Degradation Concerns related to Bridge Structures in Alberta

Introduction

There has been recent discussion regarding the identification and assessment of stream degradation in terms of how it relates to the design of bridge structures for Alberta Transportation (TRANS).

Degradation is defined as the long term lowering of a channel elevation over a significant distance. Degradation can occur naturally or as a result of manmade influences. Further background information related to degradation processes, common concerns, and TRANS case studies are provided in the Appendix.

Assessment

To assess whether degradation is occurring at a particular site, or along a particular stream reach, a river engineering review should be conducted. For a small culvert site, this may include a file history review and site inspection (if insufficient site photos are available). For more major sites (bridges or major culverts), or those where an initial screening warranted further investigation, analysis could include:

- desktop site history review:
    - comparison of historical streambed surveys,
    - history of hydraulic structures,
    - history of channel modifications,
    - maintenance concerns, etc.
- temporal aerial photography review to assess:
    - stream planform changes,
    - channel realignments,
    - bank failures over a considerable distance,
    - valley instabilities, etc.
- site visit, where degradation indicators could include:
    - streambed lowering over an extended reach,
    - vegetation levels high in comparison to streambed elevations,
    - bank toe erosion resulting in vertical banks,
    - steep ravines approaching a confluence,
    - geotechnical instabilities, etc.

This analysis should help assess i) if degradation is occurring ii) the extent iii) the cause (natural or manmade), and iv) the timeframe (single event or continual), from which recommendations can be made.

Recommendations

For sites where stream degradation is not obvious from an engineering assessment, it is recommended to follow existing guidelines. For sites where degradation is a concern, remedial measures are typically recommended until structure condition warrants replacement, with possible solutions as outlined below.

Remediation options for bridges may include:

- doing nothing (allow degradation to progress upstream),
- installing a grade control structure (culvert, weir, cutoff wall, etc.),
- channel work (regrading, installation of riprap, etc.),
- adding a span,
- headslope trimming and protection

Remediation options for culverts may include:

- using the existing structure as a control structure,
- installing a grade control structure,
- channel work,
- extending the existing structure

Replacement options for culverts:

1. Prevent degradation from progressing upstream
    - set downstream invert elevation to match existing streambed plus standard burial
    - make up existing elevation drop with a multi slope (drop) structure or by installing the structure on a steeper slope

    Potential Issues: *may impede fish passage, creation of hydraulic jumps is likely, may require more extensive outlet protection works (prevent structure undermining, energy dissipation), may require downstream remediation in the future, may make drift passage more difficult, may make future structures more difficult (greater elevation difference)*

2. Allow degradation to progress upstream
    - set downstream invert elevation lower than existing streambed (to a maximum of 1m)
    - match culvert slope to downstream channel slope

    Potential Issues: *may require substantial excavation (particularly on the upstream end), larger footprint will be required (RoW, culvert length, transition to natural channel), may cause issues to progress upstream (landowner impacts, geotechnical instabilities) may require maintenance, may require outlet protection works to prevent structure undermining in the future.*

APPENDIX

Background

Natural degradation can occur as a result of stream progression to a state of equilibrium. The majority of watercourses in Alberta are geologically young and are prone to natural bed lowering over time. This can be particularly evident in small tributaries downcutting to meet large waterbodies. In general, a stream will have a profile as shown, consisting of an erosion, transport, and deposition reach, as further defined below.

