Don Mouth Naturalization And Port Lands Flood Protection Project

Appendix N

Hydrodynamic and Sediment Transport Modelling Memorandums

N-1 Hydrodynamic Modelling Technical Memorandum

N-2 Sediment Transport Modelling Technical Memorandum

N-3 Supplemental Technical Memorandum

Toronto and Region Conservation for The Living City

WATERFRONToronto

TORONTO

Don Mouth Naturalization And Port Lands Flood Protection Project

N-1 Hydrodynamic Modelling Technical Memorandum

Toronto and Region Conservation for The Living City

WATERFRONToronto

TORONTO

www.baird.com

Baird

oceans
engineering
lakes
design
rivers
science
watersheds
construction

Don Mouth Naturalization Project
Hydrodynamic Modelling Technical Memorandum

28th June 2010
10713.000

Navigating New Horizons

Don Mouth Naturalization Project

Hydrodynamic Modelling Technical Memorandum

Prepared for

Toronto and Region Conservation

Prepared by

Baird

W.F. Baird & Associates Coastal Engineers Ltd.

For further information please contact
Alex Brunton at (905) 845-5385

Project Number

Revision	Date	Status	Comments	Reviewed by	Approved by
0	28 June 2010	Final	Final HD Memo	DAB	DAB

TABLE OF CONTENTS

1.0 STUDY BACKGROUND

Detailed two and three dimensional hydraulic modelling of the Lower Don River is being undertaken as part of the Don Mouth Naturalization and Port Lands Flood Protection Environmental Assessment (DMNP EA). This EA establishes the preferred alignment and treatment of the Don River from Riverdale Park down to its new outlet into the inner harbour, with a particular focus on the area downstream from the CNR Kingston Rail Bridge. The overall EA includes assessment of both the naturalization design requirements as well as the hydraulic requirements to contain and convey the regulatory flood through the Lower Don River reach from just north of the CN Bridge to its new outlet. In addition, the EA includes development of methodology and physical requirements for managing deposited sediment (for the purposes of flood containment), while being cognizant of the West Don Lands flood protection works.

This technical memo presents the results of the 2-D and 3-D hydrodynamic modelling using the Delft3D model to evaluate the existing conditions in the study area, and the preferred alternative that was selected through the evaluation of alternatives stage (Alternative 4WS) and has since been refined . The scope of this study is limited to examination of river flooding, and it excludes other forms of urban flooding, such as that due to surcharge of the storm water sewer system. The preferred alternative presented in the EA sets the channel widths, depths, levels of adjacent fills and the hydraulic capacity requirements of the new valley and low flow channel system. In addition, the general dimensions of the bridge structures which are required to meet the goal of containing and conveying flood waters are assessed. The final model reflects channel modifications, as well as grading modifications related to the Don Roadway connections to the Don Valley Parkway as well as other minor grading changes to allow for the containment of the regulatory flood through the reach from the CNR Kingston Line to a modified Lake Shore Blvd. bridge. For the purposes of the EA, the Gardiner ramps and piers have been modelled in terms of their existing location and their hydraulic impacts.

The DMNP EA also identifies the sediment and debris management requirements for the Don River. These include both management techniques, physical aspects of any in river sediment trap and all ancillary features necessary to ensure functional needs including any associated infrastructure. The sediment transport characteristics of the preferred alternative are currently being evaluated using the Delft model, and the results of this will be used as input to the functional design stage of the project.

1.1 Study Area

The study area encompasses the Lower Don River and Port Lands in Toronto, from Riverdale Park to the mouth of the Don in the Inner Harbour at Toronto. The Project Study Area for the DMNP EA was originally defined in the ToR as follows:

> *The Project Study Area consists of two parts: the Don Mouth from the CN railway bridge to the harbour/lake and lands adjacent to the Lower Don River, and the Don Narrows from the CN railway bridge north to Riverdale Park[1]. Within the Don Narrows, only improvements within the river channel are to be considered. The Project Study Area is the area in which project components will be constructed and operated and the area in which we are proposing alternatives. Therefore, it is in this area that the majority of the direct effects will occur. The Project Study Area is constrained by fixed infrastructure such as roads and rail lines, the result of the Lower Don River West Remedial Flood Protection Project, and opportunities for reuse of the land as identified by other planning studies and initiatives. The lands east of Parliament Street and south of Lake Shore Boulevard, commonly known as the 'Home Depot lands', and the small quay at the entrance to the Keating Channel have been included to ensure that there is sufficient area to look at options for the Don Mouth. A 300-m wide corridor immediately west of and parallel to the Don Roadway, which includes the area for the proposed Don Greenway, connects the Keating Channel to the Ship Channel to address previously identified alignments for the Don River.*

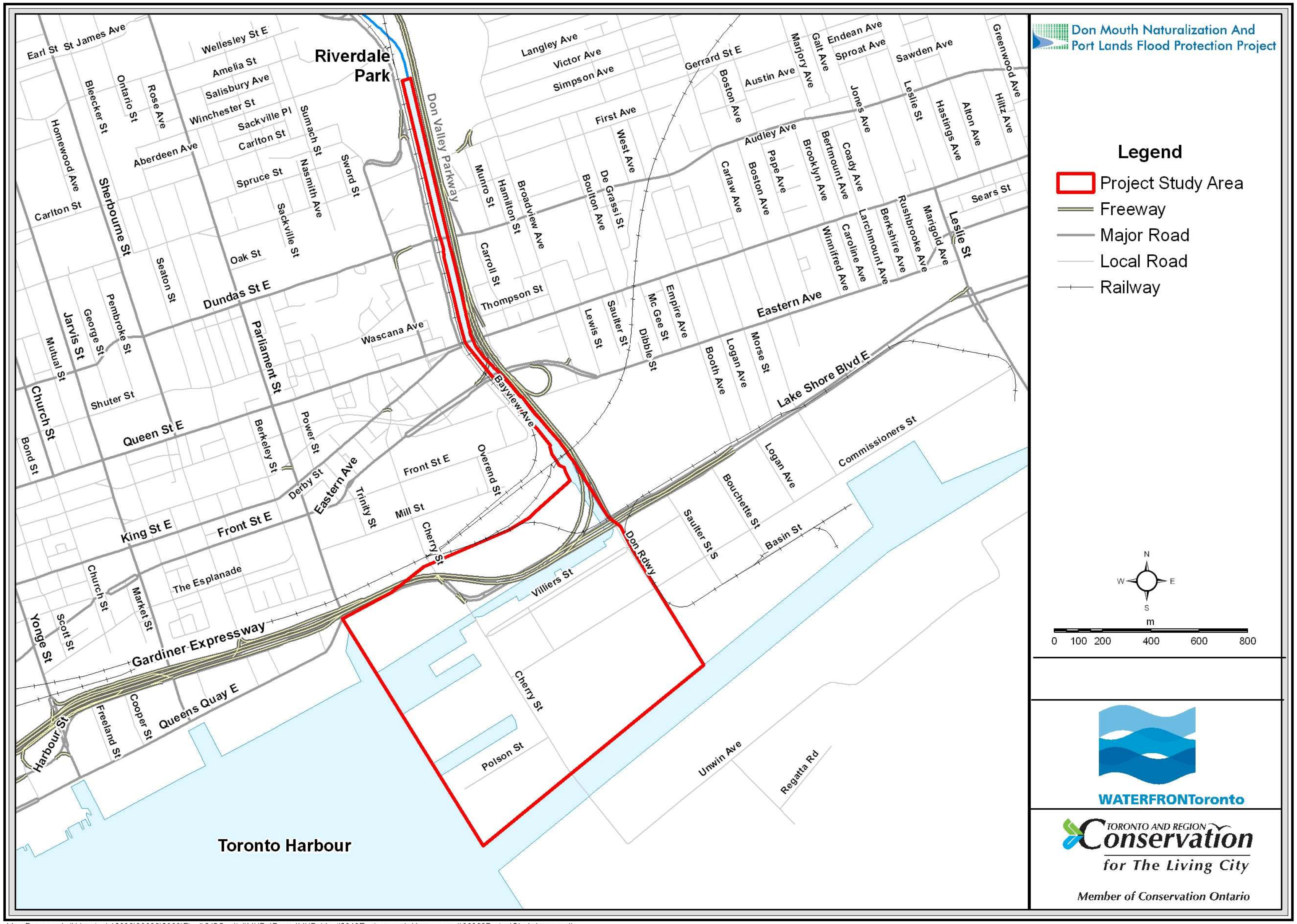
During the Design Competition, the four design teams recognized the need to expand the Project Study Area for the integration of the river mouth within built communities along with the necessary infrastructure. This change was supported by Waterfront Toronto, TRCA and the City; therefore, the Project Study Area for the DMNP EA was revised to reflect the more diverse integration opportunities available once a broader area is considered.

All four design teams considered the area bordered by the Don Rail Yard to the north, the Don Roadway to the east, the Inner Harbour to the west, and the northern edge of the Ship Channel to the south to be the area in which the naturalized river mouth, new communities and infrastructure need to be integrated together. Within this area the plans put forward included the naturalized river mouth, the development of a prescribed number of residential units, employment areas, recreational facilities, community facilities, transit, and commercial and retail areas.

Given the recognition of the need for integration within the larger area, the Project Study Area (Figure 1) for the DMNP EA was revised and presented to the public at Public Forum No. 2 in March, 2008. The Don Narrows remains as part of the Project Study Area. The area defined as the Don Mouth was revised to be an area envelope available for naturalization assuming that all of the other components of the urban fabric would be provided around this envelope. It is also noted that, as a result of the design competition, some of the infrastructure previously constraining the Project Study Area and opportunities for naturalization might be moved or reoriented, thus removing the constraint. For this study, the hydrodynamic modelling extended beyond the project study area to include the potential flood spill zone as far east as Leslie Street.

---

[1] This hydrodynamic study considers the Don Narrows to be the river from Riverdale Park to Lake Shore Boulevard as physical conditions are similar throughout this reach



Map Document: (N:\projects\2009\90066\2009\Final\GISSpatial\MXDs\ReportMXDs\April2010EnvironmentalAssessment\90066ProjectStudyArea.mxd)

Figure 1: Study Area

The river channel is situated at the outlet of a highly-urbanized watershed, and during the late 19th and early-middle 20th century, the river throughout the study area was straightened and constrained between engineered banks. The section of the river from Riverdale Park to Lake Shore Boulevard is known as the Don Narrows, and south of Lake Shore Boulevard to the channel outlet is known as the Keating Channel (Figure 2).

The hydrology of the watershed is typical of an urban watershed in Southern Ontario. The river experiences a spring freshet in March-April, and summer low flows interspersed with convective rainstorms (Figure 3). However, Figure 4 depicts how the seasonality of major run off events is no longer as pronounced due to the urbanization of the watershed. The majority of peak flows occurred during freshet up to the 1960s, but with the development of the headwaters of the watershed over the past decade and a half, peak events are now distributed more throughout the year. Analysis of the gauge data at Todmorden, the closest flow gauge to the site, estimates the mean daily flow at 3-4 m^3/s (Figure 5). The flows associated with key return periods to be evaluated by this study were provided by TRCA, and they are summarized in Section 2.

There are several bridge crossings over the existing channel. The key bridges to be evaluated as part of this study are the CNR Kingston Railway Bridge ('CN Bridge') and the Lake Shore Boulevard Bridge ('Lake Shore'). The ramps and piers from the Gardiner Expressway serve to modify flow south of CN Bridge, and these were included in the existing and design conditions models. Other structures were excluded from the models at this stage, as the design focused on modifications south of the CN Bridge. These included the old and new Eastern Avenue Bridges, and the Queen, Dundas and Gerrard Street Bridges. The known impediments to flood flow downstream from the CN Rail Bridge are:

- CN Rail Bridge;
- Utility Bridge;
- Gardiner Expressway ramps and piers;
- Lake Shore Boulevard road and Harbour Lead rail crossing (to Keating Yard);
- 90 degree bend at the upstream end of the Keating Channel.

The floodplain in the study area has been inundated many times over the past 100 years, and numerous structures in the floodplain modify this pattern. The Don Valley Parkway to the east of the channel is embanked through the upper section of the study area, but it is flooded on approximately the 2-year flow in the lower section near the CN Bridge. On the west side of the river, Bayview Avenue, Don Trail, and the Belleville/Bala Subdivisions are flooded on slightly higher flood events, and while the precise flow at which this happens has not yet been established, it occurs during the 2-5 year return period event.

Figure 2: Study Area

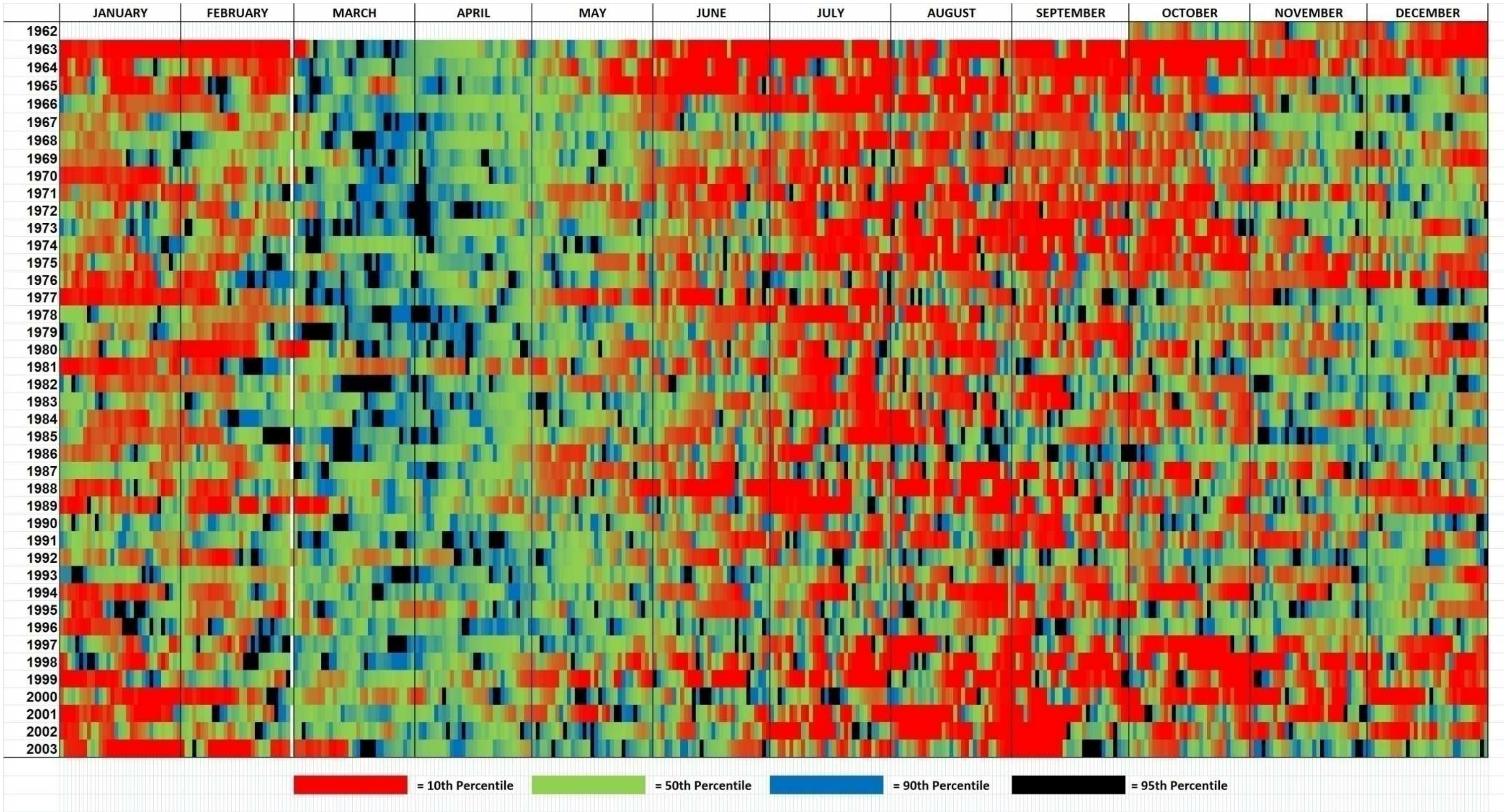


Figure 3: Seasonal Flow Variation in the Don River at Todmorden

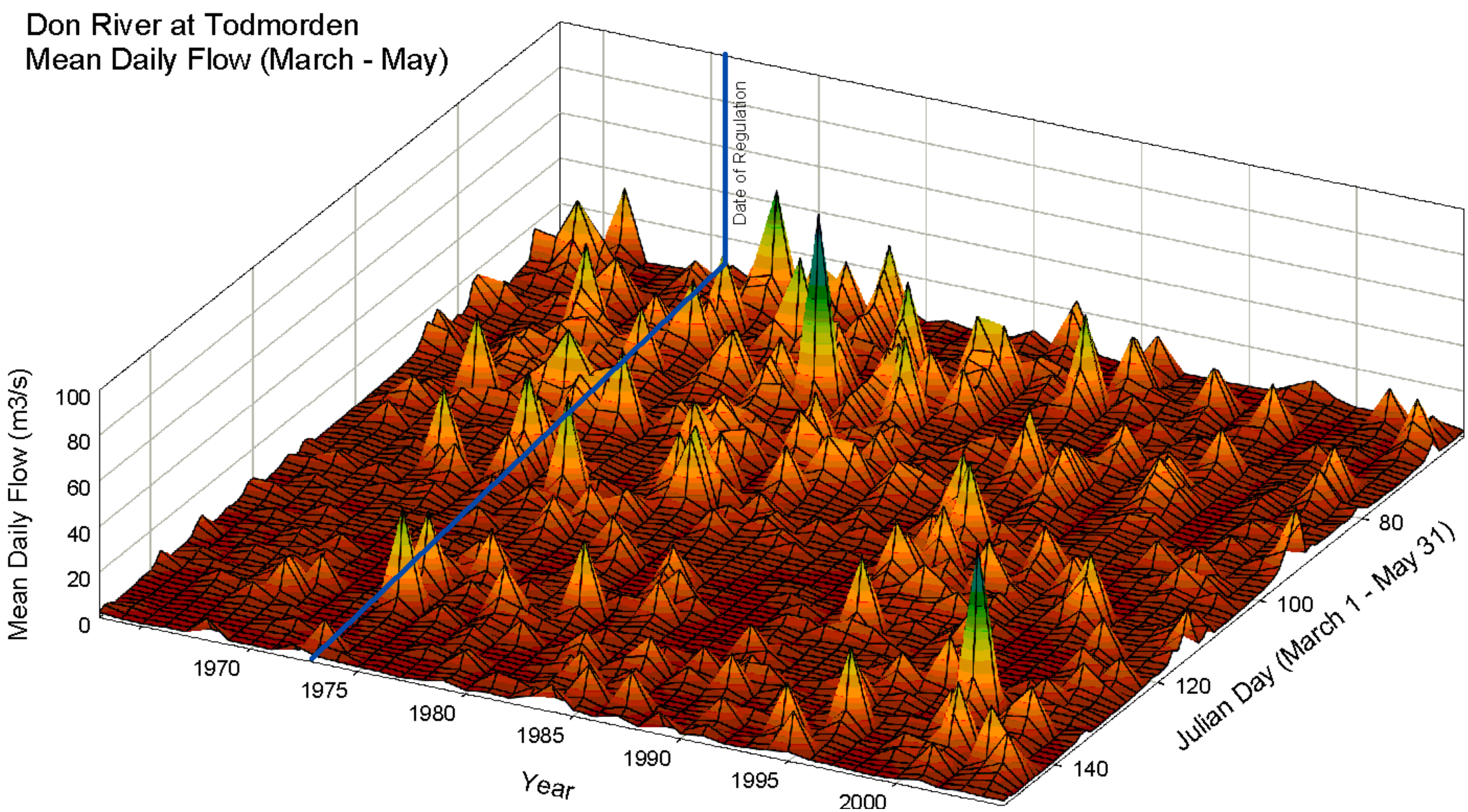


Figure 4: Changes in Spring Flow in the Todmorden Gauge Data (Source: TRCA, pers. comm.)

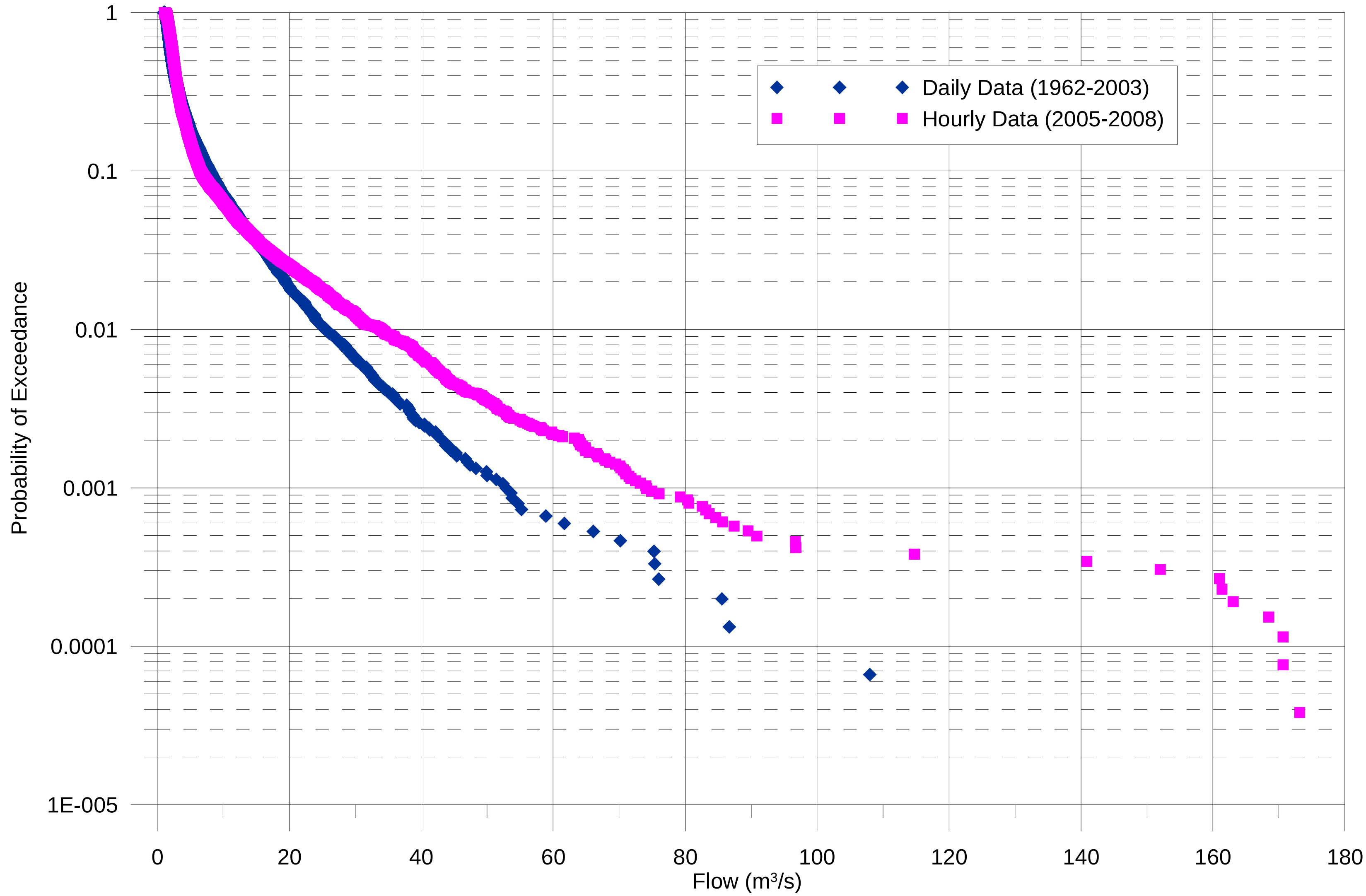


Figure 5: Probability of Exceedance Analysis for Flow in the Don River at Todmorden

2.0 METHODOLOGY

The numerical modelling was split into two stages: evaluation of existing conditions (EC) and evaluation of the preferred alternative. This section describes the Delft3D model then gives details of the two stages of numerical modelling.

2.1 Delft3D

The Delft 3D model was selected for use on this project. Delft 3D is a three-dimensional hydrodynamic model developed by Delft Hydraulics in the Netherlands. The model uses a curvilinear grid system, which is suitable for the shoreline boundary conditions in a meandering river system as found in the preferred alternative for this project. Since the shoreline in the study is complex, using a rectangular grid may cause numerical errors near the shoreline or require a very fine mesh size to model the shoreline irregularities. A model with a flexible grid is therefore required for this study.

A license for the Delft 3D hydrodynamic and sediment transport modules was purchased by Toronto and Region Conservation for this project. The model has additional modules that were not utilized in this phase of the work, but could be considered for future applications including: waves, structures, water quality and ecology.

2.2 Model Setup and Calibration

2.2.1 Existing Conditions Model Grid

The Delft 3D hydrodynamic model was set up to evaluate flooding under the regulatory flood. Due to model stability issues under the regulatory flow, the 2-D version of the model was used with a fine resolution model grid. Several versions of the model grid were set up to evaluate flow through the study area. The grid presented in this report represents the overall model grid of the Lower Don River, from an upstream boundary north of Dundas Street, to a southern boundary on the south side of the Ship Channel. The domain extends from the inner harbour in the west to Leslie Street in the east (Figure 6). A different grid, extending to a boundary upstream from Riverdale Park was used to evaluate flow and potential enhancement options in the Don Narrows (reported separately).

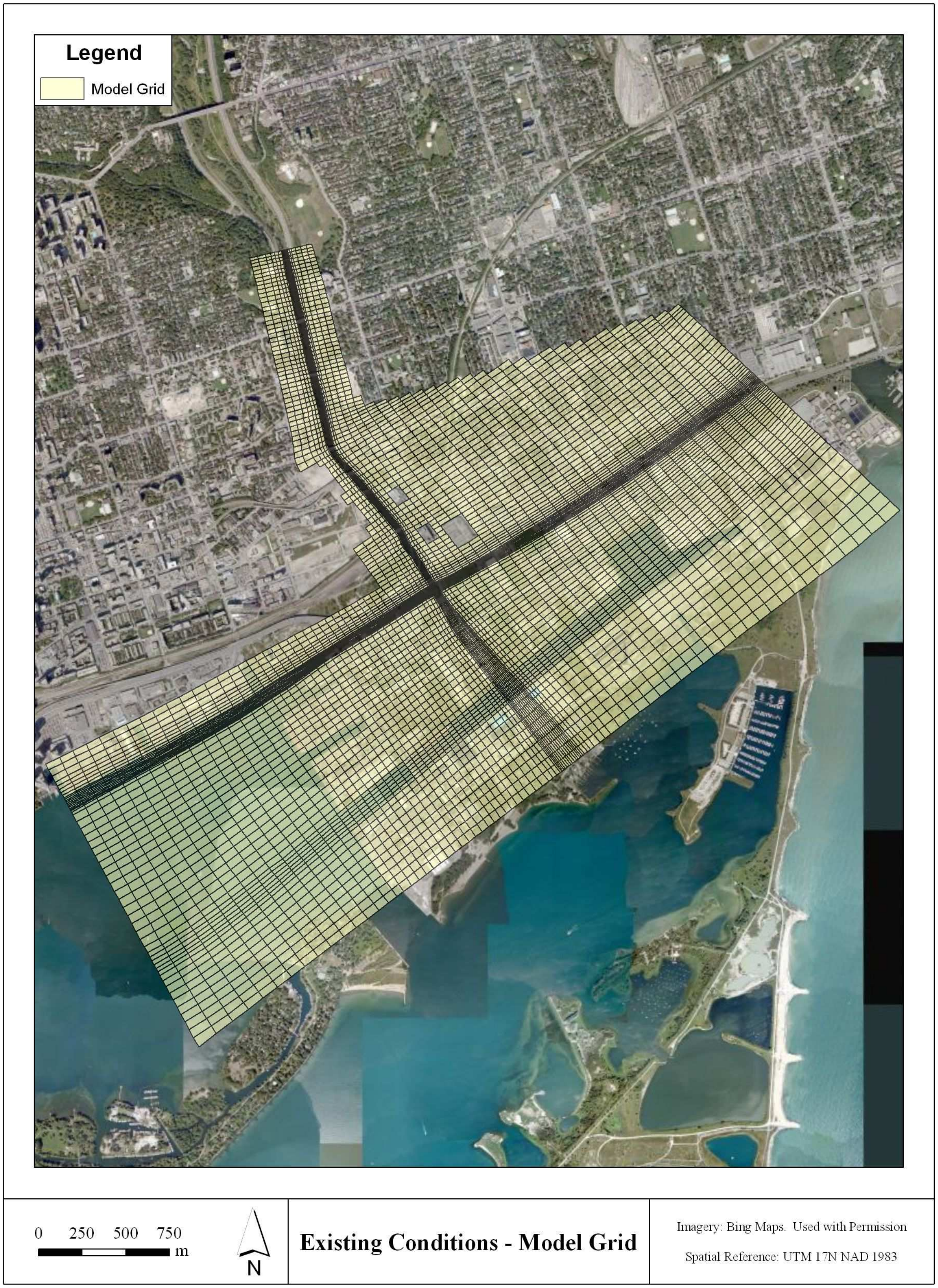


Figure 6: Existing Conditions Model Grid

2.2.2 Existing Conditions Model Bathymetry

The bathymetry for the existing conditions model was derived from a wide variety of sources, including survey data, digital elevation model data, channel bathymetric survey data, and survey data from channel and floodplain structures. The data were integrated into a single GIS layer of point data. The point data were then imported into the Delft3D model and interpolated to the model node points using an 'average value of near points' routine, which gave the best 'fit' of model bathymetry to the elevation data (i.e. the lowest residual difference between them).

Key aspects of the existing conditions model bathymetry are:

- The Keating channel post-dredge bathymetry for 2007 was used for the Regulatory Flood model;
- The West Don Lands Flood Protection Landform (FPL) (Draft) which was included in the model bathymetry;
- The CN Rail Bridge piers and embankments, the Gardiner ramps, Gardiner ramp piers, and the Lake Shore Boulevard piers were represented as dry cells in the model grid;
- Large buildings in the floodplain that were represented as dry cells in the model;
- The existing channel bathymetry as surveyed and supplied by TRCA upstream from the CN Rail Bridge, and surveyed spot levels from the Unilever site downstream from the CN Rail Bridge;
- The 30 m provincial DEM east of the Don Roadway to Leslie Street; and
- The Inner Harbour bathymetry which was digitized from chart data.

Figure 7 shows the final bathymetric layout of the Existing Conditions Model.

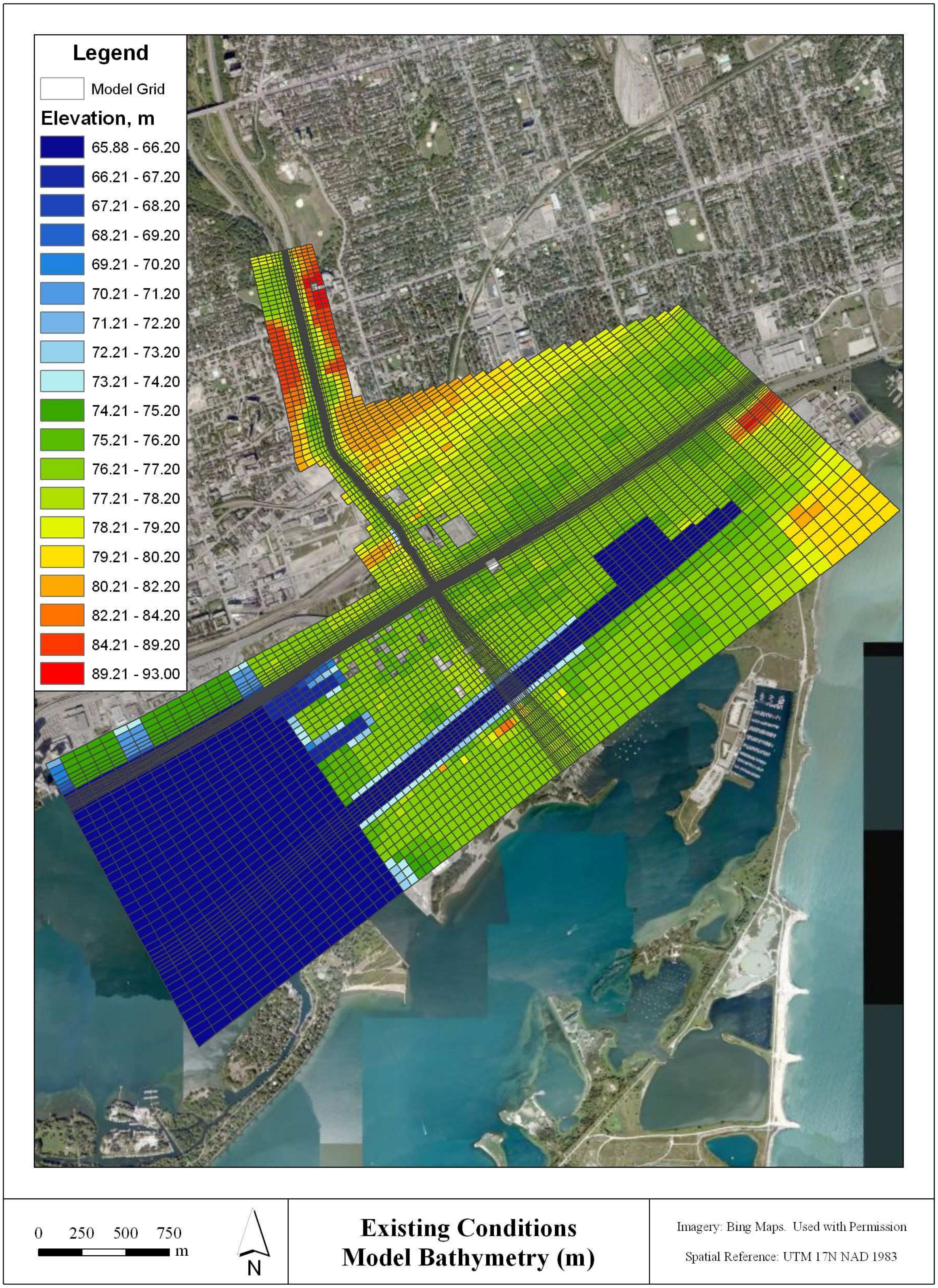


Figure 7: Existing Conditions Model Bathymetry

2.2.3 Preferred Alternative Model Grid

The Delft 3D hydrodynamic model was set up to evaluate flood conveyance by the preferred alternative under the regulatory flood. Due to model stability issues under the regulatory flow, the 2-D version of the model was used with a fine resolution model grid. However, both the 2-D and the 3-D model were used to evaluate flow conveyance for flows below the 100 year return period.

Several versions of the model grid were set up to evaluate flow through the study area. These different grids were used to evaluate several minor changes to the proposed channel configuration. These changes focused around modifications to the channel between the CN Bridge and Lake Shore Boulevard, modifications to the weirs at the upstream end of the Keating Channel, and modifications to the proposed natural channel systems and the proposed revitalization of the Keating Channel. A full summary and analysis of all these model runs is beyond the scope of this technical memo.

The grid presented in this memo represents the final model grid of the preferred alternative for the DMNP, from approximately Queen Street upstream, south to a boundary on the south side of the Ship Channel. The domain extends from the inner harbour in the west to the Don Roadway in the east (Figure 8).

2.2.4 Preferred alternative Model Bathymetry

The bathymetry for the preferred alternative model was again derived from a wide variety of sources. The key input to the bathymetry of the most recent bathymetry model was supplied by Limnotech Ltd. in March 2010. Limnotech Ltd. is a member of Michael Van Valkenburg Associates (MVVA) design team for the Lower Don Lands. This bathymetry included the proposed channel and valley system, which was then burned into the existing bathymetry for the surrounding area (Figure 9). The data were integrated into a single GIS layer of point data. The point data were then imported into the Delft3D model and interpolated to the model node points using an 'average value of near points' routine.

Key aspects of the preferred alternative model bathymetry are:

- The model bathymetry was supplied by Limnotech Ltd.;
- The West Don Lands FPL (Draft) was included in the model bathymetry;
- The CN Rail Bridge piers and embankments, the Gardiner ramps, Gardiner ramp piers, and the Lake Shore Boulevard piers were represented as dry cells in the model grid;

Figure 8: Preferred Alternative Model Grid Layout

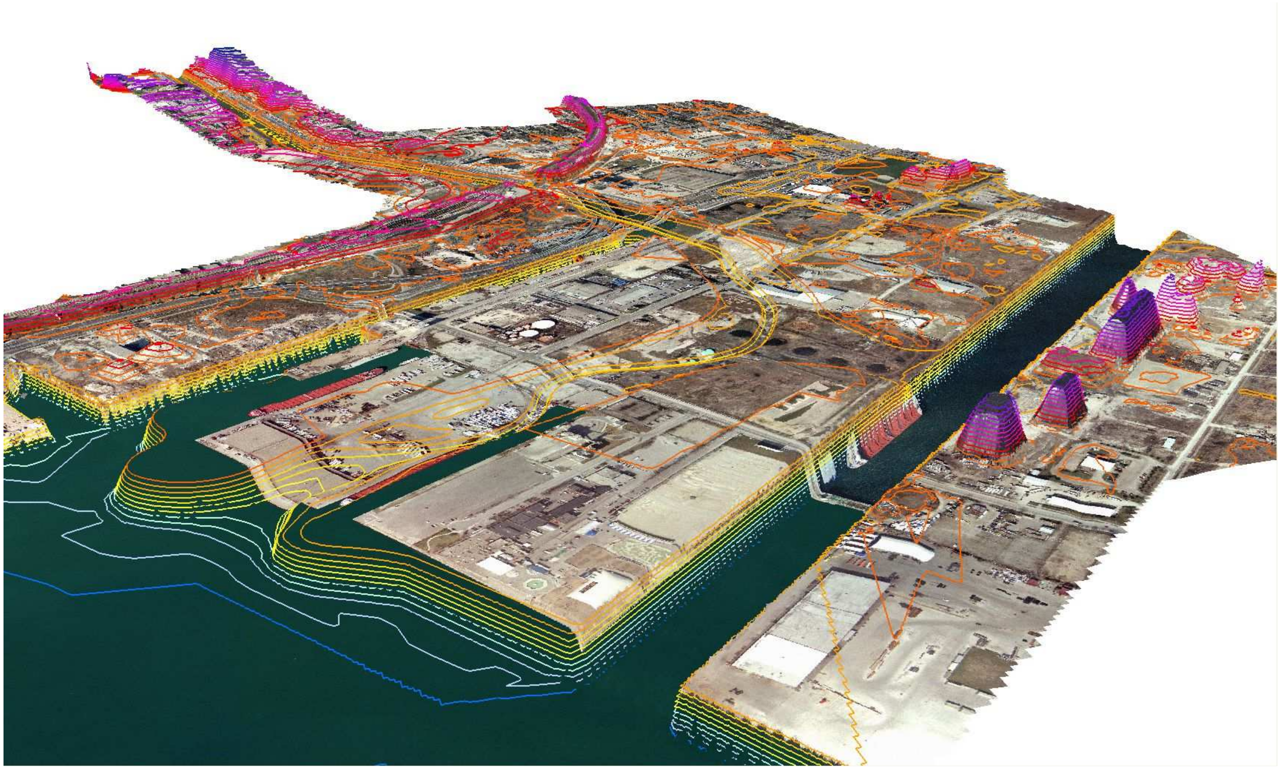


Figure 9: Visualization of Model Bathymetry Burned Into Floodplain Bathymetry

- The existing channel bathymetry was surveyed and supplied by TRCA upstream from the CN Rail Bridge, and surveyed spot levels from the Unilever site downstream from the CN Rail Bridge;

- The Inner Harbour bathymetry was digitized from chart data.

- The sediment trap which was set at a level of 71.6 m (the existing level underneath Lake Shore Boulevard) – i.e. the trap is assumed to be full. The implications of this are discussed in Section 4;

- For evaluation of conveyance of the regulatory flow, the weirs at the upstream end of the Keating Channel are set to their 'default' position. This configuration has a height of 71.6 m for the upstream weir (this weir is assumed to be adjustable, and it would default to be in the 'down' position to maximise flood conveyance), and a height of 75.25 m for the fixed, side-spill weir. These are referred to as the 'default' runs;

- A separate set of runs were undertaken to evaluate how flow is split by the weirs when they are actively used to balance flows between the Keating Channel and the naturalized channel system. This aims to direct low flows to the naturalized area to maintain river and riparian habitat. For flows at and below the 100-year return period flow, the weirs were assumed to be, at a level of 75.25 m, directing more flow to the natural channel system than would occur if the upstream weir was in the default position. These are referred to as the 'adaptive' runs;

- For flows below the 100-year return period, no scour was assumed to take place beneath the CN Bridge;

- For flows above the 100-year return period, up to the regulatory flow, the channel was assumed to scour to a depth of 70.0 m. This is likely a very conservative estimate of scour, and the implications of this are discussed in Section 4.

Figure 10 shows the final bathymetric layout of the preferred alternative model.

2.2.5 Boundary Conditions

The boundary conditions for both models were identical. The regulatory flow hydrograph supplied by TRCA was used as the upstream boundary input. This hydrograph was also used to evaluate flows at lower return periods by extracting the time step from model output that was associated with a flow of a particular return period. While this does not provide an analysis of the flood hydrograph associated with each return period, it gives an approximation of the peak flow associated with each return period. This is thought to be sufficient for the purposes of this EA, where the critical design configuration is that associated with regulatory flow conveyance. Table 1 summarizes the flows and return periods summarized in this memo. A lake level of 75.2 m, approximately the 2-year return period lake level without surge (Table 2), or the June (summer high) lake level with a probability of exceedance of 25 %, was used at the downstream lake boundary (Figure 11). This is elevated over the mean lake level in the area of 74.7 m, and it was selected to provide a slightly conservative estimate of flood conveyance, and is consistent with the TRCA flood plain mapping initial conditions at the Lake for all rivers and streams mapped.

Table 1: Summary of Flows and Return Periods in Model Runs

Flow (m^3/s)	Return Period (years)	Time on Hydrograph (hh:mm)
160	2	04:30
291	10	05:40
369	25	06:25
492	100	07:10
1694	Regulatory	12:15

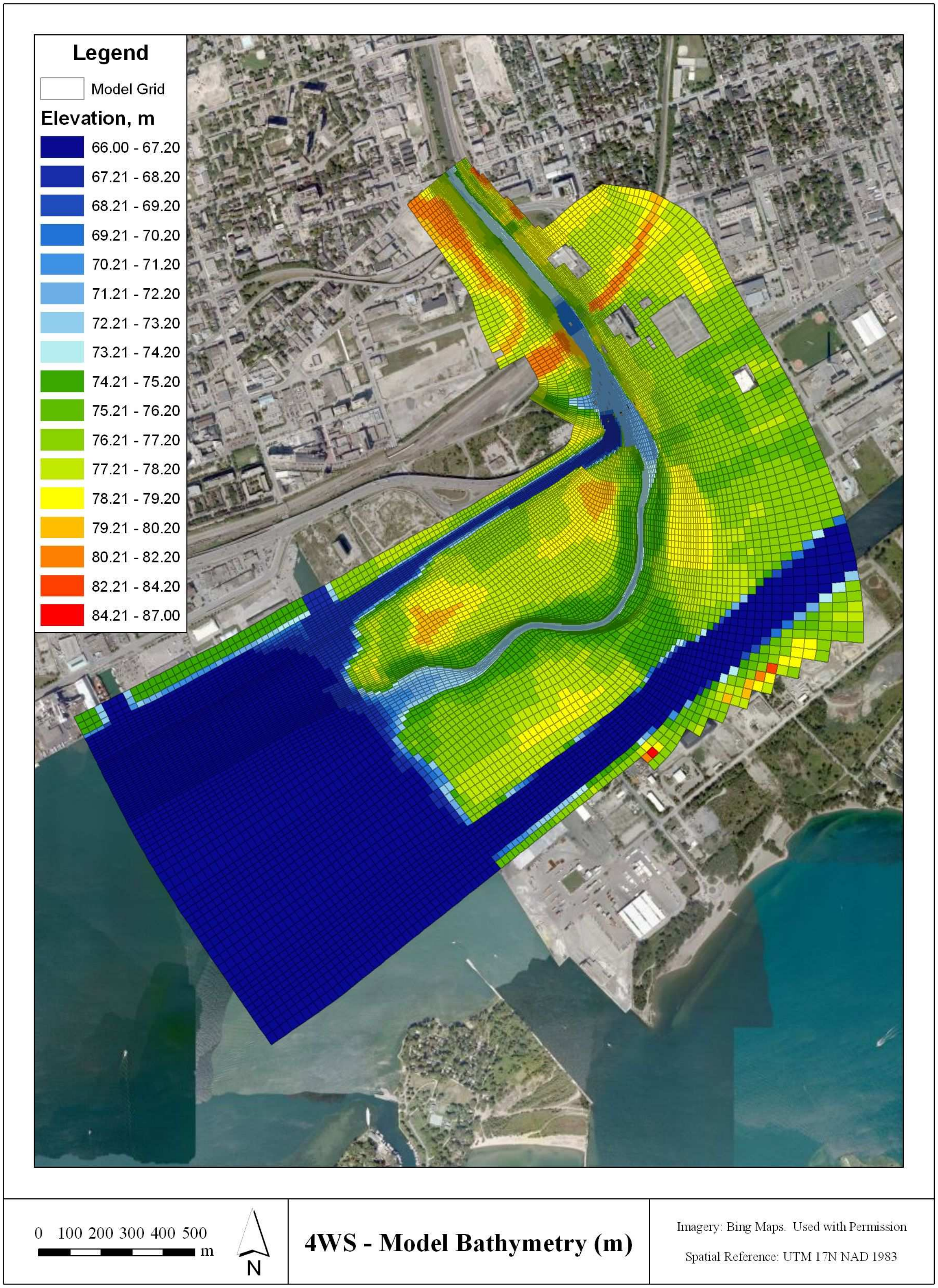


Figure 10: Preferred Alternative Bathymetry – 'Default' Runs

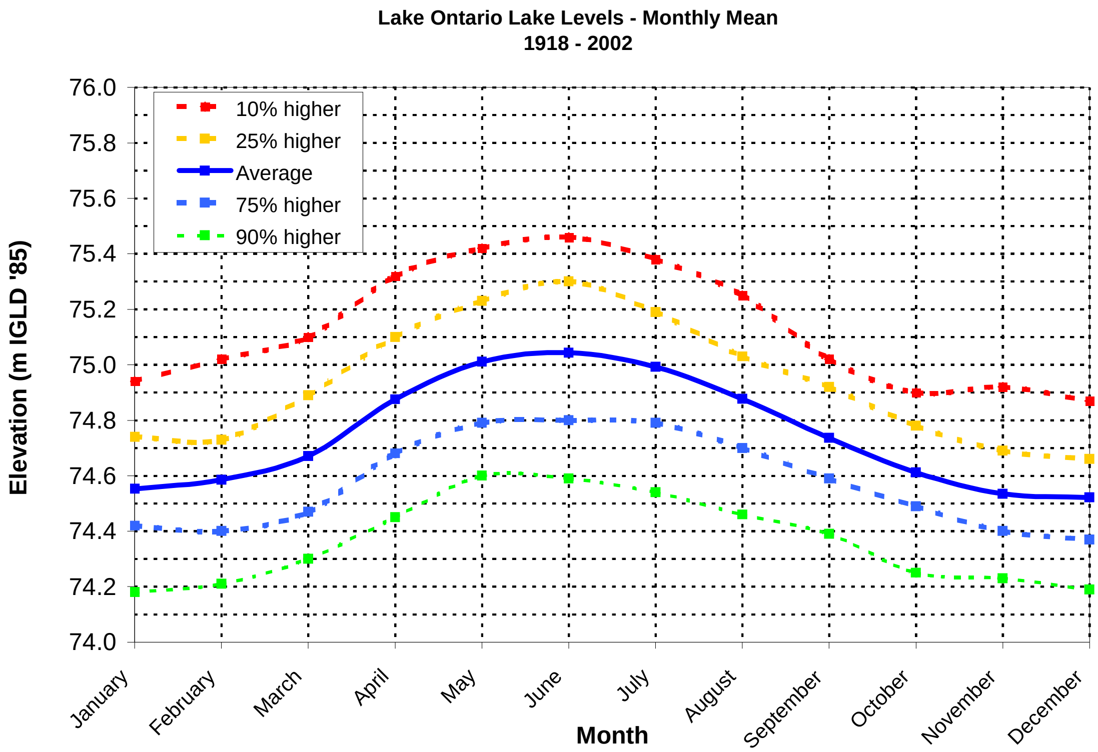


Figure 11: Summary of seasonal variations in Lake Ontario Lake Levels

Table 2: High Water Levels as a Function of Return Period (IGLD 1985)

Period	Water Level (m)	Return Period (years) 2	10	25	50	100
Full Year	Static	75.2	75.47	75.62	75.73	75.84
	Surge		0.22 m	0.24 m	0.25 m	0.26 m
	Combined		75.64	75.78	75.89	75.99
Peak Season	Static		75.46	75.59	75.68	75.76
	Surge		0.17 m	0.19 m	0.20 m	0.21 m
	Combined (swl)		75.58	75.71	75.80	75.87

2.2.6 Model Calibration

Calibration of the model was undertaken using measured flow speed data. These data were only available for one day of low flow, and they were collected by Baird in Spring 2010. No additional field data were collected for the hydrodynamic portion of this project. The low flow data were compared to low flow model runs of existing conditions undertaken as part of the Coxwell Sewer Rehabilitation Project, which was the closest model configuration to conditions on the day of survey. This model showed a good agreement with field data using a Manning Roughness of 0.035, and this value was used up to the 100-year return period flow event. This value of roughness is thought to be an over-estimate for the regulatory flow, since the bed is highly mobile and scour will remove bed roughness elements such as bars and ripples/dunes. In addition, flow resistance decreases with increasing flow stage (for main channel flow), and the regulatory flow run used a roughness of 0.02 to compensate for this decrease in flow resistance.

Given the lack of availability of observed velocity data, it was not possible to calibrate the flows in the flood model. The other available data were anecdotal. The existing conditions model was qualitatively evaluated for the flows at which the Don Valley Parkway and Bayview Avenue begin to be inundated, and there is good agreement with observed return periods at which this takes place. Further study is required to relate the modelled water surface elevations to surveyed water marks on bridge structures following a flood event.

The lack of observed data represents a limitation to the model at present, as it precludes further analysis of the validity of model predictions. Three methods are either currently being pursued, or are proposed for later stages of the project to mitigate this:

- A parallel modelling process is currently being undertaken with the MVVA team through Limnotech Ltd. (using the EFDC model). Comparisons between the modelled flows and water levels are being undertaken to assist in evaluating the level of uncertainty associated with the predictions of each model;

- A monitoring framework is proposed for the project, in which long-term measurements of flow are taken so the model can be calibrated (‘fine tuned’) and validated as an ongoing effort;

- An adaptive weir system is proposed in the preferred design so that the split of flood flows can be actively managed during actual events if required.

2.3 MODEL RUNS

Several model runs for both the Existing Conditions and preferred alternative scenario were set up to evaluate flow through the study area. The model runs numbered over 50 for the Existing Conditions and over 100 for the preferred alternative runs. These runs included variations in bathymetric or grid configuration in response to different design options. The preferred alternative model runs used different grids and bathymetry to evaluate several minor changes to the proposed channel configuration. These changes focused around modifications to the channel between the CN Bridge and Lake Shore Boulevard, modifications to the weirs at the upstream end of the Keating Channel, and modifications to the proposed natural channel systems and the proposed revitalization of the Keating Channel. The runs also varied physical parameters, such as roughness and eddy viscosity to determine the range of sensitivity in flow and water levels to these parameters.

There were also variations in input conditions, such as using different flow hydrographs upstream and different lake levels downstream. A full summary and analysis of the output from all of these model runs is beyond the scope of this technical memo. This memorandum presents results from Runs 10 (Regulatory Flow) and 11 (Sub-100 year flow) of the 2-D Final Existing Conditions model, and from Runs 54 (2-D Regulatory Flow) and 59 and 61 (3-D sub-100 year flow) of the preferred alternative model. Previous model runs will be made available for analysis if required during the detailed design stage of the project.

3.0 RESULTS

3.1 Existing Conditions Model Results

The Delft3D model was used to evaluate hydraulic conditions and flood flows during existing conditions. Summary maps of output from the Existing Conditions model runs under different flow conditions are contained in Appendices HD-A to HD-D. Appendix HD-A contains summary maps of water levels under different flow return periods for existing conditions. The water level maps are plotted in reference to the International Great Lakes Datum 1985 (IGLD). This appendix contains zoom maps of water levels for each flow return period in the vicinity of the CN Bridge and Lake Shore Boulevard. Appendix HD-B follows the same format, but shows predicted water depth in the study area, while Appendix HD-C and Appendix HD-D show predicted depth-averaged flow velocities and bed shear stress respectively. This section summarizes the main findings of the existing conditions model runs.

The existing channel floods across Bayview Avenue in the area upstream from the CN Rail Bridge during the 2-Year return period flow, at a discharge of approximately 160 m^3/s (Appendix HD-A-2). At this flow, the lower section of the Don Valley Parkway (DVP) begins to flood to a very low depth (see below).

At a flow of 291 m^3/s, the 10-year flow, (Appendix HD-A-4), there is conspicuous flooding on both sides of the Don Narrows, from Riverdale Park to the CN Bridge. The DVP lanes beneath the CN Bridge are now flooded, and Bayview Avenue is predominantly under water. Flow is contained within the Keating Channel, and within the region between CN Bridge and Lake Shore the water levels are elevated approximately 0.5-1.0 m over the 2-year flow levels.

During the 25-year flow, much of the DVP and Bayview Avenue alongside the Don Narrows are predicted to be subject to flooding (Appendix A-6). Flow is beginning to enter the Unilever property to the south of the CN Rail tracks and to the east of the Don Roadway. Water levels in the Don Narrows are elevated, with a spill just beginning on the south side of the Keating Channel.

During a 100-year flood (Appendix HD-A-8), the narrows are flooded, and the area alongside the east side of the West Don Lands FPL is flooded to a water level of approximately 78.2-78.7 m. The CN Bridge is causing a significant backwater, and flooding is occurring on the BMW property to the east of the DVP, north of the CNR crossing. Water is flowing around the Unilever building and flooding along Lake Shore Boulevard. Flow is also leaving the upstream end of the Keating Channel at the 90 degree bend and flowing along the Don Roadway into the Port Lands.

The Regulatory Flow causes extensive flooding throughout the study area (Appendix HD-A-10). There is significant backwatering at the CN Bridge, which causes flooding through the Eastern Avenue Underpass, through the southern part of South Riverdale and Leslieville, and as far east as Leslie Street. Water levels alongside the FPL range between 79.2-81.2 m, and show that water levels are affected by backwater behind the CN Bridge. The vast majority of the Port Lands area to the north of the Ship Channel is predicted to be under water, with flow dominantly along the roads in the area. There is also some flooding in the 480 Lake Shore Boulevard area, along the Keating Channel, east of Cherry Street.

While there is considerable flooding upstream from the CN Bridge, the West Don Lands landform is not overtopped by the regulatory flow. At the peak of the regulatory flow of 1694 m^3/s, the Unilever property floods to a depth ranging from 3.0 m upstream near the underpass below the CN rail bridge, to a depth of approximately 0.5 m with the existing conditions channel configuration. This flooding is a result of spillage and flow diversion under the CN rail bridge. The Unilever property is very flat, and flow appears to return towards the channel along Commissioners Street. Table 3 summarizes the overall modelled water levels.

Table 3: Summary of Water Levels in the Existing Conditions Model

Input Flow Rate (m^3/s)	Approximate Water Levels m IGLD		Effects
	Riverdale Park-Lake Shore Boulevard	Keating Channel	
160	75.2-78.2	75.2	Flooding upstream of the CN rail bridge – mainly on west side of narrows upstream from Queen Street; also minor inundation of lower section of DVP upstream from CN Bridge
291	75.7-79.2	75.3	Flooding continues on lower DVP and parts of Bayview Avenue. Flow begins entering the DVP under CN Bridge
369	75.7-79.2	75.8-76.4	Flow elevated in Keating Channel. Flow entering Unilever Property. Much flooding on both sides of Don Narrows
497	77.2-81.2	76.0-77.0	Flow around Unilever Building. Overbank flow out of the 90-degree bend at the top of the Keating Channel continues. Flow along Don Roadway, south/east of Keating Channel.
1,694	78.2-83.2	77.2-77.7	Flow through the Eastern Avenue underpass and east to Leslie Street; flooding is conspicuous throughout the entire Project Study Area

The modelled flow depths (Appendix HD-B) follow the same pattern as the modelled water levels (indeed, the flow depth is derived by subtracting the bed level from the water level model outputs). Table 4 summarizes the overall modelled flow depths.

Table 4: Summary of Approximate Flow Depths in the Existing Conditions Model

Input Flow Rate (m^3/s)	Approximate Flow Depths m Riverdale Park-Lake Shore Boulevard	Keating Channel	Alongside FPL	Unilever
160	1-2	5-9	0	0
291	1-3	5-9	0	0
369	1.5-4	5-9	0-0.2	0-0.2
497	2-5	5-9	0-1	0-0.75
1,694	4-8	6-10	1-3	0.5-3

Velocities (Appendix HD-C) upstream from Lake Shore Boulevard during the 2-year flow are in the range of 1.0-2.0 metres per second, and 0.5-1.0 metres per second in the Keating Channel (Appendix HD-C-24). During the 10-year flow (291 m^3/s), velocities are approximately 2.0-3.0 m/s in the Don Narrows, and at approximately 1.0-2.0 m/s in the Keating Channel (Appendix HD-C-26).

At 369 m^3/s (approximately the 25-year return period flow), flow speeds are predicted to be 2.0-4.0 m/s in the Don Narrows and are approximately 1.0-2.5 m/s in the Keating Channel (Appendix HD-C-28). During the 100-year flood, flow speeds are 2.0-5.0 m/s in the lower Don Narrows (south of CN Bridge), and are approximately 1.0-2.5 m/s in the Keating Channel (Appendix HD-C-30).

During the Regulatory Flow event, flow speeds are in excess of 3.0->6.0 m/s in the Don Narrows, and may peak at up to 8 m/s (Appendix HD-C-32). In the Keating Channel, flow speeds range between 1.0-4.0 m/s, with the lower value resulting from much of the flow leaving the Keating Channel at its upstream end (Figure HD-C-33). In the narrow section of the Keating Channel, flow speeds may approach 5.0 m/s. Flow speeds decline with distance away from the channel, and much of the flooding in the eastern part of the study area suggests the area is inundated, but not conveying a significant amount of flow (i.e. a 'backwater'). It is important to note that the predicted flood flows are not calibrated, and while the results appear reasonable in comparison to other flood studies, they should be interpreted and applied with caution.

The patterns of bed shear stress distribution follow the flow velocity distribution. During the 100-year flow, peak bed shear stresses are predicted to be 50-100 N/m^2 (or Pascals, Pa) in the Don Narrows below the CN Bridge. During the Regulatory Flow event, bed shear stress is in the range of 50-200 N/m^2 through the Don Narrows and in the narrow section of the Keating Channel. This suggests that considerable bed scour will be taking place during higher flow events.

Table 5 summarizes flow velocities and bed shear stresses in the Existing Conditions model runs.

Table 5: Summary of Approximate Flow Velocities and Bed Shear Stresses in the Existing Conditions Model

Flow rate (m^3/s)	Velocity (m/s)		Bed Shear Stress (N/m^2)	
	Riverdale Park-Lake Shore Boulevard	Keating Channel	Riverdale Park-Lake Shore Boulevard	Keating Channel
160	1.0-2.0	0.5-1.0	1-25	1-25
291	2.0-3.0	1.0-2.0	25-75	1-25
369	2.0-4.0	1.0-2.5 (3.0 – 3.5 in the narrow section of the Channel)	25-200	1-50
497	2.0 - 5.0	1.0-2.5	25-200	1-50
1,694	3.0-6.0	1.0-4.0	25-500	1-50

3.2 Preferred Alternative Model Results

As previously noted, the Delft3D model was also used to evaluate hydraulic conditions and flood flows for the preferred alternative conditions. Summary maps of output from the preferred alternative model runs under different flow conditions are contained in Appendices HD-E to HD-M. Two weir configurations were evaluated for the preferred alternative model runs. For evaluation of conveyance of floods up to the regulatory flow, the weirs at the upstream end of the Keating Channel are set to their ‘default’ position. This configuration has a height of 71.6 m for the upstream weir (this weir is assumed to be adjustable, and it would default to be in the ‘down’ position to aid flood conveyance), and a height of 75.25 m for the fixed, side-spill weir. These are referred to as the ‘default’ runs. A separate set of runs were undertaken to evaluate how flow is split by the weirs when they are actively used to balance flows between the Keating Channel and the naturalized channel system. This aims to direct low flows to the naturalized area to maintain river and riparian habitat at lower flows, while diverting flow to the Keating Channel to reduce erosion in the naturalized channel system at higher flows. For flows at and below the 100-year return period flow, the weirs were set to a level of 75.25 m, splitting flow more between the Keating Channel and the natural channel system. These are referred to as the ‘adaptive’ runs.

Appendix HD-E contains summary maps of water levels under different flow return periods for existing conditions. This appendix contains zoom maps of water levels for each flow return period in the vicinity of the CN Bridge and Lake Shore Boulevard. Appendix HD-F follows the same format, but shows predicted water depth in the study area, while Appendix HD-G and Appendix HD-H show predicted depth-averaged flow velocities and bed shear stress respectively. Appendices HD- I to HD-L show the same mapping as Appendices HD-E to HD-H, except that the weirs are in the adaptive position. The regulatory flow was excluded from these runs as stable flow conveyance was not possible under the regulatory flow with this configuration. This section summarizes the main findings of the preferred alternative model runs.

The preferred alternative channel floods upstream of the CN Rail Bridge to Bayview Avenue on the 2-Year return period flow, at a discharge of approximately 160 m^3/s (Appendix HD-E-46). This is similar to the Existing Conditions model as the model bathymetries are virtually identical in the upstream section of the narrows. The flooding of the lower section of the Don Valley Parkway has been removed at this flow due to the modifications downstream of the CN Bridge increasing conveyance through the bridge as the tailwater elevation is lower. The elevation of the tailwater also depends on whether the weirs are in the default or adaptive position (see below). There is little flow in the Keating Channel. In the new, natural channel system, flow is spilling from the low flow channel to the wetlands on either side. The adaptive weir condition (Appendix HD-I-90) shows flow beginning to spill over the weirs into the Keating Channel, while the bulk of the flow is directed to the natural channel system.

At a flow of 291 m^3/s (the 10-year flow), there is conspicuous flooding on the west side of the Don Narrows, from Riverdale Park to the CN Bridge (Appendix HD-E-48). The DVP lanes near the CN Bridge are under water. Flow is low within the Keating Channel since the weirs divert flow to the new, naturalized channel. In the region between CN Bridge and Lake Shore the water levels are elevated by approximately 0.5 m over the 2-year flow levels (Table 6). In the new, natural channel system, flow is spilling from the low flow channel to the wetlands on either side. Flow is contained within the valley system. The 10-year flow with the weirs in the adaptive position shows flow occupying the valley floor of the natural channel system (Appendix HD-I-92).

During the 25-year flow, more of Bayview Avenue alongside the Don Narrows is predicted to be subject to flooding (Appendix HD-E-50). Flow does not enter the Unilever property to the south of the CN Rail tracks and to the east of the Don Roadway as flow in this area is contained by a wider channel, and regrading of the surrounding land. Water levels in this run of the model were prevented from entering the Keating Channel by the weirs. In the new, natural channel system, flow is spilling from the low flow channel to the wetlands on either side, and occupying much of the new floodplain. Flow is contained within the valley system. With the weirs in the adaptive position (Appendix HD-I-94), flow is split between the naturalized channel system and the Keating Channel, thereby causing a reduction in the erosive forces in the natural channel system than would happen if all flow was through the natural channel. With the weirs in either default or adaptive position, flow is not yet occurring over the southern spillway to the ship channel. This contrasts with the EFDC model, which suggests that further optimization of the crest elevation of the spillway berm will be needed during detailed design.

During a 100-year flood, the riparian areas of the narrows are flooded, and the level of flooding upstream of the CN Bridge depends on the level of scour assumed to take place (Appendix HD-E-52). Full discussion of this is beyond the scope of this memorandum, but with scour to 70.0 m under the CN Bridge, there is not significant flooding of the FPL upstream. Flow does not enter the Unilever property to the south of the CN Rail tracks and to the east of the Don Roadway as flow in this area is contained by a wider channel, and by regrading of the surrounding land. In the new, natural channel system, flow is spilling from the low flow channel to the wetlands on either side, and occupying much of the new floodplain. Flow is contained within the valley system. The spillway to the ship channel is not operational during the 100-year flow in the Delft model, as found in the EFDC model.

The Regulatory Flow causes extensive flooding throughout the study area upstream from the CN Bridge (Appendix HD-E-54). There is significant backwatering at the CN Bridge, which causes flooding as far as the Eastern Avenue underpass, through this is much less extensive than for the existing conditions model. Water levels alongside the FPL are approximately 77.2-80.2 m. The entire Port Lands area beyond the valley system is now predicted to be removed from the flood zone as flow is contained within the valley system downstream from Lake Shore Boulevard. A significant portion of the flow (approximately 500 m^3/s) is conveyed through the Keating Channel when the weir is down. We expect that it will be possible to contain the regulatory flow on the western edge Unilever property through a combination of regrading and berm construction, although the final configuration of this will need to be addressed during the detailed design phase of the project. Table 6 and Figure 12 summarize the overall modelled water levels with the weirs in the default position. Note that the drop in water levels around the Gardiner Ramps is a result of the dry cells representing the ramp piers disrupting flow through the channel in this area. Table 7 compares water levels between the default and adaptive weir scenarios, showing an increase in water levels in the reach between CN Bridge and Lake Shore Boulevard, and in the naturalized channel system with the weirs in the adaptive position.

Table 6: Summary of Water Levels in the Preferred Alternative Model with the Weirs in the Default Position

Input Flow Rate (m^3/s)	Approximate Water Levels m IGLD		Effects
	Queen Street - Lake Shore Boulevard	Keating Channel	
160	75.7-76.7	75.2	Flooding upstream of the CN rail bridge – mainly on west side of narrows and very minor. Minor flow to wetlands
291	75.7-77.2	75.3	Flooding continues on parts of Bayview Avenue. More flow to wetlands in naturalized system
369	75.7-77.2	75.3	Flood contained in valley system. Flow through wetlands. No flow to Keating, southern spillway or Unilever
497	75.7-79.2	75.3-76.7	Flood contained in valley system. Flow through wetlands. No flow to southern spillway or Unilever
1,694	77.2-80.2	76.7-77.7	Flood contained in valley system. Flow across entire floodplain. Flooding upstream from CN Bridge. Flow over southern spillway to ship channel

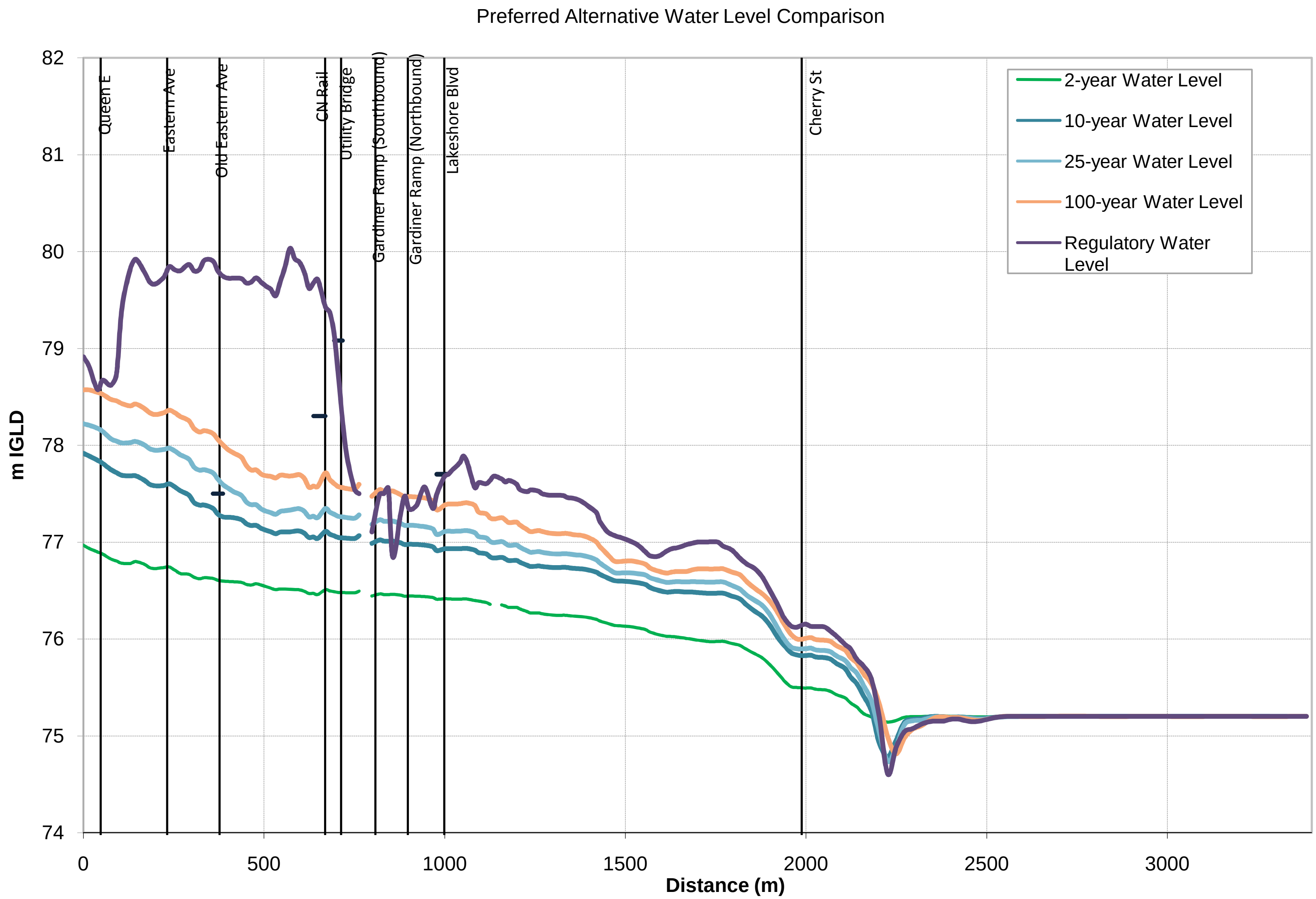


Figure 11: Preferred Alternative Water Level Comparison (Default Weirs)

Table 7: Comparison of Water Levels in With the Weirs in Default and Adaptive Modes

Input Flow Rate (m^3/s)	Approximate Water Levels m IGLD			
	Lake Shore – downstream side of CN Bridge Weirs Default	Natural Channel Weirs Default	Reach from Lake Shore – CN Bridge Weirs Adaptive	Natural Channel Weirs Adaptive
160	75.7-76.2	75.3-76.7	76.2-76.7	75.7-76.7
291	75.7-76.2	75.3-76.7	76.2-77.2	75.7-77.2
369	75.7-76.7	75.7-76.7	76.7-77.2	75.7-77.2
497	75.7-77.2	75.7-76.7	76.7-77.7	75.7-77.7
1,694	77.2-79.4	76.7-78.2	n/a	n/a

The modelled flow depths (Appendix HD-F) follow the same pattern as the modelled water levels (the flow depth is derived by subtracting the bed level from the water level model outputs). Table 8 summarizes the overall modelled flow depths for the default weirs. Appendix HD-J shows the water depths in the adaptive weirs scenario. With more flow entering the natural channel, flow depths are deeper in this area than with the weirs down.

Table 8: Summary of Approximate Flow Depths in the Preferred Alternative Model with Weirs in Default Mode

Input Flow Rate (m^3/s)	Approximate Flow Depths m			
	Queen Street - Lake Shore Boulevard	Keating Channel	Unilever	Natural Channel Floodplain
160	1-1.5	5-9	0	0-1
291	1-2	5-9	0	0-1
369	1.5-3	5-9	0	0-2
497	2-4	5-9	0	0.2-2
1,694	4-6	6-10	0	0.5-4

Velocities (Appendix HD-G) upstream from Lake Shore Boulevard during the 2-year flow are in the range of 1.0-2.0 metres per second. In the new, natural low flow channel, velocities are approximately 0.5-1.0 m/s. Flow velocities are negligible in the wetlands (Appendix G-68). The adaptive weir condition (Appendix HD-K-108) shows flow beginning to spill over the weirs into the Keating Channel, while the bulk of the flow is directed to the natural channel system. Under the adaptive weir condition, velocities are slightly reduced in the Don Narrows below CN Bridge, but increased slightly in the natural channel as less flow is split to the Keating Channel than with the weirs in the default mode.

During the 10-year flow (291 m^3/s), velocities range between 1.0-3.0 m/s in the Don Narrows below the CN Bridge, and they are approximately 1.0-2.0 m/s in the new naturalized channel (Appendix HD-G-70). With the weirs in adaptive mode (Appendix HD-K-110) flow is split between the

Keating Channel and the natural channel system, with more flow in the naturalized channel than with the weirs in default mode.

At 369 m^3/s (approximately the 25-year return period flow), flow speeds are predicted to be 2.0-4.0 m/s in the Don Narrows and are approximately 1.0-2.0 m/s in the naturalized channel (Appendix G-72). The adaptive weir condition (Appendix HD-K-112) shows flow splitting between the Keating Channel, giving a flow velocity distribution in the natural channel system of 1.0-2.0 m/s, and in general slightly higher than is predicted in this area with the weirs in default mode.

During the 100-year flood, with weirs in the default configuration, flow speeds approach 2.0-3.0 m/s in the lower Don Narrows (south of CN Bridge), and are approximately 1.0-3.0 m/s in the Keating Channel and naturalized channel (Appendix G-74). The adaptive weir condition (Appendix HD-K-114) shows flow splitting between the Keating Channel and the naturalized channel, with more flow going to the naturalized channel than with the weirs in default mode. This gives a flow velocity distribution in the natural channel system of 1.0-3.0 m/s, and in general slightly higher than is predicted in this area with the weirs in default mode.

During the Regulatory Flow event, flow speeds are 3.0-6.0 m/s in the Don Narrows, and may peak at up to 8 m/s (Appendix HD-G-76). In the narrow section of the Keating Channel, and the new naturalized channel, flow speed is 2.0-4.0 m/s, peaking at approximately 5.0 m/s. Flow speeds decline with distance away from the channel to 1.0-2.0 m/s near the valley walls. It is important to note that the predicted flood flows are not calibrated, and while the results appear reasonable in comparison to other flood studies, they should be interpreted and applied with caution. It was not possible to derive flow velocities for the regulatory flow with the weirs up because a stable model run under this configuration could not be generated. Figure 13 summarizes the downstream variations in flow velocity with the weirs in default mode.

The patterns of bed shear stress distribution (Appendix HD-H and Appendix HD-L) follow the same general patterns as observed in the flow velocity distributions. During the 100-year flow, peak bed shear stresses may reach in excess of 100 N/m^2 (or Pascals, Pa) in the Don Narrows. During the Regulatory Flow event, bed shear stress peaks at over 100 N/m^2 in several locations through the Don Narrows and in the narrow section of the Keating Channel, and in several locations in the natural channel, the bed shear stress reaches 50 N/m^2. This suggests that bed scour will be taking place in many locations throughout the new study area during higher flow events. Figure 14 summarizes the downstream variations in bed shear stress with the weirs in default mode. Table 9 summarizes flow velocities and bed shear stresses in the preferred alternative model runs.

Table 9: Summary of Approximate Flow Velocities and Bed Shear Stresses in the Preferred Alternative (Weir Down) Model

Flow rate (m^3/s)	Approximate Flow Velocity (m/s)		Bed Shear Stress (N/m^2)	
	Queen Street - Lake Shore Boulevard	Natural Channel	Queen Street - Lake Shore Boulevard	Natural Channel
160	2.0 - 2.5	1.0 - 1.5	1-25	1-25
291	3.0 – 3.5	1.0 – 2.0	1-75	1-25
369	4.0 - 5.0	2.0	1-100	1-25
497	4.0 - 5.0	2.0	1-100	1-25
1,694	> 5.0	3.0 - 5.0	25-200	1-75

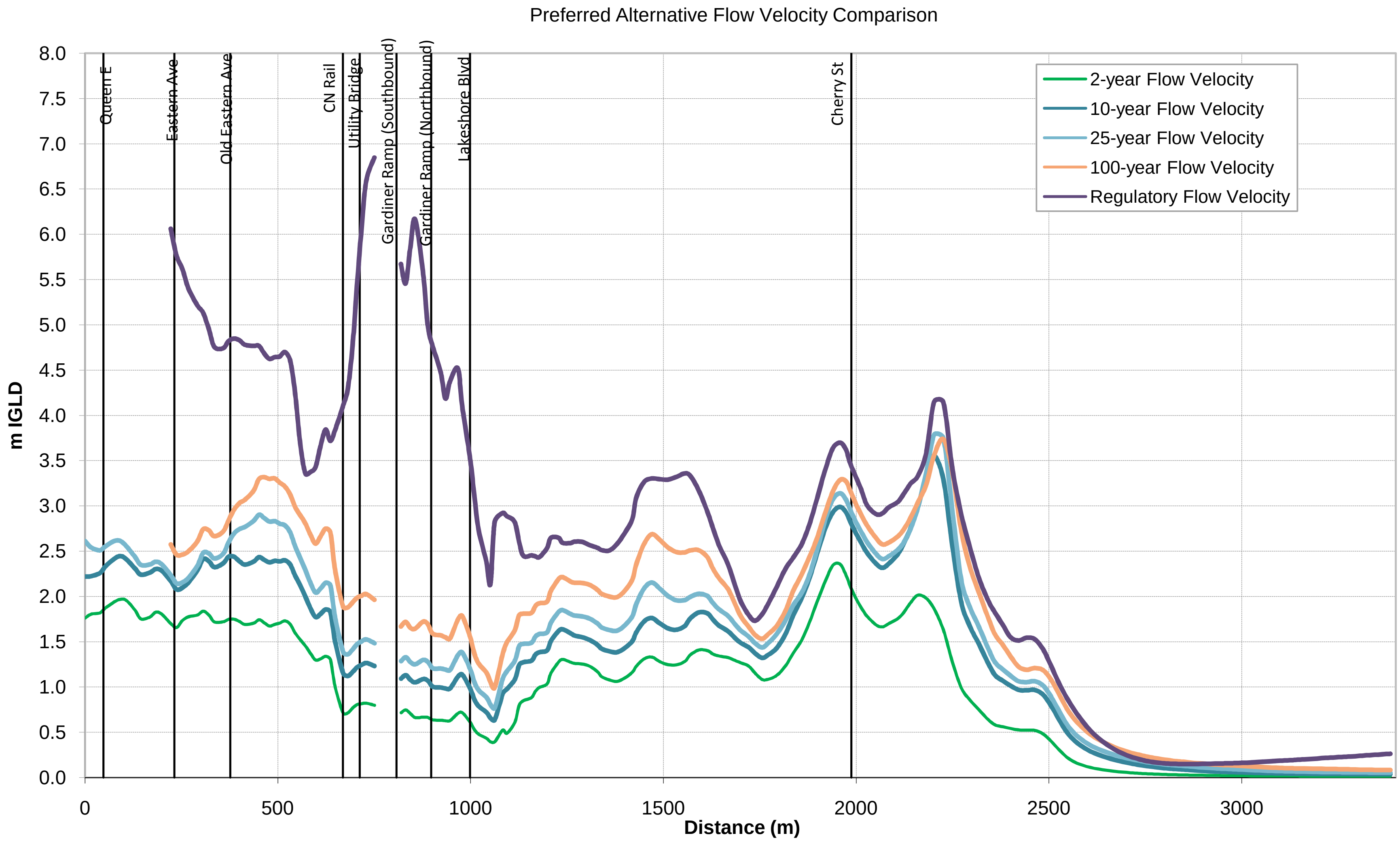


Figure 13: Preferred Alternative Flow Velocity Comparison (Default Weirs)

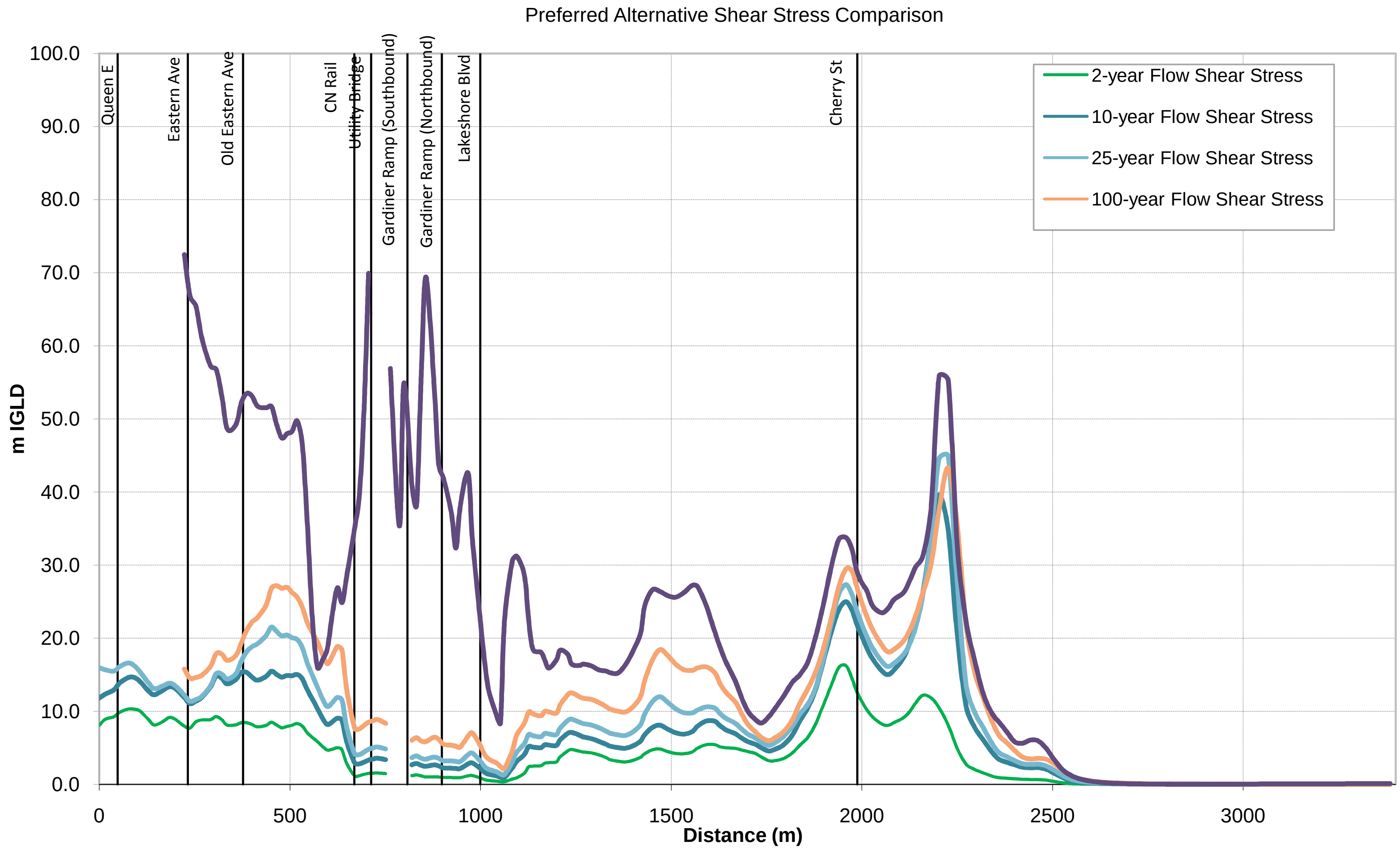


Figure 14: Preferred Alternative Bed Shear Stress Comparison (Default Weirs)

4.0 DISCUSSION

4.1 Summary of Changes in Flood Conditions in Key Locations

4.1.1 Flooding in Don Narrows

Flooding in the Don Narrows is very similar between the existing and preferred alternative runs in the upper section of the Narrows. However, flooding at the downstream end of the narrows is predicted to be reduced. This is primarily as a result of the increased conveyance downstream from the CN Bridge, which causes less of a backwater upstream from the bridge. The modelled water levels in the Don Narrows are very sensitive to the DEM configuration, and also to the physical parameterization of the model (in particular, roughness, and to a lesser extent, eddy viscosity). Further refinement of the DEM in the future as new survey data (e.g. LIDAR data) may serve to improve these estimates, as will calibration and validation of the model as more data become available. Flooding is highly dependent on the amount of scour assumed to be taking place under the CN Bridge. This issue is presently being tested as part of the sediment transport modelling study.

4.1.2 West Don Lands FPL

Flood levels in the vicinity of the West Don Lands FPL will be reduced as a result of implementing this project. This is again because of the increased conveyance downstream from the CN Bridge, which causes less of a backwater upstream from the bridge.

4.1.3 Eastern Avenue Underpass

Flood levels in the vicinity of the Eastern Avenue Underpass will be reduced as a result of implementing this project. This is again because of the increased conveyance downstream from the CN Bridge, which causes less of a backwater upstream from the bridge. The model results suggest that flow through the underpass will be greatly reduced and potentially removed, although detailed consideration of this area is necessary beyond the limits of this investigation to ensure removal of this flood risk. Accordingly, a detailed design study of this area is recommended. This is again because of the increased conveyance downstream from the CN Bridge, which causes less of a backwater upstream from the bridge.

