New Hampshire DOT

Research

Assessment of Embedded Culvert Low Flow Hydraulics

Final Report

Prepared by University of New Hampshire Department of Civil and Environmental Engineering, College of Engineering and Physical Sciences, in cooperation with the U.S. Department of Transportation, Federal Highway Administration

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16. Abstract

In 2010, New Hampshire adopted new rules for the permitting of stream crossings. One aspect of the new rules was that new culverts should be geomorphically sized and preferably have natural materials located at the stream crossing stream bed to better accommodate the passage of aquatic and other organisms. In culverts that are not open bottom, this means oversizing the culvert and partially filling the bottom with natural material. This partially filled culvert is known as an embedded culvert. Often the material placed in the embedded culvert is specifically sized to match the native material in the stream as well as to be stable. Very coarse sediments are needed for stability, and, at low flows, the water can completely disappear into these sediments leaving no aquatic habitat. While culverts are recommended to be embedded, the practice is criticized for its impact on aquatic habitat.

The proposed research had two thrusts: to study constructed embedded culverts in New Hampshire and to complete literature reviews and interviews with other states that require embedded culverts. For the field monitoring portion embedded culverts at various ages were inspected and the bed sediments were sampled for particle size distribution analysis and comparison to that of the design when available. Aquatic organism passage was assessed at low flows. The products of this research provide a diagnosis of the issue, real or perceived, and the elements of bed sediment design leading to successful embedded culverts that provide passage for aquatic organisms.

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18 February 2022

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Introduction

In 2010, New Hampshire adopted new rules for the permitting of stream crossings. One aspect of the new rules was that new culverts should be geomorphically sized and preferably have natural materials located at the stream crossing stream bed to better accommodate the passage of aquatic and other organisms. Geomorphically-designed embedded culverts are in general more resilient to climate change and also are intended to provide aquatic organism passage. In culverts that are not open bottom, for example a circular concrete pipe, this means oversizing the culvert and then partially filling the bottom with natural material (sands/gravels/rock) thereby essentially burying (embedding) the bottom of the culvert. This partially in-filled culvert is known as an embedded culvert. Often the material placed in the embedded culvert is specifically sized to match the native material in the stream as well as to be stable. The bed material sizing method for the embedded culvert normally starts with what is in the stream away from the culvert, for example at upstream riffles (shallow and faster flowing sections of streams, with locally steeper slopes). However, the larger the stream entrenchment ratio (floodplain width compared to bankfull width), the more that floodwaters are funneled into the culvert rather than naturally flowing along the floodplain. This then increases shear stresses in the embedded culvert compared to that of the natural stream, with the result being the necessity for embedment material larger than that in the stream. This can result in very coarse sediments placed in the culvert that exhibit high porosity and permeability. As such, at low flows water can completely disappear into these sediments leaving no aquatic habitat: a dry streambed makes it impossible for fish to move upstream or downstream. Thus, while culverts are recommended to be embedded, the practice is criticized for its impact on aquatic habitat.

Objectives

The objectives of this research are to: understand the hydraulic consequences of embedded culverts; assess if installations to date exhibit loss of aquatic organism passage via too porous sediments; synthesize current knowledge of embedment designs, inspect/assess previously embedded culverts, and modify design protocols to avoid such an undesirable consequence. The fundamental concern was that the embedment material specified for embedded culverts is so coarse that at low stream=flows, the stream disappears into those sediments: a condition known as "hyporheic".

Scope of Work

The proposed research has two fundamental thrusts: to field study constructed embedded culverts in NH, and a thorough literature review of the specific topic of embedded culverts creating hyporheic condition. The office portion of the research began with a literature review of embedded culvert practices across the United States. Additionally, regulators in other states were contacted to solicit their experiences with embedded culverts. This included gathering design specifications from those jurisdictions.

NH DOT provided a list of its embedded culverts and other entities (consultants, The Nature Conservancy, Trout Unlimited, and NH DES) augmented the list with permitted and constructed non-DOT structures. NH DOT personnel were interviewed to solicit if they installed embedded culverts and to collect their design plans. Embedded culverts from all sources were targeted for field visits. Knowledge of the location of each culvert also allowed investigation into watershed and hydrologic characteristics draining to each culvert. These characteristics were documented via online resources such as StreamStats and GRANIT. The NHDOT and NHDES culvert databases also yielded embedded culvert metadata such as: year constructed, embedment particles size distribution, embedment depth, etc.

For the field assessment portion of the research, all identified constructed embedded culverts were inspected, however not all had the design plans available. Bed sediments were sampled for particle size distribution analysis. Embedment depth was measured. Culverts were visited at low flow times to assess permeability and loss of above ground streamflow. The bed sediment particle size distribution and depth of infill at the time of inspection was compared to that of the design. Aquatic organism passage was assessed using standard geometric indicators as well as field observations at low flows.

Embedded culverts that demonstrated lack of infill imbrication and/or loss of aboveground flow were forensically studied to determine: the fundamental reason for the lack of intended performance; the designs facets leading to this performance; and potential remedies.

Results

Regulatory Experience

Officials from different states were interviewed via phone or email on their experience with embedded culverts specifically on the issue of low flows disappearing into the embedding sediment (a phenomenon known as “hyporheic”). The objective of the interviews was to synthesize current knowledge on embedded culvert designs and modifications to further enhance designs to avoid undesirable consequences such as loss of embedded material or subsurface flows. Regulations for the following states were found and contributing authors were contacted: New Hampshire, Massachusetts, Maine, Vermont, Connecticut, Rhode Island, Pennsylvania, New York, Oregon, Washington, California, Idaho, Alaska, and Montana.

Experience with embedded culverts from the regulatory perspectives ranged from almost no experience to roughly 35 years of direct experience. Overall perception of success or failure of embedded culverts is that they are more successful for aquatic organism passage (AOP), unless designed improperly. If not constructed properly, they needed to be remediated because of the common issue of sediment scouring (loss of the embedded sediments). Most states also require that an embedded culvert be constructed with a width no less than 1.2 bankfull widths with a recommended slope of less than 4%. The bankfull condition is depicted in Figure 1 and is a stream preferred geometry (width and depth) to move the dominant water and sediment loads. It was believed that the steeper the culvert slope, the more likely the sediment is to wash out. Modifications to the embedded culvert system may be made to prevent these problems from occurring, such as sills (also referred to as baffles), or larger stone (rock bands) that mimic sills, to retain the infill material. Sills are permanent culvert bed obstructions whereas rock bands are regularly spaced large rocks that are immobile even at the largest flows. If the incorrect mixture of infill material is added to the system, subsurface (hyporheic) flows may result. Subsurface flows can be prevented by using natural sediment from upstream or by washing in enough fines after infill installation to fill in any voids and pack down the sediment. As the system ages, the stream should help with natural transport of sediment to fill over time any voids left during embedment construction. To repeat, none of the interviewee's field investigated embedded culverts in their jurisdiction, rather these were the opinions of the interviewees. Remediation of embedded culvert systems are not common as embedded culverts are typically installed and not maintained due to limited amount of funding unless the failed culvert is a hazard to public safety. The number of embedded culverts that exist or are being installed and the rate of success/failure vary from state to state. Appendix A contains detailed information collected on the general design specifications of embedded culverts in different states.

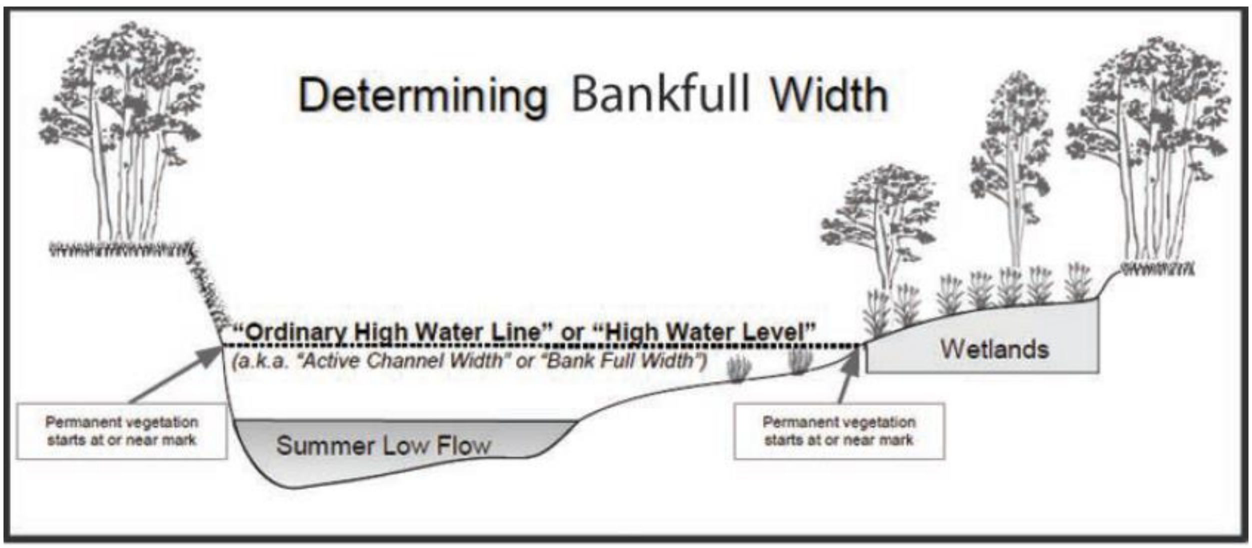

Figure 1. The bankfull condition (MEDOT, Stream Smart Road Crossing Pocket Guide)

New Hampshire Field Work

During the summers of 2019, 2020, and the early Fall of 2021, 28 embedded culverts from NHDOT, NH F&G, and other sources were visited. Of the sites, 22 were DOT, 5 were F&G and 1 was available from a consultant. The sites ranged in geographical location across New Hampshire (Figure 2). At each site, longitudinal profiles, culvert dimension measurements, stream gauging, bed sediment sampling, and aquatic organism passage assessments were performed. Longitudinal profiles were performed along the centerline of the streambed and culvert using the locations shown in Figure 3. Measured culvert dimensions included: culvert length, culvert inlet and outlet dimensions, along with any additional culvert features. Stream gauging was performed at the inlet and outlet of the culvert to assess any loss potentially due to hyporheic conditions. Bed sediment sampling was performed within the inlet, center, and outlet thirds of the culvert and particle size distributions (PSD) were performed if most sediment was less than or equal to pebble size. For larger sediment, a Wolman pebble count was performed to estimate the particle size distribution, which involved measuring and recording the median axial length of 100 sediment particles per sample location. Aquatic organism passage was visually assessed using the Vermont Aquatic Organism Passage Coarse Screen method shown in Figure 4. Stream bankfull widths were also measured and pictures were taken to catalog visits. This data is found in Appendix B.

It was found that some sites performed adequately during low flows as seen in Figure 5, but other sites either had a loss of bed material or were in hyporheic conditions, as seen in Figures 6 and 7, respectively. A loss of sediment or hyporheic conditions will inhibit aquatic organism passage.

