Beulah – West Tributary, Preliminary Findings

Mercer County, North Dakota

SWC Project #1404
October 2017

North Dakota
State Water Commission

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SWC Project #1404
North Dakota State Water Commission
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1. Introduction

As part of the Section 22 study between the Mercer County Water Resource District (District) and the United States Army Corps (USACE), the flooding caused by large events on West Tributary was examined. At the request of the District, the State Water Commission (SWC) analyzed flooding along Beulah's West Tributary. This report summarizes the SWC's findings and examines mitigation alternatives.

1.1 Site Location

West Tributary is located on the northwest side of the city (**Figure 1**) and discharges into the Knife River south of Beulah. The drainage basin of West Tributary is approximately 3.25 square miles of rolling hills with steep ravines. Portions of the lower reach, Subbasin 1, are urbanized. The basin lies within Sections 11, 12, 13, 14, 15, 22, 23, 24, 25, and 26 of Township 144 North, Range 88 West.

1.2 Background

On the morning of August 16, 2014, a severe rainfall event flooded roadways, basements, and caused severe erosion along West Tributary. The 2014 rainfall event prompted the inclusion of the West Tributary investigation into the Section 22 study.

1.3 Methodology

A dry dam analysis was completed based on the hydrology developed as part of the study. Flooding along West Tributary was examined using topographic, soil, and meteorological data. Hydrologic modeling software and Geographic Information Systems (GIS) were used to process data.

Historical rainfall events were obtained using Quantitative Precipitation Estimate Data (QPE) produced by the National Weather Service (NWS). Point precipitation frequency estimates were obtained using NWS's partial duration series Atlas-14 data (NWS, 2017).

Precipitation data was then used to derive volumes and peak flows using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) version 4.1.

2. Discussion

2.1 West Tributary Basin Parameters

West Tributary was divided into three separate subbasins (**Figure 1**). Hydrologic parameters including loss, transformation, and routing were derived for each subbasin for the HEC-HMS model.

Subbasins were delineated using GIS tools and elevation data from the National Elevation Dataset (NED). The Digital Elevation Model (DEM) used to delineate the basins was created using 10-meter data from the NED.

Loss parameters were derived based on area soils. Soils data from the Natural Resources Conservation Services' (NRCS) Soil Survey Geographic Database (SSURGO) was aggregated across each subbasin to derive loss parameters. **Table 1** provides the derived Green and Ampt loss parameters for each subbasin. The parameters were then adjusted based on the Knife River HEC-HMS model created as part of this study.

Transform parameters were derived using a GRASS GIS tool using the longest flow path method. Manning's "n" values were estimated using land cover data from the 2011 National Land Cover Database (NLCD) to develop a time of concentration for each subbasin (NLCD, 2011). Storage coefficients were calculated in order to use the Clark Unit Hydrograph Method. **Table 2** provides the calculated time of concentration and storage coefficients for each subbasin. The time of concentration is higher than expected, but greater time of concentration is insignificant when determining runoff volumes for sizing the dam.

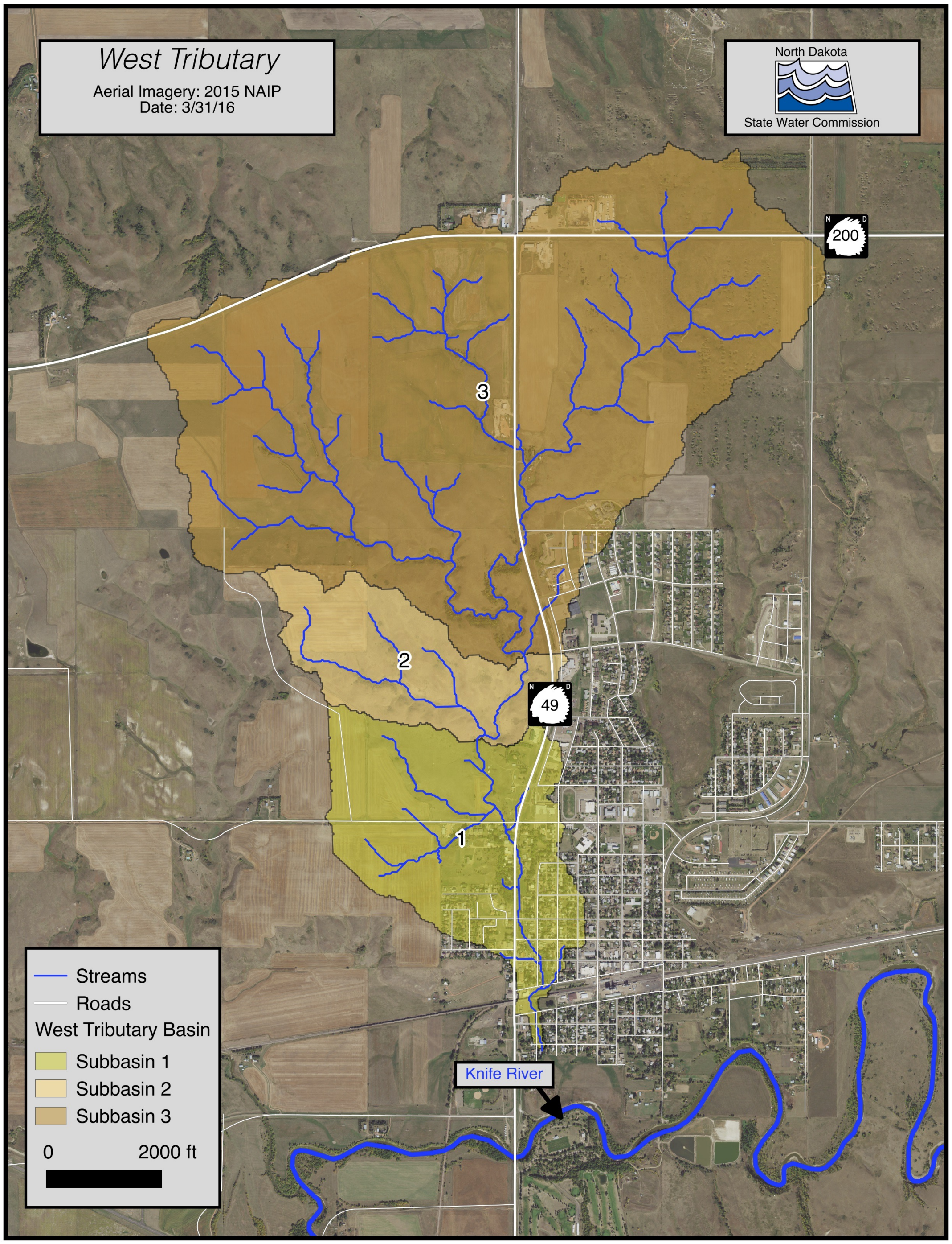

Figure 1. West Tributary Watershed – Beulah.

