Jordan Project Water Use Plan

Lower Jordan River Inflow Monitoring

Implementation Year 6

Reference: JORMON-1

Lower Jordan River Inflow Monitoring: Results from 6 Years of Monitoring

Study Period: December 2005 – September 2011

D. Burt and Associates
Nanaimo, BC

Hydroid Geoscience Ltd.
Qualicum Beach, BC

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Lower Jordan River Inflow Monitoring

Results from 6 Years of Monitoring

(December 2005 – September 2011)

Prepared For

BC Hydro
Water Use Planning
6911 Southpoint Drive, Tower
Burnaby, BC, V3N 4X8

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By

D.W. Burt[1] and R. Hudson[2]

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[1] D. Burt and Associates
2245 Ashlee Road
Nanaimo, BC, V9R 6T5
(250) 753-0027
DBurt_and_Assoc@telus.net

[2] Hydroid Geoscience Ltd.
380 Cottonwood Drive
Qualicum Beach BC, V9K 1M2
(250) 752-4477
Robert.Hudson@telus.net

EXECUTIVE SUMMARY

A major outcome of the Jordan River WUP was the decision to outfit Elliott Dam with a flow release valve and subsequently provide a continuous discharge of 0.25 m^3/s to the lower river for fisheries purposes. This release, in combination with modelled inflows for drainages below the dam, were predicted to provide a target level of fish habitat (in terms of weighted usable area, WUA) at summer base flow (August), and an additional 3 km of linear habitat in reaches below the dam. However, it was recognized that attainment of these targets was dependent on how well modelled inflows mirror actual inflows to the lower river, and whether a significant portion of the flow release were lost to subsurface conveyances. The Lower Jordan River Inflow Monitoring Program was initiated to collect empirical data on actual flows in the river, which could then be used to check the accuracy of the flows modelled by the Jordan WUP and assess potential loss of release flows to groundwater conveyances. As outlined in BC Hydro (2007), the primary management questions to be addressed by the study were:

1) How accurate were the local inflow estimates used in the WUP recommendations?
2) What implications, if any, do inflows from monitoring have on the WUP recommendations?
3) What are the reasons for differences, if any, between the monitored and modelled inflows?

The Inflow Monitoring Program included 2 years of monitoring prior to initiation of the fish flow release, followed by 4 years of monitoring after initiation of the release. Monitoring stations included 3 sites on the mainstem located in the lower, middle, and upper positions of the Jordan River (M1, M2, and M3, respectively), as well as one station on Sinn Fein Creek (T1). Continuous water level recorders were established at each station. Discharge measurements for development of stage/discharge rating curves employed salt dilution gauging methods. Annual reports for the first 5 years of the program can be found in Hudson (2006) and Burt and Hudson (2008, 2009, 2010, 2012).

The question of potential loss of the fish flow release to groundwater conveyances was assessed by comparing measured water yield at a given mainstem station with estimated water yield derived from the next upstream station. The exception was for potential losses between Elliott Dam and the uppermost station (M3) where measured values were used for each location. Results suggested there was loss of flow between Elliot Dam and the upper station (0.03–0.05 m^3/s), and between the upper and mid stations (0.15–0.17 m^3/s), but a possible gain in flow between the mid and lower stations (0.02–0.09 m^3/s).

The accuracy of the WUP modelled flows was assessed by a series of steps that involved regressing measured flows at M1 for June to September 2006 on modelled flows derived from BC Hydro's quality assured Total System Inflows (TSI's). The resultant regression equation or correction factor was then applied to TSI modelled flows For M1 for the available period of record (1990–2007). The result was a "best estimate" dataset for the low flow months of June to September spanning the years 1990 to 2007. This "best estimate" dataset was the basis for assessing the accuracy of the WUP modelled flows. The original WUP modelling was based on a period of record of 1967–1998 and only overlapped our "best estimate" dataset in the last 9 years. We therefore extended the WUP data to 2007 using their modelling protocols, namely watershed area derived flow estimates for M1 were processed whereby values ≤ 0.072 m^3/s were replaced with the WUP default minimum of 0.072 m^3/s. Monthly means were then calculated for the "best estimate" and extended WUP datasets (both spanning 1990–2007). These means are given in the table below and show that WUP modelled flows substantially overestimate the best estimate of actual flows.

The last 2 rows of this table show the approach used to derive a best estimate of actual mean monthly flows for the original WUP period of record. This involved dividing the original WUP means by the percent overestimation from the 1990–2007 data. These calculations suggests that the mean August flow for the 1967–1998 period of record was about 0.055 m^3/s as opposed to 0.160 m^3/s estimated by the original WUP modelling.

	Mean Monthly Discharge (m^3/s)			
	June	**July**	**August**	**September**
"Best estimate" (1990-2007)	0.122	0.063	0.061	0.099
WUP modelled (1990-2007)	0.338	0.169	0.176	0.285
Percent overestimation by WUP modelled (1990-2007)	277%	268%	289%	288%
Original WUP data (1967-1998)	0.389	0.214	0.160	0.323
Best estimate original WUP (1967-1998) (Original WUP ÷ % overestimation)	0.140	0.080	0.055	0.112

The implications of the above findings for the management questions posed above and can be summarized as follows:

1) The original WUP modelling substantially overestimated flows in the lower river during summer base flows (by 268% – 289%). For the lowest flow month selected by the WUP (August), actual mean monthly flow was estimated to be about 0.055 m^3/s compared with 0.160 m^3/s predicted by the WUP. The main reason for the WUP overestimation was the use of a default minimum flow that exceeded what commonly occurs in the river during low flow periods.

2) Our analyses also suggested that a portion of the fish flow release is lost to subsurface conveyances. During low flow months this loss amounted to 0.03–0.05 m^3/s (median 0.04 m^3/s). Thus, under the prescribed release of 0.25 m^3/s, the inriver flow would be reduced to about 0.21 m^3/s.

3) In the Jordan WUP, it was estimated that under the fish flow release, mean August flows in the lower river (at M1) would be the sum of the fish flow release (0.25 m^3/s) and WUP modelled inflows (0.16 m^3/s), producing a combined flow of 0.41 m^3/s. Our findings indicate that a more realistic estimate of mean August flows would be 0.265 m^3/s (0.25 m^3/s release – 0.04 m^3/s lost + 0.055 m^3/s from local inflows). This further suggests that the amount of fish habitat (WUA) targeted by the WUP would not be achieved under the prescribed flow release, and that to achieve the WUA target the flow release would have to be increased to 0.395 m^3/s (0.395 m^3/s release – 0.04 m^3/s lost + 0.055 m^3/s mean Aug. inflow = 0.410 m^3/s).

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ACKNOWLEDGEMENTS

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1. INTRODUCTION

The Jordan River Water Use Plan (JOR WUP) was initiated in April 2000, submitted to the Comptroller of Water Rights (CWR) in 2002, and approved by the CWR on July 20, 2004 (BC Hydro 2005, Attachment A). A major outcome of the Jordan WUP was to install and flow release valve in Elliott Dam and subsequently provide a minimum release of 0.25 m^3/s to the lower Jordan River. This release flow, in combination with tributary inflows estimated by modelling, were predicted to provide a target level of fish habitat as measured by weighted usable area (WUA), and an additional 3 km of wetted stream length in the channel below Elliott Dam. However, it was recognized that attainment of these two habitat targets was dependent on how well modelled inflows mirrored actual inflows to the lower river, and whether a significant portion of the flow release was lost to subsurface conveyances.

The Lower Jordan Inflow Monitoring program was implemented to address these flow uncertainties. The primary management questions to be addressed by the study included the following (BC Hydro 2007):

1) How accurate were the local inflow estimates used in the WUP recommendations?
2) What implications, if any, do inflows from monitoring have on the WUP recommendations?
3) What are the reasons for differences, if any, between the monitored and modelled inflows?

The study was designed to address the management questions by conducting the following tasks over a 6-year monitoring period:

1) Establish 3 mainstem and 2 tributary monitoring sites for continuous water level recording, and periodic discharge measurement in order to develop rating curves for each site.

2) Monitor these stations for 2 years prior to the fish flow release and for 4 years after the flow release (later changed to 3 years pre and 3 years post flow release).

3) At the end of the monitoring period, compare measured time series flow data with modelled inflow data to determine any differences.

3) Compare measured flow data from mainstem and tributary sites to determine if there is significant flow leakage from the mainstem channel bed that negates potential benefits from the flow release.

The 6-year study was conducted from November 2005 to September 2011. The first year of the program (December 2005 – 2006) was conducted by Hydroid Geoscience Ltd., while subsequent years were conducted by D. Burt and Associates with technical support provided by Hydroid Geoscience Ltd. Annual reports for the first five years of the program can be found in Hudson (2006) and (Burt and Hudson 2008, 2009, 2010, 2012). This report provides a summary of all 6 years of monitoring program and addresses the management questions outlined above.

2. METHODS

2.1 Study Area

The Jordan River is located on the southwest coast of Vancouver Island 72 km by road from the city of Victoria. The river originates in the Seymour Mountain Range in south central Vancouver Island and flows in a south-westerly direction before emptying into Juan De Fuca Strait adjacent to the community of Jordan River. It has a drainage area of 184 km^2 and a mean annual discharge at the mouth of approximately 13.7 m^3/s (Cascadia Biological Services 2001).

The Jordan River hydroelectric project was completed in 1911 and rebuilt in 1971. Current facilities include three dams, two reservoirs, a headpond, a tunnel/penstock water delivery system, and a 175 MW powerhouse on the lower Jordan River (BC Hydro 2003). The dams include Bear Creek Dam and Jordan Diversion Dam, which impound Bear Creek Reservoir (7.5 km^2) and Diversion Reservoir (18 km^2), and Elliott Dam which impounds Elliott Headpond (1.6 km^2). The current powerhouse and tailrace are located on the west side of the lower Jordan River 900 m above the mouth. These replaced the original powerhouse and tailrace in 1972 (which were located on the east side of the river closer to the mouth).

The study area for the inflow monitoring program encompasses the portion of the watershed from Elliott Dam downstream to the Jordan River Generating Station tailrace, a distance of 7.8 km (Figure 1). Prior to January 2008 no water was released into the lower Jordan mainstem except when spilling was required. Thus, flows in the mainstem were generally dependent on input from local tributaries. The most significant of these include Sinn Fein, Winkler, and Nuala Creeks, which drain the west side of the river, and one unnamed creek just above Nuala Creek which drains the east side of the river. The fish flow release commenced on January 16, 2008, thus, as of this date, mainstem discharges downstream of Elliott Dam have been ≥ 0.25 m^3/s.

Figure 1 shows the study area, locations of mainstem and tributary monitoring stations, and catchment areas for each station and for significant unmonitored tributaries. Total area for all catchments within the study area is 17.4 km^2 (Solano 2008). Monitoring sites in the mainstem include M1, M2, and M3 (lower, middle, and upper sites, respectively). Tributary sites initially included T1 (Sinn Fein Creek) and T2 (an unnamed creek), however, T2 was dropped as a monitoring site in Year 2 (2007) due to channel instability.

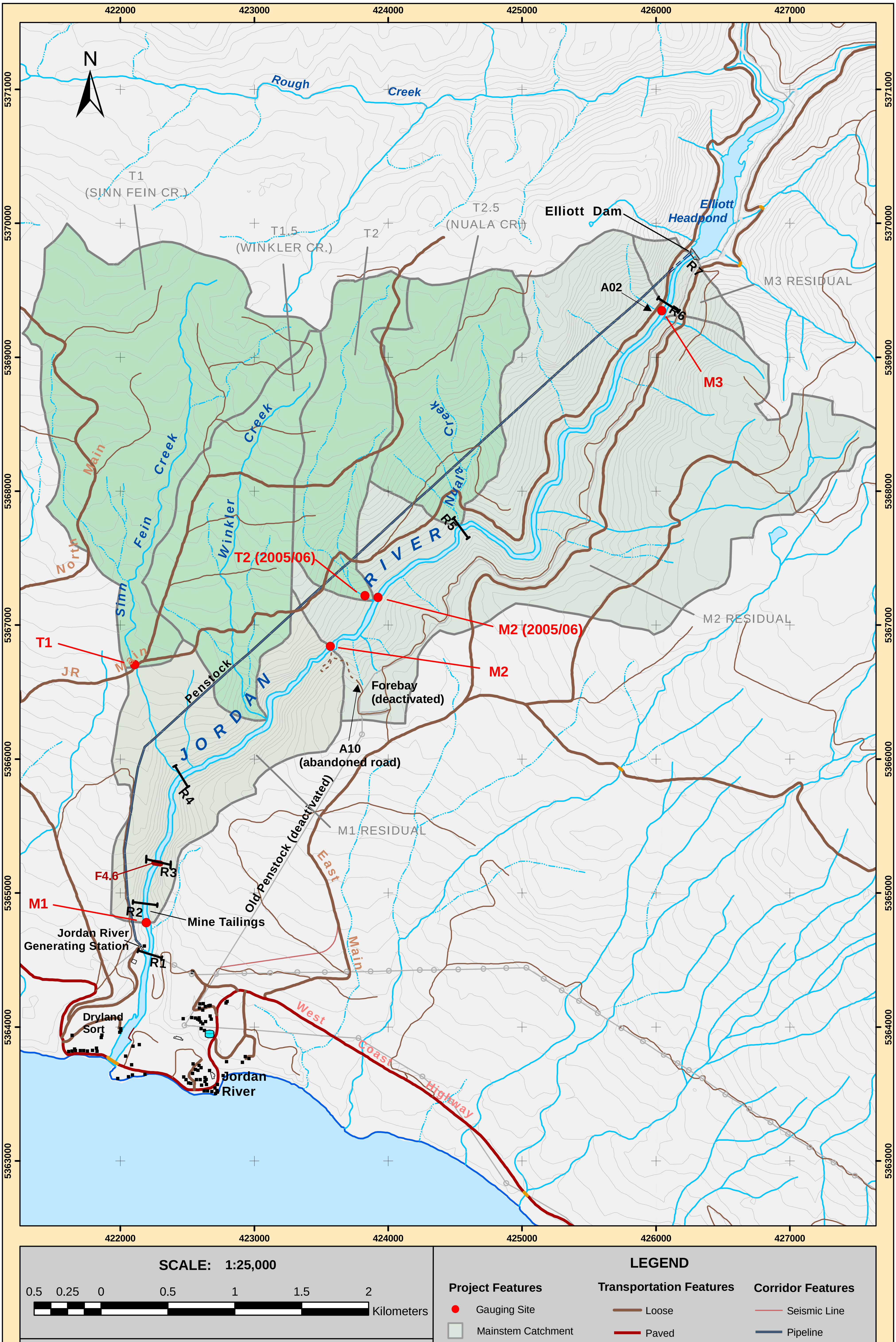

Figure 1. Map of the Lower Jordan River showing gauging sites and associated catchment areas.

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2.2 Gauge Installations

Water level Loggers

Water level loggers were first installed in November and December 2005, and included stations M1, M2, and M3 on the Jordan River mainstem, T1 on Sinn Fein Creek, and T2 on an unnamed creek adjacent to M2. Locations of these gauging stations are shown in Figure 1, while Table 1 lists equipment used at each site and dates of operation. Photos illustrating installation features are provided in Appendix B.

In November 2006, heavy rainfall necessitated spilling at Elliott Dam and the lower Jordan River experienced extremely high flows (non-power releases from BC Hydro indicated flows peaked at 459 m^3/s on November 6, 2006). These flows washed out all gauging equipment in the mainstem (M1, M2 and M3). Thus, in 2007, new equipment was purchased and re-established in the river. During installations, great effort was taken to secure the equipment in a manner that would withstand future high flow events. In the cases of M1 and M3, each transducer was fastened to a heavy anchor (weighing ~70 kg) consisting of sections of grader blades. In addition, each transducer cable was encased in wire rope which was bolted to bedrock at various places along its length. Further details on this armouring system and supporting photos were provided in the Year 1 report (Hudson 2006).

In the case of M2, the station was relocated 250 m downstream closer to the access point during the 2007 reinstallations. The original and new locations are shown in Figure 1. Access was still too far to carry in an anchor so the transducer was secured inside a 30 cm section of PVC pipe and the pipe bolted to a vertical crevice in a bedrock wall. The wire rope containing the transducer cable was bolted to the bedrock within this vertical seam. In 2009, the transducer at M2 began to malfunction producing large fluctuations in the offset, and thus, unreliable water level data. Several field trips to troubleshoot and attempt to fix this problem were unsuccessful. As a result, the transducer was pulled on August 12, 2009 and a new one installed on September 22, 2009.

T1 (Sinn Fein Creek) was installed similar to M3. Here the encased cable was bolted to bedrock as well as shackled to cables on the bridge abutment. As previously mentioned, T2 was not reinstalled and was dropped as a monitoring site in 2007.

Loggers used at each site were either Unidata or Onset Hobo Energy Loggers and were kept within waterproof housings located above the high water mark. The M1 housing was attached to a metal post, while the M2 and M3 housings were attached to tree trunks. The T1 housing was kept in a plywood box nailed to the end of the Sinn Fein bridge abutment log. All loggers were set to store water level readings every 15 minutes. Power was supplied by sealed lead-acid batteries rated at 7.2 Ah for the Hobo loggers and 33 Ah for the Unidata loggers. Batteries were stored in waterproof containers located at the base of the housings. In addition to the external power source, each logger was equipped with internal batteries to serve as a backup in case of loss of power from the external source.

Table 1. Summary of equipment used at water level monitoring stations during Years 1 through 6.

