Climate Risk in the Seacoast (C-RiSe): Stream Crossing Assessment UNH Stormwater Center Final Report

Prepared by:

Joel Ballestero

Tom Ballestero, P.E.

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Contents

Introduction

The Climate Risk in the Seacoast (C-RiSe) vulnerability assessment produced maps and quantitative assessments of sea-level rise and storm-related flooding impacts to key public assets and natural resources for the ten tidally-influenced municipalities surrounding New Hampshire's Great Bay Estuary (i.e., Durham, Dover, Exeter, Greenland, Madbury, Newfields, Newington, Newmarket, Rollinsford, and Stratham). As part of the C-RiSe project, the UNH Stormwater Center assessed the hydraulic capacity, aquatic organism passage (AOP), and geomorphic compatibility (GC) at various flows for a subset of existing road stream crossings (culverts) selected by the ten Great Bay municipalities. The UNH Stormwater Center developed an Excel model to perform these three assessments in batch mode (one or more culverts at once). Results from the hydrologic and hydraulic modeling are publicly available through the New Hampshire Coastal Viewer.

A total of 105 stream crossing locations were identified by the ten communities. Each site was then surveyed and all the field data collected in order to run all the assessments. The field data collection subscribed to common New Hampshire Department of Environmental Services (NHDES) practices and methods. In addition to the field data, all online data was obtained running scripts in GIS for each crossing location. Using the online data, peak flows at return periods of 2-, 10-, 25-, 50-, and 100-yrs were calculated at each site. These, along with site specific field data, were then input into spreadsheets that determined ratings for AOP and GC, as well as into the Federal Highway Administration's (FHWA) free hydraulic program HY-8, to calculate headwater depths. Using input from the C-RiSe technical advisory committee (TAC), the headwater depths were then used to determine hydraulic ratings at each crossing for each of the five peak flows.

Built upon the published documentation on HY-8, the formulas used in the program as well as the methods defined in the FHWA's Hydraulic Design Series #5 (HDS5, which provides the technical basis for HY-8), and the NH state protocols for assessing culverts for AOP and GC , an Excel model was created and coded. This model requires relatively little information, performs all the calculations, and rates stream crossings for the three assessments. The model is thus intended to be used to run the assessments for multiple crossings at one time, and yields coarse screening results for each culvert and simple results viewing.

In addition to creating the model, the UNH Stormwater Center developed a User's Manual, which thoroughly details the methods and calculations behind the model, as well as instructions for use and interpreting results.

Methods

Three assessments for culvert performance were performed as part of the C-RiSe project: hydraulics, aquatic organism passage (AOP), and geomorphic compatibility (GC). Together, the three may be used as a screening tool to determine the overall 'adequacy' of a crossing. New Hampshire has protocols for assessing culverts for AOP and GC, but not yet for hydraulics. To rate crossings for AOP and GC, the state's protocols were employed and coded into the Excel model. In order to rate crossings for hydraulics, a method had to be determined, and was agreed upon after discussions with the technical advisory committee (TAC) assembled at the start of the project.

Data Collection

After all ten communities provided a total of 105 crossings to be assessed as part of this project, each site was visited and had field data collected. The data collected followed the state's Culvert Assessment Protocol, plus additional, required information pertaining to the hydraulics. Data collection at each site was performed using a laser level for relative elevations, tape measures for dimensions, and observationally for other data. Coordinates were observed using GPS receivers, which then provided the exact location of each crossing for use in obtaining watershed characteristics from online data sources.

The field data for each of the crossing locations was then sent to the UNH Institute for the Study of Earth, Oceans, and Space (UNH EOS). Using scripts in GIS software and the crossing locations, all the required watershed and hydrologic data was obtained by EOS.

Hydrology

Using the watershed properties and hydrologic data collected from online sources for each crossing as well as the EOS results, five peak flows (2-, 10-, 25-, 50-, and 100-yr flows) were calculated for each stream crossing using two commonly used, widely published methods: The SCS Curve Number method, and the USGS Regression Equations for New Hampshire. Documentation states that the Curve Number method is applicable for watersheds up to about 2 square miles in size. The Regression Equations were calibrated to watersheds in NH down to 0.7 square miles in size. Therefore, coded within the Excel model, and for the purpose of this project, peak flows for stream crossings possessing watersheds equal to or smaller than 1 square mile were calculated using the Curve Number method, and for watersheds larger than one square mile the Regression Equations were used.

Hydraulics and Hydraulic Ratings

After many discussions with members of the TAC, both as a group and individually, a method was agreed upon to generate a hydraulic rating for each stream crossing. For each of the five flood flows calculated at each site (2-, 10-, 25-, 50-, and 100-yr flows), headwater depths at the inlet of each crossing was computed via HY-8 and the Excel model. These headwater depths were compared to physical metrics at each crossing in order to provide an estimate of how each crossing performed at passing flows. It was decided that there were two thresholds at which crossings may reach a critical stage in terms of hydraulic rating: when headwater depths reached the top of the culvert, and when headwater depths reached the lowest point of the road surface. When depths reach the top of the culvert, it can be assumed that the culvert is flowing nearly full, and likely at much higher than normal stream velocities. Once the headwater stage reaches the road (or similar) overtopping occurs. Overtopping flows can: lead to road embankment failure and subsequent damage to infrastructure; cause flooding upstream; and present hazards to transportation. Thus, these two stages for headwater represent a simple ability to rate the crossing and view the results in a quick manner.

