Elk Valley Water Quality Plan

Annex D.3

Hydrology Report

Teck

Elk Valley Water Quality Plan
Hydrology Report

July 2014

Teck

This report has been prepared by: This report has been reviewed by:

GOLDER ASSOCIATES LTD.

Ann Conroy, BEng. Hons.
Associate, Senior Water Resources Specialist

Deborah Chan-Yan, MASc, PEng
Associate, Assistant Project Director

SUMMARY

To support the Elk Valley Water Quality Plan (the Plan), a water quality model was developed using GoldSim, that estimates concentrations of water quality constituents of interest at locations in the Elk Valley. Monthly historical flow datasets at locations in the Elk River, the Fording River and local tributaries with mining disturbance were required to support the calibration and validation of the water quality model. Future flow scenarios were used to support the initial evaluation of how conditions may change in the future as a result of mining in the Elk Valley.

The majority of tributary watersheds in the Elk Valley are ungauged or have limited monitoring data that are representative of total watershed flows. Good-quality regional flow data are available, however, from active and discontinued Environment Canada stations. The required flow datasets were therefore derived using a combination of methods, depending on location, availability and suitability of observed flow data. Hydrologic analyses involved the simulation of historical and future flows for tributaries directly affected by historical mining activities, or that may be affected by future mining activities, and for the regional watercourses identified by Ministerial Order No. M113 issued by the BC Minister of Environment to Teck.

An empirical approach was used to derive monthly flows for ungauged watersheds, given the hydrologic regime (i.e., seasonal runoff is typically snow-dominated) and the amount/type of available data. Four different flow series were identified as representative of natural areas (derived from two representative watersheds: LCO Dry Creek and Hosmer Creek). One flow series was selected to represent mining land types (Cataract Creek).

The Fording River and Michel Creek were defined in detail (i.e., at the sub-watershed level) using the flow model. This detailed definition was prepared because of the existing and potential future mining operations and potential mitigation opportunities, and thus the potential for changes in hydrology and water quality at the local (sub-watershed) scale. Flows at the mouths of Fording River and Michel Creek are gauged and the data was used for model calibration and verification of simulated flows.

Flows along Elk River and Line Creek, as well as inflows to Lake Koocanusa, are gauged and can be characterized by existing flow records, pro-rated flow records (based on watershed area), or a combination of modelled tributary flows and observed records.

Following derivation of flows and statistics for historical conditions, a future flow simulation was conducted. Methods were similar to the historical flow simulation method; however, representative hydrographs were based on statistical flow scenarios rather than a time series of monthly average flows over a historical period.

GoldSim was also used to build a flow model to simulate three future scenarios for each watershed: mean monthly flow; high monthly average flow, based on 1-in-10-year high-flow statistics; and low monthly average flow, based on 1-in-10 year low-flow statistics. All flow statistics were generated using data from 1995 to 2010. Statistics were developed for calendar months, with each month developed independently.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

Acronym	Definition
BC	British Columbia
BC MOE	British Columbia Ministry of Environment
CCR	Coarse Coal Rejects
CMO	Coal Mountain Operations
SRK	SRK Mining Consultants
EVO	Elkview Operations
FRO	Fording River Operations
GHO	Greenhills Operations
ID	Identification
LCO	Line Creek Operations
LCO I	Line Creek Operations Phase I
LCO II	Line Creek Operations Phase II
the model	Elk Valley Water Quality Planning Model
the Plan	Elk Valley Water Quality Plan
WLC	West Line Creek

UNITS OF MEASUREMENT

%	percent
>	greater than
<	less than
+/-	positive or negative
km^2	square kilometre
m^3	cubic metre
m^2	square metre
m	metre
m^3/s	cubic metre per second
y	year

1 Introduction

1.1 Background

Teck Coal Limited (Teck) operates five open-pit steelmaking coal mines in the Elk River watershed (also known as the Elk Valley) in southeastern British Columbia (Figure 1):

- Fording River Operations (FRO)
- Greenhills Operations (GHO)
- Line Creek Operations (LCO)
- Elkview Operations (EVO)
- Coal Mountain Operations (CMO).

On 15 April 2013, Ministerial Order No. M113 (the Order) was issued by the BC Minister of the Environment. The Order requires Teck to develop an area-based management plan for the Elk Valley for the purpose of managing water quality concentrations of selenium, cadmium, nitrate and sulphate and the rate of calcite formation. Teck is referring to this area based management plan as the Elk Valley Water Quality Plan (the Plan). As part of the Plan, Teck must develop targets for water quality at specified locations in the Fording River, Elk River and Lake Koocanusa. The Order also requires Teck to develop a detailed implementation plan to demonstrate how water quality concentrations targets will be met at the specified locations.

To support the planning process, Teck has developed a regional planning and assessment tool described as the Elk Valley Water Quality Planning Model (the model). The model builds upon previous modelling tools developed to initially support the environmental assessment for the LCO Phase II project. The model was then expanded to cover Teck's other mine operations in the Elk Valley. At its core, the model is a water quality mass balance model. The main inputs to the model include surface water flows, geochemical source terms and operational mine information (such as rate and placement of waste rock). The outputs include estimates of concentrations of water quality constituents of interest at selected locations in the Elk Valley. The model was used to support the identification of water quality management measures to meet the long-term water quality targets in the initial implementation plan.

1.2 Purpose and Scope

This report details the methods and results of the hydrologic analyses undertaken to support the development of the Elk Valley Water Quality Plan (the Plan). It is one of a series of technical reports that provides information on the development of the Plan.

Monthly historical flow datasets at locations in the Elk River, the Fording River and local tributaries with mining disturbance were required to support the calibration and validation of the water quality model. Future flow scenarios were used to support the initial evaluation of how conditions may change as a result of future mining operations. The majority of the tributary watersheds in the Elk Valley are ungauged, or have limited monitoring data that are representative of total watershed flows. Good-quality regional flow data are available from active and discontinued Environment Canada stations. The required flow datasets were, therefore, derived using a combination of methods, depending on location and availability and suitability of observed flow data.

Hydrologic inputs for the water quality model were developed through five major hydrology tasks:

- Simulation of historical monthly average flows for the period 1995 to 2012, for use in calibration and validation of the water quality model. This period was chosen due to the availability of concurrent flow and water quality data for the Elk Valley. Additional detail is provided in Section 5.1.1.
- Simulation of mean monthly, design-high monthly and design-low monthly flows for the modelling future flow conditions (2013 and later) in the water quality model. High- and low-flow scenarios are based on 1-in-10-year monthly average flow statistics. These scenarios were chosen to reflect critical situations for the protection of aquatic ecosystems (BC MOE 2012).
- Calibration and validation of the flow model at locations where sufficient observed data were available for statistical comparison. No observed flow data are available for three Order stations (FR4, ER1 and ER3), and no current flow data are available for ER4 (the station was discontinued in 1996). The observed flow for ER2 is used directly in the water quality model (i.e., historical flows and future statistics that are derived from observed flows, not simulated using the flow model). Order station FR5 is simulated in the flow model, and the results are compared with the observed flows. Model performance statistics are provided in Appendix A.
- At locations where observed flow data were available but not sufficient and/or applicable for statistical comparison, evaluation of model results was completed by visual comparison of observed and simulated flows. Comparison graphs are provided in Appendix A.
- Balance and quality checks.

This report is part of a series of supporting documents that provide additional technical information on the development of the Plan, including:

- *Water Quality Modelling Methods* (Teck 2014b), which describes the setup and configuration of the model and the results of the calibration
- *Consolidation of Geochemical Source Term Inputs and Methods for Elk Valley Water Quality Modelling* (SRK 2014), which describes the geochemical inputs to the model
- *Site Conditions* (Teck 2014c), which describes site conditions at the Elk Valley mine operations, including historical operational data and future mine plans that were incorporated into the model
- *Water Quality Modelling for the Initial Implementation Plan* (Teck 2014d), which describes the selection of water quality management measures for the implementation plan and the future water quality conditions predicted by the model.

An overview of the Plan is provided in a separate publication (Teck 2014a).

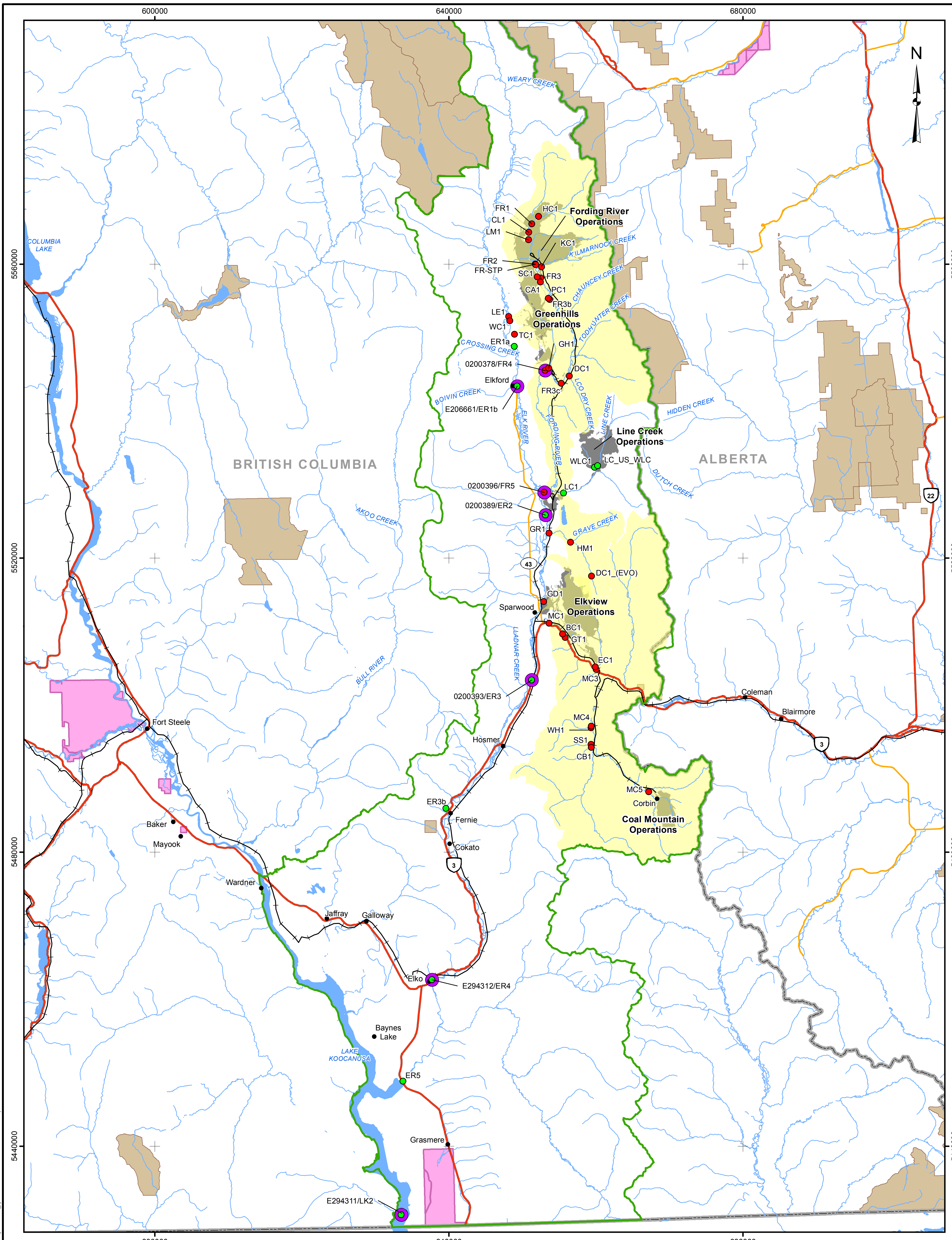
2 Designated Area

The designated area encompasses the Elk River watershed and the Canadian portion of Lake Koocanusa, as shown on Figure 2-1. The Elk River originates from the Elk Lakes Provincial Park, and flows south before turning southwest at Sparwood and finally discharging to Lake Koocanusa. Major tributaries to the Elk River include the Fording River and Michel Creek, comprising about 10% and 14% of the mean annual flow, respectively. The southern limit of the designated area represents the downstream point identified in the Order.

The hydrologic analyses involved the simulation of historical and future flows for local tributaries directly affected by historical mining activities, or ones that may be affected by future mining activities, along with the regional watercourses identified by the Order. Separate flows were defined for local watersheds at FRO, GHO, LCO, EVO and CMO 2. Local tributary flows were not defined for CMO, since further spatial definition of this site was not required to support the development of the Plan.

The Fording River and Michel Creek were defined in detail (i.e., at the sub-watershed level) using the flow model. This detailed definition was prepared because of the existing and potential future mining operations and potential mitigation opportunities, and thus the potential for changes in hydrology and water quality at the local (sub-watershed) scale.

Throughout the designated area, modelling nodes were used to forecast and assess water quality. The locations of these modelling nodes are shown on Figure 2-1. Node locations were selected to represent all watersheds affected by mining activities, or that have the potential to be affected by future mining, and/or regional locations identified by the Order (Order stations). Detailed site maps showing node locations and watersheds are provided in the Elk Valley Water Quality Plan Site Conditions Report (Teck 2014c). Historical and future flows for each of these locations were derived as part of the hydrologic inputs to the water quality model.



LEGEND

- CITY / TOWN / COMMUNITY
- FLOWS AT MODELLING NODE SIMULATED USING REPRESENTATIVE HYDROGRAPH METHOD
- MODELLING NODE
- ORDER STATION
- CANADIAN PACIFIC RAILWAY
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- WATERCOURSE
- BRITISH COLUMBIA - ALBERTA BORDER
- COAL MINING OPERATION
- DESIGNATED AREA
- FIRST NATIONS RESERVE
- PROVINCIAL PARK
- WATERBODY
- WATERSHED FLOWS SIMULATED USING REPRESENTATIVE HYDROGRAPH METHOD

15 0 15

SCALE 1:500,000 KILOMETRES

REFERENCE

Communities obtained from The Atlas of Canada, Natural Resources Canada. Roads obtained from Geobase. Parks/ protected areas, First Nations and railroad data obtained from Geogratis. Provincial boundary and hydrography data obtained from IHS Energy Inc. USA data obtained from ESRI. Projection: UTM Zone 11 Datum: NAD 83

PROJECT

TECK COAL ELK VALLEY
WATER QUALITY PLAN

TITLE

DESIGNATED AREA, ORDER STATIONS AND MODELLING NODES

Teck

PROJECT No. 13-1349-0006			SCALE AS SHOWN	REV. 0
DESIGN	AC	27 Feb. 2013	FIGURE 2-1	
GIS	DR	27 Jun. 2014		
CHECK	JC	27 Jun. 2014		
REVIEW	AC	27 Jun. 2014		

I:\CLIENTS\TECK_COAL\13-1349-0006\Mapping\MXD\Hydrology\B-Hydrology-003-GIS-LocationMap.mxd

3 Data Summary

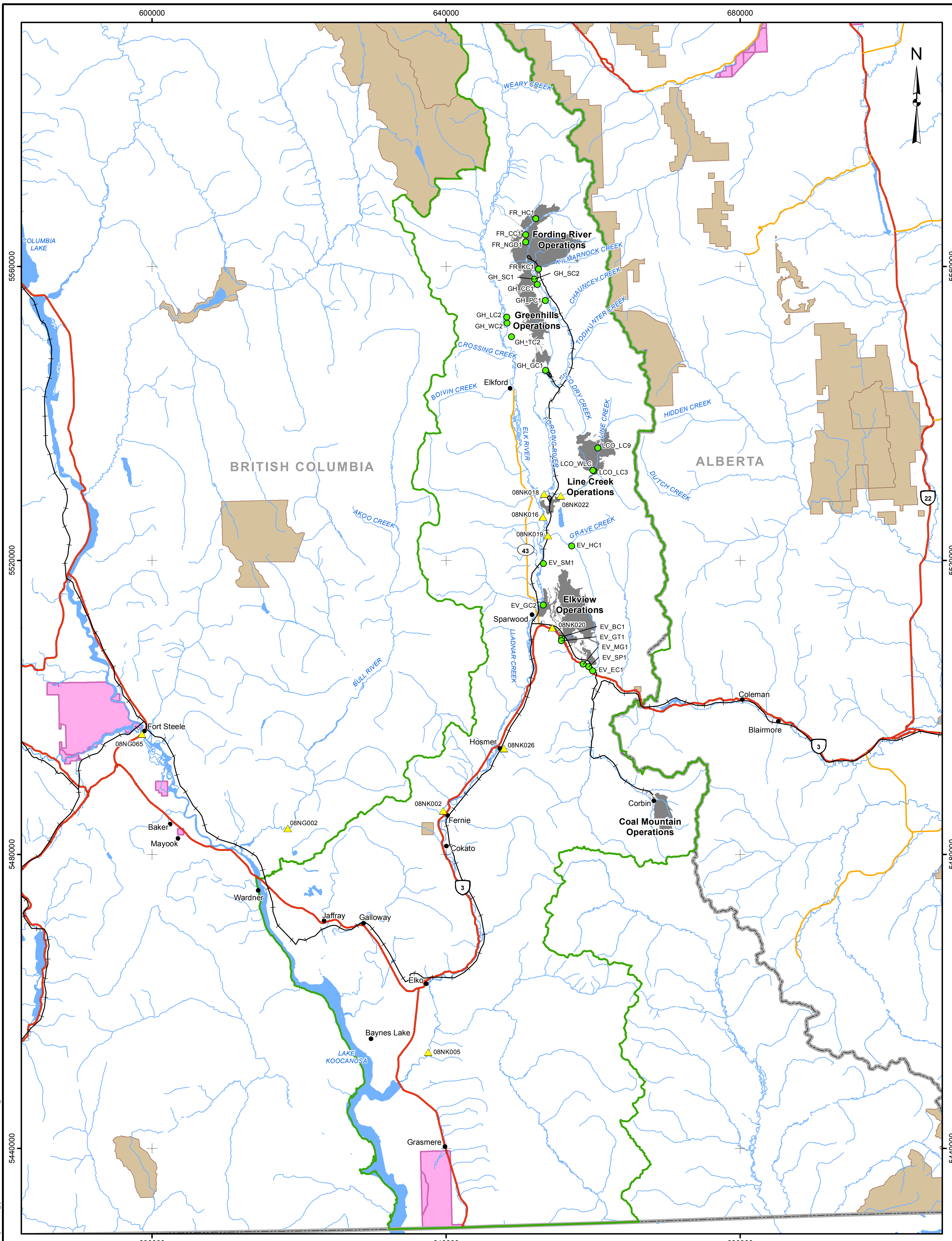
3.1 Flow Data

Flow data are available from a network of current and discontinued hydrometric stations in the designated area (Figure 3-1). The two sources of observed flow data are:

- Teck – continuous flow data from hydrometric stations and instantaneous flow measurements for local tributaries in the vicinity of the mining operations
- Environment Canada – continuous flow data from regional hydrometric stations.

Teck measures flows at about 26 local watersheds with waste rock spoils, as listed in Table 3-1. The available data are also summarized and discussed as part of Section 5.4.

Available flow data from Environment Canada that were used in the flow analyses are summarized in Table 3-2.



LEGEND

- CITY / TOWN / COMMUNITY
- ENVIRONMENT CANADA FLOW MONITORING STATION
- TECK FLOW MONITORING STATION
- CANADIAN PACIFIC RAILWAY
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- WATERCOURSE
- BRITISH COLUMBIA - ALBERTA BORDER
- COAL MINING OPERATION
- DESIGNATED AREA
- FIRST NATIONS RESERVE
- PROVINCIAL PARK
- WATERBODY

15 0 15

SCALE 1:500,000 KILOMETRES

REFERENCE

Communities obtained from The Atlas of Canada, Natural Resources Canada. Roads obtained from Geobase. Parks/ protected areas, First Nations and railroad data obtained from Geogratis. Provincial boundary and hydrography data obtained from IHS Energy Inc. USA data obtained from ESRI. Projection: UTM Zone 11 Datum: NAD 83

PROJECT

TECK COAL ELK VALLEY
WATER QUALITY PLAN

TITLE

FLOW MONITORING STATIONS FOR LOCAL WATERSHEDS WITH WASTE ROCK SPOILS

Teck

PROJECT No. 13-1349-0006			SCALE AS SHOWN	REV. 0
DESIGN	HJ	12 May 2014	FIGURE 3-1	
GIS	DR	27 Jun. 2014		
CHECK	JC	27 Jun. 2014		
REVIEW	AC	27 Jun. 2014		

I:\CLIENTS\TECK_COAL\13-1349-0006\Mapping\MXD\Hydrology\B-Hydrology-017-GIS-TeckMonitoringStations.mxd

Table 3-1 Teck Flow Data for Local Watersheds with Waste Rock Spoils

Data Source	Watershed and Monitoring Station	Completeness of Flow Data	Does Flow Data Represent Total Watershed Flow?
Fording River Operations	Clode Creek at Clode Pond (FR_CC1)	Active station Instantaneous flow measurements since 1995 (typically weekly April to June, otherwise monthly) Completeness – good (only 6% of months without a flow measurement)	No – low mean annual runoff suggests not all flow is reporting to gauge location. FRO staff confirms that water is withdrawn for dust suppression and that some of the flow may bypass the pond.
	Kilmarnock Creek (FR_KC1)	Active station Instantaneous flow measurements since 1995 (mix of seasonal and year-round) Continuous monitoring since 1997 (seasonal, mostly May to September) Completeness – fair (good peak data but limited winter flows)	Uncertain – potential subsurface flow paths (the monitoring location is in a realigned manmade channel). The largest effect may be seen on low flows.
	Lake Mountain Creek (FR_NGD1)	Active station Instantaneous flow measurements since 1995 (typically weekly mid-March to mid-July, otherwise monthly) Completeness – fair (gaps in 17% of months, mostly in winter)	Uncertain - extensive modifications to flow paths due to mining activities
	Henretta Creek (FR_HC1)	Active station Instantaneous flow measurements since 1996 (year-round from 2007 onwards) Continuous monitoring since 1998 (seasonal, mostly May to September) Quality – fair (good peak data but limited winter flows)	Yes - no known issues
Greenhills Operations	Cataract Creek at Cataract Pond (GH_CC1)	Active station Instantaneous flow measurements since 1993 (typically weekly April to July, otherwise monthly) Completeness – good (only 3% of months without a flow measurement)	Yes - no known issues
	Porter Creek (GH_PC1)	Active station Instantaneous flow measurements since 1993 (typically weekly April to July, otherwise monthly) Completeness – good (only 6% of months without a flow measurement)	Yes - no known issues
	Greenhills Creek at sediment pond decant (GH_GC1)	Active station Instantaneous flow measurements since 1993 (typically weekly April to July, otherwise monthly). No data mid-2004 to mid-2009 Completeness – poor (gaps in 44% of months)	Uncertain – low mean annual runoff suggests not all flow is reporting to gauge location and some flow may bypass the pond during freshet
	Swift Creek at Swift Pond (GH_SC1 + GH_SC2)	Active station Instantaneous flow measurements since 1995 (typically weekly April to July, otherwise monthly). No data mid-2004 to mid-2009. Completeness – poor (gaps in 44% of months)	No - high infiltration in sediment pond area (i.e., not all flow is measured at the station)
	Thompson Creek (GH_TC2)	Active station Instantaneous flow measurements since 1993 (typically weekly April to July, otherwise monthly). Completeness – good (adequate data, gaps in 14% of months, mostly in winter)	Uncertain – low mean annual runoff suggests not all flow is reporting to gauge location

Table 3-1 Teck Flow Data for Local Watersheds with Waste Rock Spoils

Data Source	Watershed and Monitoring Station	Completeness of Flow Data	Does Flow Data Represent Total Watershed Flow?
Greenhills Operations	Leask Creek upstream of Leask Pond (originally GH_LC1, then renamed GH_LC2 in 2005)	Active station Instantaneous flow measurements since 1993 (typically weekly April to July, otherwise monthly). Limited winter flows before 2005. Completeness – fair (adequate data in high flow months but gaps in winter flows)	No - flow goes subsurface in the vicinity of the sediment pond
	Wolfram Creek (including Cougar South pit) upstream of Wolfram Pond (originally GH_WC1, then renamed GH_WC2 in 2005)	Active station Instantaneous flow measurements since 1993 (typically weekly April to July, otherwise monthly). Limited winter flows. Completeness – fair (adequate data in high flow months but gaps in winter flows)	No - flow goes subsurface in the vicinity of the sediment pond
Line Creek Operations	No Name Creek	Active station Instantaneous flow measurements since 1995 (typically weekly April to mid-July, otherwise monthly). Completeness – poor (missing data in database from 2004 onwards)	Uncertain – missing data
	West Line Creek	Instantaneous flow measurements from 2001 to 2006 in the EQWIN database (variable sampling frequency). 2007 and 2008 daily flow hydrographs, based on water level measurements and rating curves developed by LCO Continuous water levels and Instantaneous flow measurements from 2009 onwards for a new gauging station Completeness – good since 2009 (older flow data are unreliable)	No – older flow data are unreliable and more recent data suggests that some of the watershed flow goes subsurface and does not report to the gauge location
	Line Creek downstream of West Line Creek	Instantaneous flow measurements since 1990 (variable sampling frequency) Completeness – poor (missing data in EQWIN database)	Uncertain – missing data
	Line Creek at the mouth	Active Daily flow data from 1971 to 2012 from Environment Canada Completeness – good	Yes - no known issues
Elkview Operations	Milligan Creek (EV_MG1)	Active station Instantaneous flow measurements since 1992 (typically weekly March to June, otherwise monthly). Completeness – poor (gaps in 42% of months)	No – some flow goes subsurface in the vicinity of the sediment pond
	Bodie Creek (including pit watershed) (EV_BC1)	Active station Instantaneous flow measurements since 1992 (typically weekly March to June, otherwise monthly). Completeness – fair (gaps in 17% of months)	No – some flow goes subsurface in the conveyance system and in the vicinity of the sediment pond In-pit water management activities (e.g. temporary storage and pumping) has an effect on flows
	South Pit (EV_SP1)	Active station Instantaneous flow measurements since 2009 (typically weekly March to June, otherwise monthly). Completeness – fair (gaps in 28% of months, mostly in fall and winter)	Yes – no known issues
	Gate Creek (EV_GT1)	Active station Instantaneous flow measurements since 1992 (typically weekly April to June, otherwise monthly). Completeness – poor (gaps in 30% of months)	No – some flow goes subsurface in the vicinity of the sediment pond

Table 3-1 Teck Flow Data for Local Watersheds with Waste Rock Spoils

Data Source	Watershed and Monitoring Station	Completeness of Flow Data	Does Flow Data Represent Total Watershed Flow?
Elkview Operations	Erickson Creek at the mouth (EV_EC1)	Active station Instantaneous flow measurements since mid-2004 (typically monthly). Since 2009 weekly instantaneous flow measurements April to June. Completeness – poor (limited high flow data and gaps in 16% of months)	No – before 2011 some high flows were not measured due to safety issues at the measuring location
	Harmer Creek at Harmer Dam (includes EVO Dry Creek) (EV_HC1)	Active station Instantaneous flow measurements since 1992 (typically weekly March to June, otherwise monthly). No data 1997 to 2000 Completeness – fair (gaps in 33% of months)	Yes - no known issues
	Six Mile Creek Pond Decant (EV_SM1)	Active station Instantaneous flow measurements since 1992 (typically weekly March to June, otherwise monthly). Limited data 1997 to 2000 Completeness – poor (gaps in 30% of months)	No – some flow goes subsurface in the vicinity of the sediment pond
	Goddard Creek (EV_GC2)	Active station Instantaneous flow measurements since 1992 (typically weekly March to June, otherwise monthly). Completeness – fair (gaps in 22% of months)	Yes - no known issues

Table 3-2 Environment Canada Daily Flow Data

Station Name	Station Number	Data Period
Line Creek at the mouth	08NK022	1971 to present
Fording River at the mouth	08NK018	1970 to present
Elk River near Natal	08NK016	1950 to present
Grave Creek at the mouth	08NK019	1970 to 1998
Michel Creek below Natal	08NK020	1970 to 1996
Hosmer Creek above Diversions	08NK026	1981 to present
Elk River at Fernie	08NK002	1919 to present
Elk River at Philips Bridge	08NK005	1924 to 1996
Bull River near Wardner	08NG002	1914 to 2012
Kootenay River at Fort Steele	08NG065	1963 to 1996

3.2 Site Information

The following information was provided by each of the Teck operations and forms the basis of the hydrological analyses in support of the Plan:

- 2013 mine plan reports and other mine plan information
- future waste rock schedules corresponding to planned projects that are sufficiently well defined to include in the Plan (herein referred to as mine plans)
- snapshots of surface topography (including waste rock dump surfaces and backfilled waste rock) corresponding to the mine plans
- snapshots of mined-out pit topography (without backfill) corresponding to the mine plans
- water management plans
- historical (up to 2012) waste rock volumes
- reclamation plans.

Additional site information is provided in the Elk Valley Water Quality Plan Site Conditions Report (Teck 2014c).

3.3 Other Information

3.3.1 Previous Hydrology Baseline and Assessment Work

The hydrological analyses for the Plan build on experience and analyses done in support of other Teck projects in the Elk Valley. Information on the approach used is provided herein.

3.3.2 Historic Flow Data Relative to Average Conditions

Historic flow data cover a range of hydrologic conditions including wet and dry periods. Table 3-3 shows the occurrence of dry (low-flow) and wet (high-flow) months and water years (April through March) at two representative locations: the mouth of the Fording River, and Elk River at Fernie. The information is presented for the 2004 to 2012 water quality model calibration validation period, as percentiles of observed monthly or annual flow for the period of record (1995 to 2013). For example, if the January flow in a particular year is in the 80th percentile then it is higher than 80% of the January flows in the period of record. The percentiles for the incomplete 2013 water year are also provided in Table 3-3 for information purposes, based on preliminary data obtained from Environment Canada.

Months and water years were considered dry (no shading) if their flows were below the 30th percentile, and wet (dark shading) if flows were above the 70th percentile. The remaining, average flows are shown in light shading. Overall, for the 2004 to 2012 period, the water years of 2004, 2009, 2010 were dry years and 2005, 2011 and 2012 were wet years. The 2012 water year was the wettest.

Table 3-3 Dry and Wet Months and Water Years for the Water Quality Model Calibration Period

Year	Location	Flow as a Percentile of the Distribution from the Period of Record												
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Water Year
2004	Fording River at the mouth	61%	0%	6%	33%	100%	100%	83%	78%	89%	94%	100%	100%	18%
	Elk River at Fernie	72%	17%	6%	11%	72%	100%	89%	67%	83%	94%	100%	67%	33%
2005	Fording River at the mouth	50%	39%	67%	67%	89%	94%	100%	94%	100%	100%	94%	94%	94%
	Elk River at Fernie	33%	39%	50%	61%	61%	94%	100%	94%	89%	100%	94%	72%	72%
2006	Fording River at the mouth	94%	78%	56%	28%	28%	44%	39%	83%	83%	50%	33%	89%	59%
	Elk River at Fernie	89%	100%	39%	22%	17%	22%	22%	83%	61%	72%	78%	100%	56%
2007	Fording River at the mouth	33%	72%	39%	22%	11%	11%	56%	28%	50%	39%	67%	39%	41%
	Elk River at Fernie	83%	83%	56%	39%	6%	33%	33%	39%	50%	28%	56%	22%	50%
2008	Fording River at the mouth	11%	67%	44%	56%	22%	39%	17%	17%	11%	6%	6%	6%	35%
	Elk River at Fernie	11%	67%	33%	56%	22%	6%	11%	6%	11%	17%	6%	0%	39%
2009	Fording River at the mouth	28%	11%	17%	17%	83%	72%	22%	44%	6%	61%	78%	50%	6%
	Elk River at Fernie	6%	0%	11%	17%	67%	11%	6%	17%	0%	39%	22%	17%	6%
2010	Fording River at the mouth	44%	22%	22%	44%	39%	89%	78%	50%	67%	44%	56%	28%	29%
	Elk River at Fernie	28%	6%	22%	33%	28%	89%	78%	28%	28%	67%	44%	28%	11%
2011	Fording River at the mouth	17%	50%	72%	89%	33%	33%	72%	56%	61%	67%	72%	61%	71%
	Elk River at Fernie	22%	50%	72%	83%	56%	39%	39%	33%	33%	44%	28%	44%	67%
2012	Fording River at the mouth	100%	89%	83%	100%	78%	61%	50%	89%	72%	78%	83%	78%	100%
	Elk River at Fernie	100%	89%	94%	100%	89%	56%	44%	78%	78%	78%	72%	78%	100%
2013	Fording River at the mouth	67%	100%	89%	78%	94%	83%	89%	67%	44%	-	-	-	-
	Elk River at Fernie	61%	78%	78%	67%	94%	83%	94%	72%	72%	-	-	-	-

Notes:

2013 data is preliminary; "-" = data not available; "water year" = April through March

Characteristics are presented for the water quality model calibration period (2004 to 2012).

Values shown are the percentiles of flows (month or water year) derived from the 19 year period of record (1995-2013).

Dry (low-flow) months or water years are those where flows are less than the 30th percentile (i.e., value < 30%; no shading).

Wet (high-flow) months or water years are those where flows are greater than the 70th percentile (i.e., value > 70%; dark shading).

4 Flow Model

4.1 Selection of Modelling Approach

The modelling approach used to support development of the Plan is based on the following factors:

- Suitability – To generate monthly historical flows and future flow scenarios in local and regional waterbodies that support simulation of concentrations in the water quality model. To predict changes in hydrological characteristics due to changes in land type in watersheds with mining disturbance. To support the incorporation and assessment of various mitigation options for water quality.
- Simplicity – To generate flows for more than 40 tributaries and sub-watersheds, the majority of which are ungauged or have limited good-quality, representative data. The available observed data are generally not sufficient to support calibration and validation of multiple parameters in a complex physically-based model; therefore, a relatively simple approach was preferred.
- Flexibility – To allow incorporation of water management options (e.g., clean water diversions), varying amounts of available data for the operations, and various flow simulation methods.
- Transparency – To enable a clear understanding of the model by reviewers.
- Adaptability – To allow for revisions from updated mine plans.

In the Elk Valley, seasonal runoff is typically snow-dominated, with a strong regional-scale pattern that supports an empirical approach to estimating monthly flows. An empirical model was selected to derive monthly flows for water quality planning purposes, given the hydrologic regime and available data. The fundamental hydrologic processes occurring in watersheds with large waste rock spoil piles are currently being studied but are not yet well-understood.

A physically-based, rainfall-runoff modelling approach was also considered; however, only limited regional data are currently available to support such an application. Long-term local climate data would be required as model inputs at each watershed, and long-term local flow data sets representing the range of land-types and watersheds would be required for calibration and validation. Because of these data gaps and uncertainties and until additional regional data are available, it is unlikely that the added complexity and representativeness of a physically-based or mechanistic model would improve the accuracy of monthly flow estimates at a tributary scale compared to the empirical approach for the purposes of regional planning. The physically-based modelling approach (using UBC Watershed Model) was employed at a local scale for LCO PII Dry Creek, where sufficient data were available.

4.2 GoldSim

A GoldSim model (see Appendix B) was used to automate the simulation of historical and future flows for local watersheds at the mining operations, the Fording River and Michel Creek watersheds, and nodes on the Elk River and Lake Koocanusa. The model was used to perform and amalgamate flow calculations in a simple, flexible, transparent, adaptable and organized fashion, based on empirical methods.

While GoldSim was used to amalgamate and balance flows at each model node, tributary watershed flows were generally derived by transposing representative flows from analogue watersheds (see Section 5), or by an alternative methods when considered more appropriate (see Section 6). Developing the flow model in GoldSim also allows for flow results to be fed directly into the water quality model, since this is also in GoldSim.

5 Flow Simulation Using Representative Hydrographs

5.1 Overview and Equations

In hydrology, flows for target sites are commonly estimated by transposing local flow data from a monitoring location in an analogous watershed with the same hydrological characteristics (i.e., similar hydrological response to precipitation and evaporation demand, and similar climatic patterns) and adequate supporting data. Flows at the analogue and target sites increase and decrease together, or with a consistent timing offset. An analogue watershed is usually geographically close to the target site, and characterized by similar baseflow conditions. To estimate flows for a target site, flows from the analogue watershed are typically normalized by area, and re-scaled to the target watershed.

Watershed properties, together with climatic factors, are the principal causes of variations in hydrologic characteristics between watersheds. These properties include topography (e.g., shape, aspect, elevation, and slope), size, land type, soil profile, storage, and groundwater conditions. Their importance depends on timeframe for which the flow hydrograph is developed. Properties such as shape, slope, size and temporary storage have a large effect on the hydrograph in the short term (e.g., hours to days). On a monthly basis, short-term variations average out, and other properties such as land type, aspect, elevation and baseflow characteristics have a larger influence.

As noted in Section 4.1, seasonal runoff in the Elk Valley is typically snow-dominated, with a strong regional-scale pattern that supports an analogue-watershed approach to estimating monthly flows. At Teck's Elk Valley operations, the flow regime of some watersheds is modified by the presence of large waste-rock spoils. One of the considerations in selecting a flow modelling approach was its ability to account for changes in the flow regime over time due to historic and/or future placement of waste rock.

Available flow data for watersheds in the Elk Valley was reviewed, and analogue watersheds were selected to represent flow regimes for two general land types:

- Natural – corresponding to predominantly forested or vegetated land
- Mining – corresponding to all mining disturbances (pits, spoil areas, roads, plant). The total mining area was further subdivided into areas of waste rock, coarse coal rejects (CCR), pitwall, and reclaimed (revegetated) waste rock.

Four different flow series were identified as representative of natural areas (derived from two analogue watersheds, LCO Dry Creek and Hosmer Creek flow series, and adjusted for timing and/or yield). These series capture the spatial variation in natural land in the Elk Valley, and the corresponding variation in flow characteristics (e.g., climatic variation, timing of freshet). One flow series (from analogue watershed Cataract Creek) was available to represent the mining land types. About 66% of the Cataract Creek watershed area is covered with spoil. The analogue watersheds, their locations, and characteristics are described in detail in Section 5.3 and Section 5.4.

All representative hydrographs were normalized by watershed area (i.e., divided by the area of the analogue watershed to obtain flow per unit area). The locations at which the representative hydrographs were applied are summarized in Section 5.5.

Flows for target watersheds were developed by applying the appropriate representative hydrograph based on land type(s), and adjusting for differences in overall yield (mean annual runoff) due to elevation differences between the target and analogue watersheds. The following equations were used to calculate flows in the model:

$$\boldsymbol{Total\ Flow} = Flow_{natural} + Flow_{mining}$$

$$\boldsymbol{Flow_{natural}} = reduction\ factor \times [analogue\ hydrograph]_{natural} \times area_{natural} \times \frac{yield_{natural\ area}}{yield_{analague\ watershed\ (natural)}}$$

$$\boldsymbol{Flow_{mining}} = [analogue\ hydrograph]_{mining} \times area_{mining} \times \frac{yield_{mining\ area}}{yield_{analogue\ watershed\ (mining)}}$$

Notes:

"*Analogue hydrograph*" is a representative hydrograph that has been normalized by watershed area (i.e., flow in L/s/km^2).

"*Yield*" is determined from generic curves relating mean annual runoff to elevation (see Section 5.5.2).

"*Reduction factor*" is a reduction factor that is only applied to Hosmer Creek representative hydrographs (see Section 5.3.3).

Flows for mining sub areas were also derived for use in the water quality model. Total mining flows were divided into flows associated with waste rock, CCR, pitwall, and reclaimed waste rock, and were calculated as a fraction of total mining flows based on contributing area. For example:

$$\boldsymbol{Flow_{CCR}} = Flow_{mining} \times \frac{area_{CCR}}{area_{mining}}$$

The components of the equations are described in the sections that follow.

5.1.1 Estimation of Historical Flows

For the purpose of calibrating the water quality model, historical monthly average flows for 1995 to 2012 were required for each watershed and at each water quality node. This timeframe was chosen for the following reasons:

- It corresponds to the period of water quality data used for water quality model calibration purposes
- Local and regional flow data are available for comparison with simulated flows
- Concurrent representative flow series are available from analogue natural and mined watersheds
- It is long enough to generate the required flow statistics (mean monthly flows and 1-in-10 year high and low monthly average flows). A frequency analysis requires a sufficient period of record to allow a probability distribution (i.e., curve) to be fitted to the data with reasonable confidence. Flows with a 10-year recurrence interval from a curve fitted to 15 years of data generally allow for a good estimate.

Flow statistics were generated from data for the period 1995 to 2010, and are provided in Section 5.8 and Section 6.4. While the historical period was later extended to 2012 for validation purposes, the statistics remain unchanged. For example, data from Environment Canada hydrometric station Fording River at the mouth (08NK018), operational since 1970, were used to compare the 1995 to 2010 historical period to the longer period of record. The results for the two periods are consistent in terms of the same mean flow (7.9 m^3/s), similar flow duration curves (Figure 5-1) and similar annual hydrographs (i.e., mean monthly flows) (Figure 5-2).

Figure 5-1 Fording River at the Mouth (08NK018) Flow Duration Curves

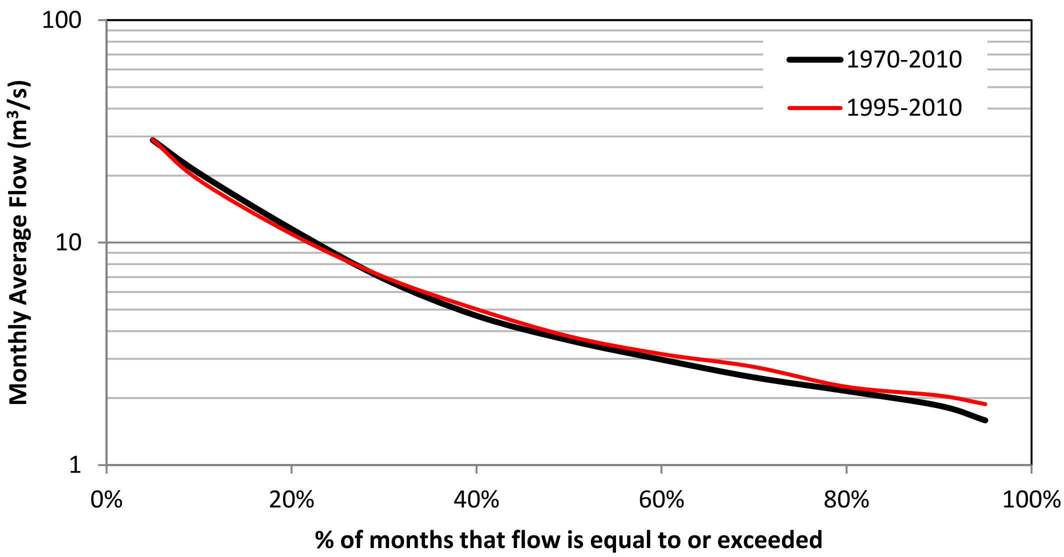
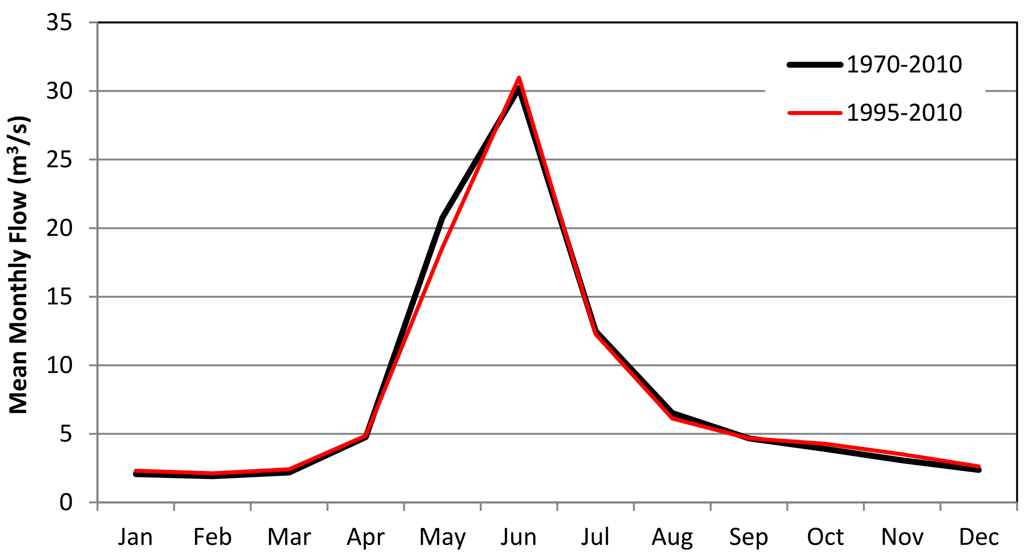


Figure 5-2 Fording River at the Mouth (08NK018) Annual Hydrographs



For each target watershed, a topographic snapshot of current watershed conditions (i.e., current mined-out contours, surface contours and disturbance area) was used to determine the area and average elevation of each land type (see Section 5.5.1). Generic runoff curves were then used to assign an average yield to the land type at the specified average elevation (see Section 5.5.2).

5.1.2 Estimation of Future Flows and Flow Statistics

Future flows were generated using the same method as historical flows. The model was run for three statistical future scenarios, to provide a range of flows for the water quality modelling:

- mean monthly flow
- high monthly average flow, based on 1-in-10 year high flow statistics (see Section 5.8)
- low monthly average flow, based on 1-in-10 year low flow statistics (see Section 5.8).

The statistics were developed for calendar months, with each month developed independently. Additional details on future flow scenarios are provided in Section 5.9 and Section 6.4. These scenarios were chosen with consideration of BC Ministry of Environment “Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators” (BC MOE 2012). The guidance document advises using a 10-year return period to define the critical high- and low-flow situations for the protection of aquatic ecosystems.

