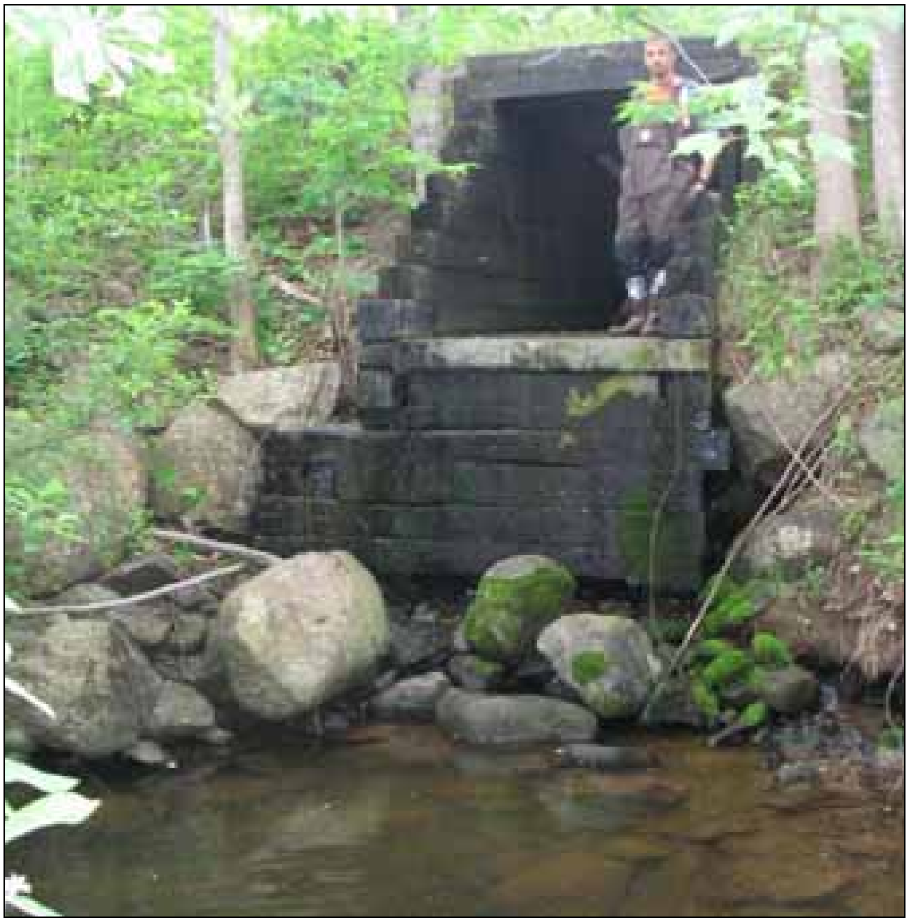
Broken Brooks:
Culvert Assessments in the Annapolis River Watershed



Kyle Hicks and Denise Sullivan
Clean Annapolis River Project
April 2008

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Table of Contents

List of Tables

List of Figures

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Executive Summary

Improperly installed culverts are having a negative impact on fish passage in rivers and streams throughout the Annapolis River Watershed. Poor culvert design can prevent fish from accessing critical upstream habitats and can also degrade habitat quality upstream, downstream, as well as near the barrier. The importance of properly placed culverts to habitat connectivity has become increasingly important as shown by recent studies in several jurisdictions.

During the spring, summer and fall of 2007, Clean Annapolis River Project (CARP) performed culvert assessments throughout the Annapolis River Watershed. Sub-watersheds were prioritized according to their ability to support healthy fish populations and assessed accordingly. 21 sub-watersheds were examined ranging from Aylesford to Clementsport.

Building on a previous study, which had identified the location of all stream crossings in the watershed, culverts were evaluated in the field and assessed as potential barriers to fish migration. The complete list of barriers identified was then prioritized according to greatest need for remediation. A total of 268 culverts were visited and 60 assessments were performed from June to October. Of the 60 assessments which were performed, 55% of culverts created either a full or partial barrier to fish migration. Based on the scoring matrix, ten priority culverts were recommended for remediation. Low-cost restoration culverts (ie: blocked with debris) are also highlighted and recommended for remediation in the near future.

Several options for retrofitting existing culverts are explored, including: tailwater control weirs, baffles, roughened channels and fishways. Retrofit options are recommended for the prioritized list of identified barriers. Finally, options for post-restoration monitoring are recommended, including parameters to monitor, field methods and useful reference documents.

Introduction

Habitat fragmentation caused by improperly placed culverts in streams can threaten the overall health and sustainability of fish populations. Such barriers impede fish migration and consequently access to essential resources such as food, shelter, refuge, and spawning grounds upstream. In the Annapolis River Watershed, a number of fish species, such as American shad (*Alosa sapidissima*), American eel (*Auguilla rostrata*), White sucker (*Catostomus commersoni*), and Brook trout (*Salvelinus fontinalis*), depend on the connectivity of diverse habitats to fulfill the requirements of their various life stages.

The importance of habitat connectivity and proper installation of culverts is becoming increasingly evident and has been the subject of a number of studies in recent years. In 2000, the Ministry of the Environment in British Columbia published a report detailing proper culvert inspection procedures (Parker, 2000). In Nova Scotia, an audit preformed by Fisheries and Oceans Canada (DFO), using similar techniques, revealed that 58% of culverts assessed in central Nova Scotia contributed to habitat fragmentation due to either excessive slopes or elevated outfall drops (Langill and Zamora, 2002). In a separate study in the Annapolis River Watershed and Bay of Fundy Shore, 1615 stream crossings were identified using GIS software and coordinates were assigned to all road-watercourse intersections (Coombs, 2006).

Most recently, Terra Nova National Park, in collaboration with Memorial University of Newfoundland and the Atlantic Service Centre of Parks Canada, created a habitat connectivity index, which quantifies structural connectivity within riverscapes (Coté *et al.*, 2007). The index provides a tool for resource managers to assess cumulative impacts of multiple barriers and to prioritize restoration activities. In addition, DFO released a working document on recommended protocols for assessing culverts within watersheds (Fisheries and Oceans Canada, 2007). Although differing in some respects, the recommended protocols are similar to those used in previous studies.

Given that habitat fragmentation can occur from manmade (ie: culverts) as well as natural means (ie: waterfall), locating and assessing barriers can allow them to be prioritized for remediation. In this study, Clean Annapolis River Project (CARP) used the list of culverts and map locations generated in Coombs' study as a basis for further investigation. Individual culverts were located and assessed in the field, using a combination of the above-noted methodologies, and priority barriers were identified for remediation.

Methodology

The culvert assessments primarily utilized the protocol developed by the British Columbia Ministry of Environment as described in Parker (2000). Other reference documents are listed throughout the report as necessary. The methodology consisted of three main parts:

1. Selecting sub-watersheds
2. Field evaluations
    - Evaluate barrier type (full, partial, none)
    - Habitat scoring index (high, moderate, low)
3. Prioritizing barriers for remediation using scoring matrix

Selecting Sub-watersheds

The Annapolis River Watershed drains an area of approximately 2,000 km², making it the third largest watershed in Nova Scotia. The river flows in a southwesterly direction, beginning in its headwaters near Aylesford, joining the Annapolis Basin at Annapolis Royal and finally reaching the Bay of Fundy at Victoria Beach near Digby (Figure 1).

Figure 1: The Annapolis River Watershed

In her 2006 study, Coombs identified as many as 1615 culverts throughout the watershed (Appendix A). Given the large area and number of barriers involved, initial efforts were focused in sub-watersheds deemed to have the most critical fish habitat. The selection of sub-watersheds was based on three important criteria: pH buffering capacity, water temperature, and productivity of fish habitat (Table 1). The ideal ranges for pH and water temperature are taken from the Canadian Environmental Quality Guidelines (CCME, 2003).

