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MaineDOT

Transportation Research Division

Technical Report 14-10

Analysis of Projected Replacement and Costs for Potential Aquatic Barriers maintained by MaineDOT

Final Report – February 2014

Technical Report Documentation Page

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16. Abstract (Limit 200 words)

Recent discussions around State and federal stream crossing regulations have focused on resolving existing barriers to fish movement created by pipe culverts associated with transportation infrastructure. Approximately 30% of Maine has been surveyed for stream barriers through the joint efforts of state and federal fisheries agencies and non-government organizations, which have mapped this data via GIS. These same entities are currently working toward prioritizing identified barriers according to potential habitat value and species status. The resulting database contains location information, but does not differentiate crossings for which the state is responsible from those under local or private responsibility. This lack of distinction makes it near to impossible to quantify specific future costs to MaineDOT other than on a crossing by crossing basis.

The overall project was focused on continued development of the Maine Barrier Database, integrating MaineDOT crossings with that database, and supporting the development of the Maine Stream Habitat Viewer http://mapserver.maine.gov/streamviewer/streamdocHome.html as a tool to be used by MaineDOT, municipalities and others for viewing aquatic habitat data in association with stream crossings. The final dataset developed for use by MaineDOT includes important attributes associated with fisheries habitat values, as well as cost estimates for evaluating addition of projects to work plans.

There are two major outcomes from this work that are already benefitting MaineDOT.

1) Completion of GIS aquatic barrier work that was started under other sponsorship: The results were delivered to MaineDOT as ArcMAP coverages and to the Maine Office of GIS for incorporation into the Maine Stream Habitat Viewer. MaineDOT has been using both products on a regular basis. The products have been of great value in enabling the Environmental Office staff to deliver quick preliminary assessments of aquatic habitat that might affect MaineDOT projects.

2) Application of culvert replacement cost model for providing fish passage: Several years ago University of Southern Maine/Muskie School developed a cost model for culvert replacement. The focus was on replacement culverts that would be accepted as providing fish passage. This cost model was applied to data generated from his GIS data in (1) above. The results show order-of-magnitude implications for various replacement strategies.

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There are two major outcomes from this work that are already benefitting MaineDOT.

1) Tasks 1 thru 8 - Completion of GIS aquatic barrier work that was started under other sponsorship: The results were delivered to MaineDOT as ArcMAP coverages and to the Maine Office of GIS for incorporation into the Maine Stream Habitat Viewer. MaineDOT has been using both products on a regular basis. The products have been of great value in enabling the Environmental Office staff to deliver quick preliminary assessments of aquatic habitat that might affect MaineDOT projects.

2) Task 9 - Application of culvert replacement cost model for providing fish passage: Several years ago University of Southern Maine/Muskie School developed a cost model for culvert replacement. The focus was on replacement culverts that would be accepted as providing fish passage. This cost model was applied to data generated from his GIS data in (1) above. The results show order-of-magnitude implications for various replacement strategies.

This report includes a very brief summary of the study activities and a more in-depth report on Task 9, Estimate Project Specific Costs, entailing a thorough review and application of Construction Cost Models.

Summary Report **Date: 2-24-14**

Prepared By: Alex Abbott, GIS Analyst/Contractor
Prepared For: Charlie Hebson, Maine Department of Transportation Environmental Office
Purpose: To provide summary information on completion of all tasks under CTM #20121212000000000374, initiated on 12-12-2012.

Our agreement had nine tasks, each of which has now been completed. The overall project was focused on continued development of the Maine Barrier Database, integrating MaineDOT crossings with that database, and supporting the development of the *Maine Stream Habitat Viewer* as a tool to be used by MaineDOT, municipalities and others for viewing aquatic habitat data in association with stream crossings. The final dataset developed for use by MaineDOT includes important attributes associated with fisheries habitat values, as well as cost estimates for evaluating addition of projects to work plans.

The original task list and associated completion target dates and costs are listed below. This report will summarize and explain each task and provide its final completion date.

