Municipal Natural Assets Initiative: City of Grand Forks, British Columbia

Final Technical Report

Making Nature Count

The Municipal Natural Assets Initiative is changing the way municipalities deliver everyday services by increasing the quality and resilience of infrastructure at lower costs and reduced risk. The MNAI team provides scientific, economic and municipal expertise to support and guide local governments in identifying, valuing and accounting for natural assets in their financial planning and asset management programs and developing leading-edge, sustainable and climate-resilient infrastructure.

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Acronyms

DEM	Digital Elevation Model
FEMA	(U.S.) Federal Emergency Management Agency
HEC-RAS	Hydrologic Engineering Centers River Analysis System
km	kilometre
m	metre
m^3/s	Cubic metres per second
MNAI	Municipal Natural Assets Initiative
USGS	United States Geological Survey
WA	Washington

Executive summary

The term "municipal natural asset" refers to the stock of natural resources or ecosystems that is relied upon, managed or could be managed by a municipality, regional district or other form of local government for the sustainable provision of one or more municipal services. Examples include wetlands, rivers, forests and foreshores. The Municipal Natural Assets Initiative (MNAI) is developing resources and helping municipalities incorporate natural assets into asset management and financial decision-making processes.

Together with MNAI, the City of Grand Forks, B.C., began to assign financial value to its natural assets, using the city's floodplain along the Kettle River as the first example. Recognizing both that development threatens the floodplain and that it has positive role in managing water surrounding and within the town, the City of Grand Forks is beginning to quantify flood-mitigation and related benefits provided by local floodplains.A recent large flood in the Kettle River has also focused attention on the role of the floodplain.

The study assessed the storage benefits of floodplains upstream of the city using high-level hydraulic modelling and economic evaluation based on differences in flood-water levels and estimated building damage values. The U.S. Army Corps of Engineers' Hydrologic Engineering Center River Analysis System (HEC-RAS) version 5.0 was used.

In the analysis, five modelling scenarios were completed with varying levels of floodplain encroachment, as defined by the U.S. Federal Emergency Management Agency (FEMA):

1. Baseline: 200-year flow, no floodway encroachment.
2. Full encroachment: 200-year flow, full development encroachment to the floodway boundary.
3. 30-metre encroachment: 200-year flow, development encroachment up to 30 metres from the floodway boundary (representing current local bylaw setback requirements).
4. 75-metre encroachment: 200-year flow, encroachment up to 75 metres from the floodway, representing a more modern approach to floodplain management.
5. Adaptive encroachment: 200-year flow, encroachment between 25 and 75 metres, depending on location of existing structures.

The economic value of the Kettle River floodplain was assessed using an avoided cost approach. In this project, the avoided cost is the value of potential damage to buildings in the downtown core of Grand Forks during the 200-year flow that would result if the upstream floodplains were lost. Due to time and resource constraints, the analysis does not consider the cost of flood-mitigation-services replacement, nor does it consider the potential damages incurred beyond buildings, including to streets, sidewalks, storm sewer systems, public spaces, etc.

The project results demonstrate that the Kettle River floodplain provides between $500 and $3,500/hectare in flood damage reduction for downtown buildings in the City of Grand Forks during high flow events. This is an existing value to the city, and represents only damage to buildings and flood mitigation during large events, thus encompassing only a very small portion of the total value provided by the floodplains.The figure also does not include a climate change component.

The results provide a strong foundation for further analysis and action.Next, Grand Forks will incorporate modelling information on natural floodplain function and trade-offs with development and floodplain protection options in upcoming floodplain mapping and hazard assessments. It will also use the information to support update of the development permit requirements for protecting sensitive ecosystems and limiting development (including land clearing) on natural hazard lands. This will be a key part of the Official Community Plan update that will support implementation of the city's new Sensitive Ecosystem Inventory and the 2018-19 floodplain mapping and risk assessment project.

1. INTRODUCTION

1.1 Municipal Natural Assets Initiative

The Municipal Natural Assets Initiative (MNAI) is developing resources to incorporate natural capital, such as natural or vegetated assets, that form part of the urban landscape into asset management plans. Through the MNAI, the City of Grand Forks is exploring options to refine, replicate and scale up the approach for municipalities that are integrating natural capital considerations into asset management and financial planning.

MNAI has completed an Overview Guidance Document for Stormwater Management for municipalities. This report details the application of the guidance document (i.e., using a stormwater-based approach and applying it to floodplains), and provides technical details on the modelling to support the assessment, as well as a framework for future floodplain assessments in the region.

1.2 Grand Forks

The City of Grand Forks is a small British Columbia town (population 4,000) just north of the Canada – United States border. The city is near the confluence of the Kettle and Granby rivers, and is largely surrounded by forest and agricultural lands.

1.2.1 Policy / governance context

Grand Forks has a strong sense of its natural assets values and is advanced in asset management planning. For example, water-related issues associated with natural areas are already top-of-mind in Grand Forks as there has been damage to the aquifer beneath the city from gas station contamination that closed the city's Well #1. The city now wants to integrate natural assets into its asset management plans.

There are numerous interconnected water issues in the area: local and regional flooding, unconfirmed aquifer sensitivity and recharge, and storm outfalls that drain directly into productive fish-bearing streams. The city's floodplain has a major influence on, and link to, these issues.

Prior to adding natural assets into asset management plans, Grand Forks needs to determine which management options associated with each asset — and each option's costs and risks — make most sense for providing municipal services such as water quality treatment, drainage and flood conveyance, and aquifer protection/recharge.

1.2.2 Natural asset of interest

The asset of interest for this analysis is the developed (rural and urban) floodplain along the Kettle River in the Grand Forks area. During large floods, floodplains mitigate downstream effects such as flooding and erosion by minimizing velocities; provide important annual recharge areas for underlying aquifers; and serve to improve water quality in terms of sediment and chemical sequestering for regional river flows and local runoff. The water and sediment storage capacity provided by the floodplain when a river overflows its banks or as upper watershed waters flow to the primary stream system provides positive effects.

2. Methods

Project methods focus on assessing the upstream storage benefits of floodplains using high-level hydraulic modelling and economic evaluation. They consider differences in flood-water levels to estimate building damage values within the city, as described below.

This approach is limited because it does not take into account the multitude of benefits a floodplain provides nor does it take into account the cost of grey infrastructure required to replace the true function of the floodplain, as recommended in the guidance (see e.g., Sheaffer et al., 2002). Due to time and resource constraints, this methodology was considered a starting point. Additional items and a framework to expand the future efforts are elaborated in Section 4.

2.1 Modelling

Hydraulic river modelling was undertaken for the study using a one-dimensional hydraulic modelling platform. The U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) version 5.0 was selected for use in modelling the relationship between Kettle River flow dynamics and floodplain connectivity. HEC-RAS is designed to perform hydraulic calculations for channels given user-input channel geometries and flow rates. The software is freely available through the U.S. Army Corps of Engineers' website[1].

Though HEC-RAS version 5.0 has the capability to perform sophisticated one- and two-dimensional calculations, this analysis was limited by time and budgetary constraints. A model was developed using available datasets. Fortunately, a similar HEC-RAS analysis for the same reach of the Kettle River was performed in 1992[2]. Using these data as a starting point, the project team was able to construct a suitably accurate model within a short time.

A baseline model was created and subsequent versions assessed encroachment effects, as described below.

2.1.1 Calibrated model

Channel geometry

To develop the calibrated HEC-RAS model, channel geometry and flow data from a 1992 HEC-RAS modelling effort was used. The available channel geometry data from this study included 57 cross-sections spanning a 27-kilometre stretch of the Kettle River, including the reach adjacent to the city and at the confluence with the Granby River (see Figure 1, below). Channel geometry for the Granby River was not used in the model.

After reviewing the 1992 channel geometry data for the cross-sections of interest, all the cross-sections were extended further into the floodplain on either side of the Kettle River to fully capture the effects of the floodplain-connectivity scenarios. The original cross-sectional data were overlaid with a high-resolution digital elevation model (DEM) where available, and points were added to either end of each transect extending out the required distance. Unfortunately, the available DEM did not encompass the entire reach of the Kettle River defined by the 57 cross-sections. Therefore, it was necessary to use a coarser topographic map overlay to manually extend the remaining cross-sections the desired distance into each floodplain. The DEM covers the entire city, including the region along the river where highly detailed elevation data was most critical.

1 http://www.hec.usace.army.mil/software/hec-ras/

2 Ministry of Environment, 1992.

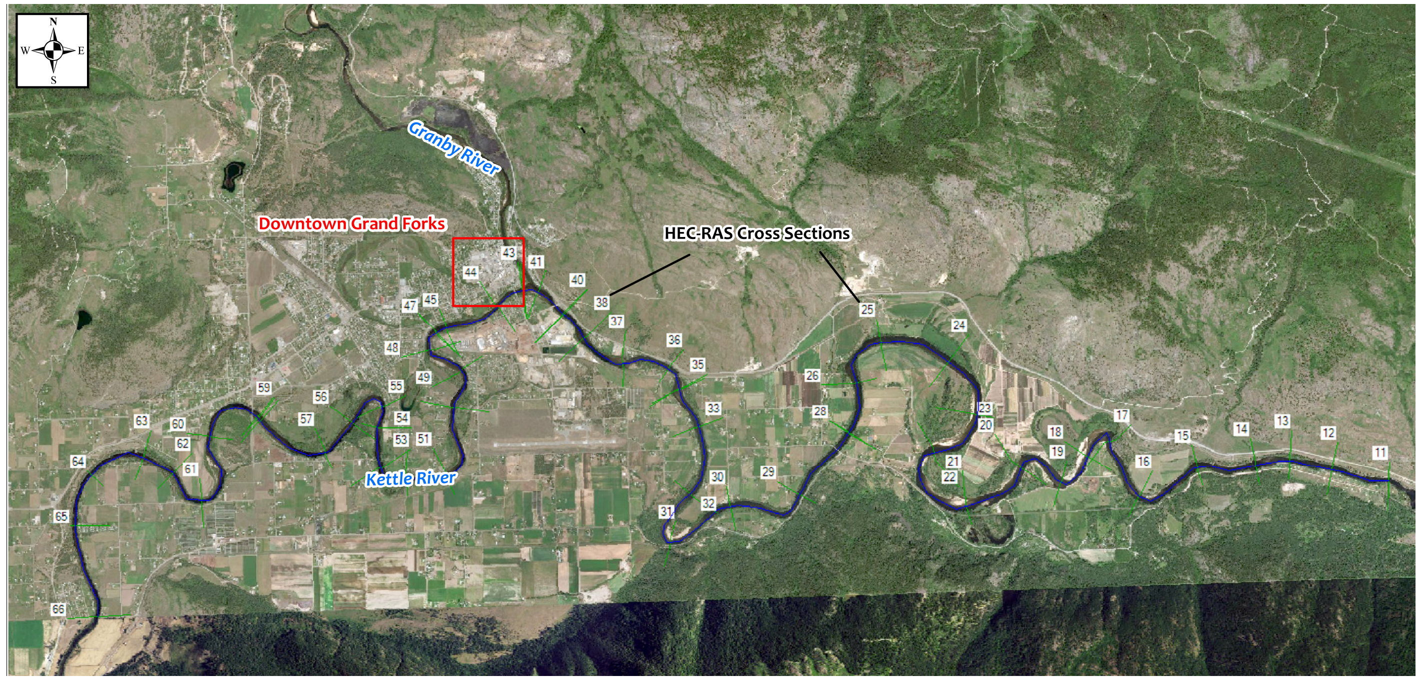

Figure 1 - HEC-RAS model schematic

Calibration and unsteady flow data

Rather than enter geometric and flow data for the Granby River, its flow contribution to the Kettle was represented by increasing the flow in the Kettle River at cross-section 41, directly downstream of the Kettle-Granby confluence.

An unsteady flow simulation was performed to calibrate the model. High-water-mark data were available for 27 of the cross-sections from a May 17, 1997, high-flow event with a peak of 579 metre^3/second (approximately equal to the 200-year flood estimate — see additional discussion below). United States Geological Survey (USGS) hourly flow data were available for the Kettle River at two gauge stations for this flood event: 1) a station just upstream of the study reach in Ferry, WA; and 2) a station just downstream of the study reach in Laurier, WA. Because the upstream gauge station is located several kilometres upstream from the top end of the study reach, the flow rates were adjusted based on the ratio of the drainage area at the highest cross-section to the drainage area at the gauge station. Hourly flow data were not available for the Granby River, but by subtracting the flow data from the downstream gauge (Laurier, WA) from the adjusted flow data from the upstream gauge (Ferry, WA) a close approximation of the contribution from the Granby was generated.

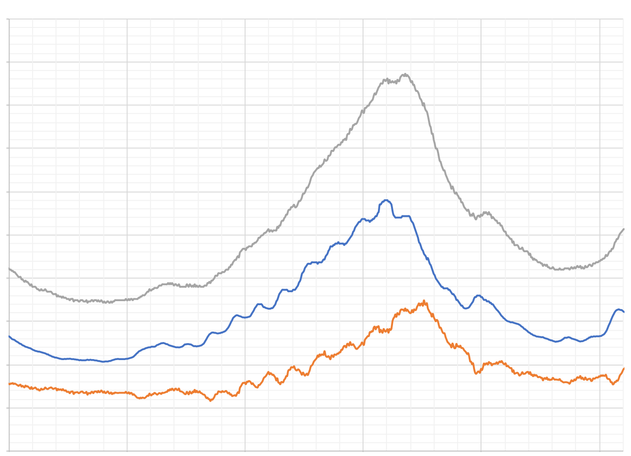

Figure 2 - Hourly flow data for the Kettle and Granby rivers

Once the hourly flow datasets were complete, an unsteady flow simulation was performed and high-water-mark predictions were compared with the high-water-mark data from the May 17, 1997, high-flow event. Adjustments were made to channel roughness until all high-water-mark predictions were within 0.5 metres of actual (see Appendix A for calibration results).

Steady-flow data

The 1992 study also included a flood-frequency analysis used to estimate 10-, 20-, 50-, 100- and 200-year flow events in both the Kettle and Granby rivers, reproduced in Table 1, below.

Table 1 - Steady-flow data from the 1992 flood frequency analysis

Return period (Years)	Kettle River near Laurier, WA (m^3/s)	Granby River at Grand Forks (m^3/s)
10	765	326
20	821	344
50	887	363
100	932	375
200	974	385

Because our analysis focused on damages associated with high-flow events, the 100-year and 200-year flow rates were used. The upstream flow condition for the study reach was determined by subtracting the Granby River flow rate from the Kettle River flow rate at Laurier, Washington. The Granby River flow contribution was added into the model at cross-section 41, just downstream of the Kettle-Granby confluence.

2.1.2 Encroachment analysis and scenarios

To define the lateral extents of the floodway used below, as defined by the U.S. Federal Emergency Management Agency (FEMA), a floodplain encroachment analysis was performed as described in Chapter 10 of the HEC-RAS 5.0 user's manual[3]. According to FEMA, a floodway is defined as "the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water-surface elevation by more than a designated height." In keeping with established norms, the base flood was set at the 100-year flow event (see Table 1, above) and the designated height was set to one foot (0.3 metres).

2.1.3 Modelling scenarios

Working with city staff, we identified five comparative modelling scenarios to form the basis of a preliminary economic valuation of the Grand Forks floodplain.

Scenario 1: 200-year flow, baseline

This scenario simulates the 200-year flow event (see Table 1, above) with no encroachments, representing flow dynamics with full floodplain-connectivity. Alternative scenarios that simulate different degrees of floodplain disconnection or encroachment can be compared.

