The Vermont Culvert Geomorphic Compatibility Screening Tool

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1.0 Introduction

The Vermont DEC River Management Program, Department of Fish and Wildlife, and others have collected stream crossing structure data across Vermont streams using the Bridge and Culvert Assessment (Appendix A) in the Vermont Stream Geomorphic Assessment (VTANR, 2007). Currently the publicly accessible database contains information on approximately 1,700 culverts that can be queried for reports containing Culvert Failure Modes - Geomorphic Incompatibility and Problem Causes. The existing reports are useful for qualitatively describing potential incompatibilities and problems with a structure, yet lack a method of screening structures to rank geomorphic incompatibility. This project consisted of creating a new *Vermont Culvert Geomorphic Compatibility Screening Tool* that will be added to the current reporting in the database. This screening score can be included in the existing culvert output reports and conveniently viewed on a GIS map. A close inspection of the existing database queries during this project revealed several minor errors that require correction (Appendix B).

The screening tool was developed based on a review and analysis of the scientific literature of important processes at crossing structures, existing culvert screening tools that largely focus on aquatic organism passage, existing design guidelines, and the previously collected Vermont culvert data. Due to the lack of culvert screening tools that attempt to quantify geomorphic incompatibility, professional judgment was required to make decisions on which variables to include and how to score each. In the end, a consensus was reached on a protocol to begin to quantify the compatibility between culverts and streams. The *Vermont Culvert Geomorphic Compatibility Screening Tool* presented here will certainly evolve over time as more data is collected and in particular the scoring of failed and optimal structures is tracked.

The screening tool has been developed based on the disruption of natural sediment/debris transport, hydrology, and deviation from natural channel dimensions. For example, identification and a qualitative description of excessive upstream aggradation and downstream channel incision during an assessment are used as a measure of the presence and degree of sediment discontinuity. A structure's deviation from the natural channel width, slope, and alignment indicates departure from natural stream conditions.

The five variables (i.e., percent bankfull width, sediment and debris continuity, slope, approach angle, and bank erosion) are each scored on a scale from 0 to 5, with 5 indicating full geomorphic compatibility between the structure and the channel and 0 indicating complete incompatible due to a strong departure from a natural condition. Some variables (i.e., slope and approach angle) do not have scores for each level of the 0 to 5 range due to limited possible values in the assessment. In these cases, the range of conditions was reviewed and the most appropriate scores were selected to describe the condition represented by the variable. The score for all variables is summed, out of a total possible score of 25, to represent an overall score indicating the level of geomorphic compatibility between the structure and stream.

Field verification is recommended prior to making management decisions for culverts based on the results of the screening tool. In addition, tracking failed and properly functioning culverts and reviewing the geomorphic compatibility identified in the screen tool will support future management decisions and allow for informed updates of the screening tool as trends emerge.

The following report summarizes the development of the *Vermont Culvert Geomorphic Compatibility Screening Tool*. The overall screening score is defined and the reasoning for inclusion and the scoring for each variable is presented. In addition, the results of a pilot project to test the screening tool are presented.

Two spreadsheet files accompany this report. VT GC Screen Tool.xls contains the screening tool for the entire Vermont assessed database, a description of the screening tool, and variable analyses (Appendix C). AOP_GC pilot study.xls contains the screening tool for the pilot study watersheds, a description of the screening tool, and the new *Vermont Aquatic Organism Passage Screening Tool* (Appendix D).

Variables explored for inclusion but not accepted into the *Vermont Culvert Geomorphic Compatibility Screening Tool* are presented to create a record of the analysis of the culvert database (Appendix E).

At the time of this project, a similar parallel effort was underway to expand the aquatic organism passage (AOP) screening tool used in Vermont. When used together, the two screening tools will offer a more complete view of how a culvert influences both the physical and biological aspects of a stream channel.

2.0 Screening Tool Summary

2.1 Overall Score and Categories

The overall score of the screen, the sum of a possible 0 to 5 for each of the 5 variables for a possible total of 25, represents the geomorphic compatibility between structure and stream. The overall score refers to categories ranging from "fully compatible" ($20 < \text{score} \leq 25$) to "fully incompatible" ($0 \leq \text{score} \leq 5$) with three intermediate levels indicating degrees of partial compatibility (Table 2-1). In addition to the combined score, variable thresholds are used to identify structures showing departure from natural conditions and resultant signs of impairment. Reduced structure width relative to the channel and poor alignment represent the cause of incompatibility, and reduced sediment continuity and increased erosion represent impairments. Undersized and poorly aligned structures are categorized as "mostly incompatible", whereas undersized and poorly aligned structures that also show reduced sediment continuity and increased erosion are “fully incompatible.”

2.2 Variables

Five variables are used in the screen, each being composed of single or multiple assessment data.

- Percent bankfull width (structure width / bankfull width*100)
- Sediment and debris continuity: upstream deposits and downstream scour
- Structure slope versus channel slope, and break in valley slope
- Approach angle
- Bank armoring & erosion upstream and downstream

Each variable is scored on a scale of 0 to 5; with scoring criteria for each set up to both represent the most important indicators of the geomorphic incompatibility while at the same time maximizing the range of conditions that may be represented from the existing assessment data (Table 2-2). A variable score of 0 indicates a poor condition, 3 approximately represents the average condition, and 5 indicates the best condition. Intermediate values were assigned if the data contained a suitable gradient.

TABLE 2-1
Summary of Overall Screen Score

Category Name	Screen Score	Threshold Conditions	Description of structure-channel geomorphic compatibility
Fully compatible	20<GC≤25	n/a	Structure fully compatible with natural channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. A similar structure is recommended when replacement is needed.
Mostly compatible	15<GC≤20	n/a	Structure mostly compatible with current channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. Minor design adjustments recommended when replacement is needed to make fully compatible.
Partially compatible	10<GC≤15	n/a	Structure compatible with either current form or process, but not both. Compatibility likely short term. There is a moderate risk of structure failure and replacement may be needed. Re-design suggested to improve geomorphic compatibility.
Mostly incompatible	5<GC≤10	% Bankfull Width + Approach Angle scores ≤ 2	Structure mostly incompatible with current form and process, with a moderate to high risk of structure failure. Re-design and replacement planning should be initiated to improve geomorphic compatibility.
Fully incompatible	0≤GC≤5	% Bankfull Width + Approach Angle scores ≤ 2 **AND** Sediment Continuity + Erosion and Armoring scores ≤ 2	Structure fully incompatible with channel and high risk of failure. Re-design and replacement should be performed as soon as possible to improve geomorphic compatibility.

TABLE 2-2
Summary of Individual Variable Scoring

Score	% Bankfull Width	Sediment Continuity	Slope	Approach Angle	Erosion and Armoring
5	%BFW ≥ 120	No upstream deposition or downstream bed scour	Structure slope equal to channel slope, and no break in valley slope	Naturally straight	No erosion **or** armoring
4	100 ≤ %BFW < 120	**Either** upstream deposition **or** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	n/a	n/a	No erosion **and** intact armoring, **or** low upstream **or** downstream erosion **without** armoring
3	75 ≤ %BFW < 100	**Either** upstream deposition **or** downstream bed scour, **with** either upstream deposits taller than 0.5 bankfull height **or** high downstream banks	Structure slope equal channel slope, with local break in valley slope	Mild bend	Low upstream **or** downstream erosion **with** armoring
2	50 ≤ %BFW < 75	**Both** upstream deposition **and** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	Structure slope higher or lower than channel slope, and no break in valley slope	Channelized straight	Low upstream **and** downstream erosion
1	30 ≤ %BFW < 50	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	n/a	n/a	Severe upstream **or** downstream erosion
0	%BFW < 30	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **and** high downstream banks	Structure slope higher or lower than channel slope, with local break in valley slope	Sharp bend	Severe upstream **and** downstream erosion, **or** failing armoring upstream **or** downstream

3.0 Description of Variables Included in Screening Tool

3.1 Percent Bankfull Width

Percent bankfull width (%BFW) is included in the screening tool to track changes in width relative to the stream channel due to the importance of width in multiple geomorphic processes. %BFW can be considered to be a surrogate for changes in cross sectional flow, velocity, sediment transport, and debris transport. Ideally, the structure would not constrict the channel (i.e., %BFW=100%) and would be allowed to flow naturally at bankfull and flood stages to reduce risks of structure failure and to protect natural river form and processes. Undersized structures lead to backwatering and thus decreased velocity, ultimately allowing sediments and organic material to be deposited upstream. Constrictions can also lead to excessive degradation downstream due to channel incision or a sediment starved channel.

The scoring system for %BFW is based primarily on common design guidelines, and the shape of the distribution of the %BFW variable in the Vermont culvert data (Figure 3-1). A score of 5 was set at %BFW ≥120%, which has recently been included in Massachusetts design standards (MARSCP, 2006) for new structures (Table 3-1). Although this desirable standard has been widely researched and reported for adequate fish passage, it is a width associated with a naturally functioning channel that includes normal hydraulics and sediment/debris transport.

A score of 4 was set for culverts with 100 < %BFW < 120. These structures do not constrict flows up to the bankfull storm event. This is the current design recommendation for the stream simulation approach in the Vermont draft crossing guidelines (Bates and Kirn, 2007). A score of 3 was assigned when 75 < %BFW < 100, as this is a range of values commonly found in transportation-based assessments and design standards.

Values of %BFW < 75% are rarely cited as they are undesirable often leading to maintenance challenges and fish blocks. The existing Vermont culvert data, and in particular the distribution of %BFW values, were examined to determine thresholds to differentiate between scores of 0, 1, and 2. The data show that 50% of the structures have %BFW of less than 48.9% and 10% of the structures have %BFW less than 31.3% (Table 3-2). These percentiles were used as a guide to set a score of 2 for 50 < %BFW < 75, a score of 1 for 30 < %BFW < 50, and a score of 0 for %BFW < 30. The majority of the assessed Vermont culverts score a 1 or 2, confirming the presence of many undersized culverts (Figure 3-2).

The %BFW scoring used here is the same as that proposed for use in the aquatic organism passage (AOP) screening tool currently under development.

