

CRE - 86 - 02

RESTORATION OF PLACER MINED STREAMS: IDENTIFICATION OF STRATEGIES TO EXPEDITE RECOVERY



Prepared for:
YUKON RIVER PANEL
Box 20973
Whitehorse, Yukon
Y1A 6P4
Phone: 867-393-1900
email: monaghan@internorth.com

Prepared by:
M. MILES & ASSOCIATES LTD.
645 Island Road
Victoria, B.C.
V8S 2T7
Phone: 250-595-0653
email: mmaa@coastnet.com

MAY 2003

EXECUTIVE SUMMARY

An overview study was conducted in August 2002 to assess the effects of historical placer mining activities on stream channel stability and to prepare conceptual recommendations to expedite the recovery of these areas. Four representative watersheds were inspected. These consisted of Upper Clear Creek, Indian River, Hunker Creek and lower Klondike River near Dawson. The effects of varying historic mining techniques were evaluated as was the performance of two sites on Hunker Creek which received the Robert E. Leckie Award for Outstanding Mining Reclamation Practices. These sites were selected as being representative of the best modern mining and reclamation procedures.

Historic placer mining is thought to have directly affected 2.5 to 5% of streams in Yukon. Our field studies indicate that placer mining has resulted in extensive changes to stream channel morphology and stability. The availability of readily erodible sediments has also been greatly increased in most mined areas. The downstream movement of sediment (originating during the mining process and from subsequent erosion or thermokarst), affects both water quality and channel conditions. A variety of previous studies have demonstrated that these changes can have adverse effects on aquatic organisms, including fish.

Our observations indicate that surface materials in dredge spoil piles are frequently poorly re-vegetated due to a lack of fine sediment and rapid drainage. Stream channels are also frequently confined to straight sections along the valley wall. Better vegetated depressions or wetlands with riparian vegetation can, however, occur between dredge spoil piles. More modern excavator and dozer operations have frequently diverted streams to confined, wall based channels to facilitate mining the valley flat and overburden is often wasted on the valley walls. These activities can result in thermokarst development in ice-rich materials and valley wall erosion. Ground sluicing to remove overburden can frequently have similar effects. Mining excavations frequently replace pre-existing valley bottom channels with a diverse range of pits, pre-settling ponds, settling ponds and spoil piles. In some locations, riparian and wetland habitats suitable for wildlife, waterfowl and possibly fish are developing around these excavations. However, in most areas, the residual spoil piles are readily erodible and form active sediment source areas. This results in the formation of wide, shallow, laterally unstable channels. In some areas the valley flat has been largely eroded with only residual spoil piles remaining above water level. Most inspected settling ponds had also failed or breached which frequently resulted in the erosion of some or all of the trapped materials. Mining on pups or gulches was commonly observed to result in a lowered channel bed elevation which caused a subsequent re-adjustment in the stream bed above the mining site. This commonly resulted in extensive post-mining sediment production (particularly in areas of ice-rich permafrost). All of the above concerns will persist for a considerable period of time. In many situations this will require spoil piles to be eroded, flood plain areas to develop and erosion resistant vegetation to be re-established before sediment loads will be reduced to pre-mining levels. This could take many decades to centuries.

Once entrained, fine textured sediments derived from black muck (loess) in the Dawson Area appear to generally remain in suspension. This fact, along with the erosion resistant nature of undisturbed banks with mature coniferous vegetation, was observed to reduce the potential for downstream changes in channel morphology on some sections of Indian River. However, in other areas where the introduced sediment is coarser in texture, downstream sediment transport and accumulation was observed to result in bed aggradation, wider river widths and increased lateral channel instability.

Our inspection of the award winning restoration sites on Hunker Creek indicates that modern mining and reclamation practices can greatly reduce the potential for long term sediment production and accelerate re-vegetation. Re-contoured ponds in old pits also have the potential to provide useful waterfowl and

possibly fish habitat. Nevertheless, stream processes are still disrupted when wall based channels are constructed and settling ponds infill or fail when not maintained. Uncontrolled surface runoff was observed to erode unvegetated surfaces and valley wall stability was adversely affected by adjacent excavations, spoil deposits, river erosion or disturbance of the thermal regime. The performance of the two inspected sites could, however, be readily improved by appropriate bio-engineering techniques and some periodic maintenance activities.

Restoration of areas disturbed by historic placer mining is a challenging task due to the extensive areas which could need to be treated. In some older areas, restoration work could also cause short term impacts which are not warranted by the resulting benefits. There may also be little benefit in conducting restoration work in areas where upslope or upstream processes, or future placer mining activity, will reduce the potential for long term success. We have, therefore, recommended that a protocol be developed to identify high priority sites or areas suitable for demonstration projects. Within these areas, work should be undertaken using a hierarchical approach which starts upstream or upslope and gradually works down the valley walls, across the valley flat and, if warranted, along the sides or into the river channel.

Where appropriate, bio-engineering or re-seeding techniques could be used to stabilise eroding sections of valley wall. Unused roads could be deactivated and stream crossings re-naturalized. Spoil piles could be re-contoured to reduce surface erosion and, in the case of dredge spoils, improve drainage characteristics and the percentage of fines in the surface materials. Spoil piles could also be breached and residual pits or ponds connected to the river channel to restore channel length, reduce the sediment transport capacity of the stream and provide waterfowl, wildlife or possibly fish habitat. Periodic settling ponds maintenance would reduce the observed high failure rate and excavated materials could be used for top dressing poorly re-vegetated sites. Bio-engineering or seeding could be used to expedite the re-growth of both valley flat and riparian vegetation. There is also the potential to use instream structures in appropriate settings to provide at least short term replacements for 'critical' or 'limiting' fish habitat. These techniques are all commonly applied in more southern regions of Canada. Standard practices may, however, need to be modified to suit conditions in Yukon. The biggest challenge is likely to be finding appropriate funding, given the large areas over which restoration work might be usefully undertaken.

Implementing the proposed restoration strategy will require both basic research to better define restoration objectives and applied research to determine the best way of implementing restoration procedures. The initial phase of any placer restoration work should include regional demonstration sites and a means of sharing the results with restoration practitioners as well as members of the placer industry. Concurrent efforts to ensure that future mining activities are undertaken in a manner which minimizes site impacts and expedites recovery is also warranted. Ideally, the results of restoration trials can be used to refine future mining practices.

ACKNOWLEDGMENTS

Mr. Al von Finster of DFO Whitehorse was the Technical Contact for this project and greatly assisted in all phases of the work. Mr. Hugh Monaghan efficiently administered the contract on behalf of the Yukon River Salmon Restoration and Enhancement Fund.

Ms. Sandra Orban of DFO Whitehorse participated in the field component of the project and kindly arranged for all required aerial photography. All her competent efforts are greatly appreciated.

Ms. Tara Christie and the members of the Klondike Placer Miners Association assisted in various stages of the project and partially funded the participation of Mr. Randy Clarkson (of New ERA Engineering Corp.) in the field component of this project. Mr. Clarkson's expertise and knowledge of the placer industry greatly benefitted this study.

Both Mr. Gerry Couture and Mr. Jake Duncan assisted with the field studies on Hunker Creek and Mr. Couture kindly took the author on an aerial inspection of the Indian River drainage. This was particularly valuable as it is frequently very difficult to reliably assess the effects of historic placer activities from the ground.

The author would also like to thank the following people for advice or assistance during the course of this study:

Ian Birtwell	DFO, Vancouver
Barry Chilibeck	Northwest Hydraulic Consultants Ltd., Vancouver
Steve Gotch	DFO, Whitehorse
Nels Jensen	Placer Miner, Clear Creek
Steve Morison	Gartner Lee Ltd., Calgary
Dianna Mueller	Yukon Territory Water Board, Whitehorse
Chuck Newcombe	BC Government, Victoria
Alan Rothwell	INAC, Dawson City
Ken Tatlow	Placer Miner, Blanch Creek
Pat Tobler	EDI Environmental Dynamics Inc., Whitehorse
Eric Val	DFO, Whitehorse
Leo Van Kalsbeek	DFO, Whitehorse

TABLE OF CONTENTS

								Page
	Executive Summary	..	..	..	..	..	..	i
	Acknowledgments	..	..	..	..	..	..	iii
	Table of Contents	..	..	..	..	..	..	iv
	List of Figures	..	..	..	..	..	..	vi
	List of Tables	..	..	..	..	..	..	vii
	List of Plates	..	..	..	..	..	..	vii
	List of Appendices	..	..	..	..	..	..	xii
	Statement of Limitations of Report	..	..	..	..	..	..	xii
1:	INTRODUCTION AND PROJECT SCOPE	..	..	..	..	..	..	1
2:	METHODOLOGY	..	..	..	..	..	..	1
3:	RESTORATION OBJECTIVES.	..	..	..	..	..	..	3
4:	FIELD OBSERVATIONS							
4.1	Clear Creek							
4.1.1	Study area	..	..	..	..	..	..	4
4.1.2	Hydrology and sediment transport	..	..	..	..	..	..	5
4.1.3	Site conditions							
	Upper Left Clear Creek	..	..	..	..	..	..	5
	Lower Left Clear Creek	..	..	..	..	..	..	5
	Upper Right Clear Creek	..	..	..	..	..	..	6
4.2	Indian River Watershed							
4.2.1	Study area	..	..	..	..	..	..	6
4.2.2	Hydrology and sediment transport	..	..	..	..	..	..	6
4.2.3	Site conditions							
	Upper Dominion Creek	..	..	..	..	..	..	8
	Dominion Creek in the Vicinity of Gold Run Creek	..	..	..	..	..	..	8
	Dominion Creek in the Vicinity of Sulphur Creek	..	..	..	..	..	..	8
	Dominion Creek/Indian River between Australia and New Zealand Creeks	..	..	..	..	..	..	9
	Indian River in the vicinity of New Zealand Creek	..	..	..	..	..	..	9
	Indian River upstream of Quartz Creek	..	..	..	..	..	..	9
	Quartz Creek	..	..	..	..	..	..	9
	Indian River downstream of Quartz Creek	..	..	..	..	..	..	10
	Indian River in the vicinity of Nine Mile Creek	..	..	..	..	..	..	10
4.3	Hunker Creek							
4.3.1	Study area	..	..	..	..	..	..	11
4.3.2	Hydrology and sediment transport	..	..	..	..	..	..	11

Table of Contents - cont'd.								Page
4.3.3	Site conditions							
	Gold Bottom Creek ..	..	..	..	..	..	..	11
	Hunker Creek Headwaters ..	..	..	..	..	..	..	11
	Marsden Reclamation Site ..	..	..	..	..	..	..	11
	Middle Hunker Creek		..	..	..	..	..	12
	Lower Hunker Creek		..	..	..	..	..	13
	Doug Busat Reclamation Site ..	..	..	..	..	..	..	13
4.4	Lower Klondike River Watershed							
4.4.1	Study area ..	..	..	..	..	..	..	14
4.4.2	Hydrology and sediment transport ..	..	..	..	..	..	..	14
4.4.3	Site conditions							
	Lower Klondike River ..	..	..	..	..	..	..	15
5:	RECOMMENDATIONS							
5.1	Preamble ..	..	..	..	..	..	..	16
5.2	Upslope Restoration Priorities ..	..	..	..	..	..	..	17
5.3	Restoration of Valley Flat Areas ..	..	..	..	..	..	..	18
5.4	Riparian and Stream Channel Restoration ..	..	..	..	..	..	..	18
5.5	Instream Channel Structure and Fish Habitat ..	..	..	..	..	..	..	19
5.6	The Need for Research ..	..	..	..	..	..	..	19
5.7	The Need for Demonstration Projects ..	..	..	..	..	..	..	20
5.8	The Need for Funding ..	..	..	..	..	..	..	21
6:	DISCUSSION	..	..	..	..	..	..	21
7:	CERTIFICATION	..	..	..	..	..	..	22
8:	SOURCES OF INFORMATION							
8.1	References ..	..	..	..	..	..	..	22
8.2	Personal Communications ..	..	..	..	..	..	..	25

LIST OF FIGURES

								Page
1.1	Distribution of placer activity in Yukon	..	..	..	..	..	..	F-1
3.1	Equilibrium morphology of alluvial stream channels	..	..	..	..	..	..	F-2
3.2	Hierarchical stream restoration protocol developed by the BC Watershed Restoration Program	..	..	..	..	..	..	F-3
4.1.1	A map of the Clear Creek watershed showing the location of the areas inspected in the field	..	..	..	..	..	..	F-4
4.1.2	Seasonal variation in flow, Clear Creek Above Barlow Creek	..	..	..	..	..	..	F-5
4.1.3	Historical variation in annual maximum daily and instantaneous discharge, Clear Creek Above Barlow Creek	..	..	..	..	..	..	F-6
4.1.4	Historical changes in channel morphology, Left Clear Creek in the vicinity of Field Site C5	..	..	..	..	..	..	F-7
4.1.5	Historical changes in channel morphology, Left Clear Creek at the confluence with Right Clear Creek	..	..	..	..	..	..	F-8
4.2.1	A map of the Upper Indian River watershed showing the location of the areas inspected in the field	..	..	..	..	..	..	F-9
4.2.2	Seasonal variation in flow, Indian River Above The Mouth	..	..	..	..	..	..	F-10
4.2.3	Historical variation in annual maximum daily and instantaneous discharge, Indian River Above The Mouth	..	..	..	..	..	..	F-11
4.2.4	Historical changes in channel morphology, Dominion Creek at the confluence with Gold Run Creek, GPS location 76	..	..	..	..	..	..	F-12
4.2.5	Historical changes in channel morphology, Dominion Creek in the vicinity of Sulphur Creek confluence, GPS location 80	..	..	..	..	..	..	F-13
4.2.6	Historical changes in channel morphology, Indian River upstream of the Quartz Creek confluence, GPS location 103	..	..	..	..	..	..	F-14
4.2.7	Historical changes in channel morphology, Indian River downstream of Quartz Creek	..	..	..	..	..	..	F-15
4.3.1	A map showing GPS locations obtained during the August 2002 site visit	..	..	..	..	..	..	F-16
4.4.1	Seasonal variation in flow, Klondike River Above Bonanza Creek	..	..	..	..	..	..	F-17
4.4.2	Historical variation in annual maximum daily and instantaneous discharge, Klondike River Above Bonanza Creek	..	..	..	..	..	..	F-18
4.4.3	Air photo mosaic showing channel conditions in 1986	..	..	..	..	..	..	F-19
4.4.4	Air photo mosaic showing channel conditions in 1986	..	..	..	..	..	..	F-20
4.4.5	Air photo mosaic showing channel conditions in 1986	..	..	..	..	..	..	F-21
4.4.6	Air photo mosaic showing channel conditions in 1986	..	..	..	..	..	..	F-22

LIST OF TABLES

	Page
4.2.1 Summary of sediment data collected at the WSC station Indian River Above The Mouth	T-1
4.2.2 Estimated suspended sediment loads, Indian River Above The Mouth	T-2
4.4.1 Summary of sediment data collected at the WSC station Klondike River Above Bonanza Creek	T-3
4.4.2 Estimated suspended sediment loads, Klondike River Above Bonanza Creek	T-4

LIST OF PLATES

4.1.1 Looking upstream along Upper Left Clear Creek, showing undisturbed channel conditions	P-1
4.1.2 Looking downstream on Left Clear Creek at SiteC4Nels, showing valley bottom clearing and overburden on spoil piles along the base of the valley walls	P-2
4.1.3 Looking upstream showing the wide shallow channel which has formed along cleared sections of Left Clear Creek	P-2
4.1.4 Looking downstream on Left Clear Creek showing how eroding spoil piles confine the channel	P-3
4.1.5 Looking upstream on Left Clear Creek showing how the channel is downcutting into a placer excavation	P-3
4.1.6 Small tributary channels are commonly downcutting through spoil piles to the lowered mainstem channel	P-4
4.1.7 Looking downstream on a settling pond constructed on the mainstem of Left Clear Creek	P-5
4.1.8 Looking downstream showing the breached outlet on the above settling pond	P-5
4.1.9 Looking downstream on a diverted section of Left Clear Creek showing the erodible banks, scarcity of riparian vegetation and lack of instream structure or complexity	P-6
4.1.10 Looking downstream on a diverted section of Left Clear Creek, showing the straight confined channel which lacks a flood plain	P-6
4.1.11 Placer excavations at tributary confluences can provide off-channel pool habitat which appears to contain fish	P-7
4.1.12 Looking downstream showing the hummock topography associated with dredge mining in lower Left Clear Creek	P-8
4.1.13 Surface materials on spoil piles from old dredges typically lack fine sediments	P-8
4.1.14 Reworked dredge spoil piles exposed fine sediments, some of which are phyllite rich and weather rapidly	P-9
4.1.15 Reworked spoil piles are less well drained and easier to revegetate	P-9

List of Plates – Cont'd.	Page
4.1.16 Well developed active, unvegetated bars indicate that elevated rates of sediment transport are occurring in the lower section of Left Clear Creek	P-10
4.1.17 Elevated rates of sediment transport have resulted in the formation of wide, shallow sections of river channel	P-10
4.1.18 Elevated rates of sediment transport result in fine-textured material being deposited on the river bed	P-11
4.1.19 Riparian vegetation has developed along old sections of relocated channel ..	P-11
4.1.20 Looking downstream on an old section of channelized stream, showing the narrow flood plain which has developed	P-12
4.1.21 Wetland areas have developed between old dredge spoil piles on Lower Left Clear Creek	P-12
4.1.22 Off-channel ponds fed by local seepage have also developed between old dredge spoil piles on Lower Left Clear Creek	P-13
4.1.23 Queenstake Resources No. 1 was the last operational dredge in Yukon	P-13
4.1.24 Pre-1989 dredging on Upper Right Clear Creek has resulted in the formation of wet-land areas between the valley walls and the spoil piles	P-14
4.1.25 Dredge spoil piles are coarse textured and well drained making them difficult to revegetate	P-14
4.1.26 Dredge spoil piles can be difficult to revegetate even along riparian areas	P-15
4.1.27 Stripping and mining activities in Upper Right Clear Creek have resulted in wide channels lacking in stream structure or riparian vegetation	P-15
4.1.28 Lateral and vertical channel shifting along mined sections of streams will result in elevated rates of sediment production until the streams form a stable profile and riparian vegetation re-establishes	P-16
4.2.1 Looking upstream showing the comparatively high sediment loads on Indian River at the confluence with Yukon River	P-17
4.2.2 An example of recent sediment deposits along Lower Indian River	P-17
4.2.3 Looking downstream in upper Dominion Creek, showing the effects of comparatively recent placer mining activity	P-18
4.2.4 Looking downstream to eroding placer spoil piles and undercut sections of valley walls	P-19
4.2.5 Looking downstream to older placer excavations showing valley flat revegetation and the narrow width of the stream channel	P-19
4.2.6 Looking upstream on Dominion Creek at GPS Location 70, showing the rectangular stream channel pattern (likely reflecting old excavation boundaries), local flood plain development and the re-establishment of riparian vegetation	P-20
4.2.7 Looking downstream on Dominion Creek near Hunter Creek [GPS Location 71], showing channel recovery in an area that was mined by dredge	P-20
4.2.8a Looking downstream to recent excavator mining activity in or near an area that was formerly dredged downstream of Jensen Creek	P-21
4.2.8b Looking downstream to an unmined section of Dominion Creek showing what the valley flat in the above area likely looked like prior to mining	P-21

List of Plates – Cont'd.	Page
4.2.9 Looking downstream on Gold Run Creek to the confluence with Dominion Creek ..	P-22
4.2.10 Looking downstream on the Dominion Creek valley flat, showing the extensive series of ponds which have developed as a result of placer mining	P-23
4.2.11: Looking upstream on Lower Sulfur Creek showing valley bottom revegetation and the small confined residual channels at the base of both valley walls	P-23
4.2.12 Looking downstream on the channelized section of Sulfur Creek above the confluence with Dominion Creek. GPS Location 80	P-24
4.2.13: Looking downstream on the Dominion Creek, showing vegetation and wetland development below the Sulfur Creek confluence. GPS Location 81	P-24
4.2.14 Looking downstream on Dominion Creek showing the changes in valley flat conditions opposite Sulfur Creek in the period between 1992 and 2002	P-25
4.2.15 Looking downstream on Dominion Creek/Indian River at GPS Location 84, showing how the channel is flowing through a series of excavated pits	P-26
4.2.16 Looking upstream to a diverted section of channel at GPS Location 85	P-26
4.2.17 Looking downstream to an excavated section of channel at GPS Location 87 ..	P-27
4.2.18 Looking downstream to an excavated section of channel at GPS Location 88 ..	P-27
4.2.19: Looking downstream at GPS Location 89 illustrating recent stripping activities upstream of an undisturbed section of Indian River	P-28
4.2.20 An example of an unmined section of channel located at GPS Location 90 ..	P-28
4.2.21 Looking downstream on an unmined section of channel at GPS Location 91 ..	P-29
4.2.22 Looking upstream from GPS Location 94 comparing mined and unmined sections of channel	P-29
4.2.23 Looking downstream from GPS Location 98 showing the section of unmined channel which occurs between GPS Locations 92 and 100	P-30
4.2.24 Looking upstream on Indian River from the Quartz Creek confluence	P-30
4.2.25 Looking downstream showing the revegetating spoil piles in lower Quartz Creek ..	P-31
4.2.26 Low-lying moist areas between dredge spoil piles in Lower Quartz Creek support well established deciduous vegetation	P-31
4.2.27 Looking upstream on Quartz Creek from GPS Location 118, showing the extensive valley bottom clearing and mining	P-32
4.2.28 Looking downstream along right margin mining of white gravels near GPS Location 118	P-32
4.2.29 Looking upstream on Quartz Creek showing revegetated overburden pushed up onto the valley walls and vegetated sediments in a settling pond	P-33
4.2.30 The toe of many overburden stock piles, such as that illustrated on Plate 4.2.29, is eroding and subject to thermokarst	P-34
4.2.31 Looking upstream over a revegetated settling pond on Lower Quartz Creek showing the development of gullies by erosion and thermokarst on burned sections of valley wall	P-34
4.2.32 Looking upstream to a left bank tributary to Quartz Creek, showing hydraulic mining in 1992	P-35
4.2.33 Hydraulic mining of black muck can expose ice rich materials which are subject to thermokarst and thermal erosion	P-35

List of Plates – Cont'd.	Page
4.2.34 Hydraulic sluicing has removed substantial quantities of overburden. This photograph shows old access ladders exposed following hydraulic sluicing on Blanch Creek ..	P-36
4.2.35 Ground sluicing is resulting in very high suspended sediment concentrations in Quartz Creek	P-37
4.2.36 Road maintenance issues are another local source of sediment	P-37
4.2.37 Looking south showing sediment deposits in the newly formed mainstem of Indian River downstream of Quartz Creek	P-38
4.2.38 Looking south showing the extensive network of pits and former settling ponds on Indian River downstream of Quartz Creek	P-38
4.2.39 A 1992 photograph showing an active placer operation on Indian River immediately downstream of Quartz Creek	P-39
4.2.40 Many of the formerly mined pits are developing riparian vegetation and were observed to contain both waterfowl and, in one location, two moose	P-39
4.2.41 Looking upstream on Indian River in 1992, showing a settling pond separated from the river by a gravel berm	P-40
4.2.42 Looking upstream on Indian River in 1992, showing an unprotected access road and a mid-channel overburden pile	P-40
4.2.43 Looking downstream to a mined section of valley flat at GPS Location 12 BRD6 ..	P-41
4.2.44 Looking downstream to a mined section of valley flat at GPS Location 107 ..	P-41
4.2.45 Looking upstream to a mined section of valley flat at GPS Location 108	P-42
4.2.46 Looking upstream to a linear spoil pile located in what used to be the mainstem channel	P-42
4.2.47 Looking downstream along a revegetated section of side-cast road fill and a cut-off section of channel	P-43
4.2.48 Some former placer mine pits are now connected to the mainstem channel and could be used as fish habitat	P-43
4.3.1 Looking downstream on Gold Bottom Creek from GPS Location 123	P-44
4.3.2: Looking upstream to the headwaters of Hunker Creek showing the nearly continuous mining activity	P-45
4.3.3 An example of retrogressive slope failures on Upper Hunker Creek	P-45
4.3.4 Bank erosion was commonly observed on both newly reclaimed areas and on older over-steepened sites with second growth vegetation	P-46
4.3.5 Looking downstream showing the failing left bank valley wall at the Marsden Reclamation Site	P-46
4.3.6 Looking upstream showing how failing sections of the left bank valley wall have infilled the settling pond	P-47
4.3.7 Looking upstream to the failed settling pond outlet	P-48
4.3.8 Looking downstream showing the eroded culvert and the sediment being delivered to the wall based channel	P-48

List of Plates – Cont'd.	Page
4.3.9 Photographs of the second settling pond on the Marsden Site which appears likely to suffer from the same fate as the upper structure	P-49
4.3.10 River bank bio-engineering using planted whips was generally unsuccessful on the Marsden property	P-50
4.3.11 Looking upstream on Hunker Creek showing the valley flat revegetation in the vicinity of GPS Location 35	P-50
4.3.12 Looking upstream showing the channel down cutting which is occurring above the active mining area on this 'pup'	P-51
4.3.13 Looking upstream on a mined tributary showing the fan which has formed at the confluence with Hunker Creek	P-51
4.3.14 Revegetated old dredge spoil piles	P-52
4.3.15 Extensive mining on a tributary to Hunker Creek	P-52
4.3.16 Looking downstream on Lower Hunker Creek showing upslope mining activity and large settling ponds in the Hunker Creek valley bottom	P-53
4.3.17 Looking up valley to the ponds constructed by D. Busat below the Hunker Creek Access Road	P-53
4.3.18 Looking up valley to the ponds constructed by D. Busat upstream of the Hunker Creek Access Road	P-54
4.3.19 Looking downstream on a luxuriantly vegetated older wetland located immediately downstream of D. Busat's reclamation project	P-54
4.3.20 Annual and perennial vegetation is establishing on many stable re-contoured surfaces	P-55
4.3.21 Revegetation is less successful on more recently contoured, well drained or unstable sites	P-55
4.3.22 Uncontrolled surface flow on unvegetated sites is locally resulting in the formation of sizeable gullies	P-56
4.3.23 Gullies are also forming on steep fine-textured cut slopes	P-56
4.3.24 Lower gradients and a toe berm to prevent water erosion result in more stable cut slopes	P-57
4.3.25 This access road was constructed in the winter of 2001/2002 and may be a barrier to fish movement	P-57
4.3.26 The inlet to this culvert under the Hunker Creek Mainline Road is also likely to be a fisheries barrier	P-58
4.4.1 Looking upstream over the Lower Klondike River, showing conditions in August 1992	P-59
4.4.2 Low-lying areas between dredge spoils can form small isolated wetlands	P-59
4.4.3 Some low-lying areas between spoil piles form channels which are connected to Klondike River	P-60
4.4.4 Undisturbed spoil piles tend to be poorly vegetated	P-60
4.4.5: Leveled spoil piles appear to be much easier to revegetate	P-61

LIST OF APPENDICES

- 1:** Project Work Plan

STATEMENT OF LIMITATIONS OF REPORT

This document has been prepared by M. Miles and Associates Ltd. [MMA] for the exclusive use and benefit of the Yukon River Salmon Restoration and Enhancement Fund for Project Cre-86-02: Restoration of Placer Mined Streams: Identification of Strategies to Expedite Recovery. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document.

This document represents MMA's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by geoscientists currently practicing under similar conditions. No warranty, expressed or implied, is made.

PROJECT CRE-86-02: RESTORATION OF PLACER MINED STREAMS: IDENTIFICATION OF STRATEGIES TO EXPEDITE RECOVERY

1: INTRODUCTION AND PROJECT SCOPE

Placer mining is thought to physically affect approximately 2.5% (KPMA, 2002) to 5% (Chilibeck, 1993) of the water courses in Yukon. As indicated on Figure 1.1, the majority of placer sites are located in the Yukon River Drainage. Many of the presently active mines are in the vicinity of Dawson, Mayo and Atlin (in British Columbia).

The Yukon River Watershed has a variety of important fish resources with chinook, chum and grayling being species having significant commercial, subsistence or recreational values. Placer mining operations, which are typically undertaken in valley bottoms, and fish bearing habitat can frequently occur in the same area. Placer-related land use practices, which can alter water quality, stream channel processes or fish habitat, have been occurring since the gold rush in the late 1800's. There is now a legacy of placer mines in various stages of recovery. These include old dredging sites through to more modern excavator and dozer operations. Substantial on-going channel disturbances occur at many of these sites.

The Yukon River Salmon Restoration and Enhancement Fund [YRSREF] is developing strategies to restore impacted salmon habitat in the Yukon River Watershed. M. Miles and Associates Ltd. [MMA] was requested to examine representative areas of both historic and contemporary placer mining activity. The objective was to review the effects of placer mining activity on channel morphology and sediment production. On the basis of this assessment, remedial strategies to expedite the recovery of impacted areas were to be identified. The author was also asked to facilitate discussions between the Department of Fisheries and Ocean [DFO] (represented by Sandra Orban) and the Klondike Placer Miners Association [KPMA] (represented by Randy Clarkson, P.Eng.) on restoration requirements. Both Ms. Orban and Mr. Clarkson participated in the field component of this project.

2: METHODOLOGY

The project was planned as a regional reconnaissance to identify restoration opportunities in a variety of placer mined settings. As discussed in the project work plan (included as APPENDIX 1), the intent was to inspect old dredge spoils, hydraulic mining or excavator and dozer projects undertaken:

- prior to implementing the Yukon Fisheries Protection Act [YFPA] in 1988 (Government of Canada, 1990 revision);
- during the YFPA (1988 to 1993); and
- following passage of the Yukon Placer Authorisation [YPA] in 1993 and revisions in 1998 (Government of Canada, 1998).

In large measure these time periods also correspond to various mining practices or guidelines (e.g. Woodsend, 1988; Yukon Territory Water Board, 1989 & 1990; Hardy BBT, 1991 and INAC, 1999).

Our field studies indicated that it is difficult to reliably separate mining activity undertaken during the YFPA or YPA regulations. Thus, while it was possible to look at various aged sites, it was not always possible to reliably determine when these projects were undertaken. Two reclaimed sites which had received the Robert E. Leckie Award for Outstanding Mining Reclamation Practices were also reviewed as examples of the best modern reclamation techniques.

The initial stages of this project consisted of discussions with Sandra Orban and Leo Van Kalsbeek of DFO, Whitehorse to locate accessible and representative field study sites. Following these discussions, air photographs were obtained and mosaics prepared for areas which were to be inspected in the field. This was only partially successful as heavy rains and high water levels prevented access to some proposed field locations.

Field studies were undertaken during the period between August 19 and 26, 2002. The author met Sandra Orban and Randy Clarkson in Dawson City. We spent one day on Clear Creek and another day on Quartz Creek and Indian River. *¹ The author subsequently spent a day with Gerry Couture (a member of the Yukon Fish and Wildlife Management Board) and Jake Duncan (the Yukon Salmon Committee Habitat Steward based in Dawson City) reviewing the two award winning restoration projects on Hunker Creek. Mr Couture also kindly took the author on an aerial inspection of Eldorado Creek, Indian River and Quartz Creek. An afternoon was spent looking at historical dredging activities on Klondike River upstream of Dawson. The author also undertook two days work on McQuesten River with Mr. Pat Tobler of Environmental Dynamics Inc. [EDI]. The McQuesten studies were undertaken as part of a second YRSRAEF contract and the results of this work are being reported directly by EDI (2003).

After returning from the field, an historical series of air photos were compiled to show changes in channel conditions over time at representative field sites. The number of years of record employed in this analysis was determined by the availability of the required air photos in the INAC library in Whitehorse. These photos were kindly scanned by Ms. Orban.

The author had previously inspected a variety of placer operations in 1992. Where appropriate, some photographs obtained during this earlier work have been included to illustrate changes in channel conditions over time, or other specific points of interest.

Finally, the issues associated with the placer mining in Yukon are complex. The author has listened to many well founded opinions and points of view during the course of this study. However, the discussion and recommendations presented in this report are primarily based on the information gathered during the field inspection and the author's 20 plus years of experience undertaking similar assignments.

The report begins with a few comments on restoration objectives and briefly discusses the BC Watershed Restoration program as some of this experience is relevant to restoration activities in Yukon [SECTION 3]. The results of the field studies are summarized in SECTION 4. This includes extensive photo documentation to illustrate typical conditions and restoration objectives. This information is used as a basis for the restoration recommendations which are presented in SECTION 5. The report concludes with a general discussion of restoration options and priorities in SECTION 6.

*¹ Ten per cent of the present project's budget was donated to KPMA to partially fund Mr. Clarkson's participation.

3: RESTORATION OBJECTIVES

The morphology of alluvial stream channel reflects factors such as channel slope, the amount of water which is being conveyed, the grain size and magnitude of the sediment load, the erosion resistance of the river bank and the composition or age of riparian vegetation. As illustrated on **Figure 3.1**, there are well determined relationships between channel morphology and these parameters.