3 Brunner, G.W., 2016.

Scenario 2: 200-year flow, full encroachment

This scenario simulates the 200-year flow event (see Table 1, above) with encroachments to the floodway boundary, as defined by the U.S. Federal Emergency Management Agency. The floodway for the study reach was determined by performing an encroachment analysis, as detailed in section 2.2.2 of this report.

Scenario 3: 200-year flow, 30-metre encroachment

This scenario simulates the 200-year flow event (see Table 1, above) with encroachments up to 30 metres from the floodway boundary. This represents a realistic development scenario given a local bylaw allowing floodplain development to extend to 30 metres of the floodway.

Scenario 4: 200-year flow, 75-metre encroachment

This scenario simulates the 200-year flow event (see Table 1, above) with encroachment up to 75 metres from the floodway. This scenario represents a more modern approach to floodplain management, giving room for the river in terms of flood storage and planform translation (i.e., bank erosion).

Scenario 5: 200-year flow, adaptive encroachment

This scenario simulates the 200-year flow event (see Table 1, above) with encroachments varying between 25 and 75 metres from the floodway, depending on the location of the nearest structure to the river at each cross-section within the study reach. This scenario also represents a more modern approach to floodplain management, giving room for the river in terms of flood storage and planform translation (i.e., bank erosion).

2.1.4 Inundation mapping

Using the HEC-RAS computed water surface elevations, the spatial extent of flooding in downtown Grand Forks was determined for each model scenario. Raster layers containing depth and water surface elevation data were generated using HEC-GeoRAS, a free utility that works in conjunction with HEC-RAS 5.0 to convert model results to geospatial data files. Using the geospatial data generated by HEC-GeoRAS, it was possible to overlay and compare results from the different scenarios.

2.2 Economic valuation

As discussed above, the preferred valuation method of the MNAI guidance document focuses on grey infrastructure replacement cost. Due to limited time and resources, this study used an alternative preliminary “avoided-cost” approach. This provides a foundation for future valuations.

2.2.1 Avoided cost

The avoided-cost method of ecosystem service valuation assumes that the value in ecosystem services can be measured by calculating the damage to infrastructure that would occur if the ecosystem service was lost.[4] In terms of this analysis, this meant determining the potential damage to buildings in Grand Forks during the 200-year flow event as a result of increased flood depth and flooding extent associated with loss of upstream floodplains.

It is important to discuss the limitations of such a study. Not only are we not provided replacement costs, we are also limiting damages to those associated with buildings. During major flood events infrastructure costs go significantly beyond damage to buildings. Other damages that should be considered in the future include (but are not necessarily limited to) damage to streets, sidewalks and related infrastructure; damage to diking and riverbank erosion protection; damage and sedimentation of storm sewer systems; damage to wastewater collection and treatment systems; damage and sedimentation of public spaces and recreational facilities; and damage to basements/groundwater.

2.2.2 Depth-to-damage assessment

Building footprint data for downtown Grand Forks was overlaid with flood depth predictions (raster format) generated for each HEC-RAS scenario described above. Each building was assigned the maximum flood depth predicted for its spatial extent (i.e., if a building encompassed two cells within the flood depth raster, the cell with a higher depth of flooding was assigned to the building for use in the depth-to-damage assessment).

Once each building was assigned a depth of flooding, depth-to-damage factors from the FEMA[5] were applied to calculate a damage estimate associated with that depth of flooding.

Table 2 - FEMA depth-to-damage factors for residential and commercial structures

Depth of flooding (m)	Damage factors	
	Residential	Commercial
0.0	0.2	0.02
0.5	0.44	0.24
1	0.58	0.37
1.5	0.68	0.47
2	0.78	0.55
3	0.85	0.69
4	0.92	0.82
5	0.96	0.91
6	1	1

Because the available depth-to-damage factors were given in 0.5-metre increments and predicted flood depths varied by less than 0.1 metres, a regression analysis was performed to generate an equation that could be used to calculate damage estimates based on depth of flooding for both residential and commercial buildings. For both categories, the line of best fit had an r-squared value exceeding 0.96, as shown in Figure 3, below. The estimated damages for each building in downtown Grand Forks were summed to determine a total avoided cost estimate for each scenario.

4 Whiteoak and Binney, 2012.

5 FEMA, 2013.

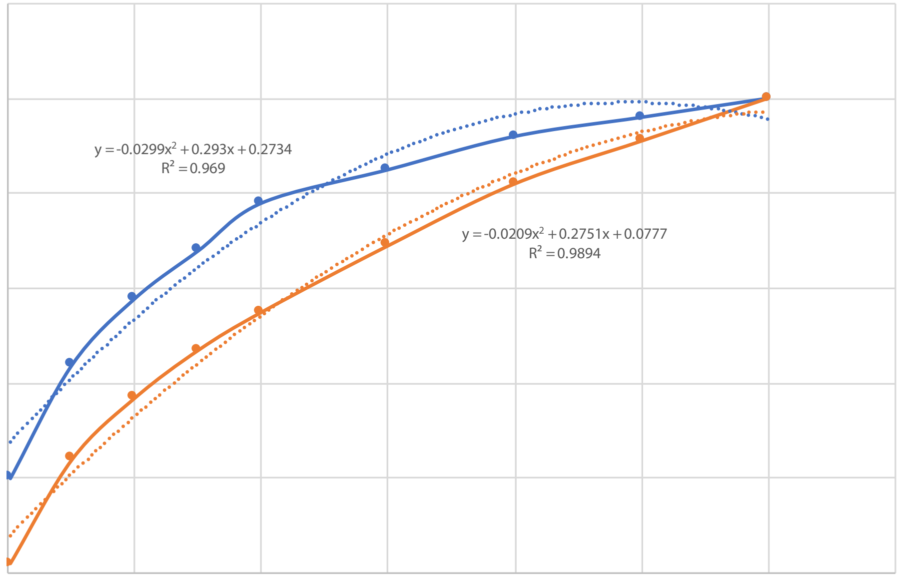

Figure 3 - Results of regression analysis based on Table 2

2.2.3 Loss of floodplain

The "baseline" scenario represents no loss of floodplain in this analysis. To determine the relative losses of floodplain associated with the other scenarios, the total "top width" of flow at each cross-section was multiplied by the downstream length to the next cross-section to generate a high-level "flow area" estimate for the reach of the Kettle River upstream of downtown Grand Forks (cross sections 45-66). By subtracting the total flow area for this reach for each scenario from baseline, an estimate for how much active floodplain is lost was derived under each encroachment scenario.

3. Results

3.1 Hydraulic modelling

3.1.1 Flooding extent

The HEC-RAS predicted flooding extents for the five scenarios described above are shown in Figure 5, below. The differences between the baseline and "full encroachment" scenarios are fairly noticeable in certain spots, while the differences between the intermediate scenarios are less pronounced. In total, 55 buildings are expected to be affected by flooding under the "full" and "variable encroachment" scenarios, and 52 buildings under the "baseline" 30-metre encroachment and 75-metre encroachment scenarios.

3.1.2 Depth of flooding

Detailed depth of flooding results by building for each modelled scenario are included in Appendix D. Figure 4 shows depth of flooding by building for the "full encroachment" scenario.

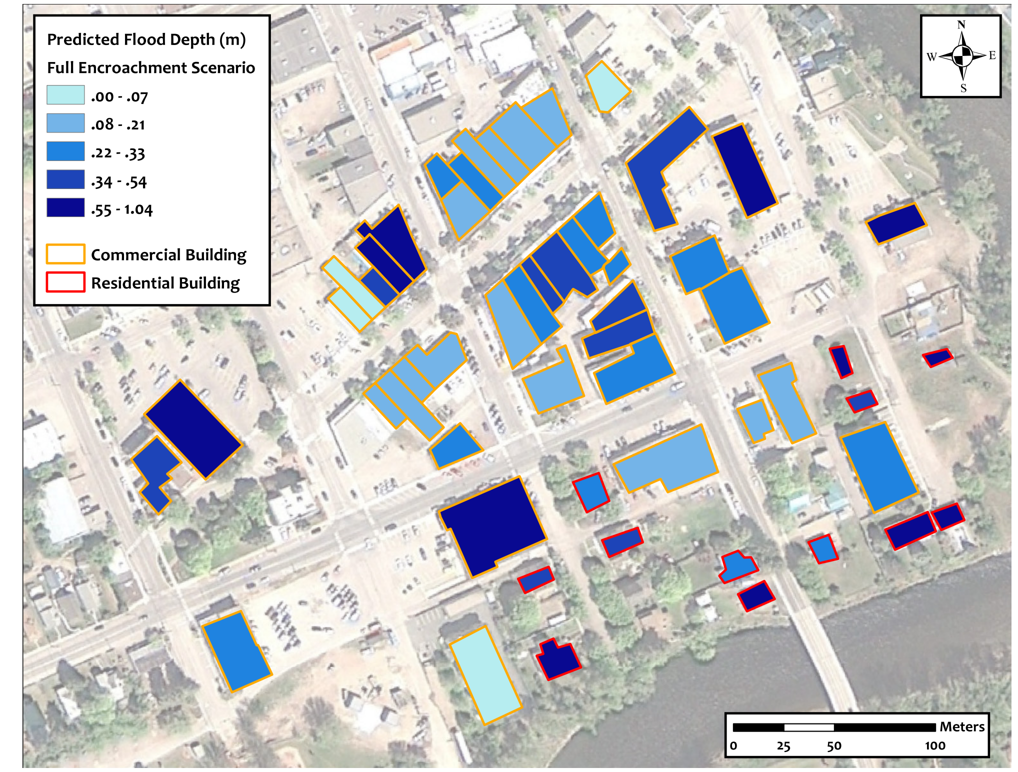

Figure 4 – Predicted flood impacts for buildings in downtown Grand Forks

Figure 5 - HEC-RAS predicted flooding extent for modelled encroachment scenarios

3.1.3 Loss of floodplain

HEC-RAS modelling predicted floodplain losses for each scenario are shown in Table 3, below. Detailed HEC-RAS results are included in Appendix C of this report.

Table 3 - HEC-RAS predicted floodplain losses

Scenario	Lost floodplain compared to baseline
Variable encroachment	45 Ha
75m encroachment	53 Ha
30m encroachment	80 Ha
Full encroachment	111 Ha

3.2 Economic valuation

3.2.1 Depth-to-damage assessment

HEC-RAS model results show that 52 buildings will experience flood impacts from the 200-year flow event under the "baseline" 75-metre encroachment and 30-metre encroachment scenarios; and 55 buildings will experience flood impacts under the "variable encroachment" and "full encroachment" scenarios. The total damage estimates for buildings associated with these flood impacts are shown in Table 4, below.

Table 4 - Total flood damage estimates by encroachment scenario

Scenario	Total damage estimate ($)	Unit value per hectare of floodplain
Baseline	$2,924,000	-
75m encroachment	$2,950,000	$500
30m encroachment	$2,975,000	$600
Variable encroachment	$3,081,000	$3,500
Full encroachment	$3,316,000	$3,500

Based on the results shown in Table 4, each hectare of floodplain upstream of Grand Forks provides between $500 and $3,500 in flood damage reduction for buildings only during high-flow events.

4. Discussion

4.1 Preliminary economic value of Kettle River floodplain in study

This analysis applied an avoided-cost approach to determine a high-level economic value based on the damaged buildings for the flood mitigation service provided by the floodplain along the Kettle River in the downtown area of Grand Forks.

Results suggest a value of between $500 and $3,500 per-hectare for buildings only. When considering this range of values, it is important to recognize that it encompass only a very small portion of the total value provided by the floodplains. The range only considers damage to buildings and the assessment considers one specific ecosystem service (flood mitigation during large flow events). These limitations are discussed in further detail in the "Assumptions and limitations" section, below.

Still, these results provide the foundation for further analysis and initial actions as well as a conceptual framework to assess other infrastructure. The floodplain provides some economic value to the town of Grand Forks, likely a significant enough value to warrant a more exhaustive analysis and based on this, steps to manage this natural asset. A framework for improving on the analysis presented in this case study is included in the "Next steps — Future considerations for floodplain valuation" section, below.

4.2 Assumptions and limitations

Due to time and budgetary constraints, many assumptions and limitations are associated with the analysis described in this report, as described below.

4.2.1 Hydraulic river modelling

The majority of data used to build the HEC-RAS hydraulic river model was gathered from a 1992 study, including channel geometry and streamflow estimates. It is likely that both the channel geometry and flood-return intervals have changed since then. Furthermore, the 1992 cross-section data were extended to reach further into the floodplain on either side of the river. Due to a lack of DEM availability, the extended cross-sections were generated using a topographic map, also from 1992. Updating cross-sectional geometries and flow estimates for the 100-year and 200-year flow events would improve the accuracy of model estimates.

The model calibration/validation process was also simplistic. While observed data were used to match with modelled water-surface elevations, the model was considered well-calibrated once all predictions were within 0.5 metres of observed values. Increasing the rigour of the calibration process would improve the defensibility of model results. In addition, including validation and sensitivity analysis steps in the modelling process would increase the reliability and decrease the uncertainty of results. Validation focuses on assessing how the model simulates real-world events after the model is calibrated. Sensitivity analysis focuses on gaining an understanding of model error and uncertainty based on uncertainty associated with input to the model (e.g., roughness, flows and topography/bathymetry).

In addition, the use of a one-dimension hydraulic model (versus two- or three-dimension) and a steady state flow assumption also introduces significant uncertainty for any study focused on floodplain storage and related effects. The one-dimensional model uses a linear interpolation of floodplain cross-sections to estimate storage between sections. This simplification does not provide an accurate representation of available flood storage. Two- and three-dimensional models address this concern by using a truly three-dimensional representation of the bathymetry of the river and topography of the floodplain. In addition, applying the steady state assumptions removes some of the sensitivity associated with adding or removing storage within the floodplain. Applying a dynamic flood wave to assess floodplain and storage loss effects will help reduce uncertainty associated with the analysis.

It is likely that a large portion of the flooding experienced in Grand Forks during large flow events originates from the Granby River or hydraulic influences associated with the confluence; however, for this analysis the Granby was not included in the HEC-RAS model. If the channel geometry of the Granby could be defined and added into the model, it is likely that we would see larger flood depths in downtown Grand Forks.

HEC-GeoRAS was used to compute inundation extents associated with each modelled scenario. This process requires a high-resolution DEM, which was only available for the area immediately around downtown Grand Forks. Having a greater extent of DEM coverage would enable the analysis to be expanded further upstream and downstream to examine impacts on residential neighbourhoods and farmland.

Finally, this analysis included no climate change component. The 100-year and 200-year flood events used in the scenario analysis were based on 1992 estimates, and there is a potential that these flood events would have a greater magnitude when compared to the present estimate, leading to more extreme flooding impacts in Grand Forks.

4.2.2 Depth-to-damage estimates

A major assumption made in this analysis involved changing the discrete depth-to-damage estimates used by FEMA (given in 0.5-metre increments) into an equation representing a continuous depth-to-damage curve. It is possible that damage to a structure increases incrementally at certain threshold depths rather than continuously. However, to generate meaningful results for this analysis, it was necessary to distinguish between damage estimates at the centimetre scale rather than the 0.5-metre scale.

Depth-to-damage estimates derived from this analysis should also be view as extremely conservative because they do not account for damage to the contents of a building or to roads, cars, time lost, business closures, health impacts and other municipal infrastructure, as described above in Section 2.2.1. If added, they would likely provide a significant increase in the estimated flood loss for each modelled scenario. Furthermore, FEMA flood damage estimates assume that damages to residential structures begin with a flood depth of 60 centimetres below ground surface due to impacts to basements. These types of damages were not included in this analysis. In addition, the depth-to-damage estimates are based on average United States values and do not represent local conditions that may influence damage estimates.