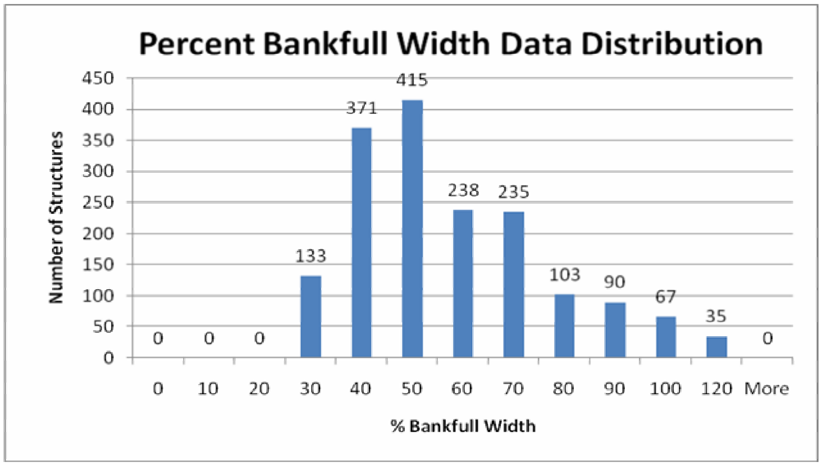


FIGURE 3-1
The Distribution of % Bankfull Width in Assessed Vermont Culverts

TABLE 3-1
Scoring of the % Bankfull Width Variable

% Bankfull Width	Score
%BFW > 120	5
100 < %BFW < 120	4
75 < %BFW < 100	3
50 < %BFW < 75	2
30 < %BFW < 50	1
%BFW < 30	0

TABLE 3-2
The Distribution of % Bankfull Width in Assessed Vermont Culverts

Percentile	Percent Bankfull Width
MAX	118.9
90 %	81.4
75 %	63.6
50 %	48.9
25 %	37.5
10 %	31.3
MIN	25.0

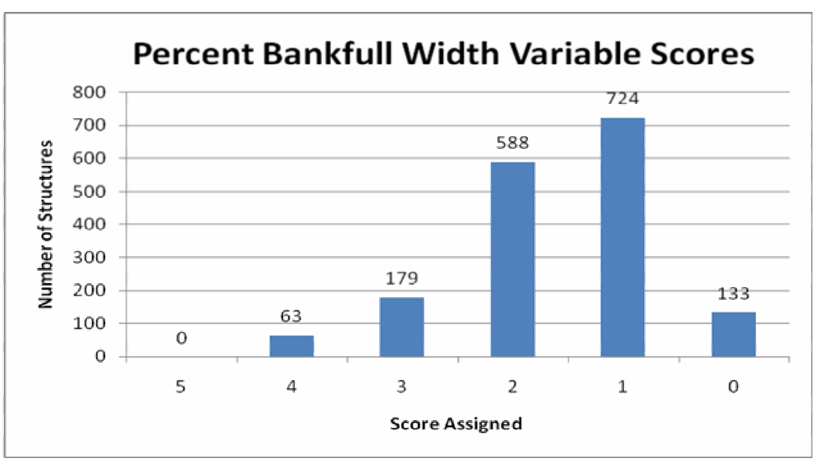


FIGURE 3-2
The Distribution of % Bankfull Width Scores for Assessed Vermont Culverts

3.2 Sediment and Debris Continuity: Upstream Deposits and Downstream Scour

Sediment and debris transport are the key processes disrupted by a structure that is incompatible with stream geomorphology. Signs of interuptions in natural sediment transport regime include upstream aggradation due to backwatering and downstream scour due to incision.

Upstream aggradation is assessed by the observation of deposits with depths relative to half of the mean bankfull depth. Larger deposits generally signify greater incompatibility with natural stream processes. Of the 1,296 structures with upstream deposits present, 495 of the structures have a deposit larger than half bankfull depth.

Downstream scour is represented by assessment data reporting the presence of scour, as well as a qualitative indication of the presence of high downstream banks. This information identifies local degradation in the bed just downstream of the structure. In the previsouly assessed Vermont culverts, 332 structures have high banks downstream while 1,322 do not.

The sediment and debris continuity variable is scored according to the presence and severity of upstream deposition and downstream scour (Table 3-3, see Appendix F for coding). A favorable condition with no upstream deposition and no downstream scour was assigned a score of 5. A score of 0 was assigned to structures with the most severe conditions identified as having large upstream deposits and downstream scour with high banks. The scores of 1 and 2 were assigned to structures where **both** upstream aggradation and downstream degredation occur, with a 1 for when the more severe condition (i.e., large deposits or high banks) is taking place at one end of the structure and a 2 for when the more severe conditions are absent. Intermediate scores of 3 and 4 were assigned to structures that had either downstream scour **or** upstream deposition, indicating that there is some locallized disruption in transport process occuring at the structure. A score of 3 is assigned if the condition at either end is severe and a score of 4 would be assigned if the condition was not as pronounced. As an example, a strucuture that has been identified to have only scour downstream with low banks would be assigned a score of 4. If there had been high banks the structure would have received a score of 3. Blank values of downstream high banks and deposit elevation were scored as though they were “large” to ensure that structures were not assigned better score values than they should. Based on the construct of the sediment and debris continuity variable, the coding order is important (i.e., 5, 0, 2, 1, 4, 3) as the structure is assigned the first score it qualifies for coded.

The distribution of the sediment and debris continity vairable scores (Figure 3-3) shows that approximately a quarter of assessed Vermont structures substantially disrupt natural movement of material (score $\leq$ 2).

TABLE 3-3
Scoring and of the Sediment and Debris Continuity Variable

Score	Sediment Continuity Score Description	Sediment Continuity Score Coding
5	neither occur	No upstream deposition or downstream bed scour
4	one occurs, but it is small	**Either** upstream deposition **or** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks
3	only one occurs, but it is large	**Either** upstream deposition **or** downstream bed scour, **with** either upstream deposits taller than 0.5 bankfull height **or** high downstream banks
2	both are small	**Both** upstream deposition **and** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks
1	both occur, but one is large and other is small	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **or** high downstream banks
0	both are large	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **and** high downstream banks

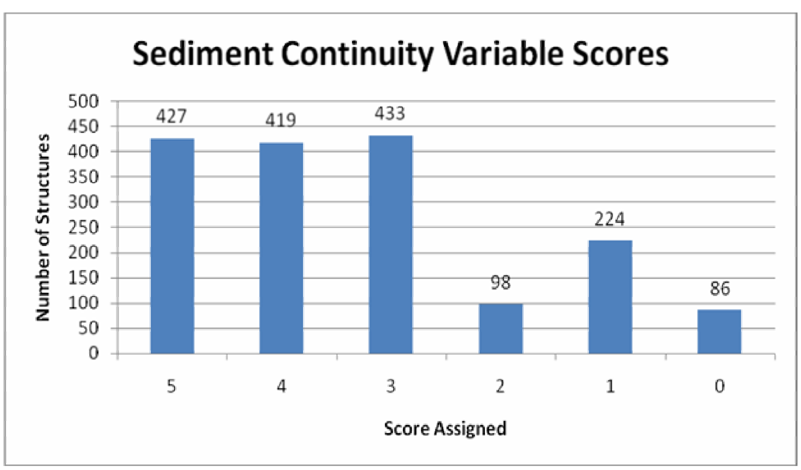


FIGURE 3-3
The Distribution of Sediment and Debris Continuity Scores for Assessed Vermont Culverts

3.3 Structure Slope versus Channel Slope, and Break in Valley Slope

The relationship between the slope of a culvert and the channel is an important consideration for geomorphic compatibility, as well is if the structure is located near a break in slope in the valley. A culvert that has a lower slope than the stream channel may cause sediment and debris to aggrade upstream of the structure and can exacerbate transport problems due to undersized structures and filled floodplains. A culvert with a steeper slope than the stream channel increases transport and water velocities, which could lead to downstream scour. Just under half (40%) of assessed Vermont culverts have a slope that differs from the channel (Figure 3-4).

Problems at a culvert can be compounded if the structure is located near a break in slope in the valley. These locations are prone to sediment and debris aggradation, and even minor constrictions of the channel can lead to strong incompatibilities between structure and channel. Approximately 13% of assessed Vermont culverts are located at a break in valley slope (Figure 3-5).

Differentiation was not made between structure slopes that are higher or lower than the channel slope, as any departure from channel slope can lead to incompatibility. Culverts with the same slope as the channel and not located near a break in valley slope are scored a 5 (Table 3-4). Culverts with the same slope as the channel and located near a break in valley slope receive a 3. Culverts that have higher or lower slopes than the channel and are not located near a break in valley slope are scored a 2 while those with different slopes that are near a break in valley slope will get a 0. The scoring system reflects the fact that a culvert with a different slope than the channel located near a break in slope of the valley is more likely to disrupt the natural sediment regime in the channel and be prone to failure than if it were not near a break in valley slope.

For the 23 “unsure” scores for break in valley slope, an assumption was made that the structure was not at a break in valley slope. The 10 blank answers for culvert slope were scored as being different than channel slope.

The distribution of slope scores shows that just under half of the assessed culverts in Vermont have different slopes than the channel, with 100 of those structures also being located at a break in valley slope (Figure 3-6).

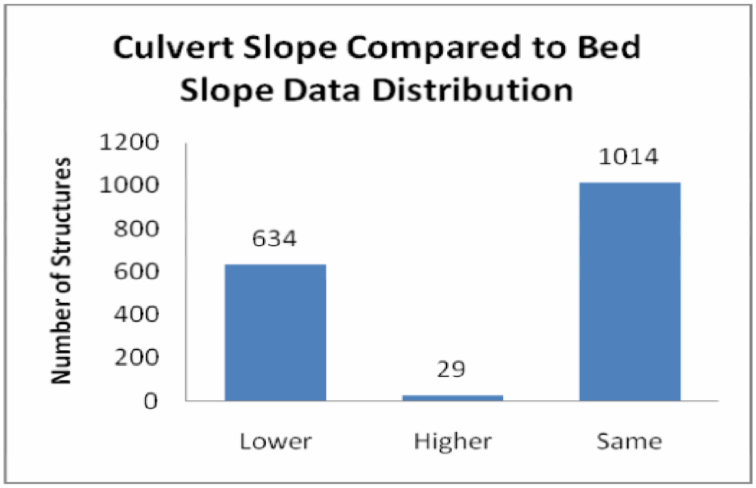


FIGURE 3-4
The Distribution of Structure Slope versus Channel Slope Variable for Assessed Vermont Culverts

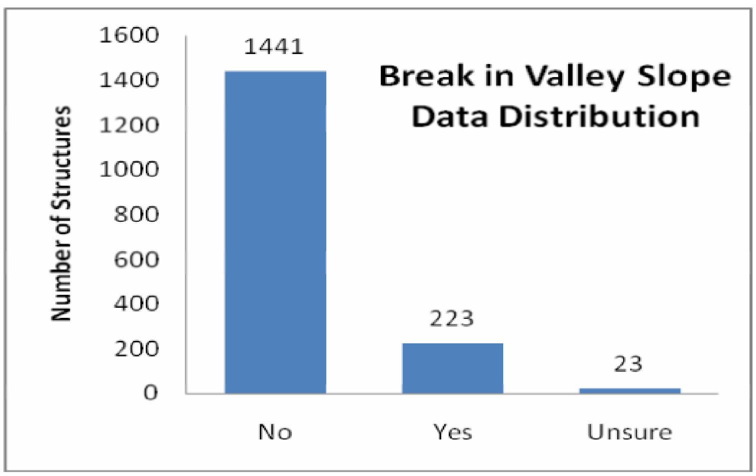


FIGURE 3-5
The Distribution of Break in Valley Slope Variable for Assessed Vermont Culverts

