DFO-3.2.4

Appendix DFO-3.2.4-1 Doris Creek and Little Roberts Outflow Fisheries Assessment – Hydraulic Modelling Results Memorandum

Memorandum

Date: January 14, 2015

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Subject: **Doris Creek and Little Roberts Outflow Fisheries Assessment – Hydraulic Modelling Results**

This memorandum was prepared at the request of TMAC Resources Inc. (TMAC) to present hydraulic modelling results quantifying the effects of stream flow reductions in Doris Creek (DC) and Little Roberts Outflow (LRO). These hydraulic models were developed to support the application for amendment (the Amendment Application) to the Project Certificate (Nunavut Impact Review Board No. 003) and the Type A Water Licence (Nunavut Water Board No. 2AM-DOH1323). The fisheries assessments of DC and LRO have drawn from these hydraulic modelling results and inferences are presented in the Doris Lake, Doris Creek, and Little Roberts Outflow Fisheries Assessment memorandum (ERM 2015a).

1. INTRODUCTION

1.1 Background

Groundwater modelling completed by SRK Consultants predicted that infiltration into the underground workings while mining in a talik zone would reduce water levels in Doris Lake. The Effects Assessment (document P4-1) of the Amendment Application indicated that Doris Lake water levels may be reduced by up to 23 cm as a result of infiltration into the underground workings. At the maximum predicted lake drawdown level, this is expected to result in approximately a 13% reduction in average monthly stream flow in DC, and a 6% reduction in LRO (ERM 2015b). Reductions in stream flow will mimic the natural hydrograph and vary throughout the open water season.

Two hydraulic models were developed to support the 2015 Doris Creek and Little Roberts Outflow Fisheries Assessment. These models were developed to assess: (1) potential losses to fish habitat as a result of stream flow reductions; and (2) potential impacts to flow connectivity as a result of stream flow reductions.

1.2 Stream Characteristics

Doris Creek is the outflow from Doris Lake and forms one of two tributaries to Little Roberts Lake (Figure 1.2-1). Little Roberts Lake is supplied by two similarly sized tributaries; DC and Roberts Creek (RC). LRO discharges out of Little Roberts Lake and empties directly into the ocean (Roberts Bay).

1.2.1 Doris Creek

Doris Creek has a watershed area of 99.6 km^2, is 4.1 km long, has three distinct reaches, no tributaries, and a mean annual discharge of 0.34 m^3/s (ERM 2015c; Table 1.2-1; Figure 1.2-1; Plate 1.2-1). Upper DC is immediately downstream of Doris Lake (Plate 1.2-1), and is separated from middle DC by a 3 m waterfall, impassable to fish. Middle DC is the reach between the waterfall and a substantial riffle / boulder garden feature that may act as a potential impediment to fish passage at low flows (Plate 1.2-1). Lower DC is the reach between the riffle / boulder garden feature and Little Roberts Lake (Figure 1.2-1; Plate 1.2-1).

1.2.2 Little Roberts Outflow

Little Roberts Outflow has a watershed area of 197.7 km^2, is 1.4 km long, has no tributaries, and has a mean annual discharge of 0.70 m^3/s (ERM 2015c; Table 1.2-1; Figure 1.2-1; Plate 1.2-1).

Table 1.2-1. Stream Reaches in Doris Creek and Little Roberts Outflow

Reach	Length (m)	Gradient[1] (%)	Max Depth (m)	Roughness[2]
Upper Doris	466	0.29	0.710	0.055
Middle Doris	306	1.80	0.915	0.169[3]
Lower Doris	3,670	0.19	1.366	0.056
Little Roberts	1,395	1.90	0.802	0.057

Notes:

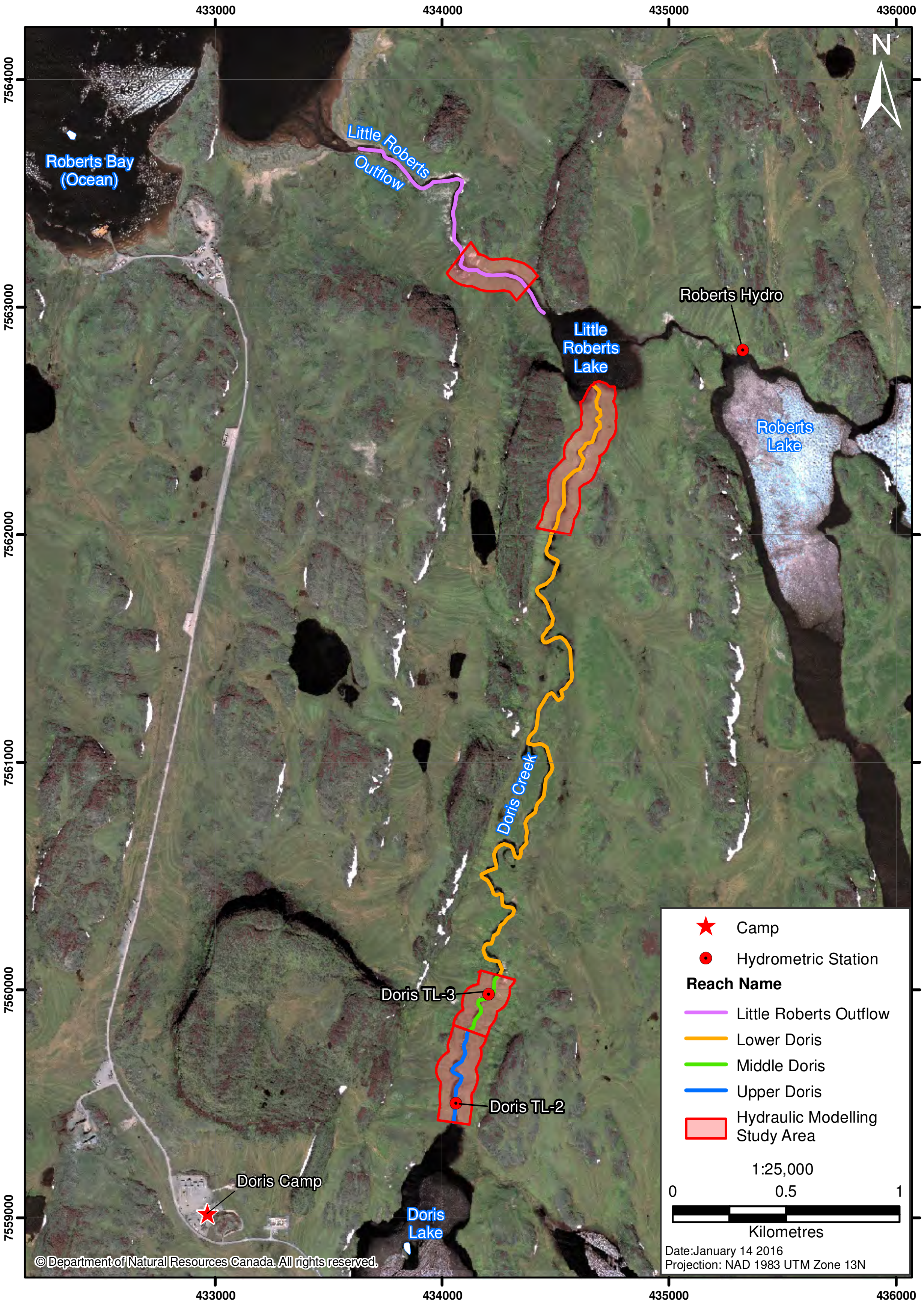
1 Reach average and does not reflect elevation loss from water fall (i.e. water fall is between upper and middle reaches)
2 Roughness is a surrogate for Manning's n which is a dimensionless value for channel roughness used in hydraulic modelling
3 Values are based on reach average. High averaged Manning's value reported represents high values in riffle / boulder garden and regular values for remainder of reach

2. OBJECTIVES

The overall objective of the 2015 Doris Lake, Doris Creek, and Little Roberts Outflow Fisheries Assessment was to estimate the potential loss of the fisheries productive capacity of Doris Lake, DC, and LRO under a reduced flow level scenario. This memorandum was developed to inform the fisheries assessment by addressing changes in stream flow within DC and LRO, the objective of which was to develop two hydraulic models that could assist in estimating potential losses to fish habitat as a result of stream flow reductions, and potential impacts to flow connectivity also as a result of stream flow reductions.

