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Abbreviations

GSD	grain-size distribution
HD	hydrodynamic
HEC-HMS	Hydrologic Engineering Center Hydrological Modeling System
kt	kilotonnes
LAA	local assessment area
MT	mud transport
PMF	probably maximum flood analysis
RAA	regional assessment area
ST	sand transport
SSC	suspended sediment concentrations
the Project	Springbank Off-stream Reservoir Project
TDR	technical data report
TDS	total dissolved solid
VC	valued component
WSG	Water Survey of Canada

6.0 ASSESSMENT OF POTENTIAL EFFECTS ON HYDROLOGY

Hydrology encompasses the occurrence and movement of fresh water on, and beneath, the surface of the earth and through the atmosphere. Included in the definition of hydrology is the transport of sediment. Springbank Off-stream Reservoir Project (the Project) flood and post-flood operation would affect hydrology (i.e., surface water quantity) and associated sediment transport in rivers, creeks and streams. These hydrological effects are intentional because the purpose of the Project is to mitigate floods from approximately the 1:10 year level (a peak flow of 200 m^3/s) to the design flood level (approximate peak flow of 1,170 m^3/s) by maintaining a flow of 160 m^3/s in the Elbow River, where possible. The Project has been designed to temporarily divert water (and associated suspended sediment) from the Elbow River at flow rates above 160 m^3/s. As a result, significant modification of the Elbow River hydrology during a flood is the desired effect of the Project in order to protect Calgary (and farther downstream) infrastructure.

The primary purpose of the hydrological assessment for flood and post-flood operation presented here is to provide data on the estimated extent of change so that other VCs can assess relevant effects and their significance. Intentional changes to the hydrology of Elbow River during floods may affect water quality, aquatic life and other ecological and human receptors as a result of changes in water flow and sediment transport during flood and post-flood operations.

6.1 SCOPE OF THE ASSESSMENT

This assessment considers two phases of the Project: flood operations and post-flood operations.

- Flood operations refers to when water and associated sediment is diverted from the Elbow River into the diversion channel and into the reservoir. Therefore, the assessment focuses on the effects of this diversion on the downstream hydrology of the Elbow River, downstream changes to sediment transport and morphology in the Elbow River, and deposition of sediment in the reservoir.
- Post-flood operations refer to the release of retained water from the reservoir, sediment partial clean-up, and maintenance activities required on project infrastructure (e.g., such as the diversion channel, floodplain berm, off-stream dam, access roads and bridges). The assessment focuses on the 1) effects of reservoir water release on the hydrology of the low-level outlet and the Elbow River, 2) effects on suspended sediment transport in the low-level outlet and at the confluence with the Elbow River, and 3) morphological effects on the low-level outlet.

The effects are assessed for three floods using hydrodynamic and sediment transport modelling (more detail is provided in Section 6.4.1 and Volume 4, Appendix J, Hydrology TDR): design flood, 1:100-year flood and 1:10-year flood. These recurrence intervals represent an increasing probability of occurrence in any given year. The best available estimates for the design flood is a less than 0.5% probability of occurring in any given year. The probability of a 1:100 year flood occurring in any given year is 1%. The probability of a 1:10 year flood occurring in any given year is 10%.

Engagement and key concerns, effects pathways and spatial boundaries for the assessment of the flood and post-flood effects on hydrology are presented in Volume 3A, Section 6. The temporal boundary for the flood and post-flood operations is indefinite, since the Project is a permanent installation. The frequency of flood and post-flood operations is unknown, except as assumed in the modelling.

The effects characterization is the same as used in Volume 3A, Section 6, except for duration. This characterization has been modified as shown in Table 6-1.

Table 6-1 Characterization of Project Effects on Hydrology and Sediment Transport

Characterization	Description	Quantitative Measure or Definition of Qualitative Categories
Duration[1]	The period of time required until the measurable parameter or the VC returns to the existing condition, or the effect can no longer be measured or otherwise perceived	Short-term –effect lasts for up to one year Medium-term –effect extends through several years up to 10 years Long-term –effect that extends longer than 10 year

NOTE:
[1] Duration time scales are modified from Knighton (1998) and reflect that changes in sediment transport and channel form, as a function of discharge and sediment supply, are not the product of instantaneous conditions.

No definition for significance is provided because the purpose of the Project is to actively modify the hydrology of the Elbow River during floods by diverting flows greater than 160 m^3/s. Included in the flood mitigation is release of retained water back into Elbow River through the low-level outlet after a flood. This flood mitigation would modify downstream flows and associated sediment transport. The modifications to the hydrology and sediment transport system would change the morphological response of the Elbow River in the LAA and the low-level outlet to floods as well as change the timing and magnitude of suspended sediment transfer downstream.

The design flood is based on the 2013 flood and the 1:10 year flood is based on the minimum flow that the Project would actively divert (Stantec 2015a) and is also representative of the 2008 flood in Calgary. The 1:100 year flood is based on the flow recurrence interval commonly used in floodway planning and management. The 1:100 year flood is based on a hypothetical or synthetic hydrograph, since unlike the design flood and 1:10 year flood, there are not measured data from such a flood. The (2013) design flood volume that is used to estimate engineering storage volumes required for the Project is based directly on volumes derived from the estimated hydrograph at Glenmore Reservoir, not at Bragg Creek, due to data limitations at the time. However, to maximize realism for the modelling used in this assessment, the hydrographs recorded by the Water Survey of Canada (WSC) at Bragg Creek are used in the model as the upstream boundary condition, where possible.

6.2 EXISTING CONDITIONS FOR HYDROLOGY

The geological and climate setting, basin characteristics, hydrology and ice dynamics are discussed in Volume 3A, Section 6.2. Sediment characteristics, more germane discussion around the hydrological modelling and assessment of the flood and post-flood effects are presented in the following sections.

6.2.1 Suspended Sediment Concentrations

The following section focuses on suspended sediment concentrations (SSC) because this fraction dominates sediment transport in the Elbow River and has a greater effect on water quality, including sedimentation in the reservoir. A discussion of total dissolved solids (TDS) is provided in Volume 4, Appendix J, Hydrology Technical Data Report.

The relationship between discharge and suspended sediment concentrations (SSC) show a decrease in slope from 2.078 at Bragg Creek to 1.311 at Sarcee Bridge. Sites with high slope values have been interpreted as indicating that most sediment transport occurs with high discharge, as a function of sediment availability and higher erosive power for transport (Asselman 2000). As a result, large parts of the annual load are transported during high discharge. However, the decrease in slope values downstream in Elbow River suggest that suspended sediments concentrations decline with higher discharge downstream.

The decrease in slope values offers some insight into how the suspended sediment regime changes downstream in the Elbow River watershed. The slope value decrease can be interpreted as indicating that a significant proportion of fine sediment goes into storage between Bragg Creek and Sarcee Bridge during high flows. This storage may play a significant role in lowering downstream concentrations, and thus suspended sediment yields, during high flows as well as providing a sediment source during non-flood flow periods in the lower reaches. The remobilization of stored sediment likely explains why the rating curve parameters suggest that suspended sediment concentrations at Sarcee Bridge are higher at low flows than at

Bragg Creek. Because low to medium flows dominate the Elbow River hydrological regime, remobilization or winnowing of fine sediment deposited during high flows and inputs from sources within or near the City of Calgary likely control the overall concentrations, and thus suspended sediment yields, of Elbow River. This control within the lower reaches of Elbow River has also demonstrated by Sosiak and Dixon (2006).

The dominance of low flows and associated SSC samples has implications for the estimation of SSC at flood flow levels. The maximum SSC recorded at Bragg Creek and Highway 22 for the period 1999 to 2016 was 3,187 mg/L and 3,570 mg/L for flows of 100 m^3/s and 71 m^3/s, respectively. As a result, no measured data exists to constrain possible SSC concentrations at flows over an order of magnitude higher than the maximum measured. In the absence of constraining data, the SSC-discharge relationships were assumed to be applicable up to 1,000 m^3/s. This assumes that no curvature effects occur at high concentrations (Asselman 2000; Warrick 2015). A 1,000 m^3/s cutoff is used because it is ten times higher than the maximum discharge that SSC has been measured at and has only been exceeded in the record during the 2013 flood. This exceedance peaked at 1,170 m^3/s with flows above 1,000 m^3/s for a total of four hours.

Maintenance of the fitted relationships up to 1,000 m^3/s generates peak SSC concentrations for the design flood of approximately 140,000 mg/L at Bragg Creek. This concentration equates to approximately 14% by weight and, assuming a density of 2,650 kg/m^3, approximately 5% by volume. Although the validity of this estimate is unknown, the concentration weight and volume percentages fall within the range of sediment concentrations associated with high magnitude floods (Scott 1988; Costa 1998). These estimates assume that sediment supply in the Elbow River is not supply limited during floods. However, recognizing the uncertainties surrounding the estimates of suspended concentrations at high discharges in Elbow River, the values and data generated from them likely represent near the maximum and should be interpreted as possible rather than probable.

Estimates of mean monthly along with maximum and minimum mean monthly suspended sediment concentrations are summarized in Figure 6-1. The data shows that the highest mean monthly concentrations, and associated variability, occur during the high flow period of June. Concentrations are higher at Bragg Creek and Highway 22, and then decline by approximately 30% downstream (Table 6-2). In contrast, downstream concentrations for the remaining open water months are typically between 100% and 400% higher.

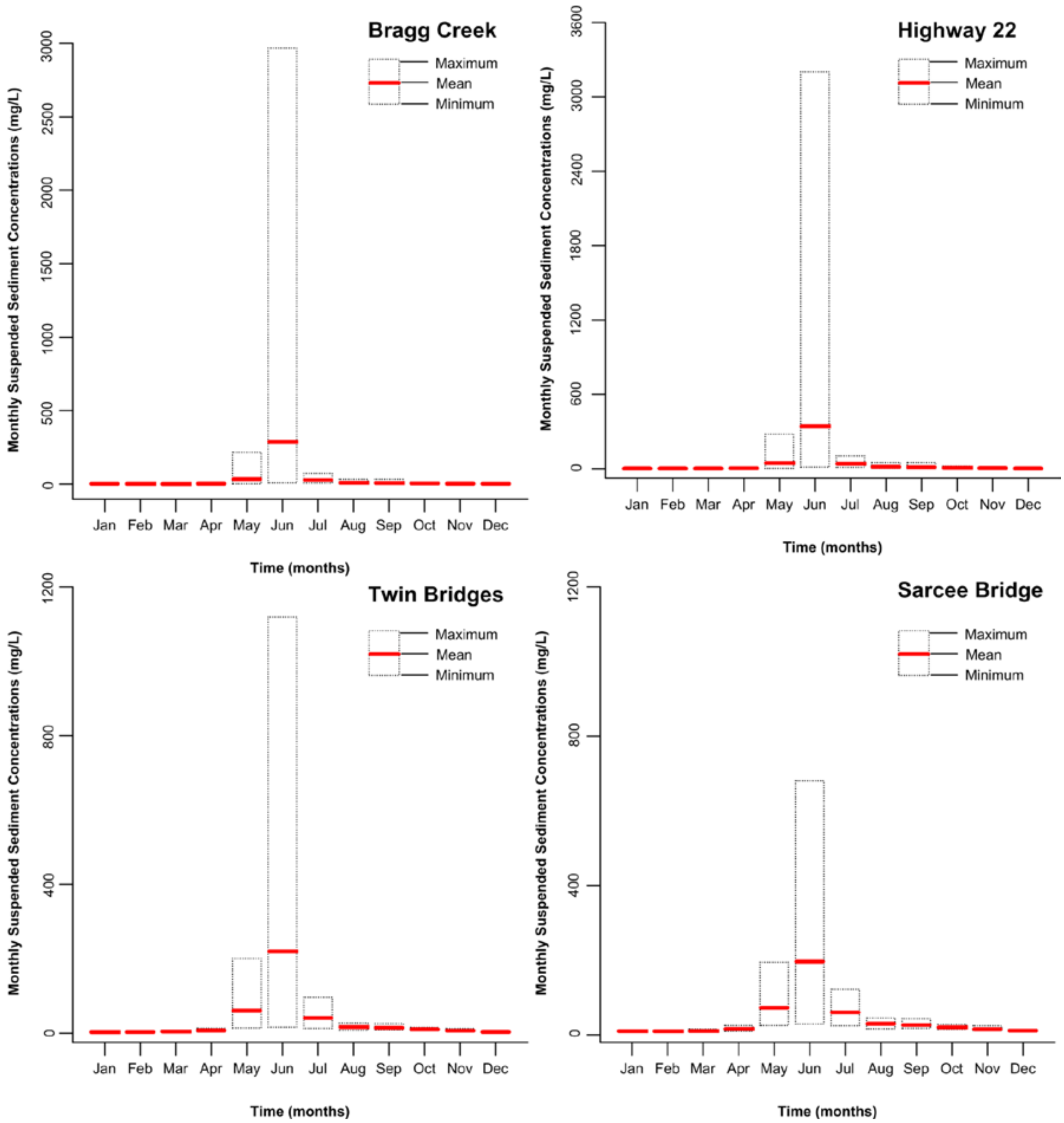


Figure 6-1 Historical Monthly Suspended Sediment Concentrations

Table 6-2 Estimated Mean Monthly Suspended Sediment Concentrations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bragg Creek[1]	2	2	1	3	33	288	28	10	8	5	3	2
Highway 22[1]	3	3	4	7	60	219	41	16	14	10	7	3
Twin Bridges[1]	3	3	4	7	60	219	41	16	14	10	7	3
Sarcee Bridge[1]	10	10	10	15	72	196	60	30	26	20	15	11
Bragg Creek/Sarcee Bridge Difference (%)	400	400	900	400	118	-32	114	200	225	300	400	450

NOTE:
[1] value are expressed in g/m^3

6.2.2 Grain-Size Distribution of Surface and Shallow Sub-Surface Sediment

The surface particle size results suggest that there is considerable variability in particle sizes along the length of the Elbow River with no evidence of a clear trend in either D_{30}, D_{50} or D_{90} from section to section (Figure 6-8). The D_{50} from Redwood Meadows to the Weaselhead averaged approximately 37 mm and 31 mm (standard deviations of 14 mm and 8 mm) for field sampled and photo sieved samples, respectively. In contrast, the D_{30}, D_{50} and D_{90} results for the subsurface samples suggest that there is a downstream fining trend. However, the variation in all shallow subsurface particle diameters also increases downstream, offsetting the apparent pattern of downstream fining.

Based on the surface and shallow subsurface grain-size distributions (GSD), the Elbow River is dominated by gravel sized material (2 mm to 64 mm) and coarse silt/sand (0.063 mm to 2 mm). For the subsurface GSD, gravels account for, on average, 77% and coarse silt/sand, 13% of the GSD. Fines account for 3%. Bore hole data collected for the Project from the Elbow River floodplain near the diversion structure, at depths of between 1.8 m and 4.0 m, show a similar GSD. Gravel-sized fractions account for between 53% and 79%; sand-sized fractions, for 17 to 36% of GSD; and fines (silt-sized) for less than 10%. The borehole data suggest that the GSD percentages measured in on the active floodplain are maintained at depth, except for a slight increase in the percentage of fine particles.

The low percentage of shallow subsurface particles less than 0.063 mm suggests that most sub-0.063 m particles have been winnowed, leaving a censored layer of coarse gravel with voids free of fines (Carling and Reader 1982; Bundt and Abt 2001). This type of bed stratification results in a higher proportion of fine in voids beneath the surficial layer, resulting in a fining of the subsurface material in comparison to the surface GSD, as typical of many gravel bed rivers. Although not strong, this pattern is observed for the Elbow River subsurface GSD data (Figure 6-8) and supported by borehole data.

The ratio between the surface and shallow subsurface D_{50} indicates the degree of armouring in a river system and sediment supply (Bundt and Abt 2001). Where the ratio is close to 1, rivers typically have a high sediment supply. Ratios close to 2 indicate a lower sediment supply. Analysis of the $D_{50\ surface}/D_{50\ subsurface}$ for the Elbow River suggests that surface armouring increases downstream and coarse sediment transport becomes increasing supply-limited (Figure 6-2) (Dietrich et al. 1989).

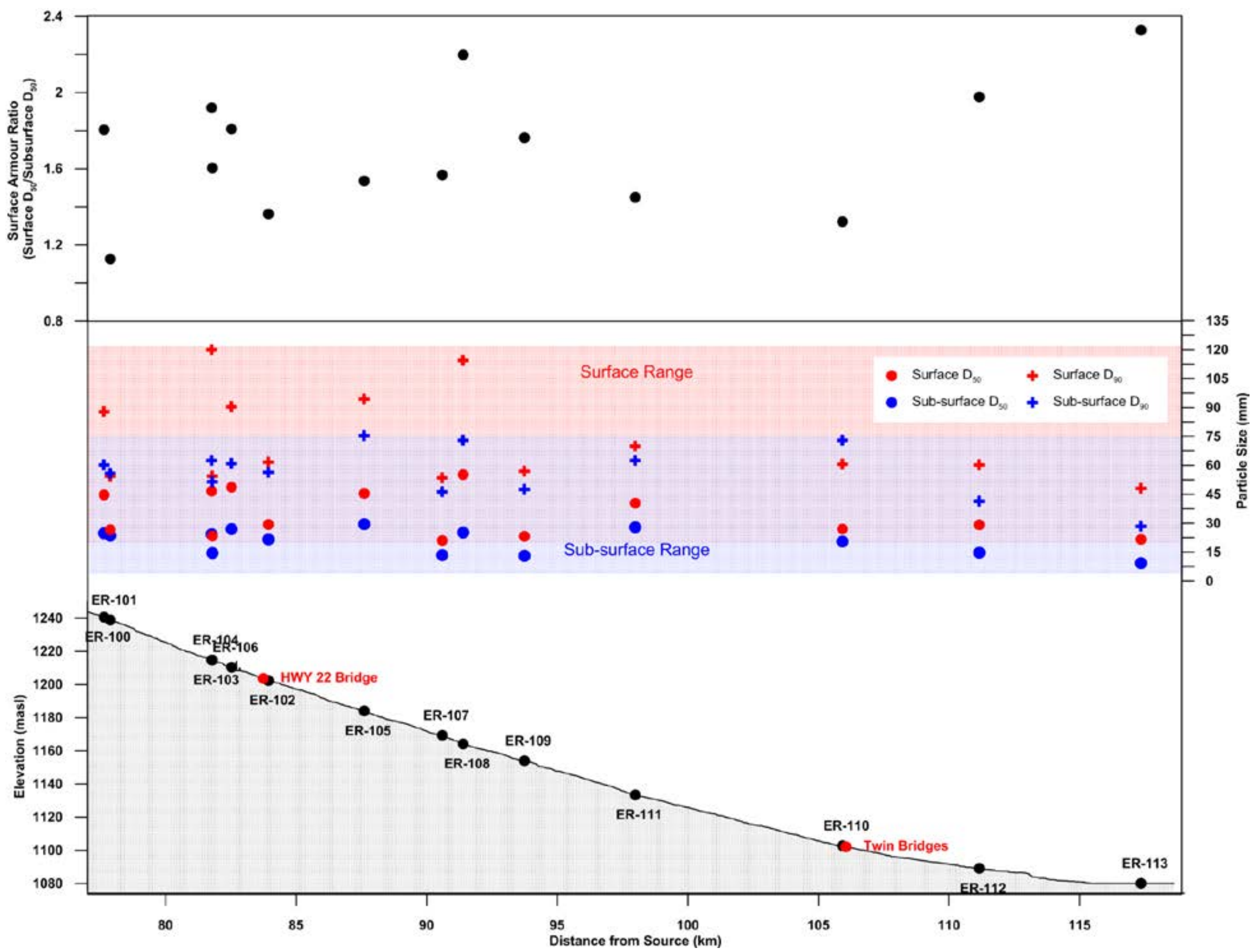


Figure 6-2 Surface and Shallow Sub-Surface Grain-size Distributions for Elbow River

6.2.3 Suspended Sediment Yields

Longer-term suspended sediment yields were estimated for Bragg Creek, Highway 22, Twin Bridges and Sarcee Bridge stations using site-specific SSC-discharge rating curves. These curves were generated using measured hourly discharge values for the:

- Bragg Creek station obtained from the WSC for the period January 1999 to December 2016
- Sarcee Bridge station (Lazowski 2016, pers. comm.) for the period March 2006 to December 2016

Flow and stage data for 2014, 2015 and 2016 is provisional and subject to change. Data from 2013 is not included due to the speculative nature of peak SSC predictions.

For the Bragg Creek station, using the longer-term data, mean annual suspended sediment yields is estimated as 28,684 t per year (36 t/km^2/y) for the period 1979 to 2016. The mean annual suspended sediment yield estimate for Bragg Creek is close to the estimate of 23,300 t per year for the period 1968-1969 and 1971-1975 by Ashmore and Day (1988). Hudson (1983) estimated the long term annual yield for Bragg Creek as 18,200 t per year, based on estimated data for 1935 to 1979, with an average unit term of approximately 34 t/km^2/y. McPherson (1975) estimated the average suspended sediment yield for Bragg Creek as 26 t/km^2/y. The coefficient of variance for Bragg Creek suspended sediment yield is high at 197%, indicating considerable variability in suspended sediment yield from year to year.

For the Sarcee Bridge station, annual average suspended sediment yield is estimated at 33,974 t per year (29 t/km^2/y) (Figure 6-9). This contrasts with estimates of 75, 600 t per year by Hudson (1983). However, Hudson's (1983) estimates had a significant variation of between 35,000 and 105, 000 t per year, resulting in a unit term of between 29.6 t/km^2/y and 88.9 t/km^2/y. This variability partially reflects the ratio methods and short record length used by Hudson (1983) and the inherent variance of suspended sediment yields within the Elbow River system. The coefficient of variance for Sarcee Bridge suspended sediment yield is reduced from that observed for Bragg Creek but is still high at 138%.

The estimated monthly, long-term, suspended sediment yields for Bragg Creek, Highway 22, Twin Bridges, and Sarcee Bridge stations are summarized in Figure 6-3 with annual loads from 1979 to 2016, excluding 2013. The annual load data for 1979 to 2016 indicates that there is considerable variability in annual yields and it is likely that this variability is largely a function of sediment source variation during different magnitude high flows (Hudson 1983).

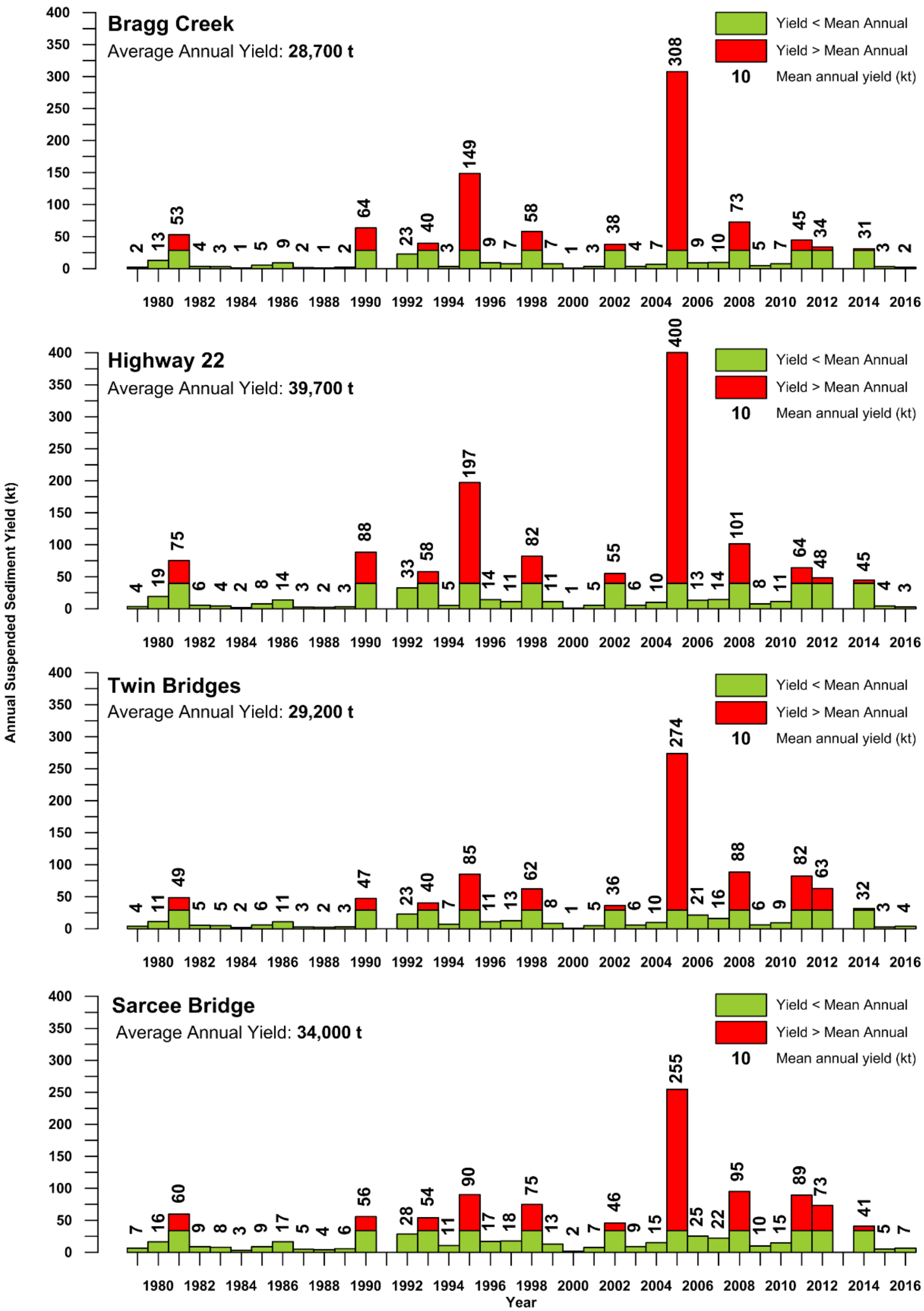


Figure 6-3 Elbow River Annual Suspended Sediment Yields 1979-2016

6.2.4 Bedload

There is limited field-measured data on bedload transport rates in the Elbow River. However, in-river measurements using basket samplers by Hollingshead (1971) and Hudson (1983) suggest that bedload transport in the Elbow River varies considerably in space and time. Based on actual sampling of bedload at Bragg Creek, Hollingshead (1971) suggested that the bed is at the point of incipient motion at around 23 m^3/s. Hudson's (1983) measurements suggest that the relationship between discharge and bedload transport is proportional to approximately the 4^{th} to 5^{th} power of discharge. However, large variations in load have been reported for similar hydraulic conditions, primarily as a function of sediment-supply limited transport and spatial variability at both micro- and meso-scales (Hudson 1983).

