TABLE OF CONTENTS

1.0 Introduction ............................................................................................................................ 2

2.0 Strategies to Improve Flood Resiliency of Roadways............................................................ 2

   2.1 Strategy 1. Relocate Road .................................................................................................. 3
   2.2 Strategy 2. Raise Road........................................................................................................ 3
   2.3 Strategy 3. Protect Road Embankment – Standard Riprap Slope .................................. 3
   2.4 Strategy 4. Protect Road Embankment – Stacked Stone Toe Wall ............................... 3
   2.5 Strategy 5. Raise and Protect Streambed ........................................................................ 4
   2.6 Strategy 6. Larger Culvert or Bridge .............................................................................. 4
   2.7 Strategy 7. Protect Road for Overtopping ....................................................................... 4
   2.8 Strategy 8. Create Low Point in Culvert/Bridge Approach ........................................... 4
   2.9 Strategy 9. Drainage Improvements ............................................................................... 5

3.0 Guidance Flowcharts for Selecting Flood Resiliency Strategies.......................................... 5

4.0 GIS-Based Screening to Identify Roadway Segments Vulnerable to Flood Damage ............. 5

5.0 Field Investigation of Potentially Vulnerable Sites ................................................................ 6

ATTACHMENTS

   A. Conceptual Sketches of Strategies to Improve Flood Resiliency of Roadways
   B. Guidance Flowcharts for Selecting Flood Resiliency Strategies
   C. GIS-Based Screening Documentation (CVRPC)
   D. Maps and Tables for Waitsfield, Warren, and Fayston
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 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 degradation.

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 cases 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
STRATEGY 2: RAISE ROAD

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

Existing road with history of flooding

Raise road to reduce frequency of flooding

Valley wall

Existing road elevation

Valley wall

Channel

Floodplain

General Notes:
STRATEGY 3: PROTECT ROAD EMBANKMENT - STANDARD RIPRAP SLOPE

Road

Plant trees on upper slope

Small riprap on upper slope. Typically V Trans Type II.

Large riprap on lower slope. Typically V Trans Type IV or larger.

1.5 (min) 1.0

9" grubbing, seed, and mulch

Maintain natural channel width

4' Scour Key

rev1
STRATEGY 4: PROTECT ROAD EMBANKMENT — STACKED STONE TOE WALL

- Plant trees on upper slope

- Smaller riprap on upper slope, Typically VTrans Type II

- Large riprap on lower slope, Typically VTrans Type IV

- Large rocks suitable for stacking, Typically 5'-6" middle dimension with no dimension less than 3'

- 6' max reveal

- Avoided river encroachment

- 4' Scour Key

- 9" grubbing, seed, and mulch
STRATEGY 5: RAISE AND PROTECT STREAMBED

Existing roadway embankment to remain in place

Restored natural channel width

Large well graded riprap used to raise channel bottom. Typically Travis Type IV or bigger.

Channel narrowed by roadway embankment
STRATEGY 6: LARGER CULVERT OR BRIDGE

New larger culvert or bridge

Existing culvert or bridge narrower than natural channel

Improved vertical clearance for debris

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
STRATEGY 7: PROTECT ROAD FOR OVERTOPPING

- Water over road during flood
- Add riprap on downstream road embankment
- 9" loam, seed, mulch
- Extend riprap 6' under roadway

Flow
STRATEGY B: LOW POINT IN CULVERT/BRIDGE APPROACH

Existing road with low point close to culvert

Existing culvert

New roadway. Low point located away from culvert or bridge.
STRATEGY 9: DRAINAGE IMPROVEMENTS

General

Slope

of

the

land

Existing cross culvert

location of road flooding or

ditch erosion

Strategy 9a

Additional Cross culvert

Strategy 9a

Additional ditch turnout

Strategy 9b

Stone-lime ditch

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.
Attachment B

Guidance Flowcharts for Selecting Flood Resiliency Strategies
Strategy Selection Flowcharts for Flood Resiliency

