Municipal Natural Assets Initiative: City of Nanaimo, BC

Final Technical Report

Making Nature Count

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

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Acronyms

BC	British Columbia
BMCA	Buttertubs Marsh Conservation Area
EPA SWMM	Environmental Protection Agency stormwater management model
GCM	Global climate model
GHG	Greenhouse gas
HEC-HMS	Hydrologic Engineering Center hydrologic modeling system
IDF-CC	Intensity-Duration-Frequency curves under Climate Change
masl	Meters above sea level
MNAI	Municipal Natural Assets Initiative
NHC	Northwest Hydrologic Consultants
PCIC	Pacific Climate Impacts Consortium
SCS	soil conservation service
WMC	Water Management Consultants
VIU	Vancouver Island University

Executive Summary

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

Together with MNAI, the City of Nanaimo began to assign financial value to its natural assets, using the Buttertubs Marsh Conservation Area (BMCA) as the first example. The BMCA comprises 55 hectares (133 acres) of reclaimed wetland and floodplain within Nanaimo. The BMCA is adjacent to the Millstone River, which flows through the centre of the city. The project objective was to assign financial value to the BMCA for its stormwater services based on the cost of replacing those natural services (water quantity control and flood mitigation) with engineered alternatives.

The project conducted a hydrologic analysis consisting of:

1. Quantifying BCMA storage benefits for detention of stormwater from the developed areas that drain into the marsh; and
2. Quantifying the attenuation of flood flows in the Millstone River afforded by storage of overbank river flow into the marsh.

The U.S. Environmental Protection Agency's PCSWMM model for stormwater assessment was applied to three development scenarios and a future climate change scenario in the analysis. The development scenarios included existing conditions, marsh infilled with grass, and marsh infilled for single-family development. The historic climate scenario used the intensity-duration-frequency (IDF) information available from Environment and Climate Change Canada's Nanaimo Public Works rainfall station. Climate change scenarios for the period 2050 to 2100 were analyzed using the IDF Curves under Climate Change tool created by the University of Western Ontario.

The project showed that the BMCA provides a very significant peak flow attenuation function and an overall water volume retention function. Under existing conditions, the peak 1 in 100-year stormwater inflow of 7.04 m^3/s to the marsh is attenuated by 92 per cent before discharge to the Millstone River. Under climate change conditions, the marsh in existing conditions attenuated inflows of between 10.07 and 13.09 m^3/s by 90 per cent. Those numbers drop to between 6 and 21 per cent attenuation under the grass-filled and single family development scenarios. The attenuation provided by the BMCA also has significant consequences for the flooding of neighborhoods downtown on the Millstone River. The magnitude of the loss in attenuation and the consequences of increased flood flows on downstream neighbourhoods and infrastructure requires a hydrodynamic model of the entire Millstone River, which was beyond the scope of this study.

The economic value of nature-based stormwater storage can be compared to the cost to design and construct alternative engineered infrastructure. Using as a local benchmark the cost of constructing a stormwater management pond or wetland for the required storage volume of $150 per cubic meter, the storage benefit of the BMCA was valued at approximately $4,694,295. Under climate change scenarios this value increases to between $6,559,676 and $8,207,305.

These numbers do not take into consideration the cost of land purchase or complex structures. The value also does not include other services provided by the BMCA such as water quality, recreation, greenhouse gas emissions reductions, and more.

The project demonstrated that the BMCA provides stormwater detention benefits commensurate with engineered infrastructure and that under climate change scenarios, the BMCA would provide similar levels of service despite receiving higher volumes and velocity of flows. The next steps in the process are to translate these results into core management and financial processes. To this end, members of the MNAI team met with City of Nanaimo senior managers in January 2018 to discuss the pilot and develop a road map for incorporating pilot results, and natural assets more broadly, into asset management and financial processes. A broad framework was outlined that includes an inventory of natural and potential engineered storm assets in the city, which will be refined over the coming months and years.

1. INTRODUCTION

1.1 Municipal Natural Assets Initiative

The term “municipal natural assets” refers to the stock of natural resources or ecosystems that is relied upon, managed, or could be managed by a municipality, regional district, or other form of local government for the sustainable provision of one or more municipal services. Municipalities like Nanaimo are working toward recognizing that it’s as important to account for natural assets as for engineered ones. The most important factor is whether the services from the asset, whether natural or engineered, are delivered reliably and cost effectively. If this fact isn’t recognized and incorporated into new planning practices, decisions on how to invest will be incomplete.

The Municipal Natural Asset Initiative (MNAI) is developing resources to incorporate natural assets (e.g. forests, wetlands) that form part of the urban landscape into asset management plans. Through the MNAI, the City of Nanaimo is exploring options to refine, replicate and scale-up the approach of a small number of municipalities that are integrating natural capital considerations into asset management and financial planning.

MNAI has completed an Overview Guidance Document for Stormwater Management for municipalities. The present report details the application of the guidance document for one particular asset, a wetland in the municipality of Nanaimo, B.C. It is important to first establish the value in monetary terms of services that natural assets provide. Without this information, there is no rational basis to make financial management choices. Nanaimo’s efforts to cost out the services from Buttertubs Marsh are a vital starting point for future financial planning and reporting. The goal of this case study is to illustrate the application of the guidance and to provide technical details on the approach.

1.2 Nanaimo

Nanaimo is a growing city on the east coast of Vancouver Island in British Columbia, located 110 kilometers northwest of Victoria, and 55 kilometers west of Vancouver, separated by the Strait of Georgia (Figure 1). It is B.C.’s sixth-largest city, supporting a population of 90,504 (Canada 2016 census), which is projected to grow to 113,000 by 2031. (City of Nanaimo, 2008.)

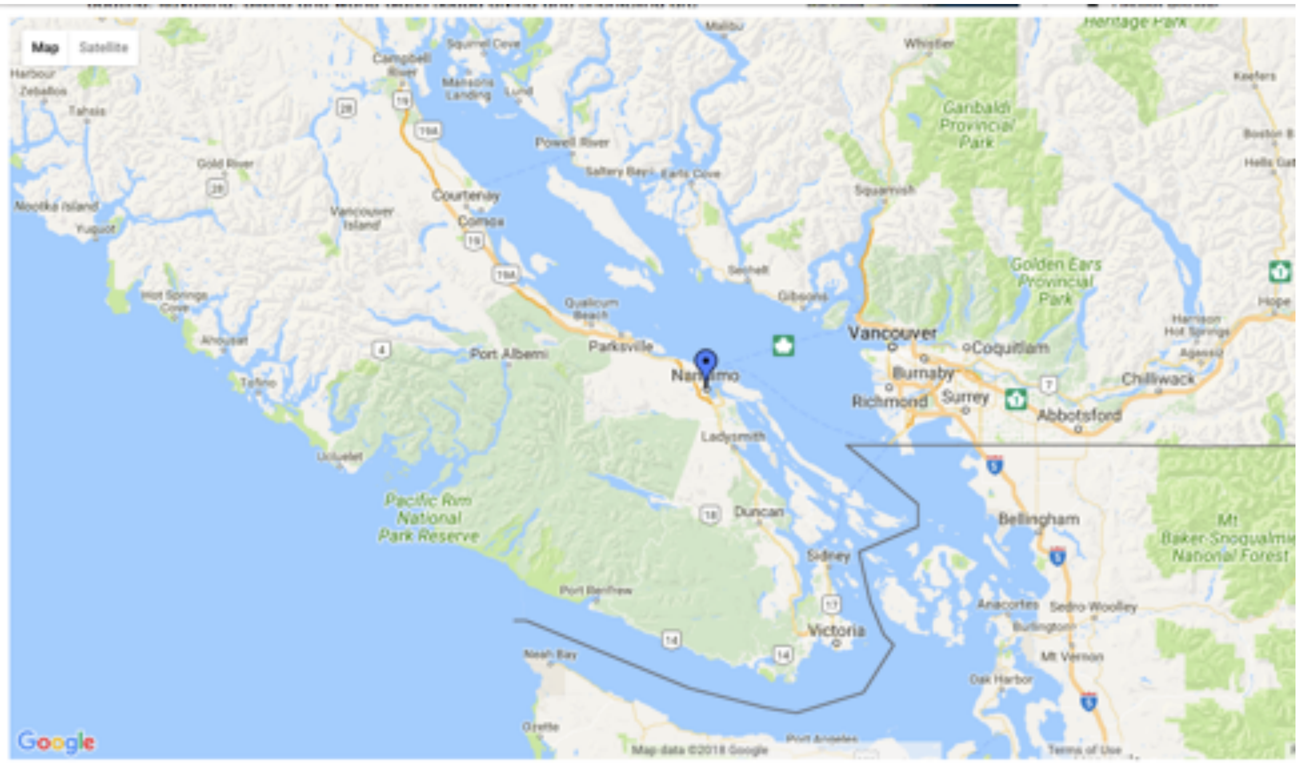


Figure 1: Google Map of Nanaimo

1.2.1 Policy / Governance Context

Nanaimo is well versed in asset management, having followed a formal asset management approach to its infrastructure for at least a decade. Currently the city owns and maintains over $3 billion in engineered infrastructure assets such as roads, water mains, facilities, drainage, parks, and the sewer system.(City of Nanaimo, 2018). This information is used to continually improve capital planning to maximize infrastructure life, renew existing infrastructure and prepare for population growth.

The city is now expanding their asset management framework to consider the role of natural assets. In those instances where natural assets provide the same service(s) provided by engineered infrastructure, incorporating them into long-term financial and asset management planning will put them on the same level as all other engineered assets and ensure they are accounted for in the decision-making process to maintain and conserve the asset. The MNAI pilot program is a first step in this process.

1.2.2 Natural Asset of Interest

The asset of interest for this analysis is the Buttertubs Marsh Conservation Area (BMCA), a 55- hectare (133 acres) reclaimed wetland and floodplain habitat in the City of Nanaimo (Figure 2). It is separated by a north-south elevated walkway that was built on top of a buried supply waterline. This has created two separated wetlands, referred to in this document as the East and West marsh.

The BMCA is adjacent to the Millstone River, which flows through the center of the city. The northern boundary of the area of interest is contiguous to the Millstone River and the western boundary follows the Nanaimo Parkway, where highway 19 bypasses the city. The surrounding landscape that drains into the Buttertubs Marsh is part of the focus area of this study.

The BMCA is comprised of several parcels of land and includes lands owned by The Nature Trust of British Columbia, Ducks Unlimited Canada and the City of Nanaimo, with substantial support received from the local community and funding organizations. In 1976 The Nature Trust of B.C. purchased the East marsh, and since then it has been managed as the

Buttertubs Marsh Conservation Area. The West marsh was privately owned until 2012, when it was jointly purchased by Ducks Unlimited Canada and the city, effectively enlarging the BMCA.

To date, management plan efforts for the BMCA have focused primarily on providing recreational and educational uses, maintaining open water habitat, inventorying and restoring natural biodiversity, and removing non-native invasive species. The Buttertubs Marsh Conservation Area Management Plan was adopted in August 2017 and applies to both east and west sides of the marsh and recognizes the stormwater management aspects of BMCA. Until this study, no costing estimates for the value of stormwater management related services and improvements have been conducted. The city is interested in understanding, quantifying and maximizing the municipal services from the BMCA in order to improve efficiencies.

The BMCA was selected because of its stormwater retention and flood mitigation properties within the community, its importance as a local natural landscape, the availability of data and ongoing partnerships with Ducks Unlimited, the Nature Trust of BC and local stewardship groups, such as the Friends of Buttertubs.

Figure 2: Aerial View of Buttertubs Marsh (from Urban Systems)

1.3 Pilot objectives and key issues

The main objective of this pilot study is to provide the city with a basis for managing assets differently; one that improves their ability to deliver core services in an affordable, financially and environmentally sustainable way. A key component of our approach involves assigning financial value to natural assets for their stormwater services. The valuation is based on the cost of engineered stormwater infrastructure required to replace stormwater services—water quantity control and flood mitigation—provided by natural assets.

Following a workshop with pilot participants, the following list of project questions and issues was identified:

1. How resilient is the site to future storm events? How well can it manage in different storm scenarios?
2. What is the value of the services provided from the BMCA? If these services were degraded, what costs would need to be incurred elsewhere by the city? Conversely, if they were enhanced, would there be savings to the city?
3. What is the value of the wetland's water retention properties? Does it offset future capital expenditures and/or justify land acquisition?
4. What is the value of the BMCA in terms of assuring downstream water quality?

2. METHODS

Reference documents were used to compile the hydraulic information associated with the BMCA, and to understand the relationship of the marshes to the Millstone River. These documents include:

- Stormwater Management Plans, Millstone River Basin (Associated Engineering, 1982)
- Millstone River Drainage Study (Water Management Consultants, Revised March 2005)
- Buttertubs Marsh Hydrologic Assessment, Phase 1 Overview (Northwest Hydraulic Consultants, January 23, 2017)

Available monitoring information confirmed that there is a regular flow interaction between the Millstone River and the West marsh, but that the interaction between the river and the East marsh is less clear. The Millstone River water level submerges the discharge pipe from the East marsh, but the water level in the East marsh is governed by an elevated spillway typically above the Millstone River water level. In the case of extreme flows in the Millstone River, both the West and East marshes are an important part of the river's floodplain.

The influence of the marshes was studied in the Millstone River Drainage Study (Water Management Consultants, revised March 2005). For that study, a 1:200 year SCS Type 1A event with a rainfall depth of 127 mm was used to generate design flows and a hydraulic profile for the river. One key finding was that, "the flood propagation in the Millstone River is complicated by the existence of the Buttertubs Marsh. During the rising limb of the hydrograph a significant volume of water is transferred from the main stem towards the marsh. This volume returns to the main stem after the peak flood. Thus, the marsh has a regulating effect, decreasing the flows during the rising limb of the hydrograph, reducing the peak flow and contributing to the flow during the falling limb." The estimated attenuation of the flood flow in the Millstone River associated with the storage of flood water from the river to the elevation of 58.37 meters above sea level (masl) was approximately 20 per cent - 105 m^3/s versus 84 m^3/s.

For this case study, the hydrologic analysis approach consisted of two parts:

1. Quantification of the storage benefits of the marsh for detention of stormwater from the developed areas that drain into the marsh.
2. Quantification of the attenuation of flood flows in the Millstone River afforded by storage of overbank river flow into the marsh.

2.1 Stormwater detention

For the stormwater assessment, the PCSWMM model was applied by Urban Systems to model the areas and waterbodies shown on Figure 2 (obtained from Urban Systems). All modeling work presented in this report was completed using PCSWMM, a dynamic hydraulic and hydrologic simulation model developed by the United States Environmental Protection Agency (US EPA). This model was chosen as it is able to represent site conditions to a reasonable extent. The methods and results from Urban Systems' analysis are detailed in an August 28, 2017 memo, which has been excerpted for this report. The full Urban Systems report is in Appendix C.

2.1.1 Development scenarios evaluated

Three development scenarios were simulated using the SWMM model in order to evaluate stormwater management benefits provided by the marsh.

1. The "existing conditions" scenario reflects current land use and the current characteristics of the Buttertubs Marsh. See Figure 4 for a SWMM model schematic.

2. The "marsh infilled and grassed" scenario reflects a potential future in which the marshes are infilled and replaced with a grassed landscape. In this case it is assumed that the infill soil will have depression storage and infiltration losses, and not be an impervious surface. It is also assumed that runoff generated from the total catchment would simply runoff into Millstone River. See Figure 5 for a SWMM model schematic.