TABLE 3-4
Scoring of the Slope Variable

Slope	Score
Structure slope equal to channel slope, and no break in valley slope	5
n/a	4
Structure slope equal to channel slope, with local break in valley slope	3
Structure slope higher or lower than channel slope, and no break in valley slope	2
n/a	1
Structure slope higher or lower than channel slope, with local break in valley slope	0

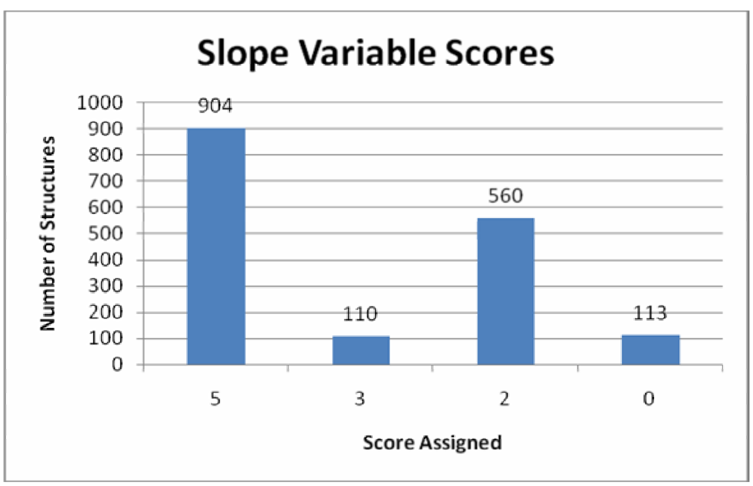


FIGURE 3-6
The Distribution of Slope Scores for Assessed Vermont Culverts

3.4 Approach Angle

The approach angle is important for geomorphic compatibility as mis-alignment can cause reduction of flow and sediment/debris transport through the structure. Skewed approach can cause scour, deposition, and likely channel adjustment, in addition to the possibility of structure failure. Assessment data show 20% of assessed Vermont culverts have a sharp bend between culvert and channel, while 30% have a mild bend (Figure 3-7).

The scoring for the approach angle variable is based on general knowledge of instream processes and professional judgement. A naturally straight culvert in line with the direction of flow receives a score of 5 (Table 3-5). A mild bend is scored a 3 due to a small chance of problems during normal flows, and an increased likelihood of socur or a jam during floods. A stucture with a channelized straight approach is scored a 2 due the presence of scour requiring armoring and the chance of outflanking the armoring. The mechanisms that increase risk are already in place in an armored approach although at the current moment excessive erosion may not be taking place. A structure that creates a sharp bend in the flow will receive a 0 due to the high risk of disruption of natural processes and culvert failure. The three structures for which this variable was left blank were assigned a score of 0.

Approximately 65% of assessed structures in Vermont deviate from the naturally straight approach, with 35% having a mild bend, 12% channelized straight, and 18% sharp bend (Figure 3-8).

TABLE 3-5
Scoring of the Approach Angle Variable

Slope	Score
Naturally straight	5
n/a	4
Mild bend	3
Channelized straight	2
n/a	1
Sharp bend	0

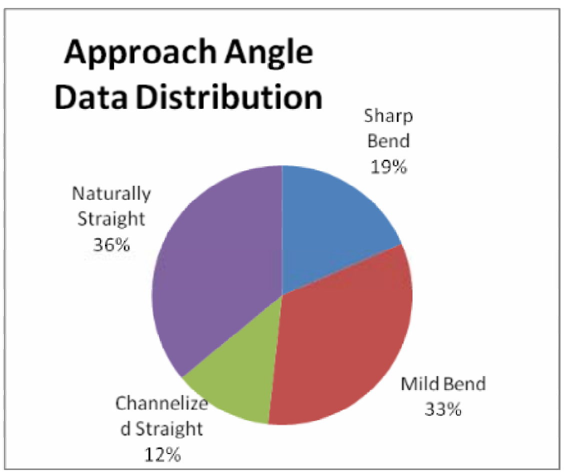


FIGURE 3-7
The Distribution of Approach Angle Variable for Assessed Vermont Culverts

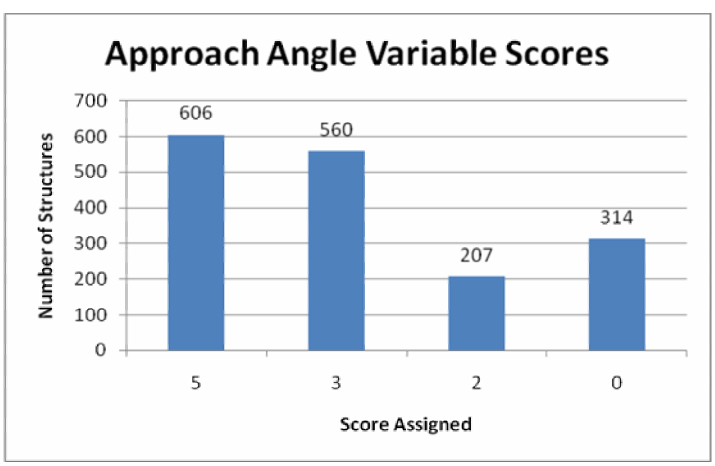


FIGURE 3-8
The Distribution of Approach Angle Scores for Assessed Vermont Culverts

3.5 Bank Armoring & Erosion Upstream and Downstream

The presence of either bank erosion or failing armoring is a strong indication that a structure is not compatible with stream processes. The more erosion and channelization present near a structure, the higher the risk of failure and the less likely that structure will remain compatible with channel adjustment over the long term.

The bank erosion variable is assessed upstream and downstream of the culvert, and includes categories of high, low, or none (no erosion). Of the assessed culverts in Vermont, 45% have no erosion upstream and 38% of structures have no erosion downstream (Figure 3-9). High levels of erosion are taking place upstream of 9% of the culverts and more than double that number of structures have high erosion downstream.

The bank armoring condition variable is also reported for upstream and downstream of the culvert. Condition categories include failing, intact, or none (none present). Data show approximately the same number of structures with upstream and downstream armoring within each category (Figure 3-10). Failing armor indicates an on-going erosion problem and suggests the potential for long-term incompatiblity. The failing conditions occurs in 9% of structures at the upstream culvert end and 10% of structures at the downstream end.

The bank erosion and armoring condition assessment data were combined to account for the current state of erosion. The most ideal condition, upstream and downstream banks with no erosion or armoring present, is scored a 5 (Table 3-6, see Appendix F for coding). A score of 4 is assigned to two different scenarios occuring either upstream **or** downstream – no erosion present with some intact armoring and low erosion with no armoring. These two conditions are considered to be troublesome and common, with the potential for more substantial problems in the future. If one end of the structure has low erosion and armoring present it receives a score of 3 as the armoring suggests the beginning of a long-term problem and possible incompatiblity. If low erosion exists at both ends of the culvert it indicates a more systemic problem exists and receives a score of 2. If there is high erosion either upstream or downstream, but not both, the structure receives a score of 1, yet the presence of any failing armoring, even if only at one end of the structure, receives a score of 0. If there is high erosion at both ends of the structure it is also scored a 0. The coding order (i.e., 0, 1, 5, 2, 4, 3) is important to ensure the correct variable scoring since the structure is assigned the first score it qualifies for.

The distribution of the bank erosion and armoring scores (Figure 3-11) indicates that 41% of structures have high erosion or failing armoring (score ≤ 2).

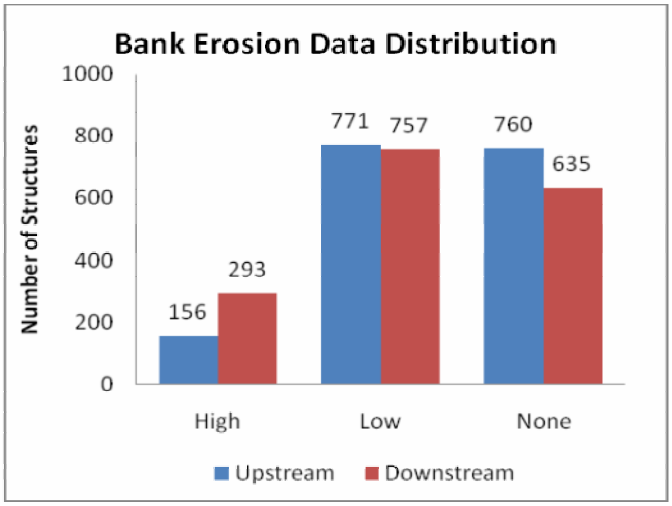


FIGURE 3-9
The Distribution of the Bank Erosion Variable for Assessed Vermont Culverts

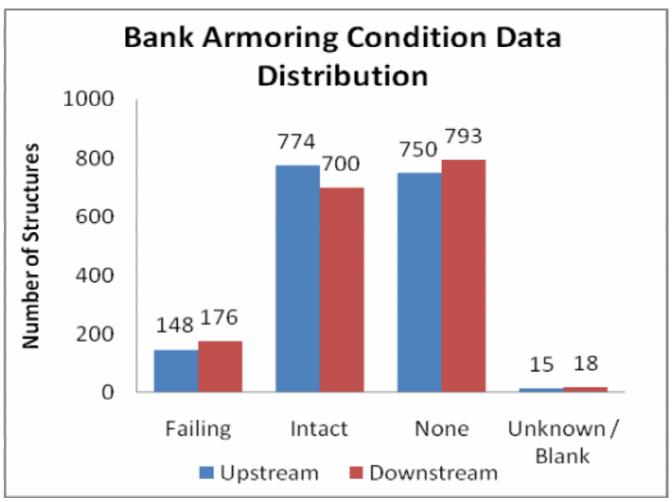


FIGURE 3-10
The Distribution of the Bank Armoring Condition Variable for Assessed Vermont

TABLE 3-6
Scoring of the Erosion and Armoring Variable

Score	Erosion and Armoring Score Description	Erosion and Armoring Score Coding
5	no erosion AND no armoring	No erosion **or** armoring
4	no erosion and intact armoring OR low erosion and no armoring	No erosion **and** intact armoring, **or** low upstream **or** downstream erosion **without** armoring
3	low erosion up OR down, armored	Low upstream **or** downstream erosion **with** armoring
2	low erosion up AND down	Low upstream **and** downstream erosion
1	high erosion up OR down, if armored then intact	Severe upstream **or** downstream erosion
0	high erosion both up and down OR any failing armoring	Severe upstream **and** downstream erosion, **or** failing armoring upstream **or** downstream

