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Silver Creek
Dam Break Analysis

FINAL REPORT

Prepared for

City of Silverton, Oregon

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1379

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Purpose

This report documents procedures used and results achieved for a dam breach analysis of the Silver Creek Dam and Reservoir (Figure 1). Two breaching scenarios were modeled, over-topping during the 100-year storm event and a piping failure during normal operation. The results of this study will assist the City of Silverton in the possible development of an Emergency Action Plan.

Background

Construction of the 65-foot-high, earth-filled dam across Silver Creek was completed in 1974. The dam has a crest length of 680 feet, including a 120-foot chute spillway. The dam and reservoir are located approximately 2 miles southeast of downtown Silverton. The dam is owned and operated by the City of Silverton for municipal water supply and recreation uses. Available construction drawings of the dam are included in Appendix A.

On March 25, 1993, a 5.6-magnitude earthquake occurred with an epicenter approximately 10 miles east of the City of Silverton (Appendix A). Following the earthquake, the City and its residents decided to create a city-wide Emergency Action Plan (EAP). The EAP is a guideline of actions put in place during specific emergency situations (e.g. earthquake, flood, fire, etc.) in order to minimize injuries and property damages. A dam break analysis of Silver Creek Dam and the resulting inundation of downstream properties may form an integral part of the EAP.

Dam Failure Scenarios

Two different failure scenarios of Silver Creek Dam were modeled: piping and over-topping. Piping failure occurs if water migrates through the dam material and develops a passage. This could be due to inadequate compaction during construction of the dam, or to changes to dam integrity caused by seismic activity, slope failure or vegetation. As water flows (pipes) through the dam material, it continues to carry away more material and the passage grows in size. Eventually the size of the passage compromises the structural integrity of the dam and causes collapse of the structure itself.

Over-topping failure occurs when sustained reservoir inflow is greater than the combined spillway discharge and reservoir storage capacity. Eventually the water surface elevation in the reservoir rises above the dam crest, causing flow down the face. Flow over the downstream face of the dam causes erosion. Eventually, as with the piping scenario, the erosion compromises the structural integrity and a breach develops.

Model Development

Two different computer models were used to estimate the inundation produced by the dam failure scenarios: *BREACH* and MIKE11. *BREACH* is a public domain computer program developed by the National Weather Service (NWS). The *BREACH* model simulation is part of the *Dambrk* suite of programs and is based on the one-dimensional St. Venant equations of unsteady flow. Parameters describing the dam's physical characteristics (storage volume of the reservoir, materials, height, initial water surface elevation in the reservoir during the simulation) are used to estimate an outflow hydrograph created by catastrophic dam failure.

The MIKE 11 model is produced by the Danish Hydraulic Institute (DHI). MIKE 11 is a one-dimensional unsteady flow computation model also implementing the St. Venant equations. The MIKE 11 model was used to estimate the water surface elevation and the time to peak as the flood hydrograph is routed downstream along Silver Creek.