Setting/Type of Flood Resiliency Issue

Is road parallel to stream channel

Yes
Use Strategy Flowchart 1/3

No

Is road perpendicular to stream channel (typically a bridge or culvert)

Yes
Use Strategy Flowchart 2/3

No

Is it a drainage issue (i.e., no stream, just local runoff)

Yes
Use Strategy Flowchart 3/3

No
May be an unusual situation. Consult river or drainage engineer.
Road Parallels Stream Channel

Is channel close enough to road to pose a risk? (Q1)

- Yes
  - Can road be moved? (Q2)
    - Yes
      - Strategy 1 Relocate Roadway
    - No
      - No further action
  - No
    - Is it a flooding issue or an erosion issue? (Q3)
      - Flooding
        - Strategy 2 Raise Roadway
      - Erosion
        - Will standard slope protection work? (Q4)
          - Yes
            - Strategy 3 Protect Embankment: rock slope
          - No
            - Seek assistance from river scientist or engineer

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.
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.
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 VTran 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/VTran 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. Intersect 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 convert 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 the following equation \( W_{bf} = 13.1 \times \text{Drainage Area (in sq miles)}^{0.44} \)
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
CVRPC
Mad River Valley
Flood Resilient
Transportation Study

Flood Resiliency Sites
Warren, Vermont

Legend

- Study Site
- 6.7.8. Improve Bridges & Culverts, Roadway Lowering
- 1.3.4.5. Stream & Road Modifications
- 2. Roadway Raising
- 9. Install Additional Cross Culverts

Roads by Importance

- Medium
- High
- Road
- Surface Water
- Town Boundary

Legend

- Study Site
- 6.7.8. Improve Bridges & Culverts, Roadway Lowering
- 1.3.4.5. Stream & Road Modifications
- 2. Roadway Raising
- 9. Install Additional Cross Culverts

Strategies:
1. Roadway relocation to eliminate fluvial erosion risks.
2. Roadway raising to reduce frequency of overtopping.
3. Modified stone fill specifications designed to ensure use of rock more flood resilient than typical VTrans varieties provide.
4. Where roads parallel river channels, stacked stone toe walls that provide additional needed channel width to reduce erosive forces.
5. Streambed raising and in some cases armorling to prevent repeated undermining of roadway embankment.
6. Replacement of numerous bridges and culverts with appropriately-sized openings.
7. Where roads cross floodplains, flattened and armored roadway embankment slopes designed to overtop without damage.
8. Sacrificial bridge approaches designed to overtop and fail before the bridge fails, thereby saving the structure.
9. Installation of additional cross culverts and ditch turnouts on steep roads to reduce collection and concentrated conveyance of excessive quantity of stormwater.

Background is World Imagery.
CVRPC
Mad River Valley
Flood Resilient Transportation Study

Strategies:
1. Roadway relocation to eliminate fluvial erosion risks.
2. Roadway raising to reduce frequency of overtopping.
3. Modified stone fill specifications designed to ensure use of rock more flood resilient than typical VTrans varieties provide.
4. Where roads parallel river channels, stacked stone toe walls that provide additional needed channel width to reduce erosive forces.
5. Streambed lowering and in some cases armoring to prevent repeated undermining of roadway embankment.
6. Replacement of numerous bridges and culverts with appropriately-sized openings.
7. Where roads cross floodplains, flattened and armored roadway embankment slopes designed to overtop without damage.
8. Sacrificial bridge approaches designed to overtop and fail before the bridge fails, thereby saving the structure.
9. Installation of additional cross culverts and ditch turnouts on steep roads to reduce collection and concentrated conveyance of excessive quantity of stormwater.

Legend
- Study Site
- 6.7.8. Improve Bridges & Culverts, Roadway Lowering
- 1.3.4.5. Stream & Road Modifications
- 2. Roadway Raising
- 9. Install Additional Cross Culverts

Roads by Importance
- Medium
- High
- Surface Water

Background is World Imagery.