Changing one or more of the factors listed above will change the stream channel character. This implies that, in a disturbed situation, it may not be possible to re-establish a pre-existing channel morphology unless the pre-existing discharge, sediment or bank vegetation regime can first be restored. This is an important principal which, in large measure, dictates long term stream restoration objectives.

The British Columbia Watershed Restoration Program [WRP] was set up to expedite the recovery of areas impacted by historic logging activities. It faced many issues which are similar to those which occur in Yukon as, in both situations, logging and placer-related land use changes began occurring over a hundred years ago. As a consequence, there is a legacy of disturbed watersheds and a wide variety of impacts which reflect different operational techniques.

The WRP developed a hierarchical approach to restoration activities (**Figure 3.2**). The initial priority was to deal with upslope or road impacts which were responsible for slope instability and elevated levels of sediment production. Once these conditions had been addressed, restoration activities were to progress across the valley flat and, where warranted, into the stream channels. A similar hierarchical assessment and restoration approach appears warranted in Yukon as, for example, there is little merit in undertaking instream restoration work if upslope or upstream conditions will likely cause the project to be unsuccessful. Similarly, there may be little long term benefit in undertaking restoration work to address legacy impacts in areas where mining activity may be re-initiated. However, in situations where specific fish stocks are thought to be at risk, short term projects to create 'limiting' habitats could be justified even if the long term performance of the project may not be guaranteed. [For example, the paper by **Pattenden et al., 1996**) indicates that instream projects to provide fish habitat perform poorly in channels which are vertically or laterally unstable, have erosion-prone banks or are carrying elevated coarse-textured sediment loads.]

Within the context of the present study, the prepared recommendations are principally focussed on methods to expedite the stabilization of sediment source areas, the re-establishment of unconfined sections of valley flat through which a channel can freely migrate and the development of valley flat and riparian vegetation. Removing channel obstructions, such as undersized culverts and bridges, is also an important component in this hierarchical approach to watershed restoration. The intent is therefore to re-establish the physical processes which form fish habitat (including factors such as water quality), rather than to artificially construct specific types of habitat.

4: FIELD OBSERVATIONS

4.1 CLEAR CREEK

4.1.1 Study Area

A map of the Clear Creek watershed is presented as **Figure 4.1.1**. The field inspection focussed on the basin headwaters as road access was available to both the upstream end of the mainstem (or 'Right') and Left Forks of Clear Creek upstream of Site C6L.*¹ This area includes sites of old dredge activities, more recent excavator operations and the area mined by the last operational dredge in Yukon (Queenstake Resources No. 1 – John W. Hoggan Dredge).

4.1.2 Hydrology and Sediment Transport

The Northern Affairs Program [NAP] has operated a stream gauging station on Clear Creek Above Barlow Creek since 1987. The basin area upstream of this site is 340 km². The seasonal variation in flow is illustrated on **Figure 4.1.2**. These data indicate that the spring snowmelt freshet in April to May is the dominant hydrologic event of the year. Late-summer or early-fall events also result in periods of elevated discharge although the size of the events appears to be smaller than those which occur during the freshet. The historical variation in annual maximum daily discharge is shown on **Figure 4.1.3**. This short compilation indicates that the largest gauged flood occurred in 1991. The calculated average return period, which is subject to considerable uncertainty due to the short period of record, is 75 years.

Sediment transport data were collected as part of the Yukon Placer Mining Study (Seakem, 1992a). Their results indicate that the annual suspended sediment loads in 1990 and 1991 were 47,500 and 71,740 tonnes, respectively. These values were obtained when there were eleven active placer mines on Clear Creek. Seakem undertook similar measurements on Moose Creek, which served as an unmined control stream. Their study concluded that:

"Suspended sediment loads in placer mined stream such as Clear ... Creek are much greater than in Moose Creek. Loads are increased 40 or more times during the freshet and 100 times or more during the sluicing season. Settling pond failure, re-suspension of sediments and erosion of channel banks or bed and other sources such as roads and bank failures all contribute to this increased load"

Suspended sediment concentrations on Clear Creek were reported to range from 300 to 1,800 mg/L in late-May and from 150 to 3,000 mg/L in late-August.

***1** Left and Right Forks of a river or creek are defined when looking upstream. Left and right banks of a stream channel are defined looking downstream. Site names refer to the GPS coordinates plotted on the location maps.

4.1.3 Site Conditions

Upper Left Clear Creek

Undisturbed sections of Upper Left Clear Creek consist of an approximately 3 m wide cobble bedded single thread channel with well developed riparian vegetation (**Plate 4.1.1**). Much of the upper section of Left Clear Creek has been recently mined by excavator. Extensive areas of the valley flat have been cleared and overburden or tailings have been deposited on both the valley flat and lower sections of the valley walls (**Plate 4.1.2**). This has resulted in the formation of wide shallow stream channels with little riparian vegetation (**Plate 4.1.3**). Wide shallow channel also occur along areas confined by eroding spoil piles (**Plate 4.1.4**). The main channel and some tributary streams are locally down-cutting into former placer excavations (see **Plates 4.1.5 and 4.1.6**).

Settling ponds have been locally constructed along the main channel (**Plate 4.1.7**) but all inspected outlets had been breached, resulting in local down-cutting, bank erosion and the loss of most or all sediment retention capacity (**Plate 4.1.8**). The reconstructed sections of stream have typically been confined to comparatively straight channels which contain little structural complexity or areas of flood plain (**Plates 4.1.9 and 4.1.10**). Former placer excavations did, however, provide small quantities of off-channel pool habitat. At least one of these sites appeared to contain fish (**Plate 4.1.11**).

Lower Left Clear Creek

The lower section of Left Clear Creek was dredged sufficiently long ago that valley bottom vegetation is regrowing in lower lying moist areas (**Plate 4.1.12**). However, the rows of dredge tailings are typically well drained and lack fines which frequently prevents vegetation establishment (**Plate 4.1.13**). Reworking these materials with a dozer exposes the underlying fines which are phyllite rich and weather rapidly (**Plate 4.1.14**). Revegetation appears to occur much more rapidly in reworked areas (**Plate 4.1.15**).

Elevated rates of sediment transport are still occurring in this section of Left Clear Creek (**Plate 4.1.16**). This locally results in wide, shallow sections of channel (**Plate 4.1.17**) and within these areas, the bed material is heavily infilled with fines (**Plate 4.1.18**). Stream channels in dredged areas which have not been recently re-mined show more recovery. Small areas of flood plain have commonly formed, riparian vegetation is better developed and cobbles or boulders are exposed in the channel bed. However, as indicated on **Plates 4.1.19 and 4.1.20**, the channels are generally steep and straight as they are still confined in the diverted channels that were constructed along the valley margins. In addition, they lack woody debris or other structures which provide a diversity of channel habitat for fish. The area between dredge spoil piles can, however, provide both wetland (**Plate 4.1.21**) and pond or off-channel habitat (**Plate 4.1.22**).

The historical changes in channel morphology which occurred between 1949 and 1989 in this vicinity (**Plates 4.1.13 to 4.1.22**) are illustrated on **Figure 4.1.4**. These images indicate that the 1949 valley bottom was completely reworked by dredging activity and that little or no revegetation had occurred. The 1989 images suggest that the valley bottom areas have been locally reworked and that 'pup' mining has extended up some of the tributary gullies. There are also at least 8 debris slides on the right bank valley wall which may reflect both fire and storm history. In contrast, there appear to be two or possibly three slides on the left bank valley wall which are associated with access road development.

Historical air photos of Left Clear Creek at the confluence with Right Clear Creek are presented on Figure 4.1.5. These photos indicate the extent of dredging activities in 1949 and the expansion of excavator mining which had occurred by 1989. It is interesting to note the extensive disturbance to the lower valley walls by stripping and spoil deposition.

Upper Right Clear Creek

As discussed in SECTION 4.1.1, the Queenstake Resources project was the last dredge to work in Yukon (Plate 4.1.23). It operated between 1985 and 1989 (R. Clarkson, pers. comm.). Dredge operation has resulted in the formation of sizeable ponds between the valley wall and the berms formed of dredge spoil (e.g. Plate 4.1.24). The surface materials in these spoil piles are again coarse textured (Plate 4.1.25) and can be difficult to revegetate even in riparian areas (Plate 4.1.26).

Lower sections of Upper Right Clear Creek have been stripped by dozer and this has resulted in wide, shallow stream channels flowing within a disturbed, poorly vegetated valley flat (Plate 4.1.27). These streams are frequently both vertically and laterally unstable (Plate 4.1.28). Continued instability and sediment production can be expected until such time as the channel forms a more stable channel profile and the banks become protected with vegetation.

The above observations indicate the channel morphology on Clear Creek is still extensively influenced by historic placer mining and that these activities continue to result in a ready supply of easily erodible materials. Sediment loads may not now be as high as those observed by Seakem in 1990 and 1991, but they are still expected to be significantly elevated above natural conditions.

4.2 INDIAN RIVER WATERSHED

4.2.1 Study Area

The Indian River is a large watershed which has been extensively mined. A sizeable percentage of the active placer operations in the Dawson Area are located within the Indian River drainage. The watershed therefore provides the opportunity to inspect various types of mining operations, including dredge, excavator and ground sluicing. There is also the opportunity to assess the extent of river recovery at relatively old sites.

Figure 4.2.1, shows the portions of the Indian River watershed which were inspected. Truck access permitted a limited review of areas along Quartz Creek and on Indian River between Quartz Creek and Ophir Creek [GPS location 12BRDG]. A fixed wing overflight on August 24, 2002 provided useful additional information as the extent of mining-related stream channel changes is frequently difficult to assess from the ground.

4.2.2 Hydrology and Sediment Transport

The Water Survey of Canada [WSC] has operated a stream gauging station on lower Indian River since 1982. The gauged basin area is 2,220 km². The seasonal variation in flow is illustrated on Figure 4.2.2. The spring freshet, which begins in early April, is the dominant hydrologic event of the year. Average flows gradually recede over the period until approximately mid-November when winter low flow conditions

become established. However, rainstorms within the open water period can result in short periods of higher flow which can exceed those associated with the snowmelt freshet.

The historical variation in annual maximum daily and instantaneous discharge is shown on **Figure 4.2.3**. This compilation indicates that the largest gauged flood occurred in 1991. The average return period is calculated to be approximately 20 years.

The WSC has collected miscellaneous sediment transport data at the Indian River gauge (**Table 4.2.1**). Suspended sediment concentrations were not undertaken during periods of high flow (compare discharge data on **Table 4.2.1** with **Figures 4.2.2** and **4.2.3**). Despite this shortcoming, the measurements indicate that the principal suspended sediment load consists of silt and clay (**see Table 4.2.2**). It is possible to use the WSC data to indicate that the total daily suspended sediment load in 1991 ranged from 26 to 90 t/d. Much higher values would be expected during the freshet (which was not measured). The data on **Table 4.2.1** indicate that the suspended sediment concentrations exceeded 150 mg/L on each of the 5 days in 1991 on which samples were obtained. It would be desirable to have similar (or better) sediment concentration data from nearby unmined streams with which to compare these results.

The author previously undertook an overview level assessment of sediment movement on Indian River in 1992. These cursory observations indicate that suspended sediment concentrations in Indian River can be higher than those on Yukon River (**see Plate 4.2.1**) and that very sizeable quantities of sand-sized sediments are being both deposited in and transported through the Lower Indian River (**see Plate 4.2.2**). The quantities of transported sediment appear to be significantly larger than those which would be expected from an undisturbed watershed.

4.2.3 Site Conditions

Upper Dominion Creek

Upper Dominion Creek has been extensively mined. The photos on **Plate 4.2.3** illustrate conditions at GPS Locations 62 and 64. The stream channel has been channelized along the edge of the valley wall. The wide shallow channel, which contains numerous unvegetated bars, is indicative of substantial sediment loads. A sizeable portion of this load is thought to originate from both erosion and thermokarst in areas where the relocated stream undercuts the valley wall. Reworking or erosion of placer mined spoil or tailing deposits is also an important sediment source (**see Plate 4.2.4**).

Much of the placer mining activity downstream of approximately Portland Creek is older than that which occurs in the headwaters. As a consequence, the size of the excavations or spoil piles appears to be smaller and the valley bottom vegetation is in various stages of regeneration (**Plates 4.2.5** and **4.2.6**). The channel width is frequently narrower than in the more recently disturbed upstream areas and the channel has more lateral freedom as flood plain areas are beginning to develop.

Dredging spoil piles are evident downstream of approximately Hunter Creek (**Plate 4.2.7**). Valley flat re-vegetation is better developed on this older site and flood plain areas occur locally. The channel is, however, still confined near the right bank valley wall and appears to be much straighter (and hence shorter and steeper) in comparison to pre-mined conditions.

Extensive excavator mining is occurring downstream of the Jensen Creek Confluence [GPS Location 74] and this has resulted in large ponds being formed in or near areas which were formerly dredged

(Plate 4.2.8a). An unmined area occurs immediately downstream of this site and provides a good example of the narrow, deep, irregular meandering channel with conifer lined banks which likely formed much of Dominion Creek prior to mining (Plate 4.2.8b). The obvious stability of this residual reach likely reflects the fine texture of the sediments being transported from the upstream mining areas and the erosion resistance of the tree lined banks.

Dominion Creek in the vicinity of Gold Run Creek

The confluence of Dominion Creek and Gold Run Creek has been extensively mined. As illustrated on Plates 4.2.9 and 4.2.10, this has resulted in the formation of extensive wetted pits and/or settling ponds. Historical air photograph analysis (shown on Figure 4.2.4) indicates that mining activities have extensively modified the pre-existing drainage patterns. Specifically, a berm has been constructed across lower Gold Run Creek, a portion of the flow in Dominion Creek has been diverted through a relic channel and the residual mainstem flow passes through a series of excavated pits or settling ponds.

Dominion Creek in the vicinity of Sulphur Creek

Lower Sulfur Creek and the adjacent area of Dominion Creek have also been extensively dredged. The changes in channel conditions and the expansion of mining activities between 1949 and 1995 are illustrated on Figure 4.2.5. Valley bottom vegetation is beginning to become established on post-1949 dredge spoils in lower Sulphur Creek (Plate 4.2.11). Nevertheless, this photo indicates that the residual channel is still confined to narrow areas at the base of both valley walls. This channel confinement continues across the Dominion Creek valley flat (Plate 4.2.12). Plate 4.2.13 illustrates vegetation development and the formation of wetland areas in old pits or settling ponds in the Dominion Creek valley flat just downstream of the Sulphur Creek Confluence. Mining activities are continuing in this area and have resulted in the on-going loss of secondary stream channels (see Plate 4.2.14).

Dominion Creek/Indian River between Australia and New Zealand Creeks

Comparatively recent placer mining activities in the area between Australia and New Zealand Creeks have resulted in the formation of numerous large valley flat excavations. In some locations the river may have been at least partially diverted along the valley wall (e.g. Plate 4.2.15). However, in the majority of areas the river now occupies these excavations (e.g. Plates 4.2.16 to 4.2.18). This type of mining is still continuing, as illustrated on Plate 4.2.19.

Unmined sections of valley flat contain a tortuously meandering channel with relic oxbow lakes (e.g. Plates 4.2.20 and 4.2.21). The difference between mined and unmined sections of channel is substantive (e.g. Plate 4.2.22). In addition to changes in channel morphometry, mining activities appear to be significantly increasing the long term supply of readily erodible sediment. [Their effect on water quality, water temperature and nutrient loadings is not known, but is also likely to be significant.]

Indian River in the vicinity of New Zealand Creek

There is an approximately 10 km section of channel between GPS Locations 92 and 101 where there has been little direct impact to the valley flat other than the construction of exploration tracks (e.g. Plate 4.2.23). The lack of channel instability in this area, despite the extensive upstream mining activity, is again thought to reflect the fine texture of the suspended sediment load and the erosion resistant character of the well-vegetated river banks.

Indian River Upstream of Quartz Creek

Historical air photo analyses, presented on **Figure 4.2.6**, indicate that placer mining has extensively altered the Indian River valley flat upstream of Quartz Creek. In 1949, Indian River consisted of an irregularly to tortuously meandering channel. By 1995 this channel was unrecognizable due to river diversions and the extensive construction of pits and settling ponds. This area is illustrated on **Plate 4.2.24**.

Quartz Creek

The lower section of Quartz Creek was being actively dredged in 1949 (see **Figure 4.2.6**). As indicated on **Plates 4.2.25 and 4.2.26**, the low-lying area between the dredge spoil piles now support well established deciduous vegetation. The middle section of Quartz Creek has had a complicated mining history. All of the valley bottom has been cleared and mined (e.g. **Plate 4.2.27**). The white gravels on the valley margins were then mined as illustrated on **Plate 4.2.28**. Extensive quantities of overburden have been pushed up on both valley walls and, following mining, a series of settling ponds were constructed across the valley bottom. Both the overburden and settling pond sediments show a robust initial growth of vegetation. However, the widespread failure of the dams containing the settling ponds, and the undermining of the valley wall by laterally constrained diverted stream channels, is causing the widespread erosion of these materials (e.g. **Plates 4.2.29 and 4.2.30**). Widespread erosion and thermokarst is also occurring along burned sections of valley wall. As indicated on **Plate 4.2.31**, the resulting gullies have the potential to extend substantial distances up the valley wall prior to stabilising.

Recent mining activity on Blanch Creek (a left bank tributary to Quartz Creek) has involved hydraulic sluicing to remove overburden. **Plate 4.2.32** shows a photograph of hydraulic mining in this area taken in 1992. **Plate 4.2.33** illustrates the fine-textured black muck (loess) deposits which, once exposed, are subject to both thermokarst and thermal erosion.

Hydraulic mining has been used to remove substantial quantities of overburden (e.g. **Plate 4.2.34**). These activities result in very high suspended sediment loads to Quartz Creek (e.g. **Plate 4.2.35**) and, as of August 2002, the coarser fractions of these materials were being deposited in the very large settling pond in the lower Indian River valley flat illustrated on **Plate 4.2.24**. Road maintenance issues, as illustrated on **Plates 4.2.35 and 4.2.36**, are also local sources of sediment in both Quartz Creek and the other inspected watersheds.

Indian River downstream of Quartz Creek

An air photo sequence of Indian River below the Quartz Creek Confluence showing post-1949 changes in channel morphology is presented as **Figure 4.2.7**. This compilation illustrates how mining activity has substantially modified this formerly single thread, irregularly meandering channel and the adjacent valley flat.

Sediment laden water from Quartz Creek is flowing out of the large settling pond illustrated on **Plate 4.2.24** and entering the mainstem of Indian River. These sediments, along with other material being delivered from the upper watershed, are being locally deposited within the mainstem channel which has formed between various pits or settling ponds (**Plate 4.2.37**). This increased sediment load, along with material eroded from the spoil piles which form much of the valley bottom, is causing the formation of a wide shallow channel.

As indicated on **Plate 4.2.38**, there are numerous former pits and settling ponds downstream of the Quartz Creek Confluence. There were a number of active mines in this area when it was inspected in 1992 (e.g.

Plate 4.2.39). Many of these recently mined sites are developing riparian vegetation and were observed to be providing habitat for waterfowl and, in one location, two moose. The ability of fish to use many of these wetlands is limited by the lack of a connection to the mainstem channel. Discussions with Mr. Ken Tatlow, a local miner, indicates that connections could be readily constructed during the initial mining activity. However, he felt that it would be challenging to rework this area with an excavator as potentially dangerous unconsolidated settling pond sediments could be encountered at shallow depth.

Indian River in the vicinity of Nine Mile Creek

Indian River in the vicinity of Nine Mile Creek was previously inspected in 1992. Extensive pits and settling ponds had been constructed which occupied much of the valley flat. As illustrated on **Plate 4.2.41**, erodible gravel berms were used to separate the ponds from the mainstem river. Similarly, areas of side-cast resulting from access road construction and mid-channel spoil piles were left exposed to the river flow (**Plate 4.2.42**). Our aerial survey indicates that many of these formerly mined sections of valley flat no longer exist other than as areas of standing water (e.g. **Plates 4.2.43 to 4.2.45**). In other areas, long linear spoil piles have been left in what used to be the main channel (e.g. **Plate 4.2.46**). However, alders have established along some side-cast road fill materials and some former sections of river channel have formed wetland areas (e.g. **Plate 4.2.47**). At sites where these wetlands are connected to the mainstem channel (e.g. **Plate 4.2.48**), rising 'circles' on the water surface suggest they may be being used as off-channel fish habitat.

4.3 HUNKER CREEK

4.3.1 Study Area

The Hunker Creek watershed has likely been continuously mined since the gold rush. Stream channel conditions therefore reflect the cumulative effects of a wide range of mining techniques. Two contemporary mining projects in the Hunker Creek watershed have recently been awarded the Robert E. Leckie Award for Outstanding Mining Reclamation Practices, see:

<http://www.emr.gov.yk.ca/Mining/IncentivePrograms/Leckie/default.htm>

Mr. Dave Marstars of Grew Creek Ventures Ltd. and Mr. Doug Busat of T.D. Oilfield Services Ltd. received this award in 2000 and 2001, respectively. Both these sites were inspected to determine what types of restoration had been undertaken and to assess how well this work has performed. A map of Hunker Creek is presented as **Figure 4.3.1**. The two restoration sites of particular interest are indicated by GPS coordinates 'H2MARS' and 'H3BUSA'.

4.3.2 Hydrology and Sediment Transport

This are no readily available streamflow or sediment transport data from Hunker Creek. ^{*1}

***1** An M.Sc. thesis was completed on Hunker Creek, but has not be reviewed.

4.3.3 Site Conditions

Gold Bottom Creek

Gold Bottom Creek is a left bank headwater tributary to Hunker Creek. **Plate 4.3.1** illustrates the wide-spread mining activity which has occurred in this and other tributary streams. Valley bottom revegetation can be seen to be in the early stages of recovery. However, the stream is frequently flowing within a laterally confined channel or has formed wide, shallow sediment deposits in more unconfined areas.

Hunker Creek Headwaters

The upper reaches of Hunker Creek have also been extensively mined, as indicated on **Plate 4.3.2**. In many areas the stream channel has been confined to one side of the valley to allow mining activity to occur on the other. However, valley wall disturbance, possibly combined with thermal erosion due to surface flow along the base of the valley wall, was observed to commonly cause thermokarst and slope instability (e.g. **Plate 4.3.3**). These retrogressive failures could potentially extend a substantial distance up the valley wall before they re-stabilise. Older disturbed areas of valley bottom were frequently becoming revegetated, however, wide-spread bank erosion was commonly occurring on both newly reclaimed areas and on older over-steepened areas with second growth vegetation (e.g. **Plate 4.3.4**). This erosion resulted in very turbid streamflow and the formation of wide shallow sections of stream channel.

Marsden Reclamation Site

The Marsden Reclamation Site, which is located near the headwaters of Hunker Creek, is illustrated on **Plate 4.3.2**. Reclamation work during 1999 and 2000 included:

“the clean up of abandoned debris and waste petroleum products from previous miners, contouring of tailings from the current operation and all previous operations to a gentler topography, and the spreading of black muck over the contoured tailings to promote rapid revegetation. In addition, a wide stable stream channel was established and small out-of-stream ponds were created to enhance the local habitat.”^{*1}

Our observations indicate that Hunker Creek has been diverted to the right bank edge of the valley flat and the mined area has been extensively graded and re-contoured. A series of settling ponds have also been constructed to control residual sediment production. Substantial reclamation efforts have obviously been undertaken at this site. However, our site inspection indicates that this well intentioned work has some substantial maintenance problems. For example, as illustrated on **Plate 4.3.5**, the left bank valley wall is locally failing into one of the constructed settling ponds. These sediments have infilled the pond (**Plate 4.3.6**), the settling pond outlet has failed (**Plate 4.3.7**) and the collected sediments are being released to the downstream wall-based channel (**Plate 4.3.8**). This channel leads to a second settling pond where inadequate storage capacity, failing sections of valley wall, an erodible toe dam and an undersized outlet pipe are expected to result in a similar failure (**Plate 4.3.9**). Bio-engineering techniques were locally employed to reduce bank erosion along sections of Hunker Creek (**Plate 4.3.10**). This material has not survived. Possible reasons include:

^{*1} from: <http://www.emr.gov.yk.ca/Mining/IncentivePrograms/Leckie/LeckieAwards2000.htm>
and http://www.kpma.ca/robert_leckie_placer_reclamation_award.htm

-
- i) the apparent use of some alder whips (which don't root vegetatively);
 - ii) leaving too much of the willow whip exposed;
 - iii) inadequate pruning of the willow whips (the leading end should be larger than the diameter of a thumb);
 - iv) possibly failing to soak the whips before planting; and
 - v) the possible difficulty in using bio-engineering techniques in this harsh environment.

Thus, significant erosion and sediment production to the downstream channel is still occurring despite the substantial reclamation efforts undertaken at this site.

Middle Hunker Creek

Substantive sections of valley flat within the middle portion of Hunker Creek are beginning to revegetate (e.g. Plate 4.3.11). However, placer spoil deposits have commonly limited the stream to small areas adjacent to the valley wall. Much of the active mining activity in this section of Hunker Creek is occurring in tributary 'pups' or 'gulches'. As indicated on Plate 4.3.12, lowering of the channel bed commonly results in down cutting and thermokarst in the area upstream of the mining activity. Substantial reclamation work, including re-establishing the stream profile, is required if significant long term sediment production to the valley bottom is to be avoided (e.g. Plate 4.3.13).

Lower Hunker Creek

Old dredge spoils in lower Hunker Creek have generally developed a substantial vegetation cover. However, as illustrated by Plate 4.3.14, the stream channel frequently remains confined by the spoil piles. Industrial scale mining is presently occurring in some tributaries (e.g. Plate 4.3.15) and on upland benches (Plate 4.3.16). All these recent activities have again diverted or locally confined the stream channel and are likely to be causing at least elevated rates of fine-textured suspended sediment transport in lower Hunker Creek.

Doug Busat Reclamation Site

This property is located near the mouth of Hunker Creek. Extensive reclamation work has been undertaken in the post-1997 period and this property received the Robert E. Leckie Award for Outstanding Mining Reclamation Practices in 2001.

" Overburden has been placed over old dredge piles and previously mined areas; old mine cuts and settling ponds have been backfilled by coarse tailings, and topped with finer-grained material in order to encourage natural revegetation.

"The post-mining landscape at the mine site, which incorporates wetlands and grasslands, is a much-improved terrain compared to the historic dredge piles and un-reclaimed tailings ponds and tailing piles left by previous operators. The reclaimed ponds are aesthetically pleasing and provide habitat for waterfowl and wildlife, as well as a recreational area for

people. For the many tourists and local people that drive the Klondike Placer Loop road, the property is an excellent example of responsible and thoughtful placer mining practices.” *1

Inspection of this area showed extensive areas of re-contoured slopes and a series of wetlands or ponds (Plates 4.3.17 and 4.3.18). Circular ripples on the surface of both larger ponds suggest that grayling or other fish species may have moved into this area. Examination of nearby similar, but older ponds, suggests that luxuriant aquatic and riparian vegetation should develop on stable sites over time (e.g. Plate 4.3.19).

Surface revegetation is beginning to be well established in some areas (e.g. Plate 4.3.20). However, thermokarst and uncontrolled runoff has resulted in surface erosion or gulying at a number of locations (e.g. Plates 4.3.21 and 4.3.22). Steep unvegetated cut slopes are also beginning to erode (Plate 4.3.23) and these unstable areas could enlarge substantially if ice rich materials occur at depth. Areas with a more gentle slope and a toe berm to protect against water erosion were observed to be much more stable (e.g. Plate 4.3.24).

A hydro line access road was constructed across the connection between two ponds in the winter of 2001/2002 (Plate 4.3.25) and this is likely to be a fish migration barrier other than during periods of high water. The trash rack and accumulated debris at the inlet to the culvert under the Hunker Creek mainline road is also likely to be a barrier to upstream migration of larger fish.

As previously mentioned, fish (possibly grayling) appear to have rapidly colonized the constructed wetlands. Discussions with Jake Duncan, Yukon Salmon Commission Habitat Steward in Dawson City, suggests that the ability of grayling to successfully over winter in the constructed ponds needs to be confirmed. He expressed some concerns that, unless they were able to out migrate in the fall, there is the potential for low oxygen levels or excessive ice thickness to affect resident grayling survival.

The reclamation measures undertaken at this property are appropriate and, over the long term, will expedite recovery. Better control of surface runoff (responsible for some gully formations) and more aggressive revegetation would, however, both be warranted. Measures to ensure external parties (in this case hydro construction workers) do not damage constructed habitat would also be desirable. Maintenance activities to enlarge undersized culverts and ensure fish access might also be warranted (assuming fish successfully over-winter or out-migrate), but may not be the miner's responsibility. Finally, it would be useful to undertake periodic fish sampling to confirm usage and over-winter survival in the constructed ponds.

4.4 LOWER KLONDIKE RIVER WATERSHED

4.4.1 Study Area

The lower Klondike River study area is located immediately upstream of Dawson City (see Figure 4.3.1). The upstream basin area is approximately 7,800 km².

*1 from: <http://www.emr.gov.yk.ca/Mining/IncentivePrograms/Leckie/LeckieAwards2001.htm>
and http://www.kpma.ca/robert_leckie_placer_reclamation_award.htm

4.4.2 Hydrology and Sediment Transport

The WSC has operated a stream gauging station on Klondike River Above Bonanza Creek since 1965. The seasonal variation in flow is illustrated on Figure 4.4.1. The spring snowmelt freshet begins in early April and elevated, although generally decreasing, flows continue to approximately mid-November. The maximum flow typically occurs in early to mid-June and rain caused peaks (which are smaller than the freshet flows) can occur throughout the open water period.

The historical variation in annual maximum daily and instantaneous flood peaks is illustrated on Figure 4.4.2. The maximum flood of record, which occurred on May 8th, 1998, has an average return period of approximately 50 years. Sizeable floods, with a return period of approximately 15 years, also occurred in 1985 and 2000.

The WSC collected suspended sediment data at the Klondike River gauge over the period between 1990 and 1991 (Table 4.4.1). These data indicate that suspended sediment concentrations are variable and can range from 2.5 mg/L in July to over 300 mg/L in June. The grain size is also variable with sand, silt and clay sized materials comprising 14%, 80% and 6%, respectively of the total load on May 10, 1990 and 38%, 58% and 4%, respectively on June 1, 1990. Initial estimates indicate that the daily suspended sediment loads can range from approximately 9 t/d in September to 2,300 t/d in June (Table 4.4.2). It is interesting to compare unit suspended sediment loads ^{*1} in 1991 on Indian River (basin area 222 km²) and Klondike River (basin area 7,800 km²).

MONTH	DATE	SUSPENDED SEDIMENT LOAD (kg/d/km ²)		RATIO INDIAN/KLONDIKE
		INDIAN RIVER	KLONDIKE RIVER	
May	9		250.8	1.6
	14	403.2		
	15		14.3	28.2
June	6	115.3		
	8		2.1	55.4
July	11	150.0		
August	27	139.6		
	28		3.7	37.9
Sept.	26		1.1	351.8
	27	386.9		

This cursory analysis suggests that in 1991 the average unit suspended sediment discharge in the Indian River ranges between 1.6 and over 300 times that on Klondike River. It is common to find that unit sediment discharges increase with increasing basin area within glaciated terrain (e.g. Church, Kellerhals and Day, 1989). It would be interesting to determine if Church et al.'s results apply to un-glaciated terrain in Yukon and, if they do, whether the larger unit sediment loads on Indian River (the smaller of the two basins) are related to the more extensive placer mining activities on this stream.

^{*1} i.e. estimated load divided by the upstream basin area.

4.4.3 Site Conditions

Lower Klondike River

As indicated on Figures 4.4.3 to 4.4.6, the Klondike River valley flat has been extensively dredged. The original location of the river channel was not determined for this report, but it is quite possible that its present position along the edge of the right bank valley wall is a result of dredging activities.

Valley flat conditions immediately upstream of the highway bridge are illustrated on Plate 4.4.1. This photograph indicates that water levels on August 23, 1992 were sufficient to extensively inundate low-lying areas between dredge spoil piles. These areas can form small isolated wetlands (Plate 4.4.2) or channels which can be connected to Klondike River (Plate 4.4.3). Many of the dredge ponds remain watered all year, as do the developing wetlands (A. von Finster, pers. comm.).

Due to the coarse surface texture and excellent drainage, undisturbed spoil piles tend to be poorly vegetated. Some vegetation has, however, developed along the edge of wetted channels or in other low-lying areas (e.g. Plate 4.4.4). However, once the piles are levelled and finer textured materials are exposed, these gravel deposits revegetate more rapidly (Plate 4.4.5). This is similar to what was previously observed in Clear Creek watershed.

