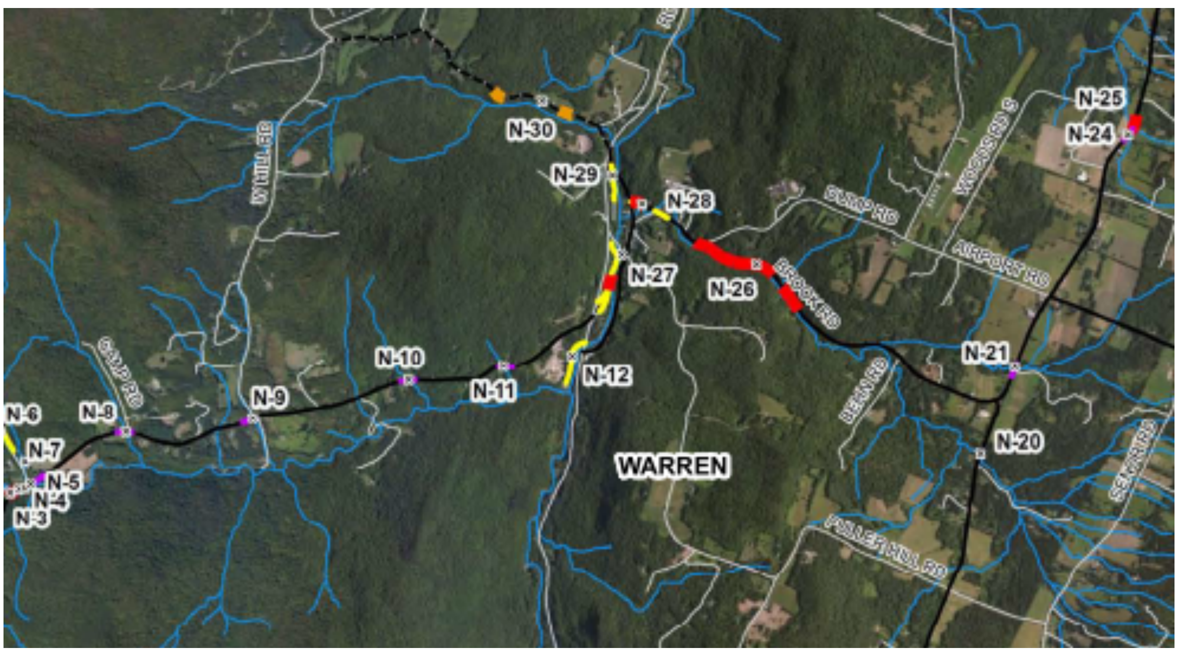
Flood Resilient Transportation Pilot Study

Waitsfield, Warren, and Fayston
Vermont

Prepared for:

Central Vermont Regional Planning Commission



Prepared by:

DuBois & King inc.

Bear Creek Environmental

September 22, 2015

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1.0 Introduction

Tropical Storm Irene in August 2011 caused widespread damage in Vermont due to flooding and erosion. This has highlighted the need for communities to improve their transportation infrastructure to become more flood resilient. The Central Vermont Regional Planning Commission (CVRPC) is interested in promoting flood resiliency and assisting its member communities to improve the flood resiliency of their transportation infrastructure.

CVRPC contracted with river engineers and scientists from DuBois & King Inc (D&K) and Bear Creek Environmental LLC (BCE) to develop a systematic approach to identify sites on a Town's road network that are vulnerable to future flood damage and to recommend mitigation strategies to improve the flood resiliency of those sites. The study focused on the Towns of Waitsfield, Warren, and Fayston. This report summarizes the process that the documents the D&K/BCE/CVRPC approach and provides the results in the three subject towns.

There were four primary components of the project:

1. Identification and Conceptual Design of Strategies to Improve Flood Resiliency of Roadways
2. Guidance for Selecting Appropriate Strategy to Improve Flood Resiliency
3. GIS-Based Screening to Identify Roadway Segments Vulnerable to Flood Damage
4. Field Investigation of Potentially Vulnerable Sites

2.0 Strategies to Improve Flood Resiliency of Roadways

The project team identified nine strategies that could be used to improve the flood resiliency of vulnerable road segments:

Strategy 1. Relocate Road
Strategy 2. Raise Road
Strategy 3. Protect Road Embankment – Standard Rip Rap Slope
Strategy 4. Protect Road Embankment – Stacked Stone Toe Wall
Strategy 5. Raise and Protect Streambed
Strategy 6. Larger Culvert or Bridge
Strategy 7. Protect Road for Overtopping
Strategy 8. Create Low Point in Culvert/Bridge Approach
Strategy 9. Drainage Improvements

The strategies include those that have commonly been applied in Vermont following storm damage, as well as others that are less commonly applied. In some cases, such as using stone riprap to protect a vulnerable road embankment, the strategies are not new, but do include improvements on the traditional use of the strategies that are intended to improve resiliency. Each of the nine strategies is described below. Sketches of each are included in Attachment A.

2.1 Strategy 1. Relocate Road

Relocating a road is applicable in locations where the road parallels the channel in close proximity, and continued or future erosion of the roadway embankment is likely. Relocation usually entails a modest shifting of the most vulnerable segment of the roadway away from the channel rather than a wholesale relocation. The clear benefit of this strategy is that once the road is moved, the potential for damage is greatly reduced or eliminated.

In practice, roads are rarely relocated because it typically requires purchase of additional right of way, and that cost coupled with the cost of constructing the new length of road is frequently more than the cost of trying to protect the roadway in its current location. Thus, it is most applicable to sites where the cost of protecting the road via traditional methods is unusually expensive, or sites where traditional methods have proven unreliable.

2.2 Strategy 2. Raise Road

Raising a road would be done to reduce the frequency that the road gets inundated by floodwaters. It is applicable in limited settings meeting two criteria: the road is parallel to the stream and the road is located at the outer extent of the floodplain (typically against the valley wall).

Raising a road that does not meet these two criteria (e.g., the road crosses the stream or the road is next the stream with extensive floodplain on the back side) would prevent water from spilling into the floodplain and result in higher, more erosive flows in the channel.

2.3 Strategy 3. Protect Road Embankment – Standard Riprap Slope

Protecting roadway embankments with stone riprap is perhaps the most common strategy for improving the resiliency of roadways in Vermont adjacent to streams. It has been used for generations. As presented in Attachment A, the strategy includes three features that increase the resiliency of a riprap slope beyond the traditional approach:

1. Type IV or larger stone on the lower slope. It is well understood that larger stone is more resilient, but in practice considerably smaller stone has been used to protect and repair roadway embankments, with predictably poor results.
2. Scour Key, to prevent undermining of the riprap that would cause the embankment to slump and put the road at risk.
3. Grubbing material over the riprap, seeded to produce a hearty stand of grass and shrubs. The vegetation offers considerable protection from erosion that may be adequate during short-duration flood events to protect the roadway without relying on the underlying stone riprap.

2.4 Strategy 4. Protect Road Embankment – Stacked Stone Toe Wall

This strategy shares most features of the Standard Riprap Slope, except larger stone is stacked at the lower slope to avoid narrowing the active stream channel. This approach is applicable in settings where a standard slope would narrow the channel and result in deeper, faster flows that may cause the channel to incise (i.e., dig down) and undermine the roadway embankment.

2.5 Strategy 5. Raise and Protect Streambed

Many roadway embankment failures can be attributed to the down-cutting of the channel bottom that leaves the toe of the embankment unsupported causing the middle and upper embankment to slump and erode. Sometimes this down-cutting is transient; channel material can be scoured away during a storm only to be replaced by new material from upstream as flows recede. In most cases, however, the down-cutting is an ongoing, long-term process that often results in the perceived need to place additional riprap to stabilize the failing roadway embankment. Where a vertical channel stability issue is identified as the root cause of a failing roadway embankment, the vertical stability issue itself should be addressed. This is done by placing stone in the channel that is large enough to prevent additional down-cutting. Depending on site specifics, this material is either placed to raise the channel to a higher original elevation, or placed at existing grade to prevent additional down cutting. A related, but slightly different method to address head cutting and raise the streambed is to install a grade control structure (a.k.a. weir), made out of stone, timber logs or other local material. This weir is embedded into the channel bottom to develop stability and the top extends into the air to a height of the desired streambed. Over time, channel bed material will fill in behind the weir, effectively raising the streambed and reducing the potential for future head cutting and dedgration.

2.6 Strategy 6. Larger Culvert or Bridge

Culverts and bridges designed to pass major floodwaters, sediment, and debris significantly improves the resiliency of a road and reduces the potential for prolonged closures and costly repairs. Key features are a culvert or bridge span at least as wide as the natural channel- and adequate vertical height to pass floating debris. This strategy as shown in the sketch in Attachment A includes an aluminum pipe arch culvert recessed below the streambed. For the typical stream crossings in the study area, this approach is the most cost-effective way to meet current state and federal permit requirements and achieve the desired flood resiliency.

2.7 Strategy 7. Protect Road for Overtopping

At sites where floods overtop and damage roads – often in the approach to a bridge or culvert that is crossing a floodplain – the road can be constructed to minimize damage during overtopping events. As shown in Attachment A, this strategy entails placing stone riprap on the downstream roadway embankment where overtopping occurs. Ideally the riprap would be extended under the travel way so that the transition from the roadway to the embankment – where erosion and road damage usually originates is protected. This strategy does not typically eliminate roadway damage, but it can considerably lessen the extent and expense of damage.

2.8 Strategy 8. Create Low Point in Culvert/Bridge Approach

This strategy involves creating a low point in a roadway near a culvert or bridge so that floodwaters flow over this low point rather than being forced entirely through the culvert or bridge. This is a design feature of nearly all intact historic covered bridges and had played a primary role in their continued survival. The low point provides a "bleed-off" for high flows that keeps peak flood elevations lower and reduces the pressure on the culvert or bridge. The roadway at the low point may be damaged by erosion as flow overtops the road. Even so, this is generally a much better outcome than the loss of a culvert or bridge; roadways are inexpensive compared to culverts and bridges, and can be repaired much faster.

2.9 Strategy 9. Drainage Improvements

Drainage improvements are meant to improve the flood resiliency of a roadway segment where potential damage is due not to a parallel stream or a stream crossing, but rather due to runoff from the road itself or the surrounding hillside. Two common drainage improvements are included with this strategy, as shown in the sketch in Attachment A:

A. Additional Cross Culverts, designed to distribute collected runoff in a more dispersed manner away from the road.
B. Additional Ditch Turnouts, designed to reduce the volume and erosive potential of roadside ditches.

3.0 Guidance Flowcharts for Selecting Flood Resiliency Strategies

While the field evaluations for this study were done by experts who have the benefit of many years of experience and training, many sites could be reliably evaluated by town personnel with less river-specific experience. Exceptions, where an expert opinion would be strongly recommended, would be sites with unique challenges or severe space limitations, and sites that have suffered repeated cycles of damage and unsuccessful repair.

The Strategy Selection Flowcharts included in Attachment B are intended to provide guidance to Town staff or other personnel charged with identifying flood resiliency issues and selecting suitable solutions. The flowcharts lead the user to one of the nine Flood Resiliency Strategies and provide guidance for three common settings in which flood resiliency issues arise:

A. Road is parallel to stream channel (Flowchart 1)
B. Road is perpendicular to stream channel (Flowchart 2)
C. Local drainage issue (Flowchart 3)

4.0 GIS-Based Screening to Identify Roadway Segments Vulnerable to Flood Damage

D&K and BCE collaborated with the CVRPC to develop a method to use existing GIS data to identify sites that are vulnerable to flood damages. Once the approach was established, CVRPC conducted the analysis. A detailed technical description of the method has been prepared by CVRPC and is included in Attachment C. An overview is provided here.

The GIS analysis focused on Town roads categorized by CVRPC as High and Moderate Importance Roads. Low Importance roads were generally excluded in an effort to reduce the number of sites identified. The High and Moderate importance roads were divided into segments, and each segment was overlaid with available GIS data sets. Metrics considered in identifying sites included proximity to a stream (in the case where the stream and road are parallel), intersections of roads and streams (i.e., a bridge or culvert crossing), bankfull channel widths relative to bridge or culvert widths, height of road fill at crossings, stream channel incision ratios, location of road segments relative to mapped floodplain, and steep roadway slopes.

The GIS analysis identified 36 sites in Warren, 35 in Waitsfield, and 22 in Fayston, with potential flood resiliency issues. Sites where roads and streams were in close proximity were the most common, followed by stream crossing sites. The results are summarized for each of the three towns in the maps and tables of Attachments D.

The GIS phase concluded with meetings with staff in each Town familiar with the local road network and flood damage history. In general, feedback at the meetings suggested that the GIS analysis did a reasonable job of identifying sites that have the potential for flood resiliency issues, though frequently the towns reported that they did not believe many of the sites had *active* issues (i.e., either hadn't yet been damaged, or was repaired adequately). Town input is summarized in the Tables in Attachment D.

5.0 Field Investigation of Potentially Vulnerable Sites

A river scientist from BCE and an engineer from D&K visited each site identified by the previous GIS-based phase. The site visits typically lasted up to 15 minutes per site, with all sites in a Town visited in a single day. Field notes for each site are summarized in the tables in Attachment B, and photographs of each site are also included in Attachment D.
The intent of the site visits was three-fold:

1. Rate the success of the GIS analysis in identifying sites with potential for flood resiliency issues
2. Determine whether there was an active flood resiliency issue
3. Identify a strategy to mitigate the flood resiliency issue (if any)

Overall, the field evaluation suggested that the GIS analysis was successful in identifying sites with potential flood resiliency issues. For approximately 50% of the sites, the specific mitigation strategy suggested by the GIS analysis (e.g., protect roadway embankment with riprap) was confirmed during the field inspection to indeed be an appropriate strategy, and in some cased the strategy had already been implemented in response to previous flood damage. For approximately 40% of the sites, the field inspection confirmed that the site either has flood resiliency issues that need addressing or has a reasonable potential to develop flood resiliency issues in the future, though the GIS analysis did not identify the appropriate mitigation strategy. For the remaining 10% of the sites, the GIS analysis appeared to erroneously identify the site; no active or potential flood resiliency issues were observed.

Active flood resiliency issues were identified at 18 of the 36 sites in Warren, 16 of the 35 in Waitsfield, and 16 of the 22 in Fayston. Protecting the roadway embankment and replacing undersized culverts at stream crossings are the two most common recommended mitigation strategies. Specific recommendations for each site as well as planning level cost estimates are included in the tables in Attachment D.