Flood Resiliency Sites
Waitsfield, Vermont
Strategies:
1. Roadway relocation to eliminate fluvial erosion risks.
2. Roadway raising to reduce frequency of overtopping.
3. Modified stone fill specifications designed to ensure use of rock more flood resilient than typical VTrans varieties provide.
4. Where roads parallel river channels, stacked stone toe walls that provide additional needed channel width to reduce erosive forces.
5. Streambed raising and in some cases arming to prevent repeated undermining of roadway embankment.
6. Replacement of numerous bridges and culverts with appropriately-sized openings. Where roads cross floodplains, flattened and armored roadway embankment slopes designed to overtop without damage.
7. Sacrificial bridge approaches designed to overtop and fail before the bridge fails, thereby saving the structure.
8. Installation of additional cross culverts and ditch turnouts on steep roads to reduce collection and concentrated conveyance of excessive quantity of stormwater.
<table>
<thead>
<tr>
<th>Site Number</th>
<th>Road</th>
<th>Roadside Importance</th>
<th>Off-Road Category of Potential Flood Resilience Improvements</th>
<th>Notes from Meeting with Town 9/11/2014</th>
<th>Field Notes 10/30/14</th>
<th>Recommended Mitigation Strategy</th>
<th>Recommendation Notes</th>
<th>Planning Level Cost Estimate [$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-2</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
<td>Replace culvert (High priority)</td>
<td>--</td>
<td>35,000</td>
</tr>
<tr>
<td>N-5</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
<td>Replace culvert (Moderate priority)</td>
<td>--</td>
<td>35,000</td>
</tr>
<tr>
<td>N-6</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
<td>Replace culvert (Low priority)</td>
<td>--</td>
<td>35,000</td>
</tr>
<tr>
<td>N-7</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<tr>
<td>N-8</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<tr>
<td>N-9</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<tr>
<td>N-10</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<tr>
<td>N-11</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<td>N-12</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
<td>--</td>
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<tr>
<td>N-13</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<td>N-14</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<td>N-15</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<td>N-16</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<td>N-17</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<td>N-18</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
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<td>N-19</td>
<td>Lincoln Gap Road</td>
<td>Low</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Lowering</td>
<td>None</td>
<td>--</td>
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<tr>
<td>Site Number</td>
<td>Road</td>
<td>Road Importance</td>
<td>GIS-Based Category of Potential Flood Resiliency Improvements</td>
<td>Notes from Meeting with Town 9/11/2014</td>
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<tr>
<td>N-21</td>
<td>E. Warren Road</td>
<td>High</td>
<td><strong>Bridge &amp; Culvert Improvements; Roadway Lowering</strong></td>
<td>No issues</td>
<td>Culvert on E. Warren Road near Galloping Wind Trail. 58' (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.</td>
<td>Larger culvert</td>
<td>Monitor for wood and sediment accumulation and blockage following major storms.</td>
<td>$101,000</td>
</tr>
<tr>
<td>N-22</td>
<td>Roxbury Mt. Road</td>
<td>High</td>
<td><strong>Additional Cross Culverts</strong></td>
<td>Cross culverts would cause more problems</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-23</td>