3. The "marsh infilled for single-family home development" scenario reflects a potential future in which the mashes are infilled and replaced with single-family development similar to the rest of the contributing catchment. It is once again assumed that runoff generated from the total catchment would simply runoff into Millstone River. See Figure 5 for a SWMM model schematic.

2.1.2 Climate scenarios evaluated

Historic and climate change scenarios were used to evaluate the stormwater management benefits of the BMCA. The historic climate scenario used the intensity-duration-frequency values (IDF) information available from Environmental Canada's Nanaimo Public Works rainfall station.

The Intensity-Duration-Frequency Curves under Climate Change (IDF-CC) tool created by the University of Western Ontario was used to generate IDF curves for analysis of climate scenarios. This tool uses results from up to 24 global climate models (GCMs), combined with historical data from a select climate station to project future IDF values for a prescribed time period. A key assumption was made in selecting the greenhouse gas (GHG) emissions scenario based upon the Pacific Climate Impacts Consortium (PCIC) and other climate change organization's recommendations that practitioners use the "business as usual" scenario. Put another way, climate is modeled assuming that little will be done to reduce GHG emissions in the future. This emissions scenario is referred to as "Representation Concentration Pathway 8.5" (RCP 8.5), and is the most conservative of the available scenarios.

IDF values were obtained from all 24 GCMs for the period 2050 to 2100. From these results, two sets of IDF curves were extracted with data from the Nanaimo City Yard rainfall station collected from 1980 to 2007—one based on the median of all 24 intensities for each combination of duration and frequency, and one based on the 90th percentile of all 24 intensities for each combination of duration and frequency (the 90th percentile means that 90 per cent of the values are less than or equal to the specified intensity). Two sets of curves were generated so that each of the 24 models has the same probability of being "correct" about future climate. If we use only the average of all 24 models, we could significantly underestimate what might occur in the future. See IDF curves in Appendix B.

The following events were modeled in PCSWMM:

3. Historic 1:100 year, 24-hour (SCS Type III)
4. Climate change (CC), 1:100 year, 24-hour (SCS Type III using median values)
5. Climate change (CC), 1:100 year, 24-hour (SCS Type III using 90th percentile values)
6. 1:200, 24-hour (127 mm), SCS Type 1A—this event was applied from the Millstone River Drainage Study (Water Management Consultants, revised March 2005) as a method of comparing the incoming hydrograph of the local catchment into the wetlands, relative to the flows and water levels projected for the Millstone River.

Note that only 24-hour storms were used for analyses. A sensitivity analysis was completed using 100-year storms with 1, 6, 12, and 24-hour durations. The analysis demonstrated that the largest water level rises, peak discharges, and total discharged volume were generated by the 24-hour storm.

2.1.3 SWMM model calibration

Northwest Hydraulic Consultants (NHC) was retained by The Nature Trust to carry out the first phase of a hydrological assessment, which included completing a water surface and hydraulic control survey and developing recommendations for installing staff gauges and water level sensors and loggers in the West marsh, East marsh, and on the Millstone River. The monitoring data collected as a result of the assessment was used to calibrate the PCSWMM model.

The proposed hydrometric program included the installation of six non-vented water level sensors, with three located on the Millstone River to obtain a minimum level of detail for validating the river and marsh dynamics. One logger was installed in the West marsh and East marsh, and one logger was installed inside the East marsh control structure to estimate how much water drains through it. Figure 3 shows the location of monitoring equipment in the study area.

Figure 3: Proposed location of water level sensors (shown as red triangles). Source: Northwest Hydraulic Consultants Ltd.

Monitoring data from March 2017 to May 2017 was provided by the city and used for model calibration. As noted above, the West marsh has a ditch linking it to the Millstone River, and when accounting for that ditch and the water levels monitored in the Millstone River as a boundary condition, the PCSWMM model matches observed data very well. In the East marsh, modelled water levels match the observed data well for the first couple weeks of simulation, however diverge after that. While the modelled water level rises and falls in response to precipitation, monitored water levels appear to continually rise, then plateau at an elevation of about 57.35 meters; this is about 100 mm higher than the model predicts. Photos taken by NHC of the East marsh outlet structure show debris around the rim of the overflow weir. The consultants strongly suspect that the difference in modelled versus observed water levels is due to build-up of debris at the control structure.

Otherwise, given the limited monitoring data available, the model would appear to fairly represent observed data. The model can be further refined as more data becomes available.

Calibration results from urban systems are included in Appendix A.

2.2 Millstone River flood flow attenuation

The quantification of the beneficial effect of the marsh on flood flows in the Millstone River was based on the 2005 study by Water Management Consultants (WMC), "Millstone River Drainage Study". This study applied the U.S. Corps of Engineers "HEC-HMS" hydrologic model to the Millstone River and its watershed to calculate the runoff within the river's sub-basins associated with the 1 in 200-year, 24-hour rainfall and "MIKE 11" to calculate the water levels at cross-sections along the river. The hydrological modelling system (HMS) model uses rainfall and the soil conservation service (SCS) method to derive runoff within the sub-drainage areas. MIKE 11 then routes the flows down the river and through any lakes and reservoirs in the Millstone River system. The rainfall distribution corresponded to a SCS Type 1a using the total 1 in 200-year, 24- hour rainfall from the intensity-duration-frequency (IDF) relationships developed by Environment Canada for the Nanaimo area. The rainfall used in the study did not account for the effects of climate change.

The flood attenuation benefits of the marsh were evaluated for the present configuration and a second scenario where the normal water level in the marsh is potentially raised from 57.0 m to 57.3 or 58 m.

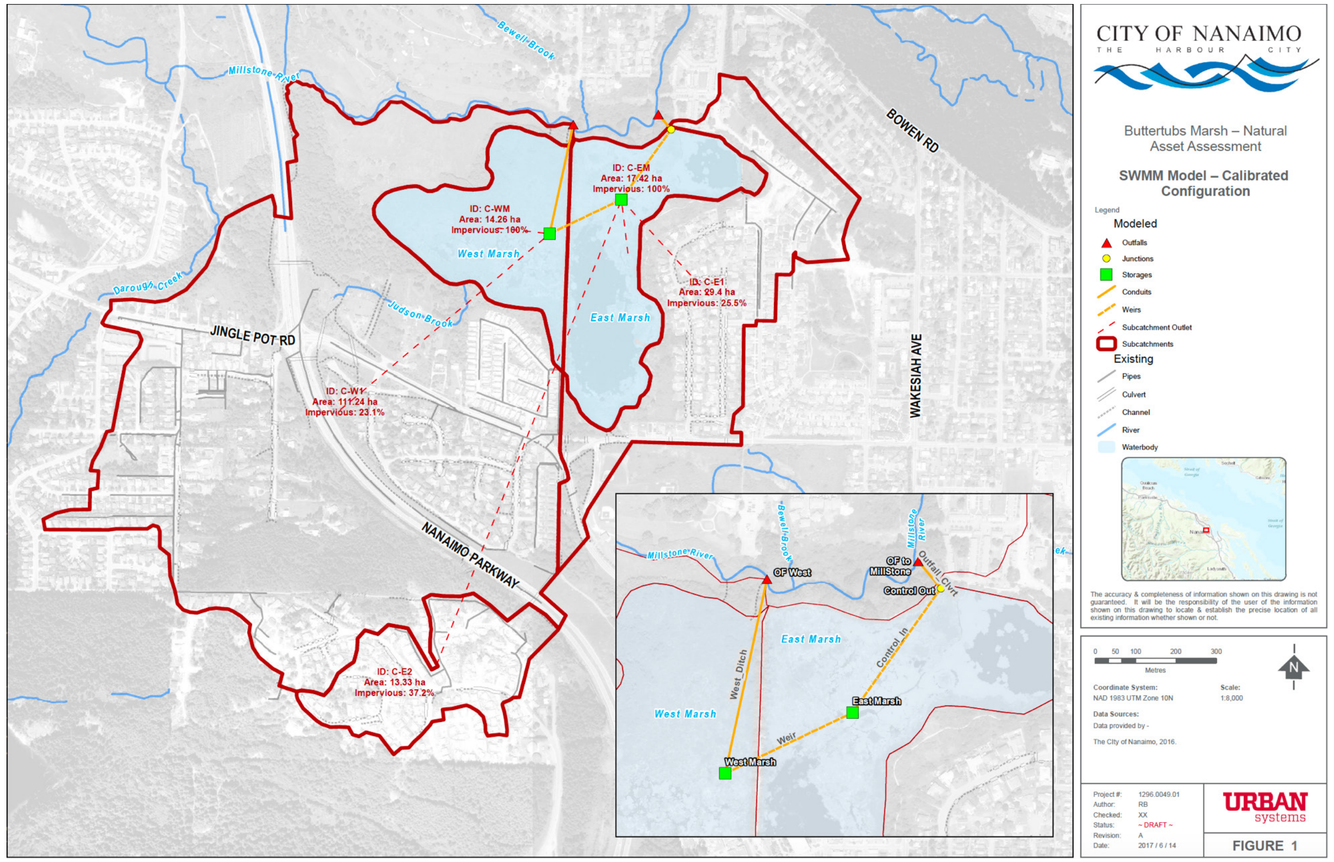


Figure 4: SWMM model schematic for existing conditions (from Urban Systems, 2017)

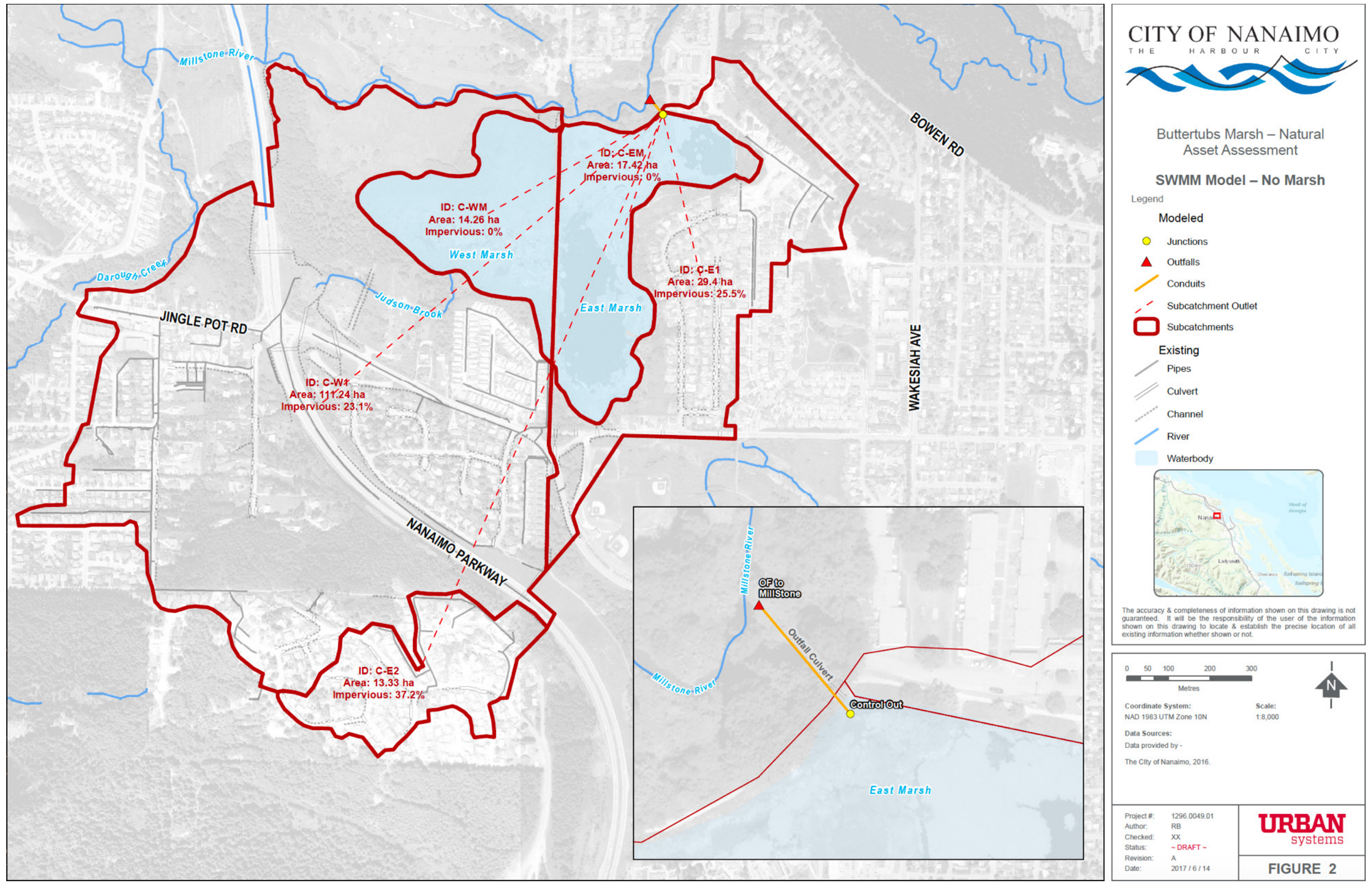


Figure 5: SWMM model schematic for scenarios with marshes removed (from Urban Systems, 2017)

3. RESULTS

3.1 SWMM model results

A summary of the modeling results is presented in Table 1. Four key parameters were used to compare each scenario; peak inflow rate, peak discharge rate, maximum water level in the marshes, and total discharge volume from the marshes. With the present marsh configuration, the peak 1 in 100-year stormwater inflow of 7.04 m^3/s to the marsh is attenuated by 92 per cent before discharge to the Millstone River (see Table 1). Under the two climate change conditions described above, the marsh attenuated inflows of between 10.07 and 13.09 m^3/s by 90 per cent.

Table 1: SWMM Results for Existing Conditions

Existing Systems	Peak Inflow Rate[1] (m^3/s)		Peak Discharge Rate (m^3/s)		Maximum Water Level (elevation, m)		Total Discharge Volume (m^3)	
Marsh	West	East	West	East	West	East	West	East
Historic 1:100-yr (101.2 mm)	3.92	3.12	0.15	0.40	57.01	57.25	17,400	20,500
CC 1:100-yr med. (127.9 mm)	5.56	4.51	0.29	0.66	57.09	57.29	26,800	28,400
CC 1:100-yr 90th (145.8 mm)	7.44	5.65	0.44	0.88	57.17	57.32	34,700	34,300
1:200-yr (127 mm)[2]	1.19	1.05	0.16	0.28	57.02	57.23	21,400	23,500

When the flows in the grass-infilled marsh are simulated, the discharge into the Millstone River increases from 0.55 to 5.97 m^3/s under current climate conditions and to between 9.4 and 12.2 m^3/s from approximately 1 m^3/s in the two potential climate change conditions. The attenuation of stormwater discharges from the marsh to the Millstone River was minimal—15 per cent for a historic rainfall event and 6 per cent for the two climate change conditions (see Table 2).