For any given flow at any specific culvert, flow control occurs as either inlet control or outlet control. Inlet control means that the inlet is throttling the flow through the culvert and therefore determines the headwater depth. Outlet control means that the culvert barrel, outlet, and tailwater control the flow and therefore the headwater depth. Inlet and outlet control headwater depths are computed for each flow, and the larger of the two is the controlling condition for headwater depth. The hydraulics (headwater depths) for this project were all performed using the software HY-8. This software is built using the methods and equations defined in HDS5. However, since HDS5 was written for more traditional hand calculations, HY-8 takes the empirical formulas used to calculate inlet control headwater depths, developed for varying culvert configurations, and fits a 5^{th} order polynomial equation to the data to use. The coefficients for all the variable culvert configurations differ from one to the next. These equations and coefficients are coded into the Excel model. Additionally, HY-8 computes outlet control. Similar methods were coded into the Excel model.

With the headwater depths calculated at each crossing for each of the five peak flows, the ratings were determined as Pass (below the top of the culvert; colored green), Fail (at or above the road surface; colored red), or Transitional (between those two stages; colored yellow) as shown in Figure 1.

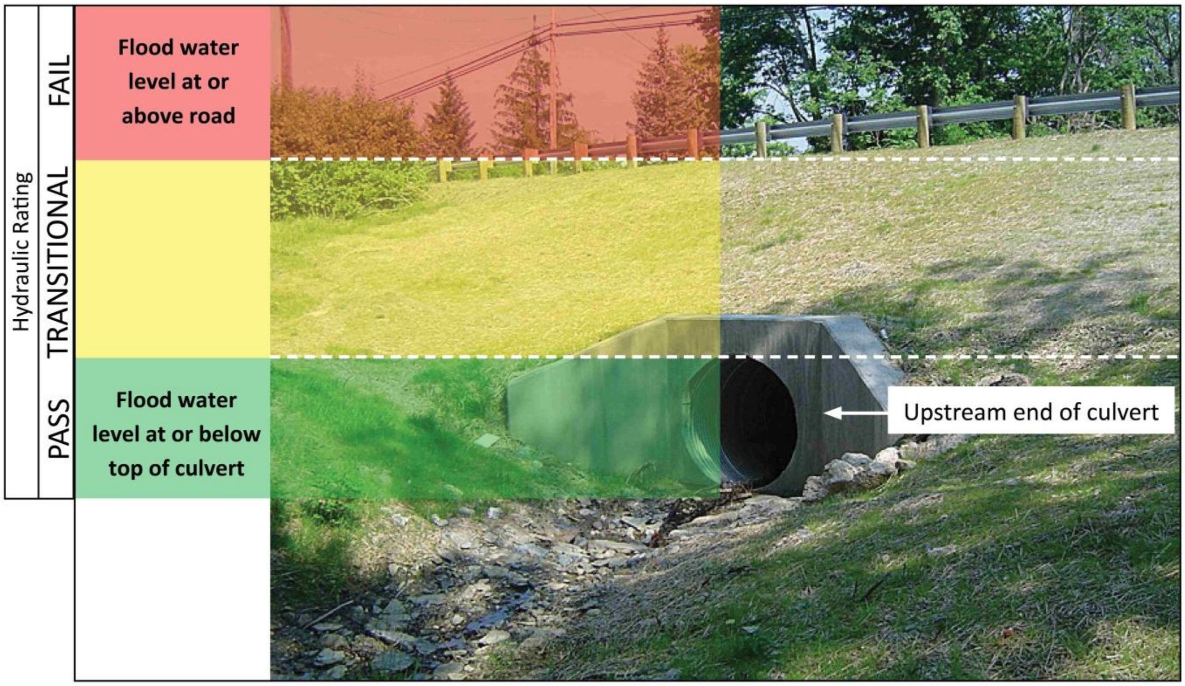

Figure 1. Hydraulic Rating Scheme

Aquatic Organism Passage

New Hampshire has a screening protocol for rating stream crossings for AOP. The screening tool and procedure was borrowed directly from Vermont, and uses physical characteristics of the culvert and site to estimate culvert passability. This screening protocol is built into the Excel model as defined in the documentation provided by the state. The AOP ratings are: Full AOP (colored green), Reduced AOP (colored gray), No AOP – Adult Salmonids (colored orange), and No AOP (colored red). A description of the four ratings is provided in Table 1.

Table 1. Aquatic Organism Passage Ratings

Full AOP	Crossing likely is fully passable by all aquatic organisms
Reduced AOP	Crossing likely has reduced passage capability by all aquatic organisms
No AOP - Adult Salmonids	Crossing likely is not passable by all aquatic organisms except for adult salmonids
No AOP	Crossing is likely impassable by all aquatic organisms including adult salmonids

Geomorphic Compatibility

Similar to AOP, New Hampshire has a screening tool for rating crossings for their geomorphic compatibility (passing sediments and debris), which was adopted directly from Vermont. This method also uses physical characteristics, as well as observational details, of the culvert and of the watercourse. Five categories are scored with a score of 1-5, and the sum of the five scores yields a total score, which is then used to determine the rating. This screening tool was built into the Excel model as well, following the documentation outlining the method. Using the screen, crossings are rated as: Fully Compatible (colored neon green), Mostly Compatible (colored pea green), Partially Compatible (colored yellow), Mostly Incompatible (colored orange), and Fully Incompatible (colored red). A description of each of the GC ratings is provided in Table 2.