Topographic snapshots were available for the mine plans for each operation. Each watershed was analyzed to determine the timing of changes in future watershed characteristics (e.g., boundary changes, pit filling, start and end of waste rock placement, change in water management). Area and elevation inputs were defined for selected snapshot years, and interpolated for intervening years. Watershed changes over time for each operation are summarized in the Site Conditions Report (Teck 2014c).

The goal of the flow model is to broadly capture planned changes in watershed characteristics over the mine life, at a scale suitable for water quality planning purposes. The model does not include all short-term events (e.g., a few years), temporary events, or upsets that may affect flows (e.g., filling periods for relatively small pits, short-term changes to diversions or discharge locations).

5.2 General Assumptions

General assumptions on which the flow model is based are summarized in Table 5-1. The supporting rationale and confidence levels for each assumption, also provided in the table, were based on a qualitative assessment. This information, in combination with similar information for other components and inputs to the water quality model, provides context for the use of the water quality model to support planning.

Table 5-1 General Assumptions in the Flow Modelling

Assumption	Confidence and Rationale	Sensitivity of Flow Model to Assumption
The drainage system is driven by the topography of the underlying mined-out or original surface, and therefore the placement of backfill and waste rock spoils (and current reclamation practice) does not affect drainage paths or spill elevations of pit lakes and backfilled pits.	High confidence This assumption is used to define drainage boundaries for input to the flow model. Anecdotal evidence from site personnel indicates that the dump surfaces typically do not generate substantial runoff. In addition, the base layer of top-down spoils acts as a rock drain, allowing flow of water along the natural or mined-out surface under the spoil.	The sensitivity of the model to this assumption varies with watershed and scale. Regional tributaries and rivers (Fording River and Michel Creek) have low sensitivity because of their large size and relatively small contribution of flow from mining areas. Small mine-affected watersheds have high sensitivity to uncertainty in boundaries and spill elevations. The total flows at various locations (e.g., to a completed pit, discharge point, or regional river node) have high sensitivity to the assumed drainage system, which defines how sub-watershed flows are combined in the model.
(A) Watershed areas are constant over the historical period in the model (fixed to 2010 watershed areas). (B) Historical mining area increases are proportional to historical waste rock volume.	Generally, medium confidence at the start of the historical period (1995) and high confidence at the first snapshot (2010). Confidence will vary between watersheds. The confidence is relatively high where the majority of waste rock in a watershed was placed before 1995 (start of the historical period in the model), and the area difference between 1995 and 2010 is small. Mining began in 1969 at EVO, 1972 at FRO and CMO, 1980 at LCO, and 1982 at GHO. For watersheds where mining and spoil placement started between 1995 and 2010, confidence is lower. Confidence is also lower for watersheds with changes in boundaries due to mining, or where historical pit-water management activities are unknown.	Generally, medium sensitivity at the start of the historical period (1995) and low sensitivity at the first snapshot (2010). Sensitivity will vary between watersheds. Watersheds with historical activities that may have altered watershed boundaries (e.g., mining, pit water management) may be sensitive to Assumption A. Watersheds with a large variation in historical waste rock volume from 1995 to 2010, and a large proportion of mining area, will have the highest sensitivity to Assumption B.
Future area of spoils and area of watersheds vary linearly between snapshots.	Medium to high confidence Confidence will vary between watersheds and will depend on the information provided in the mine plan, the number of snapshots included in the model to represent the mine plan, and the variation in model inputs between snapshots. Confidence is lower where there is large variation in model inputs between snapshots.	High (local watersheds with large proportions of mining area). Low (local watershed with small proportions of mining area, and regional creeks and rivers). The sensitivity of the model to this assumption varies with watershed and scale. Small watersheds are sensitive to the timing of future boundary changes. Watersheds with high proportions of mining area and large variations of planned mining area are also sensitive. Regional tributaries and rivers (Fording River and Michel Creek) will remain predominantly natural in the future and have lower sensitivity.

Table 5-1 General Assumptions in the Flow Modelling (continued)

Assumption	Confidence and Rationale	Sensitivity of Flow Model to Assumption
Short-term, temporary watershed events and upsets that may affect flows will have no substantial effect on water quality planning and are not included in the flow model. [a]	Medium to high confidence Confidence will be lower at the start of the future predictions and higher in the medium- to long-term. The types of events and upsets that are not included in the model include short-term reductions in flow due to temporary storage, filling of relatively small pits, and short-term changes to diversions or discharge locations. In the context of water quality planning over the mine life (multiple decades), these events are too short in duration to have a substantial effect.	The sensitivity of the model to this assumption varies with watershed. Watersheds with mining areas or that receive flows from watersheds with mining areas are potentially sensitive.
Watersheds in the designated area have similar baseflow characteristics and baseflow yield varies in proportion to total watershed yield.	Low confidence (local tributaries) Medium confidence (regional tributaries and rivers) The flow model simulates the total flow from each watershed, which inherently includes baseflow as part of the total hydrograph. Baseflows for regional tributaries and rivers are defined with relatively high confidence in the model (due to availability of observed winter flow data for comparison and calibration purposes). Confidence is low for upper watershed nodes and local tributaries as the availability of winter flow data are limited and the quality of the data are uncertain. Therefore, baseflow could not be reliably calibrated. Further sensitivity analysis of this has not been undertaken. The next steps are to evaluate finer scale modelling if/where required.	Medium (local tributaries) Low (regional tributaries and rivers)

Table 5-1 General Assumptions in the Flow Modelling (continued)

Assumption	Confidence and Rationale	Sensitivity of Flow Model to Assumption
The selected analogue watersheds (LCO Dry Creek and Hosmer Creek) representing the natural land type have the same hydrological characteristics as the natural area in the target watersheds.	Low to medium (local tributaries) High (regional creeks and rivers) Confidence is generally lower for individual months out of the historical period and higher for the overall pattern of flows (leading to higher confidence in the mean monthly hydrograph, which is used as one of the scenarios for future predictions). Confidence is also higher for creeks with suitable observed flow data for comparison and calibration of the flow model. For example: • Fording River at the mouth has the highest confidence (quality data from an Environment Canada station, and a good fit between observed and simulated flows). • Grave Creek and Michel Creek are also relatively high-confidence, for the same reasons. • Kilmarnock Creek has medium confidence in high flows, and lower confidence in low flows (continuous seasonal station with limited winter instantaneous flow measurements and an acceptable fit between observed and simulated flows). • Watersheds such as Harmer, Porter, Thompson, Leask, Wolfram and Clode have medium-low confidence (instantaneous flow data suitable for some comparisons - such as timing of flows - but low data quality and/or concerns about unrepresentative data limit further statistical comparisons). • Watersheds such as Erickson, EVO Dry, and Gate, have low confidence (low data quality, known unrepresentative data are issues). • Bodie Creek watershed has low confidence (low data quality, known unrepresentative data are issues, modifications to flow hydrograph due to pit water management not captured in flow model). Many of the Teck flow monitoring stations were installed to satisfy other site requirements (such as reporting for effluent discharge permits) and are located accordingly (e.g., at decants for sediment ponds). Flow measurements at these locations are often unrepresentative of the total yield of the watershed because of issues such as conveyance and sediment pond leakage, bypass and measurement challenges (e.g., safety concerns at high flows).	High (local and regional watersheds with large proportions of natural area) Low (local watersheds with small proportions of natural area) The sensitivity of the model to the natural hydrograph varies with watershed and scale. Watersheds with the highest proportion of natural area are the most sensitive. Regional creeks and rivers (Fording River and Michel Creek) are predominantly natural and have high sensitivity.

Table 5-1 General Assumptions in the Flow Modelling (continued)

Assumption	Confidence and Rationale	Sensitivity of Flow Model to Assumption
The selected analogue watershed (Cataract Creek) representing the mining land type has the same hydrological characteristics as the mining area in the target watersheds.	Low confidence The Cataract Creek watershed has the largest proportion of waste rock of all the monitored watersheds, a relatively small natural area, and relatively good quality, representative instantaneous flow data (see Section 5.4 for a summary review of the available data). It was the best available watershed and was selected for use in defining the hydrological characteristics of the mining land type. However, it is not an ideal analogue. The watershed has extensive mining activity over the period of record, including active pit water management and storage of water in the completed pit, with undefined effects on the hydrograph. From a flow interpretation perspective, mining activity in the upper watershed is relatively simple (a single large pit). Pit water was actively discharged to Cataract Creek until 2009, when the pit was completed and started to fill with water. Pit filling is ongoing and the pit sub-watershed does not currently contribute surface flows to Cataract Creek. Before 2009, the pitwall area in Cataract Creek watershed may have had a dominant influence on the hydrograph shape (i.e., higher runoff masking the effects of attenuation from the waste rock). The historical and ongoing effect of the pit on groundwater flows to Cataract Creek is also unknown.	High (local watersheds with large proportions of mining area) Low (local watershed with small proportions of mining area, and regional tributaries and rivers) The sensitivity of the model to the mining hydrograph varies with watershed and scale. Watersheds with the highest proportion of mining area are the most sensitive. Regional creeks and rivers (Fording River and Michel Creek) are predominantly natural and have lower sensitivity.
Annual losses due to “wetting” of the waste rock dumps are negligible.	Low confidence (short-term) Medium confidence (long-term) The simulation of flow from waste rock areas in the model relies on a representative hydrograph from Cataract Creek watershed with a relatively mature dump (spoil placement over a period of about 30 years). The mean annual yield of Cataract Creek (based on instantaneous flow measurements) is similar to regional averages from watersheds without dumps; however, it is not possible to make a definitive conclusion about losses due to “wetting” of the dump from the available data.	

[a] Short-term watershed events and upsets that may affect flows include those with up to a few years duration and temporary changes (e.g. temporary reduction in flow in a creek due to filling of a small upstream storage volume in a pit at end-of-mining).

5.3 Representative Hydrographs for Natural Areas

5.3.1 Selection and Application of Analogue Watersheds

As noted in Section 5.1, variation in watershed properties, together with climatic factors, are the principal causes of differences in hydrologic characteristics. While shape, slope, size and temporary storage affect short-term hydrographs, longer-term monthly hydrographs in the Elk Valley are influenced more strongly by land type, aspect, elevation, and baseflow. The result is that analogue watersheds that capture regional (north-south) variations in precipitation are most appropriate for use in estimating flows at ungauged sites. The increasing gradient in precipitation from north to south is evident based on a stronger pattern of fall storms in Michel Creek than in Fording River to the north. This is also supported by mean annual precipitation at Fording River Cominco station (617 mm at 1585 m elevation), Sparwood station (613 mm at 1138 m elevation), Andy Goode station (758 mm) in Michel Creek watershed and Fernie station (1227 mm at 1001 m elevation).

Flow data from two analogue watersheds (LCO Dry Creek in the north and Hosmer Creek in the centre of the designated area) were used to generate four representative hydrographs, to derive flows for the natural watershed areas. The hydrology designated area is large, and a variety of representative hydrographs were required to adequately represent variations in natural flow characteristics. Table 5-2 summarizes the representative hydrographs, and the sections that follow discuss how they were generated and why they were determined to be the best fit for the watersheds along the Elk Valley.

Table 5-2 Representative Hydrographs for Natural Areas

Land Type	Analogue Watershed	Representative Hydrograph Name	Watersheds Where Applied	Comments
Natural	LCO Dry Creek (north designated area)	LCO Dry Creek Revised	FRO (except Kilmarnock Creek) GHO (except Leask, Wolfram, and Thompson creeks) LCO Dry Creek Fording River tributaries (except Line Creek)	LCO Dry Creek is a tributary to the Fording River; the hydrograph is representative of the pattern of flows in these upper (northern) Elk Valley watersheds.
		LCO Dry Creek Shifted (–3 weeks)	GHO Leask, Wolfram, and Thompson creeks	Accounts for earlier freshet in these lower elevation and predominantly south-west facing slopes that drain to the Elk River
	Hosmer Creek (central designated area)	Hosmer Shifted (+1 week)	CMO Michel Creek tributaries EVO local creeks	Hosmer Creek is a tributary to the Elk River, located between Sparwood and Fernie, and is relatively close to CMO and EVO; it provides a better derivation of the pattern of flows in Michel Creek watershed and at EVO compared to the LCO Dry Creek hydrograph.
		Hosmer Shifted (+3 weeks)	FRO Kilmarnock Creek	The Hosmer Creek hydrograph provides a better derivation of peak flows in Kilmarnock creek watershed than the LCO Dry Creek hydrograph; the shift accounts for later freshet at Kilmarnock Creek due to higher elevation and location further to the north.

5.3.2 LCO Dry Creek Analogue Watershed

LCO Dry Creek is a tributary of the Fording River adjacent to the Line Creek watershed at LCO (Figure 2-1), with minimal mining disturbance. Hydrological modelling was undertaken for the LCO Dry Creek watershed as part of the environmental assessment conducted for the LCO Phase II project (Teck 2011a). Details of the methods, calibration and validation results for the hydrologic model used in the assessment (the University of British Columbia model) are provided in Teck 2011a and in Appendix D to this report. The modelling period was extended to 2012 as part of follow-up work for the LCO Phase II project.

The simulated flow series at LCO Dry Creek (under baseline natural conditions) from 1995 to 2012 was normalized by watershed area to derive a representative hydrograph for natural areas (Figure 5-3).

5.3.2.1 Baseflow Adjustment

The original LCO Dry Creek representative hydrograph was applied to all of the natural areas in the Fording River watershed. This approach was used to simulate monthly average flow at the mouth of the Fording River (i.e., node FR5 in the flow model), which was then compared to the observed flow at the Environment Canada station (08NK018), as shown in Figure 5-4. Application of the original LCO Dry Creek representative hydrograph slightly overestimated winter baseflows relative to observed conditions. Winter baseflows are important because the highest concentrations of some constituents currently occur during these low-flow months; as a result, the original hydrograph was adjusted down by a constant flow magnitude of 1.4 L/s/km^2, to obtain a better fit with observed flow at the mouth of the Fording River. Figure 5-3 shows the original and revised LCO Dry Creek representative hydrographs. Figure 5-4 shows simulated and observed flows at the mouth of the Fording River, on a log scale to illustrate the low flows more clearly. Figure 5-5 shows flow duration curves. The results demonstrate that there is an improvement to the baseflow for the simulated Fording River flows after adjusting the LCO Dry Creek representative hydrograph, with little effect on average and high flows. Additional model performance statistics and graphs are presented in Appendix A.

The application of the revised LCO Dry Creek representative hydrograph to natural areas in the Elk Valley is described in Section 5.5.

Figure 5-3 LCO Dry Creek Representative Hydrograph, 1995-2012, Original and Revised

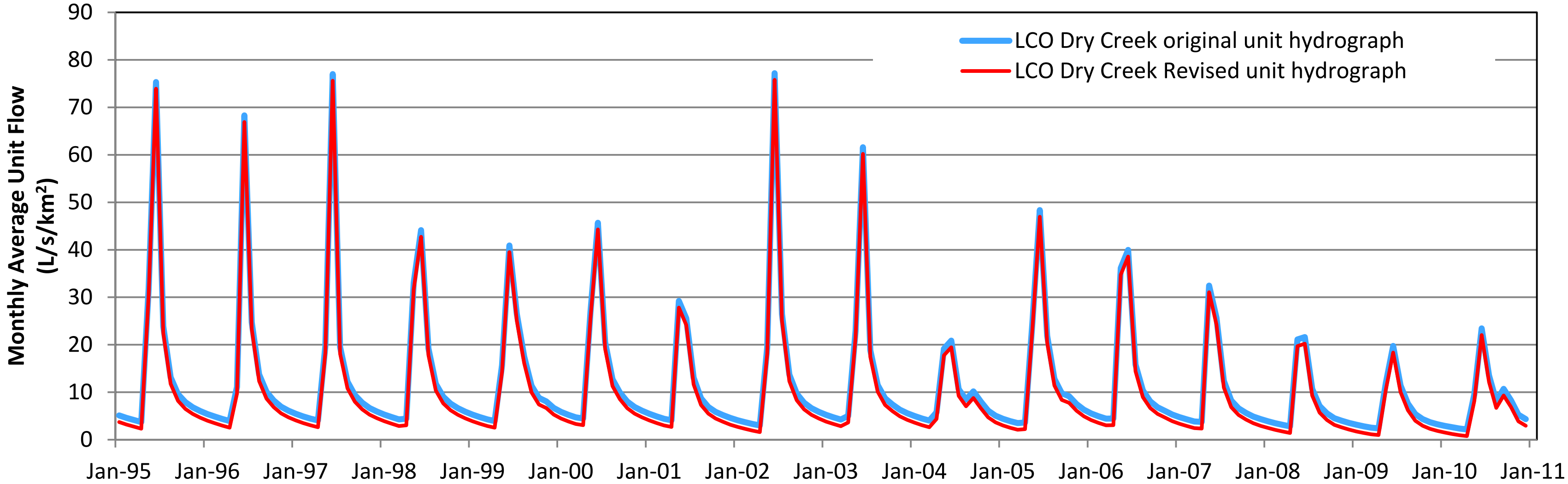


Figure 5-4 Fording River at the Mouth, Simulated and Observed Flows, 1995-2010

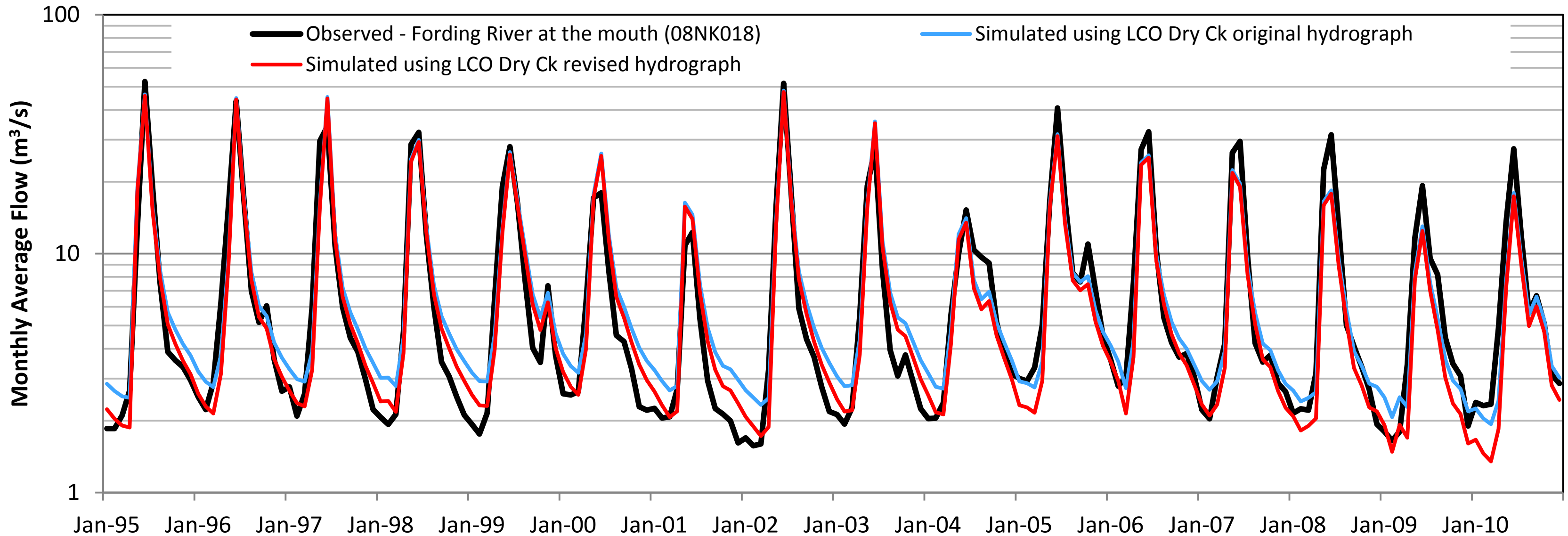
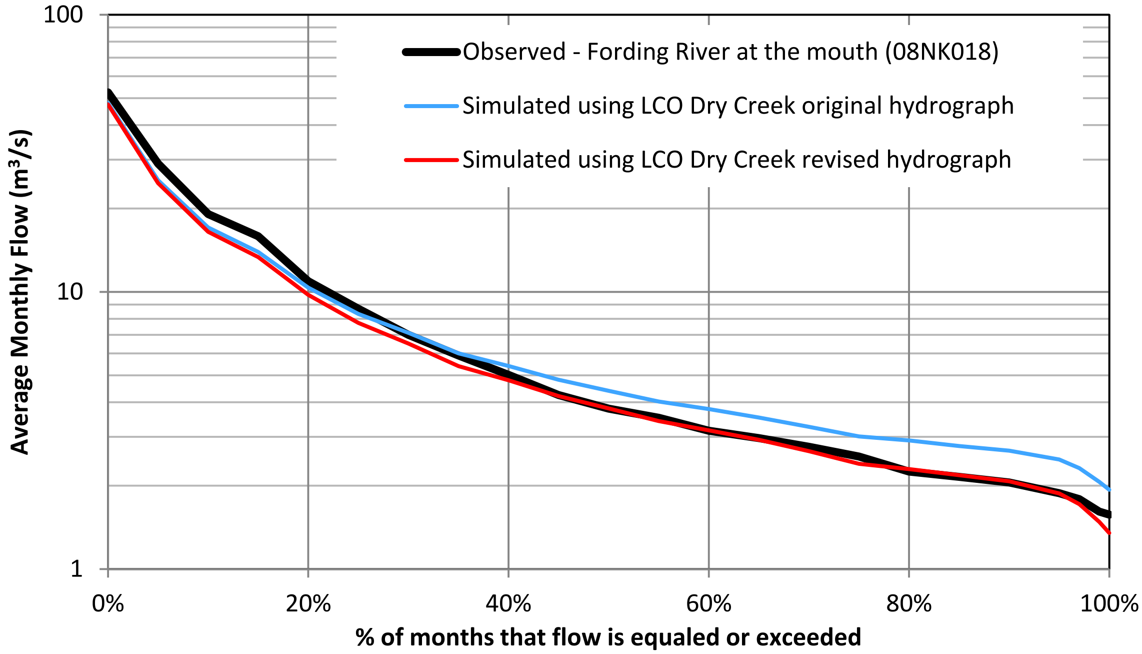


Figure 5-5 Flow Duration Curves for Fording River at the Mouth, Simulated and Observed Flows, 1995-2010



5.3.2.2 Timing Adjustment

LCO Dry Creek (the analogue watershed) has an average elevation of about 2,000 meters above sea level (masl) and a mixture of slope orientations. Watersheds on the west side of Greenhills Ridge at GHO, namely Leask, Thompson and Wolfram creeks, have lower average elevations (about 1,650 masl), and slopes that are predominantly south-west facing. The relatively warmer temperatures at these target watersheds tend to result in earlier snowmelt. Therefore, the LCO Dry Creek representative hydrograph was adjusted to account for a generally earlier freshet. This involved shifting the LCO Dry Creek daily hydrograph back three weeks, to better fit the runoff pattern shown at Thompson Creek (station GH_TC2). The LCO Dry Creek Shifted hydrograph was created by calculating average monthly flows from the shifted daily series, and then applying the baseflow adjustment (described in Section 5.3.2.1). The result is shown in Figure 5-6, along with the LCO Dry Creek Revised hydrograph for comparison.

The timing adjustment was based on comparison with observed monthly average flows calculated from instantaneous flow data for Thompson Creek (station GH_TC2). Figure 5-7 shows simulated and observed Thompson Creek flows. Using the LCO Dry Creek Revised hydrograph, the timing of simulated peaks matched the observed peaks in 5 of the 16 years of flow simulation (with the peaks in the other years trailing). Using the LCO Dry Creek shifted hydrograph, the timing of simulated peaks matched the observed peaks in eight years (with four years being early and three years being late). The results show an improved agreement between the timing of the peaks using the shifted hydrograph.

Figure 5-6 LCO Dry Creek Representative Hydrographs, 1995-2012, Revised and Shifted (-3 weeks)

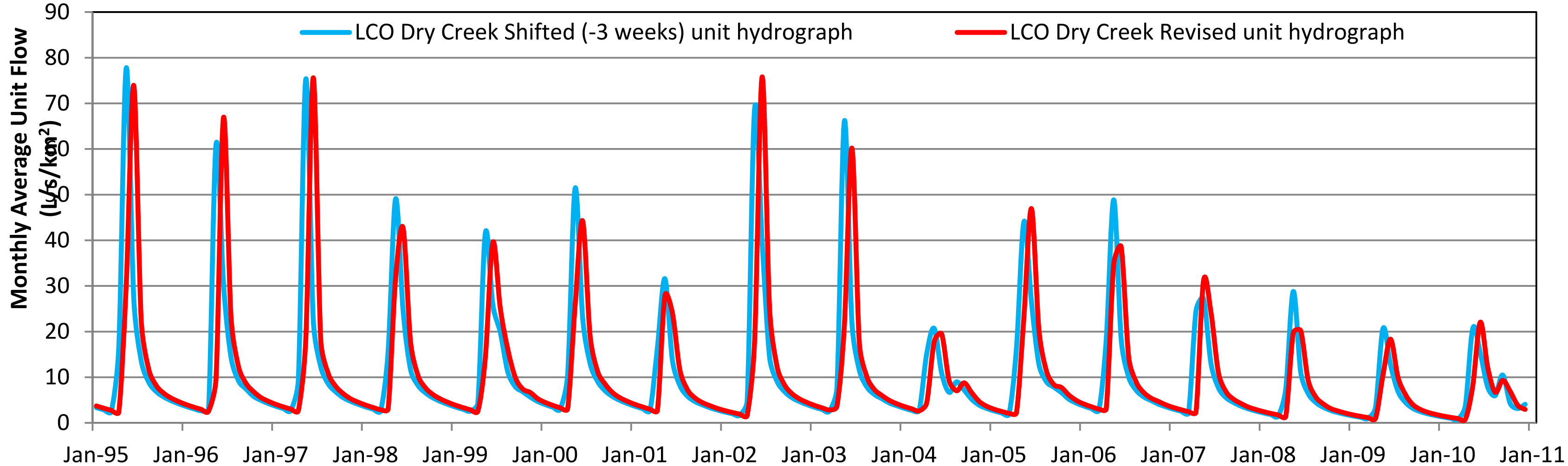
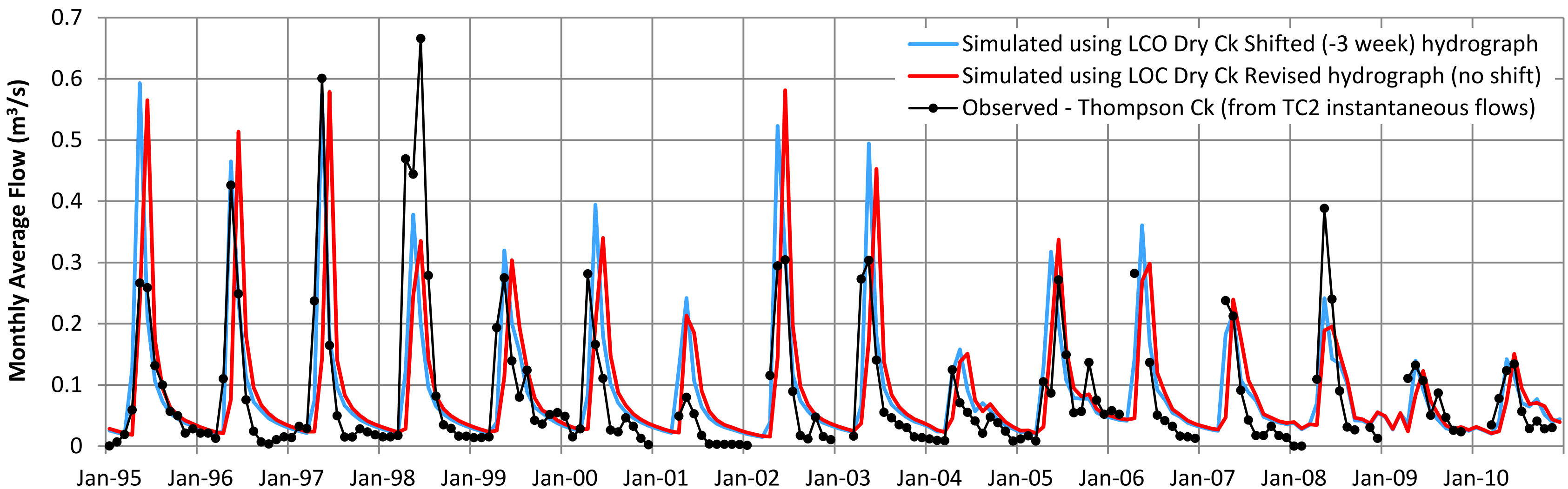


Figure 5-7 Thompson Creek Simulated and Observed Flow



5.3.3 Hosmer Creek Analogue Watershed

Hosmer Creek is a small, predominantly forested, watershed on the eastern slope of the Elk River Valley, about 19 km south of EVO (Figure 2-1). The hydrometric station Hosmer Creek above diversions (08NK026), with a contributing watershed of 6.4 km^2, has been operated by Environment Canada year-round since 1981 (with complete data from 1984). It is the smallest watershed with an active station in the designated area. The observed flow series from 1995 to 2012 was used to derive two representative hydrographs for natural areas. The hydrographs incorporate an adjustment for surface water yield, and reflect the different timing of runoff between some watersheds.

The climatic pattern of Hosmer Creek is different from LCO Dry Creek, reflecting the north-south climatic variation in the Elk Valley as discussed in Section 5.3.1. Hosmer Creek has a steeper recession in the annual hydrograph, more fall storms and a higher annual yield (likely due to higher precipitation). Hosmer Creek is a better fit with the runoff patterns in the watersheds contributing to Michel Creek.

5.3.3.1 Reduction Factor

Hosmer Creek has an average annual surface water yield (i.e., mean annual runoff) calculated from observed flow data of about 580 mm. The mean annual runoff derived from generic runoff curves (see Section 5.5.2 for details) is approximately 320 mm, based on an average watershed elevation of 1,610 masl. The smaller yield reflects that generic curves were developed from LCO Dry Creek in the Fording River watershed, and that LCO Dry Creek is further north than Hosmer Creek and therefore subject to a lower mean annual precipitation. The intermediate watersheds, such as Michel Creek and Grave Creek at EVO, exhibit lower yields than Hosmer Creek but somewhat higher than LCO Dry Creek, which is also consistent with a precipitation gradient. To account for generally lower yields, two reduction factors were applied, based on calibration of the model at discrete locations:

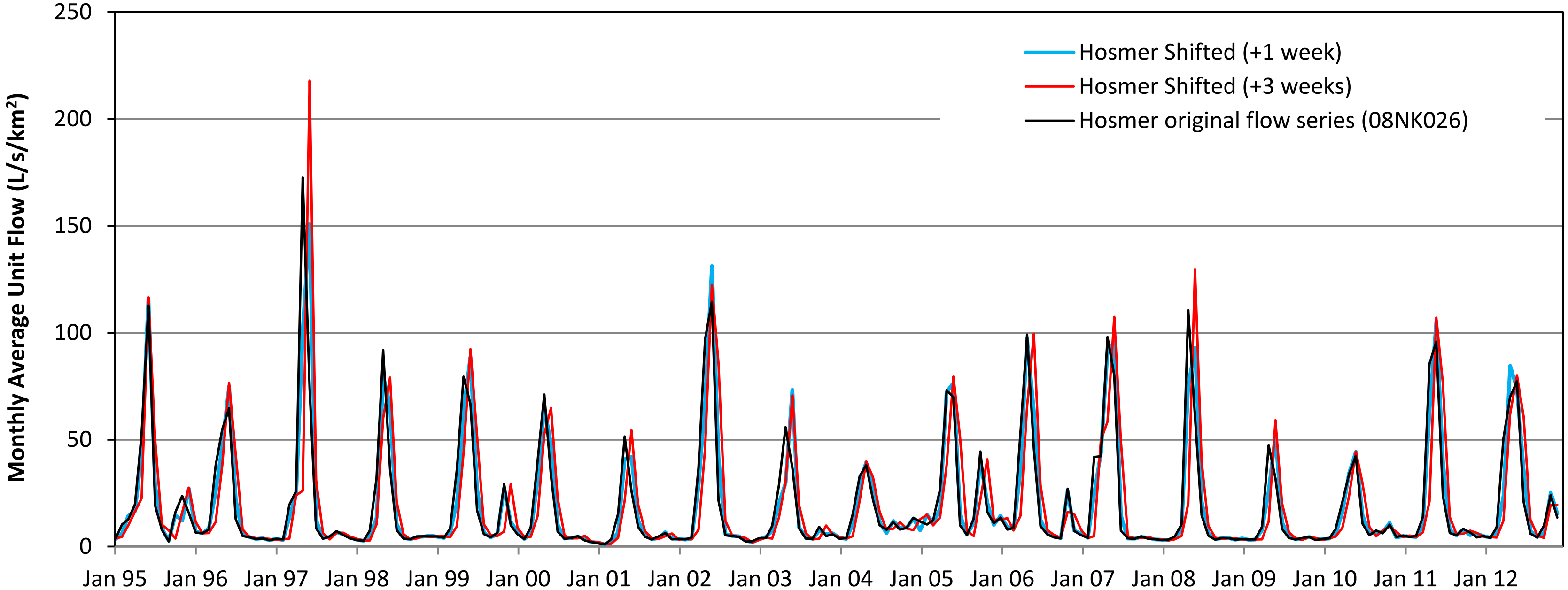
- Reduction factor of 0.54, based on an analysis of Grave Creek flows (see Section 5.3.3.2), and
- Reduction factor of 0.75, based on an analysis of Michel Creek flows (see Section 5.3.3.3).

At locations where a timing adjustment was also required, the shifted representative hydrograph was derived before the reduction factor was applied. The reduction factor was applied consistently for all months.

5.3.3.2 Timing Adjustment (+1 Week)

To better fit the observed runoff pattern for Grave Creek and Michel Creek watersheds with their higher elevations and later freshet, the Hosmer Creek representative hydrograph was adjusted forward by one week. The shift was applied to the daily flow series before re-calculating the monthly flows. The result is a slightly later freshet and change in the shape of the annual hydrograph (i.e. less flow occurring in April/May and more flow occurring in June/July). The Hosmer Shifted (+1 week) representative hydrograph is shown in Figure 5-8, and was applied to natural watersheds at EVO and the Michel Creek watershed. As discussed below, with the adjustments, the Hosmer Shifted (+1 week) representative hydrograph provides a good representation of Grave Creek and Michel Creek historical flows.

Figure 5-8 **Hosmer Creek Representative Hydrographs, 1995-2012, Shifted (+1 week) and Shifted (+3 weeks)**



Observed daily flow data for hydrometric station Grave Creek at the Mouth (08NK019) are only available before 1999 (Table 3-2), when the gauge was discontinued by Environment Canada. The concurrent period for Hosmer Creek and Grave Creek complete flow data, 1984-1999, was simulated solely for the purpose of comparing simulated and observed flows and determining the required reduction factor.
The representative hydrograph for mining areas was not available until 1995 (see Section 5.4), so mean monthly statistics were used for 1984 to 1994. The proportion of mined area in Grave Creek watershed is currently only 5%, so this has minimal effect on the comparison results.

Figure 5-9 shows simulated and observed monthly average flows for Grave Creek for the comparison period 1984-1999. The simulated mean flow for the comparison period is within 4% of the observed mean flow, indicating that the yield reduction factor of 0.54 is appropriate.

Figure 5-10 shows annual hydrographs (i.e., mean monthly flows) for Grave Creek. The annual hydrographs demonstrate that shifting the Hosmer Creek representative flows one week into the future improves the timing of simulated flows from natural areas in the Grave Creek watershed. The timing and magnitude of flows using the Hosmer Shifted (+1 week) hydrograph (with reduction factor of 0.54) is generally good. There is a tendency to underestimate July to October flows, which indicates that the Hosmer Creek hydrograph is less representative of Grave Creek natural flows during summer and early fall. Additional goodness-of-fit statistics and graphs are presented in Appendix A.

Observed daily flow data for hydrometric station Michel Creek below Natal (08NK020) are available only before 1996 (Table 3-2) when the gauge was discontinued by Environment Canada. The concurrent period for Hosmer Creek and Michel Creek complete flow data, 1984-1996, was simulated solely for comparing simulated and observed flows and determining the required reduction factor.
The representative hydrograph for mining areas was not available until 1995 (see Section 5.4), so mean monthly statistics were used for 1984-1994. The proportion of mined area in Michel Creek watershed is currently only 6%, so this has minimal effect on the comparison results.

Figure 5-11 shows simulated and observed monthly flows for Michel Creek for the comparison period 1984-1995. The simulated mean flow for the comparison period is within 2% of the observed mean flow, indicating that the yield reduction factor of 0.75 is appropriate.

Figure 5-12 shows annual hydrographs (i.e., mean monthly flows) for Michel Creek. The annual hydrographs show that shifting the Hosmer Creek representative flows one week into the future improves the timing of simulated flows from natural areas in the Michel Creek watershed. The timing and magnitude of flows using the Hosmer Shifted (+1 week) hydrograph (with reduction factor of 0.75) is generally good. Additional goodness-of-fit statistics and graphs are presented in Appendix A.

Figure 5-9 **Grave Creek Simulated and Observed Flows, 1984-1999**

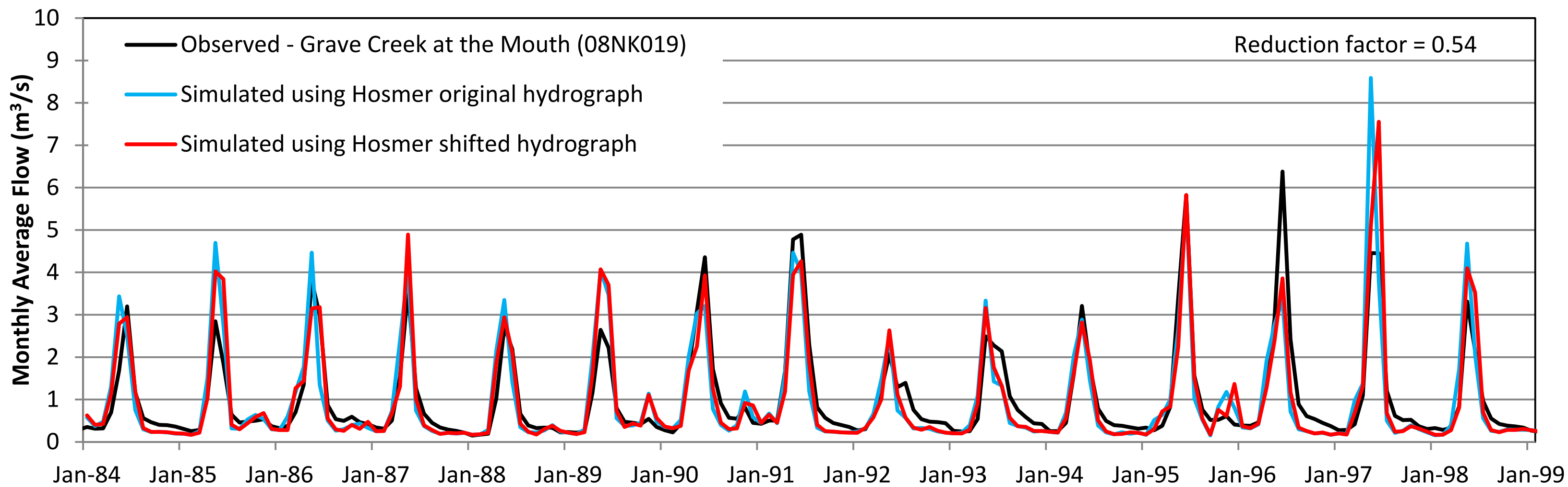


Figure 5-10 **Grave Creek Simulated and Observed Annual Hydrographs**

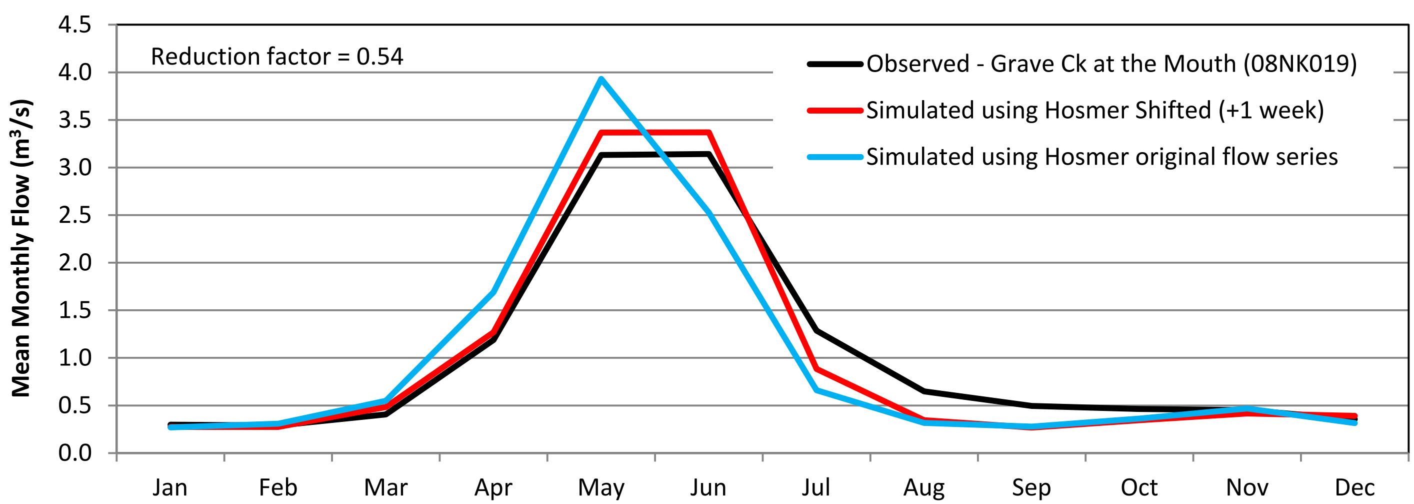


Figure 5-11 Michel Creek Simulated and Observed Flows, 1984-1995

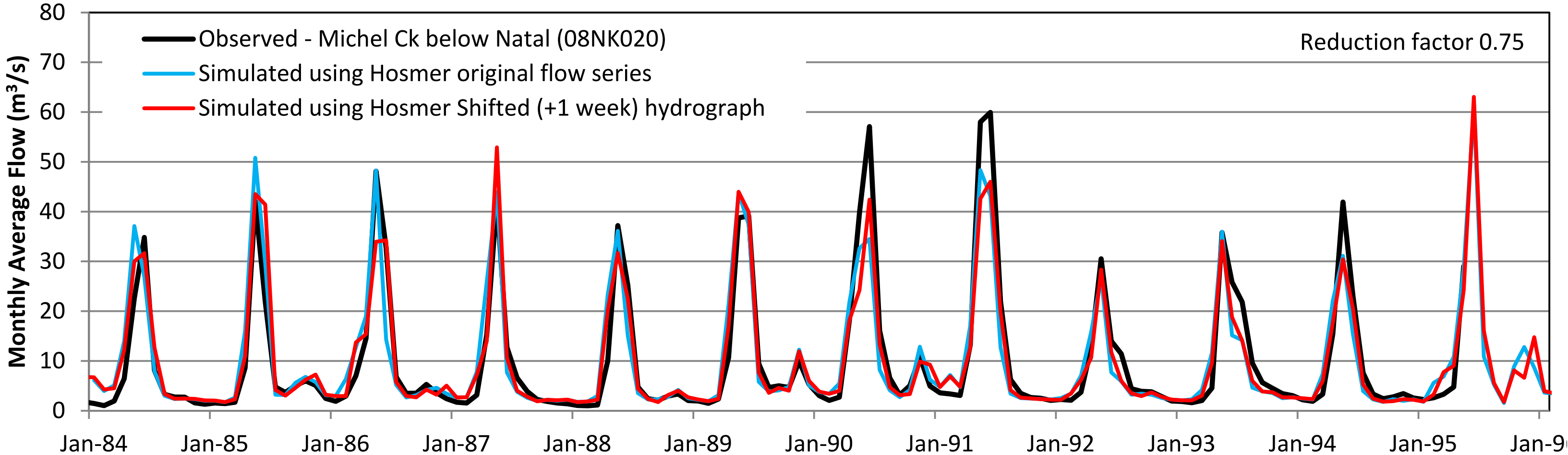
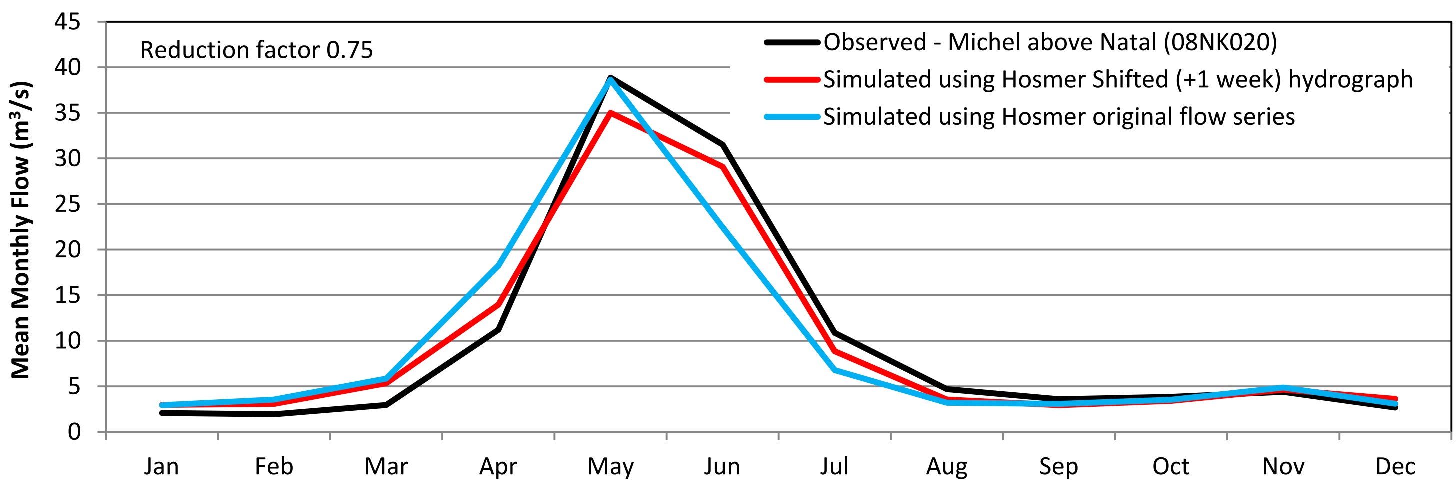


Figure 5-12 Michel Creek Simulated and Observed Annual Hydrographs



5.3.3.3 Timing Adjustment (+3 Weeks)

Kilmarnock Creek watershed at FRO has a substantial volume of waste rock. When the LCO Dry Creek representative hydrograph was used to derive flow from natural areas, overall simulated Kilmarnock Creek flows did not compare well with observed flows, generally underestimating spring peaks. To improve the simulated flows, the model was rerun with a representative hydrograph based on Hosmer Creek.

