Rehabilitation and Enhancement of Aquatic Habitat Guide

V. 1.0

by

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1.0 INTRODUCTION

1.1 Restoration and Rehabilitation

Human activities have altered the physical, chemical, and biological characteristics of a number of watersheds and as a result the subsequent habitat degradation and loss has had significant impacts on recreational fisheries. Today, people now have a better understanding about the importance of watersheds and the impacts that people can have on them. A variety of community based groups (e.g. local watershed groups), recreational fishing and angling groups, and others in the fisheries conservation field are interested in “restoring” fish habitat.

The U.S. National Research Council has defined restoration as “returning an ecosystem to a close approximation of its condition prior to disturbance” (NRC, 1992). True restoration can be extremely difficult and can usually only be accomplished by working at the watershed level. Many of the activities conducted in watersheds to improve fish habitat are, therefore, considered to be rehabilitation as most restore or improve some aspects of an ecosystem but do not restore the entire ecosystem to its condition prior to disturbance.

Examples of methods to improve the condition of a waterbody include:

- the stabilization of stream banks and shorelines;
- the addition of materials used by fish for cover, rearing, and/or spawning;
- the addition or removal of structures to allow fish passage; and
- the manipulation of water quality characteristics (e.g. dissolved oxygen, pH).

This guide and the fact sheets that are contained within it have been written to assist organizations in their rehabilitation efforts.

2.0 ASSESSMENT

To ascertain whether an area is appropriate for rehabilitation and which techniques would be useful, a thorough assessment of the area in consideration should be conducted first. This includes determining the activities in the watershed, identifying the source(s) of degradation, and identifying the degraded/limited fish habitat in the waterbody.

2.1 Historical and Current Activities in the Watershed

Both the historical and current activities in the watershed should be determined before beginning any rehabilitation project. Understanding the historical activities that have occurred in the area can help explain some of the underlying causes of the problems found in the watershed. The extent and magnitude of the changes in the watershed will impact the success of any rehabilitation project; it should be recognized that some of the observed changes may be irreversible.

Knowing the historical range of conditions that existed on the site prior to degradation can also help one determine if the desired conditions are achievable prior to starting any work. For example, it would be unreasonable to believe that a rehabilitation project will be able to significantly improve the clarity of a stream if turbidity was an issue even prior to any major development.

Current activities must also be considered as this can also help determine if a restoration technique will be successful. There may be little benefit in stabilizing a section of a stream bank if significant erosion is occurring throughout the entire watershed because of widespread urban runoff. Satellite imagery (e.g. Google Maps/Earth) can assist with the identification of some of the landscape changes that have occurred in the watershed. Table 1 provides examples of some of the activities that can occur in watersheds and the impacts that these activities may have on the waterbody and the biota itself. It should be noted that this is not a complete list and some impacts (e.g. water quality or increased angling pressure) are not included in the table as it is unlikely that smaller scale rehabilitation projects would be able to correct these types of impacts.

2.2 Identifying and Reducing or Eliminating the Source of Degradation

The first objective of any restoration plan should be to prevent further degradation of the habitat that one is trying to restore. If, for example, spawning habitat has been reduced by sediment deposition, adding additional spawning substrate would have little benefit in the long-term if the sediment deposition cannot be reduced or eliminated. To achieve long-term success, a rehabilitation project should address the causes and not just the symptoms of ecological disturbance. The cause of the degradation must be identified and eliminated or, when not possible, mitigated as rehabilitation efforts are unlikely to succeed if the source of the degradation persists.

For some sites, simply reducing or eliminating the source(s) of degradation may be enough to allow the area to naturally regenerate over time. Restoring the original hydrological properties of a wetland, for example, may be all that is needed for the native plant community to re-establish itself.

It is important to note that the source of the degradation may be difficult to identify; degradation could be due to the cumulative effect of numerous, indirect impacts (e.g. urban runoff) or from something further afield (e.g. deposition of airborne pollutants from other regions).

Table 1. List of activities that can impact waterbodies and biota (MacMillan et al., 1992).

Activity/Disturbance	Possible Impacts to Waterbody	Possible Impacts to Biota
Agriculture	Erosion from bank instability or increased runoff resulting in introduction of sediment and silt	Increased turbidity could reduce feeding success; increased egg mortality due to sedimentation of spawning habitat
	Increased inflow of sediment	Increased turbidity could reduce feeding success; reduced habitat suitability
	Loss of trees and vegetation	Loss of cover habitat
Dams, Hydroelectric Generation, Reservoirs	Altered flow regime and geomorphologic changes	Reduced habitat suitability; reduced spawning success; loss of riparian vegetation
	Altered water temperature and stratification	Reduced habitat suitability; reduced productivity; alteration in species composition
	Flow and water level fluctuations (i.e. peaking)	Reduced habitat suitability; reduced benthic productivity; dewatering and strandings of eggs and larvae
	Reservoir fluctuations	Reduced productivity in littoral zone; reduced feeding efficiency due to sediment; alteration in species composition
	Temporary or permanent blockage of fish movement (e.g. hanging culverts)	May prevent fish from accessing other habitats (e.g. feeding, overwintering); prevent or delay fish migration for spawning
	Turbine and spillway entrainment	Direct mortality; loss of migrating and resident adults, juveniles, and fry
Diversions or Water Intakes	Altered flow regime and geomorphologic changes	Reduced habitat suitability; reduced spawning success; loss of riparian vegetation
	Entrainment and impingement	Direct mortality; loss of migrating and resident adults, juveniles and fry
	Reduction in movement of fish during local movements (feeding) or migrations (spawning, overwintering)	Fish may be forced to spawn in less suitable habitat

Dredging	Removal of habitat structure	Reduced habitat and habitat suitability; reduced productivity
	Removal of substrate	Reduction in benthic production; reduced spawning success
	Temporary increase in suspended solids and siltation	Temporary reduction in primary productivity and feeding efficiency
Logging	Altered flow regime, increased peak flows, and altered channel morphology	Reduced habitat suitability; change in riparian vegetation; reduced productivity
	Erosion from bank instability resulting in introduction of sediment and silt	Increased turbidity could reduce feeding success; increased egg mortality due to sedimentation of spawning habitat
	Increased stream temperature in headwaters due to loss of cover	Alteration of fish and invertebrate community composition; loss of productivity
	Temporary or permanent blockage of fish movement (e.g. hanging culverts)	May prevent fish from accessing other habitats (e.g. feeding, overwintering); prevent or delay fish migration for spawning
Mining and Processing of Ore	Altered flow regime due to loss of vegetation, increased runoff, low flow drainage	Decreased habitat suitability and productivity
	Drainage or stack emissions can lower the pH of the water	Decreased habitat suitability; decreased benthic and fish productivity; changes in species composition; mortality
	Increased erosion and sediment inflow due to wash loads, gravel removal, loss of vegetation, grading, etc., resulting in increased turbidity and aggradation	Sedimentation of spawning and foraging habitat; increased egg mortality; reduced habitat suitability; deceased feeding efficiency; impaired movements; reduced productivity
	Loss of habitat, stream alteration for dewatering	Reduced habitat and habitat suitability; decreased reproduction; decreased productivity
	Local loss of habitat due to noise, blasting, drilling, excavation and other disturbances associated with development and operation	Loss in feeding opportunity; impaired movements; increased stress resulting in decrease in condition, disease susceptibility, gonad maturation, etc.
	Temporary or permanent blockage of fish movement (e.g. hanging culverts)	May prevent fish from accessing other habitats (e.g. feeding, overwintering); prevent or delay fish migration for spawning

Pipelines and Transmission Lines	Erosion from bank instability resulting in introduction of sediment and silt	Increased turbidity could reduce feeding success; increased egg mortality due to sedimentation of spawning habitat
Road Crossings and Access Roads	Altered flow regime	Impairment of fish movement; increased predation of fish pooled below crossing structure
	Erosion from bank instability resulting in introduction of sediment and silt	Increased turbidity could reduce feeding success; increased egg mortality due to sedimentation of spawning habitat
	Increased water levels upstream due to insufficient flow capacity of crossing structure or ice jams	Impaired fish passage; reduced habitat suitability upstream due to bank erosion; loss of riparian habitat and reduced productivity
	Loss of trees and vegetation	Loss of cover habitat
	Temporary or permanent blockage of fish movement (e.g. hanging culverts)	May prevent fish from accessing other habitats (e.g. feeding, overwintering); prevent or delay fish migration for spawning
Urban Development	Erosion from bank instability resulting in continuous introduction of sediment and silt	Increased turbidity could reduce feeding success; increased egg mortality due to sedimentation of spawning habitat
	Flow changes (high and low) and associated geomorphologic response	Reduced habitat suitability; decreased reproduction; reduced benthic activity
	Increased inflow of sediment	Increased turbidity could reduce feeding success; reduced habitat suitability
	Stream alterations and flood plain development	Reduced habitat suitability, reduced productivity
	Temporary or permanent blockage of fish movement (e.g. hanging culverts)	May prevent fish from accessing other habitats (e.g. feeding, overwintering); prevent or delay fish migration for spawning

2.3 Waterbody Habitat Survey

The waterbody should be surveyed to determine what affect the activities in the watershed are having on fish habitat (e.g. previous dredging of river has removed most of the cover and spawning habitat for fish). A waterbody may have numerous problems and it is, therefore, important to determine what the greatest issue is and focus on that first. Some rehabilitation projects may need to correct multiple deficiencies in order for a project to be effective. If, for example, spawning substrate and nursery habitat are absent in an area, both will need to be created for fish recruitment to be successful.

Some of the features that should be assessed in streams and lakes are listed in Sections 2.3.1 and 2.3.2 (Melanson et al., 2006).

2.3.1 Stream Habitat Features

Bank Stability

Bank erosion is a major input of silt that can lead to high embeddedness (amount of fine sediment surrounding coarse substrates on a streambed) in a stream, and it usually means the watercourse is unstable and realigning itself to adjust to changes in flow volumes or other disturbances.

Bank Vegetation

Bank vegetation provides a number of benefits to streams including bank stability, cover, food (e.g. insects), nutrient input, shade, etc. The amount of cover and predominant vegetation types should be noted.

Cover

Cover provides important habitat for a number of aquatic organisms. It can include areas of deep water, dark coloured waters, instream vegetation, large organic debris (e.g. logs), overhanging vegetation, unembedded instream rock and boulders, and undercut banks.

Embeddedness

The spaces between rocks and boulders in a streambed are essential habitat for aquatic invertebrates and fish (e.g. spawning, cover). Therefore, it is important that boulder, cobble, and rocks are minimally embedded (i.e. set in sand and silt; Figure 1).

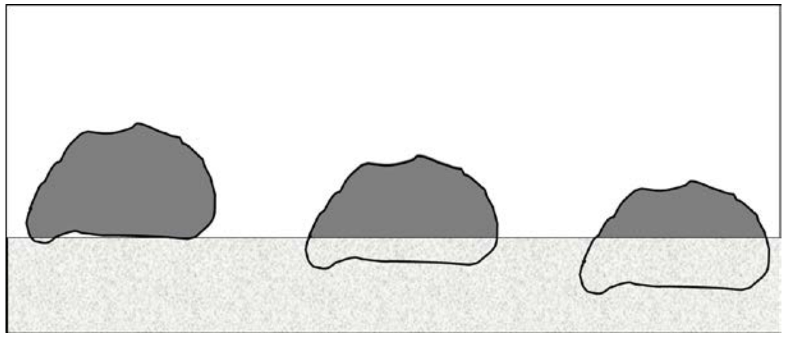
Figure 1. Examples of substrate embeddedness.

Fish Migration Barriers

There may be instances when fish movement and migration is either impeded or completely blocked in streams. Degraded watercourses can lose their thalweg (deepest part in a cross-section of the main channel of a waterway) and pool-riffle pattern. The thalweg provides fish passage during periods of low flow while pools provide important cover and resting areas during low and high flow periods. Thus, in low flow situations there may not be enough water depth for fish movement and migration, and in higher flows there may be faster velocities and nowhere to rest. Culverts, dams, debris jams, and other structures may also hinder fish passage. Problems with culverts usually occur because they are either misaligned with the watercourse or installed on an improper slope on the streambed. If these problems are not corrected, a culvert may become perched (set high off the stream bed at the downstream end), thus totally blocking fish migration.

Riffles-Pools and Step-Pools

Normal streams consist of a series of runs, riffles and pools or steps and pools (higher gradient streams). Average pool and riffle spacing varies from 5 – 7 channel widths. Pools provide cover, help regulate water temperature, aid in fish passage, and are refuges for fish during low flow periods. A lack of pools is a clear indicator that something is wrong in the watershed.

Spawning and Nursery Habitat

The type of habitat used by fish for spawning will vary greatly depending on the species present. Cobble, gravel, instream vegetation, logs, and rock are examples of the types of materials that may be used. There should be minimal embedding of the spawning substrate.
Nursery habitat is more difficult to define. In general, it can be considered to be any shallow habitat near spawning habitat that provides cover to small fish and is not easily accessible by larger fish.

Water Quality

General tests for water quality (alkalinity, dissolved oxygen, pH, temperature, etc.) are important and can help point out possible problems in a watershed.

2.3.2 Lake Habitat Features

Cover

Cover provides important habitat for a number of aquatic organisms and in lakes can include aquatic vegetation, areas of deep water, large organic debris (e.g. logs), overhanging vegetation, and unembedded boulders and rocks.

Embeddedness

The spaces between boulders and rocks in a streambed are essential habitat for aquatic invertebrates and fish (e.g. cover, spawning). Therefore, it is important that boulders, cobble, and rocks are minimally embedded (i.e. set in sand and silt). In lakes, sedimentation may occur from within the lake (e.g. shoreline erosion) or from streams depositing sediment into the lake.

Dissolved Oxygen and Temperature Regime

Dissolved oxygen and temperature can significantly affect the suitability of habitat for fish species. Lakes provide sanctuary for various fish species during the summer when temperatures are high in shallow streams and during the winter when the water levels are low due to ice formation. In most moderately deep or deep lakes, a thermocline develops that separates two distinct water temperature zones, the warmer, upper layer (epilimnion) and the cooler, bottom layer (hypolimnion). The hypolimnion becomes a refuge for cold-water species (e.g. trout) trying to find cool water during warm periods. While dissolved oxygen increases in colder water, it can become low in the hypolimnion from decaying organic matter on the lake bottom and prevent fish from utilizing this part of the lake.

Low dissolved oxygen levels can also occur in shallow lakes during the winter resulting in winterkills of fish. Lakes prone to winterkill often have up to 50% of their volume as ice and generally do not have an inflow or outflow or their inflow/outflow is frozen (Cott et al., 2008).

Nutrient Load

The amount of nutrients available in lake water directly impact the level of algae and other aquatic plants and microscopic organisms in a lake. High levels of phosphorous can cause excessive plant growth (e.g. algae blooms) and reduce oxygen levels in the hypoliminion after the algae has died and starts to decay.

pH

The pH of the water will also affect the fish population found in the lake. For most lakes, the pH ranges between 6.5 – 8.5. While some lakes may be more naturally acidic, lakes with low alkalinity can also become acidic from acidic atmospheric deposition (e.g. acid rain).

Spawning and Nursery Habitat

The type of habitat used by fish for spawning will vary greatly depending on the species present. Cobble, gravel, instream vegetation, logs, and rock are examples of the types of materials that may be used. There should be minimal embedding of the spawning substrate. Nursery habitat is more difficult to define. In general, it can be considered to be any shallow habitat near spawning habitat that provides cover to small fish and is not easily accessible by larger fish.

Shoreline Vegetation

Shoreline vegetation provides a numbers of benefits to lakes including bank stability, cover, food (e.g. insects), nutrient input, protection from wind (which can change mixing), shade, etc. The amount of cover and predominant vegetation types should be noted.

3.0 DESIGN

3.1 Feasibility

Not all rehabilitation projects are successful and some have been shown to cause more harm than good (Frissell & Nawa, 1992). Rehabilitation projects must be properly designed and located in the watercourse so that it can assist nature in restoring habitat diversity and productivity. When creating new habitat, it is important that other essential habitat is not destroyed during or after the construction of the project.

Projects fail when the physical/hydrological and biological properties of the waterbody are not sufficiently taken into account during their design and implementation. It is important to determine if the project is ecologically feasible. For example, cover habitat may be limiting in a particular section of river because flows are too high and, thus, installing cover logs in this area may yield no long-term results if they are only to be washed away during the next high flow event. Some rehabilitation projects may be complex and require the expertise of aquatic biologists, hydrologists, and/or engineers if they are to be successful. If this type of expertise is required but is not available (e.g. financial resources prohibit it), then other less complex projects should be considered. When creating instream structures it is important that you do not destroy existing habitat in the process.
The social aspects of certain projects should also be taken into consideration; the aeration of a lake during the winter might be beneficial for fish but the open water in a section of the lake might be of concern to some individuals (e.g. snowmobilers).

3.2 Sustainability

The best rehabilitation projects are ones that provide long-term results with minimum human intervention once completed. Projects that require continuous maintenance are unlikely to be as successful as the resources (labour, finances) to sustain them may not always be available.

Future activities in the watershed should be taken into consideration during the design phase of the project as it may be possible to design the rehabilitation project to withstand or even help to mitigate the effects of these new activities.

4.0 MONITORING

Monitoring before and after the completion of a project can help determine whether the goals of a project have been achieved. Many rehabilitation techniques will require some type of follow up to see how a project is performing; some minor maintenance or adjustments can be expected to be required for most projects. The area within the vicinity of the project and downstream of it should be surveyed as this can help determine if there have been any unintended consequences of the project (e.g. erosion downstream of the structure).

5.0 PROJECT PLANNING AND IMPLEMENTATION

5.1 Planning

The following is a list of the steps involved in designing and implementing a rehabilitation project:

- Determine historical and current activities in the watershed
- Determine if the watershed is degraded
- Determine the source(s) of the degradation
- Identify the specific area of the watershed to be surveyed
- Conduct survey (take photos and gather information on possible constraints of the area such as access, utilities, and staging areas)
- Determine the site-specific impact(s)
- Prioritize the impacts and the limited fish habitat
- Design a plan to rehabilitate the habitat (get assistance from experts when required)
- Make sketches and diagrams of the proposed work
- Make a list of the materials and equipment required
- Obtain permits and approvals from DFO and other federal and provincial regulatory agencies for the work if required
- Find sources (near the area and external) for the materials needed
- Obtain materials and equipment
- Select date
- Arrange to have materials, equipment, workers at the staging area on the chosen date (stage materials in advance when required)
- Implement the plan
- Take photos of the area before, during, and after the work
- Monitor habitat and adjust where necessary

5.2 Working in or near water

When implementing a rehabilitation project, the *Fisheries Act* still requires an organization to ensure they avoid causing *serious harm to fish* during any activities in or near water. The following advice will help one avoid causing harm and comply with the *Act*.

Bank Stabilization

- Design and construct approaches to the waterbody such that they are perpendicular to the watercourse to minimize loss or disturbance to riparian vegetation.
- Clearing of riparian vegetation should be kept to a minimum: use existing trails, roads or cut lines wherever possible to avoid disturbance to the riparian vegetation and prevent soil compaction. When practicable, prune or top the vegetation instead of grubbing/uprooting.
- Minimize the removal of natural woody debris, rocks, sand or other materials from the banks, the shoreline or the bed of the waterbody below the ordinary high water mark. If material is removed from the waterbody, set it aside and return it to the original location once construction activities are completed.
- Undertake all instream activities in isolation of open or flowing water, or by using other acceptable techniques, to maintain the natural flow of water downstream and avoid introducing sediment into the watercourse.
- Immediately stabilize shoreline or banks disturbed by any activity associated with the project to prevent erosion and/or sedimentation, preferably through re-vegetation with native species suitable for the site.
- Restore bed and banks of the waterbody to their original contour and gradient; if the original gradient cannot be restored due to instability, a stable gradient that does not obstruct fish passage should be restored.
- If replacement rock reinforcement/armouring is required to stabilize eroding or exposed areas, then ensure that appropriately-sized, clean rock is used and that rock is installed at a similar slope to maintain a uniform bank/shoreline and natural stream/shoreline alignment.
- Remove all construction materials from site upon project completion.