5: RECOMMENDATIONS

5.1 PREAMBLE

The observations in SECTION 4 indicate that placer mining activities can affect local stream channel conditions through physical works such as excavations, the construction of diversion channels or settling ponds, the removal of riparian or upslope vegetation, etc. Increased sediment supply can also affect water quality and channel structure or conditions for long distances downstream. In areas where sediment production consists principally of fine textured materials (e.g. black muck, which once entrained remains in suspension), the effects on downstream channel morphology or stability may be comparatively small. However, in situations where the sediment load consists of coarser materials which deposit in the downstream channel, the effects on channel morphology can be substantial (for example see EDI, 2003). The relative magnitude or importance of the effects will vary with the volume and grain size of sediment loads which are available to the river and the sediment transport capacity of the stream. The downstream extent of placer mining activities on channel stability and sediment loading does not appear to have been quantified. However, it may be significantly larger than the 'foot print' calculations which suggest that only 2.5 to 5% of Yukon streams are affected by placer operations [see SECTION 1]

Even if only 'foot print' impacts are considered, the length of stream channels which have been disrupted by placer mining is extensive. Our observations indicate that past mining activities have resulted in numerous sections of shortened, or confined, channels which can have reduced riparian vegetation, extensive supplies of readily mobile sediment, ongoing slope stability issues and elevated instream sediment loadings. The results of studies by Norecol (1989) and Seakem(1992a to d) indicate that these changes in channel conditions can be detrimental to aquatic organisms, including fish.

The physical changes to channel conditions documented in this study are long term impacts which extend over very large areas. Given this extent, it appears unfeasible to undertake widespread restoration activities at inactive placer mines unless very substantial sources of funding are available. Based on recent experience with the Watershed Restoration and Salmonid Enhancement Program in BC, this could easily involve many hundreds of millions of dollars. [This assessment is supported by restoration cost estimates prepared by Environment Canada 1983b; Jackobsen *et al.*, 1992; Chilibeck, 1993 and Perkin and Hirtle, 2002]. The availability of funding will therefore dictate both what types of work can be undertaken and over what areas this can be accomplished. Additionally, there is little point funding restoration work if the restored area is likely to be re-mined in the future, or disturbed as a result of upstream or downstream mining-related channel modifications. These are sensitive issues to the placer industry, but they must be resolved prior to the formation of any extensive program to restore historically placer-mined streams.

Our observations also suggest that at least three levels of stream channel impacts should be recognized. On streams such as Hunker Creek, the level of present mining activity, combine with the cumulative effects of historical mining, make restoration activities difficult to undertake. In these circumstances, it may make sense to simply mitigate the downstream impacts (for example by ensuring that significantly elevated sediment loads do not reach Klondike River). In other cases, such as some sections of old dredge spoil on Clear Creek or the Upper Indian River watershed, there may be no immediate need to undertake restoration work as channel recovery is progressing and efforts to expedite these processes could significantly increase sediment loadings or cause other undesirable impacts. The third class consists of sites where there are important fisheries, engineering, aesthetic or other values which justify restoration efforts and the problems are amenable to treatment.

5.2 UPSLOPE RESTORATION PRIORITIES

As discussed in SECTION 3, it is frequently desirable to initially undertake restoration work on upslope areas. Our field studies indicate that upslope impacts are most commonly associated with:

- i) road construction;
- ii) disposing of waste material on the valley walls;
- iii) undercutting the valley wall toe by margin mining;
- iv) diverting stream channels along the toe of the valley wall; and
- v) mining on gulches or 'pups'.

All these impacts are most severe in areas where the valley wall contains ice-rich permafrost.

Our limited observations indicate that the failure of road construction side-cast material was not a common occurrence. However, the provision of adequate roadside drainage, ensuring appropriately spaced or located culverts and the maintenance of ditches, culverts and bridges were all locally important issues. Similarly, erosion protection measures (including rip-rap and bio-engineering) might be warranted on areas where road construction has resulted in instream encroachments or the loss of riparian vegetation. In addition to local maintenance, there appeared to be a need for a systematic program of either temporarily or permanently deactivating unused access roads to reduce long term sediment production.

The historic disposal of overburden on the valley wall was observed to create long term slope stability problems in areas where underlying ice-rich sediments subsequently began to fail. The transport of this material back onto the valley flat is likely not warranted (or economically feasible) in most inspected sites. However, bio-engineering could be used to stabilise local problem areas and, in some areas, the re-contouring of over-steepened spoil piles may be needed to allow vegetation to develop.

Margin mining was commonly observed to result in over-steepened sections of valley wall with associated thermokarst in ice-rich material. Providing a toe berm on which failed material can collect would commonly facilitate the establishment of angle of repose slopes and revegetation. In some areas it could be desirable to move waste spoil piles into the margin excavations to expedite re-vegetation of both the source and disposal areas.

Streams have been commonly diverted to the edge of the valley flat to facilitate mining of the valley bottom. These generally straight channels have a steeper gradient in comparison to the pre-existing channel. This results in a greater sediment transport capacity and an increased ability to erode the valley walls. Where warranted, it would be desirable to re-establish a more natural channel gradient by facilitating the channel to re-occupy portions of the former valley flat. For example, in areas of old dredging it would be possible to locally breach spoil piles to open up continuous channels through which a portion of the river could flow. In areas mined by excavator, it could be possible to re-route the channel through appropriately located abandoned pits or possibly construct short sections of channel which would allow the stream channel to move away from the valley wall. This would increase the channel length and, over the long term, reduce sediment loads.

Mining on 'pups' or gulches is commonly associated with a lowering of the channel bed and the subsequent readjustment of the upstream channel profile. This was observed to result in substantial destabilisation

of the channel bed and the adjacent valley walls in areas of ice-rich permafrost. Re-establishment of the original channel bed elevation by importing waste material or by constructing check dams may be required to prevent some sites from retrogressing upstream. Similarly, bio-engineering techniques could be used to expedite the stabilisation of eroding sections of valley wall. The cost of undertaking this type of work would, however, be substantial.

5.3 RESTORATION OF VALLEY FLAT AREAS

As discussed in SECTION 4, old dredge spoil piles were generally poorly revegetated. Levelling these piles and bringing finer textured materials to the surface would, in many locations, expedite revegetation. Re-contouring steep spoil piles or other extensively disturbed areas would also have similar benefits. On sloped sections of the valley flat, making at least periodic horizontal passes over the re-contoured areas would also reduce the potential for gully formation in comparison to sites where all the regrading work is undertaken along the 'fall line'. Top dressing with finer textured sediment and seeding or staking with native plants or trees could also reduce short term surface erosion and expedite the development of a vigorous vegetation cover. It is also important to re-establish adequate drainage channels to prevent surface erosion. Lowering bed elevations on tributary channels was locally observed to result in 'icings' (sic. 'glaciers'), which had the potential to disrupt streamflow patterns in the spring. Measures to minimize 'icing' effects might include the restoration of original sub-surface drainage patterns. However, this appears to be a poorly understood topic which requires further investigation.

Deactivating unused roads, removing unused culverts, re-establishing fish access to tributary streams or taking measures to reduce sediment production due to fluvial erosion of spoil piles are also appropriate.

Another important issue is the need for the on-going maintenance of settling ponds. Our field observations suggest that these structures typically infill, the toe dam overtops, the outlet fails and much of the collected sediment is washed downstream. Periodic sediment removal, until such time as the sediment source areas stabilize, would be a relatively inexpensive and beneficial activity. This material could possibly be used to top dress poorly re-vegetating sites.

5.4 RIPARIAN AND STREAM CHANNEL RESTORATION

As discussed in SECTION 3, it may be very difficult to re-establish pre-mining stream channel morphologies in severely disturbed areas. Elevated sediment loads, increased channel slopes, the lack of erosion resistant riparian vegetation and possibly large flood flows (due to the loss of former flood plain areas) mean that present 'regime' channel conditions will be different than those which formerly existed. Nevertheless, where warranted, it would be desirable to re-establish low-lying flood plain areas and give the channel the lateral freedom it needs to re-establish a regime geometry. This could involve locally diverting the straightened channel through old placer pits (such as on Indian River near Quartz Creek). It may also be possible to divert the channel through old settling ponds, or other low points, if the long term benefits are thought to outweigh the short term impacts resulting from this relocation. [Specifically, this could cause significantly elevated rates of sediment transport over the short term.] Another option would be to breach or locally connect low points between dredge spoil piles to re-establish secondary channels which could be used to increase conveyance capacity, flood water storage and potential off-channel habitat. Reconstruction of pre-existing channel morphologies could also be technically feasible, but is likely to be prohibitively expensive.

5.5 INSTREAM CHANNEL STRUCTURE AND FISH HABITAT

Instream structures, such as those described in Slaney and Zaldokas (1997), might be successfully used to augment existing habitat on locally stable sections of channel in Yukon. However, previous investigations (see Hartman and Miles, 1995; Pattenden *et al.*, 1996; Kellerhals and Miles, 1996; Hartman and Miles, 2001) indicate that many structures constructed to provide fish habitat do not persist over the long term. These failures are particularly common in laterally unstable channels carrying significant coarse textured sediment loads. Site-specific assessments would, therefore, be needed to ensure that any instream structural measures would provide beneficial habitat and that ice action, and other factors not considered in the southern studies, did not adversely affect the performance or longevity of any proposed works.

Many of the instream structure designs employed in more southern parts of Canada attempt to increase channel 'complexity', form pools and provide instream cover in the form of large woody debris. The recent study by Mossop (2003) indicates that large woody debris is an important habitat component for juvenile chinook in small Yukon streams. However, it would be appropriate to ensure habitat structures developed in the south (which are commonly designed for coho) are appropriate before routinely employing them in Yukon.

As discussed in SECTIONS 5.3 and 5.4, there often appears to be an opportunity to connect excavated pits and ponds to the mainstem river, or re-route the channel through these areas. Our field observations suggest that grayling may be using off-channel or wetland areas formed by mining activities. Moose and waterfowl were also observed in these areas. Utilization of these area by rearing chinook does not presently appear to be well understood. This may, again, be an area where more research is needed.

5.6 THE NEED FOR RESEARCH

As discussed in SECTION 5.1, restoration priorities for placer mined streams in Yukon will need to be determined. This implies a need to understand what impacts mining has had, what are the future resource values (including the potential for future placer activities) and how well the stream channels are naturally recovering. This implies that substantive inventory programs will be needed to acquire this information.

The best way of documenting the location and magnitude of changes in stream channel conditions is through the compilation of historical air photographs. This procedure also provides an initial indication of the present state of recovery. It would therefore be desirable to compile historical air photo sequences (such as Figure 4.2.6) for high priority streams. These compilations should ideally extend from the basin headwaters to the mouth, such that the downstream rates and styles of movement of sediment or channel instability can be identified. The acquisition of current large scale colour air photographs would be an asset if this work were to be undertaken.

The long term negative impacts of excessively high rates of sediment production on aquatic organisms are now well documented (e.g. Birtwell, 1999). The recent work by Newcombe and Jensen (1996) and Newcombe (in press), also indicates that even fairly low levels of suspended sediment (as indicated by either suspended sediment concentrations or turbidity) can be damaging if they persist over the long term. This implies that the chronic sediment inputs from placer disturbed areas may be equally or more harmful than the seasonal sediment pond effluent discharges which were a principal focus of the YFPA and the YPA. [This hypothesis partly reflects the large number of failed settling ponds which were observed during our field inspection, the extensive quantities of overburden or valley flat sediments which have been

eroded in placer-mined areas and the on-going slope instability problems in areas where the thermal regime of ice-rich sediments on the valley wall has been disturbed.] Given these concerns, experiments to monitor the long term effects of placer activities on sediment loadings appear warranted. Ideally the WSC should be requested to instigate full sediment monitoring programs at selected existing stream gauging stations and on representative control watersheds.

As discussed in SECTION 4, placer activity has resulted in both channel diversion or confinement. Wide, shallow unstable channels have also been formed in areas with erosion-prone banks or elevated coarse textured sediment loads. In the short term, the formation of these altered channel morphologies are likely to be detrimental to aquatic habitat. However, the long term effects may be inadequately understood. For example, how do grayling or chinook respond to situations where a narrow, deep, cold oligotrophic channel with coniferous riparian vegetation is replaced by a wider channel which contains pools and riffles and an actively growing deciduous forest? Can grayling and/or chinook successfully utilize off-channel ponds or excavation remnants during various stages of their life? [For example, see Figure 4.2.6.] The author has received varying answers to these questions from knowledgeable northern fisheries biologists. These and similar issues appear to warrant a long term research project similar to the Carnation Creek Project which was undertaken to address coastal forestry issues in British Columbia (see Hartman and Scrivner, 1990). One of the ancillary benefits of such an inter-disciplinary program would be to train the young scientists who will be needed to make future land management decisions in Yukon.

The restoration of historic placer mines will obviously require experimentation to determine appropriate techniques and optimum locations. It will be important to monitor both the physical and biological success of these activities to ensure that the intended benefits are achieved and to learn how to undertake future projects in a more effective manner. Ideally, the intended long term benefits and associated performance indicators should be defined during the design phase of any restoration projects. As discussed above, it is likely that basic physical and biological research will need to be undertaken during these projects to improve the scientific basis on which restoration protocols are based.

5.7 THE NEED FOR DEMONSTRATION PROJECTS

Yukoners will need to develop the skills required to expedite the recovery of placer mined streams. In addition, there will be a need to demonstrate the proposed techniques and, ideally, get the placer mining community involved in this work. A variety of regional demonstration projects should, therefore, be planned. Potential sites include the two restoration projects previously undertaken on Hunker Creek as our field work indicates that additional maintenance or restoration activities could be usefully undertaken. It is our understanding that the ponds between some of the dredge spoil piles on Lower Klondike River have been recently opened up to provide fish habitat. There appears to be the opportunity to expand this work if these initial activities are successful. Similarly, it might be useful to better investigate fish or wildlife use on constructed ponds, such as those on Indian River downstream of Quartz Creek. If these results are favourable, it would be interesting to see if techniques can be developed to safely connect isolated ponds to the main channel.

An important part of any demonstration project is the transfer of knowledge between practitioners. It would therefore also be desirable to hold an annual symposium where the individuals involved in this work can get together to exchange techniques and discuss their experiences.

5.8 THE NEED FOR FUNDING

The federal Salmonid Enhancement Program [SEP] and provincial Watershed Restoration Program [WRP] have recently spent over a billion dollars on stream restoration in BC. The provincial portion (of approximately \$450 million) was largely financed through increased logging stumpage fees.

Sources of funding for placer restoration in Yukon may be more problematic as royalties on gold production are very small and, hence, the Yukon Territorial Government has little in the way of reserves on which to draw. However, there may be some possibility of federal funding as historic placer mining activities were undertaken in compliance with federal statutes. Regardless of its source, placer restoration activities will require a well organized infrastructure which has adequate funding if widespread measures to expedite the recovery of impacted stream channels are to be undertaken.

6: DISCUSSION

The field inspections undertaken during this study indicate that historic placer mining activities have significantly altered stream channel conditions and increased the availability of readily erodible sediments. These changes can alter both sediment loads and channel stability both locally and for long distances downstream. Some of these impacts will gradually decrease over time as disturbed areas revegetate or introduced sediment loads are flushed from the system. The time necessary for this to occur could vary from decades (the time necessary to move sediment through a small sized stream) to more than a hundred years (the time necessary to grow a mature conifer). The re-establishment of pre-mining channel flood plain widths or channel morphologies could take even longer or be impossible if erosion resistant materials (such as the dredged spoil piles on the Lower Klondike River) are not artificially breached or otherwise restored.

Given the long term nature of these impacts, measures to expedite channel recovery appear warranted. However, due to the wide extent of placer activities in Yukon, the areas which could need to be evaluated and treated are immense. It may therefore make sense to initiate this process through a number of demonstration projects in representative areas. Concurrent efforts to ensure future mining activities are undertaken in a manner which minimizes site impacts and expedites recovery also appears to be appropriate. The restoration efforts at sites recently awarded the Robert E. Leckie Award for Outstanding Mining Reclamation Practices indicate that placer mining techniques can be modified to achieve these objectives. More refinements of these techniques are, however, warranted and restoration trials again appear to be an appropriate method to develop this expertise.

It is hoped that the observations in this overview study will help to define some of the important factors that will need to be considered when restoring historically mined sites or undertaking new mining development.

7: CERTIFICATION

This report was prepared by:

Sandy Gibbins, B.Sc.

Elizabeth Goldsworthy, B.Sc.

Mike Miles, M.Sc., P.Geo.

8: SOURCES OF INFORMATION

8.1 REFERENCES

Birtwell, Ian K. 1999. The Effects of Sediment on Fish and their Habitat.

<http://www.pac.dfo-mpo.gc.ca/sci/psarc/HSRs/hab1.pdf>

Chilibeck, Barry. 1993. Placer Mining and Fish Habitat Restoration in the Yukon. Unpublished report prepared for Habitat Management Division, DFO, Vancouver. 14 p.

Church, Michael, Rolf Kellerhals and Terry J. Day. 1989. Regional clastic sediment yield in British Columbia. Canadian Journal of Earth Sciences Vol. 26, Number 1, pp. 31-45.

Environment Canada. 1983a. A Rationale for Standards Relating to the Discharge of Sediments into Yukon Streams from Placer Mines. Paper prepared for the Interdepartmental Committee on Placer Mining by the Departments of Environment and Fisheries and Oceans. 24 p.

Environment Canada. 1983b. The Attainment and Cost of Placer Mining Effluent Guidelines. Paper prepared for the Interdepartmental Committee on Placer Mining by the Departments of Environment and Fisheries and Oceans. 42 p.

EDI Environmental Dynamics Inc. and M. Miles and Associates Ltd. 2003. CRE 20-02: McQuesten River Watershed Assessment and Restoration Plan Draft. Unpublished report prepared for the Yukon River Panel on behalf of The First Nation of the Nacho Nyak Dun. 115 p.

-
- Government of Canada. 1990 revision. Yukon Fisheries Protection Authorization: Applicable to Placer Mines in the Yukon Territory, April 1988. 114 p.
- Government of Canada. 1998 revision. The Yukon Placer Authorization and Supporting Documents: Applicable to Placer Mining in the Yukon Territory. June 1993. 33 p.
- Hardy BBT Limited. 1991. Guidelines for the Design and Construction of Stream Channels for Yukon Placer Mined Streams: Third Edition. Report prepared for Fisheries and Oceans Canada, Pacific Region. 95 p.
- Hartman, Gordon F. and Michael Miles. 1995. Evaluation of Fish Habitat Projects in British Columbia and Recommendations on the Development of Guidelines for Future Work. Report prepared for Fisheries Branch, BC Ministry of Environment, Lands and Parks
- Hartman, G. and M. Miles. 2001. Assessment of Techniques for Rainbow Trout Transplanting and Habitat Management in British Columbia. Can. Manuscript Rept. of Fish. Aquatic Sc. No. 2562. x+135 p. Avail. online @ <http://www-heb.pac.dfo-mpo.gc.ca/english/publications/PDF/rainbow/rainbow.htm>.
- Hartman, G.F. and J.C. Scrivner. 1990. Impacts of Forestry Practices on a Coastal Stream Ecosystem, Carnation Creek, British Columbia. Canadian Bulletin Fisheries and Aquatic Sciences. 223.
- Indian and Northern Affairs Canada. 1999. Handbook of Reclamation Techniques in the Yukon: Yukon Placer Mining Land Use Regulations. Mineral Resources Directorate, Yukon. 35 p.
- Jacobsen, N.A., J. Korn and Ken Nordin. 1992. Engineering-Economic Study of the Costs of Implementing the Fisheries Restoration/Compensation Guidelines in the Yukon Fisheries Projection Authorization: Phase II. Unpublished report prepared for the Yukon Placer Mining Implementation Review Committee. 100 p.
- Johnston, N.T. and G.D. Moore. 1995. Guidelines for Planning Watershed Restoration Projects. Watershed Restoration Technical Circular No. 1. BC Ministry of Environment, Lands and Parks and Ministry of Forests. 50 pp.
- Kellerhals, R. and M. Miles. 1996. Fluvial Geomorphology and Fish Habitat: Implications for River Restoration. In: Leclerc M. et al. [edit.] Proceedings of the Second IAHR Symposium on Habitat Hydraulics, Ecohydraulics 2000, Quebec City, June 1996. pp. A261-279.
- KPMA, 2002 URL
- Mathers, J.S., N.O. West and B. Burns. 1981. Aquatic and Wildlife Resources of Seven Yukon Streams Subject to Placer Mining. Environment Canada.
- Mollard, J.D. 1973. Air photo interpretation of fluvial features. 9th Canadian Hydrology Symposium: Fluvial Processes and Sedimentation: 341-380.
- Mossop, Brent. 2003. Monitoring salmon habitat in small streams using streambed profiling and the importance of large woody debris for juvenile chinook salmon habitat in small Yukon streams. Simon Fraser University Resource and Environment Management Project No. 315. 88 p.
-

-
- Newcombe, C. In press 2003. **Impact Assessment Model for Clear Water Fishes Exposed to Excessively Cloudy Water.** JAWRA Paper No: 01228;09, August 2002. 45 p.
- Newcombe, C.P. and J.O.T. Jensen. 1996. **Channel Suspended Sediment and Fisheries: a Synthesis for Quantitative Assessment of Risk and Impact.** North American Journal of Fisheries Management. 16: 693-727.
- Norecol Environmental Consultants Ltd. 1989. **Yukon Placer Feasibility Study.** Unpublished report prepared for Yukon Placer Implementation Review Committee. File: 1-176-01.01.
- Pattenden, R., M. Miles, L. Fitch, G. Hartman and R. Kellerhals. 1996. **Can Instream Structures Restore Fish Habitat.** In: Proceedings: Forest Fish Conference 1996, Land Management Practices Affecting Aquatic Ecosystems, May 1-4, 1996. Calgary, Alberta. Trout Unlimited Canada. pp. 1-15.
- Perkin, Ross and Rick Hirtle. 2002. **Economic Study of the Yukon Placer Authorization Review.** Report by BDO Dunwoody LLP, Kamloops. 44 p.
- Seakem Group Ltd., in association with: Northwest Hydraulic Consultants Ltd., North/South Consultants Inc. and ARA Consulting Group Inc. 1992a. **Yukon Placer Mining Study: Volume I: Executive Summary.** Report prepared for Yukon Placer Mining Implementation Review Committee. 17 p.
- Seakem Group Ltd., in association with: Northwest Hydraulic Consultants Ltd., North/South Consultants Inc. and ARA Consulting Group Inc. 1992b. **Yukon Placer Mining Study: Volume II: Reports of Principal Investigators.** Report prepared for Yukon Placer Mining Implementation Review Committee. 241 p.
- Seakem Group Ltd., in association with: Northwest Hydraulic Consultants Ltd., North/South Consultants Inc. and ARA Consulting Group Inc. 1992c. **Yukon Placer Mining Study: Volume III (Part A): Data Appendices.** Report prepared for Yukon Placer Mining Implementation Review Committee.
- Seakem Group Ltd., in association with: Northwest Hydraulic Consultants Ltd., North/South Consultants Inc. and ARA Consulting Group Inc. 1992d. **Yukon Placer Mining Study: Volume III (Part B): Data Appendices.** Report prepared for Yukon Placer Mining Implementation Review Committee.
- Slaney, P.A. and D. Zaldokas. 1997. **Fish Habitat Rehabilitation Procedures.** Watershed Restoration Technical Circular No. 9. BC Ministry of Environment, Lands and Parks.
- Woodsend, A. 1988. **Reclamation and Revegetation Methods Applicable to Placer Mined Sites in the Yukon.** Unpublished report to Klondike Placer Mines Association. 18 p.
- Wolff, Ernest N. and Bruce I. Thomas. 1982. **The Effects of Placer Mining on the Environment in Central Alaska.** Mineral Industry Research Laboratory Report No. 48. 66 p.
- Yukon Territory Water Board. 1989. **Placer Mining Design Handbook.** Edition 1. 45 p.
- Yukon Territory Water Board. 1990. **Placer Mining Design Handbook.** Edition 2. 45 p.
-

7.2 PERSONAL COMMUNICATIONS

Randy Clarkson, P. Eng. NEW ERA Engineering Corp, Whitehorse, Yukon.
www.neweraengineering.com

A. von Finster DFO, Whitehorse



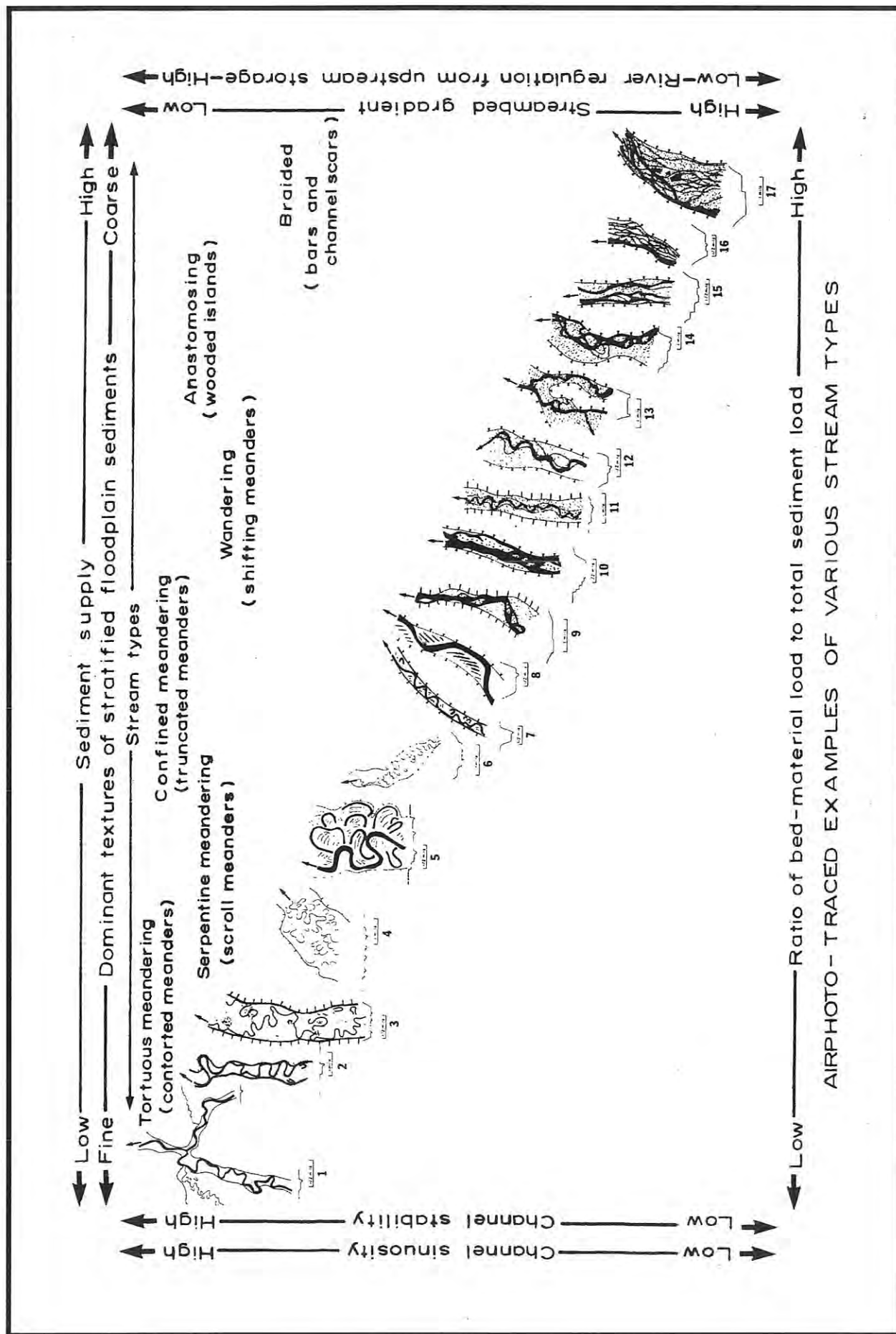


Figure 3.1: Equilibrium morphology of alluvial stream channels. (from Mollard, 1973)

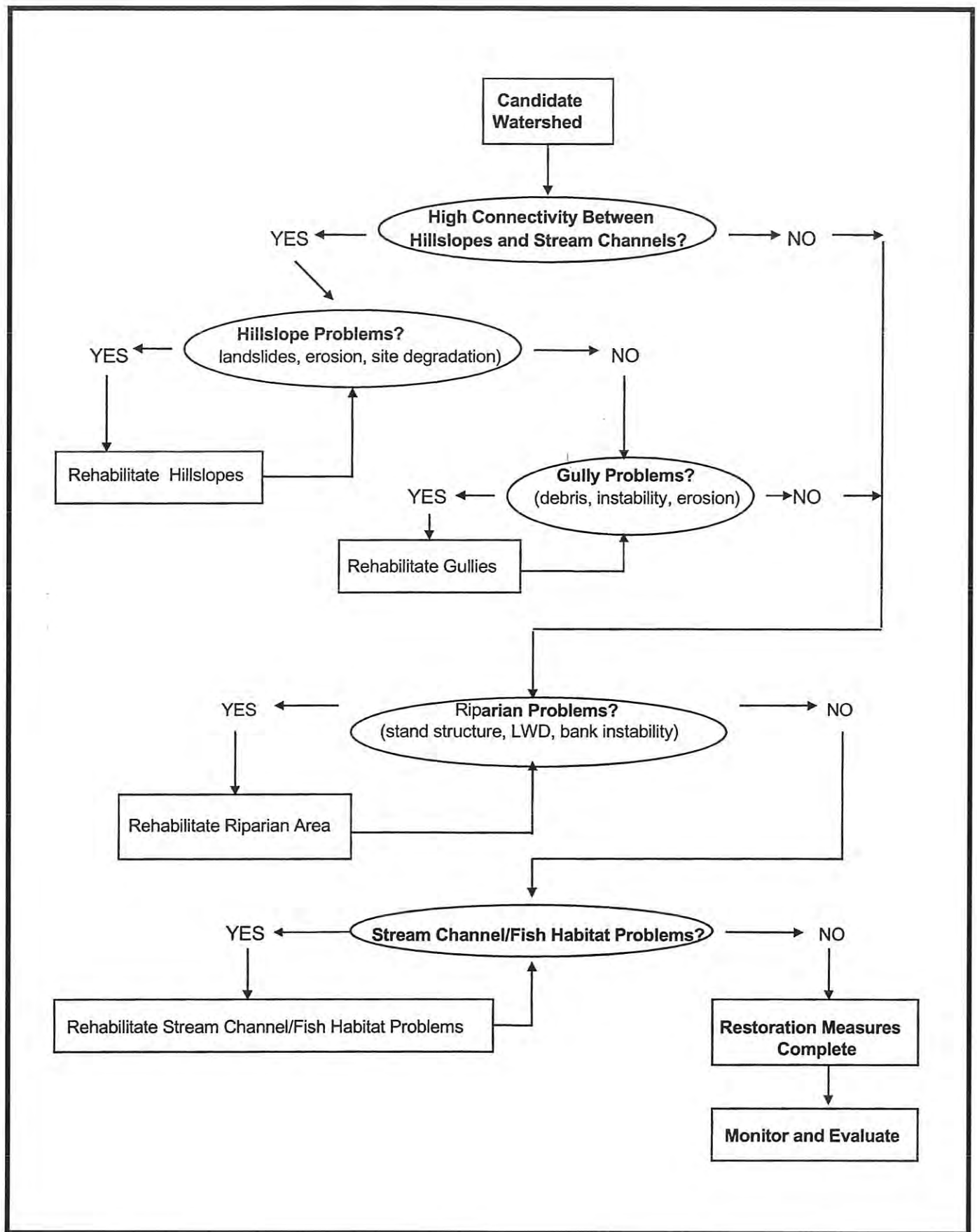


Figure 3.2: Hierarchical stream restoration protocol developed by the BC Watershed Restoration Program (Johnston and Moore, 1995).

