CITY OF
VANCOUVER

CITY CLERK'S DEPARTMENT
Access to Information

File No.: 04-1000-20-2017-335

October 13, 2017

s.22(1)

Dear s.22(1)

Re: **Request for Access to Records under the Freedom of Information and Protection of Privacy Act (the "Act")**

I am responding to your request of September 15, 2017 for:

> **Annexes to the "Coastal Flood Risk Assessment Report" prepared for the City by Northwest Hydraulic Consultants dated December, 2014. The report is available online at the following link http://vancouver.ca/files/cov/CFRA-Phase-1-Final_Report.pdf, but the Annexes at the end of the report are blank.**

All responsive records are attached.

Under section 52 of the Act you may ask the Information & Privacy Commissioner to review any matter related to the City's response to your request. The Act allows you 30 business days from the date you receive this notice to request a review by writing to: Office of the Information & Privacy Commissioner, info@oipc.bc.ca or by phoning 250-387-5629.

If you request a review, please provide the Commissioner's office with: 1) the request number assigned to your request (#04-1000-20-2017-335); 2) a copy of this letter; 3) a copy of your original request for information sent to the City of Vancouver; and 4) detailed reasons or grounds on which you are seeking the review.

Please do not hesitate to contact the Freedom of Information Office at foi@vancouver.ca if you have any questions.

Yours truly,

Cobi Falconer, FOI Case Manager, for

Cobi

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Encl.

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ANNEX A

DATA SUMMARY

TABLE A1. GIS INFORMATION ACQUIRED

Description	Source	Comment
Orthoimagery		
2011 orthophoto – 10cm resolution, MrSID format, captured May 13 & 18, 2011	CoV Open Data	Acquired for interim use, until 2013 imagery was available. Used for general reference and model mesh development.
2013 orthophoto – 7.5cm resolution, ECW format	CoV	Flight completed 17-May-2013; no information on start date. Used for general reference, base mapping and model mesh development.
Base mapping		
City boundary – polyline shapefile	CoV Open Data	
Parks – point, polygon shapefiles	CoV Open Data	
Streets – centrelines	CoV Open Data	
Railways – polyline shapefile	CoV Open Data	
Property parcels – polygon shapefile	CoV Open Data	
Port lands boundary – polygon shapefile	PMV	Approximate boundary only. NHC edited for display on maps.
Port road centrelines – polyline shapefile	PMV	
Skytrain lines and stations – polyline and point shapefiles	CoV Open Data	
Indian Reserve boundaries – polygon shapefile	GeoBC	
Topography		
2013 Lidar – various LAS, TIF and related files (including classified LAS points (bare earth and other classes), bare earth LAS points, bare earth DEM grid, full feature DSM grid, shaded relief); Lidar mission report; tile index PDF	CoV	Used for DEM for 2D hydraulic model development and 1D and 2D flood mapping.
Shoreline 2006/7 – polygon shapefile, done mostly for visual use, not measurement	CoV	Not sufficiently accurate for use in analysis and modelling.
Seawall – polyline shapefile	CoV	Not sufficiently accurate for use in analysis and modelling. City confirmed that no better data available.

Description	Source	Comment
East Fraserlands – PDF drawings and descriptive information about current development underway	CoV	Insufficient data for use in DEM revision.
Powell Street overpass construction – PDF files, CAD drawings	CoV	Used to modify current conditions DEM.
Seawall survey drawings, 2013 survey from Cambie Bridge to Jericho Beach – CAD drawings	CoV	Used for reference, but not directly incorporated in DEM.
Planned reconstruction of Pacific Blvd – CAD drawings, PDF (of vertical profile only)	CoV	Used to modify current conditions DEM. City indicated that other viaduct changes are still in planning stages and would just be applicable to future conditions (but no data provided).
DEM modifications – corrections to 2013 Lidar bare earth DEM for non-permanent features – PDF, DEM and TIF files	CoV	Used to modify current conditions DEM.
For bathymetric data, see Table A2 – Oceanographic Data Acquired, below.		
<u>Ground cover (for 2D hydraulic model mesh development and surface roughness)</u>		
Building footprints (2009) – polygon shapefile based on 2009 Lidar, with attributes for base elevation, top elevation, etc.; attribute definitions	CoV	Port lands are included.
Building footprints (2013)	CoV	Created by City as an update to the 2009 data.
Building footprints – future conditions (2041)	CoV	Created by City as a modification to the 2013 data.
2011 land use – polygons	CoV	Road areas are not mapped. Topological errors in data.
Current zoning – polygons	CoV Open Data	Used to develop future conditions surface roughness.
Tree canopy – polygon shapefiles based on 2013 Lidar	CoV	Stanley Park not included. Port lands are included.
Information on buildings, etc. in the Port lands – emails, marked up photos, marked up PDF maps	PMV	
<u>Storm water modelling</u>		
Sewer drainage network – polyline shapefile with attributes for pipe material, diameter, invert elevation	CoV	

Description	Source	Comment
Pump station locations – point shapefile with attributes for capacity, elevation	CoV	
Pump stations Stand-by Power Chart – PDF	CoV	
Catchment boundaries – polygon and polyline CAD file, no catchment attributes	CoV	
Sewer drainage network – polyline shapefiles with attributes for start and end elevation, soil type, pipe length, slope, diameter, type of material; indication of storm water system vs. sewer system	CoV	
Valve – point shapefile	CoV	
Manhole – point shapefile	CoV	
House connector – point shapefile	CoV	
Fitting – point shapefile	CoV	
Cover – point shapefile	CoV	
Basin – point shapefile	CoV	
<u>Previous flood mapping</u>		
Moffatt & Nichol (2012) "Evaluation of Flood Construction Levels" – PDF report & maps; polygon shapefiles	CoV	
BTAworks (2011) "The Local Effects of Global Climate Change in the City of Vancouver: A Community Toolkit and Atlas" – PDF report & maps	www.BTAworks.com	
<u>Historic Events</u>		
Forseth (2012) "Adaptation to Sea Level Rise in Metro Vancouver: A Review of Literature for Historical Sea Level Flooding and Projected Sea Level Rise in Metro Vancouver" – report prepared for the SFU Adaptation to Climate Change Team, PDF document	CoV	
2012 King Tide photos and videos from the LiveSmart BC King Tides Photo Initiative	LiveSmart BC, Vancouver Sun	Used to map flood extents during 2013 King Tide at a few specific locations.
2012 King Tide photos, near Sea Bus terminal – JPEG and PDF, includes some surveyed elevations	CoV	Used to map flood extents during 2013 King Tide at a few specific locations.

Description	Source	Comment
2012 King Tide photos, at the Jericho Sailing Centre – JPEG	Jericho Sailing Centre Association	Used to map flood extents during 2013 King Tide at a few specific locations.
Water, wind and wave measurements		
Murdock et al. (2012) "Georgia Basin: Projected Climate Change, Extremes, and Historical Analysis" – Word report	CoV	Report appendix includes weather station info
CoV and Metro Vancouver weather station locations – CSV files	CoV	
See Table A2 – Oceanographic Data Acquired, below.		
High Level Vulnerability Assessment		
Social Vulnerability Mapping – polygon shapefile; created by Natural Resources Can (Murray Journeay), field names added by CoV	CoV	See also paper by Susan Cutter.
Preliminary vulnerability mapping – mapping and analysis by J.O'Leary at CoV – GIS layers, PNG maps, Word reports	CoV	
Key infrastructure point locations – point shapefile of fire, police, health, school, community, park locations	CoV	Used on flood depth maps.
Emergency gathering locations on downtown peninsula – point shapefile	CoV	
Emergency access routes on downtown peninsula – polyline shapefile	CoV	
Emergency evacuation routes on downtown peninsula – polyline shapefile	CoV	
Bikeways – polyline shapefile	CoV Open Data	
Greenways – polyline shapefile	CoV Open Data	
Downtown historic railway – polyline shapefile	CoV Open Data	
Truck routes – polyline shapefile	CoV Open Data	
Drinking fountains – point shapefile	CoV Open Data	
Heritage sites – point shapefile	CoV Open Data	
Homeless shelters – point shapefile	CoV Open Data	
Non-market housing – point shapefile	CoV Open Data	
Public art – point and polyline shapefiles	CoV Open Data	