<td>Roxbury Mt. Road</td>
<td>High</td>
<td><strong>Additional Cross Culverts</strong></td>
<td>No issues</td>
<td>Flood box culvert</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-24</td>
<td>Pluvinton Road</td>
<td>High</td>
<td><strong>Bridge &amp; Culvert Improvements; Roadway Lowering</strong></td>
<td>No issues</td>
<td>4' diameter CMP (seawall above). No issues.</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-25</td>
<td>Pluvinton Road</td>
<td>High</td>
<td><strong>Stream &amp; Road Modifications</strong></td>
<td>No issues</td>
<td>No issues</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-26</td>
<td>Brook Road</td>
<td>High</td>
<td><strong>Stream &amp; Road Modifications</strong></td>
<td>No issues</td>
<td>Riprap added</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-27</td>
<td>Mill Road</td>
<td>Low</td>
<td>Roadway Raising</td>
<td>Raising road to solid put covered bridge at risk; also a stream and road modification site (on Covered Bridge Road)</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-28</td>
<td>Brook Road</td>
<td>High</td>
<td>Roadway Raising</td>
<td>Halo 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.</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-29</td>
<td>Brook Road</td>
<td>High</td>
<td>Roadway Raising</td>
<td>None</td>
<td>Road is already high.</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-29</td>
<td>Brook Road</td>
<td>High</td>
<td><strong>Stream &amp; Road Modifications</strong></td>
<td>No issues</td>
<td>Riprap added</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-30</td>
<td>W Hill Road</td>
<td>Medium</td>
<td><strong>Additional Cross Culverts</strong></td>
<td>Added 16 new culverts</td>
<td></td>
<td>None</td>
<td>Establish grass cover or place stone in newly graded ditch at downstream end.</td>
<td>$1,000</td>
</tr>
<tr>
<td>N-31</td>
<td>TH-12</td>
<td>Low</td>
<td><strong>Additional Cross Culverts</strong></td>
<td>Not enough culverts</td>
<td></td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-32</td>
<td>Sugarbush Access Road</td>
<td>High</td>
<td><strong>Bridge &amp; Culvert Improvements; Roadway Lowering</strong></td>
<td>As-- TH-12 culvert is located inside a larger older CMP. Measured bankfull width is about 7 feet. Site 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.</td>
<td></td>
<td>Embankment Protection: Rock slope</td>
<td>Grub, seed, and mulch existing riprap to add additional resistance to erosion.</td>
<td>$1,000</td>
</tr>
<tr>
<td>N-33</td>
<td>Sugarbush Access Road</td>
<td>High</td>
<td><strong>Stream &amp; Road Modifications</strong></td>
<td>No issues</td>
<td>No issues</td>
<td>None</td>
<td>Monitor road embankment and address stream/riparian erosion issues as needed.</td>
<td>$1,000</td>
</tr>
<tr>
<td>N-34</td>
<td>Sugarbush Access Road</td>
<td>High</td>
<td><strong>Additional Cross Culverts</strong></td>
<td>Water generally flows away from road. The ditch is stone-lined. No issues.</td>
<td></td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>N-35</td>
<td>Sugarbush Access Road/Steward Road</td>
<td>High</td>
<td><strong>Roadway Raising</strong></td>
<td>No issues</td>
<td>Sugarbush Access Road is already raised. Houses on Steward Road are lower than the road ditch; so raising Steward would increase flood risk to homes.</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>N-36</td>
<td>Volkstuch Road</td>
<td>Low</td>
<td><strong>Roadway Raising</strong></td>
<td>Road raising would help</td>
<td>Road is using rocky road and seems adequate to Mid-20s. Could raise the road to reduce frequency of inundation and maintain access to residences further upstream, but would lose a little flood storage.</td>
<td>None</td>
<td>None</td>
<td>$1,000</td>
</tr>
</tbody>
</table>
## Roadway Condition

