS)	2.91

Subbasin Loss Transform Baseflow Options

**Basin Name: Daniels Pond Subcatchment**

**Element Name: 1**

Observed Flow: --None--

Observed Stage: --None--

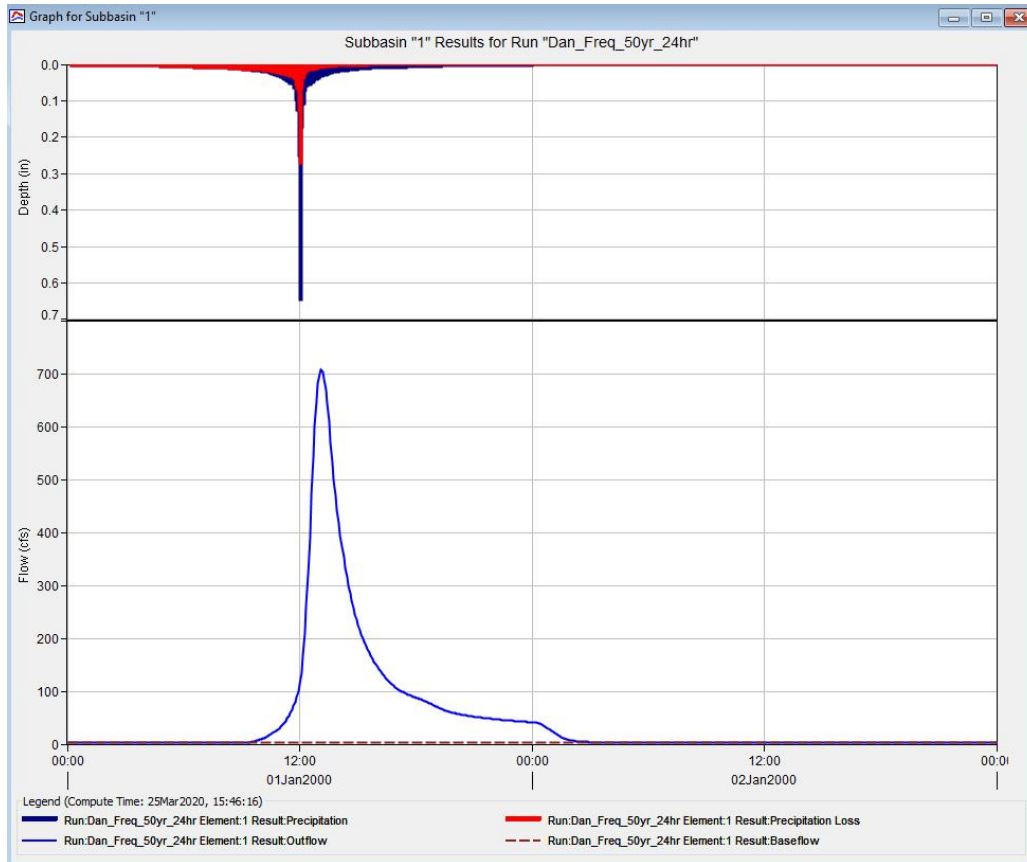
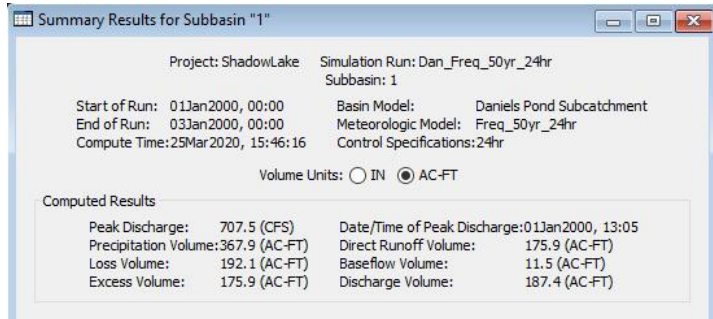
Observed SWE: --None--

Elev-Discharge: --None--

Ref Flow (CFS):

Ref Label:

# Daniels Pond Subcatchment 50-yr Output



# Daniels Pond Subcatchment 100-yr Output

Global Summary Results for Run "Dan\_Freq\_100yr\_24hr"

Project: ShadowLake Simulation Run: Dan\_Freq\_100yr\_24hr

Start of Run: 01Jan2000, 00:00 Basin Model: Daniels Pond Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_100yr\_24hr  
 Compute Time: 25Mar2020, 15:46:15 Control Specifications: 24hr

Show Elements: All Elements Volume Units:  IN  AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI <sup>2</sup> )	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
1	1.43	848.8	01Jan2000, 13:05	223.5

Summary Results for Subbasin "1"

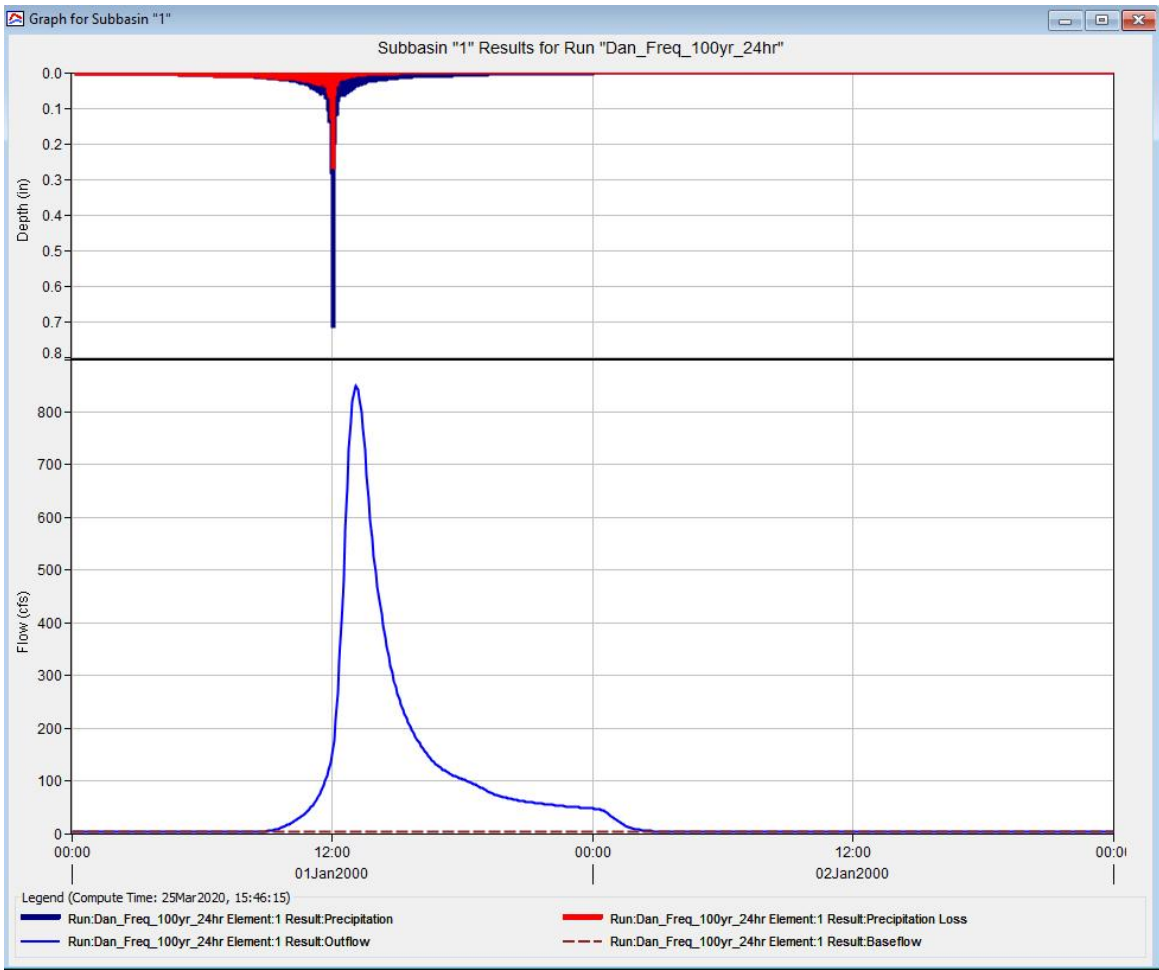
Project: ShadowLake Simulation Run: Dan\_Freq\_100yr\_24hr  
 Subbasin: 1

Start of Run: 01Jan2000, 00:00 Basin Model: Daniels Pond Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_100yr\_24hr  
 Compute Time: 25Mar2020, 15:46:15 Control Specifications: 24hr

Volume Units:  IN  AC-FT

Computed Results

Peak Discharge:	848.8 (CFS)	Date/Time of Peak Discharge:	01Jan2000, 13:05
Precipitation Volume:	412.2 (AC-FT)	Direct Runoff Volume:	212.0 (AC-FT)
Loss Volume:	200.2 (AC-FT)	Baseflow Volume:	11.5 (AC-FT)
Excess Volume:	212.0 (AC-FT)	Discharge Volume:	223.5 (AC-FT)



# Daniels Pond Subcatchment 200-yr Output

Global Summary Results for Run "Dan\_Freq\_200yr\_24hr"

Project: ShadowLake Simulation Run: Dan\_Freq\_200yr\_24hr

Start of Run: 01Jan2000, 00:00 Basin Model: Daniels Pond Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_200yr\_24hr  
 Compute Time: 25Mar2020, 15:46:16 Control Specifications: 24hr

Show Elements: All Elements Volume Units:  IN  AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI <sup>2</sup> )	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
1	1.43	1083.7	01Jan2000, 13:05	320.2

Summary Results for Subbasin "1"