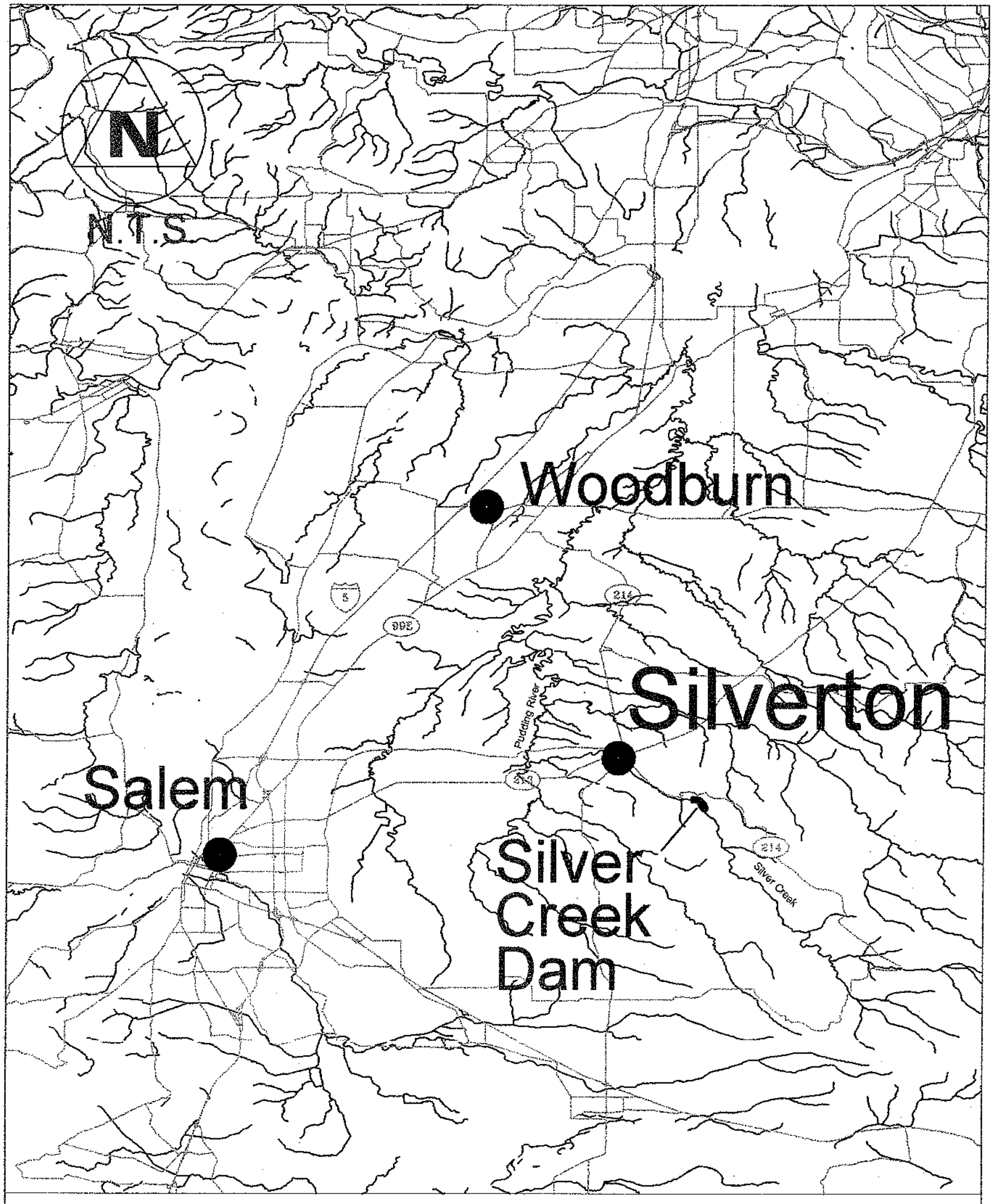


figure 1

**Vicinity Map
Silver Creek Dam**

PWA

The model NWS *Dambrk* was originally proposed for use on this study. It too is a one-dimensional model using the St.Venant equations. However, characteristics of the Silver Creek channel and floodplain require more computational stability than *Dambrk* could provide. *Dambrk* is limited to 200 total cross-sections (actual and interpolated) and nine iterations per time step. The relatively steep channel slope and high number of bridges proved too complex for this application. The *Dambrk* model for Silver Creek Dam would run to completion without bridges in the model. Once bridges were added, the model crashed due to "non-convergence" of the water surface profiles.

After consulting the Hydraulic Research Lab at the NWS for possible solutions to the "non-convergence" issue, PWA attempted to use *Fldwav.* The NWS updated *Dambrk* in the mid-1980's and created the program *Fldwav.* The model is basically identical to *Dambrk* except that it allows more total cross-sections and more iterations per time step. As with *Dambrk*, the model worked fine when no bridges were included. When the bridges were included in the model, the program would also crash for "non-convergence" reasons. For this reason the MIKE 11 was used for floodplain routing.

BREACH- The input parameters required for *BREACH* include the materials used in the construction of the dam and characteristics of the dam itself. Table 1 summarizes the parameters used for this analysis. Values shown in Table 1 were taken from a Technical Memorandum entitled *Seismic Stability Analysis, Silver Creek Dam, Silverton Oregon*, prepared by Cornforth Consultants, Inc., dated July 21, 1999.

