Habitat Assessments and Restoration Prescriptions for the "Upper and Lower Car-body Run" of the Salmo River

For

Salmo Watershed Streamkeepers Society
Salmo, B.C.

by

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Statement of Limitations

Habitat assessments and prescriptions are based on experience gained from seven years of extensive applications for the Watershed Restoration Program (1994-2001) and Greater Georgia Basin Steelhead Recovery Project (2002-2004). The success and stability of implemented prescriptions is dependant upon adherence to established best management practices. Further, because the Salmo River at the “upper and lower car body runs” are associated with private agricultural and mine lands, prescriptions should be reviewed on-site with a qualified hydraulic engineer with related experience with instream (triangular) large wood and boulder habitat/bank stability structures. In addition, a legal covenant should be established with any landholders that approve streambank stabilization of their riparian lands using prescribed large wood structures. Although such structures have been highly effective in applications throughout BC, including a 2.5 km reach of the West Kettle River (20 km north of Westbridge), there can be flood-risks associated with bank stabilization measures.

Cover Photo: Upper car-body run at the lower Salmo River on August 17, 2004

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Executive Summary

During mid-August of 2004, the condition of salmonid habitat in the Salmo River was assessed for 1.9 km using the Fish Habitat Assessment Procedure within what is known locally as the “upper and lower car body runs”. Habitat restoration prescriptions were also completed simultaneously over a distance of 1.9 km.

This lower reach of the Salmo River consists of simple riffles and flat glides interspersed with more complex turbulent glides as well as several pools. Pools, as primary pools equated to only 22 %, which is low, but if turbulent glides plus small pocket pools in riffles are included, pools rated as fair (flat glides excluded) in percent area and frequency. Frequency of functional large woody debris (LWD), a key habitat and cover feature, ranged from fair (upper section) to good (lower section) in frequency. Yet, pieces of large wood were mainly of smaller basal diameters, reflecting the young riparian forest. Unfortunately, the quality of fish habitat cover in the reach rated as poor (overhead cover and boulder cover) to fair (LWD in pools), with the latter approaching a poor rating.

The entire channel in the upper to lower car-body reach is in an unnatural vegetative state because the riparian forests of both sides of the river were historically logged or cleared to the riverbanks, and the left bank is dyked for approximately 1 km, both affecting channel geomorphology. The long-term supply of larger LWD to the channel has been reduced, thereby impacting the quality of salmonid habitats, especially salmonid cover. Accelerated bank erosion is evident under these conditions. Natural habitat recovery is at least 50 years into the future without stream restoration, and there is a significant risk that erosion will advance into the existing mine tailing piles on the east side of the river, particularly in the upper car-body-run.

Twenty five triangulated LWD habitat structures plus three sets of parallel rootwads or whole trees were prescribed, each well ballasted to assure stability. These ballasted LWD structures provide fish habitat, as well as substantive bank stabilization where bank erosion is evident within the reach. Because of back eddies at the upper car-body run, additional placements of single whole trees plus some rip-rap against the eroding bank behind the proposed LWD structures is advised. Phasing of works over 2 to 3 years is recommended to ensure the more urgent upper car-body section is completed rapidly.

Such streambank and channel-attached triangular structures, when hydraulically designed according to D’Aoust and Millar (1999, 2000), have had very high physical and biological success rates, as documented in Wilson et al. (2002). Boulder ballasting acts as a secure replacement for the very large root masses that anchor old growth large wood in unlogged natural old-growth channels. Compared to conventional rip-rap armouring/dyking, there is not a loss of fish habitat, but rather a substantial net gain.

Rehabilitation of mainstem habitats in the “car-body reach” would reduce the risk of mine tailings entering the river, and would be beneficial to fish biodiversity, significantly increasing the abundance of rainbow trout and bull trout char. Structures are expected to be functional over a 20-40 year time horizon until further riparian recovery, provided large wood is 0.5 m (>1.5 ft) in basal diameter, and preferably cedar or larch. Large wood complexes also cause re-sorting of transported sediments and accumulate wood debris and leaf litter that improve productivity of fish food chains, the latter confirmed by woody debris removal experiments.

1. Introduction

Historically, there has been extensive mining activity, land clearing and forest harvesting since the late 1800s in the Salmo River watershed. From the later part of 1800s to the mid-1950s, mining activities were the primary economic activity in the Salmo watershed as documented in Heinbuch and Nellestijn (2000). Coinciding with decreases in mine ore and in precious metal prices by 1950, mining in the watershed declined except for some base metal mining. Past mining activity is most evident from remnant mine tailings deposits located near the Salmo River and some of its tributaries. One of the larger deposits is located adjacent to the highway and river about 10 km south of the town of Salmo, where Canadian Exploration Limited's lead-zinc mining and milling operations were active from 1949 to 1970 (and small mining and milling operations since 1917) .

As in many other areas in the Pacific Northwest, historical practices of riparian logging or clearing along the Salmo River has resulted in losses of large wood and log jams along river banks and at apexes of side-channels. This process has accelerated riverbank erosion, which has led to river dyking and channelization, in many of the lower reaches of the Salmo River.

Such activities can greatly affect river geomorphology and thereby result in significant losses of fish habitat, including flood shelters and cover features (Slaney and Zaldokas 1997). The mainstem of the Salmo River supports regionally significant populations of rainbow trout and bull trout char. Westslope cutthroat trout, brook trout and mountain whitefish are also reported (from the provincial data warehouse) in some waters of the Salmo watershed. Several other non-salmonid species also inhabit the river, including longnose sucker, large scale sucker, redside shiner, slimy sculpin, and northern pike minnow. In British Columbia, the typical life history pattern for inland river trout and char is spawning in tributaries and rearing there for 1-3 years prior to further rearing to adults in the mainstream. Yet, recent radio tracking studies have indicated that trout spawning occurs in the mainstem of the Salmo River, especially among larger trout and char (G. Nellestijn personal communication 2004). Thus, quality of habitat in the mainstem is ultimately important for all their life stages.

The Salmo River is a sixth order stream that flows into Pend d'Oreille Reservoir near the USA border, and the meander-bend banks of such large streams are subject to bank erosion. Stream magnitude is relatively large (367) because there are 29 significant tributaries with high elevations throughout the river's length of 61 km. Mean annual flow at Salmo is 32 m^3/sec (Water Survey of Canada summary of 1988). The lowest mean monthly flow is 8 m^3/sec, which occurs in August and September, as well as in January and February. The highest mean monthly flow occurs in May, which has averaged 123 m^3/sec up to 1988, but extreme peak flows are much greater (up to 200 m^3/sec). In such a large stream, mature riparian forests with large trees and root masses provide substantial erosion resistance at river banks compared to young trees.

An example of an unstable reach in the lower Salmo River is "the upper and lower car body run" where the east bank of the river was dyked with rip-rap for a distance of 1 km to stabilize Canadian Exploration's tailing site in the 1950s. A combination of past riparian logging, clearing and dyking has led over the long term to channel destabilization. To reduce the further risks of tailings erosion, in the 1960s the company secured several car bodies within two sub-sections using methods described by Brown (1963) at the upper run. However, over the past 40 years, many of the car bodies have decayed or were displaced downstream, and further bank erosion of several meters has occurred into a riparian zone of the existing pole sapling to young forest. In addition, the opposite (west) riparian banks comprised of young forest have eroded up to 10 meters during high flood events.

