SOUTHWEST MABOU WATERSHED RESTORATION AND MANAGEMENT PLAN

Submitted to the Atlantic Salmon Conservation Foundation on behalf of the Inverness South Anglers Association

Report Completed by

MacInnis Natural Resource Services Inc.

With special thanks to Geoff Nishi and Dave Cameron of the Inverness South Anglers Association for their commitment to watershed stewardship and Atlantic salmon conservation.

Contents

Introduction

This report is divided into three sections: scoping, cumulative impact assessment, and a river restoration plan. The scoping section is divided into four components: (1) overview of the project area and valued ecosystem components [VECs], (2) overview of VEC habitat, (3) past and present land uses in the watershed, and (4) an aerial survey of the Southwest Mabou River. The cumulated impact assessment section will discuss how present and past developments have been detrimental to salmonid habitat, and how those changes impact fish populations. The final-section presents a river restoration plan aimed at improving salmonid habitat within the watershed. The goal of this report is to identify and understand the degradation of salmonid habitat in the Southwest Mabou river and recommend a river restoration plan to mitigate impacts.

An aerial survey of the entire South West Mabou was completed using an unmanned-aerial vehicle [UAV]. The results of the aerial survey will be incorporated into the habitat survey section in this report. The habitat survey is divided into four sections: (1) the inter-tidal section, from Mabou Harbour to Route 19 bridge, (2) the lower section, from Route 19 to the Moran Road crossing, (3) the middle section, from Moran Road to lower MacLeod Settlement, and finally (4) MacLeod settlement to the headwaters of the Southwest Mabou River. MacLeod Brook and a unnamed tributary were also surveyed and included in the habitat conditions overview.

The Southwest Mabou river supports a small run of Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis).* The river habitat is highly degraded, characterized by an over-widened and down-cut channel. Spawning habitat is sparsely found throughout the main channel, with bedrock substrate being the most prevalent. Two tributaries empty into the Southwest Mabou near MacLeod Settlement (MacLeod Brook and an unnamed tributary). Both these tributaries have been impacted by the disappearance of a stable riparian zone (Figure 30), leading to increased rates of bank erosion and a highly-mobile substrate (Figure 32).

This report will provide recommendations for fish habitat restoration on all four sections of the Southwest Mabou River and the two tributaries in MacLeod Settlement. Techniques required to mitigate the habitat degradation are armour rocking, deflectors, groynes, rock sills and riparian zone planting on the main branch of the Southwest Mabou River. The tributaries can be restored through riparian zone plantings, digger logs, deflectors and fish passage remediation.

Restoration of Atlantic salmon and trout habitat in the Southwest Mabou watershed will require a significant financial and volunteer investment. Restoration of the main channel must be completed with heavy machinery and armour stone structures such as sills, bank protection and deflectors. The river is approximately 200% over-widened and will require a professional consultant to design the work and survey the sites. Estimated cost is $100,000 per kilometer for heavy equipment work and materials. The Southwest Mabou river, despite flowing through a sparsely populated area, has many accessible sections for which heavy equipment can be brought in. The two main tributaries that enter the Southwest below MacLeod Settlement are both suitable for hands-on restoration techniques such as digger logs and deflectors.

Scoping

<u>Overview of Southwest Mabou Watershed and Valued Ecosystem Components</u>

The Southwest Mabou watershed, at 182 square kilometers, is the largest of three watersheds that empty into Mabou Harbour. The watershed was settled by Scottish immigrants in 1805, who established sheep and beef farms and cleared land for timber (MacDonald, 1952). Mabou Harbour was a known commercial salmon fishing destination as earlier as 1717 (Dunfield, 1985), supplying French troops stationed in Louisborg with a valuable source of protein. Prior to European settlement, the region was frequented by Indigenous fishermen (Dunfield, 1985). The Southwest Mabou watershed drains into the Gulf of St. Lawrence and is one of 115 Atlantic salmon rivers in the Gulf Region management area (Figure 2). The Southwest Mabou falls in Salmon Fishing Area (SFA) 18B.

Atlantic salmon and brook trout (salmonids) have been identified by the Inverness South Anglers Association [ISAA] as the most important VECs. ISSA has completed various habitat restoration projects targeted at improving salmonid habitat in their region. These projects have been completed in partnership between ISAA and the Nova Scotia Department of Environment, Nova Scotia Department of Inland Fisheries and Aquaculture, the Nova Scotia Salmon Association's (NSSA) Adopt-a-Stream program, the Unama'ki Institute of Natural Resources, Municipality of the county of Inverness, Wild Salmon Unlimited, the Nova Scotia Community College's Natural Resource Environment Technology program, the Atlantic Salmon Conservation Fund (ASCF) and the Department of Fisheries and Oceans Canada's (DFO) recreational fishery collaborative partnership program (RFCPP). Both these species are pursued by recreational and Indigenous fishers and represent an important source of food and traditional importance for all stakeholders.

Figure 1: The Southwest Mabou Watershed

The Southwest Mabou River can be characterized as degraded salmonid habitat, which lacks spawning substrate, pool depth and large-woody debris. These conditions are the result of historical land use developments within the watershed and persistent impacts such as roads and agriculture. The harvesting of riparian zone forest in the past has led to increased runoff, the absence of large woody debris and the loss of overhead cover – critical for thermal regulation and protection from predatory birds.

Salmonid Habitat

Salmonid spawning habitats have endured a great deal of pressure over the last two centuries, resulting in a decline of available habitat (Sear and DeVries, 2008). At no other time in modern history have the cumulative impacts on watersheds been so severe (Rosgen, 1994). “A functional river ecosystem is connected to everything around it, including the adjacent soils, animal and plant communities, climate and human development” (Wohl, 2004). In many North American watersheds, timber harvesting and land clearing, have increased the velocity of water and sediment transportation, degrading salmonid habitat and decreasing channel stability (Wohl,2004).

“A river channel conveys water and sediment downstream” (Wohl, 2004), as such, the stability of river channels can be altered by changes in velocities and volumes of both water and sediments. Rivers are indicators of environmental stress, for example, excess sediment supply and channel adjustments often occur following deforestation and other developments within the watershed (Rosgen, 1994). Habitat quality is reduced when the scouring process reduces spawning habitats, this is characterized by a bedrock channel bed. “For a stream to be stable it must be able to consistently transport its sediment load, both in size and type, associated with local deposition and scour” (Rosgen, 1994).

Atlantic salmon and brook trout require various habitats throughout their life cycle (Armstrong et al., 2003). The degradation of spawning habitat because of human disturbance has been well documented (Einum et al., 2008). In the freshwater environment, salmonids require cool, well-oxygenated water, overhead cover and food supply. The populations and survival rate of juvenile salmonids are heavily impacted by the availability of food, cover and water temperature. Narrow, meandering channels, with deep pools and a variety of habitats often create the most productive salmonid rivers. Unfortunately, many salmonid streams have been negatively impacted by past and present watershed developments. The loss of riparian zone vegetation can result in increased bank erosion, reduced water retention and high summer-time water temperatures.

Salmonid streams in regions with a gravel dominated geology, such as the Southwest Mabou river are particularly vulnerable to riparian zone changes. Historic riparian zone loss can create persistent long-term impacts such as an incised channel, characterized by a lowered streambed and the disconnection of the river from the floodplain (Pollock et al., 2014). Incised channels are predominantly over-widened and scoured to bedrock substrate. The Southwest Mabou River is an excellent example of an incised channel, exhibiting many of the common impacts such as lowered groundwater tables, the loss of wetlands, lower summer base flows, warmer water temperatures and the loss of habitat diversity (Pollock et al., 2014).

Habitat improvement projects have been used to improve and sustain salmonid populations throughout the Maritimes. “Habitat restoration has a proven track record. Portions of watersheds have been opened up or restored resulting in increased salmon production within freshwater systems” (Ministry’s Advisory Committee on Atlantic Salmon, 2015). Wohl et al. (2005) believe river restoration projects are most likely to succeed when implemented in the context of the watershed and aimed at the restoration of process rather than at a fixed point. Wohl (2004) cautions that if the factors that contributed to habitat loss do not change, restoration success is unlikely.

Past and Present Land Uses

Changes to the landscape of the Southwest Mabou watershed began with the arrival of Scottish settlers in the early 1800s, who cleared land for agriculture and timber. The emergence of a lumber industry in the Maritimes in the 1840s impacted many Atlantic salmon rivers and streams (Dunfield, 1985). Land was cleared, dams were built, and roads were constructed during this time. It is likely that many of the persistent impacts on the Southwest Mabou river are the result of historic developments. More recent activities such as forestry, agriculture and residential developments are likely contributing to habitat degradation to a lesser degree.

From the headwaters above MacLeod Settlement, to the inter-tidal zone below Route 19, the Southwest Mabou river has become an incised channel. The physical changes to the Southwest Mabou watershed have degraded salmonid habitat and the river ecosystem. The entire stream bed is scoured to bedrock, and the channel lacks sediment retention capacity. Natural occurrences such as large woody debris jams and beaver dams are limited.

The aerial survey and in-stream assessment of the Southwest Mabou river uncovered instances of riparian zone loss from recent forestry operations as well as sediment run-off from forestry roads and newly constructed ditches (Figure 2 and 3). The introduction of fine sediments from road construction and run-off can severely impacted the survival and development of salmonid eggs (Sear et al., 2008). “Fine sediment can influence the process of oxygen supply to incubating salmonid eggs” thus increasing mortality rates (Greig et al., 2005). Whether human induced or not, when sediment transport increases or erosion resistance decreases, the excavation and scouring of stream beds occurs at a much faster rate than the habitat can adjust for (Pollock et al., 2014).