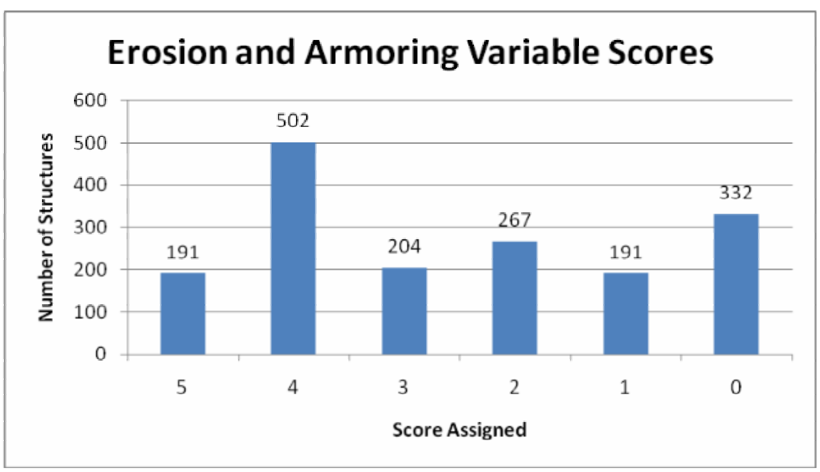


FIGURE 3-11
The Distribution of Erosion and Armoring Upstream and Downstream Scores for Assessed Vermont Culverts

4.0 Results of the Screening Tool

4.1 Results of the Screening Tool from the Study Database

The screening tool was developed and initally tested using the Vermont bridge and culvert assessment data obtained from VT DEC River Management Program (GC Screening Tool All Data 1-18.mdb). Bridges were removed from the database for this analysis. The few structures having percent bankfull widths less than 25% or greater than 120% were removed from the database to exclude extreme observations and minimize the potential for erroneous data at these extreme measures. The 1,687 structures used in this analysis were assessed between August 2003 and July 2007.

The sum of the five variable scores, for a possible total of 25, is used to categorize structures according to geomorphic compatibility with the stream (Table 4-1). In addition to the score, variable thresholds were set up to ensure identification of structures showing departure from natural conditions (i.e., low scores for % bankful width and approach angle variables) and resultant signs of impairment (i.e., low scores for sediment discontinuity and erosion variables). The thresholds are used to identify structures where the overall score was indicative of partial compatability, yet the extremely low values of cause and response variables suggested that a lower classification was needed.

The culvert geomorphic compatibility screen scores indicate that 5% of structures are fully compatible and 3% of structures are fully incompatible with the stream channel (Table 4-1). The 55 structures representing the 3% that are most incompatible are severely disrupting natural form and processes and are likely to be at risk of failure. These culverts represent an immediate opportunity to improve natural processes, channel stability, aquatic habitat, and public safety. The majority (i.e., 1,544) of structures are classified within the three intermediate levels of compatibility as expected. These structures span a range from mostly compatible to mostly incompatible, and thus some information about the relationship between culvert and channel is available even for the middle of the data distribution (Figure 4-1).

The thresholds changed the geomorphic compatibility category for 135 structures (8%). Of the changed categories, 15 mostly compatible and 120 partially compatible structures were collectively moved to 106 mostly incompatible and 29 fully incompatible.

Table 4-1

Culvert Geomorphic Compatibility Screen Study Database Results

Category Name	Screen Score	Threshold Conditions	Description of structure-channel geomorphic compatibility	# of structures	% of structures
Fully compatible	$20<GC\leq 25$	n/a	Structure fully compatible with natural channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. A similar structure is recommended when replacement is needed.	88	5
Mostly compatible	$15<GC\leq 20$	n/a	Structure mostly compatible with current channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. Minor design adjustments recommended when replacement is needed to make fully compatible.	526	31
Partially compatible	$10<GC\leq 15$	n/a	Structure compatible with either current form or process, but not both. Compatibility likely short term. There is a moderate risk of structure failure and replacement may be needed. Re-design suggested to improve geomorphic compatibility.	584	35
Mostly incompatible	$5<GC\leq 10$	% Bankfull Width + Approach Angle scores ≤ 2	Structure mostly incompatible with current form and process, with a moderate to high risk of structure failure. Re-design and replacement planning should be initiated to improve geomorphic compatibility.	434	26
Fully incompatible	$0\leq GC\leq 5$	% Bankfull Width + Approach Angle scores ≤ 2 **AND** Sediment Continuity + Erosion and Armoring scores ≤ 2	Structure fully incompatible with channel and high risk of failure. Re-design and replacement should be performed as soon as possible to improve geomorphic compatibility.	55	3

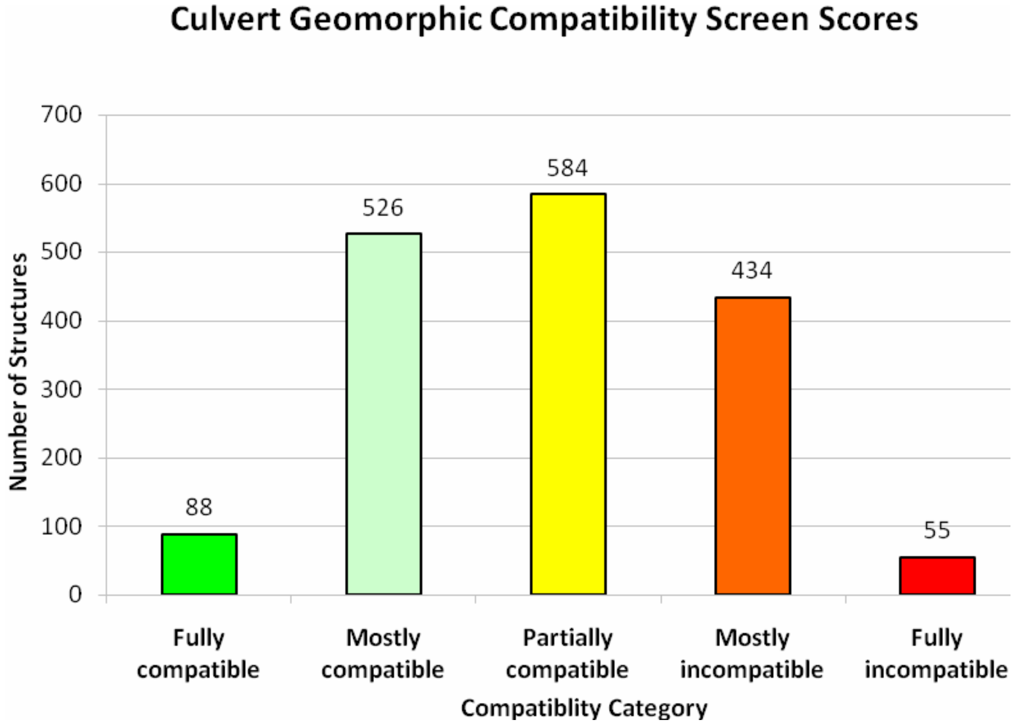


FIGURE 4-1
The Distribution of Culvert Geomorphic Compatibility Screen Scores for Assessed Vermont Culverts

4.2 Results of Pilot Study

A pilot study was conducted to test the new *Vermont Culvert Geomorphic Compatibility Screening Tool* on a watershed scale. The publicly accessible Vermont Stream Geomorphic Assessment Data Management System was accessed to download structure information for the White River and Ottauquechee River watersheds. Bridges and arches were removed from the database. The White River watershed contains 434 assessed culverts and the Ottauquechee River watershed contains 200 assessed culverts.

The geomorphic compatibility screen was applied to the data for each watershed individually. The White River watershed screen identified 5 structures that are fully compatible with the stream channel and 26 that are fully incompatible (Table 4-2). The majority (i.e., 403) of the culverts spanned the three intermediate compatibility ranges.

GIS maps containing the results of the screen are a way to locate structures and their geomorphic compatiblity. Visualization of the gemorphic compatiblity of structures may be an useful tool for road foreman and others providing maintenance and replacement of culverts. Although the results of the screen may not always help avoid initial failure, the geomorphic compatiblity previously determined for a failed structure will help answer questions as to why failure occurred and guide design improvements of a replacement structure to reduce risks and increase the chances of the culvert properly functioning over its full anticipated design life.

GIS maps of the screen results are also useful to look at collections of culverts in specific watershed areas to understand processes taking place at the segment or reach scale. For example, a map of culvert geomorphic compatiblity in the White River watershed (Figure 4-2) appears to show a general abundance of mostly incompatible (orange) structures in the lower watershed. Zooming in to a subwatershed such as the headwaters of the Second Branch (Figure 4-3), structures in streams on the eastern side of the subwatershed are less compatible than those to the west. One possible explanation is that the channels to the east are adjusting due to the presence of a stressor and the structures no longer are compatible with the current stream condition. The closeup map also reveals the limited number of structures in the subwatershed that have been assessed relative to the number of apparent crossings where the stream and road layers cross.

In the Ottauquechee River watershed, no structures received a fully compatible rating (Table 4-2) and 17 were fully incompatible. Again, the bulk of the structures are categorized among the three intermeditate compatiblity levels, with 39% being ranked as mostly incompatible.

A map of the assessed structures and culvert geomorphic compatiblity in the Ottauquechee River watershed (Figure 4-4) shows a pattern of mostly to fully incompatible culverts being abundant when structures are located close to tributary junctions with the mainstem. Confluences can be dynamic areas with irregular flow and sediment/debris transport and thus structures can become incompatible with the stream channel. A closeup map of the Broad Brook subwatershed (Figure 4-5) shows a cluster of two structures to the north that are both mostly incompatible. This could be a location where system adjustment is making the stream and culvert incompatible. Field verification and review of existing geomorphic data will help confirm trends predicted with the maps of culvert geomorphic compatibilty.

