APPENDIX 3
SALT DILUTION METHOD OF RIVER FLOW MONITORING

Appendix 3 - Salt Dilution Method of River Flow Monitoring

A3-1 Objective

The salt dilution method of river flow monitoring is a simple and robust method of flow measurement which does not require the hydrologist to enter the deepest sections of the river. It is ideal for flow measurement in fast-flowing mountain streams where it is often too dangerous to use more traditional flow measurement techniques such as hand-held flow meters. This appendix provides background information on the use of the technique, details of the methodology used for this baseline report and some discussion of the results obtained in the field. The appendix also provides a discussion of the impact of salt on aquatic life.

For any technique that requires the addition of a chemical or tracer to a river system there will be concerns over the potential impact on aquatic life. Research and the results of field tests would indicate that salt dilution will not have any impact on fish except close to the point on injection of the salt tracer (< 50 m) and only for a very short period of time (< 1 min). However, to respect the concerns of regulators and users of the land **the salt dilution technique was only used in non-fish bearing streams** during this baseline assessment.

A3-2 Reasons for Application of the Method within Study Area

The traditional velocity-area discharge measurement is most appropriate for large, low-gradient streams with uniform, steady flow. However, this approach, is unsuitable for small mountain streams due to 1) high velocities, turbulence and sediment transport that makes traditional current meter measurements difficult, dangerous or physically impossible, 2) where the rate of change of flow is rapid, and 3) where the cross-sectional area cannot be accurately measured due to irregular channel geometry (Kilpatrick and Cobb, 1985; Kite, 1994).

Salt dilution has been used for flow measurement in many applications in Canada (e.g. Church and Kellerhals 1970, Hudson and Fraser 2002, Spence and Mc Phie 1997). The technique has recently received a lot of attention in British Columbia because of its suitability for flow measurement in mountain streams where steep slopes and high flow velocities make other methods of flow monitoring hazardous. The high degree of turbulence in small, mountain streams lends itself well to the use of tracer-dilution gauging techniques, which require mixing of the tracer across the channel, such that the technique is considered more accurate than most other discharge measurement techniques for gauging high-energy mountain streams (Elder *et al.*, 1990).

Galore Creek, More Creek and Sphaler Creek are fast-flowing mountain streams. During the 2004 field season only a limited number of manual flow measurements were able to be taken under high flow conditions due to concerns over safety. The consequence of not being able to obtain flow measurements under medium to high flow conditions is that the rating equations for the monitoring stations would not be well-constrained for high flows. This would result in increased uncertainty in the flow hydrographs produced for each site. Hence, the salt dilution method was proposed as an alternative method of flow monitoring and the method was used for non-fish bearing streams throughout the study area.

A3-3 Methodology

The basis of tracer dilution gauging is the conservation of mass of a tracer substance before and after dilution by the flowing stream. The concentration of the tracer measured downstream after it has become uniformly distributed across the channel is related to the discharge of the stream; the lower the concentration the greater the discharge. Table salt (sodium chloride, NaCl) is commonly used as the tracer substance owing to the fact that it is non-toxic in the quantities present during tracer-dilution, is highly soluble in water, is low cost, and it's concentration is measurable with high sensitivity (Moore, 2004). When using NaCl as the tracer, electrical conductivity is substituted for mass concentration.

Application of slug injection salt-dilution gauging in the field is simple and straightforward. A mass, M (mg), of salt is injected instantaneously and electrical conductivity, E_C (µS cm^{-1}), is monitored as the tracer wave passes a downstream location (Figure A3-1). Conductivity is converted to mass concentration, C_M (mg L^{-1}), via a calibration relationship. The relationship between discharge, Q (L s^{-1}), M and C_M is given by (Elder *et al*., 1990)

$$M = \int_0^T Q\, C_M\, dt \qquad (1)$$

where T is the duration of the tracer wave (or measurement duration) in seconds. For steady flow (Elder *et al*., 1990)

$$Q = \frac{M}{\int_0^T C_M\ dt} = \frac{M}{T < C_M(t) >} \qquad (2)$$

where < > denotes the mean over time. Electrical conductivity at any time t is related to mass concentration via the following linear relationship

$$E_C(t) = E_{CB} + K C_M(t) \qquad (3)$$

where E_{CB} is the natural background conductivity and K is a calibration constant (Elder *et al.*, 1990). The dependence of electrical conductivity on temperature is removed by using specific conductivity in (3) (conductivity corrected to a standard temperature of 25 ^{o}C) (ISO, 1985). The calibration given by (3) is dependent upon the type of salt used and the accuracy and cell constant of the conductivity meter. Therefore, provided all discharge measurements are made with the same salt and conductivity meter, the calibration need only be completed once in advance of field measurements. The value of K is estimated by measuring the conductivity of solutions of known concentration and regressing E_C on C_M. Once K is know and field measurements of background conductivity and conductivity of the passing salt wave are taken, discharge (m^3/s) is calculated by

$$Q = \frac{M\,K}{1000T\left[<E_C(t)> - E_{CB}\right]} = \frac{M}{1000\,A_C} \qquad (4)$$

where A_C is the area under the time-concentration curve (in units of mg·s/L), corrected for background conductivity, and the factor 1000 converts litres to cubic metres. The area under the time concentration curve is estimated from

$$A_C \approx \Delta t \sum_{0}^{T} E_C(t) - E_{CB} \qquad (5)$$

where Δt is the sampling interval in seconds and E_{CB} is assumed constant during the sampling period.

Application of the slug injection technique requires that the mass of tracer, M, be fully accounted for downstream at the measurement site. Therefore, it is critical that the area under the time-concentration curve (Figure A3-2) accurately represents the dilution of the tracer (Kilpatrick and Cob, 1985). This is only achieved when the tracer is fully mixed throughout the flow of the stream. Once injected, the dispersion of the tracer takes place in all three dimensions; vertical mixing is usually completed first, lateral mixing later and longitudinal dispersion takes place indefinitely. Once complete (or near-complete) mixing has occurred the time-concentration integral, as per (5), is constant at all locations within the cross-section. If mixing is incomplete then discharge will be over- (under-) estimated where concentration is too low (high). The longitudinal distance required for sufficient lateral mixing of the salt mass (the mixing length), L_m, was estimated based on published literature and tested during preliminary salt dilution trials.

A3-4 Field Methods and Testing

An initial assessment was made based on results from an initial salt dilution trip in May, 2005. The purpose of preliminary testing was to 1) establish appropriate length of reach for complete mixing to occur 2) establish the required amount of salt to be used for injections 3) establish the range of discharges over which the salt dilution method could be applied and 4) determine the persistence and concentration of salt waves in the stream during dilution measurements. A minimum of two conductivity probes were used at each site; each placed out as far as possible into the channel from the right and left (looking upstream) bank (Plate A3-1). Where conditions permitted, three conductivity probes were used; one near each bank and one in the centre of the thalweg. Where possible, discharge measurements were made adjacent to gauging stations. During initial trials in May, 2005, discharge was measured with the salt tracer-dilution technique at 16 stations, and values ranged from 0.3 m^3/s to 25 m^3/s. In most cases, discharge measurements estimated between the two or three probes used at each site were all within 10% of each other. Some exceptions occurred suggesting that lateral mixing of the tracer was not complete at these sites. Changes in the location of the measurement sites were made for subsequent sampling trips.

The injection of dry salt was planned for a sufficient distance upstream to allow near-complete mixing of the tracer laterally across the channel. This mixing length was estimated using the following empirical formula of *Kite* (1994), which is based on data collected from glacial streams in British Columbia and Alberta:

$$L_m = 260\sqrt{w\,d}\,, \quad (1)$$

where w is the average water surface width and d is the average stream depth. The actual distance between the injection site and the measuring site varied from the ideal L_m estimated with (1) due to limited accessibility. However, using this estimate for mixing length provided decent results.

The mass of salt injected, M_{NaCl}, varied from 5 to 35 kg and was decided upon based on the judgement of the field hydrologist, considering both an estimate of discharge and the required mixing length. The salt mass was estimated such that the ratio of salt mass to stream discharge, also know as the dose ratio, R_D, was at least 2 kg/(m^3/s). The actual variation of R_D between sites ranged from a low of 1.2 at CONT to as high as 30 kg/(m^3/s) at GWM4, reflecting both the authors inexperience with these particular streams and the difficulty in estimating discharge prior to salt injection. Three runs were conduced at MORE1, with R_D varying from 2 to 5 kg/(m^3/s) at an injection distance of 600 m; the repeatability of the results (discharge measured with all probes over 3 runs was within 9%) suggest that a R_D as low as 2 kg/(m^3/s) is feasible (for an injection length of 600 m). Subsequent salt dilution measurements over the 2005 season suggest that accurate measurements can be made to about 45 m^3/s with 50 kg of NaCl, or an R_D of 1.1 kg/(m^3/s), however consistently good results were obtained when was R_D about 2.0 kg/(m^3/s).

A separate trial was conducted whereby the concentration of tracer (specifically the chloride) was measured immediately downstream of the injection site. This was accomplished by placing three probes in the stream thalweg at MORE1, located at distances of 20-, 40-, and 60-m downstream of the injection site. The trial consisted of 10 kg of NaCl injected into a stream discharge of 3.0 m^3/s (R_D = 3 kg/(m^3/s)). The background specific conductance was 155 μS/cm, which roughly equates to 78 mg/L of total dissolved solids (an approximate ratio of 2:1 for EC^C to *TDS*). This background EC^C equates to approximately 46 mg/L of background chloride if one assumes that background conductivity is entirely composed of dissolved NaCl. However, as the source of the background conductivity is unknown, all results are presented as changes with respect to background. Chloride concentration with time is given in Figure A3-3, which shows that the concentration of added chloride only exceeds 600 mg/L at the 20-m downstream probe, and then only for approximately 4.0 seconds. A concentration of 600 mg/L is the recommended level for chloride for the protection of freshwater aquatic life in the BC Aquatic Water Quality Guidelines, discussed in more detail in Section A3-5.