Table 1: Criteria for selecting sub-watersheds for assessment

Parameter	Criteria	Data Sources
pH buffering	Ideal range (Brook trout): 6.5-9.0	Historical water quality data collected by CARP and others
Water temperature	Ideal range (Brook trout): 10-18°C	MacMillan and Crandlemere, 2003; MacMillan *et al.*, 2005
Productivity of fish habitat	Abundance of fish in streams; popular fishing locations	Electrofishing data (MacMillan and Crandlemere, 2003; Mike Parker, personal communication), fishing knowledge of the author and other local anglers

Initially, ten sub-watersheds, which were known to have acceptable pH buffering, water temperature and productive fish habitat, were selected for assessment. Once the evaluations were completed in the initial ten sub-watersheds, eleven more were chosen. The list of sub-watersheds was taken from a previous report and is based on all the named waterways that discharge directly into the Annapolis River and Basin (Clean Annapolis River Project, 2002). The complete list of sub-watersheds is included in Appendix B. From a total of 86 available sub-watersheds, 21 (24%) were assessed, including:

- Bloody Creek
- Black River
- Fales River
- McEwan Brook
- McGee Brook
- Patterson Brook
- Tupper Brook
- Munros Brook
- Roxbury Brook
- Petes Brook
- South River
- Spinney Brook
- Zekes Brook
- Wiswall Brook
- Roundhill River
- Fash Brook
- Nictaux River
- Moose River
- Bear Brook
- Gould
- Hutchinson

Not all culverts within the sub-watersheds were visited. Efforts were concentrated in areas that had fish habitat; therefore, in some cases, culverts located in the small tributaries and headwaters were not visited.

Of the culverts visited, assessments were only completed at sites that supported fish habitat (ie: sufficient water and depth) or the potential for fish habitat. In many cases however, most often in the headwaters of tributaries, the streambed was dry. A survey of upstream and downstream portions of the waterways was completed before a final judgement on habitat availability was made.

Field Evaluations

The protocol for field evaluations was based on well-established methods described in Parker (2000). Although developed outside of Nova Scotia, the protocol was applicable locally with some minor revisions. Most importantly, the fish species data was adjusted to Brook Trout standards, including; habitat preference, swim speed, endurance, and jumping height. Parker was involved throughout the project, from adjusting the fish species data in the protocol to volunteering with training in the field. The field equipment used by the survey crew while performing the culvert assessments included the following:

- Maps showing all watercourse crossings
- GPS unit
- Chest or hip waders
- Survey level
- Tripod
- Survey rod
- Meter stick
- Thermometer
- Map book containing road names
- Digital camera
- 30m measuring tape
- Stopwatch
- Semi-buoyant object
- Waterproof data sheets
- Minnow trap
- Hydrolab (multi-parameter water meter)

A minimum of two fieldworkers was required to most efficiently conduct the assessments as well as to comply with the Safe Work Practices Document for working along roadways outlined by the Department of Transportation and Infrastructure Renewal (Appendix C).

For each site, a culvert evaluation form was completed. Information was collected in five broad categories including: general site information, culvert characteristics, stream characteristics, barrier evaluation and site photos. Table 2 provides a summary of all the information recorded on the evaluation form. A template data sheet is also available in Appendix D. A more detailed description of measurements taken is included in Appendix E.

Table 2: Information collected during culvert assessments

Site Information	Culvert Information	Stream Information	Barrier Evaluation	Site Photos
Date	Diameter	Sediment source	Barrier type	Inlet upstream
Stream name	Length	Pool depth at outfall	- Full	Inlet downstream
Road name	Material	Stream wetted width	- Partial	Outlet upstream
UTM Coordinates	Water velocity	Stream bankfull width	- None	Outlet downstream
Site Number	Shape	Stream water depth	- Undetermined	
Recorders name	Wetted width	Bankfull depth		
	Slope	Stream water velocities		
	High water mark	Fish presence		
	Water depth	Beaver activity		
	Outfall drop			
	Maintenance required			

Evaluation of the barrier type was performed according to specific guidelines (Table 3). The outfall drop, the pool depth at outfall, the water flow through the culvert as well as the presence or absence of debris in the culvert were all considered in making the determination of barrier type.

Table 3: Barrier types and criteria used during culvert assessments

Barrier type	Criteria
Full	• Outfall drop onto rocks • Pool depth at outfall less then 1.5 times the outfall drop (Parker, personal communication) • No water flow through culvert
Partial	• Debris blocking culvert • Culvert water depth too shallow for a mature trout (less then 5cm) • Outfall drop even with adequate pool depth is barrier to juvenile trout
None	• Sufficient water depth, no outfall drop and acceptable water velocities

A habitat scoring index was then applied to evaluate the stream habitat quality upstream and downstream of each culvert. The parameters measured included: water temperature, shade, aquatic invertebrates, sediment and pH. Water temperature was measured to the nearest ºC using a thermometer. The amount of shade was an estimate of the cover provided by riparian vegetation. The survey of aquatic invertebrates was also a visual estimate and did not focus on identifying species. Instead, rocks and sticks were overturned during the survey and examined for the presence or absence of invertebrates. The average size of the dominant sediment type was measured with a ruler to the nearest centimetre and pH was measured using a portable Hydrolab water meter. For each variable, a score was assigned, allowing the total habitat quality ranking value to be determined by adding the individual scores (Table 4). The final ranking was used in the overall scoring matrix for prioritizing barriers for remediation. Habitat scoring was subject to the time of year. If its completion was not possible, a minimum score of 0.5 was assigned to each variable.

Table 4: Stream habitat scoring index

Variables	Score = 1	Score = 0
Water temperature	Between 13-18ºC	Not between 13-18ºC
Predominant sediment diameter	Between 2-25cm	Not between 2-25cm
pH	Between 6.5-9.0	Not between 6.5-9.0
Aquatic invertebrates	Present	Absent
Shade	Present	Absent
Stream Habitat Quality Ranking		
Score 4-5: High	Score 2-3: Moderate	Score < 2: Low

The final step of the field evaluation consisted of taking a photographic record. Photos provide a visual reference to the site and can aid in the planning of rehabilitation work. While taking pictures, a crew member or object was placed within the frame for scale. At each site, four photos were captured, including: the downstream view from culvert outlet, the upstream view from culvert inlet, the culvert outlet view from downstream and the culvert inlet view from upstream. Field data was entered into a Microsoft Excel spreadsheet and the original completed assessment forms were kept on file for future reference.

Prioritizing Barriers

Once all of the assessments were completed, a scoring matrix was applied to the complete list of barriers to prioritize those in greater need of remediation. The selection criteria were based on four variables: the presence or absence of fish, the habitat value, the barrier type and the length of upstream habitat to be restored (ie: linear distance of habitat that would become available to fish after remediation). The presence or absence of another upstream barrier was also considered, with preference for streams with no additional barriers upstream. Although mainly based on Parker (2000), the scoring matrix was slightly modified to place greater weight on the length of potential upstream habitat. Each variable was assigned a score value, as seen in Table 5. A total score was given to each culvert by calculating the sum of the individual scores for each variable. Culverts with higher scores were considered top priority for remediation.

Table 5: Scoring matrix for prioritizing barriers for remediation

Variable	Criterion	Score	Variable	Criterion	Score
Fish	Present	10	Length of New Habitat	>4.5 km	20
	Absent	5		4-4.5 km	18
Habitat Value	High	10		3.5-4 km	16
	Moderate	6		3-3.5 km	14
	Low	3		2.5-3 km	12
Barrier Type	Full	10		2-2.5 km	10
	Partial	6		1.5-2 km	8
	None	3		1-1.5 km	6
				0.5-1 km	4
				<0.5 km	2

Results

Of the 268 culverts visited, 60 were assessed along 21 sub-watersheds (Table 6).

Table 6: Number of culverts visited and assessed for each sub-watershed

Subwatershed / Stream Name	# Culverts Visited	# Culverts Assessed
Bloody Creek Brook	11	1
Black River	20	4
Fales River	14	5
McEwan Brook	14	2
McGee Brook	13	3
Patterson Brook	8	5
Tupper Brook	4	1
Munros Brook	15	2
Roxbury Brook	3	1
Petes Brook	7	1
South River	22	3
Spinney Brook	12	3
Zekes Brook	9	2
Wiswall Brook	21	3
Roundhill River	22	5
Fash Brook	10	2
Nictaux River	25	5
Moose River	27	4
Bear Brook	9	6
Gould	1	1
Hutchinson	1	1
TOTAL	268	60

Of the 60 culverts assessed, a total of 33 culverts, or 55%, were found to pose a barrier to fish passage (Table 7). Of the identified barriers, 22 culverts were full barriers, while 11were only partial barriers. Of the 60 culverts assessed, 23 (38%) culverts were perched. These findings corroborate work by Zamora (2000) in central Nova Scotia, were 50% of culverts assessed were found to be barriers to fish migration and 28% were perched.