The purpose of this report is to summarize fish habitat assessments (FHAP) and habitat restoration prescriptions that were undertaken during mid-August, 2004 in the lower reach of the Salmo River at the "upper and lower car-body runs". These surveys were initiated after the Salmo Streamkeepers Society identified gradual destabilization of car-body dyked banks along the Canadian Exploration's tailing site.

2. Methods

2.1 Fish Habitat Assessments

On August 17-18, 2004, the Fish Habitat Assessment Procedure of the Watershed Restoration Program (WRP) (Johnston and Slaney 1996) was undertaken at a 1.9 km lower reach adjacent to the mine tailings site (Figure 1) which has been inactive for about 35 years.

The Fish habitat assessment procedure (FHAP) originated in the Pacific Northwest for quantitatively assessing the effects of past logging activities on forested streams (Schuett-Hames et al. 1994). The procedure was adapted for use in British Columbia (Johnston and Slaney 1996), and ideally it should be applied using diagnostic data collected from old-growth forested watersheds similar to the targeted watershed. Where diagnostic data is unavailable, which is typical, generic diagnostics are utilized (Table 5 in Johnston and Slaney 1996). During the Watershed Restoration Program (WRP) of 1994-2002, an unpublished evaluation of the technique by the Ministry of Water, Land and Air Protection provided support for its use, particularly for the large wood diagnostics. The procedure was developed mainly for small to medium sized streams in the order of 15 m channel widths, but past experience in WRP indicated that it applies well to large alluvial channels in the range of 50 m channel width. Some limitations are associated with percent pool and pool frequency ratings, but this can be resolved by including glides with primary and pocket pools as an additional rating. The procedure is also designed to identify opportunities for restoration or for offsetting impaired conditions and lost habitats.

Hydraulic units at base summer flows were separated into riffles, glides and pools. Glides were subdivided further into glide flats and glide flat-runs and pools into pools and runs, to improve designation of prime turbulent trout habitats versus more marginal non-turbulent habitats. Several physical characteristics were measured with a meter rod and a laser range finder, the latter accurate to + or - 1.0 m. Measurements included lengths of hydraulic units (riffle, glide pool), bankfull width, wetted width, bankfull depth, mean wetted depth, maximum pool depth, and residual pool depth. Channel type was also classified according to Table 1 in Johnston and Slaney (1996), which was riffle-bar-pool in the lower Salmo River.

Figure 1. Airphoto of the lower Reach of the Salmo River, with arrows indicating the surveyed river segment (scale 1cm ~ 170 m; flow direction is north to south or from the left to right of the air photo; the first pool -at arrow - not in the photo). The surveyed reach is located 10-11 km south of the town of Salmo (located 40 km west of Nelson and Trail.

Estimates of several other features were made by a well-experienced riverine habitat specialist. Parameters included dominant substrate size, sub-dominant substrate size, gradient, surface velocity, percent total cover, percent boulder cover, percent large woody debris (LWD) in pools, and cover types per habitat unit.

Total large wood, defined as all wood >2 m in length and >10 cm in diameter, was counted within the bankfull channel. Functional large wood was that which influenced the nature of the hydraulic units in terms of scour and salmonid cover, and LWD was counted by size category according to basal diameters of 10-20, 20-30, 30-40, 40-50 and >50 cm.

In the riparian zone on each bank, dominant trees were classified as pole sapling (including shrub), young forest, and mature forest. The zone was also classified as deciduous, conifer or mixed structure, and the percent canopy closure over the river was visually estimated.

Further, within each hydraulic unit, percent useable parr to adult habitat was assessed by visually estimating useable depths and velocities criteria from experience. Based on velocity measurements at a sample of riffle transects in the Capilano River in 2002, visual estimates approximated measured useable parr habitat.

Values of the various parameters were converted to those required for FHAP diagnostics as percent pool, pool frequency or spacing per channel width, total large wood per channel width, functional large wood per channel width, percent woody debris in pools, percent boulder cover in riffles, percent total cover and substrate quality.

2.2. Streambank Stabilization and Habitat Prescriptions

Fish Habitat rehabilitation prescriptions largely followed Slaney and Zaldokas (1997) including chapters by Cederholm et al., Newbury et al., Slaney et al. and Ward (1997). The primary large wood structure prescribed is the lateral triangle design owing to its high stability (Slaney et al. 1997). The fixed triangle attached to streambank trees (or very large boulders) resists frontal hydraulic drag forces, and sufficient boulder ballast on the apex offsets buoyancy forces. Further research data and hydraulic computations are described in detail in D'Aoust and Millar (1999) and D'Aoust and Millar (2000).

Minor design modifications reflect more recent experience gained with these and related structures at the West Kettle, Keogh and Seymour Rivers. For example, in addition to the two logs or rootwad-logs that form the triangle of the structure, two additional logs are employed to provide a ballasted ramp to collect driftwood, as a "hybrid" between a "debris groin" and a "lateral triangle structure". At the same time this ensures that the streambank is armoured with large wood and ballast boulders. On bank heights of 2.5 to 3.5 m at Salmo River, where erosion control is the primary objective, the anchored log/rootwad triangle is positioned on the floodplain, rather than on the bank slope as with most triangular rootwad or log structures. The apex of the triangle is thereby extended out 5 m over the river, to support a set of sloping ramp logs that collect woody debris. In-filling of the ramp logs with driftwood shifts the river thalweg away from the streambank. *Pre-loading* the ramp logs with woody debris is advised to minimize any bank erosion during collection of driftwood during the spring freshet. Further design details are provided in "Standard Habitat Structure Designs" within the Results section.

At the upper car-body run, a detailed elevation survey was also conducted with an engineering level, rod and chain to obtain bank heights, slope lengths, slopes, and water depths at the toe of the slope. These were tabled to depict elevation contours for LWD structure prescriptions, assuming removal of the remaining car bodies (about 30). The objective is two-fold:

- arrest further bank erosion into dyke/mine fill, and
- provide replacement habitat for rearing salmonids and other fishes.

3. Results and Discussion

3.1 Fish Habitat Assessments

A distance of 1.9 km was assessed and prescriptions completed to holistically incorporate both upper and lower car body runs including associated river meander bends (Figure 1). The reach surveyed was from the upstream boundary of integrated rock and LWD bank stabilization works completed in the past five years (about 300 m in length) that were designed to prevent the Salmo River from shifting towards the north end of the mine tailings deposit. These successful semi-natural works terminate at a large pool where the present assessment was implemented in a downstream direction for a targeted distance of about 2 km.

3.1.1. Habitat Ratings:

Twenty two habitat units, including two riffles and two glides as repeating variable-gradient units, were assessed, and mean overall channel and wetted widths were 60 m (range 30-100 m) and 26 m (range 14-39 m), respectively, at an estimated flow of about 3 m^3/sec on August 16-17, 2004 (Appendix 1). The upper car body section of 1 km averaged 61 m in channel width and 27 m in wetted width, whereas the lower car body section of 0.9 km averaged 58.5 m and 23 m, respectively.

Overall, riffle, glide and pool comprised 34 %, 45 % and 21 %, respectively, with the lower section dominated more by glides with only one large pool, and the upper section comprised of a near equal mix of riffles (6), glides (4) and pools (4, including a run).

Habitat depths were moderate, with an estimated mean depth of 0.68 m, which ranged from 0.2 (riffle) to 2 m (pool). Mean maximum depth was 1.1 m and ranged from 0.4 (riffle) to 3.5 m (upper car-body pool). Mean bank-full depth of all habitat units was 2.5 m, and ranged from 1.3 m to 3.5 m.