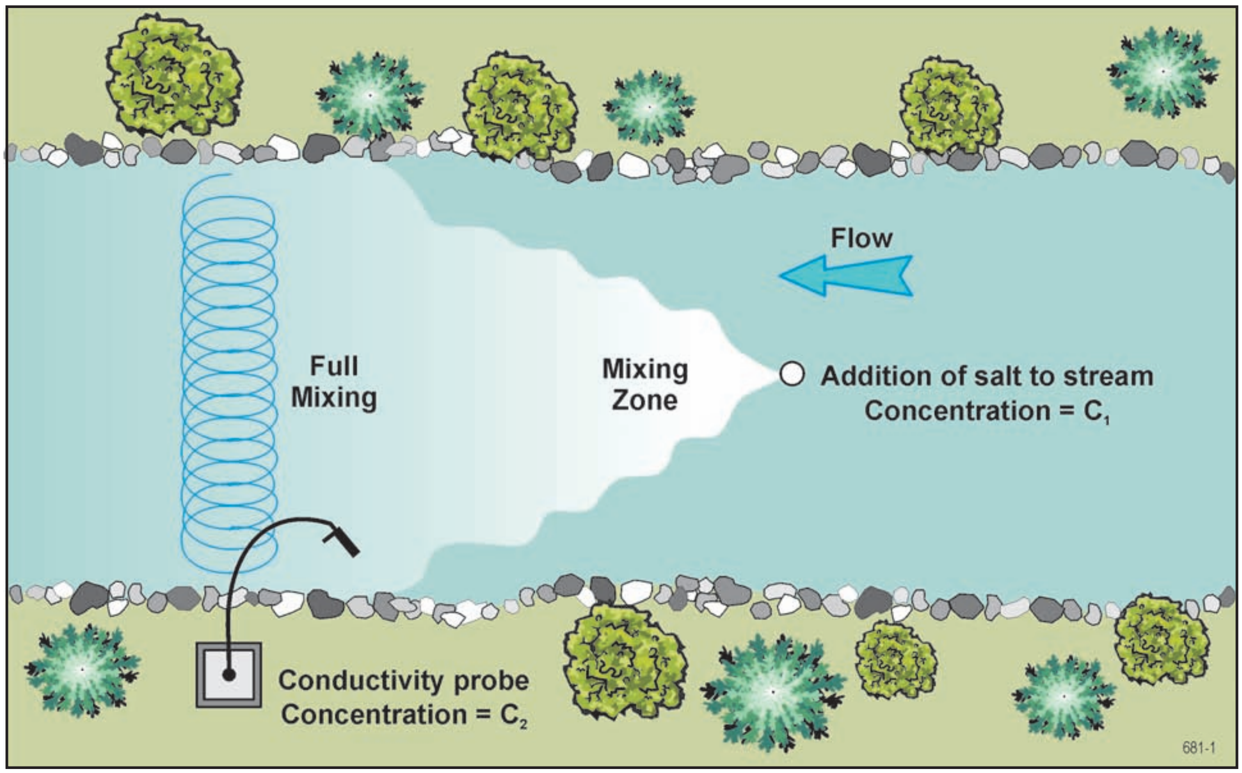

FIGURE A3-1

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Schematic of Salt Dilution Method for Flow Measurement

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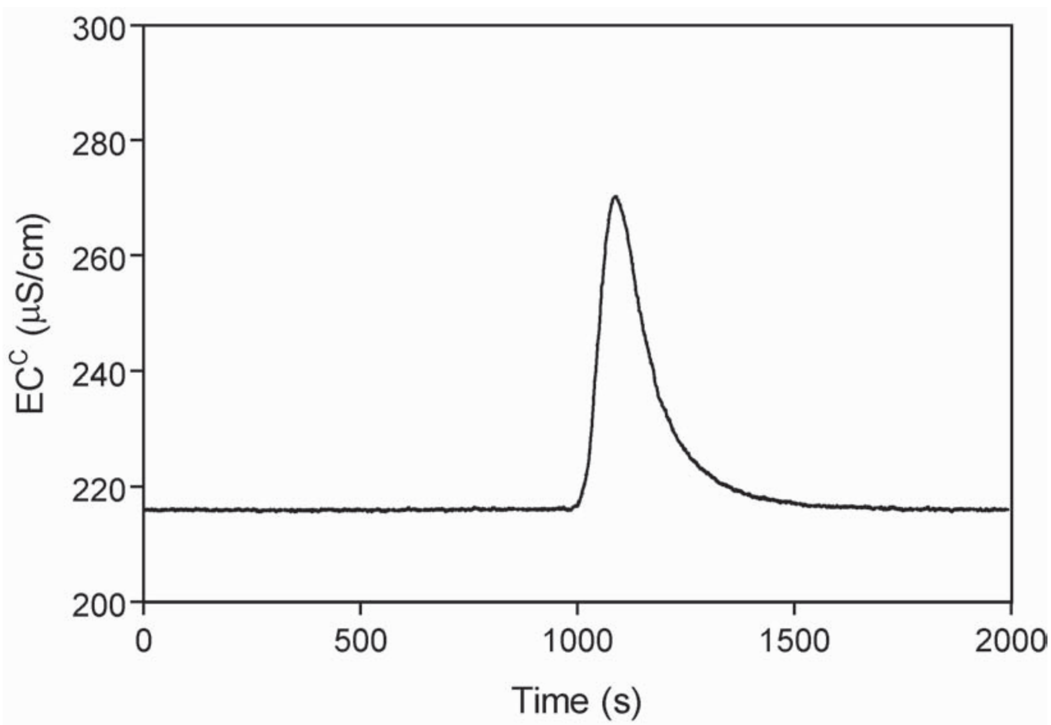

FIGURE A3-2

Example of Salt Tracer Wave Recorded at Gwm6 on 24 May 2005

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After initial flow measurements using salt dilution, consistent results suggested that both the distance of injection upstream was within the appropriate range for adequate mixing and the mass of salt injected produced a strong enough conductivity signal. After flow measurements with two conductivity probes in May, June, and July 2005, one probe was considered adequate for measurements since appropriate mixing lengths had been identified, and the error using this method had been estimated. Values of R_D ranged from 1.0 to 35.0 kg/m^3/s during the 2005 season, with a median value of 3.0 kg/m^3/s. At each station, a similar injection distance that were used in May and June were applied for the remaining flow measurements.

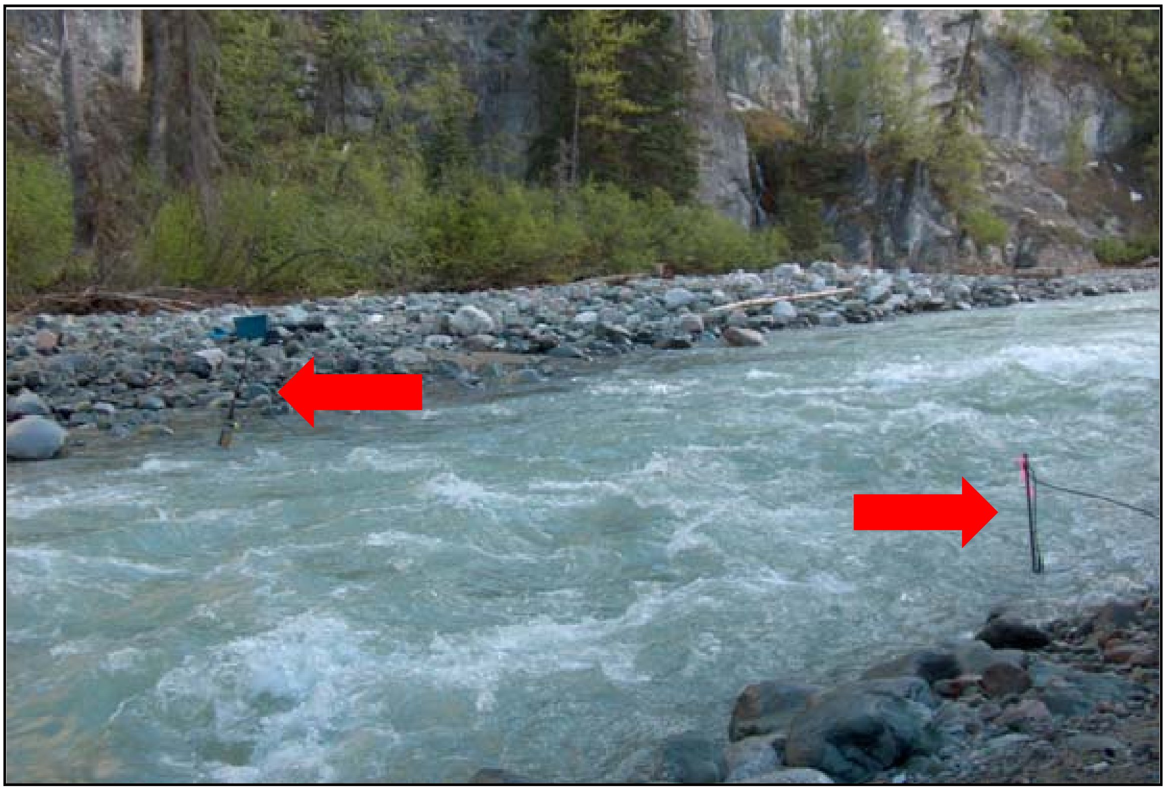


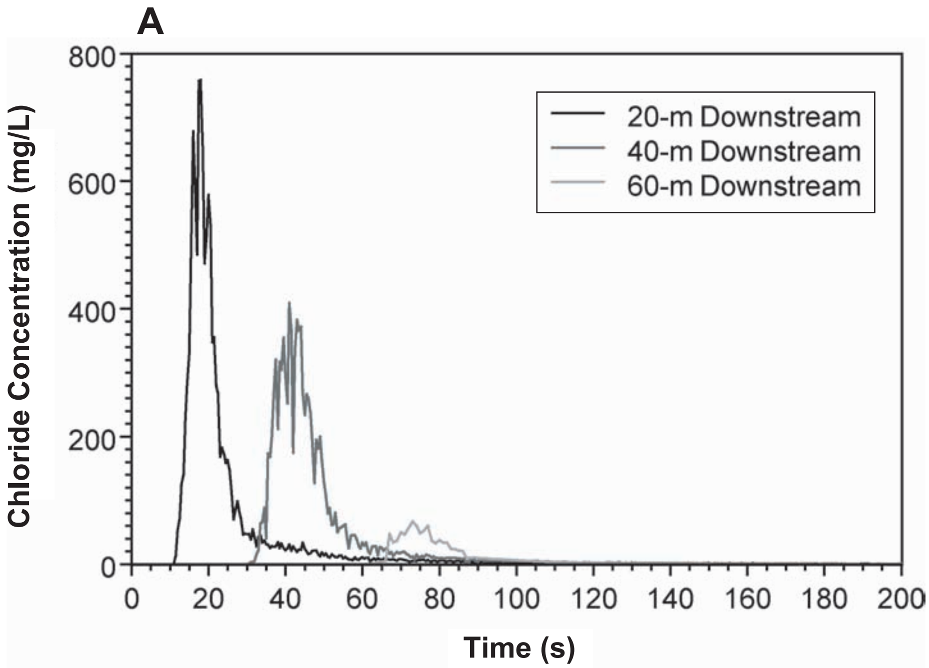
Plate A3-1. Channel at GWM8 showing location of two upstream probes (indicated by arrows) placed off the left and right banks. Flow is to the right in the photograph.

A3-5 Assessment of impact of salt on freshwater aquatic life

Small multi-cellular organisms generally do not have the mechanisms to deal with salt, and those without a permeable exoskeleton are the most intolerant (Hart *et al.*, 1991). Submergent macrophytes are extremely intolerant due to their entire structure being submerged. However, all macrophytes (including emergent macrophytes) show a range of tolerances. Macroinvertebrates are also generally intolerant to salt, although some organisms (*i.e.*, some rotifera and arthropoda) are saline-water specialists (James *et al.*, 2003). Within insects, there is a range of tolerance levels, ranging from very tolerant (*i.e.*, water bugs, beetles and dipteran flies) to organisms that are sensitive to even minor increases in salinity (*i.e.*, stone flies, some mayflies, some cadisflies, some dragon flies and certain water bugs). Overall, fish are more tolerant than invertebrates, especially species whose life history involves spending some part of their life in salt water (*i.e.*, diadromous), or species that have recently diverged from salt water species (U.S. EPA, 1988; Environment Canada/Health Canada 2001). Another concern with salt is not only the effects that might occur to adult life stages, but also to younger life stages. All animals tested, and fish in particular, appear to be much more intolerant during larval or egg stages (James *et al.*, 2003, Environment Canada/Health Canada 2001). Additionally, long-term exposure to salt, while not resulting in death, may compromise reproductive success, resulting in recruitment failure and eventual collapse of the population (James *et al.*, 2003). A final concern with high salt concentrations involves indirect effects of salt on community structure. While salt concentrations may not be at a level to directly affect a particular species, it may differentially affect other species in the system. This may impart a competitive advantage for other species in the system, effectively resulting in shifts in populations and community structure.