Task / Deliverable	Completion Date	Estimated Cost
1. Integrate New Survey Data to Maine Barrier Database	November 15	$ 2,700
2. Revise Aquatic Habitat Datasets	December 15	$ 3,600
3. Habitat/Crossing Network Analysis	January 15	$ 1,350
4. Code for Spatial and Attribute Queries	January 30	$ 900
5. Maine Barrier Database Overlay Analysis	January 30	$ 1,980
6. MaineDOT Crossing Data Verification	February 28	$ 1,800
7. Develop Replacement/Rehabilitation Timeline	March 15	$ 3,600
8. Identify Priority Sites	March 31	$ 4,050
9. Estimate Project-Specific Costs	April 15	$ 4,500
Total		**$ 24,480**

1. **Integrate New Survey Data to Maine Barrier Database – Completed 11-30-2012**
   1,608 road crossing, dam and natural barrier sites were assessed by several organizations across Maine in 2012, and all of these data needed to be properly integrated to Maine's statewide crossing and barrier database. Numerous data quality queries had to be run to clean up the data, and to make all new data records consistent with each other and prior years' data. Also in this process, sites were classified as to their status as barriers, and drainage areas were developed and used to assign estimated bankfull channel widths to sites, essential to later steps to estimate project costs.

2. **Revise Aquatic Habitat Datasets – Completed 1-31-2013**
   In preparation for inclusion to the new *Maine Stream Habitat Viewer*, several aquatic habitat datasets needed to be either created or heavily modified. These datasets included sea-run rainbow smelt spawning and access reaches, alewife ponds and streams, wild Eastern brook trout ponds and streams, Atlantic salmon modeled juvenile rearing habitat, invasive fish species, and tidal emergent wetlands.

3. **Habitat/Crossing Network Analysis – Completed 2-28-2013**
   In order to make crossing and barrier site data useful for comparing among sites and for setting priorities, a selected subset of records, primarily those classified as *Barrier* or *Potential Barrier* sites, needed to be processed in GIS, starting with application of The Nature Conservancy's *Barrier Assessment Tool*, allowing development of stream network metrics, and then additional attributes were associated with site records.

4. **Code for Spatial and Attribute Queries – Completed 2-28-2013**
   This step was essential for associating numerous habitat and stream characteristics with site data. Crossing and barrier sites were linked to data developed in task 2 above to provide further data for setting priorities. All of these coded attributes are included in the final dataset.

5. **Maine Barrier Database Overlay Analysis – Completed 6-15-2013**
   The updated Maine crossings and barrier data were overlaid with MaineDOT crossings from its several datasets in a series of GIS processes and queries to identify sites in common. MaineDOT cross culverts, large culverts and bridges were matched against the Maine Barrier Database sites, and linked to associate MaineDOT site identification attributes such as *Asset_Sys_ID* and *BridgeNo*. MaineDOT's lack of site coordinates for many crossings made this process particularly challenging.

6. **MaineDOT Crossing Data Verification – Completed 7-17-2013**
   After the overlay process above, steps were needed to filter out non-matching sites between the Maine Barrier Database and MaineDOT's crossing datasets. Due to different data structures between MaineDOT crossing datasets and lack of site coordinates for many crossings, this process involved many queries and quality control steps to verify which of MaineDOT's crossings matched correctly with Maine Barrier Database sites.

7. **Develop Replacement/Rehabilitation Timeline – Completed 11-26-2013**
   This step was actually completed after task 8, as it should have been in the original project plans. Because Maine DOT attribute related to age of structures is very incomplete, and because of the complexities involved in bridge condition ratings, the final crossing dataset reflects only current work plans. Further evaluations need to be made to interpret the *Condition_All* attribute representing both stream crossing survey and MEDOT condition ratings, as well as cost data identified in task 9, in order to build future work plans.

8. **Identify Priority Sites – Completed 10-30-2013**
   One of the most important focuses of this project was the identification of MaineDOT crossings associated with important fish habitat to provide guidance on the most valuable crossings for a selection of habitats. Data on Atlantic salmon, alewife and brook trout habitat were associated with

crossings, and codes assigned to represent whether a crossing lies on one, two, three, or none of these habitats. These priority codes can be used in conjunction with other attributes, including estimated project costs identified in the next task to select sites for work plans.

9. **Estimate Project-Specific Costs – Completed 2-13-2014**
   The last task of our agreement, just recently completed, was to identify estimated overall project costs for replacing crossings with structures that should better fit their streams. This work entailed application of the 2010 *Construction Cost Models*, prepared for MaineDOT by the New England Environmental Finance Center (NEEFC) at the University of Southern Maine. While these cost models are both somewhat out of date, and lacking in their ability to properly account for such important site factors as depth of cover, they provide a very useful comparison of relative costs from site to site, and hopefully can be used as general estimates for deciding among projects for upcoming work plans. It would be best if MaineDOT would gather the data needed from its many past projects to build even more detailed and effective cost models for the future.