4.1.4 CN Rail Bridge

Model Run 54 suggests that the centre soffit of the CN Bridge will be inundated under the Regulatory Flood. Whether the bridge soffit is inundated or not depends on the level of scour assumed to be taking place under the bridge, and also the amount of scour assumed to take place in the sediment trap area immediately downstream from the CN Bridge. This scour issue is presently being evaluated through the sediment transport modelling being undertaken as part of functional design, and it will be finalized as input to the detailed design of the project.

4.1.5 Sediment Trap

Flow velocity is reduced in the sediment trap area as a result of channel widening for regulatory flow conveyance. This is evident in Figure 11, and it supports the need for adaptive sediment management in this reach. The regulatory flow model output for the preferred alternative condition suggested that this area will scour during the regulatory flow, and the trap elevation used in this analysis may be over-conservative. This is currently under investigation as part of the sediment transport modelling study. However, under lower flow conditions, this area will likely be a key area of deposition, and adaptive management (dredging) of the trap is necessary to prevent flooding from occurring under lower floods that do not have enough power to scour the trap. This issue is presently being evaluated through the sediment transport modelling being undertaken as part of functional design, and it will be finalized as input to the detailed design of the project.

4.1.6 Unilever Property – Flood Protection Landform/Grading

It has been assumed that sufficient grading of the Unilever property can be undertaken to remove it from the regulatory flood zone. This has been accomplished in the preferred alternative model, but detailed design of this grading through this site is required. In order to provide permanent removal of flood risk, the grading will need to have minimum dimensions on the dry and wet sides of a landform feature. An example of the likely footprint of the berm, based on preliminary modelling, is shown in Figure 15. Note that this footprint may change based on refinements during Detailed Design, due to changes in anticipated water levels in this area. The grading will need to key into the CN Rail embankment and to the height of land near the Lakeshore/Keating Yard in order to remove the Unilever property from the flood spill zone. The elevation of the grading of this site will also need to account for the 0.5 m freeboard above the predicted regulatory flood water levels. Alternatively if entire site is regraded for a comprehensive site redevelopment, the more viable option may be to simply raise entire area to an elevation above 80.2 metres including the 0.5 m freeboard requirement.

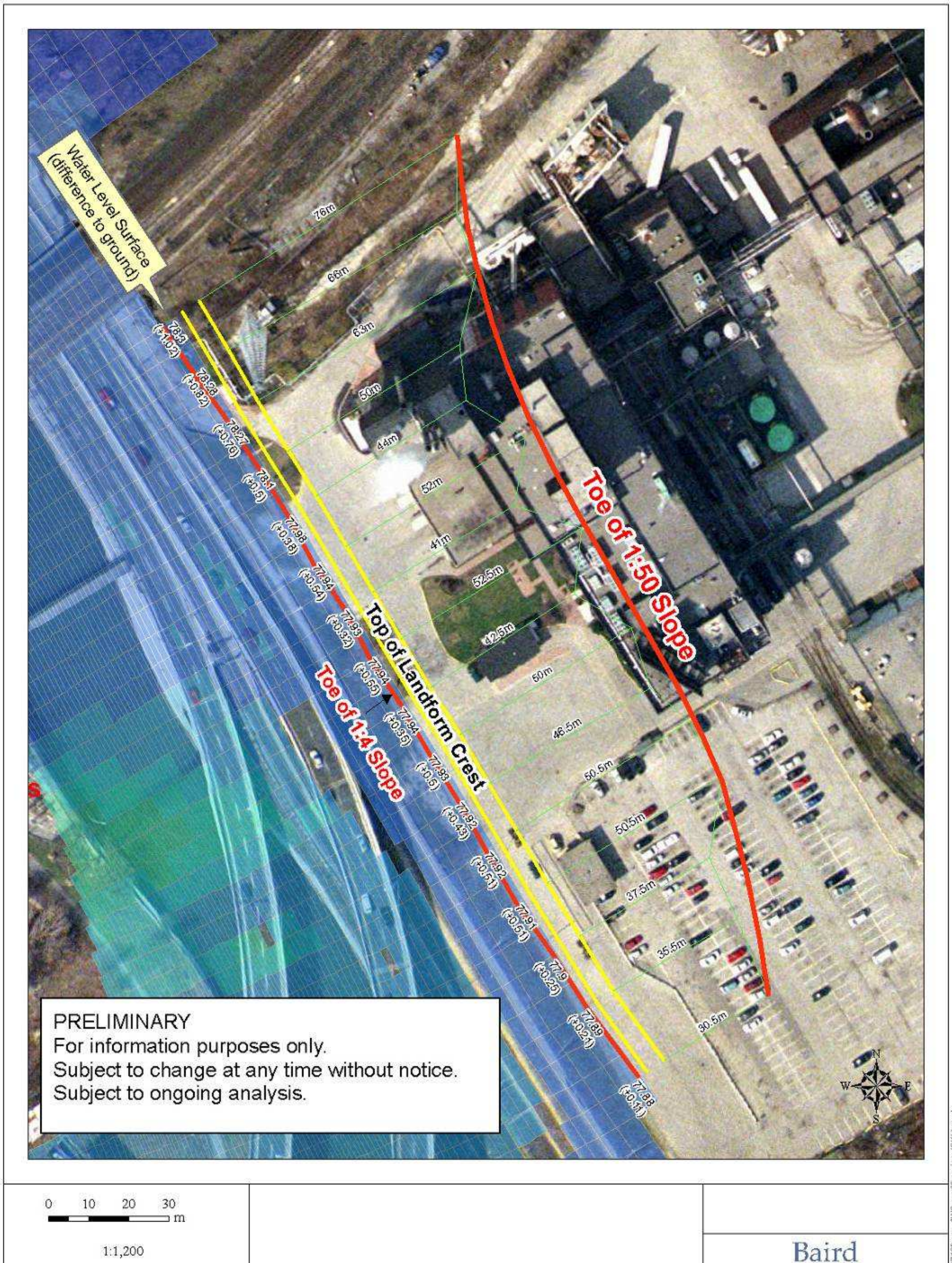


Figure 15: Example of Likely Footprint of Unilever Flood Protection Landform

4.1.7 Gardiner Ramps and Piers

The Gardiner Expressway ramps form a significant flow split under regulatory flow conditions, and the Unilever FPL or regrading is necessary to direct this flow back towards the main channel, and away from Lake Shore Boulevard.

4.1.8 Lake Shore Bridge (Modified from Existing)

The extended bays under Lake Shore Boulevard Bridge are essential to flood conveyance through the study area. Note that regardless of weir configuration, it has not been possible to achieve 0.5 m of freeboard under the Lake Shore Crossing. However, no scour beneath the Lake Shore Bridge has been assumed, which is likely to be an over-conservative assumption. The outcomes of the sediment transport analysis presently being undertaken as part of the functional design will serve to allow this assumption to be modified and tested during detailed design.

4.1.9 Keating Channel Weirs

The influence of the Keating Channel weirs on flow through the study area was evaluated by comparing model runs with the weirs in a default (down) configuration to convey floods, with model runs with the weirs in an adaptive position to direct more flow to the naturalized channel. An example of an adaptive weir (in this case, an inflatable weir) is shown in Figure 16. An aerial photograph of an adaptable weir installed on a similar project is shown in Figure 17. In addition, a drop-inlet structure attached to the side-flow weir may augment the inflatable weir, to allow for 'fine tuning' of the flow split during lower flow periods.

The upstream weir needs to be in the default (down) position in order to convey the regulatory flow. With the weir in the default position, approximately 500 m^3/s of flow was routed through the Keating Channel. With the weirs in an adaptive setting, increased levels in the Don Narrows were predicted as far as Queen Street, and a corresponding decrease in flow velocity through the area was observed. This likely reflects an increased backwater at the CN Bridge, cause by an increased water surface elevation in the sediment trap area. The adaptive weirs scenario caused increased water levels in the natural channel system, since less flow was split and diverted through the Keating Channel. The increased flows in the natural channel system cause more frequent inundation of the wetlands on the valley floor below the 10-year flow, and more flow across the entire valley floor above this flow. A key benefit of the flow split (and therefore of being able to drop the upstream weir) is that the split helps 'peel off' flows from the naturalized areas, which serves to reduce velocities/shear stresses (and therefore severity of erosion) in the naturalized areas. The height of the weir will need to be adaptively managed in response to a number of forcing factors, including variations in lake level; climate change; and potentially variations in bed levels in the vicinity of the weirs. The precise nature of these adaptive management techniques needs to be refined at the final design stage of this project.

The objectives for operation of the adaptive system need to be established during final design of the project. In addition, the upstream weir will need to default to the 'down' position in order to convey the regulatory flood, unless further modelling demonstrates that the regulatory flood can be conveyed without this feature. This will likely be accomplished though a design that allows for both automated and mechanical dropping of the weir in response to a large storm, without the need for manual intervention.

Figure 16: Example of an Inflatable Weir Structure

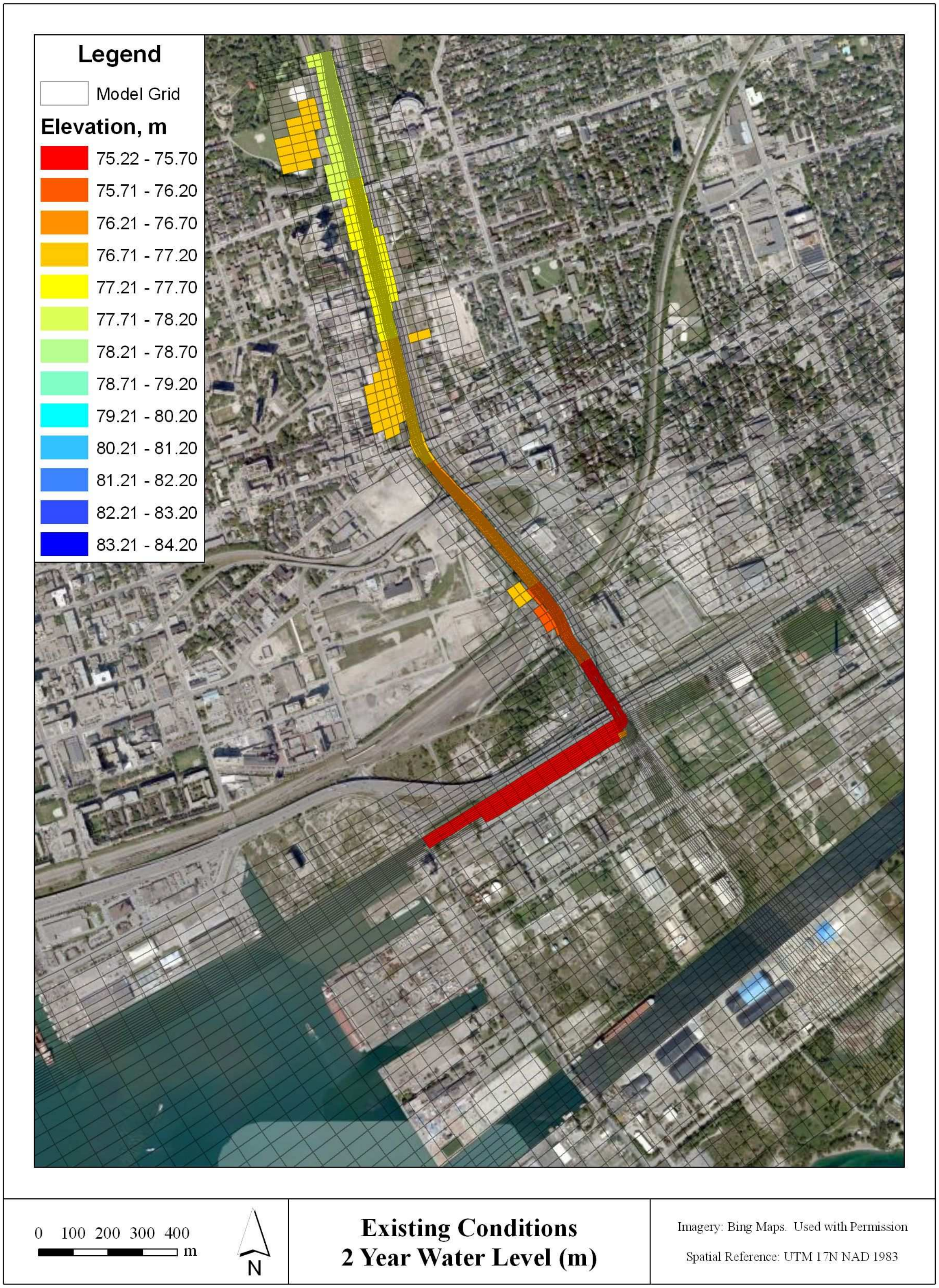
Figure 17: Aerial Photograph of an Inflatable Weir Structure

4.1.10 Keating Channel Narrowing

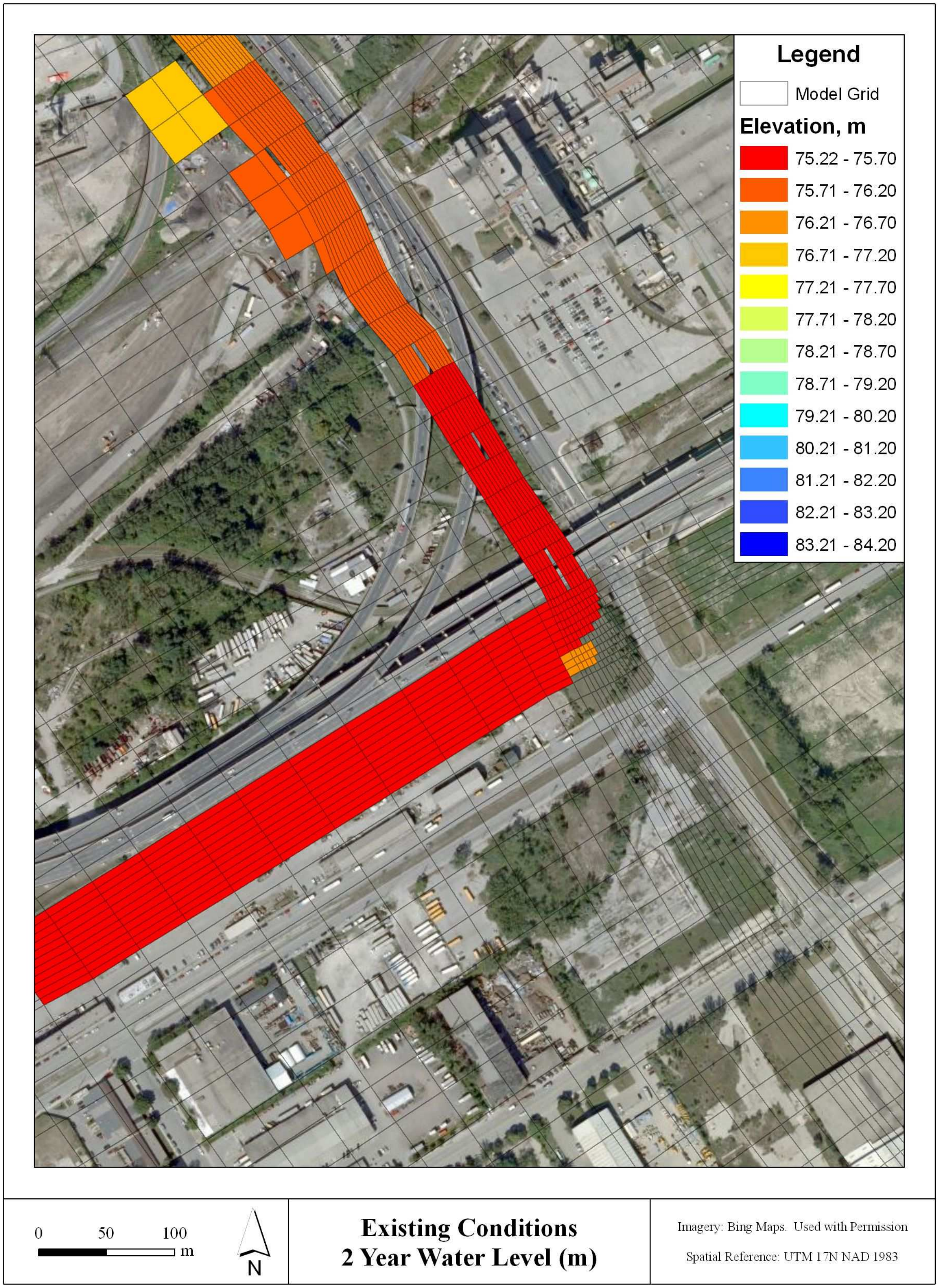
The preferred alternative includes a plan to narrow the Keating Channel. This is an urban design feature for the Lower Don Lands and Keating Precincts, and it allows space for footings for future bridges over the Keating Channel, space for shoring existing sheet pile walls and potential provision of improved fish habitat in the Keating Channel. The narrowing of the Keating Channel does affect water surface elevations in the channel. However, model results suggest that these can be contained in the channel with regrading of the area. Further confirmation of these levels is necessary during detailed design.

LIST OF APPENDICES

APPENDIX HD-A
EXISTING CONDITIONS WATER LEVEL MAPS



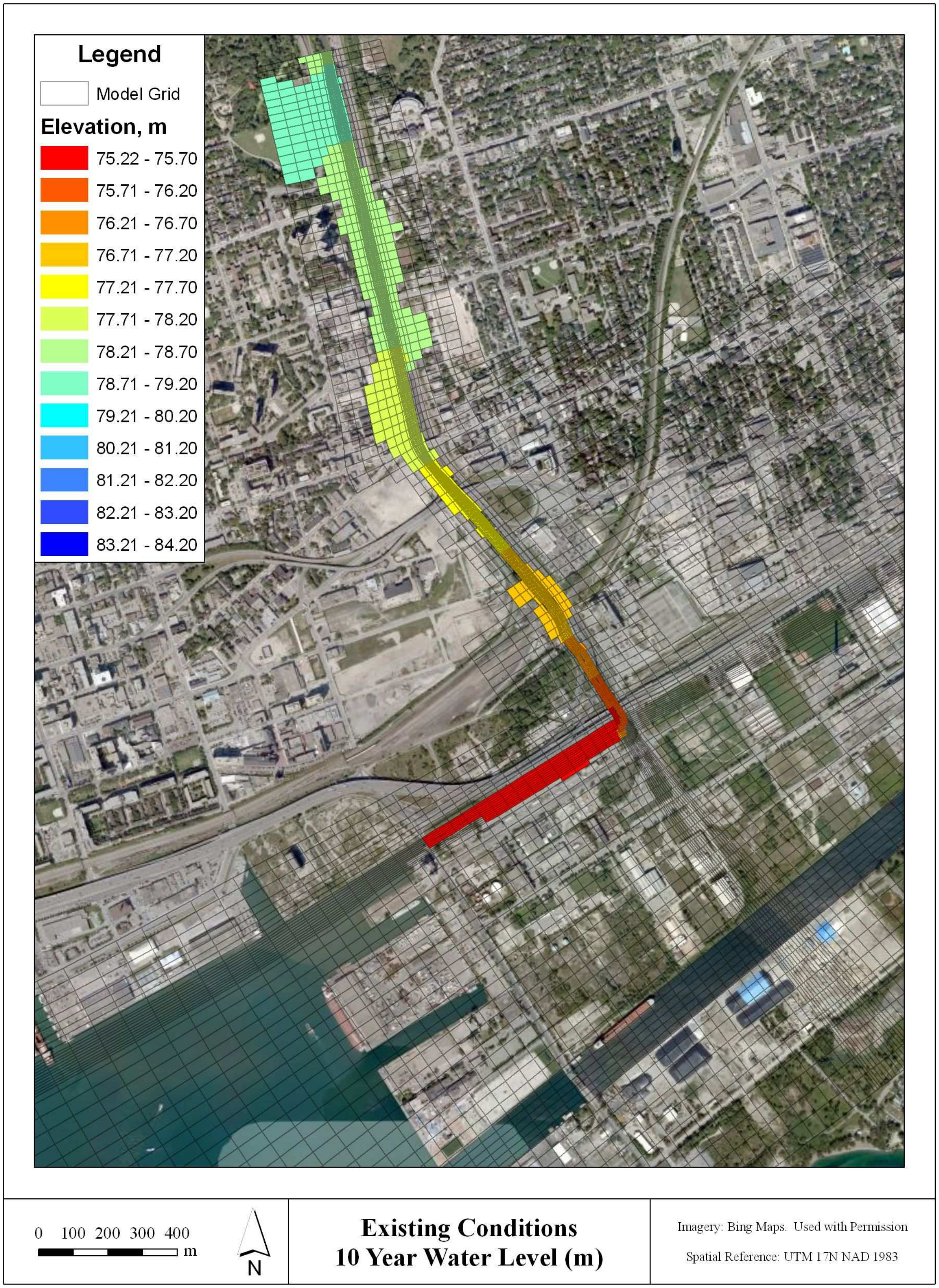
Existing Conditions
2 Year Water Level (m)



Existing Conditions
2 Year Water Level (m)

Imagery: Bing Maps. Used with Permission

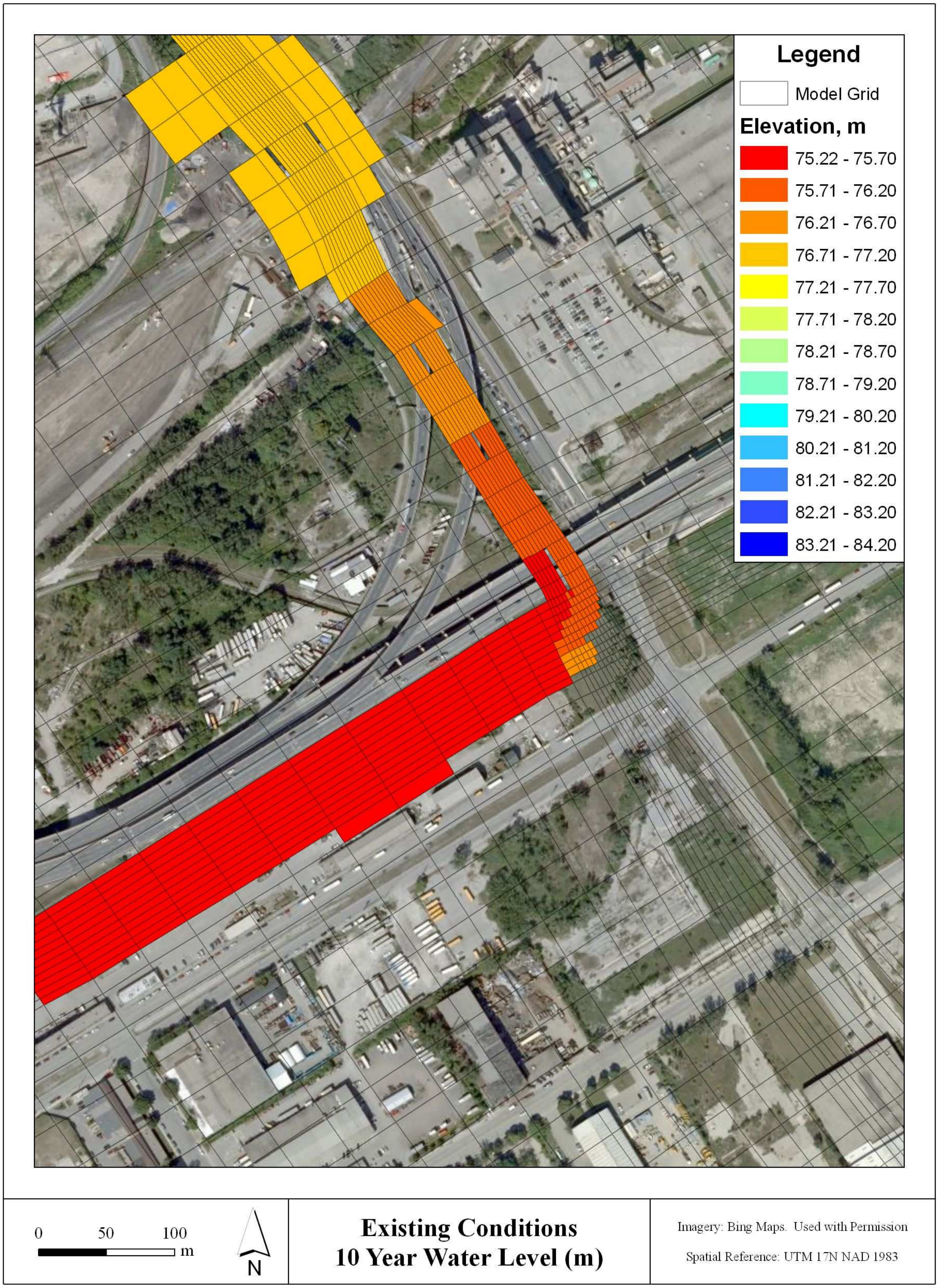
Spatial Reference: UTM 17N NAD 1983



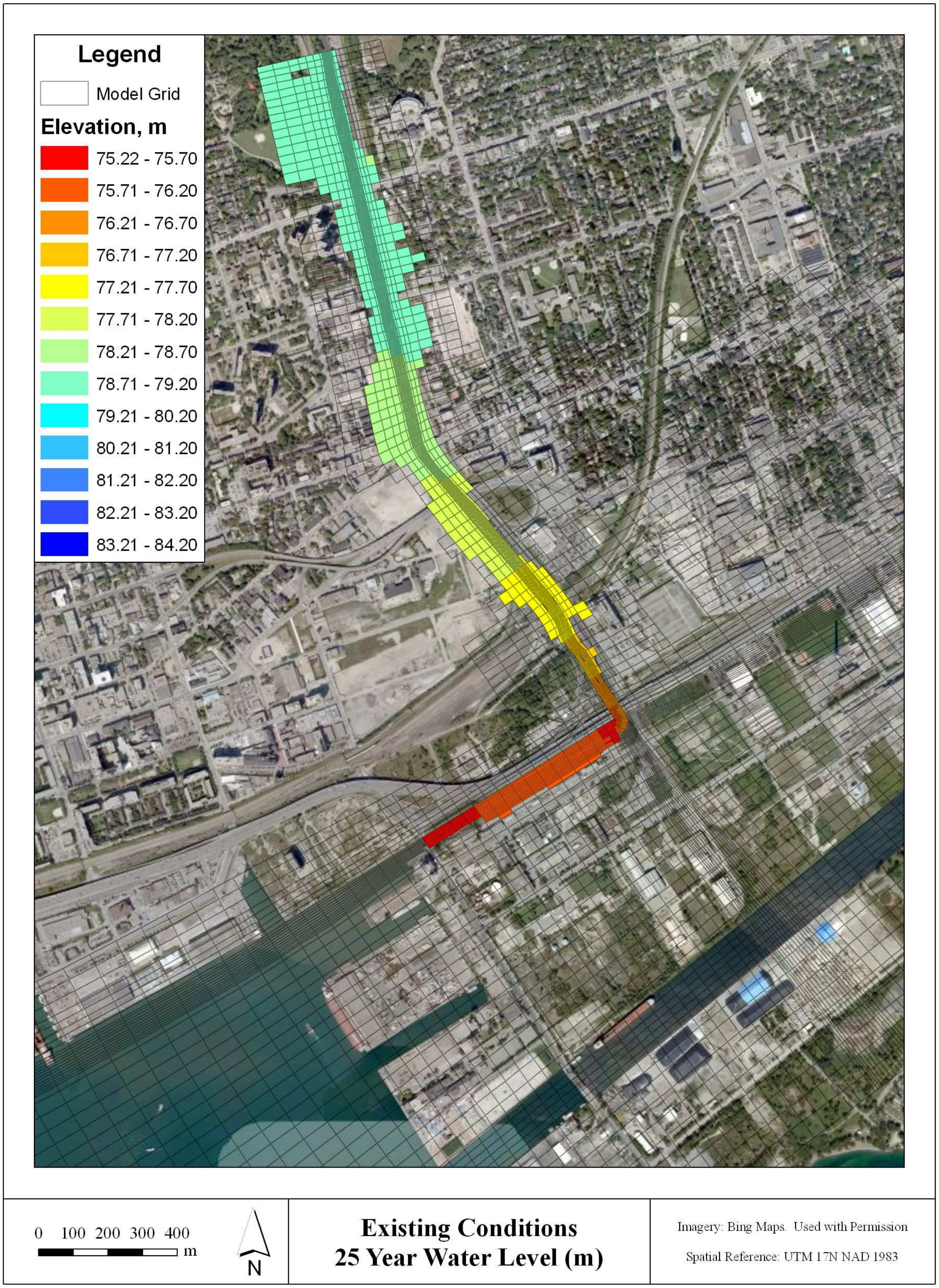
Existing Conditions
10 Year Water Level (m)

Imagery: Bing Maps. Used with Permission

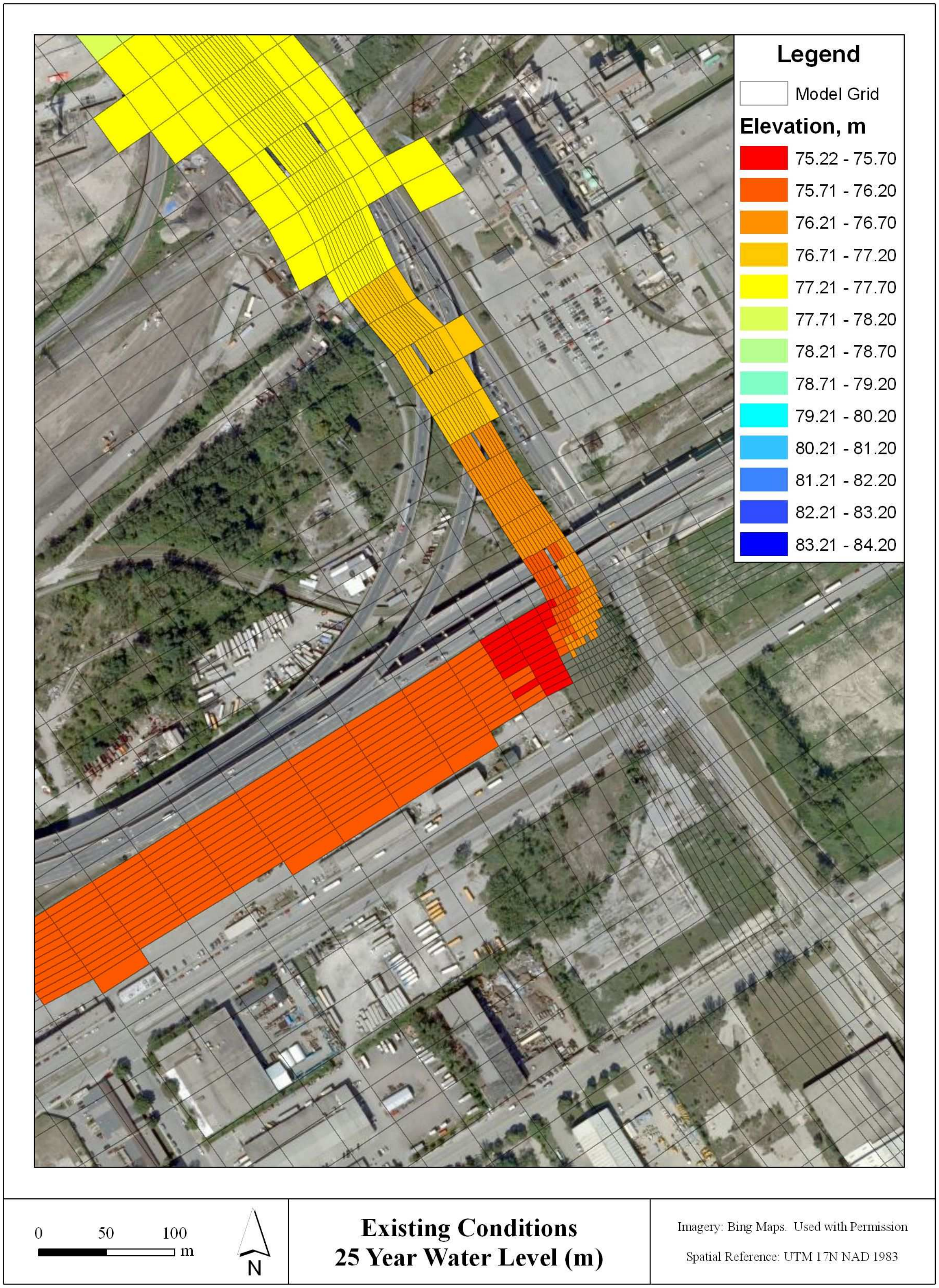
Spatial Reference: UTM 17N NAD 1983



Existing Conditions
10 Year Water Level (m)

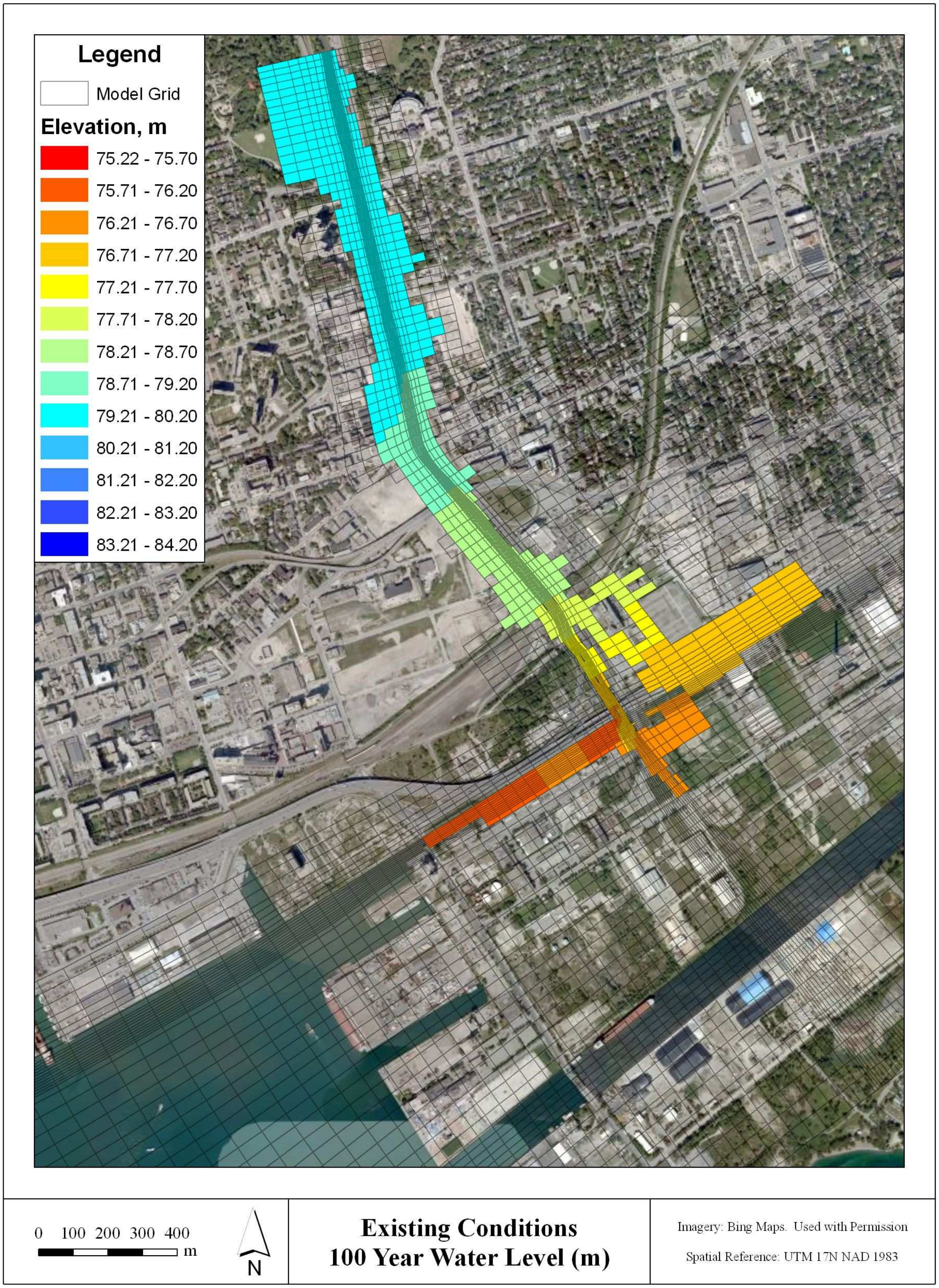


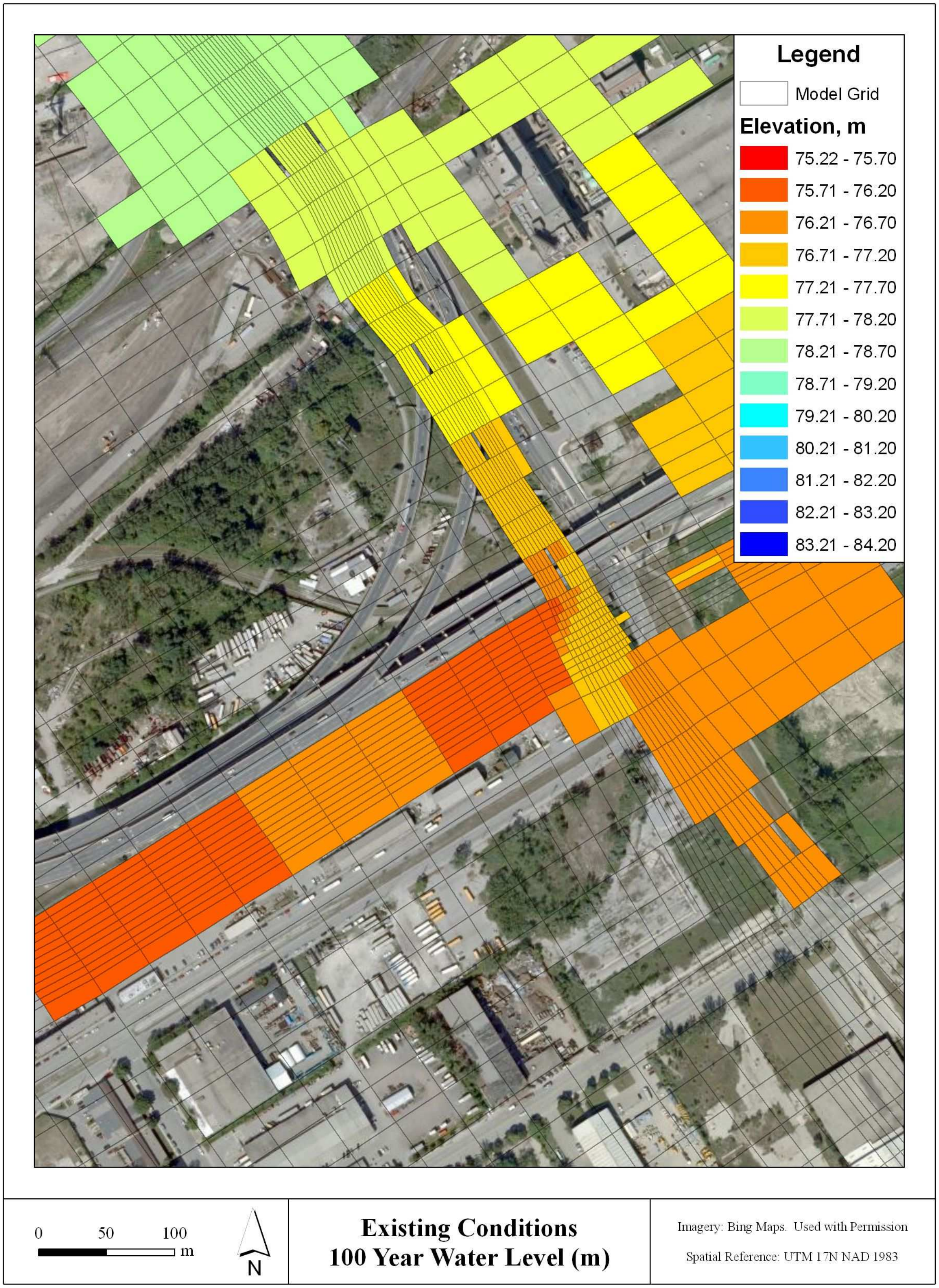
Existing Conditions
25 Year Water Level (m)



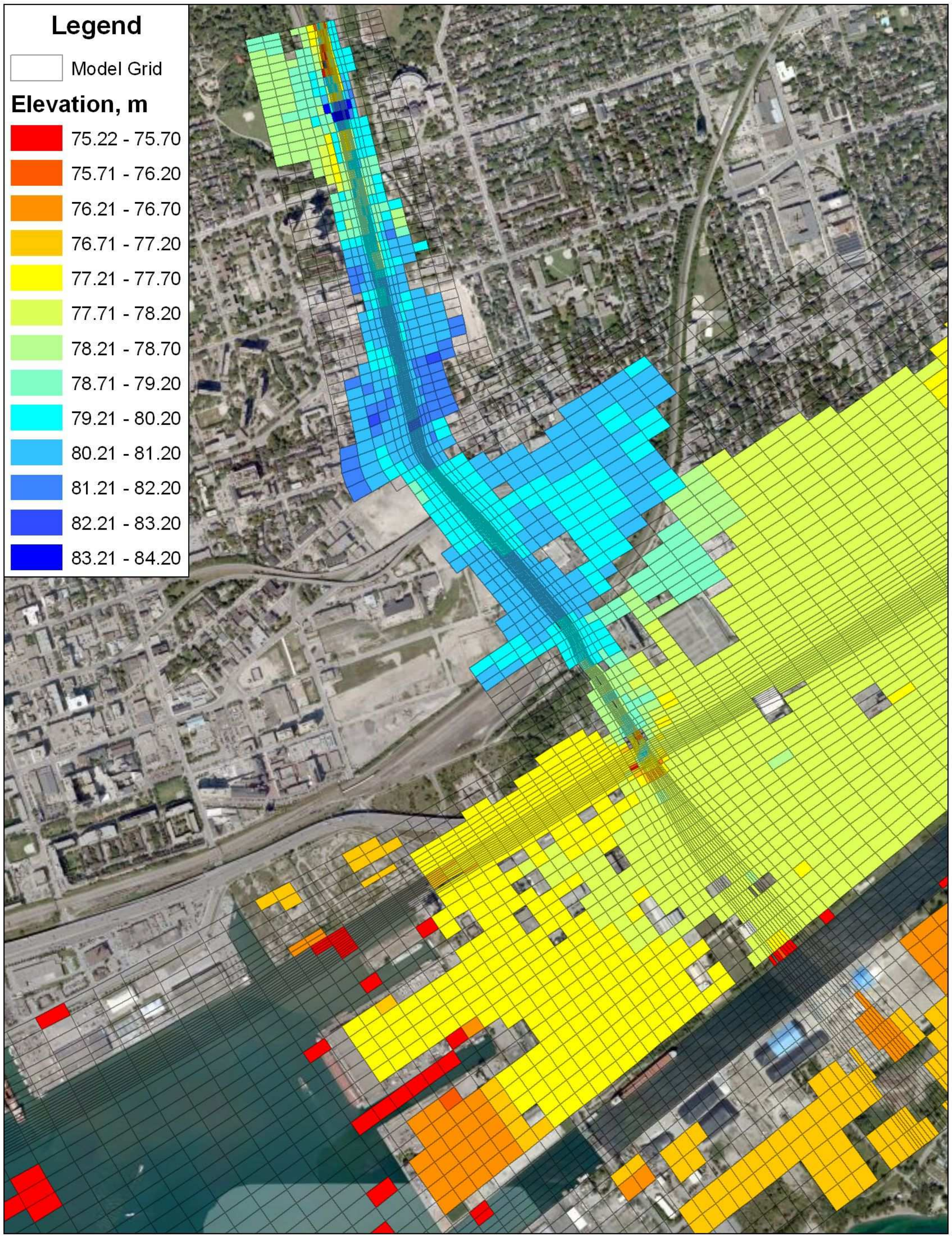
Existing Conditions
25 Year Water Level (m)

Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983


Legend
Model Grid
Elevation, m
75.22 - 75.70
75.71 - 76.20
76.21 - 76.70
76.71 - 77.20
77.21 - 77.70
77.71 - 78.20
78.21 - 78.70
78.71 - 79.20
79.21 - 80.20
80.21 - 81.20
81.21 - 82.20
82.21 - 83.20
83.21 - 84.20
0 100 200 300 400 m
N
Existing Conditions
100 Year Water Level (m)
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983



Existing Conditions
100 Year Water Level (m)



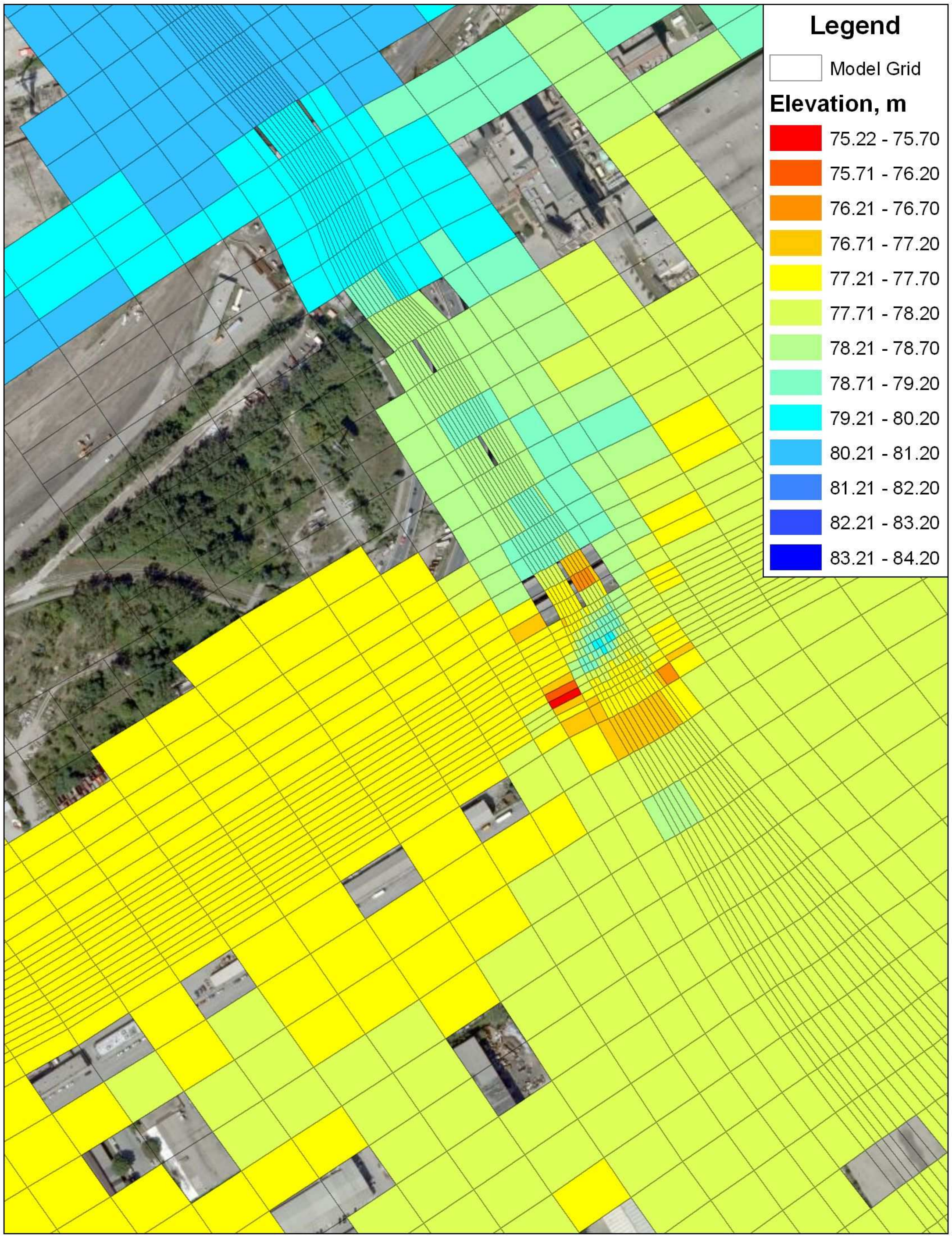
0 100 200 300 400 m

N

Existing Conditions
Regulatory Water Level (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

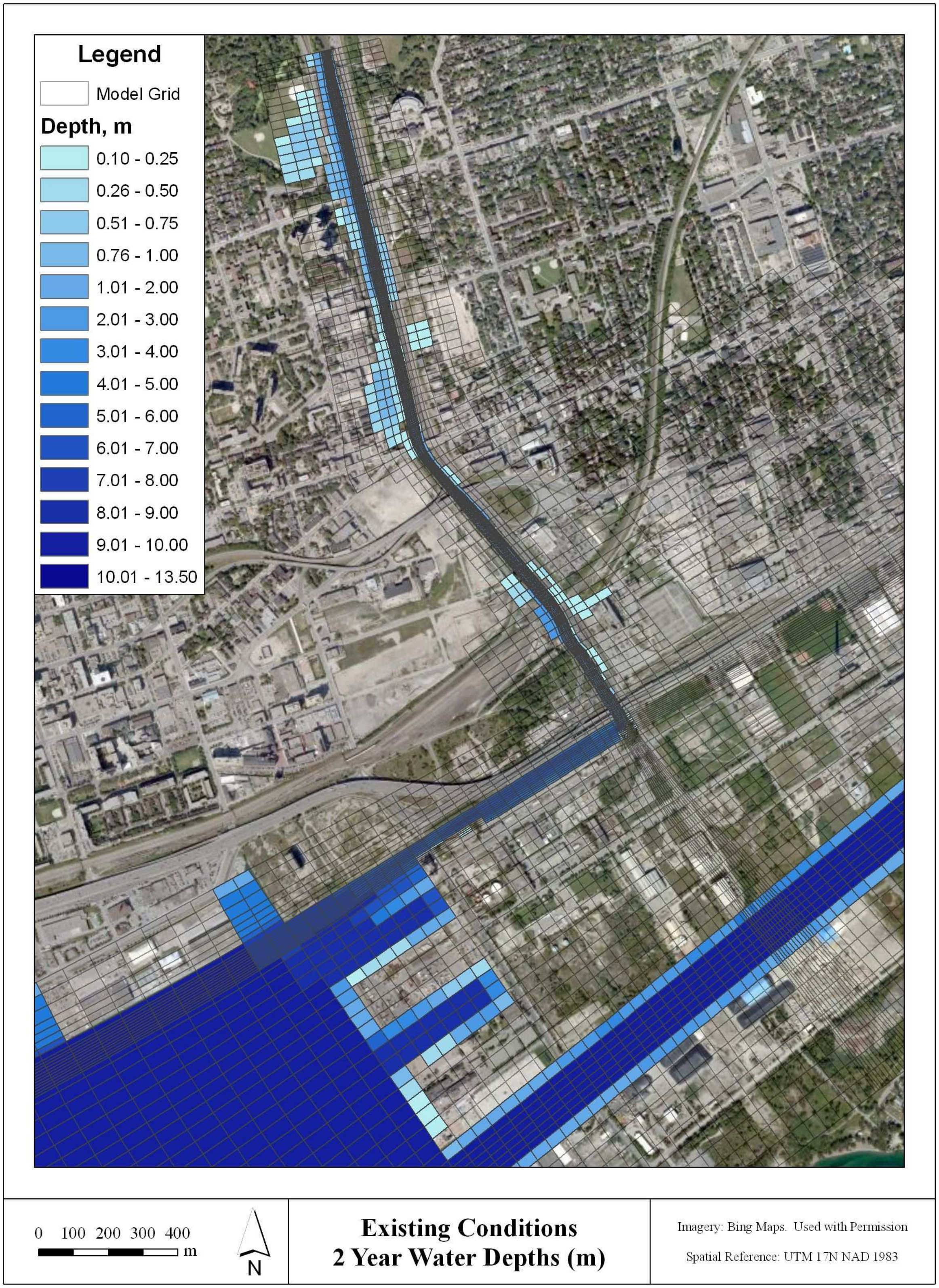


Existing Conditions
Regulatory Water Level (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

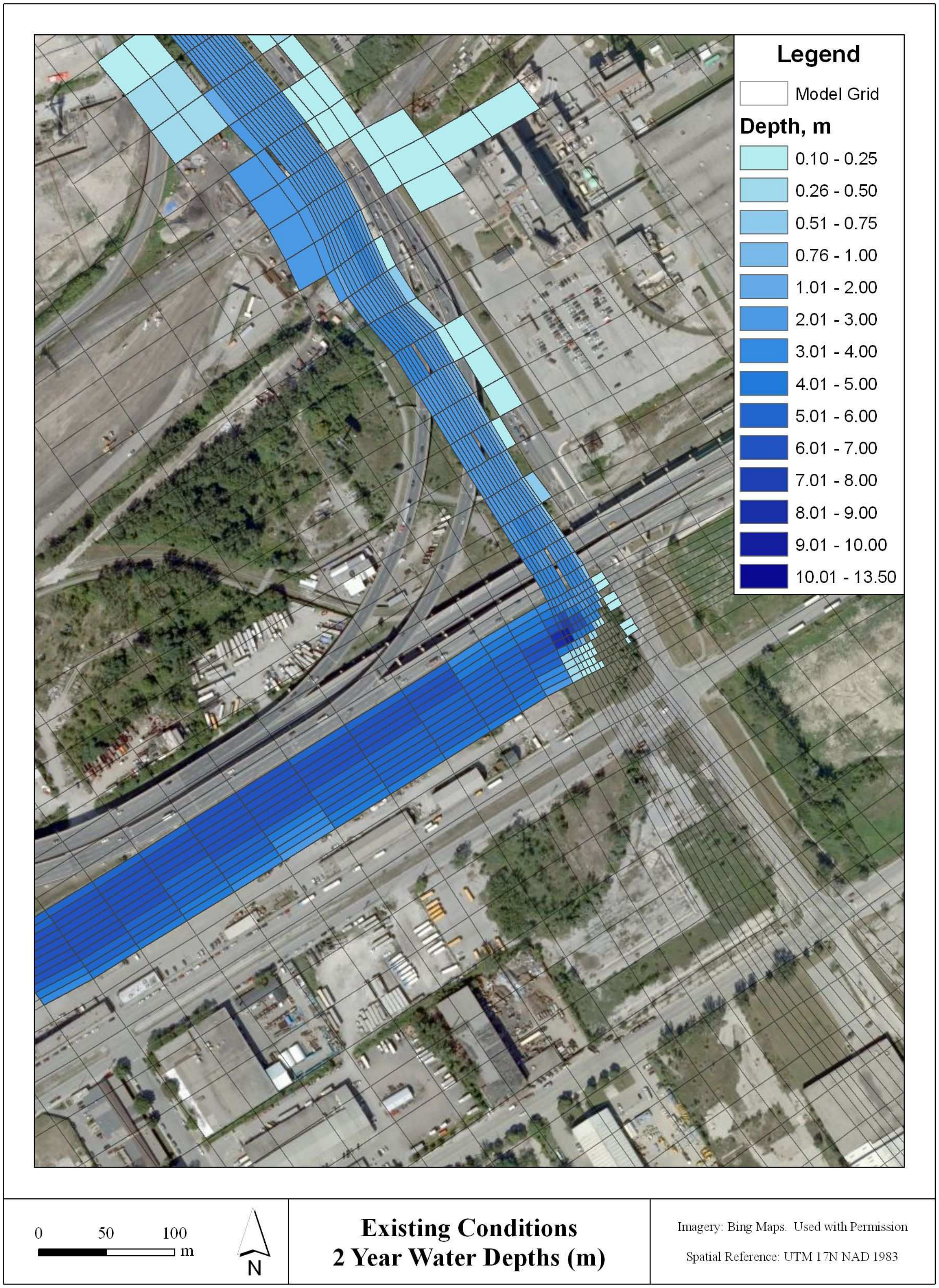
APPENDIX HD-B
EXISTING CONDITIONS WATER DEPTH MAPS



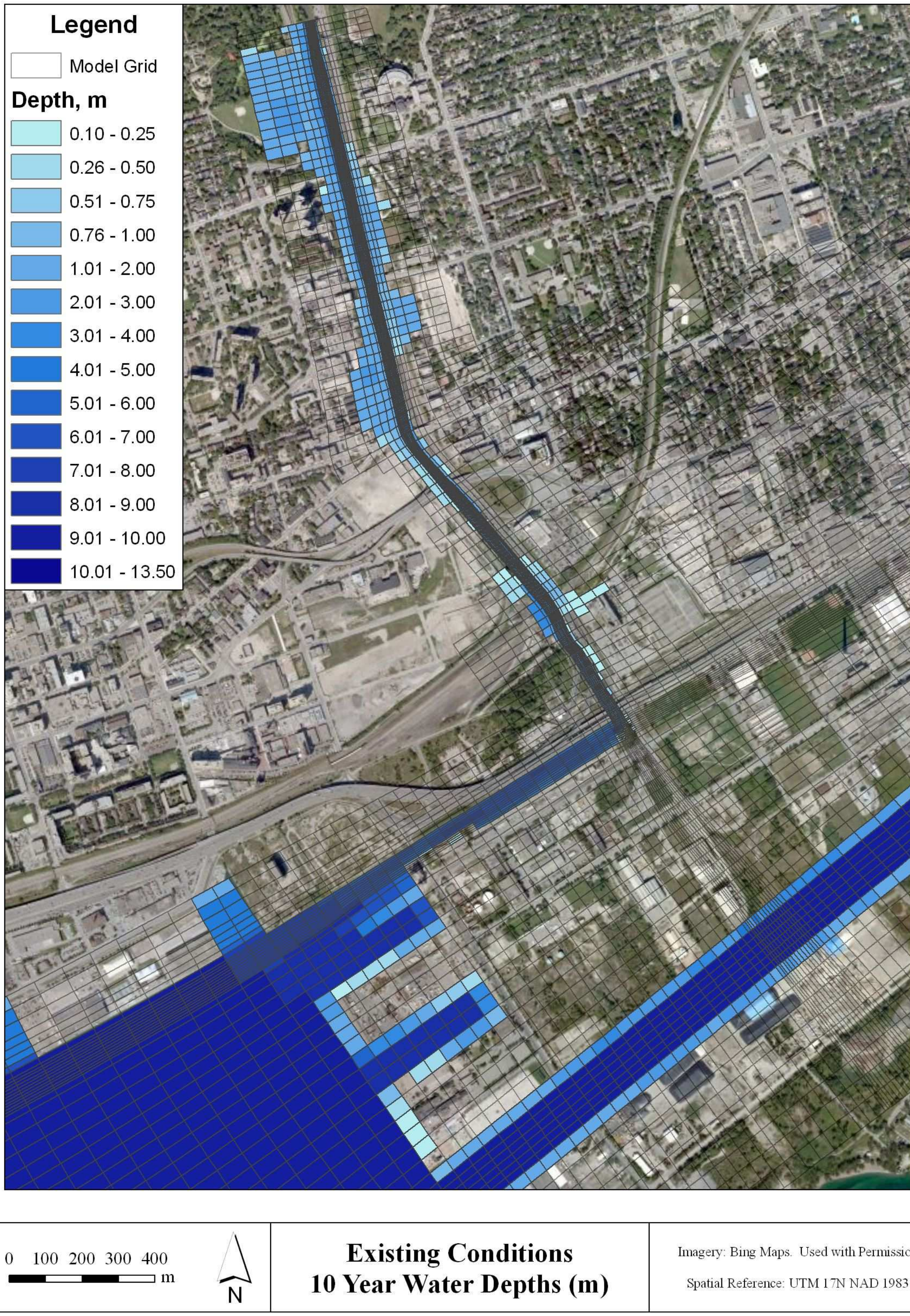
Existing Conditions
2 Year Water Depths (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



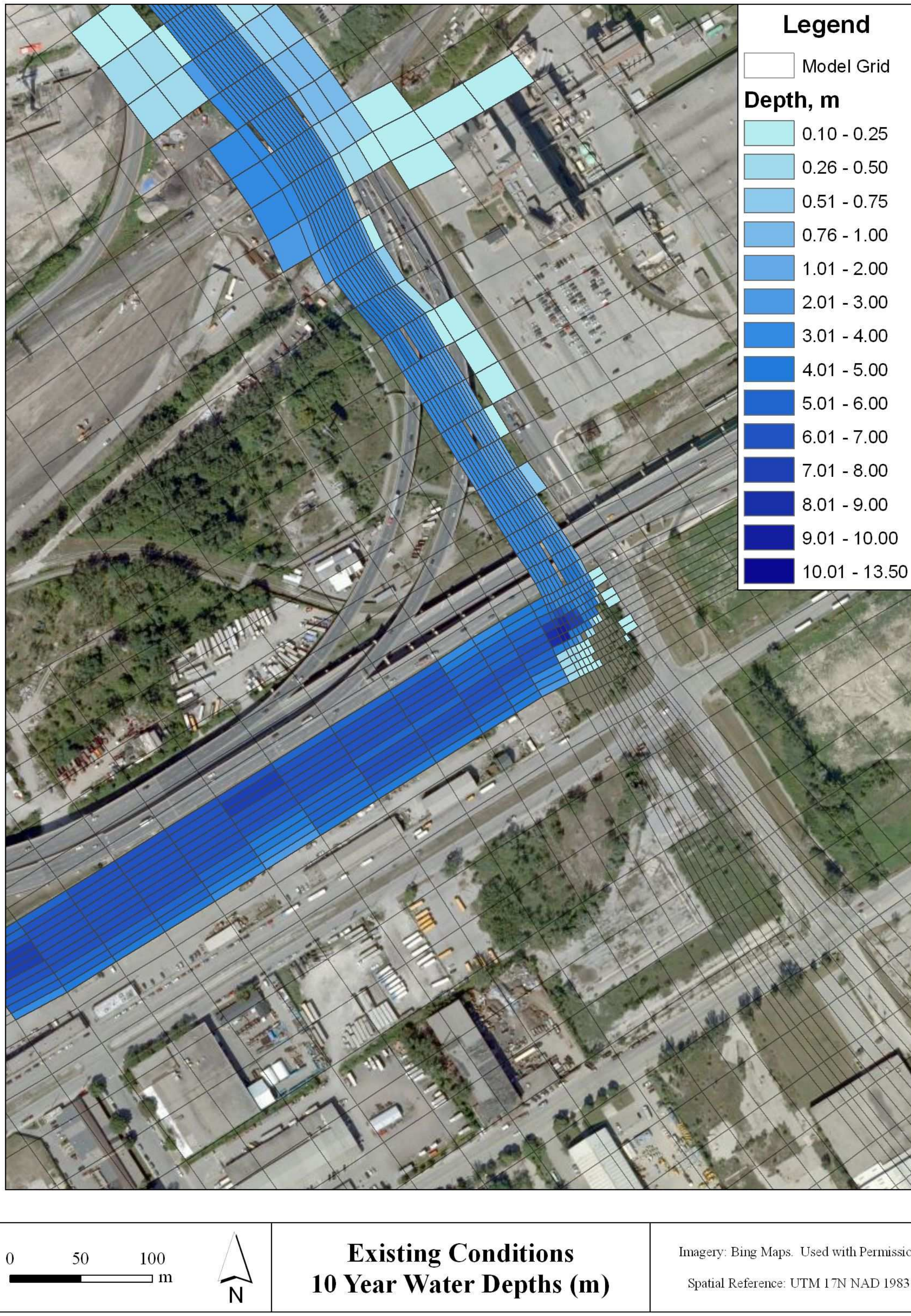
Existing Conditions
2 Year Water Depths (m)



Existing Conditions
10 Year Water Depths (m)

Imagery: Bing Maps. Used with Permission

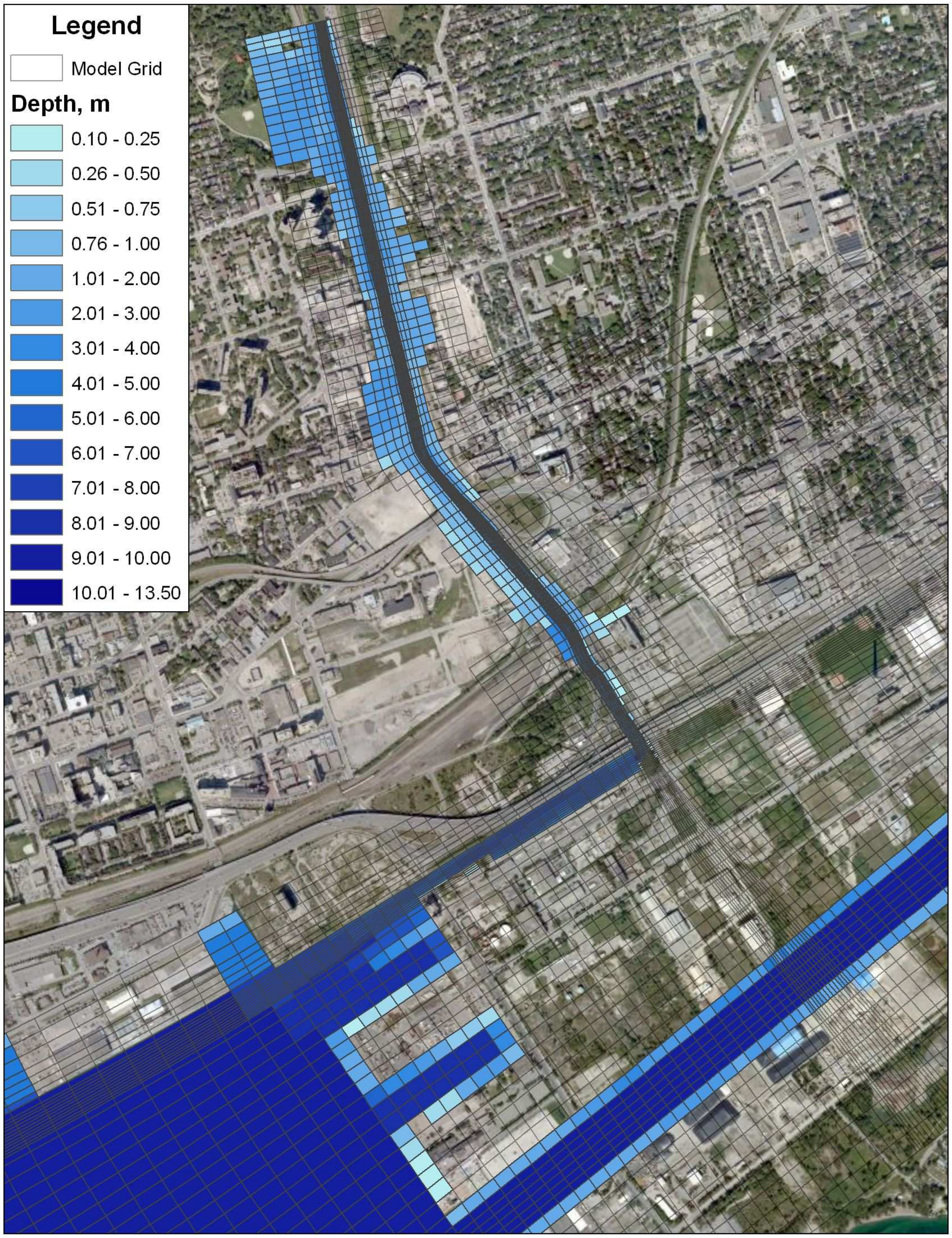
Spatial Reference: UTM 17N NAD 1983



Existing Conditions
10 Year Water Depths (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



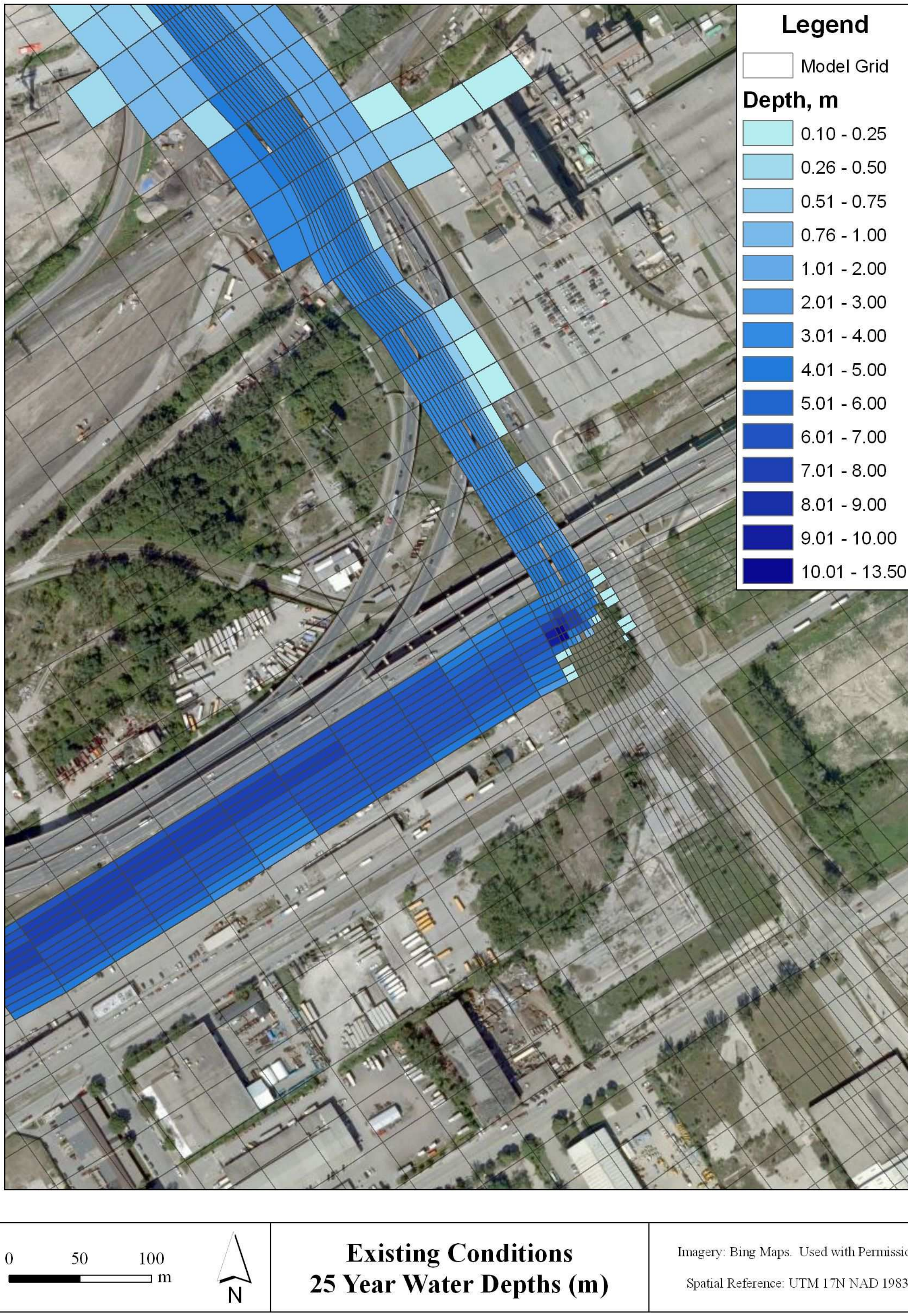
0 100 200 300 400 m

N

Existing Conditions
25 Year Water Depths (m)

Imagery: Bing Maps. Used with Permission

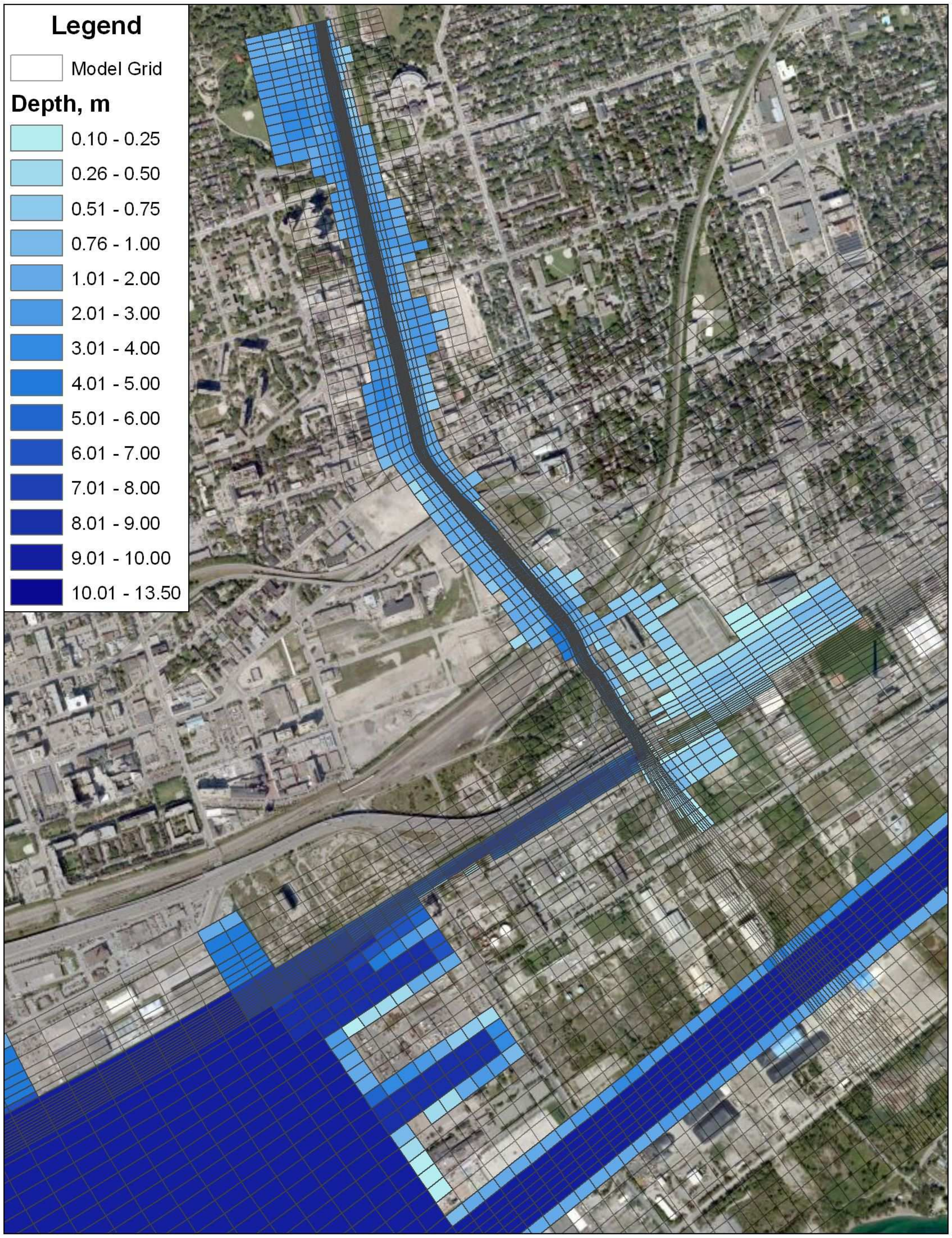
Spatial Reference: UTM 17N NAD 1983



Existing Conditions
25 Year Water Depths (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



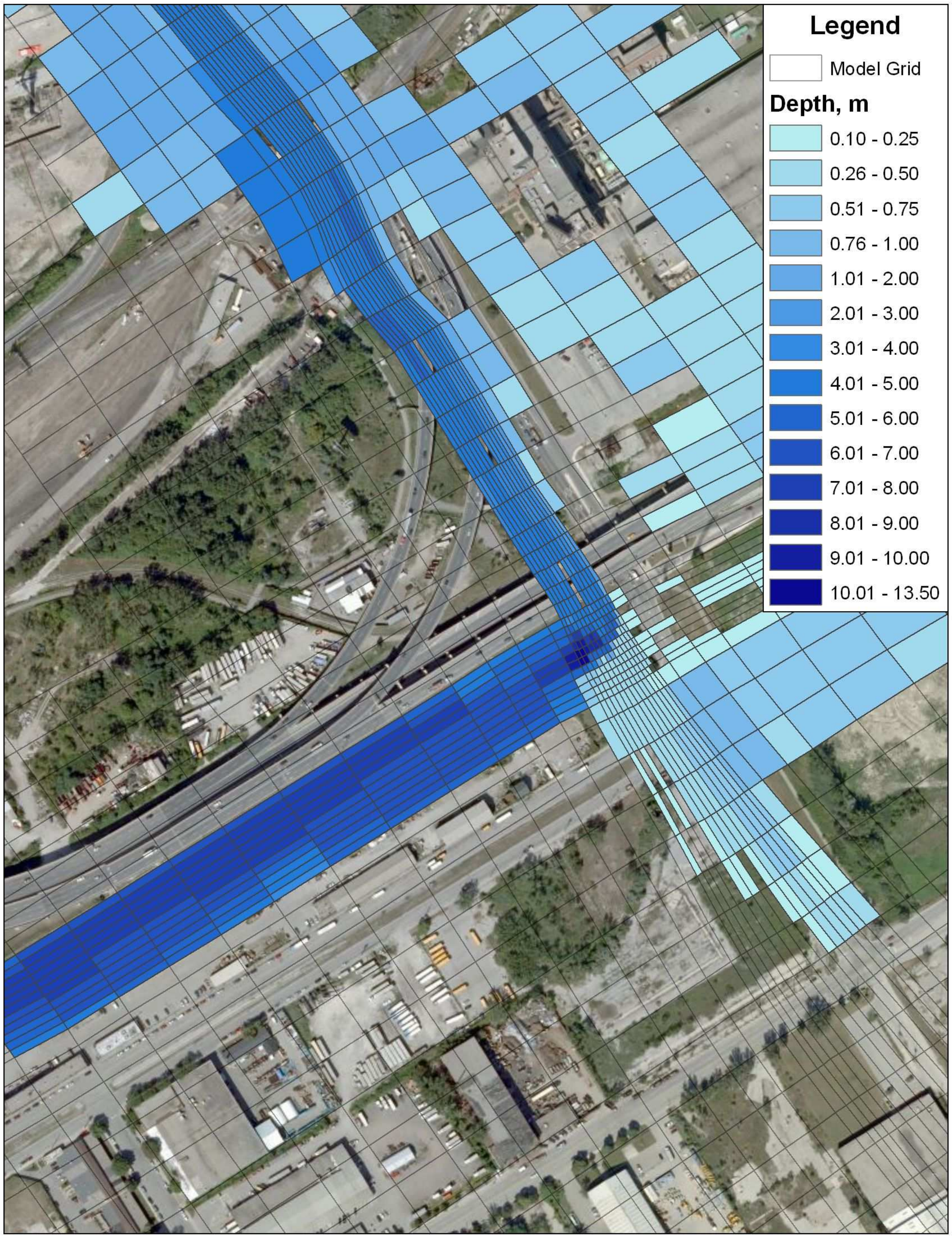
0 100 200 300 400 m

N

Existing Conditions
100 Year Water Depths (m)

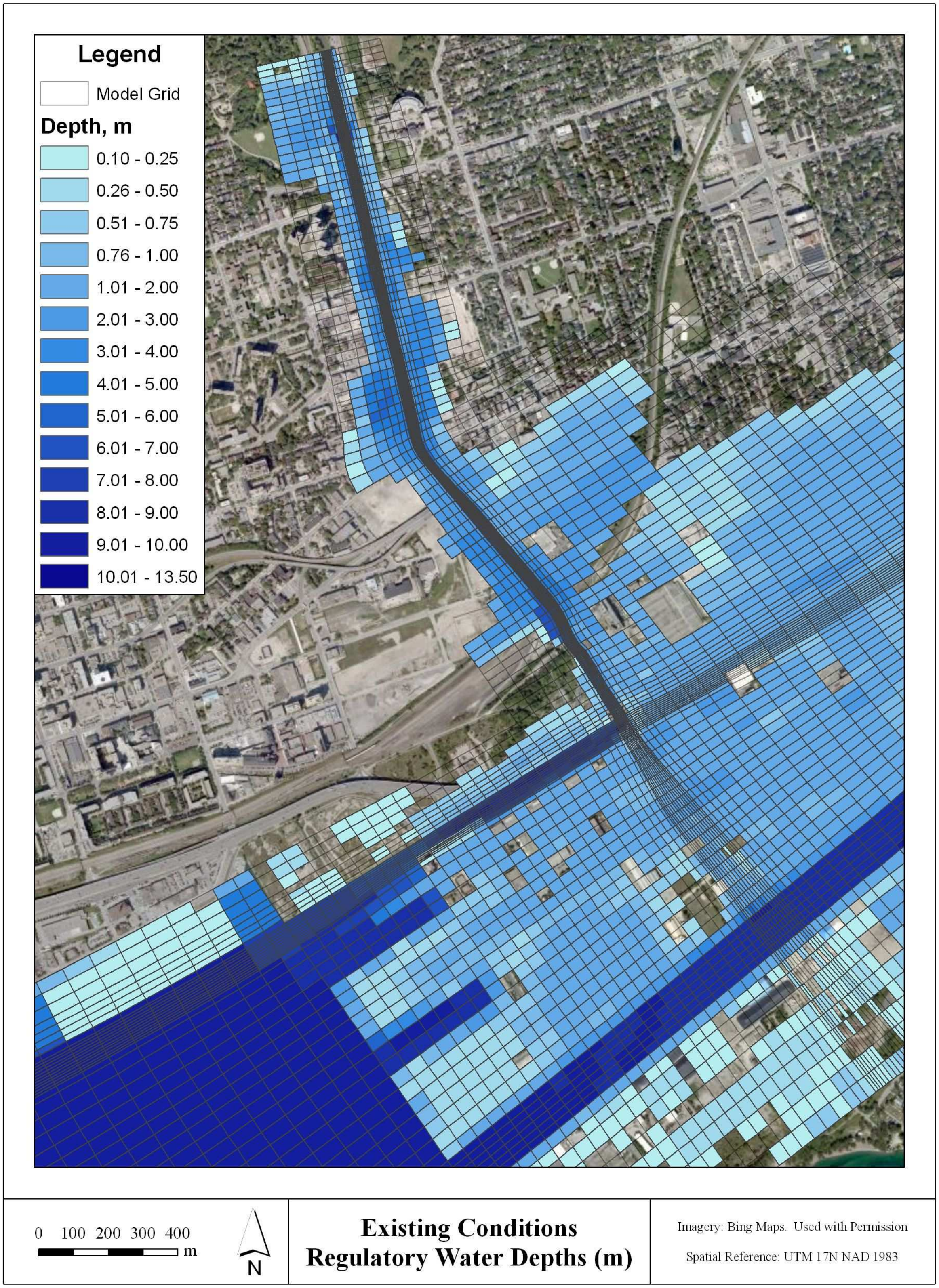
Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



Existing Conditions
100 Year Water Depths (m)

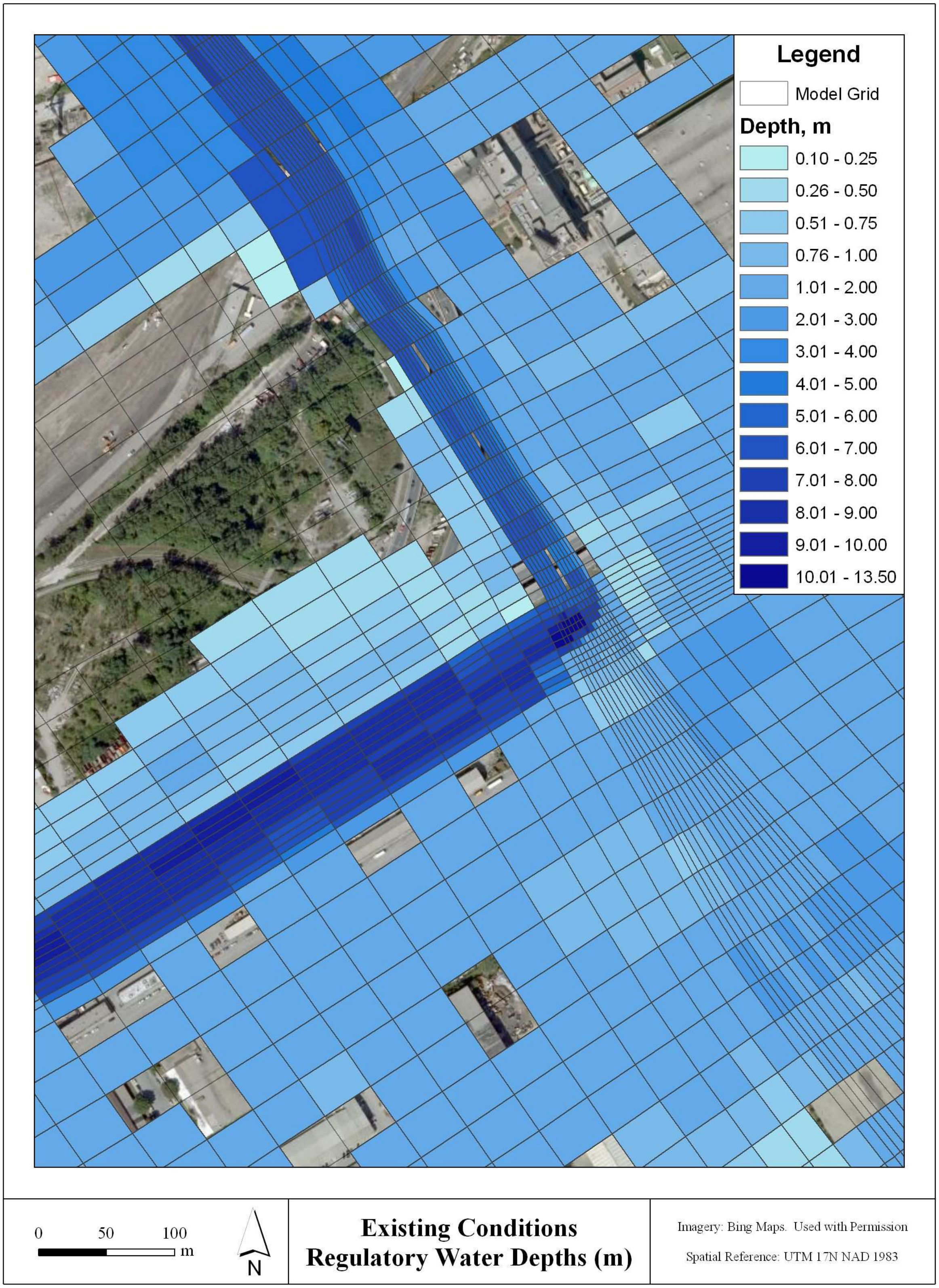
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983