Table 1. West Tributary Subbasin's Green and Ampt loss parameters

Subbasin	Initial Content	Saturated Content	Suction (in)	Conductivity (in/hr)	Impervious (%)	Subbasin Area (sq mile)
Subbasin-1	0.310	0.474	19.61	0.417	10.96	0.57
Subbasin-2	0.318	0.465	20.39	0.658	0.44	0.32
Subbasin-3	0.316	0.477	19.35	0.477	2.37	2.34

Table 2. West Tributary Subbasin's estimated time of concentration and storage coefficients.

Subbasin	Time of Concentration (hr)	Storage Coefficient (hr)	R/(R+tc)
Subbasin-1	1.20	0.80	0.4
Subbasin-2	1.70	1.13	0.4
Subbasin-3	3.07	2.05	0.4

Routing parameters were estimated for Subbasin 1 using GIS delineation tools. The total length of the routing reach is approximately 10,800 feet with an average slope of 0.008 ft/ft. A Manning's roughness coefficient was estimated for the reach using the 2011 NLCD averaged over the reach.

2.2 Precipitation Estimates

Precipitation data were collected for use in the HEC-HMS model to develop hydrographs, volumes, and peak flows to estimate mitigation alternatives. QPE data for August 14-17, 2014 was averaged for each subbasin. This rainfall produced the largest observed event on Beulah's West Tributary. The greatest rainfall depths recorded fell on August 16th between 2:00 A.M. and 6:00 A.M. (**Table 3**).

Table 3. West Tributary, August 2014 rainfall depths.

Rainfall Depths	Subbasin 1	Subbasin 2	Subbasin 3
Date/Time	(inches)	(inches)	(inches)
8/16/14 1:00	0.00	0.00	0.00
8/16/14 2:00	0.15	0.15	0.17
8/16/14 3:00	1.12	1.23	2.34
8/16/14 4:00	0.77	0.73	0.24
8/16/14 5:00	0.96	1.03	1.92
8/16/14 6:00	0.22	0.25	0.59
8/16/14 7:00	0.00	0.00	0.00
Total	3.22	3.39	5.26

Precipitation frequency estimates from NWS's Atlas 14 dataset are shown in **Table 4** and were modeled using the frequency storm option in HEC-HMS.

Table 4. Atlas 14 partial duration precipitation frequency estimate for West Tributary.

Duration	Frequency Event (Years)								
	1	**2**	**5**	**10**	**25**	**50**	**100**	**500**	**1000**
5-min:	0.27	0.32	0.42	0.52	0.66	0.78	0.92	1.27	1.44
15-min:	0.48	0.58	0.76	0.93	1.18	1.40	1.64	2.27	2.57
60-min:	0.83	1.00	1.30	1.58	2.02	2.40	2.81	3.92	4.45
2-hr:	1.00	1.20	1.56	1.90	2.43	2.89	3.38	4.72	5.36
3-hr:	1.10	1.31	1.71	2.07	2.65	3.14	3.67	5.11	5.80
6-hr:	1.28	1.52	1.96	2.37	2.99	3.52	4.1	5.64	6.38
12-hr:	1.48	1.75	2.24	2.68	3.33	3.88	4.45	5.93	6.63
24-hr:	1.72	2.01	2.52	2.98	3.65	4.20	4.79	6.28	6.98
2-day:	1.97	2.30	2.86	3.35	4.06	4.64	5.24	6.73	7.42
4-day:	2.29	2.68	3.34	3.9	4.7	5.33	5.97	7.56	8.27
7-day:	2.73	3.15	3.86	4.46	5.31	5.98	6.66	8.32	9.05

Probable Maximum Precipitation (PMP) was also estimated as part of this study. A PMP analysis was required because North Dakota's Dam Safety Handbook (NDDDH, 1985) requires dams with higher risk to be designed to handle a certain percentage of the PMP. The PMP for this study was derived using the Corps' "Application of Probable Maximum Precipitation Estimates United States East of the 105th Meridian." A 6-hour duration with a 15-minute time step was chosen to develop the PMP due to the small size of the basin and the HEC-HMS model's time step. **Figure 2** is the hyetograph developed from the Corps' PMP application.