Table 2. Geomorphic Compatibility Ratings

Fully Compatible	20 < Score ≤ 25	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 < Score ≤ 20	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 < Score ≤ 15	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 < Score ≤ 10	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 ≤ Score ≤ 5	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

Culvert Assessment Model

While there are the two individual screening tools published by NHDES for AOP and GC, and many methods, equations, and software programs to calculate culvert hydraulics, there is not a good source for determining all of these ratings for multiple crossings simultaneously. Such a screening tool would generate a more complete picture of culvert adequacy or suitability. One of the goals of the C-RiSe project was to create such a model. Using a relatively minor amount of data input – some of which can be obtained offline, and the rest collected in the field – this spreadsheet model is able to calculate hydrology and hydraulics, and determine each of the three assessment ratings, yielding easy-to-interpret color-coded results. The results may then be compared spatially, by grouping crossings on aerial images, or by viewing the results by town (or hydrologic region, county, road, etc.). Crossings with many red ratings may easily be interpreted as being very inadequate compared to those receiving mostly green ratings. This makes viewing and analyzing many crossings at once much more straightforward and streamlined. While many more detailed ways exist to assess crossings for each of the ratings, the amount of time to do so increases greatly. This model is meant to be easy to use, and provide a coarse screen for crossing adequacy.

The hydraulic model developed for this project uses the polynomial equations and coefficients defined in the HY-8 documentation to calculate headwater depths due to inlet control. It also uses the input and methods defined in the screening tools for AOP and GC. Hydrology is calculated using the SCS Curve Number method or the USGS Regression Equations for New Hampshire. The model contains tabs for Instructions and Information, followed by input tabs for General Input (location information) Hydrology, Hydraulics, Tailwater Control, AOP, and GC. Hidden tabs then contain reference tables of values, as well as calculation tabs for each of the methods. Finally, the model has tabs displaying the Ratings, Results, and Statistics. The User's Manual presents thorough explanation of all the model components, input, interface, calculations, and results.

Results

With all three assessments performed for all 105 crossings across the 10 communities, hydraulic, AOP, and GC ratings were determined for each culvert. A full table of the crossing locations by ID number and a summary table of culvert ratings are provided in the Appendix.

The total number of assessed in each of the participating C-RiSe communities is provided in Table 3. Of note, the town of Newfields actually selected 11 total crossings, however one was a massive bridge span (Route 108 over the Squamscott River), and it was deemed inapplicable to the scope of this project.

Table 3. Number of Crossings by Town	
Town	# Crossings
Rollinsford	6
Dover	12
Madbury	9
Durham	10
Newington	10
Newmarket	12
Newfields	10
Greenland	11
Stratham	10
Exeter	15
Total:	105

Hydraulic Ratings

Of the crossings analyzed, the ratings were nearly split three ways at the 10-yr peak flows, but declined quickly towards the higher peak flows. At the hundred-year event, nearly two-thirds of the crossings are rated as failing. A summary of the crossing hydraulic ratings by return periods is provided in Table 4.

Table 4. Number of Crossing Ratings by Return Period				
Rating	10-yr	25-yr	50-yr	100-yr
Pass	38	28	23	16
Transitional	34	30	28	22
Fail	33	47	54	67

The following four tables (Tables 5, 6, 7, and 8) show total crossings by hydraulic ratings for each town.

Table 5. 10-yr Ratings by Town			
Town	Pass	Transitional	Fail
Rollinsford	3	2	1
Dover	4	5	3
Madbury	3	3	3
Durham	0	2	8
Newington	5	3	2
Newmarket	5	4	3
Newfields	7	2	1
Greenland	3	5	3
Stratham	5	2	3
Exeter	3	6	6

Table 6. 25-yr Ratings by Town			
Town	Pass	Transitional	Fail
Rollinsford	2	2	2
Dover	4	4	4
Madbury	3	2	4
Durham	0	1	9
Newington	5	1	4
Newmarket	1	7	4
Newfields	6	2	2
Greenland	3	3	5
Stratham	2	5	3
Exeter	2	3	10

Table 7. 50-yr Ratings by Town			
Town	Pass	Transitional	Fail
Rollinsford	2	1	3
Dover	2	6	4
Madbury	3	1	5
Durham	0	1	9
Newington	4	2	4
Newmarket	1	7	4
Newfields	4	2	4
Greenland	3	2	6
Stratham	2	4	4
Exeter	2	2	11

Table 8. 100-yr Ratings by Town			
Town	Pass	Transitional	Fail
Rollinsford	1	1	4
Dover	1	4	7
Madbury	3	0	6
Durham	0	1	9
Newington	3	3	4
Newmarket	1	4	7
Newfields	1	4	5
Greenland	2	2	7
Stratham	2	1	7
Exeter	2	2	11

Aquatic Organism Passage Ratings

AOP ratings for the 105 crossings appear to be fairly ambiguous, with over two-thirds of the crossings having a rating of Reduced AOP. This is not unique, however, as published results from both New Hampshire and Vermont show that a rating of Reduced AOP is more common than others, followed by No AOP. All crossings contained within this project were rated for AOP, despite many having properties that would normally cause them to be unrated. Examples of such are bridges (always considered passable), tidal crossings (same), and any culvert considered a 'drainage culvert,' among other reasons. However, in order to provide ratings consistently for this project, the ratings for AOP were calculated and estimated in the most appropriate manner possible. The total number of crossings by AOP rating, and the percent of the total amount for each may be found in Table 9. To further break down the AOP ratings, the total crossings by AOP rating for each town are shown in Table 10.

