Cabot Flood Study

Cabot, Vermont

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SLR Project No.: 146.15729.00002

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Making Sustainability Happen

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1.0 Introduction

1.1 Purpose

The Town of Cabot experienced damaging flooding in July 2023 after more than 7 inches of rain fell around the region and again in July 2024 when more than 5 inches of rain fell. The mainstem of the Winooski River flows through the village to the west of Main Street behind homes and businesses. Numerous buildings were inundated and experienced severe erosion as the river overflowed its banks. Two tributaries flow down the hill from the east crossing Main Street before flowing into the Winooski River. The Northern Tributary flows through a bridge near the intersection with South Walden Road and the Southern Tributary flows through a twin culvert behind the Cabot Garage. Both tributaries experienced extreme debris flow and clogging causing flooding throughout the village.

1.2 Project Location

The focus of this study is on the flooding caused by the two tributaries (Figure 1 and Figure 2). Flood and debris flow moving down the stream channels overwhelm the structures under Main Street and cause most of the flood damage in the village. Field observations and analysis of remote data have been brought together to create a hydraulic model in the village and develop a list of alternatives to mitigate flood risk. The alternatives were evaluated using the hydraulic model and results are discussed.

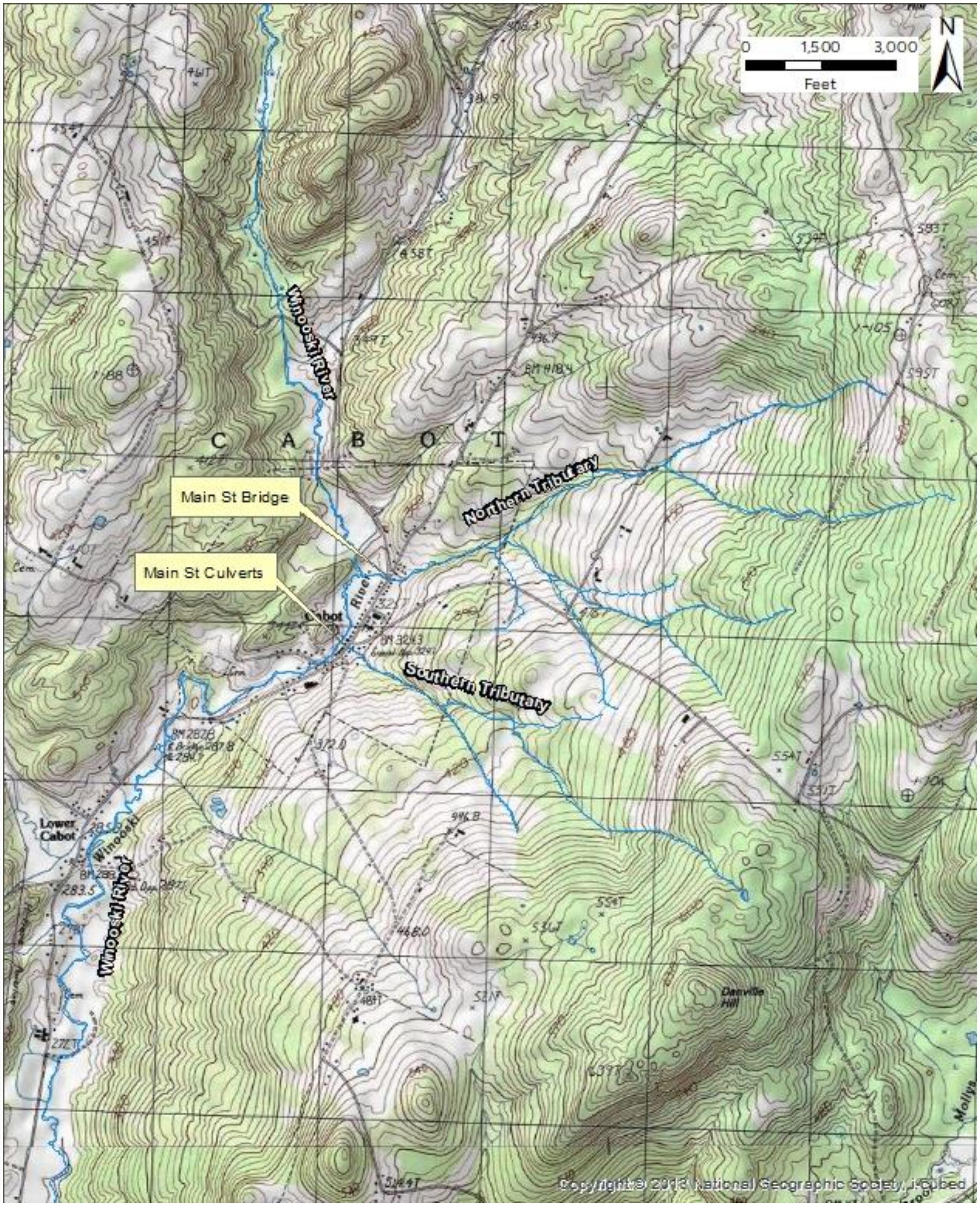

Figure 1: Topographic Location Map

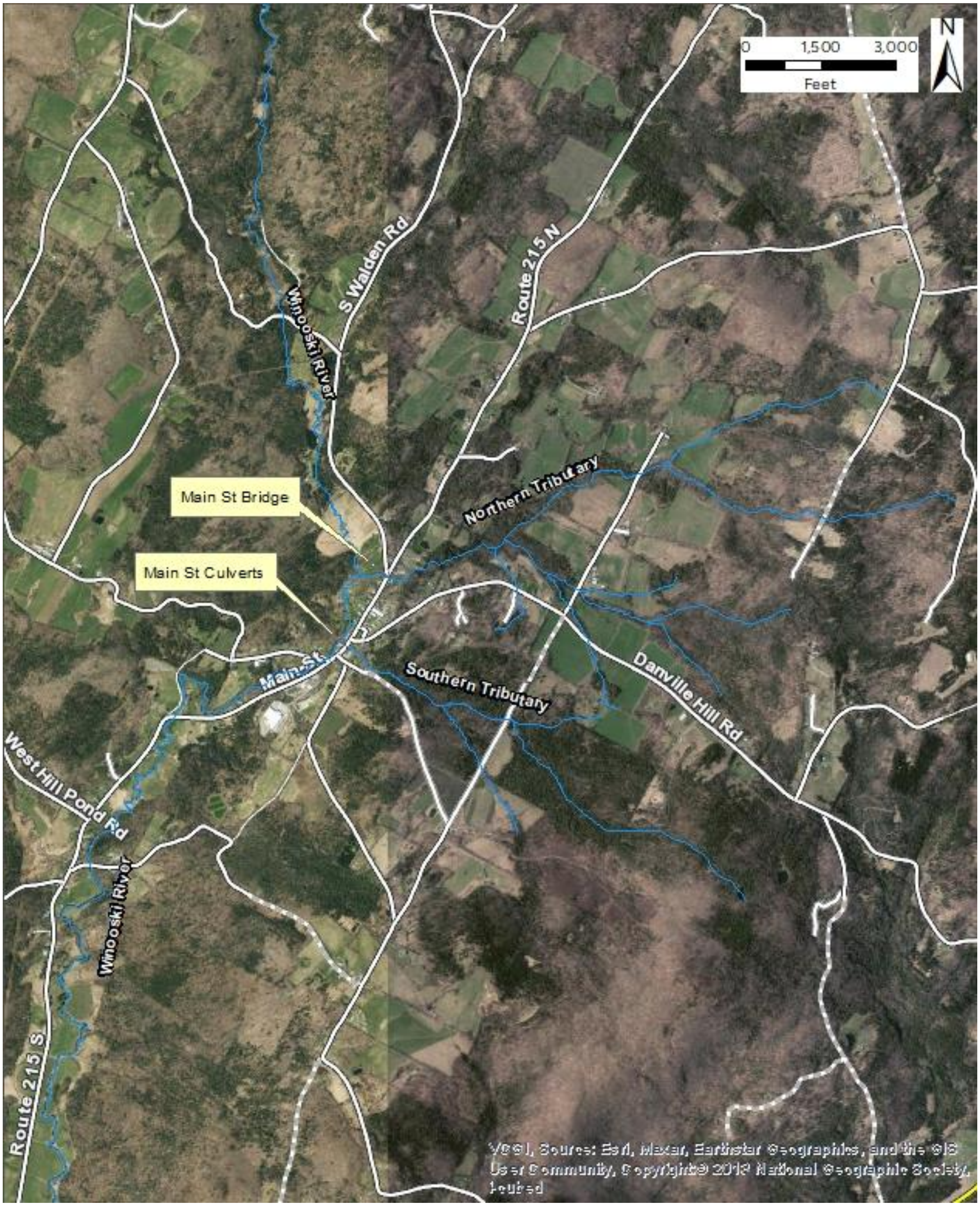

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Figure 2: Location Map with Aerial

1.3 Scope

The scope of work for this study includes the following tasks.

- Stream walk and rapid assessment of the two tributary channels
- Hydrologic modeling of the two tributary watersheds
- Hydraulic modeling of the tributary channels in the vicinity of Cabot Village
- Alternatives analyses to reduce flooding at the structures in the village
- Concept design of the preferred alternative at each structure

2.0 The Mainstem Winooski River

SLR conducted a stream walk of the mainstem Winooski River in the vicinity of the Northern and Southern Tributaries. GPS data, channel observations, and channel measurements were collected along the way.

2.1 River Morphology

The mainstem Winooski River is a riffle-pool channel (Rosgen C) that generally flows north to south through the village. This headwater location has a drainage area of 8.5 square miles at the Northern Tributary – less than 1% of the total basin drainage area at Lake Champlain (1,080 square miles).

Figure 3: Winooski River just Upstream of Northern Tributary

The bankfull channel width on the Winooski River is 25 feet at the Northern Tributary and 30 feet at the Southern Tributary. The channel bed material is dominated by cobble and gravel, but also contains boulders, sands, and finer particles.

2.2 VAST Bridge

A VAST bridge crosses the Winooski River downstream of the Southern Tributary (Figure 4). The bridge span is 52 feet. The river channel under the bridge consists of a 30-foot bankfull channel and a 22-foot flood shelf. The vertical opening of the bridge is between 5.6 feet and 6.9 feet. The bridge beam is 3 feet deep.

Figure 4: VAST Bridge viewed from Downstream

3.0 The Northern Tributary

SLR conducted a stream walk of approximately one mile of the Northern Tributary in July 2024, after the July 10th flooding. The walk began at the confluence with the Winooski River and ended at Menard Road. GPS data, channel observations, and channel measurements were collected along the way.

3.1 River Morphology

The Northern Tributary consists of a flatter 2.6% slope riffle-pool channel from the Winooski River confluence to the Main Street Bridge. The channel appears to have been recently dredged and some berming has taken place along the recreation fields (Figure 5). The channel bed material in this area is typically dominated by cobble, boulder and gravel; yet in the dredged area the channel is smoother and dominated by gravel. Gravel is building up in the post-dredge channel, the gravel is soft under foot, and the channel is less stable with signs of bank erosion.

Figure 5: Northern Tributary along the Recreation Fields

Bankfull channel widths downstream of the bridge are between 17.5 feet and 21.0 feet (Table 1).

Table 1: Northern Tributary Measured Bankfull Channel Widths

Distance from Main Street Bridge (ft) (negative values are downstream)	Measured Bankfull Width (ft)
-550	17.5
-100	21.0
550	21.0
650	22.5
1,300	36.0
2,600	21.0
4,000	24.0
5,200	16.5

Moving upstream of the bridge the channel steepens to 3.7%, the bed material changes to boulders, bedrock, and cobble, and steps and pools are present near homes. The channel has been recently excavated around the meander upstream of the bend and is over-widened (bankfull channel width is 22.5 to 36.0 feet) (Figure 6). This area will serve as a catch for sediment and large wood in the next flood.

Figure 6: Northern Tributary in Over-Wide Area Post Dredging

Moving upstream the channel enters the forest, narrows, and steepens to 4.1% (Figure 7). The bankfull channel width decreases and is in the range of 16.5 to 21.0 feet (Table 1). The channel often contains bedrock on the bed and banks, as well as dense glacial till (Figure 8). The bedrock narrows store large sediment between floods. Periodic land slides exist where the base of the dense till was eroded and the overlying tall bank collapsed (Figure 9). The mass failures are a source of sediment and large wood into the channel, some of which makes its way to the Main Street Bridge in the village and some of which is stored in the channel behind intermittent debris jams and on small flood shelfs along the channel (Figure 10). These features are important to regulate the amount of material headed to the village during a single flood event.

Figure 7: Northern Tributary Entering Forest Moving Upstream

Figure 8: Steep Bedrock and Till Northern Tributary

Figure 9: Mass Failure

Figure 10: Northern Tributary Flood Shelf

3.2 The Main Street Bridge

The Main Street Bridge, constructed in 1944, has a 16-foot span and is 25 feet wide (Figure 11). The height from the streambed to the bottom of the bridge beam (i.e., the low chord of the bridge) ranges from 3 to 4.5 feet at the upstream opening and 4 to 5 feet at the downstream opening. A vertical erosion face (i.e., a headcut) is moving upstream through the structure and was located at the downstream bridge opening during the stream walk. The channel is unstable in this area and the headcut is likely to move upstream during high flows.

The bridge is 72% of the bankfull channel width in the area (22 feet) with limited vertical clearance. The bridge constricts flow and does not fit the stream channel. Large wood clogged the bridge opening during the July 2023 flood. The existing opening does not provide space for debris to pass under the road. It has been reported that sediment has deposited in the channel around and under the bridge limiting its capacity. The bridge should be replaced with an appropriately sized structure to meet Vermont Stream Alteration Standards (VTANR, 2014) and Vermont River Management Standards (Schiff et al., 2014) – structure width = 100% to 120% bankfull channel width.

Figure 11: Main Street Bridge viewed from Upstream

4.0 The Southern Tributary

SLR conducted a stream walk of approximately one mile of the Southern Tributary in August 2024 with members of the Cabot Flood Task Force. The walk began at the first VAST bridge upstream of the village and moved upstream. The walk returned to the bridge area, moved downstream to the twin culverts at Main Street, progressed downstream to the Winooski River confluence and then concluded downstream of the VAST Bridge on the Winooski River. GPS data, channel observations, and channel measurements were collected along the way.

4.1 River Morphology

The Southern Tributary contains bedrock vanes spanning the channel just upstream of the village (Figure 12). The channel is steep with an 8.6% slope and contains small pools, bedrock drops, boulders and cobbles. The bankfull channel width ranges between 18.5 and 24 feet (Table 2). The channel width tends to be narrower in bedrock areas and wider where sediment accumulation has taken place.

Figure 12: Southern Tributary Bedrock Controls

Table 2: Southern Tributary Measured Bankfull Channel Widths

Distance from Main Street Culverts (ft) (negative values are downstream)	Measured Bankfull Width (ft)
-50	14.0
50	12.0
350	20.0
500	24.0
1,300	19.5
2,100	21.0
3,200	17.0

A strong constriction exists at the damaged VAST bridge that is 10 feet between stacked block abutments (Figure 13). The width between the abutments is about half of the bankfull channel width leading to a flood and erosion hazard. A large amount of sediment and large wood is bult up in the channel behind the abutments (Figure 14). The debris buildup is 5 feet tall in places and fills the full channel width. If the block abutments fail, this excessive accumulation would make its way to the village in a flood. This material should be removed from the channel and the abutments should be widened to 100% to 120% of the bankfull channel width.

Figure 13: Constriction at the Damaged VAST Bridge

Figure 14: Sediment and Large Wood Accumulated Upstream of Damaged VAST Bridge

Moving upstream the Southern Tributary is comprised of many bedrock areas that are steep and narrow, coupled with wider areas of valley wall mas wasting where glacial till has eroded (Figure 15). These large erosion faces input sediment and large wood into the channel during flooding. Some of this material is temporarily stored in the channel by large wood jams that will periodically release and form during flooding (Figure 16). These stepped jams and storage areas are important to reduce downstream flood risk.

Figure 15: Mass Wasting on the Southern Tributary

Figure 16: Sediment and Large Wood Storage Southern Tributary

4.2 The Main Street Culverts

Two round corrugated metal culverts pass the Southern Tributary flow under Main Street (Figure 17). The left culvert is a 6-foot diameter round corrugated metal pipe that passes under the Cabot Garage. Its length is approximately 160 feet. The right culvert is a squashed corrugated metal pipe with an 8 foot span and 5.6 foot rise. The right culvert was installed to increase flood capacity after flooding from Tropical Storm Irene. The culvert angles to the north and then bends around the footprint of the Cabot Garage. Its length is approximately 172 feet.

The channel approaching the culvert narrows from a natural bankfull channel width of approximately 20 feet to a width of 12 feet due to filling around buildings and parking lots (Figure 18). This channel is unable to carry flood flows from upstream along with sediment and large wood that move down river channels during flooding. Channel dimensions need to be naturalized as much as possible to safely pass floods into new structures and through the village.

The two culverts combined provide a total flow width of 14 feet; however, the severe skew of the right culvert reduces the effective hydraulic opening. The culverts are between 50% and 70% of the bankfull channel width, and thus are not likely to pass flood waters and debris. Past flooding illustrates that in this severely constricted setting, just a few pieces of wood or several boulders quickly clog the culvert openings.

Figure 17: Main Street Culverts viewed from Upstream

Figure 18: Narrowed Channel Upstream of the Main Street Culverts

The channel downstream of the culverts is narrow (~ 14 feet wide) and steep at 5.2% as it passes between two buildings heading to the confluence with the Winooski River (Figure 19). As is the case upstream, this channel is unable to contain and pass flood flows with sediment and large wood during flooding. Channel dimensions need to be naturalized as much as possible to safely move floods out of the Southern Tributary and into the Winooski River. Given the space limitations due to the buildings, flood walls may be needed to widen the channel to match a larger structure at Main Street.

Figure 19: Narrowed Channel Downstream of the Main Street Culverts

5.0 Hydrology

5.1 Introduction

Peak flows were estimated for the Winooski River and both tributaries for input into the hydraulic model. The flood flows were estimated using the USGS StreamStats software (Olson, 2014), the Steep Streams regression estimates (Jacobs, 2010), a comparison of similar sized, reference, gauged Vermont watersheds (Olson, 2014), and from a hydrology model developed for this project. Flow estimates were refined during hydraulic model validation to replicate the photos and videos showing flood extents during the July 2024 flood.

5.2 USGS StreamStats

Peak flows were estimated with the USGS web-based StreamStats software (Table 3) (Olson, 2014).

Table 3: Estimated Peak Flood Flows (Olson, 2014)

Annual Exceedance Probability (AEP)	Return Frequency (Years)	Winooski River (cfs)	Northern Tributary (cfs)	Southern Tributary (cfs)
50%	2	297	137	63
20%	5	467	221	102
10%	10	598	287	133
4%	25	790	386	180
2%	50	956	473	222
1%	100	1,140	570	269
0.2%	500	1,630	840	399

5.3 Steep Streams Regression Estimates

Peak flows were estimated using equations developed for estimating peak flows for steep gradient streams in New England (Table 4) (Jacobs, 2010).

Table 4: Estimated Peak Flood Flows (Jacobs, 2010)

Annual Exceedance Probability (AEP)	Return Frequency (Years)	Winooski River (cfs)	Northern Tributary (cfs)	Southern Tributary (cfs)
50%	2	332	128	**53**
20%	5	531	205	85
10%	10	711	274	113
4%	25	958	368	152
2%	50	1,151	441	182

Annual Exceedance Probability (AEP)	Return Frequency (Years)	Winooski River (cfs)	Northern Tributary (cfs)	Southern Tributary (cfs)
1%	100	1,361	519	214
0.2%	500	2,035	769	316

5.4 Gauge Analysis

An analysis of peak flood flows of similar sized gauged Vermont streams was performed to estimate peak flows (Table 5). Peak flood flows have previously been calculated for free-flowing reference gauged streams in Vermont (Olson, 2014). Peak flood flows were normalized by watershed area for the 61 gauges with a similar watershed size to the subject tributaries (0.57 – 9.27 square miles). The distribution of peak flood flows was then evaluated for the project site. Calibration of the hydraulic model against the July 2024 flood (discussed below) found that increasing the average peak flow per square mile of watershed by one standard deviation recreated the flood extents. The Winooski River flows were not adjusted from the average.

Table 5: Gauge Analysis Flood Flows (USGS, 1982)

Annual Exceedance Probability (AEP)	Return Frequency (Years)	Winooski River (cfs)	Northern Tributary (cfs)	Southern Tributary (cfs)
50%	2	398	175	**69**
20%	5	642	294	115
10%	10	848	400	157
4%	25	1,171	574	225
2%	50	1,461	736	289
1%	100	1,803	933	366
0.2%	500	2,838	1,552	609

5.5 Hydrology Model

A hydrology model was developed for both tributaries using HydroCAD® (Version 10.20-2g) modeling software. The watersheds contributing to the tributaries were delineated using available LiDAR contour data. A composite curve number (CN), a dimensionless number describing the runoff characteristics of a watershed, was calculated for the watershed using NRCS soil survey data and the Vermont High Resolution Land Cover GIS layer. Time of concentration, the time it takes for the whole watershed to contribute runoff, was calculated using the longest flow path and flow characteristics as outlined by TR-55.

Rainfall data from NOAA Atlas 14 (NOAA, 2018) was obtained for storms up to the 1,000-year event (Table 6). The SCS Type II rainfall distribution with a storm duration of 24-hours was utilized to estimate discharge rates. An antecedent moisture condition of 2 assuming normal conditions was used for this analysis.

Table 6: Rainfall Data

Return Frequency (Years)	Rainfall Depth (inches)
2	**2.46**
5	**3.14**
10	**3.70**
25	**4.47**
50	**5.04**
100	**5.66**
500	**7.51**
1,000	**8.47**

The modeled flows are up to 2.5 times larger than the next highest flows from the other methods (Table 7). Two characteristics of the watersheds may be contributing to this overestimation of peak flows. First these are very steep watersheds that result in short times of concentration that result in higher peak runoff values. Second the soils from the NRCS soil survey data indicate low infiltration capacity and high runoff. These compounding factors result in flows that are not practical for the project site. TR-55 is known to over-estimate peak flows in small steep watersheds (Hodgkins et al., 2007), and thus the scaled gauge analysis flows were selected for the hydraulic model.

Table 7: Modeled Peak Flood Flows

Annual Exceedance Probability (AEP)	Return Frequency (Years)	Northern Tributary (cfs)	Southern Tributary (cfs)
50%	**2**	**319**	**158**
20%	**5**	**567**	**288**
10%	**10**	**796**	**409**
4%	**25**	**1,131**	**588**
2%	**50**	**1,392**	**726**
1%	**100**	**1,685**	**881**
0.2%	**500**	**2,589**	**1,365**

5.6 Summary of Peak Flood Flows

Flows for each of the four methods were compared. Flows using the gauge analysis method were selected for use in the hydraulic model. Flows from each method were input into the hydraulic model and compared to the July 2024 flood images photos and videos. Flows from the gauge analysis method best represented the flood extents at the project site.

Table 8: Summary of Estimated Peak Flood Flows for the Southern Tributary (bolded flows used in hydraulic modeling)

Annual Exceedance Probability (AEP)	Return Frequency (Years)	StreamStats (Olson, 2014) (cfs)	Steep Streams Regression (Jacobs, 2010) (cfs)	Gauge Analysis (cfs)	HydroCAD (cfs)
50%	2	63	53	**69**	158
20%	5	102	85	**115**	288
10%	10	133	113	**157**	409
4%	25	180	152	**225**	588
2%	50	222	182	**289**	727
1%	100	269	214	**366**	881
0.2%	500	399	316	**609**	1,365

Table 9: Summary of Estimated Peak Flood Flows for the Northern Tributary (bolded flows used in hydraulic modeling)

Annual Exceedance Probability (AEP)	Return Frequency (Years)	StreamStats (Olson, 2014) (cfs)	Steep Streams Regression (Jacobs, 2010) (cfs)	Gauge Analysis (cfs)	HydroCAD (cfs)
50%	2	137	128	**175**	319
20%	5	221	205	**294**	567
10%	10	287	274	**400**	796
4%	25	386	368	**574**	1,132
2%	50	473	441	**736**	1,393
1%	100	570	519	**933**	1,685
0.2%	500	840	769	**1,552**	2,589

Table 10: Summary of Estimated Peak Flood Flows for the Winooski River (bolded flows used in hydraulic modeling)

Annual Exceedance Probability (AEP)	Return Frequency (Years)	StreamStats (Olson, 2014) (cfs)	Steep Streams Regression (Jacobs, 2010) (cfs)	Gauge Analysis (cfs)
50%	2	297	332	**398**
20%	5	467	531	**642**
10%	10	598	711	**848**
4%	25	790	958	**1,171**
2%	50	956	1,151	**1,461**
1%	100	1,140	1,361	**1,803**
0.2%	500	1,630	2,035	**2,838**

6.0 Hydraulic Analysis

6.1 Introduction

A two-dimensional (2D) hydraulic model was developed to evaluate flow through the village using the HEC-RAS river modeling software (USACE, 2023). Water surface elevations, flow depths, and velocities are computed for each cell in the 2D mesh based on the St. Venant shallow-water approximations of the Navier-Stokes equations that are solved using a finite-volume algorithm. Frictional energy losses are computed based on Manning's roughness coefficients applied to the terrain surface. Frictional energy losses are computed based on Manning's roughness coefficients applied to the terrain surface. The 2D mesh for the study area has an area of 60 acres and includes 2,770 feet of the Winooski River, 1,330 feet of the Northern Tributary, and 600 feet of the Southern Tributary (Figure 20). Model results including water surface elevations, flow velocities, and shear stress, are predicted across the 2D mesh and can be used to evaluate existing conditions for flooding within the study area and to test flood mitigation alternatives.

