SWEETBRIAR CREEK DAM

SWC #642

North Dakota State Water Commission

November, 2007

UPDATED HYDROLOGY, DAM BREAK ANALYSIS, AND HAZARD CLASSIFICATION

By:

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900 East Boulevard
Bismarck, ND 58505-0187

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INTRODUCTION

Sweetbriar Creek Dam underwent an investigation by Bartlett and West Engineers, Inc./Boyle Engineering Corporation (Consultant) during the winter of 2005/2006 to address seepage related issues with the dam. The Consultant was asked to develop repair alternatives to control seepage, to address the structural condition of the spillway stilling basin walls, and to increase the spillway capacity if necessary. In conjunction with the investigation by the Consultant, the North Dakota State Water Commission (NDSWC) performed an updated hydrologic analysis of the dam to determine if the existing spillway capacity meets current dam safety standards. Dam safety standards depend on the hazard classification of the dam, so the hazard classification was reviewed to ensure that it is up to date based on current guidelines and the current hazard potential.

The NDSWC first developed a hydrologic model for Sweetbriar Creek Dam, which was used to evaluate the existing spillway capacity by determining how large a precipitation event the dam can pass without overtopping. A dam break analysis was then performed to determine the impacts to homes and infrastructure downstream of the dam caused by a dam failure. The results of the dam break analysis were used to evaluate the hazard classification of the dam. Both the hydrologic model and the dam break analysis are described in detail in this report, followed by a discussion and recommendation on the hazard classification.

BACKGROUND

Sweetbriar Creek Dam is located in Morton County in south central North Dakota, approximately 20 miles west of Bismarck. The dam is on Sweetbriar Creek, a tributary of the Heart River, in the SE ¼ of Section 10 and the SW ¼ of Section 11, Township 139 North, Range 84 West. Sweetbriar Creek Dam was completed in 1964. It was built in conjunction with Interstate 94 for the purpose of providing recreation. Interstate 94 crosses Sweetbriar Creek on the crest of the dam embankment.

Sweetbriar Creek Dam is an earthen embankment with a maximum height of 51 feet above the stream bed. It is 1,200 feet in length and has a crest width of 136 feet. The dam impounds Sweetbriar Lake, which has a volume of 3,640 acre-feet at its normal pool level of 1940.0 feet (all elevations are MSL, NGVD 1929 datum). The top of the dam is not level due to the vertical curve of Interstate 94. The lowest elevation of the top of the dam is 1955.2 feet. The principal spillway consists of a reinforced concrete drop box inlet measuring 35 feet long and 34.5 feet wide, which is separated into two cells. The principal spillway conduit consists of a reinforced concrete box culvert with four barrels, each measuring 8-feet wide by 10-feet high with transition sections of increasing height on both ends. The dam has no emergency spillway. The crest of the dam is armored by Interstate 94, which consists of 10 inch thick continuously reinforced concrete pavement 38 feet wide in each direction, separated by a 54 foot grassed median.

Responsibility for Sweetbriar Creek Dam is shared by several agencies. The North Dakota Department of Transportation owns the right of way for the Interstate 94 embankment and is responsible for maintenance of the roadway itself. The maintenance of the dam and related facilities is the responsibility of the NDSWC, the North Dakota Game and Fish Department, and the Morton County Park Board. Responsibility for the operation of the reservoir is shared by the North Dakota Game and Fish Department and the Morton County Park Board (See attached agreement in Appendix A). The water rights for the reservoir are held by the North Dakota Game and Fish Department (See attached Water Permit in Appendix B).

The first extensive inspection of Sweetbriar Creek Dam was conducted on April 14, 1980 under Phase I of the U.S. Army Corps of Engineers dam inspection program that began in 1978. Since that first inspection, there has been ongoing concern about uncontrolled seepage around the spillway structure and the potential for piping of embankment material.

Sweetbriar Creek Dam is currently classified as a Medium Hazard, Class IV dam and therefore is required to pass at least 50% of the Probable Maximum Precipitation (PMP) event without overtopping the dam. The dam was classified as a medium hazard dam in the Phase I Inspection Report (Phase I report) completed in 1980 by the NDSWC. The 1980 report indicated that Sweetbriar Creek Dam could pass about 55% of the PMP event without overtopping.

HYDROLOGY

The HEC-HMS (Version 3.0.0) model was used to determine the response of Sweetbriar Creek Dam for different flood events. The loss in the watershed and the runoff transformation were modeled using the methods developed by the Soil Conservation Service (SCS), now the Natural Resources Conservation Service (NRCS). The SCS curve number method and SCS unit hydrograph method were used to model loss in the watershed and runoff transformation, respectively. For the dam, the model uses elevation versus outflow (the rating curve) in conjunction with the elevation versus capacity data to compute the stage and outflow hydrographs. The various input data required by the model are watershed area, soil type and land use, lag time, elevation versus capacity of the reservoir, elevation versus discharge of the dam, the precipitation amount and time distribution. The modeling process results in the inflow, stage and outflow hydrographs for the dam.

INPUT DATA FOR THE WATERSHED

The watershed draining into Sweetbriar Creek Dam was defined using a U.S. Geological Survey 1:24000 scale quadrangle map of the area. The watershed area is approximately 152 square miles. Using the NRCS soil maps, the soil types within the watershed were determined. The different soil types within the watershed were grouped into the hydrologic soil groups based on the classification in the Hydrology Manual for North Dakota (HMND). The land use type within the watershed was estimated using the aerial photos and site visits. The areas which had grass, hay or conservation reserve program (CRP) were included in the pasture land use type and the areas which had cultivated crops were included in the cropland. Around 71% of the total watershed area was cropland and the rest pasture. The hydrologic soil groups in the basin along with their land use distribution are shown in Table 1. The vegetative soil cover on the cropland is predominantly (80%) small grain crops and the rest row crops. Based on the soil type and the land use type, a composite curve number (CN) was determined for the entire watershed. The curve number is an index developed by the SCS to represent the combined hydrologic effect of soil, land use, agricultural land treatment class, hydrologic condition and antecedent soil moisture. The CN value for the watershed was estimated to be 79. For 10 day rainfall and snowmelt events, the curve number was reduced to 64 according to Table 3-4 in HMND. For snow melt events, 80% of the watershed area was specified as impervious in order to account for the frozen ground.

Table 1: Watershed hydrologic soil groups and land use

Hydrologic Soil Group	% of Total Watershed Area	Cropland (% of Hydrologic Soil Group Area)	Pasture (% of Hydrologic Soil Group Area)
A	1.08	62.64	37.36
B	53.31	79.52	20.48
C	24.24	83.21	16.79
D	20.94	40.52	59.48
Water	0.43		

The time of concentration (t_c), which is the measure of the time for a drop of water to travel from the hydrologically most distant point in the watershed to the point where the design is to be made, was determined to be 52 hours. The lag time (L) is defined as the time in hours from the center of mass of rainfall excess to the peak discharge. It is empirically found to be 0.6 times t_c and hence it is estimated to be 31.2 hours.

INPUT DATA FOR THE DAM

To model a reservoir, the HEC-HMS model requires the elevation versus capacity and elevation versus discharge data as input. The elevation versus capacity curve of

Sweetbriar reservoir was obtained from the Phase I Report. Table 2 shows the elevation versus capacity relationship of the reservoir.

Table 2: Elevation versus Capacity of Sweetbriar Creek Reservoir

Elevation (ft)	Capacity (Acre-Feet)
1907.7	0
1912.7	27
1917.7	130
1922.7	395
1927.7	910
1932.7	1,728
1937.7	2,928
1940	3,640
1942.7	4,483
1947.7	6,408
1952.7	8,888
1955.2	10,400
1957.7	11,915
1962.7	15,450
1965.7	18,000

The outlet works of the dam consists of a concrete drop box and a conduit. Interstate 94 forms the embankment of the dam. The top of the dam has a vertical curve with a minimum top elevation of 1955.2 ft. Flow over the top of the dam was obtained from the Phase I Report. Two different rating curves were estimated for the outlet works and the HEC-HMS model was run for both rating curves. Flow into the drop box was determined using the weir flow equation ($Q = CLH^{3/2}$). Flow through the conduit was determined by using the orifice flow equation ($Q = CA\sqrt{2gH}$) in one rating curve and using a HEC-RAS model run in the other rating curve.

Rating Curve # 1:

Flow into the drop box was calculated using reduced weir length and weir coefficient values. The weir length and weir coefficient were reduced in order to account for the reduction in flow due to contraction of the flow at the headwall and the drop box corners. This contraction reduces the effective weir length from 104.5 feet, which is the actual weir length, to less than 80 feet when the reservoir elevation is ten feet higher than the weir. For 1 and 2 feet of head over the weir, weir coefficient values of 2.98 and 3.3 respectively were used. For heads greater than 2 feet weir coefficient of 3.32 was used.

Flow through the conduit was determined by using the orifice flow equation for the section of the conduit with the least cross-sectional area. The most constricted section in the conduit is Joint 2 (Figure C.1) which has a total area of 320 square feet and the elevation of the center of the orifice is 1926 feet. The orifice coefficient used in the equation is 0.7. The orifice flow was assumed to be constant above elevation 1956 feet, since flow over the dam starts at 1955.2 ft and the top of the dam flow is comparatively greater than the orifice flow. The small difference in orifice flow because of the higher head was considered negligible and constant orifice flow was assumed.

The assumptions used for rating curve #1 should give a conservatively low estimate of the amount of flow that the dam can pass. Table 3 shows the weir flow, orifice flow, top of the dam flow and final rating curve #1. Figure 1 is the plot of conduit and weir flow for rating curve 1.

Table 3: Rating Curve # 1

Elevation	Head above the crest (H_W) (ft)	Reduced Length (L) (ft)	Weir Coefficient C	$Q_w = CLH_w^{3/2}$ (cfs)	Head for Orifice Flow (H) (ft)	Q_O=0.7 *320*SQRT (2*32.2*H) (cfs)	Top of the Dam flow (cfs)	Rating Curve # 1
1940	0	104.5	2.69	0	14	6725.97		0
1941	1	99.7	2.98	297.106	15	6962.04		297
1942	2	95.9	3.3	895.1123	16	7190.36		895
1943	3	91.7	3.32	1581.937	17	7411.66		1,582
1944	4	88.3	3.32	2345.248	18	7626.53		2,345
1945	5	85.5	3.32	3173.651	19	7835.52		3,174
1946	6	83.3	3.32	4064.527	20	8039.07		4,065
1947	7	82	3.32	5041.955	21	8237.60		5,042
1948	8	80.5	3.32	6047.403	22	8431.45		6,047
1949	9	79.3	3.32	7108.452	23	8620.94		7,108
1950	10	78.3	3.32	8220.531	24	8806.36		8,220
1951	11	78.3	3.32	9483.942	25	8987.96		8,988
1952	12				26	9165.95		9,166
1953	13				27	9340.56		9,341
1954	14				28	9511.96		9,512
1955	15				29	9680.33		9,680
1955.2	15.2				29.2	9713.65	0	9,714
1956	16				30	9845.81	443	10,289
1957	17					9845.81	2,325	12,171
1958	18					9845.81	5,539	15,385
1959	19					9845.81	10,182	20,028
1960	20					9845.81	16,361	26,207
1961	21					9845.81	24,158	34,004
1962	22					9845.81	33,491	43,337
1963	23					9845.81	44,029	53,875
1964	24					9845.81	55,618	65,464
1965	25					9845.81	68,158	78,004

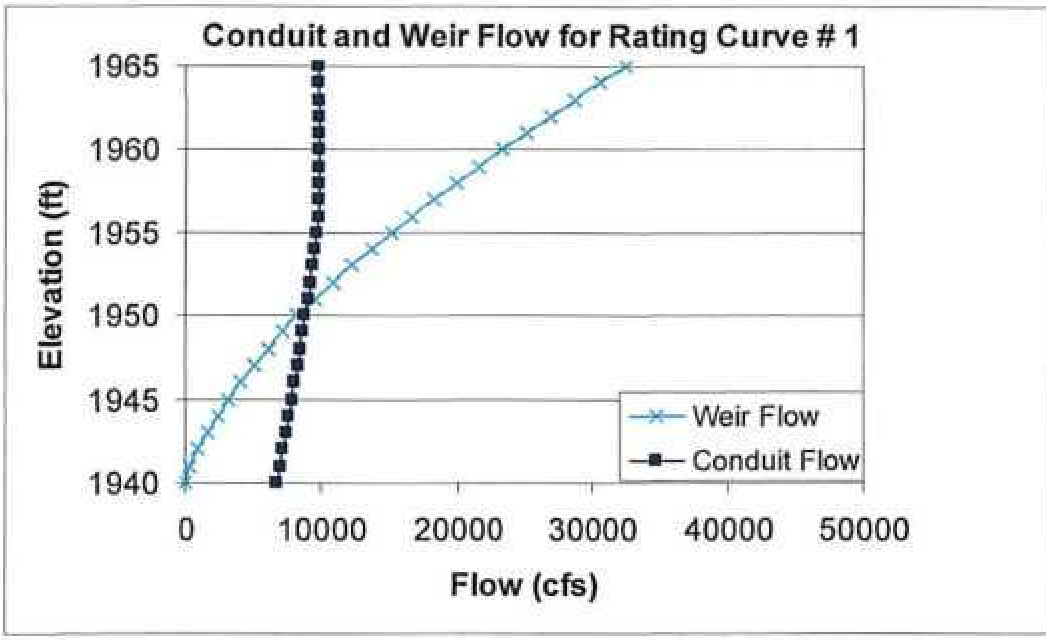


Figure 1: Conduit and Weir flow for Rating Curve #1.