Erosion and Sediment Control

Develop and implement an Erosion and Sediment Control Plan for the site that minimizes risk of sedimentation of the waterbody during all phases of the project. Erosion and sediment control measures should be maintained until all disturbed ground has been permanently stabilized, suspended sediment has resettled to the bed of the waterbody or settling basin and runoff water is clear. The plan should, where applicable, include:

- Installation of effective erosion and sediment control measures before starting work to prevent sediment from entering the water body.
- Measures for managing water flowing onto the site, as well as water being pumped/diverted from the site such that sediment is filtered out prior to the water entering a waterbody (e.g. pumping/diversion of water to a vegetated area, construction of a settling basin, or the use of another filtration system).

- Site isolation measures (e.g. silt boom or silt curtain) for containing suspended sediment where in-water work is required (e.g. dredging, underwater cable installation).
- Measures for containing and stabilizing waste material (e.g. dredging spoils, construction waste and materials, commercial logging waste, uprooted or cut aquatic plants, accumulated debris) above the high water mark of nearby waterbodies to prevent re-entry.
- Regular inspection and maintenance of erosion and sediment control measures and structures during the course of construction.
- Repairs to erosion and sediment control measures and structures if damage occurs.
- Removal of non-biodegradable erosion and sediment control materials once site is stabilized.

<u>Operation of Machinery</u>

- Ensure that machinery arrives on site in a clean condition and is maintained free of fluid leaks, invasive species and noxious weeds.
- Whenever possible, operate machinery on land above the high water mark, on ice, or from a floating barge in a manner that minimizes disturbance to the banks and bed of the waterbody.
- Limit machinery fording of the watercourse to a one-time event (i.e. over and back), and only if no alternative crossing method is available. If repeated crossings of the watercourse are required, construct a temporary crossing structure.
- Use temporary crossing structures or other practices to cross streams or waterbodies with steep and highly erodible (e.g. dominated by organic materials and silts) banks and beds. For fording equipment without a temporary crossing structure, use stream bank and bed protection methods (e.g. swamp mats, pads) if minor rutting is likely to occur during fording.
- Wash, refuel and service machinery and store fuel and other materials for the machinery in such a way as to prevent any deleterious substances from entering the water.
- Develop a response plan that is to be implemented immediately in the event of a sediment release or spill of a deleterious substance and keep an emergency spill kit on site.

<u>Timing</u>

- Time work in water to respect timing windows to protect fish, including their eggs, juveniles, spawning adults, and/or the organisms upon which they feed.
- Minimize duration of in-water work.
- Conduct instream work during periods of low flow, or at low tide, to further reduce the risk to fish and their habitat or to allow work in water to be isolated from flows.
- Schedule work to avoid wet, windy and rainy periods that may increase erosion and sedimentation.

Timing windows may vary by province, species or watercourse, please consult the following website: http://www.dfo-mpo.gc.ca/pnw-ppe/timing-periodes/index-eng.html.

6.0 HABITAT RESTORATION TECHNIQUES

The fact sheets listed in Table 2 focus on instream techniques to restore the natural functions of an aquatic ecosystem.

Table 2. Habitat restoration techniques.

Category	Habitat Feature	Level of Difficulty	Fact Sheet
Bank Stabilization	Brush Mattresses	2	B1
	Live Cribwall	3	B2
	Live Fascine	1	B3
	Live Rock Revetment	2	B4
	Tree Revetments	3	B5
	Vegetation Planting	1	B6
Cover	Boulder Groupings	1	C1
	Half Log Cover	2	C2
	LUNKERS	3	C3
	Root Wads	3	C4
Lake Habitat Enhancements	Aeration	2	L1
	Liming	2	L2
	Spawning Shoal	2	L3
Pool-Riffle Creation and Channel Narrowing	Deflectors	5	P1
	Digger Log	4	P2
	Newbury Riffle	4	P3
	Rock Cross Vane	5	P4
	Rock Sill	4	P5
Removal of Debris and Obstructions	Beaver Dam Removal	1	R1
	Man-made Debris Removal	1	R2
	Woody Debris Jams	1	R3

*Level of Difficulty ranked on a scale of 1 to 5, 1 = easy, 5 = very difficult

6.1 Bank Stabilization

B1 - Brush Mattresses Fact Sheet

Purpose

- Primarily to minimize bank erosion by stabilizing stream banks.
- To capture sediment coming into the stream from overbank areas and during flood flows.
- To provide leaf fall and shade for fish and other aquatic organisms once vegetation has become established.

Conditions where applicable

- Earth banks experiencing minor erosion.
- Brush mattresses are not recommended for stream banks steeper than 2:1 nor should they be used on stream banks where mass wasting (downslope movement of large masses of surface material) occurs.

Habitats Created

- Provides stable banks to reduce siltation.
- Provides leaf litter and shade, and a food source for instream insects.

Advantages

- Heavy equipment may not be required.
- Looks natural.
- Provides shade and can increase primary productivity of the stream.
- Self-maintaining.

Disadvantages

- Full stabilization effect takes time to develop.
- Physical labour intensive.
- Plants may need to be replaced if they do not grow.

Design Criteria

- A brush mattress, with a live fascine and/or rock at its toe, is used along the face of an eroding bank to protect it (Figure 2).
- Suitable plants should be selected for conditions (soil type and moisture content) present at the site. Some substrates may be unsuitable for plant growth (too sandy or have too much clay). The amount of sunlight available should also be considered; willow and alder require sunlight but some dogwood and viburnum species are more tolerant to shade.

- Most woody plants cannot tolerate permanent flooding so this should be taken into consideration when brush matting an area. Look at a reference reach of the stream for the plants that are being used and determine what their lowest elevation is on the streambank. This elevation can be used as rough guide for the lower limit of brush mattress installation. The upper limit will determined by soil moisture.
- In general, the toe or bottom of the brush mattress should be at or below the mean low water level of the stream.
- Branches that are live, flexible, and dormant are buried into the eroding bank. For most regions, plants are typically dormant between September – March. The branches must be flexible enough to conform to any slope irregularities otherwise there will not be good contact with the soil.
- Ideally, the branches should be long enough that they extend from the bottom to the top of the bank selected for brush matting. If this is not possible, the branches can be placed in overlapping rows along the stream bank.
- The branches are held in place with stakes and twine. Live stakes should be used wherever possible. A live fascine and/or rock at its toe is used to help anchor the branches and provides protection from undercutting.
- The brush mattress should be a minimum of 10 cm thick.

Implementation Steps

- Collect a supply of fresh, live, flexible, dormant branches and keep moist and cold until installing. Use branches that are 2.5 cm in diameter and are about the height of the bank that is to be covered.
- Prepare live stakes and live fascines immediately before installation.
- If machinery is being used, a shallow bench about the length and height of the brush mattress can be excavated. The slope should be uniform otherwise an uneven slope could lead to poor soil-to-stem contact.
- If necessary, rip-rap can be used at the toe and at the sides to prevent undercutting and flanking.
- Dig a ~20 cm deep and wide trench for the live fascine along the entire length of the area selected for brush matting at the low level water line.
- Using stakes, loosely install the live fascine in the trench.
- Using live stakes wherever possible, drive stakes to 2/3 of their length into the slope face in a grid configuration, approximately 30 – 45 cm apart.
- The branches that make up the brush mattress should be inserted into the trench at bottom of the slope below the toe protection (e.g. live fascine bundle).
- They should be placed between the stakes at a density of 20 to 50 branches per metre. The branches may be angled so that the tops of the branches are pointed slightly downstream or a criss-crossing pattern may be used.
- If the slope face length is longer, use multiple rows of brush mattress with a minimal overlap of 50 cm (basal ends of the lower row overlapping terminal ends of the upper row).
- Wrap twine around the stakes and across the branches as tightly as possible in horizontal and diagonal runs. Use multiple pieces of twine as opposed to one continuous piece.

- Drive stakes the rest of the way into the ground to further tighten the twine.
- Lightly cover the branches with soil making sure to work the soil into the brush mattress. Fill voids between the branches of the brush mattress with loose soil to promote rooting.
- Finish firmly staking the live fascine to the ground and cover with soil, working it to ensure gaps are filled. (Note: do not cover the entire top of the fascine with soil).
- To compact the soils, both the fascine and brush mattress should be tamped gently into place and walked on. The area may also be lightly watered to further help compact the soils and ensure good soil-to-stem contact.

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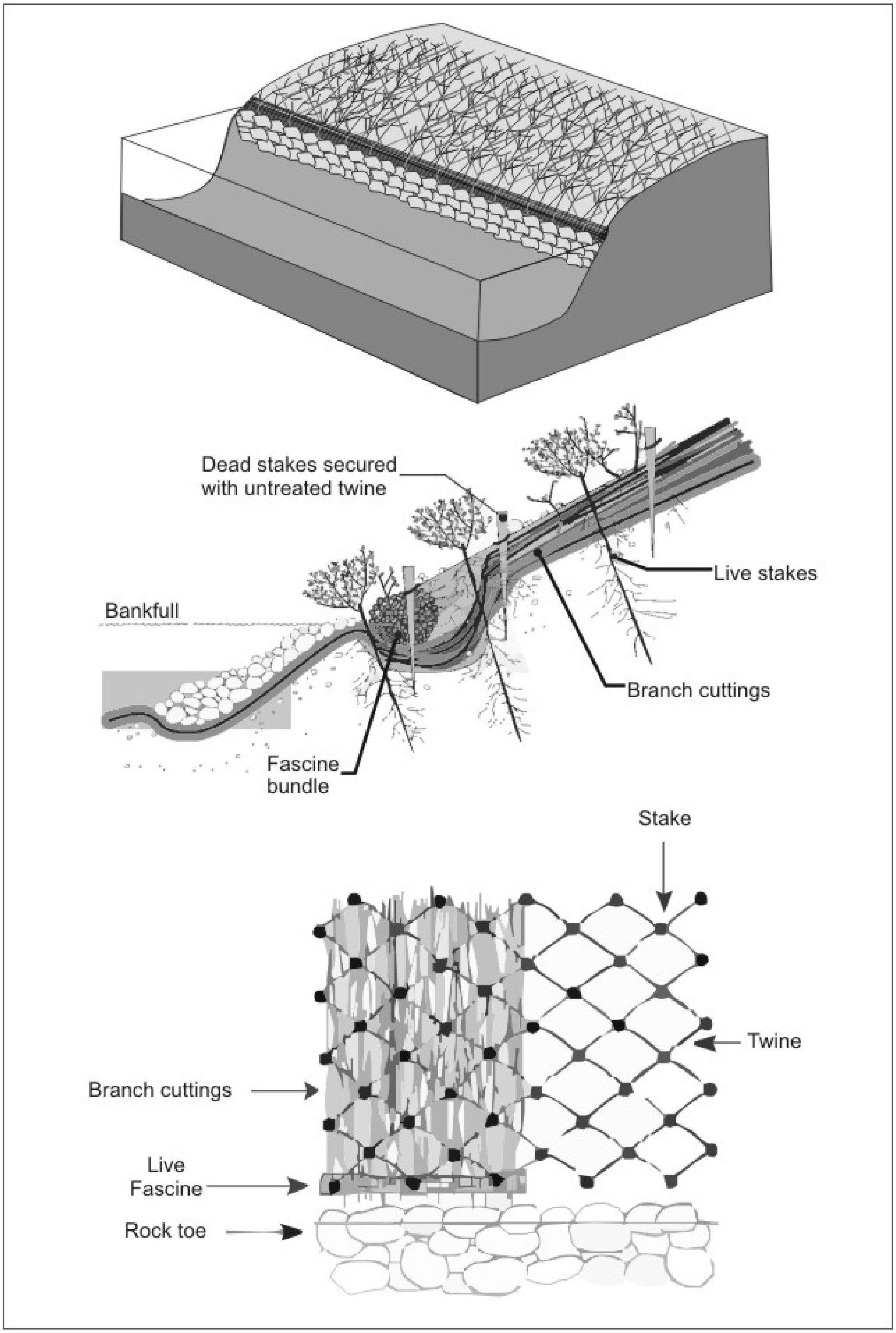

Figure 2. Drawings of brush mattresses used to protect stream bank from erosion (Modified from USDA-NRCS, n.d.a; Slaney & Zadokas, 1997; Eubanks & Meadows, 2002).

B2 – Live Cribwall Fact Sheet

Purpose

- To minimize bank erosion by stabilizing stream banks.

Conditions where applicable

- Effective for streambank stabilization on streams up to 23 m wide.
- Outside bends of streams with strong currents.
- Steep streambanks with an unstable toe of the slope.
- Should not be used in locations where the stream is down cutting because the base of the structure will be undermined.
- Should not be used in areas experiencing mass wasting (downslope movement of large masses of surface material).
- Cannot be used on sites with bedrock.

Habitats Created

- Provides stable banks to reduce sedimentation.
- Once vegetation is established, provides leaf litter and shade, and a food source for instream insects.

Advantages

- Can be used in areas where grading the bank to a more gradual slope is not possible.
- Looks more natural than other structures (e.g. rip rap).

Disadvantages

- Heavy equipment required.
- Labour and equipment intensive.
- Sedimentation may occur during construction.
- Will only last a short time (~ 5 years) unless live materials take over the structural function of the logs.

Design Criteria

- Untreated logs with a minimum diameter of 15 cm should be used to construct the cribwall structures. Species that are resistant to decay (e.g. cedar) are best. The logs should be straight and be relatively uniform in diameter.
- The cribwall structures should not exceed 6.1 m in length. They should be as high as the channel-forming flow (bankfull flow which occurs approximately every 1.5 years) but should not exceed 2.14 m without design advice from an engineer.
- Live, flexible, and dormant cuttings should be planted within the cribwall structures above the low water mark while conifer boughs or other “dead” brush can be placed

below the low water mark. These cuttings will provide some instream habitat and also protection by directing the current away from the cribwall.
- For most regions, plants are typically dormant between September – March.
- Suitable plants should be selected for conditions (soil type and moisture content) present at the site. Some substrates may be unsuitable for plant growth (too sandy or have too much clay) in which case soil should be imported. The amount of sunlight available should also be considered; willow and alder require sunlight but some dogwood and viburnum species are more tolerant to shade.
- A series of cribwalls can be used to protect an eroding streambank.
- The series of cribwalls should start at and end at areas of the bank where there is no active erosion, otherwise scouring will occur around the ends of the cribwalls.

Implementation Steps

- Collect a supply of fresh, live, flexible, dormant branches and keep moist and cold until installing. The cuttings can be 1.27 cm to 6.35 cm in diameter at the butt end and need to be longer than the depth of the cribwall (~2 to 2.44 m long).
- Obtain a supply of appropriately sized logs.
- Prior to constructing the log crib, measures must be taken to minimize stream disturbance and impacts to fish and, if necessary, isolate the work area from stream flows (e.g. dewatering and flow bypass or cofferdam). The work should be done during times of low flow.
- Excavate a large enough area for the log crib into the bank. The excavation should extend to 0.6 – 1 m below the existing streambed. The floor of the excavated area should be sloped so that it is 0.3 – 0.6 m lower closest to the bank so that the cribwall will have a batter (angle) of at least 15%. If the existing bank is significantly higher than the cribwall's design height, the bank should be excavated so that it has a slope of 2:1.
- Place two logs parallel to the streambank1.22 to 1.52 m apart within the excavated area.
- Place the second two logs on top of the others, perpendicular to and near the ends of the first course (layer). There should be about 15 cm of overhang in each direction.
- Attach the logs together with long nails (e.g. ardox spikes).
- Each successive course of logs parallel to the stream flow should be set back 15 cm to 23 cm from the log beneath it creating a stair-step effect (Figure 3).
- Continue adding alternating courses of logs up to the level of the stream's low flow. If building a series of cribwalls, construct the structures along the project's length, up to the same level.
- Place rock fill material in and around the bottoms of the structures up to the existing stream bed level. Ensure that the excavated area between the stream bed and the structures is filled with rock to protect the toe of the slope.
- Conifer boughs or brush can be installed into the openings in the face of the cribwall. This "dead" brush should extend from the footing, just below baseflow level of stream and protrude 0.5 m - 1 m into the stream.
- Fill the remaining area of the crib structures with soil up to the low flow level (i.e. up to the level constructed so far). If suitable, soil from the excavated area(s) may be used.
- Compact the soil.

- Place a row of live dormant cuttings on the compacted backfill soil. Lay the cuttings perpendicular to the flow of the stream with the bud ends protruding 30 to 60 cm out of the open face of the cribwall. The butt ends of the cuttings should extend beyond the cribwall so that their roots will eventually grow beyond the backfilled soil into the undisturbed soil.
- The cuttings should run along the entire length of the cribwall above the low flow level. The brushlayer should be as thick as the height of logs placed perpendicular to the streambank.
- Place the next course of logs, fasten, fill with soil to the top edge of these logs, and then lay the next layer of cuttings. Repeat this step until the cribwall reaches the desired height (i.e. bankfull or high water mark).
- Ensure that all waste material is removed from the work site and moved to a location where it will not re-enter the stream.
- Vegetate any disturbed areas by planting and seeding with native grasses, shrubs, or trees and cover such areas with mulch to prevent erosion and to help seeds germinate. If there is insufficient time remaining in the growing season, the site should be stabilized (e.g., cover exposed areas with erosion control blankets to keep the soil in place and prevent erosion) and vegetated the following spring.
- Maintain effective sediment and erosion control measures until re-vegetation of disturbed areas is achieved.
- During the first year, inspect the structure(s) after high flow events and then annually afterwards. The logs should be checked for proper alignment and evidence of rot. Dead vegetation above the low water mark should be replaced with new cuttings.

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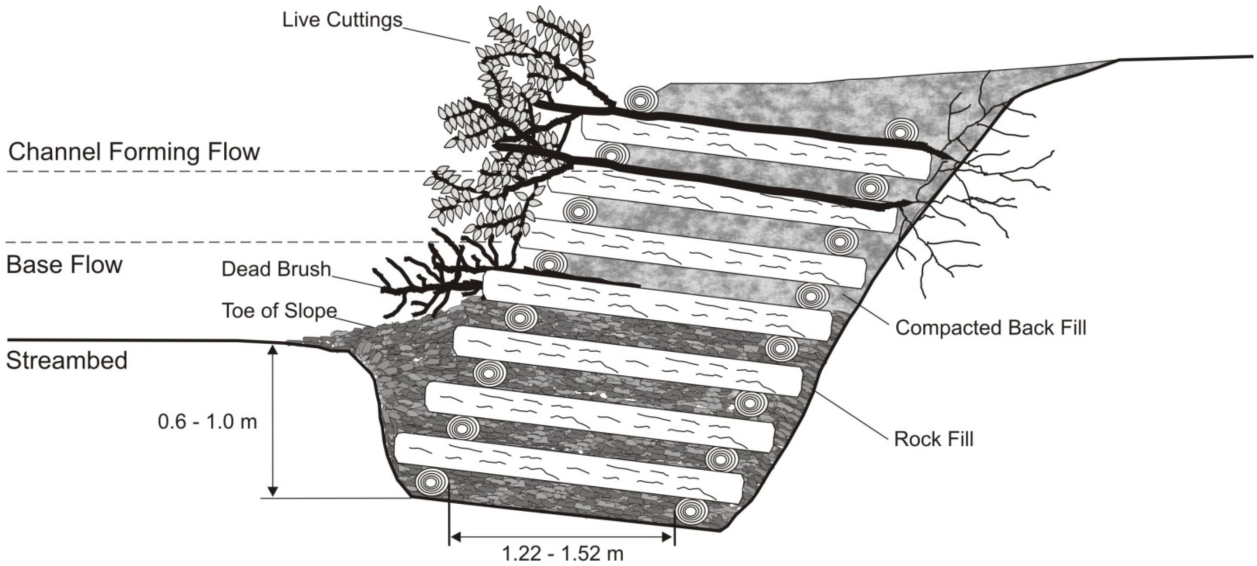

Figure 3. Drawing of a live cribwall used to protect stream bank from erosion (Modified from Ervin & Fulmer, n.d.).