The floodplain loss estimate used to generate per-hectare values for the floodplain upstream of Grand Forks was crude due to a lack of high-resolution DEM coverage. The method applied for this analysis likely overestimated the extent of floodplain lost, which would lead to an underestimation of the per-hectare value provided by the floodplains.

4.3 Future considerations for floodplain valuation

As discussed in the preceding sections, floodplain valuation can follow an "avoided-cost" approach, a "replacement-cost" approach or a combination of the two. A high-level avoided-cost approach was applied in this study to provide a foundation for future work and to give an initial conservative value (on the low side) for the floodplain using the limited time and resources available. As discussed in Section 2.2.1, to decrease uncertainty with the avoided-cost approach, future assessment should include additional costs that go beyond building damage. This assessment would significantly increase the floodplain value on a per area basis.

To provide a point of comparison, a hypothetical grey infrastructure replacement-cost approach was also developed to value the floodplain asset, which is consistent with MNAI guidance. This approach, outlined below, provides a framework to guide future assessment of the city's greenfield and sparsely developed rural floodplain values. The approach is then expanded to include city land types consistent with those found in Grand Forks. The approach identifies subcomponents of floodplain valuation that can be included as part of other water-related assessments (e.g., aquifer study assessing the value of floodplain recharge and treatment of source water) in the future. As more work is undertaken, valuation estimates can be improved.

The replacement cost approach for floodplain valuation has been advocated by others (e.g., Sheaffer et al., 2002) and is becoming a primary focus of floodplain management (e.g., Opperman et al., 2017). Considering this research and the characteristics of the Kettle River watershed and land uses in and surrounding Grand Forks, replacements-costs analysis should consider:

- Regional flood storage: Sheaffer et al. (2002) and Opperman et al. (2017) identify flood storage as a primary economic value of a floodplain. Loss of storage leads to increased flooding downstream, increased velocities and erosion concerns and limits the river's ability to transport and store alluvial sediments and nutrients. Sheaffer et al. (2002) value the floodplain using reservoir and constructed pond storage at $295,000 per hectare (based on conversion from U.S. to Canadian dollars and an inflation rate of 2.1 per cent). Although this value is not directly applicable to the Grand Forks area, it provides an order of magnitude estimate of storage value and demonstrates the significant value (two orders of magnitude greater) associated with flood storage when compared to building damage discussed above. An alternative replacement-cost valuation method for flood storage (versus the one used by Sheaffer et al., 2002) for watersheds associated with only minor urban development could be based on cost of dike structures required to transfer storage from the floodplain to the wet side of the dike plus costs of bank-erosion protection to protect the dike (where required), and associated maintenance and operation costs. It is expected that the diking approach may be more applicable to Grand Forks as the overall watershed is relatively undeveloped and hence large-scale reservoir and pond storage projects may not be applicable to the area.

- Local stormwater management (point source) and runoff treatment and retention (non-point source): Floodplains provide storage for regional flood waters as well as providing storage and treatment of local runoff, either as part of local stormwater systems or as vegetated areas that receive non point-source runoff. Natural floodplains, such as the one associated with the Kettle River, include riparian wetlands, oxbows, riparian forests, meadows and grasslands. All of these features provide management of local stormwater and runoff depending on how they have been or will be integrated into the rural and urban landscape. Sheaffer et al. (2002) estimated the worth of these features in the floodplain landscape in the context of natural asset value at $10,100 per hectare. Again, this value would vary depending on local conditions. This value does, however, provide an order of magnitude estimate of what could be expected in terms of local stormwater and runoff management benefits from urban and rural areas.

- Aquifer recharge volumes and treatment: Seasonal flooding across floodplains is a significant contributor to source water storage volumes in unconfined aquifers located within valley bottoms (similar to the situation in Grand Forks). The source water aquifer storage in Grand Forks is likely under significant influence of floodplain recharge in terms of water quantity and quality. The hypothesis is that loss of flooding across Kettle River floodplains (e.g., due to diking) would significantly decrease recharge quantity and quality. A significant amount of infrastructure would be required to replace this water or to purchase water from another source based on annual use. Sheaffer et al. (2002) estimated the worth of aquifer recharge and treatment at $2,900 per hectare. Again, this value needs to be adjusted for local variables but nonetheless highlights the potential value associated with the replacement cost of this water and treatment source.

The total value to replace the ecosystems services provided by Sheaffer et al. (2002) in relation to Grand Forks floodplain is approximately $315,000 per hectare. This per area value indicates a significant increase compared to the strictly damage-based avoided-cost assessments commonly used as an input to manage and guide development within floodplains. The goal of future floodplain valuation studies should be to develop local estimates for floodplain value based on framework discussed above.

4.3.1 Grand Forks rural and semi-urban areas assessment

The framework mentioned above works well when the floodplain is mostly undeveloped or associated with only low-density rural activity such as grazing and larger-scale farming. However, when significant residential and municipal infrastructure exists in the floodplain, the valuation approach likely needs to consider both replacement cost of the natural assets in terms of municipal benefits as well as damage costs (or avoided costs).A hypothetical example of such an assessment is described below for two floodplain types: 1) a floodplain with low-density rural land use (rural floodplain) that includes natural riparian areas; and 2) a floodplain with low- to medium-density development that also includes rural acreages and natural riparian areas (semi-urban floodplain). Both of these floodplain types exist within Grand Forks and hence this methodology could provide a framework for future decision-making and planning associated with floodplains.

The floodplain planning and development framework should be developed on a watershed basis. The best approach in terms of floodplain management is assessing the floodplain hydraulics values and determining an acceptable development approach in the floodplain that considers these values on a watershed basis. This assessment should include input from all pertinent stakeholders, including municipalities, counties and districts.

A quantitative value/cost summary of the hypothetical analysis is provided in Appendix F, Table 1. The methodology can guide future floodplain management on a watershed basis in the Grand Forks region. This table summarizes hypothetical costs based on replacement function of the floodplain in terms of grey infrastructure as well as avoided damage to existing city infrastructure for the two floodplain types (rural and semi-urban) described above. It also includes scenarios of floodplain encroachment upstream (as assessed above) and within the city. It is envisioned in the analysis that encroachment would be achieved for the land in question in the form of diking (versus complete filling of the floodplain area) and related riverbank erosion-protection schemes to protect dike infrastructure.

The assessment overview provides discussion on the five different assessments. The assessment, including the costs estimated, is hypothetical and based on professional judgement. The goal of this discussion is to provide examples of how floodplain planning could proceed considering floodplain value and avoided costs in relation to the existing context in Grand Forks.

Assessment 1: Model Scenario 1 upstream of city, no change in city

Assessment 1 estimates the value of the floodplain and associated damage costs of flooding within the city for the two land types as-is — with no dike encroachment in the upstream municipal district (watershed) or in the city. The high-level conclusions reached through this hypothetical analysis, presented in columns 2 and 3 of Table 1 in Appendix F, are as follows:

- Under existing conditions, the rural area and a semi-urban floodplain area in Grand Forks have significant value in terms of municipal asset replacement costs; and
- In this assessment scenario, the two floodplain land types have significant risk in terms of potential damage costs should a significant flood occur. However, the lower density (population, infrastructure) rural area has less risk (damage costs) than the semi-urban land type.

Conclusion: the net benefit estimates (last row of Appendix F, Table 1) under the 200-year flood scenario for Assessment 1 indicate that leaving things as-is in the rural area is supported. In the higher density semi-urban area, however, the benefit of the floodplain asset is nearly completely offset by damages from flooding. Future analysis should focus on annual average damages and benefits to support management decisions and floodplain planning.

Assessment 2: Model Scenario 2 upstream of city, no change in city

Assessment 2 estimates the value of the floodplain and flood damages within the city for the two land types, with significant encroachment upstream of the city (e.g., long, continuous dikes to protect agricultural land from flooding) and with no change (e.g., protection or diking) in the city. This scenario results in greater floodwater levels and velocities when compared to the baseline scenario due to loss of storage in the upstream floodplain area and was assessed above in terms of built "avoided-costs" in Section 3.

Practically, this scenario would likely not occur. In general, municipal areas that are subject to greater risk will undertake the initial encroachment of rivers via diking to lower infrastructure risk and public safety. Rural areas (or lower density) upstream and downstream of urban areas tend to follow suit decades later as resources become available; as large parcels are decreased in size making protection management schemes more affordable; as development is increased on the parcels; or as flooding increases due to upstream encroachment. For discussion purposes, however, the modelling scenarios assessed above provide a useful tool for proving high-level conservative estimates of floodplain value.

The high-level conclusions reached through Assessment 2, presented in Assessment 2 of Table 1 in Appendix F, are as follows:

- Under existing conditions, the rural and semi-urban floodplain areas have significant value in terms of municipal asset replacement costs. The value of both areas increases in Assessment 2 versus Assessment 1 because they provide more flood-storage volume, recharge, and treatment as flood-water levels increase; and
- Under Assessment 2 the two floodplain types also have significant risk in terms of potential damage costs if a significant flood occurs. The increased damages are due to increased water levels, velocities and sedimentation. Consistent with Assessment 1, the lower-density (population, infrastructure) rural area has less risk than the semi-urban floodplain type.

Conclusion: the net benefit estimates (last row of Appendix F, Table 1) under the 200-year flood scenario for Assessment 2 indicate that leaving things as-is in the rural area is supported. In the higher density semi-urban area, however, the benefit of the floodplain asset is almost completely offset by damages from flooding. Future analysis in this case should focus on annual average damages and benefits to more thoroughly assess the situation to support management decisions and floodplain planning.

Assessment 3: Model Scenario 2 upstream of and within city

Assessment 3 evaluates the floodplain within the city and damage costs for the two floodplain types, with:

- significant encroachment upstream of the city (e.g., long continuous dikes to protect agricultural land from flooding) with diking at the floodway boundary; and
- significant encroachment throughout the city (i.e., urban, semi-urban) in terms of diking at the floodway boundary.

This scenario results in greater floodwater levels and velocities in the city when compared to the baseline scenario (no encroachment/diking) due to loss of storage in the upstream floodplain area. The floodplain areas within the city are protected by dikes, which have also caused loss to some of the floodplain value.

From a real-world perspective, this scenario could occur in the future if floodplain-management regulations permit significant encroachment to the defined floodway boundary. This is the standard approach to floodplain management, which has led to loss of floodplain resources as well significant costs to society. This scenario does not consider the overall value of the floodplain asset and will cause a significant decrease in this value.

The high-level conclusions reached through Assessment 3, presented in the Assessment 3 of Table 1 in Appendix F, are as follows:

- Under the Assessment 3 scenario, rural and semi-urban floodplain areas within the city have lost significant value in terms of municipal asset replacement cost when compared to Assessment 1 and Assessment 2. The floodplain has been cut off from the main river channel resulting in the following impacts to asset value:
  - significant loss of water and sediment storage;
  - significant loss of aquifer water recharge and treatment; and
  - loss of some ability to manage local runoff in terms of quality and quantity.
- Under Assessment 3, however, the two land types are subject to a significant decrease in risk in terms of potential damage costs. These decreases are due to the high cost of diking and riverbank erosion protection, which was installed to decrease risk. That is, a decrease in damages costs are associated with an increase in dike infrastructure costs (design, construction, maintenance and operation).

Conclusion: the net benefit estimates (last row of Appendix F, Table 1) under the 200-year flood scenario for Assessment 3 indicate that an aggressive diking approach in a rural area is not supported economically. The loss of the asset value and the high costs of diking do not offset the gains in damages avoided. In the higher density semi-urban area, however, the loss of floodplain asset value and cost of diking is almost completely accounted for in terms of damage reduction. There is, however, no benefit overall to aggressive diking in the semi-urban area when the floodplain asset value losses are taken into consideration.

Assessment 4: Model Scenario 2 upstream and Scenario 5 within city

Assessment 4 evaluates the floodplain within the city for the two land types, with:

- significant encroachment upstream of the city (e.g., long continuous dikes to protect agricultural land from flooding); and
- selective encroachment throughout the city (i.e., urban, semi-urban) in terms of adaptive/selective diking near key locations to minimize impacts on the floodplain.

This scenario is associated with greater floodwater levels and velocities in the city when compared to the baseline scenario due to loss of storage in the upstream floodplain area. The floodplain areas within the city, however, are protected by adaptive/selective diking that attempts to minimize impacts to the floodplain. Practically, this scenario is unlikely to occur unless the city adopted a progressive floodplain management approach and the outside regional districts adopted the less-conservative standard approach to floodplain management leading to loss of floodplain value.

The high-level conclusions reached in Assessment 4, presented in Assessment 4 in Table 1 provided in Appendix F, are as follows:

- Under the Assessment 4 scenario, rural and semi-urban floodplain areas within the city lose only minor amounts of floodplain value compared to Assessment 1 and Assessment 2 (consistent with Assessment 3). The city floodplain incurs only minor impacts from adaptive/selective diking upstream, which is set back from the river channel. There are only very minor impacts to:
    - water and sediment storage;
    - aquifer water recharge and treatment; and
    - management of local runoff in terms of quality and quantity.
- Under Assessment 4, the two floodplain land types are subject to a significant decrease in risk in terms of potential damage costs. In addition, diking costs have been minimized due to adaptive/selective diking that focuses only on protecting high-risk infrastructure away from the river's floodway and keeping a large portion of the floodplain accessible to flooding and river translation. That is, there is a decrease in damage costs that is significantly greater than infrastructure protection costs (design, construction, maintenance and operation).

Conclusion: The net benefit estimates (last row of Appendix F, Table 1) under the 200-year flood scenario for Assessment 4 indicate that providing an adaptive/selective diking approach in both rural and semi-urban areas provides significant benefit compared to the first three assessment scenarios. The focus in rural areas would be on providing protection around residences and key infrastructure (e.g., wastewater treatment ponds) while allowing the remainder of the floodplain to flood (including incorporating water conveyance into roads and linear infrastructure to make sure these areas are available for flooding). Focus in urban areas would be on separate protection for acreages and for higher-density neighbourhoods. Maximizing storage, recharge and general function while minimizing loss to infrastructure and addressing public safety remains a priority. The minor loss of floodplain asset value and the relatively high costs of diking are more than offset by the gains in damages avoided.In both the rural and higher density semi-urban areas, the assessment indicates that there is a large net benefit applying this approach.

Assessment 5: Model Scenario 5 upstream and within city

Assessment 5 evaluates the floodplain within the city for the two floodplain land types, with:

- selective encroachment upstream of the city in regional district rural areas where only adaptive/selective diking near key locations is applied to lower risk and minimize impacts on the floodplain; and
- selective encroachment throughout the city (i.e., urban, semi-urban and rural) in terms of adaptive/selective diking near key locations to minimize impacts on the floodplain.

This scenario is associated with only negligible to modest flood-water level and velocity increases in the city when compared to modelling Scenario 2, associated with loss of storage in the upstream floodplain area. The floodplain areas upstream and within the city are protected by adaptive/selective diking that attempts to minimize impacts to the floodplain. From a real-world perspective, this assessment scenario is used by progressive watershed and floodplain managers to minimize costs to society and the environment and maximize benefit to local municipalities and districts.

The conclusions reached for Assessment 5 are similar to Assessment 4 and hence will not be reviewed in detail. It is important to note, however, that under Assessment 5, diking and damage costs continue to decrease in the city because flood levels and velocity increases are not transferred downstream from upstream areas as these areas are also progressively managing their floodplains.

