Large Culvert Renewal in New Brunswick

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ABSTRACT

The New Brunswick Department of Transportation and Infrastructure (NBDTI) faces numerous challenges in maintaining and renewing their aging culvert infrastructure. While bridge-sized culverts (3000 mm diameter and larger) have historically been given significant focus, an effort to better manage Large Culverts (over 1200 mm to under 3000 mm diameter) only began in 2008. Despite this effort, managing the Large Culvert infrastructure has continued to prove challenging, so NBDTI in conjunction with Englobe Corp. reviewed NBDTI's existing culvert infrastructure and management practices, on the entire process from inspection, project conception, pre-design, design, rehabilitation, and construction. This research culminated in a report summarizing the state of NBDTI's Large Culvert management with a set of recommendations for developing an improved approach to Large Culvert Renewal in New Brunswick.

Further work was completed in Phase 2 of the study focusing on several of the opportunity areas identified through the Phase 1 research and consultations, as well as discussions with the NBDTI steering committee. One of the main foci for this part of the research was to estimate the ongoing budgetary needs to manage the backlog of large culvert renewals in the medium-term and to make the program sustainable in the long-term. This task required estimating the condition of the existing inventory and estimating the replacement value of each large culvert. Other focus areas included developing a maintenance plan, renewal options decision tree, and guidance around district training, renewal of large culverts under large fills, and developing a definition of emergency as it pertains to large culvert replacement.

INTRODUCTION

Throughout the provincial roadway network, the New Brunswick Department of Transportation and Infrastructure (NBDTI) is responsible for tens of thousands of buried structures, including tens of thousands of small drainage culverts (1200 mm diameter and smaller), over 2,000 large culverts (over 1200 mm to under 3000 mm diameter), and around 1,000 bridge-sized culverts (3000 mm diameter and larger). This infrastructure allows for drainage and watercourse passage under roadways, providing integral protection for New Brunswick's road infrastructure and watersheds.

Like all infrastructure, these buried structures have limited lifespans and require ongoing renewal to ensure that the protective backbone they form maintains its integrity. NBDTI has well established processes for monitoring and maintaining their bridge-sized culvert infrastructure, but the other buried structures have historically been neglected. In 2008, NBDTI initiated a concerted effort to improve the identification, inspection, and renewal of large culverts in the Province. While this focus does not directly include the 30,000 small drainage culverts, it represents a starting point to understanding the current state of the infrastructure, exploring the process challenges being faced in non-bridge sized culvert projects, and developing processes to effectively manage the existing backlog of culvert renewals while simultaneously being proactive about New Brunswick's future infrastructure needs.

NBDTI is faced with numerous challenges in maintaining its large culvert inventory. Due to the age of the infrastructure and lack of a dedicated renewal program, many of NBDTI's large culverts are either nearing or at the end of their service lives. This has been compounded in recent years by increasingly frequent and severe storm events due to the impacts of climate change on the Province, which has increased both the rate of degradation of the infrastructure and the hydraulic sizing requirements for renewal. Additionally, many existing culverts do not meet fish passage requirements that are critical to maintaining New Brunswick's ecologically sensitive watersheds. Due to this perfect storm of circumstances, most of NBDTI's large culverts do not meet modern standards and require renewal.

Large culvert renewal is an expensive and time-consuming process that requires engagement with numerous stakeholders, including NBDTI's Design Branch, Property Services Branch, and Districts; local property owners; the Department of Environment and Local Government (NBDELG); Fisheries and Oceans Canada (DFO); the Department of Tourism, Heritage, and Culture (Archeological Services); and the Department of Aboriginal Affairs. Each of these stakeholders view large culvert projects through a different lens and while each stakeholder's perspective and processes appear reasonable individually, the combination of these individual processes has created an overall process for large culvert projects that has been found lacking in its ability to handle the volume of culvert renewals that are required in the imminent future.

Project Objectives

The broad objective of this work was to conduct a through review of NBDTI's existing processes for Large Culvert renewal, identify gaps and areas for additional study, and act on these gaps to establish a forward path for improving the status-quo for Larger Culvert renewal. Ultimately this included a Background Review, Renewal Plan Development, and …

BACKGROUND REVIEW

The background review consisted of four components: a review of the existing inventory, determining the size of the backlog of large culvert work in the province, reviewing the processes undertaken by the stakeholders in large culvert projects, and identifying improvement opportunities for further investigation (either as part of this project or other avenues).

Large Culvert Inventory Review

A detailed review of the available information on Large Culverts was undertaken in order to establish an understanding of the existing conditions of the inventory. The data analyzed was contained in the Province's BRDG software platform, which allowed inspectors to report on over 200 characteristics for each culvert and bridge in New Brunswick.

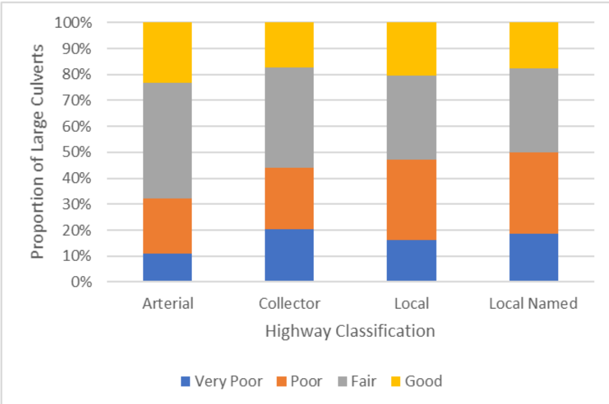
Two of the key limitations with the data related to its availability and timeliness. Of the 2,128 large culverts in the inventory, 92% had a condition rating based on the Bridge Condition Index (BCI) and only 59% had a condition rating based on the inspector's subjective estimate of the condition. This was problematic, as NBDTI placed greater value on the subjective estimate than the BCI rating. In terms of timeliness, most of the culverts had gone at least 5 years since their last inspection, which means that any analysis conducted on the data will not truly be reflective of their existing condition.

Of the culverts with available BCI scores, it was found that 46% of the inventory rated as either Poor or Very Poor, as shown in Table 1. This indicates that nearly half of the inventory needed rehabilitation or replacement. While these numbers were staggering, they corresponded with the experience of NBDTI Staff who indicated that they were expending significant effort fighting fires instead of doing proactive maintenance work. Further breakdown of the inventory found that Large culverts on arterial highways were generally in better condition than those on lower classification roads, as illustrated in Figure 1.