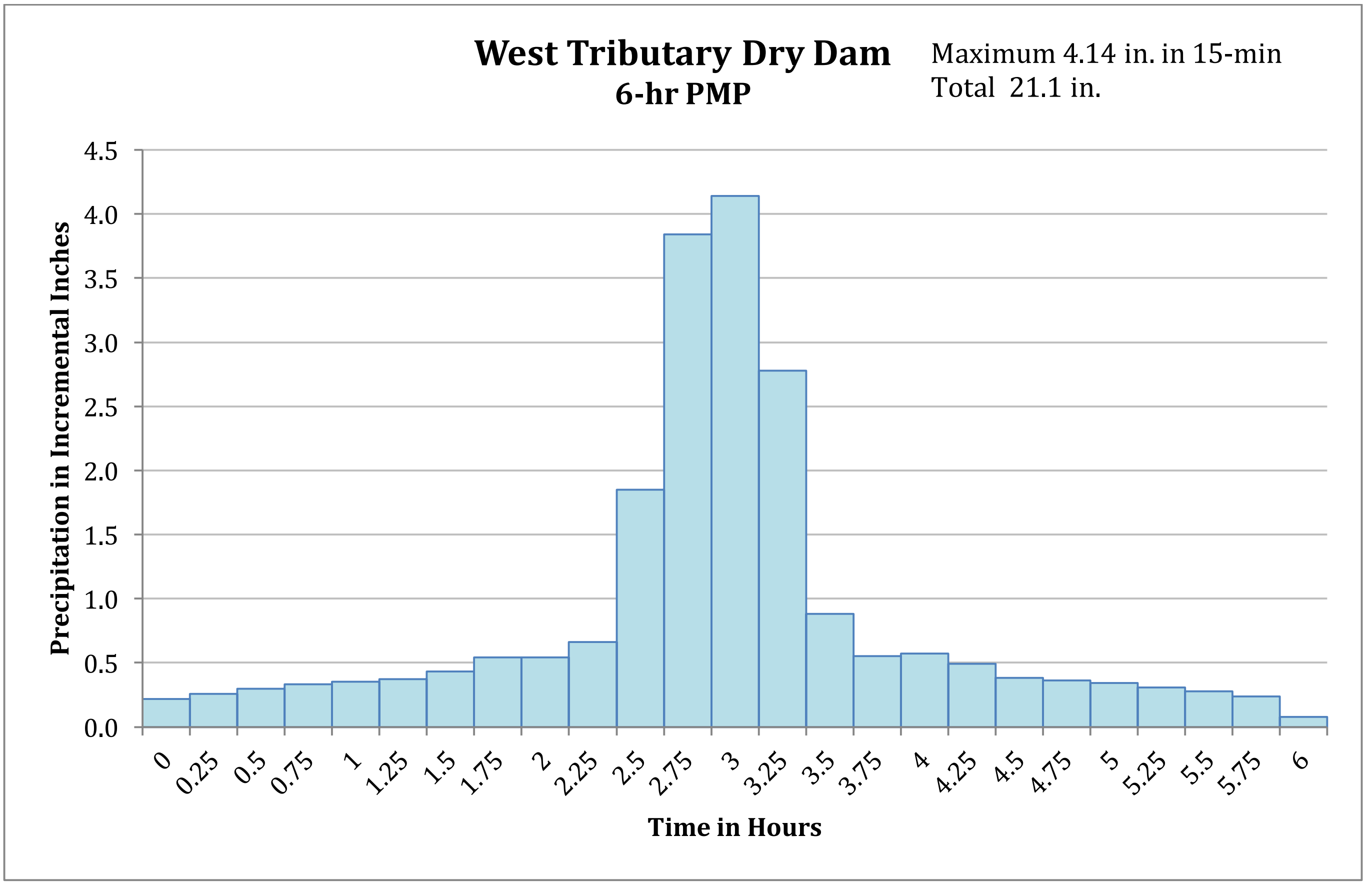

Figure 2. Balanced PMP Hyetograph.

2.3 Hydrologic Model Results

Ten events were simulated in the hydrologic model; one historic event, two theoretical events, and seven frequency events. West tributary is an ungaged tributary, with no recorded event data, therefore calibration was not possible. A frequency event comparison was then conducted to attempt to verify the hydrologic model utilized as part of this study. Frequency events were compared to USGS Stream Stats version 3.0 (USGS, 2017). Frequency events were given a storm area equal to the drainage area above the proposed reservoir. An hour duration was also used for each frequency event as well as the PMP events. The PMP, 50% PMP, and the August 2014 rainfall were modeled as specified hyetographs. The 50% PMP hyetograph was developed using the values in **Figure 2**. **Table 5** is a list of the modeled events peak stream flow and total volume at the Knife River Confluence.

Table 5. West Tributary modeled event peak flow and total volume at the Knife River Confluence.

Event	Modeled Peak Flow (cfs)	Modeled Volume (acre-ft)	USGS Stream Stats Flow (cfs)	Percent Difference
2-Year	67	21	52	29%
5-Year	164	59	150	9%
10-Year	266	97	238	12%
25-Year	422	152	371	14%
50-Year	563	201	478	18%
100-Year	749	267	589	27 %
Aug-14	842	465	-	-
500-Year	1,302	461	854	52%
50% PMP	2,476	823	-	-
PMP	6,198	2,198	-	-

2.4 Dry Dam Analysis

After peak flows and volumes were simulated for the August 2014 rainfall and each frequency event, a dry dam analysis was completed for Beulah's West Tributary.

The dam location was selected by examining the 2015 aerial photography from the National Agricultural Imagery Program (NAIP) and the 10-meter DEM was used to delineate the basin. The dry dam analysis was conducted by selecting a site and determining the available storage. The dam's storage could then be compared to the simulated events to determine if the dam could be constructed and whether or not it would benefit the community. Two sites were evaluated, but only one site offered adequate storage. **Figure 3** illustrates the dry dam location examined as part of this study.

An elevation-volume curve was created for each dam location using a 10-meter digital elevation model. **Table 6** shows the dam elevation-volume table.

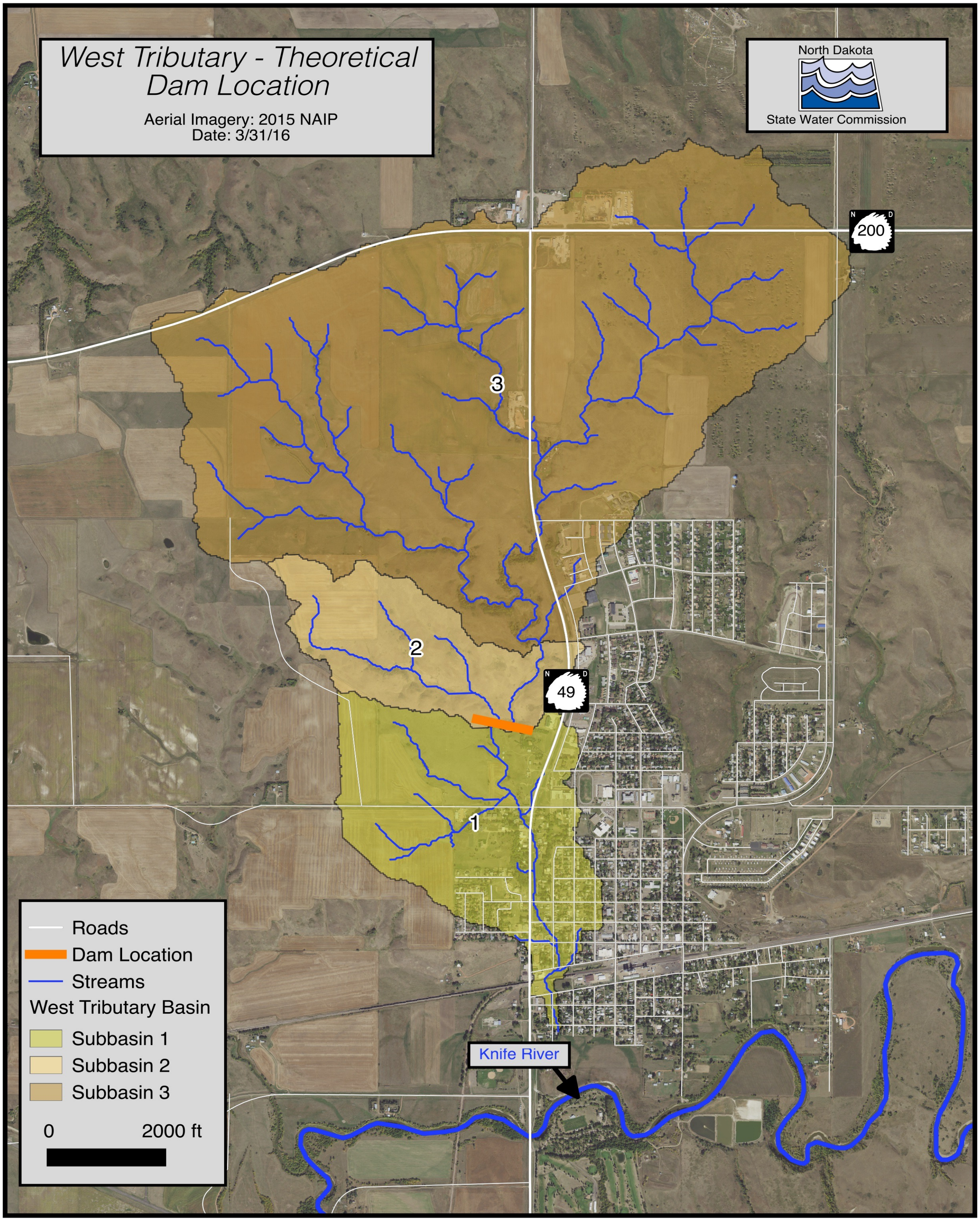

Figure 3. Evaluated Dam Site.