Figure 1.2-1

Doris Creek Fisheries Assessment: Hydraulic Modelling Study Areas



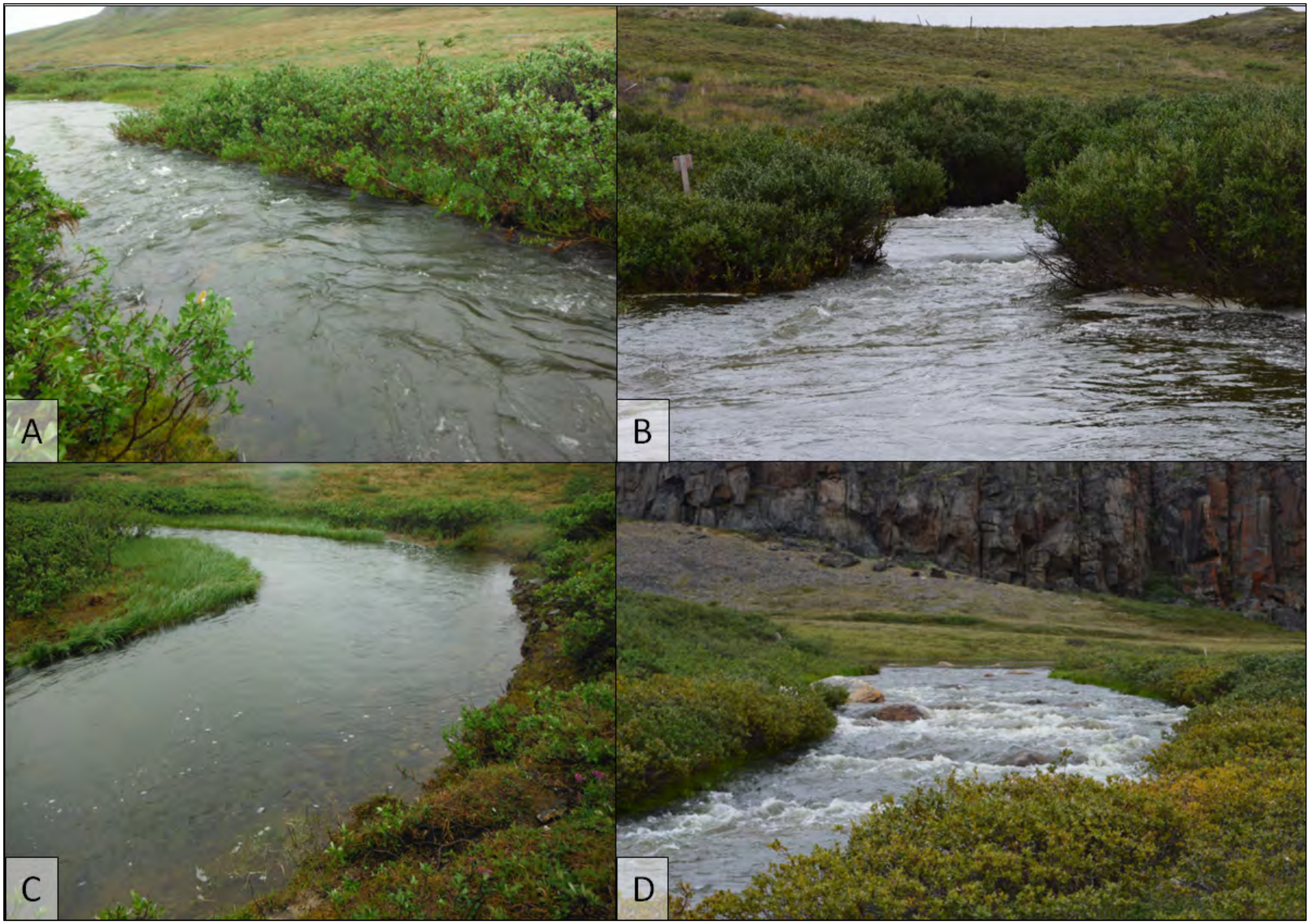


Plate 1.2-1. A) Upper Doris Creek, view looking downstream (July 18, 2015). B) Middle Doris Creek, view looking upstream (July 20, 2015). C) Lower Doris Creek, view looking upstream (July 17, 2015). D) Little Roberts Outflow, view looking upstream at riffle / boulder garden (July 19, 2015).

Two primary tasks were undertaken to support this objective:

1. Survey hydraulic cross sections in fisheries sensitive reaches in DC and LRO; and
2. Develop hydraulic models for DC and LRO to estimate potential losses to fish habitat as a result of flow reductions, and to estimate potential impacts to flow connectivity also as a result of flow reductions (i.e., 13% and 6% reduction in average monthly flow respectively).

3. HYDRAULIC MODELS

Two Hydraulic Engineering Center, River Analysis System (HEC-RAS) hydraulic models were developed to estimate water levels in DC and LRO. The first model was developed for study areas in DC, which connects Doris Lake to Little Roberts Lake; the second model was developed for the study area in LRO, which connects Little Roberts Lake to Roberts Bay (Figures 1.2-1 and 3.1-1).

3.1 Model Approach

The structures of hydraulic models were designed such that DC and LRO were autonomous models that shared a common datum (Differential Global Positioning System) with elevations based on Hope Bay site control, and were both able to use hydrology monitoring discharge (Q) data as model inputs.

The input to the DC model was discharge from hydrometric station TL-2 (Figure 1.2-1; Figure 3.1-1). The input for the LRO model was the combined discharge from hydrometric stations TL-2 and Roberts Hydro (Figure 1.2-1; Figure 3.1-1).

Daily baseline data from TL-2 (2004-2014) were used to evaluate Doris Lake water levels throughout the open water season. Daily baseline data from 2004-2014 were then averaged into a monthly dataset for the baseline model input. From this, the anticipated flow reduction scenarios were applied to this dataset across the open water season for all years from 2004-2014. Averaged monthly flow reductions were then used as model inputs for project affected flows in DC (13%) and LRO (6%).

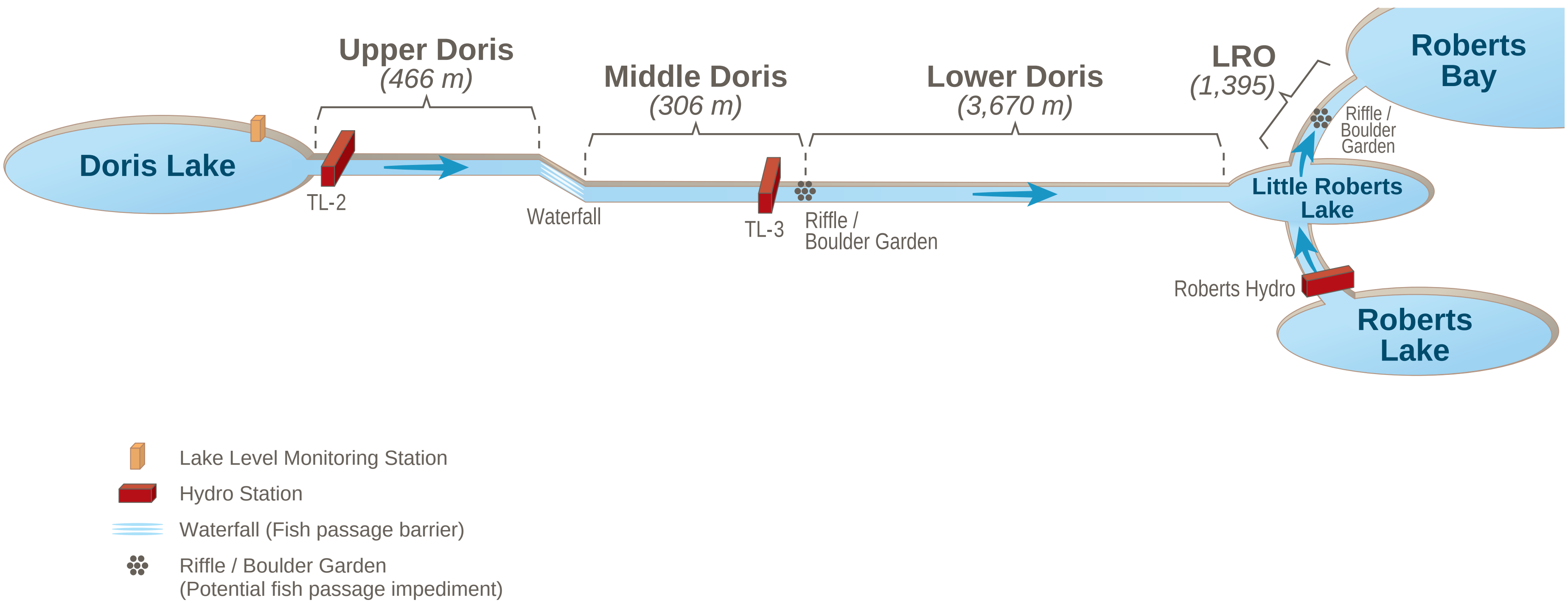
Project affected flows are presented in the memorandum as changes in flow, channel depth and wetted width, and represent changes from averaged baseline values (2004-2014) to averaged project affected flows using the 2004-2014 dataset described above.