Table 1: Overall Condition Based on BCI

Rating	BCI Score	Number of Culverts	Percentage of Inventory	NBDTI Comments
Good	80 – 100	367	19%	Ongoing monitoring
Fair	60 – 79	696	35%	Non-critical rehab required
Poor	40 – 59	558	28%	Non-critical rehab or replacement required Rehabs should be carried out as soon as possible
Very Poor	0 – 39	345	18%	Critical replacement required
Totals		1966	100%	

Figure 1: Proportion of Large Culvers in each BCI Bin by Highway Classification



Backlog Analysis

Given that 46% of the inventory was identified as needing some form of renewal through the BCI scores detailed above, an analysis was undertaken to get a batter grasp on the size of the backlog of large culvert renewals and the remaining service life of the inventory.

The first step of this process was to identify a reasonable service life estimate for each type of large culvert in the inventory. We assembled service lives based on source material as well as NBDTI's experience with managing the inventory and established a recommendation for this backlog analysis that generally leaned towards a conservative approach. These values are summarized in Table 2.

Table 2: Service Life Estimates

Material	DTI Estimate	Sources			Model Recommendation
Aluminum	80	75 (AIL)	50-75 (WisDOT)	-	**75**
Concrete	100 – 120	70-100 (CCPPA)	75 – 100 (NCHRP)	-	**85**
Steel	40 – 50	50 (CCPPA)	75 (NCSPA)	25 – 50 (NCHRP)	**35**
Wood	45	-	-	-	**45**

With the service life estimates it was possible to directly calculate the remaining service life of any culvert where the installation year and year of last inspection were known. This was not the case for most of the inventory, so further modelling of how BCI scores trend with age was conducted. Two model specifications were used: an exponential model based on the fit of the data and a linear model between the points of [0 age, 100 BCI] and [Service Life, 40 BCI]. The models developed for the concrete and steel culverts are shown in Figure 2 and the exponential model specifications are shown in Table 3. Note that there was insufficient data to model exponential deterioration for either the Aluminum or Wood culverts.

Figure 2: Plots of the Deterioration Models (solid) and an Assumed Linear Deterioration Model (dashed) Against the Inventory Data

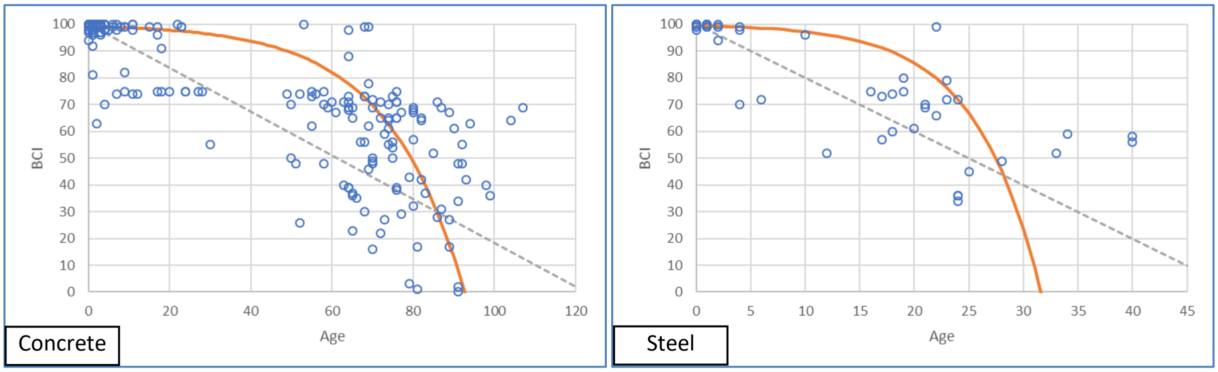


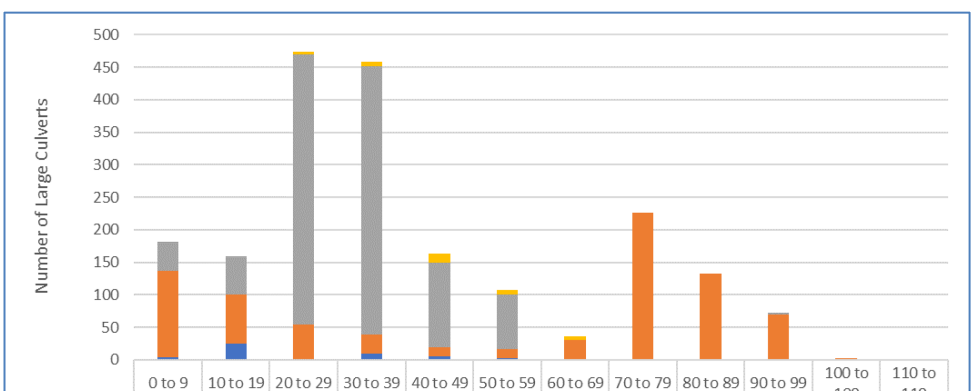
Table 3: Culvert Material Deterioration Models

Material	Data Points	Outliers	Deterioration Model	R-Squared
Concrete	203	0	$BCI = 100 - 0.7138 * e^{0.0535*age}$	0.6206
Steel	53	2	$BCI = 100 - 0.5050 * e^{0.1674*age}$	0.6567

In terms of the R-squared parameter, both exponential models fit reasonably well. There is substantial noise in the data that is likely created by environmental and geotechnical factors. From observing the plots, it appears that the exponential model is a good fit for the concrete culverts but the it is less conclusive for the steel culverts. Based on this review, the exponential model was used to estimate the ages for concrete culverts in the inventory while linear models were used for steel, aluminum, and wood culverts.

Based on these models, ages were established for all of the culverts in the inventory with a BCI score. The resulting age distribution of the inventory is shown in Figure 3. This illustrates the trends in large culvert construction over the decades, which corresponded well with NBDTI's knowledge of when different types of culverts were installed around the Province.