Attachment A

Conceptual Sketches of Strategies to Improve Flood Resiliency of Roadways

DUBOIS & KING, INC.

☐ Randolph, VT 05060 **(802) 728-3376**
☐ Williston, VT 05495 **(802) 878-7661**
☐ Bedford, NH 03110 **(603) 883-0463**

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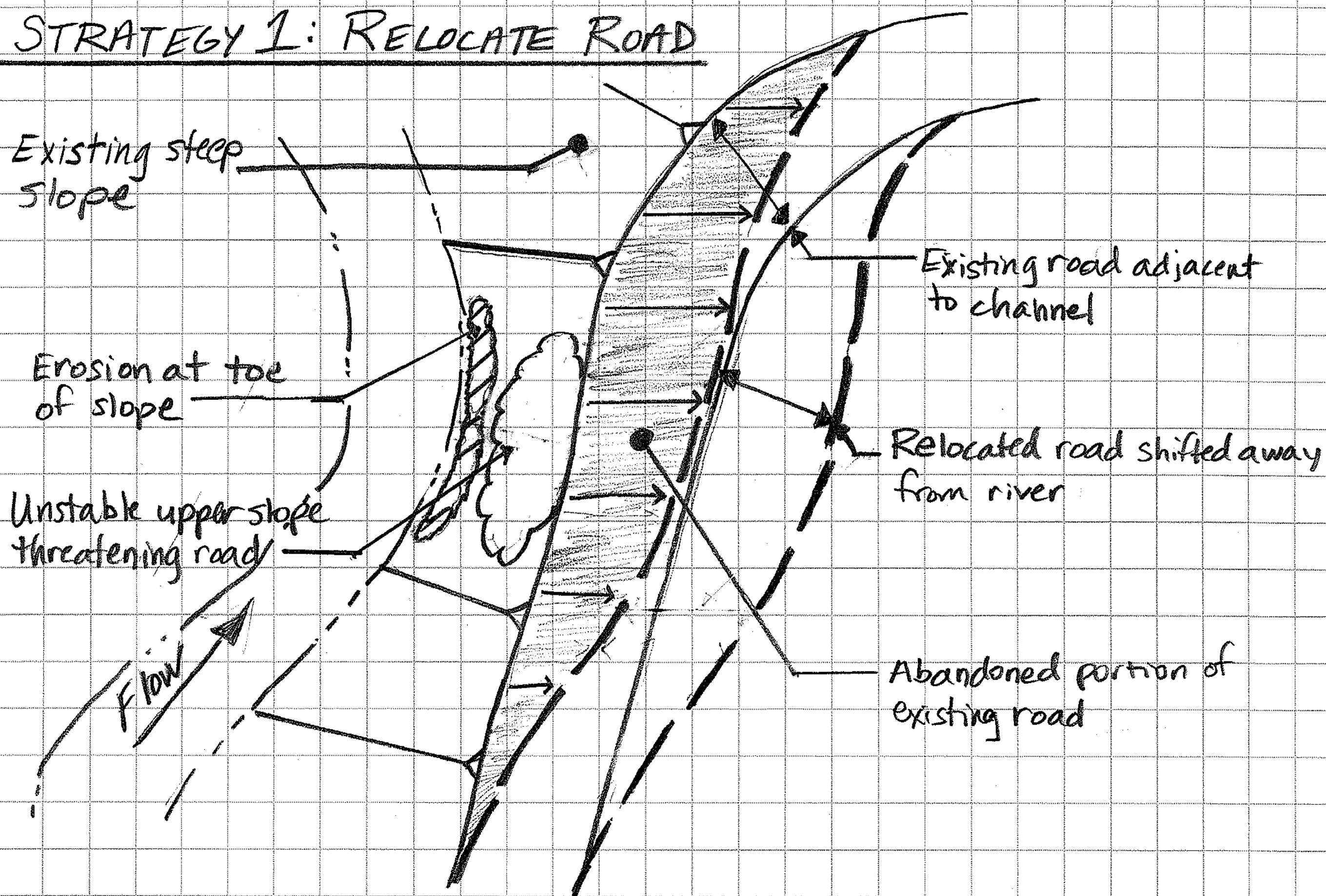
STRATEGY 1: RELOCATE ROAD



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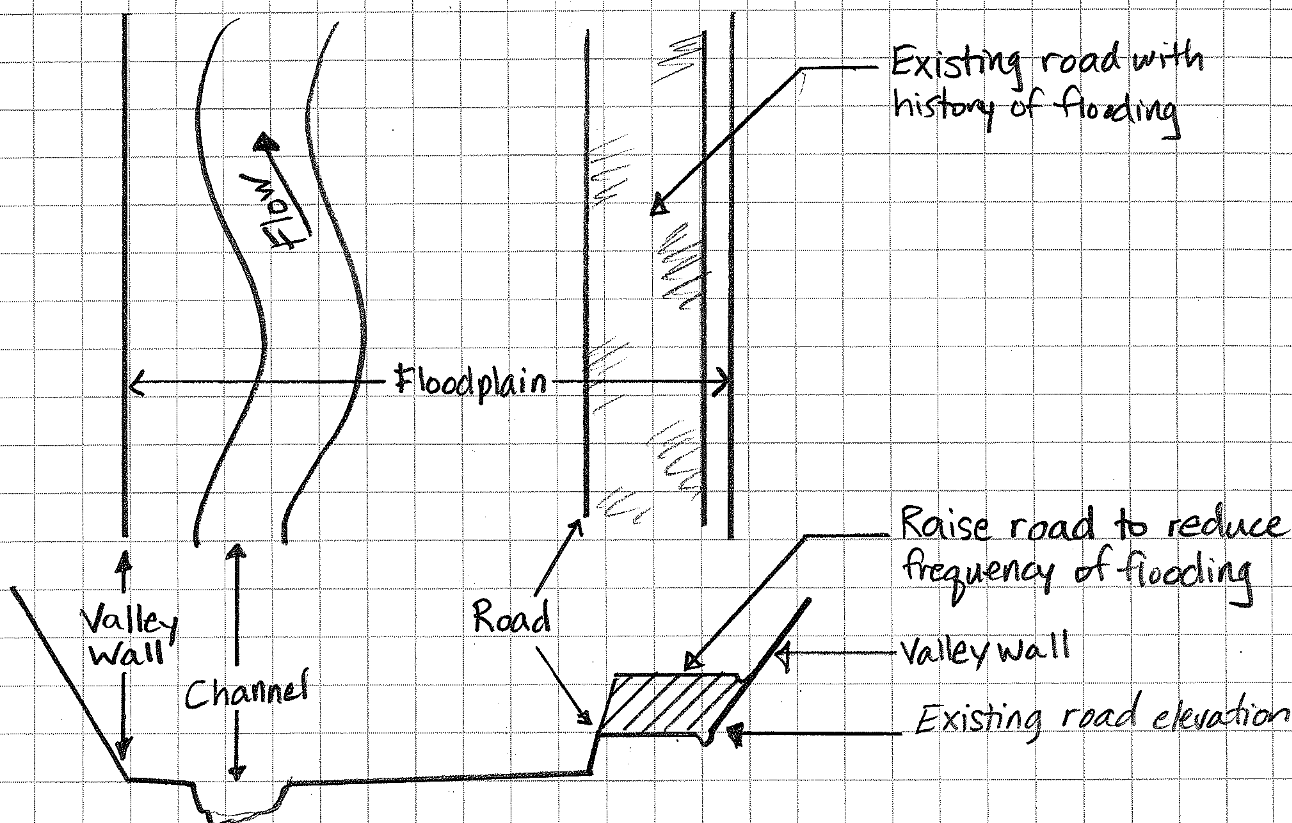
STRATEGY 2: RAISE ROAD



General Notes:

1. Strategy is applicable to sites where road is parallel to channel and is against the valley wall.

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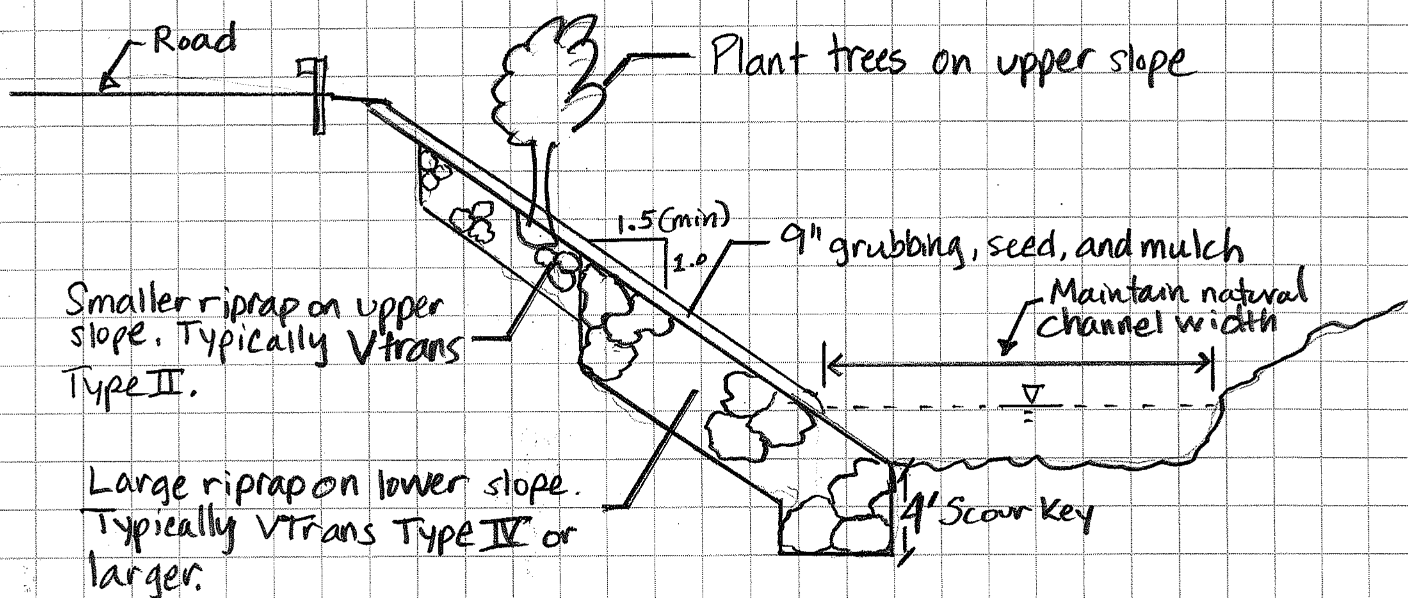
STRATEGY 3: PROTECT ROAD EMBANKMENT - STANDARD RIPRAP SLOPE



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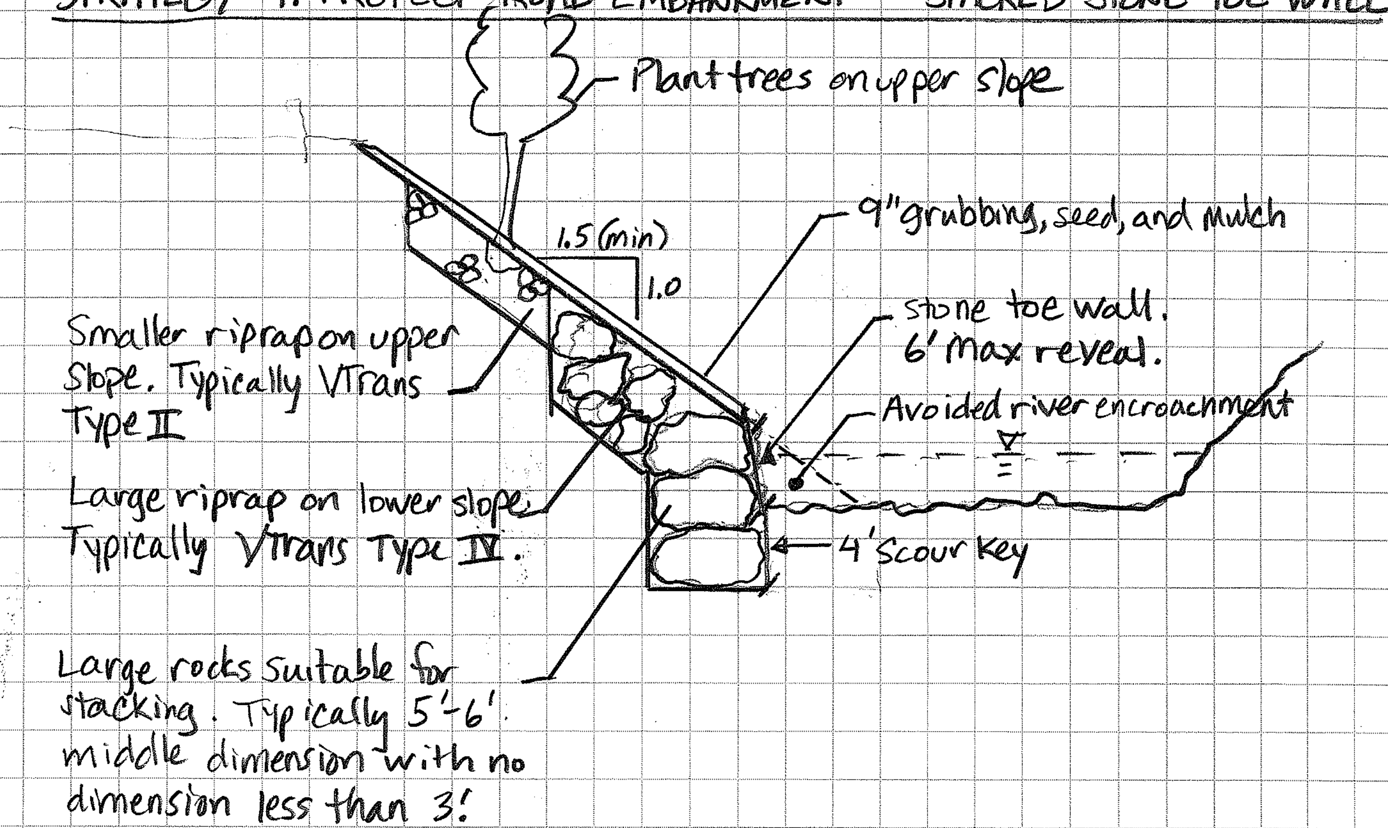
STRATEGY 4: PROTECT ROAD EMBANKMENT — STACKED STONE TOE WALL