Substrates were dominated by cobbles throughout the 1.9 km reach, with boulders mainly where banks had been dyked. Mean estimated dominant substrate size in all habitat units was 0.15 m and ranged from 0.02 to 0.3 m. Mean sub-dominant size was 0.17 m and ranged from 0.05 m to 0.5 m, with this range most evident in the upper-most pool.

Average estimated gradients varied highly from 0.01 % (pool) to 0.8 % (riffle), with an average gradient of 0.25 %, or 0.28 % and 0.19 % in the upper and lower reach, respectively. Estimated average velocity was 0.4 m/sec during mid-August flows.

Overall, percent pool (including runs) by area was 22 %, but if all glides were included as equivalent to shallow pools, “pools” were 74% by area. Inclusion of eight pocket pools in riffles increased pool area to 75 %. Therefore, percent pool plus glide was >55 % within the habitat diagnostics provide in Table 5 of Johnston and Slaney (1996), and thus rated as *good*, although such pools were dominated by glides. Pool-glide frequency rated good as 2 channel widths per pool plus glide (plus pocket pools). However, three long glides were large featureless flats, and thus if these are excluded, then percent pool (plus glide) was 41 % and pool frequency was > 2 channel widths per pool. *Thus pool ratings, including glides and pocket pools rated in the fair-good category (Table 1).*

As primary habitat and cover features, large wood in the channel was mixed in abundance. Total pieces of large wood in the 1.9 km length of channel equated to 2.5 per channel width. Functional large wood, affecting the channel geomorphology or providing fish habitat cover, was 2.34 pieces per channel width. Thus, overall functional large wood rated as *good* quality over the 2 km. However, much of the large wood was in the lower section, and the upper 1 km reach contained only 1.8 pieces of functional large wood per channel width, which only rated fair. Further, only 45 % was >30 cm basal diameter, with only 16 % > 40 cm. All 22 habitat units were associated with young forest or pole sapling, and dominated by mixed deciduous and conifer on the right bank and pole sapling on the left bank. *Thus, functional LWD frequency (Table 1), reflected limited large wood recruitment from the young riparian forest, resulting in the upper section rating as only fair.*

Overall, fish habitat cover was sparse. Total cover over the 1.9 km averaged 8.3 % and was similar in the upper reach (8.8 %) and the lower reach (7.6 %). Of this, boulder cover averaged only 1.7 % (section range, 1.4 to1.9 %), and as a diagnostic, riffles boulders averaged only 1.1 %, and *thus, boulder cover rated as poor.* Mean percent woody cover in pools as another cover diagnostic was low or only 7.2 %, and thus rated as only *fair* quality habitat and close to *poor (<5 %) (Table 1).* With glides included with pools, percent woody debris was *poor* (4.5 %). Overstream vegetative and woody cover was also observed to be low at 3.6 %, or *poor quality. Thus, cover was generally of poor quality in the reach, and especially in the upper reach.*

In contrast to the poor habitat cover, side-channel development was moderately abundant as a result of a 1 km of side-channel associated with the tailings heap.

However, velocities were low and water quality appeared contaminated by tailings drainage. Thus, side channel quality was rated as *poor*.

Interstices of stream substrates were moderately in-filled with some fine sediments from eroding banks, but not to the degree that rearing habitat was not viable; instream boulder and woody debris provided over-wintering spaces for trout and char where velocities and depths were sufficient.

Table 1. Fish habitat characteristics and ratings for car body reach of the lower Salmo River (from Table 5 of Johnston and Slaney 1996)

Habitat Parameter	Reach Amount	Rating	Target (good)
Percent Pool+Glide	75	Good	>55
Percent Pool+Glide (3 flats excluded)	41	Fair	>55
Pool plus Glide Frequency	2.0	Fair-Good	<2
Pieces of Functional LWD/ Channel Width:	Upper 1.8 Lower 3.0	Fair Good	>2 >2
Percent Woody Cover in Pools	4.5-7.2	Poor-Fair	>20
Percent Boulder Cover in Riffles	1.1	Poor	>30
Percent Over-head Cover	3.6	Poor	>20

Indicators of disturbance were common either as considerable erosion of banks or from rip-rap and car-body dyking which has provided limited habitat. Ironically, more rearing space per unit area was likely provided within car bodies than within rip-rap because of the latter's interlocking nature. Past logging/clearing of riparian areas was another indicator of disturbance.

Mean estimated trout rearing habitat (parr to adult) was only 6.4 %, and ranged from 5 % to 7.2 % in the two sections. This estimate confirms the marginal quality of salmonid rearing habitat in reach; regardless of a moderate frequency of pools and glides, the sporadic distribution of large wood and other cover provided sparse habitat overall.

In summary, addition of large woody debris and large 0.5-1 m^3 boulders would be beneficial, not only for erosion control/stabilizing of streambanks, but to provide prime trout habitat which is sparse owing to simplification and limited cover over the 1.9 km distance, and particularly in the upper section.

3.1.2. Habitat Rehabilitation Prescriptions

Habitat restoration prescriptions were focused on large wood structures in riffles and glides which lacked adequate depth and cover for sustaining rearing salmonids in both summer and winter. Prescriptions are as listed in Table 2, using distance (m) from starting points (all sites flagged). Site locations are also provided in Appendix 1 photos, and FHAP data is tabled in Appendix 2.

The layout of the proposed LWD structure sites within the reach, as well as natural log- jams and rip-rapped dyked sections, are provided in Figure 2 and 3. Conceptual drawings of the proposed two-rootwad triangle structure (with ramp logs), the triangulated debris groin structure (with ramp logs), and the parallel rootwads are provided in Figure 4, 5, 6 and 7.

Table 2. Site locations and rehabilitation prescriptions in the upper and lower car-body reach of the Salmo River. Distance is to the downstream end of habitat unit, and the starting point is top of large pool at downstream end of past bank stabilization works (habitat unit features and UTMs are provided in Appendix 2):

Habitat Unit No. & Distance		**Habitat Prescriptions** *Notes: 1. "Preload" refers to placing or securing woody debris on the structure ramp logs to improve functionality/erosion proofing until naturally load with driftwood:* *2. reach prescriptions progress from upstream to downstream.*
1	120 m	**120 m Pool:** one 2-rootwad triangle with 3 ramp logs: ***preload***: right bank at tail-out of pool at top of riffle
2	160 m	**40 m Riffle:** 1 triangulated debris groin with 3 ramp logs: right bank: ***preload*** ,plus 1 small triangulated debris groin at left bank to dry bar
3	233 m	**78 m Glide:** 2 triangulated debris groin with 3 ramp logs: right bank: ***preload***
4	272 m	**39 m Riffle:** Nil: cross-over riffle-bar
5	357 m	**85 m Riffle** (on mine tailings dyke)**:** 1 triangulated debris groin with 3 ramp logs: ***preload***: left bank: locate at upstream end of rip-rap bank
6	395 m	**38 m** (**car body) Run:** one 2-rootwad triangle without ramp logs: replaces 1st car body near d/s end of rip-rap left bank
7	514 m	**119 m (car-body) Pool:** Upper section: two 3-rootwad triangles with 3 ramp logs: ***preload*** plus install 3 parallel single whole trees and rip-rap at bank base to prevent back-eddy erosion of bank

<u>plus</u> place geo-textile over silty bank: support by rebar on bank and rocks at bank toe
<u>Lower section</u>: two 2-rootwad triangles on left bank with 2 ramp logs