Table 1: Silver Creek Dam Material Characteristics

Parameter	Core	Shell
D_{50} (mm)	0.03	1.00
Porosity	0.52	0.43
Unit weight (lb/ft^3)	100	120
Internal Friction Angle	11	36
Cohesive Strength (lb/ft^2)	360	0

The *BREACH* program requires the following physical characteristics; dimensions of the dam, spillway, and reservoir, and inflow and outflow from the reservoir. Table 2 contains the physical characteristics of Silver Creek Reservoir used for this analysis.

Table 2: Silver Creek Reservoir Parameters*

Model Element	Piping	Over-topping
Water Surface Elevation in Reservoir (ft)	423.9	439.3
Inflow to Reservoir (cfs)	30	6274
Outflow from Reservoir (cfs)	30	<100
Elevation of Initial Breach (ft)	380	439.4

*Other dam dimensions used in the Breach analysis are provided in Appendix B.

The water surface elevation (WSE) given in Table 2 for the piping breach reflects a "normal" operating elevation for the late summer months. The 30 cfs inflow into the reservoir is a "base-flow" for summer months (USGS gage 14200300) under normal operating conditions. The WSE in the over-topping scenario is taken just below the crest of the dam. The WSE is assumed to reach this elevation because of a debris blockage of the spillway. The over-topping inflow is equal to the 100-year flow rate as determined in the *Phase I Inspection Report* (June, 1981).

The breach elevations listed in Table 2 were estimated from the construction drawings. In our opinion, these elevations appear reasonable based on a site inspection of the dam itself. The over-topping breach elevation was set equal to the lowest elevation of the dam crest (439.4 ft.). Inspection of the downstream face of the dam revealed hydrophylic (water loving) plants along the lower left abutment. It was assumed that a small amount of seepage occurs at this site, so the piping breach was set for this elevation.

Using the *BREACH* modeling program and the physical dam characteristics noted above, breach dimensions and outflow hydrographs were estimated for each failure scenario. The results are summarized in Table 3, and the complete input/output for both models is provided in Appendix B.

Table 3: Silver Creek Dam Breach Modeling Results

Breach Result	**Piping**	**Over-topping**
Time of Failure (hours)	0.63	0.22
Final Bottom of Breach Elevation (ft)	394.1	376
Side Slope of Breach (ft/ft)	0.0	0.5
Bottom Width of Breach (ft)	26.5	38.0
Peak Discharge from Breach (cfs)	28,040	107,165

The Time of Failure is the duration between the initial breaching and the time at which the breach is fully formed. The Time of Failure depends on the height of the dam, the type of material used in construction and the volume available in the reservoir. Typically, Times of Failure are longer for piping than for over-topping breaches. This is due to the slow erosion process associated with the upstream face during the very early phase of the piping breach. As the piping erosion proceeds, a larger and larger opening is formed which eventually causes a cave-in of the dam above the piping site. An over-topping breach formation is created after the downstream face of the structure has started to erode away due to flow over it. A crevasse forms that progresses into the dam material, weakening the dam itself until a completed breach forms.

MIKE 11- The MIKE 11 model was used to estimate the peak WSE within Silver Creek in response to the discharge hydrograph produced by the dam failure. As the flood wave moves downstream, storage in the floodplain will attenuate the peak flow resulting in a decreased flow rate at the next downstream cross-section. MIKE 11 calculates the amount of attenuation created by the floodplain storage and also the time it takes for the floodwave to progress through the channel.

To properly model the progression of the floodwave, MIKE 11 requires a physical description of the channel, floodplain, and all significant hydraulic structures (bridges/culverts). The channel description includes: channel geometry, bridge geometry, roughness coefficient (Manning's "n") and boundary conditions.

Cross-Sections- The locations of cross-sections to be used in the model were chosen based on the following criteria: changes in channel geometry (including floodplain), changes in channel slope, location of bridges, and points of interest. Thirty-one (31) cross-sections were developed for use in the MIKE 11 model.