Table 2: SWMM Results for Scenario #2

Marshes Removed (Grass)	Peak Discharge Rate for West & East marsh combined to Millstone (m^3/s)	Total Discharge Volume for West & East marsh combined to Millstone (m^3)
Historic 1:100yr (101.2 mm)	5.97	24,900
CC 1:100yr med. (127.9 mm)	9.42	40,700
CC 1:100yr 90th (145.8 mm)	12.23	53,600
1:200yr (127 mm)[5]	1.97	25,100

The evaluation results for the third scenario—marshes removed to accommodate residential development—were similar to those of the grass-infilled marsh (see Table 3). The peak discharges to the Millstone were 5.56 m^3/s for the historic rainfall event and between 9.40 and 12.26 m^3/s for the two climate change conditions. Attenuation of the urban stormwater inflows before discharge to the Millstone was between 6 per cent for climate change conditions and 21 per cent for historic rainfall.

Footnotes

[1] Includes direct rainfall on the marshes.

[2] This event uses the SCS Type 1A storm distribution, consistent with the 2005 Millstone study, whereas all other events apply the SCS Type III storm distribution which is more "peaky". This explains why the flow rates for the CC 1:100-year scenario are significantly higher than the 1:200-year event, despite the total precipitation volume being similar.

Table 3: SWMM Results for Scenario #3

Marshes Removed (Single Family Development)	Peak Discharge Rate for West & East marsh combined to Millstone (m^3/s)	Total Discharge Volume for West & East marsh combined to Millstone (m^3)
Historic 1:100-yr (101.2 mm)	5.56	26,200
CC 1:100-yr med. (127.9 mm)	9.40	42,800
CC 1:100-yr 90th (145.8 mm)	12.26	56,100
1:200-yr (127 mm)[5]	1.72	29,800

As shown by the results above, the storage of the marshes provides a very significant peak flow attenuation function and an overall water volume retention function. Because this model only considers extreme precipitation events, by assuming the marshes are infilled the model is not showing much difference between a grassed condition and a single-family residential condition. Differences are expected if less extreme precipitation events were considered. The sheer act of infilling the marshes causes significant impact. The resulting increase in flow will be felt by Millstone River. In order to compensate, the city would either need to find an alternate form of equivalent detention storage, or complete improvements to the downstream Millstone River system. Quantifying these, however, is beyond the scope of this pilot.

3.2 Millstone River flood flow attenuation

The benefit of the storage of overbank flows from the Millstone River in the Buttertubs Marsh was taken from the Water Management Consultants (WMC) report of 2005 in which it was estimated that the water level in the Buttertubs Marsh would reach an elevation of 58.37 masl during a 1 in 200-year flood event. The estimated attenuation of the flood flow in the Millstone River associated with the storage of flood water in the marsh from the river to the elevation of 58.37 masl was approximately 20 per cent—105 m^3/s versus 84 m^3/s.

If the normal water level elevation in the marsh is increased to 57.3, or 58 masl, there will be less capacity for storage of flood flow from the Millstone to the marsh. With less flood storage available in the marsh, the downstream flood flow in the Millstone River will be attenuated by significantly less than the 20 per cent realized under the current marsh configuration and operating regime during a 1 in 200-year flood. Attenuation of all Millstone floods will be correspondingly reduced. The magnitude of the loss in attenuation and the consequences of increased flood flows on downstream neighbourhoods and infrastructure requires a hydrodynamic model of the entire Millstone River, which was beyond the scope of this study.

3.3 Economic valuation of Buttertubs Marsh

The value of the Buttertubs Marsh storage of urban stormwater and overbank flows from the Millstone can be related to the cost to construct alternative engineered infrastructure for urban stormwater detention and off-stream areas for temporary storage of overbank flows from the Millstone.

The cost of replacing the East and West marshes in Buttertubs with stormwater management ponds or constructed wetlands to provide an equivalent detention function for the urban stormwater was based on the required storage volume and a cost of $150 per cubic meter. This unit volume cost is reflective of the design and construction for a stormwater detention pond with landscaping and environmental components, but excludes land purchase. The three climate conditions require different detention storage capacities and replacement costs are shown in Table 4 below.

Table 4: Economic Value of BMCA

	West Marsh					East Marsh				
Scenarios	Surface Area at Max Level (m^2)	Starting Water Level (m)	Max Water Level (m^2)	Storage Volume (m^3)	Cost at $150 per m^3	Surface Area at Max Level (m^2)	Starting Water Level (m)	Max Water Level (m^2)	Storage Volume (m^3)	Cost at $150 per m^3
Historic 100 year	85,560	56.79	57.01	18,230	$2,734,540	145,167	57.16	57.25	13,065	$1,959,755
Climate Change (median)	85,560	56.79	57.09	24,859	$3,728,919	145,167	57.16	57.29	18,872	$2,830,757
Climate Change (90th)	85,560	56.79	57.17	31,489	$4,723,297	145,167	57.16	57.32	23,227	$3,484,008

The value of the present capacity of the marsh to absorb overbank flows from the Millstone during a historic 1 in 100-year flood event was calculated based on the storage volume between the normal water level in the marsh and the maximum water level that the marsh can contain without neighbourhood flooding or adverse effects on transportation infrastructure downstream (i.e. Bowen 4 lane bridge). This storage benefit was valued at approximately $4,694,295 based upon replacement off-stream storage. This was compared against the climate change median scenario and the climate change 90th percentile scenario using the same valuation technique, which resulted in estimated values of $6,559,676 and $8,207,305 respectively.

3.4 Operations and maintenance costs for Buttertubs Marsh

The effectiveness of a natural capital asset within a stormwater management plan needs to be measured periodically to ensure that the natural asset's performance is functioning as expected and unimpeded over time. A management plan for the East marsh was prepared in 2003 to guide activities over a 10-year period (Buttertubs Marsh Conservation Area Management Plan, 2003) The management plan sets out strategies and tasks for conservation, land use, interpretation and operational and maintenance of the conservation area to ensure management decisions protect and enhance natural values and that human use within the area does not cause unacceptable impacts. The expansion of the conservation area in 2012 resulting from the purchase of the West marsh by the city and Ducks Unlimited Canada, resulted in the desire to expand the plan to reflect the enlarged conservation area.

The BMCA Co-management Steering Committee enlisted the assistance of Madrone Environmental Services to undertake a strategic review of the 2004 management plan and to develop a five-year strategic plan for the entire marsh complex(Madrone Environmental Services, 2017). This plan describes acceptable land use activities to assist with land management decisions and establishes a number of five-year targets to meet the overall management goals. The MNAI technical team reviewed this document for gaps in management activities to secure stormwater services. It was determined that the management plan required few changes beyond the need for additional monitoring. The following recommendations were made:

1. Establish flow and water surface elevation monitoring in the marsh, at marsh outfalls, and in the Millstone River to facilitate future hydrologic modeling. This recommendation seeks to strengthen the model to develop a better understanding of the connectivity between BMCA and the Millstone River.
2. Gather bathymetry data (specifically for the West marsh) to improve understanding of marsh storage capacity.
3. Consider water treatment pre-entrance to avoid dredging costs.

These recommendations will be brought forward to the BMCA Co-management Steering Committee for consideration. There are, therefore, no additions to the operations, maintenance or monitoring plans at this time.

3.5 Beneficiaries

MNAI worked with the City of Nanaimo and its partners to identify relevant indicators to capture the populations affected by potential changes to the BMCA. Understanding the range of beneficiaries can help decision-makers consider where a change in service provision may have a large impact on vulnerable populations or other social groups of special concern. The appropriate indicators should identify changes in ecological conditions displayed in units relevant to the beneficiaries. That is, they should signal changes to ecological conditions that matter to people.

In developing the suite of indicators, consideration was given to the goals and objectives of the Buttertubs Marsh Conservation Area Management Plan (August 2017), the MNAI pilot project results, Buttertubs Marsh Neighbourhood Site Analysis (Hemphill 2016), the City of Nanaimo's Social Development Strategy (Talbot and Associates Inc. for City of Nanaimo, 2003), and the latest research on connecting ecosystem services to beneficiaries. Every effort was made to utilize existing data and committed projects.

A set of nine indicators were developed to represent and track the state of four values, including biodiversity, public use, water regulation, and governance and management. An additional category —carbon sequestration—was flagged for further consideration given work being completed by Vancouver Island University and the city's climate adaptation strategy preparation. Table 5 below provides a summary of the proposed beneficiary indicators.

Table 5: Beneficiaries Assessment

	Indicator	Methodology	Beneficiaries
Biodiversity	Abundance of native bird species	Data extracted from VIU bird monitoring and banding project, which monitors migrant and resident birds to contribute to regional and continent-wide efforts to monitor changes in population levels of these species.	Trail counters will provide an indication of the number of people visiting the marsh. Trends can be monitored and tracked against periods of high bird life/activity (March – October).
	Non-native invasive species abundance	The Nature Trust of BC performs annual inventory of non-native invasive species.	Impacted beneficiaries include visitors to BCMA and the population within propagation range
Public Use	Percentage of population within 15 minute walk to Buttertubs Marsh	GIS mapping to identify number of residential units within 1,200m (or 1.2km) of Buttertubs Marsh	Population within 1.2km of Buttertubs Marsh
	Connectivity of surrounding neighbourhoods to East side of Buttertubs Marsh	Low, medium, high measure based on number of entry points to Buttertubs Marsh.	Currently 6 vehicular/pedestrian access points serving a residential population of 875 units. This amounts to approx. 2,188 people
	Number of educational visits to Buttertubs Marsh per year	Tracking: VIU students are primary educational group using Buttertubs Marsh, but there are other one-off educational visits (e.g. high school PE/biology class, wetland keepers course to be held May 2018, Water Stewardship in a Changing Climate symposium fieldtrip April 2018)	Minimum 10 educational visits in 2016
Water regulation	Flood prevention	Number of flooding days recorded in City Tempest Database	Population (residential and business) within sub-watershed floodplain
	Drought mitigation	Proposed indicator: Defined as the proportion of days in which daily streamflow falls below a low flow threshold.	Population (residential and business) within sub-watershed floodplain
	Water quality	Water quality monitoring for Millstone River	Population (residential and business) within sub-watershed floodplain
Governance and Management	Number of agencies/ private companies/ NGOs/academic institutions/volunteers with which the city is partnering in biodiversity activities, projects & programs	Low, medium, high measure based on number of organizations involved in management of biodiversity in Buttertubs Marsh.	Minimum of 6 organizations ▪ City of Nanaimo ▪ The Nature Trust of BC ▪ Province of BC (FLNRO) ▪ Ducks Unlimited Canada ▪ Friends of Buttertubs Marsh ▪ Vancouver Island University

4. Assumptions and Limitations

Limitations can have an impact on the certainty of the results. It should be noted, however, that this was a pilot study to test the approach. More detailed data at the site and sub-watershed scale can be used to better inform the modeling analysis and decision making process. Some of these limitations may have been outlined in the preceding sections.

1. The PCSWMM model was built with available infrastructure mapping to identify a coarse hydraulic link network between the sub-catchments that represent the coarse trunk system only. It was anticipated that geometric information was lacking to define this network, so assumptions and estimates were applied for information gaps based on available mapping.

2. The gathering of input from geotechnical and hydrogeological experts on the significance of groundwater influence on the system was outside the scope of the pilot. Based on the monitoring data available, best estimates of groundwater contributions were developed in addition to soils mapping and textbook parameters for infiltration.

3. The cost and time to apply a watershed and hydrodynamic model to the Millstone (from headwaters to harbour) to estimate flows and water levels under a climate change condition precluded the evaluation of the overbank flood storage benefit provided by the marsh in a future climate condition.

4. The PCSWMM model does not have water quality simulation capability, which would have allowed quantification of pollutants reduction associated with stormwater runoff, namely nutrients and suspended solids. SWMM5, the latest model version, has this capability and should be considered for future evaluations of the marsh as a stormwater management facility.

5. A key assumption was made in selecting the greenhouse gas (GHG) emissions scenario. PCIC and other climate change organizations recommend that practitioners use the “business as usual” scenario where climate is modeled assuming that little will be done to reduce GHG emissions in the future. This emissions scenario is referred to as “Representation Concentration Pathway 8.5” (RCP 8.5), and is the most conservative of the available scenarios.

5. CONCLUSION

The pilot study has demonstrated that the natural asset of focus— the Buttertubs Marsh Conservation Area—provides stormwater detention benefits commensurate with engineered infrastructure. In addition, the modeling indicates the resilience of the BMCA to climate change conditions, providing a similar level of service despite higher volume and velocity of flows.

These conclusions are drawn after assessing volume and peak flow reduction for the 100-year storm. As part of this assignment, the city requested that IDF curves also be developed to reflect climate change projections. Two sets of IDF curves were modeled: one based on the median of 24 global climate models and one based on the 90th percentile of 24 global climate models.

Study results indicate that storage of the marshes provides significant peak flow attenuation and overall retention functions. Filling in the marsh results in considerable impact and increases the flow to the Millstone River. The city would either need to locate equivalent detention storage or complete improvements to the downstream Millstone River system to compensate for the increased flow.

Early monitoring results suggest that the East marsh is typically isolated hydraulically from the Millstone River given its elevated overflow spillway. However, the West marsh, with its lower ditch connection to the river, is frequently influenced by backwater effects from the river. A 2005 study indicates that the marshes provide a significant service to the Millstone River in the form of flood plain storage. That study suggested a significant reduction in peak flow would occur during the design 200-year flood, lessening risk to downstream river crossings. Results suggest that removal of the marshes would cause a significant increased risk to downstream systems, however the scope of this assignment does not allow us to explore that aspect.

An asset value was assigned to the marshes based on their detention function. The costs associated with engineered stormwater management ponds or constructed wetlands was estimated using a unit cost of $150 per cubic meter of stored water. This is reflective of design and construction for a well finished stormwater detention pond with comprehensive landscaping and environmental components, but excludes land purchase or any complex structures, indicating the conservative nature of the reported values. This valuation method was used to compute an estimated value of roughly $4 to $4.5 million under current climate and $8 million under climate change conditions. The difference in value under current and climate change scenarios emphasizes the increasing importance of natural assets in providing critical services to municipalities in the future and their role in increasing community resilience.

5.2 Next steps

By assigning a value to the Buttertubs Marsh Conservation Area, there is now a basis for taking concrete, evidence-based actions. There is also an understanding of the climate change values that can be included in future decisions.

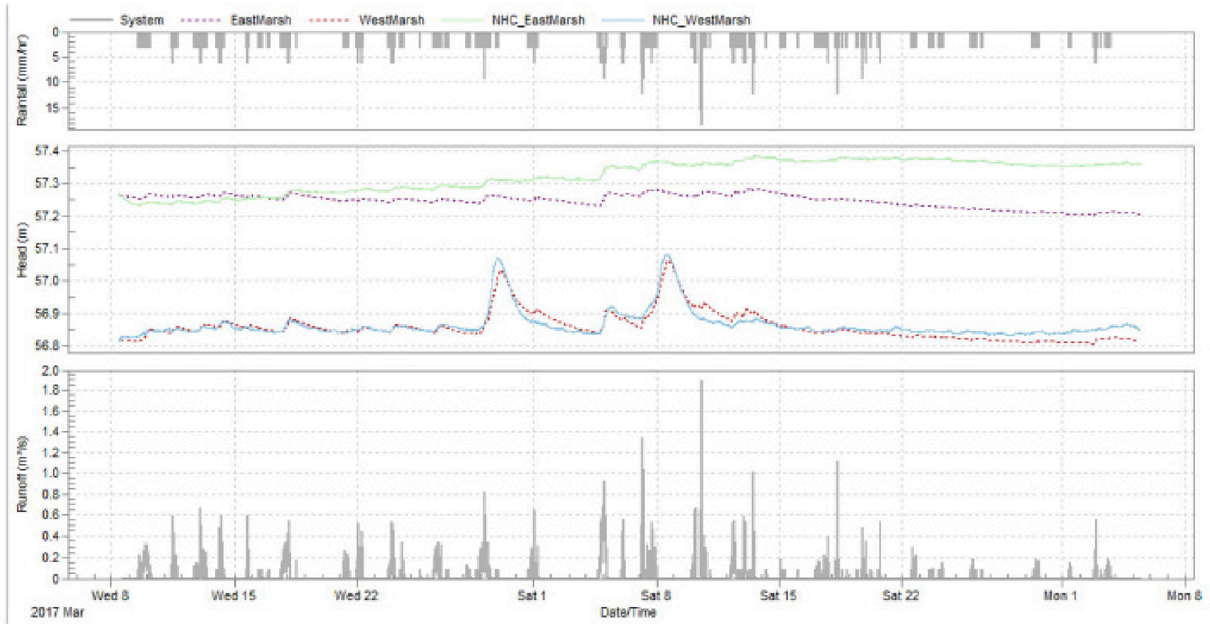
Although the MNAI pilot with the City of Nanaimo has concluded the technical aspects required to identify, manage and value natural assets, much work remains to translate the results into core management and financial processes.