Figure 2: Riparian zone clearing, unnamed tributary to Southwest Mabou River.

Figure 3: Road and newly constructed ditching leading to fine sediment runoff in MacLeod Brook.

Persistent impacts such as active agriculture operations were also observed in the lower section of the river, characterized by marginal riparian zone cover. It does appear that the riparian zones have increased in size in recent years, with farmers pulling crop production further away from the waters edge. This is likely a response to annual floods, persistent groundwater or for environmental reasons (see figure 4 for an example of current agricultural land and note the new vegetation growth).

Figure 4: Active agriculture site, lower Southwest Mabou River. Above Route 19.

The presence of roads, for both residential and forestry purposes is resulting in sedimentation and fish passage barriers, especially on MacLeod Brook, a major tributary of the Southwest Mabou River. Without mitigating the impacts of these developments, the potential recovery of salmonid habitat in the Southwest Mabou River will be limited.

Aerial Survey of Habitat

Inter-Tidal Section: Mabou Harbour to Route 19

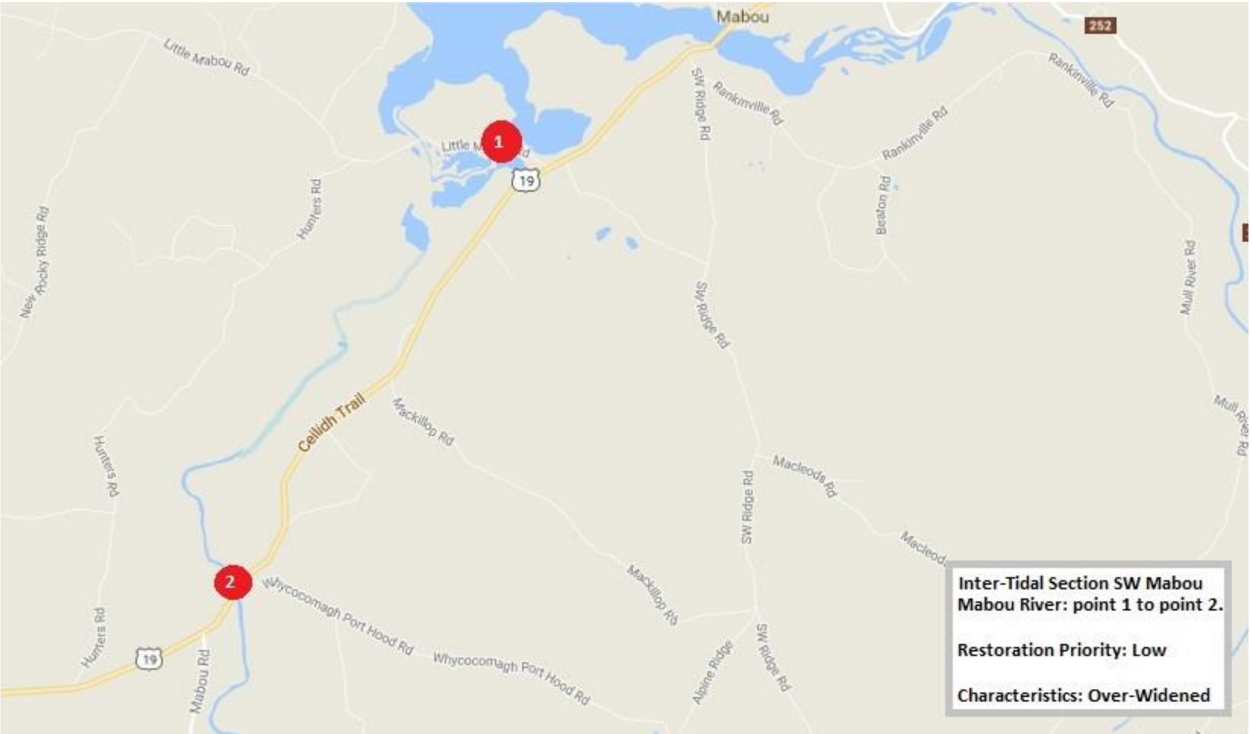


Figure 5: Map of Inter-tidal section of Southwest Mabou.

Figure 6: Southwest Mabou River - Mabou Harbour confluence.

Figure 7: Lower reaches of Southwest Mabou River.

Figure 8: Upstream view of Route 19 Bridge. Channel lacks proper meander pattern, is over widened and has insufficient riparian zone.

Figure 9: Small tributary to Southwest Mabou. 500 meters below Route 19.

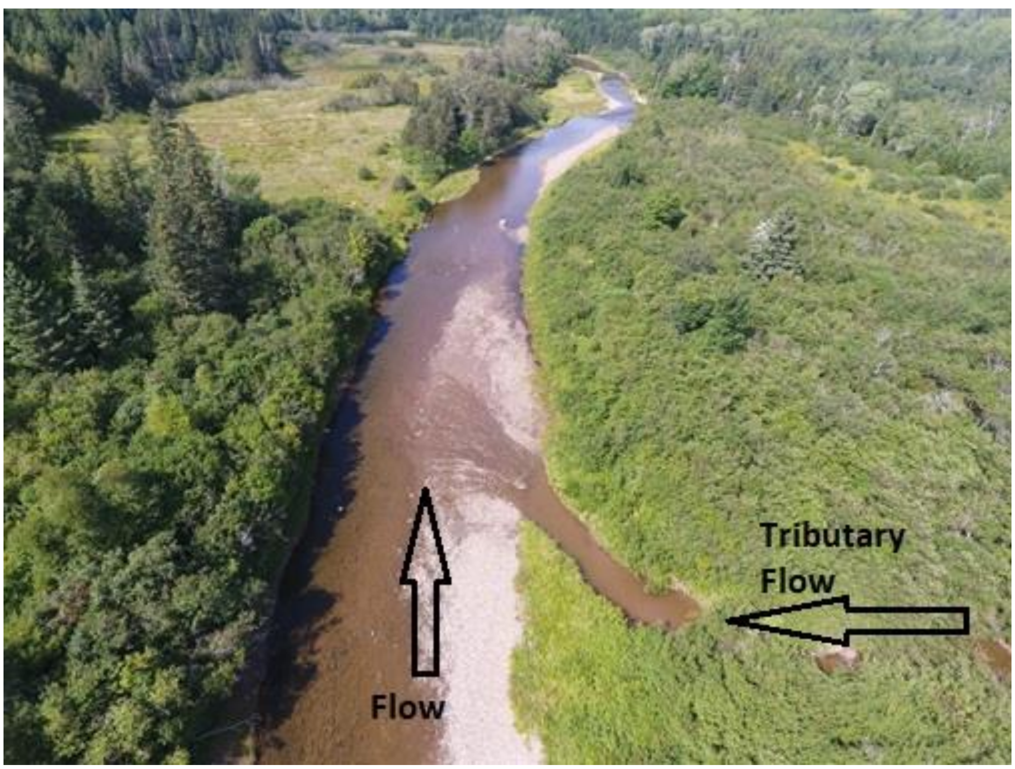


Figure 10: Entrance of small tributary. Over-widened channel limits fish passage from SW Mabou to tributary.

Figure 11: Route 19 Bridge, note scouring below bridge. Over-widened and shallow channel. Potential barrier for early run fall Atlantic salmon. Evidence of ice scouring of spawning habitat and lack of sufficient riparian zone.

Figure 12: Route 19 Bridge, mid-channel substrate deposits and split channel. Channel is also over-widened.

Lower Section: Route 19 to Moran Road crossing

Figure 13: Lower Section of Southwest Mabou.

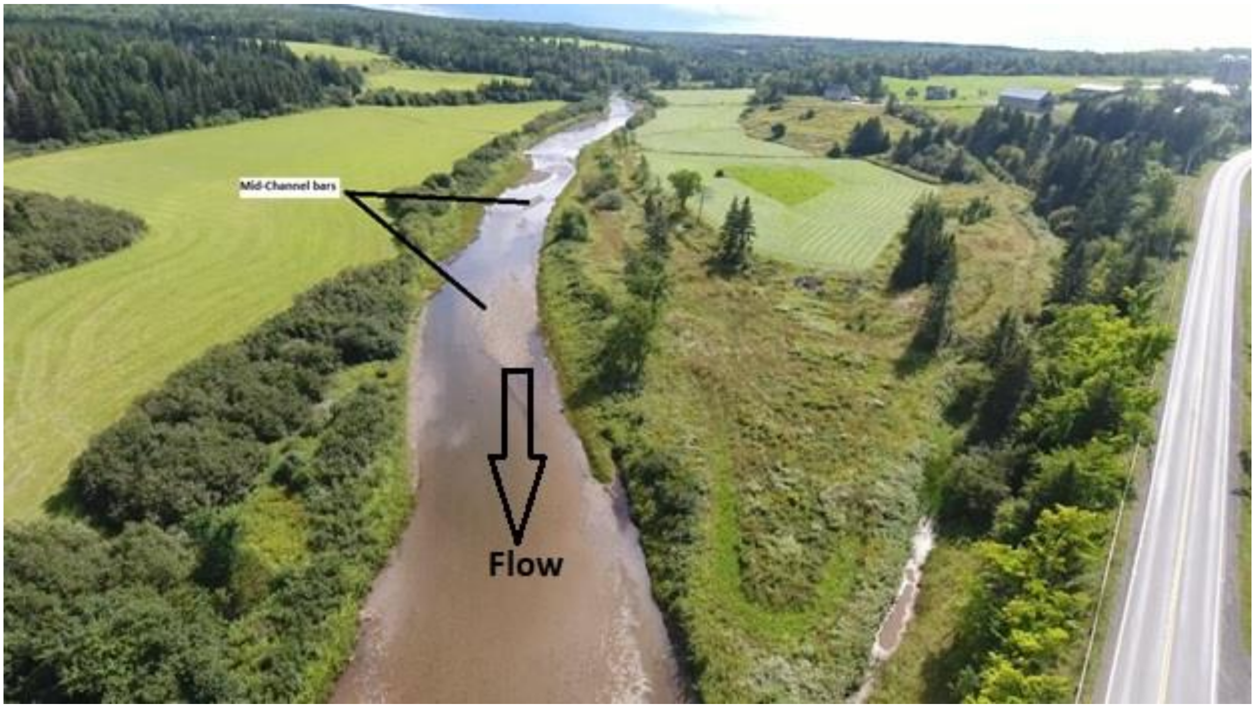


Figure 14: Upstream view from Route 19 Bridge. Over-widened channel, lacking pools and sufficient riparian zone.