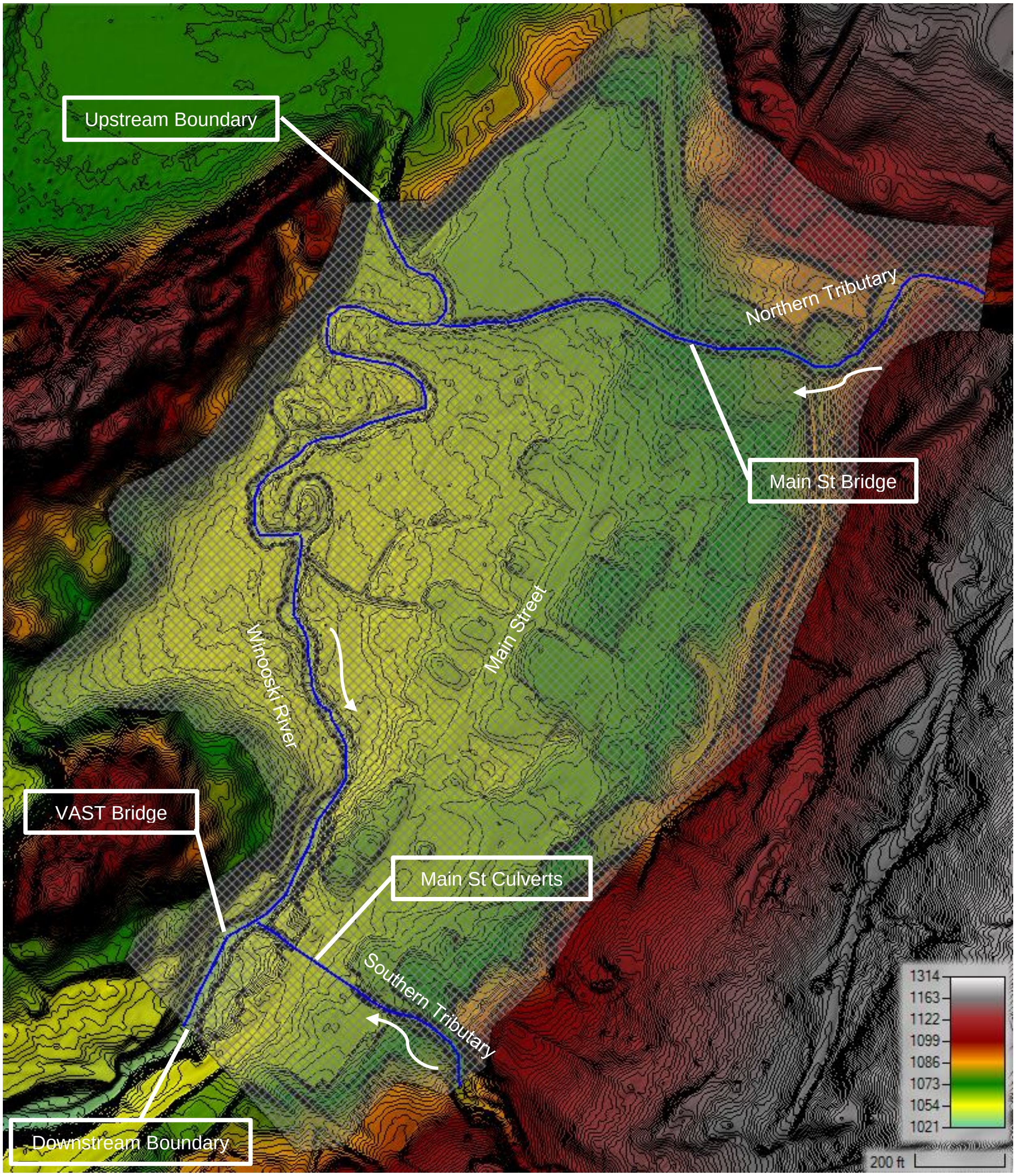

Figure 20: Hydraulic Model Mesh

6.2 Existing Conditions Model

6.2.1 Model Setup

The terrain for the model was developed from a combination of ground survey data collected by Grenier Engineering in September 2024, high-accuracy GPS data collected by SLR in August 2024, and 0.35-meter resolution LiDAR data (VCGI, 2023(preliminary)). Various sections of the terrain were modified based on channel survey and field measurements performed by SLR.

Nominal node spacing in the computational domain was set to 10 feet with a square mesh pattern. Refinement regions, with a reduced cell size of 3 feet, were used to define the river channels. The bridges and culverts were incorporated into the model mesh using a 2D connection that use weir, pressure, and momentum equations to simulate the hydraulics of each structure. Mannings roughness coefficients were categorized by landcover and assigned based on remote sensed land cover and field assessment of streambed material.

The hydraulic model was used to simulate both the estimated peak flood flows (i.e., steady flow) and the time-varying flood hydrographs (i.e., unsteady flow). Unsteady flow allows the model to account for the attenuating effects (i.e., flood reduction through storage) of floodplains. The model includes the Northern Tributary bridge under Main Street, the Southern Tributary culverts under Main Street, and the VAST bridge on the Winooski River. Flow is input into the model from the Northern Tributary, Southern Tributary, and the Winooski River. The downstream boundary condition for the model was determined using normal depth. Boundary conditions were located far enough upstream and downstream to avoid influencing modeling results in the primary study area around the village.

6.2.2 Model Validation

The hydraulic model was validated using photos and videos taken during recent floods and discussions with local residents recounting past flood events. The primary validation event is the July 2024 flood, which included much less debris flow than the July 2023 flood. This event was approximately the 100-year flow and was closer to the clear flow condition that is modeled by the software. The July 2023 flood is estimated to be close to the 500-year flood, but due to debris flow and clogging of the structures it is difficult to replicate with certainty.

Photos and videos of the Southern Tributary culverts show that water was filling up the left culvert and just overtopping to flow around the garage and onto Main Street (Figure 21). The top of the left culvert is at elevation 1059.2 ft NAVD88 and the modeled peak flood water surface elevation is at EL 1059.3 ft. The plan view of the modeled flood velocity shows a flow pattern that matched the photo around the Cabot Garage (Figure 22).

Figure 21: Flood waters overtopping culverts

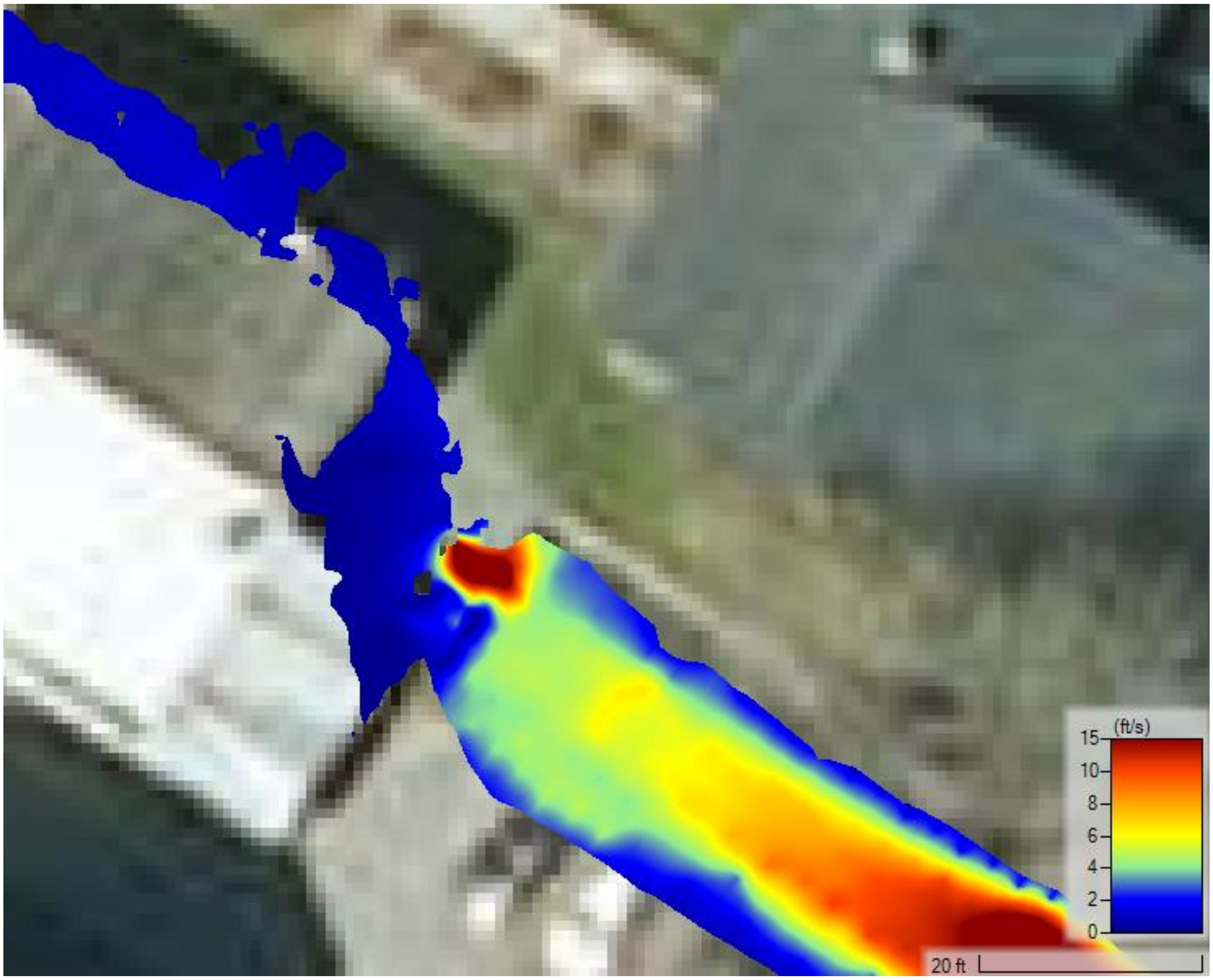

Figure 22: Modeled 100-year flood velocities as the flow overtops the culverts and flows around the garage

Model results on the mainstem of the Winooski River were compared to images of the flood waters passing under the VAST bridge. The photo shows the flood water approximately 1.5 to2 feet below the 3-foot deep steel beams (Figure 23). Model results found that the water surface under the bridge is approximately 1.8 feet below the steel beams for the 100-year flood (Figure 24).

Figure 23: Flood waters passing under the VAST bridge

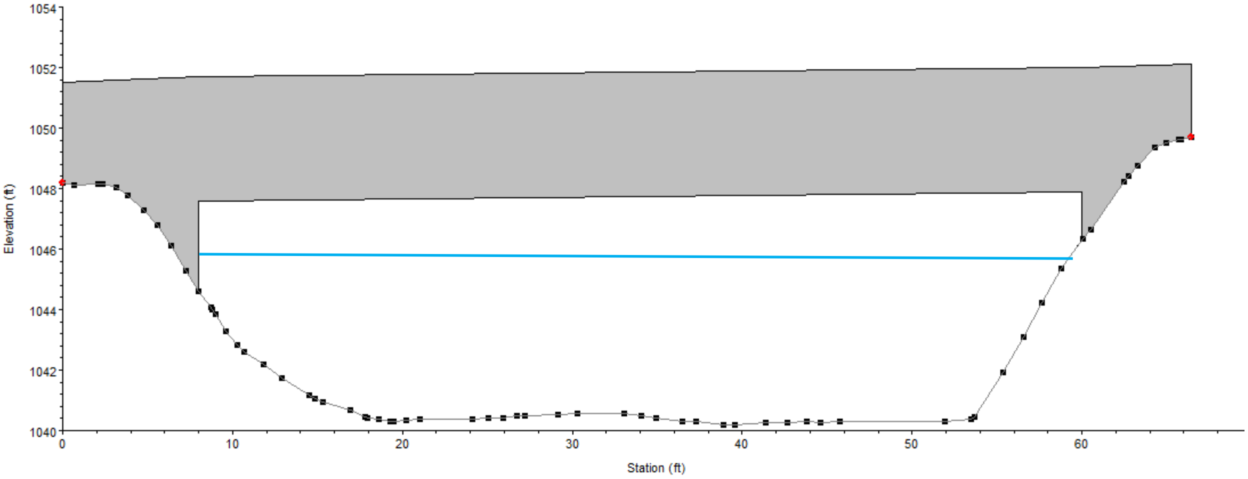

Figure 24: Modeled 100-year flow at the VAST bridge

Images of the Northern Tributary overtopping the bridge under Main Street compare well to the 100-year flood modeling results. The bridge overtopped and flow travelled down Main Street (Figure 25). Modeling results found that the left side of the bridge is overtopped by approximately 1 foot during the 100-year flood (Figure 26). These validation results indicate that the accuracy of the model is appropriate for evaluation of alternatives to understand relative changes to flood patterns associated with various flood mitigation options.

Figure 25: Northern Tributary flood waters overtopping the Main Street Bridge and flowing down Main Street

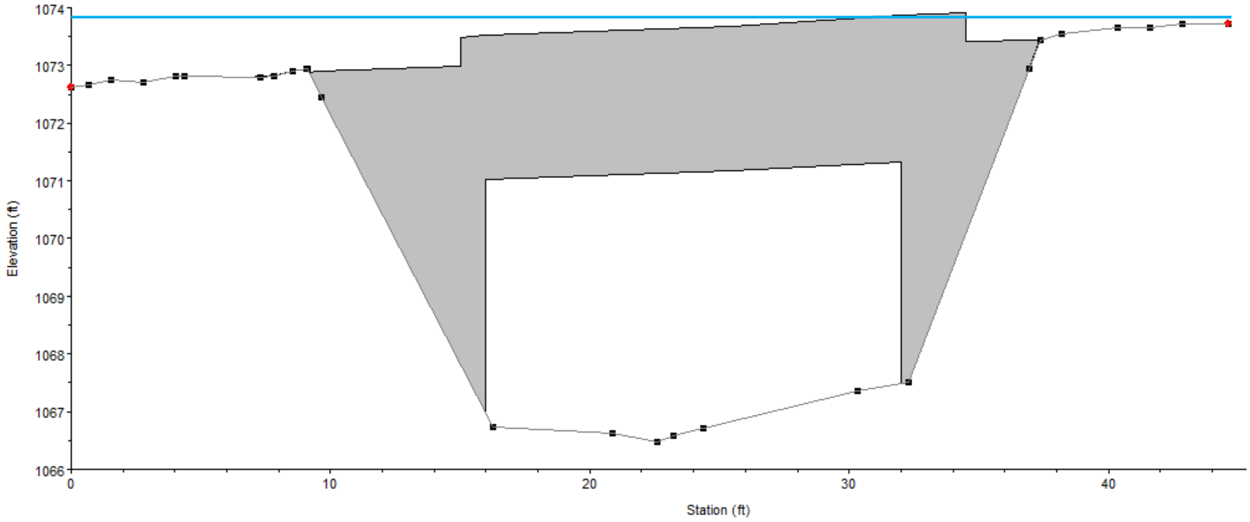

Figure 26: Modeled 100-year flow at the Main Street Bridge

7.0 Alternatives Analysis

An alternatives analysis was performed to evaluate potential flood mitigation projects within the study area (Table 11). The validated existing conditions model was used to evaluate potential flood mitigation alternatives. Sample model output results are shown on a series of flood maps (Appendix B).

Table 11: Flood Mitigation Alternatives

ID	Location	Description
1	Southern Tributary Culverts and Northern Tributary Bridge	Remove structures to naturalize stream channel and understand maximum conveyance through village
2	Southern Tributary VAST Bridge	Replace VAST bridge with wider span and remove sediment and large wood upstream of abutments
3	Southern Tributary Culverts	Remove Garage building and replace culverts with bridge
4	Southern Tributary Culverts	Keep Garage building and replace culverts with bridge
5	Southern Tributary Downstream of Culverts	Replace culverts with Alternative 3 bridge and widen downstream channel
6	Northern Tributary Bridge	Replace bridge with 30 foot span bridge
7	Northern Tributary Bridge	Elevate road and replace bridge with 30 foot span bridge
8	Northern Tributary Bridge	Elevate road and replace bridge with 50 foot span bridge
9	Upstream of Village	Construct and restore upstream storage areas
10	Both Tributaries	Sediment management

7.1 Existing Conditions (Alternative 0)

Various flood events were simulated using the hydraulic model to evaluate the effects of the existing tributary road crossing structures on flooding in Cabot. The Northern Tributary begins overtopping Main Street between the 25- and 50-year floods. When flow overtops the road it begins flowing south on the road. Once on the road flood waters cross and begin inundating the homes on the western side of Main Street. Flow paths develop around the homes and water flows into the low-lying floodplain of the Winooski River. Homes on the eastern side of Main Street are inundated between the 100- and 500-year floods.

The Southern Tributary begins overtopping Main Street between the 50- and 100-year floods. Overtopping flood waters flow around the Garage and onto Main Street. From Main Street water inundates and flows around the buildings on the western side of the road before flowing into the Winooski River. The velocity of the flood flow between the buildings exceeds 12 feet per second during the 500-year flood resulting in high erosion risk.

As the Winooski River rises during a flood water can be pushed back upstream into the tributaries in what is called a backwatering effect. Backwatering can slow flood waters from flowing from the tributaries into the Winooski River. Modeling found that the Winooski River does not backwater either structure. The bridge on the Northern Tributary is more than 500 feet upstream of the Winooski River and slope is consistent in the water surface profile between the bridge and the Winooski River. The culvert outlets on the Southern Tributary less than 100 feet upstream of the confluence with the Winooski River. The water surface profile does show backwatering in the downstream channel that ends just downstream of the culvert outlets.

The modeling shows that both structures are strong constrictions and create flood and erosion hazards in the village.

7.2 Bridge and Culvert Removal (Natural Conditions) (Alternative 1)

After evaluating the existing conditions modeling the bridge and culverts under Main Street were removed from the model to understand the influence of the structures on flood flows through the village. Although not intended as a realistic alternative to implement, removing the structures reveals the maximum potential flood conveyance along each tributary. With the bridge removed the Northern Tributary does not flood the road or homes around Main Street for any modeled flood. This result demonstrates that the existing bridge is constricting flood flows and causing flooding of the road and surrounding homes.

With the culverts removed the Southern Tributary only begins to overtop its banks during the 500-year flood. Flow is contained to the channel during the 100-year flood. During the 500-year flood flow escapes the channel in the parking lot behind the Garage, flows between the Garage location and the Willey Building, and overtops Main Street. Flood depths on the road are less than 0.5 feet and velocities are less than 3 ft/s. There is a narrow spot in the channel where the flood waters begin overtopping the bank and could be improved with a small section of channel widening. It is clear from this result that the culverts are causing flooding of the road and adjacent buildings, and channel constriction is also an issue in this area

7.3 Widen VAST Bridge on the Southern Tributary (Alternative 2)

During the stream walk the VAST Bridge was determined to be a major constriction on the stream channel and a potential hazard for releasing debris to the downstream channel. The bridge is located about 750 ft upstream of the culvert inlets along the stream channel. The channel width between the abutments is just 10 feet, less than half of the bankfull width. The bridge was damaged during the July 2023 flood and the bridge deck was removed and has not been replaced. The abutments on river left have suffered damage in the repeated flooding and were under repair during the stream walk. This area is outside of the hydraulic modeling study area.

Upstream of the undersized abutments a significant amount of sediment deposition has occurred and several large wood jams have developed (Figure 27). The strong constriction of the abutments has caused a damming effect impounding water during high flows and causing sediment and debris to settle out. Sediment has deposited across the valley, girdling and killing trees, and filling in the natural stream channel. Field measurements estimated that the quantity of impounded sediment is between 2,000 and 3,500 cubic yards.

The built up sediment and large wood is a major hazard to the downstream culverts. A failure of the bridge abutments could release thousand of yards of debris that would quickly clog the culverts and flood the village. It is recommended that the bridge abutments be widened to fit the channel and the sediment and large wood be removed from this location. All of these steps should take place in the same time frame.

Figure 27: Large wood jam and sediment deposition upstream of the abutments

7.4 Remove Garage Building and Replace Culverts with Bridge on Southern Tributary (Alternative 3)

Existing conditions modeling showed that the culverts are undersized and overtop during the large flooding events experienced recently. This alternative evaluates removing the Cabot Garage and parking lot between the Cabot Village Store and Harry’s Hardware. Removal of this infrastructure and associated fill provides space for a narrower bridge to be installed. Additionally upstream channel widening and a flood bench were included in the space of the existing parking lot. The span of the bridge is 30 feet to accommodate the bankfull width measured upstream and the structure length is 60 feet across the road. This layout provides width for two lanes of traffic and roadside parking. The structure length could be shortened to 35-40 feet if parking spaces were eliminated.

The modeled bridge passes all modeled flows including the 500-year flood. The 500-year flood depth is approximately 2.8 feet under the bridge opening leaving 2.7 feet of freeboard to accommodate debris flow (Figure 28). A small amount of flooding occurs during the 500-year flood at the upstream end of the parking lot where the streambank is low, however flood depth is less than 0.5 feet. This alternative is recommended as the bridge is able to pass large floods and provides space for debris flow to pass through its opening.

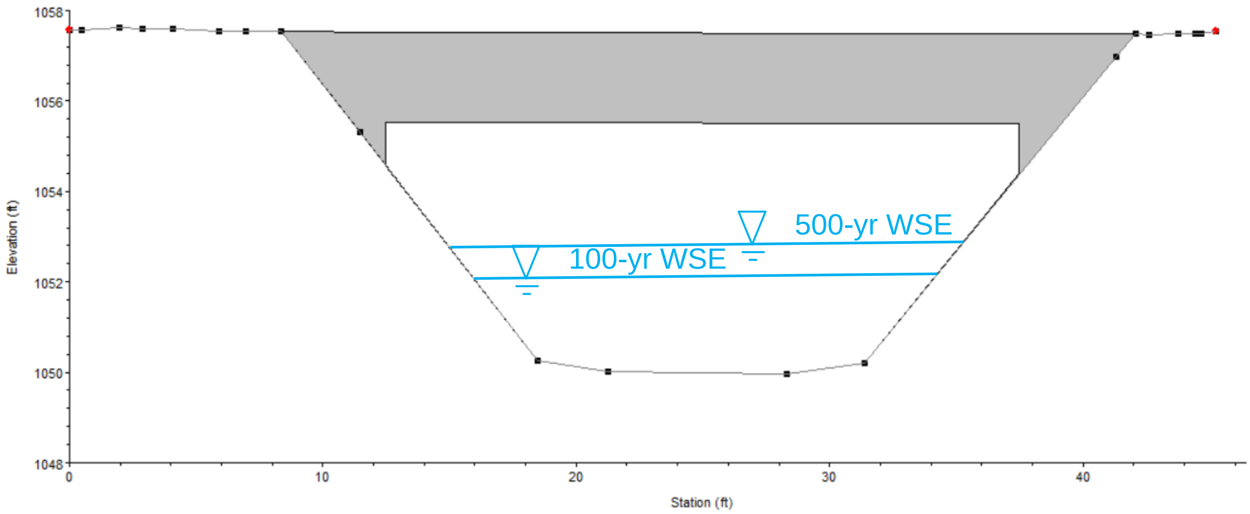

Figure 28: Model results for 30 foot span bridge

7.5 Keep Garage Building and Replace Culverts with Bridge on Southern Tributary (Alternative 4)

This alternative evaluates installation of a 30 foot span bridge while maintaining the Cabot Garage in its existing location and keeping the parking between the Cabot Village Store and Harry's Hardware. Maintaining this layout would require a 160 foot long bridge similar to the existing culverts.

This long bridge structure passes the modeled flows including the 500-year flood. The 500-year flood has a depth of 3.1 feet at the upstream bridge opening leaving about 0.7 feet of freeboard to the low chord elevation (Figure 29). This design does not allow for adequate space for debris flow to pass through the bridge.

Construction of this structure would require temporary removal of the Garage building and replacement after the bridge is completed. Costs and complication of construction would be much higher than Alternative 3. Benefits would be less as the structure provides less space for debris flow than the shorter bridge in Alternative 3. For these reasons this alternative is not recommended.