Rating Curve # 2:

The weir flow for rating curve # 2 was obtained by using a constant weir length of 104.5 feet and a weir coefficient of 3.32. The weir flow calculations in the Phase I report also used a constant weir length of 104.5 feet. In rating curve #1, the calculations indicate that the flow was controlled by the conduit at a reservoir elevation of 1951 feet, but at that point the transition between orifice flow and weir flow was not clearly defined. To better define the transition, the spillway conduit of the dam was modeled using HEC-RAS (Version 3.1.3) and a new rating curve was obtained. The HEC RAS model developed is available in the attached Digital Video Disc (DVD) under the folder "Spillway RAS Model". More details of the model is available in Appendix C. Table 4 shows the weir flow, orifice flow, top of dam flow and final rating curve #2.

Table 4: Rating Curve # 2

Elevation	Head above the crest (H_W) (ft)	Weir Length (L) (ft)	Weir Coefficient C	$Q_w = CLH_w^{3/2}$ (cfs)	Orifice flow based on HEC-RAS results	Top of the Dam flow (cfs)	Rating Curve # 2
1940	0	104.5	3.32	0	8049.21		0
1941	1	104.5	3.32	346.94	8964.91		347
1942	2	104.5	3.32	981.2945	9875.97		981
1943	3	104.5	3.32	1802.753	10134.94		1,803
1944	4	104.5	3.32	2775.52	10290.22		2,776
1945	5	104.5	3.32	3878.907	10445.50		3,879
1946	6	104.5	3.32	5098.956	10627.72		5,099
1947	7	104.5	3.32	6425.419	10824.51		6,425
1948	8	104.5	3.32	7850.356	11026.92		7,850
1949	9	104.5	3.32	9367.38	11276.22		9,367
1950	10	104.5	3.32	10971.21	11518.58		10,971
1951	11	104.5	3.32	12657.37	11698.99		11,699
1952	12	104.5	3.32	14422.02	11879.40		11,879
1953	13				12057.17		12,057
1954	14				12229.90		12,230
1955	15				12402.62		12,403
1955.2	15.2				12436.55	0	12,437
1956	16				12572.26	443	13,015
1957	17				12737.61	2,325	15,063
1958	18				12902.95	5,539	18,442
1959	19				13065.78	10,182	23,248
1960	20				13225.04	16,361	29,586
1961	21				13384.31	24,158	37,542
1962	22				13541.86	33,491	47,033
1963	23				13695.17	44,029	57,724
1964	24				13848.49	55,618	69,466
1965	25				14001.80	68,158	82,160

Figure 2 shows the flow versus elevation data at the upstream cross-section of the conduit obtained from HEC-RAS, along with the weir flow calculated using constant weir length of 104.5 feet and weir coefficient of 3.32. It is evident from the figure that the weir controls the flow until the reservoir reaches 1950 feet. From 1950 to 1965 feet, rating curve #2 is controlled by orifice flow. The final rating curve for the dam was obtained by adding the top of the dam flow data to the conduit flow after 1955.2 feet (minimum top of the road elevation).

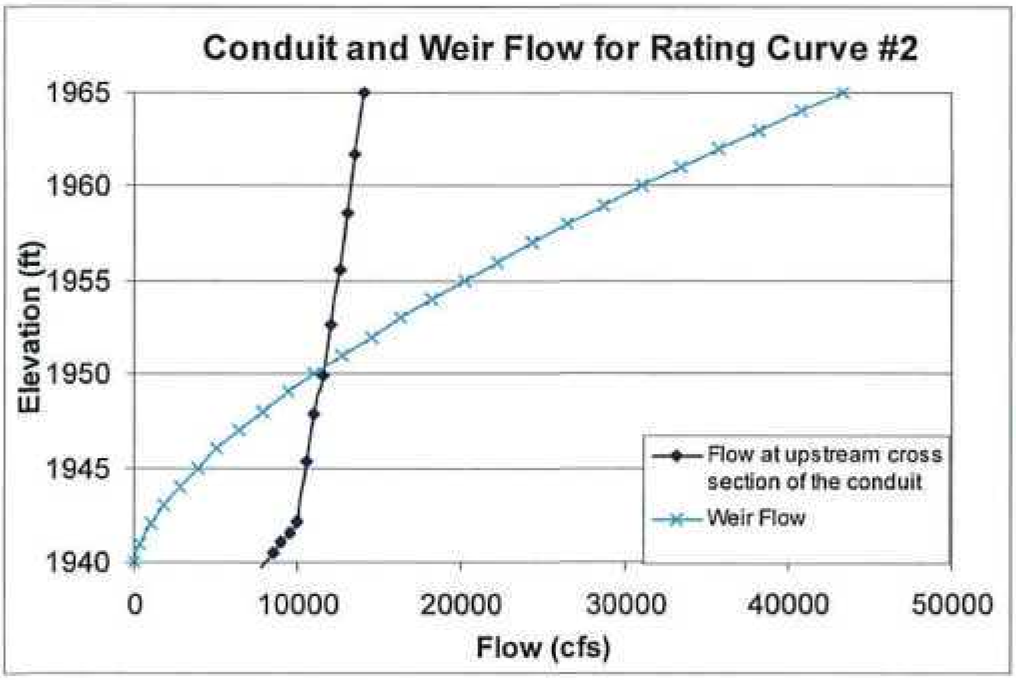


Figure 2: Conduit and Weir Flow for Rating Curve #2

Figure 3 compares rating curve #1 and rating curve #2. The comparison indicates that though in both rating curves the outflow is controlled by the weir until 1950 feet, the outflows have 25 % difference between them at 1950 feet. At higher elevations the percentage difference among the outflows gradually reduces as the top of the dam flow is very high when compared with the orifice flow. Rating curve #1 is the most conservative estimate since it uses a reduced weir length and a reduced weir coefficient, while Rating curve #2 is least conservative since the entire weir length and a constant weir coefficient are used. The orifice coefficient used in rating curve #1 is 0.7 while the orifice flow obtained from HEC RAS would result in closer to 0.9 for the orifice coefficient.

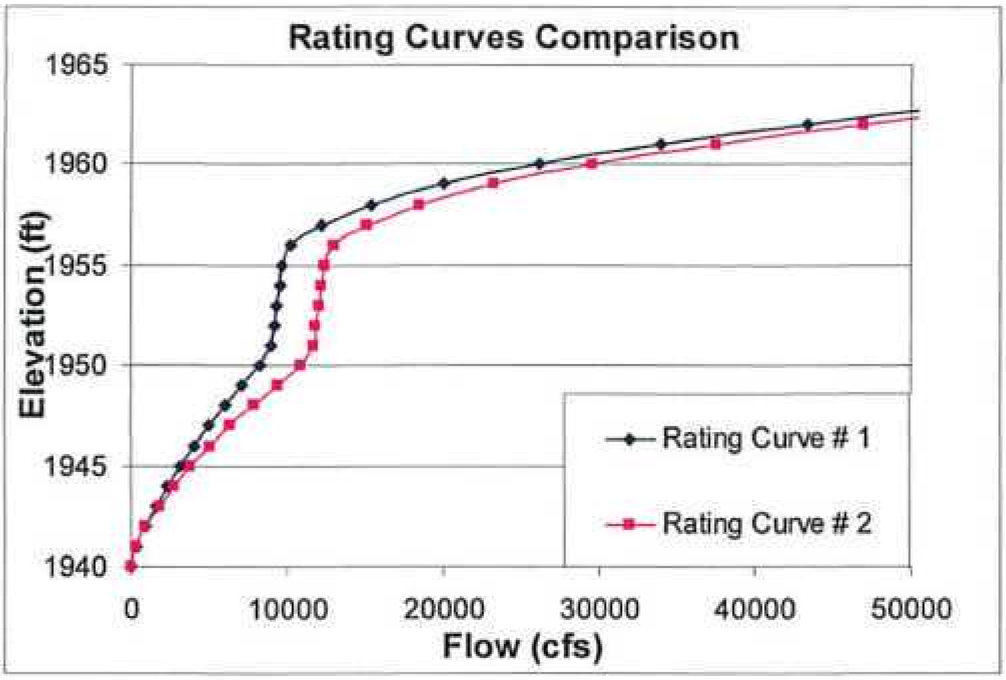


Figure 3: Rating Curves Comparison

PRECIPITATION DATA INPUT TO THE MODEL

The precipitation model had 100 year 10 day snow melt, 100 year 10 day rainfall, 100 year 2 day rainfall and 0.3, 0.4, 0.5 and full PMP with 48 hour duration defined. PMP is the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year. It should also be noted that there is no guarantee that 100 year events will occur only once in 100 years, but in any given year the probability of having a 100 year event is 1%. The 100 year rainfall and snow events were defined using the frequency storm method in HEC-HMS (cumulative precipitation was entered for predefined time intervals in the duration) and the data was obtained from HMND and Technical Paper No. 40 (TP 40). PMP data for different drainage areas and different durations were obtained from Hydro Meteorological Report No. 51 (HMR 51) and a PMP value for a 48 hour duration over a 152 square mile drainage area was interpolated from that data. The PMP events were defined by user specified hyetograph in the HEC-HMS model. The 48 hour duration was divided into 6 hour intervals and incremental precipitation data was given as input. Table 5 shows the precipitation, peak inflow and inflow volume into the dam for different design events.

Table 5: Precipitation, Peak Inflows and Volumes for Design Events

Event	Precipitation (inches)	Peak Inflow (cfs)	Inflow Volume (ac-ft)
100 Year 10 Day Snow Melt 80% Impervious	3.51	4,486	22,087
100 Year 10 Day Rainfall	7.57	5,835	24,687
100 Year 2 Day Rainfall	5.62	6,991	27,126
0.3 PMP 48 Hour	7.14	10,450	38,204
0.4 PMP 48 Hour	9.52	15,383	56,235
0.5 PMP 48 Hour	11.90	20,424	74,694
PMP 48 Hour	23.80	46,207	169,288

An inflow volume of 51,043 acre-feet for the full PMP was reported in the Phase I report, whereas the new hydrology shows an inflow volume of 169,288 acre-feet. The large difference in PMP inflow volume is most likely due to the Phase I report using a lower precipitation event (16.66 inches) and a loss of 10.45 inches, resulting in an excess of only 6.21 inches. In the new hydrology, the total precipitation is 23.80 inches with a loss of approximately 3 inches, resulting in an excess of nearly 21 inches. In the Phase I Report, a constant infiltration rate of 1.30 inch/hour is used which is too high. The rainfall input data in the Phase I report spans 24 hour duration, while the PMP duration is 48 hours in the new hydrology based on the time of concentration of approximately 52 hours. The Phase I report has 15.43 hours as the time to peak value for the Snyder's Unit Hydrograph transformation which is analogous to the time of concentration value in the SCS Unit Hydrograph used in the new hydrology.

The precipitation numbers used in the new hydrology are based on the current standard reference documents available. Based on those reference documents, the precipitation number for PMP event of 24 hour duration is 21 inches. This compares fairly well with the gross PMP value of 19.5 inches reported in the Phase I report. However, in the old hydrology the gross PMP value was reduced using a reduction factor of 0.881 and the hyetograph (graphical representation of rainfall data with time) has the maximum value of 97%, resulting in 16.66 inches of precipitation. The source for the precipitation numbers, loss numbers, rainfall reduction factor and rainfall distribution (hyetograph) used in the Phase I report is unknown.

HEC-HMS MODEL RESULTS

Results of the model run with rating curve #1 are summarized in Table 6 and Figure 4. The results indicate that the dam was overtopped by the 0.4 PMP 48 hour event. The dam was able to pass the 0.33 PMP 48 hour event with the water surface elevation barely over the minimum top of the road elevation. The water surface elevation at the dam for the 0.33 PMP event was 1955.38 feet. The minimum road elevation at the dam is 1955.2 feet.

The results of the analyses with rating curve #2 are shown in Table 7 and Figure 5. The results indicate that the dam is overtopped by a 0.4 PMP 48 Hour event. The dam is overtopped by the 0.39 PMP event with water surface elevation at 1955.59 feet.

The difference in the hydrologic performance of Sweetbriar Creek Dam with rating curve #2 is that it is able to pass a slightly higher PMP event when compared with rating curve #1. Rating Curve #1 is a very conservative estimate of the outflow from the dam since an orifice coefficient of 0.7 is used in estimating the orifice flow. Using a reduced weir length for rating curve #1 may also be conservative, but there is still some debate on whether using the full weir length is appropriate as was done in rating curve #2. The HEC-RAS model used for obtaining rating curve #2 is the better tool for estimating the flow through the spillway in the Sweetbriar Creek Dam, because the HEC-RAS model simulates the hydraulics in the spillway more accurately than the orifice and weir flow equations used in Rating Curve #1.

The real outflow through the dam is likely somewhere in between the two rating curves. Therefore, based on the hydrologic performance of the Sweetbriar Creek Dam for the two rating curves, it is reasonable to assume that the Sweetbriar Creek Dam can safely pass the 0.35 PMP event.