TABLE 4-2

Pilot Study Results

Category Name	White River Watershed		Ottauquechee River Watershed	
	#	%	#	%
Fully compatible	5	1	0	0
Mostly compatible	93	21	36	18
Partially compatible	165	38	69	35
Mostly incompatible	145	33	78	39
Fully incompatible	26	6	17	9

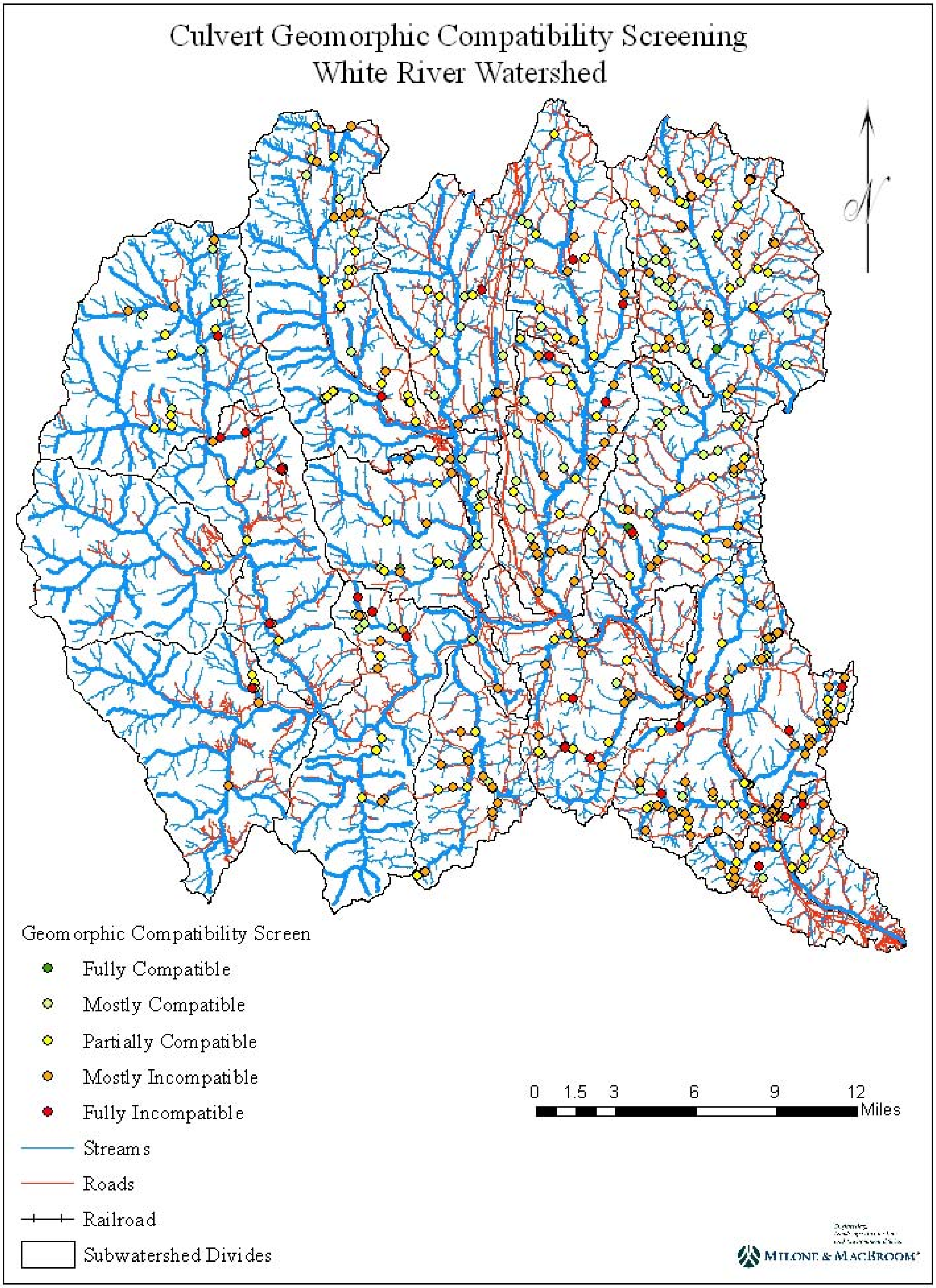


FIGURE 4-2
Culvert Geomorphic Compatibility in the White River Watershed

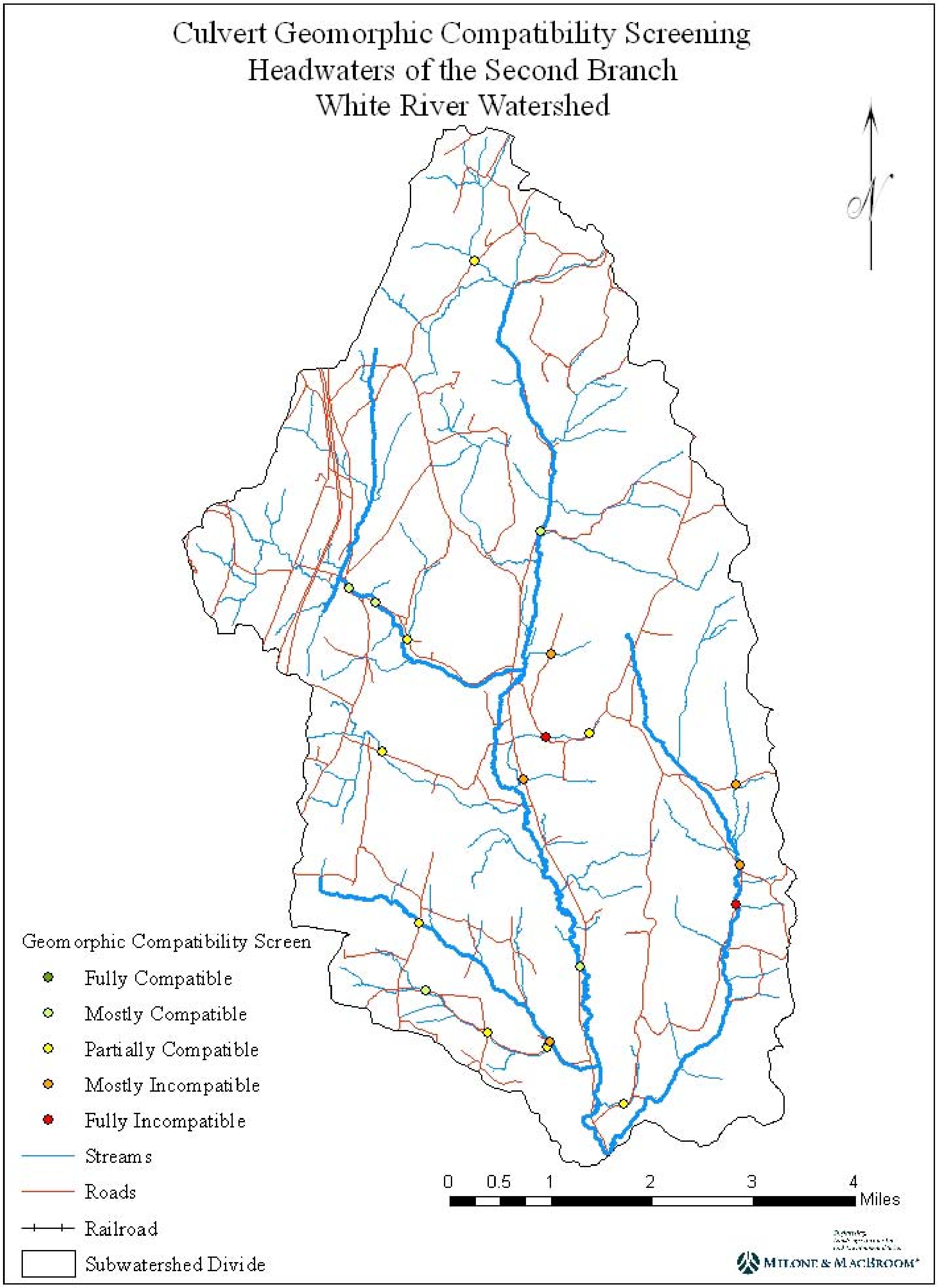


FIGURE 4-3
Culvert Geomorphic Compatibility in the Headwaters of the Second Branch Subwatershed