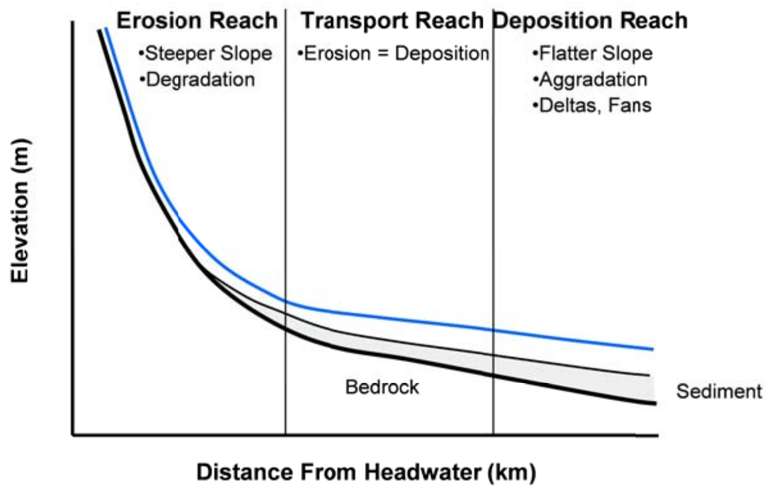


Figure 1: Typical Stream Profile (BIM, 2007)

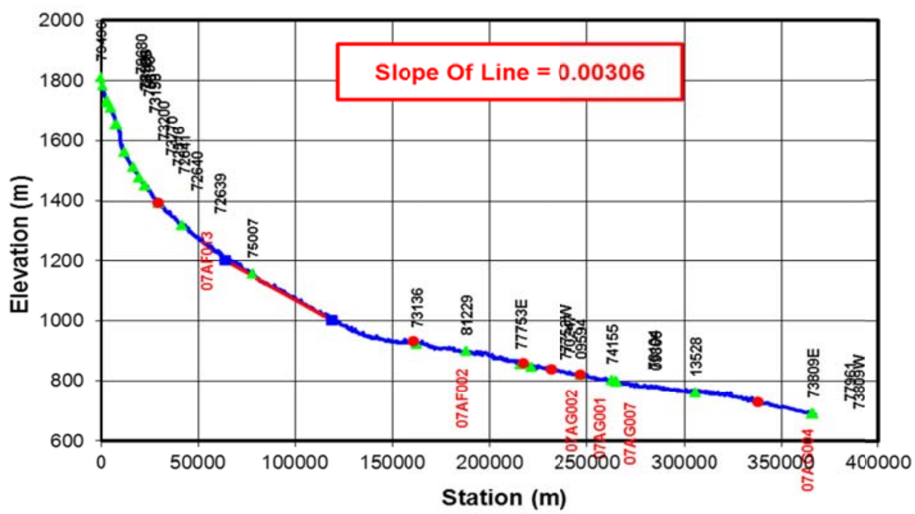


Figure 2: Stream Profile for McLeod River

Erosion Reach - Initially, the stream will be quite steep. It will be actively eroding as the stream picks up sediment to complement its sediment transport capacity. Most of the sediment transport will be in the form of bed load with larger particles tumbling along the

Stream bed. These reaches may be actively degrading. Unstable braided stream patterns are common, such as those seen along the upper McLeod River (Figure 3).

Figure 3: Upper McLeod River Reach Planform (Google Earth, 2012)

Transport Reach - This reach is characterized by a balance between erosion and deposition. The channel may still be actively eroding laterally, but will not be degrading. The typical channel pattern in this reach is the meandering river. Channel slopes will be flatter. Sediment transport will include both bed load and suspended sediment (Figure 4).