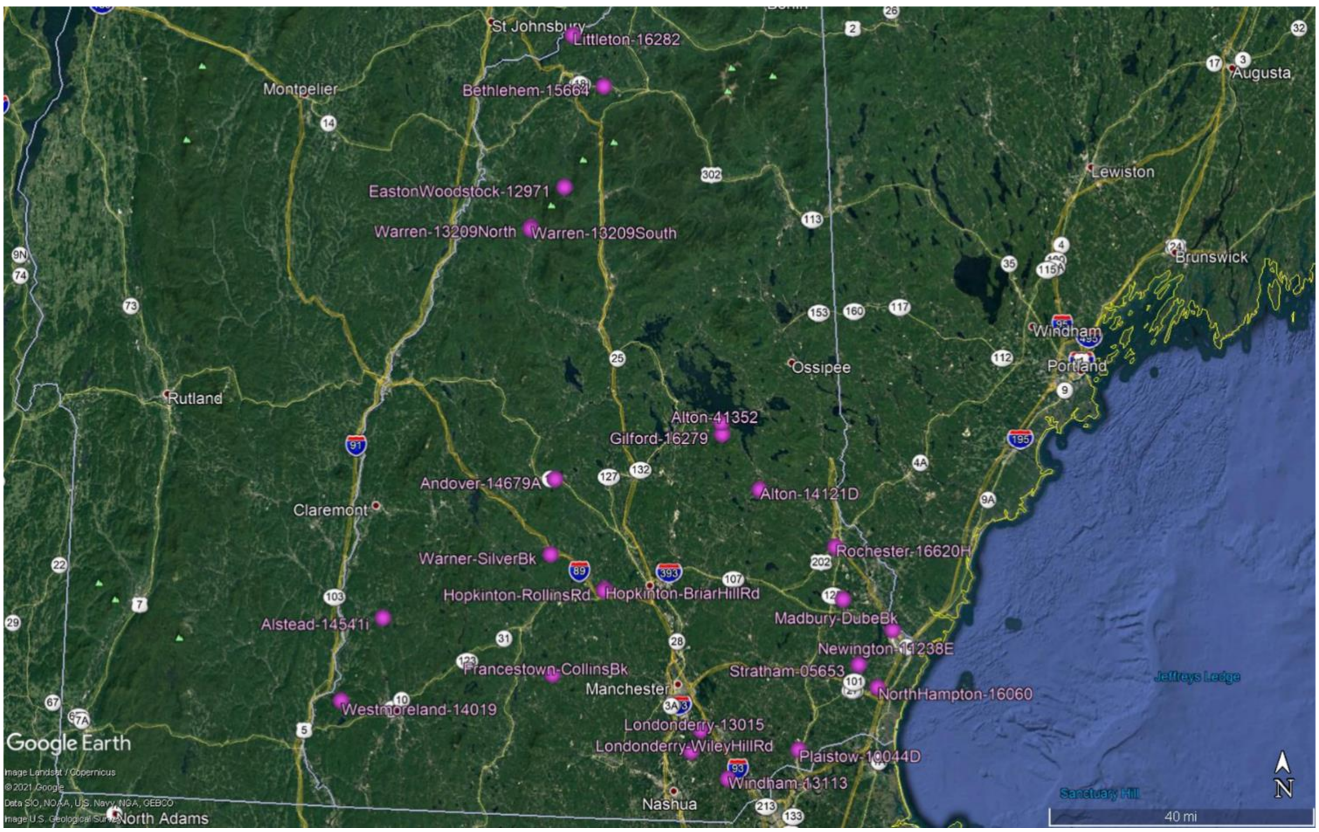

Figure 2: Studied Embedded Culvert Site Locations (purple circles)

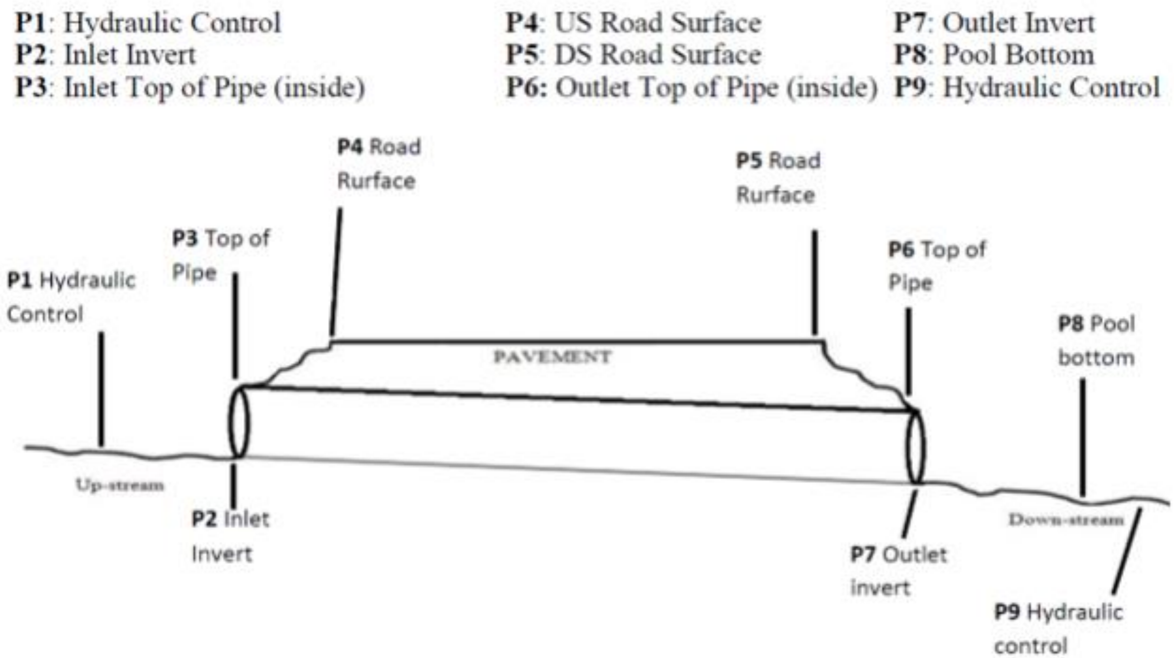

Figure 3: Culvert Longitudinal Profile Points

VT Aquatic Organism Passage Coarse Screen	Full AOP	Reduced AOP	No AOP			
Updated 2/25/2008	for all aquatic organisms	for all aquatic organisms	for all aquatic organisms except adult salmonids		for all aquatic organisms including adult salmonids	
AOP Function Variables / Values	Green (if all are true)	Gray (if any are true)	Orange		Red	
Culvert outlet invert type	at grade **OR** backwatered	cascade	free fall **AND**		free fall **AND**	
Outlet drop (ft)	= 0		> 0 , < 1 ft **OR**		≥ 1 ft **OR**	
Downstream pool present			= yes	(= yes **AND**	= no **OR**	(= yes **AND**
Downstream pool entrance depth / outlet drop			n/m	≥ 1)	n/a	< 1) **OR**
Water depth in culvert at outlet (ft)					< 0.3 ft	
Number of culverts at crossing	1	> 1				
Structure opening partially obstructed	= none	≠ none				
Sediment throughout structure	yes	no				

Notes:
Assessment completed during low flows.
Outlet drop = invert of structure to water surface.
Pool present variable is used alone if pool depths are not measured.
n/m = not measured.
n/a = not applicable.

Figure 4: Vermont Aquatic Organism Passage Coarse Screen Table

Figure 5: Outlet of Gilford Culvert, performing adequately at low flow conditions

Figure 6: Outlet of Bethlehem Culvert, loss of bed material

Figure 7: Outlet of Londonderry, Wiley Hill Road Culvert, in hyporheic conditions

The number of culverts with hyporheic issues is presented in Figure 8: 21 of the 28 study culverts (61%) exhibited no hyporheic conditions.

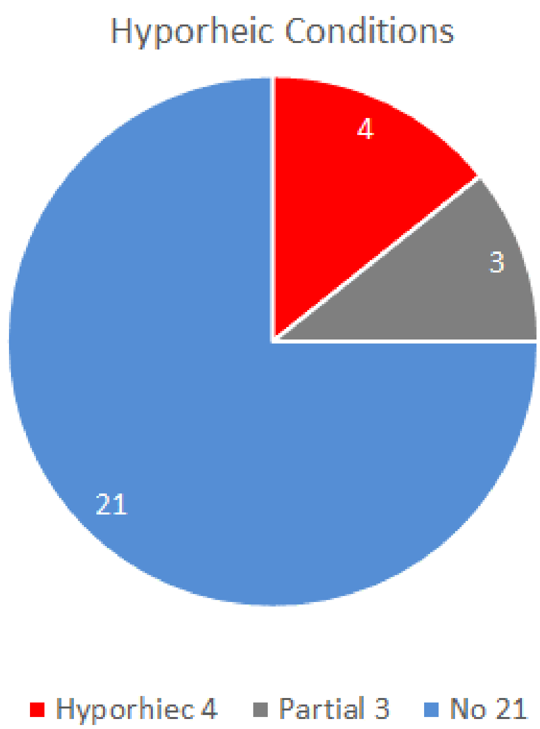

Figure 8. Hyporheic culverts.

The number of culverts that had not lost sediment was 17 of the 28 culverts in the study (61%) (Figure 9). This does not infer that the sediment in the culverts was the same as that placed at the time of construction. Very few of the culverts in the study had available the particle size distribution at the time of construction. Of the culverts that lost some or all sediment, all were NH DOT culverts and 6 of these 7 culverts specified the 304.7 sediment. All those culverts were built before 2013. The last embedded culvert to use the 304.7 specification was constructed in 2017 and was a tidal culvert that had not lost sediment.

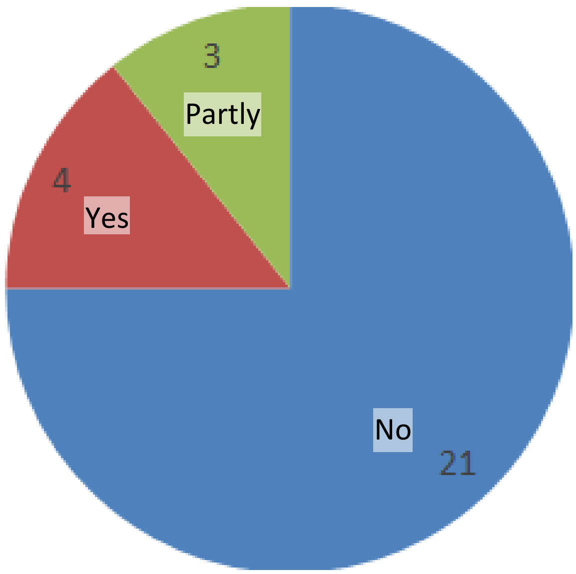

Figure 9. Culverts that Lost Sediment

One factor that can improve AOP and retain sediment is if there are backwater conditions on the culvert (water from downstream backing up to the culvert). Figure 10 indicates the culverts with backwater conditions (including tidal). Of the 5 backwatered culverts: all had sediment, one was partly hyporheic, and none were completely impassable.