8	681 m	**167 m Glide-flat:** Nil: wide flat water habitat unit
9	744 m	**63 m Riffle:** two 2-rootwad triangles on right bank upper site: 2 ramp logs: lower. site: 3 ramp logs plus ***preload***
10	838 m	**94 m Glide-flat run:** 1 triangulated debris groin with 3 ramp logs: right bank: ***preload***
11	919 m	**81 m Riffle:** 3 triangulated debris groins with 3 ramp logs: right bank: ***preload***
12	970 m	**51 m Glide:** 1 triangulated debris groin with 3 ramp logs: right bank: ***preload*** Plus fill with 2 lateral parallel rootwads at bank to u/s groin
13	980 m	**10 m Riffle:** Nil: short riffle into large mid-channel log jam
14	1044 m	**64 m Pool:** Nil: prime salmonid log-jam habitat as is (d/s end of upper reach)
15	1156 m	**112 m Riffle:** Nil: unstable open bar riffle (start of lower reach)
16	1176 m	**20 m Glide-back water:** 1 set of 2 parallel rootwads with root mass facing downstream
17	1262 m	**86 m Riffle-run:** one 2-rootwad triangle on left bank with two ramp logs
18	1490 m	**128 m Glide-flat run:** three 2-rootwad triangles on left bank with two ramp logs
19	1621 m	**131 m Glide-flat:** Nil: two existing log jam pairs (note: upper log jam provides triangular log jam template, which stabilizes the river bank to tailing pile)
20	1745 m	**124 m Riffle-glide:** two 2-rootwad triangles on left bank with two ramp logs <u>Plus</u> add one 2 rootwad triangle on existing d/s left bank LWD site
21	1798 m	**53 m Pool:** Nil: good log jam habitat at moderate to higher flows
22	1996 m	**198 m Glide-flat:** Nil: bank currently stable (defer) but needs whip/tree planting along grassed bank

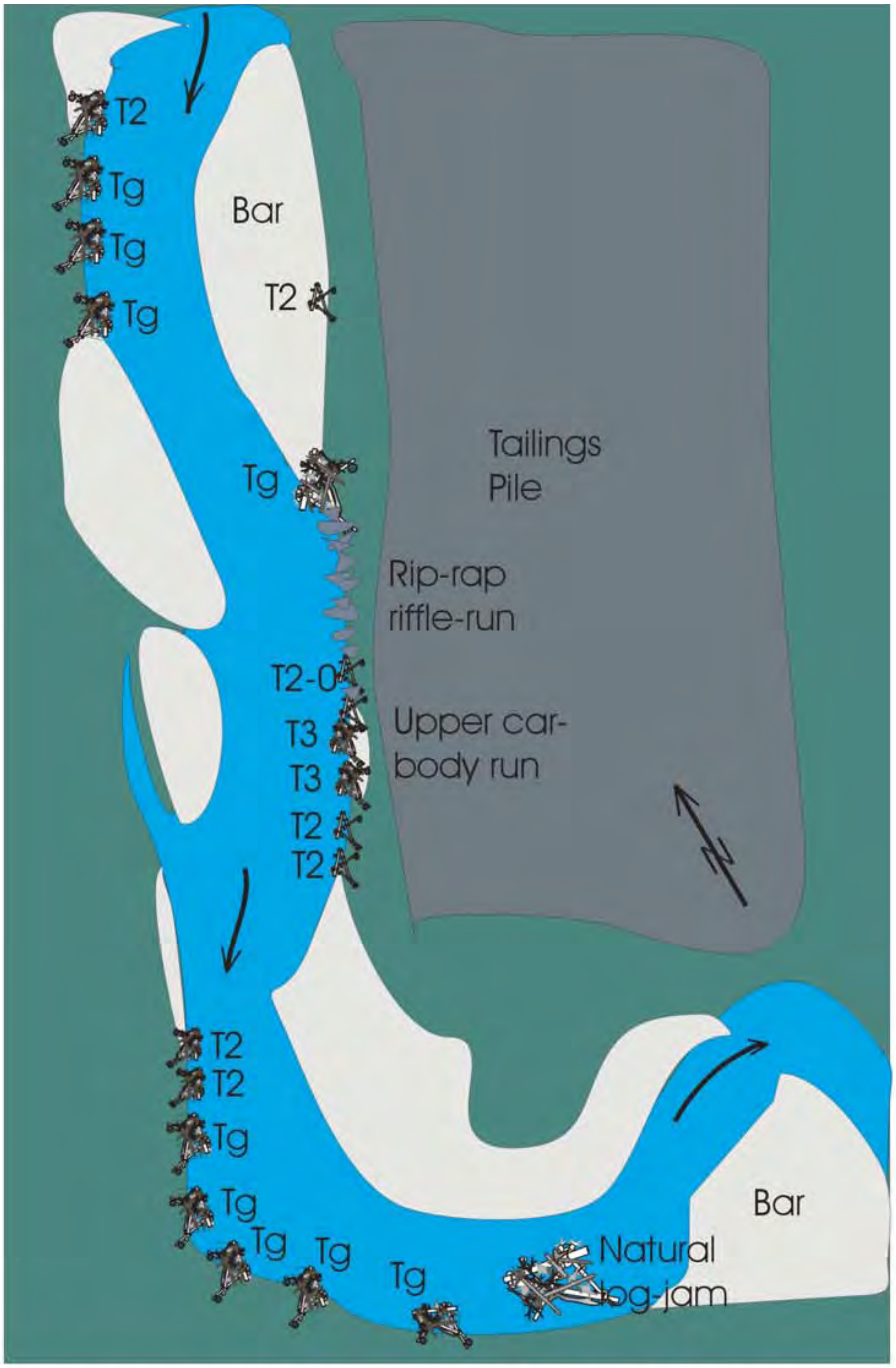

Figure 2. Layout of upper car-body section of the lower Salmo River with lateral triangular large wood structures

T2 = 2 rootwad triangle with 2 tamp logs
T2-0 = 2 rootwad triangle with 0 ramp logs
T3 = 3 rootwad triangle with 2 ramp logs
Tg = triangulated degris groin with 3 ramp logs