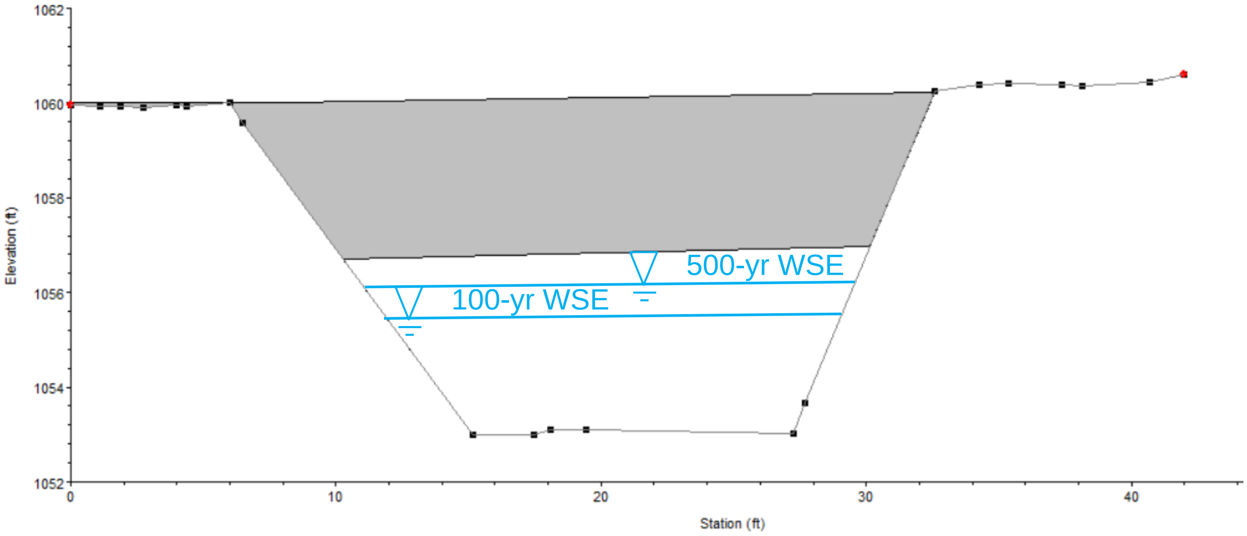

Figure 29: **Model results for 30 foot span bridge**

7.6 Widen Downstream Channel on Southern Tributary (Alternative 5)

The channel downstream of the culverts is narrow, steep and confined by walls. This alternative evaluated widening the downstream channel in combination with the bridge from Alternative 3. This would require construction of stacked stone or concrete walls to protect the adjacent buildings.

Results found that widening the downstream channel decreases 500-year flood levels in the downstream reach 0.1-0.3 feet and upstream of the bridge by less than 0.1 feet. Localized velocities decrease in the downstream channel during the 500-year flood up to 5 ft/s reducing erosions risks. This alternative should be considered to best naturalize the channel width through and reduce erosion risks through the village reach.

7.7 Replace Bridge with 30 Foot Span Bridge on Northern Tributary (Alternative 6)

The width of the existing bridge is much narrower than the measured bankfull widths of the channel. A 30 foot span bridge was evaluated as it could be built to replace the existing bridge in the existing space and layout. The wider span bridge can pass the 100-year flood, but the 500-year flood overtops the road (Figure 30). With less than one foot of freeboard between the 100-year water surface and the low chord, there is high risk of debris clogging the opening and causing flooding during the 100-year flood. Based on this result a structure with the existing deck elevation cannot provide the capacity to pass larger floods. This alternative is not recommended.

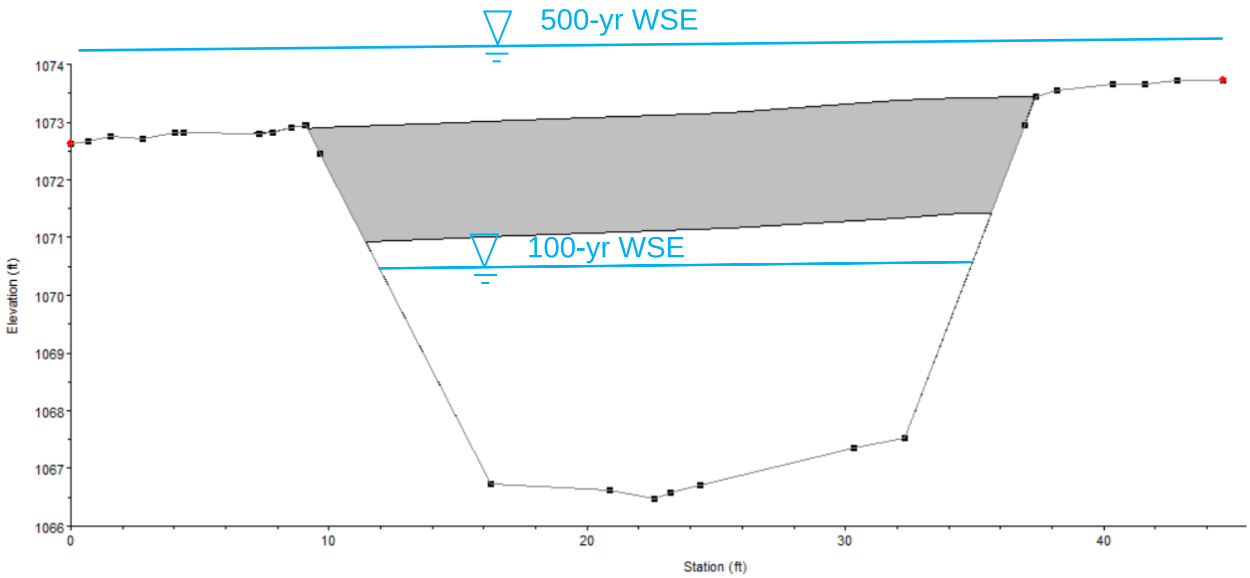

Figure 30: Model results for 30 foot span bridge

7.8 Elevate Road and Replace Bridge with 30 Foot Span Bridge (Alternative 7)

The existing structure and widened bridge in Alternative 6 have low chord elevations that are too low to pass the modeled flood flows, even if some sediment removal were to take place. Elevating the road approaching the bridge would allow for a higher low chord elevation. This alternative raises the road 4 feet at the bridge approach. This would include raising an approximately 110 foot long stretch of road to the south to tie into the existing road. Three driveways to the south would require elevating to tie into the elevated road grade. To the north the road raising would extend approximately 85 feet. One driveway would require elevating and the access road to the park would require regrading.

The elevated 30 foot span bridge passes all modeled flows up to the 500-year flow (Figure 31). The elevated bridge deck leaves additional space for debris flow. The 500-year flood depth is approximately 6 feet that leaves about 2.5 feet of freeboard for debris flow. This meets the suggested 20% of bridge opening for debris flow decreasing the risk of clogging from large wood (Furniss et al., 1998).

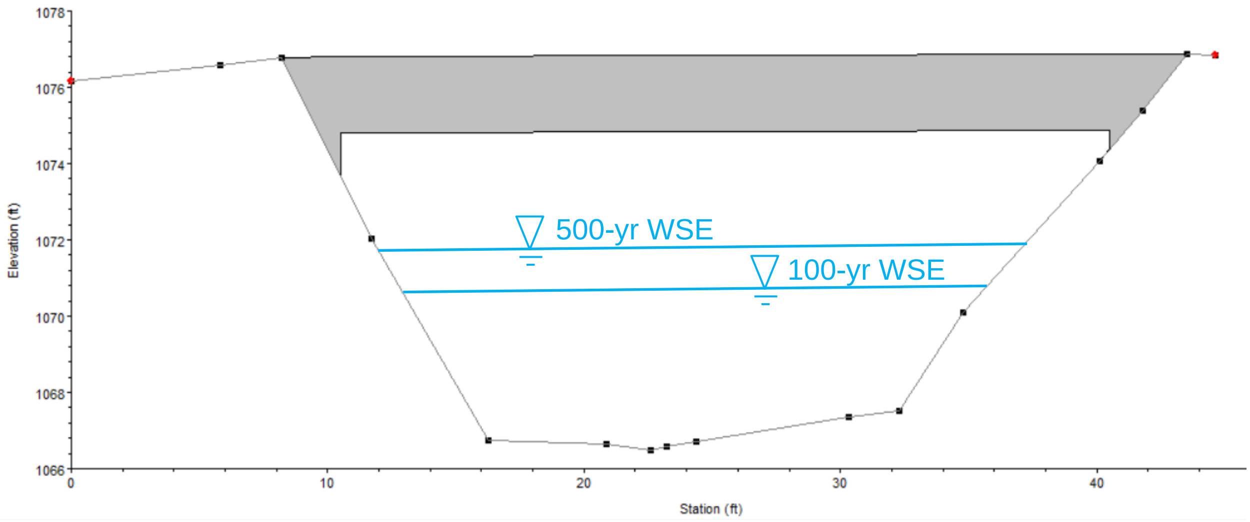

Figure 31: Model results for elevated 30 foot span bridge

7.9 Elevate Road and Replace Bridge with 50 Foot Span Bridge (Alternative 8)

This alternative includes elevating the road in the same approach as Alternative 7, plus widening the span to 50 feet to allow inclusion of a flood bench. The flood bench ties into the channel upstream and downstream of the bridge.

The 100- and 500-year water surface elevations are similar to Alternative 7 providing the same amount of freeboard for debris flow (Figure 32). However the area for additional flow and debris passage is larger with a flood bench. In the event of debris clogging, the wider span provides more capacity for passage of flood flow and other debris. This wider bridge and flood bench is a more resilient alternative.

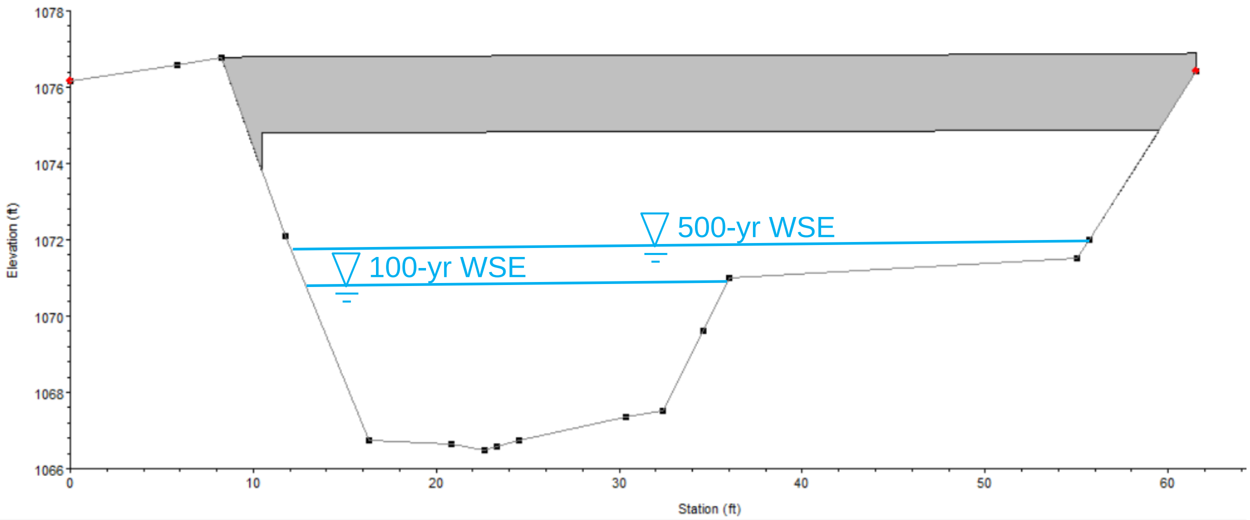

Figure 32: Model results for elevated 50 foot span bridge

7.10 Construct and Restore Upstream Storage Areas (Alternative 9)

If feasible, storing flood waters upstream of the village would decrease peak flood flows and mitigate flood impacts during large storms. To meaningfully decrease flood peaks to accommodate flood volumes (Table 12), 20 to 100 acre-ft of water would need to be stored in the upstream channel or watershed.

Table 12: Total Volume of Flood Flows

Flow Return Frequency (Years)	Volume of Flow from Northern Tributary (acre-ft)	Volume of Flow from Southern Tributary (acre-ft)
10	61.9	20.0
25	88.9	28.4
50	111.1	36.3
100	140.6	45.9
500	177.7	75.6

Locations of potential floodplain restoration were a focus of the stream walks of each tributary. Restoring floodplain by excavating to lower the land adjacent to the stream channel provides volume for flood flows to temporarily fill and reduce the volume of water flowing downstream. The stream walks identified small flood benches throughout the watersheds, but the tributaries are steep and contained in narrow valleys and there are not opportunities for large floodplain restoration projects.

Ponds or impoundments provide flood storage by having unused volume that flood waters fill during a flood then slowly flow out of when the flooding has ended. Flood control dams built in the streams can provide flood storage to decrease flows. With the steep streams and narrow valleys, flood control dams could only store a few acre-ft of water in these tributaries. The small reduction in peak flows would not justify the cost of construction and maintenance of such dams. Diverting flow into excavated ponds could store floodwaters. However study of the topography of the watershed suggests there are limited low gradient areas where large ponds could be dug (Appendix A). Additionally if ponds include construction of earthen embankment dams, Vermont Dam Safety rules would require extensive design and construction details in addition to routine maintenance and inspections. Construction of ponds and impoundments are not recommended for downstream flood mitigation in the village.

Natural upstream storage areas should be preserved and expanded where possible. Dense upland forests capture more rainfall and slow overland runoff, wetland complexes absorb and pond water, and existing small flood benches along the tributaries capture debris and add up to store flood flows. Opportunities to conserve forested areas and reforest cleared areas should be explored.

7.11 Sediment Management (Alternative 10)

The bridge on the Northern Tributary and the culverts on the Southern Tributary are located in slope decreasing areas with reduced sediment and debris transport. The locations are prone to deposition and structure clogging. Sediment management is recommended even after new structures are installed. The bed elevation to pass the design flood with an allowance for debris should be maintained. Once the hydraulic opening decreases due to sediment buildup, the material should be removed. This alternative was not modeled, but is recommended to be set up during structure design as part of normal operation and maintenance in the village. This approach has been used in other Vermont towns in similar settings where alluvial fans or highly depositional areas exist.

8.0 Climate Change and Future Flows

Studies have found that extreme precipitation events are increasing in frequency and magnitude (Collins, 2009; Armstrong et al., 2012; Guilbert et al., 2014). Methods for modeling potential future flood flows vary. New York State requires evaluation of a 20% increase in flood flow magnitude to account for climate change. Vermont does not have a standard for climate change analysis. A possible example of an extreme precipitation event occurred during the overnight hours of Jul 29th into July 30th this summer in St. Johnsbury, Lyndon, and other neighboring towns. Over a 6-hour period 7.96 inches of rain were measured in St. Johnsbury. NOAA Atlas 14 precipitation frequency estimates indicate the 1000-year 6-hour precipitation depth is 5.42 inches. Thus the late July event was 47% more extreme than the 1000-year storm according to the industry standard estimate. Flows for the north and south tributaries were estimated for such an event the developed hydrology model and run through the hydraulic model (Table 13).

Table 13: Summary of Estimated Peak Flood Flows from the St. Johnsbury Event and the 500-Year Flood for Comparison

Flood Scenario	Northern Tributary Flow (cfs)	Southern Tributary Flow (cfs)
St. Johnsbury Event	2,097	845
500-year	1,552	609

The hydraulic model was run for the existing conditions and the preferred alternatives for each tributary – Alternatives 3 and 8. The proposed bridge on each tributary passes the modeled flood flow without overtopping (Figure 33 and Figure 34). . Flood inundation of adjacent buildings and roads does occur during this event for the modeled alternatives (Appendix B). Flood flows in the Southern Tributary overflow the banks behind the Willey Building inundating the parking lot and flowing across Main Street. The Willey Building and buildings on the west side of Main Street would begin to experience inundation. Flood flows in the Northern Tributary escape the channel upstream of the bridge and begin to inundate the nearby homes. On the western side of the road inundation begins to impact the homes from the low lying floodplain of the Winooski River. Although both structures are able to pass the clear flood flow, freeboard is reduced and risks of debris becoming trapped on the bridge deck increase. The modeling shows that the structures are capable of passing an extreme flood. Flooding issues would arise as the upstream and downstream channels are unable to carry a flood event of this size. A storm of this size appears to be exceeding the capacity of the tributaries to pass flow through the village without flooding.

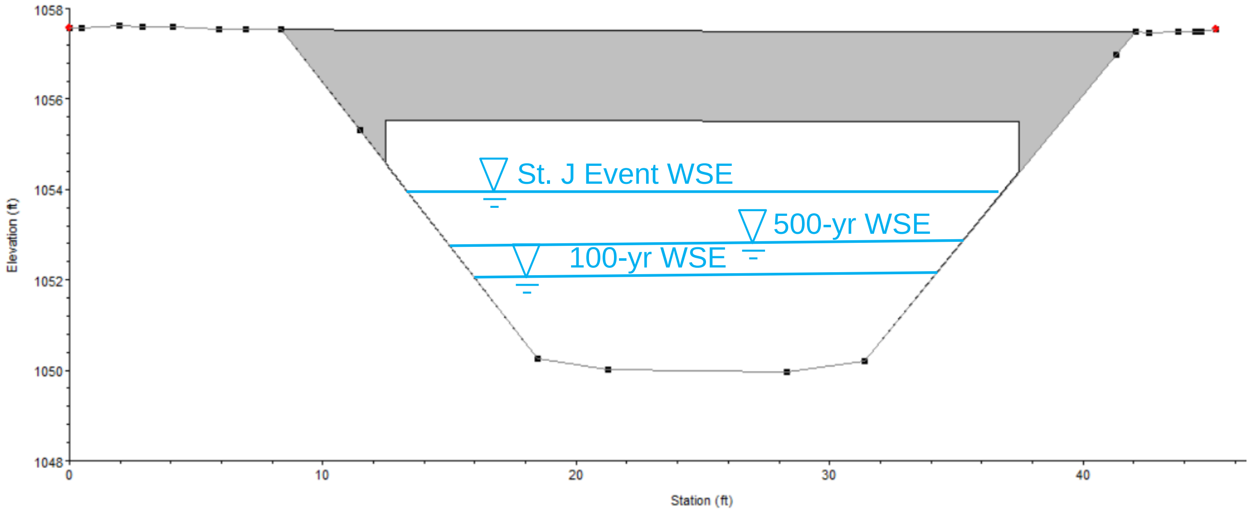

Figure 33: Model results for Southern Tributary Alternative 3 – 30 foot span bridge

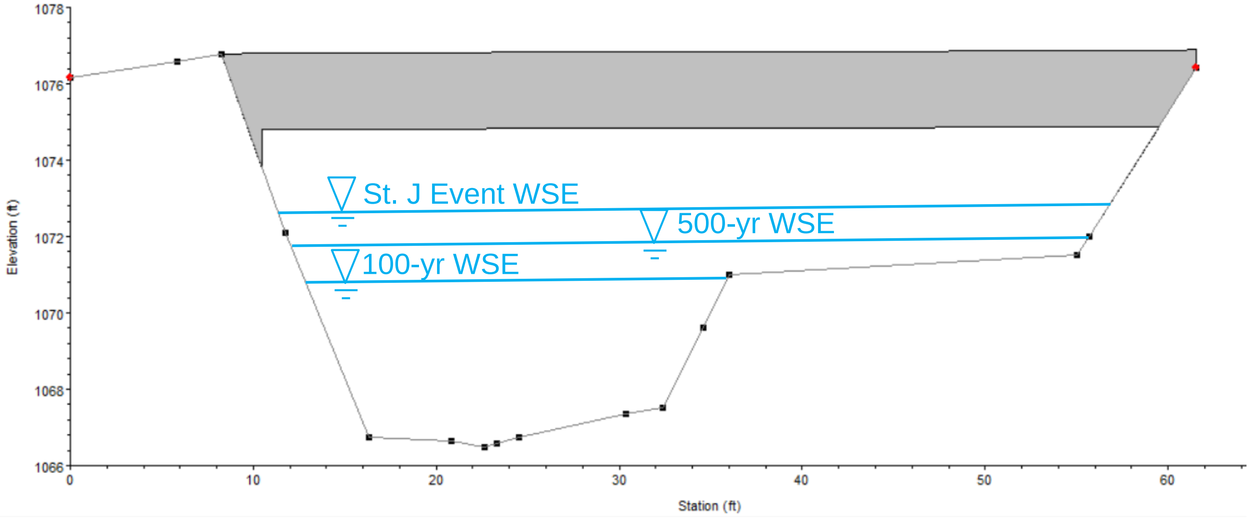

Figure 34: Model results for Northern Tributary Alternative 8 – Elevated 50 foot span bridge

9.0 Conclusions and Recommendations

The hydraulic modeling shows that the structures are primary flood risks in the village as they are undersized for the channels and do not have the capacity to carry flood waters, let alone the sediment and large wood. Based on the results of the hydraulic analysis, new structures are recommended. The 50 foot bridge with the flood shelf is preferred on the Northern Tributary. The removal of the Garage and 30 foot bridge is recommended on the Southern Tributary. Widening the approach channels and developing a sediment management plan is also recommended. The more that can be done to naturalize the stream channels through the village the more resilient it will be to future flooding.

Upstream on the Southern Tributary it is recommended that the VAST bridge abutments be widened to fit the channel and the sediment and large wood be removed. This buildup of wood and large sediment pose a hazard to the downstream culverts and will continue until the VAST bridge is replaced.

Following this analysis the next steps to be completed include concept designs to confirm feasibility of proposed larger structures, cost estimates of each concept design will be completed, and town applications for FEMA Hazard Mitigation Grants for design and construction.

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Appendix A Tributaries Watershed Map

Cabot Flood Study

Cabot, Vermont

SLR Project No.: 146.15729.00002

October 25, 2024

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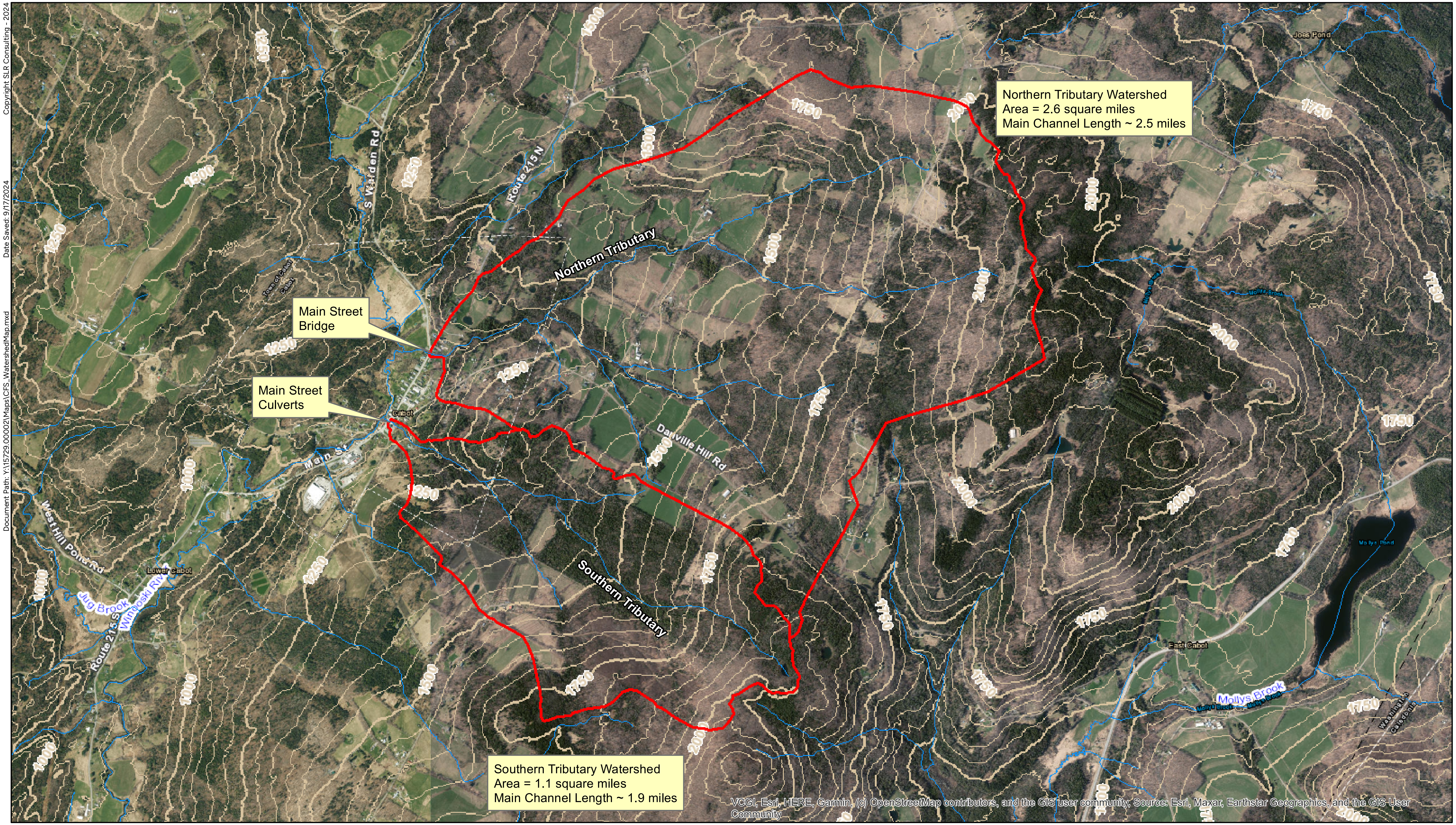
Document Path: Y:\15729.00002\Maps\CFS_WatershedMap.mxd



Northern Tributary Watershed
Area = 2.6 square miles
Main Channel Length ~ 2.5 miles