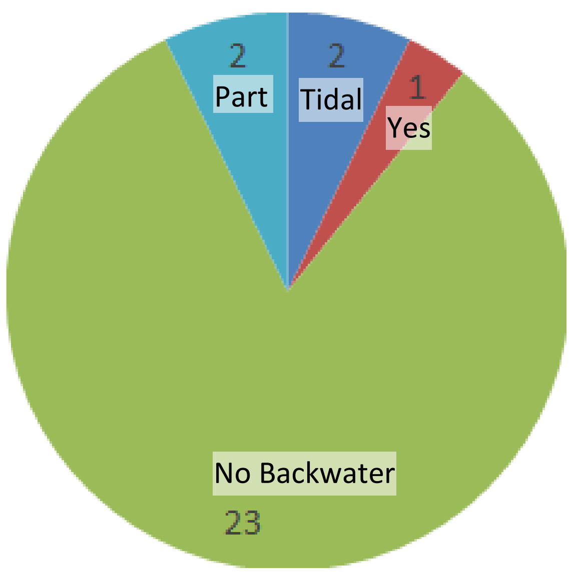

Figure 10. Culvert Hydraulic Control

A synthesis of just the seven hyporheic culverts of Figure 8 appears in Figure 11. Baffles did not necessarily prevent the embedded material from going hyporheic.

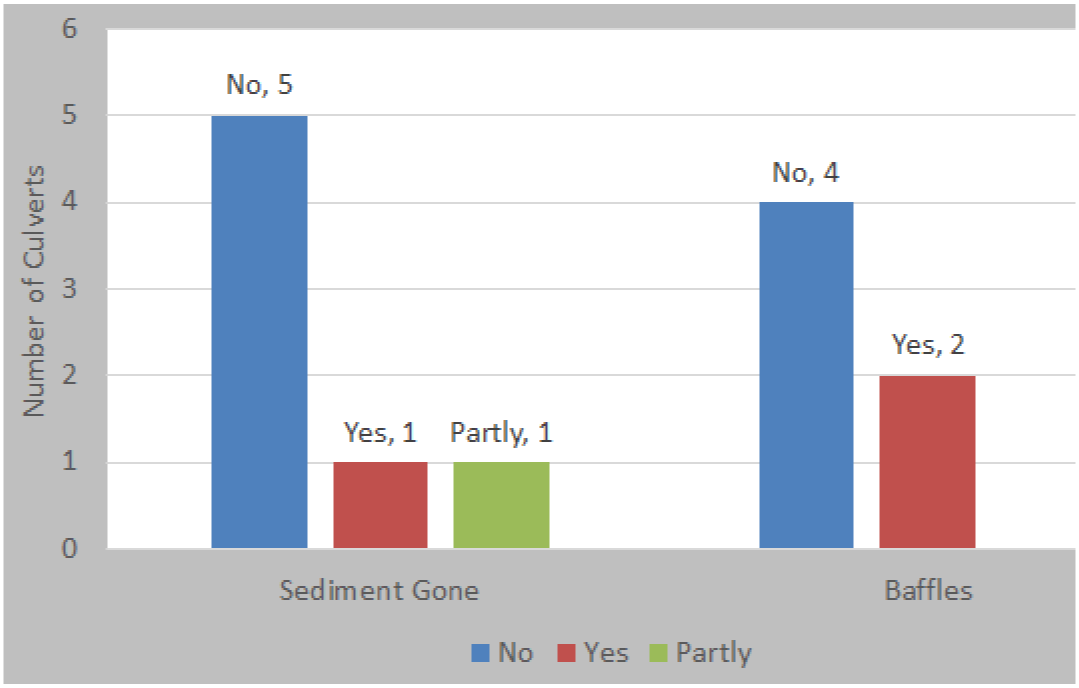

Figure 11. Statistics for the seven hyporheic culverts

Figure 12 demonstrates that although baffles may help hold sediment, baffled, embedded culverts may still lose their sediment. Of the 28 culverts in this study, four had baffles (each a NH DOT culvert) and one partially lost sediment, the other three retained their sediment. Three of the four NH DOT baffled culverts were built before 2016.

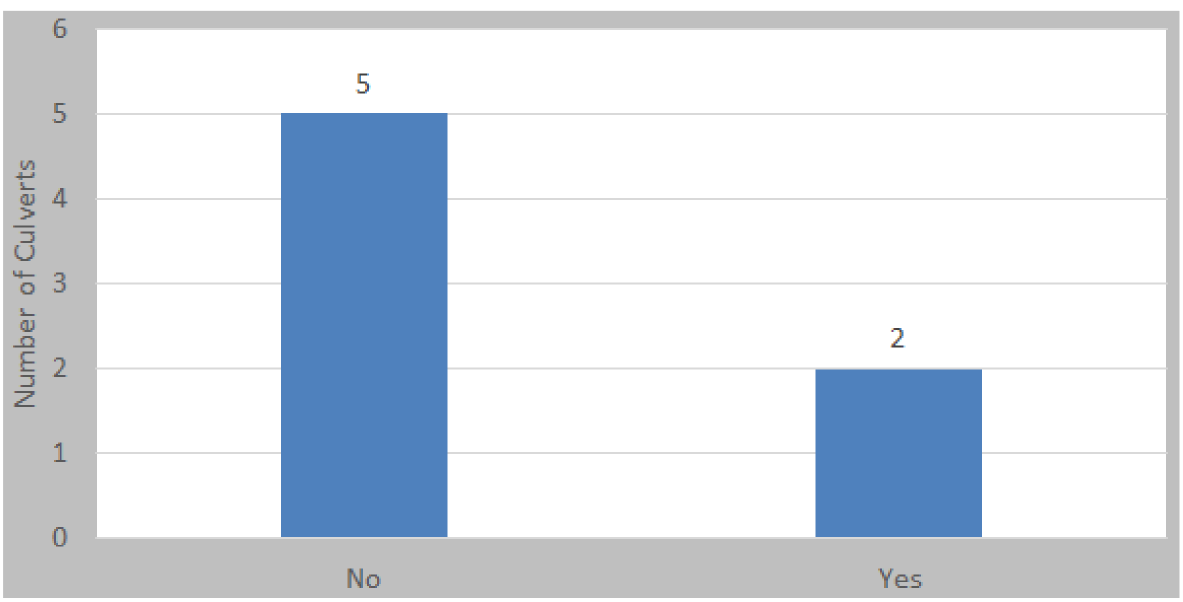

Figure 12. Relationship between the seven culverts that lost sediment on whether they had baffles.

Slope itself did not seem to be a good predictor of losing culvert sediment, as seen in Figure 13. This may indicate that sediment loss is more related to the stream entrenchment ratio and high flow bed shear stress than just slope alone.

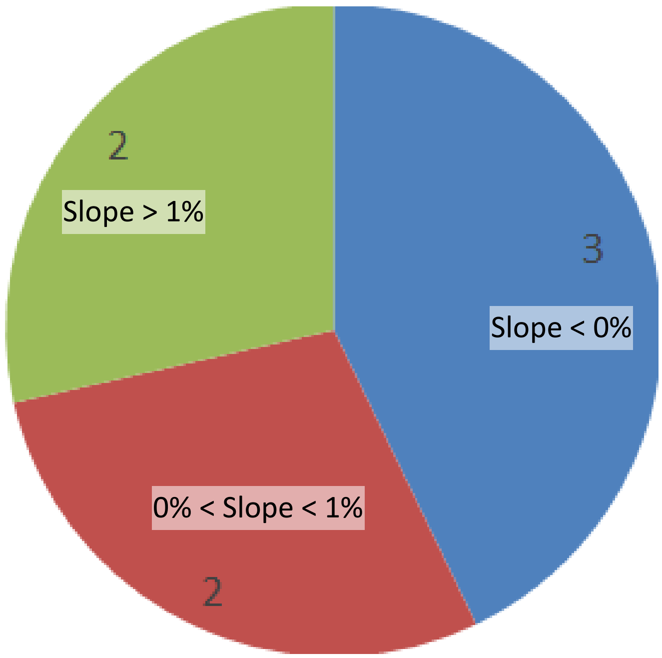

Figure 13. Relationship of slope for the seven culverts that lost sediment.

To explore the aspect of culvert slope further, the entire data set is plotted in Figure 14 and stratified by culverts that lost all, partial or no sediment. Here the field-measured culvert slope is plotted for each culvert. It may be seen that there is no strong statistical relationship between slope and whether culverts lost sediment. The steepest culvert in this dataset, is a NH DOT culvert on Carpenter Brook in Littleton, NH. The field-measured culvert slope for this culvert was 5.93% (the design plans indicated 7.42% slope). This culvert lost some sediment at the inlet. It also has baffles and is backwatered.

AOP was not guaranteed by embedment alone. Streambed material is but one criterion in the AOP assessment. Figure 15 displays the AOP assessments of all culverts in this study. As demonstrated in the Figure, of the seven culverts that lost sediment (Figures 9 and 12), two had full AOP primarily because of ponded/backwatered conditions in those two culverts.

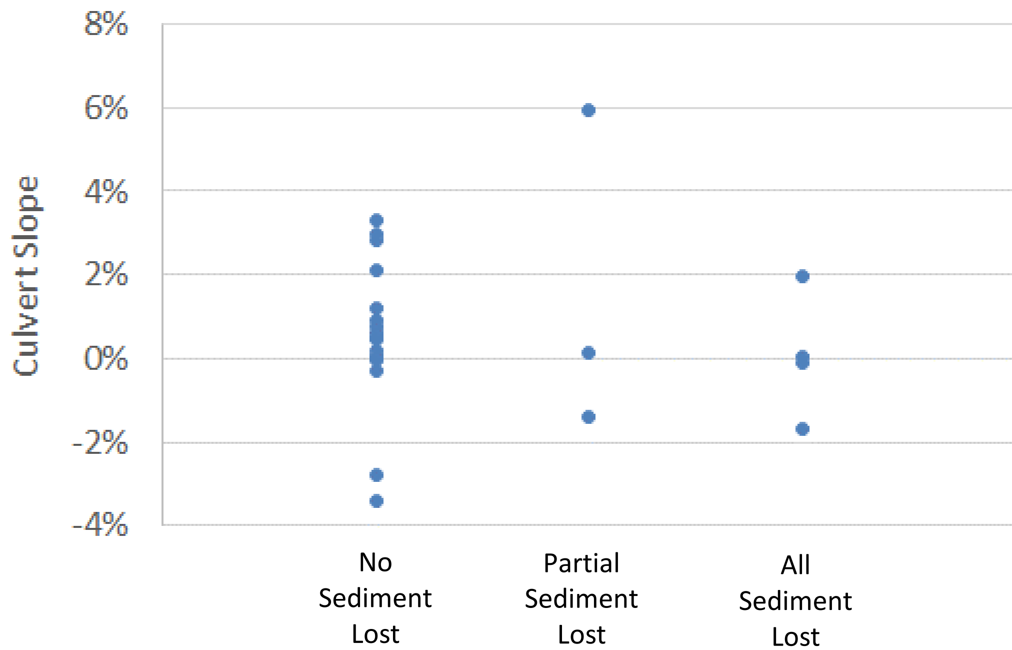

Figure 14. Relationship between field-measured culvert slope and embedded sediment loss.