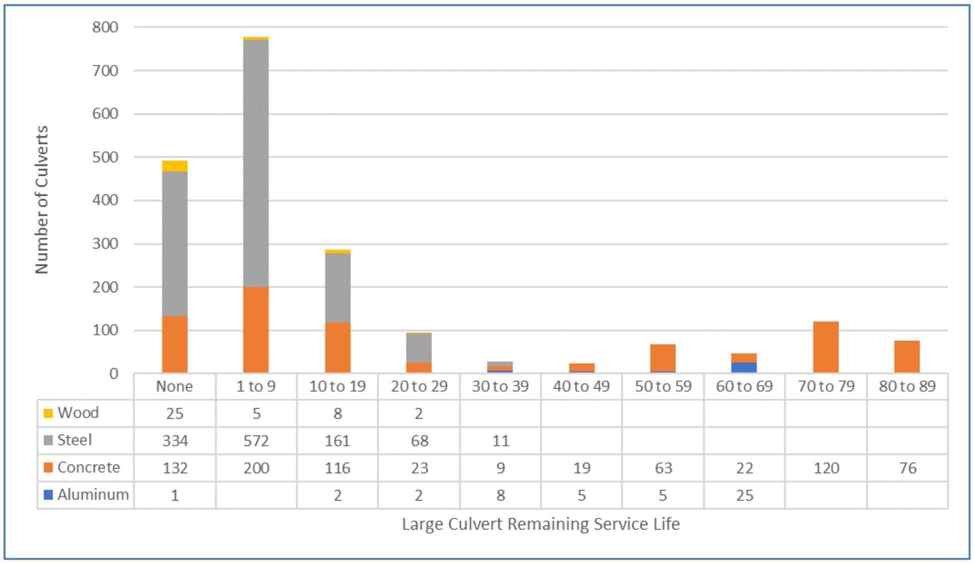
Figure 3: Age of the Existing Large Culvert Inventory



	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 to 79	80 to 89	90 to 99	100 to 109	110 to 119
Wood			5	7	14	8	6					
Steel	44	59	415	413	130	83				2		
Concrete	133	75	53	30	14	15	29	226	131	70	3	1
Aluminum	4	25	1	9	5	2	1		1			

The age data for each culvert was then used with the service lives shown in Table 2 to estimate the remaining service life of each culvert in the inventory. This is illustrated in Figure 4. It is clear from this figure that the confluence of many steel culverts that are 20-60 years old and many concrete culverts that are 70-100 years old creates a very immediate challenge for large culvert renewal. In total, 77% of the inventory was estimated to reach end-of-life within the next 20 years (including culverts that already have no remaining service life).

Figure 4: Remaining Service Life of the Existing Large Culvert Inventory



Stakeholder Engagement and Existing Process

To develop a full understanding of the existing state of large culvert renewal, our team met with 6 stakeholders in the overall process. This included 4 stakeholder groups within NBDTI (Design Branch, Property Services Branch, Districts, and Integrated Engineering) along with the New Brunswick Department of Environment and Local Governance and Fisheries and Oceans Canada. The processes that each of these stakeholders are integrated with is summarized in Table 4.

Table 4: Summary of Large Culvert Project Stakeholders and their Process Involvement

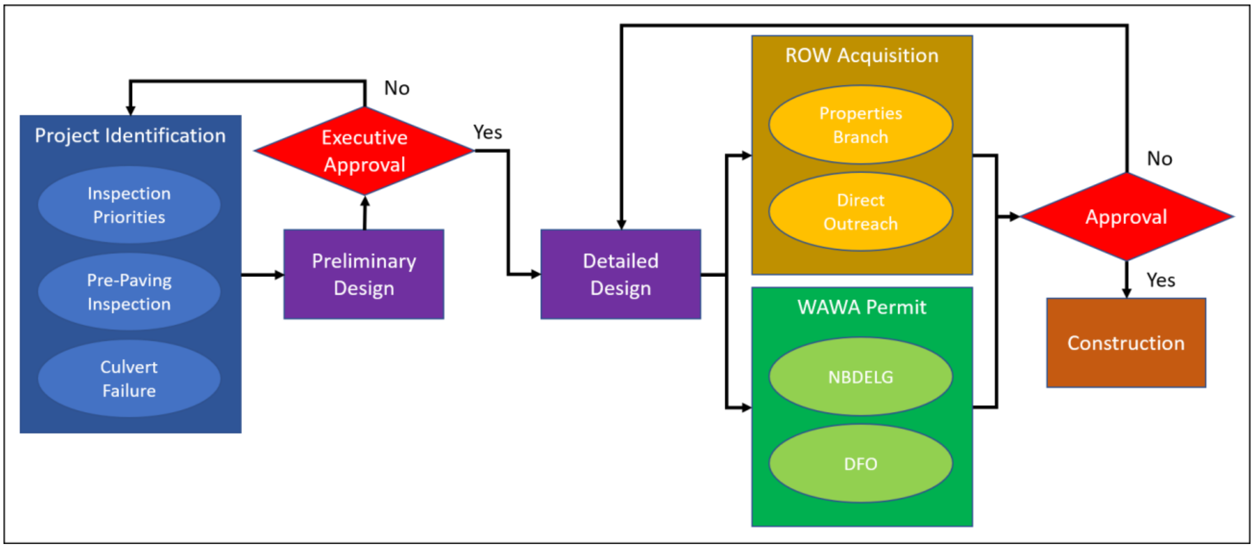
Stakeholder	Project ID	Design	ROW Acquisition	WAWA Permitting	Construction
NBDTI Design Branch	X	X			
NBDTI Property Services Branch			X		
NBDTI Districts	X	X			X
NB Department of Environment and Local Governance				X	
Fisheries and Oceans Canada				X	
NBDTI Integrated Engineering	X	X			X

From the engagement it was found that three NBDTI groups are involved with identifying and designing Large Culvert renewals: Design Branch handles the majority of the renewals that follow the typical process, the engineers at the District level will identify and design the more routine renewals, and

Integrated Engineering manages the replacement of Large Culverts under the Federal Disaster Financial Assistance Program (DFAP). All Right-of-Way (ROW) acquisition is managed by NBDTI Property Services Branch, Watercourse and Wetland Alteration (WAWA) Permitting involves Provincial and Federal bodies depending on the context, and Construction is managed by either the Districts or Integrated Engineering, depending on the funding stream for the renewal.

Overall, the Large Culvert renewal program at NBDTI was found to follow the macro-level process mapped out in Figure 5. This process map includes all of the stages identified in Table 4, with the addition of Executive and Regulator (ROW and WAWA) approval gates. While this process appears straightforward, it has been found to be extremely time consuming, as completing the whole process can take 3-5 years for typical renewals depending on the length of the regulatory processes and detailed design iterations that are ultimately required.

Figure 5: Macro-Level Large Culvert Renewal Process Map



A review of the challenges identified by each of the stakeholders presented common themes of insufficient staff, lack of dedicated resources, the time required to complete processes, incomplete information, inconsistent application of the process, and design alterations leading to regulatory reinvestigation. It was also identified that most of the existing large culverts are undersized by current standards, so most renewal projects ultimately require replacement to add capacity instead of allowing for rehabilitation.