Final Report **Date: 2-12-14**

Prepared By: Alex Abbott, GIS Analyst/Contractor
Prepared For: Charlie Hebson, Maine Department of Transportation Environmental Office
Purpose: To provide information on completion of final task under CTM #20121212000000000374

Our existing agreement had one remaining task, #9 in Deliverable E ($4,500). Task 9, *Estimate Project Specific Costs*, entailed a thorough review and application of *Construction Cost Models*, prepared by the New England Environmental Finance Center (NEEFC) for MaineDOT November 1, 2010.

The cost models created for MaineDOT developed seven scenarios for which two or more potential crossing replacements were proposed, including major elements of material, equipment and labor costs. Given the very limited number of data points available in the cost model, this report's findings should be taken with caution as generalized cost estimates based primarily on the relationship of overall project costs to the size of the crossing structures proposed. While these general cost relationships are quite strong, there are frequently site specific conditions which will increase costs significantly beyond these estimates.

To build effective work plans for replacement of crossing structures, it is most useful to know general cost ranges for sites given their stream size, optional structure types, and assumptions about costs. Important assumptions have been made here to provide useful guidance in using the data developed here for planning purposes.

Assumption 1

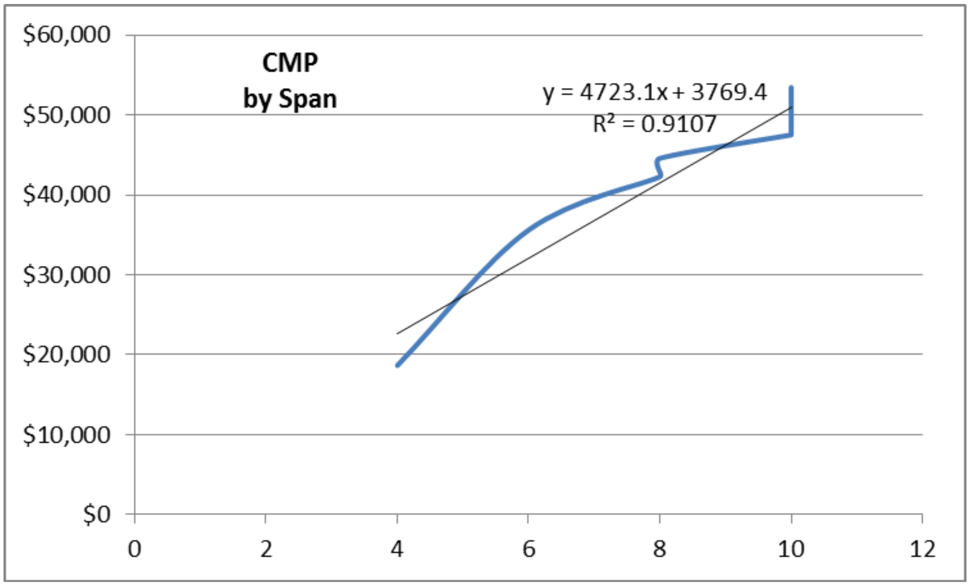
All planned structures will fit within the existing size framework used by MaineDOT to distinguish between Culverts, Large Culverts, Minor Spans and Bridges, using span limits of 5, 10 and 20 feet, and flow area limits of 20 and 80 sq. ft. All Culverts will be (embedded) CMP round pipes, all Large Culverts will be (embedded) CMP Pipe Arch or Elliptical Pipes, Minor Spans will have costs for both CMP Arches and Concrete 3-sided Box Culverts to allow for alternative approaches given site conditions and budgetary limits.