Scale
~100 m

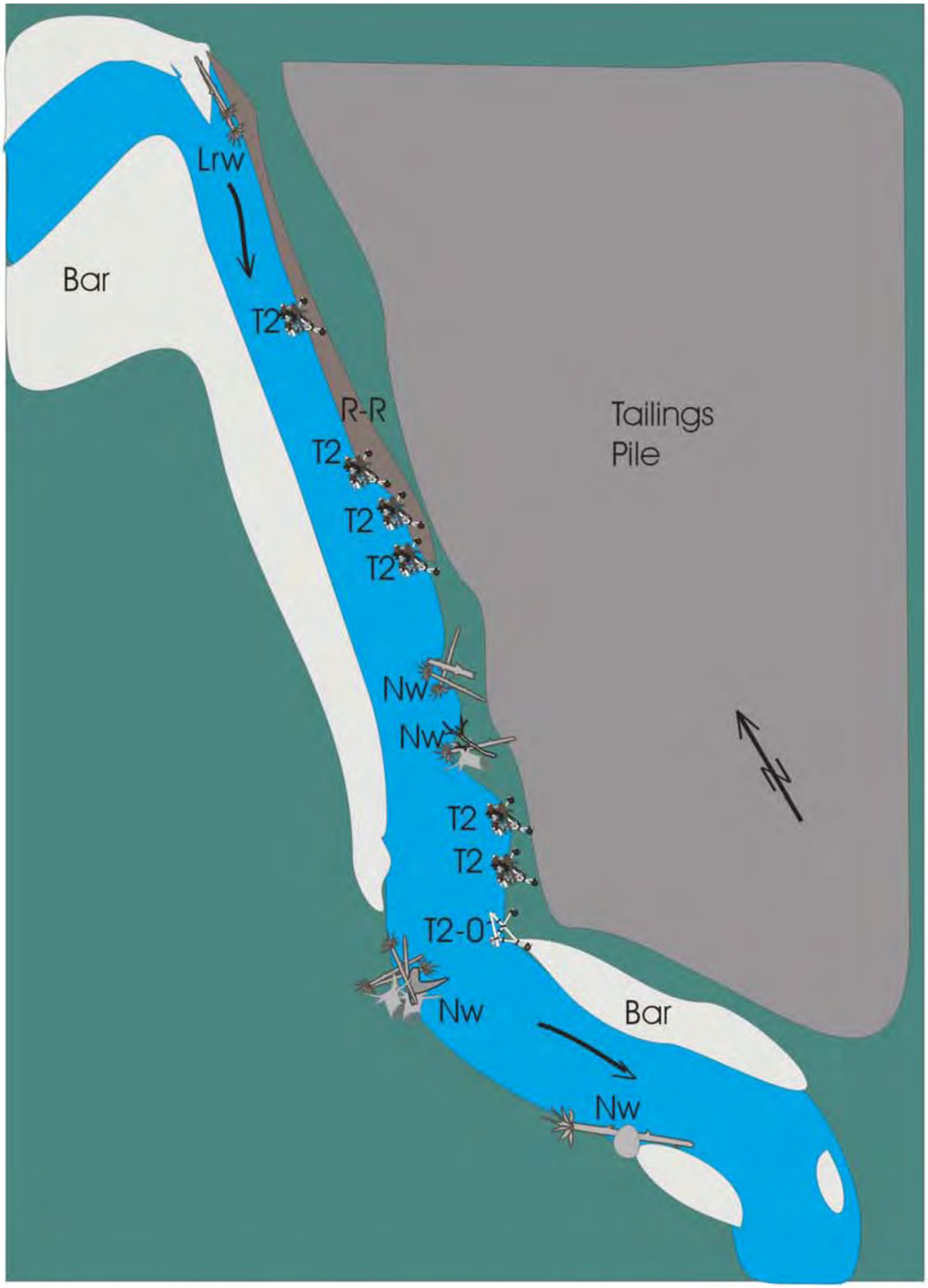

Figure 3. Layout of lower car-body section of the lower Salmo River with lateral triangular large wood structures

T2 = 2-rootwad triangle with 2 ramp logs

T2-0 = 2-rootwad triangle with 0 ramp logs

Lrw = 2-latteral rootwads

Nw = Natural functional large wood

R-R = Rip-rap bank

Scale

~100 m

3.1.3. Standard Habitat Structure Designs

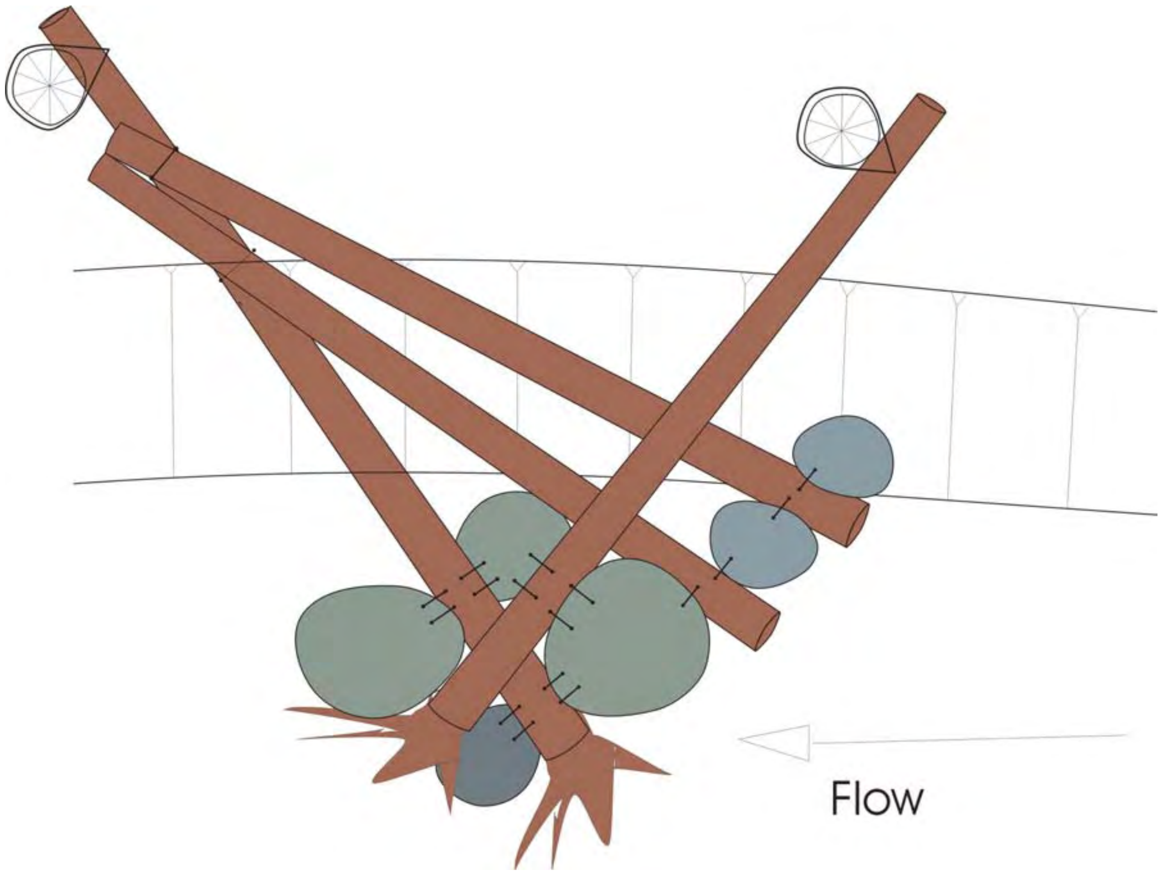

Figure 4. Lateral triangular rootwad ramp-log structure concept designed to trap driftwood, while protecting streambanks.

Conceptual Design Notes Applicable to Salmo River: The 2-3 ramp logs are placed under the upstream rootwad and over the downstream rootwad or log (as in the photo examples from the Seymour River; Figure 6a, 6b). Elevation of the ramp logs is then achieved by reducing the height of the upstream log and increasing the height of the downstream log by varying their placements on the bank slope. The ramp logs are then sloped up towards the bank to collect drift wood and minimize bank erosion; the upper ramp log ends are therefore cable secured to the upper portion of the downstream rootwad