There are only a few studies that tested the impact of short-term (< 24 hour) exposure to high salt concentrations on aquatic life. Most studies consider long-term toxicity, with major concerns being the impact of salt applied to roads in winter raising the salt concentration in neighbouring streams and ponds, and the effect of the drying out of ponds or streams in the summer producing locally increased salinity. An extensive review of data on impact of winter salt is provided in Environment Canada/Health Canada (2001) and in U.S. EPA (1988). More extensive information is provided by Australian research due to the increased risk imposed by drying rivers and lakes in that country (James et al., 2003). However, the review conducted by James *et al.*, (2003) and the larger database available from Land and Water Australia (Bailey *et al.*, 2002) are based on longer-time exposures than are useful for our purposes.

Within North America, it appears that there are only four studies examining exposures of less than 24 hours (three for fish and one for benthic invertebrates). The LC50s (concentration resulting in 50% mortality in organisms studied) from these studies range from 6,063 to 30,330 mg chloride/L, with a geometric mean of 12,826 mg/L. This is similar to a range in salt concentration of 9,995 to 50,000 mg/L. Additionally, there are seven studies examining the effects of 24 hour exposure, which although a longer exposure time than expected with salt dilution gauging, are helpful in extrapolating the few studies involving shorter time-scales. The LC50s in these studies ranged from 1,652 to 8,553 mg chloride/L, which is approximately 2,724 to 14,100 mg salt/L (Table A3-1).



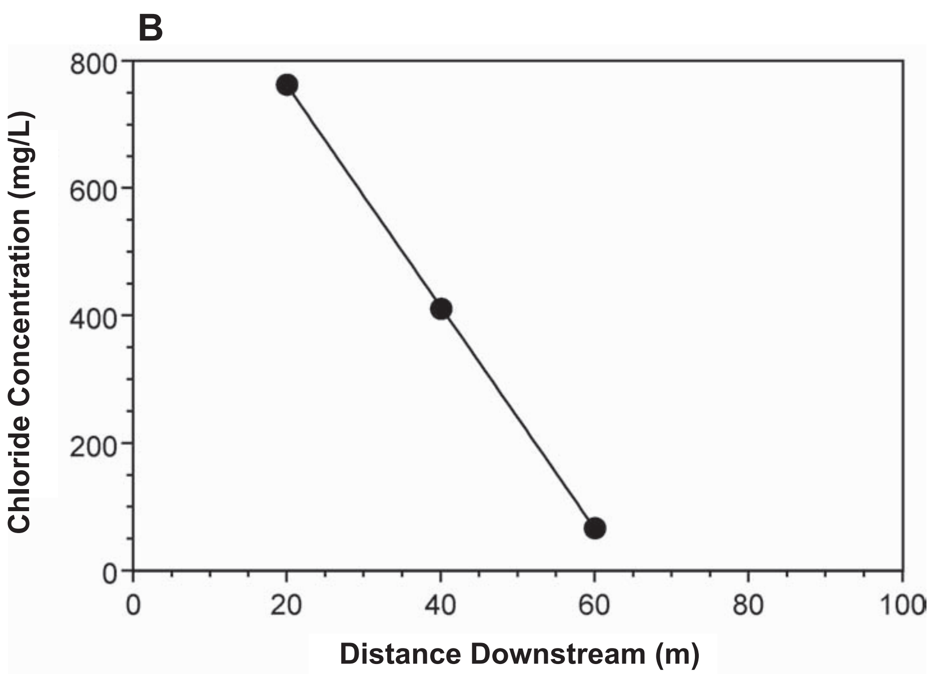


FIGURE A3-3

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Chloride Concentrations Recorded at MORE-1 during Salt Dilution Injection

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Table A3-1
Toxicity responses of organisms to sodium chloride for exposures of one day or less (from Evans and Frick, 2001, as cited in Environment Canada/Health Canada 2001)

Species	Common name/taxon	NaCl (mg/L)	Cl (mg/L)	Response	Time (hour)	Reference[1]
Salvelinus fontinalis	Brook trout	50,000	30,300	LC_{50}	0.25	Phillips, 1944
Lepomis macrochirus	Bluegill sunfish	20,000	12,132	LC_{47}	6	Waler et al., 1996
Oncorhynchus mykiss	Rainbow trout	20,000	12,132	LC_{40}	6	Waller et al., 1996
Chironomus attenatus	Chironomid	9,995	6,063	LC_{50}	12	Thorton and Sauer, 1972
Lepomis machrochirus	Bluegill sunfish	14,100	8,553	LC_{50}	24	Doudoroff and Katz, 1953
Daphnia magna	Cladoceran	7,754	4,704	LC_{50}	24	Cowgill and Milazzo, 1990
Cirrhinius mrigalo	Indian carp fry	7,500	4,550	LC_{50}	24	Gosh and Pal, 1969
Labeo rohoto	Indian carp fry	7,500	4,550	LC_{50}	24	Gosh and Pal, 1969
Catla catla	Indian carp fry	7,500	4,550	LC_{50}	24	Gosh and Pal, 1969
Daphnia pulex	Cladoceran	2,724	1,652	LC_{50}	24	Cowgill and Milazzo, 1990
Ceriodaphnia dubia	Cladoceran	2,724	1,652	LC_{50}	24	Cowgill and Milazzo, 1990

[1] **References provided in Environment Canada/Health Canada 2001**

Broad generalisations regarding salt tolerances are available from Australian studies, however, these represent long-term effects, and short-term effects will occur at much higher concentrations, given that tolerance decreases with time (Environment Canada/Health Canada, 2001; James *et al*., 2003). Therefore, these taxa-specific thresholds are included for comparison between taxa only (Table 2).

Federal and provincial water quality guidelines contain values for chloride, which serves as a reference for salt. The Canadian Council of Ministers of the Environment (CCME, 2003) only has guidelines for drinking water (250 mg Cl/L) and irrigation purposes (100-700 mg Cl/L) (CCME, 1999). The British Columbia Ambient Water Quality Guidelines for Chloride (Nagpal et al., 2003) suggest limits for drinking water (250 mg Cl/L), freshwater aquatic life (600 mg Cl/L instantaneous maximums), irrigation (100 mg Cl/L), livestock watering (600 mg Cl/L) and wildlife (600 mg Cl/L) (Nagpal et al., 2003). As irrigation and extraction for drinking water is not a concern in the immediate area of salt dilution gauging, the guidelines for freshwater aquatic life is 600 mg/L for chloride, which can be approximately converted to 990 mg salt/L. (See http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/chloride.html)

Only one study could be found that examined the effects of salt dilution gauging on aquatic life (Wood and Dykes, 2002). This study performed salt dilution gauging in two streams at three different times of the year and examined whether drifting invertebrates increased following the experiment. If pollution in a stream increases, benthic invertebrates will move into the water column to escape or “drift” downstream to less polluted environments. This study found that the number of drifting invertebrates did increase, but resumed to original levels within two hours of the experiments. Furthermore, the number of individuals lost to drift was negligible compared to the total abundance of invertebrates in the study area. They conclude that while there is an effect of salt dilution gauging, it is short lived and does not affect total abundance in such a way as to be of concern.

Overall, there is very little information on the toxic effects of salt (sodium chloride) on aquatic organisms. Also almost all of the available research considers the effect of exposure times to high concentrations of salt far in excess of the timescales possible with the salt dilution method. The BC guideline for freshwater aquatic life is equivalent to around 990 mg/L. Adverse affects for certain sensitive species for 24 hour exposures were observed at concentration in excess of 2,000 mg/L. The study with shortest time scale (0.25 hr) indicated an LC50 for Brook Trout for concentration of 50,000 mg/L. It should also be noted that studies are for laboratory conditions and in natural streams larger aquatic life, such as fish, have the opportunity to avoid areas of high salt concentration. The avoidance of areas of high concentration by invertebrates was noted in a previous study on the impact of the salt dilution method on aquatic life.

As outlined in the previous section a field trial was conducted whereby the concentration of tracer (specifically the chloride) was measured immediately downstream of the injection site. This was accomplished by placing three probes in the stream thalweg at MORE1, located at distances of 20-, 40-, and 60-m downstream of the injection site. The trial consisted of 10 kg of NaCl injected into a stream discharge of 3.0 m^3/s (R_D = 3 $kg/(m^3/s)$). The background concentration of NaCl was approximately 46 mg/L. Tracer concentrations are assessed with respect to the ambient water quality guidelines for chloride concentration published by the BC Ministry of Water, Land and Air Protection. The recommended ambient water quality guideline for chloride is a maximum concentration of 600 mg/L for freshwater aquatic life. No guidelines are published for sodium (Na). Chloride concentration with time is given in Figure A3-3a, which shows that the concentration of added chloride only exceeds 600 mg/L at the 20-m downstream probe, and then only for approximately 4.0 seconds. If one assumes a background chloride concentration of 46 mg/L, the 600 mg/L threshold is still only exceeded for 4.0 seconds at the 20-m point. The variation of peak chloride concentration with distance downstream is shown in Figure A3-3b. This relationship is well described by a linear regression of peak chloride concentration on distance downstream (R^2 = 0.99; *SE* = 3.0 mg/L; regression significant with $p < 0.01$), which suggests that the peak concentration of added chloride decreases rapidly with distance (slope = -17.4 mg/L/m) and only exceeds 600 mg/L within 30 m of the injection site. Using an average stream velocity of 1.0 m/s, the concentration of added chloride exceeds 600 mg/L for approximately 30 s (not accounting for longitudinal dispersion, which tends to delay peak occurrence with distance downstream). Again, if one assumes that background conductivity represents 46 mg/L of chloride, the distance shifts to within 35 m of the injection site. The test was completed with a conservative dose rate of 3 $kg/(m^3/s)$. The impact of salt would be reduced using a lower dose rate.

References

Bailey, P., P. Boon and K. Morris. 2002. Australian biodiversity – salt sensitivity database. Prepared for Land and Water Australia. http://www.rivers.gov.au/research/contaminants/SaltSensitivityDatabase.xls.

CCME. 2003. Canadian Environmental Quality Guidelines, 1999 plus updates. Canadian Council of Environment Ministers, Winnipeg.

Church, M. and R. Kellerhals, 1970. *Stream gauging techniques for remote areas using portable equipment*. Technical bulletin No. 25, Inland Waters Branch, Department of Energy Mines and Resources, Ottawa, Canada, 89 p.

Elder, K. and R. Kattelmann, 1990. Refinements in dilution gauging for mountain streams, In *Hydrology in Mountainous Regions. I – Hydrological Measurements; the Water Cycle*. IAHS Publication No. 193, pp. 247-254.

Environment Canada/Health Canada. 2003. Priority Substances List Assessment Report – Road Salts.

Hart, B.T., P. Bailey, R. Edwards, K. Hortle, K. James, A. McMahon, C. Meredith and K. Swadling. 1991. *A review of the salt sensitivity of the Australian freshwater biota*. Hydrobiologia 210: 105–144.

James, K.R., B. Cant, and T. Ryan. 2003. *Responses of freshwater biota to rising salinity levels and implications for saline water management: a review*. Australian Journal of Botany 51: 703–713.

Kilpatrick, F.A., and E.D. Cobb, 1985. Measurement of discharge using tracers. Techniques of Water Resources Investigations of the US Geological Survey, *Book 3: Applications of Hydraulics*, Chapter A16, 52 p.

Kite, G., 1994. Measuring glacier outflows using a computerized conductivity system. *Journal of Glaciology*, 40(134), 93-96.

Moore, R.D., 2004. Introduction to salt dilution gauging for streamflow measurement: Part 1. *Streamline Watershed Management Bulletin*, 7(4), 20-23.

