White Creek Watershed Infrastructure Flood Vulnerability and Mitigation Assessment

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Final Report

Prepared by:

Fitzgerald Environmental Associates, LLC.
18 Severance Green, Suite 203
Colchester, VT 05446

in partnership with:

MSK Engineering and Design
150 Depot Street
Bennington, VT 05201

Prepared under contract to:

Adirondack/Glens Falls Transportation Council
11 South Street, Suite 203
Glens Falls, NY 12801

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Executive Summary

White Creek Geomorphology and Historical Human Impacts

- White Creek has a drainage area of approximately 23 square miles at the VT-NY border and 36 square miles in Salem Village. The agricultural and residential development patterns found in the watershed are characteristic of typical rural watersheds in this area of Vermont and New York. Agriculture and moderate density development are more prevalent in the New York portion; however more than 70% of the watershed is undeveloped and classified as forest or shrub.
- The White Creek corridor has been historically manipulated along most of its length from West Rupert into Salem. Channel and floodplain manipulation likely started as early as the 1700's as agriculture expanded within the valley, and over the years has included channel straightening, dredging, berming, and extensive floodplain encroachment from roads and railroads.
- Most of the river valley in Salem is occupied by alluvium parent material, or fine-grained soils that have been deposited by White Creek over thousands of years. The New York portion of White Creek is found in an unconfined valley with a low sloped valley and channel (i.e., typically less than 0.5%). Under reference conditions in this setting we would expect a gravel-bottom, pool-riffle channel with a moderate to high sinuosity. However due to historic channel manipulation the resulting planform of the creek is very different from its original state, with low sinuosity in most reaches and stream type departures observed in several reaches.

White Creek Hydrology and Hydraulics

- Estimating flood discharges for different recurrence intervals in the White Creek watershed in Vermont and New York is challenging for several reasons:
    - White Creek has never had a long term USGS gage to measure continuous discharge.
    - White Creek straddles two very different landscapes: steep, mountainous terrain in Vermont where orographic rainfall is common and annual precipitation may exceed 60 inches; lower elevation terrain in New York where annual precipitation totals are typically less than 35 inches.
    - The USGS hydrologic region where White Creek is found – Region 1 – spans a vast area of upstate New York. The average parameter values used to develop flow regressions across this large region may not be appropriate for the White Creek watershed. Region 2 estimates may be more appropriate for White Creek.
- Our review of the USGS regressions and gages in the region suggests that the flood flow estimates used by NYSDOT and Washington County for evaluating the hydraulic capacity of bridge openings likely underestimate the range of possible flows in the watershed. For example, the value used by the State and the County for the 100-year flow at the Village of Salem has been in the range of 3,500 to 3,700 cfs. Our analysis suggests that the range of flows for this event likely falls between 5,000 cfs and 6,000 cfs.
- The wide river valley though the Town of Salem and the associated roads, railroad, buildings, and bridges created a complex environment for hydraulic modeling. Extensive field verification

and survey was required to understand the flooding dynamics within the study area. Documentation of Tropical Storm Irene damage and flooding extents collected by the Salem Flood Study Committee was invaluable for calibrating the hydraulic model and improving the overall accuracy of the study.

- HEC-GeoRAS and HEC-RAS 4.1 software were used to create a one-dimensional river and floodplain hydraulics model for White Creek from the Route 153 bridge in Vermont downstream to the confluence with Blind Buck Brook. LiDAR was used to determine elevations for most cross-sections in the model, however all bridge openings (and upstream/downstream sections) were field surveyed. Channel bottom elevations were checked and adjusted throughout the study area to account for LiDAR error in channel depth.

Infrastructure Vulnerability and Flood Mitigation Alternatives

- Our hydraulic analysis included an evaluation of bridge flood capacity for all 17 public and private bridges on White Creek. 10 of the 17 bridges have limited capacity to pass only the 10-year flood or less, indicating that most bridges on White Creek are hydraulically undersized by county and state standards. These assessments assume “clear flow” hydraulics, i.e., they do not account for sediment and debris accumulation upstream or within the bridge opening during flood events. Therefore the capacity at bridges prone to sediment aggradation and debris clogging is likely lower during moderate and large flood events.
- Our hydraulic analysis of the White Creek corridor indicated that there are greater opportunities to mitigate flooding depths and extents during moderate floods, as the flooding is not nearly as extensive in comparison to large floods (i.e., 2011 Irene flood). The moderate floods, those which have a 10-20% chance of occurring on any given year, occur on a frequency that regularly affects residents’ lives and property in the valley.
- We evaluated 8 project alternatives upstream of Salem Village. We began by focusing on flood resiliency for transportation infrastructure; we explored opportunities for larger bridge openings, roadway embankment stabilization compatible with river stability. Another focus was on flood flow attenuation opportunities for moderate floods including berm removals to reconnect severed floodplains, improvement of drainage beneath the rail bed to reconnect adjacent floodplains, and riparian buffer restoration.
- We evaluated over 10 project alternatives in Salem Village, and summarized the benefits and costs for 7 alternatives in greater detail. These alternatives included removal of berms, removal of the Archibald Street bridge, channel widening and deepening, and floodplain restoration with home buyouts.

Next Steps

- Upstream and Village projects were prioritized for “near term” and “long term” benefits to reducing flood vulnerability in Salem, providing a “roadmap” for the community to follow. We recommend the following steps for the community to advance these projects over time:

  - Solicit input from individuals, businesses, and officials from the Towns of Salem and Rupert at future community meetings regarding specific projects and overall project prioritization.
  - Prioritize one to two projects to pursue each year with assistance from WCDPW, A/GFTC, and other participating groups to identify appropriate funding sources and partners.
  - Apply for one to two grants each year to advance project development and/or designs.
  - Implement projects as funding allows, and monitor project success.
- To further identify and evaluate upstream floodplain restoration and reconnection opportunities, we recommend a field-based geomorphic study and river corridor plan for the White Creek reaches in Salem to complement similar work in the Vermont portion of the watershed.
- River science needs to be better incorporated into future public infrastructure projects in the watershed to ensure proper sizing and scour protection measures for bridges and roadway stabilization measures.
- There is a need for better coordination amongst partners working in the watershed, including the towns, A/GFTC, WCDPW, USFWS, Trout Unlimited, and Battenkill Watershed Alliance. The need for this coordination is two-fold: 1. to ensure that habitat enhancement work (i.e., weirs) does not increase flood vulnerability for nearby homes, farmland, and infrastructure; 2. To ensure that public infrastructure and flood mitigation projects summarized in this report are conducted in a way to minimize impacts to aquatic habitat and downstream water quality.

1.0 Introduction

1.1 Project Background

The White Creek flows out of steep terrain in the Taconic Mountains of Vermont and descends into a broad valley in New York with a long history of agricultural land use (see Figure 1.1). During large floods, the surge of floodwaters and sediment carried by White Creek poses a hazard to infrastructure and public safety along the river corridor from Rupert to Salem. In the headwaters area of Rupert, severe erosion along roads and at critical bridge crossings has led to costly repair work in recent floods such as Tropical Storm Irene in 2011. As White Creek enters the Town of Salem, inundation hazards are prevalent, particularly in areas where out of bank flow occurs and is diverted around and along the rail bed. In between the state line and the Village of Salem, White Creek flows approximately 8 river miles along farm fields and adjacent to Route 153 and the historic rail bed. Along this stretch, the potential for floodplains bordering White Creek to attenuate or diminish the flood surge downstream is compromised due to historical manipulation of the channel (i.e., berming along farm fields, channel dredging, confinement along Route 153 and the rail bed). If these floodplain areas are enhanced and allowed to function at their full potential, they may be critical in lowering flood risks to transportation infrastructure on the New York side of the watershed as well as other public and private infrastructure in downstream Salem Village.

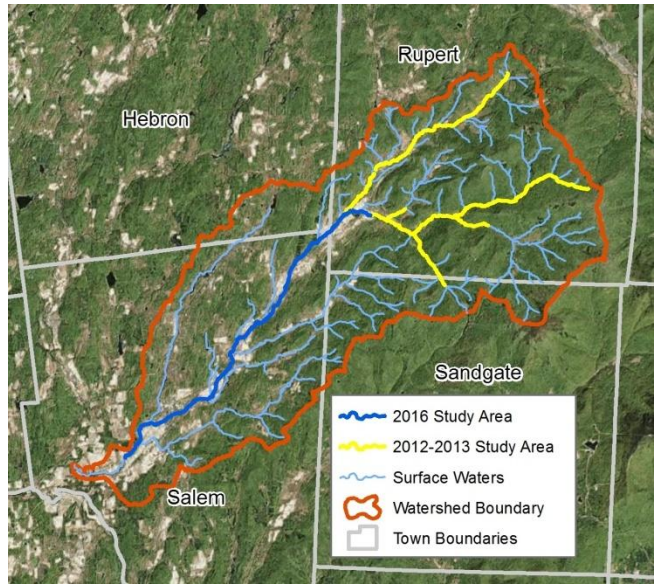

Figure 1.1: White Creek watershed boundary and the extents of the 2012-2013 White Creek/Mill Brook SGA study area and the 2016 White Creek Study.

The Adirondack/Glens Falls Transportation Council (A/GFTC) hired Fitzgerald Environmental Associates (FEA) and project partner MSK Engineering and Design (MSK) to complete a hydrologic and hydraulic study of the White Creek watershed in Rupert, Vermont and Salem, New York for the purpose of evaluating infrastructure flood vulnerability and potential mitigation opportunities. The findings from this study present a “road map” for future flood mitigation efforts including the prioritization of projects based on their benefits and costs, and recommendations for next steps.

1.2 Project Objectives

Flood vulnerability and mitigation studies are most successful when conducted at the watershed scale beginning with characterization of watershed hydrology and continuing through the evaluation of reach geomorphology and local channel and floodplain hydraulics. The scope of this project covered the hydrology, geomorphology, and hydraulics of the White Creek corridor as a basis for flood resiliency planning. The primary project objectives included:

- Characterize the White Creek corridor in Salem to understand the channel's natural geomorphic tendencies and historical context;
- Complete a defensible hydrologic and hydraulic study of the watershed to understand the flood magnitudes and dynamics of the White Creek corridor;
- Assess flood vulnerability of transportation infrastructure and public and private property in the Town of Salem;
- Identify and evaluate flood resiliency strategies and projects upstream of the Village of Salem;
- Identify and evaluate flood resiliency strategies and projects in the Village of Salem;
- Develop a "roadmap" for future flood mitigation efforts in the Town of Salem by weighing each project's benefits and costs.

2.0 White Creek Watershed Background

White Creek originates from steep forested headwaters within the Towns of Rupert and Sandgate in the southwestern corner of Vermont. The mainstem of White Creek converges with Mill Brook near the Vermont/New York state line. The channel then descends through a wide valley shared with Route 153 and the abandoned railroad bed until reaching the Village of Salem. White Creek is a prominent feature within the Village with several streets and numerous houses located adjacent to the stream banks. Downstream of the Village the channel continues to flow through a wide valley primarily occupied with corn and hay fields until it reaches the confluence with Black Creek, approximately 3 miles downstream.

2.1 Current and Historical Land Use

Land cover data based on imagery from 2011 (Homer et al., 2015) are summarized in Table 2.1. The agricultural and residential development patterns found in the watershed are characteristic of typical rural watersheds in this area of Vermont and New York. Agriculture and moderate density development are more prevalent in the New York portion; however more than 70% of the watershed is undeveloped and classified as forest or shrub.

Table 2.1: Land cover characteristics of White Creek watershed (values expressed as a percent).

Land Cover	VT Watershed (22.5 mi^2)	NY Watershed (26.1 mi^2)	Entire Watershed (48.6 mi^2)
Developed	1.8	4.9	3.4
Forest	83.6	57.3	69.7
Shrub	0.6	3.9	2.4
Grassland	0.2	0.4	0.3
Pasture	12.0	21.8	17.1
Cultivated Crops	1.1	10.3	6.0
Wetland	0.7	1.3	1.1
Water	0	0.1	0.1

Historic channel manipulation is a prominent feature along White Creek, especially through the wide agricultural valleys along the New York portion of the watershed. Channel manipulation likely started as early as the 1700's as agriculture expanded within the valley. Large scale channel

straightening in rural watersheds is typically associated with road and railroad construction, as well as agricultural land uses. Analysis of historic imagery and mapping (Scott and Smith, 1853; UNH, 2012) indicates areas where White Creek was completely relocated during the construction of the railroad (Figure 2.1). Residential and agricultural land use along the river banks and floodplains further restricts channel migration and floodplain accessibility. Decades of channel manipulation cause the stream to lock in to an erosional process referred to incision or degradation. As channel migration is limited by straightening and armoring, the channel begins to cut downward (incision) which further reduces floodplain access. Berms were constructed in many areas along White Creek in response to flooding events. While these berms protect agricultural fields and buildings on the floodplains, they reduce floodwater storage potential and increase the volume and rate of floodwaters conveyed downstream toward the Village of Salem.

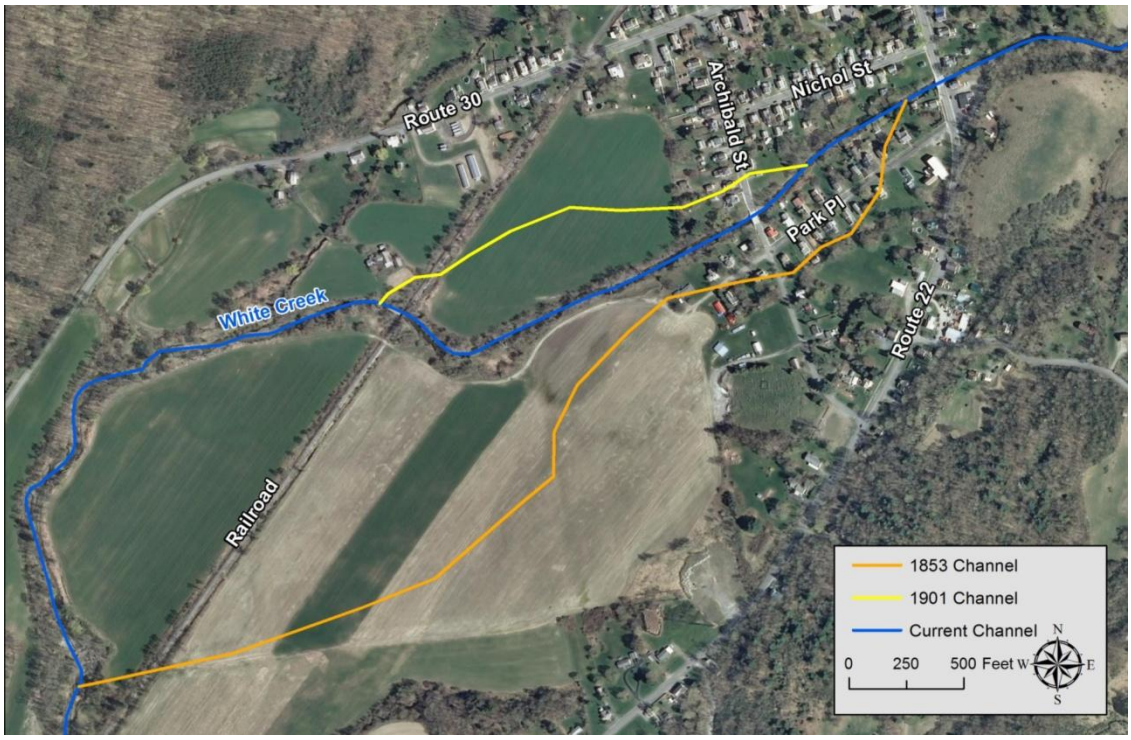

Figure 2.1: Historic channel locations indicate major channel manipulation during railroad construction and development within the Village of Salem.

2.2 Watershed Gradients

Channel slopes within the watershed follow the typical pattern of steep headwater reaches gradually transitioning to moderate slopes as tributaries converge and the channel increases in size (Figure 2.2). Channel slopes continue to decrease as the streams enter wide river valleys. As the stream reaches the state line the channel slope drops below 1% and enters a very wide and unconfined river valley. Channel slopes through the Village and extending down to the confluence with Black Brook are typically under 0.5%. The transition from high/moderate slope in Vermont to low slope in New York also signifies a shift in the types of expected flooding damage from erosion and inundation in Vermont to predominantly inundation in New York.

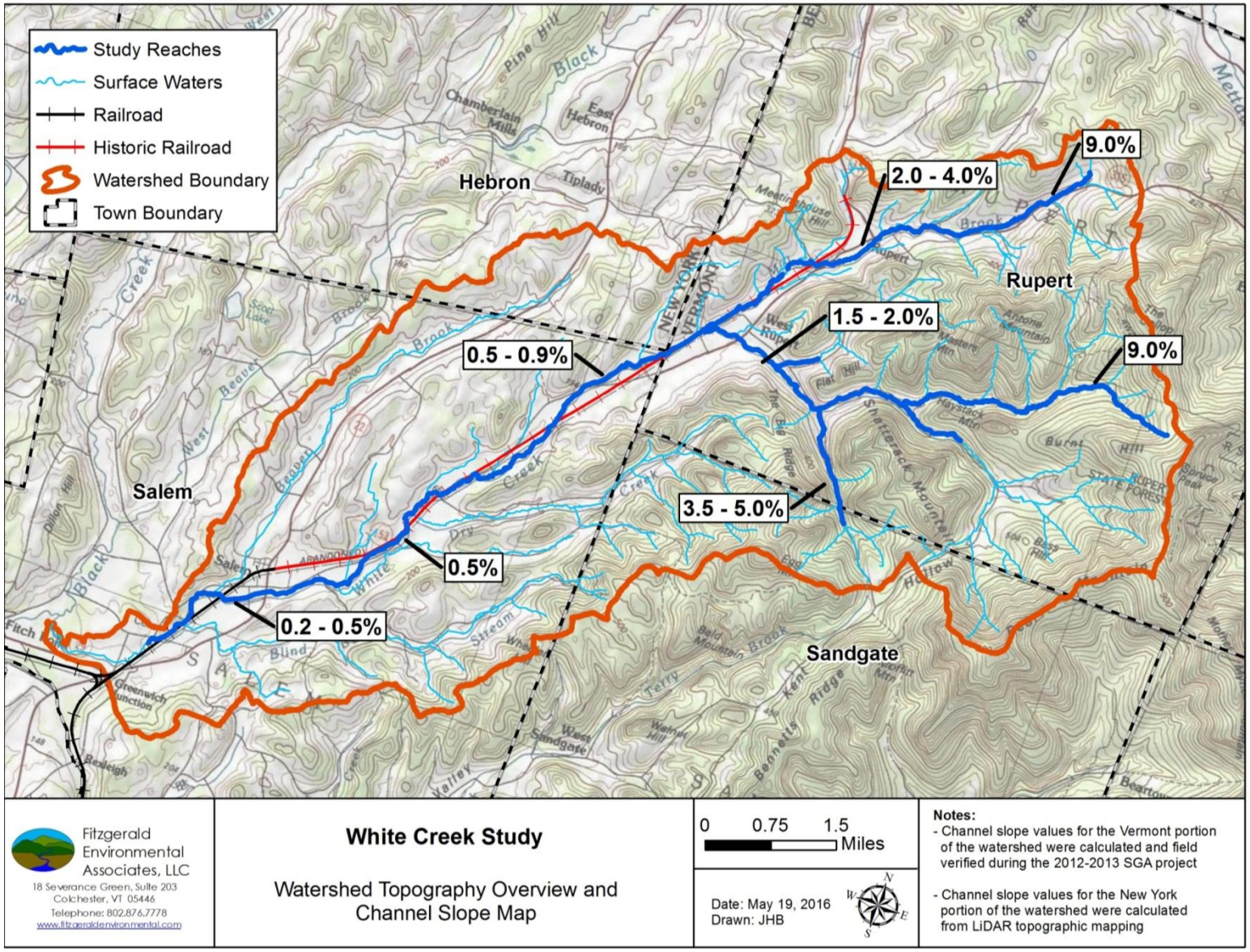

Figure 2.2: White Creek watershed and channel slope map.

3.0 Geomorphic Assessment

A preliminary geomorphic assessment of the White Creek corridor was conducted to tie into the existing geomorphic database and River Corridor Plan completed by FEA in Rupert in 2013 (FEA, 2013). The existing database of geomorphic conditions ends in Rupert at Hebron Road, approximately ½ mile east of the state line. Our assessments began downstream (west) of Salem Village at the confluence of White Creek and Blind Buck Stream, and continued upstream to West Rupert (see Figure 3.2). In order to work within the project time frame through the winter and spring months, we followed an abbreviated version of the Vermont Department of Environmental Conservation's Stream Geomorphic Assessment (SGA) Phase 1 Protocols (VTDEC, 2009), as described below.

3.1 Geomorphic Assessment Approach

- The Salem portion of White Creek was delineated into 8 reaches (along approximately 8 river miles) following VTDEC's SGA Phase 1 protocol for reach delineation.
- Step 2 of VTDEC's SGA protocol was populated, including valley and channel slope, watershed drainage area, sinuosity, reference channel geometry per Mulvihill et al. (2007), reference stream type (Rosgen, 1994), and reference bedform (Montgomery and Buffington, 1997). Valley width and confinement were generated using a percent slope map, generated from the LiDAR elevation data, to identify valley walls and measure valley width (Figure 3.1). The Step 2 data is summarized in Tables 3.1 and 3.2.

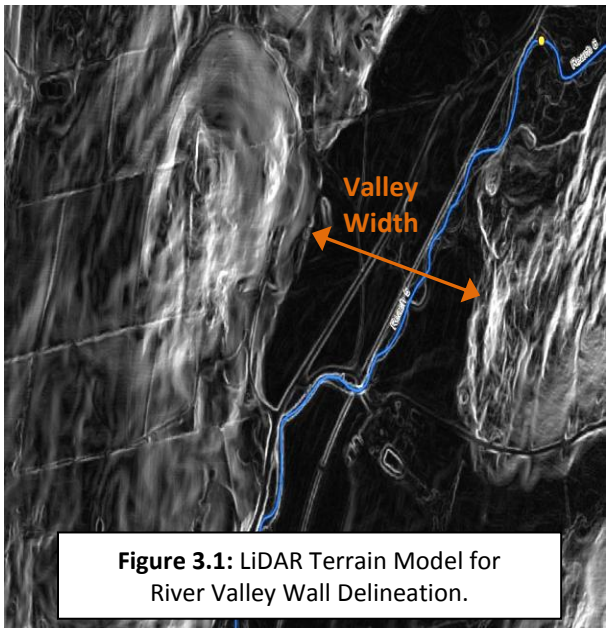

Figure 3.1: LiDAR Terrain Model for River Valley Wall Delineation.

- The study area was scanned remotely using high-resolution aerial photography and LiDAR data to locate areas with excessive sedimentation or lateral movement post-Irene flood, i.e., significant channel features such as bank erosion, large gravel deposits, debris jams, etc.
- Cross-sections cut from the HEC-RAS model at regular intervals were used to characterize reference and existing stream type, channel evolution stage, channel geometry and channel/floodplain connectivity, and estimate entrenchment and incision ratios. This data is summarized in Table 3.2.
- A windshield survey was conducted to verify data generated remotely. This included observations at access points along the Creek, such as bridge crossings and the railroad bed adjacent the channel.

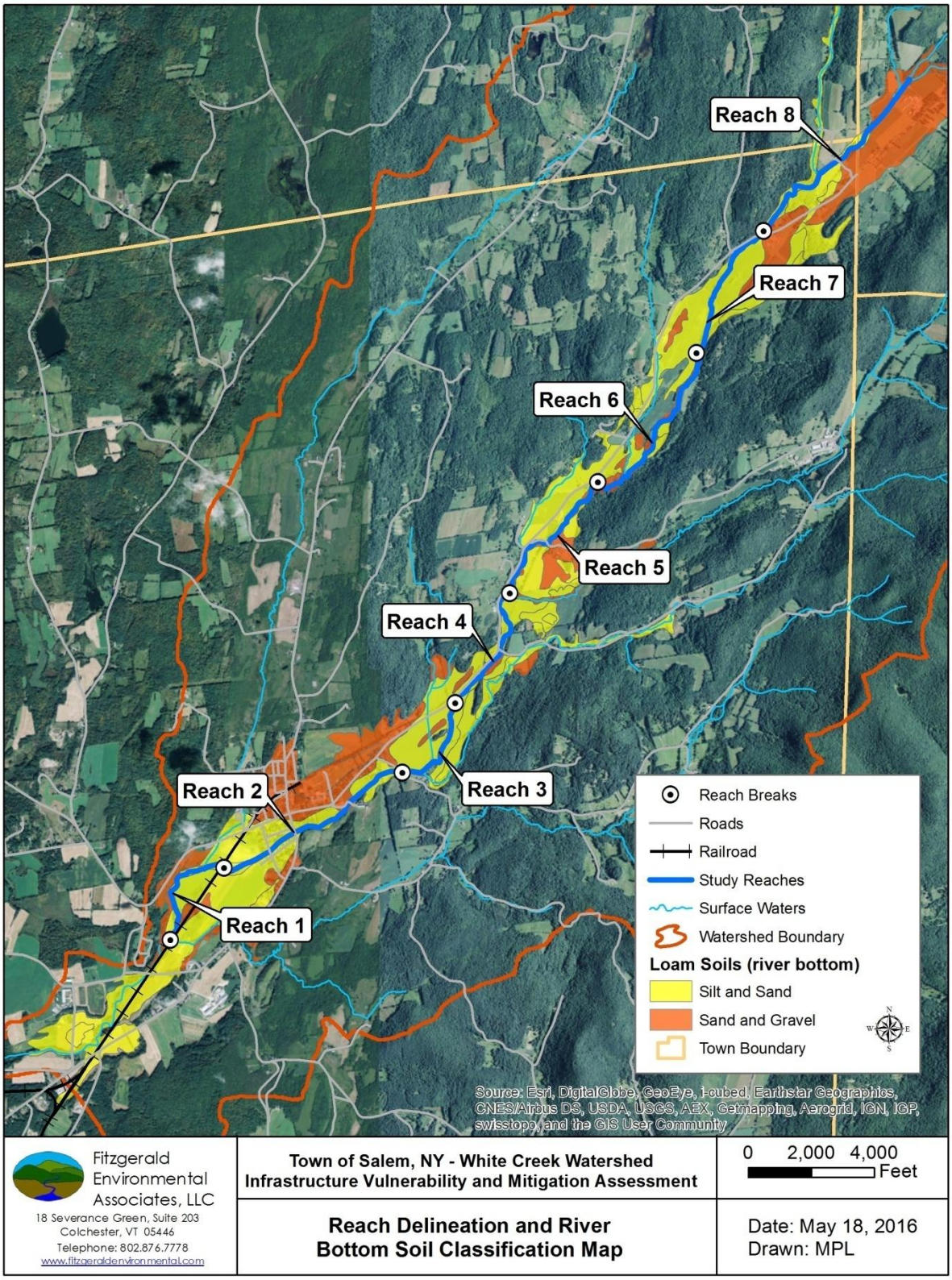

Figure 3.2: Geomorphic reach delineations along White Creek in Salem.

The information collected in this assessment assisted with assigning a channel evolution model (CEM) stage for each reach (Schumm, 1977). Channel evolution models provide a basis for understanding the temporal scale of channel adjustments and departure in the context of SGA results. Both the "D" stage and "F" stage CEMs (VTDEC, 2009) are helpful for explaining the channel adjustment processes underway in the White Creek watershed. The "F" stage CEM is used to understand the process that occurs when a stream degrades (incises) its bed. The more dominant adjustment process for the "D" stage channel evolution is aggradation, widening and planform change. D-stage CEM typically occurs where grade controls prevent severe channel incision and abandonment of the adjacent floodplain. The common stages of both CEMs are depicted in Figure 3.3 below.