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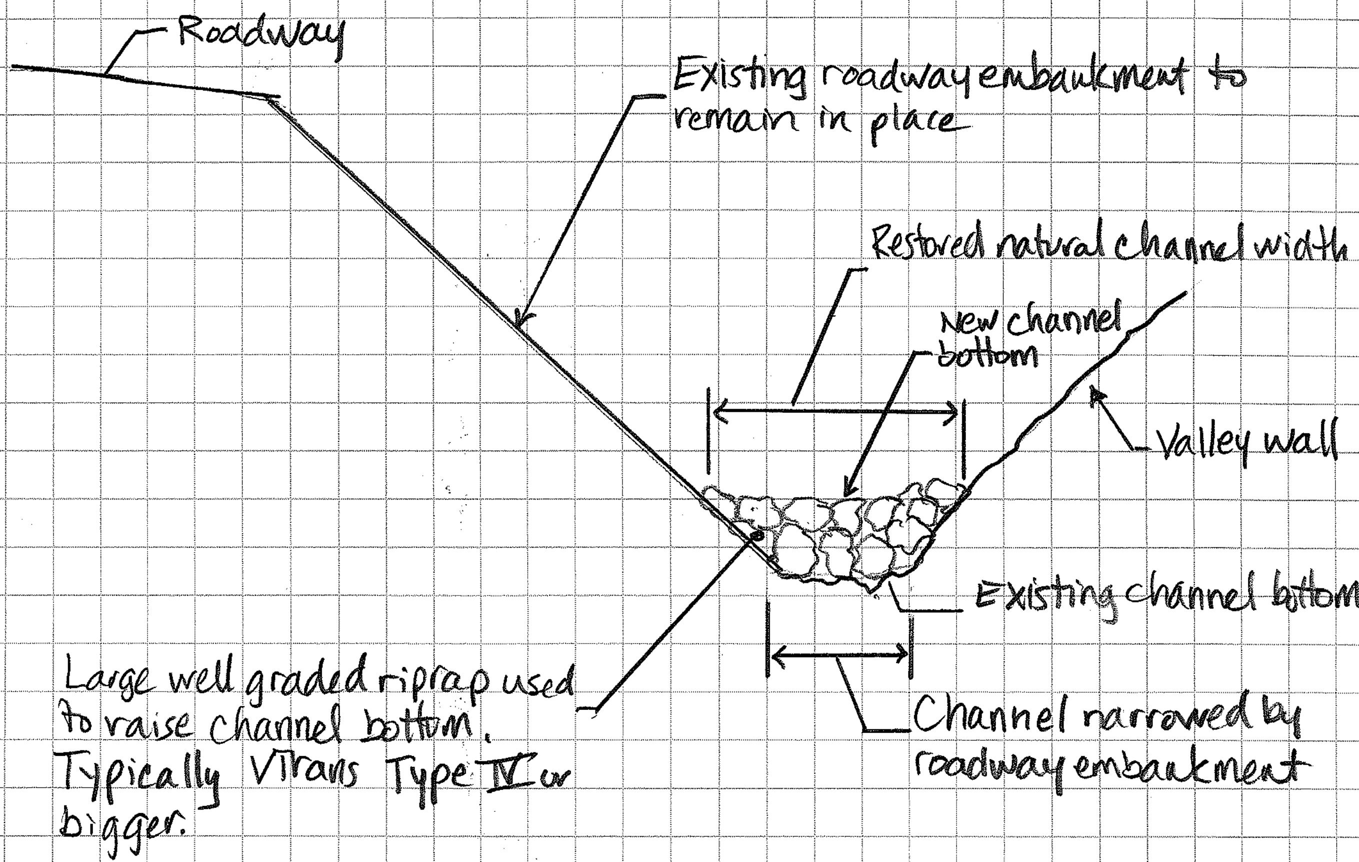
STRATEGY 5: RAISE AND PROTECT STREAMBED



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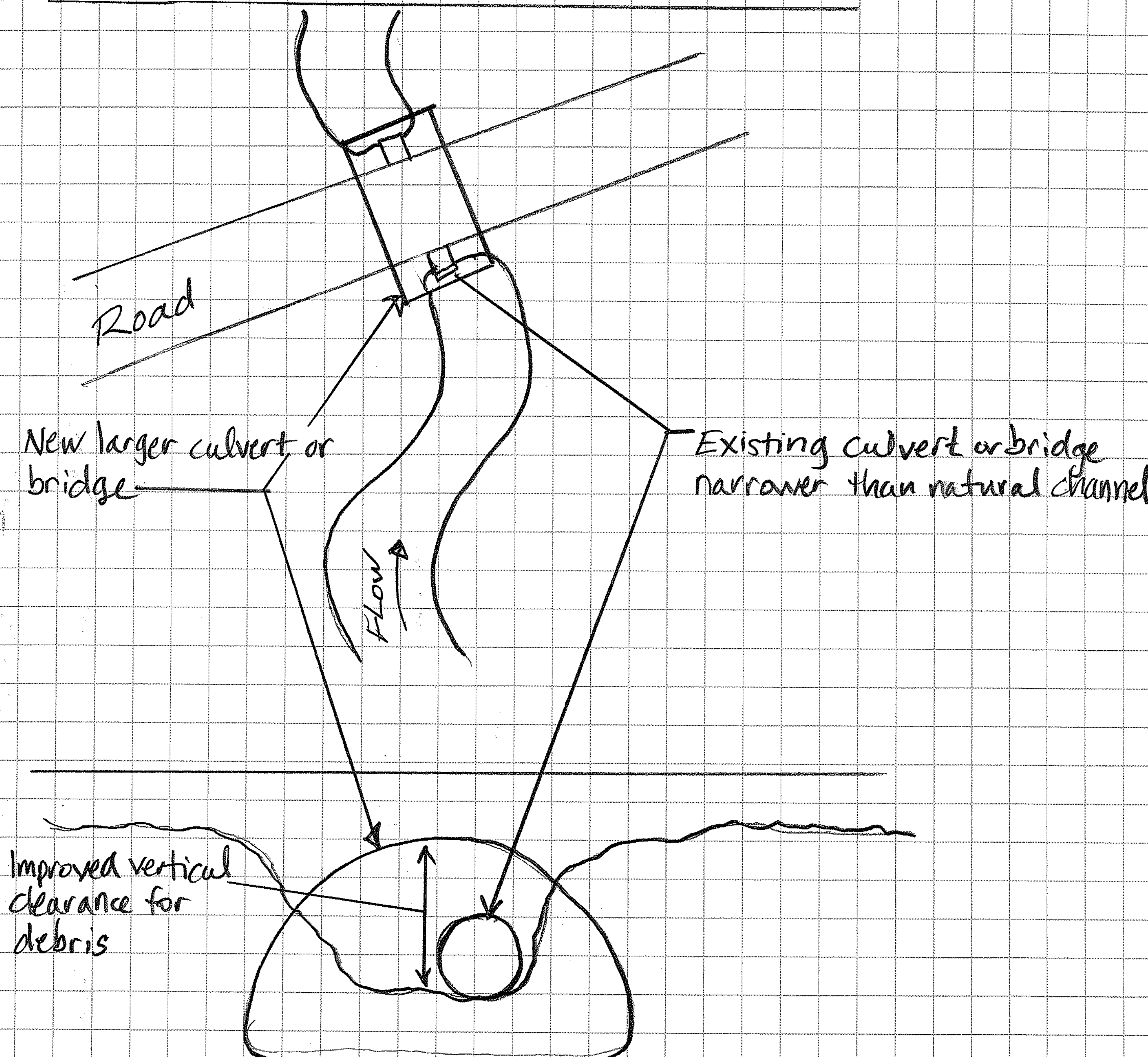
STRATEGY 6: LARGER CULVERT OR BRIDGE



General Notes:

1. Type of replacement structure will vary
2. In most cases, a pipe arch culvert as shown will be most cost-effective structure that meets state requirements

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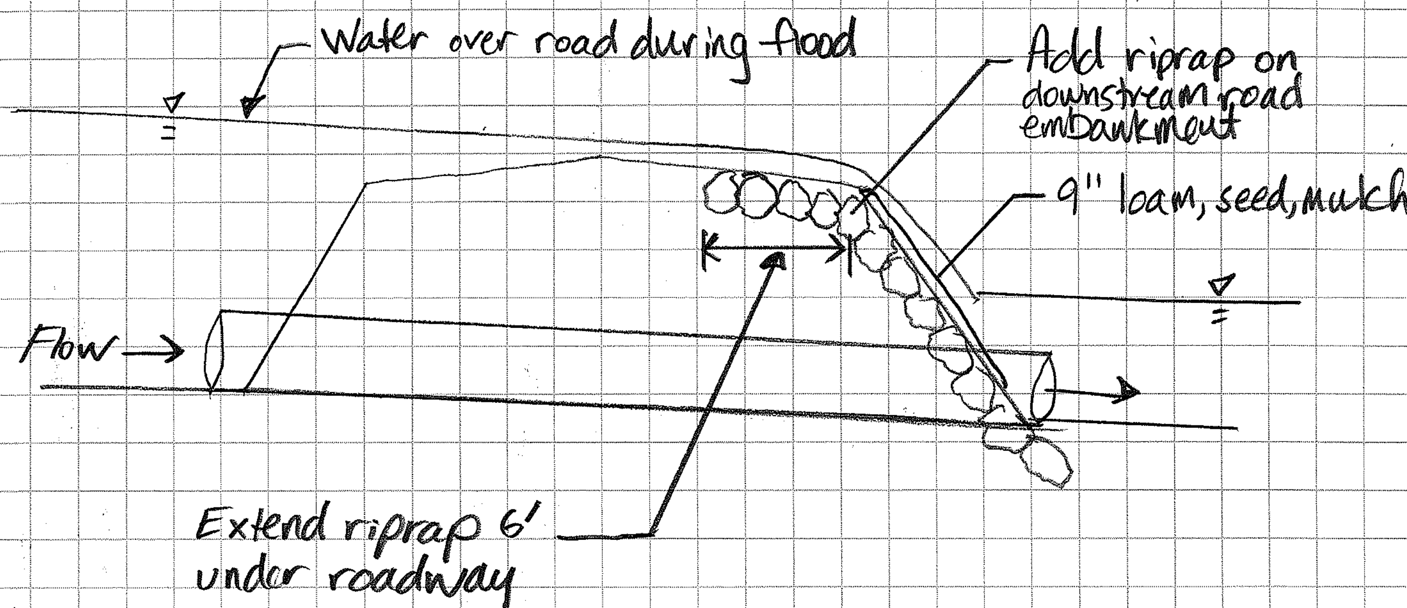
STRATEGY 7: PROTECT ROAD FOR OVERTOPPING



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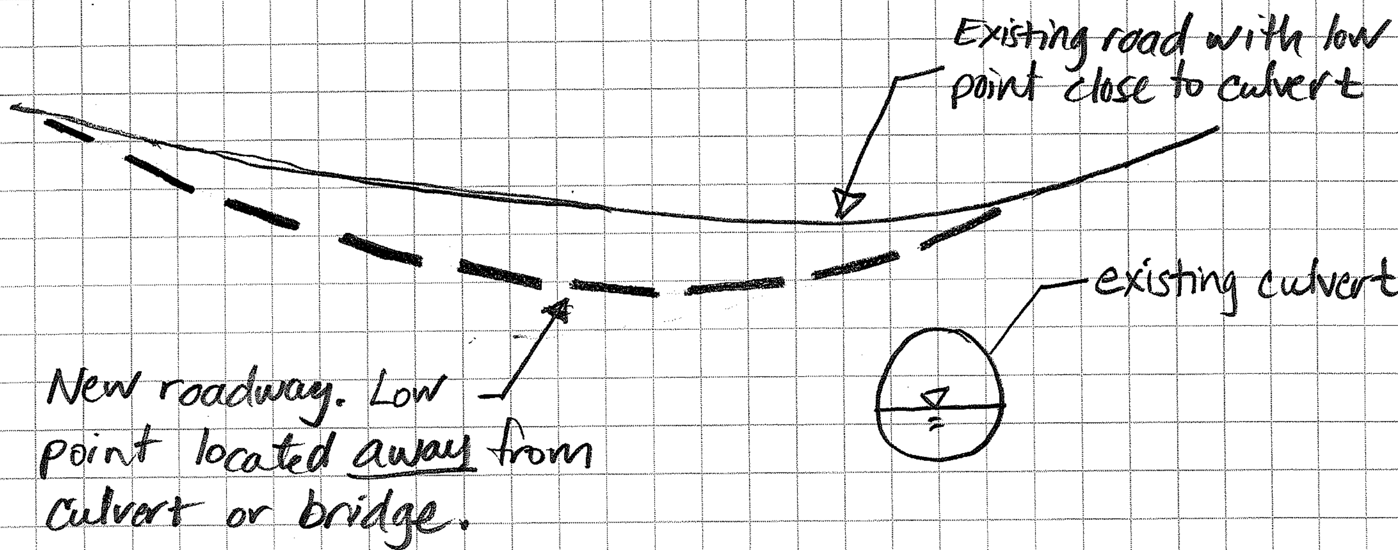
STRATEGY 8: LOW POINT IN CULVERT/BRIDGE APPROACH