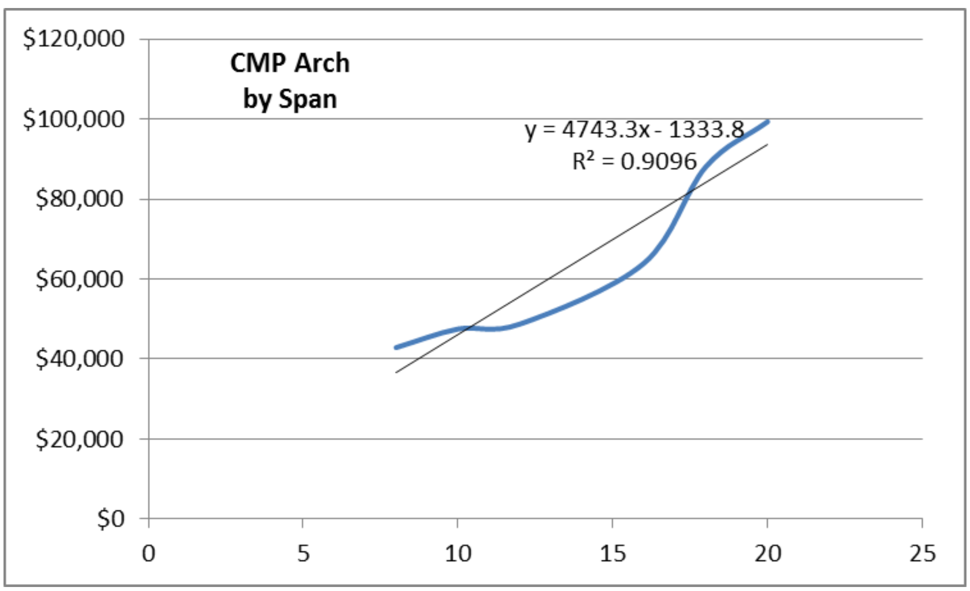
MaineDOT Crossing Classification	Planned Crossing Structure	Maximum Span (ft) *	Maximum Flow Area (sq. ft) **
Culvert	CMP Round Pipe	5	20
Large Culvert	CMP Pipe Arch or Elliptical Pipe	10	80 +
Minor Span	CMP Arch or Concrete 3-Sided Box	20	180 ++
Bridge (Span)	Designed Span Structure	?	?

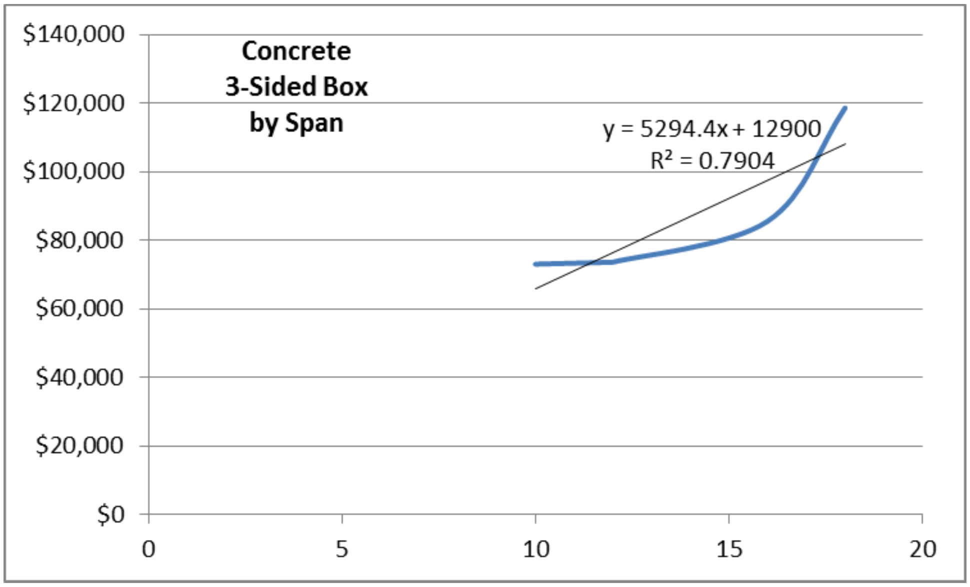
* Minimum span for round pipes is 3' on small perennial streams
** Assumes embedding closed pipes by 10-20%
\+ Real limit for listed structures is approximately 63 sq. feet given embedment and pipe geometry
++ Approximate maximum for 20' span concrete 3-sided box culvert; maximum for arch approximately = 150

Assumption 2

Coarse relationships exist between stream size (crossing span) and overall project cost for each type of crossing structure. The relationships shown below have been used to develop modeled cost estimate ranges for each structure type. The data from the original NEEFC cost model scenarios was selected here to compare relatively similar settings. They represent projects on 2-lane paved rural or suburban non-arterial feeder roads with low daily traffic volumes and several possible detour routes, in short, fairly ideal settings. Additional costs will obviously be incurred with increased depth of fill or traffic volumes, and other constraints to traffic management.