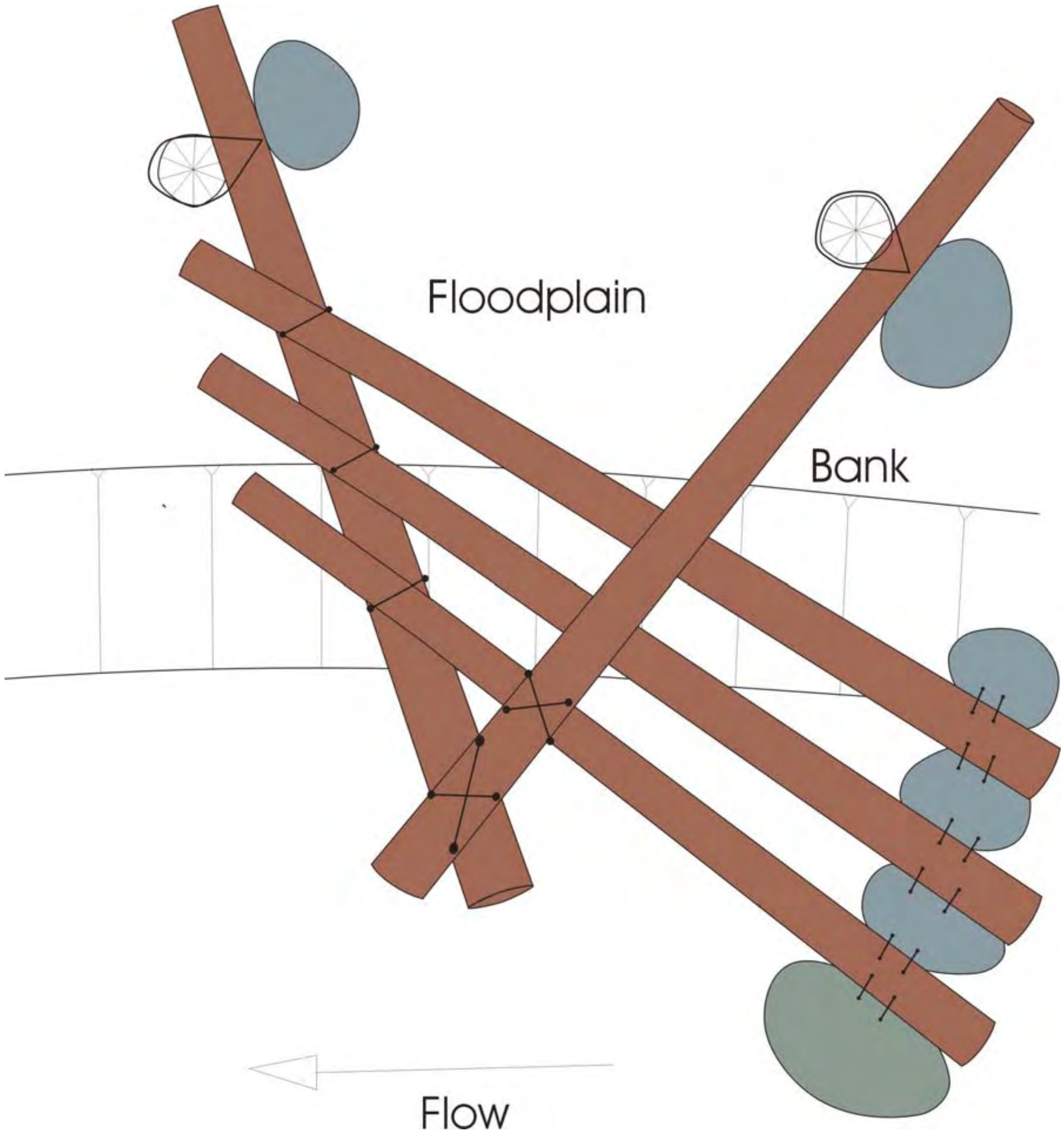

Figure 5. Modified triangular debris groin structure for high stream banks, a design concept for shifting the thalweg away from vertical eroding banks.

Conceptual Design Notes Applicable to Salmo River: For the triangulated debris groin, the triangle is placed on the floodplain or bank-bench, with the cabled apex extending over the bank by 4-5 m and the opposite ends secured to tree bases and large boulder ballast (>1 m^3 per end). Well-ballasted sloping ramp logs at <45^o extend from the river bed to the log apex where they are secured with double-clamped cables. An alternative to the floodplain tree-base/boulder anchors are buried (>2 m depth) log deadheads. Excavation of two trenches in the bank would improve long-term stability of the triangulated support logs.

Figure 6a,b. Two examples of a rootwad triangle with 3 ramp logs (to collect driftwood), secured under the front rootwad and over the rear triangle log (prior to cabling).

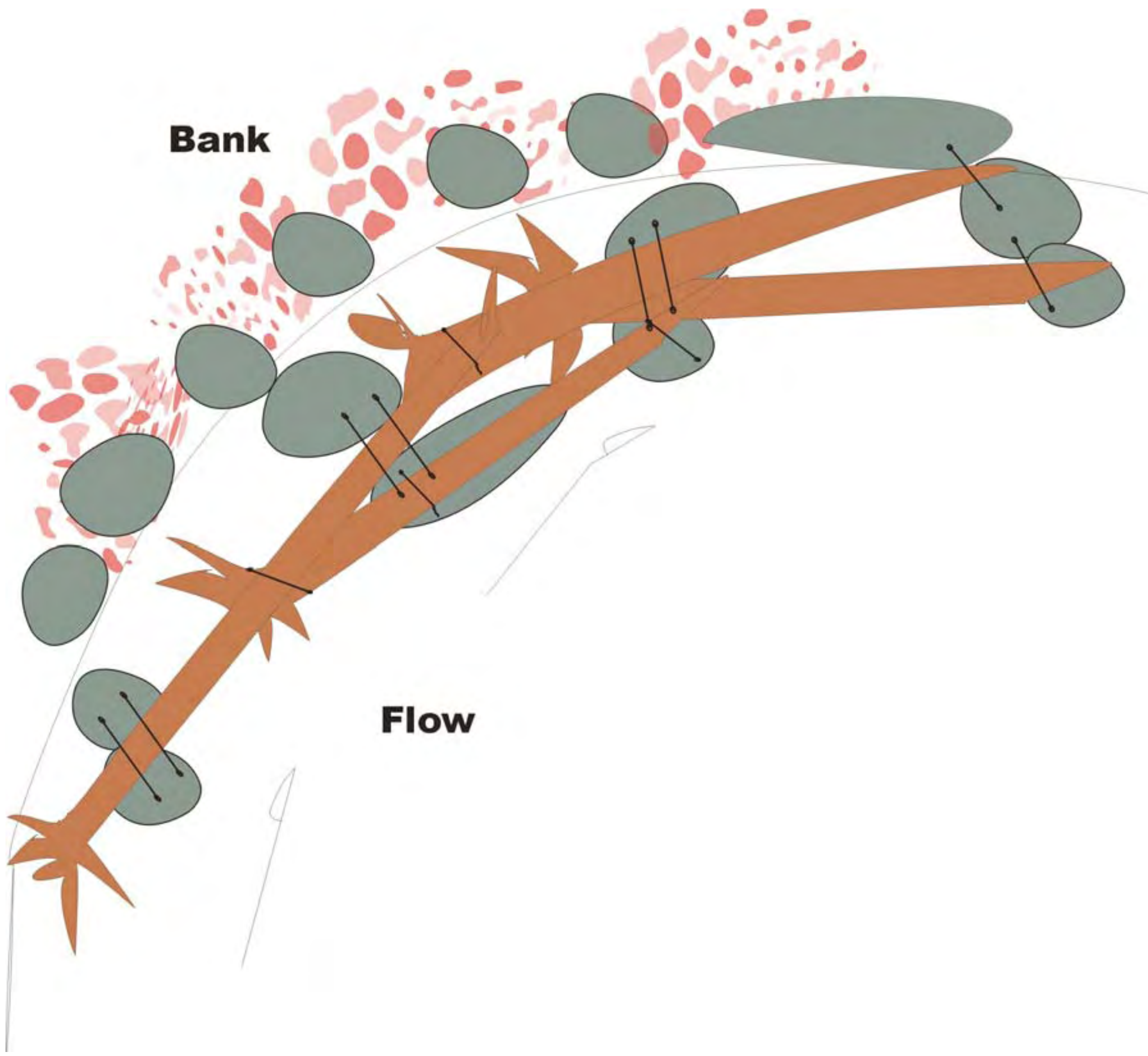

Figure 7. Parallel 4-rootwad design concept with 1.5-2 times the ballast weight of triangulated structures to offset drag forces plus buoyancy forces. Double rootwads, as prescribed at two sites in the lower reach of the Salmo River, would exclude 2 of the 4 instream rootwads. Note that rootwads should face downstream (rather than upstream as shown) if paddler navigation is a concern.