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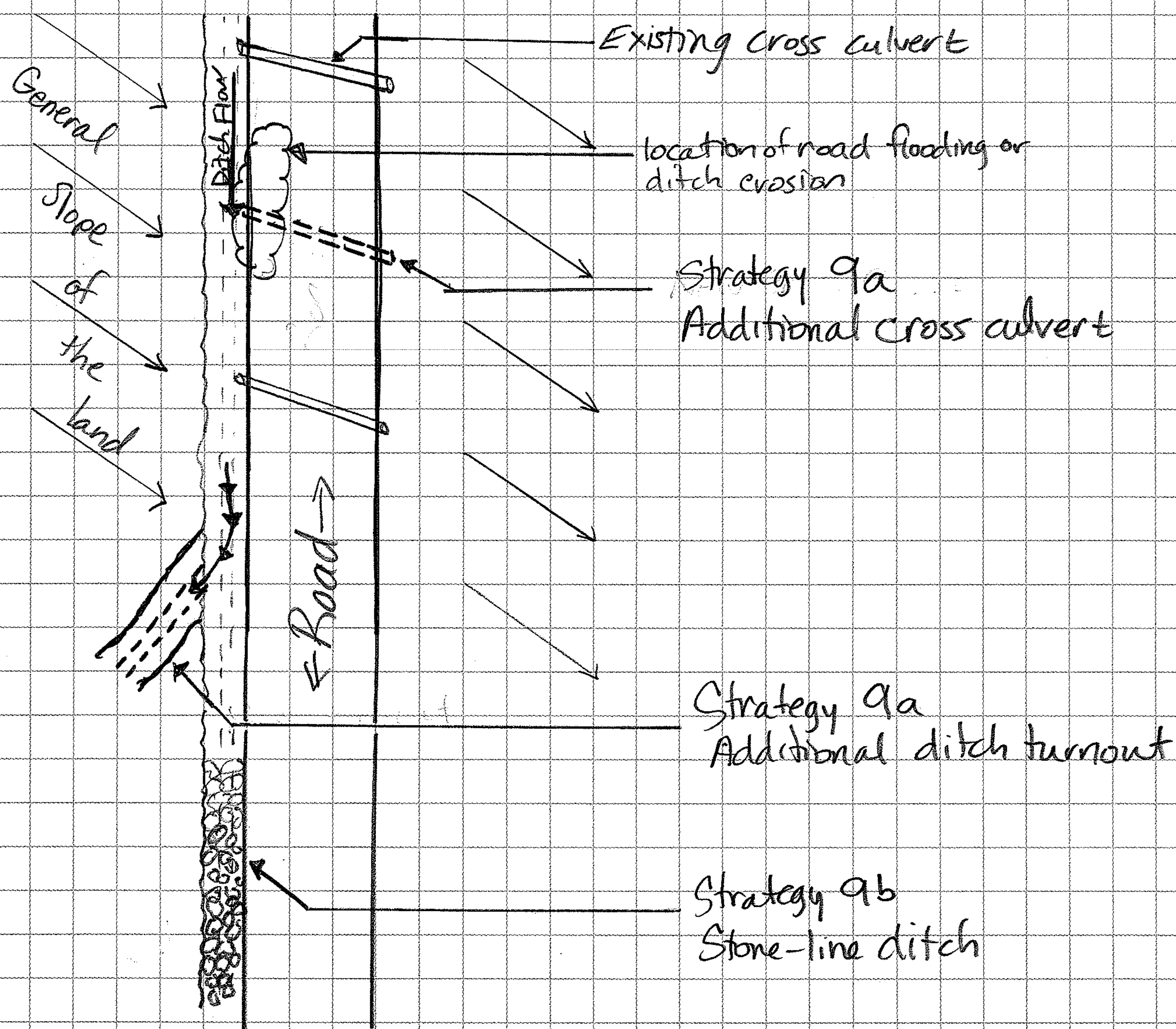
STRATEGY 9: DRAINAGE IMPROVEMENTS



General Notes:

1. Additional cross culverts and turnouts reduce the amount of water in the ditch and distribute water closer to pre-road conditions.
2. Stone lining should be considered after additional cross culverts and turnouts have been evaluated.

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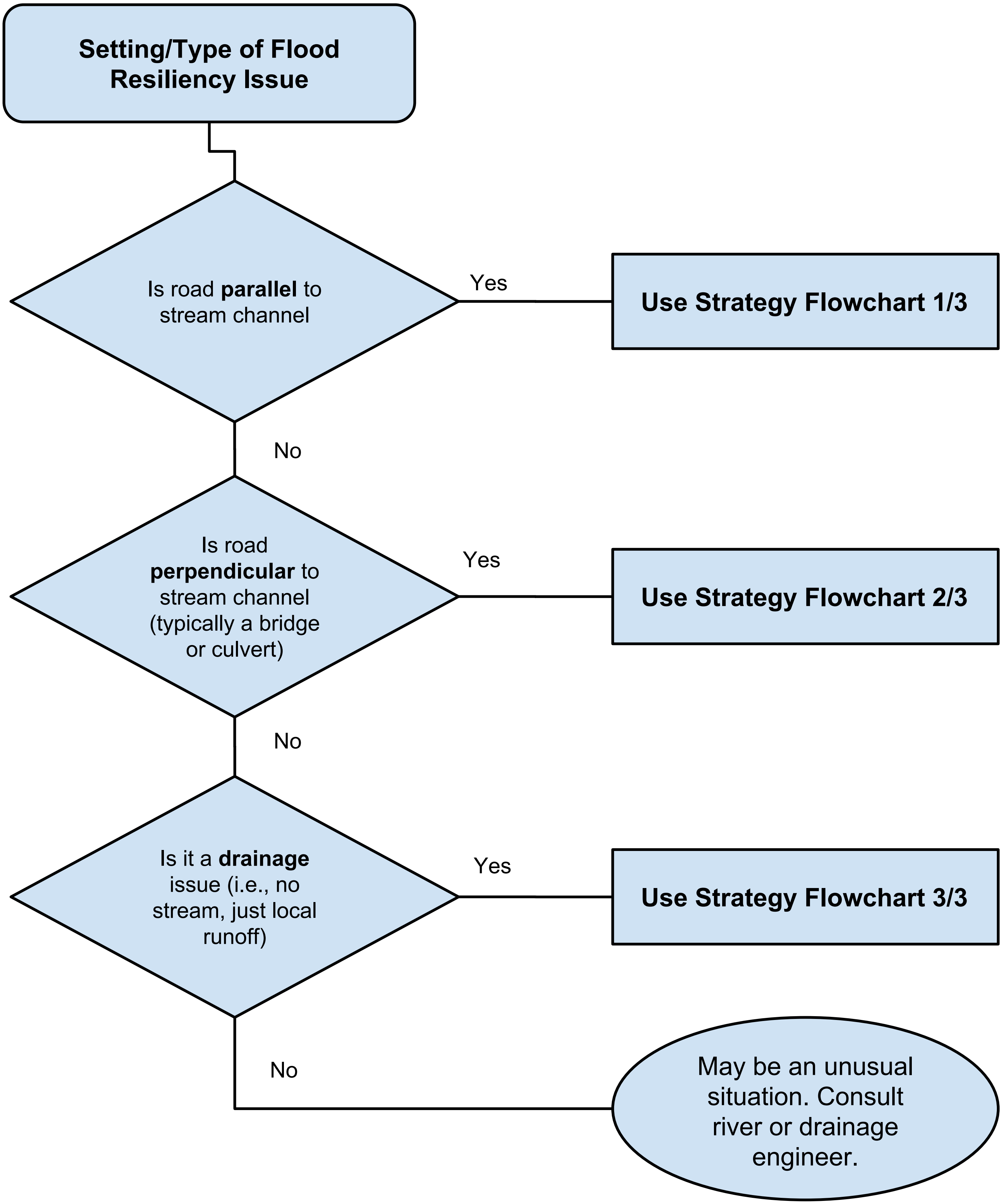
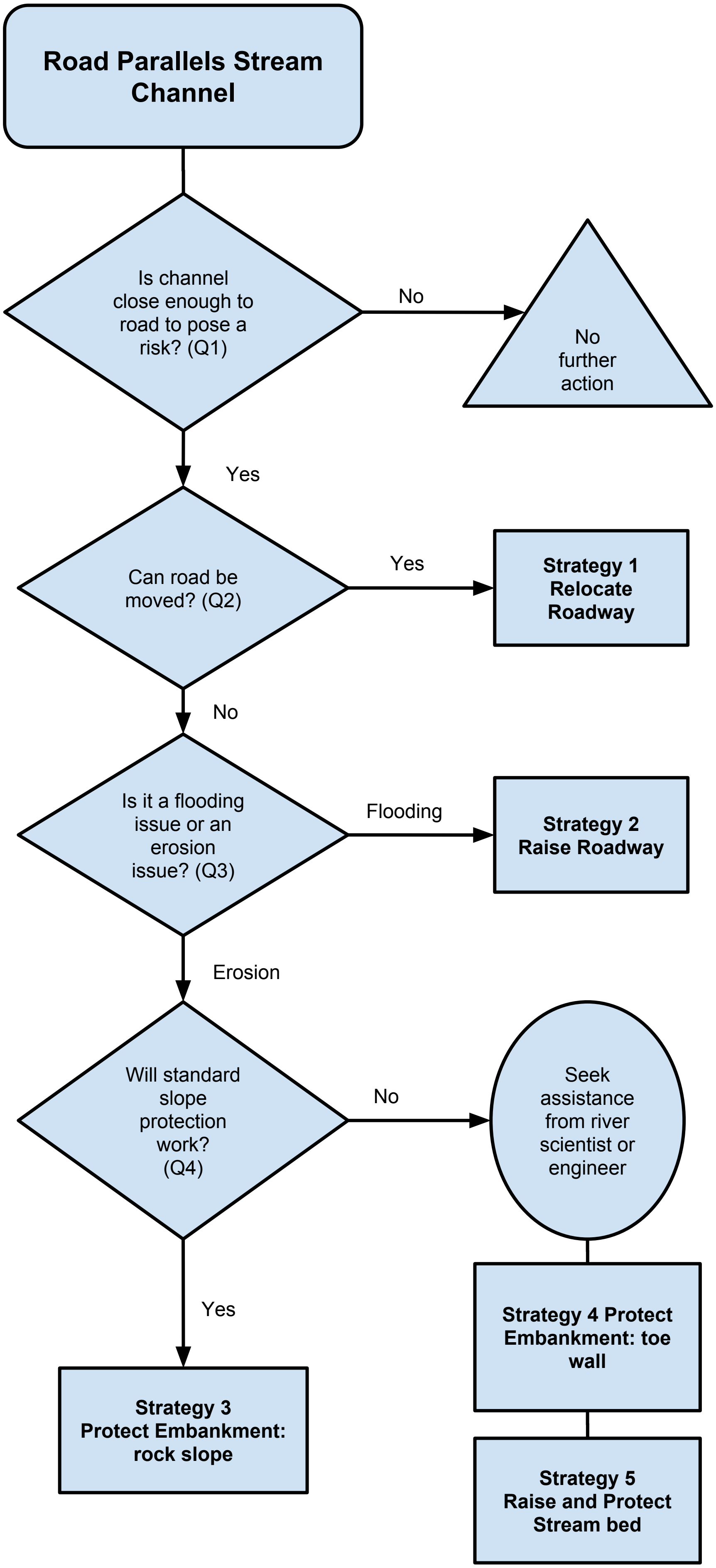
Attachment B

Guidance Flowcharts for Selecting Flood Resiliency Strategies

Strategy Selection Flowcharts for Flood Resiliency



Strategy Flowchart 1/3



GUIDANCE

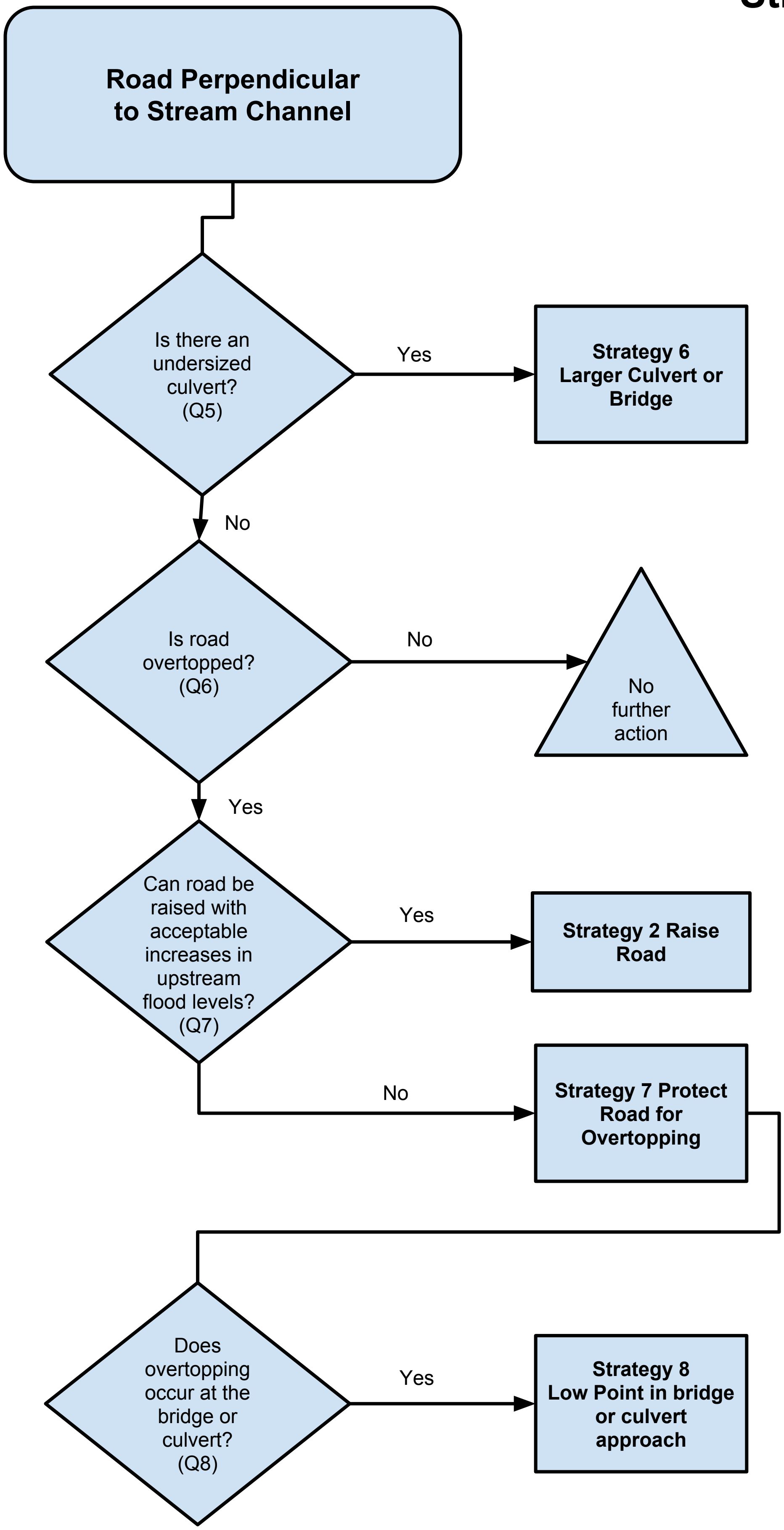
Q1. It can be a judgement call whether the road is at risk. Consider previous damage at the site (if any), damage to roads in similar settings, and presence of things like dense woody vegetation that might protect road.

Q2. It's rare, but sometimes a road can be shifted to sufficiently lower the risk. Right of way and financial considerations may steer you to answer No, but relocation may be the best long-term solution and should be given serious consideration.