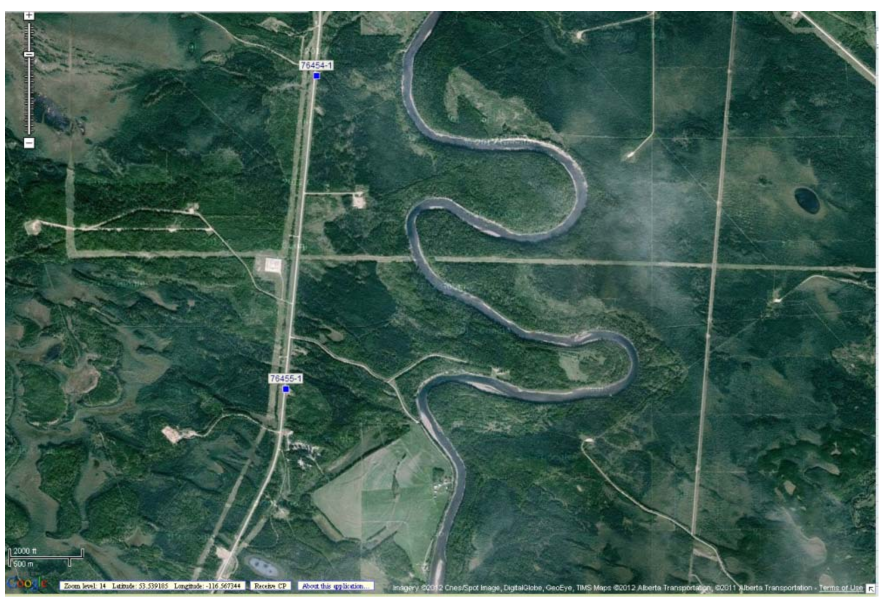


Figure 4: Middle McLeod River Reach Planform (Google Earth, 2012)

Deposition Reach - As the slope gets even flatter, the stream will lose its sediment transport capacity and there will be a net deposition of material. These reaches may be actively aggrading, and lateral channel stability decreases. These reaches may be characterized by alluvial fans and deltas.

Downcutting - An alternative to the deposition reach near the mouth of the river is a downcutting reach, where the channel may be actively degrading in order to match the elevation of the receiving stream.

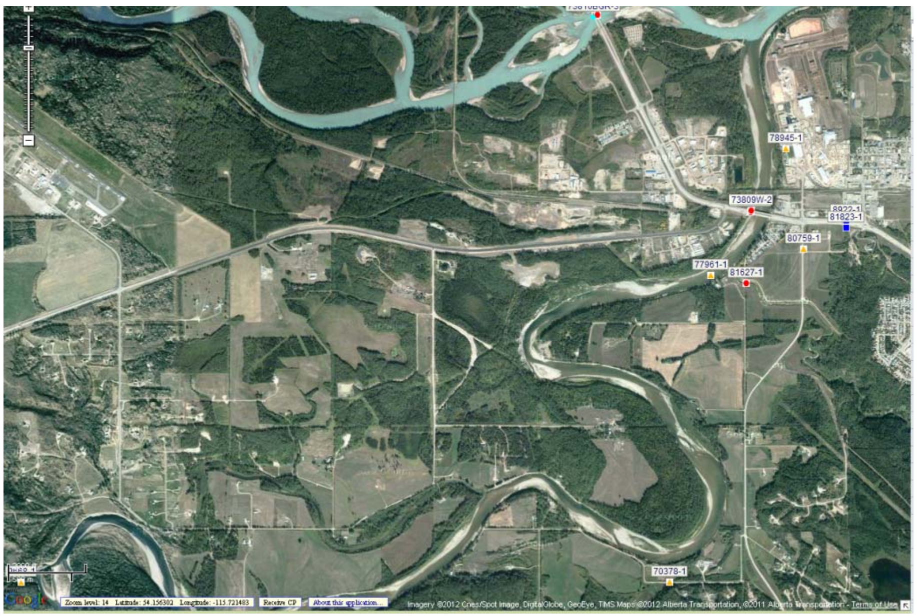


Figure 5: Lower Reach McLeod River Planform;
Downcutting to meet the Athabasca River (Google Earth, 2012)

Manmade degradation can be a result of channel realignment, where the new channel is shorter or steeper than the original channel. The relationship QS ~ Q_sD (where Q is discharge, S is energy gradeline slope, Q_s is the sediment discharge, and D is mean bed material size) describes channel response in terms of transport capacity. This relationship can be observed in the case of a dam installation (Figure 6). Upstream of the dam, the energy gradeline slope is decreased by the creation of a backwater curve behind the dam. This decrease corresponds to a decrease in sediment discharge (assuming the stream discharge and bed material remains unchanged), leading to sediment deposition (aggradation). Similarly, downstream of the dam, the water discharged will have a very low sediment discharge. This reduction is balanced by a decrease in energy gradeline slope (lowering of the stream bed over a considerable distance), resulting in degradation.