Conclusion and limitations for future considerations

The preceding discussion illustrates that floodplain value can be protected and conserved while managing existing floodplain risk, resulting in a greater benefits to the community. It also emphasizes that floodplain management should be undertaken in a watershed context as risks and planning frameworks can be transferred throughout the watershed. It is important to note that these numbers and related arguments are hypothetical and are only based on professional judgement. The general conclusions and concepts presented above, however, provide pragmatic arguments that have been supported by analysis in other regions. It is also important to remember that this analysis should not be undertaken by only focusing on a single large flood event. Rather, a range of flooding should be considered to provide a better idea of risk, costs and benefits.

4.4 Next steps

Given the results of this project, Grand Forks will be incorporating modelling information on natural floodplain function and trade-offs with development and floodplain-protection options in upcoming floodplain mapping and hazard assessments. It will also use the information to update development permit requirements for protecting sensitive ecosystems and limiting development (including land clearing) on natural hazard lands. This will be a key part of the Official Community Plan update that will support implementation of the city's new Sensitive Ecosystem Inventory and the 2018-2019 floodplain mapping and risk assessment project.

The following recommendations resulting from this assessment relate to the City of Grand Forks' 2018-19 floodplain mapping and risk-assessment project:

- Floodplain planning should be developed on a watershed basis. The best approach for floodplain management is assessing floodplain hydraulics values and determining acceptable development approaches in the floodplain by considering these values on a watershed basis.
- A watershed approach will focus on progressive approaches in the headwaters that reduce diking and damage costs as flood levels, sediment inputs and velocity increases are not transferred downstream from upstream areas.
- This risk assessment should include input from all pertinent stakeholders, including municipalities, counties and districts.
- Watershed-based approaches should minimize costs to society and the environment while maximizing benefit to local municipalities and districts. A key strategy to meeting this aim is adaptive/selective diking that lowers risk to infrastructure and minimizes impacts to the floodplain.
- The 2018-19 study should include additional values of the floodplain beyond flood mitigation, including:
  - » regional flood storage
  - » local stormwater management (point source) and runoff treatment and retention (non-point source)
  - » aquifer recharge volumes and treatment
  - » (other) environmental benefits
  - » social/recreational benefits
- The 2018-19 study should include additional costs that go beyond building damage, including:
  - » damage to streets, sidewalks and related infrastructure
  - » damage to diking and riverbank erosion protection, including natural vegetation bank protection
  - » damage and sedimentation of storm-sewer systems
  - » damage to wastewater collection and treatment systems
  - » damage and sedimentation of public spaces and recreational facilities
  - » damage to basements/groundwater.

APPENDIX A: Calibration results (high-water-mark comparison)

XS	5/17/97 High water mark (m)	HEC-RAS model water surface elevations (m)	diff. (m)
66	526.6	526.77	0.17
64	524.98	525.05	0.07
61	523.34	523.29	-0.05
58	520.38	520.77	0.39
57.5	520.38	520.57	0.19
54	518.16	518.05	-0.11
53	517.28	517.42	0.14
51	516.53	516.62	0.09
49	515.14	514.96	-0.18
47	513.83	514.15	0.32
44	513.36	513.45	0.09
43	513.36	512.96	-0.4
42	512.8	512.94	0.14
40	512.11	512.15	0.04
37	511.67	511.92	0.25
36	511.67	511.49	-0.18
35	510.88	511.21	0.33
32	510.28	510.42	0.14
30	509.39	509.56	0.17
29	509.23	509.12	-0.11
27	508.33	508.4	0.07
26	507.59	507.83	0.24
20	504.85	504.84	-0.01
18	503.98	503.92	-0.06
17	503.98	503.64	-0.34
16	503.03	503.13	0.1
14	502.05	501.81	-0.24

APPENDIX B: Model input (encroachment stations by scenario)

	100-yr floodway		25m		30m		50m		75m		100m		Variable encroachment	
XS	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
66	8.73	66.42	-16.27	91.42	-21.27	96.42	-41.27	116.42	-66.27	141.42	-91.27	166.42	-41.27	66.42
65	5.35	65.9	-19.65	90.9	-24.65	95.9	-44.65	115.9	-69.65	140.9	-94.65	165.9	-44.65	65.9
64	19.81	73.25	-5.19	98.25	-10.19	103.25	-30.19	123.25	-55.19	148.25	-80.19	173.25	-80.19	173.25
63	41.15	135.82	16.15	160.82	11.15	165.82	-8.85	185.82	-33.85	210.82	-58.85	235.82	-8.85	235.82
62	16.52	91.65	-8.48	116.65	-13.48	121.65	-33.48	141.65	-58.48	166.65	-83.48	191.65	-83.48	191.65
61	13.29	80.84	-11.71	105.84	-16.71	110.84	-36.71	130.84	-61.71	155.84	-86.71	180.84	-86.71	80.84
60	33.05	112.25	8.05	137.25	3.05	142.25	-16.95	162.25	-41.95	187.25	-66.95	212.25	-66.95	212.25
59	29.18	132.92	4.18	157.92	-0.82	162.92	-20.82	182.92	-45.82	207.92	-70.82	232.92	-45.82	232.92
58	25.75	131.78	0.75	156.78	-4.25	161.78	-24.25	181.78	-49.25	206.78	-74.25	231.78	-49.25	231.78
57.5	18.47	117.74	-6.53	142.74	-11.53	147.74	-31.53	167.74	-56.53	192.74	-81.53	217.74	-81.53	217.74
57	39.4	87.64	14.4	112.64	9.4	117.64	-10.6	137.64	-35.6	162.64	-60.6	187.64	-60.6	87.64
56	-41.06	236.82	-66.06	261.82	-71.06	266.82	-91.06	286.82	-116.06	311.82	-141.06	336.82	-141.06	336.82
55	4.26	110.53	-20.74	135.53	-25.74	140.53	-45.74	160.53	-70.74	185.53	-95.74	210.53	4.26	210.53
54	13.82	94.53	-11.18	119.53	-16.18	124.53	-36.18	144.53	-61.18	169.53	-86.18	194.53	13.82	194.53
53	47.43	110.05	22.43	135.05	17.43	140.05	-2.57	160.05	-27.57	185.05	-52.57	210.05	-52.57	185.05
52	12.7	106.69	-12.3	131.69	-17.3	136.69	-37.3	156.69	-62.3	181.69	-87.3	206.69	-87.3	206.69
51	19.34	74.31	-5.66	99.31	-10.66	104.31	-30.66	124.31	-55.66	149.31	-80.66	174.31	-55.66	174.31
50	23.82	77.36	-1.18	102.36	-6.18	107.36	-26.18	127.36	-51.18	152.36	-76.18	177.36	-51.18	177.36
49	-52.5	72.52	-77.5	97.52	-82.5	102.52	-102.5	122.52	-127.5	147.52	-152.5	172.52	-152.5	72.52
48	14.31	103.82	-10.69	128.82	-15.69	133.82	-35.69	153.82	-60.69	178.82	-85.69	203.82	-60.69	203.82
47	15.04	95.39	-9.96	120.39	-14.96	125.39	-34.96	145.39	-59.96	170.39	-84.96	195.39	15.04	195.39
46	15.6	99.43	-9.4	124.43	-14.4	129.43	-34.4	149.43	-59.4	174.43	-84.4	199.43	15.6	199.43
45	9.15	94.18	-15.85	119.18	-20.85	124.18	-40.85	144.18	-65.85	169.18	-90.85	194.18	9.15	169.18
44	-14.89	134.31	-39.89	159.31	-44.89	164.31	-64.89	184.31	-89.89	209.31	-114.89	234.31	-114.89	159.31
43	45.42	117.17	20.42	142.17	15.42	147.17	-4.58	167.17	-29.58	192.17	-54.58	217.17	45.42	142.17
42	62.36	138.48	37.36	163.48	32.36	168.48	12.36	188.48	-12.64	213.48	-37.64	238.48	62.36	163.48
41	10.7	99.01	-14.3	124.01	-19.3	129.01	-39.3	149.01	-64.3	174.01	-89.3	199.01	10.7	124.01
40	37.89	99.05	12.89	124.05	7.89	129.05	-12.11	149.05	-37.11	174.05	-62.11	199.05	37.89	199.05
39	41.86	107.87	16.86	132.87	11.86	137.87	-8.14	157.87	-33.14	182.87	-58.14	207.87	41.86	207.87
38	27	89.4	2	114.4	-3	119.4	-23	139.4	-48	164.4	-73	189.4	27	89.4
37	14.06	125.72	-10.94	150.72	-15.94	155.72	-35.94	175.72	-60.94	200.72	-85.94	225.72	-10.94	225.72
36	16.93	93.39	-8.07	118.39	-13.07	123.39	-33.07	143.39	-58.07	168.39	-83.07	193.39	16.93	118.39
35	44.09	101.7	19.09	126.7	14.09	131.7	-5.91	151.7	-30.91	176.7	-55.91	201.7	-55.91	201.7
34	40.55	118	15.55	143	10.55	148	-9.45	168	-34.45	193	-59.45	218	-59.45	218
33	23.75	111.48	-1.25	136.48	-6.25	141.48	-26.25	161.48	-51.25	186.48	-76.25	211.48	-76.25	211.48
32	18.62	95.58	-6.38	120.58	-11.38	125.58	-31.38	145.58	-56.38	170.58	-81.38	195.58	-81.38	195.58
31	-99.84	151.82	-124.84	176.82	-129.84	181.82	-149.84	201.82	-174.84	226.82	-199.84	251.82	-199.84	251.82
30	16.98	100.94	-8.02	125.94	-13.02	130.94	-33.02	150.94	-58.02	175.94	-83.02	200.94	-83.02	125.94
29	-82.19	103.77	-107.19	128.77	-112.19	133.77	-132.19	153.77	-157.19	178.77	-182.19	203.77	-182.19	103.77
28	38.17	127.03	13.17	152.03	8.17	157.03	-11.83	177.03	-36.83	202.03	-61.83	227.03	13.17	127.03
27	19.62	130.79	-5.38	155.79	-10.38	160.79	-30.38	180.79	-55.38	205.79	-80.38	230.79	-5.38	130.79
26	40.13	127.23	15.13	152.23	10.13	157.23	-9.87	177.23	-34.87	202.23	-59.87	227.23	-59.87	227.23
25	7.66	79.95	-17.34	104.95	-22.34	109.95	-42.34	129.95	-67.34	154.95	-92.34	179.95	-92.34	179.95
24	86.09	198.03	61.09	223.03	56.09	228.03	36.09	248.03	11.09	273.03	-13.91	298.03	-13.91	298.03
23	6.68	437.66	-18.32	462.66	-23.32	467.66	-43.32	487.66	-68.32	512.66	-93.32	537.66	-93.32	537.66
22	104.84	325.23	79.84	350.23	74.84	355.23	54.84	375.23	29.84	400.23	4.84	425.23	4.84	425.23
21	90.59	231.19	65.59	256.19	60.59	261.19	40.59	281.19	15.59	306.19	-9.41	331.19	-9.41	231.19
20	61.18	381.37	36.18	406.37	31.18	411.37	11.18	431.37	-13.82	456.37	-38.82	481.37	-38.82	481.37
19	9.52	122.52	-15.48	147.52	-20.48	152.52	-40.48	172.52	-65.48	197.52	-90.48	222.52	-90.48	222.52
18	154.8	241.73	129.8	266.73	124.8	271.73	104.8	291.73	79.8	316.73	54.8	341.73	54.8	241.73
17	133.94	396.25	108.94	421.25	103.94	426.25	83.94	446.25	58.94	471.25	33.94	496.25	33.94	496.25
16	16.05	96.03	-8.95	121.03	-13.95	126.03	-33.95	146.03	-58.95	171.03	-83.95	196.03	-83.95	196.03
15	66.21	145.53	41.21	170.53	36.21	175.53	16.21	195.53	-8.79	220.53	-33.79	245.53	-33.79	145.53
14	38.6	111.04	13.6	136.04	8.6	141.04	-11.4	161.04	-36.4	186.04	-61.4	211.04	-61.4	136.04
13	124.18	204.53	99.18	229.53	94.18	234.53	74.18	254.53	49.18	279.53	24.18	304.53	24.18	229.53
12	9.49	119.49	-15.51	144.49	-20.51	149.49	-40.51	169.49	-65.51	194.49	-90.51	219.49	-40.51	169.49
11	8.4	104.48	-16.6	129.48	-21.6	134.48	-41.6	154.48	-66.6	179.48	-91.6	204.48	-41.6	179.48