3.2 Model Considerations

The development of one dimensional models, such as the HEC RAS model used here, follow four basic assumptions: (1) flow is gradually varied; (2) flow is one dimensional (i.e. flow is parallel streamlines); (3) slope is generally less than 10%; and (4) subsurface flow is negligible.

Figure 3.1-1
Hydraulic Model Structure

ERM



Flow conditions in DC and LRO did not conform to all of the assumptions listed above. This is not unexpected in natural systems as: flow can vary rapidly when it transitions from a shallow run to a deep pool; and flow is rarely one dimensional in that it has horizontal and vertical components not accounted for in one dimensional modelling. Horizontal and vertical flow vectors are common in wide, shallow streams with high roughness values, such as the riffle / boulder garden features found in DC and LRO. As a result, high Manning's roughness values were applied, and ineffective flow areas were required, to calibrate the model throughout the riffle / boulder garden features. Although the values used were well within those published by Yochum and Bledsoe (2010), and are not expected to bias model outcomes, this is a limitation of one dimensional modelling, and also a limitation for the results presented in this memorandum. That said, model validation results presented for DC (Section 3.3.2) highlight the success of this approach and demonstrate that these non-conformities did not negatively impact the model results.

Lastly, mean monthly flows, averaged from 2004 to 2014, were used as model inputs. Although the resolution of daily flows is lost with monthly data, mean monthly flows were used for the following reasons: (i) they are computationally more efficient; (ii) DC and LRO are lake-headed systems which moderates daily peaks; and (iii) impacted flows were very similar to baseline flows and therefore daily resolution was deemed superfluous.

3.2.1 Flow Connectivity

Stream connectivity can be considered as the maintenance of surface flow throughout the channel. Stream connectivity can be interrupted when water levels drop and surface flow transitions to sub-surface flow. Generally speaking, interruptions in flow connectivity commonly occur at the downstream end of pools, as flow drops below the pool crest, resurfacing on the downstream side at the upstream end of riffles (Figure 3.2-1).

There are two riffles / boulder garden features within the study area that each present potential barriers to fish passage during low flow conditions. These features are located in DC, separating the lower and middle reaches, and in LRO separating Roberts Bay (ocean) from Little Roberts Lake (Figure 1.2-1; Figure 3.1-1).

To investigate flow connectivity in DC and LRO, four to five stream cross sections were surveyed in each stream, specifically within each of the two riffle / boulder garden feature. This provided four to five surveyed water surface elevations throughout these features to specifically calibrate the hydraulic models against.

It is worth noting that a one dimensional model such as HEC-RAS does not take into account sub-surface flow. To overcome this limitation, four to five cross sections were surveyed throughout each riffle / boulder garden feature, as noted above, so as to survey the actual water levels throughout the features, thereby demonstrating the presence of surface flow at the calibration flow. Although this does not completely resolve the limitations of HEC-RAS, it does provide robust calibration points in the model, where known limitations exist.

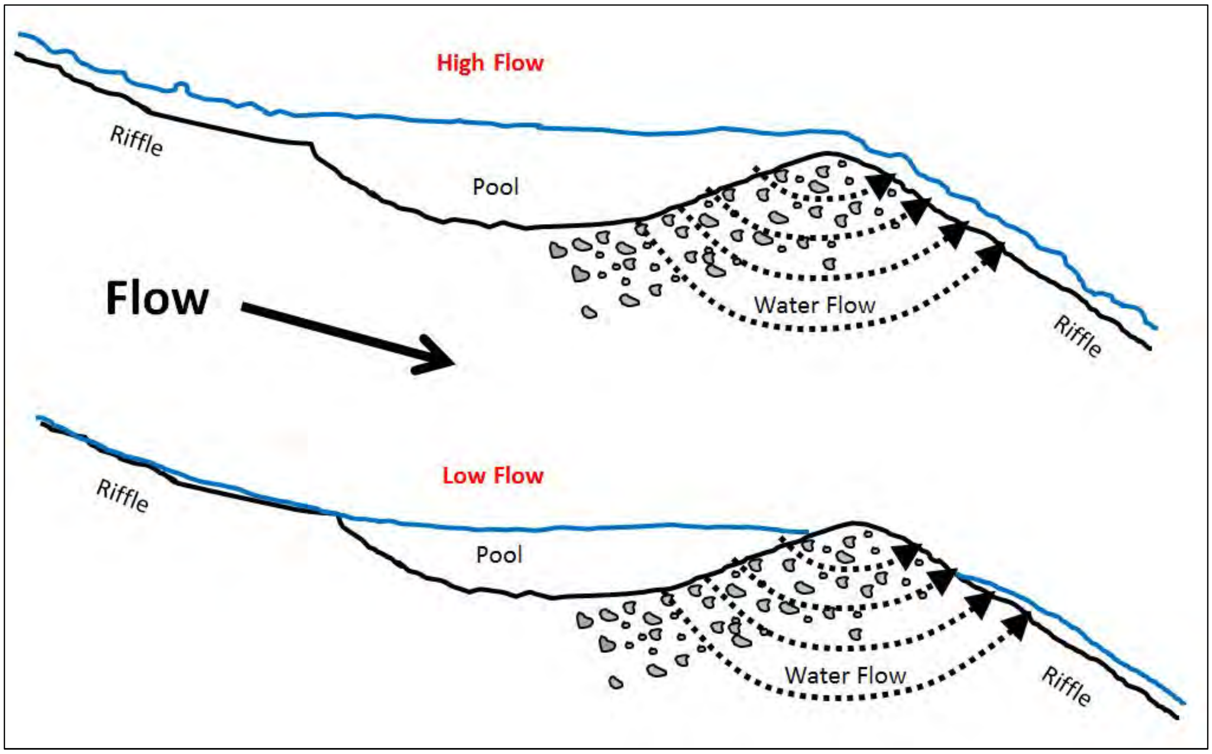


Figure 3.2-1. Loss of Flow Connectivity, as modified from Keller and Kondolf (1990).

3.2.2 *Roughness*

A roughness parameter (Mannings 'n') is used in hydraulic modelling to balance the energy grade and water surface elevation. Channel and flow irregularities, obstructions and vegetation increase the roughness of a channel. The riffle / boulder garden features found in both DC and LRO contain channel and flow irregularities, vegetation and flow obstructions (large boulders) within them resulting in increased roughness. Collectively, these riffle / boulder garden features exceed standard roughness values reported by both Chow (1959) and Cowan (1956), which are commonly used as guidelines when developing hydraulic models.

In circumstances where the roughness of a stream exceed the standard values reported by Chow (1959) and Cowan (1956), it is possible to increase the Manning's n value, when justified. For example, Yochum and Bledsoe (2010) conducted a detailed investigation into roughness coefficients used for small, rough streams, such as the riffle / boulder garden features in DC and LRO. During their investigation they reported using Manning's n values as high as 0.52 without compromising the HEC-RAS model results. Drawing from the work of Yochum and Bledsoe (2010), roughness values (Manning's 'n') ranging from 0.10 to 0.325 were applied throughout the riffle / boulder garden features in the Hope Bay hydraulic models. Using increased roughness values throughout these features provided a successful calibration of water levels through the riffle / boulder garden features in DC and LRO. The success of the model validation results suggests the roughness (Manning's 'n') values applied (0.10 to 0.325) were appropriate.

3.3 Doris Creek Hydraulic Model Results

Anticipated potential flow reductions in DC (13%), resulting from lake drawdown, has the potential to impact DC in two ways: direct loss of fish habitat from reductions in water levels; and loss of flow connectivity from pools to riffles. The DC hydraulic model was developed to inform both of these possibilities.