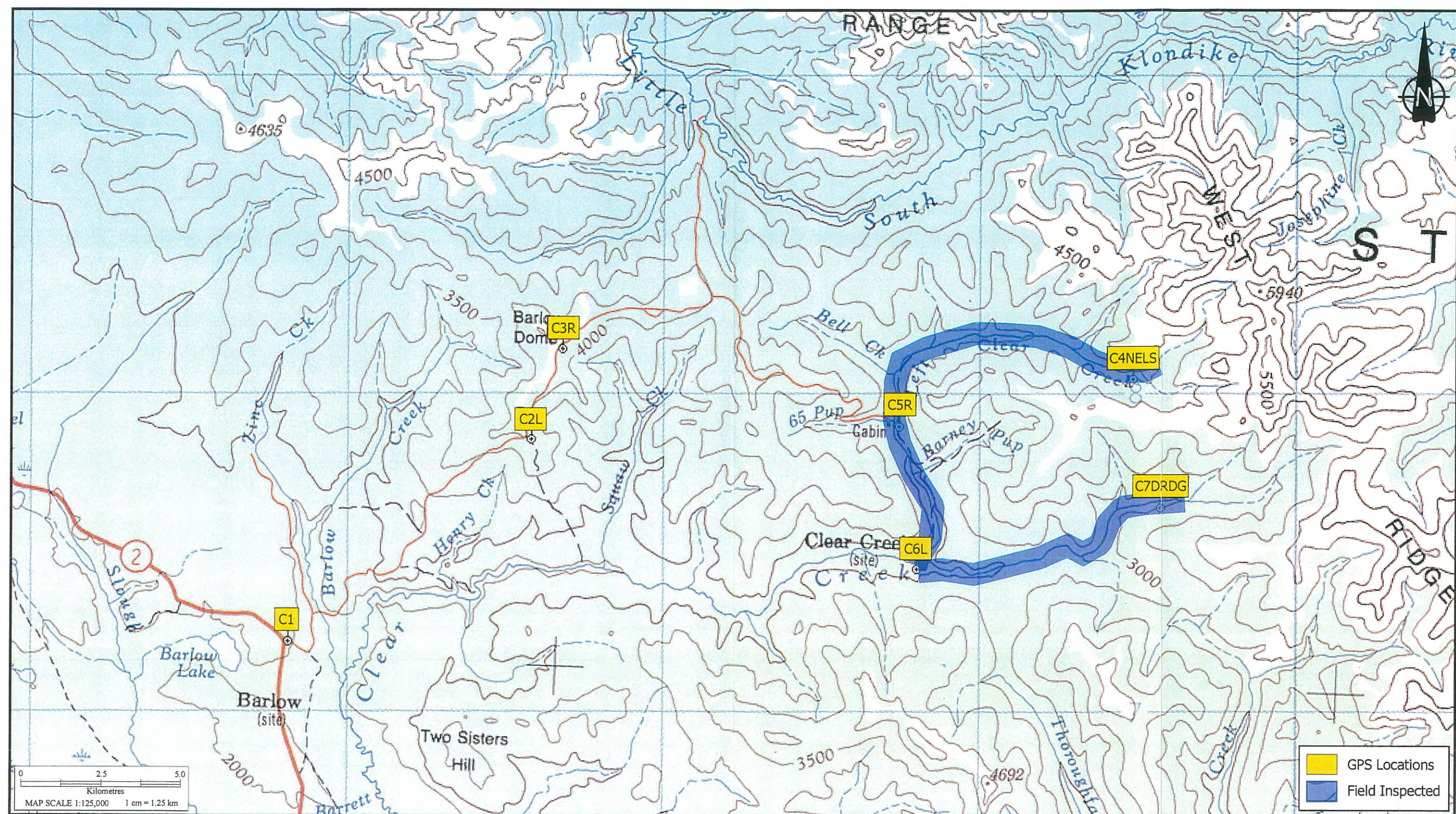


Figure 4.1.1: A map of the Clear Creek watershed showing the location of the areas inspected in the field.

CLEAR CREEK ABOVE BARLOW CREEK SEASONAL VARIATION IN FLOW, 1987-2002

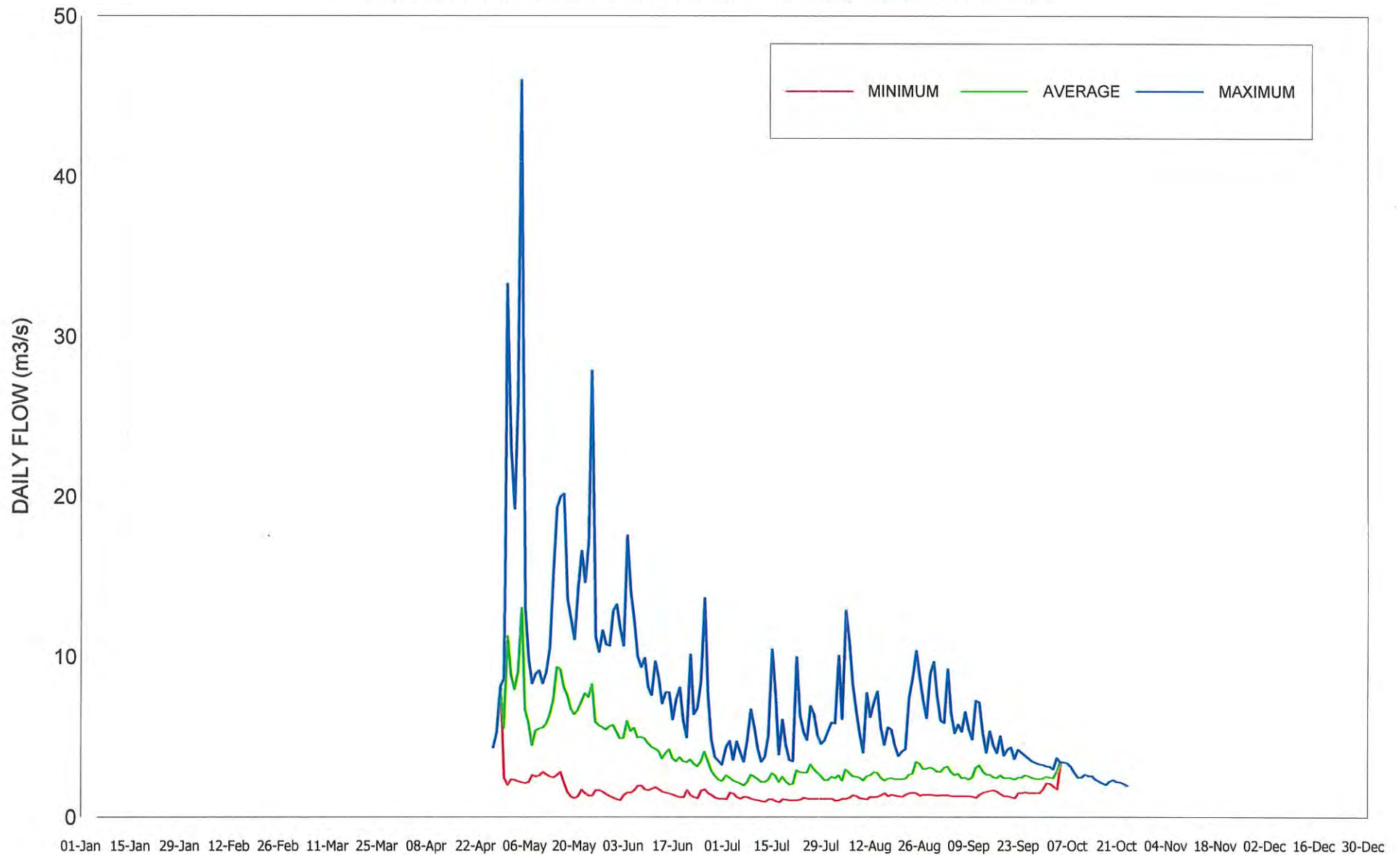
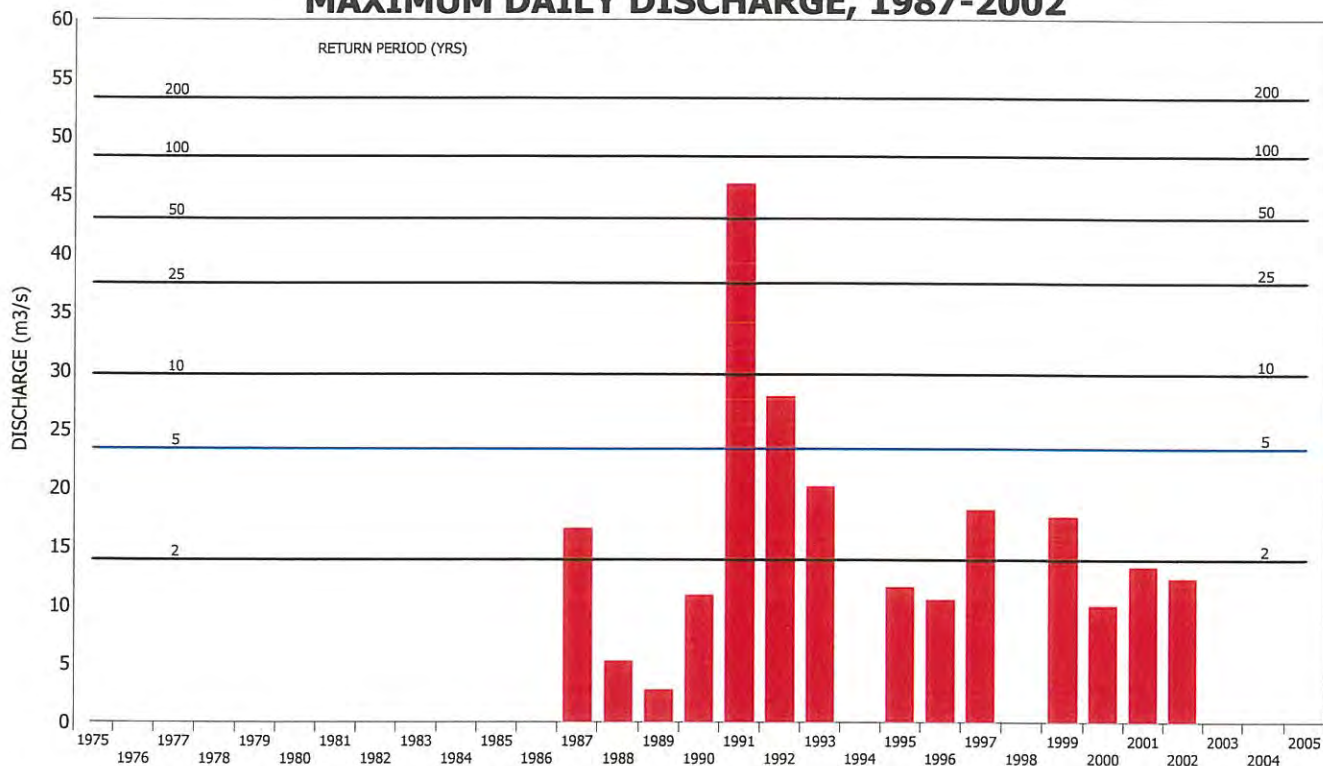


Figure 4.1.2: Seasonal variation in flow, Clear Creek Above Barlow Creek, 1987-2002.

CLEAR CREEK ABOVE BARLOW CREEK MAXIMUM DAILY DISCHARGE, 1987-2002



CLEAR CREEK ABOVE BARLOW CREEK MAXIMUM INSTANT. DISCHARGE, 1987-2002

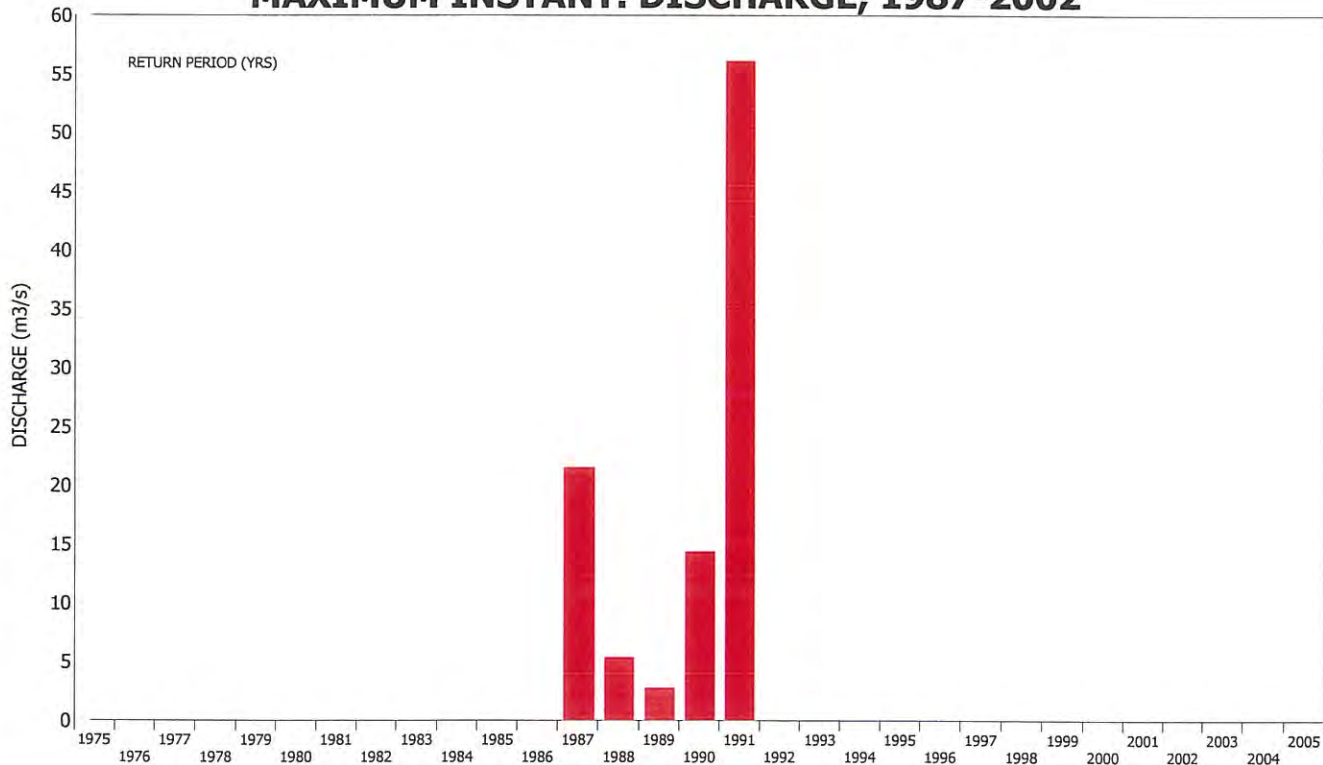


Figure 4.1.3: Historical variation in annual maximum daily and instantaneous discharge, Clear Creek Above Barlow Creek.

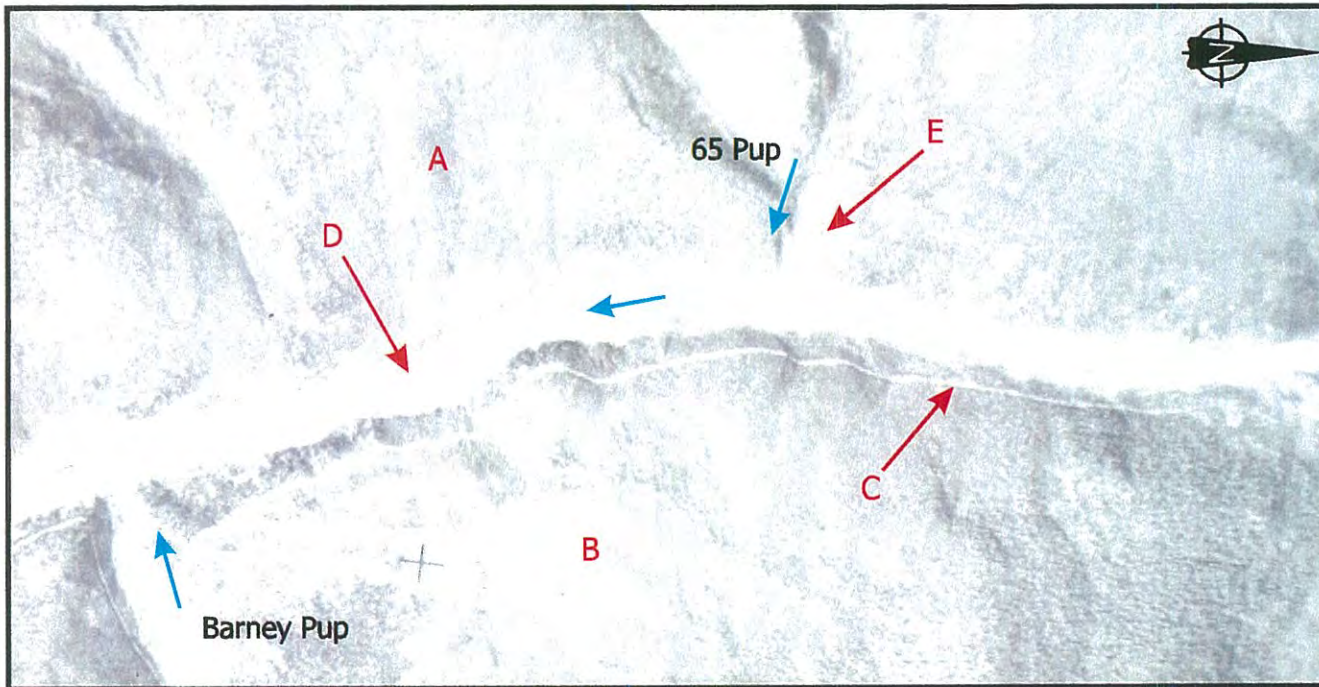


Figure i

Date: August 20, 1949

A12259 #386

NOTE:

- Sparse vegetation cover on possibly burned valley walls (A & B).
- Access road C.
- Extensive dredge spoil piles in valley bottom D.
- Limited pup mining on tributary E.

Discharge:

Clear Creek Above Barlow Creek
Stewart Rive at Mayo

na
614 m³/s

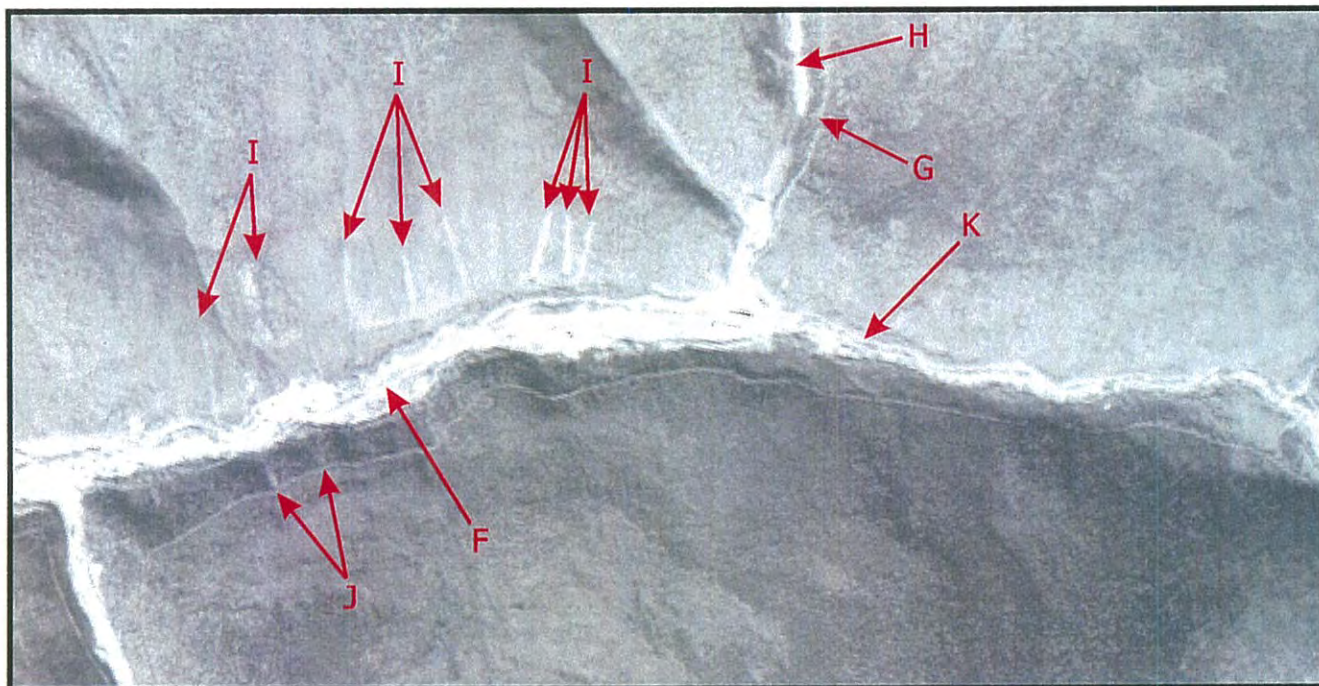


Figure ii

Date: August 11, 1989

A27519 #176

NOTE:

- Reworked dredge spoil F.
- Access road G and more extensive pup mining H.
- Open slope debris slides I.
- Debris slides downslope of access road (J).
- Limited revegetation of spoil piles (eg. K).

Discharge:

Clear Creek Above Barlow Creek
Stewart River at Mayo

1.63 m³/s
na

Figure 4.1.4: Historical changes in channel morphology, Left Clear Creek in the vicinity of Field Site C5.

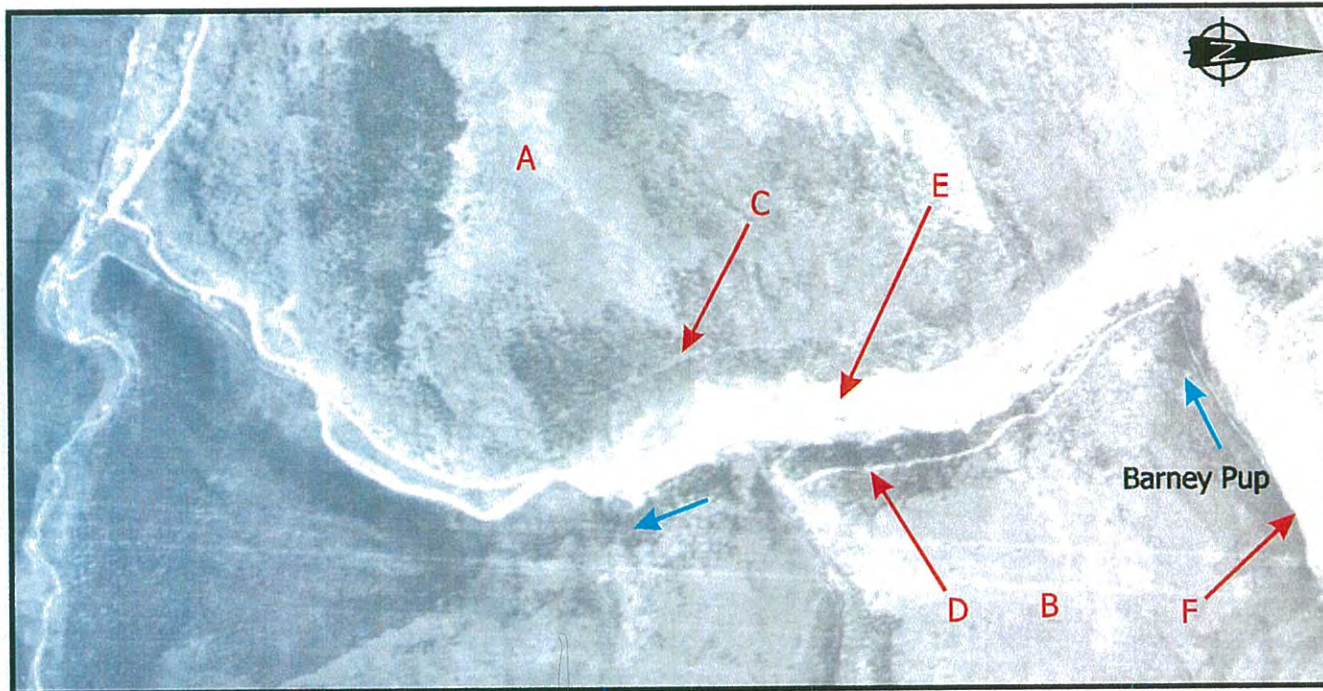


Figure i

Date: August 20, 1949

A12259 #386

NOTE:

- Sparse vegetation cover on valley walls (A & B).
- Access roads (C & D).
- Area of dredged valley bottom (E) and pup mining activities on tributary F.

Discharge:

Clear Creek Above Barlow Creek
Stewart River at Mayo

na
614 m³/s

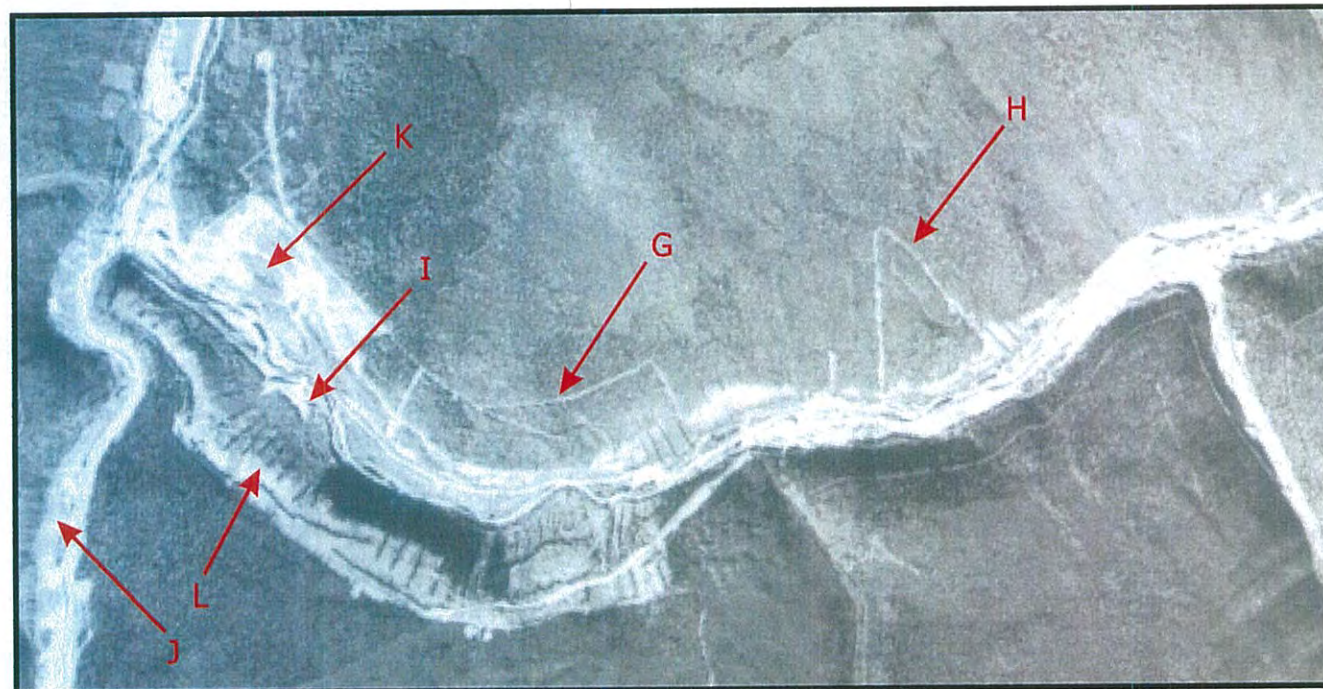


Figure ii

Date: August 11, 1989

A27519 #176

NOTE:

- Additional access road (G) and exploratory trails (H).
- New valley bottom mining (I & J), valley wall excavation (K) and overburden deposition (L).

Discharge:

Clear Creek Above Barlow Creek
Stewart River at Mayo

1.63 m³/s
na

Figure 4.1.5: Historical changes in channel morphology, Left Clear Creek at the confluence with Right Clear Creek.

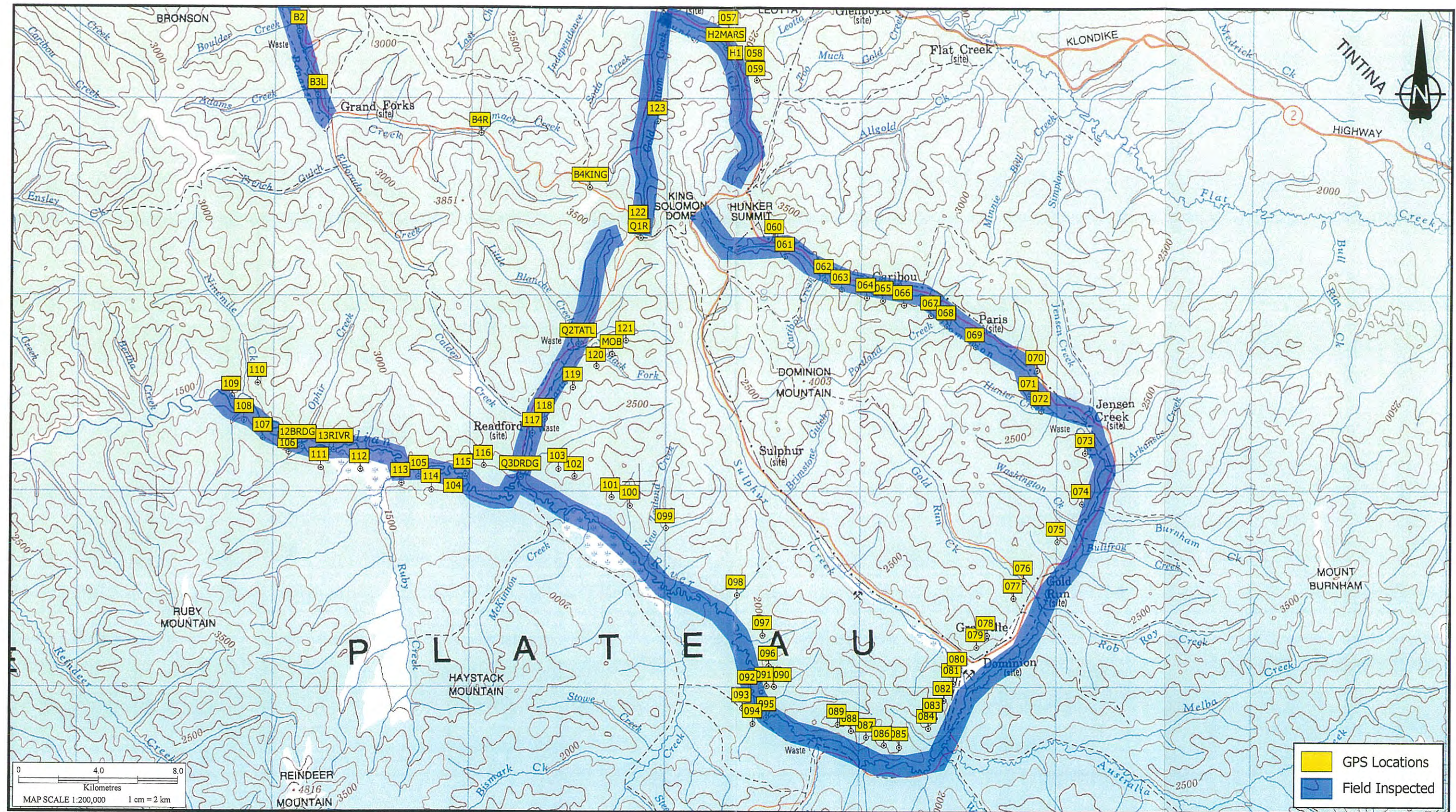


Figure 4.2.1: A map of the upper Indian River watershed showing the location of the areas inspected in the field.