Description	Source	Comment
Business Improvement Areas – polygon shapefile	CoV Open Data	
City projects sites and streets – point and polyline shapefiles	CoV Open Data	Locations of current projects.
City owned property – point shapefile	CoV Open Data	
Fraser River dikes – polyline shapefile	BC Ministry of Environment	Obtained and updated by NHC for previous studies, starting 2008. No new data available from Province. Suitable for 1:20,000 or smaller scale mapping.
Agricultural Land Reserve (ALR) areas – polygon shapefile	BC Agricultural Land Commission	
Cultural assets – point shapefile with detailed attributes on facility name, type, location	CoV	
Group care and preschool – point shapefile with detailed attributes on facility name, location, type, capacity	CoV	
Social services – point shapefile with detailed attributes on facility name, location, contacts, etc.	CoV	
Pools, rinks and Pitch and Putt – point shapefile with detailed attributes on type, name, address	CoV	City-owned properties (e.g., does not include Robson Square ice rink).
Fraser River public land ownership – polygon shapefile with property parcel attributes including owner and address, etc.	CoV	Does not include federal lands.
Fraser River Archaeological Sites – polygon shapefile	Archaeology Branch, MFLNRO	

Notes:

CoV = City of Vancouver

CoV Open Data = City of Vancouver Open Data Catalogue, http://vancouver.ca/your-government/open-data-catalogue.aspx

PMV = Port Metro Vancouver

TABLE A2. OCEANOGRAPHIC DATA ACQUIRED

Data Type	Location	Duration	Source
Tidal			
Harmonic Constituents - Derived constituents	7634 - North Arm Fraser	n.a.	CHS
Harmonic Constituents - Derived constituents	7635 - Point Grey	n.a.	CHS
Harmonic Constituents - Derived constituents	7625 – Sea Island	n.a.	CHS
Harmonic Constituents - Derived constituents	7795 - Point Atkinson	n.a.	CHS
Harmonic Constituents - Derived constituents	7735 - Vancouver	n.a.	CHS
Harmonic Constituents - Derived constituents	7743 - Cascadia Terminals	n.a.	CHS
Harmonic Constituents - Derived constituents	7747 - Stanovan	n.a.	CHS
Harmonic Constituents - Derived constituents	7755 - Port Moody	n.a.	CHS
Harmonic Constituents - Derived constituents	7765 - Deep Cove	n.a.	CHS
Hourly Measurements - Water level	Point Atkinson	1914-2013	DFO
Hourly Measurements - Water level	Vancouver	1919-2013	DFO
Hourly Measurements - Water level	Victoria	1910-2013	DFO
Hourly Measurements - Water level	Tofino	1910-2013	DFO
Meteorological			
Hourly Measurements - Wind speed, run, direction	Saturna Island CS	unknown	EC
Hourly Measurements - Wind speed, run, direction	Tsawwassen Ferry	unknown	EC
Hourly Measurements - Wind speed, run, direction	Vancouver Int'l Airport	unknown	EC
Hourly Measurements - Wind speed, run, direction	Sandheads CS	unknown	EC
Hourly Measurements - Wind speed, run, direction	Point Atkinson	unknown	EC
Hourly Measurements - Wind speed, run, direction	Vancouver harbour CS	unknown	EC
Hourly Measurements - Wind speed, run, direction	Entrance Island	unknown	EC
Hourly Measurements - Wind speed, run, direction	Merry Island Lightstation	unknown	EC

Data Type	Location	Duration	Source
Hourly Measurements - Wind speed, run, direction	Sisters Island	unknown	EC
Hourly Measurements - Wind speed, run, direction	Ballenas Island	unknown	EC
Hourly Measurements - Wind speed, run, direction	Grief Point	unknown	EC
Hourly Measurements - Wind speed, run, direction	Comox A	unknown	EC
Hourly Measurements - Wind speed, run, direction	Cape Mudge	unknown	EC
Hourly Measurements - wind speed, direction	T2 - Kitsilano	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	T6 - Second Narrows	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	T9 - Port Moody	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	T14 - Burnaby Mountain	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	T23 - Burnaby Capitol Hill	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	T24 - Burnaby North	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	T35 - Horseshoe Bay	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	S9 - Harbour/Clark Drive Mobile Trailer	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	S5 - BCIT Marine Campus	2003-2012	Air Quality, MV
Hourly Measurements - wind speed, direction	S1 - Vancouver Yacht Club (Coal Harbour, Vancouver)	2003-2012	Air Quality, MV
Wave			
Hourly Measurements - Sig Wave Height, Peak Period	Halibut Bank	1992-2013	DFO

Data Type	Location	Duration	Source
Hourly Measurements - Sig Wave Height, Peak Period	Point Grey	1978-1979	DFO
Hourly Measurements - Sig Wave Height, Peak Period	Sturgeon Bank	1974-1976	DFO
Hourly Measurements - Sig Wave Height, Peak Period	Fisherman's Cove	1979-1980	DFO
Hourly Measurements - Sig Wave Height, Peak Period	West Vancouver	1972-1974	DFO
Bathymetry			
Survey Data - Depth	Point Grey	n.a.	PMV
Survey Data - Depth	Iona	n.a.	PMV
Survey Data - Depth	2nd Narrows	n.a.	PMV
Survey Data - Depth	Centerm and Van Term	n.a.	PMV
Survey Data - Depth	Canada Place	n.a.	PMV
Survey Data - Depth	Centerm and Van Term	n.a.	PMV
Survey Data - Depth	Second Narrows	n.a.	PMV
10 ensemble multibeam data - Depth	Pt Atkinson to 2nd Narrows full coverage	n.a.	CHS
single beam tracks – Depth	Pt Atkinson to 2nd Narrows shoreline	n.a.	CHS
Bathymetry from CHS Charts (smoothed)	Outside of Burrard Inlet	n.a.	CHS

Notes:

CHS = Canadian Hydrographic Service

DFO = Department of Fisheries and Oceans

EC = Environment Canada

MV = Metro Vancouver

PMV = Port Metro Vancouver

Chart contours or simple interpolation of available data was used to cover gaps in bathymetric data (specifically, at the west end of Spanish Banks and the west side of Stanley Park).

TABLE A3. GIS DATA DELIVERABLES

Category	Title	Description	Key Attribute Description	Folder	File
Flood Model Inputs	Upland model extents	Fraser River and Burrard Inlet upland modelling areas. Polygon shapefile.	Descrip = identifies which modelling area (Fraser or Burrard).	GIS\ModelExtent\	uplandModelExtent2.shp
Flood Model Inputs	Burrard Inlet overland model zones	Burrard Inlet upland modelling zones. Polygon shapefile. (Polyline shapefile developed for cartographic purposes only.)	ZoneID = unique ID number for each zone; ZoneName = short name for each zone; ZoneDescr = description of zone.	GIS\ModelExtent\	overlandModelZones1.shp, overlandModelZones1ln_Carto.shp
Flood Model Inputs	Burrard Inlet shoreline	Shoreline digitized at approximately 1:500 scale based on 2013 orthophoto and Lidar data. Follows water side of seawall; along natural beaches, follows high tide line (best estimate); follows water side of built walkways and large stuctures built over the water (but some smaller structures were ignored). Polyline shapefile.	LineID = unique ID number for each line segment.	GIS\Shoreline\	Shoreline_NHC2013c.shp
Flood Model Inputs	DEM 2013 - Fraser River	Digital Elevation Model used for flood mapping. Input: 2013 bare earth Lidar. No bathymetric data included. Modifications: flattened to remove non-permanent features such as construction excavations and sand and gravel piles. Raster file in Esri Grid format.	Elevation in metres.	GIS\Topography\DEM2013\	gLiFraser_03
Flood Model Inputs	DEM 2013 - Burrard Inlet	Digital Elevation Model used for 2D hydraulic modelling and flood mapping. Inputs: 2013 bare earth Lidar, 2013 full feature Lidar, bathymetry. Modifications: used full feature Lidar and manual interpolation to fill in some areas that were missing from bare earth Lidar, particularly along shoreline, under bridges, and at Canada Place; added Powell Street overpass based on construction drawings; made modifications at Pacific Blvd and Griffiths Way based on plans for viaduct removal and road configuration; added bathymetry; flattened to remove non-permanent features such as construction excavations and sand and gravel piles; added pedestrian and road underpasses at Stanley Park Causeway east of Lost Lagoon; flattened interpolated surface of Lost Lagoon; manually interpolated bathymetry under some pile structures along the Inner Harbour shoreline; flattened interpolated surface of Canada Place. Raster file in Esri Grid format.	Elevation in metres.	GIS\Topography\DEM2013\	gDEM_11
Flood Model Inputs / Base Mapping	Current (2013) building footprints	Includes minor modifications to data supplied by the City. Polygon shapefile. (Subset polygon shapefiles for Fraser and Burrard developed for cartographic purposes only.)	Refer to City for definition of attributes.	GIS\Structures\	footprints 2013_region.shp, footprints2013_Burrard1.shp, footprints2013_Fraser1.shp