Nagpal, N.K., D.A. Levy, and D.D. MacDonald. 2003. *Ambient water quality guidelines for chloride*. Prepared for BC Ministry of Water, Land, and Air Protection.

Spence, C. and M. McPhie, 1997. Streamflow measurement using salt dilution in tundra streams, Northwest Territories, Canada. *Journal of the American Water Resources Association*, 33(2), pp. 285-291.

U.S. EPA. 1988. *Ambient aquatic life water quality criteria for chloride*. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Duluth, Minnesota.

Wood, P.J., and A.P. Dykes. 2002. The use of salt dilution gauging techniques: ecological considerations and insights. Water Research 36: 3054–3062.

APPENDIX 4
FLOW MEASUREMENTS AND RATING EQUATIONS

Appendix 4 – Flow Measurements and Rating Equations

This appendix provides details of flow measurements and rating equations for each of the on-site monitoring stations. Flow measurements made in the field during the 2004 and 2005 field seasons are summarized in Table A4-1. Stage information and the flow measurement technique are also noted. These measurements have been used to construct stage-discharge rating equations for individual hydrostations. All rating curves are provided in Figures A4-1 to A4-22. Situations where rating equations have been developed based on Manning's equation have been noted. Error bars on flow measurements represent measurement error as described (refer to Section 3 for further details).

Table A4-1
Summary of Discharge Measurements

Station	Date	Stage (m)	Q (m^3/s)	Method[a]
GAL-1A	14-Sep-04	0.30	1.51	v
	12-May-04	0.31	1.41	v
	14-Apr-05	0.03	0.13	v
	21-May-05	0.26	2.47	v
	24-May-05	0.26	3.75	sd
	14-Jun-05	0.33	5.38	sd
	7-Jul-05	0.31	4.45	sd
	26-Aug-05	0.31	2.99	sd
	15-Sep-05	0.24	2.40	sd
	17-Sep-05	0.24	2.10	sd
	22-Oct-05	0.23	2.21	sd
GAL-1B	10-May-04	0.38	1.64	v
	15-Apr-05	-	0.30	v
	21-May-05	0.54	3.84	v
	22-May-05	0.63	4.40	sd
	10-Jun-05	0.91	10.4	sd
	5-Jul-05	1.60	14.1	sd
	17-Sep-05	0.47	6.53	sd
	23-Oct-05	-	1.91	sd
Gwm4	16-Sep-04	0.30	0.07	v
	24-May-05	0.20	0.30	sd
Gwm4	10-Jul-05	0.04	0.38	sd
	23-Aug-05	0.01	0.27	v
	13-Sep-05	0.02	0.28	v
	23-Oct-05	-	0.14	v

(continued)

Table A4-1
Summary of Discharge Measurements (continued)

Station	Date	Stage (m)	Q (m3/s)	Method[a]
Gwm5	14-Sep-04	0.24	0.98	v
	23-May-05	0.35	1.56	v
	10-Jul-2005	0.50	3.39	sd
	17-May-05	0.34	1.41	sd
	15-Jun-05	0.42	1.75	sd
	26-Aug-05	0.50	2.56	sd
	15-Sep-05	0.37	1.60	sd
	17-Sep-05	0.37	1.65	sd
	23-Oct-05	0.19	0.60	sd
Gwm6	15-Apr-05	0.02	0.50	v
	20-May-05	0.29	5.71	v
	22-May-05	0.34	5.25	sd
	13-Jun-05	0.40	9.25	sd
	07-Jul-05	0.51	12.75	sd
	25-Aug-05	0.49	9.73	sd
	27-Aug-05	0.48	7.22	sd
	13-Sep-05	0.56	9.30	sd
	17-Sep-05	0.33	6.30	sd
	23-Oct-05	0.26	3.08	sd
Gwm7	16-Sep-04	0.289	3.72	v
	14-Apr-05	-0.13	0.80	v
	22-May-05	0.41	9.30	sd
	10-Jun-05	0.66	19.2	sd
	09-Jul-05	0.64	14.6	sd
	28-Aug-05	0.69	10.3	sd
	15-Sep-05	0.37	8.50	sd
	17-Sep-05	0.34	7.30	sd
	22-Oct-05	0.36	7.80	sd
Gwm8	15-Apr-05	0.20	1.70	v
	23-May-05	0.40	15.2	sd
	10-Jun-05	0.46	25.9	sd
	09-Jul-05	0.37	18.4	sd
	26-Aug-05	0.45	39.7	sd
	15-Sep-05	0.33	12.0	sd
Gwm8	17-Sep-05	0.29	10.0	sd
	22-Oct-05	0.33	8.70	sd
MORE-1	17-Sep-04	0.10	0.50	v
	08-May-04	0.14	0.69	v
	26-Jul-04	0.31	5.25	v
	17-Apr-05	0.31	0.10	v
	17-May-05	0.29	3.47	v
	22-May-05	0.30	2.90	sd

(continued)

Table A4-1
Summary of Discharge Measurements (continued)

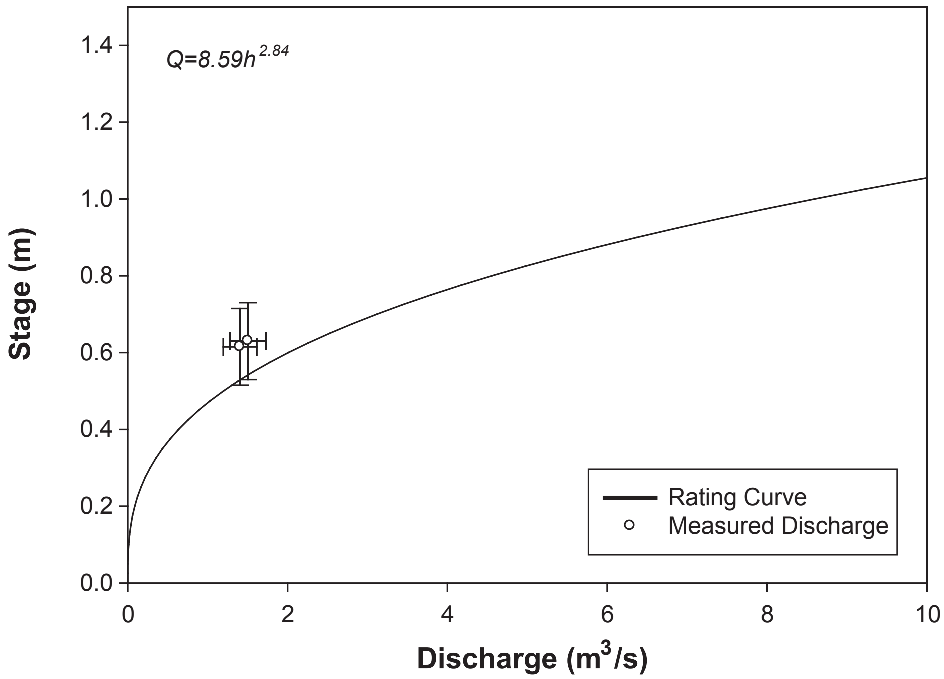
Station	Date	Stage (m)	Q (m3/s)	Method[a]
	12-Jun-05	0.32	4.7	sd
	06-Jul-05	0.30	4.2	sd
	24-Aug-05	0.30	2.65/2.90	v/fl
	13-Sep-05	0.32	3.04	v
	16-Sep-05	0.19	1.10	sd
	22-Oct-05	0.17	0.61	v
MORE-4	20-Sep-04	0.33	2.25	v
	26-Jul-04	0.55	15.4	v
	17-Apr-05	0.18	0.34	v
	25-May-05	0.72	22.8	sd
	12-Jun-05	0.77	23.9	sd
	08-Jul-05	0.66	14.2	sd
	25-Aug-05	0.55	8.20	sd
	14-Sep-05	0.45	7.50	sd
	16-Sep-05	0.42	5.30	sd
	26-Oct-05	0.45	4.10	sd
MORE-7	16-Apr-05	0.54	8.76	v
	11-Jun-05	1.10	82	est
	13-Jun-05	0.97	108	est
	08-Jul-05	0.85	86	est
	25-Aug-05	0.55	28	est
	27-Aug-05	0.52	21.0	fl
	14-Sep-05	0.70	32.0/20.0	fl/est
Mwm2	17-Sep-04	-	0.04	v
	06-Jun-05	0.16	0.63/0.60	v/sd
	06-Jul-05	0.13	0.40	sd
	24-Aug-05	0.11	0.16/0.21	v/fl
	13-Sep-05	0.10	0.17	v
	16-Sep-05	0.05	0.07	sd
	27-Oct-05	0.02	0.02	v
Mwm3	19-Sep-04	0.40	0.03	v
	21-May-05	0.58	0.34	v
	12-Jun-05	0.58	1.00	sd
	06-Jul-05	0.44	0.90	sd
	25-Aug-05	0.53	0.19	v
	14-Sep-05	0.41	0.09	v
	26-Oct-05	0.43	0.10	v
Mwm4	20-Sep-04	-0.08	0.27	v
	11-Jun-05	0.26	2.30	sd
	05-Jul-05	0.34	2.70	sd
	27-Aug-05	0.31	1.50	sd
	14-Sep-05	0.05	0.67	v
	26-Oct-05	0.01	0.55	v

(continued)

Table A4-1
Summary of Discharge Measurements (completed)

Station	Date	Stage (m)	Q (m3/s)	Method[a]
NM-1	11-Jun-05	0.49	46.3	sd
	13-Jun-05	0.38	61.3	sd
	08-Jul-05	0.31	48.8	sd
	25-Aug-05	0.03	15.7/35	fl/est
	14-Sep-05	-0.09	11.5	sd
	16-Sep-05	-0.17	10.7	sd
	26-Oct-05	-0.05	14.2	sd
MAT-1	11-Jun-05	0.38	11.2	sd
	05-Jul-05	0.48	14.8	sd
	27-Aug-05	0.33	5.50	sd
	14-Sep-05	0.27	4.50	sd
	26-Oct-05	0.28	3.80	sd
Sphaler-2	07-May-04	0.50	4.21	v
	16-Apr-05	0.10	0.49	v
	15-Jun-05	0.80	23.4	sd
	08-Jul-05	0.85	27.5	sd
	25-May-05	0.70	14.9	sd
	24-Aug-05	0.76	20.5	sd
	13-Sep-05	0.76	23.0	sd
	27-Oct-05	0.28	3.30	sd
LS-1	05-Jul-05	0.79	65	est
	24-Aug-05	0.44	40.0	fl
	13-Sep-05	0.41	32.0	fl
Contact Creek	16-Sep-04	0.24	0.50	v
	27-Jul-04	0.15	2.33	v
Contact Creek	16-Apr-05	0.00	0.36	v
	24-May-05	0.64	8.40	sd
	22-Oct-05	0.32	1.94	v
Reference Creek	12-May-04	0.00	9.03	v
	16-Apr-05	-0.46	1.40	v
	26-Aug-05	0.90	39.0	fl
	15-Sep-05	0.49	32.0	fl
Ball Creek	19-Sep-04	-0.02	6.14	v
	27-Jul-04	0.82	25.6	v
	16-Apr-05	-0.17	1.51	v
	27-Aug-05	0.58	13.0	fl
	14-Sep-05	0.40	16.0	fl
Porcupine River	05-Jul-05	-	75.5	v