Southern Tributary Watershed
Area = 1.1 square miles
Main Channel Length ~ 1.9 miles

VCGI, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

CABOT WATERSHED OVERVIEW MAP

CABOT FLOOD STUDY
TOWN OF CABOT

0 1,800 3,600
Feet
1 in = 1,800 feet

N

SLR

1 SO MAIN ST, 2ND FLOOR
WATERBURY, VT 05676
802.882.8335

Appendix B Plan View Results Maps

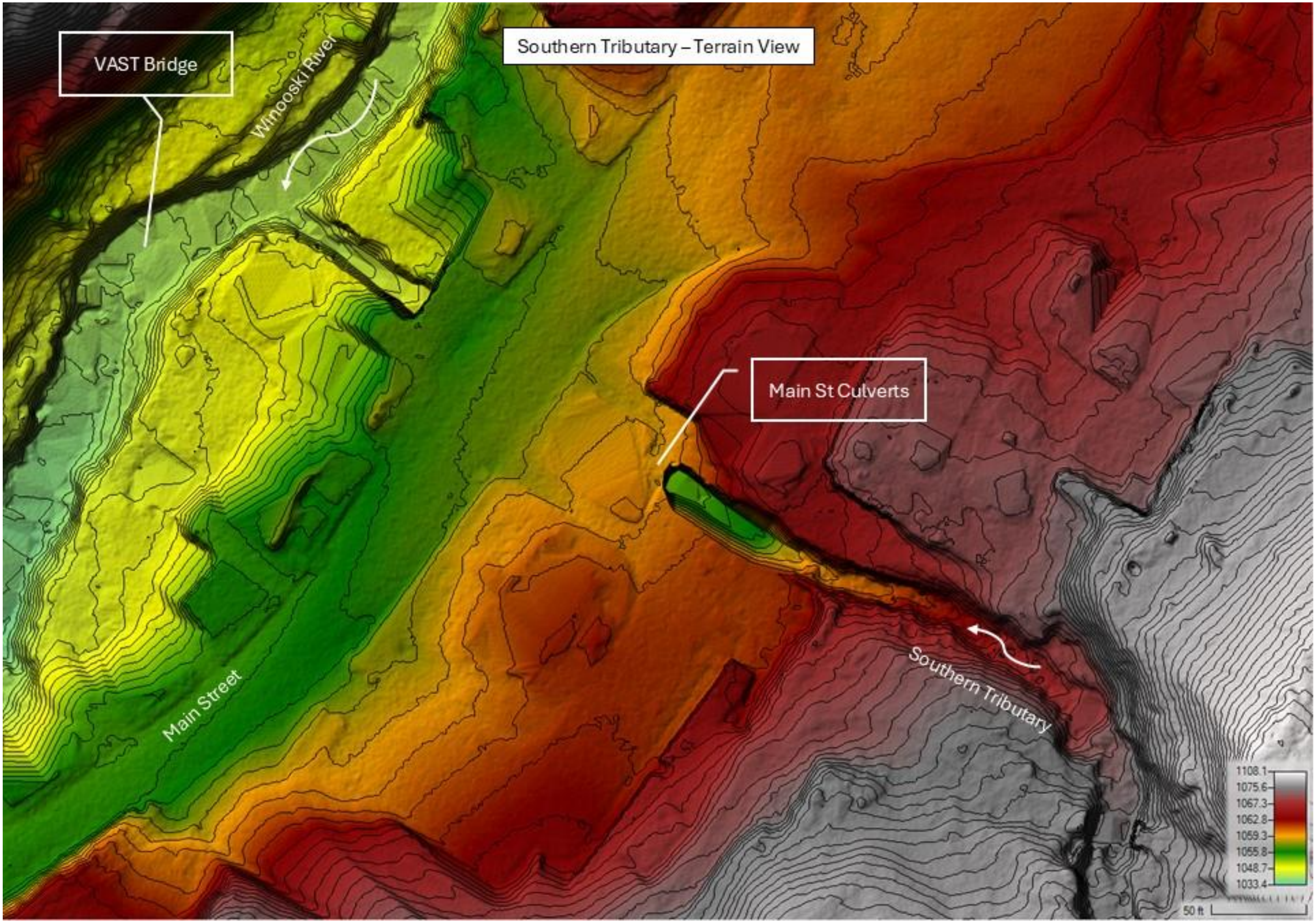
Cabot Flood Study

Cabot, Vermont

SLR Project No.: 146.15729.00002

October 25, 2024


Southern Tributary – Aerial View
VAST Bridge
Winooski River
Main St Culverts
Southern Tributary
Main Street
50 ft


Southern Tributary – Terrain View
VAST Bridge
Winooski River
Main St Culverts
Main Street
Southern Tributary
1108.1
1075.6
1067.3
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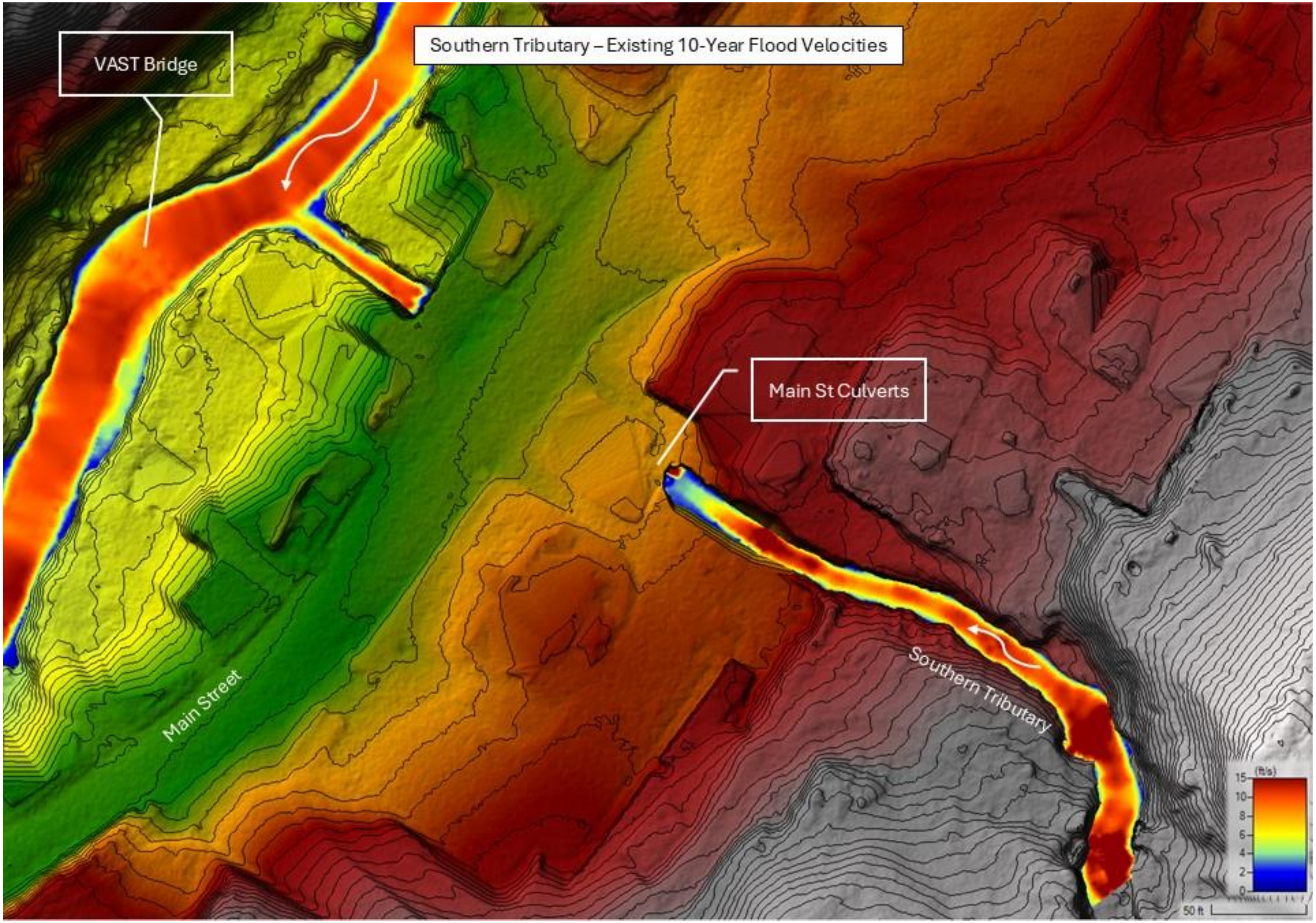
1059.3
1055.8
1048.7
1033.4
50 ft


Southern Tributary – Existing 10-Year Flood Velocities
VAST Bridge
Main St Culverts
Main Street
Southern Tributary
(ft/s)
15
10
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6
4
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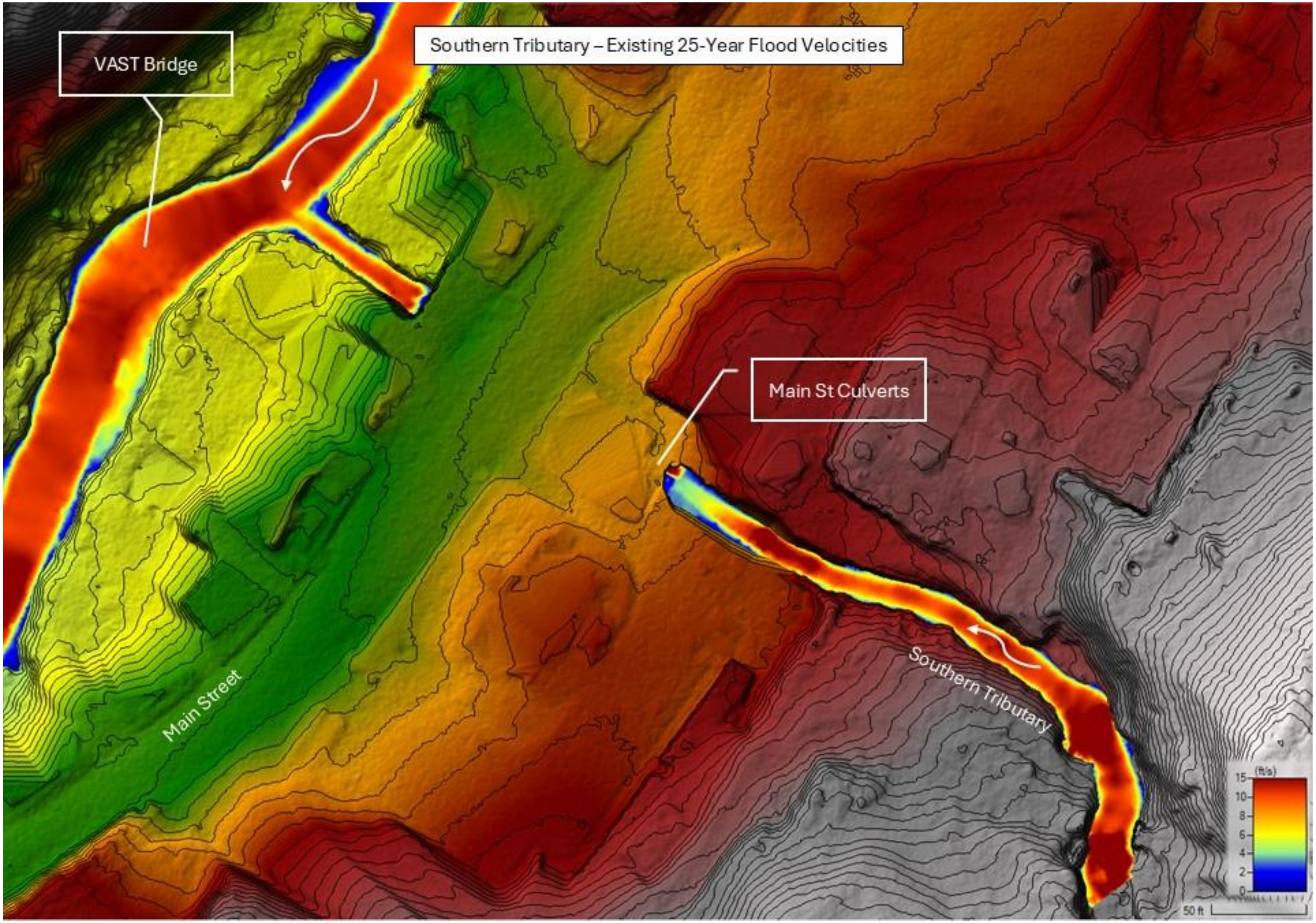
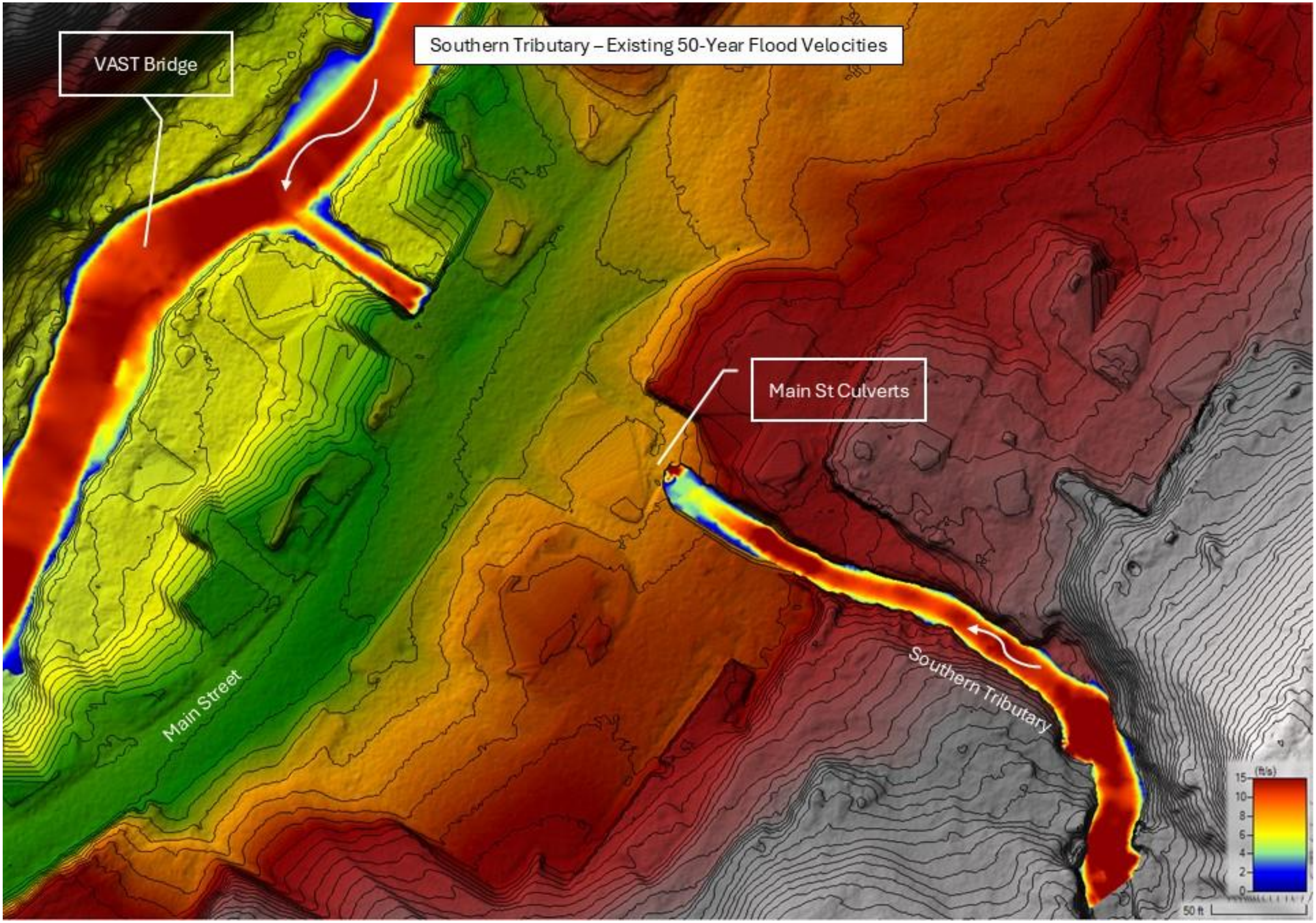
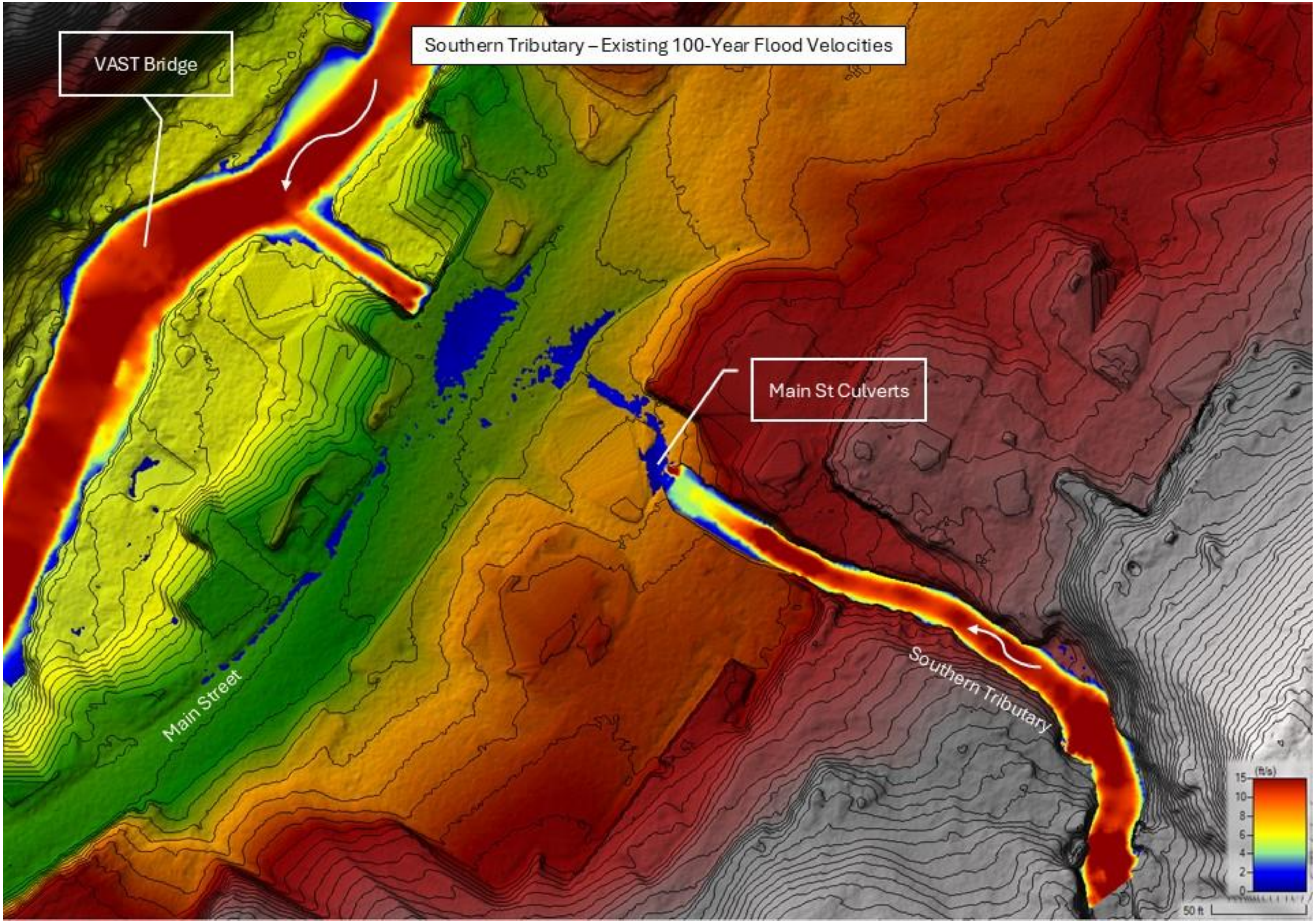
50 ft


Southern Tributary – Existing 25-Year Flood Velocities
VAST Bridge
Main St Culverts
Main Street
Southern Tributary
(ft/s)
15
10
8
6
4
2
0
50 ft



Southern Tributary – Existing 50-Year Flood Velocities


Southern Tributary – Existing 100-Year Flood Velocities
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Main St Culverts
Main Street
Southern Tributary
(ft/s)
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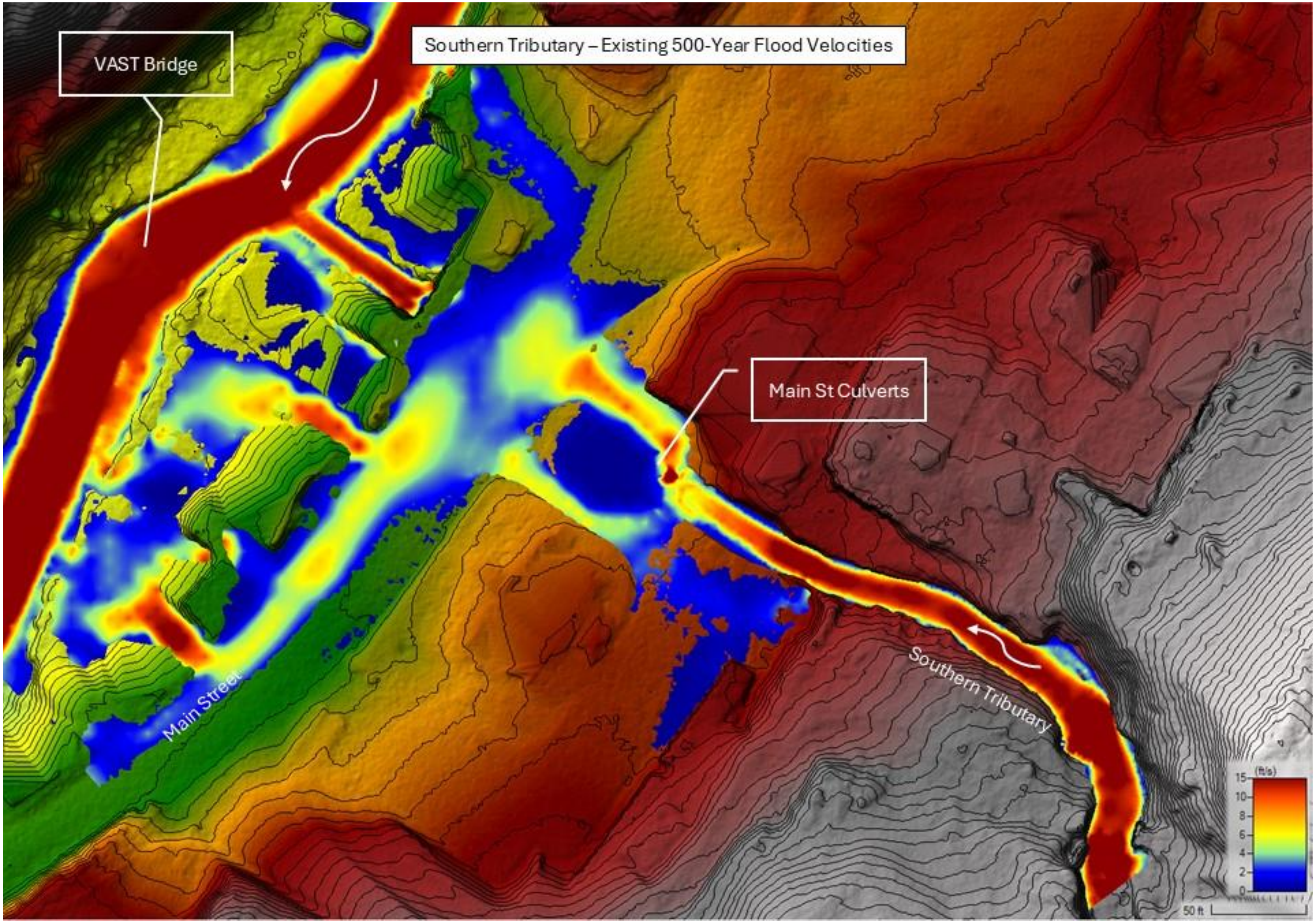
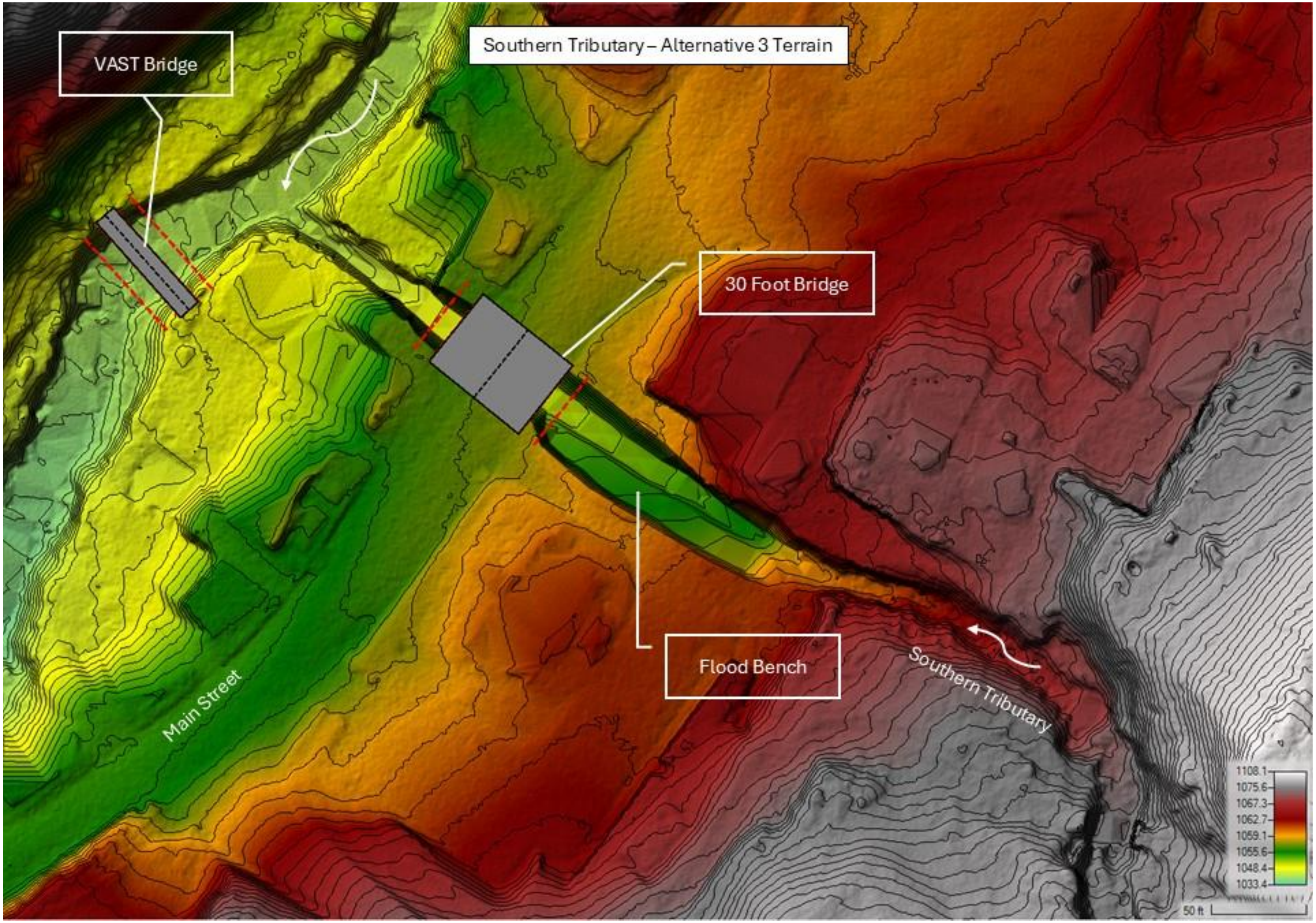
50 ft



