VTrans Working to Get You There
Vermont Agency of Transportation

Transportation Flood Resiliency Tool (TRPT)

FEBRUARY 9, 2023





SLR

Fitzgerald Environmental Associates, LLC.
Applied Watershed Science & Ecology

DuBois & King inc.

STONE ENVIRONMENTAL

smart mobility

VERMONT
AGENCY OF TRANSPORTATION

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Agenda

1. Introduction (10:00 – 11:15 AM)
   Introductions, TRPT Background, Web Application Use

2. Break (11:15 – 11:30 AM)

3. Case Studies (11:30 AM – 12:30 PM)
   Three Case Studies

4. Lunch (12:30 – 1:00 PM)

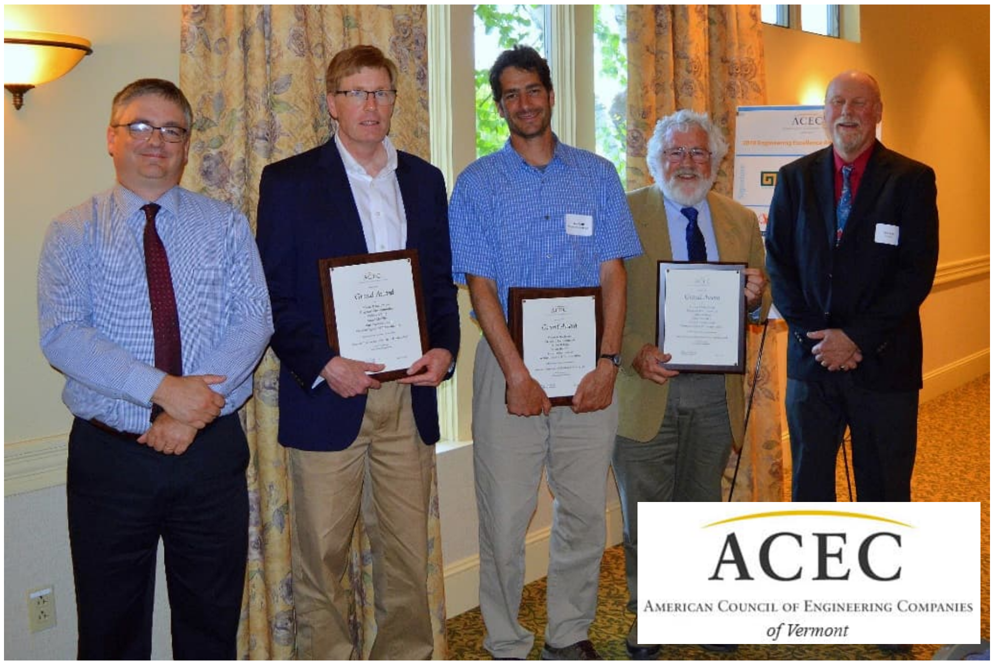
5. Planning scenarios (1:00 – 1:30 PM)
   Teacher generated, student generated, practice

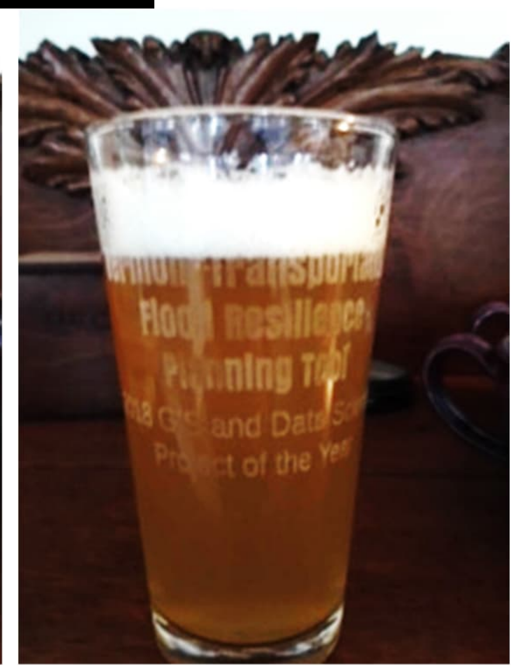
6. Student examples (1:30 – 2:30 PM)
   Set up, supported work, share results

7. Wrap-up (2:30 – 3:00 PM)
   Final questions and evaluation

TRB
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

USERS HELPING USERS
NEARC
northeast arc users group





USER STORY

Preparing for Weather Disasters: Vermont Builds Resilience into Infrastructure Plans

https://www.esri.com/en-us/lg/industry/transportation/vermont-builds-resilience-into-infrastructure-plans

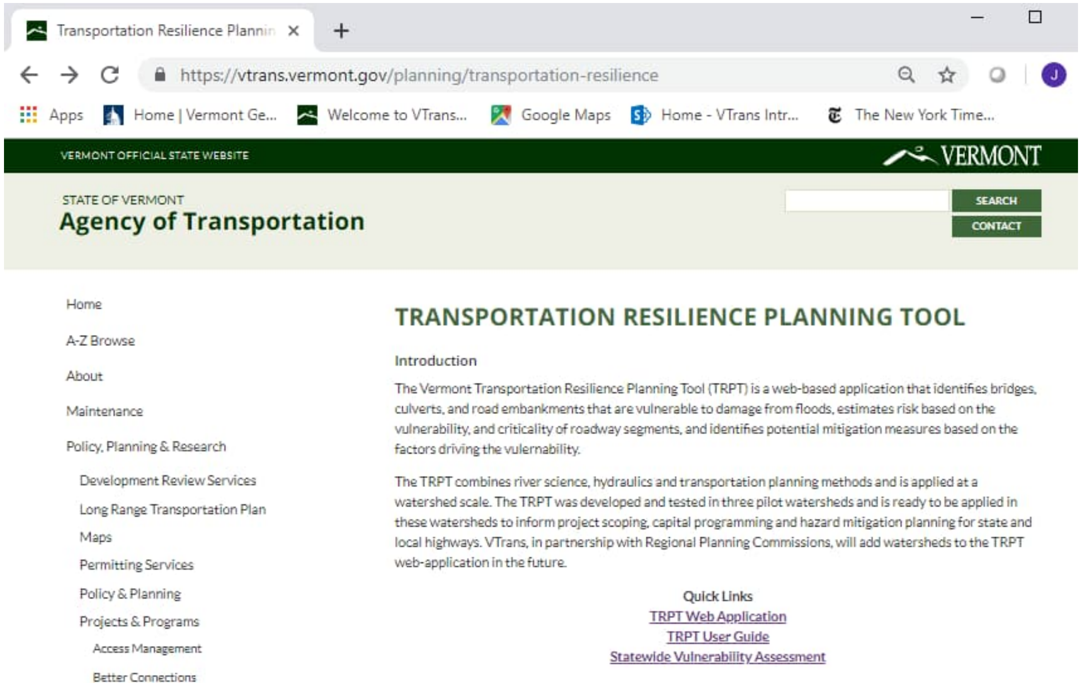
TRPT Website

- Direct link to TRPT

https://roadfloodresilience.vermont.gov

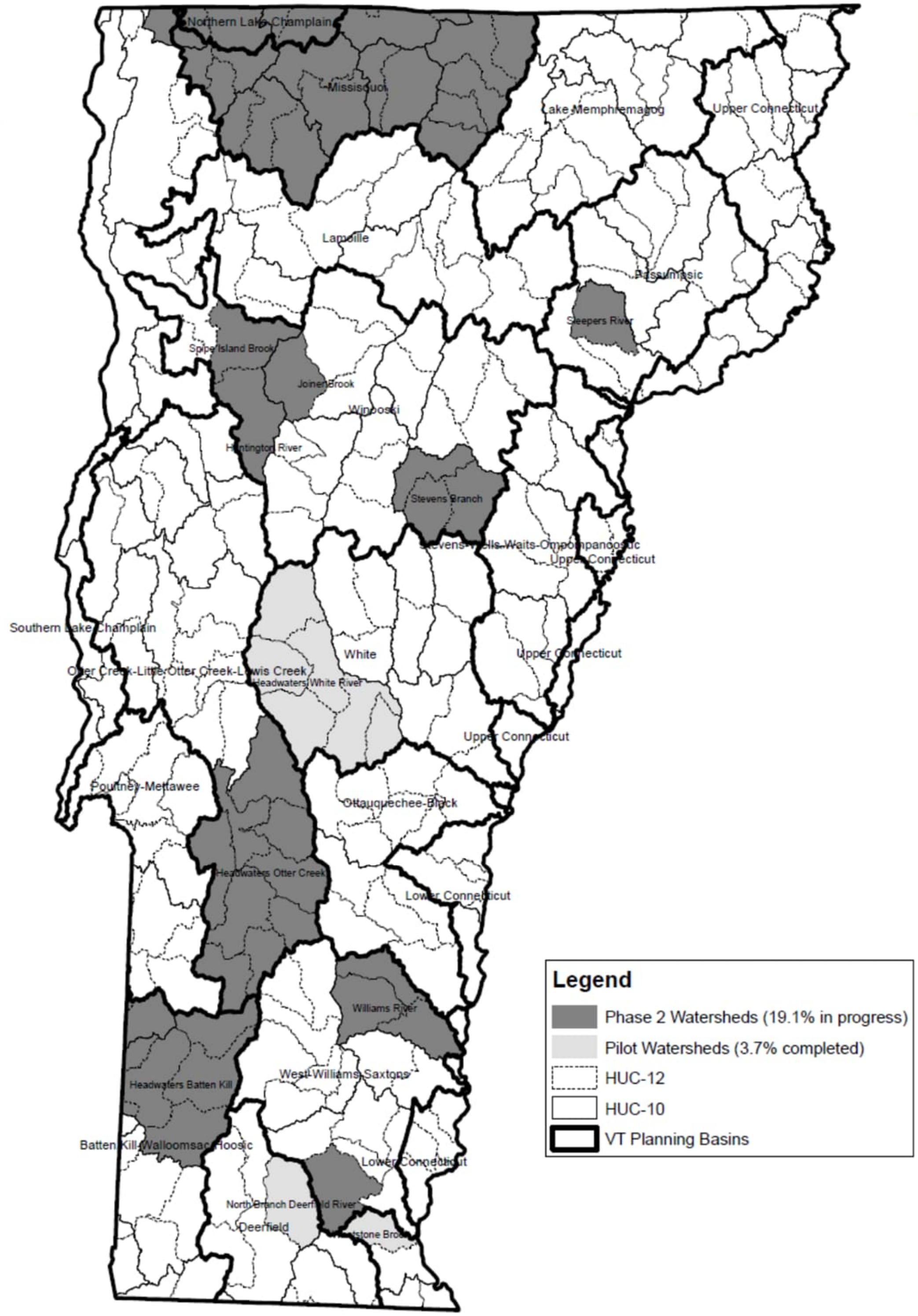
- Link to VTrans TRPT Website

https://vtrans.vermont.gov/planning/transportation-resilience



https://resources.vtrans.vermont.gov/vtransResilienceAppTEST/#/map

TRPT Buildout



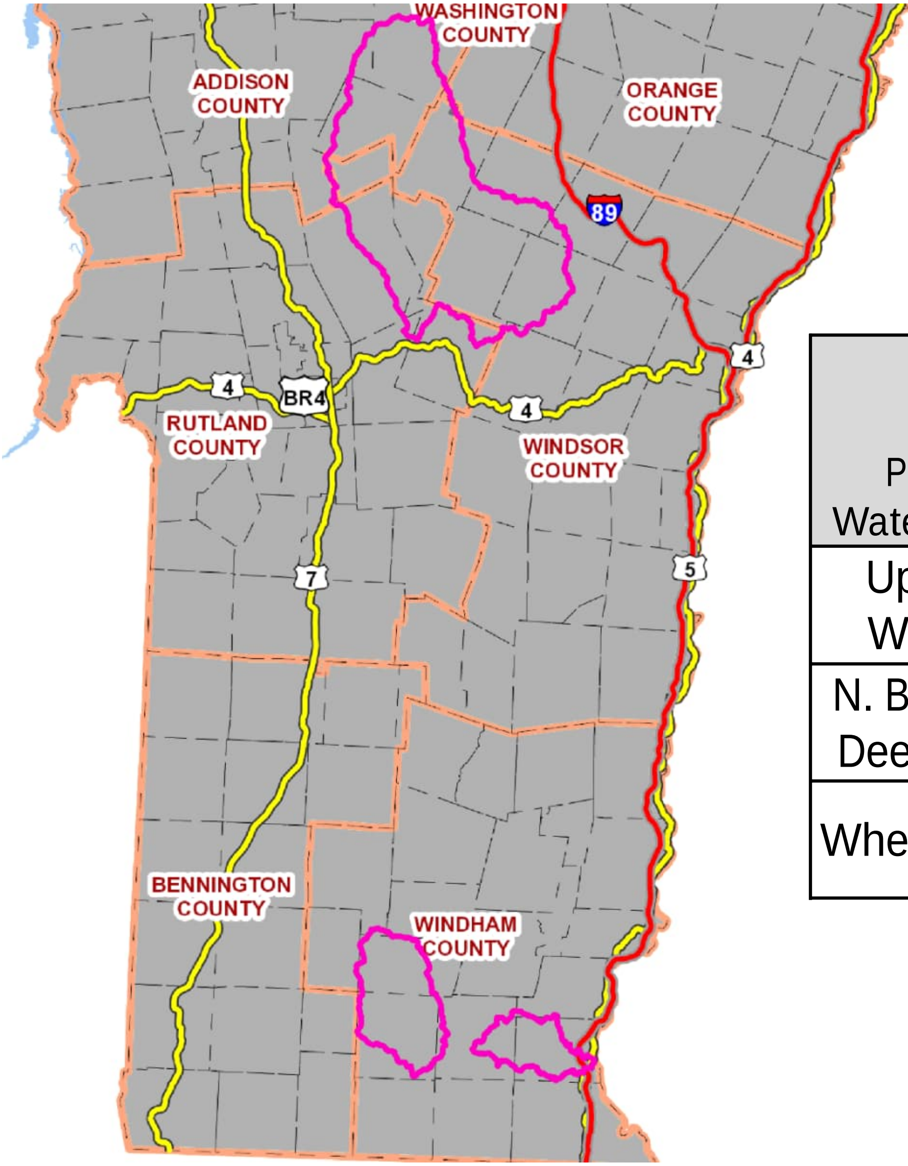
Statewide Field QA

TRPT properly identified risk at 9 of 10 sites visited.

Statewide Field QA

Basin	Number of Segments Assessed	Length of Segments Assessed (mi)	Number of Segments with Score Change	Percent Change	Percent Accuracy
Batten Kill - Walloomsac - Hoosic	280	74	46	16%	84%
Deerfield - Connecticut Direct	310	118	38	12%	88%
Lake Memphremagog	294	160	8	3%	97%
Lamoille	491	148	15	3%	97%
Missisquoi	443	177	39	9%	91%
Northern Lake Champlain	380	95	20	5%	95%
Ottauquechee - Black - CT Direct	288	84	20	7%	93%
Otter Creek - Little Otter Creek - Lewis	691	207	68	10%	90%
Passumpsic	118	75	15	13%	87%
Southern Lake Champlain	212	88	16	8%	92%
Stevens - Wells - Waits - Ompompanoosuc - CT Direct	471	163	42	9%	91%
Upper Connecticut	82	100	6	7%	93%
West - Williams - Saxons - CT Direct	228	75	11	5%	95%
White	351	127	77	22%	78%
Winooski	979	283	137	14%	86%
STATEWIDE TOTAL	**5618**	**1974**	**558**	**10%**	**90%**

Vulnerability – Validation Statistics



Pilot Watershed	Total # Scored Road Segments	Manual Changes	Damage Record Changes	% of Road Segments Changed
Upper White	836	2	45	5.6%
N. Branch Deerfield	386	0	5	1.3%
Whetstone	280	12	1	4.6%

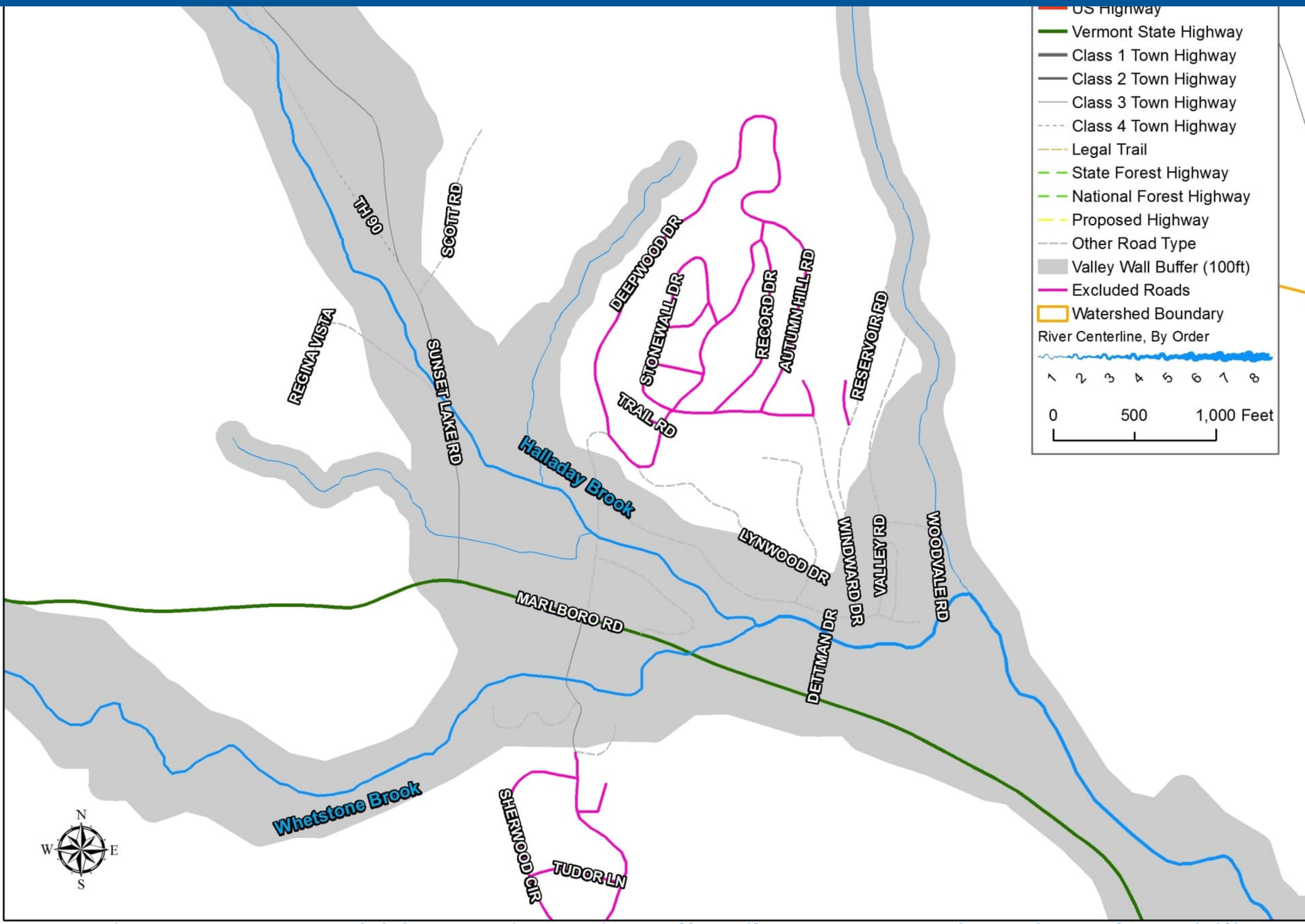
Definitions

Vulnerability: The extent that a transportation asset is exposed to a threat from inundation, erosion, or deposition.

Criticality: How important is the transportation asset that dictates the consequence of the disruption to mobility due to damage.

Risk: The combination of the probability of vulnerability and criticality.

Where is Vulnerability Unlikely?



Any road segment not within 100-feet of a valley floor were assigned a vulnerability of 0.

Deposition

Money Brook,
Route 100 in Plymouth, VT
1973
Photo taken by M. Tucker

Erosion

Mendon Brook
US 4 in Mendon, VT
9/1/2011
Photo taken by J. Louisos

Inundation

Winooski River
Cochran Road in Richmond, VT
8/29/2011
Photo taken by Shem Roose Photography

Inundation, Erosion, Deposition

Great Brook
Brook Road Damage, 10-Year Flood
Plainfield, VT
7/19/2015
Photo taken by B. Towbin

Great Brook
Brook Road Damage, 10-Year Flood
Plainfield, VT
7/20/2015
Photo taken by B. Towbin

Inundation, Erosion, Deposition

Great Brook
Brook Road Overtopping, 50 -Year Flood
Plainfield, VT
5/26/2011
Photo taken by G. Springston

Great Brook
Brook Road Failure, 50-Year Flood
Plainfield, VT
5/27/2011
Photo taken by G. Springston

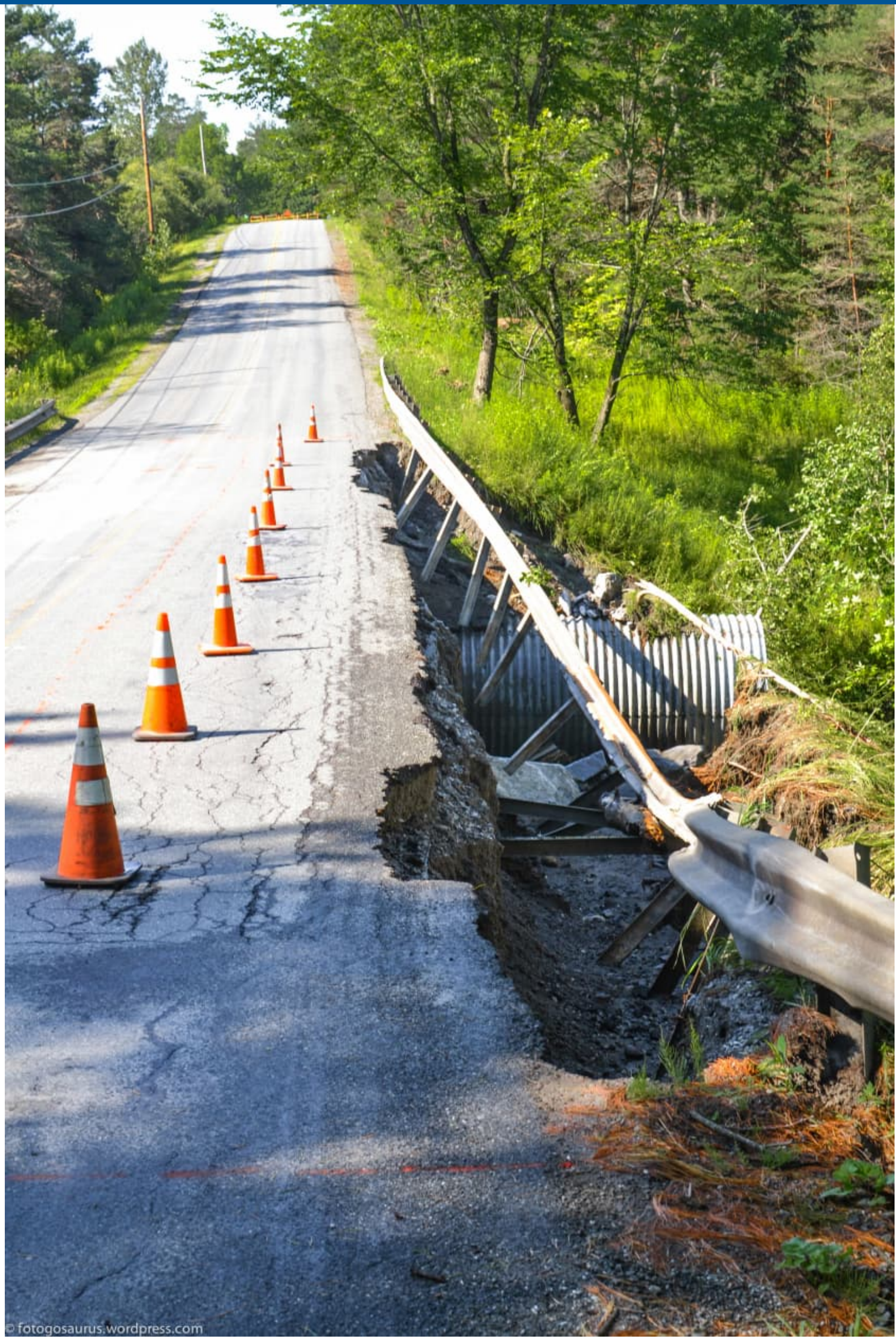
Failure Modes

Failure Mode	Influence	Damage Distance	Vulnerability Type
Partial Closure	<24 hours Single lane closure Shoulder repair Reduced capacity with some travel	100 feet or less	Temporary inundation Minor erosion Minor deposition
Full Closure	24 hours to several days Multi-lane closure Detour required	100s of feet	Large-scale Inundation Localized erosion Localized deposition
Temporary Failure	Partial destruction of facility Days to a week for recovery Maintain one lane if possible Detour required	100s to 1,000s of feet	Erosion Deposition Large-scale Inundation
Complete Failure	Complete destruction of facility A week to months for recovery Long-term travel disruptions	Varies	Erosion Deposition

(Adapted from FHWA and WSDOT, 2019)

Partial Closure

Great Brook
Creamery Street in Plainfield, VT
5/27/2011
Photo taken by G. Springston



Great Brook
Brook Road in Plainfield, VT
7/20/2015
Photo taken by B. Towbin

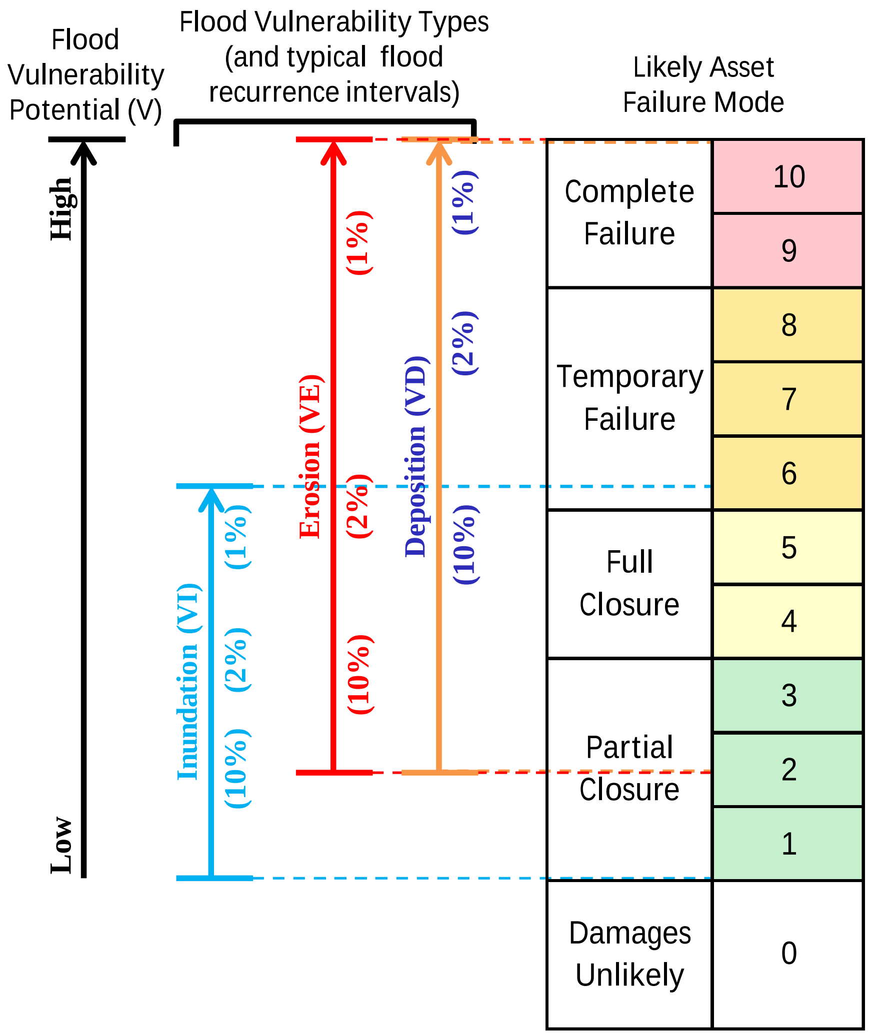
Flood Levels

Recurrence Interval (years)	Annual Exceedance Probability (AEP; %)	Typical Scenario
10	10%	High-intensity, short-duration summer thunder burst
50	2%	Local floods from repetitive thunderstorms in one or more watersheds in short periods of times (i.e., training storms) resulting in localized loss of structures and road segments
100	1%	Regional floods such as nor'easters and tropical storms that impact large areas of the state with major road and infrastructure loss

Vulnerability

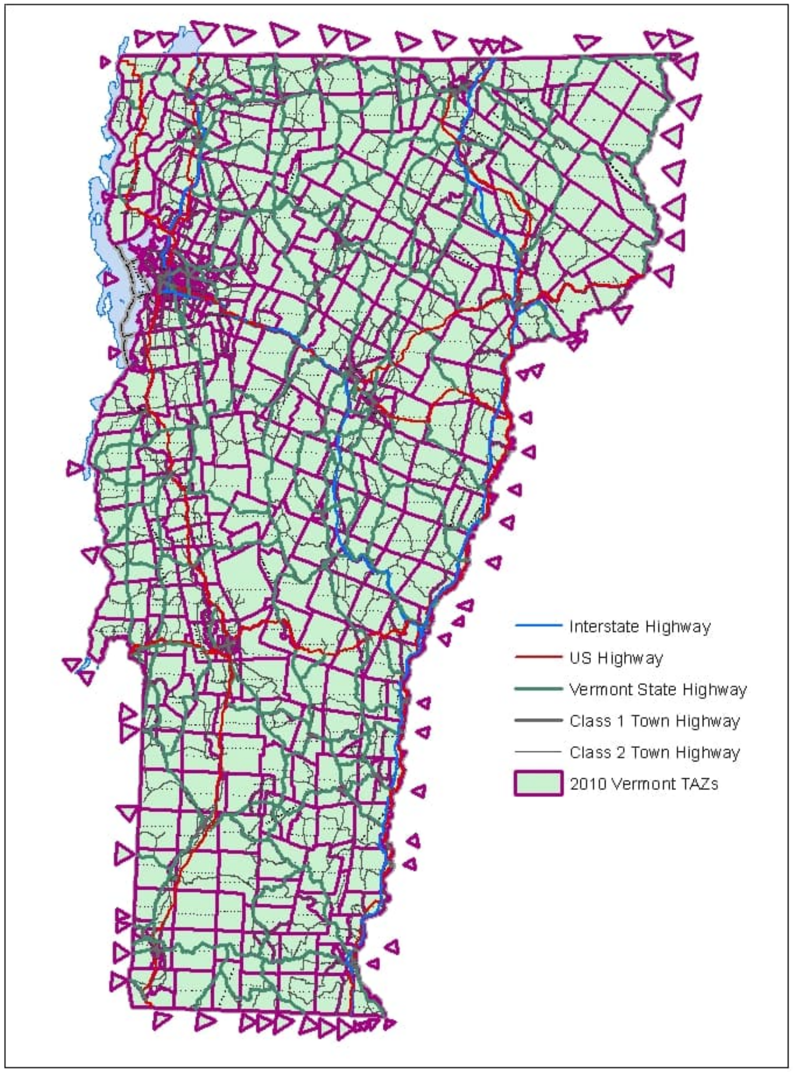
$$V_{ROAD\ EMBANKMENT} = MAX(V_{I,ROAD};\ V_{E,ROAD};\ V_{D,ROAD})$$
$$V_{BRIDGES} = MAX(V_{I,\ BRIDGES};\ V_{E,BRIDGES};\ V_{D,BRIDGES})$$
$$V_{CULVERTS} = MAX(V_{I,CULVERTS};\ V_{E,CULVERTS};\ V_{D,CULVERTS})$$

where I = inundation, E = erosion and D = deposition



Criticality

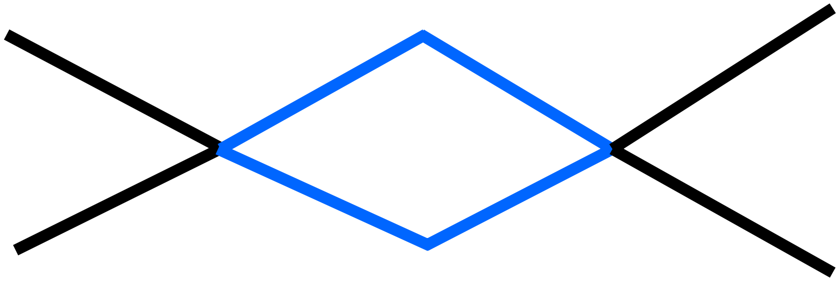
1. Travel impacts
   - Failed trips (per day)
   - Excess travel time (hours per day)
   - Isolated areas ('islands') of roads with limited network travel
2. Emergency Services Access
3. Local importance