Table 6: Results from Sweetbriar HEC-HMS Model with Rating Curve # 1

	Precipitation (in)	Loss (in)	Excess (in)	Total Runoff (acre-ft)	Peak Inflow to Reservoir (cfs)	Peak Reservoir Discharge (cfs)	Peak Reservoir Elevation (ft)
100 Year 10 Day Snow Melt 80% impervious	3.51	0.56	2.95	22,087	4,486	4,337	1946.28
100 Year 10 Day	7.57	4.13	3.44	24,687	5,835	5,639	1947.59
100 Year 2 Day	5.62	2.28	3.35	27,126	6,991	6,703	1948.62
0.3 PMP 48 Hour	7.14	2.43	4.71	38,204	10,450	9,249	1952.48
0.4 PMP 48 Hour	9.52	2.58	6.94	56,235	15,383	14,777	1957.81
0.5 PMP 48 Hour	11.9	2.69	9.21	74,694	20,424	20,282	1959.04
PMP 48 Hour	23.8	2.92	20.88	169,289	46,207	46,152	1962.27

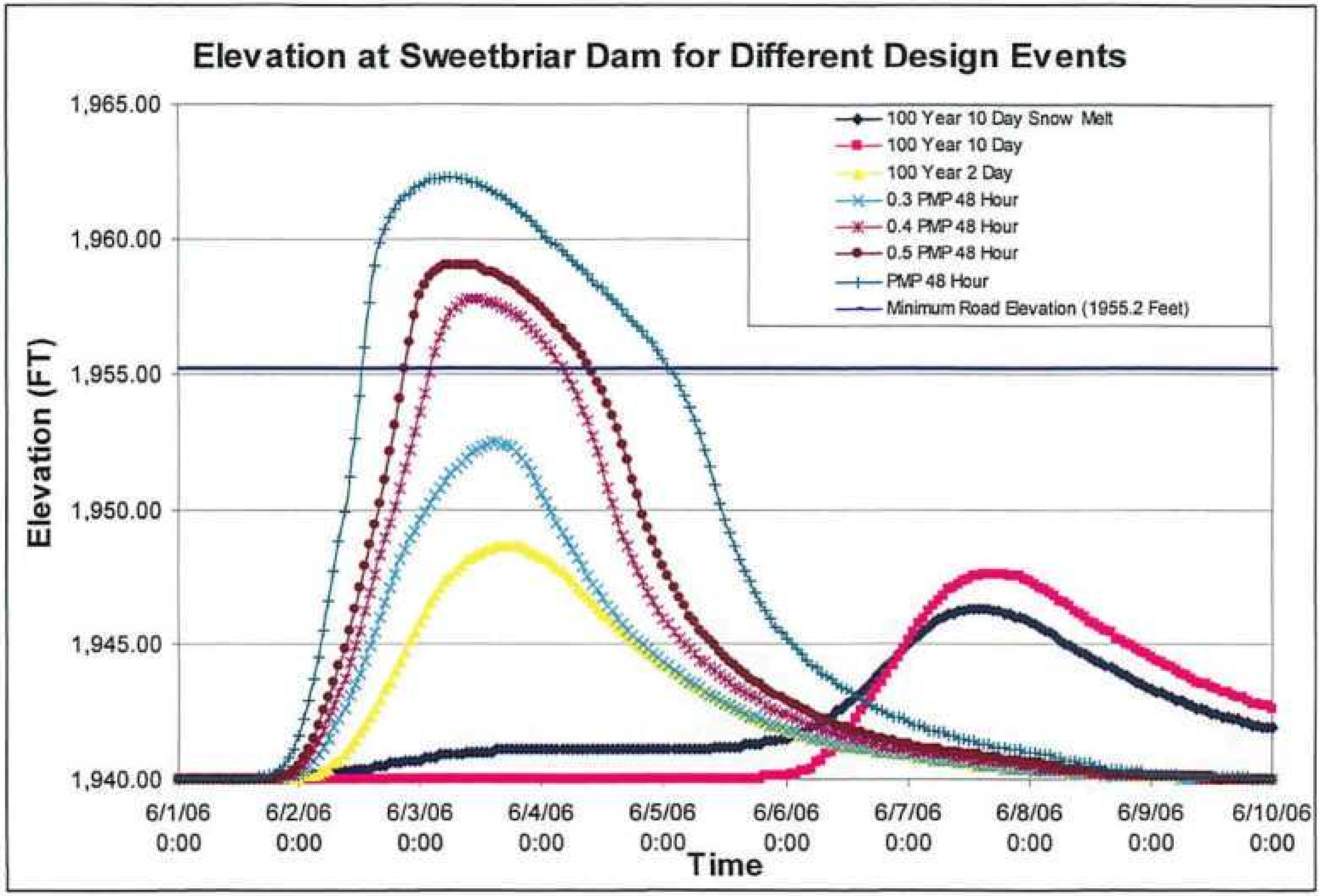


Figure 4: Reservoir Elevation for Various Design Events with Rating Curve # 1

Table 7: Results from Sweetbriar HEC-HMS Model with Rating Curve # 2

	Precipitation (in)	Loss (in)	Excess (in)	Total Runoff (acre-ft)	Peak Inflow to Reservoir (cfs)	Peak Reservoir Discharge (cfs)	Peak Reservoir Elevation (ft)
100 Year 10 Day Snow Melt 80% impervious	3.51	0.56	2.95	22,087	4,486	4,386	1945.42
100 Year 10 Day	7.57	4.13	3.44	24,687	5,835	5,728	1946.47
100 Year 2 Day	5.62	2.28	3.35	27,126	6,991	6,855	1947.30
0.3 PMP 48 Hour	7.14	2.43	4.71	38,204	10,450	10,192	1949.51
0.4 PMP 48 Hour	9.52	2.58	6.94	56,235	15,383	13,539	1956.26
0.5 PMP 48 Hour	11.9	2.69	9.21	74,694	20,424	20,125	1958.35
PMP 48 Hour	23.8	2.92	20.88	169,289	46,207	46,147	1961.91

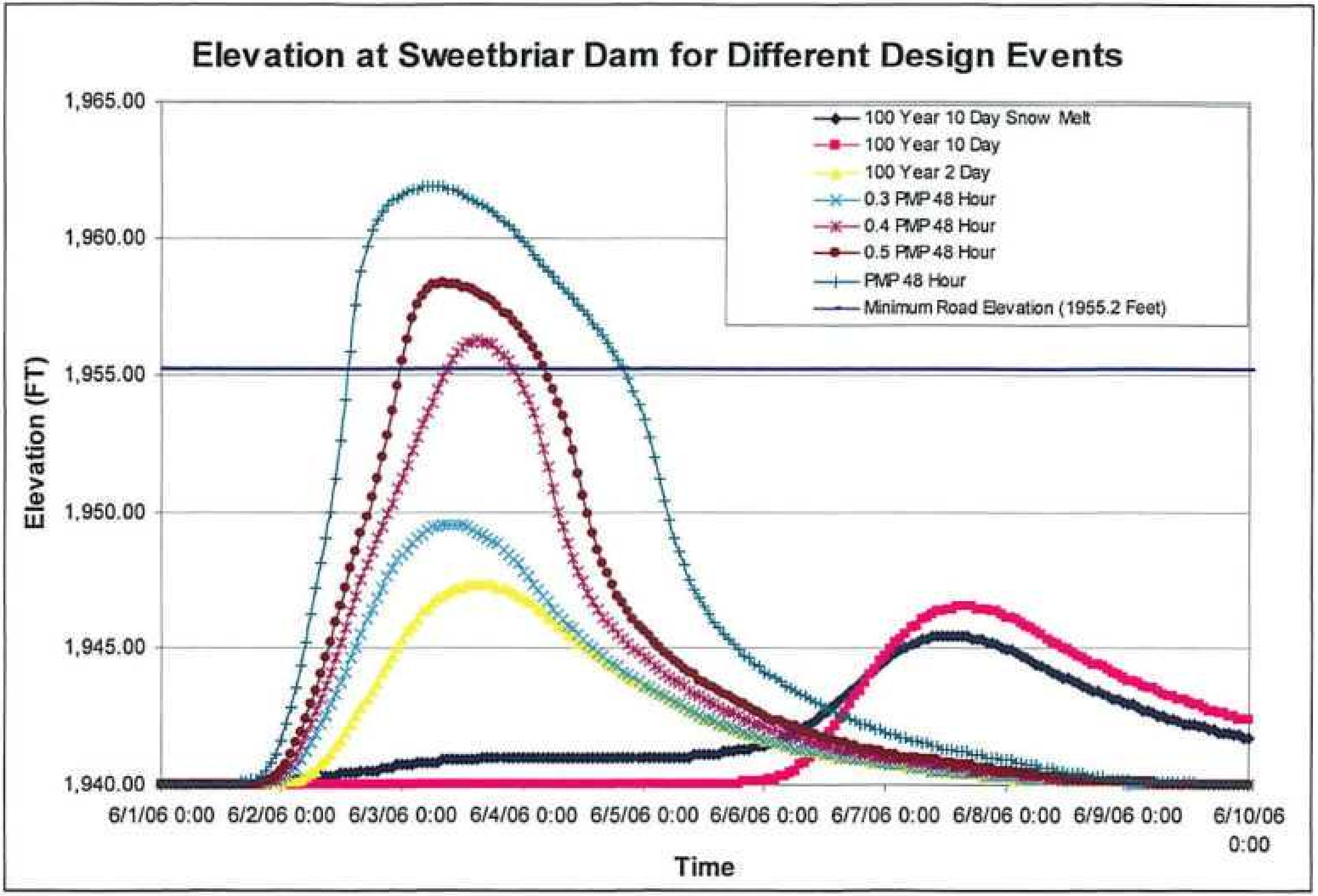
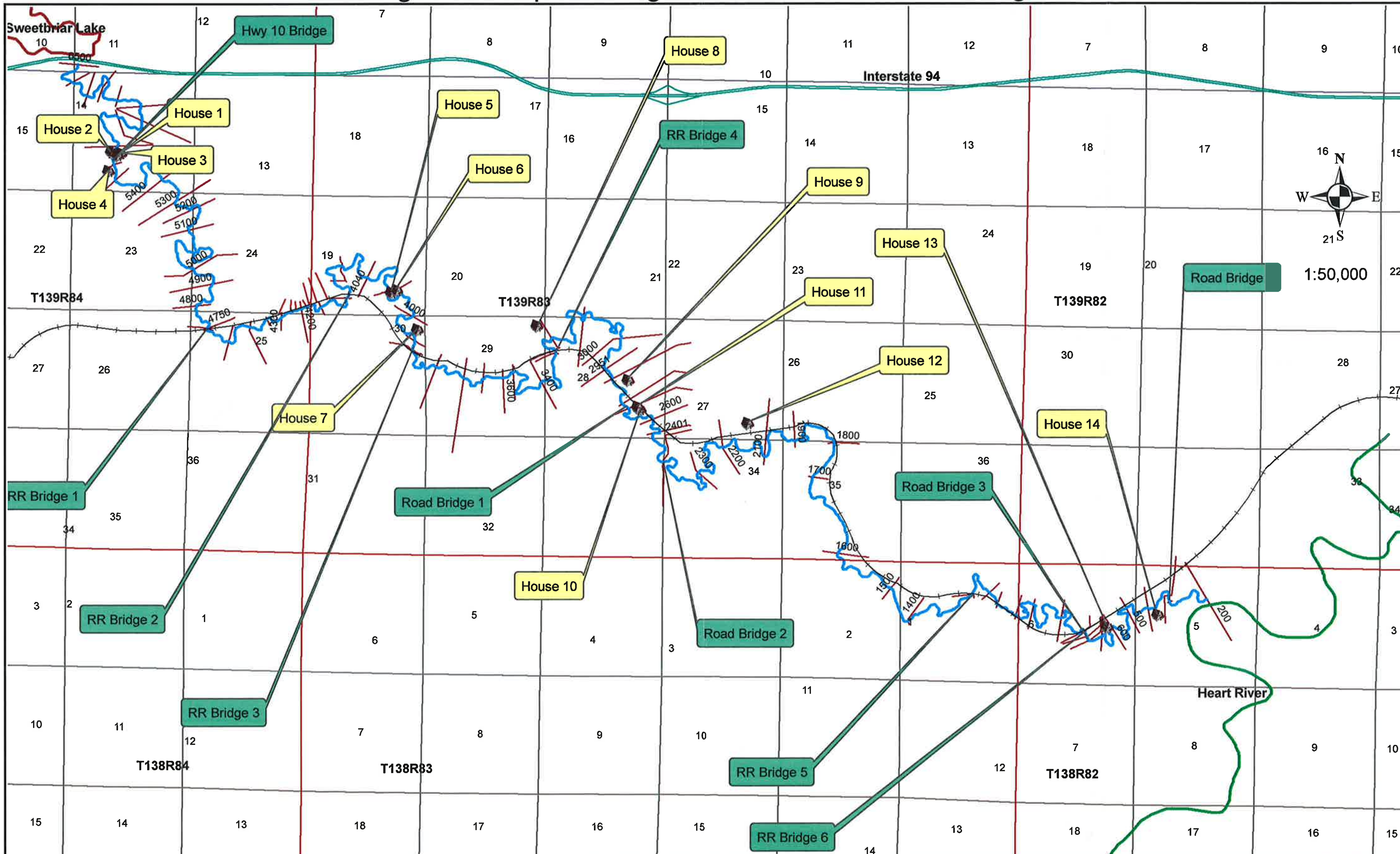


Figure 5: Reservoir Elevation for Various Design Events with Rating Curve # 2

Figure 6: Map showing location of houses and bridges



For the dam break analysis, neither of the above two rating curves were used since the HEC-HMS model requires the outlet structures to be physically defined to model a dam breach. The above two rating curves were used only to check the hydrologic performance of the dam for different flood events and to determine the event which the dam can safely pass without overtopping.

The new hydrology results indicate that the Sweetbriar Creek Dam is able to safely pass 0.35 PMP. While this is lower than 0.55 PMP indicated in the Phase I report, it is believed to be a more correct representation of the actual spillway capacity of the dam. The difference in the results is primarily due to the updated precipitation data used for the new hydrology. Also, the rating curves used for the outflow from the dam in the new hydrology are not exactly the same as used in the Phase I report. A detailed description of the HEC HMS model developed is presented in Appendix D and the model is available in the attached DVD.