Site	Dates of Operation	Transducer	Logger	Staff Gauge	Photos (App. B)
M1	a) 14-Dec-2005 — 05-Oct-2006 b) 10-Oct-2007 — 29-Sep-2011	a) Unidata b) Unidata model 6542 0-5 m	a) Unidata b) Unidata Starlog Pro 512K	Yes	1, 5
M2	a) 13-Dec-2005 — 04-Oct-2006 b) 02-Aug-2007 — 12-Aug-2009 c) 22-Sep-2009 — 29 Sep-2011	a) Unidata b) Esterline KPSI 0.1% 0-5 m c) INW PS9800 0.1% 0-5 m	a) Unidata b) Onset Hobo Energy Logger Pro c) Onset Hobo Energy Logger Pro	Yes	2, 6
M3	a) 24-Nov-2005 — 04-Oct-2006 b) 11-Oct-2007 — 03-Nov-2011	a) Unidata b) Esterline KPSI 0.1% 0-5 m	a) Unidata b) Onset Hobo Energy Logger Pro	Yes	3, 7
T1	a) 14-Dec-2005 — 04-Oct-2006 b) 30-Nov-2007 — 31-Dec-2011	a) Keller b) Unidata model 6508B 0-2 m	a) Unidata Starlog 125K b) Unidata Starlog Pro 512K	No	4, 8
T2	a) 23-Nov-2005 — 04-Oct-2006 b) Not reinstalled	a) Unidata	a) Unidata Starlog 125K		

Notes:

1. Instrumentation information for Year 1 (a in table) are from Hudson which did not supply model information. Transducers listed for M1, M2, and M3 in Year 1 were lost during the November 2006 flood.
2. In the case of M2, the Esterline transducer failed in 2009 and was replaced with an Instrumentations Northwest (INW) PS9800 transducer on Sept. 22, 2009.
3. In the case of T1 (Sinn Fein station), the original Unidata Starlog 125K exhibited a chronic problem of high battery draw and was replaced with a newer model (Starlog Pro 512K) to alleviate this problem.

Staff Gauge Installations

Staff gauges were initially installed at sites M1 and M3, but were lost in the October 2006 flood. New staff gauges were installed at M1, M2, and M3 in 2007 when the other monitoring components were reinstalled. Staff gauges consisted of 1 m aluminum gauge plates screwed to plywood (M1) or 2x8 cedar boards (M2 and M3). The boards were then bolted to bedrock in protective locations in close proximity to the water level transducers.

Surveying

Surveying was completed using a level and stadia rod and was conducted on most site visits during 2007 to 2009. In 2010 surveying was conducted only at M2. Survey points at each site included shots on the 2 benchmarks installed at each site, a staff gauge shot, a sensor shot, and a water level shot adjacent to the transducer. A simple drawing was completed for each site showing the locations of gauging equipment, the staff gauge, and each survey point.

2.3 Discharge Measurements

Stream flow measurements were conducted in Years 1 through 4 (2005/6 – 2009). Stream flow was measured using salt dilution gauging (mass balance method) as described in Hudson and Fraser (2005). Photos of the salt gauging stream sections are provided in Appendix B (Photos 5 – 8). During salt dilution trials, conductivity was recorded at 5 second intervals using a YSI Professional Plus Handheld logger outfitted with a conductivity/temperature probe on a 4 m cable. Calibration of the relationship between concentration and conductivity was performed by measuring conductivity during 3 successive additions of salt (usually 0.05 g) to 10 L of stream water in a bucket. Each calibration yielded a concentration factor (CF) for that site at ambient stream temperature. The relation between stream temperature and CF was developed as successive measurements were taken.

2.4 Rating Curve Development

Rating curves refer to the stage–discharge relationship unique to each site and are generally developed with gauge height plotted on the y-axis and discharge on the x-axis. For Jordan River mainstem sites, rating curves developed in Year 1 (2005-2006) could not be used in subsequent years. For M1 this was due to changes in channel geometry from the October 2006 flood. In the case of M2 this was due to relocation of the gauging station further downstream in 2007. In the case of M3 no rating curve was developed in Year 1. For T1 (Sinn Fein Creek), the stream channel and gauge installations remained similar to Year 1 and the rating curve was modified only slightly due to the addition of new data from subsequent years of monitoring.

Rating curves were developed using the Chapman-Richards asymptotic-exponential curve (Sit 1994). The equation for this curve has the following form:

$$GH - Offset = a\left(1 - e^{-b \times Q}\right)^{c} \qquad \textbf{(1)}$$

where: *GH* = *gauge height*
Offset = *the y-intercept of the curve (or zero flow point)*
a = *the asymptote*
b, c = *curve fitting parameters*
Q = *stream discharge*

In the above equation, gauge height refers to the distance in metres above the site's datum. The datum was an arbitrarily selected distance below the sites benchmark, with the only caveat being that the zero flow gauge height had to be a positive value. Once the datum was established, water level data were converted to gauge height. Curve fitting was then performed on available discharge and associated gauge height values using JMP statistical software. The offset, or zero flow gauge height, was selected by the curve fitting but with the constraint that it must be less than the minimum gauge height in the period of record. The horizontal asymptote was also constrained such that the offset plus the asymptote had to be greater than the maximum gauge height in the period of record.

In Year 2 (2007-08) there were relatively few data points for the curve fitting process, and the zero flow point (y-intercept or offset) had to be estimated using the graphical method described in the

RISC Standards for Hydrometric Measurement (Ministry of Environment 1998). In subsequent years there were sufficient data points and the software was allowed to define the zero flow point. In addition, test of the RISC approach on the 2008-09 curves indicated that the graphical method produced an unrealistic overestimate of the zero flow point.

After determining the best-fit curve for a given site, discharge was calculated for all gauge height data. This was done using the inverted form of equation 1 as follows:

$$Q = \frac{\ln\left(1 - \left(\frac{GH - Offset}{a}\right)^{1/c}\right)}{-b} \qquad \textbf{(2)}$$

The above equation is never extrapolated beyond the range of data upon which it was based. For gauge height data greater than the highest measured flow a linear relationship was used in place of equation 2. This relationship is based on a line taken tangential to the rating curve at the highest measured discharge. The equation for this linear relationship is as follows:

$$GH = \frac{Q - B_0}{B_1} \qquad \textbf{(3)}$$

Where: B_1 is the slope of a line that is tangential to equation 1, and
B_0 is the intercept of the tangential line.

In order to estimate discharge for gauge heights greater than the highest measured discharge, equation 3 was rearranged to solve for Q as follows:

$$Q = B_0 + B_1 \times GH \qquad \textbf{(4)}$$

The slope and intercept of the tangent line are derived from the first derivative of the rating curve equation, given by Sit (1994) as follows:

$$B_1 = \frac{1}{abc \times e^{(-bQ_T)} \times (1 - e^{(-bQ_T)})^{c-1}} \qquad \textbf{(5)}$$

$$B_0 = -B_1(GH_T - Q_T) \qquad \textbf{(6)}$$

Where: GH_T and Q_T are the transitional gauge height and discharge, respectively.

Development of Rating Curves for Moderate to High Flows

In the Year 4 report (Burt and Hudson 2010), review of BC Hydro release data for Elliott Dam indicated that the approach of using a tangential linear relationship (Equation 4) to extrapolate flows beyond measured values resulted in substantial underestimation of discharges at high flows. Since we had no measured discharges at these flows, BC Hydro release data were used to adjust the rating curves at higher stage/discharge levels. For M1 and M2 this involved estimating discharges using the sum of a) fishwater releases, b) any spills happening at the time, and c) modelled local inflows from tributaries (using total system inflows to Elliott Reservoir and watershed area ratios). The equation for predicting local inflows at each station is shown below (Equation 7). In the case of M3, its location is relatively close to Elliott Dam and so only a) and b) above were used to predict discharge. Mean daily modelled flows for each station were then paired with mean daily gauge heights, the data plotted (gauge height on the y-axis and discharge on the x-axis) and curve fitting applied to the data points.

$$Q_{\mathrm{TSI\_mod\text{-}M_i}} = Q_{\mathrm{TSI}} \times \frac{A_{\mathrm{M_i}}}{A_{\mathrm{TSI}}} \qquad \textbf{(7)}$$

Where: $Q_{TSI\_mod\text{-}Mi}$ = *modelled local inflows at a given station (M1 and M2)* (m^3/s)

Q_{TSI} = *quality assured Total System Inflows (mean daily,* m^3/s*)*

A_{Mi} = *drainage area between Elliott Dam and the station of interest (*A_{M1} = 16.87 km^2, A_{M2} = 9.58 km^2*)*

A_{TSI} = *drainage area for Total System Inflows (Bear Creek, Diversion, and Elliott Reservoirs, 144.1* km^2*)*

2.5 Comparison of Modelled and Measured Flows

During development of the Jordan WUP, BC Hydro modelled mean daily flows for a point on the lower river just upstream of the tailrace for the period 1967 – 1998 (32 years). The modelling was based on BC Hydro's inflow estimates for the drainage area between Diversion and Elliott Dams (inflows were calculated from changes in reservoir elevation and release records). The inflow data were summarized into mean daily values for the period of record (1967 – 1998), and multiplied by the ratio of drainage area below Elliott Dam (LJR, 17.4 km^2) to the drainage area between Diversion and Elliott Dams (JOR, 24.1 km^2) (resultant ratio = 0.722). The results of this analysis are housed in the Excel file "JOR RM System Inflows.xls" by Sherbot (2001).

Our initial plan for the modelled/measured comparison was to use the WUP approach to model flows for the lower river for the period of the Inflow Monitoring Program and then to compare these with measured flows at M1. Unfortunately, BC Hydro has not maintained quality assured (QA'd) inflow data specific to the JOR drainage area. However, inflow data were available for total system inflows (i.e., for Bear Creek, Diversion, and Elliott Reservoirs combined) from BC Hydro's CRO database (Commercial Resource Optimization database). These data were quality assured with noise corrected using moving averages and by comparison with hydrologically similar non-regulated streams (Solano 2008), and were provided for the period 1990 to 2010. In addition, in the Year 3 report (Burt and Hudson 2009), it was demonstrated that modelled flows based on total system inflows mirrored modelled flows from JOR inflows at all except very low flows, and were a suitable alternative for modelling lower Jordan River flows.

Another issue found upon review of the WUP dataset, is that the inflow data used by the WUP modelling had not undergone the quality assurance corrections which are particularly important for addressing anomalies at lower flows (e.g., negative values in the raw data). Low flow anomalies were addressed in the WUP modelling by assuming a default minimum value of 0.1 m^3/s for JOR inflows. When the watershed ratio of 0.722 was applied to this inflow minimum, the resultant minimum modelled flow for upstream of the tailrace was 0.072 m^3/s. As a result of this approach, the WUP modelled flows flatlined at this minimum value during low flow periods, whereas flows modelled using the CRO QA'd data dropped below this threshold and followed a more natural hydrologic pattern. Figure 2 illustrates the similarities between WUP and CRO QA'd modelled flows above the 0.072 m^3/s threshold, and differences when flows dropped below this threshold (data shown are modelled mean daily flows at the lower river gauging station for June to September in 1990).

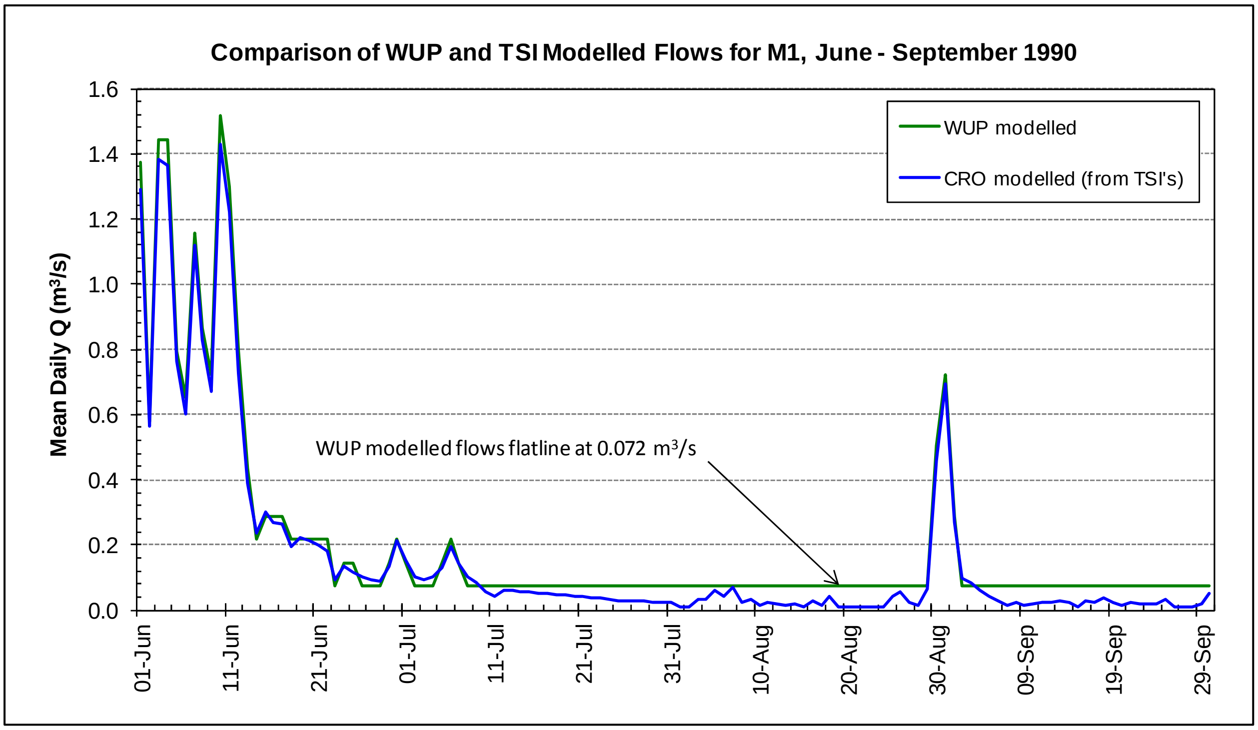


Figure 2. Example comparison of WUP and CRO total system inflow (TSI) modelled flows for M1 (June - September 1990) to illustrate how WUP flows flatline at 0.072 m^3/s.

Given this understanding of the similarities and differences between the WUP and CRO databases, the following approach was used in assessing the accuracy of the WUP modelled flows relative to measured values:

- Using QA'd mean daily total system inflows (TSI's) for Elliott Headpond from the CRO database, and the associated watershed area ratio from our digitizing (16.87 km^2/ 144.1 km^2 = 0.117), mean daily flows at M1 were modelled for the period of the Inflow Monitoring Program prior to the flow release (2005 – 2007). The formula for this calculation is the same as Equation 7 given in the previous section.
- Measured flows at M1 were then regressed on the above TSI modelled flows to develop a correction factor for adjusting the modelled flows to better fit measured values. The regression needed to focus on flows within the range of measured discharges of the M1 rating curve, and thus was restricted to data within the months of June to September.
- The above 2 steps were then applied to all June to September TSI modelled flows producing a dataset of "best estimate" modelled M1 mean daily flows for these months for the period of record in the CRO QA'd dataset (1990 – 2007).
- These Best Estimate modelled data were then compared with WUP modelled data for the same months and period of record (June to September 1990 to 2007). Since the original WUP dataset only overlapped the Best Estimate modelled data in the years 1990 to 1998, WUP data for 1999 to 2007 data had to be generated. This was done using the TSI modelled M1 flows where any flows < 0.072 m^3/s were replaced with 0.072 m^3/s.
- Mean monthly flows for June to September for the period of record were then calculated for both the Best Estimate and WUP modelled datasets, and results compared to determine whether the WUP flows over or underestimated the Best Estimate flows during July to September.

3. RESULTS

3.1 Summary of Hydrometric Measurements

A synopsis of hydrometric data collected during the Inflow Monitoring Program are provided in Table 2. The 2006 data are from Year 1 and summarize information prior to the November 2006 flood, while the 2007 – 2011 data are for Years 2 through 6 and summarize hydrometric measurements after the flood (with the new equipment installed). The discharge data are from the salt dilution gauging, and the associated gauge height data (GH) are from the water level loggers readings (stage) with the stage/gauge height offset applied. The gauge height offsets were derived from the level and rod surveys while the stage/staff gauge offsets were the difference between the stage and staff gauge readings. The stage/staff gauge offset readings served as a check for potential problems with stage data or that the sensor had shifted. Further information on stage, discharge, staff gauge readings, and survey data from individual site visits are provided in Appendix A.

We found that there was a fair amount of variance among stage/GH offsets for a given site (Appendix A). This was attributed mainly to the fact that gauge height was dependent on the water surface elevation survey shot, which was a difficult shot for the rod person to position precisely. Best results were obtained when this shot was taken with same rod person at the exact same location each time. Also, in 2007/08, rental equipment were used for surveying and were in very poor condition (e.g., worn off numbers and excessive freeplay in the stadia rod), which undoubtedly introduced some error in the Year 2 readings. The average stage/GH offsets shown in Table 2 were based on what were felt to be the best readings for each site from Appendix A.

The stage/staff gauge offset was a useful tool for checking the accuracy of the stage and survey data. Since the staff gauges were fixed structures, the stage/staff gauge relationship should not change from one visit to the next. If it did change, then this was an indication that there was something wrong with the stage reading or that the probe had shifted. If the stage/staff gauge relationship was consistent with previous visits, but the stage/gauge height relationship changed, then there had to be some error in the survey data. This validation tool proved useful for quality assurance of data as there were periods when the equipment at M1 and M2 gave erroneous readings, generally due to malfunctioning vent tubes (the transducers use the vent tubes to compensate for atmospheric pressure). These problems and their resolution are discussed below.