Southern Tributary – Existing 500-Year Flood Velocities


Southern Tributary – Alternative 3 Terrain
VAST Bridge
30 Foot Bridge
Flood Bench
Main Street
Southern Tributary
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1075.6
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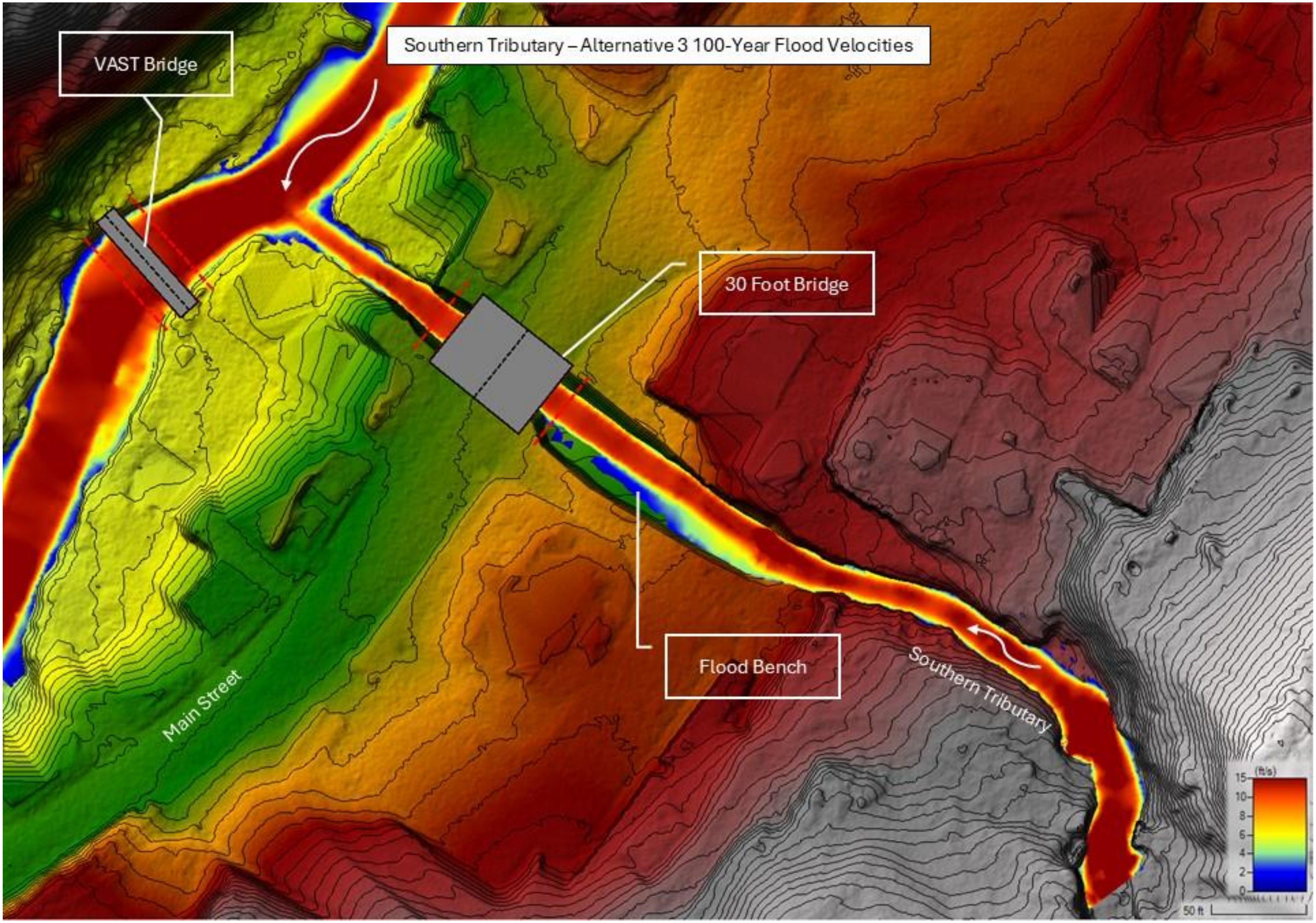
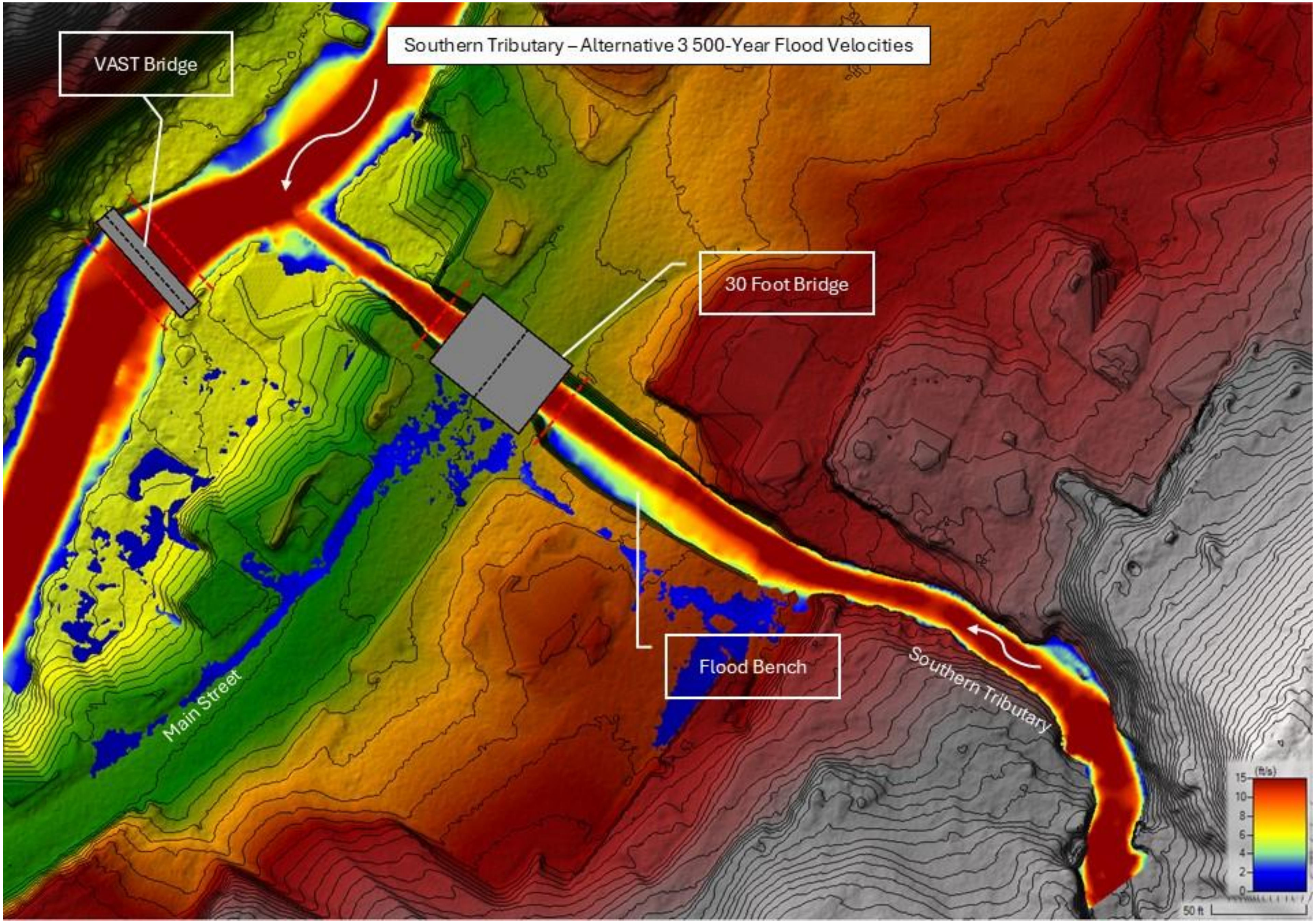
1059.1
1055.6
1048.4
1033.4
50 ft



Southern Tributary – Alternative 3 100-Year Flood Velocities


Southern Tributary – Alternative 3 500-Year Flood Velocities
VAST Bridge
30 Foot Bridge
Flood Bench
Main Street
Southern Tributary
(ft/s)
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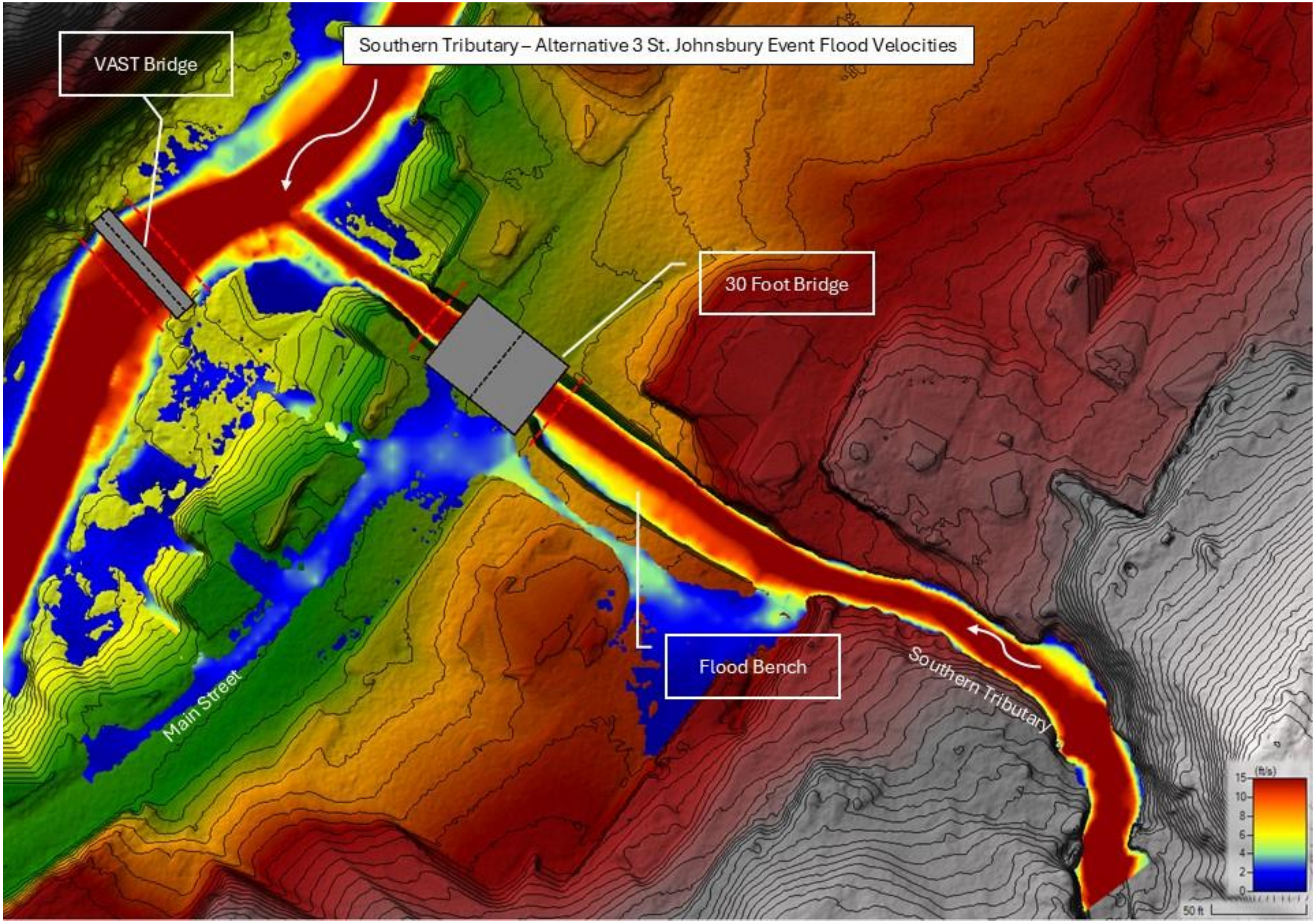
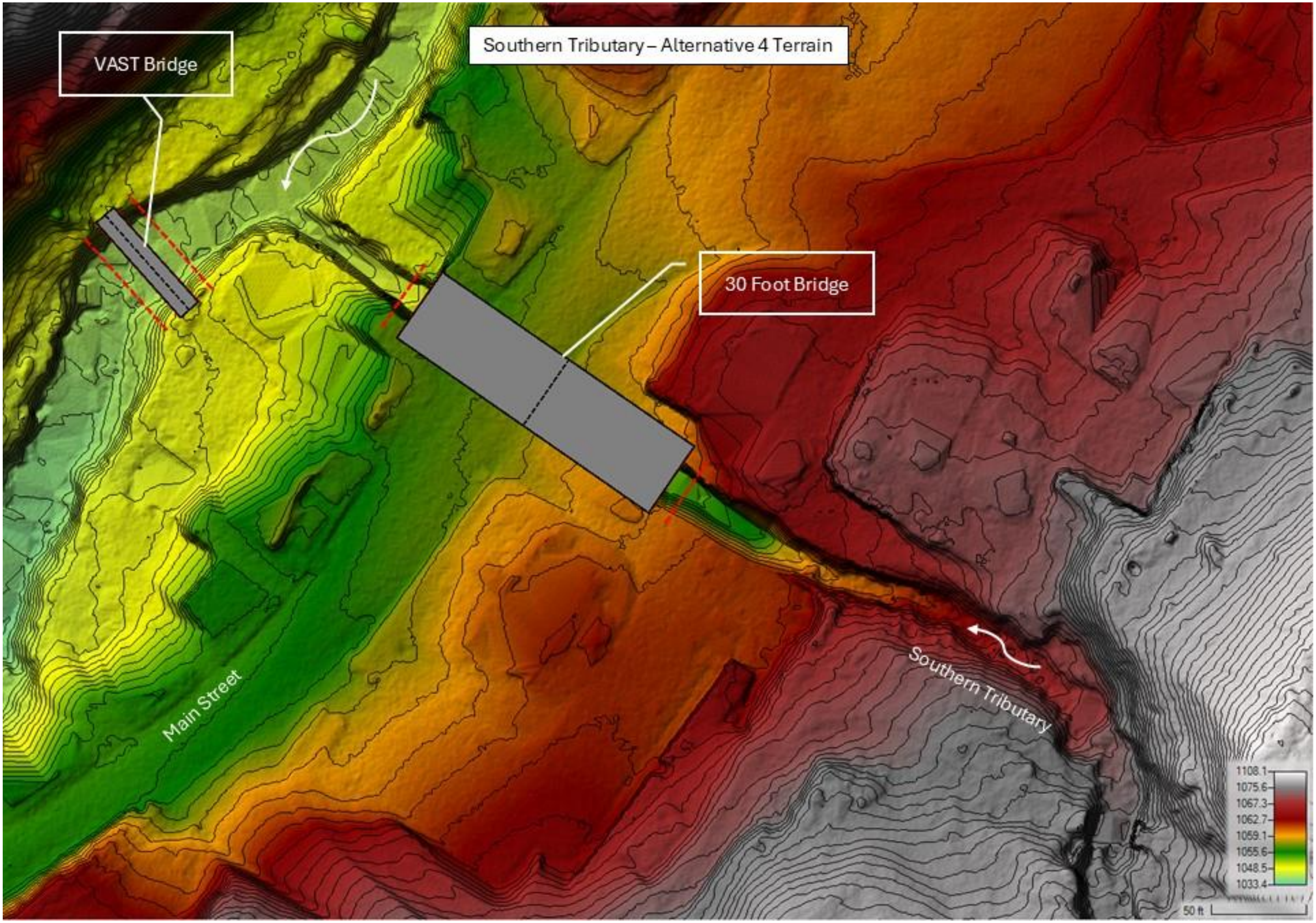
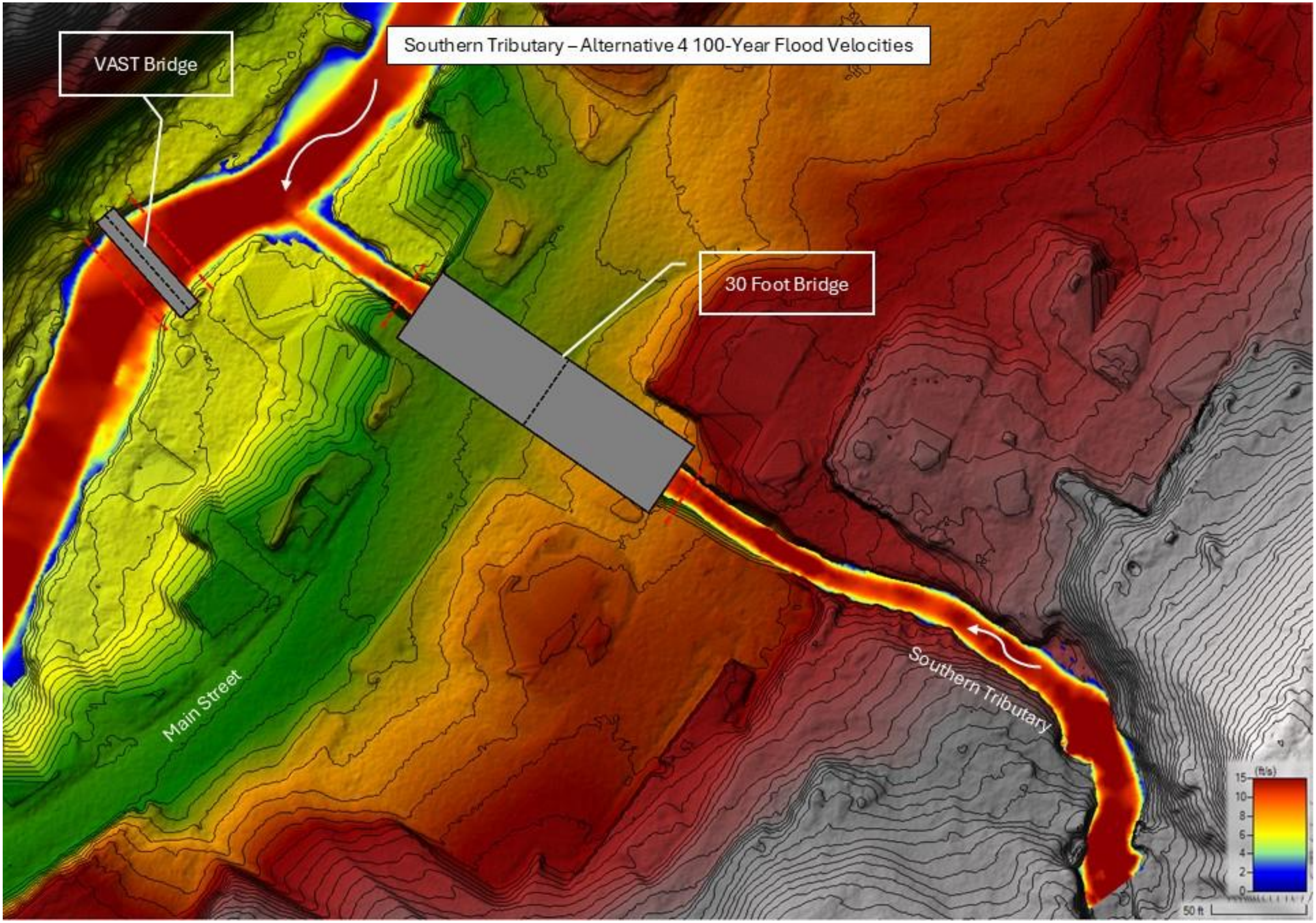
50 ft



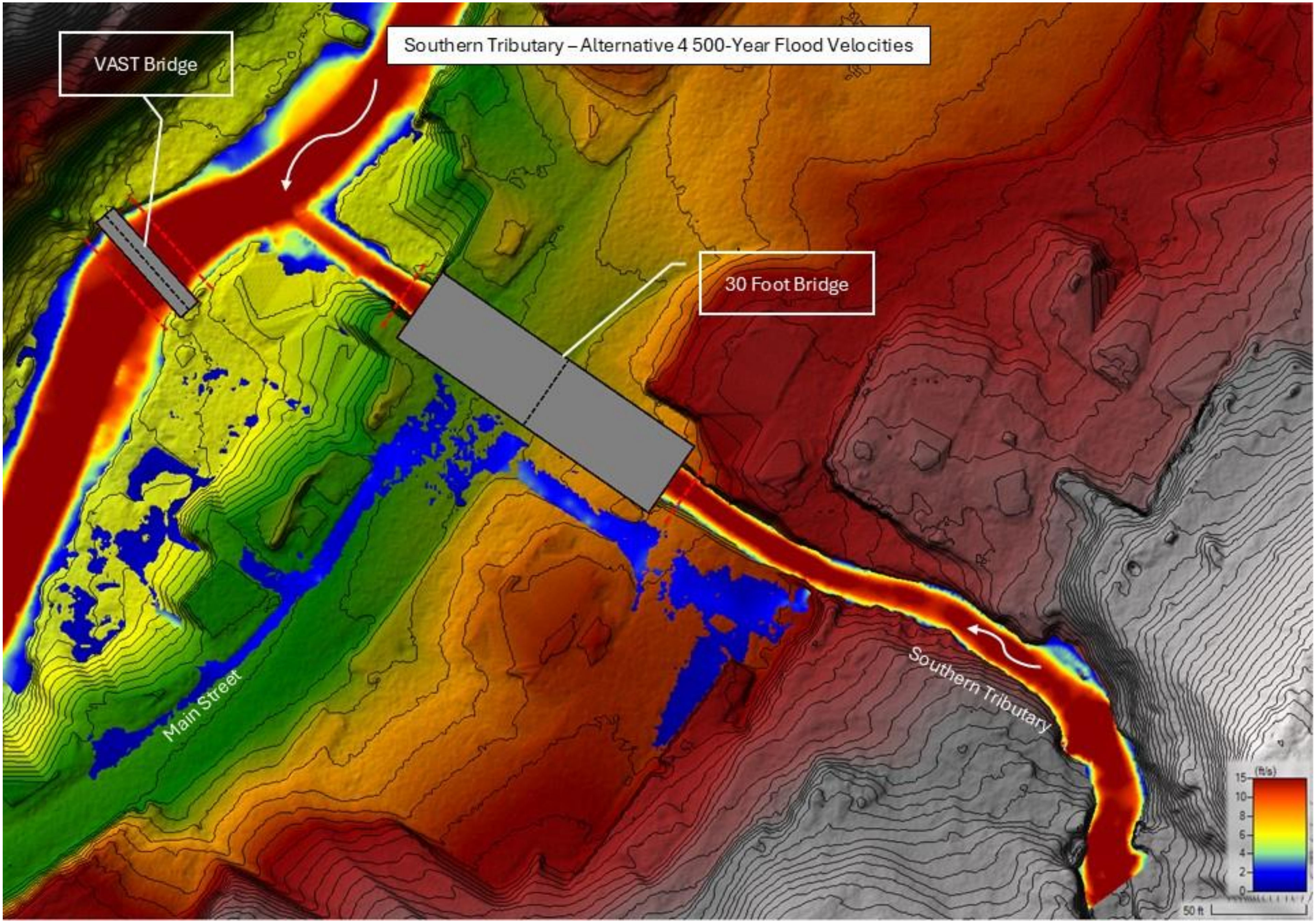
Southern Tributary – Alternative 3 St. Johnsbury Event Flood Velocities