Process Improvement Opportunities

Through the background review, the following set of improvement opportunities were identified. Many of these were explored in more detail in the subsequent phase of this project.

- Creating an ongoing multi-year planning and funding commitment to large culvert renewals;
- Increasing inspection resources;
- Training District staff in culvert sizing and planning;
- Creating a dedicated budget for large culvert renewal over and above the status quo;
- Re-evaluating the hydraulic requirements for large culverts on lower class roads;

- Creating a consistent definition of "Emergency" to be applied to large culvert renewal projects;
- Establishing a "fast track" process for property rights management with cooperative property owners;
- Educating or training staff on the information required for environmental reviews;
- Creating a consistent permitting process across NBDTI;
- Obtaining certification in watercourse alteration when it becomes available;
- Consulting DFO for guidance on fish passage requirements for complex projects; and
- Creating a stockpile of standard large culvert materials for the Districts.

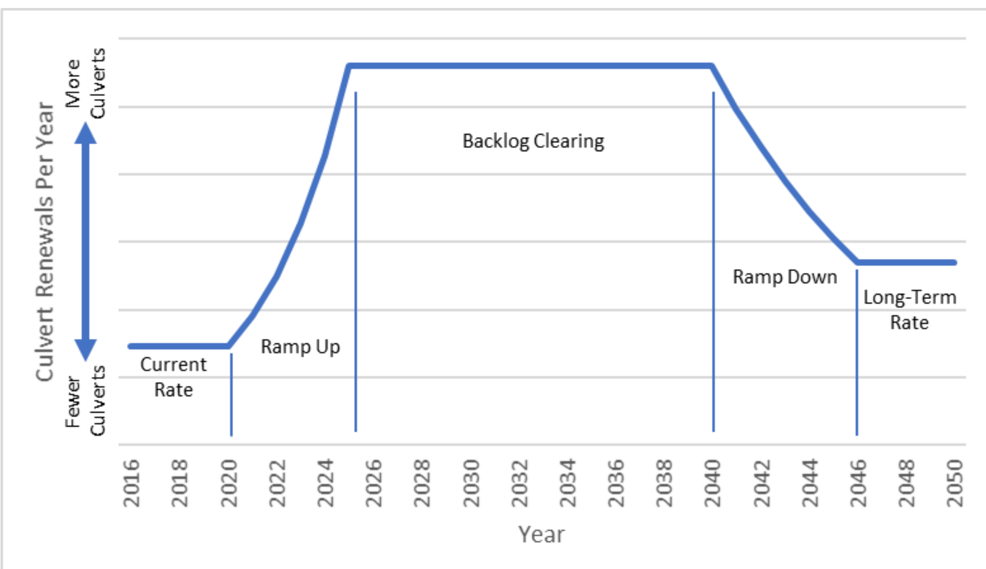
RENEWAL PLAN DEVELOPMENT

The following sections detail the methodology, replacement cost analysis, program funding model, and rehabilitation analyses that were conducted as part of developing a large culvert renewal plan for NBDTI.

Methodology

In order to effectively deal with the backlog of large culvert renewals in the Province, a strategy will be required that ramps up the current renewal rate to a significantly higher rate and then back down to a sustainable long-term renewal rate that places a greater priority on large culverts than has historically been done. A schematic of this framework is presented in Figure 6.

Figure 6: Schematic of the Large Culvert Renewal Plan



Developing this renewal plan, including estimated financial commitments, required three separate analyses to be conducted:

- **Backlog Analysis:** Estimation of the remaining service life of each culvert (detailed previously);
- **Replacement Cost Analysis:** Estimation of the replacement cost of each large culvert in the inventory; and
- **Program Funding Model:** Amalgamation of these estimates into a model that projects the impact of funding levels on the state of the large culvert inventory over time.

Replacement Cost Analysis

In order to estimate replacement costs for each culvert in the inventory, more data from the BRDG system at NBDTI was relied on. These data, and the percentage of inventory with data, included the Route # (100%), road width (97%), span quantity (97%), streambed to roadway height (94%), fill over pipe (96%), superstructure span type (96%). Where data was unavailable, the average value for the category was assumed.

To simplify the analysis, it was decided that each existing culvert would be replaced with a concrete pipe culvert, which aligns with NBDTI's typical practice but may not reflect each individual installation. For sizing, it was assumed that the new culvert would need to be upsized when compared to the existing installation; this assumption was based on recent project experience when considering the anticipated impacts of climate change. For culverts under an arterial or collector highway, it was assumed individual culverts would be upsized by two (2) standard sizes. For local highways, it was assumed the culvert would be upsized by one (1) standard size. Multi-barrel installations were applied only where a single barrel could not be accommodated by the road profile.

Based on the above data, assumptions, and methods, construction quantities were assumed following the processes detailed in Table 5. The unit costs in Table 6 were then used to calculate the replacement cost of each large culvert in the inventory.

Table 5: Quantity Estimation Key Parameters

Cost Items	Usage
Excavation Cross Section	This cost item represents the excavation required to install a new culvert according to a modified Standard Drawing 161-4. It was assumed the excavation would extend as a 1:1 slope from the bottom of the excavation. Slopes are decreased to 4:1 and 6:1 within the pavement structure as per the typical detail. Additionally, it was assumed that where Depth to Invert exceeded 5.5m, one or more benches would be required for constructability. A 5m wide bench was included on each side of the excavation for each depth increment of 5.5m (i.e. for a 12m deep culvert, two (2) benches were included).
Top Excavation Width	The top with of the required excavation was determined according to the assumptions presented above.
Backfilling Cross Section	This quantity was calculated as Excavation Cross Section minus Top Excavation Width x 1m depth (roadway subgrade material).
Culvert Length	For installations with one culvert barrel, the existing length was used. For multi-barrel installations, the length of the longest barrel was used.
Roadway Reinstatement	Roadway reinstatement area was calculated by using the Top Excavation Width calculated previously and multiplying by the roadway width. If roadway width data was not available, an assumed total width of 10m was used.
Excavation & Backfilling Quantity	Volumes for both Excavation and Backfilling were calculated similarly by multiplying their respective cross-sectional areas by the length of the culvert. To account for the roadway embankment slopes, the volume was reduced to

	account for the area between the slope and the top of roadway surface. An embankment slope of 2:1 was assumed.
Rip Rap Quantity	This was estimated by assuming the Rip Rap area is three (3) times the diameter of the culvert both for width and height. This quantity was then doubled to represent each end of the culvert and then further doubled to account for Rip Rap required for channel modifications and the outlet pool.
Guide Rail Length	It was assumed that new guiderail would be required over the entire section of roadway being reinstated. Therefore, guide rail length was estimated as twice the distance of the Top Excavation Width.