INDIAN RIVER ABOVE THE MOUTH SEASONAL VARIATION IN FLOW, 1982-2002

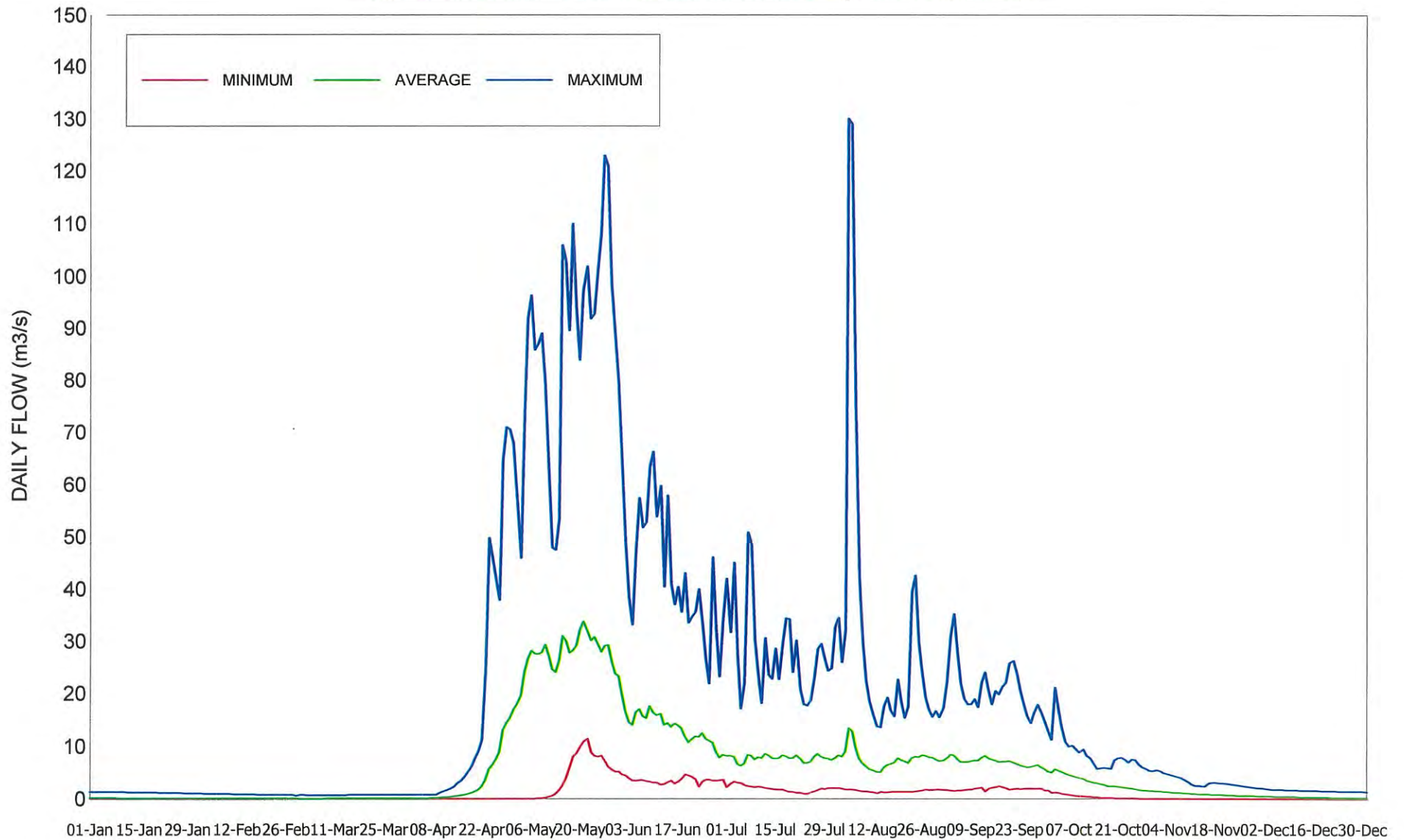
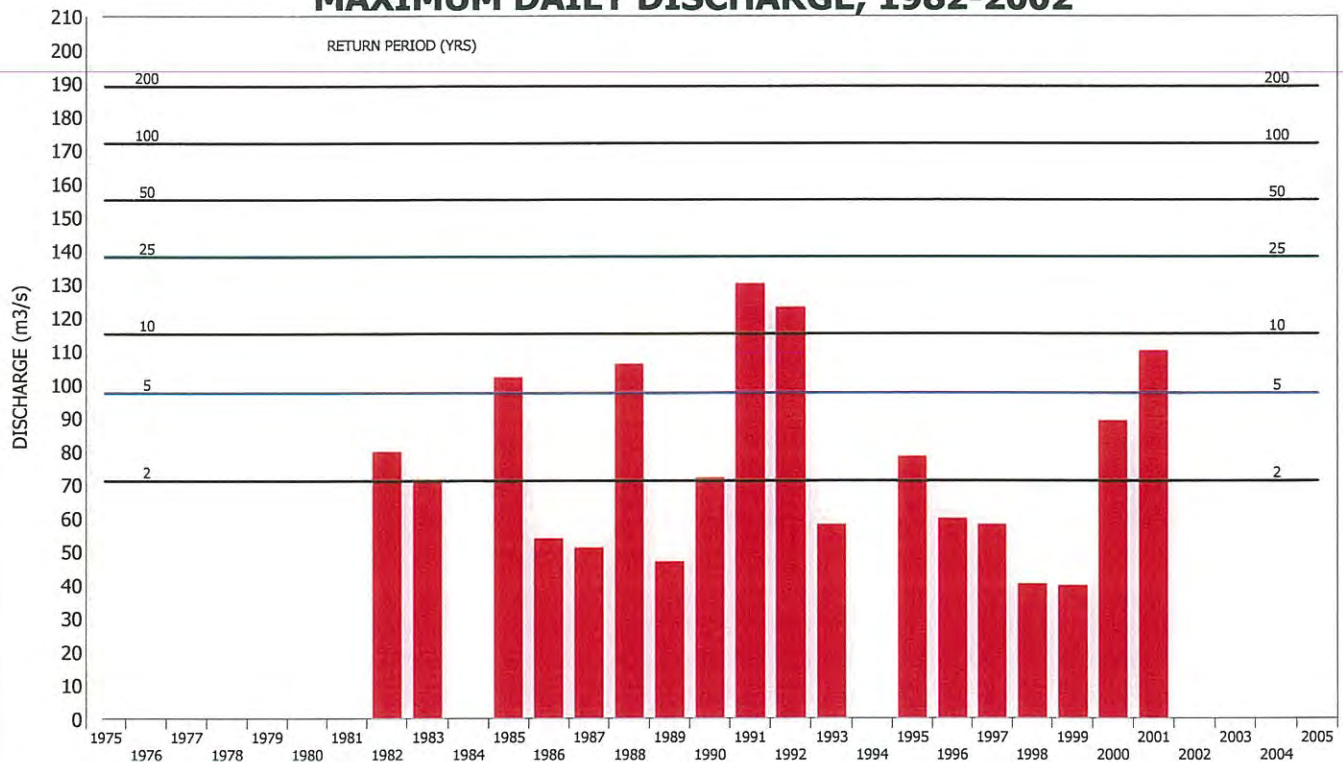


Figure 4.2.2: Seasonal variation in flow, Indian River Above The Mouth, 1982-2002.

INDIAN RIVER ABOVE THE MOUTH MAXIMUM DAILY DISCHARGE, 1982-2002



INDIAN RIVER ABOVE THE MOUTH MAXIMUM INSTANT. DISCHARGE, 1983-2002

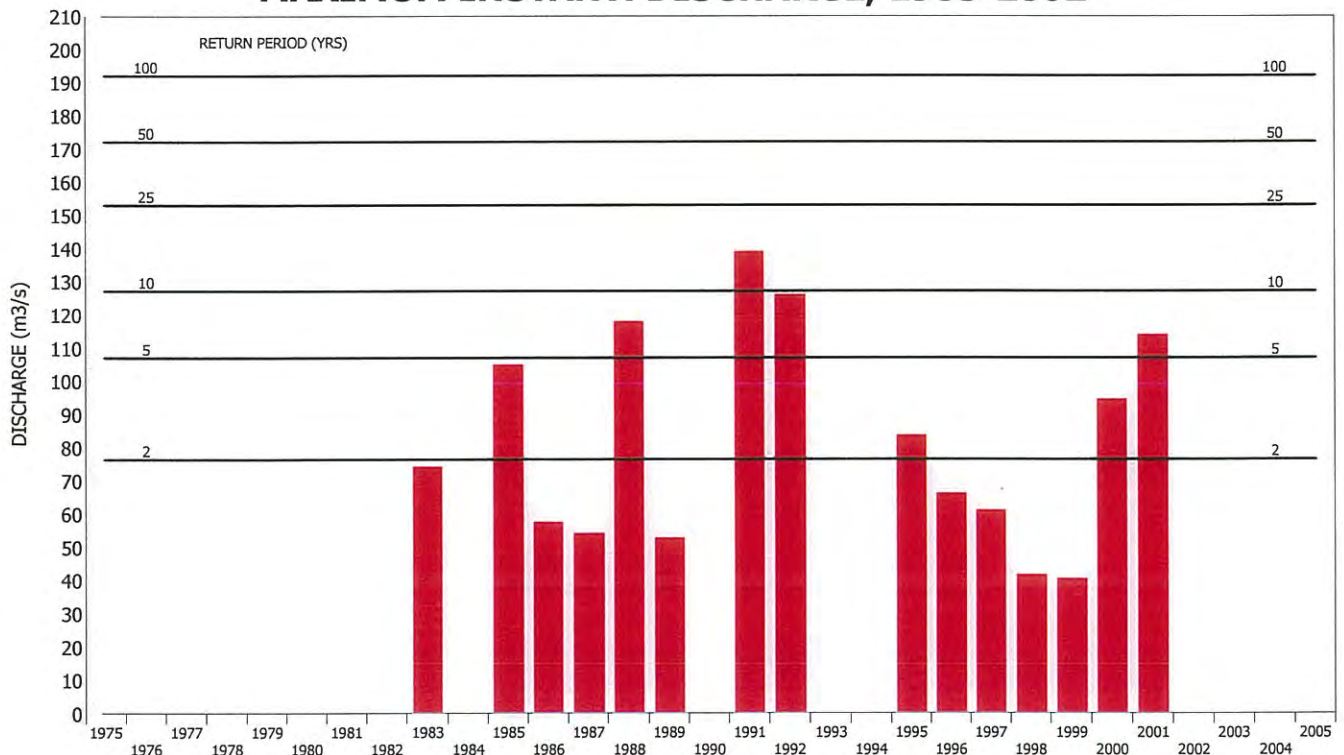


Figure 4.2.3: Historical variation in annual maximum daily and instantaneous discharge, Indian River Above the Mouth.

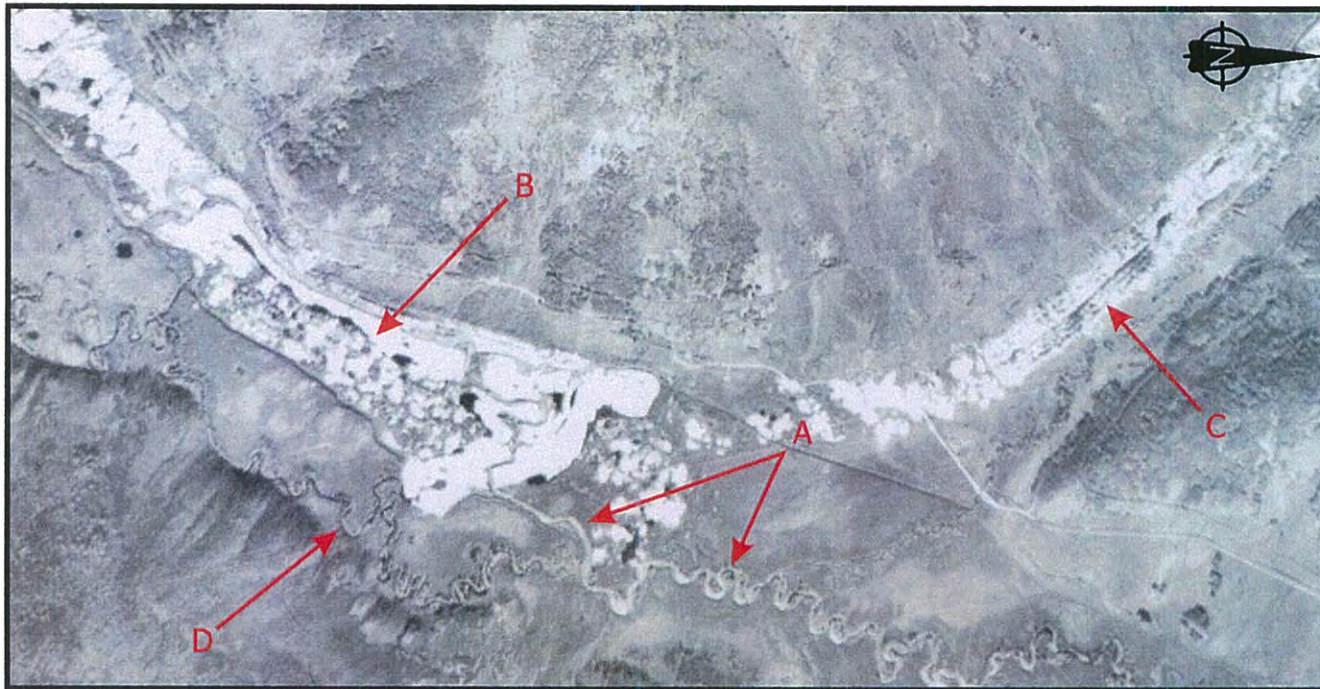


Figure i

Date: June 13, 1949

A12068 #238

NOTE:

- Pre-mining location and channel pattern on Dominion Creek (A).
- Extent of pre-1949 mining on Dominion (B) and Gold Run (C) Creeks.
- Relic Dominion Creek channel D.

Discharge:

Indian River Above the Mouth

na

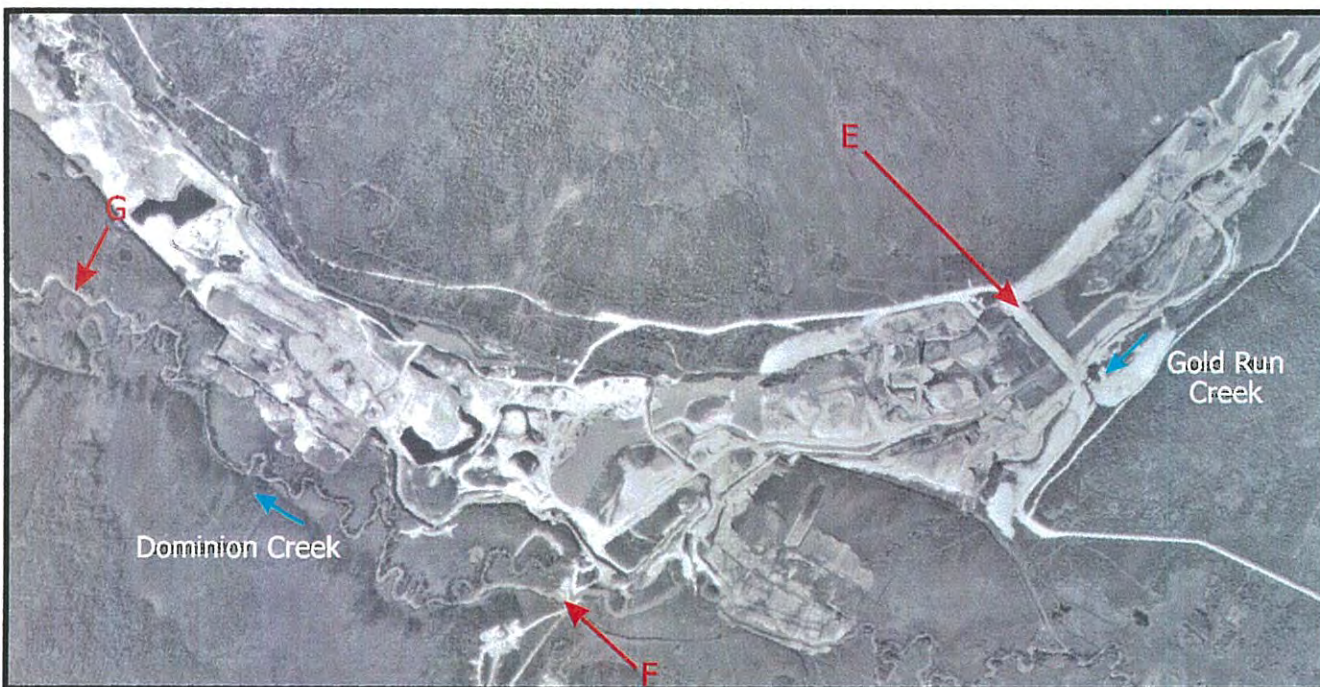


Figure ii

Date: August 10, 1995

A28227 #102

NOTE:

- Enlarged mining foot print.
- Construction of cross valley berm on Gold Run Creek (E).
- Partial diversion of Dominion Creek flow through relic channel (F) and resulting channel relocation (G).

Discharge:

Indian River Above the Mouth

8.23 m³/s

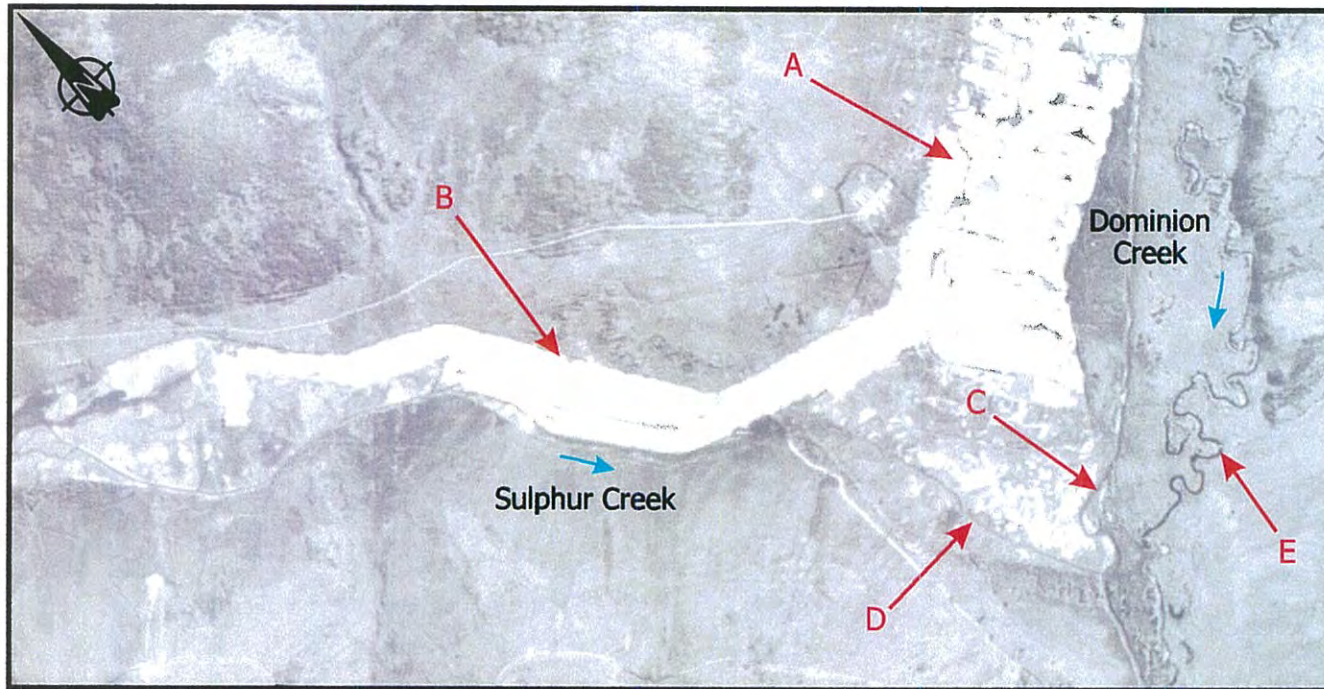


Figure i

Date: June 13, 1949

A12068 #239

NOTE:

- Extent of dredging in Dominion Creek (A) and Sulphur Creek (B).
- Relocated or disturbed sections of Dominion Creek (C) and Sulphur Creek (D).
- Possible relic channel of Dominion Creek (E).

Discharge:

Indian River Above the Mouth

na

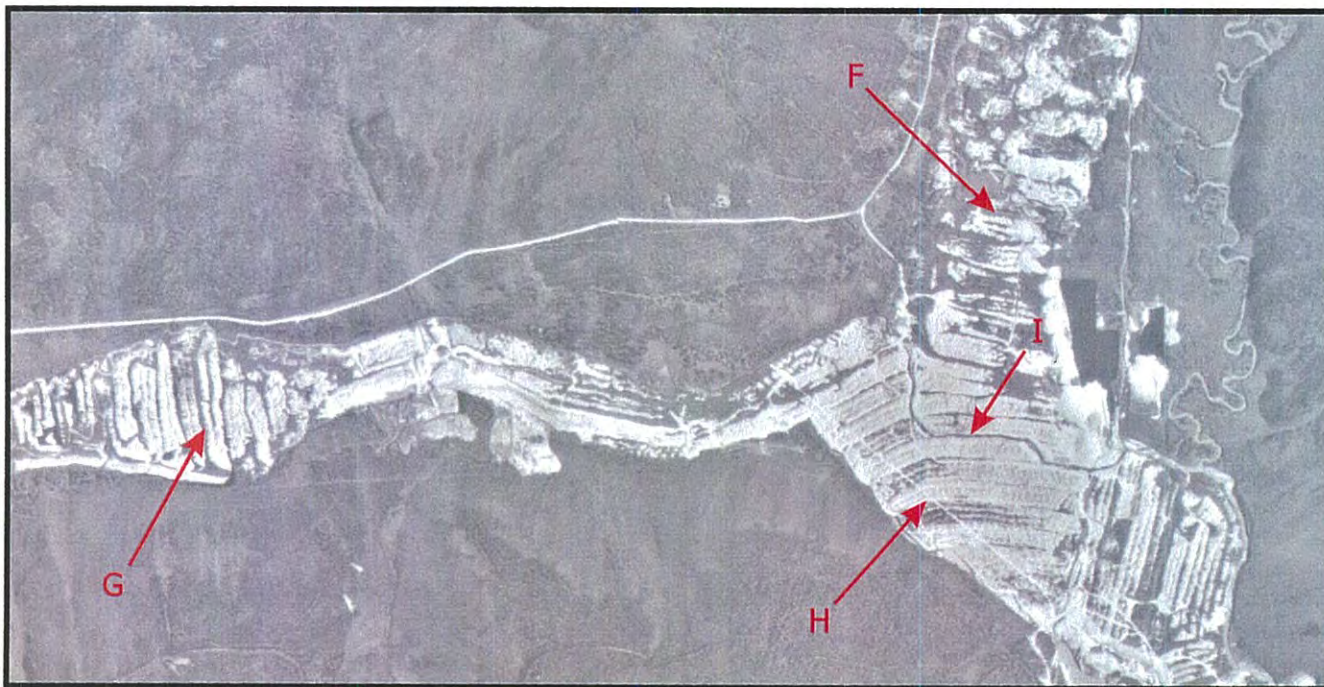


Figure ii

Date: August 10, 1995

A28227 #99 & 53

NOTE:

- Revegetation of pre-1949 dredge spoils on Dominion Creek (F).
- Increased foot print of dredging on Sulphur Creek (G) and Dominion Creek (H).
- Diverted channel of Sulphur Creek (I).

Discharge:

Indian River Above the Mouth

8.23 m³/s

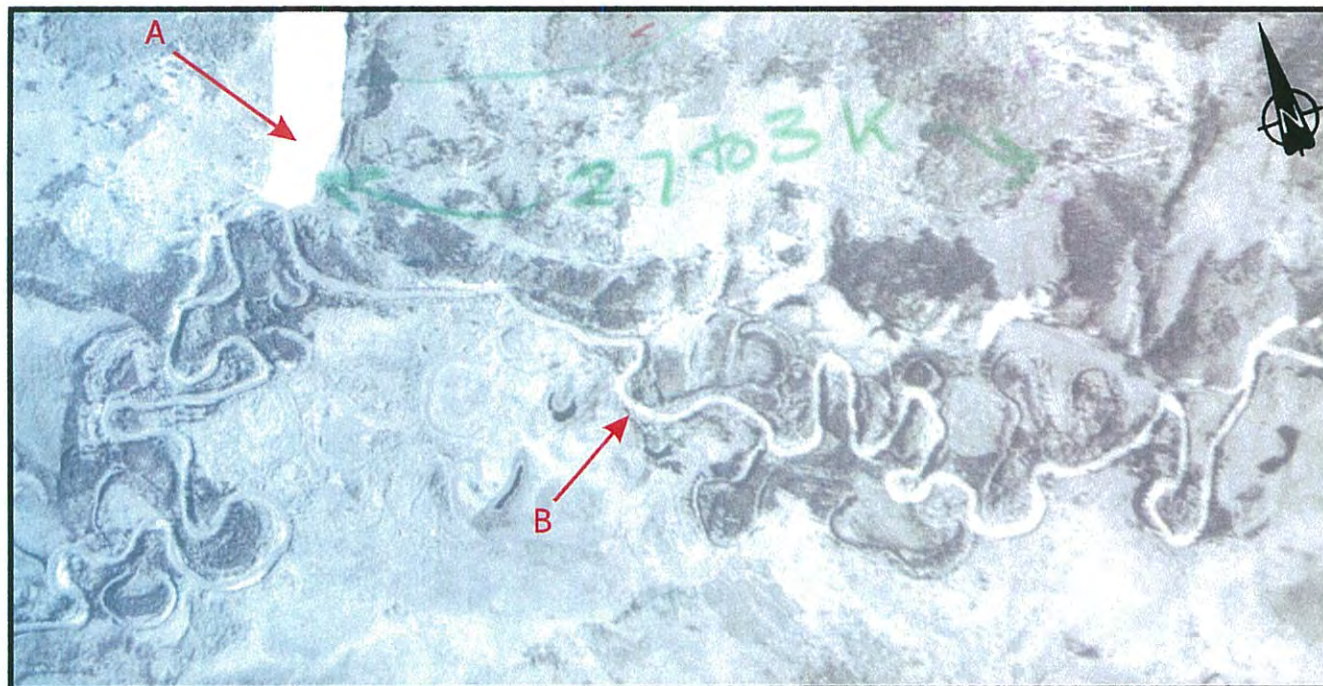


Figure i

Date: July 27, 1949

A12264 #284

NOTE:

- Pre-1949 dredge clearing or mining on Quartz Creek (A).
- Undisturbed channel morphology on Indian River (B).

Discharge:

Indian River Above the Mouth

na

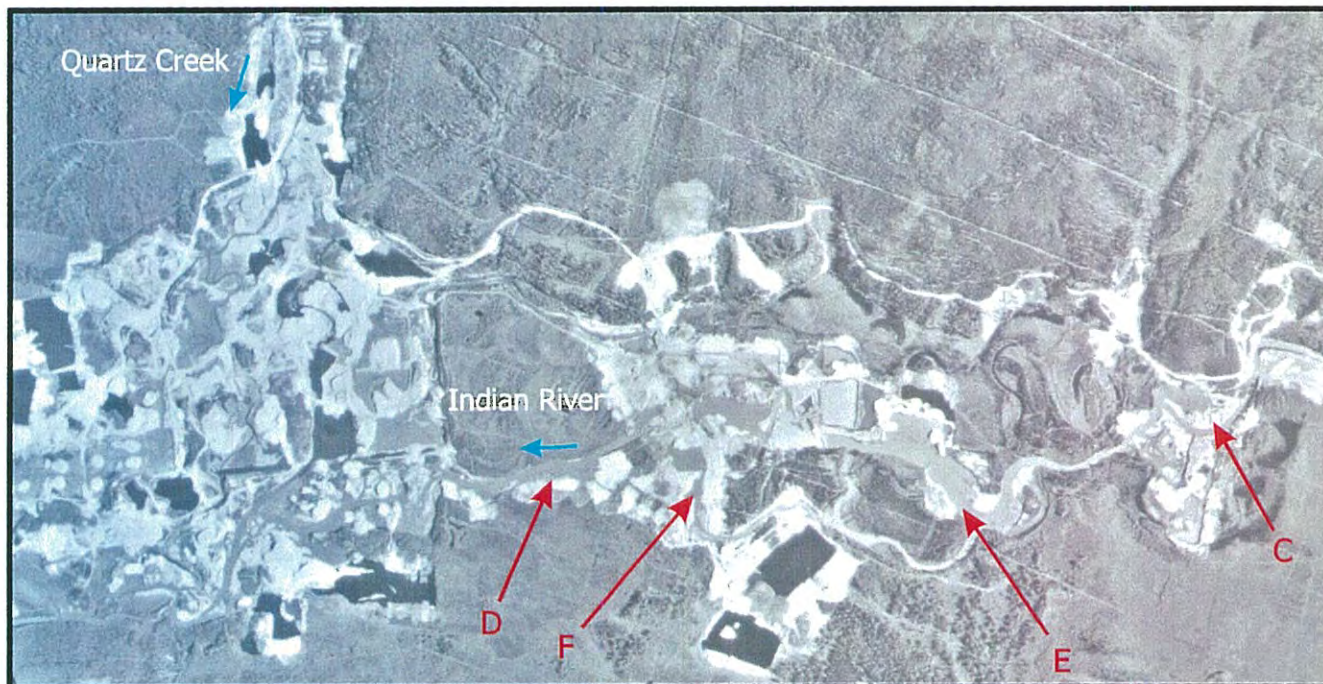


Figure ii

Date: August 10, 1995

A28237 #139

NOTE:

- Extensive construction of pits and ponds.
- Diverted mainstem channel C and D.
- Wider sediment infilled channels (eg. E).
- Extensive supply of readily erodible sediments (eg. F).

Discharge:

Indian River Above the Mouth

8.23 m³/s



(i)
Date: July 27, 1949
A12264 #259

NOTE:

- Recent dredging activities on Quartz Creek (A).
- Pre-mining channel conditions in Indian River (B).

Discharge:
Indian River Above the Mouth na



(ii)
Date: 1988
A27369 #71

NOTE:

- Extensive mining development including pits, settling ponds and spoil pits.
- Diverted sections of Indian River (eg. C & D).

Discharge:
Indian River Above the Mouth m³/s



(iii)
Date: 1989
A27483 #265

NOTE:

- Sections of Indian River diverted between 1988 and 1999 (E).

Discharge:
Indian River Above the Mouth m³/s



(viii)
Date: August 10, 1995
A28237 #140

NOTE:

- Expansion of mined area between 1989 and 1995 (eg. F & G).
- Diversion of Indian River (H) and a section of river which is flowing through a former pond I.
- Development of wide, shallow, laterally unstable sections of channel (eg. J & K).

Discharge:
Indian River Above the Mouth 8.23 m³/s

Figure 4.2.7: Historical changes in channel morphology, Indian River downstream of Quartz Creek. F - 15

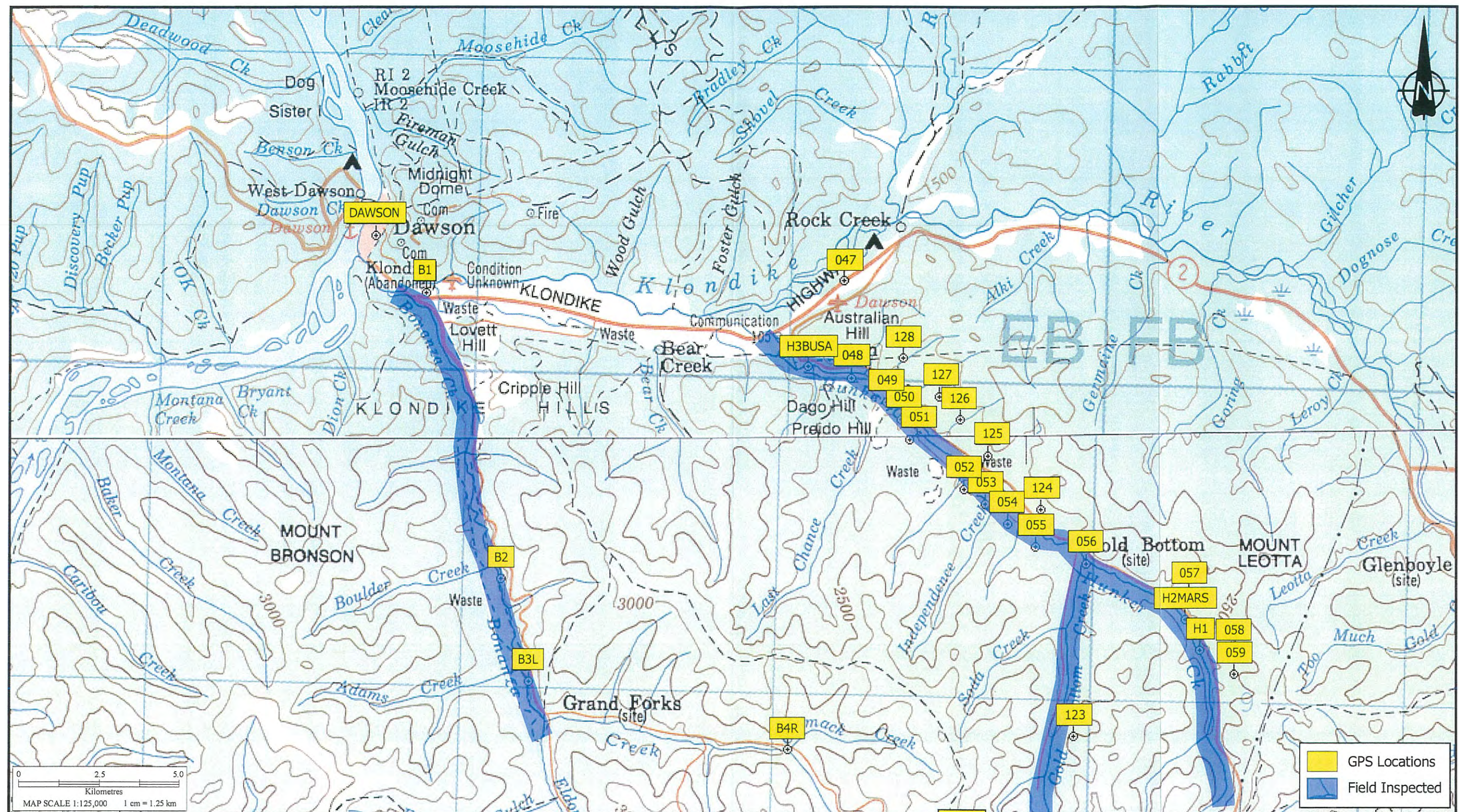


Figure 4.3.1: A map showing GPS locations obtained during the August 2002 site visit.