Category	Title	Description	Key Attribute Description	Folder	File
Flood Model Inputs / Base Mapping	Future (2041) building footprints	Compiled from data supplied by the City. Includes minor modifications. Polygon shapefile. (Subset polygon shapefiles for Fraser and Burrard developed for cartographic purposes only.)	n.a.	GIS\Structures\	footprints2041.shp, footprints2041_Burrard1.shp, footprints2041_Fraser1.shp
Flood Model Inputs	Burrard Inlet 2D hydraulic model mesh polygons	2D hydraulic model mesh polygons developed by NHC based on: City's land use; City's tree canopy; City's current and future building footprints (generalized and aggregated); correspondence from PMV; field observations; and detailed review of 2013 orthophoto, Google Map, Google Street View, Bing Maps and other sources. Describes land cover, which was used to model surface roughness. Note that the final mesh used in Telemac may have been modified slightly in comparison to this version. Polygon shapefile.	Landclass = land cover, based on City's land use classes and other inputs.	GIS\Modelling\	Mesh20140314.shp
Flood Model Validation	King Tide 2012 flood extents	Approximate flood extents of 2012 King Tide, mapped from photos. Esri file geodatabase format.	n.a.	GIS\HistoricEvents\KingTide_Dec2012\	KingTide_Dec2012.gdb
Flood Model Inputs	Fraser River model cross sections	Cross sections from the Fraser River 1D hydraulic model, extracted for this project's study area, with modelled water levels attached. Polyline shapefile.	Branch = name of Fraser River branch; Chainage = chainage, in metres, of cross-section along the branch; MaxWL_R? = Scenario ? water level from 1D model results.	GIS\FloodMappingFraser\	LFModelXS3_NorthArm1.shp
Flood Mapping Results	Fraser River flood depth grids - excluding freeboard	Flood depth raster data layers for the Fraser River, based on 1D hydraulic model results and the 2013 DEM. One raster for each modelling Scenario (5 total). No freeboard included. One-metre horizontal grid resolution. Esri grid format.	Depths in metres.	GIS\FloodMappingFraser\	gDep_r?2
Flood Mapping Results	Fraser River flood depth grids - including freeboard	Flood depth raster data layers for the Fraser River, based on 1D hydraulic model results and the 2013 DEM. One raster for each modelling Scenario (5 total). 60 cm freeboard included. One-metre horizontal grid resolution. Esri grid format.	Depths in metres.	GIS\FloodMappingFraser\	gDep_r?5
Flood Mapping Results	Fraser River flood depth categories - ArcGIS layer file	Flood depth categories (in centimetres), descriptions and colours. Based on a modifcation of the Japanese national standard. Categories are: 0 to 50 cm (yellow, RGB: 255/255/0); 50 to 100 cm (green, 85/255/0); 100 to 200 cm (light blue, 115/178/255); 200 to 500 cm (medium blue, 0/112/255); > 500 cm (dark blue, 0/38/115). ArcGIS 10.1 layer file (can be applied to any ArcGIS raster).	Flood depths in centimetres, with detailed written descriptions.	GIS\FloodMappingFraser\	Flood Depths (cm).lyr
Flood Mapping Results	Fraser River flood extent polygons - including freeboard	Flood extent polygons derived from 1D hydraulic model water level results and the 2013 DEM. Freeboard included. One shapefile per modelling Scenario. Polygon shapefiles.	Descrip = describes model scenario	GIS\FloodMappingFraser\	floodpoly_R?3.shp

Category	Title	Description	Key Attribute Description	Folder	File
Flood Mapping Results	Fraser River water level isolines	Water level isolines based on 1D hydraulic model results. Lines are located near key roads. One shapefile per modelling Scenario. Polyline shapefiles.	Id = unique ID number for each isoline; Name = name of isoline based on nearby street; WL_R?_fb = modelled water level in metres plus 0.6 m freeboard.	GIS\FloodMappingFraser\	WL_lines1_R?.shp
Flood Mapping Results	Fraser River water level - thalweg intersection points	Water level - thalweg intersection points. For cartographic purposes. Point shapefile.	Id = unique ID number for each isoline; Name = name of isoline based on nearby street.	GIS\FloodMappingFraser\	WL_StreamPts1.shp
Flood Mapping Results	Burrard Inlet flood depth grids - excluding freeboard	Flood depth raster layers for Burrard Inlet, based on 2D hydraulic model results and the 2013 DEM. One raster for each modelling Scenario and for each Burrard Inlet modelling zone (20 total). No freeboard included. One-metre horizontal grid resolution. Esri grid format.	Depths in metres.	GIS\FloodMappingBurrard\	gDep3_z?r?
Flood Mapping Results	Burrard Inlet flood depth categories - ArcGIS layer file	Flood depth categories (in centimetres), descriptions and colours. Based on a modifcation of the Japanese national standard. Categories are: 0 to 50 cm (yellow, RGB: 255/255/0); 50 to 100 cm (green, 85/255/0); 100 to 200 cm (light blue, 115/178/255); 200 to 500 cm (medium blue, 0/112/255); > 500 cm (dark blue, 0/38/115). ArcGIS 10.1 layer file (can be applied to any ArcGIS raster).	Flood depths in centimetres, with detailed written descriptions.	GIS\FloodMappingBurrard\	Flood Depths (cm).lyr
Flood Mapping Results	Burrard Inlet flood extent polygons - modelled area excluding freeboard	Flood extent polygons derived from 2D hydraulic model water level results and the 2013 DEM. One shapefile per modelling Scenario. Polygon shapefiles.	Descrip = describes model scenario and final water level (metres geodetic).	GIS\FloodMappingBurrard\	FloodExtents_R?.shp
Flood Mapping Results	Burrard Inlet flood extent polygons - freeboard area	Estimated additional flood extent due to freeboard, based on the contour (from the 2013 DEM) corresponding to the modelled water level + 0.6 metres. One shapefile per modelling Scenario. Polygon shapefiles.	Descrip = describes model scenario and final water level (metres geodetic).	GIS\FloodMappingBurrard\	FloodExtentsFBOnly_R?.shp
Flood Mapping Results	Burrard Inlet flood extent polygons - modelled area plus freeboard area	Modelled flood extent combined with freeboard extent. One shapefile per modelling Scenario. Polygon shapefiles.	Descrip = describes model scenario and final water level (metres geodetic).	GIS\FloodMappingBurrard\	FloodExtentsWFB_R?.shp
Flood Mapping Results	Burrard Inlet Scenario 5 water level boundaries	Boundaries indicating where water levels change for Scenario 5. For cartographic purposes. Polyline shapefile.	n.a.	GIS\FloodMappingBurrard\	WLBoundaries_Z2R5.shp
Flood Mapping Results	Burrard Inlet wave effect boundary	Boundary indicating where wave effects need to be accounted for, either by adding 0.3 m to the FCL, or by conducting a local wave effect study. Wave effects apply seaward of the boundary. The boundary is based on a generalization of modelled wave amplitude for the predominant storm direction. Only done for Scenario 3. Polyline shapefile.	Descrip = describes wave effect boundary and wave direction used to derive it; ModelZone = Burrard Inlet modelling zone ID number; Scenario = modelling Scenario number.	GIS\FloodMappingBurrard\	WaveEffectBndry1_R3.shp
Flood Mapping Results	Burrard Inlet wave effect critical areas	Locations where modelled waves of 0.3 m amplitude could impact structures. Only done for Scenario 3. Point shapefile.	n.a.	GIS\FloodMappingBurrard\	WaveEffectCriticalAreas1.shp