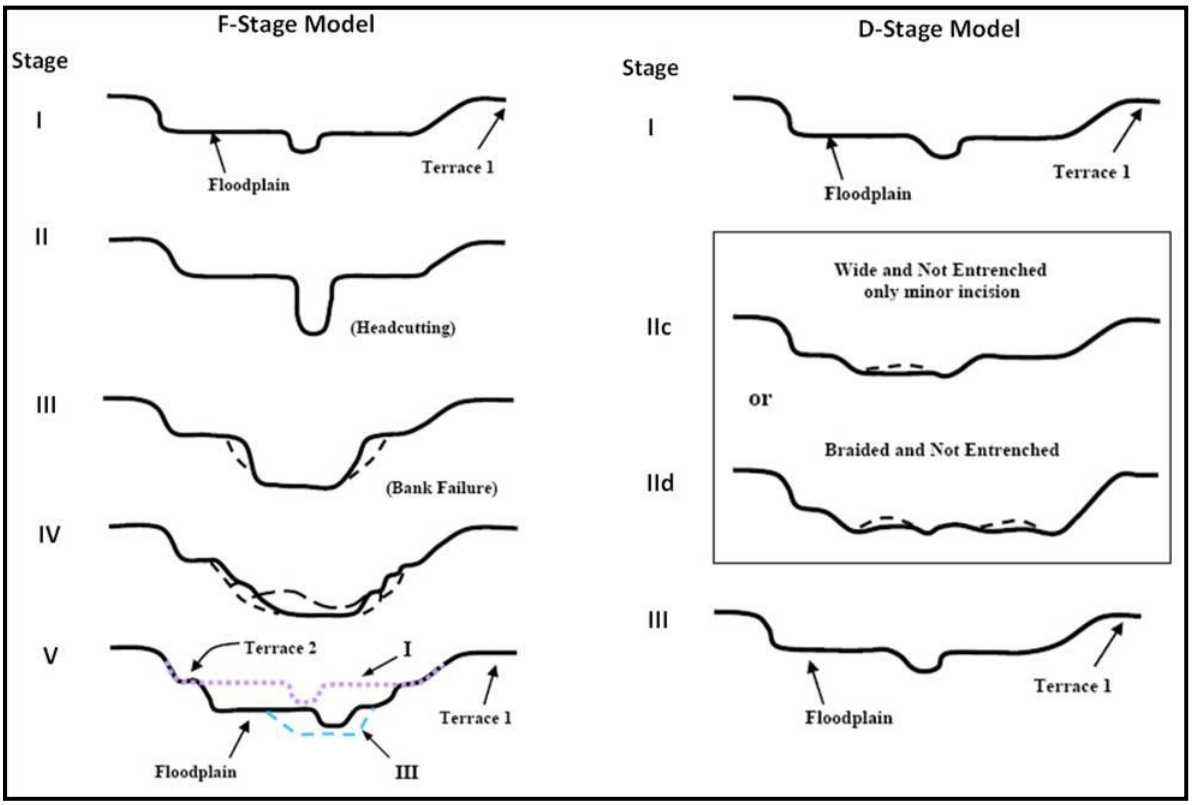

Figure 3.3: Typical channel evolution models for F-stage and D-stage (VTDEC, 2009).

3.2 Geomorphic Assessment Results

Table 3.1: Summary of reach geomorphic characteristics for the White Creek corridor in Salem, NY.

Reach	Elevation		River Valley		River Channel		Sinuosity	Drainage Area (mi^2)	HGR Channel Width*		Valley Width (ft)	Confinement	
	Up (ft)	Down (ft)	Length (ft)	Slope (%)	Length (ft)	Slope (%)			VT (ft)	NY (ft)		Ratio (NY)	Type
Reach 1	466	455	3,712	0.30	3,908	0.28	1.05	42.4	68.1	83.5	2,050	24.6	Very Broad
Reach 2	490	466	6,656	0.36	6,805	0.35	1.02	35.8	63.2	78.5	2,250	28.7	Very Broad
Reach 3	505	490	2,880	0.52	3,350	0.45	1.16	35.4	63.0	78.2	1,900	24.3	Very Broad
Reach 4	527	505	4,170	0.53	4,545	0.48	1.09	32.8	60.8	76.0	1,050	13.8	Very Broad
Reach 5	552	527	4,380	0.57	5,094	0.49	1.16	28.2	56.9	72.0	1,650	22.9	Very Broad
Reach 6	588	552	5,030	0.72	6,159	0.58	1.22	27.0	55.9	70.9	1,250	17.6	Very Broad
Reach 7	626	588	4,559	0.83	4,668	0.81	1.02	25.5	54.5	69.5	1,500	21.6	Very Broad
Reach 8	691	626	6,940	0.94	7,244	0.90	1.04	23.2	52.2	67.1	1,800	26.8	Very Broad

* Hydraulic Geometry Regressions (HGRs) for bankfull channel width estimates from Mulvihill et al. (2007) for New York and VTANR (2009) for Vermont.

Table 3.2: Summary of reach stream typing, incision, and channel evolution.

Reach	Reference			Existing		
	Stream Type[+]	Substrate	Bedform[+]	Stream Type[+]	Incision Ratio	CEM Stage[+]
Reach 1	C	Gravel	Riffle-Pool	C	Moderate	F/III
Reach 2	C	Gravel	Riffle-Pool	C	Moderate	F/III
Reach 3	C	Gravel	Riffle-Pool	F	Poor	F/II
Reach 4	C	Gravel	Riffle-Pool	B	Moderate	F/III
Reach 5	C	Gravel	Riffle-Pool	C	Good	F/IV
Reach 6	C	Gravel	Riffle-Pool	C	Good	F/III
Reach 7	C	Gravel	Riffle-Pool	F	Poor	F/II
Reach 8	C	Gravel	Riffle-Pool	C/F	Good	F/II

[+] Stream types per Montgomery and Buffington (1997) and Rosgen (1994)
Channel evolution model (CEM) per Schumm (1997)

Geomorphic conclusions:

The preliminary geomorphic assessment provides a basis for understanding the river valley setting and predicting what types of channel forms would be expected under "reference," or undisturbed conditions. This effort is useful for understanding the tendency of the White Creek corridor to support natural river forms that may be beneficial for reducing flood vulnerability in downstream areas such as Salem Village. Some key conclusions are outlined below.

- Most of the river valley is occupied by alluvium parent material (see Figure 3.2), or fine-grained soils that have been deposited by White Creek over thousands of years.
- The New York portion of White Creek is found in an unconfined valley, with a low sloped valley and channel (i.e., typically less than 0.5%). Under reference conditions in this setting, we would expect a gravel-bottom C or E-type channel (see Figure 3.4) with a sinuosity of 1.2 to 1.5. Sinuosity sometimes exceeds 1.5 in these settings. Given the high bedload supplied by the steep mountainous headwaters in the Vermont portion of the watershed, it is likely that some reaches of White Creek historically supported braided channel forms, particularly near the inflection point in the valley near the state line.
- Every reach of White Creek in New York has been heavily manipulated in the past. These manipulations include channel straightening and relocation, bank armoring, berms and levees, clearing of riparian vegetation, channel dredging, and others. The resulting planform of White Creek is very different from its original state, with sinuosity less than 1.2 in most reaches, and stream type departures observed in 3 of the 7 reaches, indicating a severe departure from the reference condition.
- Floodplain connectivity, as measured by the ability of a 2-year flood to access the adjacent benches or low floodplain, ranged from poor to good along the corridor. Areas with the most restricted floodplain access due to berms and levees along the channel include Reach 3 upstream of Blind Buck Road, and Reach 7 downstream of the NY Route 153 crossing.
- Channel evolution stages indicated a high bedload channel that is aggrading following the large floods of the last 20 years; however further field observations would be required to verify these conditions.

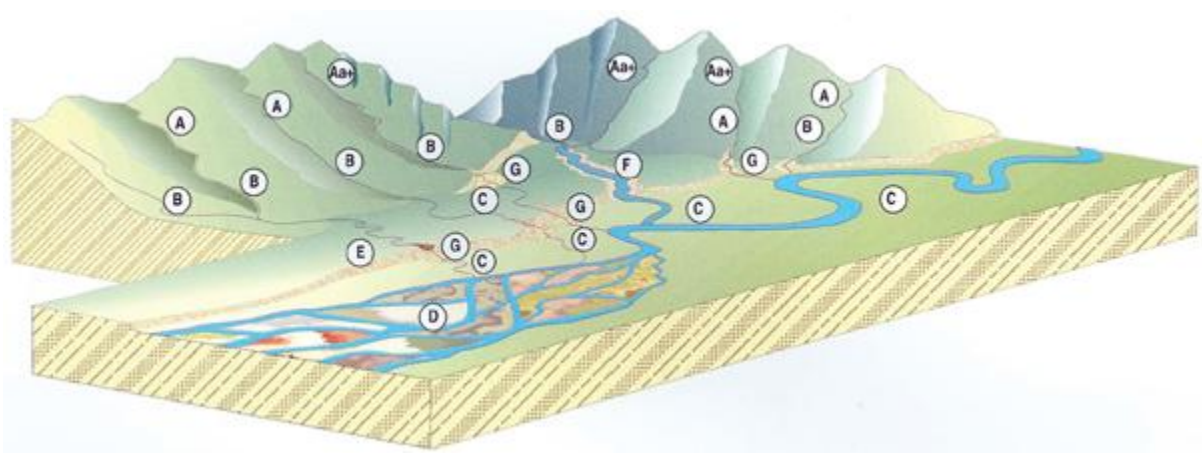

Figure 3.4: Broad level stream type classification per Rosgen (1996)

4.0 Hydrologic Analysis

This section provides a summary of the hydrologic data analysis used to estimate flood flows for different recurrence intervals in the White Creek watershed. The U.S. Geological Survey (USGS) has never operated a continuous gage in the watershed. Therefore, the records available to complete this analysis include USGS regional regressions and gage records.

4.1 Review of USGS Regional Regressions

We used USGS Regional Regression for three (3) regions to calculate flow rates in the White Creek watershed at a range of recurrence intervals: 1.5-year (bankfull), 2-year, 10-year, 25-year, 50-year, 100-year, and 500-year (abbreviated as Q1.5, Q2, etc). The USGS Streamstats program enables a user to quickly calculate flow rates at numerous locations within a watershed, based on the point location for the watershed delineation. The Streamstats program utilizes the regional hydrologic regression equation based on the location of the watershed delineation point.

White Creek in Salem, NY is located within hydrologic region 1 for New York State. Approximately half of the 49 square mile watershed is located in Vermont, and at the state line the upstream watershed is approximately 23 square miles. The portion of the watershed draining through the Village of Salem is approximately 35.8 square miles. We tested the Streamstats calculations at the state line by calculating recurrence interval flows based on a watershed drawn in NY (using Region 1 regressions) and a watershed drawn immediately upstream using the VT regressions. This yielded results with significantly larger flows predicted from the Vermont regression. Salem is located near the southern boundary of NY hydrologic region 1 (see Figure 1 in Appendix 1); therefore we also calculated flows using the regression equations for NY hydrologic region 2 (Table 4.1). Each regional calculation utilizes a different set of calculation variables shown below:

NY Region 1: Q100 = 10,300 * (Drainage Area)0.96 * (Basin Storage + 1)-0.202 * (Annual Rainfall)1.106 * (Basin Lag Factor + 1)-0.539 * (Basin Forested Area + 80)-1.638

NY Region 2: Q100 = 52.3 * (Drainage Area)0.9 * (Basin Storage + 5)-0.918 * (Basin Lag Factor +1)-0.461 * (Mean Annual Runoff)1.104

Vermont: Q100 = 0.251 * (Drainage Area)0.854 * (Basin Wetland Area)-0.297 * (Annual Rainfall)1.809

The rainfall and runoff estimates for the NY regressions were generated from a 1951-1980 dataset (Randall, 1996; Lumia et al., 2006). The Vermont regressions were recently updated and utilize a 1981-2010 rainfall dataset from the PRISM Group at Oregon State University (Olson, 2014). The data sources used for the NY Region 1 and Vermont regressions have a large difference in mean annual rainfall estimates for the watershed draining to the VT/NY border (40.3 inches from Randall; 55.3 inches from PRISM Group). Both rainfall datasets indicate an area of increased annual rainfall in the headwaters south of Rupert (see Figures 2 and 3 in Appendix 1); however the Randall estimate (45 inches) is much lower than the PRISM estimate (63.7 inches). This is likely due to a combination of data quality/resolution and a well documented trend of increased annual precipitation depth in the region in recent decades (Stager and Thill, 2010). The PRISM dataset predicts a mean annual rainfall

depth of 48.3 inches for the 35.8 mi^2 watershed draining to Salem. This value was used for regression calculations in Salem (Table 4.1).

Table 4.1: Recurrence interval flow rates for White Creek at the VT/NY border and in Salem.

Location (Drainage Area)	Regression	Q1.5	Q2	Q10	Q25	Q50	Q100	Q500
VT-NY Border (23.2 mi^2)	NY (Region 1)	691	846	1,577	1,980	2,284	2,628	3,422
	NY (Region 2)	845	1,075	2,386	3,279	4,043	4,897	7,269
	VT	NA	1,212	2,413	3,255	3,955	4,720	6,864
Salem Village (35.8 mi^2)	NY (Region 1)	1,006	1,228	2,270	2,843	3,275	3,765	4,891
	NY (Region 2)	1,115	1,468	3,156	4,290	5,250	6,319	9,252
	VT	NA	1,323	2,533	3,427	4,129	4,882	6,976

4.2 Review of USGS Regional Gages

We compared the regression equation flow estimates to recurrence interval flows described for USGS gaging stations in New York, Vermont, Massachusetts, and Connecticut (Lumia et al., 2006; Olson, 2014). We identified 20 USGS gaging stations that were similar to White Creek in Salem NY based on the following characteristics: drainage area, slope, rainfall, wetlands, and basin land cover (see Figure 1 in Appendix 1). From these we selected a subset of 11 gages which best matched the White Creek basin characteristics and are either currently operational or recently decommissioned (Table 4.2).

Table 4.2: USGS gages with similar basin characteristics; gages selected for analysis are shown in **bold**. 100-year and 2-year flow rates are area-normalized as CSM (cubic feet per second per square mile)

Source	Stream	State	USGS ID	Years of Record	Drainage Area (mi^2)	Basin Slope (ft/mi)	Q2 (CSM)	Q100 (CSM)
Lumia et al. 2006	**Salmon Cr.**	**CT**	**01199050**	**1961-2014**	**29.4**	**124.8**	**20**	**152**
	WB Sacandaga River	NY	01319000	1933-1978	28.9	81.2	40	81
	Little Hoosic River	**NY**	**01333500**	**1948-2014**	**56.1**	**60.3**	**35**	**128**
	Bushnellsville Cr.	**NY**	**01362197**	**1952-2012**	**11.4**	**142**	**31**	**223**
	Chestnut Cr.	**NY**	**01365500**	**1938-2014**	**20.9**	**88.5**	**57**	**295**
	Sandburg Cr.	NY	01366650	1957-1977	52.8	60.8	36	127
	Little Delaware River	NY	01422500	1938-2014	49.8	49.9	42	115
	Trout Cr.	NY	01424500	1941-1996	49.5	48.4	43	111
	WB Neversink River	NY	01434498	1938-2014	33.8	75.8	127	541
	Neversink River	NY	01435000	1938-2014	66.6	69.7	92	336
	Little Chazy River	NY	04271815	1990-2014	50.3	43.7	12	51
	Putnam Cr.	**NY**	**04276842**	**1990-2014**	**51.6**	**80.0**	**25**	**81**
Olson 2014	**Ayers Br.**	**VT**	**01142500**	**1927-2014**	**30.5**	**58**	**25**	**114**
	Ottauquechee River	**VT**	**01150900**	**1984-2014**	**23.3**	**53**	**43**	**197**
	Saxtons River	**VT**	**01154000**	**1936-2014**	**72.2**	**86**	**39**	**194**
	NB Hoosic River	**MA**	**01332000**	**1927-2011**	**40.9**	**69.2**	**60**	**306**
	Green River	**MA**	**01333000**	**1948-2014**	**42.6**	**67.7**	**35**	**119**
	Mettawee River	**VT**	**04280350**	**1985-2008**	**70.2**	**72**	**31**	**131**
	Little Otter Cr.	VT	04282650	1990-2014	57.1	19	15	54
	Laplatte River	VT	04282795	1990-2014	44.6	47	22	92
				White Creek in Salem, NY	35.8	74	--	
				Median value for selected gages	41	72	35	152
				Predicted flow (cfs) at VT/NY Border (23.2 mi^2)			**812**	**3,526**
				Predicted flow (cfs) in Salem (35.8 mi^2)			**1,253**	**5,442**

4.3 Hydrologic Analysis Summary

Estimating flood discharges for different recurrence intervals in the White Creek watershed in Vermont and New York is challenging for the following reasons:

- White Creek has never had a long term USGS gage to measure continuous discharge.
- White Creek straddles two very different landscapes: steep, mountainous terrain in Vermont where orographic rainfall is common and annual precipitation may exceed 60 inches; lower elevation terrain in New York where annual precipitation totals are typically less than 35 inches.
- The USGS hydrologic region where White Creek is found – Region 1 – spans a vast area of upstate New York. The average parameter values used to developed flow regressions across this large region may not be appropriate for the White Creek watershed. Region 2 estimates may be more appropriate for White Creek.

Our extensive review of the USGS regressions and gages in the region suggests that the flood flow estimates used by NYSDOT and Washington County for evaluating the hydraulic capacity of bridge openings likely underestimate the range of possible flows in the watershed. For example, the value used by the State and the County for the 100-year flow at the Village of Salem has been in the range of 3,500 to 3,700 cfs. Our analysis suggests that the range of flows for this event likely falls between 5,000 cfs and 6,000 cfs. Our hydraulic analysis using a HEC-RAS model and high water marks from Tropical Storm Irene (2011) suggests that we are within this range, as described in further detail in the following section.

5.0 Hydraulic Analysis

The wide river valley though the Town of Salem and the associated roads, railroad, buildings, and bridges created a complex environment for hydraulic modeling. Extensive field verification and survey was required to understand the flooding dynamics within the study area. Documentation of Tropical Storm Irene damage and flooding extents collected by the Salem Flood Study Committee was invaluable for calibrating the hydraulic model and improving the overall accuracy of the study.

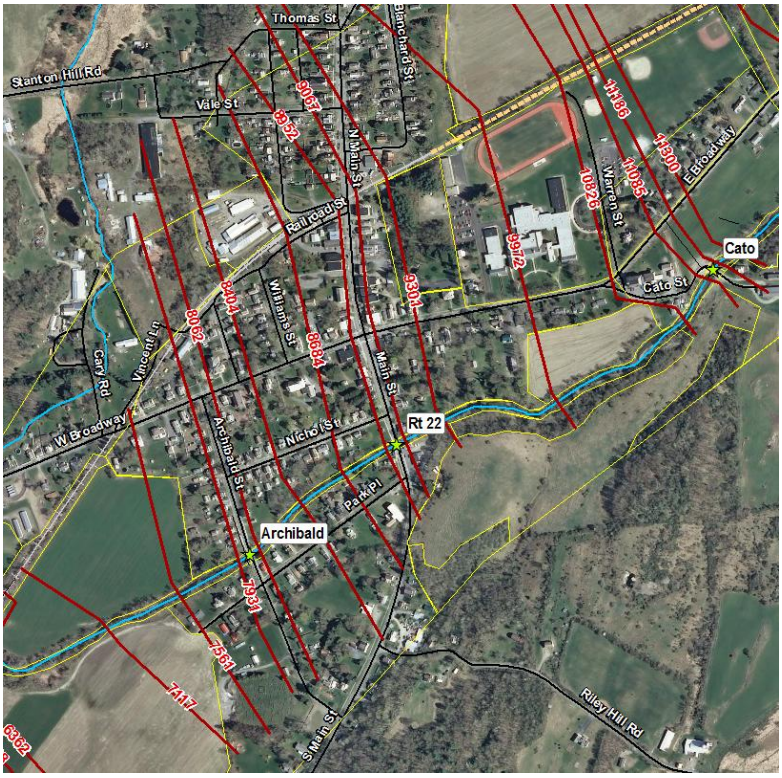

Figure 5.1: Modeled cross-sections through the Village of Salem

HEC-GeoRAS and HEC-RAS 4.1 software were used to create a one-dimensional river and floodplain hydraulics model for White Creek from the Route 153 bridge in Vermont downstream to the confluence with Blind Buck Brook. A floodplain digital elevation model (DEM) was created for the study area using high-resolution LiDAR elevation surfaces from a dataset covering the Hudson, Hoosic, and Deerfield basins collected by FEMA in 2012. We converted the DEM from meters to feet and used it to create a Triangulated Irregular Network (TIN). The TIN is an alternate method for representing the elevation surface that is much easier and faster to process for hydraulic modeling purposes.

The HEC-GeoRAS model was set up by first digitizing the stream centerline and the top of each bank. We constructed the hydraulic model as a single reach for the 48,300 foot long study area. The next step was to classify the land cover and the associated roughness values (Mannings N values) for the channel and floodplain areas. Based on 2014 aerial imagery, we manually traced areas of different land cover and assigned roughness values ranging from 0.035 (gravel bottom stream channel) to 0.08 (forest) following Chow (1959) and Arcement *et al.* (1989). Next, cross-sections were drawn perpendicular to channel and floodplain flow stretching across the valley to contain all areas of overbank flow (Figure 5.1). HEC-GeoRas allows the user to "slice" cross-sections across the floodplain and channel and the software automatically samples the DEM to create an accurate 3D lateral profile of the floodplain.

5.1 Field Survey

Field verification of important floodplain features and road crossings was completed for the entire study area in February and March, 2016. This is very important when constructing a large hydraulic model based on LiDAR derived DEMs which are inherently less accurate in areas of steep slope transitions, at bridges and along road embankments where the DEM is sometimes adjusted to reflect the “bare earth” condition, and sometimes in areas with dense coniferous tree cover. LiDAR technology also has limited ability to penetrate water, therefore channel bottom and channel bank elevations in the DEM are typically less accurate than elevations along the floodplain. The LiDAR data are processed to remove the elevation of vegetation, buildings, bridges, etc. to create a surface that represents the "bare earth" elevation. Bridge dimensions and accurate channel and bank elevations and dimensions are critical components for HEC-RAS modeling. For each of the 17 bridges in the study area we surveyed upstream and downstream sections, high and low chords, spans, and heights. A licensed surveyor from MSK collected detailed survey around all major roadway bridges within the study area using a Sprectra Precision Epoch 50 equipped with RTK smart rover. Staff from FEA collected additional survey for railroad and private road bridges and collected channel bottom and bank elevation surveys using a CST-Berger® 32x SAL Automatic Level (± 1.0mm accuracy @ 1km run) and standard survey rods. Horizontal data such as top of bank and bridge opening dimensions were collected using a handheld Ashtech MobileMapper™ M100 Series GPS device (sub half-meter accuracy). Channel bottom elevations were surveyed along any HEC-RAS cross-sections that were visible from the bridges.

5.2 Modeling Details

The output file generated from HEC-GeoRAS can be directly opened in HEC-RAS 4.1. Given the scale of the project and the width of the cross-sections, we had to manually check each "sliced" cross-section for accuracy and make adjustments as needed. Typical adjustments included bank station locations and smoothing of elevations around buildings and areas of dense vegetation. Channel bottom elevations were checked and adjusted in any areas that were field surveyed. Typical channel bottom adjustments ranged from 0.5 to 2 feet based on canopy density and water depth. We also plotted the channel longitudinal profile and looked for any unnatural slope changes. Channel width and bank profile were typically very accurate based on field measurements, LiDAR floodplain elevations were unchanged except in areas of dense development.

We included a total of 89 cross-sections in the model with added detail around bridges and important areas for overbank flow and past flood damage. The rail bed and roads through most of the study area create important lateral flow boundaries and were challenging to represent with a one-dimensional model. We utilized a combination of levees to block off areas where flooding has not been observed, and ineffective flow areas (both permanent and non-permanent) to reduce the volume of water that can be conveyed through an area that does flood. The latter approach was used to reduce the volume that is conveyed in the model to best represent downslope flow restrictions (Figure 5.2). Permanent structures (houses, barns, etc.) were digitized in ArcGIS and added to the GeoRAS database as obstructions.

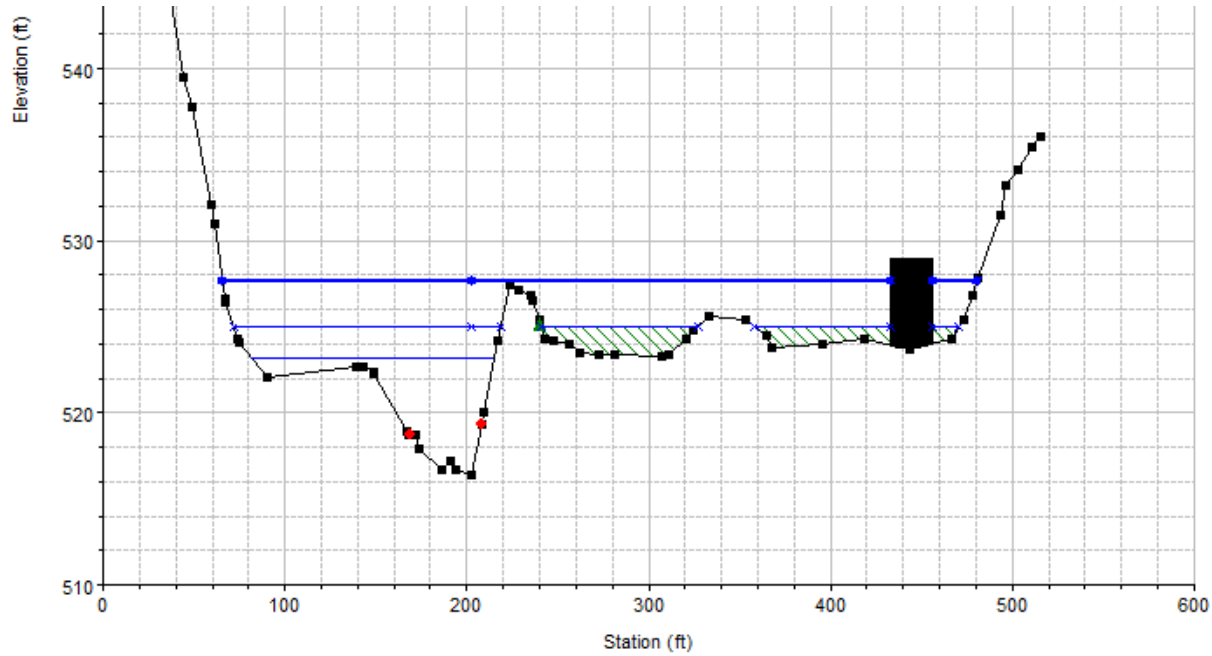

Figure 5.2: Cross-section 19271 upstream of Beatty Hollow Road where the ineffective flow area (green hashed lines) reduces the amount of floodplain available for conveyance until the water surface is high enough to flow over Route 153.

5.3 Model Calibration

We created an existing conditions plan and ran a steady flow model simulation with a mixed flow regime. The estimated discharges for different flood recurrence intervals were calculated from a series of regional regressions and from comparison to nearby USGS gaging stations in watersheds with similar size, slope, and rainfall (see Section 4). Flow change locations were designated at six (6) points along White Creek to adjust flows based on upstream drainage areas (Table 5.1); the flow change locations were generally located at tributary junctions. After generating water surface elevations and extents we fine-tuned the model with additional levees and ineffective flow area adjustments. The water surface elevations were calibrated to known high water marks and to estimated inundation extents from direct flood observations, photographs, and a series of maps and flooding descriptions provided by the Salem Flood Study Group. Two high water marks were surveyed near the Route 22 bridge and the Archibald Street bridge, providing valuable data for improving the model in this critical area.

Table 5.1: Flow estimates for select recurrence interval floods on White Creek scaled to the drainage area at each flow change location.

		Recurrence interval flow estimates (cfs)					
Cross-Section	**Drainage Area (mi^2)**	**Q2**	**Q5**	**Q10**	**Q50**	**Q100**	**Q500**
48227	16.2	632	942	1,287	2,122	2,534	3,672
44614	23.2	905	1,348	1,843	3,039	3,630	5,258
40229	27.0	1,053	1,569	2,145	3,537	4,224	6,119
27218	28.2	1,099	1,639	2,241	3,694	4,412	6,391
20698	32.8	1,279	1,906	2,606	4,297	5,131	7,434
13547	35.8	1,396	2,081	2,844	4,690	5,601	8,114

The estimated 100-year flood discharge from our hydrologic analysis (5,600 cfs), when routed through the existing conditions model, aligns well with observed water levels and flooding extents during the 2011 Tropical Storm Irene flood on White Creek, both in the Village and upstream (see maps in Appendix B). In addition, we ran a simulation that accounted for partial debris blockage (approximately 50%) of the Archibald Street bridge opening and channel aggradation (approximately 1-2 ft) in the Village, based on observations provided by the Town and the Flood Study Group. The results from this simulation indicated high water elevation agreement within 2 inches at the two high water marks in the Village. It is reasonable to assume that Tropical Storm Irene was between a 50-year and 100-year flood on White Creek, as a USGS review of the annual exceedance probabilities (AEP) on gages in Vermont and New York classified the 2011 flood as a 100-year flood (or greater) in most basins in southern Vermont (Suro *et al.*, 2015). We reviewed the 4 gages nearest and surrounding the White Creek watershed and found that the average AEP exceeded the 2% flood (i.e., 50-year flood).