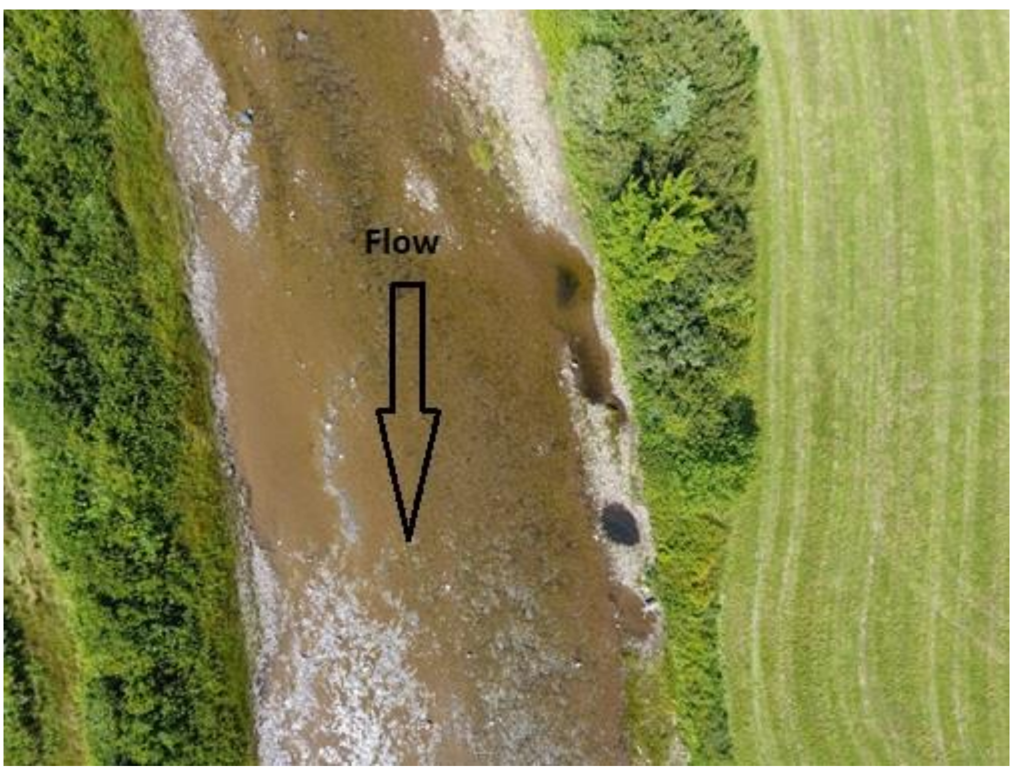


Figure 15: Ice-scouring pockets caused by over-widened channel.

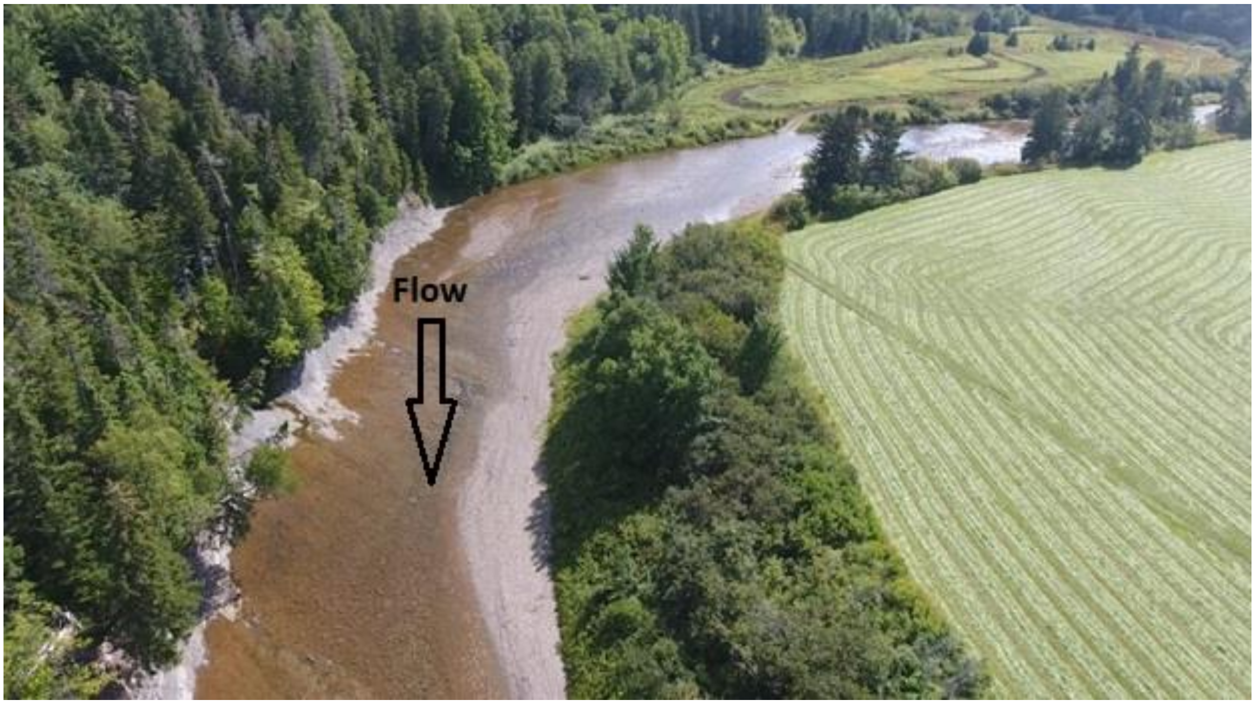


Figure 16: 1km above Route 19 Bridge. Eroding bank and heavily siltated bottom substrate. Over-widened and shallow habitat.

Figure 17: Over-widened and shallow channel, in between Moran Road crossing and Route 19. No pool habitat, no large woody debris and no overhead cover.

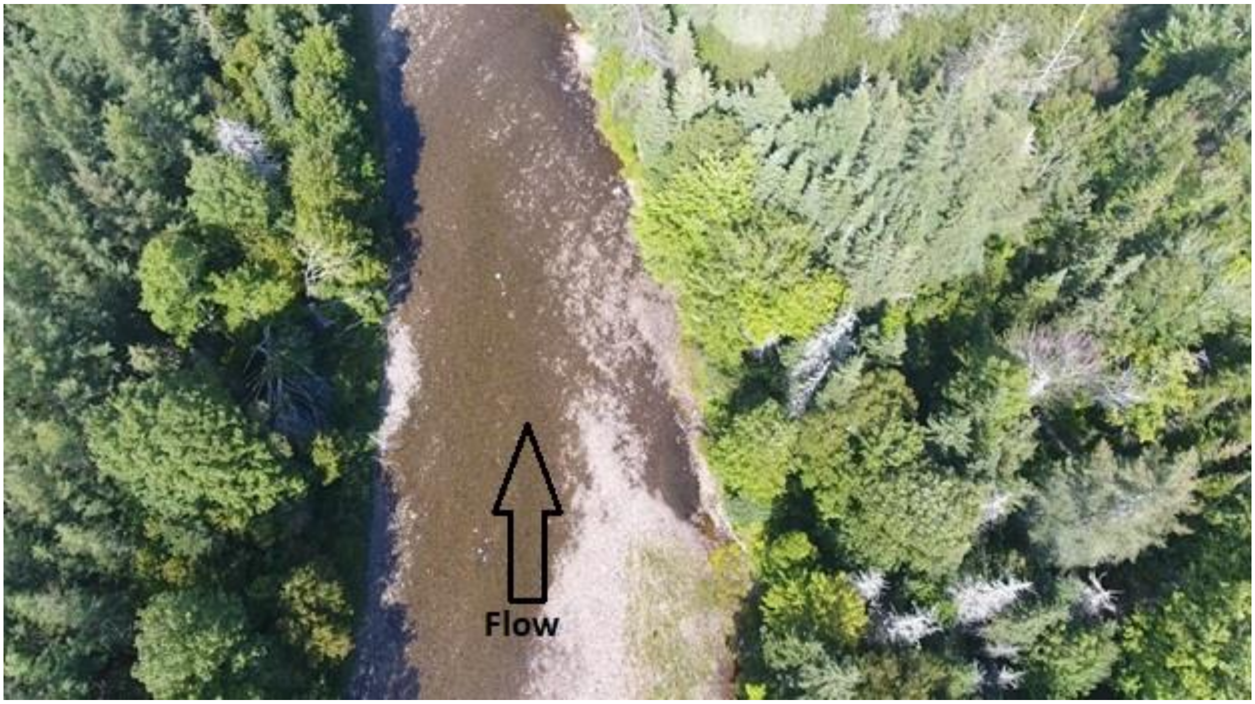


Figure 18: 1.5 km below Moran Road Bridge. Typical channel condition for this section of river. Over-widened, shallow and prone to ice-scouring.