3.3.1 Hydraulic Cross Sections

Forty-three stream cross sections were surveyed throughout DC in July 2015 to support the development of the DC hydraulic model. Approximately 15 cross sections were clustered within each reach (upper, middle and lower DC) to sufficiently characterize channel geometry, the width-depth ratio of each reach, and to adequately calibrate the model (Appendix 1). Generally, cross sections were surveyed at locations with significant changes in flow, area, or gradient, and specifically within the riffle / boulder garden feature.

Cross sections in upper DC were spread throughout the entire reach, as the reach extended approximately 465 m downstream from Doris Lake to the waterfall (Appendix 1). Conversely, cross sections in lower DC were focused within a 400 m segment of the reach immediately upstream of Little Roberts Lake. This 400 m segment was selected as a representative sub-sample of the general stream character within the Lower DC reach, which was 3,670 m long (Appendix 1).

In middle DC flow connectivity is of paramount interest for fish passage. A potential impediment for fish passage is a substantial riffle / boulder garden that demarcate the downstream end of the middle DC reach (Figures 1.2-1 and 3.1-1). At many flow levels this riffle forms a boulder garden, as numerous large boulders are visible throughout the wetted channel.

Cross sections were spread throughout the entire middle DC reach, with five cross sections specifically designated towards characterizing channel geometry and the width-depth ratio throughout the riffle / boulder garden feature.

3.3.2 Model Calibration and Validation

Calibration of the DC hydraulic model was accomplished using measured (surveyed) water levels ($Q = 1.22\ m^3/s$) from all 43 surveyed cross sections (Appendix 2). During the calibration process, the average model error was reported as a deviation in water surface elevation between computed and observed values, as well as percent channel depth (Table 3.3-1). Throughout the length of the DC hydraulic model the average calibration error was 0.44% of the baseline channel depth; with upper DC having a calibration error of 0.49% of the channel depth, middle DC at 1.17% of the channel depth, and lower DC at 0.63% of the channel depth.

Validation of the DC hydraulic model was accomplished using 2015 hydrology monitoring data from two hydrometric stations in DC (TL-2, TL-3). One of these stations was in upper DC and the other in middle DC (Figure 1.2-1); since there are no hydrometric stations in lower DC validation was not possible for this reach, validation was only performed for upper and middle DC reaches.

Table 3.3-1. Doris Creek Hydraulic Model Calibration Summary

	Reach Averaged Water Surface Elevation (WSE) (m)		Maximum Channel Depth (m)	Deviation WSE (m)	Deviation WSE (% Depth)	Roughness (Wtd. Total)
	Computed	Observed				
Upper Doris Cr.	21.835	21.858	0.710	0.023	0.49	0.055
Middle Doris Cr.	10.237	10.227	0.915	0.059	-1.17	0.169
Lower Doris Cr.	5.040	5.033	1.366	-0.006	-0.63	0.056
Mean			**0.997**	**0.025**	**-0.438**	**0.093**

Notes:

Discharge was 1.22 m³/s at the time of survey.
Roughness (Mannings n) values less than 0.1 reflect a stream with some boulders in the flow, and brush on the edges.
Roughness (Mannings n) values greater than 0.1 reflects very high values for the riffle / boulder garden averaged together with regular values (<0.1) for the remainder of the reach.

Validation results indicate that estimated water levels were, throughout a range of flows, +/- 3% of the measured water levels in upper DC (Table 3.3-2). Estimated water levels were, throughout a range of flows, within 7% of the measured water levels in middle DC, with one observation of 16%. An increased error in middle DC is an expected outcome as flow in the riffle / boulder garden feature violated several 1D modelling assumptions (see Section 3.4), thus the model was over-extended at some points in middle DC.

Table 3.3-2. Doris Creek Hydraulic Model Validation Summary

Upper Doris		Discharge (m³/s)	Water Surface Elevation (WSE) (m)		Maximum Channel Depth (m)	Deviation WSE (m)	Deviation WSE (% Depth)
			Computed	Observed			
Compliance Monitoring Field Trips	10-Jun-15	2.336	22.112	22.126	0.974	0.014	1.44
	15-Jun-15	2.721	22.151	22.173	1.013	0.022	2.17
	18-Jul-15	*1.220*	*21.962*	*21.972*	*0.824*	*0.010*	*1.21*
	15-Aug-15	1.329	21.982	21.995	0.844	0.013	1.54
	1-Sep-13	0.694	21.916	21.895	0.778	-0.021	-2.70
	Mean				**0.887**	**0.008**	**0.733**
Middle Doris		**Discharge (m³/s)**	**Water Surface Elevation (WSE) (m)**		**Maximum Channel Depth (m)**	**Deviation WSE (m)**	**Deviation WSE (% Depth)**
			Computed	**Observed**			
Compliance Monitoring Field Trips	11-Jun-15	2.336	10.834	10.919	1.310	0.085	6.49
	15-Jun-15	2.721	10.889	10.975	1.365	0.086	6.30
	20-Jul-15	*1.220*	*10.620*	*10.665*	*1.096*	*0.045*	*4.11*
	15-Aug-15	1.329	10.646	10.722	1.122	0.076	6.77
	20-Sep-15	0.694	10.379	10.516	0.855	0.137	16.02
	Mean				**1.110**	**0.086**	**8.301**

Note: Italics represent surveyed field data collected in 2015 during the field component of the hydraulic model.

3.3.3 *Doris Creek Hydrograph and Flow Reductions*

The onset of stream flow in DC begins in late May to early June as snow begins to melt. Freshet occurs quickly after the initiation of melting and typically peaks in June, with water levels declining steadily until freeze-up (Figure 3.3-1). Anticipated monthly flow reductions in DC would be the largest during freshet and very similar to baseline flows throughout the remainder of the open water season (ERM 2015b; Figure 3.3-1; Table 3.3-3). Although the proposed flow reductions will mimic the shape of the natural hydrograph, flow impacts are dependent more on the width-depth ratio of the stream than the actual reduction from baseline levels.

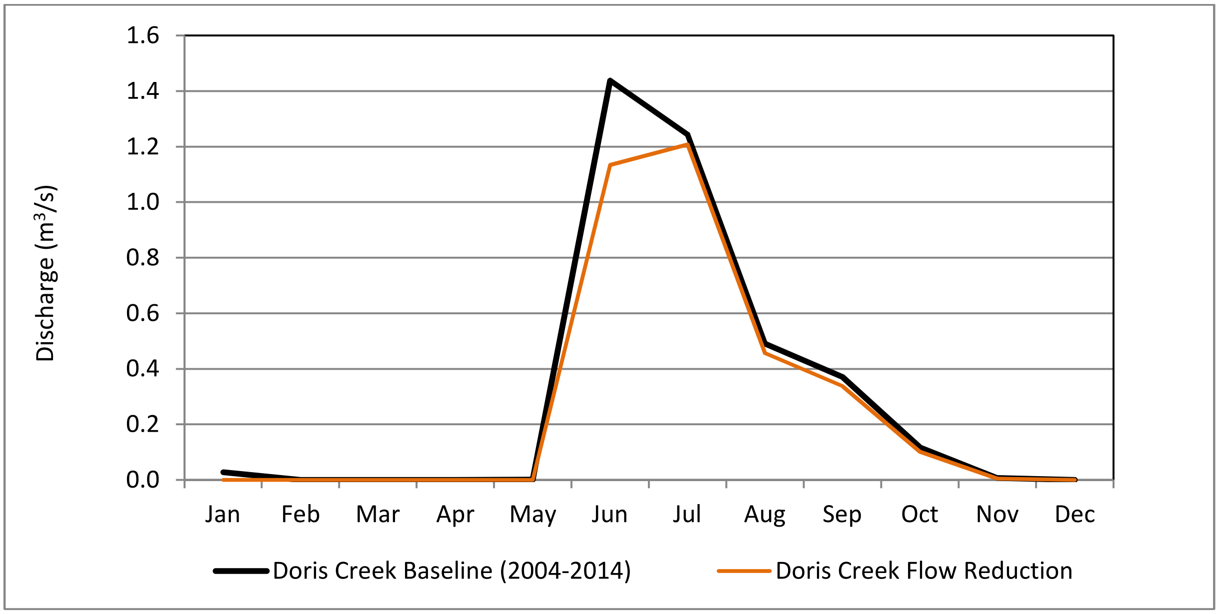


Figure 3.3-1. Doris Creek Mean Monthly Hydrograph (2004-2014 Average) Showing Anticipated Flow Reductions; Flows are based on Compliance Monitoring Station TL-2, Located in Upper Doris Creek; Flow Reductions are Greatest during the Freshet and Change from Month to Month

Potential impacts to fish habitat, as a result of flow reductions, are dependent on the width-depth ratio of the stream. Streams with a high width-depth ratio (wide and shallow) are more susceptible to impacts from flow reductions than streams with low width-depth rations (narrow and deep). Hydraulic model results indicate that each reach in DC has a low width-depth ratio throughout most of the open water season, and is therefore quite resilient to the anticipated flow reductions (Table 3.3-3).