Table 2. Summary of hydrometric data and station offsets for the Inflow Monitoring Program.

Site	No. of Salt Dilution Q Measurements	Q Range (m^3/s)	Gauge Height Range (m)	Offsets (m)		
				No. of Level & Rod Surveys	Average Stage/GH Offset	Average Stage/Staff Gg Offset
M1 (2006)	3	0.017 - 2.132	0.217 - 0.874	0	0.191	NA
M1 (2007 - 2011)	11	0.042 - 1.273	0.327 - 0.683	8	0.965	1.203
M2 (2006)	3	0.036 - 0.553	0.315 - 0.686	1	0.124	NA
M2 (2007 - 2009)	11	0.029 - 1.008	0.296 - 0.749	8	-0.022	0.064
M2 (new sensor, 2009 - 2011)	0	—	—	1	0.184	-0.157
M3 (2006)	1	0.0003	NA	0	NA	NA
M3 (2007 - 2011)	11	0.0017 - 0.404	1.325 - 1.990	8	0.092	0.984
T1 (2006)	4	0.015 - 0.866	0.570 - 0.872	3	0.186	—
T1 (2007 - 2011)	8	0.010 - 0.385	0.527 - 0.789	6	0.298	—

Notes:

1. 2006 data (Year 1) are from Hudson (2006). The stage/discharge relationships and offsets in Year 1 differed from subsequent years due to channel morphology changes from the Nov. 2006 flood and re-installation of equipment.
2. For M2, the transducer malfunctioned and was once again replaced on Sept. 22, 2009.

Equipment Issues and Their Resolution

During the 6 years of the Inflow Monitoring Program there were various problems experienced with the monitoring equipment. The following summarizes these problems and how they were resolved.

M1— Beginning in May 2009, water level readings at this site sometimes jumped up or down to new levels that were not associated with actual changes in discharge. This behaviour was probably an indication that moisture has gotten into the vent tube and periodically interfered with equalization of atmospheric pressure. There were insufficient funds in the budget to replace this sensor, however, we were able to correct most of the data by applying an adjustment factor based on staff gauge readings taken during site visits (using the stage/staff gauge relationship) and by a regression relationship developed between M1 and M2 discharges. Still, it is acknowledged that there is a degree of uncertainty for data that had to be corrected.

M2— Vent tube issues were also experienced with the sensor at M2 beginning in September 2008. Repeated attempts to fix this problem in subsequent site visits were unsuccessful and so the sensor was replace on September 22, 2009. As with M1, it was possible to salvage some of the data with a correction factor based on staff gauge readings, however this was not possible for all periods.

M3— In May 2009 this site began to have intermittent periods when the logger recorded a negative value for water level. The logger was pulled on June 3, 2009 for troubleshooting and started working properly in the office. Upon reinstallation at M3 it worked properly for 22 days and then experienced the same problem. A call to Onset technical support suggested a faulty “FlexSmart Analog Module.” A new module was purchased and installed on August 22, 2009 and the logger worked perfectly from that point to the end of the program.

T1— The first logger installed at this site was an older Unidata and showed a chronic problem of excessive drawdown on the external battery. If not changed in time, the logger then drained the internal batteries to the point that stored data were lost (the logger was supposed to shut down at 10 volts and use the remaining charge to store the data). This behaviour resulted in some loss of data in 2007 and 2008. A new Unidata logger was installed on June 22, 2009, however, initial reading were unstable (± 0.010 m). This was subsequently identified as a known issue with Unidata’s termination board and corrected on July 14, 2009. Smaller fluctuations still persisted and were corrected to some degree by increasing the warm-up time for sensor excitation. In the end, the logger continued to experience minor fluctuations of ± 0.003 m. To resolve the above issues, data were corrected with a 5-point (75 minute) moving average prior to increasing the warm-up time, and by a 3-point (45 minute) moving average after increasing the warm-up time.

3.2 Rating Curves

Rating curves were developed for each site using stage, average offset, and discharge (Q) data from Appendix A. Gauge heights for curve development (y-coordinates) were derived by adding the average offset for a given site to the individual stage readings for that site. Discharges (x-coordinates) were taken directly from Appendix A. The results of curve fitting on these data points are shown in Figures 3 though 6. Two curves are given for each site: one for the stage/discharge relationship prior to the November 2006 flood (from Hudson 2006) and one for the relationship after the flood (based on 2007 – 2010 data points). The exception to this is the new curve for T1, which was based on data points from Years 1 through 4 (its rating curve did not change after Year 1). The coefficients for the current curves are provided in Table 3.

Table 3. Rating curve coefficients.

Site	**Y-Off**	**a**	**b**	**c**	**GH Asymp**	**Min GH**	**Trans GH**	**Trans Q**	**B_1**	**B_0**
M1	0.244	9.259	0.0024	0.529	9.503	0.300	0.683	1.300	5.604	-2.528
M2	0.000	0.843	0.9764	0.305	0.843	0.220	0.770	1.400	12.728	-8.404
M3	1.000	1.080	3.0267	0.237	2.080	1.300	2.056	0.800	13.547	-27.053
T1	0.284	2.318	0.0009	0.193	2.603	0.337	0.880	1.000	8.709	-6.667

Notes:

1. Y-Offset, a, b, and c are curve fitting parameters for equations 1 and 2.
2. GH Asymptote = a + Offset.
3. Min GH represents the zero flow point and was first estimated graphically, then taken as the Y-offset determined by the curve fitting procedure. If necessary during curve fitting, the zero point was constrained to ≤ the minimum gauge height of the gauging data set.
4. Transition GH is the gauge height at which the rating curve is extrapolated by a linear relationship (equations 3, 4).
5. B1 and B0 are the coefficients of the linear relationship.

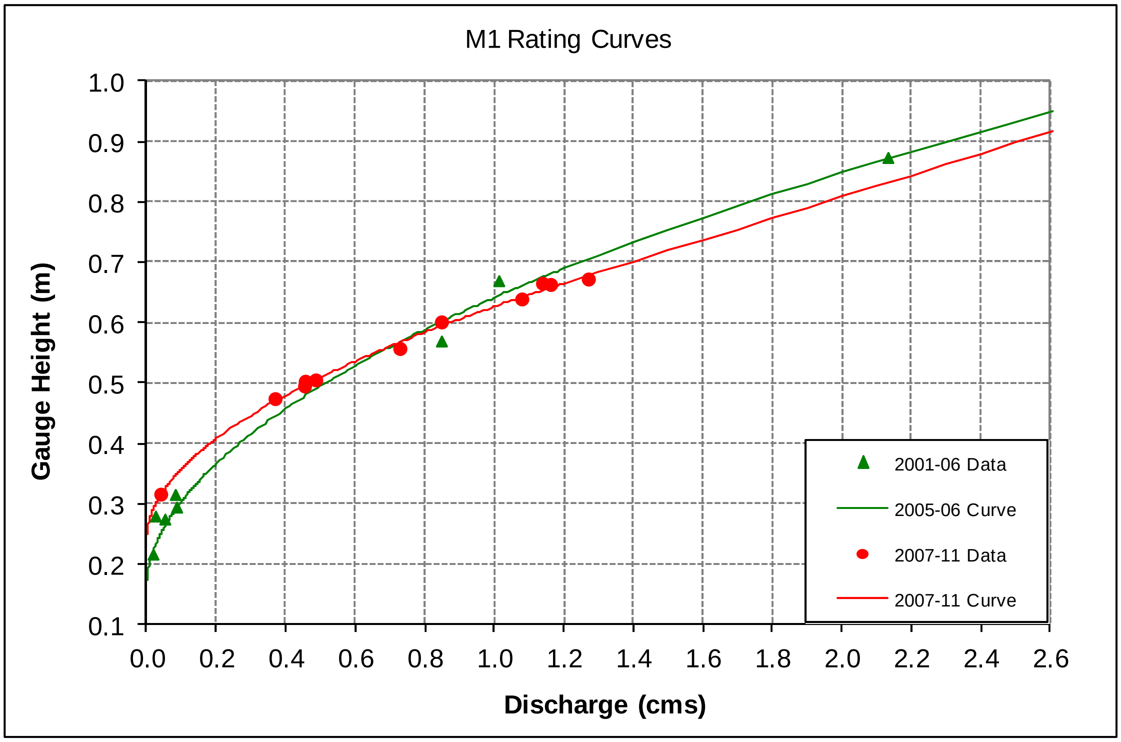


Figure 3. Rating curves for M1 prior to the Nov. 2006 flood (2005-06 curve) and after the flood (2007-10 curve).

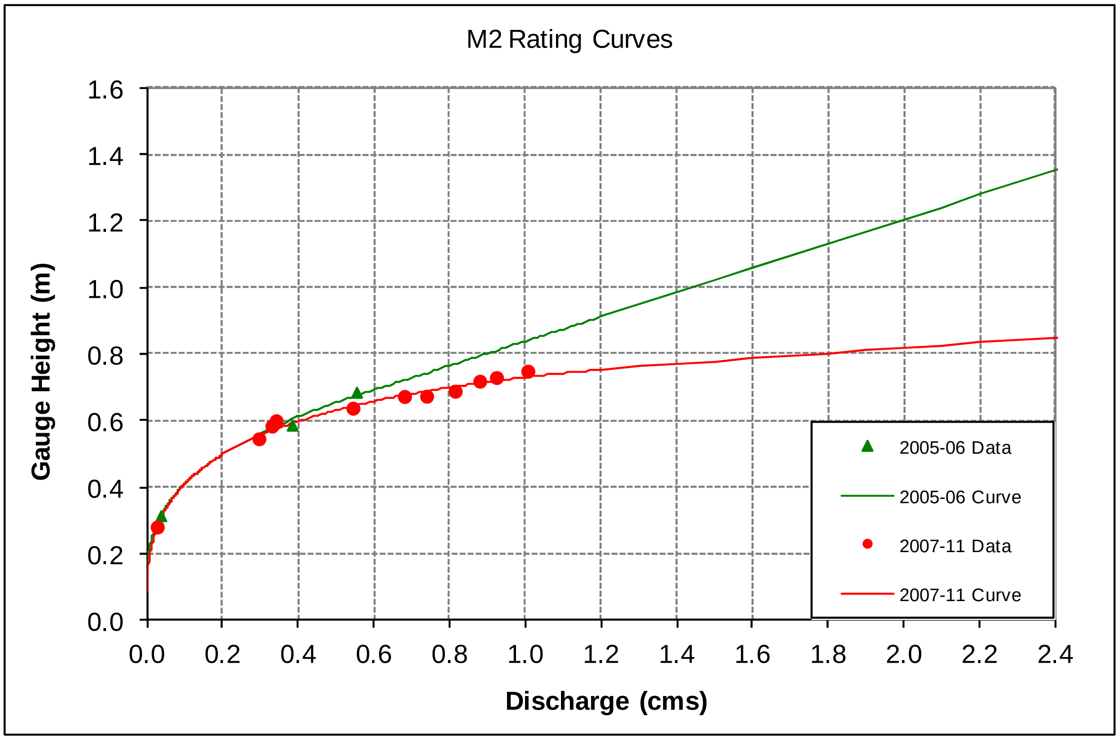


Figure 4. Rating curves for M2 prior to the Nov. 2006 flood (2005-06 curve) and after the flood (2007-10 curve).

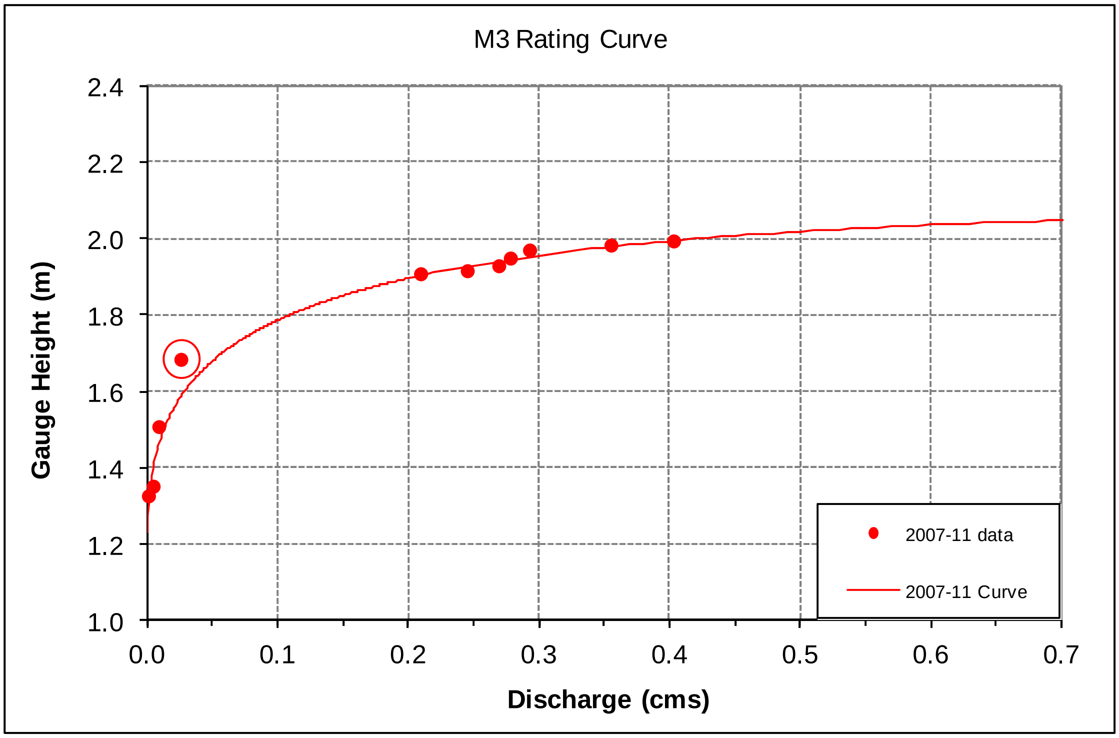


Figure 5. Rating curve for M3 since the Nov. 2006 flood (no curve was generated for M3 in Year 1). Note: the circled value was treated as an outlier and excluded from the curve fitting.

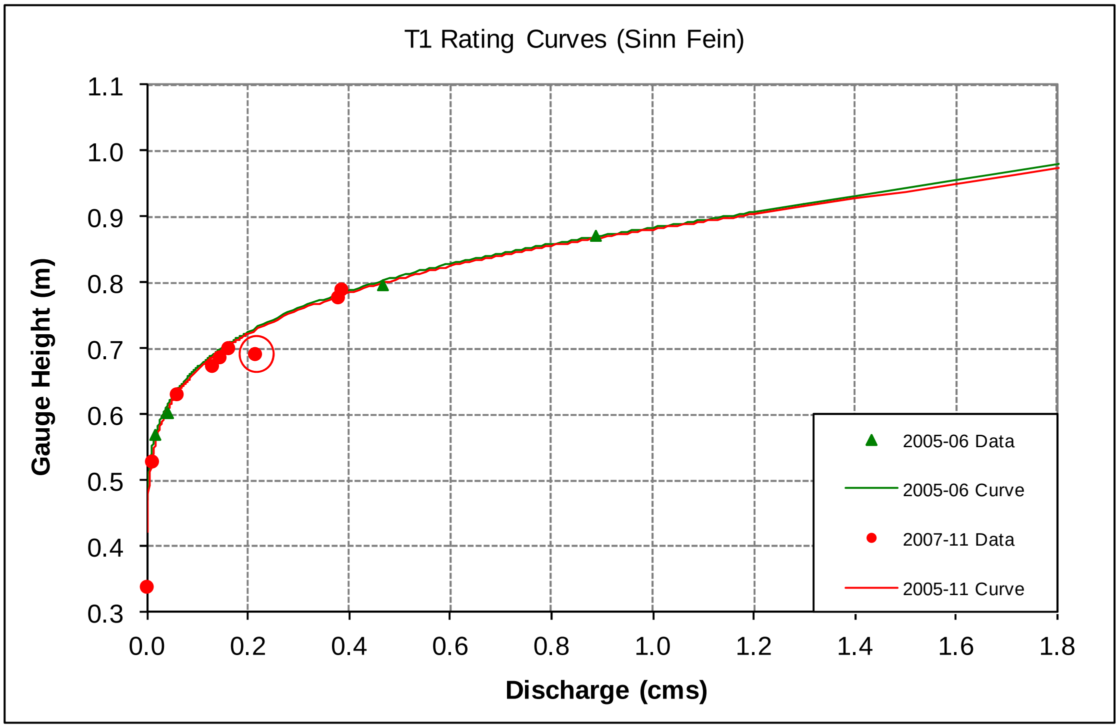


Figure 6. Rating curves for T1 (Sinn Fein) for Year 1 (based on 2005-06 data) and for Year 6 (based on all years of data). Note: the circled value was treated as an outlier and excluded from the curve fitting.

High Flow Curves

The previous section presented rating curves showing the relationship between stage and discharge within the range of empirical data (measured flows and associated stage readings). For flows beyond measured values, previous years used an assumed linear relationship between stage and discharge (Equation 4). However, comparison of these flows with BC Hydro release data indicated substantial underestimation of discharge at high flows. To provide more accurate estimates of discharge beyond the empirical range, high flow rating curves were developed using BC Hydro's release and Total System Inflow (TSI) data (described in Section 2.4). The results of curve fitting on these data are shown in Figures 7 to 9. These curves use the empirical rating curves at lower flows and switch to the modelled rating curves at higher flows. Equations and coefficients for the high flow portions of the rating curves are provided in Table 4.