B3 – Live Fascine Fact Sheet

Purpose

- Primarily to minimize bank erosion by stabilizing stream banks.
- To capture sediment coming into the stream from overbank areas and during flood flows.
- To provide leaf fall and shade for fish habitat once vegetation has become established.

Conditions where applicable

- Best suited to small streams less than 5 metres wide with bank heights less than 1.5 metres.
- Not recommended for stream banks steeper than 1:1 nor should they be used on stream banks where mass wasting (downslope movement of large masses of surface material) occurs.
- Should not be used in the stabilization of banks if the toe or base of the slope is unstable or not protected.
- Can also be used to stabilize lake shorelines with shallow slopes; the lines of vegetation that are established parallel to contour of the shore can break up the erosive force of small waves.

Habitats Created

- Provides stable banks to reduce siltation.
- Provides shade, leaf litter, and food source for instream insects once vegetation has become established.

Advantages

- Can be used with other methods (e.g. protect the toe of brush mattresses).
- Causes minimal site disturbance when properly installed.
- Cost effective.
- Encourages colonization of native vegetation.
- Heavy equipment may not be required.
- Uses local materials.

Disadvantages

- Limited areas where this technique can be used.
- Limited life span if the area does not vegetate.

Design Criteria

- Straight branches are cut from live, dormant willow, alder, or shrub dogwoods. For most regions, plants are typically dormant between September – March.
- The branches are tied together in bundles, placed in a trench, and staked into the ground (Figure 4).
- If multiple fascines are being used to stabilize a bank, this technique should only be used above bankfull discharge levels.

Implementation Steps

- Collect a variety of live, dormant straight branches (1.5 – 4.6 m long, ~1.25 - 2.5 cm in diameter). They should be relatively unbranched but can be pruned if there are multiple, hard to bend side branches.
- Unless they are used immediately, the branches must be kept moist or soaked in water until they are bundled and installed. Branches must be installed within a maximum of 48 hours after being cut.
- The branches are bundled together so that they have a diameter of 15 – 20 cm. They should be bound with untreated twine every 30 – 45 cm. The tops of the branches should be positioned in the same direction but can be staggered along the length of the bundle to increase the overall length.
- To make even longer fascines, the ends of fascines can be jammed together before placing them in the trench.
- At the base of the slope, dig a trench slightly shallower than the size of the bundle.
- Place the live fascine into the trench and cover the sides and top of the fascine with soil. The soil should be worked into the spaces of the branches. The top of the fascine should still be slightly visible when finished.
- It is important that the upstream end of the fascine is returned to the streambank otherwise the entire structure could fail. The upstream end of the fascine must, therefore, be tucked into the bank and secured very well with stakes.
- Drive dead stout stakes (60 – 120 cm long) directly through the live fascine so that the tops of the stakes are flush with the fascine. Place the stakes approximately 0.6 – 1 m apart. Where fascines have been joined together to increase the length, use extra stakes in these areas.
- Drive live stakes (5 – 10 cm in diameter 0.6 – 1 m long) into the ground immediately below the live fascine. (Note: The tops of the live stakes should be cut flat and the ends that will go into the ground can be cut at a 45^{o} angle – the buds and branches must be pointing up after planting). The stakes should protrude ~10 cm above the ground.
- Dig additional trenches at regularly spaced intervals up the bank. Depending on the level of erosion, the spacing between the rows of fascines should be between 1 – 2 m. Be sure to place a row at any ground water seepage line or spring.
- Compact the soil by walking on it and on the fascines.

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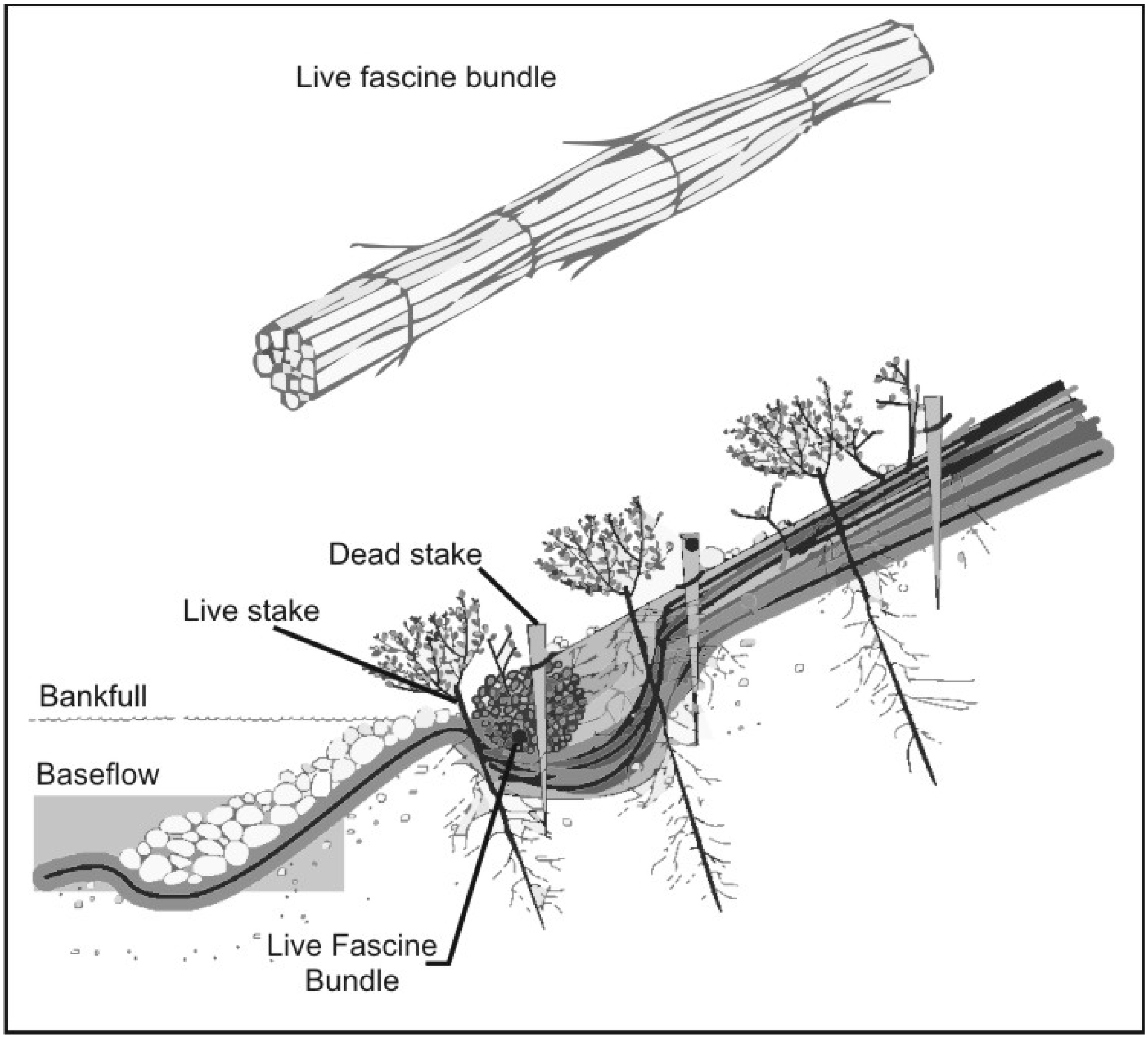

Figure 4. Drawings of live fascine bundles used to protect stream bank from erosion (Modified from Slaney & Zadokas, 1997; Eubanks & Meadows, 2002).

B4 – Live Rock Revetment (Riprap and Vegetation) Fact Sheet

Purpose

- To stabilize banks and further improve habitat by providing cover, leaf fall, and shade.

Conditions where applicable

- Where erosive forces are too strong for vegetative methods alone.
- Can be used to improve existing rip-rap structures.

Habitats Created

- Provides stable banks to reduce siltation.
- Provides leaf litter, shade, and food source for instream insects once vegetation has become established.

Advantages

- Creates a more diverse riparian habitat than typical rip-rap structures and can help control bank seepage.
- Improves bank protection by forming a root mat under the rock.
- Improved aesthetics.
- Little maintenance.
- Roughening of the surface of the rock treatment can slow current velocities and trap sediment.

Disadvantages

- Cuttings can be damaged by the rock placement.
- Cuttings have to be driven well into the soil.

Design Criteria

When constructing a live rock revetment in an existing rip-rap structure:

- Collect fresh, live, dormant cuttings (all shapes and sizes); choose species that can handle the conditions present at the site.
- In the area you want to plant, remove the rock to reach the underlying soil. If there is a layer of filter cloth, a small hole will need to be cut in it.
- Plant the bundles of cuttings, live stakes, or willow posts in the underlying soil. Place soil around the cuttings and carefully replace the rock.
- The final structure should consist of ~50% cuttings, live stakes, and/or willow posts and 50 % rock (Figure 5).

When constructing a complete live rock revetment:

- Angular quarried stone is typically recommended as the rocks fit together better, making it more difficult for the structure to be washed away. However, field stone can also work as the growing cuttings will help to hold more rounded stone in place. Avoid shales and other “soft” rocks as they can break up with the ice.
- The ability of riprap to withstand the erosive forces depends on the inter-relation of a number of variables. As conditions vary considerably from watershed to watershed and site to site, this technique should not be attempted without the assistance from a professional engineer or another qualified individual.
- Several variables (e.g. stream flow velocity, gradient (slope), and the weight of the stone) need to be taken into consideration when determining the rock size to be used. However, the following table is a general guide:

Stream Flow Velocity (m/sec)	Mean Stone Diameter (cm)
less than or equal to 2.0	8 - 11
2.0 - 2.5	11 - 18
2.5 - 3.0	18 - 22
3.0 - 3.5	22 - 23
3.5 + requires a more extensive design	

- Water velocities greater than 3.5 m/s require a more extensive design.
- Design for peak flows but construct during the low flow period.
- Rock should be placed on a well-graded slope no steeper than 2:1. The grade of the slope is determined by the site’s soil conditions.
- Riprap is generally applied at a thickness of at least 1.5 times the maximum stone size and not less than 30 cm thick.
- Extend riprap to the top of the bank or at least 0.6 m above the high flow level. This is variable depending on the river.
- The largest rocks are fitted (keyed) into the bank toe and upstream and downstream ends. The ends of the project must taper into the bank. Fitting the rock into the bank toe will require the use of a backhoe to either push the rock into a soft substrate or dig into a hard substrate to fit rock beneath the stream bed.
- Failure of the structure can result from improper grading, rock size, length of structure, installation methods, and failing to "tie" the structure into the bank at a critical location. Critical locations include the bank toe and upstream and downstream ends of the structure. An experienced backhoe operator is a great asset in combating these problems.
- Any displaced rock should be repaired immediately.
- Cuttings, live stakes, and/or willow posts can be planted during or after the placement of riprap but care must be taken to avoid damaging the plants when placing rocks. It is important that the cuttings, live stakes, and/or willow posts are embedded in the underlying soil. They should be distributed throughout the entire rip rap structure.
- The final structure should consist of ~50% cuttings, live stakes, and/or willow posts and 50 % rock.

Implementation Steps (for complete live rock revetment):

- Prepare the site.
- Clear area of debris.
- Collect fresh, live, dormant cuttings (all shapes and sizes); choose species that can handle the conditions present at the site.
- Grade banks to the recommended slope.
- Construct the toe of the riprap to the low water mark.
- Dig out the toe trench.
- Install any seepage drains required.
- Place the riprap and plant cuttings, live stakes, or live posts amongst the rip rap.
- If the layer of riprap is not too thick, it is possible to drive the stakes or live posts between the rocks and well into the soil.
- Riprap can be placed by hand or by machine. Riprap should be placed to its full thickness in one operation.
- If rock is placed under water, the riprap thickness should be increased 50 % over that above water.
- Blend or "feather" the ends of the riprap section into the upstream and downstream banks.
- A vegetative cover should be established on any areas that were graded but not covered with riprap or cuttings, stakes, and posts.

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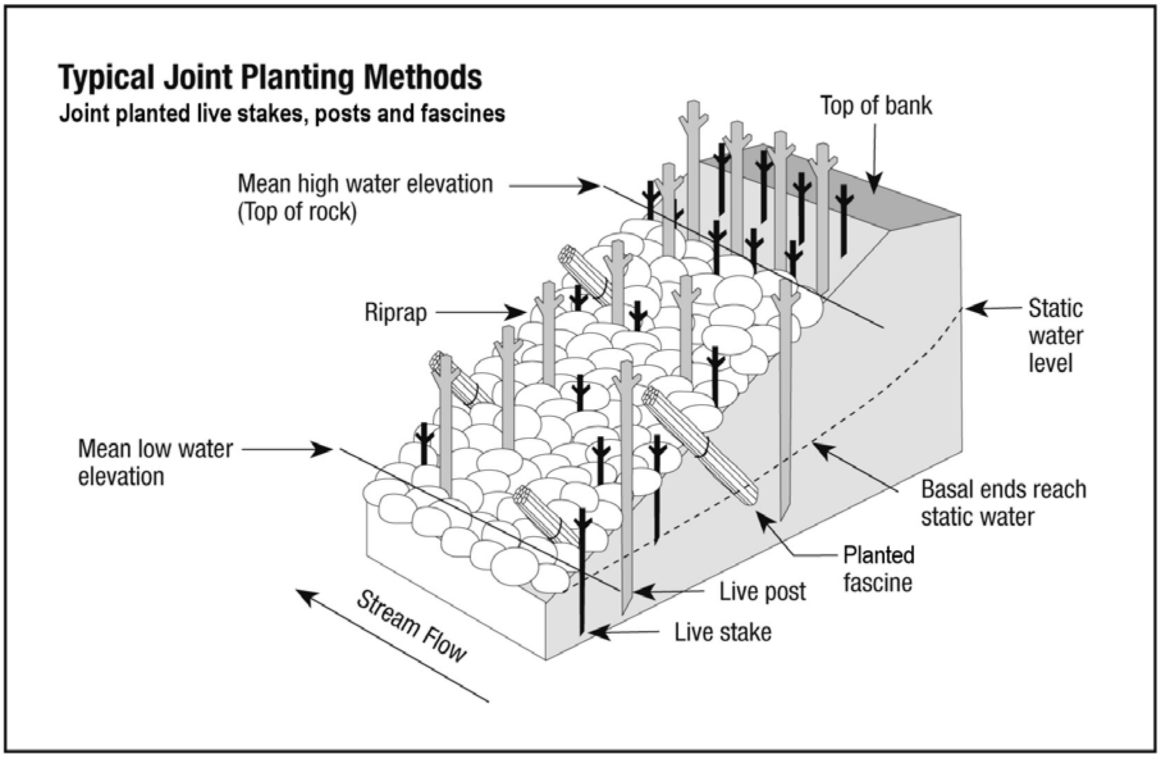

Figure 5. Drawing of live rock revetment to reduce stream bank erosion (Slaney & Zaldokas, 1997).

B5 - Planting Vegetation Fact Sheet

Purpose

- To stabilize stream banks, thereby reducing erosion and resulting sediment deposition.
- To regulate stream flow and temperature (larger trees) and to reduce sediment deposition from surface water runoff.
- To provide overhead cover for fish and food and habitat for insects.

Conditions where applicable

- Areas where streamside vegetation has been removed by human activities (e.g. agriculture, logging, and urbanization), trampling of by livestock, or through natural processes.

Habitats Created

- Provides leaf litter and food source for instream insects.
- Provides overhead cover and shade.
- Provides stable banks to reduce siltation.

Advantages

- Attracts wildlife and insects species that provide food for fish.
- Can control erosion and may reduce flooding.
- Easy to complete and costs are relatively low compared to other techniques. One of the most economical and most effective means of soil stabilization.
- Heavy equipment is not needed unless grading is required.
- Natural appearance.
- Self-renewable.

Disadvantage

- May result in the colonization of certain undesirable weed species or in the introduction of exotic plant species.
- Limited times of year (i.e. spring or fall) that this technique can be used.
- Restricts other land use possibilities (e.g. reduces land available for agriculture).

Design Criteria

- The area within the vicinity of the site should be surveyed to determine which vegetation species are present along the streambanks. Note: a reference reach can be surveyed instead if necessary.
- The drainage conditions, high water levels, soil type, sun direction, water salinity (if applicable), and wind direction must be considered prior to selecting the species to be

planted. It may be necessary to seek professional advice from a biologist or district forester when selecting plant species.

- Potential saturation of riparian soils can be predicted from data on seasonal water level fluctuation documentation. Visual inspection of soils, and comparison with adjacent soils and the vegetative communities that they support can help determine the suitability of the soils for different plant species.
- Streamside vegetation should generally consist of a mixture of grasses, shrubs and trees.
- The plants selected should be perennial species that provide good substrate stabilization. They should also be native plant species that have been used successfully in the past and that will grow and develop into a plant community that strongly resembles natural riparian communities within the project area.
- The best time for planting is generally the early spring after frost. Fall planting can be done successfully only in light, open soils, when planting stock have dropped their leaves (have become dormant).
- Grasses and legumes should be seeded first. Legumes supply nitrogen to the soil and consequently enhance the establishment of other plants. Legumes should be planted in the spring as they do not become established after mid-August.
- Grasses and shrubs should be planted closer to the edge of the bank while trees should be planted further back. Shrubs will provide more stabilization of the soils while trees will shade the stream.
- For stabilized banks with retaining walls, the area in front of the base of the wall should be planted unless it is below the low water level.
- The lower bank may need to be protected in order to prevent undercutting of the vegetated upper bank. Methods such as live fascines or tree revetments can be used.
- After seeding/planting, mulches should be used to minimize seed and soil loss from rainfall, surface water runoff, and wind and to help to retain soil moisture and limit weed growth.
- Temporary bank protection (i.e. blankets/mats) may be needed to limit bank erosion until plants have grown to an effective size.
- If erosion of the bank is so severe that the soil treatments mentioned would not adequately reduce erosion to the point of allowing vegetation to become established, more substantial structures can be used.
- Invasive, non-native species should not be used in a restoration project and it is important that care is taken not to unintentionally introduce these species.

Implementation

- Survey the area to determine which vegetation species are present along the streambanks.
- Select the appropriate vegetation to plant based on the site conditions and the species present. Consult a professional if required.
- If the shoreline is not at an acceptable slope (minimum of 2:1), grade the bank or stabilize it prior to seeding/planting.
- A soil test should be completed for the site. If the soil does not have adequate drainage, organic content, or nutrients, the soil should be conditioned or subsoil and topsoil should be placed on the site prior to seeding/planting.

- The soil should also be cultivated before seeding/planting.
- If the lower bank needs to be protected from undercutting, install live fascines or some other revetment.
- A mixture of native grasses, legumes, and fertilizer should then be spread on site by a hand cyclone or for larger areas by hydroseeder in the early spring and then mulch should be added.
- Erosion fibre mats can be used to increase substrate stability and hold seeds in place until the plants become established.
- Cuttings for most riparian shrub species may be used to establish shrub species along the banks. In most, cases straight cuttings can be used. For some hardwoods that are more difficult to get to root, heel cuttings (small section of older wood is included at the base of the cutting) or mallet cuttings (an entire section of older stem wood is included with the cutting) should be used.
- The first 2 to 3 m above the high water level should be planted with species resistant to flooding and ice damage (e.g. alder, sweet gale, and willow).
- Trees and other shrubs should be planted further back from the stream. Trees and shrub stock may need to be ordered in advance (at least six months ahead of time).
- Shrubs should be planted at a density of 1 shrub per m^2 while trees should be planted at a density of 1 tree per 5 m^2. Avoid planting shrubs and trees in straight rows.
- The best time to plant will be the early spring, while plants are still dormant and the frost is out of the ground. Alternatively, shrubs and trees may be planted in the early fall when the plants have become dormant. The site must be prepared (soil ameliorated/cultivated) prior to planting.
- Mulch should be placed around shrubs and trees.
- Fence the planted area if it is prone or is at risk to trampling by livestock, people, or vehicles.
- The area should be inspected and tended (e.g. prune, thin, add mulch) over the first three years and dead trees and shrubs should be replaced.