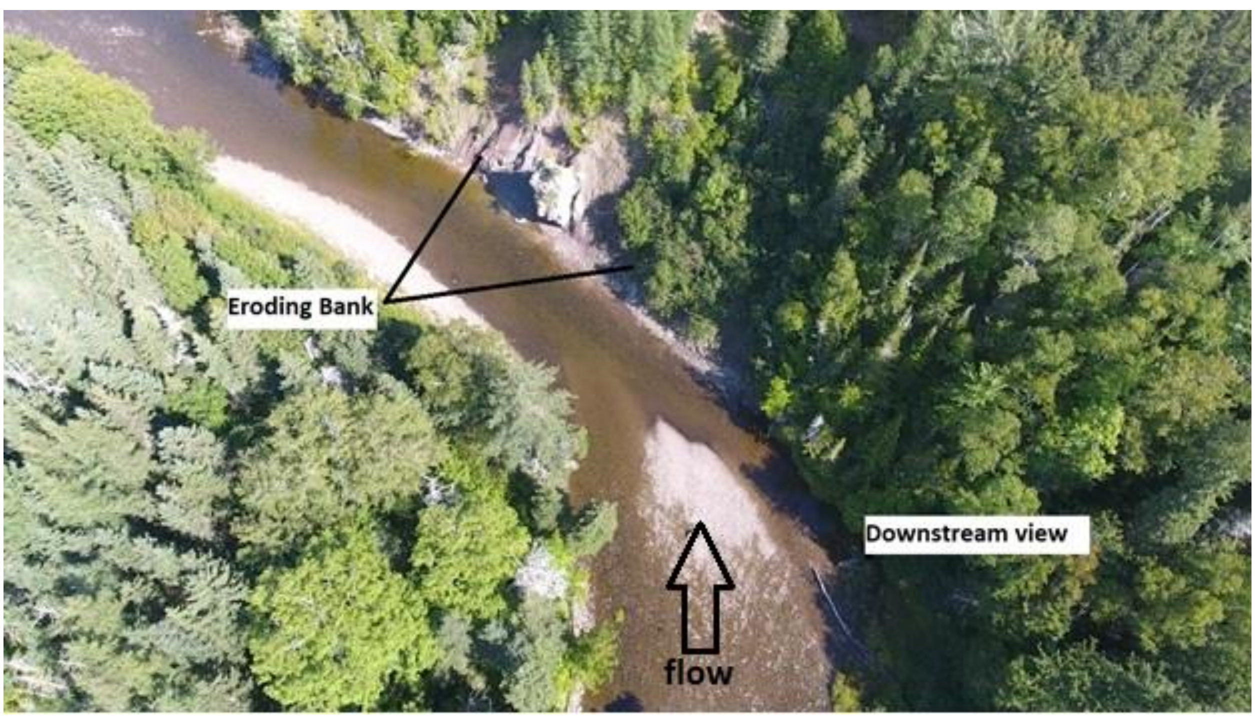


Figure 19: 500 meters below Moran Road bridge. Persistent over-widened channels, no pool habitat or overhead cover.

Figure 20: View above Moran Road bridge. (Note: little access for machines below bridge due to steep slopes)

Middle Section: Moran Road bridge crossing to lower MacLeod Settlement

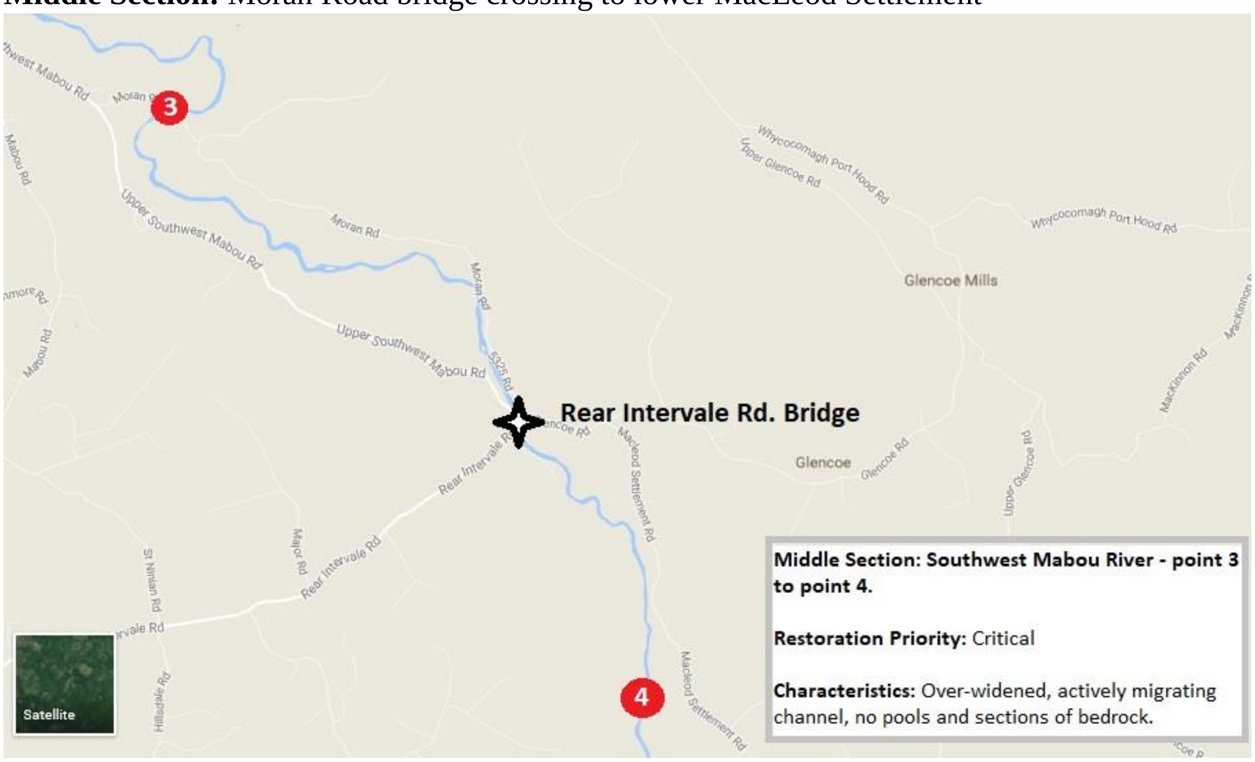


Figure 21: Map of the middle section of the Southwest Mabou River.

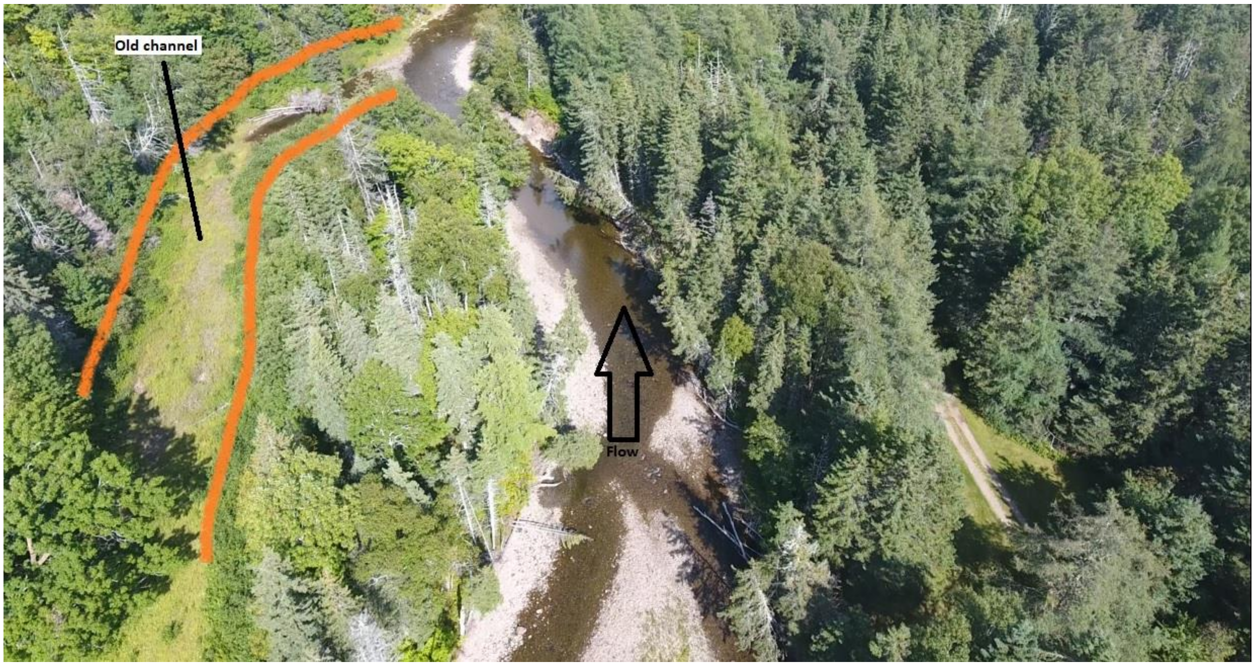


Figure 22: 500 meters Above Moran Road bridge, severe channel migration caused by over-widened channel above.