The Hosmer Creek watershed has a lower average elevation and is about 70 km further south, so the spring freshet generally earlier than the Kilmarnock Creek freshet. The Hosmer Creek representative hydrograph was adjusted forward by three weeks, to account for the generally later freshet in Kilmarnock Creek.

The observed monthly flows for Kilmarnock Creek were calculated from the daily flow series for hydrometric station Kilmarnock Creek near the mouth (KC1), operated by Teck seasonally since 1995, combined with available instantaneous flow measurements at the same station.

Figure 5-13 shows simulated and observed monthly flows for Kilmarnock Creek, and Figure 5-14 shows annual hydrographs (i.e., mean monthly flows). The hydrographs demonstrate that using the Hosmer Shifted (+3 weeks) representative hydrograph (with a reduction factor of 0.54) improves the magnitude of simulated from natural areas in Kilmarnock Creek watershed. There is a tendency to underestimate July to October flows, which indicates that the Hosmer Creek hydrograph is less representative of Kilmarnock Creek’s natural flows during that time.

The Hosmer Shifted (+3 weeks) representative hydrograph (Figure 5-8) was applied to natural watersheds at Kilmarnock Creek only.

Figure 5-13 Kilmarnock Creek Simulated and Observed Flows

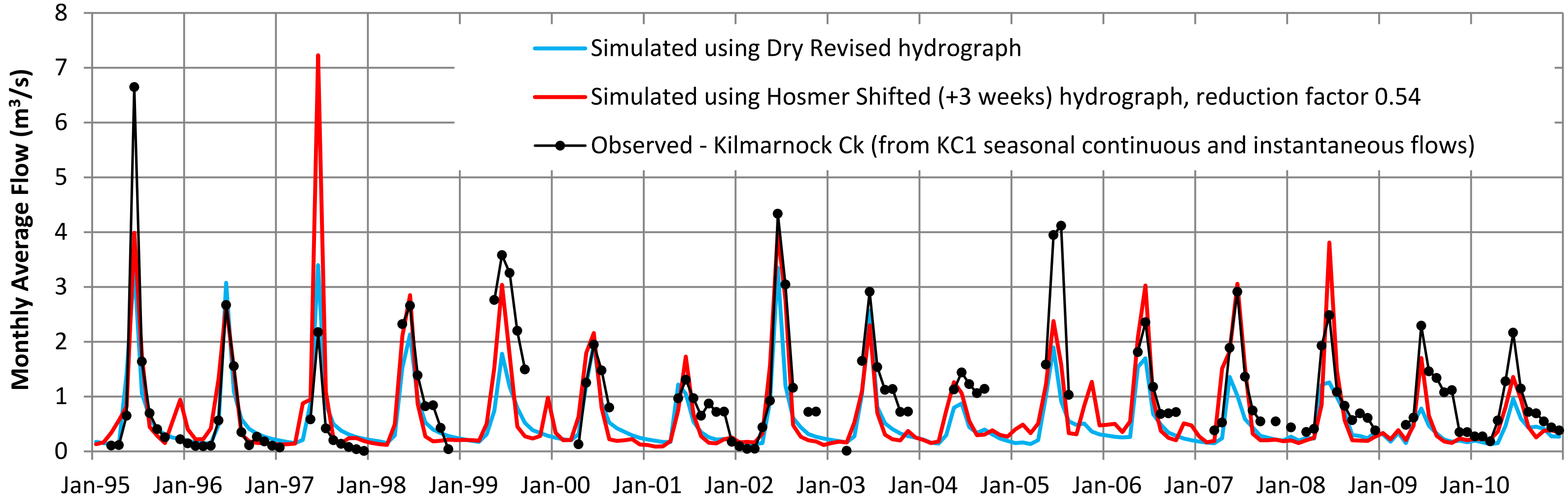
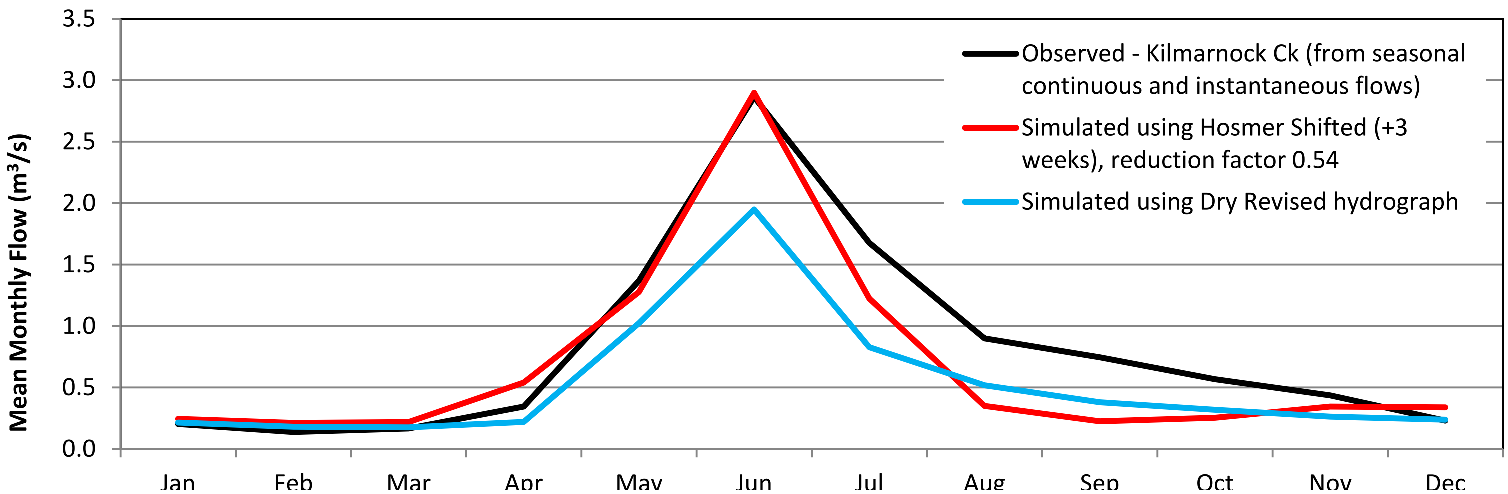


Figure 5-14 Kilmarnock Creek Simulated and Observed Annual Hydrographs



5.4 Representative Hydrograph for Mining Areas

5.4.1 Screening Review of Available Flow Data at Teck Operations

Watersheds without waste rock dumps have annual hydrographs characterized by high spring/summer flows and low fall/winter flows. Flow data from FRO shows that watersheds containing large quantities of waste rock have notably 'flattened' annual hydrographs (i.e., reduced peak flows in spring/summer and increased flows in fall/winter).

This trend suggests that the waste rock dumps are retaining water and releasing it over prolonged periods of time. However, there is only a single watershed (Cataract Creek) that is considered appropriate for assessing rock-dump-affected watersheds. Other watersheds are gauged, but the outflow data are not considered representative for many reasons, including internal dump failures and uncertain watershed limits.

Table 5-3 summarizes the 26 watersheds with waste rock at FRO, GHO, LCO and EVO. These watersheds were screened for suitability for further analysis using the following criteria:

- At least 40% of the watershed is covered by waste rock.
- At least five years of high-quality, year-round flow data are available, with minimal gaps.
- Observed annual runoff (in mm) at the gauge is consistent with regional runoff. In some cases, measured runoff is much higher or lower than the regional average, suggesting that watershed boundaries are poorly understood or that there is flow bypassing the gauge.
- The watershed is "simple". This is because "complex" watersheds – i.e., those with major dump failures, uncertain watershed boundaries, and undefined pit discharges – may have poorly understood effects on flows.

Eight of the 26 watersheds are at least 40% covered by waste rock. Of these, two (Cataract and Porter creeks) have good-quality flow data that appears to be representative of the total watershed flow. However, neither is ideal for use as an analogue watershed to represent waste rock hydrology, for the following reasons:

- The Cataract Creek watershed has extensive mining activity over the period of record, including active pit-water management and storage of water in the completed pit, with undefined effects on the hydrograph.
- The upper watershed boundary of Porter Creek is not well-defined, due to mining at GHO.
- The large natural area in Porter Creek watershed, and the pitwall area in Cataract Creek watershed, may have a dominant influence on the hydrograph shape, masking the effects of the waste rock on the hydrograph.

Table 5-3 Summary of Teck Coal Flow Data for Watersheds with Waste Rock

Watershed with Waste Rock	2010 Waste Rock Area (% of total watershed area)	Quality of flow data	Mean annual runoff from flow data (mm)	Does the flow data represent the total watershed flow?	Watershed Complexity
Cataract Creek at Cataract Pond (GH_CC1)	66%	Active station Instantaneous flows since 1993 (typically weekly April to July, otherwise monthly) Quality – good (only 3% of months without a flow measurement)	440 (1994 to 2007)	Yes - no known issues	Pit water was discharged from Cougar North Pit (GHO) in upper watershed to Cataract Creek until 2008 when the pit started filling. Large dump and rock drain.
Porter Creek (GH_PC1)	54% Historical waste rock in upper watershed, lower watershed is natural	Active station Instantaneous flows since 1993 (typically weekly April to July, otherwise monthly) Quality – good (only 6% of months without a flow measurement)	550 (1994 to 2010)	Yes - no known issues	Watershed boundary is not well-defined due to mining Historical waste rock in upper watershed
EVO Dry Creek	46% Waste rock in upper watershed	None	Not applicable	Not applicable	Historical mining and waste rock in upper watershed
Swift Creek at Swift Pond (GH_SC1 + GH_SC2)	43% Part of the upper watershed is natural	Active station Instantaneous flows since 1995 (typically weekly April to July, otherwise monthly). No data mid-2004 to mid-2009. Quality – poor (gaps in 44% of months)	100	No - high infiltration in sediment pond area (i.e., not all flow is measured at the station)	Mining disturbance in middle and lower watershed. Watershed boundary is not well-defined as history of clean water diversion in upper watershed is not known. Large dump and rock drain
Clode Creek at Clode Pond (FR_CC1)	41% Part of the upper watershed is natural	Active station Instantaneous flows since 1995 (typically weekly April to June, otherwise monthly) Quality – good (only 6% of months without a flow measurement)	250	No – low mean annual runoff suggests not all flow is reporting to gauge location. FRO staff confirms that water is withdrawn for dust suppression and that some of the flow may bypass the pond.	Extensive mine disturbance, including Eagle pits, waste rock dumps, pit water management and rock drain
No Name Creek	40% Waste rock in middle and lower watershed	Active station Instantaneous flows since 1995 (typically weekly April to mid-July, otherwise monthly). Quality – poor (missing data in EQWIN database from 2004 onwards)	Insufficient data	Uncertain – missing data	Extensive mine disturbance, including BRS and MSA pits Water management system, including clean diversion in upper watershed. Waste rock in forming cross-valley fill and rock drain.
Milligan Creek (EV_MG1)	40% Historical waste rock	Active station Instantaneous flows since 1992 (typically weekly March to June, otherwise monthly). Quality – poor (gaps in 42% of months)	Insufficient data	Uncertain – many zero flow measurements which suggests not all of the flow reports to the gauge location	Waste rock in upper watershed
Bodie Creek (including pit watershed) (EV_BC1)	36% Waste rock backfilled in-pit and in external dumps	Active station Instantaneous flows since 1992 (typically weekly March to June, otherwise monthly). Quality – fair (gaps in 17% of months)	200	Uncertain – low mean annual runoff and some zero flow measurements which suggests not all of the flow reports to the gauge location In-pit water management activities (e.g. temporary storage and pumping) will have an effect on flows	Predominately mine disturbed watershed includes all of the Cedar, Baldy and Natal pit area. Receives pit water discharges via the in-pit water management system and rock drain Waste rock backfilled in-pit and in external dumps
Thompson Creek (GH_TC2)	31% Waste rock in upper watershed	Active station Instantaneous flows since 1993 (typically weekly April to July, otherwise monthly). Quality – good (adequate data, gaps in 14% of months, mostly in winter)	280	Uncertain – low mean annual runoff suggests not all flow is reporting to gauge location	Small changes to upper watershed boundary due to mining
South Pit (EV_SP1)	30% Historical mining disturbance due to pit area and waste rock	Active station Instantaneous flows since 2009 (typically weekly March to June, otherwise monthly). Quality – fair (gaps in 28% of months, mostly in fall and winter)	Insufficient data	Yes – no known issues	Historical mining (South Pit) and waste rock in upper watershed
West Line Creek	26% Waste rock in lower watershed	Instantaneous flow measurements from 2001 to 2006 in the EQWIN database (variable sampling frequency). 2007 and 2008 daily flow hydrographs, based on water level measurements and rating curves developed by LCO Continuous water levels and instantaneous flow measurements from 2009 onwards for a new gauging station Quality – good since 2009 (older flow data are unreliable)	Insufficient reliable data	No – older flow data are unreliable and more recent data suggests that not all of the watershed flow is reporting to the gauge location	Waste rock forming cross-valley fill and rock drain. Natural area on the west side discharging to the rock drain.
Gate Creek (EV_GT1)	25% Waste rock in lower watershed	Active station Instantaneous flows since 1992 (typically weekly April to June, otherwise monthly). Quality – poor (gaps in 30% of months)	Insufficient data	Uncertain – many zero flow measurements which suggests not all of the flow reports to the gauge location	Waste rock in lower watershed
Line Creek downstream of West Line Creek	20%	Instantaneous flows since 1990 (variable sampling frequency) Quality – poor (missing data in EQWIN database)	Insufficient data	Uncertain – missing data	Waste rock in tributaries and main valley forming cross-valley fill and rock drain. Natural area in upper watershed discharging to the rock drain.

Table 5-3 Summary of Teck Coal Flow Data for Watersheds with Waste Rock (continued)

Watershed with Waste Rock	2010 Waste Rock Area (% of total watershed area)	Quality of flow data	Mean annual runoff from flow data (mm)	Does the flow data represent the total watershed flow?	Watershed Complexity
Kilmarnock Creek (FR_KC1)	20% Waste rock in middle and lower watershed	Active station Instantaneous flows since 1995 (mix of seasonal and year-round) Continuous monitoring since 1997 (seasonal, mostly May to September) Quality – fair (good peak data but limited winter flows)	490	Uncertain – potential subsurface flow paths (the monitoring location is in a realigned manmade channel)	Rock drains on Kilmarnock and Brownie Creeks Historic dump failures over the creek forming a pond Constructed channel at downstream end of rock drain
Leask Creek upstream of Leask Pond (originally GH_LC1; renamed GH_LC2 in 2005)	20% Waste rock in upper watershed	Active station Instantaneous flows since 1993 (typically weekly April to July, otherwise monthly). Limited winter flows before 2005. Quality – fair (adequate data in high flow months but gaps in winter flows)	160	No - flow goes subsurface in the vicinity of the sediment pond	Small changes to upper watershed boundary due to mining
Lake Mountain Creek (FR_NGD1)	16% Predominantly natural upper watershed	Active station Instantaneous flows since 1995 (typically weekly mid-March to mid-July, otherwise monthly) Quality – fair (gaps in 17% of months, mostly in winter)	460	Uncertain - extensive modifications to flow paths due to mining activities	Mining disturbance in middle and lower watershed, including historical pits, waste rock dumps, lakes and diversion channel
Wolfram Creek (including Cougar South pit) upstream of Wolfram Pond (originally GH_WC1; renamed GH_WC2 in 2005)	14% Waste rock in upper watershed	Active station Instantaneous flows since 1993 (typically weekly April to July, otherwise monthly). Limited winter flows. Quality – fair (adequate data in high flow months but gaps in winter flows)	310	No - flow goes subsurface in the vicinity of the sediment pond	Small changes to upper watershed boundary due to mining Receives pit water discharges from Cougar Pit South
Horseshoe Creek	14% Waste rock in lower watershed	None	Not applicable	Not applicable	Waste rock in lower watershed forming cross-valley fill and rock drain. Natural area on the east side discharging to the rock drain.
Erickson Creek at the mouth (EV_EC1)	13% Large watershed with natural area upstream and downstream of the waste rock dump	Active station Instantaneous flows since mid-2004 (typically monthly). Since 2009 weekly instantaneous flows April to June. Quality – poor (limited high flow data and gaps in 16% of months)	250	No – before 2011 some high flows were not measured due to safety issues at the measuring location	Large waste rock dump with historical dump failures over creek forming a rock drain Tailings storage since 2008 located upstream of the dump Natural area upstream and downstream of the waste rock dump
Line Creek at the mouth	11%	Active Daily flow data from 1971 to 2012 from Environment Canada Quality – good	480	Yes - no known issues	Waste rock in tributaries and main valley forming cross-valley fill and rock drain. Natural area in upper watershed discharging to the rock drain. Large natural areas discharging downstream of the rock drain.
Harmer Creek at Harmer Dam (includes EVO Dry Creek) (EV_HC1)	10% Waste rock in upper watershed	Active station Instantaneous flows since 1992 (typically weekly March to June, otherwise monthly). No data 1997 to 2000 Quality – fair (gaps in 33% of months)	400	Yes - no known issues	Historical mining and waste rock in upper watershed
Greenhills Creek at sediment pond decant (GH_GC1)	10% Waste rock in upper watershed	Active station Instantaneous flows since 1993 (typically weekly April to July, otherwise monthly). No data mid-2004 to mid-2009 Quality – poor (gaps in 44% of months)	250	Uncertain – low mean annual runoff suggests not all flow is reporting to gauge location and some flow may bypass the pond during freshet	Small changes to upper watershed boundary due to mining CCR area and tailings facility in watershed
Six Mile Creek Pond Decant (EV_SM1)	8% Small area of historical waste rock in upper watershed	Active station Instantaneous flows since 1992 (typically weekly March to June, otherwise monthly). Limited data 1997 to 2000 Quality – poor (gaps in 30% of months)	200	Uncertain – low mean annual runoff and many zero flow measurements which suggests not all of the flow reports to the gauge location	Historical waste rock in upper watershed
Henretta Creek (FR_HC1)	6% Waste rock in lower watershed	Active station Instantaneous flows since 1996 (year-round from 2007 onwards) Continuous monitoring since 1998 (seasonal, mostly May to September) Quality – fair (good peak data but limited winter flows)	700	Yes - no known issues	Relatively small area of mining disturbance in lower watershed, including Henretta pit and fish compensation channel
Grave Creek at the mouth (includes Harmer Creek and EVO Dry Creek) (08NK019)	5% Waste rock in upper watershed	Discontinued Daily flow data from 1970 to 1999 from Environment Canada Quality – good	410	Yes - no known issues	Historical mining and waste rock in upper watershed
Goddard Creek (EV_GC2)	5%	Active station Instantaneous flows since 1992 (typically weekly March to June, otherwise monthly). Quality – fair (gaps in 22% of months)	560	Yes - no known issues	Historical mining and waste rock in upper watershed

5.4.2 Cataract Creek Analogue Watershed

Cataract Creek was selected as the most appropriate of the available analogues to represent the “mining” land type. Flows from mining areas were represented by a single representative hydrograph based on Cataract Creek.

Cataract Creek is a small, predominantly mine affected watershed on the western slope of the Fording River at FRO. Since 1993, manual instantaneous flow measurements have been taken year-round at the Teck hydrometric station (GHO_CC1). Flows are typically measured weekly between April and July and monthly through the remainder of the year. Most of the watershed at Cataract Creek is covered with large spoils. Cougar North Pit (part of GHO) formed part of the upper watershed until 2009, when it stopped contributing flow.

The Cataract Creek watershed has a large proportion of waste rock and a relatively small natural area. From a flow interpretation perspective, mining activity in the upper watershed is relatively simple (a single large pit). Pit water was actively discharged to Cataract Creek until 2009, when the pit was completed and started to fill with water. Pit filling is ongoing, and the pit sub-watershed does not currently contribute surface flows to Cataract Creek. The effect of the pit on groundwater flows to Cataract Creek is not known.

An almost complete monthly flow record from 1995-2012 is available for Cataract Creek.

The following adjustments were made to the Cataract Creek monthly average flow series before generating the representative hydrograph:

- In-fill to create a continuous monthly flow record. Flow data from adjacent watersheds were used to estimate flows for six individual months without any flow measurements (3% of the total flow record).
- Removal of three anomalous winter low flow measurements and replacement with interpolated flows from adjacent months. The anomalous flows are inconsistent with adjacent months (which are expected to be consistent because winter flow is from groundwater, which changes gradually) and inconsistent with water quality measurements.
- Pro-rating of recorded flows between 2009 and 2010 by a factor of 1.7 because a portion of the upper watershed (Cougar North Pit at GHO) did not contribute during this period.

Figure 5-15 shows the observed instantaneous flow measurements used to calculate the original monthly flow series for Cataract Creek. Figure 5-15 shows the original monthly flow series, the adjusted flow series with 2009 to 2012 flows prorated, and the final representative hydrograph (prorated, with low flows removed).

Figure 5-15 Cataract Creek Instantaneous Flow Measurements, 1995-2012

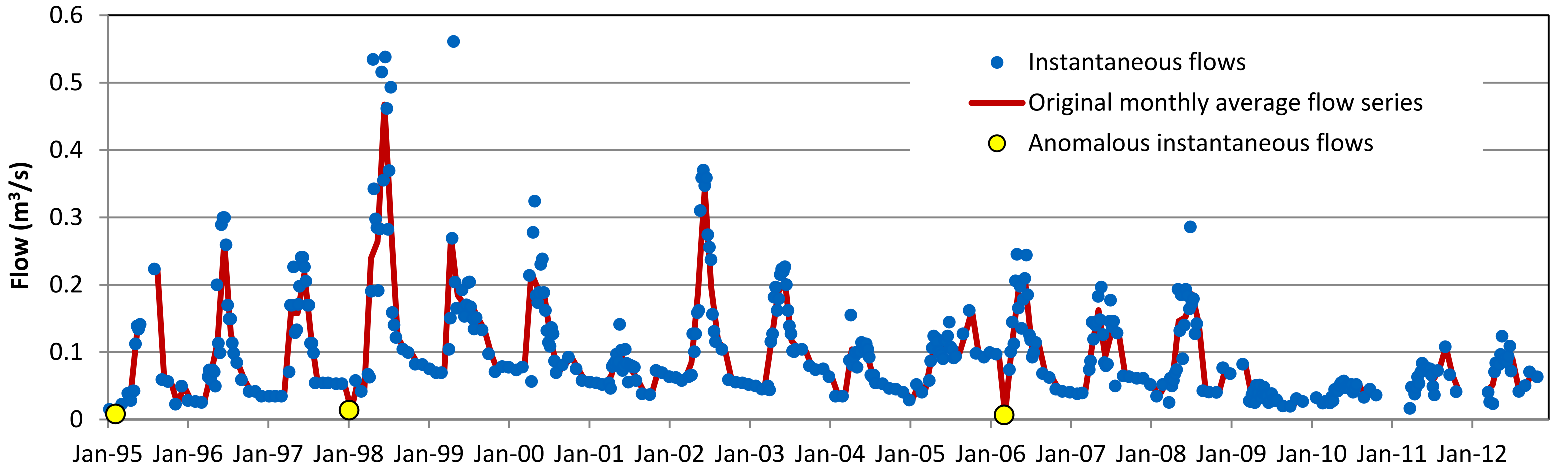
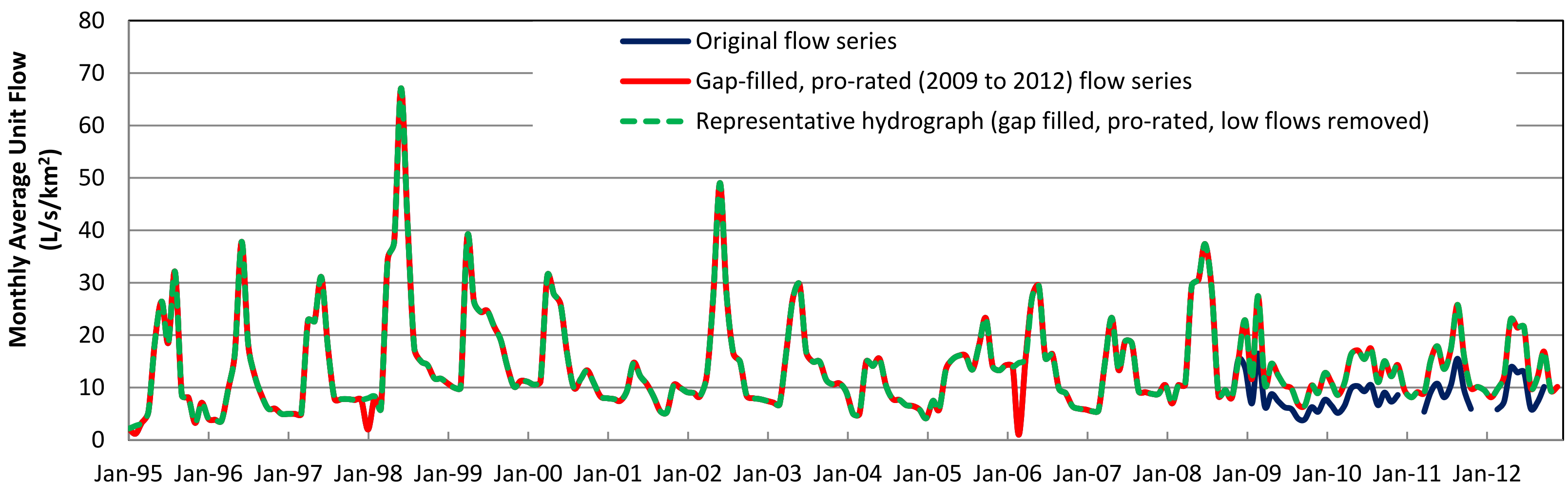


Figure 5-16 Cataract Creek Monthly Average Representative Hydrograph, 1995-2012



5.5 Application of Representative Hydrographs to Watersheds in the Flow Model

Flows were simulated using the representative hydrograph method for most of the Fording River watershed (including FRO) and Michel Creek (including CMO and part of EVO), as well as other mine-affected tributaries at GHO, LCO and EVO, as shown in Figure 2-1. Flows in Line Creek, and the Elk River were simulated using alternative methods (see Section 6).

Table 5-4 provides a summary of where each representative hydrograph was applied. The Cataract Creek hydrograph was applied to all mining areas throughout the Elk Valley, because it was the best available series of observed flow data for a mined watershed. The representative hydrograph applied to natural areas depends on location of the watershed, flow characteristics, and timing of the freshet.

Table 5-4 Application of Representative Hydrographs in the Flow Model

Analogue Watershed	Source of Flow Data	Land Type	Representative Hydrograph Name	Derivation of Representative Hydrograph (including adjustments from original flow series)	Watershed Locations where the Representative Hydrograph was Applied
LCO Dry Creek	Simulated daily flows (1970 to 2012) from UBC Watershed model	Natural	LCO Dry Creek Revised	• Generated monthly average flow series from simulated daily flows for 1995 to 2012 • Normalized by watershed area • Baseflow reduction of 1.4 L/s/km^2	FRO (except Kilmarnock Creek) GHO (except Leask, Wolfram, and Thompson creeks) LCO Dry Creek Fording River tributaries (except Line Creek)
			LCO Dry Creek Shifted (–3 weeks)	• Shifted simulated daily flows 3 weeks back (i.e., earlier peaks than original flow series) • Generated monthly average flow series from shifted daily flows for 1995 to 2012 • Normalized by watershed area • Baseflow reduction of 1.4 L/s/km^2	GHO Leask, Wolfram, and Thompson creeks
Hosmer Creek	Environment Canada daily flows (1981 to 2012) for Hosmer Creek above Diversions (08NK026)	Natural	Hosmer Shifted (+1 week)	• Shifted daily flows 1 week forward (i.e., later peaks than original flow series) • Generated monthly average flow series from shifted daily flows for 1995 to 2012 • Normalized by watershed area • Reduction factor of 0.75 applied in the model	CMO Michel Creek tributaries (not including EVO local tributaries)
				• Same derivation as above • Reduction factor of 0.54 applied in the model	EVO local creeks
			Hosmer Shifted (+3 weeks)	• Shifted daily flows 3 weeks forward (i.e., later peaks than original flow series) • Generated monthly average flow series from shifted daily flows for 1995 to 2012 • Normalized by watershed area • Reduction factor of 0.54 applied in the model	FRO Kilmarnock Creek
Cataract Creek	Instantaneous flow measurements (1993 to 2012) typically measured weekly between April and July, otherwise monthly	Mining	Cataract Creek	• Generated monthly average flow series from available instantaneous flow measurements for 1995 to 2012 • In-filled gaps in flow record (3% of total record) • Replaced anomalous winter flows (3 months) • Prorated monthly average flows between 2009 and 2012 by a factor of 1.7 because a portion of the upper watershed (Cougar North Pit at GHO) did not contribute during this period • Normalized by watershed area	Mined areas at Teck operations throughout the Elk Valley (i.e., FRO, GHO, EVO, LCO and CMO)

5.5.1 Watershed Areas

To apply the representative hydrograph method, each watershed was divided into mined and natural areas. The total mined area was further subdivided into waste rock, CCR, and pitwall areas.

5.5.1.1 Topographic Analysis

ArcGIS and Global Mapper are Geographic Information System programs that were used to delineate watershed areas and to divide watersheds into mined and natural areas, and types of mined areas (e.g., waste rock, pitwall, CCR). Average elevations were calculated for each mined and natural area from the surface topography. It was assumed that the drainage system is driven by topography of the underlying mined-out or original surface, and therefore placement of backfill and waste rock (and current reclamation practice) does not affect drainage paths or spill elevations from pit lakes or backfilled pits.

The following topographic datasets were used:

- Mined-out (without waste rock) and surface (with waste rock) contour data for 2010 and snapshots throughout the future Mine Plans for each operation
- Disturbance area for each operation
- 1:50,000 Canadian Digital Elevation Data from Geobase (Natural Resources Canada) for natural watershed areas.

5.5.1.2 Historical Mined and Natural Areas

Historical snapshots of the mine topography were not available before 2010. However, during the historical flow simulation period (1995 to 2010), some watersheds would have seen an increase in mined area (i.e., waste rock, CCR, pit wall) with operations and a corresponding decrease in natural area.

Given that annual historical waste rock series were available for all watersheds, it was assumed that total mined area increased at the same rate as waste rock volume in the watershed over the historical period. The natural area was assumed to decrease accordingly. Working backward from the 2010 snapshot, the mined area was decreased over each time-step in proportion to the percent change in waste rock volume over the same time-step. For example:

Year	Waste Rock % (from waste rock series)	Total Mined Area (km^2)
2010	100%	10*
2005	86%	8.6
2000	72%	7.2
1995	41%	4.1

* derived from 2010 snapshot of topography

For watersheds with mined area which did not contain waste rock (i.e., some pit watersheds) the waste rock series from a neighbouring watershed was used for the interpolation. The same interpolation was used for waste rock, CCR and pitwall areas, unless other information was available (e.g. historical CCR volume series).

Equations used to derive historical area are as follows:

$$Mined\ area_{(t-1)} = Mined\ area_{(t)} \times \frac{Waste\ rock\ vol_{\ (t-1)}}{Waste\ rock\ vol_{(t)}}$$

$$Natural\ area_{(t)} = Total\ area_{(t)} - Mined\ area_{(t)}$$

5.5.1.3 Future Areas

Future flows will be affected by the mine plan and water management plan for each operation. There are several contributing factors which may influence future flows, such as:

- changes in watershed area and elevation
- changes in land type (i.e., mining and placement of waste rock)
- water management systems (e.g., operational pumping, closure drainage, collection of mine-affected water for treatment)
- changes in the local groundwater system
- pits filling at end-of-mining
- revegetation of waste rock.

A summary of the events for each mine plan is given in Site Conditions Report (Teck 2014c). A snapshot approach was used to input the timing of events in each watershed into the flow model. The flow model linearly interpolates areas and elevations between each snapshot.

5.5.2 Adjustment for Average Watershed Yield

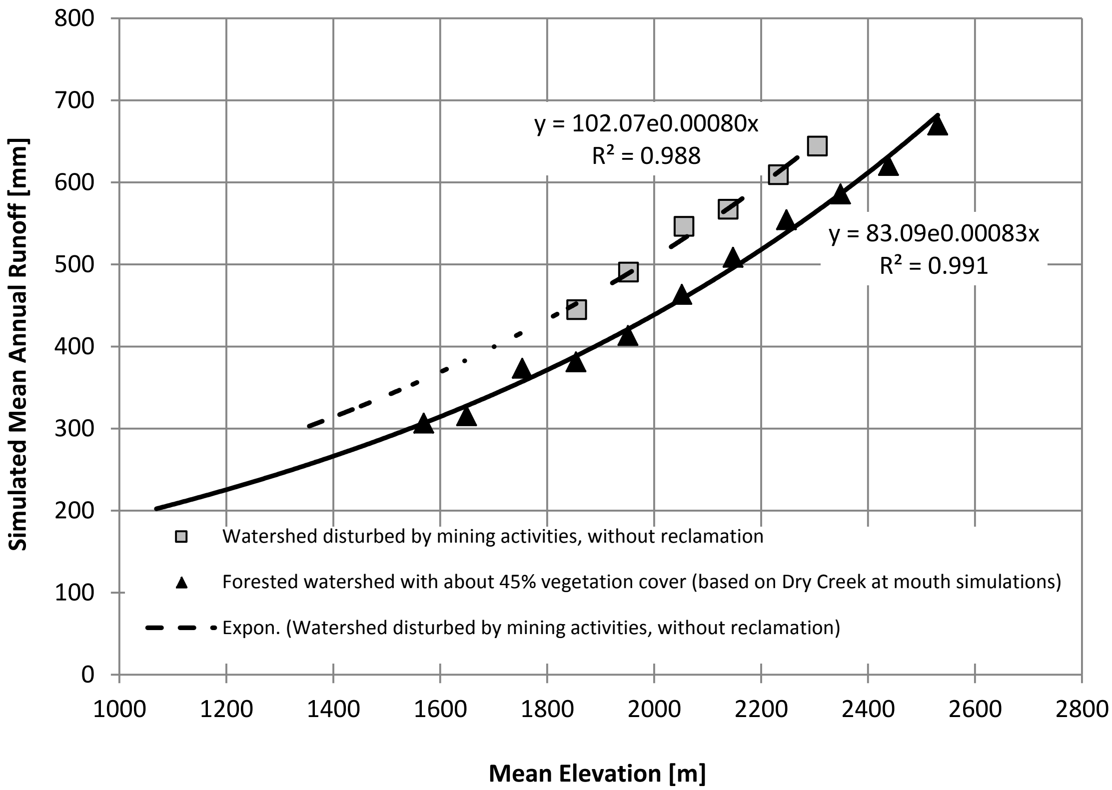
Average yield (i.e., mean annual runoff) was estimated from generic runoff curves, based on the average elevation of each land type in the watershed. The yield ratio in the equations (Section 5.1) was used to adjust the simulated flow to account for the elevation differences between the representative hydrograph watersheds and the local watersheds at the Teck operations.

During the hydrological modelling of LCO Dry Creek for the LCO Phase II Project (Teck 2011b,c) (see Appendix D for details), two main factors causing local variability in mean annual runoff were found to be elevation and land cover. Generic relationships between mean annual runoff and elevation were developed to enable the application of the LCO Dry Creek hydrological modelling results to hydrologically similar watersheds. Relationships were developed for two land types:

- natural (predominantly forested with about 45% vegetation cover)
- mine disturbed (waste rock and mining area, without reclamation).

The developed curves are shown in Figure 5-17. The estimated mean annual runoff is inclusive of groundwater flows that discharge to the creek (i.e., “base flows”). Average elevations in the flow model range from 1,250 masl to 2,300 masl (for natural watershed areas) and 1,200 masl to 2,200 masl (mining watershed areas), as shown in Appendix B.

Figure 5-17 Generic Curves Relating Simulated Mean Annual Runoff to Elevation



5.5.3 Adjustment for Reclamation

Reclamation of completed spoils using existing practices can have an effect on flows in local tributaries, due to the increased evapotranspiration that occurs with revegetation. The model was initially configured to account for increased evapotranspiration associated with current reclamation practices as 30% reduction in infiltration over a 40 year period (Integral Ecology and O'Kane 2013). Subsequent studies indicated that removal of existing reclamation practices results in small changes to flows and in-stream concentrations by 2034; and thus would have negligible effects on the Plan within its 20-year planning timeframe. As a result, this feature has been removed from the final version of the model.

5.7 Fording River Nodes

5.7.1 Derivation of Flows at Fording River Nodes

Flows at Fording River nodes (Figure 2-1) were derived by summing flows from contributing watersheds. Watershed maps and flow logic diagrams are provided in Site Conditions Report (Teck 2014c). The formulas used to derive flows at each node are summarized in Table 5-5. The entire Fording River watershed was simulated in the flow model.

Table 5-5 Fording River Node Flow Derivation

Node	Description	Formula used to derive flows [(a)]
FR1	Fording River downstream of Henretta Creek	FR1 = Henretta Creek + North Turnbull Spoil + Upper Fording
FR2	Fording River downstream of Clode Creek and upstream of Kilmarnock Creek	FR2 = FR1 + CL1 + LM1 + Lower Fording 1 + Lower Fording 2
FR3	Fording River between Swift and Cataract creeks	FR3 = FR2 + SC1 + KC1
FR3b	Fording River downstream of Porter Creek	FR3b = FR3 + PC1 + FR-CTP + CA1 + Castle mountain to FR3b
FR3c	Fording River downstream of LCO Dry Creek	FR3c = FR3b + DC1 + Additional to FR3c
FR4	Fording River downstream of Greenhills Creek	FR4 = FR3b + GH1 + Additional to FR4
FR5	Fording River at the mouth	FR5 = FR4 + LC1 + Additional to FR5

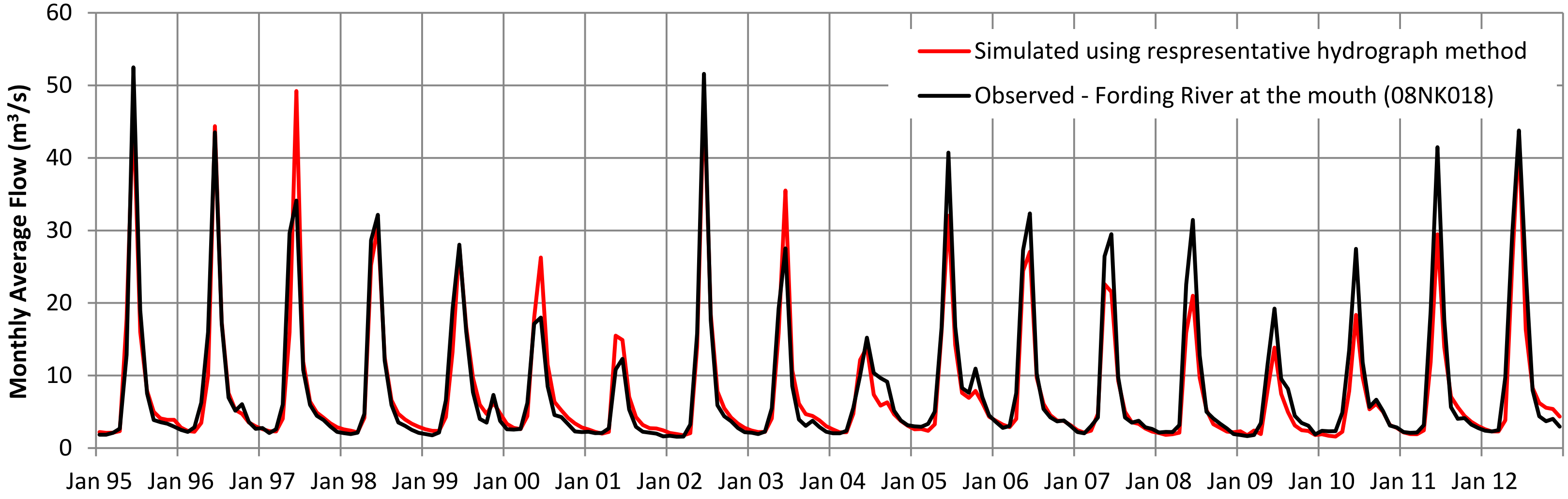
[(a)] See Appendix B for watershed descriptions, and node identifiers and locations.

5.7.2 Flow Comparison for Fording River at the Mouth

A flow comparison was undertaken at Fording River at the mouth (node FR5) to ensure that the sum of all the simulated flows in the Fording River watershed was consistent with observed data at the mouth for the historical period 1995 to 2012.

Flows at FR5 were calculated by summing simulated flows from all upstream watersheds. The simulated flows were compared with observed monthly average flows from Environment Canada station Fording River at the mouth (08NK018). The FR5 simulated flows are generally consistent with the observed data as shown on Figure 5-18. The simulated mean flow over the comparison period 1995-2012 is within 7% of the observed mean flow. Additional goodness-of-fit statistics and graphs are presented in Appendix A.

Figure 5-18 Fording River at the Mouth, Simulated and Observed Flows



5.8 Michel Creek Nodes

5.8.1 Derivation of Flows at Michel Creek Nodes

Flows at Michel Creek nodes, shown in Figure 2-1, were derived by summing flows from contributing watersheds. Watershed maps and flow logic diagrams are provided in Site Conditions Report (Teck 2014c). The formulas used to derive flows at each node are summarized in Table 5-6. The entire watershed of Michel Creek was simulated in the flow model.

Table 5-6 Michel Creek Nodes Flow Derivation

Node	Description	Formula used to derive flows [a]
MC5	Michel Creek downstream of CMO and upstream of Leach Creek confluence	MC5 is modelled as a single watershed that includes CMO
MC4	Michel Creek downstream of Wheeler Creek confluence	MC4 = MC5 + CB1 + SS1 + WH1 + Additional area to MC4
MC3	Michel Creek upstream of EVO	MC3 = MC4 + Alexander Creek + Lower Alexander Creek + Unnamed watershed to Lower Alexander + Additional Area to MC3
MC1	Michel Creek at the mouth	MC1 = MC3 + EC1 + GT1 + BC1 + Additional Area to MC1

[a] See Site Conditions Report (Teck 2014c) for watershed descriptions, and node identifiers and locations

5.8.2 Flow Comparison for Michel Creek

Observed flows for Michel Creek are not available for the selected historical period of 1995-2010. As discussed in Section 5.3.3.2, flows were simulated for the concurrent period for Hosmer Creek and Michel Creek below Natal (08NK020) using flow data from 1984 to 1996, to allow a comparison between simulated and observed flows. Using the representative hydrograph method to simulate flows in Michel Creek watershed produces a good representation of high and low flows and the timing of the peaks over the comparison period. Additional goodness-of-fit statistics and graphs are presented in Appendix A.

5.9 Future Flow Scenarios

The future-flow simulation method is similar to the historical simulation method, but makes use of representative hydrographs based on statistical flow scenarios, rather than representative hydrographs of monthly average flows over a historical period.

The flow model was built to simulate three statistical future flow scenarios for each watershed:

- mean monthly flow
- high monthly average flow, based on 1-in-10 year high flow statistics
- low monthly average flow, based on 1-in-10 year low flow statistics.

All flow statistics were generated using the 15-year period of historical flow data from 1995-2010. Statistics were developed for calendar months, and each month was developed independently.

High- and low-flow distribution analyses were run on the 15-year period (1995 to 2010) of monthly average flows for each representative hydrograph. Separate distribution analyses were completed for each month (i.e., 15 data points were used for each). Each analysis used four curve fitting methods: 3 parameter Log Normal (3P), Extreme Value (EV), Log Pearson III (LP3), and Weibull (Gumbel III). The best-fitting curve was chosen for each month, based on the Anderson-Darling test to judge goodness of fit, in addition to a qualitative graphical check.

The results of the distribution analyses are summarized in Table 5-7, and shown in Figures 5-19 to 5-23.

An analysis of LCO Dry Creek Revised hydrograph was undertaken to assess the effect on the flow statistics of extending the 1995-2010 average monthly flow series to 2012. Differences in the 1-in-10-year high and 1-in-10-year low monthly average flows for all months were within 8%, and differences between mean monthly flows were within 5%.