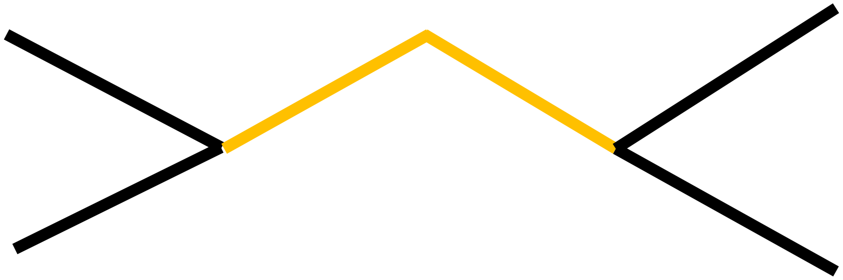
Statewide Travel Demand Model

Network Criticality

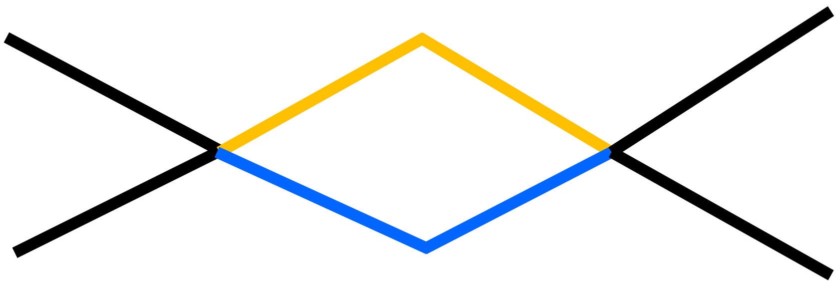
Low criticality – Parallel route



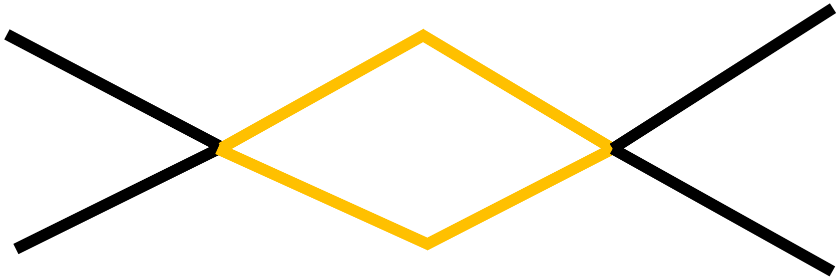
High criticality – No parallel route



Moderate criticality – Parallel route yet one is vulnerable

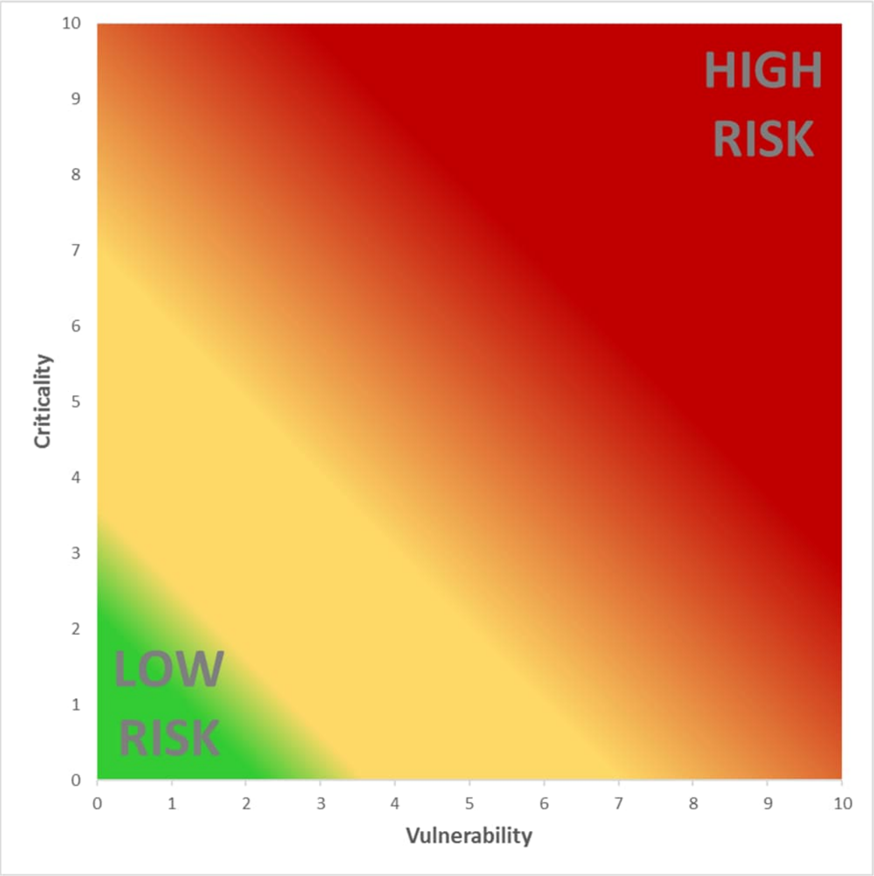


High criticality – Both routes vulnerable



Risk

Risk is equal to the average of Vulnerability and Criticality.



TRPT Limitations

- The TRPT is static data viewer. Conditions may have changed if damages have occurred or a mitigation project was implemented.
- Errors are possible with a watershed-based analysis where GIS data do not resolve key site features such as bedrock or disconnected floodplains.

Vulnerability Variables

	VARIABLES				SCALE		
More detailed variables	Inundation	Erosion	Deposition		Road Segments	Structures	River Segments
* Documented Past Damages	√	√	√		√	√	
* River-Roadway Relief (feet)	√				√		
Incision Ratio and Entrenchment Ratio	√	√					√
* FEMA 100-Year Flood Depth Above Road (feet)	√				√		
Length of Road in 100-Year Floodplain (feet)	√				√		
* Bridge/Culvert Invert-Roadway Relief (feet)	√					√	
Structure Width vs. Bankfull Channel Width (%) (HGR-based)	√	√	√			√	
Specific Stream Power (W/m^2)		√	√				√
Dominant Substrate Size		√					√
Valley Confinement		√					√
Remaining River Corridor Width where the ROW or Development Confine River (%)		√			√		
Length of ROW in River Corridor (feet)		√	√		√		
Erosion (SGA Data, GC Screen)		√				√	
Armoring (SGA Data, GC Screen)		√				√	
Culvert Slope (SGA Data, GC Screen)		√				√	
5% or Larger Slope Decrease Areas (count)			√				√
3rd Order or Larger Confluences (count)			√				√
* Change in Confinement Ratio from Upstream Reach			√				√
Road Crossings (count)			√		√		
* Mass Failures in Upstream Reach (feet)			√				√
Bank Erosion in Upstream Reach (% of Channel Length)			√				√
Channel Slope (SGA Data)			√				√
Sediment Discontinuity (SGA Data, GC Screen)			√			√	
Approach Angle (SGA Data, GC Screen)			√			√	
Less detailed variables (to replace more detailed variables when they do not exist)							
Valley Slope	√						√
Surficial Landform in Corridor Area		√					√
Steep slopes in Upstream or First Order Reach (feet)			√				√

Damage Scores

Review of DDIRs, RPC Damage Data Records, PA Records

D1-094

FEDERAL HIGHWAY ADMINISTRATION
DETAILED DAMAGE INSPECTION REPORT

D1-094
Sheet 1 of 1

APPLICANT: State of Vermont D1 — COUNTY: Windham
Disaster No.
Inspection Date 10/11/2011
LOCATION OF DAMAGE: VT 9 (mm 2.10 - 2.13) Brattleboro
Begin 42 deg 52' 15" N 72 deg 39' 08" W End 42 deg 52' 16"N 72 deg 39' 01" W
F-A Route VT 9
Across from Olson Rd pvt near Center Rumble Strips End sing assembly - East of pole# [illegible]

DESCRIPTION OF DAMAGE: EB Slope/ shoulder failure with partial lane raod failure
Full pvt width = 334'L x 39'W x 1'dp with excavation + edgeline (668 lf) and centerline (668 lf)
gravel/stone mix slope = 25' slope - {[(Depth estimated at 10 ' x width at toe of slope 23'L) x (0.5)] x 292'L} +
new segment of 30" dia CPP culvert
Excavate for stone swale 225'L x 7'W x 2'dp + stone fill = 225'L x 7'W x 1.5'dp
WB shoulder gravel = 95'L x 8'W x 1'dp
pvt patch = 232'L x 9'W x 1'dp near pole# 93/133
Sheared road area - excav = 115'L x 9'W x 10'dp + stone fill = 115'L x9'W x 7.5dp + sub-base = 115'L x 9'W x 1.5'dp

WORK COMPLETED BEFORE THIS REVIEW WAS CONDUCTED - ORIGINAL EXTENT OF DAMAGE UNKNOWN

COST ESTIMATE

Quantity	Unit	Description of Work to Date	Unit Price	Cost
		Emergency Repair Completed		
376	cy	stone fill for slopes and reconstructing failed road segment	$42.00	$15,792.00
1056	cy	common excavation - cleaning out area of complete road failure	$11.00	$11,616.00
1272	cy	gravel shoulder	$39.00	$49,608.00
58	cy	sub-base	$30.00	$1,740.00
40	LF	30" dia CPP culvert	$90.00	$3,600.00
1	LS	Traffic Control (5%)	$8,242.00	$8,242.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
Method		Local State X Contract X	Total Emergency Completed	$90,598.00
		Emergency To Do		
				$0.00
				$0.00
Method		Local State Contract	Total Emergency Remaining	$0.00
		Permanent Restoration		
1056	tons	pavement	$78.00	$82,368.00
900	LF	4" white edgeline	$0.07	$63.00
668	LF	4" dbl yellow centerline	$0.07	$46.76
1	LS	Mobilization (9%)	$14,835.04	$14,835.04
				$0.00
Method		Local State X Contract X	Preliminary Engineering	
Environmental Assessment Recommendation			Right-of-Way	$0.00
			Total Permanent Repair	$97,312.80
X NLR		EIS/EA Cat Ex	Total Estimated Cost	$187,910.80

Recommendation	X Eligible	Ineligible	FHWA Engineer Date
Concurrence	X Yes	No	State Engineer Nancy L. Avery Date 10/12/2011
Concurrence	X Yes	No	State/Local Agency Representative Date 10/14/11

Entd on 11/4/11

Extreme Erosion at Town Line

River and Road Variables – Damage Scores

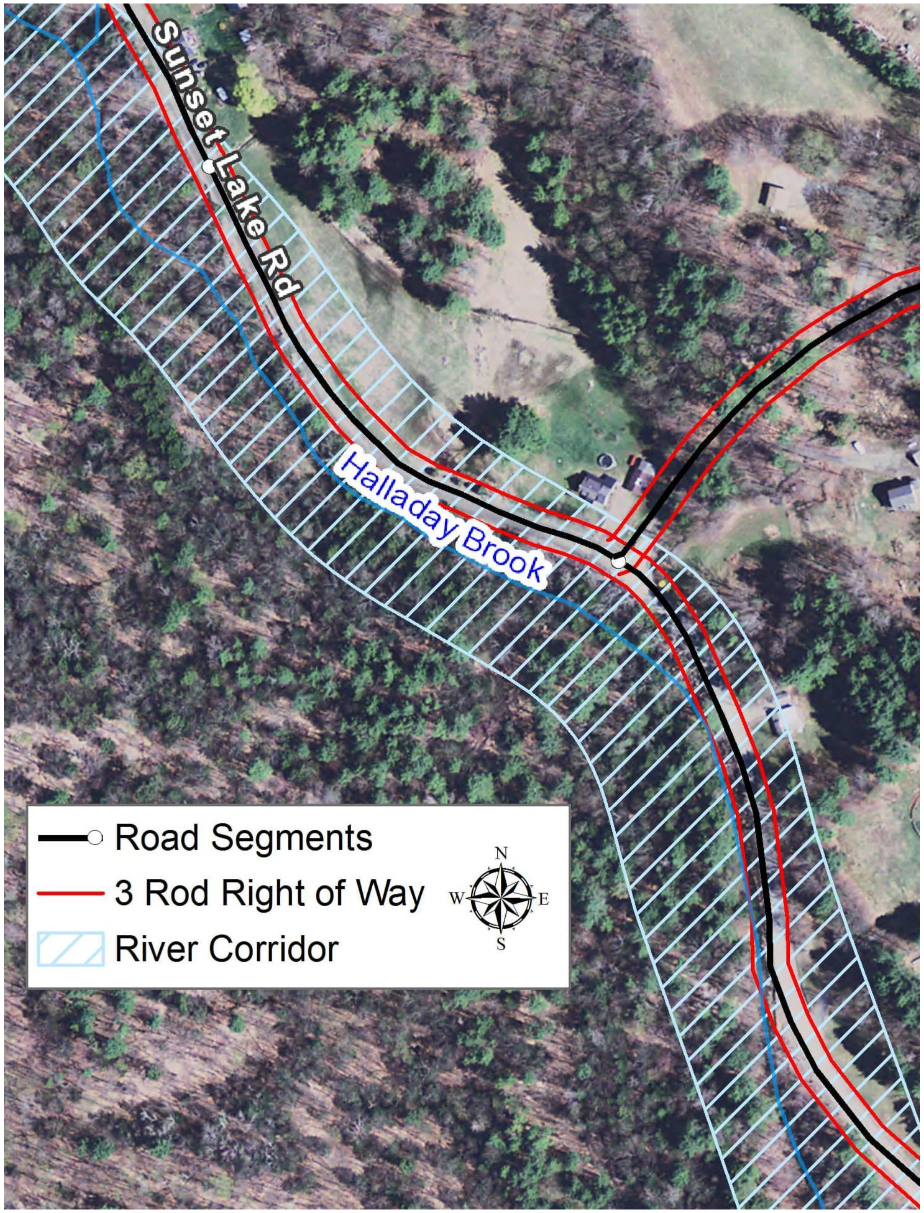
Complete Failures

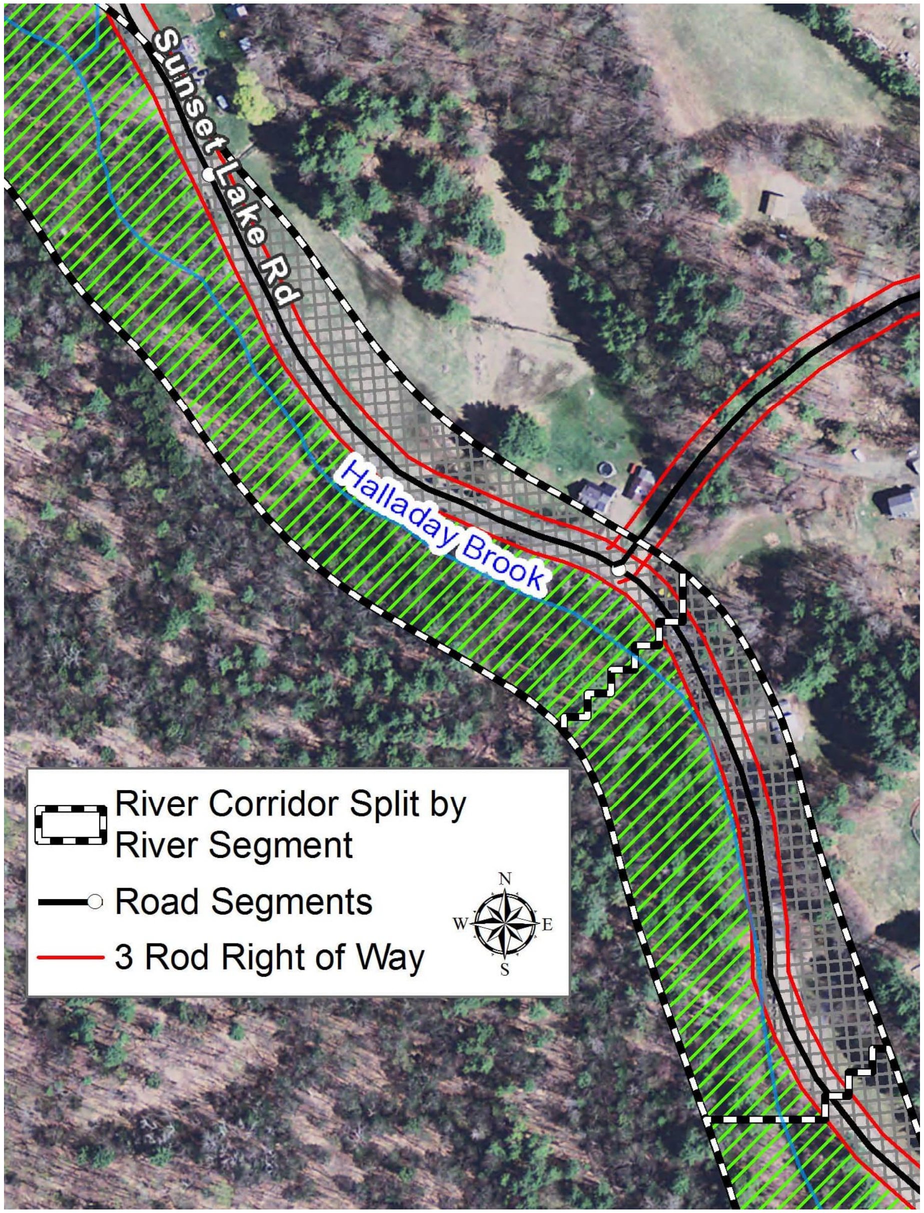
Photo credits: Lars Grange, Mansfield Heliflight

Damage Scores

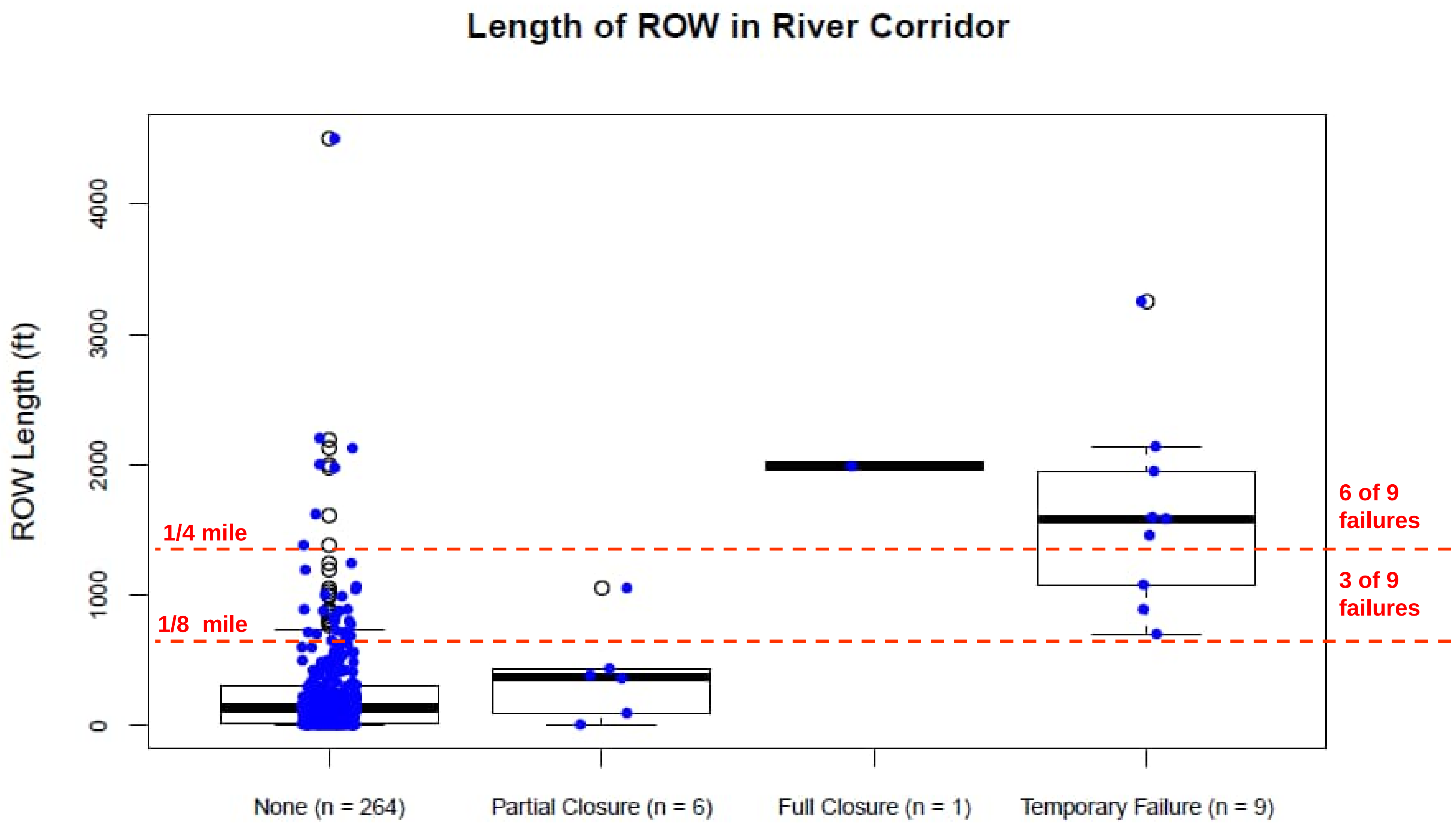
VT Route 107 Stockbridge

Length of Road in River Corridor & % Corridor Width Remaining



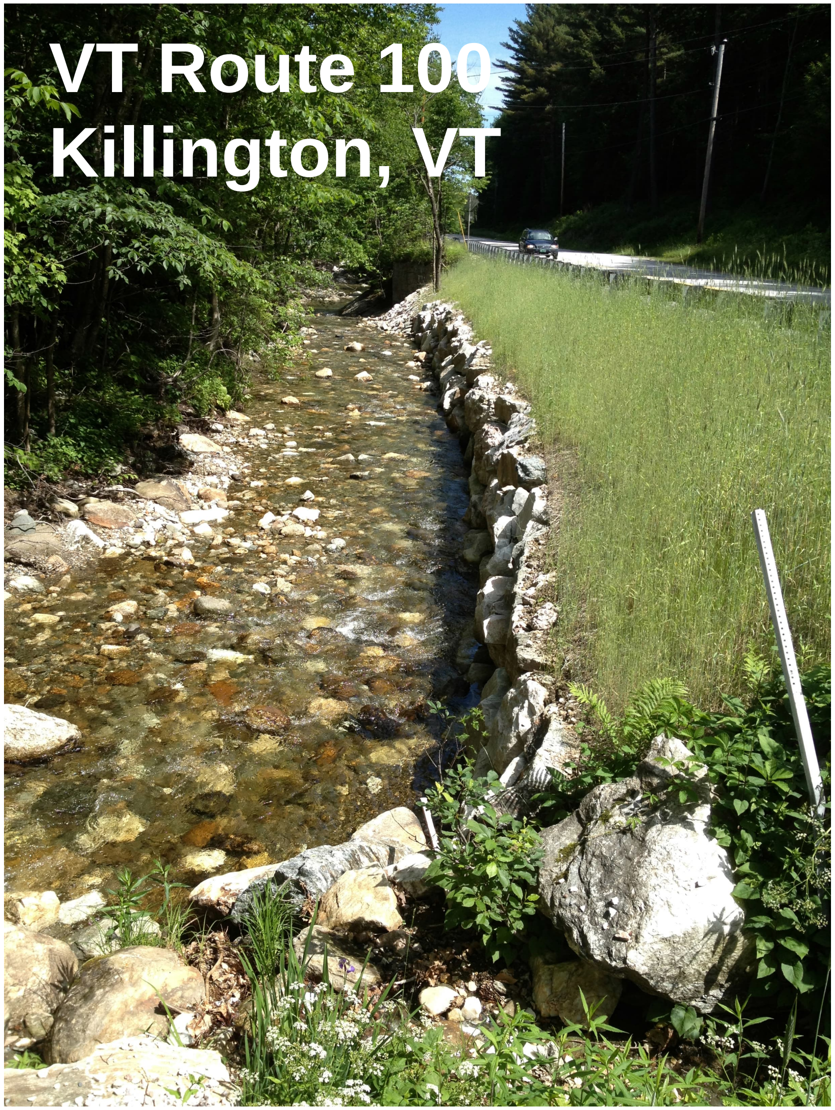


Vulnerability – Grouped by Failure Mode



Mitigation

Placed riprap wall

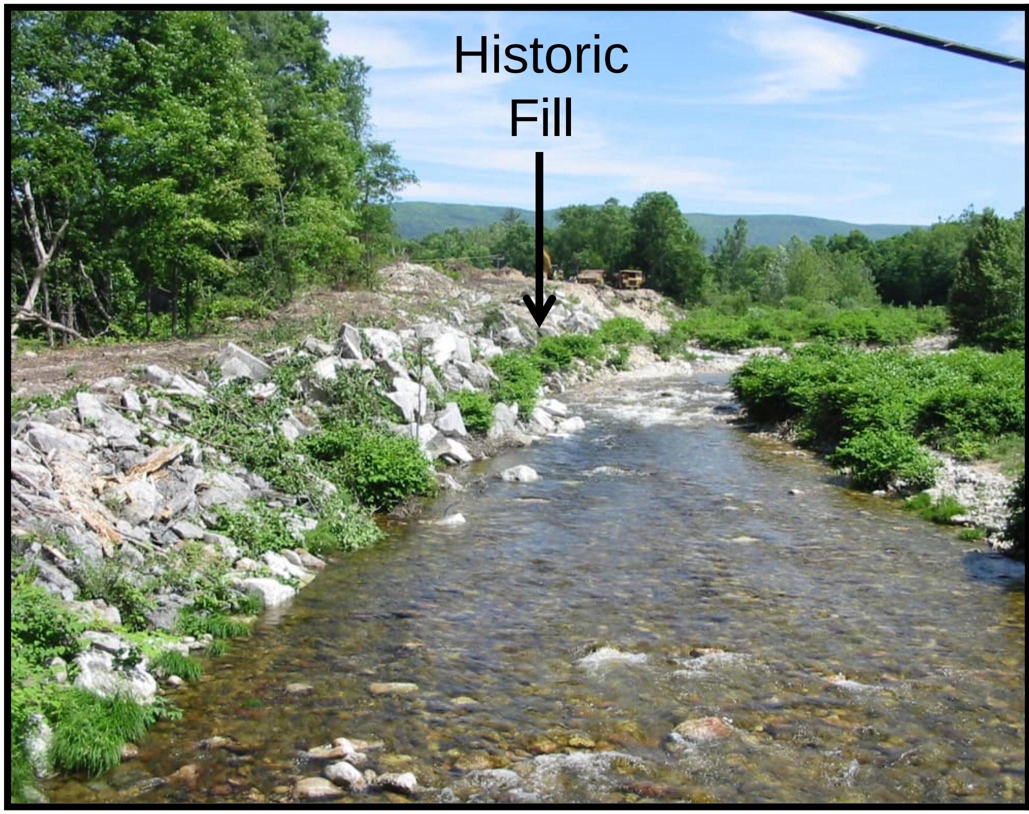


VT Route 155, Mt. Holly, VT

(E. Fitzgerald, 2013)

Mitigation

Floodplain Restoration Example



Roaring Branch
Bennington, VT
2008

Roaring Branch
Bennington, VT
2010

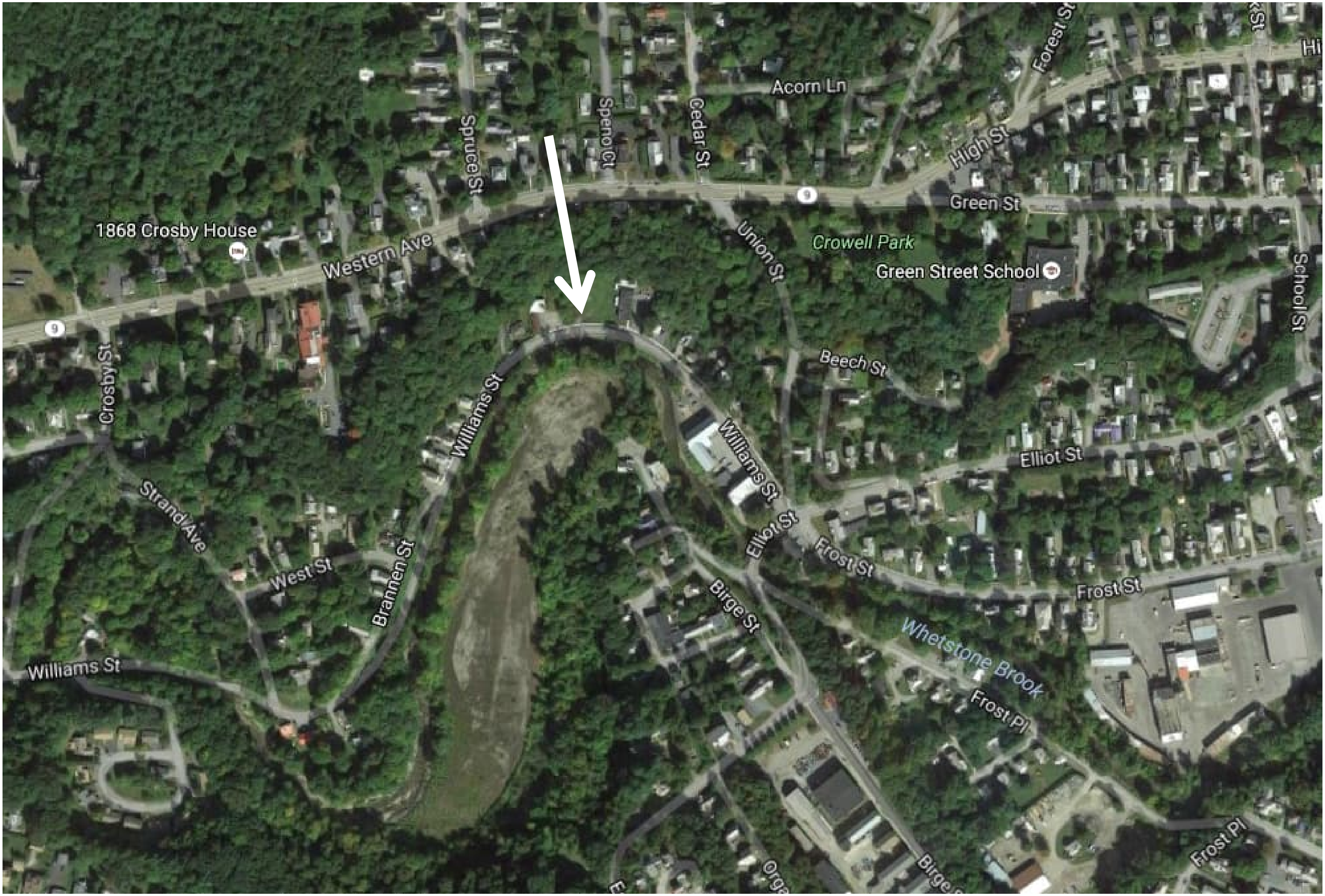
Extra Slides

Road Flooding Planning Example

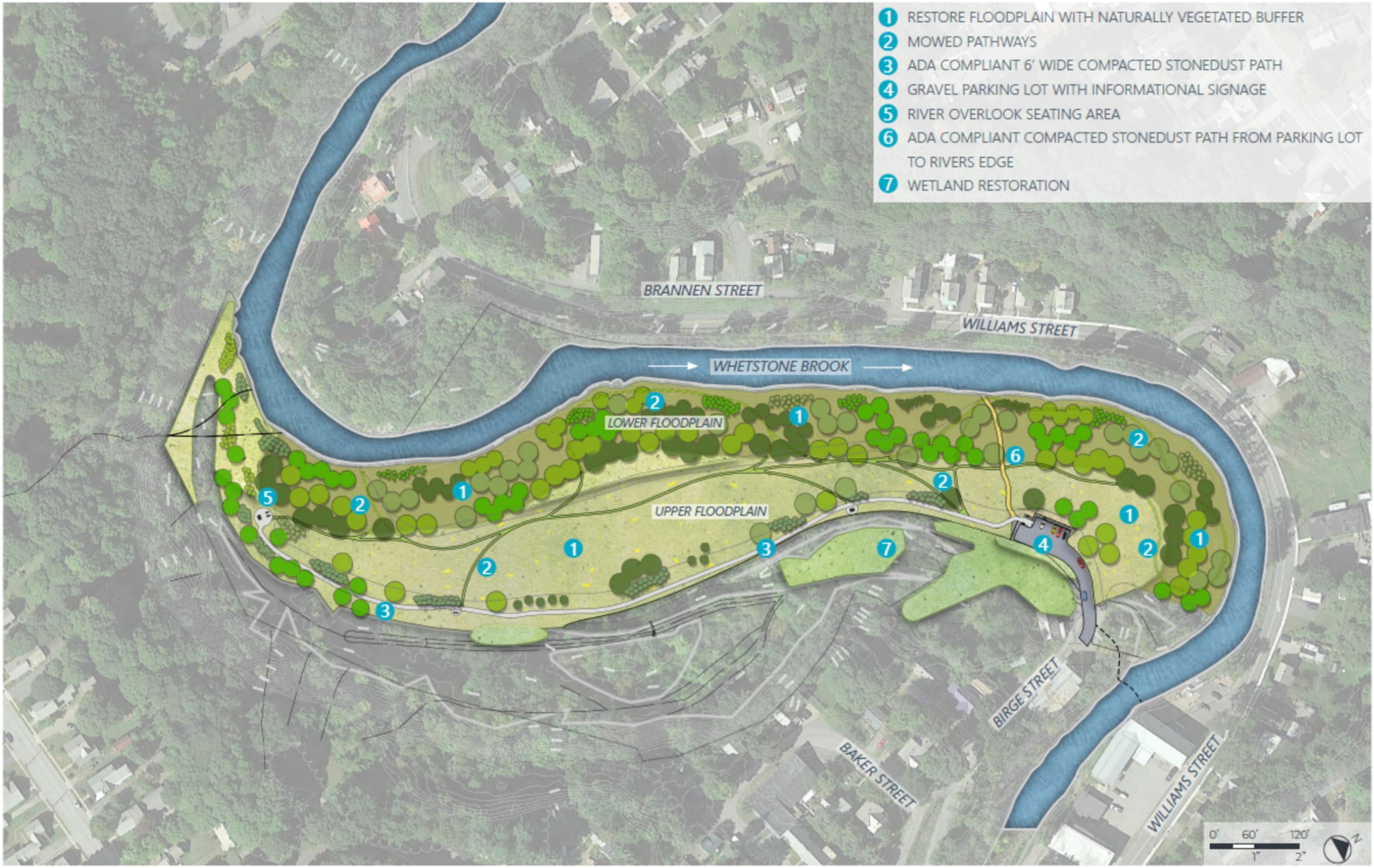
Williams Street Inundation, Brattleboro – just west of Elliot St

Williams Street, Brattleboro – just west of Elliot St

Williams Street, Brattleboro – erosion damage along sharp bend – erosion caused by deposition?