KLONDIKE RIVER ABOVE BONANZA CREEK SEASONAL VARIATION IN FLOW, 1965-2002

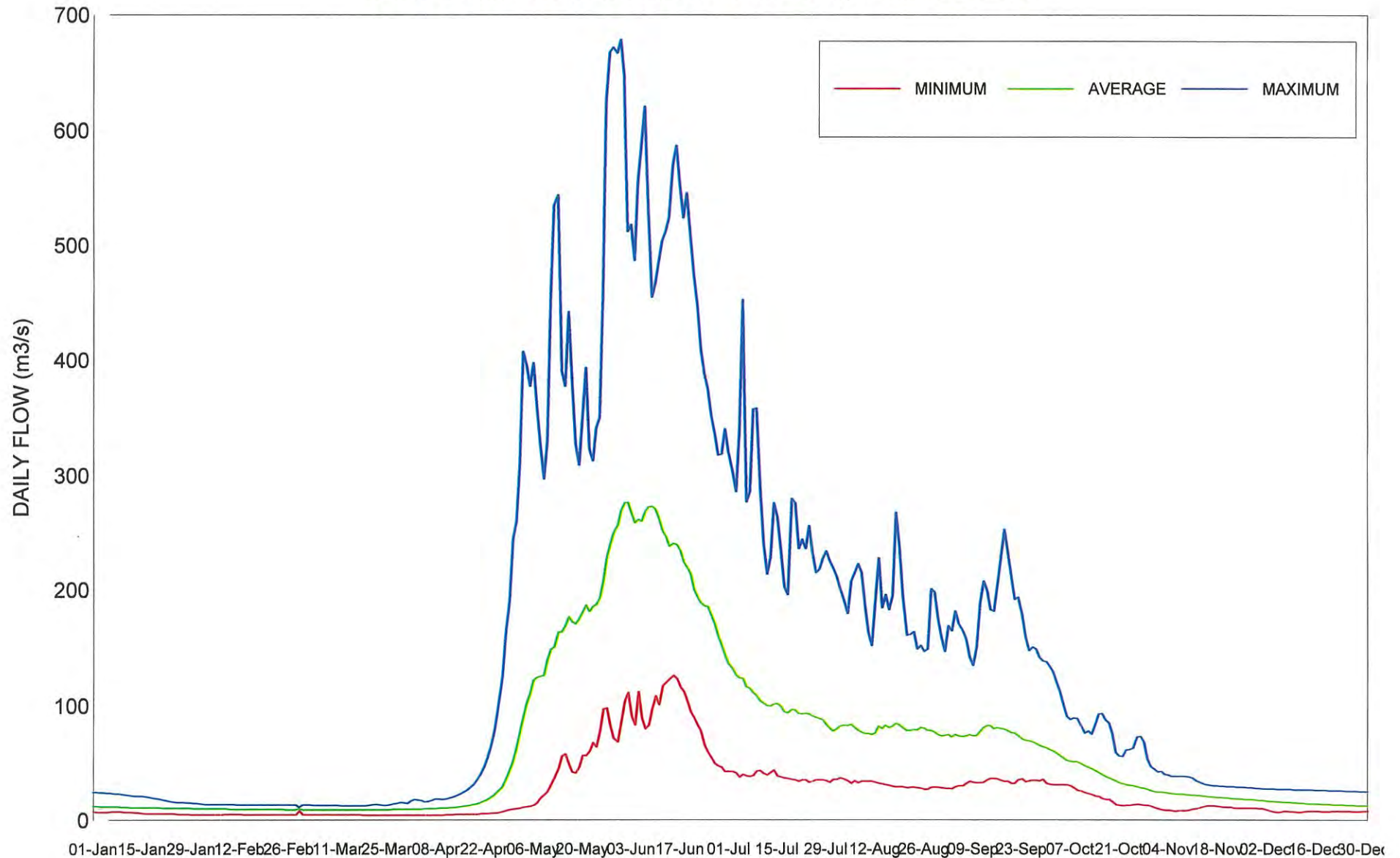
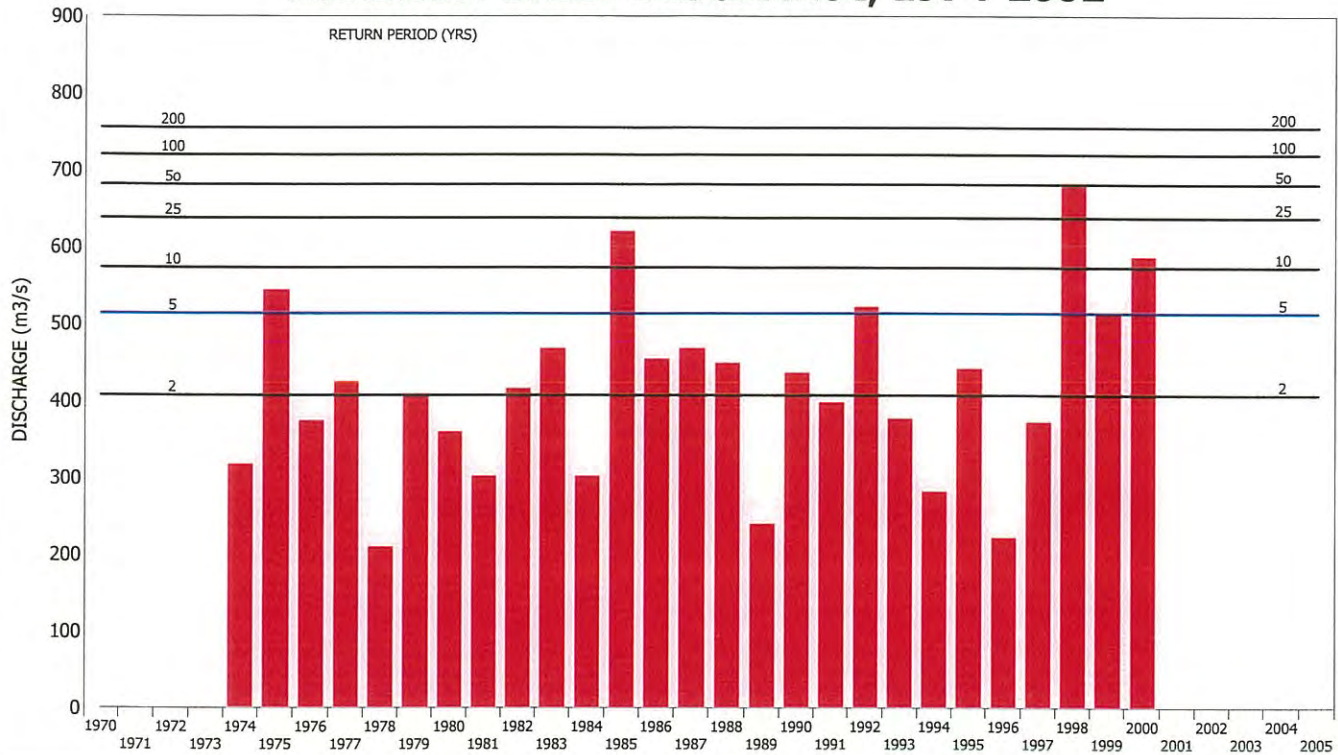


Figure 4.4.1: Seasonal variation in flow, Klondike River Above Bonanza Creek, 1965-2002.

KLONDIKE RIVER ABOVE BONANZA CREEK MAXIMUM DAILY DISCHARGE, 1974-2002



KLONDIKE RIVER ABOVE BONANZA CREEK MAXIMUM INSTANT. DISCHARGE, 1974-2002

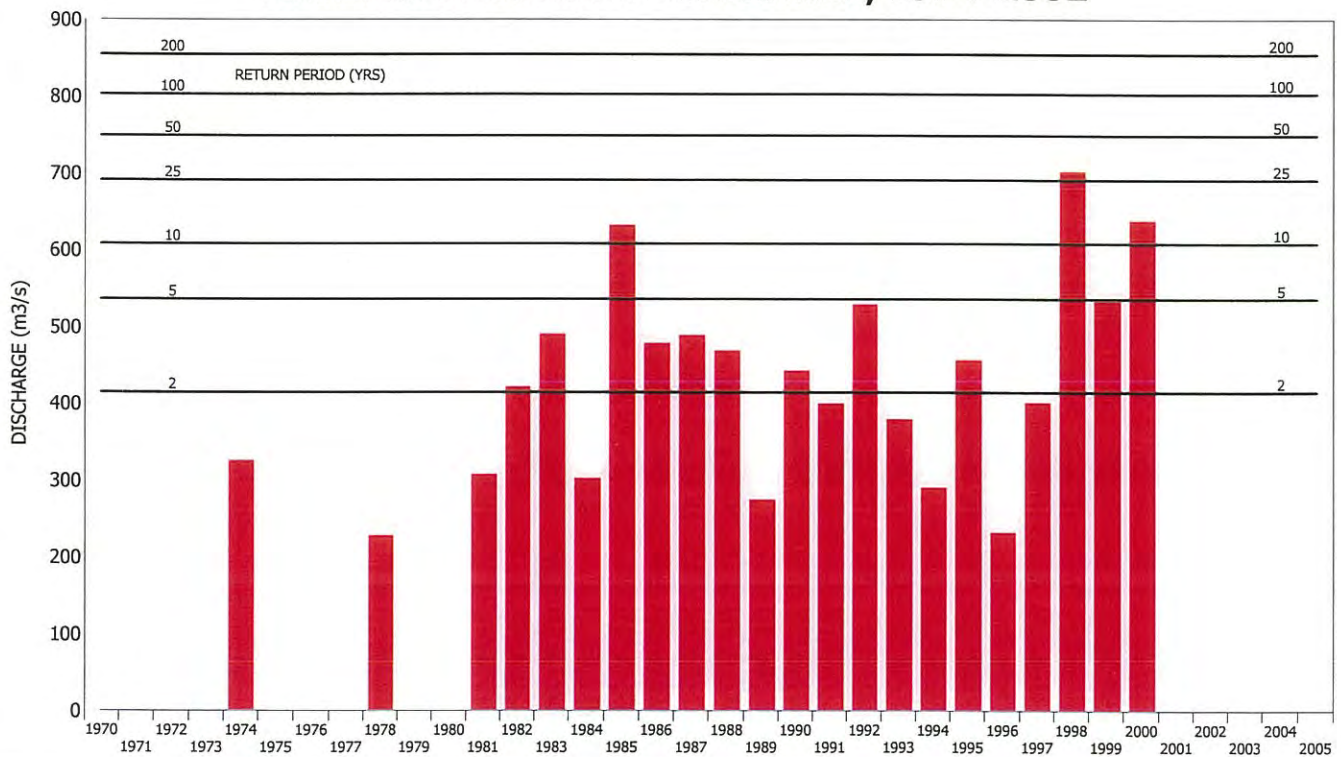
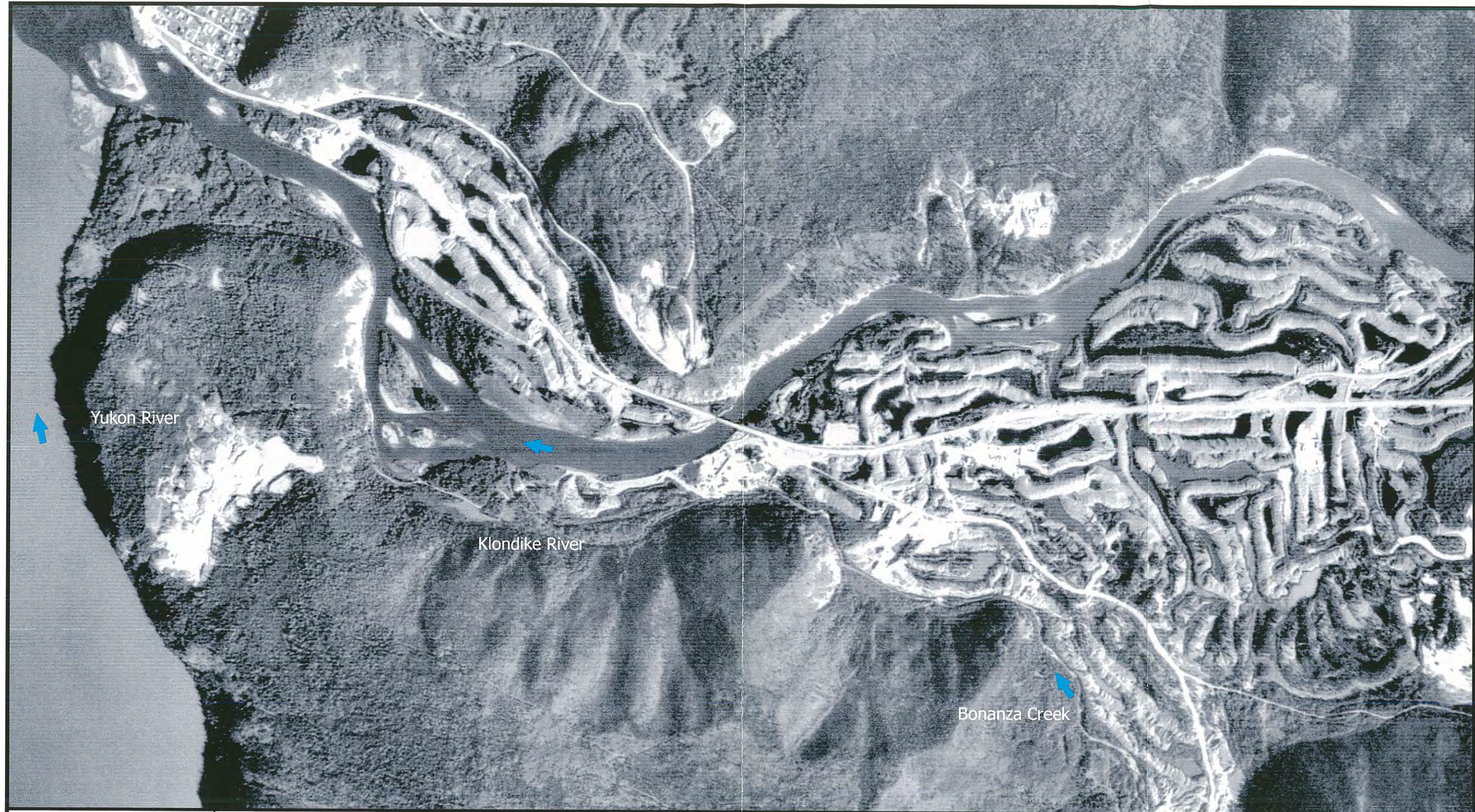


Figure 4.4.2: Historical variation in annual maximum daily and instantaneous discharge, Klondike River Above Bonanza Creek, 1974-2002.



WP8611-4 #72			1986 Air Photo			APPROXIMATE SCALE:			M. MILES AND ASSOCIATES LTD. 645 ISLAND ROAD, VICTORIA, BC, V8S 2T7 Phone: 250-595-0653 Fax: 250-595-7367 email: mmaa@coastnet.com			PROJECT: KLONDIKE RIVER					
						DATE: March 12, 2003						TITLE: AIR PHOTO MOSAIC SHOWING CHANNEL CONDITIONS IN 1986					
REFERENCED DRAWING NO.			REFERENCED DRAWING DESCRIPTION			DRAWN: S. Gibbins											
A	Mar. 12, 2003	Issued For Discussion	SG	MM		DESIGNED: S. Gibbins			CLIENT: YUKON RIVER PANEL			FIGURE 4.4.3			PROJECT NO.		REV: A
						CHECKED: M. Miles									DRAWING NO.		
F - 19						APPROVED:											



WP8611-4 #74		1986 Air Photo				APPROXIMATE SCALE:		M. MILES AND ASSOCIATES LTD. 645 ISLAND ROAD, VICTORIA, BC, V8S 2T7 Phone: 250-595-0653 Fax: 250-595-7367 email: mmaa@coastnet.com		PROJECT: KLONDIKE RIVER				
						DATE: March 12, 2003				TITLE: AIR PHOTO MOSAIC SHOWING CHANNEL CONDITIONS IN 1986				
REFERENCED DRAWING NO.		REFERENCED DRAWING DESCRIPTION				DRAWN: S. Gibbins								
A	Mar. 12, 2003	Issued For Discussion	SG	MM		DESIGNED: S. Gibbins		CLIENT: YUKON RIVER PANEL		FIGURE 4.4.4		PROJECT NO.		REV: A
						CHECKED: M. Miles						DRAWING NO.		
F - 20						APPROVED:								



WP8611-4 #75 & 76			1986 Air Photos			APPROXIMATE SCALE:			<div>M. MILES AND ASSOCIATES LTD. 645 ISLAND ROAD, VICTORIA, BC, V8S 2T7</div> <div>Phone: 250-595-0653 Fax: 250-595-7367 email: mmaa@coastnet.com</div>	PROJECT: KLONDIKE RIVER					
						DATE: March 12, 2003				TITLE: AIR PHOTO MOSAIC SHOWING CHANNEL CONDITIONS IN 1986					
REFERENCED DRAWING NO.			REFERENCED DRAWING DESCRIPTION			DRAWN: S. Gibbins									
A	Mar. 12, 2003	Issued For Discussion	SG	MM		DESIGNED: S. Gibbins									
						CHECKED: M. Miles									
F - 21						APPROVED:			CLIENT: YUKON RIVER PANEL		FIGURE 4.4.5		PROJECT NO.		REV: A
												DRAWING NO.			



WP8611-4 #77 & 78			1986 Air Photos			APPROXIMATE SCALE:			<div>M. MILES AND ASSOCIATES LTD. 645 ISLAND ROAD, VICTORIA, BC, V8S 2T7</div> <div>Phone: 250-595-0653 Fax: 250-595-7367 email: mmaa@coastnet.com</div>	PROJECT: KLONDIKE RIVER			
						DATE: March 12, 2003				TITLE: AIR PHOTO MOSAIC SHOWING CHANNEL CONDITIONS IN 1986			
REFERENCED DRAWING NO.			REFERENCED DRAWING DESCRIPTION			DRAWN: S. Gibbins							
A	Mar. 12, 2003	Issued For Discussion	SG	MM		DESIGNED: S. Gibbins							
						CHECKED: M. Miles			CLIENT: YUKON RIVER PANEL	FIGURE 4.4.6		PROJECT NO.	REV: A
F - 22						APPROVED:						DRAWING NO.	

TABLE 4.2.1: SUMMARY OF SEDIMENT DATA COLLECTED AT THE WSC STATION INDIAN RIVER ABOVE THE MOUTH

Station 09EB003: Drainage Area: 222 km²

Year	Date	Time	Water Temp.	Instant Discharge	Sampling Vertical		Type Of Sampler	Instant Conc.	Dissolved Solids	Per Cent Finer Than Indicated Size in Millimeters										Per Cent		
			(°C)	(m³/s)	(m)			(mg/l)	(mg/l)	0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.25	0.5	1	2	Sand	Silt	Clay
1990	29-May	1450	9	1.5	5.5	L	DH48	134	183													
1990	29-May	1455	9	1.66	10	L	DH48	178	189													
1990	29-May	1500	9	1.74	16	L	DH48	184	175													
1990	29-May	1505	9	1.93	24	L	DH48	176	180													
1990	29-May	1510	9	1.76	30	L	DH48	179	171													
1990	25-Jul	1308	16	0.458	13	Z	DH48	59	264													
1990	25-Jul	1312	16	0.41	20.5	Z	DH48	57	265													
1990	25-Jul	1321	16	0.382	26.5	Z	DH48	62	260													
1990	25-Jul	1327	16	0.509	32.5	Z	DH48	62	260													
1990	25-Jul	1334	16	0.344	38.5	Z	DH48	62	257													
1991	14-May	1445	6	3.9	32	L	DH48	276	144	8	12	21	46	76	98	100				2	86	12
1991	14-May	1449	6	3.78	24	L	DH48	289	145	5	8	16	42	69	98	100				2	90	8
1991	14-May	1456	6	3.26	18	L	DH48	296	138	6	10	23	48	85	97	99	100			3	87	10
1991	14-May	1500	6	3.44	12	L	DH48	298	134	6	9	19	43	76	97	100				3	88	9
1991	14-May	1505	6	3.45	6	L	DH48	293	137	1	5	15	41	75	97	100				3	92	5
1991	06-Jun	1449	10	1.51	31	L	DIP	218	189	10	21	40	75	90	98	100				2	77	21
1991	06-Jun	1456	10	1.47	25	L	DIP	208	186	21	26	46	80	96	99	100				1	73	26
1991	06-Jun	1459	10	1.44	17	L	DIP	209	195	20	28	46	79	95	99	100				1	71	28
1991	06-Jun	1503	10	1.53	11.5	L	DIP	206	195	19	27	45	76	90	96	99	100			4	69	27
1991	06-Jun	1506	10	1.13	5.5	L	DIP	207	195	15	21	39	75	97	99	100				1	78	21
1991	11-Jul	2028	14.5	1.16	29.5	L	DH48	285	216	36	46	68	89	97	99	100				1	53	46
1991	11-Jul	2034	14.5	1.31	35.5	L	DH48	290	210	28	40	64	82	93	98	100				2	58	40
1991	11-Jul	2038	14.5	1.38	43	L	DH48	302	199	29	39	59	85	93	96	98	99	100		4	57	39
1991	11-Jul	2042	14.5	1.32	50.5	L	DH48	281	202	35	44	61	93	97	99	100				1	55	44
1991	11-Jul	2045	14.5	1.48	55	L	DH48	289	198	37	49	71	89	96	99	100				1	50	49
1991	27-Aug	1233	7	2.21	32	L	DH48	162	176													
1991	27-Aug	1240	7	2.62	24	L	DH48	161	181													
1991	27-Aug	1246	7	2.26	16.5	L	DH48	153	166													
1991	27-Aug	1253	7	2.39	10.5	L	DH48	151	173													
1991	27-Aug	1257	7	2.08	4.5	L	DH48	150	181													
1991	27-Sep	1123	6.5	2.53	4.5	L	DH48	333	183	23	34	48	66	87	96	99	100			4	62	34
1991	27-Sep	1126	6.5	3.14	11	L	DH48	330	183	23	31	49	69	84	94	98	99	100		6	63	31
1991	27-Sep	1129	6.5	3.1	17	L	DH48	327	190	22	33	49	71	87	97	99	100			3	64	33
1991	27-Sep	1132	6.5	3.25	25	L	DH48	321	188	18	25	49	69	85	94	99	100			6	69	25
1991	27-Sep	1138	6.5	3.36	31	L	DH48	305	186	18	28	48	70	89	99	100				1	71	28

TABLE 4.2.2: ESTIMATED SUSPENDED SEDIMENT LOADS, INDIAN RIVER ABOVE THE MOUTH

YEAR	MONTH	DATE	DISCHARGE	AVERAGE SUSPENDED SEDIMENT CONCENTRATION	AVERAGE GRAIN SIZE DISTRIBUTION			SUSPENDED SEDIMENT LOAD				
					SAND	SILT	CLAY	All Size Fractions		SAND	SILT	CLAY
			(m ³ /s)	(mg/L)	(%)	(%)	(%)	(g/s)	(t/day)	(t/day)	(t/day)	(t/day)
1990	MAY	29	1.72	170				292.4	25.3			
1990	JULY	25	0.42	60				25.4	2.2			
1991	MAY	14	3.57	290	3	89	9	1035.6	89.5	2.3	79.3	7.9
1991	JUNE	6	1.42	210	2	74	25	296.8	25.6	0.5	18.9	6.3
1991	JULY	11	1.33	289	2	55	44	384.9	33.3	0.6	18.2	14.5
1991	AUG	27	2.31	155				359.3	31.0			
1991	SEP	27	3.08	323	4	66	30	994.2	85.9	3.4	56.5	25.9

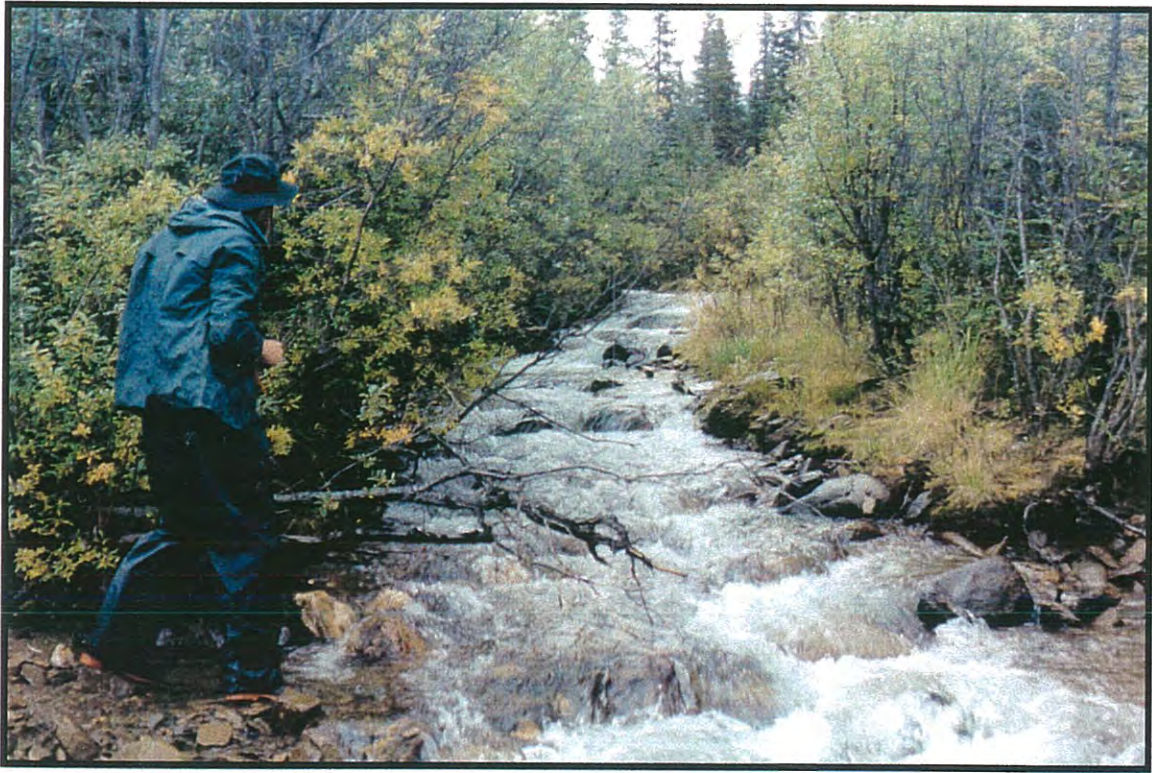
TABLE 4.4.1: SUMMARY OF SEDIMENT DATA COLLECTED AT THE WSC STATION KLONKIKE RIVER ABOVE BONANZA CREEK

Station 09EA003: Drainage Area: 7800 km²

Year	Date	Time	Water Temp.	Instant Discharge	Sampling Vertical	Type Of Sampler	Instant Conc.	Dissolved Solids	Per Cent Finer Than Indicated Size in Millimeters										Per Cent				
			(°C)	(m³/s)	(m)		(mg/l)	(mg/l)	0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.25	0.5	1	2	Sand	Silt	Clay	
1990	10-May	1457	8	26	61	M	D49	378	108	10	10	12	23	54	89	100					11	79	10
1990	10-May	1502	8	33.5	55	M	D49	328	109	6	6	9	17	50	92	99	100				8	86	6
1990	10-May	1509	8	35.4	43	M	D49	299	114	5	6	11	22	53	88	99	100				12	82	6
1990	10-May	1515	8	28.7	34	M	D49	252	114	3	5	7	15	43	80	98	100				20	75	5
1990	10-May	1521	8	37	22	M	D49	236	116	3	4	6	15	41	83	98	100				17	79	4
1990	01-Jun	1252	8	67.4	63	M	D49	268	73	1	3	16	30	49	74	92	99	100			26	71	3
1990	01-Jun	1316	8	94.5	54	M	D49	285	78	4	7	16	29	49	71	86	95	99	100		29	64	7
1990	01-Jun	1324	8	83	42	M	D49	321	81	1	2	11	25	40	57	72	83	89	100		43	55	2
1990	01-Jun	1335	8	80.8	33	M	D49	292	80	1	2	8	24	39	56	68	85	96	100		44	54	2
1990	01-Jun	1345	8	99.4	21	M	D49	380	74	2	6	12	23	35	53	66	78	87	100		47	47	6
1990	18-Jul	1003	13	14.6	24	M	DH48	3	145														
1990	18-Jul	1015	13	11.1	33	M	DH48	3	154														
1990	18-Jul	1024	13	12.8	45	M	DH48	3	148														
1990	18-Jul	1035	13	24.3	53	M	DH48	1	149														
1990	21-Sep	1135	8	16.5	61	M	D49	12	134														
1990	21-Sep	1141	8	21.9	55	M	D49	10	124														
1990	21-Sep	1147	8	23.7	44	M	D49	11	134														
1990	21-Sep	1153	8	20.7	32	M	D49	10	136														
1990	21-Sep	1157	8	23.1	22	M	D49	13	134														
1991	09-May	2130	6	231	65	X	D49	98	118														
1991	15-May	1221	6.5	26.8	62	M	D49	47	140														
1991	15-May	1228	6.5	24.3	53	M	D49	47	139														
1991	15-May	1239	6.5	25.1	44	M	D49	47	140														
1991	15-May	1246	6.5	27.1	32	M	D49	48	141														
1991	15-May	1254	6.5	29.5	20	M	D49	54	143														
1991	08-Jun	1231	7.5	22.6	63	M	D49	5	117														
1991	08-Jun	1241	7.5	26.5	53	M	D49	7	119														
1991	08-Jun	1252	7.5	25.4	44	M	D49	7	118														
1991	08-Jun	1302	7.5	28.2	32	M	D49	7	121														
1991	08-Jun	1310	7.5	31.6	20	M	D49	9	121														
1991	28-Aug	955	9.5	19.5	62	M	D49	15	160														
1991	28-Aug	1002	9.5	20.5	54	M	D49	14	157														
1991	28-Aug	1011	9.5	21.2	45	M	D49	14	155														
1991	28-Aug	1018	9.5	19.8	33	M	D49	15	156														
1991	28-Aug	1025	9.5	24.1	21	M	D49	21	145														
1991	26-Sep	1238	6.5	17.6	62.5	M	D49	1	162														
1991	26-Sep	1247	6.5	17.6	54	M	D49	6	161														
1991	26-Sep	1255	6.5	18.2	45	M	D49	3	171														
1991	26-Sep	1300	6.5	19.7	33	M	D49	9	157														
1991	26-Sep	1307	6.5	22.8	21	M	D49	7	155														

TABLE 4.4.2: ESTIMATED SUSPENDED SEDIMENT LOADS, KLONDIKE RIVER ABOVE BONANAZA CREEK

YEAR	MONTH	DATE	DISCHARGE	AVERAGE SUSPENDED SEDIMENT CONCENTRATION	GRAIN SIZE DISTRIBUTION			SUSPENDED SEDIMENT LOAD				
					SAND	SILT	CLAY	All Size Fractions		SAND	SILT	CLAY
			(m ³ /s)	(mg/L)	(%)	(%)	(%)	(g/s)	(t/day)	(t/day)	(t/day)	(t/day)
1990	MAY	10	32.12	298.60	13.60	80.20	6.20	9591.0	828.7	112.7	664.6	51.4
1990	JUNE	1	85.02	309.20	37.80	58.20	4.00	26288.2	2271.3	858.55	1321.90	90.85
1990	JULY	18	15.70	2.50				39.3	3.4			
1990	SEPT	21	21.18	11.20				237.2	20.5			
1991	MAY	9	231.00	98.00				22638.0	1955.9			
1991	MAY	15	26.56	48.60				1290.8	111.5			
1991	JUNE	8	26.86	7.00				188.0	16.2			
1991	AUG	28	21.02	15.80				332.1	28.7			
1991	SEP	26	19.18	5.20				99.7	8.6			



August 22, 2002

MM 02 - 70 - 19A

Plate 4.1.1: Looking upstream along Upper Left Clear Creek, showing undisturbed channel conditions.



August 22, 2002

MM 02 - 70 - 25A

Plate 4.1.2: Looking downstream on Left Clear Creek at SiteC4Nels, showing valley bottom clearing and overburden on spoil piles along the base of the valley walls.



August 22, 2002

MM 02 - 70 - 27A

Plate 4.1.3: Looking upstream showing the wide shallow channel which has formed along cleared sections of Left Clear Creek.



August 22, 2002

MM 02 - 70 - 26A

Plate 4.1.4: Looking downstream on Left Clear Creek showing how eroding spoil piles confine the channel.



August 22, 2002

MM 02 - 70 - 29A

Plate 4.1.5: Looking upstream on Left Clear Creek showing how the channel is downcutting into a placer excavation.