6.0 Flood Mitigation Alternatives Analysis and Feasibility Studies

6.1 Upstream Alternatives

We used the results of our geomorphic, hydrologic, and hydraulic analyses to identify potential flood resiliency opportunities along the White Creek corridor upstream of Salem Village. We began by reviewing the projects highlighted in the 2012 CT Male report (CT Male, 2012) to ensure that past work was not duplicated. The sites we evaluated represent a wide spectrum of near-term and long-term project types. The primary focus was on flood resiliency for transportation infrastructure; we explored opportunities for larger bridge openings, roadway embankment stabilization compatible with river stability, and other practices highlighted in the Vermont Agency of Natural Resources Standard River Principles and Practices (Schiff *et al.*, 2015). In addition, with the objective of ameliorating the historical impacts of channel straightening, berming, and other encroachments on the surge of floodwaters in Salem (Figure 6.1), we explored flood flow attenuation opportunities for moderate floods including berm removals to reconnect severed floodplains, improvement of drainage beneath the rail bed to reconnect adjacent floodplains, and riparian buffer restoration.

Our hydraulic analysis of the White Creek corridor indicated that there are greater opportunities to mitigate flooding depths and extents during moderate floods, as the flooding is not nearly as extensive in comparison to large floods (i.e., 2011 Irene flood). The moderate floods, those which have a 10-20% chance of occurring on any given year, occur on a frequency that regularly affect residents' lives and property. The sites we prioritized and explored in further detail are shown in Figure 6.2 on the following page.

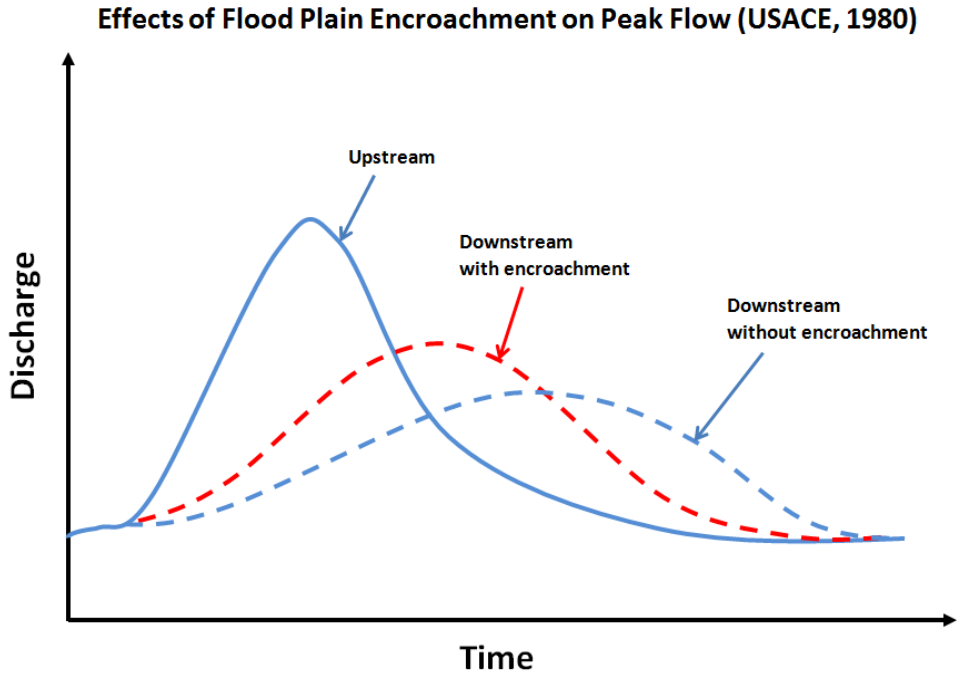

Figure 6.1: Model hydrograph illustrating the impact of floodplain encroachment on the downstream flood wave (USACE, 1980).

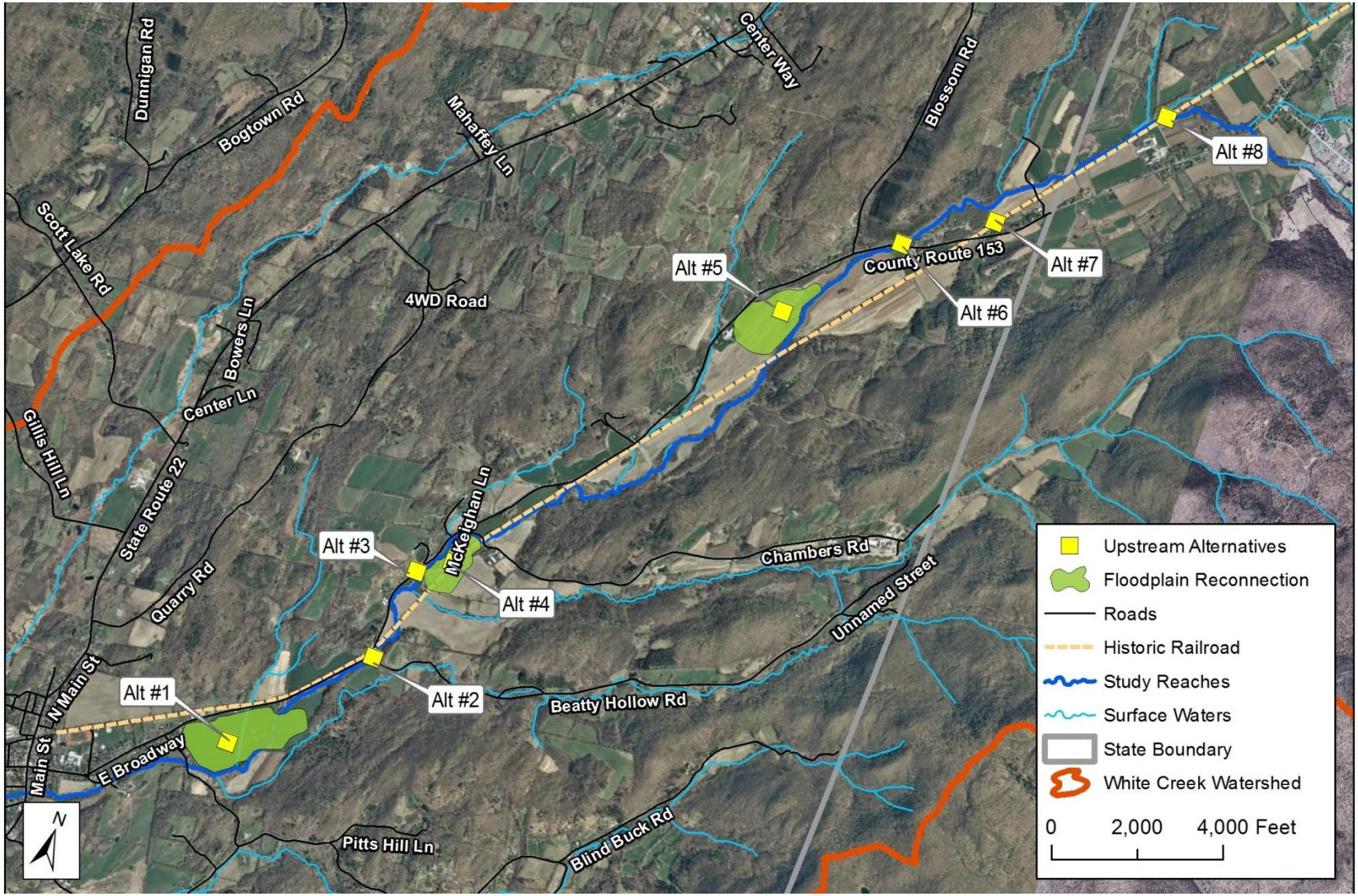

Figure 6.2: Overview map of upstream project alternatives.

Evaluation of White Creek Bridge Flood Capacity

Our upstream analysis included an evaluation of bridge flood capacity for all 17 public and private bridges on White Creek. Using our detailed hydraulic model, we evaluated the capacity of bridges to pass flood discharge associated with each flood frequency without increasing flooding to adjacent properties. In some cases the water elevation associated with a flood event is estimated to be near or above the low chord of the bridge deck without increased risk of flooding to adjacent properties (e.g., 2-year flood for Archibald Street bridge). In these cases, this flood discharge was assumed to be the maximum capacity of the bridge. A summary of key observations from this analysis is provided below to go along with Figure 6.3 on the following page.

- Only 2 bridges can safely pass the estimated 100-year flood without increasing flooding to adjacent property.
- 10 of the 17 bridges have capacity to safely pass the 10-year flood or less, indicating that most bridges on White Creek are hydraulically undersized by county and state standards.
- All railroad bridges have a capacity of the 10-year flood or less.
- There are 3 severely undersized bridges in Salem Village: Route 22, Archibald Street, and the downstream railroad bridge (RR-1). These constrictions aggravate the problem of sediment aggradation in the channel by slowing floodwater velocity and causing gravel and sand bedload to deposit through the Village, thereby increasing flood vulnerability to properties in the Village.
- Archibald Street bridge is severely hydraulically undersized; further detailed information about the capacity of this bridge is provided in Section 6.2.
- Railroad Bridge #5 in West Rupert, a bridge over the rail trail, is severely undersized. The reference bankfull channel width at this crossing is 53 feet; the structure span is 23 feet and is poorly aligned with the channel. In addition, the abutment scour protection on the south bank further constricts the channel. This undersized bridge causes channel backwater during large floods and contributes to overbank flow along the southeast side of the railroad tracks (see Section page 37 for further detail about this problematic structure).
- These assessments of flood capacity assume “clear flow” hydraulics, i.e., they do not account for sediment and debris accumulation upstream or within the bridge opening during flood events. Therefore the capacity at bridges prone to sediment aggradation and debris clogging, such as the Archibald Street bridge, is likely lower during moderate and large flood events.

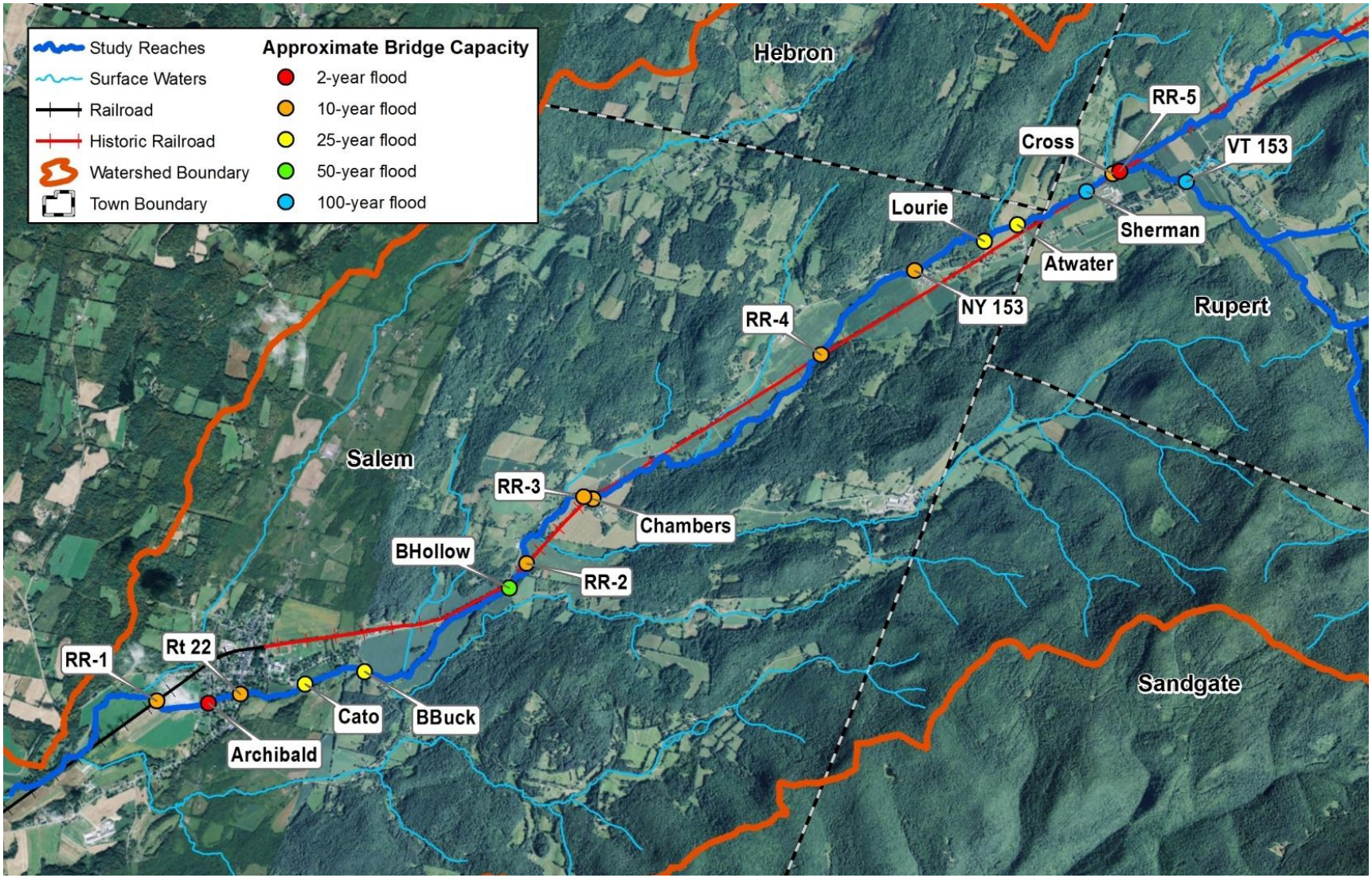

Figure 6.3: Bridge flood capacity for public and private crossings on White Creek.

Alternative 1: Floodplain Reconnection Upstream (East) of Blind Buck Road

Berms are found on the east and west banks along a farm field east of Route 153 and upstream of Blind Buck Road (Figures 6.4 and 6.5). The berms vary between 2 to 4 feet tall and restrict access to floodplains in agricultural use along both banks. During large flood events such as Irene in 2011, flow jumps out of bank at a bend in the stream between sections 14432 and 14897. However, the berms partially restrict access to a large floodwater storage area under moderate flood conditions. We estimate these floodplains contain approximately 1,500,000 cubic feet of storage, or 4% of the approximate 10-year flood volume. Reconnecting these floodplains for moderate floods would not appear to increase flood vulnerability to improved property in the immediate vicinity, and would serve to dampen the flood wave downstream in Salem. This work would require an estimated 1,800 cubic yards of excavation and easements from the farmer. The ability of the floodplain to slow the velocity of out of bank flow would be significantly enhanced by taking this farmland out of production and re-establishing native woody vegetation, however this would come at a significant loss to the farmer, perhaps beyond an amount a permanent conservation easement would reasonably cover.

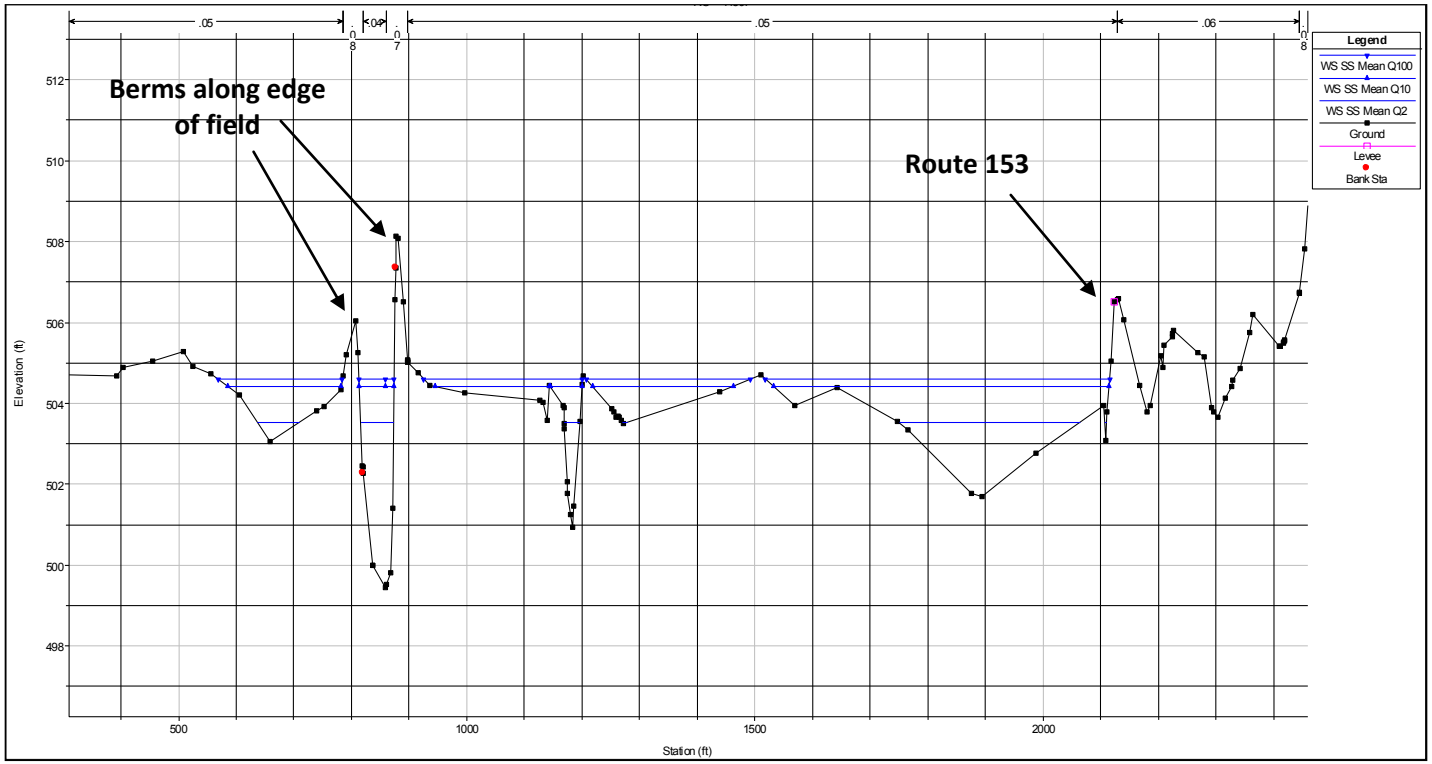

Figure 6.4: Cross-section 14897 located approximately 1,000 feet upstream (east) of Blind Buck Road.

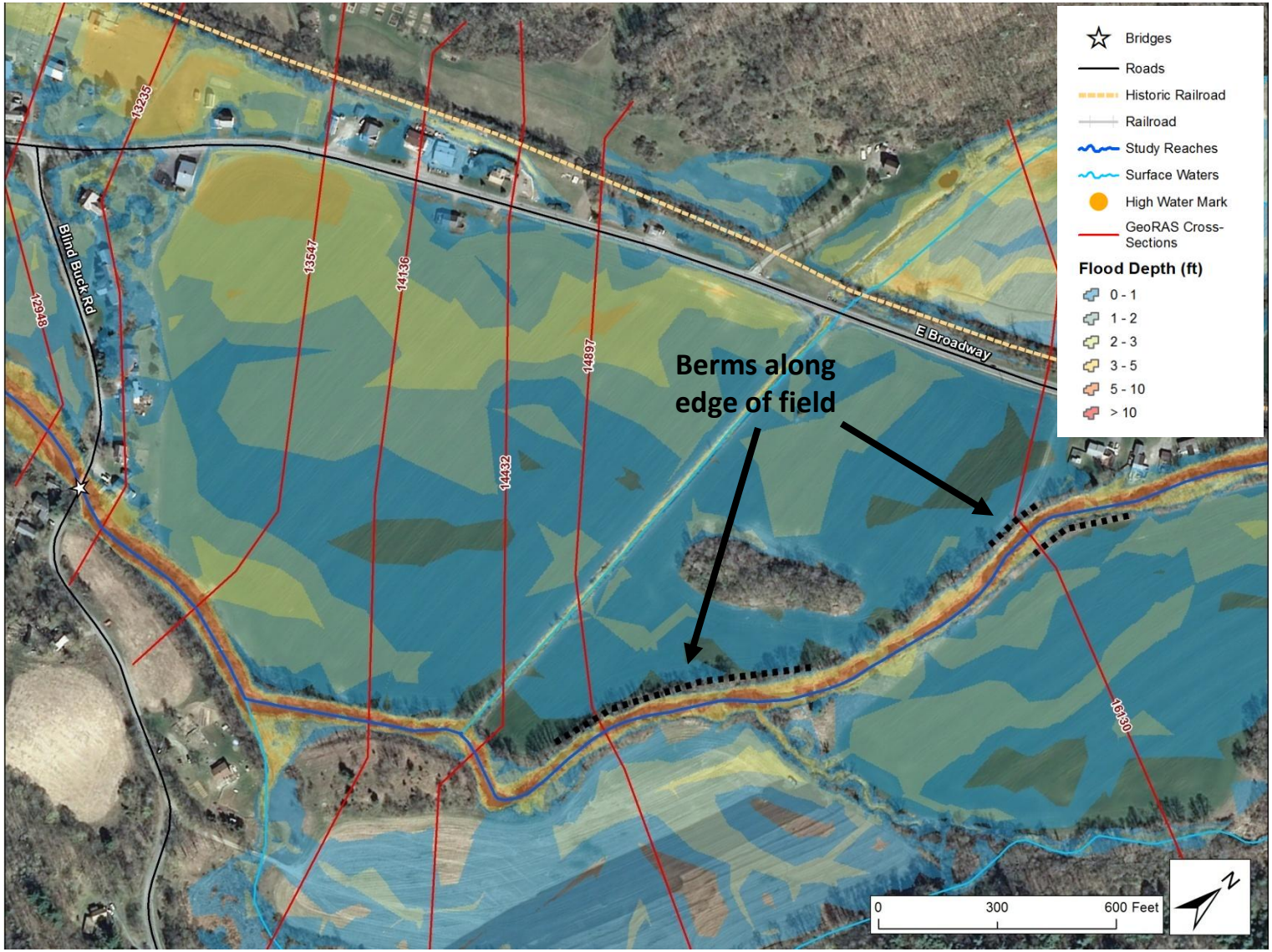

Figure 6.5: T.S. Irene flood depth map showing berms and floodplain east of Blind Buck Road.

Alternative 2: Beatty Hollow Bridge Retrofit or Replacement

The Beatty Hollow crossing of White Creek is located at a natural pinch in the valley where bedrock ledge is found on the bounding slopes to the east and west. Our hydraulic modeling of large floods suggests that this pinch point in the valley causes depths exceeding 12 feet upstream of the Beatty Hollow Road bridge (see page 7 of Appendix 2). During a large flood, water has to squeeze between the valley walls and through the current clear bridge span of 44 feet; this has caused road embankment erosion in past floods (Figure 6.6). We evaluated how a bridge span approximating the reference bankfull width (see Figure 6.7) would change local hydraulics and potentially reduce the volume of water leaving the channel upstream, and reduce the risk of embankment failure. Our analysis indicates that a bankfull span with the same height as the existing structure would lower the 100-year flood elevation by 2.7 feet (Figure 6.8), thereby reducing flooding at the adjacent house to the east. A span of this size may also help to reduce out of bank flows upstream of the railroad bridge which get trapped along the west side of Route 153 to the south and exacerbate flooding downstream near the Village. Channel velocity during large floods would be reduced by as much as 25%, reducing the vulnerability of the Route 153 and Beatty Hollow Road embankments to erosion failure.

Figure 6.6: Looking west at upstream approach of White Creek to Beatty Hollow Bridge. Note the embankment armor from repairs following the 2000 flood, and the steep bedrock slope in the background. The western abutment was moved toward Route 153 in 1999 to increase the clear span from 35 feet to 44 feet.

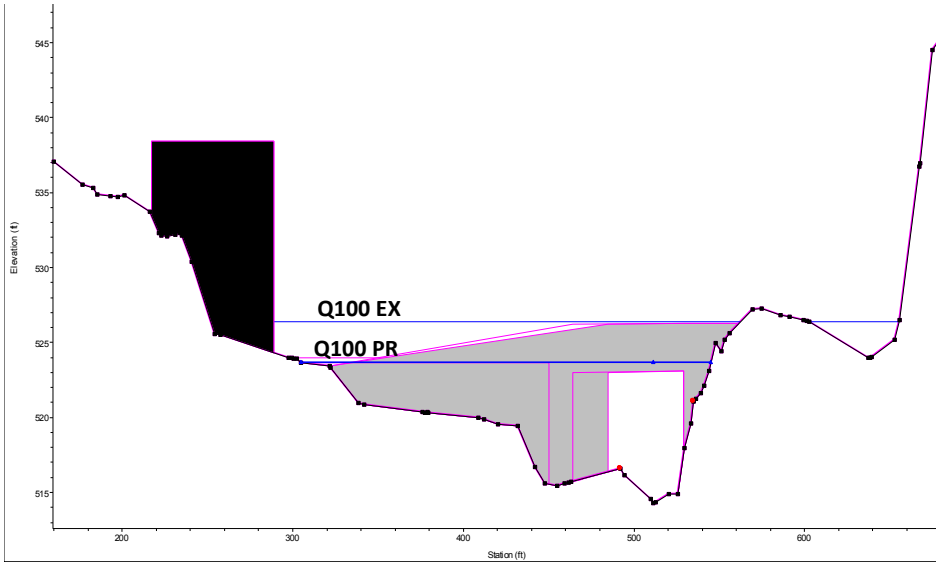

Figure 6.7: Upstream face of Beatty Hollow bridge showing the existing 100-year flood level and proposed with the increased span to 65 feet to provide a bankfull channel. Note that floodwaters impact the adjacent house under existing conditions as was observed during the Tropical Storm Irene flood.

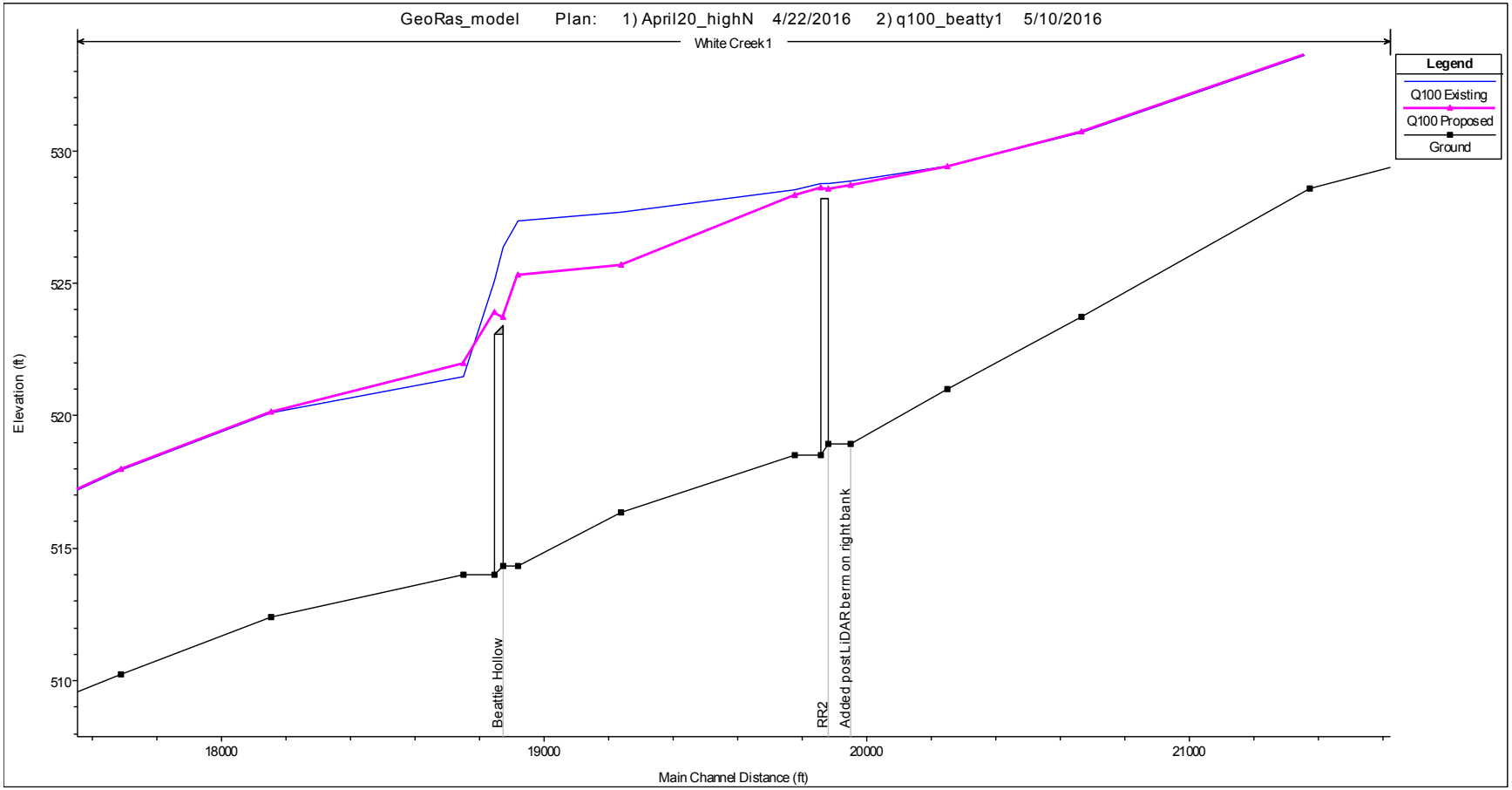

Figure 6.8: Profile of 100-year flood in the vicinity of Beatty Hollow Road crossing. Blue line represents existing conditions profile and magenta line represents proposed conditions profile with the span increased to 65 feet to provide a bankfull channel.