Acorn Ln
Spruce St
Speno Ct
Cedar St
Forest St
High St
Green St
1868 Crosby House
Western Ave
Union St
Crowell Park
Green Street School
School St
Beech St
Crosby St
Williams St
Elliot St
Strand Ave
West St
Brannen St
Frost St
Birge St
Whetstone Brook
Frost Pl


1 RESTORE FLOODPLAIN WITH NATURALLY VEGETATED BUFFER
2 MOWED PATHWAYS
3 ADA COMPLIANT 6' WIDE COMPACTED STONEDUST PATH
4 GRAVEL PARKING LOT WITH INFORMATIONAL SIGNAGE
5 RIVER OVERLOOK SEATING AREA
6 ADA COMPLIANT COMPACTED STONEDUST PATH FROM PARKING LOT TO RIVERS EDGE
7 WETLAND RESTORATION
BRANNEN STREET
WILLIAMS STREET
WHETSTONE BROOK
LOWER FLOODPLAIN
UPPER FLOODPLAIN
BIRGE STREET
BAKER STREET
WILLIAMS STREET
0' 60' 120'
1" 2"
N

Data

Road Data

Data	Source	Web Service	Data Use±	Comments
Trans Rd/AOT Master Road Centerline	VTrans	Yes	E, V, C, R, A*	Principal dataset for assessment and display of vulnerability data. Available statewide.
ARAN	VTrans	No	E, V	Available on VTrans highways, years vary.
LiDAR Digital Elevation Model	VTrans	No	E, V	At the time of analysis, LiDAR was available for parts of Routes 9, 100, and 107.
CCA	UVM	No	C, R	Available statewide. On E911 roads layer.

Bridge and Culvert Data

Data (Source)	Source	Web Service	Data Use±	Comments
Structex (Phase 2 SGA)	VTANR	No	E, V, R, A*	Available where Phase 2 Stream Geomorphic Assessments (SGA) have been conducted.
VTrans Structures data	VTrans	Yes	E, V, R, A*	Long (>20-foot span) and short structures (6 to 20-foot span). Available on VTrans highways, and for town long structures.
VOBCIT Structures data	Towns	Yes	E, V, R, A*	Town bridges and culverts available statewide.
Small Culvert Inventory	VTrans	Yes	E, V, R, A*	Less than 6-foot span. Available statewide for VTrans highways.

Data

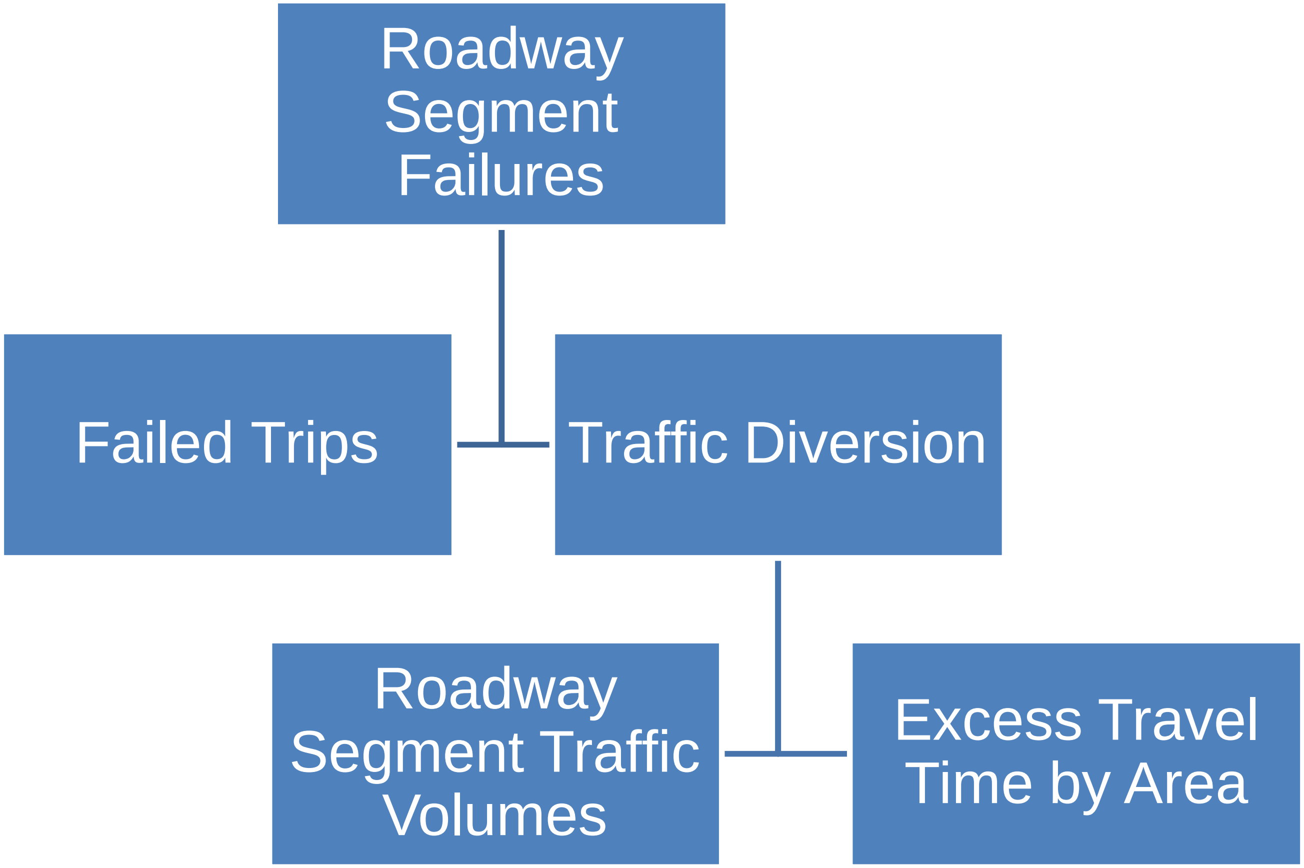
Flood Damage Data

Data (Source)	Source	Web Service	Data Use±	Comments
DDIR Sites	VTrans	No	E, V	Detailed Damage Inspection Reports (DDIR) available on VTrans highways.
RPC Damage Sites	RPCs	No	E, V	Available by region statewide. May have limited information on damage details.
Public Assistance Projects	FEMA	No	E, V	Available statewide, limited information on damage details.
Stakeholder Input	Public Meetings	No	E, V	Locally available.

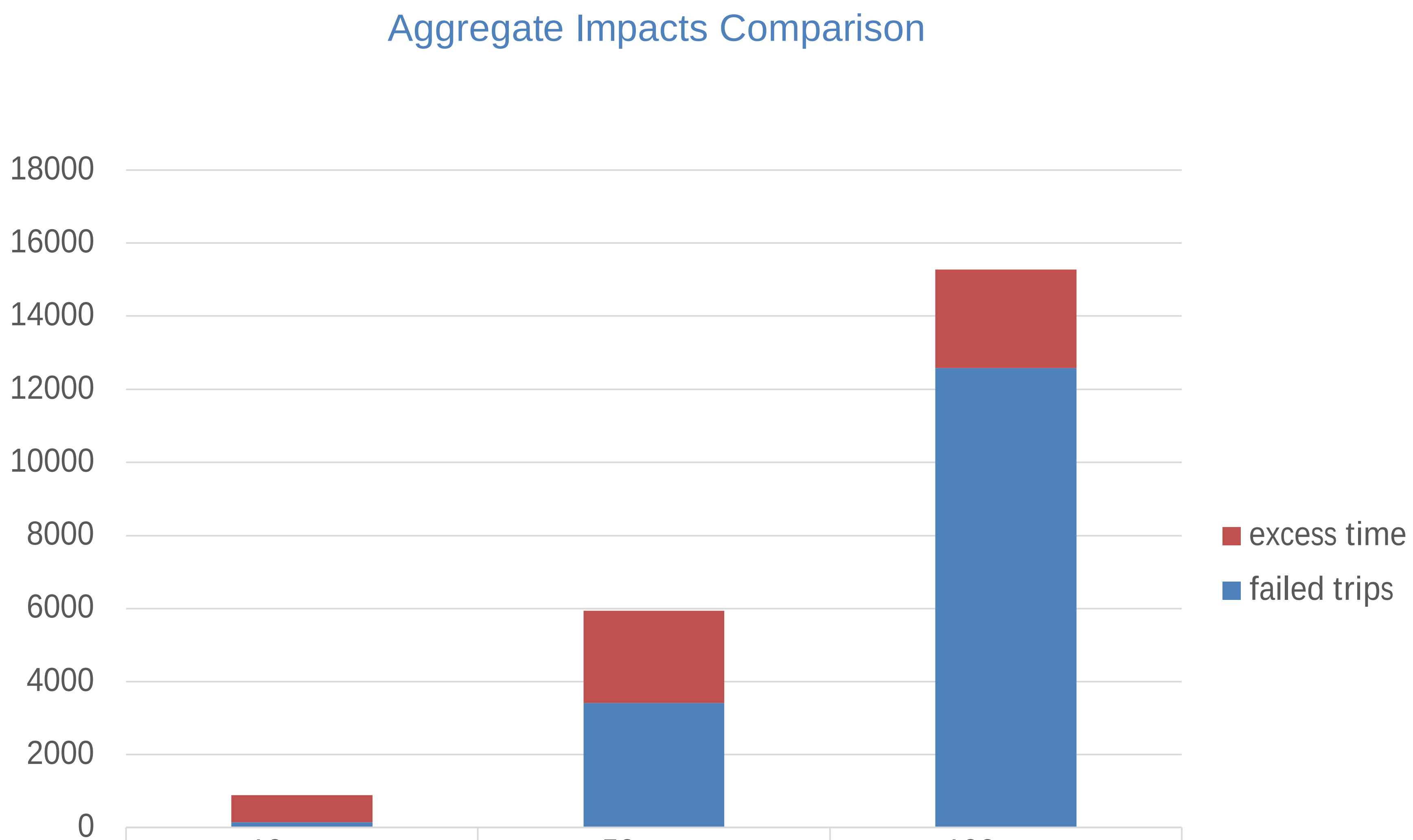
River Corridor Data

Data	Source	Web Service	Data Use±	Comments
VHD SGA Network - Assessment	VTANR	Yes; Needs Update	E, V, R, A*	Principal dataset for assessment and display of vulnerability data. Associated with road segments for scoring and display. Available statewide.
VT River Sensitivity Coarse Screen	MMI; VLT	No	E, V	Available statewide.
SGA Data: Phase 1 & 2	VTANR	No	E, V	Available for select watersheds.
VT River Corridor	VTANR	Yes; Needs Update	E, V	Available statewide for drainages over two square miles.
VT Meander Centerlines	VTANR	No	E,V	Available statewide for drainages over two square miles. Produced by VTANR for statewide river corridor mapping.
VHD SGA Network - FIT	VTANR	Yes	E, V	Available in select locations.
Valley Walls	VTANR & TNC	No	E, V	Available statewide for drainages over two square miles. Produced by VTANR for statewide river corridor mapping.
SSURGO	USDA	Yes	E, V	Available statewide.
DFIRM Floodplains and Cross-Sections	FEMA	Yes; Needs Update	E, V	Available where flood insurance rate mapping has been conducted.

Impacts

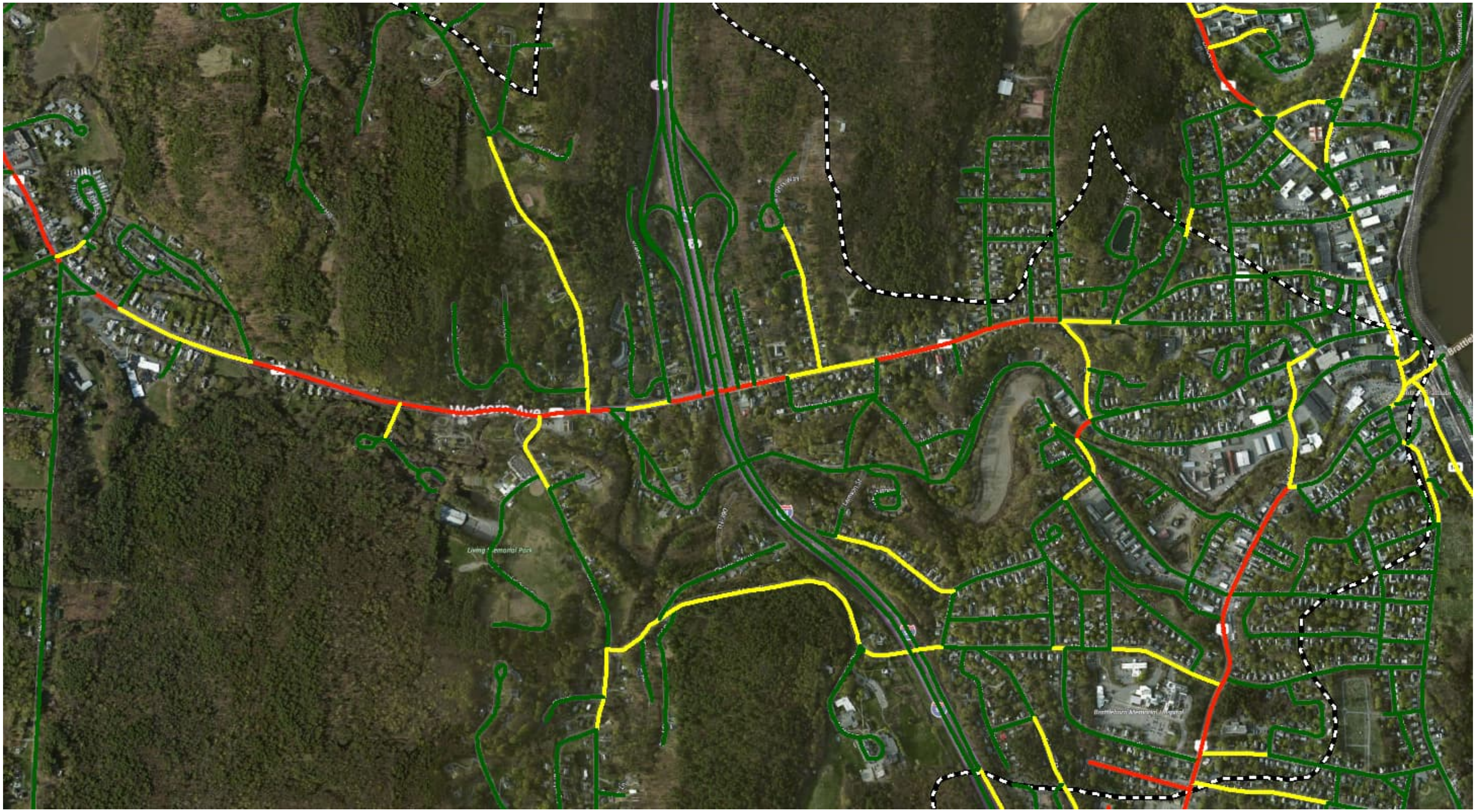

Roadway Segment Failures
Failed Trips
Traffic Diversion
Roadway Segment Traffic Volumes
Excess Travel Time by Area

Whetstone Brook Watershed



	10-year	50-year	100-year
excess time	748	2532	2683
failed trips	150	3414	12587

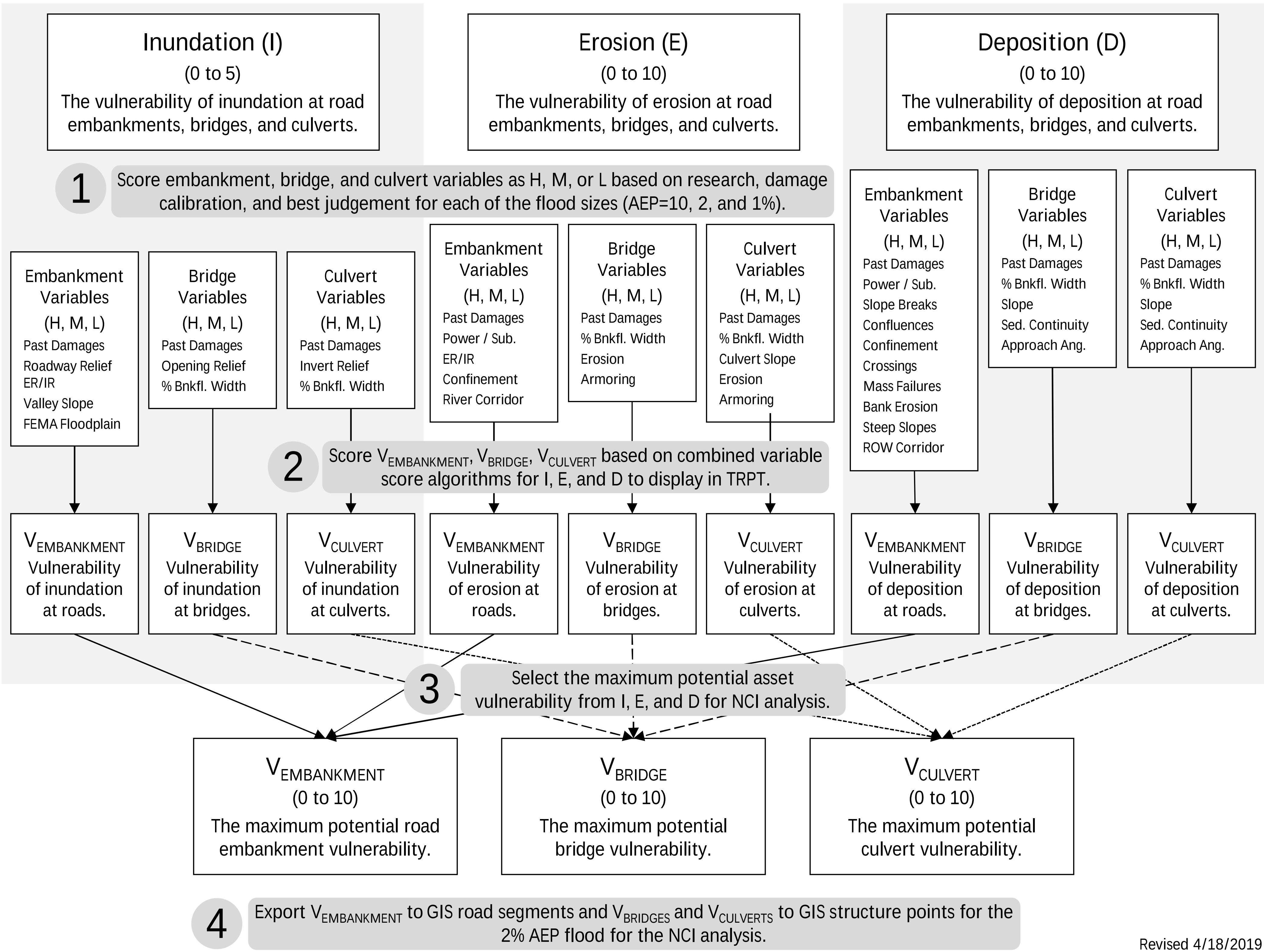
Criticality: Critical Closeness Accessibility



(Novak and Sullivan, 2014)

Criticality

SCORE	Key Link in Network Criticality Index (High or Medium)		Critical Closeness Accessibility (UVM)		Locally Important for daily regular function or for detour*	Combined Score for Map Display
10=	High or Medium	AND	High	AND	y	HIGH (RED)
9=	High or Medium	AND	Medium	AND	y	
8=	High or Medium	AND	High or Medium	AND	n	
7=	High or Medium	AND	Low	AND	y	
6=	Low	AND	High	AND	y	
5=	Low	AND	Medium	AND	y	
4=	High or Medium	AND	Low	AND	n	MEDIUM (YELLOW)
3=	Low	AND	High or Medium	AND	n	
2=	Low	AND	Low	AND	y	
1=	Low	AND	Low	AND	n	LOW (GREEN)



Inundation (I)
(0 to 5)
The vulnerability of inundation at road embankments, bridges, and culverts.
Erosion (E)
(0 to 10)
The vulnerability of erosion at road embankments, bridges, and culverts.
Deposition (D)
(0 to 10)
The vulnerability of deposition at road embankments, bridges, and culverts.
1
Score embankment, bridge, and culvert variables as H, M, or L based on research, damage calibration, and best judgement for each of the flood sizes (AEP=10, 2, and 1%).
Embankment Variables (H, M, L)
Past Damages
Roadway Relief
ER/IR
Valley Slope
FEMA Floodplain
Bridge Variables (H, M, L)
Past Damages
Opening Relief
% Bnkfl. Width
Culvert Variables (H, M, L)
Past Damages
Invert Relief
% Bnkfl. Width
Embankment Variables (H, M, L)
Past Damages
Power / Sub.
ER/IR
Confinement
River Corridor
Bridge Variables (H, M, L)
Past Damages
% Bnkfl. Width
Erosion
Armoring
Culvert Variables (H, M, L)
Past Damages
% Bnkfl. Width
Culvert Slope
Erosion
Armoring
Embankment Variables (H, M, L)
Past Damages
Power / Sub.
Slope Breaks
Confluences
Confinement
Crossings
Mass Failures
Bank Erosion
Steep Slopes
ROW Corridor
Bridge Variables (H, M, L)
Past Damages
% Bnkfl. Width
Slope
Sed. Continuity
Approach Ang.
Culvert Variables (H, M, L)
Past Damages
% Bnkfl. Width
Slope
Sed. Continuity
Approach Ang.
2
Score $V_{EMBANKMENT}$, V_{BRIDGE}, $V_{CULVERT}$ based on combined variable score algorithms for I, E, and D to display in TRPT.
$V_{EMBANKMENT}$ Vulnerability of inundation at roads.
V_{BRIDGE} Vulnerability of inundation at bridges.
$V_{CULVERT}$ Vulnerability of inundation at culverts.
$V_{EMBANKMENT}$ Vulnerability of erosion at roads.
V_{BRIDGE} Vulnerability of erosion at bridges.
$V_{CULVERT}$ Vulnerability of erosion at culverts.
$V_{EMBANKMENT}$ Vulnerability of deposition at roads.
V_{BRIDGE} Vulnerability of deposition at bridges.
$V_{CULVERT}$ Vulnerability of deposition at culverts.
3
Select the maximum potential asset vulnerability from I, E, and D for NCI analysis.
$V_{EMBANKMENT}$
(0 to 10)
The maximum potential road embankment vulnerability.
V_{BRIDGE}
(0 to 10)
The maximum potential bridge vulnerability.
$V_{CULVERT}$
(0 to 10)
The maximum potential culvert vulnerability.
4
Export $V_{EMBANKMENT}$ to GIS road segments and $V_{BRIDGES}$ and $V_{CULVERTS}$ to GIS structure points for the 2% AEP flood for the NCI analysis.
Revised 4/18/2019

Vulnerability – Scoring Example

CULVERT VULNERABILITY DUE TO EROSION	HIGH		MODERATE		LOW	
Documented Past Culvert Erosion Damages due to Erosion	Complete Failure	Temp. Failure	Full Closure	Partial Closure	N/A	
Structure Width vs. Bankfull Channel Width (%) (HGR)	<25	25-50	50-75		75-100	≥100
Structure Slope (SGA Data, GC Screen)	Steeper than channel				Same as channel or lower	
Erosion (SGA Data, GC Screen)	Severe erosion		Low level of erosion		No erosion	
Armoring (SGA Data, GC Screen)	Failing Armoing		Intact armoring		No armoring	

CULVERT VARIABLE SCORES

				1					2		3			3			3
Flood	Past Damages				Structure Width vs. Bankfull Channel Width (%) (HGR-based)					Culvert Slope		Erosion			Armoring		
(% AEP)	Complete Failure	Temp. Failure	Full Closure	Partial Closure	<25	25-50	50-75	75-100	>100	Steeper	Same, Lower	Severe	Low	None	Failing	Intact	None
10%	N/A	N/A	N/A	N/A	H	M	L	L	L	M	L	H	M	L	M	L	L
2%	N/A	N/A	N/A	N/A	H	H	M	M	L	H	L	H	M	L	H	M	L
1%	N/A	N/A	N/A	N/A	H	H	H	M	M	H	M	H	H	M	H	H	M
					high-high	high	moderate	low	low-low								

OVERALL CULVERT VULNERABILITY SCORING

SCORE	Past Damages	Structure Width vs. Bankfull Channel Width (%) (HGR-based)	Culvert Slope	Erosion	Armoring
10=	Complete erosion failure	L, M, H, null	L, M, H, null	L, M, H, null	L, M, H, null
9=	Temporary erosion failure	H	L, M, H, null	H	H
8=	Temporary erosion failure	L, M, H, null	L, M, H, null	L, M, H, null	L, M, H, null
7=	Full or partial erosion closure	H	L, M, H, null	H	H
6=	Full or partial erosion closure	L, M, H, null	L, M, H, null	L, M, H, null	L, M, H, null
6=	null	H	H	H	H
5=	null	H	L, M, H, null	L, M, H, null	L, M, H, null
4=	null	M	H	H	H
3=	null	M	M, H	M, H	M, H
2=	null	M	M, L, null	M, L, null	M, L, null
2=	null	L, null	M, H	M, H	M, H
1=	null	All other combinations	All other combinations	All other combinations	All other combinations
0=	N/A (Out of valley bottom plus 100 feet)	N/A (Out of valley bottom plus 100 feet)	ut of valley bottom plus 1	N/A (Out of valley bottom plus 100 feet	N/A (Out of valley bottom plus 100 feet

Vulnerability – Scoring Example

EMBANKMENT VULNERABILITY DUE TO EROSION	HIGH		MODERATE		LOW	
Documented Past Embankment Damages due to Erosion	Complete Failure	Temp. Failure	Full Closure	Partial Closure	N/A	
Specific Stream Power (W/m^2) and Dominant Substrate Size	SSP = 100 to 300		SSP > 300		SSP < 100	
	Gravel	Cobble (or larger)	Gravel/Cobble	Larger than Cobble	Gravel	Larger than Gravel
Entrenchment Ratio and Incision Ratio	ER<2 & IR>2	ER<2 & IR1.5-2; ER=2-5 & IR≥2	ER<2 & IR <5; ER2-5 & IR1.5-2; ER>5 & IR≥2		5 & IR<1.5; ER>5 & IR	ER>5 & IR<1.5
Valley Confinement	<6		6-10			>10
Remaining River Corridor Width where the ROW or Development Confine River (percent)	<75		75-90			>90
Length of ROW in Unclipped River Corridor (feet)	>1,320		660-1,320			0-660

EMBANKMENT VARIABLE SCORES					Specific Stream Power and Dominant Substrate Size						Entrenchment Ratio / Incision Ratio								
Flood	Past Damages				SSP = 100 to 300		SSP > 300		SSP < 100		ER<2			ER=2-5			ER>5		
(% AEP)	Complete Failure	Temp. Failure	Full Closure	Partial Closure	Gravel (Alluvium)	Cobble or larger (no Alluvium)	Gravel/Cobble (Outwash)	Larger than cobble (no Outwash)	Gravel	Larger than gravel	IR<1.5	IR=1.5-2.0	IR≥2.0	IR<1.5	IR=1.5-2.0	IR≥2.0	IR<1.5	IR=1.5-2.0	IR≥2.0
10%	FC	FC	N/A	N/A	H	M	M	L	L	L	L	M	H	L	L	M	L	L	L
2%	CF	TF	FC	PC	H	H	M	M	L	L	M	H	H	L	M	H	L	L	M
1%	CF	TF	FC	PC	H	H	H	M	M	L	H	H	H	M	H	H	L	M	H
					high-high	high	moderate	moderate-low	low	low-low	moderate	high	high-high	low	moderate	high	low-low	low	moderate