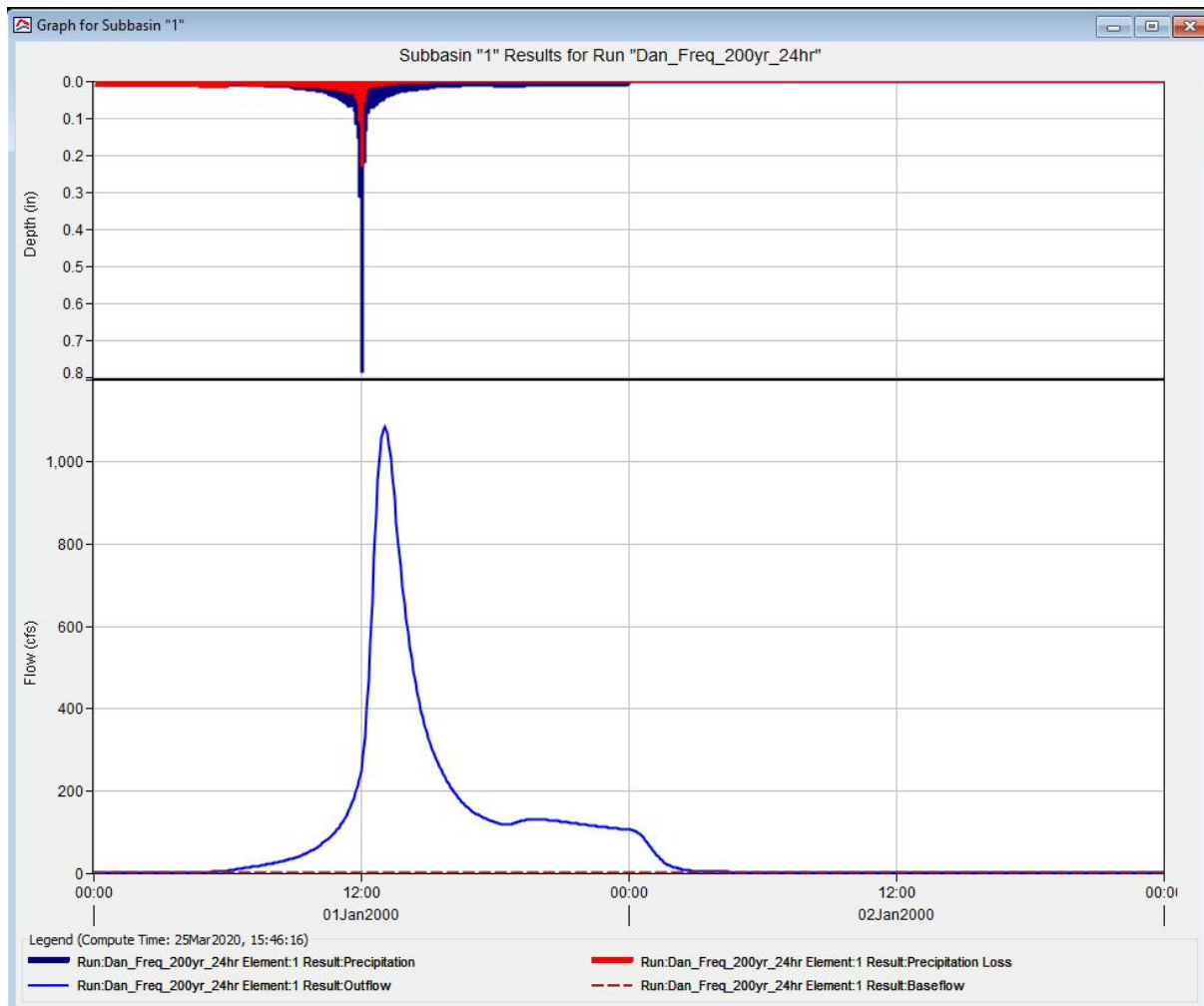
Project: ShadowLake Simulation Run: Dan\_Freq\_200yr\_24hr  
 Subbasin: 1

Start of Run: 01Jan2000, 00:00 Basin Model: Daniels Pond Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_200yr\_24hr  
 Compute Time: 25Mar2020, 15:46:16 Control Specifications: 24hr

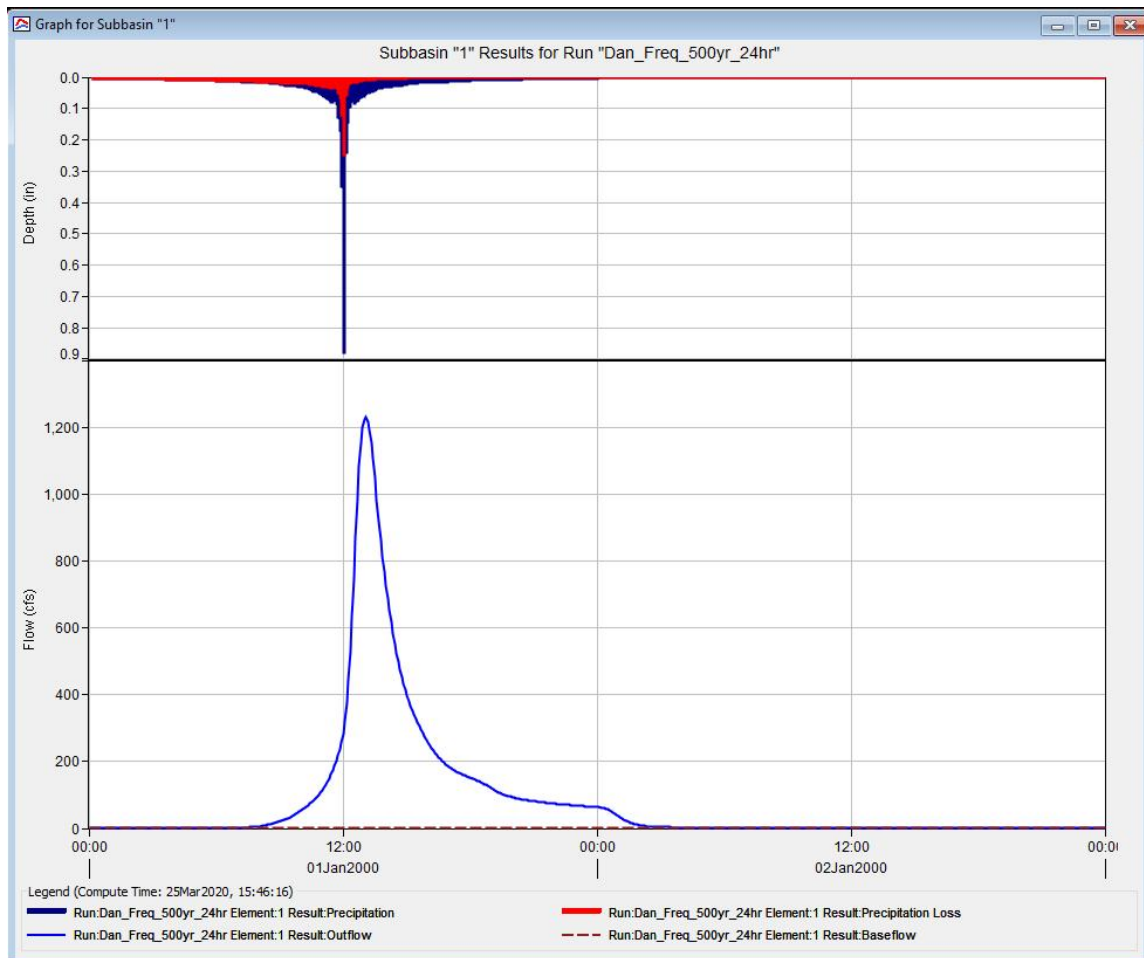
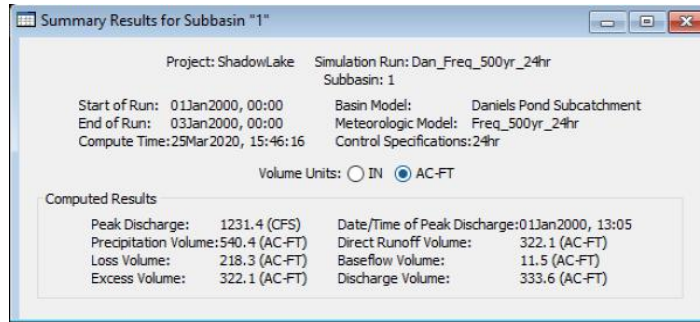
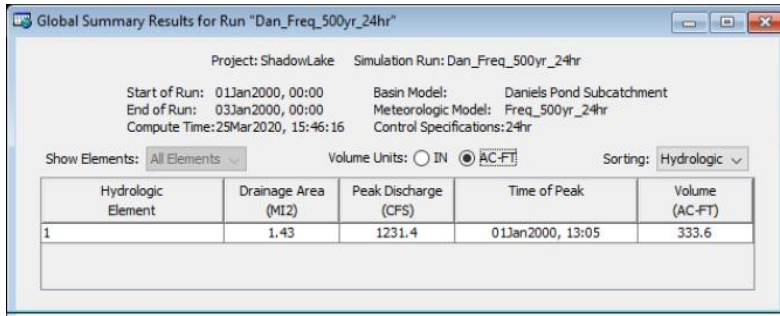
Volume Units:  IN  AC-FT