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Road</th>
<th>Importance</th>
<th>GIS-Based Category of Potential Risk</th>
<th>Flood Resiliency Improvement</th>
<th>Notes from Meeting with Town 9/1/11/2016</th>
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<th>Planning-Level Cost Estimate ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-1</td>
<td>H Fayston Road</td>
<td>High</td>
<td>Stream &amp; Road Modifications</td>
<td>Armored bank</td>
<td>Erosion riprap is marginal in terms of use, though there are some areas of large rock. Excellent floodplain access on opposite bank. Embankment Protection: rock slope</td>
<td>Grub, seed, and mulch</td>
<td>None</td>
<td>None</td>
<td>&lt;$1,000</td>
</tr>
<tr>
<td>W-2</td>
<td>Meadowl Road</td>
<td>Medium</td>
<td>Roadway Raising</td>
<td>Roadway lowered to field level; works well during flood</td>
<td>Good example of low road overbank. Road surface slightly elevated above adjacent fields and side slope is relatively flat.</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
</tr>
<tr>
<td>W-3</td>
<td>North Road</td>
<td>High</td>
<td>Stream &amp; Road Modifications</td>
<td>Road embankment is unstable, undermined toe; bank height is approx 8 H</td>
<td>Embankment Protection: rock slope</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>$55,000</td>
</tr>
<tr>
<td>W-4</td>
<td>North Road</td>
<td>High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>Replaced with box culvert</td>
<td>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 area walls, partially exposed due to scour, could not be determined.</td>
<td>Embankment Protection: rock slope</td>
<td>None</td>
<td>None</td>
<td>$5,000</td>
</tr>
<tr>
<td>W-5</td>
<td>North Road</td>
<td>High</td>
<td>Stream &amp; Road Modifications</td>
<td>No issue - Road embankment is stable</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>W-6</td>
<td>North Road</td>
<td>High</td>
<td>Stream &amp; Road Modifications</td>
<td>No slope issue; stream not running parallel to road</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>W-7</td>
<td>North Road</td>
<td>High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>No issues</td>
<td>Has 24&quot; culverts. Not a perennial stream. Wetland above and below. Not an issue.</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
</tr>
<tr>
<td>W-8</td>
<td>North Road</td>
<td>High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>No issues</td>
<td>Has 4&quot; culvert, perennial stream, large flood storage area above culvert</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
</tr>
<tr>
<td>W-9</td>
<td>North Road</td>
<td>High</td>
<td>Stream &amp; Road Modifications</td>
<td>Road embankment eroded on channel side toe is stable and mature vegetation is intact; lofty good floodplain access.</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
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<tr>
<td>W-10</td>
<td>North Road</td>
<td>High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>No issues</td>
<td>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</td>
<td>Replace culvert (Low priority)</td>
<td>$125,000</td>
<td></td>
<td></td>
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<tr>
<td>W-11</td>
<td>North Road</td>
<td>High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>24&quot; 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 streams. Low debris jam potential due to shallows upstream and not trees. Larger culvert</td>
<td>Replace culvert (Low priority)</td>
<td>$68,000</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>W-12</td>
<td>North Road</td>
<td>High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>No issues</td>
<td>No issue. Roadway perpendicular to floodplain; not a candidate site for road raising. Road appears washed out in TS. Consider also involving bridge hydraulic and riprap development in left overbank.</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
</tr>
<tr>
<td>W-13</td>
<td>North Road</td>
<td>High</td>
<td>Roadway Raising</td>
<td>No issues</td>
<td>No issue - Roadway perpendicular to floodplain; not a candidate site for road raising. Road apparently washed out in TS. 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.</td>
<td>Monitor inlet for debris and proactively remove large downed wood in close proximity to inlet. Monitor embankment erosion downstream of culvert and place riprap if necessary.</td>