APPENDIX C: HEC-RAS model output

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
			(m)	(m)	(m)	(m)	(m3/s)	(m3/s)	(m3/s)	(m)	(m)	(m)	(m)
Border - Gilpin	66	Q200 Daily - Bas	526.79		527.07	79.13	3.38	585.62			8.73	66.42	
Border - Gilpin	66	Q200 - Full Enc	526.9	0.1	527.17	56.2		589		8.73	8.73	66.42	66.42
Border - Gilpin	66	Q200 - 75m Enc	526.79	0	527.08	79.24	3.39	585.61		-66.27	8.73	66.42	141.42
Border - Gilpin	66	Q200 - Var Enc	526.8	0.01	527.08	79.4	3.42	585.58		-41.27	8.73	66.42	66.42
Border - Gilpin	66	Q200 - 30m Enc	526.8	0.01	527.08	79.56	3.45	585.55		-21.27	8.73	66.42	96.42
Border - Gilpin	65	Q200 Daily - Bas	525.84		526.09	79.73	1.72	586.91	0.37		5.35	65.9	
Border - Gilpin	65	Q200 - Full Enc	525.99	0.16	526.23	60.55		589		5.35	5.35	65.9	65.9
Border - Gilpin	65	Q200 - 75m Enc	525.84	0.01	526.1	80.04	1.73	586.88	0.39	-69.65	5.35	65.9	140.9
Border - Gilpin	65	Q200 - Var Enc	525.84	0.01	526.1	64.4	1.74	587.26		-44.65	5.35	65.9	65.9
Border - Gilpin	65	Q200 - 30m Enc	525.86	0.02	526.11	80.97	1.77	586.78	0.45	-24.65	5.35	65.9	95.9
Border - Gilpin	64	Q200 Daily - Bas	525.06		525.41	107.63	0.9	580.02	8.09		19.81	73.25	
Border - Gilpin	64	Q200 - Full Enc	525.27	0.21	525.6	53.44		589		19.81	19.81	73.25	73.25
Border - Gilpin	64	Q200 - 75m Enc	525.07	0.01	525.42	109.72	0.92	579.83	8.25	-55.19	19.81	73.25	148.25
Border - Gilpin	64	Q200 - Var Enc	525.07	0.01	525.42	109.35	0.92	579.87	8.22	-80.19	19.81	73.25	173.25
Border - Gilpin	64	Q200 - 30m Enc	525.12	0.06	525.46	87.43	1.01	577.41	10.58	-10.19	19.81	73.25	103.25
Border - Gilpin	63	Q200 Daily - Bas	524.44		524.61	152.64	89.19	491.64	8.17		59.36	135.82	
Border - Gilpin	63	Q200 - Full Enc	524.51	0.07	524.76	94.67	15.66	573.34		41.15	59.36	135.82	135.82
Border - Gilpin	63	Q200 - 75m Enc	524.48	0.03	524.64	152.79	90.3	490.24	8.47	-33.85	59.36	135.82	210.82
Border - Gilpin	63	Q200 - Var Enc	524.47	0.03	524.64	152.77	90.11	490.48	8.41	-8.85	59.36	135.82	235.82
Border - Gilpin	63	Q200 - 30m Enc	524.48	0.03	524.67	140.47	66.8	513.32	8.88	11.15	59.36	135.82	165.82
Border - Gilpin	62	Q200 Daily - Bas	524.03		524.25	250.41		576.63	12.37		16.52	91.65	
Border - Gilpin	62	Q200 - Full Enc	524.13	0.1	524.36	74.2		589		16.52	16.52	91.65	91.65
Border - Gilpin	62	Q200 - 75m Enc	524.06	0.04	524.29	149.02		580.9	8.1	-58.48	16.52	91.65	166.65
Border - Gilpin	62	Q200 - Var Enc	524.06	0.03	524.28	174		580.86	8.14	-83.48	16.52	91.65	191.65
Border - Gilpin	62	Q200 - 30m Enc	524.08	0.05	524.3	104.06		580.49	8.51	-13.48	16.52	91.65	121.65
Border - Gilpin	61	Q200 Daily - Bas	523.32		523.65	251.8	29.18	559.82			13.29	80.84	
Border - Gilpin	61	Q200 - Full Enc	523.36	0.04	523.74	58.57		589		13.29	13.29	80.84	80.84
Border - Gilpin	61	Q200 - 75m Enc	523.33	0.01	523.69	133.53	16.39	572.61		-61.71	13.29	80.84	155.84
Border - Gilpin	61	Q200 - Var Enc	523.33	0.01	523.68	158.53	19.2	569.8		-86.71	13.29	80.84	80.84
Border - Gilpin	61	Q200 - 30m Enc	523.34	0.02	523.7	88.54	11.78	577.22		-16.71	13.29	80.84	110.84
Border - Gilpin	60	Q200 Daily - Bas	521.97		522.28	91.73	0	588.6	0.4		33.05	112.25	
Border - Gilpin	60	Q200 - Full Enc	521.98	0.01	522.28	78.94		589		33.05	33.05	112.25	112.25
Border - Gilpin	60	Q200 - 75m Enc	521.97	0	522.28	91.73	0	588.6	0.4	-41.95	33.05	112.25	187.25
Border - Gilpin	60	Q200 - Var Enc	521.97	0	522.28	91.72	0	588.6	0.4	-66.95	33.05	112.25	212.25
Border - Gilpin	60	Q200 - 30m Enc	521.97	0	522.28	91.75	0	588.6	0.4	3.05	33.05	112.25	142.25
Border - Gilpin	59	Q200 Daily - Bas	520.86		521.1	94.66		589			29.18	132.92	
Border - Gilpin	59	Q200 - Full Enc	520.88	0.02	521.12	94.74		589		29.18	29.18	132.92	132.92
Border - Gilpin	59	Q200 - 75m Enc	520.86	0	521.1	94.66		589		-45.82	29.18	132.92	207.92
Border - Gilpin	59	Q200 - Var Enc	520.86	0	521.1	94.66		589		-45.82	29.18	132.92	232.92
Border - Gilpin	59	Q200 - 30m Enc	520.86	0	521.11	94.67		589		-0.82	29.18	132.92	162.92
Border - Gilpin	58	Q200 Daily - Bas	520.84		521.09	93.49		589			25.75	131.78	
Border - Gilpin	58	Q200 - Full Enc	520.86	0.02	521.11	93.54		589		25.75	25.75	131.78	131.78
Border - Gilpin	58	Q200 - 75m Enc	520.84	0	521.09	93.49		589		-49.25	25.75	131.78	206.78
Border - Gilpin	58	Q200 - Var Enc	520.84	0	521.09	93.49		589		-49.25	25.75	131.78	231.78
Border - Gilpin	58	Q200 - 30m Enc	520.84	0	521.09	93.5		589		-4.25	25.75	131.78	161.78
Border - Gilpin	57.5	Q200 Daily - Bas	520.62		521.02	82.61		589			18.47	117.74	
Border - Gilpin	57.5	Q200 - Full Enc	520.65	0.03	521.04	82.69		589		18.47	18.47	117.74	117.74
Border - Gilpin	57.5	Q200 - 75m Enc	520.62	0	521.02	82.61		589		-56.53	18.47	117.74	192.74
Border - Gilpin	57.5	Q200 - Var Enc	520.62	0	521.02	82.61		589		-81.53	18.47	117.74	217.74
Border - Gilpin	57.5	Q200 - 30m Enc	520.62	0	521.02	82.62		589		-11.53	18.47	117.74	147.74
Border - Gilpin	57	Q200 Daily - Bas	519.05		519.7	59.42	1.64	587.36			39.4	87.64	
Border - Gilpin	57	Q200 - Full Enc	519.36	0.31	519.91	48.03		589		39.4	39.4	87.64	87.64
Border - Gilpin	57	Q200 - 75m Enc	519.18	0.13	519.79	60.46	2.52	586.48		-35.6	39.4	87.64	162.64
Border - Gilpin	57	Q200 - Var Enc	519.14	0.09	519.76	60.17	2.26	586.74		-60.6	39.4	87.64	87.64
Border - Gilpin	57	Q200 - 30m Enc	519.25	0.2	519.83	61.03	3.05	585.95		9.4	39.4	87.64	117.64
Border - Gilpin	56	Q200 Daily - Bas	519.02		519.14	598.36	63.5	420.67	104.83		7.87	95.3	
Border - Gilpin	56	Q200 - Full Enc	519.22	0.19	519.41	277.88	14.24	513.54	61.22	-41.06	7.87	95.3	236.82
Border - Gilpin	56	Q200 - 75m Enc	519.09	0.07	519.24	427.88	41.05	462.27	85.68	-116.06	7.87	95.3	311.82
Border - Gilpin	56	Q200 - Var Enc	519.08	0.06	519.22	477.88	42.38	447.76	98.86	-141.06	7.87	95.3	336.82
Border - Gilpin	56	Q200 - 30m Enc	519.11	0.09	519.29	337.88	23	493.2	72.8	-71.06	7.87	95.3	266.82
Border - Gilpin	55	Q200 Daily - Bas	518.54		518.73	332.5		486.62	102.38		4.26	98.35	
Border - Gilpin	55	Q200 - Full Enc	518.61	0.06	518.9	92.72		573.29	15.71	4.26	4.26	98.35	110.53
Border - Gilpin	55	Q200 - 75m Enc	518.53	-0.01	518.77	167.5		527.22	61.78	-70.74	4.26	98.35	185.53
Border - Gilpin	55	Q200 - Var Enc	518.53	-0.01	518.76	192.51		520.39	68.61	4.26	4.26	98.35	210.53
Border - Gilpin	55	Q200 - 30m Enc	518.55	0	518.79	122.55		529.59	59.41	-25.74	4.26	98.35	140.53

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
Border - Gilpin	54	Q200 Daily - Bas	518.07		518.38	231.06	2.3	564.22	22.48		13.82	94.53	
Border - Gilpin	54	Q200 - Full Enc	518.2	0.12	518.52	80.71		589		13.82	13.82	94.53	94.53
Border - Gilpin	54	Q200 - 75m Enc	518.09	0.02	518.4	173.74	2.48	565.16	21.36	-61.18	13.82	94.53	169.53
Border - Gilpin	54	Q200 - Var Enc	518.09	0.01	518.4	180.71		565.49	23.51	13.82	13.82	94.53	194.53
Border - Gilpin	54	Q200 - 30m Enc	518.11	0.04	518.42	128.9	2.69	569.89	16.42	-16.18	13.82	94.53	124.53
Border - Gilpin	53	Q200 Daily - Bas	517.41		517.82	91.48	5.17	582.06	1.77		47.43	110.05	
Border - Gilpin	53	Q200 - Full Enc	517.65	0.24	518.02	62.62		589		47.43	47.43	110.05	110.05
Border - Gilpin	53	Q200 - 75m Enc	517.47	0.06	517.86	92.57	5.83	581.25	1.91	-27.57	47.43	110.05	185.05
Border - Gilpin	53	Q200 - Var Enc	517.45	0.04	517.85	92.23	5.62	581.51	1.87	-52.57	47.43	110.05	185.05
Border - Gilpin	53	Q200 - 30m Enc	517.53	0.12	517.91	93.43	6.63	580.29	2.07	17.43	47.43	110.05	140.05
Border - Gilpin	52	Q200 Daily - Bas	517.28		517.47	329.77	59.75	525.87	3.38		12.7	106.69	
Border - Gilpin	52	Q200 - Full Enc	517.48	0.19	517.7	93.99		589		12.7	12.7	106.69	106.69
Border - Gilpin	52	Q200 - 75m Enc	517.32	0.03	517.52	184.41	36.4	548.87	3.74	-62.3	12.7	106.69	181.69
Border - Gilpin	52	Q200 - Var Enc	517.31	0.02	517.5	209.36	44.8	540.57	3.63	-87.3	12.7	106.69	206.69
Border - Gilpin	52	Q200 - 30m Enc	517.36	0.07	517.58	139.67	15.27	569.56	4.17	-17.3	12.7	106.69	136.69
Border - Gilpin	51	Q200 Daily - Bas	516.67		517.03	207.55	5.27	579.61	4.12		19.34	74.31	
Border - Gilpin	51	Q200 - Full Enc	516.95	0.29	517.29	54.97		589		19.34	19.34	74.31	74.31
Border - Gilpin	51	Q200 - 75m Enc	516.74	0.07	517.09	134.21	8.01	576.7	4.29	-55.66	19.34	74.31	149.31
Border - Gilpin	51	Q200 - Var Enc	516.72	0.05	517.07	134.18	7.23	577.53	4.25	-55.66	19.34	74.31	174.31
Border - Gilpin	51	Q200 - 30m Enc	516.81	0.15	517.15	89.34	5.64	578.85	4.51	-10.66	19.34	74.31	104.31
Border - Gilpin	50	Q200 Daily - Bas	515.49		515.79	223.27	3.35	525.92	59.74		23.82	77.36	
Border - Gilpin	50	Q200 - Full Enc	515.69	0.2	516.07	53.54		589		23.82	23.82	77.36	77.36
Border - Gilpin	50	Q200 - 75m Enc	515.58	0.08	515.9	142.16	4.23	547.22	37.55	-51.18	23.82	77.36	152.36
Border - Gilpin	50	Q200 - Var Enc	515.56	0.07	515.88	167.1	4.07	539.5	45.43	-51.18	23.82	77.36	177.36
Border - Gilpin	50	Q200 - 30m Enc	515.63	0.13	515.98	97.4	4.89	569.23	14.88	-6.18	23.82	77.36	107.36
Border - Gilpin	49	Q200 Daily - Bas	515.05		515.24	381.79	115.27	473.15	0.58		16.73	72.52	
Border - Gilpin	49	Q200 - Full Enc	515.16	0.11	515.44	125.02	43.32	545.68		-52.5	16.73	72.52	72.52
Border - Gilpin	49	Q200 - 75m Enc	515.05	0	515.31	204.28	67.19	521.18	0.63	-127.5	16.73	72.52	147.52
Border - Gilpin	49	Q200 - Var Enc	515.06	0	515.3	225.02	78.26	510.74		-152.5	16.73	72.52	72.52
Border - Gilpin	49	Q200 - 30m Enc	515.08	0.03	515.36	159.35	49.05	539.21	0.74	-82.5	16.73	72.52	102.52
Border - Gilpin	48	Q200 Daily - Bas	514.67		514.82	232.62	52.21	510.55	26.25		14.31	103.82	
Border - Gilpin	48	Q200 - Full Enc	514.65	-0.02	514.89	89.51		589		14.31	14.31	103.82	103.82
Border - Gilpin	48	Q200 - 75m Enc	514.67	0	514.82	232.64	52.28	510.4	26.32	-60.69	14.31	103.82	178.82

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
Border - Gilpin	48	Q200 - Var Enc	514.68	0.01	514.83	232.7	52.44	510.1	26.47	-60.69	14.31	103.82	203.82
Border - Gilpin	48	Q200 - 30m Enc	514.65	-0.02	514.84	149.51	24.11	545.93	18.96	-15.69	14.31	103.82	133.82
Border - Gilpin	47	Q200 Daily - Bas	514.33		514.62	75.12	0.08	588.92			15.04	95.39	
Border - Gilpin	47	Q200 - Full Enc	514.39	0.06	514.66	72.82		589		15.04	15.04	95.39	95.39
Border - Gilpin	47	Q200 - 75m Enc	514.33	0	514.62	72.58		589		-59.96	15.04	95.39	170.39
Border - Gilpin	47	Q200 - Var Enc	514.34	0.01	514.62	72.61		589		15.04	15.04	95.39	195.39
Border - Gilpin	47	Q200 - 30m Enc	514.34	0	514.62	72.59		589		-14.96	15.04	95.39	125.39
Border - Gilpin	46	Q200 Daily - Bas	514.39		514.59	76.39		589			15.6	99.43	
Border - Gilpin	46	Q200 - Full Enc	514.44	0.05	514.64	76.79		589		15.6	15.6	99.43	99.43
Border - Gilpin	46	Q200 - 75m Enc	514.39	0	514.59	76.41		589		-59.4	15.6	99.43	174.43
Border - Gilpin	46	Q200 - Var Enc	514.4	0.01	514.59	76.44		589		15.6	15.6	99.43	199.43
Border - Gilpin	46	Q200 - 30m Enc	514.39	0	514.59	76.42		589		-14.4	15.6	99.43	129.43
Border - Gilpin	45	Q200 Daily - Bas	514.26		514.5	99.89		572.84	16.16		9.15	94.18	
Border - Gilpin	45	Q200 - Full Enc	514.29	0.03	514.55	80.13		589		9.15	9.15	94.18	94.18
Border - Gilpin	45	Q200 - 75m Enc	514.27	0	514.5	99.9		572.8	16.2	-65.85	9.15	94.18	169.18
Border - Gilpin	45	Q200 - Var Enc	514.27	0.01	514.51	99.92		572.72	16.28	9.15	9.15	94.18	169.18
Border - Gilpin	45	Q200 - 30m Enc	514.27	0	514.5	99.9		572.77	16.23	-20.85	9.15	94.18	124.18
Border - Gilpin	44	Q200 Daily - Bas	513.83		513.94	227.17	154.19	432.35	2.46		38.13	93.64	
Border - Gilpin	44	Q200 - Full Enc	513.88	0.05	513.99	227.46	158.72	427.65	2.64		38.13	93.64	
Border - Gilpin	44	Q200 - 75m Enc	513.84	0	513.95	227.19	154.57	431.95	2.47		38.13	93.64	
Border - Gilpin	44	Q200 - Var Enc	513.85	0.02	513.96	227.25	155.51	430.98	2.51		38.13	93.64	
Border - Gilpin	44	Q200 - 30m Enc	513.84	0.01	513.95	227.22	154.93	431.58	2.49		38.13	93.64	
Border - Gilpin	43	Q200 Daily - Bas	513.46		513.67	118.16	0.61	588.39			45.42	117.17	
Border - Gilpin	43	Q200 - Full Enc	513.53	0.07	513.74	155.09	1.4	587.6			45.42	117.17	
Border - Gilpin	43	Q200 - 75m Enc	513.47	0.01	513.68	121.97	0.66	588.34			45.42	117.17	
Border - Gilpin	43	Q200 - Var Enc	513.48	0.02	513.69	132.16	0.77	588.23			45.42	117.17	
Border - Gilpin	43	Q200 - 30m Enc	513.47	0.01	513.68	125.92	0.7	588.3			45.42	117.17	
Border - Gilpin	42	Q200 Daily - Bas	513.45		513.66	152.17	0.6	588.4			62.36	138.48	
Border - Gilpin	42	Q200 - Full Enc	513.53	0.07	513.72	214.44	1.79	587.21			62.36	138.48	
Border - Gilpin	42	Q200 - 75m Enc	513.46	0.01	513.66	154.67	0.67	588.33			62.36	138.48	
Border - Gilpin	42	Q200 - Var Enc	513.47	0.02	513.68	160	0.87	588.13			62.36	138.48	
Border - Gilpin	42	Q200 - 30m Enc	513.47	0.01	513.67	156.98	0.74	588.26			62.36	138.48	
Border - Gilpin	41	Q200 Daily - Bas	512.6		513.27	86.3		974			10.7	99.01	