Table 7: Culverts posing a full or partial barrier to fish passage

Site Number	Stream Name	Culvert Number[1]	Road Name	Barrier Type	Barrier Description
MG01	McGee Brook	1484	Hwy 221	Full	Perched, outfall drop onto rocks
FR01	Fales River	N/A[2]	Rocknotch	Full	Perched, outfall drop onto rocks
FR02	Fales River	1225	Rocknotch	Partial	High culvert water velocity
FR03	Fales River	1371	Crystal Falls	Full	Perched, outfall drop onto rocks
FR05	Fales River	N/A	JT Morse	Partial	Clogged with debris
PT01	Patterson Brook	N/A	Farming road downstream of culvert	Full	Brook flows over road, no culvert
PT02	Patterson Brook	N/A	Hwy 221	Full	Perched, outfall drop onto rocks
PT03	Patterson Brook	1499	Brooklyn	Full	Perched, outfall drop onto rocks
TP01	Tupper Brook	501	Unknown	Partial	Clogged with debris
MW01	McEwan Brook	994	Mount Hanely	Full	Beaver dam in culvert
MW02	McEwan Brook	985	Mount Hanely	Full	Perched, shallow water in culvert
SR01	South River	1445	Sturk	Full	Perched, shallow water in culvert
SR02	South River	N/A	Canaan	Partial	Perched
SP02	Spinney Brook	N/A	Meadowvale	Full	Perched, shallow water in culvert
SP03	Spinney Brook	1060	Torbrook	Partial	Perched, shallow pool depth at outfall
BR04	Black River	1094	East Torbrook	Full	Perched, outfall drops onto rocks, shallow culvert water depth
BR05	Black River	1093	East Torbrook	Full	Perched, no water in culvert
ZB01	Zekes Brook	1412	Hwy 201	Partial	Perched, outfall drops onto rocks
ZB02	Zekes Brook	N/A	Harmony	Full	Perched, shallow pool depth at outfall
BR02	Black River	1056	Unknown	Full	Blocked with debris
WB02	Wiswall Brook	1217	Bridge	Partial	Perched
WB01	Wiswall Brook	N/A	Spa Spring	Partial	Shallow culvert with rock barrier
RH04	Roundhill River	527	Unknown	Full	Perched, outfall drop onto rocks
FB02	Fash Brook	789	Clarence	Full	Perched
RH06	Roundhill River	488	Spurr	Full	Perched, outfall drop onto rocks
MR01	Moose River	154	Quarry	Full	Perched, outfall drop onto rocks
NR04	Nictaux River	764	Old Railway	Partial	Clogged with debris
NR01	Nictaux River	100	Hwy 201	Full	Perched, shallow pool depth at outfall
NR02	Nictaux River	N/A	Unknown	Partial	Clogged with debris
BB02	Bear Brook	N/A	Windermere	Partial	Clogged with debris
BB05	Bear Brook	1446	Prospect	Full	Perched, outfall drop onto rocks
BB06	Bear Brook	N/A	Prospect	Full	Perched
BB04	Bear Brook	N/A	Hall	Full	Perched

[1] Culvert number (Coombs, 2006).
[2] Clustering and overlapping of culvert locations in Coombs (2006) made the identification of the culvert number difficult in some cases.

The culverts that were deemed barriers to fish passage were then ranked using the scoring matrix. A list of the full and partial barriers prioritized for remediation can be seen in Table 8. The higher the total score, the greater the priority is for remediation.

Table 8: Barriers prioritized against scoring matrix

Site #	Culvert #	Road Name	Barrier	Habitat Value	Length of New Habitat	Fish Species	Total Score
PT03	1499	Brooklyn	10	10	10	10	40
MW02	985	Mount Hanely	10	10	10	10	40
FB02	789	Clarence	10	10	10	10	40
RH06	488	Spurr	10	10	10	10	40
FR01	N/A	Rocknotch	10	10	6	10	36
FR02	1225	Rocknotch	6	10	10	10	36
ZB01	1412	Hwy 201	6	10	10	10	36
BB02	N/A	Windermere	6	10	10	10	36
PT01	N/A	Hwy 221	10	10	6	10	36
RH04	527	Unknown	10	10	6	10	36
NR01	100	Hwy 201	10	10	6	10	36
FR03	1371	Crystal Falls	10	10	10	5	35
SR01	1445	Sturk	10	10	10	5	35
BR05	1093	East Torbrook	10	10	10	5	35
BB04	N/A	Hall	10	10	10	5	35
BB05	1446	Prospect	10	10	10	5	35
BB06	N/A	Prospect	10	10	10	5	35
SP02	N/A	Meadowvale	10	10	4	10	34
MR01	154	Quarry	10	10	3	10	33
SR02	N/A	Canaan	6	10	6	10	32
SP03	1060	Torbrook	6	10	6	10	32
WB01	N/A	Spa Spring	6	6	10	10	32
NR02	N/A	Unknown	6	10	6	10	32
ZB02	N/A	Harmony	10	10	6	5	31
WB02	1217	Bridge	6	10	10	5	31
BR02	1056	Unknown	10	10	6	5	31
MG01	1484	Hwy 221	10	10	3	5	28
PT02	N/A	Hwy 221	10	10	3	5	28
MW01	994	Mount Hanely	10	10	3	5	28
NR04	764	Old Railway	6	10	3	5	24
FR05	N/A	JT Morse	6	10	3	5	24
TP01	501	Unknown	6	10	3	5	24

*Barrier BR04 has been omitted from the list. Remediation of this site would have no benefit to fish passage due to the natural barrier (waterfall) located 20 m downstream of the culvert.

Given the significant time and resources required to remediate all identified barriers, a short list of barriers to undergo remediation was selected. Further information on the top 10 barriers from the matrix is provided in Table 9 below. These barriers were selected because they scored highest on the matrix and were therefore determined to provide the greatest balance between new habitat created, fish species present, value of habitat and barrier type. Photographs of the priority barriers are included in Appendix F.

Table 9: Detailed information on ten priority barriers

Stream Name	Site #	Culvert #	UTM Coordinates (NAD 83 Map Datum)	Road Name	Total Score	Barrier Description
Patterson	PT03	1499	0355493E 4989330N	Brooklyn	40	Perched, outfall drop onto rocks
McEwan	MW02	985	0331365E 4977124N	Mount Hanely	40	Perched, shallow water in culvert
Fash	FB02	789	0316597E 4969705N	Clarence	40	Perched
Roundhill	RH06	488	0312300E 4954361N	Spurr	40	Perched, outfall drop onto rocks
Fales	FR01	NA	0349381E 4979956N	Rocknotch	36	Perched, outfall drop onto rocks
Fales	FR02	1225	0349046E 4979900N	Rocknotch	36	High culvert water velocity
Zekes	ZB01	1412	0350473E 4981385N	Hwy 201	36	Perched, outfall drop onto rocks
Bear	BB02	NA	0362581E 4986208N	Windemere	36	Clogged with debris
Patterson	PT01	NA	0355531E 4991118N	Hwy 221	36	Brook flows aver road, no culvert
Roundhill	RH04	527	0318268E 4954184N	Unknown	36	Perched, outfall drop onto rocks

The above ten barriers recommended for remediation were chosen because of their high score on the matrix. The majority of those culverts are creating barriers due to being perched and their outflow dropping onto rocks. The work involved in remediating these barriers is potentially costly and time consuming. Therefore, a second prioritized list is provided for projects whose remediation may be quicker and less expensive, while still providing, albeit to a lesser degree, access to upstream habitat. Detailed information on the top five culverts, which were clogged with debris, is shown in Table 10 below.

Table 10: Detailed information on barriers blocked with debris

Stream Name	Site #	Culvert #	UTM Coordinates (NAD 83 Map Datum)	Road Name	Total Score	Barrier Description
Bear	BB02	NA	0362581E 4986208N	Windemere	36	Clogged with debris
Black	BR02	1056	0343348E 4972267N	Unknown	31	Clogged with debris
McEwan	MW01	994	0335677E 4974652N	Mount Hanely	28	Beaver dam in culvert
Fales	FR05	NA	0353024E 4979404N	JT Morse	24	Clogged with debris
Nictaux	NR04	764	0337440E 4963636N	Old railway	24	Clogged with debris

Culverts clogged with debris were deemed easier to remediate because a temporary solution could be achieved by removing the debris in question, as opposed to modifying and/or replacing the entire structure. By removing the debris inside the culvert, the partial barrier is also eliminated. Although their overall score in the matrix is lower, the culverts from Table 10 may present a short-term opportunity for culvert remediation while additional resources are secured to complete more complex remediation projects. A culvert on Tupper Brook was also clogged with debris; however, it was determined there was no fish habitat above the culvert.

Next Steps

The audit of road and watercourse crossings should be extended to include the remaining sub watersheds as well as the remaining barriers of the sub watersheds examined in the current study. A list of sub-watersheds, showing those already assessed, is included in Appendix F. The assessment protocol should be adapted and improved as required, including ground-truthing estimations of available upstream habitat. Verifying conditions in the field as well as using topographic maps may allow improved prioritization of barriers in areas where, for example, a waterfall exists a short distance upstream from a barrier.