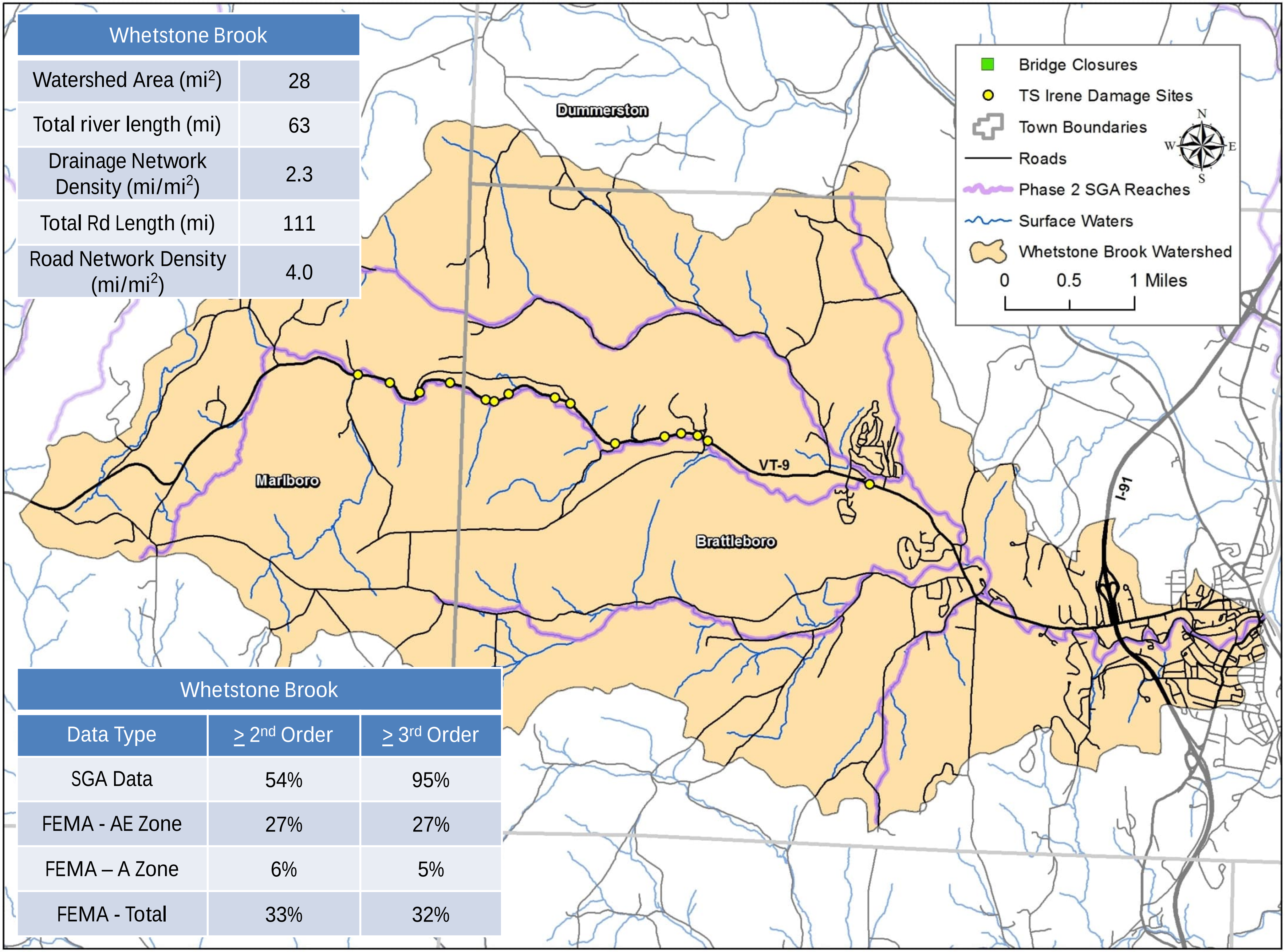
SCORE	Past Damages	Specific Stream Power and Dominant Substrate Size	Entrenchment Ratio / Incision Ratio	Valley Confinement	River Corridor
10=	Complete erosion failure	L, M, H	L, M, H, null	L, M, H, null	L, M, H, null
10=	Temporary erosion failure	H	L, M, H, null	L, M, H, null	H
9=	Temporary erosion failure	H, M	L, M, H, null	L, M, H, null	H, M
9=	null	H	L, M, H, null	L, M, H, null	H
8=	Temporary erosion failure	L, M, H	L, M, H, null	L, M, H, null	L, M, H, null
7=	null	M	L, M, H, null	L, M, H, null	H
7=	Full erosion closure	M, H	L, M, H, null	L, M, H, null	M, H
6=	null	H	L, M, H, null	L, M, H, null	M
5=	Full erosion closure	L, M, H	L, M, H, null	L, M, H, null	L, M, H, null
5=	null	H	H, M	H, M	L
5=	null	L	H, M	H, M	H
4=	null	M	H, M	H, M	M
4=	null	H	H, M, L, null	H, M, L, null	L
4=	null	L	H, M, L, null	H, M, L, null	H
4=	null	M	H, M	H, M	M
3=	Partial erosion closure	L, M, H	L, M, H, null	L, M, H, null	L, M, H, null
3=	null	M	H, M, L, null	H, M, L, null	M
3=	null	L	H, M	H, M	M
3=	null	M	H, M	H, M	L
3=	null	L	H, M	H, M	M
2=	null	M	L, null	L, null	L
2=	null	L	L, null	L, null	M
1=	null	All other combinations	All other combinations	All other combinations	All other combinations
0=	N/A (Out of valley bottom plus 100 feet)	N/A (Out of valley bottom plus 100 feet)	N/A (Out of valley bottom plus 100 feet)	/A (Out of valley bottom plus 100 fee	N/A (Out of valley bottom plus 100 feet)

Road Segment Statistics

Layer	Number of Road Segments
2010 Statewide Model	5,500
TransRoad	75,000
TransRoad less Class 4, private roads, trails, & misc.	53,000
TransRoad usable segments plus centroid connectors	54,000
2015 TransRoad Statewide Model	21,000

Thank you!

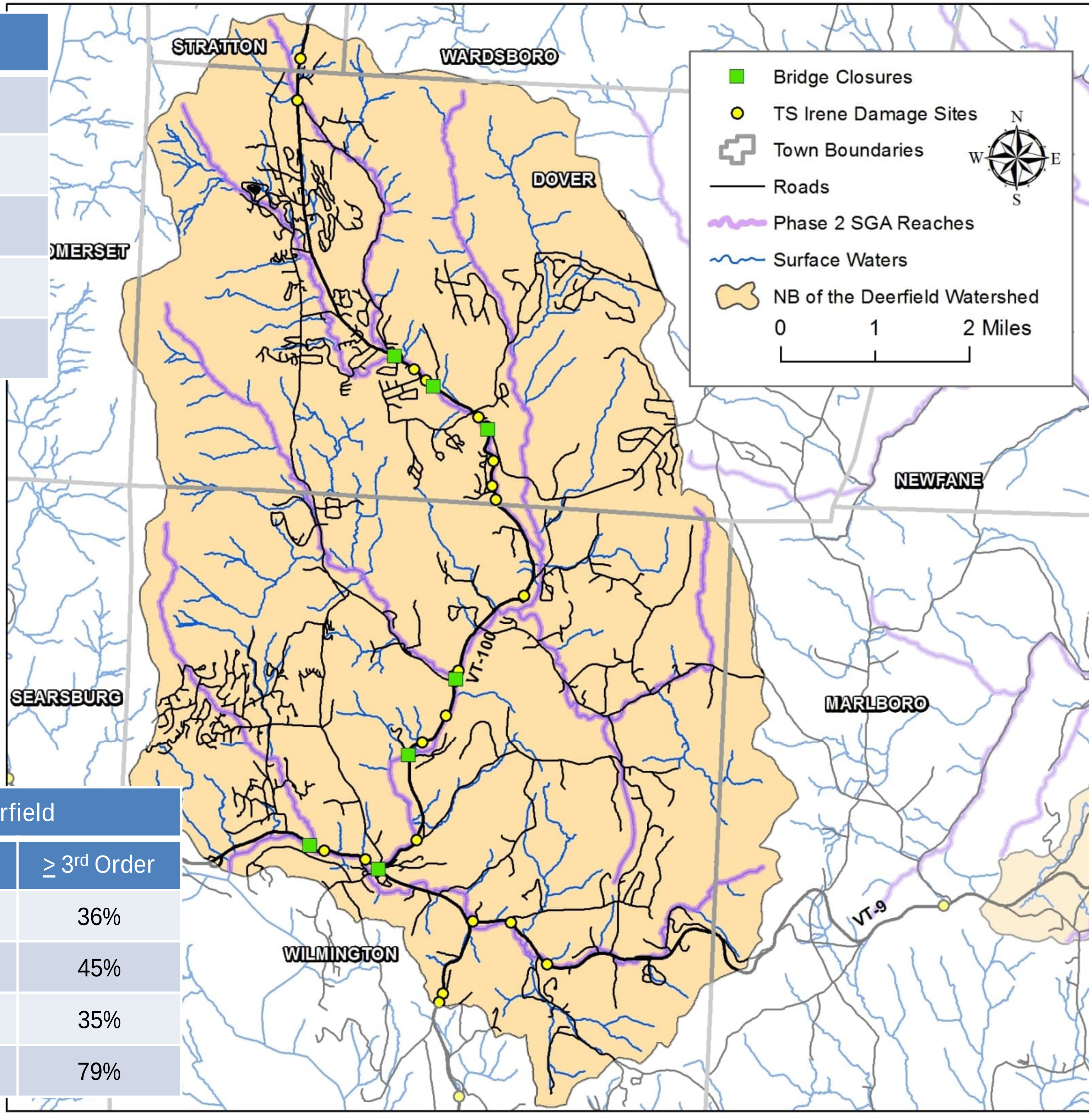
State and Main Streets (looking east)
Montpelier, VT
1927
Source: VT Historical Society



Whetstone Brook	
Watershed Area (mi^2)	28
Total river length (mi)	63
Drainage Network Density (mi/mi^2)	2.3
Total Rd Length (mi)	111
Road Network Density (mi/mi^2)	4.0

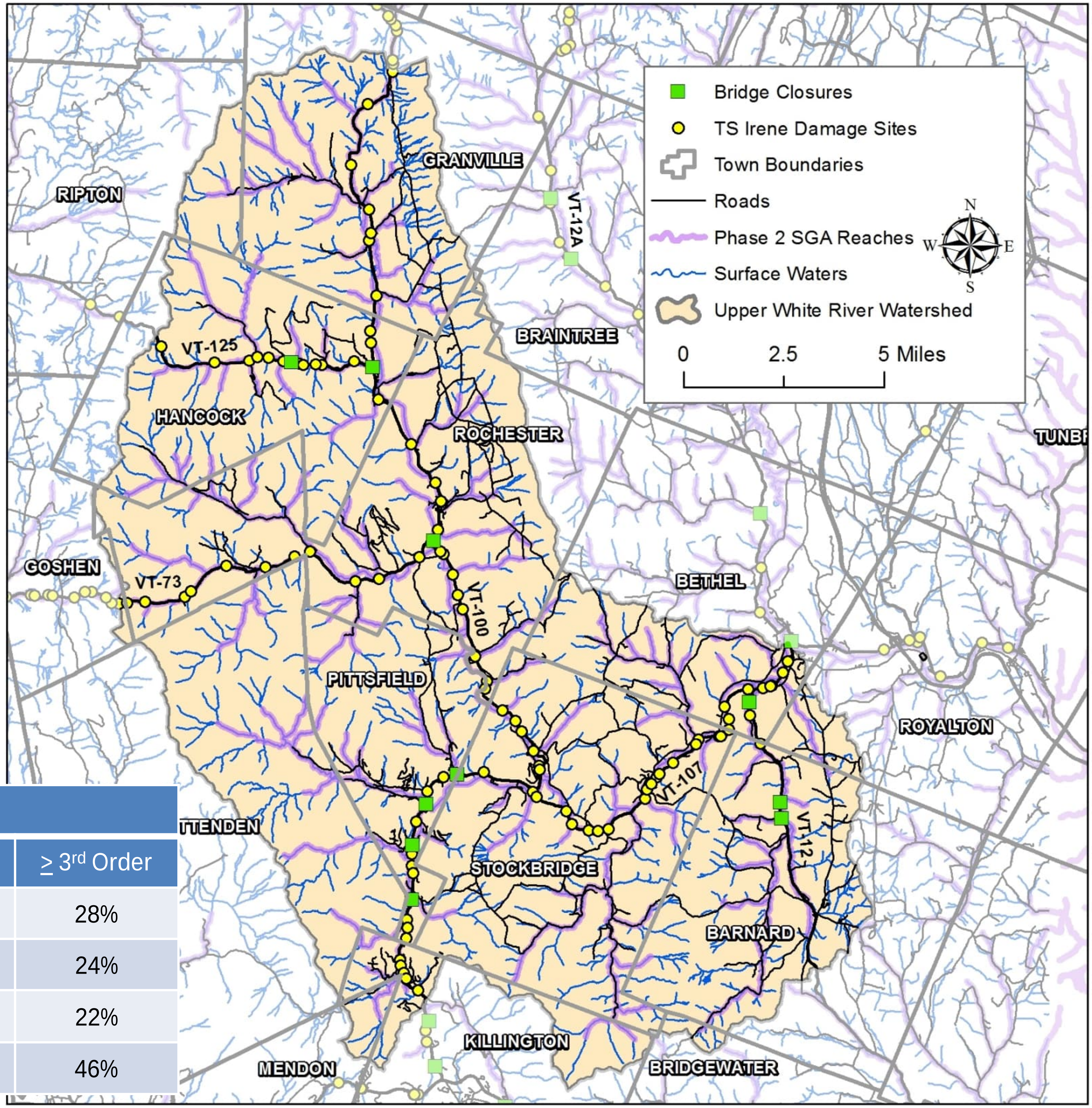
Whetstone Brook		
Data Type	$\geq$ 2nd Order	$\geq$ 3rd Order
SGA Data	54%	95%
FEMA - AE Zone	27%	27%
FEMA – A Zone	6%	5%
FEMA - Total	33%	32%

North Branch of the Deerfield	
Watershed Area (mi^2)	56
Total river length (mi)	149
Drainage Network Density (mi/mi^2)	2.7
Total Rd Length (mi)	175
Road Network Density (mi/mi^2)	3.1



North Branch of the Deerfield		
Data Type	≥ 2nd Order	≥ 3rd Order
SGA Data	20%	36%
FEMA - AE Zone	30%	45%
FEMA – A Zone	21%	35%
FEMA - Total	51%	79%

Upper White River	
Watershed Area (mi^2)	271
Total river length (mi)	663
Drainage Network Density (mi/mi^2)	2.5
Total Rd Length (mi)	360
Road Network Density (mi/mi^2)	1.3



Upper White River		
Data Type	≥ 2nd Order	≥ 3rd Order
SGA Data	15%	28%
FEMA - AE Zone	12%	24%
FEMA – A Zone	11%	22%
FEMA - Total	24%	46%

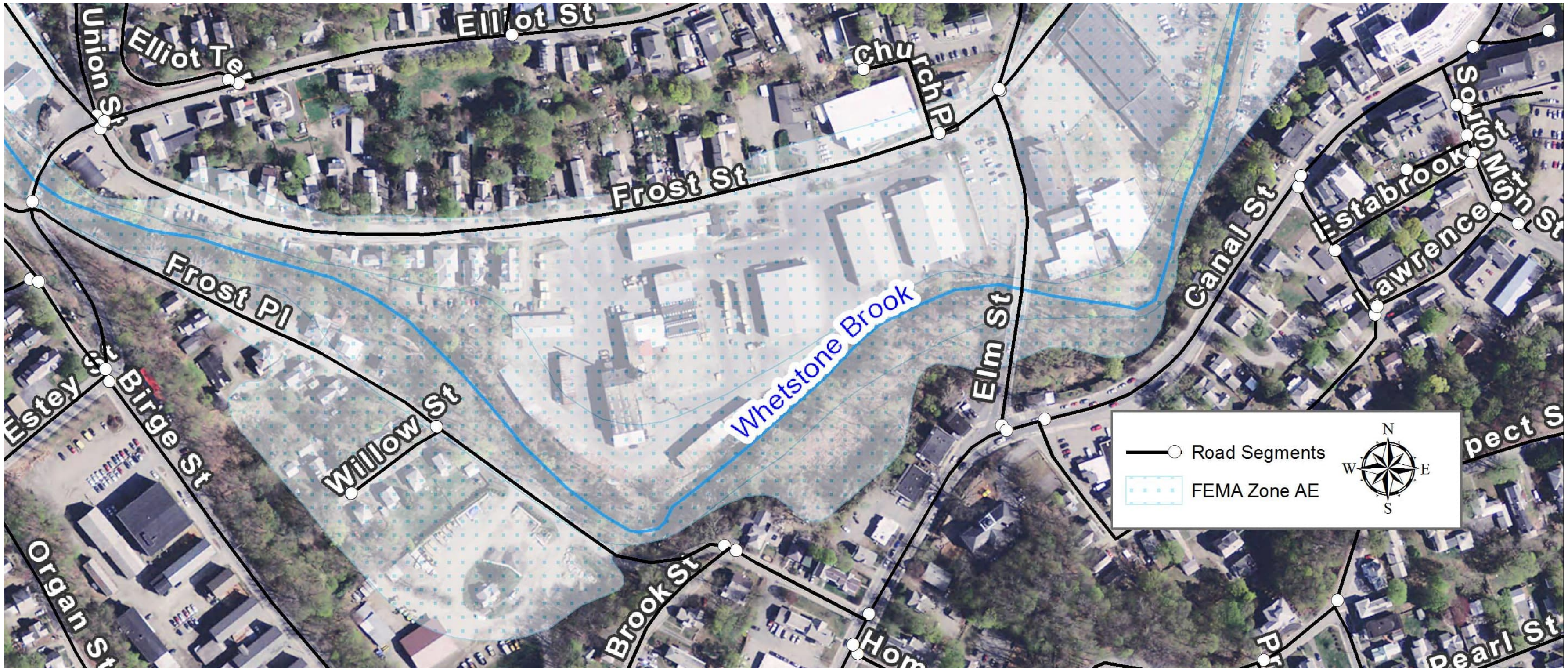
	Whetstone Brook	North Branch of the Deerfield River	Upper White River
Watershed Area(mi^2)	28	56	271
Total river length (mi)	63	149	663
Drainage Network Density (mi/mi^2)	2.3	2.7	2.5
Total Rd Length (mi)	111	175	360
Road Network Density (mi/mi^2)	4.0	3.1	1.3

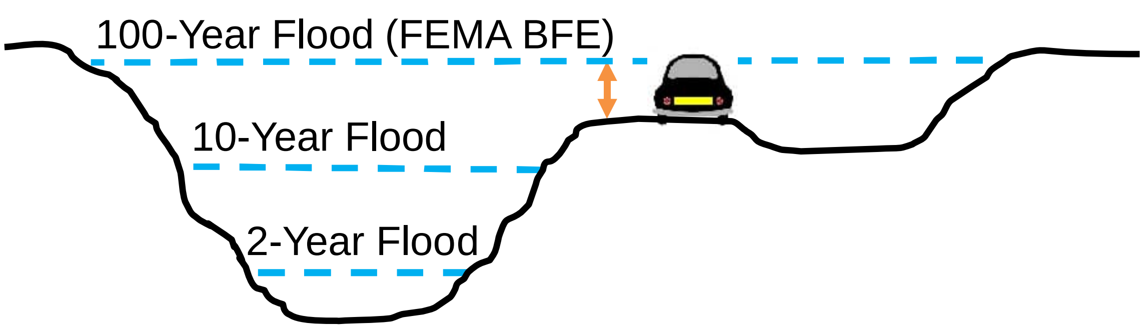
Mitigation

Develop Mitigation Options

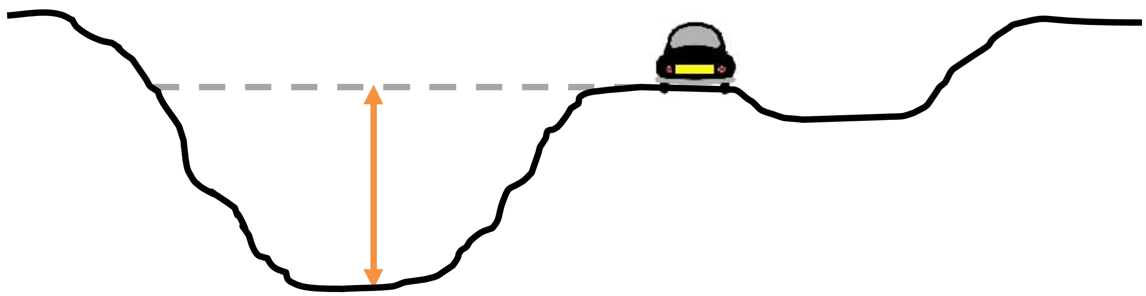
- Relocate or Detour
- Fortify Infrastructure
- Address Resiliency
- Restore Floodplain Connection
- Change Land Use
- Conservation
- Preparedness

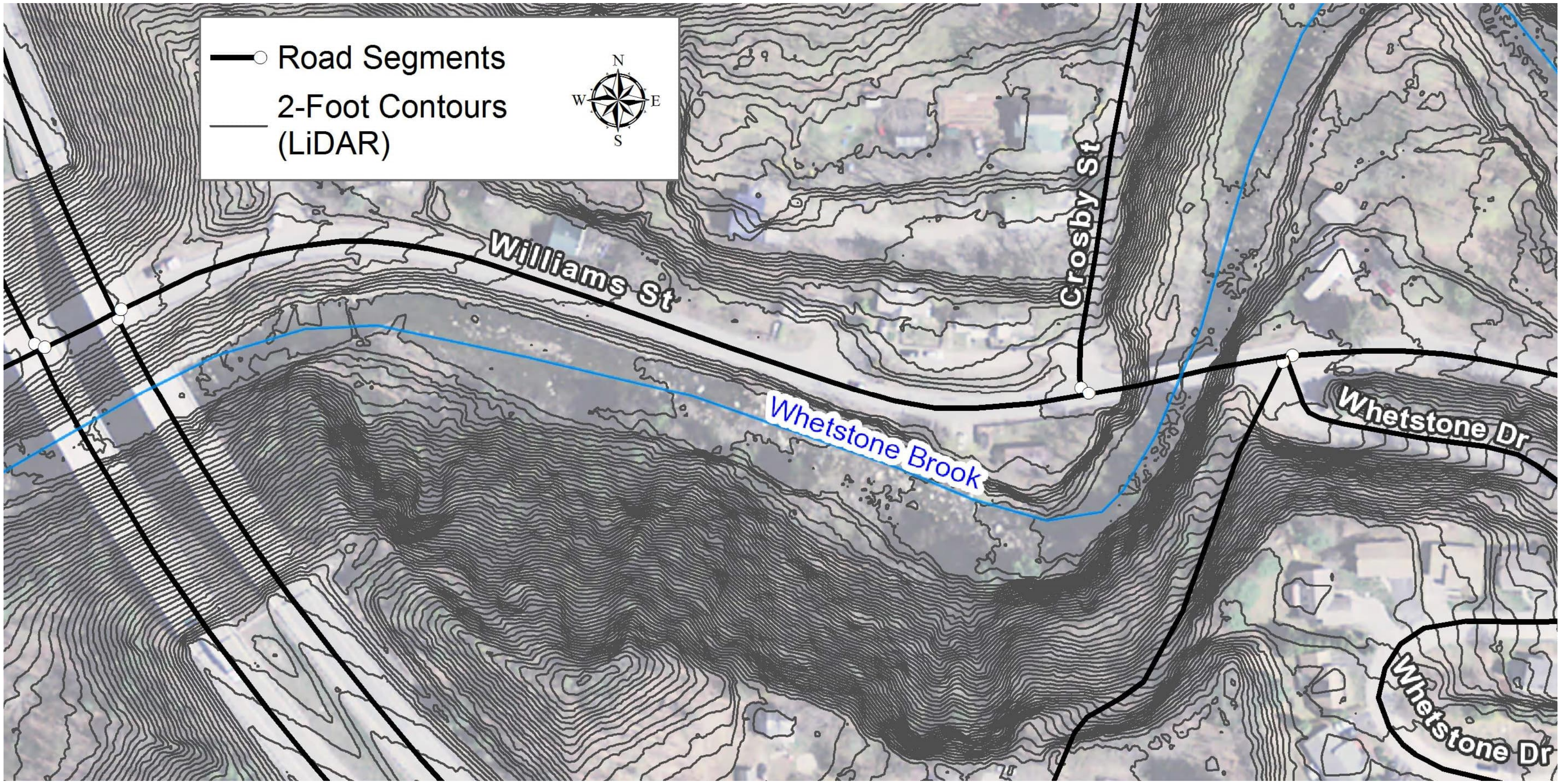
Length of Road in 100-year Floodplain & 100-Year Flood Depth Above Road





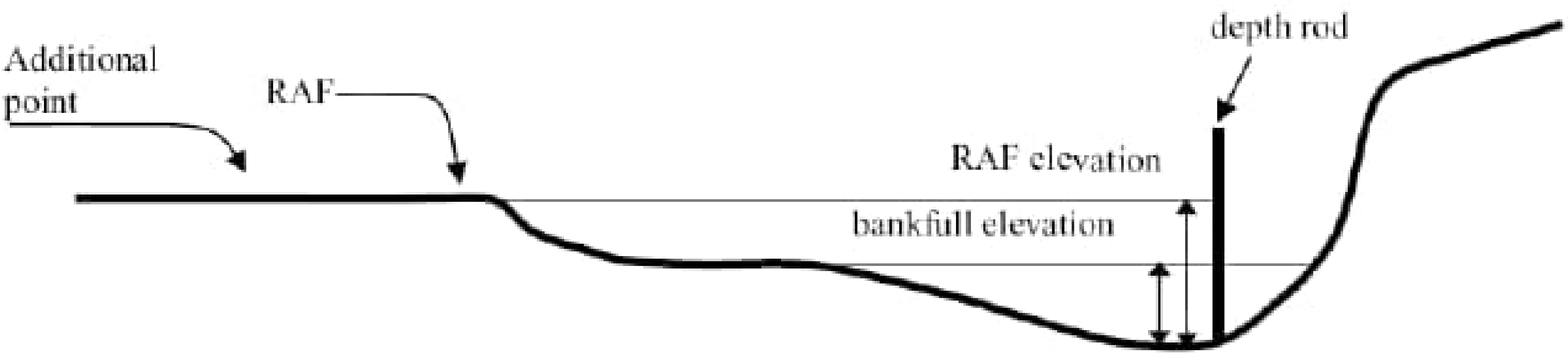
River-Roadway Relief





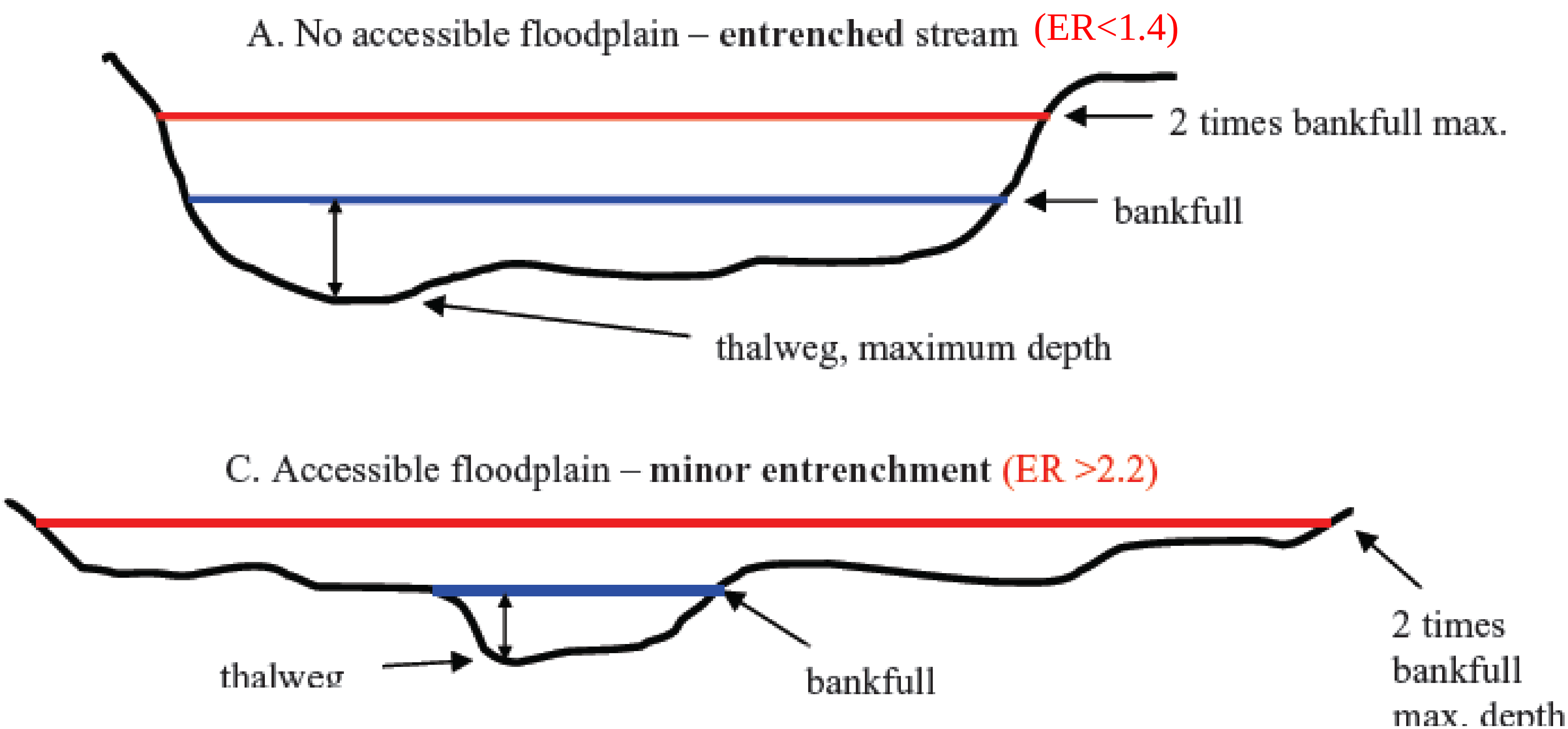
Incision Ratio

$$IR = \frac{\text{Recently abandoned floodplain (RAF)}}{\text{Bankfull elevation}} = \frac{\text{Low bank height}}{\text{Maximum bankfull height}} = \frac{\text{LBH}}{\text{BFH}}$$



(VTANR, 2009)

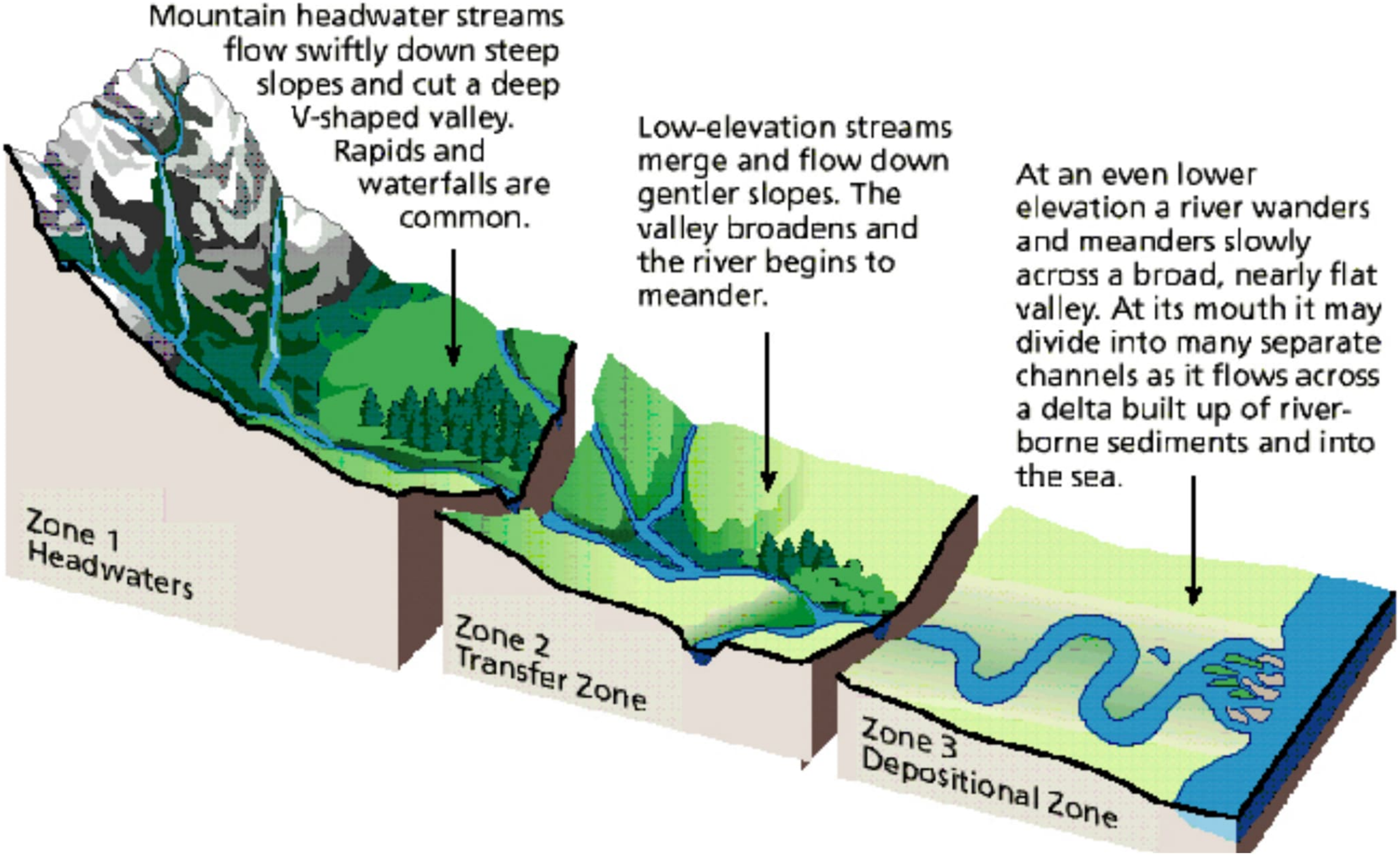
Entrenchment Ratio



(VTANR, 2009)