Table 6. Elevation-Volume.

Elevation (ft)	Depth (ft)	Area (acres)	Volume (acre-ft)
1,820.0	0.0	0.0	0.0
1,835.7	16.0	10.0	67.2
1,837.4	17.6	11.7	85.0
1,839.0	19.3	13.5	105.5
1,840.6	20.9	16.4	129.9
1,842.3	22.6	18.8	158.8
1,843.9	24.2	20.9	191.4
1,845.6	25.8	23.1	227.6
1,847.2	27.5	24.6	266.7
1,848.8	29.1	26.6	308.8
1,850.5	30.8	28.2	353.7
1,852.1	32.4	30.5	401.6
1,853.8	34.0	32.7	453.3
1,855.4	35.7	35.1	508.8
1,857.0	37.3	37.8	568.7

Figure 4 shows the inundation footprint of the dry dam at the top of dam elevation, which is 1857-ft (NAVD88) (**Table 9**). The proposed dam would be classified as high hazard due to the downstream residential development and the resulting likelihood of the loss of more than a few lives if the dam were to fail. A high hazard dam 37.0 feet in height is a Class IV dam according to the ND Dam Design Handbook (NDDDH, 1985) (**Table 7**).

Table 7. North Dakota Dam Design Classifications (Green cell is this project's classification)

Dam Design Classifications			
Dam Height (Feet)	Hazard Categories		
	Low	Medium	High
Less than 10	I	II	IV
10 to 24	II	III	IV
25 to 39	III	III	IV
40 to 55	III	IV	V
Over 55	III	IV	V

This classification determines the appropriate design standards for spillway capacities. **Table 8** is the ND Dam Design Handbook's (NDDDH, 1985) precipitation criteria for spillway design based on dam design classification.

Table 8. Precipitation Criteria for Spillway Design (Green cells are this project's classification).

Precipitation Criteria for Spillway Design			
Dam Design Classification	Principal Spillway	Emergency Spillway Criteria	
		Velocity	Freeboard
I	-	P_{10}	P_{25}
II	-	P_{25}	P_{50}
III	P_{25}	P_{100}	0.3 PMP
IV	P_{50}	0.3 PMP	0.5 PMP
V	P_{100}	0.4 PMP	PMP

Table 9. Dam Features.

Feature	Elevation (ft - NAVD88)	Height (ft)	Storage (acre -ft)
Top of Dam	1857.0	37.0	568.7
Invert of Emergency Spillway	1853.5	33.5	443.6
Invert of Principal Spillway	1820.0	0.0	0.0

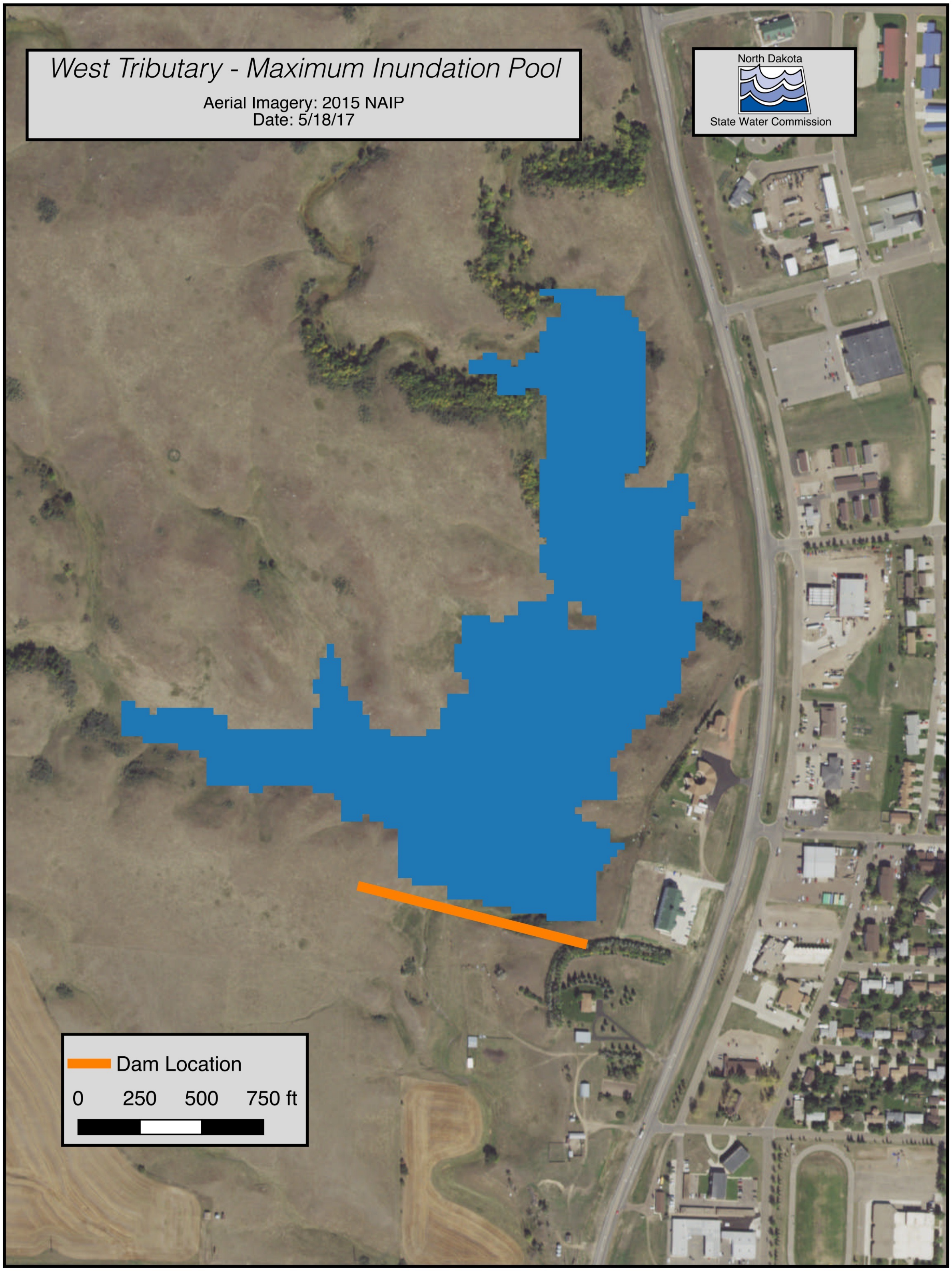

Figure 4. Maximum pool inundation.