DAM BREAK ANALYSIS

In order to determine the risk that Sweetbriar Creek Dam poses to the downstream reach if it should fail, a hydraulic model was developed using HEC-RAS (Version 3.1.3). The dam was failed in the HEC-HMS model and the outflow hydrographs from it were given as input hydrographs to the HEC-RAS model.

In order to carry out dam break analysis using HEC-HMS, the outlet structures must be physically defined. To perform the dam break analysis, the HEC-HMS program cannot use the outlet curves (rating curves) used for determining the response of the dam for different flood events as was done in the hydrology section. Consequently, the conduit was defined as an orifice in the model. Its area, center elevation and orifice coefficient were given as input. Top of the dam was defined by its distance and elevation data. The top of the dam curve was obtained from the Phase I Report. It was not possible to define the weir (drop box) in the model. The outflows from the dam using the HEC – HMS model with the outlet structure defined were compared to the corresponding outflows using the HEC – HMS model with rating curve, for different precipitation events without a dam breach. The comparison showed slight differences in the rising and receding limb of the hydrographs, but the peak flows for the respective events were essentially the same.

The different inflow hydrographs for the HEC-RAS model include "sunny day" flow, "sunny day" flow with dam break, 0.35 PMP without dam break, 0.5 PMP flow with and without dam break, and PMP flow with and without dam break. "Sunny day" failure is the failure taking place by piping without overtopping. "Sunny day" flow through the dam was obtained by having a 100 Year 2 Day rainfall event over the watershed with the reservoir's initial water surface elevation set at 1940 feet. The failure mode for the 0.5 PMP and full PMP events was assumed to be overtopping.

The "sunny day" dam break was assumed to take place in 3 hours. Literature on dam breach characteristics indicates a wide variation in the breach duration. Breach duration data is available for overtopping failure only. The maximum breach formation time indicated in literature for overtopping failure is 4 hours. Since the Sweetbriar Creek Dam embankment is massive, the maximum duration indicated in literature was slightly reduced to get the 3 hour breach duration for the "sunny day" failure (since piping failures usually take place faster than overtopping failure). The piping elevation for the "sunny day" dam break was set at 1920 feet (this is the elevation at which the breach starts and this was arbitrarily set, to get a reasonably conservative hydrograph) and the top and bottom elevation for the dam break were set at 1955 feet (this elevation corresponds to the top of the dam) and 1908 feet (this elevation corresponds to the bottom of the dam) respectively.

For the 0.5 PMP and the full PMP events, the initial reservoir elevation was set at 1940 feet. The overtopping failure for the 0.5 PMP and the full PMP was assumed to take place in 8 hours. The time for an overtopping breach to form is an important parameter in these analyses. The guidance that does exist is based on a limited number of actual failures of typical earth fill dams. Sweetbriar Creek Dam differs from the typical structure in several important features. Because it is the Interstate 94 roadbed, the earth fill structure is much wider than an ordinary dam of the same height, and its crest is armored by two lanes of concrete pavement.

Overtopping failure may occur by one of two mechanisms. In one, the crest remains intact but turbulence at the toe of the slope begins an erosion cavity, which progresses upstream until it intersects the crest and progresses across it, at which point the reservoir is no longer contained. In the other mechanism, erosion begins at the downstream edge of the crest and proceeds to the upstream edge, at which point the reservoir is released.

In the first mechanism, the great width of the embankment presents a much greater task for the progress of the erosion cavity. When it reaches the armored crest it would be significantly retarded, even if the pavement is undermined. After complete failure of the pavement on the downstream side, the same process would have to proceed through the paved surface of the upstream side as well before the reservoir is breached.

In the second mechanism, the erosion would need to begin at the edge of the concrete pavement, removing the pavement before the soil structure is even exposed. This seems highly unlikely. To reflect these conditions, a breach formation time of 8 hours was selected. This is substantially longer than any given in the literature; however, it is considered conservative in light of the specific characteristics of this dam.

The top and bottom elevation of the dam break for overtopping failure was set at 1955 feet and 1908 feet. All dam breaks had a bottom width of 100 feet. Literature indicates that the average breach width can vary anywhere between 1 to 5 times the height of the dam. Using a bottom width of 100 ft would result in an average breach width which is 3 times the height of the dam. Side slopes of 1 Horizontal to 1 Vertical were set for the breach. All dam breaks were set to reach their maximum opening area during the peak flow for the respective events.

The upstream most cross-section in the reach modeled using HEC-RAS was located just downstream of the Sweetbriar Creek Dam (south of Interstate 94). The modeled reach extended to just upstream of the confluence of Sweetbriar Creek with the Heart River. Most of the cross-section data for the model was extracted from 1:24,000 scale USGS topographic maps. The bridge data, cross-section data around the bridges and elevation of ground near the houses were obtained from the survey carried out by the NDSWC survey crew. Detailed description of the HEC-RAS model developed for the downstream reach is available in Appendix E. Figure 6 shows the locations of the cross-sections, houses, and bridges.

RESULTS OF DAM BREAK MODEL

Table 8 shows the water surface elevation and flood depth at a cross-section located near each of the surveyed houses, for each precipitation and dam break scenario modeled. Since the water surface elevations obtained from the model are mainly based on the cross-section data obtained from the 1:24,000 quad map with 20 feet contour interval, the water surface elevation obtained from the model should not be considered absolutely accurate. If the model's water surface elevation is within 1 foot greater or less than the surveyed elevation of the houses, it is considered that the houses are marginally flooded. Refer Figure 6 for location of houses.

Table 9 shows the water surface elevation at the downstream bridges and the depth of water that would overtop each bridge, for the different design events. The water surface elevation is the elevation at the cross-section immediately upstream of the bridges. For details regarding the bridge not included in modeling and the different reaches in the modeled reach as shown in Figure 6, refer to Appendix E.

Table 8: Water Surface Elevation and Flood Depth at Houses

Location of House (Refer Figure 6)	Surveyed Elevation	"Sunny Day" without Dam Break		"Sunny Day" with Dam Break		0.35 PMP Without Dam Break*	
		Water Surface Elevation	Flood Depth (ft)	Water Surface Elevation	Flood Depth (ft)	Water Surface Elevation	Flood Depth (ft)
Peak Flow (cfs)		6,340		29,250		9,550	
House 1	1901.25	1900.68	MF	1910.74	9.49	1902.89	1.64
House 2	1901.38	1900.68	MF	1910.74	9.36	1902.89	1.51
House 3	1916.71	1900.68	0	1910.74	0	1902.89	0
House 4	1907.31	1895.24	0	1901.02	0	1896.78	0
House 5	1842.85	1837.45	0	1842.77	MF	1838.92	0
House 6	1847.23	1837.45	0	1842.77	0	1838.92	0
House 7	1849.41	1831.49	0	1839.33	0	1833.8	0
House 8	1821.32	1808.61	0	1812.46	0	1810.16	0
House 9	1796.14	1790.65	0	1797.32	1.18	1793.51	0
House 10	1789.56	1788.55	0	1793.51	3.95	1790.72	1.16
House 11	1790.95	1788.55	0	1793.51	2.56	1790.72	MF
House 12	1790.3	1766.79	0	1770.5	0	1768.04	0
House 13	1698.04	1688.54	0	1693.8	0	1690.62	0
House 14	1688.67	1686.29	0	1691.63	2.96	1688.54	MF

MF – Marginal Flooding

* - Event does not overtop Sweetbriar Dam

Table 8 (Contd.): Water Surface Elevation and Flood Depth at Houses

Location of House (Refer Figure 6)	Surveyed Elevation	0.5 PMP without Dam Break		0.5 PMP with Dam Break		PMP Without Dam Break		PMP with Dam Break	
		Water Surface Elevation	Flood Depth (ft)	Water Surface Elevation	Flood Depth (ft)	Water Surface Elevation	Flood Depth (ft)	Water Surface Elevation	Flood Depth (ft)
Peak Flow (cfs)		20,050		53,000		46,150		84,150	
House 1	1901.25	1909.47	8.22	1915.36	14.11	1914.17	12.92	1919.7	18.45
House 2	1901.38	1909.47	8.09	1915.36	13.98	1914.17	12.79	1919.7	18.32
House 3	1916.71	1909.47	0	1915.36	0	1914.17	0	1919.7	2.99
House 4	1907.31	1899.86	0	1905.22	0	1904.29	0	1909.94	2.63
House 5	1842.85	1842.31	MF	1847.71	4.86	1850.15	7.3	1854.51	11.66
House 6	1847.23	1842.31	0	1847.71	MF	1850.15	2.92	1854.51	7.28
House 7	1849.41	1838.07	0	1845.5	0	1849.56	MF	1853.82	4.41
House 8	1821.32	1812.57	0	1820.9	MF	1819.98	0	1824.29	2.97
House 9	1796.14	1797.89	1.75	1802.71	6.57	1802.22	6.08	1805.52	9.38
House 10	1789.56	1793.85	4.29	1798.62	9.06	1798.00	8.44	1801.48	11.92
House 11	1790.95	1793.85	2.9	1798.62	7.67	1798.00	7.05	1801.48	10.53
House 12	1790.3	1770.85	0	1775.27	0	1774.68	0	1777.8	0
House 13	1698.04	1694.34	0	1700.63	2.59	1700.46	2.42	1705.55	7.51
House 14	1688.67	1691.66	2.99	1697.36	8.69	1698.64	9.97	1704.07	15.4

MF – Marginal Flooding

Table 9: Water Surface Elevation and Flood Depth at Bridges

Description of the bridge (Refer Figure 6)	Low Point on the High Chord	Sunny Day Without Dam Break Event		Sunny Day with Dam Break Event		0.35 PMP Without Dam Break Event*	
		Water Surface Elevation	Water depth above the bridge	Water Surface Elevation	Water depth above the bridge	Water Surface Elevation	Water depth above the bridge
Highway 10 Bridge	1902.32	1897.12	0	1908.41	6.09	1899.15	0
RR Bridge 1	1874.02	1865.76	0	1874.78	MF	1867.98	0
RR Bridge 2	1857.15	1851.2	0	1857.85	MF	1853.26	0
RR Bridge 3	1845.17	1829.78	0	1835.68	0	1831.76	0
RR Bridge 4	1816.8	1809.36	0	1821.01	4.21	1812.23	0
Road Bridge 1	1790.49	1787.46	0	1793.93	3.44	1789.52	MF
Road Bridge 2	1784.53	1784.9	MF	1789.03	4.5	1788.41	3.88
RR Bridge 5	1719.19	1714.5	0	1718.96	MF	1716.34	0
RR Bridge 6	1702.66	1695.23	0	1701.55	0	1699.62	0
Road Bridge 3	1700.49	1692.3	0	1698.31	0	1697.96	0
Road Bridge 4	1684.61	1684.94	MF	1690.74	6.13	1687.5	2.89

MF – Marginal Flooding

* - Event does not overtop Sweetbriar Dam

Table 9 (Contd.): Water Surface Elevation and Flood Depth at Bridges

Description of the bridge (Refer Figure 6)	Low Point on the High Chord	0.5 PMP Without Dam Break Event		0.5 PMP with Dam Break Event		PMP Without Dam Break Event		PMP with Dam Break Event	
		Water Surface Elevation	Water depth above the bridge	Water Surface Elevation	Water depth above the bridge	PMP Without Dam Break Event	Water depth above the bridge	PMP with Dam Break Event	Water depth above the bridge
Highway 10 Bridge	1902.32	1907.75	5.43	1910.83	8.51	1909.73	7.41	1914.73	12.41
RR Bridge 1	1874.02	1874.54	MF	1879.52	5.5	1879.16	5.14	1880.92	6.9
RR Bridge 2	1857.15	1858.09	MF	1860.47	3.32	1860.33	3.18	1863.27	6.12
RR Bridge 3	1845.17	1833.42	0	1840.41	0	1847.13	1.96	1850.91	5.74
RR Bridge 4	1816.8	1821.05	4.25	1823.43	6.63	1823	6.2	1825.72	8.92
Road Bridge 1	1790.49	1794.32	3.83	1800.28	9.79	1799.3	8.81	1804.29	13.8
Road Bridge 2	1784.53	1789.18	4.65	1793.61	9.08	1793.02	8.49	1797.77	13.24
RR Bridge 5	1719.19	1721.36	2.17	1727.48	8.29	1724.5	5.31	1728.09	8.9
RR Bridge 6	1702.66	1706.24	3.58	1709.48	6.82	1709.06	6.4	1712.06	9.4
Road Bridge 3	1700.49	1703.46	2.97	1706.68	6.19	1706.34	5.85	1709.05	8.56
Road Bridge 4	1684.61	1690.25	5.64	1696.09	11.48	1697.98	13.37	1703.52	18.91

MF- Marginal Flooding

HAZARD CLASSIFICATION

The previous section discussed the dam break modeling that was done for Sweetbriar Creek Dam. This section uses the results of the dam break analysis to evaluate the hazard classification of the dam. Based on the potential impacts of a dam failure shown by the model, a recommendation is made to update the hazard classification of the dam.

EXISTING CLASSIFICATION

The Phase I Inspection Report completed in 1980 classified Sweetbriar Creek Dam in the significant, or medium, hazard category. The hazard classification presented in the 1980 report was based on the following definitions:

> Low Hazard – No permanent or nonpermanent structures for human habitation located in the danger zone, and the economic loss must be minimal. Loss of life is limited to unexpected victims such as a sportsman, farmer, or other outdoorsman.
>
> Significant Hazard – A few permanent type living quarters are permitted in the danger zone, provided there is accessible high ground for safety exit. Also if there is a chance for appreciable economic loss.
>
> High Hazard – Lives of several people are endangered and/or the potential damage to property is excessive.