Category	Title	Description	Key Attribute Description	Folder	File
Base Mapping	City of Vancouver boundary	City boundary supplied by City. Polyline and polygon shapefiles	n.a.	GIS\AdminBnds\	city_boundary.shp, city_boundary_poly.shp
Base Mapping	Vancouver PMV boundary	PMV jurisdictional boundary, modified by NHC for map display. The original boundary is too complex to be clearly displayed on the flood maps. Polyline shapefile.	Descrip = describes line.	GIS\AdminBnds\	PMV_bndryapprox1.shp
Base Mapping	Indian reserve boundaries	Indian reserves within study area, selected from GeoData BC data set. See metadata file, CLAB_INRES_metadata.html. Polygon shapefile.	NGLSHNM = name of Indian Reserve.	GIS\AdminBnds\	CLAB_INRES_sel1.shp
Base Mapping	East Fraserlands boundary	Digitized by NHC based on information provided by City. Polygon shapefile.	n.a.	GIS\AdminBnds\	EastFraserlands_poly1.shp
Base Mapping	Critical structures	Critical structure points, supplied by City. Includes: care facilities, community centres, emergency operations centre, fire stations, libraries, neighbourhood houses, parks, police stations, post-secondary schools, public schools. Modified by NHC (e.g., added missing features). Point shapefile.	Name = name of site or facility; Civic_Addr = address; Infra_Type = infrastructure type (e.g., Park, Public School, etc.).	GIS\Places\	infrastructure_combined.shp
Base Mapping	Burrard Inlet internal water bodies	Water bodies on land and within flood plain (e.g., ponds, Lost Lagoon), mapped based on 2013 Lidar and orthophoto. Used to show areas where flood depth is not known. Polygon shapefile.	Name = name of water body.	GIS\Hydrography\	InternalWaterBodies1.shp
Base Mapping	Fraser River river polygon	Fraser River water area polygon, used to display areas where flood depths are not modelled/mapped. For cartographic purposes only. Polygon shapefile.	n.a.	GIS\Hydrography\	Fraser_WaterPoly2.shp
Base Mapping	City of Vancouver 2013 orthophoto image	City of Vancouver 2013 colour orthophoto, 7.5 cm resolution. ECW image file.	n.a.	GIS\Imagery\	No file supplied - City has data
Base Mapping	Esri satellite imagery	2010 Ikonos imagery from Esri and GeoEye. For cartographic purposes only; used to fill in gaps in City of Vancouver imagery. JPEG and TIFF image files.	n.a.	GIS\Imagery\EsriWorldImagery\	EsriWorldImage_*.*
Base Mapping	District of North Vancouver orthophoto imagery	District of North Vancouver 2013 colour orthophotos, 10 cm resolution. For cartographic purposes only; used to fill in gaps in City of Vancouver imagery. ECW image files.	n.a.	GIS\Imagery\	No files supplied - can be obtained from http://geoweb.dnv.org/data/
Cartography	Fraser River flood depth maps	ArcGIS Map Document for production of the Fraser River flood depth maps. Five map sheets at 1:5,000 scale, scenarios 1 to 5. See notes in Layout View for detailed map production instructions. Uses Data Driven pages tool. ArcGIS 10.1 SP1 MXD file.	n.a.	GIS\	300227_Map_FloodFraser.mxd
Cartography	Burrard Inlet flood depth maps	ArcGIS Map Document for production of the Burrard Inlet flood depth maps. Eigth map sheets at 1:5,000 scale, scenarios 1 to 5. See notes in Layout View for detailed map production instructions. Uses Data Driven pages tool. ArcGIS 10.1 SP1 MXD file.	n.a.	GIS\	300227_Map_BurrardFloodDepth.mxd

Category	Title	Description	Key Attribute Description	Folder	File
Cartography	Burrard Inlet flood extent maps	ArcGIS Map Document for production of the Burrard Inlet flood extent maps. Four map sheets at 1:10,000 scale, scenarios 1 to 5. See notes in Layout View for detailed map production instructions. Uses Data Driven pages tool. ArcGIS 10.1 SP1 MXD file.	n.a.	GIS\	300227_Map_BurrardFloodExtent.mxd
Cartography	Burrard Inlet flood extent maps - HHWLT + Year 2100 SLR	ArcGIS Map Document for production of the Burrard Inlet flood extent maps showing high high water large tide with Year 2100 1.0 m SLR. Four map sheets at 1:10,000 scale. See notes in Layout View for detailed map production instructions. Uses Data Driven pages tool. ArcGIS 10.1 SP1 MXD file.	n.a.	GIS\	300227_Map_BurrardHHWLT2100FloodExtent.mxd
Cartography	Image masks	Image mask polygons. For cartographic purposes only. Polygon shapefiles.	n.a.	GIS\Imagery\	Ortho2013_Mask.shp, OrthoDNV2013_Mask.shp
Cartography	Map annotation	Flood map annotation layers created by NHC. Esri file geodatabase.	n.a.	GIS\Carto\	MapAnno.gdb
Cartography	Burrard depth mapping fill and mask	Features created for cartographic purposes only. Polygon shapefiles.	n.a.	GIS\Carto\	BurrardDepthMappingFillPoly.shp, BurrardDepthMappingMaskPoly.shp
Cartography	Cartographic dummy features	Features created for cartographic purposes only. Polyline shapefile.	n.a.	GIS\Carto\	DummyLine1.shp
Cartography	Map tiles	Map tile polygons for generating Fraser and Burrard flood map series. For cartographic purposes only. Polygon shapefiles.	n.a.	GIS\Carto\	MapTiles_Burrard5K1.shp, MapTiles_Burrard10K1.shp, MapTiles_Fraser5K1.shp
Cartography	City of Vancouver logo	Logo image provided by City of Vancouver. For cartographic purposes only. JPEG image file.	n.a.	GIS\Carto\	van-emblem-cmyk-2011.jpg
Cartography	Fraser River water level legend element	Image used as part of Fraser River depth map legends. For cartographic purposes only. JPEG image file.	n.a.	GIS\Carto\	WLLabel_forLegend2.jpg
Fraser River High Level Strategy	Fraser River land use areas	Land use areas along the Fraser River, defined by The Arlington Group for the Fraser River High Level Strategy.	Id = unique ID number for each area; Location = name of for each area; FigScale = scale used for producing report figures.	GIS\Vulnerability Assessment\	FraserLUAreas1.shp
Fraser River High Level Strategy	Fraser River flood protection - dikes	Existing dikes on the Fraser River within the City. Original data obtained by NHC for previous studies, starting 2008 (no new data available from Province), and intended for small scale (1:20,000) mapping. Modified based on field observations (The Arlington Group). Polyline shapefile.	Refer to GeoBC for attribute definitions.	GIS\FloodProtection\	dikes_FraserRiverCoV1.shp

Category	Title	Description	Key Attribute Description	Folder	File
Fraser River High Level Strategy	Fraser River flood protection - other flood protection	Fraser River non-dike flood protection structures, based on 2013 orthophoto and field observations (The Arlington Group). Includes: rock revetment; sheet pile wall; flood protection under construction; other flood protection - undetermined quality. Polyline shapefile.	Id, Location = ID and name of Fraser River land use area where the structure is located; Prot_Type = protection structure type.	GIS\FloodProtection\	floodProtection_FraserRiverCoV1.shp
False Creek Stormwater Modelling	False Creek land use	Land use mapping for False Creek, based on the City's current (2011) land use mapping with some modifications.	TIA = total impervious area; EIA = effective impervious area	GIS\StormwaterModelling\Landuse\	landuse_NHC_w_added_area.shp
False Creek Stormwater Modelling	False Creek modelled features (conduits, junctions, outfalls, subcatchments)	Features (conduits, junctions, outfalls and subcatchments) included in the False Creek stormwater model. Based on data provided by the City.		GIS\StormwaterModelling\ModelledFeatures\	Conduits.shp, Junctions.shp, Outfalls.shp, Subcatchments.shp

ANNEX B

OCEAN MODEL DEVELOPMENT

1 INTRODUCTION

The frequency of occurrence of static water level events was assessed using the Empirical Simulation Technique [3]. This method is recommended by the Coastal Hydraulics Laboratory (of the US Army Corps of Engineers) and FEMA for frequency related studies.