Computed Results

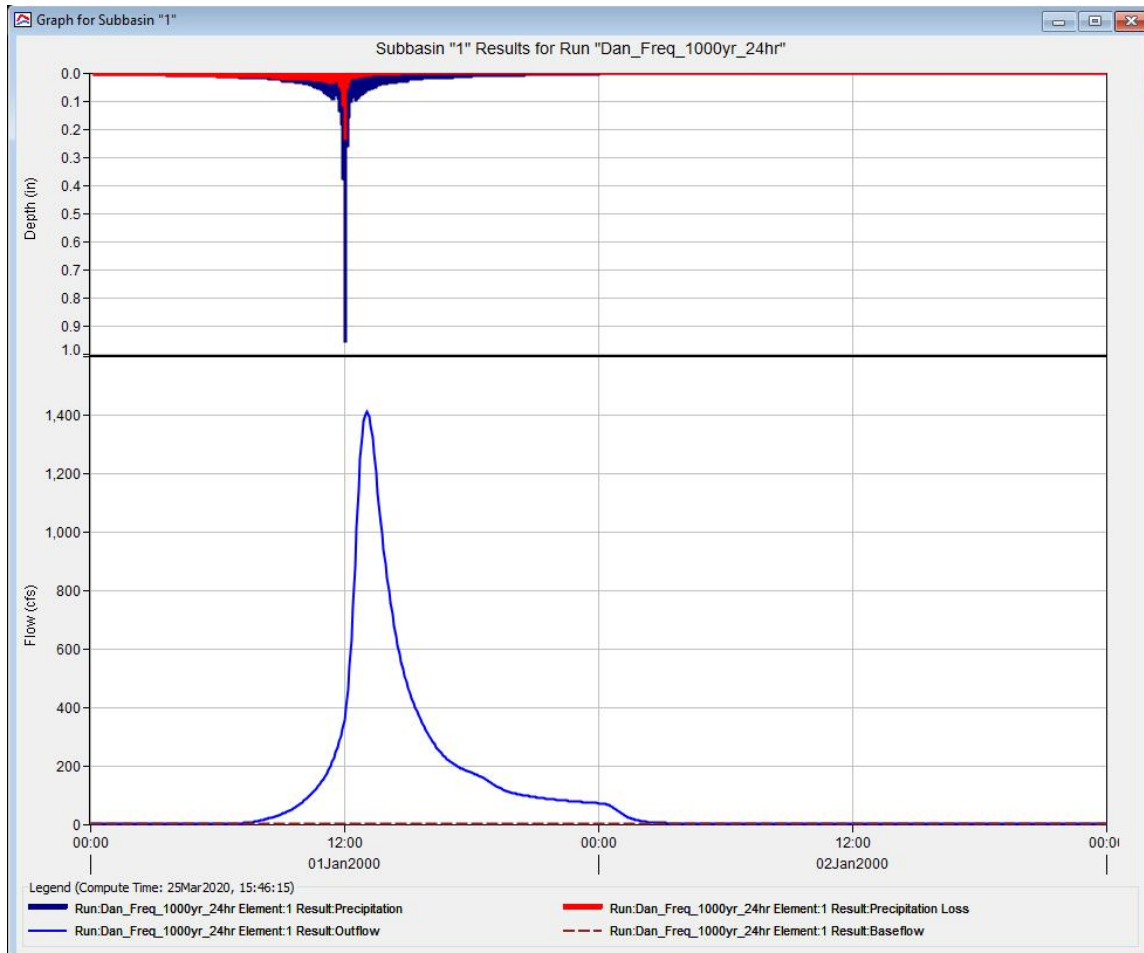
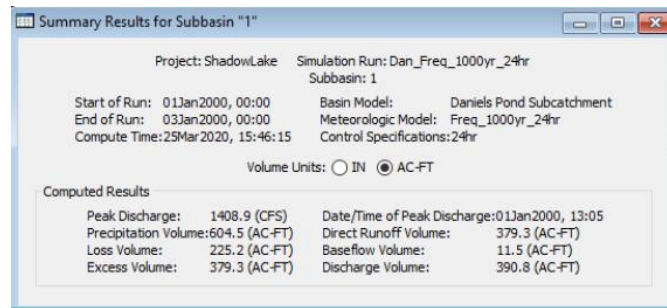
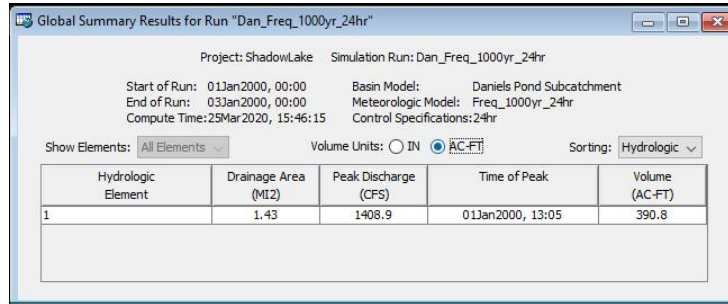
Peak Discharge:	1083.7 (CFS)	Date/Time of Peak Discharge:	01Jan2000, 13:05
Precipitation Volume:	525.2 (AC-FT)	Direct Runoff Volume:	308.6 (AC-FT)
Loss Volume:	216.5 (AC-FT)	Baseflow Volume:	11.5 (AC-FT)
Excess Volume:	308.6 (AC-FT)	Discharge Volume:	320.2 (AC-FT)



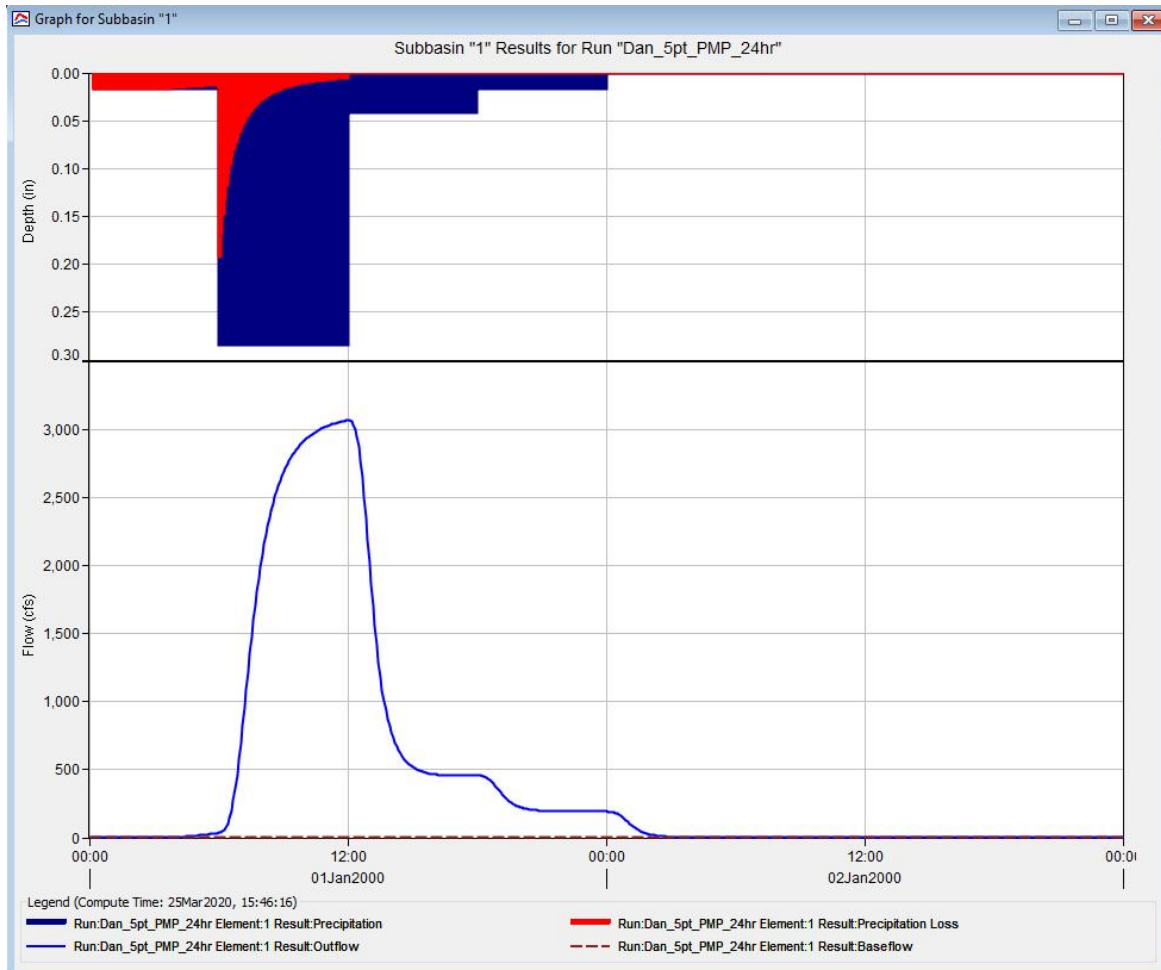
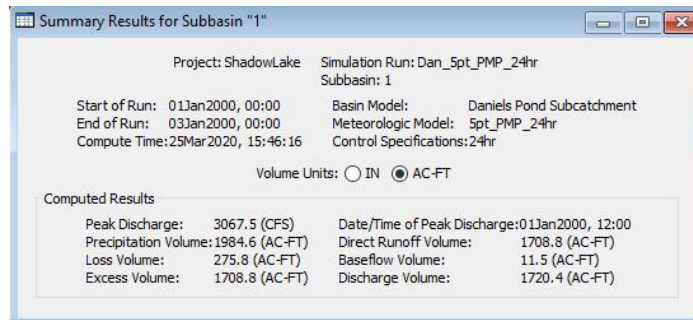
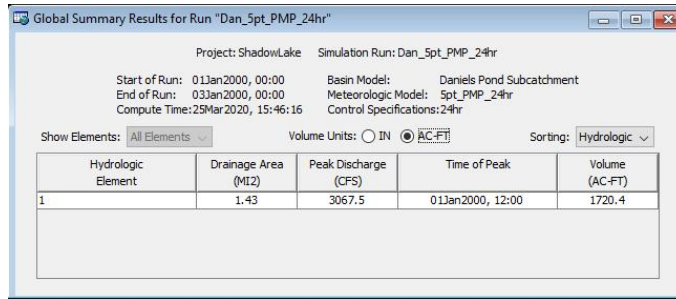
# Daniels Pond Subcatchment 500-yr Output



# Daniels Pond Subcatchment 1000-yr Output



# Daniels Pond Subcatchment PMP Output



# Shadow Lake Subcatchment Input

**Basin Model**

**Name: Shadow Lake Subcatchment**

Description:

Unit System: U.S. Customary

Sediment: No

Replace Missing: No

Local Flow: No

Flow Ratios: No

Default Grid Region: --None--

**Subbasin** | Loss | Transform | Baseflow | Options

**Basin Name: Shadow Lake Subcatchment**  
**Element Name: 1**

Description:

Downstream: --None--

\*Area (MI2): 3.8628

Latitude Degrees:

Longitude Degrees:

Canopy Method: --None--

Surface Method: --None--

Loss Method: SCS Curve Number

Transform Method: SCS Unit Hydrograph

Baseflow Method: Constant Monthly

**Subbasin** | Loss | Transform | Baseflow | Options

**Basin Name: Shadow Lake Subcatchment**  
**Element Name: 1**

Initial Abstraction (IN): 0.597

\*Curve Number: 77

\*Impervious (%): 0.0

**Basin Name: Shadow Lake Subcatchment**  
**Element Name: 1**

Graph Type: Standard (PRF 484)