The work of replacing or retrofitting identified barriers may also begin where possible. Collaborating with appropriate agencies, such as the Nova Scotia Department of Transportation and Infrastructure Renewal, may help to identify culverts or roads scheduled for repairs in the near future.

Replacing or Retrofitting Barrier Culverts

The most effective way to restore fish passage through barrier culverts is to replace them with newly designed structures that take into consideration the passage of fish. In some cases however, it may be preferable to explore retrofitting the existing culvert to avoid expensive replacements. For example, if a crossing is relatively new, structurally sound and large enough to accommodate flood flows, a retrofit may be the preferred option (Singler and Graber, 2005). Culverts should be replaced however, if they are structurally poor, degraded, or undersized for flood conditions.

When retrofitting is the preferred option, several methods are available. Some of the most commonly used methods are explained in more detail below.

1. Tailwater control weirs / gradient control weirs

Tailwater control weirs are generally used to eliminate outfall drops and to increase water levels inside culverts by backing up water toward the barrier culvert. They are often the preferred choice for remediation, as they are located outside the culvert, and therefore are easier to maintain and have a lower risk of clogging the culvert with debris (California Department of Transportation, 2007).

As seen in Figure 2 below, tailwater control weirs can include placing large boulders strategically downstream of the culvert. Given that the boulders will themselves become small barriers, care must given in its construction so as to not impede fish passage during low water conditions. Detailed information on constructing tailwater control weirs is included in Appendix G.

Figure 2: A tailwater control weir backing up water to eliminate outfall drop and/or increase water depth in culvert
(Source: CTDEP Inland Fisheries, 2008)

2. Baffles

Another common retrofit option is the installation of baffles within the culvert (Figure 3). Baffles are typically used to decrease high water velocities within culverts as well as to increase water depth by creating a series of pools and drops, until the older culvert can be replaced (California Department of Transportation, 2007; CTDEP Inland Fisheries, 2008).

There are several limitations which must be considered before baffles are installed in any culvert. Given the structure design, baffles tend to accumulate debris inside culverts and therefore required periodic maintenance. In addition, baffles occupy a certain space within a culvert, which can, especially when combined with debris, significantly reduce the flow capacity of the culvert. If not properly designed, baffles can therefore result in the greater problem of water over-topping the road during flood conditions (Mike Parker, personal communication, March 27, 2008). The 100 year flood events should also be taken into consideration when determining if a culvert has the capacity to accommodate baffles.

Figure 3: A concrete baffle system to reduce flow velocities and/or increase water depth in culvert
(Source: CTDEP Inland Fisheries, 2008)

3. Roughened channel

Culvert velocities can be reduced and flow depths increased by placing stable materials (ie: large boulders and other substrate) in the channel either inside the culvert or downstream from the culvert (California Department of Transportation, 2007). As seen in Figure 4 below, low gradient channels and culverts may be sufficiently remediated with the random placement of boulders (USDA Forest Service, 2007). More information on this culvert retrofit method is available in Appendix G.

Before

After

Boulders randomly placed below culvert

Figure 4: Before and after roughened channel
(Source: USDA Forest Service, 2007)

4. Fishways

When none of the above retrofit options are viable and the culvert is not scheduled for repair or replacement in the near future, the installation of a fishway may be another alternative (Figure 5). Fishways are however generally not recommended and require detailed site-specific design (National Marine Fisheries Service, 2001).

Figure 5: A fishway installed within a culvert to facilitate fish passage
(Source: CTDEP Inland Fisheries, 2008)

If road repairs are scheduled in the near future, or the culvert is structurally compromised, the installation of a new culvert or bridge may be the preferred option. The restoration options should follow fish-friendly design, and generally follow the hierarchy shown below (CTDEP Inland Fisheries, 2008):

- Bridges
- Open bottom arch culverts
- Single sunken or embedded culverts
- Multiple culverts (one sunken culvert in the thalweg and 'at grade' culvert(s) to accommodate high water flows)

Corrugated culverts are always preferred over smooth culverts, as they reduce water velocities and create small ripples. Several documents listed in the section on References and Further Reading provide guidelines on best practices for installing new bridges and culverts for fish passage. Table 11 below summarizes the top ten barrier culverts and recommended retrofit option.

Table 11: Recommended retrofit options for top ten barrier culverts

Stream Name	Site #	Culvert #	Barrier Description	Retrofit Option
Patterson	PT03	1499	Perched, outfall drop onto rocks	Tailwater control weir
McEwan	MW02	985	Perched, shallow water in culvert	Tailwater control weir
Fash	FB02	789	Perched	Tailwater control weir
Roundhill	RH06	488	Perched, outfall drop onto rocks	Tailwater control weir
Fales	FR01	NA	Perched, outfall drop onto rocks	Tailwater control weir
Fales	FR02	1225	High culvert water velocity	Remove debris, baffles
Zekes	ZB01	1412	Perched, outfall drop onto rocks	Roughened channel
Bear	BB02	NA	Clogged with debris	Remove debris
Patterson	PT01	NA	Brook flows over road (no culvert)	Install arched or single embedded culvert
Roundhill	RH04	527	Perched, outfall drop onto rocks	Tailwater control weir

Post-Restoration Monitoring

Once a barrier culvert has been retrofitted or replaced, it is important to continue monitoring the site to ensure the desired results are obtained. More specifically, post-restoration monitoring can be viewed as a three-part process, addressing the following key questions (Stockard and Harris, 2005; National Marine Fisheries Service, 2001):

1. Is the culvert installed and functioning according to design?

Post-restoration monitoring must be conducted to ensure that the culvert is still functioning as it was originally designed. This can include verifying the jump pool at the outlet is still of sufficient depth, leap heights and water velocities are within acceptable range for target species, and that sediment loads still pass through the restored area. Field monitoring can also ensure that the inlet is at or below grade and that the passage structure is at the designed slope (relative to natural channel). Finally, ongoing monitoring can evaluate if the new structure successfully accommodates high water flows (ie: 100-year flows and debris) and that the structural integrity remains intact.

2. Did the new structure have negative effects on stream habitat?

Once the new structure is in place, it is important to verify that channel adjustments have not impaired the passage value of the structure or upstream and downstream habitat. Monitoring may include slope measurements and sediment deposition, as well as bank erosion, head-cutting, and/or debris accumulation.

3. Is the restoration resulting in successful fish passage?

Finally it is important to confirm, where possible, that the restoration is in fact resulting in the successful passage of fish, particularly the target species such as salmon and trout. This may include ensuring that habitat types in the upstream portions are still suitable as well as conducting biological surveys to identify fish that have successfully passed through the new structure.

Field methods for monitoring all of the above factors can include repeating the original assessment protocol to determine if the culvert is no longer classified as a barrier, as well as include other post-restoration monitoring procedures, such as Stockard and Harris (2005). Thalweg profiles can measure changes in slope and the conditions of the channel bed to gain information on pool depths, leap heights, and bed elevations at the inlet. Cross section surveys can monitor changes in the condition of channel beds and surrounding banks gain information on channel scour, sediment deposition and alignment of passage restoration with the channel. Finally, stream velocity and discharge measurements can quantify average and peak water velocities to verify they are within the acceptable range.

"Monitoring the Effectiveness of Culvert Fish Passage Restoration" (Stockard and Harris, 2005), a University of California publication, is a good guidance document for post-restoration monitoring. It provides detailed diagrams and field sampling methods, suggests data analysis techniques and provides sample data sheets for all the parameters mentioned above (thalweg profiles, cross section surveys, and stream velocity and discharge measurements).