Upper DC is estimated to have the greatest potential decrease in maximum channel depth of 0.07 m (-7.70% from baseline freshet levels) during the freshet, which corresponds to a maximum reduction in wetted width of 1.93 m or 17.7% (Table 3.3-3). During the remainder of the open water season, potential changes in maximum channel depth are close to 0.01 m (1.1%), with reductions in top width of less than 0.30 m or 5% for any given month. Excluding the freshet, flow impacts are estimated to be within 5% of baseline.

Table 3.3-3. Doris Creek Hydraulic Model Results for a 13% Reduction in Flow

Reach	Variable	June	July	August	September	October	Mean Monthly
Upper Doris	Δ Q (m^3/s)[1]	-0.30	-0.04	-0.04	-0.03	-0.02	-0.08
	Δ Q (%)[1]	-21.1	-2.8	-7.3	-9.2	-12.9	-14.4
	Δ Max Chl Depth (m)[2]	-0.07	-0.01	-0.01	-0.01	-0.01	-0.02
	Δ Max Chl Depth (%)[2]	-7.70	-0.99	-2.72	-3.43	-4.78	-3.92
	Δ Top Width (m)[3]	-1.93	-0.29	-0.07	-0.11	-0.09	-0.50
	Δ Top Width (%)[3]	-17.7	-3.3	-1.4	-2.0	-2.1	-5.1
Middle Doris	Δ Q (m^3/s)[1]	-0.30	-0.04	-0.04	-0.03	-0.02	-0.08
	Δ Q (%)[1]	-21.1	-2.8	-7.3	-9.2	-12.9	-14.4
	Δ Max Chl Depth (m)[2]	-0.07	-0.01	-0.02	-0.02	-0.01	-0.03
	Δ Max Chl Depth (%)[2]	-8.09	-1.03	-3.27	-4.01	-4.98	-4.28
	Δ Top Width (m)[3]	-2.02	-0.24	-0.13	-0.17	-0.19	-0.55
	Δ Top Width (%)[3]	-11.8	-1.5	-1.2	-1.6	-2.3	-4.5
Lower Doris	Δ Q (m^3/s)[1]	-0.30	-0.04	-0.04	-0.03	-0.02	-0.08
	Δ Q (%)[1]	-21.1	-2.8	-7.3	-9.2	-12.9	-14.4
	Δ Max Chl Depth (m)[2]	-0.09	-0.01	-0.02	-0.02	-0.01	-0.03
	Δ Max Chl Depth (%)[2]	-7.45	-0.96	-2.74	-3.36	-3.59	-3.62
	Δ Top Width (m)[3]	-1.42	-0.15	-0.13	-0.12	-0.07	-0.38
	Δ Top Width (%)[3]	-15.5	-2.0	-2.5	-2.4	-2.1	-4.7

Notes:

[1] *Change in discharge from averaged baseline levels (2004-2014) as a result of flow reductions*

[2] *Change in maximum channel depth from averaged baseline levels (2004-2014) as a result of flow reductions*

[3] *Change in cross section wetted, top width from averaged baseline levels (2004-2014) as a result of flow reductions*

Middle DC is estimated to have the greatest potential decrease in maximum channel depth of 0.07 m (-8.09% from baseline levels) during the freshet, which would translate to 2.02 m reduction (11.8%) in top width (Table 3.3-3). During the remainder of the open water season, potential changes in maximum channel depth are 0.01 - 0.02 m (<5.0%), with reductions in top width of less than 0.60 m (<5.0%) for any given month. Excluding the freshet, flow impacts are estimated to be within 5% of baseline.

Lower DC is estimated to have the greatest potential decrease in maximum channel depth of 0.09 m (-7.45% from baseline levels) during the freshet, which would translate to a 1.42 m reduction (15.5%) in top width (Table 3.3-3). During the remainder of the open water season, potential changes in maximum channel depth are 0.01 - 0.02 m (3-13%), with reductions in top width of less than 0.15 m (<3.0%) for any given month.

3.3.4 *Doris Creek Flow Connectivity*

The riffle / boulder garden feature that separates lower and middle DC reaches has the potential to impede fish passage during low flow conditions. Results from the hydraulic model indicate that, with the anticipated flow reductions throughout the year, water levels through this feature would drop by an average of 0.02 m (4.4%), while the top width would be reduced an average of 0.7 m (<5.0%) (Table 3.3-4).

Table 3.3-4. Doris Creek Flow Connectivity Results

Reach	Variable	June	July	August	September	October	Mean Monthly
Riffle / Boulder Garden	Δ Q (m^3/s)[1]	-0.30	-0.04	-0.04	-0.03	-0.02	-0.08
	Δ Q (%)[1]	-21.1	-2.8	-7.3	-9.2	-12.8	-14.4
	Δ Max Chl Depth (m)[2]	-0.07	-0.01	-0.02	-0.02	-0.01	-0.02
	Δ Max Chl Depth (%)[2]	-8.30	-1.07	-3.28	-4.04	-5.14	-4.37
	Δ Top Width (m)[3]	-2.58	-0.30	-0.15	-0.21	-0.24	-0.70
	Δ Top Width (%)[3]	-13.0	-1.8	-1.0	-1.5	-2.0	-4.8

[1] *Change in discharge from averaged baseline levels (2004-2014) as a result of flow reductions*
[2] *Change in maximum channel depth from averaged baseline levels (2004-2014) as a result of flow reductions*
[3] *Change in cross section wetted, top width from averaged baseline levels (2004-2014) as a result of flow reductions*

Flow reductions would be the largest during freshet, with a reduction of 0.07 m (8.3%) maximum channel depth and 2.58 m (13.0%) top width. It should be noted that water levels, and therefore top width, throughout the riffle / boulder garden feature, have been observed to be beyond the channel resulting in overland flow during the freshet. As such, potential changes in maximum channel depth and top width during the remainder of the open water season would be less than 0.02 m (4.0%) and 0.30 m (1.8%), respectively.

In summary, modelled flow reductions throughout the riffle / boulder garden feature in DC are estimated to be within 5% of baseline values in most circumstances, excluding the freshet. The greatest reductions are anticipated to occur during the freshet with a reduction in maximum channel depth of 8.3% (0.07 m) and a commensurate reduction in top width of 13.0% (2.58 m). Changes throughout the remainder of the open water season are anticipated to 5% and 2% respectively.

3.4 Little Roberts Outflow Hydraulic Model Results

Flow reductions in DC (13%), resulting from lake drawdown, are projected to result in a 6% reduction in mean annual flow in LRO. Similar to DC, there is potential for direct impacts to fish habitat as a results of flow reductions, as well as loss of flow connectivity through the riffle / boulder garden feature in LRO. The LRO hydraulic model was developed to inform these possibilities.

3.4.1 *Hydraulic Cross Sections*

Fourteen stream cross sections were surveyed in July 2015 to support the development of the LRO hydraulic model (Appendix 1). The cross sections were spaced over a four hundred meter study reach, intended to characterize the riffle / boulder garden feature at the downstream end of the model along with channel geometry and the width-depth ratio throughout the stream segment. Generally, cross sections were surveyed at locations with significant changes in flow, area, or gradient, and specifically within the riffle / boulder garden feature.

3.4.2 *Model Calibration*

Calibration of the LRO hydraulic model was accomplished using measured (surveyed) water levels (from July 2015, at a point when average stream discharge was 2.05 m^3/s) from all 14 surveyed cross sections (Appendix 3). During the calibration process the average model error was reported as a deviation in water surface elevation between computed and observed values, as well as percent channel depth (Table 3.4-1). Average calibration error for the entire reach was 1.62% of the of the maximum channel depth.