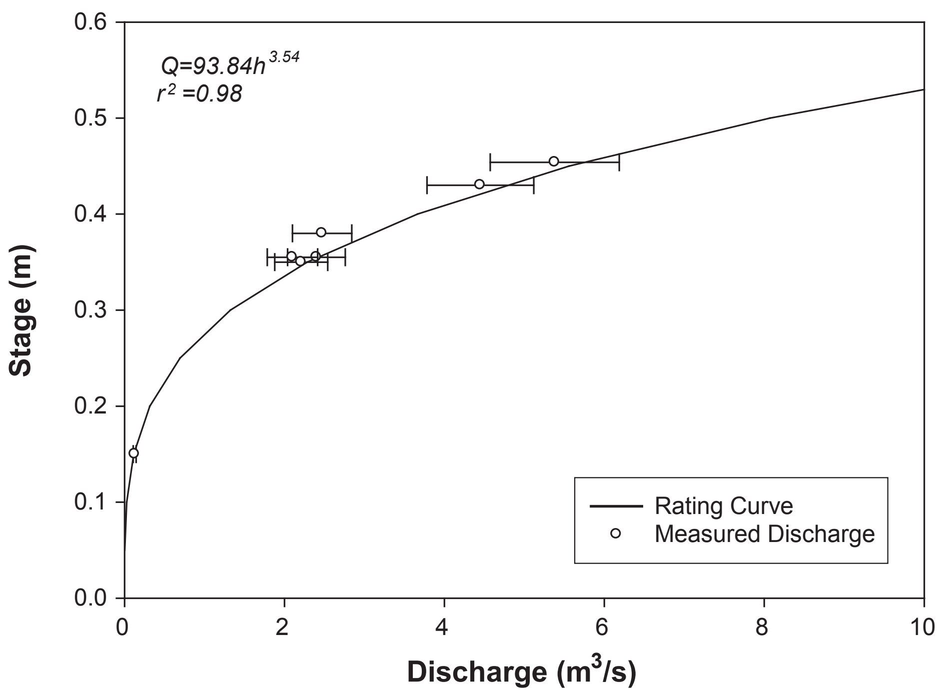
[a] Discharge measurement methods
v = velocity-area calculation using a current meter across the channel cross-section
sd = salt dilution
fl = surface velocity measurement using float and estimate of channel cross-sectional area
est = estimate of discharge based on judgment and comparison with similar flows at other sites



GAL-1A - 2004 Rating Curve

FIGURE A4-1

Notes: Rating equation derived based on channel survey and Manning's equation. Curve is best representation of field survey data. In order to fit curve to data points requires unrealistic Manning's n value.



GAL-1A - 2005 Rating Curve

FIGURE A4-2

Note: Station rebuilt in new location in 2005

Rescan™

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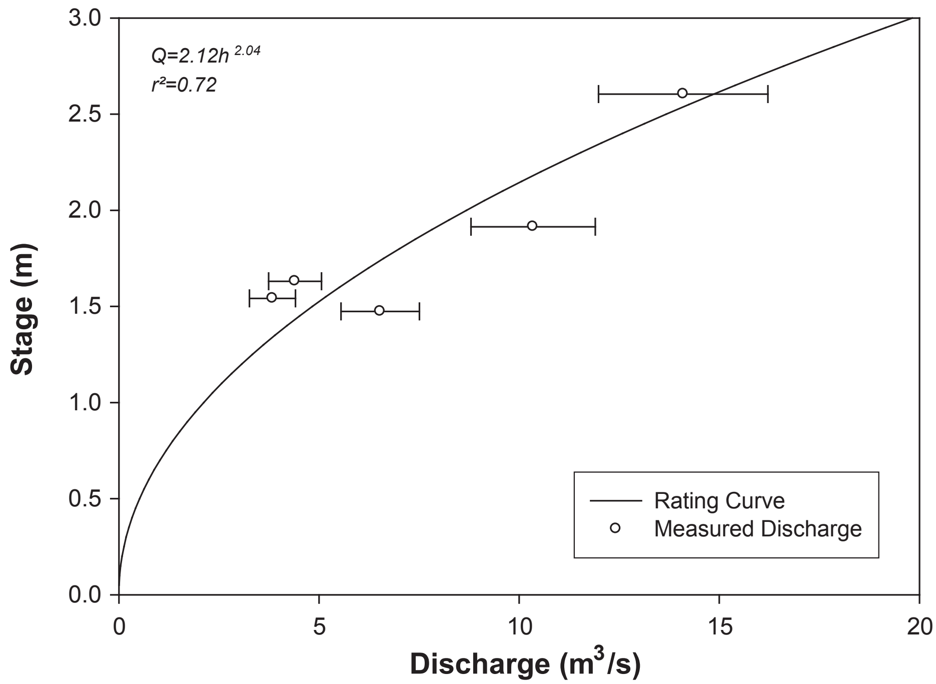
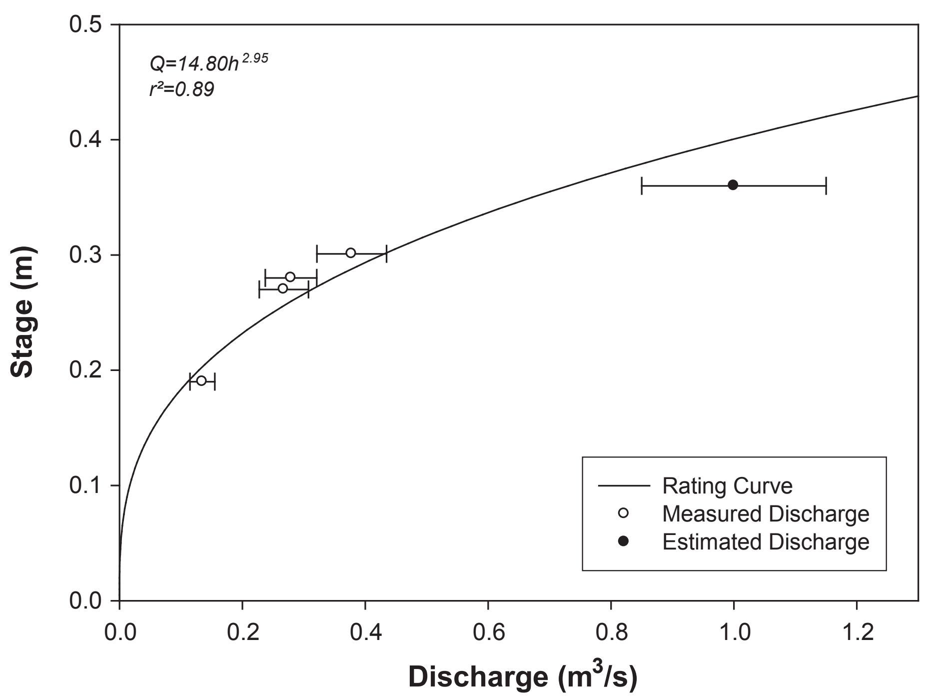


GAL-1B - 2005 Rating Curve

FIGURE A4-3



Gwm4 - 2004 and 2005 Rating Curve

FIGURE A4-4

Note: Estimate based on observed flows at Gwm5

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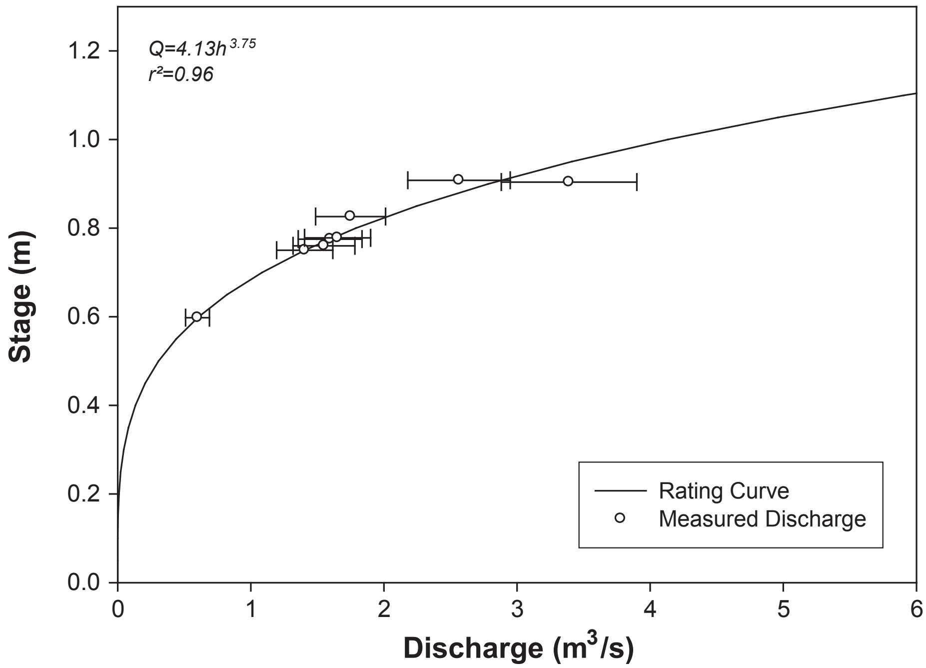
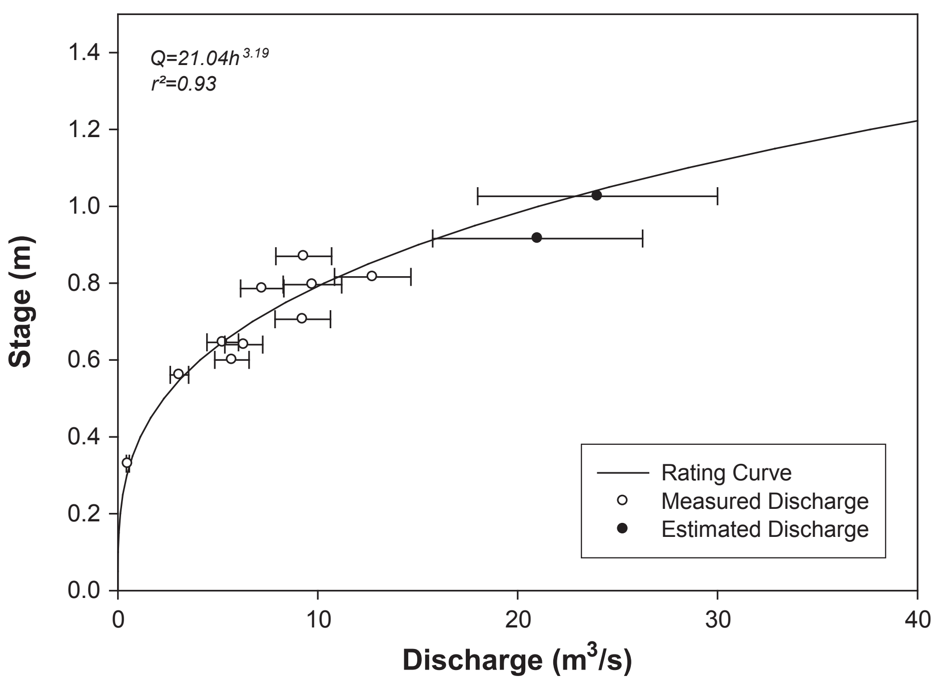