Existing Conditions
Regulatory Water Depths (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

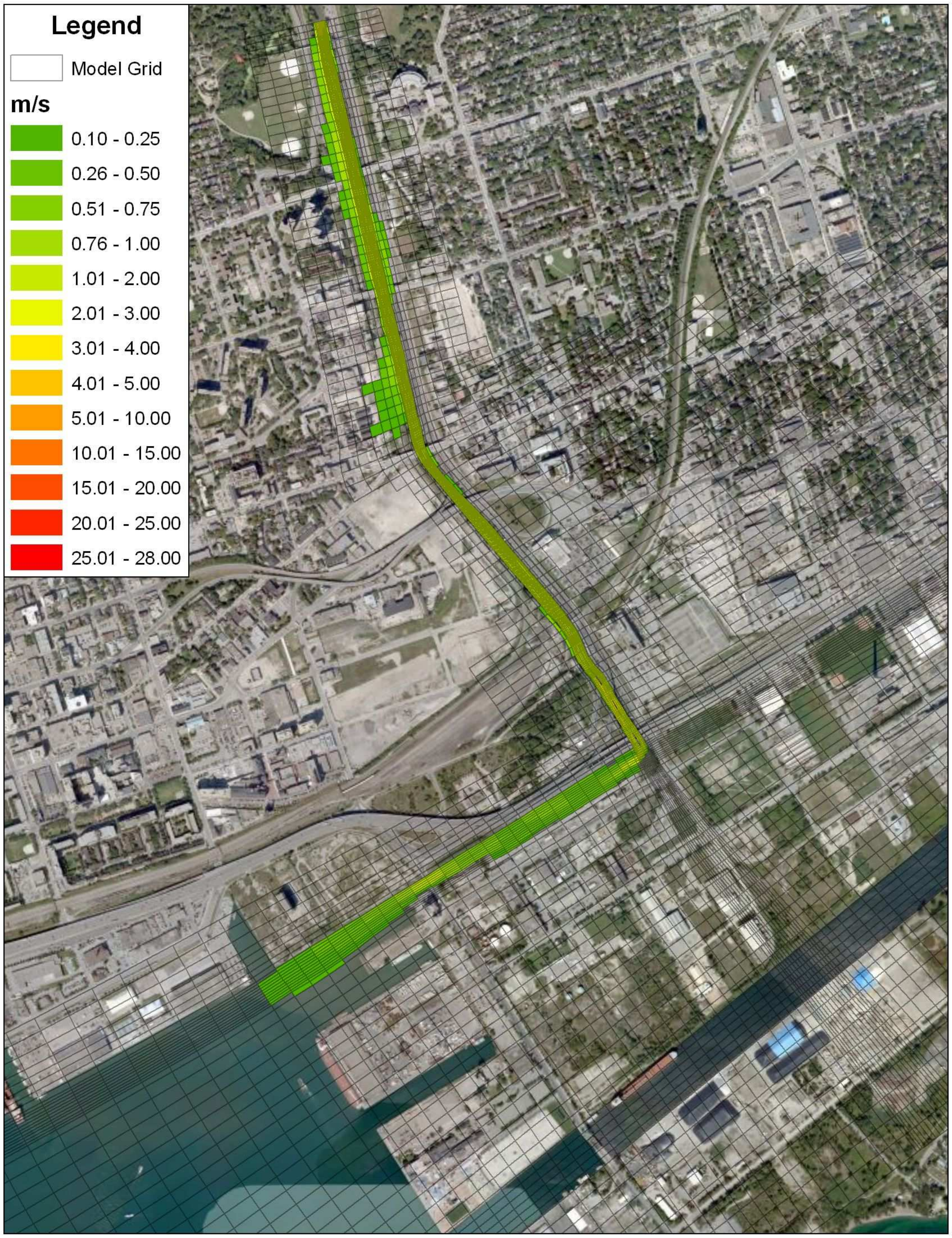


Existing Conditions
Regulatory Water Depths (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

APPENDIX HD-C
EXISTING CONDITIONS FLOW VELOCITY MAPS



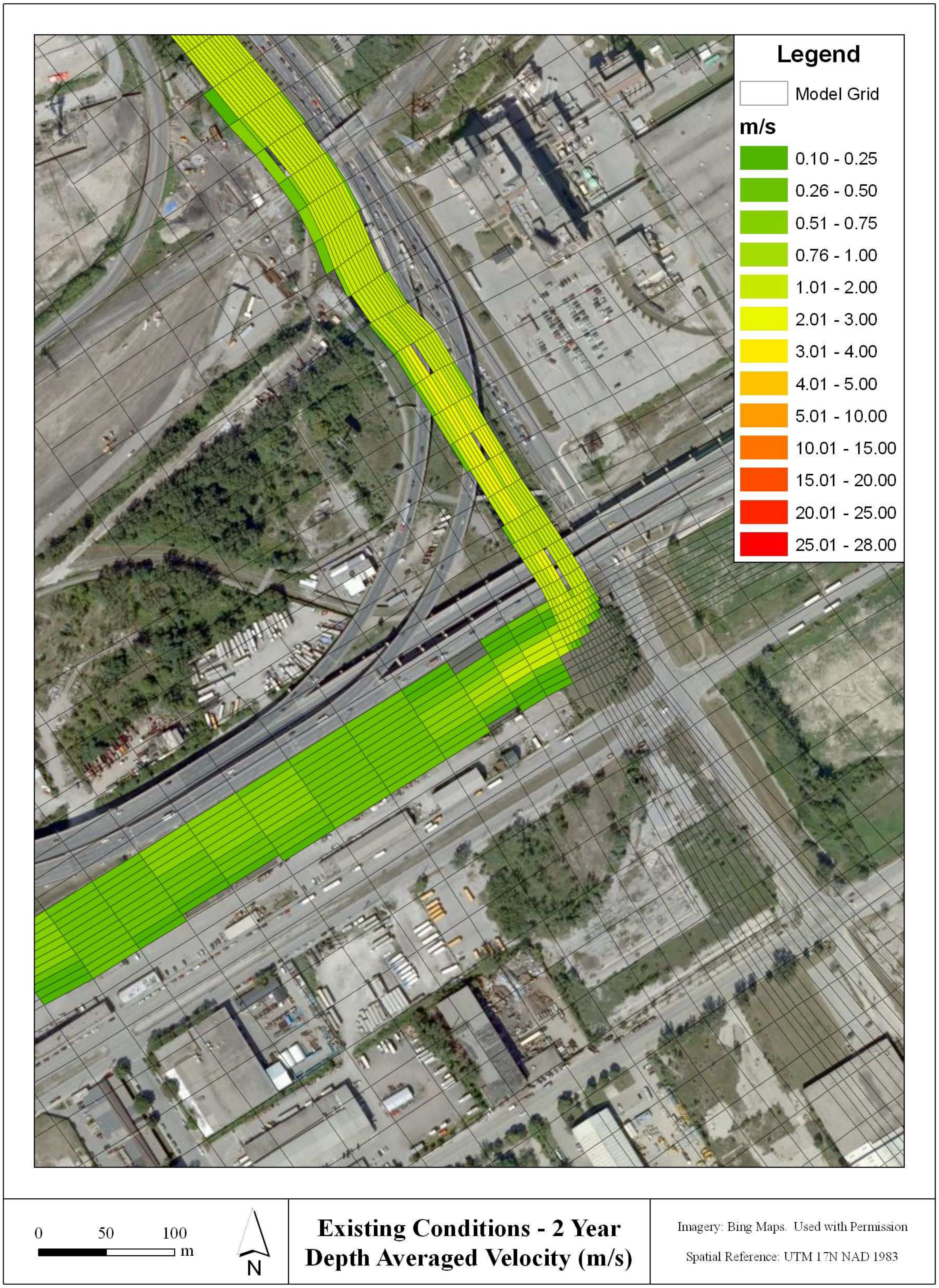
0 100 200 300 400 m

N

Existing Conditions - 2 Year Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

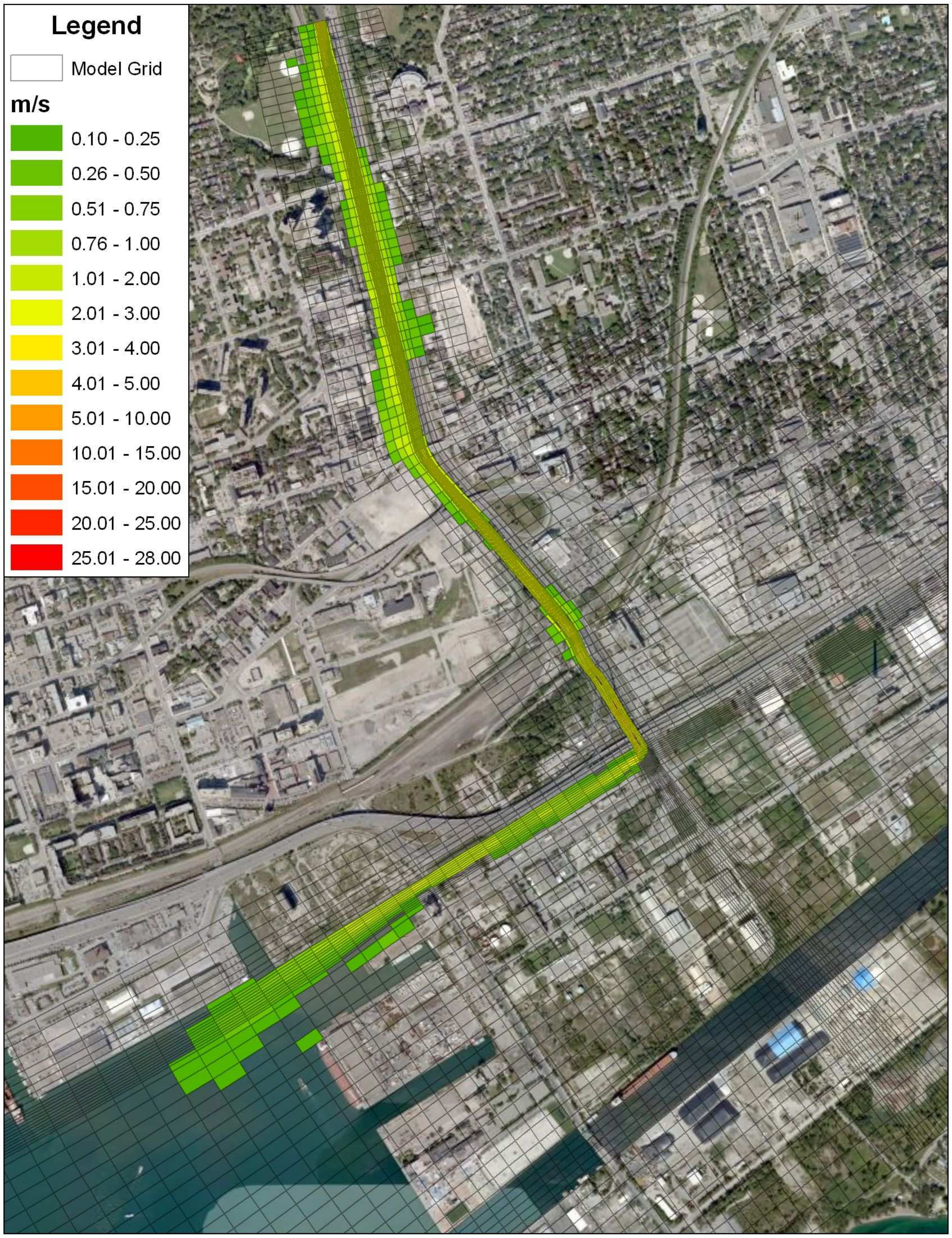
Spatial Reference: UTM 17N NAD 1983



Existing Conditions - 2 Year Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



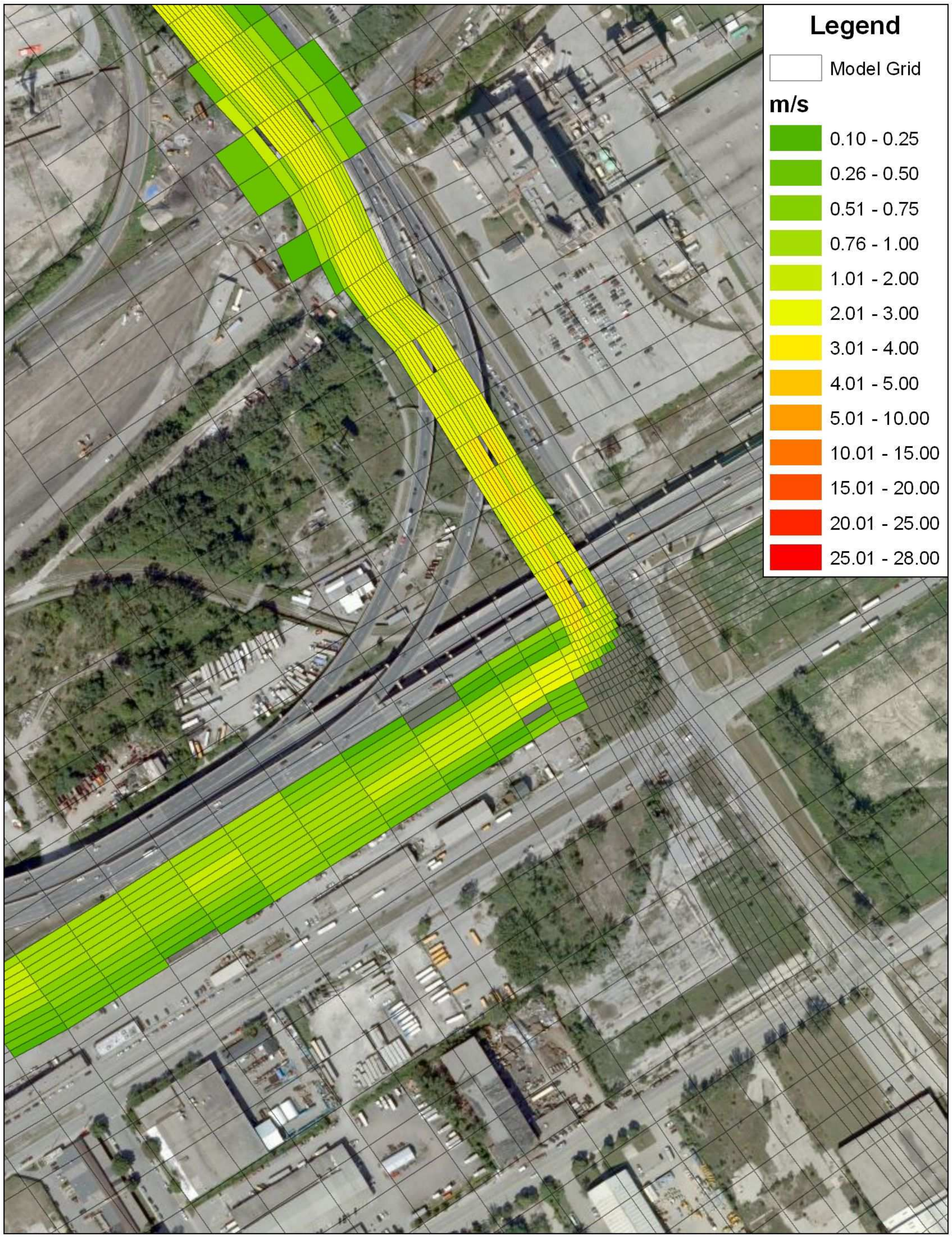
0 100 200 300 400 m

N

Existing Conditions - 10 Year Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

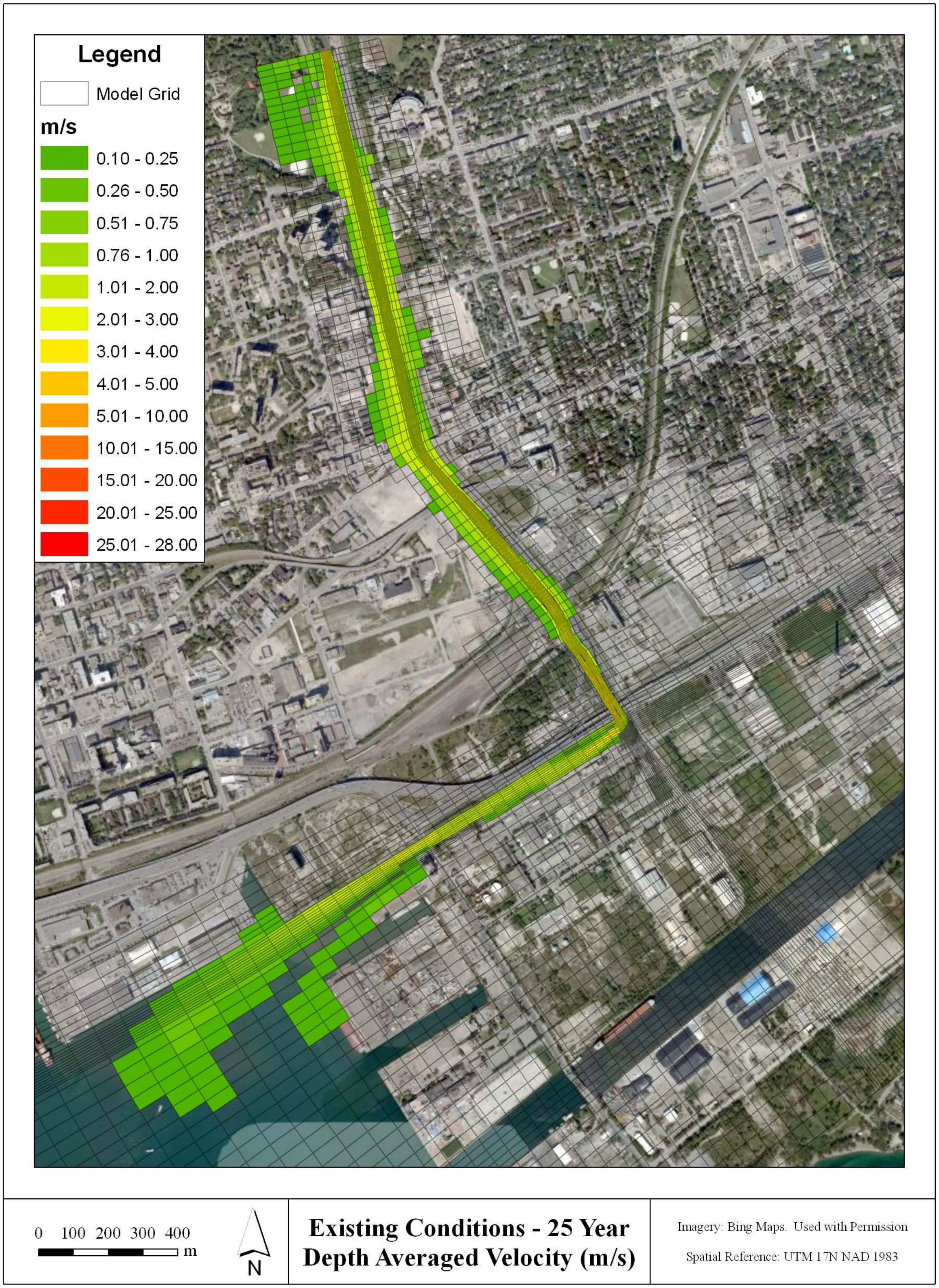
Spatial Reference: UTM 17N NAD 1983



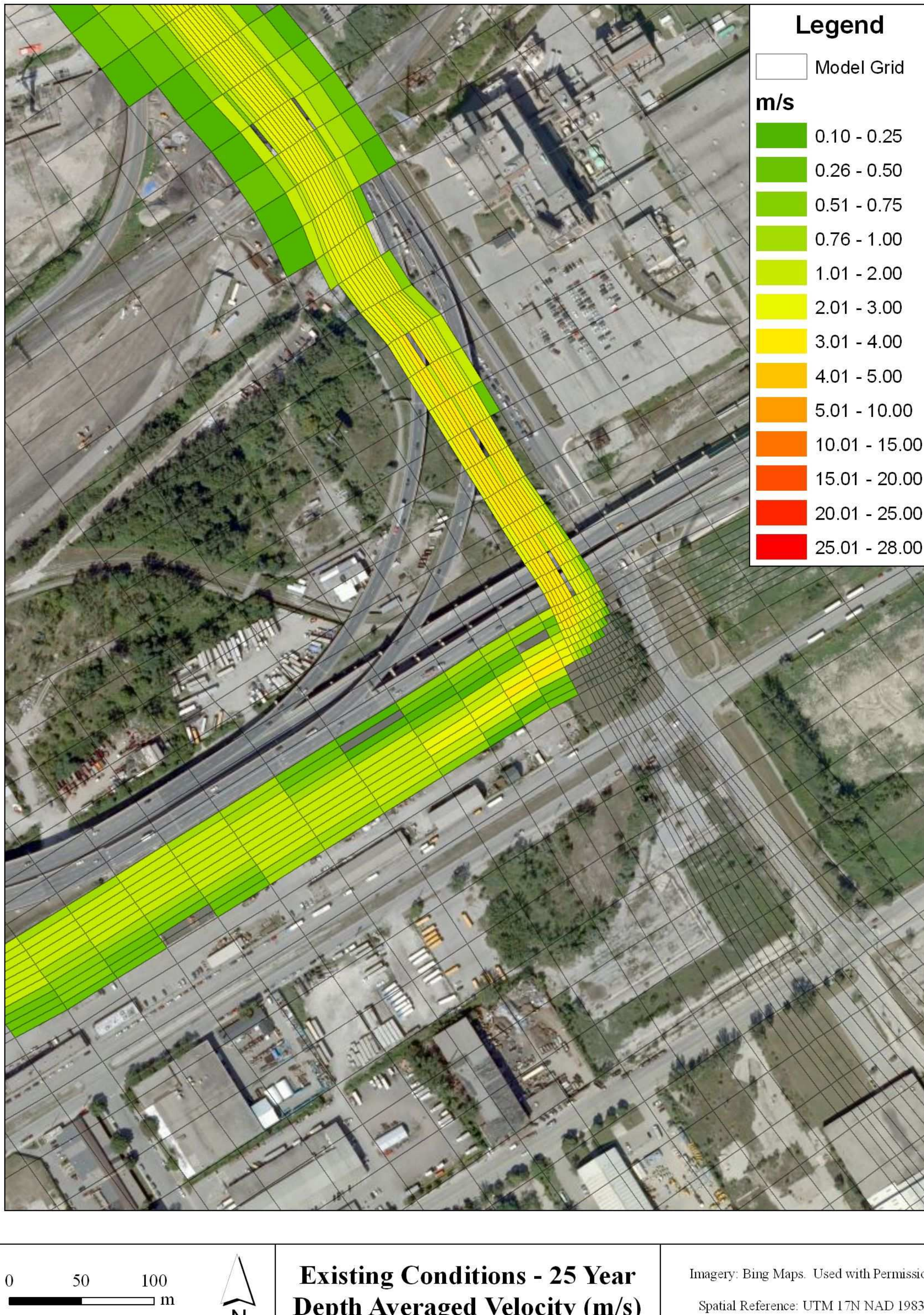
Existing Conditions - 10 Year Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



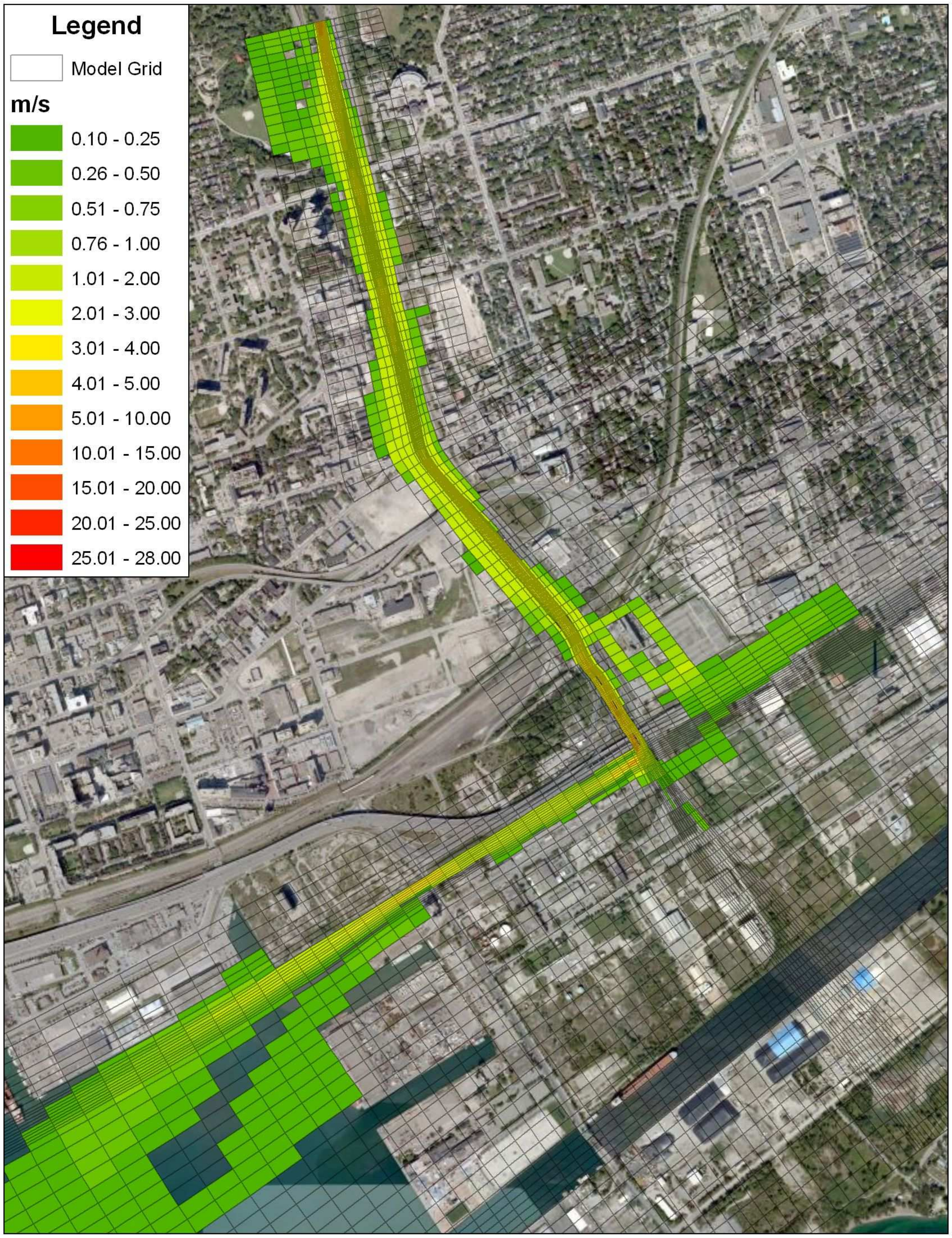
Existing Conditions - 25 Year Depth Averaged Velocity (m/s)



Existing Conditions - 25 Year Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



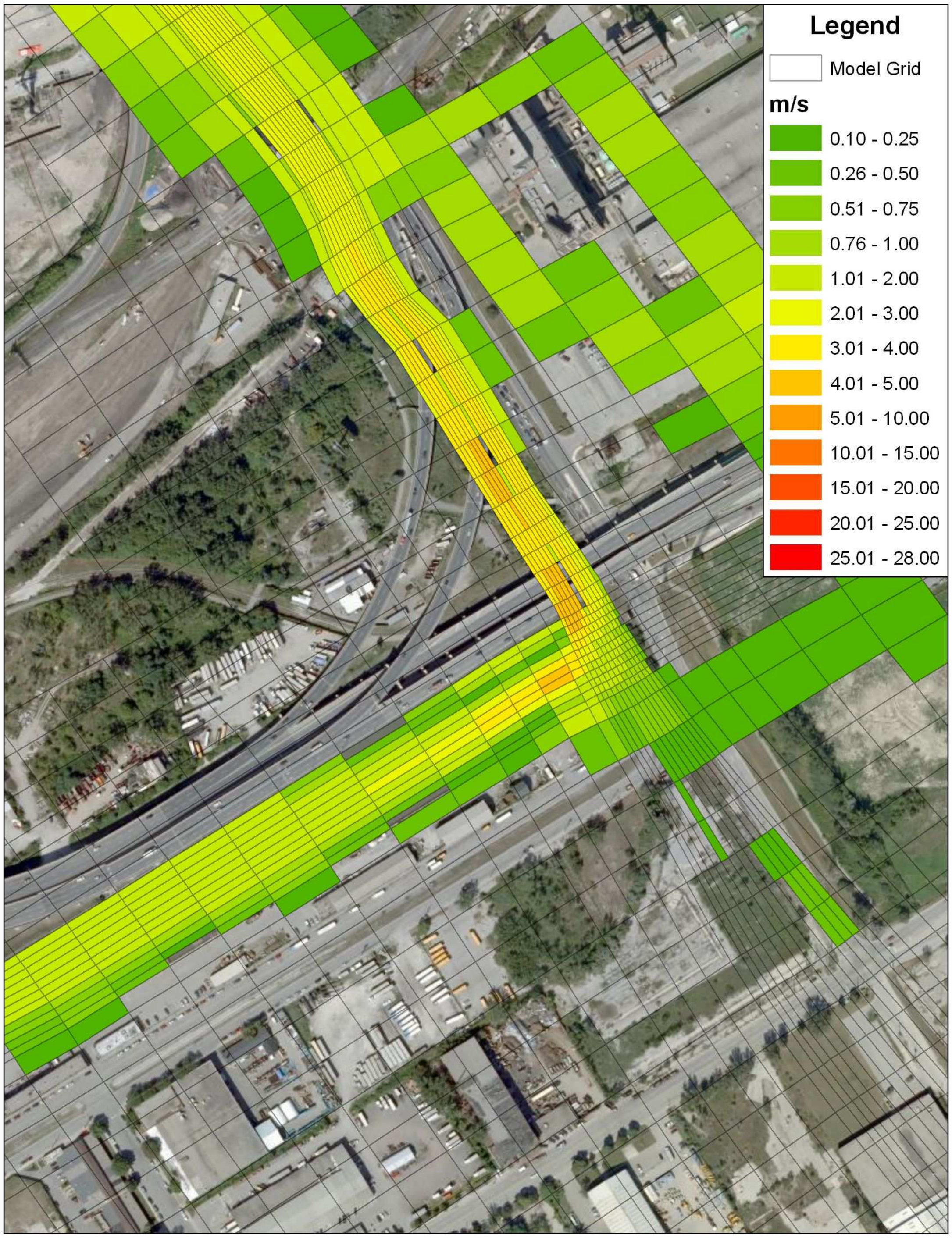
0 100 200 300 400 m

N

Existing Conditions - 100 Year Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

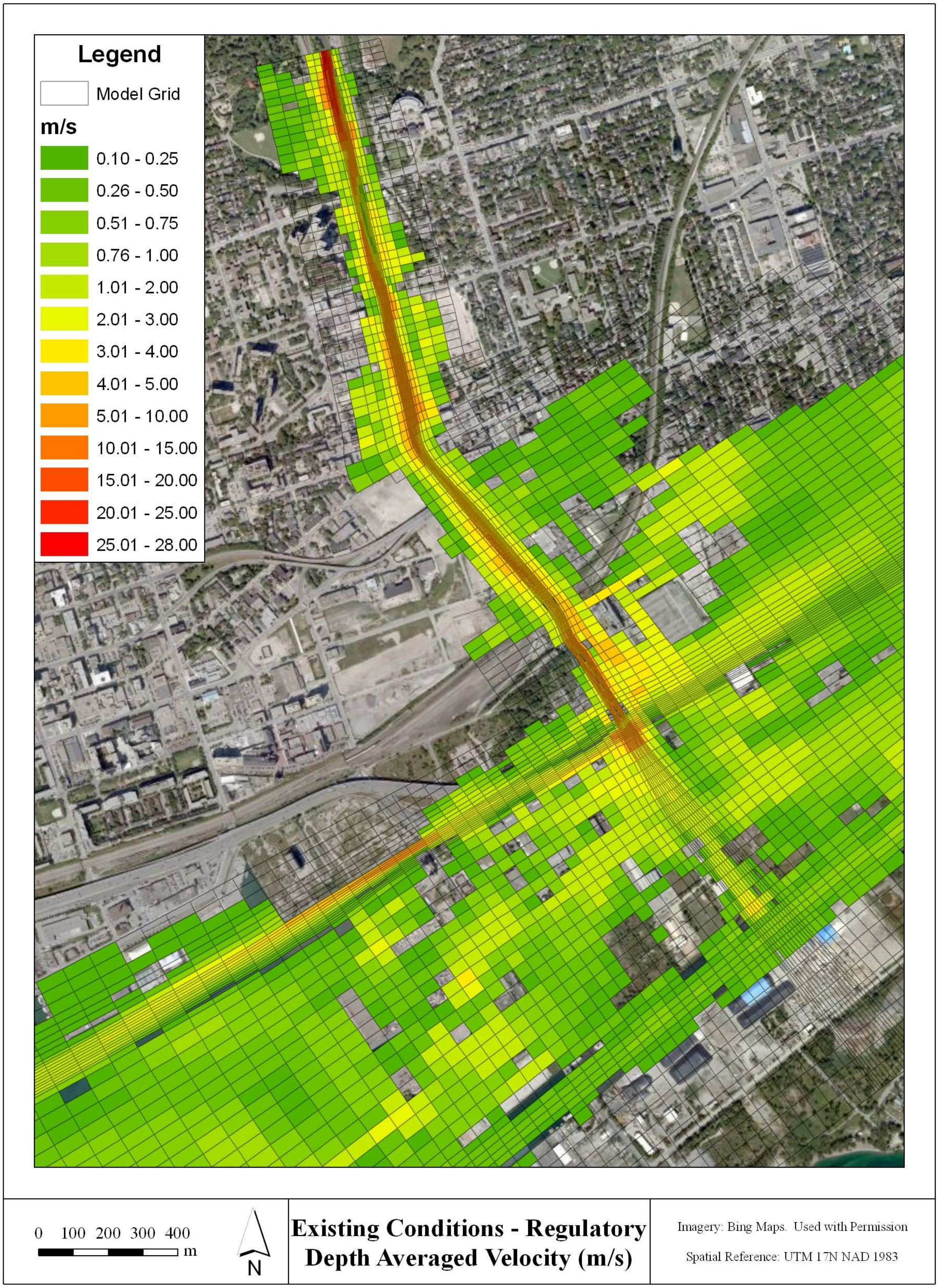
Spatial Reference: UTM 17N NAD 1983

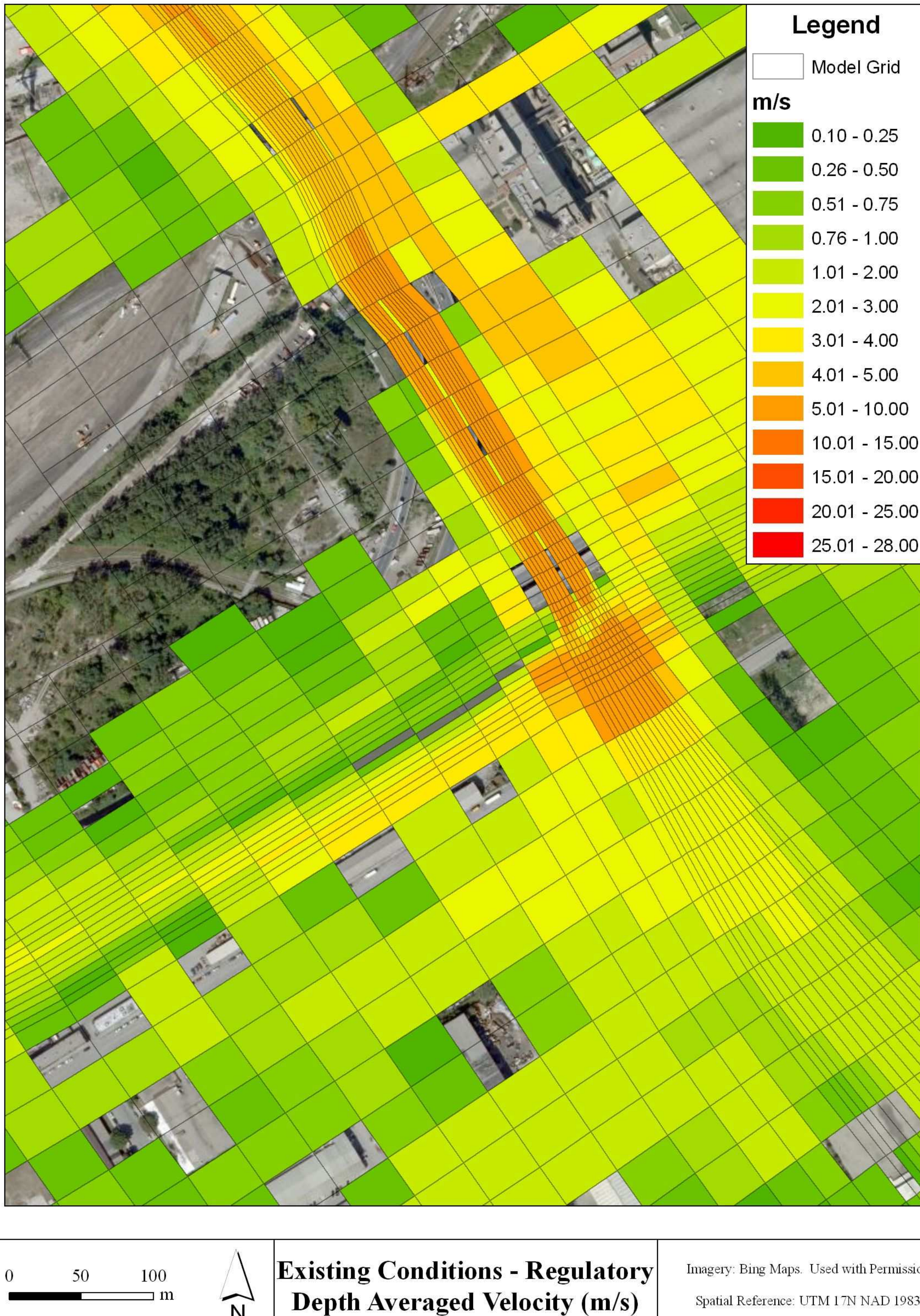


Existing Conditions - 100 Year Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983


Legend
Model Grid
m/s
0.10 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 28.00
0 100 200 300 400
m
N
Existing Conditions - Regulatory
Depth Averaged Velocity (m/s)
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983

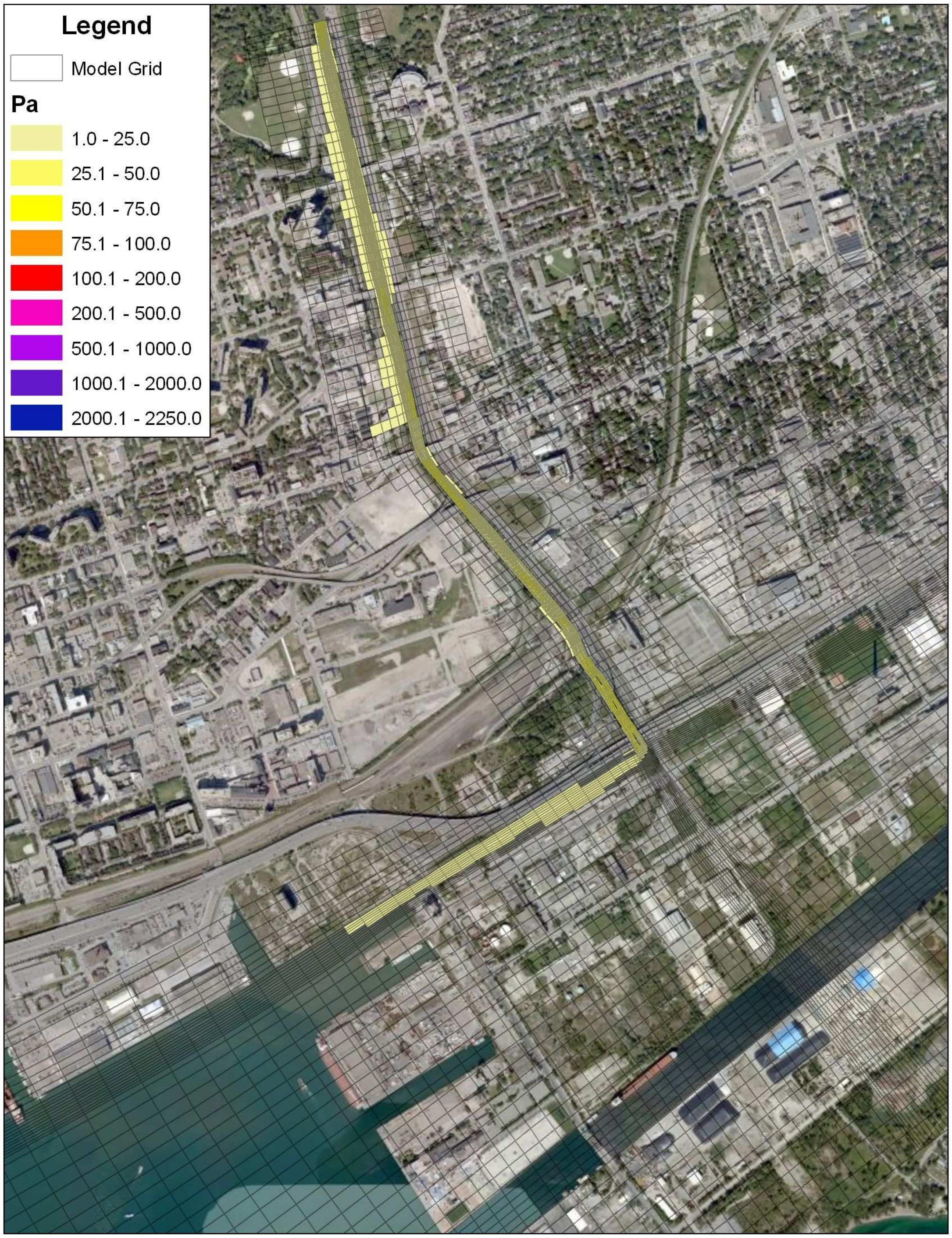


Existing Conditions - Regulatory
Depth Averaged Velocity (m/s)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

APPENDIX HD-D
EXISTING CONDITIONS BED SHEAR STRESS MAPS



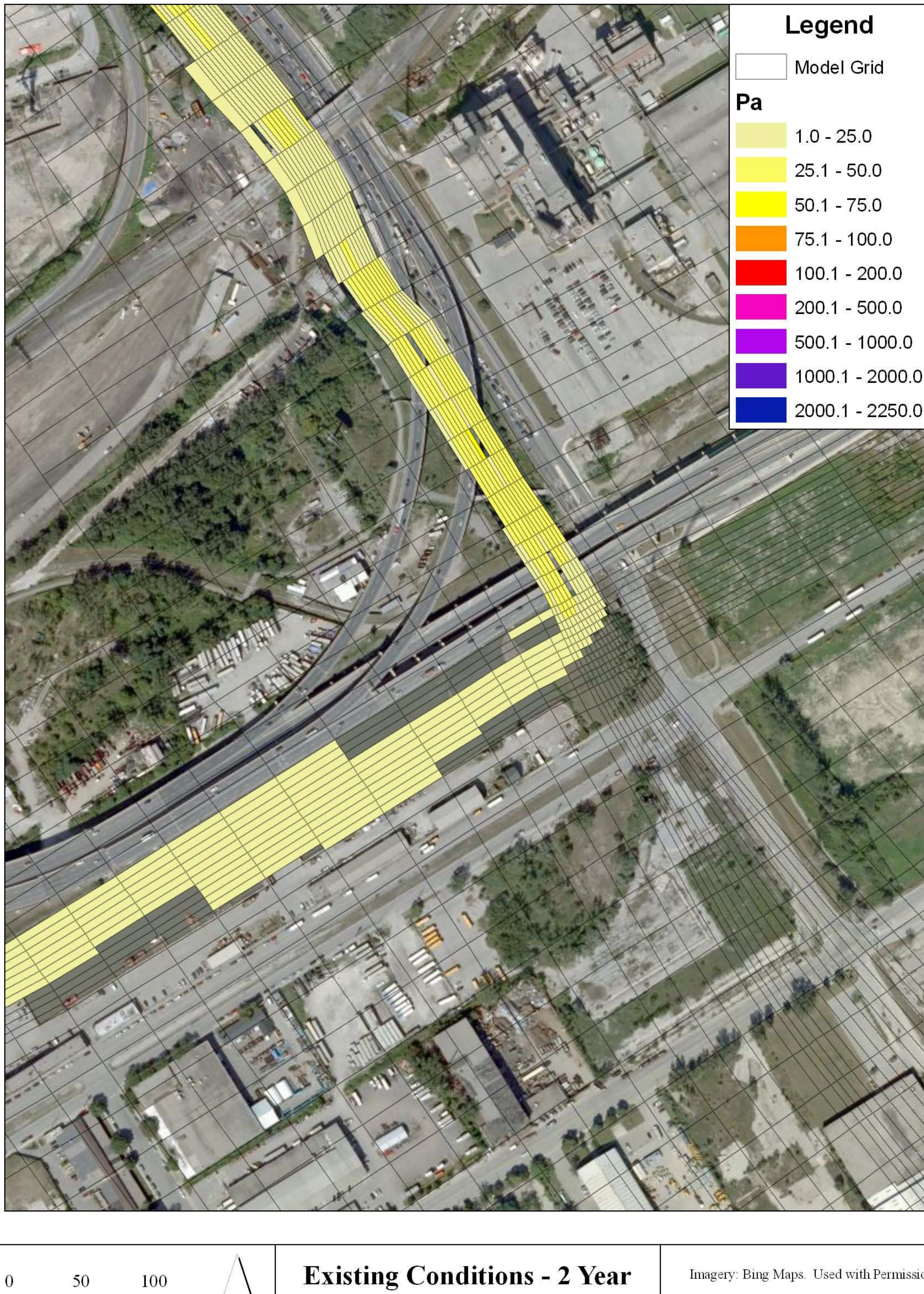
0 100 200 300 400 m

N

Existing Conditions - 2 Year Bed Shear Stress (Pa)

Imagery: Bing Maps. Used with Permission

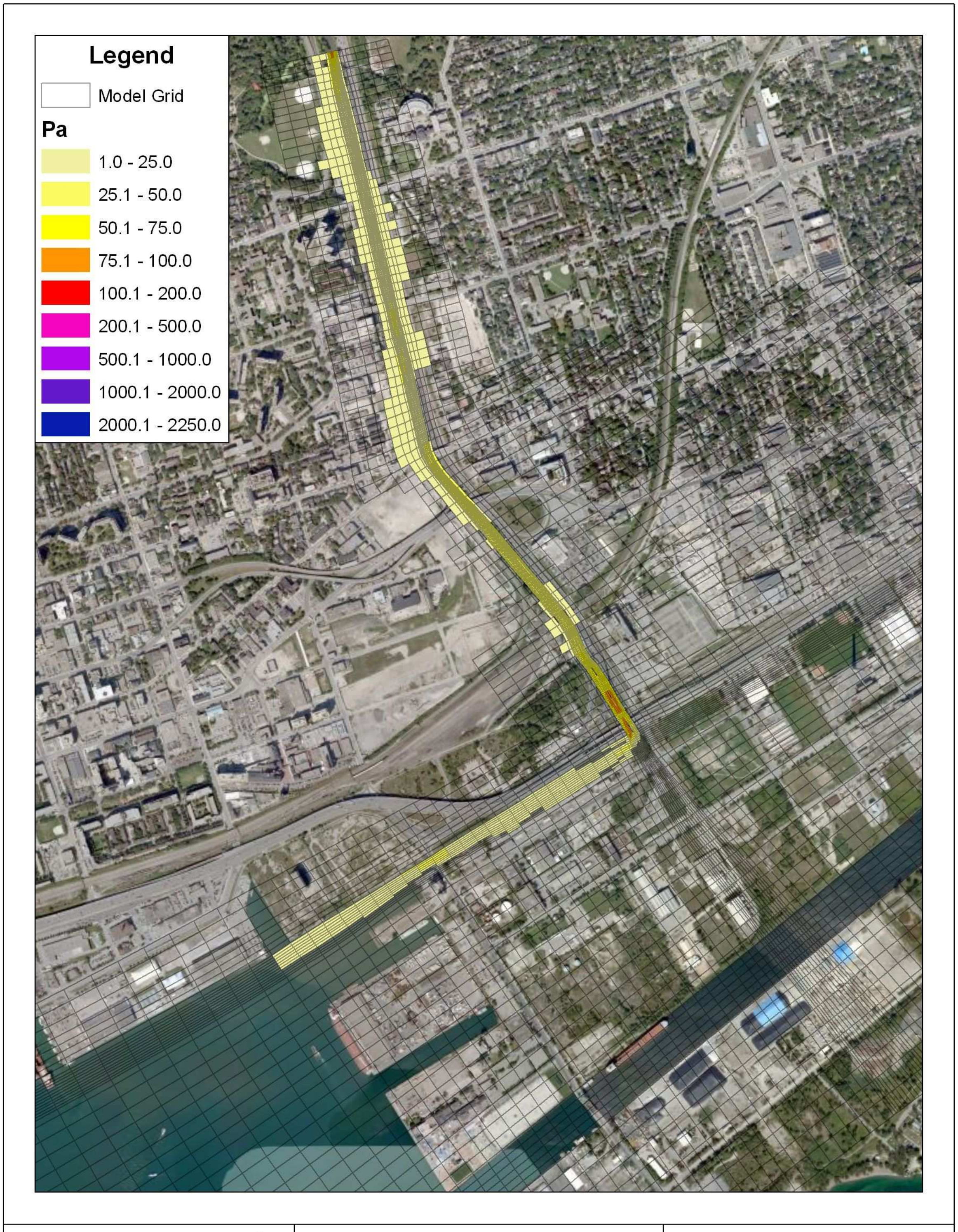
Spatial Reference: UTM 17N NAD 1983



Existing Conditions - 2 Year Bed Shear Stress (Pa)

Imagery: Bing Maps. Used with Permission

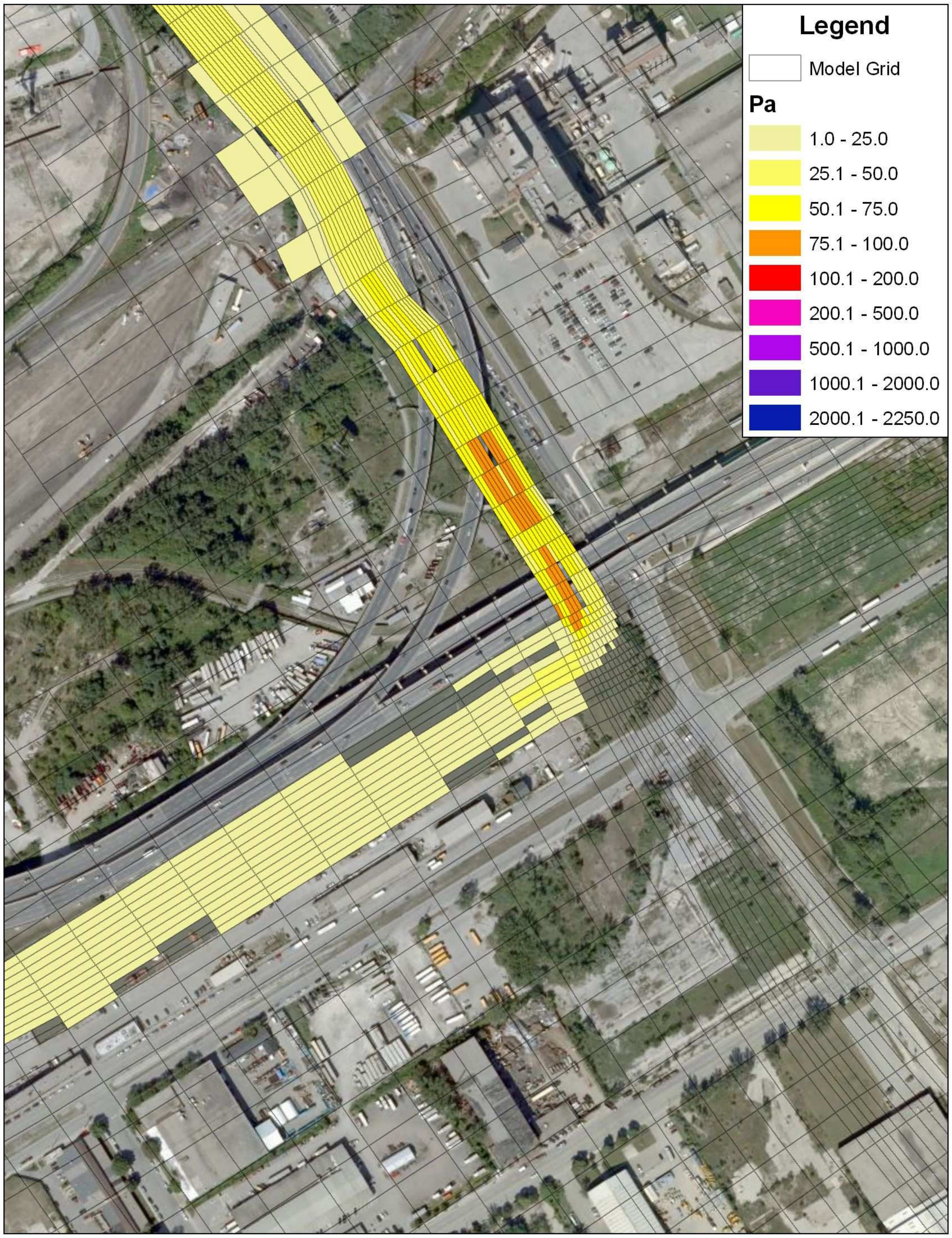
Spatial Reference: UTM 17N NAD 1983



Existing Conditions - 10 Year Bed Shear Stress (Pa)

Imagery: Bing Maps. Used with Permission

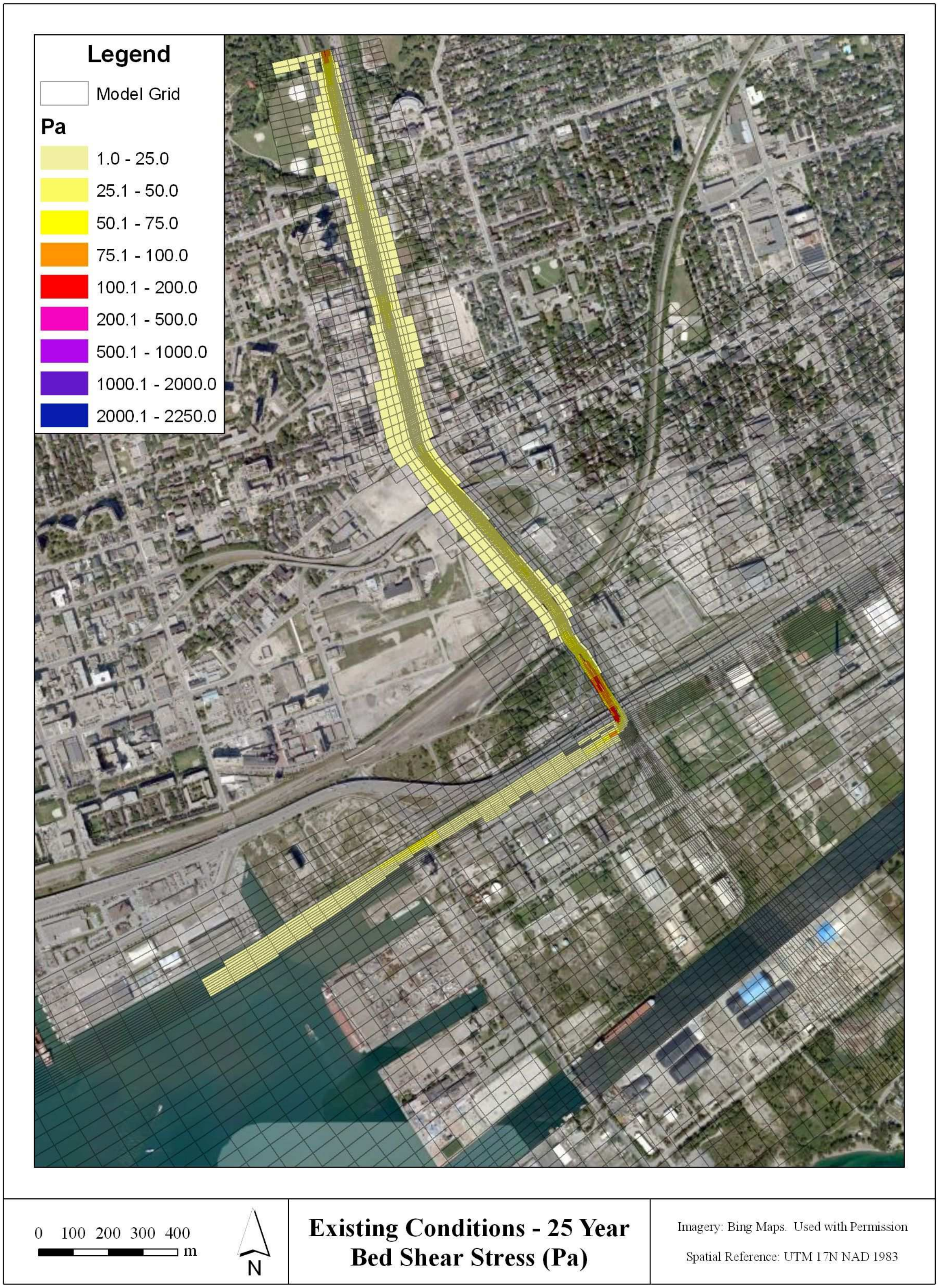
Spatial Reference: UTM 17N NAD 1983



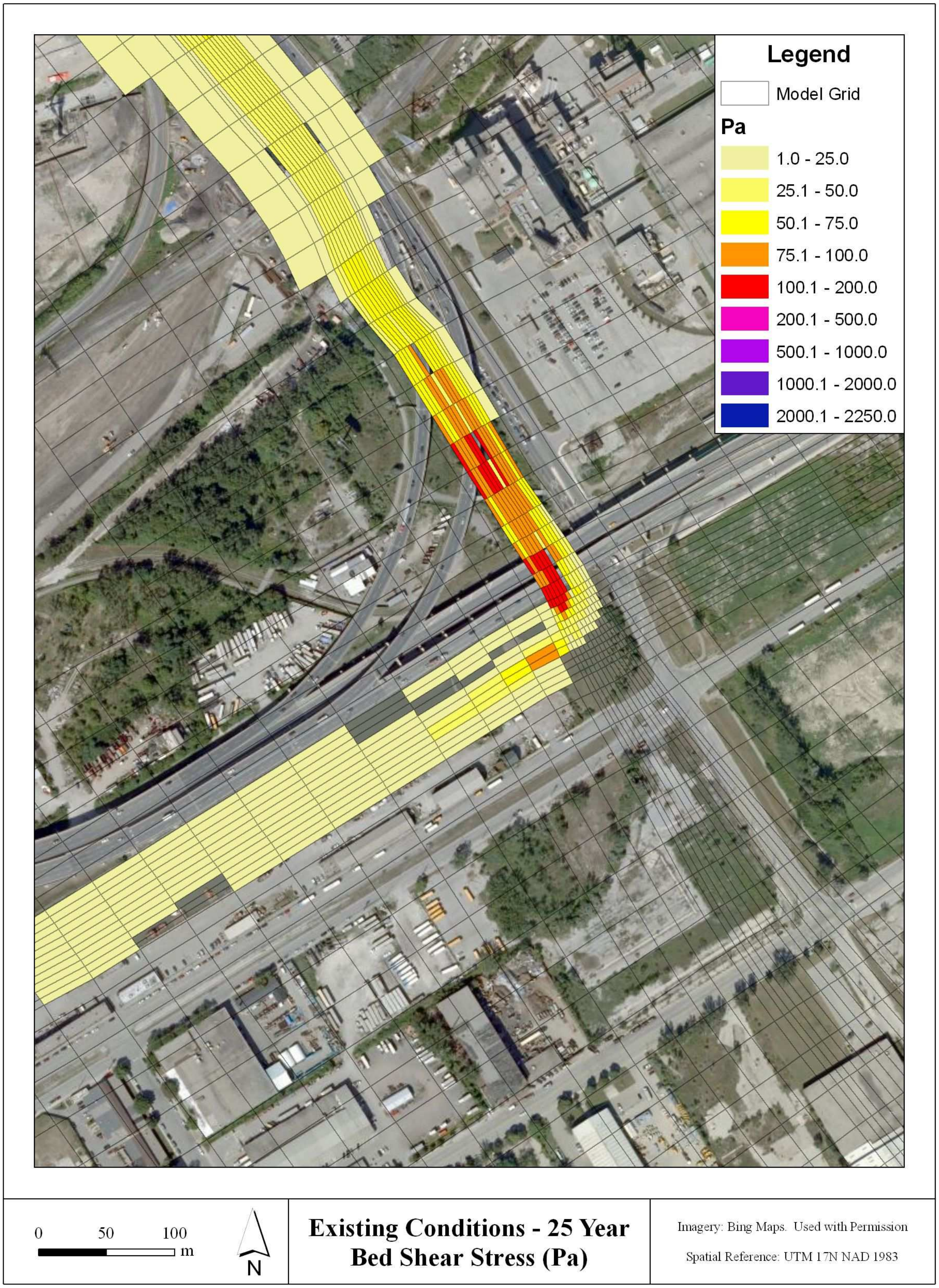
Existing Conditions - 10 Year Bed Shear Stress (Pa)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



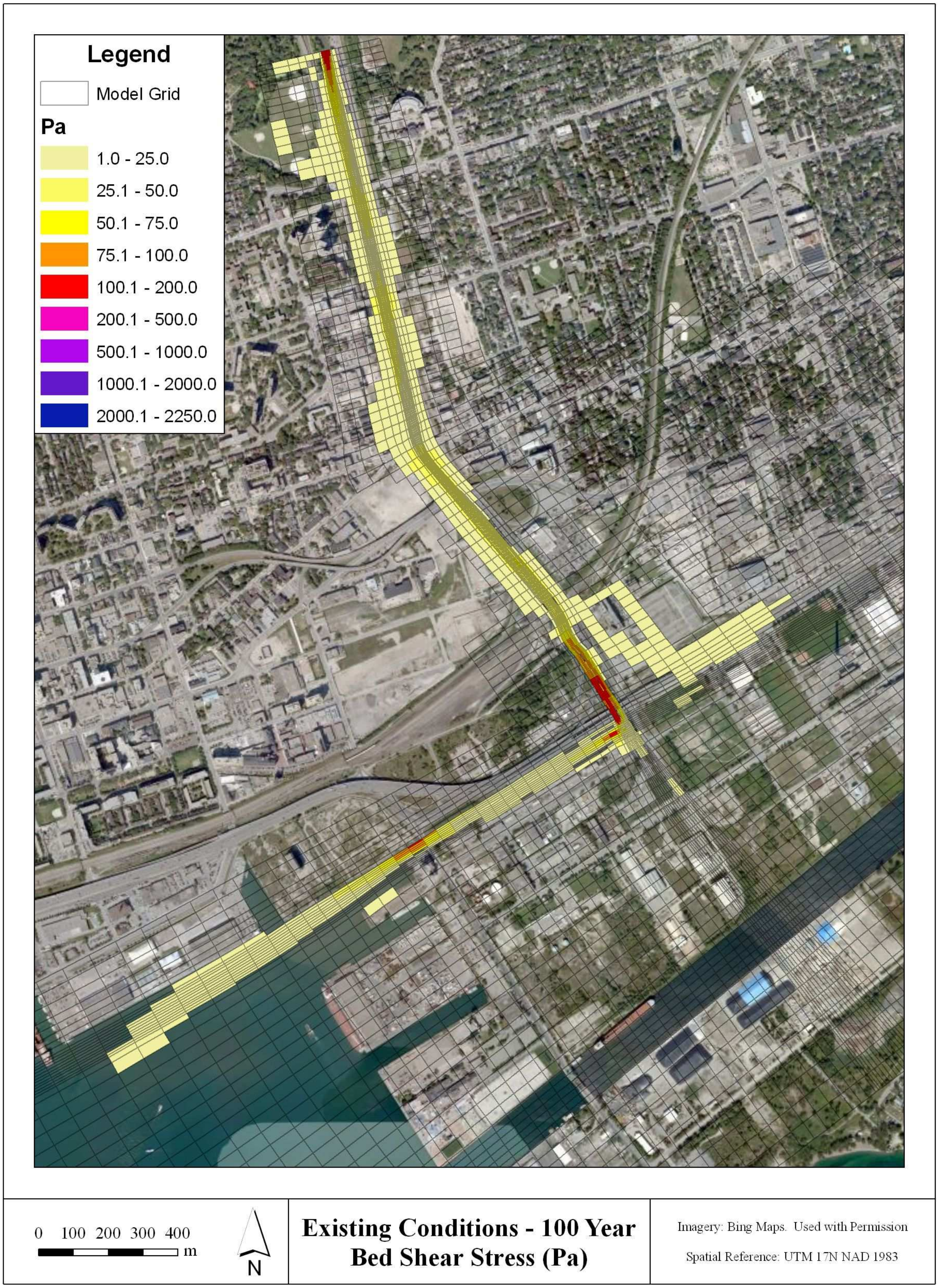
Existing Conditions - 25 Year Bed Shear Stress (Pa)



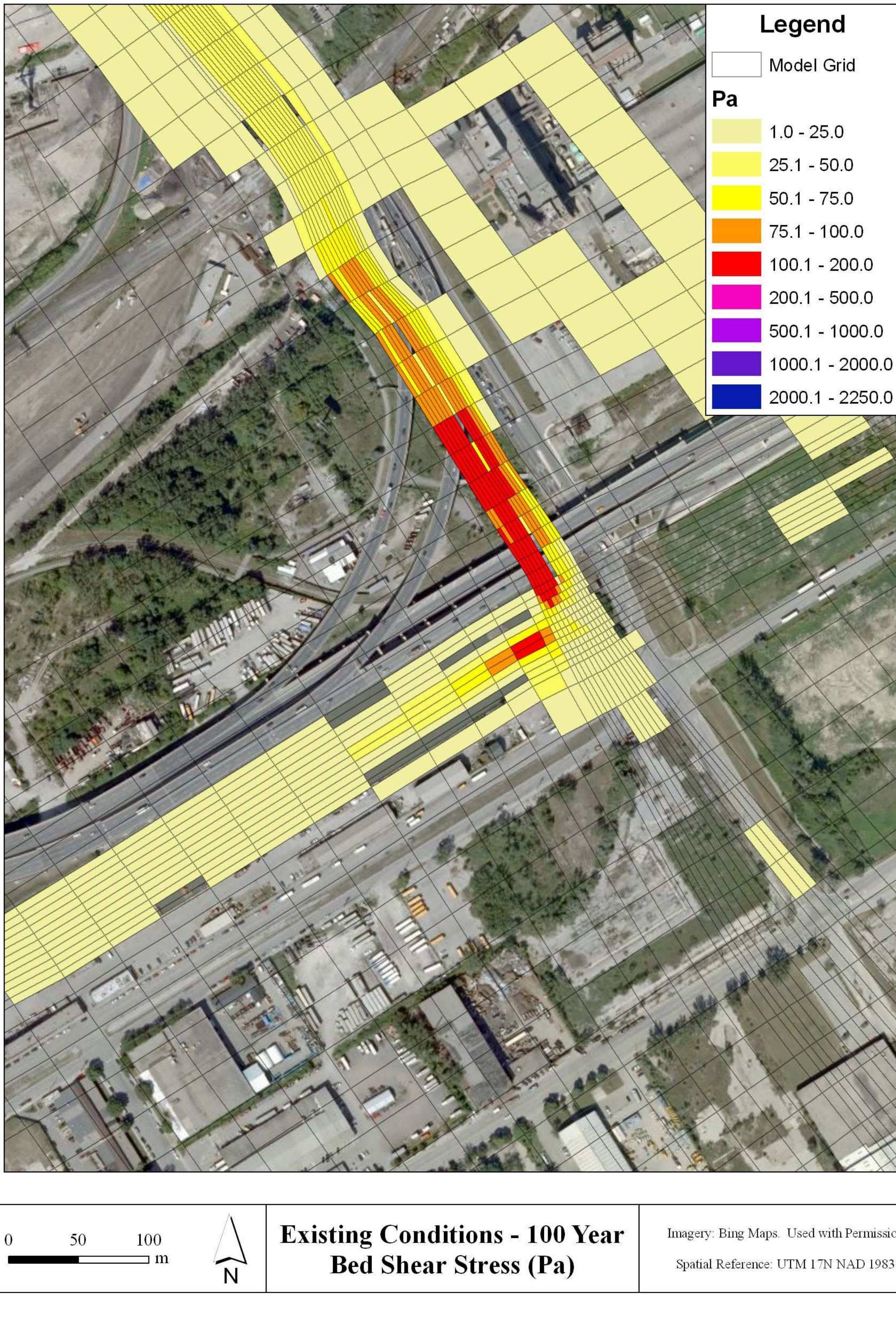
Existing Conditions - 25 Year Bed Shear Stress (Pa)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



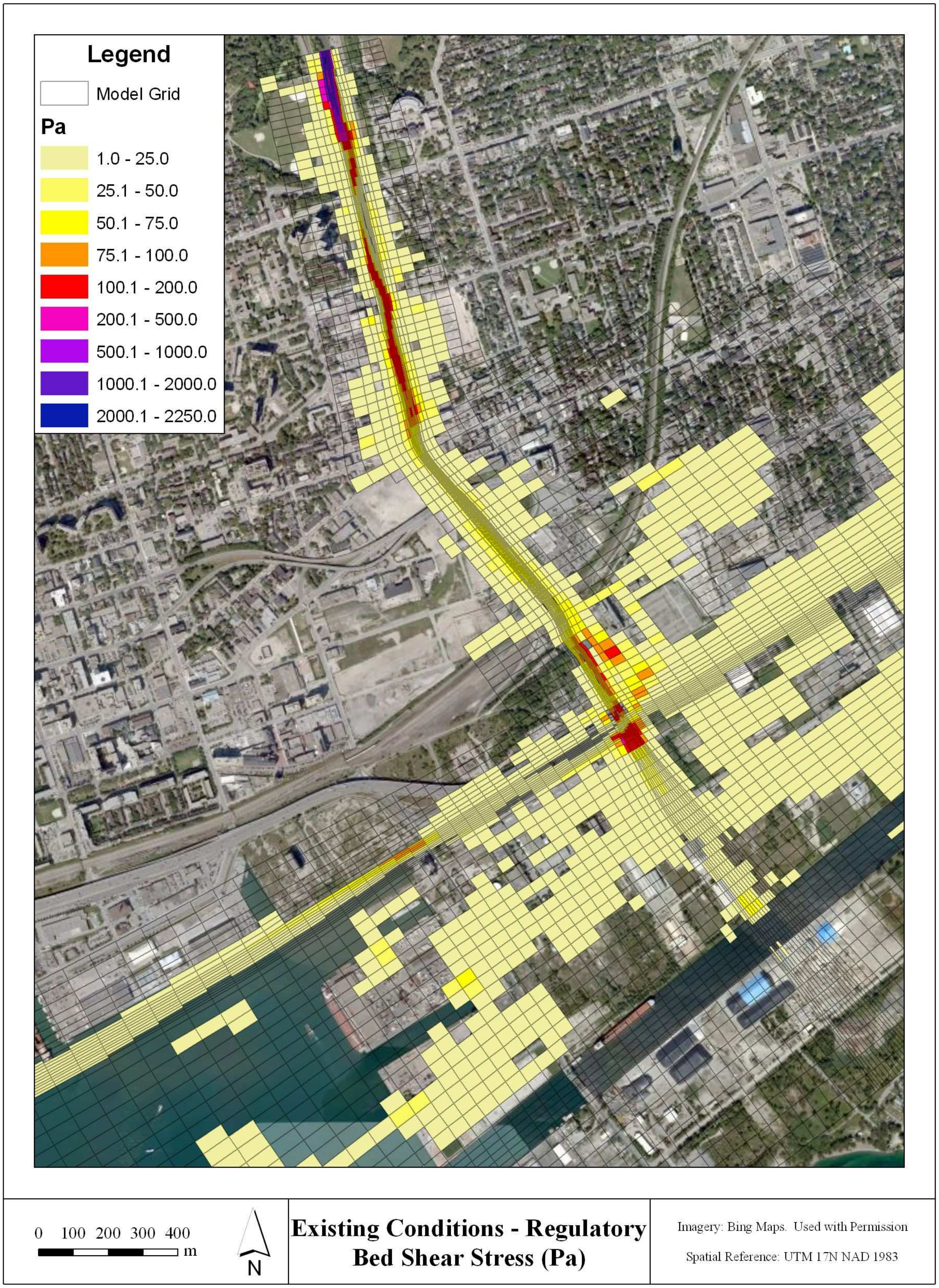
Existing Conditions - 100 Year Bed Shear Stress (Pa)



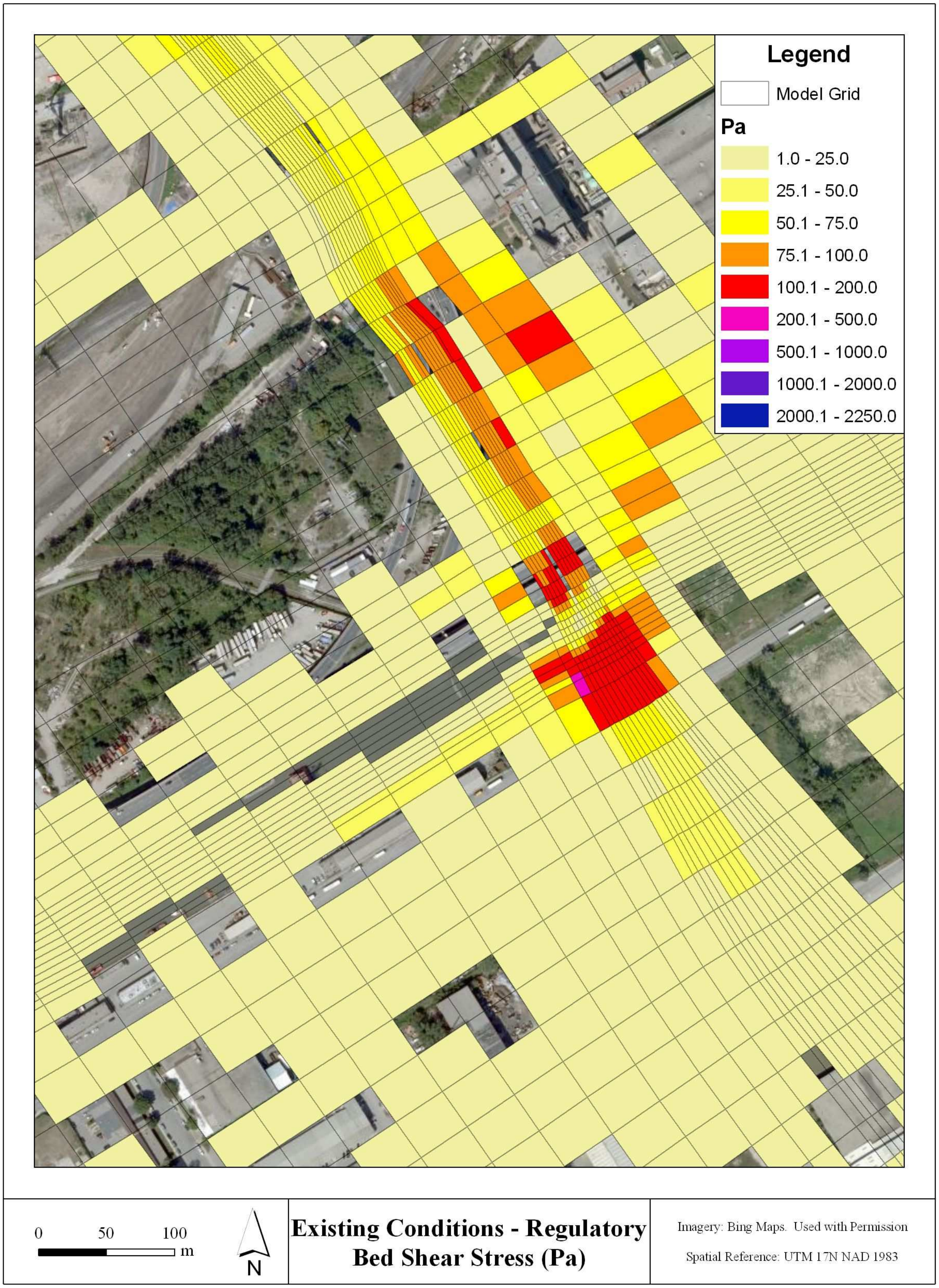
Existing Conditions - 100 Year Bed Shear Stress (Pa)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



Existing Conditions - Regulatory Bed Shear Stress (Pa)

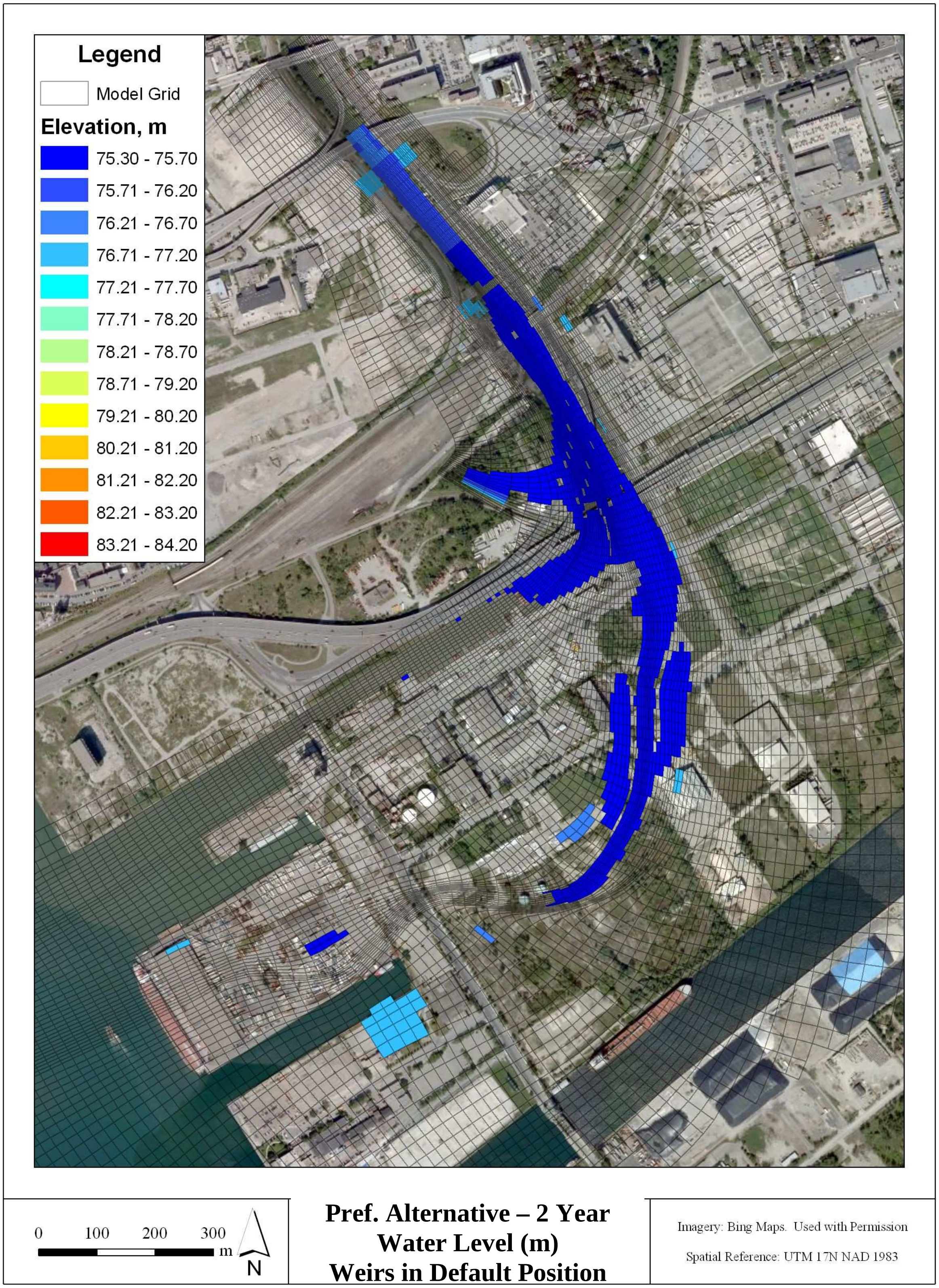


Existing Conditions - Regulatory Bed Shear Stress (Pa)

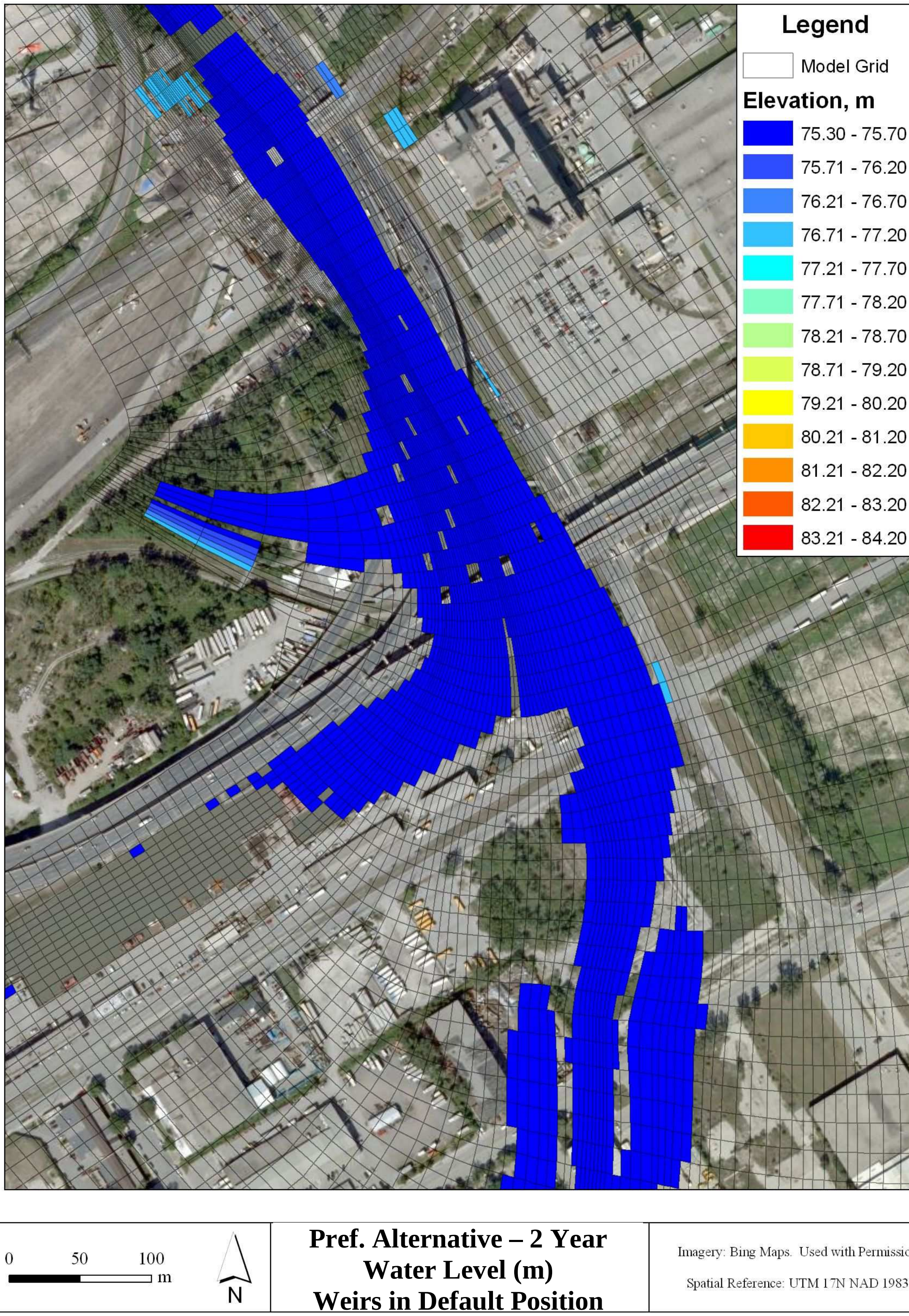
Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