The cross-sections are designated in river miles (RM) downstream from Silver Creek Dam. The cross-sections start at the dam (RM 0.00) and extend downstream to RM 4.12 (downstream of the City's wastewater treatment plant). The cross-sections are described with station and elevation coordinates. Station 0+00 is on the left side of the channel when facing downstream. The station/elevation coordinates were developed using a topographic map provided by the City of Silverton. This topographic data was generated from aerial photogrammetry. The invert of the channel was estimated from aerial topography for the upper reaches of Silver Creek. In the reaches where the existing FEMA Flood Insurance Study (FIS) was available, the channel inverts were taken from the profile sheet in the FIS. We believe this provides more accurate information within the City Limits of Silverton.

Bridges- Eleven bridges are located between Silver Creek Dam and the downstream study limit, the Wastewater Treatment Plant (WWTP). Two bridges are small pedestrian bridges and five are privately-owned bridges providing property access to the west bank of the creek. The remaining four bridges are larger structures owned by either the City of Silverton, Marion County, or the railroad.

Of the eleven bridges, eight hydraulic structures (bridges) were included in the MIKE 11 model. The two pedestrian bridges were not modeled, because it is believed that they would fail immediately upon contact with the floodwave, therefore not impeding the progression of the floodwave. The "C" Street Bridge and the railroad bridge were combined and modeled as one hydraulic structure. Limited data was available for the railroad bridge, and since the railroad bridge and the "C" Street Bridge are adjacent to each other, the lower chord and higher deck elevations of the two bridges were used to create one hydraulic structure in the MIKE 11 model.

The bridges were modeled using cross-sections. Station and elevation coordinates were used to describe the top of deck, low chord and the bridge opening geometry. This methodology allows for pressure flow and weir flow calculations when the bridge is over-topped.

Boundary Conditions- The MIKE 11 model requires upstream and downstream boundary conditions. The upstream boundary condition is the inflow hydrograph, the characteristics of which were provided by *BREACH* for each of the failure scenarios noted above. Table 3 contains the peak discharges for each of the failure scenarios used in this study.

At river mile 4.12, the downstream boundary of this study, a rating curve was developed for the cross-section (Figure 2). The rating curve was developed from the MIKE 11 program based on cross-sectional geometry, channel slope and the roughness coefficient.

Manning's "n"- The roughness coefficients used in the MIKE 11 model were based on the values established in the existing FEMA Flood Insurance Study (FIS). The FIS uses a channel roughness coefficient ranging from 0.035 to 0.050 and an overbank range of 0.05 to 0.140. Using these values as initial parameters in MIKE 11, steady-state models were run for comparison of the WSE.