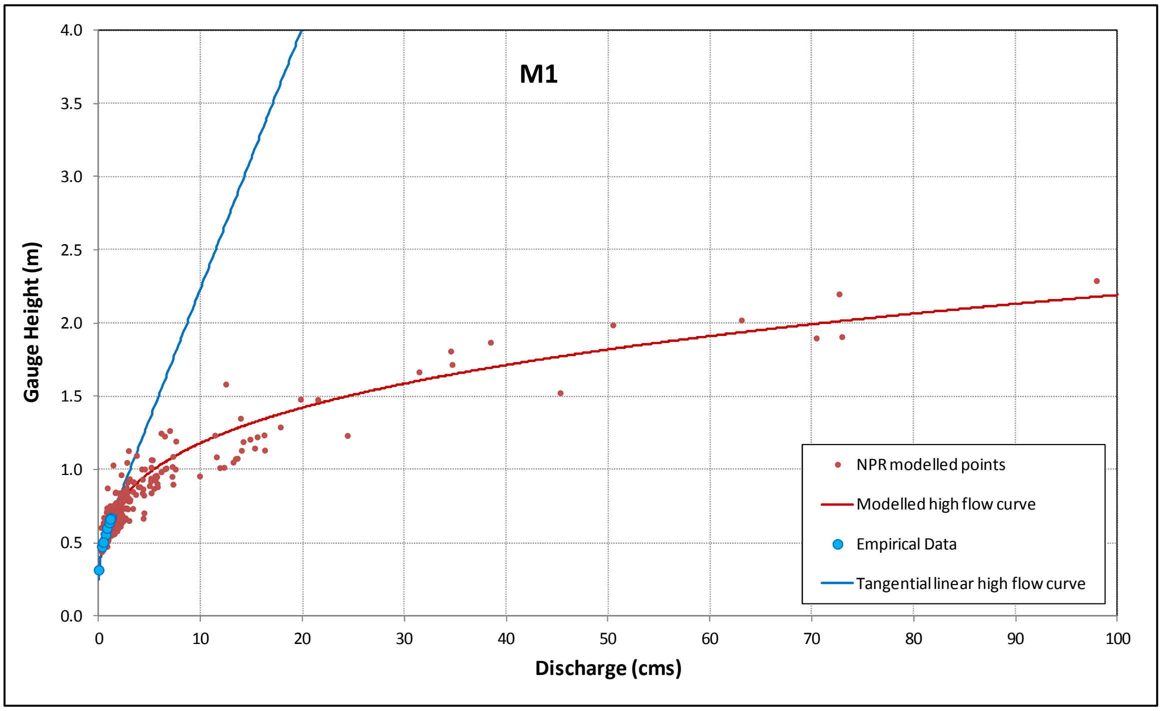


Figure 7. Rating curve at M1 for stage/discharge levels beyond the empirical data. Data points for the curve fitting were based on modelled discharge at M1 and associated gauge heights. Discharges were modelled using BC Hydro non-power releases (NPR) and total system inflows.

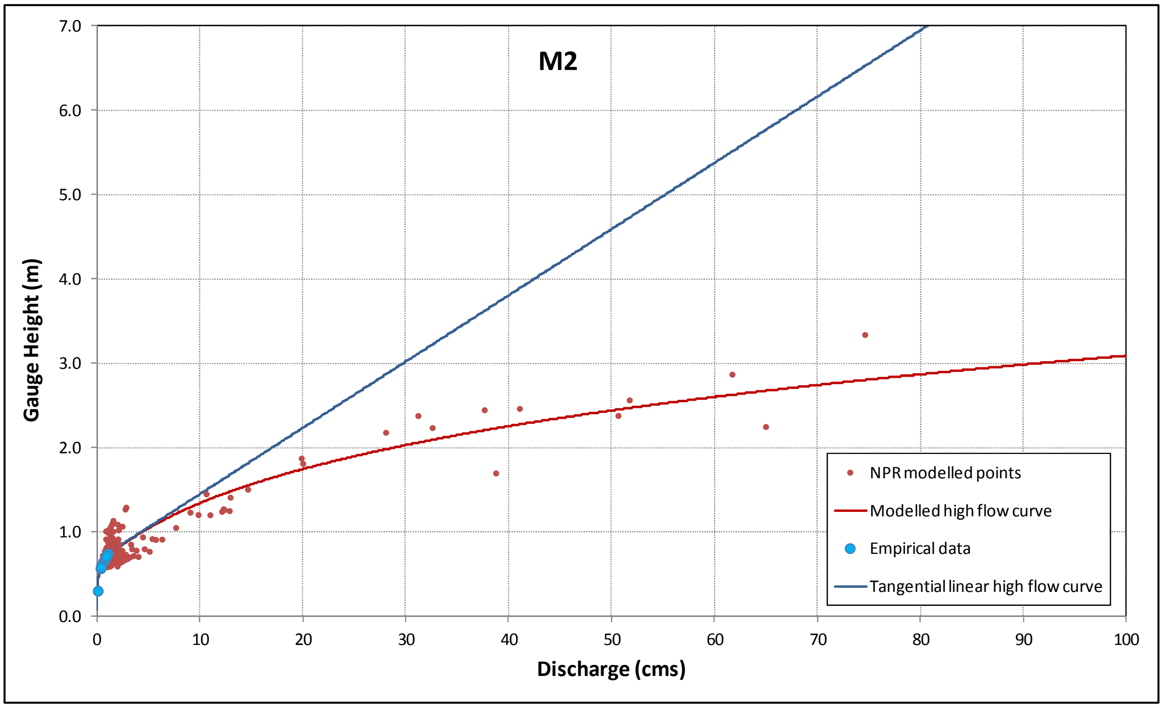


Figure 8. Rating curve at M2 for stage/discharge levels beyond the empirical data. Data points for the curve fitting were based on modelled discharge at M2 and associated gauge heights. Discharges were modelled using BC Hydro non-power releases (NPR) and total system inflows.

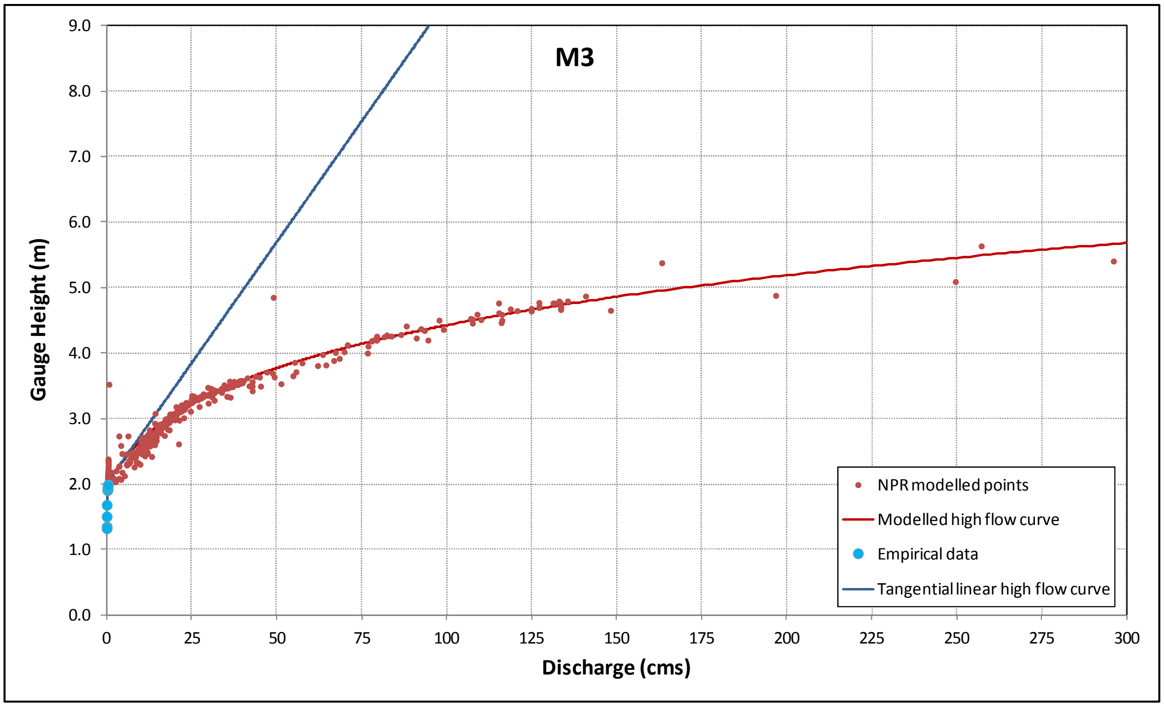


Figure 9. Rating curve at M3 for stage/discharge levels beyond the empirical data. Data points for the curve fitting were based on modelled discharge at M3 and associated gauge heights. Discharges were modelled using BC Hydro non-power releases (NPR).

Table 4. Equations and coefficients for high flow curves.

Site	Equation	a	b	Transition GH	Transition Q
M1	$y=ax^b$	0.635	0.269	0.683	1.30
M2	$y=a+b(\ln x)^2$	0.756	0.110	0.770	1.40
M3	$y=a+b(\ln x)^2$	2.070	0.111	2.366	5.00

Notes:

1. Transition GH and Q are the values at which the above equations become active in the water level database. Below these values the empirical curves were used.
2. y = gauge height (GH), x = discharge (Q).

3.3 Year 5 Hydrographs

The above rating curves were used to calculate the discharge time-series for each gauging site, i.e., using equation 2 for gauge heights below the transition GH and the equations in Table 4 for values greater than the transition GH. Figures 10 to 15 illustrate mean daily discharge at mainstem sites for 2006 to 2011. Figure 16 shows mean daily discharge at T1 (Sinn Fein) with all 6 years on the same chart. Each day's average is based on 96 daily readings (1 every 15 minutes). The y-axis is drawn on a logarithmic scale to provide resolution of discharge during low flow periods. The 15-minute readings (water level and associated discharge) and mean daily values used to construct these graphs can be found in the CD accompanying this report (file: "Water Level Database_2007-2011.xlsx").

Periods without flow data in 2006 and 2007 were due to the loss of all mainstem equipment during the November 2006 flood (Figures 10 and 11). Missing data during 2008 and 2009 were due to logger malfunction (all loggers experienced periods of failure in 2008 or in 2009). Initiation of the fish flow release from Elliott Dam occurred on January 16, 2008 and is shown by the reference arrow in Figure 12. There was temporary loss of the fish release flow from January 18 to 30, 2008 due to problems with the automatic mechanism involved in maintaining the release at 0.25 m^3/s. To avoid possible future failures of the automatic mechanism, the fish flow valve was subsequently locked in the full open position (Dwayne Walsh, Jordan Generating Station, pers. comm.).

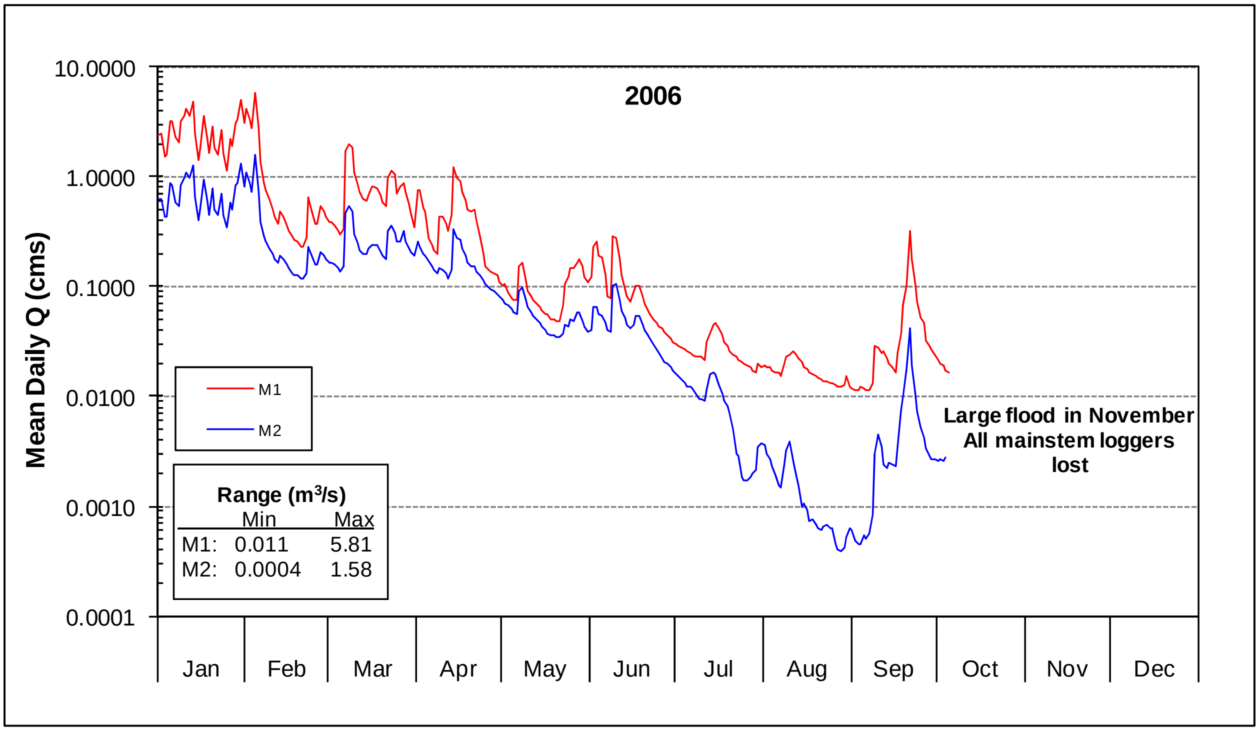


Figure 10. Hydrograph of mean daily flows at mainstem sites (M1 and M2) in 2006 (source: Excel file from Rob Hudson). A logarithmic scale was used for the y-axis to provide resolution of low flow periods. M3 was not gauged in 2006.

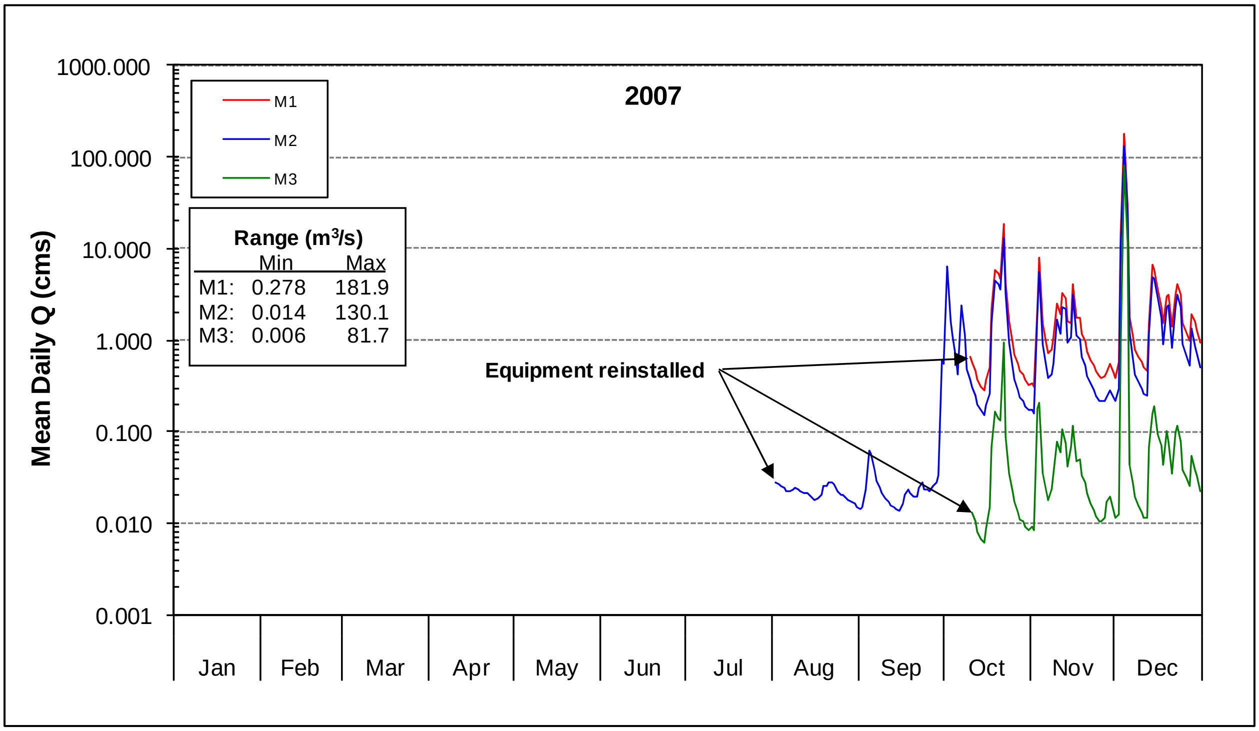


Figure 11. Hydrograph of mean daily flows at mainstem sites in 2007. A logarithmic scale was used for the y-axis to provide resolution of low flow periods.

