

JOE RICH CREEK CHANNEL ASSESSMENT & REHABILITATION OPPORTUNITIES

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- Joe Rich Watershed Monitoring Committee
- Property owners along Joe Rich Creek

The diversity of stakeholders participating in the Joe Rich Creek process is essential for the development of effective, inclusive, management strategies aimed at protecting water quality, conserving fish and wildlife habitat and planning sustainable rural communities.

Contributing authors and reviewers of this assessment report include: Phil Epp, Ministry of Water, Land & Air Protection (WLAP), Todd Cashin, RDCO and Brent Magnan, RDCO. SHIM mapping was conducted by Brent Magnan. Channel assessment and restoration prescriptions were completed by Alan Bates (Streamworks Unlimited) and Todd Cashin.

This project could not have been completed without the contributions of Todd Cashin and Brent Magnan of the RDCO. Their background work and knowledge of the watershed, technical support and constant positive attitude toward 'getting the job done' have allowed this project to progress to a higher level of quality and effectiveness.

EXECUTIVE SUMMARY

Joe Rich Creek is a major tributary of Mission Creek east of the City of Kelowna. The creek provides habitat to a resident population of rainbow trout. Licensed water users abstract flows for domestic use, stock watering and irrigation. The Joe Rich Creek watershed has been affected by development activities on crown and private land, including Highway 33. Along the creek, areas of extensive bank erosion along the channel have been identified. Additionally, poor water quality (high sediment, coliform) and channel dewatering during dry summer months have raised concerns over the health of the system. Streamworks Unlimited was retained by the Regional District of Central Okanagan (RDCO) Planning Services Department in October 2003 to assess channel conditions, identify rehabilitation opportunities and prepare preliminary prescriptions for remedial works in the Joe Rich Creek watershed.

The Joe Rich Creek Channel Assessment was based on a review of existing background information and field assessments in the Fall of 2003. Background information included an Interior Watershed Assessment Procedure (IWAP) completed for Mission Creek (Dobson 1998) and meeting summary notes from the Mission Creek Watershed Advisory Committee (WAC) meeting in November 2002. Field information was supplemented by Sensitive Habitat Inventory and Mapping (SHIM) data collected previously and concurrently with RDCO staff.

Channel conditions and processes in the Joe Rich Creek watershed were summarized as follows:

- Drainage from upper areas in the watershed is buffered by significant areas of wetland. Forest development in this area has resulted in little impact to the channel.
- Landslides associated with Highway 33 and Big White Road drainage have contributed sediment and debris to the channel. Local disturbance to the channel has been moderated by intact riparian forests. Sediment from these sources may be causing problems at the Highway 33 culverts and affecting private land downstream.
- Below the Highway 33 crossing, the channel enters an area of intense agriculture. Riparian vegetation is sparse and channel and banks are heavily used by livestock. The channel is deficient of instream structure normally provided by large woody debris (LWD). A process of bank and channel scour has been initiated, widening the channel, eroding banks and increasing sediment loads.
- Channel conditions improve again downstream as riparian vegetation density improves. Localized disturbances occur throughout the private land section. Fish access may be obstructed or limited by artificial weirs in at least two locations.

Opportunities for channel, riparian and fish habitat rehabilitation were identified in many areas of Joe Rich Creek. The recommended long term, low maintenance solution for a stable channel supporting fish habitat is the establishment of a continuous, mature riparian forest along the entire length of the Joe Rich channel. This can be accomplished through active planting, however livestock exclusion fencing is key to riparian recovery. Fencing alone may be enough to begin the process of natural revegetation.

It will take considerable time for any riparian recovery program to restore channel function and improve fish habitat. In the meantime, existing bank failures may enlarge, contributing sediment to the system and sustaining channel widening and aggradation. The over supply of sediment and under supply of

LWD has resulted in a degradation of fish habitat. Shorter term improvements to bank/channel stability and the provision of interim fish habitat are therefore recommended.

Table 2 provides a summary of rehabilitation sites with suggested approaches to rehabilitation and relative priorities. Several hundred meters in Reach 5 (upper Weddell property) were identified as severely disturbed and a key source of sediment in the channel. Preliminary prescriptions for rehabilitation of this section are provided in Appendix D. Prescribed techniques include the construction of instream rock riffles, rootwad revetments, brush layers, brush traverses and riparian planting. If a planting program is undertaken, no planting or seeding should go ahead until livestock exclusion fencing is in place so efforts are not compromised. Preliminary cost estimates and implementation considerations are provided in the report.

It was recommended by the WAC in November 2002 that ECA levels for the Joe Rich Creek basin be maintained at low levels (i.e. 20-25%) in order to avoid aggravating existing channel instabilities through the middle and lower reaches. Stakeholders in the forest resources of Joe Rich Creek should propose a schedule to re-assess conditions in Joe Rich Creek to determine the degree of channel recovery and, if appropriate, adjust long term ECA levels for the watershed.

Future monitoring of overall watershed condition should also be used to identify successful techniques and document progress in the watershed. Monitoring should also include maintenance of any constructed works and/or plantings to ensure restoration goals are met.

Streamworks Unlimited

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1.0 INTRODUCTION

1.1 Background

Joe Rich Creek is a major tributary of Mission Creek east of the City of Kelowna. The creek provides habitat to resident rainbow trout, and some fish from resident rainbow trout populations in Mission Creek may also spend time in Joe Rich Creek. Licensed water users abstract flows for domestic use, stock watering and irrigation on adjacent lands during the summer months. Flows in Mission Creek downstream are also used for domestic, agricultural and conservation purposes. Major licensees on Mission Creek include Black Mountain Irrigation District, City of Kelowna, Westbank Indian Band and the Fisheries Branch of the Ministry of Water, Land and Air Protection. Mission Creek is a designated community watershed.

The Joe Rich Creek watershed has been affected by development activities on crown and private land, including Highway 33. Along the creek, areas of extensive bank erosion along the channel have been identified. Additionally, poor water quality (high sediment, coliform) and channel dewatering during dry summer months have raised concerns over the health of the system.

Since 1998, Riverside Forest Products Ltd., Gorman Bros. Lumber Ltd., Tolko Industries Ltd. and the Small Business Forest Enterprise Program have been updating the Mission Creek Interior Watershed Assessment Procedure (IWAP) to provide information regarding both current conditions and the risks associated with future forest development in the watershed. In 2002, the IWAP for the Mission Creek watershed was updated and the Joe Rich Creek sub-basin was considered the most sensitive sub-basin in the Mission Creek watershed due to channel and water quality impacts associated with private land activities (Dobson 2002). At a Watershed Assessment Committee (WAC) meeting in November of 2002, it was recommended that private landowners, forest licensees, government agencies and other organizations collaborate to implement remedial measures through the middle and lower reaches of Joe Rich Creek.

Streamworks Unlimited was retained by the Regional District of Central Okanagan (RDCO) Planning Services Department in October 2003 to assess channel conditions, identify rehabilitation opportunities and prepare preliminary prescriptions for remedial works in the Joe Rich Creek watershed. This report summarizes the results of these assessments.

1.2 Objectives

The objectives of this project were to:

- Identify the extent of hazards as anticipated by the results of the 2002 Mission Creek IWAP update through a field (on the ground) channel assessment.
- Document evidence of channel instability, altered natural drainage, and/or significant sediment sources within the sub-basin.
- Provide comment on the level of disturbance, the likely causes of the impairment, the relative priority of the concern and the potential for restoration and/or rehabilitation.
- Develop preliminary prescriptions, work plans and cost estimates for high priority restoration and enhancement sites in the Joe Rich Creek watershed.

2.0 METHODOLOGY

The following section details the methodology used to assess channel conditions along Joe Rich Creek.

2.1 Background Information

The following reports and documents were reviewed to provide background information and context to the assessments and recommendations described herein:

- *Mission Creek Habitat Restoration Feasibility* prepared by LGL Limited (March 2003) for the Ministry of Water, Land and Air Protection.
- *Water Quality Monitoring for the South Slopes of the Joe Rich Creek Watershed (Year 3 – 2002 Data)* prepared by Dobson Engineering Ltd. (March 2003) for Gorman Bros. Lumber Ltd.
- *Joe Rich Watershed Monitoring Committee Newsletter, January 2003*. Published by the Joe Rich Ratepayers and Tenants Society (www.silk.net/joerich/wrpt.htm)
- *Final Watershed Assessment Committee (WAC) Meeting Summary Notes – Mission Creek Watershed Assessment Procedure* held November 25, 2002 at the Riverside Forest Products office in Kelowna, BC.
- *2002 Interior Watershed Assessment Update for the Mission Creek Watershed* by Dobson Engineering Ltd. (November 2002) for Riverside Forest Products Limited, Gorman Bros. Lumber Ltd., Tolko Industries Ltd. (Lavington) and the Small Business Forest Enterprise Program (Penticton Forest District).
- *Forest Development Plan 2002 -2007* by Gorman Bros. Lumber Ltd. prepared for the Ministry of Forests, Penticton Forest District.
- *Interior Watershed Assessment Procedure for the Mission Creek Watershed – Update Report* by Dobson Engineering Ltd. (December 1998) for Riverside Forest Products Limited.
- *Joe Rich Total Resource Plan* prepared for Gorman Bros. Lumber Ltd. by Silvatech Consulting Ltd (October 1998)

In addition to the above documents, maps and orthophotos of the study area were acquired for photo interpretation and general background information. These were TRIM map sheets 082E.085, 082E.075 and orthophotos 082E.085, 082E.075. Historic airphotos (BC7669 211-214, 59, 60) were reviewed to consider longer term changes in channel morphology and watershed condition.