Table 3.4-1. Little Roberts Outflow Hydraulic Model Calibration Summary

	Cross Section No.	Water Surface Elevation (WSE) (m)		Maximum Channel Depth (m)	Deviation WSE (m)	Deviation WSE (% Depth)	Roughness (Wtd. Total)
		Computed	Observed				
Little Roberts Lake Surface Elevation							
Little Roberts Outflow	xs-14	4.786	4.773	0.729	-0.013	-1.78	0.027
	xs-13	4.778	4.758	0.607	-0.020	-3.29	0.028
	xs-12	4.772	4.756	0.706	-0.016	-2.27	0.027
	xs-11	4.770	4.757	0.984	-0.013	-1.32	0.026
	xs-10	4.766	4.742	0.857	-0.024	-2.79	0.027
	xs-9	4.761	4.721	0.894	-0.040	-4.47	0.026
	xs-8	4.758	4.732	0.748	-0.026	-3.48	0.026
	xs-7	4.744	4.729	1.042	-0.015	-1.44	0.035
	xs-6	4.714	4.695	0.901	-0.019	-2.11	0.020
	xs-5	4.711	4.694	0.744	-0.017	-2.28	0.038
	xs-4	4.663	4.650	0.746	-0.013	-1.74	0.100
	xs-3	4.580	4.590	0.883	0.010	1.13	0.089
	xs-2	4.43	4.467	0.761	0.037	4.86	0.196
	xs-1	3.433	3.42	0.780	-0.013	-1.67	0.139
	Mean	**4.631**	**4.606**	**0.802**	**-0.013**	**-1.618**	**0.057**

Notes:
Discharge was 2.05 m^3/s at the time of survey
Roughness (Mannings n) values less than 0.1 reflect a stream with some boulders in the flow, and brush on the edges
Roughness (Mannings n) values greater than 0.1 reflects very high values for the riffle / boulder garden averaged together with regular values (<0.1) for the remainder of the reach

3.4.3 *Little Roberts Outflow Hydrograph and Flow Reductions*

Stream flow begins in LRO between late May and early June, as ice begins to break up on Roberts and Little Roberts Lakes, and adjacent snow begins to melt (Figure 3.4-1; Table 3.4-2). Freshet occurs quickly after the initiation of melting and typically peaks in June, with water levels declining steadily until (Figure 3.4-1). Anticipated monthly flow reductions in LRO would be the largest during freshet and very similar to baseline flows throughout the remainder of the open water season (ERM 2015b; Figure 3.4-1; Table 3.4-2).

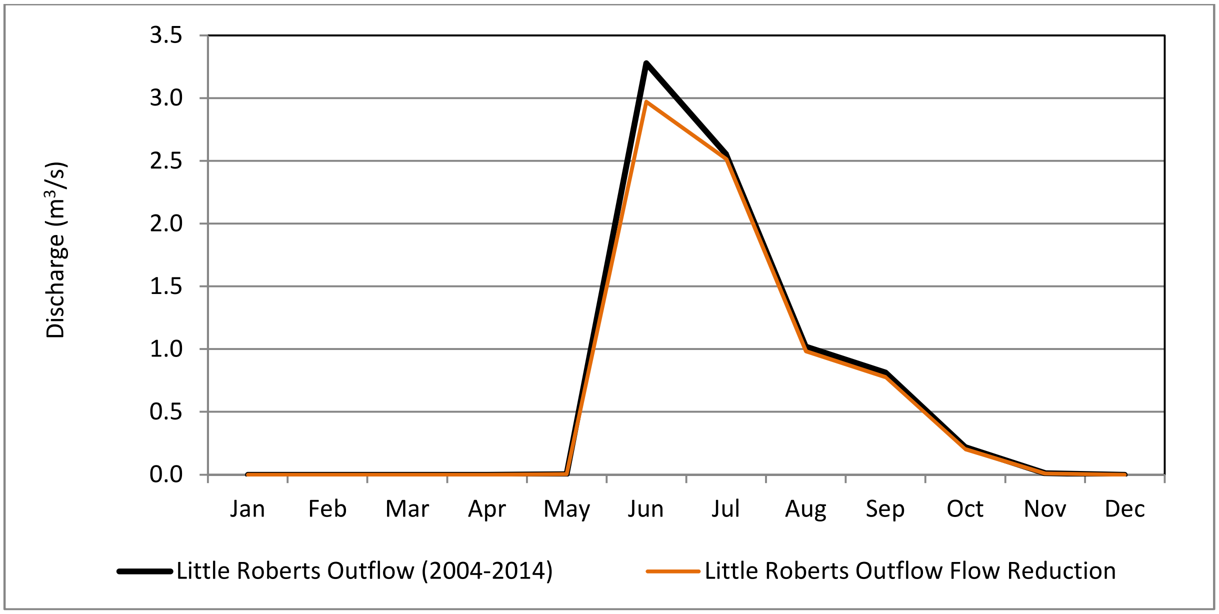


Figure 3.4-1. Little Roberts Outflow Mean Monthly Hydrograph (2004-2014 Average) Showing Anticipated Flow Reductions; Flows are Developed based on Compliance Monitoring Stations TL-2 (Located in Upper Doris Creek) and Roberts Hydro (Located at the Roberts Lake Outflow)

Table 3.4-2. Little Roberts Outflow Hydraulic Model Results

Reach	Variable	June	July	August	September	October	Mean Monthly
LRO	Δ Q (m^3/s)[1]	-0.31	-0.04	-0.04	-0.10	-0.02	-0.10
	Δ Q (%)[1]	-9.3	-1.4	-3.4	-11.8	-6.9	-6.5
	Δ Max Chl Depth (m)[2]	-0.04	0.00	-0.01	-0.02	-0.01	-0.01
	Δ Max Chl Depth (%)[2]	-3.84	-0.54	-1.13	-3.56	-1.43	-2.10
	Δ Top Width (m)[3]	-1.62	-0.20	-0.03	-0.10	-0.04	-0.40
	Δ Top Width (%)[3]	-8.2	-1.2	-0.2	-0.8	-0.4	-2.2

[1] *Change in discharge from baseline levels (2004-2014) as a result of flow reductions*
[2] *Change in maximum channel depth from baseline levels (2004-2014) as a result of flow reductions*
[3] *Change in cross section wetted, top width from baseline levels (2004-2014) as a result of flow reductions*

Hydraulic model results indicate that LRO has a moderately high width-depth ratio (wide and shallow) and is therefore potentially sensitive to flow reductions. However, LRO has Doris Lake, Roberts Lake, and Little Roberts Lake as headwaters which act to stabilize and maintain stream flow throughout the open water season. Thus, although the moderately high width-depth ratio suggests LRO is sensitive to flow reductions, modelling results indicate that LRO has stable stream flow and that flow reductions are anticipated to be very small.

Model results for LRO suggest that the largest change in channel depth is estimated to be 0.04 m (3.84%) during the freshet and less than 0.02 m (<3.6%) thereafter. These results are within 5% of baseline values and are further bolstered by stabilized flow from Roberts Lake (unaffected by flow reductions) and Little Roberts Lake (very small affect from flow reductions). Little Roberts Outflow is estimated to have the greatest potential decrease in top width of 1.62 m (8.2%) during freshet, with changes averaging 0.03 – 0.20 m (0.2 to 1.2%) throughout the remainder of the open water season.

3.4.4 *Little Roberts Outflow Flow Connectivity*

The riffle / boulder garden feature that separates Roberts Bay (ocean) from Little Roberts Lake has the potential to impede fish passage during low flow conditions. Hydraulic model results for flow connectivity through the riffle / boulder garden feature in LRO indicate that, with the anticipated average flow reductions (6%) throughout the year, the greatest potential reductions in maximum channel depth are estimated to be 0.04 m (4.0%) during the freshet, with reductions between 0.0 to 0.03 m (<5.0%) during the remainder of the year (Table 3.4-3). Estimated reductions in top width are similar with the greatest reduction of 1.08 m (7.1%) during the freshet with reduction estimated between 0.01 to 0.15 m (<1.0%) throughout the remainder of the open water season.