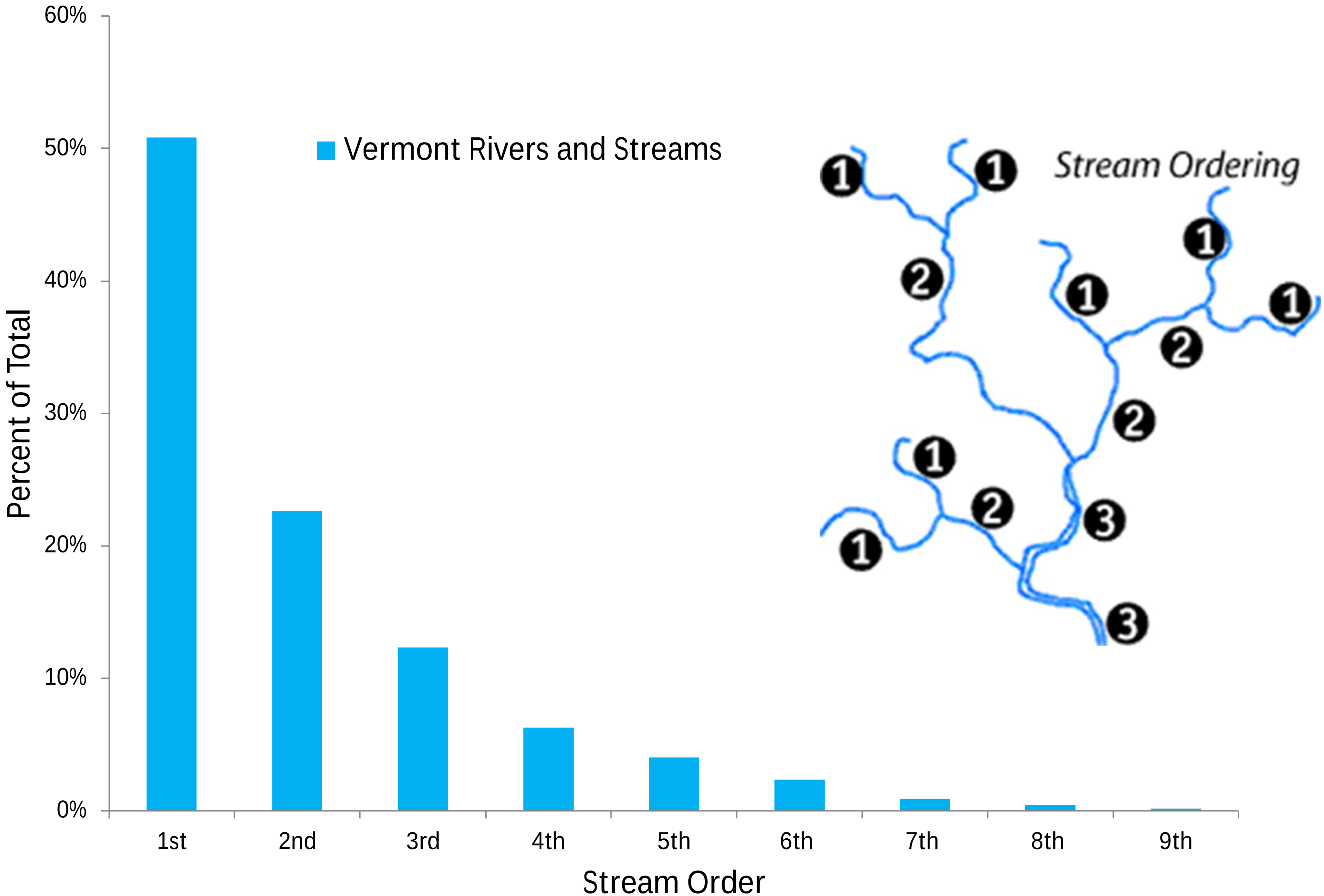
Approximately
the 50-year
floodplain width

Valley Slope

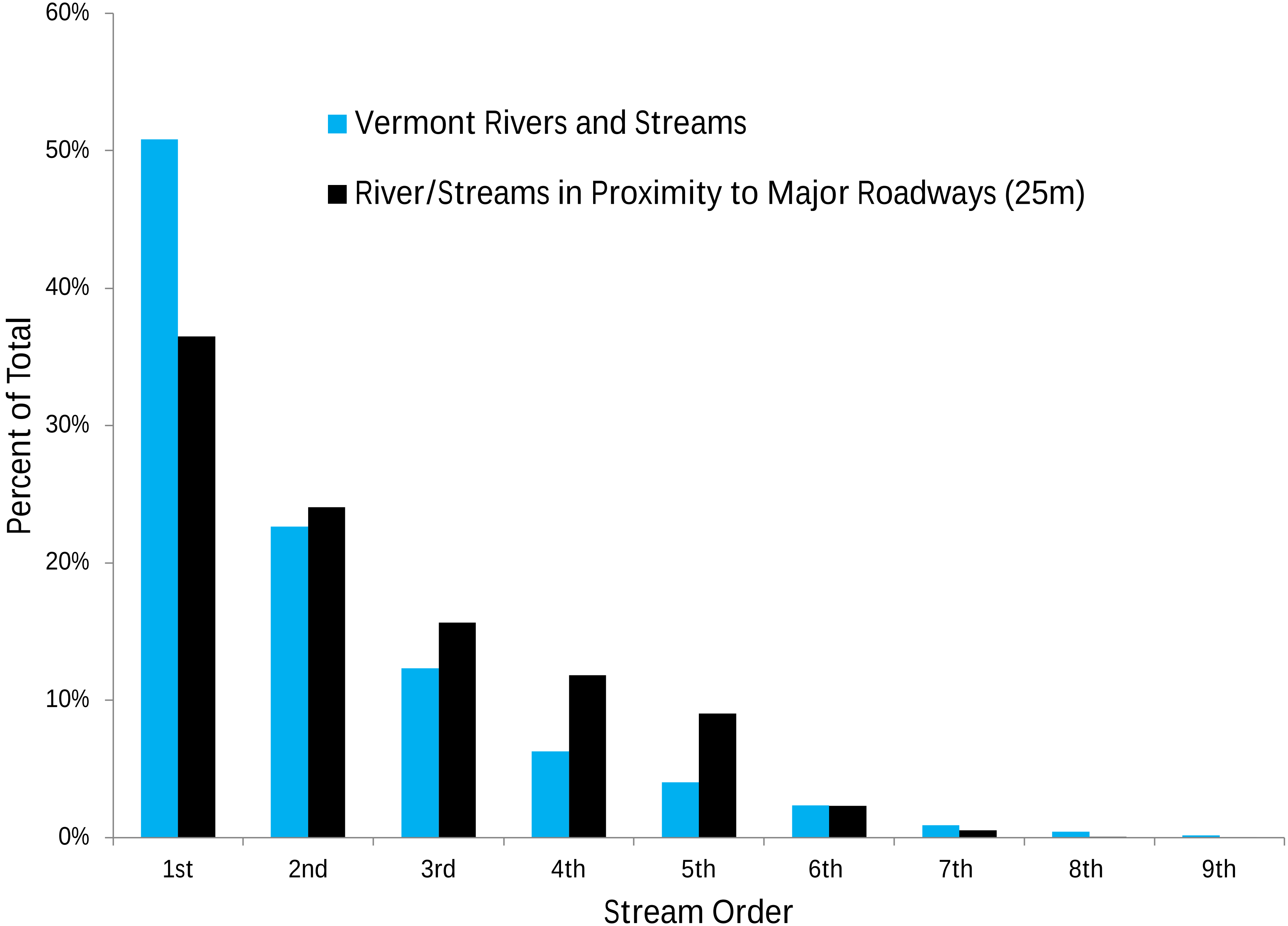


(Schumm1977; FISRWG, 1998)

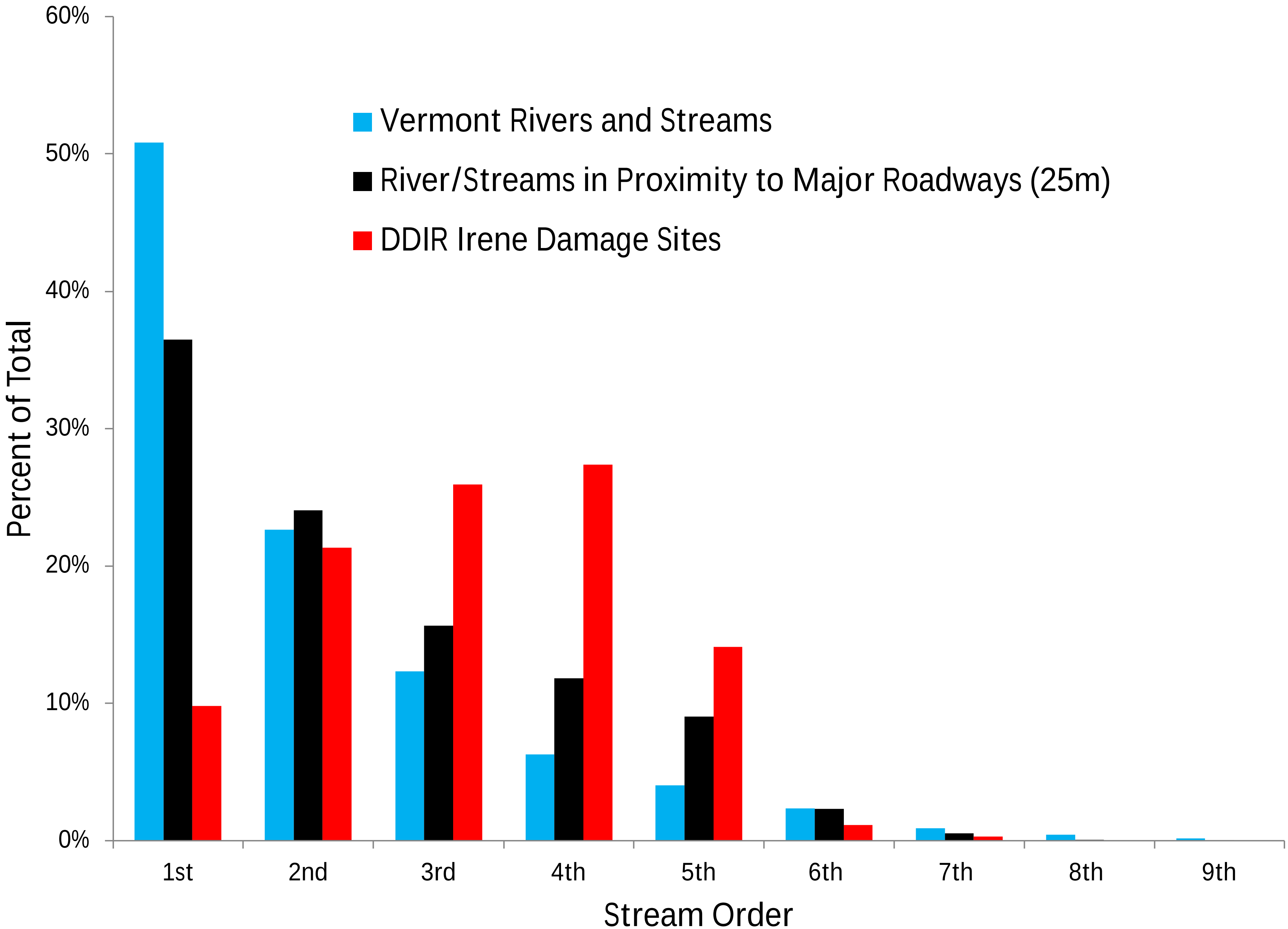
Stream Power



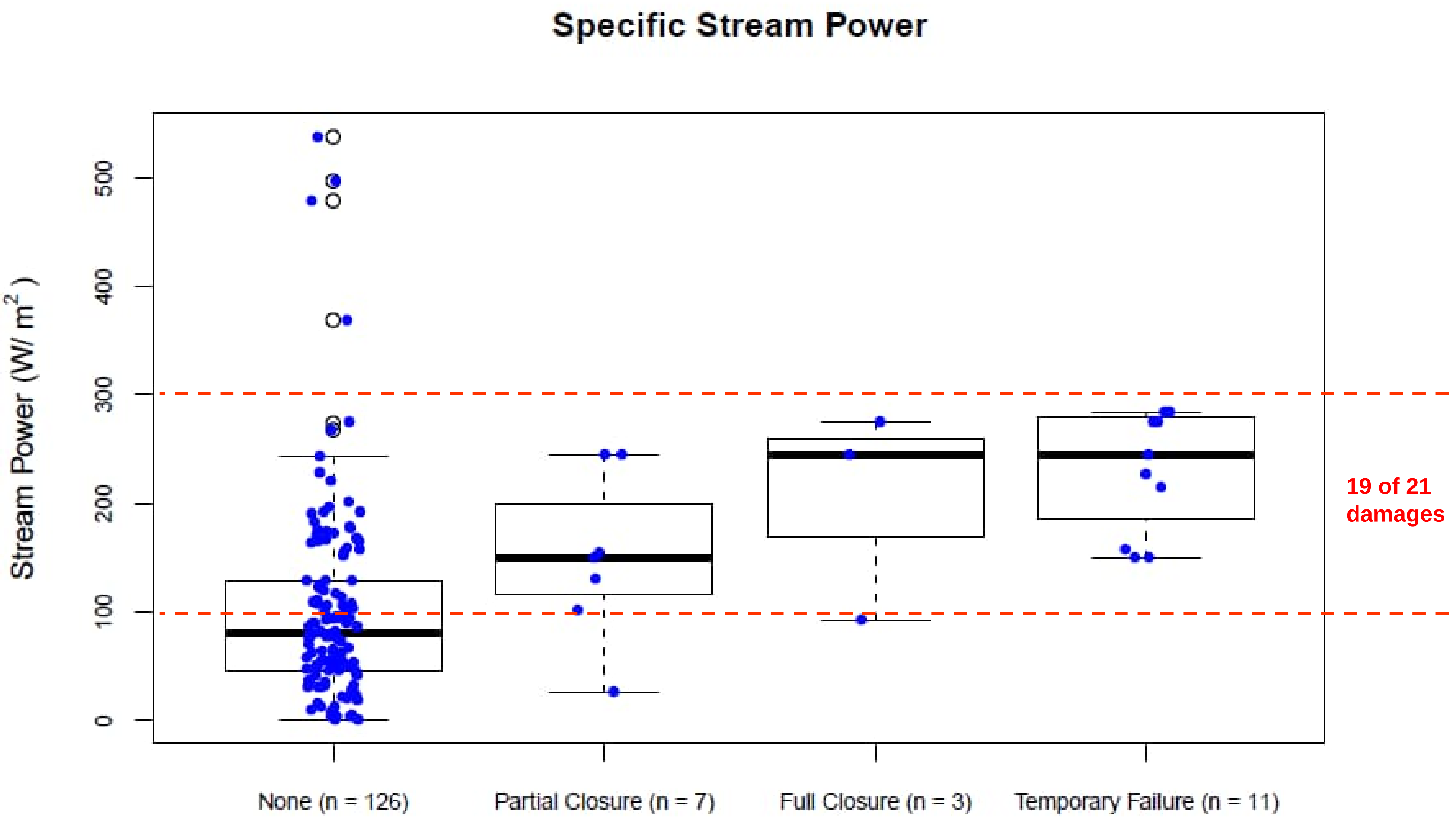
Stream Power



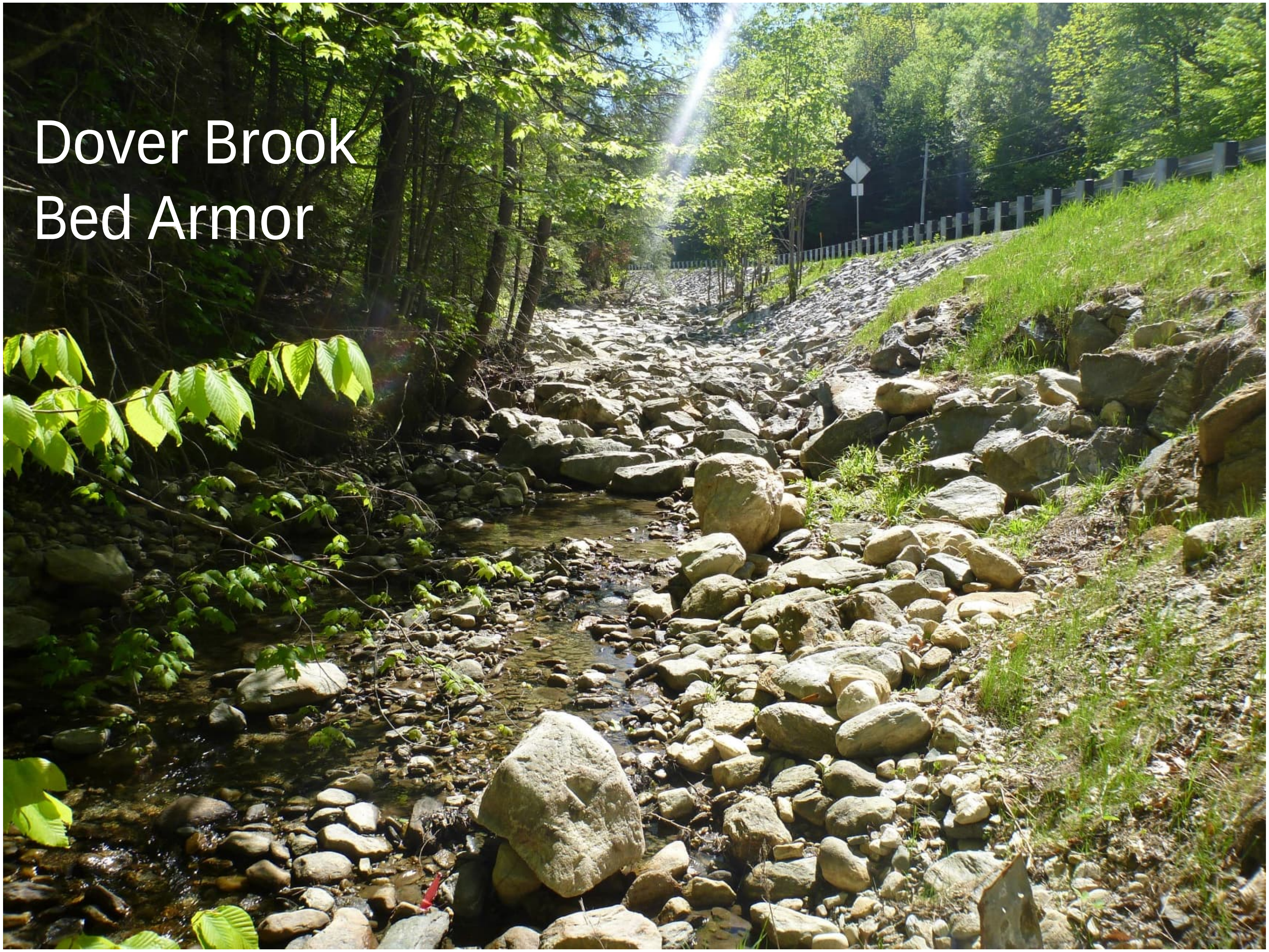
Stream Power



Stream Power



Stream Power



Confinement

Confinement = Valley Width / Channel Width

Confinement	Valley Width / Channel Width Ratio
Narrowly Confined	≥1 and < 2
Semi Confined	≥2 and <4
Narrow	≥4 and <6
Broad	≥6 and <10
Very Broad	≥10, may have abandoned terraces on one or both sides

(VTANR, 2009)

NATURAL

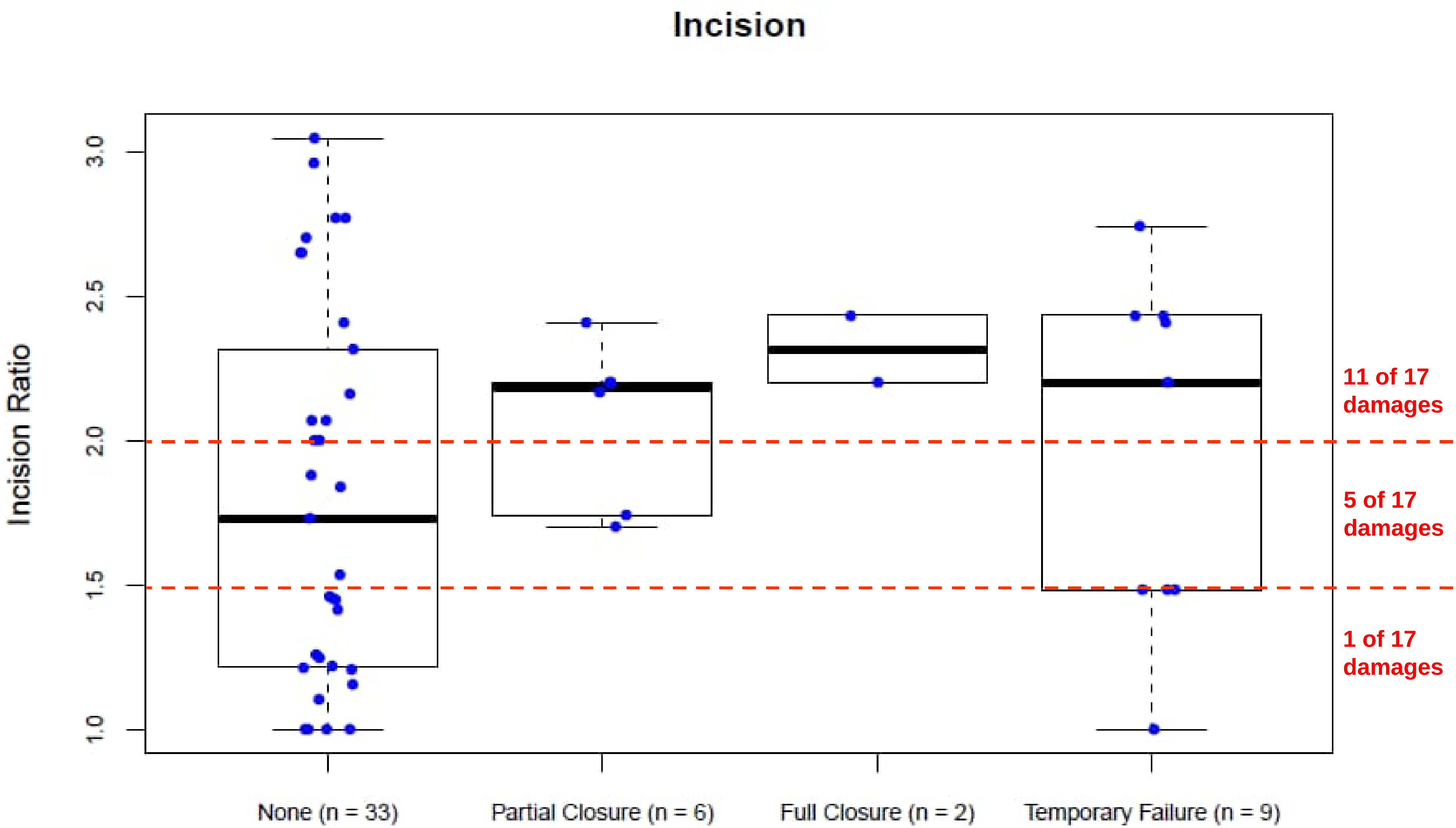
- Valley wall
- Terraces
- Alluvial fan (local)
- Natural bank levee
- Confluences

ARTIFICIAL

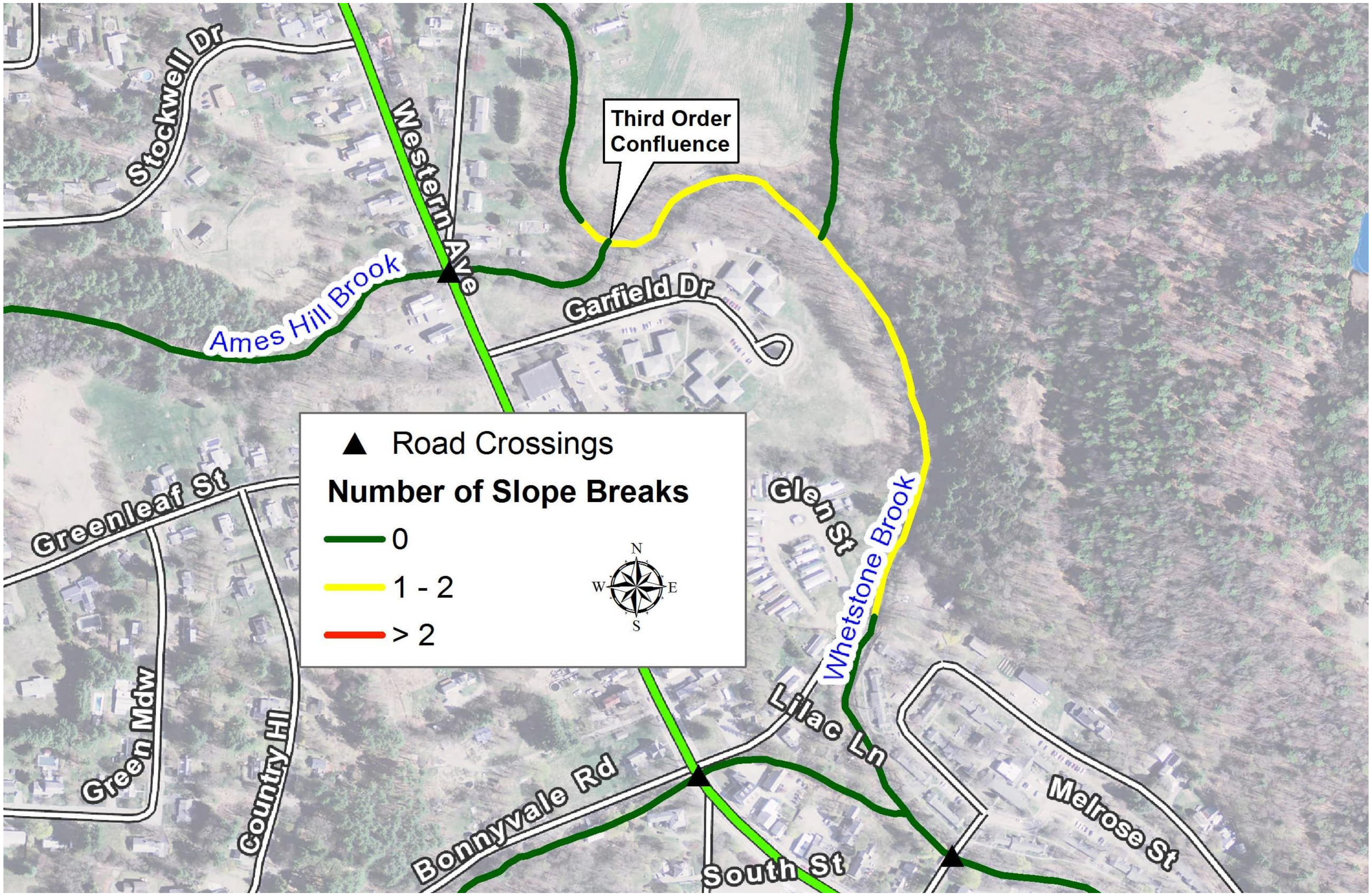
- Embankment fill
- Berm or levee

Confinement Increase due to Roads

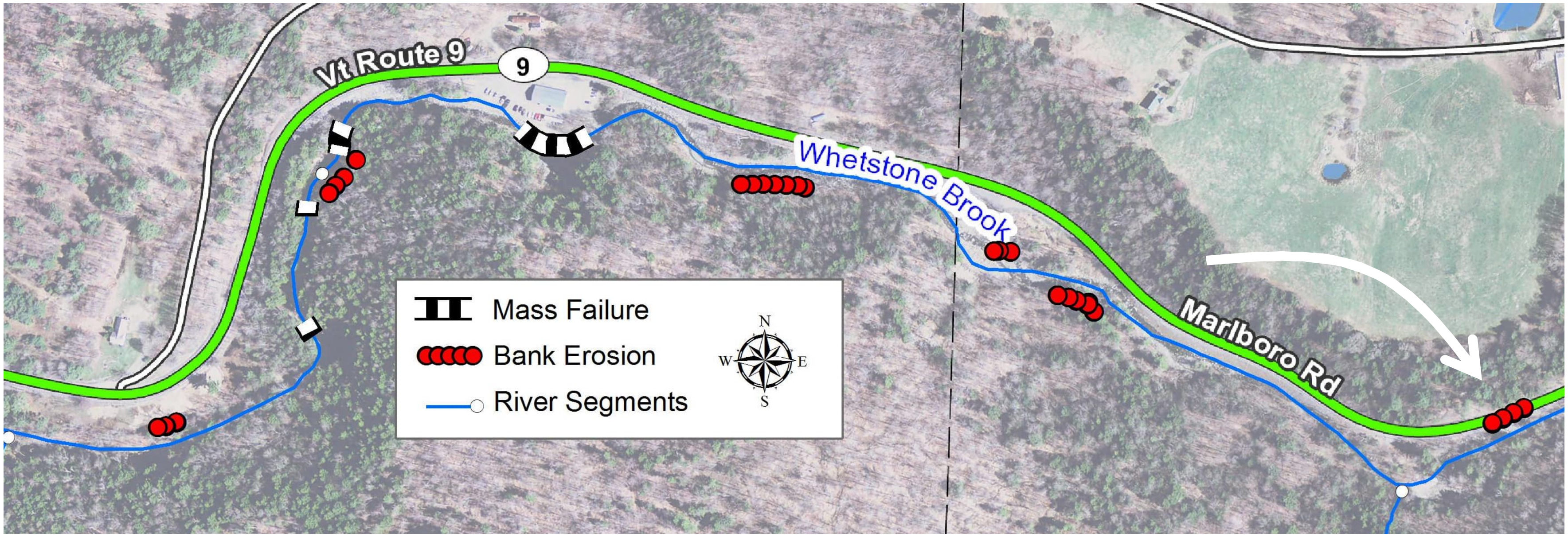
Incision Ratio and Erosion Failure Modes