Q3. Raising the road may keep floodwater off, but it is generally only acceptable in the road is close to or against a valley wall where raising it won't cut off floodplain on the other side.

Q4. If a slope of approximately 1.5H:1V will put the toe of slope into the river and make for a narrow channel, then a standard slope may not be a durable solution. Better fixes may include a stacked stone toe wall and/or raising the existing streambed to result in a wider channel.

Strategy Flowchart 2/3



GUIDANCE

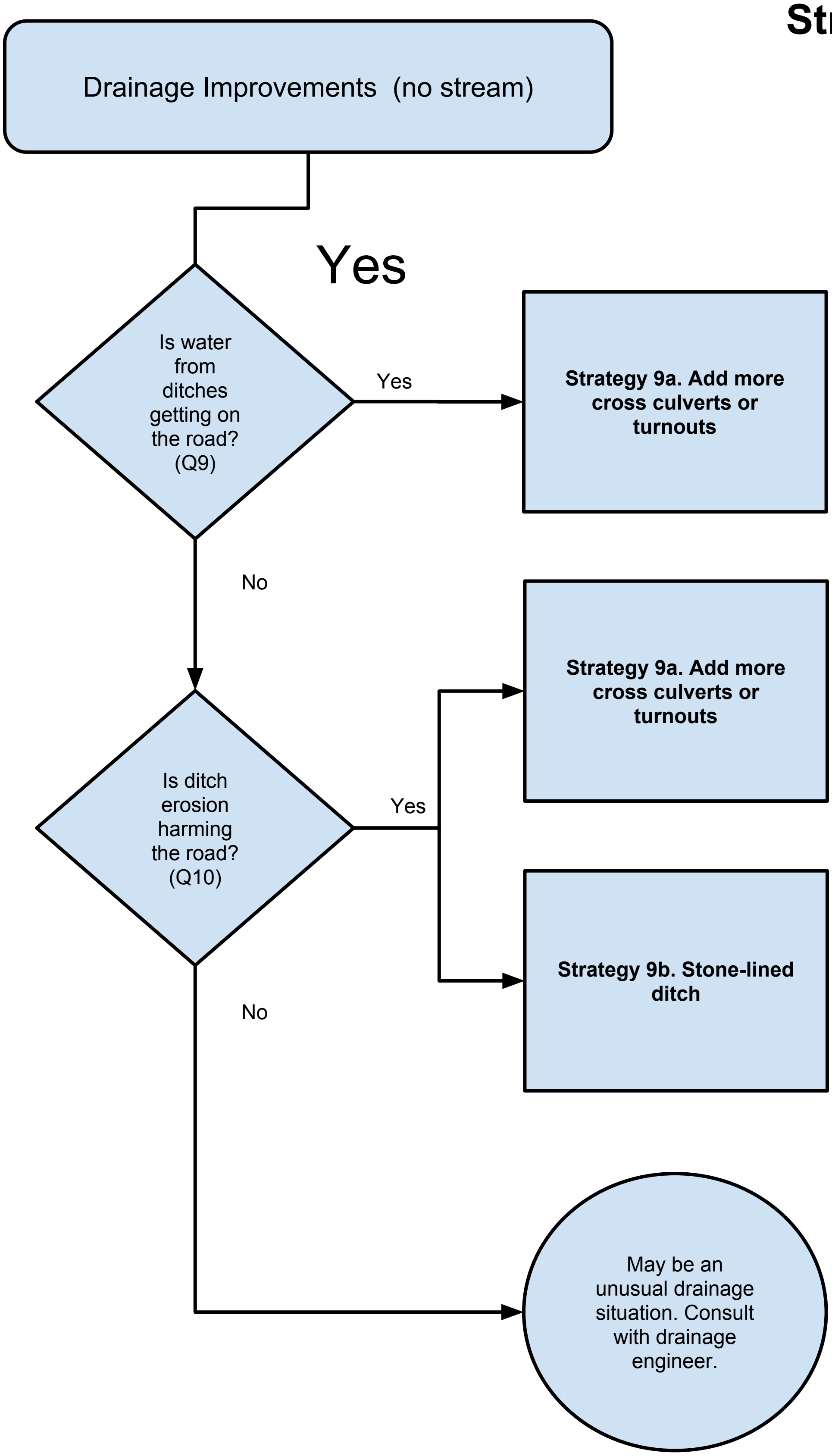
Q5. Is the existing culvert at least as wide as the natural channel? If it's significantly smaller, it may not be able to pass enough water and debris to survive the next major flood.

Q6. Is there a history of roadway overtopping during floods that leads to road damage and closure? Consider anecdotal reports and field evidence.

Q7. Raising a road typically increases upstream flood levels which may make flooding worse for upstream properties and which may put more pressure on a bridge or culvert. It is rarely an acceptable option. A better strategy is to reinforce the road to minimize damage when it does overtop.

Q8. If the bridge or culvert is at the lowest point in the road, the structure may be damaged when the road overtops. Regrading the road so that there is a low point on one bridge approach shifts the location of overtopping away from the structure. This low point on the approach may be damaged when it is overtopped, but the much more expensive structure is spared.

Strategy Flowchart 3/3



GUIDANCE

Q9. Is there a history of water exceeding the capacity of the ditch and flooding onto or over the road? Additional cross culverts and turnouts are generally more successful than increasing depth of ditch, which can lead to flows that are deeper and more erosive than the ditch can handle.

Q10. Is the ditch eroding into the travelway of the road? Ditches typically eroded downward first, and then laterally into the road, so be alert for signs of vertical erosion even if the road has yet to be damaged.

Attachment C

GIS-Based Screening Documentation (CVRPC)

GIS Analysis Methodology (Long)

Line features

Utilizing the most current VTrans road centerline data CVRPC staff did the following processing steps. Please note CVRPC utilizes an ArcGIS extension called ET GeoWizard for some of this processing.

1. Add VTrans road centerline data to project
2. Deleted all State roads from data leaving you with just town roads
3. In ET geowizard- use the split polyline tool to split the town roads into 100 meter segments (delete all extra fields from the data table except Route Number, Surface Type, Road Class, CTCode, and Road Name).
4. Add nine new fields to the split road data as follows:
   a. Attribute: Intersect Floodplain/Flood Hazard Data
      Field Name: Int_Flood
      Field: Type Short integer
   b. Attribute: Intersect River Corridor/Fluvial Erosion Hazard (FEH)Zone
      Field Name: Int_RC
      Field: Type Short integer
   c. Attribute: Intersect Stream Buffer
      Field Name: Int_Stream
      Field: Type Short integer
   d. Attribute: Intersect Road Slope
      Field Name: Int_RdSlp
      Field: Type Short integer
   e. Attribute: Valley Wall Distance
      Field Name: VW_D
      Field: Type Short integer
   f. Attribute: Stream Incision Ratio
      Field Name: Strm_Incsn
      Field: Type Short integer
   g. Attribute: Culvert Depth of Cover
      Field Name: Cvt_Dpth
      Field: Type Short integer
   h. Attribute: ANR Percent Bankfull Width
      Field Name: ANR_PrcBF
      Field: Type Short integer
   i. Attribute: RPC/VTrans Percent Bankfull Width
      Field Name: RPC_PrcBF
      Field: Type Short integer

   j. Attribute: Total of all Constraints
      Field Name: Con_Total
      Field: Type Short integer
5. Add floodplain/flood hazard data to project
6. Intersect Rdsplit_100m with floodplain (Rdsplit_100m_FP)
7. Select all road segments that intersected floodplain and calculate based on that selection Int_Flood equal to 1.
8. Add River Corridor/ FEH zone data
9. Intersected Rdsplit_100m_FP with River Corridor/ FEH (Rdsplit_100m_FP_RC)
10. Select all road segments that intersected River Corridor/ FEH and calculate based on that selection Int_RC equal to 1.
11. Add streams to project and buffer streams by 50ft (stream_buffer_50ft)
12. Intersect Rdsplit_100m_FP_RC to stream_buffer_50ft (Rdsplit_100m_FP_RC_SB50)
13. Select all road segments that intersected stream buffers and calculate based on that selection Int_Stream equal to 1.
14. Load best available Digital Elevation Model (DEM)
15. Calculate road slope using ET Geowizard tools
    a. Under surface tab click on feature to 3d tool and GO.
    b. Select Rdsplit_100m_FP_RC_SB50, DEM and output locations. Click finish. (Rdsplit_100m_FP_RC_SB50_3D)
    c. Under Polyline tab select Get Z Characteristics tool and Go.
    d. Select Rdsplit_100m_FP_RC_SB50_3D and hit next. Set target as same layer and click finished.
16. Road slopes need to be selected based on the following groups:
    Slopes 0-5% equal 0
    Slopes Greater than 5% to 15% equal 1
    Slopes Greater than 15% equal 2

Select all roads by slope groups and calculate based on that selection Int_RdSlp equal to value.

17. Load if available river/stream valley wall data. This data is typically collected during a Phase 1 and 2 Geomorphic Assessment and can be accessed from either the consultant who conducted the assessment or a VT DEC Rivers Program River Scientist.
18. Intersect Rdsplit_100m_FP_RC_SB50_3D to valley wall (Rdsplit_100m_FP_RC_SB50_3D_VW)
19. Run ET Geowizard tool near to feature between valley wall and Rdsplit_100m_FP_RC_SB50_3D_VW.(Rdsplit_100m_FP_RC_SB50_3D_VWN).
20. Valley wall distances need to be selected based on the following groups:
    Distance 0-10 meters equal 2
    Distance Greater than 10 to 30 meters equal 1
    Distance Greater than 30 meters equal 0

Select all roads by distance groups and calculate based on that selection Int_RdSlp equal to value.

21. Add if available existing Phase 2 stream geomorphic assessment data. You want to add in the stream line data that has been broken out into reaches and then segmented. This data is typically collected during a Phase 1 and 2 Geomorphic Assessment and can be accessed from either the consultant who conducted the assessment or a VT DEC Rivers Program River Scientist. To this stream data you will want to join a table exported out of the VT DEC online Stream Geomorphic Assessment Data Management System (DMS) – Web Link https://anrweb.vt.gov/DEC/SGA/Default.aspx. The table that you want to export is created by using the export Phase 2 data tool. Please follow this link to access the table export tool https://anrweb.vt.gov/DEC/SGA/projects/exports/phase2.aspx you need to have the following column attributes selected in your table numbers 0.101, 0.102, 0.103, 0.104, 0.105, 2.08a. You will need to select your project by river, and you will want to export out the table (I prefer a DBF table as it imports into ArcGIS very easily). You will want to do a table join use the RCHPTID in both the stream data and the exported table. Please note you may need to pick another field for this join based on your data. Once joined, you will be able to use the incision ratio values.
22. Intersect Rdsplit_100m_FP_RC_SB50_3DVWN to the join stream data to get the incision ratio (Rdsplit_100m_FP_RC_SB50_3D_VWN_I).
23. Incision ratio needs to be selected based on the following groups:
    Less than 1.4 (minor incision ratio) or not assessed equal 0
    1.4 - less than 2 (moderate incision ratio) equal 1
    Greater than and equal to 2 (sever incision ratio) equal 2
24. Join where available ANR SGA bridge and culvert data to your road data Rdsplit_100m_FP_RC_SB50_3D_VWN_I. If you don't have the point data already you can download a table from the online SGS DMS tool. Here is a link - https://anrweb.vt.gov/DEC/SGA/datasets/exports.aspx?rowFilter=Town you need to have the following column attributes selected in your table numbers 0.101, 0.104, 0.109, 1.01, 1.03, 1.05, 1.07, 1.08, 1.10, 1.11, 2.02, 2.06, 2.06a, and 2.10. You will need to select your filter by town, and you will want to export out the table (I prefer a DBF table as it imports into ArcGIS very easily).
25. Once the table is exported you will want to use the Latitude/Longitude values to covert the table to points. To do this you need to add the table to ArcGIS. Right click the table and select Display XY Data. Select the correct X and Y fields and your coordinate system and hit OK. A new point dataset will be added to the project. Check to be sure the data is displaying correctly.
26. XXXXXXX Rdsplit_100m_FP_RC_SB50_3DVWN_I to the ANR bridge and culvert join stream data to get the incision ratio (Rdsplit_100m_FP_RC_SB50_3D_VWN_I).

Point Features

Utilizing existing bridge and culvert points we will calculate bankfull width. Please Note this calculation is only necessary if you are using data not already loaded into VT ANR DMS or VTCulverts.org as those two sites already have bankfull width calculated where appropriate for existing bridge and culvert points.

1. Run and Intersect between roads and stream crossing exporting a point theme as the intersect.
2. Select all culverts greater than 18 inches with ("width" > 18 AND "width"< 999) and select by location all culverts that intersect a VHD stream/road intersect points (add a buffer of 10 meters). Export out as a new feature class.
3. Merge town culverts and bridges (Town Long and Short)
4. Add a new field for features crossed (feature_x)
5. Select by location, all bridges and culverts that are within 30 meters of a stream/road intersection.
6. Calculate for the selected features in the feature_x field "Stream Crossing". Do a quick visual inspection of these selected sites to check for errors. Fix as needed. Switch selection and calculate "road crossing" to all other structures.
7. Select all stream crossing culverts and run the Snap tool between the selected stream crossing culverts and all Stream/road crossings. Use snap type of Vertex and a Distance of 30 meters.
8. Build Flow Direction Raster using Flow Direction tool in ArcGIS input is OrthoDEM
9. Run Flow accumulation model on flow direction raster switch output data type to integer
10. Select all stream crossing structures and run snap to pour point to the flow accumulation grid with 15 meter snapping. Select ObjectID as the Pour Point Field
11. Switch Selection and run snap to pour point on selected road crossing structures using the flow accumulation grid with 0 meters snapping. Select ObjectID as the Pour Point Field
12. Run the Append tool to add the Pour Point roads to the Pour Point streams.
13. Run Watershed tool in ArcGIS using new Flow DEM add selected culvert points as pour points use the value field as the pour point field so that the watershed data can be likened back up with the culvert points.
14. Convert Watershed raster to shapefile polygons remember to uncheck simplify polygons
15. Add a new field to the new watershed for acres and square miles and calculate using ArcGIS those area values
16. Run Dissolve on the watersheds selecting the gridcode as the dissolve field and sum on Sq miles
17. Add three new field to the culvert data for sq miles, bankfull width, and percent bankfull
18. Link the watershed data to the culvert data using the pour point field.
19. Calculate into the culvert data the acres and sq miles from the watershed and then remove the join
20. Calculate the Banks full width using he following equation $Wbft=13.1 * \text{Drainage Area(in sq miles)}^{0.44}$

21. Add a new field for the % bankfull and then calculate that by dividing the culvert width or the bridge span by the bankfull width and multiply by 100.