2.2 Field Assessments

1:5,000 scale orthophoto (based on 2001 year aerial photography) TRIM maps were used to provide an overview of the Joe Rich Creek channel/watershed, and plan the field assessment program. Apparent problem areas and potential rehabilitation sites were highlighted on the maps. Sites of interest included:

- Widened, aggraded channel sections.
- Disturbed riparian areas.
- Areas of recent channel migration.
- Eroding or unstable banks.
- Slope and bank failures.
- Channel avulsions.
- Channel encroachments.
- Potential rock sources.

Access constraints to the selected sites were also noted during the review. Local knowledge by RDCO staff was used extensively in the planning of field assessments.

The purpose of the field assessments was to:

- Confirm the results of the previously completed (airphoto and background) assessments.
- Describe the nature and extent of any impairment.
- Assess actual/existing fish habitat conditions.
- Evaluate the potential for restoration success, incorporating considerations toward expected benefits to fish, machine access, land tenure, etc.
- Evaluate the objectives and scope of any proposed rehabilitation.
- Consider the relative priority of any rehabilitation recommended for the site.

Field assessments were completed jointly with RDCO staff in October, November and December 2003. Detailed notes were recorded at each site describing existing conditions, impairments and rehabilitation opportunities. The locations of field inspection sites were established using a handheld GPS receiver, capable of sub-metre accuracy.

During the field surveys, representative photographs were taken of exceptional and/or typical features using a digital camera. The photos also provide a visual record of riparian vegetation, barriers to fish migration, fish habitat features and representative fish samples. Selected site photographs are included with this report in Appendix F. Digital files of all photographs taken during this assessment are included on the attached disk (CD).

2.3 SHIM Assessments

Sensitive Habitat Inventory and Mapping (SHIM) methodology is currently used by the RDCO to identify and record aquatic habitats within the district. Some previous work in the Joe Rich Creek watershed had been undertaken prior to this assessment in this regard. Further SHIM documentation, in areas that had not been previously assessed, was recorded by RDCO staff during the course of this project. A summary of all the SHIM data for the Joe Rich Creek watershed is presented in Appendix B.

The methodology for the SHIM analysis used in this assessment is outlined in the 2002 Sensitive Habitat Inventory and Mapping Methods (Community Mapping Network, dated June 11, 2002). Details of the methods are discussed below.

2.3.1 GPS Data Collection

Differential GPS data was collected with a Trimble GeoXT GPS receiver. The GPS receiver was configured according to the SHIM protocol for collecting data. Both position and attribute data were captured simultaneously via the SHIM data dictionary, which provides a structure for the data entry procedure outlining the parameters required for the survey. Position and attribute data was collected with the GPS on October 20 and 21, 2003.

Stream Centerline

The stream centerline and individual stream segments were collected as line features using the GPS. Specific features were recorded as individual point features within these lines.

Stream Segments

The stream centerline was subdivided into individual segments based on similar habitat characteristics such as changes in: stream channel form, sediment supply, riparian vegetation, streambed or stream bank materials, channel confinement, and/or channel gradient. Within each segment numerous observations (attributes) and measurements were made to determine its unique habitat characteristics. These included: channel morphology, crown closure, segment gradient, substrate composition, channel dimensions, riparian class, riparian band width, riparian structural stage, presence of snags, shrub density, bank stability, and dominant bank material.

Habitat Feature Mapping

Locations and attributes of distinctive features found within the stream were mapped as point features using the GPS. Features included, but were not limited to, bank and channel modifications (bridges, water withdrawals and retaining walls), eroding banks, natural springs, channel obstructions, culverts, enhancement structures, discharge sites and side channels. Attributes of each feature were recorded including feature type, bank location, dimensions, comments and photo reference number. Detailed GPS data was also collected to ensure quality assurance / quality control.

Eroding Bank Classification

Eroding banks were documented as line features in Reach 5 using the GPS, and classified based on their observed severity. Characteristics of severity were evaluated considering degree of recent activity, length of bank affected, channel proximity, eroding bank height, material erodability, channel stability, channel width and vegetative condition. Each site was classified as Low, Medium or High priority according to its severity. High priority sites were actively contributing significant amounts of sediment into the channel. Medium priority sites were actively eroding smaller sites, or were not active but had the potential to become significant sediment sites if left untended. Low priority sites were lower or smaller banks, not actively eroding and usually some distance from the currently active channel.

2.3.2 Data Processing

Trimble Pathfinder Office software was used to transfer data from the GPS receiver to a computer and to convert the GPS rover files to Shapefile format useable in ArcView GIS. SHIM data was post processed using data downloaded from the International GPS Service site in Penticton. Data corrections were carried out with the use of SHIM ArcView extensions. Digital photographs of all point features collected during the field surveys are linked to specific GPS locations. These ArcView shape files are available from RDCO.

3.0 ASSESSMENT RESULTS

Results of the Joe Rich Creek field assessment are summarized in the following sections. Selected sites were visited in the field during October, November and December 2003.

3.1 Background Review

Joe Rich Creek originates in a series of wetlands within the Okanagan Highlands. It flows generally southward before turning west and then north, following a steep-sided, glaciated valley. The watershed is approximately 48 km² in area and flows into Mission Creek about 12 kilometres east of the City of Kelowna. Elevations range from 1540 m in the upper basin to 884 m at the Mission Creek confluence. Mission Creek is a designated community watershed.

The 2002 IWAP for Mission Creek identified the Joe Rich sub-basin as sensitive to channel and water quality impacts associated with private land development (Dobson 2002). Areas of extensive bank erosion have been identified as well as poor water quality and dewatering during dry summer months. Livestock access to the creek and the removal of riparian vegetation has likely affected bank stability and water quality (Dobson 1998). Water quality in Joe Rich Creek has been described at times as 'awful', including high sediment and coliform counts (JRWMC Newsletter Jan. 2003). Joe Rich Creek was listed as a significant sediment source (resulting from poor riparian condition and extensive bank erosion) in the Mission Creek Habitat Restoration Feasibility study (LGL 2003). The relative size of Mission Creek tends to dilute flows from Joe Rich Creek, reducing the severity of impacts downstream (WAC 2002). The LGL report proposed close to \$3 million in restoration activities for the Mission Creek mainstem downstream of East Kelowna Road, including setback dykes and instream riffles. The extent that sediment generation in Joe Rich Creek would affect the viability of these plans is not discussed.

Several landslides have occurred off Highway 33 in close proximity to Joe Rich Creek and have impacted the channel. At the WAC meeting in November 2002, the committee recommended that the surface drainage and landslides off Highway 33 be assessed for stability and remedial measures should be considered to minimize the potential for additional hydrologic impacts.

Lower Joe Rich Creek provides habitat to wild, indigenous stocks of resident rainbow trout and it is suspected that resident trout from Mission Creek may also periodically use lower Joe Rich Creek (Todd Cashin, RDCO, pers. Comm.). No detailed fisheries assessments or inventories have been undertaken.

Twenty water licenses have been issued for the mainstem of Joe Rich Creek. Permitted use includes water for domestic, irrigation, storage, and stock watering purposes. Diversion points are concentrated in the agricultural areas of the lower watershed. Several Joe Rich tributaries and associated springs have permitted water use, including Schram and Tress Creeks.

Forest development on crown land has occurred in the upper Joe Rich Creek watershed. Equivalent Clearcut Area (ECA) for the Joe Rich Creek watershed was estimated at approximately 10% in 1998 (Dobson 1998). Estimates for 2001 place the ECA level at 13.7% (Dobson 2002). It was recommended by the WAC that ECA levels for the Joe Rich Creek basin be maintained at low levels (i.e. 20-25%) in order to avoid aggravating existing channel instabilities through the middle and lower reaches. After channel recovery has been confirmed, a reassessment has been recommended by the WAC to determine appropriate long term ECA

levels for the watershed (WAC 2002).

In response to concerns for the effects of forest development on water quality, Gorman Bros. Lumber Ltd. began a water quality sampling program on Leach, Schram and Bailey Creeks in 2000 (Dobson 2003). The project was designed as a paired watershed study using Leach Creek as a control (undisturbed) basin and Schram and Bailey Creeks as treatment (disturbed/developed) basins. At the beginning of the study, Schram Creek was undeveloped, allowing comparisons of water quality before and after development. A broad range of water quality parameters was measured in 2001, including numerous dissolved minerals and coliform. The continuing program is limited to sampling for turbidity and suspended solids. To date, the monitoring does not indicate forest development related changes in water quality in these tributaries. While Leach and Bailey Creek have defined channels that connect to Joe Rich Creek, Schram Creek does not, and flows remaining in the channel are diverted for irrigation at the lower end (where they cross onto private land).

3.2 Field Assessments

The following sections briefly describe the key findings of the channel assessment on a reach by reach basis. Detailed descriptions and field measurements are available through the SHIM data provided in Appendix B. Recommendations to address the identified problems are discussed in Section 4.0.

Table 1 (following page) provides a listing of observed characteristics of each main channel reach in Joe Rich Creek. The following sections further describe the channel conditions, morphology and level of disturbance for each reach.