Gwm5 - 2004 and 2005 Rating Curve

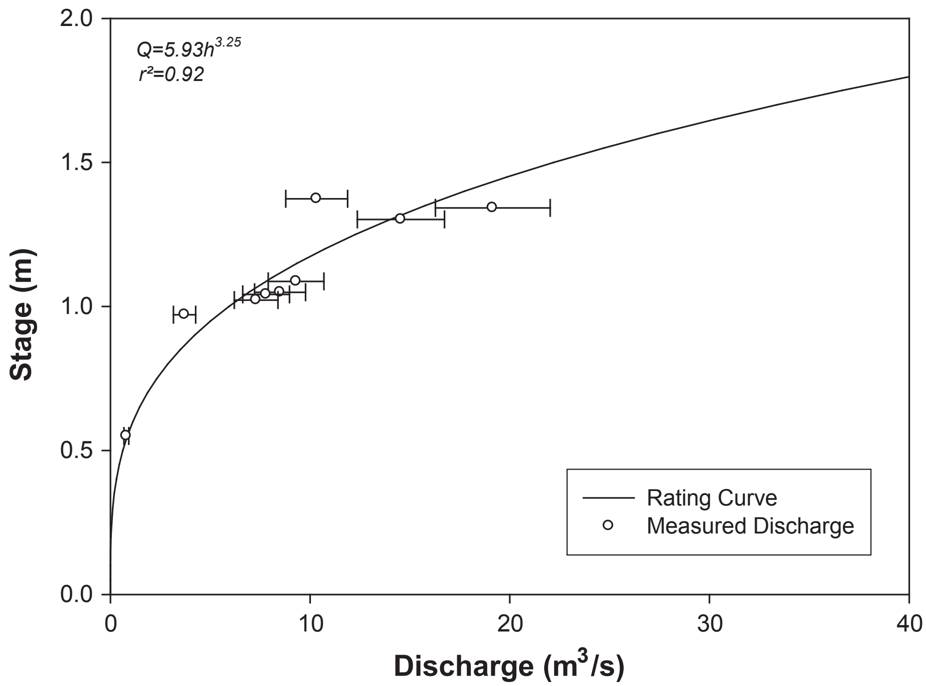
FIGURE A4-5



Gwm6 - 2004 and 2005 Rating Curve

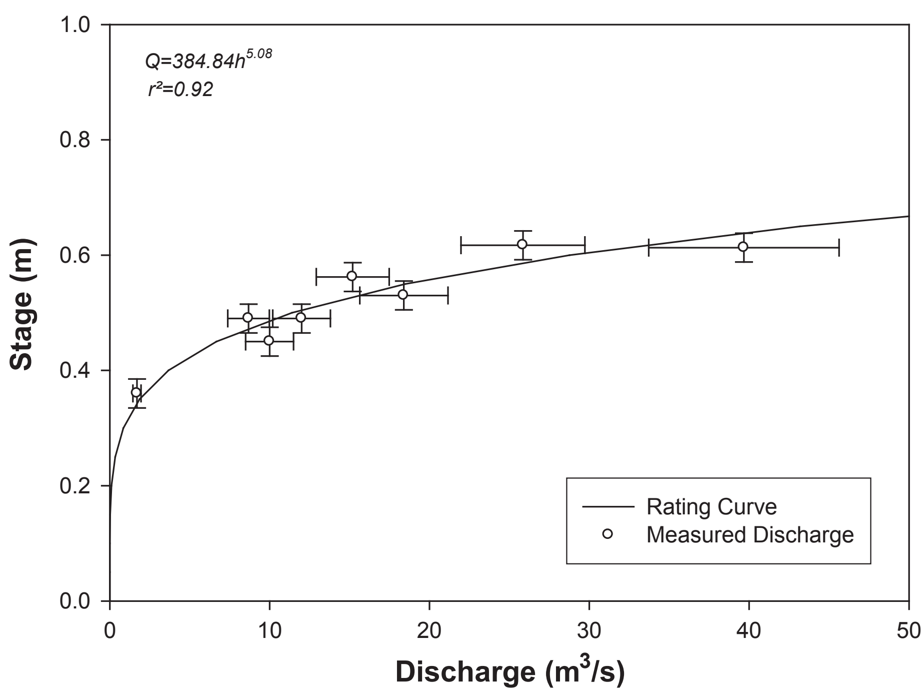
FIGURE A4-6

Note: Estimates based on discharge measurements at Gwm7



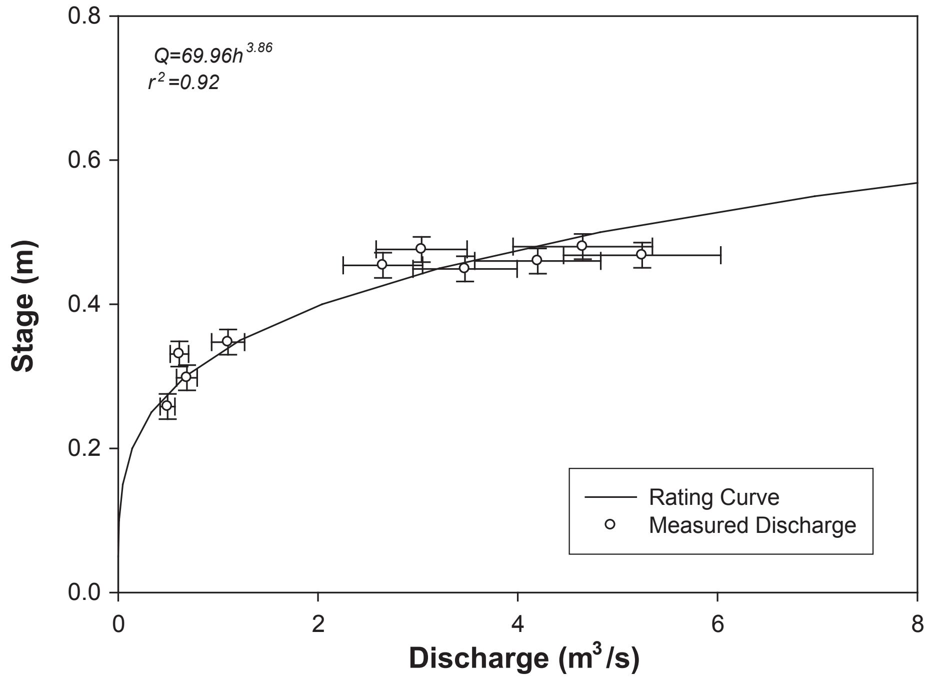
Gwm7 - 2004 and 2005 Rating Curve

FIGURE A4-7



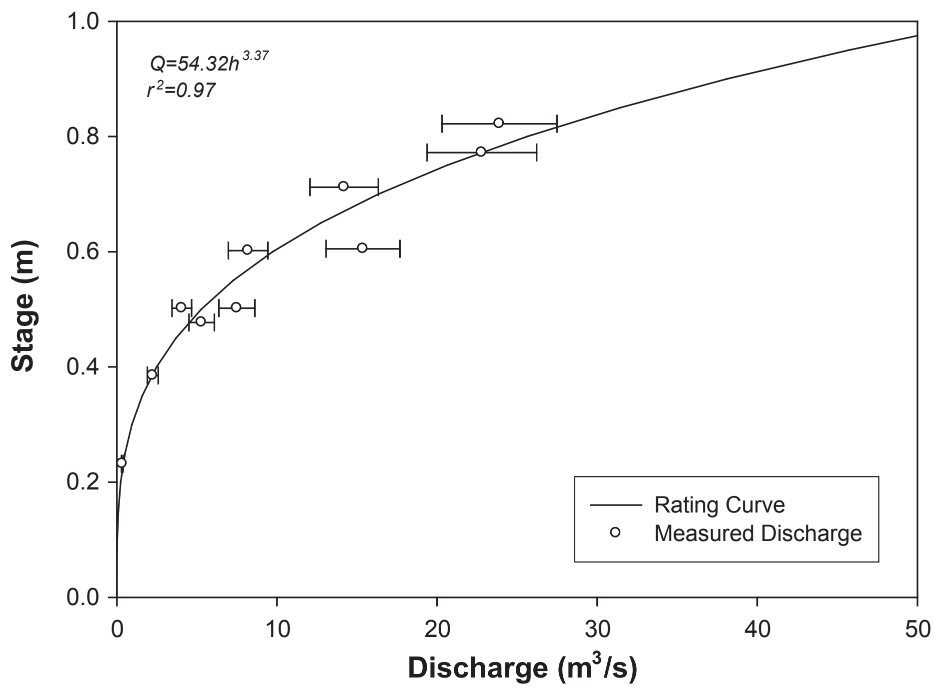
Gwm8 - 2005 Rating Curve

FIGURE A4-8



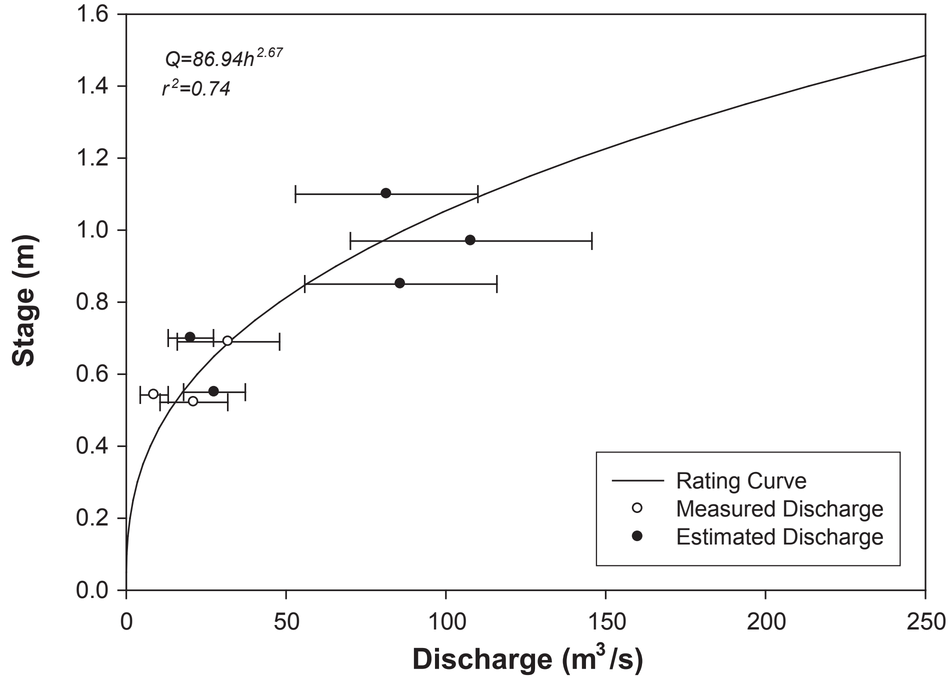
MORE-1 - 2004 and 2005 Rating Curve

FIGURE A4-9



MORE-4 - 2004 and 2005 Rating Curve

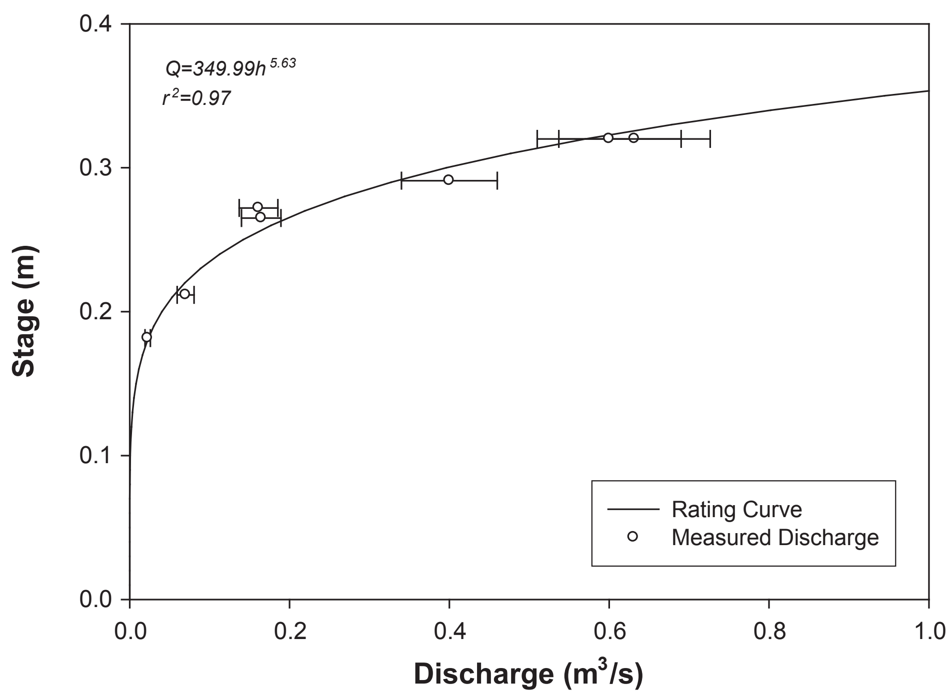