Table 9. Total Crossings by AOP Rating				
Units	Full AOP	Reduced AOP	No AOP*	No AOP
Quantity	13	72	1	19
Percentage	12.4%	68.6%	1.0%	18.1%
* No AOP for all species except Adult Salmonids				
No AOP for any species, including Adult Salmonids				

Table 10. AOP Ratings by Town				
Town	Full AOP	Reduced AOP	No AOP*	No AOP
Rollinsford	1	3	0	2
Dover	2	8	0	2
Madbury	0	6	1	2
Durham	2	6	0	2
Newington	1	7	0	2
Newmarket	2	8	0	2
Newfields	2	6	0	2
Greenland	0	9	0	2
Stratham	1	7	0	2
Exeter	2	12	0	1

Geomorphic Compatibility Ratings

All the crossings given as part of this project were rated for GC, despite many possessing properties that would normally cause them to be unrated. Due to the rating scoring scheme, select properties of the culverts themselves, as well as the watercourse, must be present in order for GC to be properly scored. However, for consistency, the GC ratings were calculated for all the sites within this project to the most appropriate degree possible. A majority (80%) of the crossings scored reasonably well – almost a near split between Mostly Compatible and Partially Compatible – and over 90% of crossings were rated between Mostly Incompatible and Mostly Compatible. This again, may seem ambiguous or skewed, however it follows the trend observed by the Vermont Department of Environmental Conservation, published as part of their Screening Tool Documentation. The total number of crossings per GC rating is shown in Table 11.

Table 11. Overall GC Ratings					
Total By	Fully Compatible	Mostly Compatible	Partially Compatible	Mostly Incompatible	Fully Incompatible
Quantity	7	44	40	14	0
Percentage	7%	42%	38%	13%	0%

Again, the GC ratings may be broken down by town. While there are not many towns with multiple crossings that are rated as Fully Compatible; there are also no crossings rated as Fully Incompatible for any of the towns. The GC ratings by town is shown in Table 12.

Table 12. GC Ratings by Town					
Town	Fully Compatible	Mostly Compatible	Partially Compatible	Mostly Incompatible	Fully Incompatible
Rollinsford	0	1	5	0	0
Dover	0	6	3	3	0
Madbury	0	3	4	2	0
Durham	1	4	5	0	0
Newington	1	4	2	3	0
Newmarket	1	7	3	1	0
Newfields	1	5	3	1	0
Greenland	0	3	6	2	0
Stratham	2	1	6	1	0
Exeter	1	10	3	1	0

Map Image Icons

In addition to having the ratings calculated and shown in the model, using colored cells to highlight each rating, these ratings have been placed onto aerial maps for each town, as well as uploaded to the New Hampshire Statewide Asset Data Exchange System (SADES) database and the NH Coastal Viewer. Since the state had previously defined protocol and assessment procedures for rating crossings for GC and AOP, their existing map symbols were used for those two ratings. These two appear on maps as dots, colored in the same manner as displayed in the model and in this report.

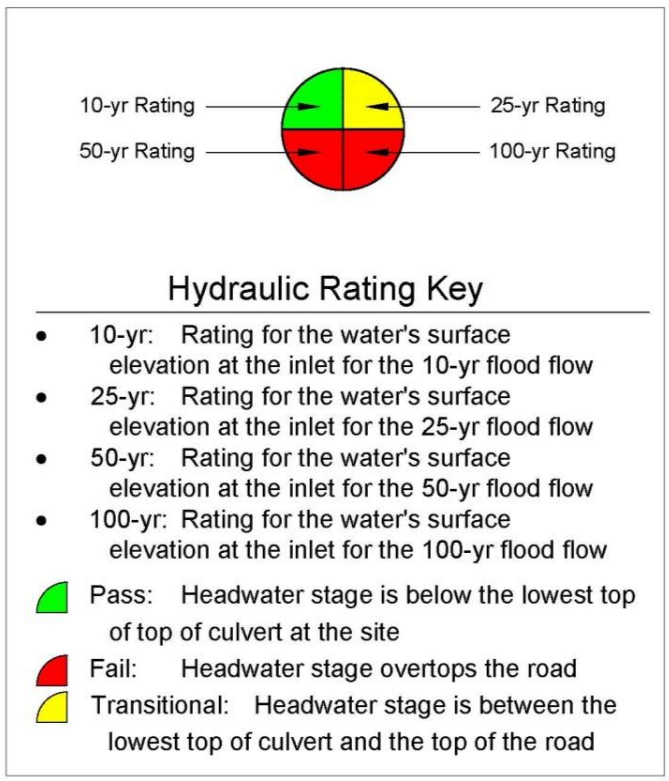

Figure 2. Hydraulic Rating Key

Since the hydraulic ratings are something new to the assessment scheme, and having no prior inclusion online, a symbol was determined in an attempt to display the hydraulic ratings in a meaningful and quick manner. Following the same scheme as for the AOP and GC ratings, a circle was used. This circle is divided into four quadrants, and each quadrant is colored according to the rating (green for pass, yellow for transitional, red for fail). The quadrants represent the 10-yr rating in the upper left quadrant, the 25-yr rating in the upper right quadrant, the 50-yr rating in the lower left quadrant, and the 100-yr rating in the lower right quadrant. This shows the four most applicable ratings in one simple symbol. A sample image of the symbol is shown in Figure 2. These results have all been presented to the towns and may be viewed online on the New Hampshire Coastal Viewer.