Table 5-7 Statistics for Future Flow Scenarios – Representative Hydrographs

Representative Hydrograph	Land Type	Flow Scenario	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LCO Dry Creek Revised	Natural	Mean flow	L/s/km^2	3.4	2.9	2.5	2.5	21.4	43.3	16.7	9.7	7.4	5.9	4.7	3.9
		10 year low	Distribution	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)	EV3	EV3	EV3	Weibull	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)
			L/s/km^2	2.2	1.8	1.5	1.2	10.2	17.8	9.2	6.1	4.9	3.9	3.1	2.5
		10 year high	Distribution	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)	EV3	EV3	EV3	Weibull	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)
			L/s/km^2	4.3	3.7	3.2	3.7	33.2	73.3	24.9	13.6	9.4	7.4	6.1	5.0
LCO Dry Creek Shifted (-3 weeks)	Natural	Mean flow	L/s/km^2	3.0	2.6	2.2	11.1	45.9	21.1	11.1	7.7	6.4	5.0	4.1	3.6
		10 year low	Distribution	3P(MLH)	3P(MLH)	3P(MLH)	LP3(moment)	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)
			L/s/km^2	1.9	1.6	1.3	3.8	22.4	12.0	7.0	5.1	4.1	3.3	2.6	2.3
		10 year high	Distribution	3P(MLH)	3P(MLH)	3P(MLH)	Weibull	Weibull	Weibull	Weibull	EV3	3P(MLH)	3P(MLH)	3P(MLH)	3P(MLH)
			L/s/km^2	3.8	3.3	2.9	19.9	72.0	32.1	16.1	10.3	8.8	6.4	5.3	4.5
Hosmer Shifted (+1 week)	Natural	Mean flow	L/s/km^2	5.0	4.8	8.5	21.6	61.1	77.6	17.2	5.5	5.0	8.0	9.5	6.9
		10 year low	Distribution	EV2	EV2	EV2	Weibull	EV3	3P(MLH)	3P(MLH)	Weibull	EV2	EV2	3P(MLH)	EV2
			L/s/km^2	2.6	2.2	3.3	8.3	29.5	39.1	9.9	3.9	3.0	3.4	3.3	2.2
		10 year high	Distribution	EV2	EV2	Weibull	Weibull	Weibull	3P(MLH)	3P(MLH)	EV3	EV2	EV2	3P(MLH)	EV2
			L/s/km^2	8.1	8.0	15.8	35.7	93.3	124.3	29.1	7.3	7.5	12.3	20.8	12.8
Hosmer Shifted (+3 weeks)	Natural	Mean flow	L/s/km^2	5.7	5.1	4.9	14.3	37.4	90.4	36.3	7.8	4.8	5.9	9.4	8.7
		10 year low	Distribution	3P(MLH)	EV2	EV2	EV2	EV3	EV2	Weibull	3P(MLH)	EV2	3P(MLH)	EV2	3P(MLH)
			L/s/km^2	2.6	2.4	2.4	5.0	17.1	44.7	16.8	5.4	3.3	3.3	3.5	2.4
		10 year high	Distribution	3P(MLH)	3P(MLH)	EV2	EV2	Weibull	3P(MLH)	Weibull	3P(MLH)	EV2	3P(MLH)	EV2	3P(MLH)
			L/s/km^2	10.9	9.1	8.0	26.2	58.8	147.8	61.5	10.7	6.6	9.7	16.0	19.1
Cataract Creek	Mining	Mean flow	L/s/km^2	9.5	8.1	9.1	17.4	23.7	28.6	21.3	17.0	11.4	10.9	9.4	10.1
		10 year low	Distribution	EV2	Weibull	EV2	EV2	Weibull	3P(MLH)	EV2	EV2	3P(MLH)	3P(MLH)	Weibull	EV2
			L/s/km^2	3.6	4.0	3.8	7.9	13.8	13.3	11.2	8.0	6.7	6.1	5.5	5.7
		10 year high	Distribution	3P(MLH)	Weibull	EV2	EV2	Weibull	EV2	EV2	EV2	3P(MLH)	3P(MLH)	Weibull	3P(MLH)
			L/s/km^2	16.9	12.2	15.9	29.6	36.6	49.3	34.1	28.5	17.4	18.1	13.0	16.2

Notes: Distributions correspond to 3 parameter Log Normal (3P), Extreme Value (EV), Log Pearson III (LP3), and Weibull (Gumbel III).

A reduction factor was applied in the flow model when using Hosmer Creek representative hydrographs to balance for the higher average runoff of Hosmer Creek, compared to other areas in the Elk Valley.

Figure 5-19 LCO Dry Creek Revised Representative Hydrograph Statistics

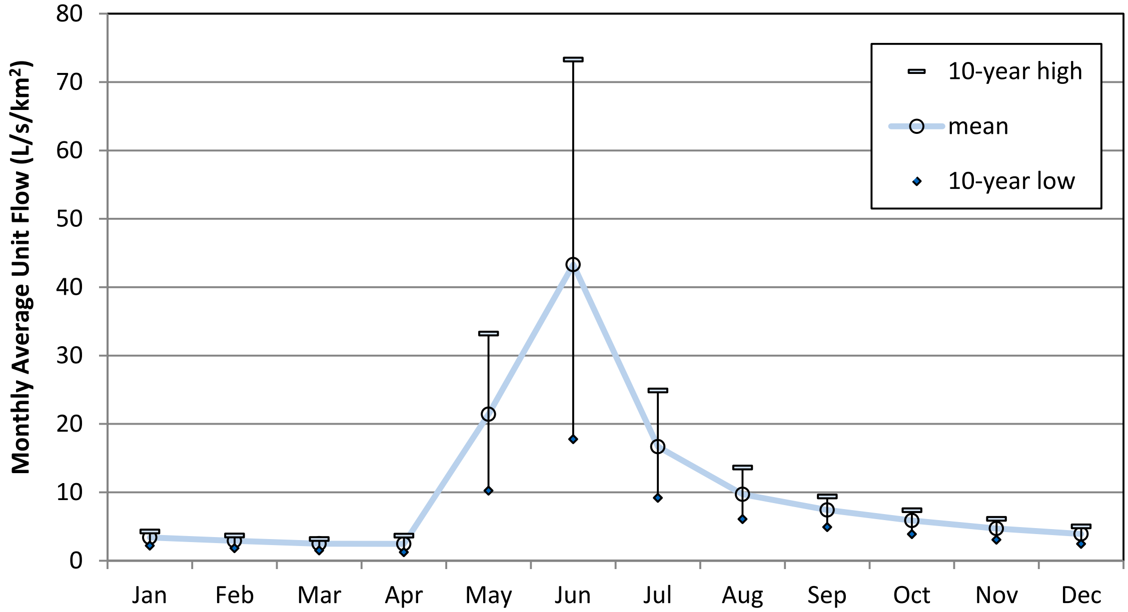


Figure 5-20 LCO Dry Creek Shifted (-3 weeks) Representative Hydrograph Statistics

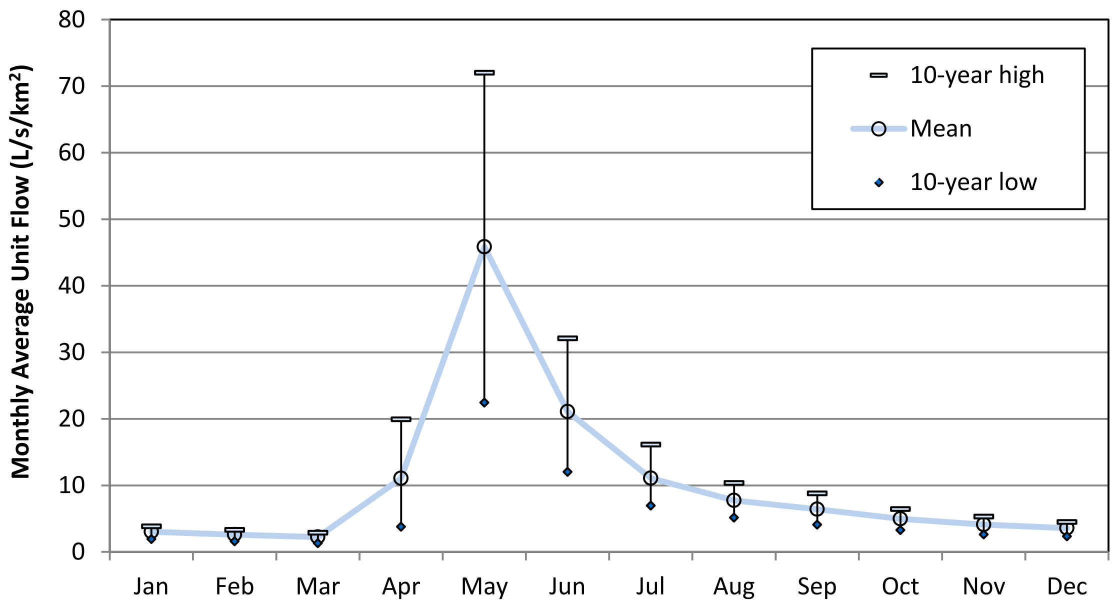
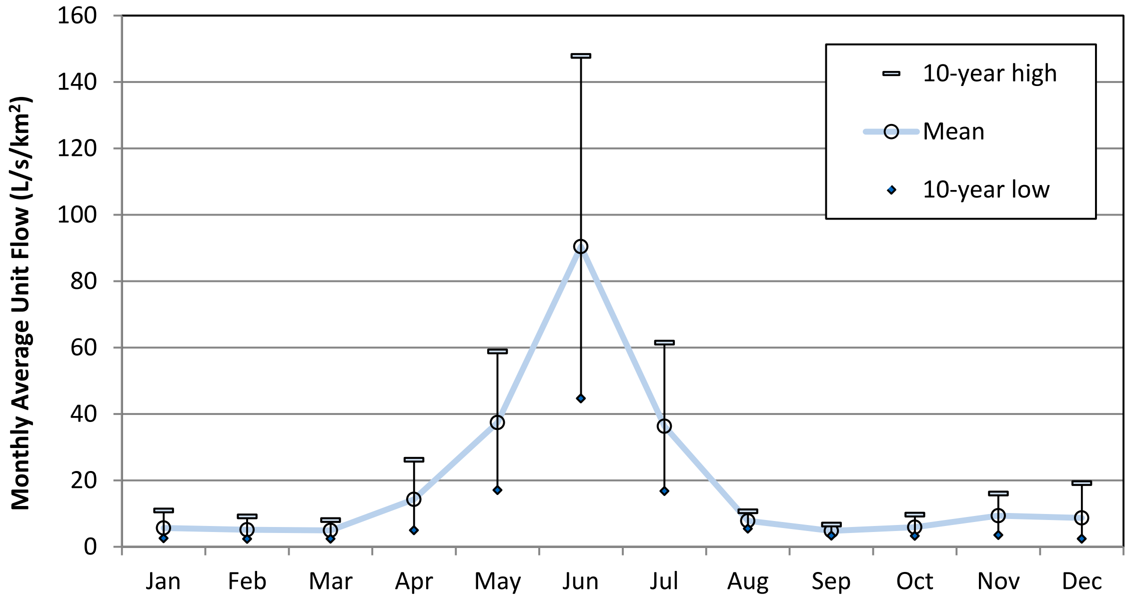
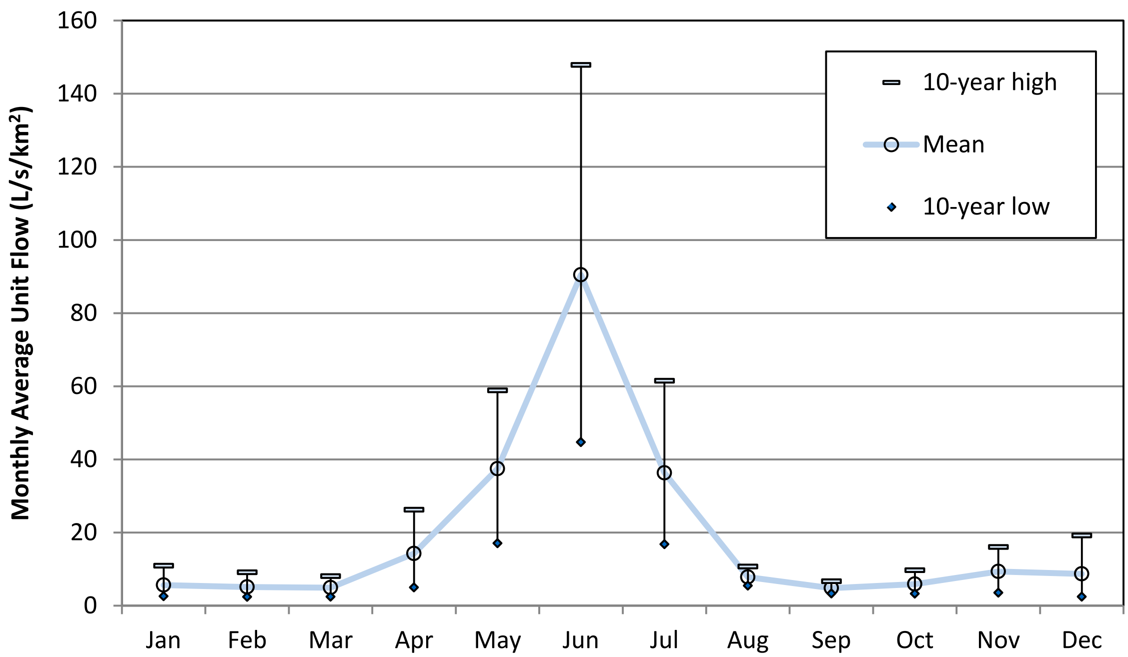


Figure 5-21 Hosmer Shifted (+1 week) Representative Hydrograph Statistics



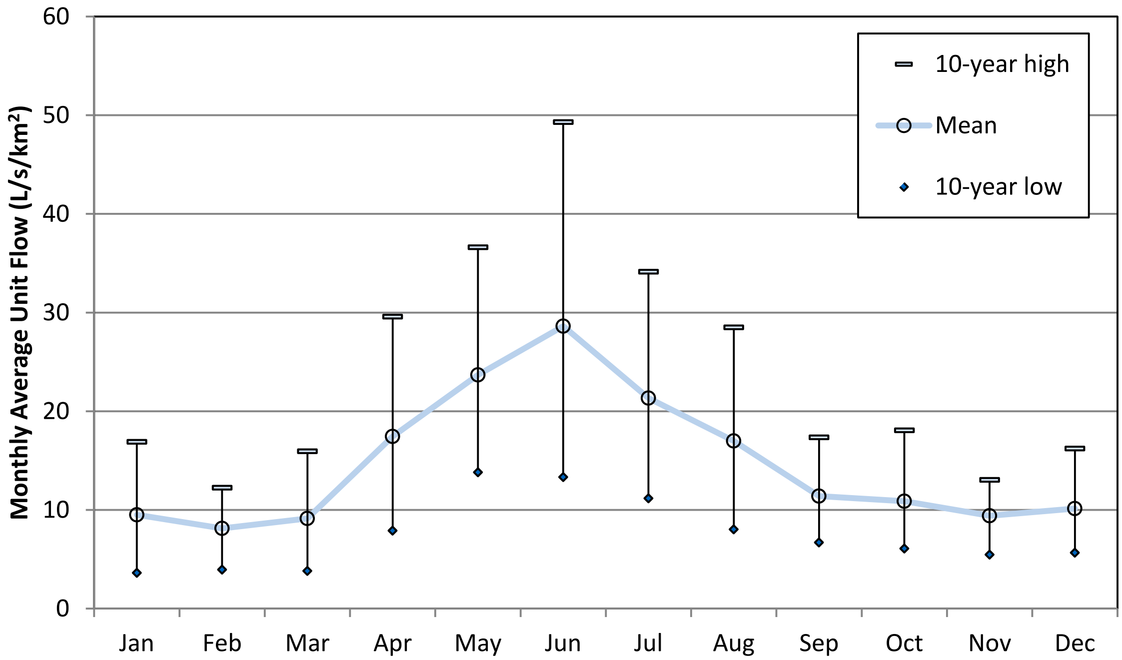
Note: An adjustment factor was applied in the flow model when using Hosmer hydrographs

Figure 5-22 Hosmer Shifted (+3 weeks) Representative Hydrograph Statistics



Note: An adjustment factor was applied in the flow model when using Hosmer hydrographs

Figure 5-23 Cataract Representative Hydrograph Statistics



6 Other Methods for Flow Simulation

6.1 Line Creek Nodes

The methods used to derive historical flows for each Line Creek node, shown in Figure 2-1, are summarized in Table 6-1. Observed daily flow data at Environment Canada station Line Creek at the mouth (08NK022) were used to estimate historical monthly average flows at node LC1, since the locations of the node and station coincide. The observed data were also used to derive flows at Line Creek upstream of West Line Creek (node LC_US_WLC). West Line Creek historical flows were sourced from the results of hydrological modelling for the LCO Phase II Project (Teck 2011a), combined with observed flows at the Teck hydrometric station from November 2009 to December 2012.

The mining operation in Line Creek watershed is almost at full build-out, and flow characteristics at the nodes are not expected to change appreciably over the remainder of the mine life.

Table 6-1 Line Creek Nodes Method

Node	Description [a]	Method used to Derive Flows	Formula
WLC1	West Line Creek (WLC) at the mouth	UBC Watershed Model results for the LCO Phase II Project (Teck 2011b,c) West Line Creek station observed flows from November 2009 to December 2012	n/a
LC_US_WLC	Line Creek upstream of WLC	Derived using observed flows at Line Creek at the mouth (08NK022) and prorated using a ratio of watershed areas (0.44)	LC_US_WLC = LC1 x 0.44
LC1	Line Creek at the mouth	LC1 is located at Line Creek at the mouth (08NK022). Gauged flows were used.	LC1 = 08NK022

[a] See Site Conditions Report (Teck 2014c) for watershed descriptions and locations.

6.2 Elk River Nodes

A separate method of flow derivation was used for the Elk River nodes. It was not appropriate to apply the representative hydrograph method to the entire Elk River watershed, because of its large area and geographic extent.

Table 6-2 summarizes flows for Elk River nodes based on gauged data from the three Environment Canada gauges in the designated area. Table 6-3 summarizes the methods used to derive historical flows for each Elk River node.

Table 6-2 Environment Canada Gauges for Elk River

Gauge	Description	Watershed Area (km^2)	Available Period of Data
08NK016	Elk River near Natal	1,870	1950 to 2012
08NK004	Elk River at Fernie	3,110	1919 to 2012
08NK005	Elk River at Philips Bridge	4,450	1924 to 1996

Table 6-3 Elk River Nodes Method

Node	Description	Method Used to Derive Flows	Formula
ER1a	Elk River downstream of Thompson Creek	ER1a is derived from ER1b by pro-rating the flow using a ratio of watershed areas.	ER1a = ER1b x 0.92
ER1b	Elk River downstream of GHO and upstream of Fording River confluence (near Elkford)	ER1b is derived by calculating the flow just upstream of FR5 and pro-rating the flow using a ratio of watershed areas.	ER1b = (ER2 – FR5simulated) x 0.78
ER2	Elk River downstream of Fording River confluence	ER2 is located at 08NK016 (Elk River at Natal). Gauged flows were used.	ER2 = 08NK016
ER3	Elk River downstream of Michel Creek confluence	Derived using Elk River at Fernie (08NK004) by pro-rating the flow using a ratio of watershed areas.	ER3 = ER3b × 0.91
ER3b	Elk River at Fernie	ER3b is located at 08NK004 (Elk River at Fernie). Gauged flows were used.	ER3b = 08NK004
ER4	Elk River at Elko Reservoir	Derived using Elk River at Fernie (08NK004) and prorated using a ratio of watershed areas.	ER4 = ER3b x 1.14
ER5	Elk River at the mouth	Derived using Elk River at Phillips Bridge (08NK005), and Elk at Fernie after 1996. Prorated flow based on a relationship between monthly flows (from scatterplot).	ER5 = 08NK005 (until 1996) ER5 = ER3b × 1.53 (after 1996)

6.3 Lake Koocanusa Inflows

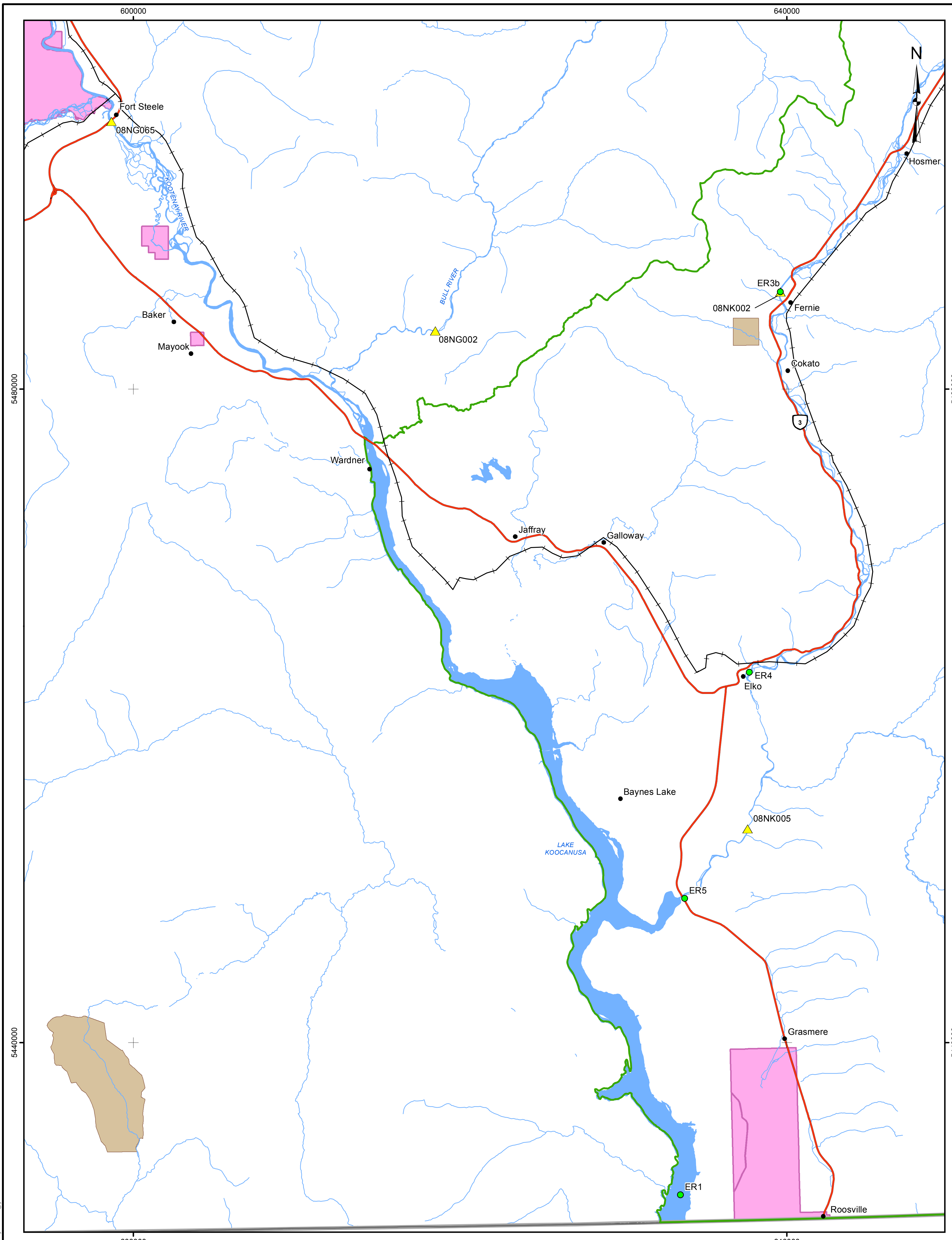
Lake Koocanusa is a BC/Montana trans-border reservoir formed by damming of the Kootenay River by the Libby Dam in 1975. The reservoir has a usable storage of about 6,100M m^3. The hydraulic residence time ranges from about 4 to 8 months (BPA 1998). Estimates of reservoir inflow were required as inputs to the water quality model.

Inflows to Lake Koocanusa in the designated area were derived based on available flow monitoring data from the hydrometric stations on the Bull River, Kootenay River and Elk River (Figure 6-1, Table 6-4).

Table 6-4 Lake Koocanusa Inflows Derivation

Operator	Station #	Station Name	Period Record		Drainage Area (km^2)
			Start	End	
Environment Canada	08NG002	Bull River near Wardner	1914	2012	1,520
Environment Canada	08NG065	Kootenay River at Fort Steele	1963	1996	11,500
Environment Canada	08NK005	Elk River at Phillips Bridge	1924	1996 (2010 [a])	4,450

[a] Measured data end in 1996. The record was extended to 2012 using a relationship with Elk River at Fernie (08NK004).



LEGEND

- CITY / TOWN / COMMUNITY
- ENVIRONMENT CANADA FLOW MONITORING STATION
- MODELLING NODE
- CANADIAN PACIFIC RAILWAY
- PRIMARY HIGHWAY
- WATERCOURSE
- BRITISH COLUMBIA - ALBERTA BORDER
- COAL MINING OPERATION
- DESIGNATED AREA
- FIRST NATIONS RESERVE
- PROVINCIAL PARK
- WATERBODY

5 0 5

SCALE 1:225,000 KILOMETRES

REFERENCE

Communities obtained from The Atlas of Canada, Natural Resources Canada. Roads obtained from Geobase. Parks/ protected areas, First Nations and railroad data obtained from Geogratis. Provincial boundary and hydrography data obtained from IHS Energy Inc. USA data obtained from ESRI. Projection: UTM Zone 11 Datum: NAD 83

PROJECT

TECK COAL ELK VALLEY
WATER QUALITY PLAN

TITLE

LAKE KOOCANUSA LOCATION MAP

Teck

PROJECT No. 13-1349-0006			SCALE AS SHOWN	REV. 0
DESIGN	AC	27 Feb. 2013	FIGURE 6-1	
GIS	DR	27 Jun. 2014		
CHECK	JC	27 Jun. 2014		
REVIEW	AC	27 Jun. 2014		

I:\CLIENTS\TECK_COAL\13-1349-0006\Mapping\MXD\Hydrology\B-Hydrology-004-GIS-LakeKoocanusa.mxd

6.4 Statistics for Future Flow Scenarios

Future flow scenarios for Elk River nodes, Line Creek nodes and Lake Koocanusa inflows were derived from gauged flows. It was assumed that there will be no measurable change in the flow statistics over the planning period due to Teck's activities. This assumption is appropriate for these regional nodes for the following reasons:

- The areas of mining and waste rock in the Line Creek watershed will not change substantially over the remaining life of the mine. Therefore, gauged flows at Line Creek at the mouth station from 1995-2010 are representative of current and future flow characteristics.
- The combined mining area of all Teck operations in the Elk Valley is currently about 128 km^2, and is planned to increase to about 174 km^2 over the life of the mines. Mine operations currently cover ~4% of the Elk River watershed (based on a watershed area of 2,841 km^2 at Elk River downstream of Michel Creek confluence), increasing to ~6% in the future. Since mining operations are a proportionately small area of the Elk River watershed, they are not expected to have a measurable effect on Elk River flows.

Potential future flow changes due to other developments, land use changes and climate change were not considered as part of the hydrological analysis.

High- and low-flow distribution analyses were run on the 15-year period (1995-2010) of monthly average flows for Elk River and Line Creek nodes. Separate distribution analyses were completed for each month (i.e., 15 data points were used for each). Each analysis used four curve fitting methods: 3 parameter Log Normal (3P), Extreme Value (EV), Log Pearson III (LP3), and Weibull (Gumbel III). The best-fitting curve was chosen for each month.

The statistics for the Elk River nodes, Line Creek nodes and Lake Koocanusa inflows and associated graphs are shown in Appendix C.

6.4.1 Comparison of High and Low Simulated Flows

Simulated high/low monthly average flow scenarios for FR5 (Fording River at the mouth) and MC1 (Michel Creek below Natal) were calculated by summing upstream flows. The majority of the contributing watersheds were simulated using the representative hydrograph method, which applies 1-in-10-year high/low statistical monthly flows at the sub-watershed level. The exception was Line Creek watershed, a tributary of the Fording River, where 1-in-10-year high/low statistical monthly flows at the mouth were derived from gauged flows. Therefore, the simulated high/low flows at FR5 and MC1 do not necessarily correspond to the 1-in-10 year return period at these locations as they consist of a specific combination of simultaneous events at a tributary and sub-watershed level. The selected approach generates high/low flow scenarios that are designed for use in a water quality planning tool.

Geochemistry and hydrology inputs to the water quality model have a higher level of confidence for average flow conditions. Calculations of concentrations under more extreme flows have higher uncertainty because of the temporal resolution in the geochemistry input data.

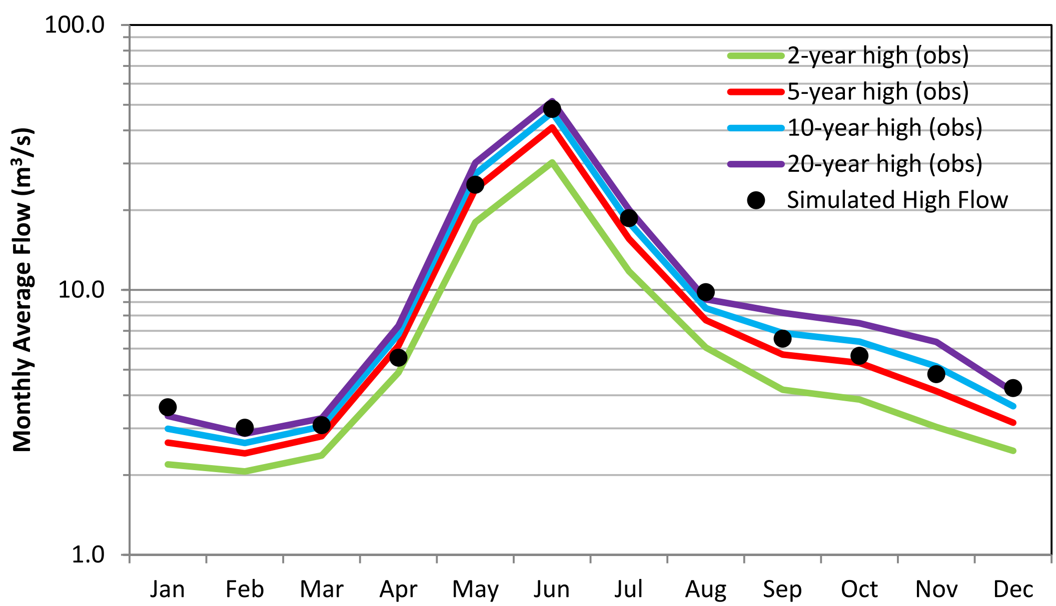
For comparison purposes, monthly high and low flow statistics for various return periods were derived using:

- Fording River at the mouth (08NK018) observed monthly average flow data for the period 1995 to 2010 (the same period as the input data for the model)
- Michel Creek below Natal (08NK020) observed monthly average flow data for the period 1970 to 1996 (this station was discontinued in 1996, so the full period of record was used to derive the statistics).

The simulated high/low flows under future flow scenarios were compared with the statistics from observed flows, to provide context and an understanding of the magnitude of the simulated flows at the gauge locations. The comparisons of FR5 (Fording River at the mouth) high and low simulated flows for current watershed conditions are shown on Figure 6-3 and Figure 6-4, respectively. The comparisons of MC1 (Michel Creek below Natal) high and low simulated flows for current watershed conditions are shown on Figure 6-5 and Figure 6-6, respectively.

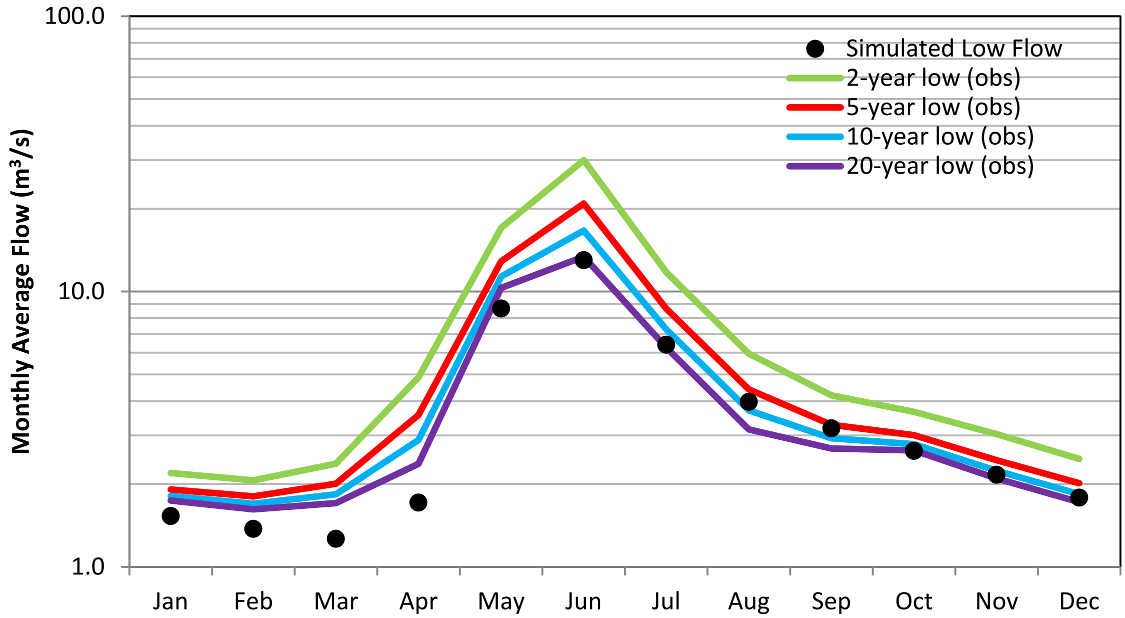
The flow model does not include simulation of the 7Q10 flow statistic. However, the simulated minimum monthly flow under low flow conditions (for the current snapshot) was compared to the observed 7Q10 flow at six locations where good quality observed daily flow data was available; Fording River at the mouth (08NK018), Line Creek at the mouth (08NK022), Elk River near Natal (08NK016), Michel Creek below Natal (08NK020), Elk River at Fernie (08NK002) and Elk River at Phillips Bridge (08NK005). At these locations, the observed 7Q10 corresponded to 73% to 87% of the simulated minimum monthly flow under low flow conditions

Figure 6-3 High-Flow Scenario at FR5 (Fording River at the Mouth) – Current Conditions



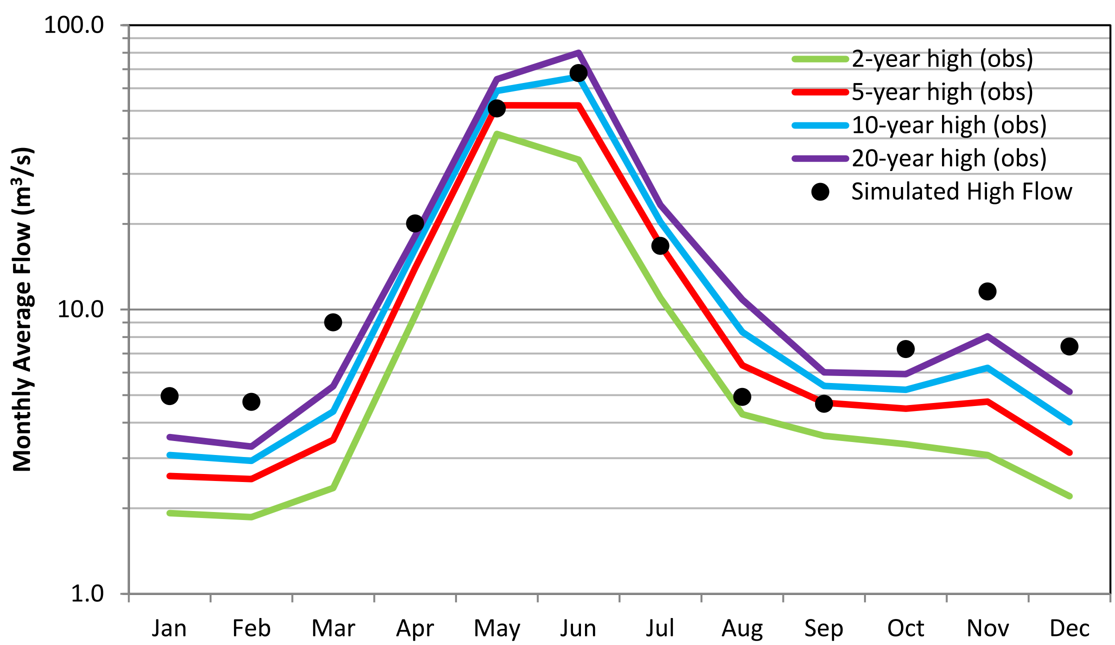
Note: “obs” = statistics calculated from observed monthly average flows for the period 1995 to 2010

Figure 6-4 Low-Flow Scenario at FR5 (Fording River at the Mouth) – Current Conditions



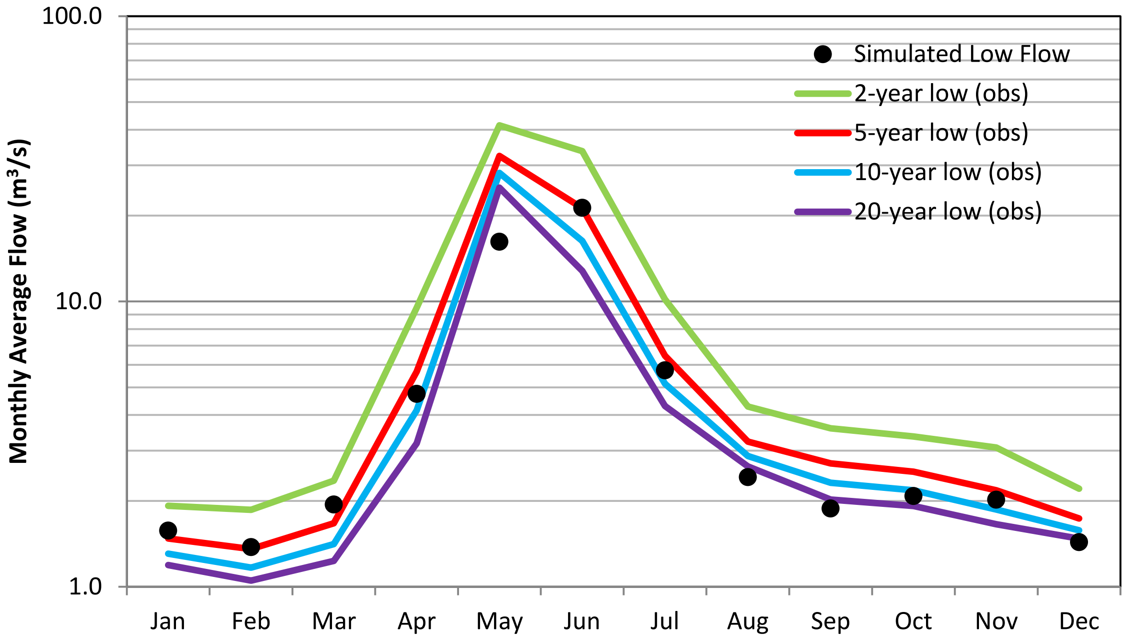
Note: “obs” = statistics calculated from observed monthly average flows for the period 1995 to 2010.

Figure 6-5 High-Flow Scenario at MC1 (Michel Creek below Natal) – Current Conditions



Note: “obs” = statistics calculated from observed monthly average flows for the period 1970 to 1996.

Figure 6-6 **Low-Flow Scenario at MC1 (Michel Creek below Natal) – Current Conditions**

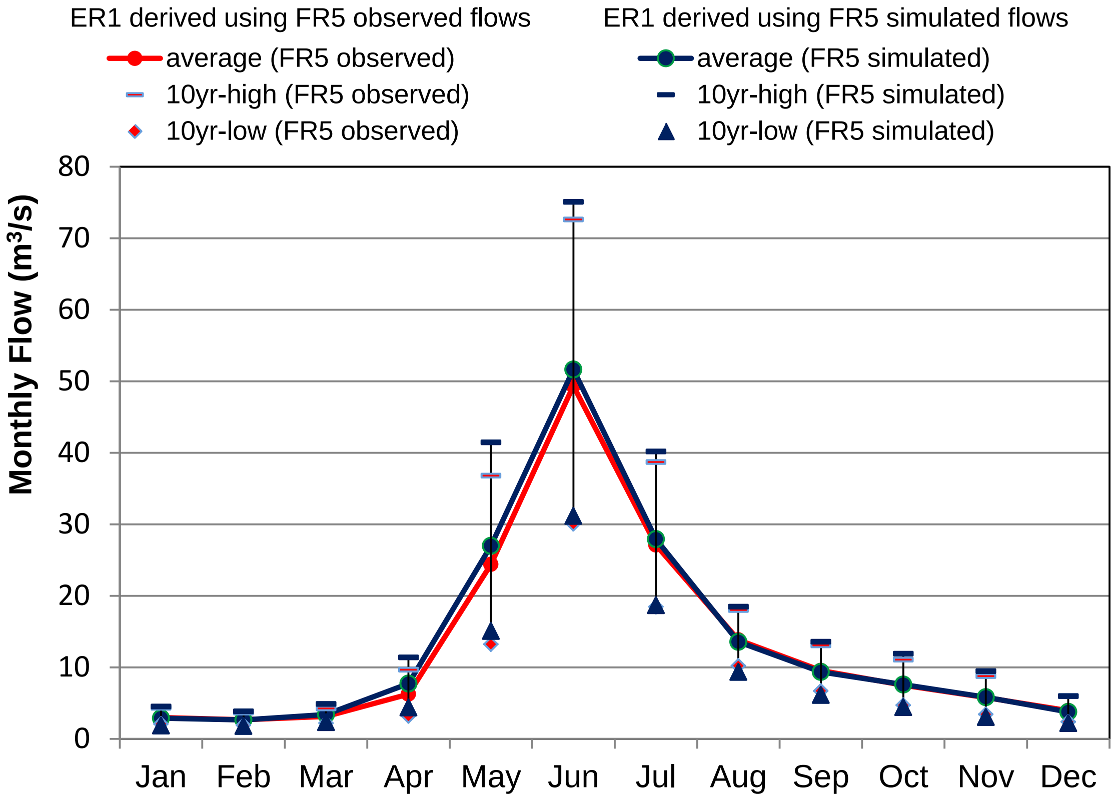


Note: “obs” = statistics calculated from observed monthly average flows for the period 1970 to1996.

6.4.2 Comparison of Elk River Flow Statistics

As outlined in Section 6.2, ER1 has been derived using Fording River at the mouth (FR5) simulated flows rather than gauged flows to maintain model consistency. For comparison purposes, simulated and observed Fording River flows were used to derive two flow series for Elk River upstream of the Fording River confluence and two corresponding sets of statistics. Figure 6-7 shows the statistical comparison. It demonstrates that both methods give similar flow statistics results. Average monthly flows are all within 10% except for April, which is within 20%.

Figure 6-7 **Elk River upstream of the Fording River Confluence – Statistical Comparison**



7 Model Performance and Quality Checks

7.1 Model Performance

Model performance figures and discussion for Kilmarnock Creek, Thompson Creek, Michel Creek, Grave Creek, the Fording River and Elk River are presented in Section 5.

A variety of model performance statistics were calculated at locations where sufficient observed data were available for statistical comparison. The results are presented in Appendix A.

At locations where observed flow data were available but not sufficient and/or applicable for statistical comparison, evaluation of model performance was undertaken by visual comparison of observed and simulated flow at an appropriate scale. Model performance comparison graphs are presented in Appendix A.

7.2 Elk River Balance Checks

The flow model does not simulate flows from all of the natural watersheds along the Elk River. Therefore, balance checks were undertaken between Elk River nodes, so that the undefined flow from the natural area over the historical and future periods was always positive.

7.2.1 ER1 to ER2

The balance check for the area from ER1 to ER2 considers the contributing simulated flows from the Fording River, derived flows at ER1 and observed flows at ER2. The balance check used the following formula:

$$\begin{gathered}\textit{Flow from undefined natural area between ER1 and ER2} = \textit{Elk River downstream Fording (ER2)} \\ - \textit{Elk River downstream GHO (ER1)} - \textit{Fording River at the mouth (FR5)}\end{gathered}$$

The results of the balance check are positive for both the historical and future periods.

7.2.2 ER2 to ER3

The balance check for ER2 to ER3 considers the contributing simulated flows from the Elk River tributaries and Michel Creek at EVO. Flows at both ER2 and ER3 are based on observed flow series (see Section 6.2). The balance check used the following formula:

$$\begin{gathered}\textit{Flow from undefined natural area between ER2 and ER3} = \textit{Elk River downstream Michel (ER3)} - \textit{Elk River downstream Fording} \\ \textit{(ER2)} - \textit{Grave Creek (GC1)} - \textit{Six Mile Creek} - \textit{Goddard Creek (GD1)} - \textit{Michel Creek (MC1)}\end{gathered}$$

The balance check is negative for one month (June 1997), indicating the model overestimates flow for this month; however this single occurrence appears to be related to the timing of the different hydrographs in Elk River and Michel Creek. The results for the remainder of the historical period, and all of the future period, are positive.

8 References

BPA 1998. Dalbey, Steve, Jay DeShazer, Larry Garrow, Thomas Hoffman, Tom Ostrowski, "Quantification of Libby Reservoir Water Levels Needed to Maintain or Enhance Reservoir Fisheries", Project No. 1983-46700, 132 electronic pages, (BPA Report DOE/BP-12660-7)

British Columbia Ministry of Environment. 2012. *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators*.

Integral Ecology Group and O'Kane Consultants Inc. 2013. *Summary of Recharge Rate Input Values for GoldSim Modelling*, Memorandum prepared for Teck Coal by Integral Ecology Group and O'Kane Consultants Inc, August 2013.

SRK Consulting (Canada) Inc. 2014. Geochemical Source Term Inputs and Methods for Elk Valley Water Quality Modelling. Prepared for Teck Coal Limited. Submitted June, 2014.

Teck Coal Limited (Teck) 2011a. *Line Creek Operations (LCO) Phase II Project Environmental Assessment Certificate Application*.

Teck. 2011b. *2011 Life of Mine Report*, Teck Coal Ltd. Greenhills Operations.

Teck. 2011c. *2011 Life of Mine Report*, Teck Coal Ltd. Fording River Operations.

Teck 2013. *Valley-wide Selenium Management Action Plan for Teck Coal Operations in the Elk Valley – Summary Report*. Teck Coal Ltd.