3.1.4. Elevations at the Car-Body Site: Riparian Area into River Channel

The car body run was measured to obtain distances and bank elevations with bank slopes (Table 3). The water surface was at 96.1 m or 4 m below the riparian bank (old dyke road), and the opposite wetted edge or wetted river width ranged from 18 m (upstream end) to 30 m (downstream end), and bank full width was 40 m.

The underwater toe of the slope was about 1 m lower in elevation, ranging from 95 m (upstream end) to 97 m (downstream end) elevation. Existing car bodies extended for 88 m in distance from 40 to 112 m, whereas those from 6 to 40 m had been largely detached, resulting in bank erosion associated with back eddies.

Table 3. Elevations (m) from the riparian zone into the Salmo River channel at the car-body run in mid-August 2004. A nominal 100 m was used as the dyke top elevation. Water surface was at 96.1 m elevation at low flow (<4 m^3/s).

		Distance (m) from top of dyke into river							
	St. m	0	2	4	6	8	10	12	14
Distance (m) from	0	100.2	100.2	100.2	99.5	98.6	96.1	95.1	
Rip-rap section	6	99.8	99.8	99.7	97.3	95.6			
Upstream (Station 0)	10	100	99.9	97.9	97.1	96.8			
	20	100	100.1	97.8	96.9	95.3			
	30	100.1	97.9	97.2	96.3	95.9			
	40	100	98.7	97.1	96.9	95.5	95.3		
	50	98.1	98.2	98.2	97.7	97.3			
	60	100.3	98.9	97.4	96.9	96.8			
	70	99.8	99.5	97.5	96.9				
	80	100.2	98.6	96.9	96.2				
	90	99.8	98.3	96.9	96.2				
	100	100	99.9	98.4	96.8	96.3			

The water surface elevation was at 96.1 m, and the last elevation measured equated approximately to the in-river toe of the slope. The slope was steep or 4 m over a width of 4 m, except where the bank was eroded (Station 10-50). There, the drop after 2 m was initially abrupt (1 m, or 90^{o}) and then more gradual, or on average 2 m over 6 m.

Further upstream by 85 m, where the rip-rap dyke was terminated, the elevation drop from the tote road was abrupt at 2 m from the old road edge, and ranged from a 2.6 m drop at the upstream end of the rip-rap dyke to 2.9 m 100 m upstream on a dry bar. This segment of bank has been eroding during spring flood flows, and is at risk of “end running” the rip-rap dyke and thus eroding into the main tailings pile. Thus, this bank requires stabilization with triangulated boulder ballasted debris groins, although large rip-rap boulder could also be applied because a lack of fish rearing habitat at the gravel bar in this geomorphic setting.

3.1.5. Project Phasing and Materials Required Per LWD Structure

The young forest to pole sapling riparian structure of the reach will result in additional bank erosion of meander bends. In addition, it is probable that the existing dykes tend to accentuate bank erosion in the meander bends. Thus, stabilization of highly eroding sandy river banks is advised, which should be phased in timing. A phased project would be most efficiently accomplished as follows (prioritized to ensure the upper tailing site, which is at risk of failure, is stabilized most rapidly):

- Year 1: upper car-body section including an upper opposite eroding bank;
- Year 2: mid-bend with eroding high banks in the upper section, and
- Year 3: lower car body section.

On average, prescribed LWD structures for the Salmo River typically require 2 rootwads and 2-3 ramp logs. Large wood required is approximately:

- Upper: 25 rootwads and 25 logs 1.5 feet diameter and >40 ft in length plus 3 whole trees as *erosion proofing* the at car-body run;
- Mid-upper: 16 rootwads and 20 logs;
- Lower: 16 rootwads and 12 logs.

On average, approximately 1 m^3 of boulder ballasting is required per log or rootwad, or if 0.5 m^3 boulders are used then 2 boulders per rootwad or log (assuming an on-shore anchor as a tree base or deadhead). Note that the larger boulders are placed where the rootwads apex is submerged into the flow, with the largest boulder placed upstream. Approximately 100 m of cable is required per structure. In addition, at the upper car-body run/pool, an estimated 40-50 m^3 of large rip-rap boulders (2-layered) is required for placement along the geotextile at the fine eroding bank, set behind the single whole trees and LWD structures.

Note: It should be noted that in some navigable waters, the upstream facing rootwad may not be approved by the Canada Navigable Waters Protection Division, and also the top of the lower rootwad may need to be cut off. Alternatively, this rootwad can be placed inside the structure to provide addition habitat**.** Fully submerging the well-ballasted root ends of the rootwads at base summer flows will eliminate navigation concerns, which generally follow an instream structure guideline maximum of 30 % of the wetted navigable channel width per structure.

3.1.6. Structure Ballasting and Boulder Sizing Guidelines

To restore large wood to the lower reach of the Salmo River channel, only well-ballasted lateral triangular structures were prescribed because hydraulic engineering research has confirmed their stability (D'Aoust and Millar 2000). Further, they generate scour at the apex in the flow thalweg, which tends to offset any reduction in channel flow capacity. The secondary apex at the bank is designed as bank armouring to ensure bank stability. Finally, ballast boulders combined with woody debris provide prime salmonid habitat. Note that final design details should be checked on site by a qualified hydraulic engineer with relevant past experience with boulder and tree base ballasted large wood structures in river channels.

Ballasting of LWD structures is set by guidelines provided in Slaney et al 1997, using a *minimum safety factor of 1.25* which can be increased to 1.5-2, based on D'Aoust and Millar (1999, 2000). A conservative safety factor (x2) should be the minimum for lateral parallel rootwads. Note that the rootwad logs need to be securely attached to these large boulders to ensure stability, and attachment to proximal (>30 cm) tree bases is required as well. Where adequate tree bases are unavailable, then boulders (or buried deadheads) must be used. Typically, 1 cubic meter of epoxy-cabled boulders are needed per log end, but a secure tree base can form the fixed anchor at the riparian end, plus cabled ramp logs do not require boulder ballast at the upper cabled ends. For the ramp logs, 0.5 m^3 of boulder per submerged end on each side of two logs is adequate from past experience owing to downward hydraulic forces on the sloped ramp logs. Triangulated log structures with a fixed apex attachment and two fixed bank attachments offset frontal drag forces, and thus buoyancy forces are ballasted to the target safety factor (D'Aoust and Millar 2000).

Further, to provide a safety factor on cable attachments, 2 attachments per boulder are advised for redundancy on the apex joint. To ensure logs do not shift, cable holes are drilled in the outer portions of the log surface, which minimizes cable flexing and cable visibility.

Cable epoxy attachments to ballast rocks ***must adhere*** to the following specifications to be highly effective:

- use only solid _" galvanized steel cable (and not cable with a plastic or rope core or used cable as the former enables the cable to compress excessively);
- 9/16" holes must de drilled to a minimum 10" depth;
- to ensure 100 % cable-epoxy bonding, holes must be thoroughly cleaned to eliminated 100 % of rock dust, by <u>repeated use</u> of a wire brush and rinse water;
- redundant cabling is to be used per apex boulder, with holes >8" apart.
- underwater applications of epoxy have about 50% less pull strength before failure; thus use of additional boulder ballast is advised if underwater epoxy use is required.