Members of the MNAI team met with City of Nanaimo senior managers on January 25, 2018 to discuss the pilot and develop a road map for incorporating pilot results, and natural assets more broadly, into asset management and financial processes. A broad framework was outlined that includes the development of a natural asset register and an inventory of natural and potential engineered storm assets in the city. Once Council endorses the approach, staff would develop policy to help define natural assets for Nanaimo and how operation and maintenance requirements can be implemented by the city. This framework will be refined over the coming months and years.

The city will continue to collect data from the water level sensors and loggers located in and around the Buttertubs Marsh and compare this data to Millstone River flows to better understand the relationship between the marsh and the river. The Buttertubs Management Plan partners will consider monitoring recommendations for the marsh's physical integrity, its performance in urban stormwater and overbank flooding management, and co-benefit maintenance to retain the marsh's asset value. The study recommended additional monitoring and maintenance relative to sustaining or enhancing the surface water management benefits.

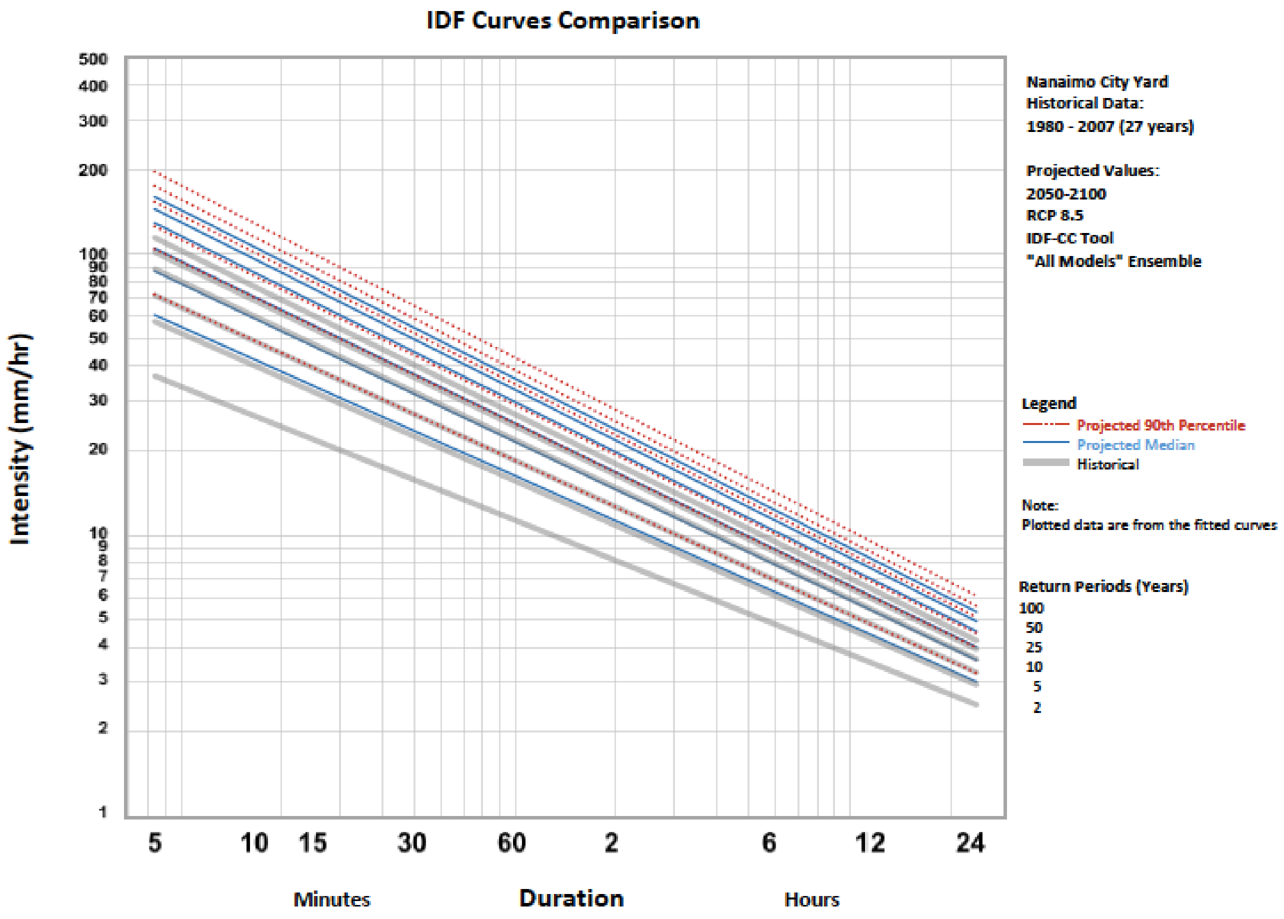
Appendix A: Model Calibration Results

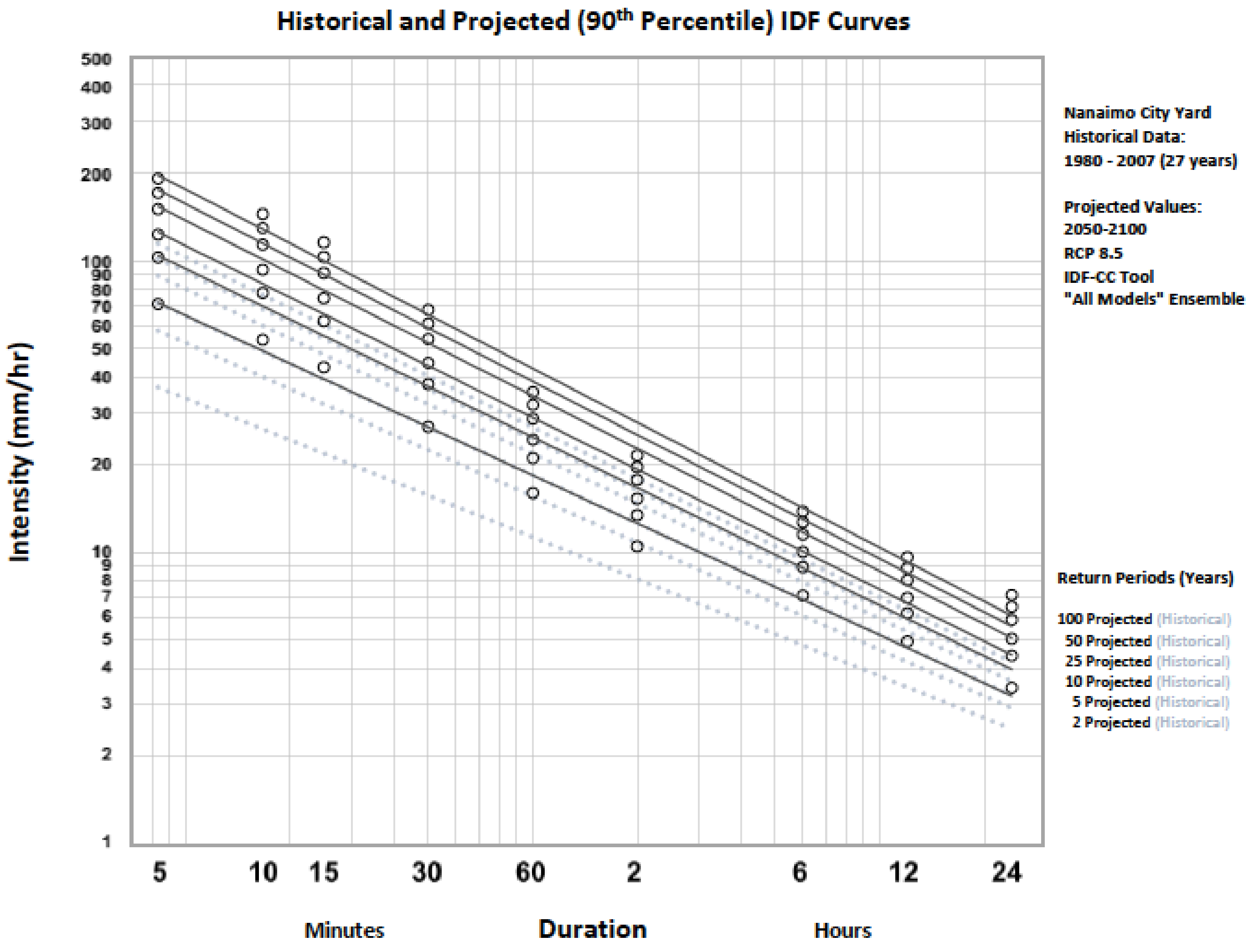
Figure 3 - Model Calibration Results

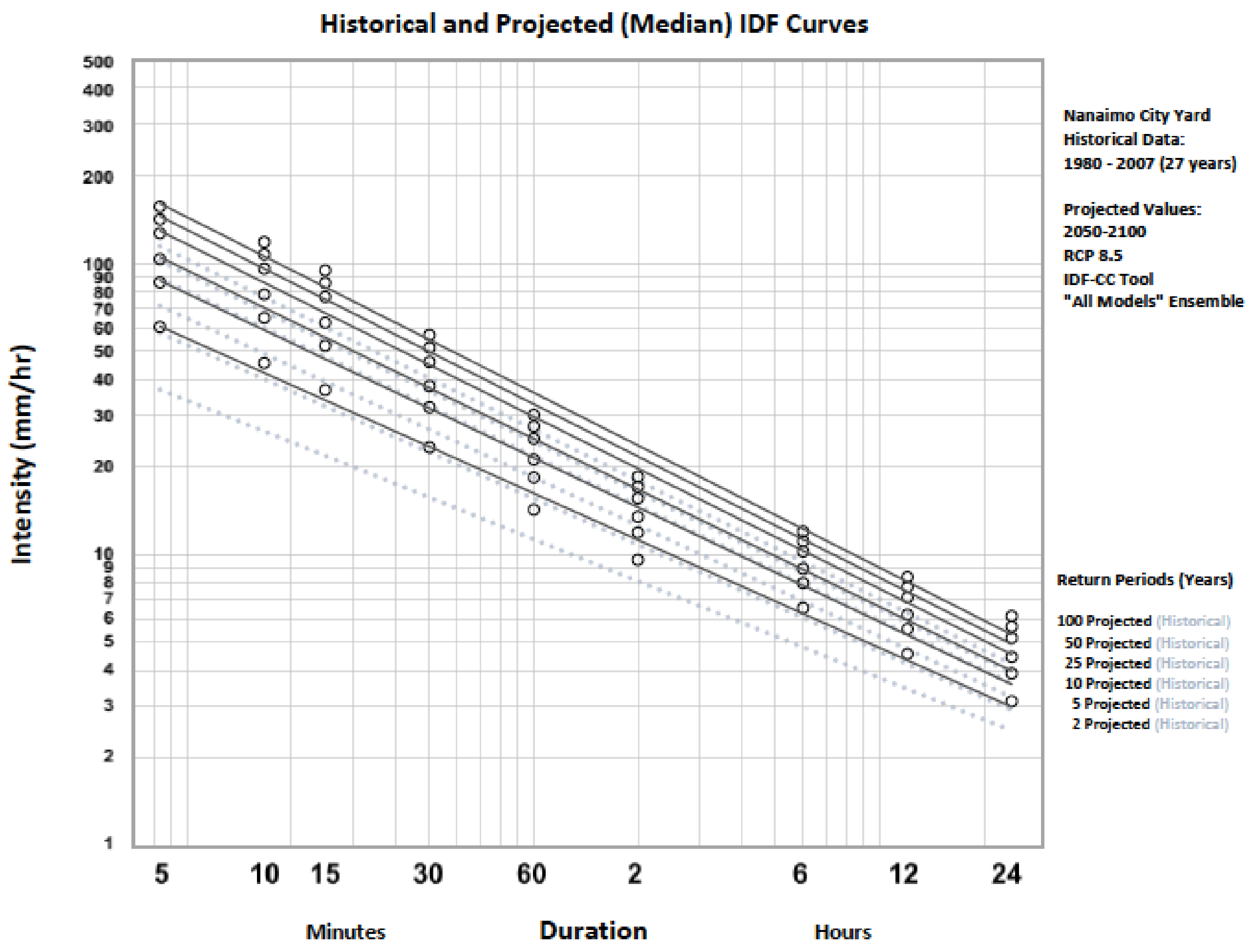


Note, dashed line are modeled, solid lines are observed per data provided by NHC.