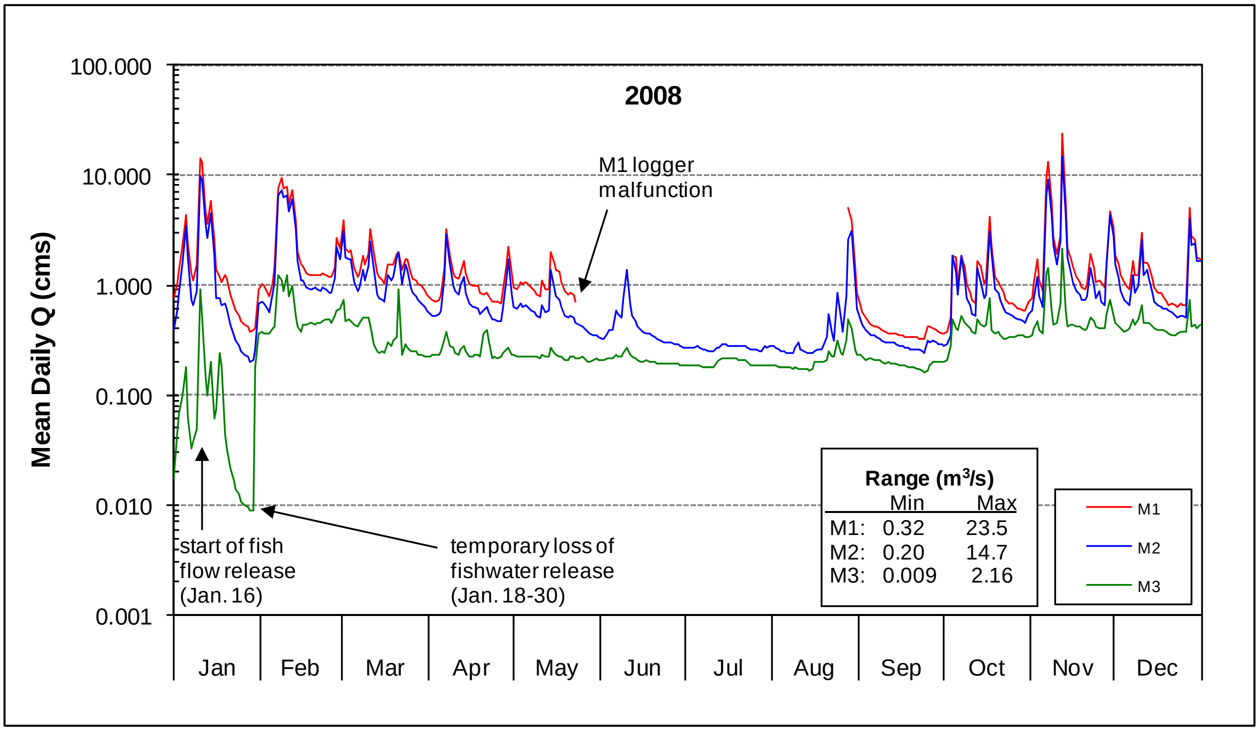


Figure 12. Hydrograph of mean daily flows at mainstem sites in 2008. A logarithmic scale was used for the y-axis to provide resolution of low flow periods.

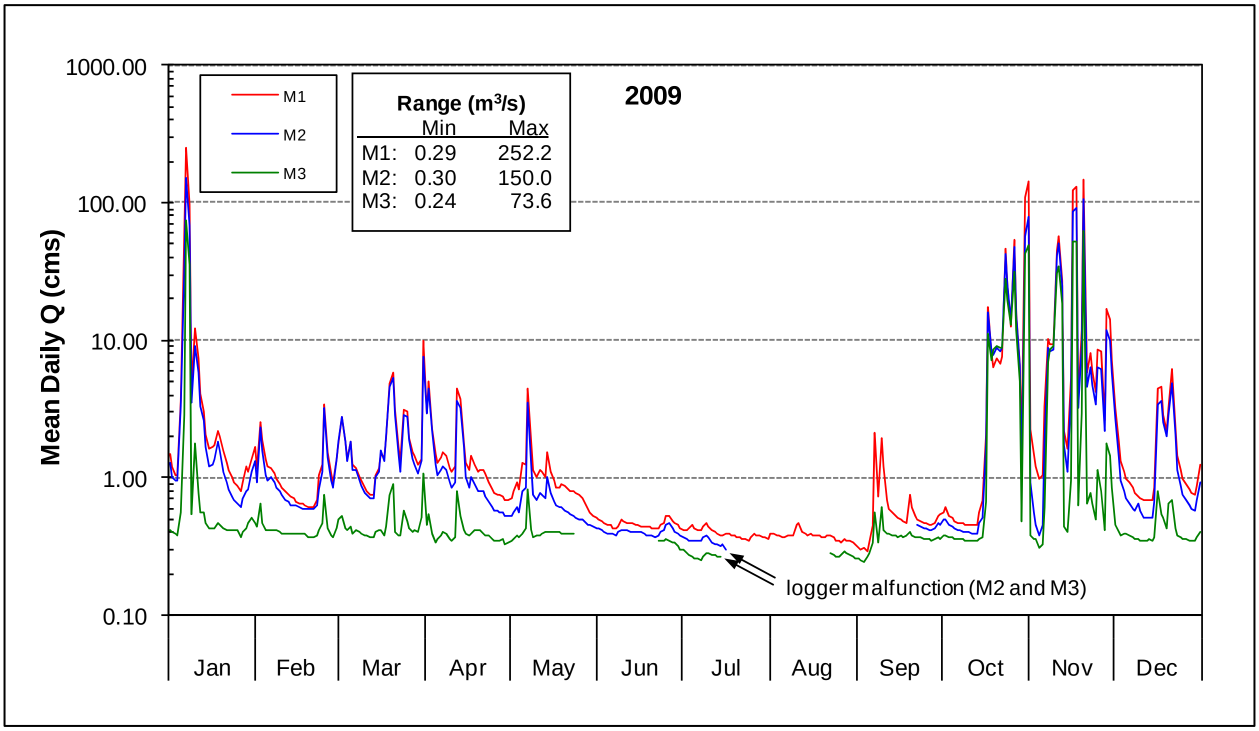


Figure 13. Hydrograph of mean daily flows at mainstem sites in 2009. A logarithmic scale was used for the y-axis to provide resolution of low flow periods.

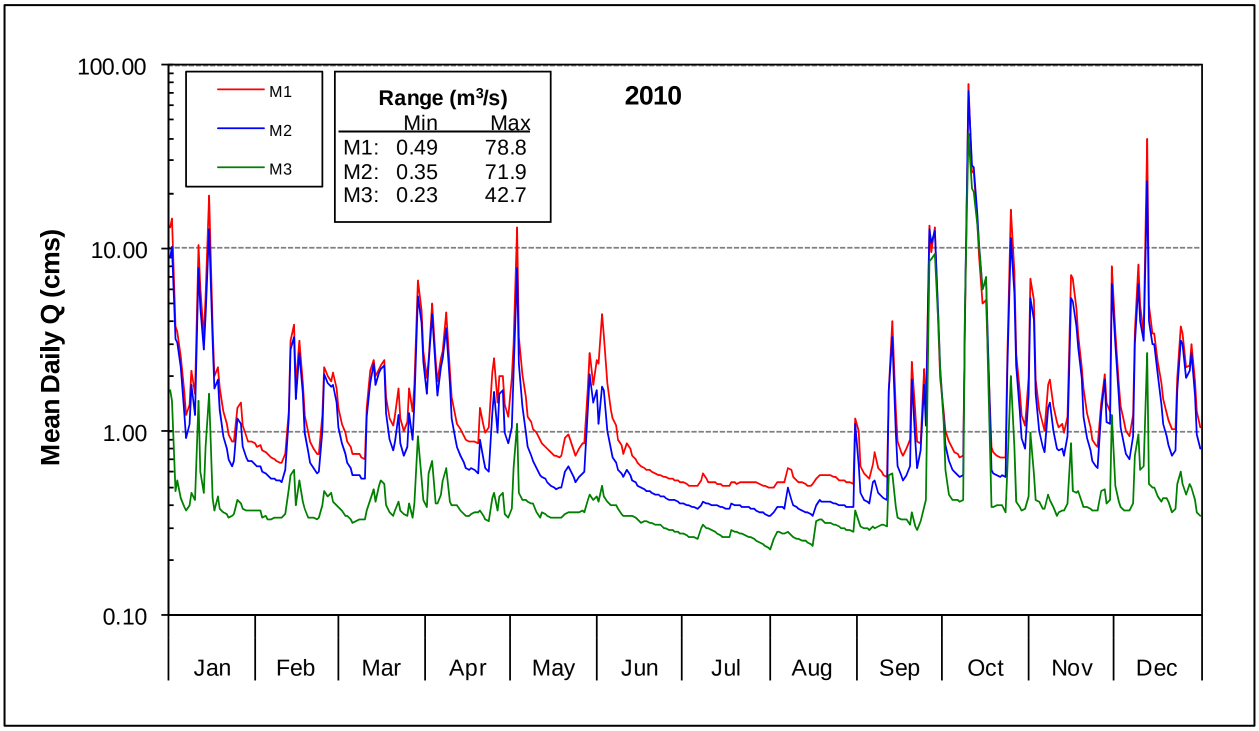


Figure 14. Hydrograph of mean daily flows at mainstem sites in 2010. A logarithmic scale was used for the y-axis to provide resolution of low flow periods.

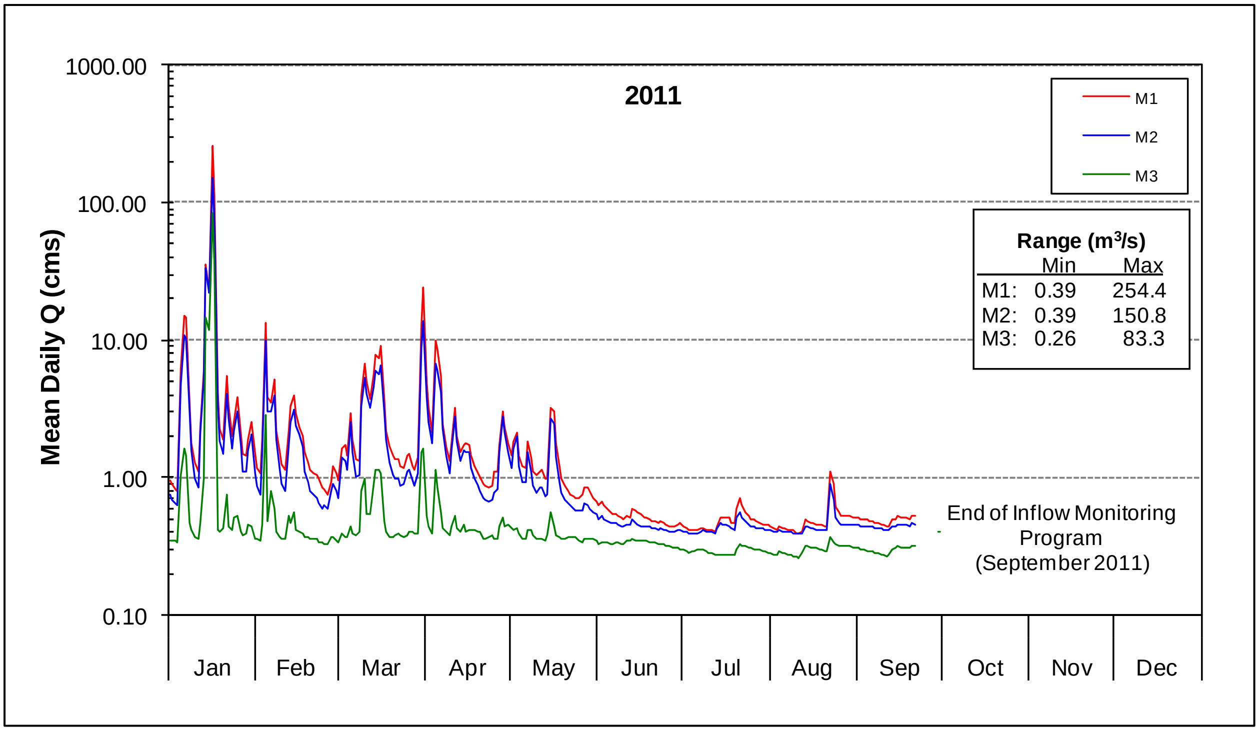


Figure 15. Hydrograph of mean daily flows at mainstem sites in 2011. A logarithmic scale was used for the y-axis to provide resolution of low flow periods.

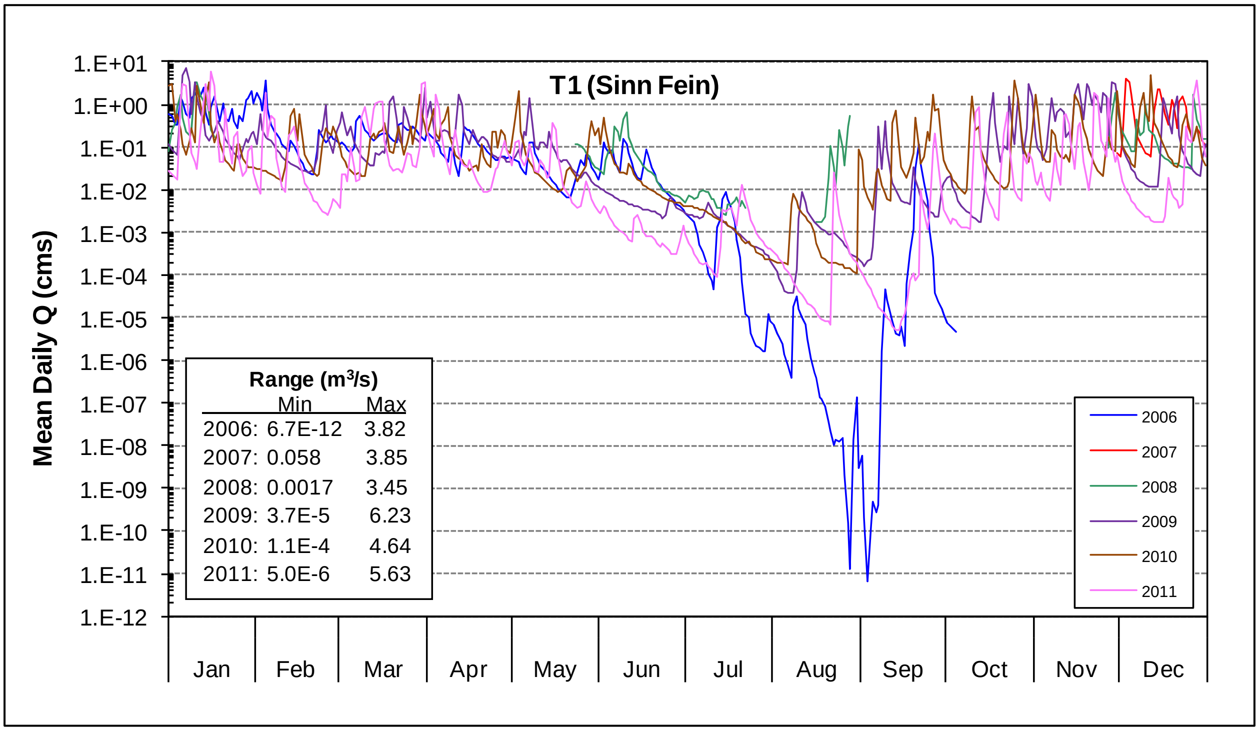


Figure 16. Mean daily flows at Sinn Fein gauging station (T1) for 2006 to 2011. A logarithmic scale was used for the y-axis to provide resolution of low flow periods.

3.4 Groundwater Losses

Potential loss of instream flow to groundwater conveyances was assessed using methods described in Hudson (2006). This involved comparing measured water yield at each mainstem gauging station with estimated water yield for that station based on the next upstream station. For example, water yield at M1 can be estimated by taking measured flows from M2 and adding in flows from Sinn Fein Creek (T1), Winkler Creek (T1.5), and the residual mainstem catchment area between M2 and M1 (M1 residual). If the measured water yield for M1 is less than the estimated amount, then there may be loss of flow between M2 and M1, whereas if the measured value is greater than the estimated value, there may be flow gain between the 2 sites. In this example, water yields for Winkler Creek and the residual area between M2 and M1 are not gauged and were estimated using nearby gauging stations and catchment area ratios (T1 was used as the reference gauge for Winkler Creek and M1 as the reference gauge for M1 residual). This exercise assumes that water yield/km^2 for the ungauged sub-basins are similar to the gauged (reference) sub-basins. Since this is not necessarily true, there is a degree of uncertainty in the assessment of flow gains/losses.

The results of this exercise are shown in Table 5. The assessment examined potential losses or gains in discharge for 4 different low flow time periods (A, B, C, and D) and for 3 different channel sections: between M2 and M1, between M3 and M2, and between Elliott Dam and M3. In the first case (channel between M2 and M1), the results suggest that there were flow gains for all 4 time periods amounting to 0.02 – 0.09 m^3/s or 5 – 19% of estimated flows. For the channel section between M3 and M2, flow losses are suggested with amounts ranging from 0.15 – 0.17 m^3/s or 27 – 32% of estimated flows. For the channel section between Elliott Dam and M3, flow losses were also indicated with amounts ranging from 0.03 – 0.05 m^3/s or 9 – 15% of estimated flows.

Table 5. Estimation of flow gains/losses between successive gauging station on the lower Jordan River.