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B6 - Tree Revetments Fact Sheet

Purpose

- To reduce streambank erosion by slowing the current along the bank and protecting the toe of the bank, capturing sediment within and behind the tree revetment, and enhancing conditions for planting or colonization of native species.

Conditions where applicable

- Typically used on the outside bends of small to medium streams that are experiencing erosion due to the removal of trees and other vegetation.
- If a streambank has plenty of trees and other riparian vegetation and it is still eroding then another technique should be selected as it is unlikely a tree revetment will provide long-term stabilization of the bank.
- It should not be used upstream of bridges or other structures where there is potential for damage or debris jams should the revetment dislodge.
- It should not be used if the streambank toe is more than 0.75 m below the waterline as undercutting may occur.
- Should not occupy more than 15 % of a channel’s cross sectional area at bankfull level.

Habitats Created

- Reduces siltation of habitats.
- Encourages deposition of sediment in and behind tree revetment allowing vegetation to colonize or to be planted along the streambank.
- Once vegetation is established, it will provide leaf litter, shade, and a food source for instream insects.

Advantages

- Provide good protection from bank erosion and instream cover during high flow periods.
- Uses inexpensive, readily available materials.
- Captures sediment and enhances conditions for colonization of native species particularly on streams with high bed material loads.

Disadvantages

- Large trees must be cut down.
- Moving large trees requires heavy machinery.
- Wire anchoring systems can present safety hazards.
- Might be severely damaged by ice flows.
- Unless vegetation becomes established within and behind the tree revetment, the tree revetment will have a limited life and must be replaced periodically.

Design Criteria

- Live trees should be used as dead ones are more prone to breaking.
- Trees should be tall (>6 m) and have a large crown with lots of limbs and fine branches; the crown should be about 2/3 of the height of the eroding bank that is being stabilized.
- Species that are resistant to decay (e.g. cedar) are best because they extend the establishment period for planted or colonizing species that succeed them.
- Work best on streams with stream bank heights under 3.7 m and bankfull velocities under 2 m/s.
- Tree revetments should start and end on portions of the streambank that are not eroding otherwise erosion may continue or possibly increase (Figure 6).
- Each end of the tree revetment should be returned or tied into the streambank.
- Trees must be anchored at the toe of the eroding streambank. If the tree revetment is set too high on the bank, then undercutting may occur and if it is placed too far out in the channel, erosion of the bank will continue behind the tree revetment.
- Tree revetments should be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerated source of streamside vegetation.

Implementation Steps

- Tree revetments can be installed at any time of the year but late winter and early spring are best. If coniferous trees are used, the tree revetments will be able to capture silt and sand during the spring runoff and then vegetative plantings can be completed later in the season.
- Obtain whole, freshly cut coniferous trees (e.g. cedar). Otherwise, needles may fall off prematurely and this will reduce the effectiveness of the structure.
- After felling the trees, the portion of the trunk that does not have limbs may be removed to make the trees more manageable to handle (less weight).
- If necessary, trees can be trimmed on their bank side for better positioning along the streambank.
- The easiest way to conduct tree revetment assembly is by starting at the downstream limit of the tree revetment and progressing upstream.
- The trees should be positioned so that their trunks are pointing upstream (downstream-oriented structures have also proven successful).
- The top of the tree should be anchored with galvanized cable tightly to the toe of the bank so it cannot move. Four typical anchor types that could be used are arrowhead anchors, duckbill anchors, disc anchors, and steel fence posts.
- Position the next tree so that its top is overlapping the base of the trunk by a minimum of 1 m; there should not be any gap between the trees.
- A second anchor should be driven into the bank beside the trunk of the first tree and the top of the second one. A cable is used to secure the trees together and to the toe of the bank.

- This process is continued upstream until the entire eroding bank has been covered with trees.
- Once there is sufficient sediment within the area of the tree revetment, plant live stakes, shrubs, trees, etc.

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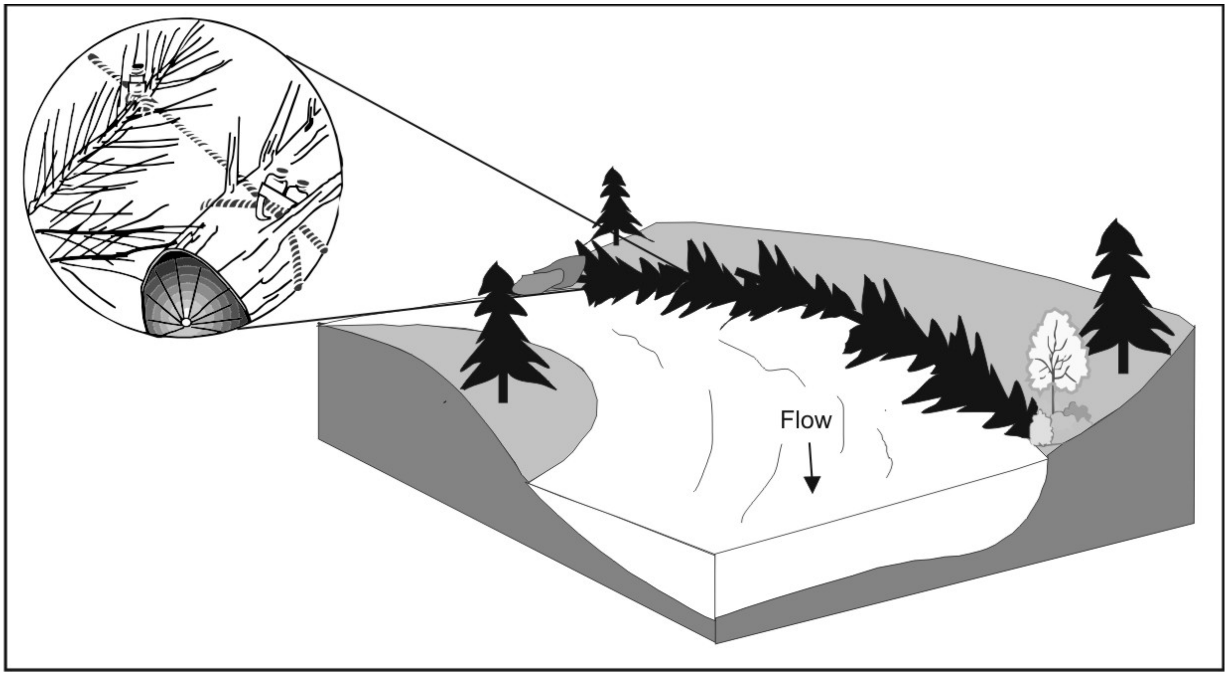

Figure 6. Drawing of tree revetments to protect stream bank from erosion (Modified from FISRWG, 1998; LCSMC & USDA-NRCS, 2002).

6.2 Cover

C1 - Boulder Groupings Fact Sheet

Purpose

- To accelerate, slow, or break up the current.
- To provide overhead and lateral cover and resting areas for fish.
- To increase the scour in pools.

Conditions where applicable

- Most effective in moderately wide, shallow streams with cobble beds or gravel but can be used in deeper streams to create cover.
- The substrate should be stable; it should not be used in unstable channels consisting of fine gravel or sand that is prone to shifting or in streams where ice scouring and flooding are an issue.
- Should not be used streams with average flows <0.6 m/s as scour pools cannot be developed.
- Should not be used near banks susceptible to erosion.

Habitats Created

- Adult holding sites.
- Fry, juvenile, and adult cover.
- Removes sand and silt from substrates and improves insect habitats.
- Scour pools for summer and winter low flow refuges.

Advantages

- Increase available cover habitat for fish.
- Improves the suitability of substrate for aquatic invertebrates.
- Looks natural.

Disadvantages

- Boulders placed near banks can cause erosion if the substrate is not stable.
- Boulders may become buried over time.
- Can be a hazard to navigation.
- Large boulders must be moved with machinery.
- Placement of boulders is labour intensive.
- Expensive if boulders are not available near the area selected for improvement.

Design Criteria

- Map out the section to be improved, detailing the depths and main current.
- Angular boulders are preferred and should be sized so that they remain stable at bankfull flows.
- Boulders are generally place in or near the thalweg if they are used for parr and adult cover.
- Boulders should occupy <10% of flow area at bank-full flow.
- Boulder size depends on the size of the stream and application and, therefore, can range from 0.3 m to 1.5 m in diameter. Boulder diameters should be no more than 1/8 the width of the stream.
- When placing boulders in clusters, 3 – 5 boulders should be used in a triangular configuration and should typically be separated by approximately one boulder diameter.
- Boulders should not lie in the wake of an upstream boulder; the downstream boulders should be placed at the periphery of the wake created by an upstream boulder (Figure 7).
- Boulder clusters placed in the same section of stream should be set a minimum of 1/3 of a stream width apart.
- Boulder clusters should not be placed in areas where they may impact or alter existing habitat features, such as riffles.

Implementation Steps

- Transport the boulders to the project site and stockpile them near the river.
- Finalize patterns and locations for rock placement.
- Works should be carried out during mid-summer low flows.
- Begin placing the boulders at the downstream end of the project and work upstream.
- Larger boulders can be carried on a rock stretcher.
- Place boulders on a substrate relatively free of larger rock and set them into holes in the stream bed at a depth of approximately 1/3 of their diameter. If significant scouring is expected, they should be placed on footer rocks and the boulders should be offset in the upstream direction.

Riffle areas

- Boulders are placed in the thalweg in a staggered fashion approximately 1 m apart.
- Boulders should be placed at the mid-point or tail of a riffle never at the crest.
- Boulders should be 25 to 35 cm in diameter.

Deep runs and pools

- Boulders can be 1 m or more in diameter.
- In a deep run, they are sized so that the top of the boulder is at the surface of the water in low flow and set in or adjacent to the thalweg.

- In pools, boulders can be set in clusters in or adjacent to the thalweg.

Fry habitat

- The intent is to create pockets of dead water along the outside edge of pools.
- This technique should only be used in rivers with 50 % or greater pools or on still waters.
- Place a large boulder (up to 60 cm) along the outer edge of the flow so that it is just breaking the water surface in low flow. Boulders are placed one boulder diameter apart.

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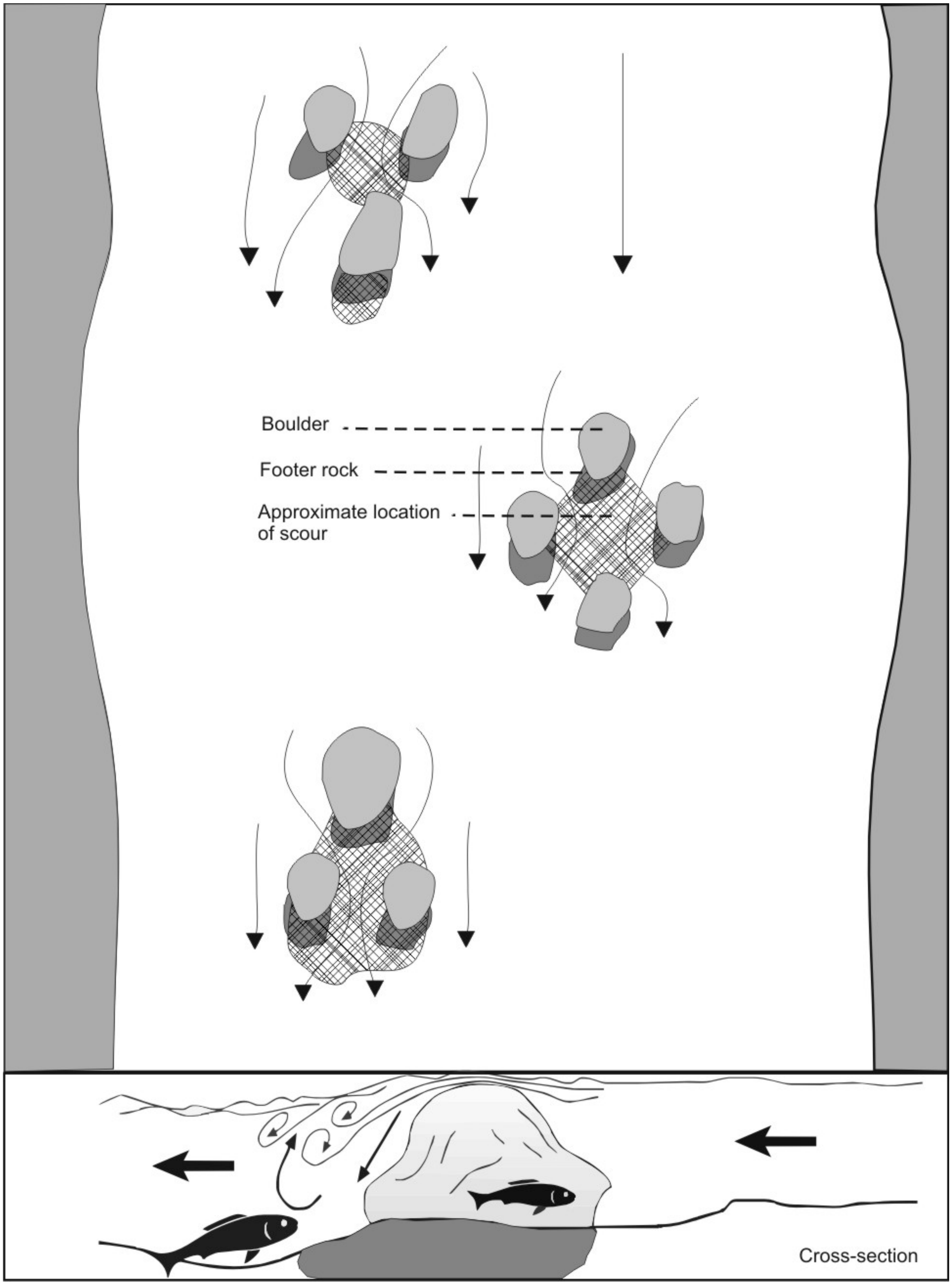

Figure 7. Drawings of boulder clusters (Modified from Bastien-Dagle et al., 1991; Schueler, 2004; Watch Your Dirt, 2014).

C2 - Half Log Cover Fact Sheet

Purpose

- **To provide instream cover for juvenile and adult fish.**

Conditions where applicable

- Use in streams where instream cover for juvenile and adult fish is limiting.
- Can be used in streams that are not prone to severe flooding and ice damage.
- Most suitable for streams <10 m wide.
- Avoid streams with a shifting sand bottom.
- Used in streams with solid substrate.

Habitats Created

- Adult cover.
- Cover for juveniles.
- Critical adult spawning cover.

Advantages

- Inexpensive and easy to install.
- Can be placed alongside the bank or in open water.
- Can be easily constructed.
- Can be adjusted with little effort for optimum success.

Disadvantages

- If not set in correct stream conditions or location, usefulness is reduced.
- Not suitable in streams with wide fluctuations in flow.
- If not installed properly, will catch debris.
- The structure may be damaged by ice.

Design Criteria

- Must remain submerged to be effective.
- Build and set in place during mid-summer to early fall.
- Materials include: log ~30 cm diameter, one to two meters long, cut in half lengthwise, wooden blocks ~30 cm diameter, and 1.5 m lengths of 1.5 cm diameter steel reinforcing rods (rebar).
- Length of logs used is variable depending on availability and size of shelter to be built.
- Set in place at the edge of the main current but angled (30°) to the main current flow (Figure 8). If this does not prove to be effective, adjust angle or location as required.

Implementation Steps

- Obtain equipment required: chain saw, drill, fence pole driver, sledge hammer, and a 1.0 m piece of 2.5 cm steel pipe (used to bend rebar).
- Cut log in half and pre-drill half logs 15 cm in from each end with a 1.5 cm diameter hole.
- Pre-drill centre of wood blocks with a 1.5 cm diameter hole.
- At the selected site, position the wooden blocks so that the half log will be slightly offset (~30^o) from the stream flow.
- Place the half log on top of the wooden blocks with the flat side down.
- Insert the rebar into the wooden blocks and the half log and drive into place with the fence pole driver until the rebar is 30 cm above the top of the log. The rebar should be driven on a slight angle directed downstream to maximize holding strength.
- Slip the 2.5 cm steel pipe over the rebar and bend the rod down until it is flush and parallel with the log. The end of the rod should be facing downstream.

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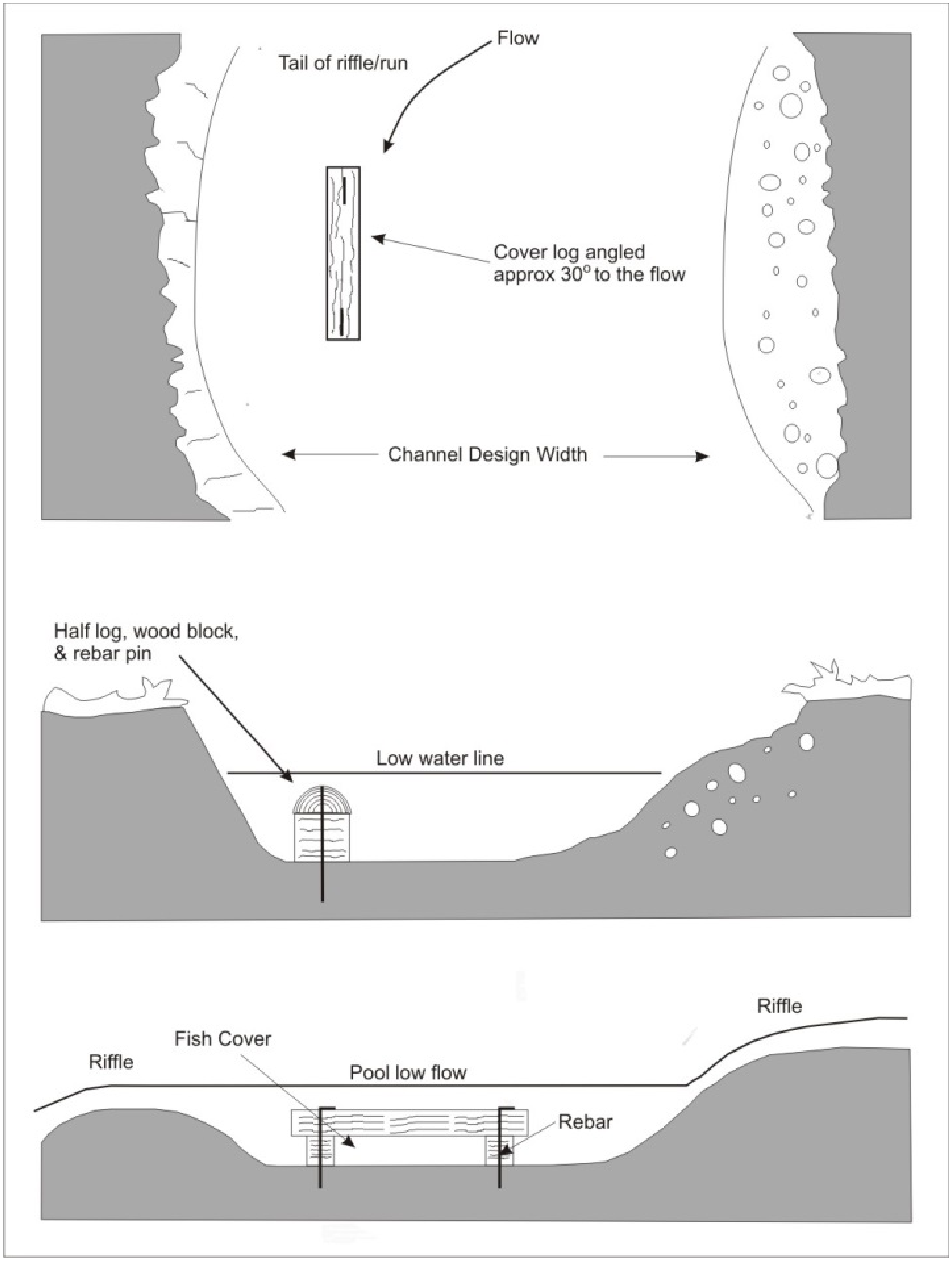

Figure 8. Drawings of a cover log (Modified from Melanson et al., 2006).

C3 – LUNKERS Fact Sheet

Purpose

- To provide overhead cover for both juvenile and adult fish.