Based on field measurements at Bragg Creek, Hudson (1983) noted that the shear stress required to mobilize thalweg deposits was approximately 146 N/m^2, which corresponds to a discharge of approximately 500 m^3/s. In contrast, the average shear stress of approximately 56 N/m^2 will mobilize bar deposition the Elbow River (Hudson 1983). These differences suggest that bedload transport is primarily occurring over bars during high flows until boundary shear stresses exceed the critical shear stress for the armoured thalweg deposits. Based on Hudson (1983), mean annual bedload transport over a 15-year period are 13, 453 t at Bragg Creek and 1,013 t at Sarcee Bridge. These differences reflect, in part, that there is significant bedload storage in sediment sinks through the course of the Elbow River, particularly where there are major changes in gradient. As noted by Hudson (1983), sediment is stored in slow moving waves which control local bedload sediment supply rates.

6.3 PROJECT INTERACTIONS WITH HYDROLOGY

Table 6-3 identifies the physical activities that might interact with hydrology during the flood and post-flood phases of the Project. A justification for no interaction for some activities is provided after the table.

Table 6-3 Project Interactions with Hydrology

Project Components and Physical Activities	Project Effects		
	Change in Hydrological Regime	Change in Suspended Sediment Transport	Change in Channel Morphology
Flood and Post-flood Operations			
Reservoir filling	NA	✓	–
Retention of water in the reservoir–	✓	✓	–
Reservoir draining	NA	✓	✓
Reservoir sediment partial clean up	NA	✓	–
Channel maintenance	NA	✓	–
Road and bridge maintenance	NA	–	–

NOTES:
✓ = Potential interaction
– = No interaction
NA = Not Applicable

The transport of TDS is not assessed as it does not have a material effect on channel morphology or sedimentation.

Road and bridge maintenance post-flood are not expected to have a measurable effect on sediment transport dynamics due to implementation of applicable sediment and erosion control practices. As a result, it is unlikely that there would be any measurable effect on sediment transport dynamics and this effect pathway is not discussed further.

Changes to existing surface and groundwater relationships because of diversion from the Elbow River are discussed in Volume 4, Appendix I, Hydrogeology Modelling Technical Data Report.

6.4 ASSESSMENT OF EFFECTS FROM PROJECT OPERATIONS

Context

The primary purpose of the Project is to mitigate downstream flood hazard to the City of Calgary by modifying the hydrology of the Elbow River during a high flow by temporarily diverting water. The Project has been designed so that diversion can occur when discharge exceeds 160 m^3/s in the Elbow River. The aim of this diversion is to maintain 160 m^3/s in the Elbow River up to flows of approximately 760 m^3/s where the diversion capacity of 600 m^3/s is met.

However, because the Project is a mitigation for downstream flood damage, this hydrological interaction is intentional and required. Assessing the effect of the Project on hydrology under this context is not applicable because the Project is expected to operate whenever hydrological conditions pose a downstream hazard.

Furthermore, the hydrological modification is short-term in the larger context of the Elbow River flow regime where the probability of the Project operating in any given year decreases with larger magnitude, and thus greater diversion, floods.

The diversion of flow from the Elbow River into the reservoir, retention of the diverted water and subsequent release through the low-level outlet back into the Elbow River would have three primary effects.

The first effect is that diversion temporarily delays the transfer of water volume to Glenmore Reservoir by reducing peak flows and flow volumes. For example, diversion would reduce the peak hourly flow for the design flood by 52%, from 1,159 m^3/s to 559 m3/s. The diversion would reduce peak hourly flow for the 1:100 flood by 79%, from 753 m^3/s to 160 m^3/s. The diversion would reduce peak hourly flow for the 1:10 flood by 21%, from 203 m^3/s to 160 m^3/s. The greatest flow rate reduction occurs when flow in the Elbow River is close to 760 m^3/s, allowing the maximum diversion rate of 600 m^3/s to maintain 160 m^3/s in the Elbow River. A flow rate of 760 m^3/s has a 1% probability of occurring in any given year. These reductions have the potential to shift the downstream flow duration curve for Sarcee Bridge by reducing the number of high flows during diversion and increasing the frequency of lower flows during release. Given that the Project may have operated approximately 12 times for the period 1934 to 2016, changes to the hydrological regime are unlikely to modify the long term median flow values in a meaningful way, given that the Elbow River is a low flow system.

The second effect is retention of water in the reservoir. This would result in increased evaporation during retention as well as evaporation from wet areas in depressions that are not fully drained upon release. As a result, evaporation of retained water and wet areas may modify the water balance of the Elbow River watershed through changed evaporation rates and lower runoff. The extent of these modifications would be a function of the volume of water diverted, surface area of retained water in the reservoir and duration of retention, where longer time periods would result in higher evaporation rates. Evaporation rates would be highest during the time there is open water in the reservoir. This effect already exists in the Elbow River watershed. Enhanced evaporation of flood waters would also occur in Glenmore Reservoir in the absence of diversion, but the extent of this evaporation would be determined by the length of time flood waters are held as opposed to a sustained drawdown of water from the Glenmore Reservoir through the outlet of Glenmore Dam into the lower Elbow River.

The third effect is the subsequent release of water from the reservoir back to the Elbow River through the low-level outlet. The peak flow rates have the potential to be substantially higher than currently experienced. However, the rate of release would vary operationally. This variability could occur, for example, from high release rates if back-to-back floods are expected or low release rates if a smaller flood is diverted. The net effect on the hydrological regime of the Elbow River watershed is not considered measurable because overall water volumes, less evaporation, are maintained. However, the potential for a substantial increase in flow magnitude in the low-level outlet would change the sediment transport regime and as a result, channel morphology.

The following topics are discussed in order to give context to the assessment of effects (change in hydrological regime, change in suspended sediment transport, change in channel morphology) on hydrology:

- evaporation from the reservoir during retention of flood waters
- change in suspended sediment concentrations in the reservoir and Elbow River (flood operations)
- deposition of sediment in the reservoir (flood operations)
- change in suspended sediment concentrations in the low-level outlet and Elbow River (post-flood operations)
- change in channel morphology in the low-level outlet and Elbow River (both flood and post-flood operations)

6.4.1 Analytical Assessment Techniques

The assessment of potential change in hydrology and sediment transport is based on existing conditions data and the results of modelling for flow and sediment transport, including suspended sediment and bedload components. The modelling domain for both is the LAA. A brief summary of the data sources and modelling approach is presented below; more detail provided in Volume 4, Appendix J, Hydrology Technical Data Report.

6.4.1.1 Hydrology

The hydrographs used in the analytical assessment are primarily based on hydrographs sourced from the WSC for the WSC Station 07BJ004 Bragg Creek. Using hourly flow data from the WSC Bragg Creek station, the design (2013) flood had an hourly peak of approximately 1,159 m^3/s at 12:00 h on June 20th with the instantaneous peak of approximately 1,170 m^3/s at 11:16 h at Bragg Creek. A single peaked, high flow flood in 2008 had an hourly peak of approximately 202 m^3/s at 21:00 h on May 24th with the instantaneous peak of approximately 204 m^3/s at 21:30 h. The hourly hydrographs from these floods are used as the best representation of the approximate 1:10 and the actual 2013 flood in the model. However, the 1:100 peak flow of 765 m^3/s has not occurred within available hourly data sets for Bragg Creek.

A predicted hourly hydrograph for the 1:100 year flood at Bragg Creek used the Hydrologic Engineering Center Hydrological Modeling System (HEC-HMS) model designed by the US Army Corps of Engineers. HEC-HMS computes runoff excess through estimating the amount of rainfall lost to infiltration and subtracting these values from precipitation. The HEC-HMS model was originally built and calibrated for the entire natural Elbow River watershed as part of a probably maximum flood analysis (PMF) by Stantec (2015b). This HEC-HMS model is used to estimate tributary inputs between Bragg Creek and Sarcee Bridge for all three floods (see Volume 4, Appendix J for more detail). These estimates allow for more accurate hydrodynamic and sediment transport modelling downstream of the PDA.

6.4.1.2 Hydrodynamic Model

DHI Water and Environment's software, MIKE21™, a 2D hydrodynamic numerical model that simulates vertically homogenous flow and sediment transport is used to assess the potential changes in flow and sediment transport due to project operation. MIKE21 is based around several modules that are used to simulate hydrodynamic and sediment transport processes within different aquatic systems. The ability to simulate multiple aquatic environments is key in this assessment because both riverine systems and a reservoir require contemporaneous modelling. This diversion of flow and sediment from a river to a reservoir introduces additional complexity; simultaneous transport of non-cohesive and cohesive sediment, current dynamics and deposition within the diversion channel and the reservoir need to be modelled while maintaining non-diverted flow downstream. To provide the best approximation of these complex interactions, three modules were coupled within the MIKE21 model: hydrodynamic (HD), mud transport (MT) and sand transport (ST) modules.

6.4.1.3 Sediment Transport Model

Sediment transport for the three floods is based pm MIKE21 and the MT and ST modules. The MT module simulates the erosion, transport, settling and deposition of cohesive sediment (silts and clays). A major advantage of the MT module is the ability to model transport, dispersion and settling of three sediment size fractions: silt, sand and gravel. Although this ability introduces additional computational complexity, it does provide a more realistic estimate of sediment transport patterns. As a result, the primary application of the MT module is to estimate the transport patterns of primarily silt and sand size fractions in the Elbow River, into the diversion channel, into the reservoir and then release back into the low-level outlet and into the Elbow River. Sediment depth and extent of deposition in the reservoir is also estimated using this module. Boundary conditions for sediment transport are based on a discharge-suspended sediment rating curve approach discussed in Section 6.2.1.

The ST module simulates the sediment transport capacity, initial rates of bed-level changes and the morphological changes of non-cohesive sediment (sand and gravels). The primary advantage of the ST module is its ability to track, with full dynamism, bed level changes by adjusting for changes in shear stress from the mean flow using helical flow. This ability allows for calculation of morphological changes at each time-step, based on sediment transport rates. the Meyer-Peter and Müller (1948) bedload transport equation is used. Grain-size distributions for the ST bedload modelling were based on subsurface samples collected from Elbow River, as discussed in Section 6.2.2.

6.4.1.4 Modelling

Diversion

Modelling is based on the following operational parameters during a flood:

- Diversion starts when flows exceed 160 m^3/s with increasing diversion occurring until flows in the diversion canal reach a maximum of 600 m^3/s.
- Any flow remaining in Elbow River above 760 m^3/s (160 m^3/s plus 600 m^3/s) is allowed to pass downstream while 600 m^3/s is continuously diverted into the diversion canal.

For example, if the flow in the Elbow River is 805 m^3/s, a maximum of 600 m^3/s can be diverted into the diversion channel, leaving 205 m^3/s in the Elbow River (160 m^3/s maintained plus the excess above 760 m^3/s, which is 45 m^3/s).

Hydrographs showing the effects of these operational parameters for each flood are shown in Figure 6-4 to Figure 6-6.

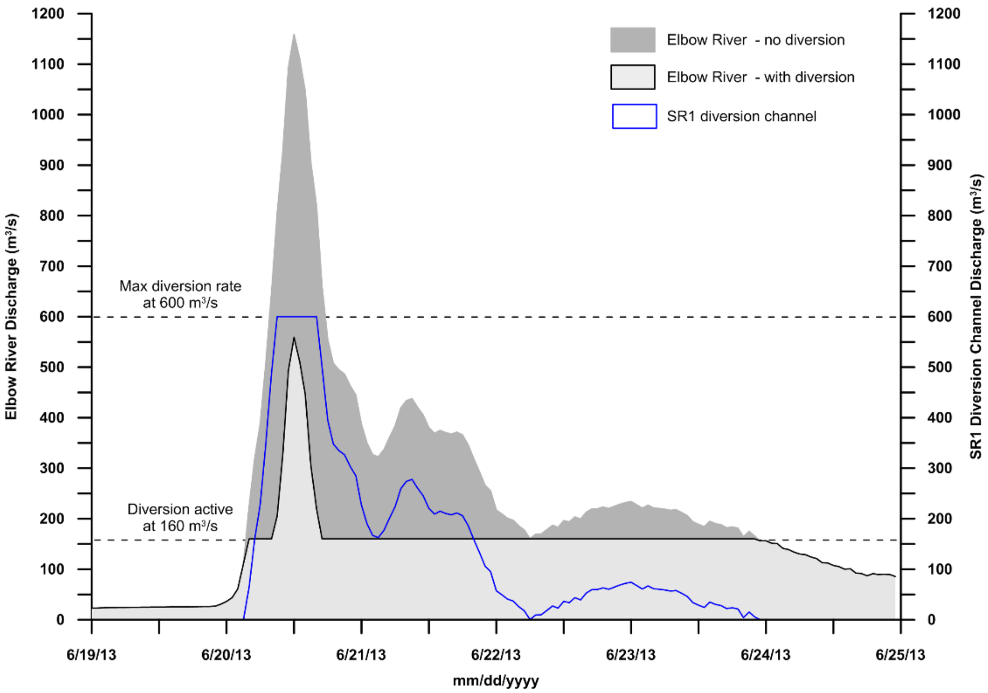


Figure 6-4 Design Flood Diversion Using Bragg Creek 2013 data

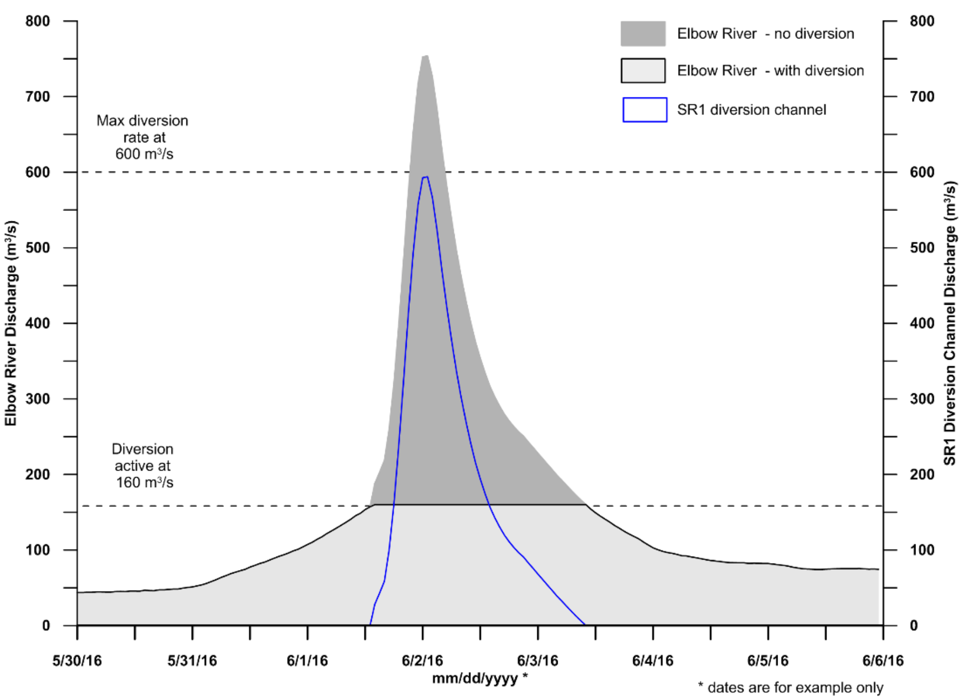


Figure 6-5 1:100 Year Flood Diversion

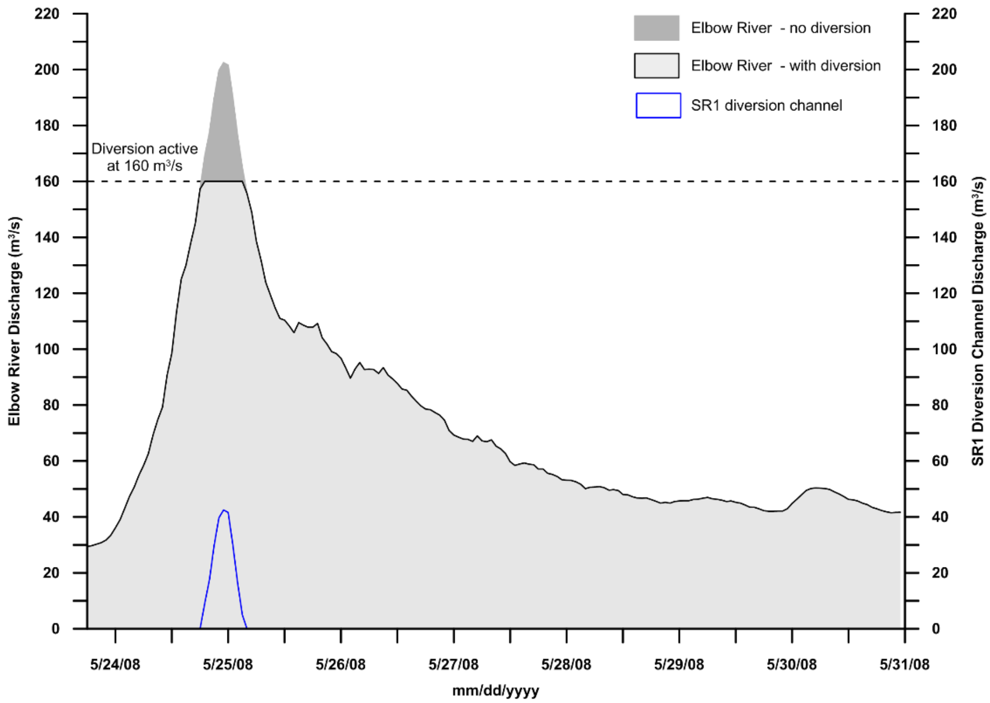


Figure 6-6 1:10 Year Flood Diversion Using Bragg Creek 2008 data

Release

The timing of release of water from the reservoir for the three floods is based on two criteria.

The first criterion is that flows in Elbow River need to be less than 20 m^3/s before release occurs. This threshold is based on a maximum design release rate of 27 m^3/s and the effective discharge for suspended sediment transport of between 35 m^3/s and 50 m^3/s (see Volume 4 Appendix J Hydrology Technical Data Report for more detail). Remobilization of sediment would occur if the combined discharge from the reservoir release and the existing discharge in Elbow River were sufficient to impart boundary shear stresses high enough to re-initiate sediment transport. This mobilization applies to both suspended sediment and bedload. To reduce this possibility, water would be held in the reservoir until the flow in Elbow River is less than the suspended sediment effective discharge rate, when combined with the released flow. The suspended sediment effective discharge is used as the threshold. Shear stresses to mobilize suspended sediment are typically lower than that for bedload (Bunte et al. 2014; Knighton 1998).

The second criterion is based on the length of time to drain the reservoir using the engineering design full service volume of approximately 77,200 dam^3. For this volume, the length of time to drain the reservoir is estimated to be 42 days. Because the diverted flows have a lesser volume, maximum release rates are based on volume drawn down over approximately 40 days (Figure 6-7). This approach provides more detail on the effects of a range of flow rates over a common period, in contrast to maximum release rates over different time periods. However, the actual operational release rate from the reservoir would vary, depending on circumstances at the time of diversion and release. For example, release rates may be increased if two back-to-back floods are forecast, or decreased to reduce potential effects on mobilization of sediment in the low-level outlet and remobilization of sediment in Elbow River downstream.

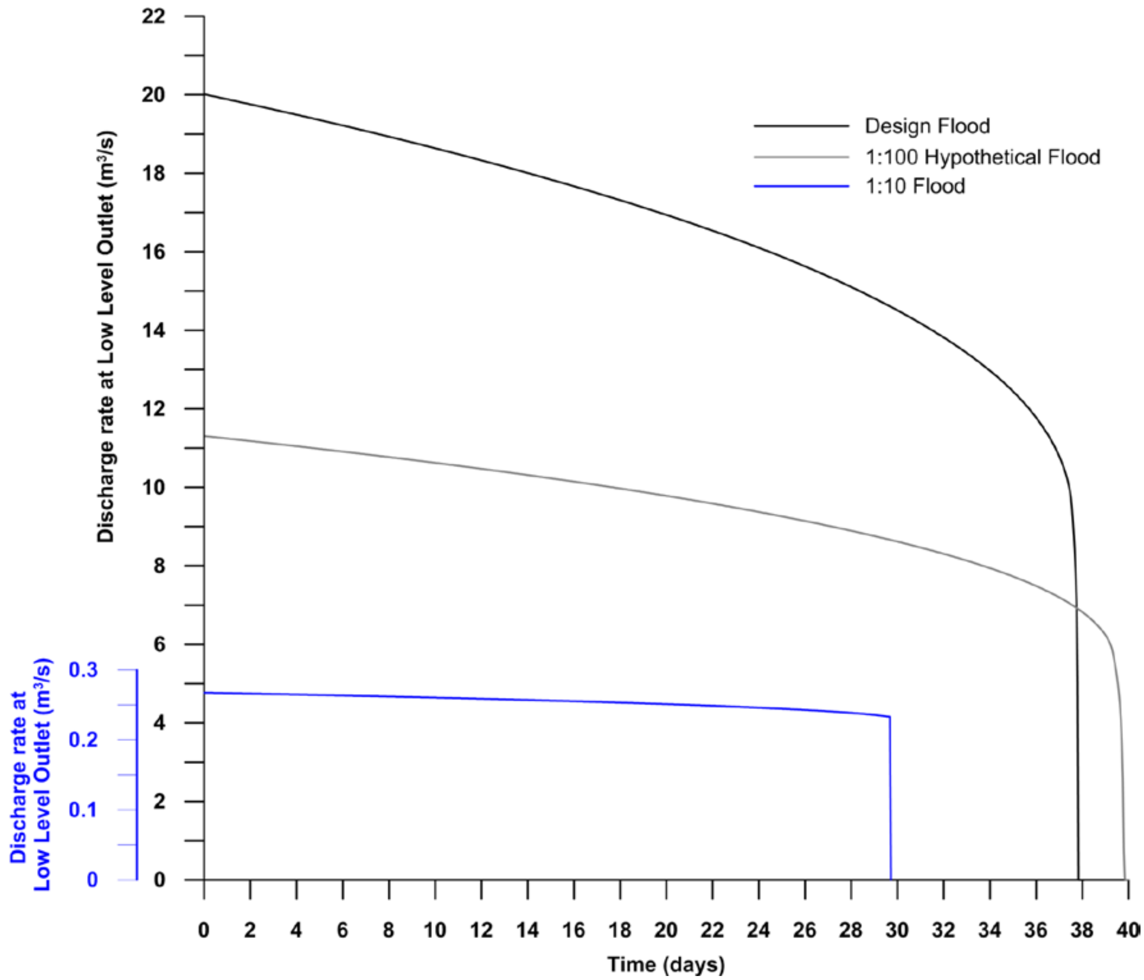


Figure 6-7 Modelled Release Rates

6.4.2 Change in Hydrological Regime

The following sections provide an assessment of project effects on hydrology as a function of water retention in the reservoir during the three floods and during post-flood operation.

6.4.2.1 Overview of Project Effect

The volume diverted during a flood is determined by the magnitude of the flood (Table 6-4). For example, during the design flood, approximately 48% of the volume in Elbow River above 160 m^3/s and below 760 m^3/s, would be diverted. Diversion would have occurred over 3.75 days or 1% of the year. In contrast, approximately 56% of the 1:100 flood volume would be diverted over 1.8 days or 0.5% of the year (Table 6-4). For the 1:10 flood, approximately 14% of the 1:10 volume would be diverted over 0.38 days or 0.1% of the year. The low percentage of annual volume temporarily diverted suggests that, on an annual basis or longer, changes in volume are unlikely to have a measurable effect on the hydrological regime of Elbow River. This lack of effect is likely given that the probability of diversion is 10% or less in any given year and that the diverted volume is returned to Elbow River, less evaporation during the time water is retained in the reservoir. For all three floods, timing is seasonal for floods occurring during the spring/summer.

Estimated evaporation rates and totals are summarized in Table 6-5. The effect of diverted volume on evaporation rates is also determined by the length of retention. In the modelling approach, a range of retention times were generated based on operational parameters.

For example, the 20 days of retention for the design flood is compared with the 43 days of retention for the 1:100 year flood (Table 6-4). The longer times resulted in 5% of the water retained in the reservoir being evaporated, more than double the evaporation for the design flood. However, the percentage of the annual volume lost to evaporation in the modelled floods is less than 0.5%. Because water licences are granted on an annual volume, this loss is unlikely to have a measurable effect on surface water users using Elbow River, especially given the inherent variability in monthly flows.

Table 6-4 Volumes Diverted, Retained in the Reservoir and Released back to the Elbow River

Flood	Elbow River Volume Non-Diversion (dam^3)	Volume Diverted (dam^3)	Elbow River Volume Reduction During Diversion (%)	Diverted Volume / Annual Volume[4] (%)	Diversion Time (days)	Residence Time in Reservoir (days)	Release Time (days)	Volume Released[5] (dam^3)	Volume Remaining In Reservoir (%)
Design[1]	113,985	55,138	48	11.2	3.75	20	38	54,380	1.4
1:100[2]	58,933	33,014	56	5.4	1.8	43	39	32,680	1.0
1:10[3]	6,017	790	14	0.2	0.38	43	30	654	17

NOTES:

[1] Period of diversion: 06/20/2013 04:00 h to 06/23/2013 22:00 h; Residence time: 06/24/2013 to 07/14/2013

[2] Period of diversion: 05/31/2100 05:00 h to 06/02/2100 02:00 h: Residence time: 06/02/2100 to 07/15/2100

[3] Period of diversion: 05/24/2008 15:00 h to 05/24/2008 23:00 h; Residence time: 05/25/2008 to 07/07/2008

[4] Based on actual WSC Record at Sarcee Bridge for Design Flood and 1:10; modelled annual data for 1:100. Calculated annual flow volumes are: 2013: 490,136 dam^3, 1:100 Synthetic: 613,411 dam^3 and 2008: 380,797 dam^3

[5] Does not include evaporated volume

Table 6-5 Summary of Estimated Evaporation Rates and Volumes for Floods

Flood	Volume Diversion (dam³)	Diversion Time (days)	Residence Time in Reservoir (days)	Average Daily Rate (mm)	Cumulative Evaporation (mm)	Total Evaporation Volume (dam³)	Evaporated/ Diverted Volume (%)	Evaporated Volume/Annual Elbow River Volume (%)
Design[1]	55,138	3.75	20	4.6	271	1,361	2.5	0.3
1:100 Year[2]	33,014	1.8	43	4.5	386	1,579	4.8	0.3
1:10 Year[3]	790	0.38	43	4.6	342	45	5.7	0.01

NOTES:
1 Period of retention and release: 06/24/2013 to 08/21/2013
2 Period of retention and release: 06/02/2100 to 08/23/2100
3 Period of retention and release: 05/25/2008 to 08/05/2008

6.4.2.2 Design Flood

The volume diverted during the design flood is approximately 11.2% of the annual flow volume of Elbow River, as recorded at Sarcee Bridge. Approximately, 1.4% of the diverted volume would remain in depressions in the reservoir area after release. This remaining volume equates to a volume loss of approximately 0.2% of the annual flow volume in Elbow River. Because this percentage is well below 10%, the effect on the hydrological regime for the design flood, in terms of annual volume, is negligible in magnitude and transient. As a result, it is unlikely to have a measurable effect, particularly because the probability of this size flood occurring is less than 0.5% in any given year.