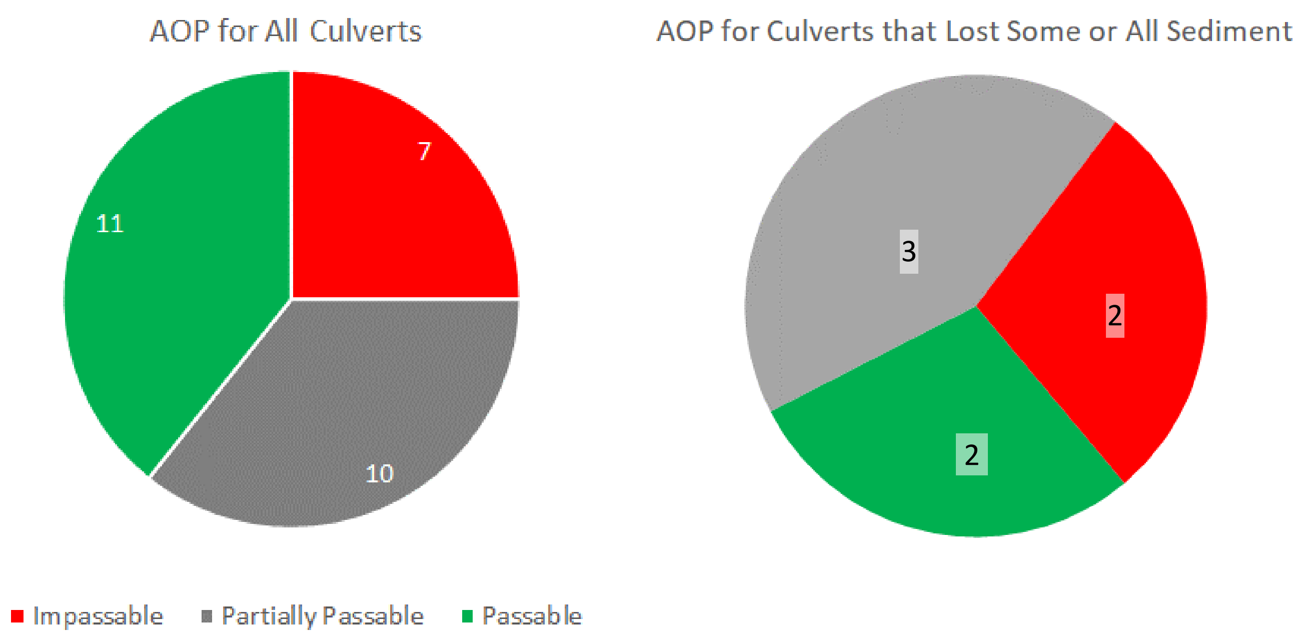

Figure 15. Aquatic Organism Passage (AOP) for all culverts (left) and those that lost some or all Sediment (right). Green – fully passable, Grey – passable by only best swimming fish, Red – impassable.

When culverts were hyporheic, some were still passable in that the entire culvert width was not hyporheic (Figure 16). However the majority of non-hyporheic embedded culverts afforded some AOP (Figure 15).

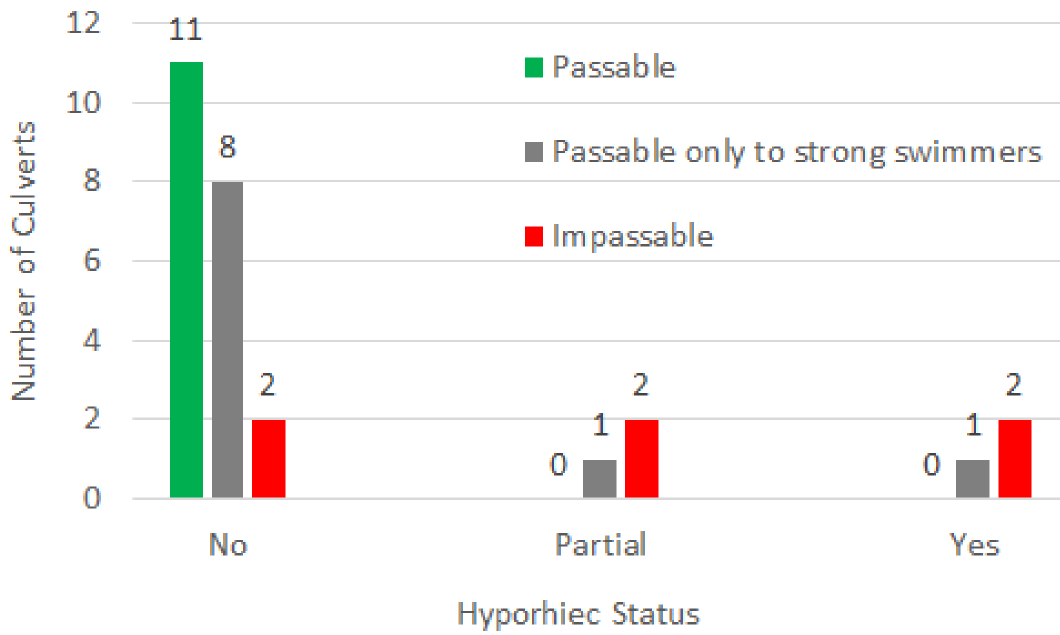

Figure 16. Aquatic Organism Passage for culverts that were Partially or Fully Hyporheic (Green – fully passable, Grey – passable by only best swimming fish, Red – impassable).

AOP appeared higher for non-baffled embedded culverts (10 of 24 fully passable) than baffled, embedded culverts (1 of 4 fully passable), or as stated previously, baffling does not necessarily enhance AOP, sediment retention, or reduce hyporheic conditions (Figure 17). Overall, the causes for limited passability in the culverts of this study had more to do with the stream than the culvert. Of the seventeen culverts that were not fully passable (Figure 17, left panel), 6 of these results were due to conditions in the culverts (steps, hyporheic, water depth) and 11 results were due to stream conditions just outside of the culverts (steps, hyporheic).

Watershed and Hydrologic Site Characteristic and Culvert Metadata

Using the StreamStats application, watershed data for each site were obtained via delineating watersheds from the downstream end of the culverts. The downstream end of the culvert was used instead of the upstream as it recognizes what the stream immediately downstream of the culvert experiences for hydrology and is consistent with the physical culvert survey that includes the stream downstream of the culvert. With this data and using NH regression equations for flood discharges at selected recurrence intervals, Q2, Q10, Q50, and Q100 discharges were calculated for each site. These results appear in Appendix C. Using the culvert hydraulics program HY8, each culvert was modeled using design and field measurements as well as the outputs from StreamStats to calculate the inlet or outlet control, normal depth, and velocity for Q2 and Q100 conditions. These outputs also appear in Appendix C.

Using DOT and other databases, culvert metadata was obtained. This metadata includes embedment particle size distribution, embedment depth, and other culvert design specifications. This data was used to determine if there are apparent causes for aquatic organism passage failure through the culverts. This data appears in Appendix D.

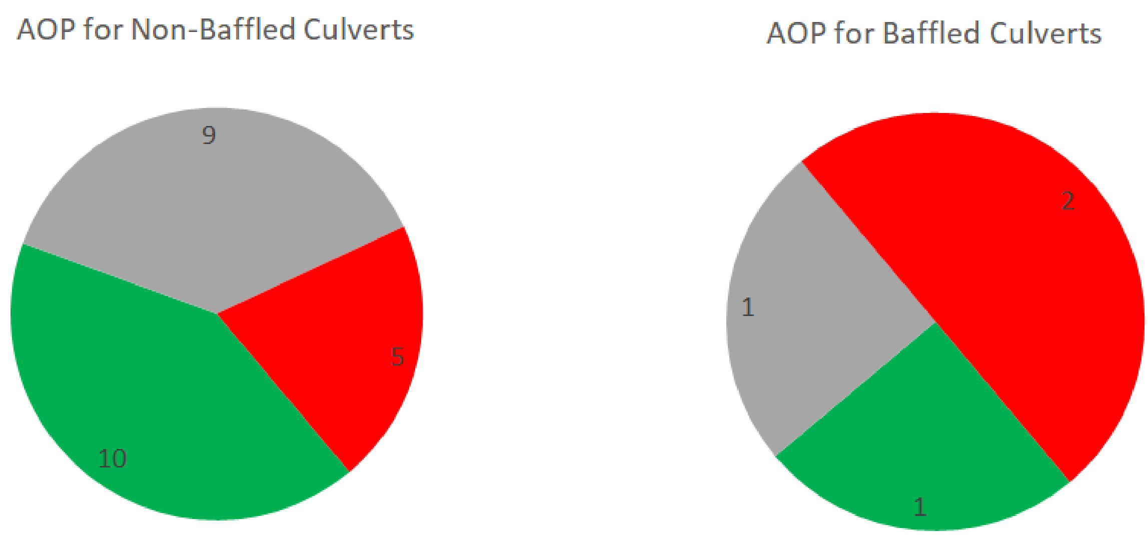

Figure 17. Aquatic Organism Passage for Culverts With and Without Baffles (Green – fully passable, Grey – passable by only best swimming fish, Red – impassable).

Embedded Culvert Performance

2020 exhibited very low streamflow conditions statewide for most of the summer. Most sites were visited that summer to investigate low flow performance. Table 1 shows which sites were hyporheic, lost sediment, or both.

Town	Project #	Stream	Design Embedment PSD
Alstead, NH	14541i	*No Name*	Items 585.21 and 209.4
Alton, Route 11, NH	41352	*No Name*	Item 585.3401 - Simulated Streambed Material
Alton, Stockbridge Corner, NH	14121D	*No Name*	
Andover, NH	14679A	Mitchell Brook	Excavated Channel Material
Bedford, NH	N/A	McQuesten Brook	
Bethlehem, NH	15664	Barrett Brook	Item 304.7 - Stream Lining Gravel
Concord, NH	N/A	Mill Brook	
Easton-Woodstock, NH	12971	Stony Brook	Granular Backfill
Francestown, Pleasant Pond Road, NH	Non-Dot	Collins Brook	
Gilford, NH	16279	West Alton Brook	Item 585.3402 - Simulated Streambed Material
Hopkinton, Briar Hill Road, NH	Non-Dot	*No Name*	
Hopkinton, Rollins Road, NH	Non-Dot	*No Name*	
Littleton, NH	16282	Carpenter Brook	Item 304.7 - Stream Lining Gravel
Londonderry, NH	13015	Little Cohas Brook	Item 304.7 - Stream Lining Gravel
Londonderry, Wiley Hill Road, NH	Non-Dot	*No Name*	
Madbury, NH	Non-Dot	Dube Brook	
Newington, NH	11238E	*No Name*	Item 304.7 - Stream Lining Gravel
Newmarket, NH	N/A	Lubberland Creek	
North Hampton, NH	16060	Winnicut River	Item 304.7 - Stream Lining Gravel
Plaistow, Kelly Brook, NH	10044D	Kelly Brook	Stone Fill, Class C (Typ)
Plaistow, Pollard Road, NH	N/A	Seaver Brook	
Rochester, NH	10620H	Axe Handle Brook	Stone Fill, Class D (Typ)

Table 1 part 1: Site Metadata with Hyporheic and Sediment Assessment Sites highlighted in yellow were hyporheic. Sites highlighted in red partially or fully lost bed sediment. Sites highlighted in orange were both hyporheic and lost bed sediment. 11 of the 28 sites had one or both problems

Town	Project #	Stream	Design Embedment PSD
Stratham, NH	15653	Jewel Hill Brook	Item 304.7 - Stream Lining Gravel
Warner, North Village Road, NH	Non-Dot	Silver Brook	
Warren, NH North	13209	*No Name*	Item 304.7 - Stream Lining Gravel
Warren, NH South	13209	*No Name*	Item 304.7 - Stream Lining Gravel
Westmoreland, NH	14019	*No Name*	No embedment material specified
Windham, NH	13113	Berry Brook	Item 585.2 - Stone Fill, Class B

Table 1 part 2: Site Metadata with Hyporheic and Sediment Assessment Sites highlighted in yellow were hyporheic. Sites highlighted in red partially or fully lost bed sediment. Sites highlighted in orange were both hyporheic and lost bed sediment. 11 of the 28 sites had one or both problems.