Depth of Cover

This value can be found in the bridge and culvert data loaded into VTCulverts.org if this is your original source for your bridge and culvert data, then the value may already exist. Otherwise you will have to measure it in the field.

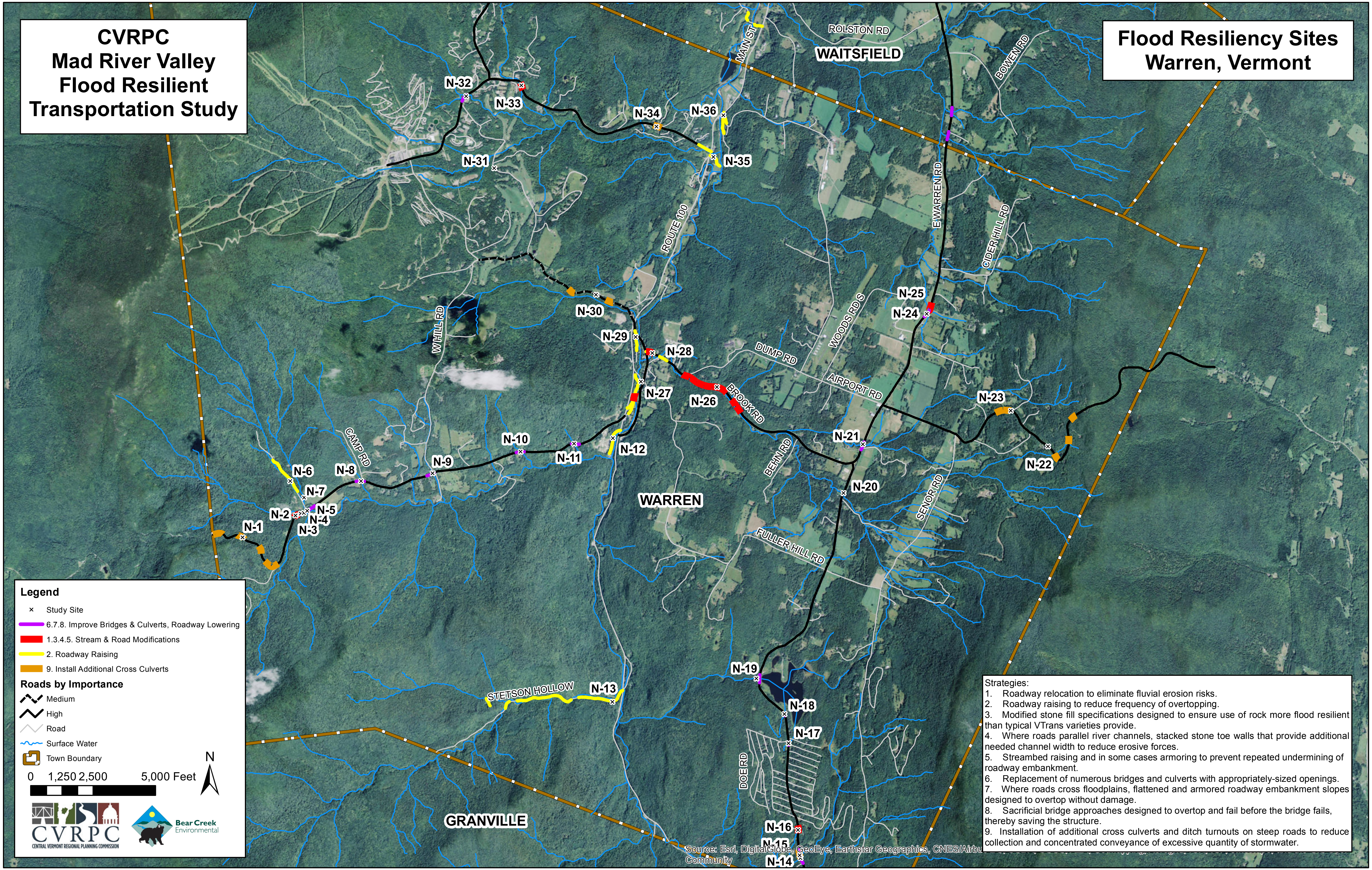
Incision Ratio

1) Join existing Phase 2 stream geomorphic assessment data table to the stream geomorphic assessment stream segments.

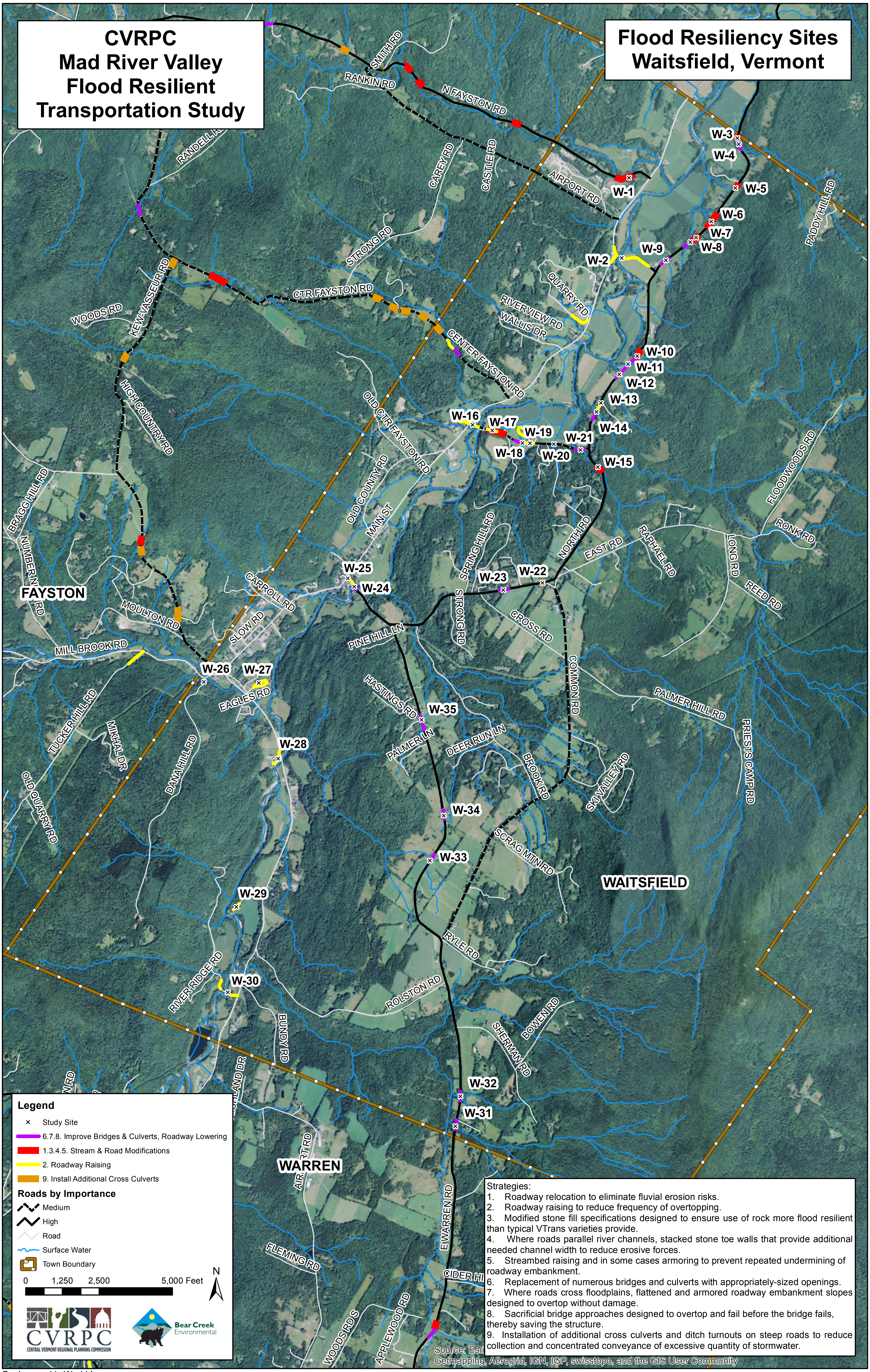
2) Intersect bridge and culvert point and joined stream geomorphic assessment data to get incision ratio value.

Attachment D

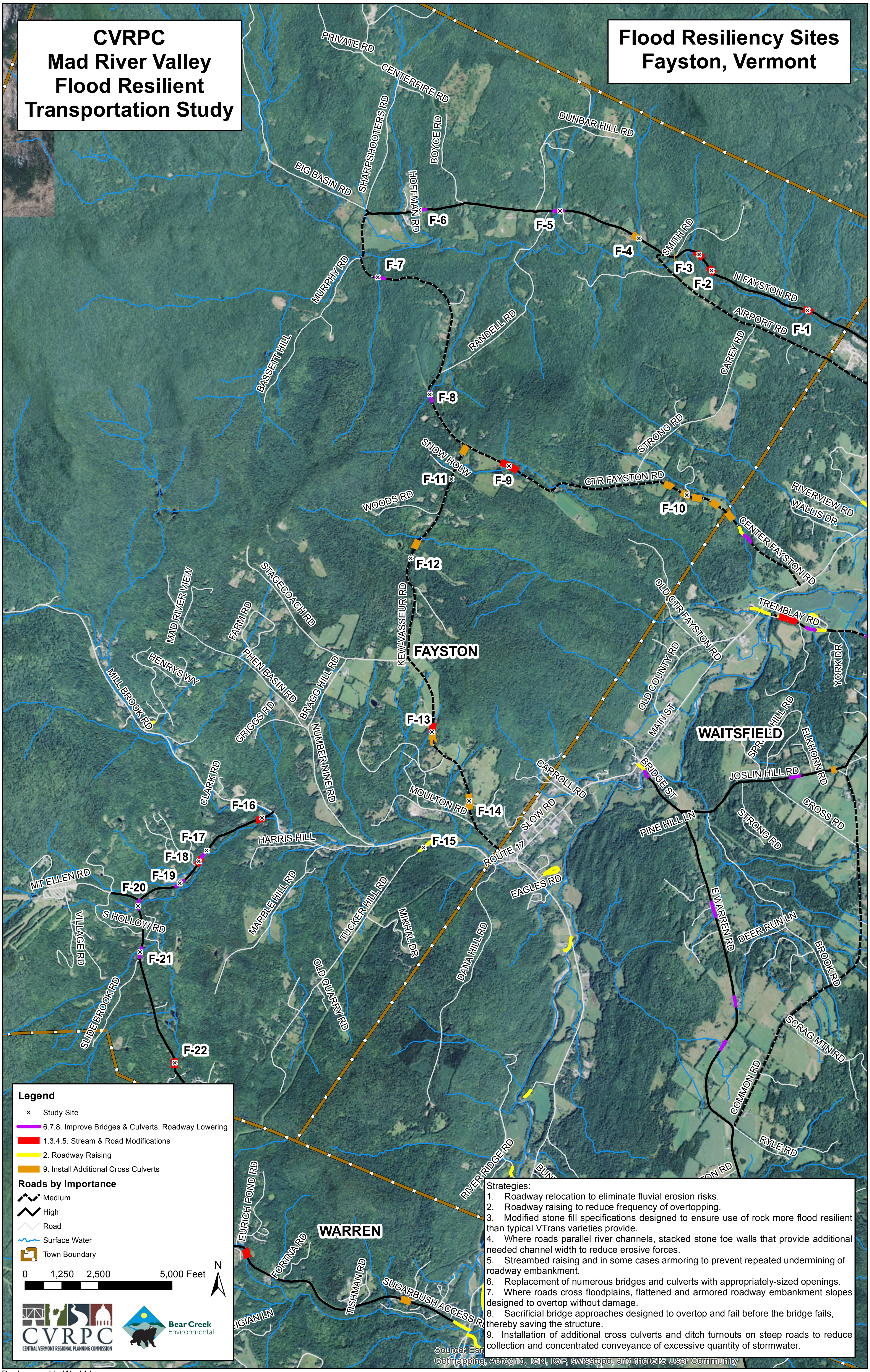
Maps and Tables for Waitsfield, Warren, and Fayston



Background is World Imagery.



Background is World Imagery.



Background is World Imagery.