Conditions where applicable

- Used in streams where cover may be limited for juvenile and adult fish.
- Usually placed in a location that allows for a gentle flow through the structure which will help to limit sediment accumulation.
- The structure can be built along an eroding bank on the outside of a bend. (Note: the term eroding bank simply refers to the bank opposite to the silt depositing side and not necessarily to an active erosion site). The lower two-thirds of a bend are preferable. It can also be built out from a natural "dead water" bay along the shore.
- Ideal in streams that are predominately cobble and boulder and have an average grade <4%.
- Should not be used in streams that experience high levels of flooding, severe ice damage, and large movement of sediment.
- Should not be placed in straight reaches unless other structures (e.g. boulder clusters, deflectors) can be used to direct water flow into the Little Underwater Neighbourhood Keepers Encompassing Rheotactis Salmonids (LUNKERS).

Habitats Created

- Juvenile and adult cover.

Advantages

- Provides hiding places for fish.
- Can be used with other bank stabilization measures.

Disadvantages

- Can catch debris and ice if not placed properly.
- May constrict flow and cause damage downstream.
- May require annual maintenance.
- Heavy equipment may be required for streambank excavation/sloping.

Design Criteria

- LUNKERS constructed with hardwood (e.g. oak) or cedar planks and should be built during the summer low flow period.
- The top of the LUNKERS should be below the known low water stage. The minimum depth required for the LUNKERS is 0.46 m.

- The entire structure should remain completely submerged as periodic wetting and drying will encourage premature decay and eventual failure.
- LUNKERS require flow entering the upstream end of the structure and sweeping through them to maintain the void created by the spacer blocks of the LUNKERS. Other structures (e.g. boulder clusters, deflectors) may be used to direct flow through the LUNKERS.
- LUNKERS are often used in a series along with other bank stabilization measures.

Implementation Steps

- Cut 15 cm lengths from a 15 cm x 20 cm beam so that there are 2 rectangular blocks (15 x 15 x 20 cm).
- Cut a 61 cm length from a 5 x 20 cm planks for the *bottom piece*.
- Cut the *top piece* from one of the 5 x 20 cm planks so that it is at least 50 percent longer than the *bottom piece*. (Example: if a 61 cm *bottom piece* is cut, then the *top piece* must be at least 91 cm.)
- Attach the *bottom piece* and *top piece* to the rectangular blocks with nails or ceramic dock screws. The *bottom piece* will be flush with the rectangular blocks. The *top piece* should overhang the rectangular blocks by at least 30 cm on one end and be flush with the rectangular block on the other end.
- The above steps should be repeated so that there are a total of three equal-sized spacers (Figure 9).
- The three spacers should be bridged using 2.4 m 5 x 20 cm planks on the bottom and top (ignore the overhang). They should be equally spaced.
- A 2.4 m 5 x 20 cm plank (cover board) should be used to cover the openings under the overhang (bankside of the LUNKERS).
- Six 1.5 cm holes are then drilled through the *top* and *bottom pieces* of the spacers as near to the bankside and streamside rectangular blocks as possible without drilling through them.
- The overhang of the LUNKERS should be keyed into the streambank.
- The bottom of the LUNKERS should rest on the streambed. Stone is usually used to provide a firm base for the LUNKERS.
- Insert 1.5 m lengths of 1.5 cm diameter steel reinforcing rods (rebar) into the drilled holes and drive into place with the fence pole driver until the rebar is 30 cm above the top of the LUNKERS.
- Slip a 2.5 cm steel pipe over the rebar and bend the rod down until it is flush and parallel with the log. The end of the rod should be facing downstream.
- Large stones, sized according to stream conditions, should be placed on top of the LUNKERS.
- The streambank should be sloped back and contoured to tie in with the back of the LUNKERS.
- Soil, mulch, native grasses, and native shrubs are then applied to the bank to create a stable 2:1 slope. Brush matting and live fascines may be used if required.

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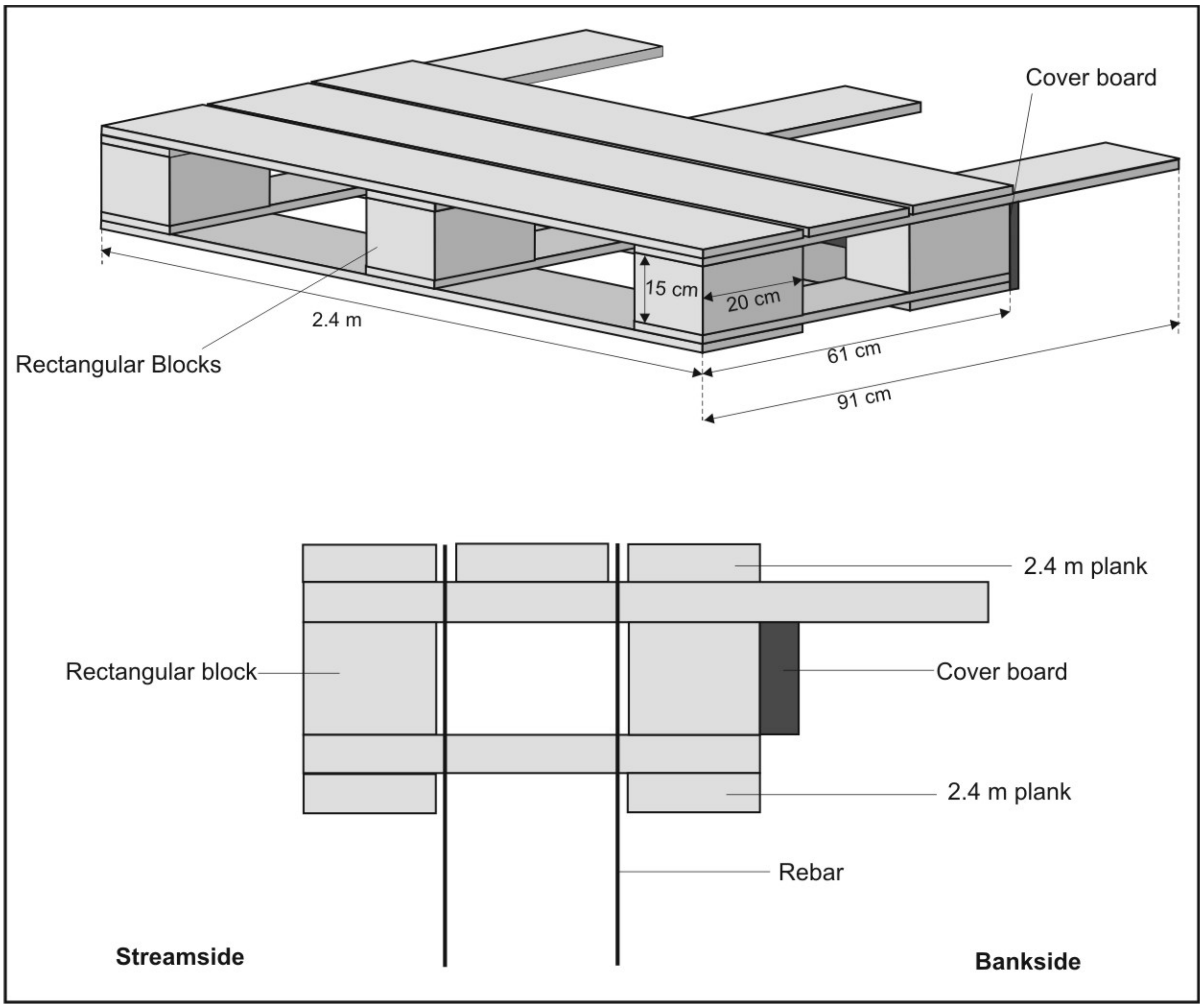

Figure 9. Drawings of a LUNKERS (Modified from USDA-NRCS, 2007).

C4 - Root Wads Fact Sheet

Purpose

- To stabilize eroding banks and provide instream cover.

Conditions were applicable

- On the outside of pools where there is a high eroding bank.
- Pools lacking cover.
- Lakeshores (for minimizing wind and wave erosion).

Habitats Created

- Instream cover, particularly for juveniles.
- Bank stabilization and reduced siltation.

Advantages

- Will tolerate high water velocities if the root wads are well anchored.
- Use of native materials can sequester sediment and woody debris, restore stream banks in high velocity streams, and improve fish rearing and spawning habitat.
- Some species, such as willow, often sprout and accelerate colonization.

Disadvantages

- Heavy equipment required for the collection, transportation, and installation of root wads.
- Site must be accessible to heavy equipment.
- Structure may have limited life and might need eventual replacement if vegetation does not grow or soil bioengineering systems are not used.
- Expensive.
- Materials might not be readily available at some locations.

Design Criteria

- Trees with root wads should be sized according to the stream and bank height. Typically, optimal root wads would be >2 m in diameter.
- Success depends on anchoring the trees well and causing a minimum of damage to the banks.
- The root wads must be installed at the toe of the bank; approximately 1/3 of the root wad should be below the baseflow (portion of stream flow that is not runoff and results from seepage of water from the ground into a channel slowly over time) elevation.
- When scour depths are high in an area, footer logs should be installed below the root wads.

- Where appropriate (e.g. trenching method), root wads should be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of stream bank vegetation.

Implementation Steps

- Obtain trees with the roots intact. Larger diameter trees (minimum of 30 cm diameter breast height – DBH) can be pushed over when soils are not frozen leaving root fans intact.
- The tops of the trees should be removed, leaving the trunks a minimum of 3 m in length with the roots attached.
- The end of the log can be sharpened with a chainsaw prior to driving it into the bank.
- The tree is driven into the bank (drive-point method) or, when not possible, it is buried in the bank (trenching method) so that the base of the root wad faces the current and deflects the water away from the bank (Figure 10). The drive-point method is preferred as it is less expensive and causes the least environmental impact (i.e. trenching method causes more bank disturbance and sedimentation issues).
- The logs can be placed so that the root wad touches the trunk of the log upstream from it but this is generally not necessary.
- When required, the logs can be anchored using cable and a dead man's log or a drivable anchor.

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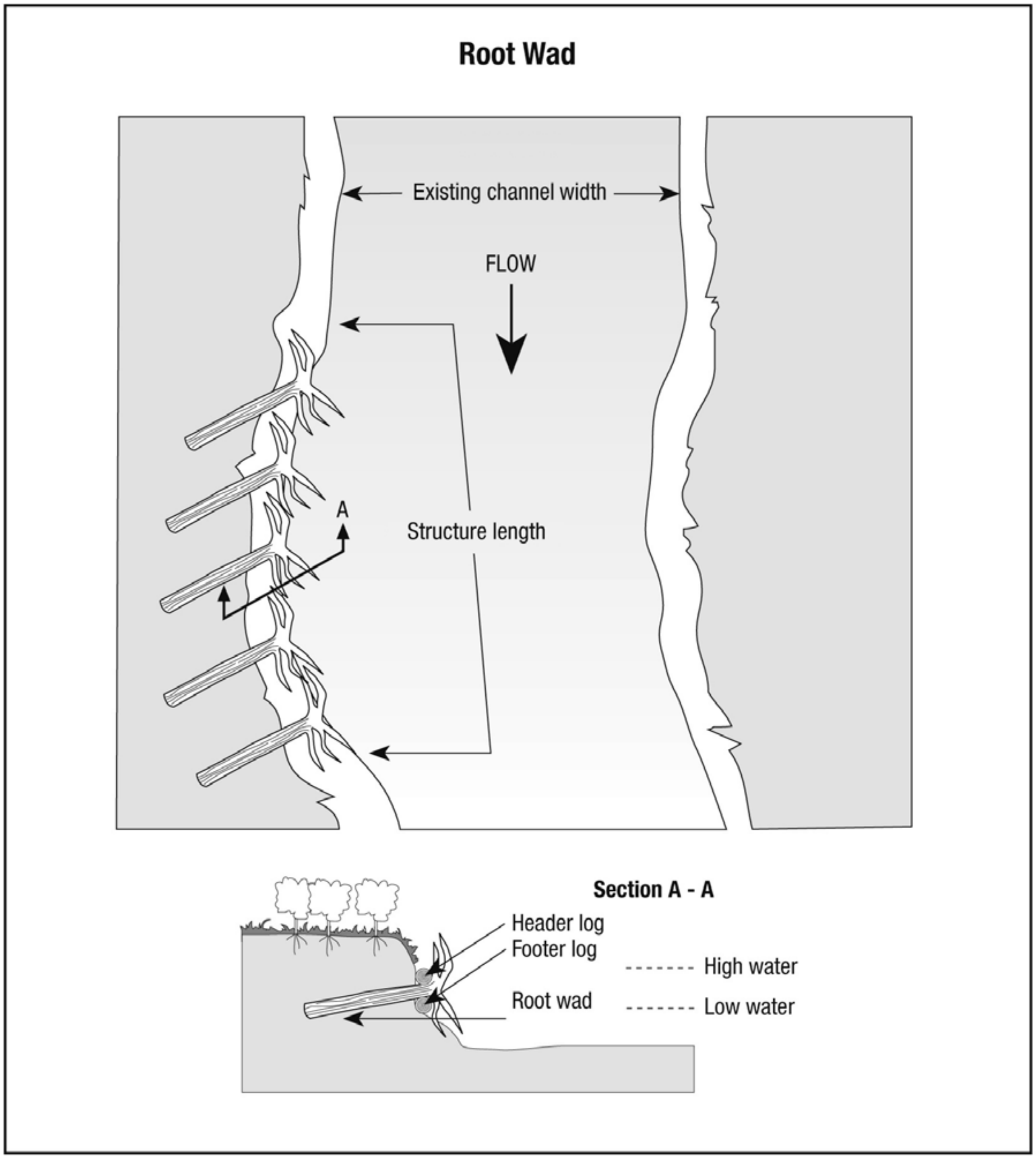

Figure 10. Drawing of root wads (Melanson et al., 2006).

6.3 Lake Habitat Enhancements

L1 – Aeration Fact Sheet

Purpose

- To increase the dissolved oxygen content of the water, particularly at the bottom of a lake.

Conditions where applicable

- Aeration is used for lakes that have low oxygen levels in the summer and/or winter and experience fish kills due to these conditions. These lakes are typically shallow (<5 m in maximum depth) and are eutrophic or have highly organic bottoms (Cott et al., 2008). Lakes prone to winterkill often have up to 50% of their volume as ice and generally do not have an inflow or outflow or their inflow/outflow is frozen (Cott et al., 2008).

Habitats Created

- Fish, zooplankton, benthic fauna, and other biota will be able to utilize more of the lake bottom habitat.

Advantages of Destratification

- Oxygen levels and other chemical properties (hydrogen sulfide, ammonia, carbon dioxide, phosphorous) will be more uniform and will allow fish, zooplankton, benthic fauna, and other biota to be better distributed through the lake (Fast, 1979).
- The types of aerators used for destratification are simpler and, therefore, cost less than hypolimnetic aerators.

Disadvantages of Destratification

- While destratification can increase the oxygen content of the entire lake, it can also increase the water temperature of the lake which will adversely impact fish species that prefer cold water (e.g. trout).
- If stratification has already occurred in the lake, the movement of water (and hydrogen sulfide, ammonia, and carbon dioxide) from the hypolimnion to the surface can adversely affect fish.
- Aerators used during the winter will prevent the entire lake from freezing and this can be an issue for other recreational activities (e.g. snowmobiling).
- Monitoring and maintenance of the aerators and any associated equipment (windmills, generators, etc.) will be required.

Advantages of Hypolimnetic Aeration

- Oxygen can be introduced to the bottom of a lake without altering the temperature of the lake (i.e. disrupting the thermocline); this is very important for any lakes that contain cold water fish species (e.g. trout).

Disadvantages of Hypolimnetic Aeration

- The transfer of oxygen to the hypolimnion is slower because of the small surface area available in the aeration equipment used. Hypolimnetic currents or any induced circulation from the aeration apparatus can be significant because of the relative thermal homogeneity and low resistance to water movement (Nordin & McKean, 1982).
- If compressed air is used instead of oxygen, nitrogen supersaturation can occur. Full lift systems, which transfer water from the hypolimnion to the surface and back to the hypolimnion, are less likely to cause nitrogen supersaturation in comparison to partial lift systems.
- Depending on the hypolimnetic aeration system used, there may be less removal of undesirable substances (e.g. hydrogen sulfide, ammonia, carbon dioxide) from the hypolimnion.
- More complex than destratification aeration systems and, thus, more expensive.
- Aerators used during the winter will prevent the entire lake from freezing and this can be an issue for other recreational activities (e.g. snowmobiling).
- Monitoring and maintenance of the aerators and any associated equipment (generators, windmills, etc.) will be required.

Design Criteria

- Two of the most common aerators used to prevent stratification are mechanical mixers and diffusers.
- Mechanical axial flow pumps have an electric motor and a propeller that are supported on top of a floatation platform. The propeller, which is just a metre or two below the surface, pushes surface water downward and generates a circulation pattern that prevents thermal stratification.
- Other mechanical circulation systems include surface spray units, impeller-aspirators, and pump and cascade systems but these systems do not prevent stratification and instead aerate the upper layers of the lake rather than the bottom. They can be used to create and maintain open water during the winter.
- For diffuser systems, a compressor on shore delivers air through lines connected to a simple diffuser (e.g. perforated pipe) that is placed near the bottom in a deep area of the lake.
- Rising air bubbles cause the water at the bottom of the lake to rise to the surface where it absorbs oxygen at the surface (air lift method). Depending on the type of airlift diffuser used it may prevent stratification of the lake or it may leave the thermocline untouched (hypolimnetic aeration).

- In order to prevent the suspension of fine sediments into the water column, the diffuser should be sized appropriately for the lake and must be raised above the bottom of the lake.
- Depending on the climate and other conditions (e.g. depth of the lake), hypolimnetic aerators may be more appropriate for lakes containing cold water species. A number of hypolimnetic aerators are available including partial and full airlift aerators, Speece Cone, and bubble-plume diffusers.

Implementation Steps

- Determine the appropriate type and size of aerators to be used based on the lake conditions and the fish species present.
- Install the aerator and power supply at the lake.
- If a destratification aeration system is going to be used, the system should be started in the spring or fall when the water column is isothermal (temperature is approximately the same at top and bottom). This allows the aeration system to maintain aerobic conditions and requires the least effort as it is easier to circulate an isothermal water column than one that already has a well-established thermal stratification.
- Monitor conditions of the lake (temperature, total suspended solids, and concentrations of various water quality parameters (e.g. dissolved oxygen, ammonia, hydrogen sulfide, carbon dioxide) and fish species present in the lake and adjust aeration accordingly.
- Maintain equipment (e.g. aerator, power supply) during its operation.

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L2 – Liming Fact Sheet

Purpose

- To increase the alkalinity, pH, and hardness (calcium and magnesium concentrations) of a lake.

Conditions where applicable

- Lakes that have low alkalinity and pH whereby the pH of the water is low and adversely affecting aquatic organisms.

Habitats Created

- pH of an existing lake is raised to a neutral level that is more suitable to fish and other aquatic organisms.

Advantages

- Increases the alkalinity, hardness, and pH of a lake.
- Decreases dissolved metal concentrations (e.g. aluminum).
- Increases fish production.

Disadvantages

- If the acid inputs to the lake continue, lime will need to be added on a repeated basis in order to maintain neutral pH levels.
- The duration of liming effectiveness is dependent on a number of factors including the retention time of water within the lake, the amount of limestone, the method used, and the limestone dissolution rate after treatment (Hasselrot & Hultberg, 1984).

Design Criteria

- Finely ground (<0.25 mm) agricultural limestone (calcite, calcium carbonate) is recommended when adding it to water as it will dissolve rapidly. Other types of lime should not be used as they are not effective (e.g. dolomite lime) or they are caustic and have been known to kill fish when improperly used (e.g. hydrated lime and quicklime).
- Calcium content should be >70% $CaCO_3$ by weight (preferably 90-100%), contaminant-free (<5% of magnesium), and low in nitrates and phosphates.
- Determining the amount of limestone needed to neutralize an acid lake is difficult as many factors must be considered including:
    - the existing alkalinity, hardness, and pH;
    - the acidity and chemistry of the lake bottom sediment;
    - the type, purity, and particle size of the limestone;
    - the volume of the lake and retention time;

- the target pH;
  - the water quality and temperature and;
  - the density and types of aquatic plants.