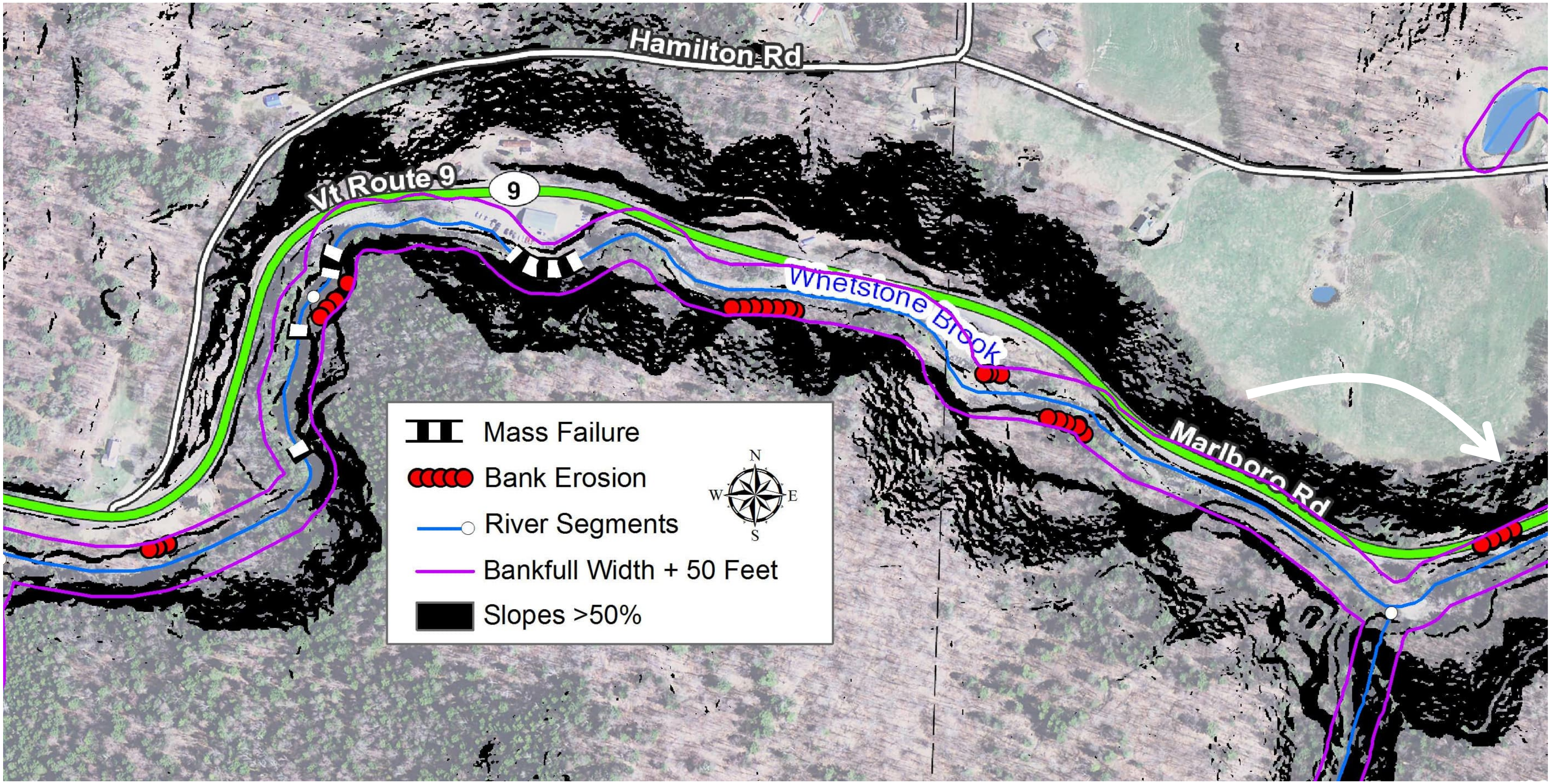
Number of Slope Breaks in Channel
Number of 3rd Order or Greater Confluences
Number of Road Crossings



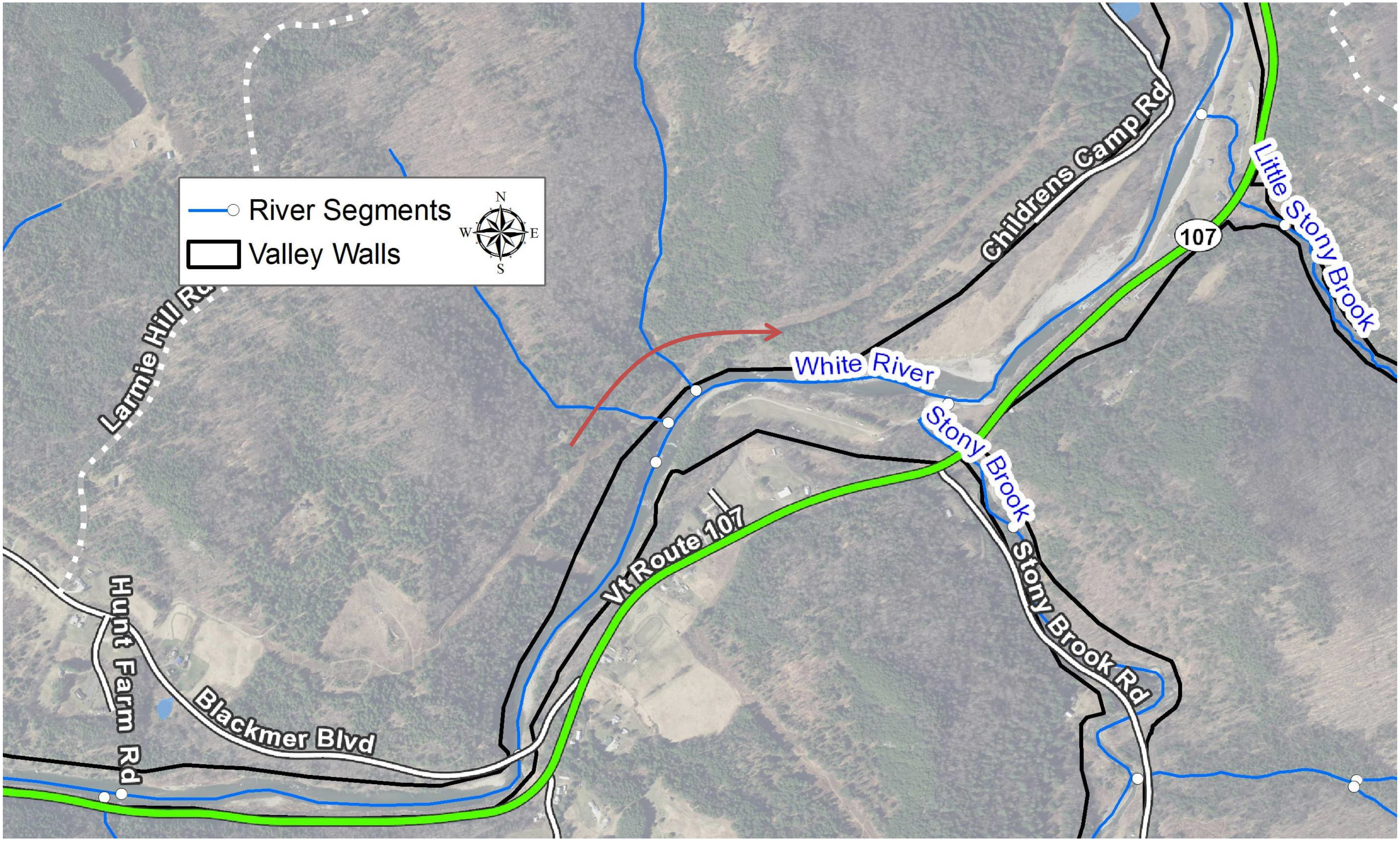
Bank Erosion in Upstream Reach
Mass Failures in Upstream Reach



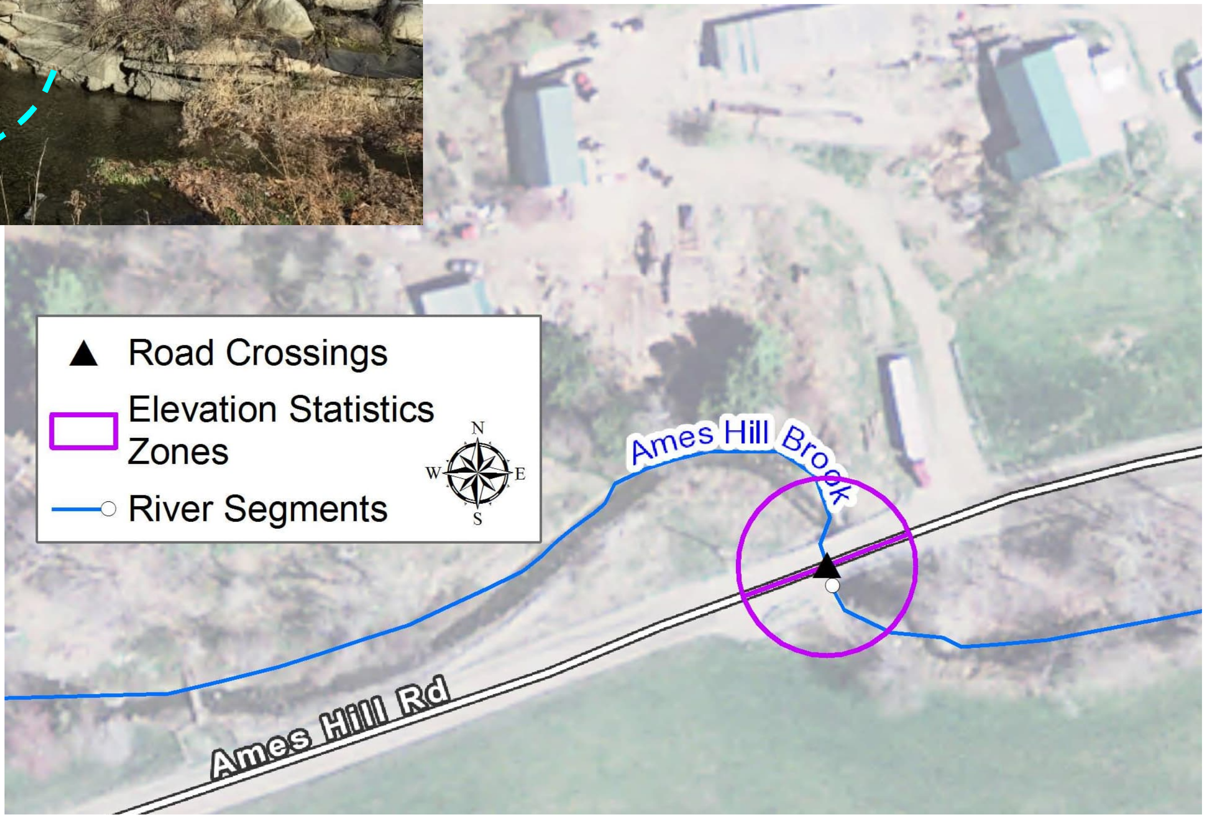
Nearby Steep Slopes in Upstream or First Order Reaches



Change in Confinement from Upstream Reach

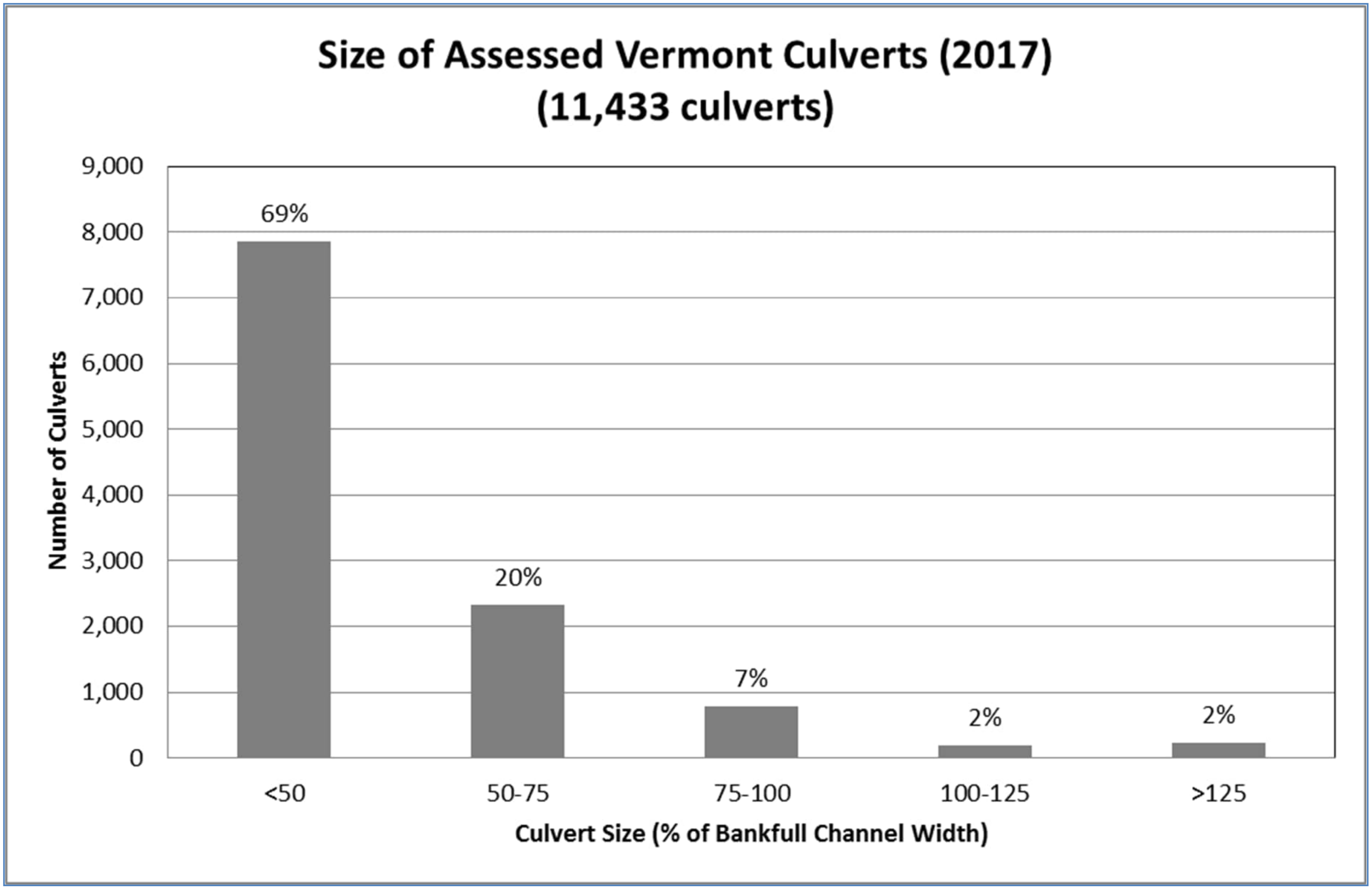


Bridge and Culvert Variables
Structure Invert – Roadway Relief



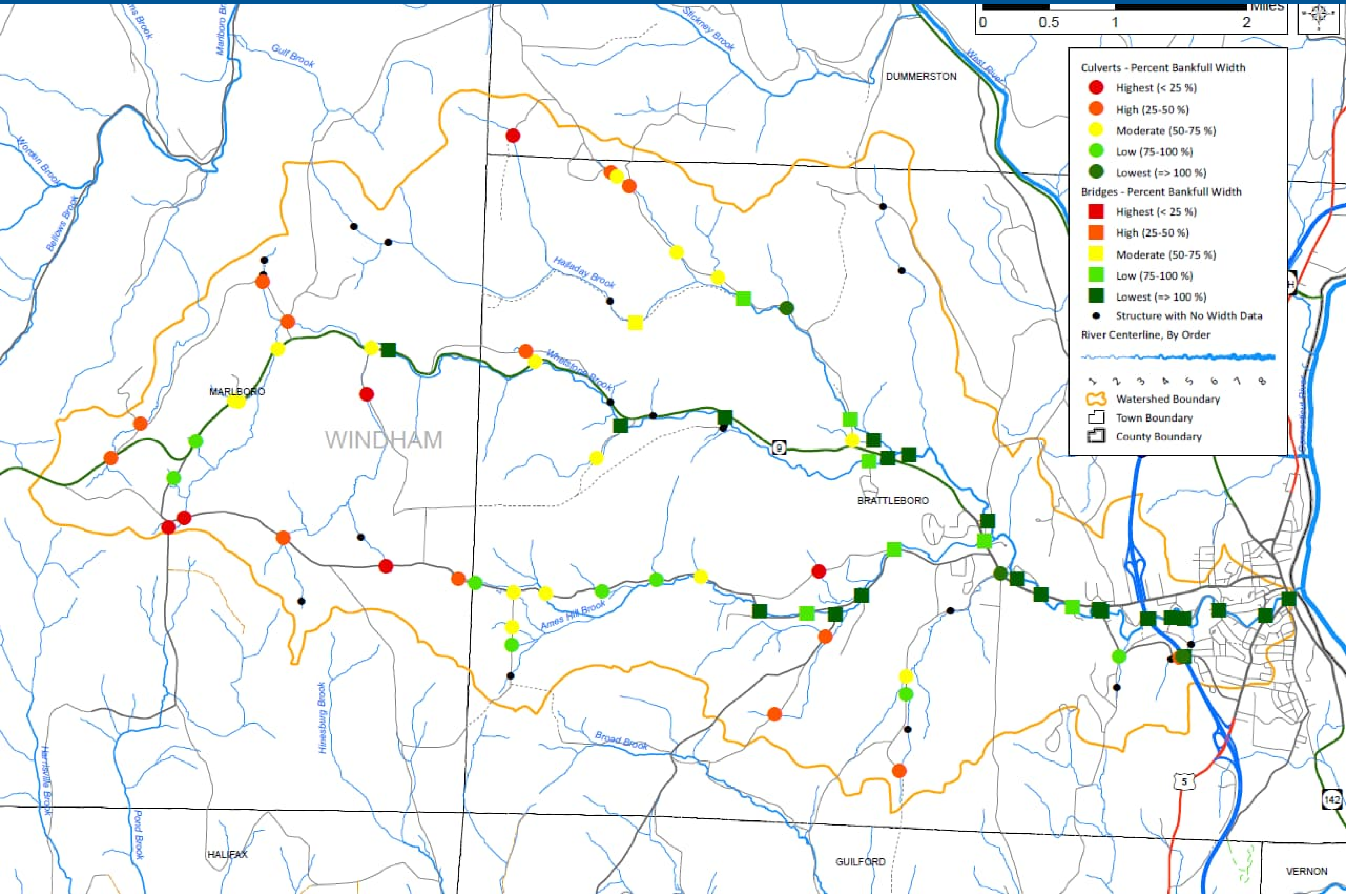
Structure % Bankfull Width

Undersized Culverts



(ANR DMS, 2018)