Warren, Vermont

Mad River Valley Flood Resilient Transportation Study

Central Vermont Regional Planning Commission

4/10/15

Site Number	Road	Road Importance	GIS-Based Category of Potential Flood Resiliency Improvements	Notes from Meeting with Town 9/11/2014	Field Notes 10/30/14	Recommended Mitigation Strategy	Recommendation Notes	Planning-Level Cost Estimate ($)
N-1	Lincoln Gap Road	High	! Additional Cross Culverts	No issues	Steep road with many existing cross culverts; significant accumulated leaf and wood debris in ditches and culvert inlets.	Roadway drainage improvements	Add cross culvert about 1325 feet from town line. Clean out ditches and culvert inlets.	$10,000
N-2	Lincoln Gap Road	High	" Stream & Road Modifications		Road parallels channel; channel contains ledge where road is close; downstream of ledge channel is incised and widening but road is far enough from channel to not be at risk.	None	None	--
N-3	Lincoln Gap Road	High	" Stream & Road Modifications		Stream bank erosion adjacent to road putting embankment at risk. It will continue in the downstream direction.	Embankment Protection: rock slope	Riprap embankment including 40' additional feet downstream of current erosion. Place additional riprap on the embankment rather than current streambank, which will leave existing trees in place for the time being while anticipating future channel movement.	$36,000
N-4	Lincoln Gap Road	High	# Bridge & Culvert Improvements; Roadway Lowering	Looking to replace with multiplate	6'H x8'W pipe arch; BF is about 12 feet (measurement may still be in zone of influence from culvert)	Larger culvert	Replace culvert (Moderate priority)	$106,000
N-5	Lincoln Gap Road	High	# Bridge & Culvert Improvements; Roadway Lowering		12'Wx7'H culvert with 1' perch'; 3 foot deep scour hole below and steep riffle above. Measured bankfull width is about 18 feet. Geomorphic stability is poor and structure is also an AOP issue.	Larger culvert	Replace culvert (Moderate priority)	$133,000
N-6	Hanks Road	Low	G Roadway Raising	Culvert washed out	Not a road raising issue. Road is high and ledge is present in channel. Not clear why this is a mapped floodplain.	None	None	--
N-7	Hanks Road	Low	# Bridge & Culvert Improvements; Roadway Lowering		Site added by river engineers in the field. Two 36" CMP culverts at different elevations. Lower culvert is deformed and filled almost entirely with sediment. Significant risk of roadway overtopping. Measured bankfull is 12-13 feet. Site is good candidate for CMP arch.	Larger culvert	Replace culvert (High priority).	$103,000
N-8	Lincoln Gap Road	High	# Bridge & Culvert Improvements; Roadway Lowering	No issues	5' diameter CMP culvert near Camp Road. 6' perch (freefall). Sediment deposition above inlet. Measured bankfull width is about 10 feet.	Larger culvert	Replace culvert (Moderate priority)	$90,000
N-9	Lincoln Gap Road	High	# Bridge & Culvert Improvements; Roadway Lowering	No issues	4' HDPE culvert near West Hill Road. Perch of 4'. Measured bankfull width is about 11'. Minor sediment accumulation apparent above inlet.	Larger culvert	Replace culvert (Moderate priority)	$95,000
N-10	Lincoln Gap Road	High	# Bridge & Culvert Improvements; Roadway Lowering		24" CMP culvert with perch of 0.3'. Velocity barrier for fish. Steep stream channel slope. Measured bankfull width is about 10'. Culvert overtopped previously and ran down road and shoulder. Evidence of pavement repair, but short of complete road failure. Bank erosion upstream indicating elevated sediment load.	Larger culvert	Replace culvert (Moderate priority)	$90,000
N-11	Lincoln Gap Road	High	# Bridge & Culvert Improvements; Roadway Lowering		18" CMP, intermittent stream. Surrounding landscape and small channel not likely to generate much debris. However, an 18" inlet is prone to leaf and stick blockage. Bankfull width is estimated to be about 4.5 feet.	Larger culvert	Replace Culvert (Low priority)	$60,000
N-12	Bobbin Mill Ln	Low	G Roadway Raising	No issues	Road is high and is already against the valley wall.	None	None	--
N-13	Stetson Hollow Road	Low	G Roadway Raising	Impassable Class 4	Could not access road during site visit due to propane truck blocking the road.	None	None	--
N-14	Plunkton Road	High	# Bridge & Culvert Improvements; Roadway Lowering	Due for larger culvert	New structure is in place that is 12' wide by 7' tall, on concrete footers. BF width is at least 20'. Alignment is fair.	None	None	--
N-15	Plunkton Road	High	! Additional Cross Culverts		Ditch lines on north side of bridge are relatively long and thus prone to erosion, but adding cross culverts is impractical and turnouts would be well outside right of way.	Roadway drainage improvements	Consider additional turnouts on east side, recognizing need to work outside of right of way; riprap ditch to reduce velocities and protect from erosion.	$5,000
N-16	Plunkton Road	High	" Stream & Road Modifications		Road not immediately threatened, but there is local vertical instability (head cut) immediately upstream, and it is a relatively tall and steep embankment that could be undermined in the future.	Embankment Protection: rock slope	Monitor now in anticipation of need for future work to stabilize the embankment	<$1000
N-17	Plunkton Road	High	# Bridge & Culvert Improvements; Roadway Lowering		Culvert on Plunkton Road near Hillside Road. 24 inch CMP (appears to be aluminum coated). Upstream wetland appears to effectively catch wood and sediment before it reaches the inlet. With time, the capacity of the wetland will be reduced and potential for road overtopping increased. Erosion at outlet splash pad is extending back toward road.	Streambed raising/armoring	Reconstruct splash pad to keep water on surface and slope gradually into downstream bed.	$5,000
N-18	Plunkton Road	High	# Bridge & Culvert Improvements; Roadway Lowering	No issues	18 inch CMP. Wetland above culvert and outlets into lake. No issues.	None	None	--
N-19	Plunkton Road	High	# Bridge & Culvert Improvements; Roadway Lowering		This is the outlet of Blueberry Lake Dam.	None	None	--
N-20	Plunkton Road	High	# Bridge & Culvert Improvements; Roadway Lowering	Stream not aligned with bridge. Town is concerned about vulnerable bank upstream of inlet.	Site added to address town's concern regarding alignment. Significant channel meander immediately upstream of bridge with channel directed at roadway embankment before turning right then left to enter bridge. While tortuous, the alignment promotes sediment and debris deposition before bridge inlet. The south bridge approach is lower than bridge deck, which provides valuable water bleed-off during major floods.	Embankment Protection: rock slope	Monitor upstream embankment and protect if erosion develops. Plant trees on the embankment to increase natural resilience.	$5,000

Site Number	Road	Road Importance	GIS-Based Category of Potential Flood Resiliency Improvements	Notes from Meeting with Town 9/11/2014	Field Notes 10/30/14	Recommended Mitigation Strategy	Recommendation Notes	Planning-Level Cost Estimate ($)
N-21	E. Warren Road	High	# Bridge & Culvert Improvements; Roadway Lowering	No issues	Culvert on E. Warren Road near Galloping Wind Trail. 66" (5.5') CMP; very deep to structure (approx 20' cover). Clearly undersized relative to stream, but no location to get a reliable bankfull width measurement.	Larger culvert	Monitor for wood and sediment accumulation and blockage following major storms.	$101,000
N-22	Roxbury Mtn Road	High	! Additional Cross Culverts	Cross culverts would cause more problems	11 culverts or turnouts in 0.7 miles. 7 are cross culverts, 3 are stream crossing and one turnout. Average distance between crossings is approx 320 feet. Appears to be opportunities to add cross culverts at selected locations without contributing to reported down-gradient drainage problems.	Roadway drainage improvements	1. Add additional cross culvert (above middle orange GPS polygon) 2. Riprap ditch below (west) of lowest orange GPS polygon (along right side of road looking downstream)	$10,000
N-23	Roxbury Mtn Road	High	! Additional Cross Culverts	Fixed box culvert	Distance is about 0.3 miles. 3 turnouts and 5 cross culverts. Looks like good spacing.	None	None	--
N-24	Plunkton Road	High	# Bridge & Culvert Improvements; Roadway Lowering		4' diameter CMP (wetland above). No issues.	None	None	--
N-25	Plunkton Road	High	" Stream & Road Modifications	No issues	No issues	None	None	--
N-26	Brook Road	High	" Stream & Road Modifications	Riprap added	Channel is incised and banks are collapsing resulting in debris jams in channel. The weirs that were installed to prevent incision failed. Weir installation took place during the cold weather under harsh conditions without sufficient oversight. There is a significant vertical channel stability issue that puts Brook Road at immediate risk of damage.	Streambed raising/armoring	Install robust weirs under the direction of an experienced river engineer and evaluate continuous bed raising in most vulnerable locations. Remove downed trees from channel and proactively cut falling trees (leaving roots) at selected downstream landslides.	$50,000 - $100,000
N-27	Mill Road	Low	G Roadway Raising		Raising road would put covered bridge at risk; also a stream and road modification site on Covered Bridge Road	None	None	--
N-28	Brook Road	High	G Roadway Raising	No issues	Photo taken in wrong location; also a stream and road modifications site. Riprap present at some distance from active channel. Roadway raising not practical due to adjacent buildings, and roadway inundation not clearly an issue.	None	None	--
N-29	Trout Hollow Road	Low	G Roadway Raising	No issues	Road is already high.	None	None	--
N-30	W Hill Road	Medium	! Additional Cross Culverts	Added 16 new culverts	GPS points taken at top and bottom of site (~3430 feet) - 12 cross culverts and one turn out over this distance resulting in about 264 feet between crossing culverts/turnouts) . Site looks okay in terms of number of cross culverts; however, there is a raw ditch near the bottom of the site that needs attention.	None	Establish grass cover or place stone in newly graded ditch at downstream end.	<$1,000
N-31	TH-53	Low	! Additional Cross Culverts	Not enough culverts	Site added due to concerns expressed by town of not having enough culverts. No issue noted in the field with this location during the 11/24/14 site visit.	None	None	--
N-32	Sugarbush Access Road	High	# Bridge & Culvert Improvements; Roadway Lowering		30" HDPE culvert is slipped inside a larger older CMP. Measured bankfull width is about 7 feet. The culvert is undersized. However, there is a large floodplain above the inlet that catches debris thereby reducing the risk associated with the undersized culvert. Undersized riprap used to armor road embankment on approach to culvert inlet.	Embankment Protection: rock slope	Grub, seed, and mulch existing riprap to add additional resistance to erosion.	<$1,000
N-33	Sugarbush Access Road	High	" Stream & Road Modifications	No issues	A few patches of small riprap on bank. Stormwater appears to be an issue. Large rock and ledge present in channel that is mitigating bank failure.	None	Monitor road embankment and address stormwater erosion issues as needed.	<$1,000
N-34	Sugarbush Access Road	High	! Additional Cross Culverts		Water generally flows away from road. The ditch is stone lined. No issues.	None	None	--
N-35	Sugarbush Access Road/Steward Road	High/Low	G Roadway Raising	No issues	Sugarbush Access Road is already raised. Houses on Steward Road are lower than the road itself, so raising Steward would increase flood risk to homes.	None	None	--
N-36	Volkstown Road	Low	G Roadway Raising	Raising road would help	Road is along valley wall and is lowest adjacent to Rte 100. Could raise the road to reduce frequency of inundation and maintain access to residences further upstream, but would lose a little flood storage.	Roadway raising	Investigate frequency and depth of road inundation and prepare conceptual plan, cost, and brief feasibility evaluation.	$5,000

Waitsfield, Vermont

Mad River Valley Flood Resilient Transportation Study

Central Vermont Regional Planning Commission

4/10/15

Site Number	Road	Road Importance	GIS-Based Category of Potential Flood Resiliency Improvements	Notes from Meeting with Town 9/11/2014	Field Notes 10/30/14	Recommended Mitigation Strategy	Recommendation Notes	Planning-Level Cost Estimate ($)
W-1	N Fayston Road	High	" Stream & Road Modifications	Armored bank	Existing riprap is marginal in terms of size, though there are some areas of large rock. Excellent floodplain access on opposite bank.	Embankment Protection: rock slope	Grub, seed, and mulch	<$1,000
W-2	Meadow Road	Medium	G Roadway Raising	Road lowered to field level; works well during flood	Good example of low road overbank. Road surface slightly elevated above adjacent fields and side slope is relatively flat.	None	None	--
W-3	North Road	High	" Stream & Road Modifications		Road embankment is unstable; undermined toe; bank height is approx 8'H	Embankment Protection: rock slope	Place riprap to stabilize embankment	$26,000
W-4	North Road	High	# Bridge & Culvert Improvements; Roadway Lowering	Replaced with box culvert	New Box culvert with bed retention sills; Good sediment deposition/retention in culvert bed between retention sills; perch at outlet is 3 feet above a scour hole; culvert should have been recessed further. Inlet 5.5'H x 12'W; outlet from sill to roof 5.5' from bed to sill. Depth of outlet wing walls, partially exposed due to scour, could not be determined.	Embankment Protection: rock slope	Review constructed depth of outlet wing walls and place large riprap as necessary to address risk of undermining.	$5,000
W-5	North Road	High	" Stream & Road Modifications		No issue. Road embankment is stable	None	None	--
W-6	North Road	High	" Stream & Road Modifications	Deep culvert remove; may need to be restored	No slope issue; tall embankment is unsupported beneath 18 inch cross culvert outlet.	Streambed raising/armoring	Add rock to fill hole and support road embankment below culvert outlet	$5,000
W-7	North Road	High	" Stream & Road Modifications		No slope issue; stream not running parallel to road	None	None	--
W-8	North Road	High	# Bridge & Culvert Improvements; Roadway Lowering	No issues	Two 24" culverts. Not a perennial stream. Wetland above and below. Not an issue.	None	None	--
W-9	North Road	High	# Bridge & Culvert Improvements; Roadway Lowering	No issues	24 inch culvert; perennial stream; large flood storage area above culvert	None	None	--
W-10	North Road	High	" Stream & Road Modifications		Road embankment eroded on channel bend but toe is stable and mature vegetation is intact; fairly good floodplain access	None	Monitor	--
W-11	North Road	High	# Bridge & Culvert Improvements; Roadway Lowering		6 foot diameter steel boiler (no perch); estimated bankfull width is 12 feet (accurate field measurement not made due to property access); sediment deposition (aggradation) evident in channel above inlet	Larger culvert	Replace culvert (Low priority)	$125,000
W-12	North Road	High	# Bridge & Culvert Improvements; Roadway Lowering		24" culvert. Small wetland/stream channel above. Culvert causing geomorphic instability (sediment starved and incised downstream). Not a significant issue in terms of flood resiliency. Small culvert for perennial stream. Low debris jam potential due to willows upstream and not trees.	Larger culvert	Replace culvert (Low priority)	$68,000
W-13	North Road	High	G Roadway Raising	No issues	No issue - no need to raise road. Floodplain on west side of road is lower.	None	None	--
W-14	North Road	High	# Bridge & Culvert Improvements; Roadway Lowering		Pine Brook Covered Bridge: span 39.3', height - 8.6' from WS and 8.9' from bed. Bridge built in 1870. Has low left (looking downstream) overbank to serve as bleed-off during floods. Boundary markings in left overbank on downstream side suggests proposed development, which could block flood flows and put additional hydraulic pressure on bridge and raise risk of damage.	Road resilient to overtopping	Consider evaluating bridge hydraulics and limiting development in left overbank	$5,000
W-15	North Road	High	" Stream & Road Modifications	Debris issues	Deposition above undersized culvert - debris issue. Culvert is 6.5'W x 5'H CMP arch. Culvert perch is about 0.7'. Erosion visible in downstream channel for length of approx 60 feet, but not posing an imminent risk.	None	Monitor inlet for debris and proactively remove large down wood in close proximity to inlet. Monitor embankment erosion downstream of culvert and place riprap if necessary.	<$1,000
W-16	Tremblay Road	Medium	G Roadway Raising	Water goes on both sides of bridge. Road Foreman mention lowering road, but waterline present. More culverts under bridge approaches.	Roadway perpendicular to floodplain; not a candidate site for road raising. Road apparently washed out in TSI. Check with Road Foreman for details. Culverts under roadway approaches would be relatively small because of available cover and would likely provide insignificant hydraulic capacity.	None	None	--
W-17	Tremblay Road	Medium	" Stream & Road Modifications		No slope issue ; there is no stream that parallels road	None	None	--
W-18	Tremblay Road	Medium	# Bridge & Culvert Improvements; Roadway Lowering		24" HDPE. Perennial stream. Erosion around inlet (2 'back). Estimated BFW is 4-5'; sediment deposition (now vegetated) above inlet	Larger culvert	Monitor for sediment blockage at inlet. Replace culvert (Low priority)	$61,000