3.2.1 Mission Creek Confluence

Joe Rich Creek joins into Mission Creek on the left bank just downstream of the Highway 33 bridge crossing. The area appears to be stable and little evidence of sediment discharge from Joe Rich Creek was observed (e.g. no obvious bars were observed in Mission Creek downstream of the confluence). Some stabilization in the area may have occurred in the past, as was evidenced by what appeared to be remnants of rock placements. No evidence of active channel erosion or migration was observed (see Photo A).

Mission Creek appears to have enough power/transport capacity to deal with sediment inputs from Joe Rich Creek. Suspended sediments delivered by Joe Rich likely remain in suspension and are easily carried downstream by Mission Creek. Mission Creek may be affected in depositional zones downstream, however according to previous studies, the hydrologic condition of Mission Creek is dominated by landslides directly connected to the mainstem and Fish Hawk Creek (Dobson 2002). It has also been reported by locals that poor water quality in Joe Rich Creek is readily diluted by Mission Creek (WAC 2002).

Table 1: Joe Rich Creek Reach Characteristics

Reach #	Reach Segment (SHIM)	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
1	1.0	81	1.5	Riffle/Pool	4.80	0.70	Gravel	Deciduous Forest	Deciduous Forest
1	2.0	347	3.0	Riffle/Pool	3.90	0.60	Cobble/Gravel	Deciduous Forest	Deciduous Forest
1	Total	428	2.8	Riffle/Pool	4.07	0.65	Cobble/Gravel	Deciduous Forest	Deciduous Forest

2	3.0	82	4.0	Cascade/Pool	3.10	0.90	Cobble/Gravel/Boulder	Mixed forest	Mixed forest
2	4.0	64	5.0	Cascade/Pool	3.20	0.70	Cobble/Gravel/Bedrock	Coniferous forest	Coniferous forest
2	Total	146	4.4	Cascade/Pool	3.15	0.80	Cobble/Gravel/Bedrock	Mixed forest	Mixed forest

3	5.0	207	2.0	Cascade/Pool	3.50	0.80	Gravel	Coniferous forest	Coniferous forest
3	6.0	121	0.5	Riffle/Pool	3.50	0.40	Gravel	Coniferous forest	Coniferous forest
3	8.0*	687	3.0	Riffle/Pool	3.50	0.40	Gravel	Coniferous forest	Coniferous forest
3	9.0	144	3.0	Riffle/Pool	4.00	0.40	Gravel	Deciduous Forest	Deciduous Forest
3	Total	1160	2.6	Riffle/Pool	3.63	0.50	Gravel	Coniferous forest	Coniferous forest

4	10.0	1270	1.0	Riffle/Pool	4.80	0.40	Gravel	Shrub/herb	Shrub/herb
4	11.0	574	1.0	Riffle/Pool	3.50	0.40	Gravel	Mixed forest	Mixed forest
4	Total	1844	1.0	Riffle/Pool	4.15	0.40	Gravel	Shrub/herb	Shrub/herb

5	12.0	995	2.0	Riffle/Pool	11.20	n/a	Gravel	Shrub/herb	Shrub/herb
5	13.0	1113	2.0	Riffle/Pool	5.20	n/a	Gravel	Shrub/herb	Shrub/herb
5	Total	2108	2.0	Riffle/Pool	8.20	n/a	Gravel	Shrub/herb	Shrub/herb

6	14.0	340	2.0	Riffle/Pool	8.00	n/a	Gravel	Mixed forest	Mixed forest
6	15.0	264	2.0	Riffle/Pool	n/a	n/a	Gravel	Deciduous Forest	Deciduous Forest
6	16.0	102	2.0	Riffle/Pool	n/a	n/a	Gravel	Shrub/herb	Deciduous Forest
6	Total	706	2.0	Riffle/Pool	n/a	n/a	Gravel	Mixed forest	Mixed forest

*Note: SHIM Segment 7 does not exist. Field numbering error.

Table 1: Joe Rich Creek Reach Characteristics (continued)

Reach #	Reach Segment (SHIM)	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
7	-	2476	3.8	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
8	-	1430	5.6	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
9	-	303	6.5	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
10	-	1483	9.4	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
11	-	2575	4.0	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
12	-	757	0.0	Wetland	n/a	n/a	Organics	Wetland	Wetland
13	-	1442	5.5	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
14	-	276	14.5	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
15	-	516	0.0	Wetland	n/a	n/a	Organics	Wetland	Wetland
16	-	842	0.0	Wetland	n/a	n/a	Organics	Wetland	Wetland

Note: Reaches 7 through 16 not subject to SHIM assessment. Data from mapping, site checks and/or assumed from airphoto interpretation.

3.2.2 Reach 1

Reach #	Reach Segment	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
1	1.0	81	1.5	Riffle/Pool	4.80	0.70	Gravel	Deciduous Forest	Deciduous Forest
1	2.0	347	3.0	Riffle/Pool	3.90	0.60	Cobble/Gravel	Deciduous Forest	Deciduous Forest
1	Total	428	2.8	Riffle/Pool	4.07	0.65	Cobble/Gravel	Deciduous Forest	Deciduous Forest

Reach 1 begins at the confluence of Joe Rich Creek with Mission Creek and extends upstream to the lower end of the bedrock canyon near the end of Thelwell Road. Due to its proximity to Mission Creek, and the presence of barriers upstream, this reach may provide key spawning habitats for fluvial fish entering from Mission Creek.

The channel in Reach 1 of Joe Rich Creek is generally stable with moderate impacts from private land use activities. The channel is slightly aggraded, pools are few and substrates are mostly uniform (see Photo B). Small channel avulsions have occurred, likely the result of debris jams and deposition. There is a clear lack of large woody debris (LWD) instream and future LWD recruitment is limited to cottonwood. Livestock have access to the channel for watering through most of Reach 1.

At the top end of the reach (at the reach break) is a small weir (1.2m high x 3m wide) constructed from timber and riprap (see Photo C). The structure was likely erected to control scour below a driveway crossing immediately upstream. As there is no pool at the foot of the weir, this structure is likely a barrier to fish passage, certainly at smaller life stages and/or low flows.

3.2.3 Reach 2

Reach #	Reach Segment	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
2	3.0	82	4.0	Cascade/Pool	3.10	0.90	Cobble/Gravel/Boulder	Mixed forest	Mixed forest
2	4.0	64	5.0	Cascade/Pool	3.20	0.70	Cobble/Gravel/Bedrock	Coniferous forest	Coniferous forest
2	total	146	4.4	Cascade/Pool	3.15	0.80	Cobble/Gravel/Bedrock	Mixed forest	Mixed forest

Reach 2 describes a relatively short section of bedrock controlled canyon upstream of Thelwell Road. The gradient increases through this section and some fish obstructions and/or barriers may exist, especially at low flows (see Photo F). This section of channel is very stable and provides for some fish habitat. Although LWD is not necessary for channel stability, it does provide occasional cover for fish. Both banks are naturally forested.

At the lower end of the reach, the channel makes a sharp bend to pass beneath a driveway bridge, just above the reach break (weir). Discussions with the landowner indicated that problems had occurred in the past at this location, and old sandbags were indicative of past

problems (see Photos D,E). If the bridge opening becomes plugged, bank overflows may run onto Thelwell Road, causing damage to properties downslope. This potential avulsion site is discussed as a rehabilitation opportunity in Table 2.

3.2.4 Reach 3

Reach #	Reach Segment	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
3	5.0	207	2.0	Cascade/Pool	3.50	0.80	Gravel	Coniferous forest	Coniferous forest
3	6.0	121	0.5	Riffle/Pool	3.50	0.40	Gravel	Coniferous forest	Coniferous forest
3	8.0	687	3.0	Riffle/Pool	3.50	0.40	Gravel	Coniferous forest	Coniferous forest
3	9.0	144	3.0	Riffle/Pool	4.00	0.40	Gravel	Deciduous Forest	Deciduous Forest
3	total	1160	2.6	Riffle/Pool	3.63	0.50	Gravel	Coniferous forest	Coniferous forest

Reach 3 flows through mostly forested private land, however some disturbances were identified. A bank failure (10m long x 3m high) in clayey till was noted (see Photo G). The clay was relatively erosion resistant and controlled channel gradient in some locations. Several rock or log riffles have been constructed to create pools/sumps for water intakes (see Photo L). These pools acted as bedload traps and collected gravel. One landowner had built a series of (40cm high) rock riffles through his property, apparently to control erosion and create (50cm deep) pools during low flows (see Photo H). At the upper end of this property, a new steel span bridge had been constructed directly overtop an older log bridge. The collapsing log bridge almost fills the new bridge opening, causing extensive ponding and deposition upstream (see Photo I). The sediment wedge created by the bridge obstruction reached as wide as 15m (the natural channel in this area was 3m wide). Total volume of material stored in the channel was estimated at 1800 m³. Numerous trees were dead as a result of flooding and deposition around their bases (see Photos J,K).

In general the reach was noted to be slightly aggraded through most of its length. Some woody debris function remains as a result of the mostly intact riparian zone. Occasional bedrock outcrops were observed nearer the upstream end of the reach.