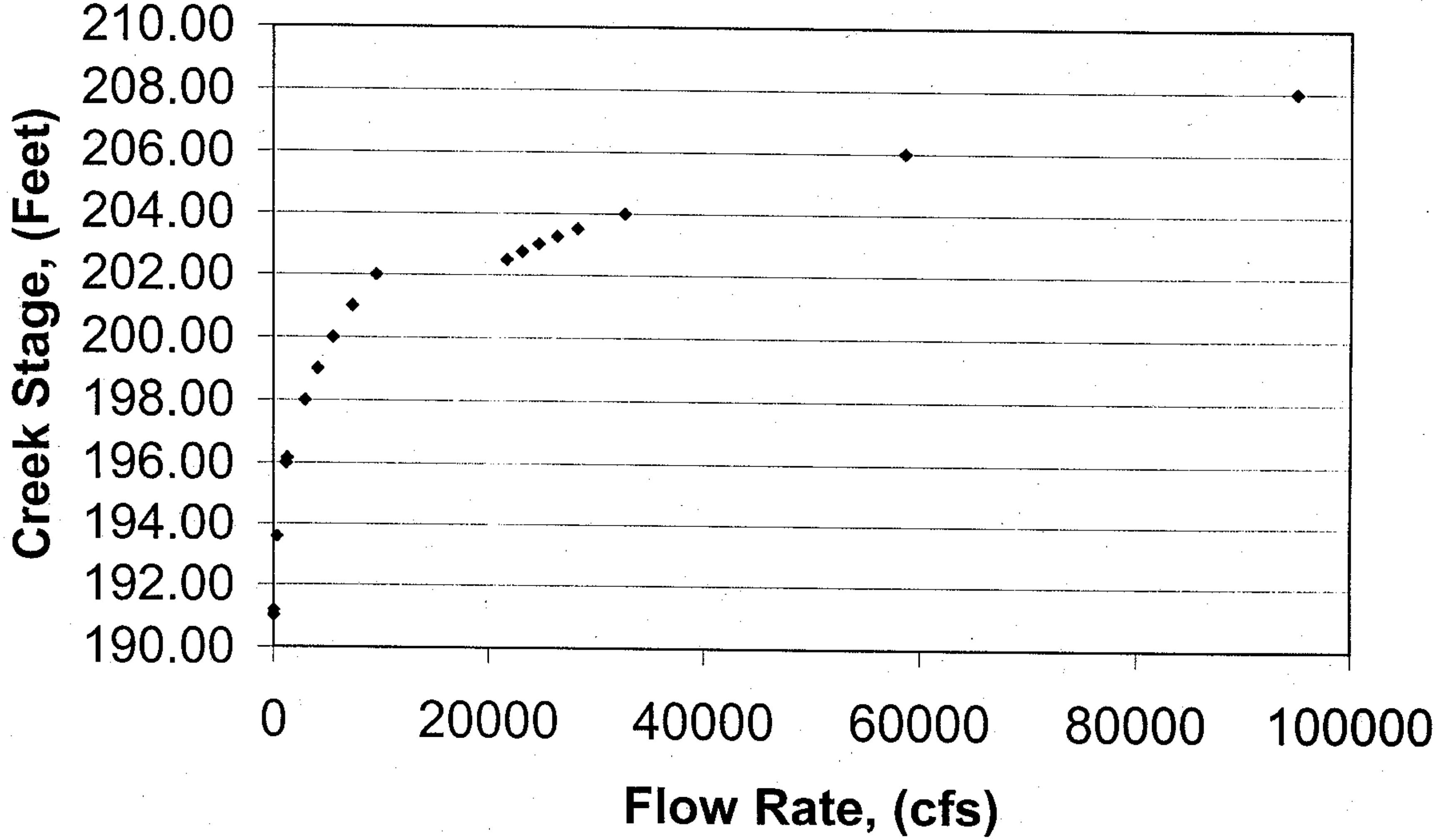
Based on the steady-state computer runs, the Manning's coefficient was adjusted until the water surface elevations produced by the MIKE 11 model were relatively close to the results in the FIS. Table 4 contains the results of the model comparisons.

Table 4: Water Surface Elevation Comparison Between FIS and MIKE 11 Model.

Cross-section	Water Surface Elevation, Feet					
	10-Year		50-Year		100-Year	
	FIS	MIKE 11	FIS	MIKE11	FIS	MIKE 11
2.70	237.0	237.2	238.6	239.1	239.2	239.9
3.02	229.1	228.5	230.5	230.6	231.1	231.5
3.16	225.2	224.9	227.0	227.0	228.0	227.9
3.42	218.5	218.4	219.5	220.5	219.8	221.0

The range for Manning's number used in the MIKE 11 model is 0.04 to 0.05 in the channel and 0.10 to 0.11 in overbank and floodplain areas. The presence of structures within the floodplain was compensated for in the hydraulic model by increasing the Manning's "n" value.

Figure 2: Rating Curve for Cross Section 4.12



Results

Modeling- The BREACH and MIKE 11 models together provide estimates of both failure scenarios. Tables 5a and 5b summarize the results. Both tables contain the peak water surface elevation at each cross-section along with the time it takes the floodwave crest to reach that point. Time is referenced to the peak outflow from the failed dam. Also included in the tables are the peak flow rates associated with the water surface elevations. The peak flow rate decreases as the floodwave moves downstream due to attenuation of flow in the floodplain. Under both failure scenarios, the peak flow is attenuated more than 50 percent from cross-section 0.00 to cross-section 4.12. The model results also indicate that the floodwave will progress through the study area in approximately one hour. This time frame is from the time of breach to the beginning of the recession limb of the floodwave hydrograph at cross-section 4.12. Therefore, the average wave speed through the 4.12-mile study area is approximately 6 fps (feet per second).