APPENDIX HD-E
PREFERRED ALTERNATIVE WATER LEVEL MAPS – WEIRS IN DEFAULT POSITION



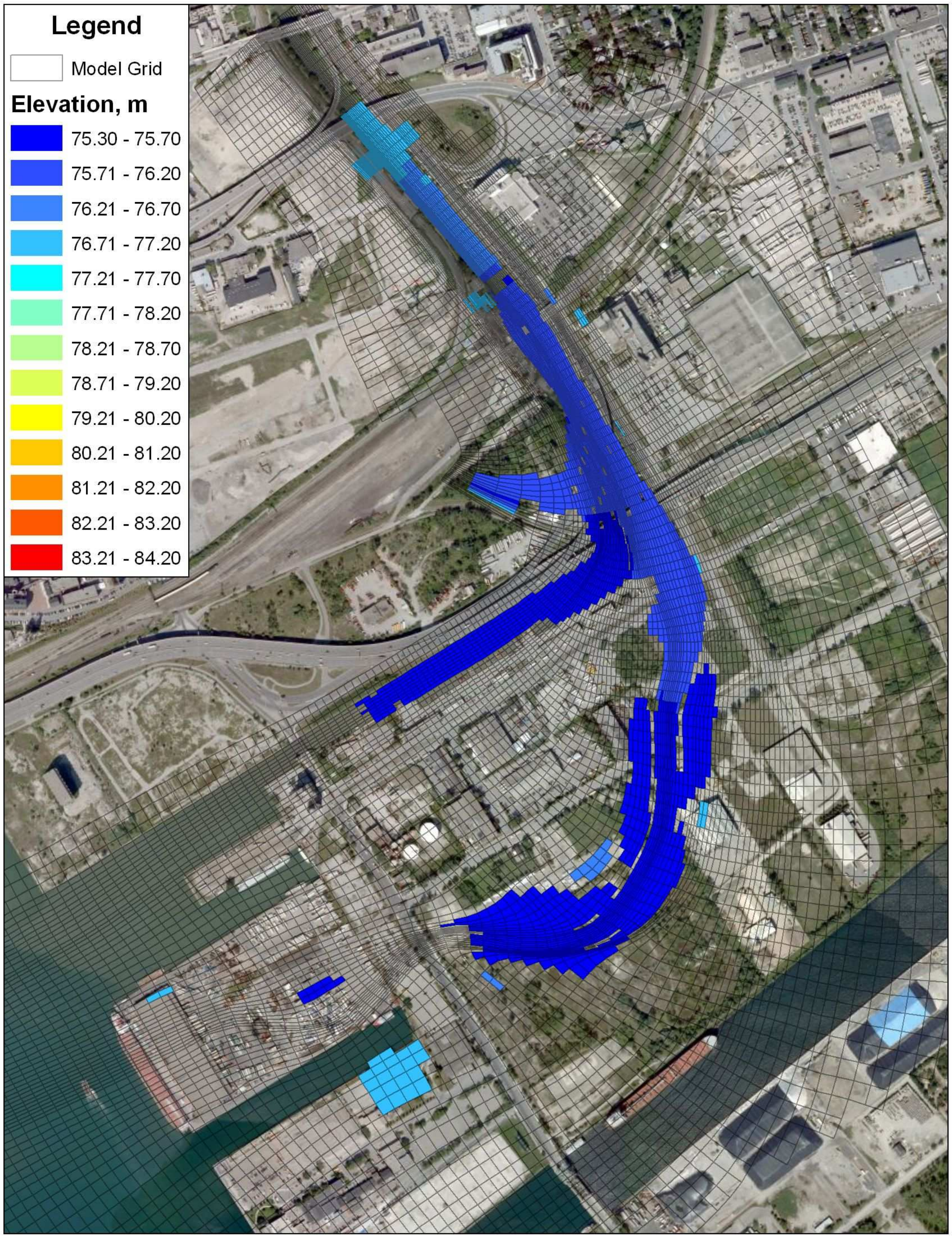
Pref. Alternative – 2 Year
Water Level (m)
Weirs in Default Position



Pref. Alternative – 2 Year Water Level (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

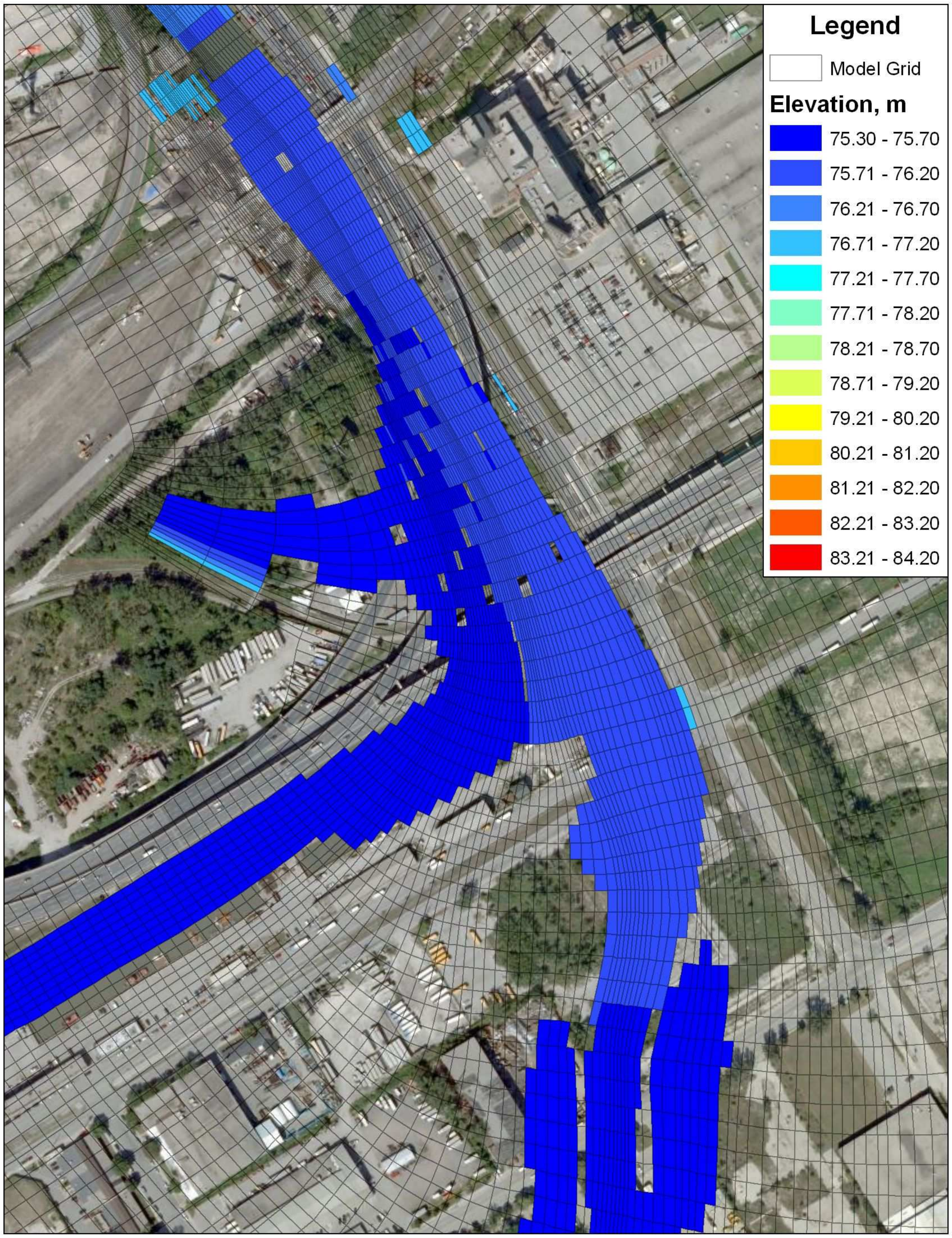
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 10 Year Water Level (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



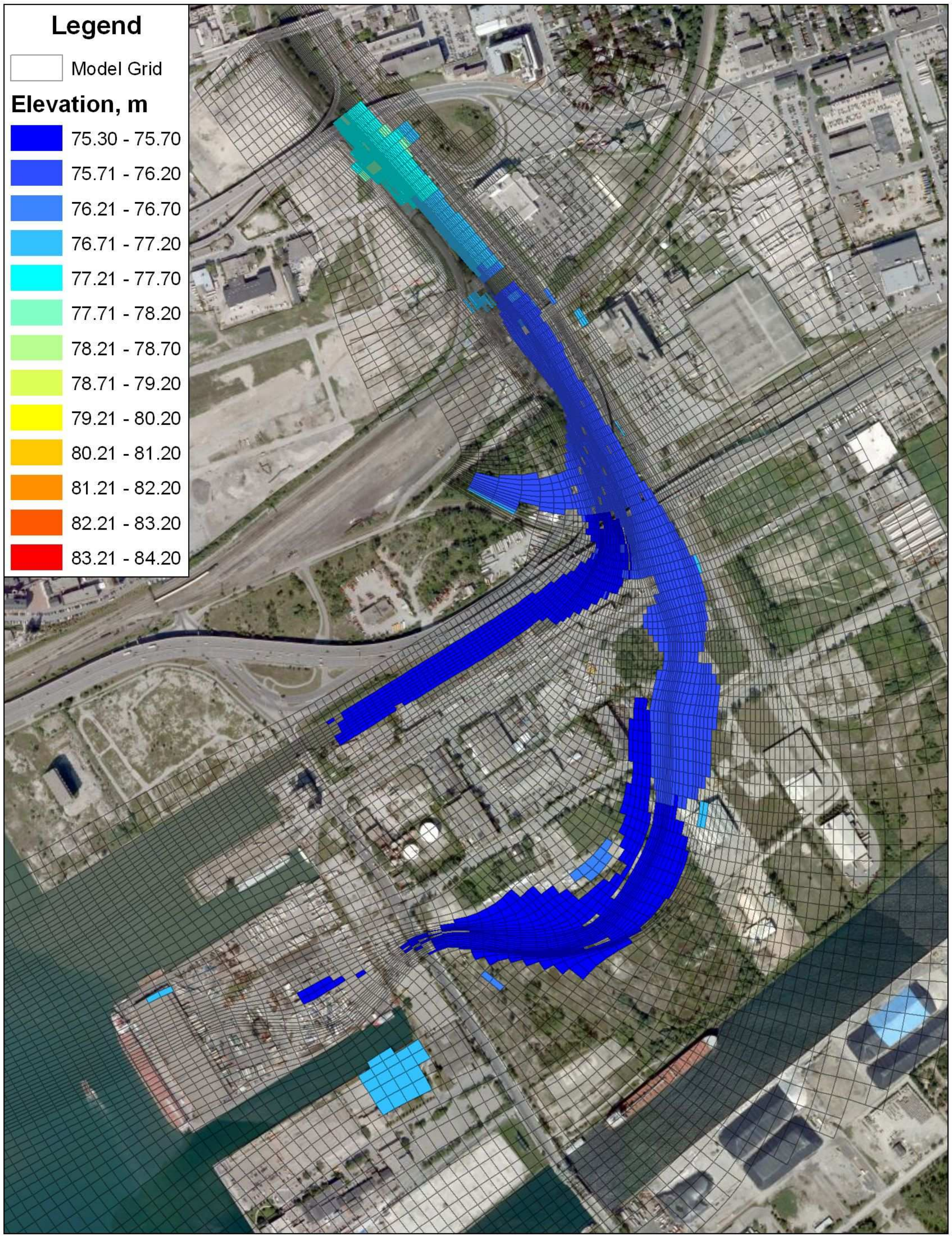
0 50 100 m

N

Pref. Alternative – 10 Year Water Level (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

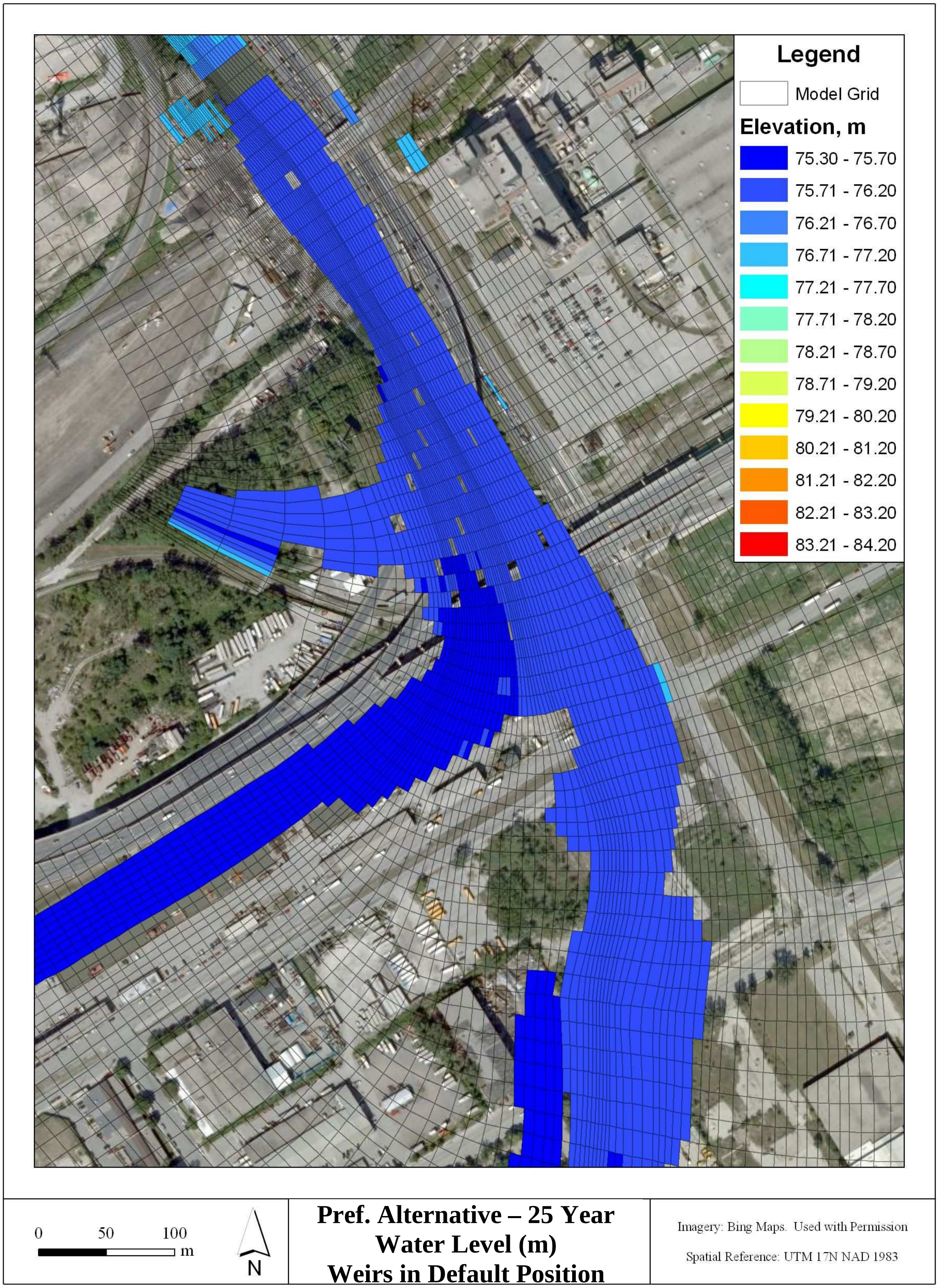


0 100 200 300 m N

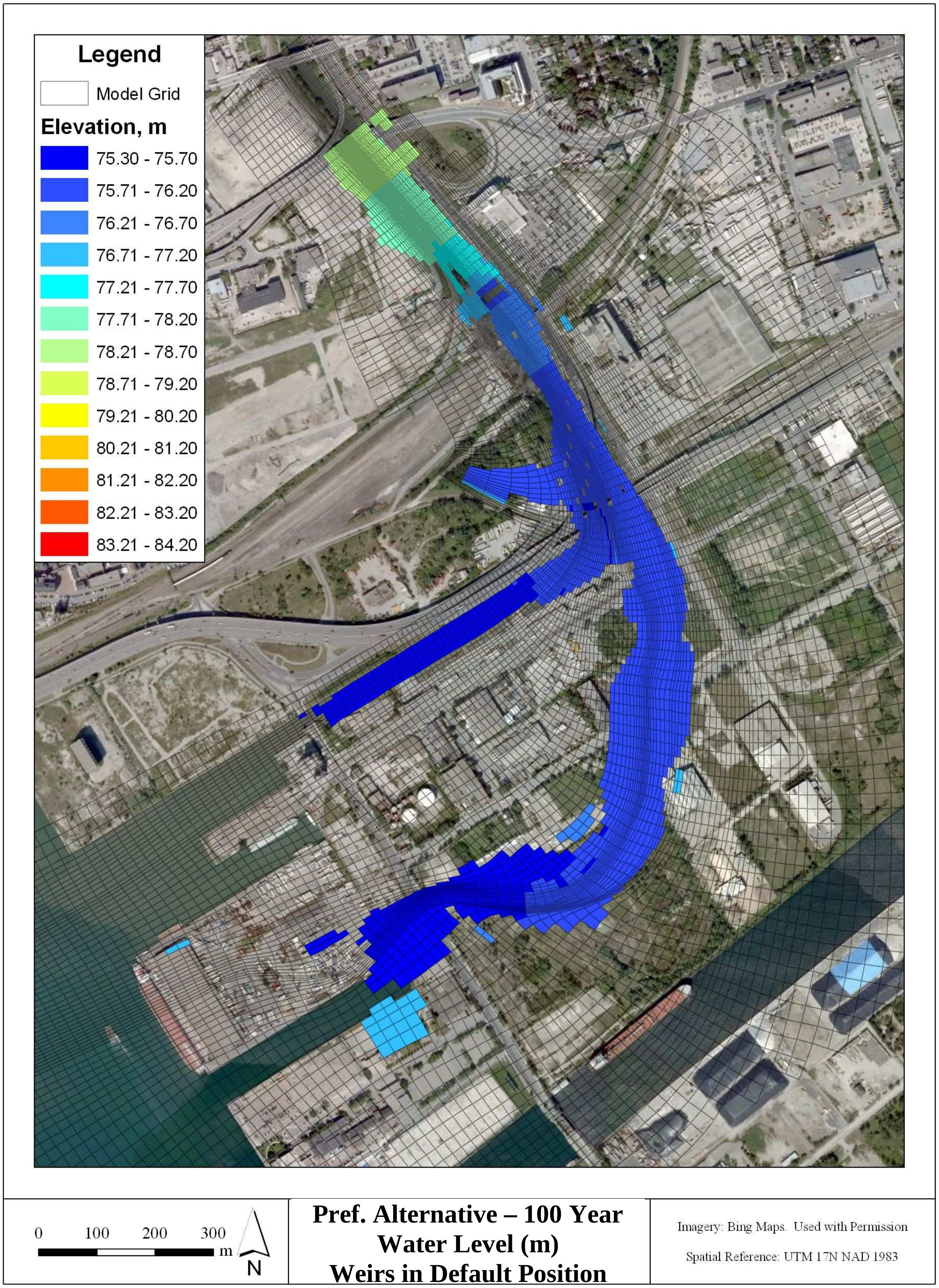
Pref. Alternative – 25 Year Water Level (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



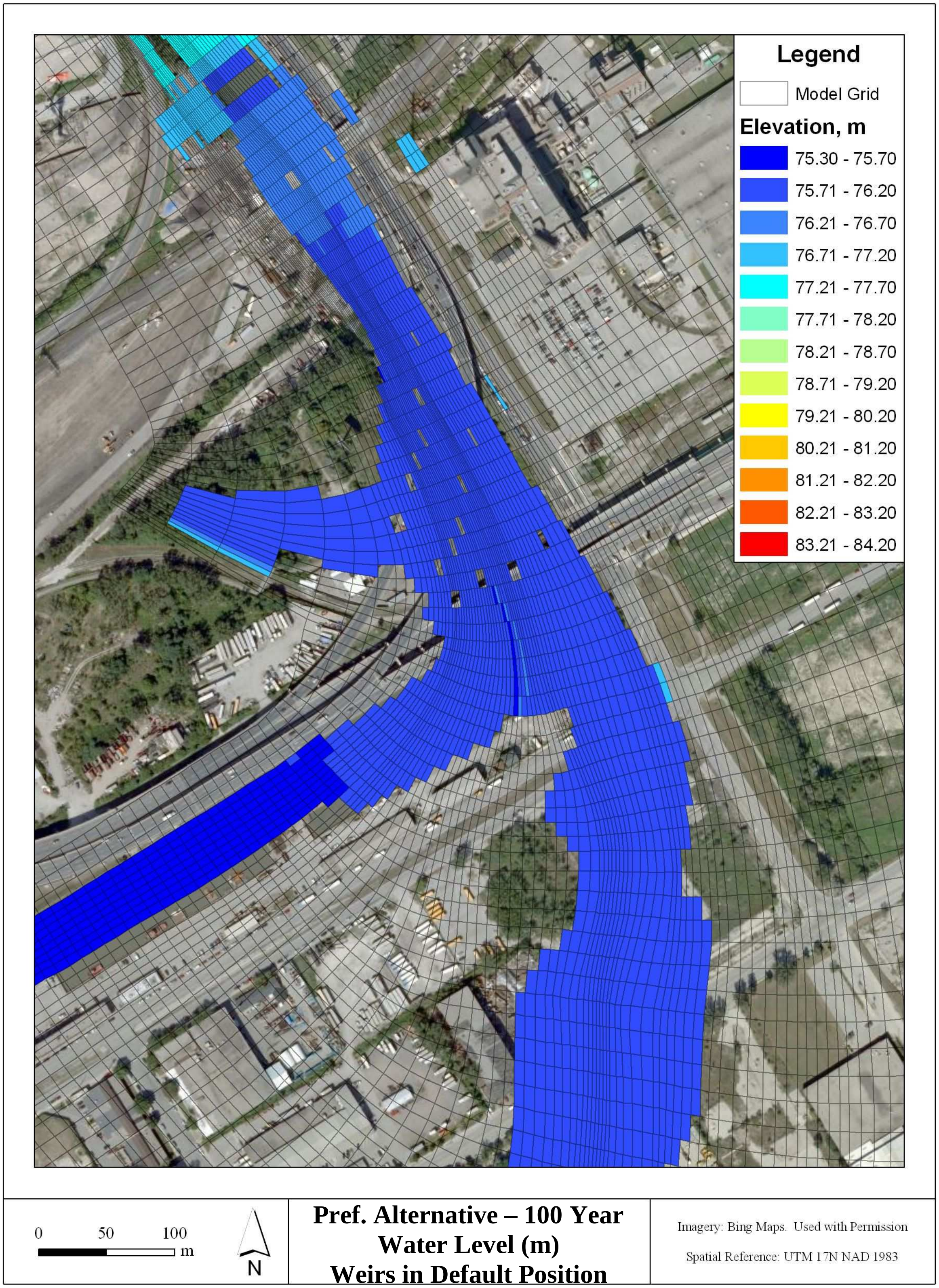
Pref. Alternative – 25 Year Water Level (m) Weirs in Default Position



Pref. Alternative – 100 Year Water Level (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

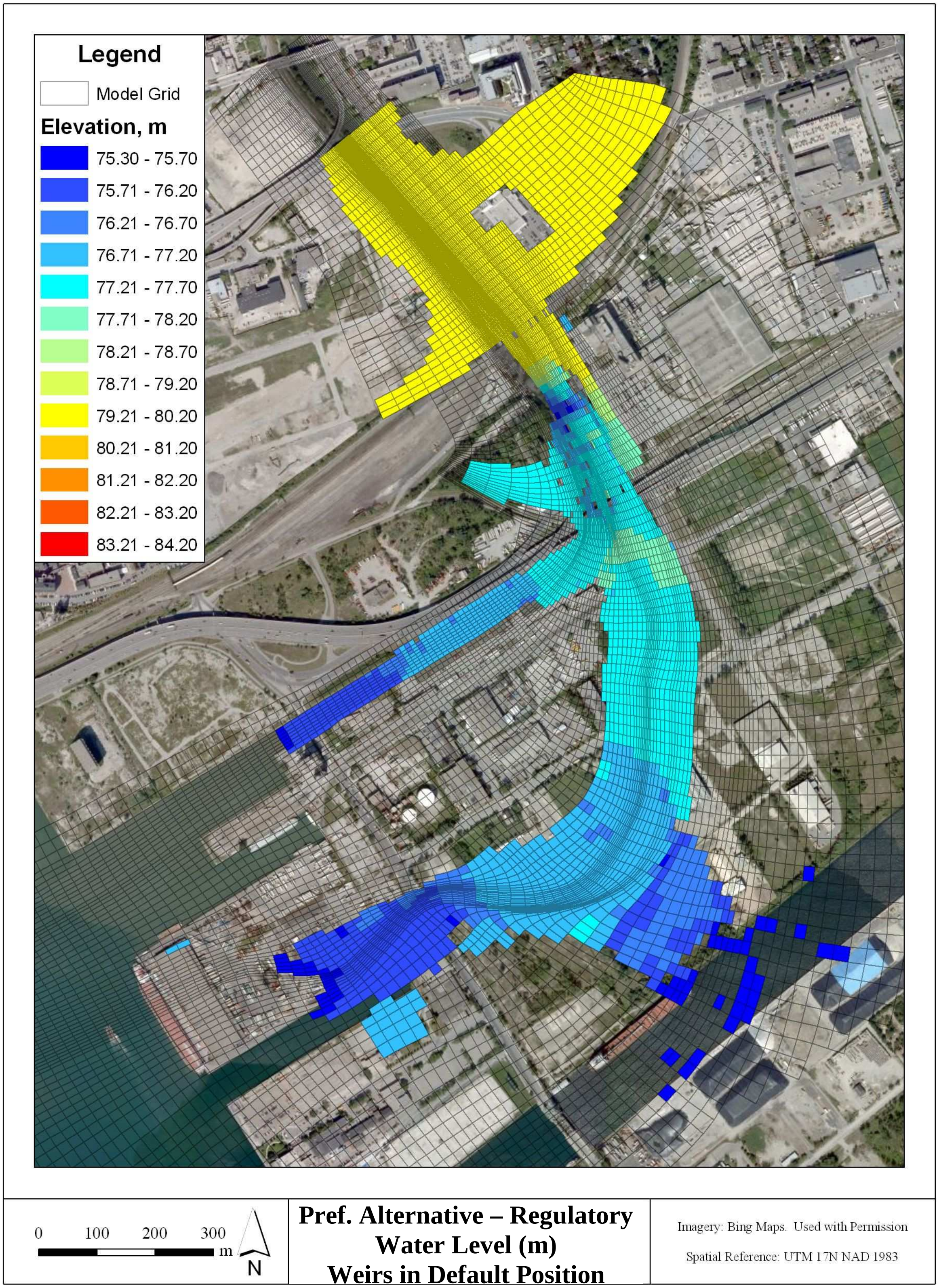
Spatial Reference: UTM 17N NAD 1983

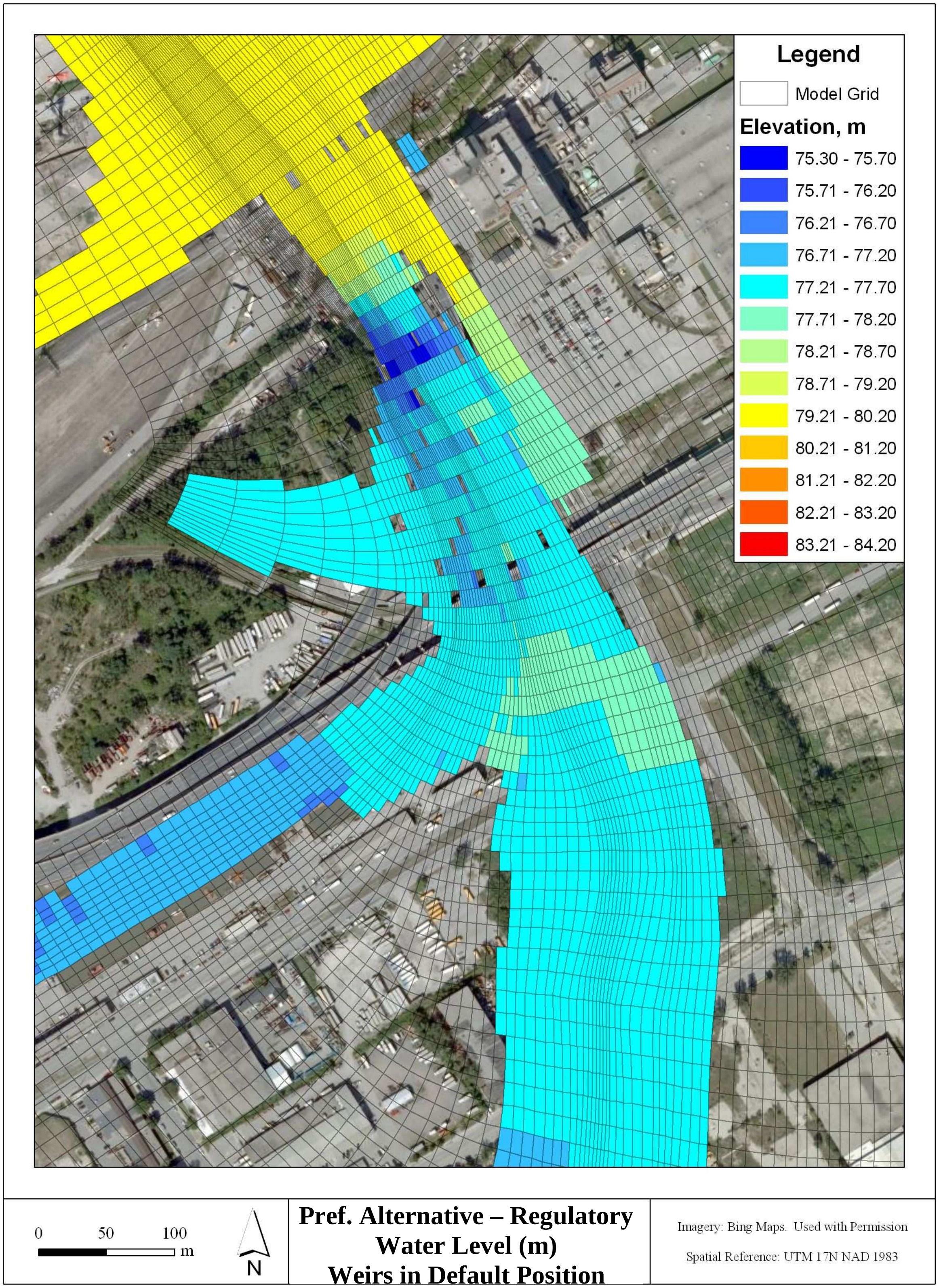


Pref. Alternative – 100 Year Water Level (m) Weirs in Default Position

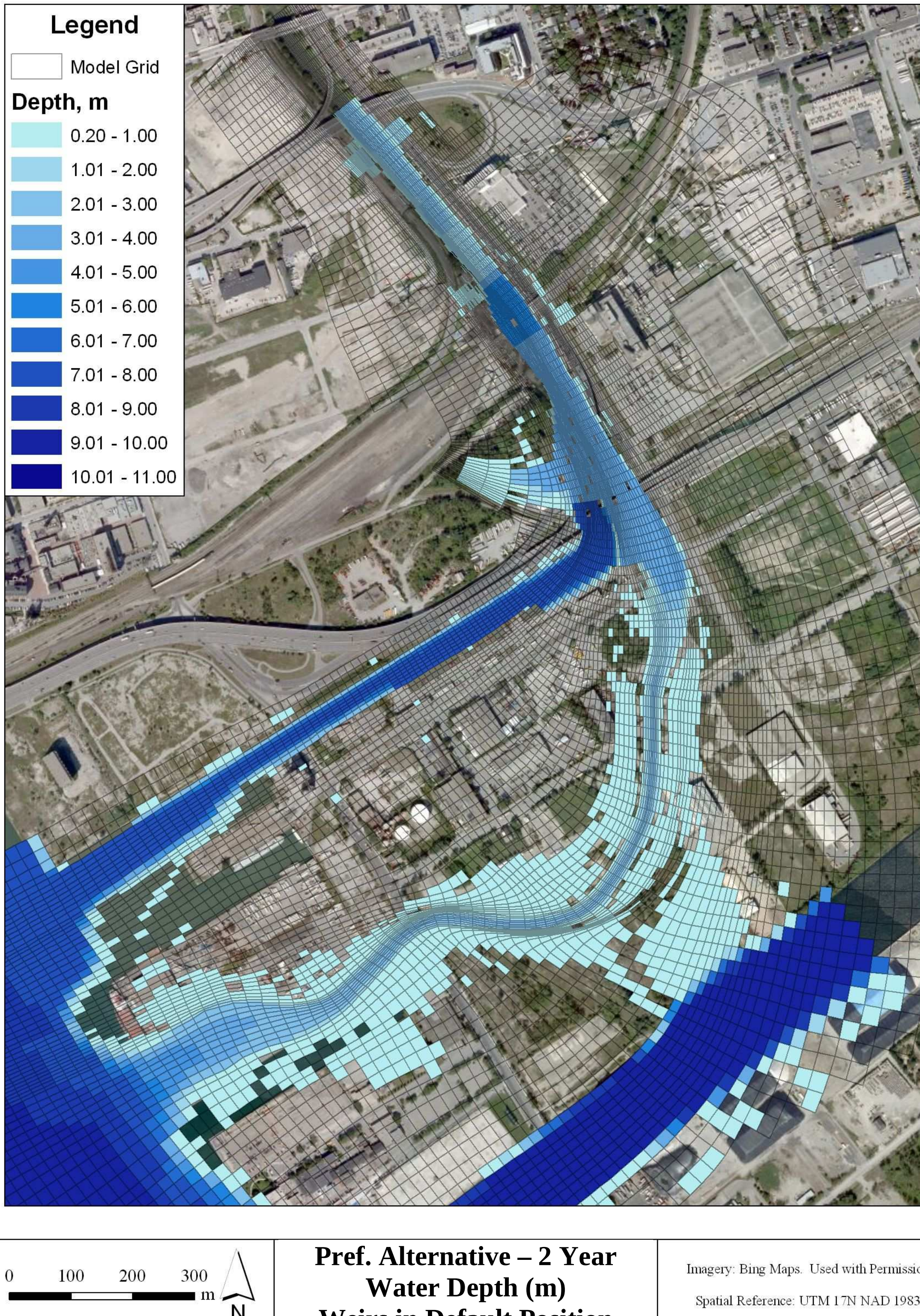
Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983


Legend
Model Grid
Elevation, m
75.30 - 75.70
75.71 - 76.20
76.21 - 76.70
76.71 - 77.20
77.21 - 77.70
77.71 - 78.20
78.21 - 78.70
78.71 - 79.20
79.21 - 80.20
80.21 - 81.20
81.21 - 82.20
82.21 - 83.20
83.21 - 84.20
0 100 200 300 m
N
Pref. Alternative – Regulatory Water Level (m) Weirs in Default Position
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983


Legend
Model Grid
Elevation, m
75.30 - 75.70
75.71 - 76.20
76.21 - 76.70
76.71 - 77.20
77.21 - 77.70
77.71 - 78.20
78.21 - 78.70
78.71 - 79.20
79.21 - 80.20
80.21 - 81.20
81.21 - 82.20
82.21 - 83.20
83.21 - 84.20
0
50
100
m
N
Pref. Alternative – Regulatory
Water Level (m)
Weirs in Default Position
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983

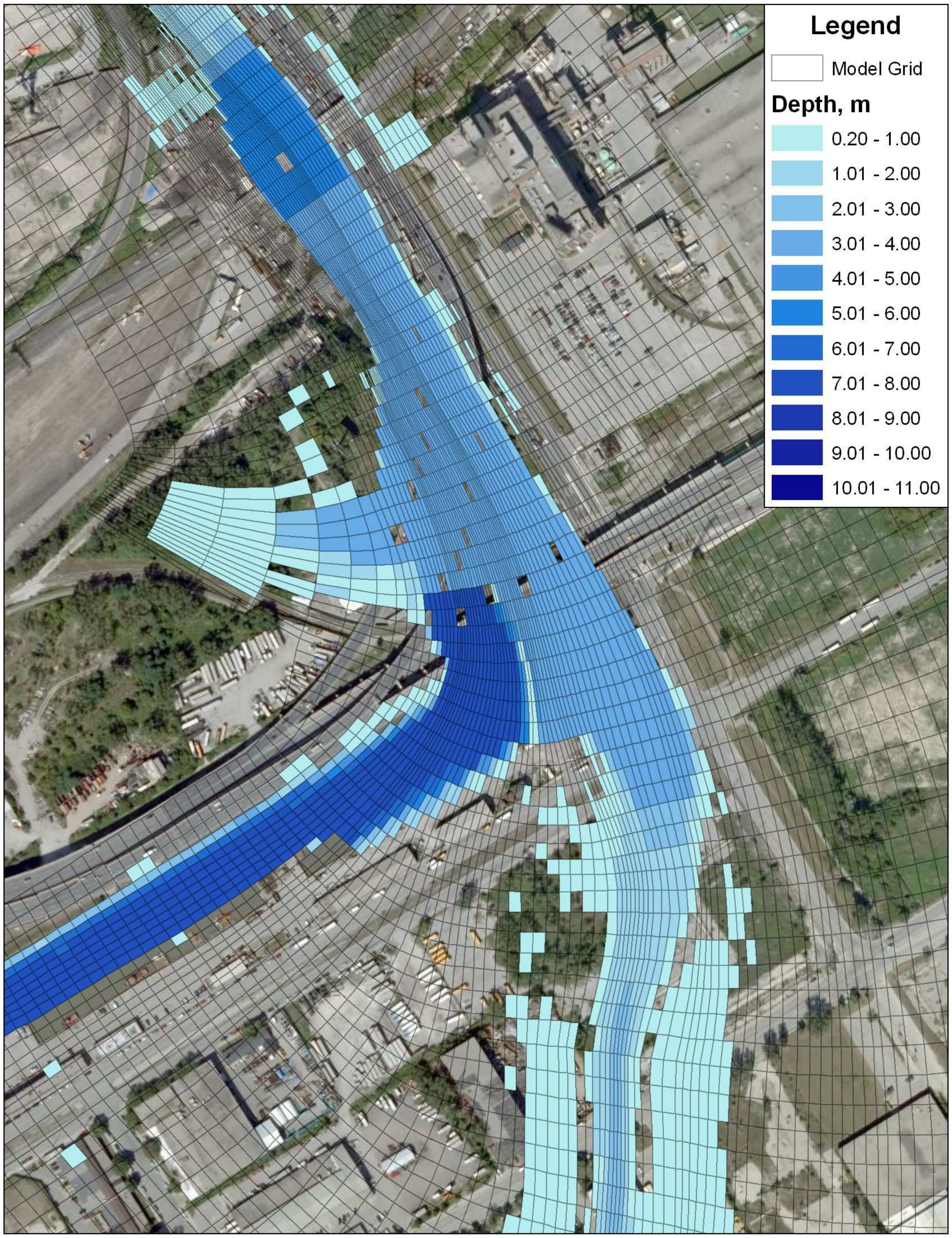
APPENDIX HD-F
PREFERRED ALTERNATIVE WATER DEPTH MAPS – WEIRS IN DEFAULT POSITION



Pref. Alternative – 2 Year Water Depth (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

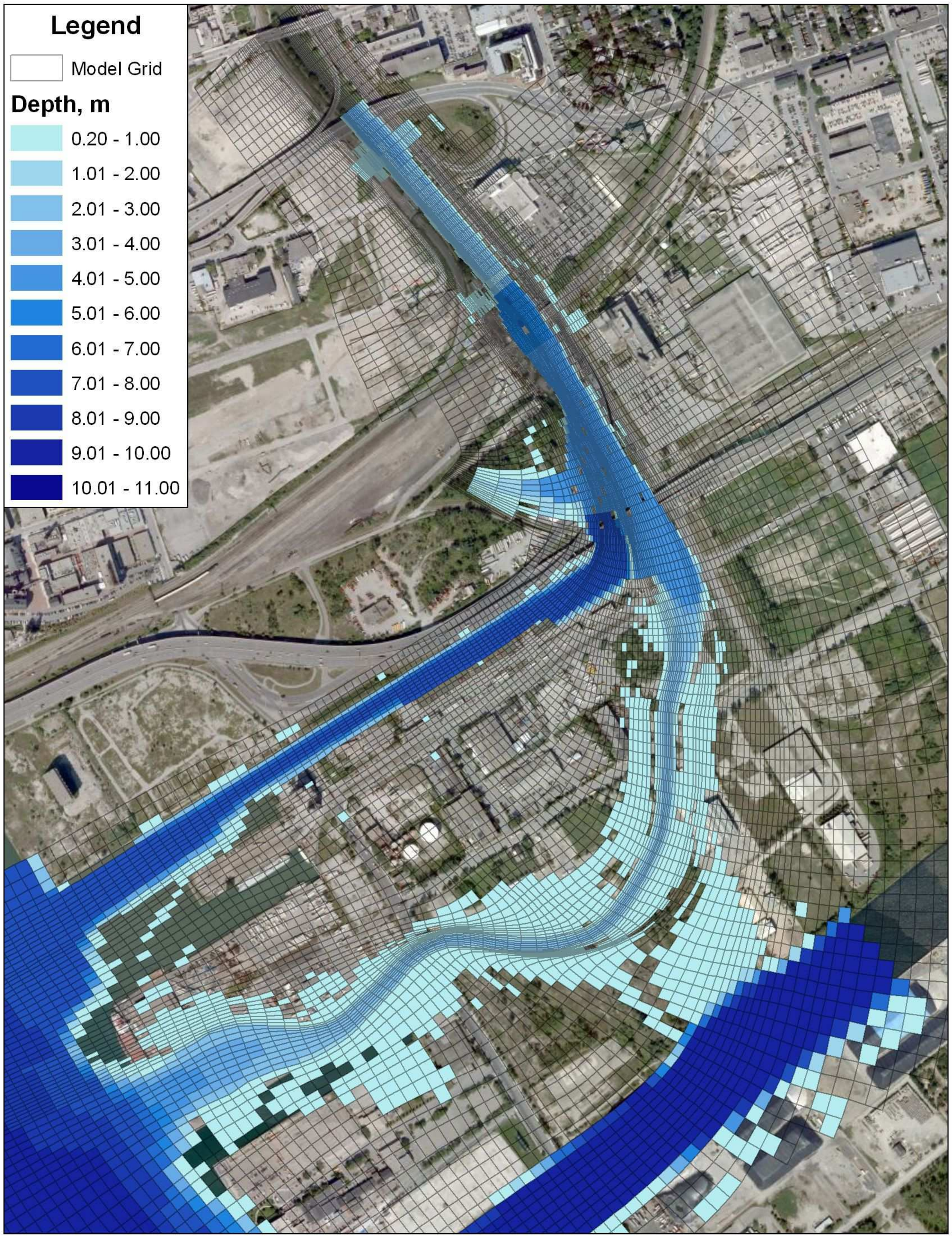
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 2 Year Water Depth (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



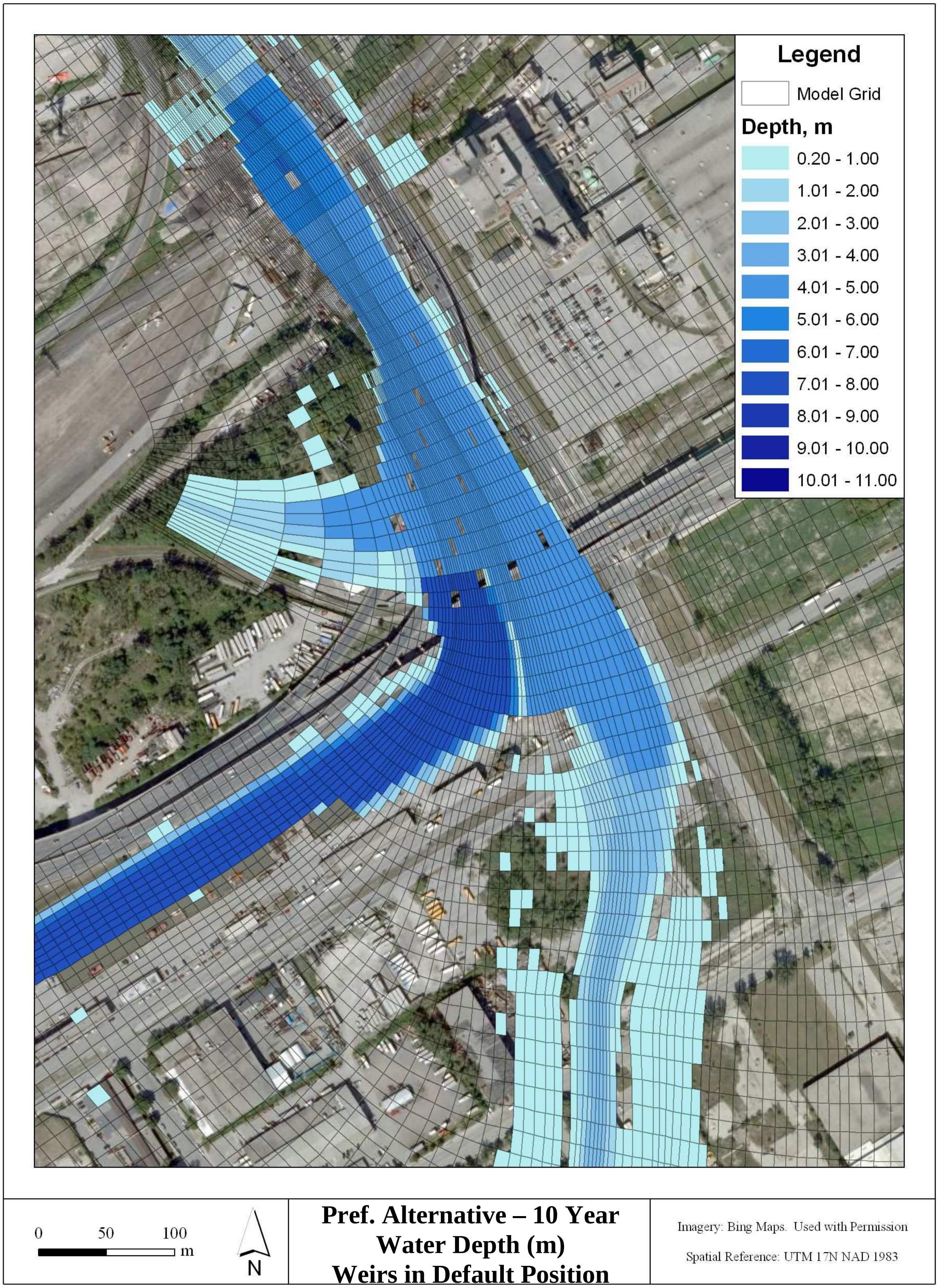
0 100 200 300 m

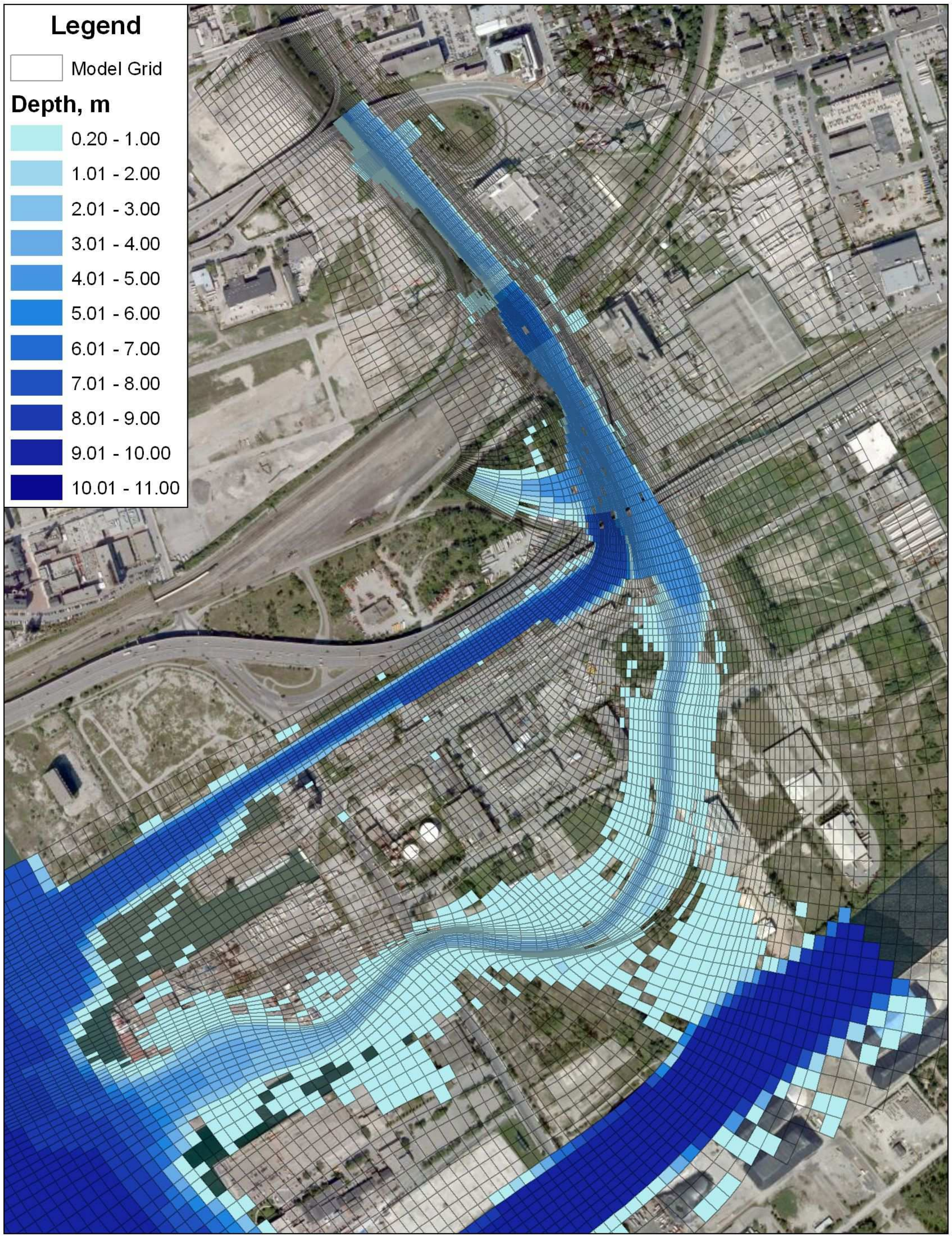
N

Pref. Alternative – 10 Year
Water Depth (m)
Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

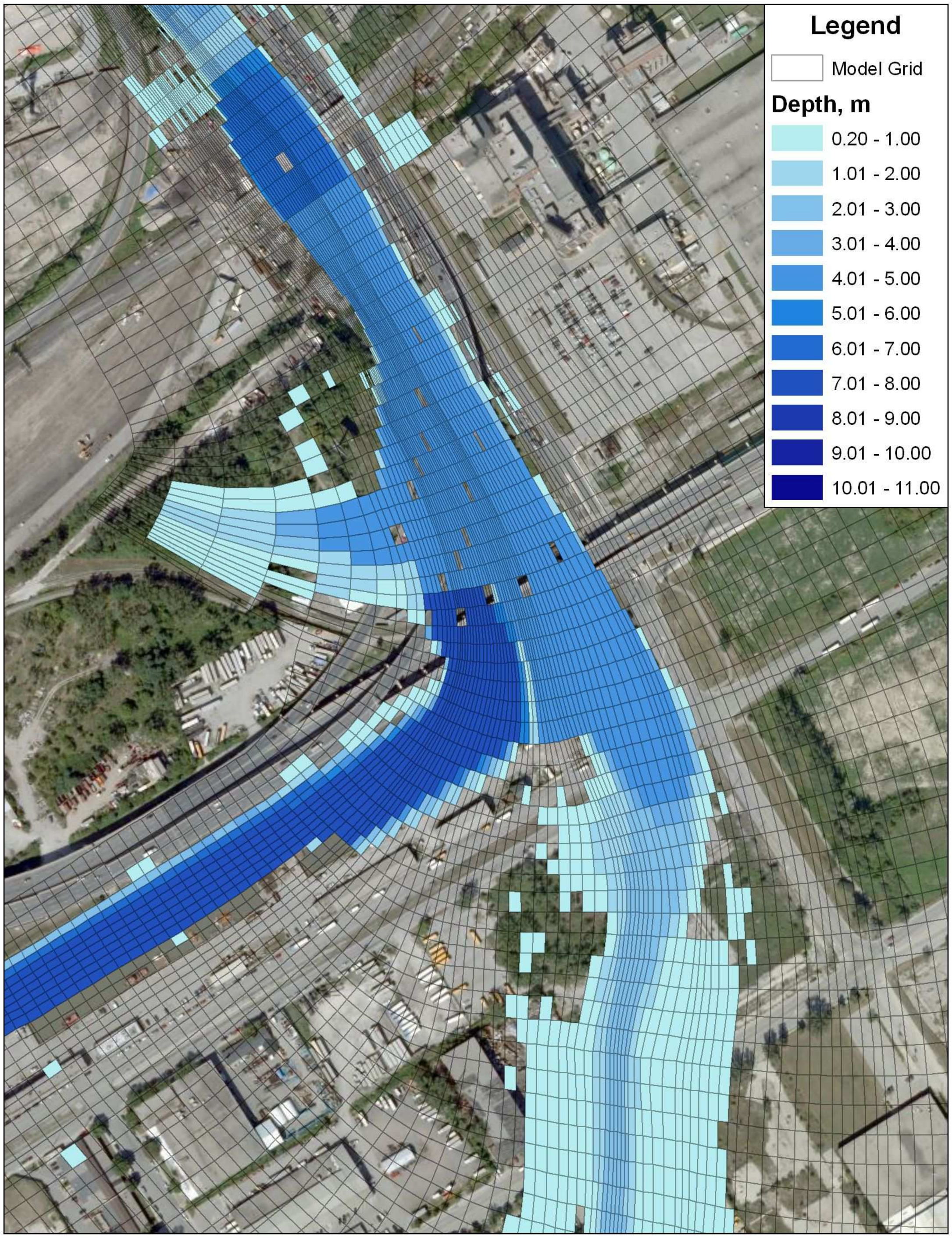

Legend
Model Grid
Depth, m
0.20 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
0
50
100
m
N
Pref. Alternative – 10 Year
Water Depth (m)
Weirs in Default Position
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 25 Year Water Depth (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

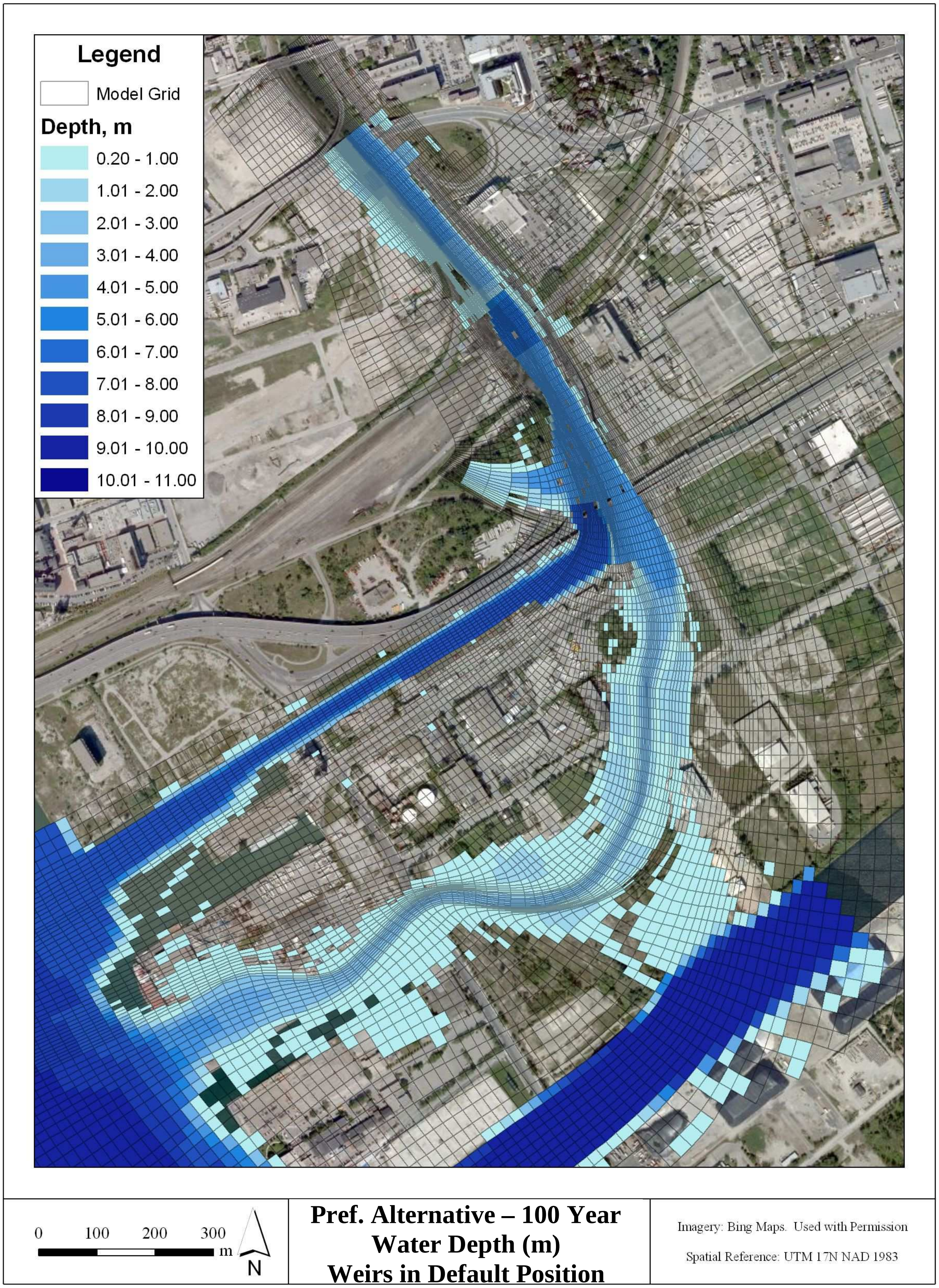
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 25 Year Water Depth (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

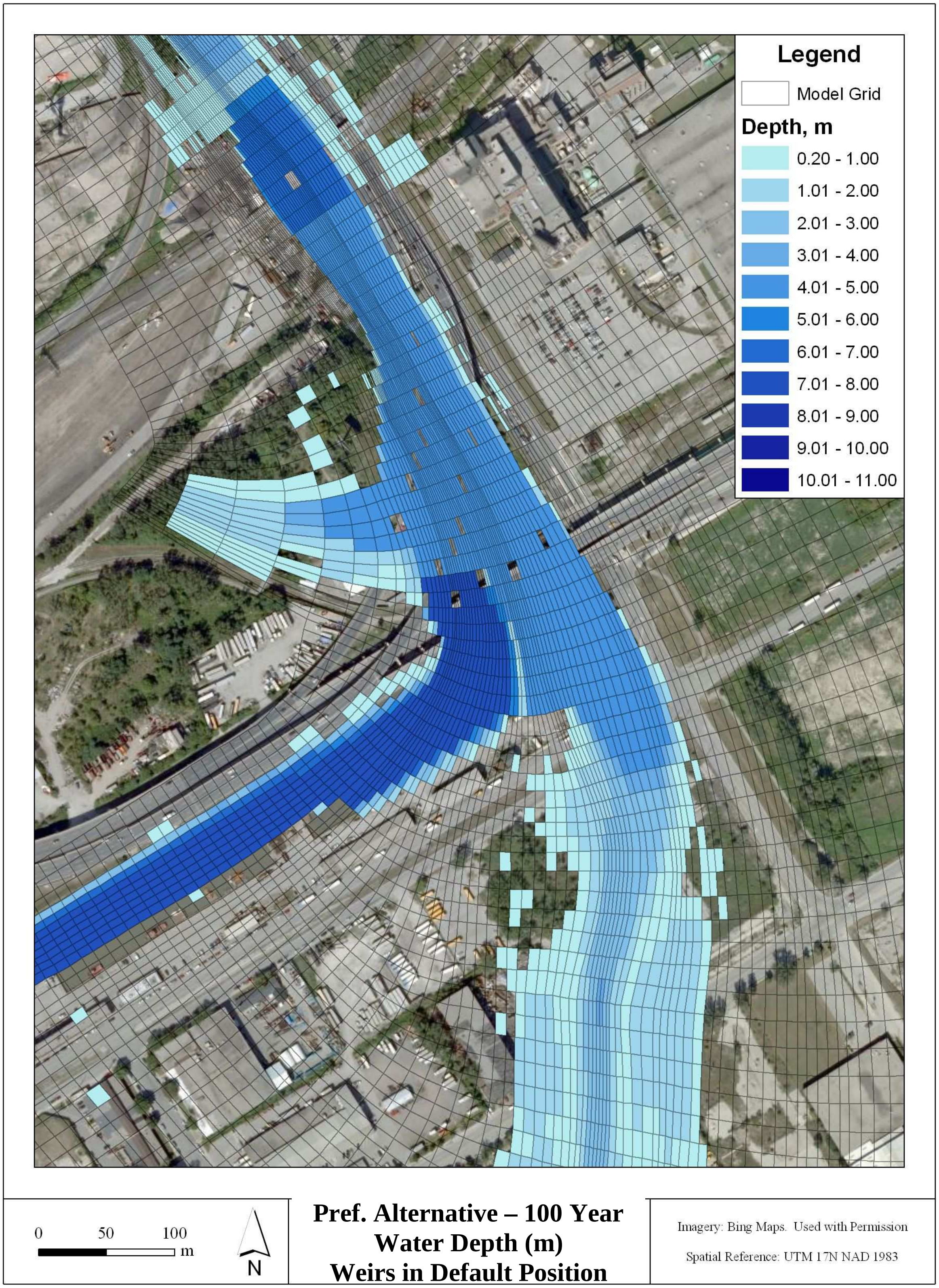
Spatial Reference: UTM 17N NAD 1983

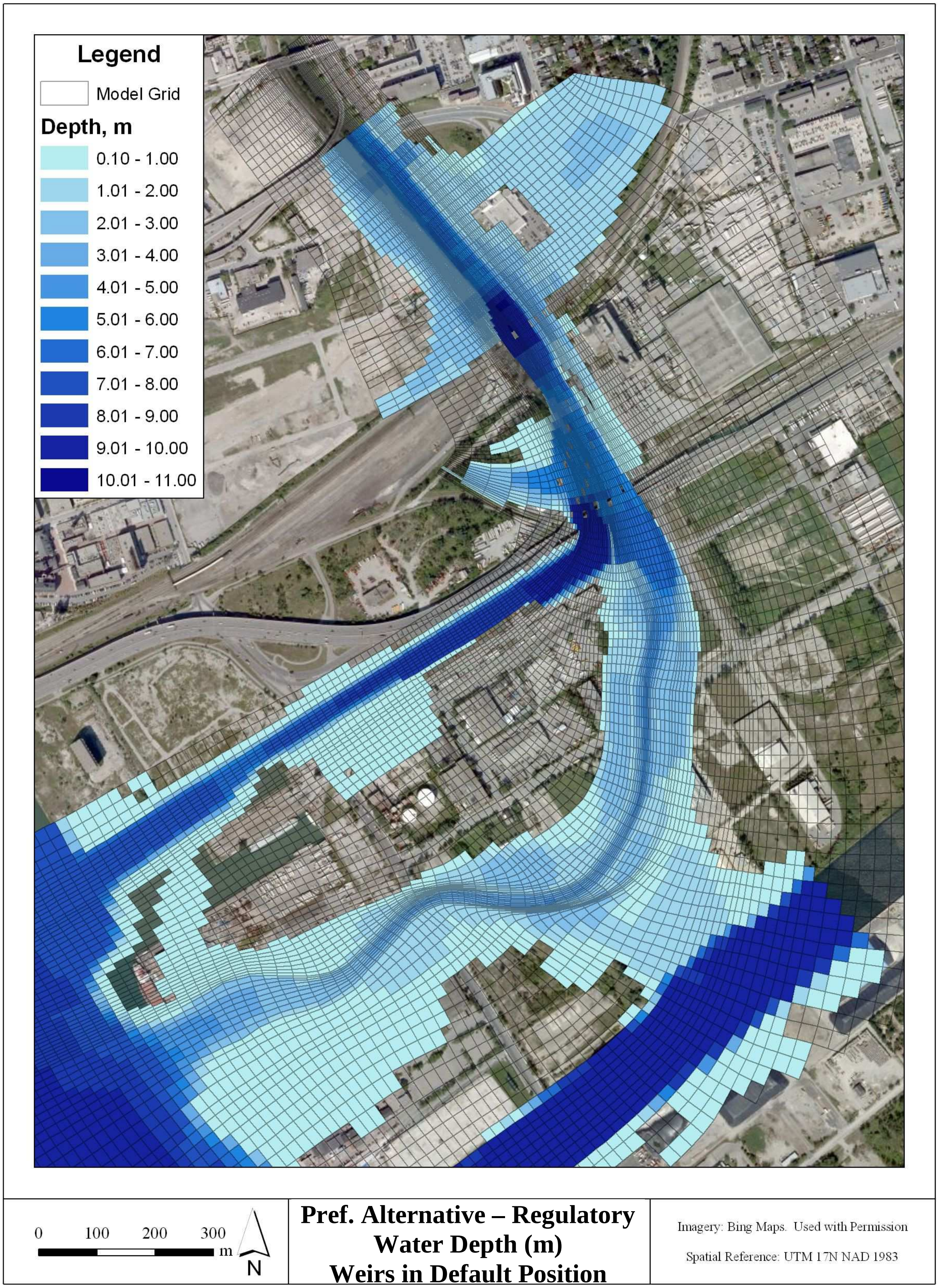


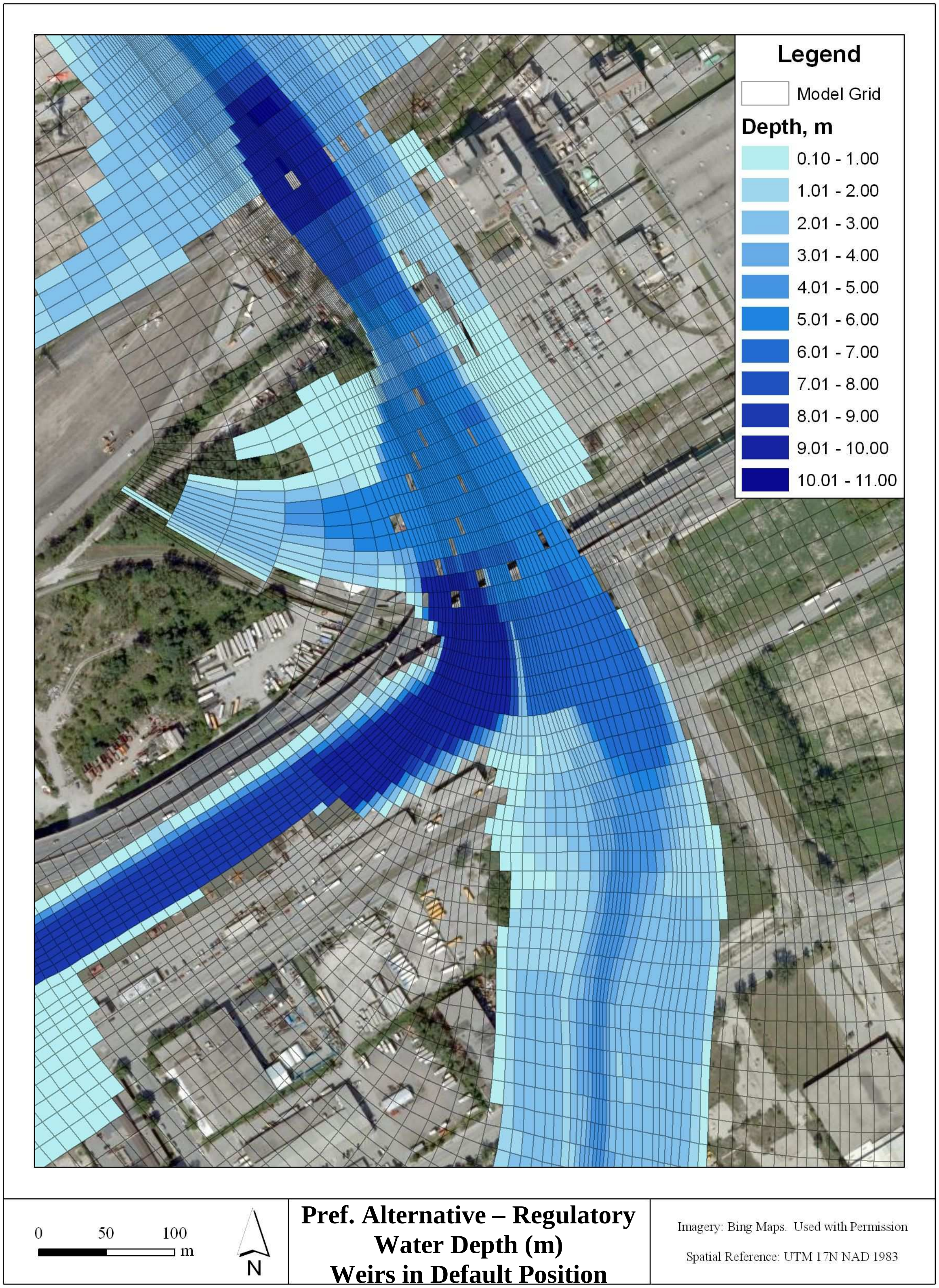
Pref. Alternative – 100 Year Water Depth (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983


Legend
Model Grid
Depth, m
0.20 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
0 50 100 m
N
Pref. Alternative – 100 Year
Water Depth (m)
Weirs in Default Position
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983


Legend
Model Grid
Depth, m
0.10 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
0
100
200
300
m
N
Pref. Alternative – Regulatory
Water Depth (m)
Weirs in Default Position
Imagery: Bing Maps. Used with Permission
Spatial Reference: UTM 17N NAD 1983

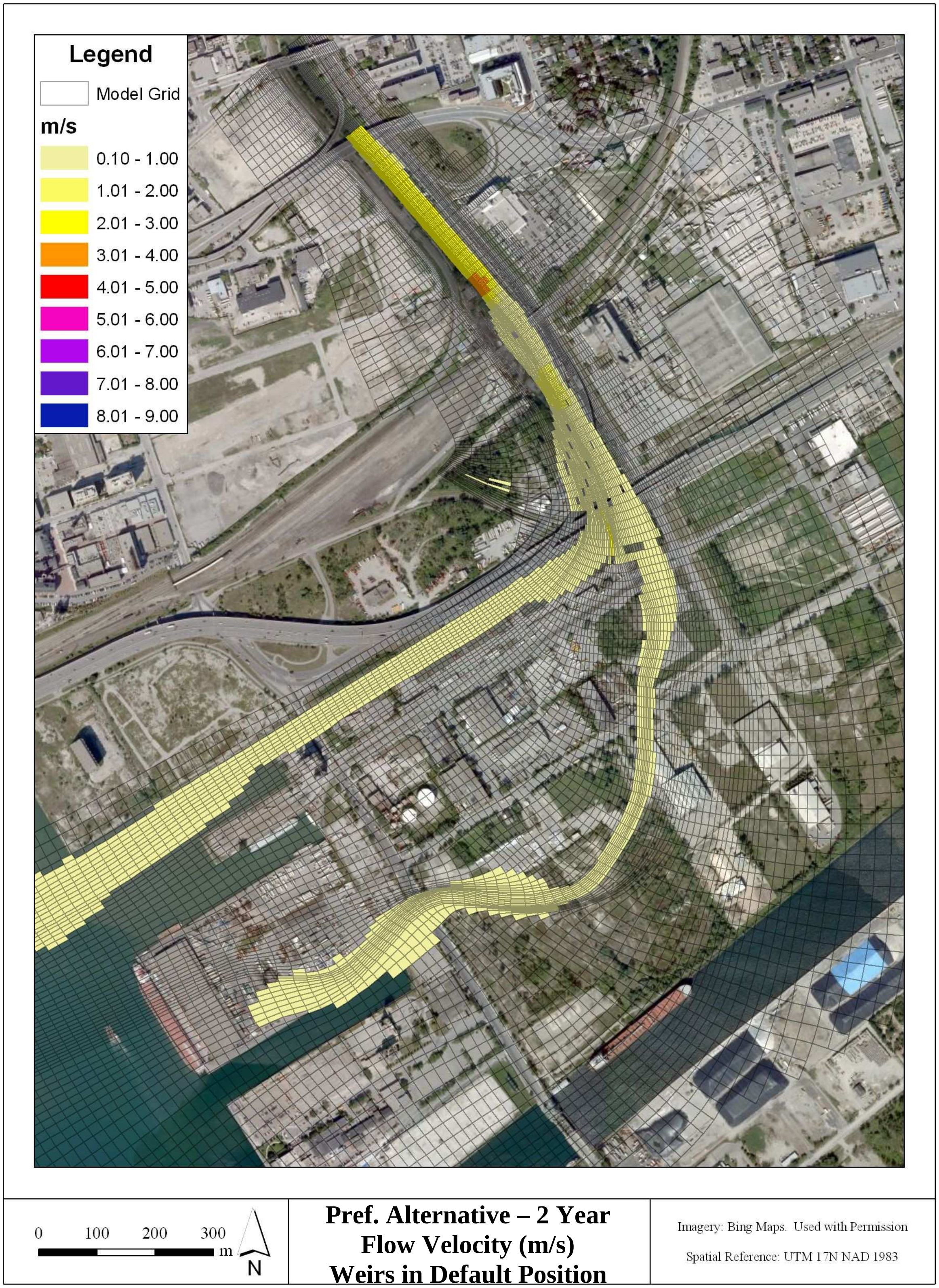


Pref. Alternative – Regulatory Water Depth (m) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

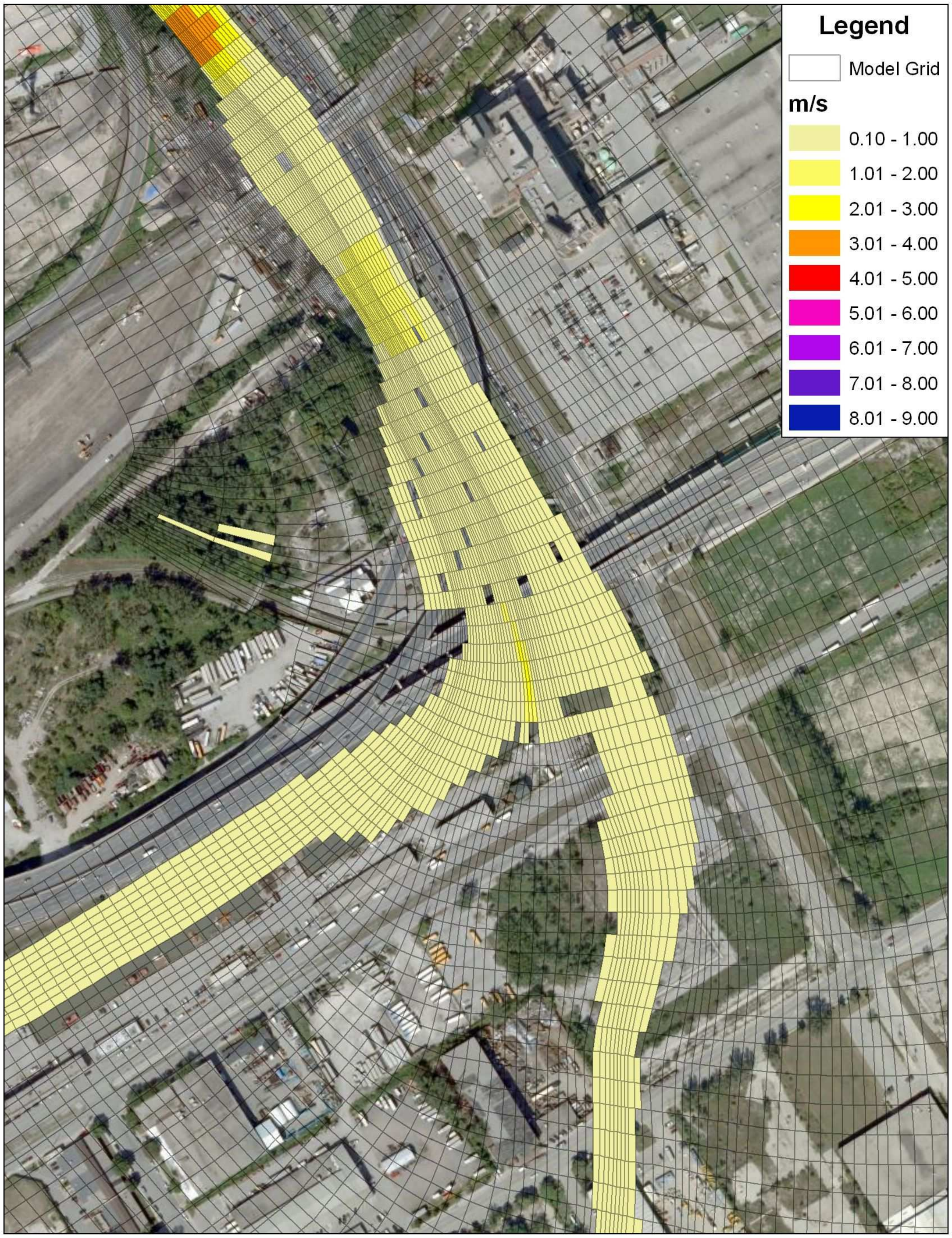
APPENDIX HD-G
PREFERRED ALTERNATIVE FLOW VELOCITY MAPS – WEIRS IN DEFAULT POSITION



Pref. Alternative – 2 Year Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

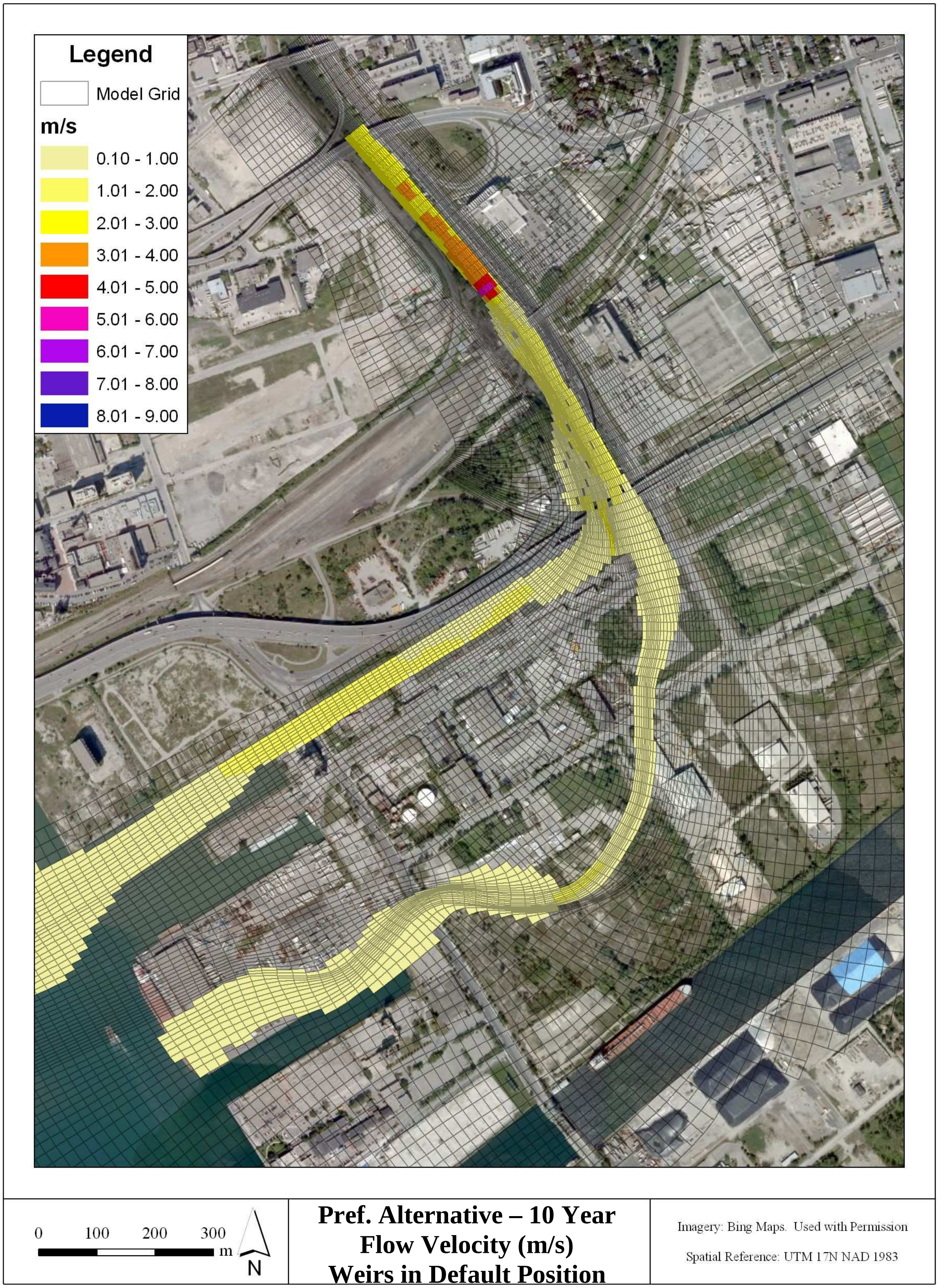
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 2 Year Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

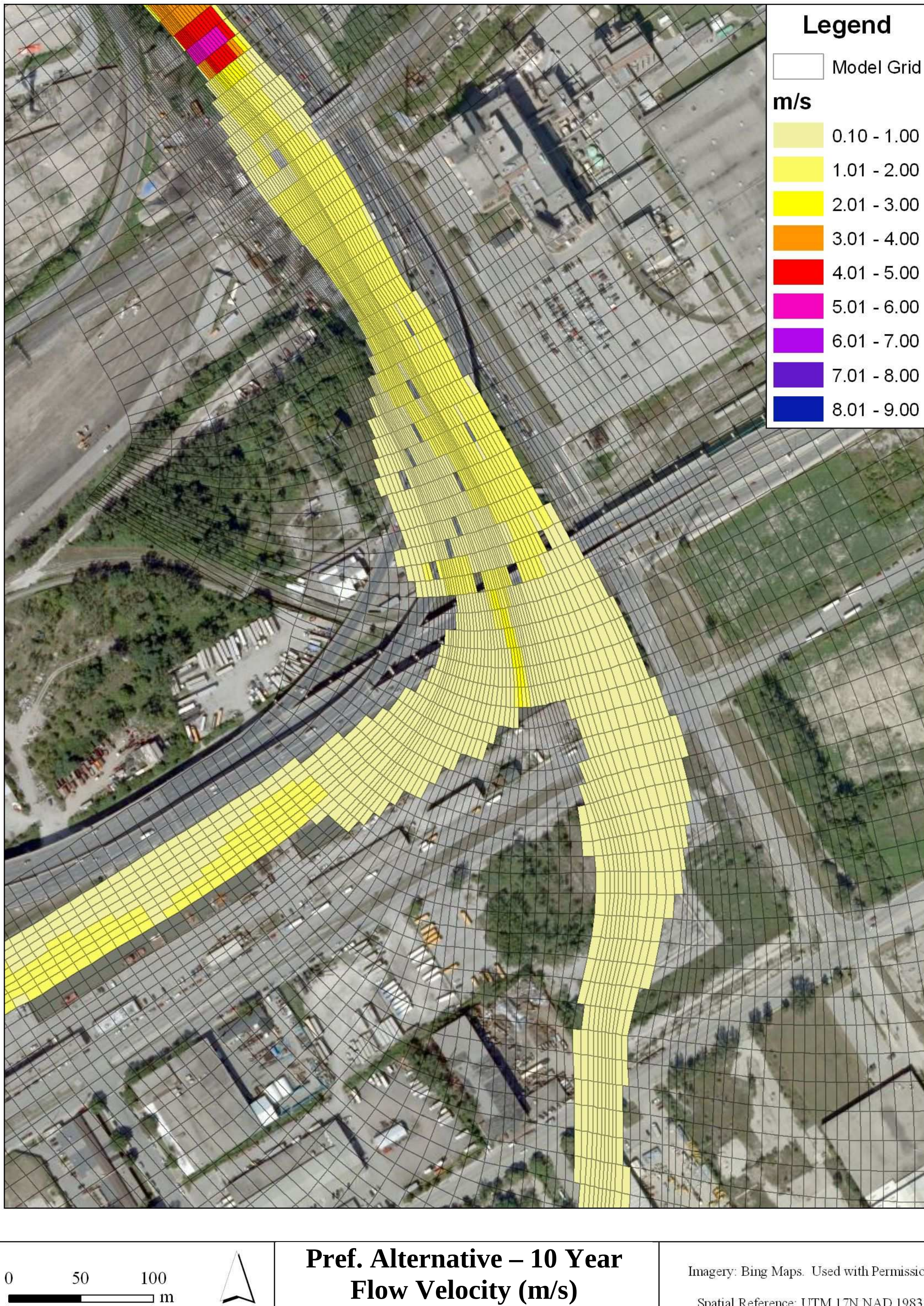
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 10 Year Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