3.2.5 Reach 4

Reach #	Reach Segment	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
4	10.0	1270	1.0	Riffle/Pool	4.80	0.40	Gravel	Shrub/herb	Shrub/herb
4	11.0	574	1.0	Riffle/Pool	3.50	0.40	Gravel	Mixed forest	Mixed forest
4	total	1844	1.0	Riffle/Pool	4.15	0.40	Gravel	Shrub/herb	Shrub/herb

Reach 4 brings Joe Rich Creek into a zone of more intensive agriculture. The surrounding floodplain has been cleared leaving only sparse riparian vegetation (see Photo M) [a discussion of the importance of riparian vegetation is provided in Section 3.3.1]. In some areas natural vegetation has been displaced by reed canary grass. Grazing has been allowed to occur right up to the stream edge and numerous livestock access and crossing points exist (see Photo O).

At least one corral has been established immediately adjacent to the creek. The channel is generally less complex, slightly widened and poorly incised. Occasional areas of bank erosion were noted on outside bends, some active, others old (see Photo N). Little stream shading or fish habitat exists. Bridges appeared to be the most productive habitat features in this zone, due to their associated shade, cover and deeper water. Ponds developed in association with water intakes provided occasional deeper water, however, constructed weirs may be obstructing fish passage (see Photos Q,R).

Livestock exclusion fencing has recently been erected through the Red Star Ranch (see Photo P). Natural regeneration of riparian shrubs is apparent in these areas after only one season. In some areas dense growth of reed canary grass may inhibit natural succession and the establishment of larger tree species. One of the functions of a riparian forest is to supply large woody debris for the stream. Fallen logs and debris jams function to reduce stream energy, cause local scour and deposition and provide instream cover for fish. While livestock exclusion is an essential first step, it will take many years of growth before instream LWD function is naturally sustained by inputs from the riparian zone.

Landowners described the past existence of an irrigation/storage pond on the main channel through the Takoff property. Little evidence of the pond remained at the time of the survey. At the upper end of the reach, some channelization had occurred including the addition of some riprap (see Photos S,T). While the channel appeared relatively stable, it was severely lacking in habitat complexity.

3.2.6 Reach 5

Reach #	Reach Segment	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
5	12.0	995	2.0	Riffle/Pool	11.20	n/a	Gravel	Shrub/herb	Shrub/herb
5	13.0	1113	2.0	Riffle/Pool	5.20	n/a	Gravel	Shrub/herb	Shrub/herb
5	total	2108	2.0	Riffle/Pool	8.20	n/a	Gravel	Shrub/herb	Shrub/herb

Reach 5 falls entirely on the upper Weddell property and is the focus of much of the rehabilitation effort recommended by this report. The floodplain has been cleared for grazing leaving only scattered riparian vegetation. Grazing has been allowed to occur right up to the stream edge and numerous livestock access and crossing points exist. Extensive areas of bank erosion exist on outside bends, many of them active or poised to reactivate during high flows (see Photos U,V,W,X,Y,Z,AA). This reach has produced a considerable amount of sediment in recent years. A process of unraveling has begun and if left unaddressed, is likely to continue. Despite the obvious impacts to channel and habitat complexity, fish were observed in occasional existing deep pools remaining within Reach 5. In addition, rainbow have been observed spawning in riffle areas throughout Reach 5 (pers. comm. Todd Cashin, RDCO – see Photo AB).

The largest bank failures were found at the lower end of the reach, with their frequency and magnitude decreasing upstream through the reach. In general, bank heights decreased from the lower to upper end of the reach (see Photo AE). Some of the down-cutting identified at the lower end of Reach 5 may be partially related to the removal of an irrigation dam downstream in Reach 4.

The RDCO has undertaken some rehabilitation efforts on two of the larger sites near the downstream end. This work included the installation of modified brush layers (as per Polster 1999) and grass seeding. Although some survival of the plantings was observed, the dry summer of 2003 likely reduced the success of the revegetation efforts (see Photo V). Some of the work was apparently damaged by continued livestock access. In anticipation of further restoration efforts, RDCO has undertaken detailed surveys of Reach 5 including GPS mapping of the channel and top of banks.

Further discussions of the importance of riparian vegetation are provided in Section 3.3. Approaches to restoration are discussed in Section 4.0.

3.2.7 Reach 6

Reach #	Reach Segment	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
6	14.0	340	2.0	Riffle/Pool	8.00	n/a	Gravel	Mixed forest	Mixed forest
6	15.0	264	2.0	Riffle/Pool	n/a	n/a	Gravel	Deciduous Forest	Deciduous Forest
6	16.0	102	2.0	Riffle/Pool	n/a	n/a	Gravel	Shrub/herb	Deciduous Forest
6	total	706	2.0	Riffle/Pool	n/a	n/a	Gravel	Mixed forest	Mixed forest

Reach 6 is a relatively short reach extending from the top of the cleared portion of the upper Weddell property to the Gun Range Road crossing. The reach includes the Highway 33 crossing of Joe Rich Creek. Reach 6 is characterized by extensive deposition. Its average gradient is less than the channel upstream where several sediment sources (landslides) have been identified.

Between the Highway 33 crossing and the upper Weddell property the channel is severely aggraded (see Photo AF). Although the riparian zone remains mostly intact, the oversupply of sediment and infilling has led to multiple channels, low banks and severe widening (up to 10m).

The Highway 33 crossing of Joe Rich Creek consists of twin 1200mm culverts. At the time of the survey, the east culvert was $\frac{3}{4}$ full of sand and gravel. Apparently, the culverts had plugged in 2001, causing overflows to follow the highway westward, filling the ditch line and damaging the roadway (pers. comm. Todd Cashin, RDCO). The channel immediately downstream of the culvert outlets has recently been excavated in an attempt to clear the culverts and restore capacity (see Photo AG).

Above the culverts to the top of the reach there is less deposition; however, recent work done by the landowner has destabilized the channel. The land has been cleared (including the riparian zone) and the channel appears to have been forced/moved to one side of the property (see Photos AH,AI,AJ,AK). The constructed channel is devoid of structure and stable boundaries/banks. Erosion through this area may also have contributed to deposition at the culverts. Upstream of the cleared land the channel is slightly aggraded but more stable due to the intact riparian vegetation. Structure in the channel has slowed the movement of sediment.

3.2.8 Reaches 7 through 10

Reach #	Reach Segment	Length (m)	Gradient (%)	Chan-nel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
7		2476	3.8	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
8		1430	5.6	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
9		303	6.5	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
10		1483	9.4	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest

Reaches 7 through 10 are mostly on crown land and both banks remain forested. Some historic harvesting and road building has taken place in the lower valley. The most significant disturbance to the channel was from landslides originating along Highway 33 and from the switchback on the Big White Road (see Photos AM thru AY). A detailed discussion of these failures is provided in Section 3.3.2. In general, the slides have created an over supply of sediment in the lower portions of Reach 7. This section is characterized by areas of aggradation and low banks.

Just above Gun Range Road, a patch of recent windfalls have affected channel conditions (see Photo AL). Fallen trees in the channel are diverting flows and encouraging sedimentation. Todd Cashin visited the site subsequent to the assessment and noted that the windfall trees have since been salvaged. This may allow recently stored sediments to move downstream.

Historic logging trails on the east side of the valley have caused some small slope failures. The identified failures remain unconnected to the Joe Rich channel and have likely had little effect and produced only minor amounts of sediment. Just downstream of the Highway 33 slides, the main channel appears to follow an old logging trail for several hundred metres. Although the channel and habitats are somewhat simplified along this section, the current channel is well established and mostly stable (see Photo AU). Restoring flows to the original channel was not considered worthwhile during the assessment.

3.2.9 Reaches 11 through 16

Reach #	Reach Segment	Length (m)	Gradient (%)	Channel Type	Bank-full Width (m)	Bank-full Depth (m)	Substrate Type	Left Bank Riparian	Right Bank Riparian
11		2575	4.0	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
12		757	0.0	Wetland	n/a	n/a	Organics	Wetland	Wetland
13		1442	5.5	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
14		276	14.5	Cascade/Pool	n/a	n/a	Cobble/Gravel	Coniferous forest	Coniferous forest
15		516	0.0	Wetland	n/a	n/a	Organics	Wetland	Wetland
16		842	0.0	Wetland	n/a	n/a	Organics	Wetland	Wetland

Reaches 11 through 16 represent the upper portions of the watershed. In this zone, disturbance is solely related to forest development. The channel was only spot checked at key locations during this assessment.

Forest harvesting operations have generally maintained suitable riparian buffers along Joe Rich Creek. Disturbance is localized at channel crossings. High LWD loads in Joe Rich Creek and its tributaries inhibit the transport of sediment downstream (see Photo AZ). Many tributaries appear to be intermittent or dry gullies. Well-drained soil types and dry climatic conditions generate little surface runoff or erosion. Ditch lines along resource roads likely flow infrequently and lose water to infiltration.

In Reach 12, Joe Rich Creek becomes a large wetland (9 ha), storing upland drainage for slow release (see Photo BA). An inspection of the wetland outlet was made and identified as an old, overgrown and breached beaver dam. The flow control appeared stable and little gradient break (drop) was noted through the structure. Sudden changes in flow were not anticipated as a result of dam future failure due to decay. No indication of recent beaver activity was observed.

Joe Rich Creek steepens to 7% upstream of the wetland and Reaches 13 through 16 and riparian buffers have been maintained (see Photo BB). Several other smaller wetlands form the headwaters of the mainstem and some of its tributaries.