Daily evaporation and cumulative evaporation as a function of reservoir water surface area for the design flood are summarized in Figure 6-8. The estimated total volume evaporated is approximately 1,361 dam^3. This volume is 0.3% of the annual volume in Elbow River, as based on the 2013 hydrograph at Sarcee Bridge. This percentage is less than 10% from existing conditions and, as a result, is negligible and would not have a measurable effect on the hydrology of Elbow River, especially given the inherent variability in flows. Furthermore, the existing long-term effect of Glenmore Reservoir on evaporation rates in the Elbow River watershed are ongoing and likely exceed any effect from operation of the Project due to the low probability of water diversion into project infrastructure and the short time water is retained.

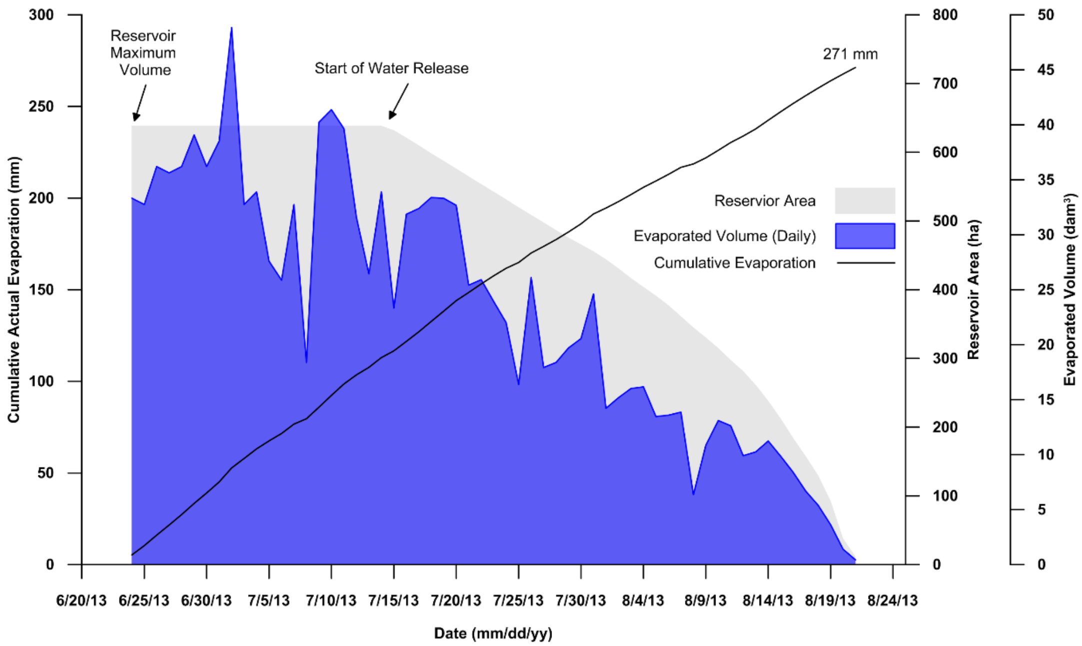


Figure 6-8 Modelled Change in Evaporation: Design Flood

6.4.2.3 1:100 Year Flood

The volume diverted during the 1:100 flood is approximately 5.4% of the annual flow volume of Elbow River, as estimated at Sarcee Bridge. The annual flow volume estimated for the 1:100 flood (613,411 dam^3) is substantially larger than for the design flood (490,136 dam^3). This difference represents the effect of generating an annual hydrograph to match 7- and 56-day volumes estimated from a statistical analysis of flood frequency. This means that although the peak flow of the 1:100 year flood is smaller than the design flood, the total amount of water discharged (statistical average) over a year for a 1:100 year flood is considerably greater than that, over a year, for the design flood. The period of medium and higher flows after the peak flow are likely overestimated, resulting in the increased estimation of volume. This overestimation provides, therefore, a conservative approach.

Approximately, 1.0% of the diverted volume would remain in depressions in the reservoir area after release. This remaining volume equates to a volume loss of approximately 0.1% of the annual flow volume. Because this percentage is well below 10%, the effect on the hydrological regime for the design flood, in terms of annual volume, is negligible in magnitude and transient. As a result, it is unlikely to have a measurable effect, particularly because the probability of this flood occurring is approximately 1.0% in any given year.

Daily evaporation and cumulative evaporation as a function of reservoir water surface area for the 1:100 flood is summarized in Figure 6-9. The estimated total volume evaporated is approximately 1,579 dam^3. This volume is 0.3% of the annual volume in Elbow River. This percentage is less than 10% from existing conditions and as a result, is negligible and would not have a measurable effect on the hydrology of Elbow River, especially given the inherent variability in flows. Furthermore, the existing long-term effect of Glenmore Reservoir on evaporation rates in the Elbow River watershed are ongoing and likely exceed any effect from operation of the Project due to the low probability and short operational time for a flood.

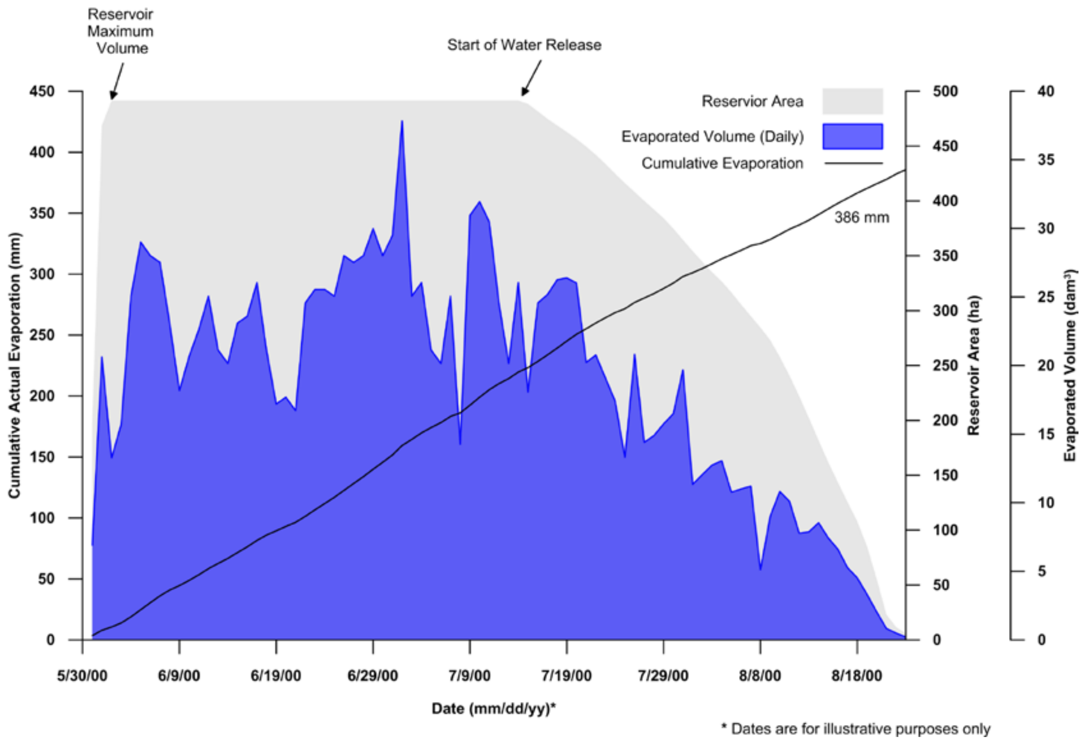


Figure 6-9 Modelled Change in Evaporation, 1:100 Year Flood

6.4.2.4 1:10 Year Flood

The volume diverted during the1:10 flood is approximately 0.2% of the annual flow volume of Elbow River, as recorded at Sarcee Bridge. Approximately, 17% of the diverted volume would remain in depressions in the reservoir area after release. This remaining volume equates to a volume loss of approximately 0.04% of the annual flow volume. The effect on the hydrological regime for the 1:10 year flood, in terms of (statistical) annual volume, is negligible in magnitude and transient. As a result, it is unlikely to have a measurable effect, particularly because the probability of this flood occurring is approximately 10% in any given year.

Daily evaporation and total evaporation as a function of reservoir water surface area for the 1:10 flood are summarized in Figure 6-10. The estimated total volume evaporated is approximately 45 dam^3. This volume is 0.01% of the annual volume in the Elbow River, as based on the 2008 hydrograph at Sarcee Bridge. This percentage is less than 10% of existing conditions and, as a result, is negligible and would not have a measurable effect on the hydrology of the Elbow River, especially given in the inherent variability in flows. Furthermore, the existing long-term effect of Glenmore Reservoir on evaporation rates in the Elbow River watershed are ongoing and likely exceed any effect from operation of the Project due to operational low probability and short time.

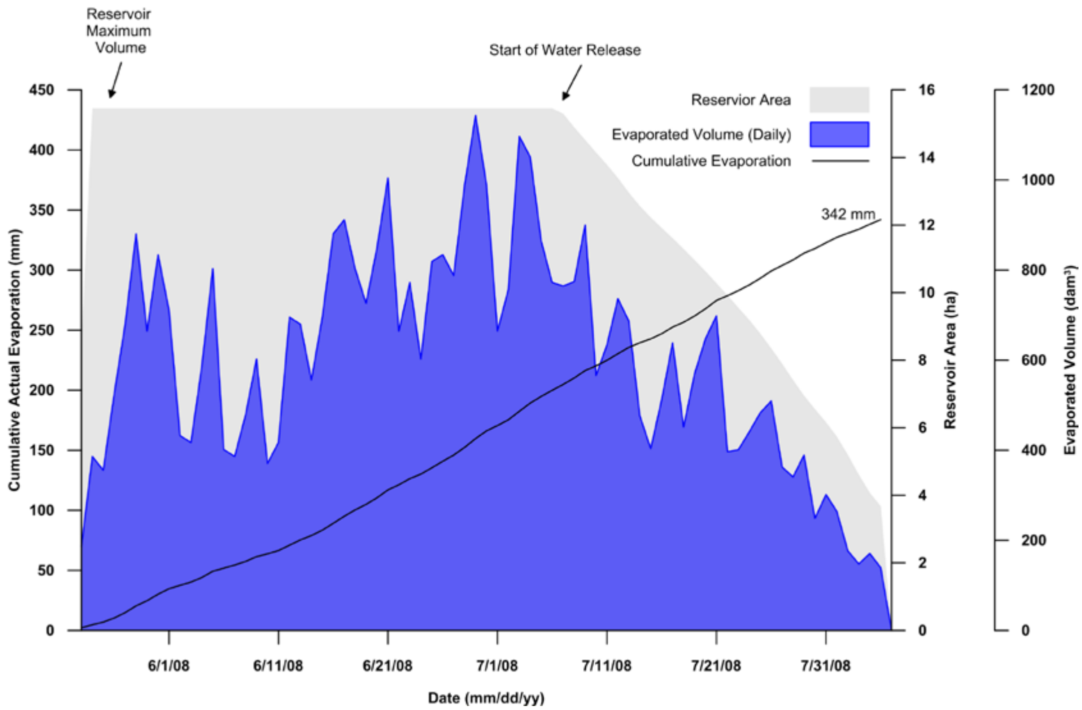


Figure 6-10 Modelled Change in Evaporation, 1:10 Year Flood

6.4.3 Change in Suspended Sediment Transport

Suspended sediment are particles held temporality in suspension in the water column by turbulence and suspended sediment yields typically dominate watershed scale sediment in systems, as demonstrated for Elbow River (Hudson 1983). Typically, the range of particle sizes than can be transported in suspension are limited to clays and silts (i.e., particles less than 0.063 mm in size). However, depending on flow conditions, sand size material may also be transported in suspension. Under flood conditions, the primary particle size carried in flow diverted from, and remaining in the Elbow River, would likely be coarse silt/very fine sand (average grain size of 0.063 mm) and medium sand sized material (average grain size of 0.36 mm). These values are based on the current grain size distribution in the Elbow River (see Volume 4, Appendix J, Hydrology Technical Data Report for more detail). Although bedload movement can be significant during a flood, its contribution to diverted sediment yields is minimal because most material would remain in the Elbow River where changes in flow rate would contribute to shifts in downstream channel morphology changes as a function of reduced mobility (see Section 6.4.4 for a detailed discussion of changes in Elbow River channel morphology).

The effects of diversion would be to change suspended sediment concentrations and local suspended sediment yields in the Elbow River. The effect on suspended sediment yields would be localized because the effects of sediment storage and tributary inputs downstream would contribute or remove unknown quantities of suspended sediment.

During retention of water in the reservoir, a portion of the suspended sediment would permanently settle at the bottom of the reservoir. The locations of sedimentation are determined by circulatory patterns within the reservoir during active water inflow and retention, as influenced by existing topography. Sedimentation depths would be determined, in part, by concentration, water depth, the effects of the underlying topography and residence time in the reservoir. The longer the residence time, the greater the deposition. Upon release back into Elbow River through the low-level outlet, sediment remaining in suspension within the reservoir would be removed together with sediment remobilized and resuspended.

The extent of remobilization and resuspension during release from the reservoir would be determined by location in the reservoir, particle size and the applied shear stresses, and distance to the low-level outlet. The factor determining the degree of remobilization would be the shear stress applied to the sediment as water flows out. If the applied shear stress exceeds the critical shear stress for a particle size, there is potential for movement. The extent of that movement (i.e., resuspension and transport into the low-level outlet or localized resuspension and settling) would be a function of where and when water is moving and its interaction with the bed morphology. This interaction would vary in time and space as water is released from the reservoir.

The released water would also combine with sediment mobilized into suspension from the low-level outlet. This combination would temporarily increase suspended sediment concentrations in the Elbow River at the confluence of the outlet and for a distance downstream in the Elbow River. As a result, suspended sediment yields would vary with location throughout the release phase where localized channel erosion and deposition, in combination with existing suspended sediment concentrations, would change with shifts in discharge.

6.4.3.1 Overview of Project Effect

Table 6-6 lists the key parameters associated with suspended sediments for each of the floods. For all three floods, timing is seasonal for flood events occurring during the spring/summer. For the design flood, approximately 50% of the suspended sediment that would have been transported downstream without the Project would be diverted into the reservoir. The mass diverted is estimated at 2,389 kilotonnes (kt). After 20 days of retention, approximately 90 kt of suspended sediment would be released into the low-level outlet. Volumetrically, the deposited sediment in the reservoir constitutes 1.1% of the full service volume.

Model results for the 1:100 year flood suggest that up to 65% of the suspended sediment in the Elbow River would be diverted into the reservoir. After retention, approximately 220 kt are estimated as being released into the low-level outlet. This is larger than for the design flood because of differences in the sediment deposition pattern in the reservoir for the 1:100 year flood. This is due to the smaller water volume and different circulatory patterns in the reservoir for a smaller diversion volume. Volumetrically, the deposited sediment remaining in the reservoir after release is estimated as 0.5% of the full-service volume (Table 6-6).

Model results for the 1:10 year flood indicate that up to 5% of the suspended sediment in the Elbow River would be diverted into the reservoir. After retention, approximately 1.1 kt are estimated as being released into the low-level outlet. This mass is minimal compared to the larger floods and is indicative of the relative size of the 1:10 year flood. Volumetrically, the deposited sediment remaining in the reservoir after release is estimated as 0.5% of the full-service volume (Table 6-6).

The Project causes a high magnitude effect on suspended sediment concentrations and yields in Elbow River. Floods larger than the 1:10 year flood would cause yield reductions greater than 30% from existing conditions. However, if flood flow rates in Elbow River exceed 760 m^3/s, a larger portion of the flood flow and associated suspended sediment would remain in Elbow River. As a result, the effect of the Project on concentrations and yields would diminish with floods greater that the 1:100 year flood. This effect can be seen in the reduced percentage of suspended sediment mass change in Elbow River for the design flood (50% reduction) compared to the 1:100 flood (65% reduction) (Table 6-6). However, the 1:10 year flood would be associated with a 5% reduction in suspended sediment mass in Elbow River. Because smaller floods have a higher probability of occurrence in any given year, suspended sediment yields in the Elbow River would be reduced.

Table 6-6 Estimated Suspended Sediment Concentrations and Yields in the Elbow River, With and Without Diversion

Flood	Elbow River Peak Suspended Sediment Conc. Non-Diversion (g/m^3)	Diversion Channel Average Suspended Sediment Conc. (g/m^3)	Diversion Channel Peak Suspended Sediment Conc. (g/m^3)	Diversion Time (days)	Elbow River Suspended Sediment Mass Non-Diversion (kt)	Diversion Suspended Sediment Mass (kt)	Elbow River Suspended Sediment Mass Reduction (%)	Suspended Sediment Mass Released into the Low-level Outlet (kt)	Loss of Retention Volume Due to Sediment Remaining In Reservoir[4] (%)
Design[1]	139,682	18,709	89,166	3.75	4,819	2,389	50	90	1.1
1:100 Year[2]	77,649	19,228	74,715	1.80	1,943	1,268	65	220	0.5
1:10 Year[3]	4,818	1,258	2,064	0.38	24	1.3	5	1.1	0.0

NOTES:

[1] Period of diversion: 06/20/2013 04:00 h to 06/23/2013 22:00 h; Residence time: 06/24/2013 to 07/14/2013

[2] Period of diversion: 05/31/2100 05:00 h to 06/02/2100 02:00 h: Residence time: 06/02/2100 to 07/15/2100

[3] Period of diversion: 05/24/2008 15:00 h to 05/24/2008 23:00 h; Residence time: 05/25/2008 to 07/07/2008

[4] Based on full service volume of 77,220 dam^3 and assuming a sediment density of 2650 kg/m^3

6.4.3.2 Design Flood

The pattern of suspended sediment transport in the diversion channel during water flow into the reservoir is dependent on fluctuations in discharge. Figure 6-11 depicts reservoir behavior if it had been operational in during the 2013 flood. Concentrations peak at approximately 89,166 g/m³ for the design flood with an average concentration of 18,709 g/m³ (Table 6-6). Concentrations drop sharply in the reservoir centre after initial filling, as a result of deposition and changing circulatory patterns. During retention of water in the reservoir, concentrations remain stable until the start of release. Suspended sediment concentrations stay relatively low (200-300 g/m³) until approximately the 8/6/2013 (46 days after the flood start) where a rapid increase in suspended sediment concentration occurs at both the reservoir center and at the low-level outlet. Concentrations peak at approximately 21,000 g/m³ before dropping rapidly to zero as water would be released back into Elbow River through the low-level outlet. The lag between the reservoir peak concentrations and those at the outlet can be seen in Figure 6-11.

Modelled reservoir sediment spatial extent and depths for the design flood are shown in Figure 6-12. The figure shows sediment extent and depth after release has occurred. Sediment depth ranges between 0 m and approximately 3.8 m. The average sediment depth is 0.12 m. Highest sediment depths are located close to the low-level outlet and along the dam interior face. Depths of approximately 3 m to 3.5 m are also present in the centre of the reservoir. These deposits reflect circulatory patterns during filling and retention, as influenced by the underlying topography. The morphology of the deposits indicate wide-crested mounds of silty-sand are likely to form where sediment depths are higher. For depths less than approximately 0.1 m, these deposits would likely be thin drapes over existing topography and vegetation.

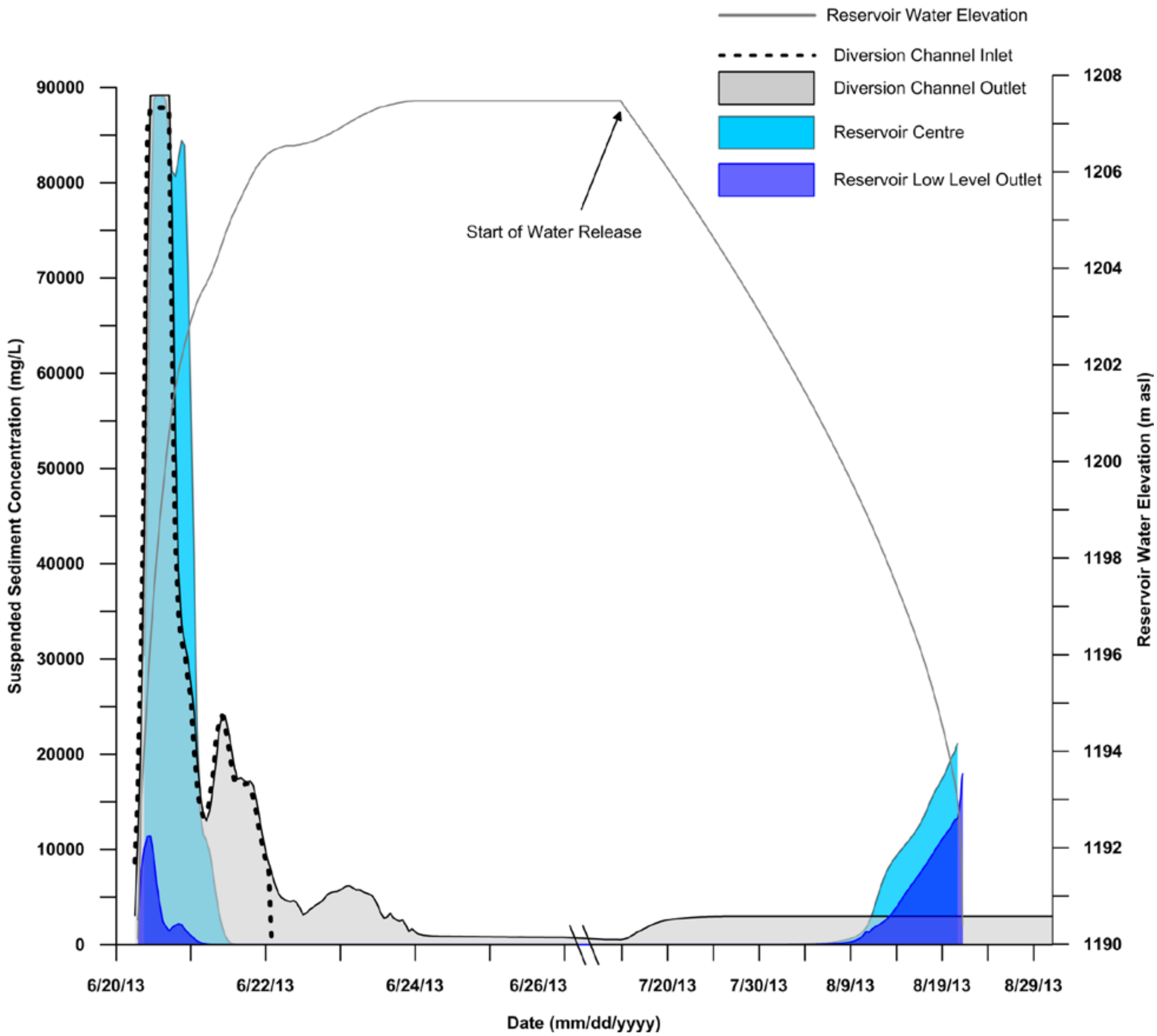
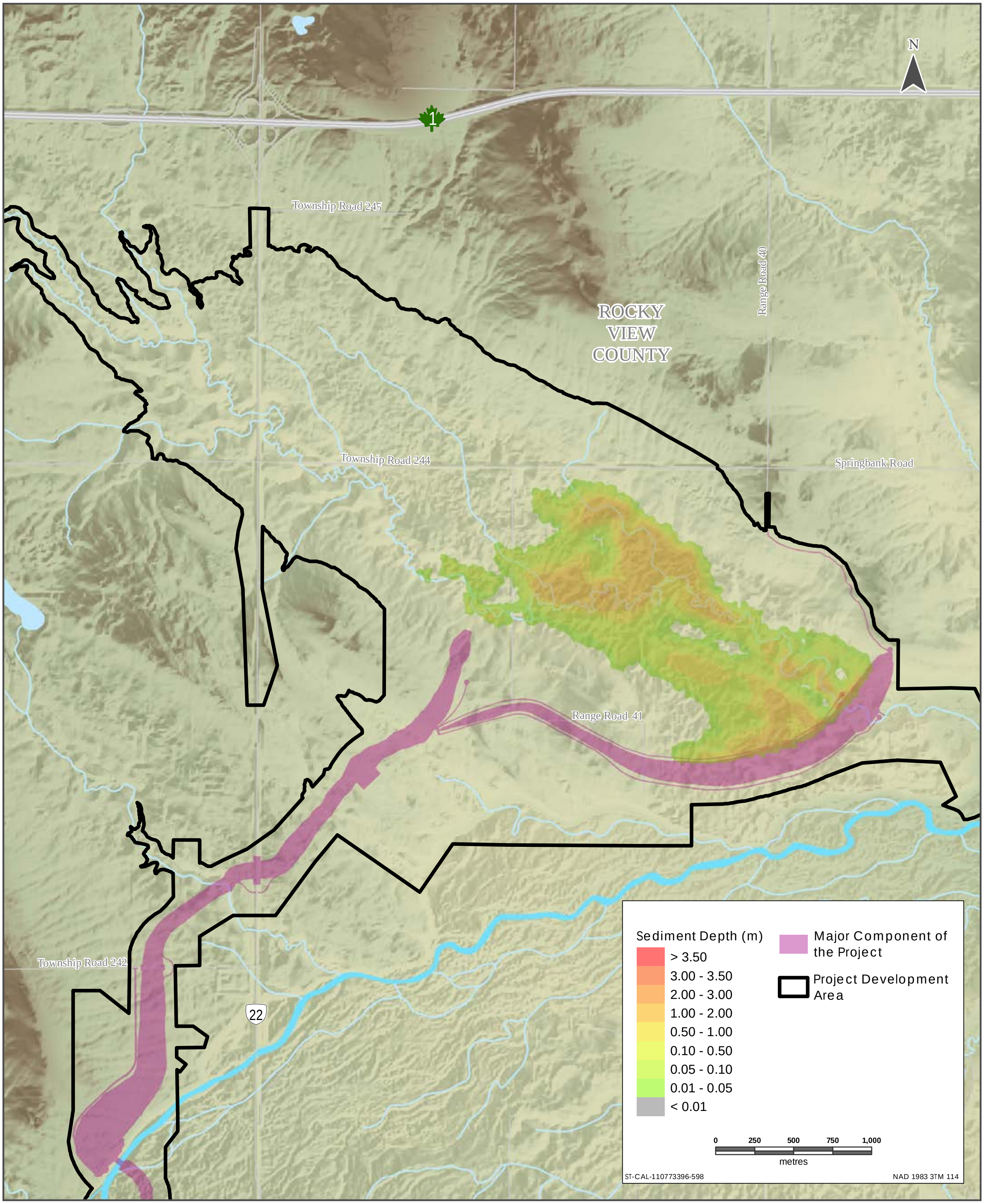


Figure 6-11 Estimated Suspended Sediment Concentrations in the Diversion Channel and Reservoir during Diversion, Retention and Release for the Design Flood



Sources: Base Data - Government of Alberta, Government of Canada
Thematic Data - Stantec Ltd

Estimated Reservoir Sedimentation Depths
Post Release: Design Flood

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Figure 6-12

The effects of diversion on shear stress and suspended sediment concentrations at Highway 22 are shown in Figure 6-13. The Highway 22 station is located approximately 300 m downstream of the diversion infrastructure and would show the greatest effect. Peak suspended sediment concentrations are reduced by approximately 2% during diversion. This reduction likely reflects that even though flows have been reduced in the Elbow River, shear stresses and velocities are still capable of maintaining the high suspended sediment concentrations sourced from upstream. Although there is a reduction in shear stress, the stresses are still maintained at an average of approximately 61 N/m^2 and a maximum of approximately 84 N/m^2 during diversion. These values suggest that bed particles with diameters of up to 87 mm would be at the point of incipient motion (using a Shields parameter, θ, of 0.06). Given that the sub-surface d_{50} is 21mm, downstream mobilization and maintenance of suspended sediment (and bedload) transport during diversion would continue. A mass balance based on the model data shown in Table 6-6 suggests that downstream suspended sediment yield would be reduced by approximately 50% from 4,819 kt to 2,389 kt at Highway 22.