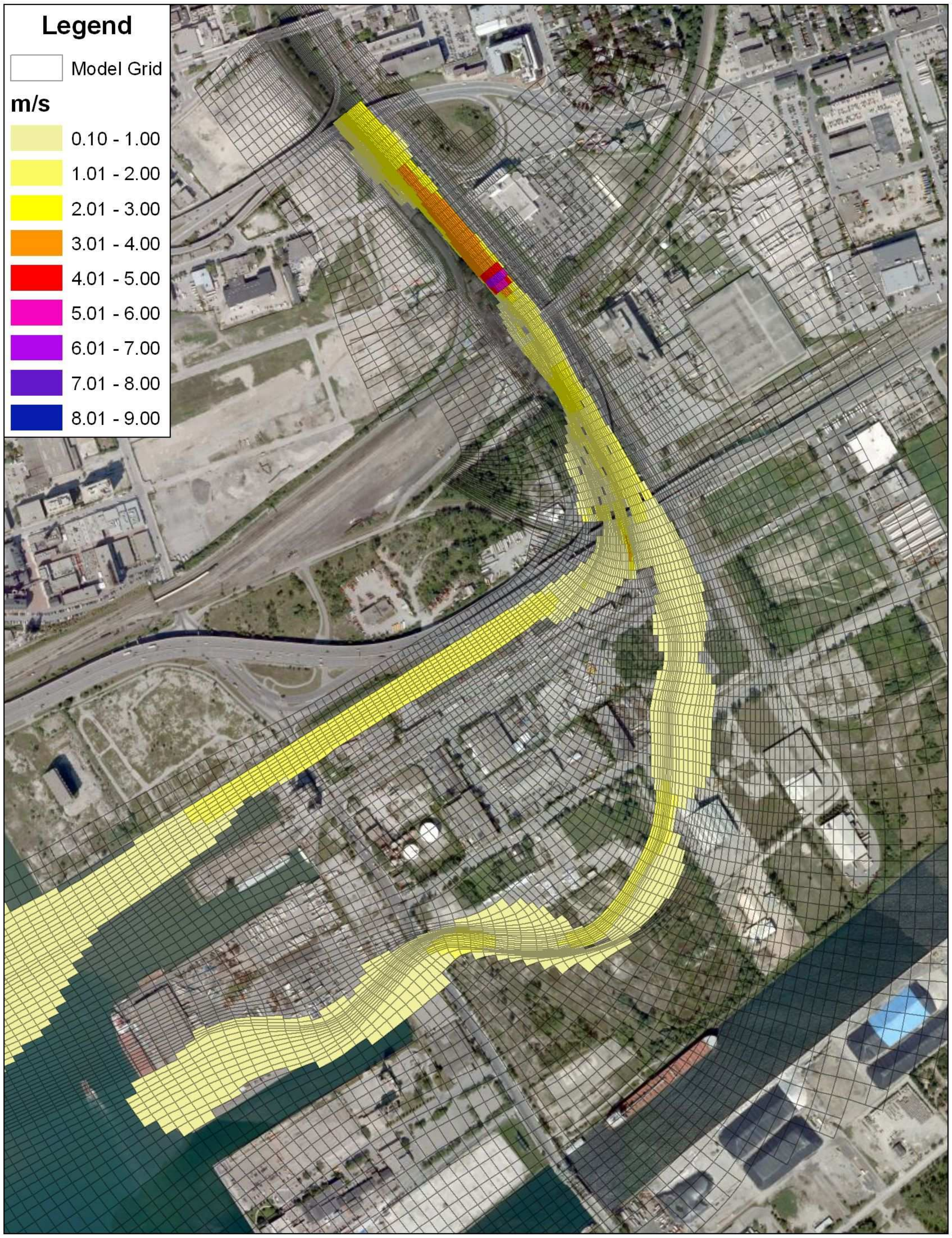
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 10 Year Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

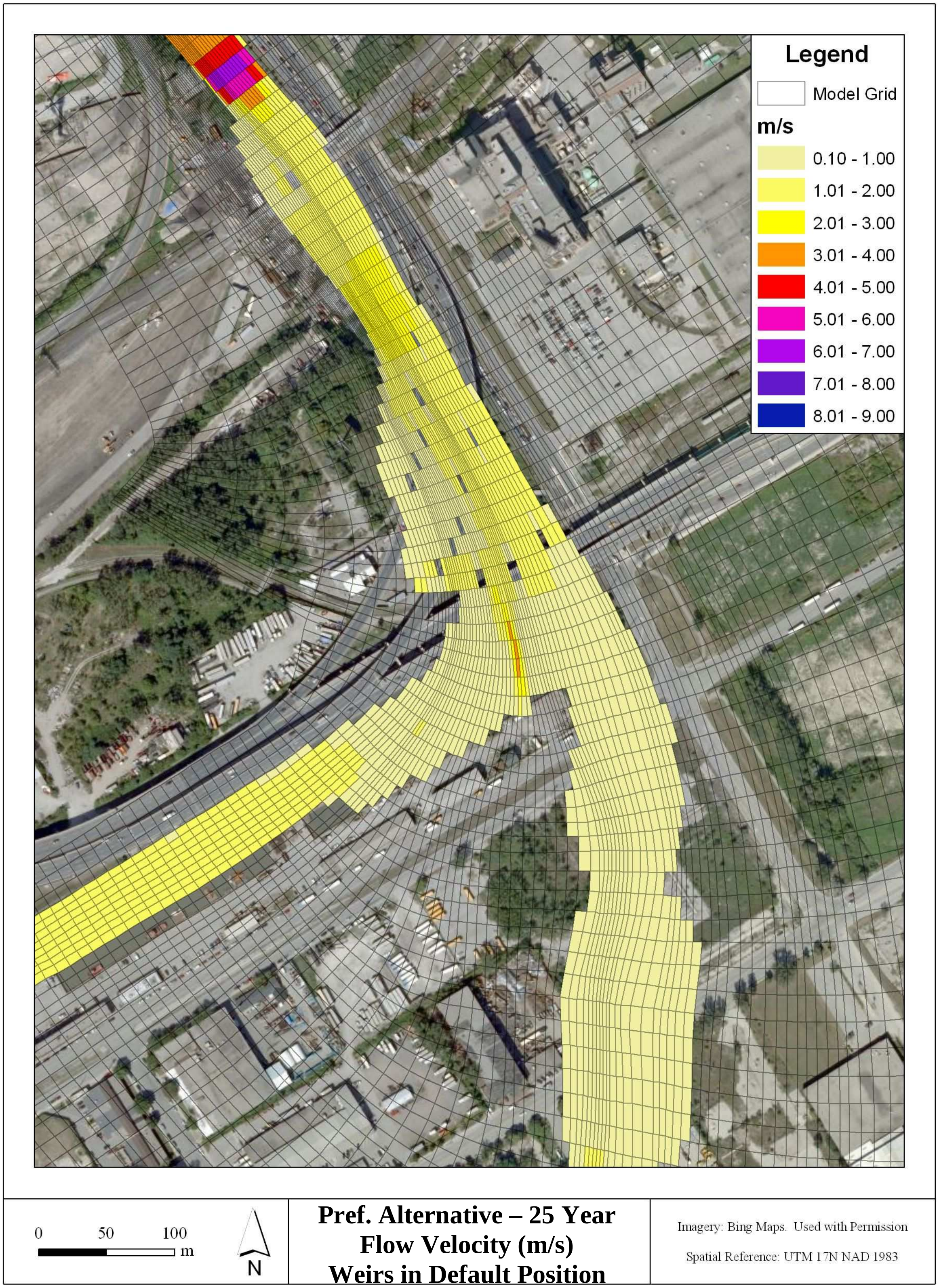


0 100 200 300 m
N

Pref. Alternative – 25 Year Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

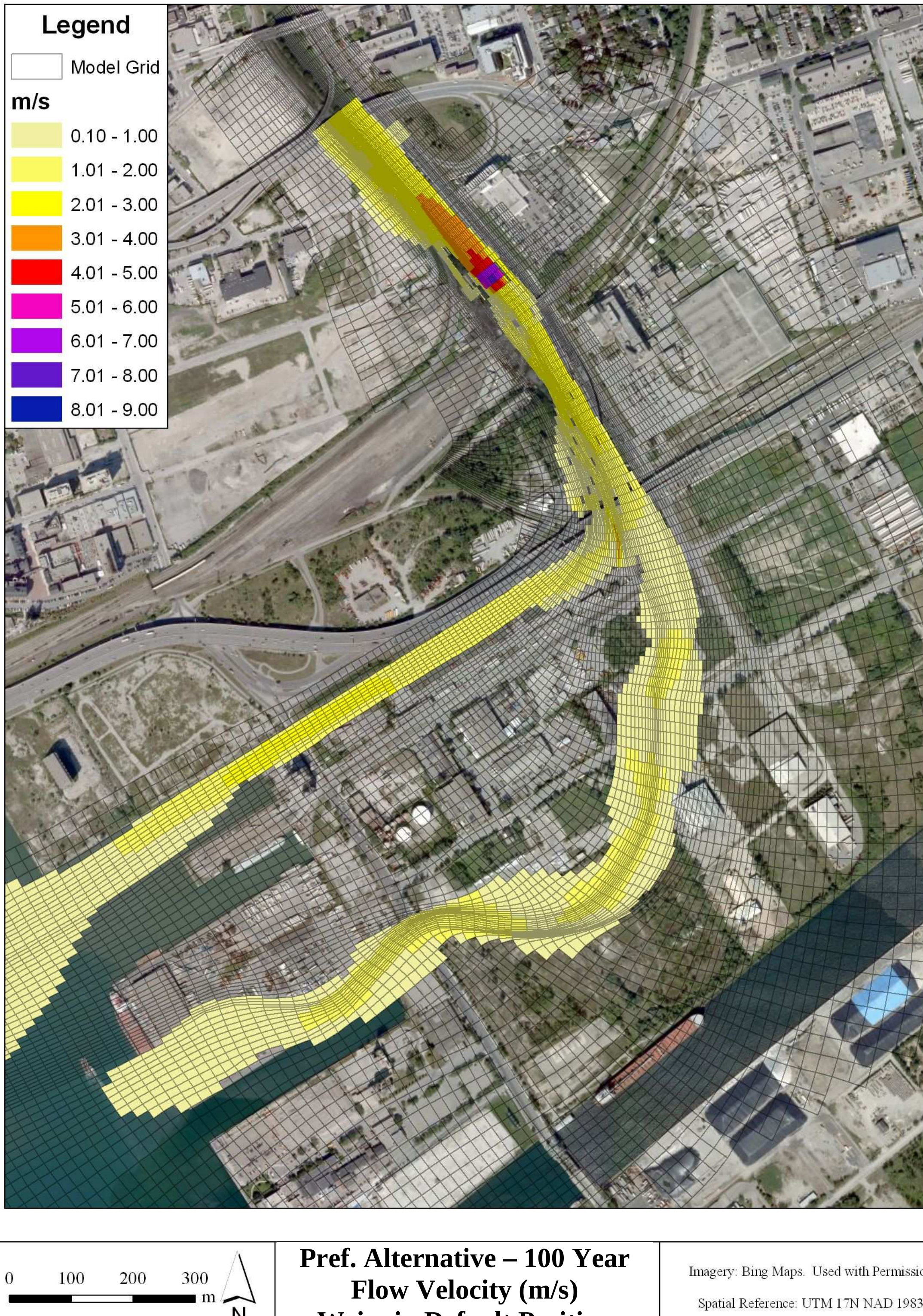
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 25 Year
Flow Velocity (m/s)
Weirs in Default Position

Imagery: Bing Maps. Used with Permission

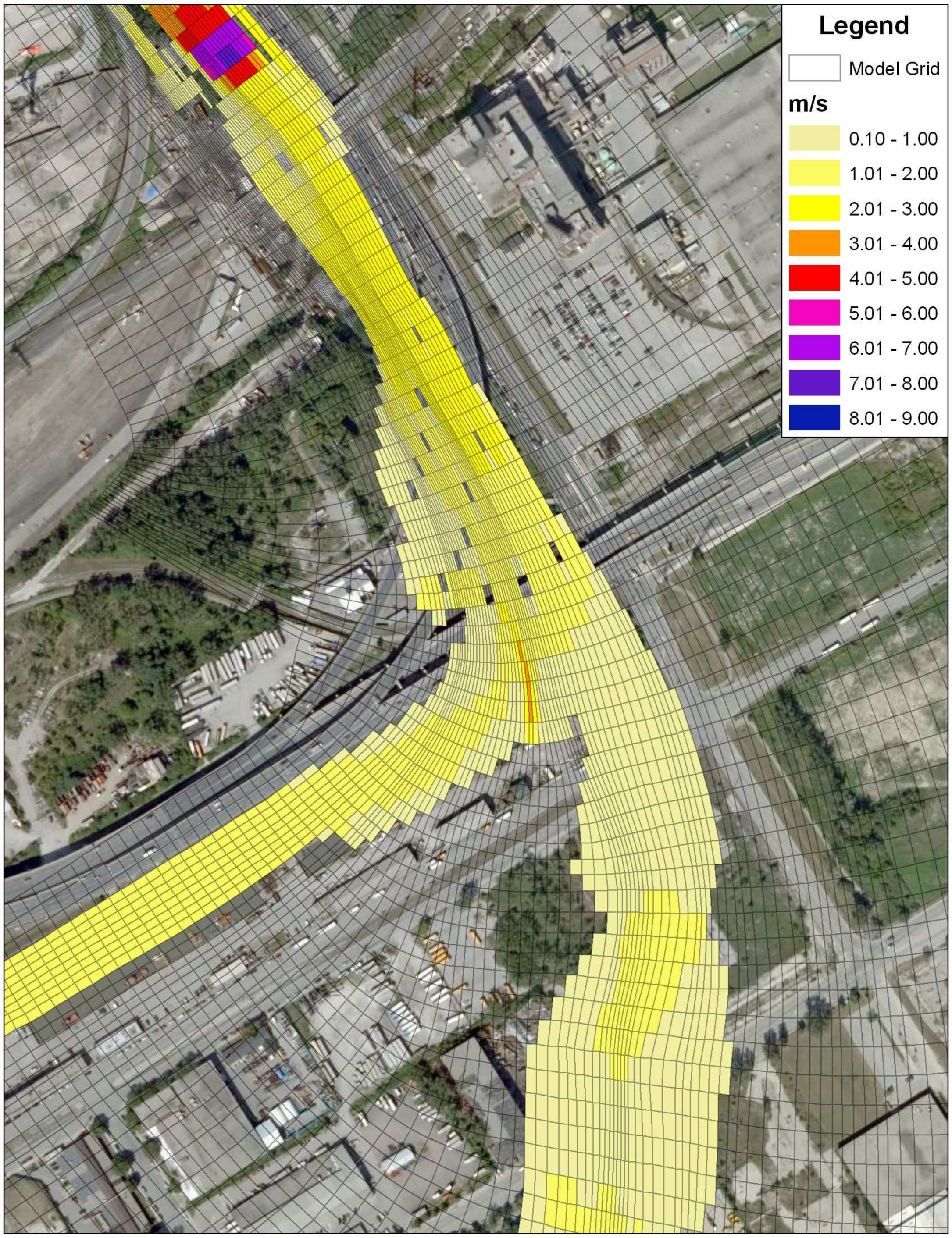
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 100 Year Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



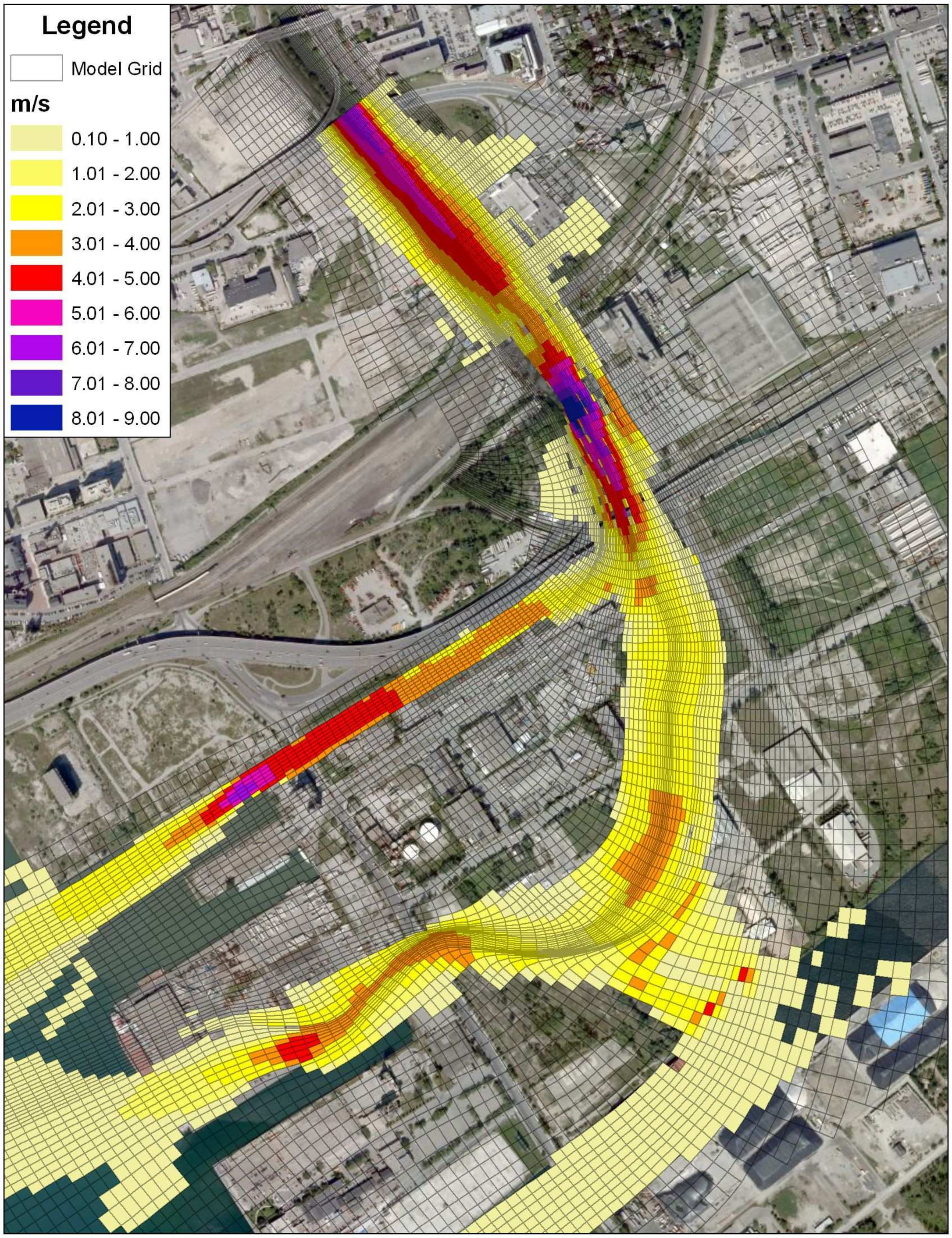
0 50 100 m

N

Pref. Alternative – 100 Year Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



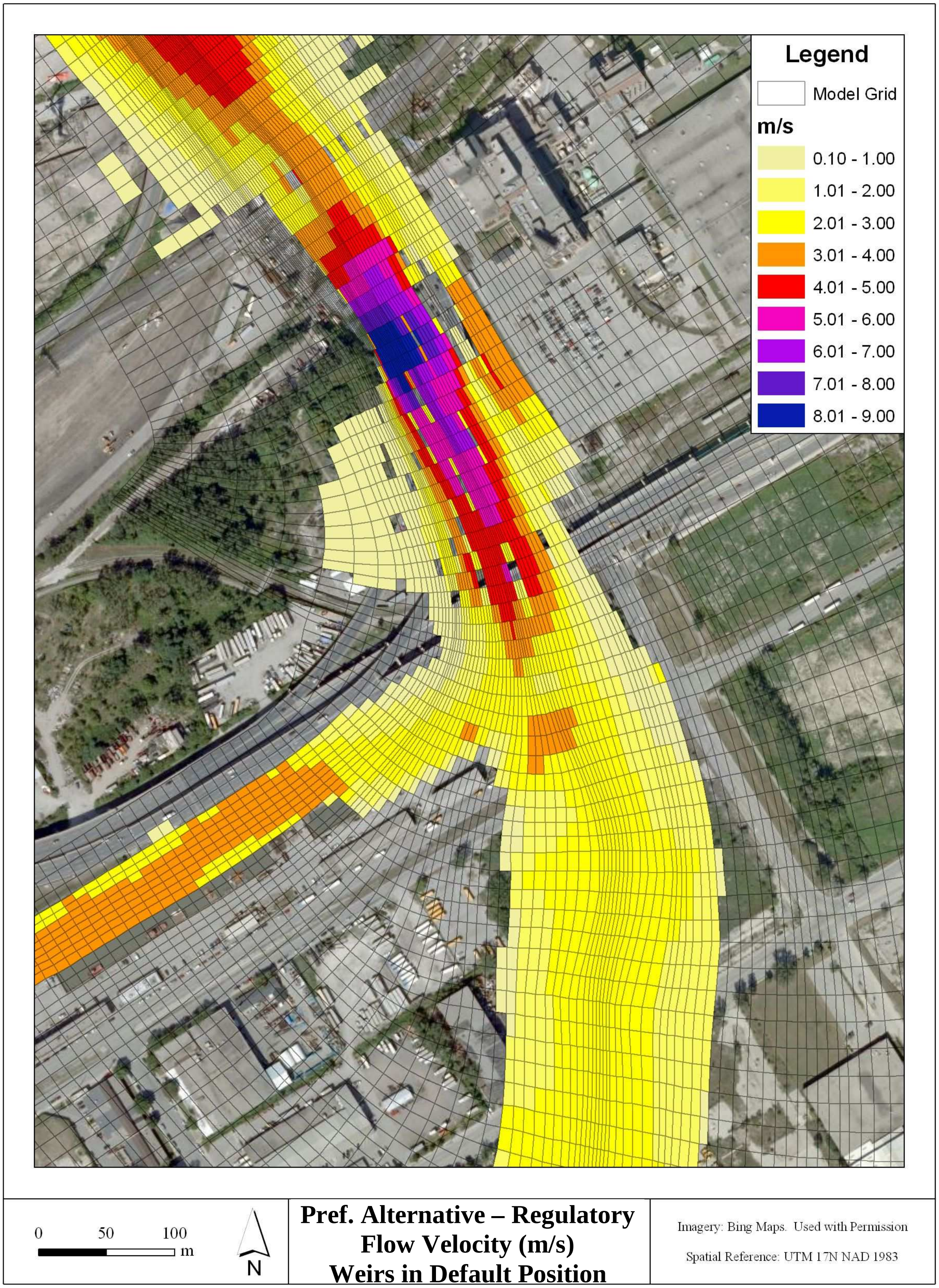
0 100 200 300 m

N

Pref. Alternative – Regulatory Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

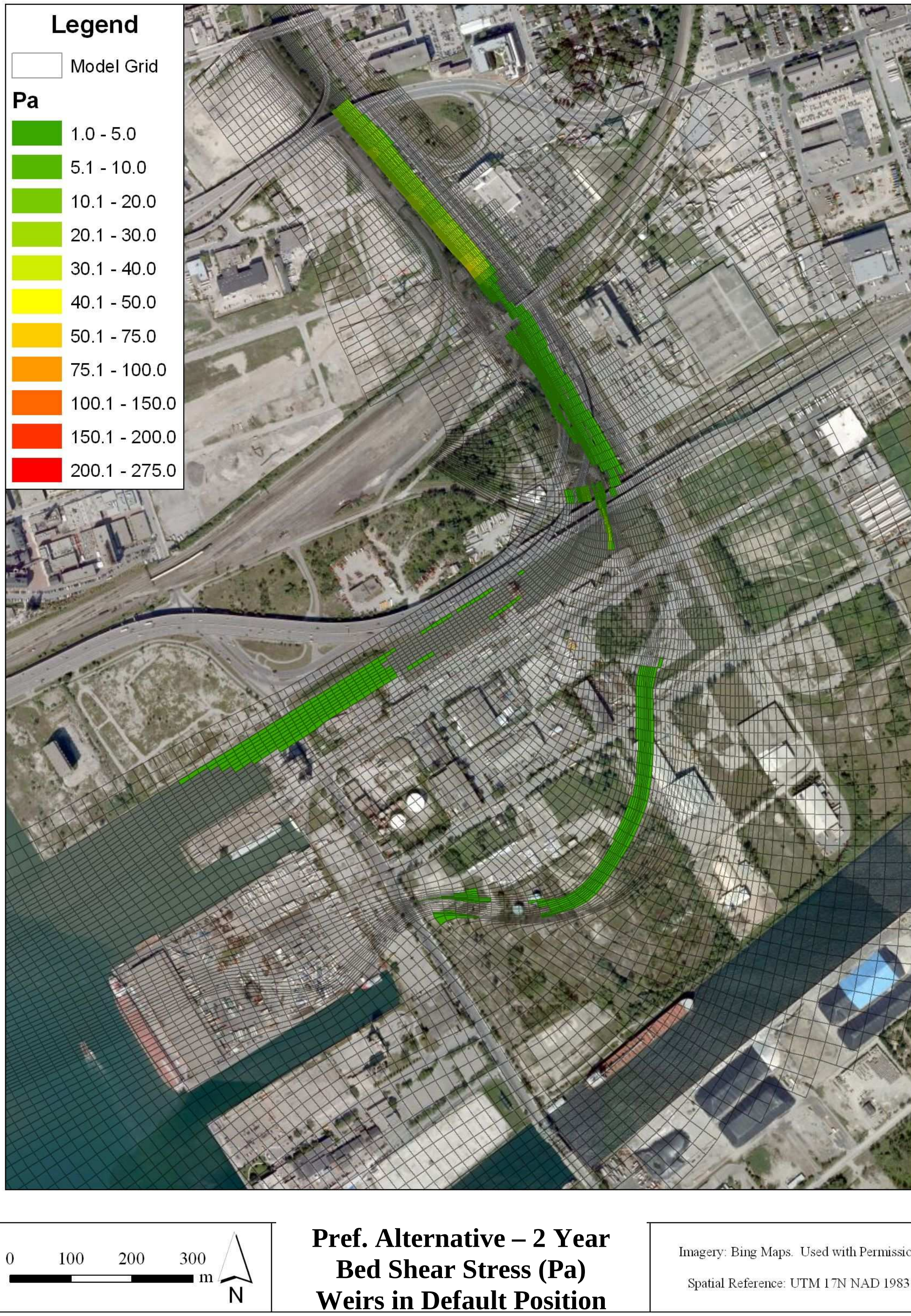


Pref. Alternative – Regulatory Flow Velocity (m/s) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

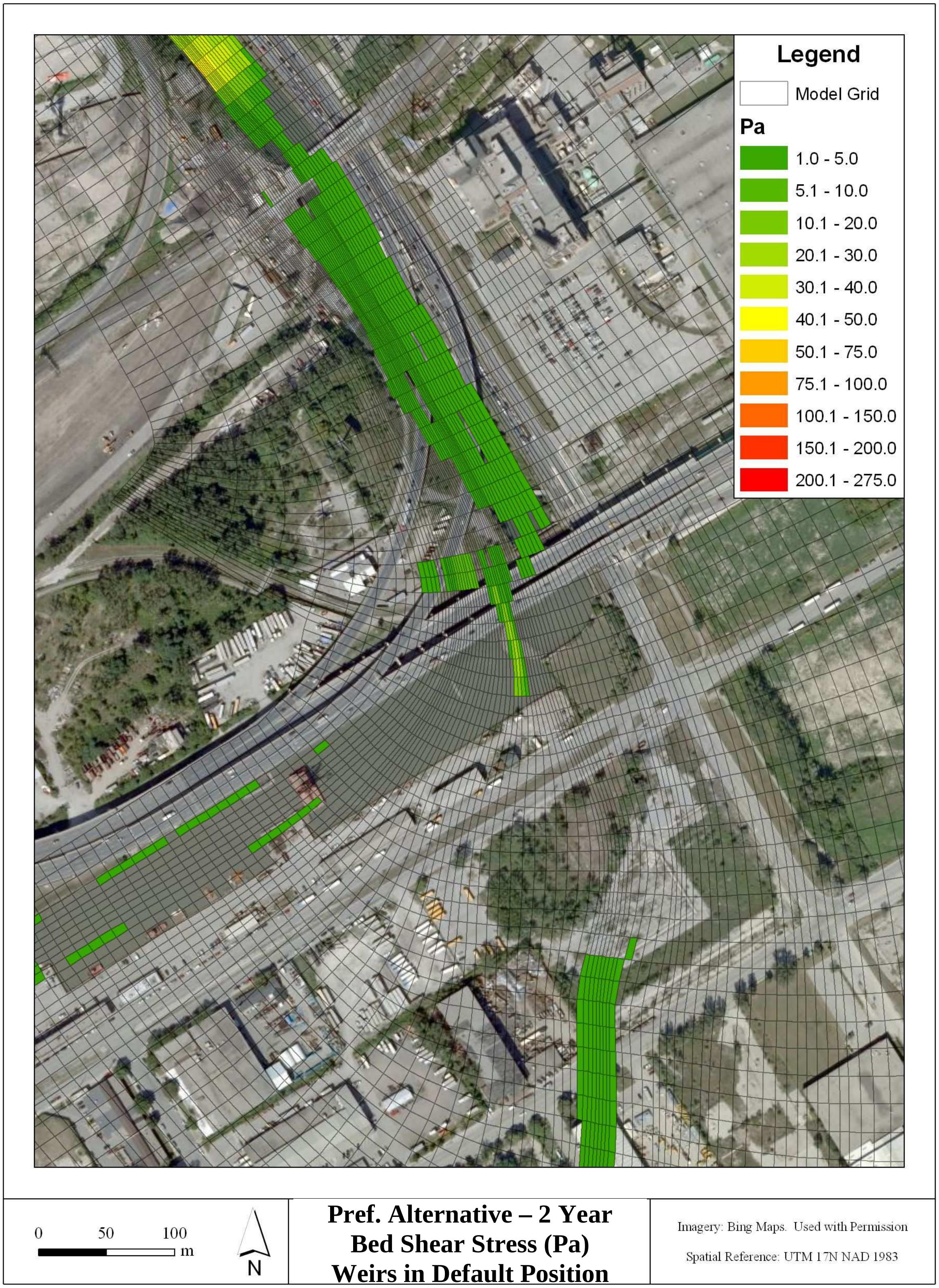
APPENDIX HD-H
PREFERRED ALTERNATIVE BED SHEAR STRESS MAPS – WEIRS IN DEFAULT POSITION



Pref. Alternative – 2 Year Bed Shear Stress (Pa) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

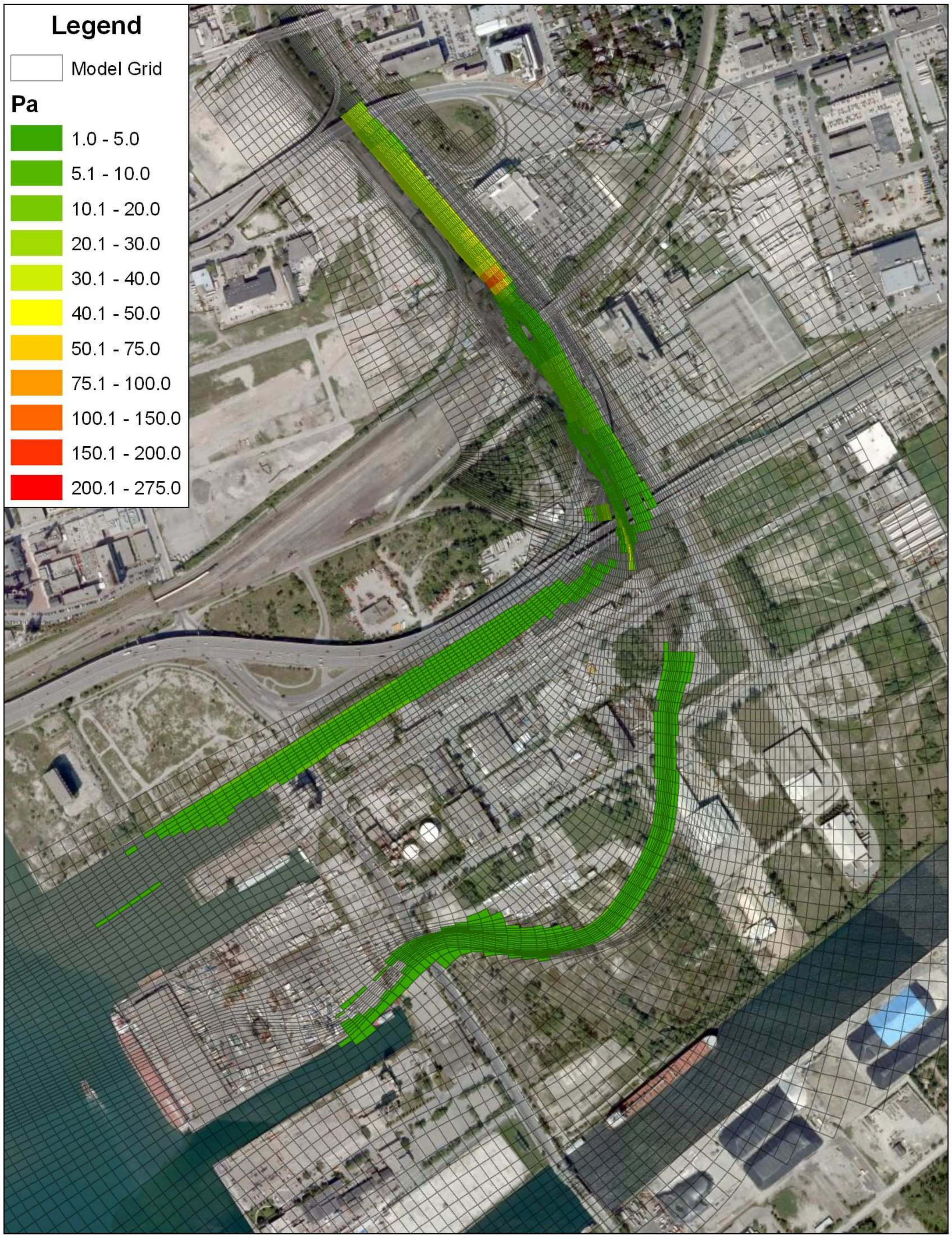
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 2 Year Bed Shear Stress (Pa) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



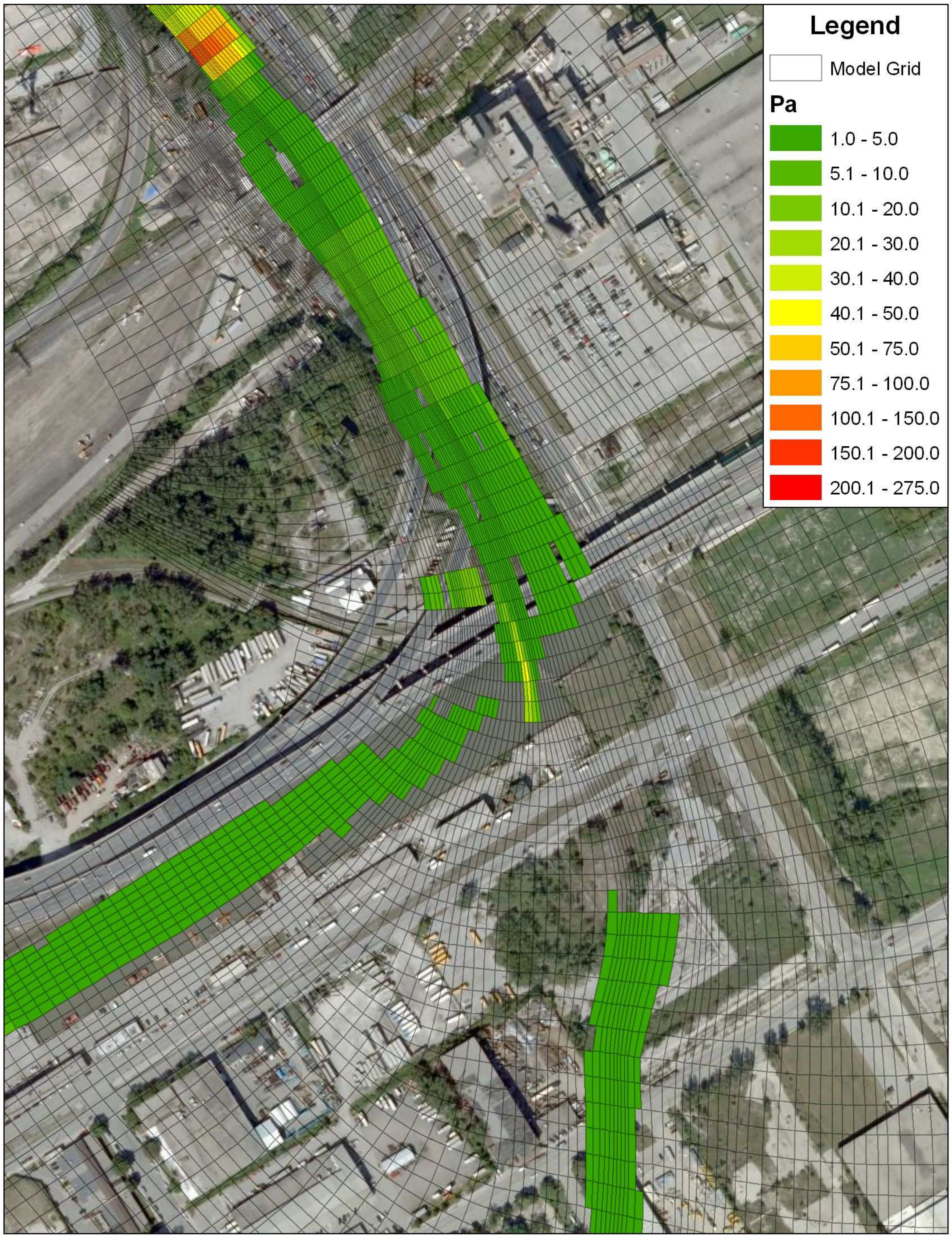
0 100 200 300 m

N

Pref. Alternative – 10 Year
Bed Shear Stress (Pa)
Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



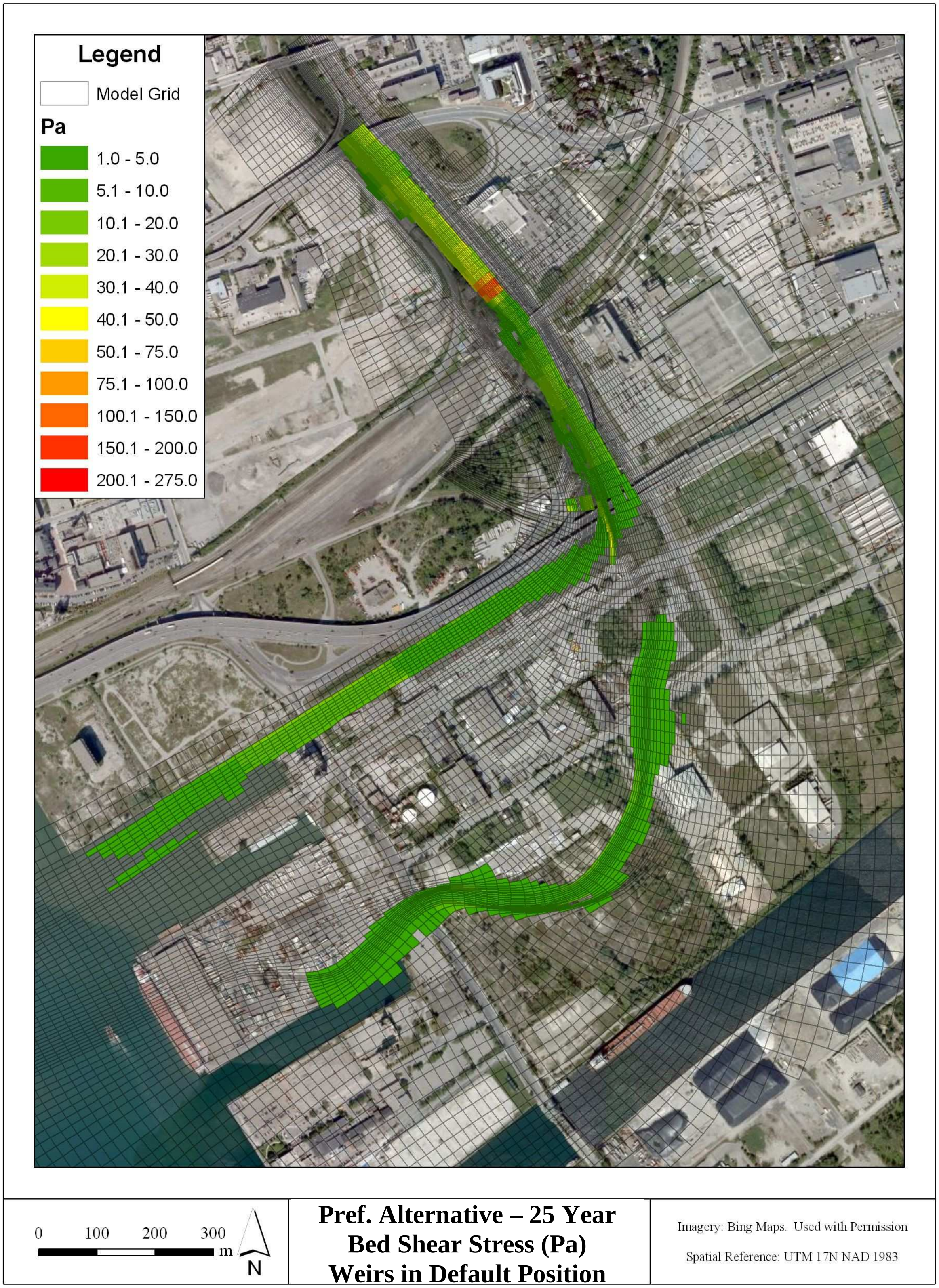
0 50 100 m

N

Pref. Alternative – 10 Year Bed Shear Stress (Pa) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

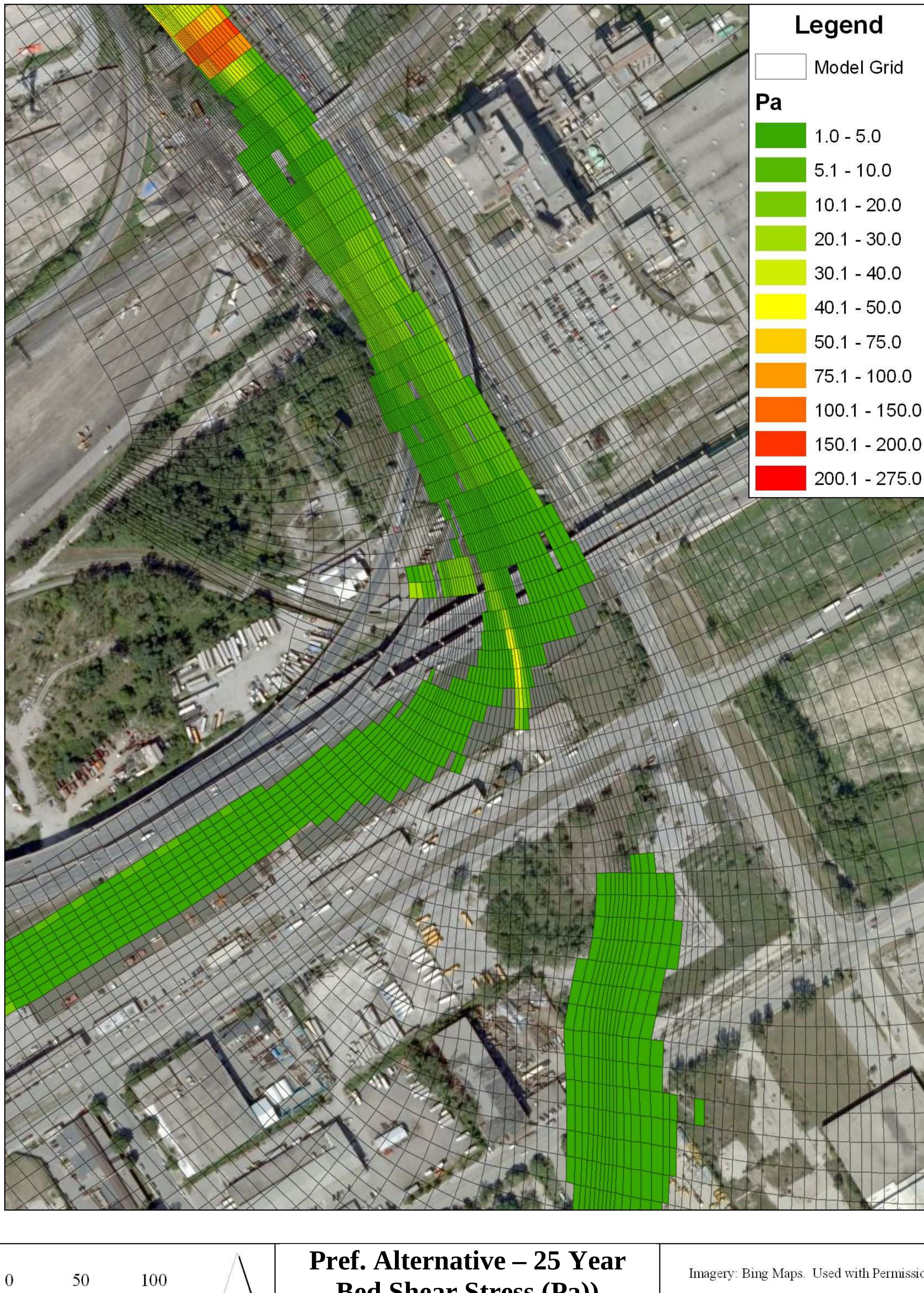
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 25 Year Bed Shear Stress (Pa) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

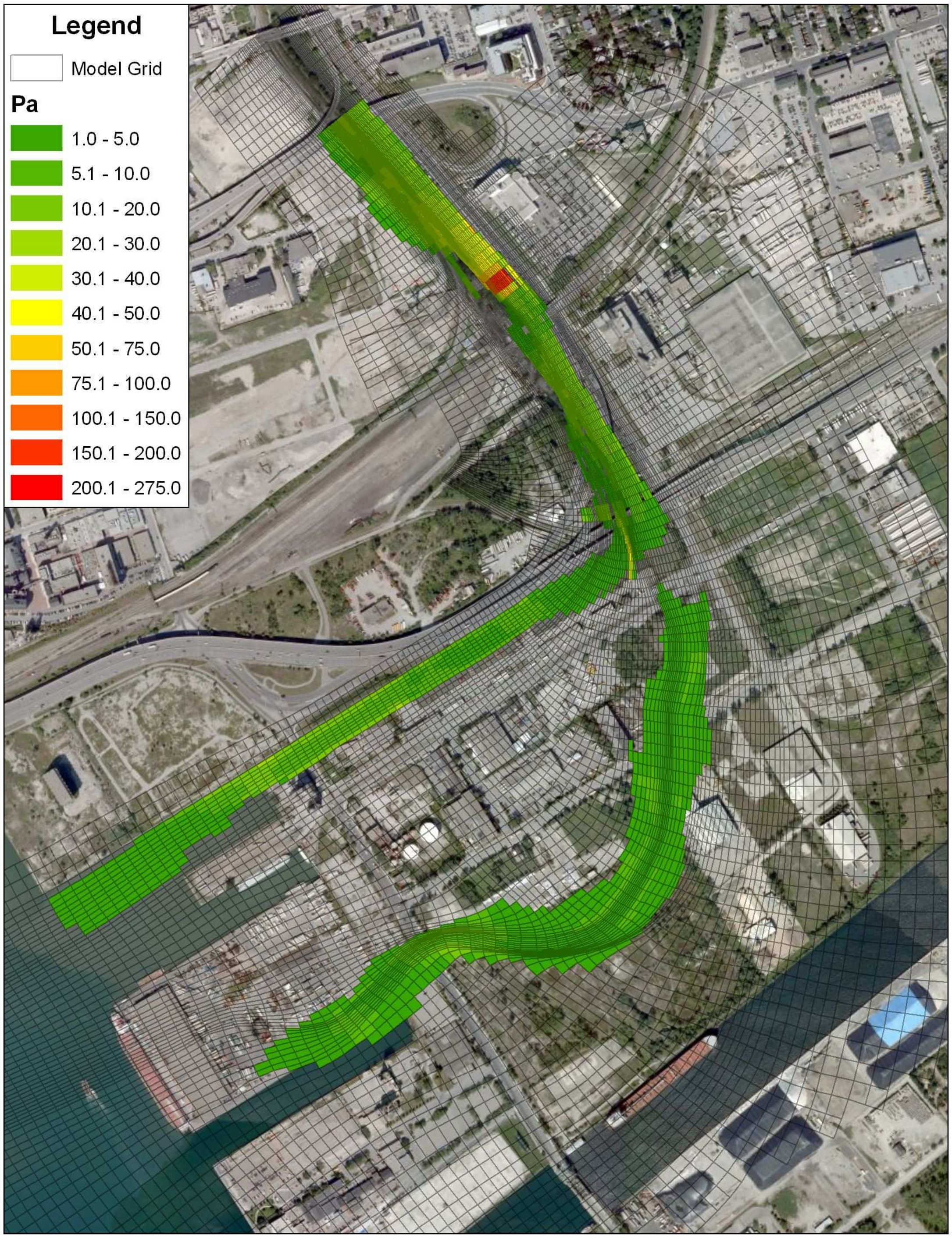
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 25 Year Bed Shear Stress (Pa)) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

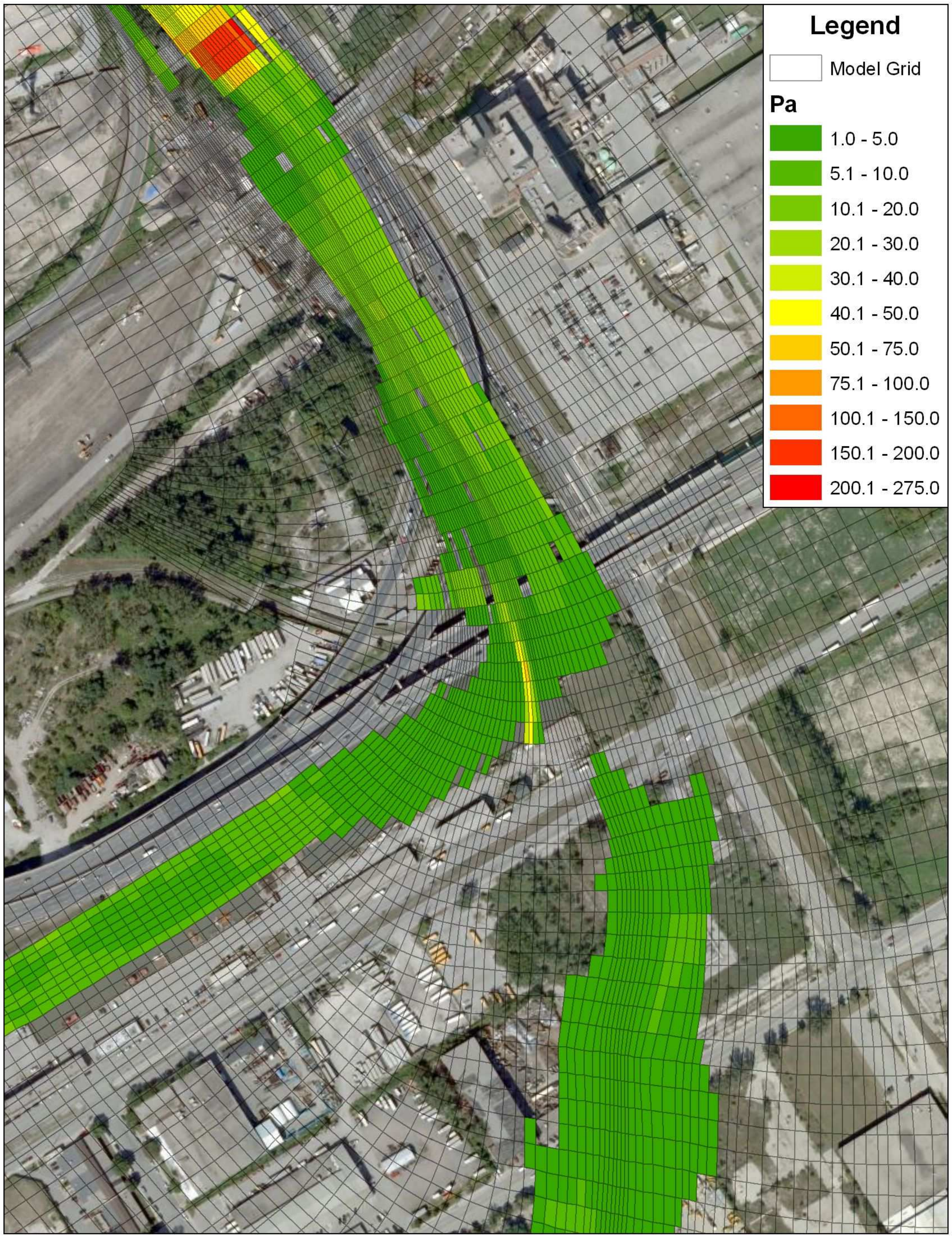


0 100 200 300 m N

Pref. Alternative – 100 Year Bed Shear Stress (Pa) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

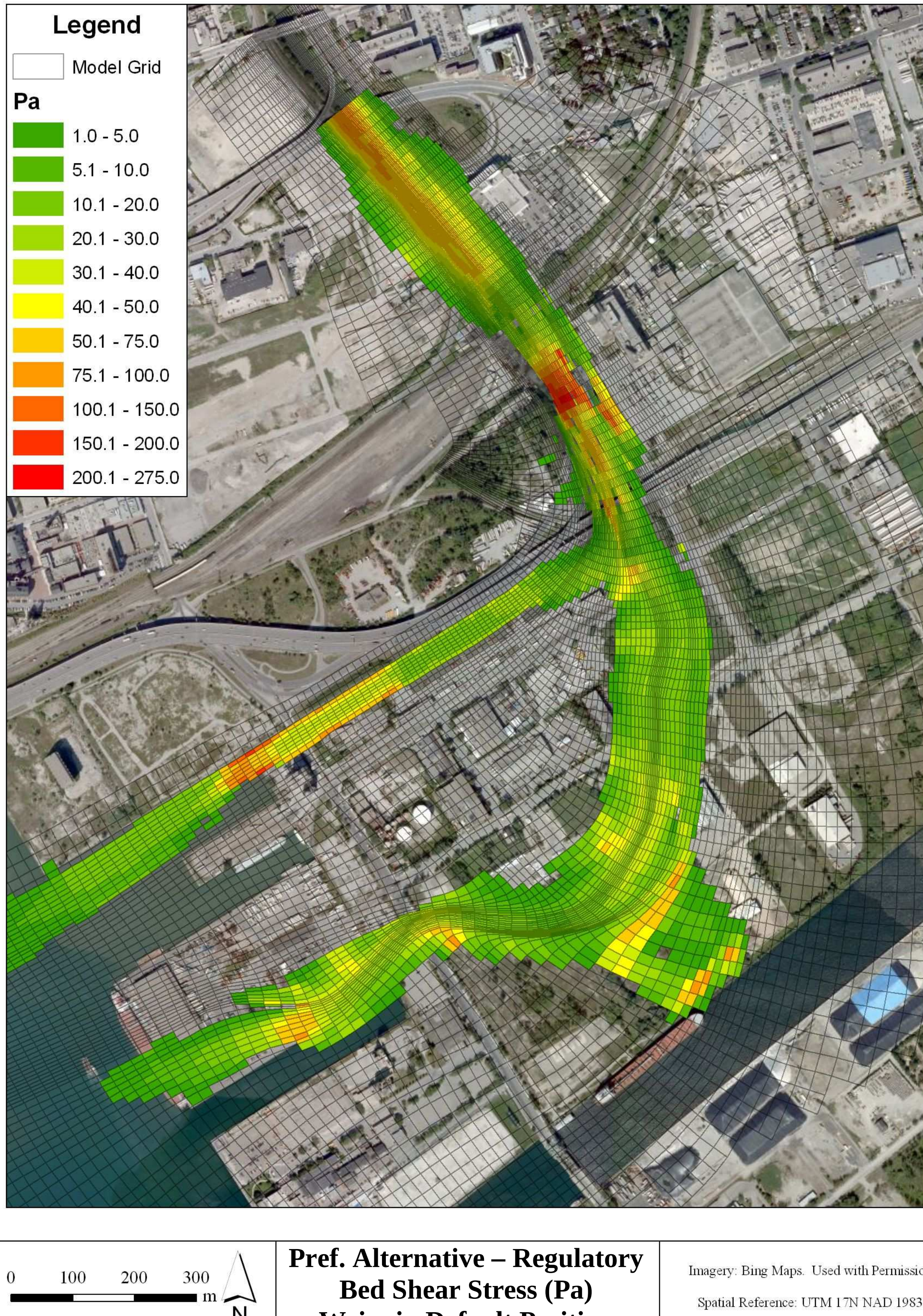
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 100 Year Bed Shear Stress (Pa) Weirs in Default Position

Imagery: Bing Maps. Used with Permission

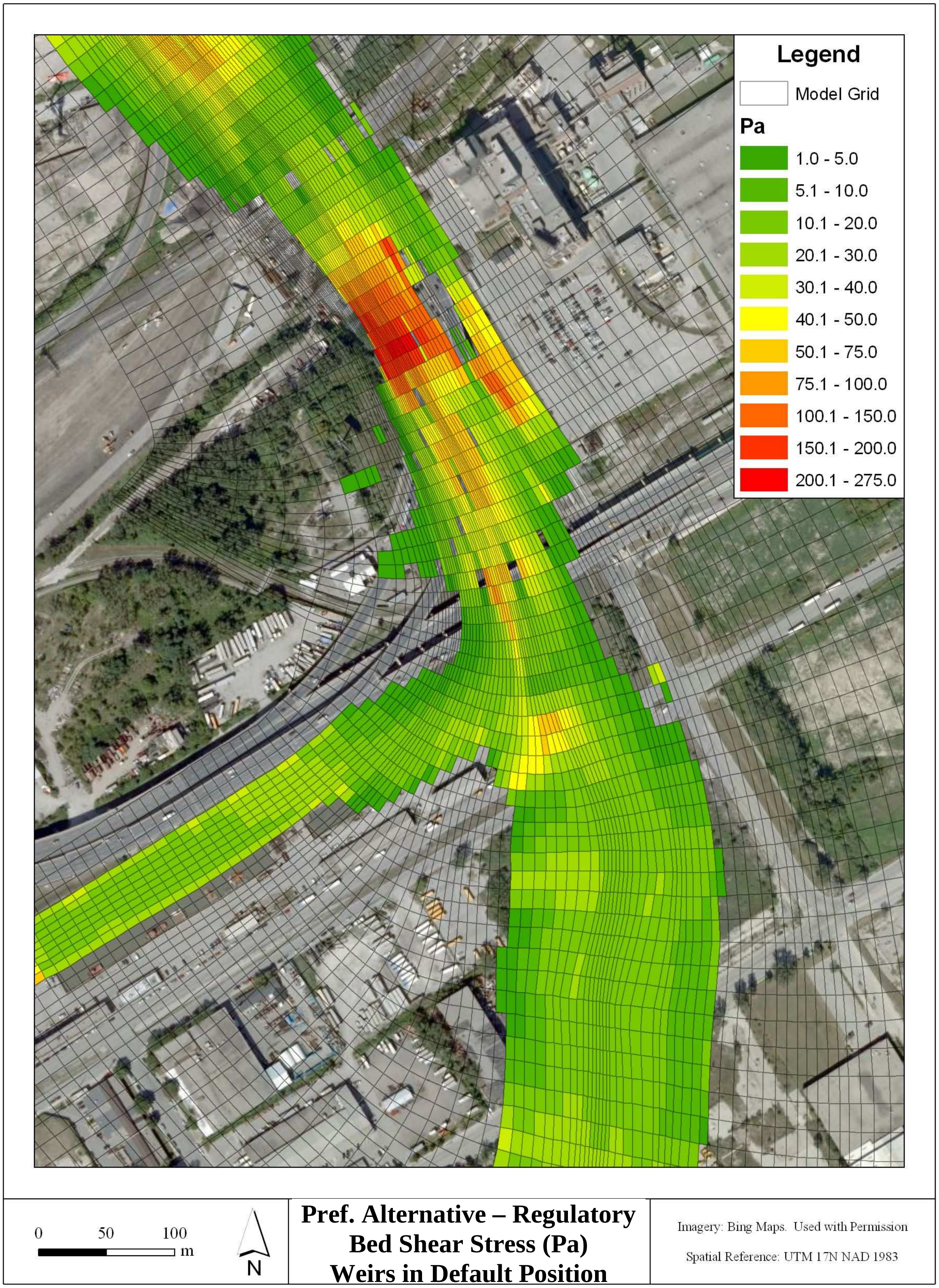
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Regulatory
Bed Shear Stress (Pa)
Weirs in Default Position

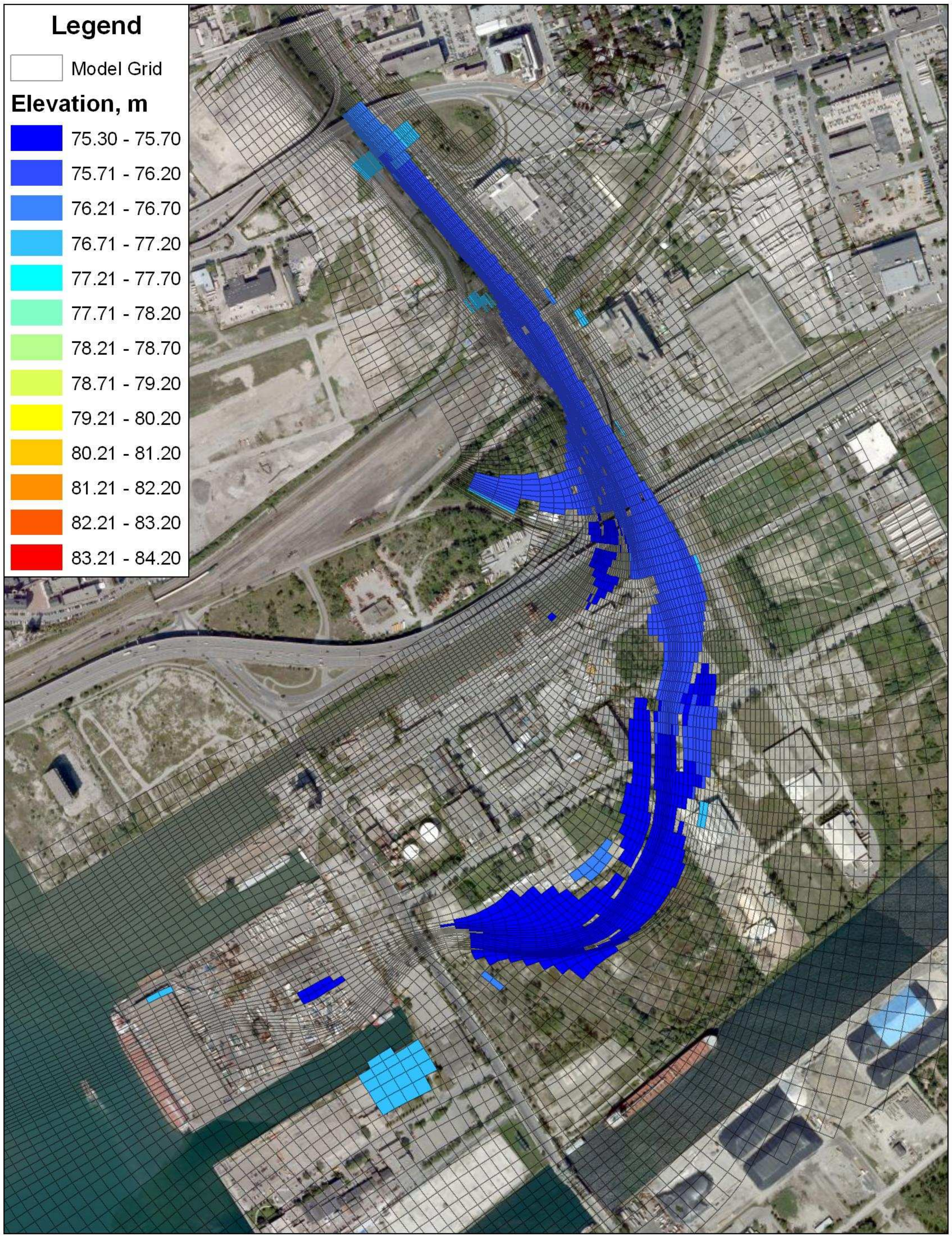
Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Regulatory
Bed Shear Stress (Pa)
Weirs in Default Position

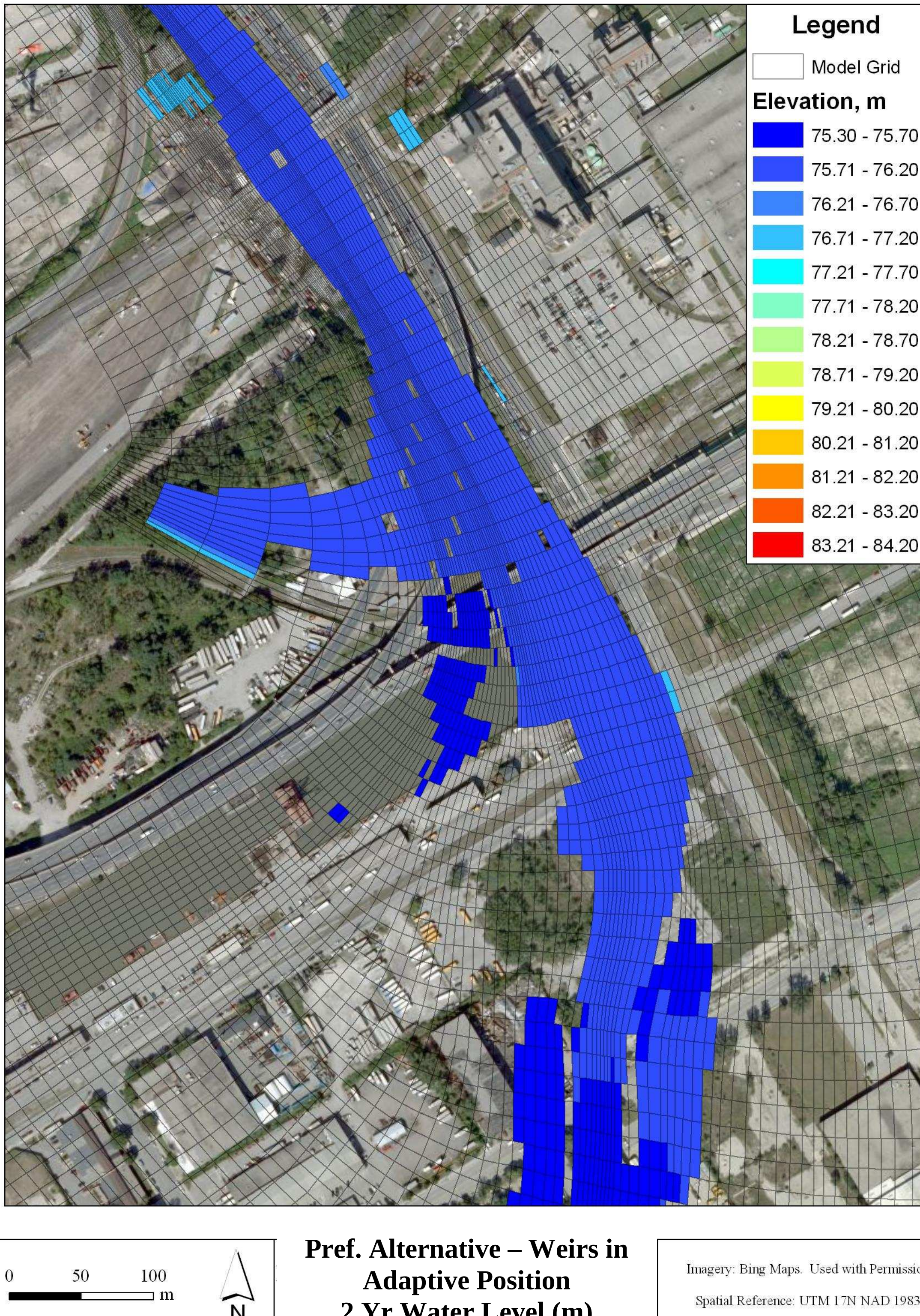
APPENDIX HD-I
PREFERRED ALTERNATIVE WATER LEVEL MAPS – WEIRS IN ADAPTIVE POSITION



Pref. Alternative – Weirs in Adaptive Position
2 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

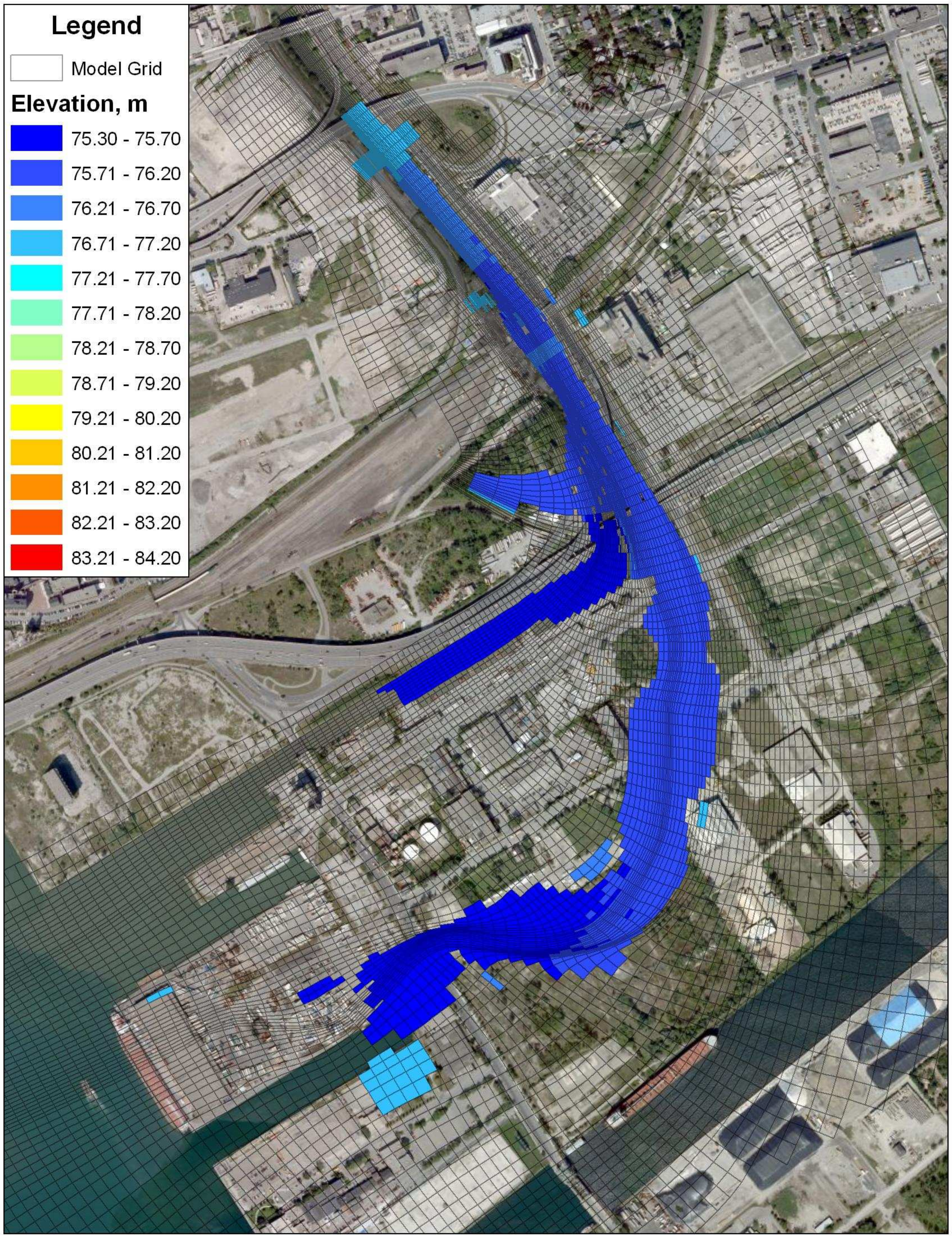
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position
2 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

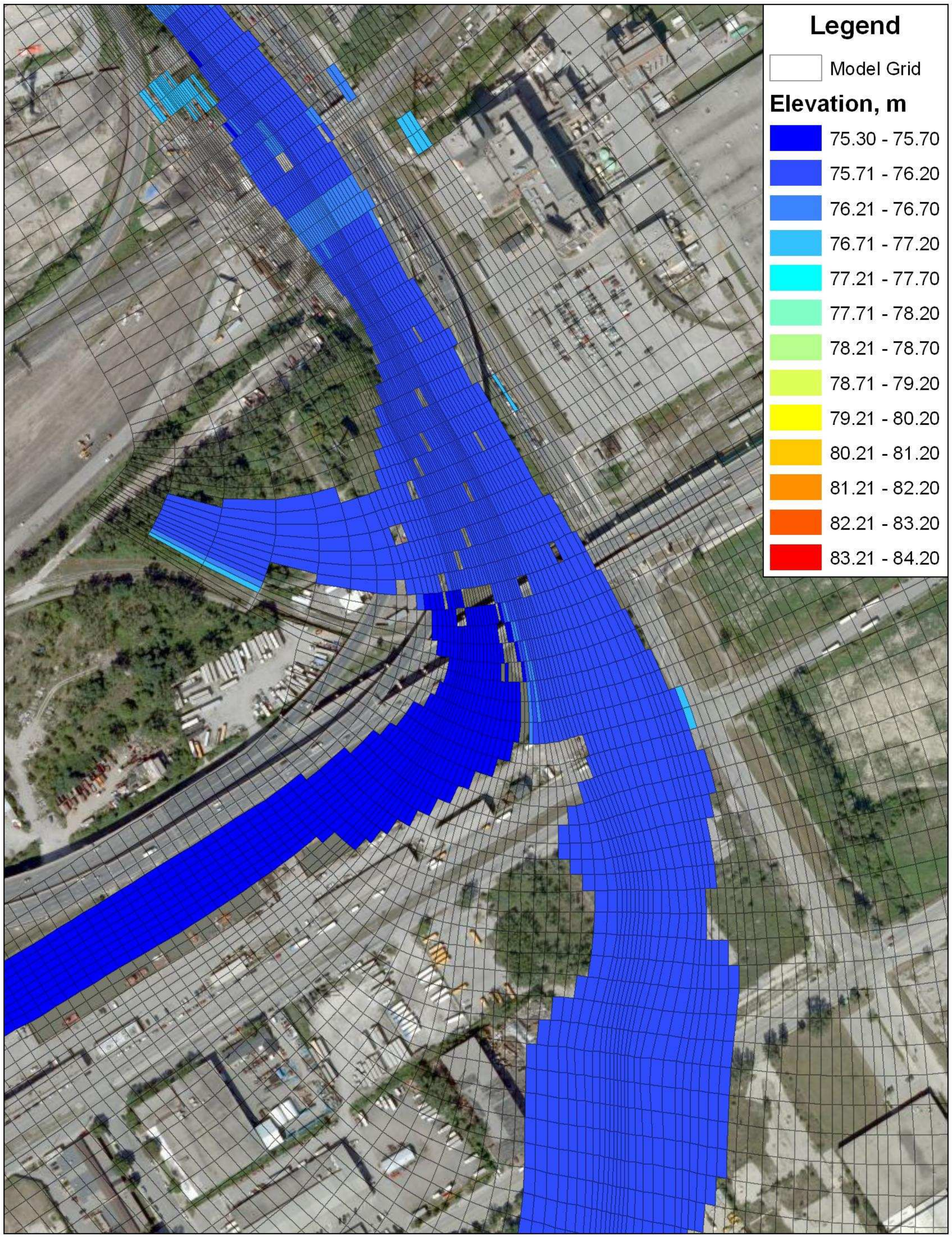


0 100 200 300 m N

Pref. Alternative – Weirs in Adaptive Position
10 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

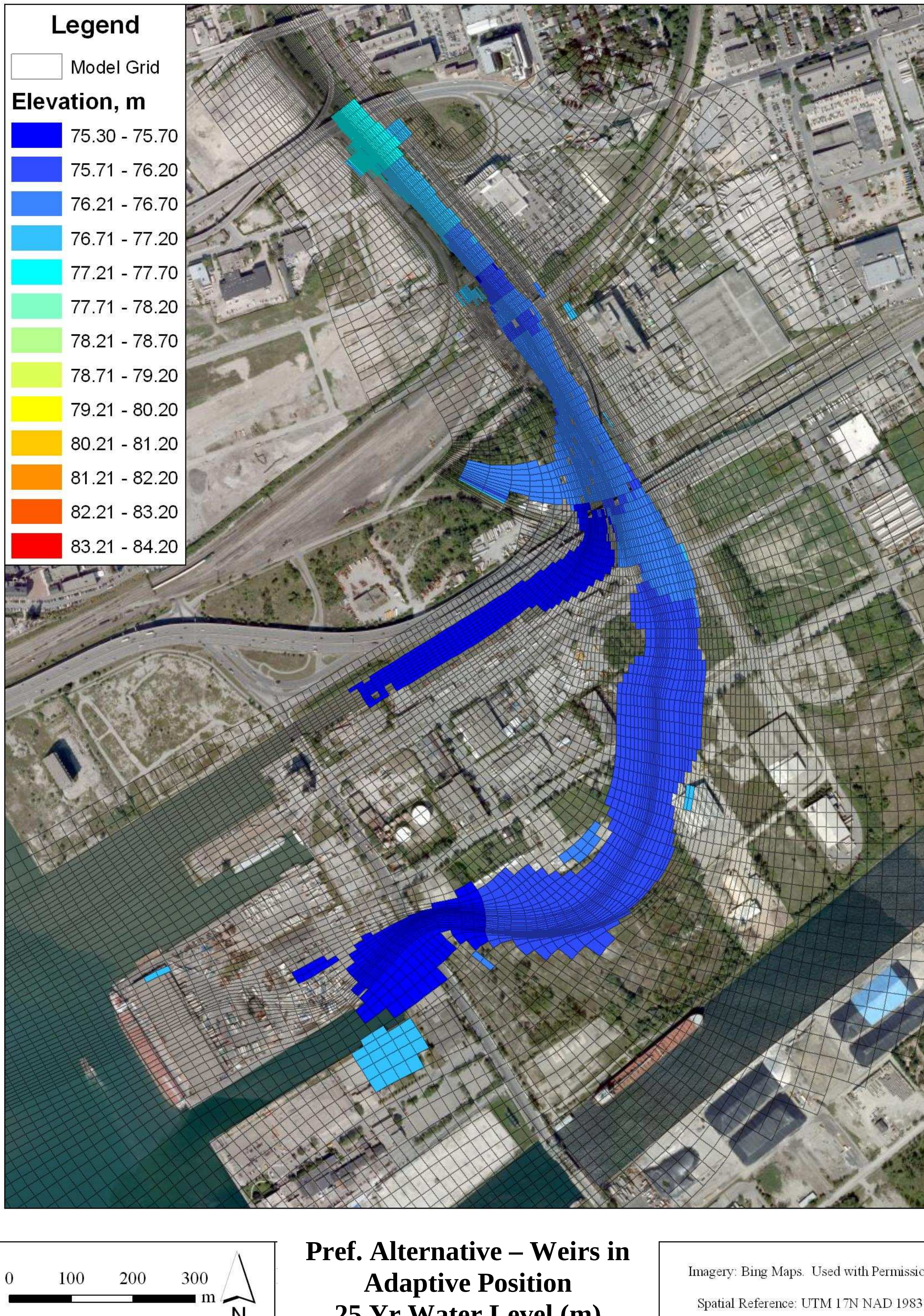
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position
10 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

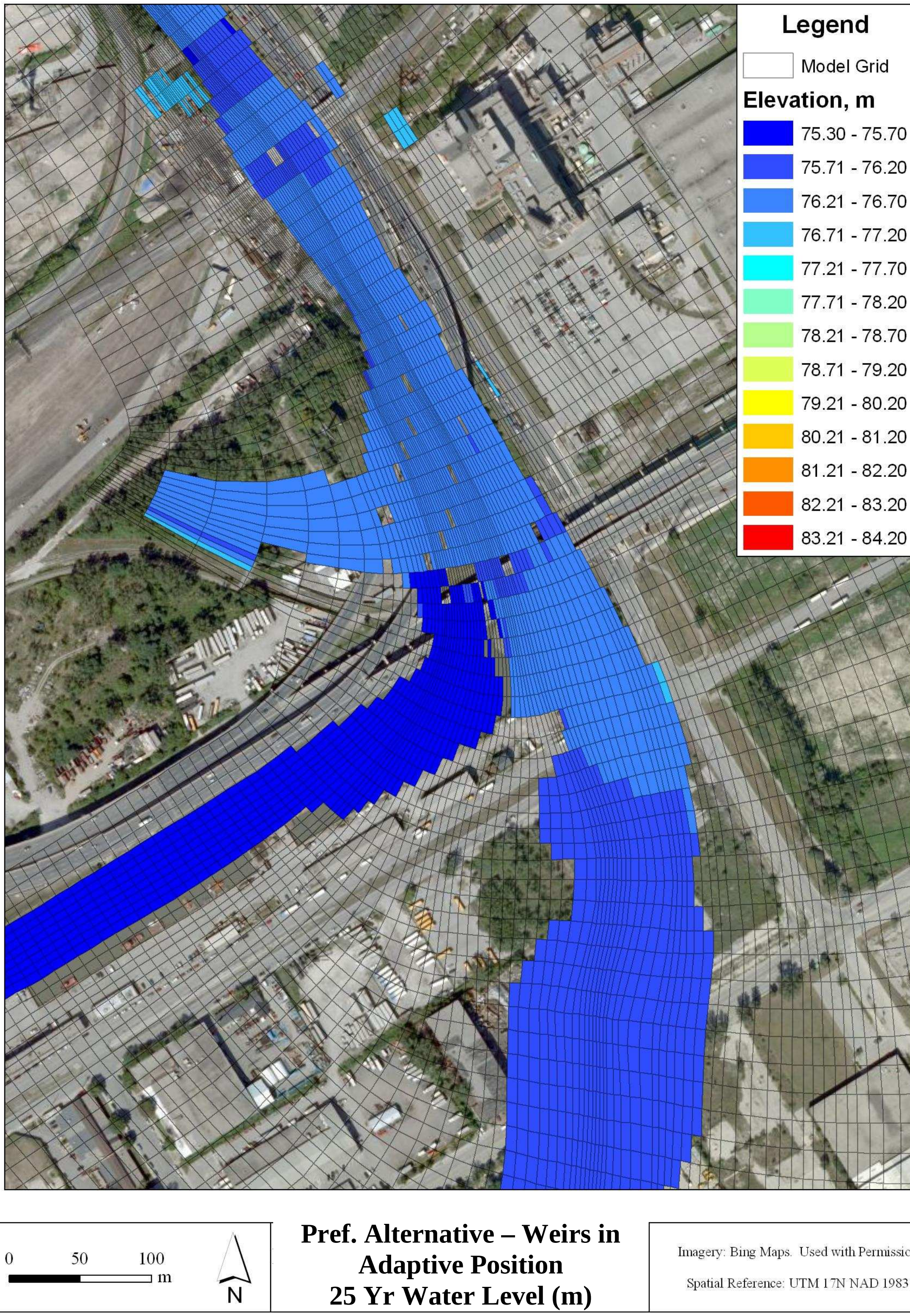
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position
25 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

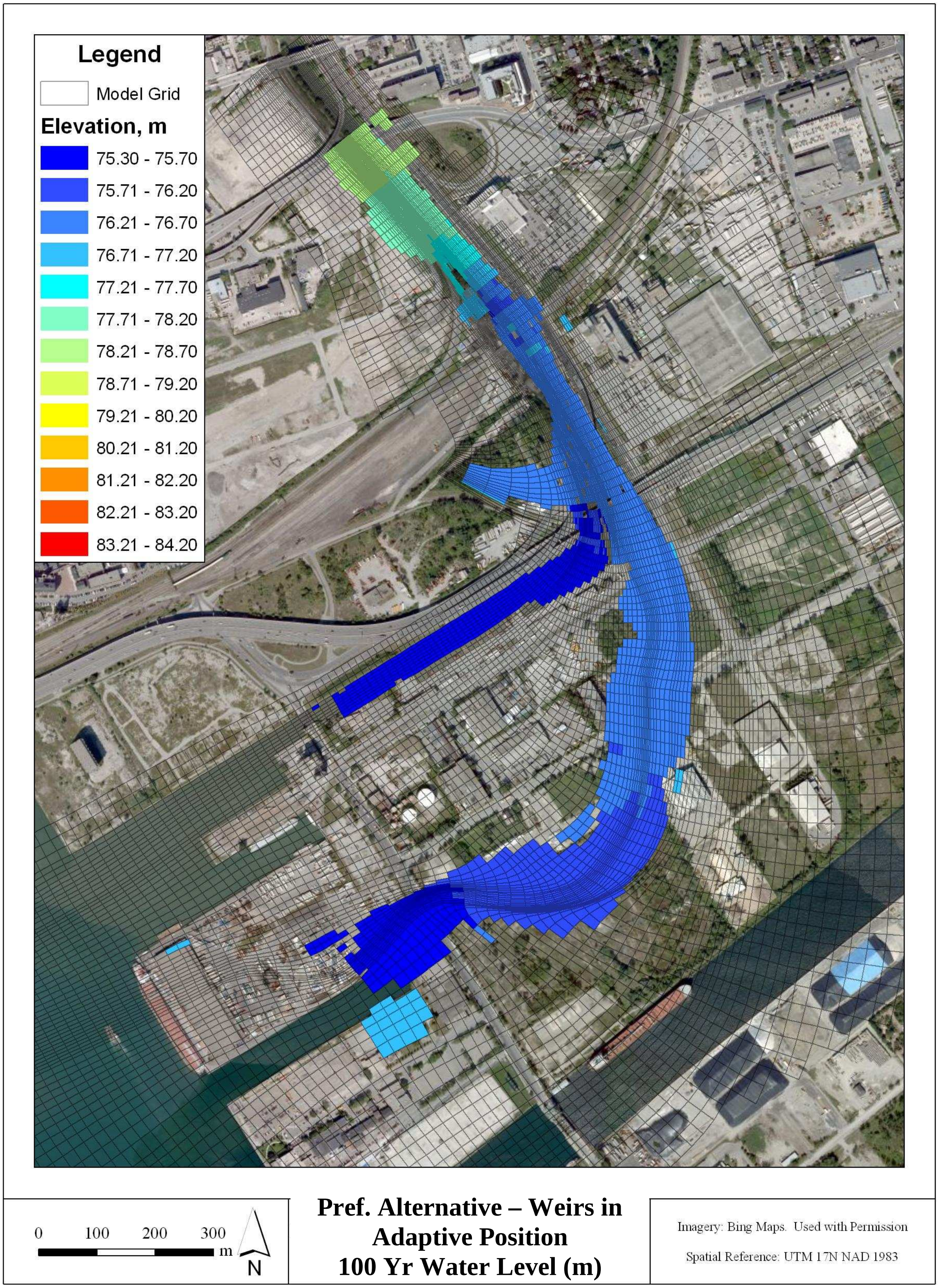
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position 25 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