Table 5a: Modeling Results for Over-topping Breach of Silver Creek Dam

Over-topping Scenario Results			
Cross-section (River Miles)	**Time to Peak (hours:min)**	**Peak WSE (feet)***	**Peak Flow Rate (cfs)**
0.00	0:00	400.13	107165
0.10	0:00	396.21	103951
0.19	0:00	390.42	103563
0.24 (Private Bridge)	0:01	388.28	102426
0.26	0:01	386.18	102426
0.49	0:02	371.01	105163
0.63	0:02	358.26	101976
0.77	0:03	345.40	
1.00 (Private Bridge)	0:10	335.41	84431
1.01	0:10	334.60	
1.35 (Schooley Road Bridge)	0:15	320.35	
1.39	0:16	317.94	79967
1.74	0:22	302.16	
1.78 (Peach Street Bridge)	0:22	302.16	74536
1.79	0:22	301.32	
2.08	0:28	287.08	70020
2.09 (Central Street Bridge)	0:28	286.83	
2.10	0:28	286.11	
2.40	0:35	270.89	66845
2.68	0:40	258.79	61183
2.70 (Main Street Bridge)	0:40	258.30	
2.72	0:41	257.03	
3.00	0:48	245.50	
3.02 (C Street Bridge)	0:49	245.00	
3.06	0:50	243.89	
3.14	0:51	241.86	56693
3.16 (James Street Bridge)	0:51	241.17	
3.20	0:51	239.06	
3.42	0:58	230.05	54214
3.80 (WWTP)	1:10	219.08	49363
4.12	1:19	204.57	47873

* Based on the Aerial Topographic Map Provided by the City of Silverton.

Table 5b: Modeling Results for Piping Breach of Silver Creek Dam

Piping Scenario Results			
Cross-section (River Miles)	**Time to Peak (hours:min)**	**Peak WSE (feet)***	**Peak Flow Rate (cfs)**
0.00	0:00	383.14	28040
0.10	0:00	380.58	27784
0.19	0:00	376.07	27363
0.24 (Private Bridge)	0:00	372.40	27019
0.26	0:01	370.99	27019
0.49	0:02	359.10	26710
0.63	0:02	349.49	26457
0.77	0:03	335.97	
1.00 (Private Bridge)	0:07	327.91	24425
1.01	0:07	327.25	
1.35 (Schooley Road Bridge)	0:12	308.94	
1.39	0:13	307.16	20779
1.74	0:24	292.29	
1.78 (Peach Street Bridge)	0:24	292.14	18996
1.79	0:25	291.53	
2.08	0:16	273.36	17064
2.09 (Central Street Bridge)	0:16	271.56	
2.10	0:16	270.56	
2.40	0:18	256.15	16961
2.68	0:20	246.55	16455
2.70 (Main Street Bridge)	0:21	245.06	
2.72	0:21	245.48	
3.00	0:35	239.20	
3.02 (C Street Bridge)	0:36	238.46	
3.06	0:38	236.93	
3.14	0:39	235.53	15163
3.16 (James Street Bridge)	0:39	234.84	
3.20	0:40	232.84	
3.42	0:45	224.50	14569
3.80 (WWTP)	1:01	214.21	12166
4.12	1:09	200.38	11628

* Based on the Aerial Topographic Map Provided by the City of Silverton.

Mapping- The water surface elevation generated for the two failure scenarios was used to produce the inundation areas displayed in Figures 3a and 3b. From the figures, it is apparent that significantly more creek valley is inundated as a result of the over-topping failure (Figure 3a). Under the piping failure (Figure 3b), the smaller flows are mostly contained with the channel near the main city development. The WSE is between 10 to 13 feet higher under the over-topping scenario.

Table 6 summarizes the flood depth at particular areas of interest within the study limits. The existing ground elevations are taken from the aerial topography, and the WSE is estimated from the results generated during this study.