Discussion

Overall, the crossings analyzed as part of this project performed poorly across the board, due to many factors. First, the towns were asked to provide anywhere from 5 to 15 "problem" culverts they wished to have analyzed. The crossings provided were of concern to the towns, and are likely to have known problems, or are of special interest. Since new, highly functional crossings are usually not in need of analysis or repair, the town-supplied crossings were expected to perform poorly. Also, in performing hydrologic calculations as part of this project, the most current precipitation data was used, which reflects increased precipitation amounts manifested in recent years. These values are likely larger than those used during the design of many of the culverts (assuming that most are likely older culverts, and not new ones). In addition to the larger flows calculated for each site, the hydrology is calculated without any regard for upstream storage – both in the form of upstream impoundments, and considering storage routing at each site (where the stream crossing acts as an impoundment, the road as the overflow weir, and the culvert as the outlet). There are also a few special cases where crossings are influenced by tidal flows – either as a tidal crossing themselves, or immediately upstream of the Mean High High Water (MHHW) elevation. Even fewer, but still occurring, are cases where crossings are influenced downstream by flood stages in larger rivers. In both cases, the hydraulics were calculated using worst-case scenarios, which may not be likely, but would account for a more critical situation rating.

While the previously mentioned situations apply mostly to hydraulics, special considerations exist for the AOP ratings and GC ratings. For both assessments, many crossings contained within this project would be considered not applicable to one or both of the assessments, as per the protocol for each. Both assessments were performed as part of this project for all the crossings, but the ratings for AOP and GC should be considered with caution.

Crossings that are tidal, or are bridges are not considered for AOP, as both are considered to have a Full AOP rating. Crossings that are over ephemeral or intermittent watercourses are also not considered, as to fully run the assessment, the data is required to be taken during a period of low-flow.

The GC assessment includes five scores for measurable data and observational properties of the stream crossing and the watercourse it passes. The sum of these individual scores gives an overall score, which is then used to determine the GC rating. Any crossing that does not have one of the five individual scores available to score cannot be rated. Many of the crossings in this project – due to a variety of reasons – did not have the applicable data available to score. More specifically, crossings not considered applicable to the GC screening assessment include tidal crossings as well as crossings over ephemeral or intermittent watercourses. Tidal crossings are considered to have their own geomorphic properties that are not quite applicable to this screening tool, as do ephemeral or intermittent streams. Crossings that are at impoundments are also not considered for this tool.

Appendix

Table A1. Crossing IDs and Locations					
Crossing #	Town	Road	Stream	Latitude	Longitude
				dec. deg.	dec. deg.
1	Rollinsford	Jessie Doe Rd	Unnamed	43.235676	-70.8276665
2	Rollinsford	Willey St	Unnamed	43.2309872	-70.8246759
3	Rollinsford	Watson Ln	Fresh Creek	43.2293642	-70.8414293
4	Rollinsford	Sligo Rd	Unnamed	43.2193009	-70.8147081
5	Rollinsford	Sligo Rd	Sligo Brook	43.2084471	-70.8221013
6	Rollinsford	Old Mill Rd	Fresh Creek	43.2071739	-70.8435301
7	Dover	Pickering Rd	Blackwater Brook	43.2389082	-70.935895
8	Dover	Long Hill Rd	Tryner's Brook	43.2323679	-70.9126412
9	Dover	Sixth St	Reyner's Brook	43.2217175	-70.9192522
10	Dover	County Farm Rd	Jackson Brook	43.2182893	-70.9327253
11	Dover	County Farm Rd	Reyner's Brook	43.2170987	-70.9244239
12	Dover	Portland Av	Unnamed	43.2012826	-70.8658568
13	Dover	Atlantic Av	Unnamed	43.2007374	-70.8620219
14	Dover	Bellamy Rd	Unnamed	43.1807772	-70.8893154
15	Dover	Bellamy Rd	Bellamy River	43.1802628	-70.8896329
16	Dover	Drew Rd	Unnamed	43.153837	-70.879365
17	Dover	Garrison Ln	Unnamed	43.158355	-70.8647357
18	Dover	Spur Rd	Varney Brook	43.1595093	-70.8512049
19	Madbury	Nute Rd	Unnamed	43.193481	-70.979304
20	Madbury	Nute Rd	Bellamy River	43.188648	-70.977374
21	Madbury	Mill Hill Rd	Bellamy River	43.1801207	-70.9479113
22	Madbury	Hayes Rd	Unnamed	43.1773719	-70.9676869
23	Madbury	Hayes Rd	Unnamed	43.1744565	-70.9527854
24	Madbury	Cherry Hill Ln	Unnamed	43.169324	-70.967073
25	Madbury	Sarah Paul Hill Rd	Gerrish Brook	43.159239	-70.934008
26	Madbury	Madbury Rd	Beard's Creek	43.1589148	-70.9332285
27	Madbury	Freshett Rd	Johnson Creek	43.1495707	-70.8899917
28	Durham	Madbury Rd	Littlehale Creek	43.1457	-70.928338
29	Durham	Edgewood Rd	Littlehale Creek	43.145131	-70.927258
30	Durham	Bagdad	Littlehale Creek	43.142982	-70.921207
31	Durham	Madbury Rd	Pettee Brook	43.135127	-70.925105
32	Durham	Griffith Rd	Chesley Brook	43.117429	-70.966656
33	Durham	Bennett Rd	Woodman Brook	43.107001	-70.945488
34	Durham	Bennett Rd	La Roche Brook	43.109275	-70.935544
35	Durham	Bennett Rd	Beaudette Brook	43.1114987	-70.9300179
36	Durham	Longmarsh Rd	Longmarsh Brook	43.114178	-70.923927
37	Durham	Newmarket Rd	Hamel Brook	43.118926	-70.922369
38	Newington	Fox Point Rd	Knight Brook	43.1102364	-70.8452967
39	Newington	Nimble Hill Rd	Unnamed	43.1083192	-70.8270442