Figure 5. West Tributary Dam.

The principal spillway was designed to be a 2.5-foot diameter pipe with a Manning's roughness coefficient equal to 0.012 and an upstream invert at 1820-feet (NAVD88) (**Table 9**). **Figure 6** shows the elevation-discharge curve for the principal spillway.

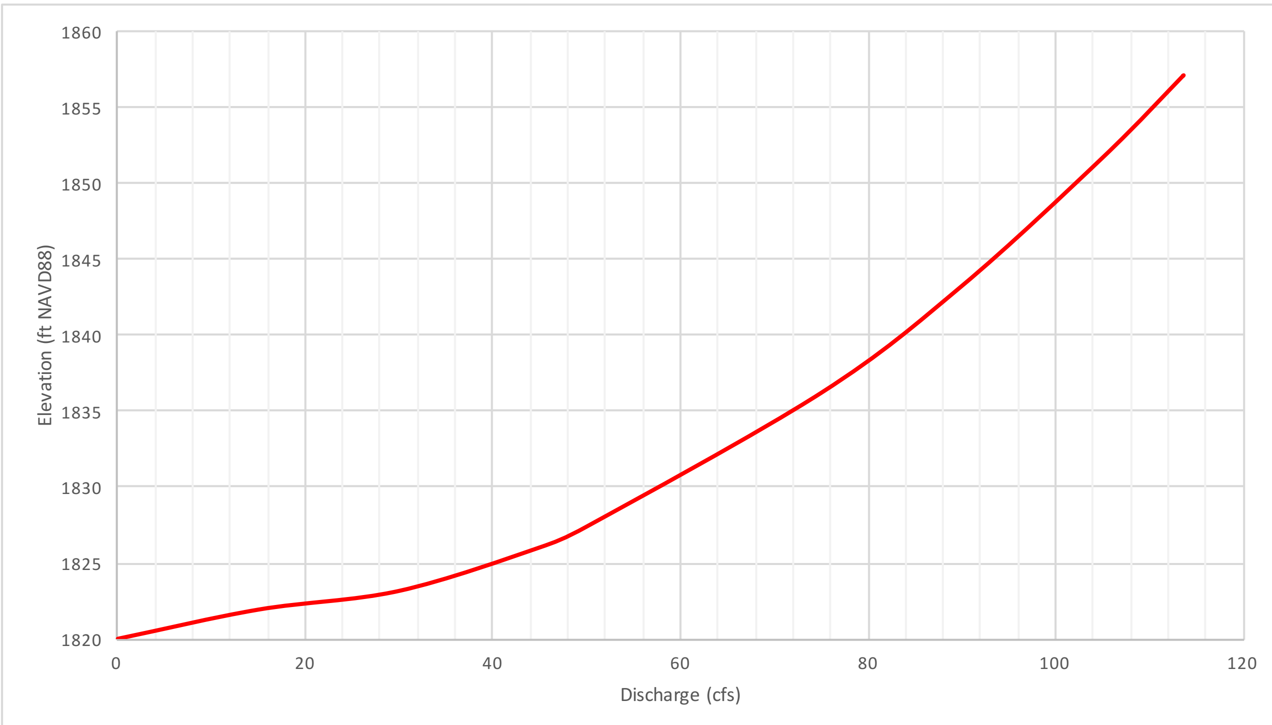

Figure 6. Principal Spillway Elevation-Discharge Curve.

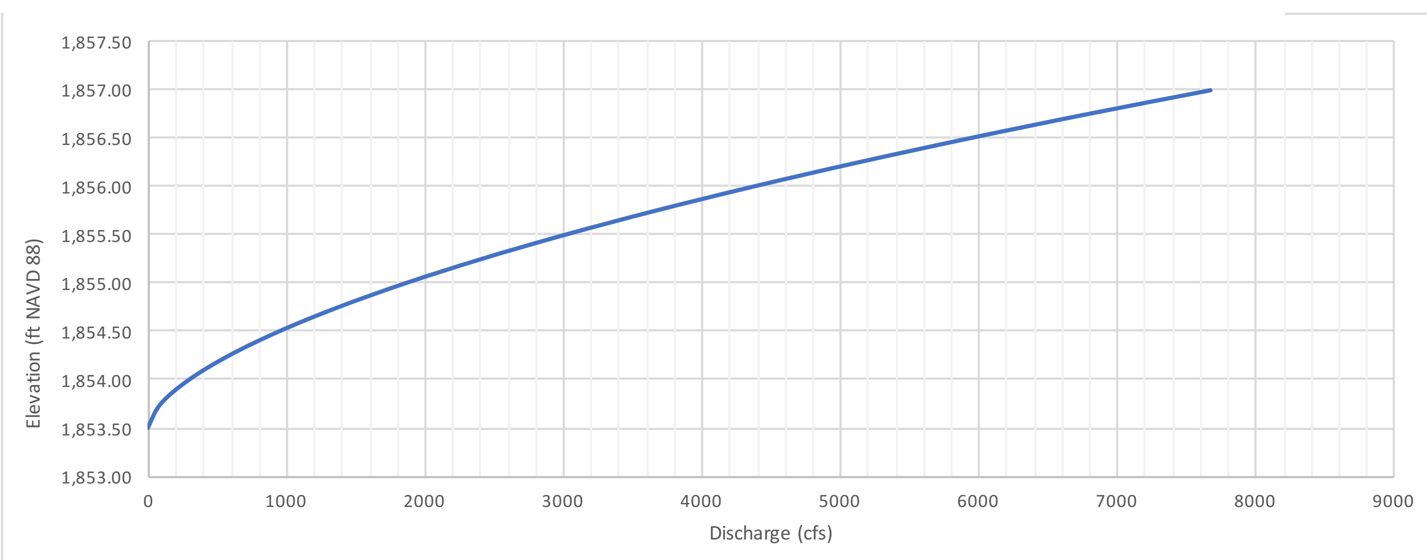

Figure 7. Emergency Spillway Elevation-Discharge Curve.

The proposed invert of the emergency spillway is 1853.5-feet (NAVD88) (**Table 9**). At this elevation, the dam would provide benefit beyond the 500-year event without using the emergency spillway. The emergency spillway is designed to have a 200-foot bottom width with 3 to 1 side slopes and would be placed on the right side of the embankment (see **Figure 5**). **Figure 7** is the elevation-discharge curve for the emergency spillway.