Figure 7 below shows how this concept applies to a channelized stream. Over time, aggradation and degradation will occur to achieve a new equilibrium. Examples of manmade stream degradation in Alberta include Bear River, West Prairie River, and Cucumber Creek.

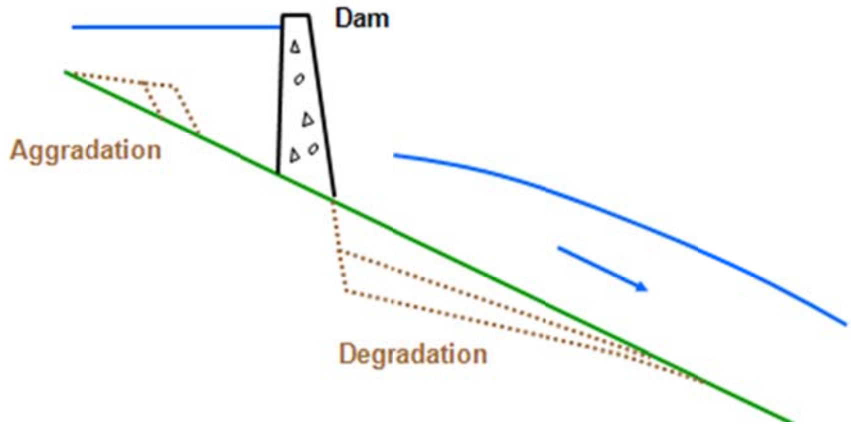


Figure 6: River Response due to Transport Capacity (BIM, 2007)

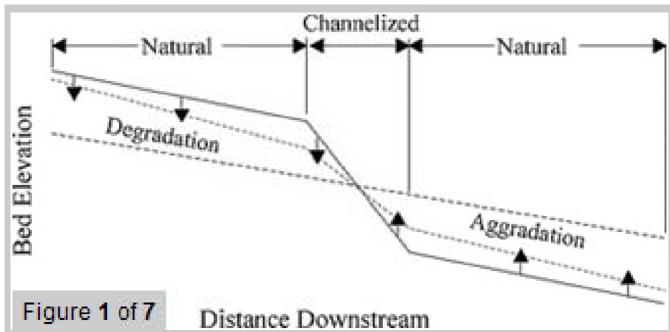


Figure 7: Reestablishment of Natural Equilibrium after Channelization (adapted from FHWA, 1991)

The current AT process of embedding bridge size culverts by D/4 (to a maximum 1m) accounts for the temporal geological stream lowering process over the life of a structure. This practice also provides environmental connectivity and allows for natural substrate to be transported into the structure to establish a natural streambed equilibrium over time.

Common Concerns

Degradation is sometimes misinterpreted as general (constriction) scour, the lowering of the streambed through a bridge crossing. Higher stream velocities, due to channel constriction, cause a general lowering of the stream bed across its width. The depth of scour will depend on the degree of constriction of the flow, the geotechnical conditions, and the runoff hydrograph properties. General scour (Figure 8) is confined to the vicinity of the structure while degradation will occur along the watercourse as well.