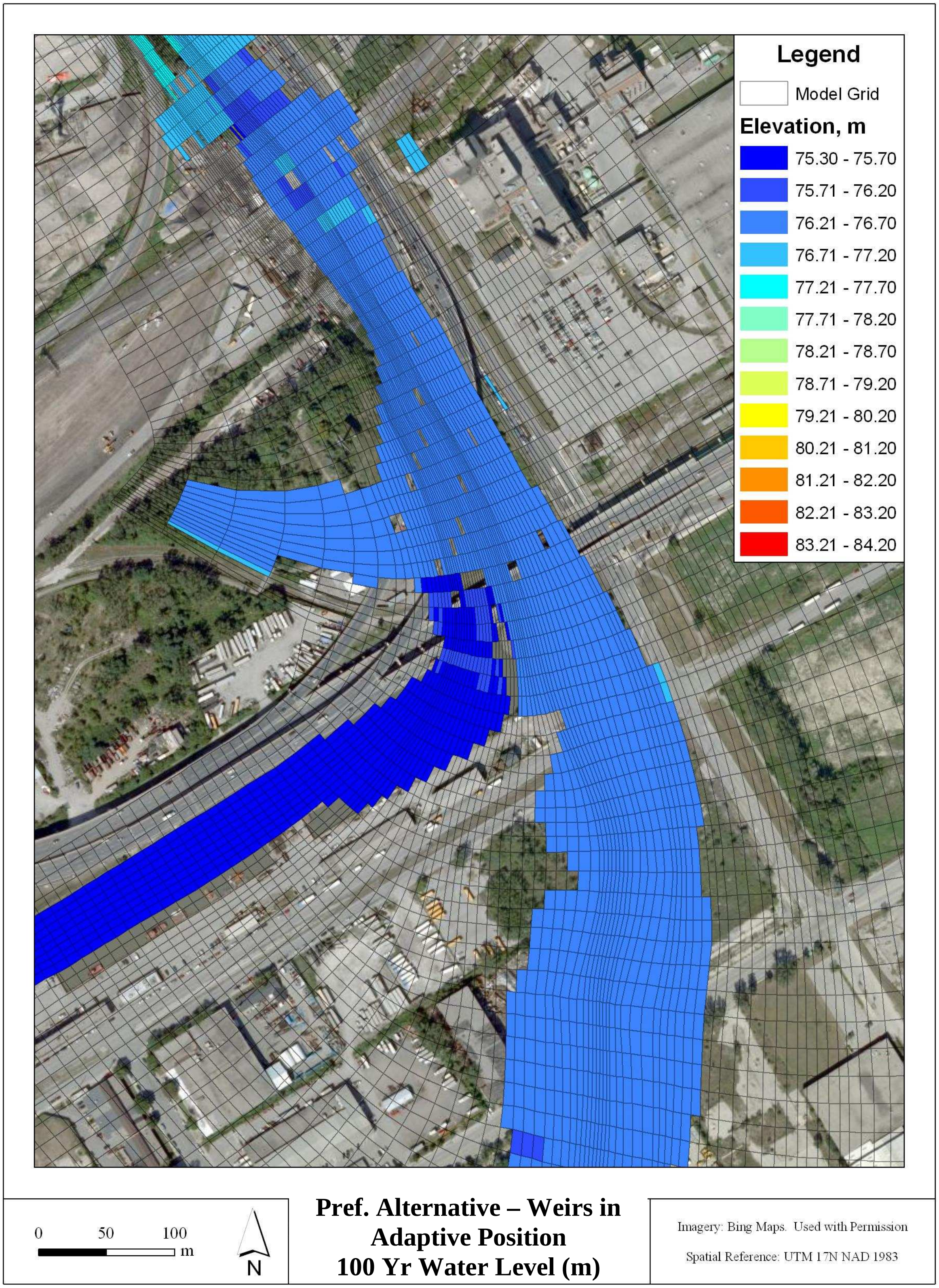
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position 100 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

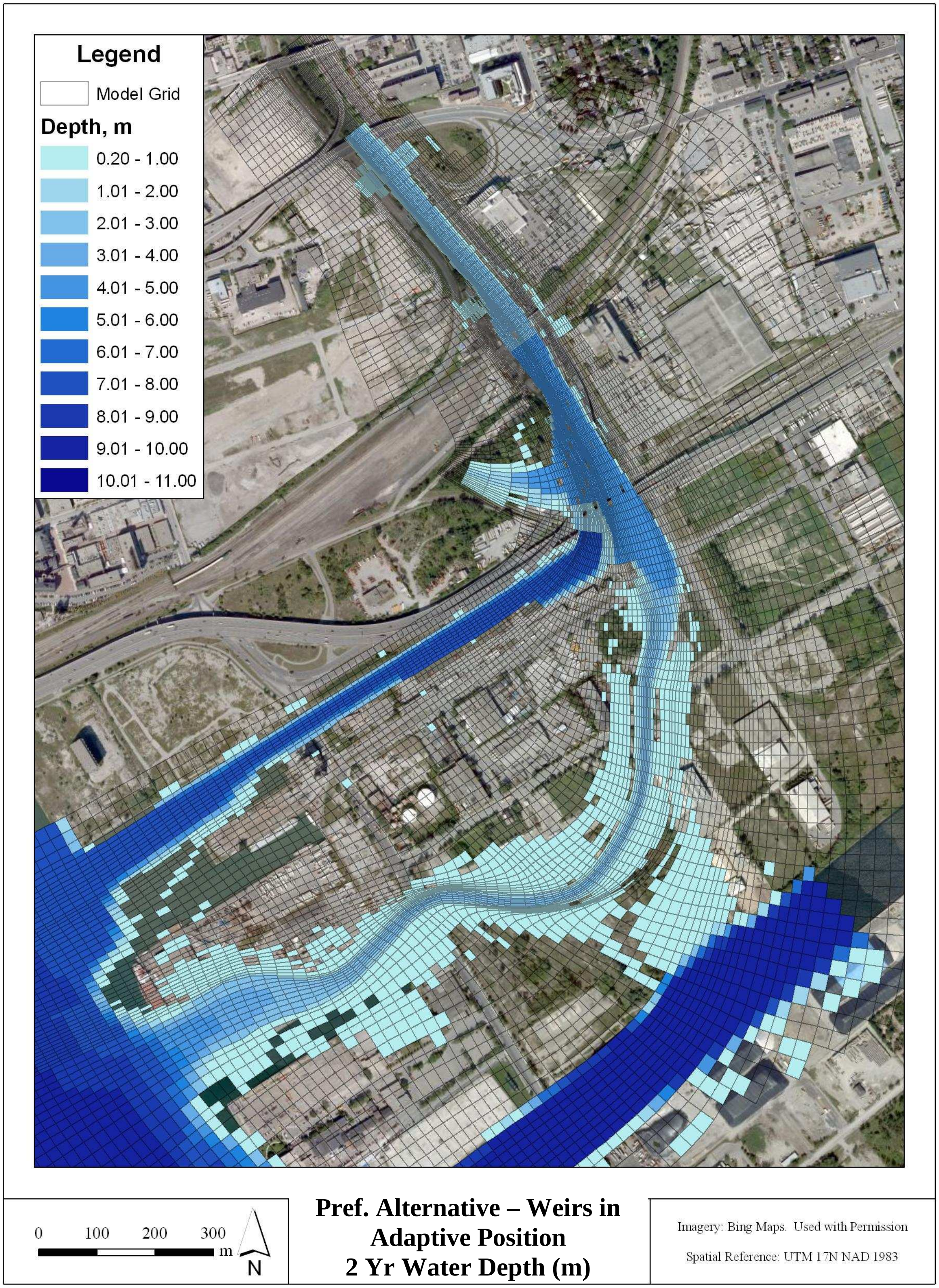


Pref. Alternative – Weirs in Adaptive Position
100 Yr Water Level (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

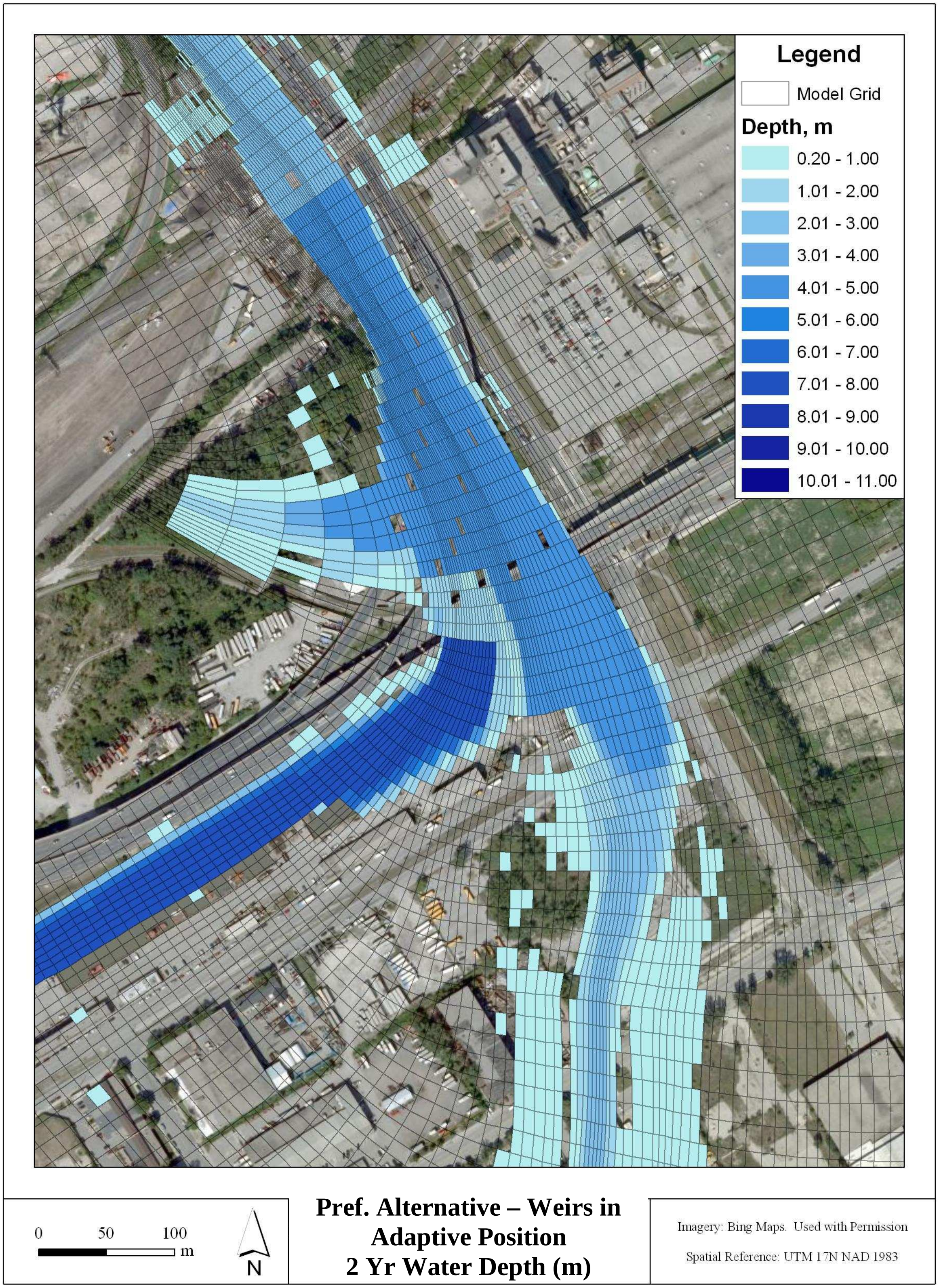
APPENDIX HD-J
PREFERRED ALTERNATIVE WATER DEPTH MAPS – WEIRS IN ADPATIVE POSITION



Pref. Alternative – Weirs in Adaptive Position
2 Yr Water Depth (m)

Imagery: Bing Maps. Used with Permission

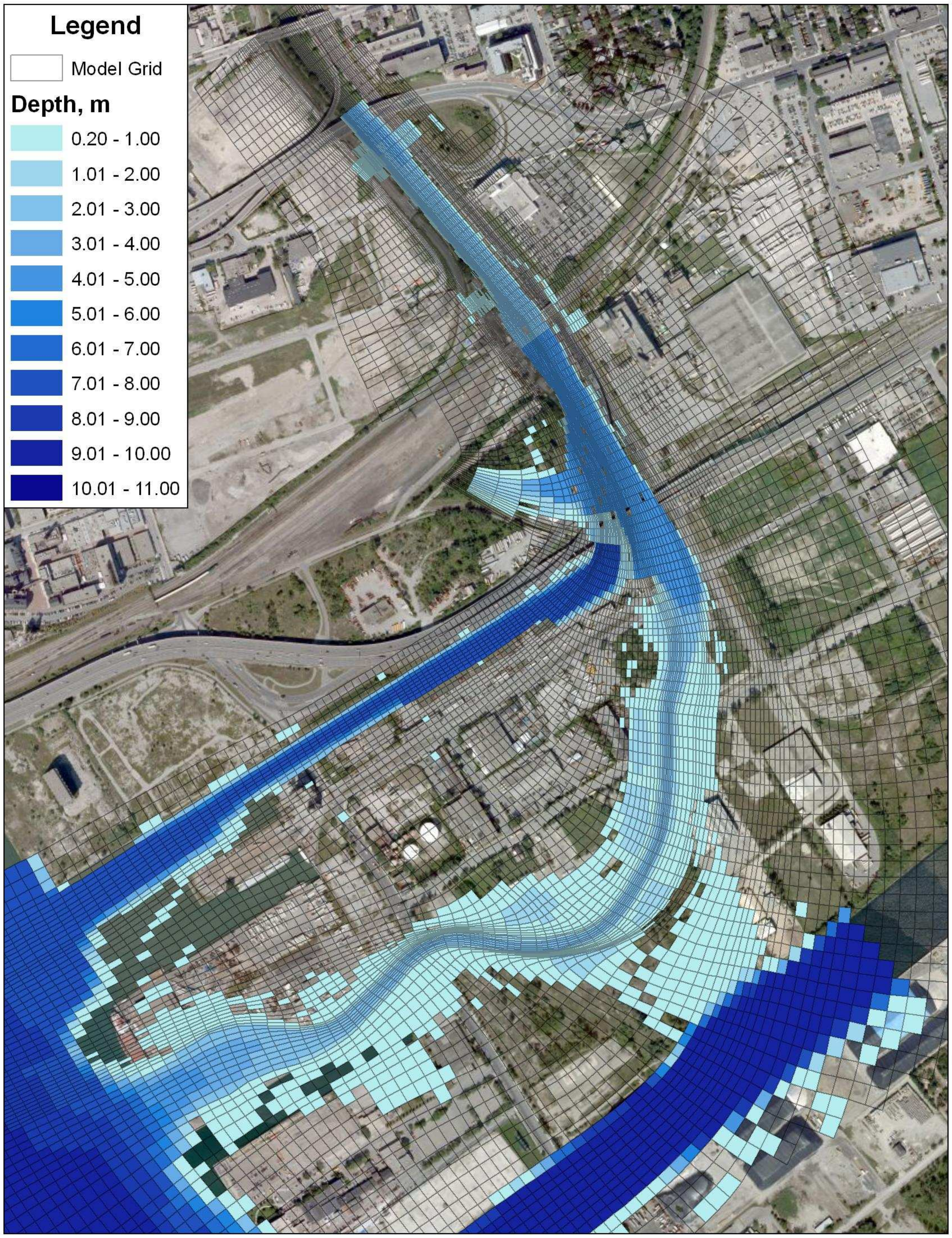
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position
2 Yr Water Depth (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

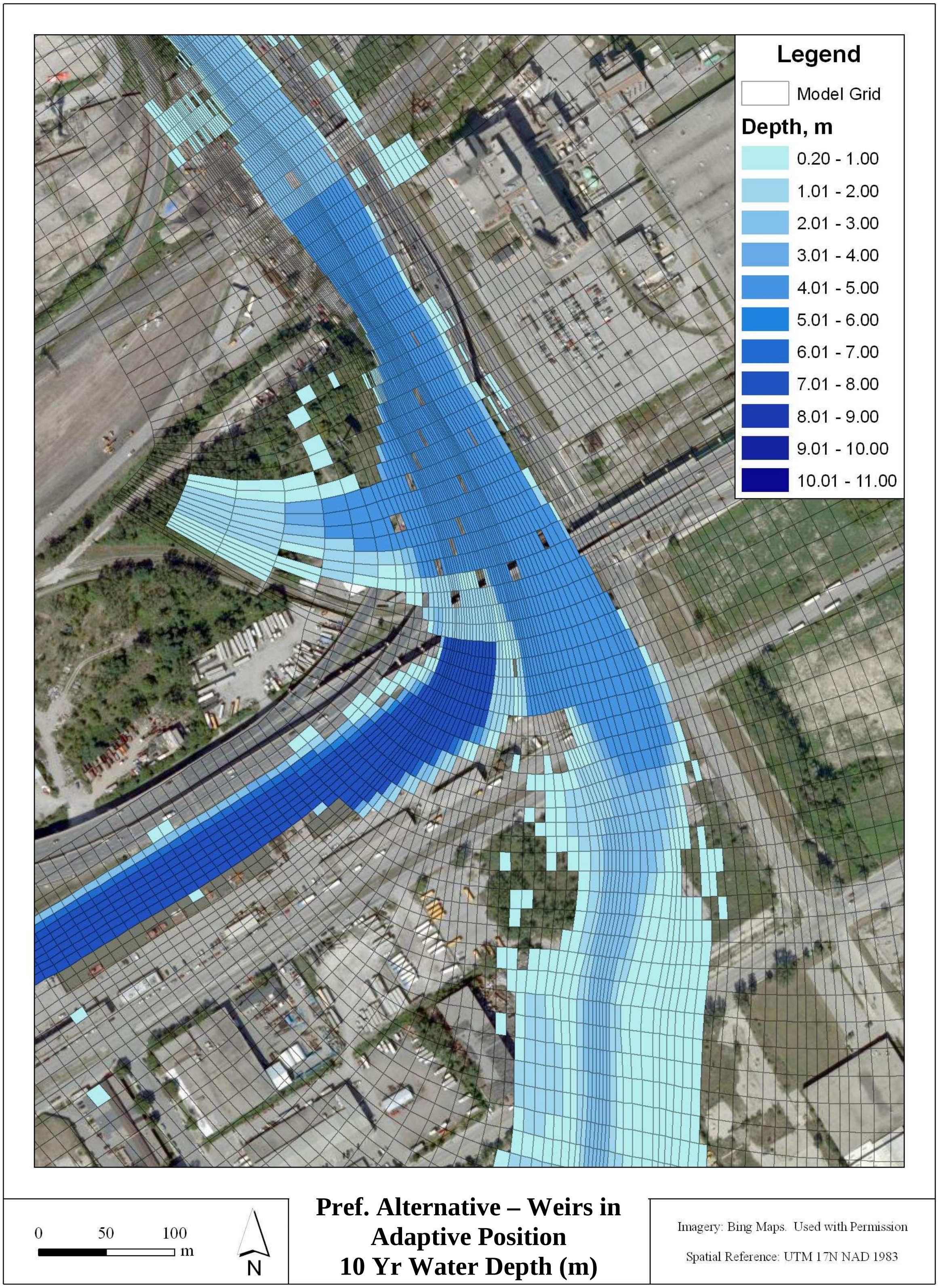


0 100 200 300 m N

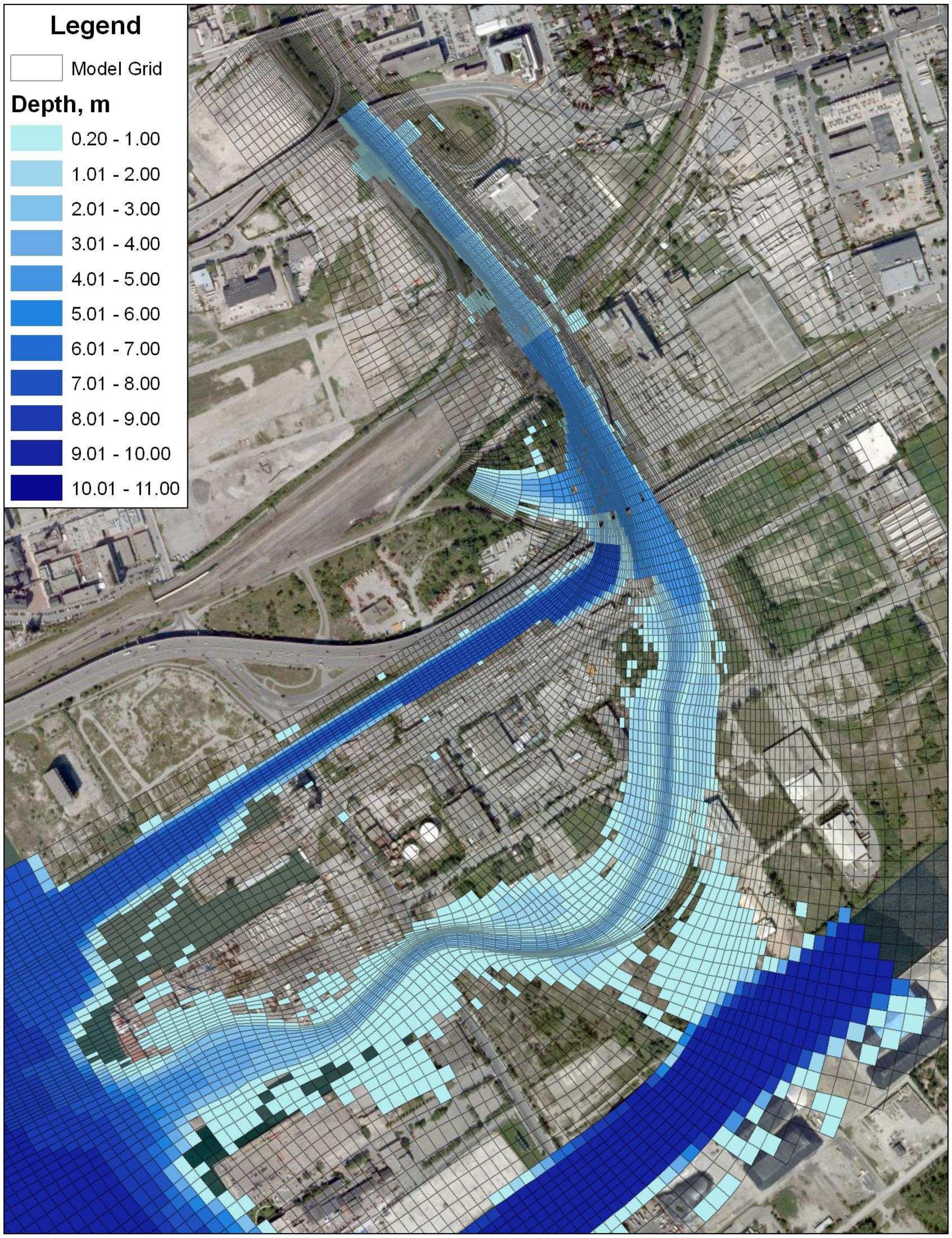
Pref. Alternative – Weirs in Adaptive Position
10 Yr Water Depth (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position
10 Yr Water Depth (m)



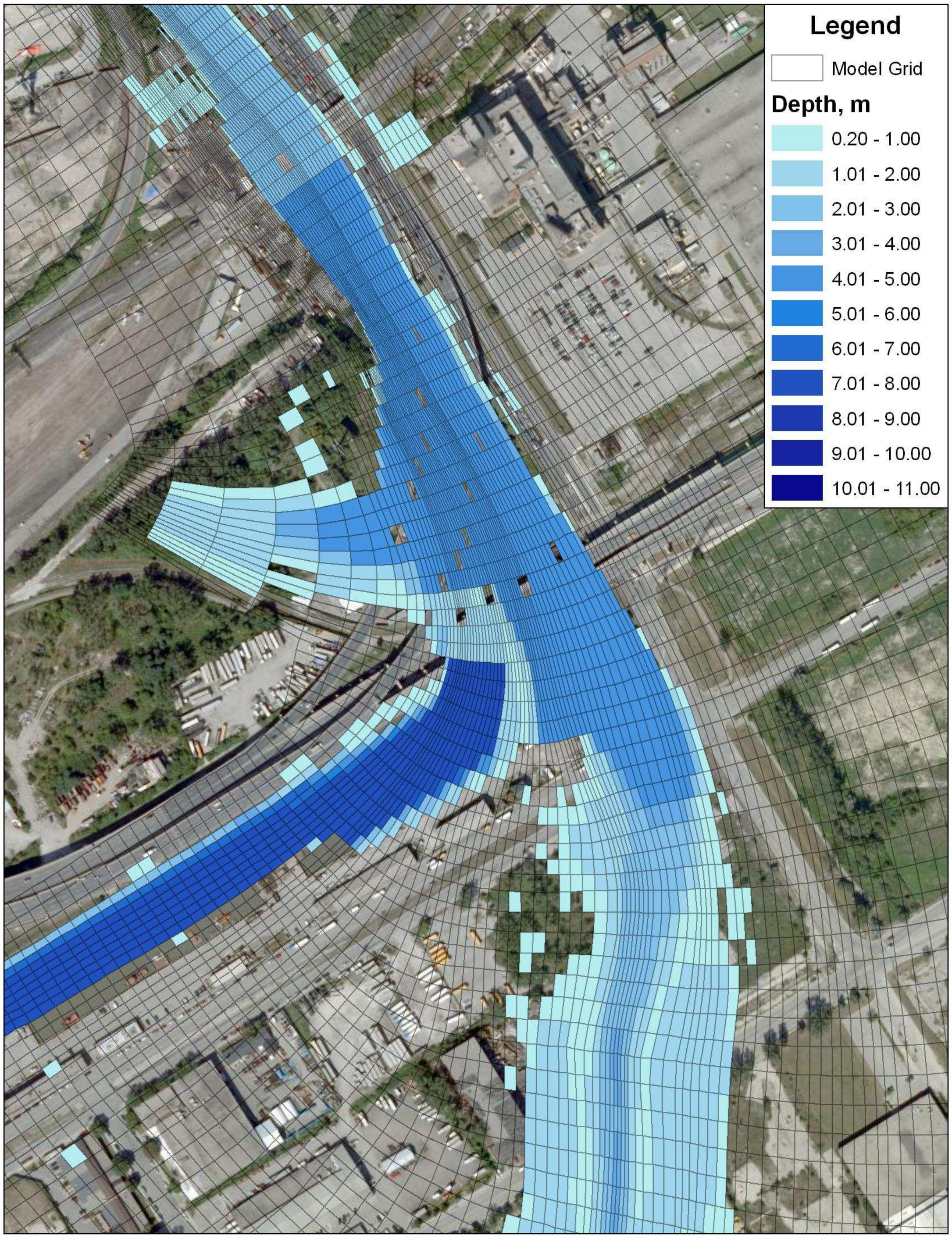
0 100 200 300 m

N

Pref. Alternative – Weirs in Adaptive Position
25 Yr Water Depth (m)

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



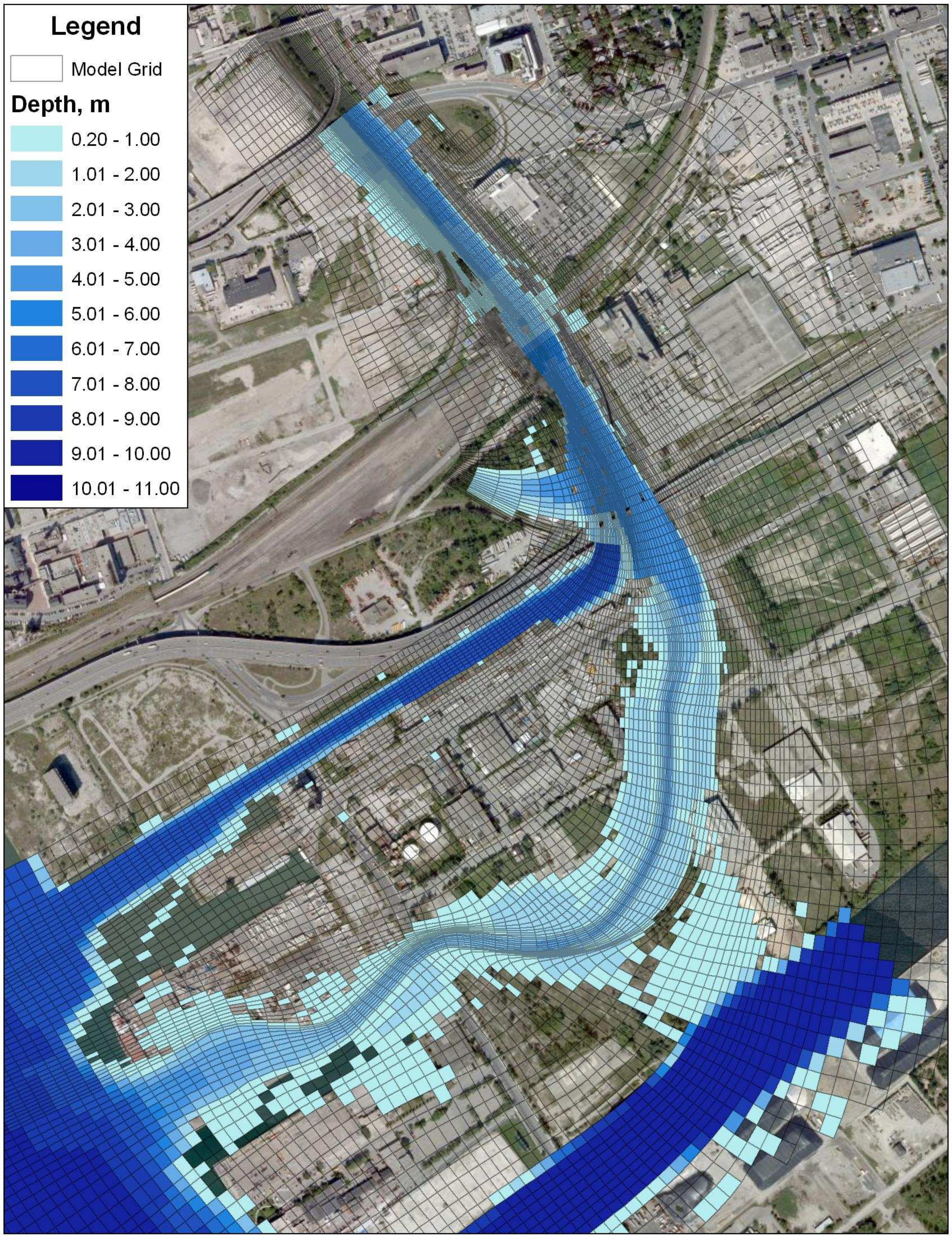
0 50 100 m

N

Pref. Alternative – Weirs in Adaptive Position
25 Yr Water Depth (m)

Imagery: Bing Maps. Used with Permission

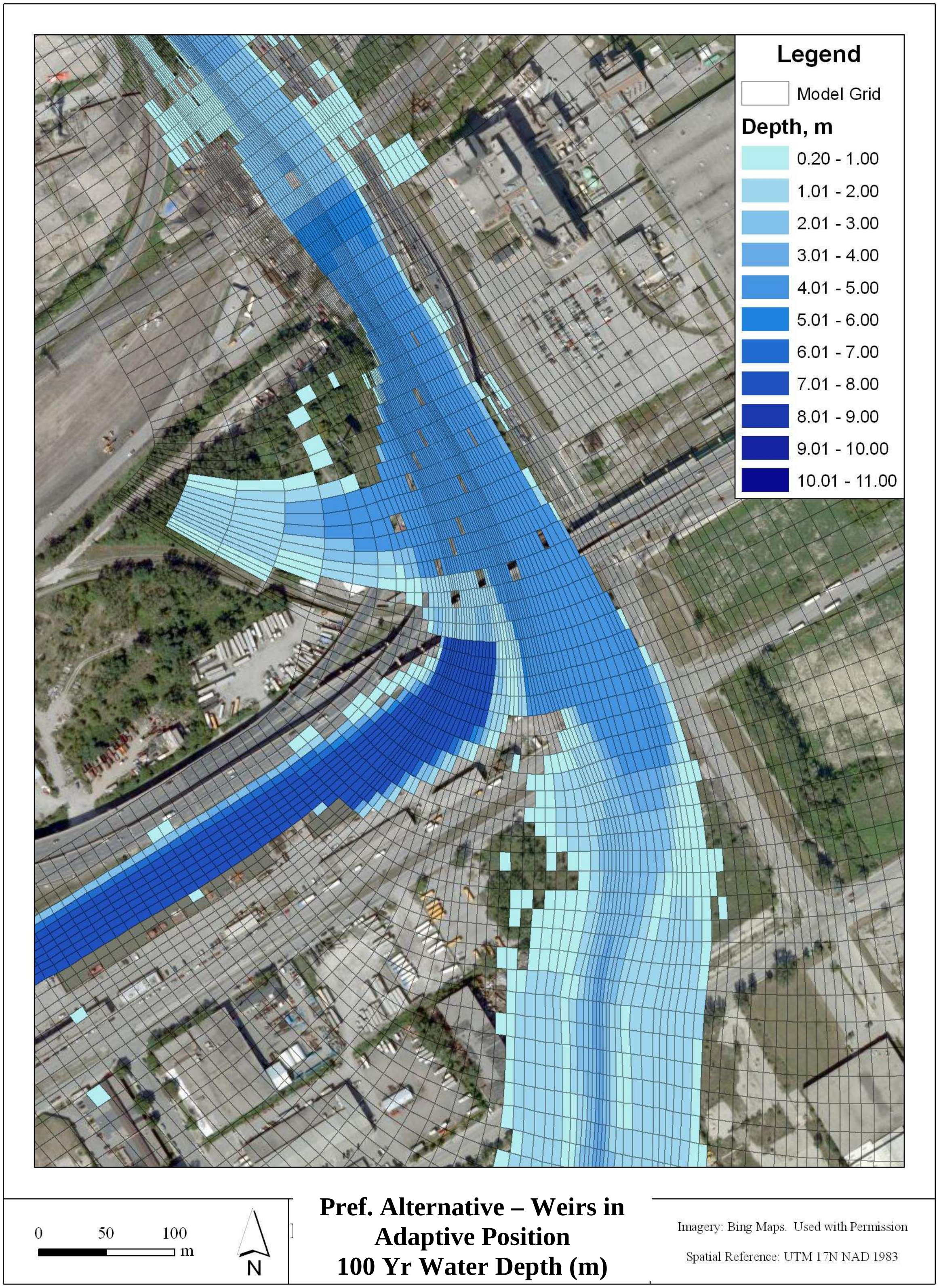
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position
100 Yr Water Depth (m)

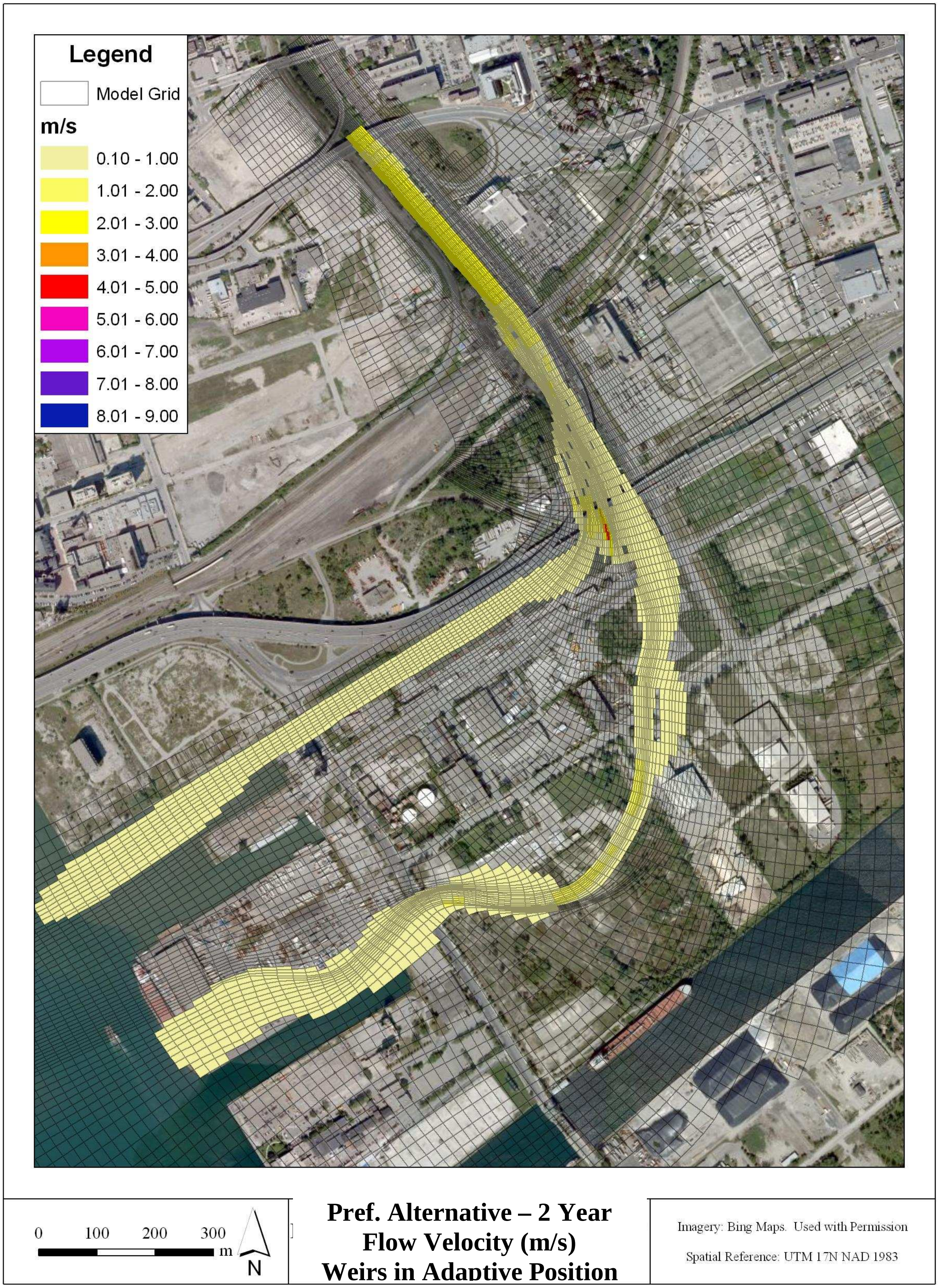
Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – Weirs in Adaptive Position
100 Yr Water Depth (m)

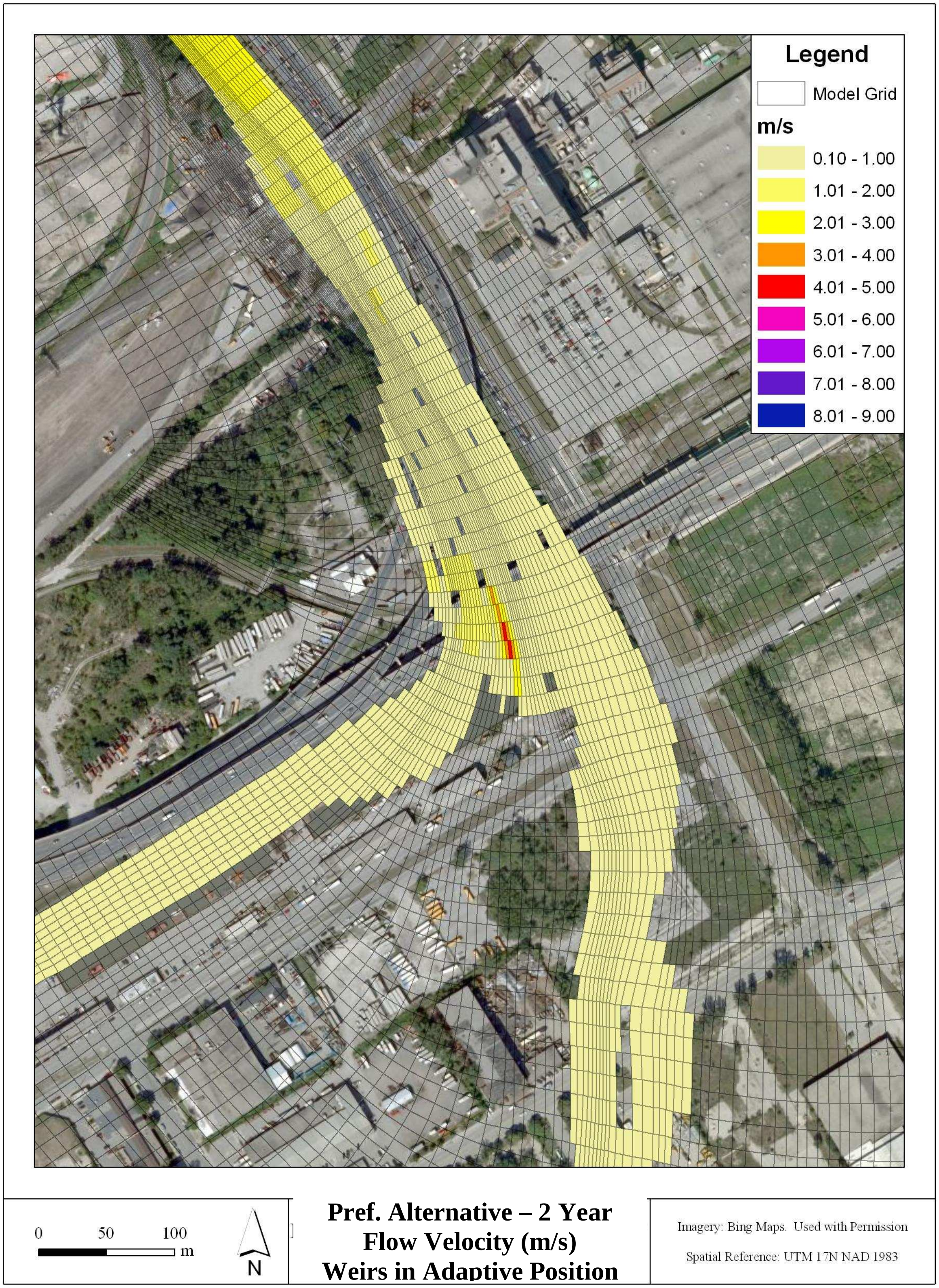
APPENDIX HD-K
PREFERRED ALTERNATIVE DEPTH AVERAGED VELOCITY MAPS – WEIRS IN ADAPATIVE POSITION



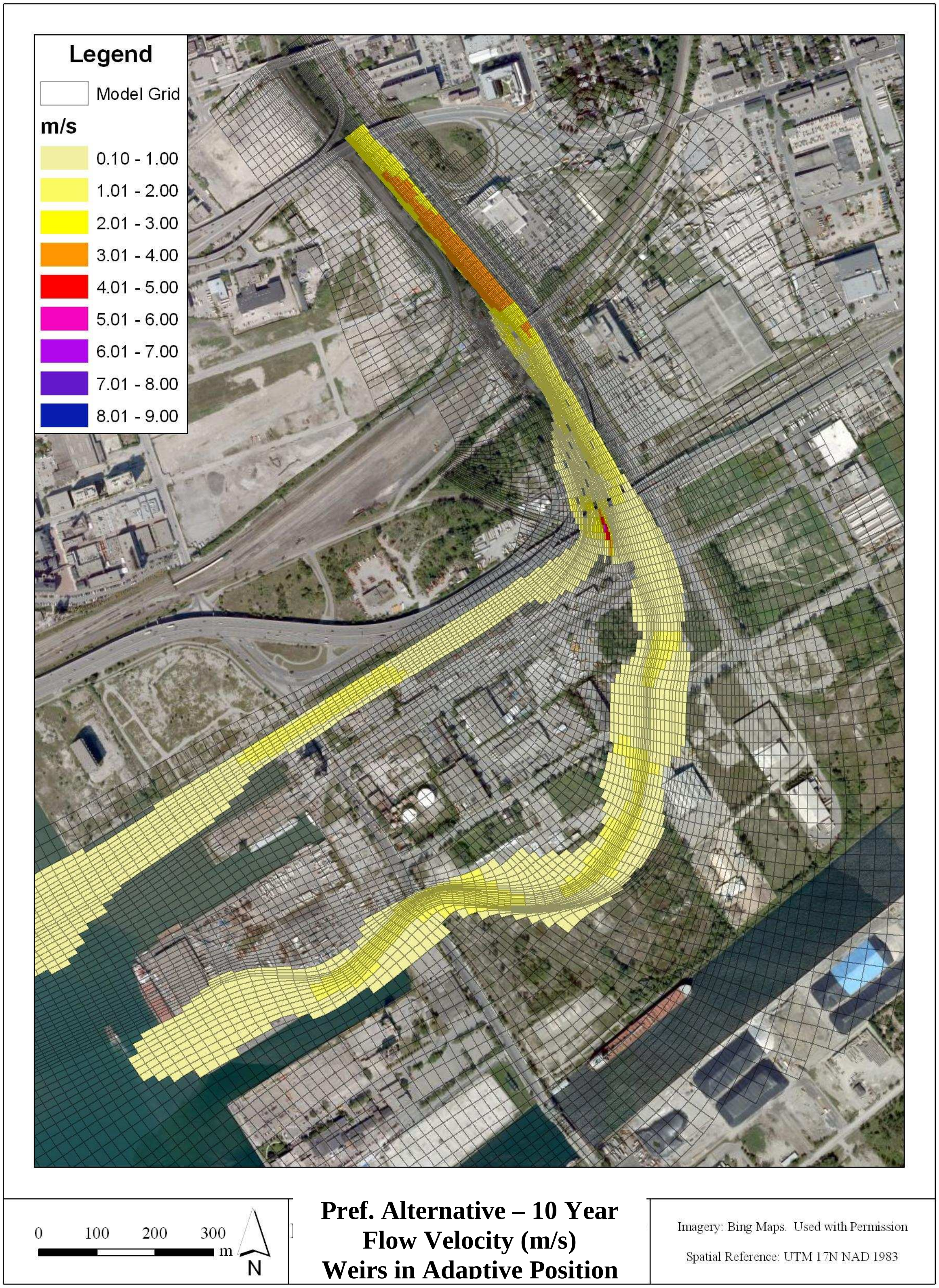
Pref. Alternative – 2 Year Flow Velocity (m/s) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



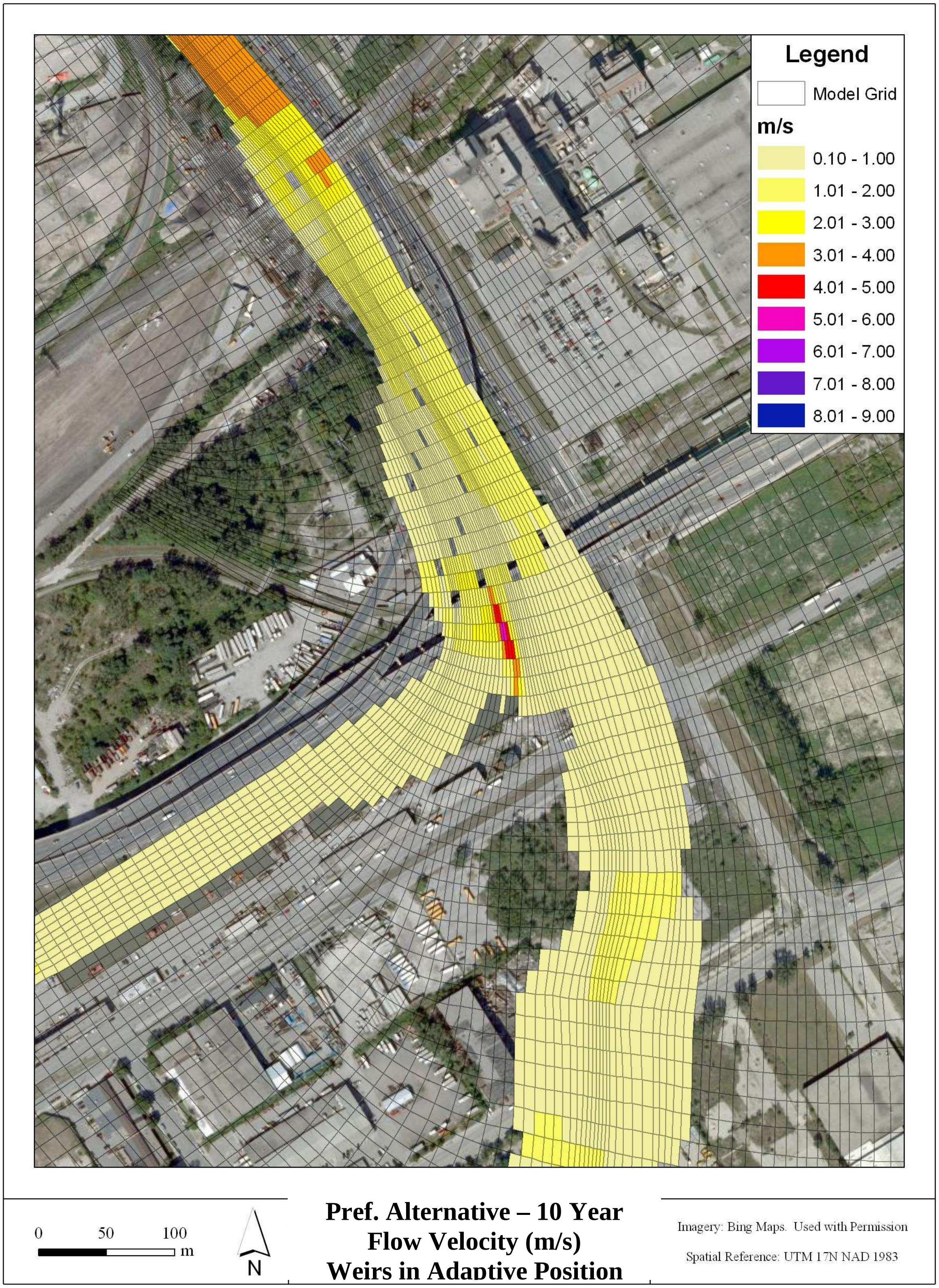
Pref. Alternative – 2 Year Flow Velocity (m/s) Weirs in Adaptive Position



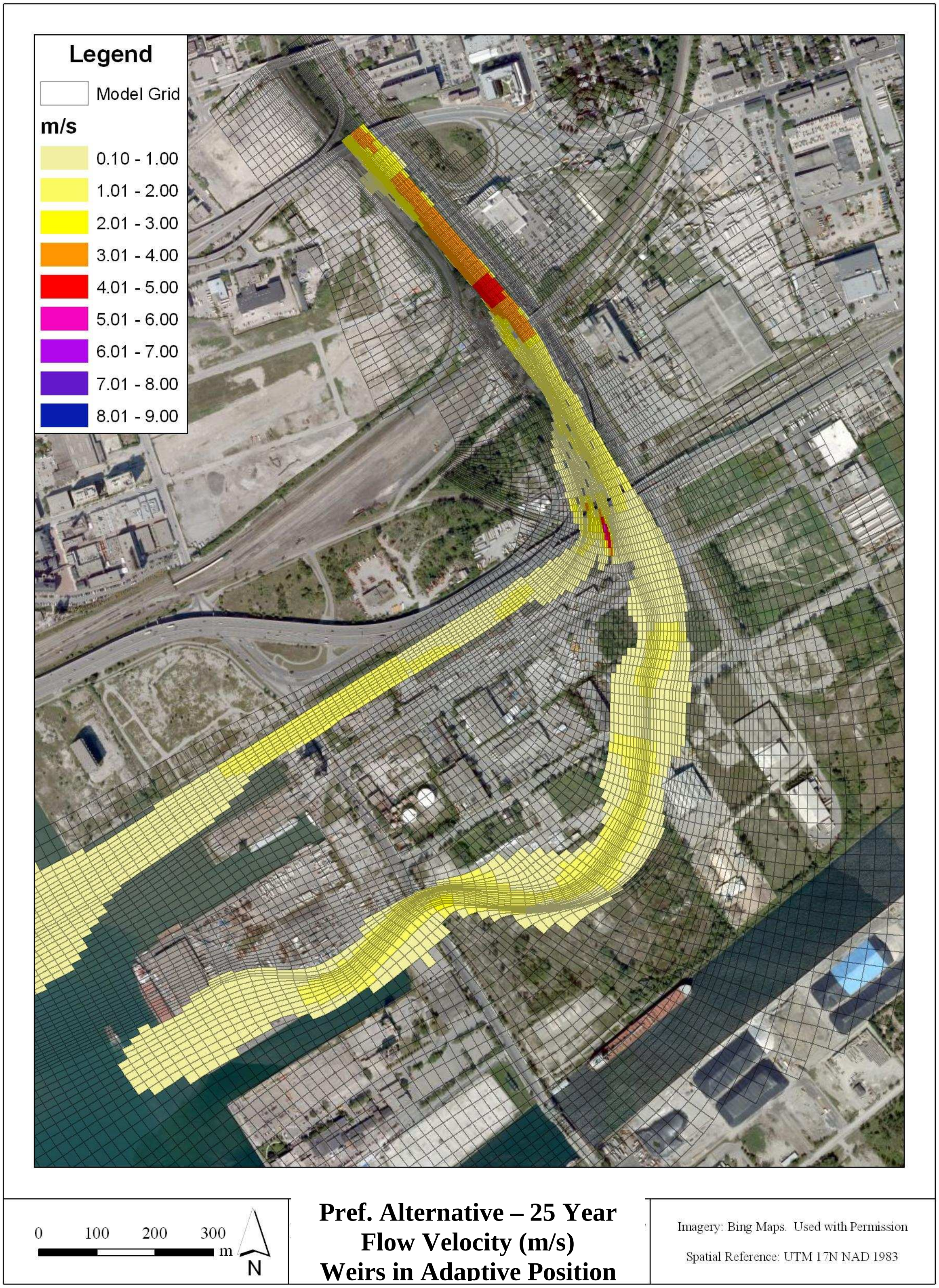
Pref. Alternative – 10 Year Flow Velocity (m/s) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

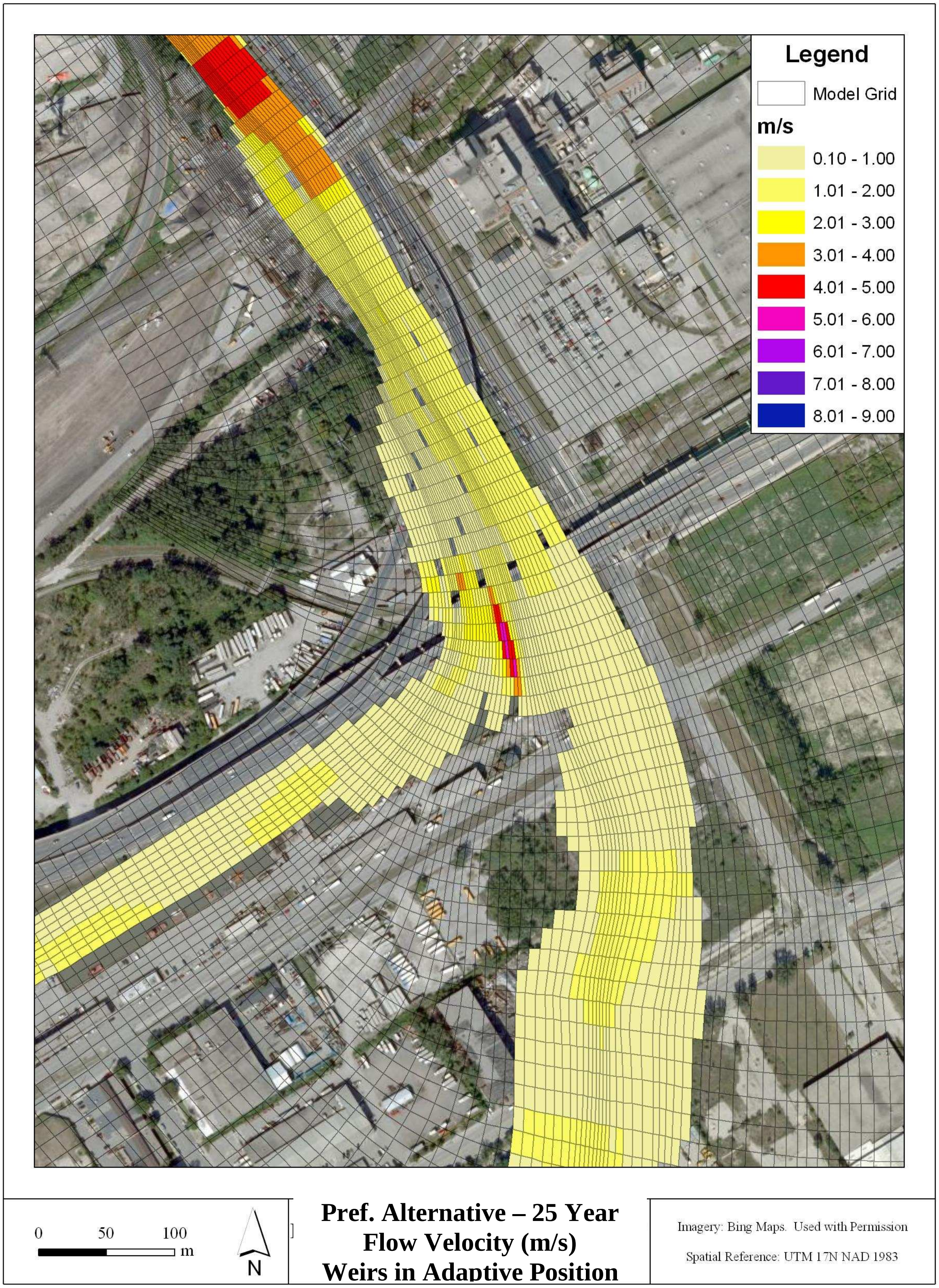
Spatial Reference: UTM 17N NAD 1983



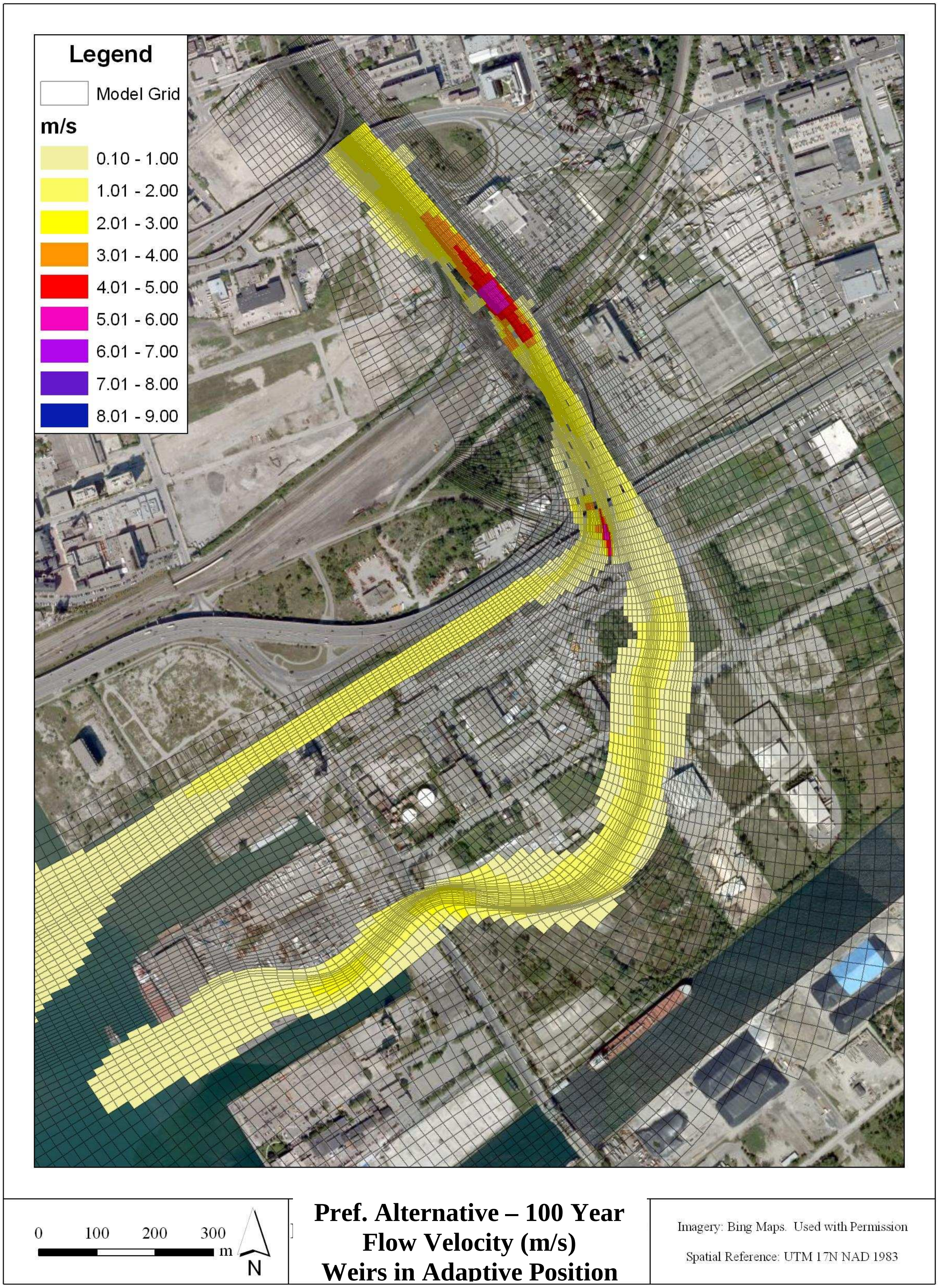
Pref. Alternative – 10 Year Flow Velocity (m/s) Weirs in Adaptive Position



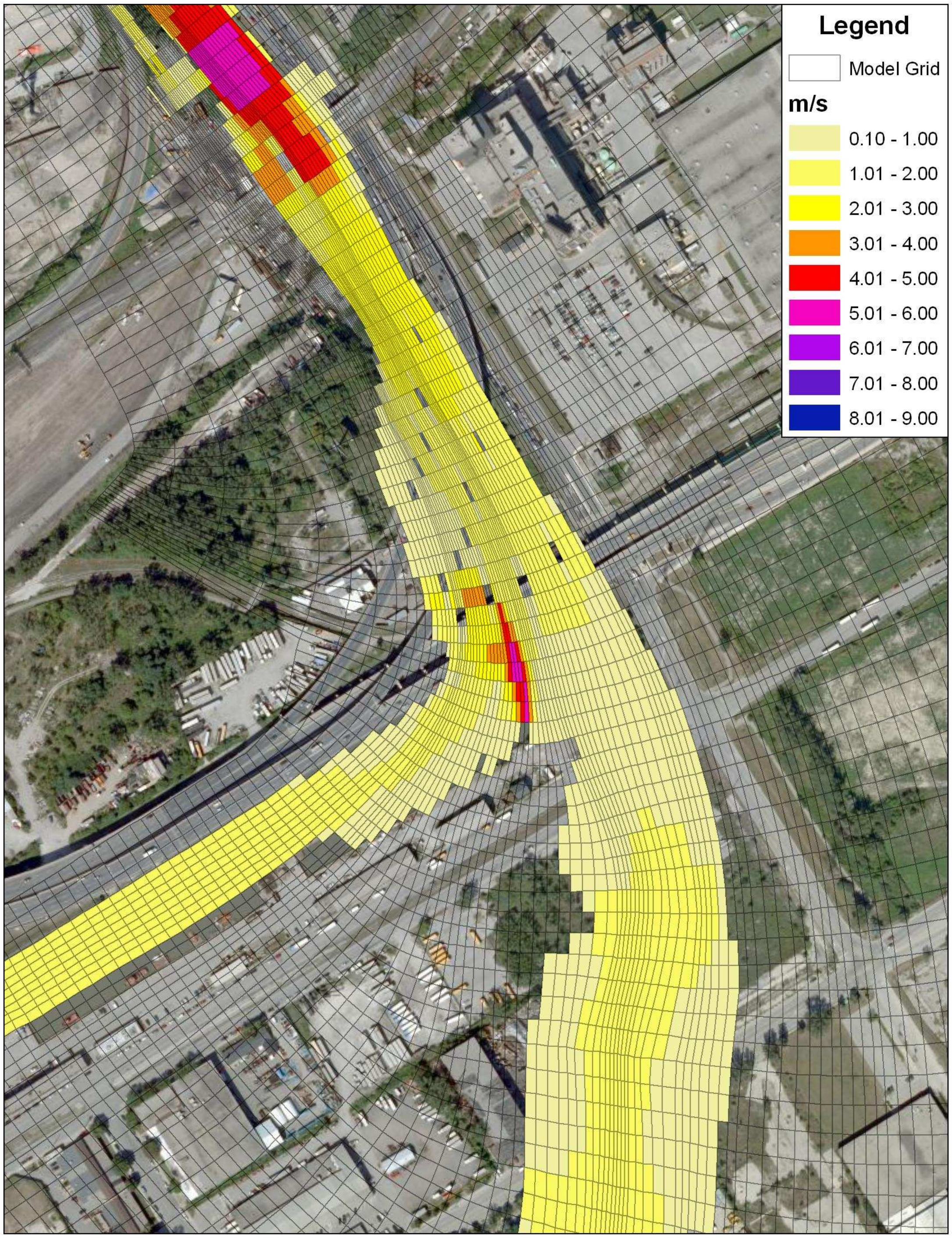
Pref. Alternative – 25 Year Flow Velocity (m/s) Weirs in Adaptive Position



Pref. Alternative – 25 Year Flow Velocity (m/s) Weirs in Adaptive Position



Pref. Alternative – 100 Year Flow Velocity (m/s) Weirs in Adaptive Position



0 50 100 m

N

Pref. Alternative – 100 Year Flow Velocity (m/s) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

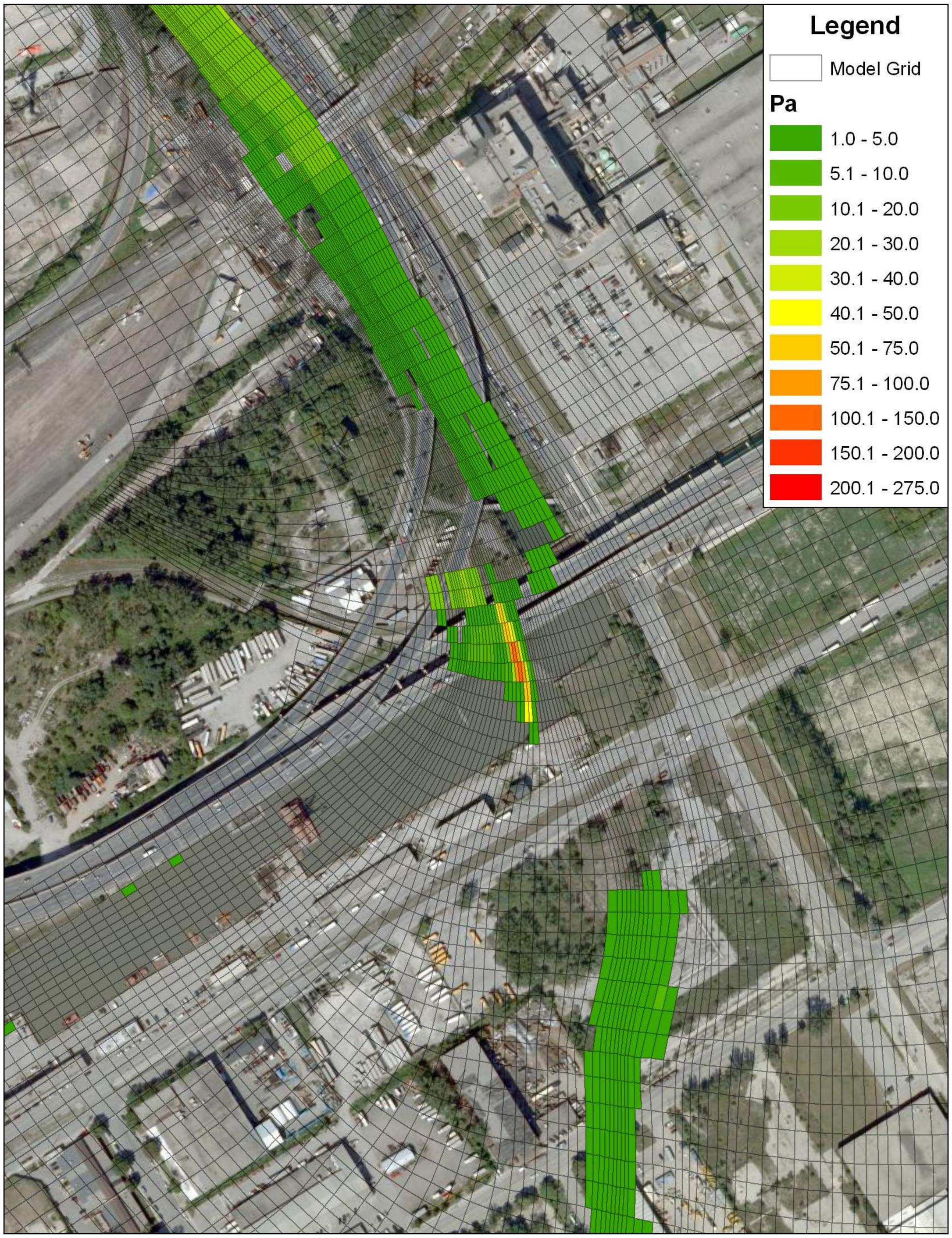
Spatial Reference: UTM 17N NAD 1983

APPENDIX HD-L
PREFERRED ALTERNATIVE BED SHEAR STRESS MAPS – WEIRS IN ADAPATIVE POSITION

Pref. Alternative – 2 Year Bed Shear Stress (Pa) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



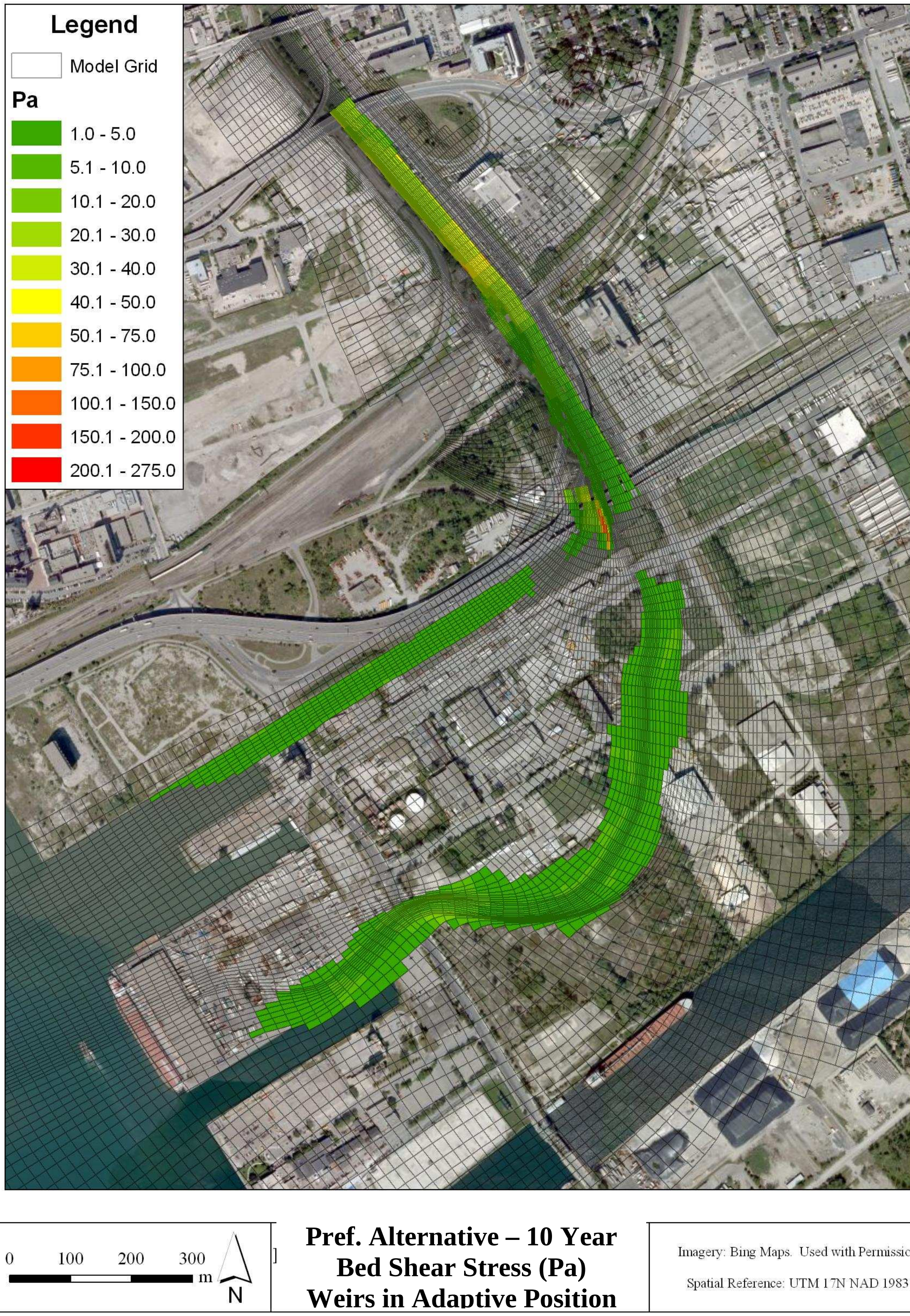
0 50 100 m

N

Pref. Alternative – 2 Year
Bed Shear Stress (Pa)
Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

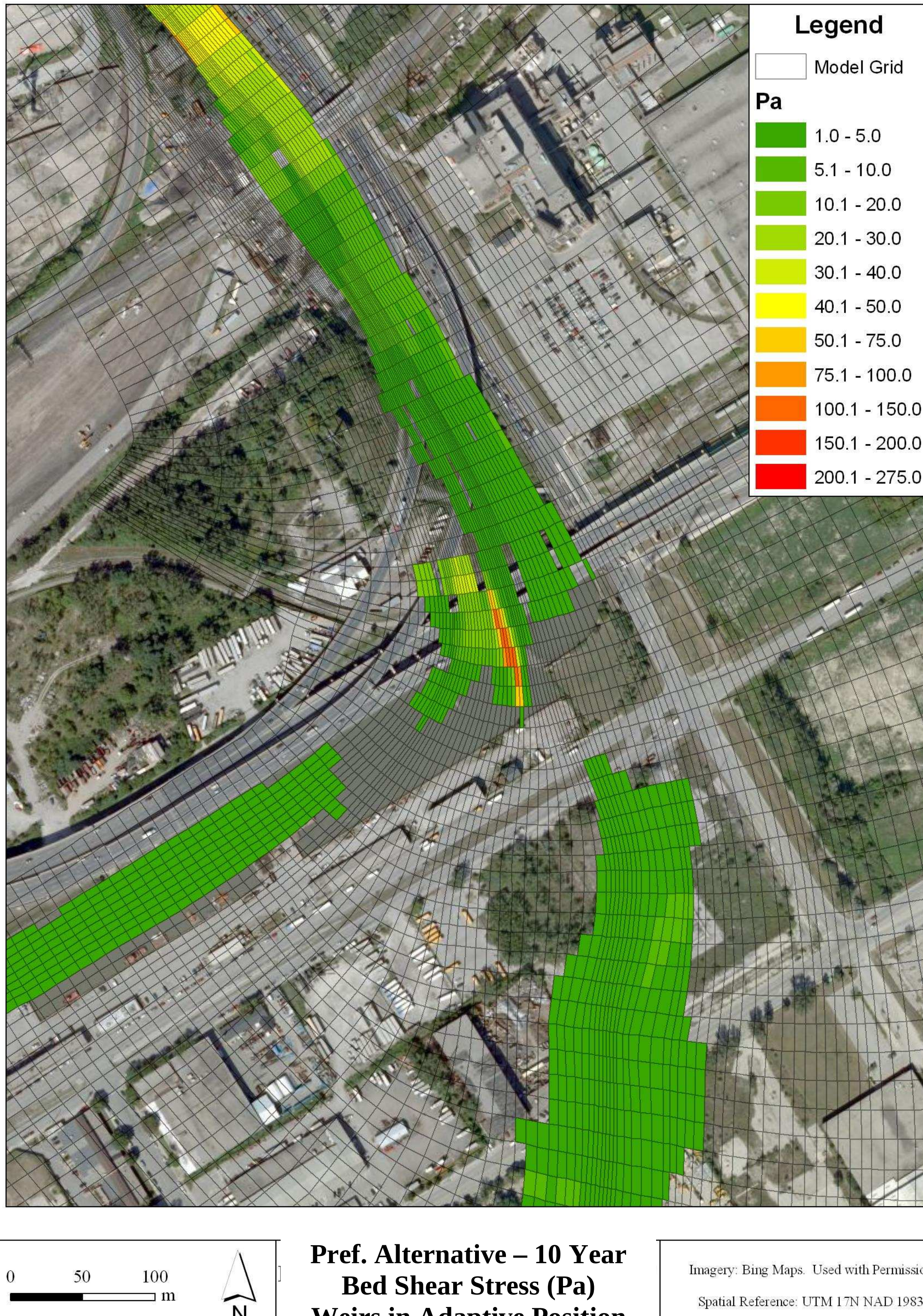
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 10 Year Bed Shear Stress (Pa) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

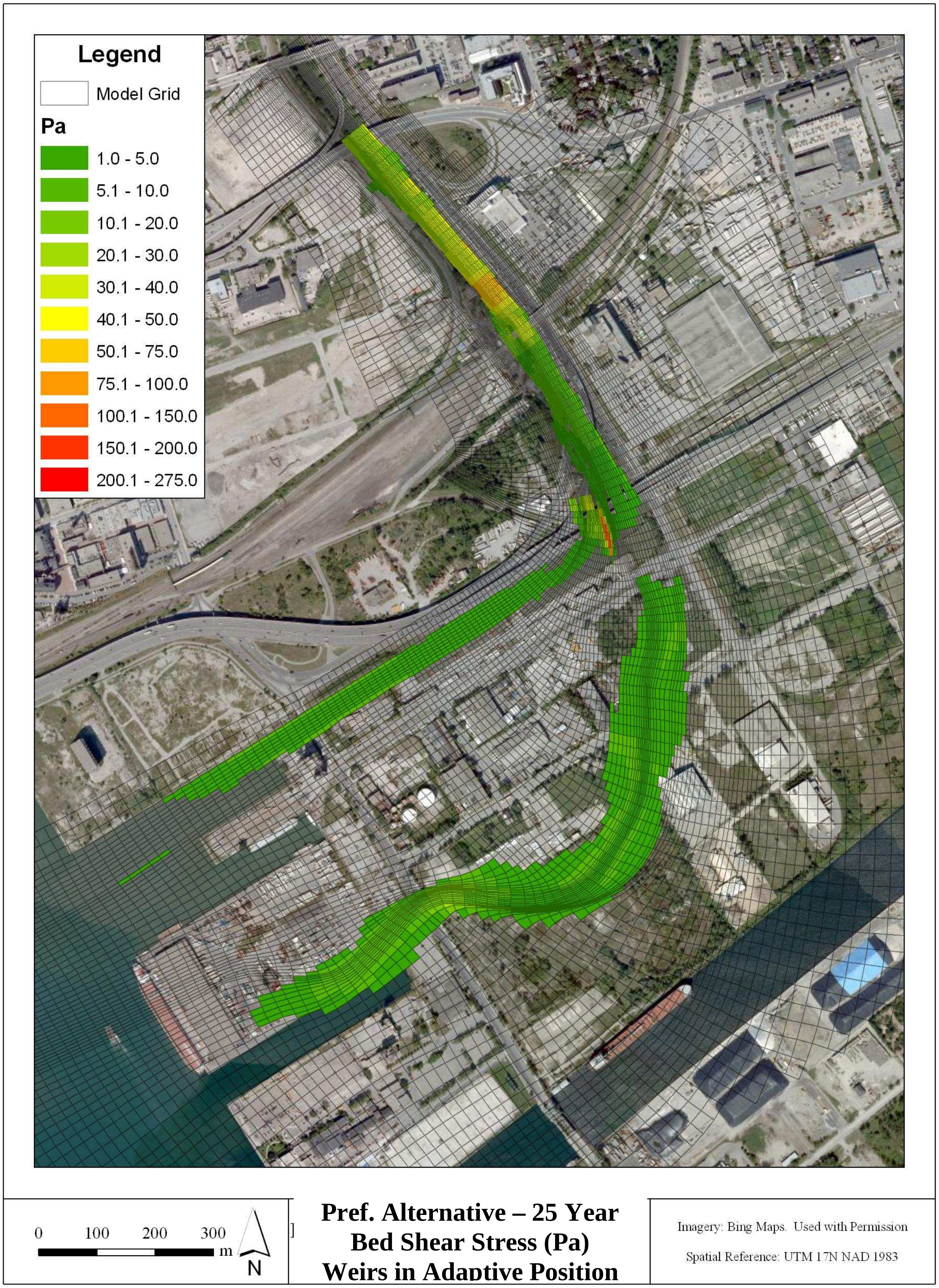
Spatial Reference: UTM 17N NAD 1983



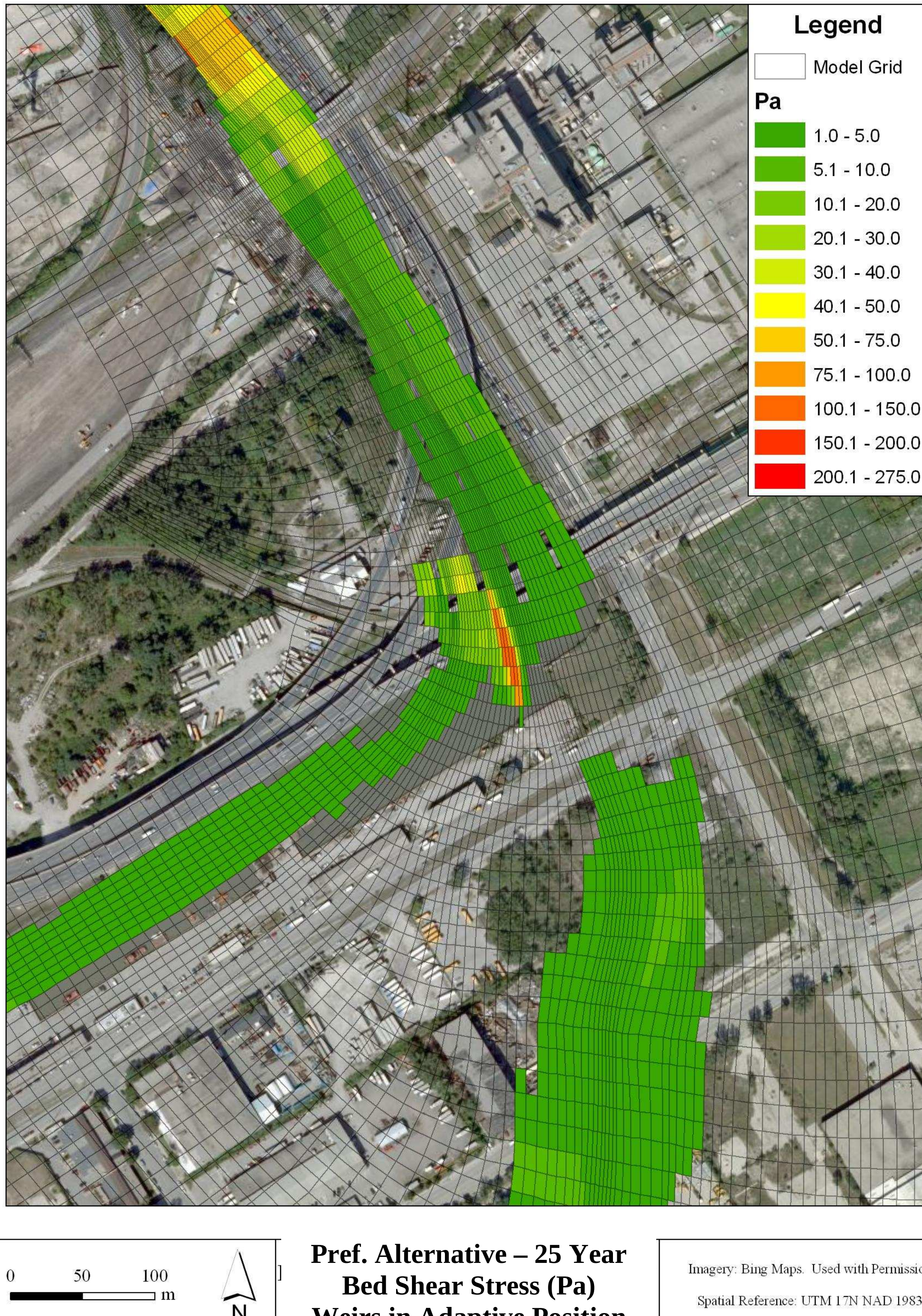
Pref. Alternative – 10 Year Bed Shear Stress (Pa) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



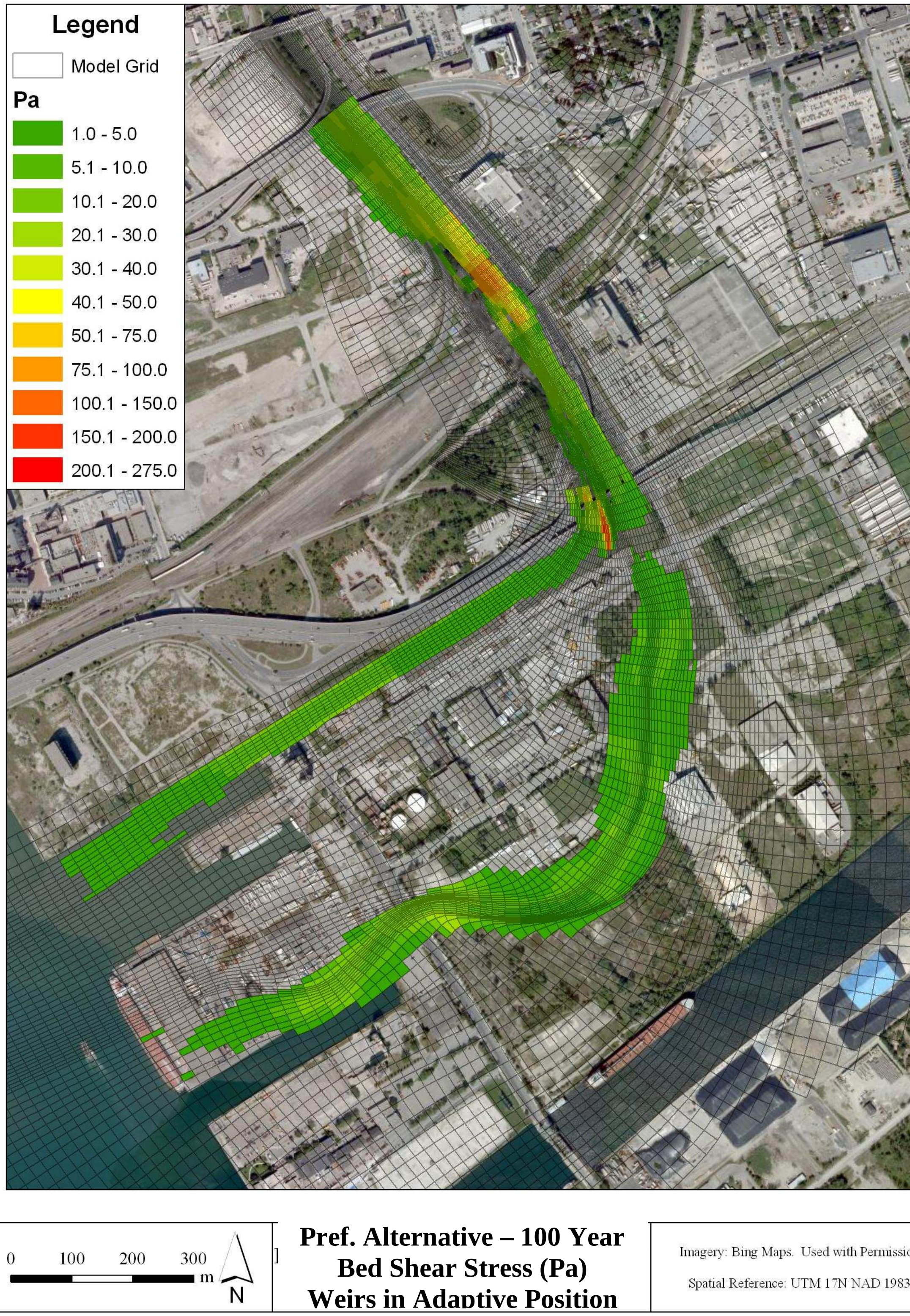
Pref. Alternative – 25 Year
Bed Shear Stress (Pa)
Weirs in Adaptive Position



Pref. Alternative – 25 Year Bed Shear Stress (Pa) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

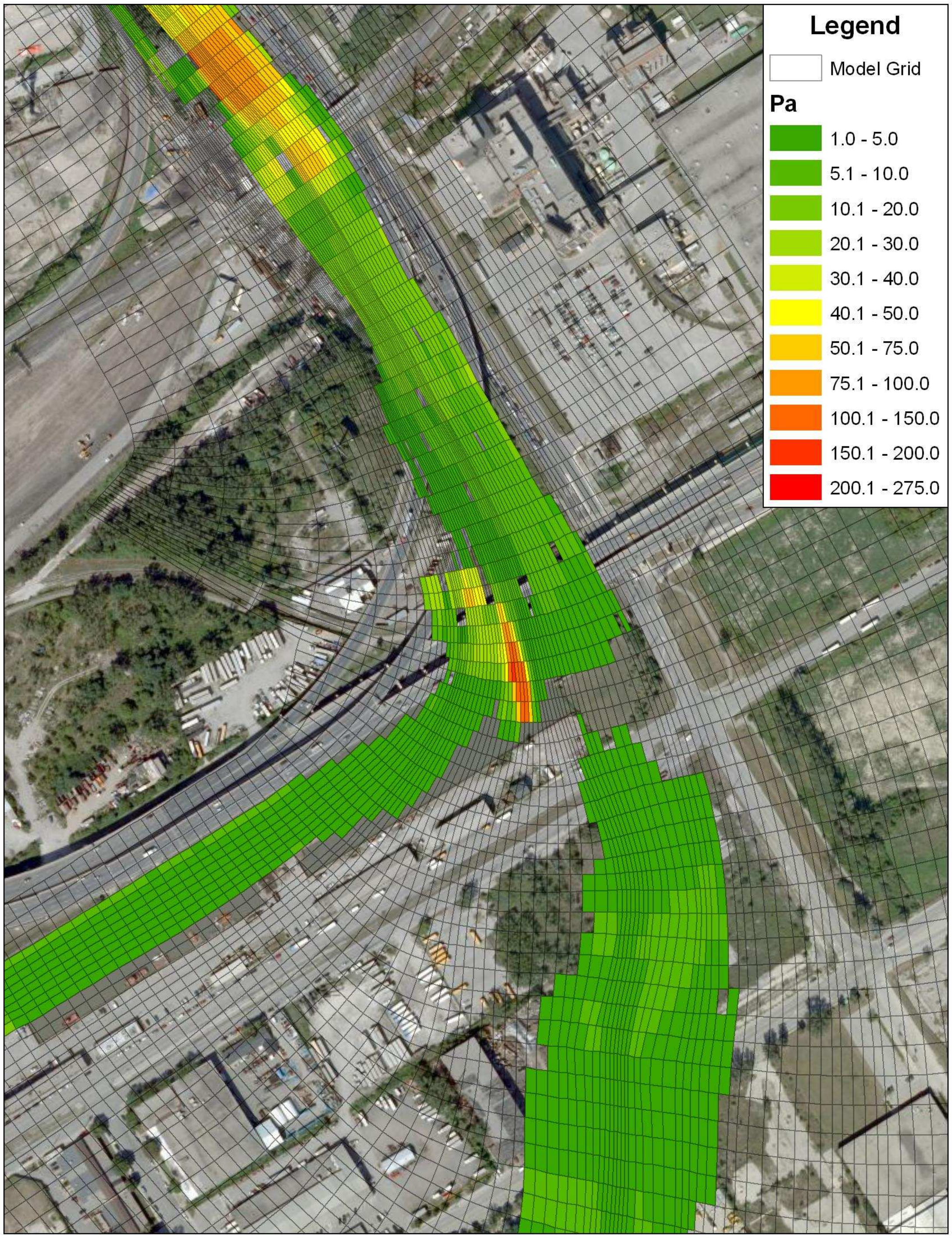
Spatial Reference: UTM 17N NAD 1983



Pref. Alternative – 100 Year Bed Shear Stress (Pa) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983



0 50 100 m

N

Pref. Alternative – 100 Year Bed Shear Stress (Pa) Weirs in Adaptive Position

Imagery: Bing Maps. Used with Permission

Spatial Reference: UTM 17N NAD 1983

Don Mouth Naturalization And Port Lands Flood Protection Project

N-2 Sediment Transport Modelling Technical Memorandum

Toronto and Region Conservation for The Living City

WATERFRONToronto

TORONTO

www.baird.com

Baird

oceans

engineering

lakes

design

rivers

science

watersheds

construction

Final Report

Don Mouth Naturalization and Port Lands Flood Protection Project

Sediment Transport Modelling Technical Memorandum

27th October 2010
10713.000




www.baird.com

Don Mouth Naturalization and Port Lands Flood Protection Project

Sediment Transport Modelling Technical Memorandum

Prepared for

Toronto and Region Conservation

Prepared by

Baird

W.F. Baird & Associates Coastal Engineers Ltd.