Each modeled event was run with the designed principal and emergency spillways in place. **Table 10 and Figure 8** provide the modeled results for the proposed dry dam.

Table 10. Modeled Dry Dam Results.

Event	Dam Inflow (cfs)	Dam Outflow (cfs)	Peak Storage (acre-ft)	Storage Available (acre-ft)	Pool Elevation (ft NAVD88)
2-Year	56	42	2.6	566.1	1,825.5
5-Year	138	54	19.7	549.0	1,828.9
10-Year	231	61	43.5	252.2	1,831.4
25-Year	370	72	80.5	488.2	1,835.2
50-Year	492	79	114.3	454.4	1,838.1
100-Year	655	87	160.2	408.5	1,841.7
Aug-14	799	96	260.7	308.0	1,846.5
500-Year	1148	99	305.5	263.2	1,848.4
50% PMP	2494	1647	483.7	85.0	1,854.8

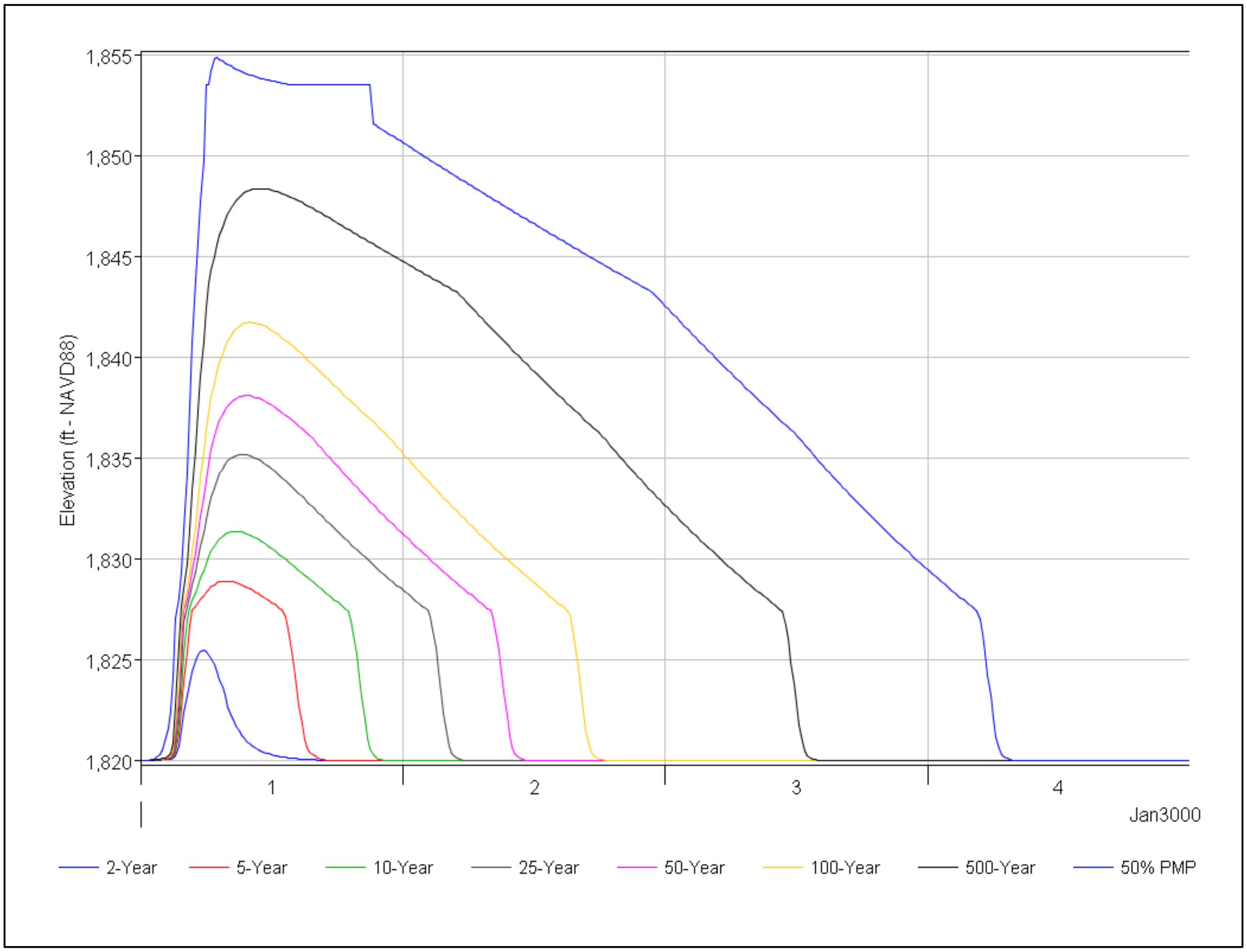

Figure 8. Reservoir Elevation for Frequency Events.

The dry dam provides benefits up to the 50-percent PMP, but also presents risks. Large volume dams directly above a community should be of major concern to the City of Beulah. Dry dams require a draw down period after an event occurs. When another event hits the contributing basin before the dam's pool is drawn down, it can compound the flooding effects for the downstream community and increase the potential of dam failure. Failure of such a structure has potential loss of life concerns that should be carefully considered. Due to the potential impacts of such a failure, a dam break model was created to assess these impacts.

2.7 Dam Break Analysis

A two-dimensional hydraulic model was created with the Hydrologic Engineer Center's – River Analysis System (HEC-RAS 5.0.3). The LiDAR data utilized for this study consisted of a bare earth 1-meter DEM. The LiDAR was collected using North American Vertical Datum of 1988 (NAVD88) and horizontal datum Universal Transverse Mercator Zone 14 North in meters. The LiDAR was flown in the fall of 2015. The LiDAR elevations in the model are based on the NAVD88 (GEOID03) with the horizontal coordinate system being the North Dakota State Plane System (NDSPCS), South Zone, units in international feet, based on the NAD83 (1986). Individual LiDAR tiles were obtained from the NDSWC's LiDAR web service and merged using Quantum GIS. The DEM used for this study is included electronically with this report.

A HEC-RAS terrain file was created from the LiDAR. It was assumed that during a dam breach scenario, culverts along West Tributary channel would be washed out of the channel. Due to this assumption, roadways crossing the West Tributary channel were removed. Break lines were entered into the hydraulic model to capture features within the terrain. Roadways, channel banks, and other topographic features were delineated as break lines. Manning's roughness coefficients were estimated based on land use and aerial photographs.