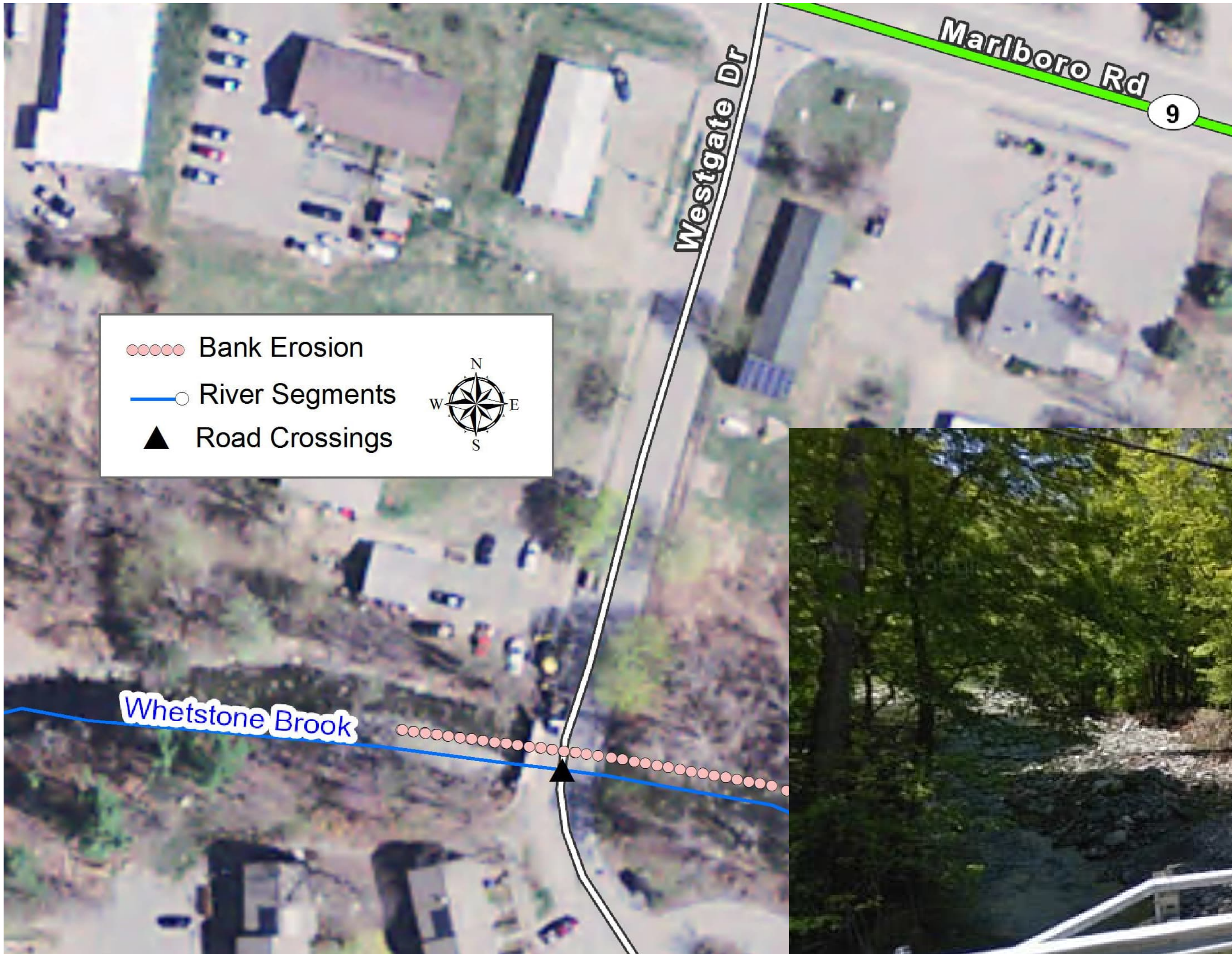
Structure % Bankfull Width



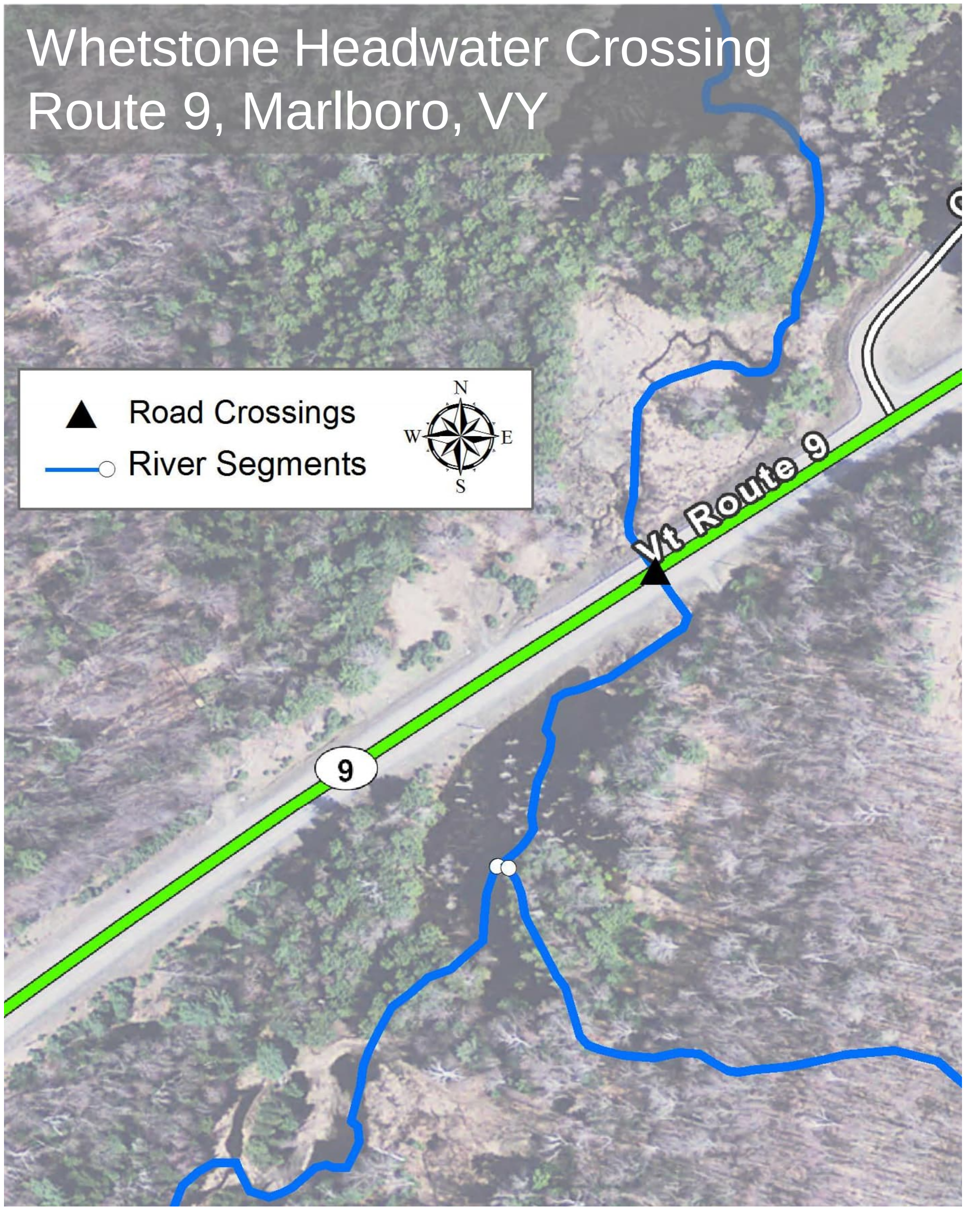
Downstream/Upstream Armoring

Bonnyvale Road
West Brattleboro

Downstream/Upstream Erosion

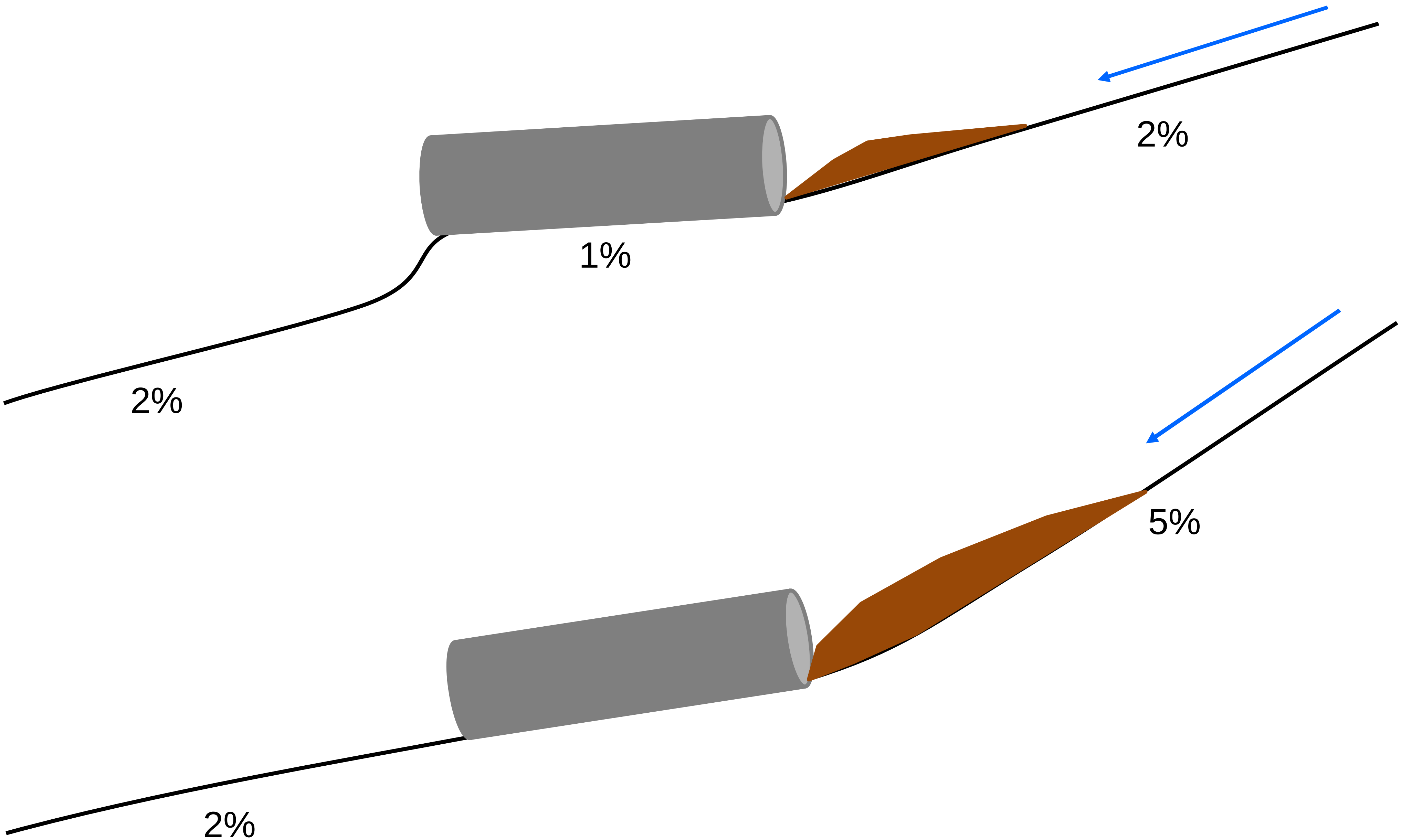


Approach Angle



Sediment Discontinuity

Culvert Slope vs. Channel/Valley Slope



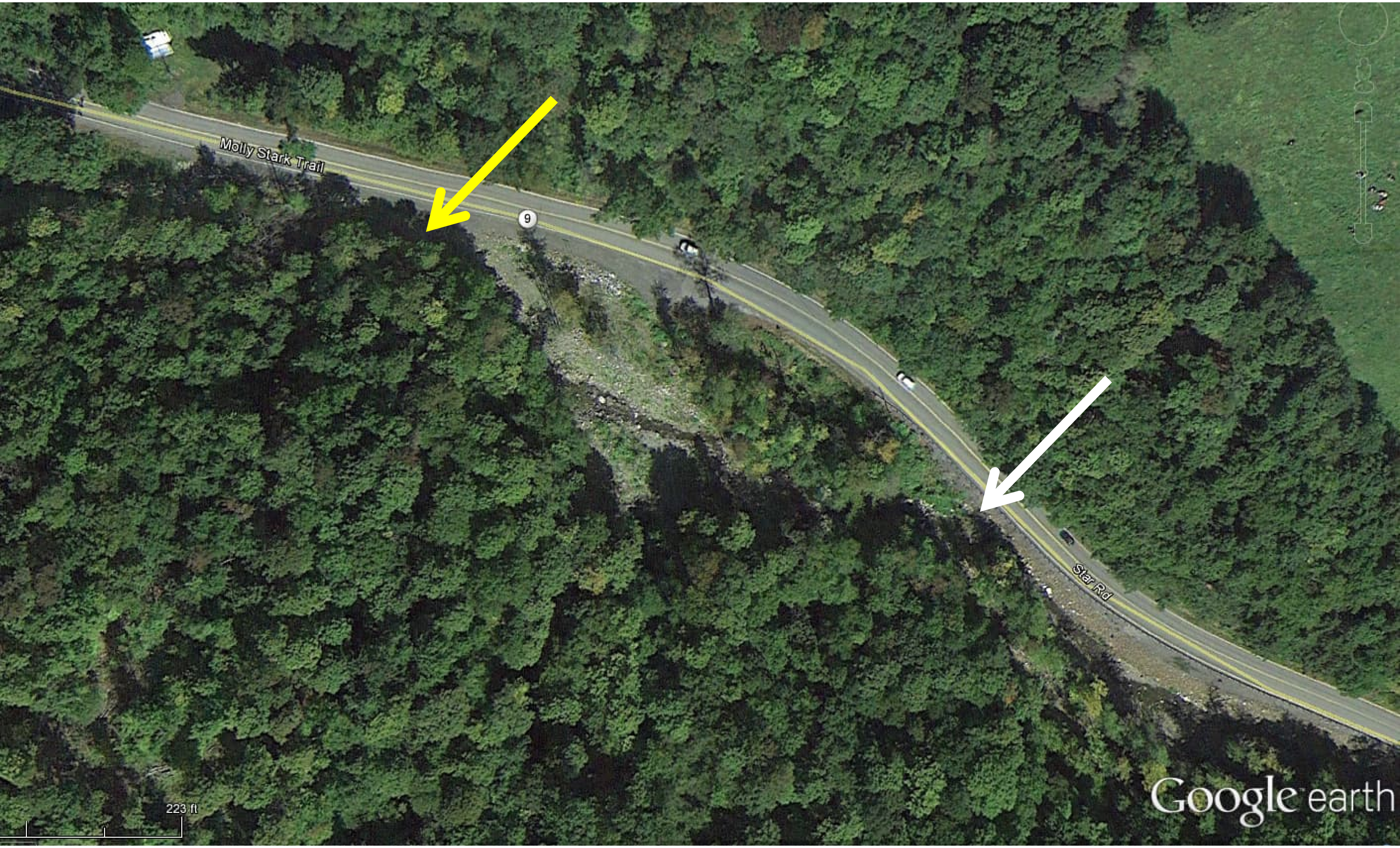
TRPT Planning Examples


Whetstone Brook Berm’
Brattleboro, VT
2011
Photo by MMI


Whetstone Brook Pinch Point
Brattleboro, VT
2011
Photo by TYLin


Whetstone Brook Berm'
Brattleboro, VT
2011
Photo by MMI

High Vulnerability Areas

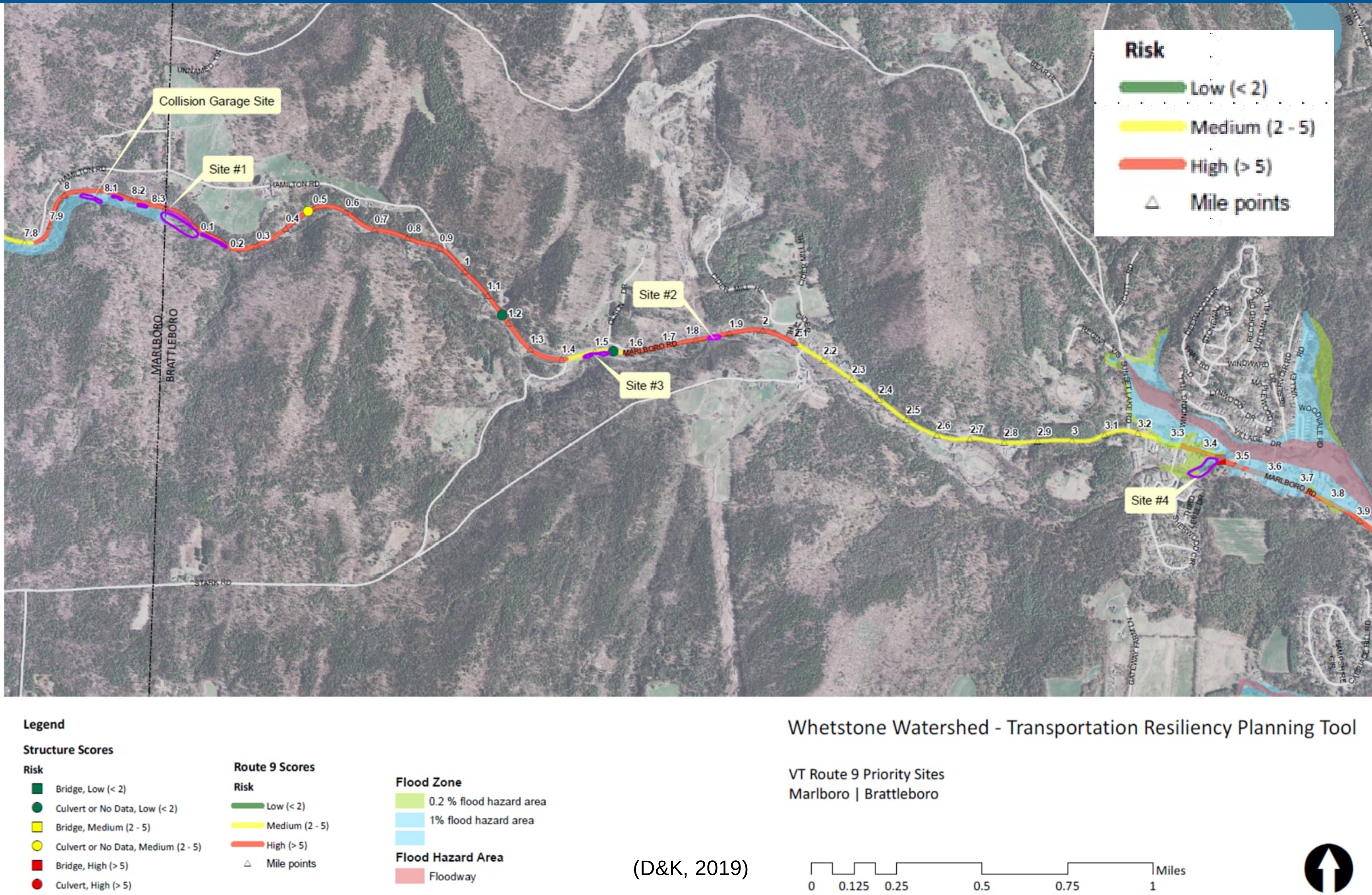


TRPT Implementation Example

TRPT Ranked Sites [2]	From mm	To mm	Constraints and Issues: Right-of-way Difficulty	Prioirity	NOTES	Recommended
	8.00	8.10		-	Check bed and bank armoring that was placed after Irene; consider project to remove acces sroad and restore floodplain; consider buyout.	No; bed armouring is holding up well, repair is successful but right-of-way would be prohibility
1	8.14	8.17	Low	Medium	Recent erosion on road embankment	Requires repair and reinforcement of eroding section of embankment
1	8.23	8.25	Moderate	High	Remove berm	Yes - will reduce flood impacts
1	0.00	0.10	Moderate	High	Reconnect floodplain; see M&M design; restore flood chute	Yes, most effective way to reduce downstream vulnerability
1	0.13	0.22	Moderate	Medium	Check armor from post-Irene project	Armor appears small, check plans to determine if sized appropriately
	0.33	0.41		-	Check bank from post-Irene project	OK, no need for further repairs
	0.57	0.64		-	Check bed armor repair from post-irene project	OK, no need for further repairs
	0.68	0.80		-	Check condition of embankment armor and tall bank from post-Irene project	OK, no need for further repairs
	0.95	1.05		-	Check on floodplain conditions	No; too far from Route 9 ROW
	1.07	1.10		-	Check on condition of post-Irene permanent repair	OK, no need for further repairs
	1.35	1.42		-	Check town and private bridges, restore floodplain, address deposition from tributary, consider buyout	No; too far from Route 9 ROW
3	1.46	1.54	Moderate	Medium	Check on condition of post-Irene permanent repair	Partially collapsed riprap and pavement damage; need to review plan details to determine approach
2	1.83	1.87	Moderate	Medium	Narrows - check condition	Lots of erosion; undercutting fallen trees; large rocks on bank dislodged; 200 ft stretch. Trees can be placed lengthwise in waterway to improve habitat

(D&K, 2019)

TRPT Implementation Example

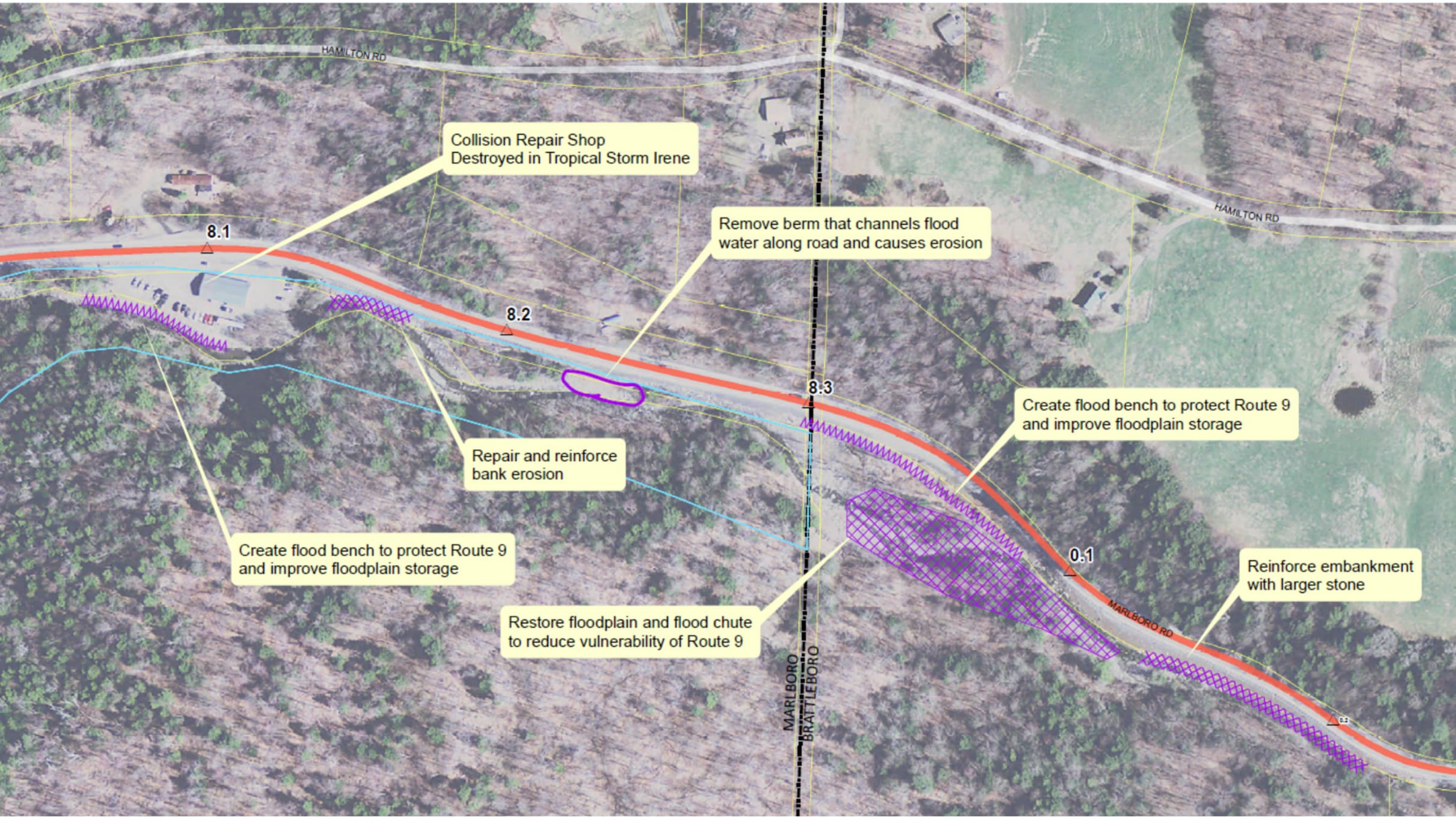


(D&K, 2019)

TRPT Implementation Example

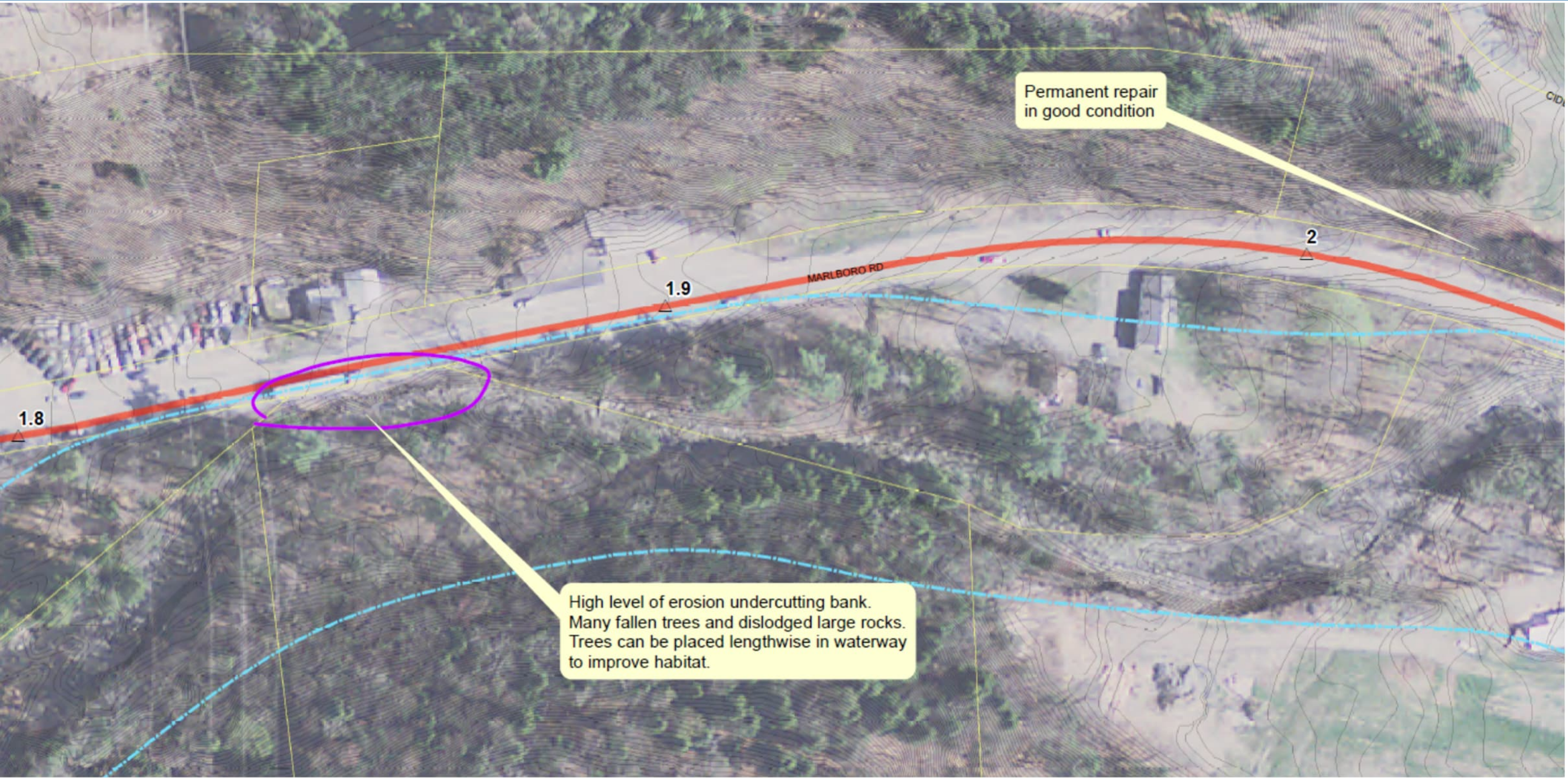
(D&K, 2019)

TRPT Implementation Example



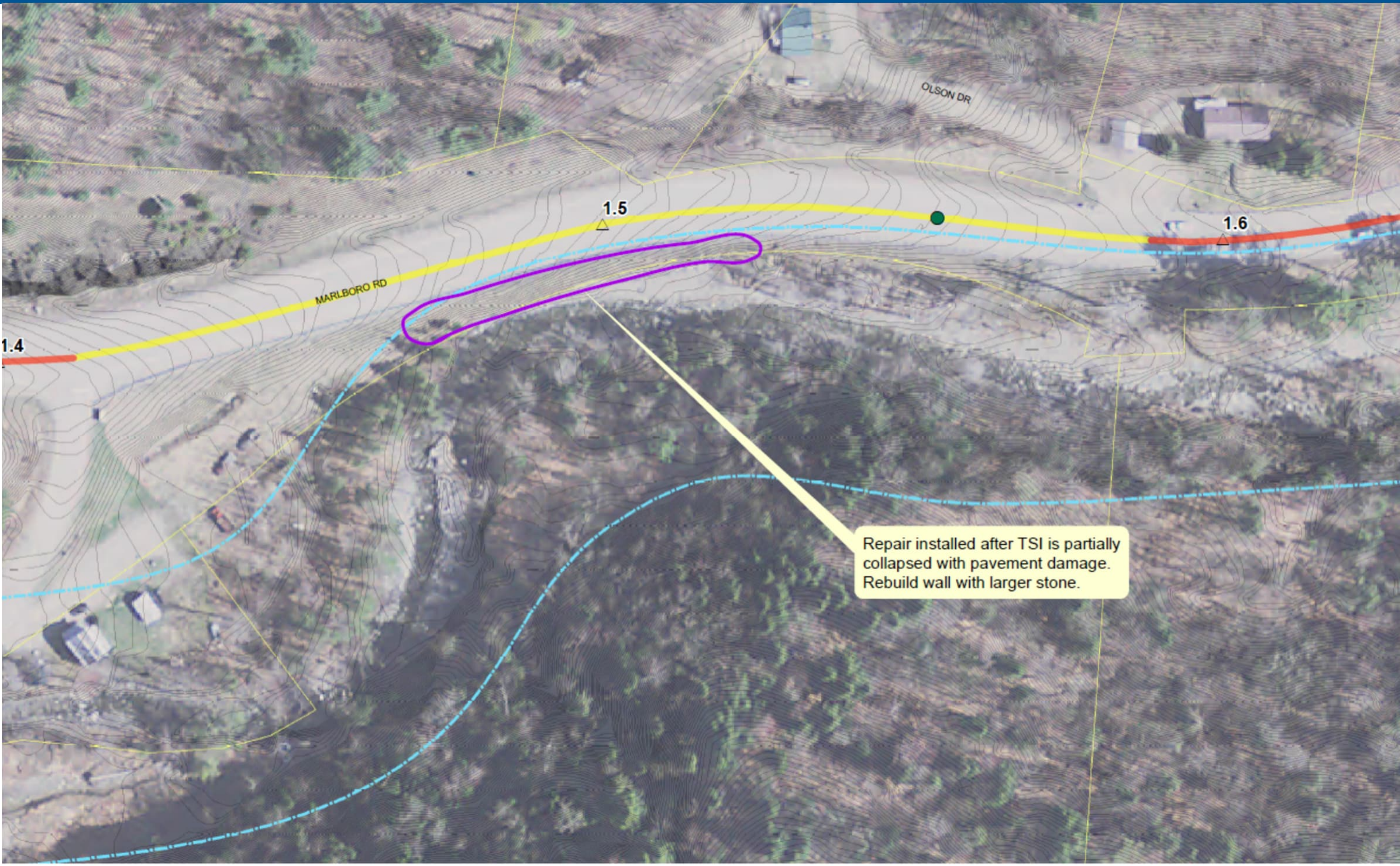
(D&K, 2019)

TRPT Implementation Example



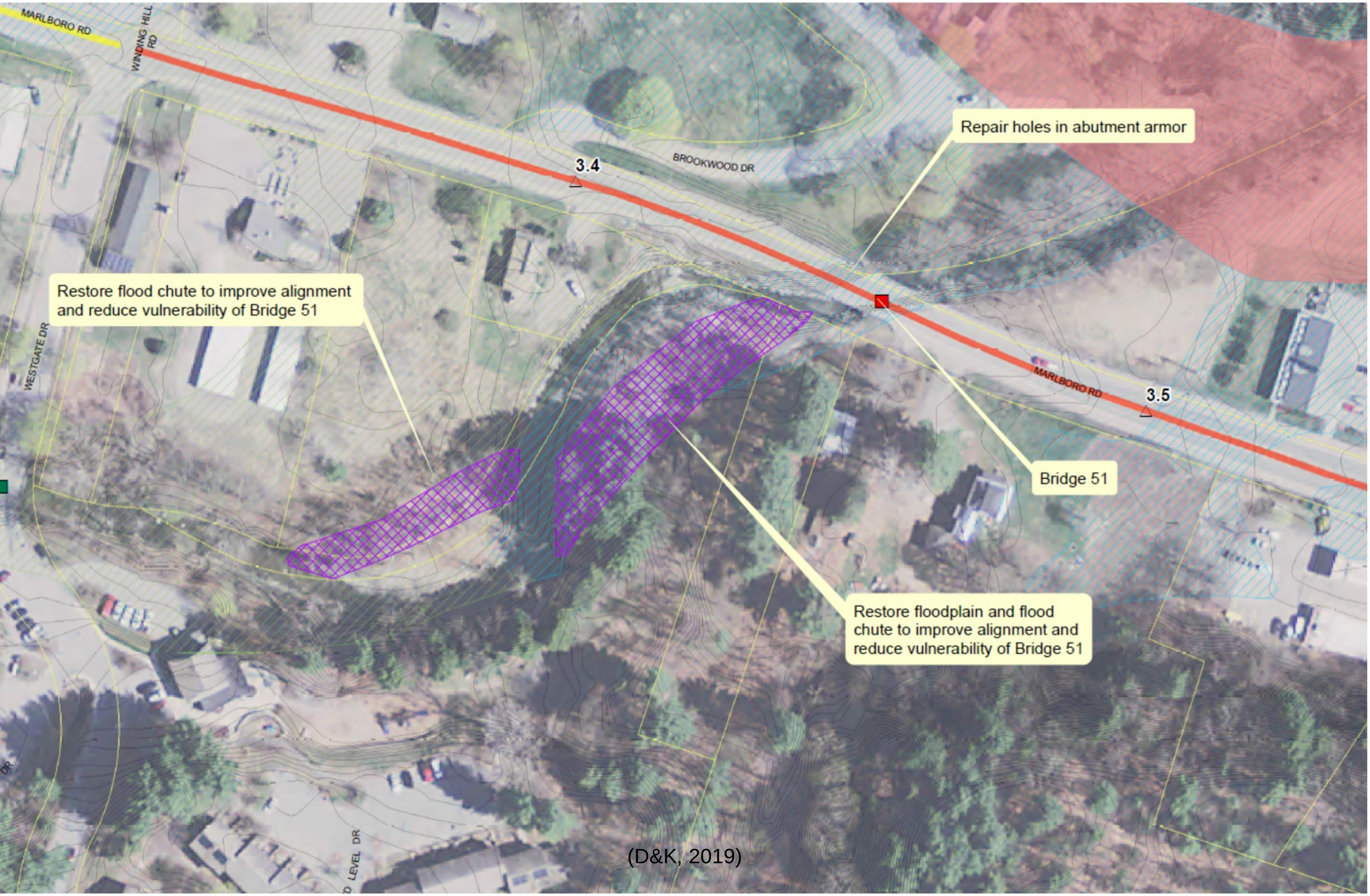
(D&K, 2019)

TRPT Implementation Example



(D&K, 2019)

TRPT Implementation Example

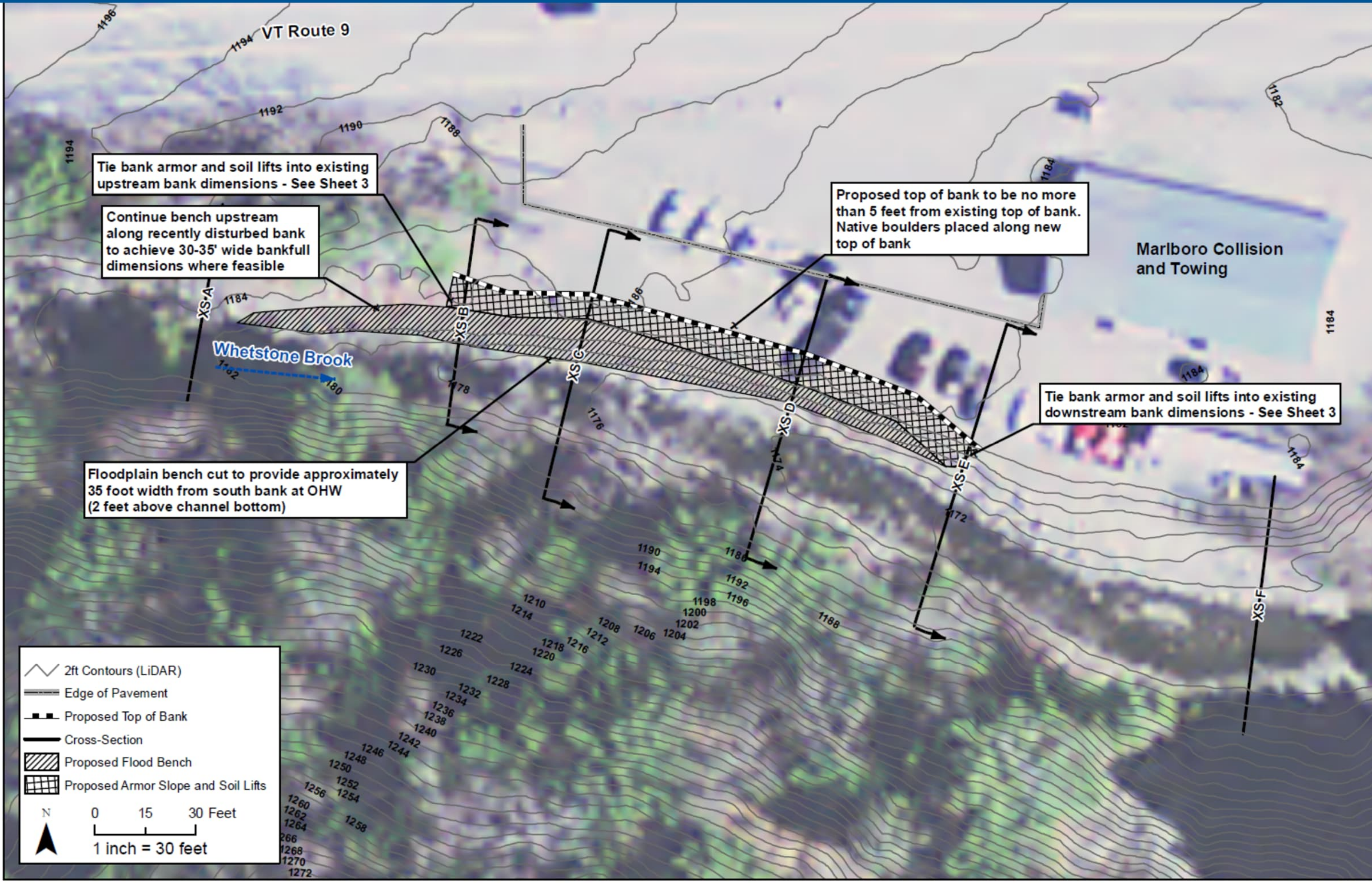


(D&K, 2019)

TRPT Implementation Example

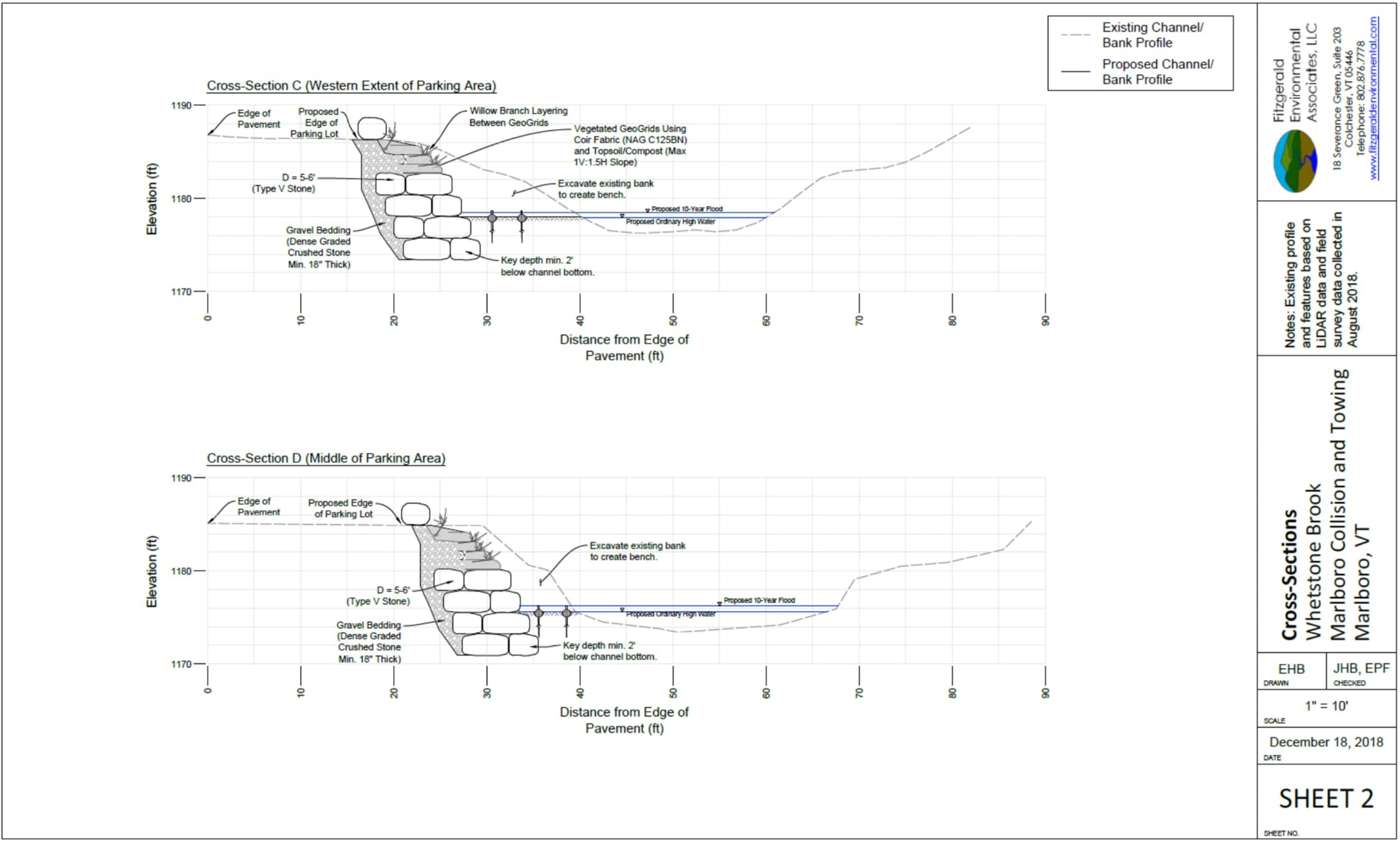
(MMI, 2019)

TRPT Implementation Example



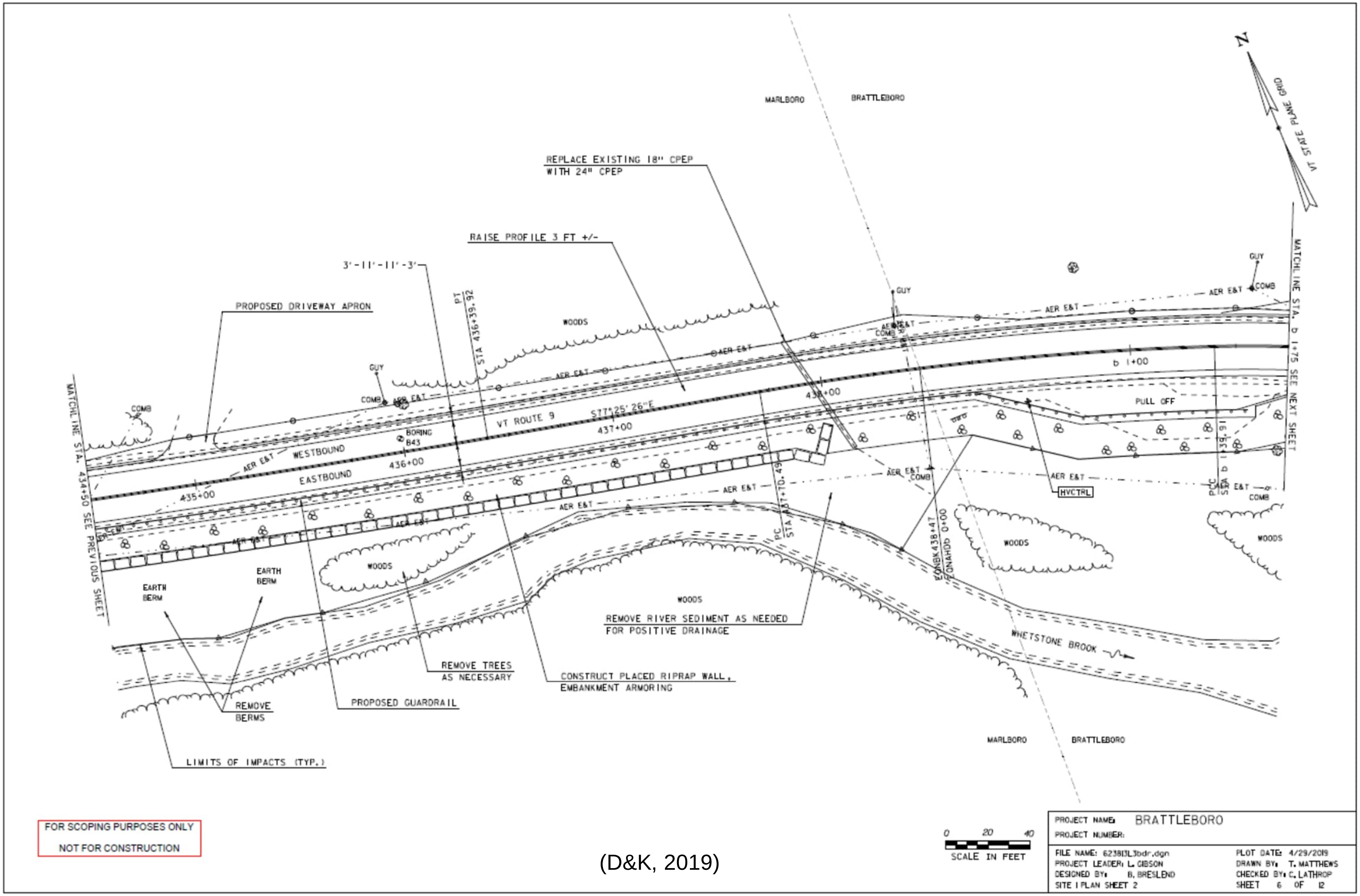
(FEA, 2019)