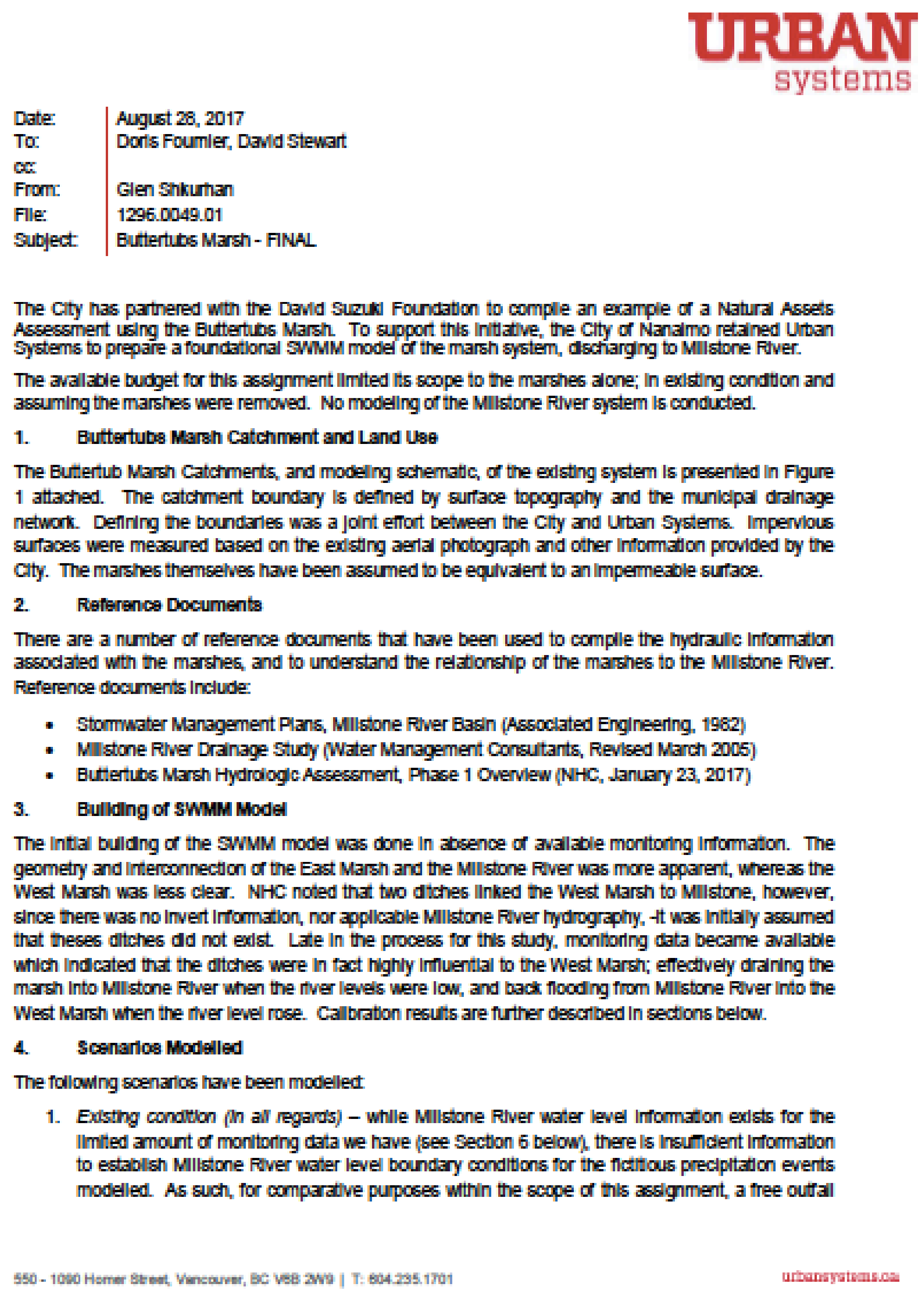
Appendix B: Historic and Climate Change IDFs







Appendix C: Urban Systems Report



URBAN systems

Date: August 28, 2017
To: Doris Fournier, David Stewart
cc:
From: Glen Shkurhan
File: 1296.0049.01
Subject: Buttertubs Marsh - FINAL

The City has partnered with the David Suzuki Foundation to compile an example of a Natural Assets Assessment using the Buttertubs Marsh. To support this initiative, the City of Nanaimo retained Urban Systems to prepare a foundational SWMM model of the marsh system, discharging to Millstone River.

The available budget for this assignment limited its scope to the marshes alone; in existing condition and assuming the marshes were removed. No modeling of the Millstone River system is conducted.

1. Buttertubs Marsh Catchment and Land Use

The Buttertub Marsh Catchments, and modeling schematic, of the existing system is presented in Figure 1 attached. The catchment boundary is defined by surface topography and the municipal drainage network. Defining the boundaries was a joint effort between the City and Urban Systems. Impervious surfaces were measured based on the existing aerial photograph and other information provided by the City. The marshes themselves have been assumed to be equivalent to an impermeable surface.

2. Reference Documents

There are a number of reference documents that have been used to compile the hydraulic information associated with the marshes, and to understand the relationship of the marshes to the Millstone River. Reference documents include:

- Stormwater Management Plans, Millstone River Basin (Associated Engineering, 1982)
- Millstone River Drainage Study (Water Management Consultants, Revised March 2005)
- Buttertubs Marsh Hydrologic Assessment, Phase 1 Overview (NHC, January 23, 2017)

3. Building of SWMM Model

The initial building of the SWMM model was done in absence of available monitoring information. The geometry and interconnection of the East Marsh and the Millstone River was more apparent, whereas the West Marsh was less clear. NHC noted that two ditches linked the West Marsh to Millstone, however, since there was no invert information, nor applicable Millstone River hydrography, -it was initially assumed that theses ditches did not exist. Late in the process for this study, monitoring data became available which indicated that the ditches were in fact highly influential to the West Marsh; effectively draining the marsh into Millstone River when the river levels were low, and back flooding from Millstone River into the West Marsh when the river level rose. Calibration results are further described in sections below.

4. Scenarios Modelled

The following scenarios have been modelled:

1. *Existing condition (in all regards)* – while Millstone River water level information exists for the limited amount of monitoring data we have (see Section 6 below), there is insufficient information to establish Millstone River water level boundary conditions for the fictitious precipitation events modelled. As such, for comparative purposes within the scope of this assignment, a free outfall

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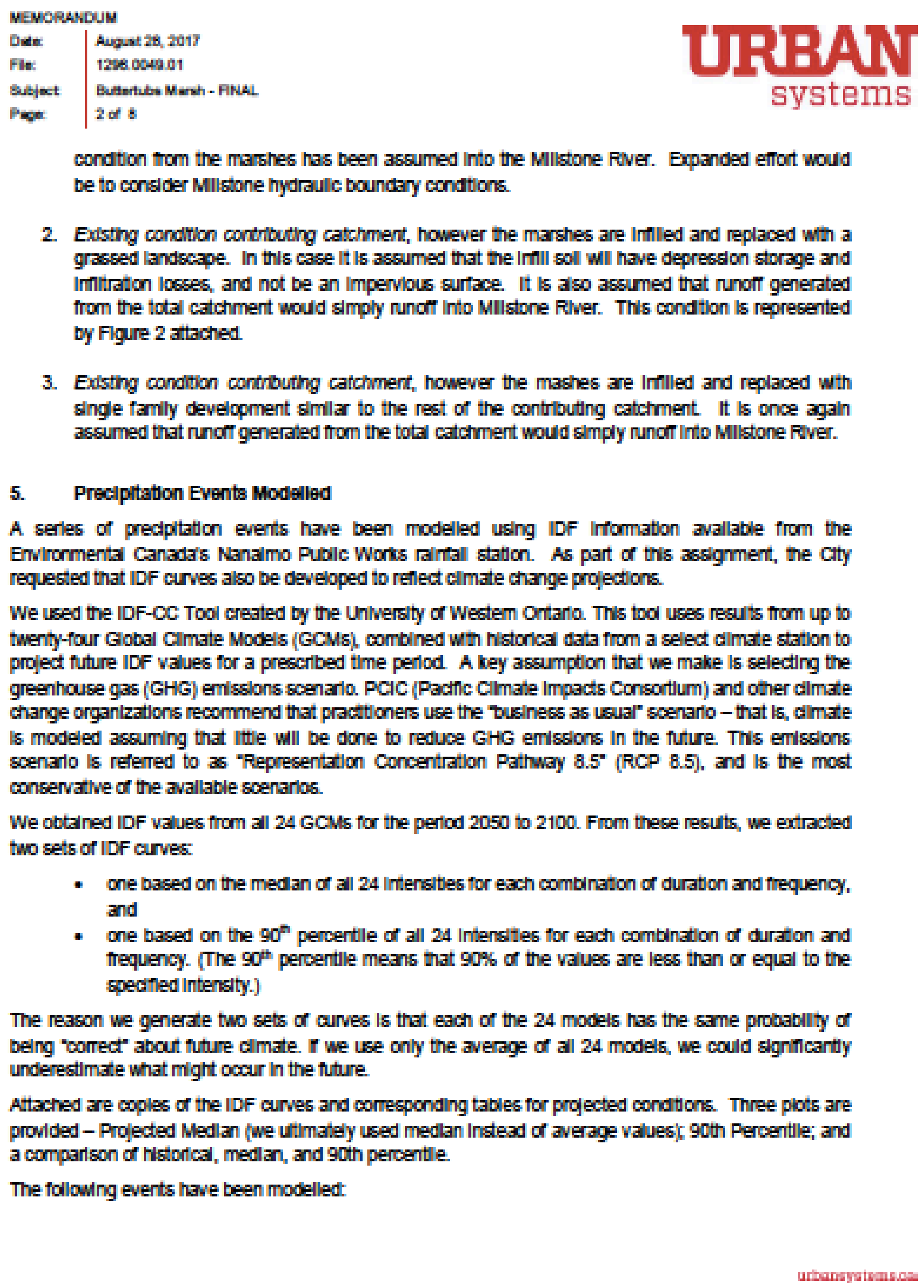

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condition from the marshes has been assumed into the Millstone River. Expanded effort would be to consider Millstone hydraulic boundary conditions.

2. *Existing condition contributing catchment*, however the marshes are infilled and replaced with a grassed landscape. In this case it is assumed that the infill soil will have depression storage and infiltration losses, and not be an impervious surface. It is also assumed that runoff generated from the total catchment would simply runoff into Millstone River. This condition is represented by Figure 2 attached.

3. *Existing condition contributing catchment*, however the mashes are infilled and replaced with single family development similar to the rest of the contributing catchment. It is once again assumed that runoff generated from the total catchment would simply runoff into Millstone River.

5. Precipitation Events Modelled

A series of precipitation events have been modelled using IDF information available from the Environmental Canada's Nanaimo Public Works rainfall station. As part of this assignment, the City requested that IDF curves also be developed to reflect climate change projections.

We used the IDF-CC Tool created by the University of Western Ontario. This tool uses results from up to twenty-four Global Climate Models (GCMs), combined with historical data from a select climate station to project future IDF values for a prescribed time period. A key assumption that we make is selecting the greenhouse gas (GHG) emissions scenario. PCIC (Pacific Climate Impacts Consortium) and other climate change organizations recommend that practitioners use the "business as usual" scenario – that is, climate is modeled assuming that little will be done to reduce GHG emissions in the future. This emissions scenario is referred to as "Representation Concentration Pathway 8.5" (RCP 8.5), and is the most conservative of the available scenarios.

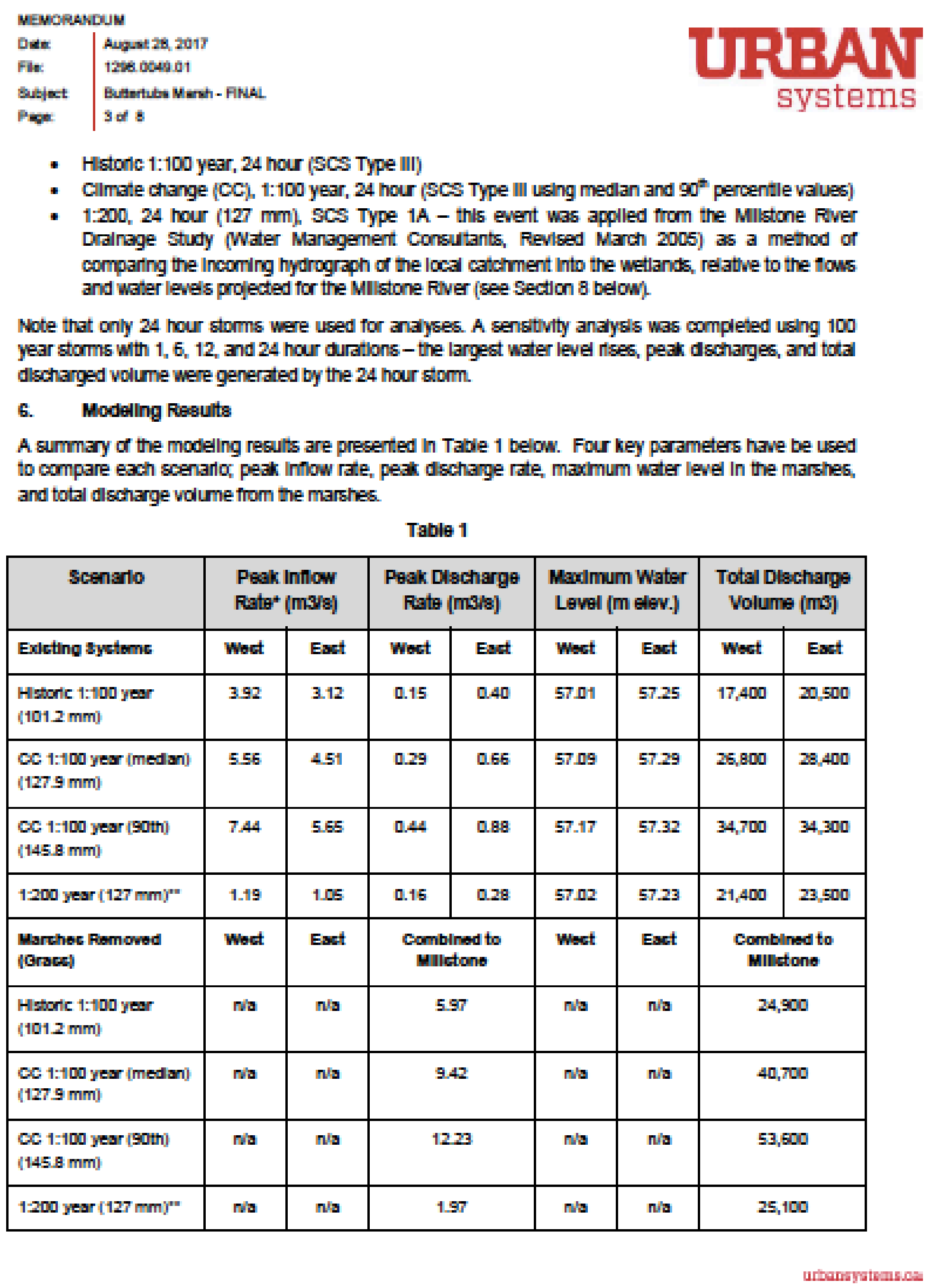
We obtained IDF values from all 24 GCMs for the period 2050 to 2100. From these results, we extracted two sets of IDF curves:

- one based on the median of all 24 intensities for each combination of duration and frequency, and
- one based on the 90th percentile of all 24 intensities for each combination of duration and frequency. (The 90th percentile means that 90% of the values are less than or equal to the specified intensity.)

The reason we generate two sets of curves is that each of the 24 models has the same probability of being "correct" about future climate. If we use only the average of all 24 models, we could significantly underestimate what might occur in the future.

Attached are copies of the IDF curves and corresponding tables for projected conditions. Three plots are provided – Projected Median (we ultimately used median instead of average values); 90th Percentile; and a comparison of historical, median, and 90th percentile.

The following events have been modelled:



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- Historic 1:100 year, 24 hour (SCS Type III)
- Climate change (CC), 1:100 year, 24 hour (SCS Type III using median and 90th percentile values)
- 1:200, 24 hour (127 mm), SCS Type 1A – this event was applied from the Millstone River Drainage Study (Water Management Consultants, Revised March 2005) as a method of comparing the incoming hydrograph of the local catchment into the wetlands, relative to the flows and water levels projected for the Millstone River (see Section 8 below).