Table 6: Flood Depth at Points of Interest Within Study Limits.

Site of Interest	Ground Elevation (feet)	Flood Depth, feet	
		Piping Failure	Over-topping Failure
City Hall (S. Water St./Jersey St)	256.5	Not flooded	8.5 feet
Eugene Field (N. Water St./Park St.)	244.4	Not flooded	7.6 feet
S. Water St./Main St.	252.3	Not flooded	6.0 feet
S. Water St./ Ike Mooney Rd	315.7	4.3 feet	10.3 feet
First St./"C" Street	234.1	4.4 feet	11.1 feet
Silver Gardens Care Facility (James Ave./Silver Avenue)	227.0	7.8 feet	14.0 feet
Silverton Union High School (James Ave./Schlador St.	225.2	9.6 feet	15.8 feet
WWTP-Digester Bldg.	209.0	5.2 feet	10.0 feet

Under both failure scenarios, an area of particular interest is in the vicinity of the high school. The water surface elevation in this area is above the existing topography. In this case, flow from Silver Creek may actually leave the Silver Creek watershed and discharge into one of the smaller tributaries of the Pudding River. If this occurs, the peak water surface elevations and flow rates for areas downstream of the high school may be lower. An evaluation of the flow split between the Pudding River tributary and lower study reach of Silver Creek is beyond the scope of this contract.

The modeling results presented in Tables 7a and 7b are the estimated out-of-bank duration along Silver Creek. These values are important because they forecast how long after the breach before emergency vehicles can enter the area.

Table 7a: Duration of Out-of-Bank Flow for Piping Failure Scenario

Cross-section	Approximate Top of Bank Elevation	Time When Flow Leaves Channel*	Time When Flow Returns to Channel*	Total Time Flow is Out of Banks
(River Miles)	(feet)	(hours:min)	(hours:min)	(hours:min)
0.77 (near division St.)	325	12:31	13:13	0:42
1.00 (Private Bridge)	320	12:37	13:11	0:33
1.35 (Schooley Road Bridge)	306	12:47	13:42	0:25
1.78 (Peach Street Bridge)	282	12:46	13:25	0:39
2.09 (Central Street Bridge)	268	12:49	13:26	0:37
2.40 (Public Pool)	258	Never Leaves the Channel		
2.70 (Main Street Bridge)	242	12:51	13:33	0:42
3.02 (C Street Bridge)	232	12:52	13:45	0:52
3.16 (James Street Bridge)	227	12:52	13:52	1:00
3.80 (WWTP)	204	12:55	2:54	13:59

*The MIKE 11 program uses military time, 12:00 would be noon and 0:00 would be midnight.

Table 7b: Duration of Out-of-Bank Flow For Over-topping Failure Scenario

Cross-section	Approximate Top of Bank Elevation	Time When Flow Leaves to Channel*	Time When Flow Returns to Channel*	Total Time Flow is Out of Banks
(River Miles)	(feet)	(hours:min)	(hours:min)	(hours:min)
0.77 (near division St.)	325	12:05	at 9:00	325.5 at 21 hrs.
1.00 (Private Bridge)	320	12:07	0:50	12:43
1.35 (Schooley Road Bridge)	306	12:13	22:11	9:58
1.78 (peach Street Bridge)	282	12:14	0:35	12:19
2.09 (Central Street Bridge)	268	12:17	0:03	11:46
2.40 (Public Pool)	258	12:27	19:23	8:56
2.70 (Main Street Bridge)	242	12:20	1:00	12:40
3.02 (C Street Bridge)	232	12:21	5:22	17:01
3.16 (James Street Bridge)	227	12:21	at 9:00	227.3 at 21 hrs.
3.80 (WWTP)	204	12:23	at 9:00	208.5 at 21 hrs

*The MIKE 11 program uses military time, 12:00 would be noon and 0:00 would be midnight.