\*Lag Time (MIN): 60.9

**Basin Name: Shadow Lake Subcatchment**  
**Element Name: 1**

*January (CFS)	7.84
*February (CFS)	7.84
*March (CFS)	7.84
*April (CFS)	7.84
*May (CFS)	7.84
*June (CFS)	7.84
*July (CFS)	7.84
*August (CFS)	7.84
*September (CFS)	7.84
*October (CFS)	7.84
*November (CFS)	7.84
*December (CFS)	7.84

**Subbasin** | Loss | Transform | Baseflow | Options

**Basin Name: Shadow Lake Subcatchment**  
**Element Name: 1**

Observed Flow: --None--

Observed Stage: --None--

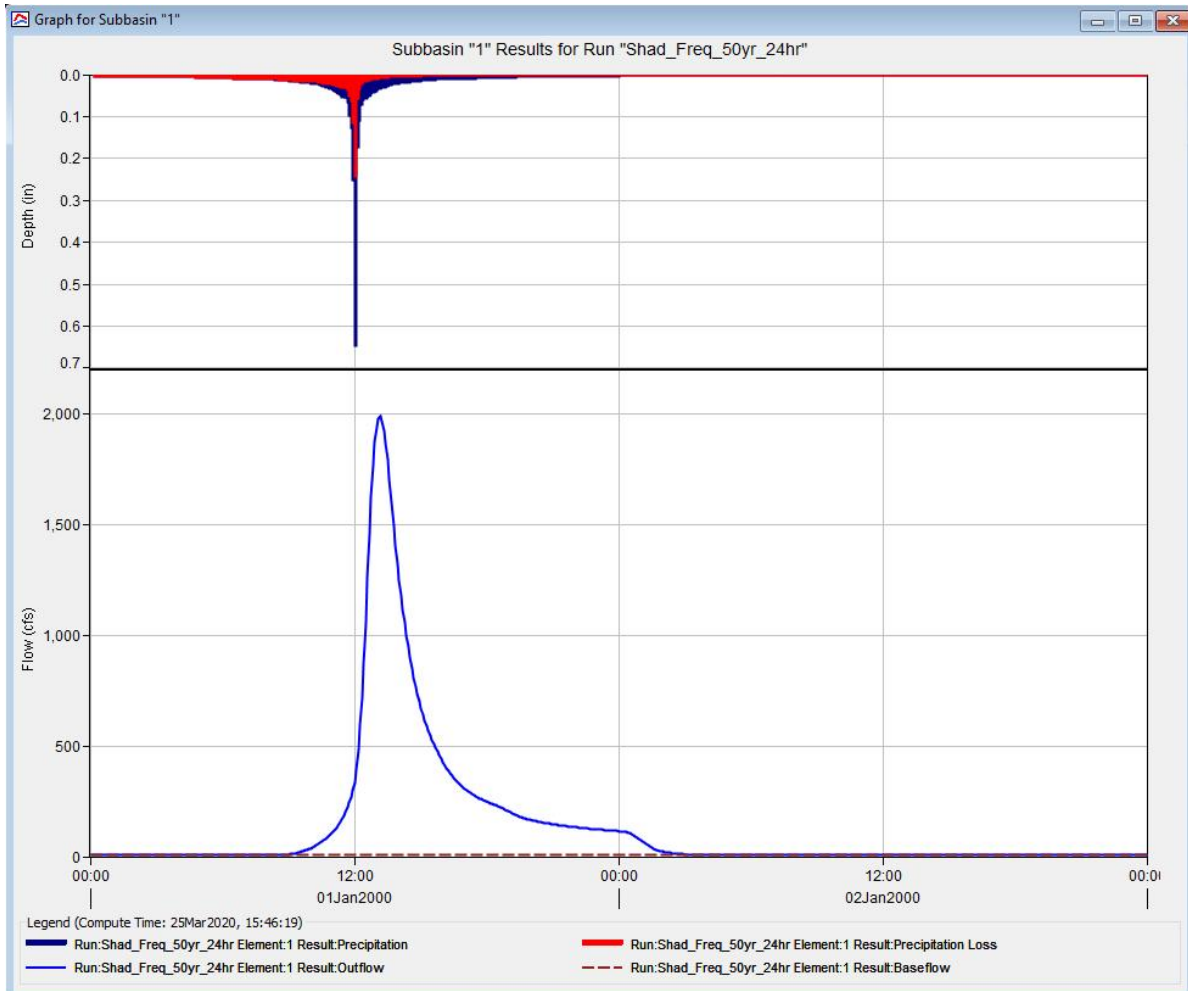
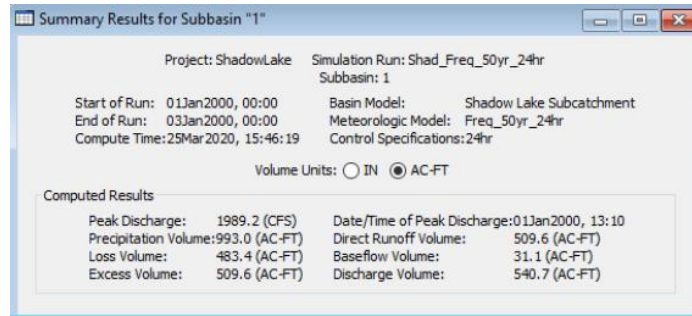
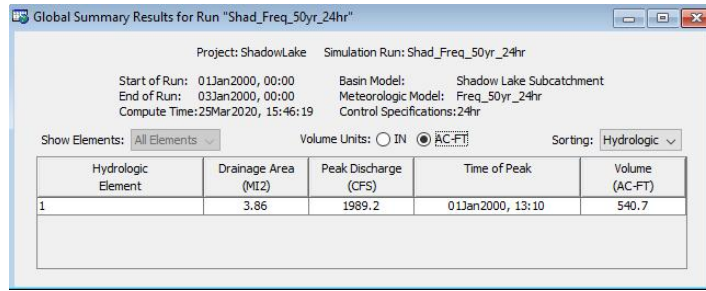
Observed SWE: --None--

Elev-Discharge: --None--

Ref Flow (CFS):

Ref Label:

# Shadow Lake Subcatchment 50-yr Output



# Shadow Lake Subcatchment 100-yr Output

Global Summary Results for Run "Shad\_Freq\_100yr\_24hr"

Project: ShadowLake Simulation Run: Shad\_Freq\_100yr\_24hr

Start of Run: 01Jan2000, 00:00 Basin Model: Shadow Lake Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_100yr\_24hr  
 Compute Time: 25Mar2020, 15:46:18 Control Specifications: 24hr

Show Elements: All Elements Volume Units:  IN  AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI <sup>2</sup> )	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
1	3.86	2364.9	01Jan2000, 13:10	641.2

Summary Results for Subbasin "1"

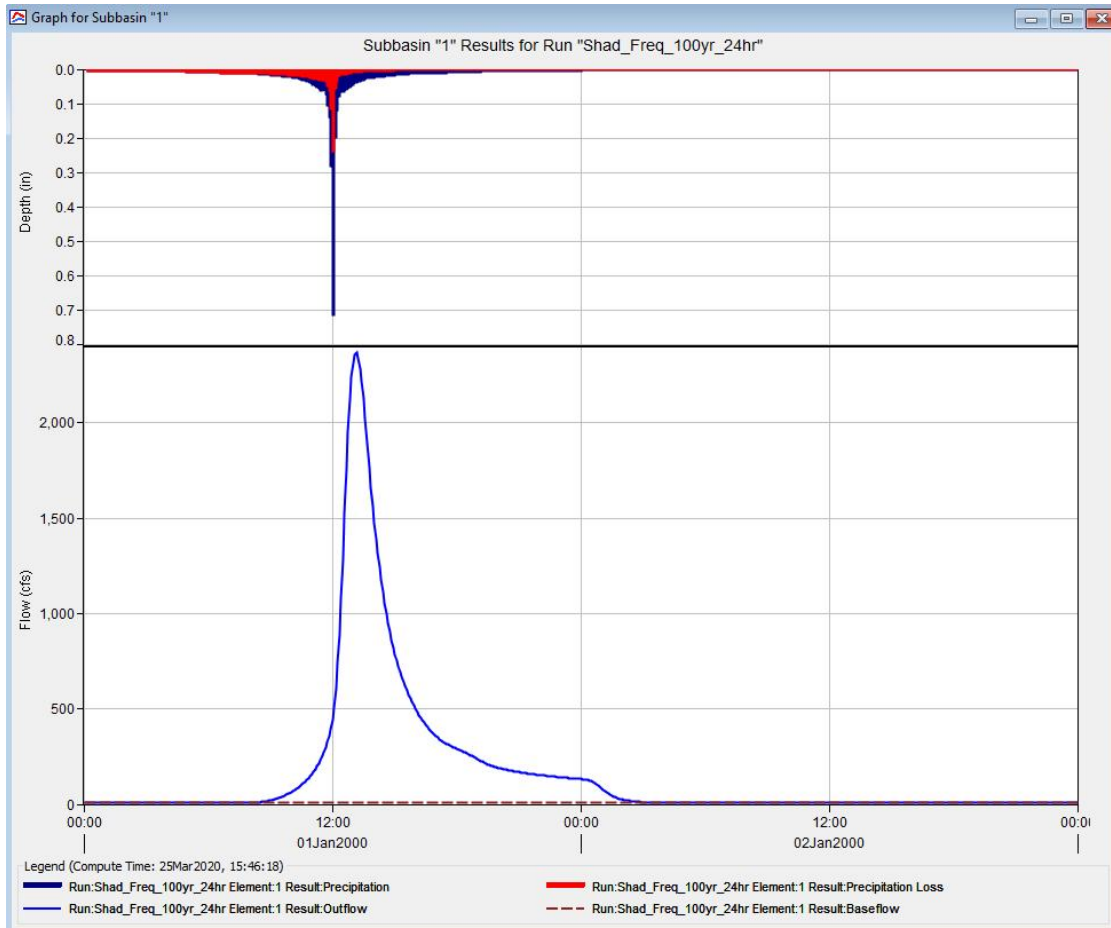
Project: ShadowLake Simulation Run: Shad\_Freq\_100yr\_24hr  
 Subbasin: 1