FIGURE A4-10



MORE-7 - 2005 Rating Curve

FIGURE A4-11

Note: Estimates based on scaled discharge measurements from MORE-4



Mwm2 - 2005 Rating Curve

FIGURE A4-12

Rescan™ RTEC Keepers of the Land

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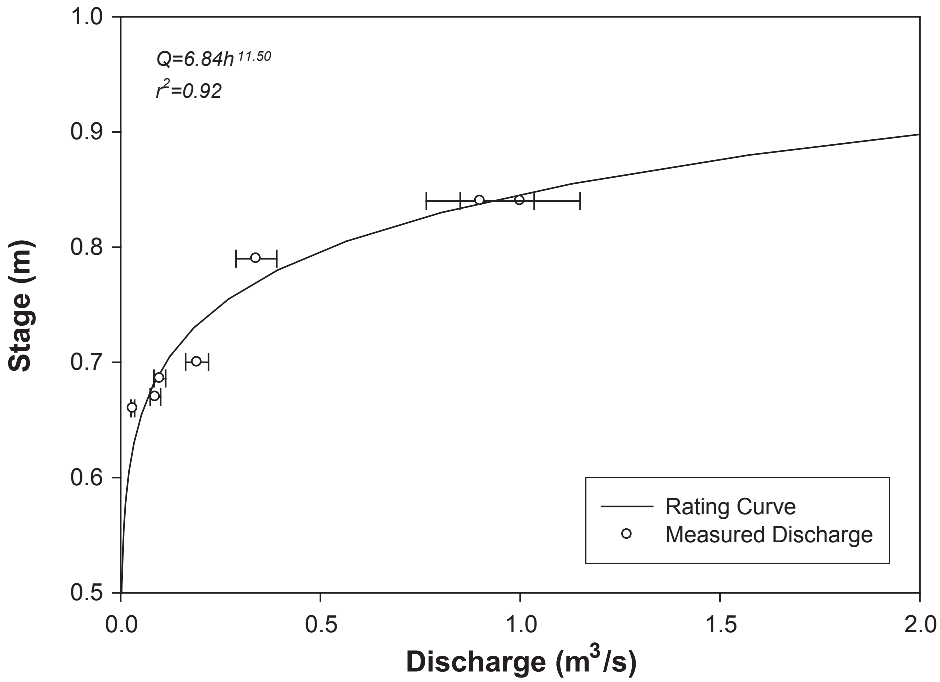
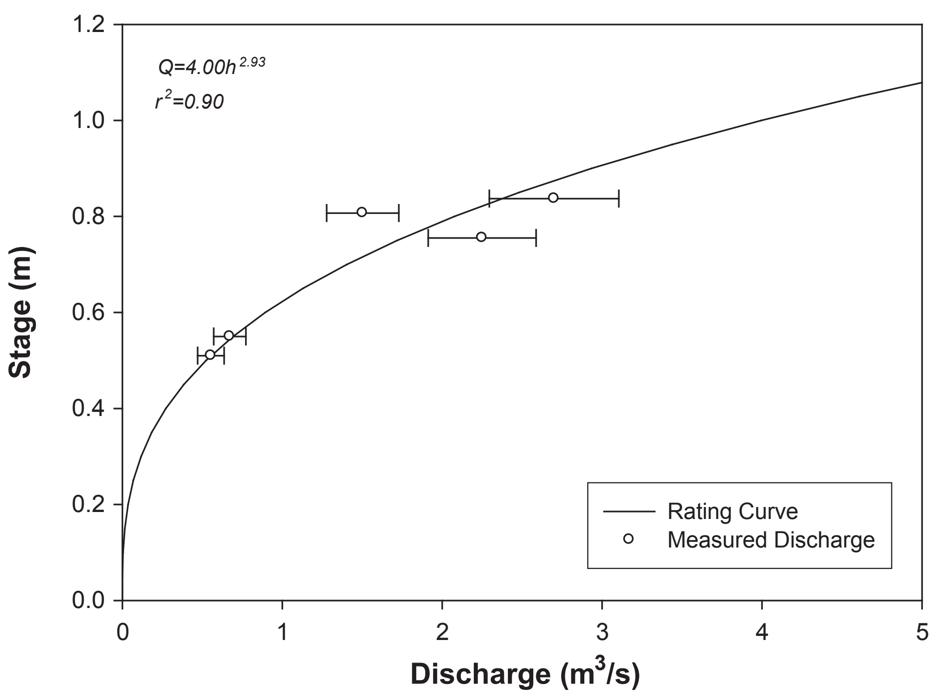


Mwm3 - 2004 and 2005 Rating Curve

FIGURE A4-13



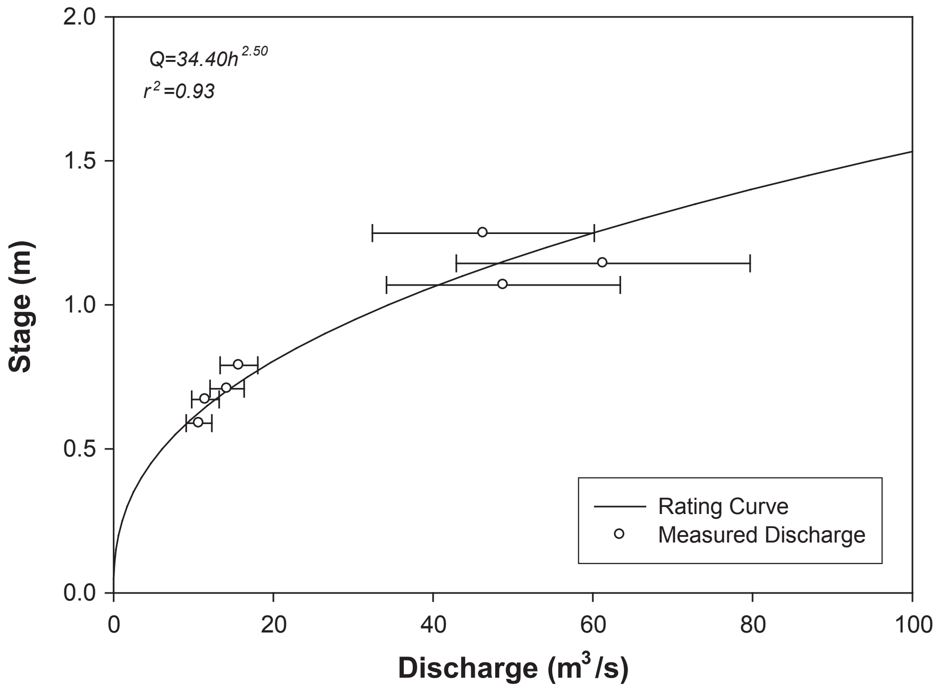
Mwm4 - 2004 and 2005 Rating Curve

FIGURE A4-14

Rescan™

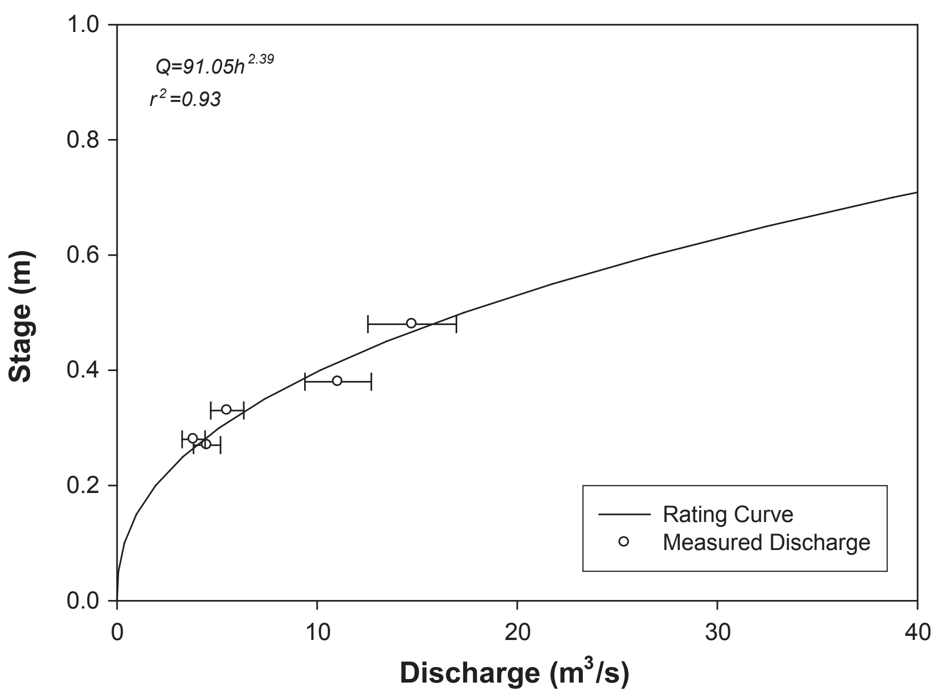
RTEC Keepers of the Land

NovaGold Canada Inc.