3.3 Summary of Channel Assessments

The impact of specific disturbances related to riparian harvesting, highway and forest development are discussed and summarized below.

3.3.1 Riparian Disturbance

Riparian disturbance has been identified as a key factor affecting channel conditions in Reaches 1, 4 and 5. The loss of riparian vegetation reduces the resilience of the channel to changes in flow and/or sediment regimes and ultimately leads to a deficiency of LWD in the channel. Resistance to bank erosion is reduced and overbank flows are more likely to scour

new channels where no vegetation is maintained. In thickly vegetated riparian zones, overbank flood velocities are slowed, encouraging deposition of fines and the development of higher banks or levees. While it is true that even well-vegetated banks can be swept away and channel avulsions still occur along forested valleys, these events are usually less frequent and less severe.

The flat, broad valley bottom found in Reaches 4 and 5 of Joe Rich Creek was likely formed by glacio-fluvial outwash deposits at the end of the Fraser Glaciation period (Roed, 1995). Since these materials were deposited by fluvial processes, they are granular, somewhat sorted and relatively easily erodible (e.g. sands and gravels). In these types of deposits, the removal of riparian vegetation and its associated root structure reduces the cohesion of the soil and its erosion resistance. Undercut banks readily ravel and collapse into the stream on outside bends where no root mats and/or falling trees slow the process.

Riparian harvesting also interrupts the re-supply of instream large woody debris (LWD). Instream LWD works to increase channel friction, creating gradient steps and controlling sediment movement down the channel. If instream LWD are not continually replaced by the riparian zone, existing structures rot and fail, leaving the channel deficient in structure. Flows accelerate and erosive power increases. This puts more pressure on the bed and banks and the channel begins to scour both. The resultant increase in suspended sediment load further increases the erosive power of the flow and the process accelerates. The normal equilibrium between the channel and its surroundings is lost and may take many years to re-establish to a new balance. In the interim, the channel is unstable and fish habitat and water quality are degraded.

Section 4.0 discusses approaches to riparian restoration.

3.3.2 Effects of Highway Development

Five landslides have been identified initiating on steep slopes adjacent to Highway 33, directly above Joe Rich Creek, just north of the Big White Road junction (see Photos AM,AN,AO,AP,AQ). Three additional slope failures were identified near the first switchback on the Big White Road as part of this assessment (see Photos AV,AW,AX,AY). It was recommended by the WAC in November 2002 that the landslides associated with Highway 33 near Joe Rich Creek should be assessed for stability and that remedial measures be considered to minimize the potential for additional hydrologic impacts. Several of the landslides continue to exhibit active surface raveling.

The landslides were inspected and photographed by Todd Cashin and Brent Magnan of the RDCO in 2002. Further inspections of these landslides were made during this channel assessment. From the highway, it was apparent that many of the failures had been caused by poor drainage control at the roadway (Photo AS). The failures occurred near culvert outlets or where highway surface drainage was directed onto the steep slopes above Joe Rich Creek. To maintain support for the roadway, MOT has back-filled the slide scarps from the road edge with imported materials (see Photo AO).

Below Highway 33, four of the failures have deposited materials into the Joe Rich Creek channel. Deposits were subsequently eroded by the creek (Photo AT). The channel was noted as moderately aggraded for some distance downstream of the failures and multiple/abandoned channels were observed. Dense riparian vegetation found in this channel section likely increased the resilience of the channel/banks to the supplemental sediment load resulting from the slides.

The failures associated with the switchback on the Big White Road were similarly related to poor drainage management. Ditch flows, collected for more than 500m of roadway above the switchback, were directed off the steep slope that the switchback turned to avoid. The three failures at this location had occurred at different times as they were observed to be in different stages of recovery. The most recent failure showed recent activity as ditch flows continue to be released from the end of the switchback.

The failures from Big White Road also deposited sediment and debris into the Joe Rich channel, creating a substantial debris jam/sediment wedge. The channel in this area was noted as relatively steep and based on bedrock. Disturbance from the failures appeared to be local and did not propagate downstream. Finer sediments likely washed through the debris jam, temporarily affecting water quality downstream.

It was clear that failures associated with the public roads have affected Joe Rich Creek and under current conditions, further failures can be expected. Some of the identified deposits in Reach 6, including those plugging the culverts at the Highway 33 crossing, likely originated at the failure sites.

Just above the Big White Road junction, a tributary of Joe Rich Creek has been diverted east towards a gravel pit after passing below the highway in twin 600mm culverts. Flows do not appear to return to Joe Rich Creek and they may simply infiltrate into gravelly soils near the pit. This diversion may be affecting the flow regime of Joe Rich Creek, allowing low flows to be lost to infiltration. The drainage area above the culverts is 310 ha and representing 6.4% of the total watershed area for Joe Rich Creek. Further investigation during a period of active surface flow is required to determine the actual extent of impacts.

In addition to the problems associated with diversion, the capacity of the culverts at the highway crossing may be inadequate for this tributary. Small culverts such as the 600mm type used at this crossing are prone to obstruction by debris. Ponding at the culvert inlets could easily result in overflows down the highway ditchline toward the area of the existing slope failures. Excessive ditch flows could lead to overtopping of the road, increased pore pressures and further slide activity.

3.3.3 Effects of Forest Development

It was recommended by the WAC in November 2002 that ECA levels for the Joe Rich Creek basin be maintained at low levels (i.e. 20-25%) in order to avoid aggravating existing channel instabilities through the middle and lower reaches. It was also recommended that once channel recovery had been confirmed, a reassessment be conducted to determine appropriate long term ECA levels for the watershed.

Tributaries from the south and west slopes of the watershed show little evidence of sediment delivery and connections are often non-existent. An on-going water quality monitoring program in the larger tributaries will identify future effects should they occur. Based on the observed channel and bank conditions along the Joe Rich Creek mainstem, and the levels of suspended sediments measured to date in these smaller tributaries, sediment loads in Joe Rich Creek can be expected to dominate (and diminish) the effects of forest development in this area.

During this assessment, little evidence of stress related to increased flow regimes was observed at any point in the system. In the upper (east) watershed, forest development does not appear to have concentrated or increased surface drainage. In general, the soils were

thought to be well-drained, and surface runoff events rare. Forest harvesting operations have maintained suitable riparian zones along Joe Rich Creek, buffering it from direct impacts. Observed disturbance was localized at channel crossings.

In the middle of the developed uplands, the large wetland is likely to buffer any peak flow effects associated with upslope harvesting (see Photo BA). In addition to attenuating peak flows, the wetlands also serve to filter sediment originating upstream. In general, the wetlands provide a steady flow of clean water to Joe Rich Creek. Properly managed forest development at the currently proposed levels is expected to have a minimal effect on water quality and quantity in Joe Rich Creek downstream.

3.3.4 Summary of Channel Processes

Channel conditions and key processes in the Joe Rich Creek watershed can be summarized as follows:

- Drainage from upper areas in the watershed is buffered by significant areas of wetland. Forest development in this area has resulted in little impact to the channel.
- Landslides associated with Highway 33 and Big White Road drainage have contributed sediment and debris to the channel downslope. Local disturbance to the channel has been moderated by intact riparian forests. Sediment from these sources is being deposited in Reach 6, causing problems at the Highway 33 culverts and affecting private land downstream.
- Below the Highway 33 crossing, the channel enters an area of intense agriculture. Riparian vegetation is sparse and channel and banks are heavily used by livestock. The channel is deficient of instream structure normally provided by LWD. A process of bank and channel scour has been initiated, widening the channel, eroding banks and increasing sediment loads.
- Channel conditions improve downstream as riparian vegetation density improves. Only finer sediments remain in suspension and are discharged into Mission Creek.
- Localized disturbances occur throughout the private land section. Fish access may be obstructed or limited by artificial weirs in at least two locations.

4.0 REHABILITATION RECOMMENDATIONS

Opportunities for channel, riparian and fish habitat rehabilitation were identified in many areas of Joe Rich Creek. Poor habitat conditions extended for considerable distances. Aggraded channel sections and reduced instream LWD left few pools and simplified habitats. The lack of stream shading likely raises stream temperatures and decreases food sources for fish and aquatic invertebrates. Livestock access to the creek may be affecting water quality through increased coliform levels. Outside meander bends with diminished riparian vegetation frequently showed evidence of accelerated erosion. Several sediment sources related to human activity were identified. Anthropogenic alterations (constructed weirs) in the channel may be affecting fish distribution in the system.

Natural river function includes some channel migration, bank erosion, flooding and loss of land. These processes have been accelerated by the cumulative effects of development, encroachment, riparian harvesting and other disturbances in the watershed. Considering the extent of disturbances in Joe Rich Creek, it is essential to work toward the long-term restoration of natural channel and riparian function. It would not be prudent to riprap every bank, nor would the end result be particularly beneficial to fish and fish habitat. If natural function is restored in the channel, including a well-vegetated riparian zone, then improvements to fish habitat and water quality will follow. The recommended long term, low maintenance solution for a stable channel supporting fish habitat is the establishment of a continuous, mature riparian forest along the entire Joe Rich Creek channel.