- As a general guide, 900 – 1800 kg of agricultural limestone per surface acre should be used when liming a lake for the first time.
- The end result of the liming should be a lake with a pH near 7 and a total alkalinity greater than 20 mg/l. Additional limestone can be added to the lake if these targets are not reached.
- If a lake has a long retention time (average time water remains in a lake), the limestone can be added directly to the water and should be distributed over the entire lake surface, with areas of deep water requiring proportionally greater amounts of limestone. Fall is considered to be the best time to deposit lime in a lake.
- Limestone is typically introduced into a lake from a boat or barge. It can be shovelled into the wake of a boat or flushed from a barge with a high pressure water hose (better dissolution). If limestone is mixed with water in a slurry box, the solution can be pumped into the lake and this will increase the dissolution rate of the limestone.
- Limestone can also be spread over the ice of the entire lake during the winter. It will be distributed into the lake during spring break up. This method may be more appropriate when limestone is being added to a lake on a regular basis.
- Aircraft can be used to distribute lime on very large lakes or remote lakes where access is difficult but the costs are significantly higher.
- If a lake has a shorter retention time (e.g. <5 years), a single dose of limestone is unlikely to achieve any long-term results; maintaining the pH of the lake would likely require the addition of limestone on an annual basis. An alternative would be to add limestone to the lake watershed (fields, forest, and shores of the lake, and the stream(s) feeding the lake). The slow leaching from the limestone on the landscape would provide continuous inputs of $CaCO_3$ in to the lake over time. However, to achieve the same results up to significantly greater amount of limestone could be required when distributing it on land as opposed to water (Helfrich et al., 2009; Bengtsson et al., 1980).

Implementation Steps

- Measure the alkalinity, hardness, and pH of the water. If alkalinity is less than 20 mg/l, hardness is below 25 mg/l, and the pH is under 6.5 and varies greatly in a 24 hrs period, then adding limestone to a lake may be useful.
- Determine the appropriate amount of limestone to use.
- Notify recreational users of the lake that liming will be occurring; increased cloudiness and reduced water clarity will occur for a short period.
- Distribute the limestone into the lake.
- After limestone treatment, the alkalinity and pH can be measured to determine if additional limestone is needed. The target pH should be approximately 7 and total alkalinity should be above 20 mg/l.
- If limestone has been added directly to the water, results are typically achieved approximately a month after the liming. If limestone was added to the watershed of the lake, neutralization of the lake will take longer.

- Limestone should be added again to a lake when the pH returns to levels below 6.5 and total alkalinity is less than 10 mg/l.

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L3 - Spawning Shoal Fact Sheet

Purpose

- To provide spawning habitat for various fish species.
- To increase the recruitment of target fish species.

Conditions where applicable

- When spawning habitat has been determined to be limited, additional spawning substrates can be added to a lake to increase recruitment.

Habitats Created

- Spawning habitat
- Resting areas for adult fish

Advantages

- Provides additional spawning habitat for target fish species.
- Provides resting areas for adult fish and habitat for invertebrates.
- Structure looks natural.
- Increases the diversity of the lake bottom.

Disadvantages

- Can be a hazard to navigation.
- Due to seasonal water temperature changes and levels, the shoal may only be utilized by fish for part of the year.
- The installation of artificial spawning shoals has rarely been demonstrated to increase fish recruitment/production. While increased spawning has been observed on artificial reefs by lake trout (*Salvelinus namaycush*), lake trout populations have not increased and thus other factors are contributing to low lake trout recruitment/production (Fitzsimons, 1996). Similarly, Geiling et al. (1996) determined that enhancement of spawning habitat rarely appeared to increase adult walleye (*Sander vitreus*) abundance.

Design Criteria

- The size of the gravel and rock and shoal location will be dependent on the target fish species (e.g. a shoal for lake trout should consist of 10 – 20 cm rock that is stacked approximately 1 m high and is placed near a steep drop off ; Fitzsimons, 1996). Seek advice from a fisheries biologist on the appropriate size and placement of rock for the shoal.
- In general, the shoal should be positioned at a depth between 3 – 9 m to ensure maximum utilization of the shoal throughout the year.

- If possible, the shoal should be placed in an area with a gradient going from shallow to deeper water; the deepest portion of the shoal should be slightly deeper than the late summer depth of the thermocline (Philips, 1991).
- If recruitment is to be successful, nursery habitat for the target fish species should be within the vicinity of the spawning habitat that is created.
- The shoal must be placed on firm substrate, such as clay, sand, or stone in order to prevent sinking.
- Soft bottoms, characterized by silt and mud are not recommended as gravel and rock may eventually subside and become covered by sediment.
- It is important to avoid placing the shoal on productive bottom habitat (e.g. natural shoals, submerged trees, brush, vegetation) already being utilized by fish.
- Shoals should not be placed in boating lanes and must be of sufficient depth to allow for safe boat passage (consult Navigable Waters at Transport Canada prior to any work).

Implementation Steps

- Area within the vicinity of the proposed shoal location should be inspected to first determine if there will be any issues with sedimentation or detritus.
- If there are concerns with sedimentation or detritus, these should be corrected (e.g. banks near the spawning shoal could be stabilized to minimize erosion and siltation) or another location should be selected.
- The lake bottom should be probed by boat or by checked by diver.
- The bottom substrate of the shoal may be prepared/stabilized by placing a 10 cm to 15 cm layer of 1.27 cm to 5 cm rock or synthetic filter cloth on the bottom prior to placement of larger rock that will be used for spawning.
- Obtain appropriate size gravel and rock that the fish species will require for spawning; clean gravel and rock must be used.
- Gravel and rock can be placed by divers. Alternatively, it may be possible to place rock and gravel on top of the ice prior to spring breakup. During the spring, the rock will fall through the ice. If this method is to be used, the lake bottom should be inspected and prepared, if necessary, beforehand. This method would not be suitable in lakes that have significant movement of ice flows.

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6.4 Pool-Riffle Creation and Channel Narrowing

P1 – Deflectors Fact Sheet

Purpose

- To minimize bank erosion in the immediate area by deflecting/directing the flow of the stream and to scour and sort channel materials.
- To decrease the width of the stream during low periods and increase the depth of the water for fish by developing a narrower, deeper channel.
- To increase the velocity of the stream and to create a scour pool downstream.
- To create sinuosity in the channel.

Conditions where applicable

- Deflectors are typically used in shallow, slow, widened sections of streams that have a low gradient (< 2%) to moderate (2 - 4%) gradient.
- Should be positioned below the crest of riffles or in glides and straight runs of the stream.
- Should not be used in streams that are braided (has numerous channels that split off and rejoin each other) or actively meandering.
- Should not be used in streams that have high gradients, highly erodible substrates, or large volumes of debris and ice movement.

Habitats Created

- Development of the thalweg which can provide deeper habitat for fish.
- Scour pool habitat that captures leaf litter and organics, supports larger insect populations, and provides overhead cover, over-wintering habitat, and resting areas for fish.
- Substrates are sorted; sands and silt are moved downstream.

Advantages

- In addition to protecting the bank from erosion within the immediate vicinity of the structure, the deflector can create additional fish habitat (e.g. deeper thalweg and scour pool).
- Can divert flows and create meandering in an otherwise straight section of a stream.

Disadvantages

- Deflectors can cause erosion and add to bank and watercourse instability if they are not properly located. Considerable experience is required to determine their proper location.
- The opposite bank, downstream of the deflector, may require bank stabilization.
- Ice and debris jams may occur.
- Construction of larger deflectors will require heavy machinery and as a result, costs may be high.

- Silt may be deposited immediately downstream of deflectors.

Design Criteria

- Prior to selecting this rehabilitation technique, one should understand the channel characteristics the stream should have, the existing pattern of stream flow, and the dynamic nature of seasonal flow, ice formation, debris movement, and sediment transport of the stream.
- Proper positioning of the deflector within the channel is critical. Deflectors can cause significant erosion and add to bank and watercourse instability if they are not properly located. Considerable experience is required to determine their proper location and, therefore, this rehabilitation project should not be carried out without the support of aquatic biologists, hydrologists, and engineers.
- Deflectors may be installed as single structures, twin structures, or as a series of alternating single structures (Figure 11).
- A single deflector will deflect water away from the bank and ideally towards the centre of the channel. Single deflectors should not occupy more than one third of the bankfull channel width.
- Some erosion may occur on the opposite of the bank just downstream of the deflector. If the water cannot be deflected towards a stable section of the stream on the opposite bank (e.g. area with boulders or a stable root system which can withstand undercutting without sloughing), then the bank may need to be stabilized.
- A series of alternating single deflectors will create sinuosity by deflecting the thalweg (main current) toward the centre of the stream or opposite bank. They should be placed 5-7 bankfull widths from each other.
- In a twin deflector design, the two deflectors are placed opposite of each other. The purpose is to constrict the stream by 70 – 80%. This will increase the velocity of the stream and create a narrower, deeper, thalweg as well as a scour pool immediately downstream of the structure. Typically, a single unit is installed but several may be used in reaches that have long, straight stretches of slow moving water.
- Single log deflectors are typically used in narrower streams (<6 m) with low flooding when larger rock is not available. Rock deflectors are used in wider streams (single - <9 m; double - >9 m) with low to moderate flooding.
- The deflector should be keyed into the stream bank 1.2 - 2.5 metres and protected (e.g. rip-rap).
- Approximately 25% of the average height of the deflector should be embedded in the stream bed. The upstream angle of the deflector should be 30^o from the bank, 90^o at the point out in the stream, and 60^o at the downstream bank.
- The 30^o angle should guide the flow of the stream towards the centre of the channel as opposed to the opposite bank.
- The point of the deflector should be in line with the centre of a stable structure on the opposite bank.
- The point of the deflector should not be higher than two times the height of the stream at low flows. The deflector should taper upward toward the bank to the bankfull height. Ice and debris should be able to pass over the structure during high flows.
- It is important that the structure remains stable under high flows.

Implementation Steps

Rock Deflector

- Excavate a trench into the stream bed and bank to create the outline of triangular shape of the deflector. The upstream angle of the deflector should be 30^{o} from the bank, 90^{o} at the point out in the stream, and 60^{o} at the downstream bank. The trench depth should be approximately 25% of the average height of the deflector.
- Two layers of rock (footer and header) should be used along the edge of the deflector. Large angular rocks that will not move during the highest flows expected for the location should be used.
- The largest rock should be used along the upstream edge of the deflector, with the very largest being positioned at the point of the deflector.
- Slightly smaller rock can be used along the downstream edge of the deflector.
- Place the course (layer) of footer rock inside the trench interlocking it as much as possible.
- Place the header rock so that each one sits on the halves of two footer rocks below it and that it is interlocked with other head rock. For greater stability, it should be slightly offset with a portion of the header rock sitting within the trench.
- Any gaps along the upstream edge of the deflector should be filled in with smaller rock.
- Fill the interior of the structure with smaller stone.
- The deflector should gradually slope upward toward the bank to the bankfull height.
- The deflector should be keyed into the stream bank 1.2 - 2.5 metres. If building the deflector beside an eroded bank, the bank may need to be graded to an appropriate slope (3:1).
- Riprap should be used to armour the keyed sections of the deflector.
- Surplus bank material can be used to fill in the gaps of the interior rock so that native grasses and/or shrubs (e.g. willows) can be planted as this will provide greater stability to the structure.
- The bank opposite the deflector should be stable otherwise it may have to be protected to prevent erosion.
- Once the work has been completed, re-vegetate any disturbed areas by planting and seeding with native grasses and/or shrubs and cover such areas with mulch to prevent erosion and to help seeds germinate.

Log Deflector

- Obtain appropriate size logs that are 30 to 50 cm in diameter. Note: It is better to obtain a longer log than is necessary and then cut it to its proper size during the installation.
- Excavate a trench into the stream bed and bank to create the outline of the triangular shape of the deflector. It should be deep enough to contain half of the log. The upstream angle of the deflector should be 30^{o} from the bank, 90^{o} at the point out in the stream, and 60^{o} at the downstream bank.
- If building the log deflector beside an eroded bank, the bank may need to be graded to an appropriate slope (3:1)

- Place the main log (upstream log) so that it sits inside the trench and 1.2 – 2.5 metres into the stream bank.
- Place the brace log (downstream log) into the trench so that it sits behind the main log and 1.2 – 2.5 metres into the stream bank. While the main log (upstream log) may extend slightly beyond brace log (downstream log) for the purposes of cover or increased scour, the brace log must never extend beyond the main log.
- Pin the two logs together using 60 cm rebar pins.
- A second layer of logs can be used for additional height although frequent exposure to the air can cause decay. Removing the bark can help to slow the decay.
- Pre-drill 1.5 cm diameter holes into the logs at 1.5 m intervals.
- Insert 1.2 - 1.5 m lengths of 1.5 cm diameter steel reinforcing rods (rebar) into the log(s) and drive into place with the fence pole driver until the rebar is 30 cm above the top of the log(s). The rebar should be driven on a slight angle directed downstream to maximize holding strength.
- Slip a 2.5 cm steel pipe over the rebar and bend the rod down until it is flush and parallel with the log. The end of the rod should be facing downstream.
- There should be no protrusions on which debris can accumulate on the deflector.
- Rocks can be placed behind the brace log to provide additional support. However, the rock must be tapered downstream to prevent a scouring effect in this area.
- Fill the interior of the structure with smaller stone. Larger stone should be used where the logs meet the streambed.
- The deflector should gradually slope upward toward the bank to the bankfull height.
- Riprap should be used to armour the keyed sections of the deflector.
- Surplus bank material can be used to fill in the gaps of the interior rock so that native grasses and/or shrubs (e.g. willows) can be planted as this will provide greater stability to the structure. The logs will eventually decay so it is very important that vegetation becomes established in the interior of the deflector.
- The bank opposite the deflector should be stable otherwise it may have to be protected to prevent erosion.

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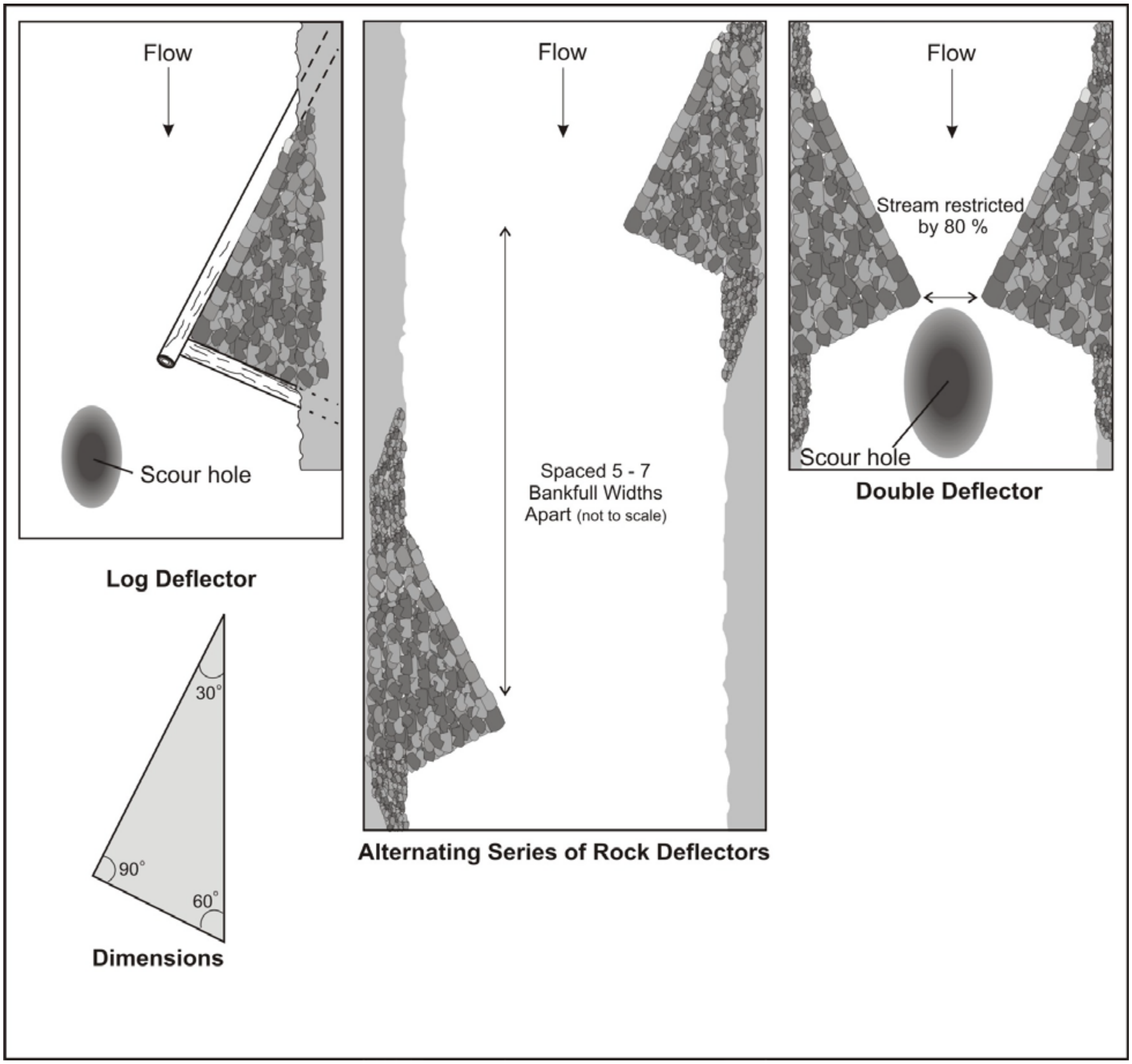

Figure 11. Drawings of various types of deflectors (Modified from Lutz, 2007).

P2 - Digger Log Fact Sheet

Purpose

- To provide desirable scouring and sorting of channel materials and to create or enhance an existing pool downstream of a riffle.

Conditions where applicable

- In a stream with low to moderate grade (up to 2 %), with gravel or small cobble substrate, and where natural flows and currents can be allowed to shape the streambed.
- The log acts as a gradient control holding the riffle/run substrate from falling into the pool. They are not intended to create a significant head difference and plunge pool.

Habitat Created

- Pool habitat that captures leaf litter and organics, supports larger insect populations, and provides overhead cover, resting areas, and over-wintering habitat for fish.
- Sorted substrates; sands and silt are moved to point bars or flood plain downstream.
- Encourages the development of the thalweg between pools.

Advantages

- Creates overhead instream cover and helps develop a proper riffle/pool ratio and sorted gravels in disturbed streams.
- Can be built with on-site materials in remote or poorly accessible forested areas.
- Imitates natural digger log processes in streams.

Disadvantages

- Bank erosion and formation of unwanted silt bars can occur downstream of structure.
- Debris dams may be formed.
- Can be labour intensive to install.
- If not positioned/anchored correctly, digger logs will do nothing, wash away, or further disturb habitat.
- If not placed properly, may disrupt navigation in the waterway for small craft such as canoes.

Design Criteria

- Digger logs work with the stream flows to sort gravel and shape pools and riffle thalweg. The substrate that is scoured from the pool area will build point bars and shape the channel and will typically take two to three years to fully form.
- Digger logs are most effective in streams under 6 m wide.

- For best results, the digger log should be placed at the head of a natural pool or where one is forming.
- If positioned correctly, the pool created or enhanced by the digger log will not fill in.
- Log diameter is typically 15 to 25 cm with a minimum of taper from one end to the other.
- The log should be placed across the stream and angled 30^{o} from the stream bank (Figure 12).
- The log must be firmly anchored to the substrate.
- The upstream end of the log should be set lower (~15 cm or more) than the rest of the log to concentrate low flows on the pool side of the stream.
- The ends of the log must fit tightly to the banks and be well rocked in place to prevent erosion of the banks. If the log is placed in a gravel bar or in other soft bank material, the log should be set into the bank a minimum of 1 - 2 m and be well armoured to prevent erosion.
- A rock ramp should be built upstream of the log, sloping the streambed up to the log on a 20:1 ratio. Typically, this means a 1 - 3 m long ramp on the upstream side.
- Cobble and large rocks armouring the surface should be removed from the pool area to assist the scour by the flows.
- When the pool has formed, any cobble and large rocks that were removed initially and not used in the construction of the rock ramp may be replaced to provide juvenile instream cover as needed.
- Logs and ramps may need periodic maintenance until the stream has achieved its new form and vegetation has stabilized the new banks.