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
Border - Gilpin	41	Q200 - Full Enc	512.78	0.18	513.38	86.78		974			10.7	99.01	
Border - Gilpin	41	Q200 - 75m Enc	512.61	0.02	513.28	86.34		974			10.7	99.01	
Border - Gilpin	41	Q200 - Var Enc	512.65	0.06	513.31	86.45		974			10.7	99.01	
Border - Gilpin	41	Q200 - 30m Enc	512.63	0.03	513.29	86.38		974			10.7	99.01	
Border - Gilpin	40	Q200 Daily - Bas	512.41		512.8	71.91	4.67	964.39	4.95		37.89	99.05	
Border - Gilpin	40	Q200 - Full Enc	512.56	0.15	512.94	61.16		974		37.89	37.89	99.05	99.05
Border - Gilpin	40	Q200 - 75m Enc	512.43	0.02	512.82	71.92	4.7	964.28	5.02	-37.11	37.89	99.05	174.05
Border - Gilpin	40	Q200 - Var Enc	512.45	0.04	512.84	68.1		968.78	5.22	37.89	37.89	99.05	199.05
Border - Gilpin	40	Q200 - 30m Enc	512.45	0.04	512.83	71.92	4.72	964.19	5.09	7.89	37.89	99.05	129.05
Border - Gilpin	39	Q200 Daily - Bas	512.45		512.78	74.63	8.61	964.75	0.64		41.86	107.87	
Border - Gilpin	39	Q200 - Full Enc	512.59	0.15	512.92	66.01		974		41.86	41.86	107.87	107.87
Border - Gilpin	39	Q200 - 75m Enc	512.47	0.02	512.8	74.63	8.65	964.69	0.66	-33.14	41.86	107.87	182.87
Border - Gilpin	39	Q200 - Var Enc	512.48	0.03	512.82	68.86		973.3	0.7	41.86	41.86	107.87	207.87
Border - Gilpin	39	Q200 - 30m Enc	512.48	0.03	512.81	74.64	8.7	964.63	0.68	11.86	41.86	107.87	137.87
Border - Gilpin	38	Q200 Daily - Bas	512.33		512.64	85.24	8.04	964.98	0.97		27	89.4	
Border - Gilpin	38	Q200 - Full Enc	512.47	0.14	512.78	62.4		974		27	27	89.4	89.4
Border - Gilpin	38	Q200 - 75m Enc	512.35	0.02	512.66	86.14	8.11	964.86	1.03	-48	27	89.4	164.4
Border - Gilpin	38	Q200 - Var Enc	512.35	0.02	512.67	62.4		974		27	27	89.4	89.4
Border - Gilpin	38	Q200 - 30m Enc	512.37	0.04	512.68	72.74	8.17	964.97	0.86	-3	27	89.4	119.4
Border - Gilpin	37	Q200 Daily - Bas	512.15		512.4	143.04	0.12	973.88			14.06	125.72	
Border - Gilpin	37	Q200 - Full Enc	512.31	0.16	512.54	110.28		974		14.06	14.06	125.72	125.72
Border - Gilpin	37	Q200 - 75m Enc	512.17	0.02	512.42	144.34	0.15	973.85		-60.94	14.06	125.72	200.72
Border - Gilpin	37	Q200 - Var Enc	512.17	0.01	512.42	135.05	0.11	973.89		-10.94	14.06	125.72	225.72
Border - Gilpin	37	Q200 - 30m Enc	512.2	0.04	512.44	140.1	0.24	973.76		-15.94	14.06	125.72	155.72
Border - Gilpin	36	Q200 Daily - Bas	511.71		512.04	120.35		947.13	26.87		16.93	93.39	
Border - Gilpin	36	Q200 - Full Enc	511.86	0.16	512.2	74.2		974		16.93	16.93	93.39	93.39
Border - Gilpin	36	Q200 - 75m Enc	511.74	0.03	512.06	121.63		946.33	27.67	-58.07	16.93	93.39	168.39
Border - Gilpin	36	Q200 - Var Enc	511.73	0.03	512.06	99.01		942.75	31.25	16.93	16.93	93.39	118.39
Border - Gilpin	36	Q200 - 30m Enc	511.78	0.07	512.09	104.07		941.57	32.43	-13.07	16.93	93.39	123.39
Border - Gilpin	35	Q200 Daily - Bas	511.37		511.76	68.92		967.41	6.59		44.09	101.7	
Border - Gilpin	35	Q200 - Full Enc	511.56	0.19	511.94	54.81		974		44.09	44.09	101.7	101.7
Border - Gilpin	35	Q200 - 75m Enc	511.41	0.04	511.79	69.23		967.04	6.96	-30.91	44.09	101.7	176.7
Border - Gilpin	35	Q200 - Var Enc	511.4	0.03	511.79	69.21		967.15	6.85	-55.91	44.09	101.7	201.7
Border - Gilpin	35	Q200 - 30m Enc	511.45	0.08	511.83	69.31		966.6	7.4	14.09	44.09	101.7	131.7

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
Border - Gilpin	34	Q200 Daily - Bas	511.37		511.75	64.41		974			40.55	118	
Border - Gilpin	34	Q200 - Full Enc	511.57	0.2	511.93	64.77		974		40.55	40.55	118	118
Border - Gilpin	34	Q200 - 75m Enc	511.41	0.04	511.79	64.48		974		-34.45	40.55	118	193
Border - Gilpin	34	Q200 - Var Enc	511.4	0.03	511.78	64.47		974		-59.45	40.55	118	218
Border - Gilpin	34	Q200 - 30m Enc	511.45	0.08	511.82	64.55		974		10.55	40.55	118	148
Border - Gilpin	33	Q200 Daily - Bas	511.19		511.48	122.29	18.88	954.91	0.21		23.75	111.48	
Border - Gilpin	33	Q200 - Full Enc	511.39	0.21	511.68	87.73		974		23.75	23.75	111.48	111.48
Border - Gilpin	33	Q200 - 75m Enc	511.23	0.05	511.52	122.85	19.59	954.13	0.28	-51.25	23.75	111.48	186.48
Border - Gilpin	33	Q200 - Var Enc	511.22	0.04	511.51	122.72	19.42	954.32	0.26	-76.25	23.75	111.48	211.48
Border - Gilpin	33	Q200 - 30m Enc	511.28	0.09	511.56	123.41	20.3	953.35	0.35	-6.25	23.75	111.48	141.48
Border - Gilpin	32	Q200 Daily - Bas	510.54		510.89	260.26		935.22	38.78		18.62	95.58	
Border - Gilpin	32	Q200 - Full Enc	510.76	0.22	511.12	76.87		974		18.62	18.62	95.58	95.58
Border - Gilpin	32	Q200 - 75m Enc	510.56	0.03	510.94	151.62		955.31	18.69	-56.38	18.62	95.58	170.58
Border - Gilpin	32	Q200 - Var Enc	510.55	0.02	510.93	176.61		951.4	22.6	-81.38	18.62	95.58	195.58
Border - Gilpin	32	Q200 - 30m Enc	510.63	0.09	511	106.7		959.89	14.11	-11.38	18.62	95.58	125.58
Border - Gilpin	31	Q200 Daily - Bas	510.29		510.39	477.98	190.87	739.9	43.24		41.41	151.82	
Border - Gilpin	31	Q200 - Full Enc	510.48	0.18	510.6	251.66	139.94	834.06		-99.84	41.41	151.82	151.82
Border - Gilpin	31	Q200 - 75m Enc	510.33	0.04	510.42	365.82	196.55	747.66	29.8	-174.84	41.41	151.82	226.82
Border - Gilpin	31	Q200 - Var Enc	510.32	0.03	510.41	390.82	194.63	743.47	35.9	-199.84	41.41	151.82	251.82
Border - Gilpin	31	Q200 - 30m Enc	510.37	0.08	510.48	311.66	175.44	784.39	14.17	-129.84	41.41	151.82	181.82
Border - Gilpin	30	Q200 Daily - Bas	509.83		510.03	127.13	1.09	947.79	25.12		16.98	100.94	
Border - Gilpin	30	Q200 - Full Enc	510.02	0.19	510.22	83.96		974		16.98	16.98	100.94	100.94
Border - Gilpin	30	Q200 - 75m Enc	509.88	0.05	510.08	130.73	1	947.06	25.94	-58.02	16.98	100.94	175.94
Border - Gilpin	30	Q200 - Var Enc	509.87	0.04	510.07	117.64	1.01	948.34	24.64	-83.02	16.98	100.94	125.94
Border - Gilpin	30	Q200 - 30m Enc	509.93	0.1	510.12	126.5	1.02	943.73	29.25	-13.02	16.98	100.94	130.94
Border - Gilpin	29	Q200 Daily - Bas	509.41		509.55	323.26	173.4	800.1	0.5		23.84	103.77	
Border - Gilpin	29	Q200 - Full Enc	509.54	0.13	509.72	185.96	86.59	887.41		-82.19	23.84	103.77	103.77
Border - Gilpin	29	Q200 - 75m Enc	509.43	0.03	509.59	271.52	139.06	834.34	0.6	-157.19	23.84	103.77	178.77
Border - Gilpin	29	Q200 - Var Enc	509.43	0.03	509.58	285.96	158.8	815.2		-182.19	23.84	103.77	103.77
Border - Gilpin	29	Q200 - 30m Enc	509.47	0.06	509.64	226.62	106.71	866.53	0.76	-112.19	23.84	103.77	133.77
Border - Gilpin	28	Q200 Daily - Bas	508.71		508.95	101.8	5.77	965.96	2.28		38.17	127.03	
Border - Gilpin	28	Q200 - Full Enc	508.86	0.15	509.08	88.86		974		38.17	38.17	127.03	127.03
Border - Gilpin	28	Q200 - 75m Enc	508.74	0.03	508.97	101.97	5.94	965.73	2.33	-36.83	38.17	127.03	202.03

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
Border - Gilpin	28	Q200 - Var Enc	508.73	0.02	508.97	97.99	5.98	968.02		13.17	38.17	127.03	127.03
Border - Gilpin	28	Q200 - 30m Enc	508.79	0.08	509.02	102.27	6.24	965.33	2.43	8.17	38.17	127.03	157.03
Border - Gilpin	27	Q200 Daily - Bas	508.68		508.93	103.03		974			19.62	130.79	
Border - Gilpin	27	Q200 - Full Enc	508.84	0.16	509.08	104.57		974		19.62	19.62	130.79	130.79
Border - Gilpin	27	Q200 - 75m Enc	508.71	0.03	508.96	103.31		974		-55.38	19.62	130.79	205.79
Border - Gilpin	27	Q200 - Var Enc	508.7	0.02	508.95	103.24		974		-5.38	19.62	130.79	130.79
Border - Gilpin	27	Q200 - 30m Enc	508.76	0.08	509.01	103.82		974		-10.38	19.62	130.79	160.79
Border - Gilpin	26	Q200 Daily - Bas	508.07		508.38	91.58	5.6	968.4			40.13	127.23	
Border - Gilpin	26	Q200 - Full Enc	508.29	0.22	508.57	86.64		974		40.13	40.13	127.23	127.23
Border - Gilpin	26	Q200 - 75m Enc	508.12	0.05	508.42	91.71	5.75	968.25		-34.87	40.13	127.23	202.23
Border - Gilpin	26	Q200 - Var Enc	508.11	0.04	508.41	91.68	5.71	968.29		-59.87	40.13	127.23	227.23
Border - Gilpin	26	Q200 - 30m Enc	508.2	0.13	508.49	92.8	5.54	968.46		10.13	40.13	127.23	157.23
Border - Gilpin	25	Q200 Daily - Bas	507.43		507.85	155.57		953.52	20.48		7.66	79.95	
Border - Gilpin	25	Q200 - Full Enc	507.69	0.26	508.09	70.91		974		7.66	7.66	79.95	79.95
Border - Gilpin	25	Q200 - 75m Enc	507.52	0.09	507.92	145.57		949.69	24.31	-67.34	7.66	79.95	154.95
Border - Gilpin	25	Q200 - Var Enc	507.5	0.07	507.9	157.1		950.51	23.49	-92.34	7.66	79.95	179.95
Border - Gilpin	25	Q200 - 30m Enc	507.6	0.17	508	100.73		965.63	8.37	-22.34	7.66	79.95	109.95
Border - Gilpin	24	Q200 Daily - Bas	506.97		507.18	394.68		914.63	59.37		86.09	198.03	
Border - Gilpin	24	Q200 - Full Enc	507.27	0.3	507.49	111.94		974		86.09	86.09	198.03	198.03
Border - Gilpin	24	Q200 - 75m Enc	507.04	0.07	507.27	186.87		957.82	16.18	11.09	86.09	198.03	273.03
Border - Gilpin	24	Q200 - Var Enc	507.02	0.05	507.25	211.82		950.02	23.98	-13.91	86.09	198.03	298.03
Border - Gilpin	24	Q200 - 30m Enc	507.17	0.2	507.39	148.79	0.02	959.46	14.52	56.09	86.09	198.03	228.03
Border - Gilpin	23	Q200 Daily - Bas	506.62		506.71	479.01		645.59	328.41		6.68	122.5	
Border - Gilpin	23	Q200 - Full Enc	506.93	0.32	507.04	404.56		715.47	258.53	6.68	6.68	122.5	437.66
Border - Gilpin	23	Q200 - 75m Enc	506.74	0.13	506.83	479.22		625.79	348.21	-68.32	6.68	122.5	512.66
Border - Gilpin	23	Q200 - Var Enc	506.71	0.09	506.79	479.18		631.38	342.61	-93.32	6.68	122.5	537.66
Border - Gilpin	23	Q200 - 30m Enc	506.83	0.22	506.94	434.38		687.49	286.51	-23.32	6.68	122.5	467.66
Border - Gilpin	22	Q200 Daily - Bas	506.28		506.37	468.41	10.01	786.41	177.58		104.84	260.52	
Border - Gilpin	22	Q200 - Full Enc	506.58	0.31	506.7	220.39		908.94	65.06	104.84	104.84	260.52	325.23
Border - Gilpin	22	Q200 - 75m Enc	506.38	0.11	506.5	320.17	12.26	860.77	100.97	29.84	104.84	260.52	400.23
Border - Gilpin	22	Q200 - Var Enc	506.34	0.07	506.46	344.86	11.6	850.1	112.3	4.84	104.84	260.52	425.23
Border - Gilpin	22	Q200 - 30m Enc	506.48	0.2	506.6	275.85	13.71	880.98	79.31	74.84	104.84	260.52	355.23
Border - Gilpin	21	Q200 Daily - Bas	505.43		505.63	424.46	166.76	807.24			142.64	231.19	