TRPT Implementation Example



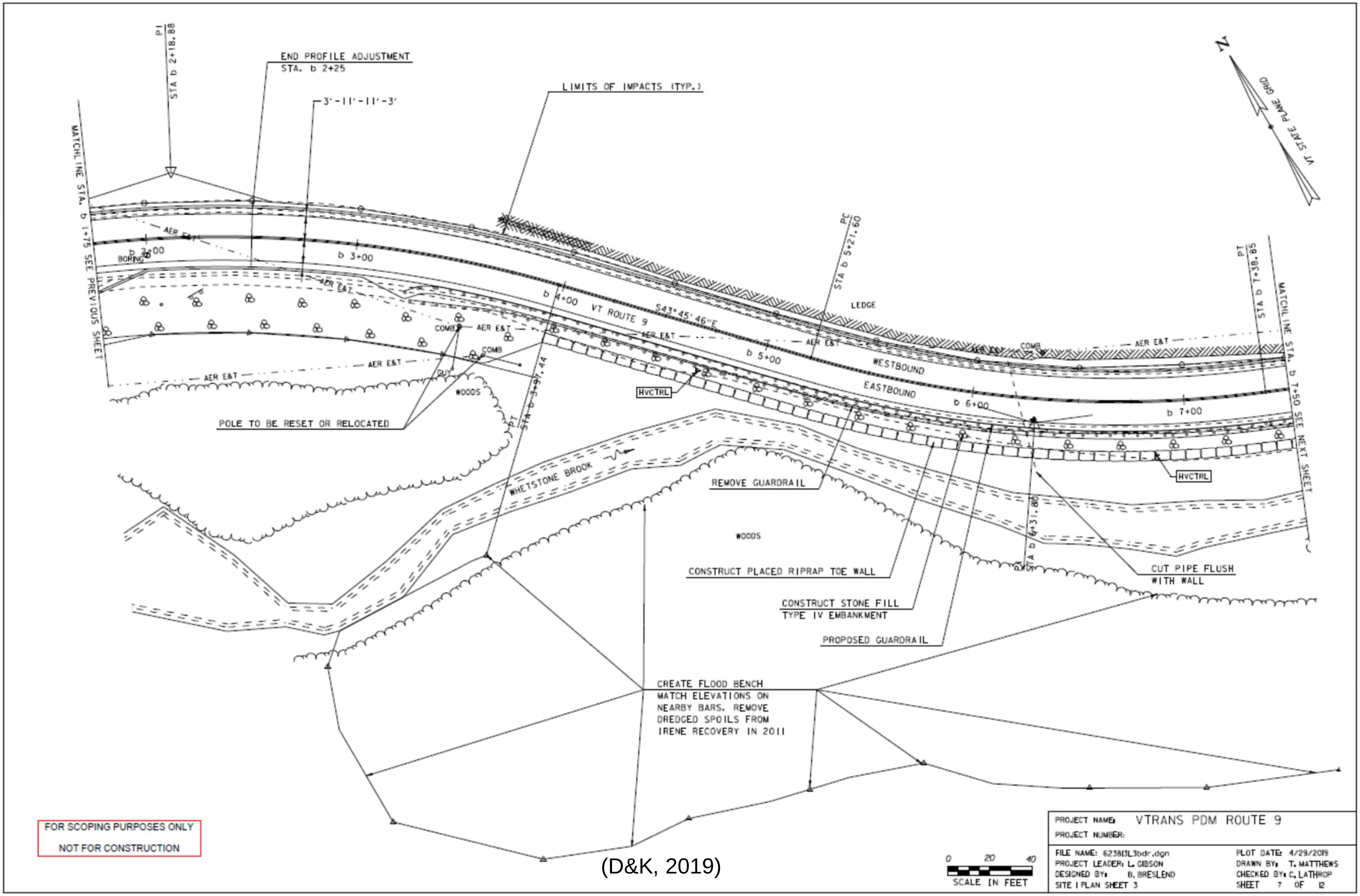
(FEA, 2019)

TRPT Implementation Example – Site 1



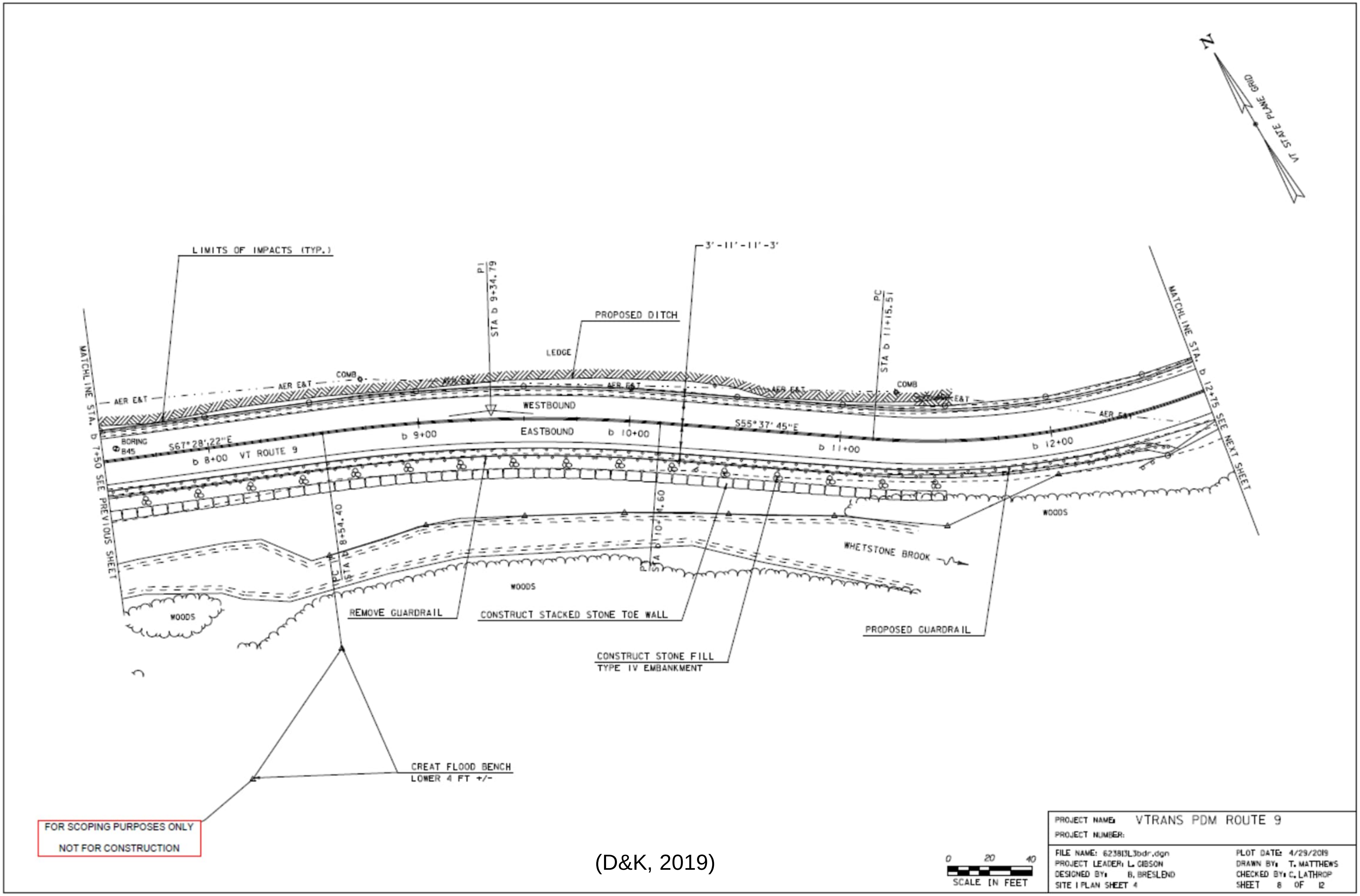
(D&K, 2019)

TRPT Implementation Example – Site 1



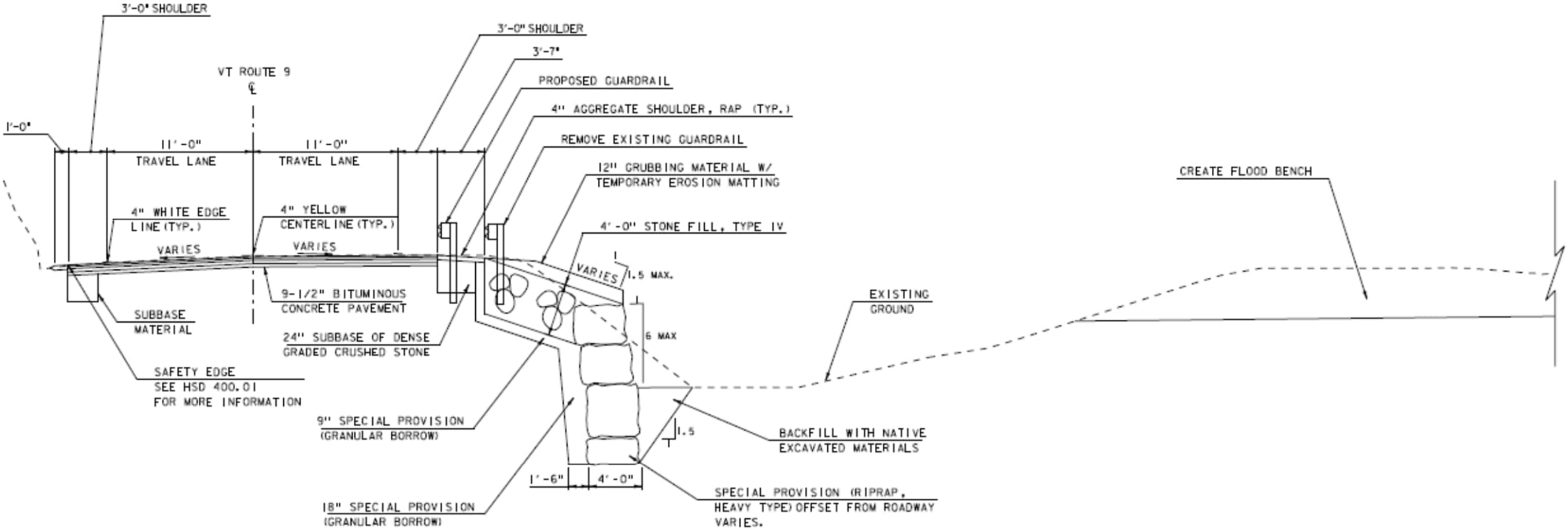
(D&K, 2019)

TRPT Implementation Example – Site 1



(D&K, 2019)

TRPT Implementation Example – Site 1

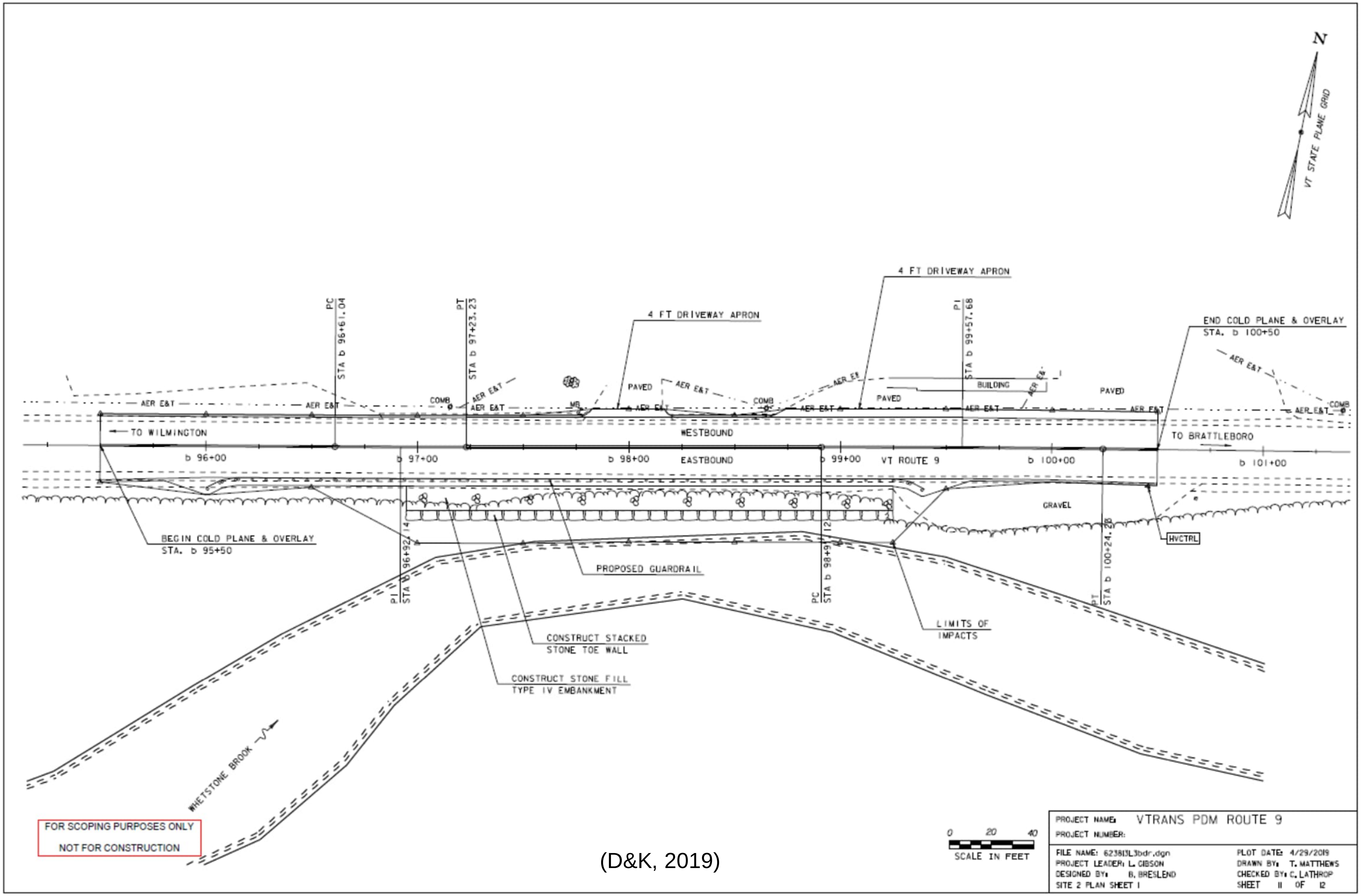


TYPICAL RIPRAP SLOPE WITH STONE TOE WALL SECTION

SITE 1
STA. b 3+97 TO STA. b 11+50

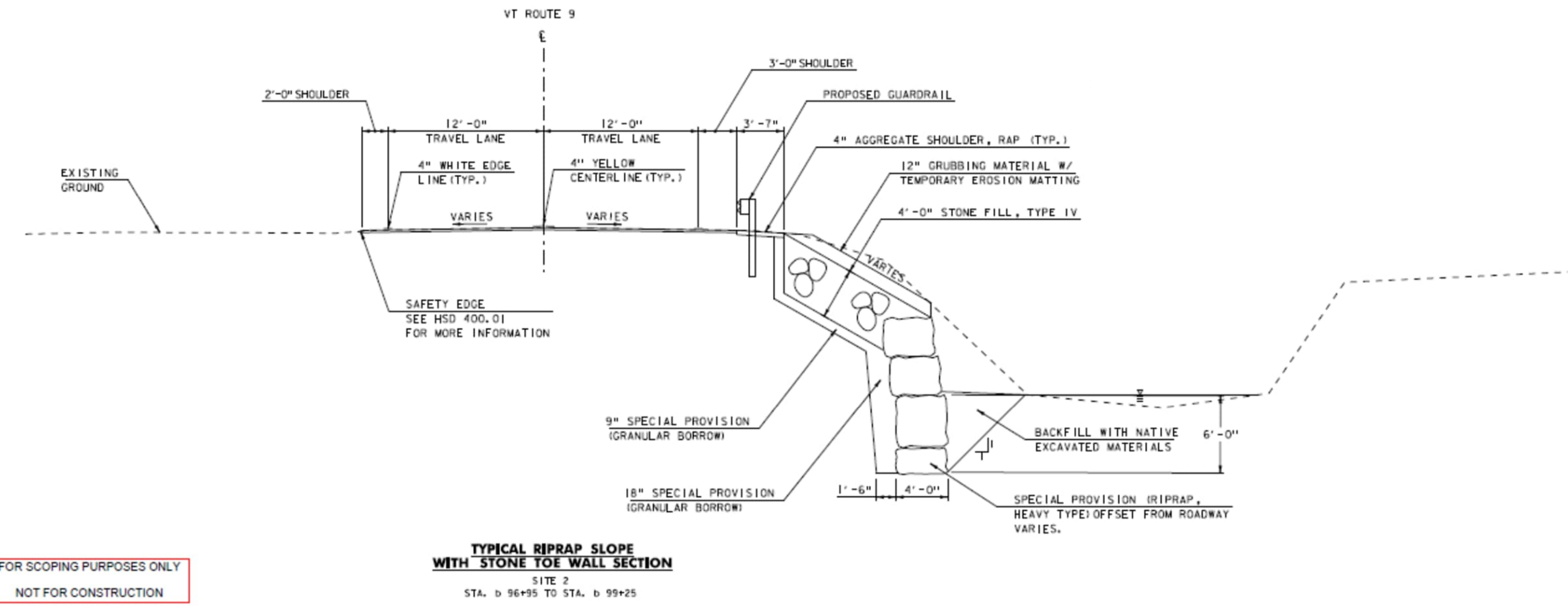
(D&K, 2019)

TRPT Implementation Example – Site 2



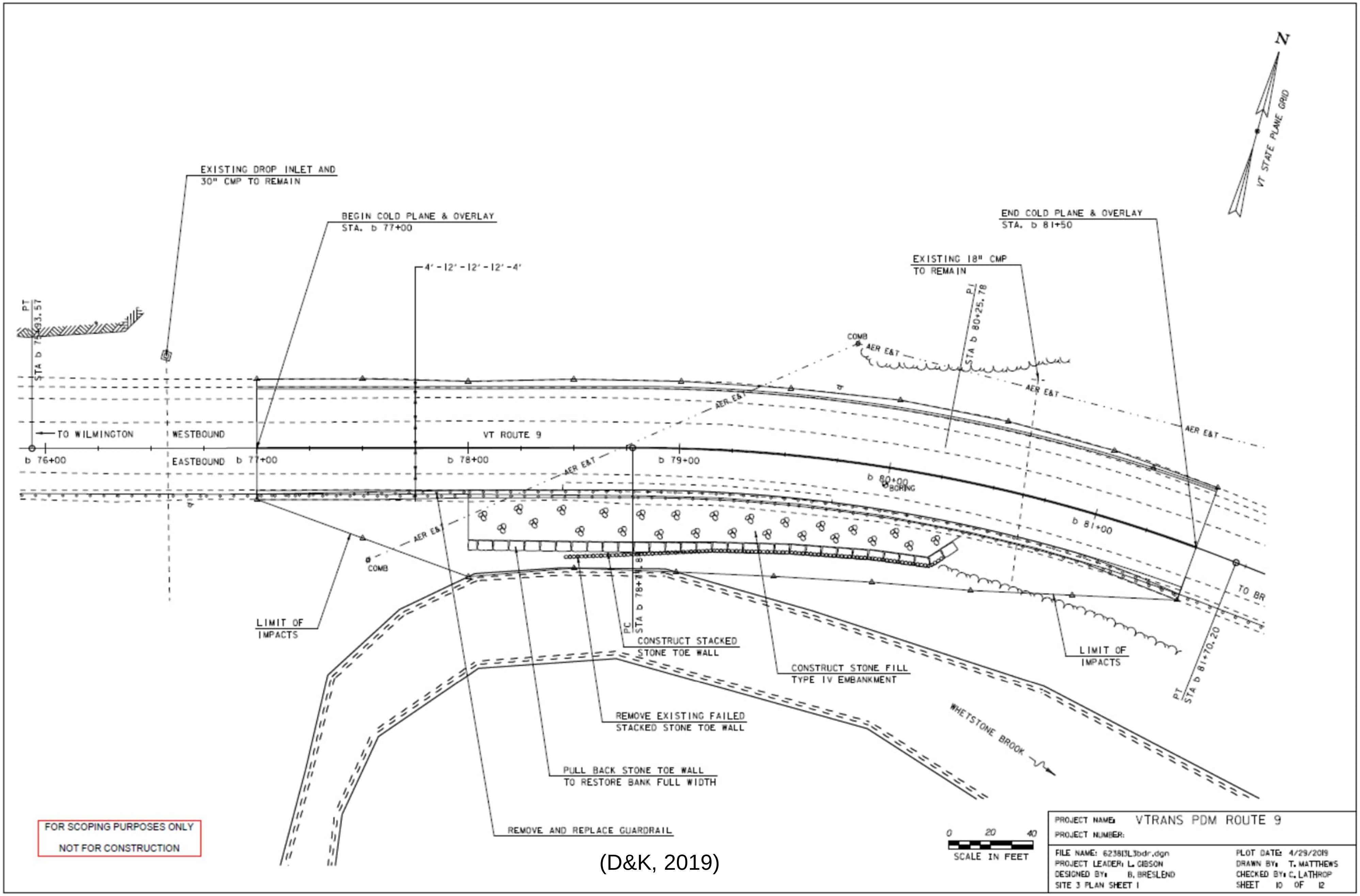
(D&K, 2019)

TRPT Implementation Example – Site 2



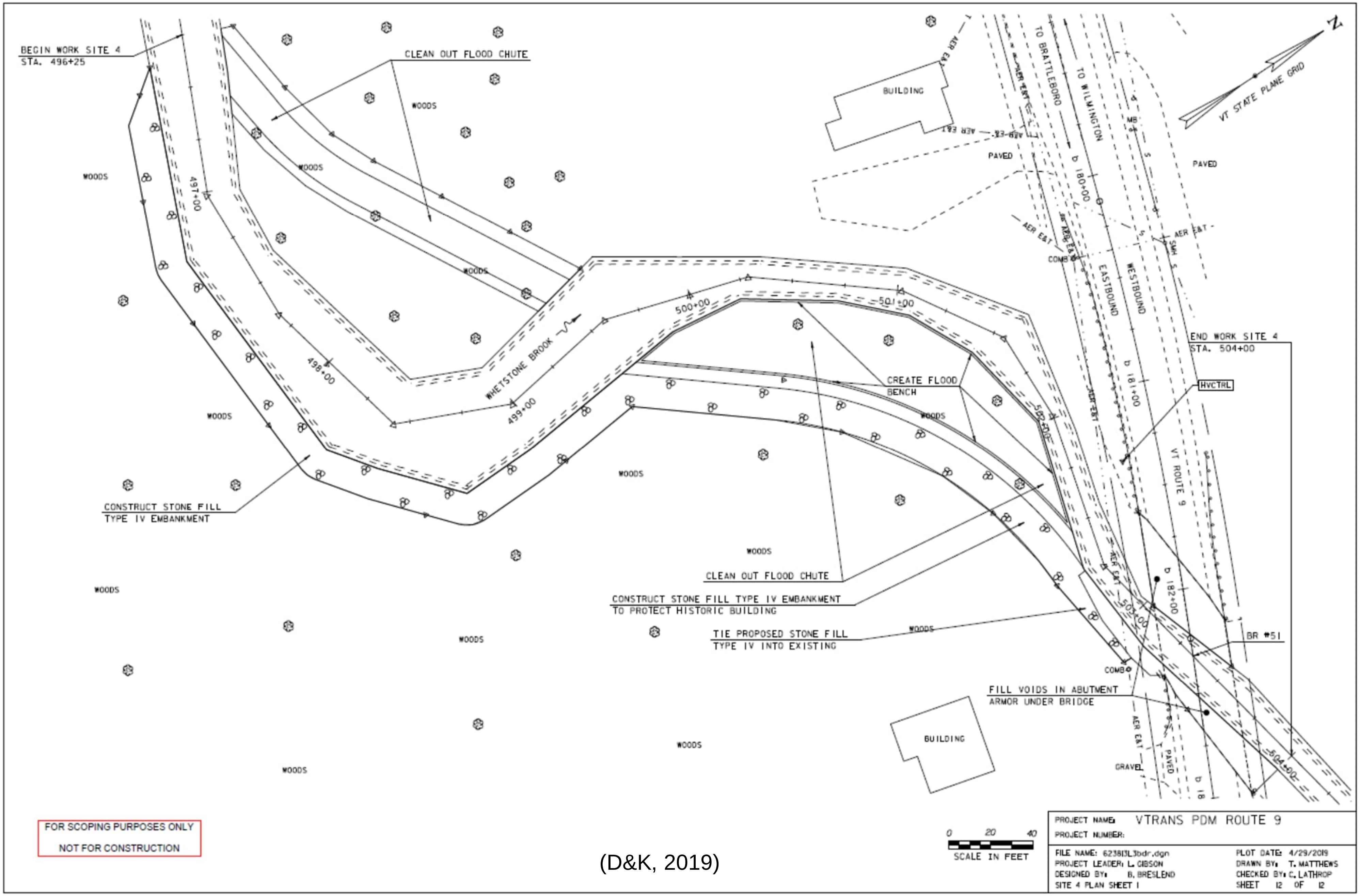
(D&K, 2019)

TRPT Implementation Example – Site 3



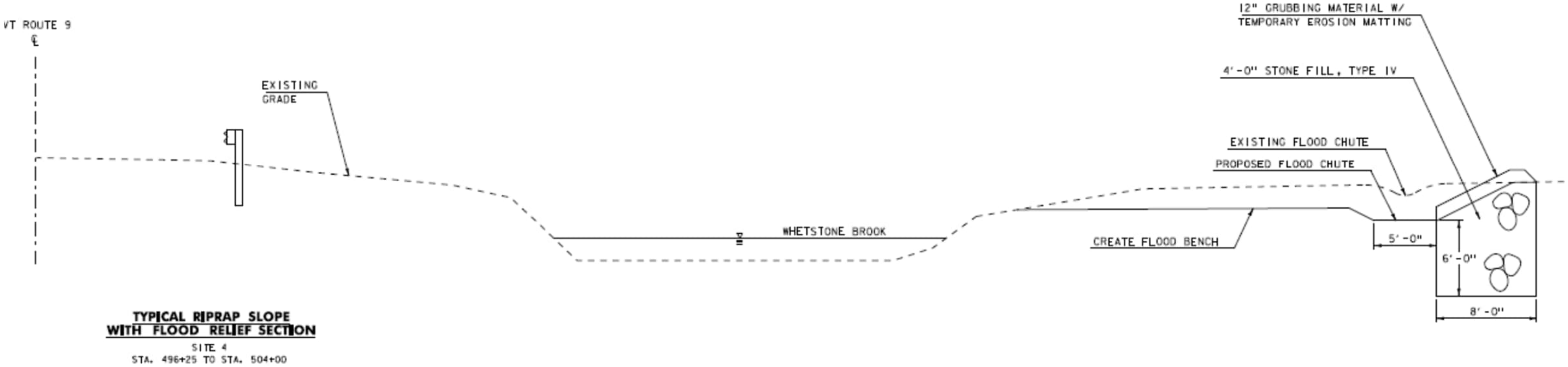
(D&K, 2019)

TRPT Implementation Example – Site 4



(D&K, 2019)

TRPT Implementation Example – Site 4



(D&K, 2019)

TRPT Implementation Example

- Benefit-Cost Ratio (BCR) of 1.14
- Estimated project cost = $4,552,409
- Estimated benefits = $5,180,998
- Trips per day = 9,700
- Detour time = 41 minutes
- Additional miles = 34
- Irene: full road closure for 10 days and one-lane closure for 25 days.
- 2017 Flood: One-lane closure for 16 hours.
- Initial BCR = 0.92.
- Environmental Benefits for 84,200 square feet of riparian area increases BCR to 1.14.

TRPT Implementation Example

Tropical Storm Irene Damage Data from
Federal Highway Administration Detailed Damage Inspection Reports (DDIRs)

Total Estimated Cost	DDIR	Town	Mile Marker
$ 201,138.27	D1-086	Marlboro	7.92-8.00
$ 514,203.04	D1-087	Marlboro & Brattleboro	8.2 - 0.0
$ 762,696.02	D1-088	Brattleboro	0.2
$ 294,568.75	D1-089	Brattleboro	0.4
$ 305,617.63	D1-090	Brattleboro	0.4
$ 6,278.04	D1-095	Brattleboro	1.8
$ 37,423.05	D1-093	Brattleboro	1.41
$ 39,814.97	D1-097	Brattleboro	2.15 - 3.45
$ 2,161,739.77	**= Sum Over Project Area**		

October 30, 2017 Damage Data from
VTrans Daily Work Reports (DWRs)

Total Estimated Cost	DWR/ Invoice	Town	Mile Marker
$ 15,125.00	Invoice 1792	Brattleboro	0.15
$ 812.74	4542808	Brattleboro	0.15
$ 16,053.18	4543229	Brattleboro	0.15
$ 4,266.50	4542710	Brattleboro	0.15
$ 2,573.81	4545720	Brattleboro	0.15
$ 38,831.23	**= Sum Over Project Area**		

(VTrans, 2019)

FEMA
MITIGATION POLICY – FP-108-024-01

III. POLICY STATEMENT:

FEMA will allow the inclusion of environmental benefits in benefit-cost analyses (BCA) to determine cost effectiveness of acquisition projects.

IV. PURPOSE:

The purpose of this policy is to identify and quantify the types of environmental benefits that FEMA will consider in the BCA for acquisition projects.

Table I: Annual Estimated Monetary Benefits per Acre per Year

Environmental Benefit	Green Open Space	Riparian
Aesthetic Value	$1,623	$582
Air Quality	$204	$215
Biological Control	--	$164
Climate Regulation	$13	$204
Erosion Control	$65	$11,447
Flood Hazard Reduction	--	$4,007
Food Provisioning	--	$609
Habitat	--	$835
Pollination	$290	--
Recreation/Tourism	$5,365	$15,178
Storm Water Retention	$293	--
Water Filtration	--	$4,252
Total Estimated Benefits	$7,853	$37,493

Table II: Green Open Space and Riparian Benefits Allowed in the BCA Toolkit

Land Use	Total Estimated Benefits	Total Estimated Benefits (projected for 100 years with 7 percent discount rate)
Green Open Space	$7,853 per acre per year	$2.57 per square foot
Riparian	$37,493 per acre per year	$12.29 per square foot

(FEMA, 2013))