3.1.7. Estimated Restoration Costs: Salmo River

Costs vary with ease of material access and by how much large wood and boulders are available locally or nearby. A cost of $50,000 per km is an average cost for all types of stream restoration from experience in the Watershed Restoration Program, where road access was readily available and materials did not require heli-transport (whereby costs typically increased to $80,000-90,000 per km).

A more accurate cost estimate can be made from past experience with triangulated large wood structures, ranging from $1200 to $3000 per structure. The lower cost was at the West Kettle River where access was readily available from adjacent roads and stream bars, large wood was donated (aside from transport), and boulders were available at no cost (aside from local transport). The higher cost was where materials were transported long distances to the stream reach by truck and then by helicopter. Using these estimates, cost is estimated to average $2500 per structure, but $3000 per structure is a more conservative estimate to account for advisory input and contingency costs for purchasing boulders and large wood.

3.1.8. Estimated Benefits of Instream Rehabilitation: Lower Salmo River

Prescribed LWD structures would more than double functional pieces of large wood in the channel beyond existing LWD (with collection of driftwood during flood events) thus, substantially increasing functional LWD and the frequency of small lateral log jams. *Thereby, the upper car-body section would increase from fair to excellent quality, and key cover features in both sections would increase from poor to high quality*. Further, aquatic insect abundance can be expected to increase significantly with woody debris restoration, based on woody debris removal experiments in the south eastern USA: a 5-fold difference was documented.

The LWD structure sites are anticipated to largely generate prime run habitat rather than existing glides to flat pools, most of which are estimated to be either marginal or featureless in summer, and provide limited over-winter cover in winter-spring. Based on monitoring of parr to adult rainbow trout at the West Kettle River, a substantial increase (3-fold) in trout (and char) abundance can be expected in sections rehabilitated.

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Appendix 1. Photo series of habitat restoration prescription sites at the middle reach of Salmo River (Aug 17-28, 2004).

Pool tailout at 120m site: one 2-rootwad triangle on right bank with 3 ramp logs.

Riffle at 160 m site: 1 triangulated (on top of bank) debris groin with 3 ramp logs.


Glide 233 m site: 2 triangulated (on top right bank) debris groin with 3 ramp logs.


Riffle 357 m site: 1 triangulated debris groin (on top of left bank) with 3 ramp logs

Run (car body) 395 m site: One 2-rootwad triangle on d/s end of rip-rap with no ramp logs: remove old car bodies except for wood-filled one under natural log.

Pool (car body) at 414 m site on left bank: upper section; two 3-rootwad triangles with 3 ramp logs ramped up on rear log into bank; place 3 whole trees behind triangle plus rip-rap base of eroding bank and geotextile (remove car bodies);

Pool (car body) at 414 m site at lower section; two 2-rootwad triangles on car bodies (after removal) on left bank slope with 2 ramp logs.

Riffle 744 m site (opposite cattle): two 2-rootwad triangular right bank LWD structures: upper site with 2 ramp logs.

Riffle 744 m site (opposite cattle): two 2-rootwad triangular right bank LWD structures: lower site with 3 ramp logs (tie into large extending log)

Riffle 838 high eroding right bank site(upper):1 triangulated 2-rootwad debris groins secured onto bank top, with 3 ramp logs from river to protruding tri-apex.
Glide 838 m high eroding right bank site: 1 triangulated 2-rootwad debris groin secured onto bank top, with three ramp logs from river to protruding tri-apex.

Riffle 919 m right eroding bank site: 3 triangulated 2-rootwad debris groins secured onto bank top, with three ramp logs from river to protruding tri-apex

Glide 970 m eroding right bank site: 1 triangulated 2-rootwad debris groins secured onto bank top, with three ramp logs from river to protruding tri-apex, with 2 parallel rootwads ballasted against bank.

1262 Riffle-run 86 m site on left dyked bank (flagged): one 2-rootwad triangle with 2 ramp logs, plus 1490 Glide-flat: three 2-rootwad triangles with2 ramp logs; (note:1176 glide with two parallel rootwads is located 20 m upstream of photo)

1745 Riffle-glide ("lower car run") on left bank: two 2-rootwad triangles with 2 ramp logs plus one 2-rootwad triangle with no ramp logs added to existing natural LWD structure in background of photo (remove remaining car bodies).

Natural *template* triangle LWD structure in the lower Salmo River with collection of driftwood, armouring the left bank of the lower car-body run.

Example of a low profile Debris Groin (1999) at West Kettle River, showing accumulated gravels and woody debris on ramp logs, thus armouring the bank and deflecting the river thalweg.

Appendix 2. Definitions of abbreviations of fish habitat assessment parameters

St	station
Rh	reach
Dist.m	cumulative distance in m from starting point in reach or section
Hab.	habitat types: (where abbreviated): Rif = riffle; Gl = glide; Sub-habitat types: po = pool ru = run; fl = flat; fr flat run; g = glide; cs = cascade
HabCl	habitat geomorphological class
Len.m	length in m of habitat unit
MxDm	maximum depth in m
MBDm	Mean bankfull depth: mean depth plus lowest flood plain height: flood plain height used instead of bankfull depth owing to regulated flows
MWDm	mean water depth in m
BFWm	bankfull width in m
WtWm	Wetted width in m
PoT	pool type (scour, dam, falls)
PmxD	pool maximum depth in m
PMnD	pool mean depth in m
PRsD	pool residual depth at tailout
DomSb.m	dominant substrate in m
SdomSb.m	sub-dominant sustrate in m
Est.%Grad.	Estimated or measured gradient in %
Est.Vel.	Estimated velocity in m/sec.
#PkPo	number of pocket pools in habitat unit (mainly riffles)
M2PPo	m^2 of pocket pools in habitat unit
TW	total large woody debris (>2 m in length and 10 cm in diameter)
L1020	large woody debris (LWD) 10-20 cm in average diameter
L2030	large woody debris (LWD) 20-30 cm in average diameter
L3040	large woody debris (LWD) 30-40 cm in average diameter
L4050	large woody debris (LWD) 40-50 cm in average diameter
L>50	large woody debris (LWD) >50 cm in average diameter
CovTy	cover types: LWD, boulders, cutbank, near-surface vegetation, pool or run turbulence
TCv%	percent total estimated cover
B%	percent boulder cover (as protruding boulders providing parr habitat)
OCT	off-channel habitat type (alcove, pond, side-channel)
OfA	off-channel access (yes, no)
Ofm	measured (or estimated) lineal m of off-channel habitat
RipTy	riparian type (conifer, deciduous, shrub)
RipSt	sh = shrub; ps = pole sapling; yf = young forest[1], mf = mature forest
CpyC	percent canopy closure (shading)
Ob?	Obstruction to fish passage (0 = no)

Appendix 2. (continued)

%Ufry	estimated percent useable fry habitat in habitat unit, using weighted useable depth and velocity criteria
%UP	estimated percent useable parr habitat in habitat unit, using weight depths, velocity and cover criteria Note: visual estimates should be derived by concensus of two individuals with experience with measuring and calculating weighted useable widths
Rehab.Presc.	habitat rehabilitation prescription (e.g., 6Bx3 = six boulders in clusters of 3 Bould. Restor. to Thal. = boulder restoration by shifting boulders); Lat Tri+RW-4log = lateral triangle constructed of 2 rootwads and 2 logs;

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[1] young forest is <80 years of age of conifer tees in the riparian forest