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
Border - Gilpin	21	Q200 - Full Enc	505.69	0.26	505.95	140.28	67.85	906.15		90.59	142.64	231.19	231.19
Border - Gilpin	21	Q200 - 75m Enc	505.51	0.09	505.74	215.01	139.74	834.26		15.59	142.64	231.19	306.19
Border - Gilpin	21	Q200 - Var Enc	505.47	0.05	505.69	239.95	155.17	818.83		-9.41	142.64	231.19	231.19
Border - Gilpin	21	Q200 - 30m Enc	505.6	0.17	505.84	170.14	103.82	870.18		60.59	142.64	231.19	261.19
Border - Gilpin	20	Q200 Daily - Bas	505.04		505.09	487.23	0.04	735.99	237.97		61.18	326.93	
Border - Gilpin	20	Q200 - Full Enc	505.3	0.26	505.38	320.19		894.81	79.19	61.18	61.18	326.93	381.37
Border - Gilpin	20	Q200 - 75m Enc	505.13	0.09	505.19	400.71	0.05	789.11	184.84	-13.82	61.18	326.93	456.37
Border - Gilpin	20	Q200 - Var Enc	505.1	0.06	505.15	424.83	0.03	759.82	214.15	-38.82	61.18	326.93	481.37
Border - Gilpin	20	Q200 - 30m Enc	505.2	0.16	505.27	357.78	0.12	848.32	125.55	31.18	61.18	326.93	411.37
Border - Gilpin	19	Q200 Daily - Bas	504.5		504.74	291.54		840.57	133.43		9.52	87.3	
Border - Gilpin	19	Q200 - Full Enc	504.7	0.21	505	103.92		922.04	51.96	9.52	9.52	87.3	122.52
Border - Gilpin	19	Q200 - 75m Enc	504.54	0.04	504.81	178.75		882.46	91.54	-65.48	9.52	87.3	197.52
Border - Gilpin	19	Q200 - Var Enc	504.53	0.03	504.79	203.74		865.79	108.21	-90.48	9.52	87.3	222.52
Border - Gilpin	19	Q200 - 30m Enc	504.59	0.1	504.88	133.8		904.94	69.06	-20.48	9.52	87.3	152.52
Border - Gilpin	18	Q200 Daily - Bas	504.16		504.39	489.59	91.6	864.75	17.65		167.78	241.73	
Border - Gilpin	18	Q200 - Full Enc	504.34	0.18	504.63	86.93	21.49	952.51		154.8	167.78	241.73	241.73
Border - Gilpin	18	Q200 - 75m Enc	504.2	0.04	504.45	236.93	74.84	888.99	10.17	79.8	167.78	241.73	316.73
Border - Gilpin	18	Q200 - Var Enc	504.18	0.02	504.43	186.93	82.12	891.88		54.8	167.78	241.73	241.73
Border - Gilpin	18	Q200 - 30m Enc	504.24	0.08	504.51	146.93	52.98	915.51	5.51	124.8	167.78	241.73	271.73
Border - Gilpin	17	Q200 Daily - Bas	503.96		504.08	530.2	65.14	781.13	127.73		133.94	256.15	
Border - Gilpin	17	Q200 - Full Enc	504.11	0.15	504.27	262.31		897.98	76.02	133.94	133.94	256.15	396.25
Border - Gilpin	17	Q200 - 75m Enc	503.98	0.02	504.11	412.31	54.53	825.06	94.41	58.94	133.94	256.15	471.25
Border - Gilpin	17	Q200 - Var Enc	503.98	0.01	504.1	462.31	68	803.37	102.63	33.94	133.94	256.15	496.25
Border - Gilpin	17	Q200 - 30m Enc	504	0.03	504.15	322.31	16.67	877.94	79.38	103.94	133.94	256.15	426.25
Border - Gilpin	16	Q200 Daily - Bas	503.47		503.69	282.04	1.51	953.13	19.35		16.05	96.03	
Border - Gilpin	16	Q200 - Full Enc	503.63	0.17	503.86	79.98		974		16.05	16.05	96.03	96.03
Border - Gilpin	16	Q200 - 75m Enc	503.47	0.01	503.7	160.17	1.55	965.62	6.83	-58.95	16.05	96.03	171.03
Border - Gilpin	16	Q200 - Var Enc	503.47	0	503.7	185.16	1.53	964.17	8.3	-83.95	16.05	96.03	196.03
Border - Gilpin	16	Q200 - 30m Enc	503.49	0.03	503.72	115.19	1.61	967.96	4.43	-13.95	16.05	96.03	126.03
Border - Gilpin	15	Q200 Daily - Bas	502.86		503.15	168.53	82.9	891.1			66.21	145.53	
Border - Gilpin	15	Q200 - Full Enc	502.89	0.03	503.27	68.76		974		66.21	66.21	145.53	145.53
Border - Gilpin	15	Q200 - 75m Enc	502.86	0	503.16	143.72	77.68	896.31		-8.79	66.21	145.53	220.53
Border - Gilpin	15	Q200 - Var Enc	502.86	0	503.15	168.52	82.89	891.11		-33.79	66.21	145.53	145.53
Border - Gilpin	15	Q200 - 30m Enc	502.85	-0.01	503.17	98.72	61.51	912.49		36.21	66.21	145.53	175.53

Reach	River Sta	Profile	W.S. Elev	Prof Delta WS	E.G. Elev	Top Wdth Act	Q Left	Q Channel	Q Right	Enc Sta L	Ch Sta L	Ch Sta R	Enc Sta R
Border - Gilpin	14	Q200 Daily - Bas	502.21		502.52	101.5	1.12	968.16	4.72		38.6	111.04	
Border - Gilpin	14	Q200 - Full Enc	502.21	0	502.53	72.44		974		38.6	38.6	111.04	111.04
Border - Gilpin	14	Q200 - 75m Enc	502.21	0	502.52	101.5	1.12	968.16	4.72	-36.4	38.6	111.04	186.04
Border - Gilpin	14	Q200 - Var Enc	502.21	0	502.52	101.49	1.12	968.17	4.71	-61.4	38.6	111.04	136.04
Border - Gilpin	14	Q200 - 30m Enc	502.21	0	502.52	101.5	1.12	968.17	4.71	8.6	38.6	111.04	141.04
Border - Gilpin	13	Q200 Daily - Bas	501.78		502.1	75.11		974			124.18	204.53	
Border - Gilpin	13	Q200 - Full Enc	501.78	0	502.1	75.11		974		124.18	124.18	204.53	204.53
Border - Gilpin	13	Q200 - 75m Enc	501.78	0	502.1	75.11		974		49.18	124.18	204.53	279.53
Border - Gilpin	13	Q200 - Var Enc	501.78	0	502.1	75.11		974		24.18	124.18	204.53	229.53
Border - Gilpin	13	Q200 - 30m Enc	501.78	0	502.1	75.11		974		94.18	124.18	204.53	234.53
Border - Gilpin	12	Q200 Daily - Bas	501.38		501.64	92.83		974			9.49	119.49	
Border - Gilpin	12	Q200 - Full Enc	501.38	0	501.64	92.83		974		9.49	9.49	119.49	119.49
Border - Gilpin	12	Q200 - 75m Enc	501.38	0	501.64	92.83		974		-65.51	9.49	119.49	194.49
Border - Gilpin	12	Q200 - Var Enc	501.38	0	501.64	92.83		974		-40.51	9.49	119.49	169.49
Border - Gilpin	12	Q200 - 30m Enc	501.38	0	501.64	92.83		974		-20.51	9.49	119.49	149.49
Border - Gilpin	11	Q200 Daily - Bas	500.8		501.1	79.26		974			8.4	104.48	
Border - Gilpin	11	Q200 - Full Enc	500.8	0	501.1	79.26		974		8.4	8.4	104.48	104.48
Border - Gilpin	11	Q200 - 75m Enc	500.8	0	501.1	79.26		974		-66.6	8.4	104.48	179.48
Border - Gilpin	11	Q200 - Var Enc	500.8	0	501.1	79.26		974		-41.6	8.4	104.48	179.48
Border - Gilpin	11	Q200 - 30m Enc	500.8	0	501.1	79.26		974		-21.6	8.4	104.48	134.48

APPENDIX D: Flood depth estimates by structure

FID	building	improvement	category	Depth (Baseline)	Depth (75m)	Depth (Var. Enc.)	Depth (30m)	Depth (Full Enc.)
0	retail	2469000	commercial	0	0	0	0	0
1	commercial	106000	commercial	0	0	0	0	0
2	civic	2608000	commercial	0	0	0	0	0
3	civic	5098000	commercial	0	0	0	0	0
4	commercial*	646000	commercial	0.244629	0.249023	0.259949	0.253174	0.297974
5	apartments	1752000	commercial	0	0	0	0	0
6	apartments	2502000	commercial	0.0101318	0.0149536	0.0267944	0.0194092	0.0681763
7	commercial	129300	commercial	0	0	0	0	0
8	commercial	866000	commercial	0	0	0	0	0
9	commercial	575000	commercial	0	0	0	0	0
10	commercial	147000	commercial	0	0	0	0	0
11	commercial	270000	commercial	0	0	0	0	0
12	commercial	44300	commercial	0.308777	0.313782	0.32605	0.31842	0.368896
13	commercial	137000	commercial	0.950134	0.955139	0.967468	0.959839	1.01056
14	commercial	50600	commercial	0.25708	0.262329	0.275146	0.267151	0.319946
15	commercial	106700	commercial	0.255188	0.260559	0.273621	0.265503	0.319214
16	commercial	108000	commercial	0.302063	0.307312	0.320129	0.312134	0.36499
17	commercial	121000	commercial	0.15979	0.165161	0.178223	0.170044	0.223877
18	commercial	325000	commercial	0.30365	0.30896	0.321899	0.313843	0.367188
19	retail	139000	commercial	0	0	0.0024414	0	0.0449219
20	commercial	101000	commercial	0.102661	0.108215	0.121704	0.113281	0.169006
21	commercial	658000	commercial	0.622498	0.62738	0.639404	0.631958	0.681458
22	commercial	244200	commercial	0.0602417	0.0657959	0.0793457	0.0709229	0.12677
23	commercial	560000	commercial	0.132874	0.138	0.150574	0.142761	0.19458
24	commercial	451000	commercial	0.488586	0.493042	0.504211	0.497314	0.542969
25	commercial	110000	commercial	0	0	0	0	0
26	commercial	982000	commercial	0.282715	0.288208	0.301575	0.293213	0.348328
27	commercial	50000	commercial	0	0	0	0	0
28	commercial	2140000	commercial	0.267822	0.273376	0.286926	0.278503	0.334473
29	commercial	628000	commercial	0	0	0.0021973	0	0.0485229
30	commercial	177000	commercial	0.349182	0.354492	0.367432	0.359375	0.412842
31	commercial	120000	commercial	0	0	0	0	0
32	commercial	56400	commercial	0	0	0	0	0
33	commercial	50000	commercial	0	0	0	0	0
34	commercial	160000	commercial	0	0	0	0	0
35	commercial	1118000	commercial	0.688477	0.693054	0.704346	0.697327	0.743713
36	retail	205000	commercial	0	0	0	0	0

FID	building	improvement	category	Depth (Baseline)	Depth (75m)	Depth (Var. Enc.)	Depth (30m)	Depth (Full Enc.)
37	retail	73000	commercial	0	0	0	0	0
38	commercial	183000	commercial	0.138733	0.143982	0.156799	0.148804	0.201599
39	commercial	222700	commercial	0.0791016	0.0843506	0.097168	0.0891724	0.141846
40	commercial	128000	commercial	0.172119	0.177185	0.189453	0.181824	0.232422
41	apartments*	2838000	commercial	0	0	0	0	0
42	retail	224000	commercial	0.0604248	0.0653076	0.0773315	0.0698853	0.119385
43	retail	137600	commercial	0.0567017	0.0616455	0.0737305	0.0662231	0.115845
44	commercial	123000	commercial	0.340515	0.345825	0.358826	0.350708	0.404175
45	commercial	345000	commercial	0.179321	0.184753	0.197876	0.189697	0.243958
46	commercial	218000	commercial	0	0	0	0	0
47	professional	88600	commercial	0	0	0	0	0
48	retail	100000	commercial	0.115173	0.120117	0.132324	0.124756	0.174866
49	house	105000	residential	0.192566	0.197693	0.210327	0.202454	0.254395
50	commercial	474400	commercial	0.256042	0.261536	0.274841	0.266541	0.321472
51	retail	180000	commercial	0.148376	0.15332	0.165588	0.157959	0.208313
52	commercial	122000	commercial	0.212952	0.21814	0.230835	0.222961	0.275269
53	commercial	166000	commercial	0.100098	0.105347	0.118103	0.110168	0.162659
54	commercial	254800	commercial	0.0548706	0.0599976	0.0725708	0.0647583	0.116577
55	commercial	91800	commercial	0.218018	0.223206	0.23584	0.227966	0.28009
56	commercial	200000	commercial	0	0	0	0	0
57	commercial	278000	commercial	0.0675659	0.072998	0.0860596	0.0779419	0.131958
58	commercial	216000	commercial	0.0472412	0.0525513	0.0654907	0.0574341	0.110779
59	commercial	216000	commercial	0.745544	0.75061	0.762939	0.755249	0.80603
60	commercial	87400	commercial	0	0	0.0025635	0	0.0452271
61	commercial	487000	commercial	0.0512695	0.0565186	0.0693359	0.0613403	0.114258
62	retail	487000	commercial	0	0	0	0	0
63	house	105000	residential	0.305603	0.310608	0.322815	0.315247	0.36554
64	house	105000	residential	0.329346	0.334595	0.347351	0.339417	0.39209
65	house	105000	residential	0.742737	0.747742	0.76001	0.75238	0.802979
66	house	105000	residential	0.160645	0.166077	0.17926	0.171082	0.225403
67	commercial	487000	commercial	0.243225	0.248657	0.26178	0.253601	0.3078
68	commercial	487000	commercial	0.661743	0.667419	0.681152	0.672546	0.729309
69	commercial*	487000	commercial	0.843018	0.848877	0.863037	0.854248	0.91272
70	house*	105000	residential	0.658875	0.664612	0.678406	0.6698	0.726929
71	house*	105000	residential	0.432251	0.437988	0.451782	0.443176	0.500305
72	apartment*	2000000	commercial	0.183716	0.189453	0.203247	0.194641	0.251709
73	house*	105000	residential	0.974304	0.980225	0.994446	0.985596	1.0443701
74	house*	105000	residential	0.260315	0.26593	0.279541	0.271057	0.327271
75	house*	105000	residential	0.752747	0.758484	0.7724	0.763733	0.821167
76	house*	105000	residential	0.589539	0.595459	0.60968	0.600769	0.659668
77	house*	105000	residential	0.629395	0.634827	0.64801	0.639771	0.694153