The times shown in Tables 7a and 7b are for whenever flow is out of banks. The top of bank elevation was taken from the aerial topographic map provided by the City of Silverton. The number of structures involved when flow leaves the bank varies within the study reach. Even when the creek is out of bank, no structures may be involved. In the upper reach of Silver Creek, very few structures are affected until flow crests over S. Water Street. In the lower reaches, below Peach Street, the floodplain for Silver Creek basically starts at the top of bank, so more structures are affected as soon as flow reaches above top of bank.

The durations for Table 7b reveal some areas with flow out of bank 21 hours after the breach. This is because the breach is assumed to coincide with the 100-year storm event. Flooding will occur within the lower reach of Silver Creek due to precipitation runoff as well. The extent of the 100-year floodplain below "C" Street is quite significant.

The effects on the calculated water surface profile created by the modeled bridges are minor. The MIKE 11 model assumes that the bridges are permanent structures that will remain in place during the breach event. Table 8 summarizes the bridge data included in the MIKE 11 model, along with the approximate surface elevation for each breach scenario.

Table 8: Comparison of WSE and Bridge Elevations

Modeled Bridge	Approximate Top of Deck Elevation	WSE for Piping Failure	WSE for Over-topping Failure
Private Bridge @ RM 0.24	360'	372.4'	388.3'
Private Bridge @ RM 1.00	322'	327.9'	335.4'
Schooley Rd.	304'	308.9'	320.4'
Peach St.	284'	292.1'	302.2'
Central St.	270'	271.6'	286.8'
Main St.	251'	245.5'	258.3'
"C" St.	230'	238.5'	245.0'
James St.	233'	234.8'	241.7'

The model neglects the effect of debris bulking or jams created by possible bridge failure. For this reason, the actual effects of the bridges may be underestimated. Due to the high floodwave velocities and the depth of water over the bridges, it is assumed that the smaller private bridges will be washed out. If this occurs, the debris from the bridges and from the dam itself may collect on the upstream face of the larger bridges, creating a debris jam. This extra lateral pressure from the jam may cause additional failures as well. Due to the low percentage of flow in Silver Creek compared to the amount of flow in the overbank area, debris bulking may have little effect on the peak water surface elevation. As flow recedes, any debris jams will cause localized backwater flooding.

Conclusions and Recommendations

The results of any breach of Silver Creek Dam would be catastrophic for the City of Silverton. As illustrated in the inundation maps, significant portions of the valley are estimated to be under water during an over-topping failure (Figure 3a). The inundation area for a piping failure (Figure 3b), affects far fewer structures and does not extend into the city center as much as the over-topping breach. The major issue associated with a possible failure of Silver Creek Dam is the potential for loss of life. The total elapsed time from dam failure to the passage of the floodwave is less than one hour. This creates a challenge for alerting residents of the impending danger and initiating an evacuation plan.

To ensure proper advanced warning of a possible dam breach, the City of Silverton should install and maintain an early warning system at the dam. This system should be tied to water level monitors in the reservoir and on the downstream face of the dam. An example of a possible alarm scenario would be a rapid rise in the water surface elevation within the reservoir. This could coincide with a maximum water surface alarm. If the water surface elevation in the reservoir rises rapidly or is above a predetermined elevation, an alarm would sound. Both of these alarm scenarios indicate a situation where inflow into the reservoir is greater than the storage and spillway capacity. This situation could lead to an over-topping breach of the dam.

The monitoring system for a possible piping failure may consist of collecting and measuring the flow volume at the downstream toe of the dam. If a set increase in flow is surpassed, an alarm would sound. The response to any of the alarms should be an immediate visual inspection and verification of the situation at the dam. The proximity of the dam to the City of Silverton and the good condition of the existing roads make visual inspection possible under most conditions. For a possible piping failure, the initial visual inspection of the downstream face may not locate the area of piping. Continued visual monitoring may be required until either the piping is located or the flow monitor indicates normal readings.

An Emergency Action Plan (EAP) can be developed that would direct actions following the activation of an alarm at Silver Creek Dam. The EAP could include a "Phone Tree" for emergency contacts, an easy-to-follow flow chart of actions to take for each alarm scenario, public notification of the situation, evacuation plans, and evacuation centers. An EAP developed for the failure of Silver Creek Dam can be incorporated into any existing action plans the City may have already developed.