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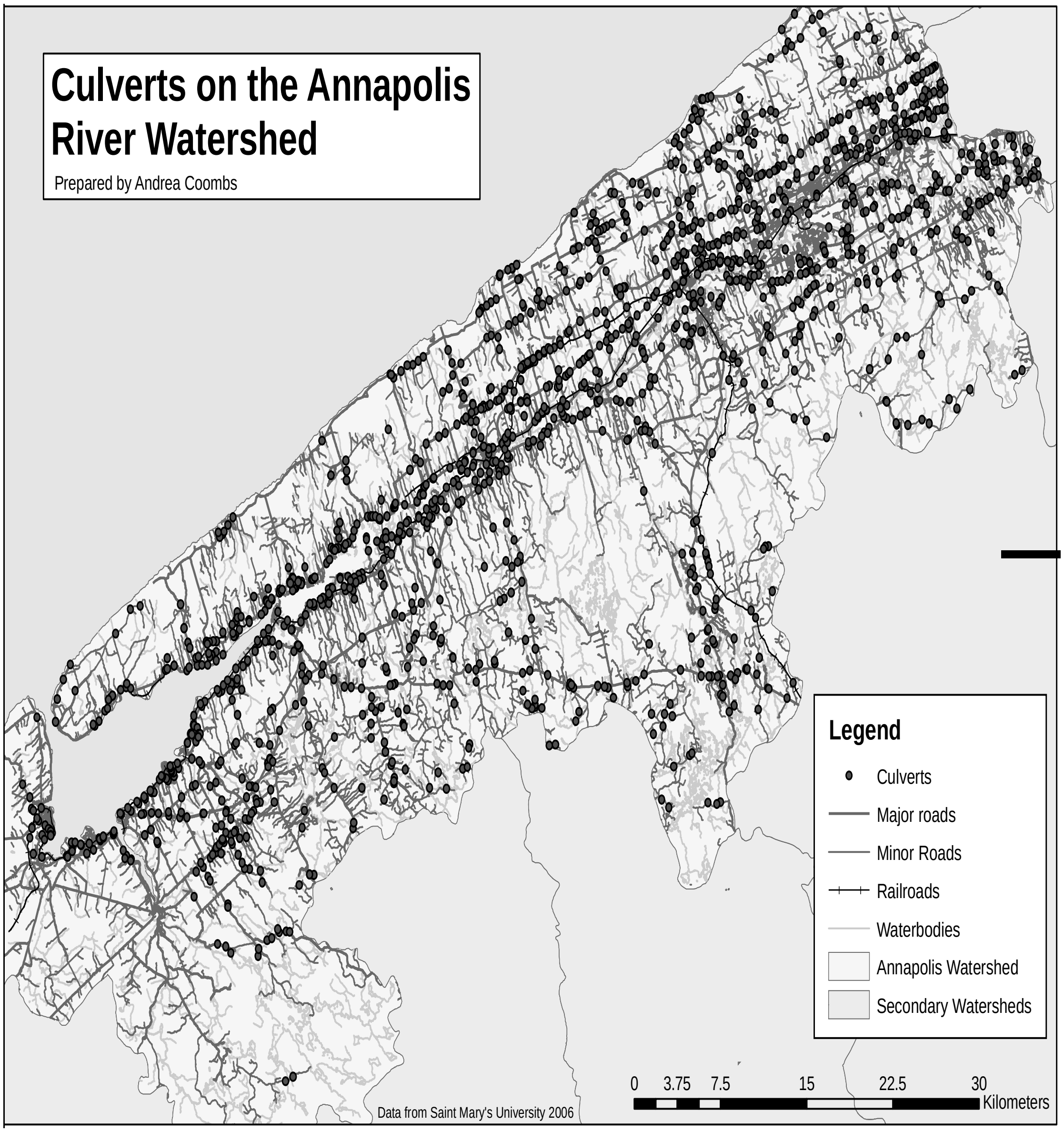
Appendices

Appendix A: Annapolis River Watershed and Culvert Locations

(Source: Coombs, 2006)



Appendix B: Annapolis River Sub-watersheds

(Sub-watersheds partially completed marked in bold)

Skinner	Parker	Button
Patterson	Hazelwood	Nome 9
Graves	East Troop	Walker / Nome 4
McGee	Fraser / Hollow	**Bloody Creek**
Avery	Mills	Messinger / Hooper
Walker	Troop	**Tupper**
Wiswal	Wocester	Bent
Walton	Kennedy	Spurr
Evans	Dixon	**Round Hill**
Morton	Croscup	Sawmill
Lily Lake	Burke	Allain's River
Slokum	Thornes	Balcom
Burbidge	Rockland	Woodland
McEwan	**South**	Ryerson
Oak Hollow	**Zeke**	Potter
Leonard	**Fales**	**Moose**
Shearer	**Black**	Ditmars
Balcom	**Nictaux**	Deep Brook
Munros	Kempt	Purdy's
Saunders West	Delancy / Keith	Boyce
Solomon-Chute	Gehues	**Bear**
Fash	**Petes**	Roach
Bath	Millers	Walsh
Chesley	Barteaux	Acacia
Foster	**Paradise / Roxbury**	Bacon
Ray	Saunders	Holdsworth
Gesner	Sheridan	Turnbulls
Luxton	Daniels	**Spinney**
Gould	**Hutchinson**	

Appendix C: Safe Work Practices Document

Broken Brooks Project	
Hazards Identified	Falling, working over water, slippery surfaces, unstable slopes, traffic, dust, noise, air quality in culvert, loss of balance (damaged culverts, beaver dams, loose sediment), face injury (branches), insects, poison ivy, animals (wild & domestic), falling rocks, electric fence, barbwire fence, farming equipment, sunburn, discharge of firearms during hunting season.
Hazard Specific Personal Protective Equipment	As required, life preservers, approved boots with aggressive & ankle support, hearing protection, orange safety vest, respiratory protection (mask), eye protection, insect repellent, sunscreen, long pants, waders
Hazard Specific Training	Job-specific training

Safe Work Practices

- A #2 First Aid Kit is required
- No less then 2 persons must be present for culvert inspection and subsequent stream inspections
- Evaluate area before starting the culvert inspections to identify any possible hazards
- If birds nests are present in culvert, take necessary respiratory actions (ie: wear a mask)
- Be aware of unstable slopes and weather conditions (ie:rain) that may increase likelihood of slips and falls
- Ensure a mobile phone will be present and powered at all times
- Ensure that the office is aware of culvert inspection locations before leaving to perform the fieldwork
- Take precautions around unstable terrain such as river banks, damaged culverts, and boulders
- Review the UV index before leaving the field and wear sunscreen at all times
- Wear hunter's orange during autumn hunting season
- When carrying gear, make sure that one hand remains free to brace a fall; backpacks will be used when appropriate
- Park vehicle completely off the road and onto the shoulder
- Set up a yellow flashing light on top of truck during all inspections for increased visibility
- Walk on the shoulder in the direction of on coming traffic
- A reflective vest will be worn at all times when working near the road
- Stay hydrated and stay aware of extremes in temperature
- Always be alert of others and traffic that is near your area of work

Note: Where necessary, refer to:

- CARP Health and Safety Policy
- CARP Remote Location Plan

Clean Annapolis River Project
P.O. Box 395, Annapolis Royal, NS, B0S 1A0, 902 532 7533

Appendix D: Culvert Inspection Field Data Sheet

Fish Passage – Culvert Inspection Procedures

Form A – Fish Passage – Culvert Inspection – Side 1

Date (mm/dd/yy)	/ /	Stream Name	
Road Name/ID#		Road Location (MoF district)	
UTM/GPS Location		Watershed Code	
1:20 000 Map Sheet		Recorders Name	
Site Number			

Culvert Characteristics: ______________________________

Culvert Diameter (mm)	mm			Culvert Slope (%)	Us	Ds	%
Culvert Length (m)	m			High Water Mark (cm)	cm		
Culvert Material				Culvert Water Depth (cm)	cm		
Culvert Water Velocity (m•sec-1)				Culvert Outfall Drop (cm)	cm		
Culvert Shape				Culvert Maintenance	Hi / Mod / L / No		
Culvert Wetted Width (cm)	cm			Fill Slope Depth (m)	m		

Stream Characteristics: ______________________________

Stream Reach		Stream Classification	S1 S2 S3 S4 S5 S6 P
Pool Depth at Outfall (cm)	cm	Blue Listed/Significant	
Sediment Source/Degree	Yes / No – Hi / Mod / L		

Measure	Measurement(s) Below Culvert			Measurement(s) Above Culvert			Average Measurement
Wetted Width (m)							m
Bankfull Width (m)							m
Water Depth (cm)							cm
Bankfull Depth (cm)							cm
Stream Water Velocity (m•sec-1)							m•s-1
Stream Gradient (%)							%
Fish Presence	Yes / No / No survey			Yes / No / No survey			NA
Fish Sampling Method							NA
Sampling Effort (time)							NA
Species Present							NA
Beaver Activity/Type							NA

Barrier Evaluation:

Barrier	Full	Partial	None	Undetermined
Barrier Type				

Site Photos:

Roll # ______________________

Inlet upstream photo # ______________________ Inlet downstream photo # ______________________

Outlet upstream photo # ______________________ Outlet downstream photo # ______________________