Start of Run: 01Jan2000, 00:00 Basin Model: Shadow Lake Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_100yr\_24hr  
 Compute Time: 25Mar2020, 15:46:18 Control Specifications: 24hr

Volume Units:  IN  AC-FT

Computed Results

Peak Discharge:	2364.9 (CFS)	Date/Time of Peak Discharge:	01Jan2000, 13:10
Precipitation Volume:	1112.5 (AC-FT)	Direct Runoff Volume:	610.1 (AC-FT)
Loss Volume:	502.4 (AC-FT)	Baseflow Volume:	31.1 (AC-FT)
Excess Volume:	610.1 (AC-FT)	Discharge Volume:	641.2 (AC-FT)



# Shadow Lake Subcatchment 200-yr Output

Global Summary Results for Run "Shad\_Freq\_200yr\_24hr"

Project: ShadowLake Simulation Run: Shad\_Freq\_200yr\_24hr

Start of Run: 01Jan2000, 00:00 Basin Model: Shadow Lake Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_200yr\_24hr  
 Compute Time: 25Mar2020, 15:46:19 Control Specifications: 24hr

Show Elements: All Elements Volume Units:  IN  AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI <sup>2</sup> )	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
1	3.86	2969.2	01Jan2000, 13:10	908.4

Summary Results for Subbasin "1"

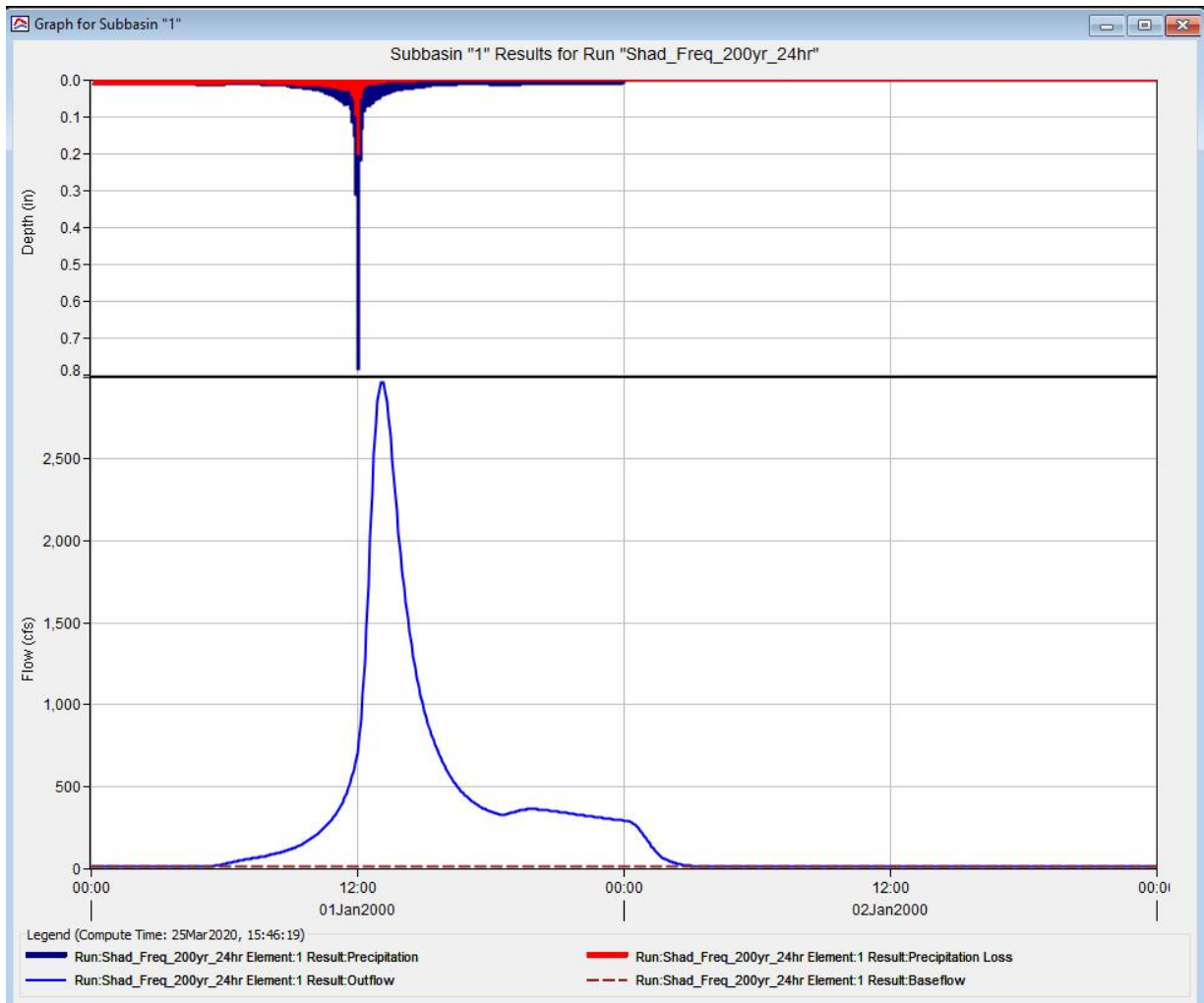
Project: ShadowLake Simulation Run: Shad\_Freq\_200yr\_24hr  
 Subbasin: 1

Start of Run: 01Jan2000, 00:00 Basin Model: Shadow Lake Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_200yr\_24hr  
 Compute Time: 25Mar2020, 15:46:19 Control Specifications: 24hr

Volume Units:  IN  AC-FT

Computed Results

Peak Discharge:	2969.2 (CFS)	Date/Time of Peak Discharge:	01Jan2000, 13:10
Precipitation Volume:	1417.4 (AC-FT)	Direct Runoff Volume:	877.3 (AC-FT)
Loss Volume:	540.1 (AC-FT)	Baseflow Volume:	31.1 (AC-FT)
Excess Volume:	877.3 (AC-FT)	Discharge Volume:	908.4 (AC-FT)



# Shadow Lake Subcatchment 500-yr Output

Global Summary Results for Run "Shad\_Freq\_500yr\_24hr"

Project: ShadowLake Simulation Run: Shad\_Freq\_500yr\_24hr

Start of Run: 01Jan2000, 00:00 Basin Model: Shadow Lake Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_500yr\_24hr  
 Compute Time: 25Mar2020, 15:46:20 Control Specifications: 24hr

Show Elements: All Elements Volume Units:  IN  AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI <sup>2</sup> )	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
1	3.86	3372.7	01Jan2000, 13:10	945.4

Summary Results for Subbasin "1"

Project: ShadowLake Simulation Run: Shad\_Freq\_500yr\_24hr

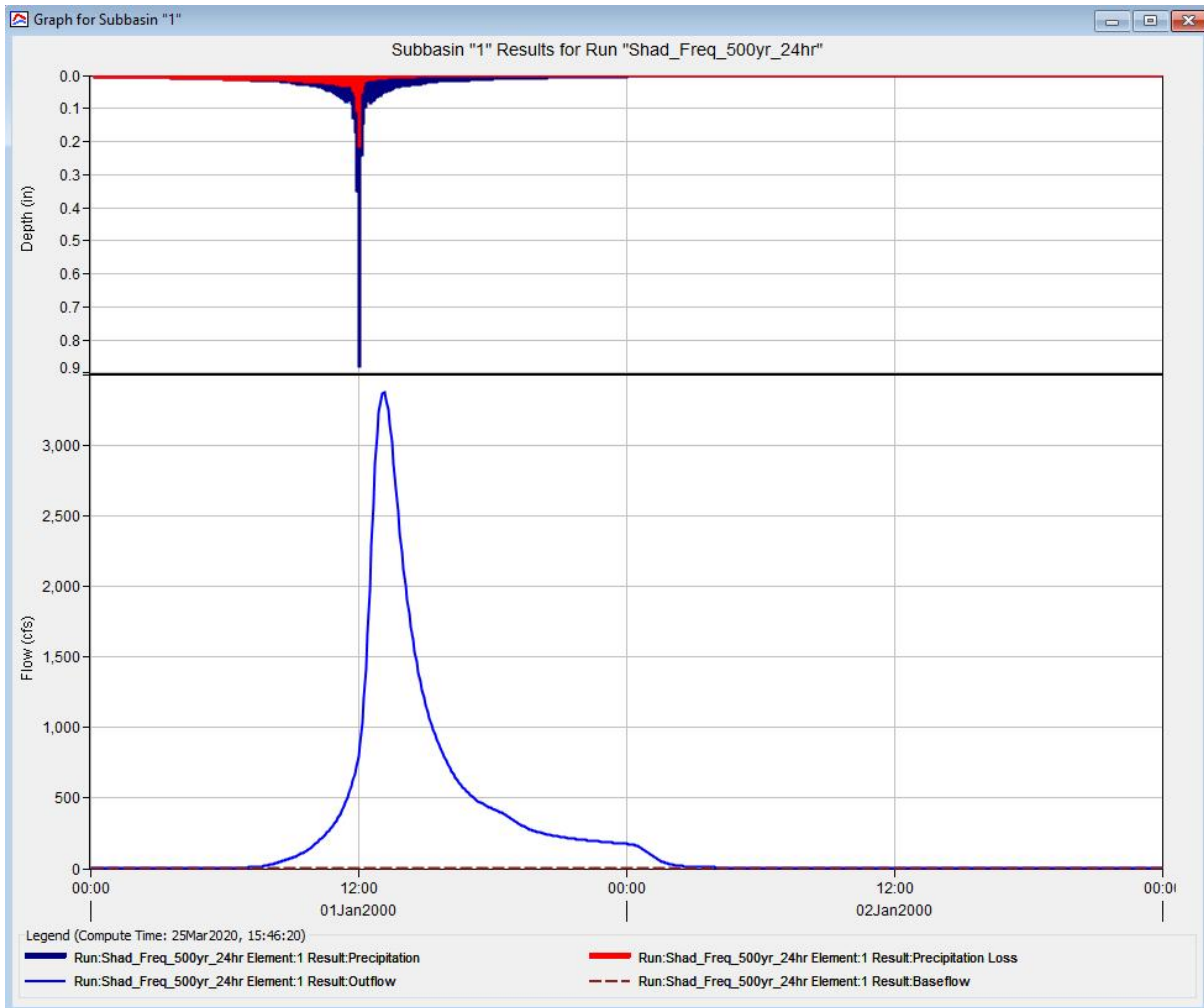
Subbasin: 1

Start of Run: 01Jan2000, 00:00 Basin Model: Shadow Lake Subcatchment  
 End of Run: 03Jan2000, 00:00 Meteorologic Model: Freq\_500yr\_24hr  
 Compute Time: 25Mar2020, 15:46:20 Control Specifications: 24hr