Estimation of Flow Gains or Losses Between M2 and M1

	Areas	Total Discharge (dam^3) by Period			
	(km^2)	A) Jul 1-14, 2009	B) Jun 11-30, 2010	C) Jul 1-31, 2010	D) Aug 1-30, 2010
M1 residual*	1.968	60	95	163	165
Sinn Fein (T1)	3.404	3.25	11.06	4.76	3.08
Winkler (T1.5)*	1.916	1.83	6.22	2.68	1.74
M2	9.582	423	622	1,039	1,016
M1 Estimated		487	735	1,209	1,185
M1 Measured	16.870	511	812	1,398	1,413
Gain or loss of flow		23	78	189	228
Mean gain or loss (m^3/s)		0.02	0.06	0.07	0.09
Percent gain or loss		5%	11%	16%	19%

Estimation of Flow Gains or Losses Between M3 and M2

	Areas	Total Discharge (dam^3) by Period			
	(km^2)	A) Jul 1-14, 2009	B) Jun 11-30, 2010	C) Jul 1-31, 2010	D) Aug 1-30, 2010
Sinn Fein (T1)	3.404	3.25	11.06	4.76	1.57
M2 residual*	6.545	289	425	709	659
T2*	1.242	1.19	4.03	1.74	0.57
Nuala (T2.5)*	1.512	1.44	4.91	2.11	0.70
M3	0.283	328	423	728	735
M2 Estimated		619	857	1,441	1,431
M2 Measured	9.582	423	622	1,039	1,016
Gain or loss of flow		-196	-234	-403	-416
Mean gain or loss (m^3/s)		-0.16	-0.17	-0.15	-0.16
Percent gain or loss		-32%	-27%	-28%	-29%

Estimation of Flow Gains or Losses Between Elliott Dam and M3

	Areas (km^2)	Total Discharge (dam^3) by Period			
		A) Jul 1-14, 2009	B) Jun 11-30, 2010	C) Jul 1-31, 2010	D) Aug 1-30, 2010
Elliott Dam releases		364	464	858	860
M3 Measured	0.283	328	423	728	735
Gain or loss of flow		-36	-42	-130	-125
Mean gain or loss (m^3/s)		-0.03	-0.03	-0.05	-0.05
Percent gain or loss		-10%	-9%	-15%	-15%

Notes:

1. Areas are based on digitized polygons on 1:20,000 TRIM maps in ArcView (see project map). For M1 I closed the catchment area at the M1 gauging site, not at the generating station as done by Rob Hudson in the Year 1 report and BC Hydro in their modelling. This results in exclusion of an area amounting to 0.641 km^2 which includes a small creek flowing into the large pool immediately downstream of the mine tailings.
2. Total discharges for catchment areas marked with an asterisk were estimated from gauged stations as follows:

M1 residual:	based on M1 discharge and M1resid/M1 area ratio (0.117)
Winkler (T1.5):	based on T1 discharge and Winkler/T1 area ratio (0.563)
M2 residual:	based on M2 discharge and M2resid/M2 area ratio (0.683)
T2:	based on T1 discharge and T2/T1 area ratio (0.365)
Nuala (T2.5):	based on T1 discharge and Nuala/T1 area ratio (0.444)

3. Elliott Dam releases were based on readings from the flow gauge within the release pipe. For July 1-14, 2009, release pipe flows were estimated using a regression relationship developed between pipe gauge flows and BC Hydro's non-power release database which uses reservoir elevation and inflow data to estimate releases at Elliott Dam (Equation: $Q_{gauge} = 0.790 \times Q_{NPR} + 0.034$, $R^2 = 0.965$). Flows from the non-power release database could not be used as they consistently overestimate discharge at low flows.

3.5 Comparison of Modelled and Measured Flows

The goals of the modelled/measured flow comparison were to a) assess the accuracy of the flows modelled for the Jordan WUP (whether they overestimated or underestimated actual flows) and b) to derive a "correction factor" that could be applied to modelled flows to provide a closer match with actual flows. The period of most relevance was summer base flow, in particular, August, as this was the period indicated in the Jordan WUP to have the lowest flow, and which was used to model available rearing habitat. Thus, for our comparative analysis of modelled and measured flows we focused on the June to September period. The other reason for restricting analysis to this time period is that the rating curves developed by the Inflow Monitoring Program were based on data points collected at lower flows ($\leq 1.3\ m^3/s$ at M1) and were not validated for higher flows.

The approach used to compare modelled and measured flows was outlined in the Methods (Section 2.5) and involved the following:

1. Use of total system inflows (TSI's) to model discharge for station M1 for the pre flow release years of the Inflow Monitoring Program.

2. Regression of measured flows on the above modelled flows to develop an equation that corrects the modelled data to better match measured values.

3. Use of the TSI's and regression correction factor to generate a dataset of "best estimate" lower Jordan River flows for the available period of record.

4. Calculation of mean monthly discharges from the "best estimate" dataset and comparison of these with mean monthly flows from the WUP dataset.

For the generation of modelled data for M1 (Step 1), we used quality assured (QA'd) total system inflows (TSI's) from BC Hydro's CRO database, and drainage area ratio to model flows at M1 (Equation 7). For the regression analysis (Step 2), our only measured data in the June to September period prior to the flow release was in 2006 (M1 malfunctioned in summer 2007 and flows release started in January 2008). Thus, these data (June to September 2006) and TSI modelled data for the same time period were used in this analysis. Mean daily flows from each dataset were paired and measured flows regressed on modeled flows. The results of this regression are shown in Figure 17. Note that there was a lot of noise in the TSI data and it was necessary to remove outliers (circled data points) in order to achieve a reasonable fit.

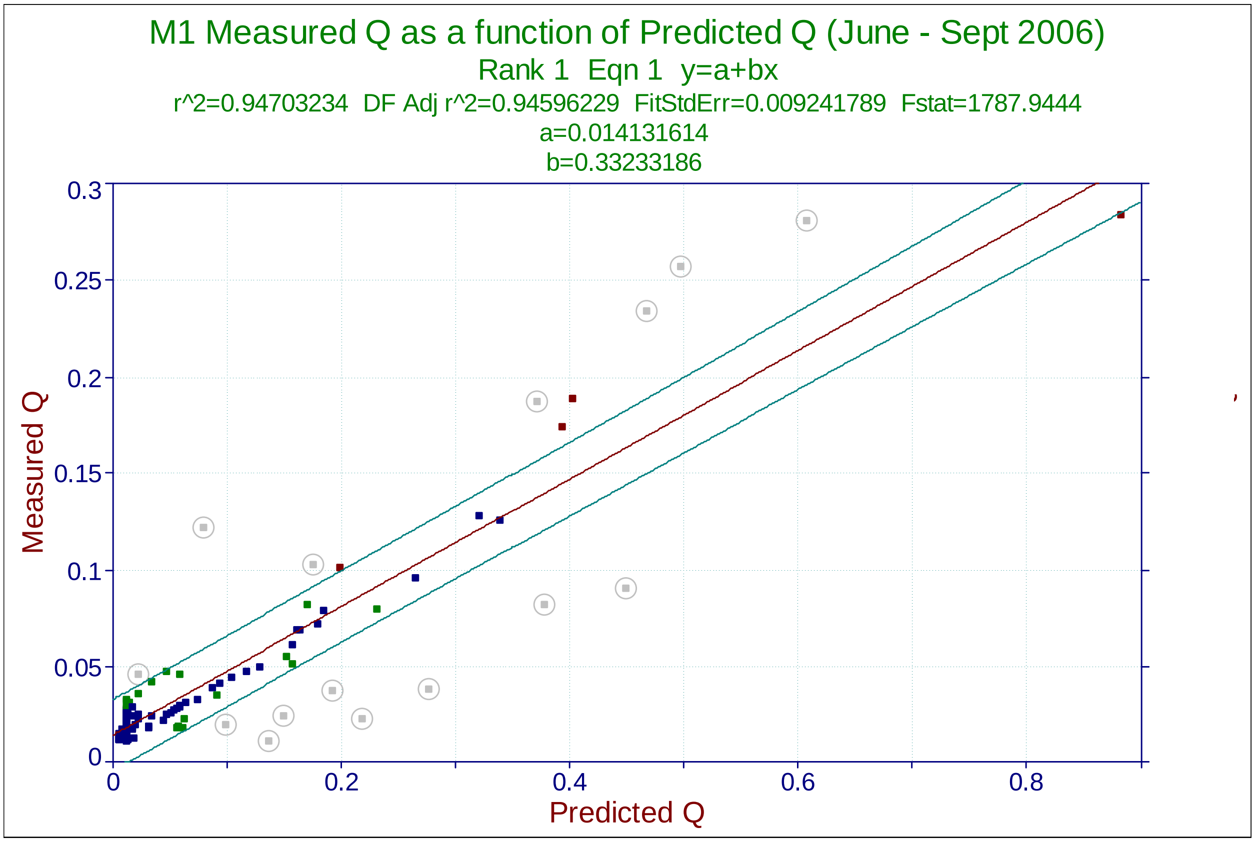


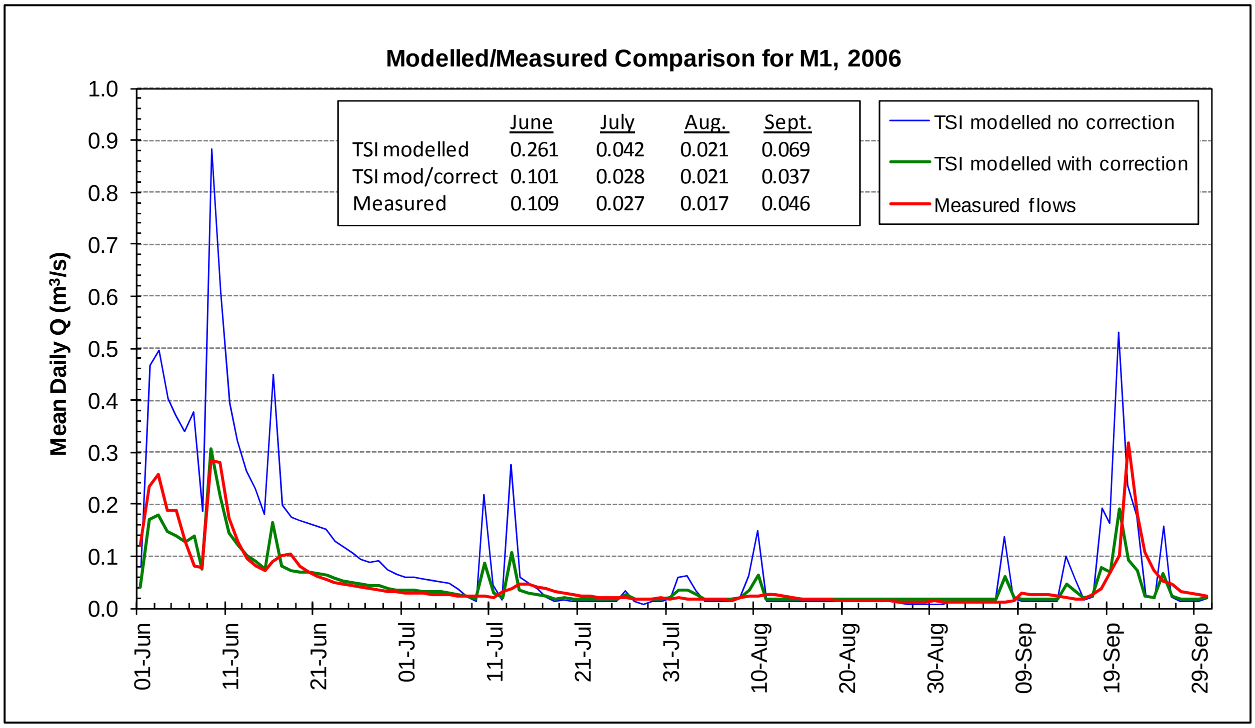
Figure 17. Regression of measured discharge at M1 on TSI modelled discharge at M1 using mean daily flows for June to September, 2006. Curve fitting was with TableCurve 2D; outliers were removed (grey circled points).

The best fit was a simple linear relationship which indicated the following equation for correcting the TSI modelled flows to yield "best estimate" flows:

$$Q_{best\_est} = a + b \times Q_{TSI\_mod} \qquad \textbf{(8)}$$

Where: Q_{best_est} = *Corrected modelled discharge at M1 ("best estimate") (m*^{3}*/s)*
Q_{TSI_mod} = *TSI modelled discharge for M1 from Equation 7*
a = *curve fitting parameter for the y intercept (0.0141)*
b = *curve fitting parameter (0.3323)*

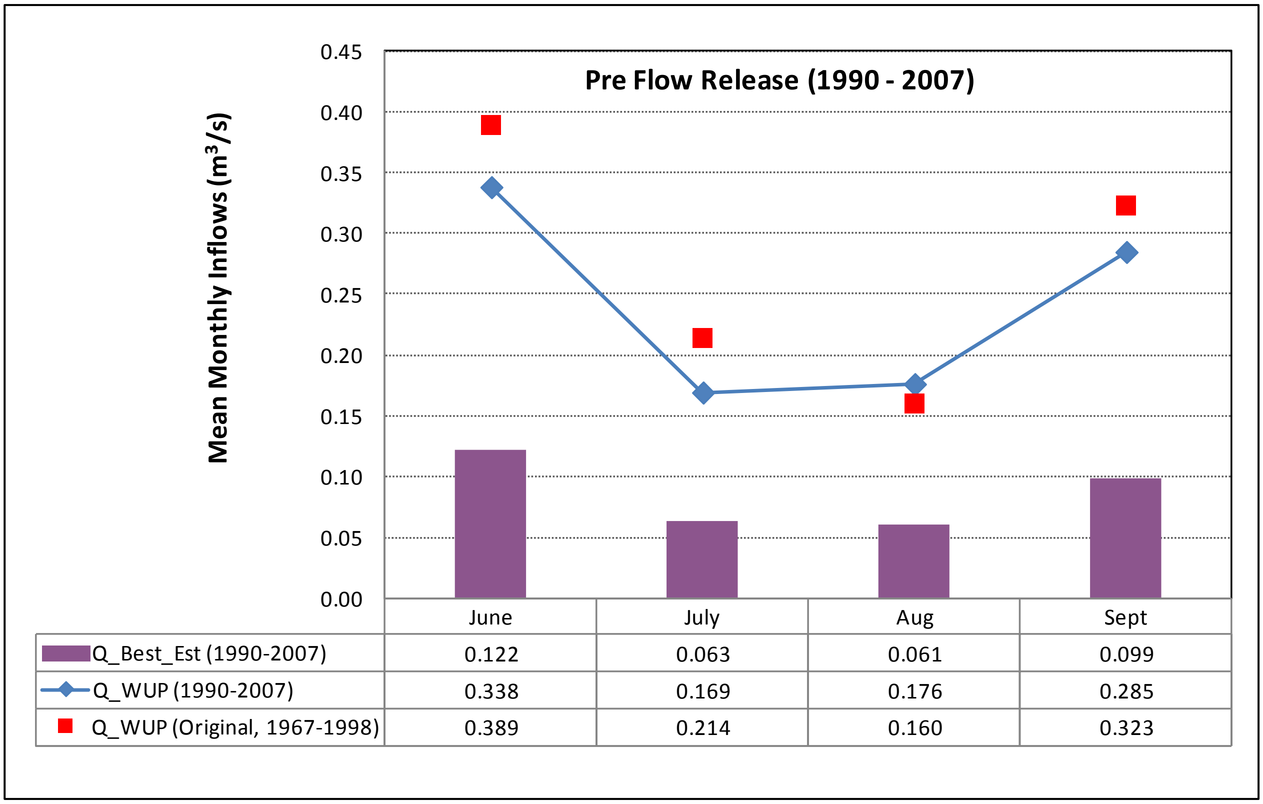
The accuracy of the TSI corrected or "best estimate" flows in relation to measured values are shown in Figure 18. The comparison shows that corrected values track measured values fairly well during periods of stable or slowly changing flows, but slightly underestimated measured values during flow spikes in June and September. Some of the smaller corrected value flow spikes in midsummer show as abrupt ups and downs whereas inriver flows were less pronounced in amplitude but more prolonged in duration. Mean monthly values for these flows (text box in Figure 18) indicated that when the data are averaged, that monthly corrected values are relatively close to measured values. The chart also shows the modelled flows prior to correction. These flows would typically be used by BC Hydro to model discharge in the lower river – Figure 18 shows that this results in substantial overestimation of actual flows at discharges > 0.04 m^3/s.



	June	July	Aug.	Sept.
TSI modelled	0.261	0.042	0.021	0.069
TSI mod/correct	0.101	0.028	0.021	0.037
Measured	0.109	0.027	0.017	0.046

Figure 18. Comparison of mean daily TSI modelled/corrected flows ("best estimate flows") relative to measured values for June to September 2006. The text box shows mean monthly values for 2006.

The next step in the analysis (Step 3) was to apply the correction factor (Equation 8) to TSI modelled flows for M1 for the available period of record. In the WUP analysis, the period of record was 1967 to 1998 (32 years). However, for our assessment, the TSI dataset from BC Hydro only covered the period from 1990 to present, and thus only overlapped the WUP dataset in the last 9 years (1990 – 1998). To expand the period of record beyond 9 years, we extended the WUP dataset to 2007 using TSI modelled flows with replacement of any values < 0.072 m^3/s with the WUP default value of 0.072 m^3/s (as was done in the original WUP data). This gave us a period of record of 1990 to 2007 (18 years) ending in the last year prior to initiation of the flow release. The results of this analysis are shown in Figure 19. The intent was to compare our best estimate of actual mean flows for June to September (i.e., modelled/corrected flows) with WUP flows for the same time period (1990–2007). These results suggest that the "best estimate" of actual mean August flow in the lower Jordan River prior to the flow release was approximately 0.061 m^3/s as opposed to 0.176 m^3/s predicted by the WUP approach for the same time period (an overestimation of 0.115 m^3/s or 289%). It is important to note that in some years, mean August flows can be substantially less than our estimated long-term mean, an example being 2006 when measured inflows averaged 0.017 m^3/s (Figure 18).



	June	July	Aug	Sept
🟪 Q_Best_Est (1990-2007)	0.122	0.063	0.061	0.099
◆ Q_WUP (1990-2007)	0.338	0.169	0.176	0.285
🟥 Q_WUP (Original, 1967-1998)	0.389	0.214	0.160	0.323

Figure 19. Comparison of mean monthly inflows at M1 for June to September based on the period of record 1990 to 2007. The chart shows a) TSI modelled and corrected (best estimate) flows, b) WUP based flows for the same time period, and c) WUP flows from the original period of record (1967–1998).