The EST User Guide [3] describes EST:

> *"The Empirical Simulation Technique (EST) [is a] procedure for simulating multiple life-cycle sequences of nondeterministic multiparameter systems such as storm events and their corresponding environmental impacts. The EST is based on a "Bootstrap" resampling-with-replacement, interpolation and subsequent smoothing technique in which random sampling of a finite length database is used to generate a larger database. The only assumption is that future events will be statistically similar in magnitude and frequency to past events. The EST begins with an analysis of historical events that have impacted a specific locale. The selected database of events is then parameterized to define the characteristics of the event and impacts of the event. Parameters that define the storm are referred to as input vectors. Response vectors define storm related impacts such as surge elevation, inundation, shoreline/dune erosion, etc. These input and response vectors are then used as a basis for generating life-cycle simulations of storm-event activity with corresponding impacts."*

The "extratropical approach" to EST is employed; the deterministic component of water levels (the tides) is separated from the probabilistic component (the tidal residual). In this approach the tidal residual time series is used to build a database of large-residual (storm) events. A peak-over-threshold technique is used to identify the storm events. The storm database is used to calculate a storm probability density function and a statistic tail is added to the distribution. From the storm database, the average storm frequency and duration is calculated. From the tide signal time series, a tidal water level probability distribution is calculated. Then, using the database of storm events, the average frequency of events and the probability distribution of storm water levels and tidal water levels may be combined randomly to estimate one realization of storm activity over a given time period (e.g. 10,000 years). This realization may be ordered to give an estimate of the return period of each storm event in the realization. If many realizations are produced (say 1,000), they may be averaged to give a mean water level for each return period, as well as confidence limits.

There are two main advantages of the EST over traditional extreme value analysis methods: First, the splitting of the tide and residual signal allows the available data to be better utilized. If a large storm occurs at low tide, typically it might not stand out in the water level record. But in reality, that storm has a similar chance of occurring at high tide as in low tide – the EST accounts for this situation by allowing for multiple realizations of the same storm-event. Second, unlike other extreme value analysis methods, EST makes no assumptions about the shape of the probability distribution. The only assumption is that future storm activity will be similar to past storm activity.

The following sections detail the steps of the EST analysis.

1.1 IDENTIFICATION OF LARGE TIDAL RESIDUAL EVENTS

Large tidal residual events were identified using a 'peak-over-threshold' technique. In this technique events are found by searching for periods where the tidal residual exceeds a specified threshold. **Figure 1** shows the tidal residual for Zone 1 during the December 17, 2012 event as well as the threshold for peak identification and the peak itself.

In this work a threshold of 0.5-0.6 m was used, depending on the shoreline zone. This level was selected with three goals in mind: a) to only capture very large events, b) to capture as many legitimate large events as possible, and c) to minimize the interdependency of events. Further to goal (c), only events more than 3 days apart were retained. These criteria resulted in an average storm rate of approximately 9 events per year and a database of 450 storm events for each shoreline zone.

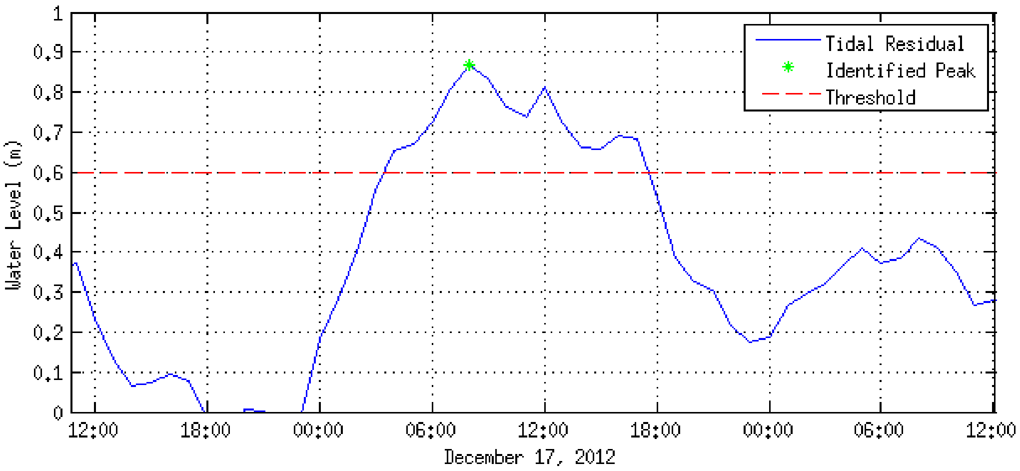


Figure 1. **Tidal Residual during in Zone 1 December 17, 2012. The threshold for peak identification is shown in red; the peak is shown in green.**

1.2 PROBABILITY OF LARGE TIDAL RESIDUAL EVENTS

For each shoreline zone, the database of storm events was used to calculate a probability density function (pdf). The empirically calculated pdf was augmented with a statistical tail to account for possible storm events not captured in the hind-cast. The tail was added by fitting a generalized pareto distribution (GPD) to the storm event distribution, but only the tail (beyond the extent of the hind-cast data) was added to the pdf. The probability distribution for Zone 1 is given in **Figure 2**.

Both tides and storm surge have a seasonal trend, with larger and more frequent events in the winter months and smaller, shorter duration events in the summer months. This correlation must be accounted for in the statistical analysis.

The correlation has been accounted for here by assessing the storm surge and tidal characteristics by month. The mean event frequency during each month for Zone 1 is given **Figure 3**. As expected, large tidal residual events are much more probable during the winter months.

Here the storm duration is defined as the number of hours that the tidal residual is within 10cm of the peak residual. The average storm duration in Zone 1 is given in **Figure 4**. As expected, events are longer in duration during the stormier winter months and shorter during the calmer summer months.