Site Number	Road	Road Importance	GIS-Based Category of Potential Flood Resiliency Improvements		Notes from Meeting with Town 9/11/2014	Field Notes 10/30/14	Recommended Mitigation Strategy	Recommendation Notes	Planning-Level Cost Estimate ($)
W-19	Verd-mont Road	Low	G	Roadway Raising		Road already elevated above floodplain (raised 1.5-2 feet on access road to trailer park). If road inundation is an ongoing problem (not aware that it is), additional raising could be beneficial to maintain access to approx 30 mobile homes. GIS analysis correctly identified this road as a candidate for raising.	Roadway raising	Investigate history of road inundation and evaluate cost-benefit of raising it.	$5,000
W-20	Trembley Road	Medium	G	Roadway Raising		It is not clear that this portion of the road is getting inundated by the Mad River. If it is, it's location if far enough removed from the river that it could be raised with insignificant downsides.	Roadway raising	Investigate history of road inundation and evaluate cost-benefit of raising it.	$5,000
W-21	Trembley Road	Medium	#	Bridge & Culvert Improvements; Roadway Lowering	Replaced	New CMP steel arch with 10 baffles. 12'W x 6' H.	None	None	--
W-22	Joslin Hill Road	High	!	Additional Cross Culverts	No issues	No issues, not a steep road	None	None	--
W-23	Joslin Hill Road	High	#	Bridge & Culvert Improvements; Roadway Lowering	No issues	Roadside ditch - no issue; 24" CMP	None	None	--
W-24	Bridge Street	High	#	Bridge & Culvert Improvements; Roadway Lowering		Covered Bridge - 1833 Village Bridge; GIS analysis identified this as an undersized structure due to missing data in the GIS database.	None	None	--
W-25	Bridge Street	High	G	Roadway Raising		Road is perpendicular to floodplain. Not a candidate for road raising.	None	None	--
W-26	Dana Hill Road	Low	"	Stream & Road Modifications	Not included in GIS analysis (should be "red site")	Small trib runs down right side of Dana Hill Road. Erosion/ incision above Mill Brook. Upper culvert 3.5'H x 5'W CMP arch; lower culvert 3.0' diameter boiler. There is risk that erosion below lower culvert will fail that culvert.	Streambed raising/armoring	Armor tributary channel bottom from Mill Brook to first culvert - will require ACOE permit	$10,000
W-27	Private Road	Low	G	Roadway Raising		Unclear precisely what GIS analysis identified. Road is perpendicular to floodplain and not a candidate for raising.	None	none	--
W-28	Lareau Road	Low	G	Roadway Raising	Raise?	Road is parallel to floodplain, but right on the edge of the river where overtopping can be expected and encouraged because of the significant floodplain storage beyond. High velocity over road could scour it. Route 100 is high in this location at beginning of road.	None	none	--
W-29	Kingsbury Road	Low	G	Roadway Raising		Road is already relatively high; no apparent benefit to raising it.	None	none	--
W-30	Butternut Hill Road	Low	G	Roadway Raising	Water crosses road. Needs to be looked at.	Water at meander in Mad River flows across road and returns to river at the downstream end of meander. Homes located on inside of meander. Butternut Hill Road higher at Route 100 side of bridge. Raising road would force more water into bridge opening and raise upstream flood elevations. Armoring road to reduce damage during overtopping and allow immediate road re-opening may be best approach. Requires more investigation.	Road resilient to overtopping	Investigate history of road overtopping and damage and evaluate cost-benefit of armoring it.	$5,000
W-31	East Warren Road	High	#	Bridge & Culvert Improvements; Roadway Lowering	No issues	6'H x 5.3'W CMP; BF ~ 14-17' . channel is over wide and aggrading. Culvert is free fall with 3' perch. Nice stream with ledge at structure. Not incised below crossing. Poor debris passage potential because of small culvert	Larger culvert	Replace culvert (Moderate priority)	$120,000
W-32	East Warren Road	High	#	Bridge & Culvert Improvements; Roadway Lowering	No issues	4' diameter CMP; Bankfull width approx 10'. Gravel accumulation upstream; minor erosion of headwall.	Larger culvert	Replace culvert (Low priority)	$90,000
W-33	East Warren Road	High	#	Bridge & Culvert Improvements; Roadway Lowering	No issues	24" HDPD; perennial; difficult to determine bankfull width due to cattle grazing on/in channel.	Larger culvert	Replace culvert (Low priority)	$69,000
W-34	East Warren Road	High	#	Bridge & Culvert Improvements; Roadway Lowering	No issues	24" HDPE; wetland above. Looks stable.	None	none	--
W-35	East Warren Road	High	#	Bridge & Culvert Improvements; Roadway Lowering	No issues	24" HDPE; small stream. Scour pool at downstream end. Bankfull width estimated at 4-5'.	Larger culvert	Replace culvert (Low priority)	$61,000

Fayston, Vermont

Mad River Valley Flood Resilient Transportation Study

Central Vermont Regional Planning Commission

4/10/15

Site Number	Road	Road Importance	GIS-Based Category of Potential Flood Resiliency Improvements	Notes from Meeting with Town 9/11/2014	Field Notes 10/30/14	Recommended Mitigation Strategy	Recommendation Notes	Planning-Level Cost Estimate ($)
F-1	N Fayston Road	High	" Stream & Road Modifications	Riprap done	Existing stacked stone wall; large boulders sitting on ledge. Repair is consistent with current flood resilient recommendations.	None	None	--
F-2	N Fayston Road	High	" Stream & Road Modifications	Riprap done	Existing riprapped bank with large rock (3 foot dia.) ; flow into bank; low floodplain on opposite site of brook; wide channel	Embankment Protection: rock slope	Grub, seed, and mulch	<$1,000
F-3	N Fayston Road	High	" Stream & Road Modifications	Riprap done	Existing riprapped bank with large rock (3 foot dia.)	Embankment Protection: rock slope	Grub, seed, and mulch	<$1,000
F-4	N Fayston Road	High	! Additional Cross Culverts	Box culvert	New 4' H x 7'W box culvert; culvert could be wider and deeper; would be better with bed retention sills; BF is 12 to 15 feet; head cut observed about 70 feet above new culvert which will contribute to bank erosion and debris/sediment production; stream is steep; no ditch noted nor need for additional cross culverts.	None	Monitor for debris and sediment at inlet	<$1,000
F-5	N Fayston Road	High	# Bridge & Culvert Improvements; Roadway Lowering	Footings undermined	Box culvert - 5'H x 4'W; wing walls with roof - road widening in 2001; scour hole downstream; recommend guardrail for safety (not flood resiliency); measured BF is 15- 17 feet.	Larger culvert	Replace culvert (Moderate priority)	$109,000
F-6	N Fayston Road	High	# Bridge & Culvert Improvements; Roadway Lowering	No issues	4' dia. CMP in good condition; undersized and potential for debris jams; floodplain available where debris can deposit upstream of culvert; good floodplain access; measured bankfull is 10-12'. Cascade at outfall with effective perch of 4'. Berm below structure on left bank.	Larger culvert	Replace culvert (low priority)	$95,000
F-7	Ctr Fayston Road	Mod.	# Bridge & Culvert Improvements; Roadway Lowering	Deep, hard to work on debris	30" dia. CMP (deformed and 1/3 blocked by sediment); measured bankfull is about 11 feet; nice step-pool bedform above structure. Structure is deep, which is more of an issue in terms of cleaning out debris than flood resiliency. Outlet of structure is perched 2.5 to 3' with an undercut right bank immediately downstream. There is no development within vicinity of structure. Concrete blocks failing at outlet; leakage at outlet. Height to road around 20 feet. Riprap on downstream side suggests repairs following previous overtopping events.	Larger culvert	Replace culvert (Moderate to High priority)	$95,000
F-8	Ctr Fayston Road	Mod.	# Bridge & Culvert Improvements; Roadway Lowering	Undersized	30"dia. bituminous coated CMP; when overtops flow would travel stream left down ditch in road; head cuts in both channels above culvert indicating elevated sediment load. Perch height about 2.5 feet; culvert bottom rusted; bankfull measured to be 7-8.5'.	Larger culvert	Replace culvert (Moderate priority)	$78,000
F-9	Ctr Fayston Road	Mod.	" Stream & Road Modifications	No issues	Erosion along embankment - length about 60 feet; 5 to 7' measured BF channel width; stream layer probably off at upstream end of site (not close to road); flow moderated by upstream pond.	Embankment Protection: toe wall	Riprap road embankment using stacked stone toe wall. Maintain existing grade control at downstream end.	$13,000
F-10	Crt Fayston Road	Mod.	! Additional Cross Culverts	Turnouts used	11 turnouts and 3 cross culverts; nice job with steep road	Roadway drainage improvements	Add one additional cross culvert above Town line	$5,000
F-11	Kew Vasseur Road	Mod.	! Additional Cross Culverts	No issues	No issues observed in area identified in GIS analysis, but there is a long, erosion-prone ditch in the upslope area that warrants attention.	Roadway drainage improvements	Add cross culvert and/or stone line ditch on west side	$10,000
F-12	Kew Vasseur Road	Mod.	! Additional Cross Culverts	Riprap ditch	Ditch needs to be stone lined; site extends to south of that shown on GIS layer (from culvert to height of land).	Roadway drainage improvements	Add stone in west ditch and add 2-3 cross culverts from W to E side.	$15,000
F-13	Kew Vasseur Road	Mod.	" Stream & Road Modifications	No issues	Stable ditch with some ledge on bottom; water sheets off west side of road; channel does not parallel road.	None	None	--
			! Additional Cross Culverts			None		--
F-14	Kew Vasseur Road	Mod.	! Additional Cross Culverts	Undersized	Cross culvert density appears adequate, though culverts appear undersized.	Roadway drainage improvements	Selective stone lining of ditch	$5,000
F-15	Tucker Hill Roadd	Low	G Roadway Raising	No issues	FEMA mapping is likely incorrect; no issues. The road is considerably elevated above channel	None	None	--
F-16	German Flats Road	High	" Stream & Road Modifications	No issues	Some erosion on left bank; stream is about 20 feet away from road; some leaning trees, but probably not eminent risk. Good floodplain access.	None	Monitor	<$1,000
F-17	German Flats Road	High	# Bridge & Culvert Improvements; Roadway Lowering		2' dia. CMP, measured bankfull width is about 4.5'; low gradient, small channel; good floodplain for trees to settle on. Perch is about 3.2 feet. Undersized, but perhaps low priority.	Larger culvert	Replace culvert (Low priority)	$70,000
F-18	German Flats Road	High	" Stream & Road Modifications	Riprap done	Big rock at toe of riprap	Embankment Protection: rock slope	Grub, seed, and mulch existing riprap to add additional resistance to erosion.	<$1,000
F-19	German Flats Road	High	# Bridge & Culvert Improvements; Roadway Lowering	Undersized	7.5' (W) x 8.8' (H) ; very steep riffle into structure. Velocity barrier to fish passage. Near Fayston Elementary School. Poor ability to pass debris.	Larger culvert	Replace culvert (Moderate priority)	$134,000

Site Number	Road	Road Importance	GIS-Based Category of Potential Flood Resiliency Improvements	Notes from Meeting with Town 9/11/2014	Field Notes 10/30/14	Recommended Mitigation Strategy	Recommendation Notes	Planning-Level Cost Estimate ($)
F-20	German Flats Road	High	# Bridge & Culvert Improvements; Roadway Lowering	Undersized	6' dia. Aluminum (looks new); 7.5' measured bankfull width	None	None	--
F-21	German Flats Road	High	" Stream & Road Modifications	Horseshoe Road culvert overtopped during TSI	Near Slide Brook Road. Evidence of erosion and riprap repair where overtopping water returned to brook.	Larger culvert	Replace culvert (Moderate priority)	$103,000
F-22	German Flats Road	High	" Stream & Road Modifications	Horseshoe Road culvert overtopped during TSI	Near Horseshoe Road. Ledge in channel bottom prevents incision and keeps German Flats Rd embankment relatively stable. Evidence that culvert under Horseshoe Rd has overtopped and eroded the embankment as it returns to the channel.	Larger culvert	Replace culvert (on Horseshoe Rd, Low priority)	$78,000

MITIGATION CATEGORIES

Additional Cross Culverts	!
Stream & Road Modifications	"
Bridge & Culvert Improvements; Roadway Lowering	#
Roadway Raising	G

COST ESTIMATE NOTES

Culvert Replacement Cost

Replacement culvert costs assume the following

1. Assumes corrugated aluminum pipe arch (typically most cost-effective way to get a natural bottom that spans the channel and provides adequate headspace for debris)
2. Span equal to larger of measured bankfull width or bankful width from regional curve
3. Length of culvert is 65 feet (adequate for typical 2-lane road installations)
4. Cost is the summation of

   A. Culvert delivered to site. Depends on span. Using historical pricing from from Contech, the delivered cost can be approximated as $/LF = 33*span+27.5.

   B. $5,000 allowance culvert assembly, based on 2014 bid prices

   C. Installation including the myriad of associated items from excavation to guardrail. Install cost variable based on recent projects: $48k for 12' arch, adjusted downward ($35k for 6') and upward ($61k for 18') based on prof judgement.

   D. 25% add-on for engineering and permitting

   E. Round to nearest thousand

Slope Riprap

Cost per linear foot based on bid tabulations for post-Irene projects in Central Vermont. Assumes 4' blanket thickness, keyed in toe, 1.5:1 angle. Price per cubic yard ranged roughly from $50 to $80. Contract price typically toward low end.

Bank Ht (ft)	@ $50 /CY	@ $80 /CY	Mean ($65/CY)
5	$100	$160	$130
10	$160	$250	$205
15	$210	$340	$275
20	$270	$430	$350

Use mean bid price for corresponding bank height is documented. If bank height NOT documented, assume 15' ($275/LF).

Add allowance for eng and permitting of $5k min up to $10k for complex sites, based on professional judgement and experience.

Round to nearest thousand

Cross Culverts

Use $5k per installation, which is roughly 70/LF for a typical site.

Other measures

Based on professional judgement and past experience.

Misc

Costs are intended to reflect market prices. Small projects may be constructable by Town crews for lower cost.