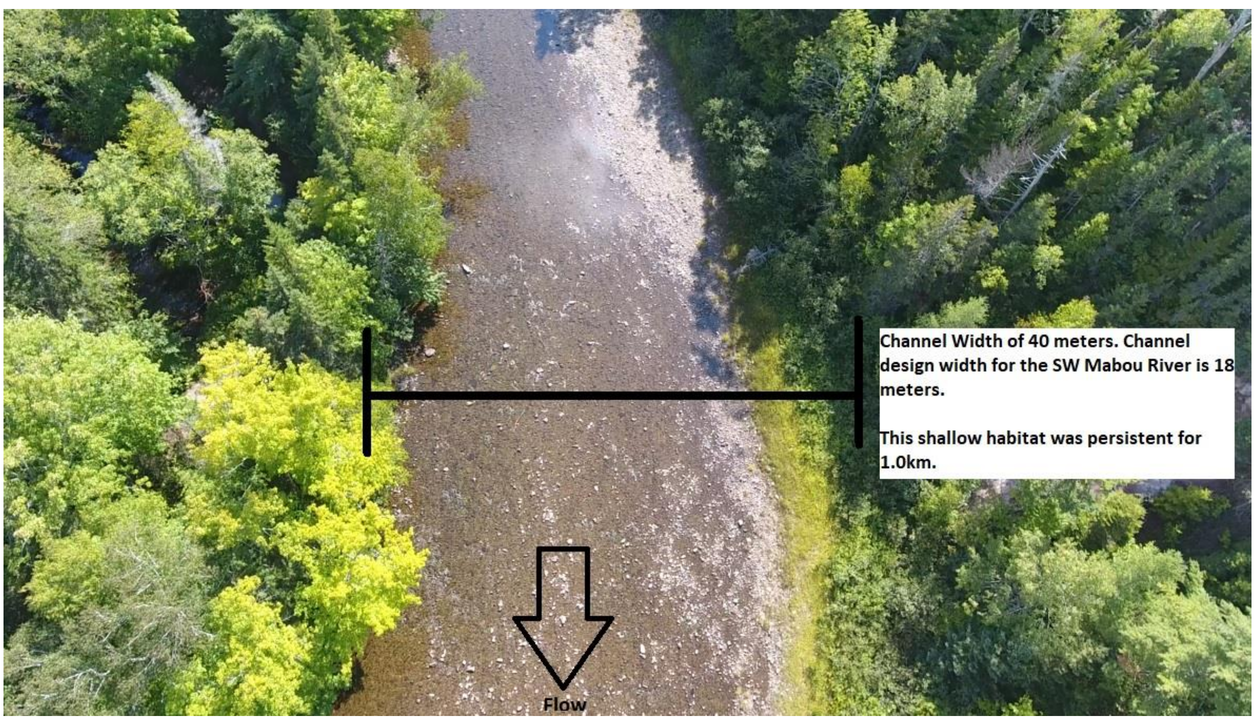


Figure 23: 1.5km above Moran Road bridge.

Figure 24: 2.5km above Moran Road bridge. Note - severe channel migration because of incised upstream habitat.

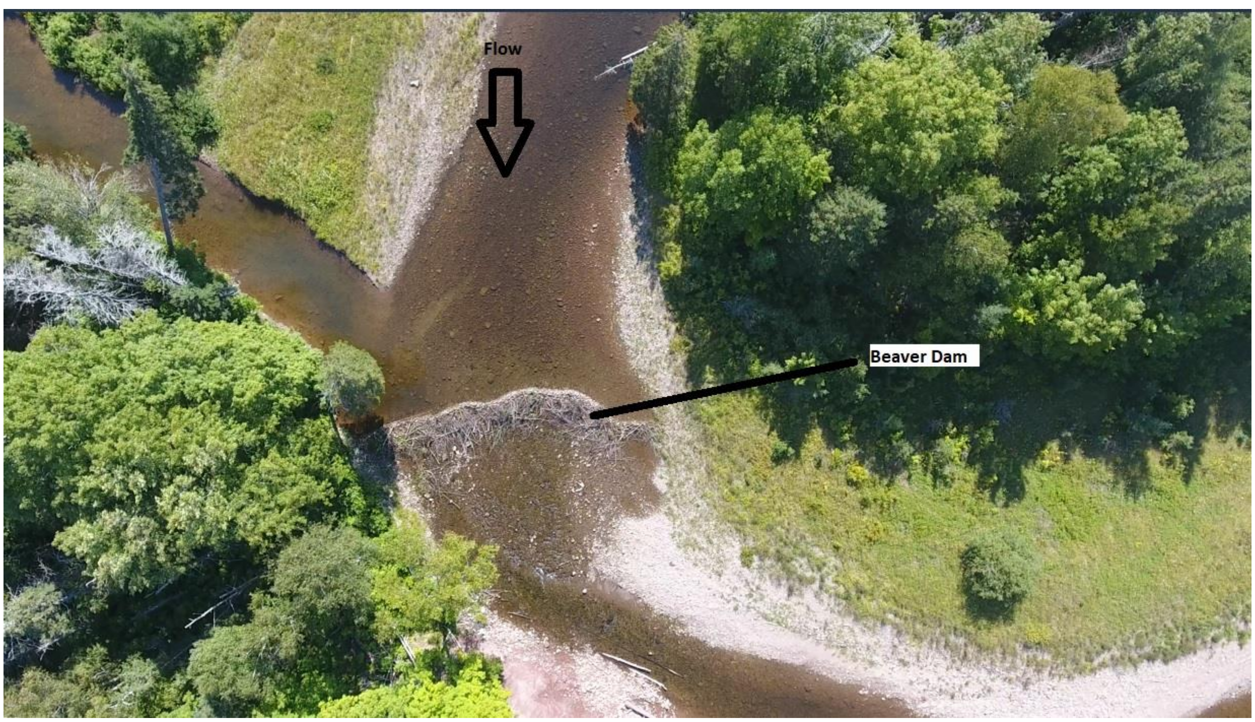


Figure 25: 3km above Moran Road bridge. This beaver dam is facilitating the natural deposition of sediment and is protecting the eroding bank downstream. Recommended course of action – leave.

Figure 26: 3.5km above Moran Road bridge. Channel lacks meander pattern and is over-widened (Upstream view).

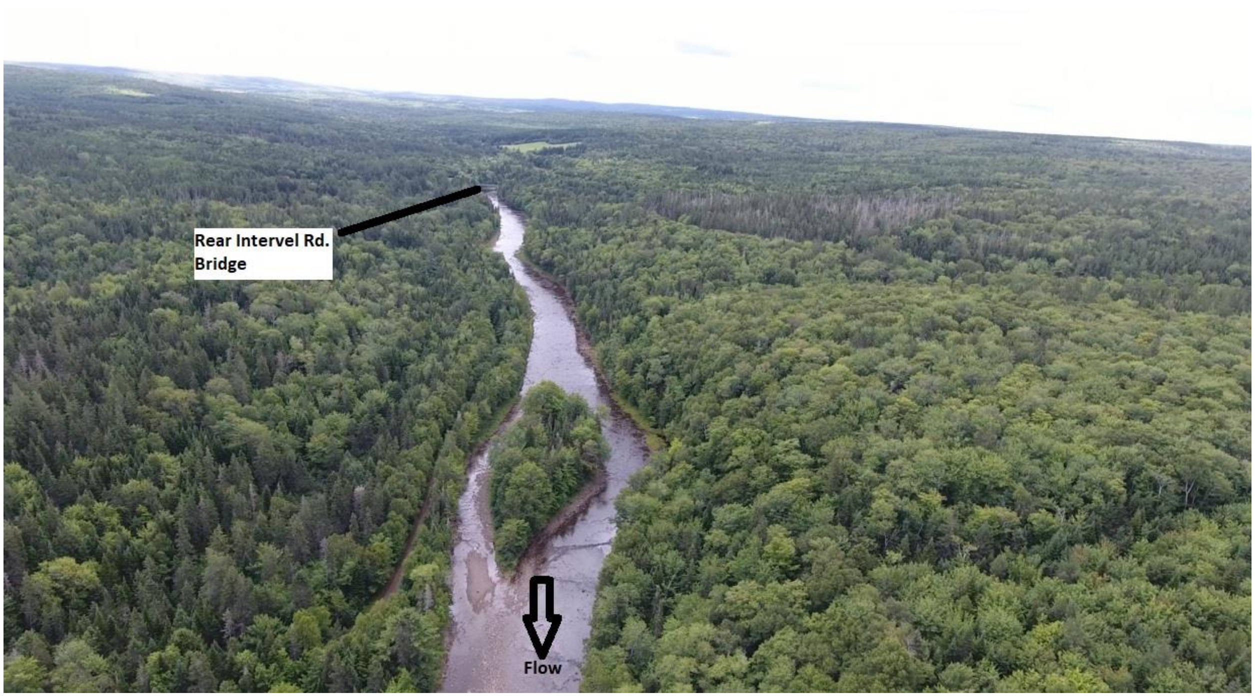


Figure 27: Looking upstream towards Rear Intervale Rd. bridge. Channel is over-widened, and the bottom substrate is predominantly bedrock for over 1km. This section of stream is easily accessible by heavy machinery.