Table 3.4-3. Little Roberts Outflow Flow Connectivity Results

Reach	Variable	June	July	August	September	October	Mean Monthly
Riffle / Boulder Garden	Δ Q (m^3/s)[1]	-0.31	-0.04	-0.04	-0.10	-0.02	-0.10
	Δ Q (%)[1]	-9.3	-1.4	-3.4	-11.8	-6.9	-6.5
	Δ Max Chl Depth (m)[2]	-0.04	0.00	-0.01	-0.03	-0.01	-0.02
	Δ Max Chl Depth (%)[2]	-4.00	-0.57	-1.51	-5.08	-2.41	-2.71
	Δ Top Width (m)[3]	-1.08	-0.15	-0.01	-0.04	-0.04	-0.26
	Δ Top Width (%)[3]	-7.1	-1.0	-0.1	-0.3	-0.7	-1.8

Notes:
[1] *Change in discharge from baseline levels (2004-2014) as a result of flow reductions*
[2] *Change in maximum channel depth from baseline levels (2004-2014) as a result of flow reductions*
[3] *Change in cross section wetted, top width from baseline levels (2004-2014) as a result of flow reductions*

In summary, modelled flow reductions throughout the riffle / boulder garden feature in LRO are estimated to be small, and often within 5% of baseline values. The greatest reductions are anticipated to occur during the freshet with the greatest reduction in maximum channel depth of 4% (0.04 m) and a commensurate reduction in top width of 7.1% (1.08 m). Changes throughout the remainder of the open water season are anticipated to less than 5% and 1% respectively.

4. SUMMARY AND CONCLUSIONS

To inform the assessment of potential impacts of flow reductions on fish habitat in DC and LRO, two objectives were defined: (1) Survey hydraulic cross sections in fisheries sensitive reaches in DC and LRO; and (2) develop hydraulic models for DC and LRO to estimate potential losses to fish habitat as a result of flow reductions, and to estimate potential impacts to flow connectivity also as a result of flow reductions.

Modelling results suggest that the anticipated flow reductions in DC (13%) and LRO (6%) will result in small reductions in maximum channel depth and wetted width. Specifically, flow reductions in DC (13%) are estimated to have an average reduction in maximum channel depth across the open water season of 0.03 m (<5%) with LRO slightly less at 0.01 m (2.1%). Similarly, flow reductions in DC (13%) are estimated to have an average reduction in top width across the open water season of 0.56 m (<5%) with LRO slightly less at 0.40 m (2.2%).

Modelling results are similarly small for impacts to flow connectivity in each stream. Results suggest that the anticipated flow reductions will result in small reductions in maximum channel depth and top width throughout the riffle / boulder garden features in DC and LRO. Specifically, flow reductions in DC (13%) are estimated to have an average reduction in maximum channel depth across the open water of 0.02 m (<5%) with LRO slightly less at 0.02 m (2.8%). Similarly, flow reductions in DC (13%) are estimated to have an average reduction in top width across the open water of 0.70 m (<5%) with LRO slightly less at 0.26 m (1.9%).

Flow reductions would mimic the shape of the natural hydrograph with the largest reduction occurring during the freshet when flow connectivity is not impeded and channel depth is at a maximum (Figure 3.3-1; Figure 3.4-1). Flow connectivity is, however, naturally impeded during the autumn as stream flow slows and then ceases with freeze-up.

In summary, DC and LRO were most resilient to flow reductions during freshet. Model estimates suggest that the anticipated flow reductions account for small reductions in maximum channel depth (≤ 5%) and top width (<0.50 m) throughout the open water season, and these reductions would have limited impact on available habitat, and on flow connectivity through the riffle / boulder garden features.

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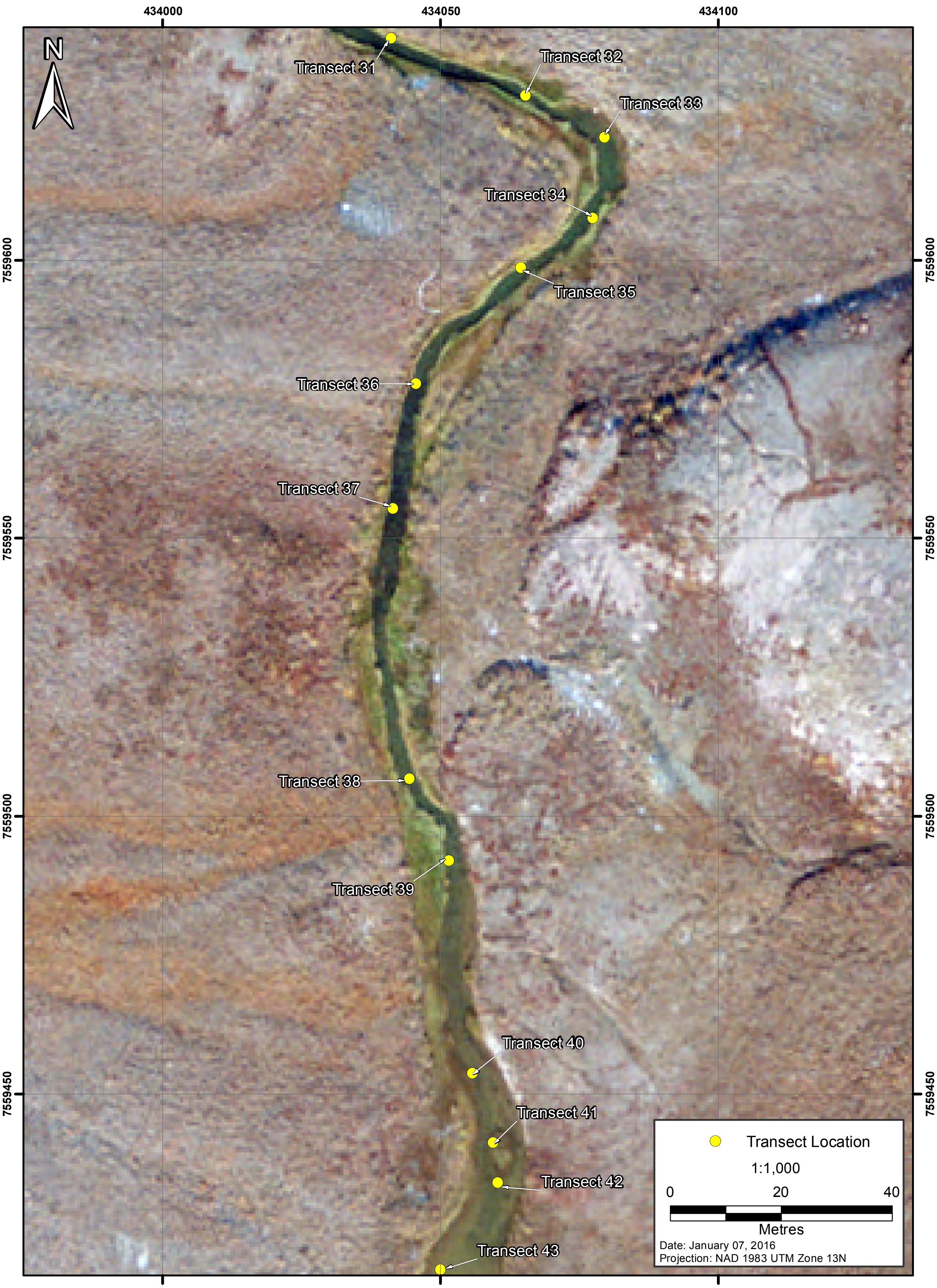
— Appendix 1 —