August 22, 2002

MM 02 - 70 - 30A

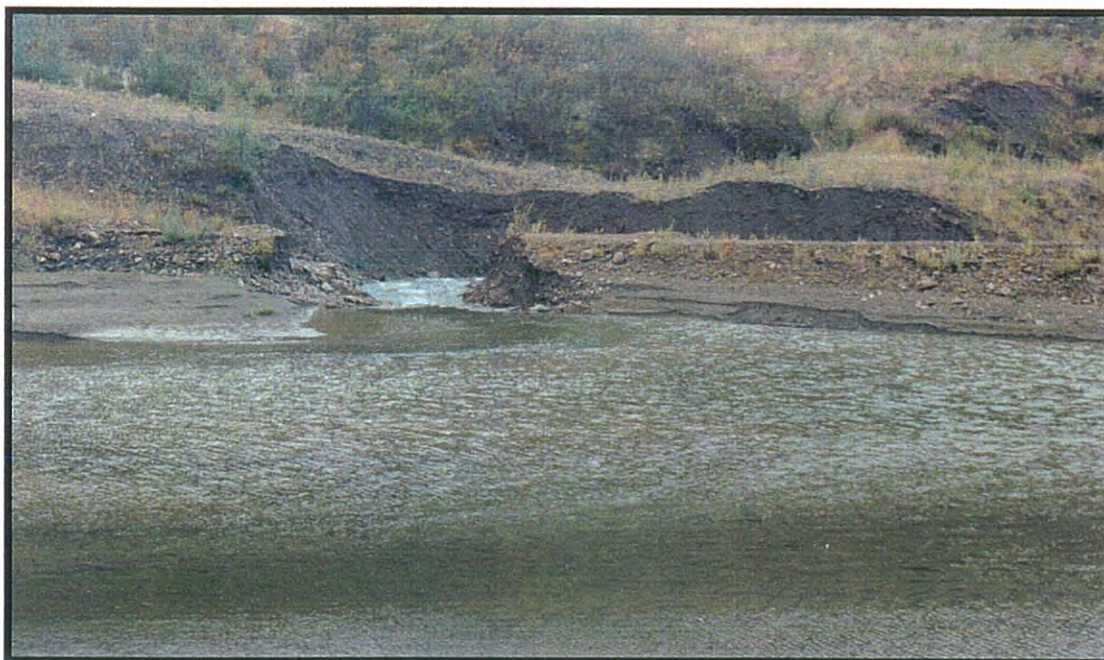
Plate 4.1.6: Small tributary channels are commonly downcutting through spoil piles to the lowered mainstem channel.



August 22, 2002

MM 02 - 71 - 03

Plate 4.1.7: Looking downstream on a settling pond constructed on the mainstem of Left Clear Creek.



August 22, 2002

MM 02 - 71 - 06A

Plate 4.1.8: Looking downstream showing the breached outlet on the above settling pond.



August 22, 2002

MM 02 - 71 - 08

Plate 4.1.9 Looking downstream on a diverted section of Left Clear Creek showing the erodible banks, scarcity of riparian vegetation and lack of instream structure or complexity.



August 22, 2002

MM 02 - 70 - 31A

Plate 4.1.10: Looking downstream on a diverted section of Left Clear Creek, showing the straight confined channel which lacks a flood plain.



August 22, 2002

MM 02 - 71 - 10

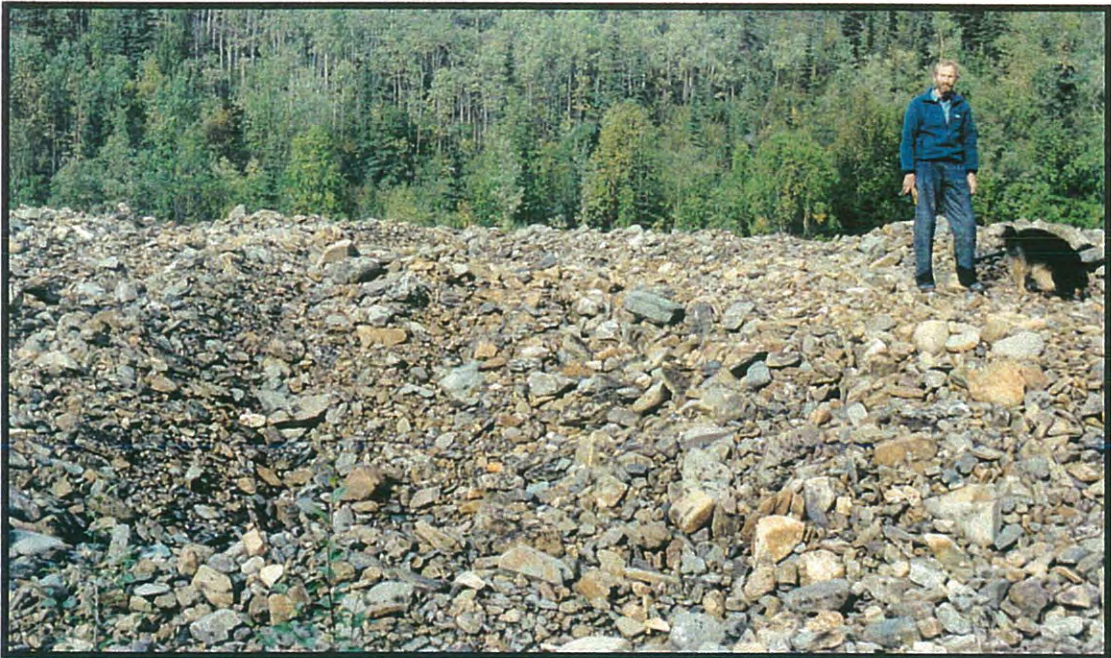
Plate 4.1.11: Placer excavations at tributary confluences can provide off-channel pool habitat which appear to contain fish.



August 22, 2002

MM 02 - 71 - 12

Plate 4.1.12: Looking downstream showing the hummock topography associated with dredge mining in lower Left Clear Creek.



August 22, 2002

MM 02 - 71 - 15

Plate 4.1.13: Surface materials on spoil piles from old dredges typically lack fine sediments. It is difficult to establish vegetation on these well drained materials.



August 22, 2002

MM 02 - 71 - 11

Plate 4.1.14: Reworked dredge spoil piles exposed fine sediments, some of which are phyllite rich and weather rapidly.



August 22, 2002

MM 02 - 71 - 17

Plate 4.1.15: Reworked spoil piles are less well drained and easier to revegetate.



August 22, 2002

MM 02 - 71 - 18

Plate 4.1.16: Well developed active, unvegetated bars indicate that elevated rates of sediment transport are occurring in the lower section of Left Clear Creek.



August 22, 2002

MM 02 - 71 - 25

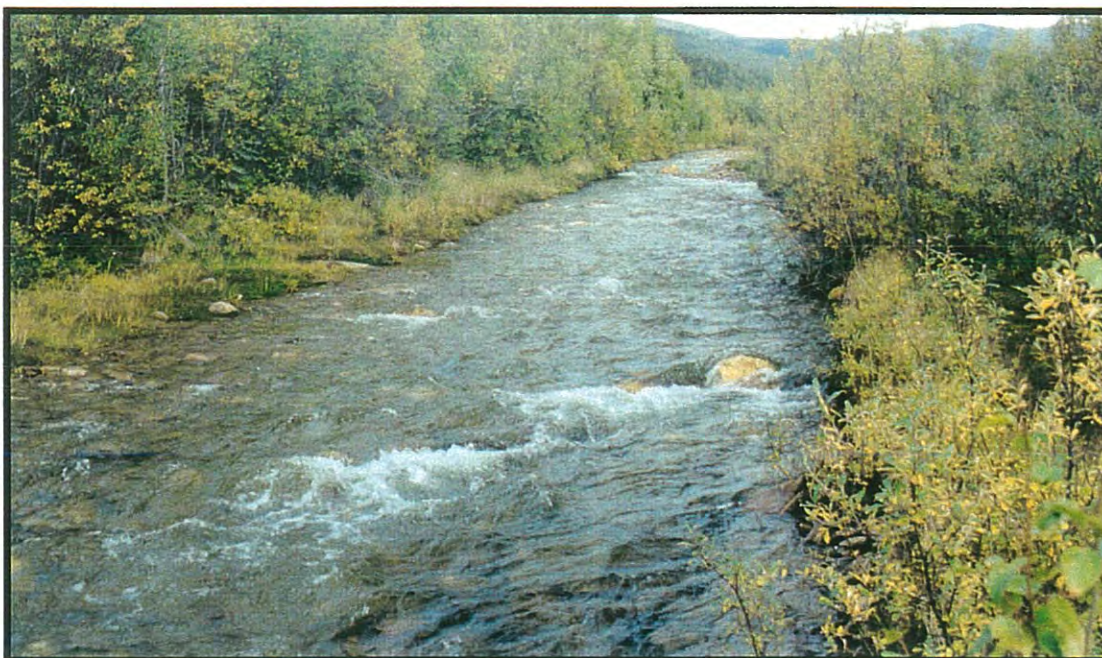
Plate 4.1.17: Elevated rates of sediment transport have resulted in the formation of wide, shallow sections of river channel.



August 22, 2002

MM 02 - 71 - 26

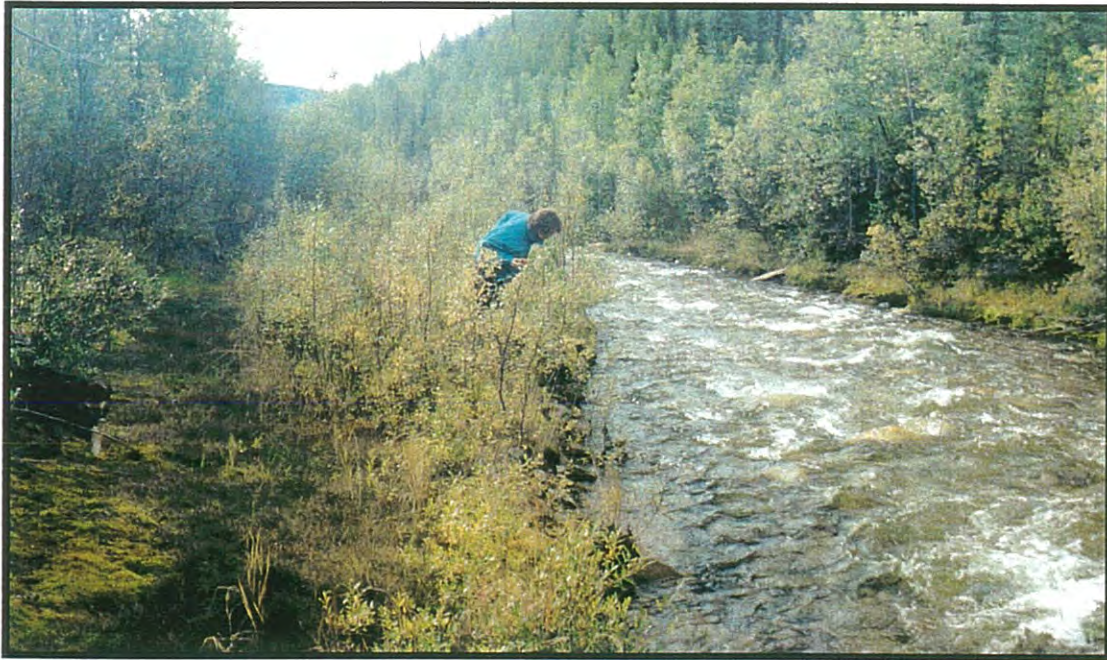
Plate 4.1.18: Elevated rates of sediment transport result in fine-textured material being deposited on the river bed.



August 22, 2002

MM 02 - 71 - 23

Plate 4.1.19: Riparian vegetation has developed along old sections of relocated channel. These straight sections still lack woody debris or complexity.



August 22, 2002

MM 02 - 71 - 24

Plate 4.1.20: Looking downstream on an old section of channelized stream, showing the narrow flood plain which has developed.



August 22, 2002

MM 02 - 71 - 14

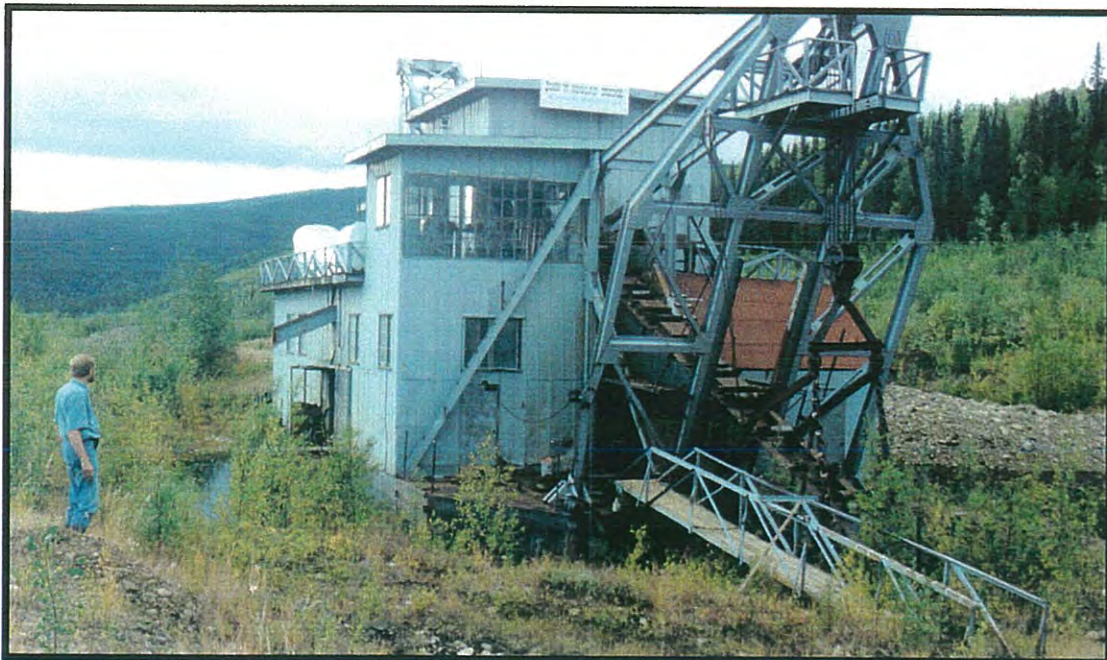
Plate 4.1.21: Wetland areas have developed between old dredge spoil piles on Lower Left Clear Creek.



August 22, 2002

MM 02 - 71 - 20

Plate 4.1.22: Off-channel ponds fed by local seepage have also developed between old dredge spoil piles on Lower Left Clear Creek.



August 22, 2002

MM 02 - 71 - 31

Plate 4.1.23: Queenstake Resources No. 1 was the last operational dredge in Yukon.



August 22, 2002

MM 02 - 71 - 27

Plate 4.1.24: Pre-1989 dredging on Upper Right Clear Creek has resulted in the formation of wetland areas between the valley walls and the spoil piles.



August 22, 2002

MM 02 - 72 - 13A

Plate 4.1.25: Dredge spoil piles are coarse textured and well drained making them difficult to revegetate.



August 22, 2002

MM 02 - 72 - 10A

Plate 4.1.26: Dredge spoil piles can be difficult to revegetate even along riparian areas.



August 22, 2002

MM 02 - 72 - 16A

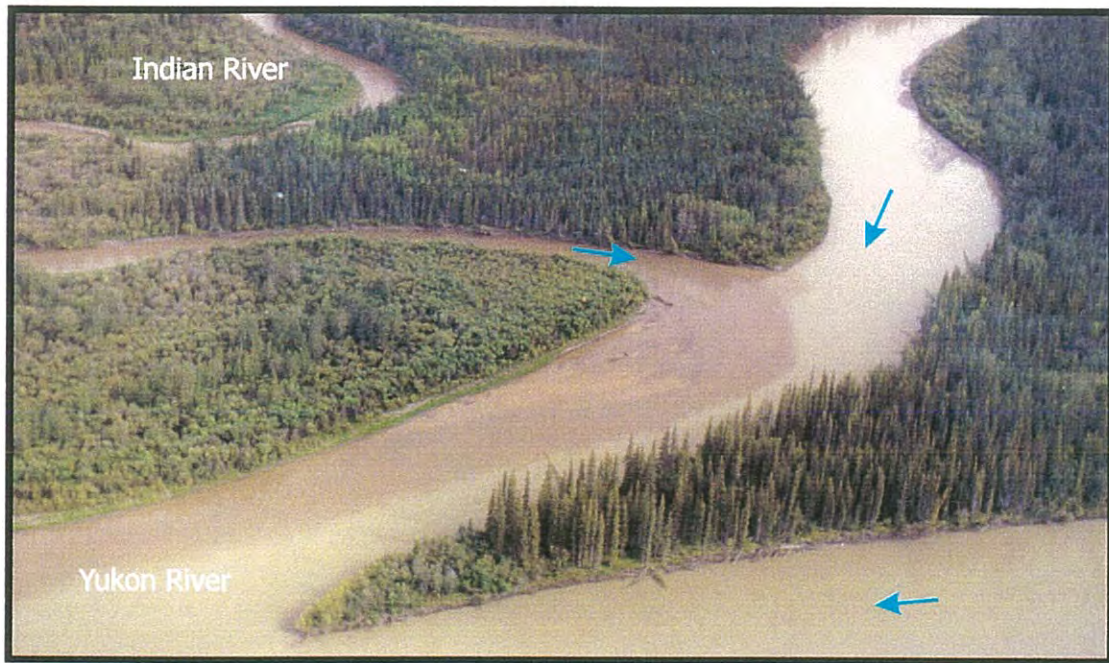
Plate 4.1.27: Stripping and mining activities in Upper Right Clear Creek have resulted in wide channels lacking in stream structure or riparian vegetation.



August 22, 2002

MM 02 - 72 - 14A

Plate 4.1.28: Lateral and vertical channel shifting along mined sections of streams will result in elevated rates of sediment production until the streams form a stable profile and riparian vegetation re-establishes.



August 19, 1992

MM 92 - 41 - 06

Plate 4.2.1: Looking upstream showing the comparatively high sediment loads on Indian River at the confluence with Yukon River.



August 19, 1992

MM 92 - 40 - 20

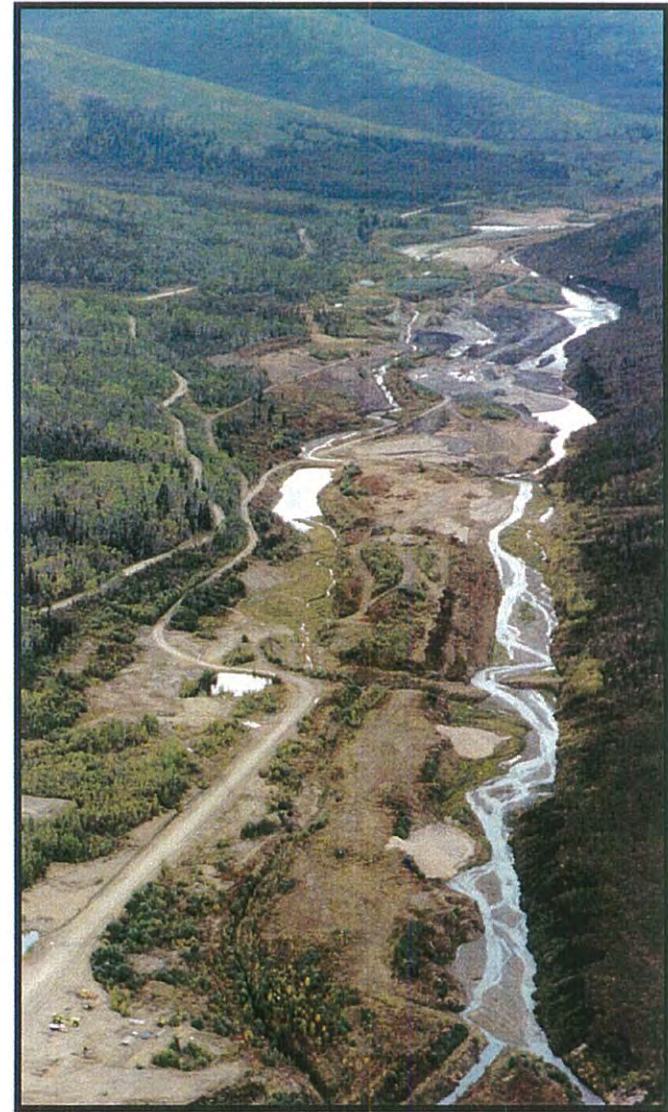
Plate 4.2.2: An example of recent sediment deposits along Lower Indian River.



August 24, 2002

MM 02 - 77 - 18

GPS Location 62



August 24, 2002

MM 02 - 77 - 21

GPS Location 64

Plate 4.2.3: Looking downstream in upper Dominion Creek, showing the effects of comparatively recent placer mining activity.



August 24, 2002

MM 02 - 77 - 22

Plate 4.2.4: Looking downstream to eroding placer spoil piles and undercut sections of valley walls. Dominion Creek at GPS location 65.



August 24, 2002

MM 02 - 77 - 26

Plate 4.2.5: Looking downstream to older placer excavations showing valley flat revegetation and the narrow width of the stream channel. Dominion Creek at GPS location 68.



August 24, 2002

MM 02 - 77 - 30

Plate 4.2.6: Looking upstream on Dominion Creek at GPS Location 70, showing the rectangular stream channel pattern (likely reflecting old excavation boundaries), local flood plain development and the re-establishment of riparian vegetation.



August 24, 2002

MM 02 - 77 - 31

Plate 4.2.7: Looking downstream on Dominion Creek near Hunter Creek [GPS Location 71], showing channel recovery in an area that was mined by dredge.



August 24, 2002

MM 02 - 77 - 34

Plate 4.2.8a: Looking downstream to recent excavator mining activity in or near an area that was formerly dredged downstream of Jensen Creek. Dominion Creek at GPS Location 74.



August 24, 2002

MM 02 - 78 - 01

Plate 4.2.8b: Looking downstream to an unmined section of Dominion Creek showing what the valley flat in the above area likely looked like prior to mining. Dominion Creek at GPS Location 74.



August 24, 2002

MM 02 - 78 - 01

Plate 4.2.9: Looking downstream on Gold Run Creek to the confluence with Dominion Creek.
GPS Location 76.



August 24, 2002

MM 02 - 78 - 04

Plate 4.2.10: Looking downstream on the Dominion Creek valley flat, showing the extensive series of ponds which have developed as a result of placer mining. GPS Location 74.



August 24, 2002

MM 02 - 78 - 07

Plate 4.2.11: Looking upstream on Lower Sulfur Creek showing valley bottom revegetation and the small confined residual channels at the base of both valley walls.



August 19, 1992

MM 92 - 42 - 26

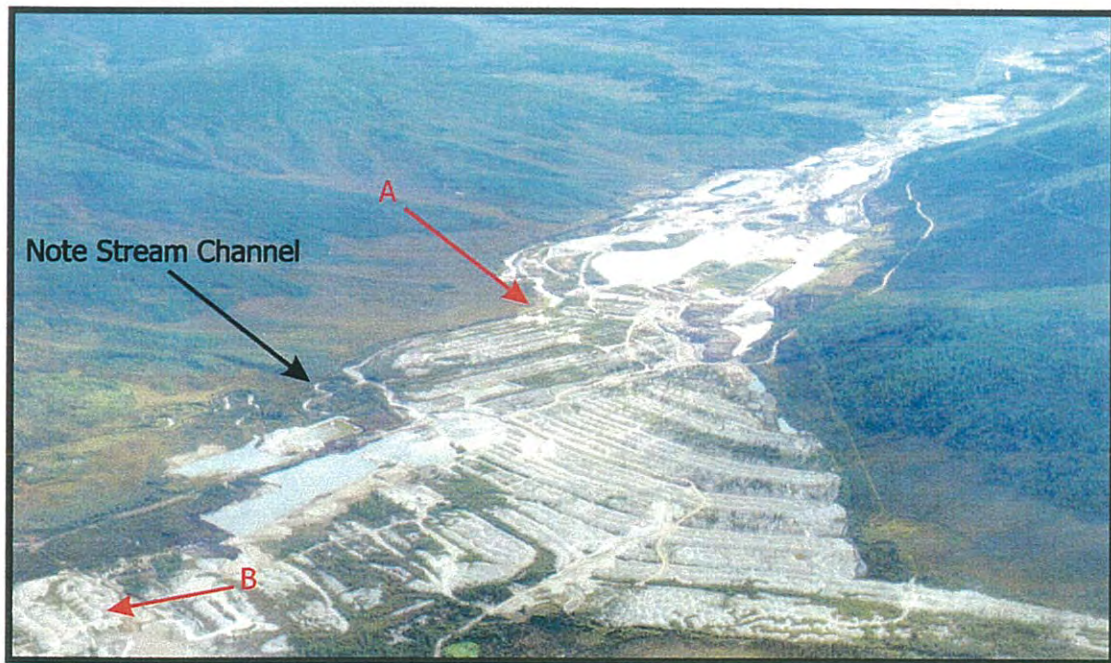
Plate 4.2.12: Looking downstream on the channelized section of Sulfur Creek above the confluence with Dominion Creek. GPS Location 80.



August 24, 2002

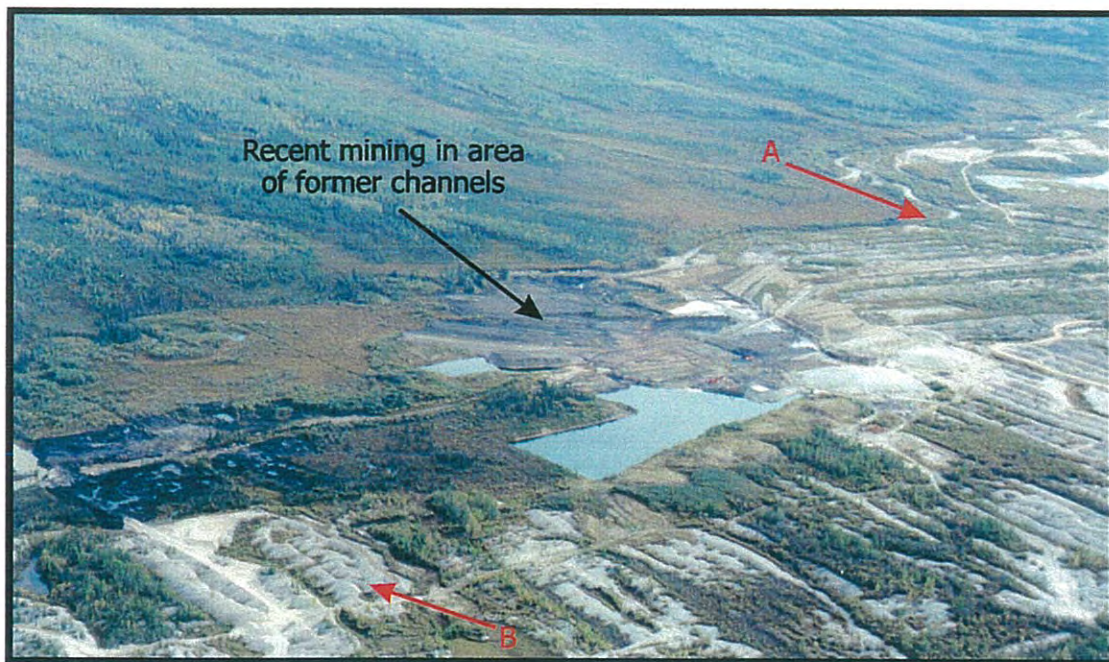
MM 02 - 78 - 09

Plate 4.2.13: Looking downstream on the Dominion Creek, showing vegetation and wetland development below the Sulfur Creek confluence. GPS Location 81.



August 19, 1992

MM 92 - 42 - 24



August 24, 2002

MM 02 - 78 - 05

Plate 4.2.14: Looking downstream on Dominion Creek showing the changes in valley flat conditions opposite Sulfur Creek in the period between 1992 and 2002. GPS Location 80.



August 24, 2002

MM 02 - 78 - 12

Plate 4.2.15: Looking downstream on Dominion Creek/Indian River at GPS Location 84, showing how the channel is flowing through a series of excavated pits. Note the formerly diverted channel along the base of the right bank valley wall.



August 24, 2002

MM 02 - 78 - 14

Plate 4.2.16: Looking upstream to a diverted section of channel at GPS Location 85.



August 24, 2002

MM 02 - 78 - 16

Plate 4.2.17: Looking downstream to an excavated section of channel at GPS Location 87.



August 24, 2002

MM 02 - 78 - 18

Plate 4.2.18: Looking downstream to an excavated section of channel at GPS Location 88.



August 24, 2002

MM 02 - 78 - 19

Plate 4.2.19: Looking downstream at GPS Location 89 illustrating recent stripping activities upstream of an undisturbed section of Indian River.



August 24, 2002

MM 02 - 78 - 20

Plate 4.2.20: An example of an unmined section of channel located at GPS Location 90.



August 24, 2002

MM 02 - 78 - 21

Plate 4.2.21: Looking downstream on an unmined section of channel at GPS Location 91.



August 24, 2002

MM 02 - 78 - 25

Plate 4.2.22: Looking upstream from GPS Location 94 comparing mined and unmined sections of channel.



August 24, 2002

MM 02 - 78 - 30

Plate 4.2.23: Looking downstream from GPS Location 98 showing the section of unmined channel which occurs between GPS Locations 92 and 100.



August 24, 2002

MM 02 - 79 - 14

Plate 4.2.24: Looking upstream on Indian River from the Quartz Creek confluence. GPS Location 116.



August 24, 2002

MM 02 - 80 - 22A

Plate 4.2.25: Looking downstream showing the revegetating spoil piles in lower Quartz Creek. GPS Location 117.



August 23, 2002

MM 02 - 73 - 10

Plate 4.2.26: Low-lying moist areas between dredge spoil piles in Lower Quartz Creek support well established deciduous vegetation.



August 24, 2002

MM 02 - 80 - 26A

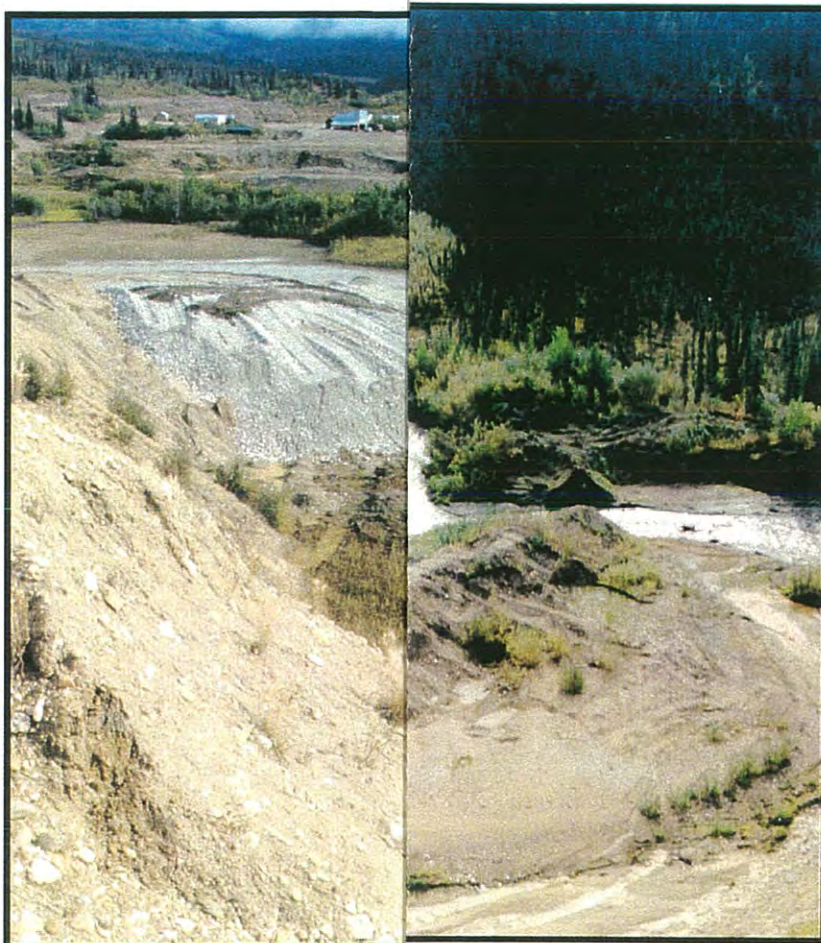
Plate 4.2.27: Looking upstream on Quartz Creek from GPS Location 118, showing the extensive valley bottom clearing and mining.



August 23, 2002

MM 02 - 73 - 09

Plate 4.2.28: Looking downstream along right margin mining of white gravels near GPS Location 118.



August 23, 2002

MM 02 - 72 - 30A/35A

Plate 4.2.29: Looking upstream on Quartz River erosion in the diverted and laterally constrained channel is eroding



August 23, 2002

MM 02 - 74 - 13A

Plate 4.2.30: The toe of many overburden stock piles, such as that illustrated on Plate 4.2.29 is eroding and subject to thermokarst.



August 23, 2002

MM 02 - 73 - 07

Plate 4.2.31: Looking upstream over a revegetated settling pond on Lower Quartz Creek showing the development of gullies by erosion and thermokarst on burned sections of valley walls.