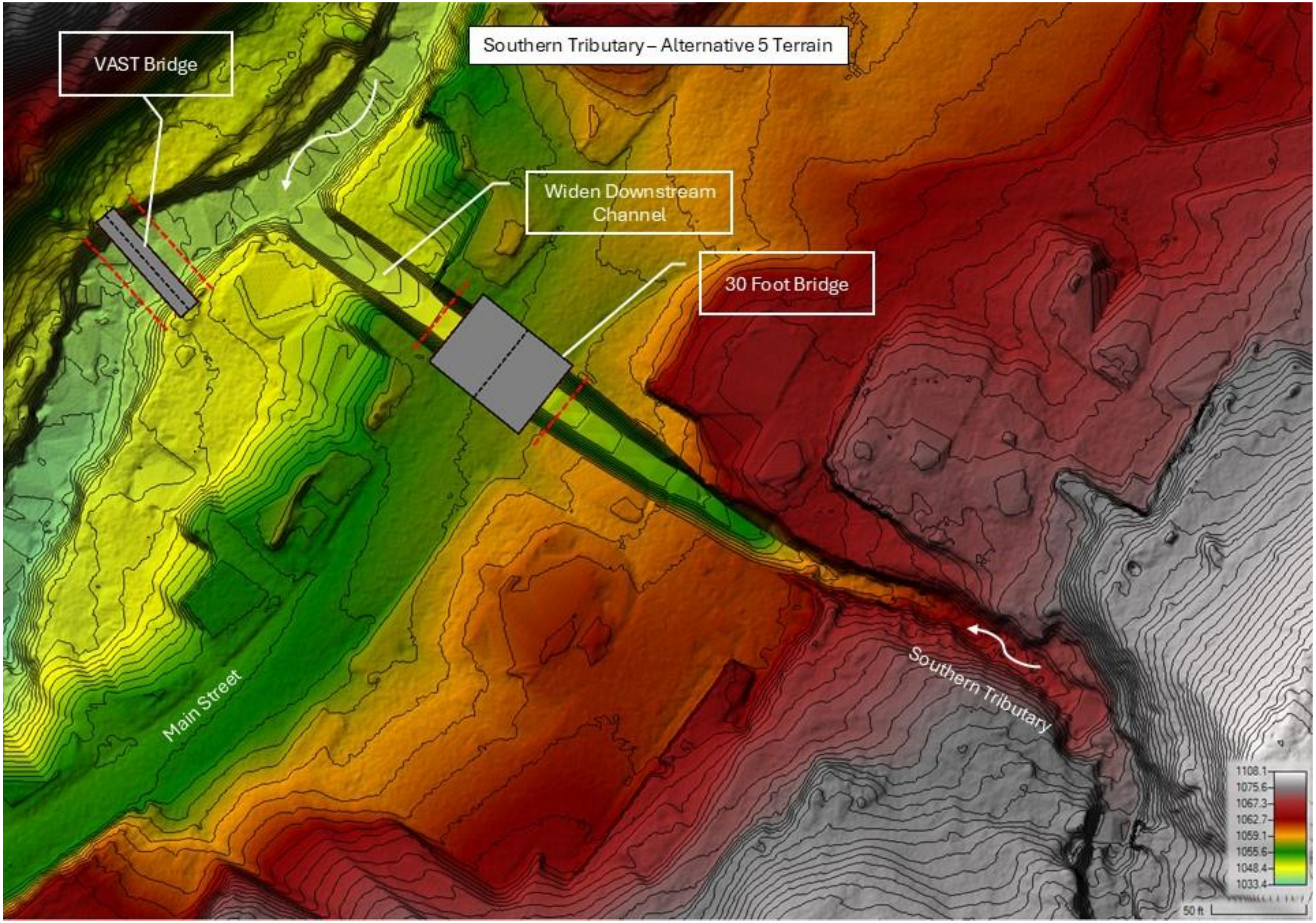
Southern Tributary – Alternative 4 Terrain



Southern Tributary – Alternative 4 100-Year Flood Velocities



Southern Tributary – Alternative 4 500-Year Flood Velocities


Southern Tributary – Alternative 5 Terrain
VAST Bridge
Widen Downstream Channel
30 Foot Bridge
Main Street
Southern Tributary
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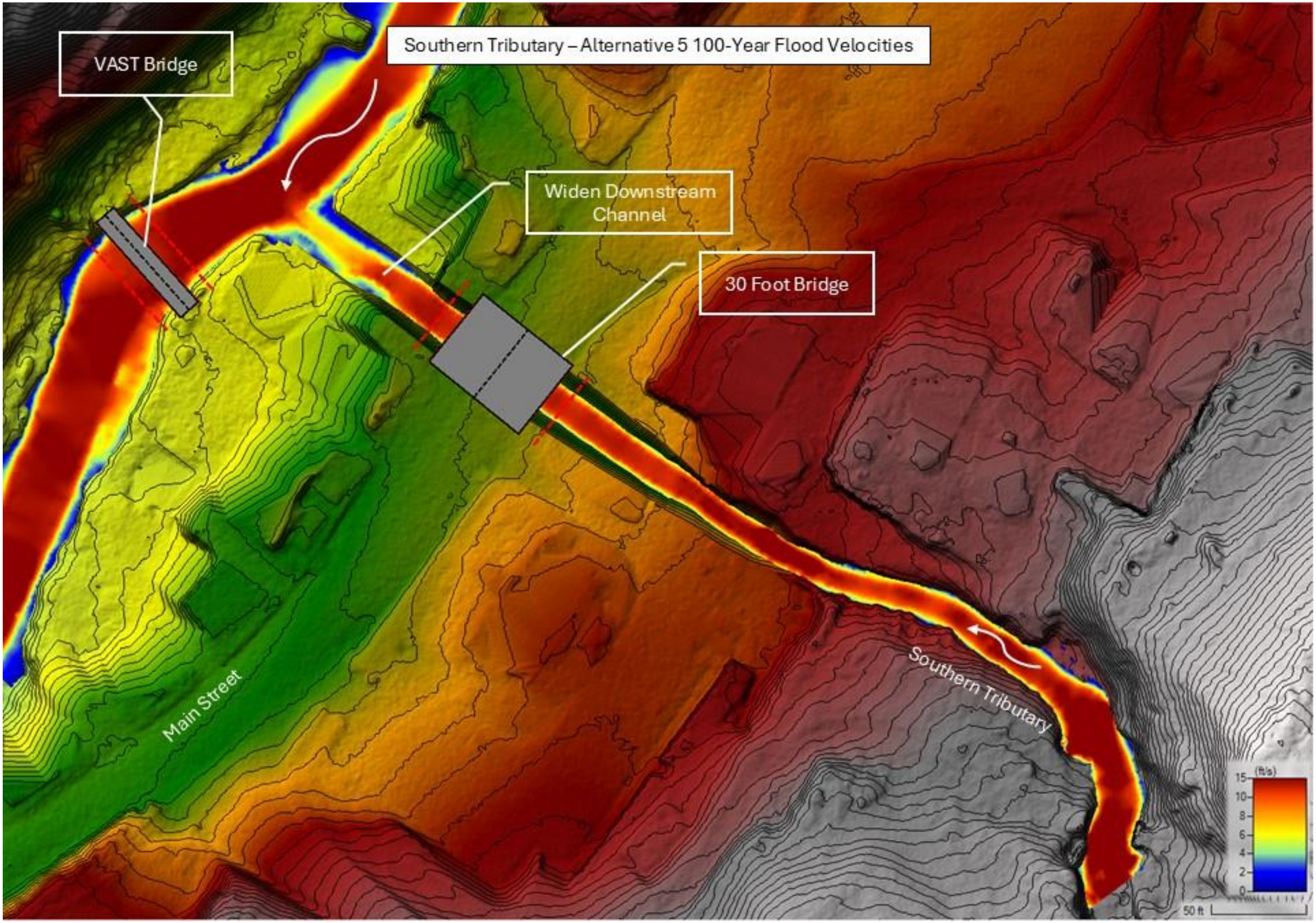
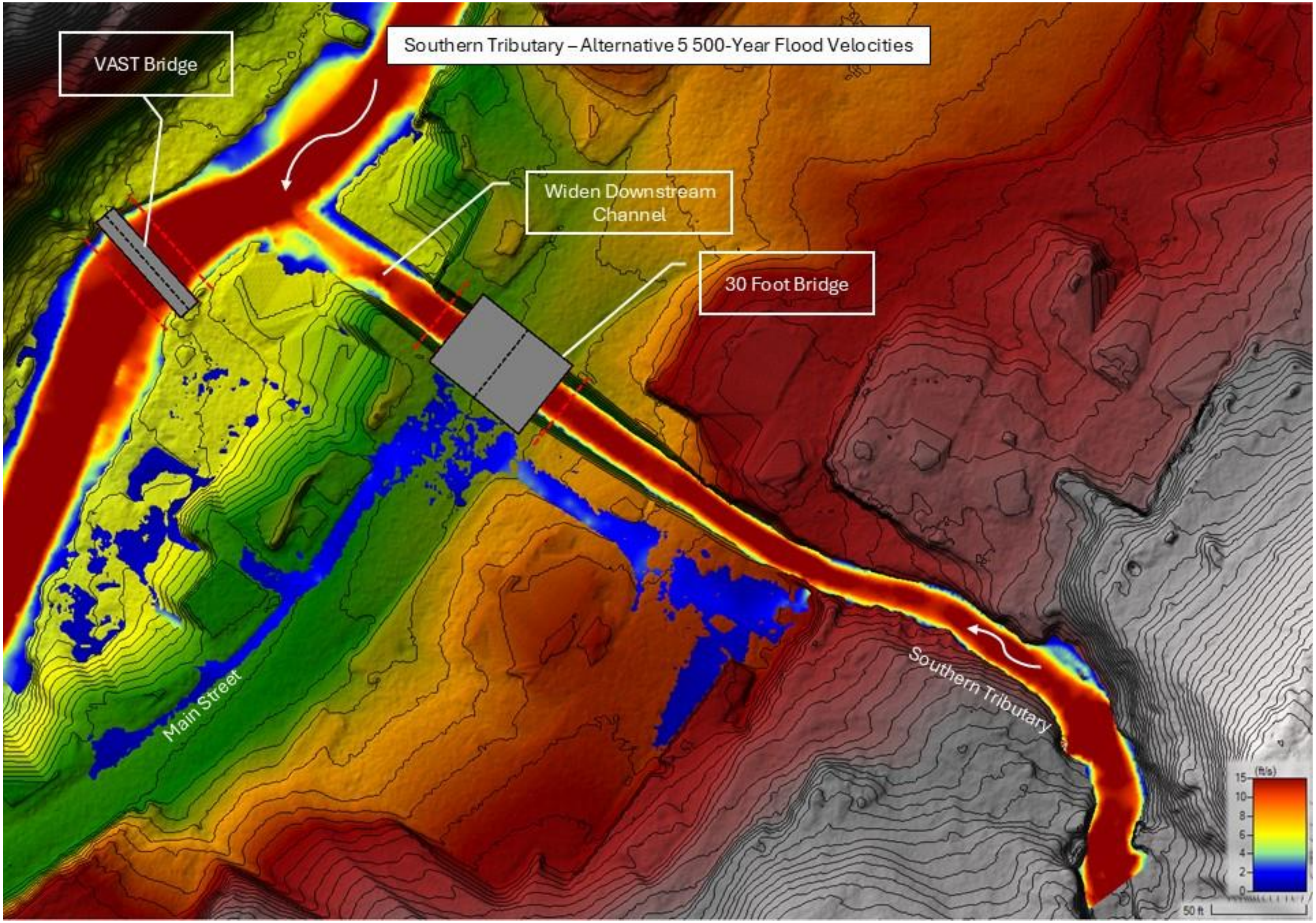
1055.6
1048.4
1033.4
50 ft

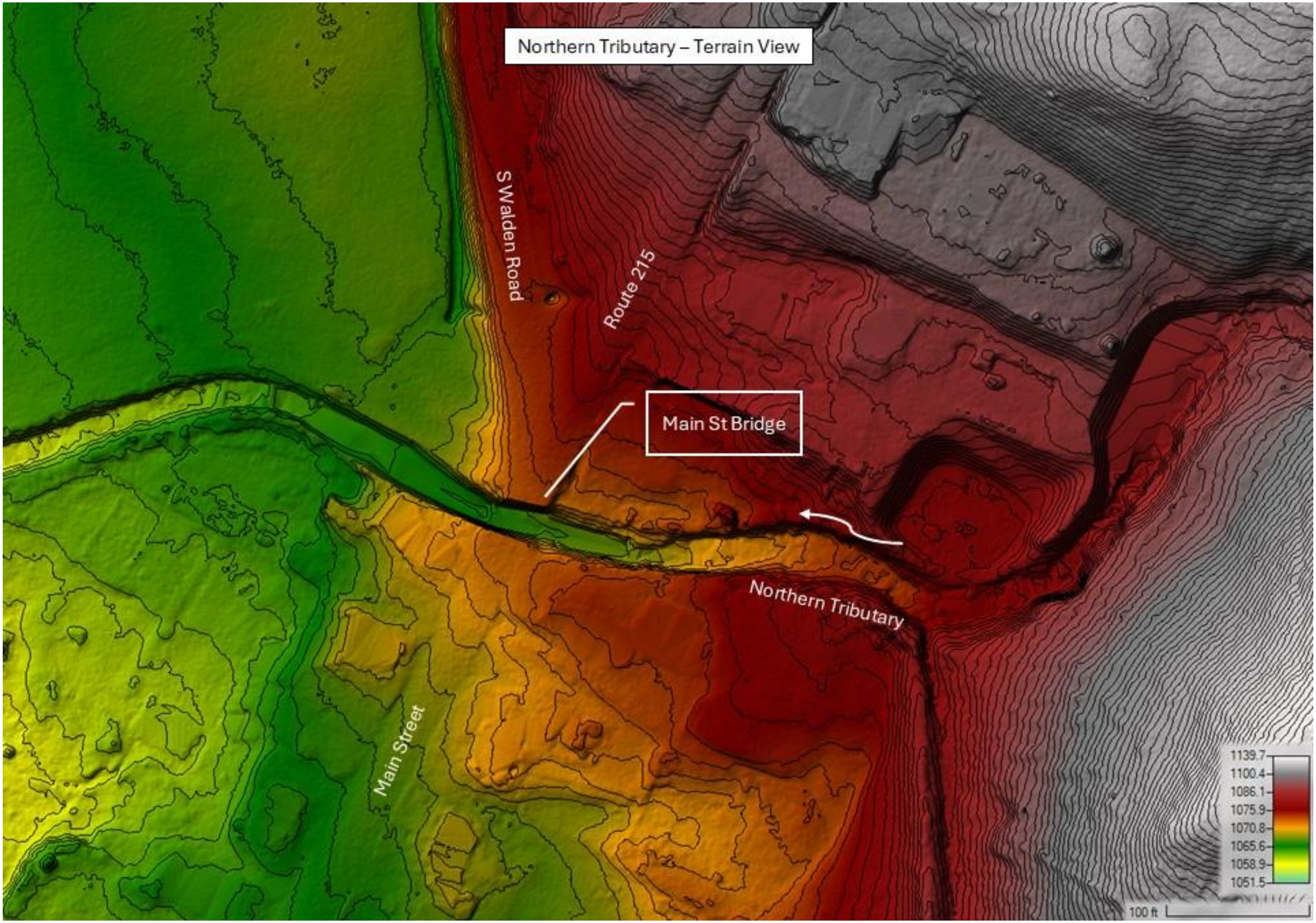


Southern Tributary – Alternative 5 100-Year Flood Velocities

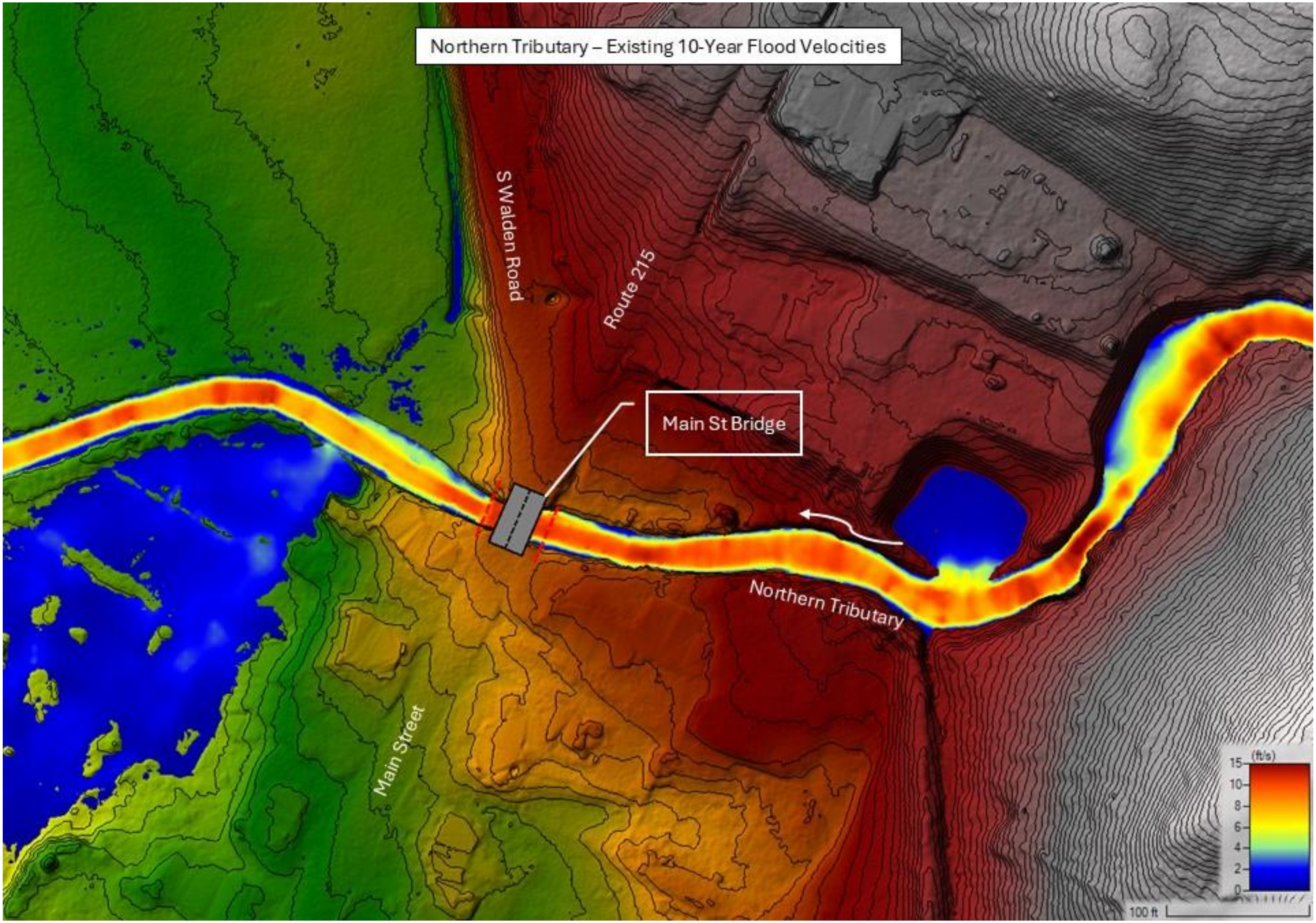


Southern Tributary – Alternative 5 500-Year Flood Velocities


Northern Tributary – Aerial View
S Walden Road
Route 215
Main St Bridge
Northern Tributary
Main Street
100 ft



Northern Tributary – Terrain View


Northern Tributary – Existing 10-Year Flood Velocities
S Walden Road
Route 215
Main St Bridge
Northern Tributary
Main Street
(ft/s)
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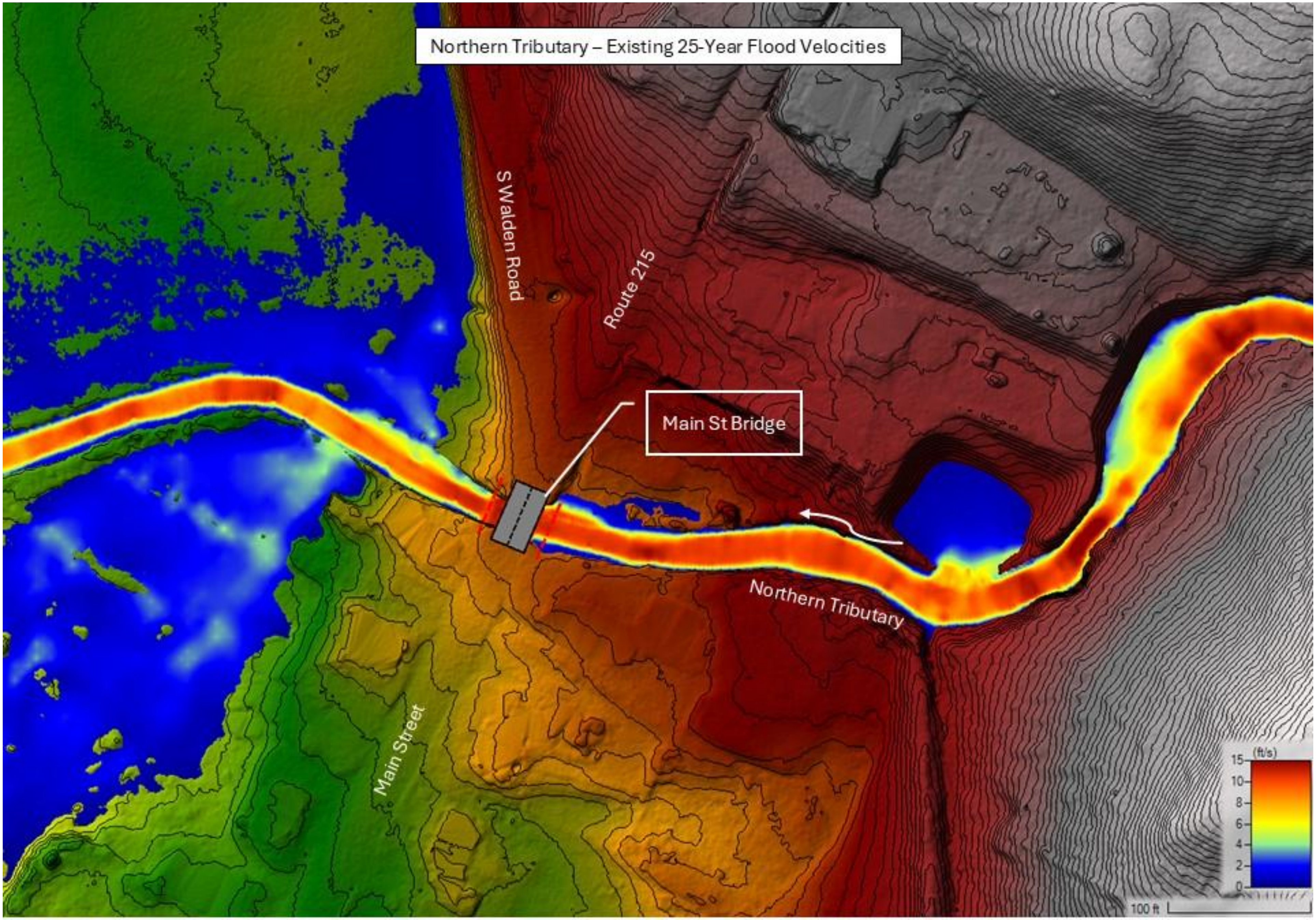
100 ft