Riparian recovery can be accelerated through active planting of appropriate shrub and tree species. While active planting may accelerate recovery, revegetation will only occur if livestock are excluded from the zone. Hungry cattle often browse new deciduous growth, arresting the recovery process and reducing plant survival rates (see Photos AC,AD). Livestock exclusion fencing is key to riparian recovery, and fencing alone may be enough to begin the process of natural revegetation. Once some recovery has been attained and plants are well-established in the riparian zone, occasional grazing of the riparian zone may be permitted to control weeds and encourage natural succession. **If a planting program is undertaken, no planting or seeding should go ahead until livestock exclusion fencing is in place so efforts are not compromised.**

It will take considerable time for any riparian recovery program to generate enough large stems to restore LWD function to the stream along the disturbed reaches. In the interim, existing bank failures may enlarge, contributing sediment to the system and sustaining the process of channel widening and aggradation. More immediate methods aimed at adding structure to the channel may be considered. Although an overall 'softer' approach toward long term recovery is recommended, some interim 'harder' stabilization measures are recommended to slow the current deterioration of the system.

Fish habitat in Joe Rich Creek was found to be in a degraded condition. As with improvements to channel stability, it will take considerable time for any riparian recovery to augment current fish habitat conditions. The provision of interim fish habitat to maintain stocks through the recovery process may be considered a priority. Based on these concepts the following action plan/approach to rehabilitation in Joe Rich is proposed:

1. Address key areas of instability

Control key erosion sites and sediment sources. Where possible combine goals of erosion control with the provision of interim fish habitat, keeping in mind long term goals and solutions. Work with natural processes giving the channel some room to adapt.

2. Address riparian management issues

Encourage recovery of riparian areas through livestock exclusion fencing. Where budgets allow, augment fencing with riparian planting. Work together with landowners to develop appropriate management strategies for riparian lands. Assist in the provision of off-channel watering sites. Continue with educational workshops, consensus building and promote positive attitudes toward a stable, functioning riverine ecosystem.

2. Provide some interim fish habitat

Build structures that combine fish habitat improvement with bank stabilization and river training (see above). Conduct further investigations into fish habitat use and limiting factors in Joe Rich Creek. Ensure that any constructed habitats are appropriate to target species.

This approach addresses short term issues as well as taking steps toward the long term recovery of the system. An adaptive management loop may be established that identifies key problem areas and builds upon rehabilitation successes to eventually restore natural function to the entire watershed.

When restoring a system such as Joe Rich Creek, it is important to keep costs low to allow for restoration improvements to be spread over a larger area. 'Low tech' solutions that can be managed by volunteer groups and/or local landowners will be more cost effective than heavy construction. Avoid building for extreme events where human safety is not an issue. Stakeholders should be willing to accept some failures if large events occur in the short term. Channels are generally not stable under 200 year flows. If a design is expected to be stable under such extreme flow conditions, it is unlikely to allow for natural stream processes and/or channel morphology in the long term.

4.1 Recommended Rehabilitation Works/Prescriptions

The following sections discuss conceptual prescriptions for high and moderate priority sites in the Joe Rich watershed. A summary of priority sites is provided in Table 2. Work priorities were assigned by applying the following criteria (in no particular order):

- Level of threat to human life, public utilities or private property.
- Landowner support and interest.
- Current level of site impacts.
- Potential for downstream/watershed level impacts.
- Answer the question: If left untreated, would the site tend toward stability or instability?
- Likelihood of rehabilitation success.
- Potential for the production of appropriate fish habitat.

Recommended approaches to rehabilitation and fish habitat improvements at the priority sites are provided in Table 2.

Unlike the numerous localized restoration sites listed in Table 2, several hundred meters in Reach 5 were identified as severely disturbed and a priority for restoration. Restoration of this channel section involves a series of recommendations and a range of structures has been proposed. A more detailed plan of preliminary prescriptions for Reach 5 is provided in Appendix D. Prescribed restoration techniques outlined in the following sections. Examples of design sketches are provided in Appendix E.

4.1.1 Rock Riffles

One of the techniques prescribed for Reach 5 is the construction of rock riffles in the channel. A total of twelve riffles have been recommended at 30 to 50m spacing. The intent of the riffles is to control channel down-cutting and bank scour, dissipate stream energy, improve channel

complexity and develop pools for fish habitat. In series, the riffles will step the gradient of the channel. Energy will be dissipated at the riffle sites and reduced through the intervening pools. During low water, deeper water between the riffles will provide for improved fish habitat and winter survival. Rock riffles have been used successfully on many stream restoration projects in the Southern Interior.

Rock riffles are constructed by placing the rock directly on existing substrates. Heights of the individual riffles, based on gradient and spacing, have been specified in the prescription plan. The upstream face of the riffle should be 4:1 or less, and the downstream face of the riffle should taper at 10:1 or less. Oversized boulders should be included in the downstream face of the riffle (protruding) to create complex velocities and dissipate energy. The riffle crest should be V-shaped to provide a low water passageway for fish. Riffle crests should be tied at least one metre into both banks to prevent circumvention of the structure.

A typical riffle design is provided in Appendix E. The sketch lists dimensions and material sizes suitable for use in Reach 5. In general, riffles should be constructed in series from downstream to upstream. Ideally, the backwater from one riffle should inundate the toe of the next riffle upstream.

4.1.2 Bank Stabilization

Bank pull-back and brush layers have been prescribed at existing erosion sites along Joe Rich Creek in Reach 5. Pull-back of over-steepened areas prevents further collapse of banks into the stream and provides a better surface for the establishment of vegetation. While the machine is doing the pull back, brush layers can be incorporated into the bank. This involves the placement of live cuttings (usually willow or cottonwood, 1-2m in length) along a temporary bench and burying them almost entirely with backfill. Properly done, the cuttings will sprout and quickly establish dense shrub and tree growth along the bank. Planting should be undertaken in the spring or fall when dormant cuttings can be obtained and periods of drought are less likely.

Where plantings cannot be timed with a machine on site, modified brush layers may be installed by hand. In this case, a wattle fence (also using live cuttings) is constructed and used to create a bench for the brush layers. Material is pulled down on top of the brush layers and another bench can then be constructed up the bank using a second wattle fence (while standing on the first). This process can be repeated until the full bank height has been achieved. Sketches of both types of brush layering are shown in Appendix E. Consult with plant specialists having experience in the region to confirm which methods and plant species have been successful in similar situations.

At some locations, the addition of buried or anchored rootwads has been recommended. These have been prescribed at sites where near bank velocities are expected to be more severe. Properly spaced rootwads can reduce near bank velocities and provide for easier fish passage, refuge and holding habitat. These structures are also beneficial to fish through the provision of interim LWD and by encouraging pool development through scour. A sketch of a typical rootwad revetment is provided in Appendix E.

Preferably, rootwads can be obtained for use in the project with 3 to 5m long stems (or boles) attached. This allows easy anchoring of the rootwads by simply burying the stem. If rootwads with stems are unavailable, additional anchoring systems may be required such as using onsite trees, buried deadmen or "manta ray" type anchors driven into the bank (Rodman 2000, Arndt

2001). Galvanized chains or cable are required to connect the rootwads to the anchors. Banks above the rootwads should be stabilized using brush layers as described above.

As previously stated, no effort toward revegetation should be undertaken until work areas can be protected from livestock. Livestock exclusion fencing is described in the Section 4.1.4.

Areas disturbed during construction may be grass seeded to reduce sediment generation through surface erosion in the short term. Landowners and vegetation specialists should be consulted to ensure appropriate grass seed varieties are selected. Periodic irrigation of seeded and planted areas will greatly increase survival and growth rates. Where possible, this should be arranged with the landowner. This is often easily accomplished in conjunction with spray irrigation of neighbouring hay crops.

4.1.3 Bar Stabilization

Bar stabilization can be accomplished by using brush traverses across the channel, perpendicular to the flow direction. Once established, the brush traverses obstruct flow across the bars, reducing local velocities and encouraging deposition. Tightly spaced brush traverses often recruit floating small debris, further disrupting flow. This focuses the flow back into the main channel, increasing scour and improving channel definition. Large woody debris pieces can be placed between the brush traverses to 'preload' the bar surface. Once established, the fast growing shrubs will control the movement of the debris, reducing the need for anchoring. The protection provided by the brush traverses and woody debris helps to create stable and/or shaded sites on the bars where other types of vegetation can seed and establish.

Brush traverses are best planted using a machine to dig trenches across the bar. Where possible, trenches should be deep enough to reach the water table. This greatly improves survival rates. Cuttings should be placed against the downstream face of the trench (leaning downstream) to mimic natural conditions for the spread of pioneering species. Once placed, the trench can be backfilled by the machine. The construction of these brush traverses using a machine in conjunction with a hand crew goes quick, and by far the most time consuming activity is the collection (harvesting) and processing of the live materials. Source areas of dense, even-age live plant stock should be sought out for efficient harvesting and transport. Once again, planting should be undertaken in the spring or fall when dormant cuttings can be readily obtained. A sketch of typical brush traverses aimed at bar stabilization is provided in Appendix E.

As previously stated, no effort toward revegetation should be undertaken until work areas can be protected from livestock. Livestock exclusion fencing is described in the next section.

4.1.4 Riparian Recovery

Disturbed riparian areas along Joe Rich Creek total more than 5500m in length including both banks. RDCO policy, as stated by the Joe Rich Rural Land Use Bylaw, suggests a minimum 10m wide 'no disturb zone' adjacent to all creeks. This represents a total affected area of 5.5 hectares. Normal restocking densities (conifers only) for forested land are on the order of 2,000 stems per hectare. To plant the currently disturbed area to this density would require 11,000 seedlings.