Table 6: Unit Price Estimates

Cost Items	**Unit Price Assumed**	**Notes**
Excavation	$15/m^3	Based on past project experience and consultation with NBDTI
Backfill + Backfilling	$30/m^3	Based on past project experience and consultation with NBDTI
Pavement Restoration	$90/m^2	Assumes 450mm of subbase, 150mm of base and 140mm of asphalt. Unit prices for those items were based on past project experience and consultation with NBDTI.
Rip Rap	$70/m^2	Assumes approximately 1.5 tonne of material per meter squared. This price is increased by 50% for larger culverts (>1800mm dia.) to account for the increased Rip Rap depth in these cases.
Guide Rail	$125/m	Includes posts. Based on past project experience and consultation with NBDTI.
Culverts	-	Supplier pricing obtained for the various section sizes, including delivery cost per load. Assumes average of 300km delivery distance (central province). A 20% contractor markup was assigned for material + freight costs. Placement costs for each section size were established based on past experience. Placement costs ranged from $200/m (1200 mm dia.) to $1000/m (3000 mm dia. assuming crane).
1200 mm	$ 700	
1350 mm	$ 800	
1500 mm	$ 1,100	
1800 mm	$ 1,500	
2100 mm	$ 2,000	
2400 mm	$ 3,000	
2700 mm	$ 3,700	
3000 mm	$ 4,500	

The results from the cost model are shown in Table 7. These results were validated against available data from a variety of large culvert projects and appeared to be reasonable estimates for a “typical” replacement project. One key finding that this illustrated was that it’s a small portion of the inventory that drives up the average replacement cost; this is illustrated by the difference between the average and median replacement costs.

Table 7: Cost Model Results

Parameter	Cost Model Results	Notes
Average Cost	$268,521	
Minimum	$44,708	6m long, 1800mm dia., total depth of 2.35m
Maximum	$6,715,577	116m long, 3000mm dia., total depth of 22.0m
Median	$166,600	

Program Funding Model

The program funding model was developed as a function of BCI, Age, Remaining Service Life, Existing Culvert Material, and replacement cost. This information was available for 2014 of the 2128 culverts in the inventory. To account for the remaining 114 culverts, 5.26% (114/2128) was removed from the budget for each year to account for spending on these culverts over time.

The model that was developed was essentially a worst-first asset management model that ran through the algorithm detailed below from years 2021 through 2100. All of the financial analysis was conducted in terms of present value (PV), assuming an annual inflation rate of 2.0% and construction cost escalation of 2.7% annually.

1. Identify which culverts have no remaining service life at the start of the year;
2. Running down the list of culverts sequentially, budget is allocated to replace culverts that have no remaining service life until the budget has been exhausted;
    a. The list of culverts is sorted by remaining life (ascending) and then BCI (ascending) to create a "worst first" process.
3. The culverts identified through the budget allocation process are selected for Replacement;
4. Remaining service lives and ages are adjusted forward one year:
    a. For culverts that are replaced, their remaining life is set to 85 years (the estimated service life of a concrete culvert);
    b. All other culverts have a year subtracted from their remaining service life, to a minimum of 0.

To establish the funding levels and durations of each of the funding periods shown in Figure 6, we assumed that:

- The current funding level would be $4 million per year, consistent with recent expenditure levels;
- The ramp-up and ramp-down periods would occur over a maximum of 4 years and have a minimum funding level increment of $2 million per year;
- The maximum funding level would be in place for as long as required to ensure that the backlog is cleared by the end of the ramp down period; and
- The long-term investment rate would be $6.7 million per year, which is the annualized replacement value of the entire inventory over the anticipated service live of a concrete culvert.

The maximum funding levels that were applied in the model, and the macro results from the model, are shown in Table 8. Note that the funding levels of $4 million through $8 million per year did not clear the backlog. The PVs of all the programs are similar because each program ultimately replaces the same set of culverts, just at different times; the lower funding level programs have higher overall PVs because construction cost inflation was assumed to outpace general inflation.

Table 8: Funding Levels and Implications on Large Culvert Assets and Program Delivery

Max Annual Funding Level (2021 Dollars)	**Avg. Culverts per Year @ Max Level**	**Program Duration**		**Backlog PV (2021 Dollars)**		**PV Thru 2100 (2021 Dollars, Millions)**
		to Clear Backlog	Years @ Max Level	Max (Millions)	Max Year	
$4 Million	13	-	79	$498	2100	-
$6 Million	18	-	79	$337	2037	-
$8 Million	23	-	78	$307	2037	-
$10 Million	31	56	53	$284	2034	$649
$12 Million	39	45	40	$264	2034	$636
$14 Million	46	38	33	$242	2034	$627
$16 Million	53	33	27	$219	2034	$620
$18 Million	61	29	23	$198	2032	$615
$20 Million	69	26	20	$179	2032	$612
$22 Million	77	23	17	$162	2031	$609
$24 Million	85	21	15	$145	2031	$607
$26 Million	92	20	14	$132	2029	$605

The figures below illustrate how different maximum funding levels effect the size of the backlog (Figure 7) and the average condition (Figure 8) of the inventory over time. From Figure 7 it was found that even at very high maximum funding levels, NBDTI should not expect the backlog to start reducing immediately, but higher funding levels will clear the backlog faster and bring the overall condition of the inventory up faster than lower maximum funding levels. Through this review we ultimately recommended that a maximum funding level of $16 million per year achieved a fair balance between clearing the backlog in a reasonable amount of time while limiting the stress that would be placed on NBDTI, consulting, and contracting resources to deliver the rate of renewals.