Northern Tributary – Existing 25-Year Flood Velocities
S Walden Road
Route 215
Main St Bridge
Northern Tributary
Main Street
(ft/s)
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6
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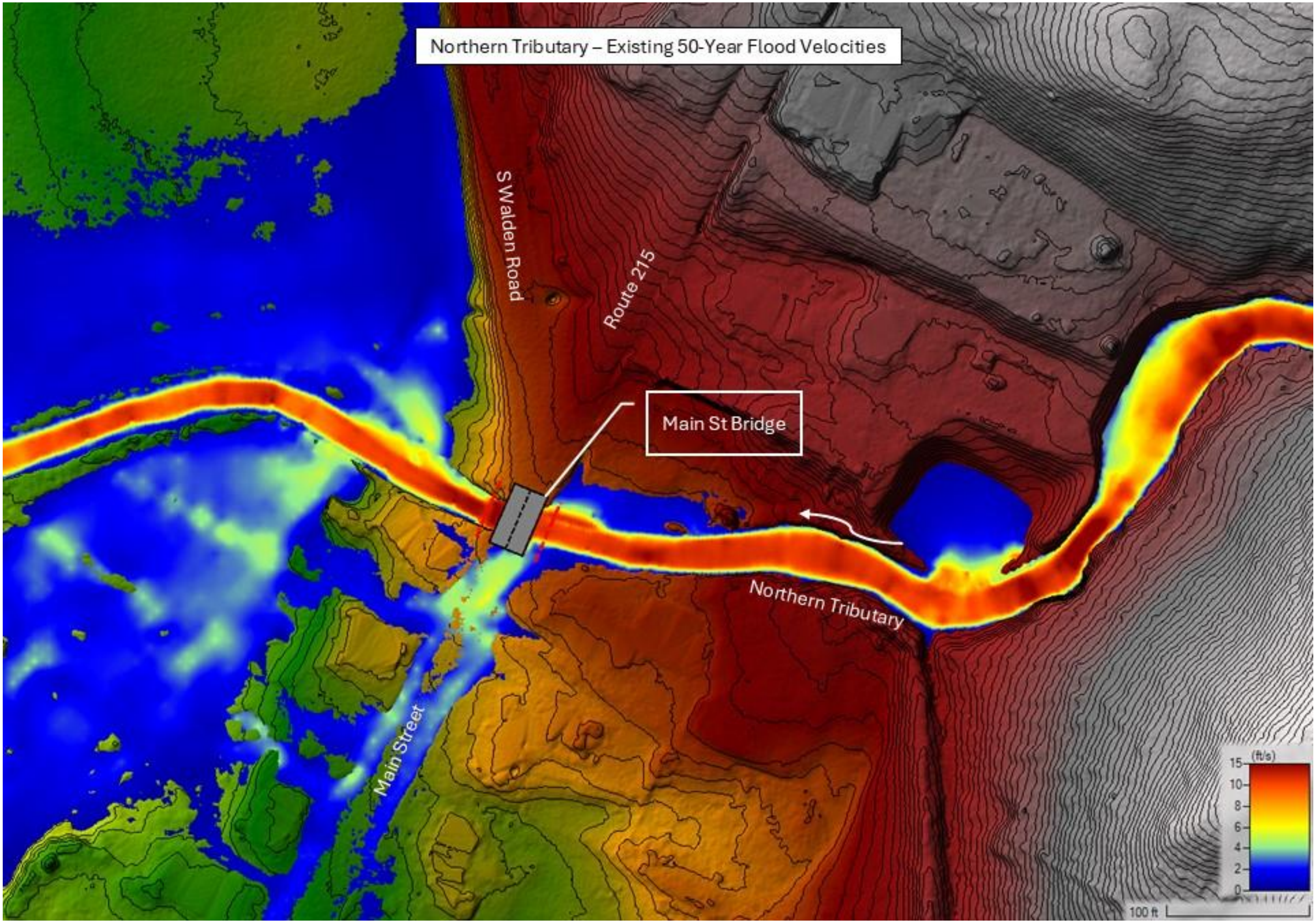
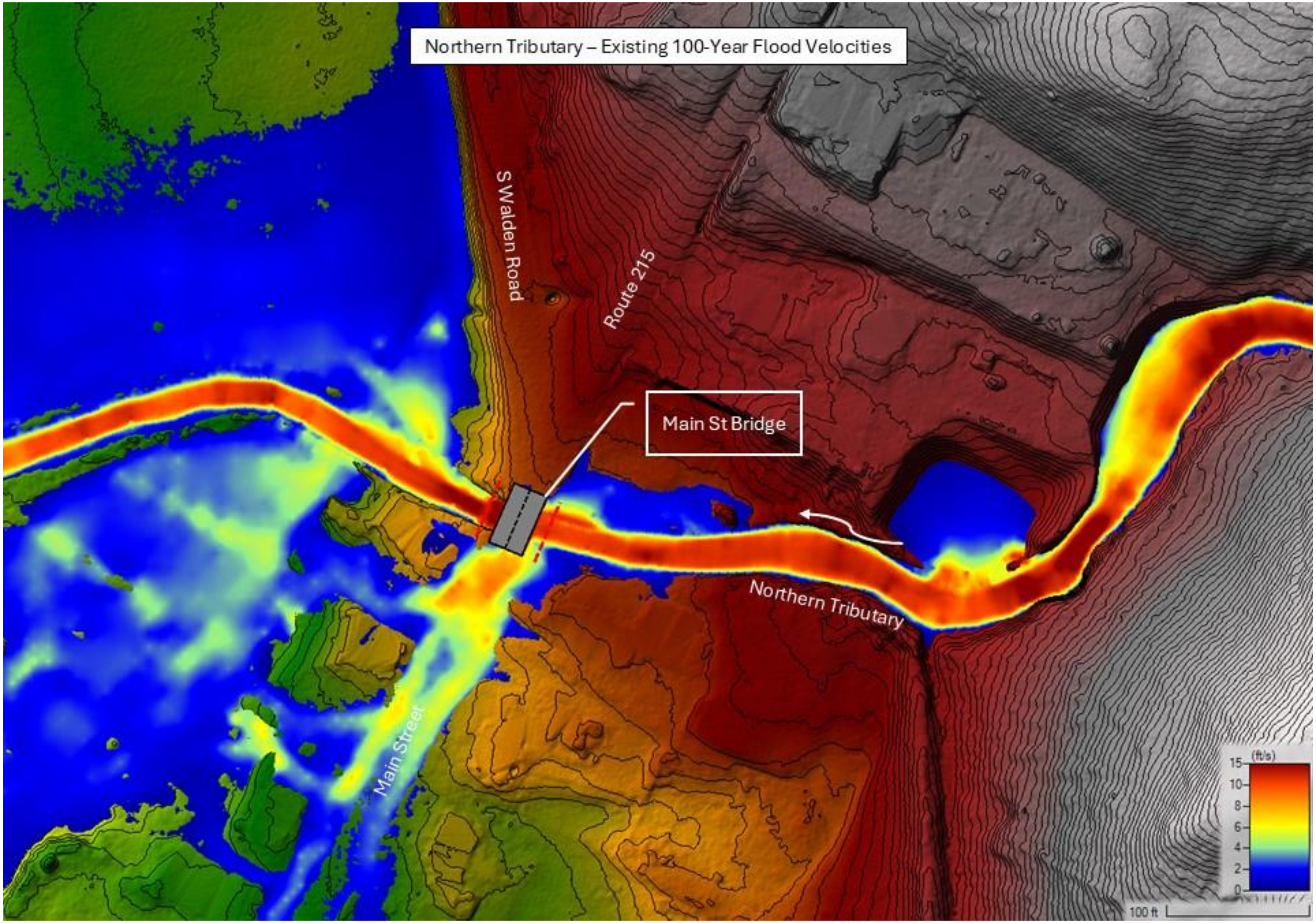
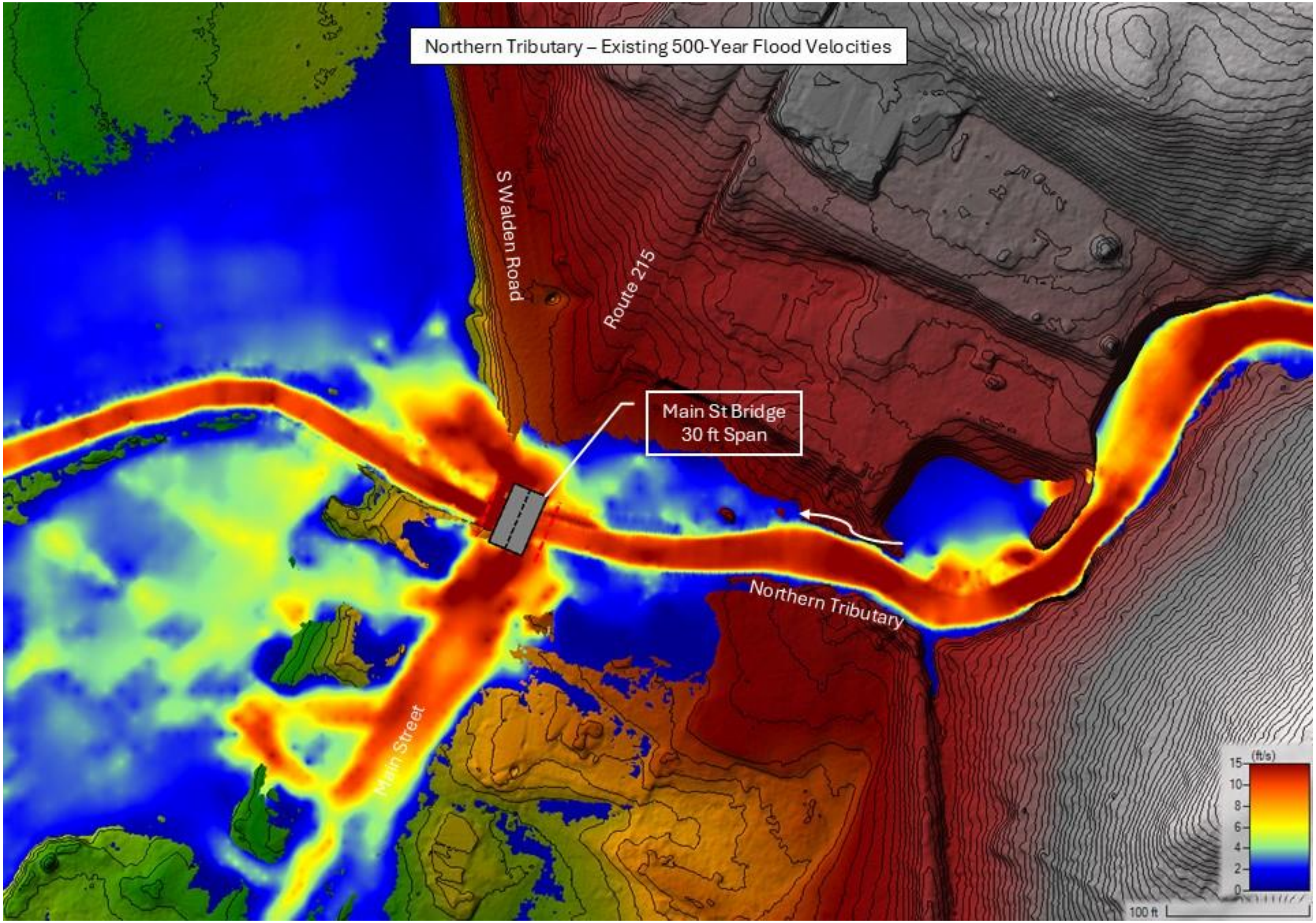
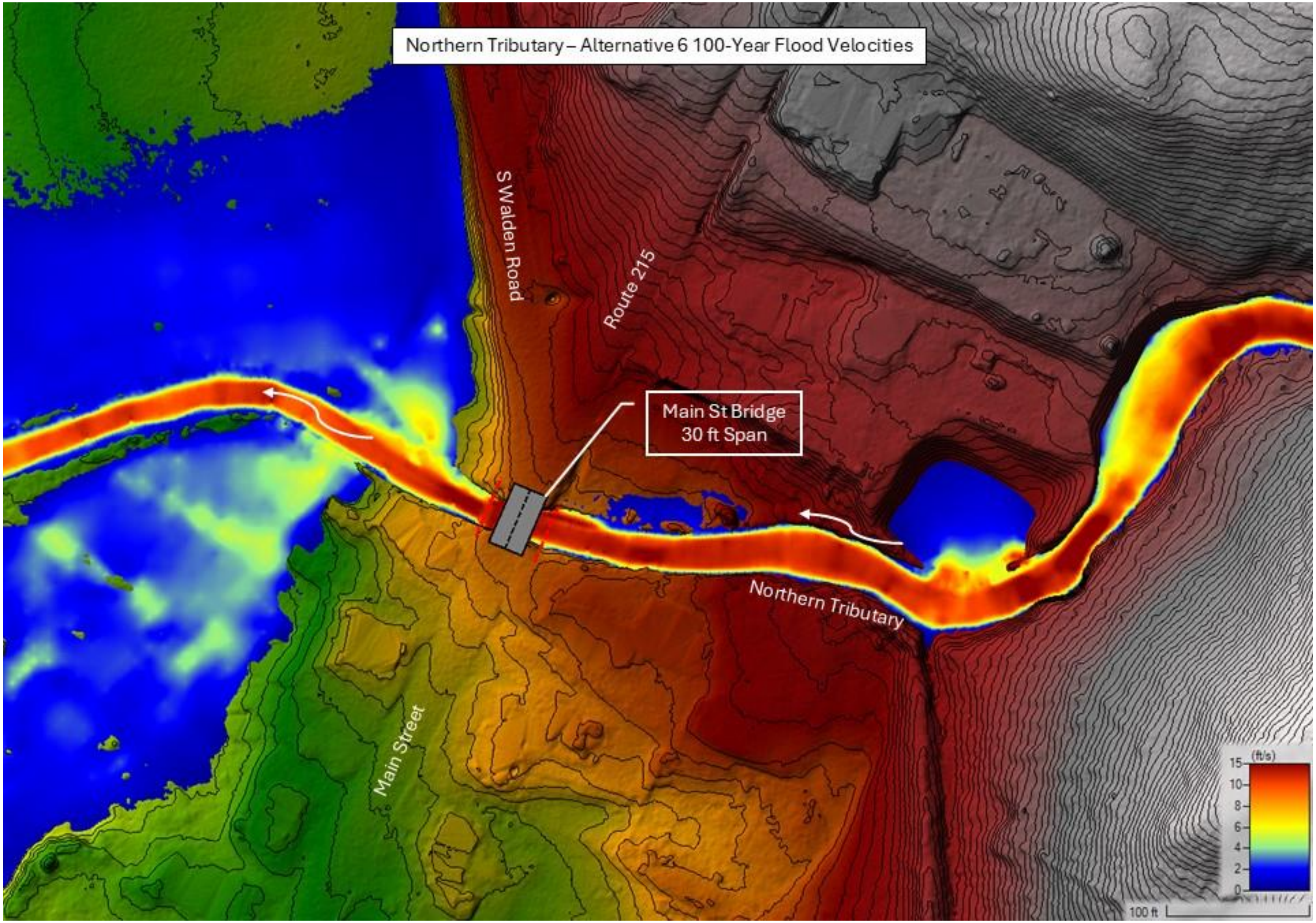
0
100 ft



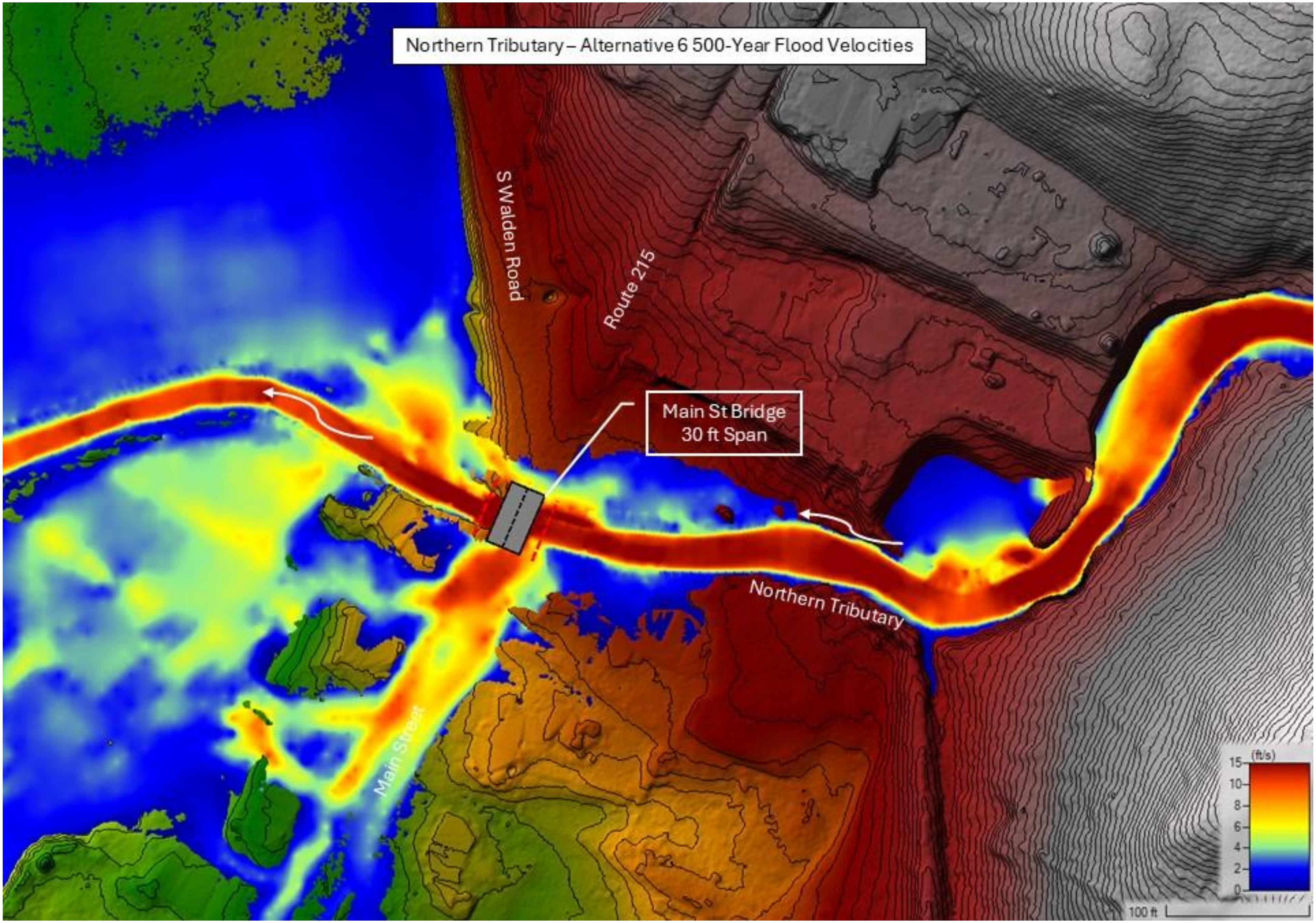
Northern Tributary – Existing 50-Year Flood Velocities

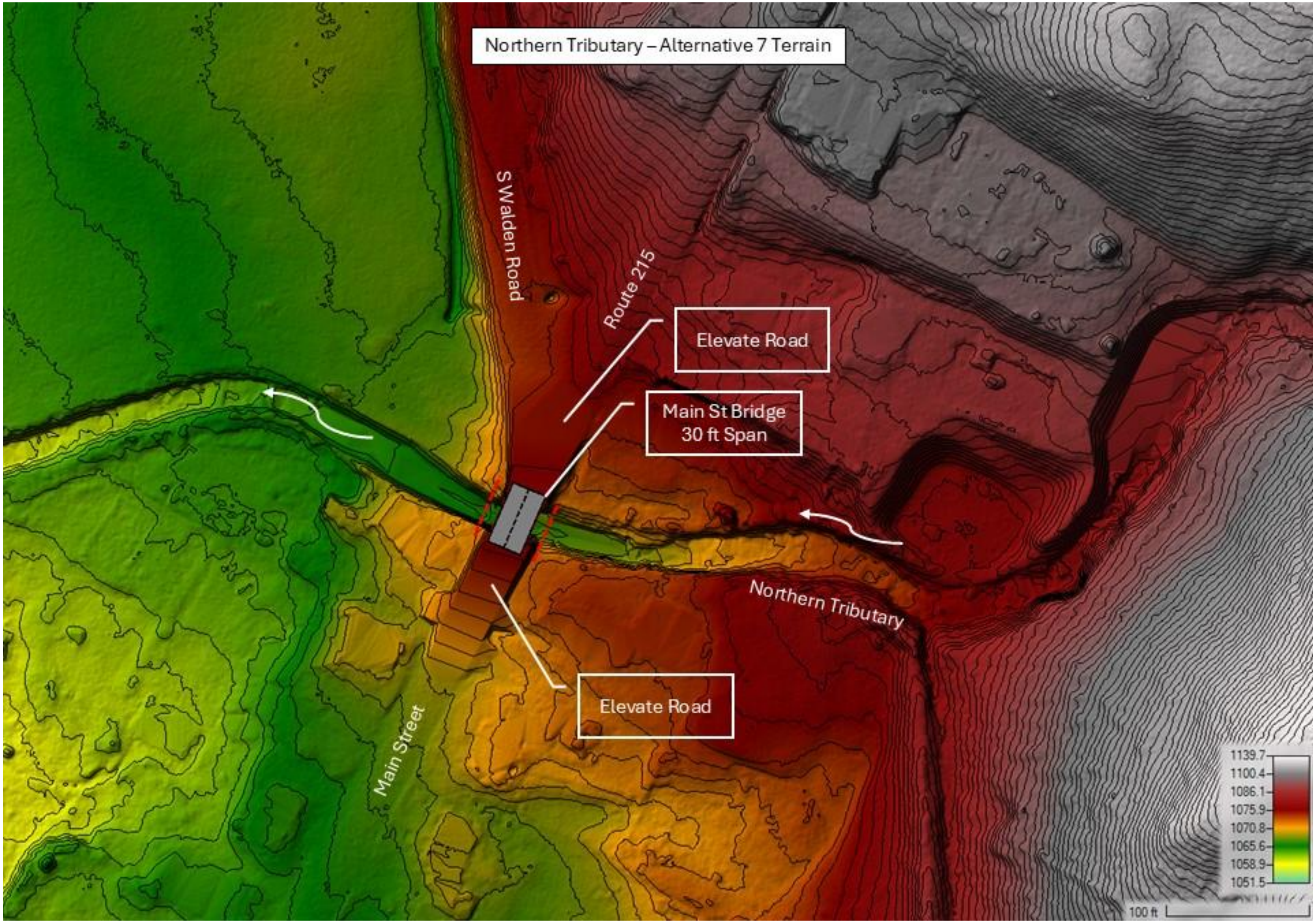

Northern Tributary – Existing 100-Year Flood Velocities
S Walden Road
Route 215
Main St Bridge
Northern Tributary
Main Street
(ft/s)
15
10
8
6
4
2
0
100 ft

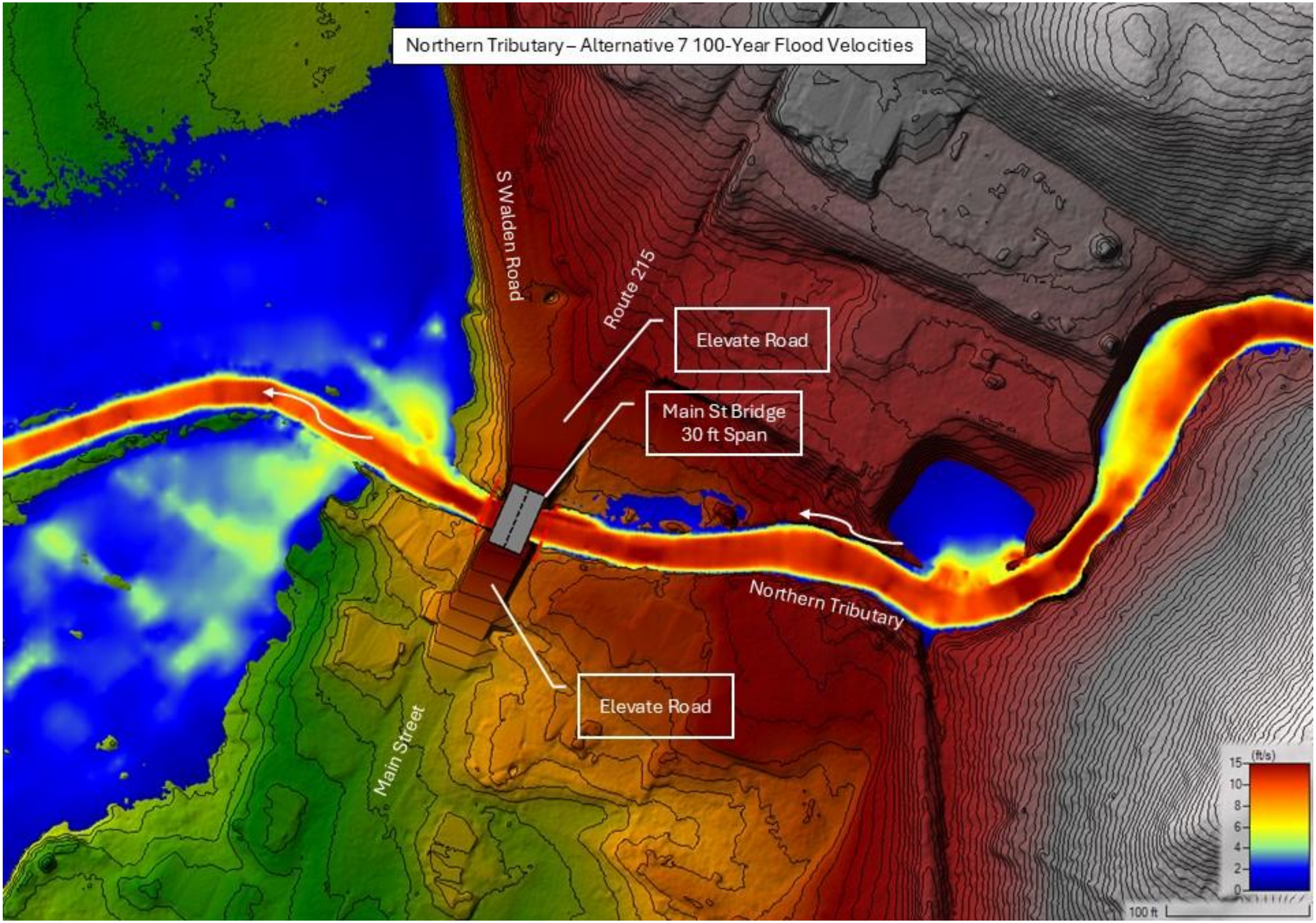

Northern Tributary – Existing 500-Year Flood Velocities
S Walden Road
Route 215
Main St Bridge
30 ft Span
Northern Tributary
Main Street
(ft/s)
15
10
8
6
4
2
0
100 ft