Table A1. Crossing IDs and Locations					
Crossing #	Town	Road	Stream	Latitude	Longitude
				dec. deg.	dec. deg.
40	Newington	Shattuck Wy	Unnamed	43.1124072	-70.8162899
41	Newington	B&M Railroad	Unnamed	43.1093031	-70.8064405
42	Newington	Little Bay Rd	Unnamed	43.101586	-70.84998
43	Newington	Arboretum Dr	Upper Pickering Bk	43.1025787	-70.8220983
44	Newington	Arboretum Dr	Flagstone Ditch	43.100929	-70.817042
45	Newington	Shattuck Wy	Paul Brook	43.100749	-70.80045
46	Newington	Newington Rd	McIntyre Brook	43.069603	-70.831869
47	Newington	Newington Rd	Kennard Pond	43.062373	-70.829265
48	Newmarket	Ash Swamp Rd	Unnamed	43.07865	-70.98635
49	Newmarket	Grant Rd	Unnamed	43.06373333	-71.00091667
50	Newmarket	Doe Farm Ln	Unnamed	43.06538333	-70.99846667
51	Newmarket	Ash Swamp Rd	Unnamed	43.06738333	-70.97741667
52	Newmarket	Grant Rd	Unnamed	43.061005	-70.975454
53	Newmarket	Langs Ln	Unnamed	43.07163333	-70.96766667
54	Newmarket	Grant Rd	Unnamed	43.06451667	-70.9668
55	Newmarket	Grant Rd	Piscassic River	43.069021	-70.962015
56	Newmarket	S. Main St	Moonlight Brook	43.073578	-70.945344
57	Newmarket	Maple St	Moonlight Brook	43.07437	-70.941483
58	Newmarket	B&M Railroad	Moonlight Brook	43.075398	-70.939248
59	Newmarket	Bay Rd	Lubberland Creek	43.078261	-70.917646
60	Newfields	Bald Hill Rd	Unnamed	43.04372	-71.0018
61	Newfields	Cuba Rd	Piscassic River	43.03423	-70.99703
62	Newfields	Piscassic Rd	Piscassic River	43.03424	-70.96803
63	Newfields	Old Lee Rd	Unnamed	43.04354	-70.95882
64	Newfields	Piscassic Rd	Parting Brook	43.03413	-70.95567
65	Newfields	Bassett Ln	Parting Brook	43.03186	-70.95496
66	Newfields	Finn Av	Unnamed	43.02804	-70.95179
67	Newfields	Deertrees Ln	Sloan's Brook	43.02259	-70.94638
68	Newfields	Exeter Rd	Parting Brook	43.03135	-70.94381
69	Newfields	Main St	Unnamed	43.041	-70.93307
70	Newfields	College Rd	Squamscott River	43.0397	-70.92824
71	Greenland	Willowbrook Av	Johnson Brook	43.03558	-70.86919
72	Greenland	Great Bay Rd	Foss Brook	43.03872	-70.86748
73	Greenland	Coast Wy	Shaw Brook	43.03356	-70.85735
74	Greenland	Portsmouth Av	Shaw Brook	43.03524	-70.85432
75	Greenland	Winnicut Rd	Thompson Brook	43.027339	-70.854287
76	Greenland	Bayside Rd	Shaw Brook	43.039994	-70.850234
77	Greenland	Portsmouth Av	Winnicut River	43.03608	-70.84811
78	Greenland	Riverside Dr	Unnamed	43.035895	-70.846199
79	Greenland	Greenland Rd	Packer Brook	43.04155	-70.82188
80	Greenland	Post Rd	Norton Brook	43.00972	-70.84277
81	Greenland	Breakfast Hill Rd	Berry's Brook	43.01071	-70.8156
82	Stratham	Squamscott Rd	Jewell Hill Brook	43.0369427	-70.9219395