A dam breach hydrograph for the proposed dam was created using the Natural Resources Conservation Service's Technical Report 60 calculator (NRCS2, 2017). The calculator is constructed using a Microsoft Excel spreadsheet and requires basic information regarding the dam's geometry to be entered in order to calculate the breach hydrograph. The breach hydrograph was created using a water surface elevation equal to the top of dam with no tailwater condition. Outflow from the emergency spillway and principal spillway were not included in the hydrograph. The reservoir would likely be discharging at full capacity prior to a dam breach, with a capacity of nearly 7,500 cfs. Operation of the emergency spillway would have major implications for safety downstream and could potentially lead to a loss of life event. The total failure time-step used for the computation was 15-minutes, meaning the total breach formation would occur within a 15-minute period. **Table 11** is the input data used for the breach calculator and **Figure 9** is the breach hydrograph. The peak discharge from the 15-minute dam breach which occurs at the time of complete breach results in a flow of nearly 27,000 cfs.

The hydrograph was included in the model and run using the full momentum equations due to the high velocities a dam breach would produce. The calculation time-step for the hydraulic model was set at a half of a second for the same reasons.

Figure 10 is a maximum inundation map computed from the hydraulic model for the dam breach and the maximum inundation from a 50% PMP event's outflow from the reservoir. Inundation for the dam breach was computed using only the dam breach hydrograph, which does not include outflows from the principal and emergency spillway. Inundation from the 50% PMP event was computed from the hydrologic model and includes outflows from the principal and emergency spillway. The residents directly downstream of the dam would likely receive less than 6 minutes of warning time from the start of a breach to their homes being inundated. The failure of the dam is likely to be catastrophic to the community and would likely occur with no time to evacuate, which could lead to a significant loss of life event.

Table 11. Breach Calculator - Input Data.

Input data required		
data	**variable**	**Description**
1857	crestEL	dam crest elevation
1857	wsEL	w.s. elev at time of breach
30	TW	dam top width (feet)
3	SSup	dam side slope (upstream, SSup:1)
3	SSdn	dam side slope (downstream, SSdn:1)
1820	floorEL	valley floor elev
570	Vs	resv vol at time of breach (acre-feet)
210	L	valley width at dam axis & w.s. elev (feet)
-	ELwave	top of wave berm elevation
-	Wwave	width of top of wave berm feet
-	SSwave	wave berm side slope (SSwave:1)
-	ELstab	top of stability berm elevation
-	Wstab	width of top of stability berm (feet)
-	SSstab	stability berm side slope (SSstab:1)
15	ts	timestep (minutes) for breach hydrograph

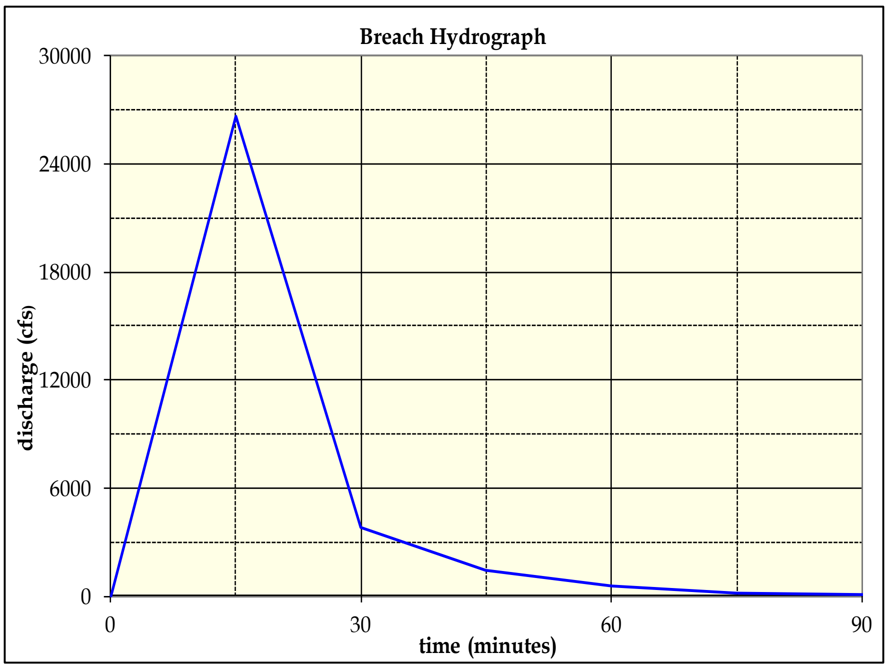

Figure 9. Calculated Breach Hydrograph.