Implementation Steps

- Survey stream to locate proper position for digger log.
- Obtain a log (15 -25 cm in diameter) that is the size of the bankfull width of the channel (or at least 2 m longer if the log is being installed into the streambank). Note: It is better to obtain a longer log than is necessary and then cut it to its proper size during the installation.
- Pre-drill 1.5 cm diameter holes into log at lengths of ¼, ½, and ¾ of the channel width.
- Place digger log into stream, angled 30^{o} from the stream bank. The upstream end of the log should be 15 cm lower and this can be accomplished by setting the log into the streambed at this point.
- Ensure ends of the log fit tightly to banks or insert the log into the stream bank if required.
- Insert 1.5 m lengths of 1.5 cm diameter steel reinforcing rods (rebar) into the log and drive into place with the fence pole driver until the rebar is 30 cm above the top of the log. The rebar should be driven on a slight angle directed downstream to maximize holding strength.
- Slip a 2.5 cm steel pipe over the rebar and bend the rod down until it is flush and parallel with the log. The end of the rod should be facing downstream.
- Place rock over each end of the log and tie it into the stream bank. Bank rocking around the ends of the log should be enough to prevent erosion but not intrude into the channel any significant distance.

- Remove cobble and large rocks within the pool. This material can be used to build the rock ramp leading to the digger log.
- Build a rock ramp so that it is gradually sloping up from the streambed to the log on a 20:1 ratio. Use larger rock against the log so that it does not fall through if undercutting occurs.
- Structure should be checked regularly to make sure it is still functioning correctly.

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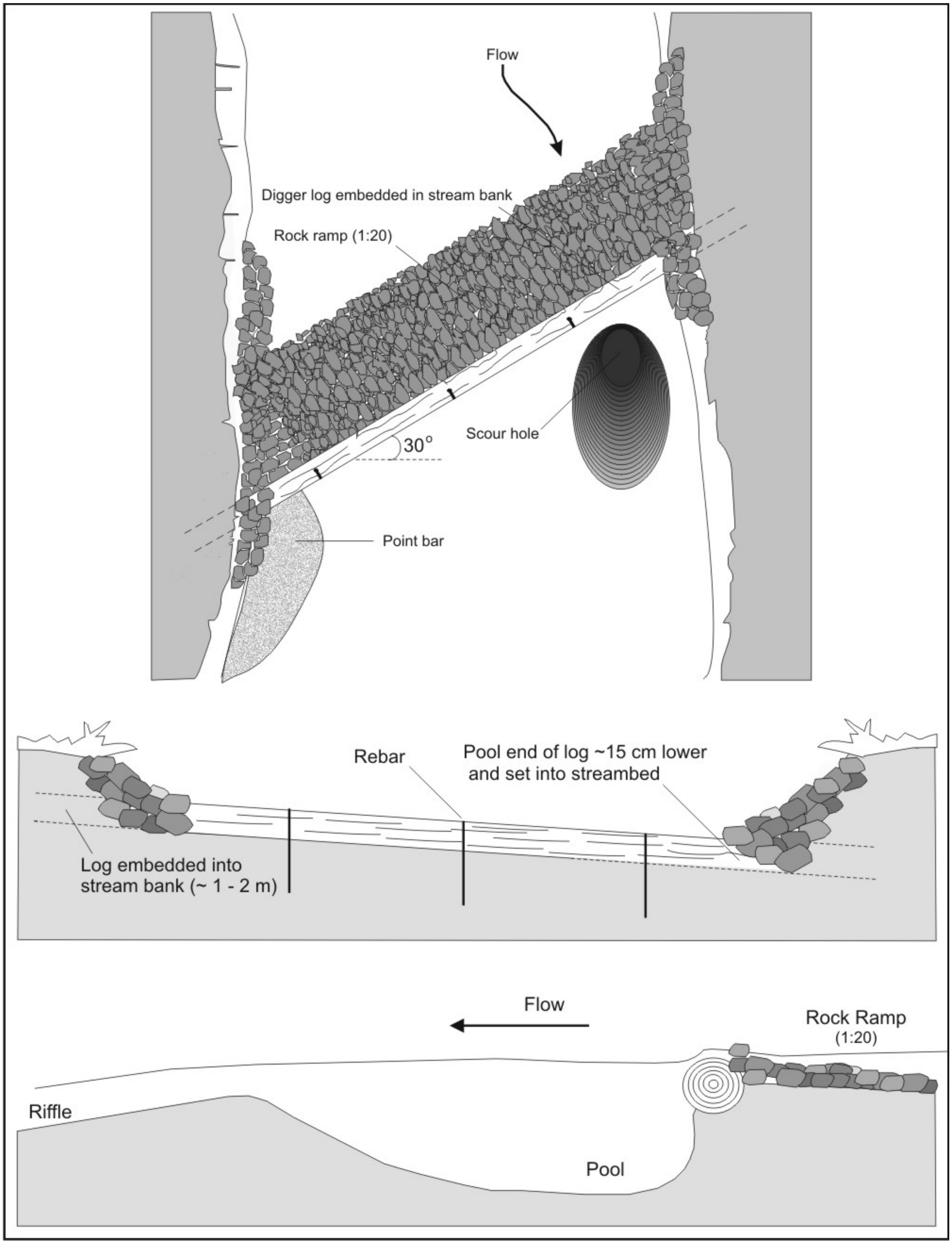

Figure 12. Drawings of a digger log (Modified from Melanson et al., 2006).

P3 - Newbury Riffle Fact Sheet

Purpose

- To enhance pools, recruit gravel, re-aerate flows, and assist fish passage.

Conditions where applicable

- Typically used in channelized stream reaches to help restore run-pool-riffle sequences.
- Suitable for watercourses <30 m wide.

Habitats Created

- Riffle habitat and spawning habitat (e.g. salmon, trout, walleye).

Advantages

- Can aerate water.
- Controls the gradient of a stream and creates fish habitat in the process.
- Looks natural.
- Materials (e.g. rock and cobble) may be locally available.
- Increases fish production.

Disadvantages

- Can be a hazard to navigation.
- If not constructed properly, can be a barrier to fish during low flows.
- May require maintenance.
- May require dewatering and cofferdam or flow diversion.
- Requires heavy equipment.

Design Criteria

- Considerable experience is required when designing these structures and, therefore, this rehabilitation project should not be carried out without the support of experts (e.g. aquatic biologists, engineers, and hydrologists).
- The height of riffle crests will depend on the local profile elevation, the slope of the stream, and the desired depth of the low-flow pools. The riffle crest elevations should be adjusted to follow the average reach gradient. The height of the riffle crests, the site location, and the spacing between the riffles should be adjusted during the design phase so that the riffles do not impede normal bankfull flow velocities in the channel.
- The riffle crest and downstream surface of the riffle should extend across the full width of the channel. The riffle slopes towards the centre of the channel to form a shallow V-shape (Figure 13). This directs the flow towards the centre of the downstream channel and allows fish passage during low flows.

- While the largest rocks are used in the riffle crest, large rocks and boulders should also be used to armour the downstream slope of the riffle.
- Emergent boulders and cobble should be placed on the surface of the riffle and aligned and spaced so that they break the flow into paths that can be followed up the riffle face by migrating fish.
- A variety of rock sizes are used to build riffles. Some of the larger rocks that are used to create chutes and small drops for fish passage at low flows are most vulnerable to movement. These rocks should be stable at bankfull flows and represent the upper range of rock size required for the riffle. The stable rock size in the riffle can be estimated using the following equation:

  Stable rock diameter (cm) = 1500 D S

  Where:
  D = depth of flow (m)
  S = slope of water surface

- Riprap should extend from top of the stream banks, upstream and downstream of the riffle for the entire length of riffle.

Implementation Steps

- Build riffle crest (see rock sill fact sheet) across the stream to the toes of the banks with large diameter boulders; back up with next largest stone downstream.
- Construct downstream face of riffle at a shallow re-entry slope (20:1) that will allow fish passage. The back of the riffle crest (upstream of the riffle crest) should have a slope of 4:1.
- V-shape the crest and face downwards (0.3 m to 0.6 m) to the centre of the riffle. It should slope from the bank to the centre of the riffle crest at a slope of 4 to 8 %.
- Place large rocks randomly on the downstream face 20 to 30 cm apart to dissipate energy and create low flow fish passage channels.
- Rip-rap both banks with embedded boulders and cobbles to the flood plain level.
- Any remaining rock may be stockpiled nearby for adjustments to the riffle and banks following the first few flood events, or used as boulder clusters at the base of the riffle at the entrance to the pool.
- The riffle should be inspected after the first significant flooding events. If significant shifting of rocks is observed, there are likely some deficiencies in the construction and/or design of the weir. These deficiencies will need to be corrected otherwise the weir will eventually fail.

The above technique requires detailed design and expert advice. Additional information can be found in the following documents:

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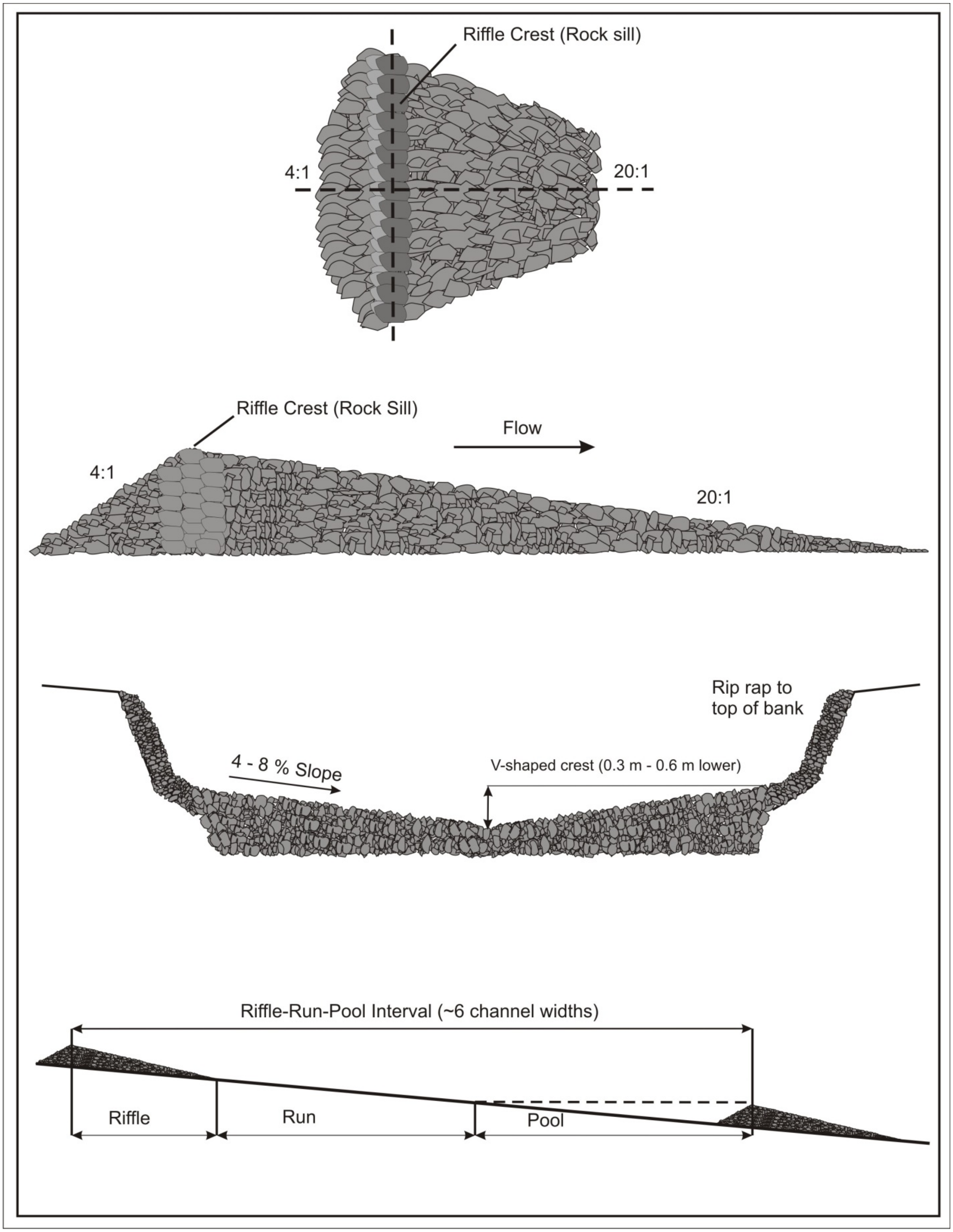

Figure 13. Drawings of a Newbury riffle (Modified from Slaney & Zaldokas, 1997; Newbury, 2013).

P4 – Rock Cross Vane Fact Sheet

Purpose

- To control the gradient of a stream and create scour pool habit below the weir.

Conditions where applicable

- Predominantly cobble or gravel streams that have low to moderate bedload transport with gradients less than 3%.
- Not recommended for sandbed streams.
- Should not be used in streams that are braided (has numerous channels that split off and rejoin each other) or actively meandering as the structure may be flanked.
- Usually placed in a straight section of a stream near the downstream end of a riffle where a pool would form naturally.

Advantages

- Can divert water away from banks and more to the centre of the channel.
- Can be made to look natural.
- Can aerate water.
- Controls the gradient of a stream and creates fish habitat in the process.

Disadvantages

- Can be barriers to fish during low flows.
- Can be a hazard to navigation.
- May require maintenance.
- May require dewatering and cofferdam or flow diversion.
- Requires detailed plans for approvals.
- Requires heavy equipment.

Habitat Created

- Mid-channel scour pool below the weir that provides overhead cover, resting areas, and over-wintering habitat for fish.

Design Criteria

- Considerable experience is required when designing these structures and, therefore, this rehabilitation project should not be carried out without the support of experts (e.g. aquatic biologists, engineers, and hydrologists).
- Typically consist of a double layer of stones in a U shape with the trough oriented upstream (Figure 14).

- Large angular rocks that will not move during the highest flows expected for the location should be used.
- Rock sizing depends on the debris and ice loading, depth of the stream, flow rate, location in the stream, and size of the stream and, therefore, it should be determined by a qualified individual.
- However, as a general guide, angular rock should have the following characteristics: 1 m in diameter or more, a minimum specific gravity of 2.5, and the smallest dimension shall not be less than 1/3 the greatest dimension of the rock.
- The largest rocks should be used in the exposed middle section of the weir.
- The middle of the weir should be perpendicular to the stream bank and flat (no slope) while the arms of the weir will be angled approximately 20 to 30^{o} relative to the streambank and extend downstream.
- The arms should rise to the channel forming elevation of the stream at a slope of 2 to 7%. The channel forming elevation should be determined by an expert but an approximation would be the elevation of the water during a 1.5 year event. A steeper slope (up to 15 %) for the arms may be used if required but it should be understood that this could negatively affect the stability of the weir.
- The arms will be the highest point of the weir (channel forming elevation) while the lowest point (desired height) will be the middle section of the weir.
- The middle section of the weir should be no higher than 15 cm above the streambed. To accommodate species other than salmon or trout, the maximum drop may need to be less than 15 cm. Vane rocks in the middle section of the weir can be gapped to allow fish passage but it is important to understand that the top of the footer rocks would then be considered the actual height of the weir for grade control.
- The bank key must be long enough and high enough to prevent water from flanking the structure and eroding it. The arms of the weir should be keyed into the bank a minimum of 1 m to prevent flanking during high flows. A more extensive design is required if the banks are frequently overtopped in that section of stream.
- Bank protection upstream and downstream of the weir should be considered particularly if the weir is skewed or located near a migrating bend as flanking will be exacerbated.
- If multiple weirs are to be installed to control gradient, then the spacing of the weir should be calculated by an appropriate expert as it will be dependent on a number of factors including the slope, length of back water effects created and associated depth, and length of thalweg created downstream. The most downstream weir must fit into the natural meander pattern of the stream.

Implementation Steps

- Prior to constructing the weir, measures must be taken to minimize stream disturbance and impacts to fish and, if necessary, isolate the work area from stream flows (e.g. dewatering and flow bypass or cofferdam).
- Excavate a trench along the bottom of the stream bed so that it is equal to or below the scour depth and just wide enough to contain the footer stones. If a scour analysis cannot be completed, the minimum depth of the trench needed can be estimated by multiplying the height of the rock vane above the stream bed by 2.5. For example, a 15 cm high rock vane will have a scour depth of 37.5 cm so the trench should be at least this deep.

- The trench should extend into the stream bank and should be deep enough to contain the desired number of courses (layers) of footer rocks as well as a portion of the vane rock.
- All of the footer and vane rocks should be positioned individually (i.e. do not dump a pile of rock). The long axis of the rocks should be positioned parallel to the streambank.
- Ensure all of the footer and vane rocks are interlocked and stable as possible otherwise the structure will fail.
- Place the first course (layer) of footer rock inside the trench interlocking it as much as possible.
- If a second course of footer rock is required, the second course of footer rocks should interlock with each other and should be placed so that each footer rock sits upon two halves of each footer rock below it. It should be offset in the upstream direction so that it slopes against the direction of the flow of the stream.
- Place the vane rock so that each one sits on the halves of two footer rocks below it and that it is interlocked with other vane rock. It should be offset in the upstream direction so that it slopes against the direction of the flow of the stream. Part of the vane rock should sit within the trench and the remainder should be no more than 15 cm above the stream bottom.
- The trench can be backfilled with cobble and any gaps in the footer and vane rocks should be chinked.
- The arms of the weir will slope up (2 – 7 %) towards the streambanks and should reach the channel forming level before being keyed at least 1 m into the streambank. Riprap should be used to armour the keyed sections of the arms.
- If finer substrate is present, the upstream portion of the weir can be sealed with filter cloth and then covered with rock and other substrate so that it is not visible.
- The weir should be inspected after the first significant flood event for evidence of undercutting and flanking. If significant shifting of rocks is observed, there are likely some deficiencies in the construction and/or design of the weir. These deficiencies will need to be corrected otherwise the weir will eventually fail.