Appendix E: Detailed Description of Variables Assessed

#	Variable	Units	Description	Significance
1	Stream Name	N/A	Using the Nova Scotia Atlas, the name of the stream on which the culvert resides is indicated.	Stream name indicates which sub-watershed is being surveyed.
2	Road Name	N/A	The maps produced by Andrea Coombs have all the provincial roads labelled. Some roads are unmarked and a road name is unknown.	Road name is important when trying to locate the culvert. Also, if remediation should take place, the road name indicates who must cover the costs.
3	Coordinates	UTM	The specific location of the culvert is taken with a hand held Garmin GPS (map datum NAD83). These coordinates are compared against those provided by Coombs (2006) for accuracy.	UTM coordinates make it much easier to relocate the culvert site at a later date.
4	Site Number	N/A	The order in which assessments are completed is recorded. For example; MR01, stands for Moose River and the assessment number along that sub-watershed. The site numbers are recorded in chronological order from the first culvert visited to the last.	Site number keeps track of how many culverts where visited per sub-watershed.
5	Recorders Name	N/A	The names of individuals doing the assessment.	Recorders names identify who was responsible for the assessments, in the event that problems or questions arise.
6	Culvert Diameter	mm	For round culverts, the diameter is the measurement across; for oval culverts, it is the widest portion; and for box culverts, it is the width.	Diameter of culvert is used to measure water volume flowing in culvert.
7	Culvert Length	m	The total distance from one end of the culvert to another. Some culverts are large enough to walk in and measure; others are not. In the latter case, the length is measured by attaching a measuring tape to a float. Some culverts may become blocked, so the measurement is taken over land (ie: over the road).	Length measurement is used in calculating culvert slope.
8	Culvert Material	N/A	Distinguish between wood, metal, plastic (PVC) and concrete.	Take note of any baffles or other special characteristics such as smoothness of the culvert.

#	Variable	Units	Description	Significance
9	Culvert Water Velocity	m/s^2	The water velocity is recorded at three points along the culvert length: upstream, middle and downstream. Velocity is determined by measuring the time required for a semi-buoyant object to move along a known distance.	Culverts move water very efficiently and can move the same amount of water as the natural stream without being the same size. This is due to the smoothness of the culvert lowering the turbulence of the water. However, if a culvert is 1/3 the size of the stream, the water velocity will be 3 times greater in the culvert compared to the natural stream flow (Parker, 2000).
10	Culvert Shape	N/A	Round or box (square).	Other shapes that can occur, but were not seen throughout during the assessments are; open bottom box, open bottom arch, elliptical, trough box and stacked.
11	Culvert Wetted Width	cm	The total wetted width in the culvert.	Used for determining volumes of water flow.
12	Culvert Slope	%	Using a surveyor's level and measuring rod, the slope of the culvert is determined. The elevation of the bottom of the culvert is measured both upstream and downstream. The difference in elevation and culvert length are then used to calculate the culvert slope.	Culvert slopes should closely resemble the natural slope of the stream, as excessive slopes can cause high water velocities.
13	High Water Mark	cm	The distance from the water level to the top of a visible high water mark stained on the culvert is measured. This mark is evident in most steel culverts, but is hard to see when assessing culverts made from other materials.	Provides a better understanding of water flows throughout the year. If a high water mark exists, an assessment during times of higher flow may be needed.
14	Culvert Water Depth	cm	Water depth is recorded with a meter stick at three points along the culvert length, upstream, middle, and downstream. These points are averaged to get the overall water depth.	Shallow culverts are a barrier to fish passage.
15	Culvert Outfall Drop	cm	The distance from the bottom of the culvert to the surface of the outfall pool.	Excessive outfall drops are the leading cause of barriers.
16	Culvert Maintenance	N/A	The need for maintenance is determined. If maintenance is required, it is recorded as low, moderate or high need.	Condition of the culvert is important for remediation purposes.
17	Fill Slope Depth	m	Using a meter stick, the distance from the top of the culvert to the top of the road surface is measured.	This measure is used when determining what type of repair work may be needed.

#	Variable	Units	Description	Significance
18	Sediment Source/Degree	N/A	The amount of sediment is evaluated. If there is more than in a natural stream, the degree of impact is recorded as high, moderate or low.	This is an observational record of whether or not sedimentation is occurring and what impact it may be causing.
19	Pool Depth at Outfall	cm	The depth of the pool immediately where the culvert discharges. The depth is measured using a meter stick or survey rod. If there is no pool outfall drop, this measure is not needed.	Used to determine approximate jump heights for trout.
20	Stream Wetted Width	m	The distance from one side of the stream to the other (wet portion only). This measure is taken at three places along the upstream and downstream portions of the stream.	These measures are taken at least 25m away from the culvert to avoid the effects of the culvert on the natural stream system. Subsequent measurements are taken approximately 10-15 paces away.
21	Stream Bankfull Width	m	The full width of the stream, from one stream bank to the other. The bank can be identified by the presence of woody plant growth or a defined high water mark.	This measure is taken three times, in the same location as the stream wetted widths.
22	Stream Water Depth	cm	One depth measurement is taken with a meter stick at the same three upstream and downstream locations as the width measurements.	In order to capture the overall stream profile, the measurement is taken at ¼ the distance across the stream, then ½ the distance across and finally ¾ the way across.
23	Bankfull Depth	cm	The distance from the water's surface to the high water bank full height. For example, measure from the stream surface until the base of woody vegetation or the top of an erosion mark.	This measure is recorded at the same location as the previous three measures. It gives a profile of the stream during high water flows.
24	Stream Water Velocities	m/s^2	This measure is taken by floating a semi-buoyant object for 1m or less, depending on the stream size and recording the time it takes to travel that distance.	This measure is recorded at the same location as the previous four measures. Compare these velocities to the culvert velocities.
25	Fish Presence	N/A	The presence or absence of fish is noted. In some cases, minnow traps are used when no fish are observed during the assessment.	Fish presence can be confirmed but not rejected. The presence or absence is a qualitative measure only.
26	Beaver Activity/Type	N/A	Any signs of beaver activity in the area are recorded.	Identifies possible barriers upstream or downstream.

Appendix F: Photographs

Figure F1: Downstream view from culvert, Patterson's Brook (PT03)

Figure F2: Outlet view from downstream, Patterson's Brook (PT03)

Figure F3: Downstream view from culvert, McEwan Brook (MW02)

Figure F4: Outlet view from downstream, McEwan Brook (MW02)

Figure F5: Upstream view from culvert, Fash Brook (FB02)

Figure F6: Outlet view from downstream, Fash Brook (FB02)

Figure F7: Downstream view from culvert, Roundhill River (RH06)

Figure F8: Outlet view from downstream, Roundhill River (RH06)

Figure F9: Outlet view from downstream, Fales River (FR01)

Figure F10: Downstream view from culvert, Fales River (FR01)

Figure F11: Inlet view from upstream, Fales River (FR02)

Figure F12: Upstream view from culvert, Fales River (FR02)

Figure F 13: Outlet view from downstream, Zekes Brook (ZB01) (Photo taken during spring high water flows)

Figure F14: Downstream view from culvert, Zekes Brook (ZB01) (Photo taken during spring high water flows)

Figure F15: Inlet view from upstream, Bear Brook (BB02)

Figure F16: Upstream view from culvert, Bear Brook (BB02)

Figure F15: Downstream view, Patterson Brook (PT01)

Figure F16: Upstream view, Patterson Brook (PT01)

Figure F17: Downstream view from culvert, Round Hill River (RH04)

Figure F18: Outlet view from downstream, Round Hill River (RH04)

Appendix G: Construction of Tailwater Control Weirs and Roughened Channels

(Source: Chapter 8 of: "Fish Passage Design for Road Crossings: An Engineering Document Providing Fish Passage Design Guidance for Caltrans Projects". California Department of Transportation, May 2007, Available at: http://www.dot.ca.gov/hq/oppd/fishPassage/)

8 GRADE CONTROL DESIGN

8.1 Grade Control Applicability

Grade control structures are used in fish passage culvert projects to enhance fish passage conditions in the stream channel upstream and downstream of the culvert, as well as in the culvert itself. The four most common uses of grade control structures are to:

- Increase the water depth a channel or culvert barrel,
- Raise the downstream channel up to the level of the culvert, or bridge and
- Stabilize the channel streambed near the culvert or bridge.

A frequent reason for having to increase water depth is when the geometry of the stream channel or culvert barrel has a large cross sectional area, producing shallow water depths. This condition can be especially prevalent with existing culvert facilities having broad, concrete outlet aprons (Figure 8-1a); and with box culverts or any large diameter culvert, whether new or existing. Placement of a grade control weir can help insure a minimum water depth upstream of the weir. A low flow notch, sized to contain the fish passage low flow, is commonly used to focus the flow pattern and encourage sediment transport through the low flow fish passage condition.