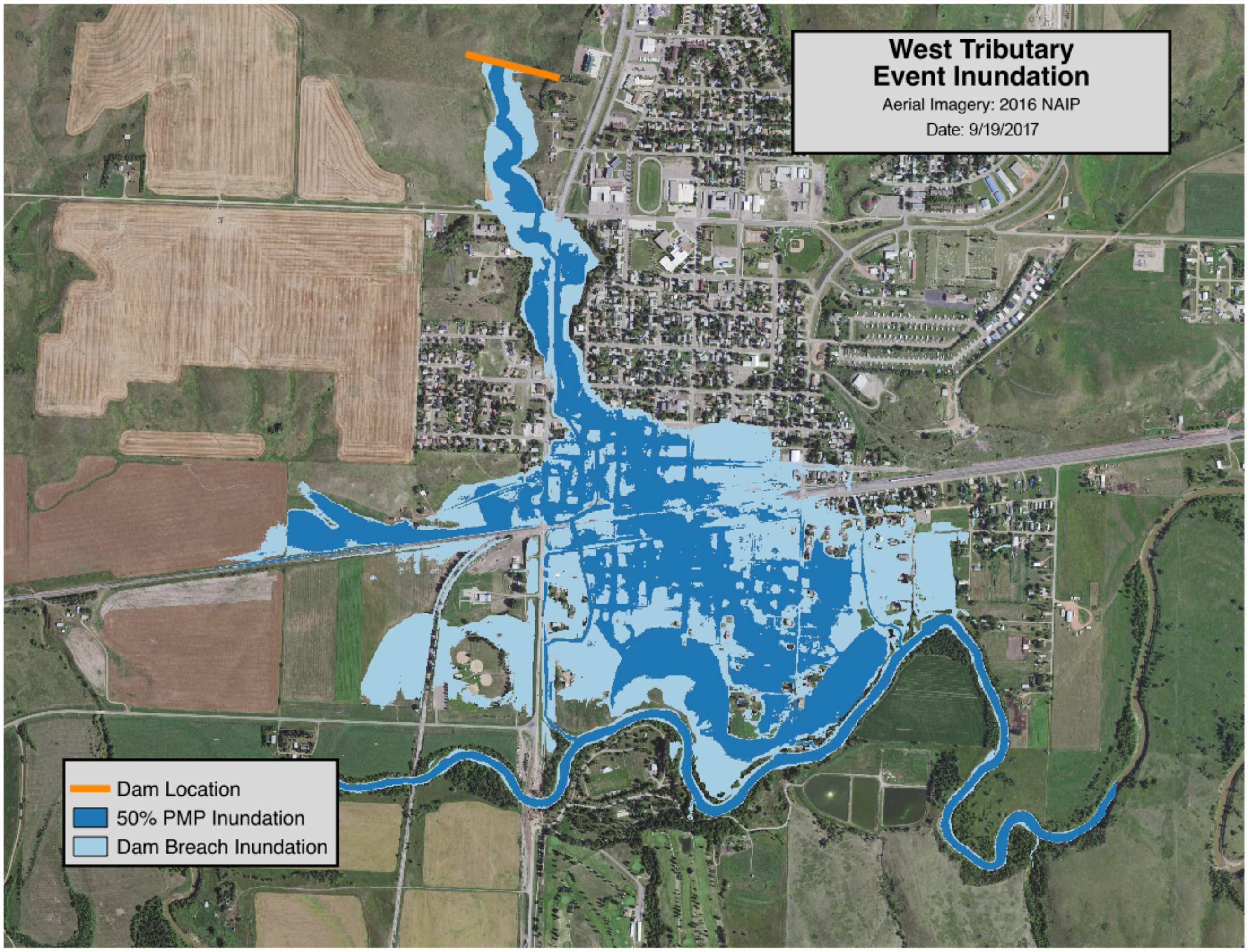

Figure 10. Event Inundation.

2.6 Available Materials

The potential benefits the dam could provide for the downstream community warrant exploration of construction materials and development of a cost estimate. Material availability near the project area would decrease the overall cost of the structure and increase the feasibility of the project. The National Resources Conservation Service (NRCS) classifies the locally available material as an inorganic clay with medium plasticity, which is ideal for constructing embankments. **Figure 11** is the composition of available soil near the area of interest (AOI) from the NRCS' web soil survey (NRCS, 2017).

MAP UNIT SYMBOL	MAP UNIT NAME	RATING	ACRES IN AOI	PERCENT OF AOI
E1301F	Cohagen-Vebar-Parshall fine sandy loams, 9 to 35 percent slopes	SC-SM	4.8	4.60%
E3527B	Williams-Bowbells loams, 3 to 6 percent slopes	CL	24.8	24.00%
E3531C	Williams loam, 6 to 9 percent slopes	CL	28.5	27.60%
E3559E	Zahl-Max loams, 15 to 25 percent slopes	CL	26.3	25.50%
E4139A	Korchea-Fluvaquents complex, channeled, 0 to 2 percent slopes, frequently flooded	CL	18.7	18.10%
E4165A	Straw silt loam, 0 to 2 percent slopes, rarely flooded	CL	0.1	0.10%

Figure 11. Web Soil Survey - Soil Composition.

The dam was designed to meet the regulatory requirements of the North Dakota Dam Design Handbook (NDDDH, 1985) and was optimized to ease earthwork. The optimization of the dam's emergency spillway height and width was necessary to balance the material cut out of the spillway that could be used to produce the embankment for the dam. Ideally the fill/cut ratio is nearly 115 percent cut to compacted fill. **Table 12** provides the cut/fill ratio and volumes for the dam.

Table 12. Cut/fill ratio.

Fill		Cut		Fill/Cut Ratio
Total Embankment Fill (Cubic meters) =	80,169	Total Spillway Cut (Cubic meters) =	98,682	123%
Total Embankment Fill (Cubic Yards) =	104,220	Total Spillway Cut (Cubic Yards) =	128,286	

2.6 Project Cost Estimate

Preparing a cost estimate without a geotechnical exploration requires many assumptions. Without a geotechnical analysis, it was assumed that the foundation and construction material was suitable for construction of a dry dam. RSMeans "Heavy Construction Cost Data 2014" was used to develop a cost estimate for the proposed dry dam. This cost estimate does not include permitting and land acquisition for the footprint of the dam or area inundated.

Table 13. Cost Estimate.

Cost Estimate	Line Item	Source	Unit Cost	Units	Cost
Principal Spillway	Concrete Pipe 30", 150 PSI	RS MEANS 33 11 13.10, 3050	$ 170.00	L.F.	$ 43,180
	Inlet, Outlet, Riprap	Assumption	$20,000.00	Lump Sum	$ 20,000
Emergency Spillway	Topsoil removal and stockpiling	RS MEANS 31 14 13.23, 1440	$ 1.72	C.Y.	$ 43,178
	Bulk excavation, scrapers, clay 3000' haul	RS MEANS 31 23 16.50, 550	$ 8.40	B.C.Y.	$ 1,077,602
	Compation, Sheepsfoot, 6"lifts 4 passes	RS MEANS 31 23 23.23, 5600	$ 1.80	E.C.Y.	$ 230,915
	Topsoil placement and grading	RS MEANS 32 91 19.13, 400	$ 6.15	C.Y.	$ 154,387
	Hydroseeding - Fescue -5.5#	RS MEANS 32 91 19.13, 2400	$ 67.50	M.S.F.	$ 91,502
Embankment	Topsoil removal and stockpiling	RS MEANS 31 14 13.23, 1440	$ 1.72	C.Y.	$ 8,464
	Rough Grading 75100-100000 S.F.	RS MEANS 31 22 13.20, 0280	$ 0.52	Ea.	$ 138,177
	Compation, Sheepsfoot, 6"lifts 4 passes	RS MEANS 31 23 23.23, 5600	$ 1.80	E.C.Y.	$ 187,596
	Topsoil placement and grading	RS MEANS 32 91 19.13, 400	$ 6.15	C.Y.	$ 30,263
	Hydroseeding - Fescue -5.5#	RS MEANS 32 91 19.13, 2400	$ 67.50	M.S.F.	$ 17,936
				Subtotal	***$ 2,043,200***
Adjustment	Location Factor - Minot, ND	RS MEANS, 587	88%	Percent of	$ 1,798,016
	Location Factor Value Adjusted to Present Cost	rsmeansonline.com	102%	Percent of	$ 1,833,976
	Survey & Engineering 10% (Based on Present Cost)	Assumption	10%	Percent of	$ 183,398
	20% contingency (Based on Present Cost)	Assumption	20%	Percent of	$ 366,795
				Total	***$ 2,384,169***

3. Findings

In conclusion, constructing a dry dam on Beulah's West Tributary could benefit the community by reducing large event flooding. However, the August 2014 rainfall was an extremely rare event, roughly a 250-year rainfall that resulted in only minor damage to the community. The risk of a high hazard dam failure this close to a community should be considered in the community's decision making. The failure of the dam is likely to be catastrophic to the community and would likely occur with no time to evacuate, which could lead to significant loss of life. The cost of the proposed project and minimal damages resulting from the 2014 event should also be considered.

4. References

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