The 1980 report states that at that time there were two homes located approximately one mile downstream from the dam that could be endangered by a dam failure, but that there was accessible high ground for an exit. It also states that failure of the dam would severely damage Interstate 94 and that "the cost of repairing the highway in addition to the costs incurred due to this major highway not being available would be an appreciable economic loss." For these reasons, Sweetbriar Creek Dam was classified as a significant hazard dam. The hazard classification of Sweetbriar Creek Dam has not been updated since the 1980 report was written.

UPDATED CLASSIFICATION

Since the original hazard classification of Sweetbriar Creek Dam, there have been some changes to the hazard category definitions that are accepted by the NDSWC. The following hazard category definitions are provided in Chapter IV of the NDSWC 1985 Dam Design Handbook and are the current definitions used by the NDSWC:

> Low Hazard – Dams located in rural or agricultural areas where there is little possibility of future development. Failure of low hazard dams may result in damage to agricultural land, township and county roads, and farm buildings other than residences. No loss of life is expected if the dam fails.
>
> Medium Hazard - Dams located in predominately rural or agricultural areas where failure may damage isolated homes, main highways, railroads or cause interruption of minor public utilities. The potential for the loss of a few lives may be expected if the dam fails.
>
> High Hazard - Dams located upstream of developed and urban areas where failure may cause serious damage to homes, industrial and commercial buildings and major public utilities. There is a potential for the loss of more than a few lives if the dam fails.

In order to update the hazard classification of Sweetbriar Creek Dam, a dam break analysis was performed to determine the downstream impacts that would result from a dam failure. The results of the analysis show that a failure of the dam would impact both homes and infrastructure downstream. Table 10 summarizes the flooding depths that could be expected at the houses and bridges downstream of the dam, both with and without a dam failure, for the various precipitation events that were modeled.

The "sunny day" failure scenario is the most critical scenario for determination of the hazard classification because a dam failure as a result of piping could occur quickly and without warning. The results of the dam break analysis show that six houses would be flooded by a "sunny day" failure of Sweetbriar Creek Dam (see Table 10). A seventh house would be marginally flooded, meaning that the dam break model showed a water surface elevation within one foot greater or less than the surveyed elevation of the house. Two of the houses that would be flooded (Houses 1 and 2) are located approximately one mile downstream of the dam, just upstream of old Highway 10. The results show that a "sunny day" dam failure would cause these two houses to be flooded by over nine feet of water. Further downstream, four other houses (Houses 9, 10, 11, and 14) would be flooded by water depths ranging from approximately 1.1 feet to 3.9 feet during a "sunny day" dam failure. Houses 9, 10 and 11 are located near the Sweetbriar town site and House 14 is located near the confluence of Sweetbriar Creek with the Heart River.

Table 10: Summary of Flooding Depths (ft) at Houses and Bridges

Location of House or Bridge (Refer Figure 6)	"Sunny Day"		0.35 PMP	0.5 PMP		PMP	
	without Dam Break	with Dam Break	without Dam Break	without Dam Break	with Dam Break	without Dam Break	with Dam Break
House 1	MF	9.49	1.64	8.22	14.11	12.92	18.45
House 2	MF	9.36	1.51	8.09	13.98	12.79	18.32
House 3	0	0	0	0	0	0	2.99
House 4	0	0	0	0	0	0	2.63
House 5	0	MF	0	MF	4.86	7.3	11.66
House 6	0	0	0	0	MF	2.92	7.28
House 7	0	0	0	0	0	MF	4.41
House 8	0	0	0	0	MF	0	2.97
House 9	0	1.18	0	1.75	6.57	6.08	9.38
House 10	0	3.95	1.16	4.29	9.06	8.44	11.92
House 11	0	2.56	MF	2.9	7.67	7.05	10.53
House 12	0	0	0	0	0	0	0
House 13	0	0	0	0	2.59	2.42	7.51
House 14	0	2.96	MF	2.99	8.69	9.97	15.4
Highway 10 Bridge	0	6.09	0	5.43	8.51	7.41	12.41
RR Bridge 1	0	MF	0	MF	5.5	5.14	6.9
RR Bridge 2	0	MF	0	MF	3.32	3.18	6.12
RR Bridge 3	0	0	0	0	0	1.96	5.74
RR Bridge 4	0	4.21	0	4.25	6.63	6.2	8.92
Road Bridge 1	0	3.44	MF	3.83	9.79	8.81	13.8
Road Bridge 2	MF	4.5	3.88	4.65	9.08	8.49	13.24
RR Bridge 5	0	MF	0	2.17	8.29	5.31	8.9
RR Bridge 6	0	0	0	3.58	6.82	6.4	9.4
Road Bridge 3	0	0	0	2.97	6.19	5.85	8.56
Road Bridge 4	MF	6.13	2.89	5.64	11.48	13.37	18.91

MF-Marginal Flooding

Given the flooding depths that would be expected at Houses 1 and 2 as a result of a "sunny day" failure, there would undoubtedly be the potential for loss of life in these two homes. The fact that these two homes are located so short of a distance downstream of the dam increases the potential for loss of life because the flood wave would reach the houses very quickly, giving very little time to evacuate the residents of these two houses. Although less likely, potential danger to the residents of the other four flooded houses can not be ruled out, particularly Houses 10, which could experience flooding nearly four feet deep. All six houses that would be flooded by a "sunny day" dam failure would have water deep enough to cause substantial damage to the houses. Damage to Houses 1 and 2 could be particularly severe. The velocities that the model predicts at the downstream houses are shown in Table 11.

Table 11: Velocity at Downstream Houses

	Average velocity at cross-section upstream of the house for the Maximum water surface profile of each event (ft/s)					
Location of House	Sunny Day without DB	Sunny Day with DB	0.5 PMP Without DB	0.5 PMP With DB	PMP Without DB	PMP With DB
House 1	3.43	4.54	3.91	6.33	6.04	7.43
House 2	3.43	4.54	3.91	6.33	6.04	7.43
House 3	3.43	4.54	3.91	6.33	6.04	7.43
House 4	13.04	14.87	15.28	13.62	13.7	12.49
House 5	5.91	7.12	7.13	7.24	4.79	5.96
House 6	5.91	7.12	7.13	7.24	4.79	5.96
House 7	1.96	2.71	2.88	4.04	2.74	3.94
House 8	8.47	15.72	15.91	5.51	5.24	6.67
House 9	9.51	13.6	13.76	3.84	3.89	3.51
House 10	1.91	2.54	2.6	3.18	3.11	3.31
House 11	1.91	2.54	2.6	3.18	3.11	3.31
House 12	4.21	6.02	6.18	8.49	8.17	9.83
House 13	6.28	8.78	9.48	12.54	11.72	9.07
House 14	2.36	2.56	2.99	3.71	2.97	3.15

In the case of a failure caused by an extreme precipitation event such as the 0.5 PMP or full PMP event, the creek would already be flooding and people would likely be on alert, possibly decreasing the potential danger to residents downstream. There would also be substantial flooding and damage to homes during these events even without a dam failure. However a dam failure during such an event would increase the depths of flooding over what would occur naturally, potentially causing greater damage to the houses downstream.

Table 12 shows the increase in flooding depth that would occur at each house and bridge downstream, compared to the flooding depth that would occur for that precipitation event without a dam failure. The incremental depths shown in Table 12 assumed a flooding depth of zero in cases where the model indicated marginal flooding. There are two houses that would be flooded by more than one foot of water by a dam failure during a 0.5 PMP event that would not be flooded by the 0.5 PMP alone (or would be only marginally flooded). Four additional houses would be flooded by a dam failure during the full PMP that would not be flooded by the PMP alone (or would be only marginally flooded).

Other infrastructure downstream of the dam would also be impacted by a dam failure. Old Highway 10 crosses Sweetbriar Creek approximately one mile downstream of the dam, and four other county road bridges cross the creek between the dam and the confluence with the Heart River. The Burlington Northern Santa Fe Railway has seven bridges across Sweetbriar Creek downstream of the dam. The results of the dam break analysis show that during a "sunny day" dam failure, the Highway 10 bridge would be overtopped by approximately 6.0 feet of water (see Table 10). Three county road bridges would be overtopped by water ranging from about 3.4 feet to 6.1 feet deep, and one railroad bridge would by overtopped by 4.2 feet of water. A dam failure during either the 0.5 PMP or full PMP flood event would cause greater flood depths over bridges than what would occur naturally. In the case of the 0.5 PMP, two railroad bridges that would experience only marginal flooding as a result of the 0.5 PMP alone would be flooded by 3.3 to 5.5 feet of water as the result of a dam failure during the 0.5 PMP.

Based on these results of the dam break analysis, it is apparent that Sweetbriar Creek Dam should be reclassified as high hazard. In the NDSWC hazard category definitions, one of the main distinctions between medium hazard and high hazard is "the potential for the loss of a few lives" versus "the potential for the loss of more than a few lives" if the dam fails. "A few" is not defined and the number of people living in the homes downstream of the dam is not known, but it reasonable to expect that "more than a few" lives could be endangered in just the two houses immediately downstream of the dam. There is also potential danger to residents of the homes further downstream that would be flooded.

Table 12: Incremental Flooding Depths at Downstream Houses and Bridges

	Incremental Flooding Depth, feet		
Location of House or Bridge (Refer Figure 6)	**"Sunny Day" with Dam Break vs. "Sunny Day" without Dam Break**	**0.5 PMP with Dam Break vs. 0.5 PMP without Dam Break**	**PMP with Dam Break vs. PMP without Dam Break**
House 1	9.49	5.89	5.53
House 2	9.36	5.89	5.53
House 3	0	0	2.99
House 4	0	0	2.63
House 5	0	4.86	4.36
House 6	0	0	4.36
House 7	0	0	4.41
House 8	0	0	2.97
House 9	1.18	4.82	3.3
House 10	3.95	4.77	3.48
House 11	2.56	4.77	3.48
House 12	0	0	0
House 13	0	2.59	5.09
House 14	2.96	5.7	5.43
Highway 10 Bridge	6.09	3.08	5
RR Bridge 1	0	5.5	1.76
RR Bridge 2	0	3.32	2.94
RR Bridge 3	0	0	3.78
RR Bridge 4	4.21	2.38	2.72
Road Bridge 1	3.44	5.96	4.99
Road Bridge 2	4.5	4.43	4.75
RR Bridge 5	0	6.12	3.59
RR Bridge 6	0	3.24	3
Road Bridge 3	0	3.22	2.71
Road Bridge 4	6.13	5.84	5.54

No flooding or only marginal flooding without dam failure

<5 feet flooding depth without dam failure

Another criteria listed in the definition of a high hazard dam is that "failure may cause serious damage to homes". The flooding depths that would be expected downstream of Sweetbriar Creek Dam as a result of a dam failure could cause potentially serious damage to a number of houses, particularly the two houses immediately downstream of the dam that would be flooded by over nine feet of water during a "sunny day" failure. The houses further downstream that would have large incremental increases in flooding depths, over five feet in some cases, during a 0.5 PMP or PMP dam failure (when compared to the 0.5 PMP or PMP with no dam failure) could also suffer significant damage as a result of a dam failure. This potentially serious damage to houses downstream of the dam further supports a high hazard classification.

The county road bridges and railroad bridges flooded by a failure of the dam would be impassable during the flooding and could be washed out or seriously damaged. A dam failure during the 0.5 PMP or PMP would increase the likelihood of serious damage to these bridges because of the greater depths of water over the bridges. In addition, a failure of Sweetbriar Creek Dam would make Interstate 94 impassable. The cost of rebuilding this infrastructure combined with the costs incurred by interruption of Interstate 94 traffic and railroad service could result in substantial economic losses. Further, there is the potential for loss of life due to motorists driving into flooded or washed out roadways.

According to the NDSWC hazard category definitions, potential damage to a main highway falls under the medium hazard classification. However, there is a big difference between minor damage to a relatively lightly traveled state highway and major damage to Interstate #94, which is one of the main traffic arteries in the state. Serious damage to the interstate could potentially have just as much impact as damage to a major public utility, which is included in the definition of a high hazard dam.

Many other states, the Natural Resource Conservation Service (NRCS), the US Army Corps of Engineers, and the Federal Energy Regulatory Commission all include damage to interstates or main highways in their definitions of high hazard dams[1]. Montana's criteria includes interstate in a list of structures where "loss of life is assumed to occur" if present in the area flooded by a dam failure. The NRCS criteria indicate that a dam should be classified as high hazard if serious damage to the interstate would result from a dam failure. Serious damage is defined as "interruption of service for more than 1 day".

SUMMARY

Based on the results of the dam break analysis, Sweetbriar Creek Dam is reclassified as a high hazard dam. A high hazard classification can be justified solely by the potential loss of life in the two homes near Highway 10. These homes would experience sudden flooding more than nine feet deep as the result of a "sunny day" dam failure. There is also potential danger to residents of four homes further downstream that would also be flooded during a "sunny day" failure and the potential for loss of life due to motorists driving into flooded or washed out roadways. Potentially serious damage to houses downstream of the dam and to Interstate 94 further supports a high hazard classification. In addition, a "sunny day" failure of the dam would cause potentially serious damage to the Highway 10 bridge, three county road bridges, and one railroad bridge.