Culvert Bed Particle Size Distribution

Between the bed sediment sampling and Wolman pebble counts, D10, D50, D85, and D100 for the upstream, center, and downstream thirds of the culverts were determined. This data appears in Appendix E. Most of the NHDOT designed embedment material specified 304.7 material and its successor 585.3401. The oldest 304.7 specification encountered by NHDOT was dated 11/6/2003 and it had the requirements to closely match existing streambed material and washing to remove fines. This specification was likely used as a template until 2016, when the 585.3401 specification was created. The 304.7 spec may have had project specific modifications and it would have been treated as a true specification, although a very general one. The more recent 304.7 (date of change 2016) states to use material which closely matches the existing stream bed and that the material shall be washed beforehand to remove as much fines as possible. Specification 585.3401 added a table to include the breakdown of culvert bed material in terms of sand, gravel, cobble, and boulder. It is made very clear in both documents that each project will have its own unique conditions, but the goal is to have culvert bed material that simulates existing stream material.

Statistical Analysis

A Principal Component Analysis was performed on the culvert metadatabase to determine connections between variables and culvert performance. Principal Component Analysis is performed to reduce many variables while retaining the variation of the original data. A preferred result is to obtain few principal components that explain most of the variation in the data.

The results of the analysis may suggest that hyporheic sites are caused by culvert, not watershed characteristics and hyporheic sites are caused by culvert dimensions, not culvert slopes. Figure 18 shows a loading plot with the first two principal components as the axes. The farther the variable is from the origin, the stronger its influence on the principal component. Figure 19 shows a score plot which shows how other site variables compare to the first two principal components. Figure 20 displays the eigenvalues of each principal component and the cumulative percent of the variation that each principal component explains. The results of the analysis demonstrate that the principal components are not able to adequately explain the variation in the data. For the culvert data, the first two principal components only explain about 50% of the variation, where above 80% is preferred in order to make a strong conclusion.

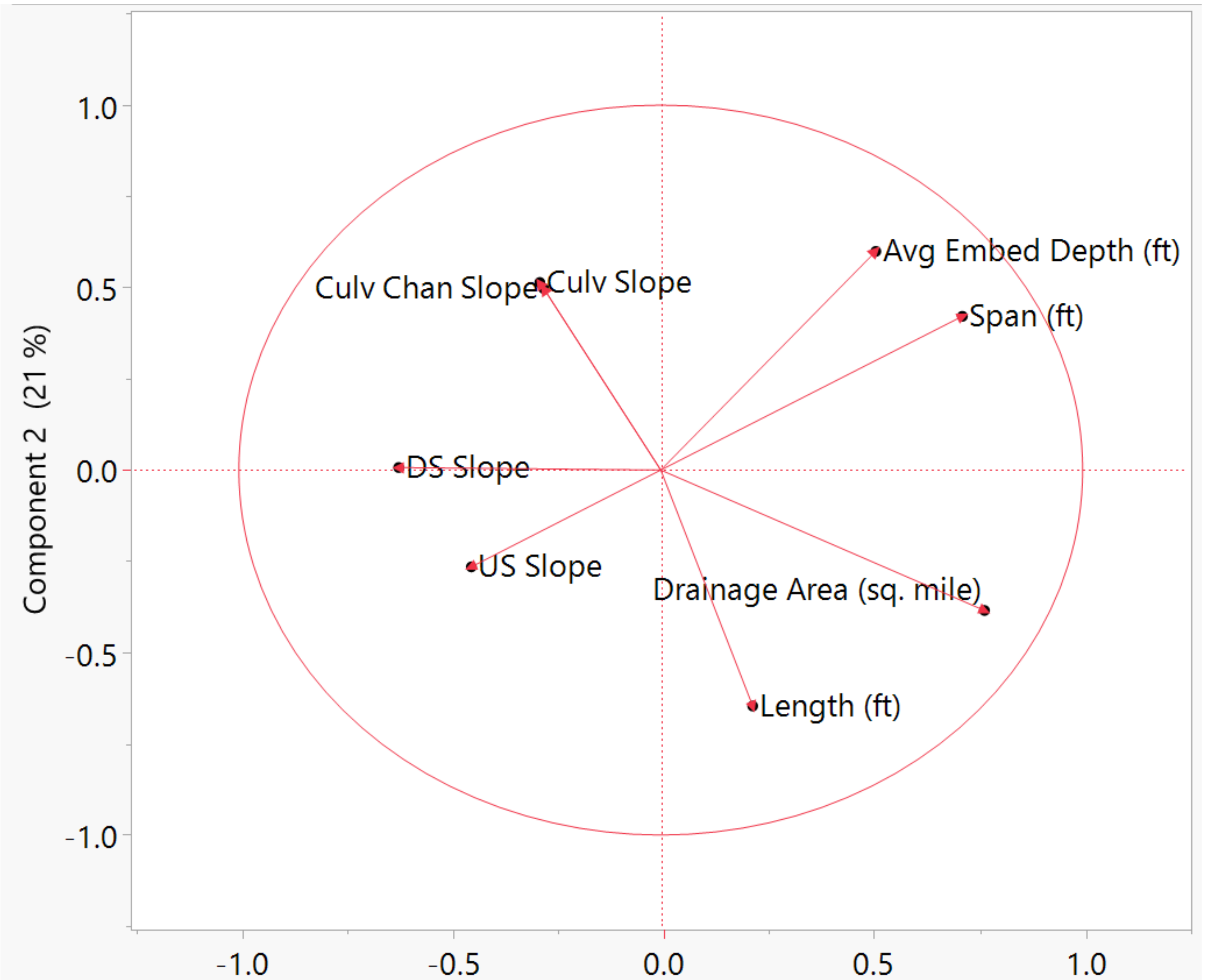

Figure 18: Principal Component Loading Plot

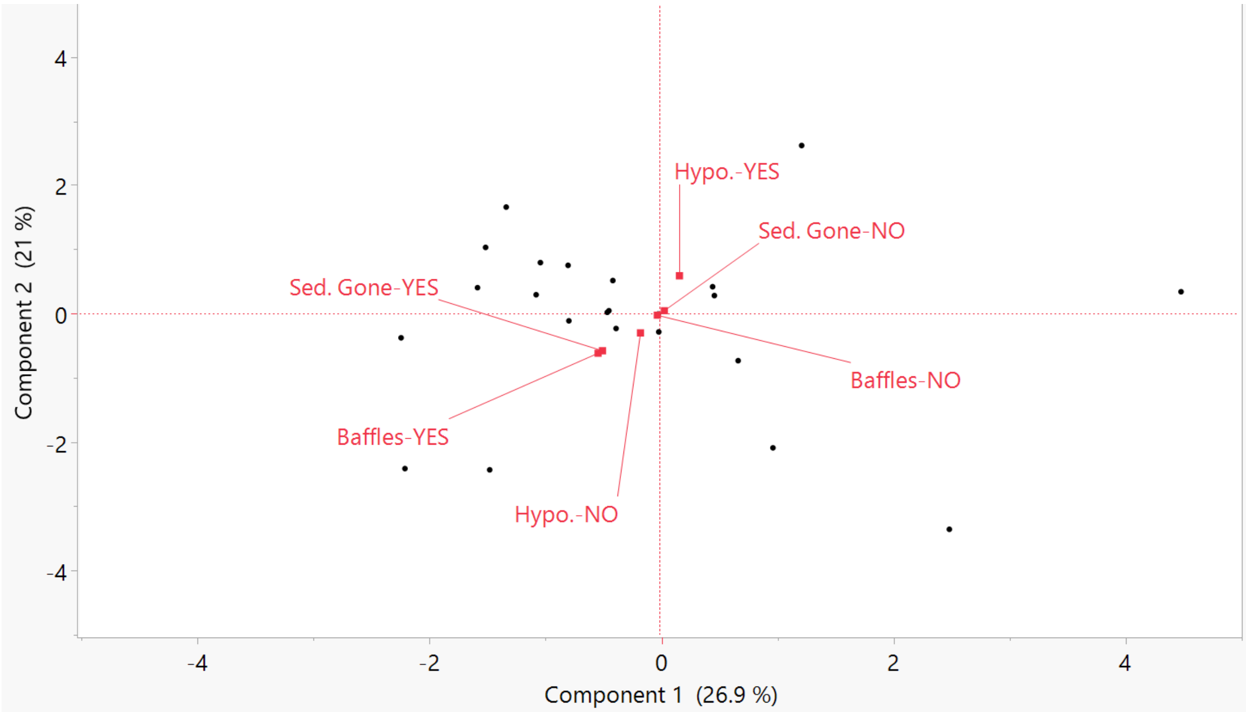

Figure 19: Principal Component Score Plot

Number	Eigenvalue	Percent	20 40 60 80	Cum Percent
1	2.1534	26.917		26.917
2	1.6838	21.047		47.964
3	1.3908	17.385		65.350
4	1.0658	13.323		78.673
5	0.7518	9.398		88.071
6	0.5331	6.663		94.734
7	0.2598	3.248		97.982
8	0.1615	2.018		100.000

Figure 20: Principal Component Eigenvalue Table

Conclusion

Results from Interviews

Interviews with regulators revealed that in their opinion, embedded culverts work well for aquatic organism passage. The most common failures mentioned were hyporheic conditions and loss of bed material. None of the interviewed regulatory agencies outside of New Hampshire has performed an embedded culvert performance study like the one described here. It was opined by interviewees that if the culvert was installed at 1.2 times the bankfull width with a slope mimicking the natural stream bed and adequately sized embedded material, a culvert would function properly however these statements from people in other states were not backed up by field data, rather more as anecdotal evidence. Enhanced success was also recommended by the addition of culvert bottom topography such as sills, ribs, or corrugations. Sills (baffles) for culverts take many shapes and forms. Figure 21 displays a section of HDPE corrugated pipe with pre-installed, notched baffles. Figure 22 displays an example of rock bands in a re-constructed streambed. However, if the sill, etc. bed topography is too high, aquatic organism passage could be hindered. Respondents felt that for steeper culvert slopes or incorrectly sized bed material that culvert failure is more common, failure not being defined but seemingly referring to loss of embedment material and/or lack of full AOP. Inadequate bed material is not exclusive to embedded culverts, the same issues can arise in open bottom culverts. Lastly from interviewees, projects that included a significant amount of fines in the embedment material were believed to prevent bed material transport. Embedded culvert "aging" is also important to project success. Whether adding fines to the embedded material at the time of construction or allowing the embedded material to age via natural stream sediment transport mechanisms, both allow for finer sediment to fill gaps between larger sediment which stabilizes the culvert embedment material and mimics the natural stream. In general, the interviewed regulators were in unison that when designed properly, embedded culverts perform adequately for aquatic organism passage. Incorrectly sized bed material appears to cause hyporheic or sediment transport conditions.