Figure 28: Downstream view below Rear Intervale Rd. Bridge. Channel lacks meander pattern, is over-widened and heavily bedrock laden.

Upper Section: MacLeod Settlement to headwaters

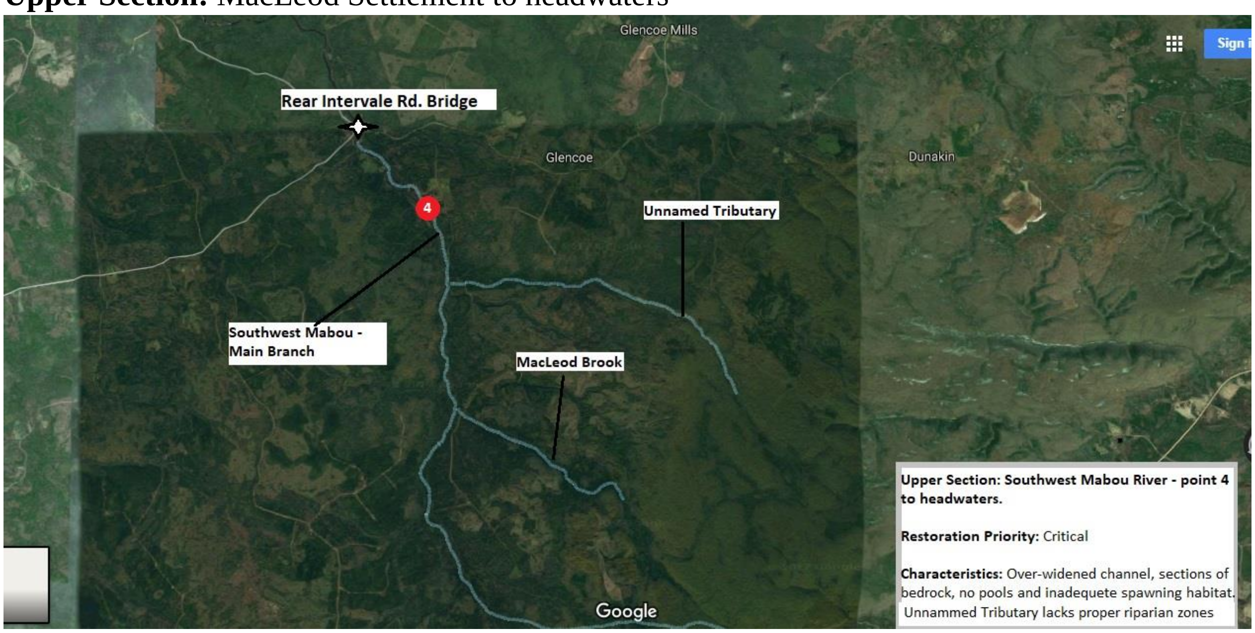


Figure 29: Map of upper section, including two tributaries

Figure 30: Unnamed Tributary (MacLeod Settlement). Riparian zone loss from recent forestry activity. 45.562751, 61.218869

Figure 31: Unnamed Tributary, eroding banks and mobile substrate. Riparian zone loss.

Figure 32: Unnamed Tributary - Highly-mobile substrate, freshly deposited below riparian zone loss.

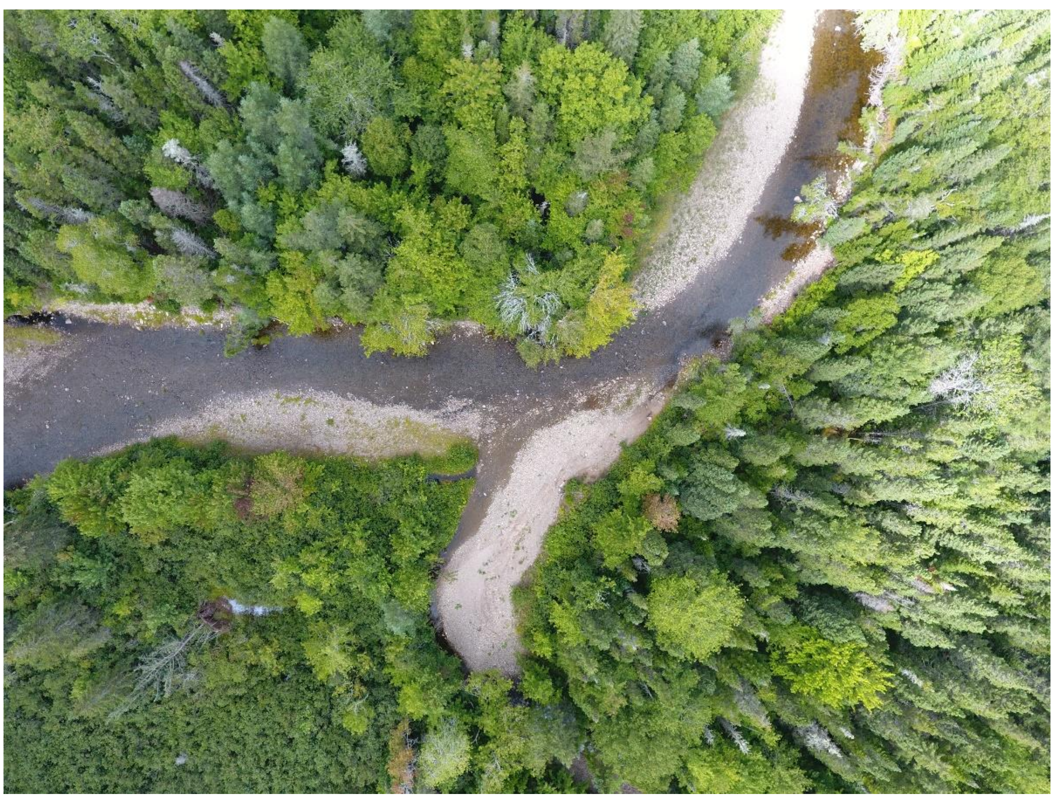


Figure 33: Confluence of unnamed tributary and Southwest Mabou.

Figure 34: Unnamed tributary confluence – note the sedimentation from upstream erosion.

Figure 35: MacLeod Brook crossing. (Culvert requires fish passage remediation)

Figure 36: Fish passage barrier - MacLeod Brook (Looking downstream)

Figure 37: Culvert (Looking upstream) - Remediation required for fish passage

Figure 38: MacLeod Brook (looking upstream). Adequate riparian zone, habitat degradation persists from historical land use.

Figure 39: One kilometer upstream from culvert. Good riparian zone, habitat is lacking pools.

Figure 40: Confluence of MacLeod Brook and Southwest Mabou River

Figure 41: Upper Southwest Mabou (looking downstream) in MacLeod Settlement. Note the channel is over-widened and lacks a meander pattern.

Cumulative Impact Assessment

Short-run mountainous streams, such as the Southwest Mabou River, are often highly degraded because of cumulative alterations to the watershed landscape (Wohl, 2000 and 2005, Rosgen, 1994). Cumulative impact assessments are used to understand the accumulation of change on the landscape due to multiple stressors (natural and manmade) over scales of time and space and from a predictive and retrospective position (Dube et al., 2013). Understanding past developments and persistent impacts is an appropriate starting point for any restoration project.

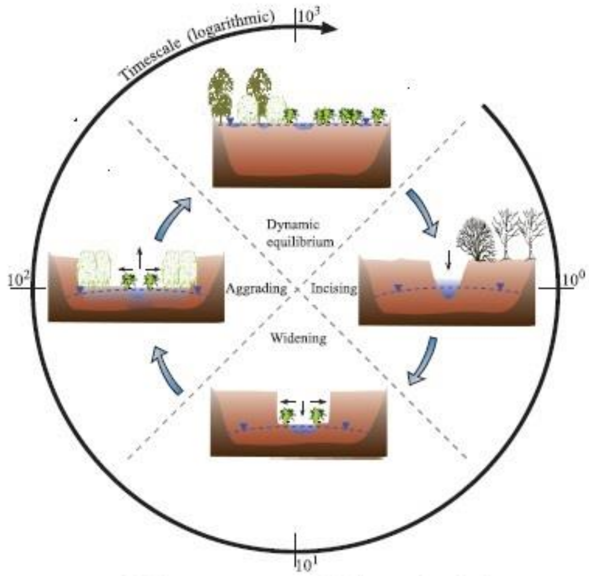
In the Southwest Mabou River historical developments since European settlement in the early 1800s have and continue to contribute to in-stream habitat degradation. The clearing of the uplands for farming and forestry by early settlers is likely the most detrimental and persistent impact in the watershed. The removal of the old-growth forest that once dominated the landscape changed the rate of drainage and limited sediment retention, resulting in an over-widened, scoured and un-productive river. Atlantic salmon and other fish species in the Southwest Mabou River have declined dramatically over the last century because of human activity.

Rivers have some capacity to recover through natural processes, however the persistent impacts of human development limit the capacity for this to occur. Restoration projects must attempt to address these issues, therefore understanding the cumulative effects is a critical first step.

An aerial survey of the whole Southwest Mabou River uncovered only one biogenic river feature (e.g. beaver dams, large woody debris or live vegetation). An absence of biogenic features is indicative of an incised river channel (Pollock et al., 2014). The aerial survey and in-stream habitat assessment completed for this report in September 2017, found that the channel is predominantly incised and lacks sufficient habitat for salmonid populations.