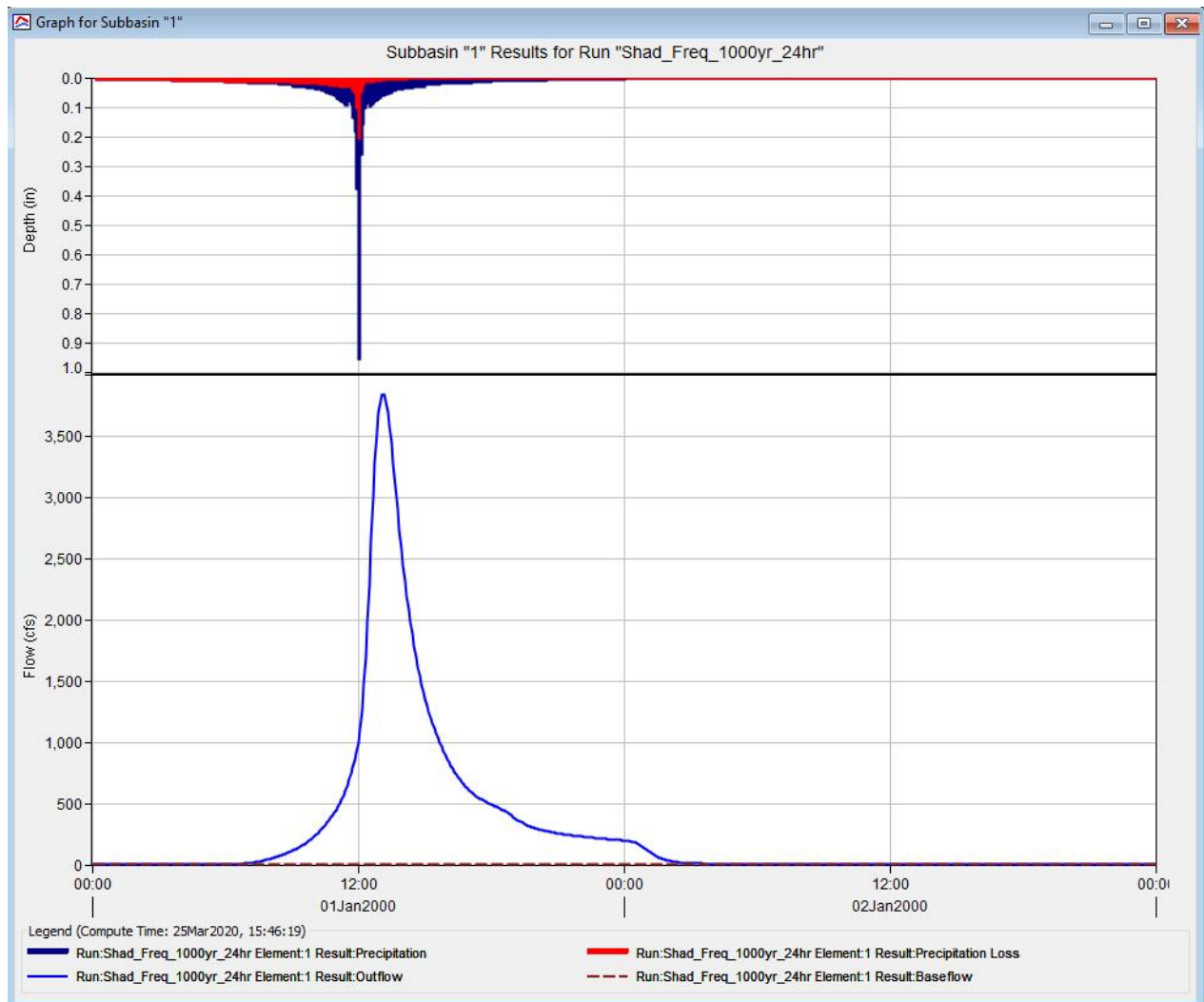
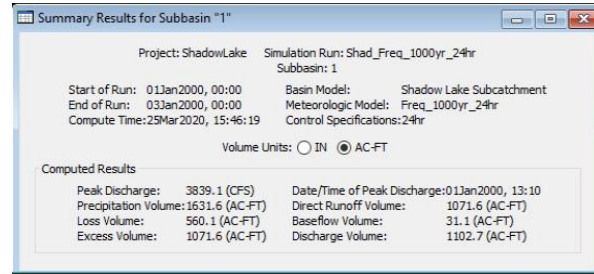
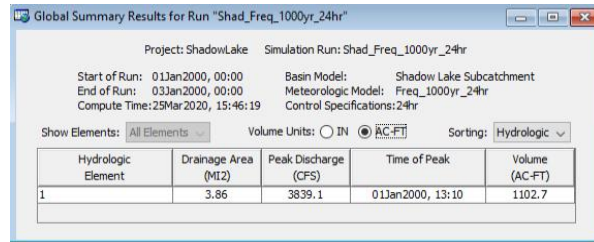
Volume Units:  IN  AC-FT

Computed Results

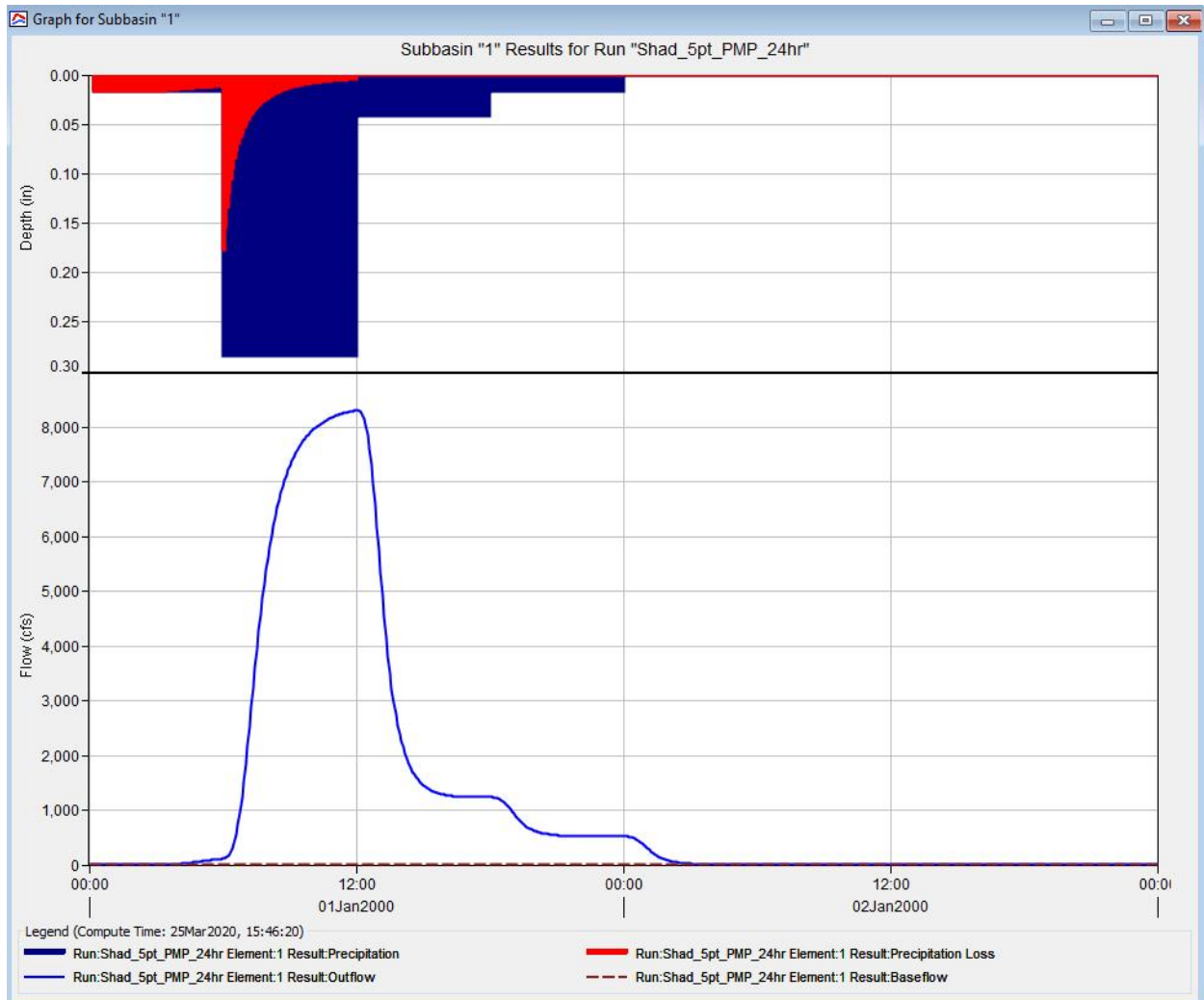
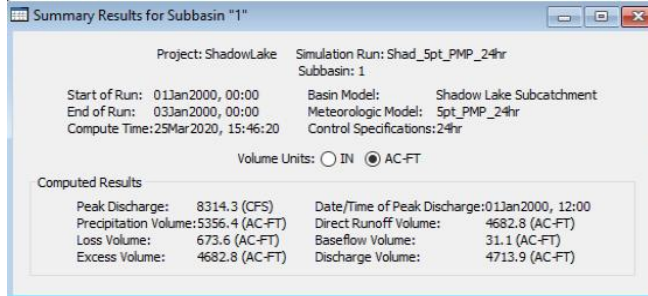
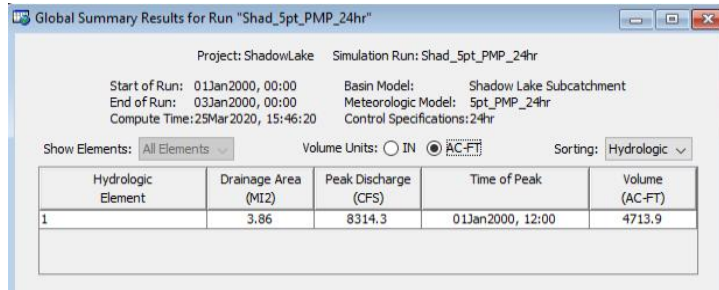
Peak Discharge:	3372.7 (CFS)	Date/Time of Peak Discharge:	01Jan2000, 13:10
Precipitation Volume:	1458.6 (AC-FT)	Direct Runoff Volume:	914.3 (AC-FT)
Loss Volume:	544.3 (AC-FT)	Baseflow Volume:	31.1 (AC-FT)
Excess Volume:	914.3 (AC-FT)	Discharge Volume:	945.4 (AC-FT)