Figure 7: Percentage of Large Culverts in the Backlog Per Year

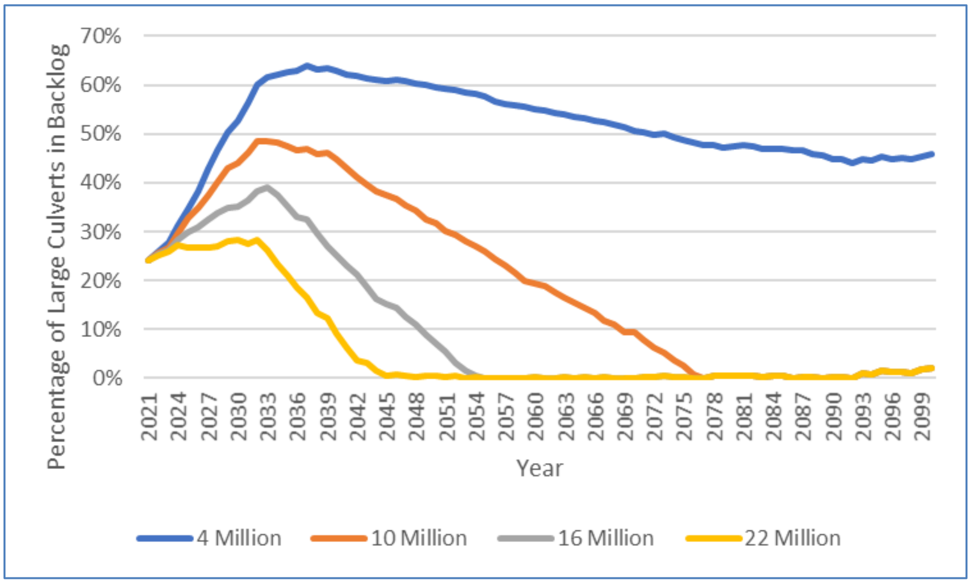
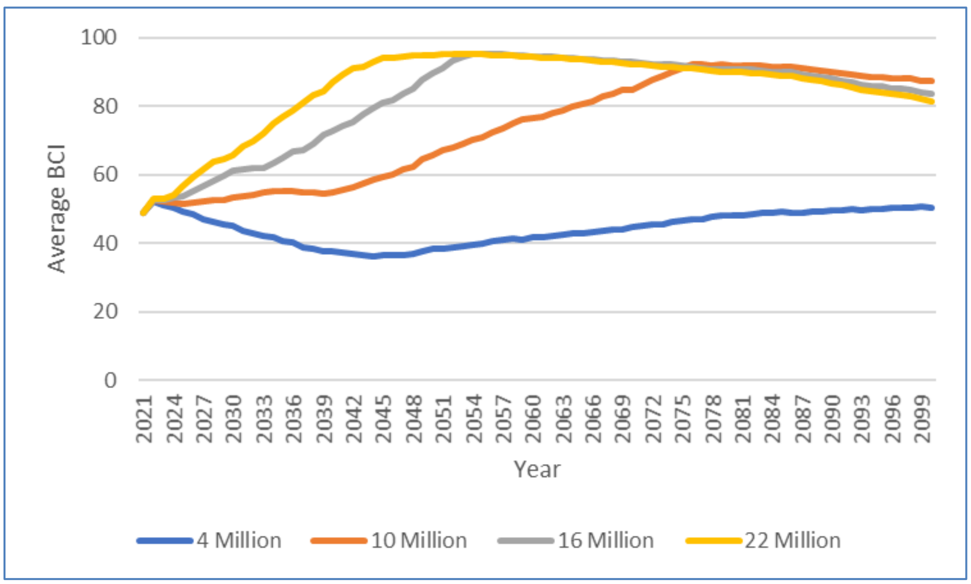


Figure 8: Average BCI of the Inventory Per Year



Effect of Rehabilitations on the Large Culvert Renewal Program

One of the drawbacks of the above renewal plan was that it is solely focused on replacing culverts that are at the end of their service life and does not incorporate extending the life of the existing inventory through rehabilitation. To examine the effect of rehabilitations on the plan, we assumed that:

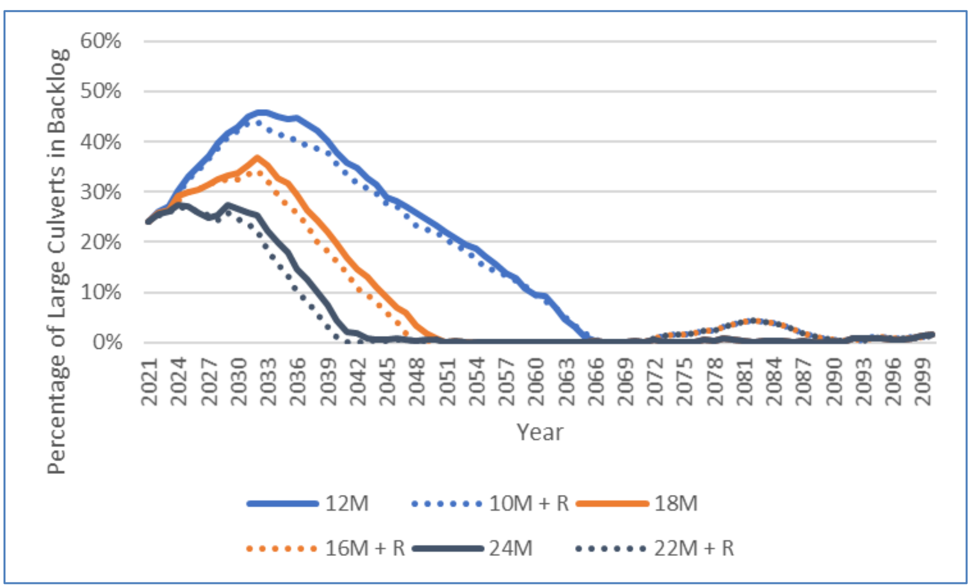
- 20% of the inventory are candidates for rehabilitation when they have reached 90-100% of their anticipated service life;
- Culverts can only be rehabilitated once before requiring replacement; and
- Rehabilitated culverts have an anticipated service life off 50 years.

This analysis required significant modification to the model detailed above, including the following:

- Culvert locations that were rehab eligible were assigned using a random number generator such that 20% of the inventory locations were rehab eligible.
    - To account for selection bias, multiple iterations of the model were run with different sets of random numbers to evaluate the effect of this selection bias on the results;
- Rehab candidates for each year were identified based on the following criteria:
    - The location was eligible for rehabilitation;
    - The “last action” at the location was installing a new culvert or unknown; and
    - The age of the culvert was within the target range for its material group.
- A select number of culverts were identified for rehabilitation in each year (starting with 12/year), with priority given to culverts with a higher replacement cost.
    - This biases the rehab selection towards larger, deeper, and longer culverts, and makes rehabilitation a more cost-effective proposition. This follows from the internal prioritization of rehabs undertaken by the NBDTI Design Branch.
- The “last action” for each culvert was updated, based on whether it was replaced or rehabilitated in each year.