Assumption 3

The NEEFC cost model does not account well for increased project complexity related to sites with greater depth of fill or need for more involved traffic management such as when viable detours are unavailable. Lacking sufficient data on increased costs due to staged construction where detours are unavailable, no additional guidance is given here on how to account for these in overall project costs. The scenario testing done as part of the NEEFC project provides only limited examples of projects completed under relatively high fill depths (e.g., 14 feet from stream bottom to road surface in a 10 foot wide stream). In addition, the Maine Barrier Database only contains depth of cover information for some sites, while the MaineDOT MATs database contains a depth of cover attribute, but it isn't accurate for all sites, so applying depth of fill data to projected costs is of limited utility. Attempts were made to minimize the potential for incorrect estimates based on the errors in the MATS depth of cover data. The scenarios presented by the NEEFC cost model indicate an approximate doubling of project costs for structures under deep fill (defined here as ≥ 6 feet of cover, roughly equal to 10 feet from stream bottom to road surface), so the upper end of the cost range estimates (*Cost2* values) incorporate this doubling of costs to account for sites under deep fill.

The above assumptions have been used to guide the application of the cost model relationships to the MaineDOT span size classes listed above. As the weakest relationship exists for concrete 3-sided box culverts, cost estimates for those structures are considered only as an alternative to CMP arches. While box culvert cost estimates are in the data and referred to in various parts of this report, for the primary application of the cost models, CMP arches will be considered the first choice for replacing Minor Spans of 10-20 feet.

Database Fields

Attributes have been added to the *Public_Crossings_MEDOT* feature class to identify potential overall project costs for replacement of sites with a **BarrierClass** of *Barrier* or *Potential Barrier*. The attributes added are listed below with explanations of their content:

Target_Span – Expected replacement structure span in feet based on roughly 1.2 times estimated stream bankfull width. Bankfull widths are estimated based on Dudley (USGS. 2004) for drainage areas over three square miles, and on Craig & Koenig (USFWS. 2009) for drainage areas of less than three square miles.

Target_Structure – Expected structure type among four options:

Embedded Pipe – round CMP for *Target_Span* < 5 feet (MaineDOT "Culvert")

Embedded Pipe Arch/Elliptical – for *Target_Span* between 5 and 10 feet (MaineDOT "Large Culvert")

CMP Arch/Conc. 3-Sided Box – either standard CMP arch on concrete footers, or concrete 3-sided box culvert, depending on cost and site considerations for *Target_Span* between 10 and 20 feet (MaineDOT "Minor Span")

Bridge/Major Span – for *Target_Span* > 20 feet (MaineDOT "Major Span")

Target_FlowArea – estimated flow area in square feet; for CMP Arch/Conc. 3-Sided Box to reflect maximum for arch (box would be greater by an approximately additional 20%)

Pipe_Cost1 – Low estimate for overall project costs for an embedded CMP Pipe installation assuming 2-lane paved rural or suburban non-arterial feeder road with low daily traffic volume, several possible detour routes and depth of cover < 5 feet.

Pipe_Cost2 – High estimate for overall project costs for an embedded CMP Pipe assuming 2-lane paved rural or suburban non-arterial feeder road with low daily traffic volume, several possible detour routes and depth of cover > 5 feet (only varies from *Pipe_Cost1* for sites of depth of cover > 5 feet)

Arch_Cost1 - Low estimate for overall project costs for a CMP Arch installation with above assumptions for depth of cover < 5 feet

Arch_Cost2 - High estimate for overall project costs for a CMP Arch installation with above assumptions for depth of cover > 5 feet (only varies from *Pipe_Cost1* for sites of depth of cover > 5 feet)

Box_Cost1 - Low estimate for overall project costs for a concrete 3-sided box culvert installation with above assumptions for depth of cover < 5 feet

Box_Cost2 - High estimate for overall project costs for a concrete 3-sided box culvert installation with above assumptions for depth of cover > 5 feet (only varies from *Pipe_Cost1* for sites of depth of cover > 5 feet)

MaineDOT Crossing Replacement Cost Estimates by BarrierClass

A table has been created and is attached here to give a summary of the above database attributes along with additional columns to provide useful data to compare across structure types. While difficult to digest, the table is meant to give ranges, averages and totals of costs for groups of proposed "target structure" types (i.e., Embedded Pipe Arches or Concrete 3-Sided Box Culverts) based on the cost modeling explained above. The columns of the table are listed below with explanations to make interpretation of the table easier:

Barrier Class – subgroups of crossings identified as either *Barrier* or *Potential Barrier* divided into further groups by proposed span (i.e., by stream size)

Target Structure – proposed structure type for each span size class – two major groups: embedded pipes and arches/3-sided box culverts, with each group composed of two subgroups

Min. Target Span – the minimum expected span within the proposed target structure type group

Max. Target Span – the maximum expected span within the proposed target structure type group

Avg. Target Span – the average of all spans in each group of target structures
Avg Pipe Cost1 – average low cost estimate for either group of embedded pipe target structures
Sum Pipe Cost1 – total of all low cost estimates for either group of embedded pipe target structures (i.e., if all of a group of Barriers or Potential Barriers of a particular target structure type are replaced)
Avg Pipe Cost2 – average cost estimate for either group of embedded pipe target structures, including high cost estimates to account for depth of cover for some sites
Sum Pipe Cost2 – total of all cost estimates for either group of embedded pipe target structures, including high cost estimates to account for depth of cover for some sites
Avg Arch Cost1 – average low cost estimate for all CMP Arch target structures
Sum Arch Cost1 – total of all low cost estimates for all CMP Arch target structures
Avg Arch Cost2 – average cost estimate for all CMP Arch target structures, including high cost estimates to account for depth of cover for some sites
Sum Arch Cost2 – total of all cost estimates for all CMP Arch target structures, including high cost estimates to account for depth of cover for some sites
Avg Box Cost1 – average low cost estimate for all Concrete 3-Sided Box Culvert target structures
Sum Box Cost1 – total of all low cost estimates for all Concrete 3-Sided Box Culvert target structures
Avg Box Cost2 – average cost estimate for all Concrete 3-Sided Box Culvert target structures, including high cost estimates to account for depth of cover for some sites
Sum Box Cost2 – total of all cost estimates for all Concrete 3-Sided Box Culvert target structures, including high cost estimates to account for depth of cover for some sites
Avg US Blocked Miles – average number of miles of upstream perennial stream blocked by each crossing for a group of target structures
Sum US Blocked Miles – total of all miles of upstream perennial stream blocked by all crossings for a group of target structures

Note that there are separate rows for embedded round pipes and embedded pipe arches because they represent different span size classes, whereas, CMP arches and concrete 3-sided box culverts are listed on one row as alternative approaches to be used within one span size class, depending on site conditions or other factors. It is hoped that this table can provide broad guidance on potential costs across different stream size (span size) and barrier classes for general planning purposes. Of course, further evaluation of sites for potential remediation is necessary both through use of the barrier and MATS databases, and through field evaluations and detailed individual cost estimates.

The table points out some important basic facts about MaineDOT crossings. *Barrier* sites represent 37% of all identified *Barrier* and *Potential Barrier* crossings (only 15% of all surveyed crossings), and they are generally smaller crossings than the average *Potential Barrier* site (10.3’ v. 14.7’ target span). While these sites as a large group, and more important as barriers to stream connectivity than the *Potential Barriers*, they exist on streams with a range of habitat values that can be further used to narrow MaineDOT’s focus on priorities for site restoration. Another point worth noting in the table is that there are many smaller crossings in the range of 5-10 foot target spans that represent many miles of blocked habitat (average of 0.53 miles; total of 143.8 miles) which can be replaced at a relatively low per unit cost compared with major and minor spans.

One way to begin to break down the often overwhelming numbers and costs of sites is to filter (query) for sites that are on the most valuable habitat, and/or those which are already known to be in poor condition and needing replacement soon. The table below represents one such query.

Habitat_Class "1B" Sites in Public_Crossings_MEDOT	**# Sites**	**Total Estimated Cost ***
1B = Barrier (Brook Trout or Salmon or Alewife)	435	$ 22.2 mil. +
1B Barriers in Critical or Poor Condition	35	$ 1.9 mil.
1B Barriers in Critical or Poor Condition Blocking > 1 mile	14	$ 824,000

* Using Cost2 Estimates including deep fill sites replaced with embedded pipes, pipe arches or CMP Arches, depending on size

\+ 27 of these sites should be Bridges/Major Spans, for which costs are not projected, so total costs would actually be considerably higher

Another way to look at managing replacement of sites is to look across all of MaineDOT's regions to plan for restorations in each region. If we filter for the top sites in each region looking at Blocked Upstream Miles, we get the results in the table below.