Although suspended sediment concentrations and yields would be reduced because of diversion, suspended sediment concentrations also decrease slightly downstream during post-flood operation (Figure 6-14). This downstream decrease is likely a function of downstream storage. Post-flood, peak suspended sediment concentrations decrease by 0.2% between Highway 22 and Twin Bridges and 2% between Twin Bridges and Sarcee Bridge. However, average concentrations show a slight increase of 0.5% between Highway 22 and Twin Bridges versus a 7% decrease between Twin Bridges and Sarcee Bridge. These differences suggest that temporal and spatial changes in storage losses and gains play a significant role in controlling suspended sediment yields in Elbow River, as shown by the inter-annual variability in annual suspended sediment yields (Section 6.2.2.5).

Active diversion would slightly reduce suspended sediment concentrations and suspended sediment yields up to 50% for the design flood, with approximately 2,389 kt of suspended sediment diverted into the reservoir. The suspended sediment yield is transferred downstream, as subject to storage effects between Highway 22 and Sarcee Bridge. The magnitude of these effects on suspended sediment concentration and yields is not determined here because they are a direct consequence of flow diversion, the intent of the Project.

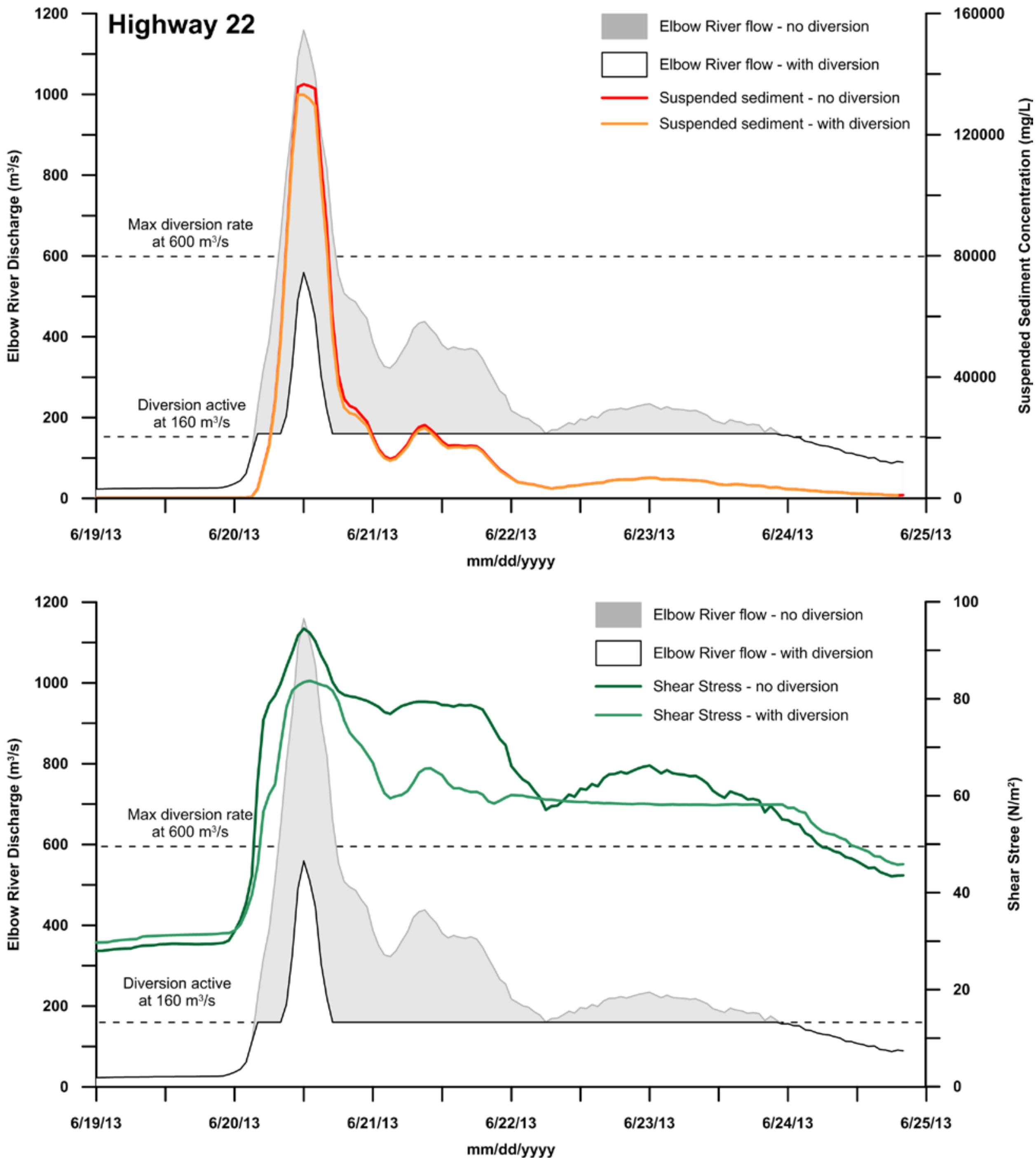


Figure 6-13 Suspended Sediment Concentrations and Shear Stress at Highway 22, Design Flood

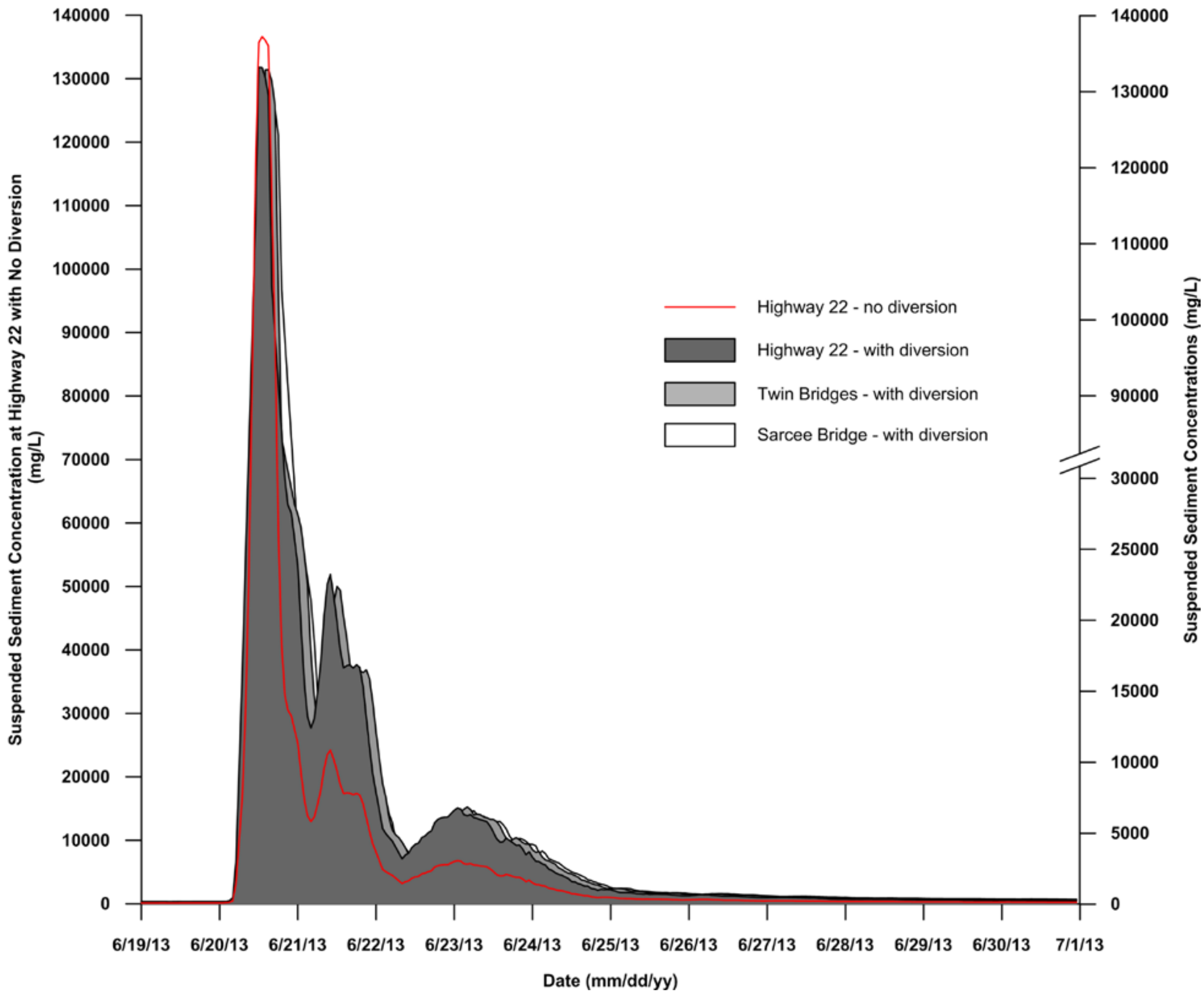


Figure 6-14 Downstream Changes in Suspended Sediment Concentration During Diversion, Design Flood

The release of water from the reservoir would result in a transient increase in suspended sediment concentrations at the low-level outlet and the Elbow River (Table 6-7 and Figure 6-15). Discharge would have increased from approximately 20 m^3/s to 40 m^3/s over an hour at the onset of release. The bankfull discharge for the Elbow River at this location is approximately 47 m^3/s (recurrence interval of 1.54 years). Peak concentrations modelled at the confluence of the low-level outlet and Elbow River are in the range of 18,000 g/m^3 but decline to 5,700 g/m^3 approximately 1.0 km downstream (Table 6-7). Historical data suggests that monthly suspended sediment concentrations at the time of release in August, without 2013 data, average 16 g/m^3, with a maximum of approximately 50 g/m^3, at Highway 22 (Figure 6-1).

Up to 0.2 kt of suspended sediment material may be mobilized and transported from the low-level outlet, which would increase the suspended sediment yield from 89.5 kt to 89.7 kt before the confluence with the Elbow River. Flow and storage effects in Elbow River dilutes this suspended sediment input to 68.6 kt, a 25% decrease, by approximately 1.0 km downstream of the confluence with the low-level outlet. This addition of new suspended sediment partially offsets the material remaining in the reservoir that would have been transferred downstream in the absence of active diversion. This addition effectively reduces the sediment yield loss for the design flood by a negligible amount.

Table 6-7 Estimated Suspended Sediment Concentrations and Yields in the Low-level Outlet and Elbow River During Release for the Design Flood

Location	Peak Suspended Sediment Conc. (g/m^3)	Average Suspended Sediment Conc. (g/m^3)	Release Time (days)	Peak Suspended Sediment Load During Release (t/h)	Suspended Sediment Yield (kt)
Low-level outlet	17,961	2,188	38	660	89.5
Confluence with Elbow River	17,955	2,173	38	653	89.7
Elbow River Downstream Boundary[1]	5,666	754	38	471	68.6

NOTE:
[1] Location is approximately 1.0 km downstream of the confluence

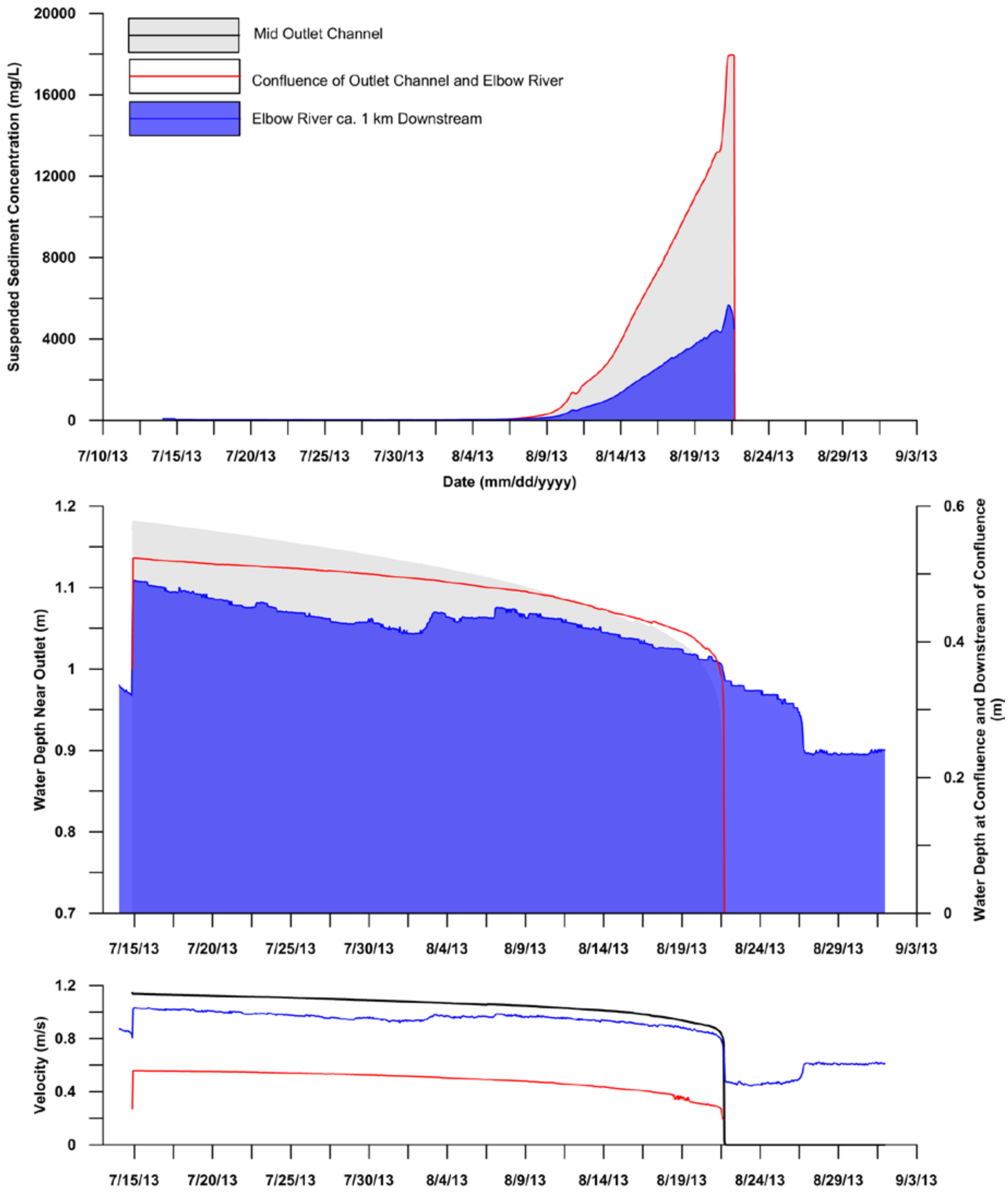


Figure 6-15 Suspended Sediment Concentration in the Low-level Outlet and Confluence with Elbow River, Design Flood

6.4.3.3 1:100 Year Flood

Concentrations peak with discharge at concentrations of approximately 74,715 g/m^3 and an average concentration of 19,228 g/m^3 (Table 6-6). Concentrations drop sharply in the reservoir centre after initial filling because of deposition and changing circulatory patterns. During retention, sediment concentrations do not remain as stable initially as modelled for the design flood (Figure 6-16). This instability is likely due to differences in circulatory patterns as a result of a smaller diverted volume. Once stabilized, suspended sediment concentrations are about 200-300 mg/L until a water release would cause a rapid increase in concentration at both the reservoir center and at the low-level outlet occurs. Concentrations peak at approximately 69,000 g/m^3 in the reservoir centre and approximately 27,000 g/m^3 at the low-level outlet before dropping rapidly to zero as water is released. There is a time lag between the reservoir peak concentrations and those at the low-level outlet as water is released (Figure 6-16). The pattern of suspended sediment concentrations in the reservoir centre fluctuates more than for design flood draining. This is because of differences in circulation patterns and interaction with the underlying topography, which includes deposited sediment.

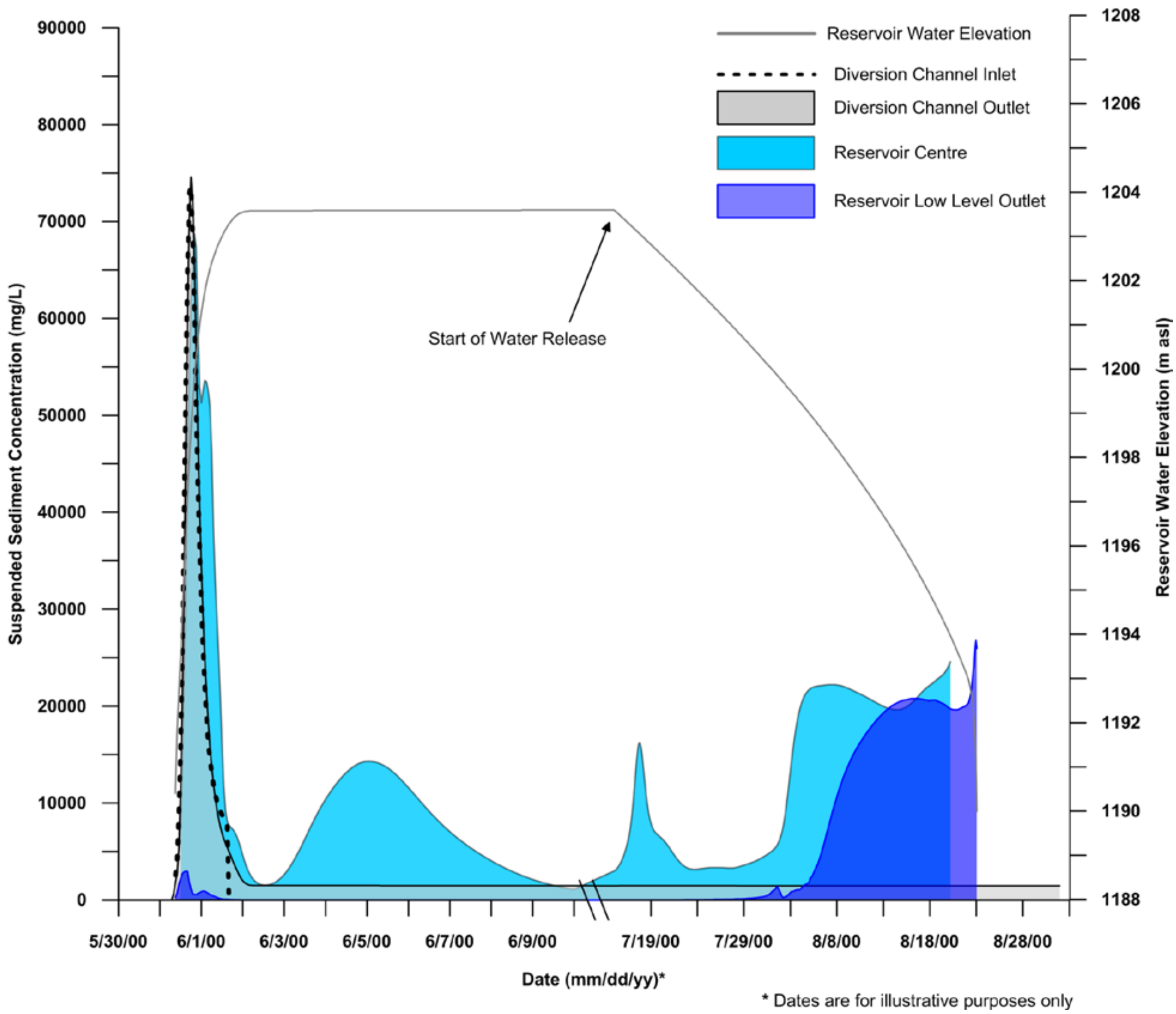


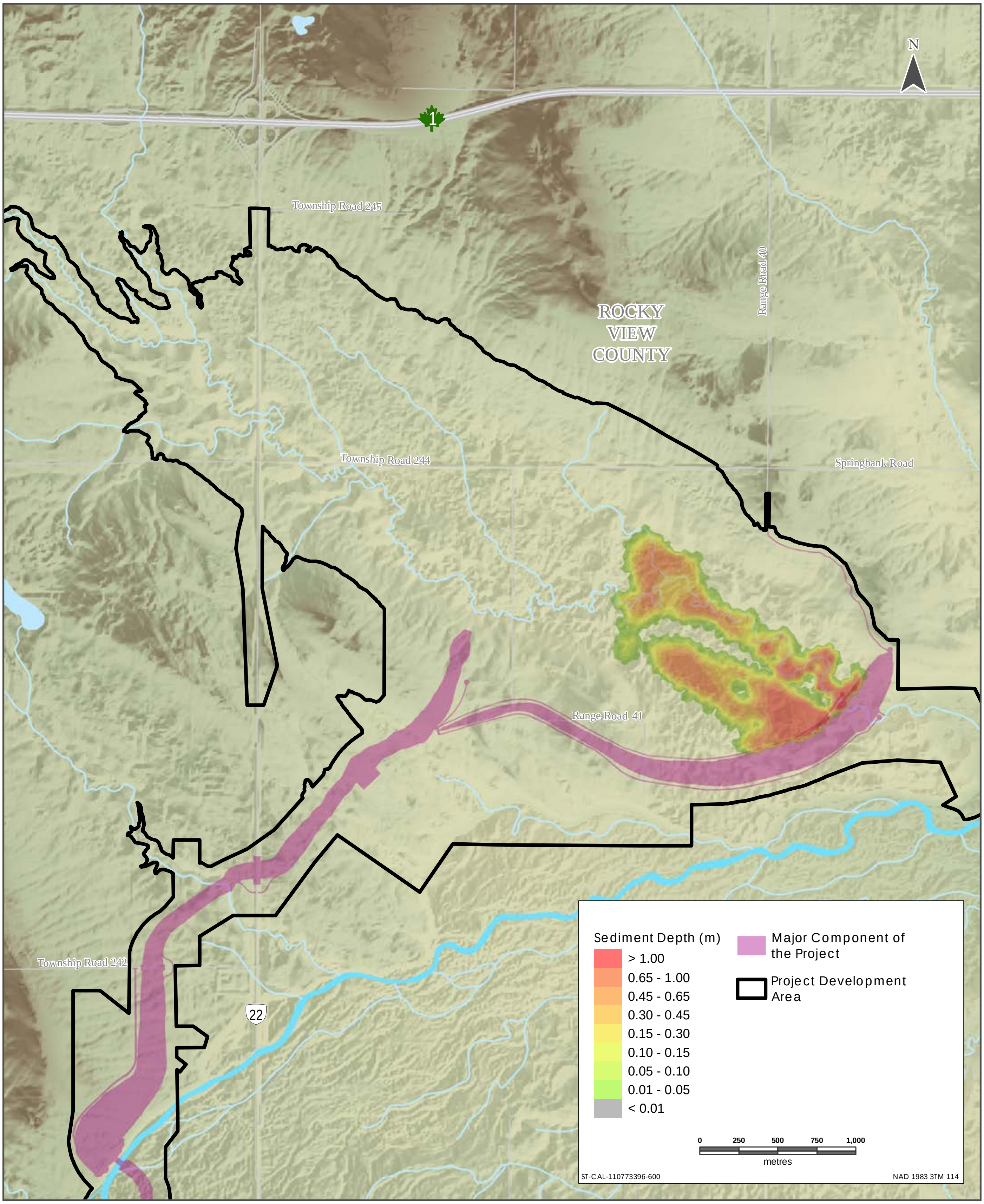
Figure 6-16 Suspended Sediment Concentrations in Diversion Channel and Reservoir during Diversion, Retention and Release, 1:100 Year Flood

Modelled reservoir sediment spatial extent and depths for the 1:100 flood are shown in Figure 6-17. The figure shows sediment extent and depth after release has occurred. Sediment depth ranges between 0 m and approximately 3.4 m. This peak sediment depth is located close to the low-level outlet and in the same area as observed for the design flood. Differences in deposit thickness is to be expected due to different circulatory patterns during filling and retention, as influenced by the underlying topography. Further differences are to be expected based on retention time. The retention time for the 1:100-year flood would be 43 days in contrast to 20 days for the design flood; thus, higher deposition rates in some areas would be expected for the 1:100 year flood.

The effects during diversion on shear stress and suspended sediment concentrations at Highway 22 are shown in Figure 6-18. Highway 22 is located approximately 300 m downstream of the diversion infrastructure and would, therefore, show the greatest effect. Suspended sediment concentrations are reduced by approximately 7% along with an associated reduction in shear stresses. However, shear stress is maintained at approximate average of 66 N/m^2 during diversion. This average suggests that bed particles with a diameter of approximately 68 mm would be at the point of incipient motion (using a Shields parameter, θ, of 0.06). Given that the sub-surface d_{50} is 21 mm, downstream mobilization of suspended sediment (and bedload) during diversion would continue. A mass balance based on the model data shown in Table 6-6 suggests that downstream suspended sediment yield would be reduced by 65% from 1,943 kt to 1,268 kt at the diversion.

Suspended sediment concentrations decrease slightly downstream during release of water from the reservoir (Figure 6-19). This downstream decrease is likely a function of downstream storage. Peak suspended sediment concentrations decrease by 0.3% between Highway 22 and Twin Bridges and 10% between Twin Bridges and Sarcee Bridge. However, average suspended sediment concentrations show an increase of 8.7% between Highway 22 and Twin Bridges and a decrease of 3% between Twin Bridges and Sarcee Bridge. These differences suggest that temporal and spatial changes in storage losses and gains play a significant role in controlling suspended sediment yields in the Elbow River, as shown by the inter-annual variability in annual suspended sediment yields.