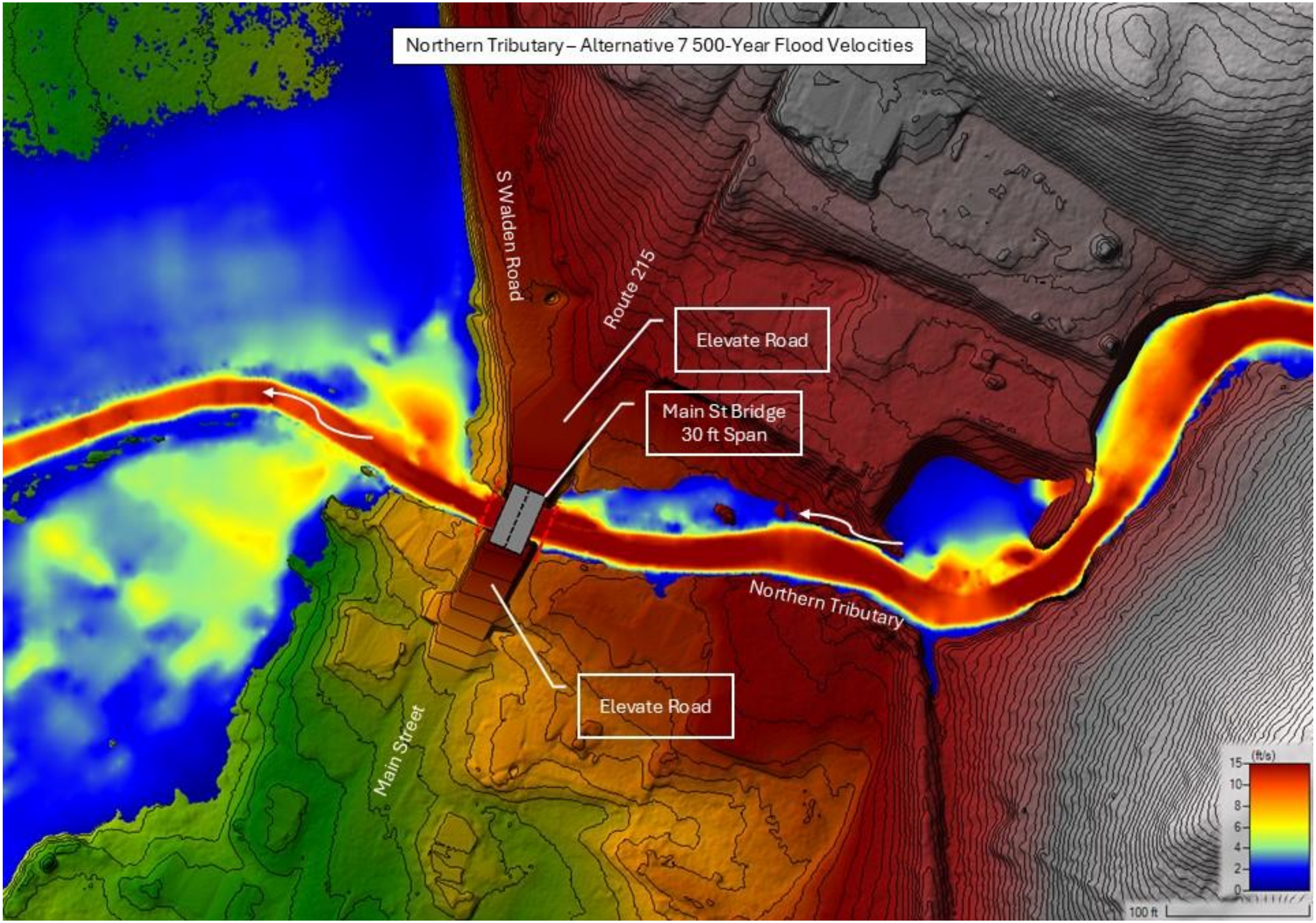


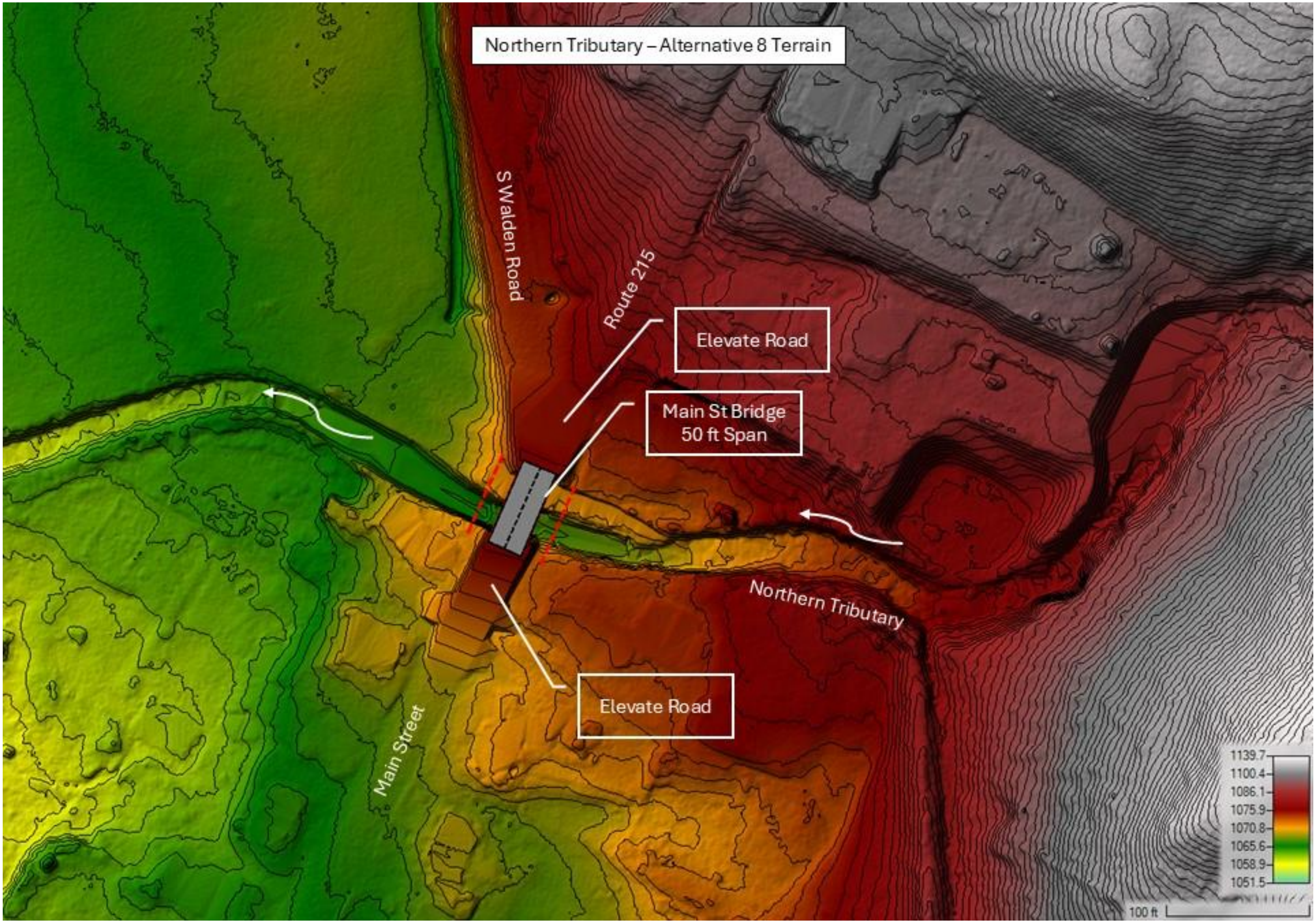
Northern Tributary – Alternative 6 100-Year Flood Velocities


Northern Tributary – Alternative 6 500-Year Flood Velocities
S Walden Road
Route 215
Main St Bridge
30 ft Span
Northern Tributary
Main Street
(ft/s)
15
10
8
6
4
2
0
100 ft

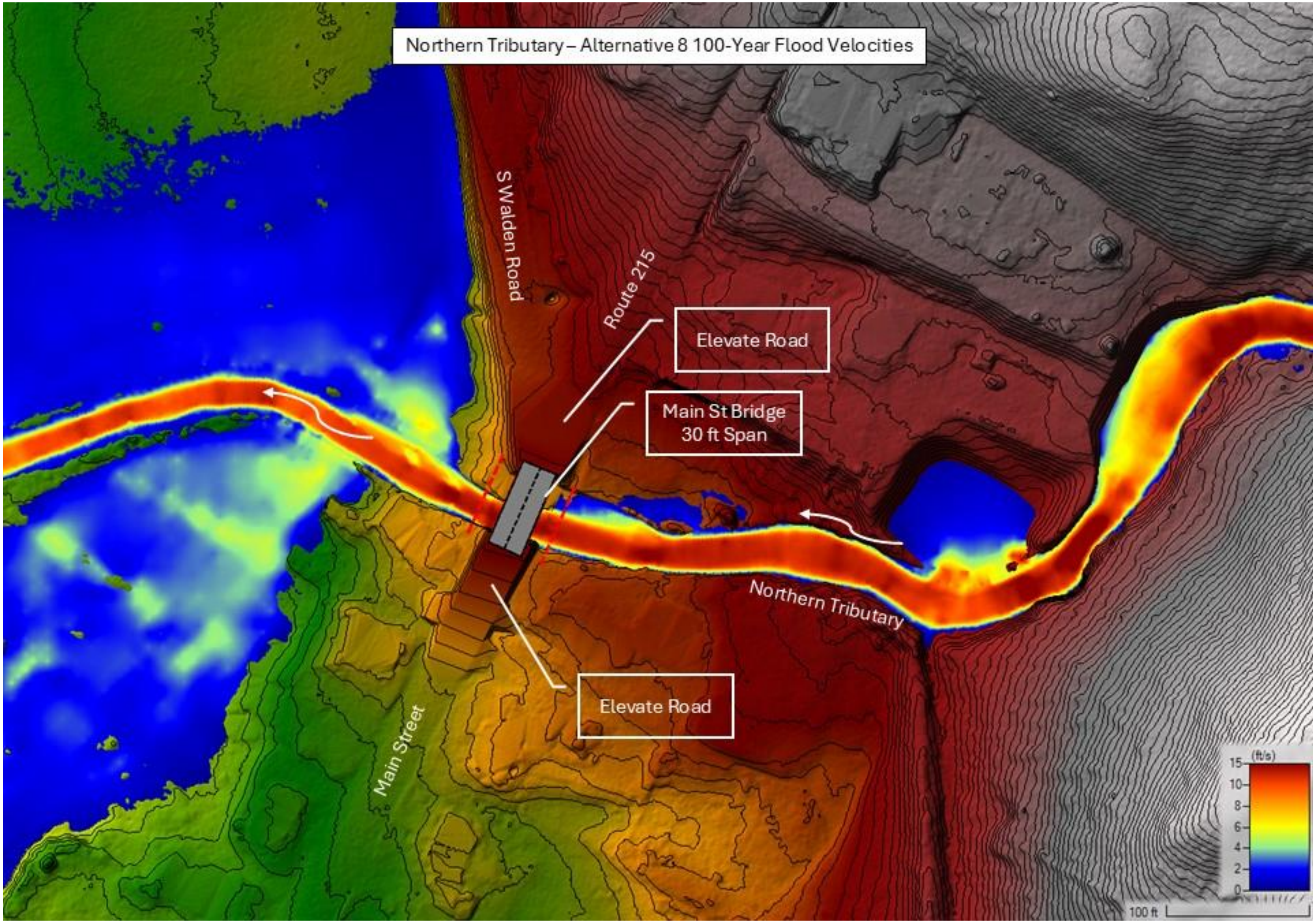

Northern Tributary – Alternative 7 Terrain
S Walden Road
Route 215
Elevate Road
Main St Bridge
30 ft Span
Northern Tributary
Elevate Road
Main Street
1139.7
1100.4
1086.1
1075.9
1070.8
1065.6
1058.9
1051.5
100 ft

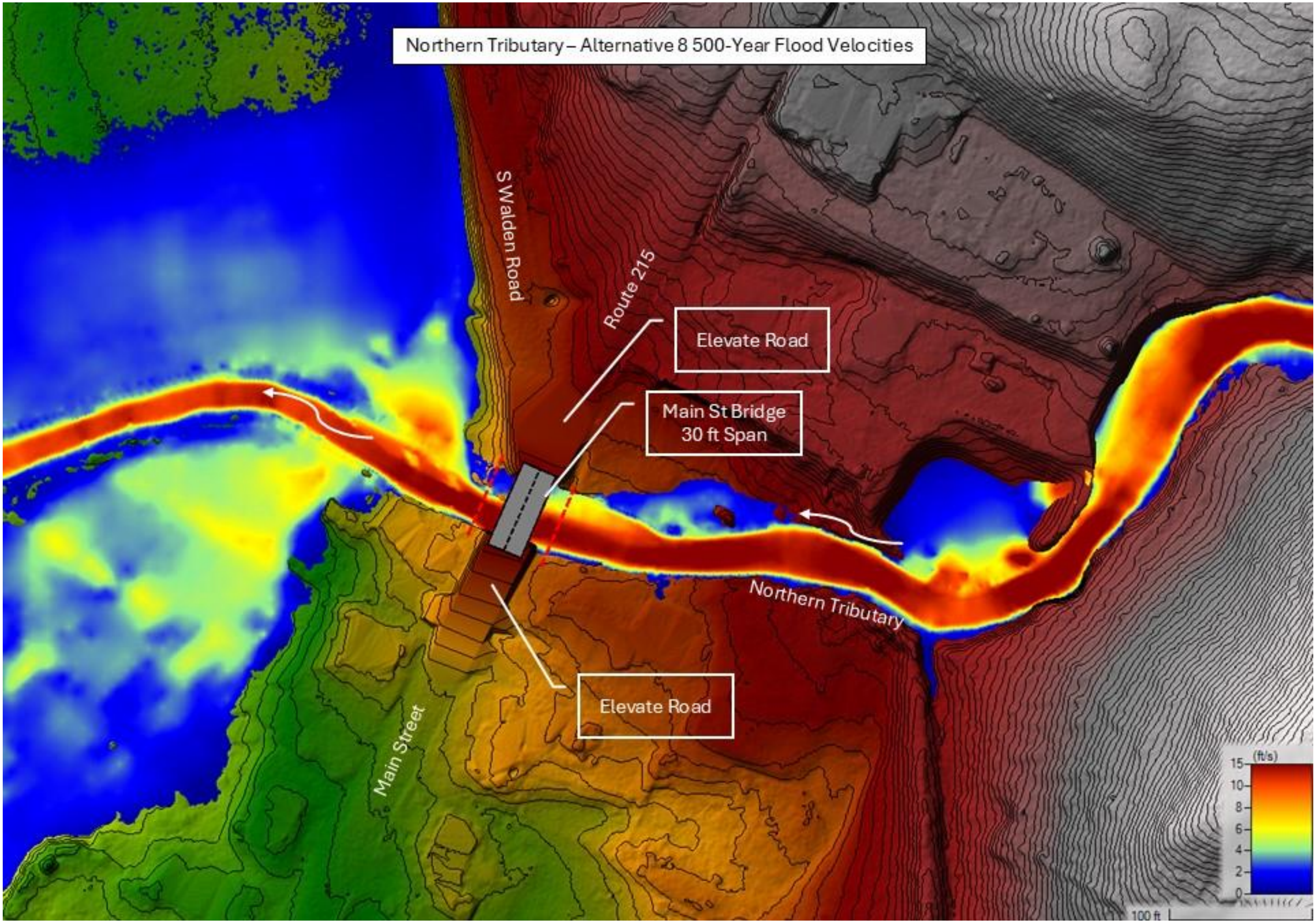

Northern Tributary – Alternative 7 100-Year Flood Velocities
S Walden Road
Route 215
Elevate Road
Main St Bridge
30 ft Span
Northern Tributary
Elevate Road
Main Street
(ft/s)
15
10
8
6
4
2
0
100 ft


Northern Tributary – Alternative 7 500-Year Flood Velocities
S Walden Road
Route 215
Elevate Road
Main St Bridge
30 ft Span
Elevate Road
Northern Tributary
Main Street
(ft/s)
15
10
8
6
4
2
0
100 ft

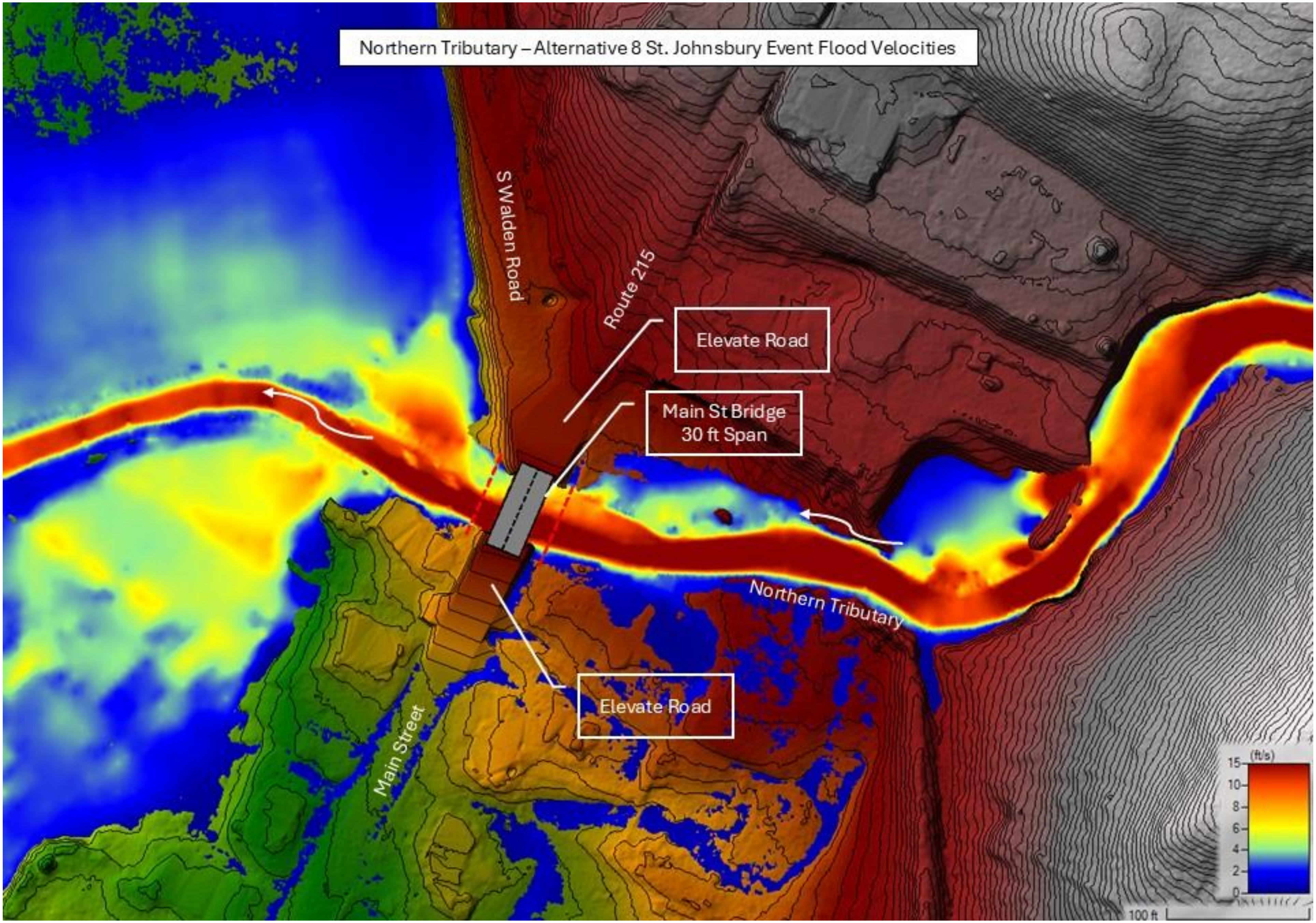


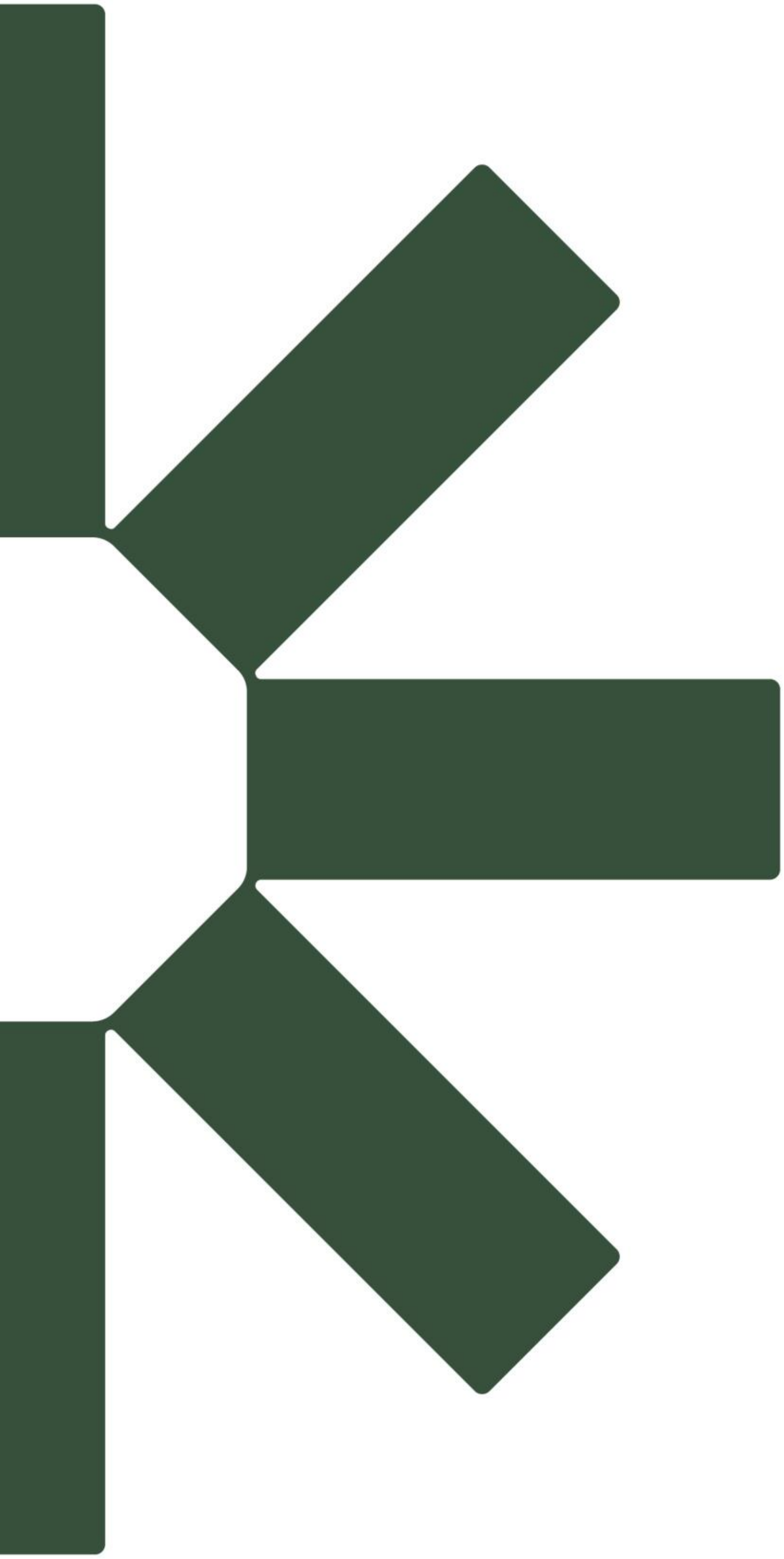
Northern Tributary – Alternative 8 Terrain


Northern Tributary – Alternative 8 100-Year Flood Velocities
S Walden Road
Route 215
Elevate Road
Main St Bridge
30 ft Span
Northern Tributary
Elevate Road
Main Street
(ft/s)
15
10
8
6
4
2
0
100 ft



Northern Tributary – Alternative 8 500-Year Flood Velocities


Northern Tributary – Alternative 8 St. Johnsbury Event Flood Velocities
S Walden Road
Route 215
Elevate Road
Main St Bridge
30 ft Span
Northern Tributary
Elevate Road
Main Street
(ft/s)
15
10
8
6
4
2
0
100 ft



Making Sustainability Happen