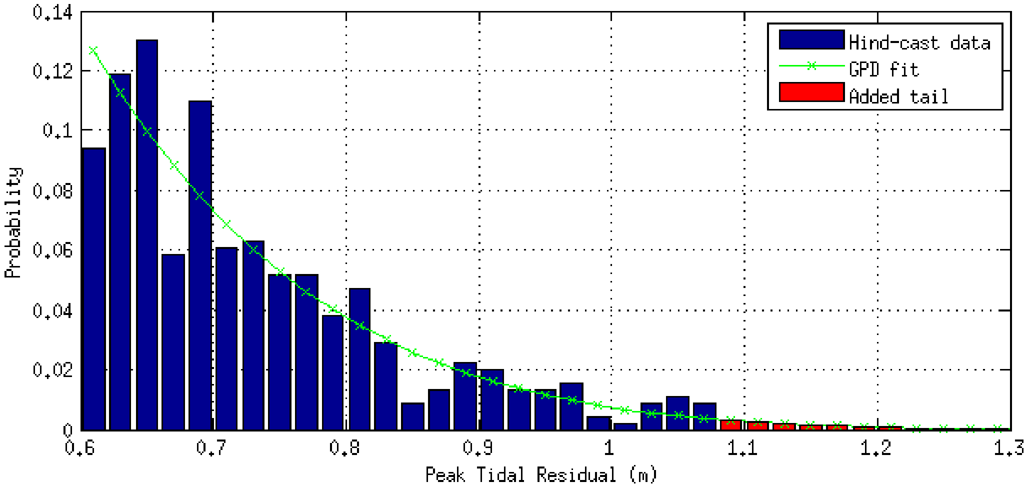


Figure 2. **Storm tidal residual probability function for Zone 1. A threshold on 0.6 m and a bin-width of 0.2 m were used.**

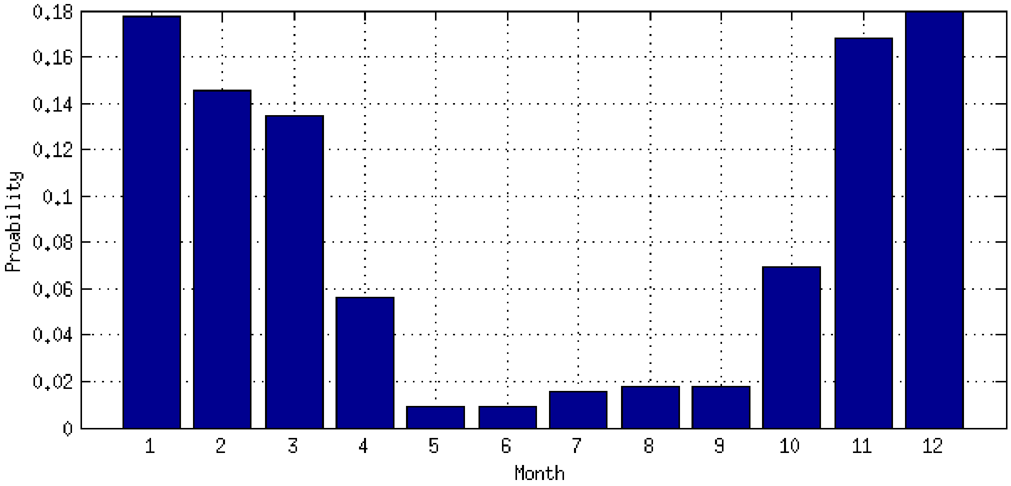


Figure 3. **Probability of large tidal residual events occurring in each month.**

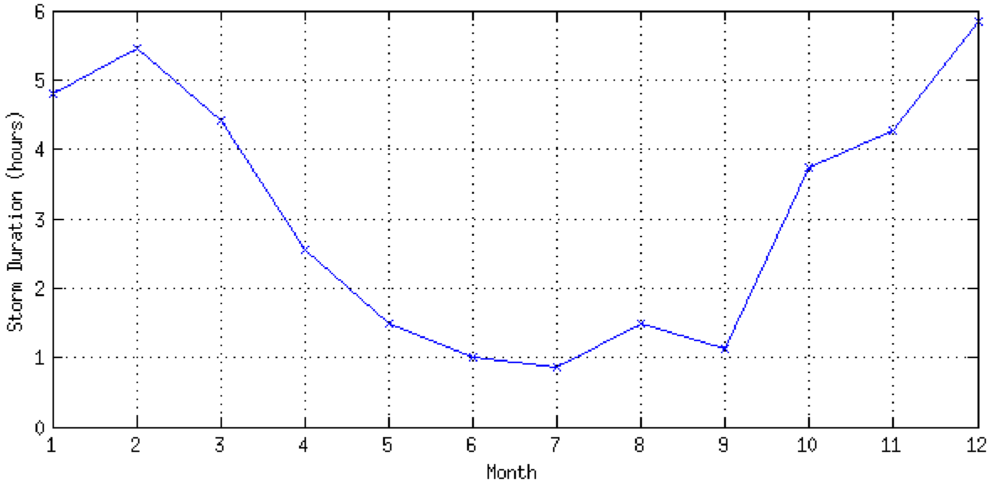


Figure 4. **Average storm duration by month at Zone 1.**

1.3 TIDAL WATER LEVEL

For the EST process we need to estimate the tidal water level during each large residual event. First the tidal water level was predicted through a 19 year tidal epoch. The time series was then filtered by a windowed maximum. The window size was made equal to the average storm duration during the month the window presently resided in. For example, during January the filtering window would be 5 hours wide; during June the window would be 1 hour wide. This filtering ensures that when a tidal water level is selected for a storm event, it corresponds to maximum tidal elevation within 10cm of the peak tidal residual.

The resulting population of filtered water levels (**Figure 5**) will be discussed further in the following section covering the EST calculations.

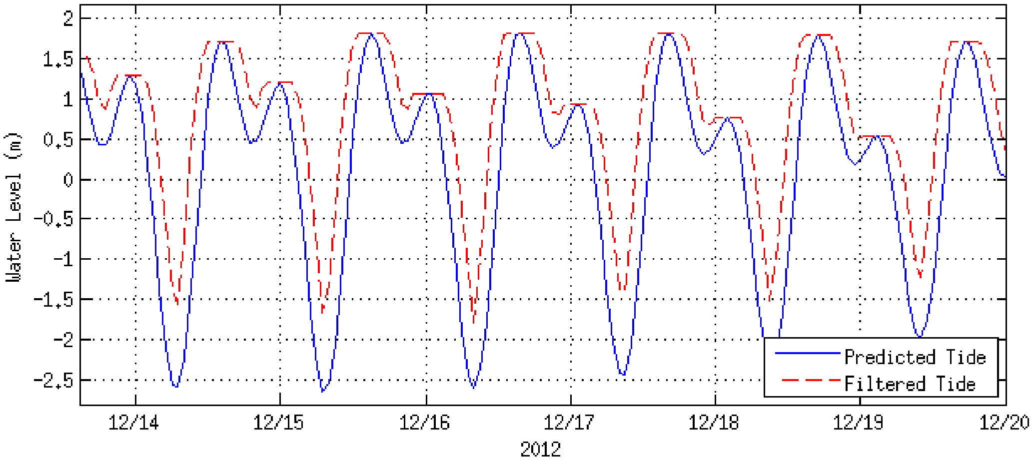


Figure 5. **Predicted and filtered tide - Zone 1, December 2012.**

1.4 EST CALCULATIONS

The Empirical Simulation Technique is a complex iterative process which recreates multiple realizations of the storm record. Each realization of storm record is, given the available information of storm probability, a possible record of storm activity.

A schematic of the calculation process is given in **Figure 6** and the steps are detailed here:

1. First select the length of the record to simulate and the number of realizations.
2. For each simulated record 'j' of storm activity:
    a. Select the number of storms per year in from a Poisson distribution with a mean equal to the mean number of storms per year observed in the hind-cast. The selected storm frequency and the duration of the simulation are then used to calculate the number of storms in the realization.
    b. For each storm 'i' in realization 'j':
        i. Select the storm month randomly based on the storm frequency pdf (**Figure 3**).
        ii. Given the storm month, select the tidal water randomly from the population of filtered water levels that fall within that month.
        iii. Select a tidal residual randomly based on the tidal residual pdf (**Figure 2**).
        iv. Add the tidal residual to the tidal water level to give a peak static water level for storm 'i' of realization 'j'.
3. Perform extreme value analysis on each simulated storm record to produce a set of frequency – response curves.
4. From the set of frequency response curves, calculate the mean curve and confidence limits.

The EST results for Zones 1-4 are given in **Figure 7**. Each individual grey line is a frequency – response estimate of static water level from a single realization of the storm record. The blue line is the mean estimate of the static water level frequency - response curve and the red lines are the 5% and 95% confidence limits.

The static water levels used in specifying the Designated Flood Levels in **Section 4.6** were interpolated from the mean frequency – response curve calculated for each shoreline zone.

It should be noted that the confidence limits in **Figure 7** do not account for the uncertainty in the fit of the statistical tail to the tidal residual distribution (see **Figure 2**).