The absence of large-woody debris is caused by a shortage of large mature trees. The native tree species such as Red Oak, Eastern Hemlock and White Pine that once dominated the landscape no longer exist. The establishment of early successional species such as poplar and fir are likely to create the same natural processes produced by the old growth forest species. Over-time, the absence of large woody debris has contributed to the over-widening and scouring of the streambed. As the channel widens, the likelihood of large-woody debris jams forming decreases significantly.

The lower reaches of the river were completely void of beaver dams, except one located a kilometer above Moran Road bridge (Figure 25). The development of agriculture in the rich floodplain of the middle section of the Southwest Mabou has likely caused a shortage of young vegetation used by beavers during the construction of dams. The reestablishment of natural processes will result in channel migration and wetland development – thus impacting private property and requiring changes to land use. Natural processes can be artificially produced using stream restoration techniques, allowing for land-use practices to shift slowly over-time. For an illustration on how natural processes can restore an incised channel see figure 42 below. This type of regeneration is only possible if persistent impacts have been mitigated.



A simplified stream succession model showing the cyclical nature of incision-prone stream ecosystems on alluvial floodplains. Succession is divided into four phases: rapid incision, trench widening, slow aggradation, and dynamic equilibrium. This model highlights the dominant physical processes driving each phase and the common timescales for each phase. The small arrows highlight the direction of dominant and subdominant erosion or deposition; the dashed lines indicate water table elevation. Source: Adapted from Cluer and Thorne (2014).

Figure 42: Source Pollock et al. 2014

The cumulative impacts created by the incised channel are above normal water temperatures, loss of spawning grounds, reduction in cover from predators and the long-term decline of salmonid populations. Fish passage to the upper 90% of MacLeod Brook has been limited by an improperly installed set of culverts (Figure 37). The section of MacLeod Brook above the barrier culvert contained the best trout and Atlantic salmon spawning grounds in the whole watershed. The cumulative impact of this barrier to fish passage is hard to estimate but would be substantial.

In northern climates, incised channels are prone to ice scouring during the winter and spring. Ice scouring can destroy salmonid redds and can greatly reduce egg survival (Figure 43).

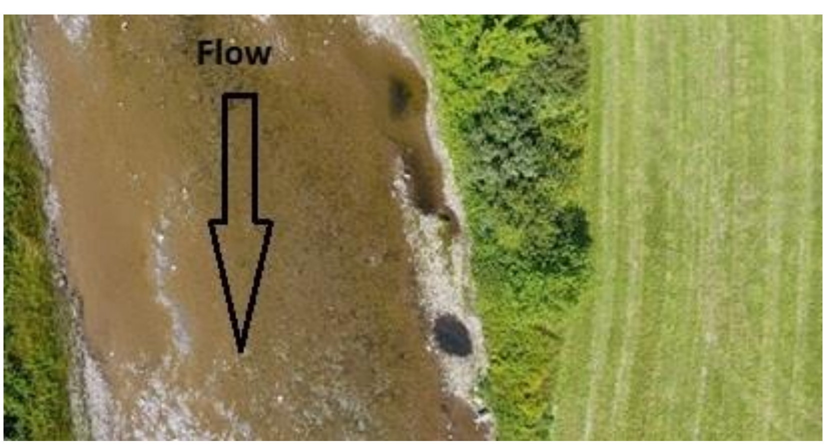


Figure 43: Ice scouring on gravel bar above Route 19

Recent forest harvesting, particularly in MacLeod Settlement will create cumulative impacts on the Southwest Mabou River and the unnamed tributary adjacent to recent activity. Bank erosion and channel adjustment were observed during a September 2017 in-stream habitat assessment. The loss of the riparian zone for 500 meters of the unnamed tributary will result in warmer summer time water temperatures, contributing to habitat degradation downstream.

It is possible that the riparian zone loss, and subsequent erosion may help mitigate downstream impacts. Downstream from MacLeod Settlement, the Southwest Mabou River is sediment starved. The introduction of restoration structures coupled with the increased erosion may facilitate streambed aggradation (sediment accumulation). Newly regenerative forest vegetation may also increase the presence of beavers, which over-time may increase the water retention capacity of the unnamed tributary. The construction of in-stream restoration structures, particularly digger logs may help mitigate recent activity and should reduce channel adjustment.

Figure 44: Actively eroding bank, downstream from unnamed tributary - MacLeod Settlement road crossing

Wohl (2004) believes that successful stream restoration requires an understanding of past river conditions and current hydrological processes. The aim of this cumulative impacts assessment is to provide those involved with the management and implementation of this restoration plan with an understanding of how past and present impacts have impacted the Southwest Mabou river. It is important to recognize that within a watershed, environmental impacts are not only additive but synergistic (Seitz et al., 2011).

Habitat Restoration

The restoration of aquatic habitat was identified by the Minister's Advisory Committee on Atlantic Salmon as one of the most important undertakings that can be done to improve salmon stocks (2015). Giller (2005) identified habitat restoration as an integral element in the conservation and management of salmon rivers and streams. The restoration of watersheds is important because "such habitat is essential for the maintenance of biological diversity, including commercially important species, and for providing other important ecosystem services such as flood control, groundwater recharge and carbon storage" (Pollock et al., 2014).

Restoration is fundamentally about enhancing ecological integrity, which can be defined as the ability to self-sustain the ecological entities (VECs) and processes (e.g. sediment transportation and water retention) (Wohl et al., 2005). There is growing evidence that the most effective and sustainable approach to restoring the ecological integrity of rivers is "to let them 'heal themselves' by facilitating or restoring the physical processes of flooding, sediment transport, erosion, deposition, and channel migration that create and maintain complex river forms" (Kondolf, 2011). In river systems with persistent impacts such as roads and agriculture land exist, restoration techniques can be used to replace natural processes.

Recommendations

The restoration of salmonid habitat in the Southwest Mabou watershed will require installation of artificial structures such as rock sills, deflectors and groynes to mitigate the persistent changes within the watershed (see appendix for structure examples). The two main tributaries that empty into the Southwest Mabou river below MacLeod Settlement can be restored using hand tools and techniques such as digger logs, deflectors and bank logs. The protection of natural structures such as debris jams and beaver dams should be prioritized as necessary steps in the restoration of salmonid habitat.

The construction of restoration structures in the main branch of the Southwest Mabou will require the use of heavy machinery. The estimated cost for this type of work ranges from $50,000 to $150,000 per kilometer restored. The costs will vary between sites and will depend on property access and proximity to local quarries. It is recommended that this work begin at the top of MacLeod Settlement. The presence of an incised channel results in increased ice production, therefore restoring lower reaches must not begin until upstream conditions have been restored. Restoring the Southwest Mabou River from MacLeod Settlement to the Route 19 bridge will likely take ten consecutive years of restoration work to complete.

It is recommended that ISAA collect baseline data of both the unnamed tributary and MacLeod Brook at the beginning of the restoration process. The NS Department of Inland Fisheries has expressed a willingness to complete baseline data collection (i.e. electrofishing) on both these tributaries. Pursuing this course of action will improve the scientific context of the restoration work. The fish passage barrier on MacLeod Brook has been identified as a critical limiting factor, remediation of this issue should be prioritized to the top of any restoration activities. We recommend having Adopt-a-Stream survey the culvert in the spring of 2018, with culvert replacement occurring by the fall of 2018 or the summer of 2019. Port Hawkesbury Paper, who manages the adjacent forest lands may be willing to partner with ISSA on this remediation.

Summary of key recommendations

- Begin restoration on the upper section of the Southwest Mabou river in MacLeod Settlement. The success of restoration efforts will be influenced by habitat conditions that exist upstream, therefore work must begin at the top of the watershed.

- Digger logs, deflectors and bank logs can be installed by the ISAA restoration crew on MacLeod Brook and the unnamed tributary.

- MacLeod Brook requires fish passage remediation, likely through a culvert replacement where the brook crosses MacLeod Settlement Road. The culvert should be surveyed in the spring of 2018 and be replaced by the summer of 2019 (Figure 36).

- Where possible, ISSA should protect and leave natural structures such as debris jams and beaver dams. The incised channel habitat found throughout the Southwest Mabou watershed requires a reduction in water and sediment velocity. Natural processes represent the most effective and cost-efficient means to achieve this.

- Riparian zones, particularly in agriculture zones should be planted with a variety of tree species to promote bank stability, thermal regulation and organic production.

- ISAA must work with NS Inland Fisheries to arrange the collection of baseline data from both tributaries surveyed in this report. This work should be completed in 2018, preferably before restoration work begins.

- The design work for each section must be completed by an experienced river restoration professional. Prior to the design stage, ISSA should obtain written permission from adjacent landowners. Restoration work may lead to channel adjustments and landowners consent should be obtained.

References

Armstrong, J. D., Kemp, P. S., Kennedy, G. J. A., Ladle, M., & Milner, N. J. (2003). Habitat requirements of atlantic salmon and brown trout in rivers and streams. *Fisheries Research, 62*(2), 143-170.

Department of Fisheries and Oceans Canada. (2012). *Stock status of atlantic salmon (salmo salar) in DFO gulf region (salmon fishing areas 15 to 18)*Government of Canada.