Grade control structures are also used to raise the downstream channel up to the level of the culvert. A common condition requiring this type of remediation is when existing culverts have been undersized, resulting in scour holes at the culvert outlet (Figure 8-1b). The two approaches generally used to correct these elevation differentials are 1) grade control weirs, which use a series of separate structures to produce incremental small drops in the water surface, and 2) roughened channels.


a)


b)

Figure 8-1. Applications for the use of grade control design include a) sites with concrete outlet aprons and b) perched culverts.

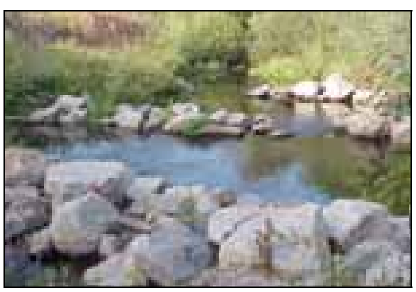
A third condition requiring grade control measures may occur when the existing streambed channel has potential to rise (agrade) or lower (degrade) over the life span of the project. A common need for this may occur with culvert replacement projects, where a substantial amount of sediment has accumulated upstream of the existing culvert over many years. When a larger culvert replaces the existing culvert, there is potential that the accumulated sediment will wash away during high stream flow events, resulting in downcutting of the channel from its preremediation condition. In such cases, grade control structures might be installed at the time of culvert replacement to promote stabilization of the revised channel configuration.

Retrofitting an existing culvert with grade control measures can be an attractive alternative to full culvert replacement. However, retrofitting an existing culvert with grade control structures may have unintended consequences. As an example, a project may propose the use of downstream weirs to improve stream depths at the outfall during periods of low flow. This downstream grade control structure may recruit bed material at the bottom of the culvert. While recruitment of this material may enhance fish passage, the conveyance capacity of the existing culvert may be reduced. This reduction can result in more frequent roadway overtopping and upstream flooding. Additionally, the ability for the existing culvert to pass debris during periods of high stream flow may also be reduced. Therefore, design criteria such as conveyance capacity and maintenance must be evaluated prior to full design and construction.

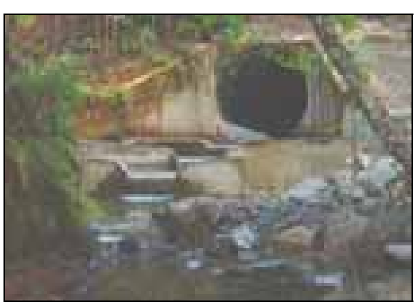
8.2 Control Structure Types

Three types of grade control structures most likely to be used for Caltrans projects (Figure 8-2):

- two types of grade control weirs: rock weirs or concrete weirs, and
- roughened channels.



a) Rock weirs



b) Concrete weirs

c) Roughened channel

Figure 8-2. Common types of grade control structures.

8.2.1 Grade Control Weirs

Weirs are a common type of structure built in the channel to control the water surface profile. Weirs for Caltrans projects must be constructed to be as durable and long lasting as the road crossing structure they are associated with. Any loss or lowering of the grade control structures could result in a new fish passage barrier, or it could negatively affect the structural integrity of the culvert or road crossing structure.

Any grade control structures must anticipate future conditions and the probability that continuing channel incision will occur. Scour may occur below grade control structures. When grade control structures are built downstream of a perched culvert, some of the energy that was dissipated at the culvert is moved to the grade control structures. Downstream scour can be exacerbated if there will be substantial bedload infilling between grade control structures upstream. The last grade control structure downstream should always be at or below the existing streambed grade. Additional buried controls are recommended where there is significant variability in bed elevation or possible future incision is expected. Those controls would become exposed and effective only as the downstream channel incises.

When required, control structures upstream may either have rigid elevations or they might be designed with the expectation that they will gradually adjust over time. The choice depends on project objectives and considerations from the profile design section of this manual. All or part of the upstream headcut may in some cases be allowed to occur uncontrolled. Grade control structures must not be placed near the culvert inlet. If the energy dissipated below the structure scours the culvert bed, the entire culvert bed can be affected and in some cases, entirely washed out of the culvert. The recommended distance to the nearest upstream control is a function of channel width and slope. In channels with slopes up to about four percent and with widths between ten and twenty feet, the upstream control should be thirty to forty feet from the culvert inlet. In steeper channels, pools are naturally more closely spaced. Spacing upstream of a culvert might be three times the stream width or a minimum of 25-feet apart.

8.2.1.1 Rock Weirs

Rock weirs have been used in recent years to backwater perched culverts and low dams. Their durability and passage effectiveness depends to a very large degree on the size and quality of material used, the care and skill of the hand labor or equipment operator, supervision, and equipment used to place the rocks. It should be noted that boulder weirs carry the risk of domino failure. If one weir within a series of weirs fails, the risk of additional weir failures is increased. Due to the potential for a domino style failure, construction quality at each structure is critical. To create a permanent structure, rock should be durable and of a shape that allows individual rocks to be keyed together. Boulders with somewhat of a rectangular form are much more stable than round boulders. Specific rocks should be selected for boulder weirs, and the placement of each rock should be done carefully with an understanding of the design concept. See Figures 8-3 and 8-4 for examples of rock weir profile and cross section.

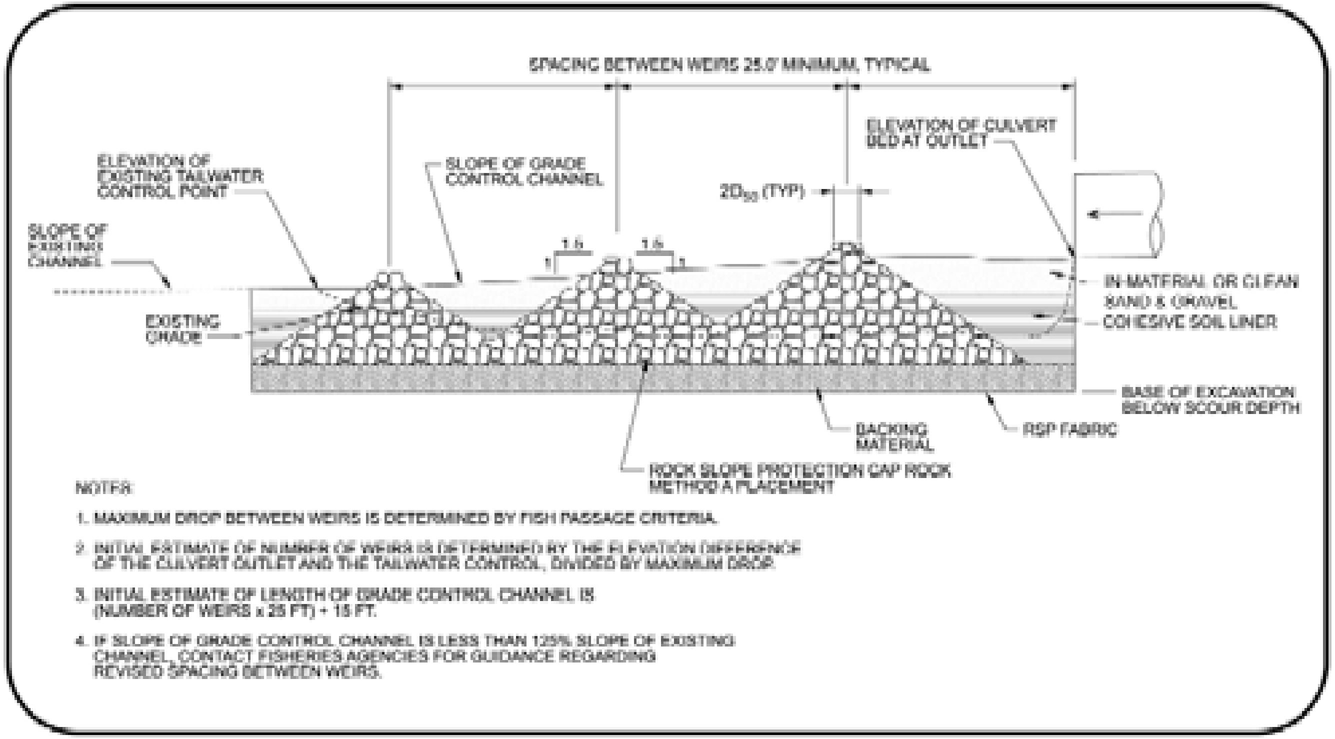


Figure 8-3. Typical profile for a rock weir system.