Top Two Habitat_Class "1B" Sites by Region	**# Sites / Miles Blocked**	**Total Estimated Cost ***
1	2 / 3.3	$ 120,000
2	2 / 3.1	$ 146,000
3	2 / 6.6	$ 124,000
4	2 / 3.5	$ 127,000
5	2 ** / 1.2	$ 126,000
Total	10	$ 126,000

* Using Cost2 Estimates including deep fill sites replaced with embedded pipes, pipe arches or CMP Arches, depending on size (does not include Bridge/Major Spans)

** One in "Fair" condition

The key to making good use of the data developed as part of this project is for MaineDOT biologists and others to begin to explore and test the data to find how it can best be incorporated to their planning and mitigation work.

Recommendations

1. MaineDOT should review carefully the updated database feature class, *Public_Crossings_MEDOT*, to evaluate the utility of modeled cost estimates used alone or in conjunction with *Habitat_Class* codes to focus limited restoration funding toward certain crossings, and should begin to incorporate this data to work plans.
2. MaineDOT should continue to improve the accuracy and completeness of its crossing data by improving in three important areas:
   A. Collect accurate coordinate data for all crossings to better record locations for effective use in GIS when conducting analyses of road impacts on aquatic habitats
   B. Expand collection of crossing survey data to incorporate the majority of the elements represented in the *Maine Stream Crossing Survey Manual* to be able to identify barriers to aquatic connectivity where data has not yet been conducted by others.
   C. Verify *Depth of Cover* values for crossings, and if possible, acquire LIDAR remote sensing data to confirm fill depth data and allow more effective GIS assessments of site conditions to improve cost model estimates.
3. MaineDOT should specifically track project cost data in a consistent manner, particularly in relation to stream size and depth of cover to allow development of more accurate cost models and work plan budgets.
4. MaineDOT should make use of the data represented by Maine's statewide stream connectivity survey efforts to identify crossings where survey and more data is needed to allow prioritization of additional sites.

MaineDOT Crossing Replacement Cost Estimates by BarrierClass

Target Structure	#	Min. Target Span	Max. Target Span	Avg. Target Span	Avg Pipe Cost1 ($)	Sum Pipe Cost1 ($)	Avg Pipe Cost2 ($)	Sum Pipe Cost2 ($)	Avg Arch Cost1 ($)	Sum Arch Cost1 ($)	Avg Arch Cost2 ($)	Sum Arch Cost2 ($)	Avg Box Cost1 ($)	Sum Box Cost1 ($)	Avg Box Cost2 ($)	Sum Box Cost2 ($)	Avg US Blocked Miles	Sum US Blocked Miles
Embedded Round Pipe	76/15*	3	< 5	3.6	21,000	1,598,000	25,000	1,913,000		* Lower number represents deep fill sites							0.21	15.9
Embedded Pipe Arch/ Elliptical	243/72*	5	< 10	7.1	37,000	9,054,000	48,000	11,749,000									0.59	138.7
CMP Arch/Concrete 3-Sided Box	199	10	20	13.1					49,000	9,751,000	65,000	12,920,000	82,000	16,389,000	109,000	21,695,000	0.81	161.3
Bridge/Major Span	41	> 20	49	28.8	(no cost estimates projected)												3.8	156.6
Total	559			10.35		10,652,000		13,662,000		9,751,000		12,920,000		16,389,000		21,695,000	0.86	472.5
Embedded Round Pipe	84/11*	3	< 5	3.7	21,000	1,792,000	24,000	2,025,000		* Lower number represents deep fill sites							0.22	19.1
Embedded Pipe Arch/ Elliptical	312/72*	5	< 10	6.9	36,000	11,309,000	45,000	13,984,000									0.50	155.9
CMP Arch/Concrete 3-Sided Box	389	10	20	14.0					53,000	20,622,000	62,000	24,213,000	87,000	33,781,000	102,000	39,806,000	1.43	554.8
Bridge/Major Span	176	> 20	182	34.4	(no cost estimates projected)												5.03	448.1
Total	961			14.7		13,101,000		16,009,000		20,622,000		24,213,000		33,781,000		39,806,000	1.68	1,597.4

A. Abbott 2/12/2014