Dubé, M.,G., Duinker, P., Greig, L., Carver, M., Servos, M., Mcmaster, M., et al. (2013). A framework for assessing cumulative effects in watersheds: An introduction to canadian case studies. *Integrated Environmental Assessment and Management, 9*(3), 363-369.

Dunfield, R. W. (1985). *The atlantic salmon in the history of north america*. Ottawa: Canadian Special Publication of Fisheries and Aquatic Sciences.

Einum, S., Nislow, K. H., Reynolds, J. D., & Sutherland, W. J. (2008). Predicting population responses to restoration of breeding habitat in atlantic salmon. *Journal of Applied Ecology, 45*(3), 930-938.

Greig, S. M., Sear, D. A., Smallman, D., & Carling, P. A. (2005). Impact of clay particles on the cutaneous exchange of oxygen across the chorion of atlantic salmon eggs. *Journal of Fish Biology, 66*(6), 1681-1691.

Kondolf, G. M. (2011). Setting goals in river restoration: When and where can the river "heal itself". *Stream restoration in dynamic fluvial systems* (pp. 29). Washington, DC: American Geophysical Union.

MacDonald, A. D. (1952). *Mabou pioneers : A genealogical tracing pioneer families who settled in Mabou and district*. Antigonish, N.S.: Antigonish, N.S. : Formac Publishing Co.

Minister's Advisory Committee on Atlantic Salmon. (2015). *A special report on wild atlantic salmon in eastern canada*Government of Canada.

Pollock, M. M., Beechie, T. J., Wheaton, J. M., Jordan, C. E., Bouwes, N., Weber, N., et al. (2014). Using beaver dams to restore incised stream ecosystems. *Bioscience, 64*(4), 279.

Sear, David and DeVries, Paul (Ed.). (2008). *Salmonid spawning habitat in rivers: Physical controlsm biological responses and approaches to remediation*. Maryland, USA:

Sear, D., DeVries, P., & and Greig, S. (2008). The science and practice of salmonid spawning habitat remediation. In D. Sear, & P. DeVries (Eds.), *Salmonid spawning habitat in rivers* (pp. 1). Maryland, USA: American Fisheries Society.

Seitz, N. E., Westbrook, C. J., & Noble, B. F. (2011). Bringing science into river systems cumulative effects assessment practice. *Environmental Impact Assessment Review, 31*(3), 172-179.

Wohl, E. (2017). The significance of small streams. *Frontiers of Earth Science, 11*(3), 447-456.

Wohl, E. E. (2004). *Disconnected rivers linking rivers to landscapes*. New Haven: Yale University Press.

Wohl, E., Angermeier, P. L., Bledsoe, B., Kondolf, G. M., Macdonnell, L., Merritt, D. M., et al. (2005). River restoration. *Water Resources Research, 41*(10), n/a-n/a.

Appendix: River restoration techniques

Rock Sills

Rock sills support the riffle upstream of the structure and dig pools on the downstream side (DFO, 2006). They can also be constructed with deflectors and side sloping to narrow and deepen the river channel (MacInnis and Flynn, 2014). Rock sills are constructed at the head of a pool site and can be installed every six channel widths on alternating sides of the river. By alternating the direction of each successive sill, the structures can help re-establish proper meander patterns.

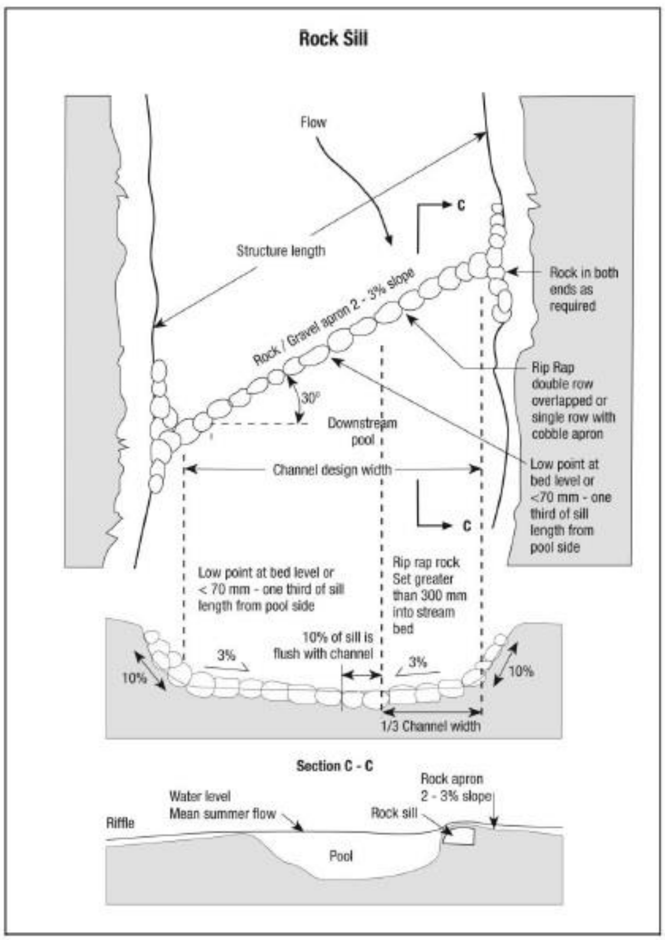


Figure 45: Rock sill design (DFO, 2006)

Deflectors and Groynes:

Deflectors and groynes are built much like a rock sill except the structure only cross a portion of the channel width. They serve to deflect water away from eroding banks and are often coupled with bank protection. Sediment often collects below deflectors and between groynes, helping to narrow the channel. Deflectors allow the restoration consultant to choose the direction that the river's energy will be directed.

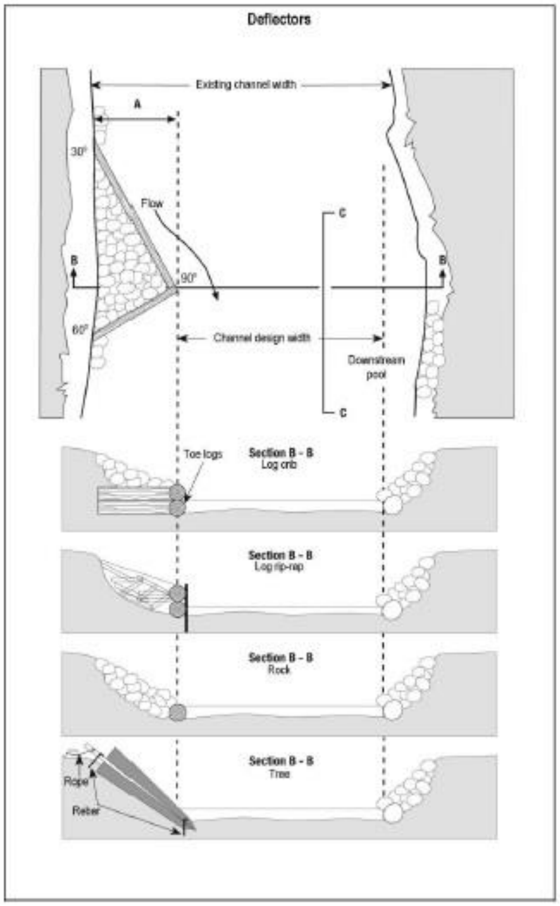


Figure 46: Example of Groyne

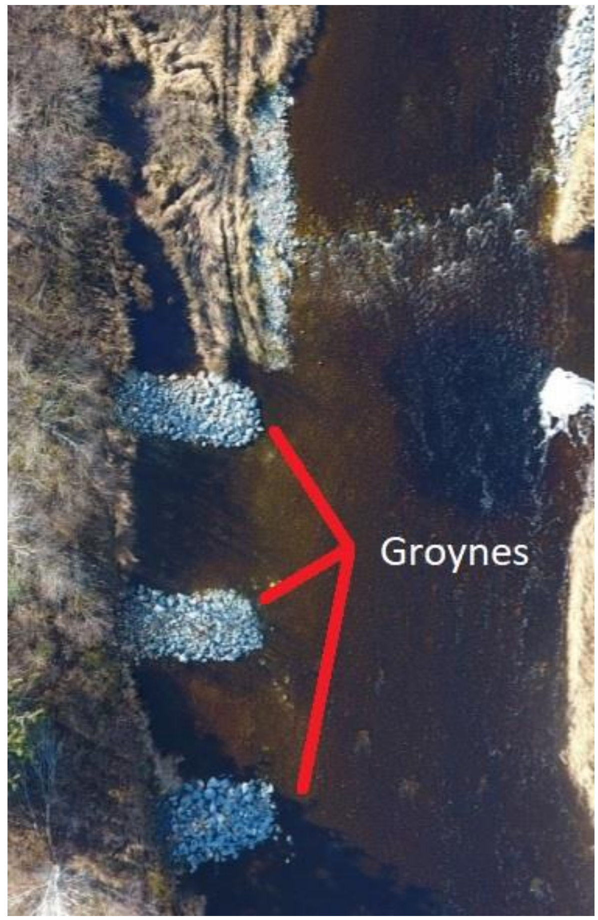


Figure 47: Deflector Design (DFO, 2006)

Figure 48: *An example of how multiple structures function in combination. Sills dig pools and groynes collect settling sediments below (Source – MacInnis Natural Resource Services Inc)*.

<u>Armour Rocking:</u>

Armour rocking is used to stabilize river banks and prevent erosion. Erosion of fine sediments leads to deterioration of salmon spawning and fry habitat. Armour rocking on the Southwest Mabou should only be completed adjacent to other types of structures such as sills and groynes.