In addition to the grade control structures, rock revetment on the banks will be required to prevent flanking of the grade control structures. The revetment should be installed to a height greater than the design flood or 100-year storm, as deemed appropriate by project goals (Figure 8-4).

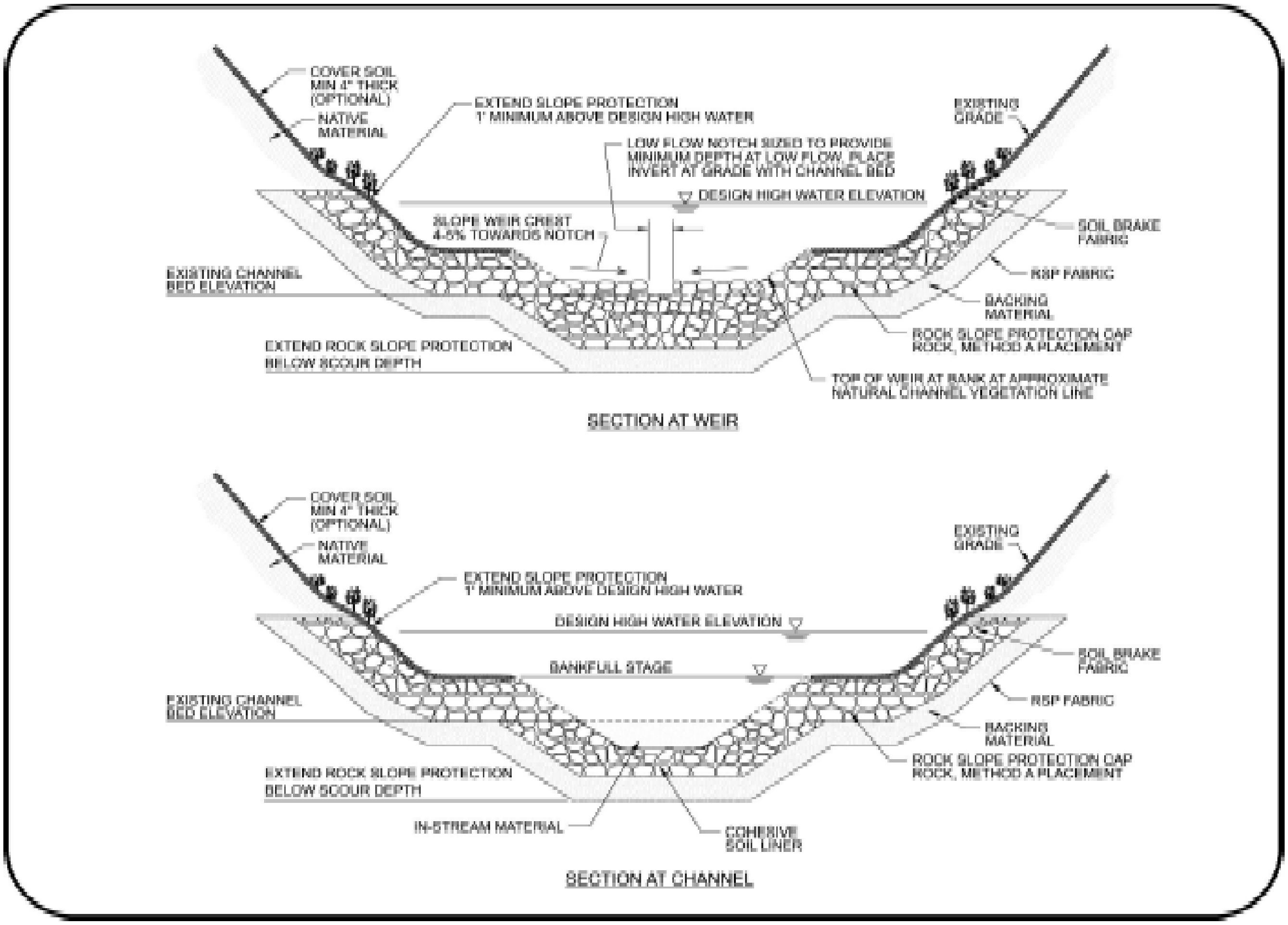


Figure 8-4. Typical sections for a rock weir.

The project area is excavated to provide proper keying depths into the bank, protect against scour, and provide sufficient layer depths as outlined in Table 5-3 of the RSP Manual. RSP fabric is placed over the native material and covered with the backing material. The outside layer and inner layer (if required) are placed over the backing layer. The plan view shape of the inner and outer layers, should be a vortex shape pointing upstream so rocks support each other in an arch pattern. The vortex orientation of weirs upstream of a culvert can be offset across the channel if necessary to improve culvert inlet alignment. Individual boulders need to be placed to ensure a minimum 3-point bearing on the underlying rock, as required by Method A placement. Special attention should be made to ensure the three-point bearing is provided on the downstream side of the individual boulder. This is critical to the longevity of the structure as the force of the streamflow and bedload is then transferred through the structure and into the banks and native material.

If bedrock is experienced prior to the proper depth being reached, the rock weirs should be keyed into the bedrock a minimum of eight to ten inches. Epoxy can be used to provide extra stability in areas with shallow bedrock depths. Hand labor may be required in this situation.

A low flow notch in typically provided to concentrate flow to the center of the grade control measure during periods of low flow. A 1-foot deep by 2-foot wide notch is typically the minimum size required but may be limited by the size of cap material. The cross section of the weir crest should slope toward the low flow notch at an approximate slope of 5%.

Much of the structural integrity and sealing of boulder weirs is provided by bed material that accumulates on the upstream face of the weir. It is therefore imperative that streambed material is recruited upstream of the structures. If material is not recruited, the structures may become porous, leak, and become vulnerable to failure. To that end, cohesive material can be placed over the backing material between the weir structures. The use of this material is intended to protect against subsurface flow.

In-stream material or imported clean sand and gravel is selected so that the material is mobile during more frequent flooding events. The intent is to provide a material that is similar to material already present in the stream. If the material is sized too small, it will be removed faster than upstream bed load can replace it and the stream will become degraded after construction. If the material, is specified too large, it will move slower than the upstream and aggrade over time potentially impacting culvert conveyance capacity. The best solution is to mimic the native material found at the site. It should be noted that there has been some reluctance from regulating agencies to reuse native material already at the project site. This problem may be attributed to potential deterioration of water quality immediately following construction.

8.2.1.2 Concrete Weirs

Concrete weirs are grade control structures that can be used to control the channel profile quite precisely. An advantage of concrete weirs is they can often be built at a steeper slope than rock weirs, therefore minimizing the footprint of a project. Concrete weirs are usually considered less desirable for fish passage than rock weirs, due to the lack of complexity and diversity in their structure. Full channel-spanning concrete weirs lack the variety of passageways that stream simulation provides and therefore do not comply with the premise of stream simulation.

Precast concrete weirs are a subset of the concrete weir grade control design. Advantages of a precast design are they can be precisely manufactured so that they seal well, have a varied cross-section similar to the natural channel, and have a crest shape that is specifically designed for fish passage. Another precast concrete design includes a weir, stilling basin, and wing walls in a single precast unit.

8.2.2 Roughened Channel

A roughened channel is n steep section of channel that has been engineered and constructed to provide sufficient roughness and hydraulic diversity to enable fish passage despite its steepness. A roughened channel provides grade control at a gradient steeper than the natural stream channel.

The bed material of a roughened channel is not intended to evolve as a natural channel with bed material scouring and replenishing; it is a fixed semi-rigid structure. Individual rocks are expected to adjust position and location but the larger grain sizes are not expected to scour out of the reach. As a result it may be steeper and have more severe hydraulic conditions than other sections of the stream.

Roughened channel designs use channel dimensions, slope, and material to create depths, velocities, low turbulence, and a hydraulic profile suitable for a target species to pass through. The rock used to provide a roughened channel must conform to rock sizing found in the *California Bank and Shore RSP Design* report.

8.3 Grade Control Design Process Overview

The design process for grade control design consists of several basic elements as follows:

1. Collect engineering data.
2. Identify the grade control design criteria.
3. Determine high fish passage flow, low fish passage flow, 10-year flow, 50-year flow, and 100-year flow.
4. Conduct a hydraulic evaluation of the culvert conditions, focusing on the conditions at the culvert or bridge outlet and in the channel just downstream of the culvert/bridge.
5. Conduct a hydraulic analysis based on preliminary the preliminary configuration.
6. Size grade control material.
7. Re-assess hydraulic conditions based on final configuration.
8. Finalize design.