Deciduous plantings such as birch, aspen and other species available from nurseries should be included in a riparian planting program. Species such as black cottonwood and willow can grow quickly from live cuttings. Deciduous species are more likely than conifers to establish through

natural seed dispersion assuming existing local sources. A revegetation specialist with experience in the region should be consulted to help select appropriate native species and improve the success of the program. Once again, irrigation can greatly increase survival and growth if it can be arranged with the landowner.

Riparian recovery will (only) occur if livestock are excluded from the riparian zone. The type of livestock exclusion fencing to be erected should generally be selected by the landowner as suitable for his/her particular use and/or circumstance. Often, landowners prefer to build their own fences if the materials are provided. Locations of the fence line and defined water access points (if used) should be discussed with the landowner on a site by site basis. Alternative livestock watering systems away from the creek may be discussed. In some areas, gravity fed systems may be possible using tributary gullies/sources for at least part of the year. Pumped water systems are often problematic and expensive, but may be the only alternative. Ensuring that the landowner is 'on-side' with the long term goals of riparian recovery is key to any program.

4.1.5 Fish Habitat Improvement

With the exception of the recommendations aimed at addressing obstructions to fish passage, no recommendations have been made solely for the purpose of improving fish habitat. Recommended rock riffles will improve fish habitat by increasing pool size, depth and frequency. Rootwad revetments will augment fish habitat by increasing instream large woody debris (cover) and promoting localized scour. Riparian vegetation and livestock exclusion will benefit fish habitat in the longer term. Once channel stability is better established, the addition of further LWD may be considered to provide interim habitats as riparian vegetation matures. Prior to this, some investigation to identify the 'critical limiting' or preferred habitats for fish in Joe Rich Creek should be undertaken.

4.2 Cost Estimates

Cost estimates for preliminary budgeting have been included in Table 2. These cost estimates are based on typical values for machine time and labour, and experience on similar rehabilitation projects. Actual costs may vary considerably once more specific prescriptions are developed and the full extent of the work is defined. 'Ball-park' estimates have been provided for the suggested drainage improvements to the highway. The cost of this work may vary greatly depending upon the results of more detailed assessment by MOT, and the resulting scope of works. Prices for rock and materials used in the prescriptions will vary depending on the sources used and associated hauling distances. The total cost of the rehabilitation activities recommended within this report is approximately \$200,000.

4.3 Implementation Considerations

Many different recommendations and prescriptions have been outlined in this report. It is not necessary that any or all of this work be undertaken at one time, or under one budget. Individual improvements can be done at landowners/agency discretion, when flow and/or planting conditions are suitable, if and when funding sources become available. Although relative priorities have been suggested in Table 2, the actual order of completion of the recommended works is not critical, and most work sites can be treated on an individual basis.

Many sites identified in this assessment were located on private land. Restoration work cannot be undertaken at these sites without full cooperation of the landowner. Some landowners may decline to have work done on their property for undisclosed reasons, and this must be respected. Those who choose to participate and allow improvements on their land should be

supported by the watershed group and assisted to the extent possible. Landowners should be consulted, both during the preparation of detailed prescriptions and the construction phase, to ensure restoration works are compatible with landowner needs and visions.

Reach 5 on the upper Weddell property has been identified as a key area for restoration and the control of sediment. Preliminary prescriptions for this channel section have been provided in Appendix D. RDCO has previously undertaken bank reparations in this area and will likely proceed with future work should funding be obtained. Although specific prescriptions have not been discussed, the Weddell family has expressed support for channel restoration work on their property.

Recommendations aimed at identified problem areas along Highway 33 and Big White Road should be considered by professional staff at the Ministry of Transportation and further investigation undertaken as required.

4.4 Maintenance and Monitoring

As previously stated, until a continuous, dense, mature vegetated riparian corridor has been established along Joe Rich Creek, the channel will not be entirely stable or self-maintaining. Maintenance of any constructed restoration works may be required in the interim. Minor adjustments may be necessary to ensure continued structure performance. Plantings may fail and have to be redone. Money spent on restoration could be wasted without adequate follow-up. A maintenance budget and schedule for inspections should be developed, appropriate for any completed works in Joe Rich Creek. Funding and responsibilities in this regard may be discussed by the WAC committee.

It is unlikely that sufficient funds will be made available to undertake all of the prescribed works outlined in this report in a single season. If all or a portion of the works are constructed, effectiveness monitoring should be undertaken to identify which techniques have been the most successful. The results of this effectiveness monitoring program can be used to refine prescriptions and/or improve techniques used in future works.

Several 'control' sites have already been identified and photographed in the field by RDCO for monitoring revegetation. The locations of these and other photo reference points should be established through field markers and or map (GPS) coordinates. Re-photographing stream bank areas will assist in documenting and evaluating riparian recovery.

The current water quality monitoring program managed by Gorman Bros. Lumber Ltd in the Joe Rich Creek tributaries will provide useful data for the effects of forest development in the south and west portions of the watershed. This program will contribute little to the monitoring of sediment loads and channel/bank stability in the Joe Rich Creek mainstem. Although not specifically aimed at forest development impacts, the WAC committee may consider expanding the program to include some water quality sampling in the lower mainstem of Joe Rich Creek.

Recommendations have been made by the WAC (2002) regarding the level of harvest in the Joe Rich Creek. Stakeholders in the forest resources of Joe Rich Creek should propose a schedule to re-assess conditions in Joe Rich Creek to determine the degree of channel recovery and, if appropriate, adjust long term ECA levels for the watershed.

Table 2. Summary of Prioritized Rehabilitation Opportunities

Site #	Reach #	Photo Reference	Priority (H,M,L)	Landowner	Description	Existing Fish Habitat Values (H,M,L)	Sediment Production/Hazard (H,M,L)	Machine Access	Restoration Approach	Expected Benefits	Constraints And/or Potential Risks	Likelihood For Success (H,M,L)	Estimated Restoration Cost (\$)
1	1-2		M	Hryciw	A 1.2m high waterfall has been constructed instream to prevent scour near a private bridge. Riprap has been placed to ensure no pool forms at the bottom of the cascade. The structure is likely a barrier to fish passage.	L	L	Good. Adjacent to public road.	Break the drop into several steps using rock or log weirs downstream of the existing structure.	Restore fish passage to Reach 2 and possibly beyond. Create some pool habitat at site.	Landowner participation required. Fish passage may be naturally restricted in bedrock canyon upstream. May affect driveway stability (see next site)	M	\$3,000
2	2		H	Hryciw	Driveway bridge on a sharp bend is a potential debris jam site. If bridge opening were sufficiently blocked, flow could easily overtop right bank and flow onto Thelwell Road. Washouts have occurred at this site in the past.	L	L	Good. Adjacent to public road.	Reconstruct bridge to increase capacity and reduce risk of debris jams. Construct berm to keep flows in channel in case of jam.	Prevent flooding and property damage along road downstream.	Landowner participation required. Existing bridge was recently constructed and approved by BC Gov't. Difficult to eliminate risk.	M	\$20,000
3	3		H	Pearson	A steel span bridge has been constructed directly over an old collapsing log structure. The resultant blockage is causing extensive flooding and deposition upstream. The sediment wedge extends approximately 120m up the channel.	L	H	Good. Along private trail.	Carefully dismantle log structure and restore bridge opening. Undertake during low flows to control release of collected sediments. Vegetate the surface of the wedge with quick-growing, colonizing plants.	Avoid catastrophic failure of bridge and release of sediments.	Landowner participation required. May not be able to keep stored sediments in place.	H	\$2,500
4	4	5441	M	Weddell	Eroding right cutbank on outside bend. 1.8m high by 26m long. Channel is currently flowing toward inside of bend. Will reactivate at high flows.	L	M	Good through pasture.	Pull back over-steepened areas. Revegetate banks and bars with brush layers.	Control bank erosion and initiate establishment of riparian vegetation.	Survival rates of plantings may be low in dry, exposed area. A severe flood shortly after planting could wash away efforts.	M	\$2,500
5	4	5442	M	Weddell	Eroding right cutbank on outside bend. 1.8m high by 18m long.	L	M	Good through pasture.	Pull back over-steepened areas. Bury rootwads with stems to reduce bank velocities. Revegetate banks and bars with brush layers.	Control bank erosion and initiate establishment of riparian vegetation.	Survival rates of plantings may be low in dry, exposed area. A severe flood shortly after planting could wash away efforts.	M	\$2,500
6	4	5444	M	Weddell	Corral in creek. Fence line has initiated debris jam causing some widening. Devoid of vegetation. Manure in creek.	L	L	Good through pasture	Move corral away from creek. Establish livestock inclusion fencing. Initiate riparian recovery through seeding and planting.	Improved channel stability and water quality.	An off-channel livestock watering system may be required in alternative corral.	H	\$2,000
7	4	5448	M	Red Star Ranch	Collapsing weir, 3.6m wide by 0.65m drop likely an obstruction to fish. Good scour pool downstream.	M	L	Good through pasture	Notch the weir to create low flow channel.	Improved fish passage.	May need improvements to water intake.	H	\$2,000
8	4		M	Demitor	Weir constructed to create intake pond may be seasonal barrier to fish passage.	M	L	Good	Notch the weir to create low flow channel.	Improved fish passage.	Private facility.	H	\$2,000
9	4	-	M	Weddell	Riparian vegetation has been removed and livestock continue to access many areas of Reach 4. Continued browsing and trampling of the riparian zone is hindering recovery.	L	L	Good through pasture	Erect livestock exclusion fencing through remaining unprotected areas of Reach 4.	Rapid natural recovery of riparian areas resulting in improved channel stability, stream shading and long term improvements to fish habitat.	Off-channel livestock watering system may be required.	H	\$5,000
10	5	-	H	Weddell	The removal of riparian vegetation and the subsequent loss of stream and bank structure has resulted in increased stream energy, causing extensive channel widening, downcutting and bank scour. Livestock continue to access many areas. Continued browsing and trampling of the riparian zone is hindering recovery and has hampered previous efforts at restoration.	M	H	Good through pasture	Reduce stream energy and control downcutting by constructing rock riffle steps at key locations. Install rootwad groynes to reduce near bank velocities. Pull back and revegetate over-steepened banks using modified brush layers. Erect livestock exclusion fencing to allow natural recovery of riparian zone. (see Appendix E)	Improved channel stability, reduced sediment production and land loss. Short (riffle pools) and long term improvement to fish habitat. Eventual establishment of a functioning riparian zone (including stream shading, food and detritus supply, and LWD recruitment).	Rock source is currently unknown and expense may be prohibitive. Off-channel livestock watering system may be required.	H	\$60,000
11	6	5483	H	MOTH	One of two 1200mm culverts under Highway 33 is ¾ full of sand and gravel, reducing culvert capacity. Overflows from culvert inlet have flowed down the highway in the past depositing sediment and damaging the roadway.	L	M	Good along Highway 33	Some cleaning has already been undertaken. Recommend improvements at culvert inlets to contain overflows and allow higher head/ponding. Increased head/velocities will help mobilize sediment through pipe.	Reduced frequency of problems at culvert crossing, including damage to roadway (safety issues). Improved fish passage.	Improvements may encroach on private land. Continued sediment delivery from upstream may hamper efforts.	M	\$5,000
12	6		M	n/a	Riparian vegetation has been removed and Joe Rich Creek channel has been reconstructed across private	L	M	Good	Develop a more natural channel size and pattern across the	Improved channel stability and water quality.	Landowner participation required. Natural deposition	M	\$15,000