In summary, suspended sediment concentrations would reduce slightly, but with suspended sediment yields reduced by up to 65% during active diversion. In the 1:100 year flood, the model shows approximately 1,269 kt of suspended sediment being diverted into the reservoir. The suspended sediment yield is transferred downstream, as subject to storage effects between Highway 22 and Sarcee Bridge. The magnitude of these affects is not determined here because they are a direct consequence of flow diversion, the intent of the Project.



Sources: Base Data - Government of Alberta, Government of Canada
Thematic Data - Stantec Ltd

Estimated Reservoir Sedimentation Depths
Post Release: 1:100 Year Flood

Figure 6-17

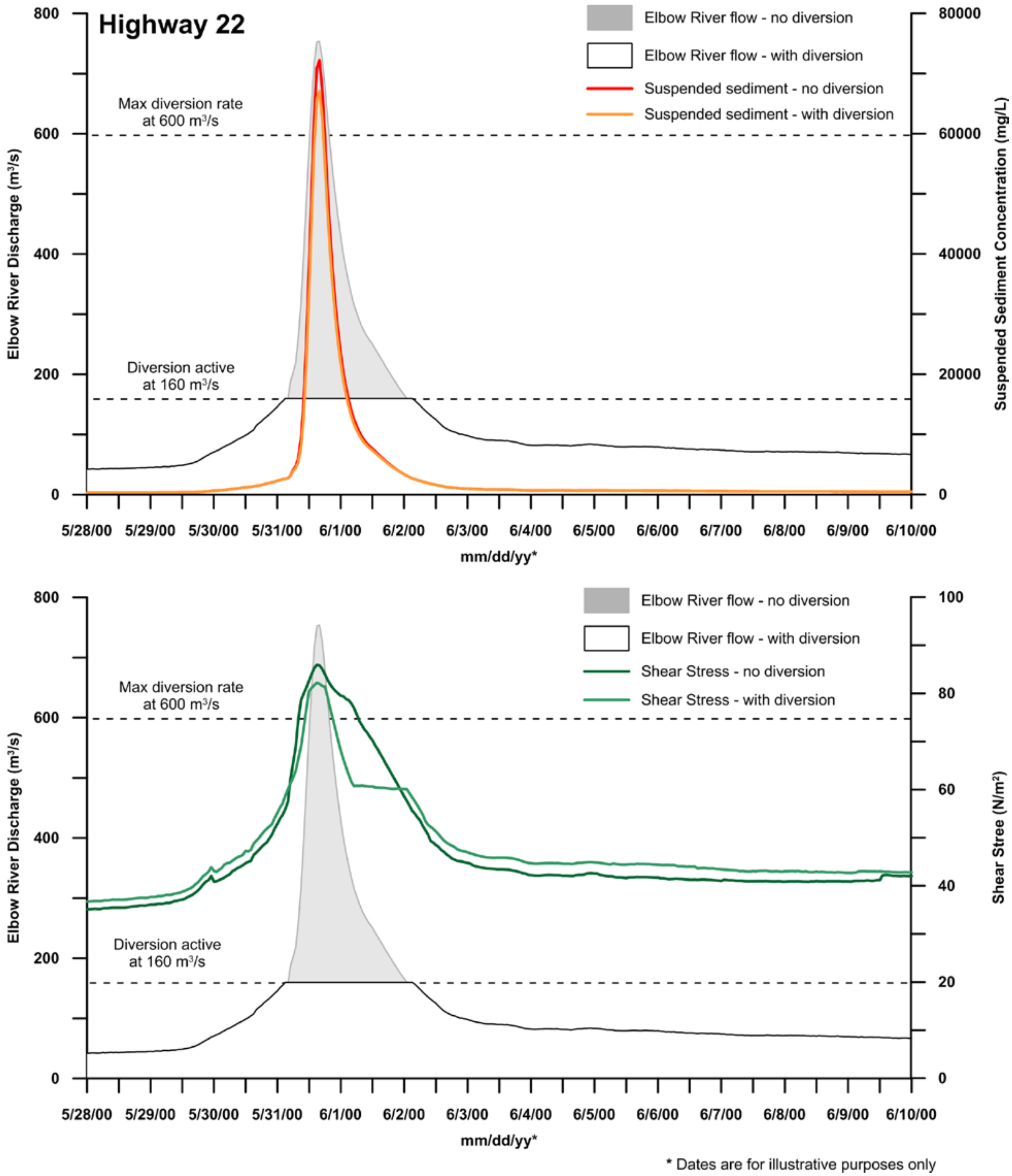


Figure 6-18 Suspended Sediment Concentrations and Shear Stress at Highway 22 During Active Diversion for the 1:100 Year Flood

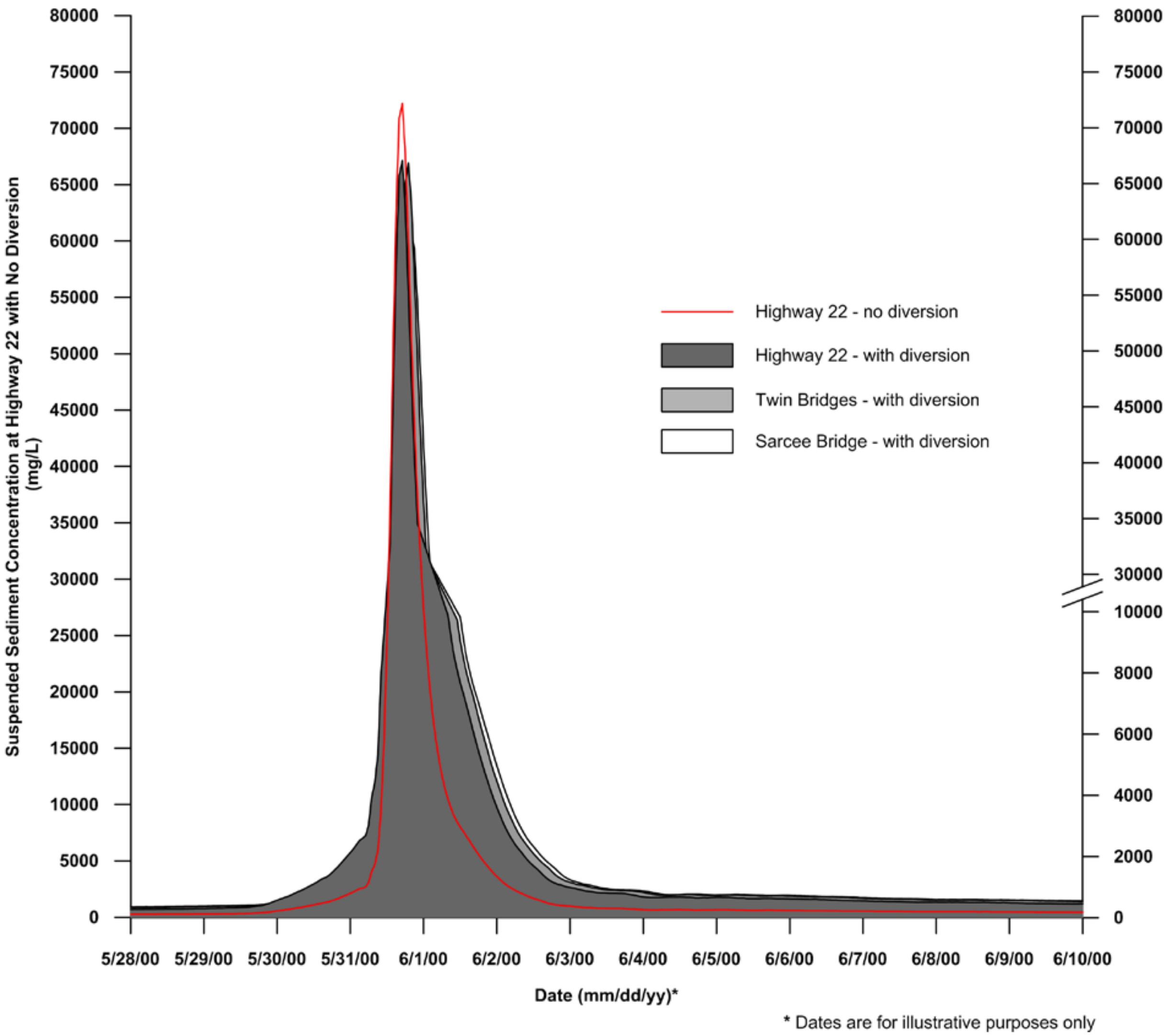


Figure 6-19 Downstream Changes in Suspended Sediment Concentration During Active Diversion for the 1:100 Year Flood

Release of water from the reservoir would result in a transient increase in suspended sediment concentrations in the low-level outlet and the Elbow River (Table 6-8 and Figure 6-20). Discharge would have increased from approximately 29 m^3/s to 40 m^3/s over an hour at the onset of release. The bankfull discharge at the confluence of the low-level outlet with the Elbow River is approximately 47 m^3/s (recurrence interval of 1.54 years). Peak concentrations modelled at the confluence are in the range of 22,500 g/m^3 but decline to 4,800 g/m^3 in the Elbow River at approximately 1.0 km downstream (Table 6-8). Historical data suggests that monthly suspended sediment concentrations at the time of release in August, without 2013 data, average 16 g/m^3 with a max of approximately 50 g/m^3, at Highway 22 (Figure 6-1).

Up to 219.1 kt of suspended sediment material may be mobilized and transported from the low-level outlet to the confluence with the Elbow River. Flow and storage effects in the Elbow River dilutes this suspended sediment input to 150.5 kt, a 31% decrease, by approximately 1.0 km downstream of the confluence.

There would be a much higher output of suspended sediment mass from the reservoir, compared to the design flood, despite a lower discharge rate from the reservoir. For the 1:100 year flood, there is very little change in suspended sediment mass as a result of erosion within the low-level outlet. The high sediment yield released from the reservoir is likely due to remobilization and suspension of material deposited at the low-level outlet. Because there is a large amount of sediment deposited in this area, sediment supply is not limited. The modelled peak and average concentrations are higher for the 1:100 year flood than for the design flood (Table 6-7 and Table 6-8). Erosion effects in the low-level outlet may be masked because of the high initial suspended sediment concentrations.

The input of suspended sediment from the low-level outlet modifies the suspended sediment yield in the Elbow River by introducing additional material that partially offsets the material remaining in the reservoir that would have been transferred downstream in the absence of active diversion. This addition of material effectively reduces the suspended sediment yield loss for the 1:100 year flood from 65% to 58%.

Table 6-8 Suspended Sediment Concentrations and Yields in the Low-level Outlet and Elbow River During Release for the 1:100 Year Flood

Location	Peak Suspended Sediment Concentration (g/m³)	Average Suspended Sediment Concentration (g/m³)	Release Time (days)	Peak Suspended Sediment Load During Release (t/h)	Suspended Sediment Yield (kt)
Low-level Outlet	20,789	7,333	38	627	220.0
Confluence with Elbow River	20,692	7,285	38	623	219.1
Elbow River Downstream Boundary[1]	4,704	1,576	38	437	150.5

NOTE:
[1] Location is approximately 1.0 km downstream of the confluence

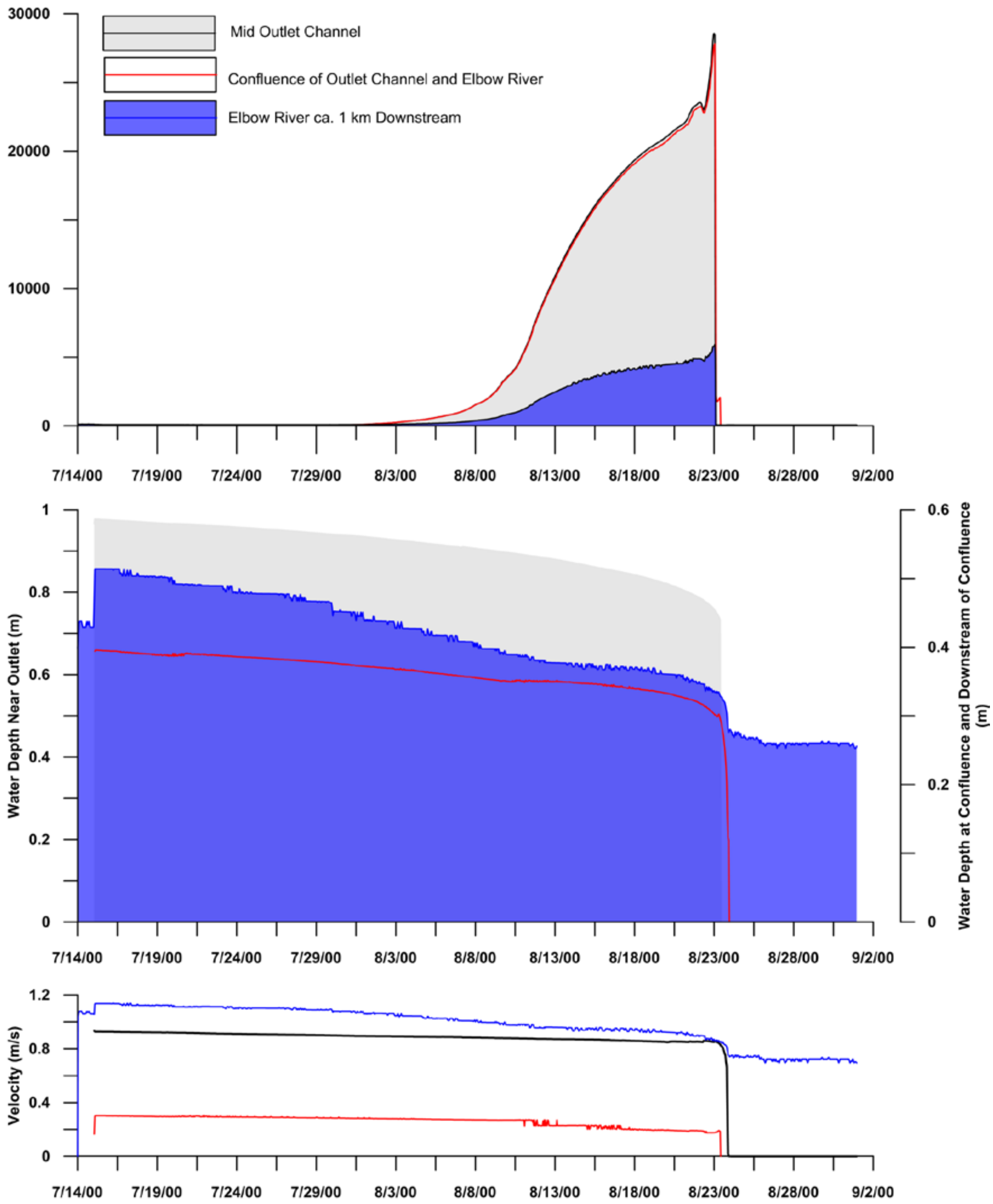


Figure 6-20 Suspended Sediment Concentration in the Low-level Outlet and its Confluence with Elbow River for the 1:100 Year Flood

6.4.3.4 1:10 Year Flood

Concentrations peak at approximately 2,064 g/m³ with an average concentration of 1,258 g/m³ (Table 6-6). The diverted volume of 790 dam³ is insufficient to reach the reservoir centre after active diversion ends. During retention, sediment concentrations show a slight decline from a peak of 1,835 g/m³ to approximately 1,797 g/m³ near the low-level outlet. The concentrations in this location remain stable throughout the retention period (Figure 6-21). Concentrations decline when release commences. This decrease is likely a function of the low rate of release (about 0.250 m³/s) being insufficient to remobilize deposited sediment. The pattern of suspended sediment concentrations during release does fluctuate, reflecting differences in circulation patterns and interaction with the underlying topography, which includes deposited sediment.

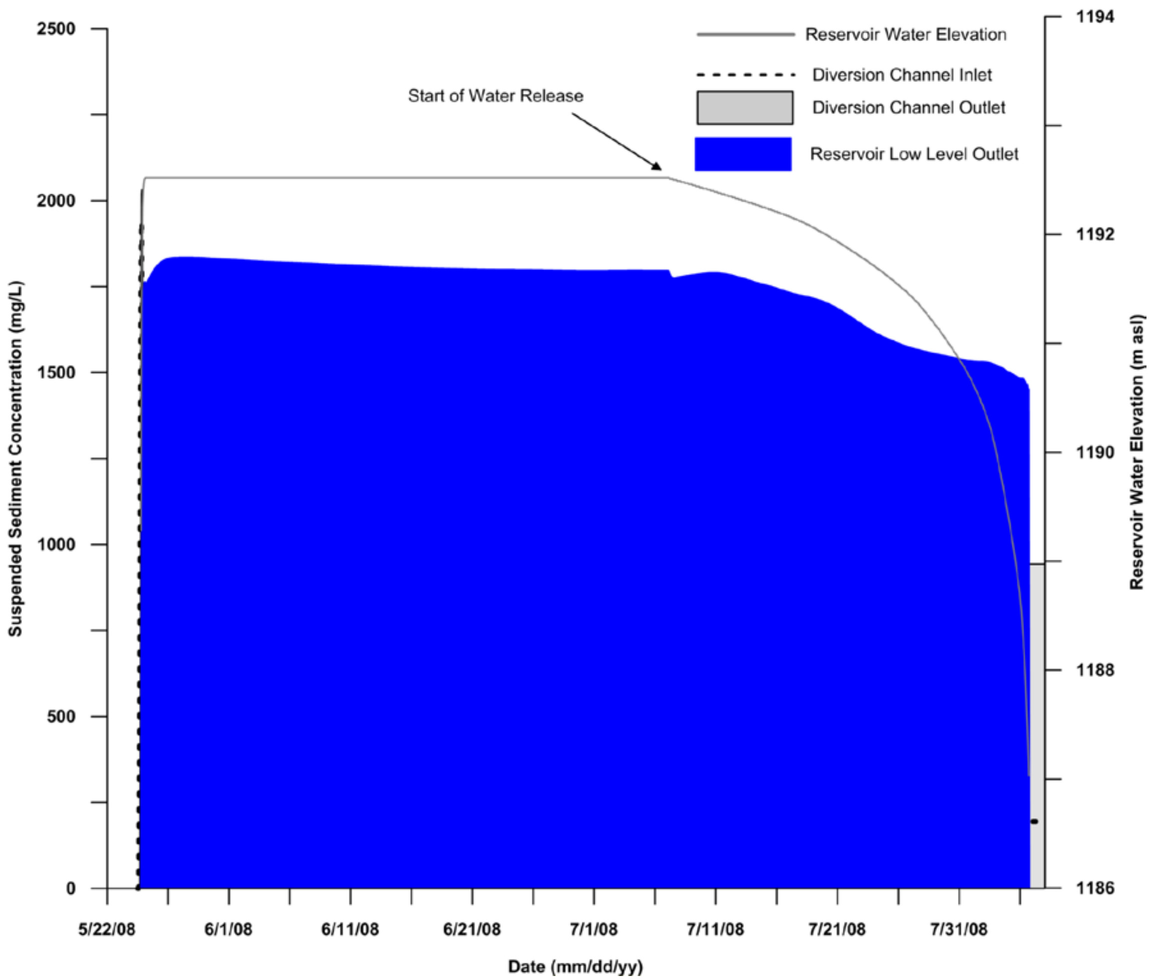


Figure 6-21 Suspended Sediment Concentrations in the Diversion Channel and Reservoir during Diversion, Retention and Release during a 1:10 Year Flood

Given the low suspended sediment concentrations and volumes associated with the 1:10 year flood, the model is not able to resolve sediment thicknesses beyond thin drapes. The location of these drapes would be modified by underlying vegetation and microtopography. This level of detail is not available in the modelling domain and as a result, no figure is presented for reservoir sedimentation depths.

The effects of active diversion on shear stress and suspended sediment concentrations at Highway 22 are shown in Figure 6-22. Suspended sediment concentrations are reduced by approximately 1% along with an associated 2% average reduction in shear stresses. However, shear stress is maintained at approximate average of 60 N/m^2 during active diversion. This shear stress suggests that bed particles with a diameter of approximately 61 mm would be at the point of incipient motion (using a Shields parameter, θ, of 0.06). Given that the sub-surface d_{50} is 21 mm, downstream mobilization of suspended sediment (and bedload) during diversion would continue. A mass balance based on the model data shown in Table 6-6 suggests that downstream suspended sediment yield would be reduced by 5% from 24 kt to 22.7 kt at Highway 22.

Suspended sediment concentrations also show variable change downstream during and post-flood operation (Figure 6-23). During release, peak suspended sediment concentrations would increase by 0.3% between Highway 22 and Twin Bridges and decrease by 1% between Twin Bridges and Sarcee Bridge. Average suspended sediment concentrations would increase by 21% between Highway 22 and Twin Bridges and by 3% between Twin Bridges and Sarcee Bridge. These differences suggest that temporal and spatial changes in storage losses and gains play a significant role in controlling suspended sediment yields in the Elbow River, as shown by the inter-annual variability in annual suspended sediment yields (Section 6.2.3). Active diversion of this flood is unlikely to have a measurable effect on downstream suspended sediment dynamics.

In summary, suspended sediment concentrations and suspended sediment yield are reduced by up to 5% during active diversion (compared to no diversion) with approximately 1.3 kt of suspended sediment diverted into the reservoir. The suspended sediment yield is transferred downstream, as subject to storage effects between Highway 22 and Sarcee Bridge. The magnitude of these affects is not determined here because they are a direct consequence of flow diversion, the primary intent of the Project.

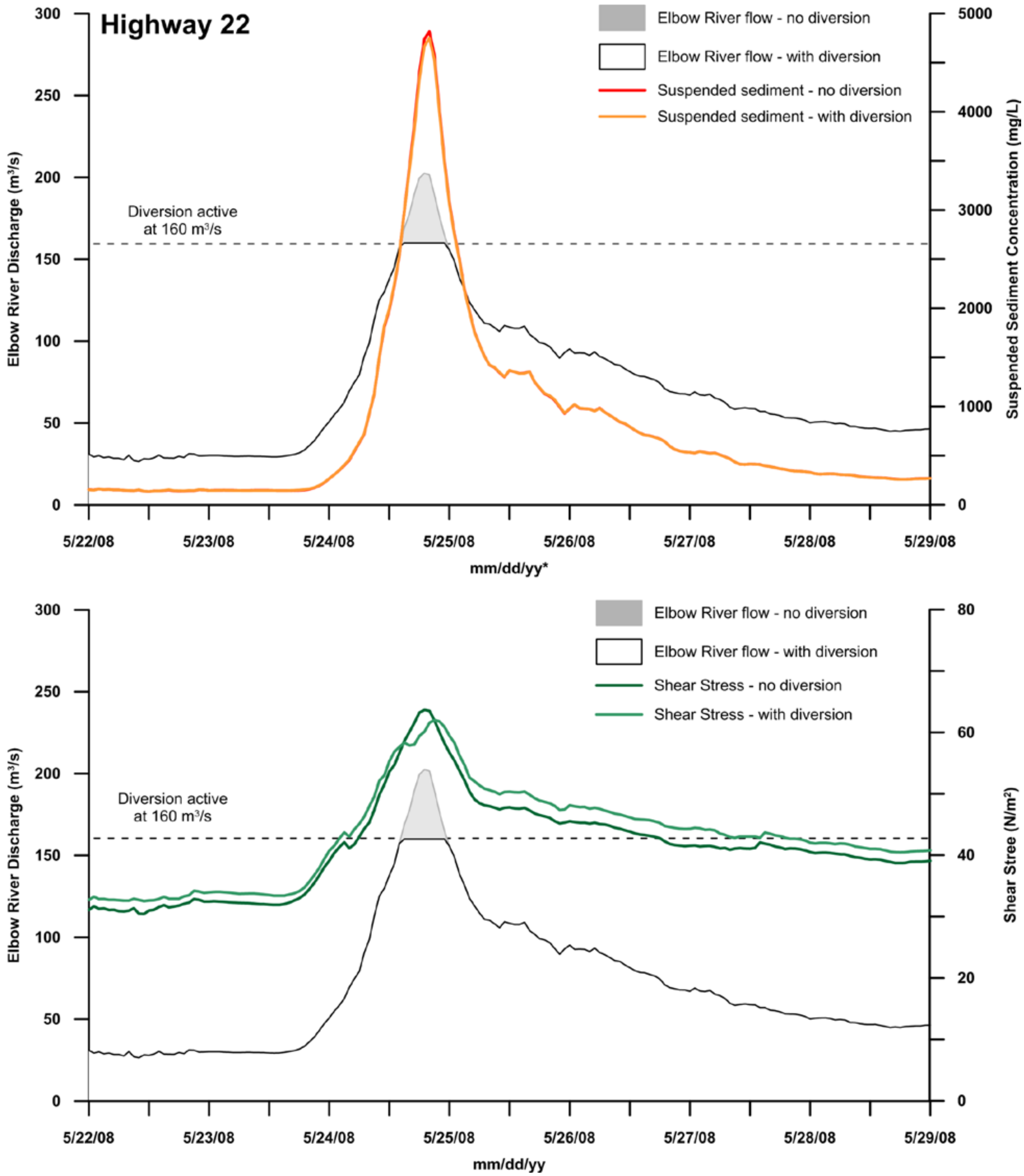


Figure 6-22 Suspended Sediment Concentrations and Shear Stress at Highway 22 During Active Diversion for the 1:10 Year Flood

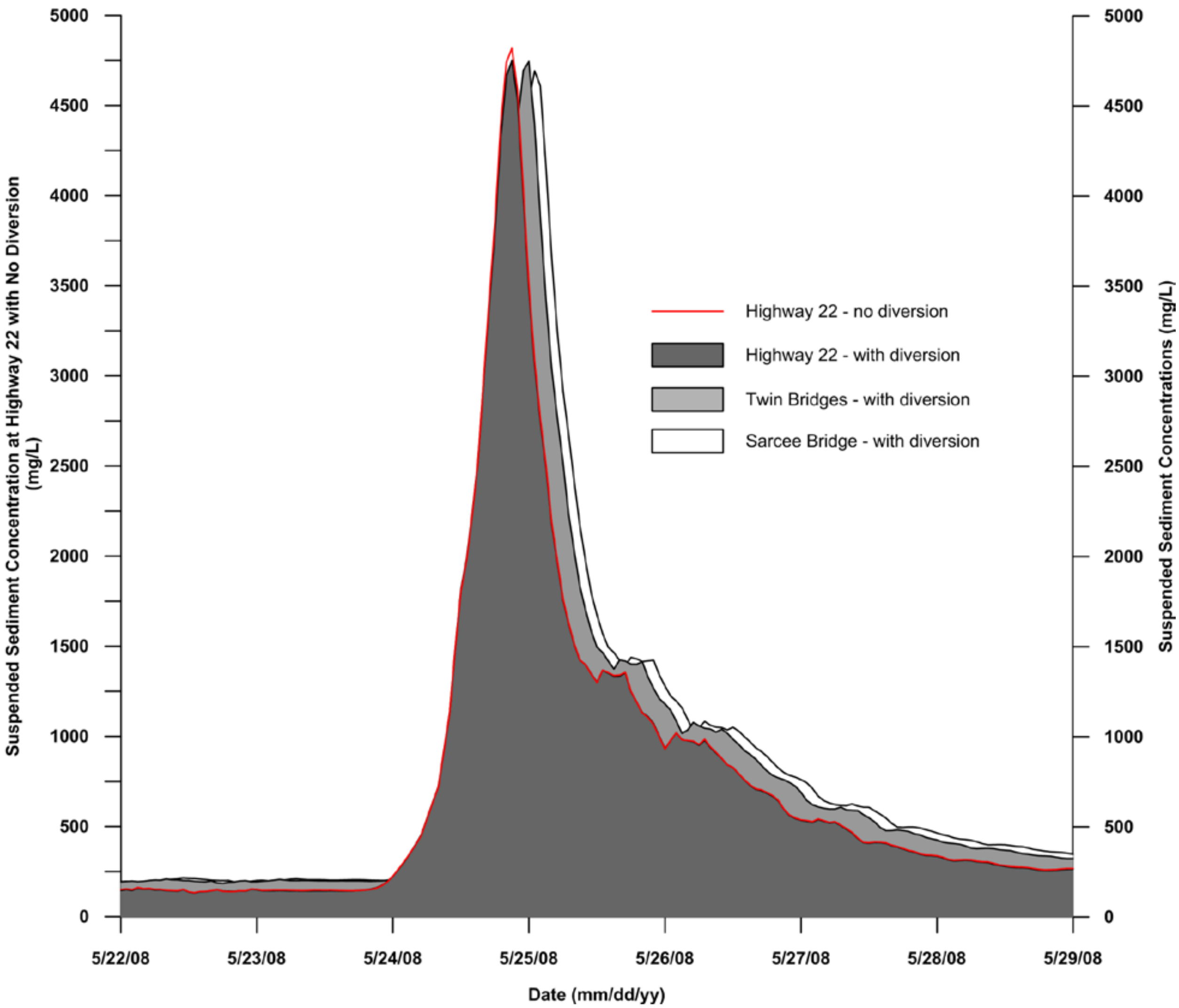


Figure 6-23 Modelled Downstream changes in Suspended Sediment Concentration Due to Diversion: 1:10 Year Flood

Release of water from the reservoir would result in a minor and transient increase in suspended sediment concentrations in the low-level outlet and Elbow River (Table 6-9 and Figure 6-24). No substantial effect on discharge in the Elbow River would occur (Figure 6-24). Peak concentrations modelled at the confluence of the low-level outlet with Elbow River approximately 1,800 g/m^3 but decline to 99 g/m^3 once in the Elbow River approximately 1.0 km downstream Table 6-9). Historical data suggests that monthly suspended sediment concentrations in August, without 2013 data, average 16 g/m^3 with a maximum of approximately 50 g/m^3, at Highway 22 (Figure 6-1). Release of water from a 1:10 year flood would have a negligible effect on suspended sediment concentrations in Elbow River.