A dam failure during either the 0.5 PMP or the PMP would cause greater flood depths at the houses and bridges downstream, and would cause flooding of houses and bridges not flooded by the precipitation event without a dam failure. A failure during the 0.5 PMP would cause the flooding of two additional houses and two additional railroad bridges. A failure during the PMP would cause the flooding of four additional houses.

Changing the hazard classification of Sweetbriar Creek Dam to high hazard will make it a Class V dam. A Class V dam is defined as any high hazard dam that is 40 feet high or taller. A Class V dam is required to pass 100% of the PMP event without overtopping the dam.

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[1] " Federal Guidelines for Dam Safety: Hazard Potential Classification System for Dams." Federal Emergency Management Agency, October 1998.

APPENDIX A

AGREEMENT FOR CONSTRUCTION AND MAINTENANCE, SWEET BRIAR DAM

MORTON COUNTY, NORTH DAKOTA

PROJECT I-94-4(18)

This Agreement entered on this 18th day of July, 1963, by and between:

(1) The North Dakota State Water Conservation Commission, acting by and through Milo Hoisveen, Chief Engineer and Secretary; (2) The North Dakota State Highway Department, acting by and through Walter R. Hjelle, State Highway Commissioner; (3) The North Dakota State Game and Fish Department, acting by and through Russell R. Stuart, State Game and Fish Commissioner; and (4) The Morton County Board of Park Commissioners.

WHEREAS, it is deemed to be in the public interest that a dam be built and maintained as a multiple use facility, to provide a crossing of Sweet Briar Creek for Interstate Highway 94, to provide an impoundment of water for public use and recreation, and for flood control and other water conservation purposes;

NOW THEREFORE, it is agreed:

I.

That the North Dakota State Highway Department shall plan and design, in a manner approved by the North Dakota State Water Conservation Commission, a combination dam and highway crossing of Sweet Briar Creek in Morton County, North Dakota and shall advertise and award a contract for the construction thereof in the manner and form required by law and as a federal aid highway project and will furnish all preliminary engineering and inspection required during the construction of said project. The North Dakota State Water Conservation Commission will furnish all preliminary engineering relative to water facilities.

II.

Upon the completion of the construction of said project, and upon being billed therefor by the North Dakota State Highway Department, the North Dakota State Water Conservation Commission will pay to the North Dakota State Highway Department a sum equal to 14.24 per cent of the total actual costs for all items in said Project I-94-4(18) required in the construction of said project.

III.

The North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners will reimburse the North Dakota State Water Conservation Commission each in such sum as shall be agreed upon by the North Dakota State Water Conservation Commission, the North Dakota State Game and Fish Department and Morton County Board of Park Commissioners.

IV.

The responsibility for normal and routine highway maintenance shall be solely on the North Dakota State Highway Department and the maintenance responsibility otherwise, for the dam and related facilities shall be on the North Dakota State Water Conservation Commission, the North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners, as per supplemental agreement between the North Dakota State Water Conservation Commission, the North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners, provided however, that all maintenance activities requiring access to the Interstate Highway right of way shall be under the supervision and control of the North Dakota State Highway Department. Any costs incurred by the North Dakota State Highway Department for maintenance activities which are the responsibilities of the other agencies shall be reimbursable in three equal shares by the North Dakota State Water Conservation Commission, the North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners.

V.

Full authority and responsibility for the operation of the impoundment, the management of the water level and the public use lands, shall be jointly shared by the North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners, provided however that at no time shall lands and rights therein acquired for said project be devoted to other than public purposes. In exercising their responsibility for the operation of the impoundment and in managing the water level the North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners shall cooperate with the North Dakota State Highway Department to insure and protect the safety and operation of the highway. No access to the impoundment will be permitted at any point but by way of an established interchange.

VI.

The acquisition of all necessary right of way for the Interstate Highway itself shall be the responsibility and at the sole cost of the North Dakota State Highway Department. The acquisition of all water rights shall be the responsibility of the North Dakota State Water Conservation Commission. The acquisition of all other rights and easements and lands shall be the responsibility of the North Dakota State Game and Fish Department, and the Morton County Board of Park Commissioners, and the cost thereof shall be shared equally by said two agencies.

VII.

The relocation of or providing necessary protection for public or private utilities, public or private roads, bridges, fences or other improvements shall be the responsibility of the North Dakota State Game and Fish Department, and the MortonCounty Board of Park Commissioners and the cost thereof shall be shared equally by said two agencies.

VIII.

The North Dakota State Water Conservation Commission, the North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners do hereby accept responsibility for, and hold the North Dakota State Highway Department harmless from, any and all claims for damage to public or private properties, rights or persons arising out of the impounding of water resulting from the construction of Project I-94-4(18).

IX.

Nothing herein shall be construed as limiting or affecting in any way any power or authority of the North Dakota State Water Conservation Commission, the North Dakota State Highway Department, the North Dakota State Game and Fish Department and the Morton County Board of Park Commissioners.

Executed at Bismarck, North Dakota on the day and year first above cited.

WITNESS:

Hagen A. Sandvik

Wendell W. Clarke

NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

By: Milo W. Hoisveen

Chief Engineer and Secretary

APPROVED:

R.E. Bradley

Chief Engineer

NORTH DAKOTA STATE HIGHWAY DEPARTMENT

By: Walter R. Hjelle

State Highway Commissioner

WITNESS:

Milo W. Hoisveen

NORTH DAKOTA STATE GAME AND FISH DEPARTMENT

By: Russell W. Stuart

State Game and Fish Commissioner

APPROVED:

State's Attorney

MORTON COUNTY BOARD OF PARK COMMISSIONERS

By: Robert F. Pouis

Chairman

APPENDIX B

OFFICE OF STATE ENGINEER

STATE OF NORTH DAKOTA

Perfected Water Permit No. 1002

Conditional Permit No. 1002 Priority Date December 28, 1961

Name of Conditional Permit Holder North Dakota State Game & Fish Department (Sweetbriar Dam)

Address Bismarck, North Dakota

Source of Water Sweetbriar Creek, tributary to the Heart River

Quantity of Water Approved in Conditional Permit 3,300 acre-feet storage plus 950 acre-feet annual use / Nature of Use Recreation

Date Application Approved and Conditional Permit Issued July 19, 1962

Date Water Beneficially Used 1964

This is to certify that the holder(s) of the conditional permit to divert and appropriate water as indicated above has completed construction of the works as set forth therein. And that the holder(s) of said conditional permit did, on the 8th day of October, 1964, submit proof of the application to beneficial use of 3,300 acre feet storage plus 950 acre-feet annual use of water, for the following purpose Recreation

Now, therefore, by virtue of the authority vested in me by the laws of the State of North Dakota, I hereby grant and confirm to North Dakota State Game & Fish Department of Bismarck, North Dakota, holder(s) of said Conditional Permit No. 1002, a right dating from December 28, 1961 to appropriate and divert from at a point located in the [illegible] ¼ Sec. 11, Twp. 139, Rge. 84, SE¼SE¼ Sec 10 Twp 139 Rge 84 a quantity of water limited to the amount that can be beneficially used herein, but not to exceed 3,300 acre feet storage plus 950 acre-feet annual use

Recreation
(Purpose)

and if purpose is irrigation, water is to be applied to the following lands to which this Water Permit is appurtenant:

Sec.	Twp.	Rge.	NE¼				NW¼				SW¼				SE¼				TOTAL
			NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	

Estimated return flow to stream

This Water Permit is subject to the limitation on the use of water as set forth in the laws of this State and to the rights of prior claimants recognized under the laws of North Dakota, and to the following additional limitations

The right to use water for irrigation set forth herein is limited to the above described lands and is subject to cancellation for nonuse.

WITNESS my hand and seal at Bismarck, North Dakota, this 19th day of June, 1970.

(SEAL)

Milo W. Hoisveen

State Engineer — State of North Dakota

STATE OF NORTH DAKOTA, } ss.
COUNTY OF BURLEIGH.

On this 19th day of June, 1970, before me a notary public, personally appeared Milo W. Hoisveen, known to me to be the same person who executed the Perfected Water Permit and acknowledged to me that he executed the same.

M. C. Emerson

Notary Public

SWCC Form 113 (1R-5/70)

"Buy North Dakota Products"

M. C. EMERSON
Notary Public, BURLEIGH CO., N. Dak.
My Commission Expires March 1, 1975

APPENDIX C

Spillway HEC RAS Model (For Rating Curve 2)

The HEC RAS model developed is available in the attached DVD under the folder "Spillway RAS Model". The HEC-RAS model consists of two components: Geometry file, which describes the physical features of the river and the boundary conditions file, which contains the flow data. In the geometry data, the physical description of the conduit downstream of the inlet structure and upstream of the stilling basin was defined. The conduit was modeled as a culvert in HEC-RAS. In HEC-RAS, only culverts of uniform shape and size can be modeled. So, the conduit region between the inlet structure and Joint 2, which is 87 feet downstream of the inlet structure, was defined as cross-sections with lids and the uniform 125-foot long reach between Joint 2 and 4 was defined as a culvert with 4 uniform barrels (see Figure C.1). The name of the geometry file in the model is "Final Geometry File".

Flow data in the range 2,000 to 40,000 cfs was given as input for determining the response of the conduit for the different flood frequency events desired. The name of the steady flow file in the model is "2k – 40k". Boundary conditions need to be specified in the flow data. For mixed flow analyses, boundary conditions have to be specified both upstream and downstream. Critical depth, which is the depth at which the total energy head is a minimum, was specified as the upstream boundary condition. When critical depth is specified as a boundary condition, the program will calculate the critical depth and use that as a boundary condition. Normal depth, which uses the energy slope between the downstream cross-sections, was specified as the downstream condition. When normal depth is specified as the boundary condition, the program calculates the normal depth at the downstream cross-section using the energy slope in Manning's equation. The normal depth value given as input was 0.1013 ft/ft which is the slope between Joint 4 and 5. (see Figure C.1).

The plan file that combines the flow file and the steady flow file is named "Rating Curve 2 Plan". The results (Water Surface Elevation) for the upstream most cross-section number 265 was extracted for different flow data. It should be noted that the plans for the structure used an arbitrary datum, so the elevation data was off the NGVD datum by 200 ft. So the elevation results were reduced by 200 ft to get the rating curve 2.

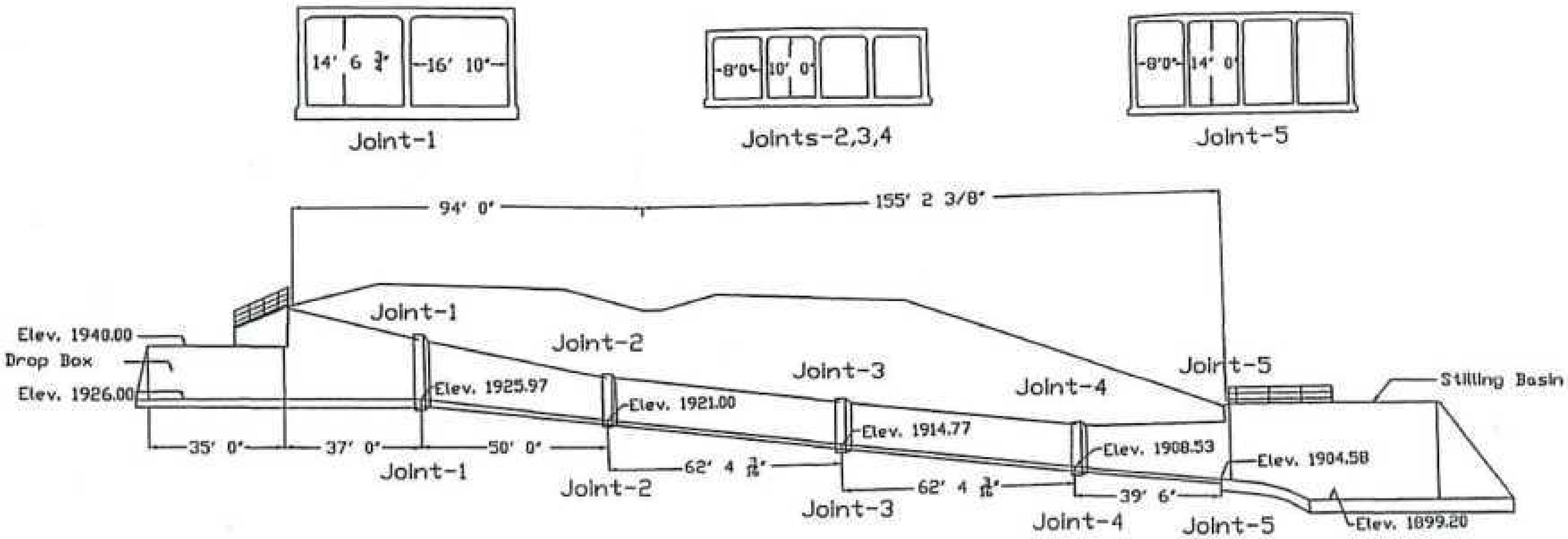


Figure C.1: Spillway of Sweetbriar Creek Dam

APPENDIX D

HEC-HMS Model

The HEC-HMS model developed is available in the attached DVD under the folder hydrology. HEC-HMS model has three components. 1. The basin model, 2. The meteorological model and 3. The control specification. In the basin model the physical description of the watershed such as its area, loss and transformation coefficients curve number and lag time and the reservoir's area-capacity, elevation-storage and elevation-discharge are defined. In the meteorological model, the precipitation depths are defined. In the control specifications, the time duration for the simulation is defined. The basin model used for hydrology had outflow curves defined for the dam. But in order to carry out dam break in HEC-HMS the outflow structures needed to be physically defined. Meteorological models and the control specifications are the same for both hydrology and hydraulics.