4. DISCUSSION

Rating Curve Confidence

Confidence in the rating curves produced by the Inflow Monitoring Program is related to the number of stage/discharge data points per site and the spread of these points around the fitted line. The collection of discharge and associated stage data were undertaken in the first 4 years of the study (2005/06 to 2009). One setback was from the winter 2006/07 floods, which necessitated redevelopment of all rating curves except T1, and thus starting over with the collection of stage/discharge data points. By the end of Year 4 there were 11 data points to define the curves at M1, M2 and T1, and 10 points to define the curve at M3 (1 point was discarded as an outlier). While it would have been helpful to have greater number of data points to improve curve confidence limits, and extend the range of flows covered by the fitted line, budget constraints prevented collection of additional data. The resultant 95% confidence limits for the rating curves are shown by the bounding lines in Figures 20 to 23. These lines are the 95% prediction limits and represent the 95% confidence interval around new values calculated by the curve fit equations. The charts also show the goodness of fit statistics (r^2, fit standard error, and F statistic). All fitted lines had a high r^2 value and were significant ($p < 0.01$).

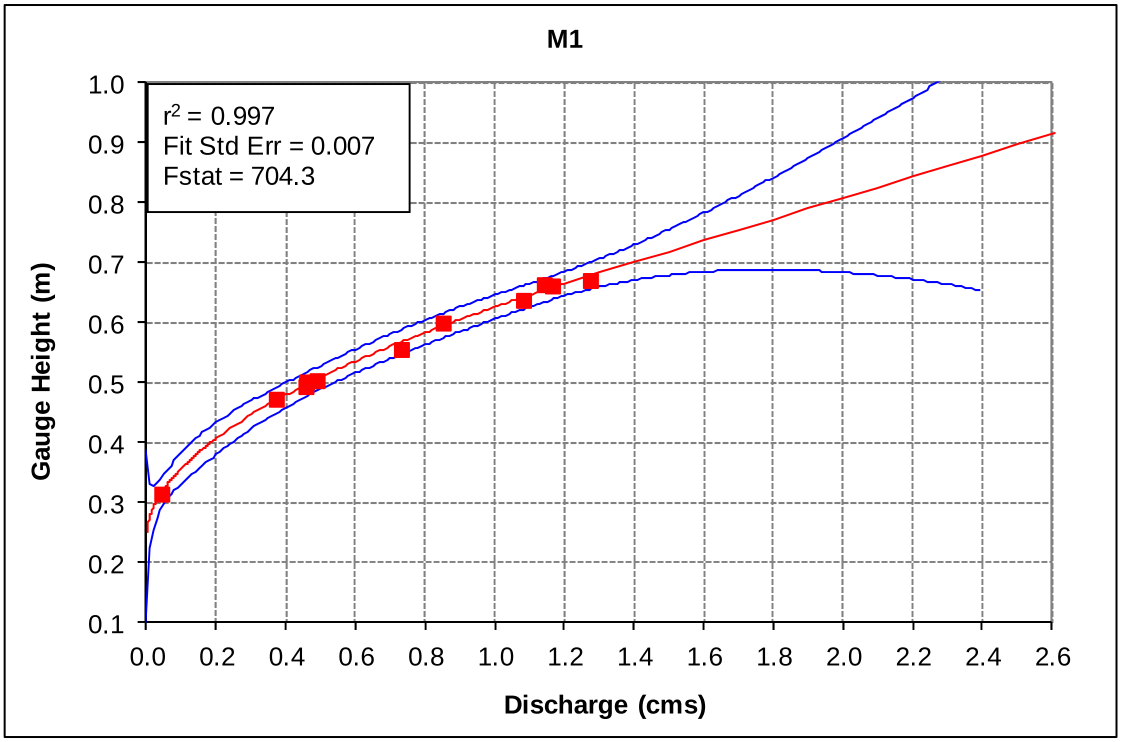


Figure 20. Rating curve for M1 with 95% prediction limits and goodness of fit statistics.

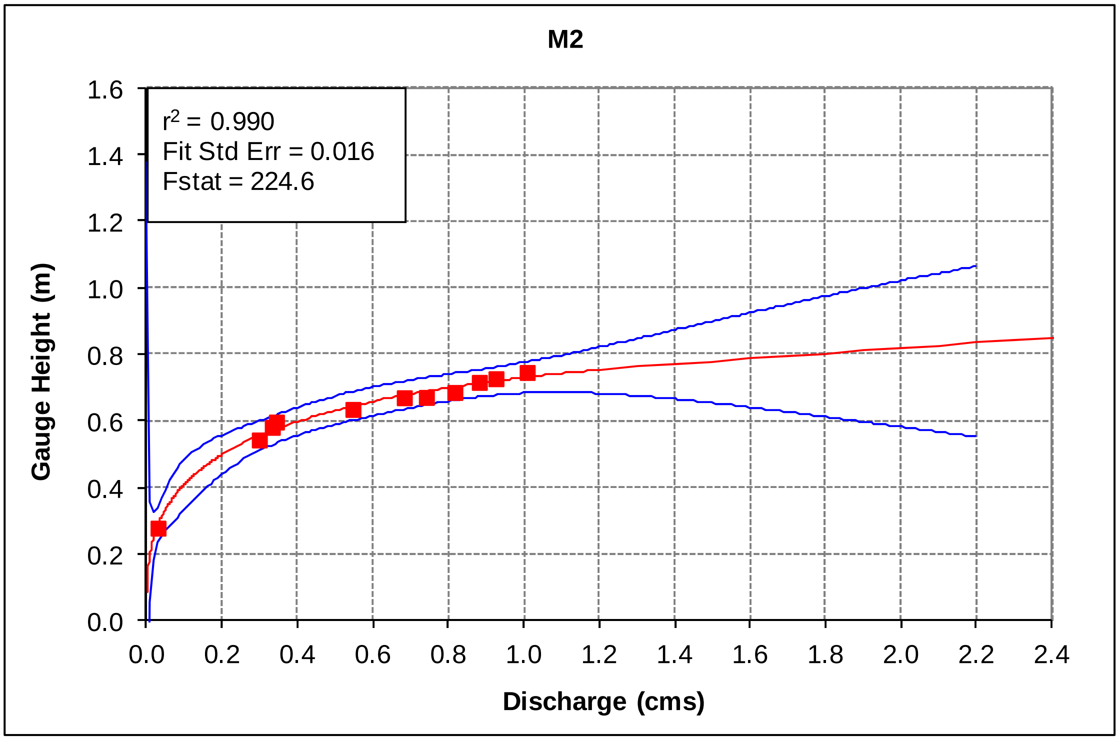


Figure 21. Rating curve for M2 with 95% prediction limits and goodness of fit statistics.

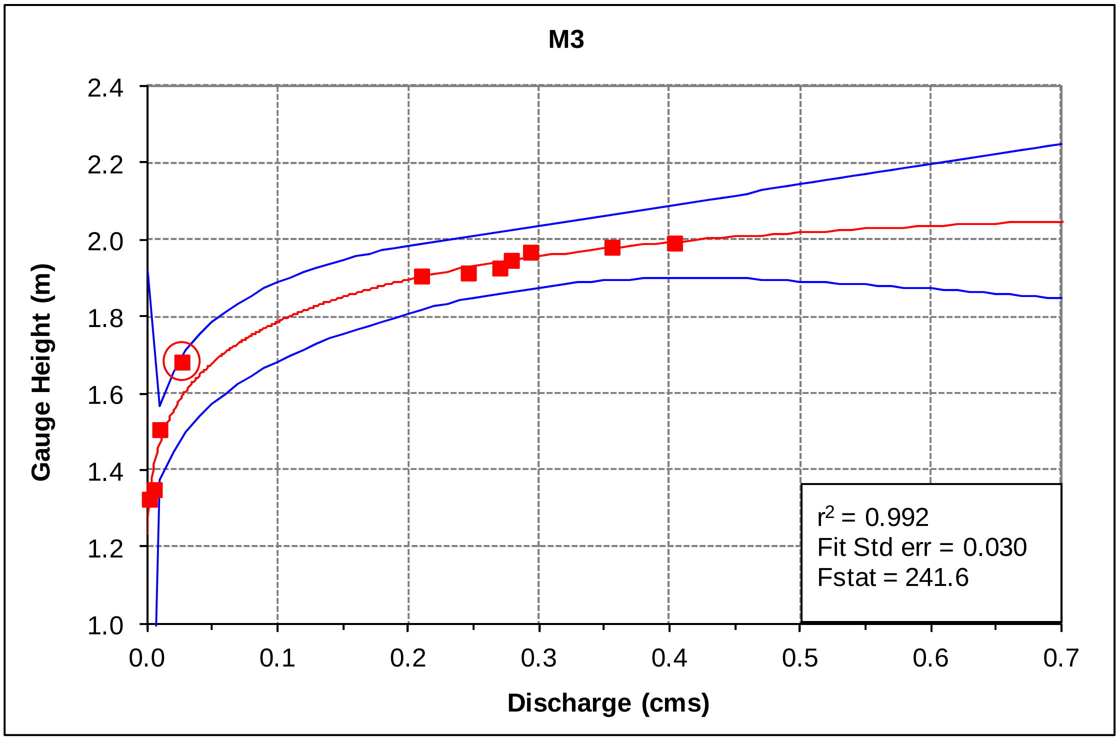


Figure 22. Rating curve for M3 with 95% prediction limits and goodness of fit statistics.

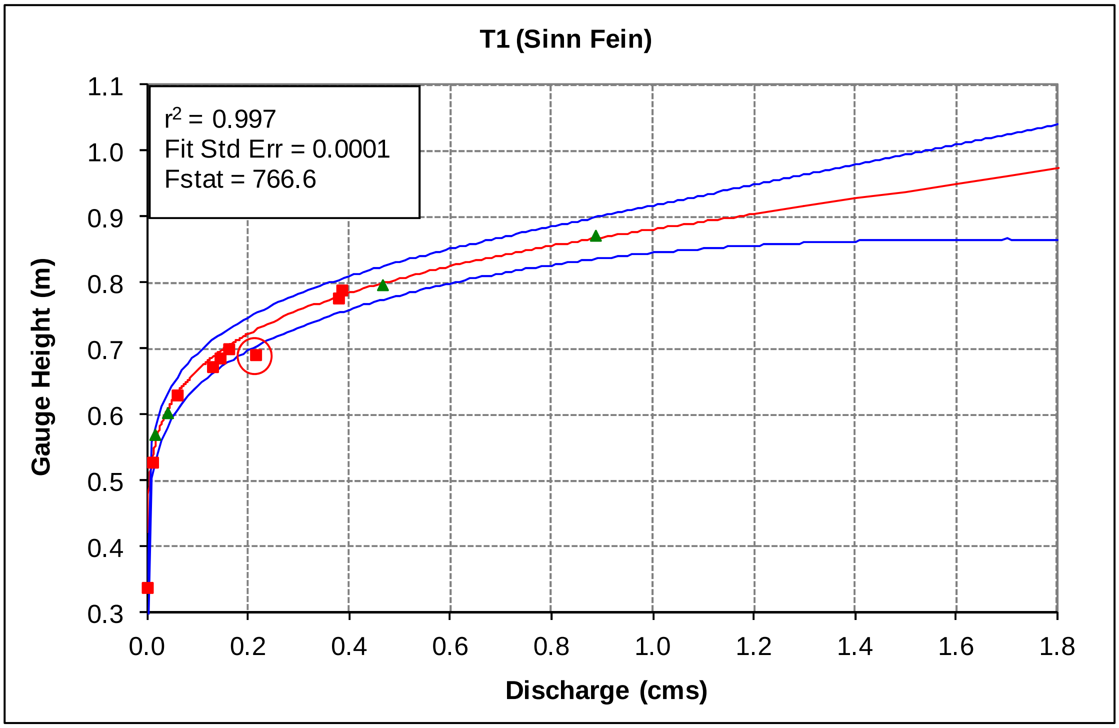


Figure 23. Rating curve for T1 with 95% prediction limits and goodness of fit statistics.

As indicated by the prediction limits in Figures 20 to 23, the main weakness in the rating curves is when predicting values beyond the highest data point. After this point the prediction limits expand outwards and the curves transition from an exponential relationship (Equation 2) to a linear one (Equation 4). Currently, there are no data points at high discharges to determine whether the inflection points are accurate, however, comparisons with modelled flows using BC Hydro's total system inflows (TSI's) indicated that the linear extrapolations highly underestimated high flows (due to the point of inflection being set too low as shown in Figures 7 to 9). For this reason, the flow database used TSI modelled relationships for stages greater than the inflection point.

Groundwater Losses

The assessment of potential loss of flow to groundwater conveyances was assessed by comparing measured values at a given station with modelled values based on the next upstream station (described in Section 3.4). Results suggested a net gain in flow between M2 and M1 of 0.02–0.09 m^3/s (5–19%), but losses in flow between M3 and M2 of 0.15–0.17 m^3/s (27–32%), and between Elliott Dam and M3 of 0.03–0.05 m^3/s (9–15%) (Table 5). The assessed gain in flow between M2 and M1 should be treated with caution due to problems experienced with the transducer at M1 (discussed in Section 3.1).

The above loss of flow for the channel between Elliott Dam and M3 has bearing on the fish flow release. During the period of the study, the fish release valve was locked in the full open position as opposed to maintaining a steady release of 0.25 m^3/s as proposed in the Jordan WUP. As a result of this valve configuration, mean daily release discharge (as recorded by the pipe gauge) averaged 0.31–0.33 m^3/s during the June to August periods of 2009 to 2011(range 0.27–0.38 m^3/s). This extra water generally resulted in the prescribed minimum flow being achieved or exceeded in the channel even after losses to subsurface conveyances. However, if the release had been maintained at 0.25 m^3/s, the amount of water remaining in the channel after losses would be expected to be in the range of 0.20–022 m^3/s (after subtraction of 0.03–0.05 m^3/s).

Comparison of Modelled and Measured Flows

The objective of the modelled/measured comparison was to determine the accuracy of the modelled flows used in the Jordan WUP. These flows, combined with the 0.25 m^3/s release, were predicted to provide certain gains in fish habitat in terms of weighted usable area (WUA) during summer base flows (identified as August in the CC Report). Thus if modelled flows were ≤ measured flows, actual discharge in the lower river would be greater than predicted by the WUP, and anticipated WUA gains would be met (or exceeded). Conversely, if modelled flows were > measured flows, then actual discharge in the lower river would be less than predicted by the WUP, and the WUA performance target would not be met.

In the Year 3 report (Burt and Hudson 2009), it was found that the WUP flow modelling included a protocol of defaulting to a value of 0.1 m^3/s for Elliott Reservoir (JOR) inflows during low flow periods. When the watershed area ratio was applied, this resulted in a modelled minimum flow of 0.072 m^3/s for the lower river. The Year 3 report indicated that this protocol likely led to overestimation of discharge in the lower river during base flow periods. For example, in 2006 measured flows at the lower river station (M1) dropped below the 0.072 m^3/s WUP minimum for 98 days during that summer and reached an actual minimum of 0.011 m^3/s. Thus, the Year 3 report demonstrated that the WUP analysis undoubtedly overestimated the mean August flow, though the extent of this overestimation could not be determined at that time due to a lack of long-term quality assured total system inflows (TSI's).

For this report, BC Hydro was able to supply long-term quality assured total system inflows 1990 to September 2011 and so an assessment of the WUP overestimation was possible. For the comparative analysis we focused on the typical low flow months of June to September and a period of record spanning 1990 to 2007 (18 years ending with the last year before initiation of the flow release). These data were used to model flows at M1 along with a correction factor based on measured flows (Equation 8) to provide a dataset of "best estimate" M1 flows. These flows were then compared with the WUP modelled flows for the same months and period of record. The results of this analysis were shown in Figure 19 and are abbreviated here in rows A and B of Table 6 (below). Row C of this table shows the percentage by which WUP modelled flows for the comparison period of record (1990–2007) overestimated the best estimate of actual flows. For the month of interest selected by the WUP (August) this amounted to an overestimate of 289%.

The above analysis was based on the period 1990 – 2007, whereas the original WUP modelling used 1967 – 1998. One way to determine how much the original WUP data overestimated actual flows would be for BC Hydro to run the original WUP data set through their quality assurance procedures and then undertake the comparative analysis as we did on the 1990 – 2007 data. An alternative used in this report was to apply the overestimate percentages from row C in Table 6 to the original WUP data (Original WUP mean flow ÷ % overestimation). The results of this approach are shown in row E of Table 6. This approach suggests a "best estimate" mean August flow of 0.055 m^3/s for the 1967 – 1998 period compared with 0.160 m^3/s estimated by the original WUP modelling.

Table 6. Comparison of the original WUP flows (1967–1998) with the best estimate of actual flows for the same time period for the months of June through September.

	Mean Monthly Discharge (m^3/s)			
	June	**July**	**August**	**September**
A) Modelled/corr. Q ("best estimate") (1990-2007)	0.122	0.063	0.061	0.099
B) WUP modelled Q (1990-2007)	0.338	0.169	0.176	0.285
C) Percent overestimation by WUP modelled Q	277%	268%	289%	288%
D) Original WUP Q (1967-1998)	0.389	0.214	0.160	0.323
E) Best estimate actual Q (1967-1998) (Original WUP ÷ % overestimation)	0.140	0.080	0.055	0.112

Conclusions and Management Implications

The main conclusions and their management implications from the Inflow Monitoring Program include the following:

1) The original WUP modelling substantially overestimated actual discharge in the lower river during summer base flows. The amount of overestimation was calculated to range from 268% – 289% for the months of June through September. For the lowest flow month selected by the WUP (August), our analysis indicated a mean monthly flow of about 0.055 m^3/s compared with 0.160 m^3/s predicted by the original WUP modelling (Table 6).