Based on the model suspended sediment concentration results, up to 1.1 kt of suspended sediment material may be mobilized from the reservoir and transported down the low-level outlet. There is little to no further addition of material from the low-level outlet itself. The lack of increase is a function of release flow rates averaging approximately 0.250 m^3/s, well below the estimated bankfull discharge of 1.0 m^3/s. Flow and existing suspended concentrations in the Elbow River suggest that this suspended sediment input would be increased to 3.2 kt, a 290% increase, by approximately 1.0 km downstream of the confluence. This indicates that the released sediment load actually dilutes sediment loads in the river. This increase further supports the lack of effect on suspended sediment concentrations and yields in the Elbow River during release of water from the reservoir.

Table 6-9 Suspended Sediment Concentrations and Yields in the Low-level Outlet and Elbow River During Release for a 1:10 Year Flood

Location	Peak Suspended Sediment Concentration (g/m^3)	Average Suspended Sediment Concentration (g/m^3)	Release Time (days)	Peak Suspended Sediment Load During Release (t/h)	Suspended Sediment Yield (kt)
Low-level outlet	1,798	1,656	30	1.7	1.1
Confluence with Elbow River	1,798	1,657	30	1.7	1.1
Elbow River Downstream Boundary[1]	99	81	30	7.3	3.2

NOTE:
[1] Location is approximately 1.0 km downstream of the confluence

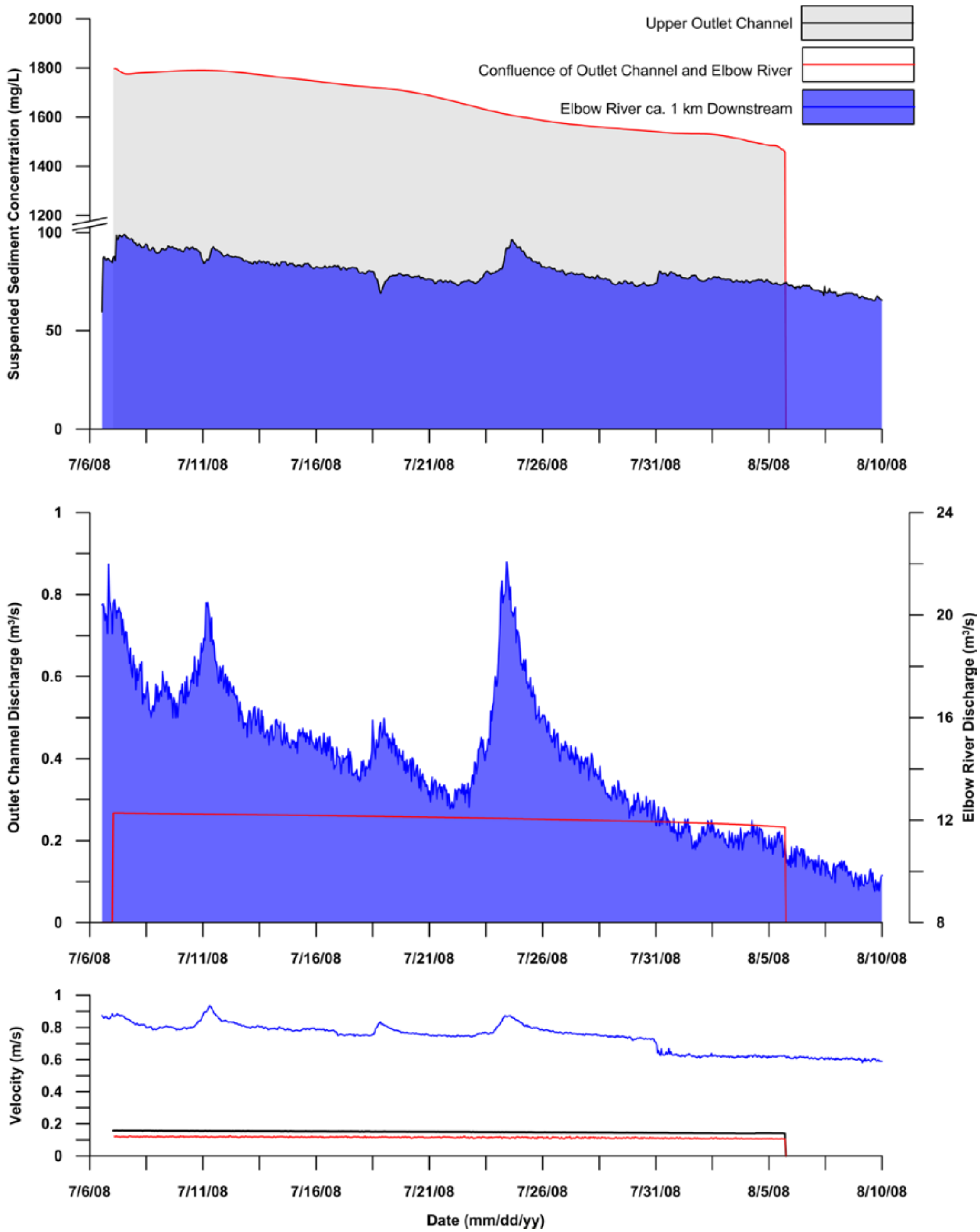


Figure 6-24 Suspended Sediment Concentration in the Low-level Outlet and Confluence with Elbow River for the 1:10 Year Flood

6.4.4 Change in Channel Morphology

Operation of the Project would change the nature of bedload transport in the Elbow River. Bedload transport is typically sporadic and particles are moved by rolling, sliding or saltation (Knighton 1998). If shear stresses are sufficiently high, some smaller particles may be held temporality in suspension in the water column by turbulence. Typically, the range of particle sizes than are transported as bedload are restricted to those greater than 0.063 mm in size. Under flood conditions, the primary particle size transported in the Elbow River would likely be gravel-sized material, with a median grain size of 21 mm. This value is based on the current grain size distribution in the Elbow River (see Volume 4, Appendix J, Hydrology Technical Data Report for more detail). Although bedload movement can be significant during a flood, bedload yields do not typically dominate watershed scale sediment transfer in the Elbow River and bedload transport varies significantly in time and space in this river system (Hudson 1983). However, Hudson (1983) demonstrated that bedload in Elbow River typically moves as sheets over the bed as short period kinematic waves. As a result, the effect of project operation would manifest in downstream changes in channel morphology as a function of reduced shear-stresses and, thus, the potential for mobility.

6.4.4.1 Overview of Project Effect

The effect of diversion on downstream channel geomorphology and changes to the geomorphology of the low-level outlet would be a function of the reduction in shear stress downstream due to flow diversion and increases in shear stresses in the low-level outlet during release. Changes in morphology in the Elbow River would likely take the form of reduced mobilization on bar heads, decreases in degradation and aggradation and potentially changes in channel planform. The extent of these changes would result from a complex interaction between forces applied to the active channel bed and banks, the influence of bedforms in armouring the substrate and variations in grain-size distribution. These interactions are also dynamic and would vary in both time and space throughout a flood. Part of this variability is the inheritance of morphological effects from previous large floods that affected flow dynamics and thus, aggradation and degradation patterns. Additional input of discharge from tributaries also changes flow dynamics downstream of those confluences and subsequently, the geomorphology. Overall, the combination of these effects may affect fish habitat structure downstream of Highway 22 to Glenmore Reservoir due to changes in bed mobility during large, low probability floods, which would modify substrate composition and structure (e.g. changes in bedform structure). This effect on fish habitat is discussed in Section 8.2.

To assess the effect of active diversion on downstream geomorphology, three locations are used to illustrate potential effects. These locations represent changes in the upper, middle, and lower sections of the Elbow River downstream of the diversion inlet. These locations account for tributary flow input and the effect of changing gradients downstream (see Volume 4, Appendix J, Hydrology Technical Data Report). Locations that do not show natural dynamics of the Elbow River system were avoided. The approximate locations are:

- Location 1: 1.3 km downstream of Highway 22
- Location 2: 1.9 km upstream of Twin Bridges
- Location 3: 0.9 km upstream of Sarcee Bridge

The geomorphology of the low-level outlet would be modified by the release of water from the reservoir. The area at the confluence of the low-level outlet with Elbow River is used to estimate the potential geomorphology changes from transported bedload material in the low-level outlet.

The net change in aggradation and degradation for the low-level outlet and for Elbow River (from the location of the diversion inlet to Glenmore Reservoir) for each flood is summarized in Table 6-10. The greatest change for the range of degradation/aggradation occurs during the design flood. Net overall range is reduced by approximately 16.8%. This means that while degradation and aggradation would still occur, the magnitudes are reduced. In contrast, for the 1:100 flood, there is likely no shift in overall net aggradation/degradation ranges during active diversion. This difference likely reflects the higher sustained shear stresses within the diversion inlet during the design flood (without diversion) being able to mobilize and transport more bedload sediment than during the 1:100 year flood. The overall range reduction of the 1:10 year flood is approximately 24% with the Project.

The net change in aggradation and degradation in the low-level outlet suggests that the geomorphological effect would be similar for both the design and synthetic 1:100 flood. Although a higher release rate and volume is associated with the design flood, the majority of this flow would be overbank and not in the active channel. As a result, the actual flows contained in the low-level outlet would be at bankfull for the same period for the design flood and 1:100 year flood, hence the similarity in net change. For the 1:10 year flood release, there is a much lower net change. The net change in aggradation and degradation in the low-level outlet suggests that the geomorphological effect would be similar for both the design and 1:100 floods. Although a higher release rate and volume is associated with the design flood, the majority of this flow would be overbank and not in the low-level outlet. Given that the floodplain is heavily vegetated with high roughness values, the reduction as a result of less than bankfull flow reducing degradation/aggradation during release.

Table 6-10 Net Change in the Geomorphology of the Elbow River and Low-level Outlet

Flood	Location	Operation	Maximum Degradation (m)	Maximum Aggradation (m)	Range (m)	Change in Range with Diversion (%)
Design	Elbow River	without diversion	-2.55	2.66	5.21	-17
		with diversion	-2.44	1.89	4.33	
1:100 year	Elbow River	without diversion	-2.25	1.86	4.11	3
		with diversion	-2.20	2.03	4.23	
1:10 year	Elbow River	without diversion	-2.01	2.28	4.29	-24
		with diversion	-1.97	1.29	3.27	
Design	Low-level outlet	release	-0.56	0.40	0.96	NA
1:100 year	Low-level outlet	release	-0.56	0.46	1.02	NA
1:10 year	Low-level outlet	release	NC (-0.01)	NC (0.01)	(NC (0.01)	NA

NOTES:
NA: Not applicable
NC: No change

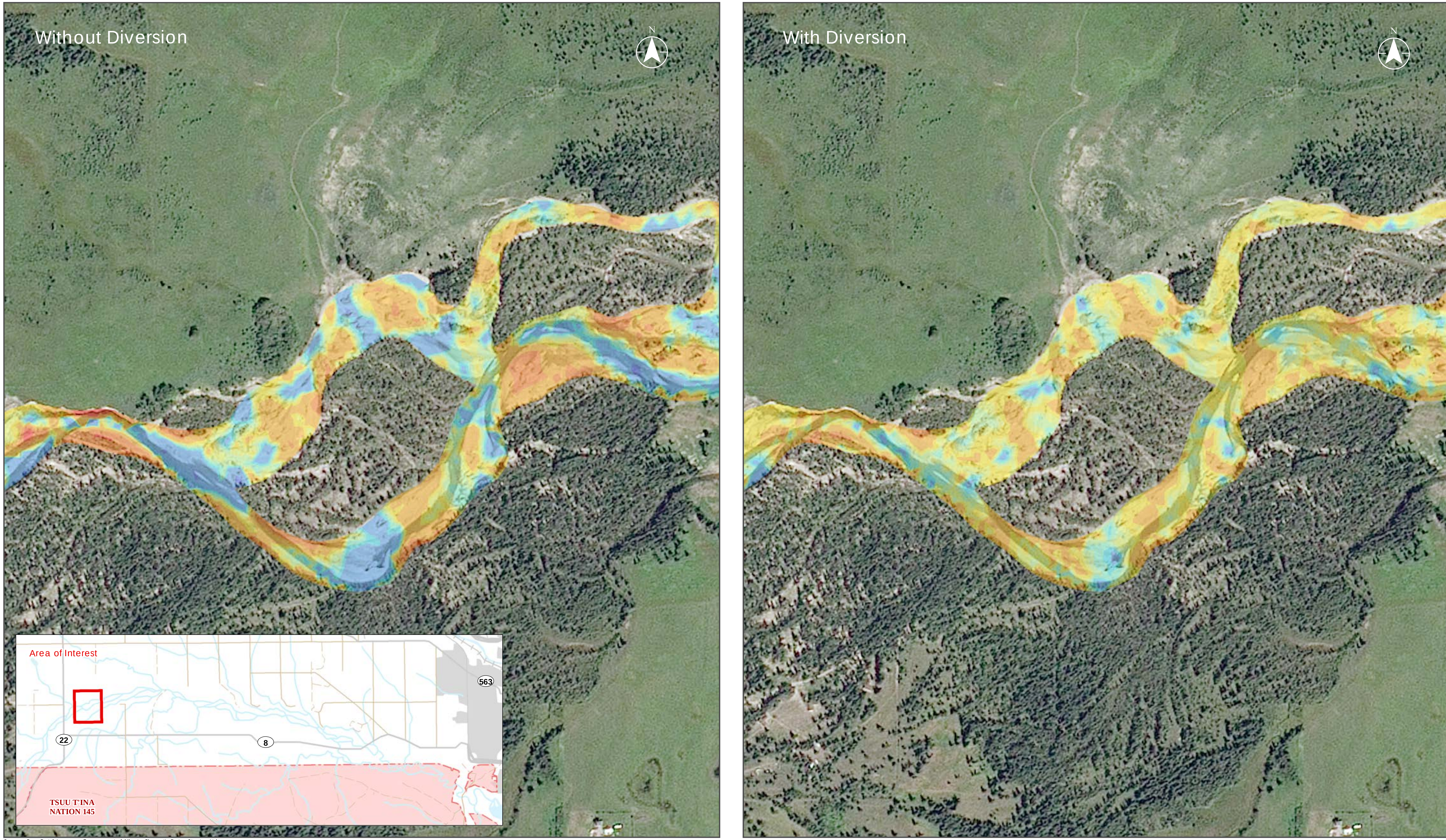
6.4.4.2 Design Flood

The net geomorphic change for the design flood at the upper, middle, and lower sections of the Elbow River downstream of Highway 22 suggest that the gravel bar morphology would be maintained during active diversion, without any significant alteration of channel planform (Figure 6-25 to Figure 6-27). The pattern of erosion of bar heads and subsequent deposition downstream would be maintained with active diversion, albeit with an expected reduction in magnitude of approximately 65%. Bank erosion would be reduced during active diversion. For example, erosion rates on a clearly eroding bank shown in Figure 6-27 would be reduced from -2.03 m to -0.12 m. This range would potentially lower the amount of sediment entering Elbow River from bank erosion during floods, for the period of active diversion.

The effect on the Elbow River geomorphology from diversion of a design flood, based on the percentage reduction, is long-term in duration. However, given the low probability of a design flood and continued reworking of channel bars during non-diverted flood years, coupled with known spatial and temporal variability of bed movement in the Elbow, the effect is more likely medium-term in duration. The current form of Elbow River is unlikely to change significantly from current lateral and vertical variability. Bed movement is maintained under diversion and only the magnitude of aggradation and degradation during diverted floods would be affected.

Model estimated geomorphic changes for the low-level outlet are shown in Figure 6-28. The model results indicate that the range of degradation/aggradation varies between ± 0.5 m for a total range of approximately 1.0 m, a high magnitude effect. The spatial distribution of modelled geomorphology change largely coincides with existing zones of degradation. The highest levels of degradation occur where there are increases in channel gradient over short distances. Bed material is not transported significant distances but rather eroded and then immediately deposited downstream as lobate sheets. This pattern suggests that the current pool-riffle morphology would change as the channel forms adjusts to a different bed-material load, post-flood operation of the Project and would be permanent. The nature and time scale of the form adjustment would be determined by the size of the floods and their ability to mobilize and transport the deposited bed material. As the nature of these flows is unknown, it is not possible to predict the exact form or timescale of the adjustments.

A localized gravel fan with an area of approximately 500 m^2 and a depth of approximately 0.05 to 0.1 m would develop at the confluence of the low-level outlet and the Elbow River (see Inset, Figure 6-28). The depth is well within the expected range of aggradation and degradation of -2.44 to 1.89 m in the Elbow River as a result of diversion. This fan would interact with flow in the Elbow River and potentially temporarily modify the location of the active channel of Elbow River. However, the fan's extent and depth is unlikely to result in any permanent alteration. As a result, any fan deposited at the confluence is likely transient in nature and subsequent higher flows in the Elbow River would remobilize the deposited material downstream. Based on the model results, no long-term effect is expected in Elbow River.



Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

Morphology Change (m)

- >1
- 0.50 - 1.00
- 0.20 - 0.50
- 0.15 - 0.20
- 0.10 - 0.15
- 0.05 - 0.10
- 0.00 - 0.05
- -0.05 - 0.00
- -0.30 - -0.05
- -0.80 - -0.30
- <-0.80

0 100 200 300 400
metres

110773396-599 REVA

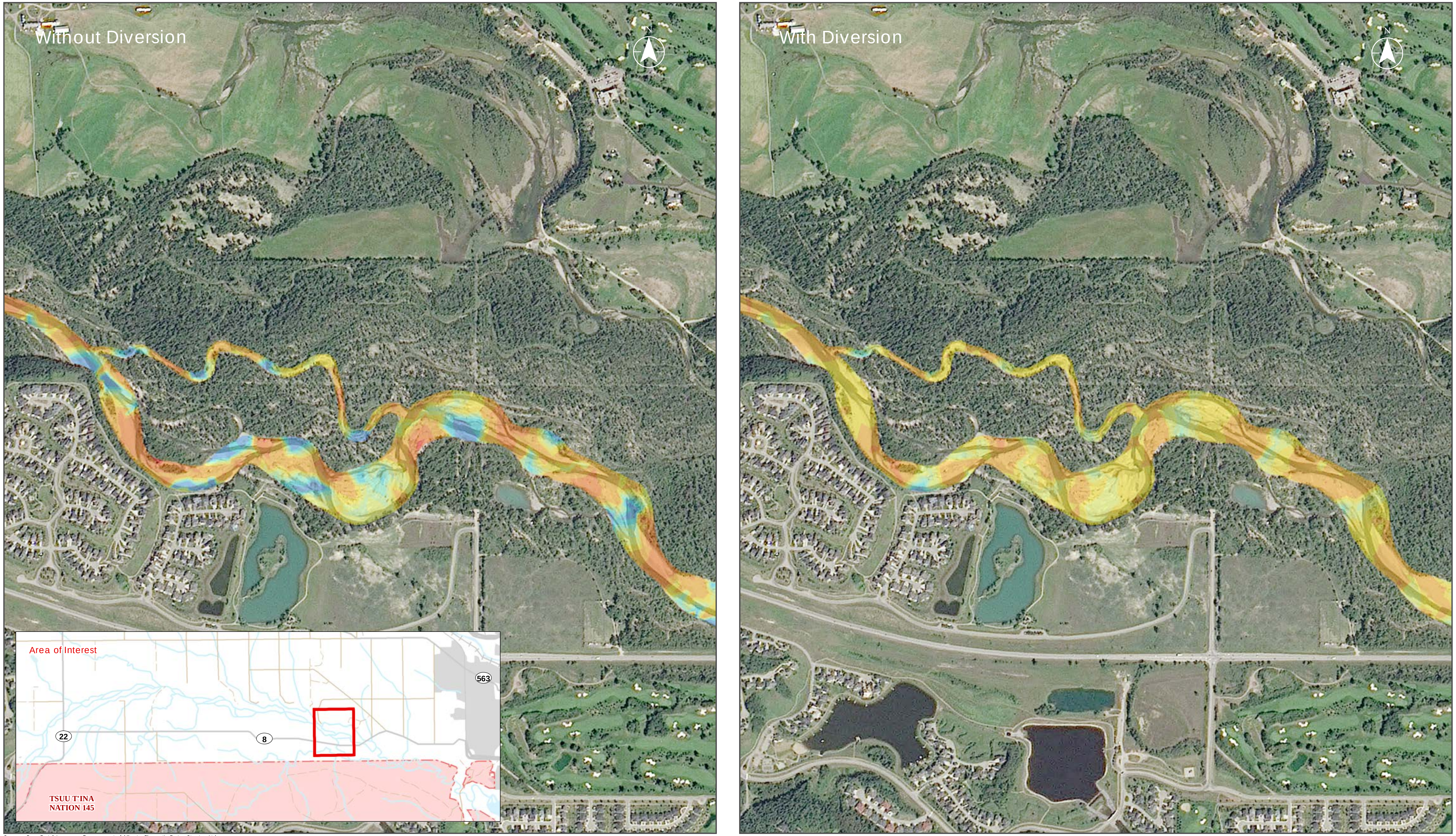
NAD 1983 3TM 114

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Elbow River Net Bed Morphology Changes With and Without Diversion: Design Flood, Location 1

Figure 6-25



Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

Morphology Change (m)

- >1
- 0.50 - 1.00
- 0.20 - 0.50
- 0.15 - 0.20
- 0.10 - 0.15
- 0.05 - 0.10
- 0.00 - 0.05
- -0.05 - 0.00
- -0.30 - -0.05
- -0.80 - -0.30
- <-0.80

0 100 200 300 400
metres

110773396-601 REVA

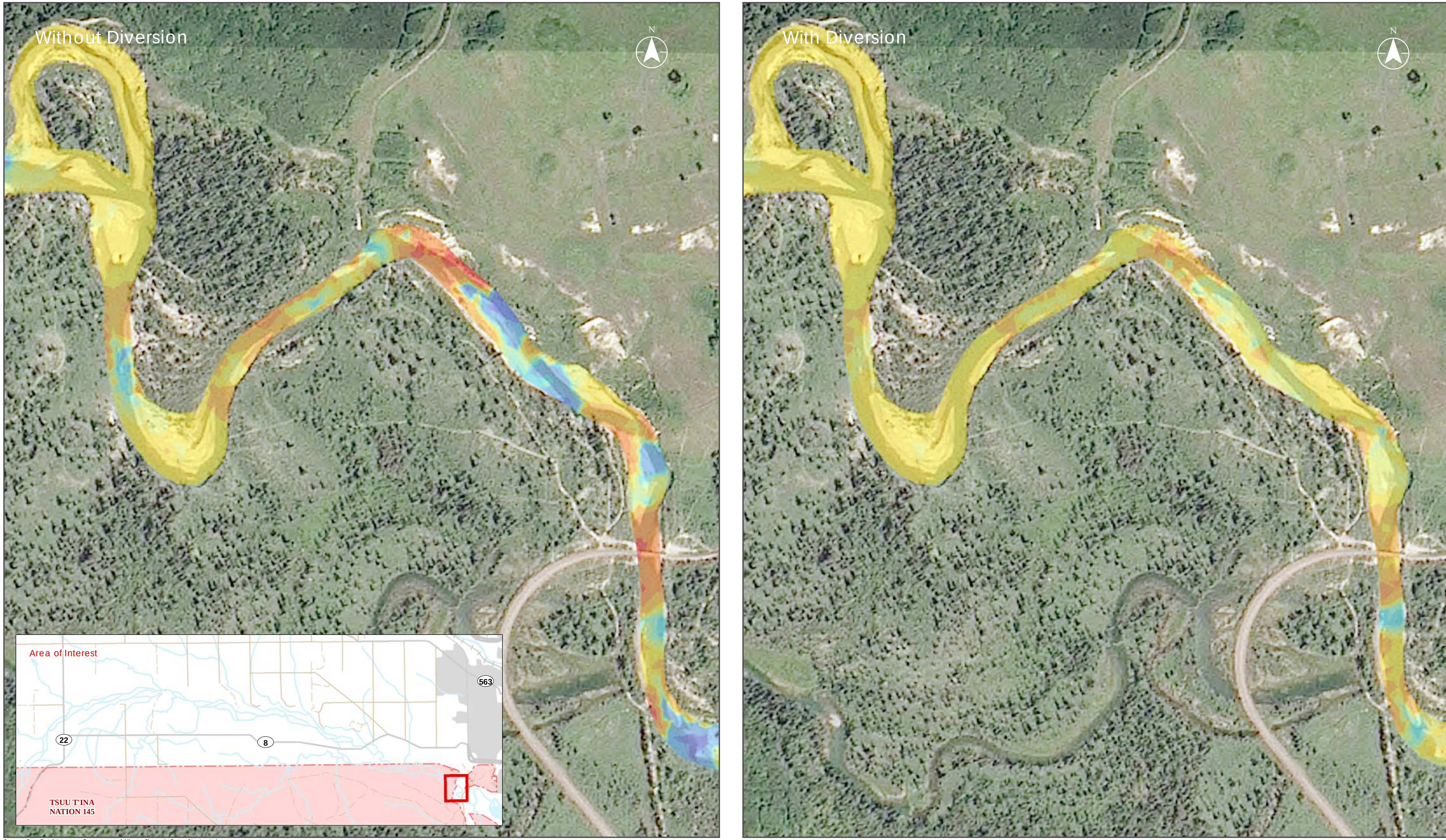
NAD 1983 3TM 114

Stantec

SALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Elbow River Net Bed Morphology Changes With and Without Diversion: Design Flood, Location 2