# Shadow Lake Subcatchment 1000-yr Output



# Shadow Lake Subcatchment PMP Output



# Attachment D

HEC-RAS

## Shadow Lake Stage Storage Curve

Elevation NAVD88 ft	Surface Area sq. ft.	Surface Area acres	Volume cu. ft.	Volume acre-ft	Description
1386.2	8513403	195.4	0	0.0	Streambed elevation at toe of slope.
1386.6	8534391	195.9	3409242	78.3	
1387	8556434	196.4	6827622	156.7	
1388	8612090	197.7	15411939	353.8	
1389	8667533	199.0	24051752	552.2	
1390	8723055	200.3	32746958	751.8	
1390.6	8768314	201.3	37991639	872.2	
1391	8832597	202.8	41511890	953.0	
1392	9004009	206.7	50429876	1157.7	
1393	9179238	210.7	59521173	1366.4	
1394	9358282	214.8	68789601	1579.2	
1394.6	9467527	217.3	74437281	1708.8	Approx. Normal Pool (Primary Spillway Invert)
1395	9585279	220.0	78238716	1796.1	LIDAR Contours begin
1396	9638450	221.3	87850880	2016.8	
1396.2	9648118	221.5	89779437	2061.1	Auxiliary Spillway Invert
1397	9688011	222.4	97512436	2238.6	
1398	9740273	223.6	107225664	2461.6	
1399	9799508	225.0	116994087	2685.8	
1399.8	9842054	225.9	124851077	2866.2	Top of Dam (Height = 13.6 feet)
1400	9855405	226.3	126820549	2911.4	
1401	9916496	227.7	136704384	3138.3	
1402	9992223	229.4	146654018	3366.7	
1403	10090536	231.6	156686821	3597.0	
1404	10246247	235.2	166832694	3830.0	
1405	10475002	240.5	177161372	4067.1	
1406	10715447	246.0	187734835	4309.8	
1407	10941814	251.2	198542077	4557.9	
1408	11145737	255.9	209568207	4811.0	
1409	11334336	260.2	220790409	5068.7	
1410	11499835	264.0	232199206	5330.6	

\*Values computed using ArcGIS volume tool on merged bathymetry & LIDAR surface. Bathymetry based upon digitized contours from VT DEC mapping.

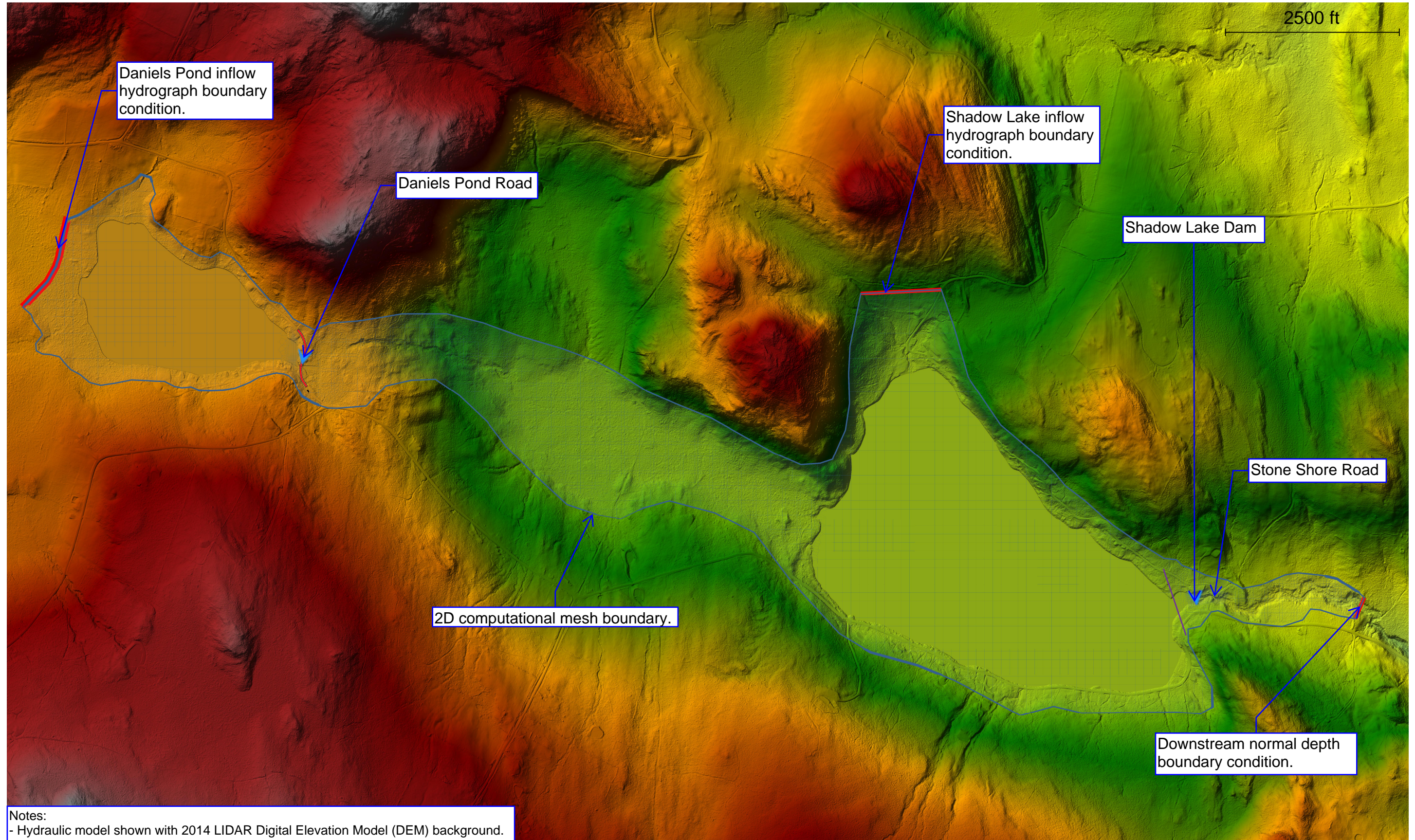
## Shadow Lake Dam Principal Spillway Approximate Rating Curve

Normal Pool (NAVD88 ft)	1394.6
Aux Spillway Crest (NAVD88 ft)	1396.2
Top of Dam (NAVD88 ft)	1399.8
Orifice Coefficient	0.6
Orifice Diameter (ft)	3.0
Acceleration due to gravity (ft/s <sup>2</sup> )	32.2
Weir Length (ft)	5.0
Weir Coefficient	2.6