For further information please contact
Alex Brunton at (905) 845-5385

10713.000

Revision	Date	Status	Comments	Reviewed by	Approved by
1	23 September 2010	Draft	EA team review	DAB	DAB
2	27 October 2010	Final		DAB	DAB

of such Third Parties. Baird & Associates accepts no responsibility for damages, if any, suffered by any Third Party as a result of decisions made or actions based on this report.

TABLE OF CONTENTS

List of Figures

1.0 INTRODUCTION

Detailed two and three dimensional hydraulic modelling of the Lower Don River is being undertaken as part of the Don Mouth Naturalization and Port Lands Flood Protection Project Environmental Assessment (DMNP EA). This EA establishes the preferred alignment of the Don River from CN Rail Bridge down to its new outlet into the Toronto Inner Harbour. The overall EA includes assessment of the naturalization design requirements, the integration with urban fabric requirements, as well as the hydraulic requirements to contain and convey the regulatory flood through the Lower Don River reach from just north of the CN Bridge to its new outlets. In addition, the EA includes development of methodology and physical requirements for managing deposited sediment (for the purposes of flood containment, maintenance of navigation and protection of the future naturalized river mouth), while being cognizant of the Lower Don River West flood protection works.

This technical memo presents the preliminary results of the 2-D sediment transport modelling using the Delft3D model to evaluate the existing conditions in the Project Study Area, and the preferred alternative that was selected through the evaluation of alternatives (Alternative 4WS) and has since been refined. A 3-D version of the model runs was not undertaken due to the long model run times, a result of the need of small model time steps so that the model was stable under larger discharges. The scope of this study is limited to examination of general sediment transport patterns through the existing river and of potential sediment transport patterns in the preferred alternative. The preferred alternative presented in the EA sets the channel widths, depths, levels of adjacent fills and the hydraulic capacity requirements of the new valley and low flow channel system. The preferred alternative sediment transport model was run for two cases:

- 'General conditions': A trap bed level of 70 m (i.e. the trap was 1.6 m below the existing bed level at Lake Shore Boulevard. Both weirs are at 75.25 m, with the upstream weir (north of Lake Shore Boulevard) in the 'up' position to direct flow into the new naturalized channel;

- 'Worst case': the trap is 'full at 71.6 m, the existing bed level at Lake Shore Boulevard. The upstream weir is in the 'down position' (71.6 m). This is the 'worst case' initial conditions for sediment trapping as the trap is least efficient under these conditions. This presents a conservative estimate of the amount of sediment trapped in the trap area.

This memo should be read in conjunction with the Baird Hydrodynamic Modelling Technical Memorandum of 28th June 2010, which summarizes the model setup, study background, and hydrodynamic conditions in the existing and preferred alternative models.

2.0 METHODOLOGY

The numerical modelling was split into two stages: evaluation of flooding and hydrodynamic conditions, and evaluation of sediment transport. This memo provides a summary of sediment transport under existing conditions and also under the preferred alternative. The overall model setup is described in detail in the June 2010 Hydrodynamic Modelling Technical Memorandum. This section describes setup of the Sediment Transport Module in the Delft3D model.

The data used for this modelling analysis included:

- Bathymetric data;
- River flow discharge measured at the Todmorden gauge;
- Sediment transport data from sampling data measured at the Todmorden gauge;
- Bed material data from samples in the Keating Channel and the Don Narrows (although a fully-mobile bed was not represented due to the long model run times);
- Pre- and post- dredging survey records from the Keating Channel;
- Lake levels from the in Lake Ontario gauge in Toronto Harbour.

2.1 Incoming Sediment

The sediment transport data, including sediment sample grain size distributions and Total Suspended Solid concentrations (TSS) from data at the Todmorden gauge were used in this study. Using the river flow data recorded at the gage, the correlation between river flow and TSS is shown in Figure 1. The mean TSS concentration can be estimated from the river flow using the following fit equation:

$$C_{mean} = 18.3Q^{1.0627}$$

The fitting lines for 5% and 95% confidence were also plotted in the figure. The above equation was used to calculate the daily suspended sediment concentration carried by the river flow, and used as an input boundary condition to the sediment transport models.

Note that this modelling analysis is limited by the available sediment transport and flow data being at the Todmorden Gauge. The potential impacts of the limitations to the modelling analysis are discussed at the end of this memorandum. The Todmorden Gauge is approximately 5 km upstream from the Project Study Area, and there are likely to be differences in sediment transport and particle size distribution characteristics between the observed data at Todmorden and the flow in the Project Study Area. A new monitoring station is recommended in the Don Narrows and/or the Keating Channel to collect data to inform the Detailed Design of the study (see Section 3.2).

The grain size distribution of suspended sediment and bed sediment are plotted in Figure 2 and Figure 3, respectively. Note that the available data for suspended sediment particle size distributions were limited to the samples at Todmorden. The dominant suspended sediment size is medium silt. A further limitation of this relationship is that sampling is limited to lower flows (under 120 m/s). Sampling transported suspended and bed load sediment characteristics at higher flows should be undertaken prior to the detailed design of the DMNP.

The grain size distribution of transported sediment also changes with river flow discharge. The variations in suspended sediment particle size characteristics were then compared to discharge on the day of sampling to generate a relationship between flow and particle size distribution . The percentage of coarse sediment increases as the river flow increases (Figure 4).

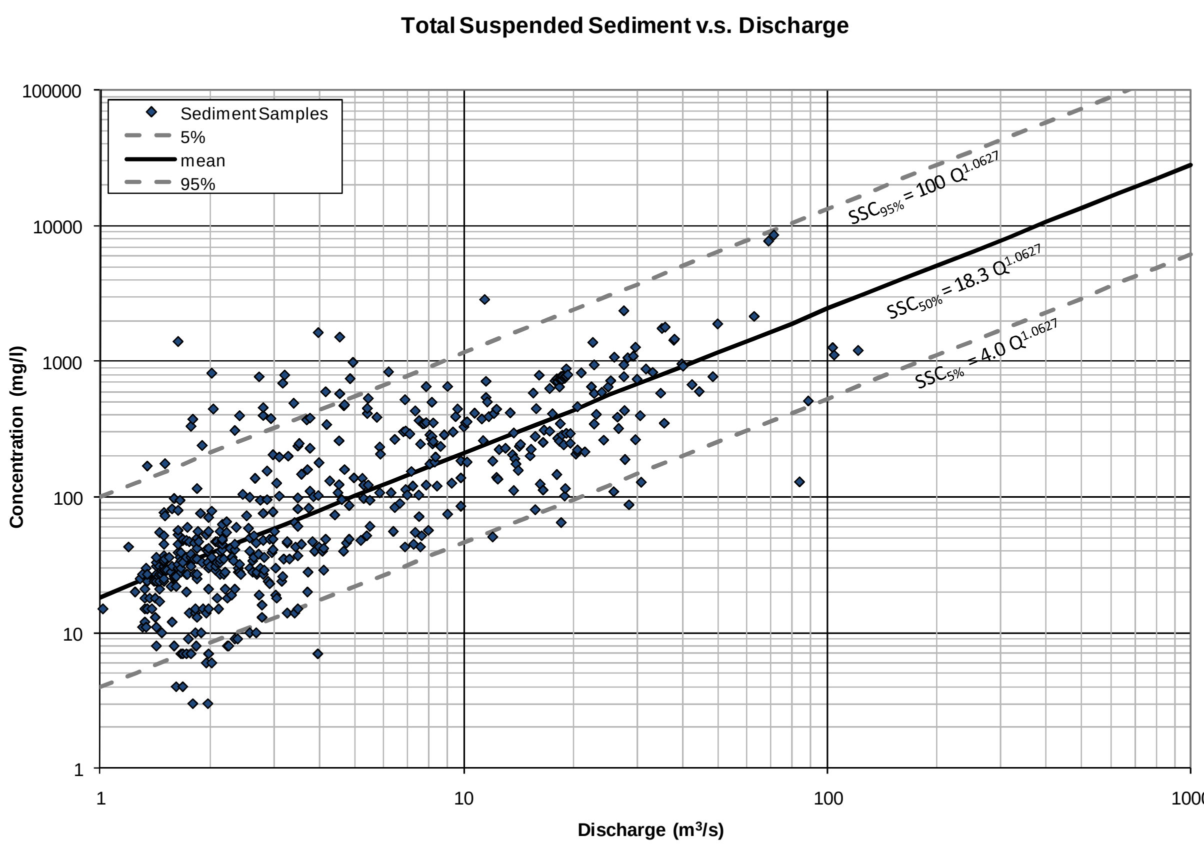


Figure 1 Correlation of TSS concentration with river flow discharge

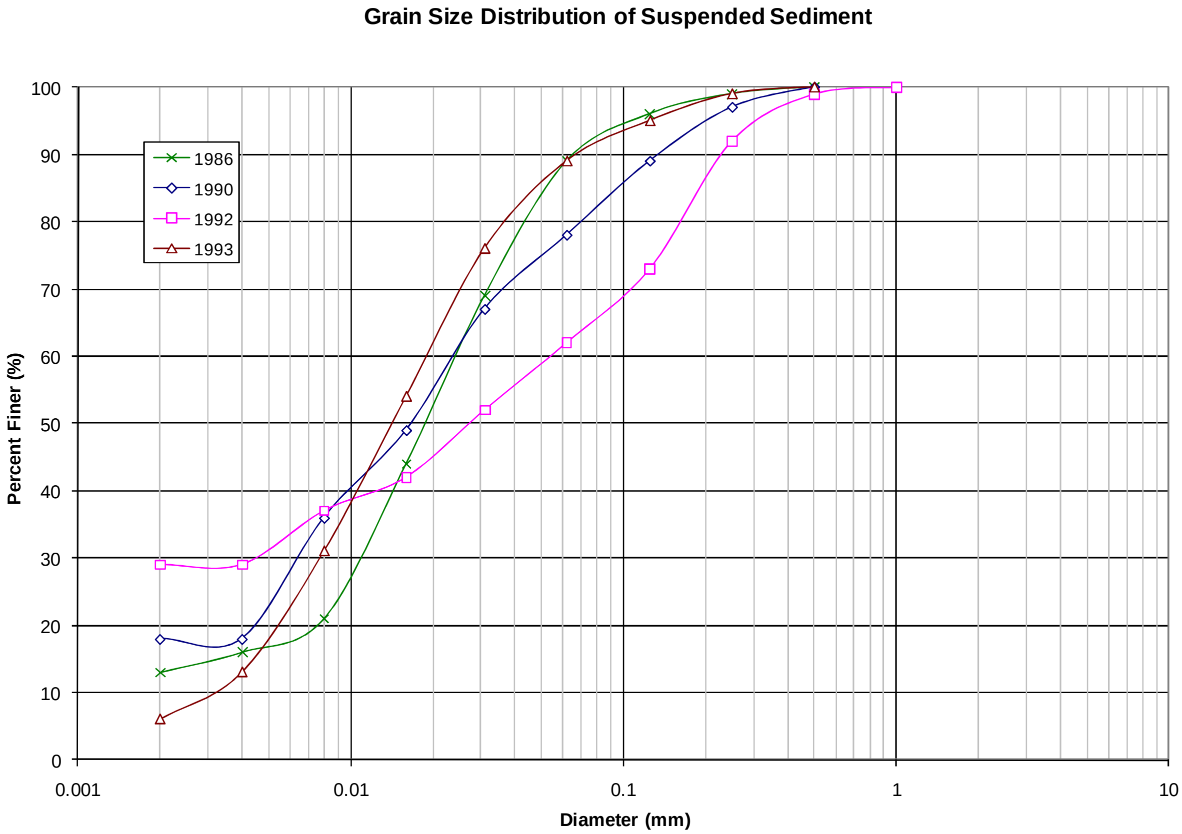


Figure 2 Grain size distribution of suspended sediment measured at the Todmorden Gage

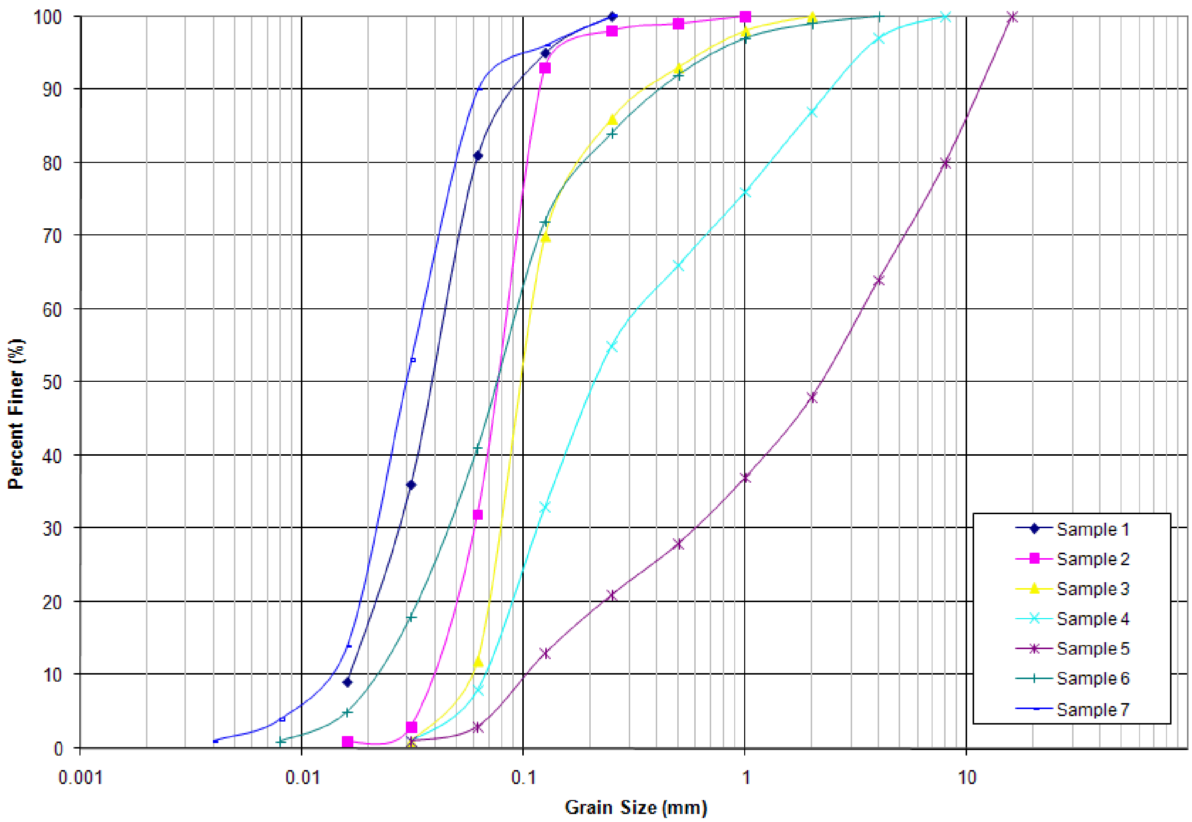


Figure 3 Grain size distribution of bed material samples collected near the Todmorden Gauge on 11 April 1986

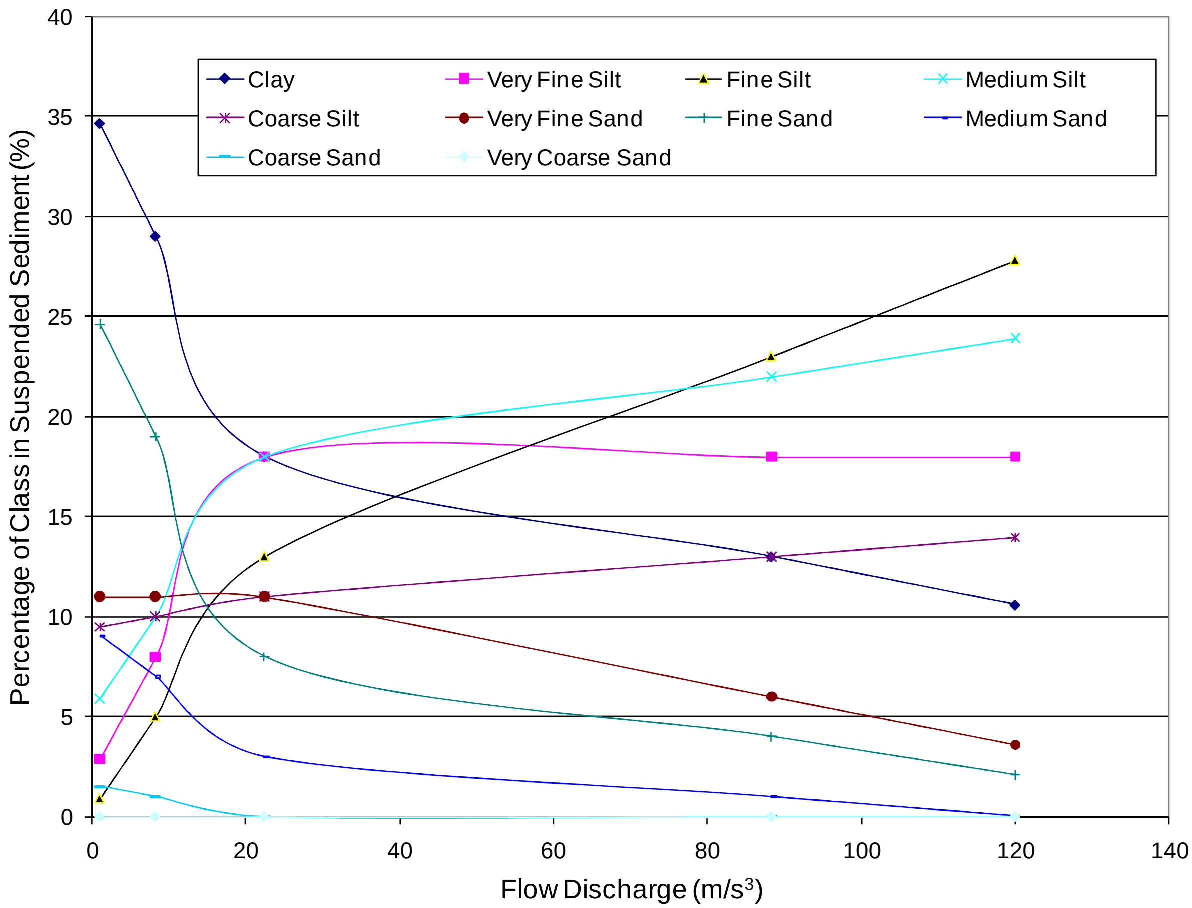


Figure 4 Variation of grain size distribution of the suspended sediment with river flow

2.2 Frequency Analysis

A flow frequency analysis was conducted on the flow data from the Todmorden gauge between 1962 and 2008. The frequency distribution of the data was normalized, and the log (Q) distribution was used to develop the bin numbers for the flow frequency analysis (see Table 1). The bin numbers partitioned the flow record into discrete categories, based on different rates of discharge. This was so that each daily flow rate could be 'looked up', then assigned a bin number, that could then be related to the closest modelled discharge for that particular day. The distribution of these daily flows during the modelling period was then assembled into a sediment budget for the 2006-2007 flow period (see below). The percentage of time for each daily flow condition between 1962-2003 is shown in Figure 5. The most frequent flow in Don River is 2.5 m^3/s, and this represents the baseflow condition in the river. The proportion of total (i.e. approximately annual) sediment load carried by each flow condition, is also listed in Table 1. Approximately 77% of sediment was carried by flows between 10 to 63 m^3/s. However, the duration of flows in this range is approximately 14% of the total flow duration.

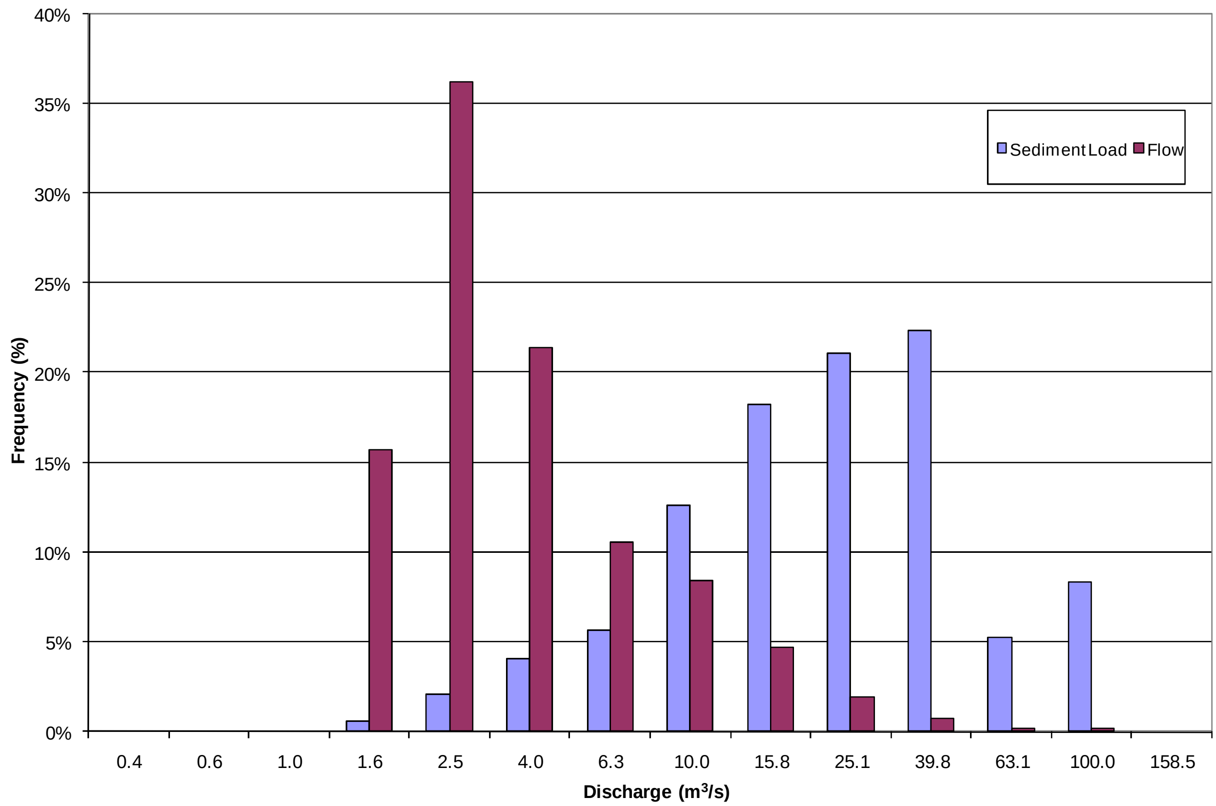


Figure 5 Frequency of flow and sediment load in the Don River

Table 1 Frequency distribution of mean daily flow and sediment load in the Don River

Scenarios to Run Model (Daily)									
Flow Bin		Statistical Analysis				Frequency (%)			
		Flow duration	Total Sediment Load (kg)			Flow	Sediment Load		
Log(Q)	Q	Days	5%	mean	95%	Freq(Q)	5%	mean	95%
0	1.00	0	-	-	-	0.0%	0.0%	0.0%	0.0%
0.2	1.58	11	9,141	41,910	229,616	4.1%	0.2%	0.2%	0.2%
0.4	2.51	86	137,768	631,635	3,460,582	32.3%	3.2%	3.2%	3.2%
0.6	3.98	89	320,557	1,469,680	8,052,037	33.5%	7.3%	7.3%	7.3%
0.8	6.31	40	352,121	1,614,393	8,844,883	15.0%	8.1%	8.1%	8.1%
1	10.00	22	504,275	2,311,982	12,666,813	8.3%	11.6%	11.6%	11.6%
1.2	15.85	9	518,061	2,375,190	13,013,116	3.4%	11.9%	11.9%	11.9%
1.4	25.12	6	802,208	3,677,936	20,150,561	2.3%	18.4%	18.4%	18.4%
1.6	39.81	2	962,212	4,411,514	24,169,665	0.8%	22.0%	22.0%	22.0%
1.8	63.10	1	759,476	3,482,019	19,077,175	0.4%	17.4%	17.4%	17.4%

The hourly flow data from 2003-2008 were compared to the daily flow data to determine the likely implications of running the model with hourly versus daily data. Figure 6 shows the time series comparing daily and hourly flow rates for the calibration period.

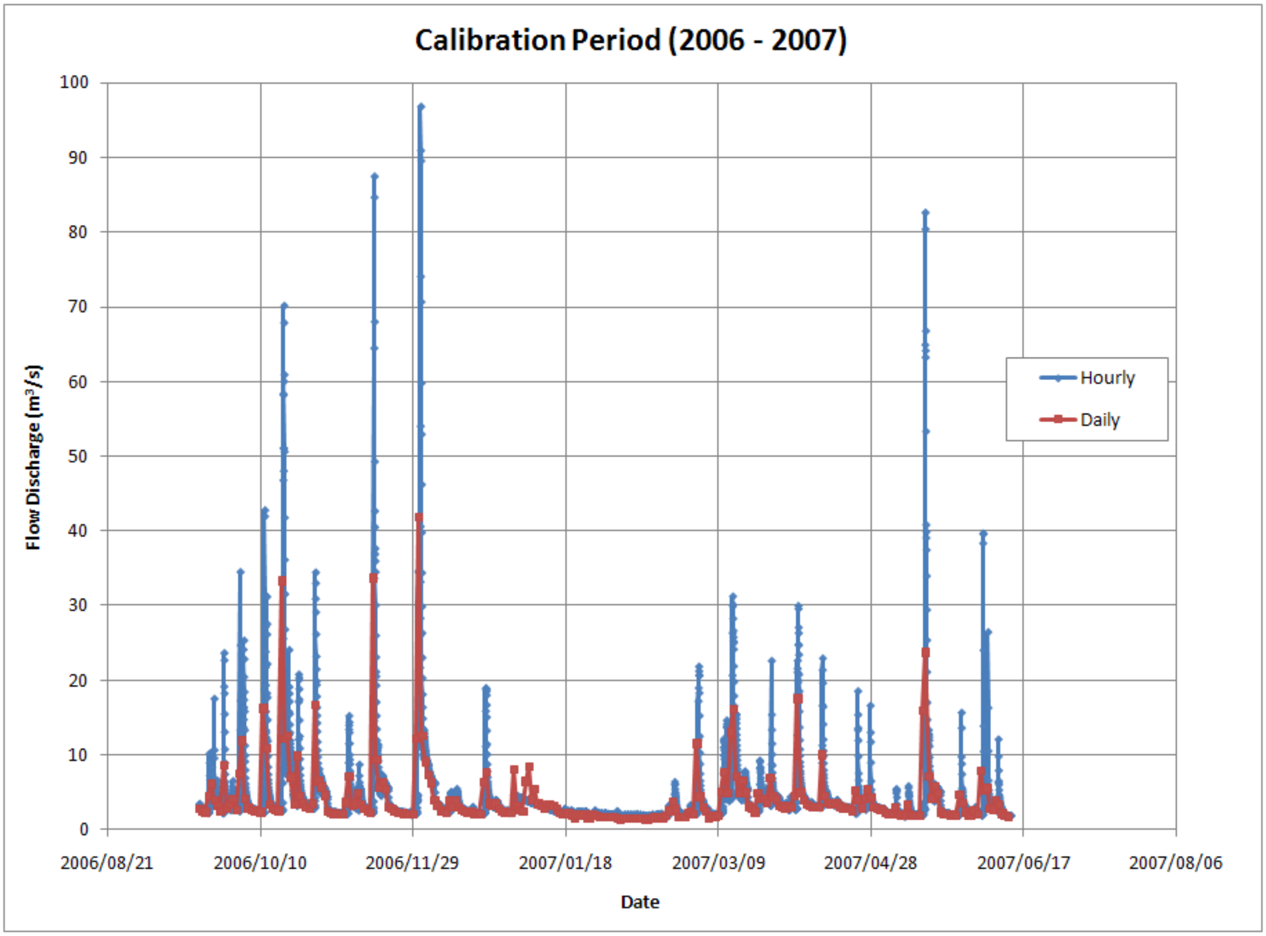


Figure 6 Comparison of hourly vs. daily time series for the calibration period

The difference between the two datasets is visible when comparing higher discharges. The daily flow does not fully capture the high flow conditions (evident in the hourly dataset) due to averaging the flow over a day in a river with a rapid hydrologic response to rainfall events. Figure 7 shows that the high hourly flow rates are captured in the last bin '100' (where $63.1<Q<100$), which has 0.3 % of the total hourly data. During the calibration period, this is approximately 20 hours of high flow conditions, which the daily flow data lacks. These high flow conditions correspond when sediment transport is at its peak. Bin '100' corresponds to 30 % of the suspended sediment load for the calibration period, with only 0.3 % of the flow duration (Figure 8).

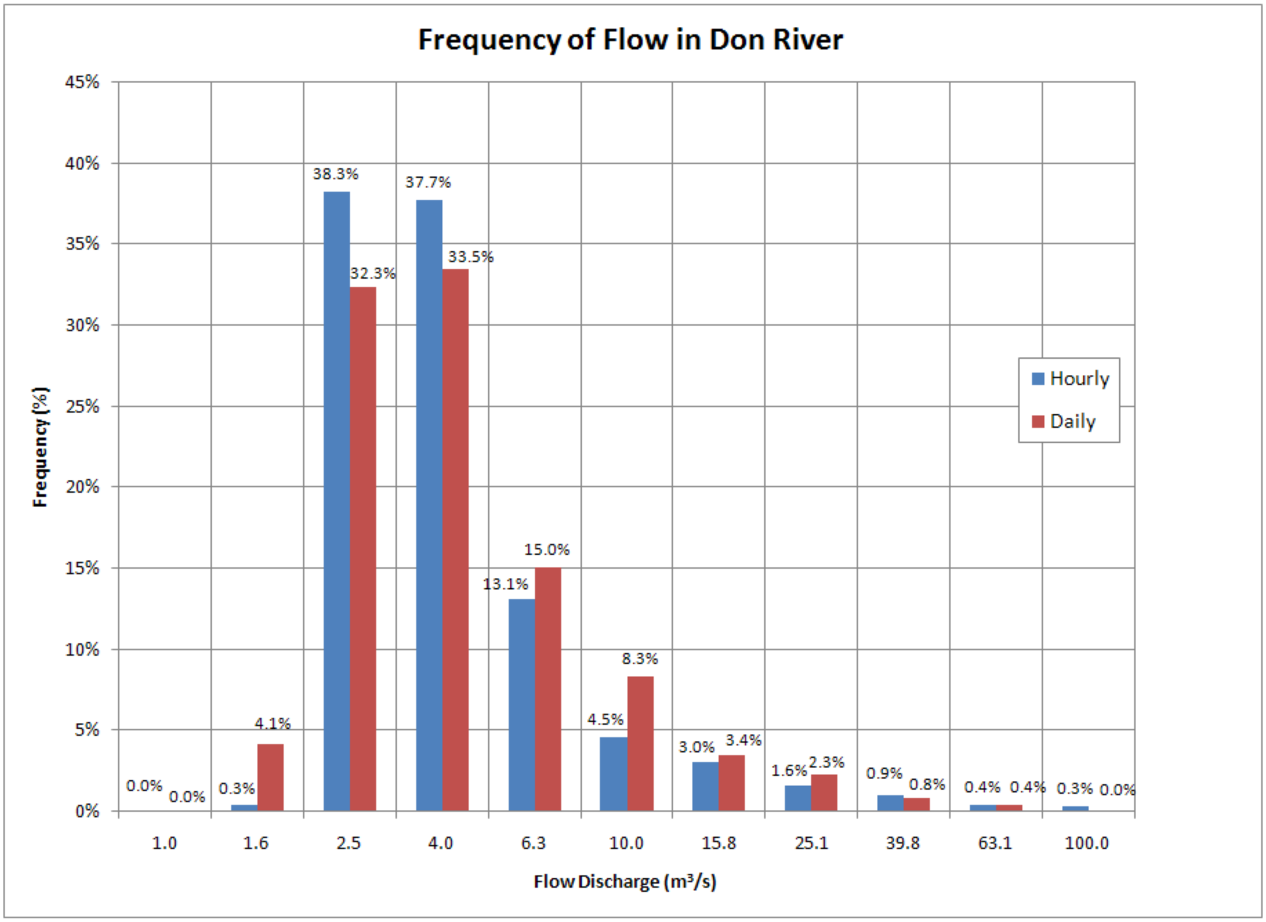


Figure 7 Frequency of hourly versus daily flow in the Don River

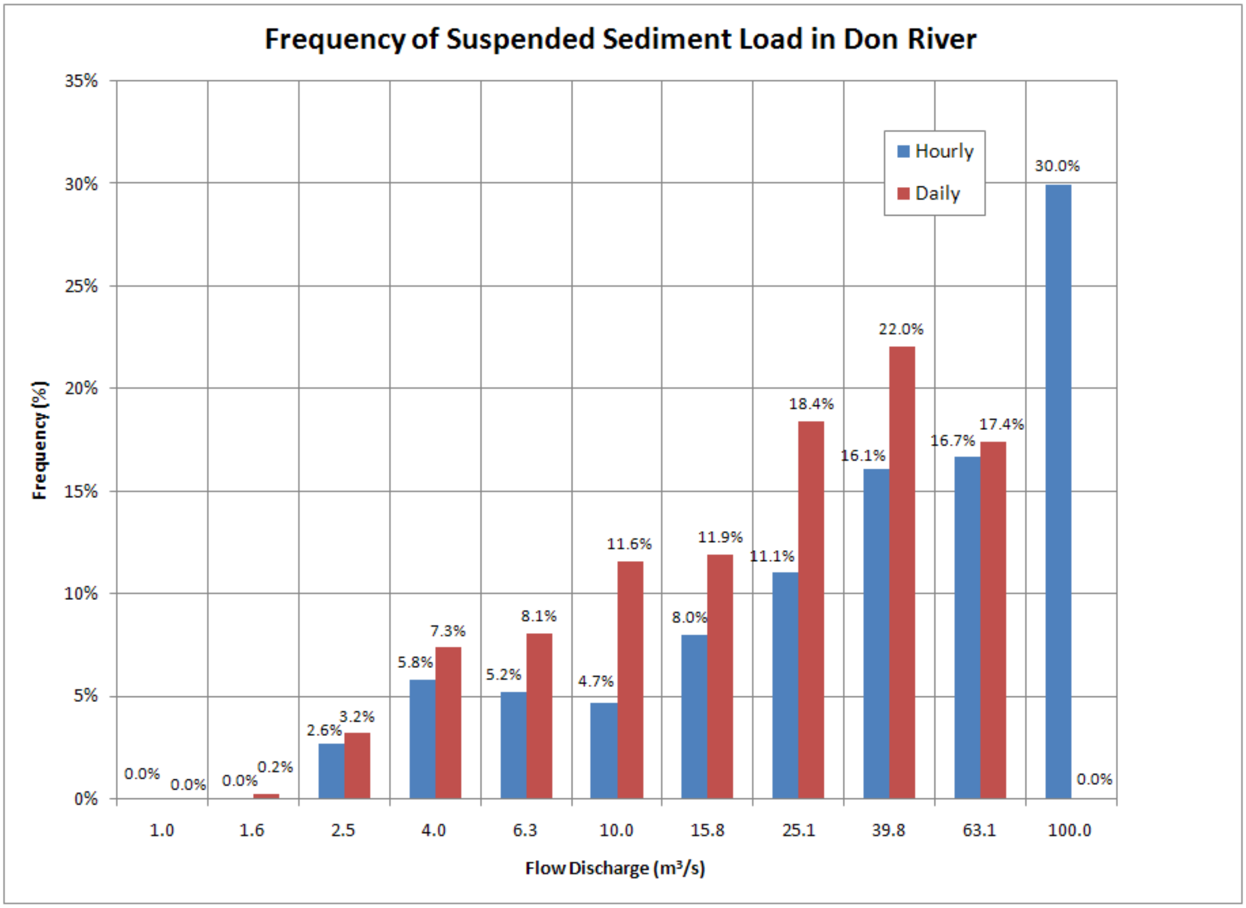


Figure 8 Frequency of suspended sediment load based on hourly versus daily flow data in the Don River

The statistical analysis for the hourly flow is shown in Table 2. The total mean daily sediment load at Todmorden for the calibration period is 20 x 10^3 tonnes, while the total mean hourly sediment load is 28.6 x 10^3 tonnes. Note the wide range of uncertainty in the sediment inflow record, with over an order of magnitude of range in estimated sediment loads over the 5 % - 95 % confidence range. This leads to uncertainty in the absolute magnitude of sedimentation predicted by the numerical model. However, this uncertainty can be constrained by comparing the sedimentation rates predicted by the existing conditions model to the dredging records in the Keating Channel.

Table 2 – Suspended Sediment Hourly Concentrations

Scenarios to Run Model (Hourly)											
Flow Bin		Statistical Analysis					Frequency (%)				
		Flow duration	Flow duration	Total Sediment Load (kg)			Flow	Sediment Load			
Log(Q)	Q	Hours	Days	5%	mean	95%	Freq (Q)	5%	mean	95%
0	1.00	0	0.0	-	-	-	0.0%	0.0%	0.0%	0.0%
0.2	1.58	19	0.8	658	3,019	16,539	0.3%	0.0%	0.0%	0.0%
0.4	2.51	2426	101.1	165,177	757,296	4,149,049	38.3%	2.6%	2.6%	2.6%
0.6	3.98	2392	99.7	359,481	1,648,138	9,029,766	37.7%	5.8%	5.8%	5.8%
0.8	6.31	831	34.6	322,204	1,477,228	8,093,392	13.1%	5.2%	5.2%	5.2%
1	10.00	287	12.0	290,098	1,330,033	7,286,943	4.5%	4.7%	4.7%	4.7%
1.2	15.85	188	7.8	497,252	2,279,782	12,490,394	3.0%	8.0%	8.0%	8.0%
1.4	25.12	100	4.2	689,971	3,163,356	17,331,292	1.6%	11.1%	11.1%	11.1%
1.6	39.81	58	2.4	1,001,777	4,592,914	25,163,509	0.9%	16.1%	16.1%	16.1%
1.8	63.10	23	1.0	1,039,849	4,767,465	26,119,833	0.4%	16.7%	16.7%	16.7%
2	100.00	17	0.7	1,869,624	8,571,787	46,962,834	0.3%	30.0%	30.0%	30.0%

2.3 Model setup

The existing conditions model grid is shown in Figure 9. This is a 'trimmed down' version of the model grid and bathymetry used in the hydrodynamic model (see June 2010 Hydrodynamic Modelling Technical Memo). The model grid for the sediment transport model was limited to those areas which were inundated at some point during the 2006-2007 flow period used in this study. The model bathymetry (Figure 10) includes the 2006 post-dredging bathymetry in the Keating Channel. A full description of the model grid and bathymetry can be found in the June 2010 memo.

Four inflow sediment classes: clay; medium silt; very fine sand and medium sand, were represented in the sediment transport model. These were based on the flow-particle size relationships established from the Todmorden data. The September 2006-June 2007 calibration period (Figure 11) was selected as it represented a 'typical' range of flows that would be observed in a given year. Since a short time step was required for the model to be numerically stable under high flow conditions, the model runs with the full flow record over the calibration period from September 2006-June 2007 were partially complete at the time of reporting. To overcome this, two types of model runs were undertaken:

- Steady-state, 'binned' runs were used to evaluate overall sedimentation volumes over the entire calibration period from September 2006-June 2007. These were necessary so that the model-predicted sedimentation volumes could be compared to observed volumes from dredging records.

- Continuous model runs, based on hourly flow data, with unsteady flow and morphological response (scour and sedimentation) were used for the period September 2006-November 2006 so that existing and preferred alternative sedimentation patterns could be compared at a greater level of detail than allowed by the binned approach.

The limitation of the 'binned' approach is that it does not provide for morphological updating to the bed during the period of interest (i.e. there is no scour and erosion accounted for). A higher than expected amount of sedimentation may be predicted as there is no remobilization of deposited sediment under higher flows, although this represents a conservative assumption for the purposes of this study. In the 'binned' model, sediment deposition and remobilization was limited to the sediment flowing into the model at the upstream boundary. This led to deposition in the vicinity of the boundary, and then remobilization of this sediment to give an equilibrium inflow sediment load just downstream from the model boundary for each run. The model domain in the vicinity of the boundary is excluded from sedimentation calculations for this reason. Since the initial bed sediment was not mobile in these runs, changes in bed sediment characteristics were not incorporated in to the model at this stage. It is recommended that the variations in bed material grainsize through the Narrows and Keating Channel should be incorporated into the detailed design modelling to provide a more exhaustive prediction of sediment transport patterns in the existing and proposed designs. This would include the coarser materials in these areas (not represented by the sampling at Todmorden). The continuous model runs for the entire calibration period will be complete well in advance of detailed design, and these will replace the 'binned' runs in this analysis.

The continuous model runs were extracted from the running model for the period from 26th September 2006-21st November 2006. This enabled the Existing Conditions and Preferred Alternative configurations to be compared over a two month period, with hourly flow input data and morphological response of the channel system (scour and erosion). In order to be able to compare the long-term model performance with dredging data over the calibration period, the model was run for twelve discrete scenarios of flow conditions over this period (matching the flow bins used in the frequency analysis). These hourly daily flow scenarios can then be assembled into a sediment budget for the calibration period, providing an interim assessment of model performance until the full, continuous model runs are complete.

An example of the hydrodynamic model output for one of the 'binned' sediment transport scenarios is shown in Figure 12. A lookup table was then used to determine morphological change over the calibration period by correlating the observed daily flow with its equivalent model scenario. The flow discharge and SSC for each class for each scenario run are listed in Table 3.

Table 3 Suspended sediment concentrations used for model input

Scenarios	Flow	Flow Duration	Suspended Sediment Concentration (mg/m^3)				
			Total	Clay	M-Silt	VF-Sand	M-Sand
Scenario 1	1.00	0.01%	0.0183	0.0029	0.0101	0.0051	0.0003
Scenario 2	1.58	15.85%	0.0299	0.0047	0.0164	0.0083	0.0005
Scenario 3	2.51	38.84%	0.0487	0.0076	0.0268	0.0135	0.0008
Scenario 4	3.98	20.54%	0.0794	0.0124	0.0437	0.0220	0.0013
Scenario 5	6.31	10.53%	0.1296	0.0203	0.0713	0.0359	0.0022
Scenario 6	10.00	6.96%	0.2114	0.0331	0.1163	0.0585	0.0035
Scenario 7	15.85	3.97%	0.3449	0.0540	0.1897	0.0954	0.0057
Scenario 8	25.12	2.26%	0.5626	0.0881	0.3095	0.1557	0.0094
Scenario 9	39.81	0.80%	0.9178	0.1438	0.5048	0.2539	0.0153
Scenario 10	63.10	0.20%	1.4973	0.2346	0.8235	0.4143	0.0250
Scenario 11	100.00	0.04%	2.4426	0.3827	1.3434	0.6758	0.0407

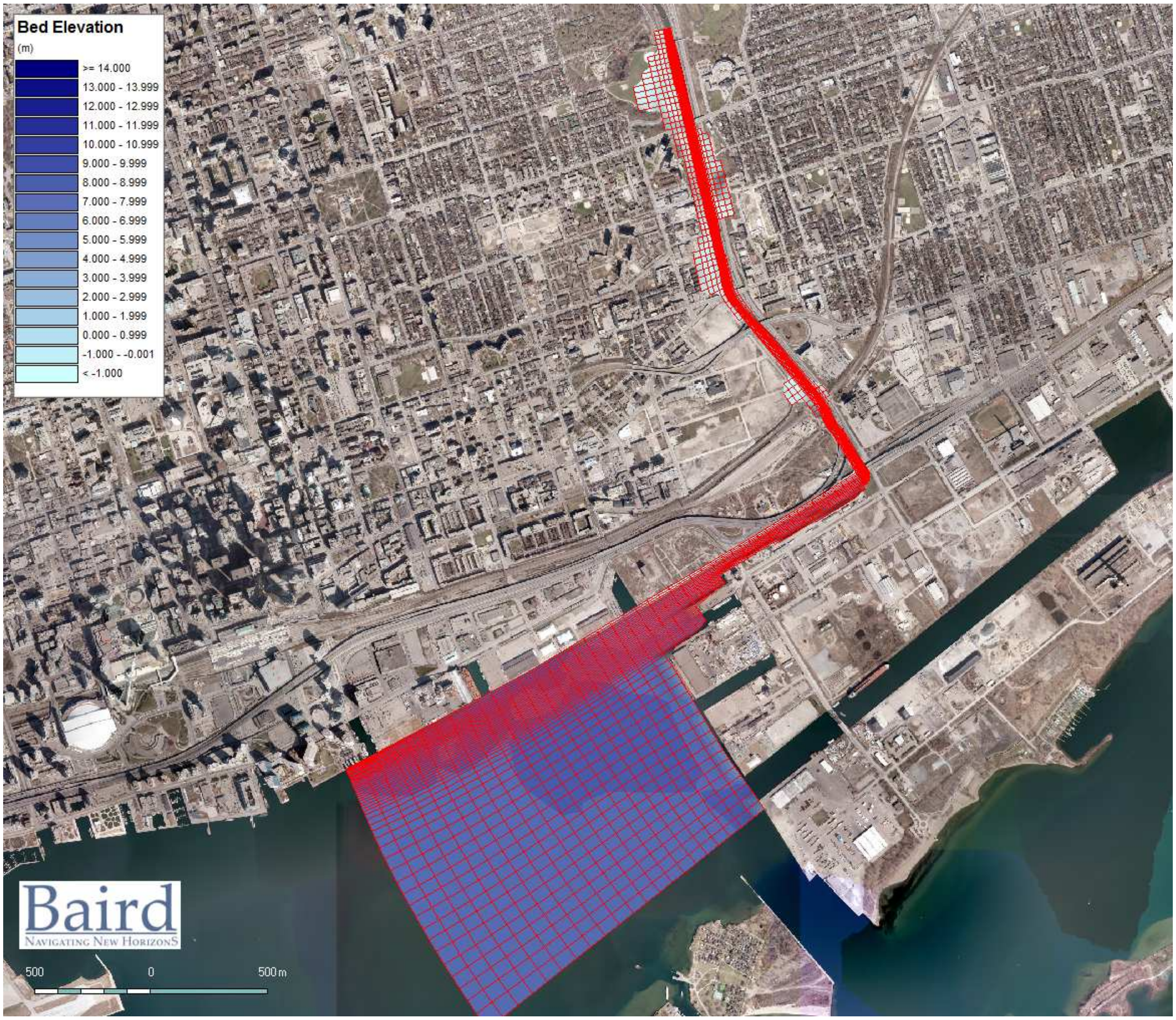


Figure 9 Model grid for the existing conditions sediment transport model

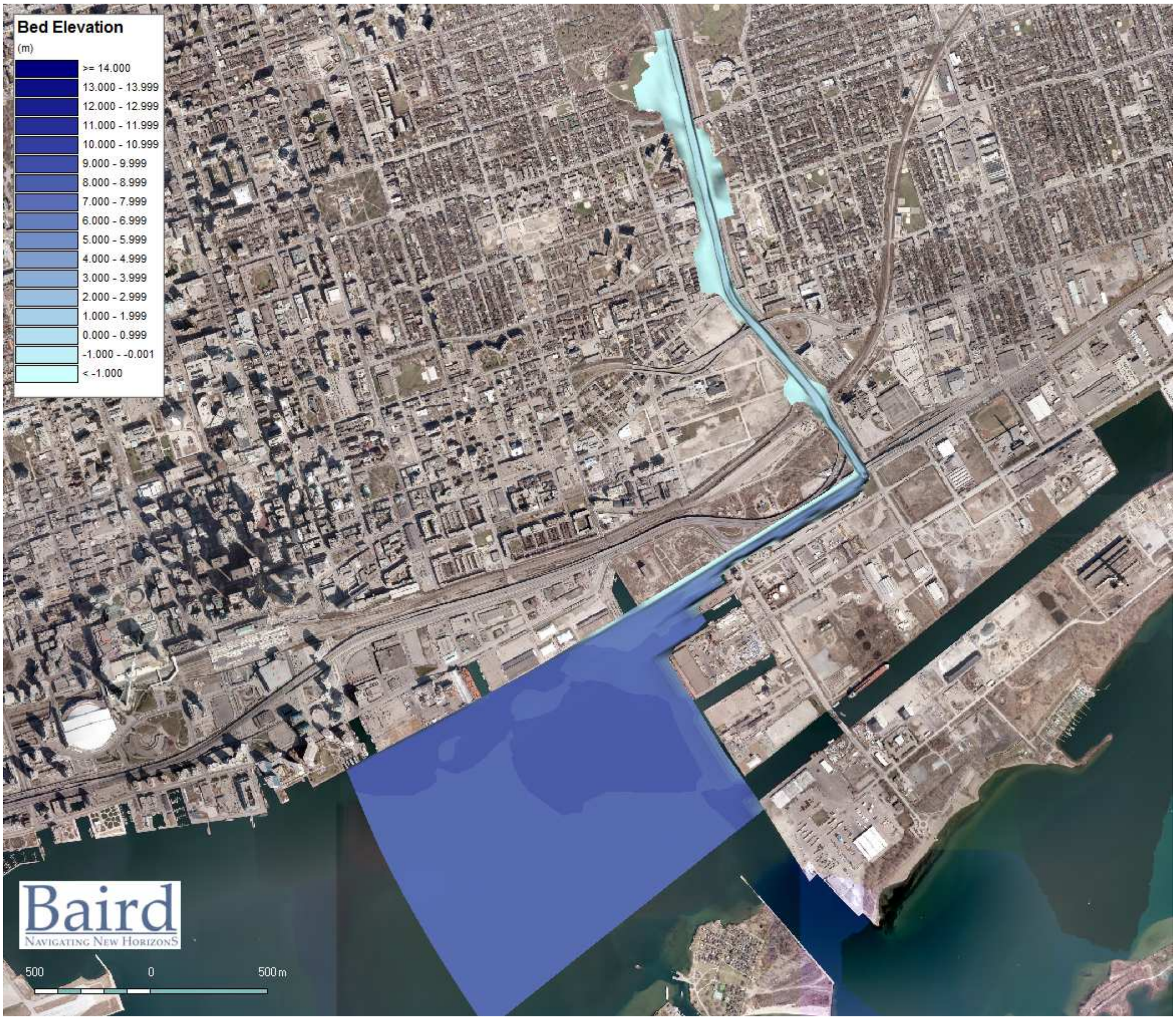


Figure 10 Model bathymetry for the existing conditions sediment transport model

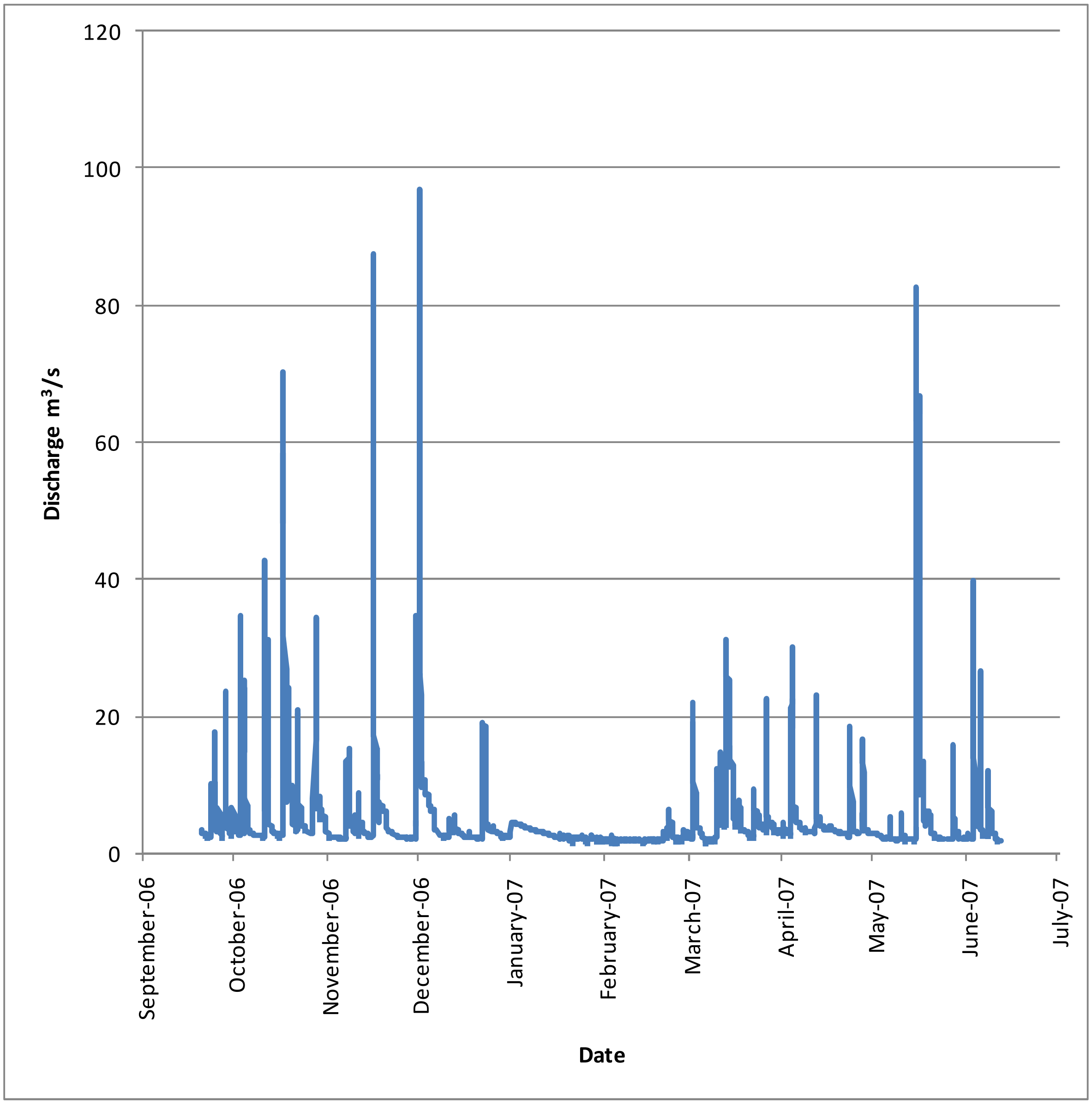


Figure 11 2006-2007 daily flow data used in the modelling study

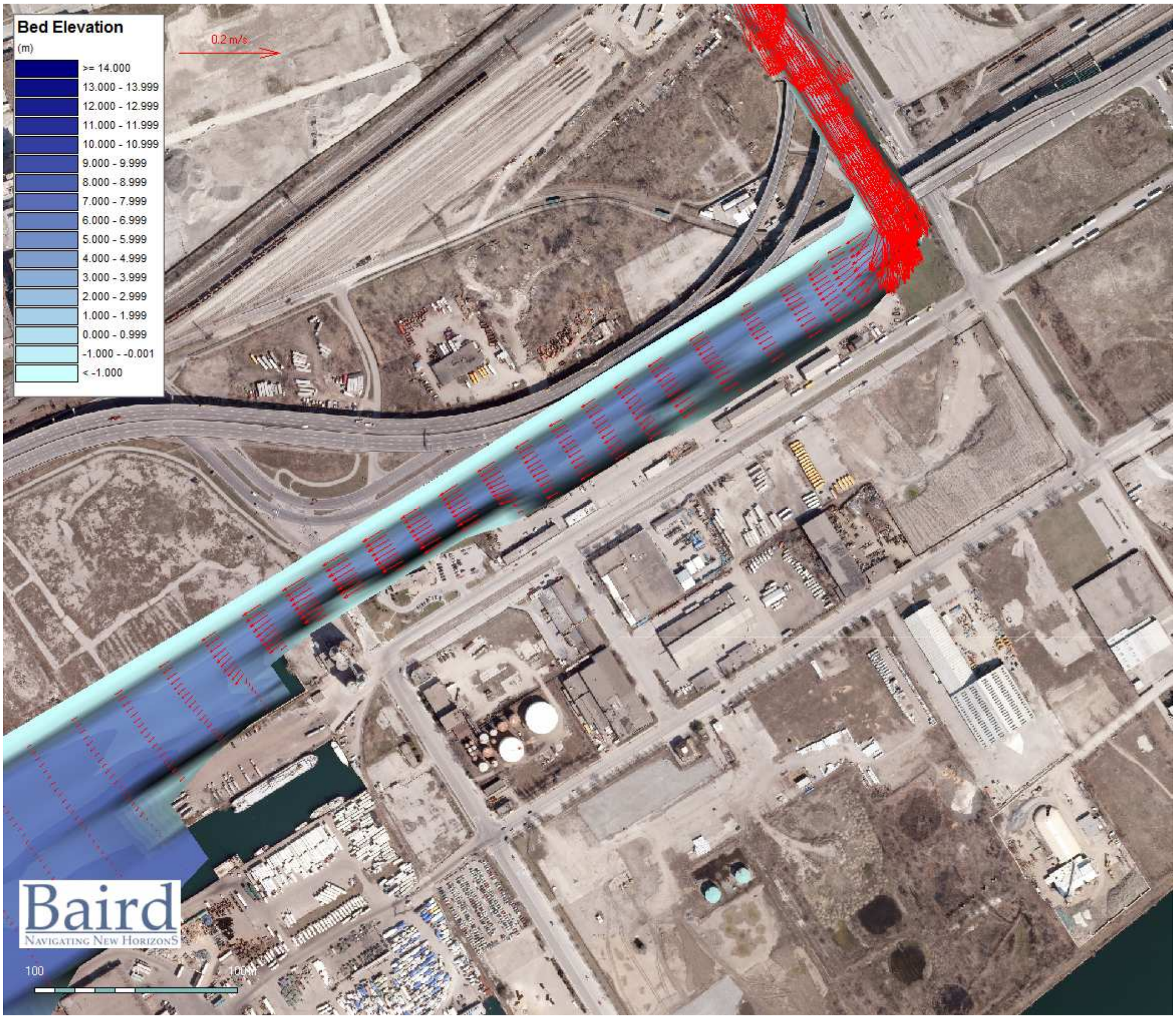


Figure 12 Model-predicted flow velocity vectors in the existing conditions model for Scenario 6

2.4 Existing Conditions Model Sediment Transport Calibration

The existing conditions model (using the 'binned' approach) was calibrated to compare the modeled bed change with the measured bed change between September 2006-June 2007 in the Keating Channel. The distribution of deposited sediment was calculated from the bathymetry measured post-dredging in September 2006, which was subtracted from the pre-dredging survey bathymetry in June 2007 (see Figure 13). According to the pre-and post-dredging bathymetric surveys the net volume of sedimentation in Keating Channel is approximately 25,100 m^3 over this time period. The modeled sedimentation during the same period is shown in Figure 14. The total sedimentation volume predicted by the model (using daily flow conditions) is 27,600 m^3, which is approximately 10 % higher than the measured volume. The difference between predicted versus observed sedimentation based on the daily flow data is shown in Figure 15.

Figure 15 shows that, while predicted and observed overall sedimentation rates are in the same order of magnitude, the spatial pattern of sedimentation is different between the two. The model under-predicts sedimentation in the upstream section of the Keating, and over-predicts it downstream. This is thought to be largely a function of the moderating effect of the Don Narrows upstream in the model, causing coarser sediment to be deposited in the Narrows, and then not being remobilized into the Keating. An additional factor in this is that the sediment transport relationships used at the model boundary were established at Todmorden, not in the vicinity of the model boundary. A more thorough analysis of this will be possible in advance of detailed design, once the full, continuous model runs area complete. At that point the model may be more closely calibrated to observed flow and sediment transport characteristics in the Don Narrows and the Keating Channel (See Section 3.2). Note that due to the high degree of uncertainty in model inflow and sediment load data at the upstream boundary, a program of data collection in the Narrows and Keating Channel prior to detailed design is recommended (see below). Re-evaluating the model calibration is recommended as an initial element of detailed design, once the continuous flow runs are complete for the entire calibration period.

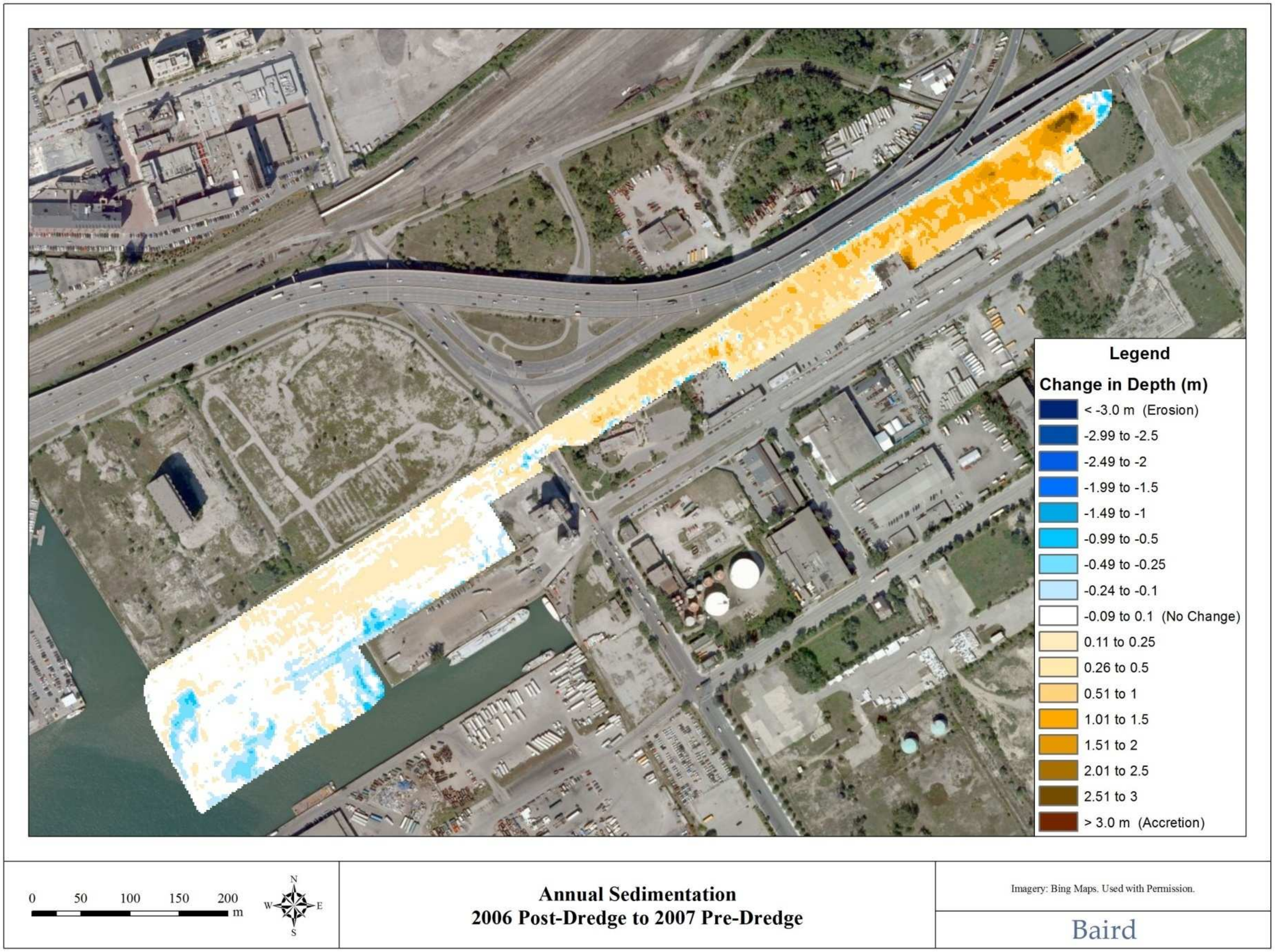


Figure 13 Sedimentation calculated from pre- and post-dredge surveys between September 2006-June 2007

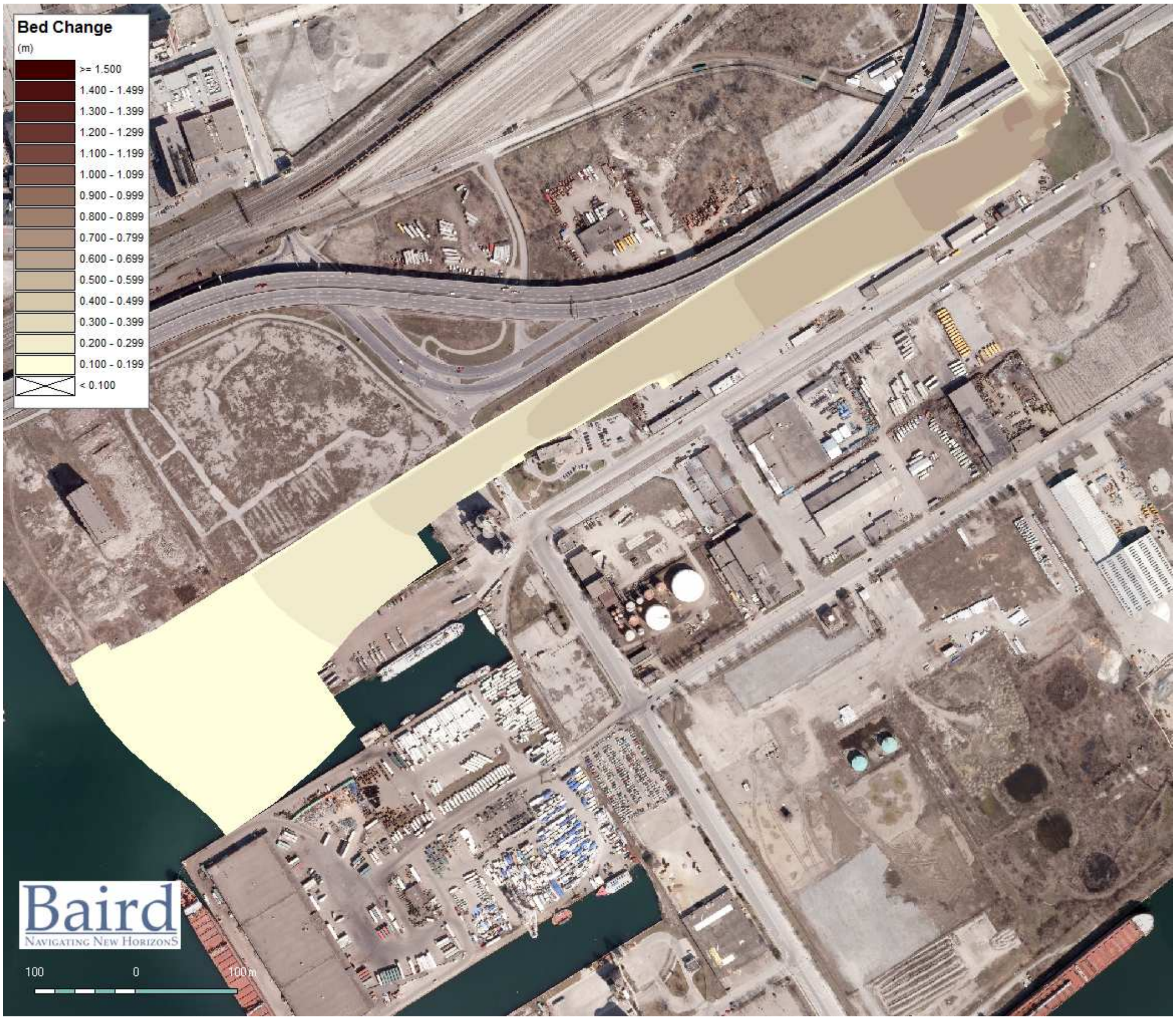


Figure 14 Sedimentation estimated by the existing conditions model during the calibration period

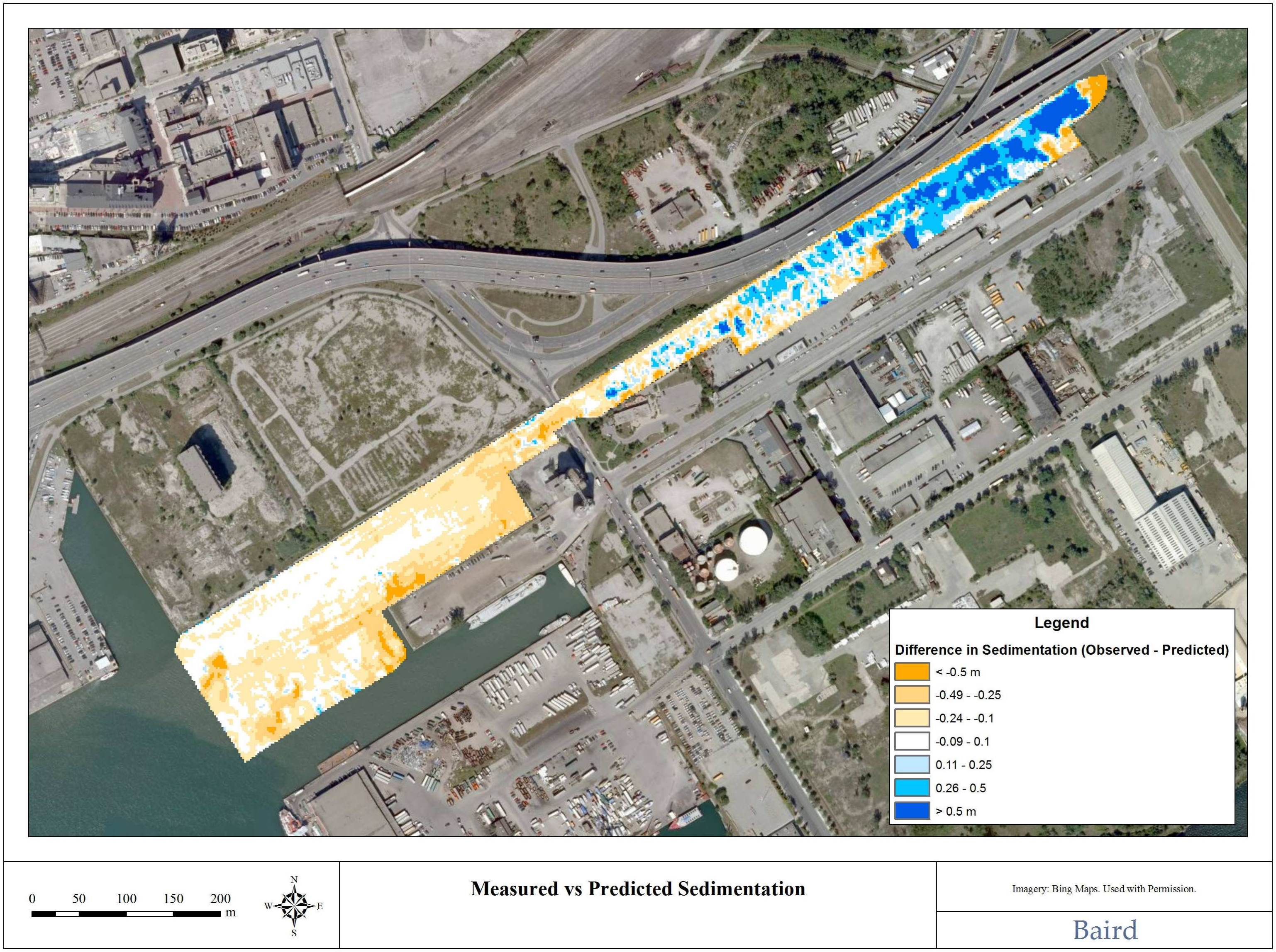


Figure 15 Difference between observed and predicted sedimentation during the calibration period

2.5 Preferred Alternative Model Setup

The preferred alternative model grid is shown in Figure 16. Like the existing conditions model grid, this is a 'trimmed down' version of the model grid and bathymetry used in the hydrodynamic model. The model grid for the sediment transport model was limited to those areas which were potentially inundated at some point, when the observed flows during the 2006-2007 calibration period are applied to the boundary of the preferred alternative model. The model bathymetry (Figure 17) includes the 2006 post-dredging bathymetry in the Keating Channel. A full description of the model grid and bathymetry can be found in the June 2010 memo.

In the preferred alternative configuration, for evaluation of conveyance of the regulatory flow, the weir at the upstream end of the Keating Channel, north of Lake Shore Boulevard, can be set to the 'default' position. This configuration has a height of 71.6 m for the upstream weir (this weir is assumed to be adjustable, and it would default to be in the 'down' position to maximise flood conveyance), and a height of 75.25 m for the fixed, side-spill weir. This configuration, with the upstream weir in the 'down' position is thought to be a 'worst case', in terms of sediment trap efficiency, because this gives a conservative estimate of sediment trap performance, since velocities are greater through the trap area under the weir down scenario. The sediment trap is also less efficient when it is 'full' (the bed level is at the existing level under Lake Shore Boulevard). A binned approach was used to evaluate the lowest trapping in the area which can be expected over the calibration period from September 2006-June 2007. Similar to the existing conditions model run, a series of steady-flow model runs were used to evaluate sediment transport under different flow discharges, then a lookup table was then used to determine morphological change over the calibration period by correlating the observed daily flow with its equivalent model scenario.

The sediment transport runs undertaken with the existing conditions model used the same inputs and parameters from the calibrated existing conditions model. Four sediment classes: clay; medium silt; very fine sand and medium sand, were represented in the sediment transport model.

Since a short time step was required for the model to be numerically stable under high flow conditions, the model runs with the full flow record over the calibration period from September 2006-June 2007 were partially complete at the time of reporting. The continuous model runs were extracted from the running model for the period from 26th September 2006-21st November 2006. This enabled the Existing Conditions and Preferred Alternative configurations to be compared over a two month period, with hourly flow input data and morphological response of the channel system (scour and erosion). The model was run for the same scenarios of flow conditions as the existing conditions model over this period.

The continuous time series model run (in progress at the time of reporting) is being undertaken to evaluate trap performance under 'general conditions': the trap bed level under this scenario is 70 m (i.e. the trap was 1.6 m below the existing bed level at Lake Shore Boulevard). The weir north of Lake Shore Bouldevard is in the 'up' (75.25 m) position to direct flow into the new naturalized channel.