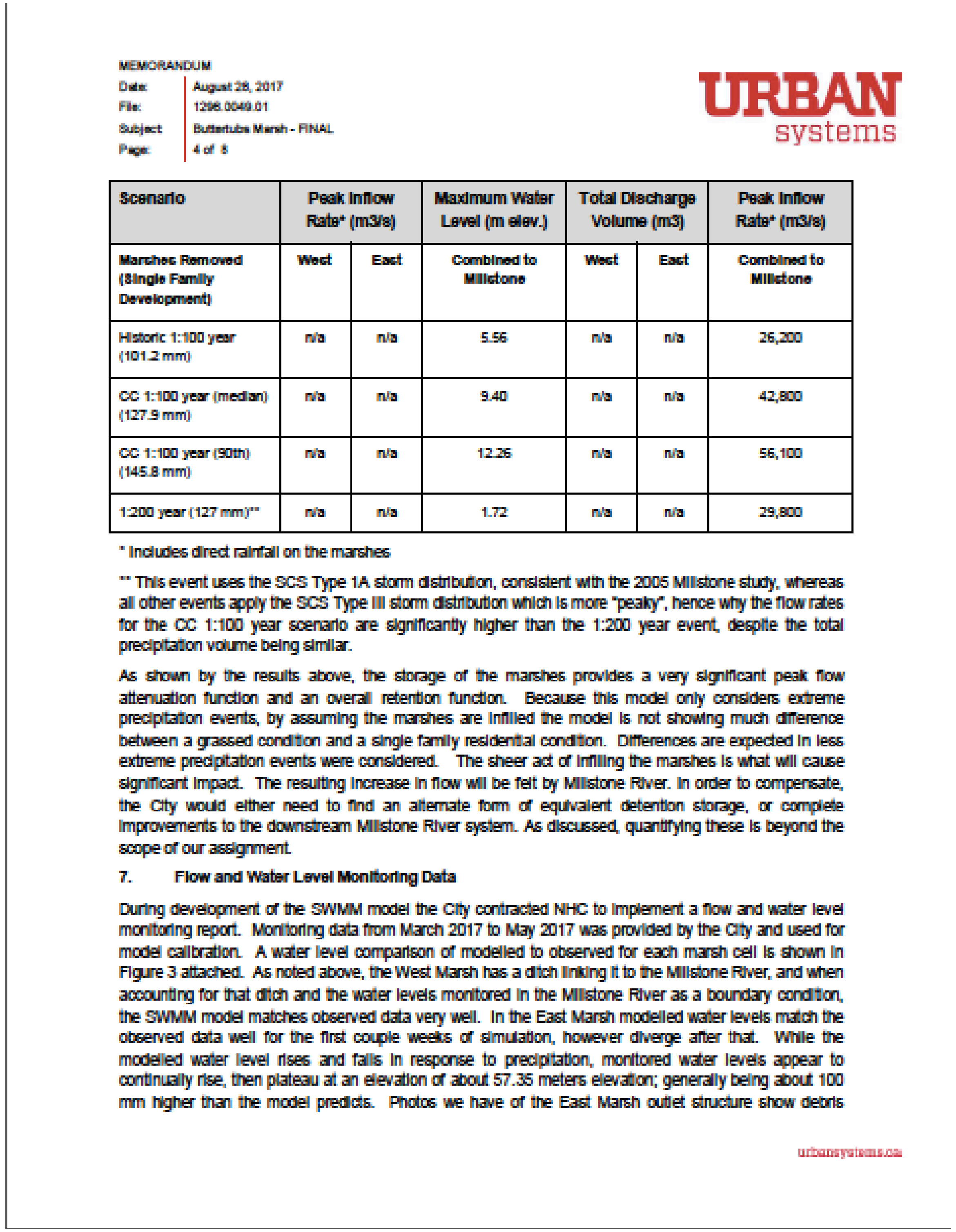
Note that only 24 hour storms were used for analyses. A sensitivity analysis was completed using 100 year storms with 1, 6, 12, and 24 hour durations – the largest water level rises, peak discharges, and total discharged volume were generated by the 24 hour storm.

6. Modeling Results

A summary of the modeling results are presented in Table 1 below. Four key parameters have be used to compare each scenario; peak inflow rate, peak discharge rate, maximum water level in the marshes, and total discharge volume from the marshes.

Table 1

Scenario	Peak Inflow Rate* (m3/s)		Peak Discharge Rate (m3/s)		Maximum Water Level (m elev.)		Total Discharge Volume (m3)	
Existing Systems	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**
Historic 1:100 year (101.2 mm)	3.92	3.12	0.15	0.40	57.01	57.25	17,400	20,500
CC 1:100 year (median) (127.9 mm)	5.56	4.51	0.29	0.66	57.09	57.29	26,800	28,400
CC 1:100 year (90th) (145.8 mm)	7.44	5.65	0.44	0.88	57.17	57.32	34,700	34,300
1:200 year (127 mm)**	1.19	1.05	0.16	0.28	57.02	57.23	21,400	23,500
Marshes Removed (Grass)	**West**	**East**	**Combined to Millstone**		**West**	**East**	**Combined to Millstone**	
Historic 1:100 year (101.2 mm)	n/a	n/a	5.97		n/a	n/a	24,900	
CC 1:100 year (median) (127.9 mm)	n/a	n/a	9.42		n/a	n/a	40,700	
CC 1:100 year (90th) (145.8 mm)	n/a	n/a	12.23		n/a	n/a	53,600	
1:200 year (127 mm)**	n/a	n/a	1.97		n/a	n/a	25,100	



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Scenario	Peak Inflow Rate* (m3/s)		Maximum Water Level (m elev.)	Total Discharge Volume (m3)		Peak Inflow Rate* (m3/s)
Marshes Removed (Single Family Development)	**West**	**East**	**Combined to Millstone**	**West**	**East**	**Combined to Millstone**
Historic 1:100 year (101.2 mm)	n/a	n/a	5.56	n/a	n/a	26,200
CC 1:100 year (median) (127.9 mm)	n/a	n/a	9.40	n/a	n/a	42,800
CC 1:100 year (90th) (145.8 mm)	n/a	n/a	12.26	n/a	n/a	56,100
1:200 year (127 mm)**	n/a	n/a	1.72	n/a	n/a	29,800

* Includes direct rainfall on the marshes

** This event uses the SCS Type 1A storm distribution, consistent with the 2005 Millstone study, whereas all other events apply the SCS Type III storm distribution which is more "peaky", hence why the flow rates for the CC 1:100 year scenario are significantly higher than the 1:200 year event, despite the total precipitation volume being similar.

As shown by the results above, the storage of the marshes provides a very significant peak flow attenuation function and an overall retention function. Because this model only considers extreme precipitation events, by assuming the marshes are infilled the model is not showing much difference between a grassed condition and a single family residential condition. Differences are expected in less extreme precipitation events were considered. The sheer act of infilling the marshes is what will cause significant impact. The resulting increase in flow will be felt by Millstone River. In order to compensate, the City would either need to find an alternate form of equivalent detention storage, or complete improvements to the downstream Millstone River system. As discussed, quantifying these is beyond the scope of our assignment.

7. Flow and Water Level Monitoring Data

During development of the SWMM model the City contracted NHC to implement a flow and water level monitoring report. Monitoring data from March 2017 to May 2017 was provided by the City and used for model calibration. A water level comparison of modelled to observed for each marsh cell is shown in Figure 3 attached. As noted above, the West Marsh has a ditch linking it to the Millstone River, and when accounting for that ditch and the water levels monitored in the Millstone River as a boundary condition, the SWMM model matches observed data very well. In the East Marsh modelled water levels match the observed data well for the first couple weeks of simulation, however diverge after that. While the modelled water level rises and falls in response to precipitation, monitored water levels appear to continually rise, then plateau at an elevation of about 57.35 meters elevation; generally being about 100 mm higher than the model predicts. Photos we have of the East Marsh outlet structure show debris

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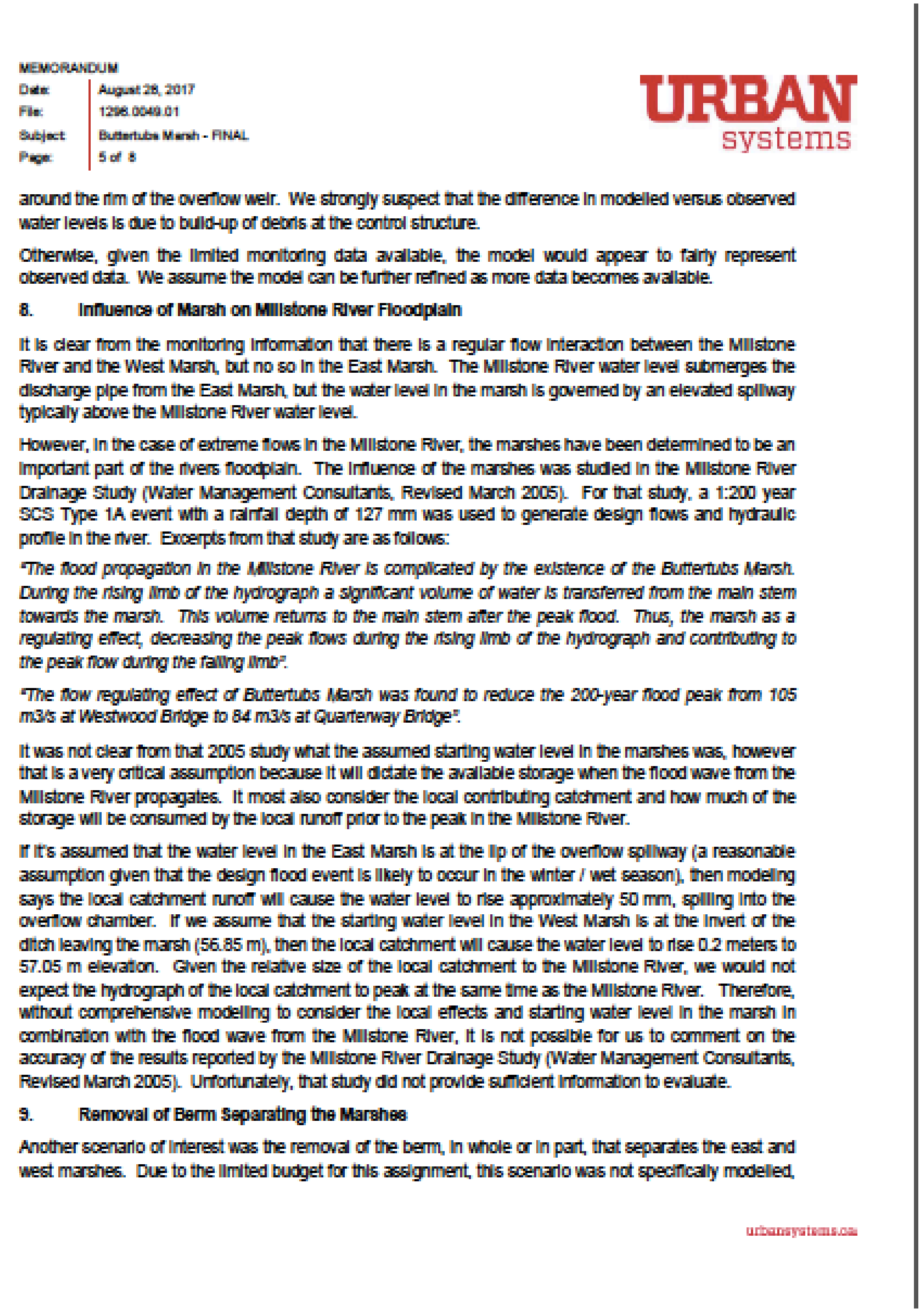

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around the rim of the overflow weir. We strongly suspect that the difference in modelled versus observed water levels is due to build-up of debris at the control structure.

Otherwise, given the limited monitoring data available, the model would appear to fairly represent observed data. We assume the model can be further refined as more data becomes available.

8. Influence of Marsh on Millstone River Floodplain

It is clear from the monitoring information that there is a regular flow interaction between the Millstone River and the West Marsh, but no so in the East Marsh. The Millstone River water level submerges the discharge pipe from the East Marsh, but the water level in the marsh is governed by an elevated spillway typically above the Millstone River water level.

However, in the case of extreme flows in the Millstone River, the marshes have been determined to be an important part of the rivers floodplain. The influence of the marshes was studied in the Millstone River Drainage Study (Water Management Consultants, Revised March 2005). For that study, a 1:200 year SCS Type 1A event with a rainfall depth of 127 mm was used to generate design flows and hydraulic profile in the river. Excerpts from that study are as follows:

"The flood propagation in the Millstone River is complicated by the existence of the Buttertubs Marsh. During the rising limb of the hydrograph a significant volume of water is transferred from the main stem towards the marsh. This volume returns to the main stem after the peak flood. Thus, the marsh as a regulating effect, decreasing the peak flows during the rising limb of the hydrograph and contributing to the peak flow during the falling limb".

"The flow regulating effect of Buttertubs Marsh was found to reduce the 200-year flood peak from 105 m3/s at Westwood Bridge to 84 m3/s at Quarterway Bridge".

It was not clear from that 2005 study what the assumed starting water level in the marshes was, however that is a very critical assumption because it will dictate the available storage when the flood wave from the Millstone River propagates. It most also consider the local contributing catchment and how much of the storage will be consumed by the local runoff prior to the peak in the Millstone River.

If it's assumed that the water level in the East Marsh is at the lip of the overflow spillway (a reasonable assumption given that the design flood event is likely to occur in the winter / wet season), then modeling says the local catchment runoff will cause the water level to rise approximately 50 mm, spilling into the overflow chamber. If we assume that the starting water level in the West Marsh is at the invert of the ditch leaving the marsh (56.85 m), then the local catchment will cause the water level to rise 0.2 meters to 57.05 m elevation. Given the relative size of the local catchment to the Millstone River, we would not expect the hydrograph of the local catchment to peak at the same time as the Millstone River. Therefore, without comprehensive modelling to consider the local effects and starting water level in the marsh in combination with the flood wave from the Millstone River, it is not possible for us to comment on the accuracy of the results reported by the Millstone River Drainage Study (Water Management Consultants, Revised March 2005). Unfortunately, that study did not provide sufficient information to evaluate.