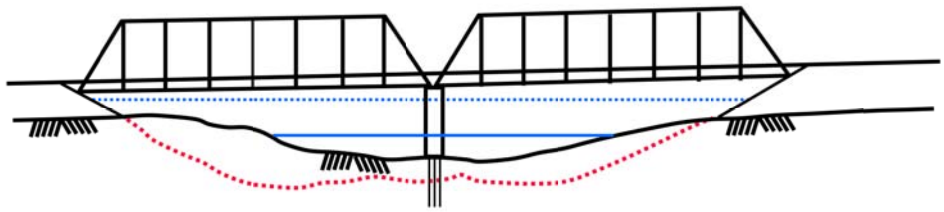


Figure 8: General Scour at a Bridge Opening (BIM, 2007)

Degradation may also be misinterpreted as local scour, such as the lowering of a streambed downstream of a culvert. In the past, TRANS installed culverts at streambed elevation, with minimal protection works, and, oftentimes, at a slope greater than that of the natural channel. Historical culverts also had a tendency to be hydraulically undersized. These past practices resulted in high exit velocities and resulted in scour holes forming at many outlets. These scour holes, at times, have been misinterpreted as degradation. It is important to note that degradation is a global channel process while scour is a local process. The examination of the stream away from a structure during a site assessment can help differentiate between local or general scour and channel degradation.

Case Studies

BF74852 – Local Road over Bear River

Site History:

1958 – Bridge built. Deck height = 11' (~3.3m)
1969 – LaCrete drainage project: meander cutoffs to steepen channel (S~0.006 vs. S~0.0034) and alleviate upstream flooding. Drop structures and bridge protection were recommended but not installed.
1977 – Bridge built. Deck height = 18' (~5.4m).
1987 – Drop structures installed. Aggradation expected.
1988 – Deck height = 7.9m
1992 – Deck height = 7.6m
1993 – Deck height = 7.3m

1987 Photo: note paint elevation and vertical banks

Assessment:

- steepening and shortening of the channel in 1969 resulted in degradation (about 2.1m in almost 20 years) until drop structures were constructed. The channel was attempting to achieve a new equilibrium (Figure 6). Since streambed surveys were not obtained over the years, we do not know the timing and progression of the degradation. The majority of degradation could have occurred initially with minimal progression in the later years, it could have occurred at an average rate per year, or as a scenario in between.
- installation of the drop structures resulted in aggradation at the bridge site (about 0.6m over 5 years).

Remediation:

- Do nothing. The existing drop structures are minimizing streambed elevation changes and threat is no threat of foundation undermining at the current bridge structure

BF73235 – Local Road over Cucumber Creek

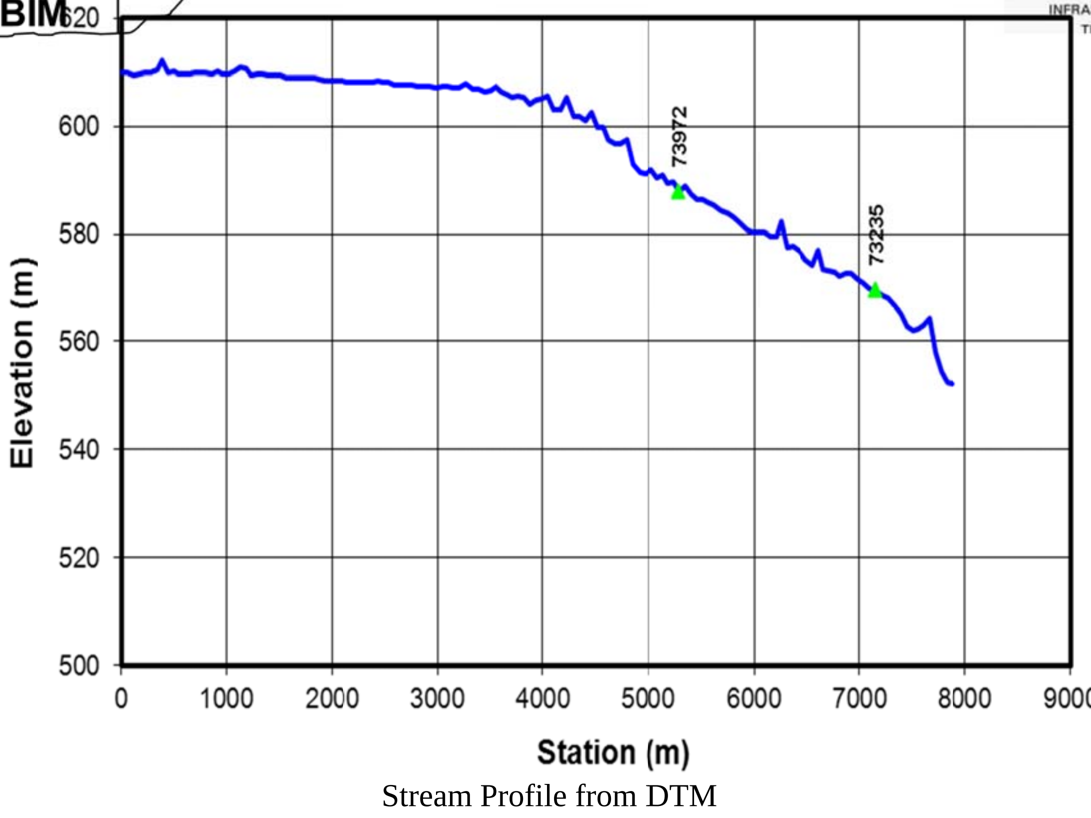
Site History:

1952 – 2 x 24” + 1 x 15” culverts. Highwater over grade.
1953 – 77” x 57” arch pipe installed.
1956 – Deck height = 7’ (2.1m); 24” culvert installed, u/s end raised 2’, grade raised by 1.5’. Highwater over grade.
1966 – Culvert washout. 16’ bridge built, deck height = 8’, u/s channel straightened.
2006 – 2.4m culvert installed.
2007 – High flow event, streambed surveyed

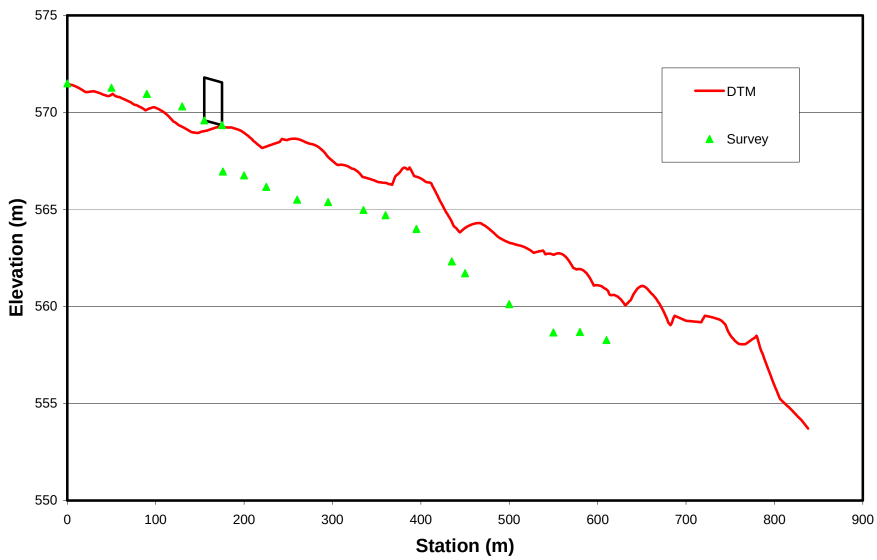
2007 Photo – note vegetation elevation, near vertical banks

BF73235 – Cucumber Ck

2007 Photo – note hanging outlet, vertical banks



Stream Profile from DTM



Local Stream Profile in Comparison to DTM

Assessment:

- there is a lack in historical information from 1966 to 2006 to assess if the straightening undertaken in 1966 had an impact on the channel (aggradation/degradation). The lack of information may suggest that major issues were not observed.

- from the local streambed survey and DTM extracted survey, it is evident that the channel downstream of the culvert has degraded (by 2.5m +/-) and that the culvert is acting as a control structure preventing the progression of this degradation upstream.