Basin Models:

Basin Models for Hydrology:

Different basin models are defined for Rating curve 1 and Rating Curve 2. Even with the same rating curve, different basin models had to be defined for 10 day rainfall and snow melt event since the curve number has to be reduced for both the events and the percent impervious data had to be included for the snow melt event. So in total there are 6 different basin models for hydrology. Listed below are the different basin models defined and their description.

CN Method RC 1:

The curve number used in the watershed is 79, the dam uses rating curve 1 for its elevation discharge relationship.

CN Method RC 1 for 10 Day RF:

The curve number used in the watershed is reduced to 64, for the 10 day rainfall event and the dam uses rating curve 1 for its elevation discharge relationship.

CN Method RC 1 SM 80%:

The curve number used in the watershed is reduced to 64, for the 10 day snow melt event, 80% of the watershed is considered impervious in order to account for the frozen ground and the dam uses rating curve 1 for its elevation discharge relationship.

CN Method RC 2:

The curve number used in the watershed is 79, the dam uses rating curve 2 for its elevation discharge relationship.

CN Method RC 2 for 10 Day RF:

The curve number used in the watershed is reduced to 64, for the 10 day rainfall event and the dam uses rating curve 2 for its elevation discharge relationship.

CN Method RC 2 SM 80%:

The curve number used in the watershed is reduced to 64, for the 10 day snow melt event, 80% of the watershed is considered impervious in order to account for the frozen ground and the dam uses rating curve 2 for its elevation discharge relationship.

Basin Models for Hydraulics:

For hydraulics, there are 4 basin models defined. One for the without dam break events and separate basin models for 0.5 PMP with dam break event, PMP with dam break event and "sunny day" with dam break event since the breach trigger time, breach duration are different for each case. Listed below are the different basin models defined and their description.

Hyd. Basin Model without DB:

This basin model did not have dam break defined, and it is used for "Sunny Day" without dam break event, 0.5 PMP event without dam break, PMP without dam break event. The initial elevation at the dam was set at 1940 feet and tail water was set at zero.

Piping failure for SD:

This basin model is used for the "Sunny Day" event with dam failure. This model has the dam break for "sunny day" failure defined in addition to the without dam break basin model. The following were defined in the dam break.

Breach Method: Piping

Breach Top Elevation: 1955 feet

Breach Bottom Elevation: 1908 feet

Breach Bottom width: 100 feet

Left Side Slope: 1

Right Side Slope: 1

Piping Elevation: 1920 feet

Piping Coefficient: 0.6

Breach Duration: 3 hours

Breach Trigger Time: 03 June 2006, 17:00 hours

Breach Progression: Linear

Breach trigger time was set at 03 June 2006 17:00 Hours, since the peak outflow from the dam for the sunny day event was at 03 June 2006, 20:00 hours and the dam breach is set to have maximum opening area at the time of peak outflow.

Overtopping 0.5 PMP:

This basin model is used for the 0.5 PMP with dam break event . This model has the dam break for the 0.5 PMP event in addition to the without dam break basin model. The following were defined in the dam break.

Breach Method: Overtop

Breach Top Elevation: 1955 feet

Breach Bottom Elevation: 1908 feet

Breach Bottom width: 100 feet

Left Side Slope: 1

Right Side Slope: 1

Breach Duration: 8 hours

Breach Trigger Time: 03 June 2006, 1:00 hours

Breach Progression: Linear

Breach trigger time was set at 03 June 2006 1:00 hours , since the peak outflow from the dam for the 0.5 PMP event was at 03 June 2006,9:00 hours and the dam breach is set to have maximum opening area at the time of peak outflow.

Overtopping PMP:

This basin model is used for the PMP with dam break event . This model has the dam break for the PMP event in addition to the without dam break basin model. The following were defined in the dam break.

Breach Method: Overtop

Breach Top Elevation: 1955 feet

Breach Bottom Elevation: 1908 feet

Breach Bottom width: 100 feet

Left Side Slope: 1

Right Side Slope: 1

Breach Duration: 8 hours

Breach Trigger Time: 02 June 2006, 22:00 hours

Breach Progression: Linear

Breach trigger time was set at 02 June 2006, 22:00 hours, since the peak outflow from the dam for the PMP event was at 03 June 2006, 6:00 hours and the dam breach is set to have maximum opening area at the time of peak outflow.

Meteorological Models:

The 100 year 10 day rainfall, snow melt and the 100 year 2 day rainfall events are defined as frequency storm and the PMP events are defined as frequency storm with incremental precipitation inputted as gage data. Table D.1 and Table D.2 shows the precipitation data inputted for the different 100 year and the PMP events.

Control Specifications:

The model was run from June 1, 2006 0:00 hours till June 10, 2006 0:00 hours with one hour computation interval. The control specification is named June 1-10 1hr

Model Runs:

Table D.3 shows the basin model, meteorological model and control specifications used for the different model runs.

Table D.1: Meteorological Model input for 100 Year Events

Meteorological Model Name	Event	Event- Duration Distribution (in)						
		6 Hrs	12 Hrs	1 Day	2 Day	4 Day	7 Day	10 Day
100 Year 10 Day RF	100 Year 10 Day Rainfall Event	3.6	4.3	4.65	5.99	6.68	7.24	8.2
100 Year 10 Day SM	100 Year 10 Day Snow Melt Event	1.67	1.99	2.15	2.78	3.1	3.36	3.8
100 Year 2 Day RF	100 Year 2 Day Rainfall Event	3.6	4.3	4.65	5.99	-	-	-

Table D.2: Meteorological Model input for PMP Events

Meteorological Model Name	Event /Total Depth (in)	Event- Duration Distribution (in)							
		6 Hrs	12 Hrs	18 Hrs	24 Hrs	30 Hrs	36 Hrs	42 Hrs	48 Hrs
0.3 PMP 48 Hour	0.3 PMP 48 Hour / 7.14	0.21	0.21	0.21	0.78	5.1	0.21	0.21	0.21
0.4 PMP 48 Hour	0.4 PMP 48 Hour / 9.52	0.28	0.28	0.28	1.04	6.8	0.28	0.28	0.28
0.5 PMP 48 Hour	0.5 PMP 48 Hour / 11.9	0.35	0.35	0.35	1.3	8.5	0.35	0.35	0.35
100% PMP 48 Hour	PMP 48 Hour / 23.8	0.7	0.7	0.7	2.6	17	0.7	0.7	0.7

Table D.3.: Different model runs

Run Name	Run Description	Basin Model	Meteorological Model	Control Specification
Hydrology Model				
RC 1 100Yr10DyRF	100 Year 10 Day Rainfall event with Rating Curve 1	CN Method RC 1 for 10 Day RF	100Year 10 Day RF	June 1-10 1hr
RC 1 100Yr10DySM	100 Year 10 Day Snow Melt event with Rating Curve 1	CN Method RC 1 SM 80%	100 Year 10 Day SM	June 1-10 1hr
RC 1 100Year2DyRF	100 Year 2 Day Rainfall event with Rating Curve 1	CN Method RC 1	100 Year 2 Day RF	June 1-10 1hr
RC 1 0.3PMP 48 HR	0.3 PMP 48 Hour event with Rating curve 1	CN Method RC 1	0.3 PMP 48 Hr	June 1-10 1hr
RC 1 0.4PMP 48 HR	0.4 PMP 48 Hour event with Rating curve 1	CN Method RC 1	0.4 PMP 48 Hr	June 1-10 1hr
RC 1 0.5PMP 48 HR	0.5 PMP 48 Hour event with Rating curve 1	CN Method RC 1	0.5 PMP 48 Hr	June 1-10 1hr
RC 1 PMP 48 HR	PMP 48 Hour event with Rating curve 1	CN Method RC 1	100% PMP 48 Hr	June 1-10 1hr
RC 2 100 Yr 10 Dy RF	100 Year 10 Day Rainfall event with Rating Curve 2	CN Method RC 2 for 10 Day RF	100Year 10 Day RF	June 1-10 1hr
RC 2 100 Yr 10 Dy SM	100 Year 10 Day Snow Melt event with Rating Curve 2	CN Method RC 2 SM 80%	100 Year 10 Day SM	June 1-10 1hr
RC 2 100 Year 2 Dy RF	100 Year 2 Day Rainfall event with Rating Curve 2	CN Method RC 2	100 Year 2 Day RF	June 1-10 1hr
RC 2 0.3 PMP 48 HR	0.3 PMP 48 Hour event with Rating curve 2	CN Method RC 2	0.3 PMP 48 Hr	June 1-10 1hr
RC 2 0.4 PMP 48 HR	0.4 PMP 48 Hour event with Rating curve 2	CN Method RC 2	0.4 PMP 48 Hr	June 1-10 1hr
RC 2 0.5 PMP 48 HR	0.5 PMP 48 Hour event with Rating curve 2	CN Method RC 2	0.5 PMP 48 Hr	June 1-10 1hr
RC 2 PMP 48 HR	PMP 48 Hour event with Rating curve 2	CN Method RC 2	100% PMP 48 Hr	June 1-10 1hr
Hydraulics Model				
SD with Dam Break	"Sunny Day" event with dam break	Piping failure for SD	100 Year 2 Day RF	June 1-10 1hr
SD Without Dam Break	"Sunny Day" event	Hyd. Basin Model without DB	100 Year 2 Day RF	June 1-10 1hr
0.35 PMP Without DB	0.35 PMP event without dam break	Hyd. Basin Model without DB	0.35 PMP 48 Hr	June 1-10 1hr
0.5 PMP Without DB	0.5 PMP event without dam break	Hyd. Basin Model without DB	0.5 PMP 48 Hr	June 1-10 1hr
100% PMP without Dam Break	PMP event without dam break	Hyd. Basin Model without DB	100%PMP 48 Hr	June 1-10 1hr
Overtopping 0.5 PMP	0.5 PMP event with dam break	Overtopping 0.5 PMP	0.5 PMP 48 Hr	June 1-10 1hr
Overtopping PMP	PMP Event with dam break	Overtopping PMP	100%PMP 48 Hr	June 1-10 1hr

APPENDIX E

HEC-RAS Model

The HEC-RAS model developed is available in the attached DVD under the folder Dam Break. The upstream most cross-section in the downstream reach modeled using RAS is located just downstream of the Sweetbriar Creek Dam (south of Interstate 94) and the reach extends until near the confluence of the Sweetbriar Creek and the Heart River. The HEC-RAS model has two components 1. Geometry file and 2. Boundary Conditions file.

Geometry file:

The geometry files contain the cross-section data along the river reach, bridge data, lateral weir and storage area data. Except for the geometry file for 0.35 PMP without dam break event, the geometry file for other events are divided into three reaches. The reach from cross-section 6500 (Which is located immediately downstream of the Interstate 94) till cross-section 4073, (Which is located in Section 19, Township 139, Range 83) is called "Dam Downstream" reach. In this reach a lateral weir is defined along the rail road between cross-section 4600 and cross-section 4090. The water leaving this lateral weir is connected to another reach called "SAtoRiverReac" which has the area in the south end of section 2, township 139, range 84 defined as storage area in its upstream end and the topography north of the rail road between cross-sections 4300 and 4090 in the "Dam Downstream" reach defined as cross-sections. In the "SAtoRiverReac" the rail road is defined as lateral weir and water overflowing the lateral river is again connected to the "Dam Downstream" reach at cross-section 4200. The reach downstream of cross-section 4073 till the river merges with Heart River is called "R below SA Conn" reach. All three reaches are connected using a junction in the model. In the geometry file for the 0.35 PMP event without dam break, the "Dam Downstream" reach and the "R below SA Conn" reach is combined into one single reach and it is called "Dam Downstream". The lateral reach "SAtoRiverReach" is removed since there was no water leaving the lateral weir defined in the "Dam Downstream" reach. Refer Figure E.1 and Figure E.2 for the schematic representation of the geometry model and the quad map of the study area respectively.