A more immediate solution to increasing the hydraulic capacity of the bridge opening is to remove a constriction caused by riprap armor at the downstream side of the bridge (Figure 6.9). We estimate this riprap is obstructing the downstream hydraulic opening by 10-15%. This encroachment causes further channel constriction to approximately 35 feet. This armor does not appear to be protecting critical infrastructure; The stone could be repositioned to create more of a stacked stone wall to protect the road pull-off while eliminating the encroachment.

Figure 6.9: View of Beatty Hollow Bridge opening from upstream (taken by Evan Fitzgerald, May, 2016). Note the riprap stone projecting out into the channel at the downstream end of the bridge.

In the long term a realignment of the road crossing would significantly improve the hydraulic capacity of this pinch point in the valley. Figure 6.10 illustrates a possible realignment of the road intersection; this would need to be evaluated further by the County to ensure safety with respect to traffic patterns and sight distances. The realignment would reduce the sharp bend in the channel immediately upstream of the current bridge opening. In addition, the west bank upstream of the bridge could be lowered in elevation (hatched area) to allow for some overbank conveyance, thereby improving the hydraulics upstream of the structure. Finally, if a more comprehensive flood resiliency project is considered in the future with the bridge realignment, the removal of the railroad embankment upstream (north) of the bridge may also provide additional flood reduction benefits. Removal of the railroad embankment would allow floodwaters leaving the channel upstream of the next upstream railroad bridge to rejoin the main channel near Beatty Hollow Road, assuming the headwater depth is reduced with a large span. This could alleviate flooding downstream in the Village by reducing the volume of water crossing Route 153 to the west.

Figure 6.10: Beatty Hollow Bridge current alignment versus an alternative alignment which would improve the channel approach and hydraulic capacity.

Alternative 3: County Road 153 Unstable Embankment near Braymer Road

This site was addressed in 2012 as part of the post-flood recovery work planned and engineered by CT Male for the Town and Village of Salem. The purpose of the project was to reconnect an abandoned meander to the east (Figure 6.12), which would lead to lower flood flow velocity and erosion risk along Route 153. The abandoned channel is currently steeper than the reconnected meander; the reconnected meander dissipates energy over a longer run. The diversion weir at the upstream end has likely exacerbated erosion along the Route 153 embankment (Figure 6.14), as it has further steepened the head of an already over-steepened channel, leading to higher flood velocities (Figure 6.11). To prevent further erosion along the embankment, we propose bank armor in conjunction with grade control in the channel adjacent the road either in the form of 2-3 discrete weirs or vanes (Figure 6.13), or naturalized bed armor to raise the channel grade at or near the adjacent meander channel.

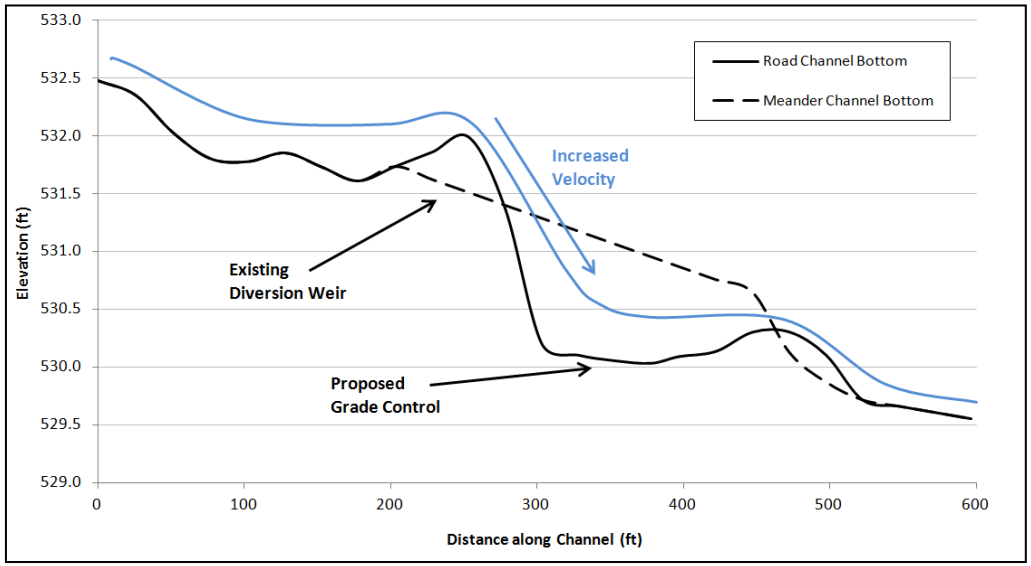

Figure 6.11: Longitudinal profile from LiDAR and field observations.

Figure 6.12: Site location map

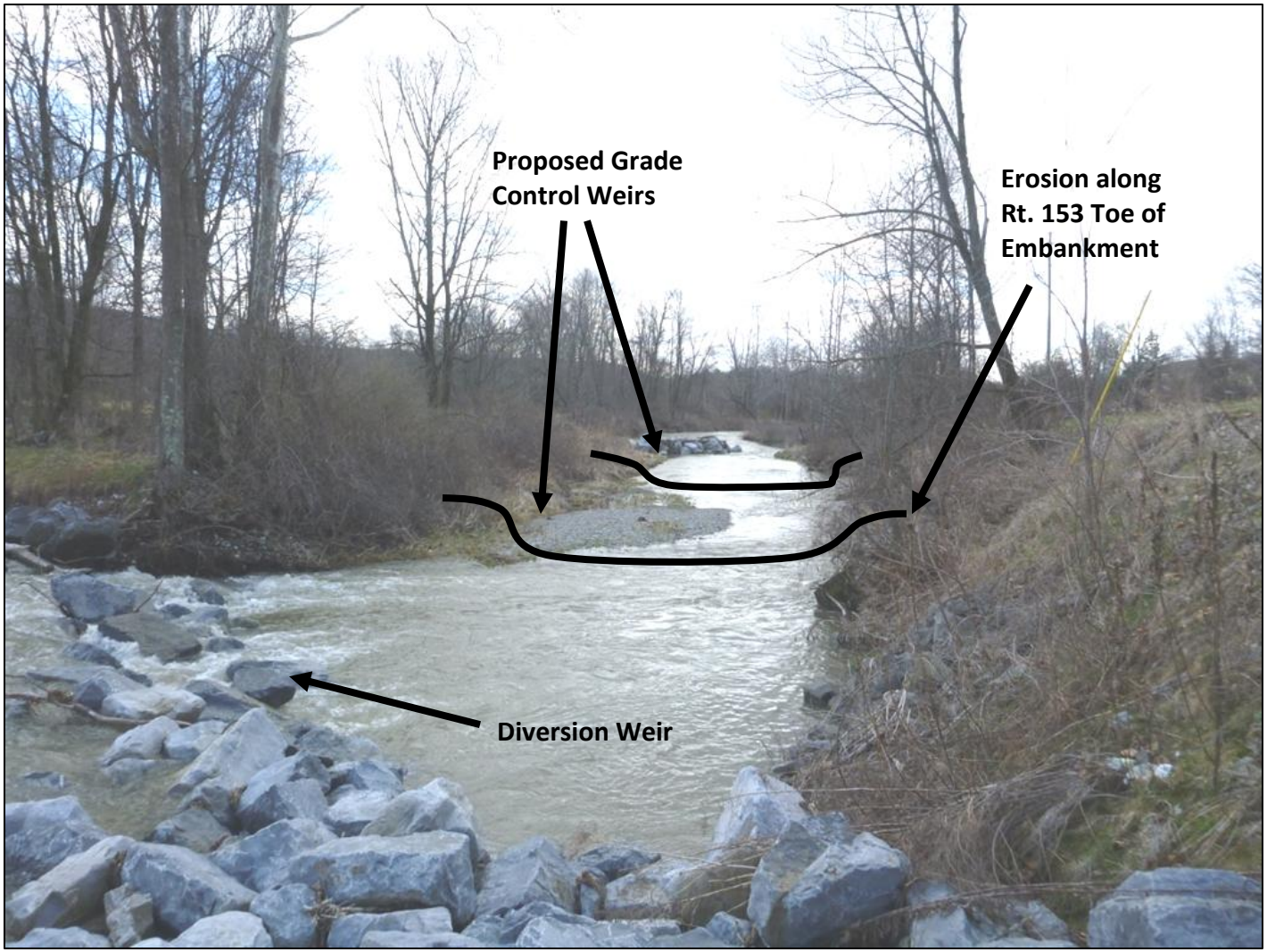

Figure 6.13: Looking south along Route 153 at site of proposed grade control to prevent further downcutting and undermining of roadway embankment. The roadway embankment would need to be armored. Stone from the downstream diversion, which we deem unnecessary, could be repurposed for a portion of the grade control and bank armor.

Figure 6.14: Looking north (upstream) at the unstable bank. Route 153 is on the top of the slope, and the upstream diversion weir is seen in the background.

Alternative 4: Floodplain Reconnection Downstream (West) of Chambers Road

A berm stretches along the south bank downstream from the Chambers Road bridge and adjacent railroad bridge for approximately 900 ft, extending beyond cross-section 22800 (Figures 6.15 and 6.16). The berm is typically 1.5ft tall and restricts access to a 5 acre floodplain in agricultural use that is bounded by the railroad to the east. In addition, the railroad bed severs a portion of the floodplain to the east. These combined areas represent approximately 530,000 cubic feet of floodplain storage. Reconnecting these floodplains for moderate floods would not increase flood vulnerability to improved property in the immediate vicinity (i.e., out of bank flows would return to the channel safely without affecting residences), and would serve to dampen the flood wave downstream in Salem. This work would require an estimated 8,600 cubic yards of excavation and easements from the farmer. The ability of the floodplain to slow the velocity of out of bank flow would be significantly enhanced by taking this farmland out of production and re-establishing native woody vegetation to increase floodplain roughness.

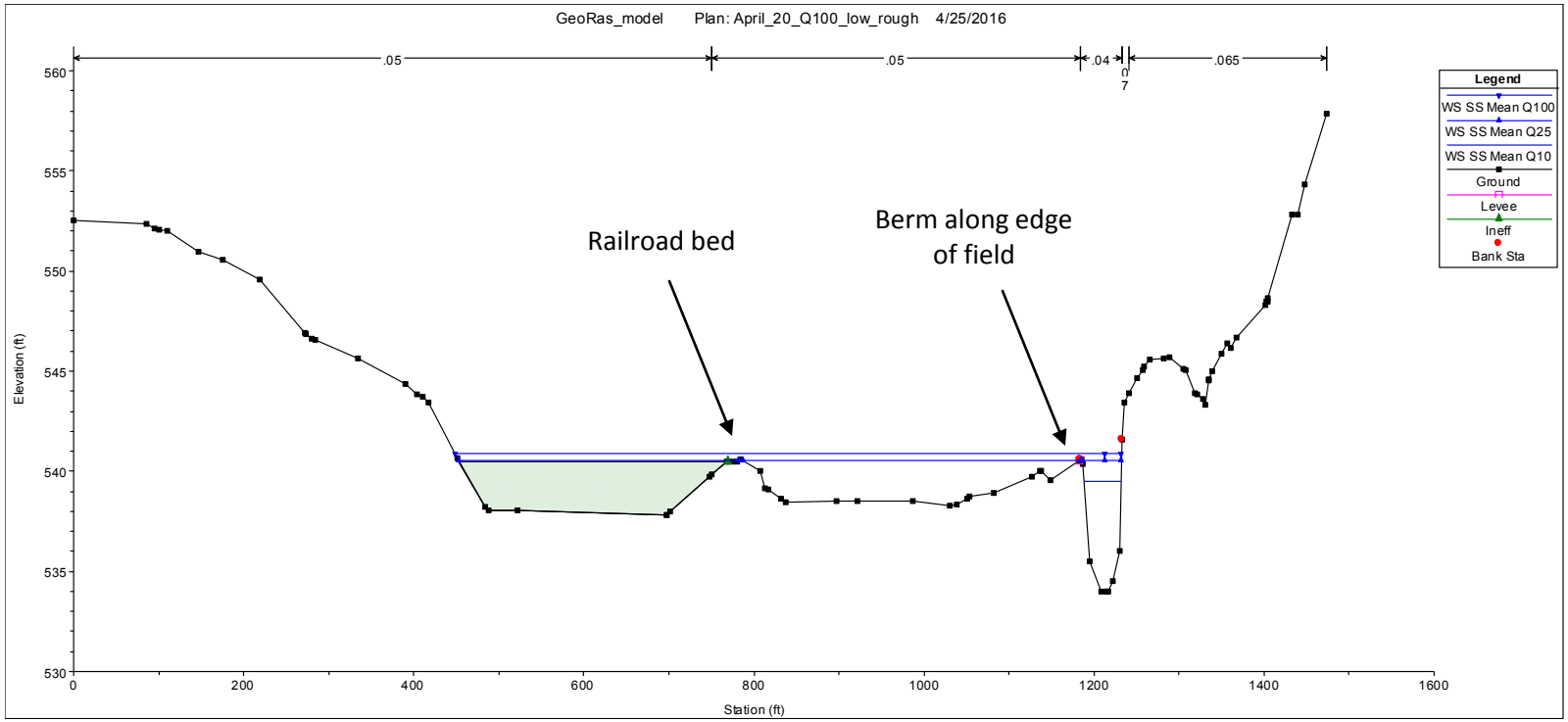

Figure 6.15: Model cross-section 22800 downstream of Chambers Road showing a near bank berm and the railroad bed which both sever the channel from the floodplain in the 10-year flood. Removing both confining features would reconnect an estimated 530,000 cubic feet of floodplain storage, which represents approximately 1% of the runoff volume in this flood event.

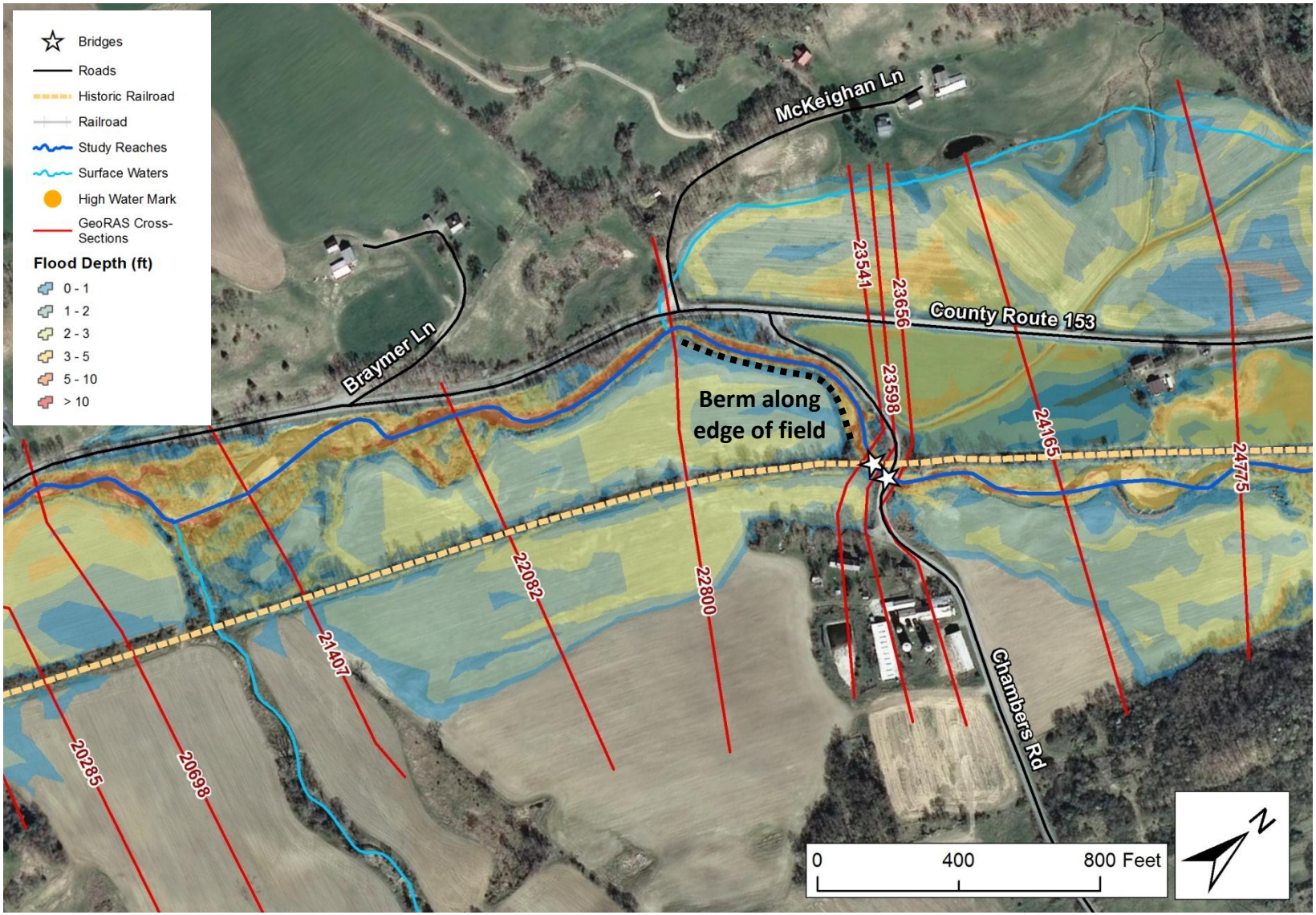

Figure 6.16: T.S. Irene flood depth map showing floodplain, berms, and railroad bed.

Alternative 5: Floodplain Reconnection Upstream (East) of Railroad Bridge #4

Berms are found along the north bank along a farm field west of the Route 153 crossing (Figures 6.17 and 6.18). The berms vary between 2 to 5 feet tall and restrict access to a large floodplain in agricultural use that is bounded by Route 153 to the west. During large flood events such as Irene, flow jumps out of bank at a low point along the channel at Section 34583. However, the berms restrict access to a large floodwater storage area under moderate flood conditions. We estimate this floodplain contains approximately 1,400,000 cubic feet of storage, or 4% of the approximate 10-year flood volume. Reconnecting these floodplains for moderate floods would not appear to increase flood vulnerability to improved property in the immediate vicinity, and would serve to dampen the flood wave downstream in Salem. This work would require an estimated 4,000 cubic yards of excavation and easements from the farmer. The ability of the floodplain to slow the velocity of out of bank flow would be significantly enhanced by taking this farmland out of production and re-establishing native woody vegetation.

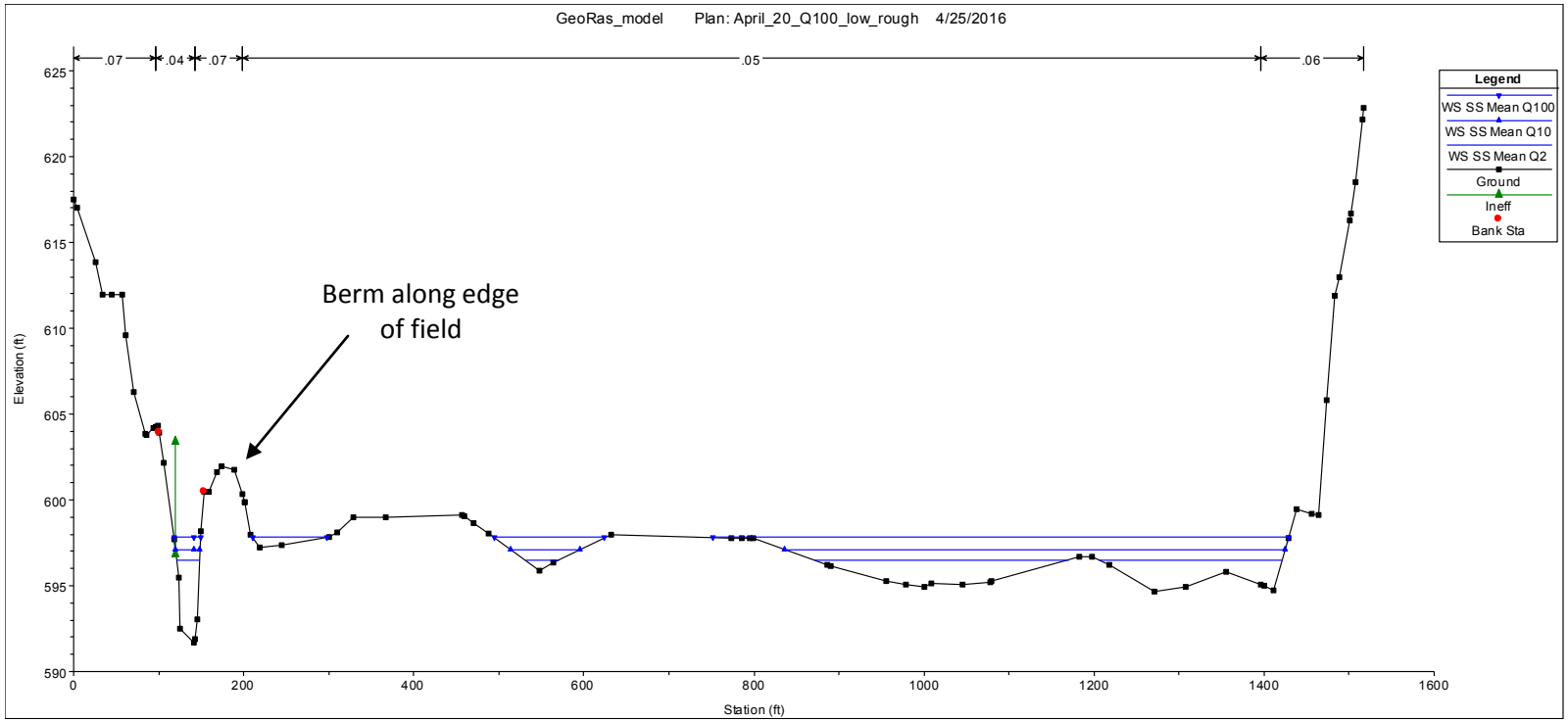

Figure 6.17: Model cross-section 33573 upstream of Railroad Bridge #4 showing a near bank berm which severs the channel from the floodplain. Removing the berm would reconnect an estimated 1,400,000 cubic feet of floodplain storage.

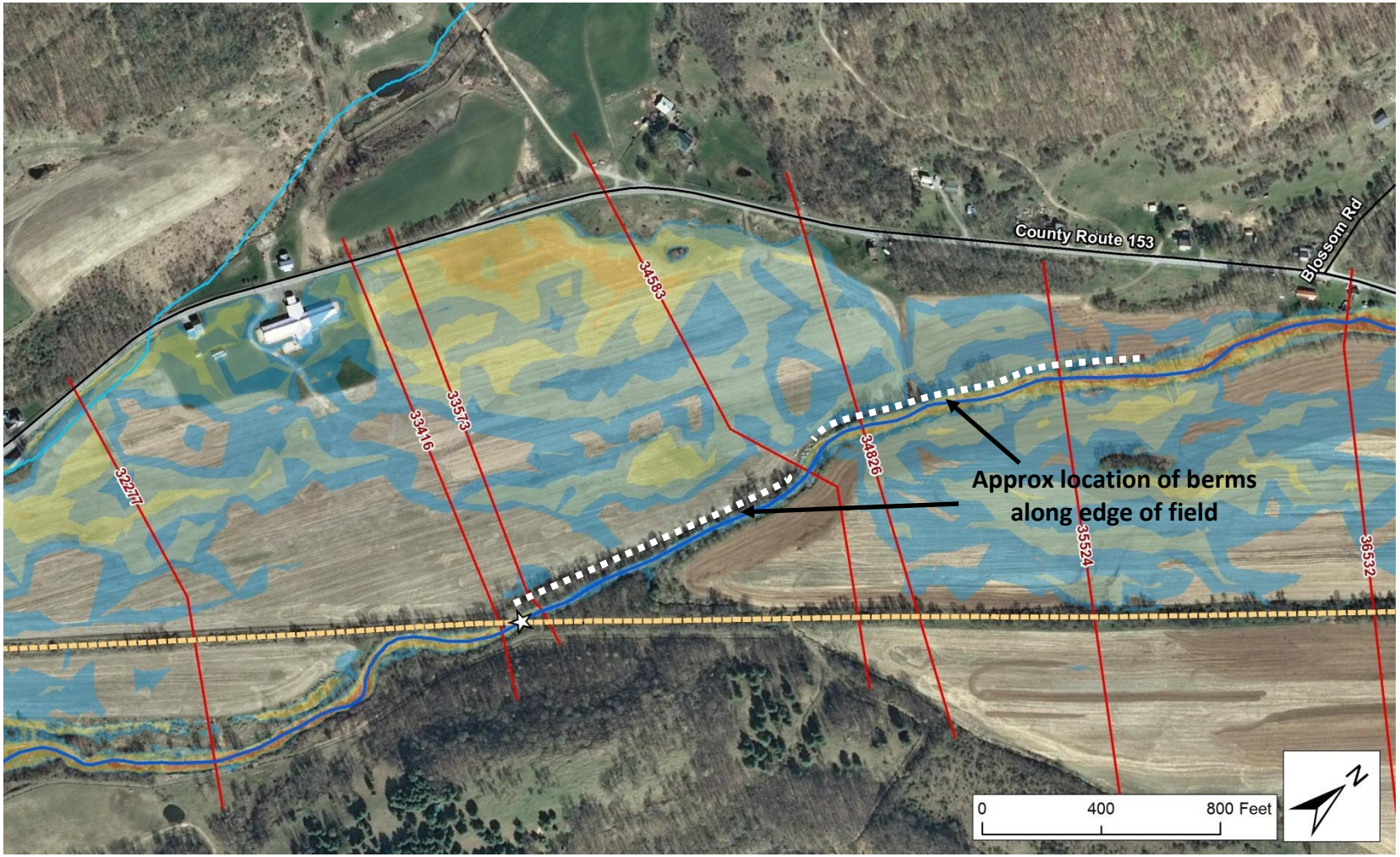

Figure 6.18: T.S. Irene flood depth map showing floodplain and berms.

Alternative 6: County Route 153 Bridge Upstream Constriction

An old laid up stone abutment upstream of the Route 153 bridge constricts the channel (Figure 6.19), aggravating out of bank flows and flooding of adjacent properties to the south and east during large floods. The bridge has an estimated capacity of the 10-year flood, and the constriction further reduces the channel capacity. The bankfull channel upstream and downstream of the bridge ranges from 30 to 35 feet, while the constriction at the abutment is approximately 20 feet. There is good machinery access to remove the stone (approximately 90 cubic yards) from a private gravel road west of Route 153. A temporary easement from the landowner would be needed as the stone is likely outside of the road right-of-way.

Figure 6.19: View of County Route 153 Bridge opening from upstream (taken by Evan Fitzgerald, May, 2016). Note the old laid up stone abutment projecting into the channel upstream of the bridge.

Alternative 7: Lowering of Railroad Bed and Removal of Culvert at Lenhardt Residence

During large floods water is diverted out of the bank in West Rupert at the rail trail bridge and gets trapped on the east side of the rail bed. Ponded water south of the Atwater farm cannot easily return to the White Creek channel after the floodwaters recede due to limited capacity through a 30-inch culvert. Lowering a portion of the rail bed around the culvert will provide additional relief back to the Creek, thereby relieving trapped floodwaters and reducing prolonged flooding of homes.

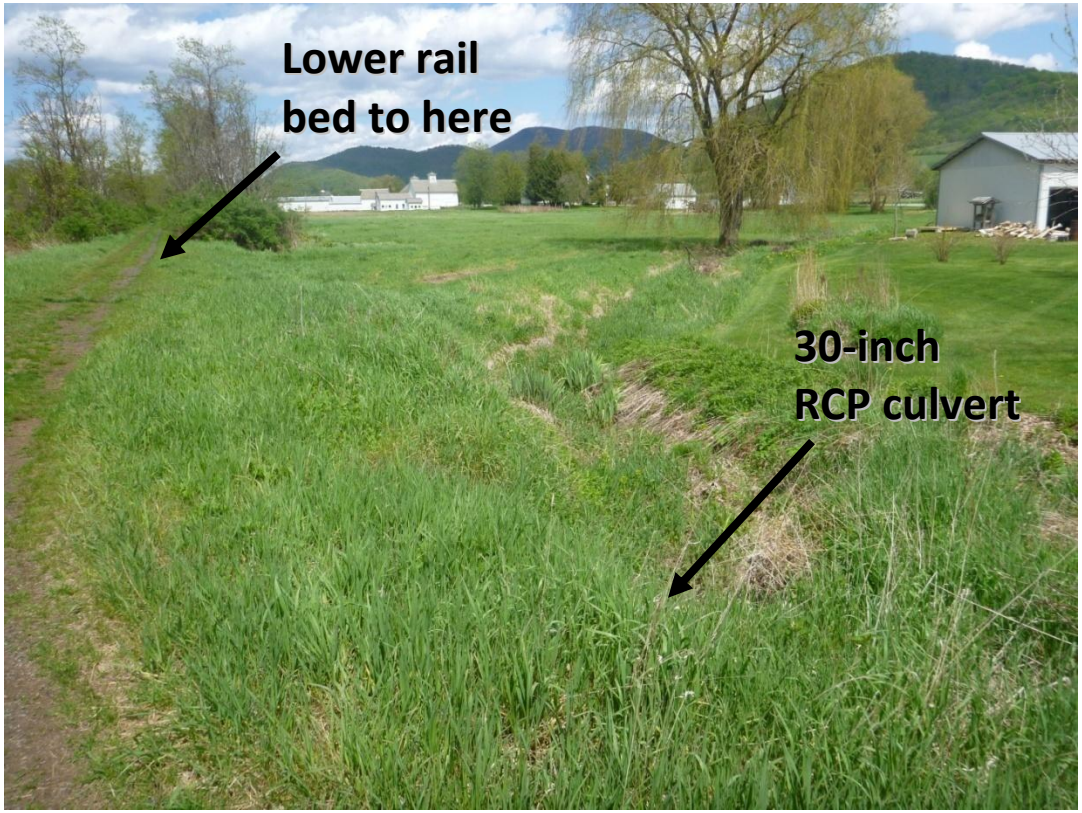

Figure 6.20: View north along rail bed where a ditch crosses through a 30-inch culvert (taken by Evan Fitzgerald, May, 2016).