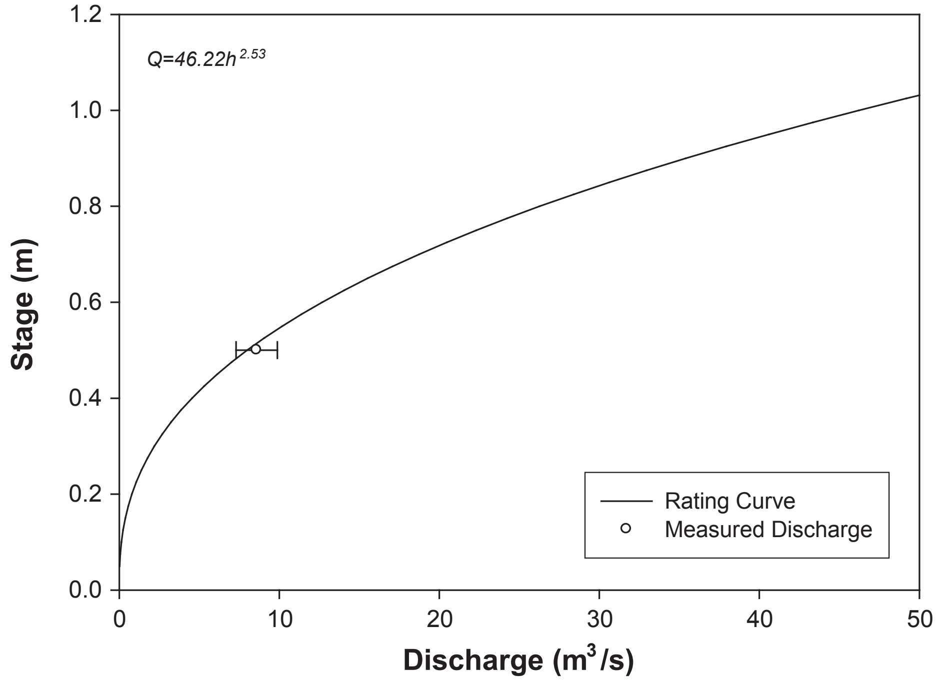
NM-1 - 2005 Rating Curve

FIGURE A4-15



MAT-1 - 2005 Rating Curve

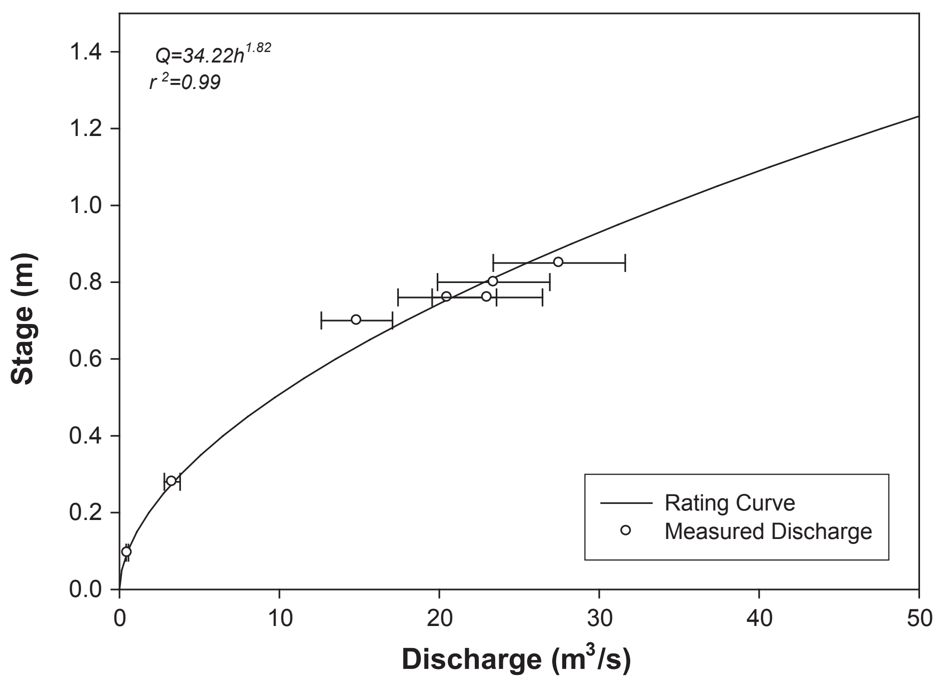
FIGURE A4-16



Sphaler-2 - 2004 Rating Curve

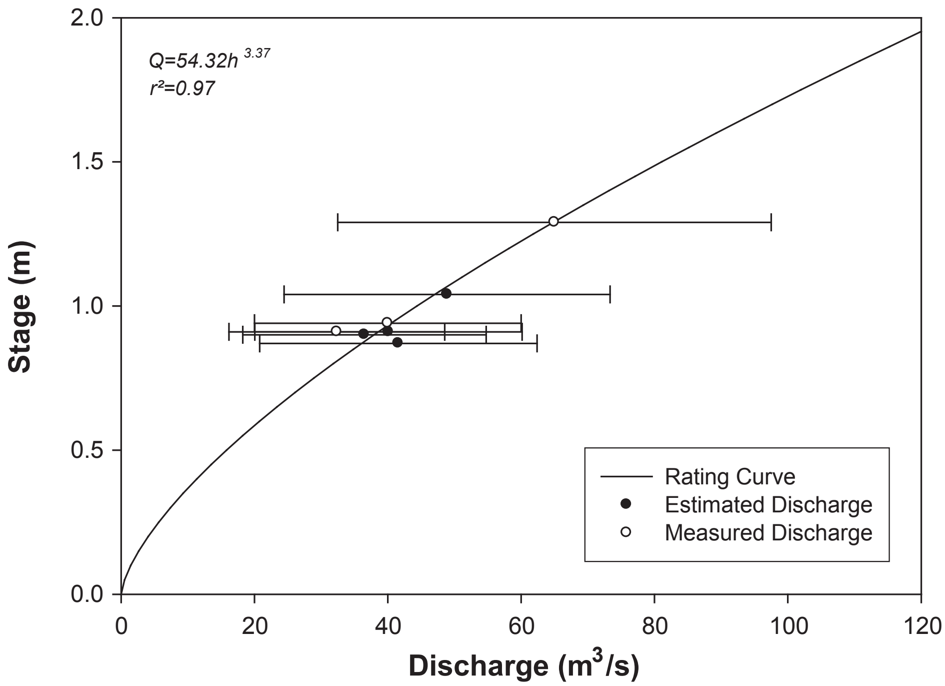
FIGURE A4-17

Note: Rating equation derived based on channel survey and Manning's equation.



Sphaler-2 - 2005 Rating Curve

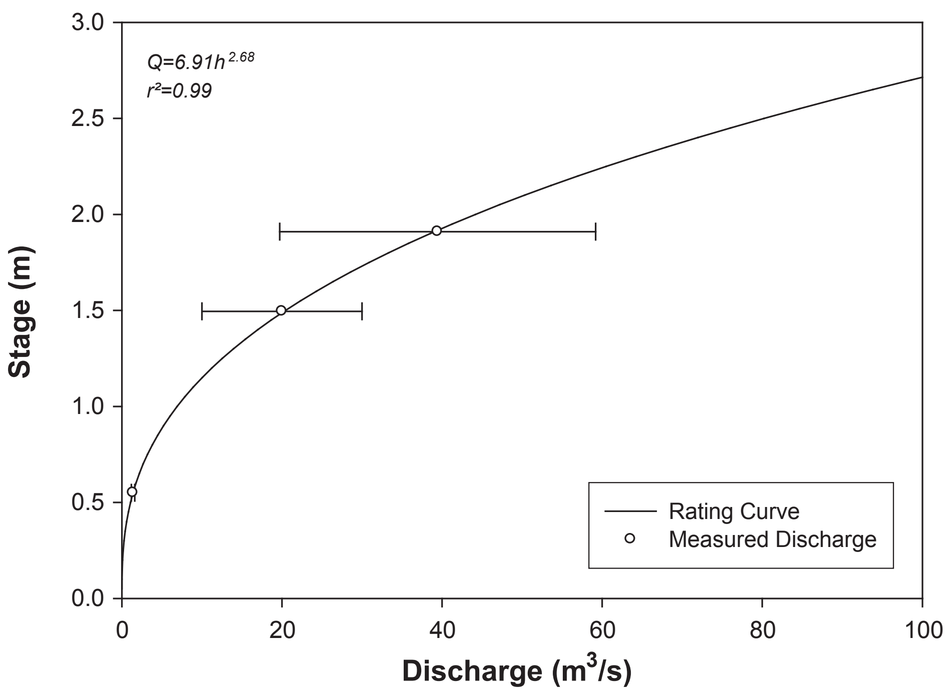
FIGURE A4-18



LS-1 - 2005 Rating Curve

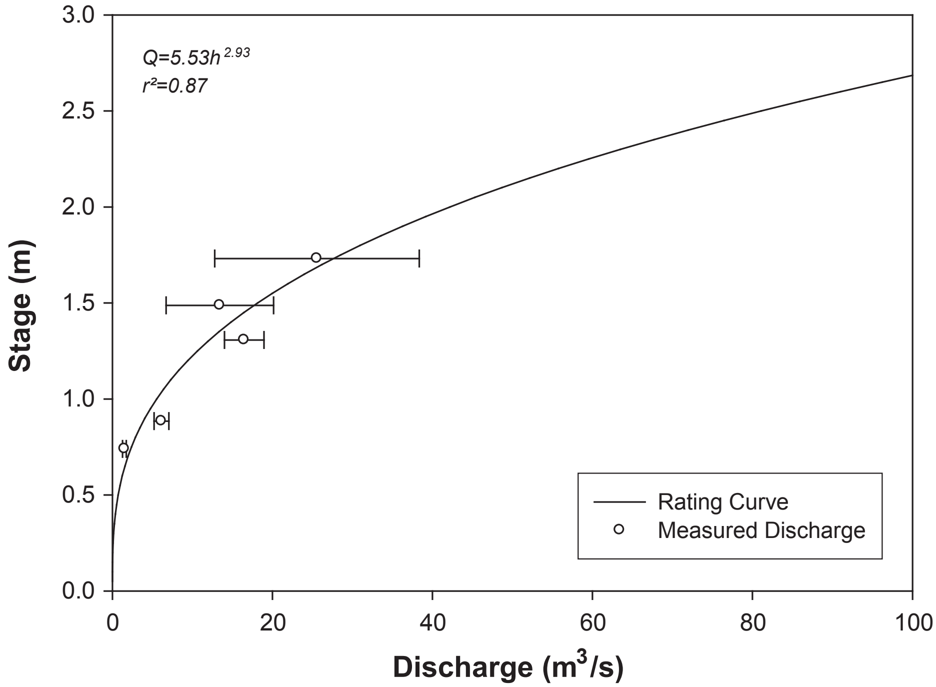
FIGURE A4-19

Note: Estimates based on scaled discharge measurements from Sphal-2



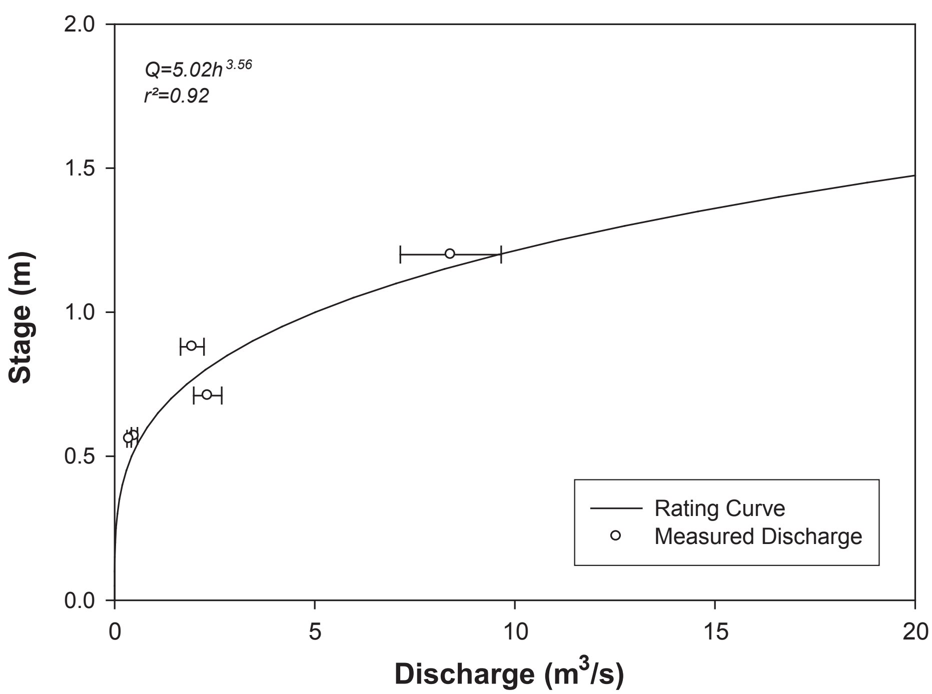
REF-2 - 2004 and 2005 Rating Curve

FIGURE A4-20



Ball Creek - 2004 and 2005 Rating Curve

FIGURE A4-21



Contact Creek - 2004 and 2005 Rating Curve

FIGURE A4-22