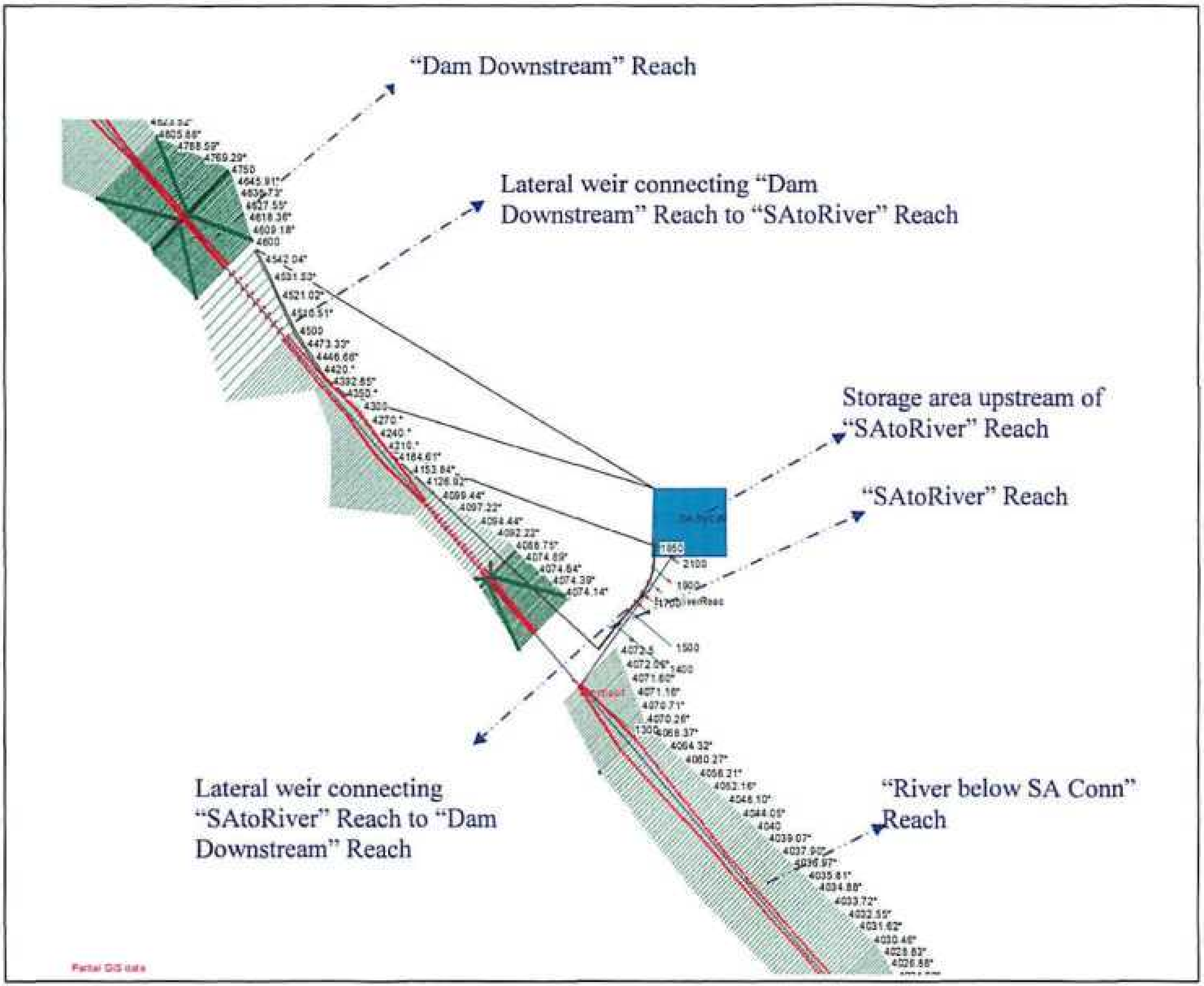
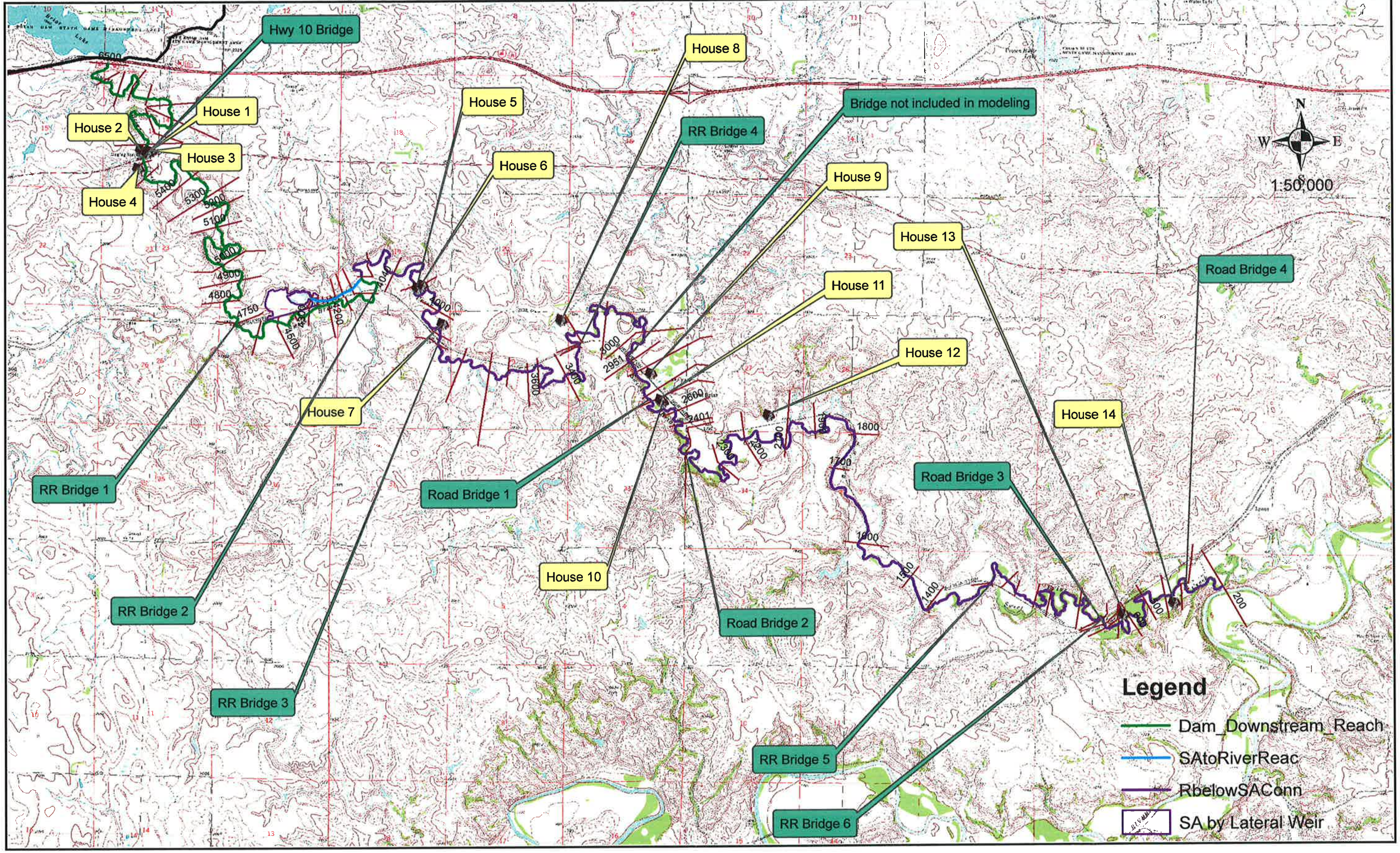


Figure E.1: Schematic Representation of the Geometry file

Figure E.2: Map of the study area along with the river reaches



In all the geometry files, the bridge located in section 28, Township 139, Range 83 is not included. The bridge is not included in the model because; the model requires cross-sections normal to the flow. If the bridge is included, cross-sections running along the rail road should be included. If those cross-sections are included, the constricted region just downstream of the bridge cannot be modeled since the cross-sections will overlap. The constricted natural topography is considered more important to model and more over the structural stability and existence of the bridges for the events modeled is also questionable and so the bridge is not included in modeling. Refer Figure E.3 for the location of the bridge and the constricted topography.

Flow file:

In the flow files the upstream and downstream boundary conditions and the initial boundary conditions for every reach are defined. At the upstream most cross-section the output flow obtained from the HMS was given as the inflow hydrograph. Though the HMS model was run for 10 days, the input hydrograph to the HEC-RAS model does not include the entire hydrograph. The input hydrograph to the RAS model extended at least 18 hours after the peak for each event.

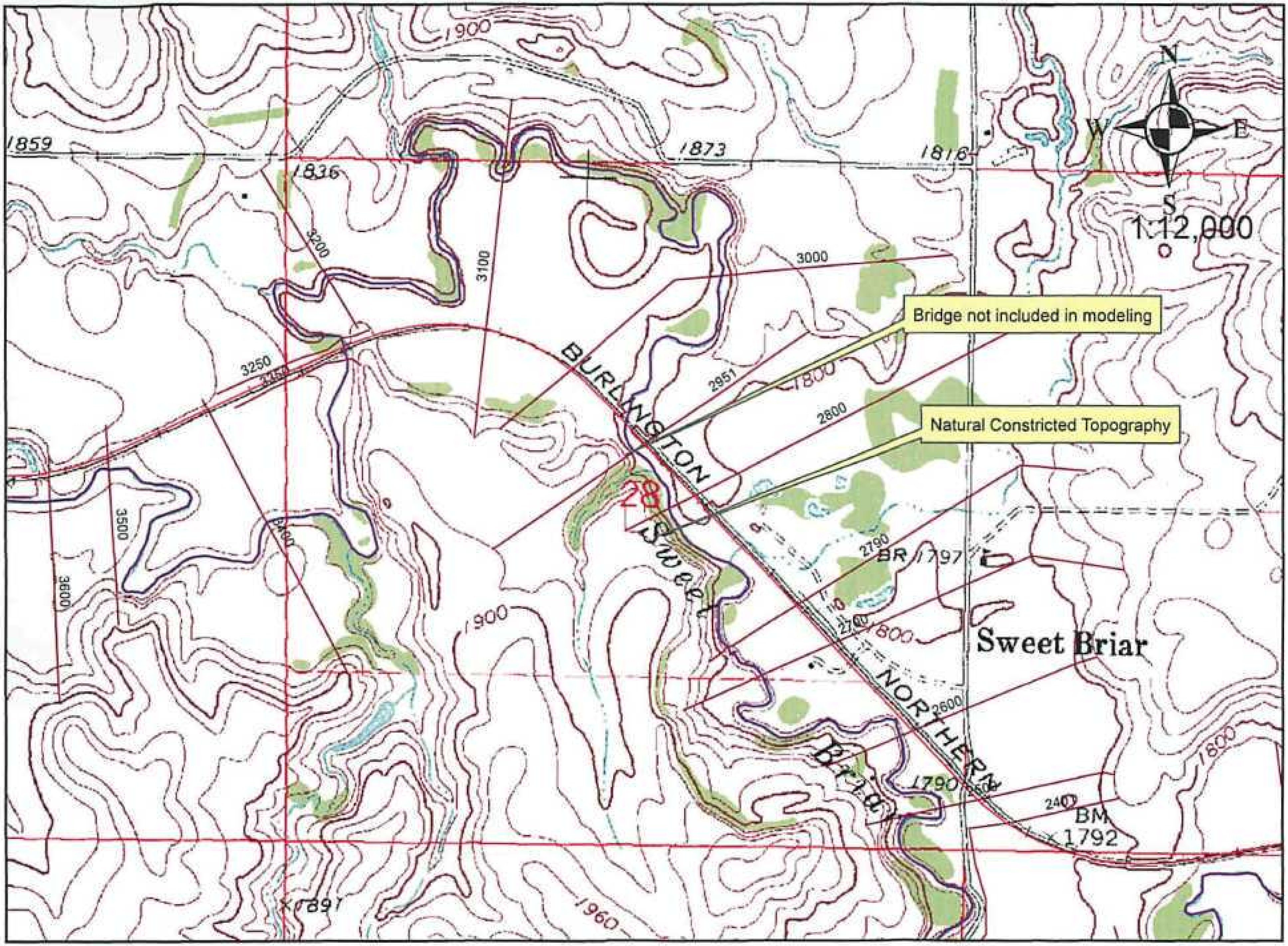
For the downstream boundary condition, the normal depth which is the slope of the channel at the downstream end was defined. The value for the depth inputted in the model is 0.0001. The initial flow for every reach was set at 5000 cfs and the initial elevation for the storage area was set at 1860 ft. For the "Sunny Day" event and the "Sunny Day" with dam failure event, a uniform lateral inflow hydrograph of 500 cfs for the simulation period was given. This was given, because for the "Sunny Day" event there was no flow leaving the lateral weir defined in the "Dam Downstream" reach and thus the "SAtoRiverReac" reach did not have any flow. Since "Sunny Day" event and "Sunny Day" with dam failure event should be identical with respect to geometry and flow except for the dam break hydrograph, the lateral inflow hydrograph was given for "Sunny Day" with dam failure event also.

Model Runs:

Table E.1 shows the geometry file, flow file for the different model runs along with its description.

Model Results:

Figure E.3: Map showing bridge not included in modeling and natural constricted topography



The HEC RAS model results can be visualized using different options in the program. The UNET program that solves the matrix for the unsteady simulation calculates the stage and flow for every cross-section at every time step. Using the stage and flow data at every cross-section at every time step, the SNET program which runs the steady flow simulation calculates all the other parameters. The profile plot in the HEC RAS model comes from the SNET program. At some bridge locations, for some of the PMP events and for "Sunny Day" with dam failure event, the water surface elevation shown in the profile plot is unrealistically high. This happens at the internal cross-sections constructed by the program based on the upstream cross-section and the bridge deck/roadway data. UNET does not calculate water surface elevation for the cross-sections internal to the bridge and so this result comes from the SNET. The data reported in the main report for the water surface elevation at the bridge is obtained for the cross-section upstream of the bridge. Whether the bridges would withstand the huge hydrographs of PMP events and dam break events modeled is doubtful and moreover, the water surface elevation inside of the bridge is not necessary to evaluate the dam, the visual representation in the profile plot can be ignored.

Table E.1: Model Runs along with the geometry and flow file

Plan Name	Plan Description	Geometry File	Flow File
Sunny Day without Dam Break	"Sunny Day" Event	Geometry file for Sunny Day Event	Sunny Day input flow without Dam Break
Sunny Day WITH Dam Break	"Sunny Day" failure with Dam Break Event	Geometry file for Sunny Day Event	Sunny Day input flow with Dam Break
0.35 PMP Without DB	0.35 PMP Event without Dam Break	Geometry file for 0.35 PMP Event	0.35PMP input flow without Dam Break
0.5 PMP without DB	0.5 PMP Event without Dam Break	Geometry file for 0.5 PMP Event	0.5PMP input flow without Dam Break
0.5 PMP With DB	0.5 PMP Event with Dam Break	Geometry file for 0.5 PMP Event	0.5PMP input flow with Dam Break
PMP Without DB	PMP Event without Dam Break	Geometry file for PMP Event	PMP input flow without Dam Break
PMP With DB	PMP Event with Dam Break	Geometry file for PMP Event	PMP input flow with Dam Break