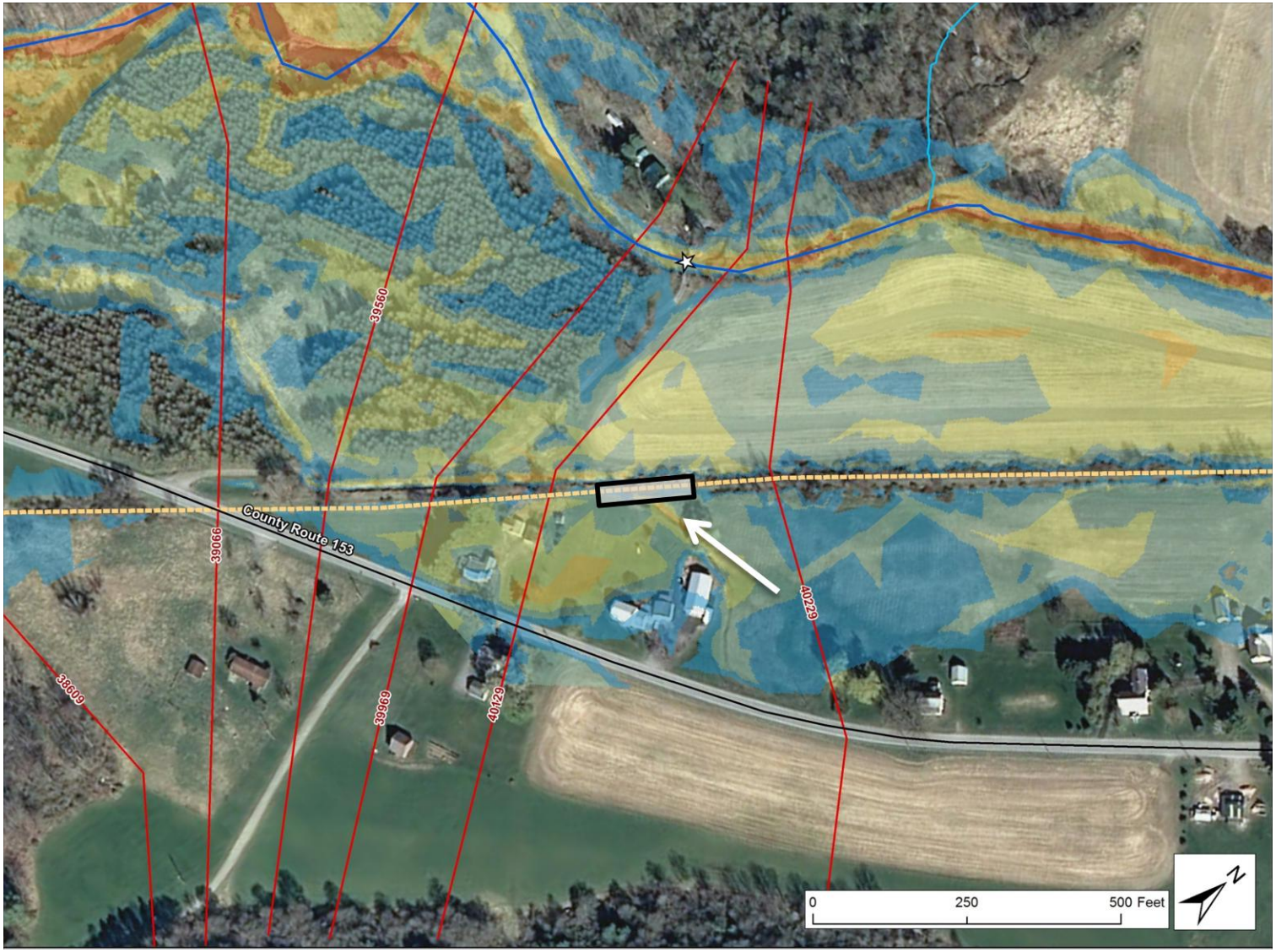

Figure 6.21: Map of proposed rail bed lowering to allow out of bank floodwaters from the north to return to the White Creek floodplain and channel following recession of flood surge.

Alternative 8: Replace Undersized Railroad Bridge #5

The rail trail bridge in West Rupert in severely undersized and poorly aligned, and contributes to out of bank flows during large floods. Floodwaters get trapped on the south side of the rail bed and cannot return to the Creek. The current bridge span is 23 feet. The bridge span should be at least 50 feet to match the channel bankfull width. In addition, riprap stone placed along the south bank along the toe of the new abutment appears to have been placed for scour protection, however this further constricts the channel.

Figure 6.22: View west at upstream end of rail trail bridge in Rupert. The confluence of White Creek and Mill Brook is just downstream in the photo background (taken by Evan Fitzgerald, April, 2016).

6.2 Salem Village Alternatives

We created two different HEC-RAS geometry files to model small floods (Q2-Q10) and large floods (Q50-Q500) in the Village of Salem. Levees and ineffective flow areas specific to flood depth were required in many areas to control flood extents across the variable topography in the very wide river valley. The two existing geometry files were used as the basis for a series of alternatives models to evaluate flood mitigation options.

Most of the Village-specific alternatives we considered had only minimal flood risk reduction in the large floods (Q100) in comparison to the more frequent moderate floods (Q5 or Q10). This is due to the simple fact that during a very large flood a significant portion of the Village along White Creek is inundated, and there are fewer practical opportunities besides extensive property buyouts to significantly reduce flood risk. Whereas, during the moderate floods there are greater opportunities to mitigate the flooding depths and extents, as the flooding is not nearly as extensive. The moderate floods, those which have a 10-20% chance of occurring on any given year, occur on a frequency that affects residents' lives with enough regularity that we chose to focus our efforts on mitigating these floods.

We selected the 10-year flood, with a modeled discharge of 2,844 cfs, as the representative flood to analyze mitigation opportunities in the Village. The alternatives analysis for the Village included six (6) types of channel and floodplain modifications which were investigated for flood depth and velocity reductions both independently and iteratively (Table 6.1 and Figure 6.23). All alternatives were compared to the "do nothing" alternative, and the incremental flood risk reduction with each added intervention was reviewed. A series of flood depth maps for key alternatives is provided in Appendix 3, and each alternative is described in greater detail in the following sections.

Table 6.1: Summary of channel and floodplain modifications from Village alternatives analysis.

Alternative	Remove Berms along Field	Deepen Channel	Remove Archibald Bridge	Overflow Box Culvert	Widen Channel w/ Flood Benches	Create Floodplain near Archibald
1	Do Nothing - Existing Conditions					
2	X					
2a	X	X				
3			X			
3a				X		
4	X		X			
5	X	X			X	
6	X	X	X		X	
7	X	X	X		X	X

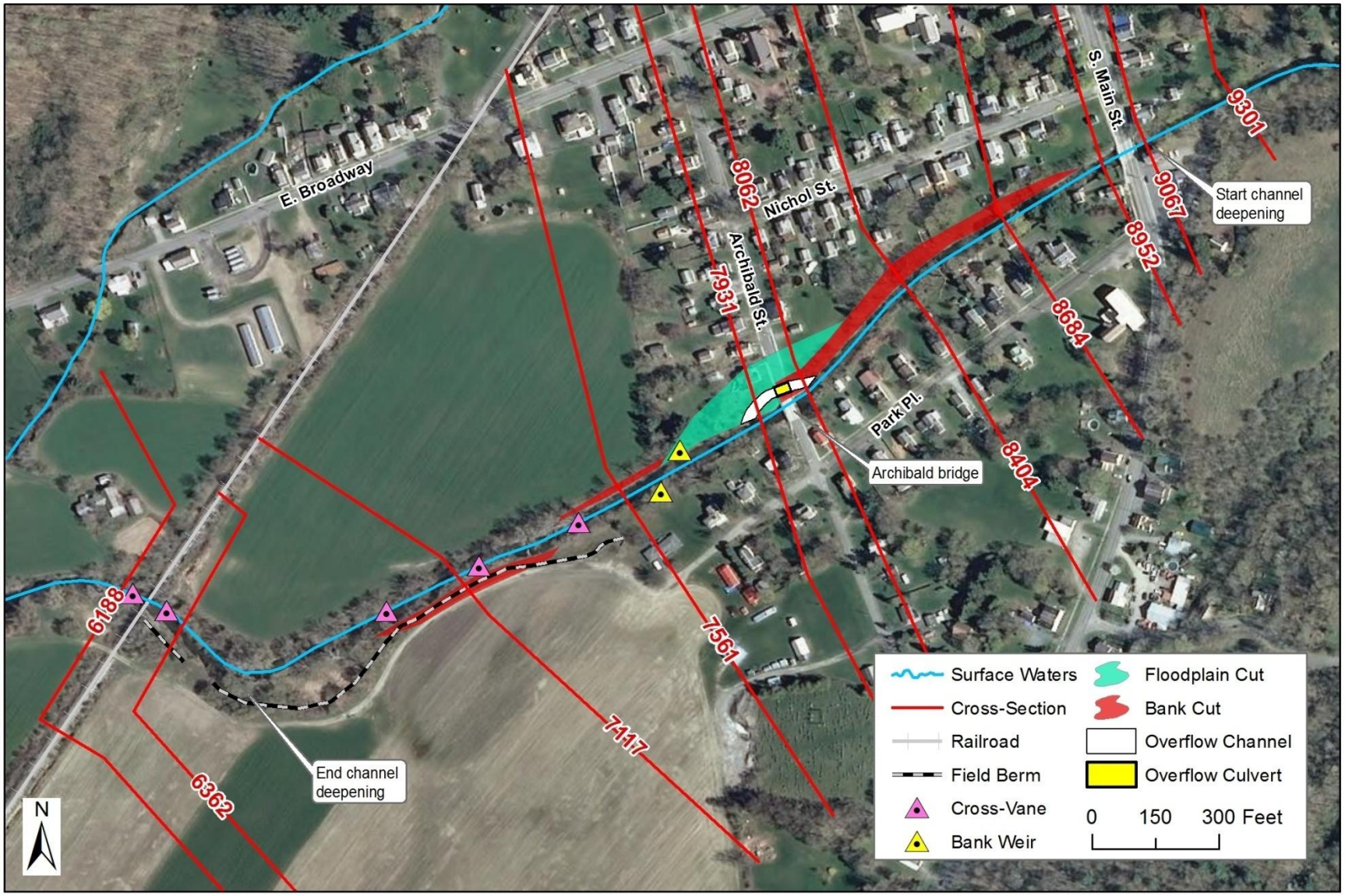

Figure 6.23: Map of channel, floodplain, and bridge modifications considered during the alternatives analysis.

Alternative 2

This scenario involves the removal of berms along the south bank extending from the end of Park Place to the railroad crossing. Berm removal will restore access to a large floodplain during small to medium sized flood events. The berms are typically 1.5-2.5 feet tall and are continuous except for a small break near the railroad (Figures 6.24 and 6.25). The berms total approximately 1,200ft in length and we estimate the total berm volume to be 1,000-1,400 CY. Coordination with the owner (Woody Hill Farms) would be required. In talking with staff from the Washington County Soil and Water Conservation District, we understand that the farmer placed these berms along the river to prevent overflow onto the crop fields and reduce erosion. However, this has the effect of creating tailwater in small and moderate floods (Figure 6.25), before the berms are overtopped, exacerbating flooding on the west end of the Village.

Figure 6.24: Berm along field edge west of Park Place.

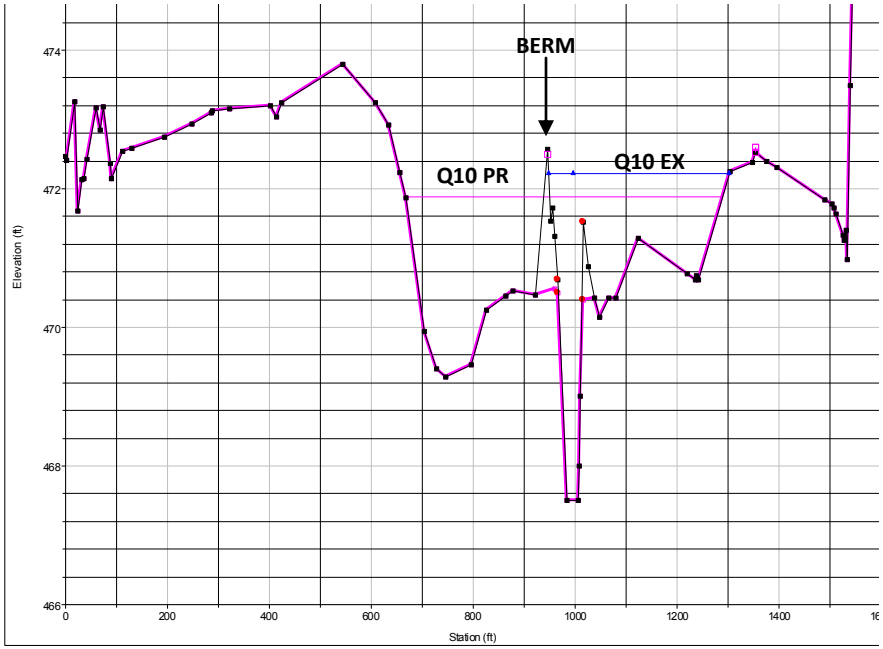

Figure 6.25: Berm removed at XS 7117 in the model resulting in a 6-inch decrease in the 10-year flood (Q10) water surface elevation.

Alternative 2a

This scenario involves the removal of berms along the south bank extending from the end of Park Place to the railroad crossing and deepening the channel from the Route 22 bridge through cross-section 7117. We estimate the channel has aggraded approximately 1-2 feet of gravel and sand through this section compared to pre-Irene conditions (Figure 6.26). This is supported by the 2005 County site plans for the construction of the Archibald bridge, which indicate a maximum clearance of 7.5 feet at the upstream face of the bridge in 2005 in comparison to 6 feet currently. Some minor bank shaping may be required to maintain stable bank slopes of no greater than 2H:1V as the channel bed is excavated. We estimate that approximately 3,000-4,000 CY of material would be removed over the 2,200 foot length of channel, in addition to the berm removal volume described in Alternative 2.

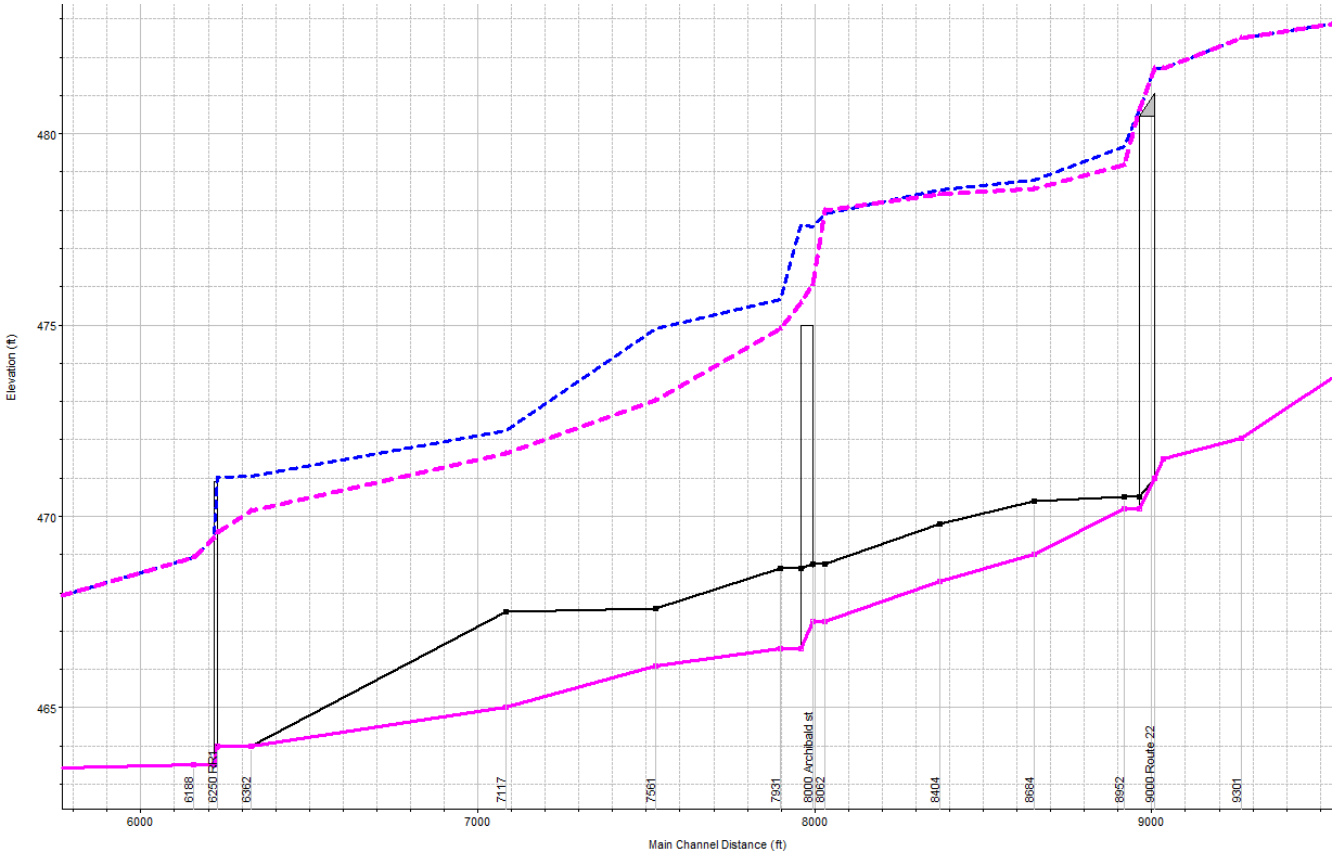

Figure 6.26: Channel deepening to increase capacity from Route 22 to Archibald Street. The magenta lines represent the proposed channel bottom (solid) and 10-year flood profile (dashed). The predicted 10-year surface water elevation does not overtop the Archibald bridge following channel deepening, however flooding upstream of the bridge is not reduced.

Alternatives 3, 3a, and 4

Alternatives 3 and 4 include removing the Archibald Street bridge and the north abutment to increase channel width and capacity. The bridge is currently a significant obstruction to flows at or above the 2-year event (Figure 6.27). Tailwater from the constricted channel increases water surface elevation upstream to the Route 22 bridge in large events. Water surface elevations for the 10-year flood are predicted to drop 1 to 1.5 feet during moderate floods at cross-section 8062 following bridge removal. This would significantly decrease the number of vulnerable homes along Archibald Street, Nichols Street, and Park Place during moderate storm events. Alternative 4 includes the removal of the downstream berms and is predicted to further reduce water surface elevations during the 10-year storm by approximately 0.5 to 1ft at the west end of the Village. Berm removal further reduces water surface elevations through the farm fields and allows the 10-year storm to pass through the railroad bridge below the low chord. Alternative 3a does not remove the bridge and includes a 20ft wide by 5ft tall concrete box culvert installed under Archibald Street immediately north of the bridge. Based on the hydraulic model, the box culvert will achieve the same flood water elevation reductions as bridge removal in Alternative 3. It is important to note that bridge removal will reduce the risk debris catchment during storms and will likely improve sediment transport. Adding a second hydraulic opening (culvert) may actually increase debris catchment risk over the current configuration. We estimate that alternative 3a will require approximately 1,500CY of excavation to create the overflow channel through the culvert. Additional heavy stone armoring will be recommended for the banks of the overflow channel to protect adjacent properties and the bridge abutment.

Figure 6.27: Archibald Street bridge at capacity during the Christmas 2014 flood which we estimated to be an approximate 1-year flood, based on records from nearby USGS gages for this event. Our hydraulic model indicates that a discharge between the 1-year flood estimate (1,250 cfs) and the 2-year flood estimate (1,400 cfs) will exceed the current capacity of the opening. This is further evidence that our model aligns well with large and small flood hydraulics in the Village. Photo courtesy of the Salem Flood Study Committee.

Alternatives 5 and 6

Alternatives 5 and 6 include berm removal, channel deepening, and bank cuts to create flood benches. The flood benches are located below the predicted 2-year flow elevation and increase the available channel and floodplain width during the 2-year and 5-year floods from 40-70 feet to 90-120 feet. The bank cuts between Route 22 and Archibald are typically 20-40 feet wide on the north bank. A larger cut is proposed at cross-section 7117, where the channel is currently very narrow and along the berm (Figures 6.28 and 6.29). These widths are well above the predicted bankfull width for White Creek based on the NY Region 1 regressions, however it is important to increase available floodplain given the repeat flood damage through the Village and the current lack of undeveloped floodplain. Bank cuts will require the removal of approximately 90 large trees that are currently along the top of the north bank in between Route 22 and Archibald Street. The design plans will require dense plantings of native trees and fast growing shrub species (i.e., willows) along the flood bench and the banks. We estimate that the bank cuts will require approximately 5,500-6,500 CY of excavation in addition to the 4,000-5,000 CY described in Alternative 2a for channel deepening.

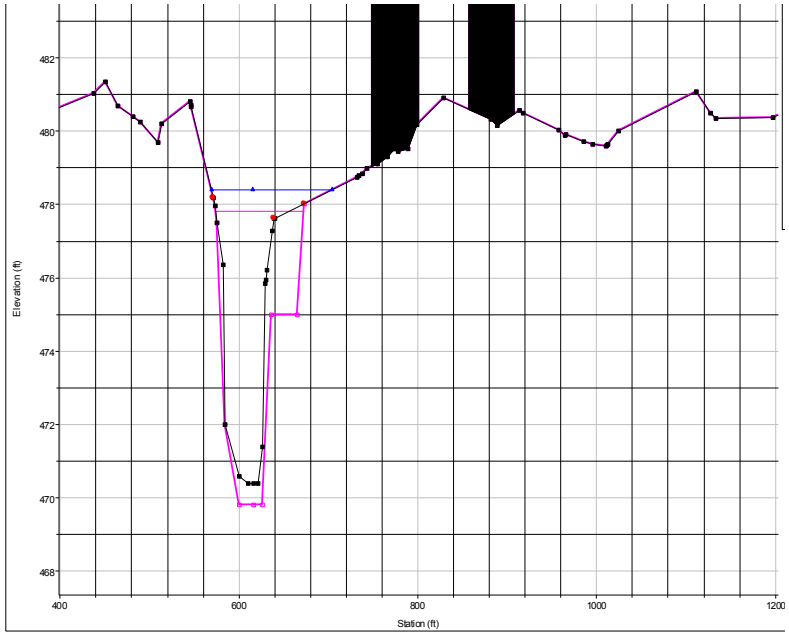

Figure 6.28: Moderate bank cut (40ft) at cross-section 8684. The magenta lines represents proposed channel bottom and flood profile.

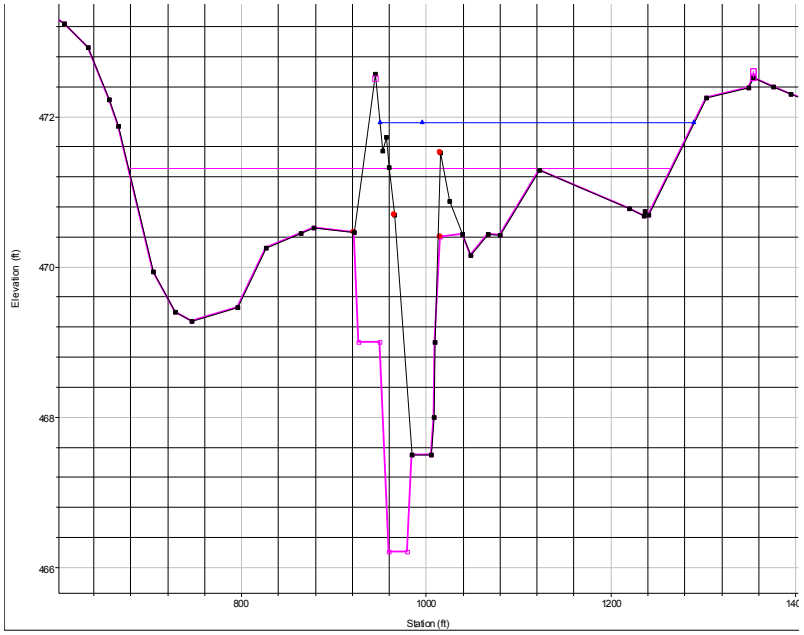

Figure 6.29: Large bank cut (45-50ft), channel deepening, and berm removal at cross-section 7117. The magenta lines represents proposed channel bottom and flood profile.

Alternative 7

Alternative 7 includes the berm removal, channel deepening, and bank cuts described in Alternative 6 with the addition of a large floodplain cut centered on the current Archibald bridge location. The existing floodplain area along the north bank of White Creek approaching the Archibald bridge is somewhat elevated and we predict that it is only accessed during storm events larger than the 2-year flow (Figure 6.30). Unfortunately there is little relief between the floodplain elevation and adjacent houses, therefore floodplain access is likely associated with property damage. The proposed floodplain cut will lower the elevation of the floodplain by approximately 2 feet and extend 90-100 from the current river bank. This cut will require the removal of the house at 41 Archibald St and the removal of approximately 110 ft of roadway extending to the north of the bridge (Figure 6.31). The new floodplain will be accessible at the 2-year storm and is predicted to reduce flood depths upstream to the Route 22 bridge by 0.2 to 0.6 feet compared to Alternative 6, and approximately 2 feet of flood elevation reduction compared to Alternative 1. We estimate that Alternative 7 will require approximately 3,500-4,000 CY of excavation in addition to Alternative 6.

Figure 6.30: Undeveloped floodplain on the north bank approaching the Archibald bridge. The floodplain elevation is only slightly lower than surrounding houses and the road.

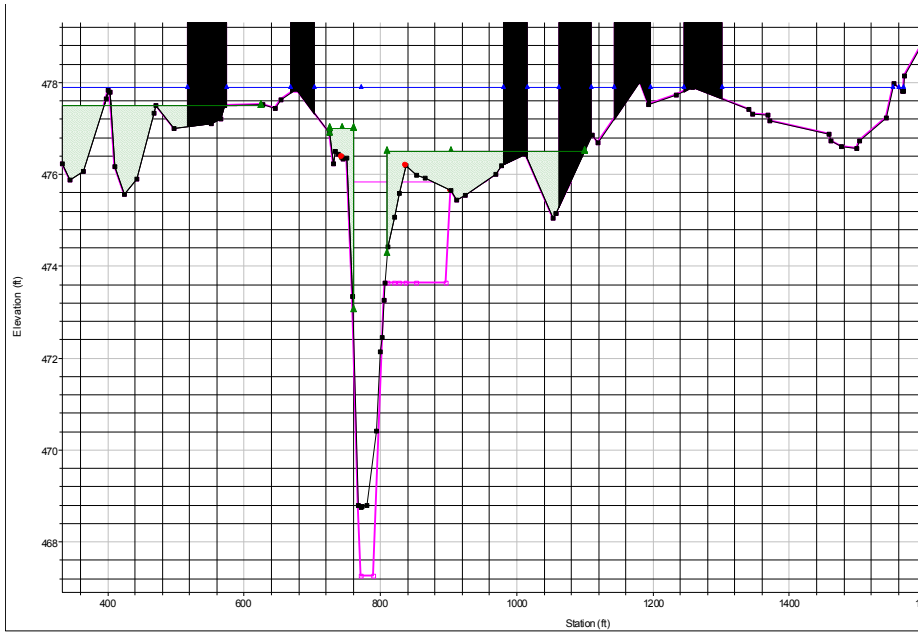

Figure 6.31: Large floodplain cut at Archibald Street including removal of the bridge and the house at 41 Archibald. The magenta lines represents proposed channel bank cuts, channel bottom, and flood profile.