Teck 2014a. *Elk Valley Water Quality Plan.* Prepared by Teck Coal Limited, July 2014.

Teck 2014b. *Elk Valley Water Quality Plan – Water Quality Modelling Methods*. Prepared for Teck Coal by Golder Associates Ltd, July 2014.

Teck 2014c. *Elk Valley Water Quality Plan - Site Conditions*. Prepared for Teck Coal by Golder Associates Ltd, July 2014.

Teck 2014d. *Elk Valley Water Quality Plan - Water Quality Modelling for the Initial Implementation Plan*. Prepared for Teck Coal by Golder Associates Ltd, July 2014.

APPENDIX A

FLOW MODEL PERFORMANCE

1 INTRODUCTION

In evaluating the performance, or “fit-for-purpose”, of a flow or hydrological model it is standard practice to apply a number of statistics and techniques, including “goodness-of-fit” statistics, absolute error measures, and other tools such as scatter and time series plots.

The selected statistics and techniques used to describe the performance of the EVWQP flow model are described below.

2 STATISTICS

2.1 ROOT MEAN SQUARE ERROR (RMSE) AND MEAN ABSOLUTE ERROR (MAE)

$$\mathrm{RMSE} = \sqrt{N^{-1}\sum_{i=1}^{N}(O_i - P_i)^2}$$

$$\mathrm{MAE} = N^{-1}\sum_{i=1}^{N}|O_i - P_i|$$

Where: O_i = measured (observed) data, P_i = modelled (predicted) data

The root mean square error, RMSE, and mean absolute error, MAE, are well-accepted absolute error goodness-of-fit indicators that describe differences in observed and predicted values in the appropriate units (Legates and McCabe 1999).

RMSE or MAE can be used to compare results from different models (where a smaller value may indicate better performance) but it is not an absolute criterion. Judging a “good” value of RMSE or MAE would first require a determination of the degree of forecasting accuracy that is required for the specific application.

2.2 COEFFICIENT OF DETERMINATION (R^2)

$$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right)^2$$

Where: O_i = measured (observed) data, P_i = simulated (predicted) data, $\bar{O}$ = mean of observed data, $\bar{P}$ = mean of simulated data

The coefficient of determination describes the proportion of the total variance in the observed data that can be explained by the model. It ranges from 0 to 1, with higher values indicating better agreement.

The coefficient of determination is limited in that it only evaluates linear relationships between the variables and is insensitive to additive and proportional differences (Legates and McCabe 1999). Correlation-based measures are also more sensitive to outliers than to observations near the mean

(Legates and Davis 1997). The fact that only the dispersion is quantified is one of the major drawbacks of r^2 if it is considered alone (Krause et.al. 2005).

2.3 NASH-SUTCLIFFE EFFICIENCY (E)

$$E = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2}$$ *Nash and Sutcliffe [1970]*

Where: O_i = measured (observed) data, P_i = simulated (predicted) data, $\bar{O}$ = mean of observed data

The range of *E* lies between 1.0 (perfect fit) and minus infinity (-∞). If *E* = 0.0, it indicates that the square of the differences between the model simulations and the observations is as large as the variability in the observed data (i.e. the observed mean is as good a predictor as the model). If *E* < 0.0, it indicates that the observed mean is a better predictor than the model.

The Nash-Sutcliffe efficiency has been widely used to evaluate the performance of hydrologic models and represents an improvement over the coefficient of determination for model evaluation purposes (Legates and McCabe 1999).

The largest disadvantage of the Nash-Sutcliffe efficiency is the fact that the differences between the observed and predicted values are calculated as squared values. As a result larger values in a time series are strongly overestimated whereas lower values are neglected (Legates and McCabe 1999). The Nash-Sutcliffe Efficiency is not very sensitive to systematic model over- or underprediction especially during low flow periods (Krause et.al. 2005).

2.4 INDEX OF AGREEMENT (D)

$$d = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} \left(\left|P_i - \bar{O}\right| + \left|O_i - \bar{O}\right|\right)^2}$$ *Willmott et.al. [1981]*

Where: O_i = measured (observed) data, P_i = simulated (predicted) data, $\bar{O}$ = mean of observed data

The Index of Agreement ranges from 0 (no correlation) and 1 (perfect fit).

Practical applications of *d* show that it has some disadvantages: (1) relatively high values (more than 0.65) of *d* may be obtained even for poor model fits, leaving only a narrow range for model calibration; and (2) despite Willmot's intention, *d* is not sensitive to systematic model over- or underprediction (Krause et.al. 2005); and (3) d is sensitive to extreme values, owing to the squared differences.

2.5 MODIFIED FORMS OF E AND D

$$E_j = 1 - \frac{\sum_{i=1}^{n} |O_i - P_i|^j}{\sum_{i=1}^{n} |O_i - \bar{O}|^j} \text{ with } j \in \mathrm{N}$$

$$d_j = 1 - \frac{\sum_{i=1}^{n} |O_i - P_i|^j}{\sum_{i=1}^{n} \left(|P_i - \bar{O}| + |O_i - \bar{O}|\right)^j} \text{ with } j \in \mathrm{N}$$

Willmott et.al.

Where: O_i = measured (observed) data, P_i = simulated (predicted) data, $\bar{O}$ = mean of observed data, $|X-Y|$ = absolute value

The modified index of agreement (d_1) and modified coefficient of efficiency (E_1) are produced from the above equations where j=1. The advantage of these modified forms is that errors and differences are given their appropriate weighting, not inflated by their squared value (i.e. the overweighting of the flood peaks is reduced significantly resulting in a better overall evaluation). In practice, $d_2 > d_1$ for the range of most values, although this relationship does not hold for extremely low values of both statistics (Legates and McCabe 1999).

3 OTHER TOOLS TO EVALUATE MODEL PERFORMANCE

Other useful tools to evaluate model performance include:

- Scatter plot: a graphical representation of paired (observed-simulated) values.
- Comparison of flow duration curves: a graphical representation of a ranking of all the flows in a given period, from the lowest to the highest, where the rank is the percentage of time the flow value is equalled or exceeded.
- Comparison of flow time series: a simple graph of flow over time.
- Comparison of annual hydrographs: mean monthly flows calculated from the concurrent period of the two flow series.

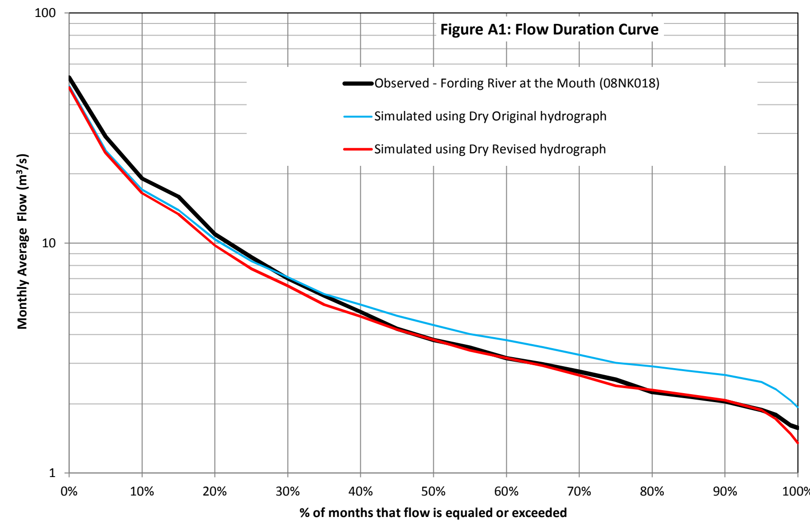
Guide Table for Flow Model Results

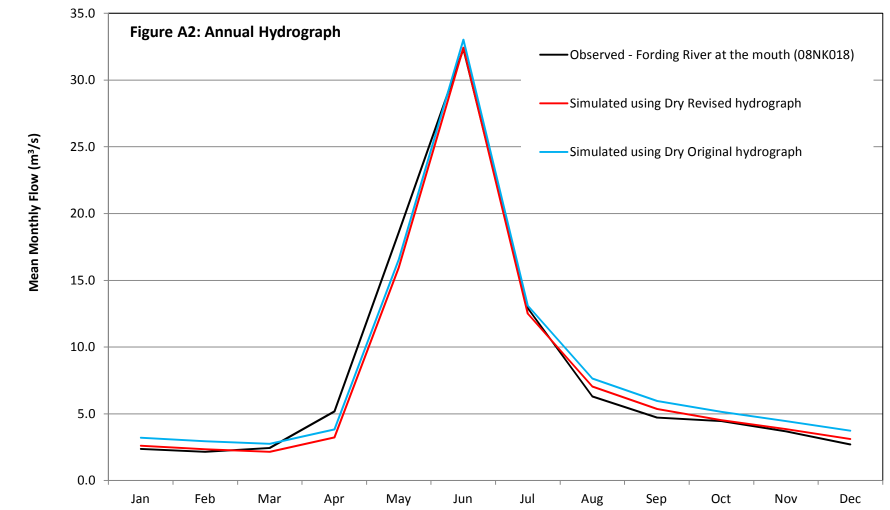
SHEET	CONTENT	FIGURE #	WATERSHED	SITE	NODE	OBSERVED DATA	
A	Comparison of results using two different hydrographs	A1-A5	Fording River	n/a	FR5	08NK018	Continuous
B	Comparison of results using two different hydrographs	B1-B5	Grave Creek	n/a	GR1	08NK019	Continuous
C	Comparison of results using two different hydrographs	C1-C5	Michel Creek	n/a	MC5	O8NK020	Continuous
D	Statistics and graphs for Revision 6.0 flow results	D1-D4	Fording River	n/a	FR5	08NK018	Continuous
E	Graphs for Revision 6.0 flow results	E1	Henretta Creek	FRO	HC1	FR_HC1	Seasonal continuous and instantaneous flows
		E2	Fording River at FR1	FRO	FR1	FR_FR1	Instantaneous flows
		E3	Clode Creek	FRO	CL1	FR_CC1	Instantaneous flows
		E4	Lake Mountain Creek	FRO	LM1	FR_NGD1	Seasonal continuous and instantaneous flows
F	Graphs for Revision 6.0 flow results	F1	Fording River at FR2	FRO	FR2	FR_NTP	Instantaneous flows
		F2	Kilmarnock Creek	FRO	KC1	FR_KC1	Seasonal continuous and instantaneous flows
		F3	Cataract Creek	FRO	CC1	GH_CC1	Instantaneous flows
		F4	Porter Creek	FRO	PC1	GH_PC1	Instantaneous flows
G	Graphs for Revision 6.0 flow results	G1	Greenhills Creek	GHO	GH1	GH_GH1	Instantaneous flows
		G2	Thompson Creek	GHO	TC1	GH_TC2	Instantaneous flows
		G3	Wolfram Creek	GHO	WC1	GH_WC1 and GH_WC2	Instantaneous flows
		G4	Leask Creek	GHO	LE1	GH_LC1 and GH_LC2	Instantaneous flows
H	Graphs for Revision 6.0 flow results	H1	Upper Line Creek	LCO		LC_LC1	Instantaneous flows
		H2	Line Creek upstream of West Line Creek	LCO	LC_US_WLC	LC_LC3 minus LC_WLC	Seasonal continuous
		H3	West Line Creek	LCO	WLC	LC_WLC	Seasonal continuous
I	Graphs for Revision 6.0 flow results	I1	EVO Dry Creek	EVO	DC1_EVO	EV_DC1	Instantaneous flows
		I2	Harmer Creek	EVO	HM1	EV_HC1	Instantaneous flows
		I3	Grave Creek	EVO	GR1	08NK019	Continuous
		I4	Six Mile Creek	EVO		EV_SM1	Instantaneous flows
J	Graphs for Revision 6.0 flow results	J1	Goddard Creek	EVO	GD1	EV_GC2	Instantaneous flows
		J2	Bodie Creek	EVO	BC1	EV_BC1	Instantaneous flows
		J3	Gate Creek	EVO	GT1	EV_GC1	Instantaneous flows
		J4	Erickson Creek	EVO	EC1	EV_EC1	Instantaneous flows

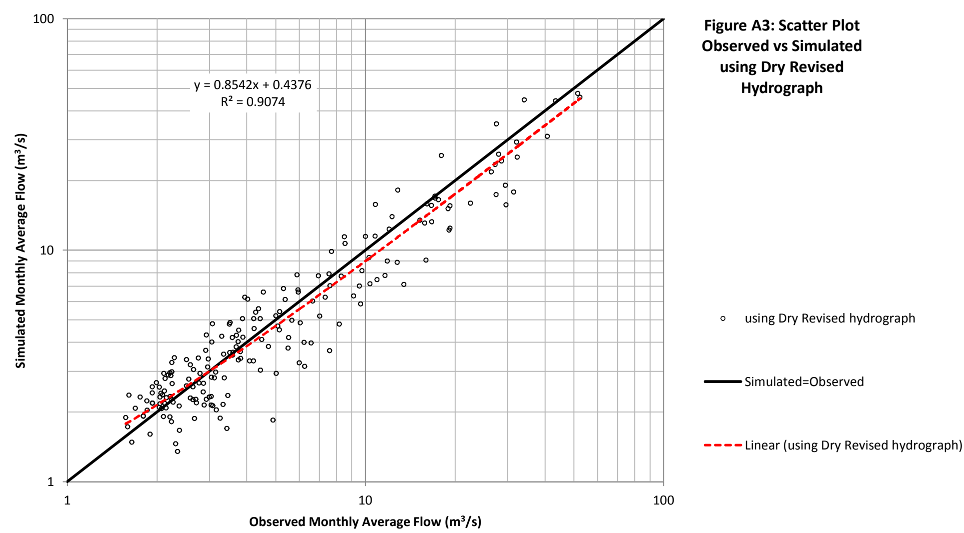
Sheet A: Comaparison of Results for Fording River at the Mouth - Simulation using Dry Original and Revised Hydrographs

	Observed	Simulated	
Statistic	Fording River at the mouth (08NK018)	using Dry Original hydrograph	using Dry Revised hydrograph
Mean (m^3/s)	7.89	7.78	7.18
Standard Deviation (m^3/s)	9.35	8.39	8.39
Nash-Sutcliffe Efficiency (E)		0.90	0.90
Modified Nash-Sutcliffe Efficiency (E1)		0.72	0.73
Index of Agreement (d)		0.97	0.97
Modified Index of Agreement (d1)		0.85	0.86
Mean Absolute Error (MAE)		6.45	6.45
Root Mean Square Error (RMSE)		2.89	2.97
Coefficient of Determination (R^2)		0.91	0.91
Linear function (y = ax + b) slope (a)		0.85	0.85
intercept (b)		1.04	0.44

RMSE / MAE are used to compare results between models (a lower value may indicate better performance)
E / EI have a range of 1.0 (perfect fit) to minus infinity (where $E<0$ indicates the observed mean is a better predictor than the model)
d has a range from 0 (no correlation) to 1 (perfect fit)
R^2 ranges from 0 to 1, with higher values indicating better agreement







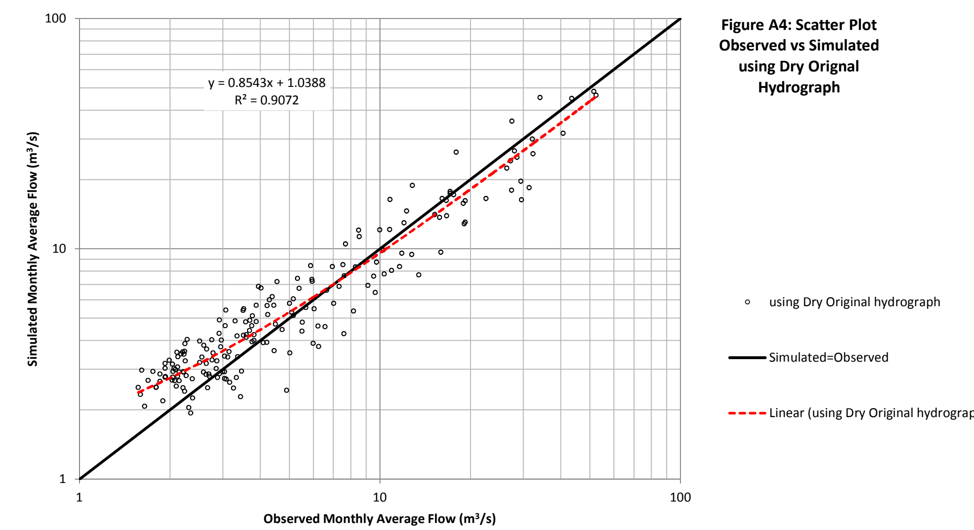
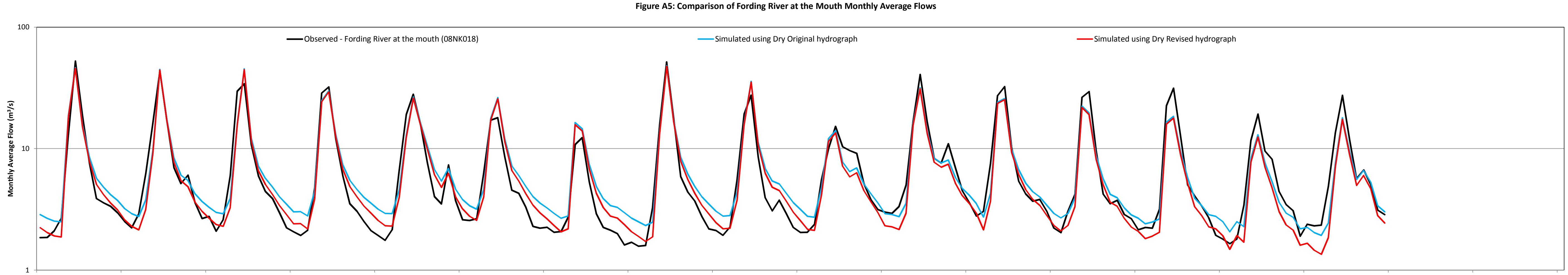


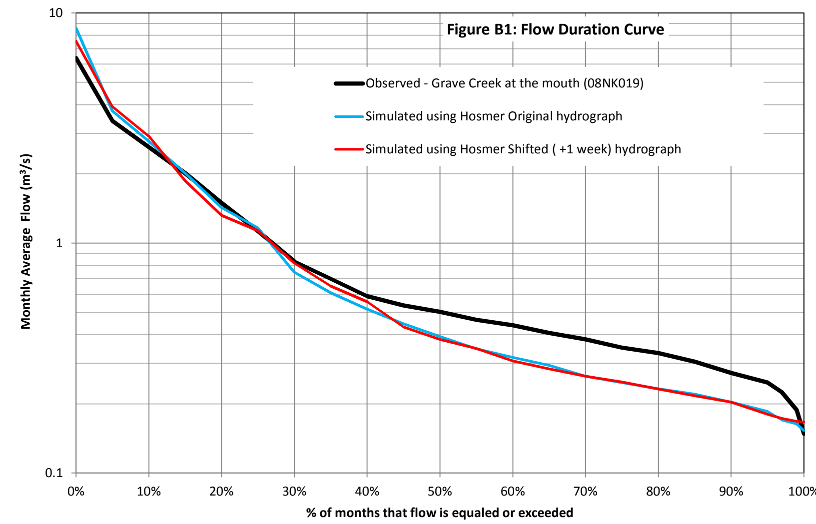
Figure A5: Comparison of Fording River at the Mouth Monthly Average Flows

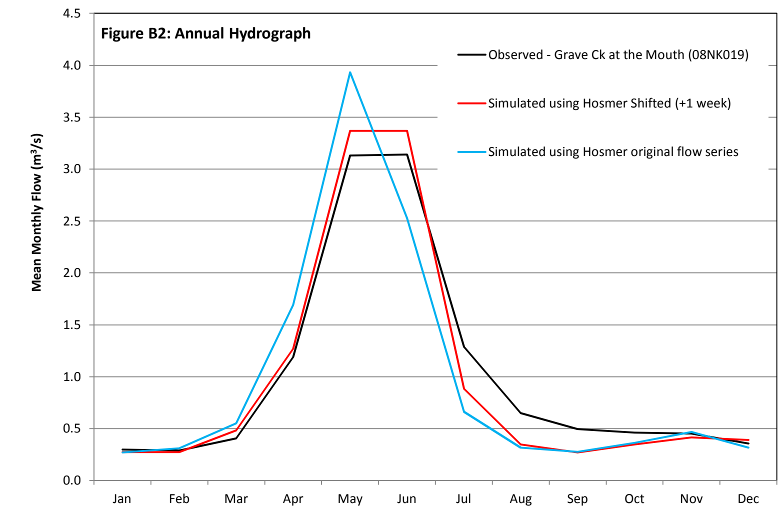


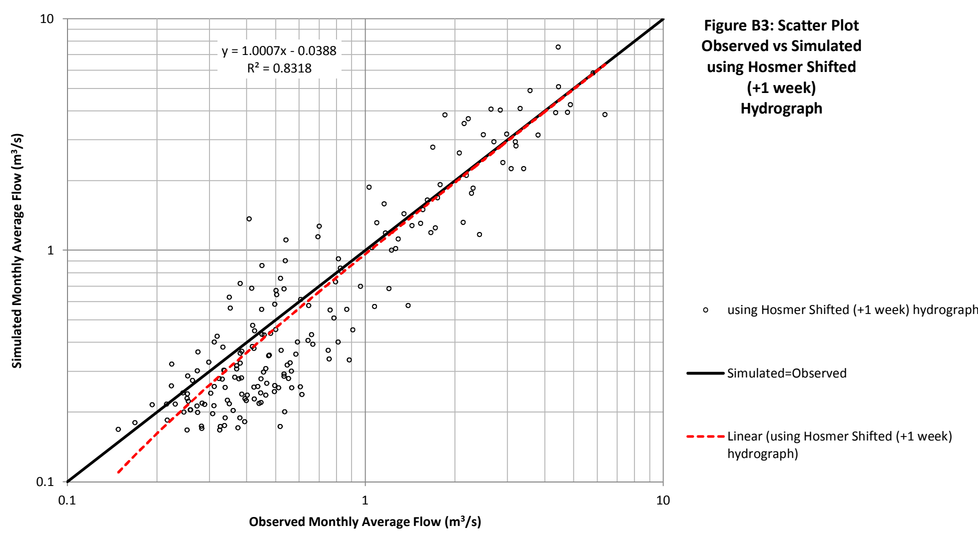
Sheet B: Comaparison of Results for Grave Creek at the Mouth - Simulation using Hosmer Original and Shifted (+1 week) Hydrographs

	Observed	Simulated	
Statistic	Grave Ck at the Mouth (08NK019)	using Hosmer Shifted (+1 week) hydrograph	using Hosmer Original hydrograph
Mean (m^3/s)	1.00	0.96	0.96
Standard Deviation (m^3/s)	1.14	1.25	1.26
Nash-Sutcliffe Efficiency (E)		0.80	0.71
Modified Nash-Sutcliffe Efficiency (E1)		0.63	0.55
Index of Agreement (d)		0.95	0.93
Modified Index of Agreement (d1)		0.82	0.79
Mean Absolute Error (MAE)		0.81	0.81
Root Mean Square Error (RMSE)		0.51	0.61
Coefficient of Determination (R^2)		0.83	0.76
Linear function (y = ax + b) slope (a)		1.00	0.97
intercept (b)		-0.039	-0.008

RMSE / MAE are used to compare results between models (a lower value may indicate better performance)
E / E1 have a range of 1.0 (perfect fit) to minus infinity (where *E*<0 indicates the observed mean is a better predictor than the model)
d has a range from 0 (no correlation) to 1 (perfect fit)
R^2 ranges from 0 to 1, with higher values indicating better agreement







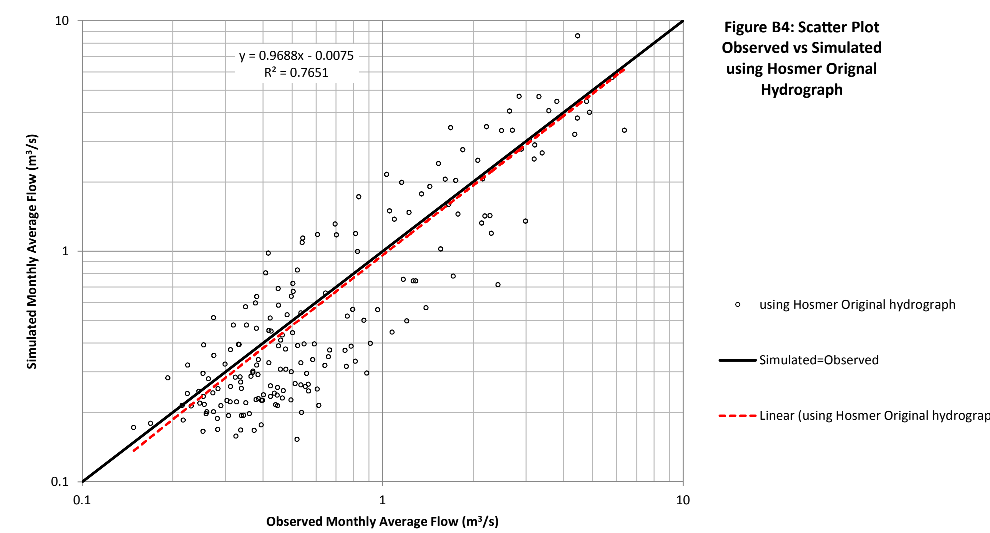
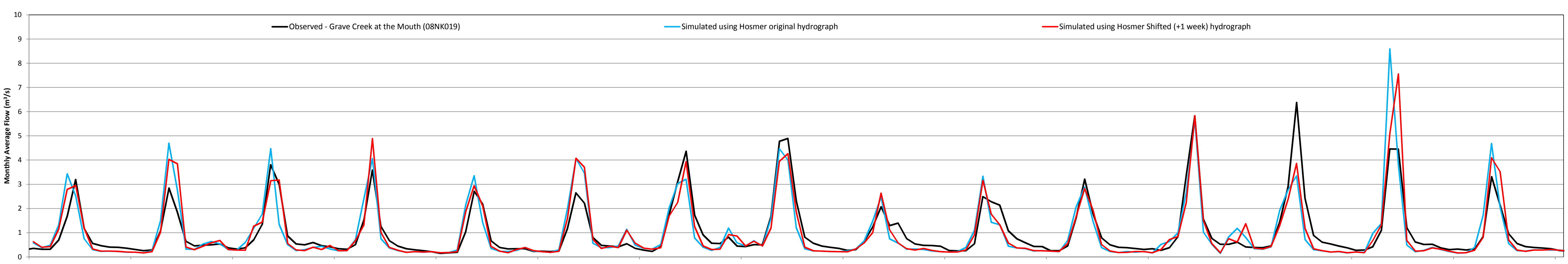


Figure B5: Comparison of Grave Creek at the Mouth Monthly Average Flows



Sheet C: Comaparison of Results for Michel Creek below Natal - Simulation using Hosmer Original and Shifted (+1 week) Hydrographs

	Observed	Simulated	
Statistic	Michel Creek below Natal O8NK020	using Hosmer Shifted (+1 week) hydrograph	using Hosmer Original hydrograph
Mean (m^3/s)	9.93	9.79	9.83
Standard Deviation (m^3/s)	13.16	11.72	11.85
Nash-Sutcliffe Efficiency (E)		0.89	0.85
Modified Nash-Sutcliffe Efficiency (E1)		0.74	0.68
Index of Agreement (d)		0.97	0.96
Modified Index of Agreement (d1)		0.86	0.83
Mean Absolute Error (MAE)		9.45	9.45
Root Mean Square Error (RMSE)		4.33	5.02
Coefficient of Determination (R^2)		0.89	0.85
Linear function (y = ax + b) slope (a)		0.84	0.83
intercept (b)		1.42	1.57

RMSE / MAE are used to compare results between models (a lower value may indicate better performance)
E / E1 have a range of 1.0 (perfect fit) to minus infinity (where E<0 indicates the observed mean is a better predictor than the model)
d has a range from 0 (no correlation) to 1 (perfect fit)
R^2 ranges from 0 to 1, with higher values indicating better agreement

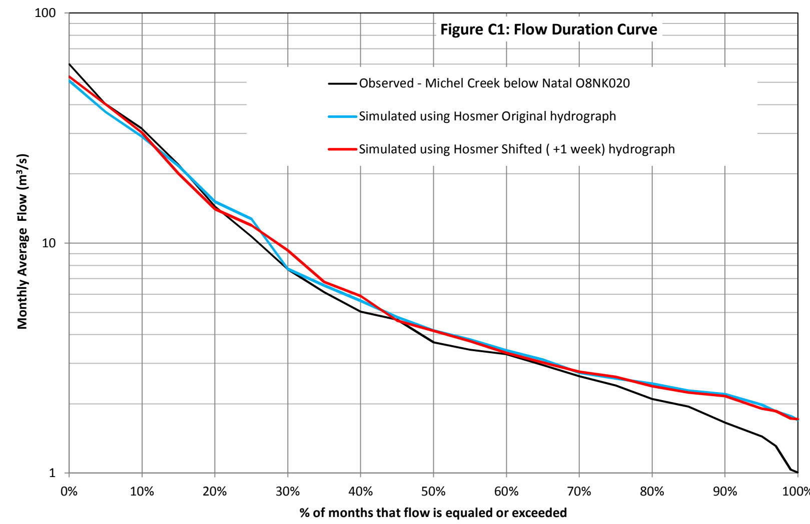


Figure C1: Flow Duration Curve

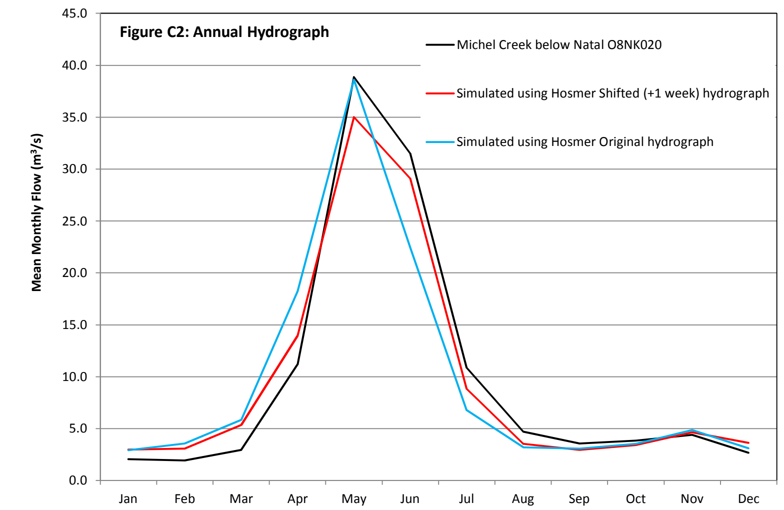


Figure C2: Annual Hydrograph

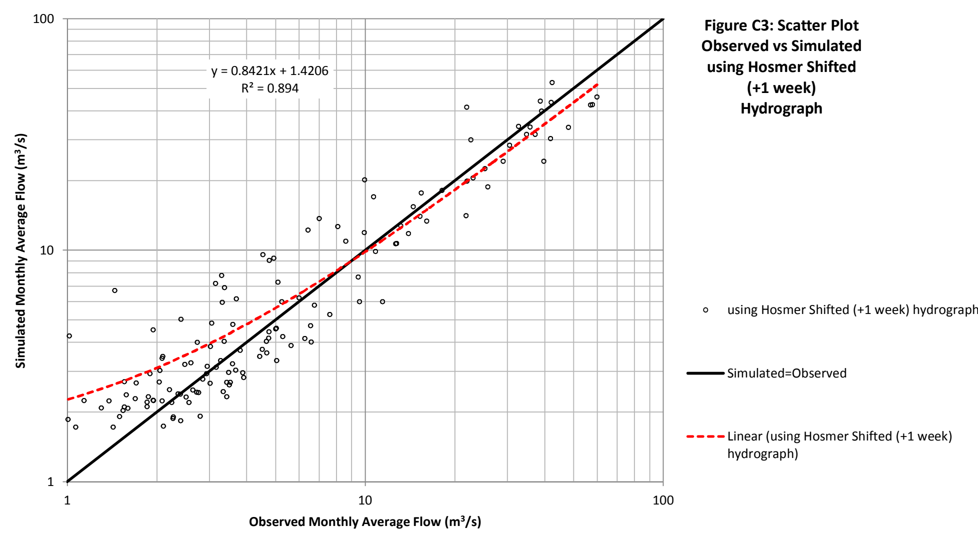


Figure C3: Scatter Plot Observed vs Simulated using Hosmer Shifted (+1 week) Hydrograph

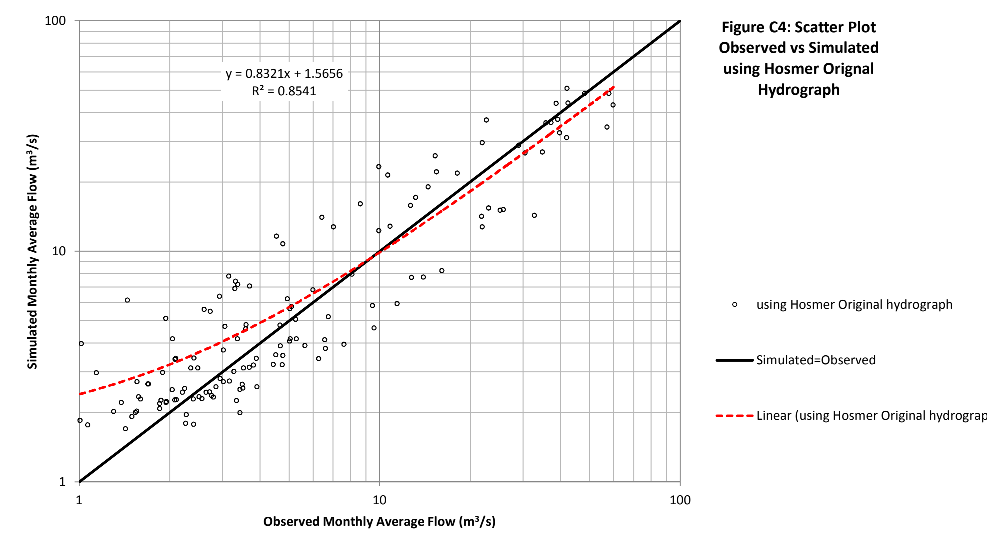
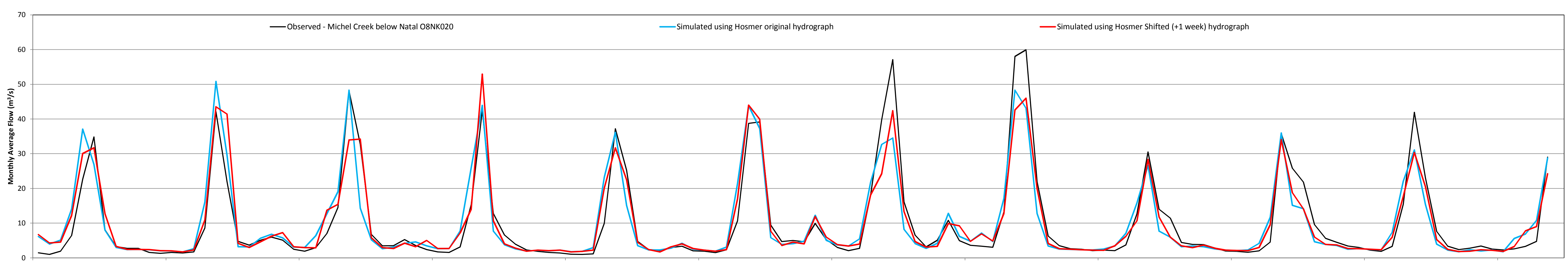


Figure C4: Scatter Plot Observed vs Simulated using Hosmer Orignal Hydrograph

Figure C5: Comparison of Michel Creek below Natal Monthly Average Flows



Sheet D: Results for Fording River at the Mouth Simulation (Flow Model Rev 6.0) - 1995 to 2012

	Observed	Simulated
Statistic	Fording River at the mouth (08NK018)	Flow model Rev 6.0
Mean (m^3/s)	8.15	7.64
Standard Deviation (m^3/s)	9.74	8.92
Nash-Sutcliffe Efficiency (E)		0.91
Modified Nash-Sutcliffe Efficiency (E1)		0.76
Index of Agreement (d)		0.98
Modified Index of Agreement (d1)		0.88
Mean Absolute Error (MAE)		6.80
Root Mean Square Error (RMSE)		2.89
Coefficient of Determination (R^2)		0.92
Linear function (y = ax + b) slope (a)		0.88
intercept (b)		0.50

RMSE / MAE are used to compare results between models (a lower value may indicate better performance)
E / E1 have a range of 1.0 (perfect fit) to minus infinity (where *E*<0 indicates the observed mean is a better predictor than the model)
d has a range from 0 (no correlation) to 1 (perfect fit)
R^2 ranges from 0 to 1, with higher values indicating better agreement

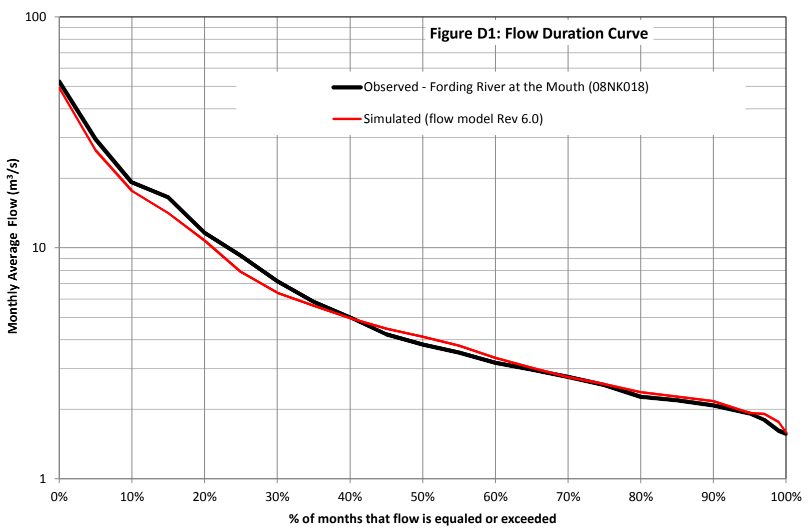


Figure D1: Flow Duration Curve

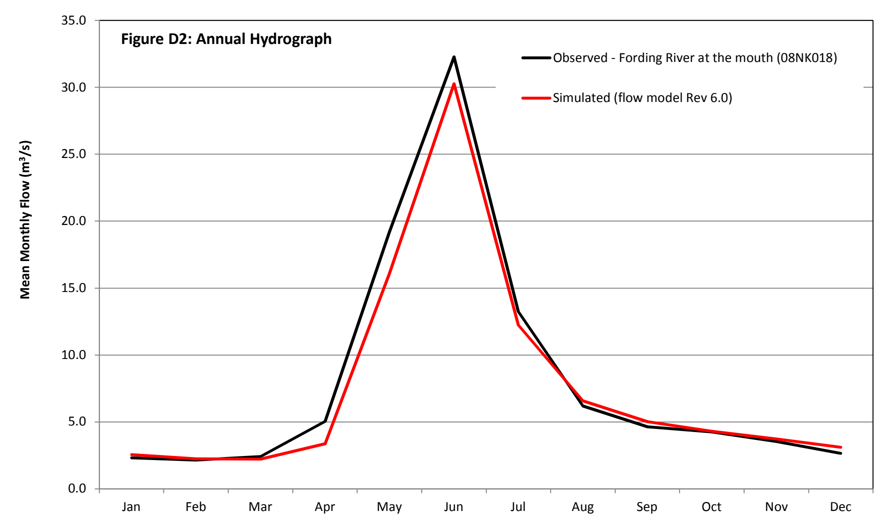


Figure D2: Annual Hydrograph

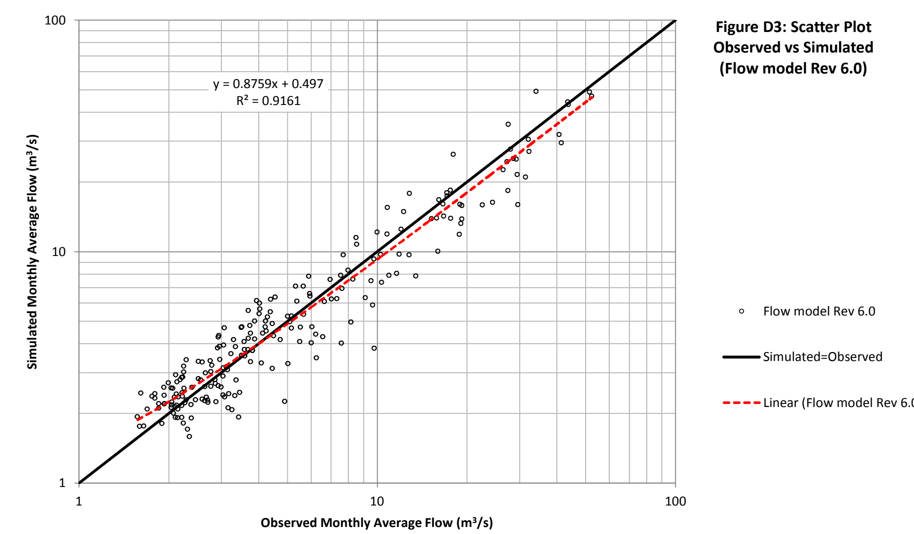
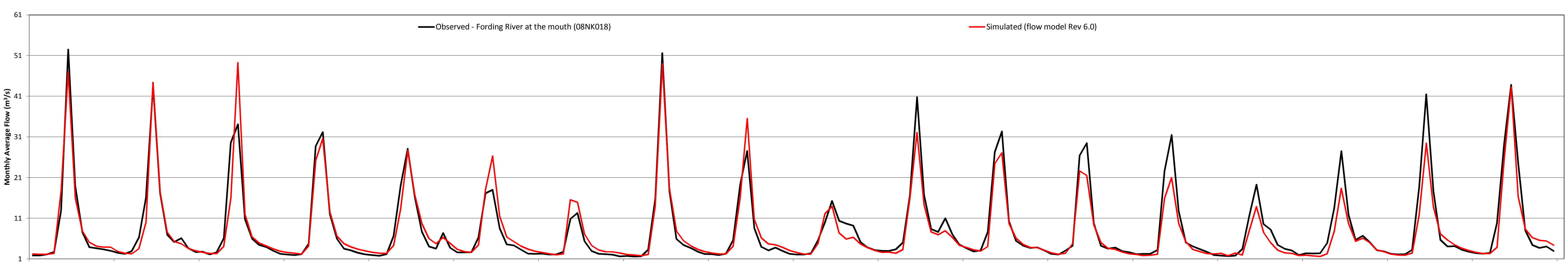


Figure D3: Scatter Plot Observed vs Simulated (Flow model Rev 6.0)

Figure D4: Comparison of Fording River at the Mouth Monthly Average Flows (1995 to 2012)



Sheet E: Graphs for Revision 6.0 flow results

Figure E1: Henretta Creek (HC1)

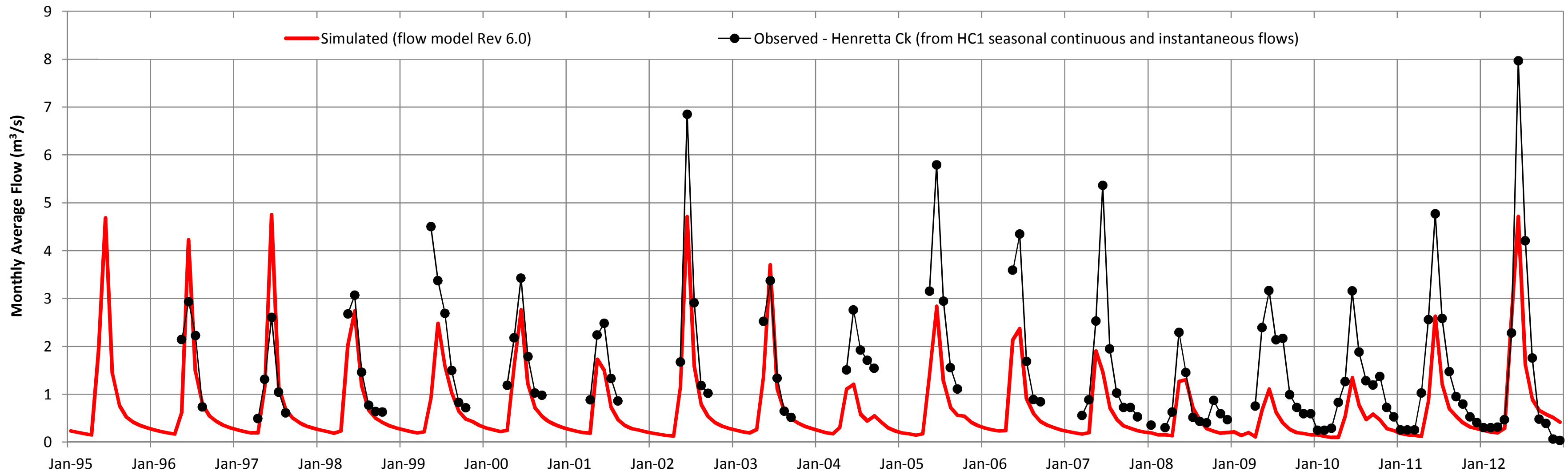


Figure E2: Fording River (FR1)