Doris Creek and Little Roberts Outflow Field Transect Survey Locations

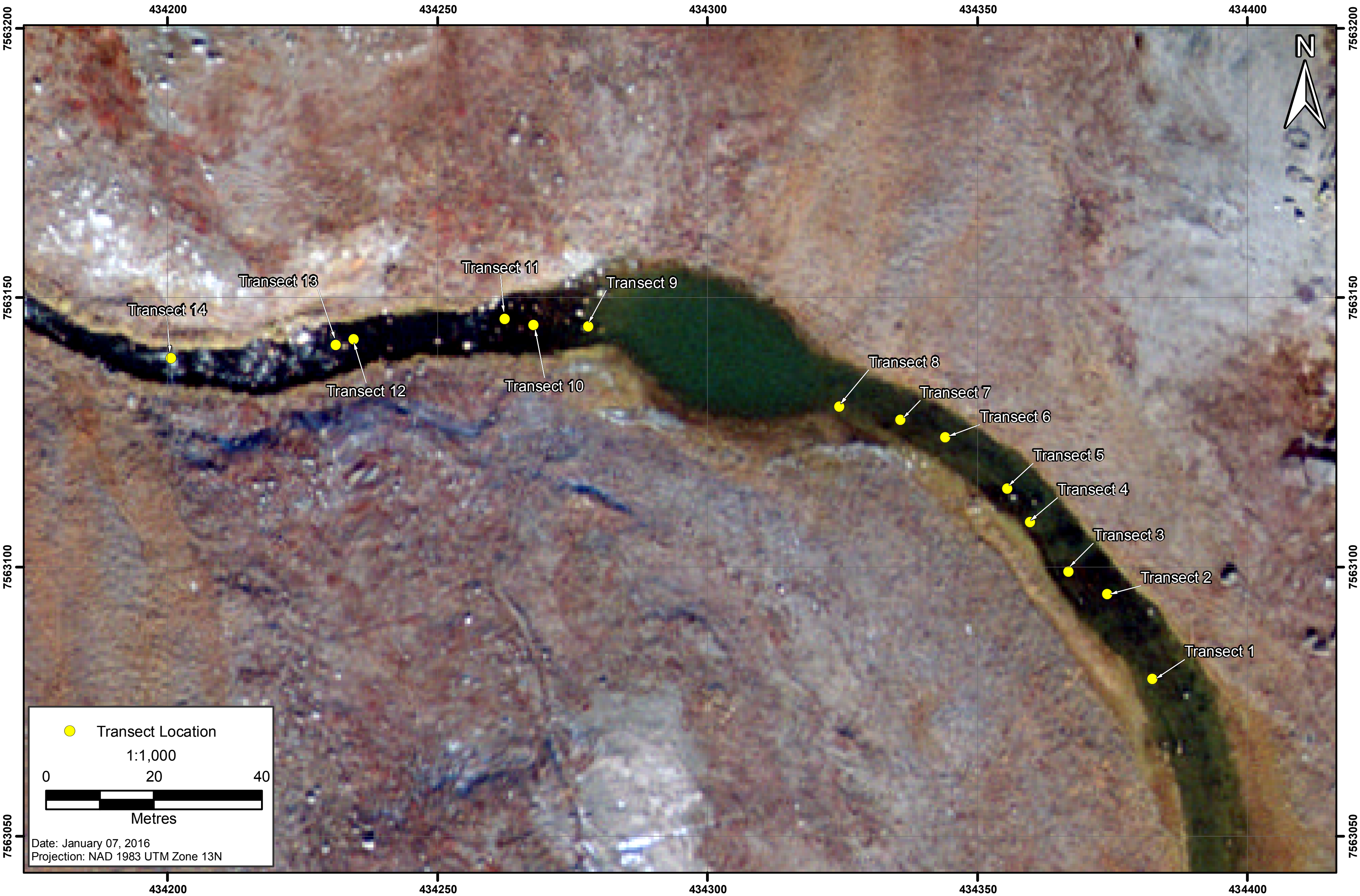
Transect Locations on Upper Doris Creek



Transect Locations on Middle Doris Creek

Transect Locations on Lower Doris Creek

Transect Locations on Little Roberts Outflow



— Appendix 2 —

Doris Creek Hydraulic Model – Calibration Results

Appendix 2. Doris Creek Hydraulic Model - Calibration Results

Transect		Water Surface Elevation (m)		Maximum Channel Depth (m)	Deviation WSE (m)	Deviation WSE (% Depth)	Roughness (Wtd. Total)
		Computed	Observed				
Doris Lake Outflow							
Upper Doris Creek	xs-43	22.040	22.050	0.553	0.010	1.81	0.040
	xs-42	22.035	22.045	0.648	0.010	1.54	0.040
	xs-41	22.032	22.051	0.737	0.019	2.58	0.050
	xs-40	22.022	22.015	0.540	-0.007	-1.30	0.050
	xs-39	21.977	21.968	0.814	-0.009	-1.11	0.060
	TL-2	21.962	21.964	0.8190	0.002	0.31	0.060
	xs-38	21.946	21.960	0.824	0.014	1.70	0.060
	xs-37	21.813	21.817	0.413	0.004	0.97	0.028
	xs-36	21.768	21.758	0.568	-0.010	-1.76	0.034
	xs-35	21.735	21.737	1.063	0.002	0.19	0.060
	xs-34	21.716	21.717	1.036	0.001	0.10	0.080
	xs-33	21.691	21.705	0.774	0.014	1.81	0.080
	xs-32	21.662	21.658	0.776	-0.004	-0.52	0.054
	xs-31	21.286	21.564	0.378	0.278		0.080
	Mean	**21.835**	**21.858**	**0.710**	**0.023**	**0.486**	**0.055**
	Doris Creek Waterfall Separates Middle and Lower Doris Creek						
Middle Doris Creek	xs-29	11.030	11.020	0.810	-0.010	-1.23	0.247
	xs-28	10.685	10.674	1.259	-0.011	-0.87	0.079
	xs-27	10.662	10.686	1.102	0.024	2.18	0.080
	xs-26	10.646	10.652	0.879	0.006	0.68	0.070
	xs-25	10.620	10.601	1.096	-0.019	-1.73	0.064
	xs-24	10.604	10.583	0.894	-0.021	-2.35	0.232
	xs-23	10.542	10.534	0.965	0.753	-0.83	0.325
	xs-22	9.728	9.691	0.764	-0.037	-4.84	0.094
	xs-21	9.662	9.688	0.656	0.026	3.96	0.193
	xs-20	9.234	9.210	0.942	-0.024	-2.55	0.238
	xs-19	9.197	9.160	0.698	-0.037	-5.30	0.234
	Mean	**10.237**	**10.227**	**0.915**	**0.059**	**-1.172**	**0.169**
	Riffle / Boulder Garden Separating Lower and Middle Doris Creek						
Lower Doris Creek	xs-18	5.197	5.19	0.849	-0.007	-0.82	0.069
	xs-17	5.210	5.198	1.523	-0.012	-0.79	0.049
	xs-16	5.208	5.190	1.588	-0.018	-1.13	0.050
	xs-15	5.200	5.180	1.153	-0.020	-1.73	0.050
	xs-14	5.127	5.120	0.814	-0.007	-0.86	0.050
	xs-13	5.131	5.120	2.202	-0.011	-0.50	0.049
	xs-12	5.131	5.140	1.744	0.009	0.52	0.050
	xs-11	5.121	5.090	1.096	-0.031	-2.83	0.038
	xs-10	5.106	5.058	0.822	-0.048	-5.84	0.085
	xs-9	5.009	5.000	2.436	-0.009	-0.37	0.065
	xs-8	5.008	5.023	2.440	0.015	0.61	0.068
	xs-7	5.007	5.010	2.070	0.003	0.14	0.065
	xs-6	4.998	4.990	0.928	-0.008	-0.86	0.065
	xs-5	4.904	4.915	0.904	0.011	1.22	0.068
	xs-4	4.861	4.865	0.882	0.004	0.45	0.058
	xs-3	4.832	4.850	0.916	0.018	1.97	0.058
	xs-2	4.835	4.830	1.085	-0.005	-0.46	0.038
	xs-1	4.832	4.832	1.132	0.000	0.00	0.031
	Mean	**5.040**	**5.033**	**1.366**	**-0.006**	**-0.627**	**0.056**
	Little Roberts Lake Surface Elevation						

— Appendix 3 —

Little Roberts Outflow Hydraulic Model – Calibration Results

Appendix 3. Little Roberts Outflow Hydraulic Model - Calibration Results

Transect		Water Surface Elevation (m)		Maximum Channel Depth (m)	Deviation WSE (m)	Deviation WSE (% Depth)	Roughness (Wtd. Total)
		Computed	Observed				
Little Roberts Lake Surface Elevation							
Little Roberts Outflow	xs-14	4.786	4.773	0.729	-0.013	-1.78	0.027
	xs-13	4.778	4.758	0.607	-0.020	-3.29	0.028
	xs-12	4.772	4.756	0.706	-0.016	-2.27	0.027
	xs-11	4.770	4.757	0.984	-0.013	-1.32	0.026
	xs-10	4.766	4.742	0.857	-0.024	-2.79	0.027
	xs-9	4.761	4.721	0.894	-0.040	-4.47	0.026
	xs-8	4.758	4.732	0.748	-0.026	-3.48	0.026
	xs-7	4.744	4.729	1.042	-0.015	-1.44	0.035
	xs-6	4.714	4.695	0.901	-0.019	-2.11	0.020
	xs-5	4.711	4.694	0.744	-0.017	-2.28	0.038
	xs-4	4.663	4.650	0.746	-0.013	-1.74	0.100
	xs-3	4.580	4.590	0.883	0.010	1.13	0.089
	xs-2	4.43	4.467	0.761	0.037	4.86	0.196
	xs-1	3.433	3.42	0.780	-0.013	-1.67	0.139
	Mean	**4.619**	**4.606**	**0.813**	**-0.013**	**-1.618**	**0.057**