- the break in slope seen in the DTM slope, with a steeper portion closer to the receiving stream, is evidence of the stream downcutting to meet a receiving channel. Cucumber Creek is degrading to match the elevation of the receiving North Saskatchewan River

Remediation:

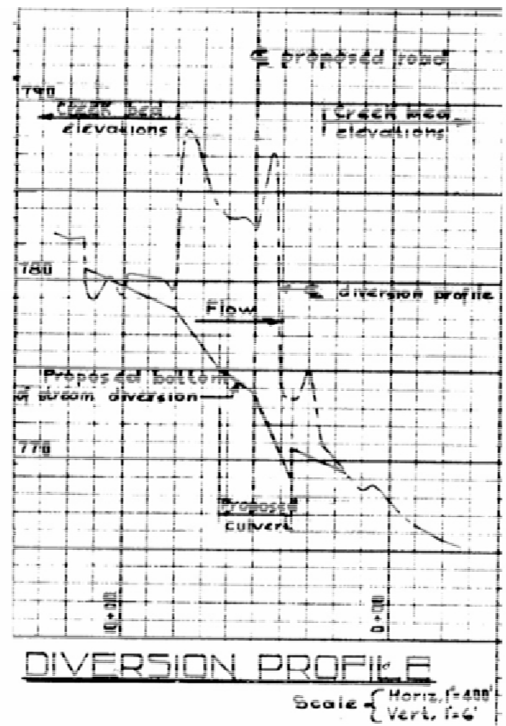
- if the structure integrity is not comprised, remediation may include preventing future structure issues, namely undermining. This may involve the design of a cut off wall to hold up the outlet and/or installation of protection works (rip rap) to prevent loss of backfill material and to dissipate high outlet velocities.

- for a new structure design, considerations could involve allowing the degradation to progress upstream (cost, potential liabilities), installing a structure to act as a control (maintain status quo), or somewhere in between (allow for a certain amount of degradation). For each option, there should be consideration given to cost (both capital and future maintenance) and potential risks or liabilities (known vs. potential concerns, legal consequences).

BF75700 – Highway 733 over Bad Heart River

Site History:

1963 – 2 -3670mm culverts installed on stream diversion (Figure below)
1990 – Highwater event. Hanging outlets (~1.5m above streambed)
2001 – Cut off wall installed beneath hanging outlets.
2010 – Structure condition warrants replacement



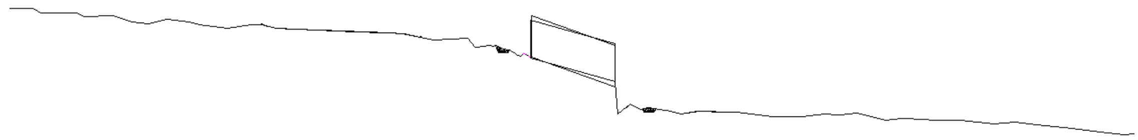
Stream Diversion Profile (extracted from DD385, 1963)


Looking at Downstream (note banks slumping/vertical banks)


Looking at Upstream Channel from Upstream of the Drift Catcher

Looking at outlets from Downstream (note ~2m drop, scour hole)

2007 Airphoto (note number of slides d/s compared to u/s)



2012 Streambed Survey, ~500m u/s and d/s from structure
(note local scour hole downstream, elevation difference between u/s and d/s)

Assessment:

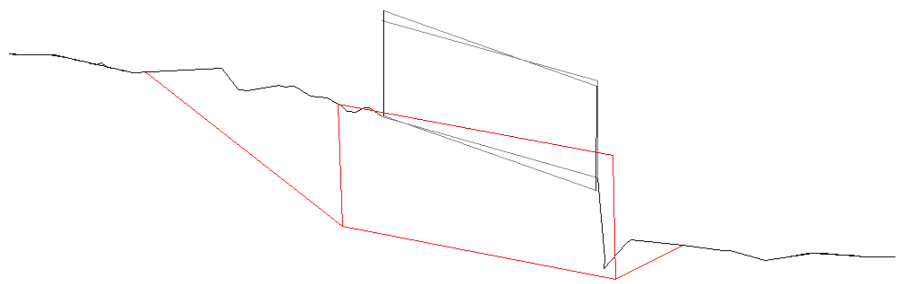
- from sites photos, a large scour hole downstream of the outlet can be seen. This local scour hole is also seen on the survey. Site photos also show slumping, vertical banks in the downstream channel which could be indicative of degradation (if occurring along an entire section) and/or lateral stream instability (if occurring locally; outside of meander bends).
- from the 2012 survey, it is evident that degradation has occurred in the past and that the existing culvert structures are acting as controls to prevent degradation progression upstream. The stream has approximately the same slope upstream and downstream, with an elevation difference of about 2m.
- the air photo shows a much greater number of landslides downstream of the structure than upstream. This could be from degradation (toe slope undermining). A review of historical air photos may help to determine if this was a continual process over time or occurred as a result of a specific event(s).

Remediation:

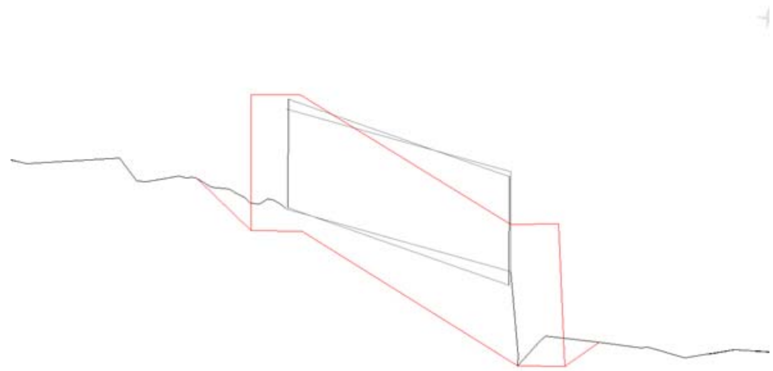
- since the structure condition warrants replacement, remediation was not considered. In the past, a cutoff wall was installed to support the culvert structures and riprap was placed in the scour hole to dissipate outlet velocities and prevent structure undermining.

Replacement:

- two options were considered during replacement 1) setting the invert downstream and matching the downstream channel slope (upstream invert below streambed); allowing degradation to progress upstream and 2) setting the invert downstream and upstream to the existing streambed elevations (slope steeper than natural stream), preventing degradation progression



Schematic for Option 1



Schematic for Option 2

Option 1

<u>Pros:</u> better connectivity for fish passage, better for watercraft navigability, lower velocities within the structure (no hydraulic jump created).

<u>Cons:</u> greater depth of fill (potential settlement concerns), greater depth of excavation (potential constructability, geotechnical concerns), greater culvert length, greater length of channel impacted, more RoW required, greater risk (uncertainty associated with progression of degradation upstream).

Option 2

Pros: less fill depth, shallow excavation, shorter structure, shorter length of channel impacted, less RoW required, less risk.

Cons: worse for fish passage, worse for watercraft navigability, high velocities within the structure requiring energy dissipation design.

Discussion

- Since fish sampling revealed only forage fish, fish passage was not considered a governing factor for design.
- Transport Canada advised that this stream was considered non-navigable due to high levels of drift and shallow water level. Navigability was therefore not considered a governing factor for design.
- Geotechnical review revealed unstable banks within the Bad Heart River valley
- Large volumes of drift were viewed to be a major concern for both options with either option requiring a flared inlet with additional freeboard allowance.

Replacement

Option 2 was recommended as the replacement structure.

References

Hydrotechnical Considerations, BIM Course Presentation, Alberta Transportation, 2007.

Design Guidelines for Bridge Size Culverts, Alberta Transportation, 2011.

Federal Highway Administration, HEC-20, Stream Stability at Highway Structures, 1991.