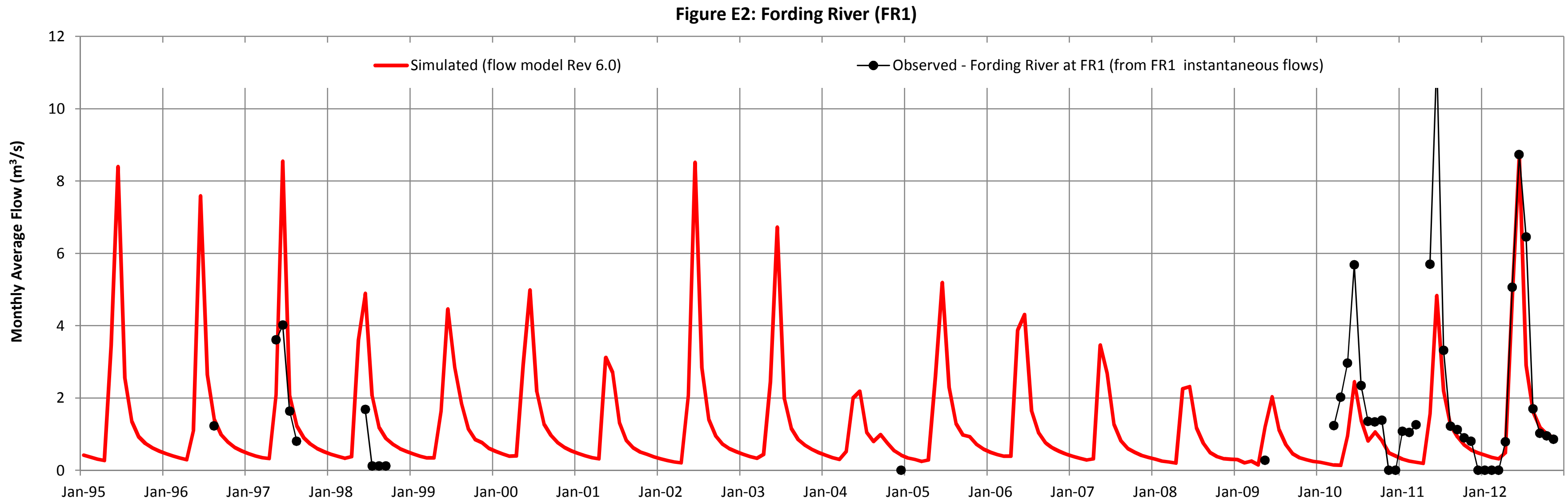


Figure E3: Clode Creek (CL1)

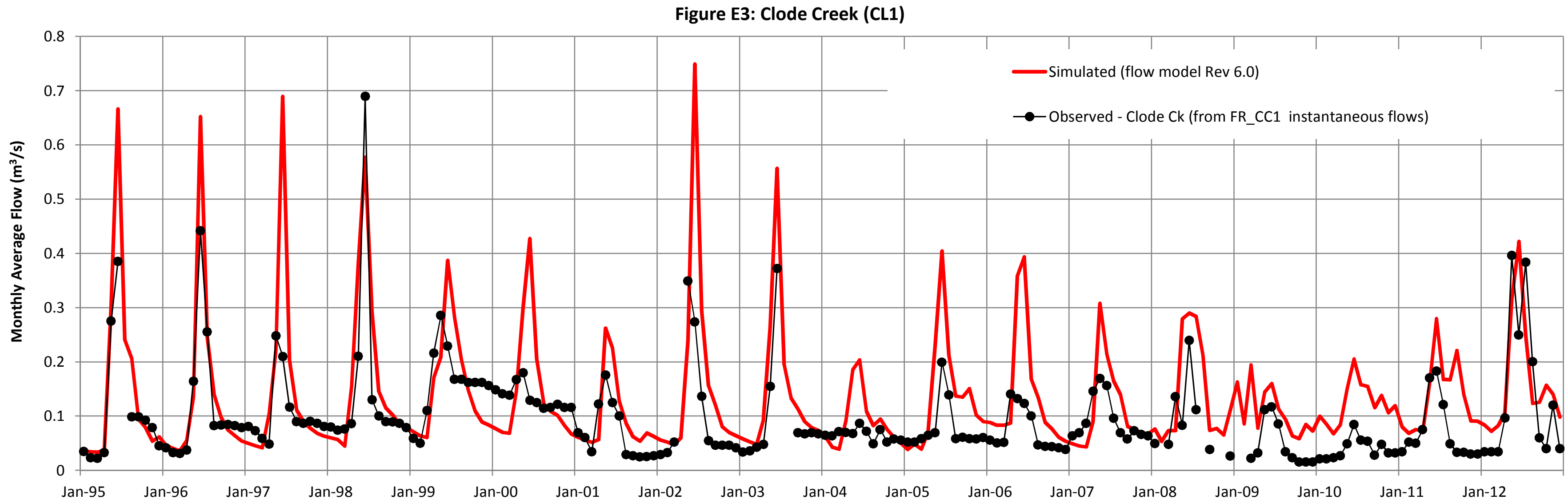
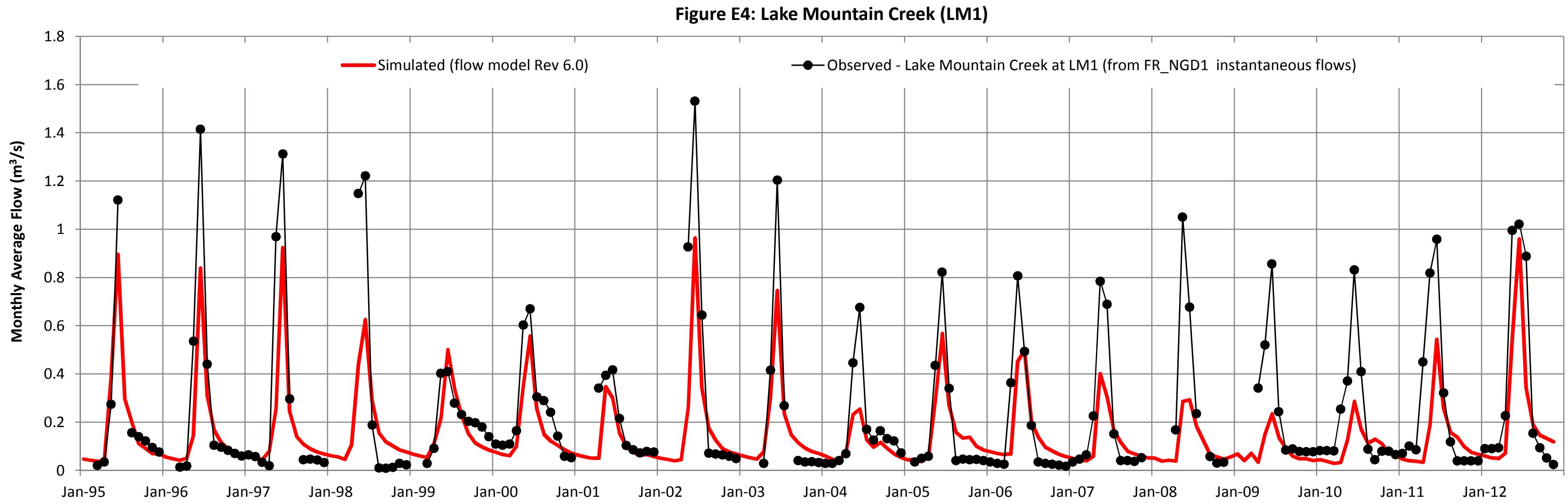


Figure E4: Lake Mountain Creek (LM1)



Sheet F: Graphs for Revision 6.0 flow results

Figure F1: Fording River (FR2)

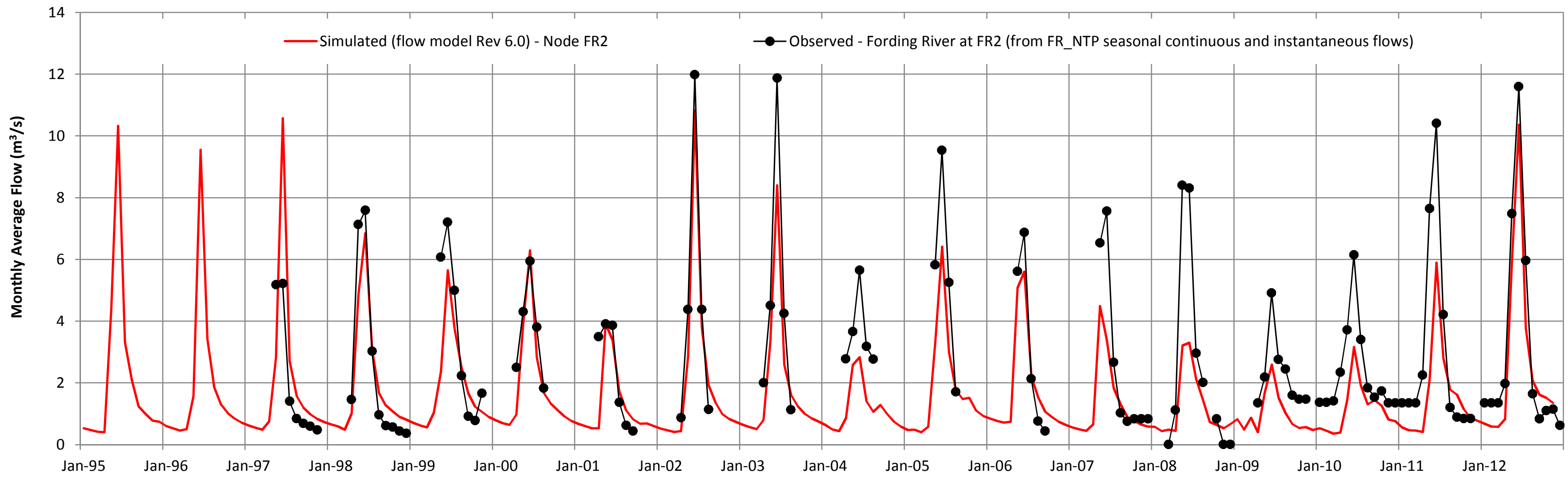


Figure F2: Kilmarnock Creek (KC1)

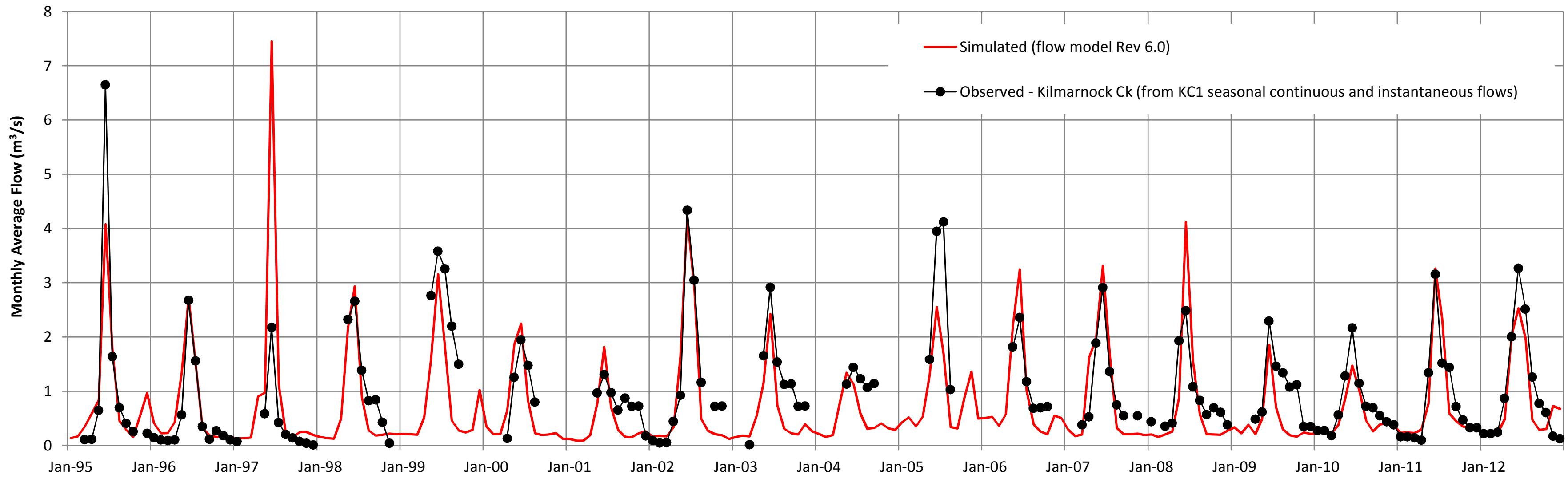


Figure F3: Cataract Creek (CA1)

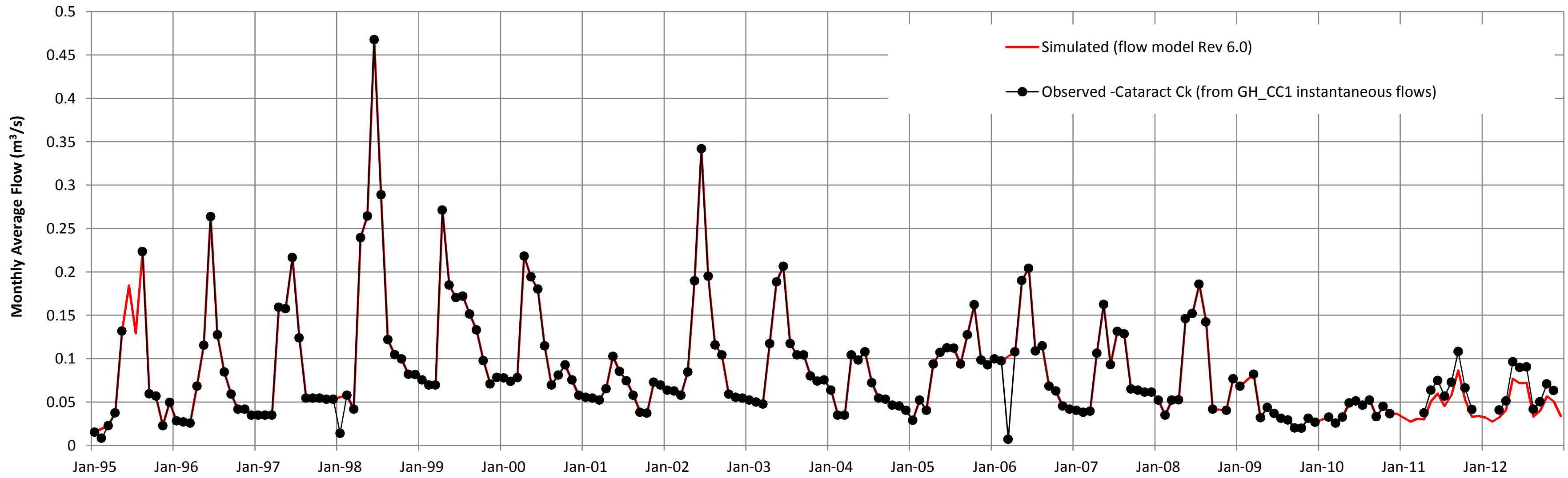
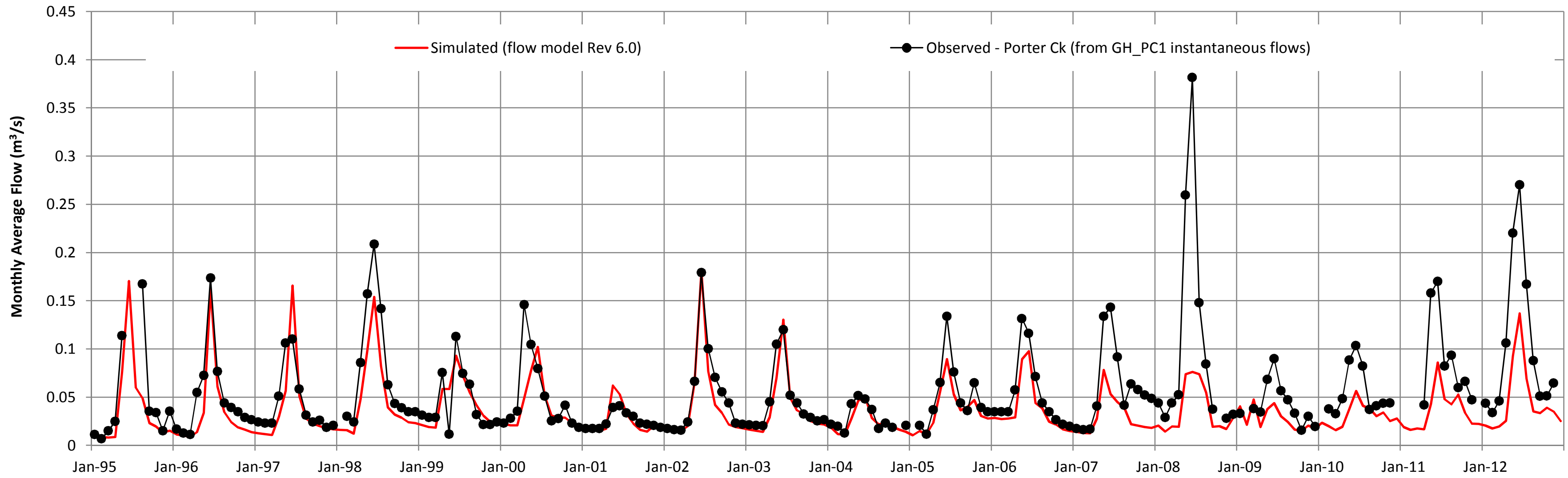


Figure F4: Porter Creek (PC1)



Sheet G: Graphs for Revision 6.0 flow results

Figure G1: Greenhills Creek (GH1)

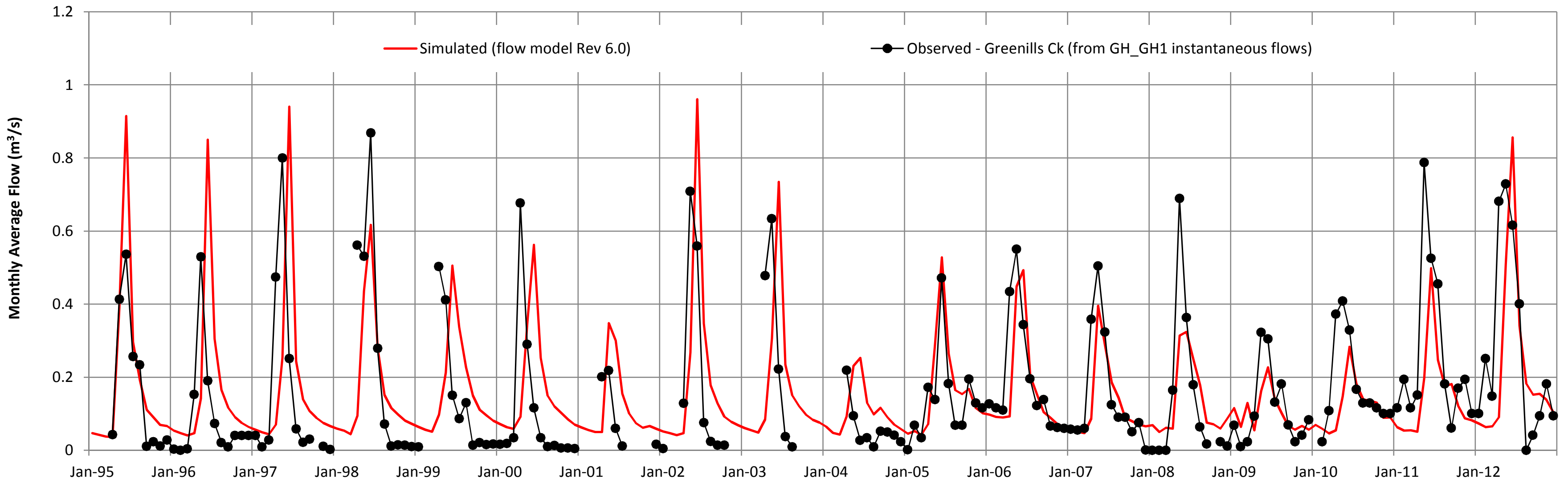


Figure G2: Thompson Creek (TC1)

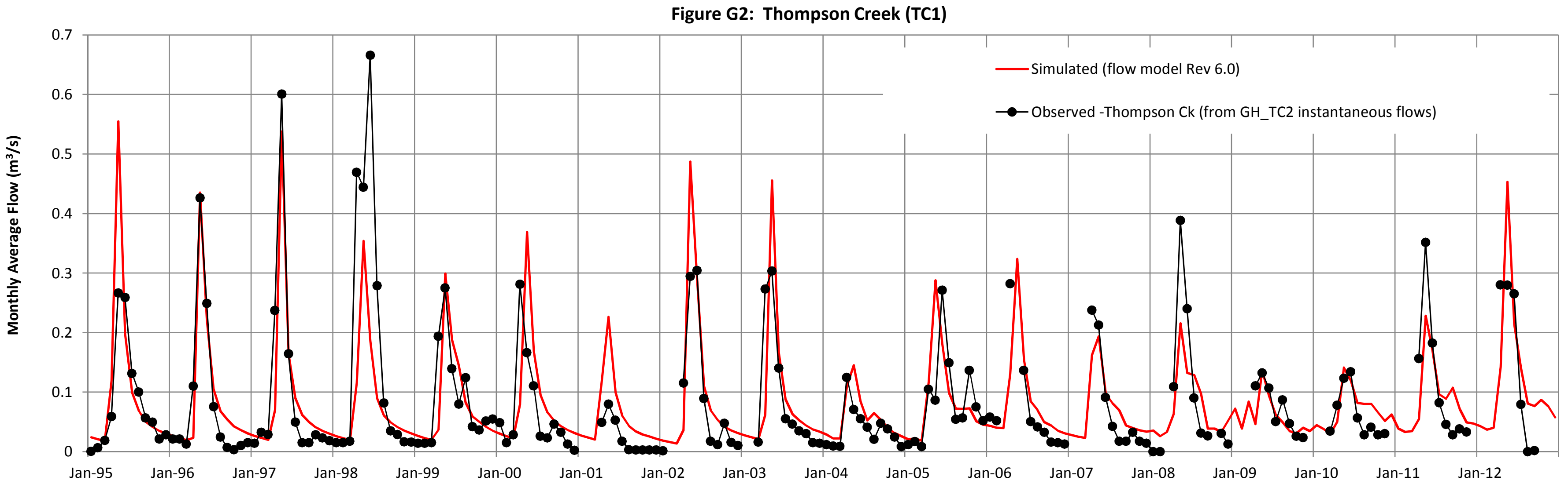


Figure G3: Wolfram Creek (WC1)

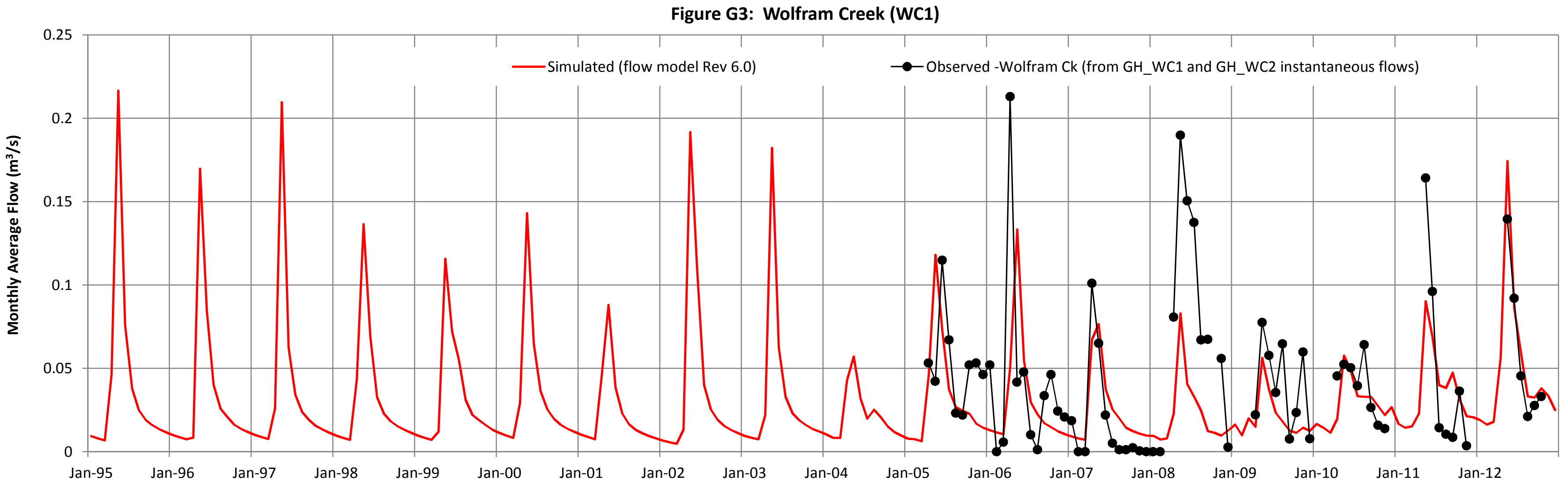
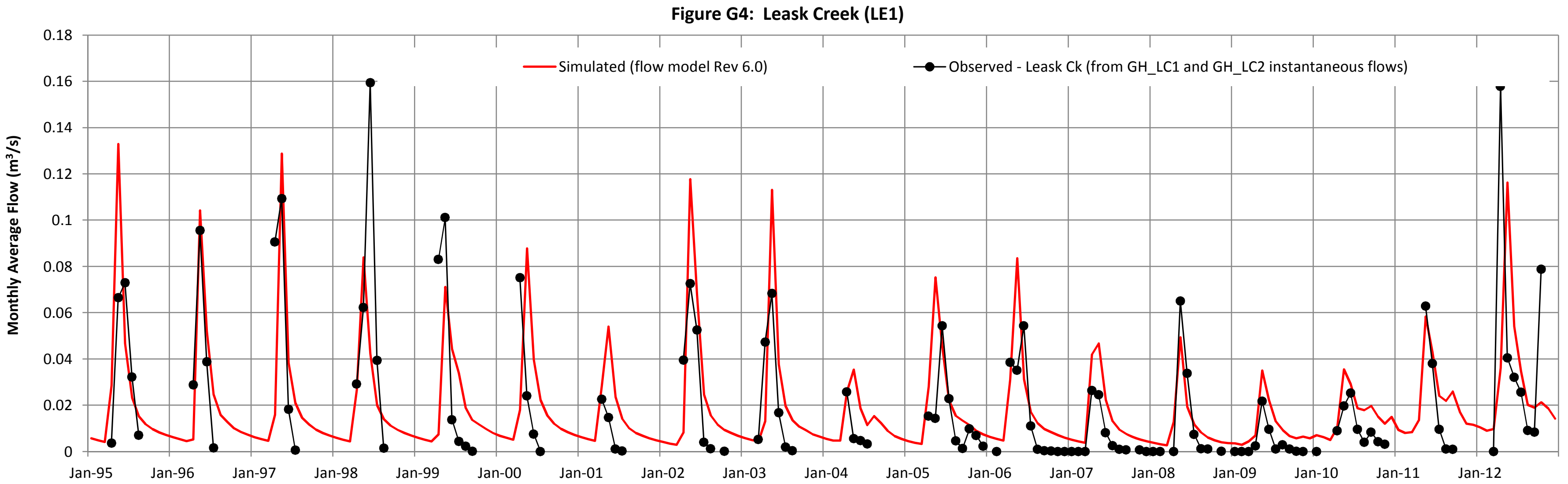
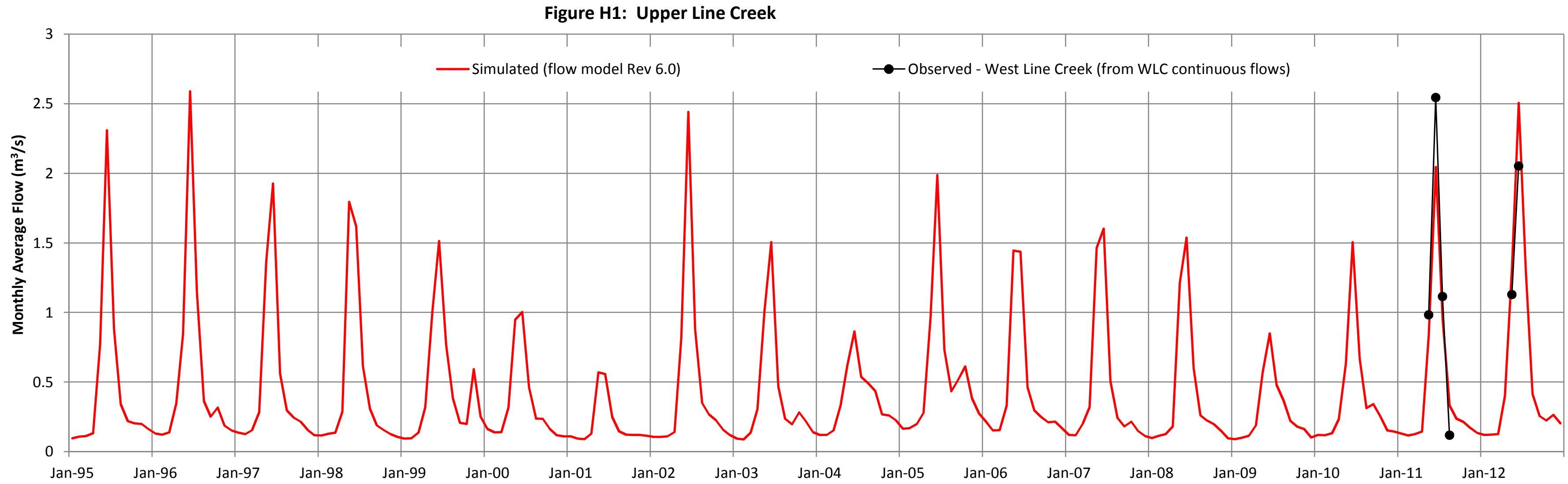
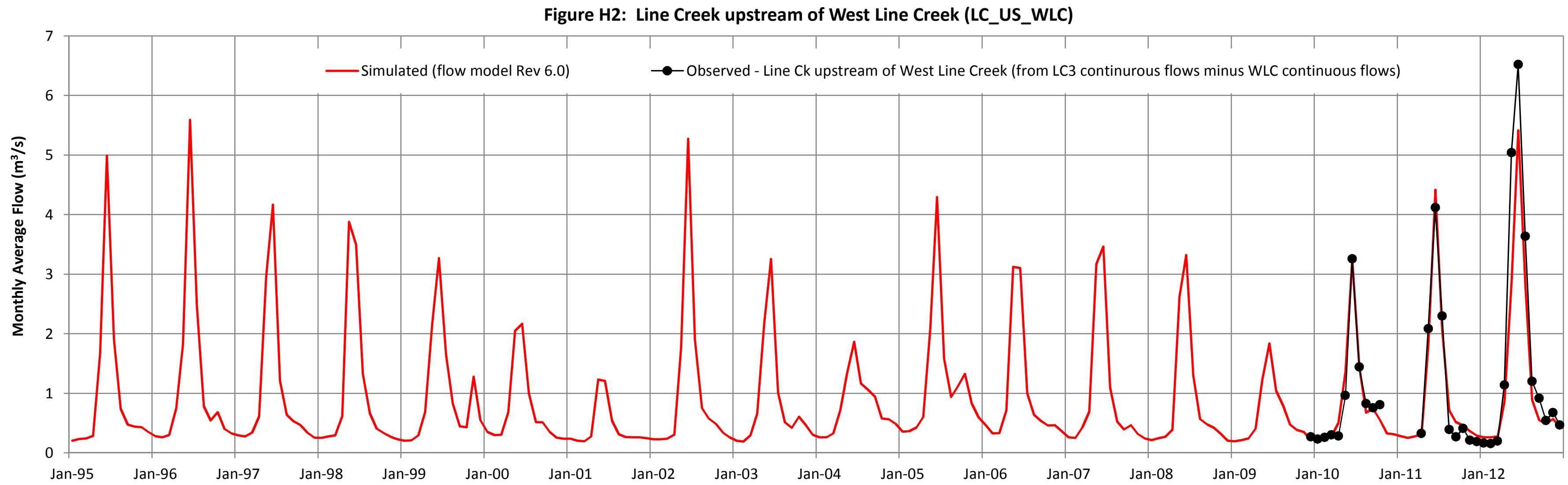


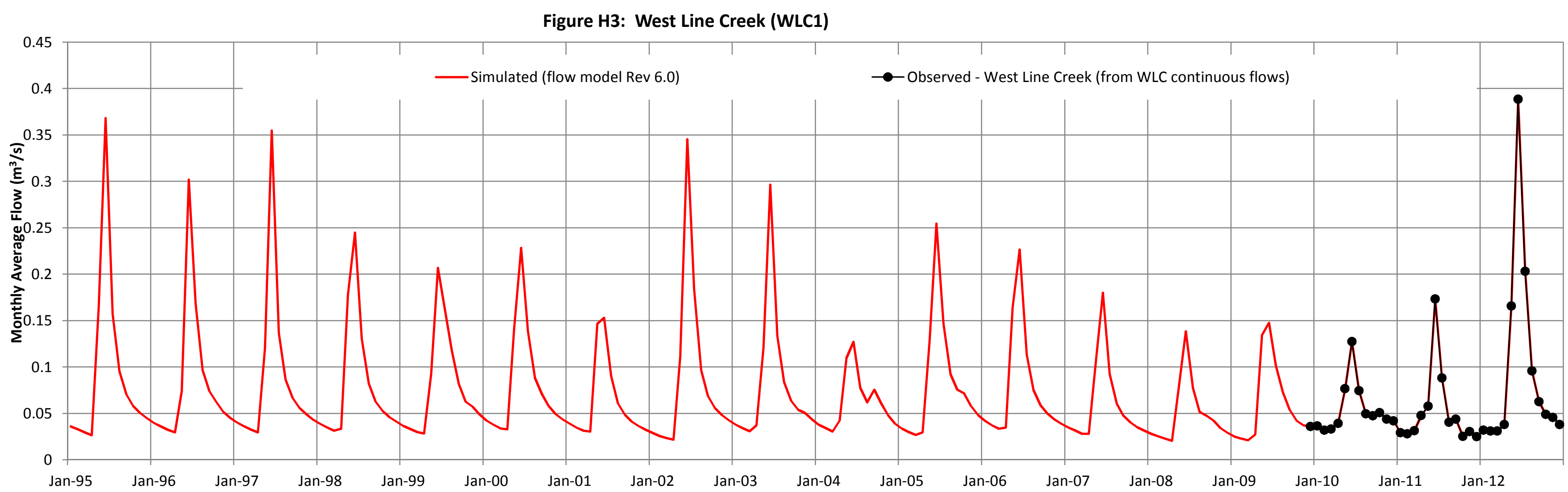
Figure G4: Leask Creek (LE1)



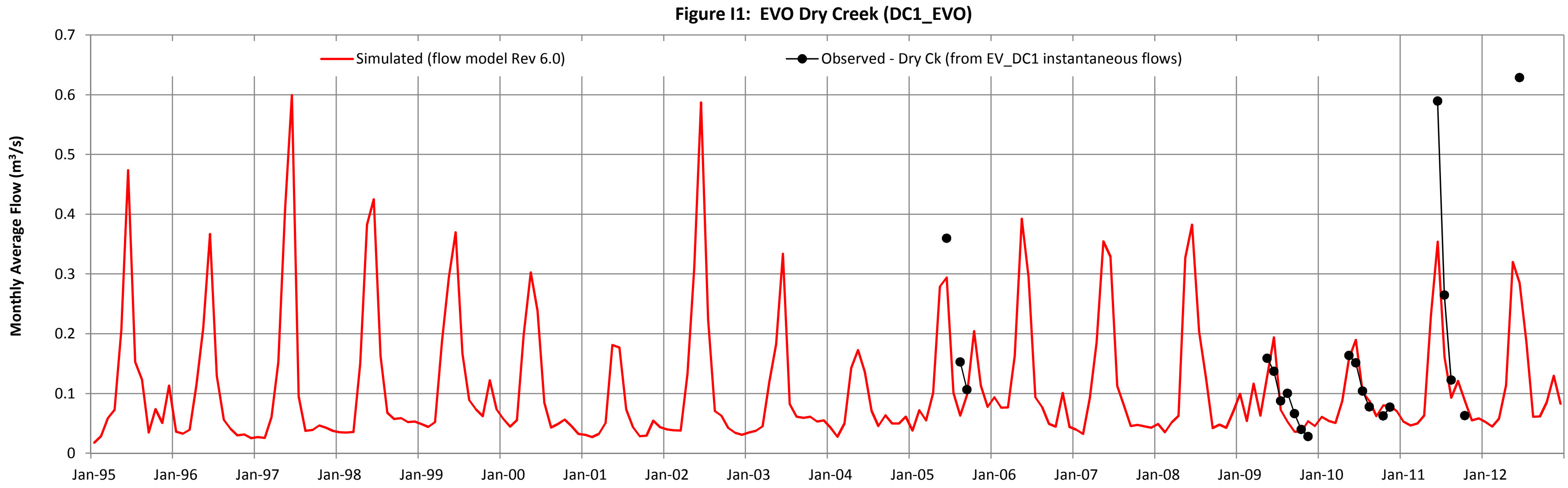
Sheet H: Graphs for Revision 6.0 flow results

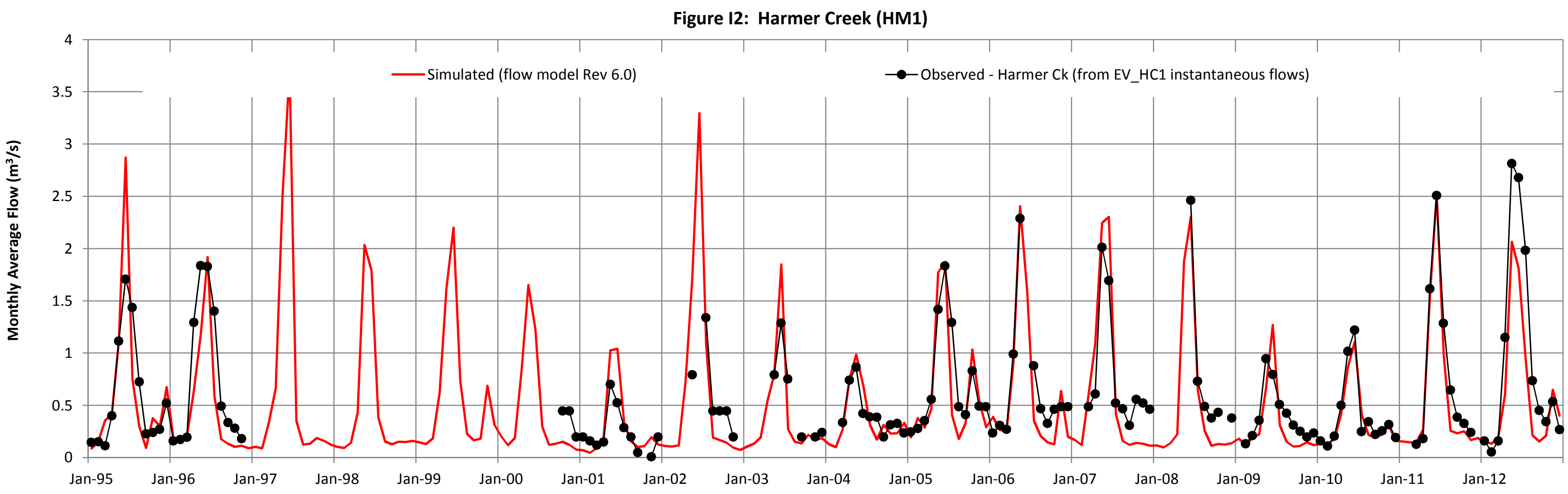


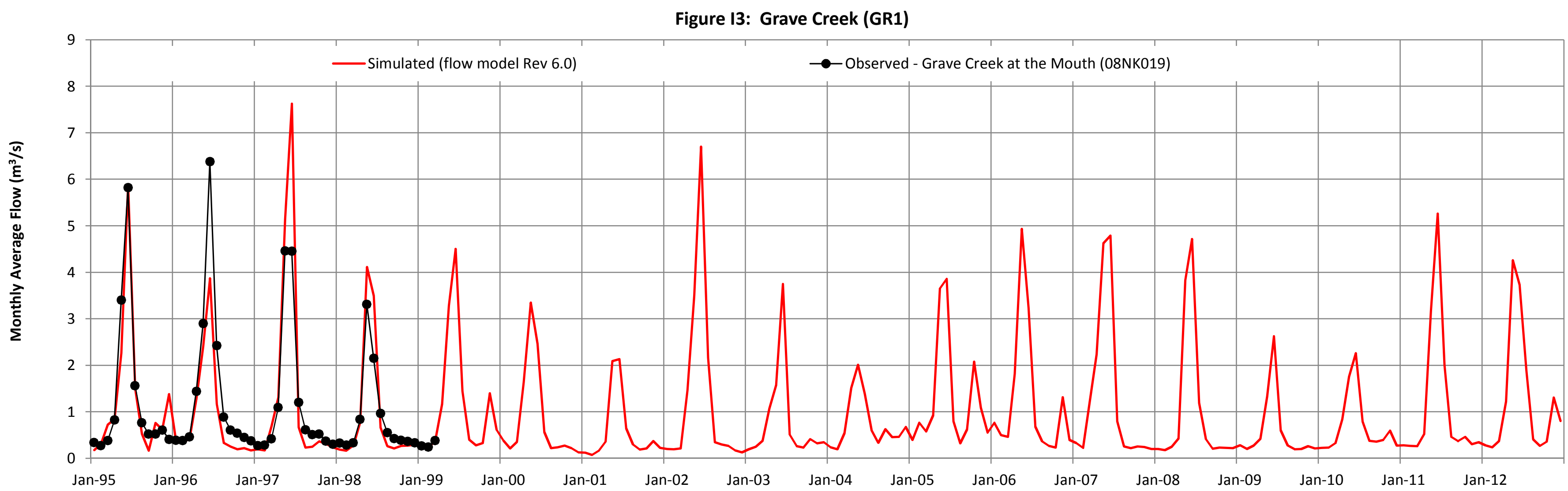


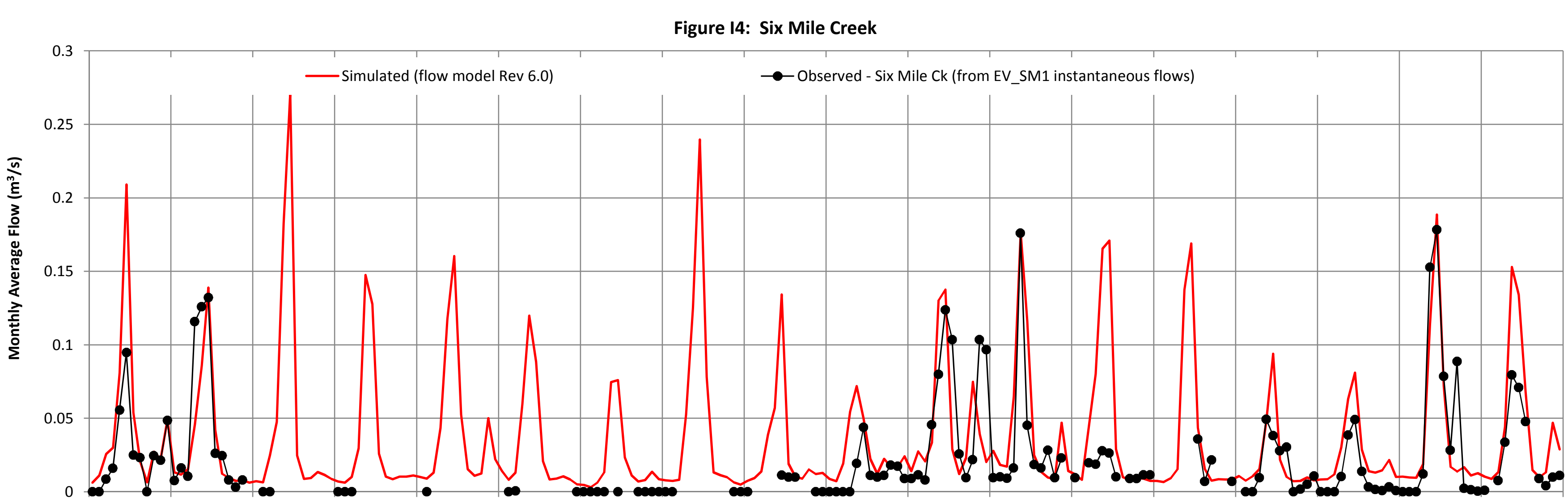


Sheet I: Graphs for Revision 6.0 flow results









Sheet J: Graphs for Revision 6.0 flow results

Figure J1: Goddard Creek (GD1)

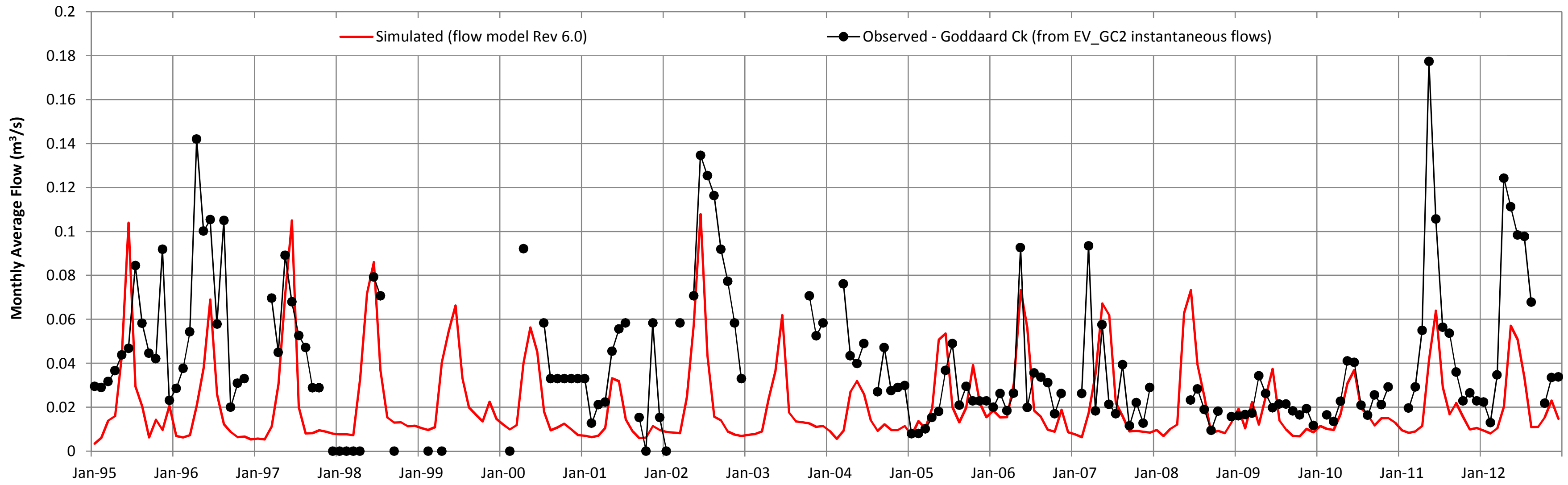


Figure J2: Bodie Creek (BC1)