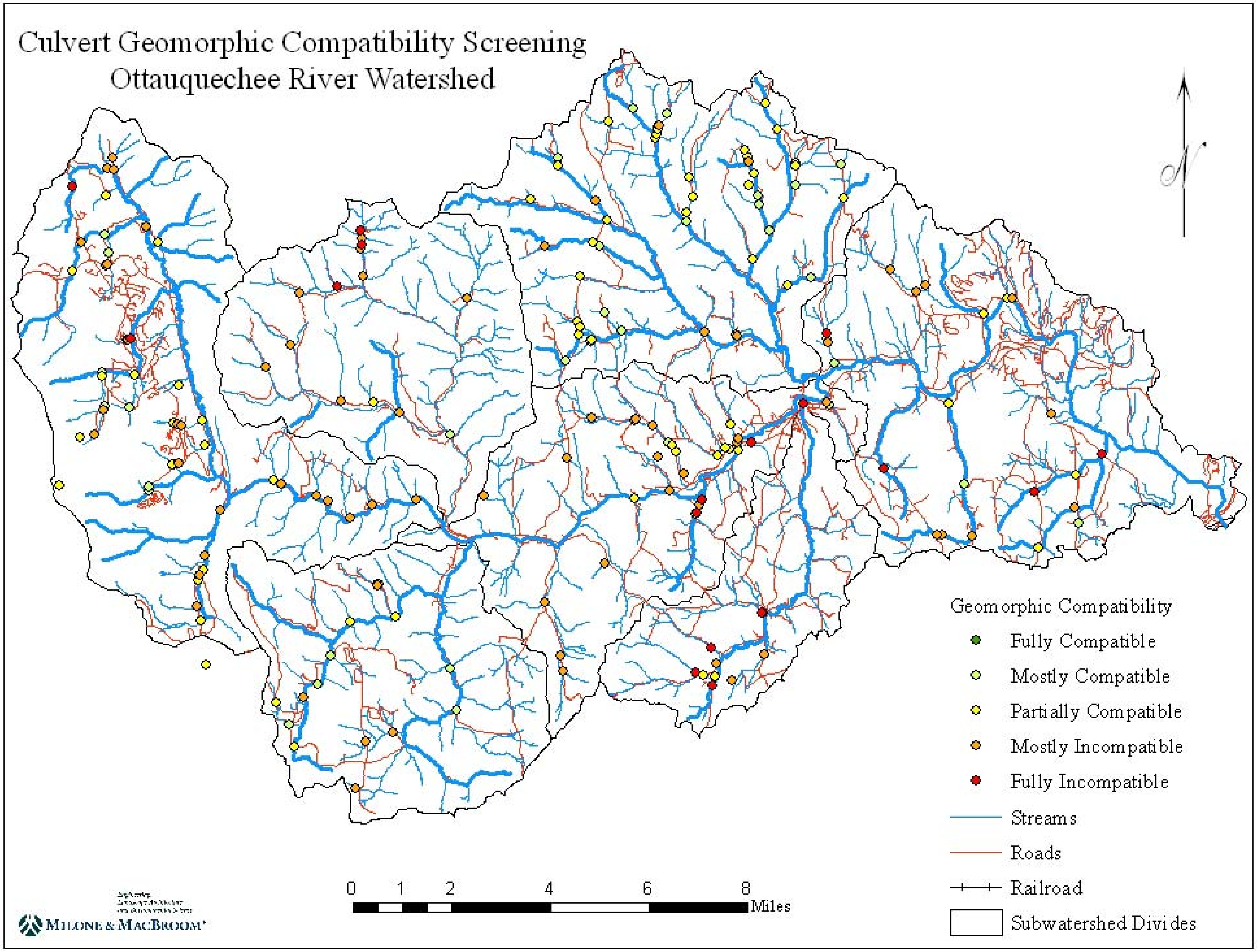


FIGURE 4-4
Culvert Geomorphic Compatibility in the Ottauquechee River Watershed

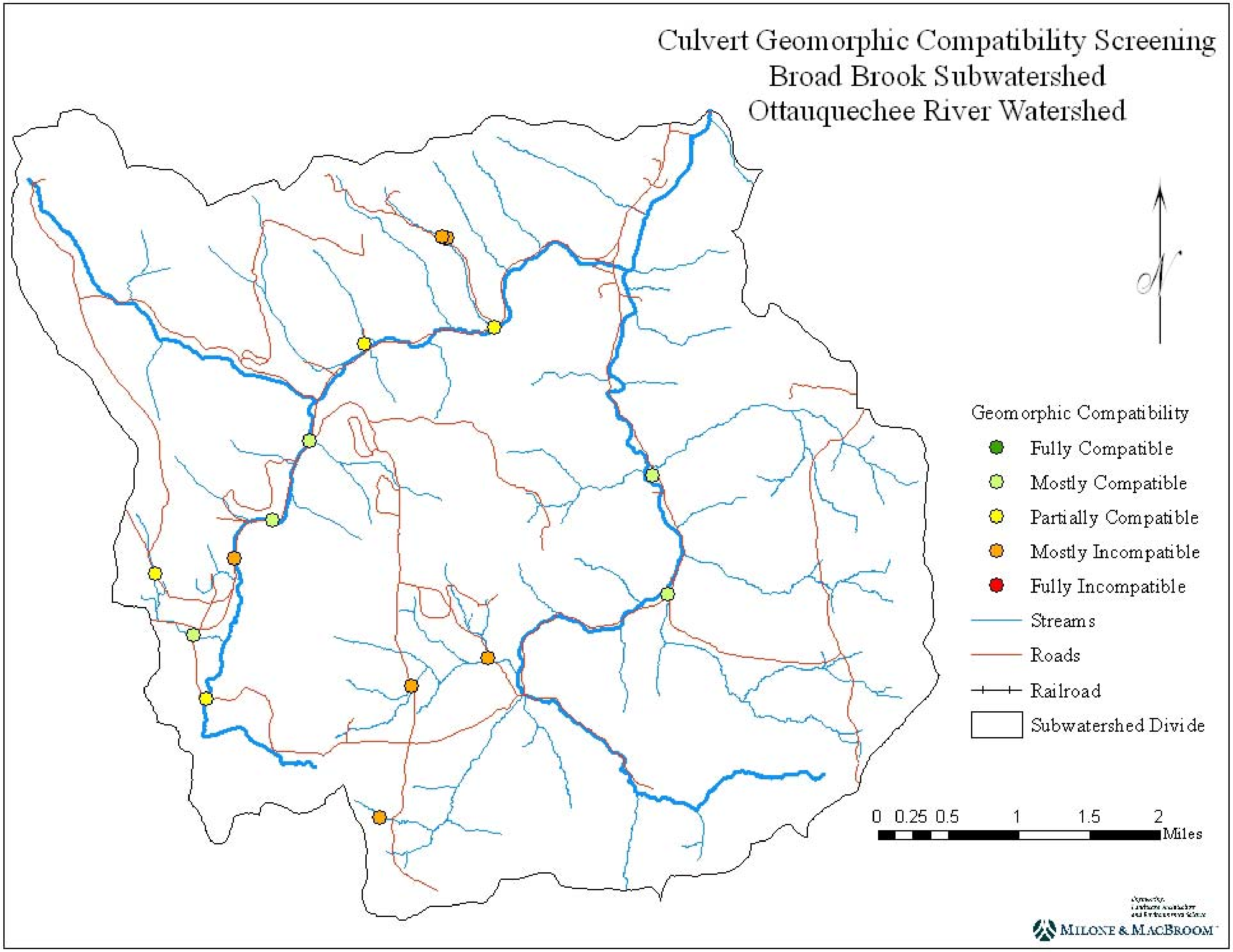


FIGURE 4-5
Culvert Geomorphic Compatibility in the Broad Brook Subwatershed

5.0 References

Bates, K. and R. Kirn, 2007. Draft Guidelines for the Design of Stream/Road Crossings for Passage of Aquatic Organisms in Vermont. Vermont Department of Fish and Wildlife, Agency of Natural Resources, Waterbury, VT.

MARSCP, 2006. Massachusetts River and Stream Crossing Standards. The Massachusetts River and Stream Crossing Partnership including University of Massachusetts Amherst, MA Riverways Program, and The Nature Conservancy, Amherst, MA.

VTANR, 2007. Vermont Stream Geomorphic Assessment Protocol Handbooks: Remote Sensing and Field Surveys Techniques for Conducting Watershed and Reach Level Assessments (Http://Www.Anr.State.Vt.Us/Dec/Waterq/Rivers/Htm/Rv_Geoassesspro.Htm). Acquired via the internet May 17, 2007. Vermont Agency of Natural Resources, Department of Environmental Conservation, Division of Water Quality, River Management Program, Waterbury, VT.

Appendix A – Vermont Culvert Assessment

Culvert Assessment - Geomorphic & Habitat Parameters

Field Map # _____

SGA Structure ID			Local ID	
Observer(s) / Organization(s)			Date	
Town			Phase 1 Project	
Location			Longitude (E/W)	
Reach VTID			Latitude (N/S)	
Road Name			Road Type	**paved gravel trail railroad**
Stream Name			High Flow Stage	**yes no**
Culvert Length	(ft.)	Structure Material: **concrete plastic corrugated plastic smooth tank steel corrugated stone aluminum corrugated other mixed**	Channel Width **curve measured**	(ft.)
Culvert Height	(ft.)		# of culverts at crossing	
Culvert Width	(ft.)		Overflow pipe(s)	**yes no**
			Structure skewed to roadway	**yes no**

Geomorphic and Fish Passage Data

General

Floodplain filled by roadway approaches: **entirely partially not significant**

Structure located at a significant break in valley slope: **yes no unsure**

Culvert slope as compared with the channel slope is: **higher lower same**

Upstream

Is structure opening partially obstructed by (circle all that apply): **wood debris sediment deformation none**

Steep riffle present immediately upstream of structure: **yes no**

If channel avulses, stream will: **cross road follow road unsure**

Estimated distance avulsion would follow road: __________ (feet)

Angle of stream flow approaching structure: **sharp bend mild bend naturally straight channelized straight**

Downstream

Water depth in culvert (at outlet): __________ (0.0 feet)

Culvert outlet invert: **at grade cascade free fall**

Outlet drop (invert to water surface): __________ (0.0 feet)

Pool present immediately downstream of structure: **yes no**

Pool depth at point of streamflow entry: __________ (0.0 feet)

Maximum pool depth: __________ (0.0 feet or >4feet)

Downstream bank heights are substantially higher than upstream bank heights: **yes no**

Geomorphic and Fish Passage Data	UPSTREAM	DOWNSTREAM	IN STRUCTURE
Dominant bed material at structure	1 2 3 4 5 UK bedrock present: yes no	1 2 3 4 5 UK bedrock present: yes no	0 1 2 3 4 5 UK material throughout: yes no
Sediment deposit types	none delta side point mid-channel	none delta side point mid-channel	none delta side point mid-channel
Elevation of sediment deposits is greater than or equal to ½ bankfull elevation:	yes no	yes no	yes no
Bank erosion	high low none	high low none	
Hard bank armoring	intact failing none unknown	intact failing none unknown	
Streambed scour causing undermining around/under structure (circle all that apply)	none culvert footer wing walls	none culvert footer wing walls	
Beaver dam near structure Distance from structure to dam	yes no distance: __________ ft.	yes no distance: __________ ft.	

Bed Material Codes
0-none
1-bedrock
2-boulder
3-cobble
4-gravel
5-sand
UK-unknown

Wildlife Data (left/right bank determined facing downstream)	LEFT	RIGHT	LEFT	RIGHT
Dominant vegetation type				
Does a band of shrub/forest vegetation that is at least 50' wide start within 25' of structure and extend 500' or more up/downstream?	yes no	yes no	yes no	yes no

Vegetation Type Codes
C-coniferous forest
D-deciduous forest
M-mixed forest
S-shrub/sapling
H-herbaceous/grass
B-bare
R-road embankment

Road-killed wildlife within ¼ mile of structure? (circle none or list species)	species: none

Wildlife sign and species observed near (up/downstream) and inside structure (circle none or list species and sign types)	Outside Structure		Inside Structure	
	species (none)	sign	species (none)	sign

Spatial data collected w/GPS: yes no Photos taken: yes no Please fill out photo log below	**Comments:**

Roll and Frame #	Photo View	Description of Features in Photo

Appendix B – Recommended Updates to the Culvert Report Querries in the Vermont Stream Geomorphic Assessment Data Management System

The "pseudo-code" showing the selection criteria for the existing culvert reports (i.e., Failure Modes - Geomorphic Incompatibility and Problem Causes) generated in the Vermont Stream Geomorphic Assessment Data Management System differed from the database queries received at the beginning of this project (GC Screening Tool All Data 1-18_MMI.mdb). New querries have been added to the database to correct the three **descrepancies** described below.