<td>$9,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-14</td>
<td>North Road</td>
<td>High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>Debris issues</td>
<td>Deposition above underdrain culvert - debris issue. Culvert is 6.5' H x 5'7&quot; CMP arch. Culvert pitch is about 0.7'. Erosion visible in downstream channel for length of approx 60 feet, but not posing an imminent risk.</td>
<td>None</td>
<td>Monitor inlet for debris and proactively remove large downed wood in close proximity to inlet. Monitor embankment erosion downstream of culvert and place riprap if necessary.</td>
<td>&lt;$2,000</td>
<td></td>
</tr>
<tr>
<td>W-25</td>
<td>Tremblay Road</td>
<td>Medium</td>
<td>Roadway Raising</td>
<td>Roadway perpendicular to floodplain; not a candidate site for road raising. Road apparently washed out in TS. 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.</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>W-26</td>
<td>Tremblay Road</td>
<td>Medium</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>No slope issue; there is no stream that parallels road</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>W-27</td>
<td>Tremblay Road</td>
<td>Medium</td>
<td>Stream &amp; Road Modifications</td>
<td>No slope issue; there is no stream that parallels road</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>W-28</td>
<td>Tremblay Road</td>
<td>Medium</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>24&quot; HDPE. Perennial stream. Swoow around inlet (2' back). Estimated BFW is 4-3'; sediment deposition (new vegetated) above inlet</td>
<td>Larger culvert</td>
<td>Monitor for sediment blockage at inlet. Replace culvert (Low priority)</td>
<td>$61,000</td>
<td></td>
<td></td>
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<tr>
<td>Site Number</td>
<td>Road</td>
<td>Road Importance</td>
<td>GIS-Based Category of Potential Flood-Resiliency Improvements</td>
<td>Notes from Meeting with Town 9/11/2014</td>
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<td>----------------------</td>
<td>----------------------------------</td>
<td></td>
</tr>
<tr>
<td>W-15</td>
<td>Westmore Road</td>
<td>Low</td>
<td>G</td>
<td>Roadway Raising</td>
<td>Road already elevated above floodplain (raised 1.5-2.5 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.</td>
<td>Roadway raising</td>
<td>Investigate history of road inundation and evaluate cost-benefit of raising it.</td>
<td>$3,000</td>
<td></td>
</tr>
<tr>
<td>W-20</td>
<td>Trembley Road</td>
<td>Medium</td>
<td>G</td>
<td>Roadway Raising</td>
<td>No issues</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-21</td>
<td>Trembley Road</td>
<td>Medium</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Replaced 24&quot; CMP sheet with 10 bottles, 12&quot; W x 8&quot; H</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-22</td>
<td>Jozlin Hill Road</td>
<td>High</td>
<td>!</td>
<td>Additional Cross Culverts</td>
<td>No issues</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-23</td>
<td>Reklaw Hill Road</td>
<td>High</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>No issues</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-24</td>
<td>Bridge Street</td>
<td>High</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>Replaced Bridge. 1833 Village Bridge. GIS analysis identified this as an undersized structure due to missing data in the GIS database.</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-25</td>
<td>Bridge Street</td>
<td>High</td>
<td>Roadway Raising</td>
<td>Road is perpendicular to floodplain. Not a candidate for road raising.</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-26</td>
<td>Dana Hill Road</td>
<td>Low</td>
<td>G</td>
<td>Stream &amp; Road Modifications</td>
<td>Not included in GIS analysis (should be &quot;red tape&quot;).</td>
<td>Small trib runs down right side of Dana Hill Road. Erosion/erosion above Mill Brook. Upper culvert 3.5' x 5' CMP arch. Lower culvert 3.0' diameter boiler. There is risk that erosion below lower culvert will fail that culvert. Streambed raising/armoring</td>
<td>Armour tributary channel bottom from Mill Brook to first culvert - will require ACOE permit</td>
<td>$10,000</td>
<td></td>
</tr>
<tr>
<td>W-27</td>
<td>Private Road</td>
<td>Low</td>
<td>G</td>
<td>Roadway Lowering</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-28</td>
<td>Burrell Road</td>
<td>Low</td>
<td>G</td>