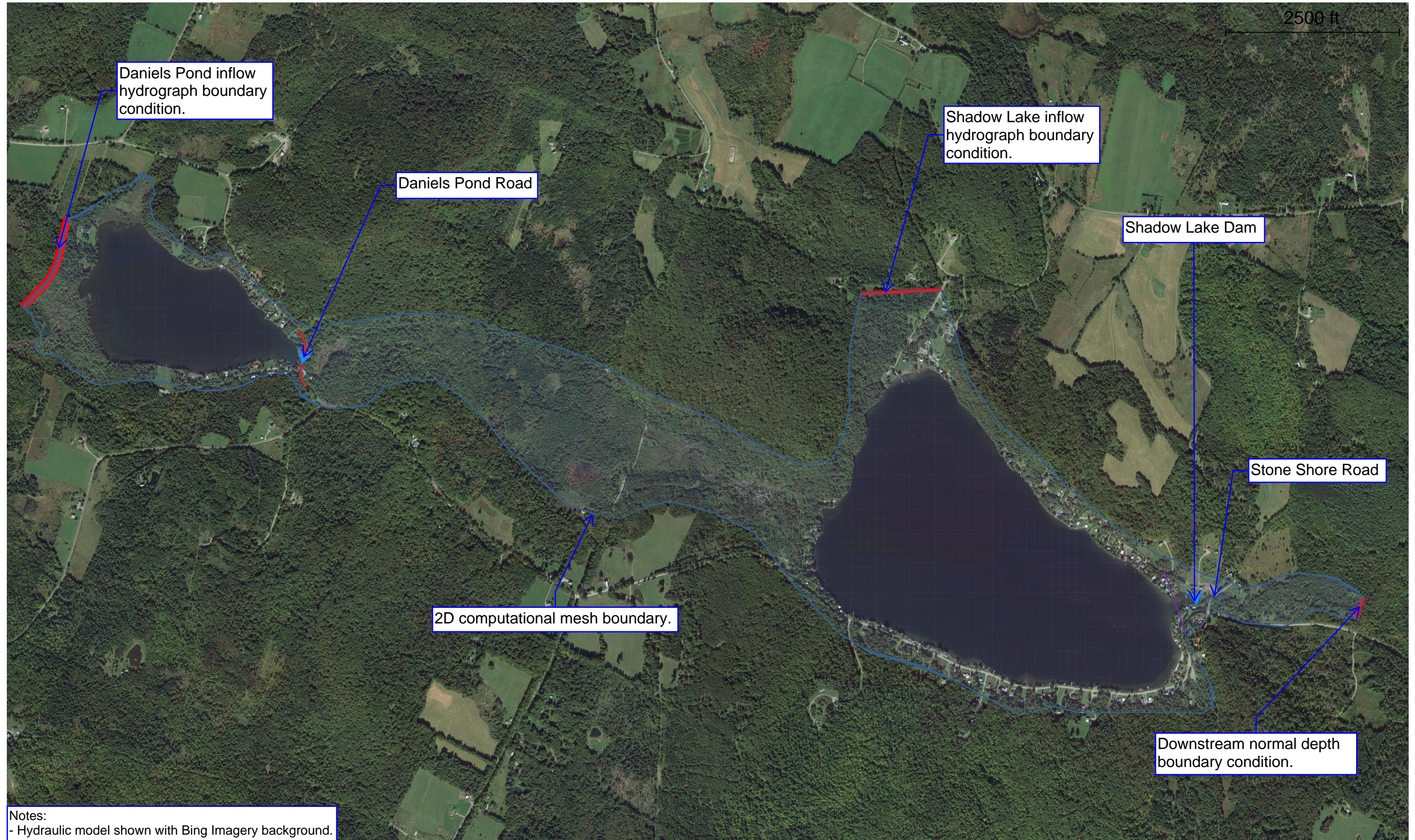
\* assumes free discharge

\*\* assumes no submergence and constant discharge coefficient

Water surface Elevation (NAVD88 ft)	Weir Head (ft)	Weir Flow (cfs) *	Orifice Head (ft)	Orifice Flow (cfs) **	Selected Rating Curve Flow (cfs)
1394.6	0	0.0	-1.5	0.0	0.0
1394.7	0.1	0.4	-1.4	0.0	0.4
1394.8	0.2	1.2	-1.3	0.0	1.2
1394.9	0.3	2.1	-1.2	0.0	2.1
1395	0.4	3.3	-1.1	0.0	3.3
1395.1	0.5	4.6	-1	0.0	4.6
1395.2	0.6	6.0	-0.9	0.0	6.0
1395.3	0.7	7.6	-0.8	0.0	7.6
1395.4	0.8	9.3	-0.7	0.0	9.3
1395.5	0.9	11.1	-0.6	0.0	9.3
1395.6	1	13.0	-0.5	0.0	9.3
1395.8	1.2	17.1	-0.3	0.0	9.3
1396	1.4	21.5	-0.1	0.0	9.3
1396.2	1.6	26.3	0.1	10.8	10.8
1396.4	1.8	31.4	0.3	18.6	18.6
1396.6	2	36.8	0.5	24.1	24.1
1396.8	2.2	42.4	0.7	28.5	28.5
1397	2.4	48.3	0.9	32.3	32.3
1397.2	2.6	54.5	1.1	35.7	35.7
1397.4	2.8	60.9	1.3	38.8	38.8
1397.6	3	67.5	1.5	41.7	41.7
1397.8	3.2	74.4	1.7	44.4	44.4
1398.1	3.5	85.1	2	48.1	48.1
1398.6	4	104.0	2.5	53.8	53.8
1399.1	4.5	124.1	3	58.9	58.9
1399.6	5	145.3	3.5	63.6	63.6
1399.8	5.2	154.2	3.7	65.4	65.4
1400.1	5.5	167.7	4	68.0	68.0
1400.6	6	191.1	4.5	72.2	72.2
1401.1	6.5	215.4	5	76.1	76.1
1401.6	7	240.8	5.5	79.8	79.8
1402.1	7.5	267.0	6	83.3	83.3
1402.6	8	294.2	6.5	86.7	86.7
1403.1	8.5	322.2	7	90.0	90.0
1403.6	9	351.0	7.5	93.2	93.2
1404.1	9.5	380.7	8	96.2	96.2
1404.6	10	411.1	8.5	99.2	99.2
1405.1	10.5	442.3	9	102.1	102.1
1405.6	11	474.3	9.5	104.9	104.9
1406.1	11.5	507.0	10	107.6	107.6
1406.6	12	540.4	10.5	110.2	110.2



Notes:  
- Hydraulic model shown with 2014 LIDAR Digital Elevation Model (DEM) background.



Notes:  
- Hydraulic model shown with Bing Imagery background.







Shadow Lake Dam H&H Analysis  
Glover, VT  
24-hr 500-yr Velocity & Inundation Map







Shadow Lake Dam H&H Analysis  
Glover, VT  
24-hr 1/2 PMP Velocity & Inundation Map



Shadow Lake Dam H&H Analysis  
Glover, VT  
24-hr 3/4 PMP Velocity & Inundation Map



Shadow Lake Dam H&H Analysis  
Glover, VT  
24-hr Full PMP Velocity & Inundation Map



# **Attachment E**

## Revisions to Analysis

## Attachment E – Revised Analysis Notes - July 13<sup>th</sup>, 2020

A draft of the Shadow Lake Dam H&H Analysis and subsequent technical memorandum was completed on December 3, 2019 and presented to the Town of Glover Selectboard & VT DEC Chief Dam Safety Engineer for initial review and feedback. The final technical memorandum incorporated feedback from the Town & the Chief VT Dam Safety Engineer, as well as some changes to the analysis based upon internal DuBois & King, Inc. (D&K) review. The following is a brief summary of the key changes that were made in order to finalize the Technical Memorandum.

1. The auxiliary spillway was modeled with a broad crested weir coefficient instead of the weir coefficient which was closer to that of an Ogee spillway. This change was made to better represent the discharge capacity of the auxiliary spillway because while the spillway does have a concrete chute it is not designed to function like an ogee spillway. At the top of the chute is a broad crested weir. This change effectively reduced the discharge capacity of the auxiliary spillway.
2. The principal spillway discharge capacity was included into the model via rating curve. The preliminary analysis excluded the principal spillway discharge because it had a manually operated gate. Following conversations with the dam owner it was decided to include the principal spillway in the analysis because the gate is reportedly left in the fully open position year round. The lake level is controlled with stop logs and not the gate mechanism. This resulted in additional dam discharge capacity. The additional discharge capacity in reference to peak discharge of the dam safety criteria design storms is relatively insignificant.
3. The PMP storm was previously analyzed as a 48-hr event. The updated analysis models the PMP using as a 24-hr event. Following conversations with a NRCS hydrologist it was concluded that the current federal guidance by one of the leading federal agencies in hydrology and hydraulics was to model PMP storm events using a 24-hr distribution. Some reasons for this include;
  - a. Providing some consistency in hydraulic adequacy analysis across all dams (analyzing different storm durations will often time produce differing results)
  - b. NRCS hydrologists felt based on regional climatic characteristics 24-hr duration PMP event was applicable to the New England region (including the State of Vermont).

Typically analyzed PMP storm durations are 6 to 72 hours; 24 hours falls within this range. This change resulted in a lower total rainfall depth (26.0 inches over 24 hours instead of 29.0 inches over 48-hours).

4. The rainfall distribution for the PMP event was changed from a center weighted frequency distribution with a 5-minute peak intensity to the NRCS critically stacked 5-pt PMP distribution which has a peak intensity duration of 6-hours. This change was made because the peak inflow values from storm run off for both subcatchments (Daniels Pond & Shadow Lake) based upon cfs discharge per square mile seemed excessive in comparison to other H&H studies performed in the State of Vermont by D&K as well as other qualified consultants. While no substantial evidence exists to show that a PMP event could not have a 5-minute peak intensity duration opposed to the 6-hour peak intensity duration. It was concluded that the default of 6-hours has been applied in federal guidance dating back to the NOAA's HMR reports which were originally

produced to aid in probable maximum flood studies. The NCRCS 5-pt distribution was derived from guidance included in HMR-51 & HMR-52. It was decided that because Vermont's regulations default to conducting analyses in accord with federal guidance it would be more appropriate to model the PMP storm using a federally developed and approved distribution. This change resulted in lower peak discharge values for the PMP storm hydrographs.

5. The recurrence interval storms were analyzed using a center weighted frequency distribution in HEC-HMS instead of HydroCAD. Initially the storms were modeled in HydroCAD for convenience, but when finalizing the analysis it was decided to analyze them using HEC-HMS for consistency purposes since the PMP storms were being analyzed with HEC-HMS. This resulted in slightly higher peak discharge values for the recurrence interval storms than presented previously.

The net effects of the above described changes can be observed in the following two tables which compares the results of the preliminary draft memo to the final memo. The change in water surface elevations during the storms analyzed are relatively minor. Ultimately the conclusions of the memo in terms the hydraulic performance of the dam in reference to VT DEC Dam Safety criteria remained the same.

### Preliminary Analysis

Event	Shadow Lake Dam Composite Peak Inflow (cfs)	Shadow Lake Dam Composite Routed Peak Outflow (cfs)	Shadow Lake Peak Water Surface Elevation (NAVD88 ft)	Available Freeboard Freeboard (+) or Overtopping Depth (-) (feet)
50-yr (24-hr)	1,810	26	1397.1	2.7
100-yr (24-hr)	2,150	46	1397.5	2.3
200-yr (24-hr)	2,530	78	1398.0	1.8
500-yr (24-hr)	3,070	140	1398.7	1.1
1000-yr (24-hr)	3,480	203	1399.2	0.6
1/4 PMF (48-hr)	3,610	261	1399.6	0.2
1/2 PMF (48-hr)	7,220	2,100	1402.7	-2.9
3/4 PMF (48-hr)	10,880	5,240	1405.2	-5.4
PMF (48-hr)	14,530	8,950	1407.2	-7.4

### Final Analysis

Event	Shadow Lake Dam Composite Peak Inflow (cfs)	Shadow Lake Dam Composite Routed Peak Outflow (cfs)	Shadow Lake "Level Pool" Peak Water Surface Elevation (NAVD88 ft)	Shadow Lake Peak Water Surface Elevation at Dam (NAVD88 ft)	Available Freeboard (+) or Overtopping Depth (-) (feet)
50-yr (24-hr)	1,791	96	1397.3	1397.2	2.6
100-yr (24-hr)	2,142	144	1397.7	1397.6	2.2
200-yr (24-hr)	2,670	278	1398.7	1398.6	1.3
500-yr (24-hr)	3,055	294	1398.8	1398.7	1.1
1000-yr (24-hr)	3,420	378	1399.3	1399.2	0.6
1/4 PMF (24-hr)	1,836	474	1399.9	1399.7	0.1
1/2 PMF (24-hr)	4,243	2,801	1403.5	1403.1	-3.3
3/4 PMF (24-hr)	7,541	6,098	1406.0	1405.4	-5.6
PMF (24-hr)	10,699	9,661	1407.7	1407.0	-7.2