Figure 6-26



Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

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ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Morphology Change

- >1
- 0.50 - 1.00
- 0.20 - 0.50
- 0.15 - 0.20
- 0.10 - 0.15
- 0.05 - 0.10
- 0.00 - 0.05
- -0.05 - 0.00
- -0.30 - -0.05
- -0.80 - -0.30
- <-0.80

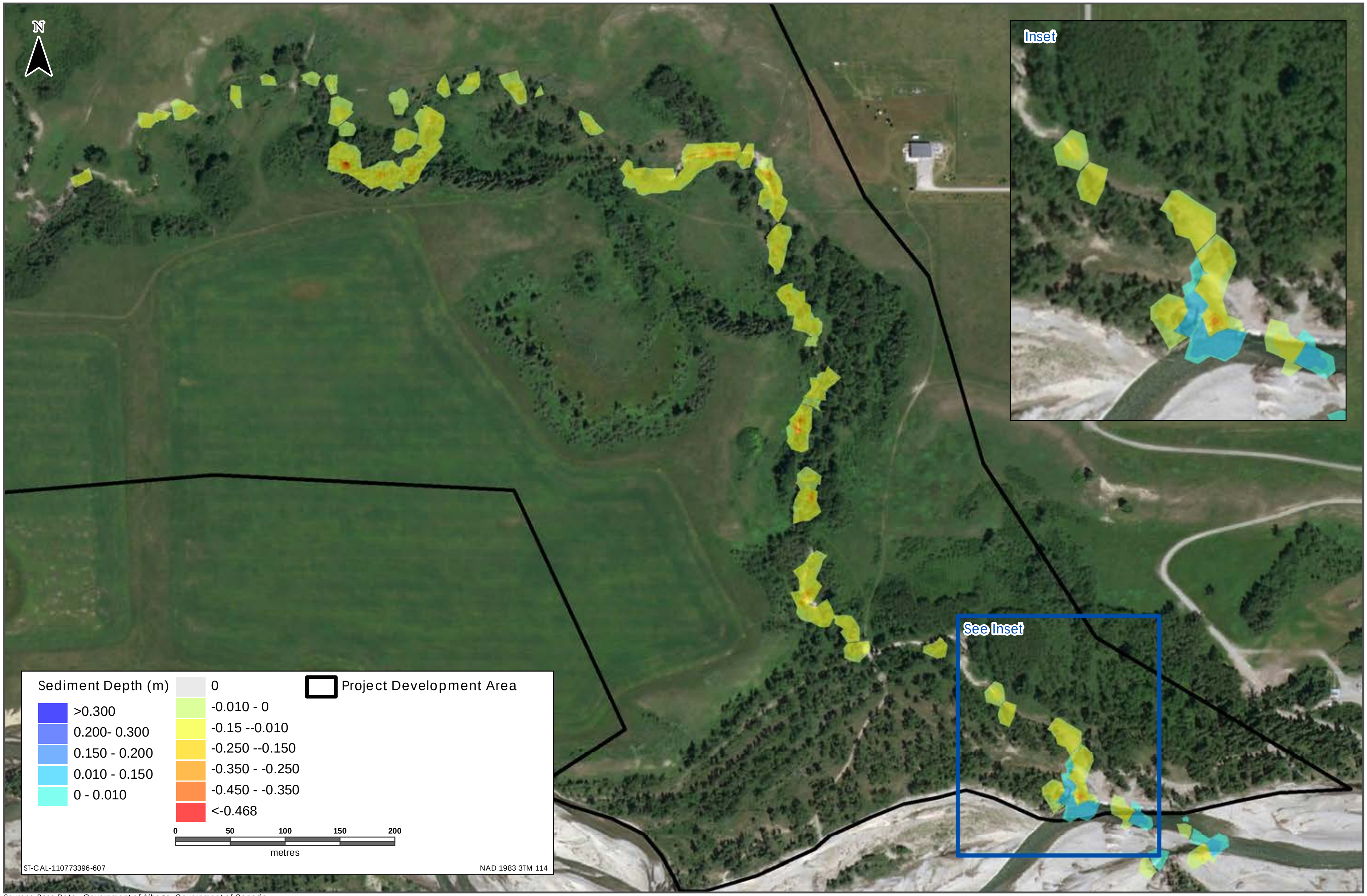
0 100 200 300 400
metres

110773396-602 REVA

NAD 1983 3TM 114

Elbow River Net Bed Morphology Changes With and Without Diversion: Design Flood, Location 3

Figure 6-27



Sources: Base Data - Government of Alberta, Government of Canada
Thematic Data - Stantec Ltd
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Geomorphology Change of the Low-level Outlet for the Design Flood

Figure 6-28

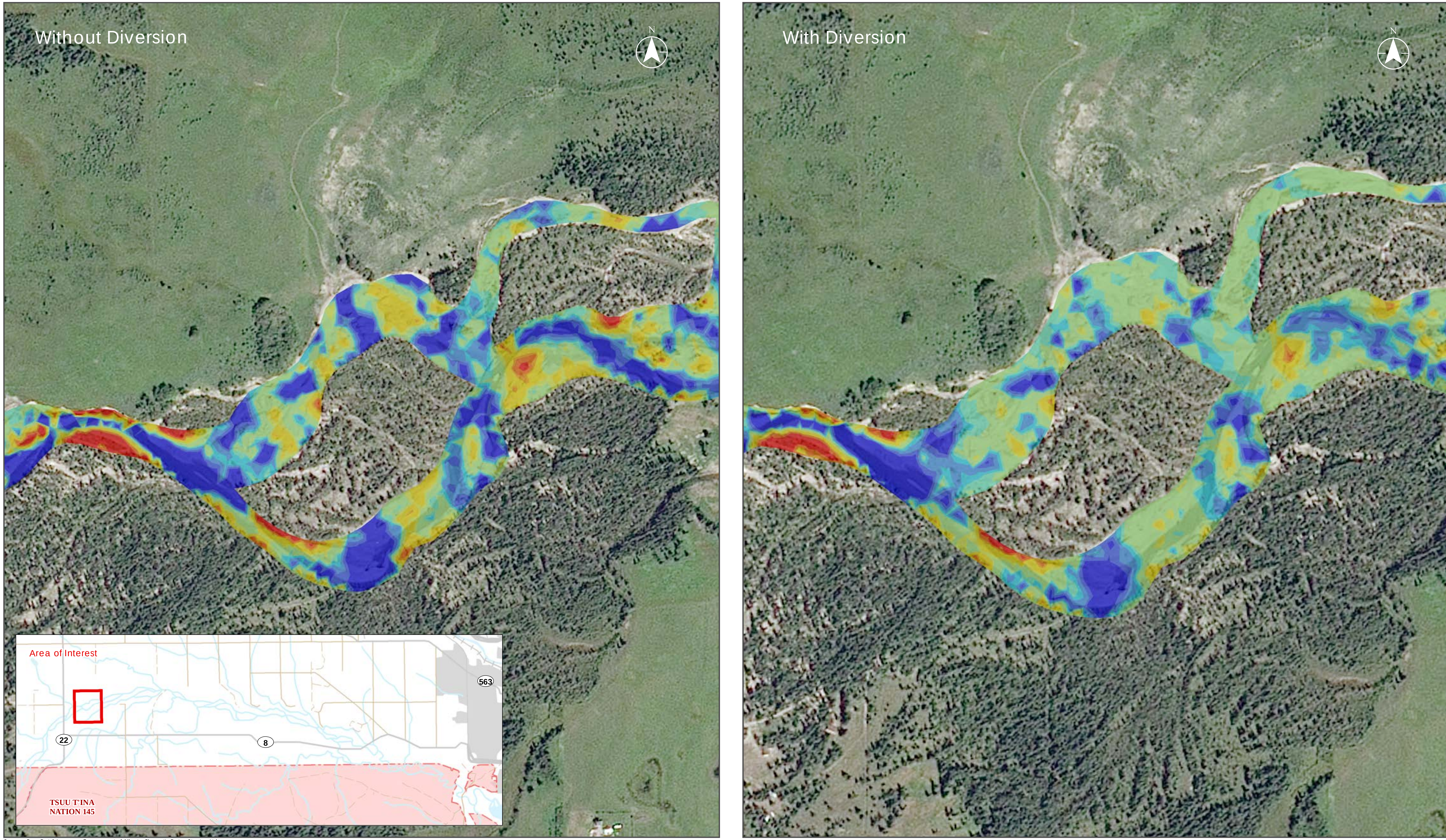
6.4.4.3 1:100 Year Flood

The net geomorphic change for the 1:100 flood at the upper, middle, and lower sections of the Elbow River downstream of Highway 22 suggest that the gravel bar morphology would be maintained during diversion, without any significant alteration of channel planform (Figure 6-29 to Figure 6-31). The pattern of erosion of bar heads and subsequent deposition downstream would be maintained during diversion, albeit with a reduction in magnitude of 5%. The model results also suggest that bank erosion would be reduced during diversion. For example, erosion rates on a clearly eroding bank shown in Figure 6-31 are modelled to reduce from -1.17 m to -0.98 m. This reduction would potentially lower the amount of sediment entering the Elbow River from bank erosion during floods, for the period that the diversion is occurring.

The effect on the Elbow River geomorphology during diversion of a 1:100 year flood is likely medium-term in duration, based on percentage change from existing conditions. However, given the lower probability of this flood occurring and continued reworking of channel bars during non-diverted flood years, coupled with known spatial and temporal variability of bed movement in the Elbow, the effect is more likely short- to medium-term in duration. The current form of Elbow River is unlikely to change significantly from current lateral and vertical variability. Bed movement is maintained during diversion and only the magnitude of aggradation and degradation during diverted floods would be affected.

Model estimated geomorphic changes for the low-level outlet are shown in Figure 6-32. The range of degradation/aggradation has a total range of approximately 1.0 m. As with the design flood, this effect has a high magnitude. The spatial distribution of modelled geomorphology change largely coincides with existing zones of degradation and follows the same pattern as for with the design flood. The highest levels of degradation occur where there are increases in channel gradient over short distances. Bed material is not transported significant distances but rather eroded and then immediately deposited downstream as lobate sheets. This pattern suggests that the current pool-riffle morphology would change as the channel forms adjusts to a different bed-material load during release and be permanent. The nature and time scale of the form adjustment would be determined by the magnitude of subsequent flows and their ability to mobilize and transport the deposited bed material. As the nature of these flows is unknown, it is not possible to predict the exact form or timescale of the adjustments.

A localized gravel fan with an area of approximately 150 m^2 and a depth of approximately 0.05 to 0.17 m would develop at the confluence of the low-level outlet and Elbow River (see Inset, Figure 6-32). The depth is well within the expected range of aggradation and degradation of -2.20 to 2.03 m in the Elbow River as a result of diversion of this size flood. This fan would interact with flow in Elbow River and potentially temporarily modify the location of the active channel of Elbow River. However, the fan’s extent and depth is unlikely to result in permanent alteration. As a result, a fan deposited at the confluence is likely transient in nature and subsequent higher flows in Elbow River would remobilize the deposited material downstream. Based on the model results, no long-term effect on Elbow River is expected.



Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

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ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Morphology Change (m)

- >0.15
- 0.100 - 0.150
- 0.050 - 0.100
- 0.020 - 0.050
- 0 - 0.020
- -0.100 - 0
- -0.150 - -0.100
- -0.300 - -0.150
- -0.350 - -0.300
- -0.455 - -0.350
- <-0.455

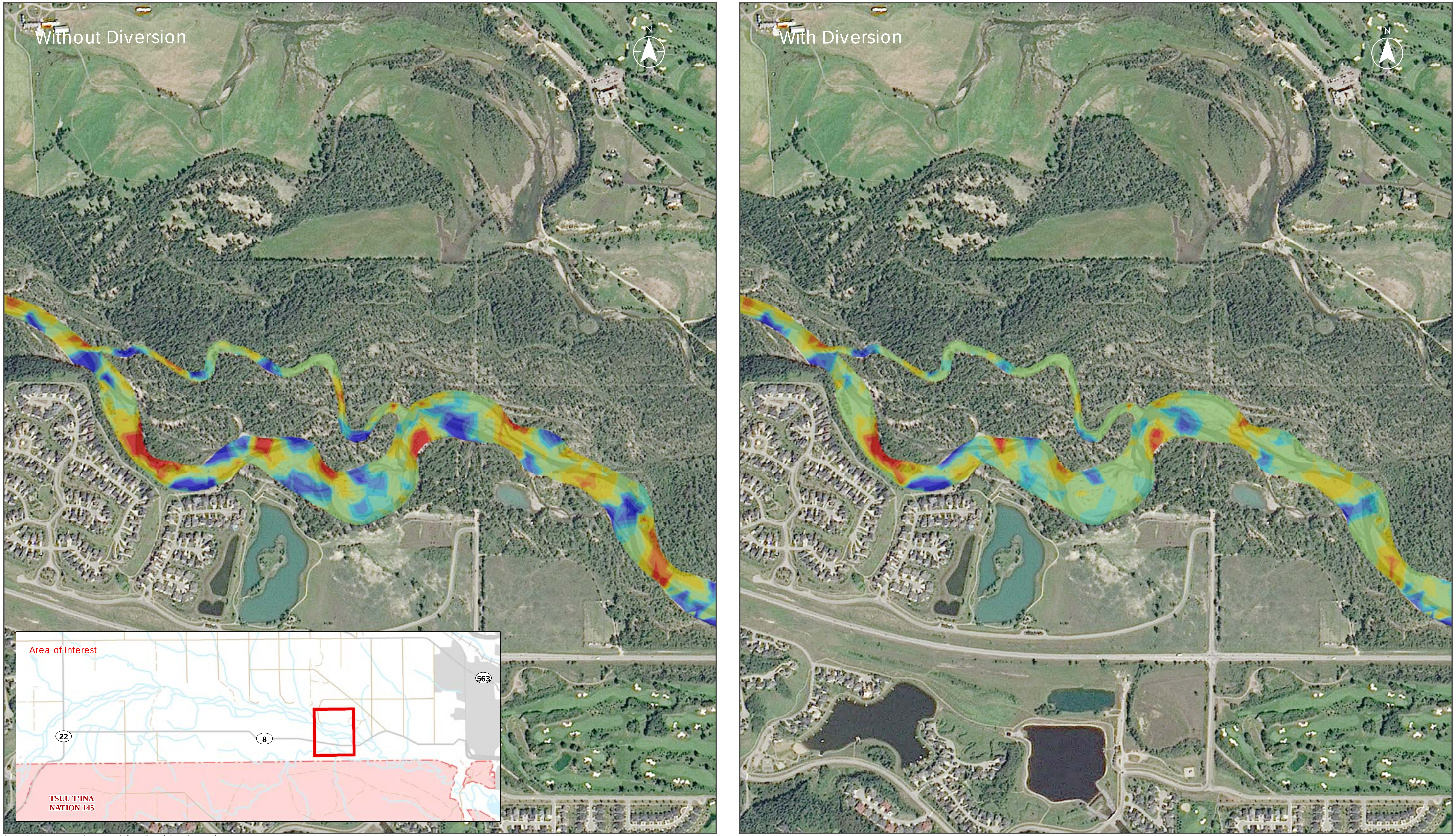
0 100 200 300 400
metres

110773396-603 REVA

NAD 1983 3TM 114

Elbow River Net Bed Morphology Changes With and Without Diversion: 1:100 Year Flood, Location 1

Figure 6-29



Sources: Base Data & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

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ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Morphology Change (m)

- >0.15
- 0.100 - 0.150
- 0.050 - 0.100
- 0.020 - 0.050
- 0 - 0.020
- -0.100 - 0
- -0.150 - -0.100
- -0.300 - -0.150
- -0.350 - -0.300
- -0.455 - -0.350
- <-0.455

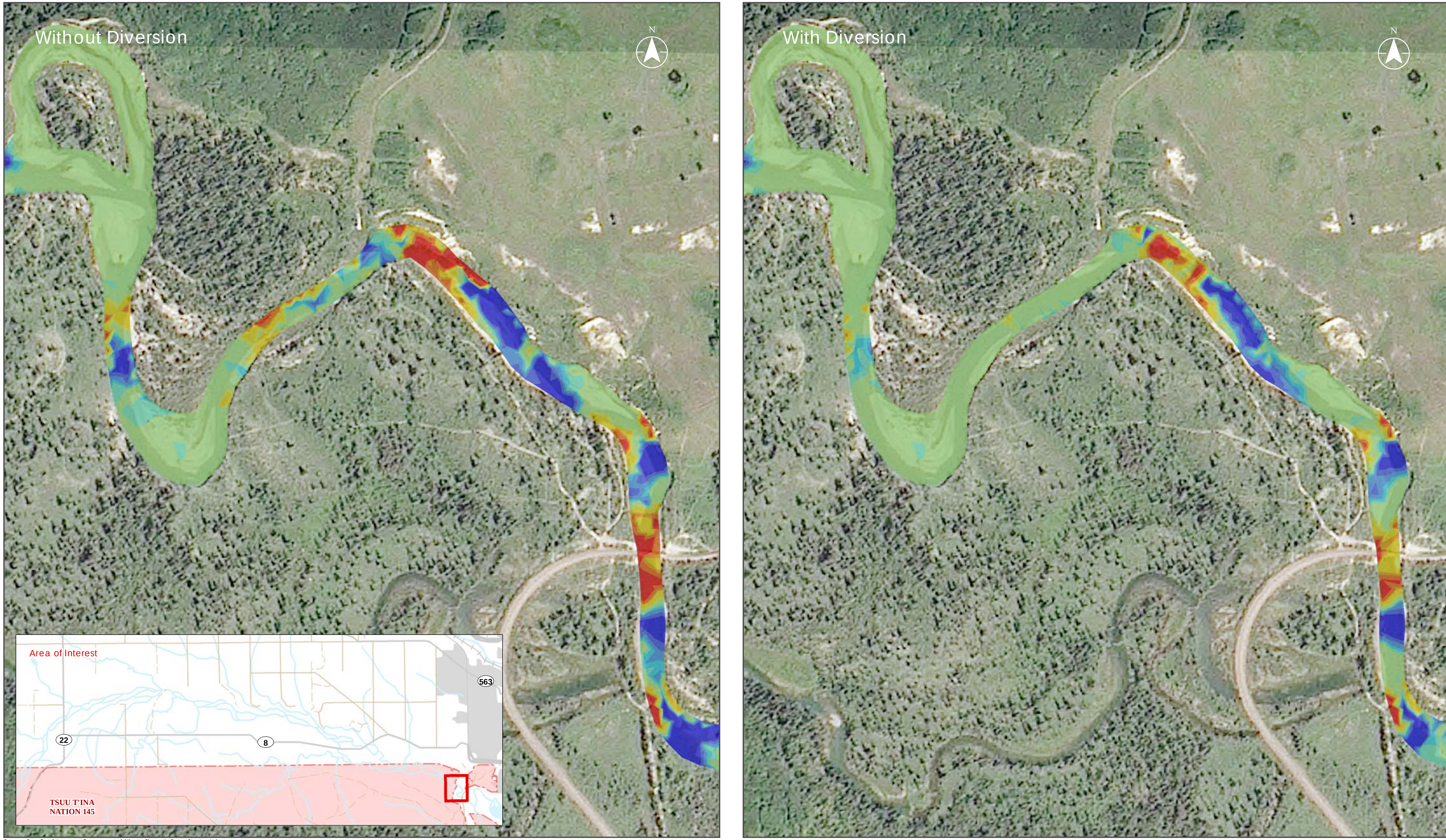
0 100 200 300 400
metres

110773396-604 REVA

NAD 1983 3TM 114

Elbow River Net Bed Morphology Changes With and Without Diversion: 1:100 Year Flood, Location 2

Figure 6-30



Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Morphology Change (m)

- >0.15
- 0.100 - 0.150
- 0.050 - 0.100
- 0.020 - 0.050
- 0 - 0.020
- -0.100 - 0
- -0.150 - -0.100
- -0.300 - -0.150
- -0.350 - -0.300
- -0.455 - -0.350
- <-0.455

Shear Stress Data Created: 20160912

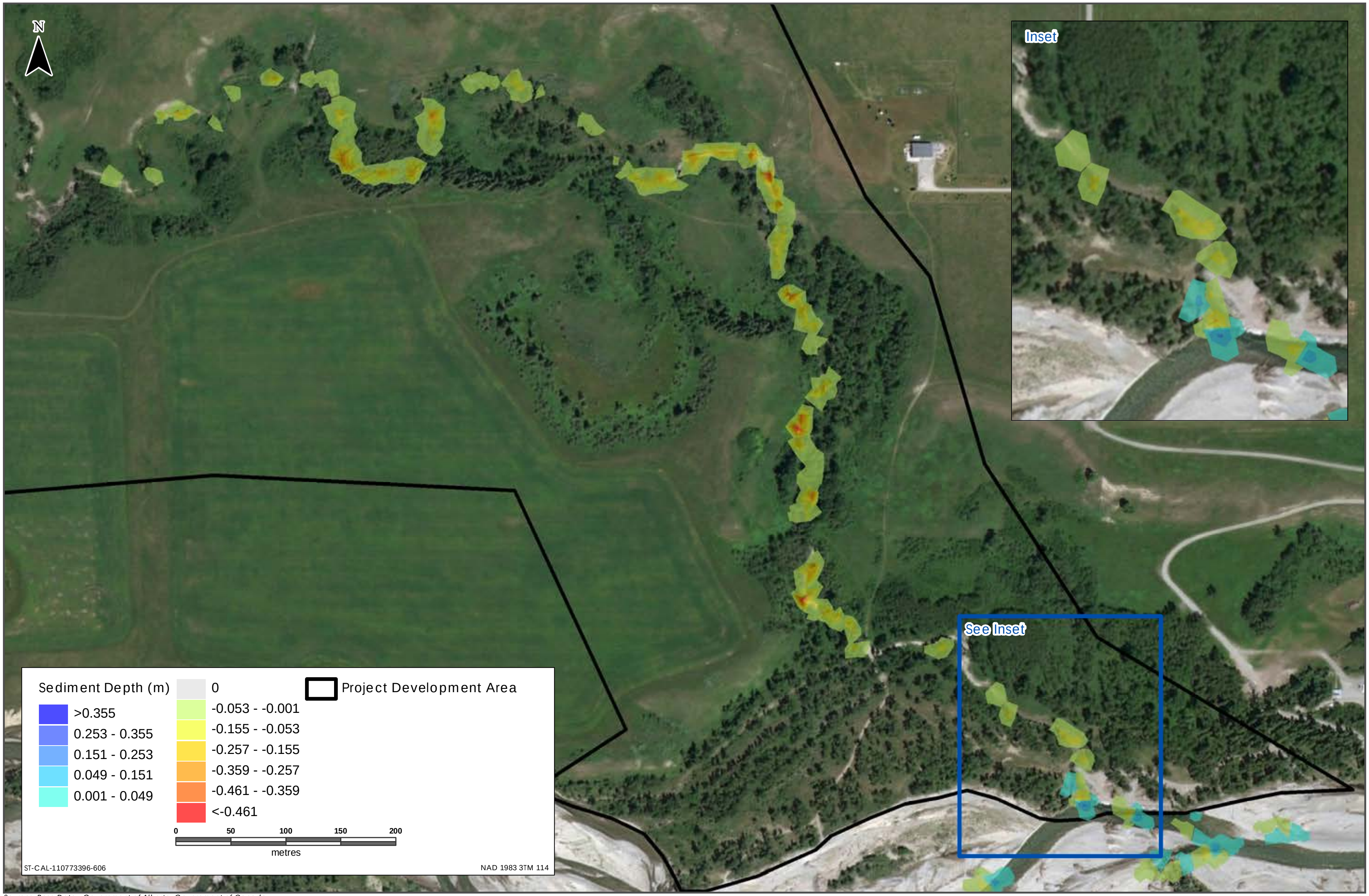
0 100 200 300 400
metres

110773396-605 REVA

NAD 1983 3TM 114

Elbow River Net Bed Morphology Changes With and Without Diversion: 1:100 Year Flood, Location 3

Figure 6-31



Sources: Base Data - Government of Alberta, Government of Canada
Thematic Data - Stantec Ltd
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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Geomorphology Change of the Low-level Outlet for the 1:100 Year Flood