<td>Roadway Lowering</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-29</td>
<td>Kingsbury Road</td>
<td>Low</td>
<td>G</td>
<td>Roadway Lowering</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-30</td>
<td>Adirondack Hill Road</td>
<td>Low</td>
<td>G</td>
<td>Roadway Lowering</td>
<td>Watercross road. Needs to be looked at.</td>
<td>Water at inundator in Mill 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 reopening may be best approach. Requires more investigation.</td>
<td>Road resident to overtopping</td>
<td>Investigate history of road overtopping and damage and evaluate cost-benefit of armoring it.</td>
<td>$3,000</td>
</tr>
<tr>
<td>W-31</td>
<td>East Warren Road</td>
<td>High</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>No issues</td>
<td>Larger culvert Replace culvert (Moderate priority)</td>
<td>$12,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-32</td>
<td>East Warren Road</td>
<td>High</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>No issues</td>
<td>Larger culvert Replace culvert (Low priority)</td>
<td>$50,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-33</td>
<td>East Warren Road</td>
<td>High</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>No issues</td>
<td>Larger culvert Replace culvert (Low priority)</td>
<td>$105,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-34</td>
<td>East Warren Road</td>
<td>High</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>No issues</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-35</td>
<td>East Warren Road</td>
<td>High</td>
<td>#</td>
<td>Bridge &amp; Culvert Improvements; Roadway Lowering</td>
<td>No issues</td>
<td>Larger culvert Replace culvert (Low priority)</td>
<td>$95,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Site Number** | **Road** | **Road Importance** | **GIS-Based Category of Potential Flood Resilience Improvements** | **Notes from Meeting with Town 9/11/2014** | **Field Notes 10/30/14** | **Recommended Mitigation Strategy** | **Recommendation Notes** | **Planning-Level Cost Estimate ($)**
--- | --- | --- | --- | --- | --- | --- | --- | ---
F-1 | F-3 Fayston Road | High | Stream & Road Modifications | Riprap drive | Existing stacked stone wall; large boulders sitting on ledge. Repair is consistent with current flood resilient recommendations. | None | None | –
F-2 | F-4 Fayston Road | High | Stream & Road Modifications | Riprap drive | Existing riprapped bank with large rock (1 foot dia.), flow into bank, low floodplain on opposite side of brook; wide channel | Embankment Protection: rock slope | Grub, seed, and mulch | <$4,000
F-3 | F-4 Fayston Road | High | Stream & Road Modifications | Riprap drive | Existing riprapped bank with large rock (1 foot dia.) | Embankment Protection: rock slope | Grub, seed, and mulch | <$4,000
F-4 | F-7 Fayston Road | High | Additional Cross Culverts | Box culvert | New 4’ 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 sediments/debris production; stream is steep; no ditch noted nor need for additional cross culverts. | None | None | <$5,000
F-5 | F-9 Fayston Road | High | Bridge & Culvert Improvements; Roadway Lowering | Erosion undermined | Box culvert - 4’ x 4’W, wing walls with roof - road widening in 2001; scour hole downstream; recommend gravel for safety (not flood resilience); measured BF is 15-17 feet. | Larger culvert | Replace culvert (Moderate priority) | $109,000
F-6 | F-11 Fayston Road | High | Bridge & Culvert Improvements; Roadway Lowering | No issues | 4' dia. CASP in good condition, undermined and potential for debris jets; floodplain available where debris can deposit upstream of culvert; good floodplain access; measured bankfull is 10-12’. | Larger culvert | Replace culvert (low priority) | <$9,000
F-7 | F-13 Fayston Road | Mid | Bridge & Culvert Improvements; Roadway Lowering | Deep, hard to work on debris | 30” dia. CMP (deteriorated and 1/3 blocked by sediment); measured bankfull is about 14 feet; nice step pool bedform above structure. Structure is deep, which is more of an issue in terms of clearing out debris than flood resilience. Outlet of structure is perched 2.5 to 3 with an undercut right bank indirectly 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) | <$9,000
F-8 | F-15 Fayston Road | Mid | Bridge & Culvert Improvements; Roadway Lowering | Understood | 24” dia. slotted concrete culvert; 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 7.6’. | Larger culvert | Replace culvert (Moderate priority) | <$79,000