Site #	Reach #	Photo Reference	Priority (H,M,L)	Landowner	Description	Existing Fish Habitat Values (H,M,L)	Sediment Production/Hazard (H,M,L)	Machine Access	Restoration Approach	Expected Benefits	Constraints And/or Potential Risks	Likelihood For Success (H,M,L)	Estimated Restoration Cost (\$)
					land. Bank erosion and deposition will likely lead to continued instability.				property. Pull back and revegetate over-steepened banks using modified brush layers. Erect livestock exclusion fencing to allow natural recovery of riparian zone.		area leading to chronic instability as stored sediments move downstream from area of landslides upstream.		
13	7		H	MOTH	Poorly managed drainage along Highway 33 has resulted in several landslides, some of which have reached the Joe Rich Creek channel. Problems include infrequent cross-drainage allowing surface runoff to concentrate into fewer culverts and culverts discharging flows on to unprotected erodible slopes.	L	H	Good at highway level.	Increase cross-drainage frequency and/or provide erosion protection on slopes below culvert outlets.	Prevent future slope failures and control active raveling and enlargement of existing failures. Reduce sediment inputs to Joe Rich Creek.	Work on public highway may be expensive. Rearranging drainage may initiate failures at new locations.	M	\$50,000
14	8		M	MOTH	Tributary to Joe Rich Creek has been diverted to gravel pit, potentially affecting flow regime (reduced summer flows). Twin 600mm culverts may easily plug, and resulting overflows will follow highway to area of known instability.	L	H	Good at highway level.	Further investigate extent of diversion and locate ultimate discharge. Increase culvert size and/or construct containment berm in event of overflow.	Potentially increase low flows. Prevent damage to highway and avoid future slope failures in area of instability.	Further investigation required.	M	\$5,000
15	8		H	MOTH	Drainage off switchback on Big White Road has caused several slope failures into Joe Rich Creek. Extended ditchline on road above the switchback intercepts and concentrates flows. All of this drainage is directed to steep slope off switchback.	L	H	Good at highway level.	Increase cross-drainage frequency. Bring surface drainage back across the inside of the switchback.	Prevent future slope failures and control active raveling and enlargement of existing failures. Reduce sediment inputs to Joe Rich Creek.	Work on public highway may be expensive.	H	\$10,000

5.0 REFERENCES

- Arndt, S. 2001. *A Caution on the Use of Manta Ray Anchors for Ballasting Large Woody Debris in Streams*, *Watershed Restoration Technical Bulletin - Streamline*, Vol. 5 No. 3. Watershed Restoration Program, BC Ministry of Environment, Lands and Parks, Vancouver, BC.
- Beeson, C.E. and Doyle, P.F. 1995. *Comparison of Bank Erosion at Vegetated and Non-vegetated Channel Bends*. Water Resources Bulletin, American Water Resources Association, Vol. 31, No. 6.
- Dobson Engineering Ltd. March 2003. *Water Quality Monitoring for the South Slopes of the Joe Rich Creek Watershed (Year 3 – 2002 Data)*. Gorman Bros. Lumber Ltd., Westbank, BC.
- Dobson Engineering Ltd. November 2002. *2002 Interior Watershed Assessment Update for the Mission Creek Watershed*. Riverside Forest Products Limited, Gorman Bros. Lumber Ltd., Tolko Industries Ltd. (Lavington) and the Small Business Forest Enterprise Program (Penticton Forest District).
- Dobson Engineering Ltd. December 1998. *Interior Watershed Assessment Procedure for the Mission Creek Watershed – Update Report*. Riverside Forest Products Limited, Kelowna Division.
- Donat, Martin. 1995. *Bioengineering Techniques for Streambank Restoration, A Review of Central European Practices*. Watershed Restoration Project Report No. 2. BC Ministry of Environment, Lands and Parks and Ministry of Forests, Vancouver, BC.
- Gorman Bros. Lumber Ltd. 2002 *Forest Development Plan 2002 -2007*. BC Ministry of Forests, Penticton Forest District.
- Griggs Tassie & Associates. May 1998. *Joe Rich Rural Land Use Bylaw, Bylaw #730, Schedule 'A'*. Regional District of Central Okanagan, Kelowna, BC.
- LGL Limited. March 2003. *Mission Creek Habitat Restoration Feasibility*. Ministry of Water, Land and Air Protection, Penticton, BC.
- Mason, B. and R. Knight. 2002. *Sensitive Habitat Inventory and Mapping*. Community Mapping Network, Vancouver, BC
- Mission Creek Watershed Assessment Committee *Final Watershed Assessment Committee (WAC) Meeting Summary Notes – Mission Creek Watershed Assessment Procedure* held November 25, 2002 at the Riverside Forest Products office in Kelowna, BC.
- Morris, Jules (Chairperson) *Joe Rich Watershed Monitoring Committee Newsletter, January 2003*. Published by the Joe Rich Ratepayers and Tenants Society (www.silk.net/joerich/wrpt.htm)
- Newbury, R.W., M.N. Gaboury and Bates, D.J. 1997. *Restoring Habitats in Channelized or Uniform Streams Using Riffle Pool Sequences*. In Slaney, P.A. and Zaldokas, D. (eds.) *Fish Habitat Rehabilitation Procedures*. Province of BC, Watershed Restoration Program Technical Circular No. 9.
- Newbury, R.W., M.N. Gaboury. 1993. *Stream Analysis and Fish Habitat Design, A Field Manual*. Newbury Hydraulics Ltd., Gibsons, BC.

- Polster, David F. 1999. *Soil Bioengineering for Steep/Unstable Slopes and Riparian Restoration*. Paper presented at the Fourth Annual Roads, Rails and Environment Workshop, November 2,3, 1999, Revelstoke, BC.
- Rodman, R. 2000. *A Large Woody Debris Anchoring System for Sites With Limited Access, Watershed Restoration Technical Bulletin - Streamline, Vol. 5 No. 2*. Watershed Restoration Program, BC Ministry of Environment, Lands and Parks, Vancouver, BC.
- Roed, Murray A. 1995. *Geology of the Kelowna Area and Origin of the Okanagan Valley British Columbia*. Kelowna Geology Committee, Kelowna BC.
- Schiechtl, H.M. and R. Stern. 1997. *Water Bioengineering Techniques for Watercourse, Bank and Shoreline Protection*. Blackwell Science Ltd., Oxford, England
- Sime, Grant R. (Silvatech Consulting Ltd.) 1998. *Joe Rich Total Resource Plan* Gorman Bros. Lumber Ltd., Westbank, BC.
- Slaney, P.A., D. Zaldokas. 1997. *Fish Habitat Rehabilitation Procedures, Watershed Restoration Technical Circular No. 9*. Watershed Restoration Program, Vancouver, BC.

APPENDIX A

Orthophoto Base Map

APPENDIX B

Sensitive Habitat Inventory and Mapping (SHIM) Data Summary

APPENDIX C

Joe Rich Creek Longitudinal Profile

APPENDIX D

Map of Preliminary Prescriptions for Reach 5 (Weddell Property)

APPENDIX E

Example Sketches of Prescribed Structures

APPENDIX F

Selected Site Photographs