August 18, 1992

MM 92 - 40 - 00

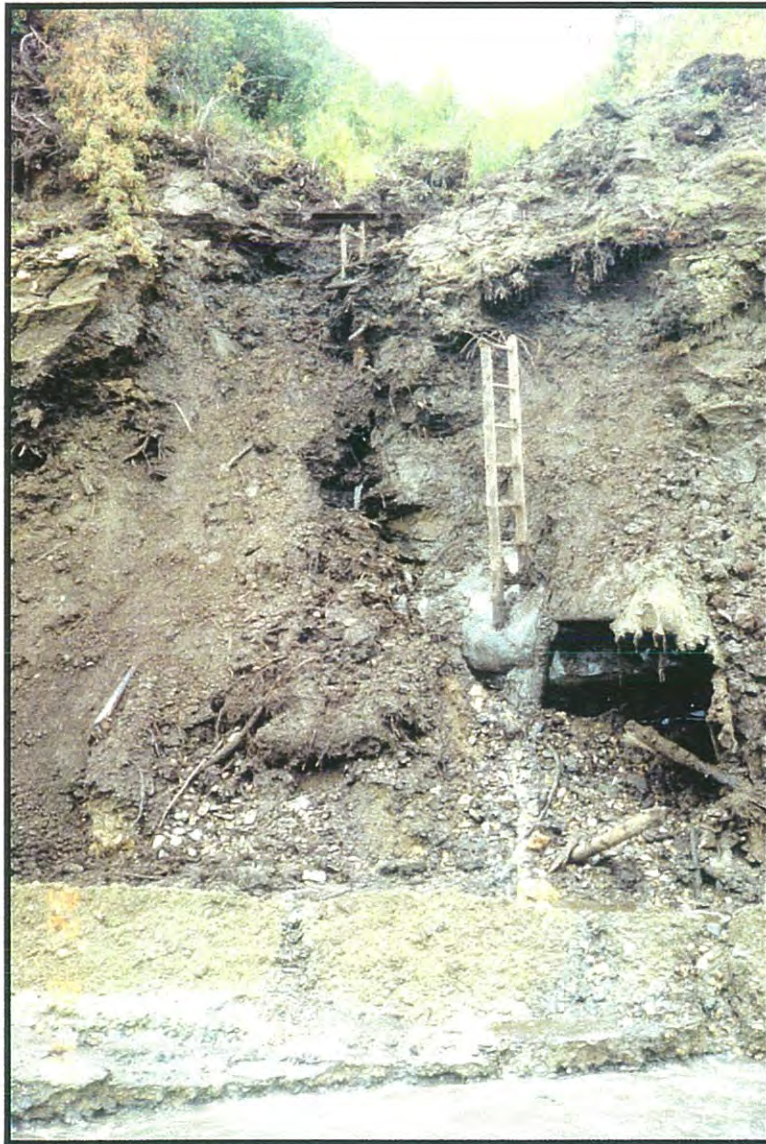
Plate 4.2.32: Looking upstream to a left bank tributary to Quartz Creek, showing hydraulic mining in 1992. [Near GPS Location 121.]



August 24, 2002

MM 02 - 74 - 26A

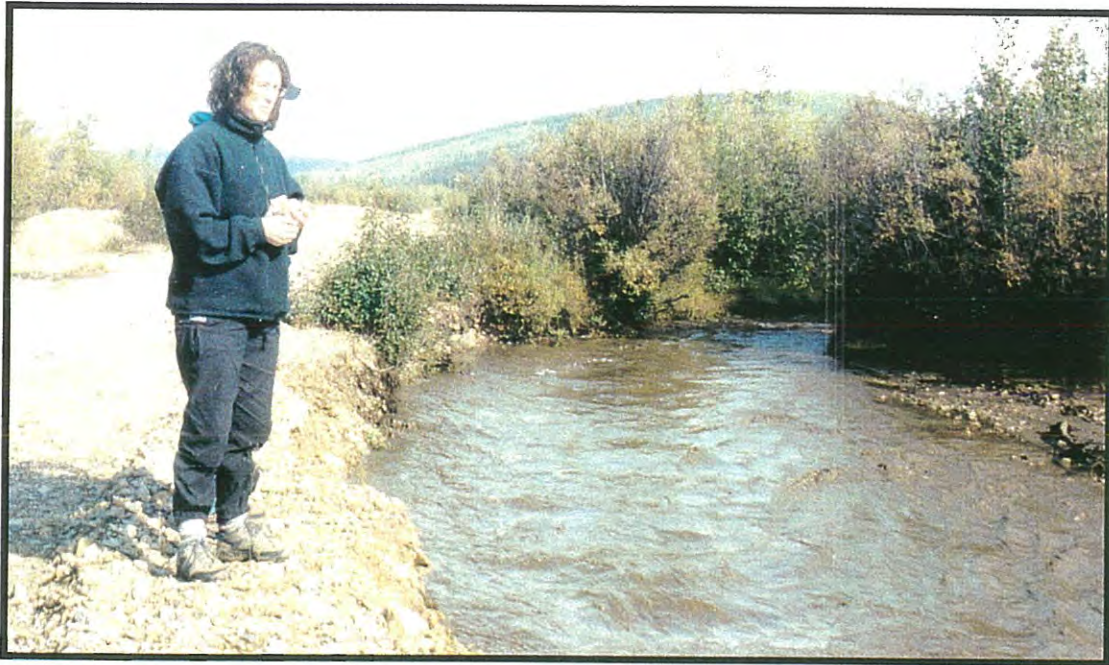
Plate 4.2.33: Hydraulic mining of black muck can expose ice rich materials which are subject to thermokarst and thermal erosion.



August 18, 1992

MM 92 - 40 - 01

Plate 4.2.34: Hydraulic sluicing has removed substantial quantities of overburden. This photograph shows old access ladders exposed following hydraulic sluicing on Blanch Creek.



August 23, 2002

MM 02 - 73 - 13

Plate 4.2.35: Ground sluicing is resulting in very high suspended sediment concentrations in Quartz Creek. These flows are directed into a large settling pond on the Indian River Valley Flat.



August 23, 2002

MM 02 - 73 - 12

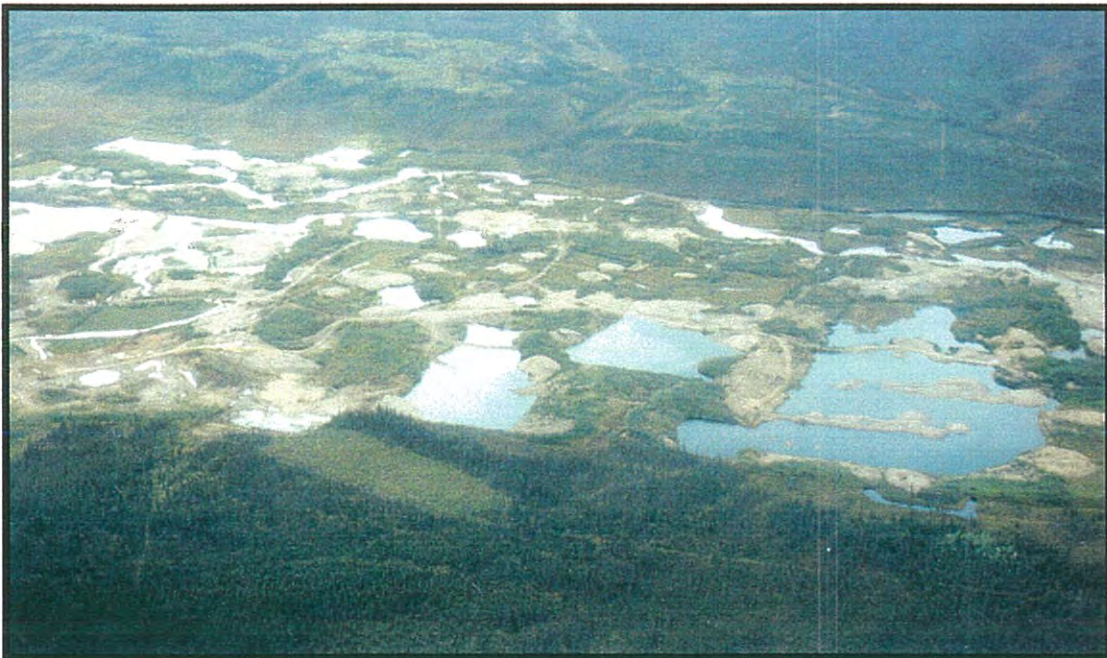
Plate 4.2.36: Road maintenance issues are another local source of sediment.



August 24, 2002

MM 02 - 80 - 17A

Plate 4.2.37: Looking south showing sediment deposits in the newly formed mainstem of Indian River downstream of Quartz Creek. [GPS Location 116.]



August 24, 2002

MM 02 - 80 - 20A

Plate 4.2.38: Looking south showing the extensive network of pits and former settling ponds on Indian River downstream of Quartz Creek. [GPS Location 115.]



August 20, 1992

MM 92 - 47 - 18

Plate 4.2.39: A 1992 photograph showing an active placer operation on Indian River immediately downstream of Quartz Creek.



August 23, 2002

MM 02 - 73 - 23

Plate 4.2.40: Many of the formerly mined pits are developing riparian vegetation and were observed to contain both waterfowl and, in one location, two moose.



August 20, 1992

MM 92 - 46 - 07

Plate 4.2.41: Looking upstream on Indian River in 1992, showing a settling pond separated from the river by a gravel berm.



August 20, 1992

MM 92 - 46 - 24

Plate 4.2.42: Looking upstream on Indian River in 1992, showing an unprotected access road and a mid-channel overburden pile.



August 24, 2002

MM 02 - 79 - 21

Plate 4.2.43: Looking downstream to a mined section of valley flat at GPS Location 12 BRD6.



August 24, 2002

MM 02 - 79 - 24

Plate 4.2.44: Looking downstream to a mined section of valley flat at GPS Location 107.



August 24, 2002

MM 02 - 79 - 32

Plate 4.2.45: Looking upstream to a mined section of valley flat at GPS Location 108.



August 24, 2002

MM 02 - 80 - 15A

Plate 4.2.46: Looking upstream to a linear spoil pile located in what used to be the mainstem channel. [GPS Location 115.]



August 23, 2002

MM 02 - 73 - 34

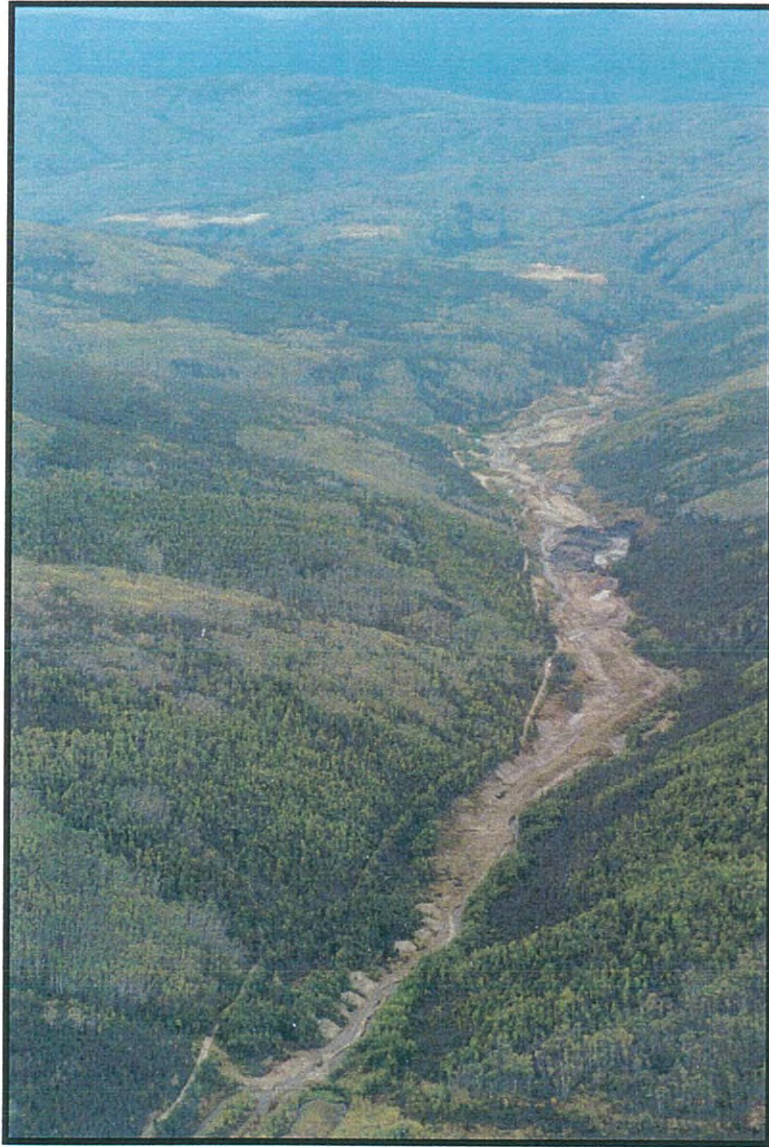
Plate 4.2.47: Looking downstream along a revegetated section of side-cast road fill and a cut-off section of channel.



August 23, 2002

MM 02 - 73 - 29

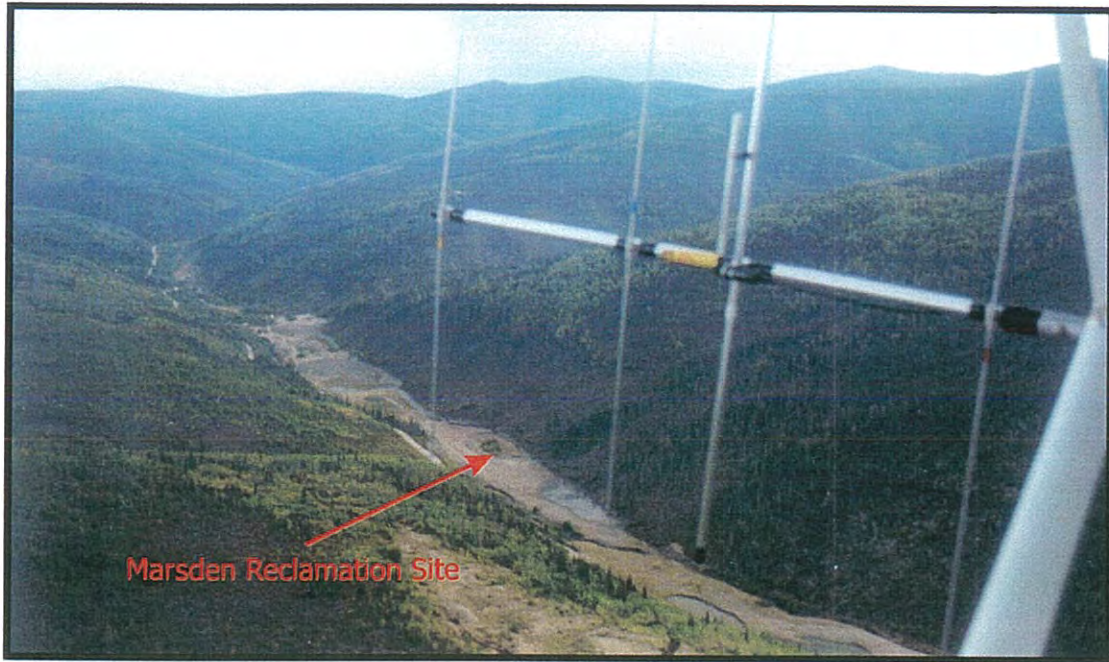
Plate 4.2.48: Some former placer mine pits are now connected to the mainstem channel and could be used as fish habitat.



August 24, 2002

MM 02 - 80 - 35A

Plate 4.3.1: Looking downstream on Gold Bottom Creek from GPS Location 123.



August 24, 2002

MM 02 - 77 - 13

Plate 4.3.2: Looking upstream to the headwaters of Hunker Creek showing the nearly continuous mining activity. [GPS Location 57.]



August 24, 2002

MM 02 - 77 - 15

Plate 4.3.3: An example of retrogressive slope failures on Upper Hunker Creek. [GPS Location 59.]



August 24, 2002

MM 02 - 77 - 12

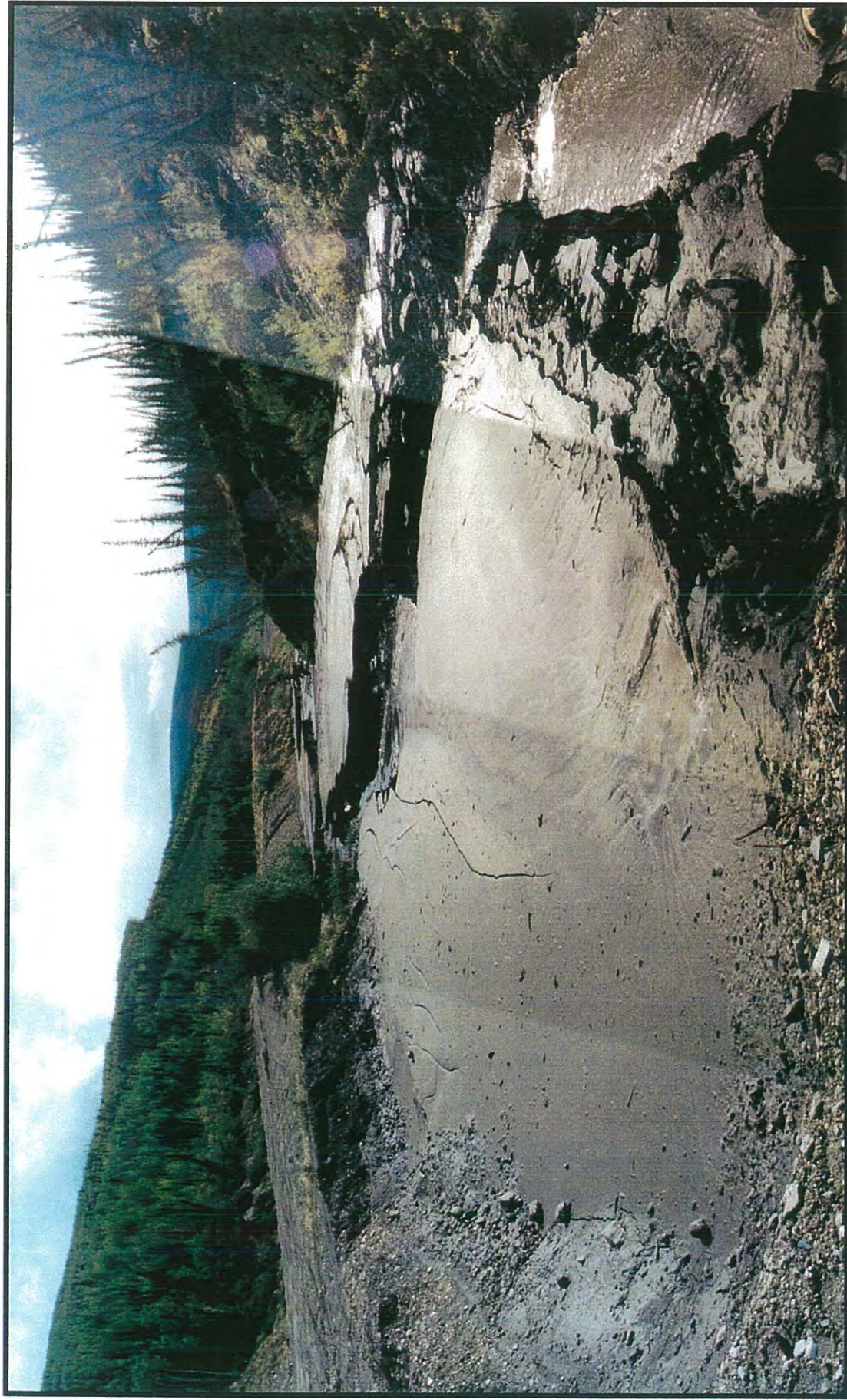
Plate 4.3.4: Bank erosion was commonly observed on both newly reclaimed areas and on older over-steepened sites with second growth vegetation. [GPS Location 56.]



August 24, 2002

MM 02 - 76 - 04

Plate 4.3.5: Looking downstream showing the failing left bank valley wall at the Marsden Reclamation Site.



August 24, 2002

MM 02 - 76 - 06/09

Plate 4.3.6: Looking upstream showing how failing sections of the left bank valley wall have infilled the settling pond.



August 24, 2002

MM 02 - 76 - 13

Plate 4.3.7: Looking upstream to the failed settling pond outlet.



August 24, 2002

MM 02 - 76 - 12

Plate 4.3.8: Looking downstream showing the eroded culvert and the sediment being delivered to the wall based channel.



August 24, 2002

Looking downstream to the toe dam

MM 02 - 76 - 22



August 24, 2002

Looking upstream over the toe dam

MM 02 - 76 - 27

Plate 4.3.9: Photographs of the second settling pond on the Marsden Site which appears likely to suffer from the same fate as the upper structure.



August 24, 2002

MM 02 - 76 - 33

Plate 4.3.10: River bank bio-engineering using planted whips was generally unsuccessful on the Marsden property.



August 24, 2002

MM 02 - 77 - 09

Plate 4.3.11: Looking upstream on Hunker Creek showing the valley flat revegetation in the vicinity of GOS Location 35.



August 24, 2002

MM 02 - 77 - 07

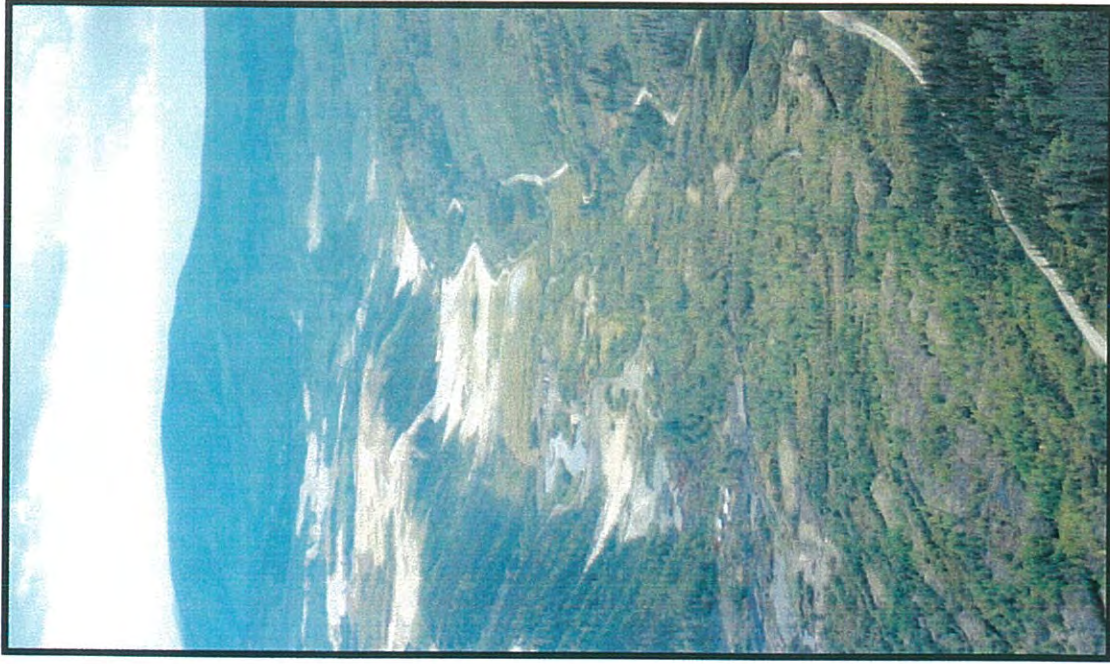
Plate 4.3.12: Looking upstream showing the channel downcutting which is occurring above the active mining area on this 'pup'. [GPS Location 52.]



August 24, 2002

MM 02 - 77 - 14

Plate 4.3.13: Looking upstream on a mined tributary showing the fan which has formed at the Confluence with Hunker Creek. [GPS Location 58.]



August 24, 2002

MM 02 - 81 - 02

GPS Location 125

Plate 4.3.14: Revegetated old dredge spoil piles.



August 24, 2002

MM 02 - 77 - 03

GPS Location 48

Plate 4.3.15: Extensive mining on a tributary to Hunker Creek.



August 24, 2002

MM 02 - 81 - 06

Plate 4.3.16: Looking downstream on Lower Hunker Creek showing upslope mining activity and large settling ponds in the Hunker Creek valley bottom. [GPS Location 125.]



August 24, 2002

MM 02 - 75 - 09A

Plate 4.3.17: Looking up valley to the ponds constructed by D. Busat below the Hunker Creek Access Road.



August 24, 2002

MM 02 - 75 - 23A

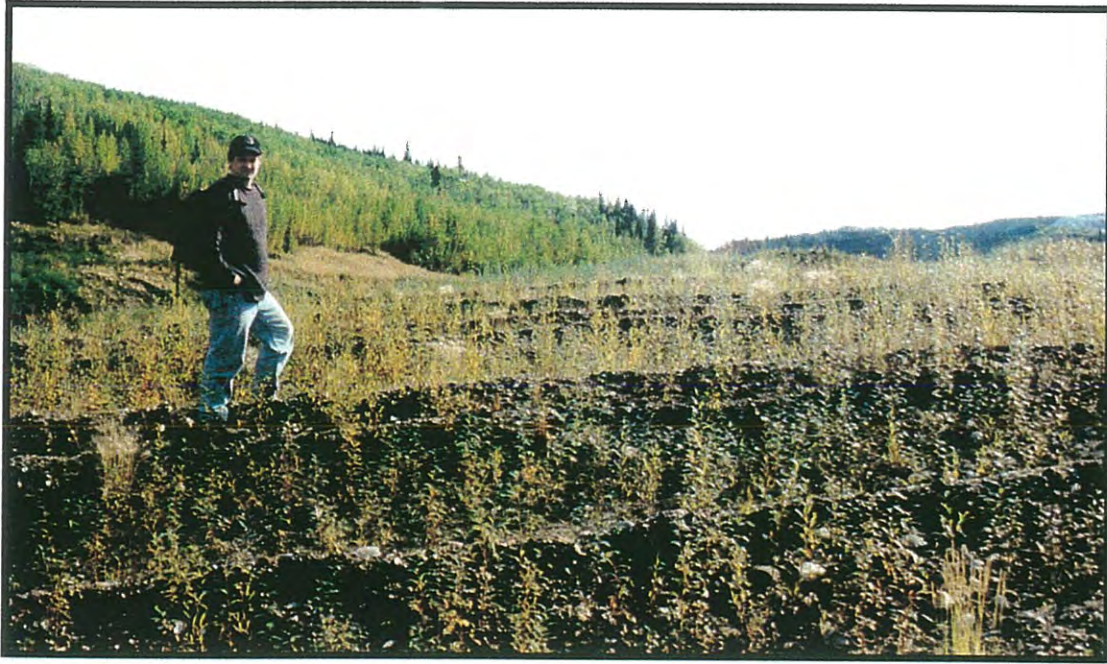
Plate 4.3.18: Looking up valley to the ponds constructed by D. Busat upstream of the Hunker Creek Access Road.



August 24, 2002

MM 02 - 75 - 13A

Plate 4.3.19: Looking downstream on a luxuriantly vegetated older wetland located immediately downstream of D. Busat's reclamation project.



August 24, 2002

MM 02 - 75 - 33

Plate 4.3.20: Annual and perennial vegetation is establishing on many stable re-contoured surfaces.



August 24, 2002

MM 02 - 74 - 31A

Plate 4.3.21: Revegetation is less successful on more recently contoured, well drained or unstable sites.



August 24, 2002

MM 02 - 75 - 17A

Plate 4.3.22: Uncontrolled surface flow on unvegetated sites is locally resulting in the formation of sizeable gullies.



August 24, 2002

MM 02 - 75 - 32A

Plate 4.3.23: Gullies are also forming on steep fine-textured cut slopes.



August 24, 2002

MM 02 - 75 - 24A

Plate 4.3.24: Lower gradients and a toe berm to prevent water erosion result in more stable cut slopes.



August 24, 2002

MM 02 - 74 - 33A

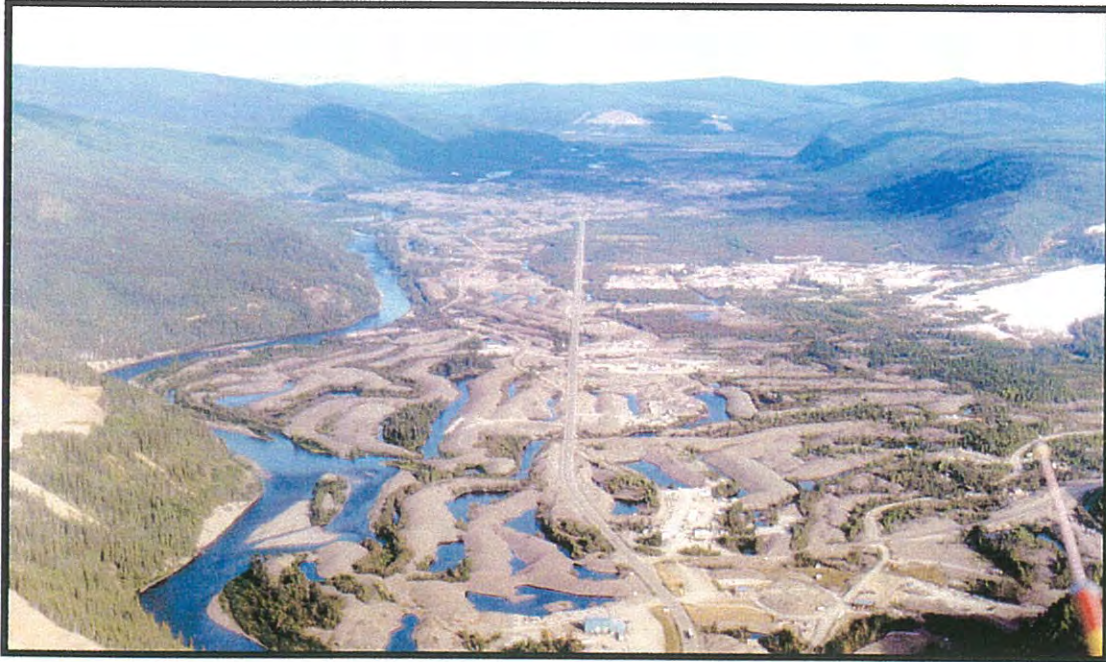
Plate 4.3.25: This access road was constructed in the winter of 2001/2002 and may be a barrier to fish movement.



August 24, 2002

MM 02 - 76 - 01

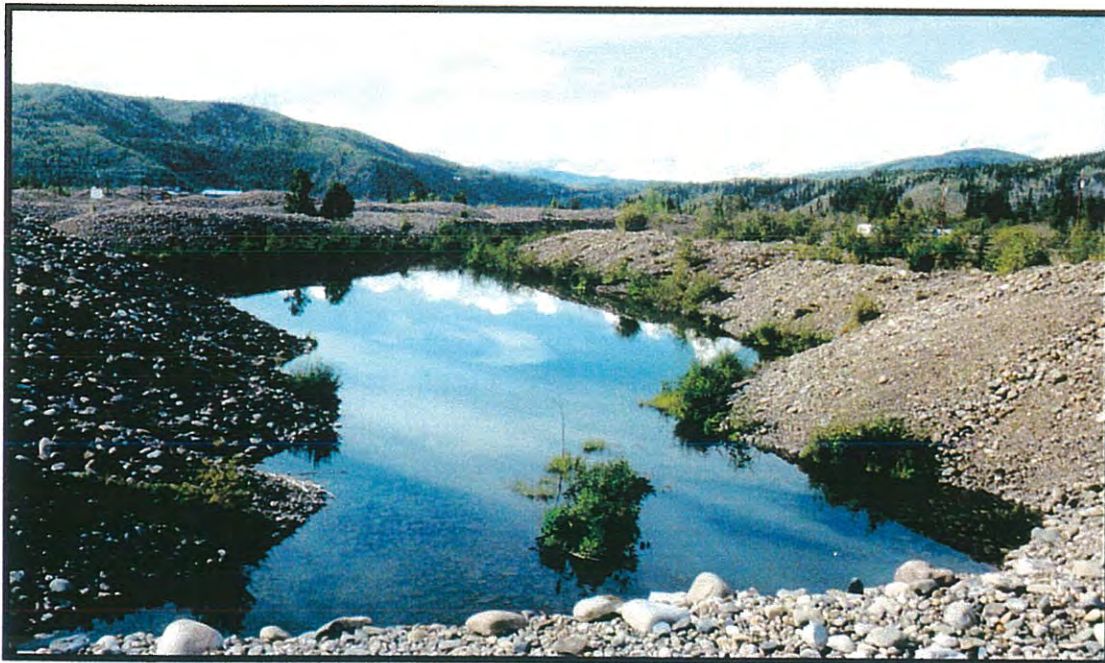
Plate 4.3.26: The inlet to this culvert under the Hunker Creek Mainline Road is also likely to be a fisheries barrier.



August 23, 1992

MM 92 - 54 - 05

Plate 4.4.1: Looking upstream over the Lower Klondike River, showing conditions in August 1992.



August 24, 2002

MM 02 - 76 - 36

Plate 4.4.2: Low-lying areas between dredge spoils can form small isolated wetlands.



August 24, 2002

MM 02 - 76 - 34

Plate 4.4.3: Some low-lying areas between spoil piles form channels which are connected to Klondike River.



August 24, 2002

MM 02 - 76 - 35

Plate 4.4.4: Undisturbed spoil piles tend to be poorly vegetated.



August 24, 2002

MM 02 - 76 - 37

Plate 4.4.5: Levelled spoil piles appear to be much easier to revegetate.