9. Removal of Berm Separating the Marshes

Another scenario of interest was the removal of the berm, in whole or in part, that separates the east and west marshes. Due to the limited budget for this assignment, this scenario was not specifically modelled,

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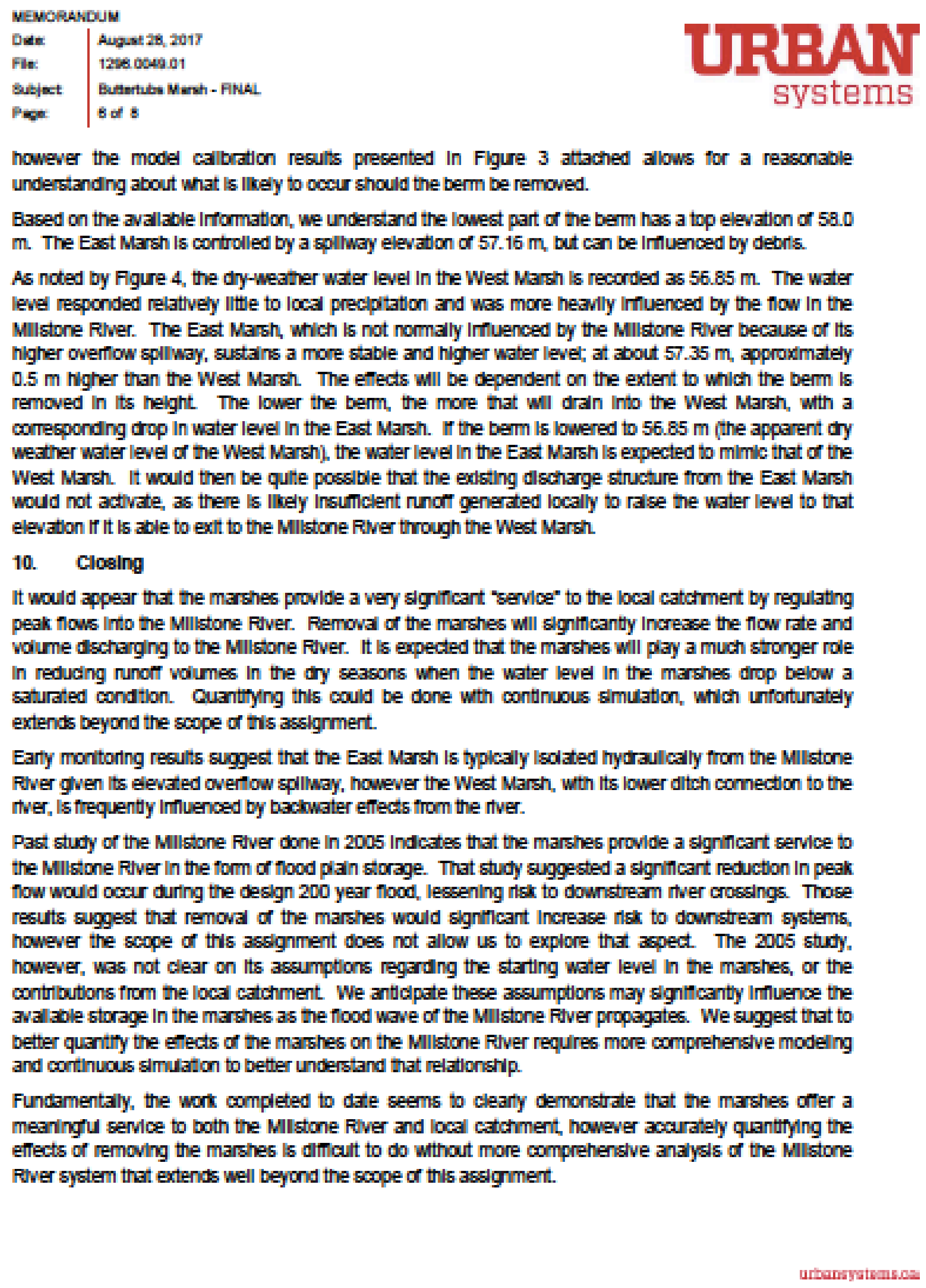


however the model calibration results presented in Figure 3 attached allows for a reasonable understanding about what is likely to occur should the berm be removed.

Based on the available information, we understand the lowest part of the berm has a top elevation of 58.0 m. The East Marsh is controlled by a spillway elevation of 57.16 m, but can be influenced by debris.

As noted by Figure 4, the dry-weather water level in the West Marsh is recorded as 56.85 m. The water level responded relatively little to local precipitation and was more heavily influenced by the flow in the Millstone River. The East Marsh, which is not normally influenced by the Millstone River because of its higher overflow spillway, sustains a more stable and higher water level; at about 57.35 m, approximately 0.5 m higher than the West Marsh. The effects will be dependent on the extent to which the berm is removed in its height. The lower the berm, the more that will drain into the West Marsh, with a corresponding drop in water level in the East Marsh. If the berm is lowered to 56.85 m (the apparent dry weather water level of the West Marsh), the water level in the East Marsh is expected to mimic that of the West Marsh. It would then be quite possible that the existing discharge structure from the East Marsh would not activate, as there is likely insufficient runoff generated locally to raise the water level to that elevation if it is able to exit to the Millstone River through the West Marsh.

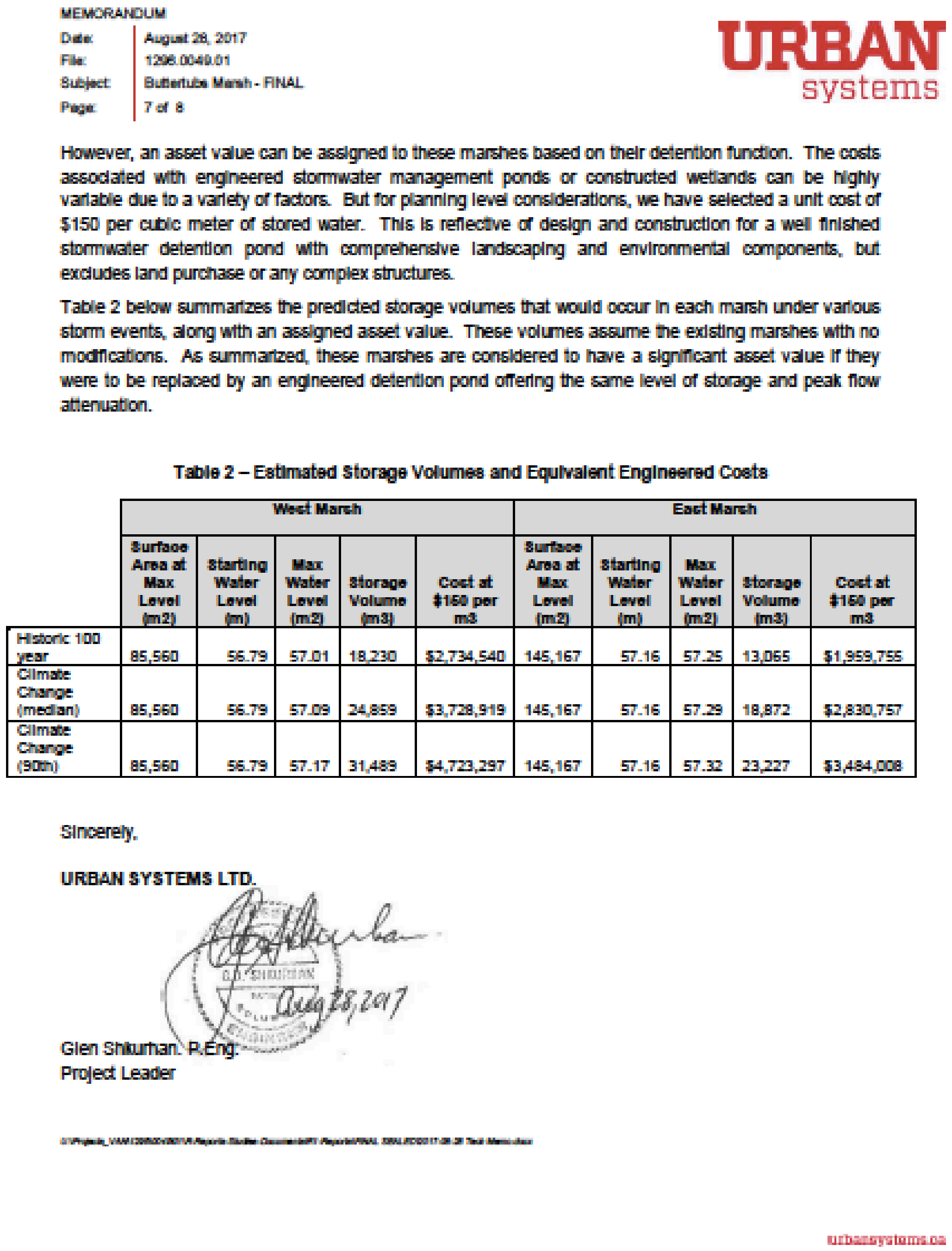
10. Closing

It would appear that the marshes provide a very significant "service" to the local catchment by regulating peak flows into the Millstone River. Removal of the marshes will significantly increase the flow rate and volume discharging to the Millstone River. It is expected that the marshes will play a much stronger role in reducing runoff volumes in the dry seasons when the water level in the marshes drop below a saturated condition. Quantifying this could be done with continuous simulation, which unfortunately extends beyond the scope of this assignment.

Early monitoring results suggest that the East Marsh is typically isolated hydraulically from the Millstone River given its elevated overflow spillway, however the West Marsh, with its lower ditch connection to the river, is frequently influenced by backwater effects from the river.

Past study of the Millstone River done in 2005 indicates that the marshes provide a significant service to the Millstone River in the form of flood plain storage. That study suggested a significant reduction in peak flow would occur during the design 200 year flood, lessening risk to downstream river crossings. Those results suggest that removal of the marshes would significant increase risk to downstream systems, however the scope of this assignment does not allow us to explore that aspect. The 2005 study, however, was not clear on its assumptions regarding the starting water level in the marshes, or the contributions from the local catchment. We anticipate these assumptions may significantly influence the available storage in the marshes as the flood wave of the Millstone River propagates. We suggest that to better quantify the effects of the marshes on the Millstone River requires more comprehensive modeling and continuous simulation to better understand that relationship.

Fundamentally, the work completed to date seems to clearly demonstrate that the marshes offer a meaningful service to both the Millstone River and local catchment, however accurately quantifying the effects of removing the marshes is difficult to do without more comprehensive analysis of the Millstone River system that extends well beyond the scope of this assignment.



However, an asset value can be assigned to these marshes based on their detention function. The costs associated with engineered stormwater management ponds or constructed wetlands can be highly variable due to a variety of factors. But for planning level considerations, we have selected a unit cost of $150 per cubic meter of stored water. This is reflective of design and construction for a well finished stormwater detention pond with comprehensive landscaping and environmental components, but excludes land purchase or any complex structures.

Table 2 below summarizes the predicted storage volumes that would occur in each marsh under various storm events, along with an assigned asset value. These volumes assume the existing marshes with no modifications. As summarized, these marshes are considered to have a significant asset value if they were to be replaced by an engineered detention pond offering the same level of storage and peak flow attenuation.

Table 2 – Estimated Storage Volumes and Equivalent Engineered Costs

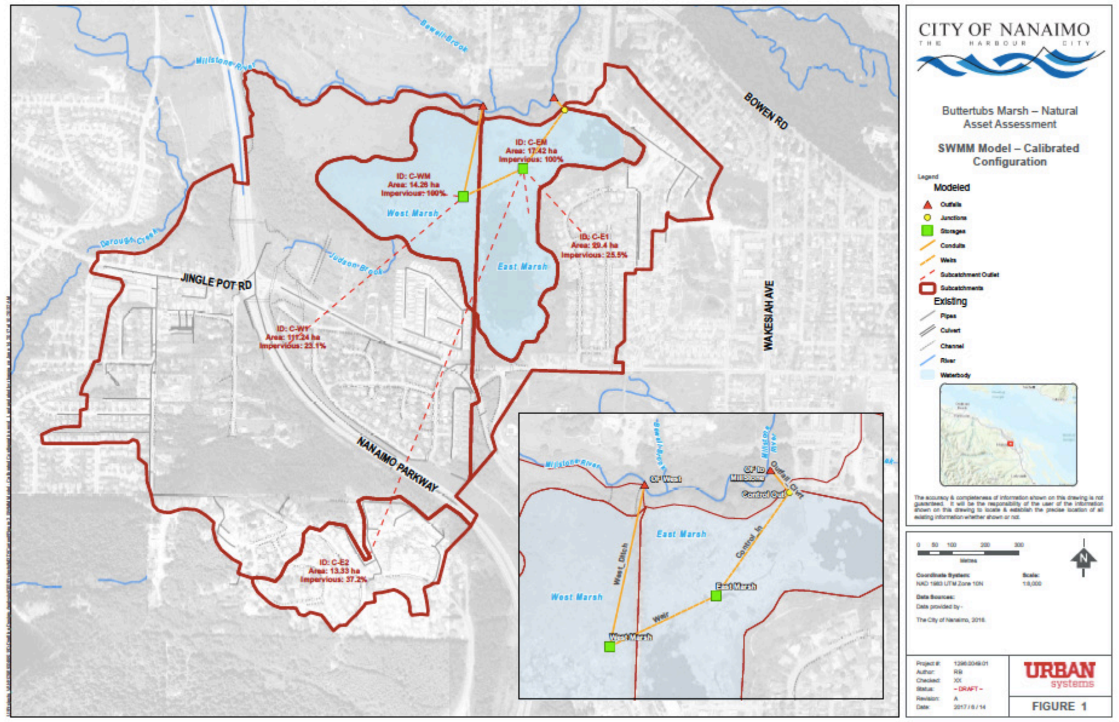
	West Marsh					East Marsh				
	Surface Area at Max Level (m2)	Starting Water Level (m)	Max Water Level (m2)	Storage Volume (m3)	Cost at $150 per m3	Surface Area at Max Level (m2)	Starting Water Level (m)	Max Water Level (m2)	Storage Volume (m3)	Cost at $150 per m3
Historic 100 year	85,560	56.79	57.01	18,230	$2,734,540	145,167	57.16	57.25	13,065	$1,959,755
Climate Change (median)	85,560	56.79	57.09	24,859	$3,728,919	145,167	57.16	57.29	18,872	$2,830,757
Climate Change (90th)	85,560	56.79	57.17	31,489	$4,723,297	145,167	57.16	57.32	23,227	$3,484,008

Sincerely,

URBAN SYSTEMS LTD.

G.D. SHIURMAN
Aug 28, 2017

Glen Shkurhan. P.Eng.
Project Leader



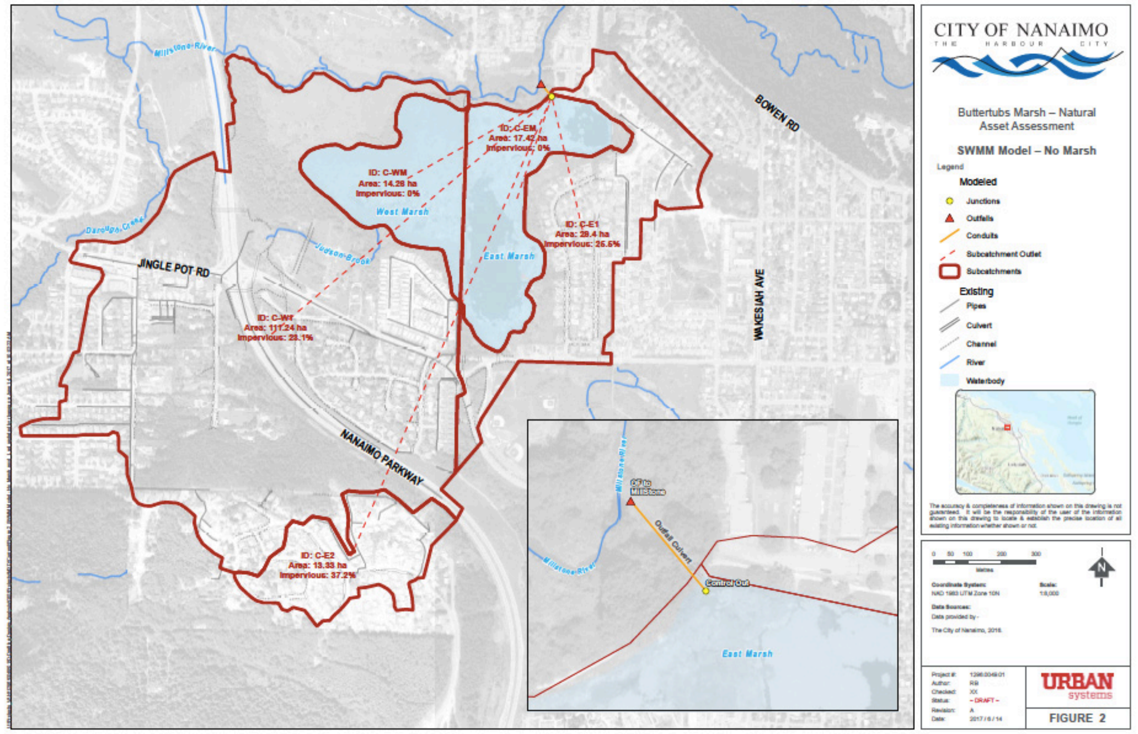
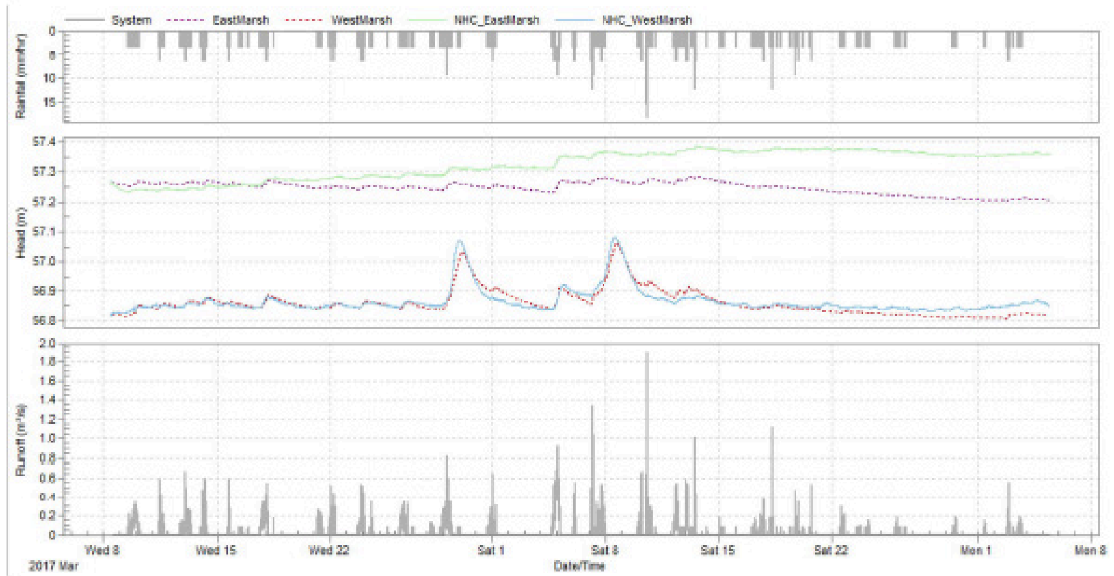


Figure 3 - Model Calibration Results



Note, dashed line are modeled, solid lines are observed per data provided by NHC.