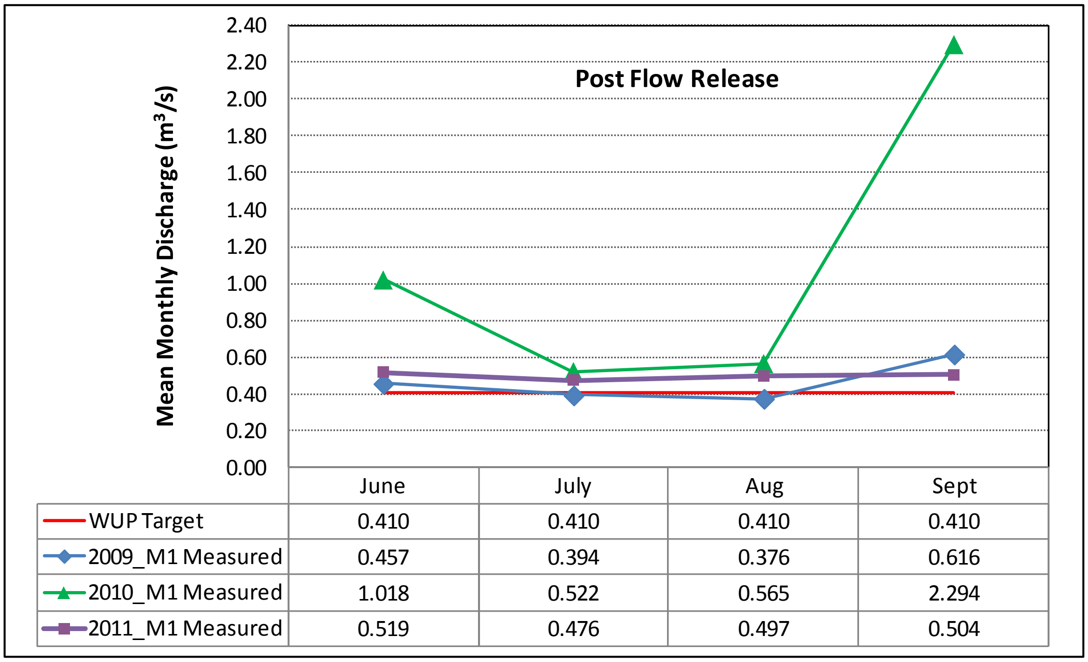
   The main reason for this overestimation was due to the WUP protocol of using a minimum mean daily flow of 0.072 m^3/s for the lower river during low flow periods. We suspect that this protocol was adopted due to a lack of quality assured data at the time of the WUP modelling (raw inflow data tends to have frequent negative values during low flow periods and the protocol of assuming a default minimum value may have seemed a logical solution for these instances).

   Though of lesser influence, a second reason for this overestimation is that watershed area based calculations tend to overestimate flows in the lower river at measured values ranging from roughly 0.04 – 0.30 m^3/s (Figure 18). This suggests that water yield per km^2 in the upper river is greater than in the lower river at these flow regimes.

2) Another finding is that there appears to be an immediate loss of a portion of the Elliott Dam release flow to subsurface conveyances. The data indicate that this loss amounts to about 0.03–0.05 m^3/s during base flow periods (Table 5). Thus, under the prescribed flow release of 0.25 m^3/s, the inriver flow below the dam would be reduced to 0.20–0.22 m^3/s.

3) These findings have significant implications for the Jordan WUP. The original WUP modelling predicted a mean August flow of 0.160 m^3/s for the lower river, and that this plus the prescribed release of 0.25 m^3/s would provide a minimum flow of 0.41 m^3/s in the lower river. This minimum flow was then applied to a weighted usable area (WUA) fish habitat model which predicted a certain level of fish habitat at that flow. Our results suggest that August inflows for the original WUP period of record were actually about 0.055 m^3/s and that the prescribed release after groundwater losses would amount to about 0.21 m^3/s (median value). Thus, estimated mean August flow in the lower river under the prescribed flow release is estimated to be 0.265 m^3/s (0.055 + 0.21), or 0.145 m^3/s less than estimated by the original WUP modelling. To attain 0.41 m^3/s in the lower river, and the associated fish habitat (WUA) targeted in the WUP, the prescribed release at Elliott Dam would have to be increased to 0.395 m^3/s (0.395 m^3/s release – 0.04 m^3/s lost + 0.055 m^3/s mean Aug. inflow = 0.410 m^3/s).

It should be noted that since initiation of the flow release in January 2008, releases have consistently been greater than 0.25 m^3/s due to the fact that the control valve on the release pipe has been locked in the full open position. Data from the release pipe flow meter indicate that minimum mean monthly releases were in July (as opposed to August) and amounted to 0.299 m^3/s in 2009, 0.320 m^3/s in 2010, and 0.328 m^3/s in 2011. Associated measured flows at the lower river station (M1) were 0.394 m^3/s in July 2009, 0.522 m^3/s in July 2010, and 0.476 m^3/s in July 2011 (Figure 24). Thus, with the control valve locked in the full open position, minimum mean monthly flows in the lower river have ranged from slightly less to slightly greater than the WUP target of 0.410 m^3/s during the summer period.



	June	July	Aug	Sept
WUP Target	0.410	0.410	0.410	0.410
2009_M1 Measured	0.457	0.394	0.376	0.616
2010_M1 Measured	1.018	0.522	0.565	2.294
2011_M1 Measured	0.519	0.476	0.497	0.504

Figure 24. Comparison of post flow release mean monthly discharge at M1 for June to September with the WUP target flow of 0.41 m^3/s.

5. REFERENCES

BC Hydro. 2003. Jordan River Project water use plan. BC Hydro, Burnaby, BC. 33 p.

BC Hydro. 2005. Lower Jordan River fish indexing, invitation for proposals - Attachment A. BC Hydro, John Hart Generating Station, Campbell River, BC. 6 p.

BC Hydro. 2007. Lower Jordan River inflow monitoring - monitoring terms of reference (May 2007 revision). BC Hydro, Burnaby, BC. 6 p.

Burt, D.W., and R. Hudson. 2008. Lower Jordan River inflow monitoring: Year 2 results (2007-2008). Prepared for BC Hydro, Water Use Planning, Burnaby, BC. 44 p.

Burt, D.W., and R. Hudson. 2009. Lower Jordan River inflow monitoring: Year 3 results (2008-2009). BC Hydro, Water Use Planning, Burnaby, BC. 40 p.

Burt, D.W., and R. Hudson. 2010. Lower Jordan River inflow monitoring: Year 4 results (2009). BC Hydro, Water Use Planning, Burnaby, BC. 23 p.

Burt, D.W., and R. Hudson. 2012. Lower Jordan River inflow monitoring: Year 5 results (2010). BC Hydro, Water Use Planning, Burnaby, BC. 23 p.

Cascadia Biological Services. 2001. Lower Jordan River transect survey and biophysical assessments. BC Hydro and Power Authority, 6911 Southpoint Drive, Burnaby, BC. 54 p.

Hudson, R. 2006. Jordan River Water Use Plan: Lower Jordan River inflow monitoring. Consultant report for BC Hydro, Burnaby, BC. 28 p.

Hudson, R., and J. Fraser. 2005. Introduction to salt dilution gauging for streamflow measurement. Part IV: the mass balance (or dry injection) method. Streamline Water Management Bulletin **9**(1): 6-12.

Ministry of Environment, Lands and Parks. 1998. Manual of standard operating procedures for hydrometric surveys in British Columbia. Resource Inventory Committee, Victoria, BC.

Sherbot, D. 2001. Cumulative inflow: Lower Jordan River. *In* Excel File "JOR RM System Inflows.xls". BC Hydro, Burnaby, BC.

Sit, V. 1994. Catalogue of curves for curve fitting. Biometrics information handbook #4. Ministry of Forests, Victoria, BC.

Solano, C. 2008. Method used to derive the discharge at the Lower Jordan River. BC Hydro Inter-office memo to Ian Dodd, BC Hydro, Burnaby, BC, 2 p.

Appendix A . Summary of hydrometric and survey data collected by the Inflow Monitoring Program.

Date	Time (PST)	Stage (m)	Q (m^3/s)	Gauge Ht (m)	Staff Gauge (m)	Survey Data (m)			Offsets (m)	
						BM Elevation	Level to BM	Level to Water	Stage/GH Offset	Stage/Staff Gg Offset
M1										
07-Mar-06	11:52	0.683	2.132	0.874	0.874					
01-Jun-06	12:03	0.125	0.081	0.316	0.316	NA: GH = Staff Gauge			0.191	0.191
05-Oct-06	09:15	0.026	0.017	0.217	0.217					
28-Sep-07	12:00	1.280*	0.042	0.327	0.077	1.311				
10-Oct-07	13:15	1.521	0.730	0.568	0.320	1.311	2.400	3.143	**-0.953**	**1.201**
16-Jan-08	15:45	1.636	1.273	0.683	0.434	1.311				**1.202**
17-Jan-08	11:45	1.629	1.141	0.676	0.426	1.311				**1.203**
21-May-08	11:15	1.565	0.850	0.585	0.362	1.311	2.255	2.981	**-0.980**	**1.203**
26-Aug-08	13:05	1.467*	0.458	0.508	0.264	1.311	1.917	2.720	-0.959	1.203
26-Nov-08	12:00	1.603	1.081	0.625	0.398	1.311	1.903	2.589	**-0.978**	**1.205**
06-Feb-09	10:45	1.627	1.164	0.657	0.424	1.311	1.648	2.302	**-0.970**	**1.203**
05-Jun-09	11:00	1.459†	0.456	0.490	0.256	1.311	1.627	2.448	**-0.969**	1.203
22-Aug-09	12:15	1.438†	0.371	0.474	0.235	1.311	1.408	2.245	**-0.964**	1.203
23-Sep-09	16:00	1.469†	0.488	0.518	0.266	1.311	1.434	2.227	**-0.951**	1.203
								Average:	-0.965	1.203
M2										
07-Mar-06	13:30	0.562	0.553	0.686	NA	1.185	0.512	1.011	0.191	
23-Mar-06	15:53	0.463	0.383	0.587	NA	1.185	0.323	0.921	0.191	
31-May-06	14:02	0.191	0.036	0.315	NA	1.185	0.456	1.326	0.191	
02-Aug-07	15:30	0.322	0.029	0.296	NA	3.350	0.793	3.847	-0.026	
29-Nov-07	15:00	0.587	0.298	0.543	0.523	3.350				**0.064**
16-Jan-08	11:45	0.730	0.816	0.696	0.667	3.350	0.702	3.356	-0.034	**0.063**
18-Jan-08	14:30	0.715	0.741	0.671	0.654	3.350				**0.061**
22-May-08	10:45	0.679†	0.546	0.643	0.616	3.350	0.655	3.362	**-0.036**	0.063
27-Aug-08	10:45	0.771†	0.925	0.738	0.708	3.350	0.774	3.386	**-0.033**	0.063
27-Nov-08	11:00	0.714†	0.682	0.663	0.650	3.350	0.585	3.272	**-0.051**	0.064
11-Dec-08	14:00	0.790	1.008	0.743	0.725	3.350	0.796	3.403	**-0.047**	**0.065**
05-Feb-09	12:30	0.760†	0.881	0.712	0.696	3.350	0.843	3.481	**-0.048**	0.064
04-Jun-09	12:15	0.641†	0.343	0.595	0.577	3.350	0.673	3.428	**-0.046**	0.064
12-Aug-09	14:30	0.626*	0.332	0.581	0.562	3.350				
22-Sep-09	16:15	0.515	NA	0.614	0.595	3.350			0.099	-0.080
08-Dec-09	14:15	0.466	NA	0.650	0.622	3.350			**0.184**	**-0.156**
18-Mar-10	13:30	0.565	NA	0.749	0.722	3.350	0.864	3.465	**0.184**	**-0.157**
							Average (old sensor):		-0.044	0.063
							Average (new sensor):		0.184	-0.157

Date	Time (PST)	Stage (m)	Q (m^3/s)	Gauge Ht (m)	Staff Gauge (m)	Survey Data (m)			Offsets (m)	
						BM Elevation	Level to BM	Level to Water	Stage/GH Offset	Stage/Staff Gg Offset
M3										
31-May-06	12:00	0.322	0.0003	NA	NA				NA	NA
04-Aug-07	13:15	1.258*	0.0053	1.344	0.274	5.400	0.074	4.130	0.086	
29-Aug-07	14:00	1.233*	0.0017	1.325	0.249	5.400				
11-Oct-07	14:15	1.414	0.0096	1.520	0.432	5.400	0.079	3.959	0.106	**0.982**
15-Jan-08	13:30	1.590	0.0265	1.682	0.605	5.400				**0.985**
18-Jan-08	11:00	1.835	0.2698	1.927	0.841	5.400				0.994
23-May-08	10:30	1.814	0.2100	1.915	0.829	5.400	0.087	3.572	**0.101**	**0.985**
26-Aug-08	10:00	1.822	0.2457	1.910	0.840	5.400	0.083	3.573	**0.088**	**0.982**
27-Nov-08	15:10	1.900	0.4036	1.990	0.915	5.400	0.160	3.570	**0.090**	**0.985**
03-Apr-09	12:15	1.884	0.2934	1.982	0.900	5.400	0.116	3.534	**0.098**	**0.984**
22-Aug-09	09:45	1.855	0.2787	1.939	0.871	5.400	0.303	3.764	**0.084**	**0.984**
23-Sep-09	10:45	1.889	0.3557	1.982	0.905	5.400	0.091	3.509	**0.093**	**0.984**
								Average:	0.092	0.984
T1										
14-Dec-05	09:38	0.397	0.040	0.603	—	2.400	0.324	2.121	0.206	—
23-Jan-06	10:15	0.666	0.886	0.872	—	2.400	0.198	1.726	0.206	—
23-Mar-06	11:23	0.571	0.465	0.797	—	2.400	0.224	1.827	0.226	—
01-Jun-06	10:02	0.384	0.015	0.570	—	2.400	0.158	1.988	0.186	—
27-Nov-07	13:15	0.332	0.059	0.619	—	2.492	0.693	2.566	0.287	—
15-Jan-08	16:00	0.491	0.385	0.789	—	2.492				—
17-Jan-08	14:00	0.402	0.161	0.700	—	2.492				—
23-May-08	13:15	0.375	0.129	0.674	—	2.492	0.276	2.094	**0.299**	—
27-Aug-08	14:30	0.479†	0.378	0.777	—	2.492	0.313	2.028	0.298	—
26-Nov-08	15:30	0.388	0.144	0.684	—	2.492	0.662	2.470	**0.296**	—
05-Feb-09	16:00	0.393	0.214	0.686	—	2.492	0.548	2.354	**0.293**	—
03-Jun-09	14:30	0.225	0.010	0.527	—	2.492	0.527	2.492	**0.302**	—
								Average:	0.298	—

Notes:

1. Year 1 data (2006) are from Hudson (2006). The stage/discharge relationships and offsets in Year 1 differed from subsequent years due to channel morphology changes from the November 2006 flood and re-installation of equipment.
2. Values used to generate average stage/GH and stage/staff gauge offsets are shown in bold.
3. Any values shown in light grey have uncertainty or are suspected errors.
4. For M2, readings beginning with Sept. 22, 2009 are with the new transducer.
5. For M3, 29-Aug-07, discharge was measured with a 1 L cup at the point where flows enter the M3 pool.
6. * Indicates value estimated from staff gauge reading (water level data not available).
7. † Indicates a stage value that was adjusted due to an unstable offset caused by equipment problems.

Appendix B. Site photos.

Photo 1. View of the M1 water level monitoring pool (looking downstream). The transducer was located on the right bank behind the bedrock outcrop; the staff gauge was located on the back side of the next downstream outcrop (see arrows). Photo from September 4, 2006 at an M1 flow of 0.012 m^3/s.

Photo 2. View of the transducer and cable installation at the M2 gauging station (2007–2011 location). The sensor was housed within a short section of PVC pipe while the sensor cable was encased in wire rope. Both were bolted to the bedrock wall at various locations.

Photo 3. View of the large pool housing the M3 water level logger and staff gauge (August 30, 2006, M3 Q estimated at 1 L/s). The staff gauge is shown against the bedrock in the background; the transducer was situated at depth in front and to the left of the staff gauge. These installations were blown out during the November 2006 flood and reinstalled more securely on October 11, 2007.

Photo 4. Plywood housing for the T1 logger and battery on Sinn Fein Creek. The box was nailed to the Sinn Fein bridge abutment; the transducer cable was sheathed in wire rope which was shackled to the bridge cables. The transducer was bolted to a heavy metal anchor situated in a pool under the bridge.

Photo 5. M1 salt dilution gauging section (looking upstream). Salt was released in the vicinity of the arrow and intercepted by the conductivity meter immediately below the photographer (distance ~ 75 m). Photo taken Aug. 26, 2008; gauged flow was 0.456 m^3/s.

Photo 6. M2 salt dilution gauging section (looking downstream). Salt is released in the cascade and intercepted by the conductivity meter at the arrow. Photo taken Aug. 27, 2008; gauged flow 0.925 m^3/s.

Photo 7. M3 salt dilution gauging section (looking upstream). Salt is released at the top of the cascade and intercepted by the conductivity meter at the arrow. Photo taken Aug. 26, 2008; gauged flow 0.246 m^3/s.

Photo 8. T1 (Sinn Fein) salt dilution gauging section (looking upstream). Photo taken Nov. 26, 2008; gauged flow 0.144 m^3/s.