Figure 21: Corrugated HDPE culvert with pre-installed, notched baffles

Figure 22: Streambed with rock bands prior to setting bridge deck

Results from the Embedded Culverts of This Study

The original objective of this study was to identify if the embedded material for an embedded culvert was so coarse that at stream low flows the stream would disappear into the sediments (a condition referred to as 'hyporheic'). Seven of the sites in this study (Figure 8) exhibited fully to partially hyporheic conditions. Of these seven sites, five had the stream itself dry. Of the two remaining sites where the stream was flowing but the embedded culverts were hyporheic, both were non-DOT culverts. This demonstrates that the culvert may not always be the limiting factor in aquatic organism passage. As to the objective of this study, NH DOT embedded culvert designs did not result in hyporheic conditions in the embedded culverts. Statistically, none of the field or design variables of this study could statistically describe with confidence why some culverts were hyporheic.

The sites investigated in this study in general reflected the sentiments of those interviewed. Most sites with bottom topography (baffles, sills) did not have hyporheic or sediment issues. Sites with steep culvert channel slopes resulted in problems with hyporheic conditions or loss of sediment. Some of these steeper culvert slopes mimicked a steeper natural stream bed, therefore loss of embedment sediments may be related to inadequately sized bed material. There was a change in the New Hampshire DOT embedment material specifications in 2016. Of the seven culverts that lost embedded sediment, all were NH DOT culverts and all were installed before 2016. There were seven NH DOT embedded culverts installed before 2016 that did not lose the embedment material: three of these had circumstances that assisted in maintaining the sediment (baffles, backwater, tidal). All four NH DOT embedded culverts constructed after 2016 still have their embedded sediments. In addition, these same four culverts were not hyporheic and half had full AOP, the other half limited AOP. One of those four culverts had baffles.

Subscribing to state and federal guidance for sizing embedment material (Culvert Design for Aquatic Organism Passage, FHWA Publication No. FHWA-HIF-11-008, 2010) it is important to match the culvert embedment sediment to the existing stream bed sediment, however if the embedment material is broken down into classes of particle sizes (sand, gravel, cobble, and boulder), it is left to interpretation of the current NH DOT specification for the exact sizing of the culvert bed material. The original specification 304.7 stated to wash material to remove fines, which contradicts interviews with other agencies who suggest adding fines to fill in gaps between larger material. The original intent of the washing may have been to minimize/prevent stream turbidity with the focus being construction erosion and sediment control.

Because of simplifications employed in the development of the original stream crossing guidelines (in NH and elsewhere, FHWA-HIF-11-008), the recommendation that the culvert width be *at least* 1.2 times the stream bankfull width (w_{BKF}) should be considered as guidance with the key here being "*at least*". Sediment dynamics relate to the stream/culvert hydraulics over the range of all flows. The 1.2 w_{BKF} is a surrogate variable for the stream entrenchment ratio, which is the floodplain width (~at the 100-year flood) divided by the bankfull width. Streams with high entrenchment ratios and that carry significant flows in their floodplains should have culvert width and embedded sediment size hydraulically tailored to higher flows in those systems since here much more water from the floodplain is squeezed into the culverts compared to settings where floodplain flows are a small fraction of the total flow. In this sense, the embedment material size should be based on the critical shear stress for the design flow. The design flow is the higher of the highest flow for AOP or a target flood peak return period (for example, 25-yea, 50-year, etc.).

Appendix A: Comparison of Embedded Culvert Designs

State, etc.	Width	Embedment depth	Embedment material	Slope	Openness ratio	Embedded material PSD	Modifications
NH	- 1.2 * w_{BKF} + 2 ft *Where w_{BKF} is the stream bankfull with away from the culvert*	- Greater than or equal to 2 feet for box culverts and other culverts with smooth internal walls - Greater than or equal to 1 foot for corrugated pipe arches - Greater than or equal to 1 foot and at least 25 percent for corrugated round pipe culverts	- If natural sediment transport is maintained, upstream sediment is expected to fill in voids and lost substrate - Substrate is usually at grade with the upstream inlet	- Slope should be similar to the gradient of the natural stream	- Minimum of 0.25 m	- The substrate within the structure should match that of the substrate in the natural stream channel (mobility, slope, stability, confinement) at the time of construction	- Step pools or baffles to prevent flushing of substrate
MA	- All new culverts need to meet the standard of 1.2 * w_{BKF} instead of what used to be 1.5 * w_{BKF}	- Minimum of 2 feet - If sediment is upsized, then it typically requires a greater embedment depth and a larger structure - Round pipe culverts at least 25% - Minimum width at ground level is 5 feet - When embedment material includes sediment >15 inches in diameter, embedment depths should be at least twice the D84 of the embedment material	- Natural stream like substrate should be developed for the embedment material - Often requires the fill material to be upsized to resist the high stream velocities	- Slope should mimic natural stream channel profile	- Minimum of 0.25 m	- Hydraulic analysis is helpful to try and mimic the roughness and material needed to withstand flows - Larger stones can mimic retention sills	- Sills can be incorporated to retain the infill material
ME	- At least 1.2 * w_{BKF}	- At least 25% of the culvert height or 1-2 feet below streambed elevation - Typically, 2 feet is the most successful	- Adding large substrate will help ensure a natural flow path develops sooner while allowing smaller areas to improve AOP during drier periods	- Recommended to be less than 4%. Typically constructed where there is relatively low bed slope of 0.1% - 3%	- N/A	- Substrate should match substrate in the natural stream channel	- Rock ribs below inlet - Baffles/sills

State, etc.	Width	Embedment depth	Embedment material	Slope	Openness ratio	Embedded material PSD	Modifications
VT	- At least 1.25 * w_{BKF}	- At least 30% of culvert height - Deeper embedment is required at sites dominated by boulder-sized bed material - Less embedment is permitted at sites with channel slopes <0.5%	- Substrate should be well graded to include fine materials for an initial mix that is impermeable and allow stream to fill in with natural mobile substrate	- Can work between 0-6% slope	- Minimum of 0.25 m	- Can create bed material gradation to control porosity based on the D84 and/or D100 - Verify culvert bed is trapping natural sediment from upstream	- Baffles/sills - Increase culvert size to reduce shear stress
CT	- At least 1.2-1.25 * w_{BKF}	- At least 25% or greater than or equal to 1-2 feet for round culvert - At least 20% or greater than or equal to 1-2 feet for box or pipe arch culvert - Deeper embedment depth may be needed if sediment >15 inches in diameter	- Substrate matching characteristics of substrate in natural stream channel and banks	- Match culvert slope to stream channel profile	- Minimum of 0.25 m	- Match substrate of existing stream - Add riprap to provide scour protection	- Culvert width, culvert length, number of culverts and configuration, inlet/outfall improvements, invert angle, culvert alignment, and baffles
RI	- At least 1.2 * w_{BKF}	- At least 20% of culvert height downstream with a minimum of 2 feet	- Natural substrate should be used to match up/downstream substrates	- Used for slopes <3%	- Minimum of 0.25 m (0.82 ft) - Preferably 1-1.5 ft	- Substrate should resist displacement during floods - Designed to maintain stability during normal flows	- Baffles/sills

State, etc.	Width	Embedment depth	Embedment material	Slope	Openness ratio	Embedded material PSD	Modifications
PA	- At least w_{BKF} - w_{BKF} at embedment depth for arch pipe - Additional benefits if designed wider than w_{BKF}	- Minimum of 6 inches embeddedness if the watershed is under a square mile and 12 inches if over a square mile - Typically, between 20-40% of culvert height - Arch pipe greater than 20% - Round culvert greater than 40% or 2 feet (0.6 m)	- Size sediment similar to that found in adjacent natural streambed - Ensure sufficient fines to fill voids	- Slope ≤6% - Preferably ≤2% for AOP	- N/A	- Simulate/model the natural streambed - Must be well graded to "seal" streambed - Supplement with D90 material to help retain substrate - D90 is particularly important in channels with 3-6% slopes	- Downstream weir - Hydraulic roughness related to bed material used - Riprap at inlet and outlet
NY	- 1.25 * w_{BKF}	- Minimum of 20% of culvert height	- Sediment excavated shall be used for embedment material	- Slopes <3% shall have culvert installed with 0% slope - Slopes >3% must have a bottomless culvert or bridge installed	- N/A	- Natural deposition of excavated sediment shall occur	- N/A
OR	- Must meet existing w_{BKF}	- Requires 20% embedment - Arch pipe greater than 20% or 18 inches - Round culvert greater than 40% or 24 inches - If less than 2.5% channel slope, culvert needs to be embedded minimum of 6 inches	- Need to match stream characteristics to prevent changes in sedimentation patterns	- Must meet existing stream slope - Up to 8% gradient - If less than 2.5% culvert should be placed less than 0.5%	- N/A	- PSD should be conducted to match sedimentation patterns	- Large boulders to retain bed load -Baffles

State, etc.	Width	Embedment depth	Embedment material	Slope	Openness ratio	Embedded material PSD	Modifications
WA	- 1.2 * w_{BKF} + 2 ft - No slope: equal to w_{BKF}	- At least 20% of the rise - Typically, between 30-50% of the rise - No Slope: minimum 20% of downstream, and maximum 40% of upstream	- Substrate should mimic that of the substrate in the natural stream channel	- Must be <0.2 * rise/length or <3% - Bed slope should be less than 1.25 * avg upstream channel slope - Can use no slope culvert design for stream beds <3% slope	- N/A	- Median particle size should be within 18% of median natural streambed particle size	- Log sills - Baffles - Roughened channel
CA	- Oversized pipe that is as close to the natural channel width as possible -Low slope designs (<1%) need at least 1.25 * w_{BKF} - Minimum w_{BKF}	- Between 20-40% of the culvert height	- Bed material is placed in culvert with expectation that flows will distribute material into natural configuration - Fines should be jetted/flooded in to fill voids - Material in original bed may be suitable for portion of culvert	- Placed in low gradient channels - Matching natural stream slope - Must provide uniform stream channel gradient	- N/A	- Simulate natural streambed characteristics - If low slope culvert less than 50 ft in a mobile bed, fill is not requiring as streambed will quickly fill culvert and form natural bed	- Baffles/sills - Boulder control to allow channel to regrade slowly - Roughened channel

State, etc.	Width	Embedment depth	Embedment material	Slope	Openness ratio	Embedded material PSD	Modifications
ID	- At least w_{BKF}	- Between 20-50% of the culvert diameter. - Assumes embedded depth is uniform throughout the length of the culvert.	- Natural substrate	- Requires longitudinal channel profile analysis.	- N/A	- Requires bed material distribution analysis.	- Grade control (logs or rock weirs) - Roughened channel or sills - Rock ramp
AK	- Minimum of 90% of natural channel width at ordinary high water	- Embedded min 0.5 foot to accommodate potential AOP. - Recommended 2 feet. - Minimum of 40% of culvert diameter. - Circular and box culverts must be embedded at least 20% of their height.	- Native streambed material or engineered fill. - Excavation activities along stream can sometimes be used as fill material.	- Recommended to match stream gradient. - Minimum allowable culvert slope is 0.5%. - Recommended to be within 1% of natural channel slope. - Less than 4% for AOP.	- Minimum culvert size equal to 1% of the length of the pipe.	- Material should reflect naturally occurring substrate in stream (may need to move up/downstream to avoid roadbed material).	- Baffles - Design specs are constantly being modified to construct a more successful embedded culvert.