MEMORANDUM
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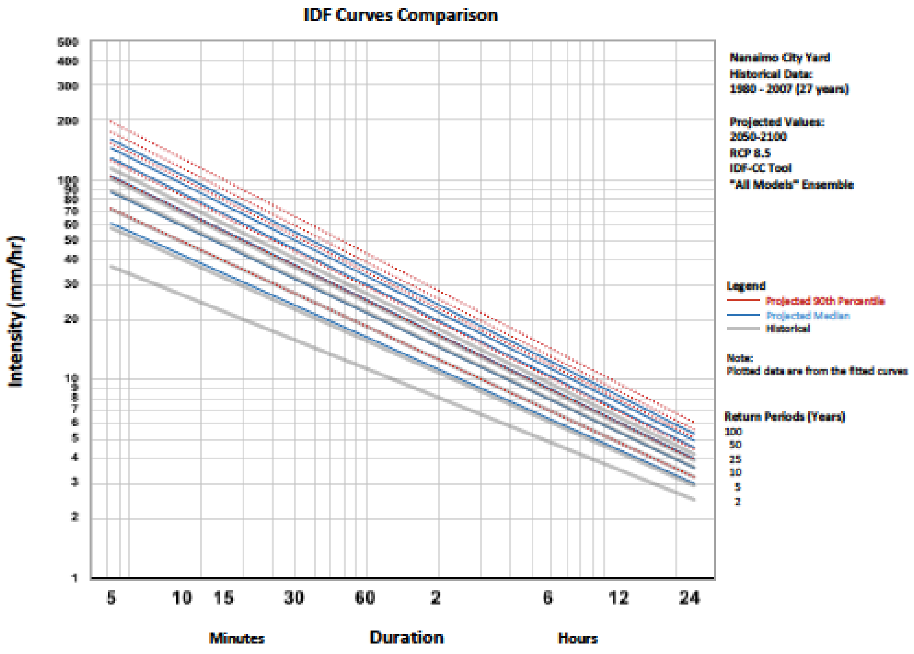
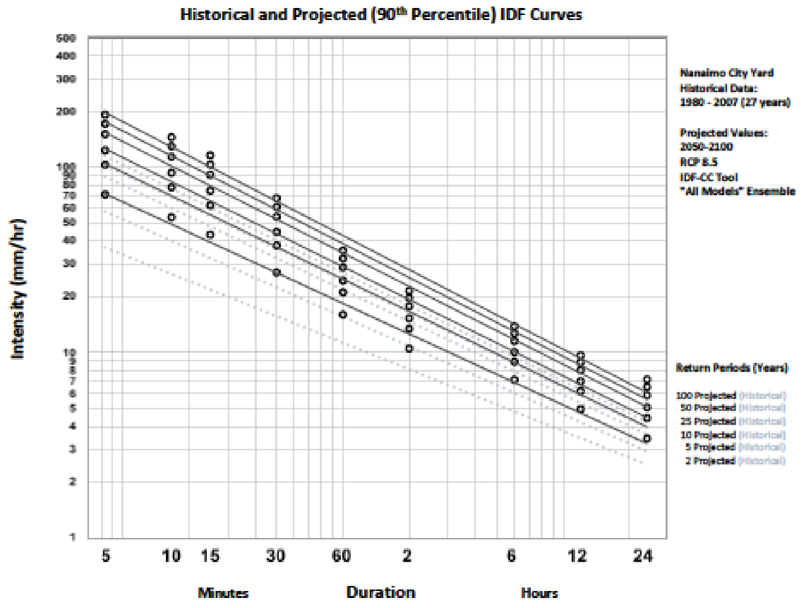
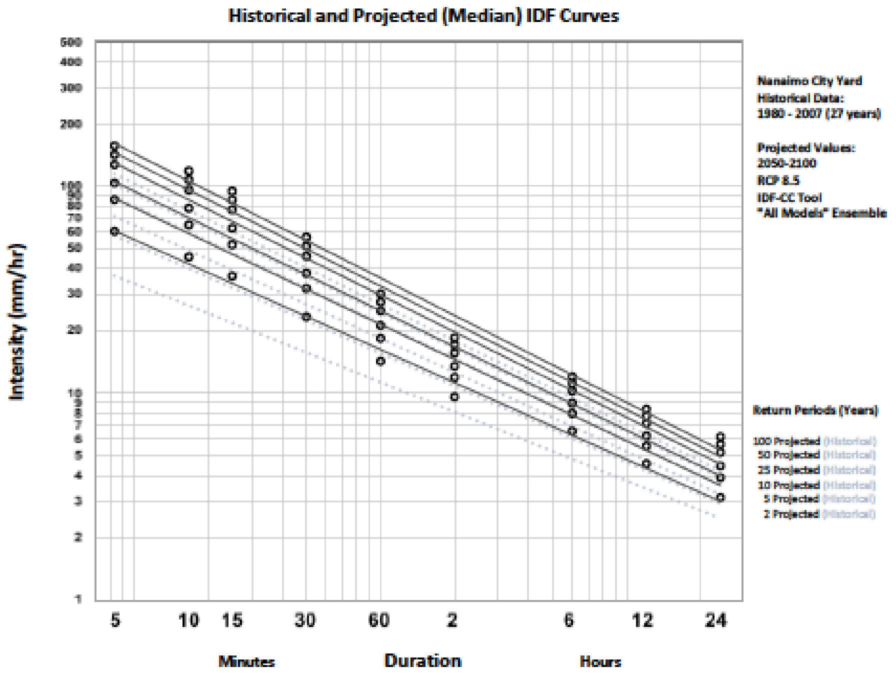
APPENDIX – Historic and Climate Change IDF's







Standard Environment Canada Tables for IDF Curves

Based on ECCC Station Nanaimo City Yard (1980-2007) and
IDF-CC Tool "All Models" Ensemble (2050-2100); RCP 8.5 - 90th Percentile Values

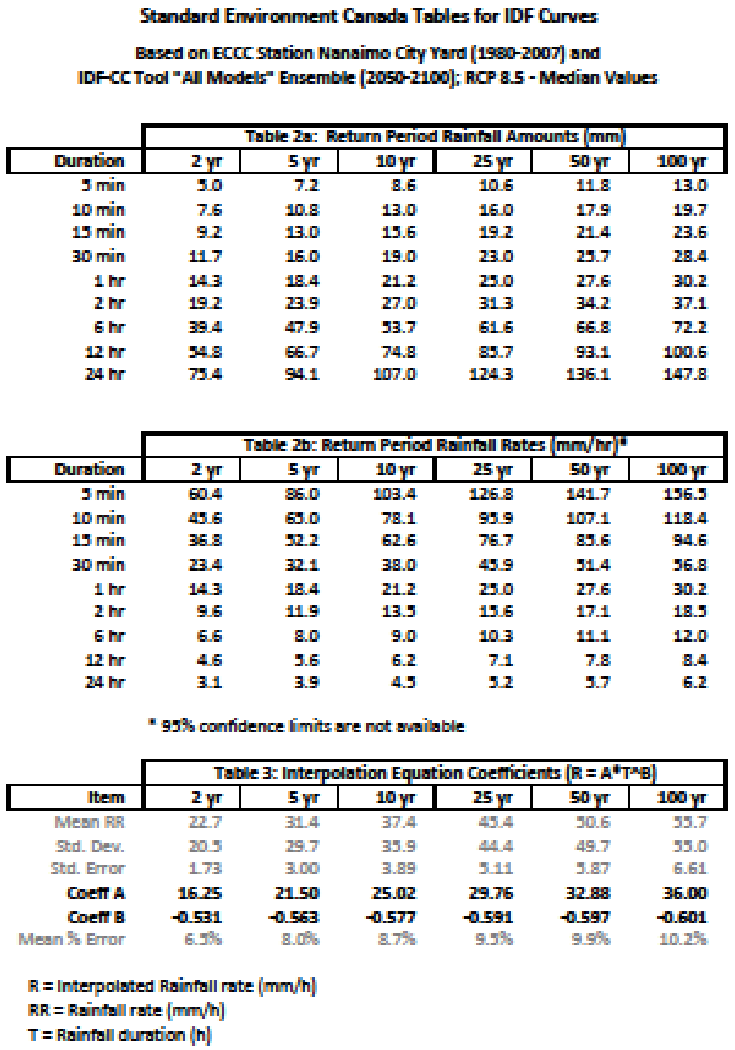
	Table 2a: Return Period Rainfall Amounts (mm)					
Duration	**2 yr**	**5 yr**	**10 yr**	**25 yr**	**50 yr**	**100 yr**
5 min	5.9	8.6	10.3	12.5	14.2	16.0
10 min	8.9	12.9	15.5	18.9	21.6	24.2
15 min	10.8	15.5	18.6	22.7	25.8	28.9
30 min	13.5	18.9	22.4	27.0	30.5	34.0
1 hr	16.0	21.1	24.4	28.8	32.2	35.5
2 hr	21.0	26.9	30.6	35.5	39.3	43.0
6 hr	42.8	53.5	60.3	69.4	76.3	83.1
12 hr	59.5	74.5	84.0	96.6	106.2	115.8
24 hr	82.7	106.5	121.7	141.5	156.8	171.9

	Table 2b: Return Period Rainfall Rates (mm/hr)*					
Duration	**2 yr**	**5 yr**	**10 yr**	**25 yr**	**50 yr**	**100 yr**
5 min	71.1	102.7	123.2	150.3	171.0	191.5
10 min	53.7	77.6	93.1	113.7	129.3	144.9
15 min	43.2	62.2	74.5	90.8	103.3	115.6
30 min	27.0	37.7	44.7	53.9	60.9	67.9
1 hr	16.0	21.1	24.4	28.8	32.2	35.5
2 hr	10.5	13.4	15.3	17.8	19.7	21.5
6 hr	7.1	8.9	10.1	11.6	12.7	13.9
12 hr	5.0	6.2	7.0	8.0	8.9	9.7
24 hr	3.4	4.4	5.1	5.9	6.5	7.2

* 95% confidence limits are not available

	Table 3: Interpolation Equation Coefficients (R = A*T^B)					
Item	**2 yr**	**5 yr**	**10 yr**	**25 yr**	**50 yr**	**100 yr**
Mean RR	26.3	37.2	44.2	53.4	60.5	67.5
Std. Dev.	24.4	35.7	43.1	52.9	60.3	67.7
Std. Error	2.27	3.86	4.92	6.35	7.45	8.57
Coeff A	**18.42**	**24.89**	**29.04**	**34.48**	**38.65**	**42.77**
Coeff B	**-0.548**	**-0.577**	**-0.589**	**-0.601**	**-0.608**	**-0.614**
Mean % Error	7.2%	8.7%	9.3%	10.1%	10.6%	11.0%

R = Interpolated Rainfall rate (mm/h)
RR = Rainfall rate (mm/h)
T = Rainfall duration (h)



Standard Environment Canada Tables for IDF Curves

Based on ECCC Station Nanaimo City Yard (1980-2007) and
IDF-CC Tool "All Models" Ensemble (2050-2100); RCP 8.5 - Median Values

Table 2a: Return Period Rainfall Amounts (mm)

Duration	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5 min	5.0	7.2	8.6	10.6	11.8	13.0
10 min	7.6	10.8	13.0	16.0	17.9	19.7
15 min	9.2	13.0	15.6	19.2	21.4	23.6
30 min	11.7	16.0	19.0	23.0	25.7	28.4
1 hr	14.3	18.4	21.2	25.0	27.6	30.2
2 hr	19.2	23.9	27.0	31.3	34.2	37.1
6 hr	39.4	47.9	53.7	61.6	66.8	72.2
12 hr	54.8	66.7	74.8	85.7	93.1	100.6
24 hr	75.4	94.1	107.0	124.3	136.1	147.8

Table 2b: Return Period Rainfall Rates (mm/hr)*

Duration	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5 min	60.4	86.0	103.4	126.8	141.7	156.5
10 min	45.6	65.0	78.1	95.9	107.1	118.4
15 min	36.8	52.2	62.6	76.7	85.6	94.6
30 min	23.4	32.1	38.0	45.9	51.4	56.8
1 hr	14.3	18.4	21.2	25.0	27.6	30.2
2 hr	9.6	11.9	13.5	15.6	17.1	18.5
6 hr	6.6	8.0	9.0	10.3	11.1	12.0
12 hr	4.6	5.6	6.2	7.1	7.8	8.4
24 hr	3.1	3.9	4.5	5.2	5.7	6.2

* 95% confidence limits are not available

Table 3: Interpolation Equation Coefficients (R = A*T^B)

Item	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
Mean RR	22.7	31.4	37.4	45.4	50.6	55.7
Std. Dev.	20.5	29.7	35.9	44.4	49.7	55.0
Std. Error	1.73	3.00	3.89	5.11	5.87	6.61
Coeff A	**16.25**	**21.50**	**25.02**	**29.76**	**32.88**	**36.00**
Coeff B	**-0.531**	**-0.563**	**-0.577**	**-0.591**	**-0.597**	**-0.601**
Mean % Error	6.5%	8.0%	8.7%	9.5%	9.9%	10.2%

R = Interpolated Rainfall rate (mm/h)
RR = Rainfall rate (mm/h)
T = Rainfall duration (h)

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