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

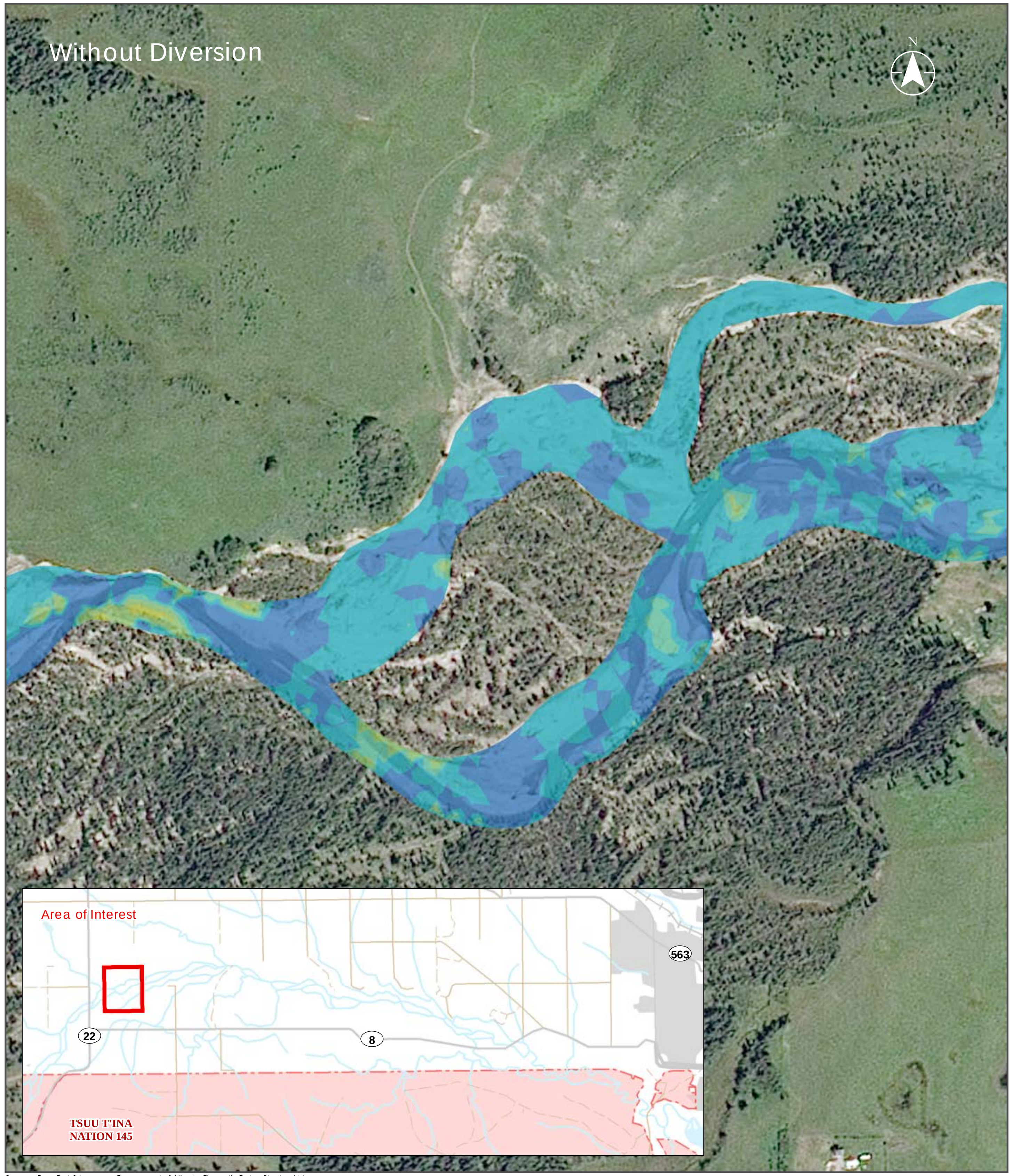
Figure 6-32

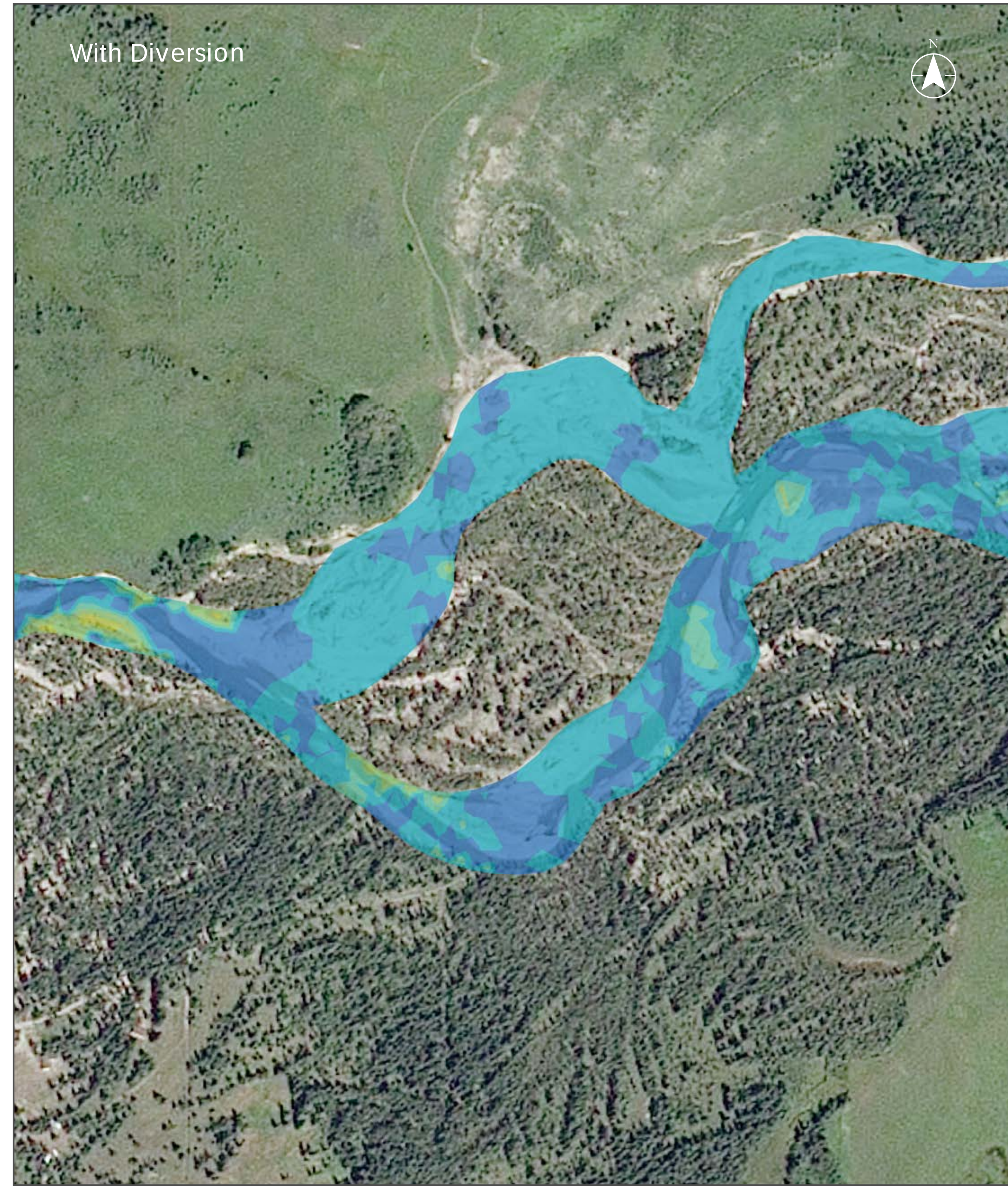
6.4.4.4 1:10 Year Flood

The net geomorphic change for the 1:10 flood at the upper, middle, and lower sections of the Elbow River downstream of Highway 22 suggest that the gravel bar morphology would be maintained during diversion, without any significant alteration of channel planform (Figure 6-33 to Figure 6-35). The pattern of erosion of bar heads and subsequent deposition downstream would be maintained during diversion, albeit with a moderate reduction in magnitude of 24%.

The effect on the Elbow River geomorphology during diversion of a 1:10 year flood is likely short- to medium-term in duration, based on percentage change from existing conditions. However, continued reworking of channel bars during non-diverted flood years, coupled with known spatial and temporal variability of bed movement in Elbow River, the effect might be short-term in duration. The current channel form of Elbow River is unlikely to change significantly from current lateral and vertical variability. Bed movement is maintained during diversion and only the magnitude of aggradation and degradation during diverted floods would be affected.

Model estimated geomorphic changes for the low-level outlet are shown in Figure 6-36. The range of degradation/aggradation is negligible, with no substantial modification to channel morphology or interaction with the Elbow River. Based on the model results, no effect on Elbow River is expected.





Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

Morphology Change (m)

- >1.50
- 1.00 - 1.50
- 0 - 1.00
- -0.100 - 0
- -0.200 - -0.100
- -0.400 - -0.200
- -0.600 - -0.400
- -0.800 - -0.600
- -1.200 - -0.800
- -1.600 - -1.200
- <-1.600

0 100 200 300 400
metres

110773396-609 REVA

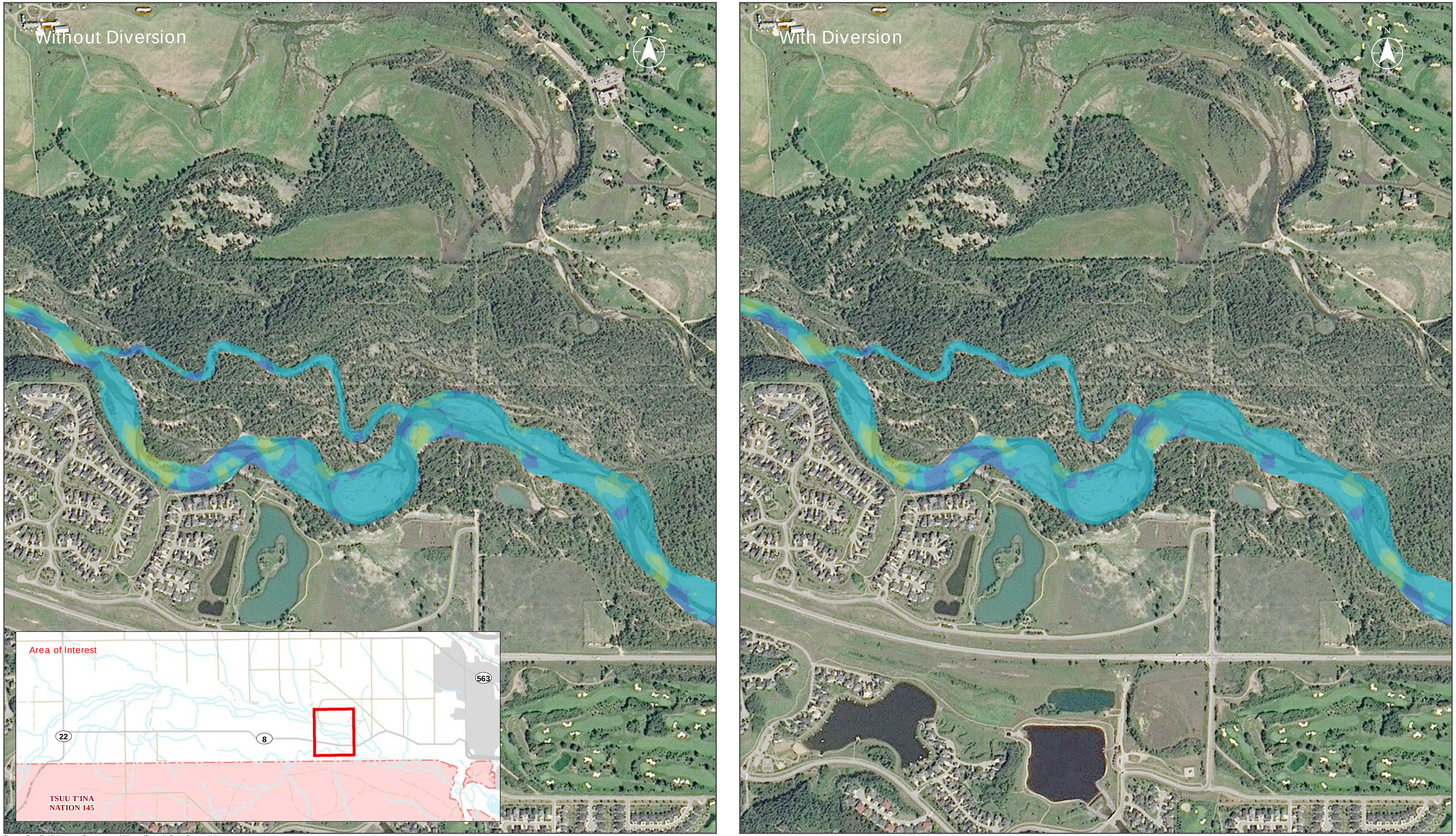
NAD 1983 3TM 114

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Elbow River Net Bed Morphology Changes
With and Without Diversion: 1:10 Year Flood,
Location 1

Figure 6-33



Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

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ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Morphology Change (m)	
>1.50	-0.400 - -0.200
1.00 - 1.50	-0.600 - -0.400
0 - 1.00	-0.800 - -0.600
-0.100 - 0	-1.200 - -0.800
-0.200 - -0.100	-1.600 - -1.200
	<-1.600

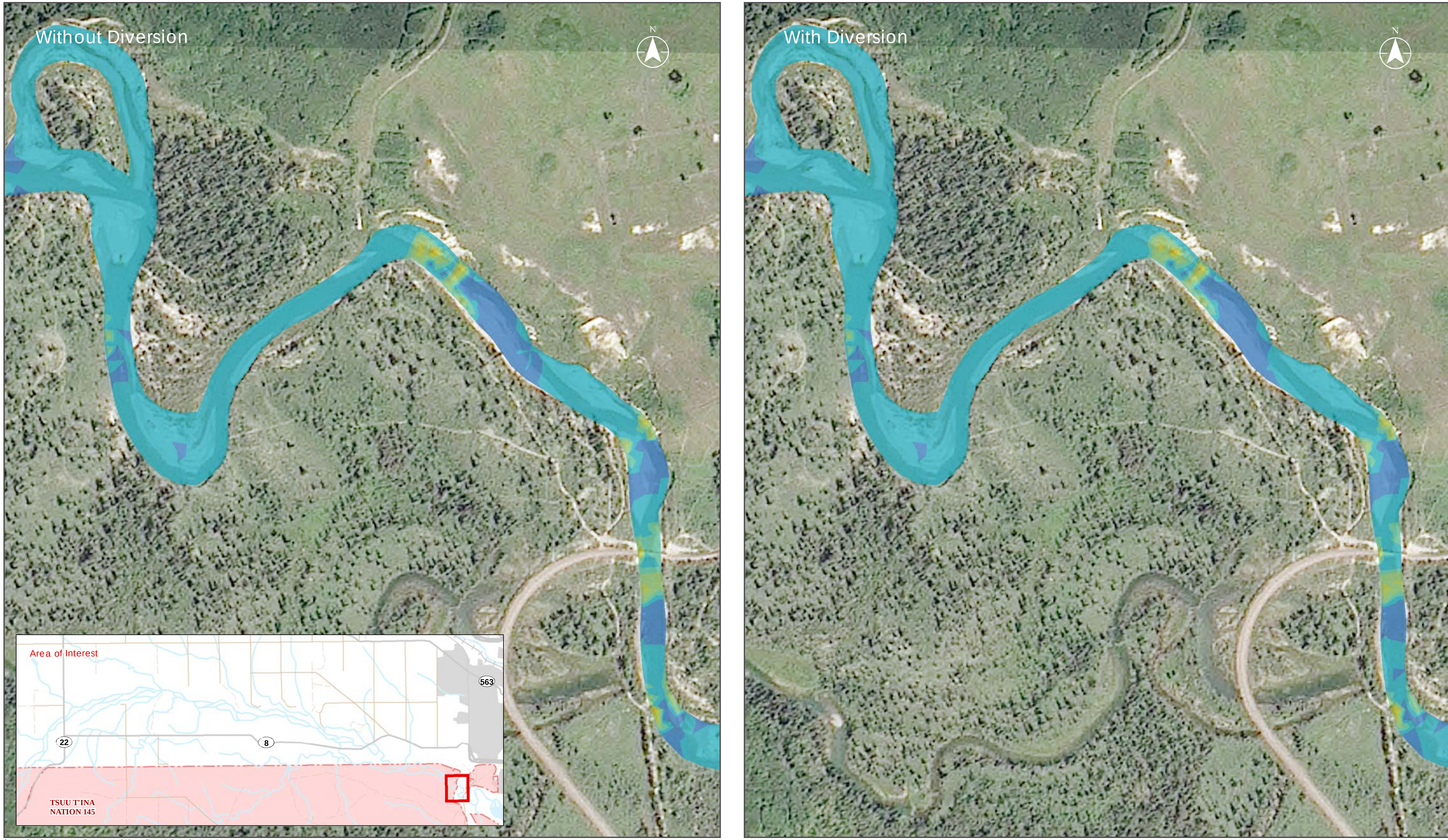
0 100 200 300 400
metres

110773396-610 REVA

NAD 1983 3TM 114

Elbow River Net Bed Morphology Changes With and Without Diversion: 1:10 Year Flood, Location 2

Figure 6-34



Sources: Base Dat & Imagery - Government of Alberta; Thematic Data - Stantec Ltd.

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Morphology Change (m)

- >1.50
- 1.00 - 1.50
- 0 - 1.00
- -0.100 - 0
- -0.200 - -0.100
- -0.400 - -0.200
- -0.600 - -0.400
- -0.800 - -0.600
- -1.200 - -0.800
- -1.600 - -1.200
- <-1.600

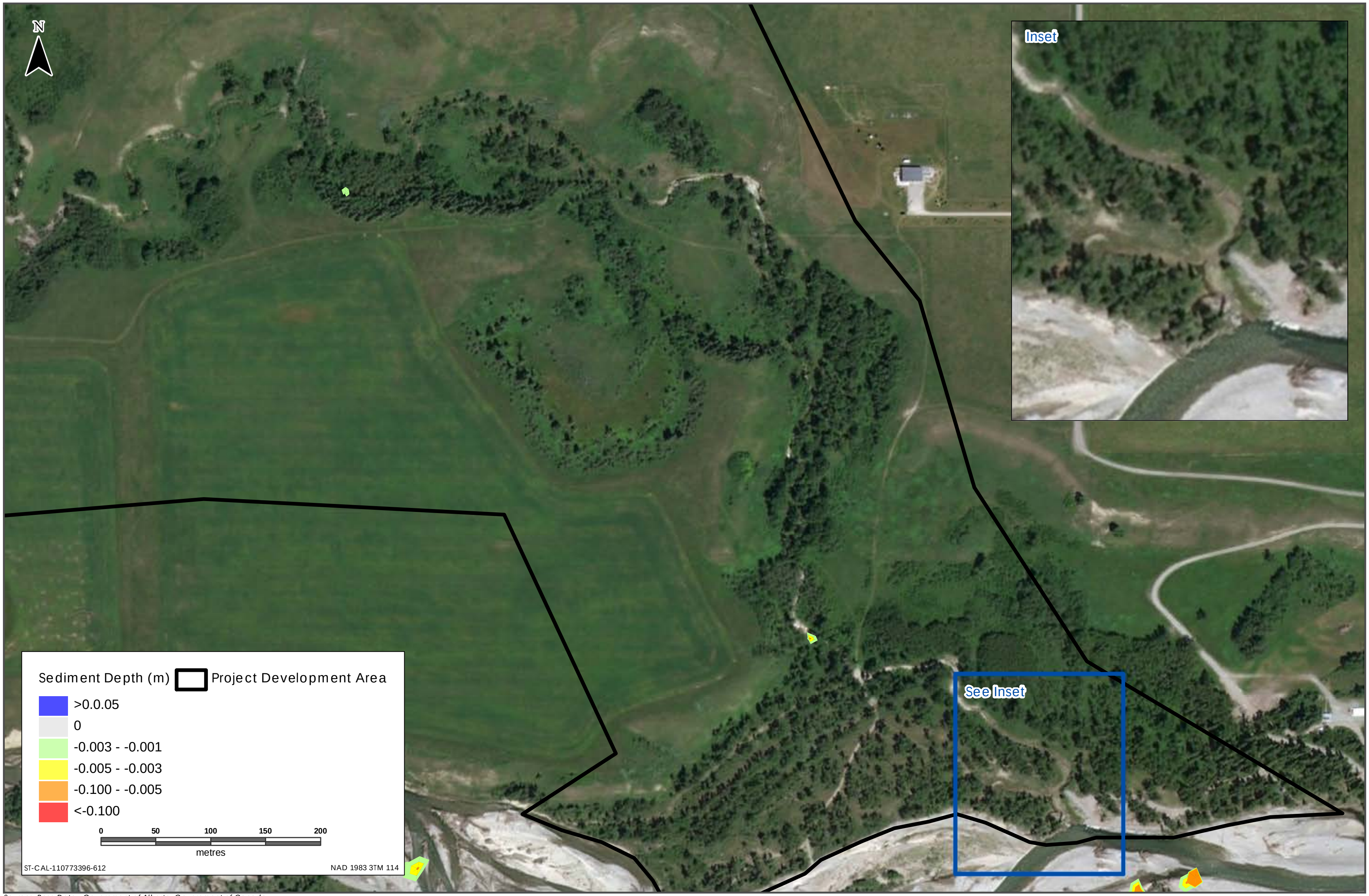
0 100 200 300 400
metres

110773396-611 REVA

NAD 1983 3TM 114

Elbow River Net Bed Morphology Changes With and Without Diversion: 1:10 Year Flood, Location 3

Figure 6-35



Sources: Base Data - Government of Alberta, Government of Canada
Thematic Data - Stantec Ltd
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Geomorphology Change of the Low-level Outlet for the 1:10 Year Flood

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ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

Figure 6-36

6.4.5 Summary of Project Effects

The effects on hydrology during flood and post-flood operations are summarized in Table 6-11.

Table 6-11 Project Effects on Hydrology during Flood and Post-Flood Operations

Effect	Effects Characterization								
	Project Phase	Timing	Direction	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Socio-economic Context
Change in Hydrology	F, PF	N/A	A	N	PDA	ST	IR	I	D
Change in Suspended Sediment Transport	F, PF	N/A	A	H	LAA	ST to LT	IR	I	D, U
Change in Channel Morphology	F, PF	N/A	A	H	PDA	LT	IR	I	D

KEY
See Table 6-2 in Volume 3A for detailed definitions

Project Phase
F: Flood Operations
PF: Post-Flood Operations

Timing Consideration
S: Seasonality
T: Time of day
R: Regulatory

Direction:
P: Positive
A: Adverse
N: Neutral

Magnitude:
N: Negligible
L: Low
M: Moderate
H: High

Geographic Extent:
PDA: Project Development Area
LAA: Local Assessment Area
RAA: Regional Assessment Area

Duration:
ST: Short-term;
MT: Medium-term
LT: Long-term

N/A: Not applicable

Frequency:
S: Single event
IR: Irregular event
R: Regular event
C: Continuous

Reversibility:
R: Reversible
I: Irreversible

Ecological/Socio-Economic Context:
D: Disturbed
U: Undisturbed

6.5 DETERMINATION OF SIGNIFICANCE

Determination of significance is not relevant for changes in hydrology because the purpose of the Project is to actively modify the hydrology of the Elbow River. However, as the hydrology is being intentionally modified and this modification would also change sediment transport, the significance of any resulting changes is assessed by other VCs.

6.6 PREDICTION CONFIDENCE

The suspended sediment data for the Elbow River used in the modelling are based on a discharge-suspended sediment rating curve approach. Because there is no measured field data for Elbow River, several assumptions were used to estimate suspended sediment behavior. The suspended sediment concentration estimates are theoretical. However, the assumptions used are reasonable and conservative (i.e., predicted concentrations are likely over estimated).

Similarly, bedload transport in the model is based on the assumption of a uniform grain-size distribution throughout the Elbow River. Although field data validates this assumption, localized variation in grain sizes and the effect of, for example, imbrication or armouring, would change bed mobility thresholds.

Uncertainties are introduced when developing any model to represent real-world conditions. Although some of the complex interactions between hydrodynamics. sediment mobilization and deposition during floods can be reasonably approximated in a model, not all can. For example, the effect of imbrication over time in increasing localized bed resistance and changes in suspended sediment concentrations due to source variability. The model results, therefore, can only provide a reasonable approximation of how the hydrology and sediment transport in Elbow Bow River and low-level outlet respond during flood and post-flood operations of the Project.

In summary, prediction confidence of flood and post-flood operations on hydrology and sediment transport is moderate.

6.7 CONCLUSIONS

6.7.1 Change in Hydrological Regime

Alteration of both peak flow rate and flow volume is the intended purpose of the Project and the diverted volumes are released back into Elbow River, less evaporation. At a RAA scale, the percentage lost to evaporation is less than 0.5% of the annual flow volume. Given that the probability of diversion is 10% or less in any given year, changes to the hydrological regime due to diversion are unlikely to modify the long term median flow values in a meaningful way. Due to the limited nature of this interaction, the effects on hydrology over the long-term have been assessed to be negligible with a moderate degree of confidence.

6.7.2 Change in Suspended Sediment Transport

The modelled effect on suspended sediment concentrations and yields in the Elbow River suggest that during diversion there would be a high magnitude effect. Higher magnitude floods would have yield reductions greater than 30% compared to existing conditions in Elbow River.

Release of water from the reservoir through the low-level outlet would temporarily increase localized suspended sediment concentrations and yields in the Elbow River.

6.7.3 Change in Channel Morphology

During diversion, there would be a high magnitude effect on the morphology of Elbow River. The project would reduce aggradation and degradation on Elbow River during a large flood. During release, there would be a high magnitude effect on the morphology of the unnamed creek at the low-level outlet. Although high magnitude effects are predicted in Elbow River, channel planform and bedload movement is predicted to be maintained and that only the magnitude of aggradation and degradation, during diversion, would be affected.

During release, high magnitude changes to geomorphology are expected in the low-level outlet. However, the majority of the mobilized bed material is predicted to remain within the low-level outlet and minimal interaction with Elbow River would occur.

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6.8.2 Personal Communications

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6.9 GLOSSARY

Aggradation	The increase in topographical elevation in a waterbody resulting from the deposition of sediment.
Bar Deposits	Sediment that is part of an elevated portion of a waterbody that is the result of ongoing, or historical flows.
Bedload Transport Rates	The speed that material that comprises the bed of a waterbody moves downstream because of flow.
Channel planform	The view of a waterbody channel from above.
Degradation	The decrease in topographical elevation in a waterbody resulting from the erosion of sediment.
Discharge-suspended Sediment Rating Curve	A mathematical relationship between the discharge, and sediment concentrations or loads.
Fining	The result of processes that ‘select’ for smaller substrate materials. For example, systems with debris that provide resistance to flows and therefore promote the deposition, are said to promote fining.

Lobate sheets	A morphological substrate pattern that is characterized by lobes of one substrate type that extend into neighboring substrates.
Shear stress	The strain that is applied to an object when a force is applied in parallel to the surface of the object.
Shields parameter	A value used to estimate the movement of sediment in a fluid flow.
Sediment load	The mass of sediment transported through a waterbody during a defined time period.
Sediment yield	The total mass of sediment transported through waterbody during a defined time period.
Synthetic hydrograph	An fictional, artificially produced dataset that includes time, flow, and discharge.
Thalweg Deposits	The sediment located in the lowest elevation of waterbody or the deepest channel of a waterbody that is the result of ongoing, or historical flows.