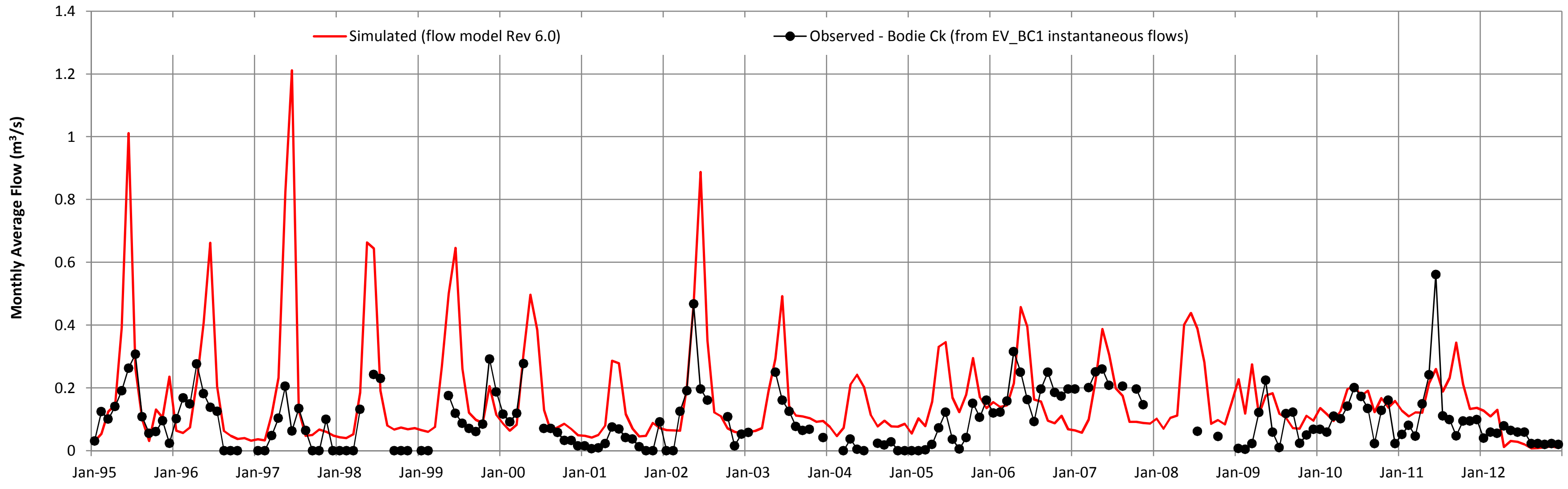


Figure J3: Gate Creek (GT1)

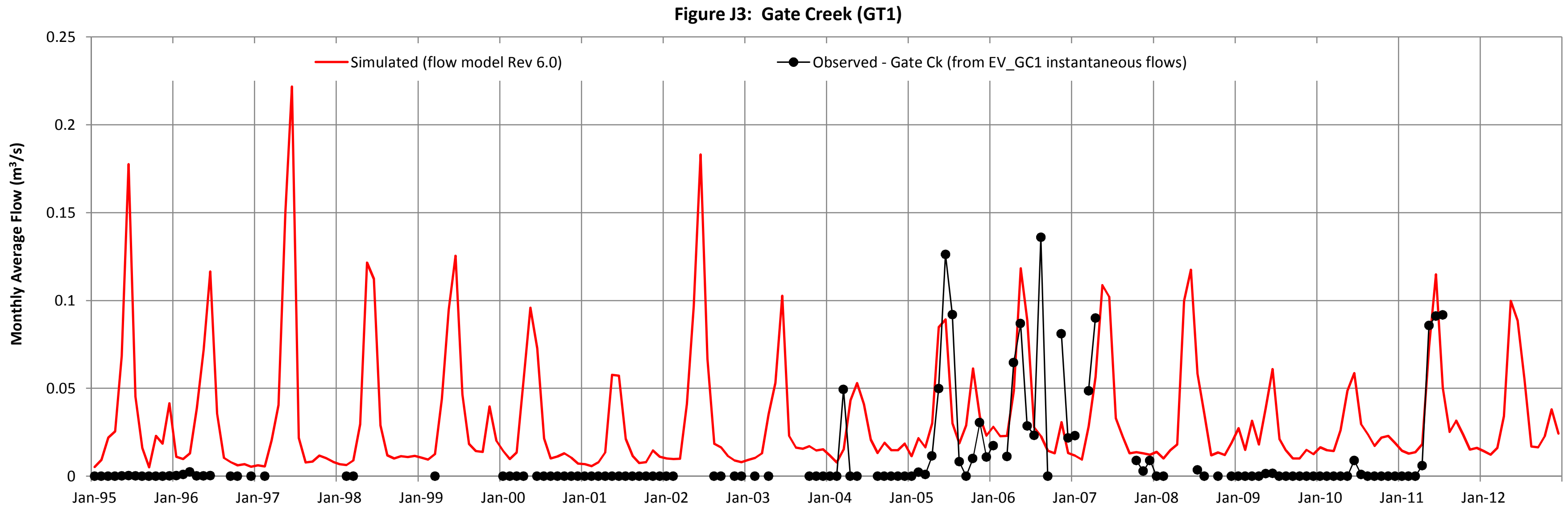
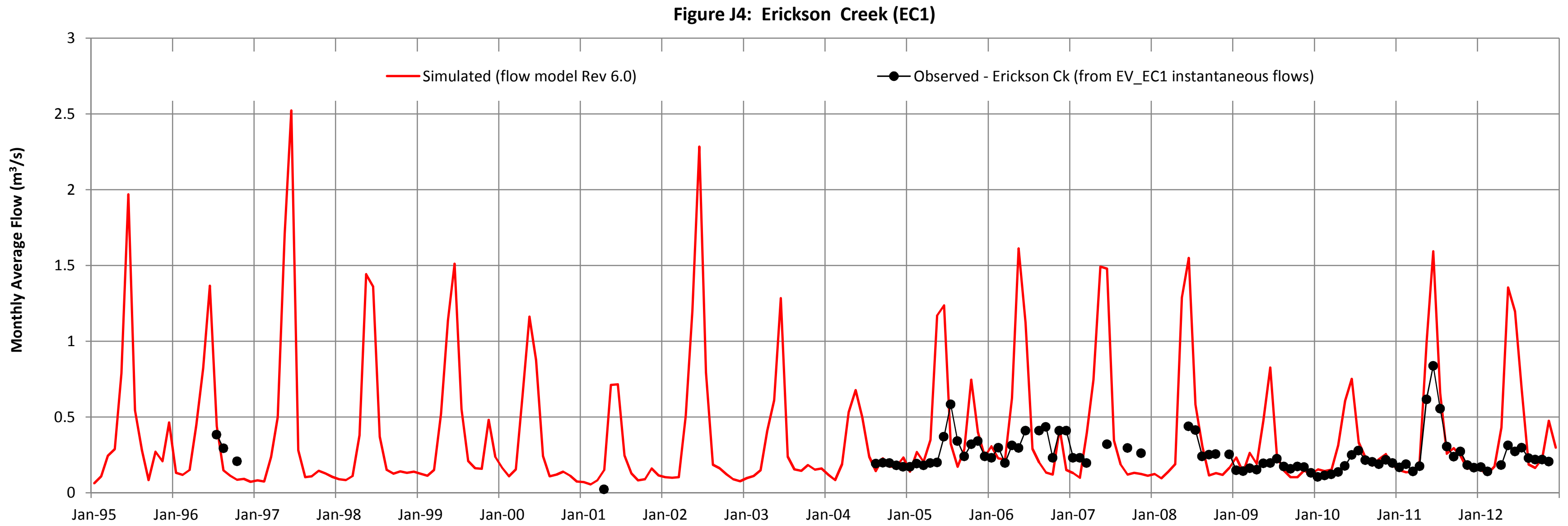


Figure J4: Erickson Creek (EC1)



4 REFERENCES

Krause, P., D.P. Boyle and F. Base. 2005. *Comparison of different efficiency criteria for hydrological model assessment*. Advances in Geosciences. 5: 89-97.

Legates, D.R. and G.J. McCabe Jr. 1999. *Evaluating the use of "goodness-of-fit" measure in hydrologic and hydroclimatic model validation*. Water Resour. Res. 35 (1), 233-241.

Nash, J.E. and J.V. Sutcliffe. 1970. *River flow forecasting through conceptual models. Part 1: A discussion of principles*. *J. Hydrol*., 10(3): 282–290.

Willmott, C.J. 1981. *On the validation of models*. Phys. Geogr. 2: 184-194.

Willmott, C.J. et.al. 1985. *Statistics for the evaluation and comparison of models*. J.Geophys. Res. 902, 8995-9005.

APPENDIX B

ABOUT GOLDSIM

GoldSim is a graphical Windows-based simulation software developed by GoldSim Technology Group. It is used to dynamically model complex systems to support decision making. It is often applied to environmental, mining and water resource systems.

GoldSim has a general purpose, flexible modeling framework that can be applied by multiple disciplines. It uses a high-level programming language in a visual and hierarchical modeling environment, which allows users to construct models by adding elements that represent data, equations, processes or events, and linking them together. The result is a graphical representation, similar to a simple flow diagram; where links and formula influences are clearly visible. Complex systems can be translated into hierarchical GoldSim models by creating layers of containers (sub-models). GoldSim has in-built Monte Carlo simulation capability. This allows inputs to be defined as stochastic distributions so that the entire system can be simulated multiple times (realisations) to provide probabilistic results. The model's ability to simulate uncertainty allows the user to explore the future performance of a system.

GoldSim also provides a platform to develop a user interface for models. The user can construct a series of dashboards for editing of inputs, which allows comparison multiple possible scenarios. GoldSim serves as decision support tool by providing a way in which alternative designs, plans and policies can be evaluated, compared and optimized.

APPENDIX C

STATISTICS FOR FUTURE FLOW SCENARIOS – ELK RIVER NODES, LINE CREEK NODES AND LAKE KOOCANUSA INFLOWS

Figure C-1 West Line Creek (WLC) at the mouth Statistics

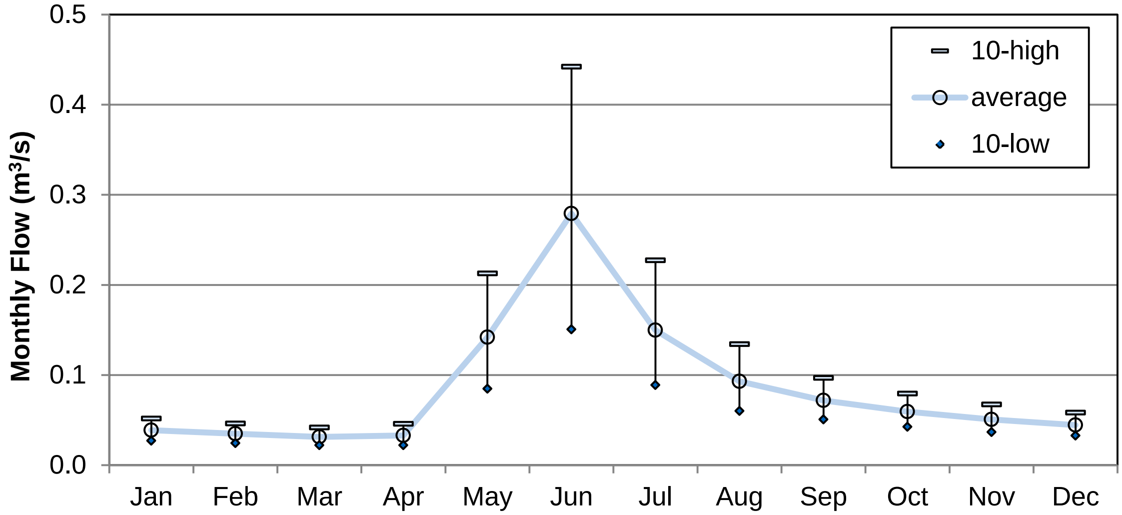


Figure C-2 Line Creek upstream of West Line Creek (LC_US_WLC) Statistics

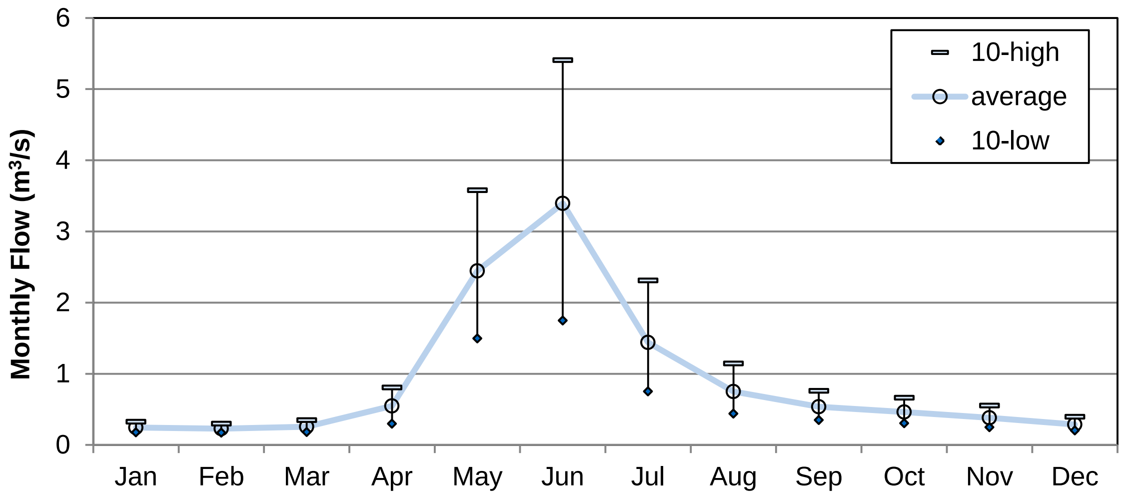


Figure C-3 Line Creek at the Mouth (LC1) Statistics

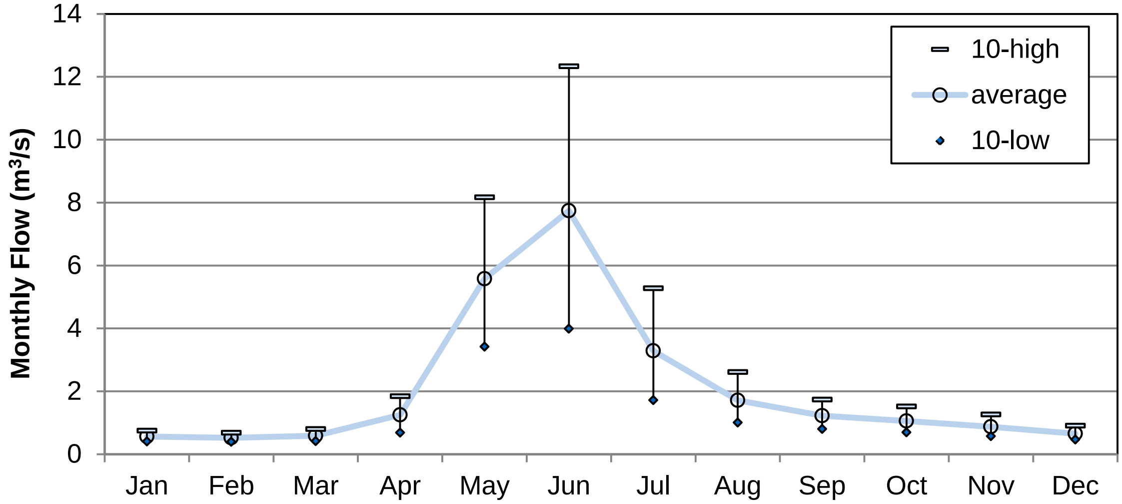


Figure C-4 Elk River downstream of Thompson Creek (ER1a) Statistics

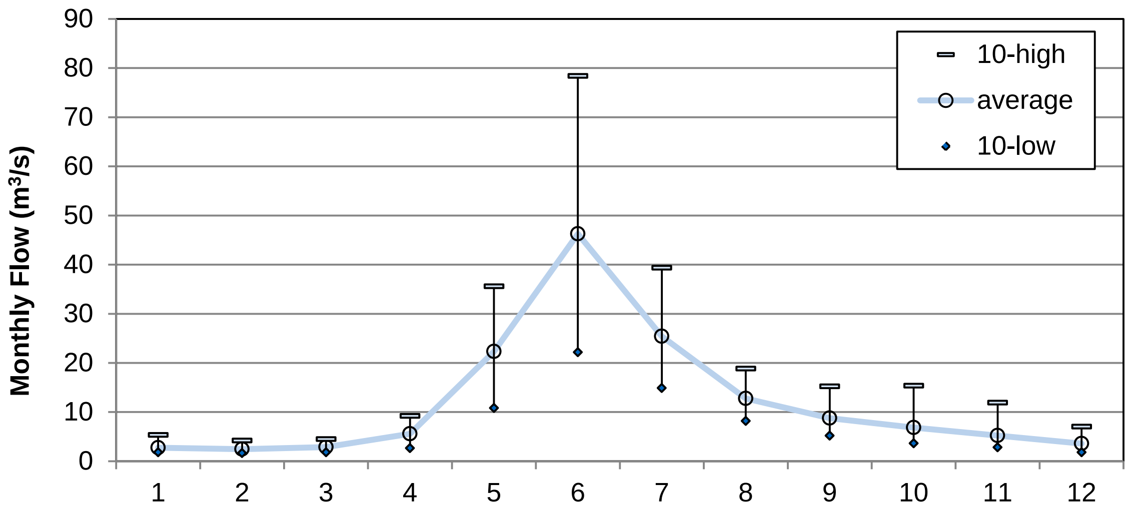


Figure C-5 Elk River near Elkford (ER1b) Statistics

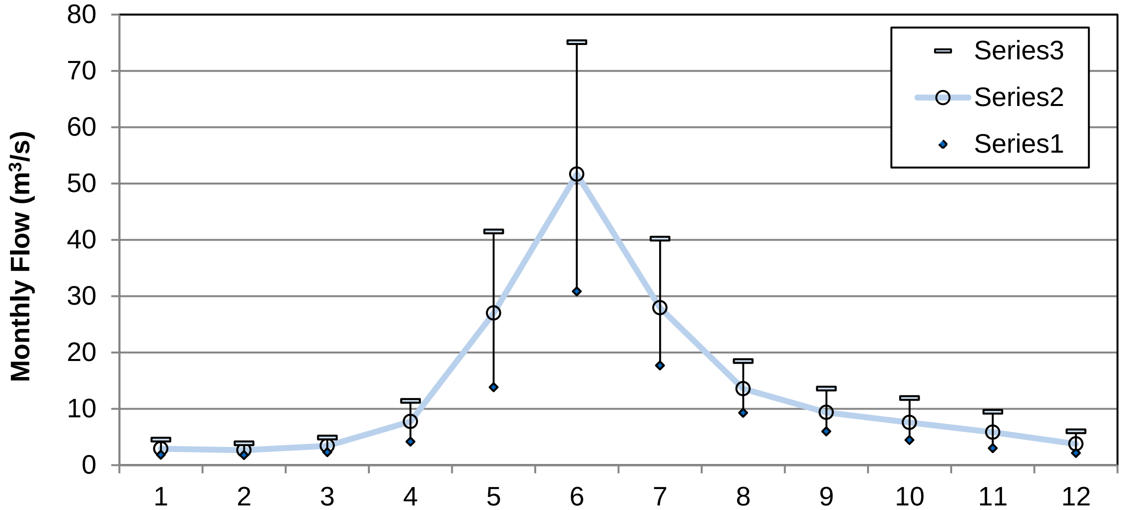


Figure C-6 Elk River Downstream of Fording River Confluence (ER2) Statistics

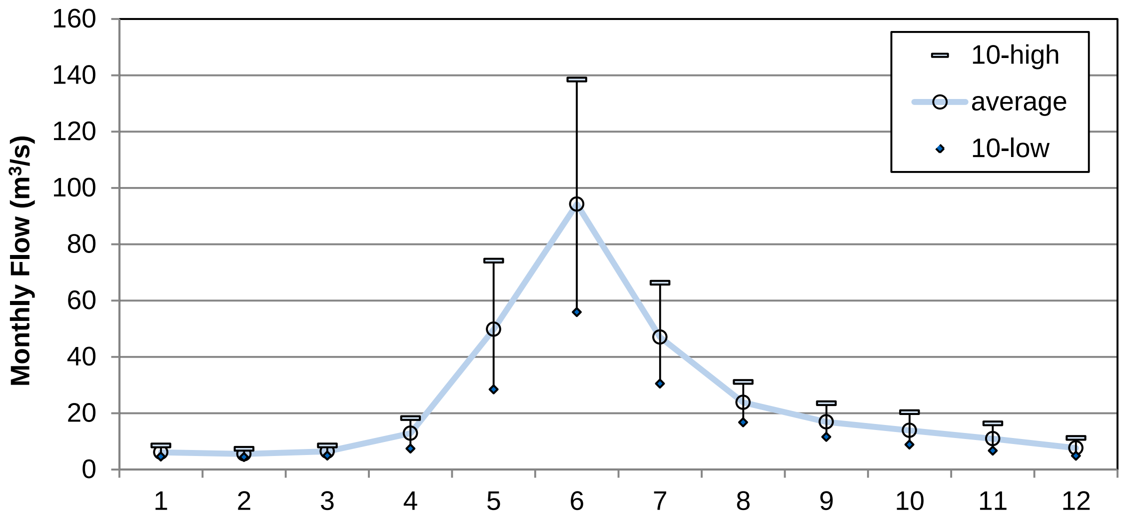


Figure C-7 Elk River Downstream of Michel Creek Confluence (ER3) Statistics

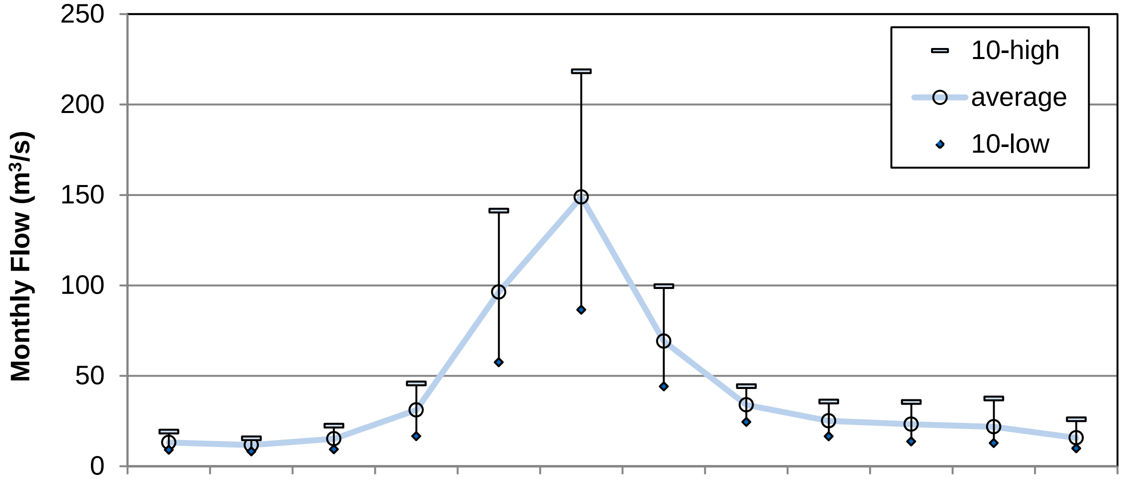


Figure C-8 Elk River at Fernie (ER3b) Statistics

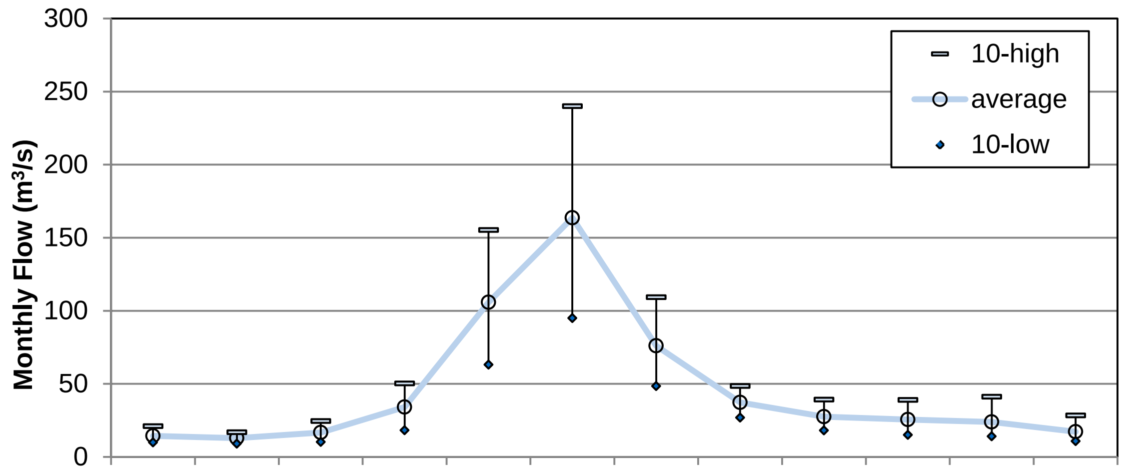


Figure C-9 Elk River at Elko Reservoir (ER4) Statistics

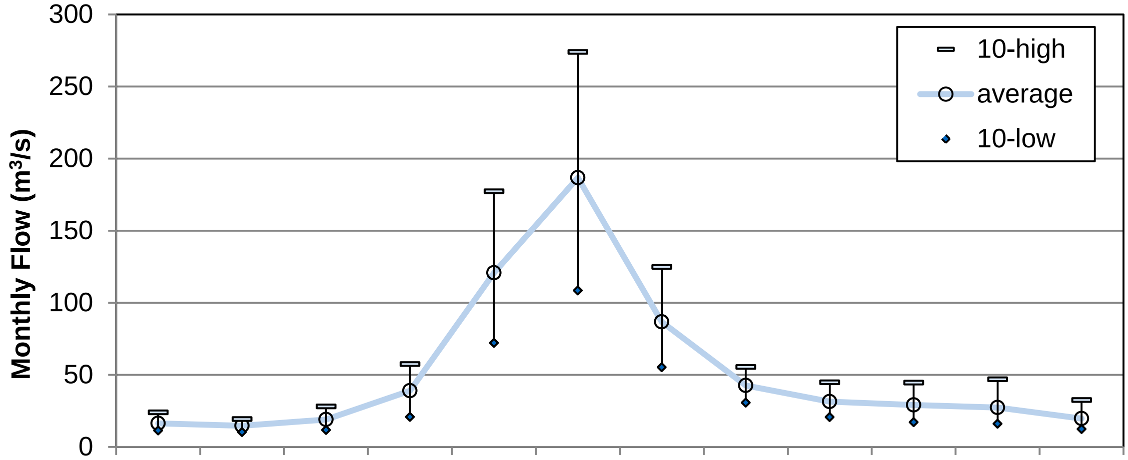


Figure C-10 Elk River at the Mouth (ER5) Statistics

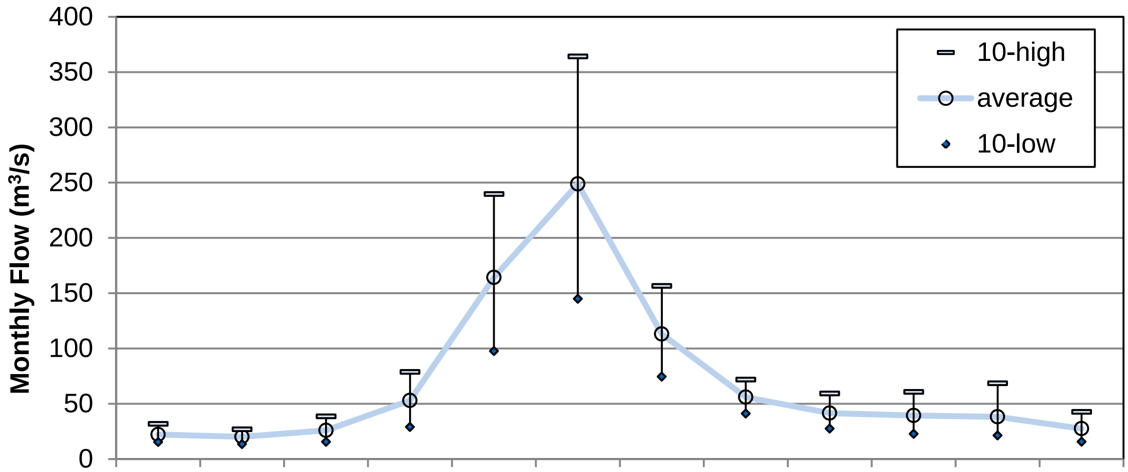


Figure C-11 Lake Koocanusa Inflow – Kootenay River at Fort Steele (08NG065)

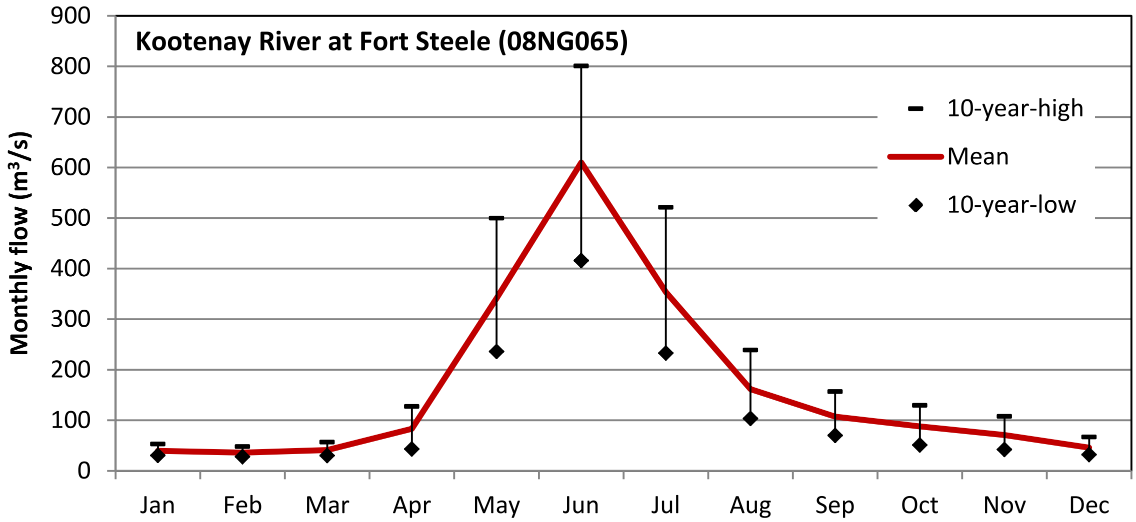
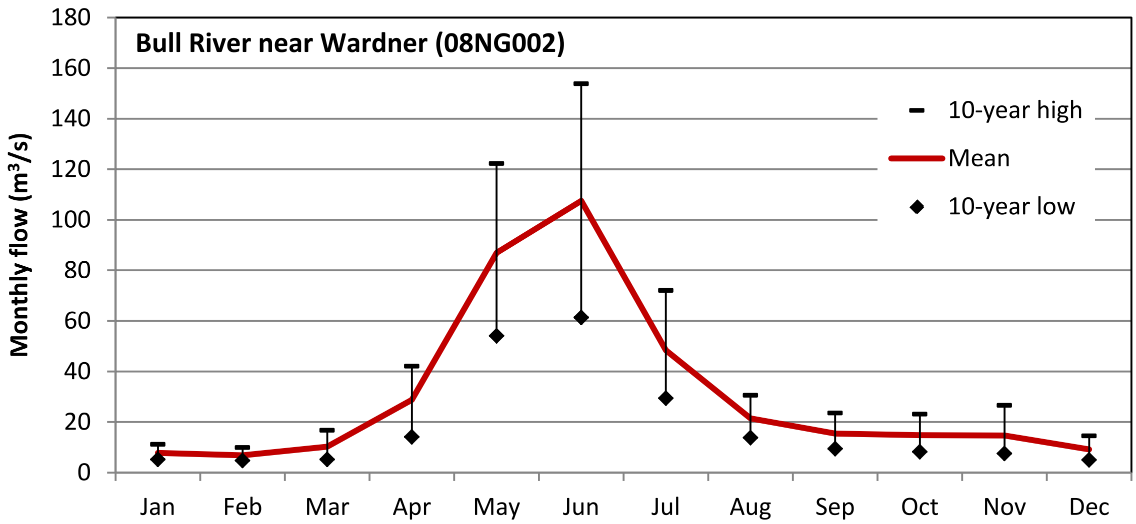


Figure C-12 Lake Koocanusa Inflow – Bull River near Wardner (08NG002)



APPENDIX D

LCO PHASE II PROJECT HYDROLOGICAL MODELLING REPORT

December 2011

TECK COAL LIMITED LINE CREEK OPERATIONS PHASE II PROJECT

LCO Phase II - Dry Creek Hydrological Modelling Methods and Results

Submitted to:

Line Creek Operations
Teck Coal Limited
15 kms North, Hwy 43
P.O Box 2003
Sparwood, BC, Canada V0B 2G0

REPORT

Report Number: 09-1349-0005/R007

A world of capabilities delivered locally

Table of Contents

TABLES

FIGURES

ATTACHMENTS

Attachment A
UBC Watershed Model Parameters – Analogue Watersheds

Attachment B
UBC Watershed Model Parameters – Dry Creek Watershed

Abbreviations and Acronyms

AAFC	Agriculture and Agri-Food Canada
BC	British Columbia
BRN	Burnt Ridge North
CCOG	Canadian Council on Geomatics
CFS	Canadian Forest Service
CSA	Canadian Space Agency
DEM	Digital Elevation Model
e.g.	for example
EA	Environmental Assessment
EOSD	Earth Observation for Sustainable Development
et al.	And others
GIS	Geographic Information System
Golder	Golder Associates Ltd.
i.e.	That is
LCO	Line Creek Operations
MM	Mount Michael
NLWIS	National Land and Water Information Service
Teck	Teck Coal Limited
TEM	Terrestrial Ecosystem Map
UBC	University of British Columbia

Units of Measure

%	percent
fasl	feet above sea level
km	kilometre
km^2	square kilometres
m	metre
m^2	square metres
m^3	cubic metres
m^3/s	cubic metres per second
masl	metres above sea level
mm	millimetres
Mmtcc	million metric tonnes of clean coal
Mm^3	million cubic metres

Glossary

Catchment	The area of land from which water finds its way into a particular watercourse, lake or reservoir (also termed “river basin” or “watershed”).
Colluvium	Rock detritus and soil accumulated at the foot of a slope.
Digital Elevation Model (DEM)	A three-dimensional grid representing the height of a landscape above a given datum.
Drainage Area	The area of a drainage basin, catchment or watershed. A two-dimensional measure of land contributing water to a particular waterbody or watercourse.
Drainage Basin	A region of land that eventually contributes water to a river or lake.
Flow Statistics	The organization and interpretation of flow data to derive parameters (e.g. minimum, mean, maximum, etc.) useful in defining the characteristics of a watercourse.
Geographic Information System (GIS)	Computer software designed to develop, manage, analyze and display spatially referenced data.
Groundwater	That part of the subsurface water that occurs beneath the water table, in soils and geologic formations.
Hydrology	The science of waters of the earth, their occurrence, distribution, and circulation; their physical and chemical properties; and their reaction with the environment, including living beings.
Mean Annual Yield	The average annual runoff contribution, expressed as depth on a per unit area basis, from a drainage catchment (i.e. mean annual runoff from particular catchment is equal to average annual yield multiplied by catchment area)
Mean Monthly Flow	The average of all flows occurring within the period of one month (i.e. the total volume of water passing a fixed section of a watercourse divided by the total time in a month)
Observed monthly Flow	Measured flow in a watercourse.
Orographic Effects	Associated with or induced by the presence of mountains.
Polygon	The spatial area delineated on a map to define one feature unit (e.g., one type of ecosite phase).
Reclamation	The restoration of disturbed land or wasteland to a state of useful capability. Reclamation is the initiation of the process that leads to a sustainable landscape (see definition), including the construction of stable landforms, drainage systems, wetlands, soil reconstruction, addition of nutrients and revegetation. This provides the basis for natural succession to mature ecosystems suitable for a variety of end uses.
Seepage	Slow water movement in subsurface. Flow of water from constructed retaining structures. A spot or zone, where water oozes from the ground, often forming the source of a small spring.
Selenium	A non-metallic chemical element that is an essential mineral nutrient.
Waste Rock	Rock moved and discarded in order to access coal resources.
Watershed	The area of land bounded by topographic features that drains water to a larger waterbody such as a river, wetlands or lake. Watershed can range in size from a few hectares to thousands of kilometres.

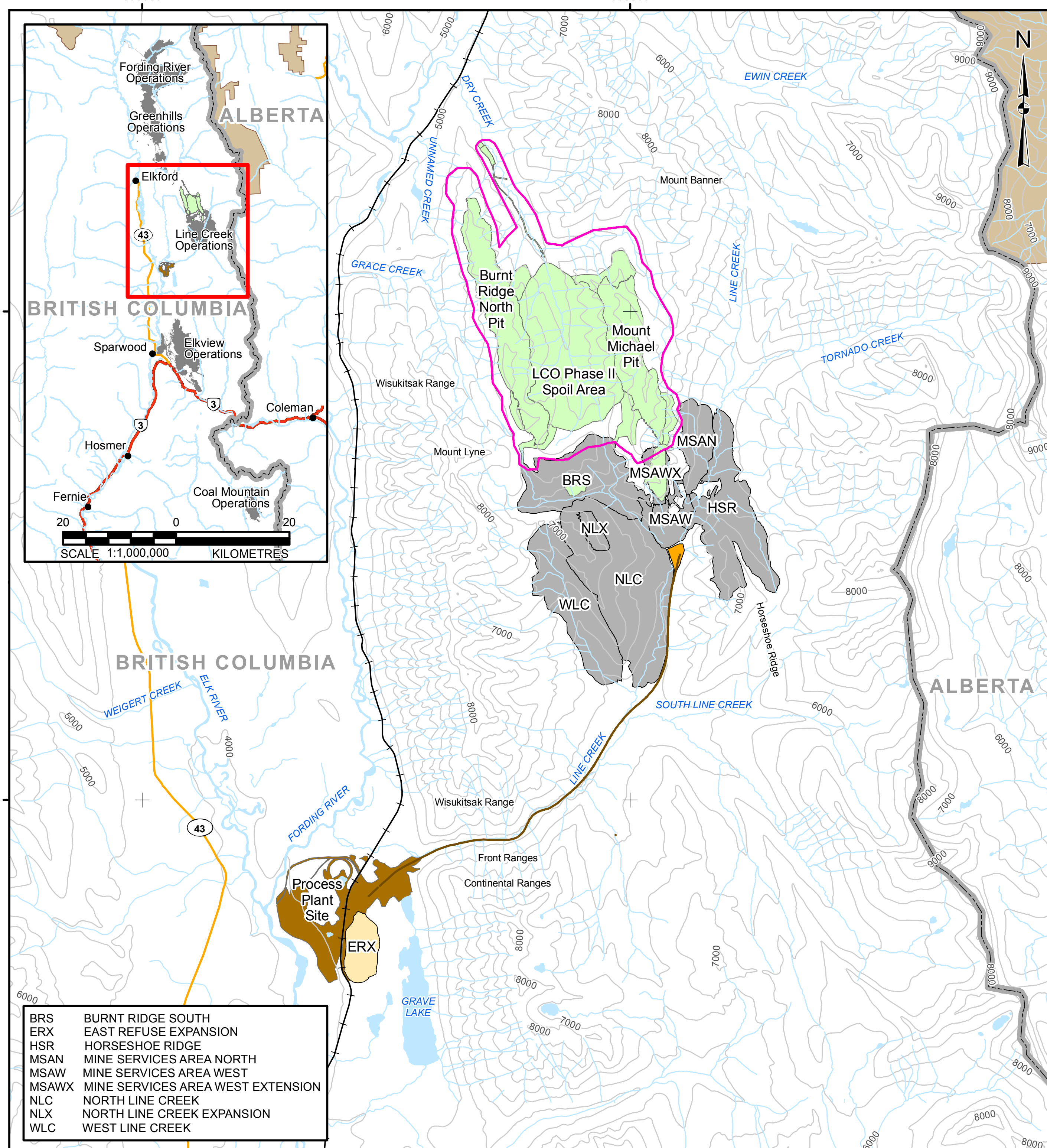
1.0 INTRODUCTION

Teck Coal Limited's (Teck's) proposed Line Creek Operations (LCO) Phase II Project (the Project) includes the development of two new operating areas referred to as Burnt Ridge North (BRN) and Mount Michael (MM), as shown in Figure 1. Combined, these areas are estimated to provide 59 million metric tonnes of clean coal (Mmtcc) reserves and extend overall operational mine life by 18 years. The proposed development will generate about 637 million cubic metres (Mm^3) of waste rock. Waste rock will be placed in both new spoil areas within the upper reaches of the Dry Creek valley and in existing operational spoil areas (including the Mine Services Area West Extension and Burnt Ridge South pits). The plan for development of the Project will result in a new disturbance of approximately 1,140 hectares. Development of the Project is planned in several phases. The construction phase is planned to begin in the second quarter of 2013. Operations are planned to begin in the first quarter of 2014, with mining beginning in the south phases of MM and BRN. Mining will end in the year 2031. Activities following 2031 will comprise those necessary to complete reclamation and closure. The main components and activities associated with the construction and operations phases of the Project comprise development and operation of:

- the BRN and MM open pit mining areas;
- transportation and electrical transmission infrastructure for coal and waste hauls, pit access and provision of power to operating areas;
- a marshalling area, a fuel and lube station and parts storage areas;
- waste spoils both in the Dry Creek valley and in existing operating areas;
- a rock drain on Dry Creek to convey surface water through the waste spoils;
- surface water management systems including construction of outlet structures to drain water from final pit areas, a debris trap and inlet berm to facilitate collection of mine-affected water from the toe of the Dry Creek rock drain, and a pipe diversion system to convey mine-affected water to a new sediment pond in the Dry Creek valley bottom; and
- selenium management activities currently proposed as an active selenium water treatment plant in the Dry Creek valley, with a projected commissioning in 2022.

As part of the environmental assessment (EA) the Project, Golder Associates Ltd. (Golder) conducted hydrological modelling of the Dry Creek watershed for existing conditions and two Project snapshots. This report provides the methodology and results of the modelling study.

The purpose of the hydrological modelling is to provide simulated, long-term flow series for Dry Creek at representative snapshots in the Project life. Flow statistics generated from the simulated flow series will be used directly in the EA to quantify flow changes as a result of the Project, and as inputs to the water quality and aquatic health and fish and fish habitat assessments.