Erosion of Adjacent Property:

ORIGINAL: QryErosionOfAdjacentProperty (returned 1,310 structures)
CORRECTED: Qry ErosionOfAdjacentPropertyCorrect (returns 1,165 structures)

Erosion of Adjacent Property Pseudo-Code:

If (upstream or downstream bank erosion=high) **or**

If (diameter/channel width < 0.7) **and…**
(structure opening obstructed by: wood debris, sediment, **or** deformation) **or**
[(upstream **or** downstream sediment deposits=mid-channel, point, delta, **or** side)
and (elevation of upstream **or** downstream sediment deposits greater than ½ bankfull=yes)
or (upstream **or** downstream hard bank armoring=failing)**]** **or**
(if channel avulses, stream will=follow road)

Corrections Needed to Ice/Debris Jam Code:

- **AND** after (diameter/channel width < 0.7) coded as an **OR** statement
- Seems like failing armoring should be linked to sediment deposits, but is coded as an individual **OR** statement

Ice/Debris Jam:

ORIGINAL: QryIceDebrisJam (returned 1,652 structures)
CORRECTED: QryIceDebrisJamCorrect. (returns 1,615 structures)

Ice/Debris Jam Pseudo-Code:

If (structure opening obstructed by: wood debris, sediment, **or** deformation) **or**

If (# of culverts: >1)

If (**diameter/channel width < 0.7**) **or**

If (**diameter/channel width < 1.0**) **and**

(floodplain filled by roadway approaches=entirely) **or**
(located at a significant break in the valley slope=yes) **or**
(angle of stream flow approaching structure=sharp) **or**
(culvert slope as compared with channel slope is significantly=lower) **or**
(steep riffle present immediately upstream=yes) **or**
[(upstream sediment deposits=mid-channel, point, delta, **or** side)
and (elevation of upstream sediment deposits greater than ½ bankfull=yes)**]**

Corrections Needed to Ice/Debris Jam Code:

- "# of culvert>1" was coded as CulvertOverflowPipe = yes
- "Diameter/channel width < 0.7" was repeated two times
- "Diameter channel width <1.0 **AND"** was not included in the code

Scour:

ORIGINAL: QryScour (returned 1,552 structures)
CORRECTED: QryScourCorrect (returns 1,482 structures)

Scour Pseudo-Code:

If (stream bed scour causing upstream **or** downstream undermining around/under=culvert) **or**

If (culvert outlet invert=cascade **or** freefall) **or**

If (diameter/channel width < 0.7) **and…**

(structure opening obstructed by: wood debris, sediment, **or** deformation) **or**
[(upstream **or** downstream sediment deposits=mid-channel, point, delta, **or** side)
and (elevation of upstream **or** downstream sediment deposits greater than ½ bankfull=yes)
or (upstream **or** downstream hard bank armoring=failing)**]** **or**
(steep riffle present immediately upstream=yes)

Corrections needed to Scour Coding:

- **AND** after (diameter/channel width < 0.7) coded as an **OR** statement
- Seems like failing armoring should be linked to sediment deposits, but is coded as an individual **OR** statement

Appendix C – Guide to the Worksheets in VT GC Screen Tool.xls

Worksheet Name – Description

Screen – Contains the Vermont Assessed Structures data, Vermont Geomorphic Culvert Screening Tool in the last columns, screen summary information at the bottom of the screening columns.

Criteria – A table summarizing each variable included in the screening tool and the scoring breakdown.

ExploredDraftScreenChanges – Contains the same database of structures used in the Screen worksheet, but with different scoring and variables included in the draft screen in the last columns. This exploratory information was used in setting the scoring criteria for the screening tool.

ExploredScreenChanges – Comparison tables describing how the screen scoring would have been changed with the alternatives explored during screening tool creation.

Sensitivity – Multiple queries were used to examine how many structures had particular characteristics related to geomorphic compatibility. This analysis was based on the existing Culvert Failure Modes Report and identified which criteria were driving each individual failure mode.

Catagorical New Data – This worksheet contains the breakdown and plots of all variables in the Culvert Assessment related to geomorphic compatibility which are catagorical in nature. This data is from the Access Database GC Screening Tool All Data 1-18.mdb.

Catagorical Old Data – This worksheet similar to Catagorical New Data worksheet provides data analysis on catagorical data, but is from the Access Database GC Screening Tool.mdb received July 11, 2007.

DiaByWidth – Contains all bankfull width information from the GC Screening Tool All Data 1-18.mdb and its value distribution.

Beaver Dam Dist. – Contains all beaver dams identified in the GC Screening Tool All Data 1-18.mdb and examines the distances measured to the culverts.

VariablesPerQuery – This table breaks down each of the variables used in the Culvert Failure Modes report and which failure mode they help to identify.

Deposits – All deposits were returned from the QryAllDeposits in GC Screening Tool All Data 1-18_MMI.mdb and analysed here.

Obstructions – All deposits were returned from the QryAllObstructions in GC Screening Tool All Data 1-18_MMI.mdb and analysed here.

Scour – All deposits were returned from the QryAllScour in GC Screening Tool All Data 1-18_MMI.mdb and analysed here.

Appendix D – Guide to the Worksheets in AOP_GC pilot study.xls

White GC – The *Vermont Culvert Geomorphic Compatibility Screening Tool* has been applied to the White River Basin culvert data.

Ottauquechee GC – The *Vermont Culvert Geomorphic Compatibility Screening Tool* has been applied to the Ottauquechee River Basin culvert data.

GC Screen - The *Vermont Culvert Geomorphic Compatibility Screening Tool* is defined in tables describing scoring catagories and variable scoring breakdown, corresponding to Tables 2-1 and 2-2 in this report.

White AOP_RF – The *Vermont Culvert Aquatic Organism Passage (AOP) and Retrofit Potential Screening Tools* have been applied to the White River Basin culvert data.

Ottauquechee AOP_RF – The *Vermont Culvert Aquatic Organism Passage (AOP) and Retrofit Potential Screening Tools* have been applied to the Ottauquechee River Basin culvert data.

AOP_RF screen – Describes the *Vermont Culvert Aquatic Organism Passage (AOP) and Retrofit Potential Screening Tools* variables and scoring breakdown.

White Reduced - This worksheet contains the White River Basin culvert data used in the pilot study. It was reduced in size by removal of all bridges and arches, removal of structures with no channel dimensions, and identified small watersheds (DA < 0.25 mi^2) for further removal from the AOP_RF screening tool analysis.

Ottauquechee Reduced - This worksheet contains the Ottauquechee River Basin culvert data used in the pilot study. It was reduced in size by removal of all bridges and arches, removal of structures with no channel dimensions, and identified small watersheds (DA < 0.25 mi^2) for further removal from the AOP_RF screening tool analysis.

White DMS – All culvert data obtained from the Data Management System for the Ottauquechee River Basin streams.

Ottauquechee DMS – All culvert data obtained from the Data Management System for the White River Basin streams.

Variable List DMS – Variable name code, data type, and full variable name for all variables included in the data lists obtained from the Data Management System.

Appendix E – Alternatives Explored for Possible Inclusion in the Screening Tool

The descriptions below summarize various alterntives explored yet not included in the *Vermont Culvert Geomorphic Compatibility Screening Tool*. This information is provided to establish a record of the analyses of the assessed culvert data. Additional analyses may be found in the accompanying spreadsheet and database files.

Alternative 1: Change to Percent Bankfull Width Variable Scoring

An alternative method of identifying the lowest score category of % BFW was explored. Most of the other categories have been cutoff at a percentage corresponding to an increment of 25. The distribution of overall scores was found if the lower score category cutoff was changed to 25% BFW instead of 30% BFW. Results showed to shift about 8% of the structures from a score of 0 up to a score of one. This influences the overall score distribution to shift slightly toward higher scores (see table below). This alternative cutoff value can be used in the scoring without greatly influencing the overall scoring. The database does not include values of % BFW less than 25%, so this cutoff value does not currently score any structures with a 0 value in this category. Identification of the most constrictive structures is valuable to include in the screening tool. It is recommended to use the current technique of identifying the worst structures according to the 10% quartile.

		Variable Score Distribution						Screen Score Distribution				
		5	4	3	2	1	0	Green	Lemon-Lime	Yellow	Orange	Red
Existing BFW% <30%	#	0	63	179	588	724	133	88	541	704	328	26
	%	0	4	11	35	43	8	5	32	42	19	2
Change BFW% lower score range to <25%	#	0	63	179	588	857	0	92	544	710	318	23
	%	0	4	11	35	51	0	5	32	42	19	1
Difference	Δ%	0	0	0	0	8	-8	0.2	0.2	0.4	-0.6	-0.2

Alternative 2: Change to Approach Angle Variable Scoring

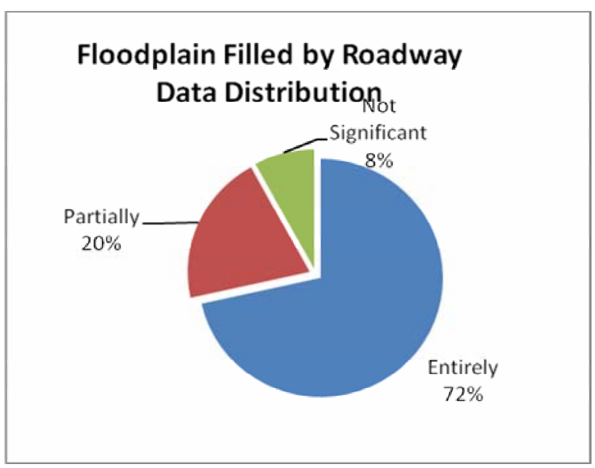
The scoring within this category is based on professional judgement and knowledge of instream processes. Because of this variability, alternative scoring schemes were explored (see table below). Our screen has ranked a stucture with a channelized straight approach angle relatively low due to instabilities which could occur as the stream regained sinuosity. This is an assumption that adjustment would occur, as not all stream types would go through this process. This variable could be scored higher due to its current correct alignment. Scores of 3 and 4 were explored. An alternative was explored which scores both channelized straight and mild bend as 3. In this alternative, both conditions are considered to be average,as there is potential for future problems, but no immediate incompatability. The alternative scoring channelized straight as a 4 and a mild bend as a 3 is also shown. This alternative ranks channelized straight as not ideal, but better than average because the flow direction at the approach is in line with the opening. In this alternative the other variables remain unchanged, with mild bend still receiving the average score of 3.

The change in distribution of overall screen scores was minimal with changes in the scoring of the channelized straight approach angle, but shifted the overall scores to be slightly higher. The current scoring is recommended because the channelized straight indicates that the culvert was installed according to the waterway's altered state and readjustment is possible, justifying the lower score than a mild bend. A mild bend is a natural condition and necessary in sinuous channels. A mild bend should not be scored lower than the average condition score of 3.

		Variable Score Distribution						**Screen Score Distribution**				
		5	**4**	**3**	**2**	**1**	**0**	**Green**	**Lemon-Lime**	**Yellow**	**Orange**	**Red**
Channelized Straight = 2 and Mild Bend = 3	#	606	0	560	207	0	314	88	541	704	328	26
	%	36	0	33	12	0	19	5	32	42	19	2
Channelized Straight & Mild Bend both = 3	#	606	0	767	0	0	314	93	570	702	296	26
	%	36	0	45	0	0	19	6	34	42	18	2
Difference	Δ%	0	0	12	-12	0	0	0.3	1.7	-0.1	-1.9	0.0
Channelized Straight = 4 & Mild Bend = 3	#	606	207	560	0	0	314	97	576	704	287	23
	%	36	12	33	0	0	19	6	34	42	17	1
Difference	Δ%	0	12	0	-12	0	0	0.5	2.1	0.0	-2.4	-0.2

Alternative 3: Addition of Floodplain Filled by Roadway Variable

The inclusion of the floodplain fill variable was explored in multiple ways to see how it influenced the overall screen scoring presented above. When scoring this variable out of a total of 5, even if only allowing a maximum value of 2, this variable strongly skewed the overall scores down, as seen in the table below. If scoring this variable out of 2, the effect is not seen as strongly. It is recommended that if this variable is included in the future it should be scored with a maximum of 2 out of 2 to dampen



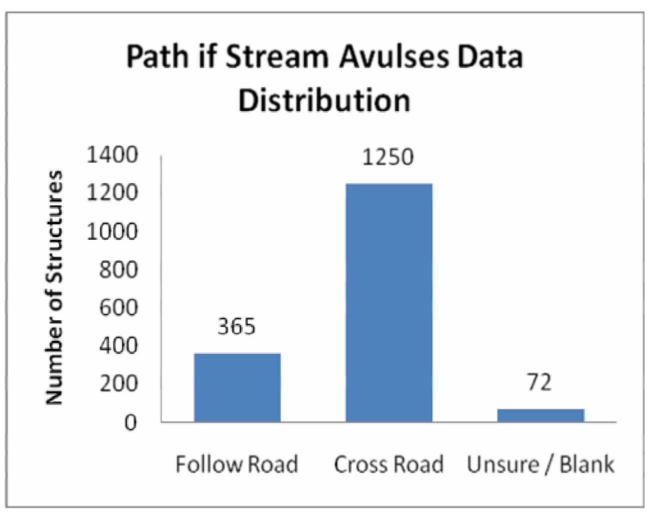
its strong effects.