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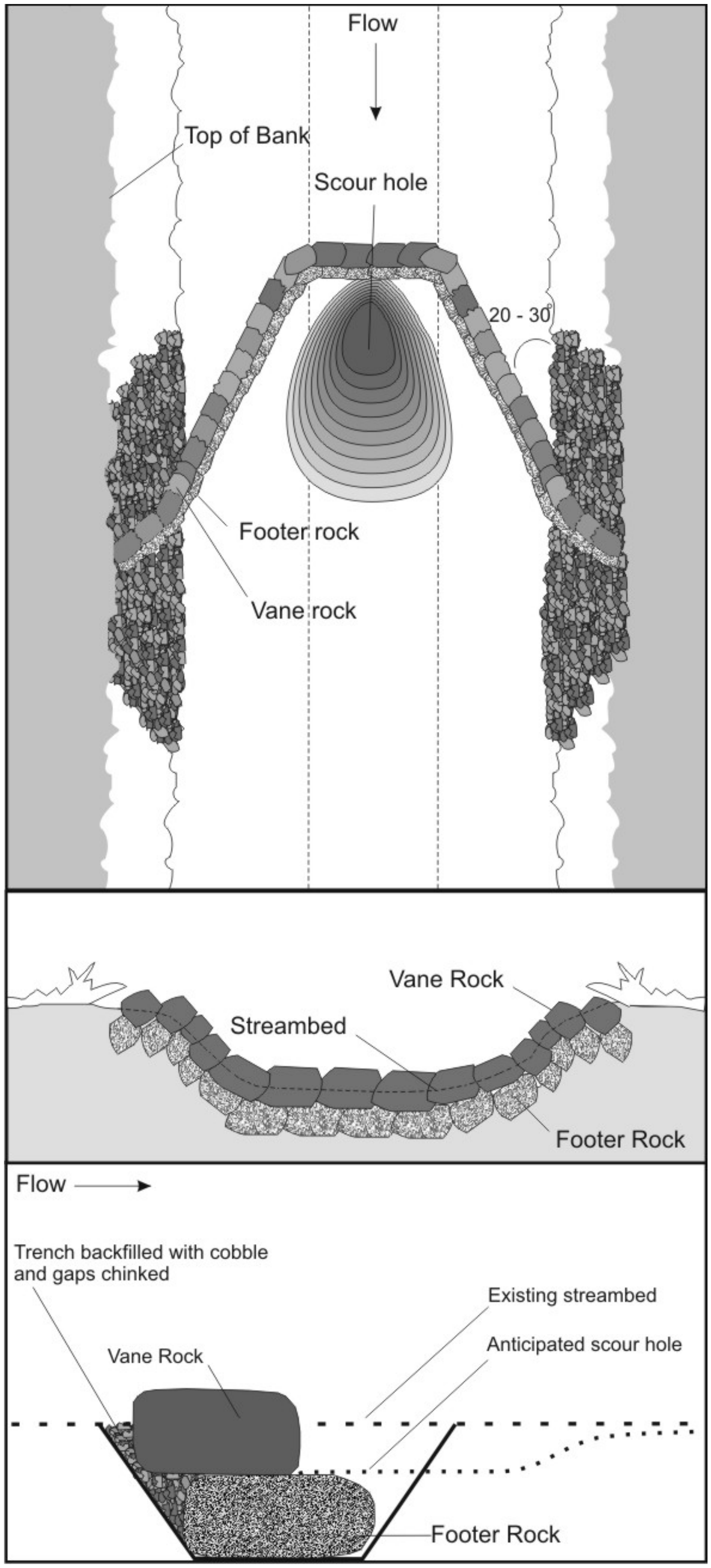

Figure 14. Drawings of a rock cross vane (Modified from Bastien-Daigle et al., 1991; Schueler et al., 2004; Renteria 2005).

P5 - Rock Sills Fact Sheet

Purpose

- To support a section of riffle upstream and create a pool downstream to enhance trout and salmon habitats and develop habitat diversity.
- Used to create stable deep water habitat in a stream.

Conditions where applicable

- In a section of stream with low to moderate grade (up to 2 %), with gravel or small cobble substrate, and where natural flows and currents can be allowed to shape the streambed.
- The rock sill acts as a gradient control holding the riffle/run substrate from falling into the pool. They are not intended to create a significant head difference and plunge pool.
- The sills serve the same function as the digger logs and can be found in natural streams. They can be scaled up for larger streams and rivers when suitable sized logs cannot be found.

Habitats Created

- Sorted substrate and pools that capture leaf litter and organics, support larger insect populations, provides better spawning and juvenile escape cover, and overwintering habitats. Sands and silt redistributed to point bars and the flood plain.
- Encourages the development of the thalweg between pools.

Advantages

- Uses natural processes to develop deep pools; the continuing scour will prevent pools from filling in.
- Helps develop a proper riffle/pool ratio and sorted gravels in disturbed streams.
- May be built with materials available at the site.
- Looks natural.

Disadvantages

- If not positioned, sized, and anchored correctly, rock sills will breach or wash away, do nothing, or further disturb habitat.
- If placed too high, may disrupt navigation in the waterway for small craft such as canoes.
- Requires machinery on larger steams and on rivers to move rocks into position.
- Can be done by hand on smaller streams but requires extensive manual labour.
- Disruption of substrate will cause turbidity and possible sedimentation of fine materials downstream.
- Does not provide the undercut cover that digger logs do.
- Maintenance can be higher than properly built digger logs in small streams.

- Access for materials and equipment can be difficult.

Design Criteria

- Considerable experience is required when designing these structures and, therefore, this rehabilitation project should not be carried out without the support of experts (e.g. aquatic biologists, engineers, and hydrologists).
- The channel at the site of construction should be a single, main channel with cobble/gravel substrates and stable vegetated banks.
- For best results, the rock sill should be placed at the head of a natural pool. These occur approximately every six channel widths based on the width of a 1:2 year daily peak flow flood channel (bankfull width) and on alternating sides of the stream.
- Large angular rocks that will not move during the highest flows expected for the location should be used.
- Rock sizing depends on the debris and ice loading, depth of the stream, flow rate, location in the stream, and size of the stream and, therefore, it should be determined by a qualified individual.
- The sill should be constructed perpendicular to the stream or rotated to a 30^{o} angle from straight across the stream and when looking downstream, turned toward the side the pool is on (Figure 15).
- The sill should be at streambed level at the thalweg for 10 % of the channel width. It should then rise on a 3 % (34:1) slope to the width of the design channel then 10 % (10:1) to the banks of the existing channel.
- The structure should be keyed into the bank a minimum of 1 m to prevent flanking during high flows. Bank protection should be considered upstream and downstream of the rock sill.
- The thalweg and channel design width section of the rock sill can be moved from side to side in an over-widened channel to increase meander length, lower gradient, and help dig deeper pools. Alternately, they can be aligned to maintain the existing gradient depending on needs.
- A rock sill works with the stream flow to sort gravel and shape pools and riffle thalweg. This typically takes two to three years to fully form.
- A rock ramp should be built on the upstream side, sloping the stream bed up to the sill on a 20:1 ratio.
- Rock sills and ramps need periodic maintenance until the stream has achieved its new form and vegetation has stabilized the new banks.

Rock Sills (to create riffles)

- Rock sills are really gradient controls. To dig and develop pools they are used in the same way as digger logs. However, they can be used in other locations in the watercourse to achieve different results.
- When a river gradient is changed by realignment, channelization, or over-widening of a reach, the stream bottom cuts back or degrades to find a new stable slope and to provide material to rebuild the reach below. In this case, the altered section of stream needs to be

rebuilt but sills can also be used at the crests of riffles to stop them from degrading faster or to restore their original height.

- The design of the sill is the same as if it was at the head of a pool with the thalweg on the same side as the pool adjacent to and above it.
- In steep streams with a step-pool pattern, rock sills can be used to step the watercourse down over steep sections.

Implementation Steps

- Prior to constructing the rock sill, measures must be taken to minimize stream disturbance and impacts to fish and, if necessary, isolate the work area from stream flows (e.g. dewatering and flow bypass or cofferdam).
- Excavate a trench along the bottom of the stream bed so that it is equal to or below the scour depth and just wide enough to contain the footer rocks.
- The trench should extend into the stream bank and should be deep enough to contain the footer rocks as well as a portion of the vane rock.
- All of the footer and vane rocks should be positioned individually (i.e. do not dump a pile of rock). The long axis of the rocks should be positioned parallel to the streambank.
- Ensure all of the footer and vane rocks are interlocked and stable as possible otherwise the structure will fail.
- Place the first course (layer) of footer rock inside the trench interlocking it as much as possible.
- Place the vane rock so that each one sits on the halves of two footer rocks below it and that it is interlocked with other vane rock. It should be offset in the upstream direction so that it slopes against the direction of the flow of the stream. Part of the vane rock should sit within the trench. The sill should be at streambed level at the thalweg for 10 % of the channel width before rising from the stream bottom.
- Key the rock sill into the bank a minimum of 1 m in order to prevent flanking.
- Cobble and large rocks armouring the surface should be removed from the pool area to assist the scour by the flows.
- When the pool has formed, the cobble and large rocks, removed initially, may be replaced to provide juvenile instream cover as needed.
- The rock sill should be inspected after the first significant flood event for evidence of undercutting and flanking. If significant shifting of rocks is observed, there are likely some deficiencies in the construction and/or design of the sill. These deficiencies will need to be corrected otherwise the sill will eventually fail.
- Structure must be checked regularly to make sure it is still functioning correctly.

The above techniques require detailed design and expert advice. Additional information can be found in the following documents:

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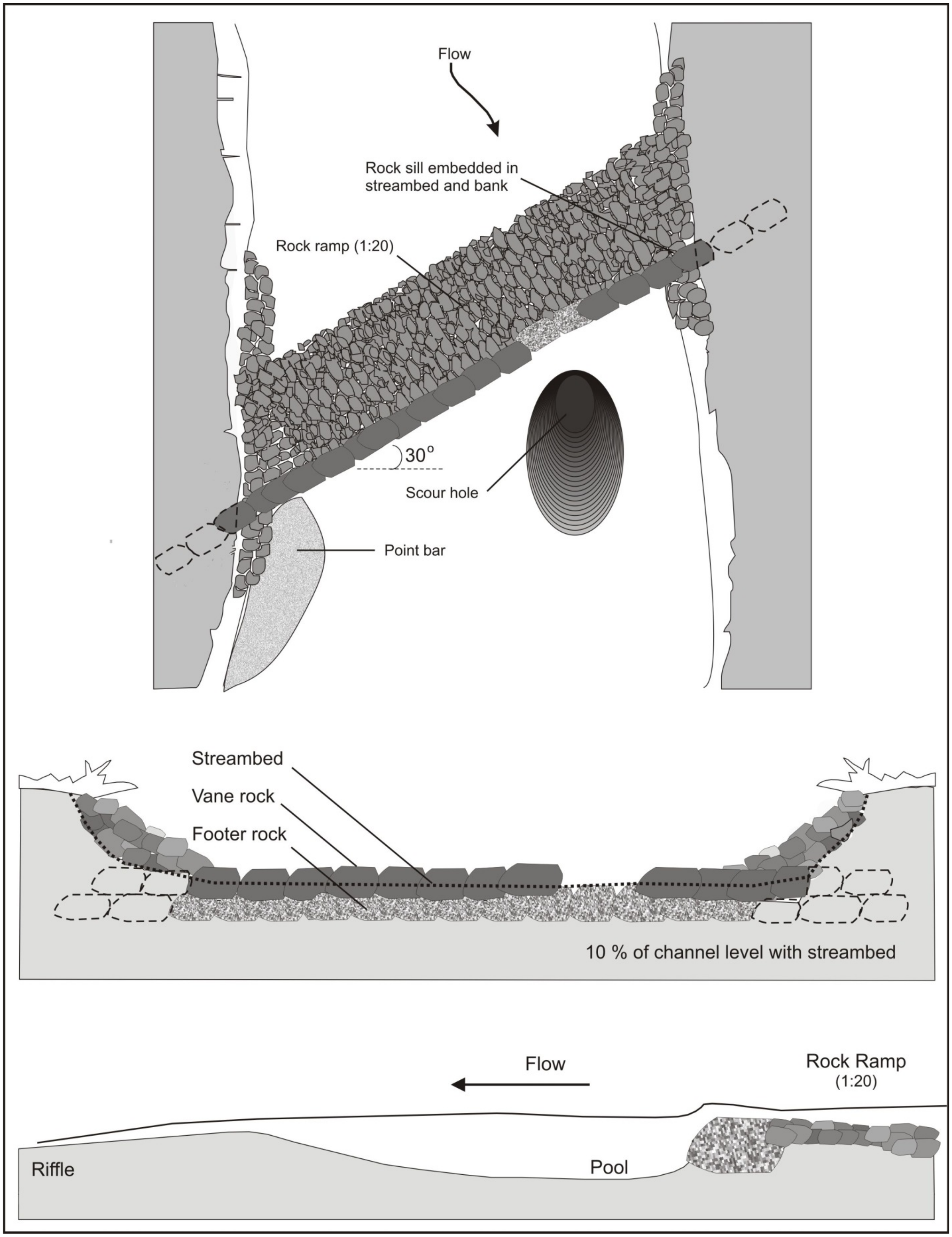

Figure 15. Drawings of a rock sill (Modified from Melanson et al., 2006).

6.5 Removal of Debris and Obstructions

R1 - Beaver Dam Removal Fact Sheet

Purpose

- To breach or remove beaver dams in order to provide fish passage.

Conditions were applicable

- Streams that have beaver dams that are negatively impacting fish populations by preventing fish movement. Note: Not all beaver dams are fish passage problems under normal migration flows.
- The decision to remove beaver dams should be made in consultation with your local wildlife biologist.

Habitats Created

- Restores habitat to its former condition prior to the construction of the beaver dam.

Advantages

- Allows fish to move upstream and downstream.
- Restores flow, sediment transport, and temperature regimes in the stream.

Disadvantages

- Active dams are rebuilt quickly unless beaver population is managed.
- Can release sediment and large volumes of water downstream resulting in negative impacts to fish and the streambank (e.g. erosion).
- Drains a pond that may be important summer refuge and overwintering habitat for fish.
- Removes a structure which can help to stabilize flows in a stream.

Design Criteria

- Carefully review provincial guidelines, as they could vary among provinces. Contact your local provincial wildlife biologist for more information regarding the removal of beaver dams.
- Carry out the work according to guidelines, permits, or direction from a provincial wildlife biologist.
- Time the removal to prevent disruption to sensitive fish life stages by adhering to appropriate fisheries timing windows.
- Remove the dam by hand or light machinery whenever possible.

- It is preferable if the beaver dam is not removed in the winter as overwintering fish habitat will be lost in the upstream pond and it may result in the discharge of water devoid of oxygen downstream.
- To be effective, other beaver management techniques must be used in conjunction with beaver dam removal otherwise the dam will be repaired quickly. Trapping will remove the beaver in the short-term but other beavers may move into the area and build another dam. To stop beaver from rebuilding, beaver should be cut off from the stand of trees they are using in the area.
- Beavers have been known to forage as far as 100 m from the water's edge but most of their cuttings will occur closer to the shore. To prevent beavers from cutting down trees, 5 cm x 10 cm welded wire fencing can be used to encircle trees within at least 50 m of the water's edge. Each cage should be at least 1.2 m high and a space of 25 – 30 cm should be left between the cage and the tree so that it has space to grow. Stakes should be used to anchor the cages to the ground.
- 1.2 m fencing can also be installed around a stand of trees. The fence should be installed between the trees and the stream. It does not necessarily have to enclose the entire stand.

Implementation Steps

- Remove the beaver and implement measures to prevent other beaver from using the trees in the area (i.e. cages or fencing).
- Before starting work, install effective sediment and erosion control measures to prevent the entry of sediment into the watercourse due to machinery operation or other activities that disturb the bank during the removal project. Inspect them regularly during the course of construction and make all necessary repairs if any damage occurs.
- If blasting is required, individual detonations should be minimized (no more than one kilogram and preferably smaller). If larger charges are required, contact DFO prior to commencing the work.
- If machinery is required, operations should be conducted in the manner described in Section 5.2.
- Remove the dam gradually (~20 cm at a time) to allow the water to release slowly and prevent sediment at the bottom of the pond from being released downstream. As the water levels drop in the upstream pond, increase the size of the opening to drain the pond to the desired level. The width of the breach opening of the beaver dam should not exceed the width of the original stream channel to prevent bank erosion and flooding of adjacent properties.
- When a series of dams is to be removed, this should be done from downstream to upstream in order to avoid severe flooding and damage to fish habitat.
- Relocate any fish that become trapped in isolated pools or stranded in newly flooded areas to the main channel of the watercourse.
- Ensure that all waste material is removed from the work site and moved to a location where they will not re-enter the stream.
- Vegetate any disturbed areas by planting and seeding with native grasses, shrubs, or trees and cover such areas with mulch to prevent erosion and to help seeds germinate. If there is insufficient time remaining in the growing season, the site should be stabilized (e.g.,

cover exposed areas with erosion control blankets to keep the soil in place and prevent erosion) and vegetated the following spring.

- Maintain effective sediment and erosion control measures until re-vegetation of disturbed areas is achieved.

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R2 - Man-made Debris Removal Fact Sheet

Purpose

- To remove man-made debris that may contaminate water, hinder fish passage, or alter the stream's hydrology.

Conditions where applicable

- Any area that contains material foreign to the normal composition of a watercourse. Examples of debris include car bodies, containers, litter, shopping carts, and tires.

Habitat Created

- None

Advantages

- Aesthetically pleasing.
- Can remove contaminants.
- Can prevent bank erosion.
- Can permit fish passage.

Disadvantages

- Can remove important cover.

Design Criteria

- Precautions must be taken to ensure any contaminants such as oil do not leak out during removal.
- Care must be taken not to damage stream banks when removing heavy objects.
- If the debris has remained in the watercourse for a long period of time, it may have become so deeply embedded that removing it may cause more damage than leaving it in place.

Implementation Steps

- All garbage should be disposed of according to local, municipal, and/or provincial procedures and in approved dumps.
- No heavy equipment (e.g. bulldozers, tractors, or backhoes) are allowed in the watercourse or on the banks to carry out the work.
- Material should be winched out of the streambed by machinery or equipment stationed away from the edge of the bank of the watercourse.

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R3 - Woody Debris Jams Fact Sheet

Purpose

- To remove excess branches, logs, and fallen trees that are preventing fish passage or adversely altering the stream's hydrology.

Conditions where applicable

- Large woody debris plays a role in the development of fish habitat and provides instream cover. Excessive amounts of large woody debris should only be removed when they significantly:

    - Become a barrier to fish migration.
    - Cause bank erosion.
    - Flood adjacent lands.
    - Increase ice jams.

- Small streams and those with low gradients are more likely to benefit from the selective removal of woody debris compared to larger streams and those with higher gradients.

Advantages

- Can prevent bank erosion.
- Can permit fish passage.
- Can help with the navigation of streams.

Disadvantages

- Can reduce channel stability, increase flows, and cause erosion of streambed and banks.
- Can remove important cover for fish and other aquatic organisms.
- Loss of spawning sites.
- Removal of pool habitat formed by debris dams and scouring.

Design Criteria

- Unless large woody debris is having a significant adverse effect on a stream or fish population, it should not be removed.
- If the debris has remained in the watercourse for a long period of time, it may have become so deeply embedded that removing it would cause more damage (e.g. sedimentation or erosion issues downstream) than leaving it in place.
- If fallen trees are securely fastened to the banks of a watercourse, it is recommended that they be left in place as the root systems may be preventing erosion of the bank.
- If some large woody debris must be removed, "a clean and open" approach should be considered. By only creating an opening in the debris jam, localized flooding and erosion

can be reduced and fish habitat and other benefits (e.g. flow reduction/gradient control) of the debris jam can be preserved.
- If removing all of the large woody debris is necessary, it should be done slowly and sedimentation controls should be in place downstream.
- Debris removal should only be done during low flow periods (e.g. late summer, autumn).

Implementation

Clean and Open Method

- Remove any man-made debris that has accumulated at the debris jam.
- Loose, floating logs are removed to create an opening in the debris at the centre of the stream flow. A handsaw or chain saw can be used to create an opening if required.
- Do not disturb any anchor points. Rooted or embedded stumps and/or logs should not be removed. Branches near the streambank should be left intact.
- Branches that are near or extend above the water surface should be cut off so they do not trap smaller pieces of free floating debris. Branches from overhanging trees which would also catch debris floating in the watercourse should also be trimmed.
- Branches and woody debris should be either disposed of or placed well above the flood plain so that it does not re-enter the stream and cause a jam elsewhere.

Complete Removal

- Effective erosion and sediment control measures should be installed before starting work to prevent sediment from entering the water body.
- Remove any man-made debris that has accumulated at the debris jam.
- Starting on the upstream side, remove any loose branches.
- Cut off any large branches prior to removing the entire log. If branches underneath the water need to be cut, use caution as the debris jam may shift suddenly.
- If suitable, the logs may be salvaged for other stream restoration projects. Otherwise, cut the logs into smaller pieces for easier removal.
- Removing the debris jam should be down slowly otherwise large quantities of sediment may be released quickly.
- If heavy equipment is required, it should be operated in the manner described in Section 5.2.
- Branches and woody debris should be either disposed of or placed well above the flood plain so that it does not re-enter the stream and cause a jam elsewhere.
- If several debris jams must be removed, start downstream and then work upstream.
- Any areas that have been disturbed by the operation should be restored.
- The area should be monitored for a year to determine if there are any erosional issues within the vicinity and downstream of the original debris jam.

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