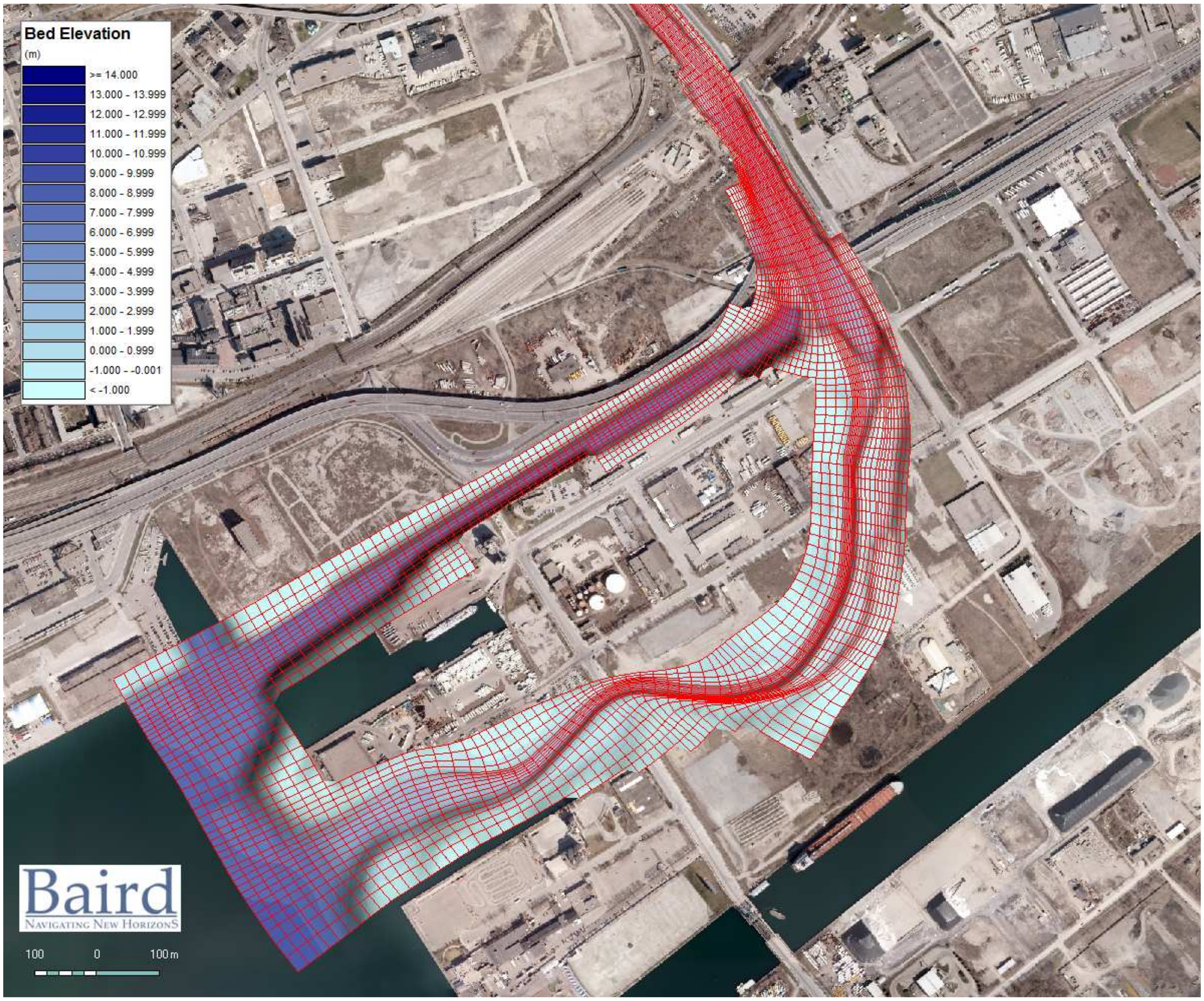


Figure 16 Preferred alternative sediment transport model grid

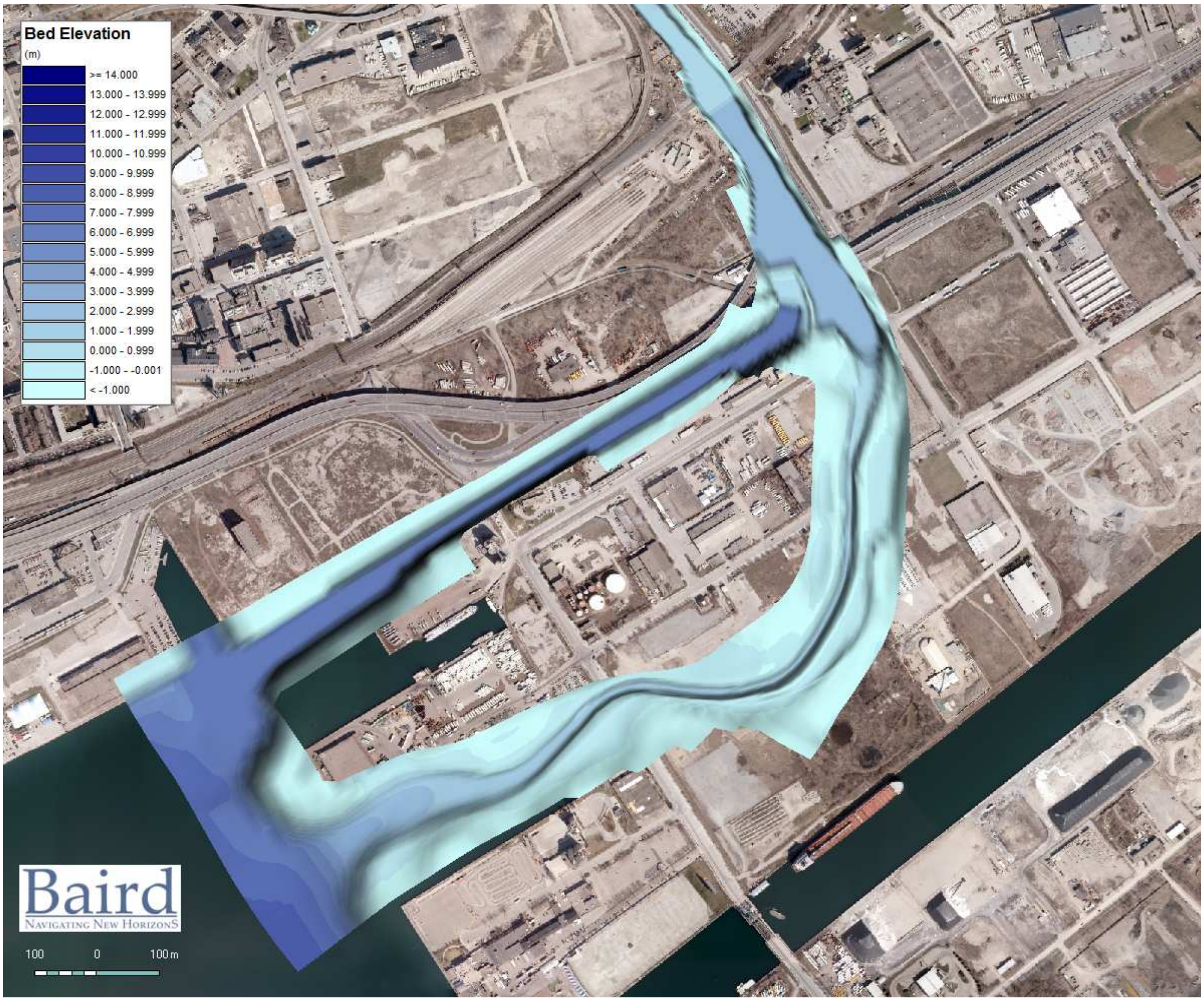


Figure 17 Preferred alternative sediment transport model bathymetry

3.0 PREFERRED ALTERNATIVE MODEL RESULTS AND DISCUSSION

The preferred alternative sediment transport model was run for two cases:

- 'Worst case': the trap is 'full at 71.6 m, the existing bed level at Lake Shore Boulevard. The weir north of Lake Shore Boulevard is in the 'default' (down) position (71.6 m). This is the 'worst case' initial conditions for sediment trapping as the trap is least efficient under these conditions. This presents a conservative estimate of the amount of sediment trapped in the trap area. The binned approach was used to evaluate 'worst-case' trapping using the daily flow record from September 2006-June 2007.

- 'General conditions': A trap bed level of 70 m (i.e. the trap was 1.6 m below the existing bed level at Lake Shore Boulevard. The upstream weir is in the 'up' (75.25 m) position to direct flow into the new naturalized channel. The downstream (static) weir is also at 75.25 m. This model was run under continuous flow conditions from September 2006-November 2006, using hourly flow data.

An example of the hydrodynamic model output for one of the sediment transport scenarios under the 'worst case' condition is shown in Figure 18. The sedimentation predicted over the period from September 2006-June 2007 under the 'worst case' condition is shown in Figure 19. The greatest degree of sedimentation is found in the sediment trap downstream from the CN Rail crossing. Sedimentation is also predicted in the widened bay under the CN Rail Crossing, although this is expected to be remobilized on higher flow events. The area between the CN Crossing and Lake Shore Boulevard has a sedimentation volume of 18,700 m^3 during the run period. There is a three-fold increase in the amount of trapped sediment in comparison to the existing conditions sedimentation volume of 5,600 m^3 during the same period. This sedimentation rate is in response to the channel widening downstream from the CN Rail crossing under the 'trap full' scenario, and it represents a 'worst case' condition.

In the 'worst case' model scenario, since the upstream weir is down for the modeled time period, some of the flow enters the Keating Channel, and approximately 12,300 m^3 of sedimentation occurs in the Keating Channel. This represents a maximum amount of sediment entering the Keating, as the weir was down for the entire period. Were the weir to be in the up position during this period, as in the 'general conditions' model run, this sediment would enter the new naturalized channel system.

Approximately 4,700 m^3 of sediment was modeled to be deposited in the area between Lake Shore Boulevard and the upstream entrance to the naturalized low flow channel. 5,300 m^3 of sediment was deposited in the new low flow channel under the preferred alternative (worst case) scenario.

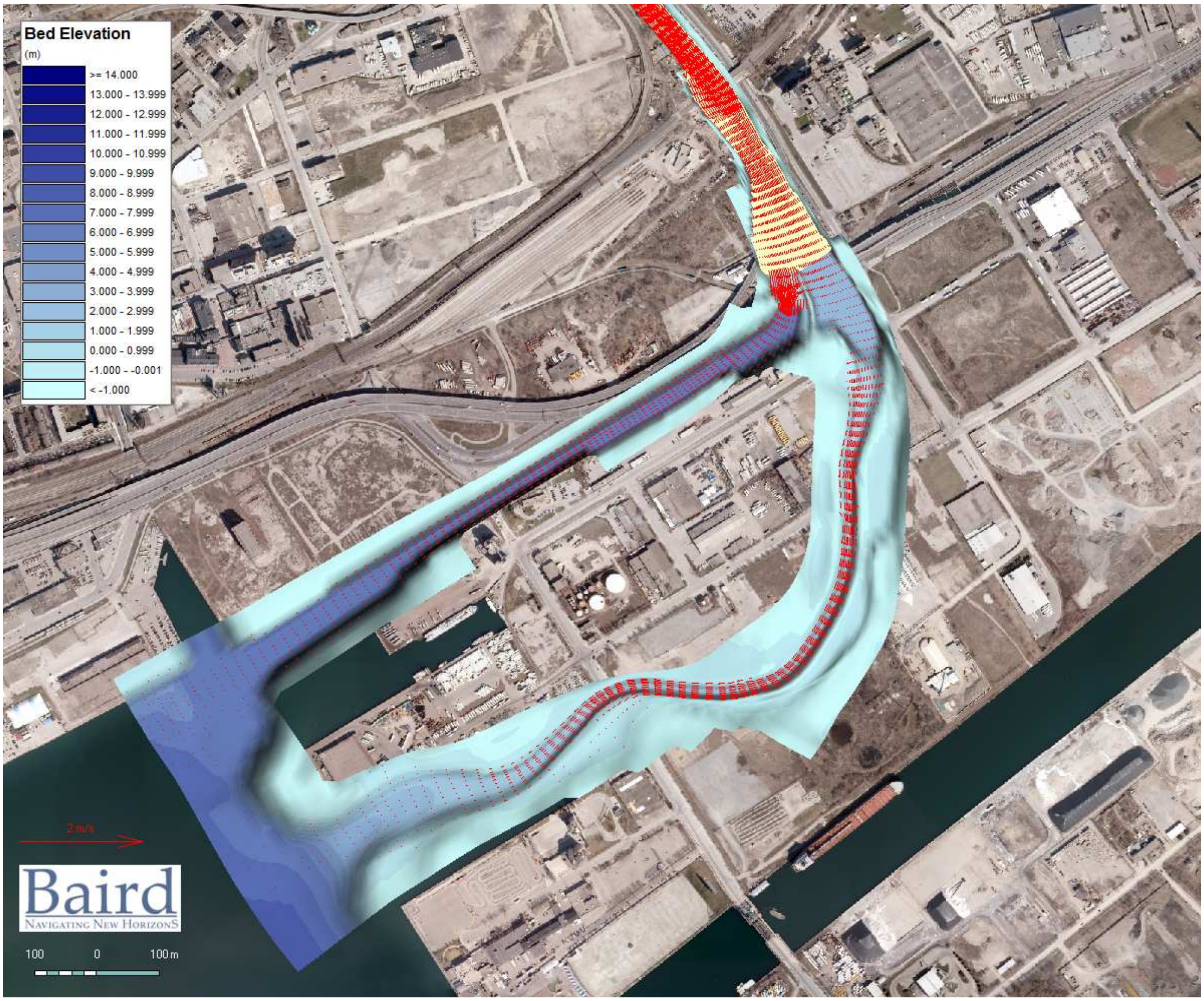


Figure 18 Flow velocity vectors for preferred alternative (worst case) model Scenario 6 (10 m^3/s)

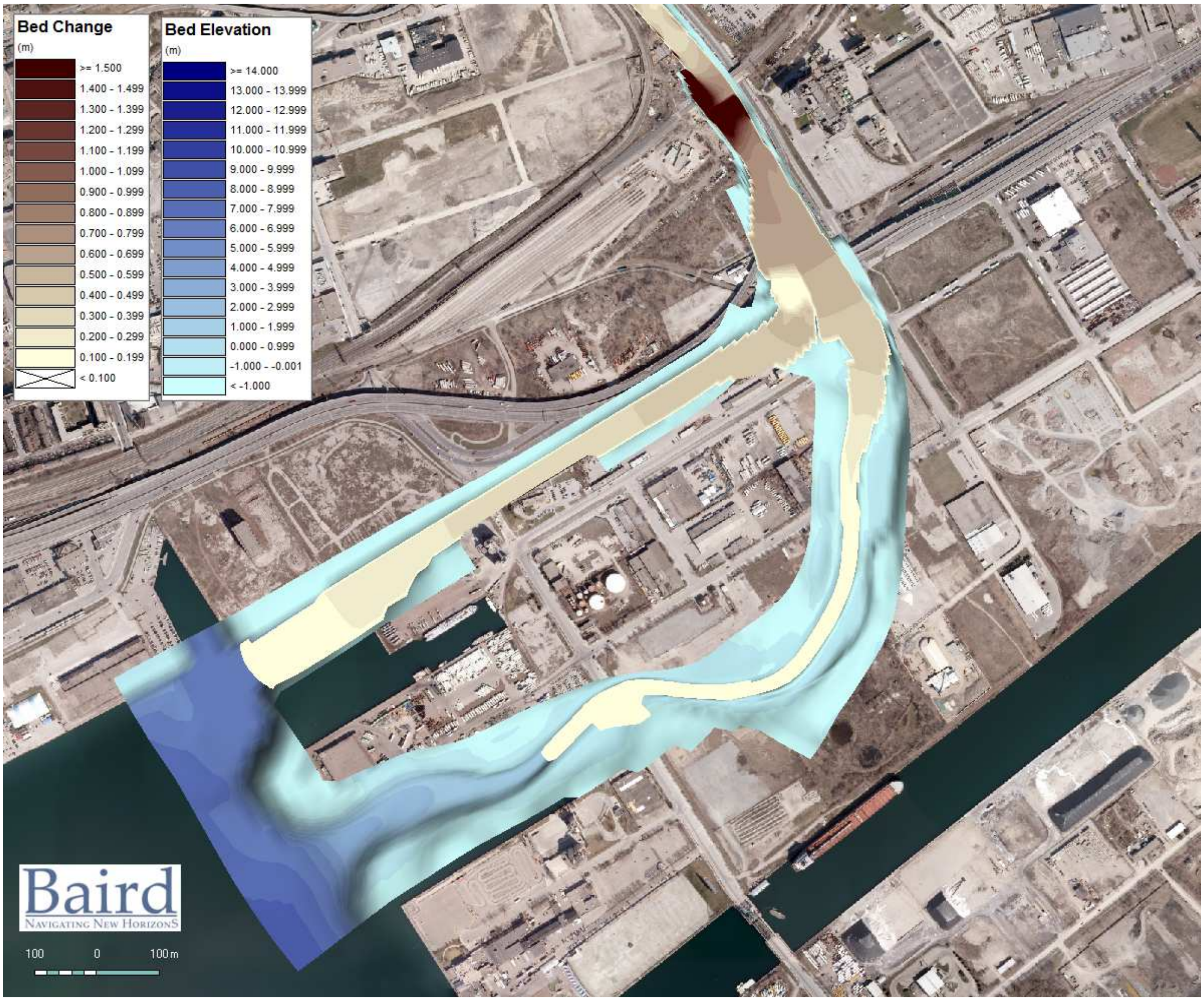


Figure 19 Sedimentation under preferred alternative (worst case) configuration between September 2006-June 2007

The existing conditions and preferred alternative model predictions were compared for the 'general case' using continuous runs over the period from September 2006-November 2006. While the annual trapping performance of the sediment trap cannot be fully evaluated until the continuous runs are complete, the performance of the sediment trap can be examined over a shorter time period by evaluating sedimentation patterns in comparison to the existing conditions model.

Figure 20 shows bed change under existing conditions over the period from September 2006-November 2006. During this period, the model predicts that 2,000 m^3 of sediment will be deposited in the Keating Channel, and 2,000 m^3 of sediment will be deposited in the mouth of the Keating Channel and the Inner Harbour. This suggests that the Keating Channel has a trapping efficiency of approximately 50 %. It should be noted that the absolute amounts of sedimentation, and therefore the trapping efficiency values may change once the full, continuous model is complete and calibrated. However, a comparison of the relative values of trapping efficiency allows for evaluation of the performance of the preferred alternative sediment trap prior to detailed design.

The preferred alternative 'general conditions' model (Figure 21) shows that the sediment trap is functional, trapping approximately 50 % of the deposited sediment in the Project Study Area. A further 17 % of the deposited sediment is trapped between Lake Shore Boulevard and the natural channel. This suggests that the trap is similar in efficiency to the existing Keating Channel, and of greater efficiency if the area south of Lake Shore Boulevard is included. The remainder of the sediment is deposited in the wetlands/ floodplain of the naturalized channel, and the relative amount reaching the Inner Harbour is reduced compared to existing conditions.

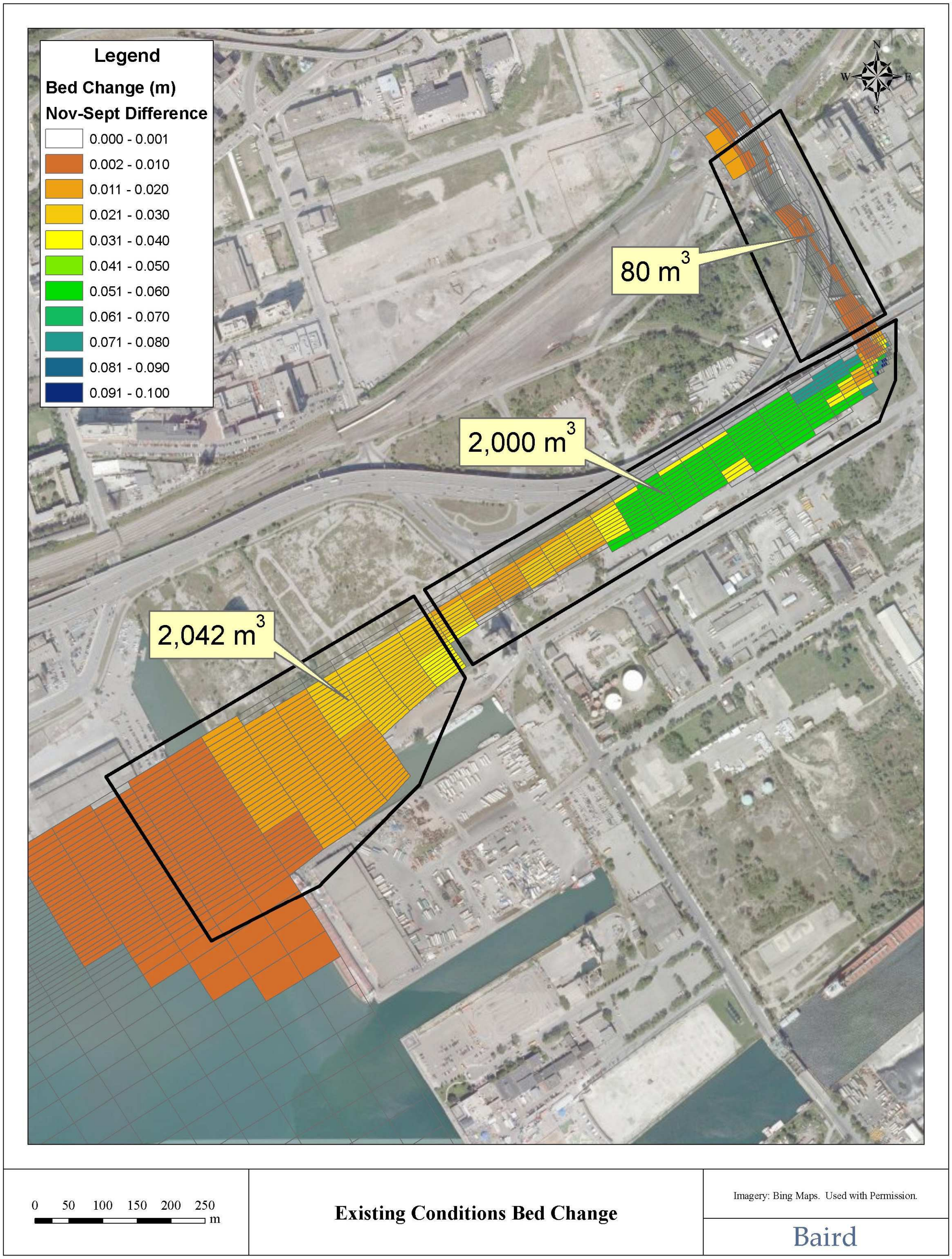


Figure 20 September 2006 – November 2006 bed change predicted by continuous simulation runs: existing conditions

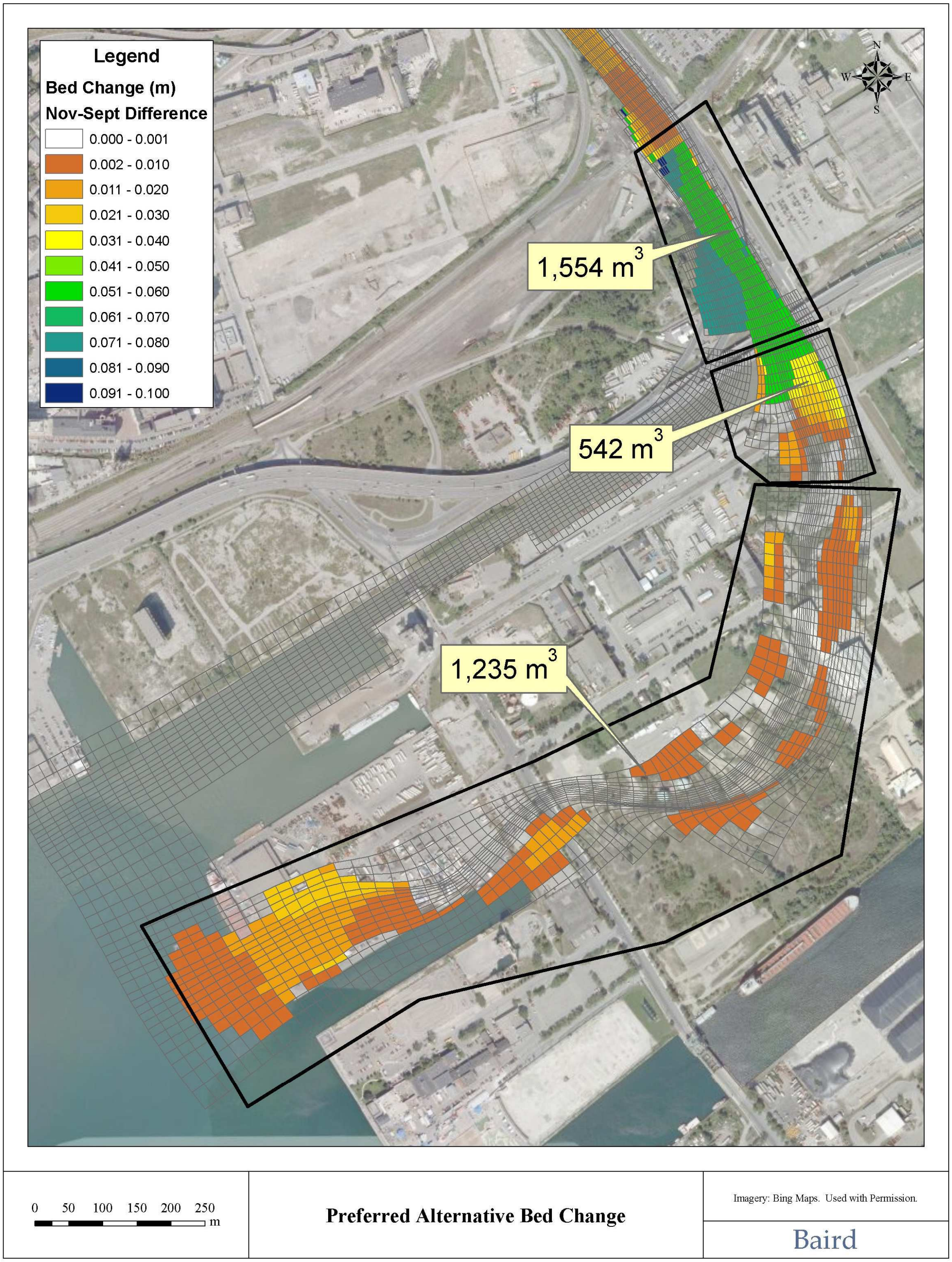


Figure 21 September 2006 – November 2006 bed change predicted by continuous simulation runs: preferred alternative

4.0 CONCLUSION

Overall, the model results show that the future sediment trap area is functional, but requires careful consideration during detailed design The model runs show that careful optimization of the trap performance is necessary through testing sedimentation response to different flows and weir height settings during detailed design. The preliminary sediment transport analysis suggests that the trap will achieve the desired effect of managing sediment in the upstream area of the DMNP, which is important for flood management and also for the long-term viability of the naturalized low-flow channel. The specific details of the trap configuration will need to be addressed during detailed design. The following limitations of the sediment transport analysis are acknowledged at this time:

- The hydrodynamic model is calibrated only for baseflow;
- The model is calibrated only for sediment deposition in the Keating Channel, and not for deposition and erosion in other parts of the model domain;
- The model input boundary conditions are based on flow and TSS samples at Todmorden, not at the model boundary. There is a large amount of available sediment in the channel system between Todmorden and the model boundary that is unaccounted for;
- There is a high degree of uncertainty in the relationship between flow and the upstream boundary and sediment inflow to the model domains;
- The modifying effects of the Don Narrows in terms of storage and remobilization of sediment on a long-term basis are not included in this analysis;
- The ‘binned’ results from the 12 flow scenarios were used to assemble sedimentation rates over the evaluation period. Therefore, hysteresis effects in the flow-sediment discharge relationship are not included in this analysis, which would lead to more sediment redistribution in the Project Study Area.
- The continuous flow models with morphological change and hourly flow data were still in progress at the time of reporting. These models will allow for further calibration of sediment transport in the detailed design stage.

While the binned approach to long-term sedimentation is limited in scope, the binned results suggest that the model represents sedimentation in the Keating Channel that is similar to that observed from the dredging records. However, the continuous flow modelling will allow more complete calibration of the sediment transport model output. The interim continuous flow results suggest that the sediment trap performance of the preferred alternative is similar to the Keating Channel under in the existing conditions model. This indicates that the sediment trap will be sufficient to manage the majority of sediment entering the study area. Some sediment is deposited in the naturalized wetland system, and overall sediment delivery to the Inner Harbour should be reduced compared to existing conditions. The model results suggest that the location and size of the sediment trap are appropriate, and that the trap is of an appropriate size to balance operational efficiency and frequency of dredging, with spatial constraints from existing and future land demands.

While the initial sediment transport modelling shows that the trap can be effective under two extremes of weir settings, detailed design will need to consider the operational response of the weir in order to maximize trap efficiency under a more diverse range of conditions. We recommend that during detailed design, a fully-calibrated flow and sediment transport model is run to determine the optimal sediment trap performance, and to further evaluate the maintenance dredging frequency of the sediment trap, and any potential sediment maintenance requirements downstream from Lake Shore Boulevard. This can be based on the continuous flow models that are presently running for the full calibration period. While the modelling undertaken in this study shows that the sediment trap is capable of trapping material over an extended flow period, the trap performance needs to be 'fine-tuned at a later stage'. This fine-tuning will need to address:

- Sediment trap functionality under different flows;
- Weir settings to optimize trap functionality while maximizing sediment sustainability in other areas;
- Balance between sediment trapping and flood protection targets at higher flows;
- Sedimentation of wetlands in naturalized channel system;
- Impacts of long-term sediment delivery to the mouth of the naturalized channel.

We recommend that the following data collection and modelling analyses are included in the detailed design of the study:

- Model predictions have not yet been analyzed for effects of individual storms on trap sedimentation. Analysis of this issue is necessary to optimize trap functionality by understanding how the weir configuration impacts trap performance.
- Model runs have been post-processed for overall sedimentation volumes. Model predictions can be further analyzed for the behaviour of individual particle size classes. This will have important implications on the ecological functionality of the naturalized channel and connected wetland system;

- The influence of different trap maintenance depths is not yet included in this analysis, and the results presented were for two discrete trap conditions. The full range of trap operational modes should be evaluated during detailed design;

- The long-term effects of the trap filling up and not being maintained, and the implications for flooding in the Project Study Area have not been analyzed;

- Long-term performance beyond the 2006-2007 study period should be evaluated on a reach-by-reach basis.

In addition to the detailed numerical modelling to be undertaken during detailed design, we acknowledge that a key limitation to the present study is the lack of measured velocities and accompanying sediment transport rates in the Don Narrows and Keating Channel. We therefore recommend that a detailed field measurement program is undertaken prior to entering the detailed design of the DMNP. This will allow the sediment transport and hydrodynamic models to be calibrated and validated to observed values in the Project Study Area, rather than the relationships established from measurements at the Todmorden gauge site. In particular, a season of Acoustic Doppler Current Profiler measurements, along with sediment load samples, will provide valuable input to the detailed design as the model can then be evaluated for accuracy of predictions, and an appraisal of the amount of uncertainty in the model predictions can be made.

Don Mouth Naturalization And Port Lands Flood Protection Project

N-3 Supplemental Technical Memorandum

Toronto and Region Conservation for The Living City

WATERFRONToronto

TORONTO

www.baird.com

Baird

oceans

engineering

lakes

design

rivers

science

watersheds

construction

Final Report

Don Mouth Naturalization EA Modelling Supplemental Technical Memorandum

November 5, 2013
10713.201

Innovation, Excellence & Service

Don Mouth Naturalization EA Modelling Supplemental Technical Memorandum

Prepared for

Toronto and Region Conservation

Prepared by

Baird

W.F. Baird & Associates Coastal Engineers Ltd.

For further information please contact
Alex Brunton, Ph.D., at (905) 845-5385

10713.201

Revision	Date	Status	Comments	Reviewed by	Approved by
0	05 Nov 2013	Final		DAB	DAB

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

Detailed two and three dimensional hydraulic modelling of the Lower Don River was undertaken as part of the Don Mouth Naturalization and Port Lands Flood Protection Environmental Assessment (DMNP EA). This supplemental memorandum presents an update of the original model results with respect to the phased approach to construction proposed under the Port Lands Acceleration Initiative (PLAI). This report should be read in conjunction with the Hydrodynamic Modelling Technical Memorandum (Baird, 2010a) and the Sediment Transport Modelling Technical Memorandum (Baird, 2010b). The results in this addendum provide additional information with respect to the original reports, and this addendum is not a replacement for the 2010 reports.

2-D hydrodynamic and sediment transport processes in the lower Don River were represented in the Delft3D model to evaluate the existing conditions in the study area; along with Phases I, II and III of the PLAI (Figure 2). Phase IV was considered to be similar enough to Phase III that separate modelling of these two phases was not warranted for the purposes of the EA. The scope of this study is limited to an examination of river flooding under Regulatory flood flow conditions, and it excludes other forms of urban flooding, such as that due to surcharge of storm water sewer systems in the area.

The DMNP EA also identified the sediment and debris management requirements for the Don River. These include both management techniques, physical aspects of any in river sediment trap and all ancillary features necessary to ensure functional needs including any associated infrastructure. The sediment transport and depositional characteristics of Phase II and Phase III of the PLAI were evaluated for comparison to the original management requirements identified for the EA preferred alternative. Phase I was excluded from the sediment transport modelling due to its similarity to the present configuration of the channel, so the Existing Conditions sediment transport model is considered to adequately represent Phase 1 conditions.

2.0 REGULATORY FLOOD MODELLING

2.1 Existing Conditions

The original existing conditions (EC) model was finalized in June 2010, with an update in February 2012. This model has served as the baseline for the comparison of model results during the EA selection of a preferred alternative. In order for development to be considered, the peak water levels of a given design could not exceed those of the original existing conditions model.

In 2013, the EC model was further refined by increasing mesh resolution, adding more detailed survey data, and including more buildings near the Eastern Avenue underpass and CN Rail bridge in order improve representation of flood levels. The original scour assumptions of existing bed levels remain unmodified for the base existing conditions model. The inundation extents of the revised EC model under the Regulatory flood are shown in Figure 3.

2.2 Phase I

Phase I of the project features new development blocks in the vicinity of Cherry Street and Commissioners Street, but the rest of the study area is identical to the existing conditions model. In order to determine whether water levels during the Regulatory storm met the requirement of not being higher than under existing conditions, several different spillway configurations were tested. The runs showed that no spillway was necessary, provided that the Keating Channel constriction at Cherry Street is removed to improve conveyance of the Regulatory flood. It is also assumed that the Keating Channel is dredged to a depth of -6.2 m CD.

Figure 4 shows the inundation extents during the Regulatory flood for Phase I of the PLAI. The overall extent of flooding does not change significantly from the EC flood extents. Much of the Port Lands and Leslieville remain flooded, although water levels are not increased elsewhere by the presence of the new developments. Note that the Phase I model runs were completed in late 2012, and they are based on the 2010 EC model, and not the 2013 EC model update. The updated EC model includes a more detailed grid and more bathymetric representation, with more buildings than the original (Figure 1). The overall spill patterns are very similar for both models, so no additional impacts are anticipated.

2.3 Phase II

Phase II of the project shows a considerable change from Phase I (Figure 2). Most significantly, flooding to the east of Don Roadway is restricted by the construction of a valley wall feature (VWF) south of Lake Shore and floodplain landform (FPL) north of Lake Shore. The valley wall feature is an extension of the valley wall beyond its existing crest, whereas a floodplain landform is a separate, standalone landform. To compensate for the lost conveyance in the eastern area of the Port Lands, a spillway needs to be constructed to the west of the Don Roadway. An approximately 200 m wide spillway extends from Keating Channel to Commissioners Street, then narrowing to 150 m from Commissioners to the Ship Channel. An earthen vegetated levee is in place at Basin Street to decrease the frequency of discharge into the Ship Channel and reduce the frequency of disruption to shipping traffic. The main river channel is widened and deepened between the CN Rail bridge and Lake Shore Boulevard to create a sediment management area and increase flood conveyance. The Lake Shore and railway spur bridges will need to be extended to accommodate the wider channel. The Keating Channel will continue to be dredged to a depth of -6.2 m CD to ensure adequate conveyance. These works allow further grade increases within the Lower Don Lands north of Commissioners and west of Munitions Street.

This phase requires that the spill through Eastern Avenue has been eliminated prior to completion of the works associated with Phase II. During the Regulatory flood, Phase II performs quite differently to Phase I (Figure 5). The construction of the Don Roadway valley wall feature and floodplain landform north of Lake Shore to CN eliminates flooding in the eastern Port Lands and Leslieville. The new spillway mitigates the impact of the VWF, FPL, and increased grades north of Commissioners and west of Munitions. These works eliminate flooding east of the Don Road, and in conjunction with Phase 1, the risk due to flooding surrounding Cousins and Polson Quays. Phase III is required to remove the flooding risk for the remainder of the Lower Don Lands.

2.3.1 Eastern Avenue Underpass Flooding

In order for Phase II to be implemented, Baird evaluated the threat of spilling at the Eastern Ave and CN Bridge using the existing conditions model. The spill through the underpass leaves the eastern Port Lands and Leslieville at risk of flooding under a Regulatory Flood scenario, even with the Don Roadway potentially raised during Phase II of the PLAI. The flooding through the underpass needs to be prevented in order for the area to the east of the Don Roadway to be removed from the floodplain. The Existing Conditions model predicts that spilling through the underpass occurs at a flow of approximately 1,100-1,200 m^3/s, whereas the Phase II model predicts spilling at 1,550 m^3/s. Thus, investigating Eastern Avenue is more prone to spilling in existing conditions, and provides a more conservative approach. Sensitivity testing of flooding at the underpass was conducted using the Existing Conditions model rather than the Phase II or Phase III model because it has the most detailed representation of the neighbourhood affected by the spill. The spill zone was not included in Phase II or Phase III models because this spill needs to be addressed prior to completion of Phase II.

The Existing Conditions model was modified with a series of potential for removing the spill at Eastern Avenue. This section provides a summary of the results of the Eastern Avenue modelling. However, this issue needs to be investigated as part of the detailed design phase. Previous Existing Conditions models did not represent this area at a high resolution as this spill was not a primary focus of previous modelling efforts. The Existing Conditions model was modified in the vicinity of the underpass to incorporate:

- Increased mesh resolution
- More accurate grading plans – certain features (ie. DVP on-ramp) are not well-represented
- Increased definition of buildings as dry cells

Previous modelling efforts (Baird, 2010a) showed that channel depth at the CN Rail Bridge and Lake Shore Boulevard bridges has a significant influence on flooding at Eastern Avenue. Scour in the reach between both bridges results in improved flood conditions at the underpass, but water levels at CN and Lake Shore bridges still exceed soffit elevations. This indicates the potential for overtopping at those bridges under existing conditions. Beyond a scour depth of 4 m in this reach, flooding at Eastern Avenue is eliminated completely.

Several different options for flood protection barriers and systems were also evaluated under Existing Conditions. In the model, overland flow towards Eastern Avenue originates near the Don Valley Parkway on-ramp and at the southern end of the BMW parking lot. Therefore, raising the elevation of the on-ramp and adding a floodplain landform (FPL) along the DVP to the west of the BMW parking lot were tested. Another FPL immediately west of the Eastern Avenue underpass was also tested, although this configuration would not be realistic due to the presence of nearby building and the existing grades of the road. As an alternative to flood protection works on the western side of the underpass, the effectiveness of a FPL on the eastern side was tested. The immediate surroundings of the underpass are slightly less developed on the eastern side, which may make it easier to construct flood protection works.

Regrading the on-ramp was ineffective and showed no improvement over existing conditions. The BMW FPL is slightly more effective and delays flooding at Eastern Ave but cannot stop it completely. The FPL at Eastern Avenue west of CN shows little improvement and is impractical for real-world implementation. The FPL on the east side of the underpass is a potentially effective strategy in preventing flooding to the eastern section of the Port Lands. When used in combination with scour of the river between CN Bridge and Lake Shore Boulevard, the FPL is able to contain the flood completely. This issue will need to be evaluated in detail during the preliminary design phase of the study.

A detailed-design level model is needed to make further conclusions as to the most appropriate method of containing the flood through the Eastern Ave Underpass. Similar analysis for later phases of the PLAI should also be conducted. However, initial results suggest that a floodplain landform to the east of the underpass can be designed to contain the flood as part of the later phases of the study.

2.4 Phase III

As with Phase II, this phase requires that the spill through Eastern Avenue has been eliminated. From a flow conveyance standpoint, Phase III is effectively the final stage of the project. It features the full build-out of the naturalized channel, extending from the Phase II spillway to Polson Slip. The naturalized floodway features wetland areas that are disconnected from the main channel under normal conditions, but which help convey flow in extreme events. Wetlands are connected to lake levels by decanting through small feeder channels in the design. River flows do not go directly through the wetland. Two weirs are in place: one upstream of Lake Shore Boulevard and one downstream of Lake Shore. The upstream weir is designed to be operational, meaning that it can be opened completely during large flood events, thus maximizing the amount of flow that goes through the Keating Channel. The downstream weir will be parallel with the direction of flow as a fixed sideflow weir. This weir will direct majority of base flows south into the naturalized valley system.

During the Regulatory Flood, the new naturalized channel, Keating Channel and spillway are effective at conveying flows through the study area, allowing for the remaining blocks to be released for development in the western Port Lands (Figure 6). During Phases I-III, the land surface of several blocks will need to be raised to remove them from the floodplain. This is a vital flood protection component and the model will be used as a tool to set appropriate elevations.

3.0 SEDIMENT TRANSPORT MODELLING

Previous sediment transport modelling efforts were primarily concerned with quantifying long-term deposition in the Keating Channel and the EA Preferred Alternative to determine maintenance dredging requirements. This was updated for Phase II and Phase III of the PLAI, and the 2013 EC model was also revised for sediment transport to better understand scour of bed sediments during extreme events. The long-term models focus mainly on low to medium flows, and as such only deposition is calculated. For the extreme event simulations, time scales are much shorter and erosion is a more prevalent process, so a more complex dynamic bed is modeled by the inclusion of morphologic feedback from the sediment transport to the hydrodynamic model.

Sediment characteristics at the upstream boundary were defined based on sampling data at the Todmorden gauge. The dominant suspended sediment size at that location is medium silt. Sediment characteristics in the bed were determined from core samples taken throughout the lower reach of the river (Figure 7). A simplified bed material grain size distribution was used uniformly throughout the model (Table 1). It is recommended that spatially-varying (and layered) bed material is included in the model as part of detailed design.

Table 1. Grain size distribution for mobile bed

Sediment Type	Grain Size Distribution
Clay	**0%**
Silt	**20%**
Very Fine Sand	**20%**
Medium Sand	**60%**

The previous study examined bathymetric changes between a 2006 post-dredge survey and a 2007 pre-dredge survey. This was selected as the model calibration period for long-term continuous morphologic runs. To overcome the long simulation times of long-term sediment transport modelling, a "morphologic acceleration factor" approach was also applied during the sediment transport model study. Based on statistical analysis of flow and sediment transport behaviour over the calibration period, 12 scenarios of varying magnitude were developed (Table 2). Each scenario was run for a week, and then multiplied by a weighting factor to find the total morphologic change for the calibration period. These "binned" runs were run in parallel with the long-term continuous runs to provide results in a more timely fashion. A two month subset of the calibration period from September to November 2006 was used to compare the binned and continuous runs.

Table 2. Flow frequency for binned model

Scenario	Flow (m^3/s)	Hours	% of time flow occurs
1	1.00	0	0.00%
2	1.58	0	0.00%
3	2.51	275	18.19%
4	3.98	671	44.38%
5	6.31	270	17.86%
6	10.00	120	7.94%
7	15.85	85	5.62%
8	25.12	46	3.04%
9	39.81	24	1.59%
10	63.10	15	0.99%
11	100.00	6	0.40%
12	158.49	0	0.00%
Total Hours:		1512	100.00%

3.1 Existing Conditions Sediment Transport

Under existing conditions, the Don Narrows has a 35 m wide, relatively shallow channel until it reaches the deeper dredged Keating Channel. As such, much of the sediment carried by the river is deposited at the upstream end of the Keating Channel where depth increases and the flow slows down (Figure 8).

Under Existing Conditions, the Keating Channel is still a navigable waterway that requires regular maintenance dredging. Approximately 22,500 m^3 of sediment accumulated in the Keating Channel during the calibration period. However, the total predicted accumulation by the model is below this value, at 14,700 m^3.[1] There is a wide range of uncertainty in the sediment inflow record, with over an order of magnitude of range in estimated sediment loads over the 5 % - 95 % confidence range (see Baird, 2010b for more details). While uncertainty exists for the sediment inflow data, the model appears to produce sedimentation in the Keating Channel that is consistent with observed sedimentation rates from dredge records during the calibration period. The model is therefore appropriate for making comparisons of the relative sediment transport performance of the proposed EA design options. We recommend that the uncertainty in sediment loads to the area be resolved through additional field data collection and analysis prior to detailed design. The key sources of error are:

- Applying the sediment rating curve from Todmorden (with a great deal of uncertainty in values) at the EC model boundary, which leads to a greater degree of sedimentation in the Don Narrows as coarser material settles out after flowing into the model domain. This

[1] This value assumes the sediment predicted by the model to occur in the channel below Queen Street is actually occurring in the Keating Channel, and that the Don Narrows is presently adjusted to the average annual sediment load.

causes a 'knock-on effect' of uncertainty in the absolute magnitude of sedimentation predicted by the numerical model.

- No sediment transport data for calibration or validation at discharges above low flow.
- Lack of available bedload measurements, which are typically 20% of the sediment loads in tributaries in the area.
- Lack of critical shear stress values for bed sediments in the study area.

As a result of the above uncertainties, we recommend that the model is used to evaluate the relative distribution of sediments, rather than the absolute sedimentation rate, until such time that the model can be calibrated against further ADCP and TSS levels and particle size distributions.

In relative terms, during the long-term continuous simulation, of the sediment passing the Queen Street Bridge, 35 % of sediment deposited in the study area is in the Keating Channel, and 15% is deposited in the reach upstream from Lake Shore Boulevard (Table 3). In this latter reach, most of the deposition occurs under the CN Rail Bridge and downstream towards Lake Shore Boulevard. The remainder of the sediment is throughput to the Inner Harbour.

Table 3. Distribution of Sediments Deposited in EC Model

Reach	Sediment Deposition (Model)	Sediment Deposition (Actual)
Keating Channel	14,700 m^3	21,600 m^3
Sediment Throughput to Harbour	~15,000 m^3	Not known

Based on the model, approximately 50% of deposited sediment is trapped in the Keating Channel, with the remaining 50% settling out in the harbour. Actual sediment deposition in the harbour was not measured.

3.2 Phase II

The widened, deepened area upstream of Lakeshore provides the most fundamental change from Existing Conditions under normal flows (Figure 7). Deposition in the Keating Channel has decreased by approximately 60 %, while deposition has increased in the sediment trap area by approximately 235 %. We anticipate that, based on a relativistic comparison of the changes between model runs, and the existing (observed) sedimentation rates in the Keating Channel, that approximately 15,000 m^3 per year of sediment will accumulated in the sediment trap once Phase II is complete, while approximately 6,000 m^3 per year will accumulate in the Keating Channel (Table 4). The remainder is deposited in the new, deeper area immediately south of Lake Shore. Regular maintenance dredging on the order of 2000 m^3/year will need to be conducted in the area south of Lake Shore Boulevard. We anticipate that this area will also be the dominant reach for ice and debris accumulation, so maintenance of this reach will need to be planned accordingly.

Table 4: Comparison of Distribution of Deposited Sediment: EC – Phase II

Reach	Anticipated Sediment Deposition*	Percent Change from Existing Conditions	Implications
Queen St-Lakeshore	15,000 m^3/year	+235%	Sediment Trap works – CN Bridge – Lake Shore is dominant depositional area
Keating Channel	6,000 m^3/year	-60%	Assumes weirs not yet active so some ongoing sedimentation in Phase II
New Channel south of Lake Shore Boulevard	2,000 m^3/year	N/A	Some maintenance may be required in wetland south of Lake Shore Boulevard
Sediment Throughput to Harbour+	~7,000 m^3	N/A	N/A

*Corrected for model underprediction to observed rates
+Assuming supply from upstream remains constant

3.3 Phase III

For sediment transport purposes, Phase III is approximately equivalent to the final Port Lands configuration. The construction of the new naturalized channel and addition of weirs at Lakeshore significantly change the sediment dynamics of the Don Mouth system. The weirs prevent sediment from entering the Keating Channel under low-medium flows and average lake levels, diverting most of it through the new channel and valley. Under Phase III, very little sediment is deposited in the Keating Channel (except when the weirs are opened during large events), suggesting that the sediment maintenance obligation will be minimal in this area once the project is complete. Most sediment entering the system is deposited in the sediment trap upstream of Lakeshore (Table 5). The remainder is deposited throughout the new naturalized channel or passed through to the Harbour. With the naturalized channel and weirs in place, dredging requirements in the Keating channel drop significantly, but the sediment trap will still require periodic maintenance.

Table 5: Comparison of Distribution of Deposited Sediment: EC – Phase II – Phase III

Reach	Anticipated Sediment Deposition*	Percent Change from Existing Conditions	Implications
Queen St-Lakeshore	15,000 m^3/year	+235%	Sediment Trap works – CN Bridge – Lake Shore is dominant depositional area
Keating Channel	420 m^3/year	-97%	Maintenance dredging now minimal as weirs direct flow to naturalized channel under normal

			conditions
Naturalized Channel (Lake Shore – Spillway)	2,700 m^3/year	N/A	Maintenance dredging periodically required in section immediately downstream from Lake Shore Boulevard
Naturalized Channel (Spillway - Harbour)	3,500 m^3/year	N/A	Maintenance dredging may be periodically required
Sediment Throughput to Harbour	~8,500 m^3/year	N/A	N/A

*Corrected for model underprediction to observed rates
+Assuming supply from upstream remains constant

3.4 Sediment Transport under Regulatory Flood Conditions

Scour plays an important role in defining the characteristics of a river during large flood events as there is a feedback between the shape of the channel and the flow patterns within it, leading to changes in channel form over the course of a large flood. Key infrastructure may be threatened by rapid erosion, and hydraulic conveyance may change. Hence, the morphodynamic sediment transport model was run under Regulatory Flood conditions for both Existing Conditions and Phase III to determine potential channel changes during the regulatory event.

During a Regulatory Flood under existing conditions (Figure 9), 2 to 5 m of scour occurs between Queen Street and the Keating Channel. Because the model does include sheet-pile walls, the Keating Channel erodes out its south bank and forms a new alignment. The model does not evaluate the integrity of bank protection (such as sheet pile walls) and does not imply their stability or failure under flood conditions. Other small new channels form across the Port Lands near Villiers Street and Don Roadway. On the recession limb of the flood, a great deal of deposition occurs on the flood plain surrounding the channel and in the Port Lands.

During a Regulatory Flood in Phase III (Figure 10), there is also up to 5 m of erosion between Queen Street and Lakeshore Boulevard. The majority of sediment is deposited in the sediment trap and entrance to the naturalized channel. Sedimentation occurs throughout the naturalized channel system on the recession limb of the flood, although there is erosion along the thalweg and in the spillway. In keeping with its design for operation during a regulatory flood, a ‘weir-down’ scenario at Lakeshore was modelled, resulting in deposition in the Keating Channel.

It is important to note that there is considerable uncertainty in the Regulatory Flood sediment transport simulations. Sampling at the Todmorden gauge is limited to lower flows (under 120 m^3/s), so the data required significant extrapolation beyond the range of observed values to 1,694 m^3/s. A more thorough sampling program of suspended sediment and bedload at high flows should be undertaken prior to detailed design. Furthermore, certain aspects of the terrain, such as sheet pile walls, bridge pier foundations and paved surfaces were not accounted for in the erodible bed model. The model also does not account for debris such as trees or vehicles that would change the characteristics of flow or sediment transport in the river during an event of such magnitude.

4.0 RECOMMENDATIONS

During detailed design, a fully-calibrated flow and sediment transport model is necessary to determine the optimal sediment trap performance, further evaluate the maintenance dredging frequency of the sediment trap, and determine potential sediment maintenance requirements downstream from Lake Shore Boulevard. While the modelling undertaken in this study shows that the sediment trap is capable of trapping material over an extended flow period, the trap performance needs to be 'fine-tuned at a later stage'. This fine-tuning will need to address:

- Sediment trap functionality under different flows;
- Weir settings to optimize trap functionality while maximizing sediment sustainability in other areas;
- Balance between sediment trapping and flood protection targets at higher flows;
- Sedimentation of wetlands in naturalized channel system;
- Impacts of long-term sediment delivery to the mouth of the naturalized channel.

Baird recommends that the following data collection and modelling analyses are included in the detailed design of the study:

- Model predictions have not yet been analyzed for effects of individual storms on trap sedimentation. Analysis of this issue is necessary to optimize trap functionality by understanding how the weir configuration impacts trap performance.
- Model runs have been post-processed for overall sedimentation volumes. Model predictions can be further analyzed for the behaviour of individual particle size classes. This will have important implications on the ecological functionality of the naturalized channel and connected wetland system;
- The influence of different trap maintenance depths is not yet included in this analysis, and the results presented were for two discrete trap conditions. The full range of trap operational modes should be evaluated during detailed design;
- The long-term effects of the trap filling up and not being maintained, and the implications for flooding in the Project Study Area have not been analyzed;
- Long-term performance beyond the 2006-2007 study period should be evaluated on a reach-by-reach basis.

In addition to the detailed numerical modelling to be undertaken during detailed design, we acknowledge that a key limitation to the present study is the lack of measured velocities and accompanying sediment transport rates in the Don Narrows and Keating Channel. We therefore recommend that a detailed field measurement program is undertaken prior to entering the detailed design of the DMNP. This will allow the sediment transport and hydrodynamic models to be calibrated and validated to observed values in the project study area, rather than the relationships established from measurements at the Todmorden gauge site. In particular, a season of Acoustic Doppler Current Profiler measurements, along with sediment load samples, will provide valuable input to the detailed design as the model can then be evaluated for accuracy of predictions, and an appraisal of the amount of uncertainty in the model predictions can be made.

REFERENCES

Baird, 2010a. Hydrodynamic Modelling Technical Memorandum. Prepared for Toronto and Region Conservation.

Baird, 2010b. Sediment Transport Modelling Technical Memorandum (Baird, 2010b). Prepared for Toronto and Region Conservation.

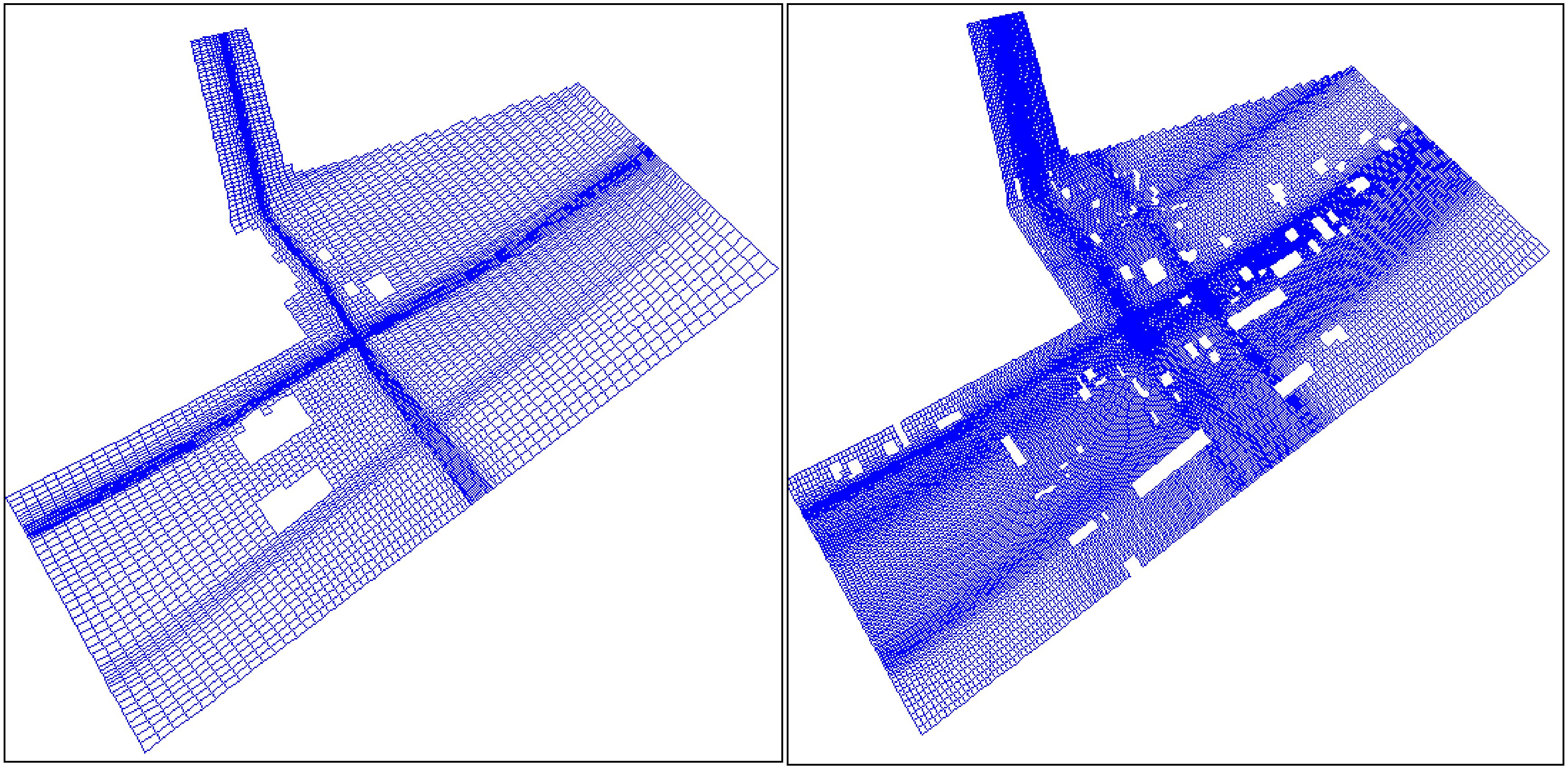


Figure 1. Differences between Phase I (left) and 2013 Existing Conditions model grids (right).

Figure 2. PLAI Phasing. Source: Waterfront Toronto, 2013. Numbers in circles represent different phases.

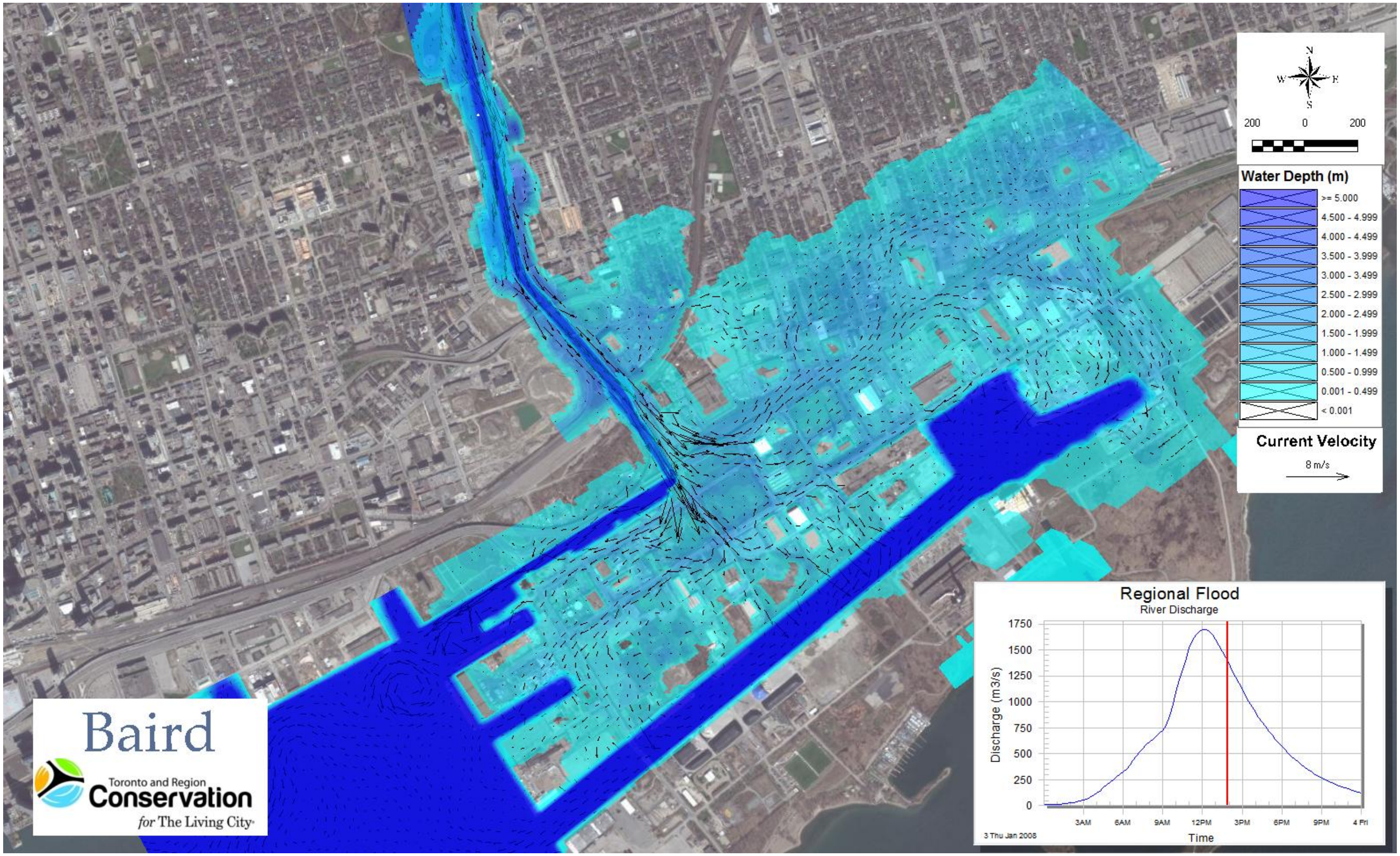


Figure 3. Regulatory flood extents under Existing Conditions

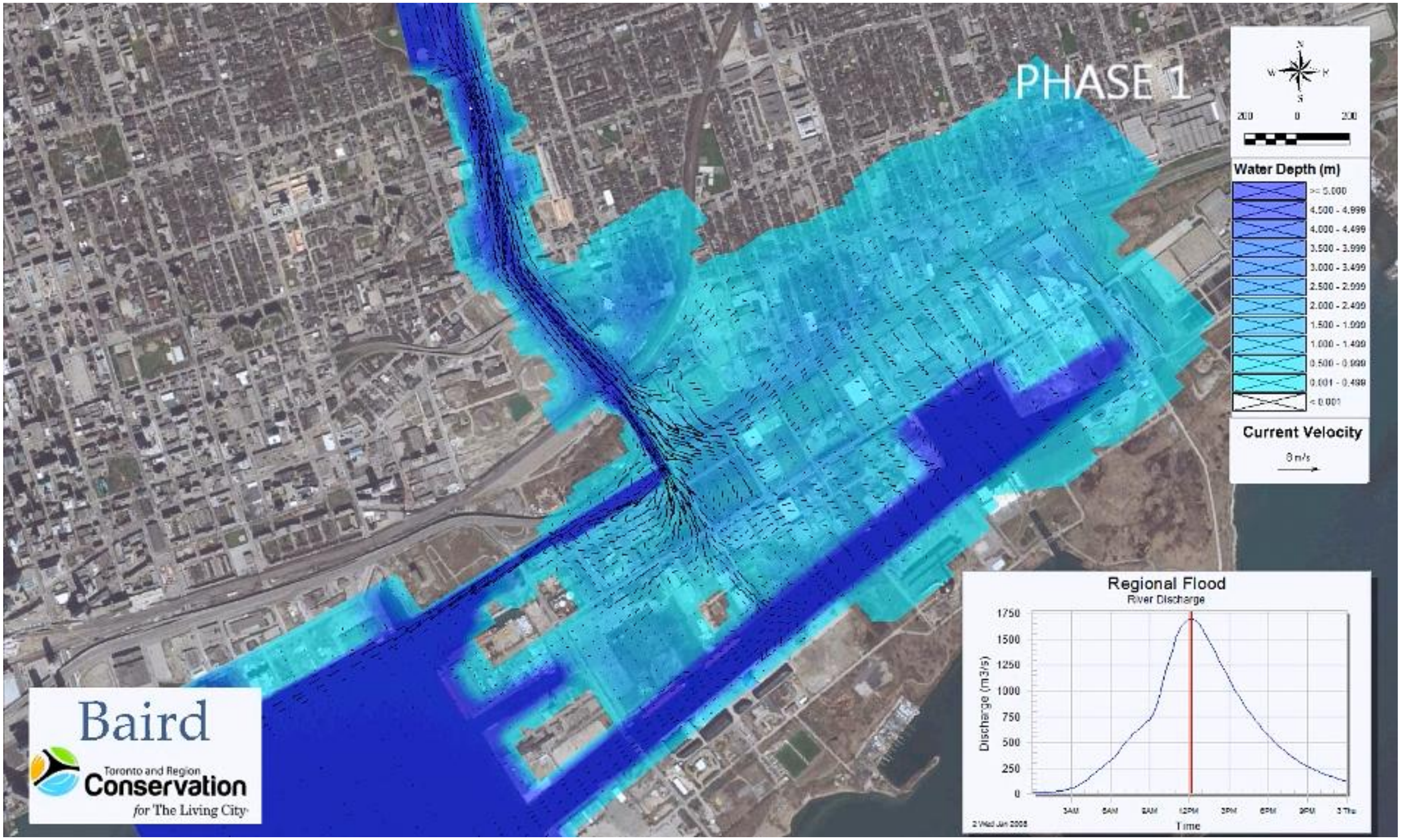


Figure 4. Regulatory flood extents for Phase I

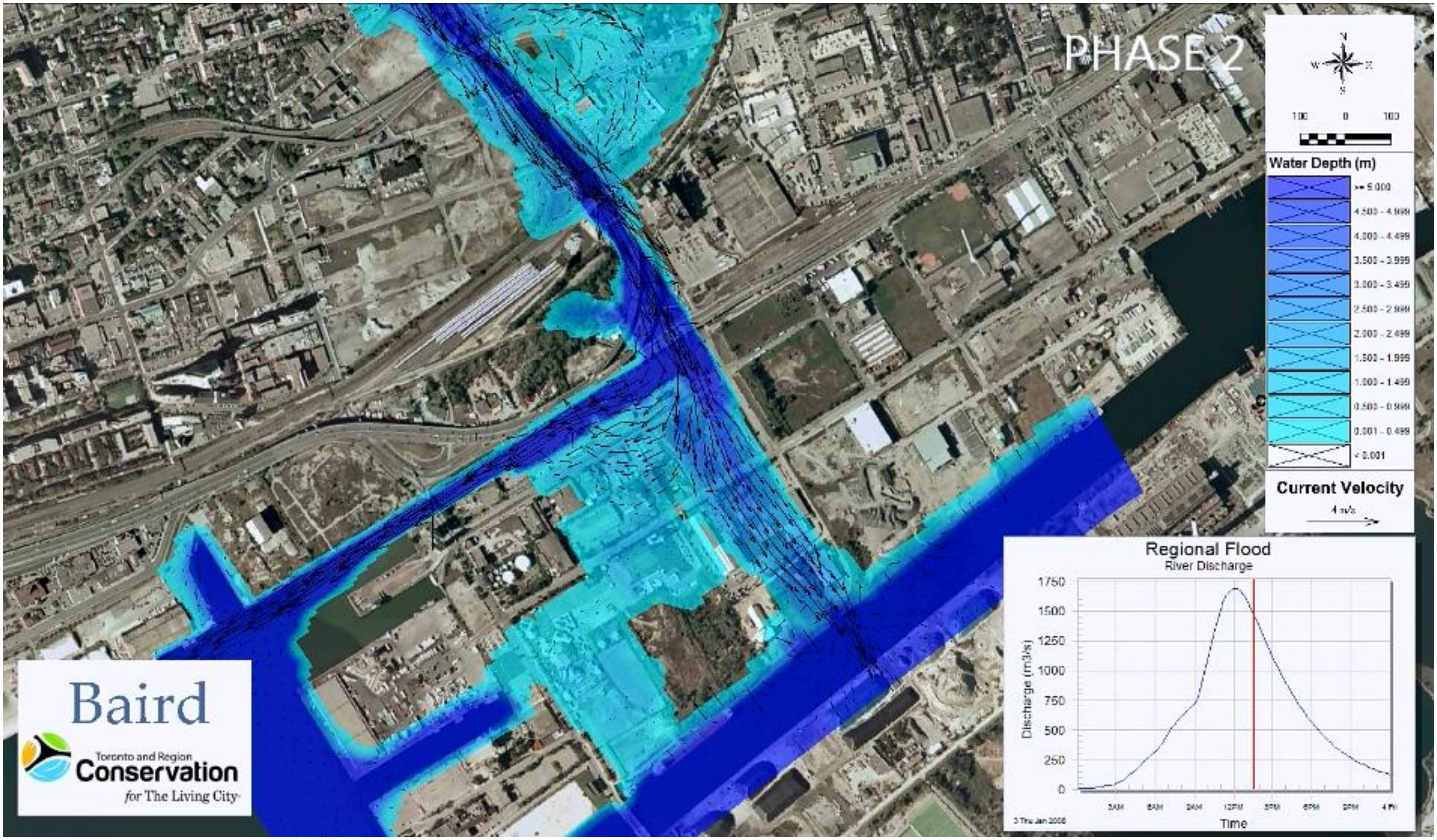


Figure 5. Regulatory flood extents for Phase II

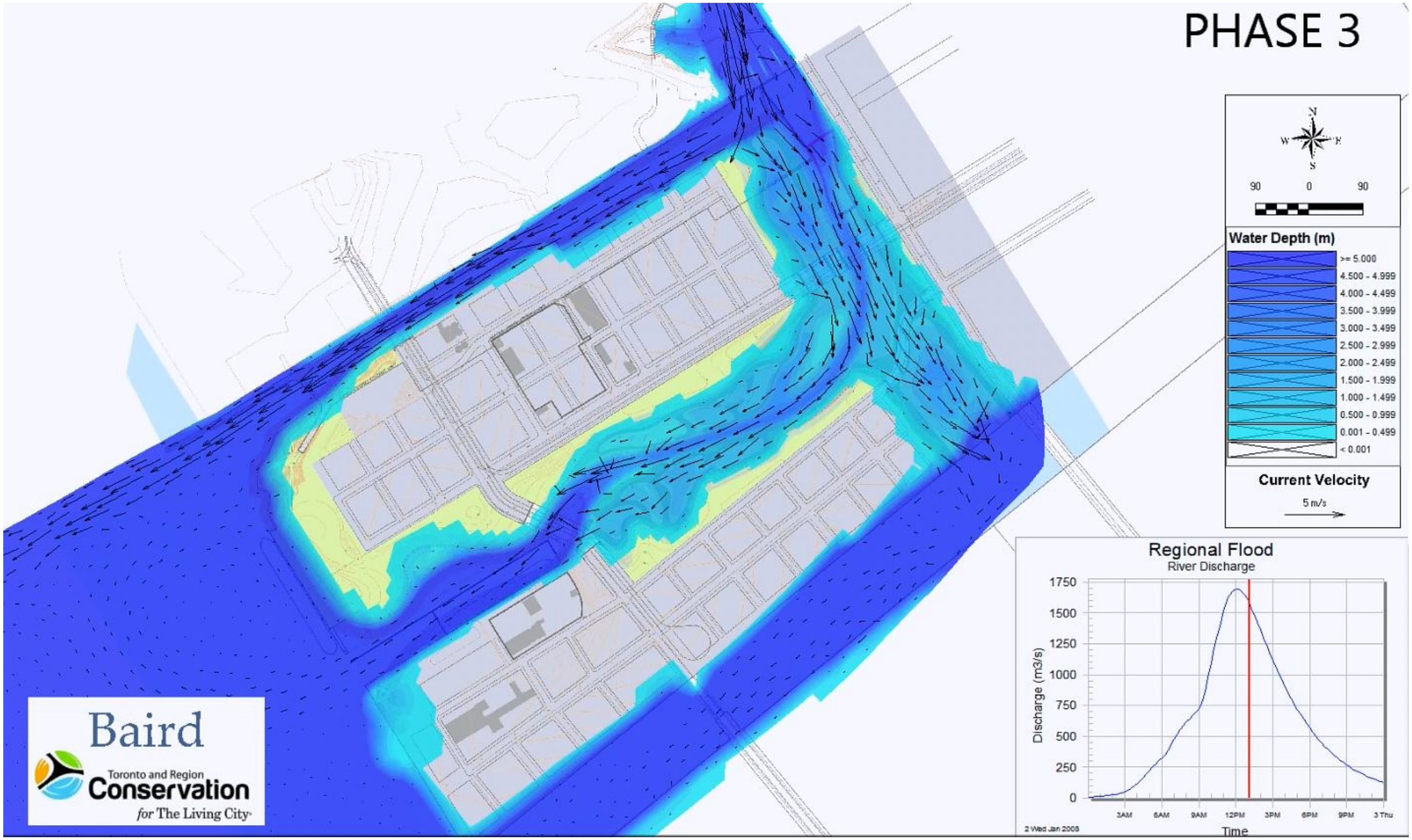


Figure 6. Regulatory flood extents for Phase III

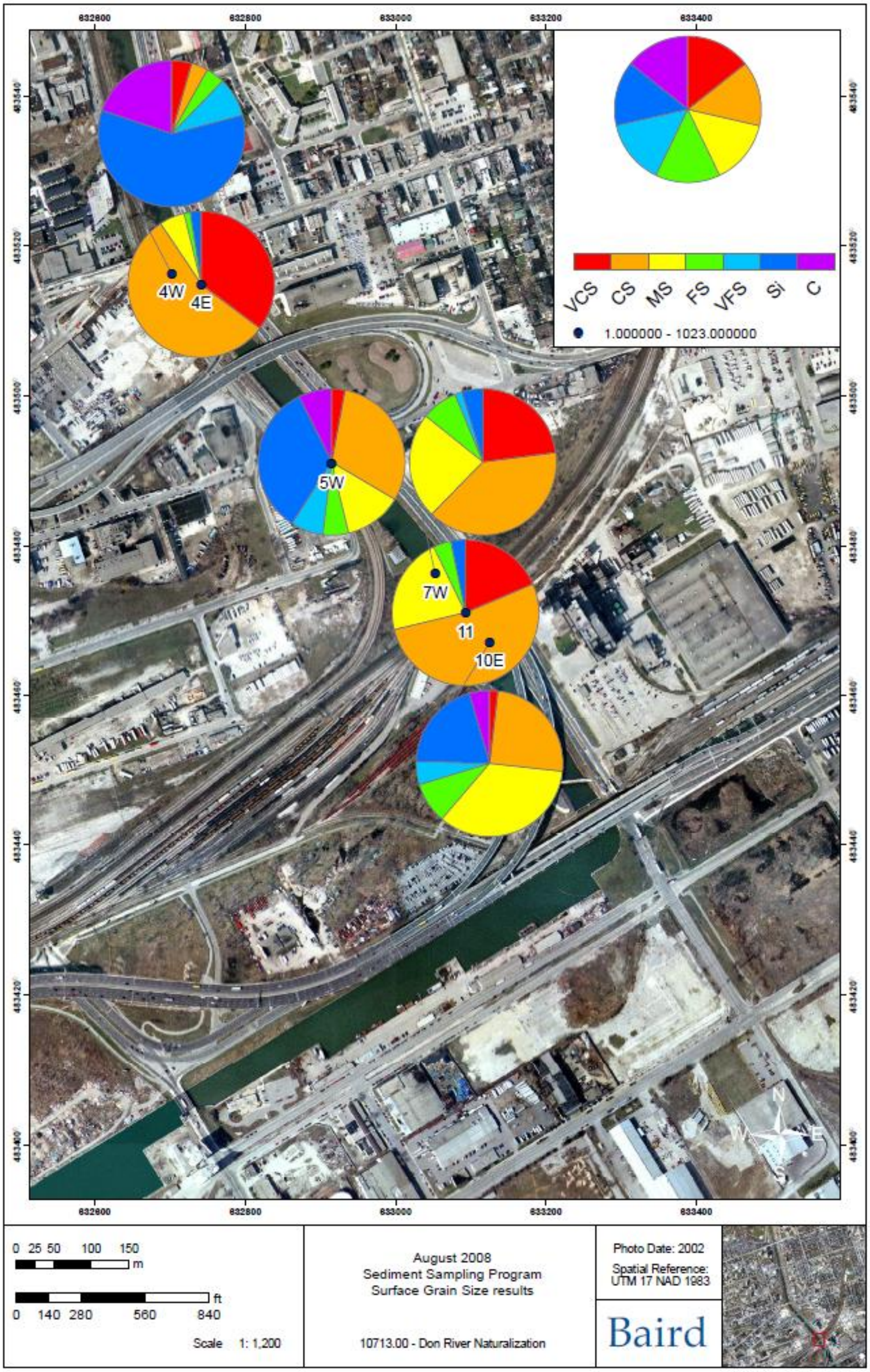


Figure 7. Grain size distribution at sediment sampling locations

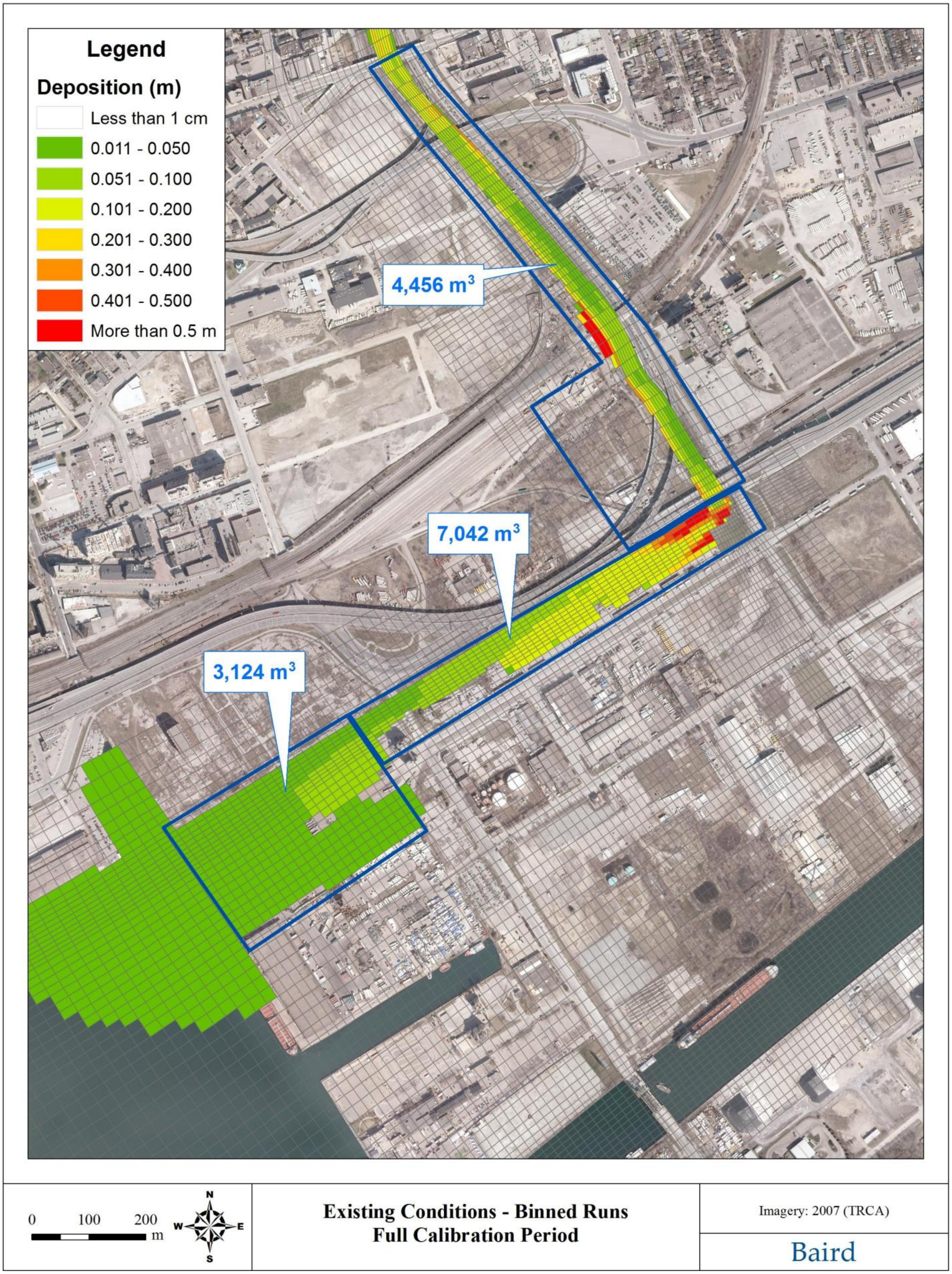


Figure 8. Long-term deposition for Existing Conditions

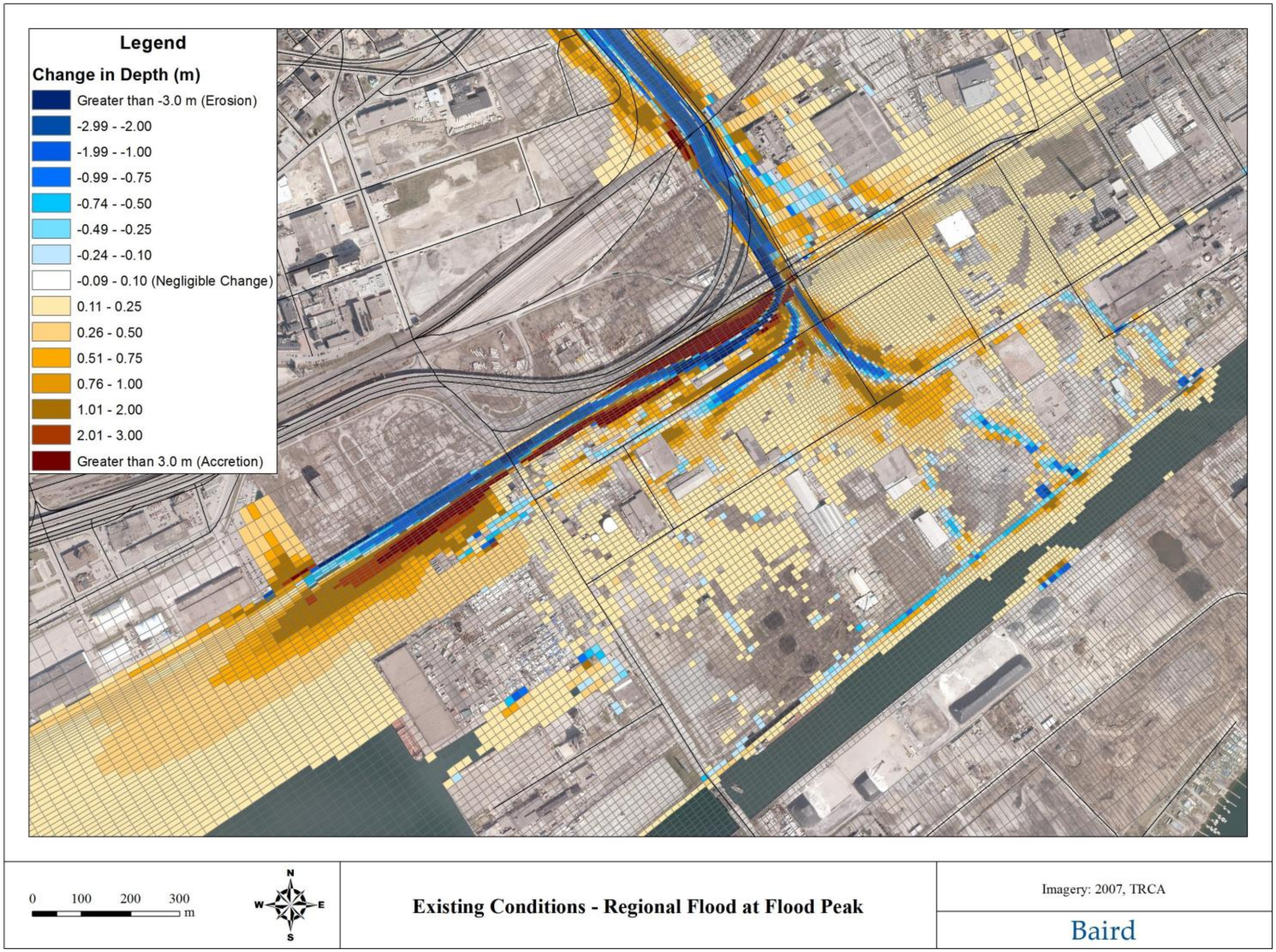


Figure 9. Erosion and sedimentation during Regulatory Flood [Existing Conditions]

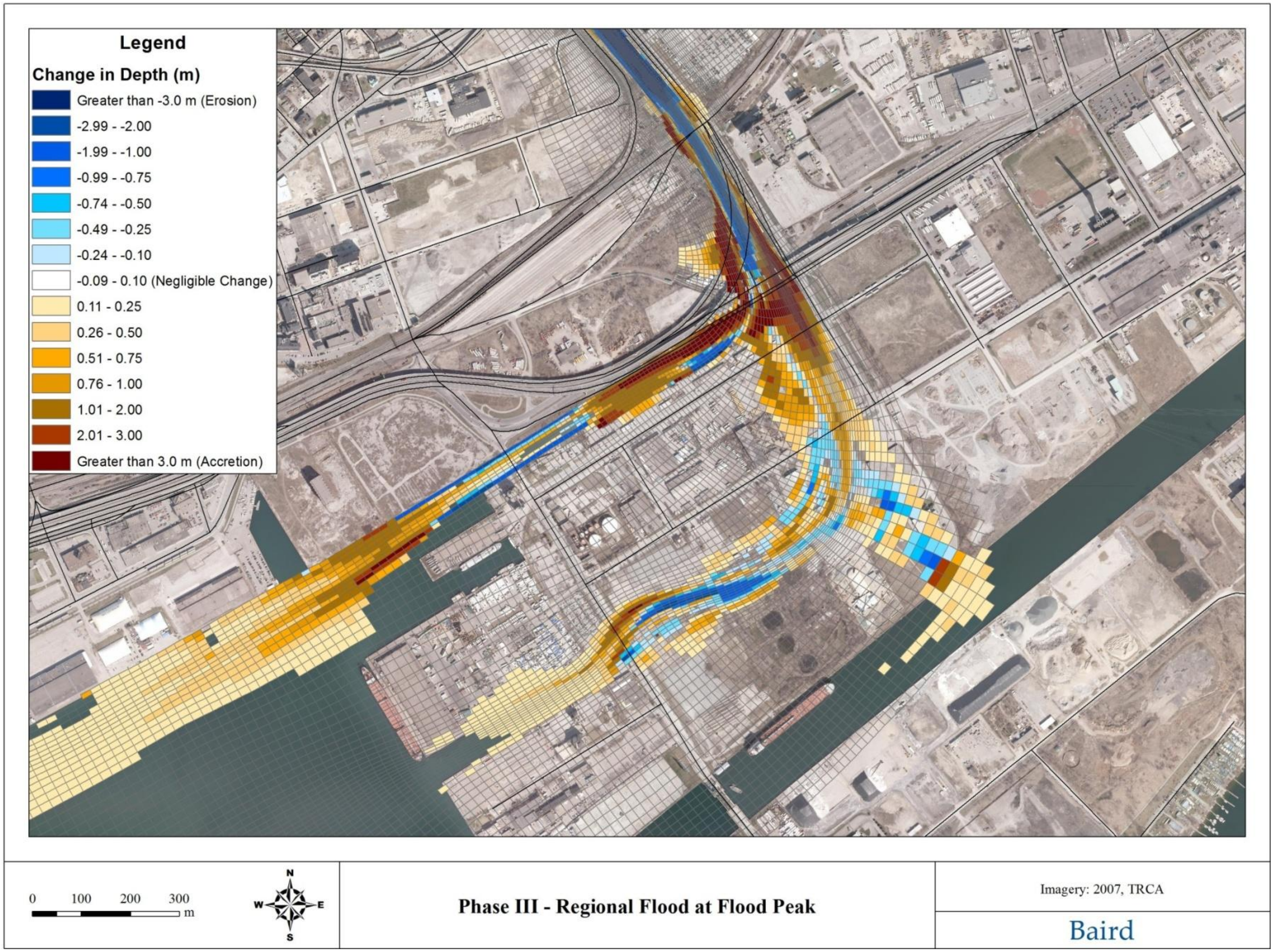


Figure 10. Erosion and sedimentation during Regulatory Flood [Phase III]