Table A1. Crossing IDs and Locations					
Crossing #	Town	Road	Stream	Latitude	Longitude
				dec. deg.	dec. deg.
83	Stratham	Squamscott Rd	Unnamed	43.037619	-70.917848
84	Stratham	Squamscott Rd	Unnamed	43.03796	-70.916932
85	Stratham	Squamscott Rd	Unnamed	43.038876	-70.908154
86	Stratham	Portsmouth Av	Unnamed	43.030033	-70.909115
87	Stratham	Portsmouth Av	Jewell Hill Brook	43.0317497	-70.9076094
88	Stratham	Binum Woods Rd	Mill Brook	43.019932	-70.889577
89	Stratham	Winnicutt Rd	Winnicutt River	43.0093293	-70.87110348
90	Stratham	Portsmouth Av	Parkman Brook	42.9950574	-70.9254196
91	Stratham	Stratham Heights Rd	Unnamed	42.990033	-70.900882
92	Exeter	Oaklands Rd	Unnamed	43.024643	-70.972332
93	Exeter	Beech Hill Rd	Beech Hill Brook	43.01793	-70.983882
94	Exeter	Pine Rd	Unnamed	43.011903	-71.009047
95	Exeter	Watson Rd	Bloody Brook	43.010306	-70.972743
96	Exeter	Dogtown Rd	Unnamed	42.9838189	-71.002574
97	Exeter	Industrial Dr	Watson Brook	42.992017	-70.968756
98	Exeter	Portsmouth Av	Wheelwright Creek	42.987821	-70.934259
99	Exeter	Pickpocket Rd	Pennell Pond	42.968967	-70.987823
100	Exeter	Tamarind Ln	Scamen Brook	42.970573	-70.975324
101	Exeter	Court St	Little River	42.972578	-70.950964
102	Exeter	Drinkwater Ln	Unnamed	42.971534	-70.93205
103	Exeter	Hampton Falls Rd	Unnamed	42.972362	-70.917795
104	Exeter	Hampton Rd	Ash Brook	42.971468	-70.901271
105	Exeter	John West Rd	Perkins Brook	42.9596411	-70.9917698
106	Exeter	Powder Mill Rd	Perkins Brook	42.9617046	-70.9821343

Table A2. Complete Summary of Crossing Ratings							
Crossing #	Town	Hydraulic Ratings				AOP Ratings	GC Ratings
		10-yr	25-yr	50-yr	100-yr	Rating	Rating
1	Rollinsford	Transitional	Fail	Fail	Fail	No AOP	Partially Compatible
2	Rollinsford	Pass	Transitional	Transitional	Fail	No AOP	Partially Compatible
3	Rollinsford	Transitional	Transitional	Fail	Fail	Reduced AOP	Partially Compatible
4	Rollinsford	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible
5	Rollinsford	Pass	Pass	Pass	Transitional	Reduced AOP	Partially Compatible
6	Rollinsford	Pass	Pass	Pass	Pass	Full AOP	Mostly Compatible
7	Dover	Pass	Pass	Transitional	Transitional	Full AOP	Mostly Compatible
8	Dover	Transitional	Transitional	Transitional	Fail	Reduced AOP	Mostly Compatible
9	Dover	Pass	Pass	Pass	Transitional	Reduced AOP	Mostly Incompatible
10	Dover	Transitional	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
11	Dover	Transitional	Transitional	Transitional	Fail	Reduced AOP	Partially Compatible
12	Dover	Transitional	Transitional	Transitional	Fail	Reduced AOP	Mostly Compatible
13	Dover	Fail	Fail	Fail	Fail	No AOP	Mostly Incompatible
14	Dover	Pass	Pass	Transitional	Transitional	No AOP	Mostly Incompatible
15	Dover	Pass	Pass	Pass	Pass	Reduced AOP	Mostly Compatible
16	Dover	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
17	Dover	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible
18	Dover	Transitional	Transitional	Transitional	Transitional	Full AOP	Partially Compatible
19	Madbury	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
20	Madbury	Pass	Pass	Pass	Pass	Reduced AOP	Mostly Compatible
21	Madbury	Pass	Pass	Pass	Pass	Reduced AOP	Partially Compatible
22	Madbury	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Incompatible
23	Madbury	Transitional	Transitional	Fail	Fail	No AOP	Mostly Incompatible
24	Madbury	Fail	Fail	Fail	Fail	No AOP	Mostly Compatible
25	Madbury	Transitional	Transitional	Transitional	Fail	Reduced AOP	Partially Compatible
26	Madbury	Transitional	Fail	Fail	Fail	Reduced AOP	Partially Compatible
27	Madbury	Pass	Pass	Pass	Pass	No AOP**	Partially Compatible
28	Durham	Fail	Fail	Fail	Fail	No AOP	Partially Compatible
29	Durham	Transitional	Fail	Fail	Fail	Reduced AOP	Partially Compatible
30	Durham	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible
31	Durham	Transitional	Transitional	Transitional	Transitional	Full AOP	Mostly Compatible
32	Durham	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
33	Durham	Fail	Fail	Fail	Fail	No AOP	Partially Compatible
34	Durham	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible
35	Durham	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
36	Durham	Fail	Fail	Fail	Fail	Reduced AOP	Fully Compatible
37	Durham	Fail	Fail	Fail	Fail	Full AOP	Mostly Compatible
38	Newington	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
39	Newington	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Incompatible
40	Newington	Pass	Pass	Transitional	Transitional	Full AOP	Fully Compatible
41	Newington	Transitional	Transitional	Transitional	Transitional	Reduced AOP	Mostly Compatible
42	Newington	Transitional	Fail	Fail	Fail	Reduced AOP	Mostly Incompatible
43	Newington	Pass	Pass	Pass	Pass	Reduced AOP	Mostly Incompatible
44	Newington	Pass	Pass	Pass	Pass	No AOP	Mostly Compatible