Overall, it was found that adding a rehabilitation program did improve the rate of backlog reduction. This is illustrated in Figure 9, which compares the backlog size of plans including rehabilitations and plans with a funding level $2 million higher but no rehabilitations. The gains were limited by the pool of rehabilitation eligible culverts being exhausted within 10-15 years. The cost effectiveness of the program was also highly dependent on which culverts were rehabilitation candidates. Lastly, it was found that there were diminishing returns adding a rehabilitation program larger than 12 culverts/year.

Figure 9: Backlog comparison between programs with rehabilitations (dotted) and replacement-only programs with increased annual budgets by $2 million/year (solid)



RENEWAL OPTIONS REVIEW

Another component of this project involved identifying renewal options for large culverts and developing guidance on how to select the appropriate option for a given culvert. The result of this work was a guide that was intended to be used in the following way:

1. Culvert is identified as a candidate for Renewal as part of the Departments prioritization sequence;
2. The designer refers to the Renewal Option Decision Tree;
3. The designer is guided to the list of viable Renewal options for further consideration;
4. Once the list of viable options has been established, the Designer refers to the Renewal Options Sheets for more consideration;
5. One or more preferred options are selected for further review in preliminary design and cost estimation.

A review of large culvert renewal options identified 9 options that were relevant to NBDTI's existing inventory. These options are summarized in Table 9 below with respect to the culvert materials and shapes they apply to and their effects on hydraulic capacity, fish passage, structural capacity, and renewal cost. One-page summary sheets were also created for each of these options; however, they were omitted from this paper.

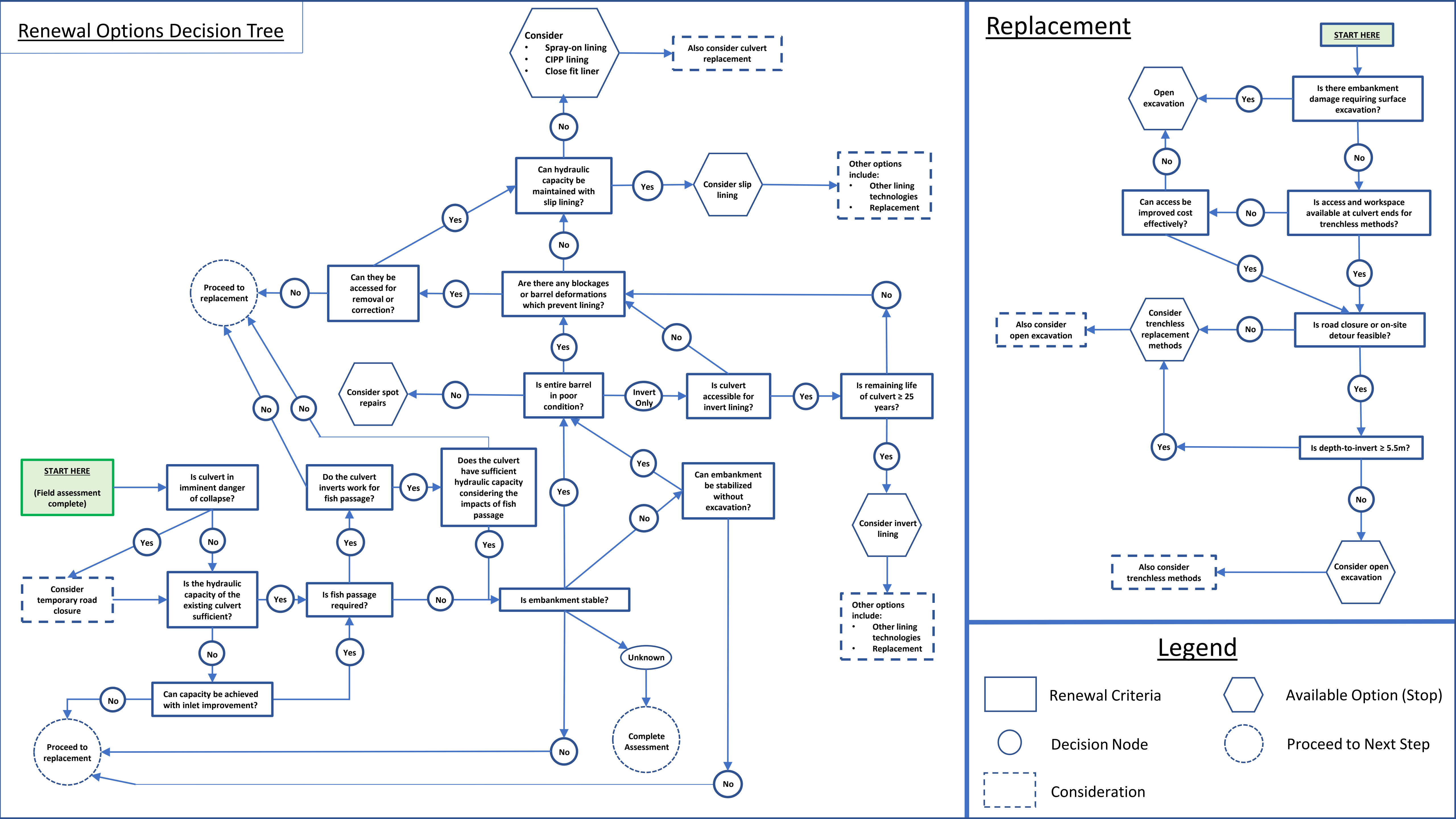
Table 9: Summary of Large Culvert Renewal Options

Renewal Option	**Applicable Materials***			**Applicable Shapes****			**benefits / Disbenefits**			
	C	M	O	B	P	O	Hydraulic Capacity	Fish Passage	Structura l Capacity	Relative Cost
Open Excavation	X	X	X	X	X	X	↑	↑	↑	$$$$
Slip Lining	X	X			X		↓	↓	↑	$$
Cured-In-Place Pipe (CIPP)			X		X	X	↓	–	↑	$$
Spiral Wound Lining			X		X	X	↓	–	↑	$$
Spray-On Lining	X		X		X	X	↓	–	↑	$$
Pipe Jacking/Ramming	X	X			X		↑	↑	↑	$$$$
Horizontal Directional Drilling (HDD)		X	X		X		↑	↓	↑	$$$$
Micro-Tunneling	X	X			X		↑	↑	↑	$$$$
Concrete Invert/Bottom	X			X	X	X	↓	–	↑	$

NOTES: * Applicable Materials includes **C**oncrete, **M**etal, and **O**ther

** Applicable Shapes includes **B**ox, **P**ipe, and **O**ther

The decision tree, shown on the following page was developed as a reference to further guide the identification of appropriate Renewal options to consider under general conditions. When using this tool, the designer starts where indicated (far left of decision tree) and proceeds to answer questions about the culvert location being reviewed. Where appropriate, additional guidance documents are referenced to aid the designer in answering each question. At the end of every decision tree branch, a list of viable options is presented for consideration.