Notes:

MT had no interview responses and the only information found regarding embedded culvert design in the state was a study of a high gradient stream. The gradient of the study was between 2-5% of large substrate (primarily cobble and boulder). Average bank full width was approximately 8 m.

All states recommend flushing in additional fines to fill any remaining voids in the streambed.

Appendix B: New Hampshire Field Work Results

Town	Field Data												
	US Slope	Culv Chan Slope	Culv Slope	DS Slope	Rise Inlet (ft)	Rise Outlet (ft)	Avg Embed Depth (ft)	Min Embed Depth (ft)	Sed. Gone?	Backwater?	Hyporheic?	Baffles?	AOP Assessment
Alstead, NH	11.37%	2.74%	2.81%	6.47%	8.84	8.6	1.28	1.16			No		Gray
Alton, Route 11, NH	1.07%	0.93%	2.97%	1.93%	4.95	4.2	1.425	1.05			No		Green
Alton, Stockbridge Corner, NH	37.94%	-54.60%	0.46%	2.61%	3	2.7	0.4	0.25			Partly	YES	Red
Andover, NH	3.37%	-0.38%	0.61%	0.22%	6.63	6.1	1.635	1.37			No		Gray
Bedford, NH	2.70%	-0.01%	0.00%	0.22%	3.5	3					No		Green
Bethlehem, NH	19.56%	2.08%	1.94%	0.13%	4	4	0	0	YES		No		Red
Concord, NH	0.66%	-0.01%	0.00%	-0.26%	3	2.45					No		Green
Easton-Woodstock, NH	4.00%	0.69%	-1.38%	3.31%	9.785	9.41	0.4025	0.215	PARTLY, IN		No		Green
Francestown, Pleasant Pond Road, NH	0.63%	-2.55%	-0.29%	-12.41%	7.7	7	92.65	92.3			Partly		Gray
Gilford, NH	2.07%	1.38%	0.52%	1.70%	7	7.5	0.75	0.5			No	YES	Gray
Hopkinton, Briar Hill Road, NH	0.69%	1.09%	0.91%	0.49%	5.4	5.31	0.645	0.6			No		Green

Town	Field Data												
	US Slope	Culv Chan Slope	Culv Slope	DS Slope	Rise Inlet (ft)	Rise Outlet (ft)	Avg Embed Depth (ft)	Min Embed Depth (ft)	Sed. Gone?	Backwater?	Hyporheic?	Baffles?	US Slope
Hopkinton, Rollins Road, NH	-0.71%	1.27%	2.09%	1.68%	5.6	5.45	0.475	0.4			No		Gray
Littleton, NH	9.21%	4.97%	5.93%	-0.63%	6	5.2	0.4	0	AT INLET	OUTLET	Partly	YES	Orange
Londonderry, NH	0.57%	3.45%	0.02%	0.68%	4.28	4.61	1.555	1.39	YES		Yes		Gray
Londonderry, Wiley Hill Road, NH	0.57%	3.45%	0.02%	0.68%	4.28	4.61	1.555	1.39			Yes		Red
Madbury, NH	1.19%	1.24%	0.47%	7.62%	2.915	3.24	0.9225	0.76			No		Red
Newington, NH	-0.49%	-0.35%	-1.67%	3.05%	7	7	0	0	YES		No		Gray
Newmarket, NH	0.81%	0.00%	0.00%	0.45%	6.13	6.09					No		Green
North Hampton, NH	3.23%	0.34%	0.03%	N/A	5.2	5.5	1.65	1.5		TIDAL	No		Green
Plaistow, Kelly Brook, NH	4.63%	0.82%	-2.79%	-1.69%	6.38	7.2	1.21	0.8		YES	No	YES	Green
Plaistow, Pollard Road, NH	0.66%	0.00%	0.00%	0.85%	3.35	4.8					No		Green
Rochester, NH	0.84%	-0.36%	0.11%	2.25%	12.92	11.975	0.5525	0.08	MOSTLY, IN	MOSTLY BOTH	No		Gray
Stratham, NH	-0.08%	1.15%	-3.40%	1.24%	6.04	6.9	1.53	1.1		TIDAL	No		Green

Town	Field Data													
	US Slope	Culv Chan Slope	Culv Slope	DS Slope	Rise Inlet (ft)	Rise Outlet (ft)	Avg Embed Depth (ft)	Min Embed Depth (ft)	Sed. Gone?	Backwater?	Hyporheic?	Baffles?	AOP Assessment
Warner, North Village Road, NH	1.64%	1.95%	3.32%	0.55%	6.29	5.65	94.03	93.71			Yes		Red
Warren, NH North	6.91%	0.63%	0.78%	-4.17%	2.9	2.7	1.2	1.1			No		Gray
Warren, NH South	1.22%	1.20%	1.19%	0.69%	3.2	2.9	0.95	0.8			No		Gray
Westmoreland, NH	-2.40%	-0.12%	-0.12%	1.93%	5	5			YES		No		Green
Windham, NH	1.31%	1.00%	0.20%	-7.79%	6.05	5.83	0.06	0			No Flow		Red

US Slope- The stream slope measured upstream of the culvert

Culv Chan Slope – The slope of the stream channel constructed in the culvert embedment material

Culv Slope – The slope of the culvert invert

DS Slope - The stream slope measured downstream of the culvert

Negative slopes mean that the elevation downstream is higher than the elevation upstream (adverse slope)

Appendix C: Watershed and Hydrologic Site Characteristics

Town	StreamStats Data										Q2			Q100		
	Watershed Area (mi^2)	Mean April Precipitation (in)	Wetland (%)	Channel Slope (ft/mi)	Bankfull Width (ft)	Bankfull Depth (ft)	Q2 (cfs)	Q10 (cfs)	Q50 (cfs)	Q100 (cfs)	Inlet/Outlet Control	Normal Depth (ft)	Velocity (ft/s)	Inlet/Outlet Control	Normal Depth (ft)	Velocity (ft/s)
Alstead, NH	1.13	3.47	0.21	370	8	0.43	62.72	145.34	243.12	296.31	Inlet	0.84	6.2	Inlet	2.18	11.16
Alton, Route 11, NH	1.09	4.01	0.19	373	26	1.40	75.62	184.21	313.48	384.46	Outlet	2.09	7.4	Inlet	3.79	10.09
Alton, Stockbridge Corner, NH	0.23	4.12	0.00	666	17	1.00	20.19	53.50	95.69	119.37	Outlet	1.07	5.07	Outlet	2.75	8.64
Andover, NH	1.67	3.63	0.49	512	29	1.54	102.56	237.33	392.68	476.37	Outlet	6	6.18	Outlet	6	10.31
Bedford, NH	0.38	3.48	0.76	43	19	1.11	13.83	33.28	58.68	73.23	Outlet	3	2.86	Outlet	3	4.99
Bethlehem, NH	0.16	3.01	0.00	790	15	0.92	9.23	22.44	39.19	48.44	Outlet	0.49	3.9	Inlet	1.37	7.06
Concord, NH	6.68	3.18	12.22	47	43	2.09	100.78	205.52	322.02	384.71	Outlet	3	3.79	Outlet	3	7.58
Easton-Woodstock, NH	0.87	3.64	0.00	885	24	1.33	63.53	152.23	256.50	312.87	Outlet	1.18	5.27	Outlet	3.13	7.24
Francestown, Pleasant Pond Road, NH	7.78	4.11	4.77	51	45	2.16	264.31	584.44	944.47	1141.26	Outlet	10	3.52	Outlet	10	6.35
Gilford, NH	3.73	3.02	2.16	236	37	1.84	130.84	273.27	433.42	518.57	Outlet	1.36	6.41	Inlet	3.16	10.24
Hopkinton, Briar Hill Road, NH	1.71	3.61	4.47	64	29	1.55	54.25	123.44	206.46	252.51	Outlet	1.23	5.79	Outlet	3.19	9.67
Hopkinton, Rollins Road, NH	1.65	3.61	4.66	71	29	1.54	53.07	121.02	202.44	247.54	Outlet	1.5	6.58	Outlet	4	5.41
Littleton, NH	1.65	2.99	0.00	387	29	1.54	73.82	160.22	260.40	314.05	Inlet	0.78	7.91	Inlet	1.88	13.65
Londonderry, NH	0.81	3.83	5.48	72	24	1.31	28.15	67.62	116.44	143.88	Outlet	0.9	4.65	Outlet	2.45	8.01

Town	StreamStats Data										Q2			Q100		
	Watershed Area (mi^2)	Mean April Precipitation (in)	Wetland (%)	Channel Slope (ft/mi)	Bankfull Width (ft)	Bankfull Depth (ft)	Q2 (cfs)	Q10 (cfs)	Q50 (cfs)	Q100 (cfs)	Inlet/Outlet Control	Normal Depth (ft)	Velocity (ft/s)	Inlet/Outlet Control	Normal Depth (ft)	Velocity (ft/s)
Londonderry, Wiley Hill Road, NH	0.99	3.92	6.09	72	25	1.37	33.99	81.48	139.62	172.21	Inlet	0.84	6.77	Inlet	2.3	12.26
Madbury, NH	0.31	4.17	5.88	43	18	1.06	11.17	28.75	51.77	65.09	Outlet	0.48	3.56	Outlet	1.42	6.4
Newington, NH	1.19	4.38	3.73	51	27	1.43	51.02	125.64	217.80	269.99	Outlet	5	6.9	Inlet	5	12.02
Newmarket, NH	0.76	4.20	12.86	37	23	1.29	17.50	43.15	74.97	93.04	Outlet	0.55	3.21	Outlet	1.53	5.61
North Hampton, NH	4.82	4.33	30.50	7	39	1.94	28.05	63.01	102.66	124.81	Outlet	1.26	4.83	Outlet	3.19	7.95
Plaistow, Kelly Brook, NH	3.51	4.16	7.13	29	36	1.81	97.80	224.17	373.07	456.13	Outlet	1.92	4.26	Outlet	5.09	7.24
Plaistow, Pollard Road, NH	0.68	4.27	2.61	80	23	1.26	33.54	84.34	148.18	184.42	Outlet	0.92	3.85	Outlet	2.6	6.79
Rochester, NH	11.18	4.46	8.12	56	50	2.34	356.30	795.15	1275.30	1536.29	Outlet	13	7.61	Outlet	13	12.39
Stratham, NH	1.29	4.29	8.20	64	27	1.45	43.53	106.01	181.61	224.01	Outlet	1.37	5.75	Outlet	3.87	9.69
Warner, North Village Road, NH	2.28	3.98	0.59	179	32	1.65	127.40	297.79	496.81	605.83	Inlet	1.12	6.32	Inlet	2.69	11.05
Warren, NH North	0.73	3.16	2.59	497	23	1.28	33.34	76.49	127.83	155.63	Outlet	1.4	3.41	Outlet	2.06	3.45
Warren, NH South	1.02	3.11	3.16	447	25	1.38	42.43	95.24	157.16	190.50	Outlet	1.33	6.11	Inlet	2.91	9.25
Westmoreland, NH	1.94	3.40	0.77	183	30	1.59	85.66	191.49	315.52	383.01	Outlet	5	5.82	Outlet	5	9.59
Windham, NH	3.02	4.01	10.52	30	34	1.75	67.02	152.71	253.33	309.31	Outlet	1.43	6.21	Outlet	3.08	6.38