F-9 | F-13 Fayston Road | Mid | Stream & Road Modifications | No issues | Channel along embankment - length about 60 feet; is - 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 slotted stone toe wall. Maintain existing grade control at downstream end. | $13,000
F-10 | F-15 Fayston Road | Mid | Additional Cross Culverts | None used | As terraced stone edge; cross-cuts; not job with spring road | Roadway drainage improvements | Add one additional cross culvert above town line | $5,000
F-11 | N Vassour Road | Mid | Additional Cross Culverts | No issues | No issues observed in area identified in GIS analysis, but there is a long, apron-trough ditch in the upgradient area that warrants attention. | Roadway drainage improvements | Add cross culvert and/or stone fix ditch in west side | $10,000
F-12 | N Vassour Road | Mid | Additional Cross Culverts | Riprap ditch | Ditch needs to be stone lined; side 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. | $10,000
F-13 | N Vassour Road | Mid | Stream & Road Modifications | No issues | Channel with stone ridge on bottom; water sheets off west side of road; channel does not parallel road. | None | None | –
F-14 | N Vassour Road | Mid | Additional Cross Culverts | Understood | Grub, seed, and mulch existing riprap to add additional resistance to erosion | Roadway drainage improvements | Selective stone lining of ditch | $5,000
F-15 | Tucker Hill Road | Low | Roadway Raising | No issues | FEM 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 | Stream crested on left bank; stream is about 20 feet away from road, some-leafing trees, but probably not erodible risk. Good floodplain access. | None | Monitor | <$1,000
F-17 | German Flats Road | High | Bridge & Culvert Improvements; Roadway Lowering | Erosion undermined | 4’ dia. CASP - measured bankfull width is about 4.5’; low gradient, small channel; good floodplain for trees to settle on. Perch is about 3.2 feet. Understeeped, but perhaps low priority. | Larger culvert | Replace culvert (low priority) | <$10,000
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 | Understood | -1.5’ (W) x 1.8’ (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) | $165,000
<table>
<thead>
<tr>
<th>Site Number</th>
<th>Road</th>
<th>Road Importance</th>
<th>GIS-Based Category of Potential Flood Resiliency Improvements</th>
<th>Notes from Meeting with Town 9/11/2014</th>
<th>Field Notes 10/30/14</th>
<th>Recommended Mitigation Strategy</th>
<th>Recommendation Notes</th>
<th>Planning-Level Cost Estimate ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-20</td>
<td>German Flats Road High</td>
<td>Bridge &amp; Culvert Improvements, Roadway Lowering</td>
<td>Undersized 6&quot; dia. Aluminum (looks new), 7.5' measured bankfull width</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>--</td>
</tr>
<tr>
<td>F-21</td>
<td>German Flats Road High</td>
<td>Stream &amp; Road Modifications</td>
<td>Horseshoe Road culvert overtopped during TSI near slide brook Road. Evidence of erosion and riprap repair where overtopping water returned to brook.</td>
<td>Larger culvert</td>
<td>Replace culvert (on Horseshoe Rd, Low priority)</td>
<td>Larger culvert</td>
<td>Replace culvert (on Horseshoe Rd, Low priority)</td>
<td>$103,000</td>
</tr>
<tr>
<td>F-22</td>
<td>German Flats Road High</td>
<td>Stream &amp; Road Modifications</td>
<td>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.</td>
<td>Larger culvert</td>
<td>Replace culvert (on Horseshoe Rd, Low priority)</td>
<td>Larger culvert</td>
<td>Replace culvert (on Horseshoe Rd, Low priority)</td>
<td>$78,000</td>
</tr>
</tbody>
</table>
MITIGATION CATEGORIES

- Additional Cross Culverts
- Stream & Road Modifications
- Bridge & Culvert Improvements;
  Roadway Lowering
- Roadway Raising
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 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.

<table>
<thead>
<tr>
<th>Bank Ht (ft)</th>
<th>@ $50/CY</th>
<th>@ $80/CY</th>
<th>Mean ($65/CY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>$100</td>
<td>$160</td>
<td>$130</td>
</tr>
<tr>
<td>10</td>
<td>$160</td>
<td>$250</td>
<td>$205</td>
</tr>
<tr>
<td>15</td>
<td>$210</td>
<td>$340</td>
<td>$275</td>
</tr>
<tr>
<td>20</td>
<td>$270</td>
<td>$430</td>
<td>$350</td>
</tr>
</tbody>
</table>

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.