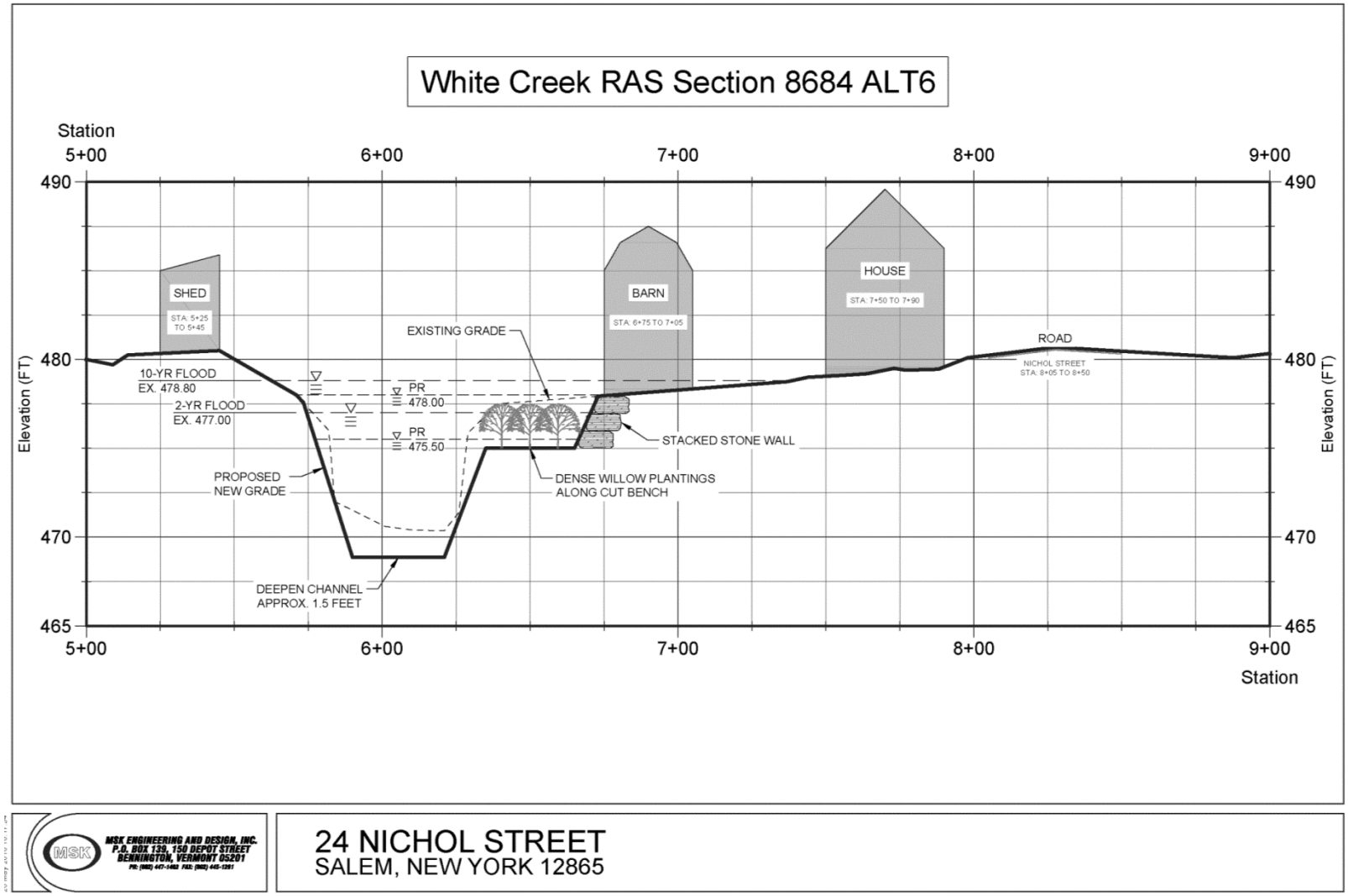

Figure 6.32: Typical cross-section of Alternative 6 and 7 channel widening and deepening to lower flood levels.

6.3 Mitigation Project Prioritization and Potential Funding

Included in Appendix 4 are alternatives matrices summarizing the benefits, ballpark costs, estimated implementation time frame, and permitting jurisdictions for each alternative. These tables provide a way for the community and other stakeholders to compare each alternative and chart a path forward to reduce flood vulnerability in Salem. Below we have used our professional judgment to prioritize projects for near and long term implementation, with potential funding sources listed for each alternative.

Upstream Project Prioritization

Near Term Projects	Potential Funding Sources
1. Unstable embankment along County Route 153 near Braymer Road (Alternative 3)	• WCDPW
2. Improve downstream hydraulic opening at Beatty Hollow Road Bridge (Alternative 2)	• WCDPW
3. Remove Upstream Constriction at County Route 153 Bridge (Alternative 6)	• WCDPW

Long Term Projects	Funding Source
1. Floodplain reconnection upstream of Blind Buck Road (Alternative 1)	• FEMA; NRCS
2. Replace Beatty Hollow Road Bridge to improve alignment and hydraulic capacity (Alternative 2)	• WCDPW; FEMA
3. Floodplain reconnection upstream of Railroad Bridge #4 (Alternative 5)	• FEMA; NRCS

Village Project Prioritization

Near Term Projects	Potential Funding Sources
1. Remove Archibald Street Bridge Deck and North Abutment (Alternative 3)	• WCDPW; NYDEC
2. Deepen channel through Village and develop a long-term sediment maintenance plan. (Alternative 2a)	• FEMA; Town of Salem
3. Remove berms on south bank downstream of Salem Village. (Alternative 2)	• NRCS

Long Term Projects	Funding Source
1. Bank cut on north bank in between Route 22 and Archibald Street. (Alternative 6)	• FEMA; Town of Salem
2. Bank cut and floodplain restoration on north bank in between Route 22 and Archibald Street; Buyout of home at 41 Archibald Street. (Alternative 7)	• FEMA; Town of Salem

7.0 Conclusions and Recommendations

The White Creek corridor has been historically manipulated along most of its length from West Rupert into Salem, leading to increased flood vulnerability in the Village of Salem. The lack of historical flow monitoring on White Creek and the highly modified channel and floodplain made it challenging to estimate watershed flood hydrology and model river corridor hydraulics. We put significant effort into the hydrologic and hydraulic analysis to develop a sound basis for evaluating flood mitigation alternatives in Salem. The hydraulic model served as a tool for this evaluation, and can be used and refined in the future to support subsequent steps such as engineering design, grant applications, and permitting. Below we suggest next steps for the communities in the watershed to move this planning process forward, including project and planning recommendations.

7.1 Next Steps

As part of the ongoing community discussion regarding flood resiliency planning in the White Creek watershed, we recommend the following steps to incorporate the community's input into the final prioritization and advance the projects over time:

- Solicit input from individuals, businesses, and officials from the Towns of Salem and Rupert at future community meetings regarding specific projects and overall project prioritization.
- Prioritize one to two projects to pursue each year with assistance from WCDPW, A/GFTC, and other participating groups to identify appropriate funding sources and partners.
- Apply for one to two grants each year to advance project development and/or designs.
- Implement projects as funding allows, and monitor project success.

7.2 Project and Planning Recommendations

- Improving hydraulic capacity at the Archibald Street crossing, either by removing the bridge deck and north abutment or installing an overflow box culvert, should be a priority for reducing flood vulnerability in Salem Village.
- Sediment management options for the White Creek channel in Salem Village should be explored in further detail in the near-term to reduce flood vulnerability in the Village. This will require additional survey work to set benchmarks for long-term monitoring and aggradation levels that trigger maintenance, and extensive coordination with NYDEC, USACE, and other stakeholders to ensure impacts to aquatic habitat and downstream water quality are minimized.
- Floodplain restoration and reconnection projects upstream of the Village are a priority for reducing flood vulnerability in the long-term. Our modeling indicates that floodplain reconnections totaling 10% of the volume of a moderate flood (i.e., 10-year flood), could reduce the peak discharge in Salem Village by as much as 25%. The three (3) upstream floodplain reconnection projects we scoped in this study could cumulatively achieve this reduction over the long-term.
- River science needs to be better incorporated into future public infrastructure projects in the watershed to ensure proper sizing and scour protection measures for bridges and roadway stabilization.

- To further identify and evaluate upstream floodplain restoration and reconnection opportunities, we recommend a field-based geomorphic study and river corridor plan for the White Creek reaches in Salem to complement similar work in the Vermont portion of the watershed. This work would follow the Vermont Agency of Natural Resources Protocols referenced in this report (VTANR, 2009; VTANR, 2010).
- There is a need for better coordination amongst partners working in the watershed, including the towns, A/GFTC, WCDPW, USFWS, Trout Unlimited, and Battenkill Watershed Alliance. The need for this coordination is two-fold: 1. to ensure that habitat enhancement work (i.e., weirs) does not increase flood vulnerability for nearby homes, farmland, and infrastructure; 2. To ensure that public infrastructure and flood mitigation projects summarized in this report are conducted in a way to minimize impacts to aquatic habitat and downstream water quality.

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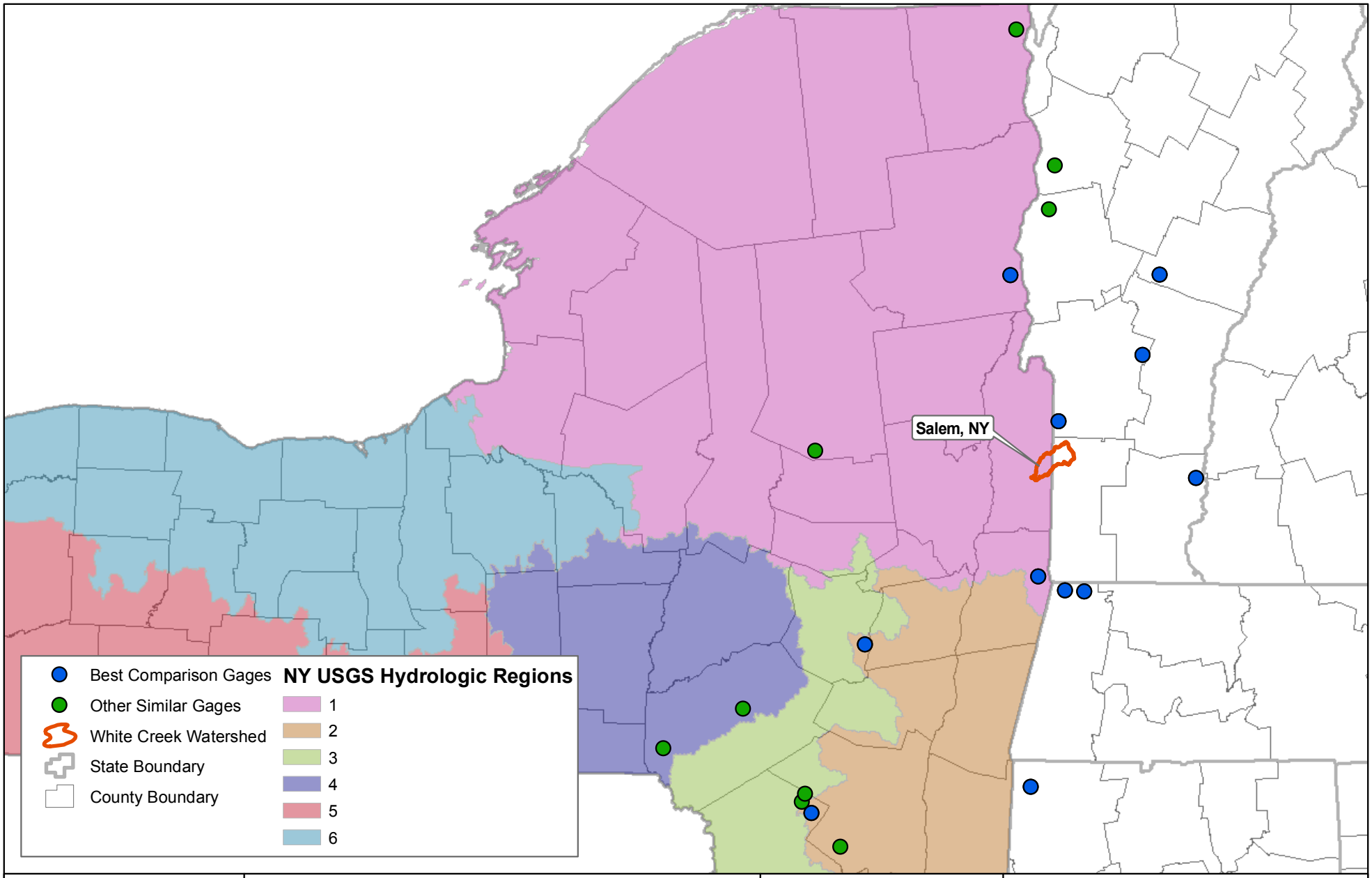
APPENDIX 1:

HYDROLOGIC ANALYSIS MAPS



Fitzgerald Environmental Associates, LLC
18 Severance Green, Suite 203
Colchester, VT 05446
Telephone: 802.876.7778
www.fitzgeraldenvironmental.com

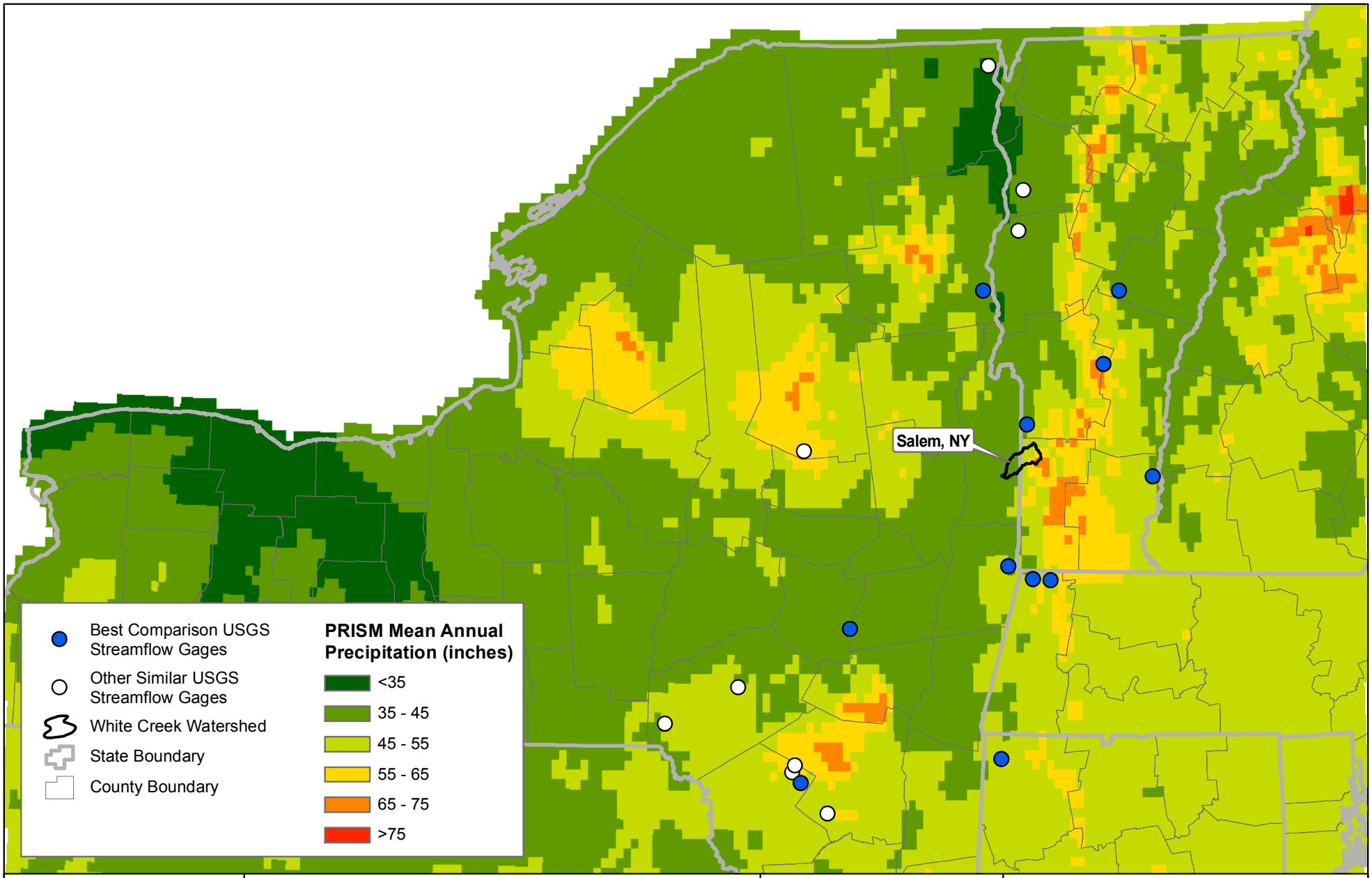
White Creek Study Hydrologic Modeling

Figure 1: USGS Hydrologic Regions and Gaging Station Comparison

0 20 40 Miles

Date: Jan 18, 2016
Drawn: JHB

Notes:
-USGS comparison gaging stations were selected based on several basin characteristics: drainage area, basin slope, annual precipitaiton, basin runoff, basin storage, and lag.



Fitzgerald Environmental Associates, LLC
18 Severance Green, Suite 203
Colchester, VT 05446
Telephone: 802.876.7778
www.fitzgeraldenvironmental.com

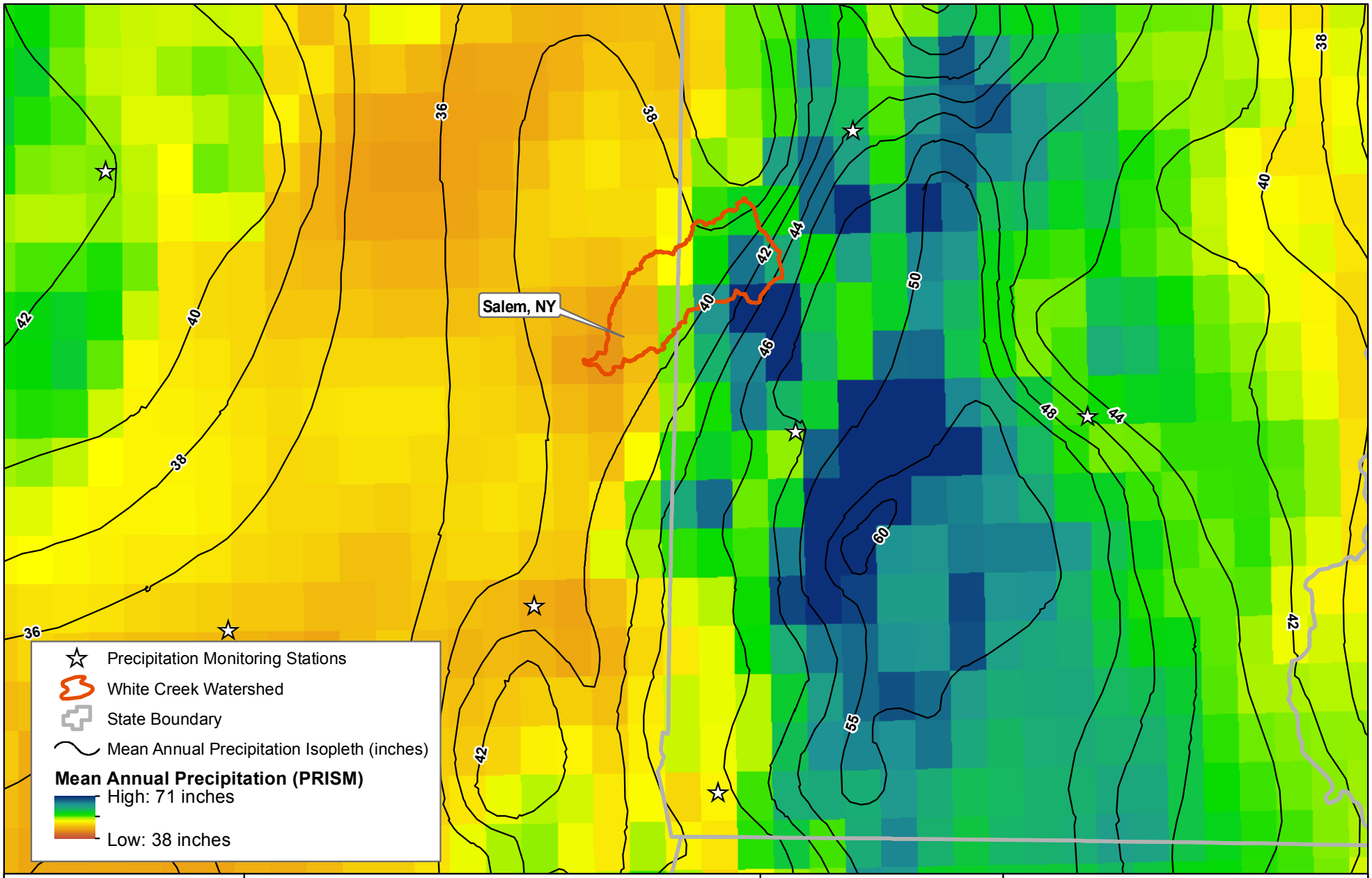
White Creek Study Hydrologic Modeling

Figure 2: Regional Annual Precipitation Estimates

0 25 50 Miles

Date: Jan 18, 2016
Drawn: JHB

Notes:
- Rainfall isopleths are based on a 1951-1980 dataset described by Randall (1996).
- PRISM rainfall grid data is based on 1981-2010 dataset described by Olson (2014).
- USGS comparison gaging stations were selected based on several basin characteristics: drainage area, basin slope, annual precipitaiton, basin runoff, basin storage, and lag.



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Colchester, VT 05446
Telephone: 802.876.7778
www.fitzgeraldenvironmental.com

White Creek Study Hydrologic Modeling

Figure 3: Recurrence Interval Rainfall Depth Estimates

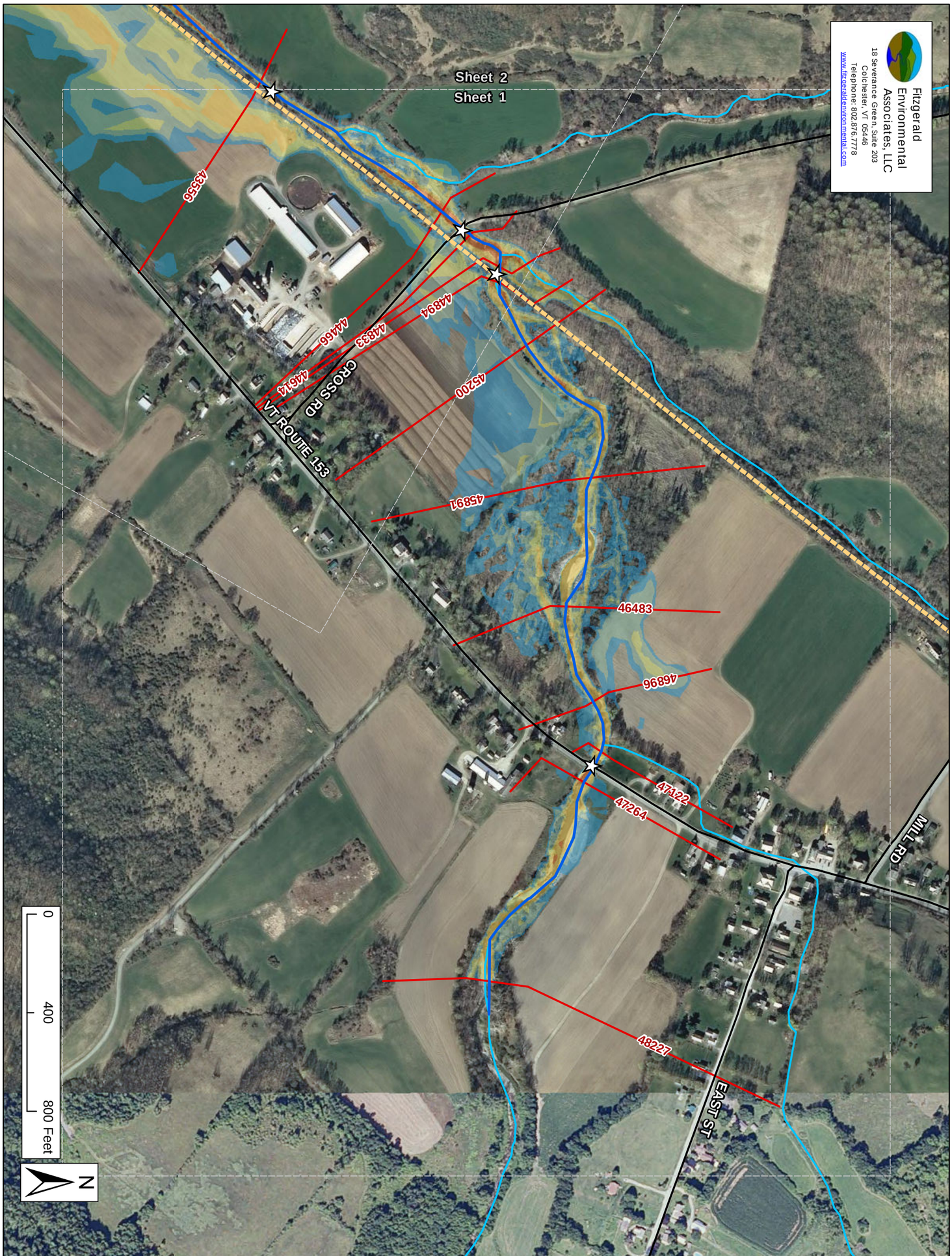
0 5 10 Miles

Date: Jan 07, 2016
Drawn: JHB

Notes:
- Rainfall isopleths are based on a 1951-1980 dataset described by Randall (1996).
- PRISM rainfall grid data is based on 1981-2010 dataset described by Olson (2014).
- Precipitation monitoring stations used to determine recurrence interval rainfall depths from NCRC/NRCS Extreme Precipitation Model

APPENDIX 2:

TROPICAL STORM IRENE FLOOD SIMULATION MAPS



Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 1 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel

Notes:
- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel

Bridges
Roads
Historic Railroad
Railroad
Study Reaches
Surface Waters
High Water Mark
White Creek Watershed
Map Grid
GeoRAS Cross-Sections

Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10

White Creek Study

Hydraulic Modeling

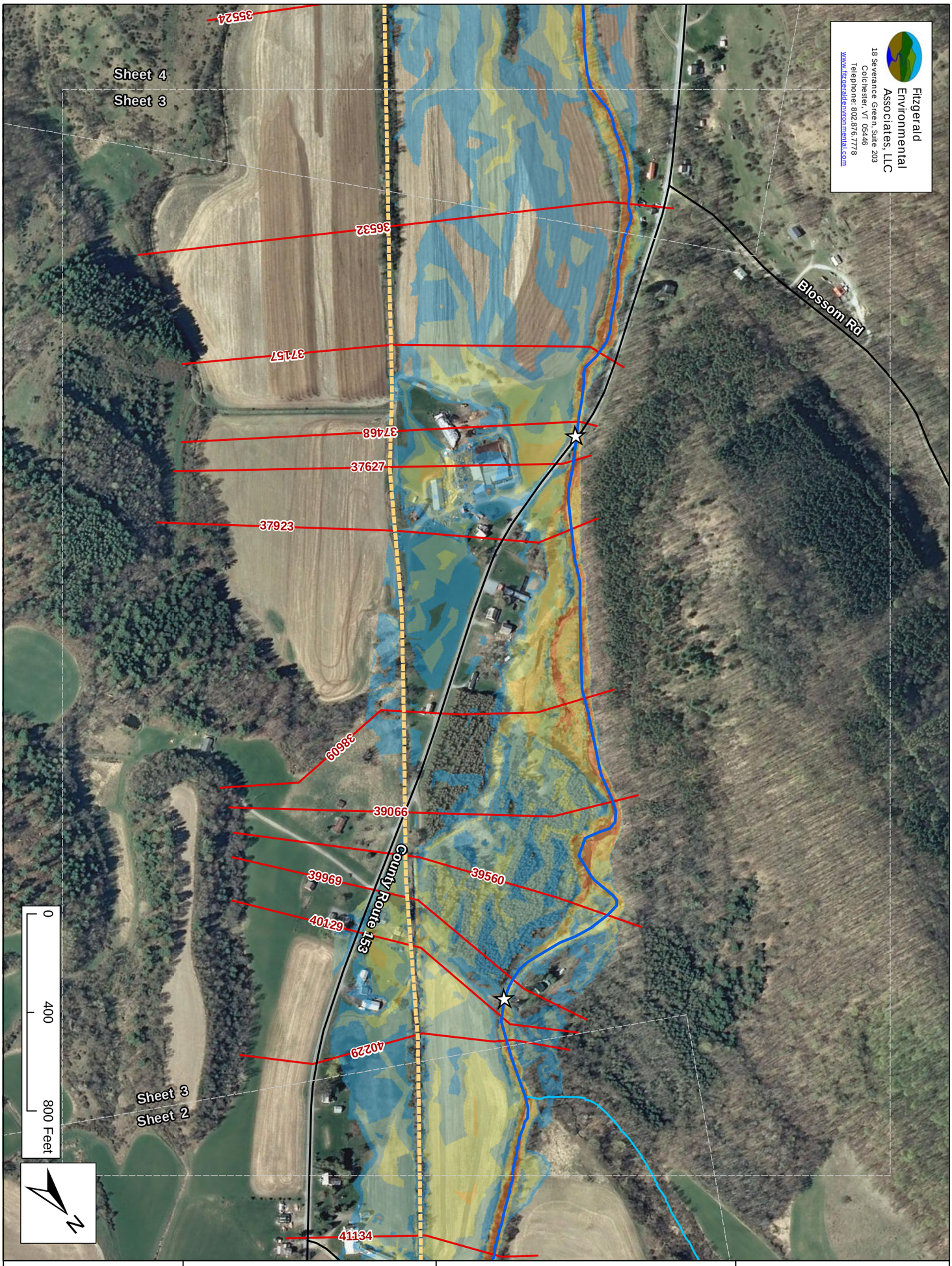
Salem, NY

Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 2 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016



Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 3 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

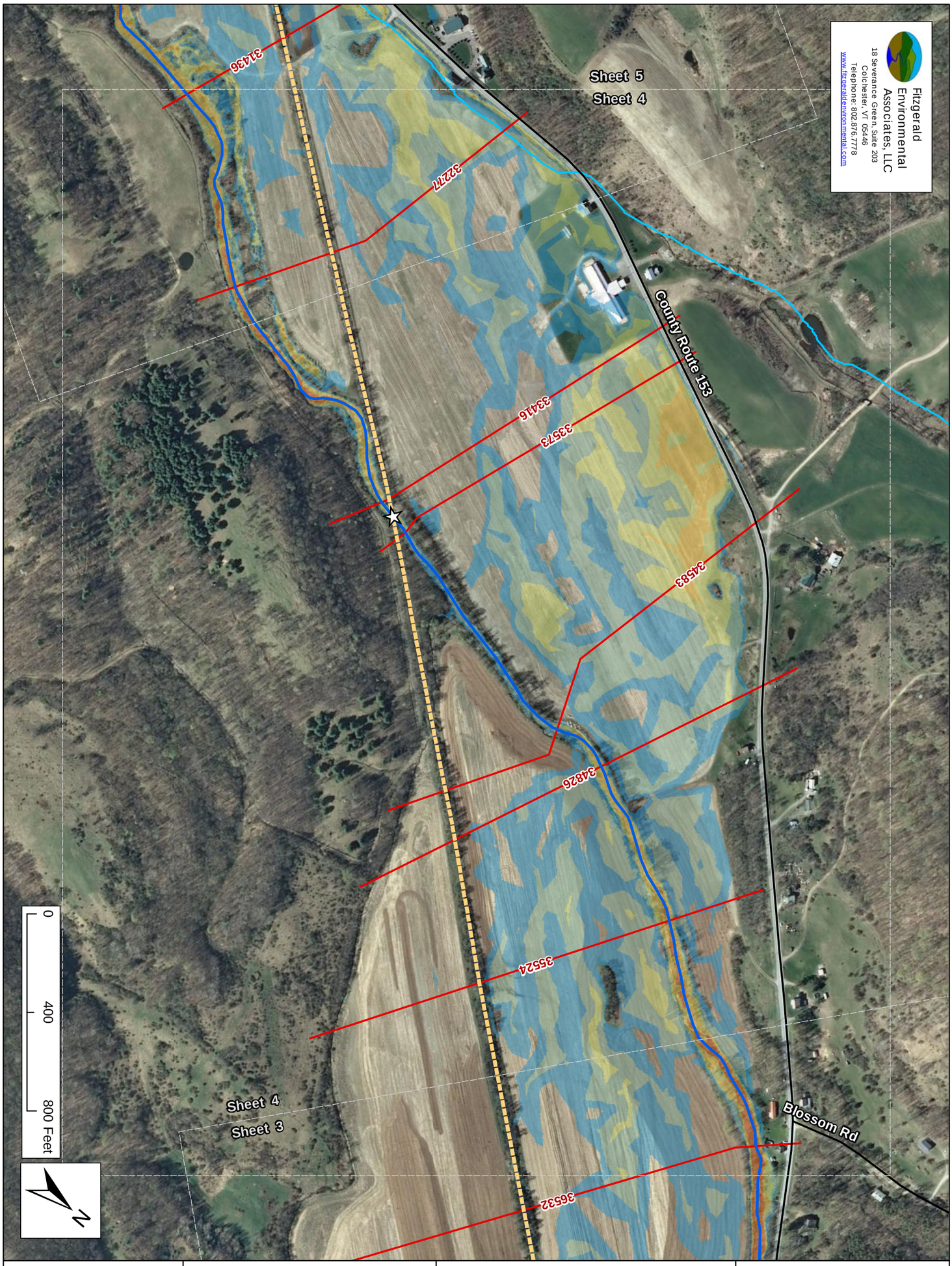
- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel



Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 4 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

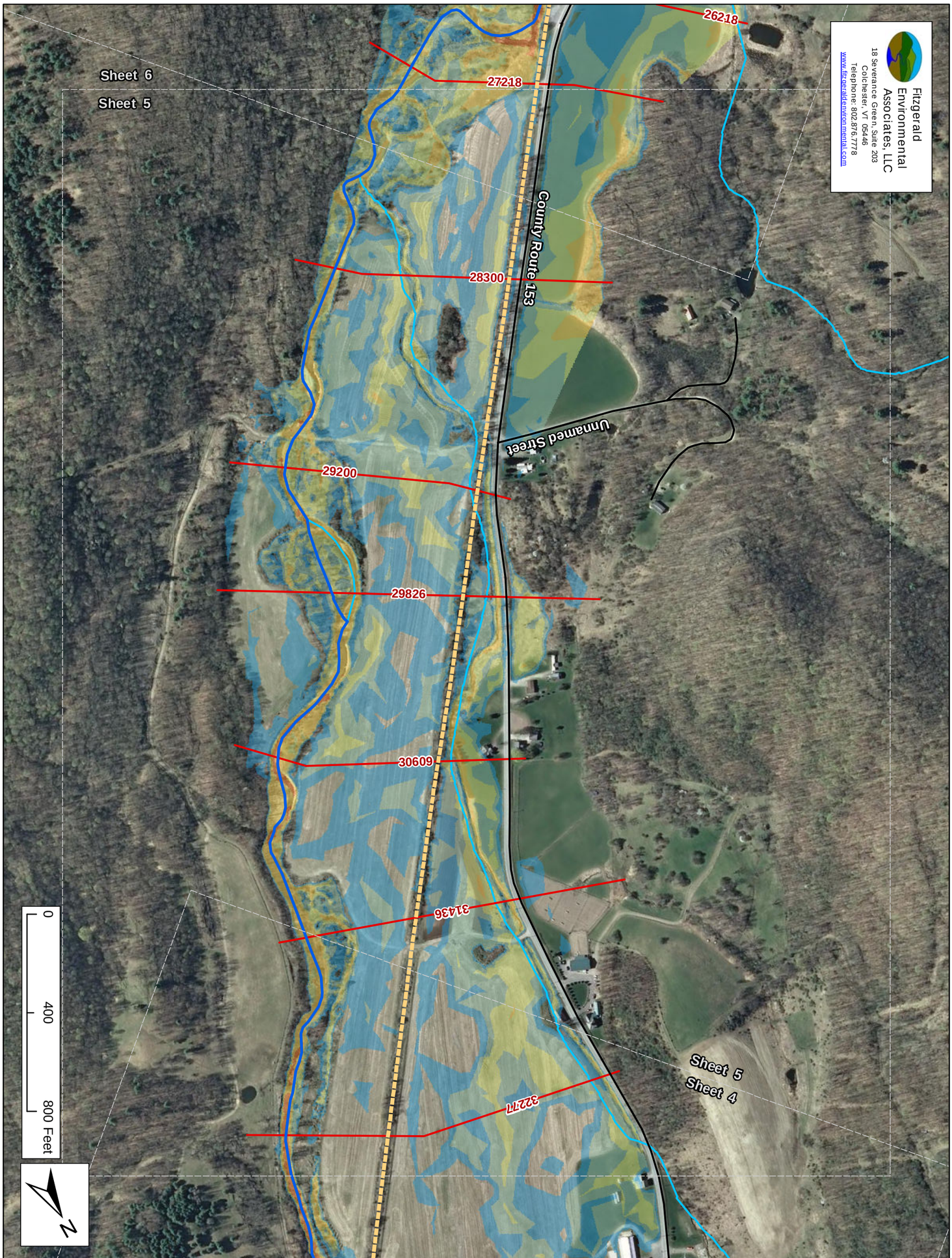
- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel



Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 5 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

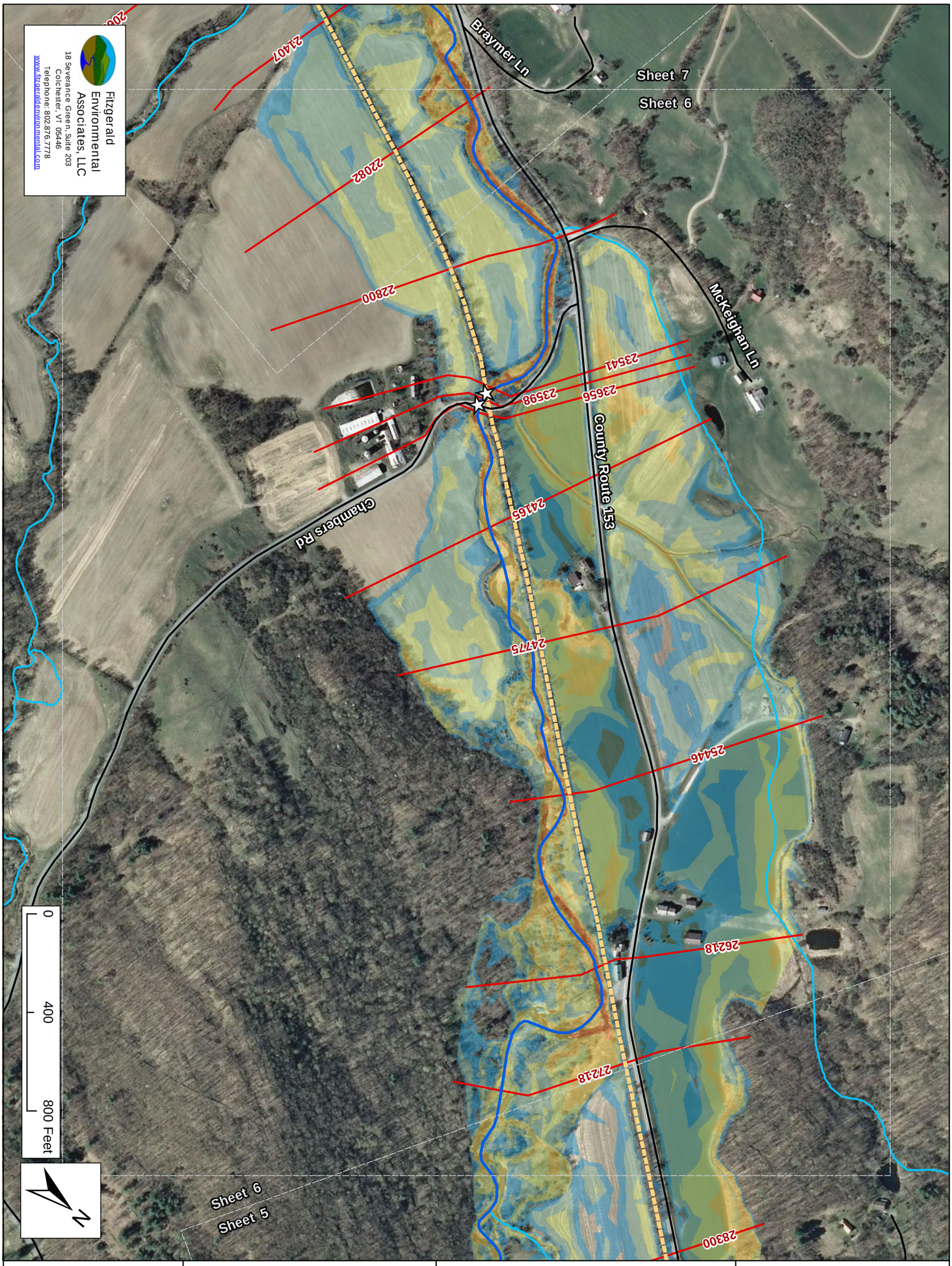
- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel



Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 6 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
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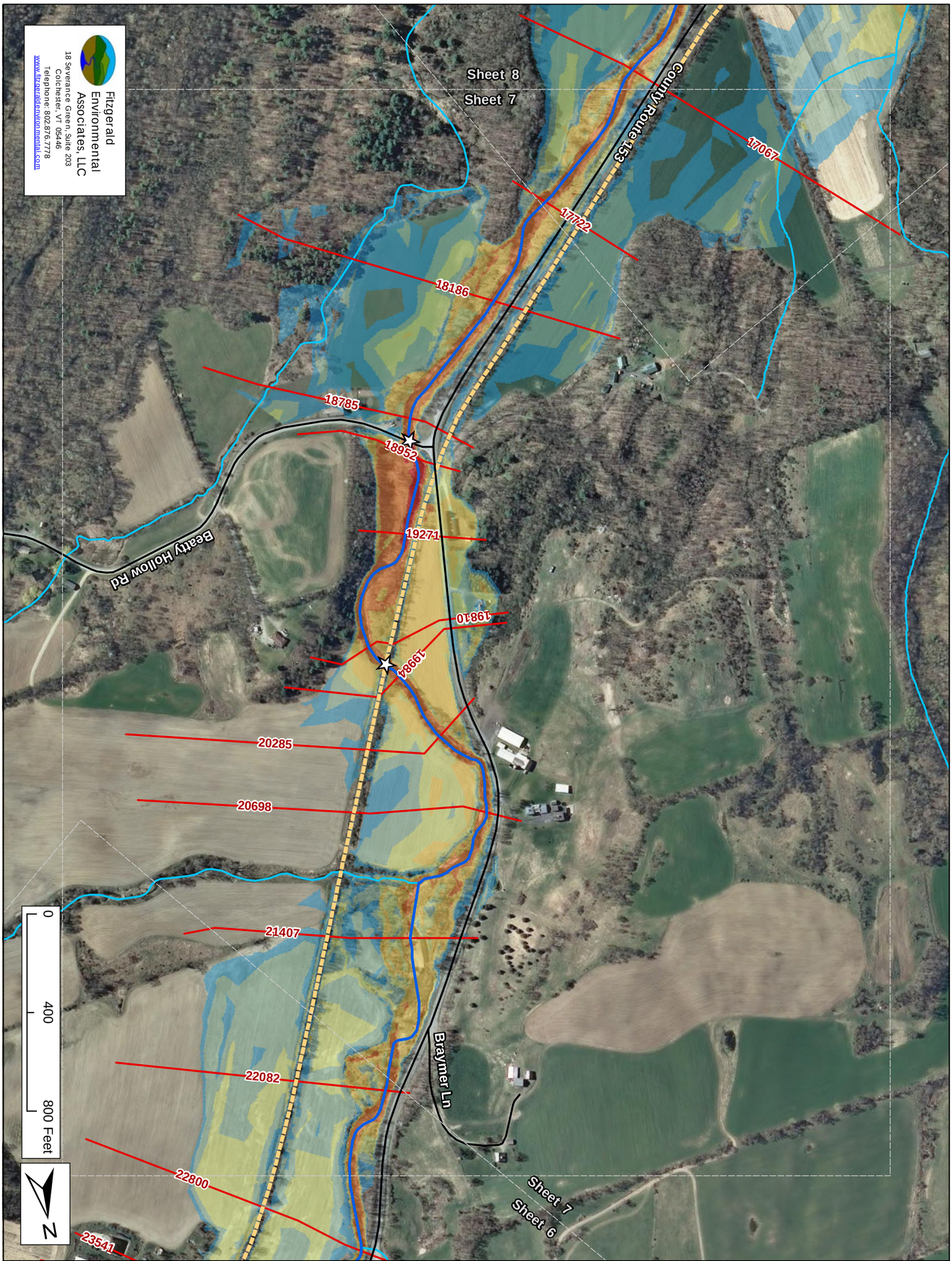


Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 7 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

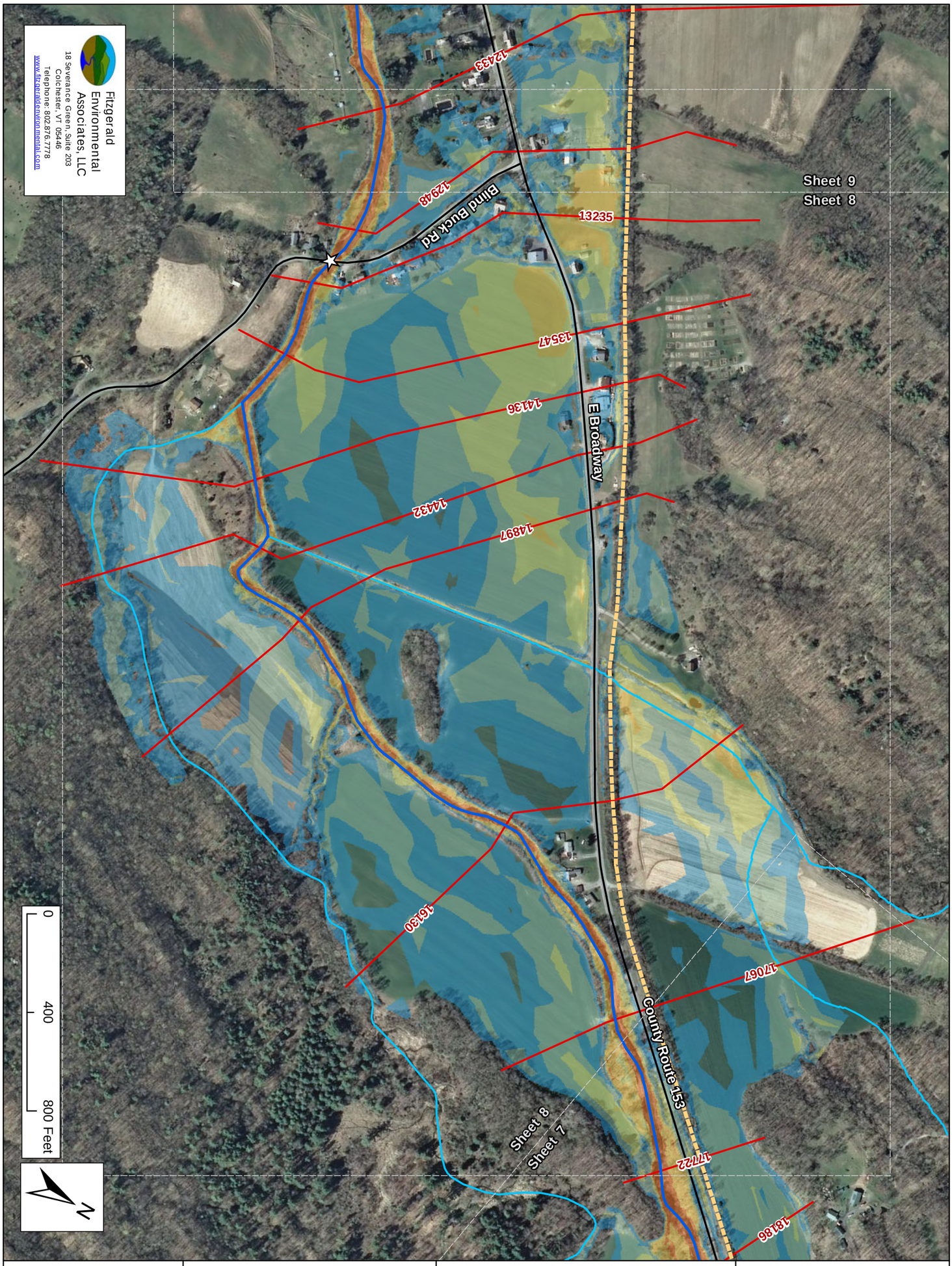
- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel



Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 8 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel

Notes:
- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel

Bridges
Roads
Historic Railroad
Railroad
Study Reaches
Surface Waters
High Water Mark
White Creek Watershed
Map Grid
GeoRAS Cross-Sections

Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10

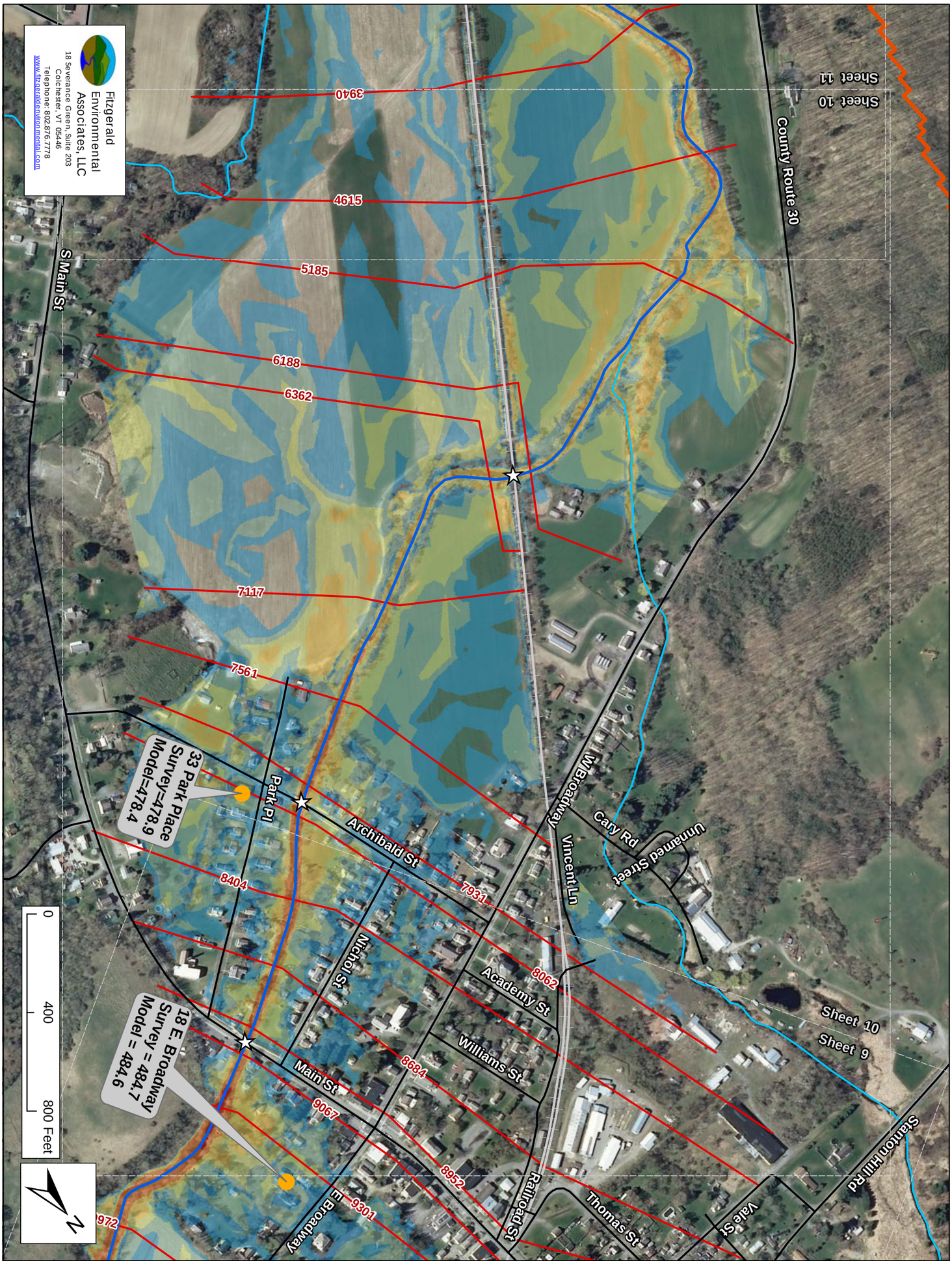
White Creek Study
Hydraulic Modeling
Salem, NY

Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 9 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016



Flood Depth Mapping

Simulated T.S. Irene 2011 Flood

Map 10 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

- Bridges
- Roads
- Historic Railroad
- Railroad
- Study Reaches
- Surface Waters
- High Water Mark
- White Creek Watershed
- Map Grid
- GeoRAS Cross-Sections

Flood Depth (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Notes:

- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Map tile orientation is variable to best follow the stream channel

Notes:
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- Map tile orientation is variable to best follow the stream channel

Bridges
Roads
Historic Railroad
Railroad
Study Reaches
Surface Waters
High Water Mark
White Creek Watershed
Map Grid
GeoRAS Cross-Sections

Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10

White Creek Study
Hydraulic Modeling
Salem, NY

Flood Depth Mapping

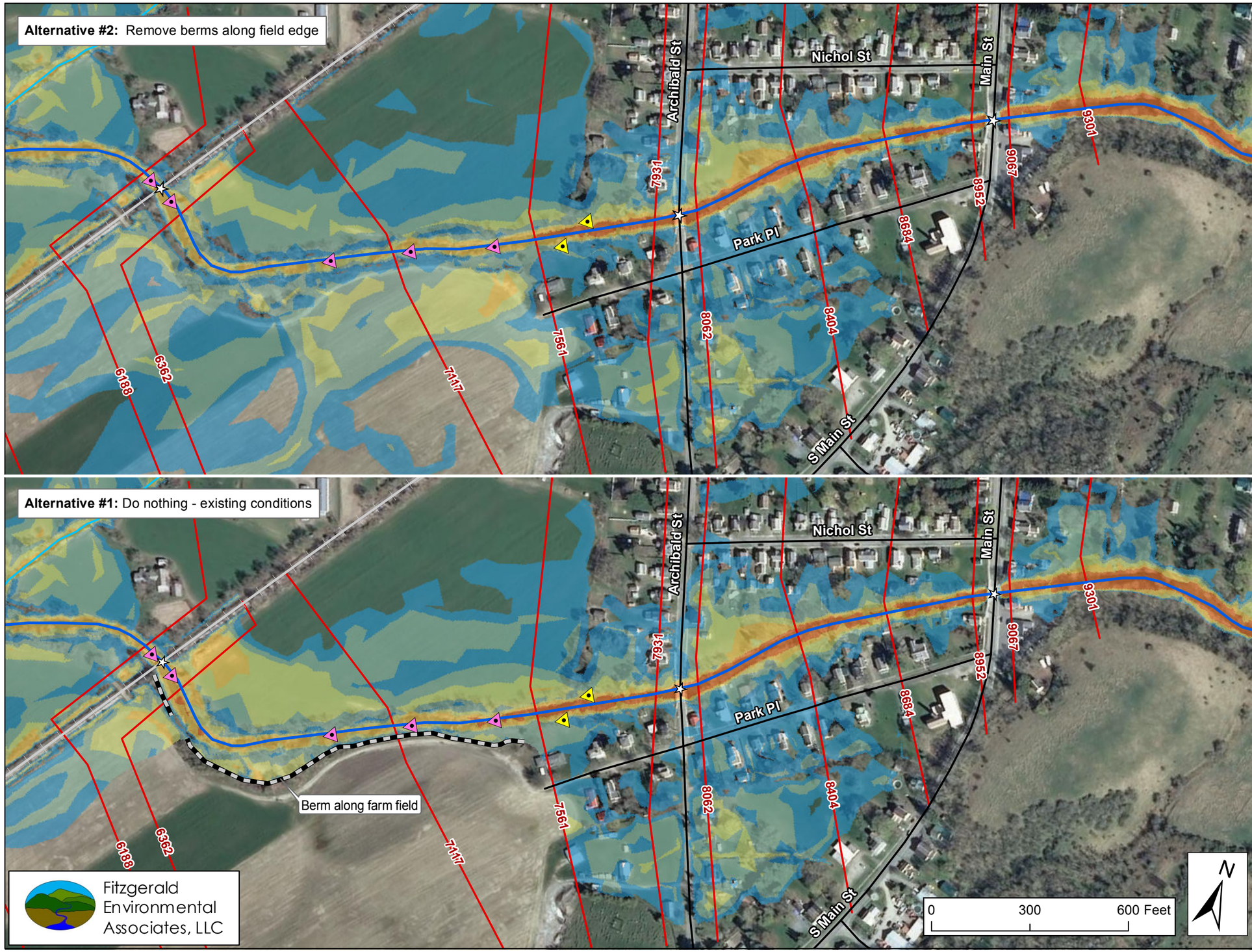
Simulated T.S. Irene 2011 Flood

Map 11 of 11

Drawn: JHB and EPF
Date: Apr 1, 2016

APPENDIX 3:

ALTERNATIVES ANALYSIS MAPS



Bridges
Roads
Railroad
Study Reaches
Surface Waters
White Creek Watershed
Cross-Vane
Bank Weir
Field Berm
GeoRAS Cross-Sections

Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10

Notes:
- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Flood depths are based on an estimated 5-year storm flow of 2,080cfs and an estimated 10-year storm flow of 2,844cfs

Drawn: JHB and EPF
Date: May 9, 2016

White Creek Study

Hydraulic Modeling

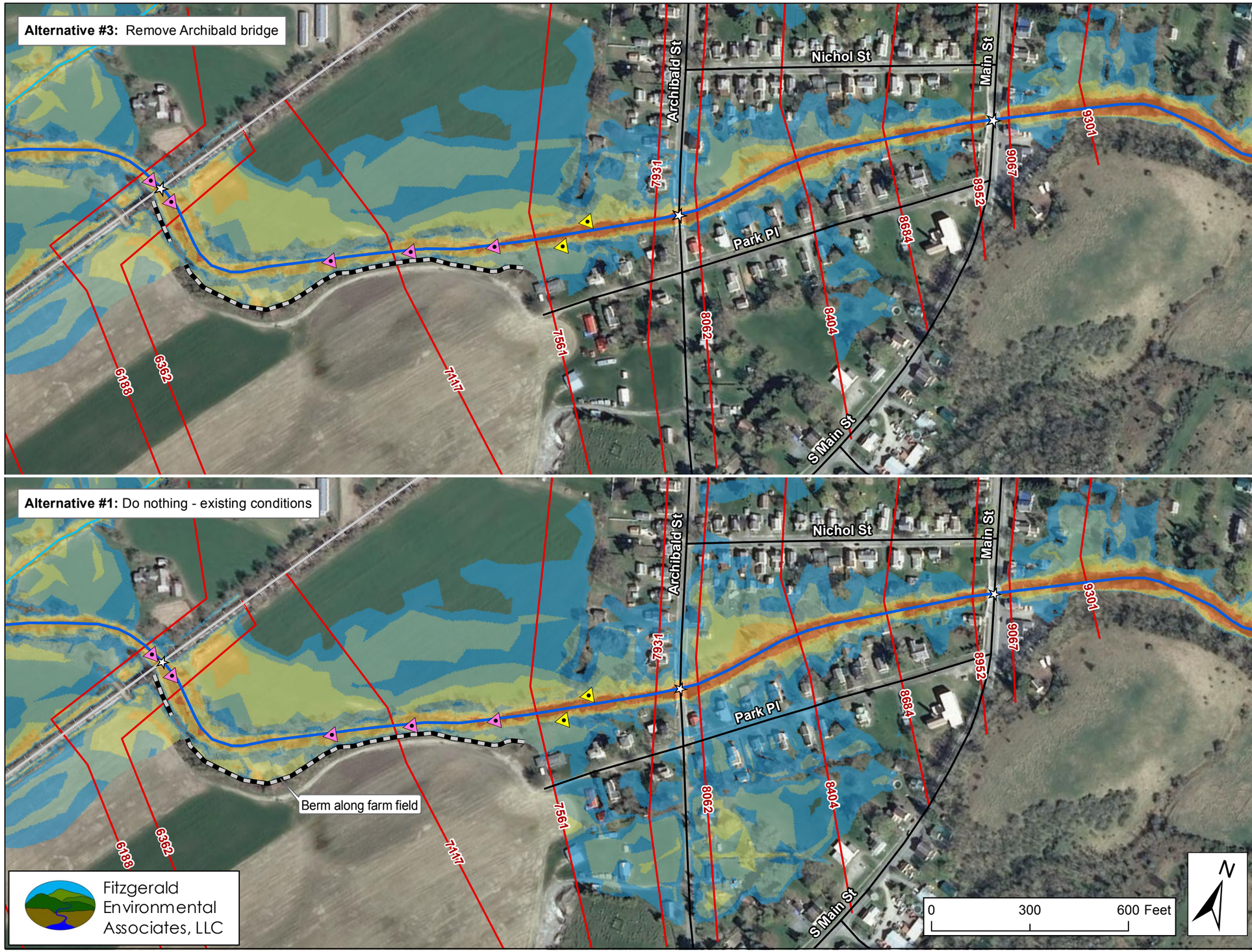
Salem, NY

Flood Depth Mapping

Alternative 2

Approximate 10-year flood

Alternative #2a: Remove berm along field edge and deepen channel
Alternative #1: Do nothing - existing conditions
Berm along farm field
Archibald St
Nichol St
Main St
Park Pl
S Main St
6188
6362
7141
7561
7931
8062
8404
8684
8952
9097
9301
0
300
600 Feet
N
Fitzgerald Environmental Associates, LLC
Bridges
Roads
Railroad
Study Reaches
Surface Waters
White Creek Watershed
Cross-Vane
Bank Weir
Field Berm
GeoRAS Cross-Sections
Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10
Notes:
- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Flood depths are based on an estimated 5-year storm flow of 2,080cfs and an estimated 10-year storm flow of 2,844cfs
Drawn: JHB and EPF
Date: May 9, 2016
White Creek Study
Hydraulic Modeling
Salem, NY
Flood Depth Mapping
Alternative 2a
Approximate 10-year flood



Notes:
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- Flood depths are based on an estimated 5-year storm flow of 2,080cfs and an estimated 10-year storm flow of 2,844cfs

Drawn: JHB and EPF
Date: May 9, 2016

Bridges
Roads
Railroad
Study Reaches
Surface Waters
White Creek Watershed
Cross-Vane
Bank Weir
Field Berm
GeoRAS Cross-Sections

Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10

White Creek Study
Hydraulic Modeling
Salem, NY

Flood Depth Mapping

Alternative 3

Approximate 10-year flood

Notes:
- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Flood depths are based on an estimated 5-year storm flow of 2,080cfs and an estimated 10-year storm flow of 2,844cfs

Drawn: JHB and EPF
Date: May 9, 2016

GeoRAS Cross-Sections

Flood Depth (ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 10
- > 10

Bridges
Roads
Railroad
Study Reaches
Surface Waters
White Creek Watershed
Cross-Vane
Bank Weir
Field Berm

White Creek Study

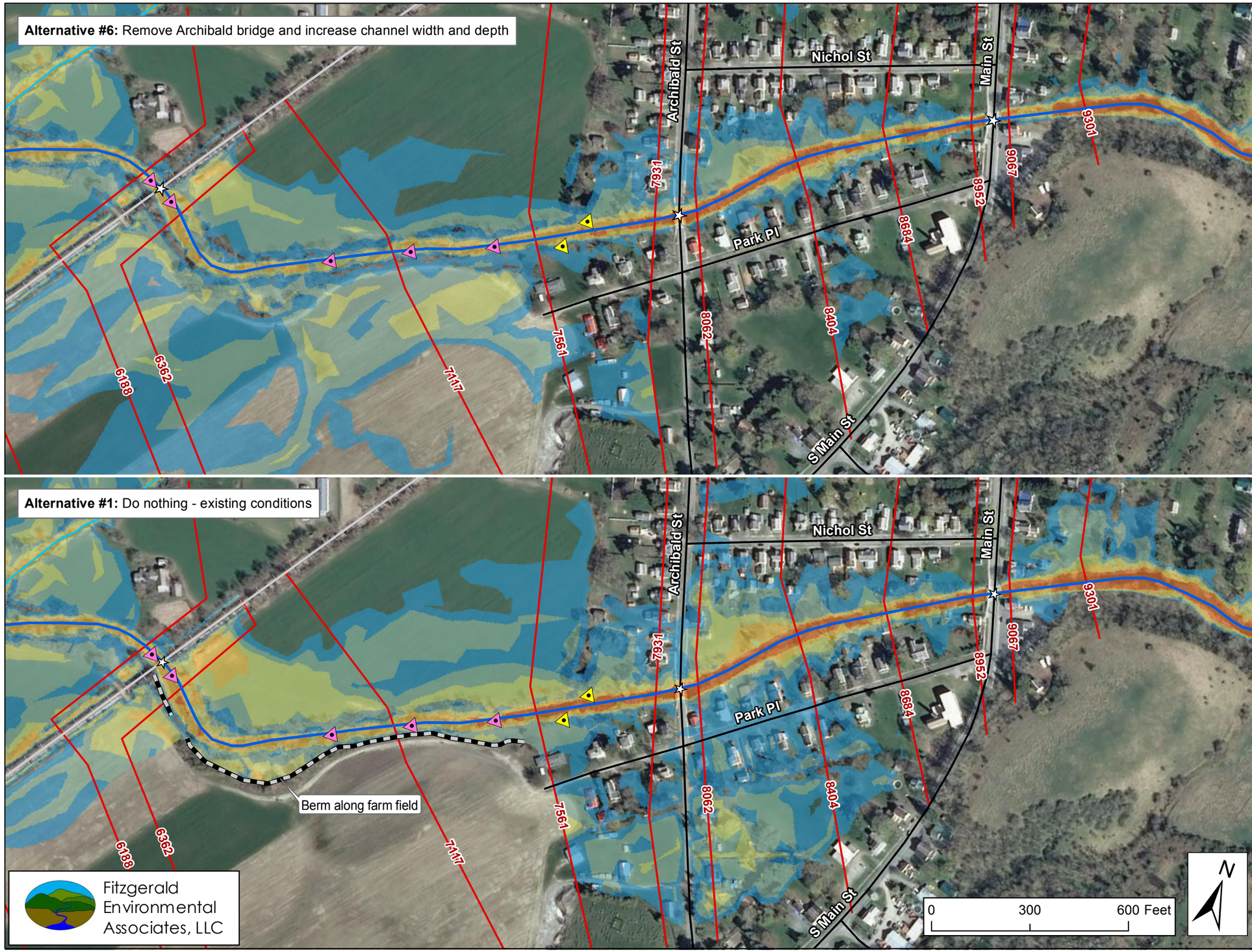
Hydraulic Modeling

Salem, NY

Flood Depth Mapping

Alternative 4

Approximate 10-year flood



Notes:
- Flood depth grid is mapped from water surface elevations calculated at each cross-section using a HEC-RAS hydraulic model and predicted flows from a hydrologic analysis
- Flood depths are based on an estimated 5-year storm flow of 2,080cfs and an estimated 10-year storm flow of 2,844cfs

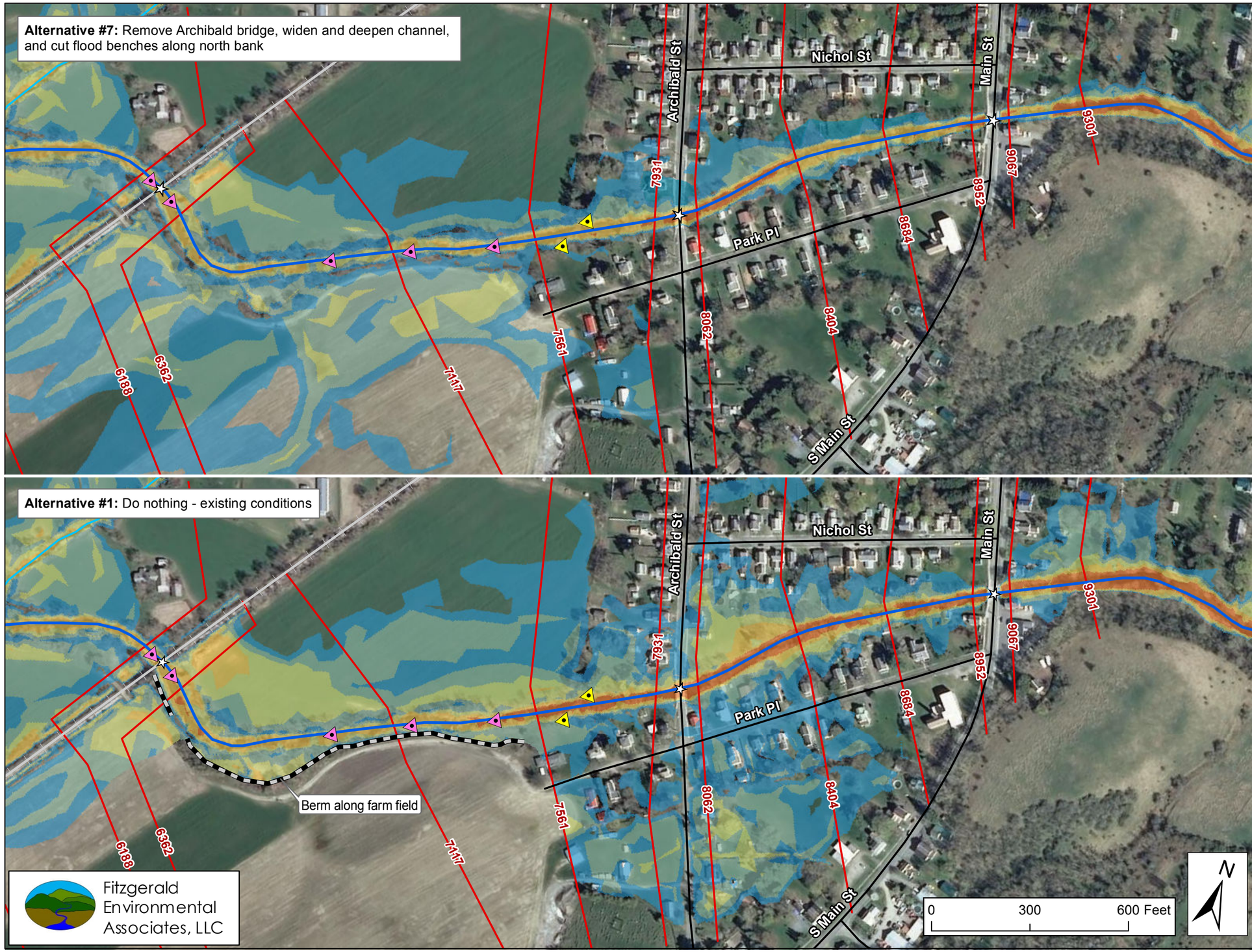
Drawn: JHB and EPF
Date: May 9, 2016

Bridges
Roads
Railroad
Study Reaches
Surface Waters
White Creek Watershed
Cross-Vane
Bank Weir
Field Berm
GeoRAS Cross-Sections

Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10

White Creek Study
Hydraulic Modeling
Salem, NY

Flood Depth Mapping
Alternative 6
Approximate 10-year flood



Bridges
Roads
Railroad
Study Reaches
Surface Waters
White Creek Watershed
Cross-Vane
Bank Weir
Field Berm
GeoRAS Cross-Sections

Flood Depth (ft)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10

Notes:
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Drawn: JHB and EPF
Date: May 9, 2016

White Creek Study

Hydraulic Modeling

Salem, NY

Flood Depth Mapping

Alternative 7

Approximate 10-year flood

APPENDIX 4:

MITIGATION PROJECT MATRICES

White Creek Watershed, Rupert, VT & Salem, NY

Recommended Projects to Protect Infrastructure, Residences, and Businesses from Future Flooding

July 19, 2016

Legend

● Effective ◒ Limited ○ Ineffective

		OBJECTIVES				FEASIBILITY				
Project	**What is At Risk?**	**Reduces Flood Risk[1]**	**10-year Flood Level Reduction in Village**	**Reduces Erosion Risk[2]**	**Protects Businesses, Infrastructure, and Property**	**Ease of Implementation**	**Implementation Cost Range**	**Estimated Time for Implementation**	**Permitting Jurisdictions**	**Comments**
Upstream Alternatives										
Alternative 1: Floodplain Reconnection Upstream (East) of Blind Buck Road	Businesses, Residences, & County/Town Infrastructure	●	0.5 - 1ft	●	●	Difficult	$100K-150K	2-3 years	NYDEC; USACE	Berms along both banks restrict access to floodplains on both sides of river during 10-year floods and greater. Approximately 33 acre-ft of floodplain storage could be reconnected for moderate floods. Berm removal would require excavation of approximately 1,800CY of material along the banks, with some tree removal likely. Temporary and permanent easements with farm owner would be needed.
Alternative 2: Beatty Hollow Bridge Retrofit or Replacement; Improve downstream hydraulic opening	Businesses, Farms, Residences, & County/Town Infrastructure	●	N/A	●	●	Difficult	$500K (replacement); $10K-$15K (improve opening)	2-3 years (replacement); <1 year (improve opening)	NYDEC; USACE	Widening clear span to predicted bankfull width of 65 feet (from USGS regression) and realigning opening would lower flood depths during large floods by 3 feet or more, reducing risk of neaby flooding and erosion along the road embankment. A temporary solution to increasing capacity involves removing a downstream constriction caused by existing bank riprap projecting into the channel (approximately 60CY).
Alternative 3: Unstable Embankment along County Road 153 near Braymer Road	County Transportation Infrastructure	○	N/A	●	●	Moderate	$60K-$75K	1-2 years	NYDEC; USACE	The well intentioned Irene recovery work to reconnect an abandoned meander made the Rt 153 embankment more vulnerable to erosion by increasing floodwater velocity over the upstream diversion weir. Embankment armoring and grade control with large stone (approximately 220CY) would protect the roadway during future flood events.
Alternative 4: Floodplain Reconnection Downstream (West) of Chambers Road	Businesses, Farms, Residences, & County/Town Infrastructure	●	0.5 - 1ft	●	●	Difficult	$250K-$300K	2-3 years	NYDEC; USACE	Berms and the abandoned railroad bed east of the Creek restrict access to floodplains during 10-year floods and greater. Approximately 12 acre-ft of floodplain storage could be reconnected for moderate floods. Berm removal would require excavation of approximately 8,600CY of material, with some tree removal likely along the banks. Temporary and permanent easements with farm owner would be needed.
Alternative 5: Floodplain Reconnection Upstream (East) of Railroad Bridge #4	Businesses, Farms, Residences, & County/Town Infrastructure	●	0.5 - 1ft	●	●	Difficult	$150-$200K	2-3 years	NYDEC; USACE	Berms along the west bank restrict access to floodplains during 10-year floods and greater. Approximately 32 acre-ft of floodplain storage could be reconnected for moderate floods. Berm removal would require excavation of approximately 4,000CY of material along the banks, with some tree removal likely. Temporary and permanent easements with farm owner would be needed.
Alternative 6: County Route 153 Bridge Upstream Constriction	Businesses, Farms, Residences, & County/Town Infrastructure	◒	N/A	◒	◒	Easy	$5K-$10K	1 year	None	An old laid up stone abutment upstream of the Rt 153 bridge constricts the channel, aggravating out of bank flows and flooding of adjacent property during large floods. There is good access to remove the stone (approximately 90CY) from a private gravel road west of Rt 153. A temporary easement from the landowner would be needed as the stone is likely outside the road ROW.
Alternative 7: Lowering of Railroad Bed and Removal of 30-inch RCP at Lenhardt Residence	Farms and Residences	◒	N/A	○	◒	Moderate	$15K-$20K	1-2 years	NYDEC; USACE	During large floods water is diverted out of the bank in West Rupert at the rail trail bridge and gets trapped on the east side of the rail bed. Ponded water south of the Atwater farm cannot easily return to the White Creek channel after the floodwaters recede due to limited capacity through a 30-inch culvert. Lowering a portion of the rail bed around the culvert will provide additional relief back to the Creek.
Alternative 8: Replace Undersized Railroad Bridge #5	Farms and Residences	●	N/A	●	●	Difficult	$150K-$200K	2-3 years	NYDEC; USACE; VTrans	The rail trail bridge in West Rupert in severely undersized and poorly aligned, and contributes to out of bank flows during large floods. Floodwaters get trapped on the south side of the rail bed and cannot return to the Creek. The current bridge span is 23 feet. The bridge span should be at least 50 feet to match the channel bankfull width.

[1]**Reduces Flood Risk** - The proposed project/strategy lowers the flood level.

[2]**Reduces Erosion Risk** - The proposed project/strategy lessens the vulnerability of a location to erosion.

White Creek Watershed, Rupert, VT & Salem, NY

Recommended Projects to Protect Infrastructure, Residences, and Businesses from Future Flooding

July 19, 2016

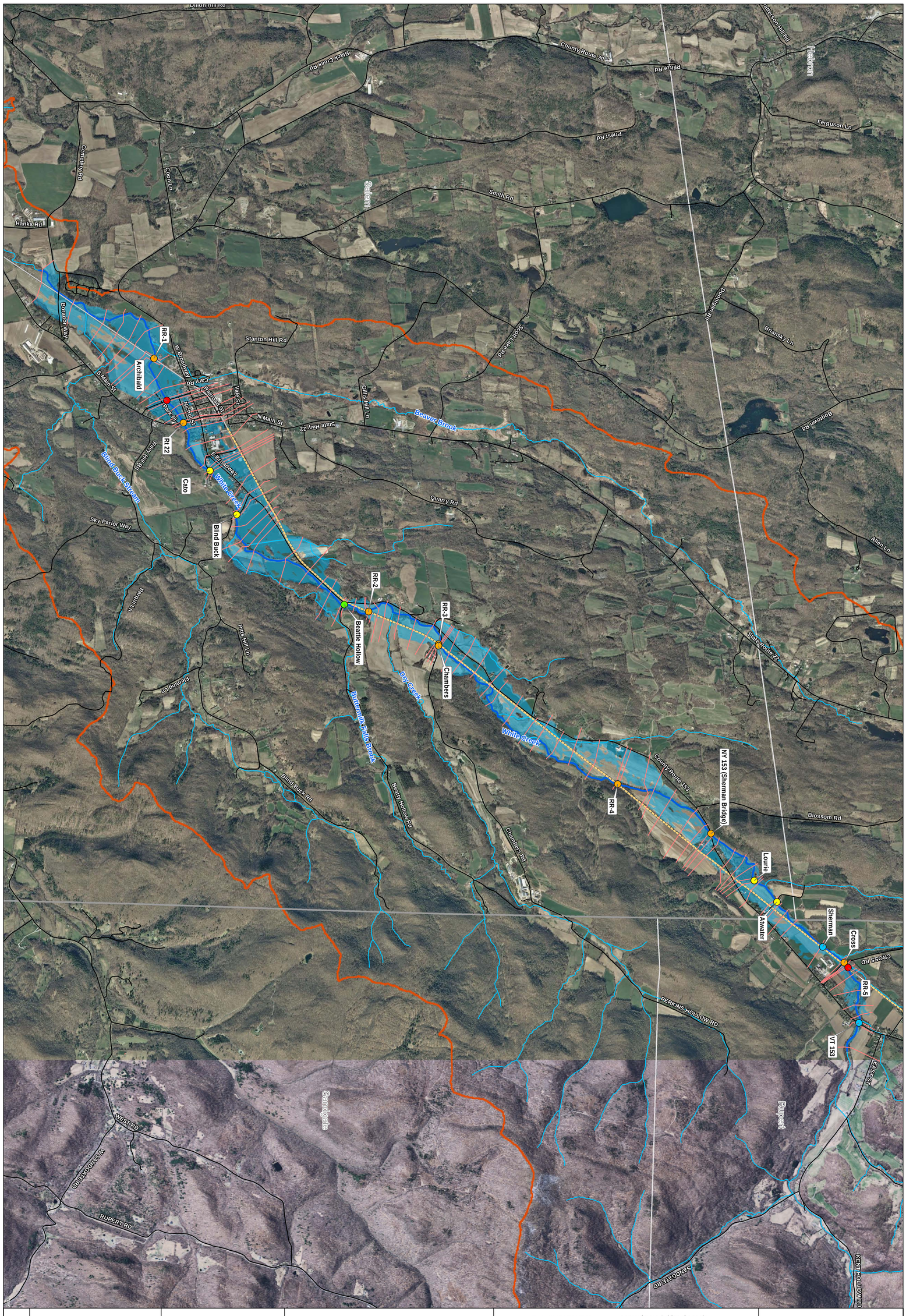
Legend

● Effective ◓ Limited ○ Ineffective

		OBJECTIVES				FEASIBILITY				
Project	**What is At Risk?**	**Reduces Flood Risk[1]**	**10-year Flood Level Reduction in Village**	**Reduces Erosion Risk[2]**	**Protects Businesses, Infrastructure, and Property**	**Ease of Implementation**	**Implementation Cost Range**	**Estimated Time for Implementation**	**Permitting Jurisdictions**	**Comments**
Salem Village Alternatives										
Alternative 2: Remove Berms Downstream of Salem Village	Businesses, Residences, & County/Town Infrastructure	○	0 - 0.5ft	○	○	Moderate	$40-50K	1-2 years	None	Project involves coordination with landowner (Woody Hill Farms) to remove berms along farm fields for approx. 1,200 linear feet. Total volume estimated to be 1,000-1,400 CY. Berms create minor tailwater in small to moderate floods and affects the western edge of the Village.
Alternative 2a: Remove Berms Downstream of Salem Village; Deepen Channel	Businesses, Residences, & County/Town Infrastructure	◓	0.5 - 1ft	○	○	Moderate	$50K-$80K	1-2 years	NYDEC; USACE	Deepening the channel from the Route 22 bridge through cross-section 7117. Channel has aggraded approximately 1-2 feet compared to pre-Irene conditions. Some minor bank shaping may be required. We estimate that approximately 3,000-4,000 CY of material would be removed over the 2,200 foot length of channel. A sediment maintenance plan would need to be established in conjunction with state and federal agencies. This would requre additional channel survey work to establish benchmarks associated with levels of aggradation that increase flood vulnerability.
Alternative 3 & 3a: Remove Archibald Street Bridge or Install an Overflow Box Culvert to North of Existing Bridge	Businesses, Residences, & County/Town Infrastructure	●	1 - 1.5ft	◓	◓	Moderate	$50K (removal); $250K-$350K (overflow culvert)	2-3 years	SEQR; NYDEC; USACE	For removal option, the south abutment would be left in place to accommodate a future pedestrian crossing, but the north abutment would be removed to widen the floodway. Overflow box culvert (20ft span, 5ft height) would be installed on the north bank and would require an easement from the property owner to create an overflow channel.
Alternative 4: Remove Berms Downstream of Salem Village; Remove Archibald Street Bridge	Businesses, Residences, & County/Town Infrastructure	●	1 - 1.5ft	◓	◓	Moderate	$80K-$100K	2-3 years	SEQR; NYDEC; USACE	See above comments. The combination of berm removal with bridge removal (or overflow box culvert) provides only marginal improvement over Alternative 3.
Alternative 5: Remove Berms Downstream of Salem Village; Deepen Channel; Widen Channel with Flood Benches	Businesses, Residences, & County/Town Infrastructure	◓	0.5 - 1ft	◓	◓	Difficult	$250K-$350K	3-5 years	SEQR; NYDEC; USACE	Widening of the channel without Archibald Street bridge removal (or overflow culvert) provides only limited flood reduction, as the bridge constriction remains severe. This is not a viable alternative considering the high costs and limited benefits.
Alternative 6: Remove Berms Downstream of Salem Village; Deepen Channel; Widen Channel with Flood Benches; Remove Archibald Street Bridge	Businesses, Residences, & County/Town Infrastructure	●	1.5 - 2ft	◓	◓	Difficult	$400K-$500K	3-5 years	SEQR; NYDEC; USACE	Easements would be required on approximately 14 properties to excavate the flood benches, primarily along the north bank in between Route 22 and Archibald Street. Many large trees lining the north bank would need to be removed. A revegetation plan would be required as part of the final design and permitting.
Alternative 7: Remove Berms Downstream of Salem Village; Deepen Channel; Widen Channel with Flood Benches; Remove Archibald Street Bridge;	Businesses, Residences, & County/Town Infrastructure	●	1.5 - 2ft	●	●	Difficult	$500K-$700K	>5 years	SEQR; NYDEC; USACE; FEMA	See above comments. The Fleming house (41 Archibald Street) would be bought-out and demolished to allow for the re-establishment of a floodplain on the north bank. This alternative would also reduce the 100-year flood elevations in the Village 1-1.5 feet.

[1]**Reduces Flood Risk** - The proposed project/strategy lowers the flood level.

[2]**Reduces Erosion Risk** - The proposed project/strategy lessens the vulnerability of a location to erosion.



Map 1

Notes:

- All layers downloaded from NY GIS Clearinghouse and the Vermont Center for Geographic Information
- Background Imagery is from 2014
- Cross sections were analyzed using HEC-GeoRAS software

0 1,500 3,000 Feet

1 inch = 1,500 feet

Drawn: JHB, EPF
Date: May 10, 2016

White Creek Flood Study

Project Area Map
Salem, NY

Study Reaches
Surface Waters
Roads
Railroad
Historic Railroad
State Boundary
Town Boundary
White Creek Watershed

Approximate Bridge Capacity
2-year flood
10-year flood
25-year flood
50-year flood
100-year flood
HEC-RAS Cross Sections
Approx. 100-year Flood Extent

Fitzgerald Environmental Associates, LLC
18 Severance Green, Suite 203
Colchester, VT 05446
Telephone: 802.876.7778
www.fitzgeraldenvironmental.com