Renewal Options Decision Tree
START HERE
(Field assessment complete)
Is culvert in imminent danger of collapse?
Yes
No
Consider temporary road closure
Is the hydraulic capacity of the existing culvert sufficient?
Yes
No
Can capacity be achieved with inlet improvement?
No
Yes
Proceed to replacement
Is fish passage required?
Yes
No
Do the culvert inverts work for fish passage?
Yes
No
Does the culvert have sufficient hydraulic capacity considering the impacts of fish passage
Yes
No
Proceed to replacement
Is embankment stable?
Yes
No
Unknown
Complete Assessment
Can embankment be stabilized without excavation?
Yes
No
Is entire barrel in poor condition?
No
Consider spot repairs
Yes
Invert Only
Is culvert accessible for invert lining?
Yes
No
Is remaining life of culvert ≥ 25 years?
Yes
No
Consider invert lining
Other options include:
Other lining technologies
Replacement
Are there any blockages or barrel deformations which prevent lining?
Yes
No
Can they be accessed for removal or correction?
Yes
No
Can hydraulic capacity be maintained with slip lining?
Yes
No
Consider slip lining
Other options include:
Other lining technologies
Replacement
Consider
Spray-on lining
CIPP lining
Close fit liner
Also consider culvert replacement
Replacement
START HERE
Is there embankment damage requiring surface excavation?
Yes
No
Open excavation
Is access and workspace available at culvert ends for trenchless methods?
Yes
No
Can access be improved cost effectively?
Yes
No
Is road closure or on-site detour feasible?
No
Yes
Consider trenchless replacement methods
Also consider open excavation
Is depth-to-invert ≥ 5.5m?
Yes
No
Consider open excavation
Also consider trenchless methods
Legend
Renewal Criteria
Available Option (Stop)
Decision Node
Proceed to Next Step
Consideration

DEFINITION OF "EMERGENCY"

One of the issues raised by NBDTI's Property Services Branch was that it seemed like every project that was brought to their attention was being labelled as an "emergency". This dilutes the meaning of the word, so there was a desire to create a more uniform definition that would bring greater meaning to other stakeholders (property negotiation, environmental regulators, etc.).

A framework was established that was based on the failure likelihood and failure severity for each culvert Failure likelihood was established on a four-point scale (low, medium, high, extreme). The assessment of failure likelihood was based on the shape, rate of change of conditions, and flow capacity. To achieve an "Extreme" rating the structural integrity of the roadway has to be reduced to the point where the next significant rainfall would be expected to cause failure, which each remaining step down in rating representing a lower level of likelihood.

Failure severity was defined as a combination of downstream/environmental impacts, infrastructure impacts, and traffic impacts. The downstream/environmental factors identified included the sudden release of sediment/water from a blockage, capacity of downstream culverts and stream management, salmonoid habitat either upstream or downstream, and infrastructure crossings, failure of which would cause an environmental emergency. Infrastructure impacts considered the impacts of a failure on other linear infrastructure (communications, utilities, municipal, etc.) and property immediately downstream. Traffic impacts were related to the criticality of the roadway to the network, traffic volumes being detoured, length of detour routes, and availability of property access. More detail on the rating criteria was provided in the report but omitted from this paper.

The resulting ratings would then be applied to Table 10 to identify the correct urgency level in Table 11.

Table 10: Large Culvert Failure Likelihood and Severity Ratings

Factor	**Rating**			
	Low	**Medium**	**High**	**Extreme**
LIKELIHOOD				
Imminent Failure of the Roadway	Low	Medium	High	Extreme
SEVERITY				
Downstream / Environmental Impacts	Low (1)	Medium (2)	High (3)	-
Infrastructure Impacts	Low (1)	Medium (2)	High (3)	-
Traffic Impacts	Low (1)	Medium (2)	High (3)	-
OVERALL SEVERITY SCORE				
Sum of the Above Severity Scores	**Low (3-4)**	**Medium (5-6)**	**High (7+)**	**-**

Table 11: Large Culvert Urgency Definitions

Severity	**High (7+)**	Medium	High	**Emergency**	**Emergency**
	Medium (5-6)	Low	Medium	Medium	**Emergency**
	Low (3-4)	Low	Low	Medium	**Emergency**
		Low	**Medium**	**High**	**Extreme**
		Likelihood			

ADDITIONAL COMPONENTS

The following sections provide a brief overview of additional tasks that were undertaken to refine NBDTI's large culvert renewal and management processes.

Maintenance Plan

A survey of the District engineers, the people responsible for the ordinary maintenance of large culverts, and literature review were conducted to identify ordinary maintenance tasks that are required for large culverts in New Brunswick. Through this review, 7 tasks were identified: repairing damage to culvert pipe/ends, repairing armouring around inlets/outlets, vegetation control, removing debris, removing beaver dams, embankment repair/stabilization, and grout injection.

An analysis of the ordinary maintenance tasks for the likelihood of a culvert requiring it on an annual basis and the labour and equipment costs of completing each task estimated an annualized ordinary maintenance cost of $940.50 per culvert. Across the whole inventory, this extrapolates to just over $2 million per year. It was also highlighted that annual inspection of culverts is required to deliver effective ordinary maintenance interventions.

District Training

To make better use of the resources available at the District level for culvert renewal planning, a guide was developed that summarizes the approach used by NBDTI for the design of typical large culverts. Culverts where a generalized rule-of-thumb based approach were not covered in this guide.

Documentation on Large Fill Excavation Projects

Open excavations to replace large culverts that are under a large fill are expensive operations; however, there are situations where they are unavoidable due to numerous considerations. A "large fill" was defined as a culvert having a streambed to roadway centerline depth of 5.5m or greater; this was established based on a review of reach limitations of conventional excavation equipment. 21% of NBDTI's large culvert inventory is classified as being under a "large fill" by this definition.

This document summarized the opportunities (hydraulic improvements, structural/embankment replacement, fish passage and environmental considerations, and extensive provincial experience) and challenges (cost, construction duration, traffic impacts) that come with open excavation of culverts under large fills. A review of the other potential renewal options and reasons why they may not be appropriate in all situations was also summarized.

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