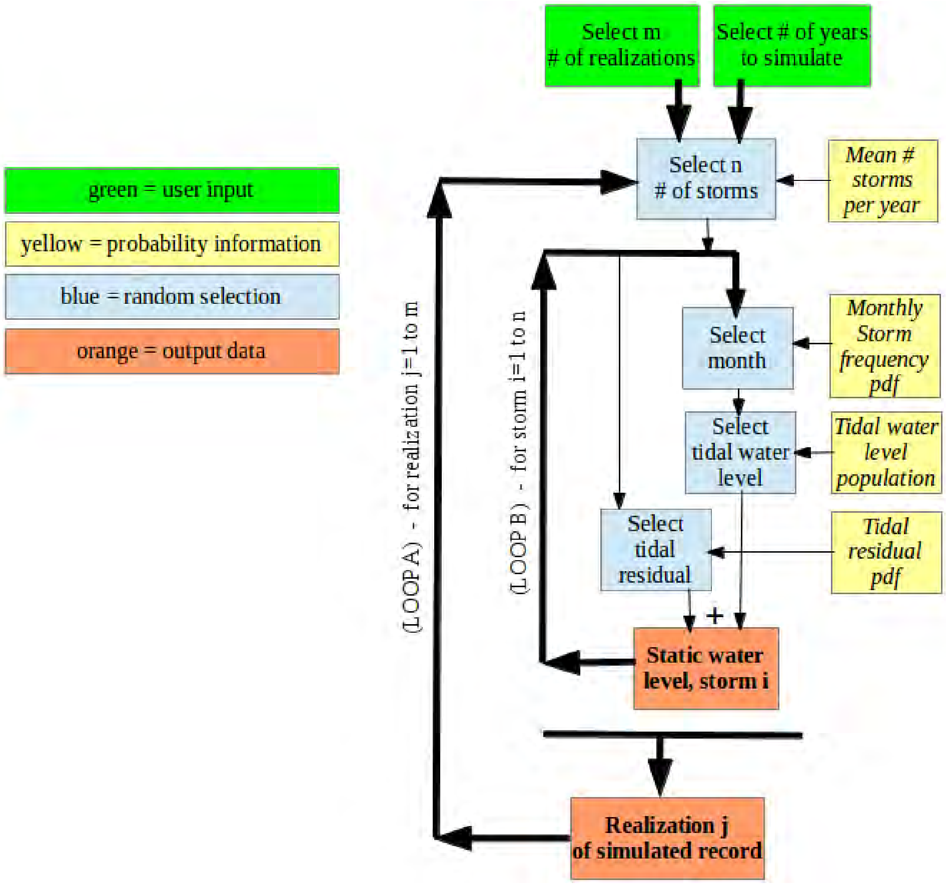
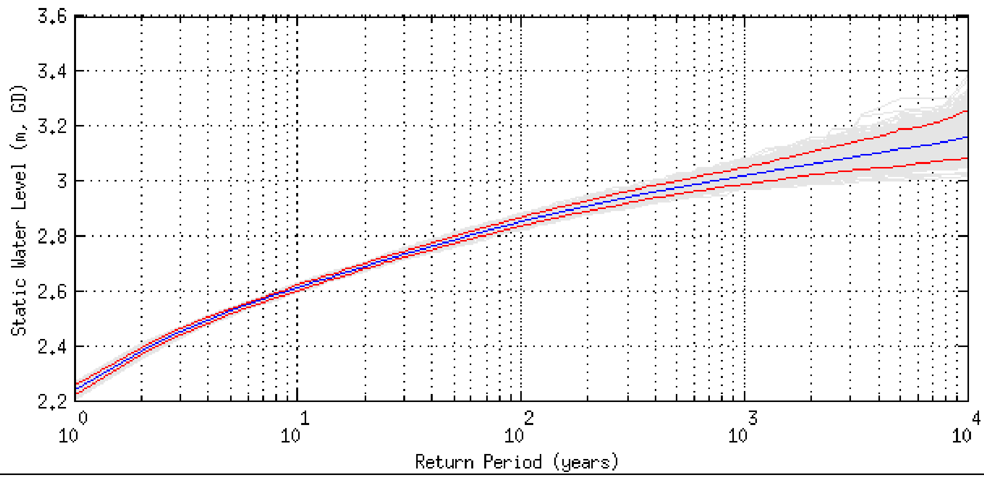


Figure 6. A schematic of the EST process.

(a)