APPENDIX E: Damage costs by structure

FID	building	improvement	category	Cost (Baseline)	Cost (75m)	Cost (Var. Enc.)	Cost (30m)	Cost (Full Enc.)
0	retail	2469000	commercial	$-	$-	$-	$ -	$-
1	commercial	106000	commercial	$-	$-	$-	$ -	$-
2	civic	2608000	commercial	$-	$-	$-	$ -	$-
3	civic	5098000	commercial	$-	$ -	$-	$ -	$-
4	commercial*	646000	commercial	$ 92,860	$93,612	$95,479	$94,322	$101,950
5	apartments	1752000	commercial	$-	$ -	$-	$ -	$-
6	apartments	2502000	commercial	$201,374	$204,686	$212,810	$207,745	$241,088
7	commercial	129300	commercial	$-	$ -	$-	$ -	$-
8	commercial	866000	commercial	$-	$ -	$-	$ -	$-
9	commercial	575000	commercial	$-	$ -	$-	$ -	$-
10	commercial	147000	commercial	$-	$ -	$-	$ -	$-
11	commercial	270000	commercial	$-	$ -	$-	$ -	$-
12	commercial	44300	commercial	$7,117	$ 7,175	$ 7,317	$ 7,229	$7,812
13	commercial	137000	commercial	$ 43,869	$44,031	$44,427	$44,182	$ 45,808
14	commercial	50600	commercial	$7,440	$ 7,510	$ 7,682	$ 7,575	$8,277
15	commercial	106700	commercial	$ 15,636	$15,787	$16,155	$15,927	$ 17,433
16	commercial	108000	commercial	$ 17,160	$17,309	$17,672	$17,445	$ 18,935
17	commercial	121000	commercial	$ 14,656	$14,830	$15,254	$14,989	$ 16,727
18	commercial	325000	commercial	$ 51,775	$52,227	$53,329	$52,643	$ 57,166
19	retail	139000	commercial	$-	$ -	$10,894	$ -	$ 12,512
20	commercial	101000	commercial	$ 10,678	$10,830	$11,198	$10,968	$ 12,483
21	commercial	658000	commercial	$158,480	$159,279	$161,246	$160,029	$168,095
22	commercial	244200	commercial	$ 23,003	$23,372	$24,273	$23,713	$ 27,409
23	commercial	560000	commercial	$ 63,775	$64,549	$66,443	$65,267	$ 73,045
24	commercial	451000	commercial	$ 93,411	$93,923	$95,204	$94,413	$ 99,630
25	commercial	110000	commercial	$-	$ -	$-	$ -	$-
26	commercial	982000	commercial	$151,036	$152,455	$155,905	$153,748	$167,911
27	commercial	50000	commercial	$-	$ -	$-	$ -	$-
28	commercial	2140000	commercial	$320,740	$323,876	$331,513	$326,767	$358,183
29	commercial	628000	commercial	$-	$ -	$49,175	$ -	$ 57,148
30	commercial	177000	commercial	$ 30,304	$30,549	$31,145	$30,774	$ 33,225
31	commercial	120000	commercial	$-	$ -	$-	$ -	$-
32	commercial	56400	commercial	$-	$ -	$-	$ -	$-
33	commercial	50000	commercial	$-	$ -	$-	$ -	$-
34	commercial	160000	commercial	$-	$ -	$-	$ -	$-
35	commercial	1118000	commercial	$287,542	$288,802	$291,906	$289,978	$302,682
36	retail	205000	commercial	$-	$ -	$-	$ -	$-
37	retail	73000	commercial	$-	$ -	$-	$ -	$-
38	commercial	183000	commercial	$ 21,130	$21,388	$22,019	$21,626	$ 24,213

FID	building	improvement	category	Cost (Baseline)	Cost (75m)	Cost (Var. Enc.)	Cost (30m)	Cost (Full Enc.)
39	commercial	222700	commercial	$ 22,121	$22,438	$23,213	$22,730	$ 25,900
40	commercial	128000	commercial	$ 15,927	$16,101	$16,521	$16,260	$ 17,985
41	apartments*	2838000	commercial	$-	$ -	$-	$ -	$-
42	retail	224000	commercial	$ 21,111	$21,409	$22,142	$21,688	$ 24,695
43	retail	137600	commercial	$ 12,829	$13,014	$13,467	$13,186	$ 15,038
44	commercial	123000	commercial	$ 20,781	$20,951	$21,368	$21,108	$ 22,813
45	commercial	345000	commercial	$ 43,594	$44,095	$45,304	$44,551	$ 49,531
46	commercial	218000	commercial	$-	$ -	$-	$ -	$-
47	professional	88600	commercial	$-	$ -	$-	$ -	$-
48	retail	100000	commercial	$ 10,911	$11,044	$11,374	$11,170	$ 12,517
49	house	105000	residential	$ 13,639	$13,783	$14,137	$13,917	$ 15,365
50	commercial	474400	commercial	$ 69,626	$70,315	$71,981	$70,942	$ 77,791
51	retail	180000	commercial	$ 21,250	$21,490	$22,082	$21,714	$ 24,138
52	commercial	122000	commercial	$ 16,511	$16,679	$17,091	$16,836	$ 18,525
53	commercial	166000	commercial	$ 17,435	$17,671	$18,243	$17,887	$ 20,234
54	commercial	254800	commercial	$ 23,628	$23,984	$24,857	$24,315	$ 27,897
55	commercial	91800	commercial	$ 12,548	$12,674	$12,982	$12,790	$ 14,056
56	commercial	200000	commercial	$-	$ -	$-	$ -	$-
57	commercial	278000	commercial	$ 26,741	$27,152	$28,139	$27,526	$ 31,591
58	commercial	216000	commercial	$ 19,580	$19,893	$20,655	$20,181	$ 23,310
59	commercial	216000	commercial	$ 58,575	$58,842	$59,491	$59,086	$ 61,746
60	commercial	87400	commercial	$-	$ -	$ 6,853	$ -	$7,875
61	commercial	487000	commercial	$ 44,682	$45,379	$47,080	$46,020	$ 53,015
62	retail	487000	commercial	$-	$ -	$-	$ -	$-
63	house	105000	residential	$ 16,781	$16,919	$17,254	$17,046	$ 18,424
64	house	105000	residential	$ 17,434	$17,578	$17,927	$17,710	$ 19,147
65	house	105000	residential	$ 28,402	$28,530	$28,844	$28,649	$ 29,938
66	house	105000	residential	$ 12,742	$12,895	$13,266	$13,036	$ 14,558
67	commercial	487000	commercial	$ 69,824	$70,524	$72,214	$71,161	$ 78,113
68	commercial	487000	commercial	$122,039	$122,723	$124,374	$123,340	$130,134
69	commercial*	487000	commercial	$143,549	$144,233	$145,883	$144,859	$151,641
70	house*	105000	residential	$ 26,238	$26,387	$26,745	$26,521	$ 27,997
71	house*	105000	residential	$ 20,234	$20,389	$20,761	$20,529	$ 22,061
72	apartment*	2000000	commercial	$255,070	$258,137	$265,500	$260,908	$291,242
73	house*	105000	residential	$ 34,219	$34,364	$34,713	$34,496	$ 35,932
74	house*	105000	residential	$ 15,529	$15,685	$16,062	$15,827	$ 17,377
75	house*	105000	residential	$ 28,659	$28,805	$29,160	$28,939	$ 30,399
76	house*	105000	residential	$ 24,425	$24,581	$24,954	$24,720	$ 26,258
77	house*	105000	residential	$ 25,470	$25,611	$25,955	$25,740	$ 27,152

Appendix F: Overview of costs

Assessment 1:

Table 1: Hypothetical analysis to guide floodplain management and development			
Items (value of equivalent service or costs of flooding)		Assessment 1: Modelling Scenario 1 upstream of city, no change in city	
Part 1		**Semi-urban**	**Rural floodplain**
Value of equivalent grey infrastructure to achieve natural function			
Stormwater quality/quantity (point and non-point source)		$3,000,000	$2,500,000
Groundwater recharge/stored for use		$800,000	$800,000
Storage of flood water (based on diking and erosion protection equivalent cost)		$13,000,000	$11,000,000
Environmental *		$0	$0
Social/Recreation *		$0	$0
	Total value of floodplain	$16,800,000	$14,300,000
Part 2			
200-year flood protection costs[1]			
Storage of flood water (diking)		$0	$0
O&M storage (diking)		$0	$0
Erosion effects mitigation (erosion control plus damages)		$0	$0
O&M erosion mitigation (erosion control)		$0	$0
200-year flood-damage costs[1]			
Damage repair (water levels) —private infrastructure		-$2,000,000	-$1,000,000
Damage repair (water levels) — private land flood		-$1,000,000	-$500,000
Damage repair (erosion) — private land and infrastructure damage		-$5,000,000	-$1,500,000
Damage repair (general) — social		-$3,000,000	-$500,000
Damage repair (water level) — public infrastructure		-$3,000,000	-$1,000,000
Damage repair (water level) — public land		-$800,000	-$300,000
Damage repair (erosion) — public land and infrastructure damage		-$500,000	-$100,000
	Total cost of scenario	-$15,300,000	-$4,900,000
Net benefit = total value of floodplain — total cost including damage and protection		$1,500,000	$9,400,000
Notes:			
	* Value not included not associated with grey infrastructure or materials		
	1. 200-year costs should be replaced with annual average damage costs or costs over design life of project		

Assessment 2:

Table 1: Hypothetical analysis to guide floodplain management and development			
Items (value of equivalent service or costs of flooding)		Assessment 2: Modelling Scenario 2 upstream of city, no change in city	
Part 1		**Semi-urban**	**Rural floodplain**
Value of equivalent grey infrastructure to achieve natural function			
Stormwater quality/quantity (point and non-point source)		$3,000,000	$2,500,000
Groundwater recharge/stored for use		$800,000	$800,000
Storage of flood water (based on diking and erosion protection equivalent cost)		$14,300,000	$12,100,000
Environmental *		$0	$0
Social/Recreation *		$0	$0
	Total value of floodplain	$18,100,000	$15,400,000
Part 2			
200-year flood protection costs[1]			
Storage of flood water (diking)		$0	$0
O&M storage (diking)		$0	$0
Erosion effects mitigation (erosion control plus damages)		$0	$0
O&M erosion mitigation (erosion control)		$0	$0
200-year flood damage costs[1]			
Damage repair (water levels) — private infrastructure		-$2,200,000	-$1,100,000
Damage repair (water levels) — private land flood		-$1,100,000	-$550,000
Damage repair (erosion) — private land and infrastructure damage		-$5,500,000	-$1,650,000
Damage repair (general) — social		-$3,000,000	-$500,000
Damage repair (water level) — public infrastructure		-$3,300,000	-$1,100,000
Damage repair (water level) — public land		-$880,000	-$330,000
Damage repair (erosion) — public land and infrastructure damage		-$650,000	-$130,000
	Total cost of scenario	-$16,630,000	-$5,360,000
Net benefit = total value of floodplain - total cost including damage and protection		$1,470,000	$10,040,000
Notes:			
	* Value not included not associated with grey infrastructure or materials		
	1. 200-year costs should be replaced with annual average damage costs or costs over design life of project		

Assessment 3:

Table 1: Hypothetical analysis to guide floodplain management and development			
Items (value of equivalent service or costs of flooding)		Assessment 3: Modelling Scenario 2 upstream and within city (dikes and erosion protection installed)	
Part 1		**Semi-urban**	**Rural floodplain**
Value of equivalent grey infrastructure to achieve natural function			
Stormwater quality/quantity (point and non-point source)		$1,000,000	$1,000,000
Groundwater recharge/stored for use		$0	$0
Storage of flood water (based on diking and erosion protection equivalent cost)		$1,300,000	$1,100,000
Environmental *		$0	$0
Social/recreation *		$0	$0
	Total value of floodplain	$2,300,000	$2,100,000
Part 2			
200-year flood protection costs[1]			
Storage of flood water (diking)		-$8,000,000	-$7,000,000
O&M storage (diking)		-$1,600,000	-$1,400,000
Erosion effects mitigation (erosion control plus damages)		-$5,000,000	-$4,000,000
O&M erosion mitigation (erosion control)		-$1,000,000	-$800,000
200-year flood damage costs[1]			
Damage repair (water levels) — private infrastructure		-$800,000	-$400,000
Damage repair (water levels) — private land flood		-$400,000	-$200,000
Damage repair (erosion) — private land and infrastructure damage		-$2,000,000	-$600,000
Damage repair (general) — social		-$1,000,000	-$200,000
Damage repair (water level) — public infrastructure		-$1,200,000	-$400,000
Damage repair (water level) — public land		-$320,000	-$120,000
Damage repair (erosion) — public land and infrastructure damage		-$260,000	-$52,000
	Total cost of scenario	-$5,980,000	-$1,972,000
Net benefit = total value of floodplain - total cost including damage and protection		-$3,680,000	$128,000
Notes:			
	* Value not included not associated with grey infrastructure or materials		
	1. 200-year costs should be replaced with annual average damage costs or costs over design life of project		

Assessment 4:

Table 1: Hypothetical analysis to guide floodplain management and development			
Items (value of equivalent service or costs of flooding)		Assessment 4: Modelling Scenario 2 upstream and Scenario 5 within city (adaptive dikes and minimal erosion protection installed)	
Part 1		**Semi-urban**	**Rural floodplain**
Value of equivalent grey infrastructure to achieve natural function			
Stormwater quality/quantity (point and non-point source)		$3,000,000	$2,500,000
Groundwater recharge/stored for use		$800,000	$800,000
Storage of flood water (based on diking and erosion protection equivalent cost)		$11,700,000	$9,900,000
Environmental *		$0	$0
Social/recreation *		$0	$0
	Total value of floodplain	$15,500,000	$13,200,000
Part 2			
200-year flood protection costs[1]			
Storage of food water (diking)		-$3,200,000	-$700,000
O&M storage (diking)		-$640,000	-$140,000
Erosion effects mitigation (erosion control plus damages)		-$2,500,000	-$2,000,000
O&M erosion mitigation (erosion control)		-$500,000	-$400,000
200-year flood damage costs[1]			
Damage repair (water levels) — private infrastructure		-$880,000	-$440,000
Damage repair (water levels) — private land flood		-$440,000	-$500,000
Damage repair (erosion) — private land and infrastructure damage		-$2,200,000	-$660,000
Damage repair (general) — social		-$1,000,000	-$200,000
Damage repair (water level) — public infrastructure		-$1,320,000	-$880,000
Damage repair (water level) — public land		-$352,000	-$132,000
Damage repair (erosion) — public land and infrastructure damage		-$390,000	-$78,000
	Total cost of scenario	-$6,582,000	-$2,890,000
Net benefit = total value of floodplain - total cost including damage and protection		$8,918,000	$10,310,000
Notes:			
	* Value not included not associated with grey infrastructure or materials		
	1. 200-year costs should be replaced with annual average damage costs or costs over design life of project		

Assessment 5:

Table 1: Hypothetical analysis to guide floodplain management and development			
Items (value of equivalent service or costs of flooding)		Assessment 5: Modelling Scenario 5 upstream and city (adaptive dikes, minimal erosion protection, floodplain conservation	
Part 1		**Semi-urban**	**Rural floodplain**
Value of equivalent grey infrastructure to achieve natural function			
Stormwater quality/quantity (point and non-point source)		$3,000,000	$2,500,000
Groundwater recharge/stored for use		$800,000	$800,000
Storage of flood water (based on diking and erosion protection equivalent cost)		$11,700,000	$9,900,000
Environmental *		$0	$0
Social/recreation *		$0	$0
	Total value of floodplain	$15,500,000	$13,200,000
Part 2			
200-year flood protection costs[1]			
Storage of flood water (diking)		-$1,280,000	-$70,000
O&M Storage (diking)		-$256,000	-$14,000
Erosion effects mitigation (erosion control plus damages)		-$500,000	-$400,000
O&M erosion mitigation (erosion control)		-$100,000	-$80,000
200-year flood damage costs[1]			
Damage repair (water levels) — private infrastructure		-$320,000	-$160,000
Damage repair (water levels) — private land flood		-$160,000	-$500,000
Damage repair (erosion) — private land and infrastructure damage		-$800,000	-$240,000
Damage repair (general) — social		-$1,000,000	-$200,000
Damage repair (water level) — public infrastructure		-$480,000	-$320,000
Damage repair (water level) — public land		-$128,000	-$96,000
Damage repair (erosion) — public land and infrastructure damage		-$156,000	-$31,200
	Total cost of scenario	-$3,044,000	-$1,547,200
Net benefit = total value of floodplain - total cost including damage and protection		$12,456,000	$11,652,800
Notes:			
	* Value not included not associated with grey infrastructure or materials		
	1. 200-year costs should be replaced with annual average damage costs or costs over design life of project		

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