LEGEND

- CITY / TOWN / COMMUNITY
- CANADIAN PACIFIC RAILWAY
- CONTOUR (500 FOOT INTERVAL)
- EXISTING CABLE BELT
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- WATERCOURSE
- BRITISH COLUMBIA - ALBERTA BORDER
- EXISTING LINE CREEK OPERATIONS DEVELOPMENT AREA
- EXISTING TRUCK DUMP
- LINE CREEK OPERATIONS PHASE II PROJECT FOOTPRINT
- OPERATIONAL BOUNDARY FOR LINE CREEK PHASE II PROJECT
- PERMITTED COAL REJECTS AREA
- PROCESS PLANT SITE
- PROVINCIAL PARK
- WATERBODY

2.5 0 2.5

SCALE 1:115,000 KILOMETRES

REFERENCE

1: 50,000 scale hydrography, elevation data and provincial parks obtained from GeoGratis. Railway and Provincial boundary data obtained from DMTI. Projection: UTM Zone 11 Datum: NAD 83

PROJECT

LINE CREEK OPERATIONS
PHASE II

TITLE

LOCATION OF PROJECT

Golder Associates
Calgary, Alberta

PROJECT No. 09-1349-0005			SCALE AS SHOWN	REV. 0
DESIGN	KL	14 Jul. 2011	FIGURE: 1	
GIS	DR	27 Oct. 2011		
CHECK	GJ	11 Nov. 2011		
REVIEW	SDL	11 Nov. 2011		

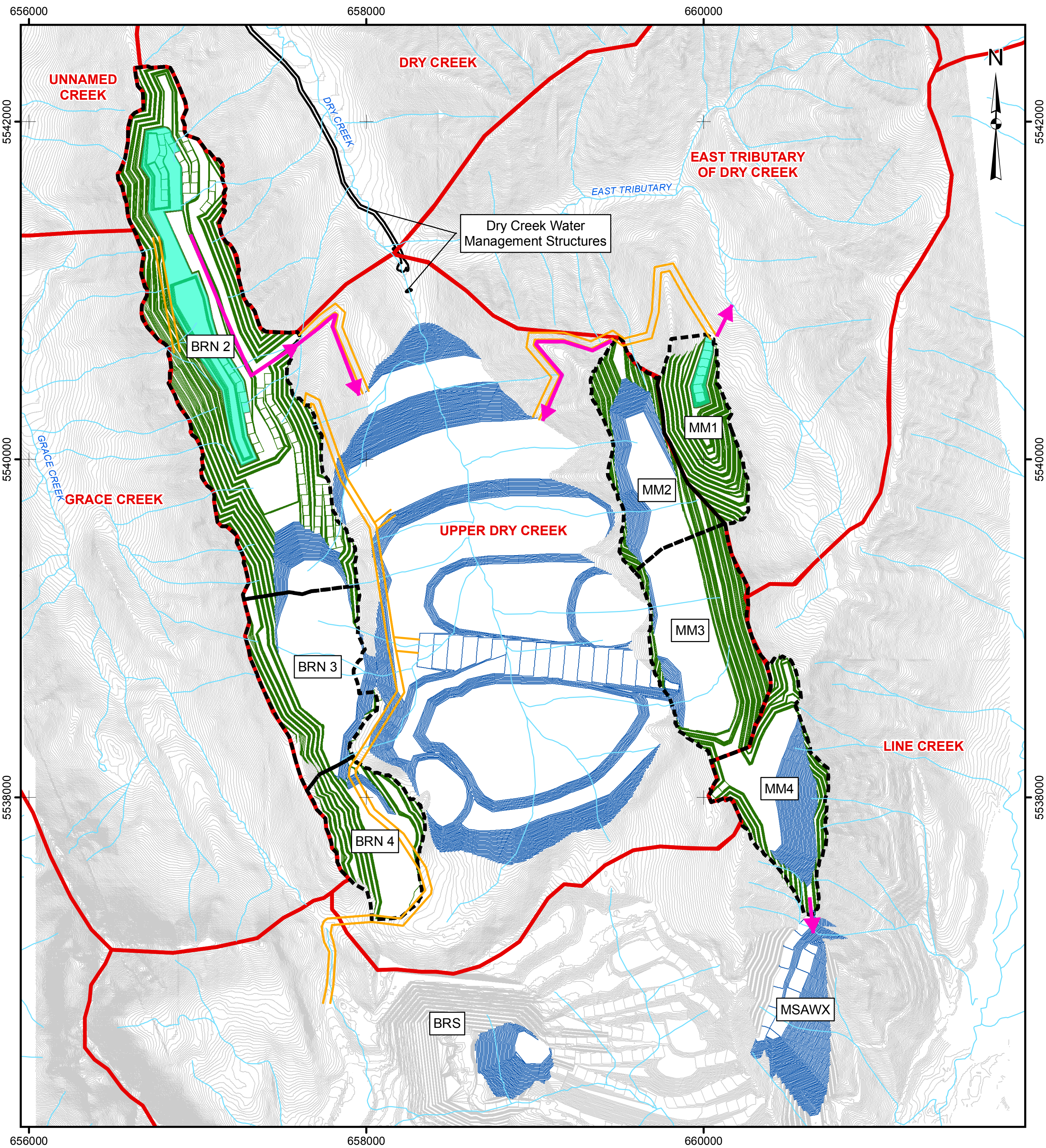
I:\2009\09-1349\09-1349-0005\Mapping\MXD\EA_Shared_Figures\E_EASharedFigures_002-LocationofProject-GolderLogo.mxd

2.0 WATERSHED DESCRIPTION

Dry Creek (British Columbia Watershed Code 349-248100-48300-39400) is the watercourse that will be most affected by the Project (Figure 2). It is about 9 km long, has a total drainage area of about 26 km^2 at the Fording River confluence, and an elevation range of about 1,500 masl (4,920 fasl) to over 2,475 masl (8,040 fasl). Information derived from fish habitat surveys (refer to the Project *Fish and Fish Habitat Baseline Report* presented as Annex H) indicates that the average gradient of the mainstem of Dry Creek varies from 2% to 6.5%.

The majority of the hillslopes in the Dry Creek watershed have slope gradients between 26% and 70%. Colluvium is the most common surficial material. Colluvial soils range in thickness from less than 30 cm on the upper steep slopes of BRN and MM to more than several metres on colluvial fans at the base of these ridges. A majority of the soils occur on steep slopes and mid or upper slope positions, which are usually well to very rapidly drained. Further description of the soils and surficial geology is presented in the Project *Surficial Geology, Soils, Terrain and Vegetation Baseline Report* presented in Annex I.

The upper portion of the Dry Creek watershed is divided into two tributaries, denoted the east tributary and upper Dry Creek for the purposes of this assessment. About 60% of the total Dry Creek watershed is covered by the two sub-watersheds (27% in the east tributary and 33% in upper Dry Creek).



LEGEND

- CONTOUR (5 m INTERVAL)
- PIT WALL
- WASTE ROCK SPOIL
- PIT OUTFLOW CHANNEL
- ROAD
- WATERCOURSE
- LINE CREEK OPERATIONS PHASE II DRY CREEK WATER MANAGEMENT STRUCTURES
- PIT LAKE WATER SURFACE
- PIT WATER BALANCE SUB-CATCHMENT
- SUBWATERSHED

BRN	BURNT RIDGE NORTH
BRS	BURNT RIDGE SOUTH
MM	MOUNT MICHAEL
MSAWX	MINE SERVICES AREA WEST EXTENSION

1,000 0 1,000

SCALE 1:32,000 METRES

REFERENCE

1: 50,000 scale hydrography data obtained from GeoGratis. Other data obtained from Teck Coal Limited.
Projection: UTM Zone 11 Datum: NAD 83

PROJECT

LINE CREEK OPERATIONS
PHASE II

TITLE

WATER BALANCE SUBCATCHMENTS - END OF 2031

Golder Associates
Calgary, Alberta

PROJECT No. 09-1349-0005			SCALE AS SHOWN	REV. 0
DESIGN	AC	10 Aug. 2011	FIGURE: 2	
GIS	DR	09 Sep. 2011		
CHECK	SDL	21 Nov. 2011		
REVIEW	GJ	21 Nov. 2011		

I:\2009\09-1349\09-1349-0005\Mapping\MXD\Hydrology\WaterBalanceMemo\WB-005-GIS_Year2031.mxd

3.0 MODELLING SNAPSHOTS

Hydrological modelling was undertaken for three snapshots, selected to represent the range of watershed conditions over the temporal bounds of the Project:

1) Baseline conditions – existing (pre-development) watershed conditions.

2) End-of-mining -- Project snapshot where the upper Dry Creek waste rock spoil area (i.e., rock drain) is at its maximum extent. A conservative case was assumed, with all pits completed and filling (i.e., no outflows from pits) and no revegetation.

3) Post-closure – Project closure snapshot with full reclamation, mature revegetation and all pits full and spilling. For the purposes of this assessment, this snapshot is considered an active closure period, defined as a post-mining, post-reclamation period of time, where some water management systems remain in place that will require on-going monitoring and maintenance. The active closure period for the Project is open-ended, pending the results of research and development programs into alternative "walk-away" closure solutions associated with selenium management. The end-of-mining snapshot (year 2031) for the Project is shown in Figure 3.

4.0 DESCRIPTION OF THE UNIVERSITY OF BRITISH COLUMBIA WATERSHED MODEL

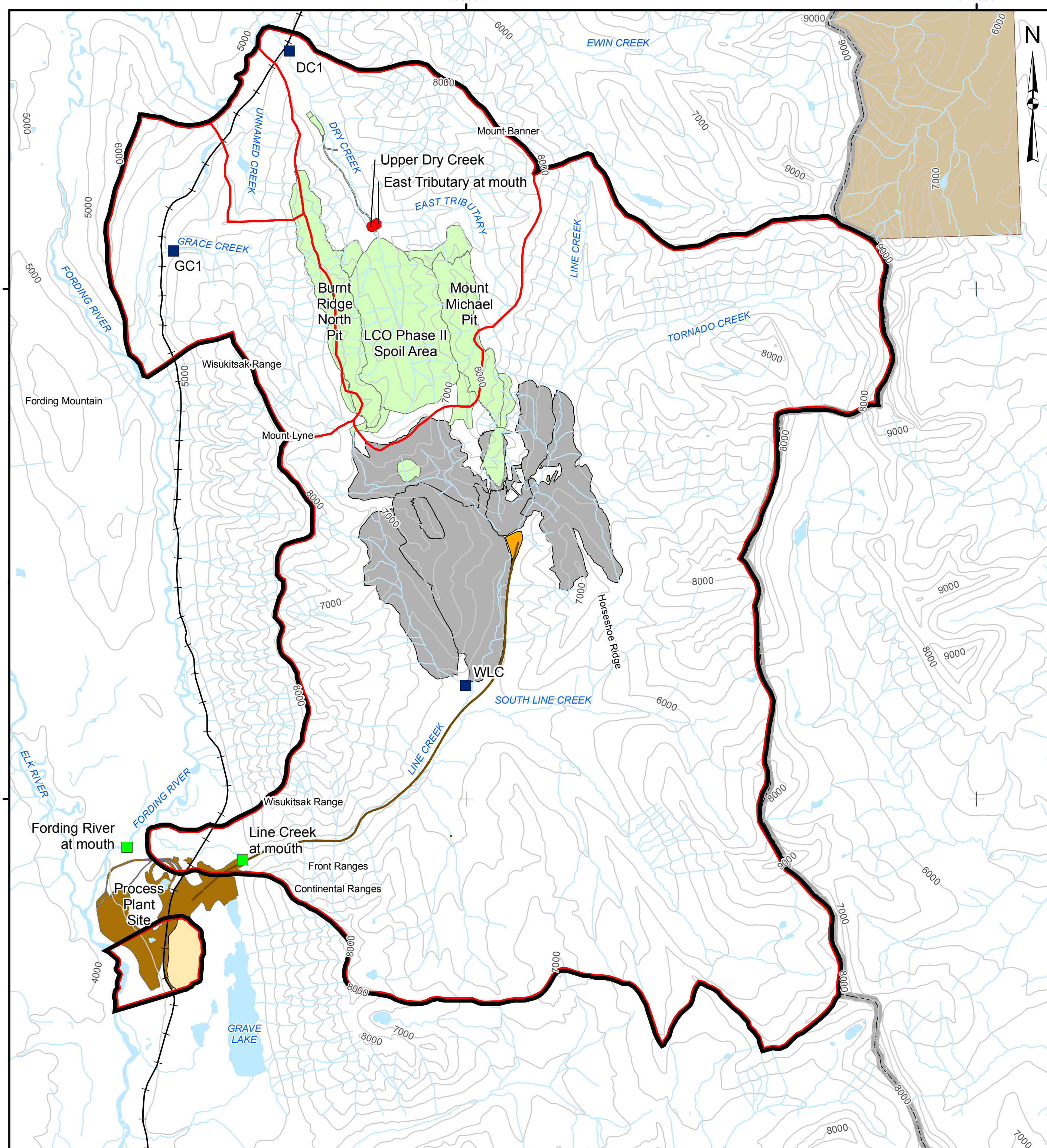
Long-term flow series for Dry Creek were simulated using the University of British Columbia (UBC) Watershed Model. This model, developed by Quick (1995), simulates the hydrologic responses of watersheds in mountainous areas and is widely used in British Columbia (BC).

The UBC model calculates watershed flows due to elevation-dependent snowmelt and rainfall using maximum and minimum daily temperature, and daily precipitation as inputs. Precipitation inputs to the model are dependent on elevation and on the temperature regime. The UBC Model is considered to be an appropriate model for generating flows from the Dry Creek watershed.

The model uses watershed elevation, divided into elevation bands, to simulate the variability in snow depth and melt rate, as well as orographic effects on rainfall intensities. For each elevation band, the following data are assigned:

- mean elevation;
- area;
- forested area;
- density of the forested area;
- relative north/south orientation; and
- fraction of impermeable areas.

The UBC model can also simulate glacial melt, but no glaciated areas exist within the modelled watershed.



LEGEND

- FLOW MONITORING STATION OPERATED BY LCO
- FLOW SIMULATION NODE
- HYDROMETRIC STATION OPERATED BY ENVIRONMENT CANADA
- CANADIAN PACIFIC RAILWAY
- CONTOUR (500 FOOT INTERVAL)
- EXISTING CABLE BELT
- WATERCOURSE
- AQUATIC LOCAL STUDY AREA
- BRITISH COLUMBIA - ALBERTA BORDER
- EXISTING LINE CREEK OPERATIONS DEVELOPMENT AREA
- EXISTING TRUCK DUMP
- LINE CREEK OPERATIONS PHASE II PROJECT FOOTPRINT
- PERMITTED COAL REJECTS AREA
- PROCESS PLANT SITE
- PROVINCIAL PARK
- WATERSHED
- WATERBODY

3,500 0 3,500

SCALE 1:110,000 METRES

REFERENCE

1: 50,000 scale hydrography, elevation data and protected areas obtained from GeoGratis. Transportation data obtained from DMTI. Projection: UTM Zone 11 Datum: NAD 83

PROJECT

LINE CREEK OPERATIONS PHASE II

TITLE

LOCAL WATERSHEDS

Golder Associates
Calgary, Alberta

PROJECT No. 09-1349-0005			SCALE AS SHOWN	REV. 0
DESIGN	AC	10 Aug. 2011	FIGURE: 3	
GIS	DR	11 Nov. 2011		
CHECK	GJ	11 Nov. 2011		
REVIEW	SDL	11 Nov. 2011		

I:\2009\09-1349\09-1349-0005\Mapping\MXD\Hydrology\E-Hydrol-001-GIS-MainWatersheds.mxd

5.0 SELECTION OF AN ANALOGUE WATERSHED

Long-term measured flow data are not available for Dry Creek. Therefore, alternate watersheds were required for calibration of the UBC model parameters under baseline and Project conditions.

5.1 Baseline Conditions

For baseline (pre-development) conditions in Dry Creek, the most representative watershed with long-term gauged flow data is that of the Fording River. The Fording River at the Mouth hydrometric station (Station 08NK018) has flow data from 1970 to 2009. The location of the station is shown in Figure 3.

5.1.1 Fording River Model Calibration and Verification

The period of 1970 to 1979 was selected for the calibration and verification of the Fording River model for baseline (pre-development) watershed conditions, as this represents a period of least watershed disturbance. The Fording River model calibration and validation is presented in Annex D.

A detailed description of the methodology of the baseline modelling is provided in Section D4.3.2 of the Project *Surface Water Hydrology Baseline Report* presented as Annex D of Teck's EAC Application. The elevation bands and elevation band parameters determined for the Fording River watershed for the calibration and verification period of 1970 to 1979 are shown in Attachment A.

5.2 Project Conditions

For Project conditions in Dry Creek, the most representative watershed with long-term gauged flow data is that of Line Creek. The Line Creek watershed has extensive disturbance due to mining activities, including waste rock dumps and rock drains on the main stream and tributaries, similar to the proposed Project conditions in Dry Creek. The Line Creek at the Mouth hydrometric station (Station 08NK022) has reliable flow data from 1971 to 2010. The location of the station is shown in Figure 3.

5.2.1 Line Creek Model Calibration and Validation

The UBC Model can use up to five climate stations and one hydrometric station for calibration. During calibration, the observed hydrographs of a gauged stream are compared with the hydrographs simulated by the UBC Model. The model uses historical meteorological and stream flow records as reference data and calculates statistics on volume and the simulated hydrograph shape.

The UBC Model was calibrated and validated using daily flow data from the gauged Line Creek at the Mouth station (Station 08NK022). This station records flows from a drainage area of 138 km^2. The model was run beginning in October, when the sub-basins in the watershed are usually snow free, through to September for each calibration year.

The period of 2000 to 2006 was selected for the calibration and validation of the model for current, intensively mined watershed conditions, as this represents the period of greatest watershed disturbance. The period between 2000 and 2003 was used for optimizing the model parameters. The remaining data set (2004 to 2006) was used to validate the calibrated model.

Climate data for the model calibration and verification were obtained from the Fording River Cominco climate station. Missing data (corrected for elevation differences) were transferred from regional stations in the following order of preference, depending on the availability of data at these stations: Elkford, Sparwood and LCO MSA.

These data are adjusted in the model to account for elevation effects. The period of record and quality of the climate data from the LCO MSA station precluded its use as a primary source of long-term climate data for the study area.

Sources of data for defining the watershed parameters included the following:

- Digital Elevation Model (DEM) provided by Teck (2010).
- Impermeable polygons and forestry data from Land Cover. Land Cover information is the result of vectorization of raster thematic data originating from classified Landsat 5 and Landsat 7 ortho-images, for agricultural and forest areas of Canada and its northern territories. The forest cover was produced by the Earth Observation for Sustainable Development (EOSD) project, an initiative of the Canadian Forest Service (CFS) with the collaboration of the Canadian Space Agency (CSA) and in partnership with the provincial and territorial governments. The agricultural coverage is produced by the National Land and Water Information Service (NLWIS) of Agriculture and Agri-Food Canada (AAFC).
- Watershed boundaries delineated by hydrology professionals and converted to geographic information system (GIS) format.
- Historical watershed imagery (from 2008).

The elevation bands and elevation band parameters determined for the Line Creek watershed for the calibration and verification period of 2000 to 2006 are shown in Attachment A.

The calibrated model was used to generate synthetic series of daily flows at the mouth of Line Creek for the periods of calibration and validation (only whole years are illustrated). Figure 4 shows the comparison of observed and simulated daily flows in Line Creek over the simulation period. Table 1 and Figure 5 show the comparison of observed and simulated mean monthly flows. The model slightly over-predicts the mean annual flow for the calibration period and under-predicts the mean annual flow for the verification period, however the results are reasonable and the timing of the peaks is generally good.

Figure 4 Observed and Simulated Hydrographs for Line Creek during Calibration (2000 to 2003) and Verification (2004 to 2006) Periods

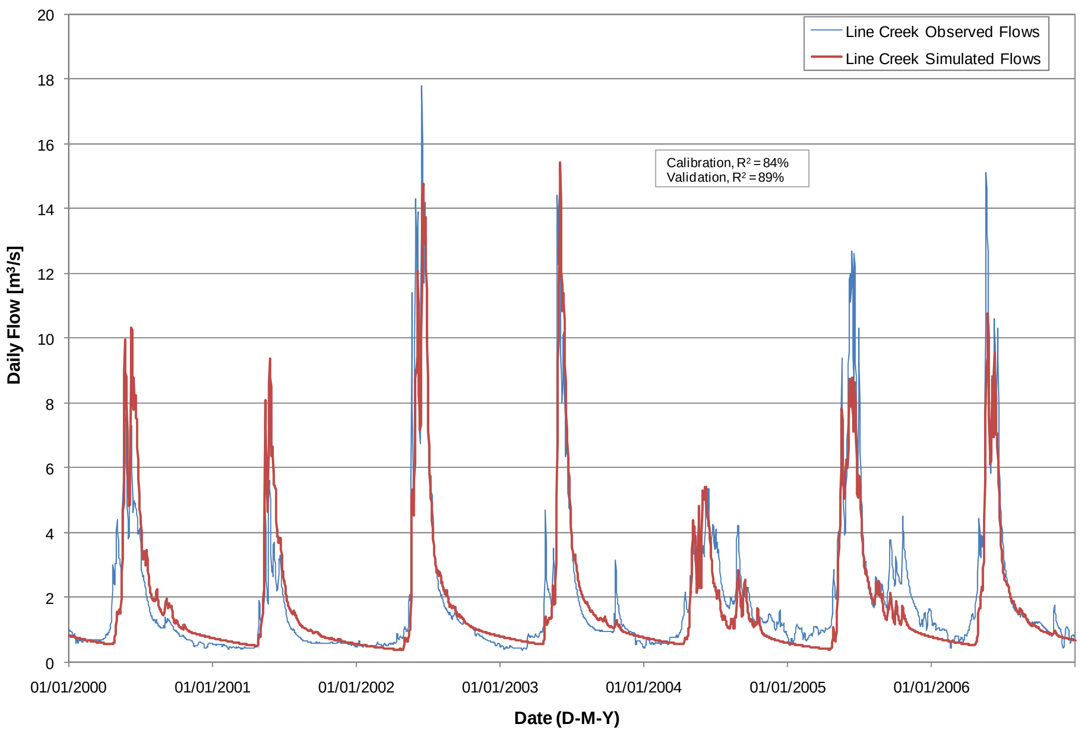


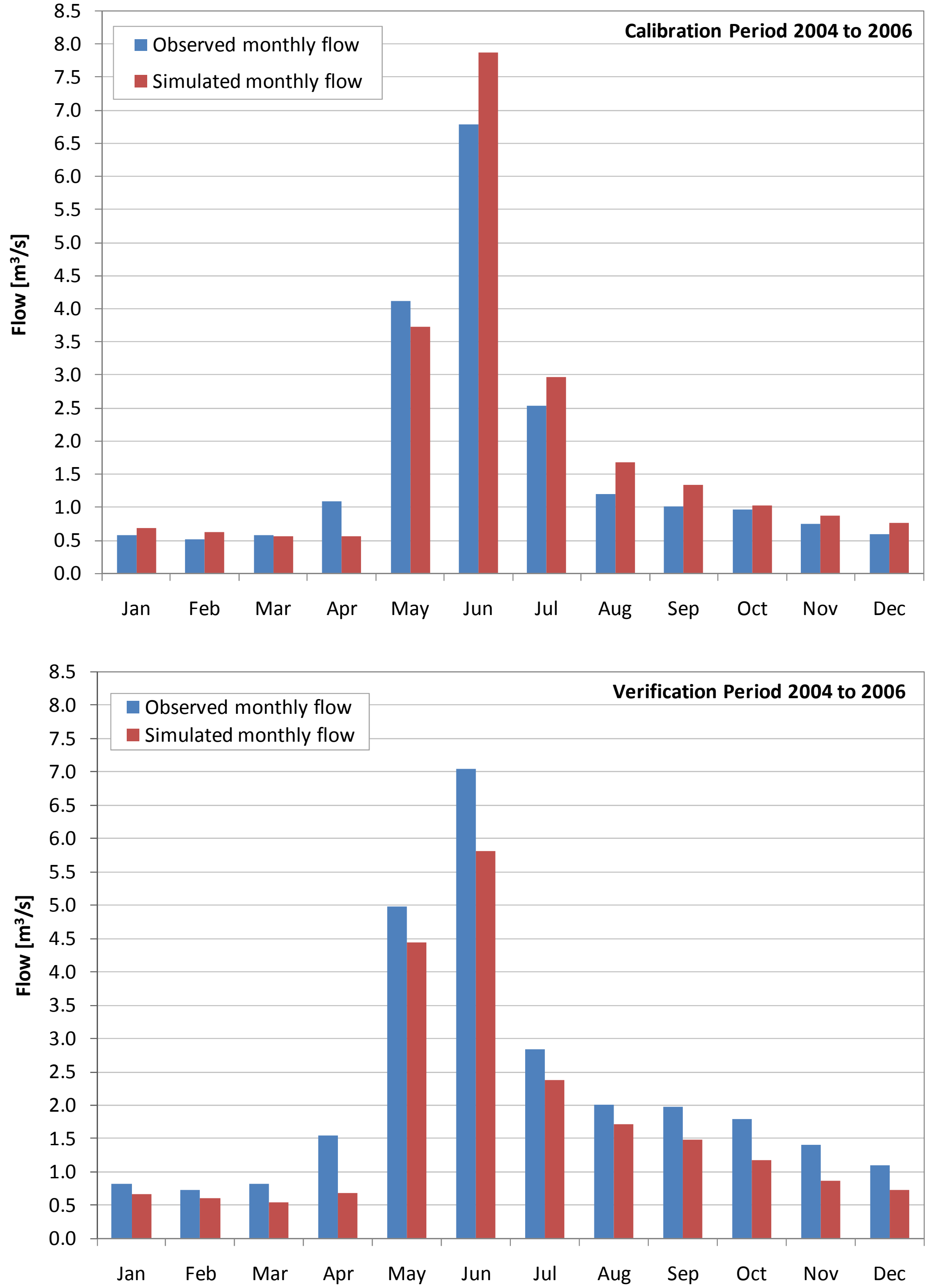
Table 1 Comparison of Observed and Simulated Monthly Flows for Line Creek at the Mouth (Station 08NK022)

Statistic	Calibration (2000 to 2003)		Verification (2004 to 2006)	
	Observed	Simulated	Observed	Simulated
Mean Monthly Flows [m³/s]				
January	0.58	0.69	0.83	0.67
February	0.52	0.62	0.73	0.60
March	0.59	0.56	0.83	0.54
April	1.09	0.57	1.55	0.68
May	4.12	3.73	4.98	4.44
June	6.79	7.88	7.04	5.82
July	2.54	2.96	2.85	2.38
August	1.20	1.68	2.01	1.71
September	1.01	1.35	1.97	1.48
October	0.97	1.03	1.79	1.17
November	0.76	0.87	1.41	0.87
December	0.60	0.76	1.10	0.73
Mean Annual Flow [m³/s]	1.73	1.89	2.26	1.76
Mean Open-Water Flow [a] [m³/s]	3.12	3.51	3.76	3.16
Mean Winter Flow[b] [m³/s]	0.80	0.74	1.19	0.77

[a] Open water season period is from May 1 to September 30. This is also referred to as the mean summer flow.

[b] Winter season period is from October 1 to April 30.

Figure 5: Comparison of Observed and Simulated Mean Monthly Flows for Line Creek at the Mouth (2000 to 2006)



6.0 DRY CREEK MODEL

6.1 Baseline Conditions

A detailed description of the Dry Creek model under baseline conditions is provided in Section D5.2.2 of the Project *Surface Water Hydrology Baseline Report* (Annex D). The elevation bands and elevation band parameters determined for the Dry Creek sub-watersheds are shown in Attachment B.

6.2 Project Conditions

A UBC model of the Dry Creek watershed was developed to simulate daily flows at key locations in the creek for the period 1970 to 2010. In-filled, elevation-adjusted precipitation and temperature data from the Fording River Cominco climate station were used as a model input. Details on the derivation of the precipitation and temperature data sets are provided in Section D4.3.1 of the Project *Surface Water Hydrology Baseline Report* presented as Annex D. Calibration parameters were adopted from the calibrated UBC model of the Line Creek watershed.

The watershed parameters were adjusted to reflect the physical characteristics of the Dry Creek watershed under Project conditions. Watershed parameters were assigned for two representative snapshots, End-of-Mining and Post-Closure. The elevation bands and elevation band parameters determined for Dry Creek are shown in Attachment B.

Sources of data for defining the watershed parameters included the following:

- 1:50,000 scale DEM, obtained from CCOG (2009).
- Impermeable polygons and forestry data from the Project terrestrial ecosystem map (TEM) (refer to the Project *Surficial Geology, Soils, Terrain and Vegetation Baseline Report* presented in Annex I).
- Watershed boundaries delineated by hydrology professionals and converted to GIS format.
- Mine plan snapshots provided by Teck (refer to Section A3.7).

7.0 SUMMARY OF RESULTS

The simulated daily flows for Dry Creek were analyzed to calculate the stream flow statistics shown in Table 2. Baseline flows were simulated for three locations on Dry Creek: (1) east tributary, (2) upper Dry Creek and (3) at the mouth. Flows under Project conditions were simulated at the mouth of Dry Creek only, where the uncertainty in the predicted flow statistics is lowest. The mouth of Dry Creek is the location where the assumptions inherent in the calibration methodology for Project conditions are valid (i.e. the overall hydrological characteristics of Dry Creek watershed under Project conditions are analogous to the overall hydrological characteristics of Line Creek watershed for recent mining conditions). Further discussion of uncertainty is provided in Section 9.0.

The mean annual water yield of Dry Creek at the Mouth under baseline conditions is estimated to be 457 mm, corresponding to mean annual discharge of 0.38 m^3/s. The mean annual water yield of Dry Creek is comparable to the mean annual water yields of other streams in the region. The 100-year flood peak discharge is estimated to be 8.05 m^3/s. The 7Q10 low flow (7-day low flow with a 10-year return period) is estimated to be 0.073 m^3/s.

A comparison of the simulated mean monthly flows of Dry Creek at the Mouth for the three representative snapshots is shown in Figure 6. The simulated highest mean monthly flows occurred in June; and the simulated lowest mean monthly flows occurred in March or April. Comparing baseline conditions to post-closure conditions, the predicted long term effect of the Project is to modify the monthly flow distribution, reducing May and June high flows and increasing low flows.

Table 2 Summary of Flow Statistics from Dry Creek Hydrological Modelling (simulation from 1971 to 2008)

Location on Dry Creek	Baseline Conditions			End-of-Mining Snapshot	Post-Closure Snapshot
	Dry Creek at the Mouth [(a)]	Upper Dry Creek [(b)]	East Tributary [(c)]	Dry Creek at the Mouth	Dry Creek at the Mouth
Drainage Area [km^2]	26.4	8.8	7.0	22.4	27.1
Mean Annual Yield (mm)	457	461	506	486	464
Flow Statistics [m^3/s]					
Mean Annual Flow	0.382	0.128	0.113	0.345	0.400
Mean Open-Water Flow [(d)]	0.700	0.235	0.207	0.598	0.685
Mean Winter Flow [(e)]	0.153	0.051	0.045	0.162	0.194
2-Year Peak Flow	2.35	0.819	0.747	1.60	1.75
5-Year Peak Flow	3.46	1.21	1.11	2.44	2.63
10-Year Peak Flow	4.34	1.50	1.39	3.12	3.34
25-Year Peak Flow	5.65	1.93	1.76	4.16	4.38
50-Year Peak Flow	6.77	2.29	2.07	5.07	5.28
100-Year Peak Flow	8.05	2.69	2.40	6.11	6.29
7Q10 Low Flow	0.073	0.024	0.022	0.076	0.088
Mean Monthly Flows [m^3/s]					
January	0.144	0.048	0.042	0.153	0.183
February	0.129	0.043	0.038	0.138	0.165
March	0.116	0.039	0.034	0.124	0.148
April	0.119	0.039	0.032	0.121	0.143
May	0.751	0.239	0.192	0.557	0.600
June	1.533	0.520	0.482	1.186	1.326
July	0.603	0.207	0.184	0.599	0.722
August	0.358	0.123	0.106	0.374	0.449
September	0.266	0.090	0.078	0.283	0.335
October	0.217	0.073	0.064	0.231	0.274
November	0.185	0.061	0.054	0.197	0.235
December	0.163	0.054	0.048	0.173	0.207

(a) Dry Creek at the Mouth refers to the main channel of Dry Creek, before confluence with Fording River.

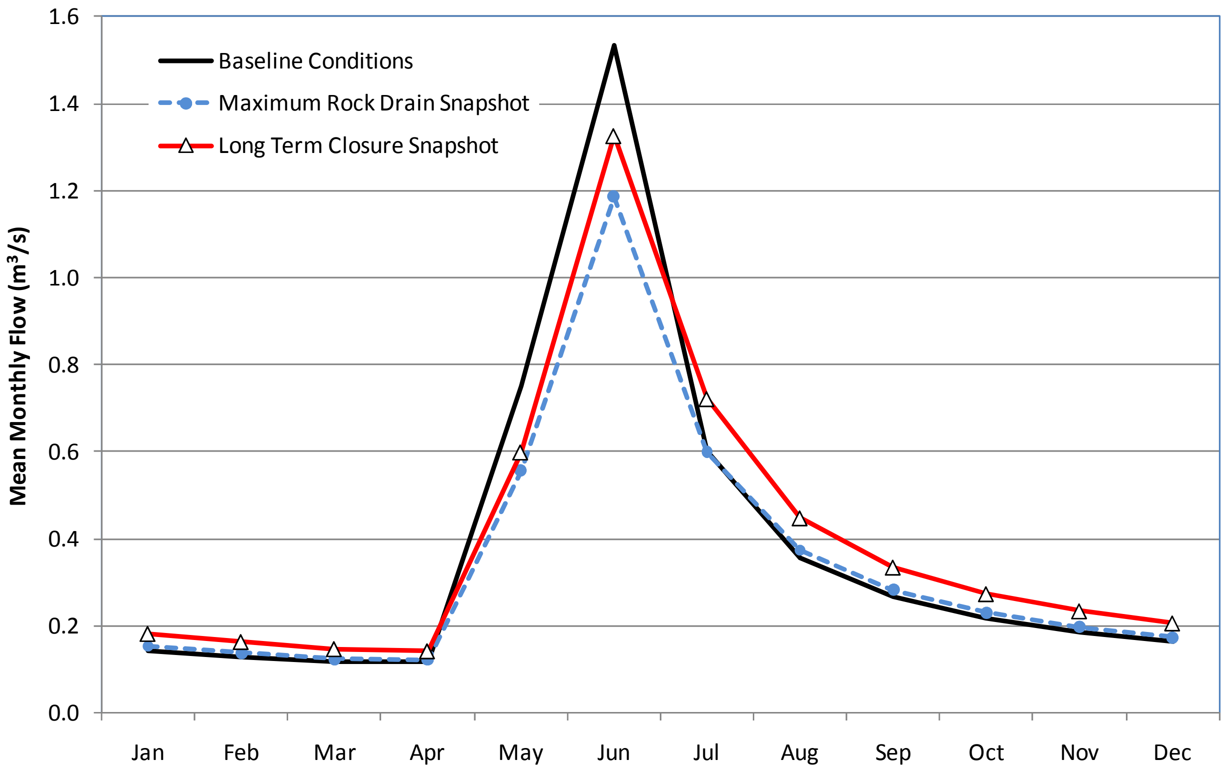
(b) Upper Dry Creek refers to the main channel of Dry Creek, before confluence with east tributary.

(c) East tributary - main tributary of Dry Creek, before confluence with upper Dry Creek.

(d) Open water season period is from May 1 to September 30.

(e) Winter season period is from October 1 to April 30.

Figure 6   Dry Creek at the Mouth – Mean Monthly Flow Distribution



8.0 KEY ASSUMPTIONS

The key assumptions of the modelling approach are as follows:

- The overall hydrological characteristics of Fording River watershed, calibrated for the period 1970 to 1979, are assumed to be representative of Dry Creek under baseline conditions. This assumption is considered to be reasonable as: i) Dry Creek is a tributary of the Fording River; and ii) the selected calibration period of 1970 to 1979 represents a period of least disturbance in the Fording River watershed, analogous to the low-level of existing disturbance in Dry Creek watershed.
- The overall hydrological characteristics of Line Creek watershed, calibrated for the period 2000 to 2006, are assumed to be representative of Dry Creek under Project conditions. This assumption is considered to be reasonable for simulating flows at the mouth of Dry Creek as: i) Line Creek watershed is adjacent to Dry Creek watershed; ii) the selected calibration period of 2000 to 2006 represents a period of extensive mining disturbance (about 25% of the total area) in the Line Creek watershed, analogous to the proposed mining disturbance (about 30% of the total area) in Dry Creek watershed; and iii) the types of mining disturbance are similar (i.e. open pits, waste rock dumps and rock drains).

9.0 UNCERTAINTIES

The UBC Watershed Model does not specifically account for waste rock dump processes, such as "wetting up" of the waste rock, infiltration through dumps and the attenuation of flow peaks. Rather, changes to the hydrological characteristics of the watershed due to waste rock dumping are implicitly accounted for by the selection of Line Creek as an analogue watershed and calibration of Line Creek flows for a recent time period, when there is extensive watershed disturbance due to mining activities (including waste rock dumps). The application of the calibrated model for Project conditions was limited to predicting flow statistics at the mouth of Dry Creek, where the proportion of mining disturbance under Project conditions is similar to the analogue watershed and the corresponding uncertainty is lowest.

In general, under Project conditions, there is lower uncertainty associated with the monthly and annual flow statistics and higher uncertainty associated with the flow statistics for short term (daily and weekly) flow statistics. Most of the selected flow statistics for water quality are based on monthly and annual flows, with the exception of 7-day average low flows. Flow statistics for fish and fish habitat are also based on monthly and annual flows. The selected statistics are shown in the hydrology EA (Section B2.2.3).

One potential source of difference between measured and simulated flows at Dry Creek (DC1) is spatial variation in precipitation between the Dry Creek watershed and locations of the climate stations. The climate data inputs for the model were sourced from the Fording River Cominco station, located about 20 km northwest of the Dry Creek watershed, with data gaps infilled primarily from the Sparwood climate station, located about 30 km to the southwest.

Further discussions about uncertainties around waste dump processes are provided in the Hydrology EA (Section B2.2.3.6.2) and Long Term Geochemical Source Terms Memorandum (Appendix B.IV).

Report Signature Page

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

Report prepared by:

Adam Auckland, M.Sc. signing for
Ann Conroy, B.Eng.
Water Resources Specialist

Report reviewed by:

Murray Fitch, M.A.Sc., P.Eng.
Principal, Senior Water Resources Engineer

AC/MF/SDL

THIRD PARTY DISCLAIMER

This report has been prepared by Golder Associates Ltd. (Golder) for the benefit of the client to whom it is addressed. The information and data contained herein represent Golder's best professional judgment in light of the knowledge and information available to Golder at the time of preparation. Except as required by law, this report and the information and data contained herein area to be treated as confidential and may be used and relied upon only by the client, its officers and employees. Golder denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents without the express written consent of Golder and the client.

REFERENCES

CCOG (Canadian Council on Geomatics). 2009. *Canadian Digital Elevation Data.* Available at: http://www.geobase.ca/geobase/en/data/cded/index.html. Accessed November 2009 and January 2010.

Teck. 2010. *Line Creek Operations Phase II Project Draft Application Information Requirements*. Submitted to the BC Environmental Assessment Office May 2010.

Quick, M.C. 1995. *UBC Watershed Model, Mountain Hydrology Group*. Department of Civil Engineering, University of British Columbia, Victoria, BC.

ATTACHMENT A

UBC Watershed Model Parameters – Analogue Watersheds

Table A1: UBC Watershed Model Parameters, Fording River at the Mouth – Analogue for Baseline Conditions

Band #	Band Range	Band Area	Mid-Elevation	Impermeable Area		Forested Area	Vegetation Cover	Orientation (Facing S, E, W, SE, SW)
	m	km^2	m	km^2	Fraction	Fraction	%	Fraction
1	1100-1300	6.6	1,259	0.0	0.00	0.52	44	0.75
2	1300-1500	33.0	1,418	0.0	0.00	0.61	45	0.81
3	1500-1700	88.2	1,617	0.5	0.01	0.69	48	0.74
4	1700-1900	134.5	1,807	2.4	0.02	0.64	51	0.71
5	1900-2100	139.9	1,998	7.3	0.05	0.62	53	0.67
6	2100-2300	120.5	2,189	26.5	0.22	0.45	54	0.66
7	2300-2500	63.3	2,389	38.8	0.61	0.06	53	0.68
8	2500-2700	25.0	2,580	20.1	0.81	0.001	43	0.67
9	2700-2900	7.4	2,769	6.3	0.85	0.002	59	0.72
10	2900-3100	0.4	2,919	0.4	0.91	0.008	43	0.73

Note: Watershed parameters based on 1979 imagery.

% = percent

Table A2: UBC Watershed Model Parameters, Line Creek at the Mouth – Analogue for Project Conditions

Band #	Band Range	Band Area	Mid-Elevation	Impermeable Area		Forested Area	Vegetation Cover	Orientation (Facing S, E, W, SE, SW)
	m	km^2	m	km^2	Fraction	Fraction	%	Fraction
1	1100-1300	1.43	1266	0.000	0.000	0.410	44	0.26
2	1300-1500	7.23	1426	0.000	0.000	0.291	48	0.63
3	1500-1700	21.7	1615	0.404	0.019	0.480	52	0.70
4	1700-1900	29.4	1805	0.724	0.025	0.542	54	0.65
5	1900-2100	32.8	1997	2.43	0.074	0.561	56	0.67
6	2100-2300	28.1	2185	7.30	0.260	0.347	54	0.69
7	2300-2500	14.8	2389	8.02	0.544	0.037	53	0.68
8	2500-2700	3.61	2571	2.46	0.682	0.002	43	0.71
9	2700-2900	0.532	2756	0.416	0.782	0.001	43	0.71
10	2900-3100	0.005	2930	0.002	0.483	0.000	0	0.00

Note: Impermeable polygons and forestry data from the Project TEM (refer to the Project *Surficial Geology, Terrain and Soils Baseline and Vegetation Report* presented as Annex I).

% = percent

ATTACHMENT B

UBC Watershed Model Parameters – Dry Creek Watershed

Table B1: UBC Watershed Model Parameters, Dry Creek at the Mouth

Band #	Band Range	Band Area	Mid-Elevation	Impermeable Area		Forested Area	Vegetation Cover	Orientation (Facing S, E, W, SE, SW)
	m	km^2	m	km^2	Fraction	Fraction	%	Fraction
BASELINE CONDITIONS								
1	1500 - 1600	0.960	1569	0.018	0.019	1.00	32	0.55
2	1600 - 1700	1.96	1649	0.040	0.020	0.97	41	0.66
3	1700 - 1800	2.16	1753	0.172	0.080	0.87	41	0.64
4	1800 - 1900	2.92	1854	0.053	0.018	0.98	42	0.62
5	1900 - 2000	3.80	1951	0.004	0.001	1.00	40	0.61
6	2000 - 2100	4.25	2052	0.085	0.020	1.00	36	0.62
7	2100 - 2200	4.23	2148	0.190	0.045	0.98	33	0.61
8	2200 - 2300	2.99	2248	0.049	0.016	0.97	25	0.67
9	2300 - 2400	2.00	2349	0.009	0.005	0.99	22	0.76
10	2400 - 2500	0.951	2438	0.000	0.000	0.98	18	0.78
11	2500 - 2600	0.184	2530	0.000	0.000	1.00	10	0.78
MAXIMUM ROCK DRAIN SNAPSHOT								
1	1500 - 1600	0.960	1569	0.018	0.019	1.00	32	0.55
2	1600 - 1700	1.96	1649	0.040	0.020	0.97	41	0.66
3	1700 - 1800	1.88	1751	0.134	0.071	0.86	39	0.63
4	1800 - 1900	2.07	1851	0.045	0.022	0.95	36	0.58
5	1900 - 2000	2.32	1950	0.001	0.0003	0.94	33	0.60
6	2000 - 2100	4.41	2053	0.012	0.003	0.50	32	0.61
7	2100 - 2200	4.42	2143	0.283	0.064	0.55	35	0.60
8	2200 - 2300	2.40	2242	0.022	0.009	0.67	21	0.70
9	2300 - 2400	1.34	2347	0.000	0.000	0.95	15	0.78
10	2400 - 2500	0.705	2440	0.000	0.000	1.00	11	0.79
11	2500 - 2600	0.184	2529	0.000	0.000	1.00	10	0.77
LONG-TERM CLOSURE SNAPSHOT								
1	1500 - 1600	0.960	1569	0.018	0.019	1.00	32	0.55
2	1600 - 1700	1.96	1649	0.040	0.020	0.97	41	0.66
3	1700 - 1800	1.88	1751	0.134	0.071	0.87	40	0.63
4	1800 - 1900	2.15	1852	0.045	0.021	0.98	35	0.58
5	1900 - 2000	3.34	1950	0.001	0.0002	1.00	31	0.61
6	2000 - 2100	5.51	2053	0.012	0.002	0.99	38	0.61
7	2100 - 2200	5.76	2143	0.283	0.049	0.97	37	0.61
8	2200 - 2300	3.24	2246	0.024	0.007	0.99	30	0.68
9	2300 - 2400	1.64	2345	0.000	0.000	0.98	21	0.79
10	2400 - 2500	0.780	2438	0.000	0.000	0.98	14	0.79
11	2500 - 2600	0.184	2529	0.000	0.000	1.00	10	0.77

% = percent

Table B2: UBC Watershed Model Parameters, Upper Dry Creek – Baseline Conditions

Band #	Band Range	Band Area	Mid-Elevation	Impermeable Area		Forested Area	Vegetation Cover	Orientation (Facing S, E, W, SE, SW)
	m	km^2	m	km^2	Fraction	Fraction	%	Fraction
BASELINE CONDITIONS								
1	1500 - 1600	0.000	na					
2	1600 - 1700	0.006	1697	0.000	0.031	0.91	50	0.21
3	1700 - 1800	0.433	1757	0.095	0.220	0.70	50	0.62
4	1800 - 1900	1.01	1859	0.032	0.031	0.96	54	0.65
5	1900 - 2000	1.55	1950	0.000	0.000	1.00	51	0.59
6	2000 - 2100	1.76	2052	0.053	0.030	1.00	43	0.59
7	2100 - 2200	1.87	2148	0.138	0.074	0.96	37	0.61
8	2200 - 2300	1.27	2245	0.048	0.038	0.93	33	0.65
9	2300 - 2400	0.628	2342	0.009	0.015	0.98	39	0.80
10	2400 - 2500	0.220	2425	0.000	0.000	0.91	45	0.82
11	2500 - 2600	0.000	na					

% = percent

Table B3: UBC Watershed Model Parameters, East Tributary – Baseline Conditions

Band #	Band Range	Band Area	Mid-Elevation	Impermeable Area		Forested Area	Vegetation Cover	Orientation (Facing S, E, W, SE, SW)
	m	km^2	m	km^2	Fraction	Fraction	%	Fraction
BASELINE CONDITIONS								
1	1500 - 1600	0.000	na					
2	1600 - 1700	0.007	1696	0.000	0.000	0.99	16	0.87
3	1700 - 1800	0.281	1767	0.000	0.000	0.86	29	0.59
4	1800 - 1900	0.579	1853	0.000	0.000	1.00	34	0.56
5	1900 - 2000	0.947	1952	0.000	0.000	1.00	36	0.63
6	2000 - 2100	1.32	2053	0.000	0.000	1.00	33	0.64
7	2100 - 2200	1.38	2148	0.000	0.000	1.00	31	0.61
8	2200 - 2300	1.06	2248	0.000	0.000	1.00	18	0.67
9	2300 - 2400	0.85	2348	0.000	0.000	1.00	13	0.72
10	2400 - 2500	0.447	2441	0.000	0.000	0.99	10	0.81
11	2500 - 2600	0.169	2528	0.000	0.000	1.00	10	0.81

% = percent

At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
102, 2535 - 3rd Avenue S.E.
Calgary, Alberta, T2A 7W5
Canada
T: +1 (403) 299 5600