The overwhelming number of streams with their floodplains entirely filled leads to limited new information for the screen by including this variable, yet a strong influence on the overall scoring. Another concern is that the assessment of this variable is subjective and difficult to assess in the field. We suggest leaving this variable out of the screen until it is expanded upon in the assessment to make it more quantitative.

		Variable Score Distribution						**Screen Score Distribution**				
		5	**4**	**3**	**2**	**1**	**0**	**Green**	**Lemon-Lime**	**Yellow**	**Orange**	**Red**
Current Scores	#	Newly Added- no change in individual variable						88	541	704	328	26
	%							5	32	42	19	2
Adding Floodplain Fill, scored 0,1,2 out of 5	#	0	0	0	135	345	1207	7	294	813	523	50
	%	0	0	0	8	20	72	0	17	48	31	3
Difference	Δ%							-4.8	-14.6	6.5	11.6	1.4
Adding Floodplain Fill, scored 0,3,5 out of 5	#	135	0	345	0	0	1207	49	350	763	482	43
	%	8	0	20	0	0	72	3	21	45	29	3
Difference	Δ%							-2.3	-11.3	3.5	9.1	1.0
Adding Floodplain Fill, scored 0,1,2, out of 2	#	0	0	0	135	345	1207	79	465	813	308	22
	%	0	0	0	8	20	72	5	28	48	18	1
Difference	Δ%							-0.5	-4.5	6.5	-1.2	-0.2

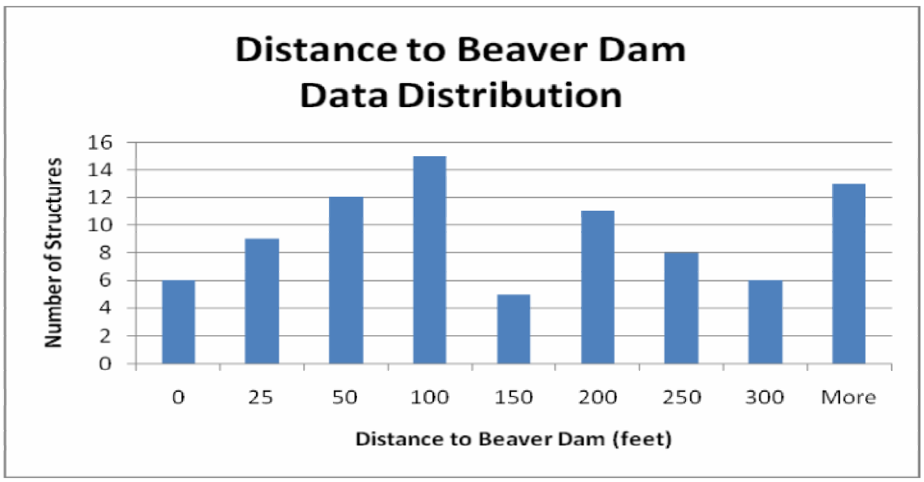
Alternative 4: Addition of Avulsions Path Variable

The path if the stream avulses has a different relationship to geomorphic processes than most of the other variables used in the screening tool. This is a potential hazard that is a symptom of an incompatible structure. Therefore this variable would not add much information to the screen describing the actual geomorphic condition by describing altered channel form or process. Another concern with this particular variable is the vague nature of the information, and that the majority of the structures are in the Cross Road category which would skew the scoring.



Alternative 5: Addition of Beaver Dam Variable

The beaver dam variable has not been included in the screening of structures. Beaver dams are highly variable and easily removed/ destroyed/ abandoned. A beaver dam being present does not provide information as to the geomorphic compatibility of the structure. It does not adequately identify either structural problems or stream response symptoms of an incompatibility. This is a variable which could continue to be included in the query for the failure modes report. Beaver dams are not included in the queries at this point unless they are closer than 25 feet to the structure. This value does not capture most beaver dams. The actual distance these dams affect a culvert may want to be expanded to 100 feet.



Alternative 6: Addition of Outlet Type Variable

Although culvert outlet type does give an indication of downstream scouring or degradation at the mouth of the culvert, it is only partially indicative of geomorphic change. A culvert that was originally designed and installed perched would also show up as a Free Fall, without scour or degradation as the cause.

Outlet Type:	All Structures	Only Structures with Downstream Scour
Total #	1687	607
At-Grade	39%	26%
Cascade	16%	16%
Free Fall	45%	58%

The occurrence of each outlet type was examined to see how the distribution of the entire database compared to just structures with downstream scour. The distribution of this variable is similar for all the structures and only the structures with downstream scour. This indicates that in the database outlet type is not strongly correlated with downstream scour occurrence, although there are a larger percentage of Free Fall outlets in structures with downstream scour. The variables of downstream scour and presence of high banks downstream identify the processes of scour and sediment discontinuity with a higher confidence than this variable. This variable is not included in the screening tool at this time.

Alternative 7: Addition of # of Culverts Variable

Double barrel culverts are known to negatively affect debris and sediment transport within reaches, due to variable flow patterns associated with turbulent flow and stagnation points. These culverts should be identified and replaced as soon as possible. The culvert screen score distributions were similar for the multiple opening structures as compared to the overall database. This indicates that the geomorphic compatibility difficulties presented by these structures with multiple openings are not picked up in the current screening tool.

The number of culverts was explored as an additional variable for inclusion in the screening tool. This variable was found to dramatically skew the overall results of the screening scores as seen below, due to the vast majority of the structures with just one opening. In general, the overall scores were shifted up to indicate more structures are more compatible with geomorphic processes. This variable is not included in the screening tool at this time. If this variable is to be included in the future, we suggest screening these structures out before the screening tool is used.

		Variable Score Distribution						**Screen Score Distribution**				
		5	**4**	**3**	**2**	**1**	**0**	**Green**	**Lemon-Lime**	**Yellow**	**Orange**	**Red**
Current Scores	#	Newly Added- no change in individual variable						88	541	704	328	26
	%							5	32	42	19	2
Adding Number of Culverts 1 = 5, more = 0, out of 5	#	1620	0	0	0	0	67	166	749	677	93	2
	%	96	0	0	0	0	4	10	44	40	6	0
Difference	Δ%							4.6	12.3	-1.6	-13.9	-1.4
Adding Number of Culverts 1 = 3, more = 0, out of 5	#	0	0	1620	0	0	67	38	608	815	221	5
	%	0	0	96	0	0	4	2	36	48	13	0
Difference	Δ%							-3.0	4.0	6.6	-6.3	-1.2

Alternative 7: Addition of Steep Riffle Immediately Upstream to the Sediment Discontinuity Variable

The steep riffle immediately upstream is a variable indicating a sediment discontinuity. At this time this variable is not included in the sediment discontinuity scoring with upstream deposition and downstream scour, although it could be added. 67% of the structures with upstream deposits were reported as having a steep riffle immediately upstream. This means that many of the structures with a steep riffle upstream are already included in the sediment continuity variable. In the database there are 15% of the structures which have a steep riffle, but do not have an upstream deposit.

Steep riffles could be included into the screening tool as a condition similar to upstream deposits. Including steep riffles in the sediment continuity variable would identify these 15% of the structures and assign them lower scores due to the inclusion of steep riffles in the scoring criteria. This variable is not included in the screening tool at this time.

	Total # Structures with Steep Riffle	% of total structures with Steep Riffle	Total # Structures with Up Deposits	% of total structures with UpDeposits	# Structures with steep riffle and UpDeposits	% of structures with steep riffle and UpDeposits
yes	958	56%	1061	63%	706	42%
no	724	43%	626	37%	981	58%
blank	5	0%	9	1%		

Appendix F – Coding for Sediment Continuity and Erosion Variables

Score	Sediment Continuity Score Description	Sediment Continuity Score Coding
5	neither occur	(Downstream Bed Scour = None) AND (Upstream Bed Deposit = None)
4	one occurs, but it is small	(Downstream Bed Scour = Not None AND High Banks = No) OR (Upstream Bed Deposit = Not None AND Deposit Elevation <.5 BF)
3	only one occurs, but it is large	(Downstream Bed Scour = Not None AND High Banks = Yes (or blank)) OR (Upstream Bed Deposit = Not None AND Deposit Elevation >.5 BF (or blank))
2	both are small	(Downstream Bed Scour = Not None AND Down High Bank = No) AND (Upstream Bed Deposits = Not None AND Deposit Elevation <.5 BF)
1	both occur, but one is large and other is small	{(Downstream Bed Scour = Not None) AND (Upstream Bed Deposits = Not None)} AND {(Down High Banks = Yes (or blank) AND Deposit Elevation <.5 BF) OR (Down High Banks = No AND Deposit Elevation >.5 BF (or blank))}
0	both are large	(Downstream Bed Scour = Not None AND Down High Bank = Yes (or blank)) AND (Upstream Bed Deposits = Not None AND Deposit Elevation >.5 BF (or blank))

Score	Erosion and Armoring Score Description	Erosion and Armoring Score Coding
5	no erosion AND no armoring	(UpErosion = None AND DnErosion = None) AND (UpArmoring = None AND DnArmoring = None)
4	no erosion and intact armoring OR low erosion and no armoring	{(UpErosion = None AND DnErosion = None) AND (UpArmoring = Intact, Unknown, Blank OR DnArmoring = Intact, Unknown, Blank)} OR {(UpErosion = Low OR DnErosion = Low) AND UpArmoring = None AND DnArmoring = None}
3	low erosion up OR down, armored	UpErosion = Low OR DnErosion = Low (armored)
2	low erosion up AND down	UpErosion = Low AND DnErosion = Low
1	high erosion up OR down, if armored then intact	UpErosion = High OR DnErosion = High
0	high erosion both up and down OR any failing armoring	(UpErosion = High AND DnErosion = High) OR (UpArmoring = Failing OR DnArmoring = Failing)