Appendix D: Site Design Specifications

Town	Project #	Stream	Design Embedment PSD	Other Features	From AsBuilt or Design Plans (feet)						
					Rise	Span	Elev In	Elev Out	Length	Slope	Embed
Alstead, NH	14541i	*No Name*	Items 585.21 and 209.4		10	12	805.00	802.50	56	4.46%	2.6
Alton, Route 11, NH	41352	*No Name*	Item 585.3401 - Simulated Streambed Material		6	6	505.98	504.47	45	3.36%	2
Alton, Stockbridge Corner, NH	14121D	*No Name*		6" baffle	3.25	5	603.05	602.80	48	0.52%	0.5
Andover, NH	14679A	Mitchell Brook	Excavated Channel Material		8	14	609.00	609.00	60	0.00%	2
Bedford, NH	N/A	McQuesten Brook				19			34		
Bethlehem, NH	15664	Barrett Brook	Item 304.7 - Stream Lining Gravel	Removable Top	4	5	1478.64	1478.15	56	0.88%	1
Concord, NH	N/A	Mill Brook				16			48		
Easton-Woodstock, NH	12971	Stony Brook	Granular Backfill		10	14	1369.00	1369.00	33	0.00%	1
Francestown, Pleasant Pond Road, NH	Non-DOT	Collins Brook			100	22	non-DOT		31		

Town	Project #	Stream	Design Embedment PSD	Other Features	From AsBuilt or Design Plans (feet)						
					Rise	Span	Elev In	Elev Out	Length	Slope	Embed
Gilford, NH	16279	West Alton Brook	Item 585.3402 - Simulated Streambed Material	10" baffles	8	16	836.83	835.47	43	3.18%	0.83
Hopkinton, Briar Hill Road, NH	Non-DOT	*No Name*			6	9	non-DOT		55		
Hopkinton, Rollins Road, NH	Non-DOT	*No Name*			6	6	non-DOT		43		
Littleton, NH	16282	Carpenter Brook	Item 304.7 - Stream Lining Gravel	V shape fish baffles	6	12	1042.00	1037.25	64	7.42%	0.75
Londonderry, NH	13015	Little Cohas Brook	Item 304.7 - Stream Lining Gravel		6	9	315.00	314.45	76	0.72%	1
Londonderry, Wiley Hill Road, NH	Non-DOT	*No Name*			6	6	non-DOT		45		
Madbury, NH	Non-DOT	Dube Brook			4	8	117.14	116.97	40	0.43%	1
Newington, NH	11238E	*No Name*	Item 304.7 - Stream Lining Gravel		5	5	10.92	11.15	81	-0.28%	1.5

Town	Project #	Stream	Design Embedment PSD	Other Features	From AsBuilt or Design Plans (feet)						
					Rise	Span	Elev In	Elev Out	Length	Slope	Embed
Newmarket, NH	N/A	Lubberland Creek				17			30		
North Hampton, NH	16060	Winnicut River	Item 304.7 - Stream Lining Gravel		7	8	42.10	42.00	64	0.16%	2
Plaistow, Kelly Brook, NH	10044D	Kelly Brook	Stone Fill, Class C (Typ)	Interior baffle walls	8	9	99.40	99.00	140	0.29%	1
Plaistow, Pollard Road, NH	N/A	Seaver Brook				19			45		
Rochester, NH	10620H	Axe Handle Brook	Stone Fill, Class D (Typ) NHDOT coarse aggregate for concrete (size#467). Size range from 3/8” to 1 ½” with max of 5% fines.	Twin Cell Box Culverts	13	13 (x2)	207.00		200		0.5
Stratham, NH	15653	Jewel Hill Brook	Item 304.7 - Stream Lining Gravel	HDPE Pipe	8	8	-0.50	-0.50	40	0.00%	2.5
Warner, North Village Road, NH	Non-DOT	Silver Brook			100	18	non-DOT		56		

Town	Project #	Stream	Design Embedment PSD	Other Features	From AsBuilt or Design Plans (feet)						
					Rise	Span	Elev In	Elev Out	Length	Slope	Embed
Warren, NH North	13209	*No Name*	Item 304.7 - Stream Lining Gravel		4	6			65	0.50%	1
Warren, NH South	13209	*No Name*	Item 304.7 - Stream Lining Gravel		4	6			72	0.40%	1
Westmoreland, NH	14019	*No Name*	Item 304.7 for channel work only		5	14	351.00	351.00	33	0.00%	
Windham, NH	13113	Berry Brook	Item 585.2 - Stone Fill, Class B		6	9	177.60	177.25	68	0.51%	2

Appendix E: Site Particle Size Distributions

	D10 (mm)			D50 (mm)			D85 (mm)			D100 (mm)		
Site	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd
Alstead, NH	2	2	2	9.51	52	26	9.51	110	112	9.51	214	264
Alton, Stockbridge Corner, NH	0.85	2	0.25	9.51	9.51	0.85	9.51	9.51	2	9.51	9.51	9.51
Alton, Route 11, NH	5	5	5	25	16	18	57	36	34	163	99	84
Andover, NH	0.425	0.25	0.425	9.51	2	4.76	9.51	9.51	9.51	9.51	9.51	9.51
Bedford	0.25	0.3375	0.425	9.51	5.18	0.85	9.51	7.135	4.76	9.51	9.51	9.51
Bethlehem, NH	No particles											
Concord	0.25	0.25	0.25	0.425	0.6375	0.85	0.85	5.18	9.51	9.51	9.51	9.51

	D10 (mm)			D50 (mm)			D85 (mm)			D100 (mm)		
Site	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd
Easton-Woodstock, NH	0.85	2	2	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51
Francestown, Pleasant Pond Road, NH	2	2	2	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51
Gilford, NH	0.25	0.25	0.425	0.85	0.85	0.85	2	2	2	9.51	9.51	9.51
Hopkinton, Rollins Road, NH	2	7	5	80	43	51	180	120	130	292	265	223
Hopkinton, Briar Hill Road, NH	0.85	2	2	9.51	16	26	9.51	82	160	9.51	430	320
Littleton, NH	0.85	0.85	0.85	9.51	2	9.51	9.51	9.51	9.51	9.51	9.51	9.51
Londonderry, NH	0.05	0.85	0.25	72	9.51	0.85	123	9.51	9.51	222	9.51	9.51

	D10 (mm)			D50 (mm)			D85 (mm)			D100 (mm)		
Site	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd
Londonderry, NH, Non-DOT	0.05	0.05	2	76	67	78	110	115	136	185	241	310
Madbury, NH	0.15	0.15	0.25	2	0.85	2	9.51	9.51	9.51	9.51	9.51	9.51
Newington, NH	0.85	0.85	0.85	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51
Newmarket	0.15	0.075	0.15	9.51	4.76	4.76	9.51	9.51	9.51	9.51	9.51	9.51
North Hampton, NH	Too deep											
Plaistow, NH	2	Too deep		75	Too deep		160	Too deep		310	Too deep	
Plaistow, Pollard Road	0.15	0.15	0.15	2	2	2	4.76	7.135	9.51	9.51	9.51	9.51
Rochester, NH (RL)	0.25	0.425	0.25	0.425	9.51	9.51	0.85	9.51	9.51	4.76	9.51	9.51
Rochester, NH (RR)	0.425	0.425	0.25	0.85	9.51	9.51	2	9.51	9.51	4.76	9.51	9.51

	D10 (mm)			D50 (mm)			D85 (mm)			D100 (mm)		
Site	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd	Upstream 3rd	Center 3rd	Downstream 3rd
Stratham, NH (Jewell Hill)	14	1	1	37	5	4	70	20	16	280	100	260
Warner, North Village Road, NH	28	36	4.76	66	61	9.51	115	86	9.51	320	196	9.51
Warren, NH North Station	0.85	0.075	0.25	9.51	0.425	9.51	9.51	9.51	9.51	9.51	9.51	9.51
Warren, NH South Station	0.425	0.15	0.15	4.76	0.425	0.25	9.51	2	2	9.51	9.51	9.51
Westmoreland, NH	0.85	0.15	10	9.51	0.425	68	9.51	2	137	9.51	9.51	323
Windham, NH	0.425	0.05	9.51	2	152	9.51	9.51	342	9.51	9.51	556	9.51

Appendix F: Construction Years

Town	Project #	Stream	Construction Year
Alstead, NH	14541i	*No Name*	2007
Alton, Route 11, NH	41352	*No Name*	2019
Alton, Stockbridge Corner, NH	14121D	*No Name*	2014
Andover, NH	14679A	Mitchell Brook	2015
Bedford, NH	N/A	McQuesten Brook	2017
Bethlehem, NH	15664	Barrett Brook	2010
Concord, NH	N/A	Mill Brook	2019
Easton-Woodstock, NH	12971	Stony Brook	2003
Francestown, Pleasant Pond Road, NH	Non-DOT	Collins Brook	unknown
Gilford, NH	16279	West Alton Brook	2017
Hopkinton, Briar Hill Road, NH	Non-DOT	*No Name*	unknown
Hopkinton, Rollins Road, NH	Non-DOT	*No Name*	unknown
Littleton, NH	16282	Carpenter Brook	2012
Londonderry, NH	13015	Little Cohas Brook	2009
Londonderry, Wiley Hill Road, NH	Non-Dot	*No Name*	2008
Madbury, NH	Non-DOT	Dube Brook	2019
Newington, NH	11238E	*No Name*	2006
Newmarket, NH	N/A	Lubberland Creek	2019
North Hampton, NH	16060	Winnicut River	2017
Plaistow, Kelly Brook, NH	10044D	Kelly Brook	2008
Plaistow, Pollard Road, NH	N/A	Seaver Brook	2020
Rochester, NH	10620H	Axe Handle Brook	2011
Stratham, NH	15653	Jewel Hill Brook	2012
Warner, North Village Road, NH	Non-DOT	Silver Brook	unknown
Warren, NH North	13209	*No Name*	2007
Warren, NH South	13209	*No Name*	2007
Westmoreland, NH	14019	*No Name*	2006
Windham, NH	13113	Berry Brook	2009