Table A2. Complete Summary of Crossing Ratings

Crossing #	Town	Hydraulic Ratings				AOP Ratings	GC Ratings
		10-yr	25-yr	50-yr	100-yr	Rating	Rating
45	Newington	Transitional	Fail	Fail	Fail	Reduced AOP	Partially Compatible
46	Newington	Pass	Pass	Pass	Pass	No AOP	Mostly Compatible
47	Newington	Pass	Pass	Pass	Transitional	Reduced AOP	Partially Compatible
48	Newmarket	Fail	Fail	Fail	Fail	Reduced AOP	Fully Compatible
49	Newmarket	Pass	Transitional	Transitional	Transitional	Reduced AOP	Mostly Compatible
50	Newmarket	Pass	Transitional	Transitional	Transitional	Reduced AOP	Mostly Compatible
51	Newmarket	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
52	Newmarket	Transitional	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
53	Newmarket	Pass	Transitional	Transitional	Fail	No AOP	Partially Compatible
54	Newmarket	Pass	Transitional	Transitional	Transitional	Reduced AOP	Mostly Compatible
55	Newmarket	Pass	Pass	Pass	Pass	Full AOP	Mostly Compatible
56	Newmarket	Transitional	Transitional	Transitional	Fail	Reduced AOP	Partially Compatible
57	Newmarket	Transitional	Transitional	Transitional	Transitional	Reduced AOP	Mostly Compatible
58	Newmarket	Transitional	Transitional	Transitional	Fail	Full AOP	Partially Compatible
59	Newmarket	Fail	Fail	Fail	Fail	No AOP	Mostly Incompatible
60	Newfields	Pass	Pass	Pass	Transitional	Full AOP	Fully Compatible
61	Newfields	Transitional	Transitional	Fail	Fail	Full AOP	Mostly Compatible
62	Newfields	Pass	Pass	Pass	Pass	Reduced AOP	Partially Compatible
63	Newfields	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
64	Newfields	Pass	Transitional	Transitional	Transitional	Reduced AOP	Mostly Compatible
65	Newfields	Pass	Pass	Pass	Transitional	Reduced AOP	Mostly Incompatible
66	Newfields	Pass	Pass	Pass	Transitional	Reduced AOP	Mostly Compatible
67	Newfields	Pass	Pass	Transitional	Fail	No AOP	Mostly Compatible
68	Newfields	Transitional	Fail	Fail	Fail	Reduced AOP	Partially Compatible
69	Newfields	Pass	Pass	Fail	Fail	No AOP	Partially Compatible
70	Newfields	-	-	-	-	-	-
71	Greenland	Transitional	Transitional	Fail	Fail	No AOP	Mostly Compatible
72	Greenland	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible
73	Greenland	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
74	Greenland	Transitional	Transitional	Transitional	Fail	Reduced AOP	Mostly Incompatible
75	Greenland	Pass	Pass	Pass	Pass	No AOP	Partially Compatible
76	Greenland	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible
77	Greenland	Pass	Pass	Pass	Pass	Reduced AOP	Mostly Incompatible
78	Greenland	Transitional	Fail	Fail	Fail	Reduced AOP	Partially Compatible
79	Greenland	Pass	Pass	Pass	Transitional	Reduced AOP	Mostly Compatible
80	Greenland	Transitional	Transitional	Transitional	Transitional	Reduced AOP	Partially Compatible
81	Greenland	Transitional	Fail	Fail	Fail	Reduced AOP	Partially Compatible
82	Stratham	Pass	Transitional	Transitional	Transitional	Full AOP	Fully Compatible
83	Stratham	Transitional	Transitional	Fail	Fail	Reduced AOP	Mostly Compatible
84	Stratham	Fail	Fail	Fail	Fail	Reduced AOP	Fully Compatible
85	Stratham	Pass	Transitional	Transitional	Fail	Reduced AOP	Mostly Incompatible
86	Stratham	Transitional	Transitional	Transitional	Fail	Reduced AOP	Partially Compatible
87	Stratham	Pass	Transitional	Transitional	Fail	No AOP	Partially Compatible
88	Stratham	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible

Table A2. Complete Summary of Crossing Ratings							
Crossing #	Town	Hydraulic Ratings				AOP Ratings	GC Ratings
		10-yr	25-yr	50-yr	100-yr	Rating	Rating
89	Stratham	Pass	Pass	Pass	Pass	Reduced AOP	Partially Compatible
90	Stratham	Pass	Pass	Pass	Pass	No AOP	Partially Compatible
91	Stratham	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible
92	Exeter	Transitional	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
93	Exeter	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
94	Exeter	Pass	Pass	Pass	Pass	Full AOP	Fully Compatible
95	Exeter	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Incompatible
96	Exeter	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
97	Exeter	Transitional	Transitional	Transitional	Transitional	Full AOP	Mostly Compatible
98	Exeter	Pass	Pass	Pass	Pass	Reduced AOP	Mostly Compatible
99	Exeter	Pass	Transitional	Fail	Fail	Reduced AOP	Mostly Compatible
100	Exeter	Fail	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
101	Exeter	Transitional	Transitional	Transitional	Transitional	Reduced AOP	Partially Compatible
102	Exeter	Transitional	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
103	Exeter	Transitional	Fail	Fail	Fail	Reduced AOP	Partially Compatible
104	Exeter	Transitional	Fail	Fail	Fail	Reduced AOP	Mostly Compatible
105	Exeter	Fail	Fail	Fail	Fail	No AOP	Mostly Compatible
106	Exeter	Fail	Fail	Fail	Fail	Reduced AOP	Partially Compatible