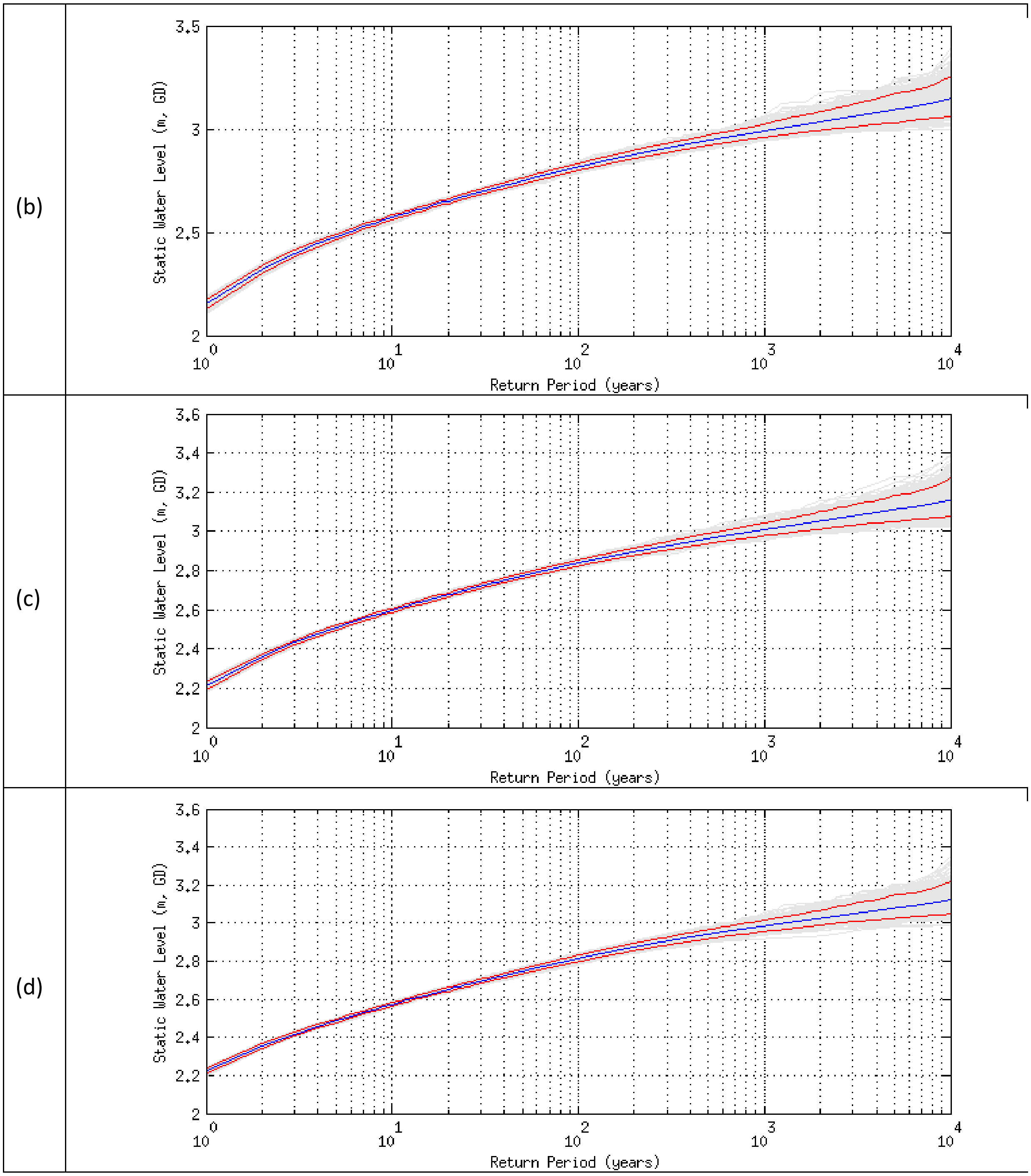


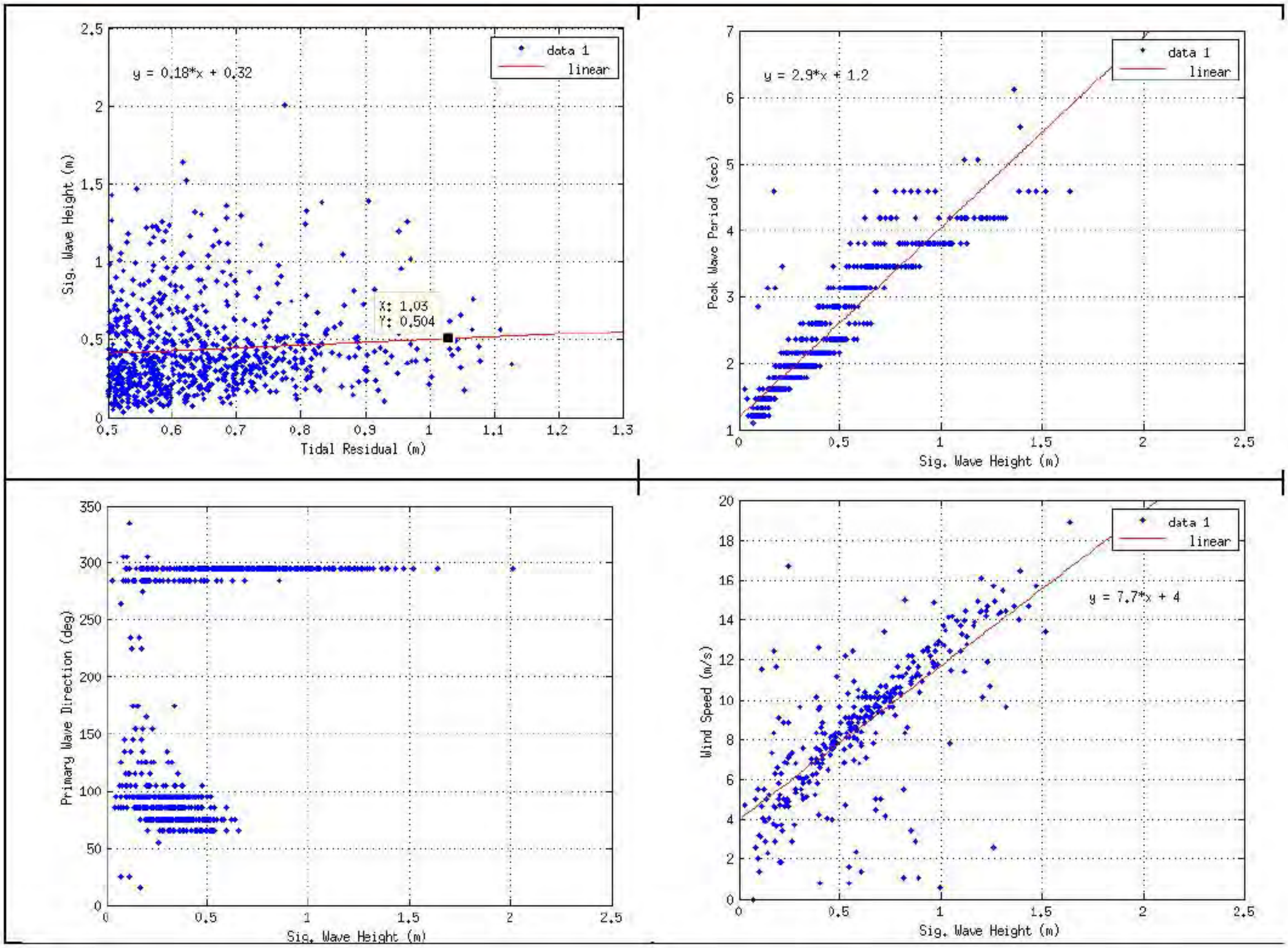
Figure 7. **Static water level frequency - response curve for Zone 1-4 (a-d). Grey lines give individual realizations; blue line gives mean estimate; red lines give the 5% and 95% confidence limits.**

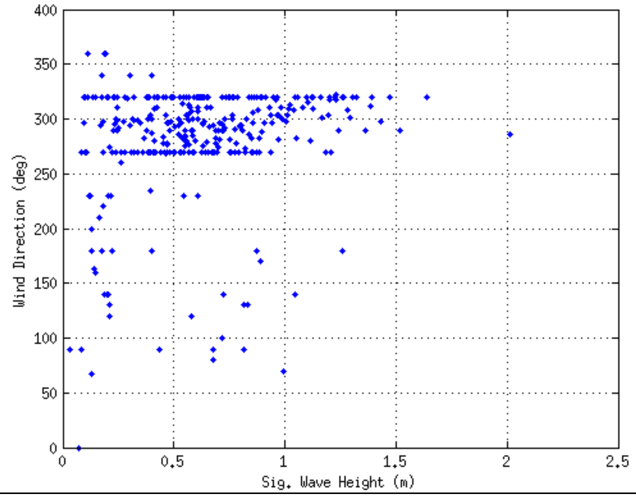
2 OVERLAND WAVE BOUNDARY CONDITIONS

The wave conditions during each extreme event scenario were selected by examining the significant wave height concurrent to large tidal residual events in the hind-cast. The concurrent conditions were plotted and a linear relationship was fit to the data. This fitted linear relationship was then used to specify the offshore significant wave height for the extreme event scenario simulations. Subsequently the peak wave period was selected based on the relationship between wave height and period. The wave direction was selected as the direction typical of large events. The wind speed was selected based on the relationship between wave height and wind speed. The wind direction was selected as the direction typical during large events.

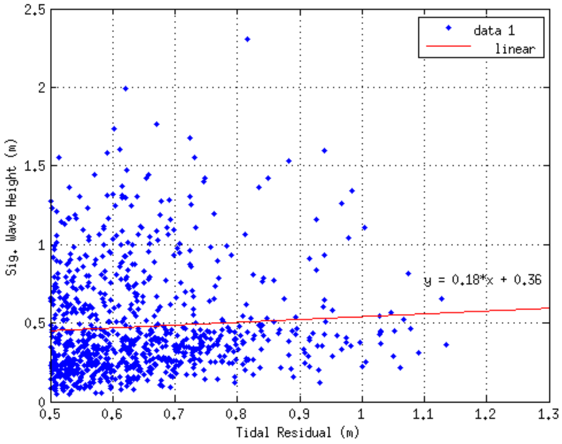
The following sections give provide the plots that were used to specify the overland wave modelling boundary conditions for each of the shoreline zones. Note that two different storm scenarios were used for Zone 4; the first from the NE and the second from the NW. The conditions used in each zone and modelling scenario are summarized in **Section 4.7**.

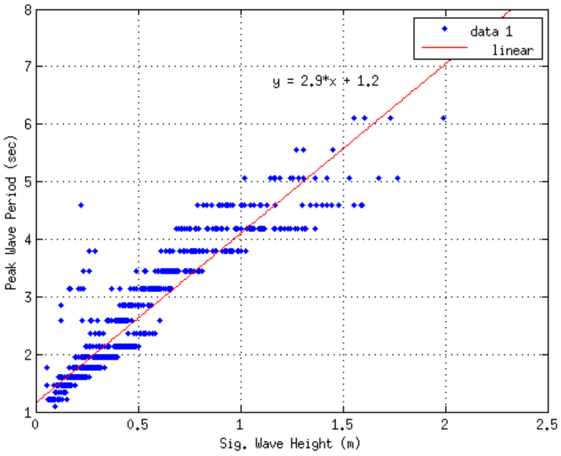
2.1 OVERLAND WAVE MODEL BOUNDARY CONDITIONS – ZONE 1

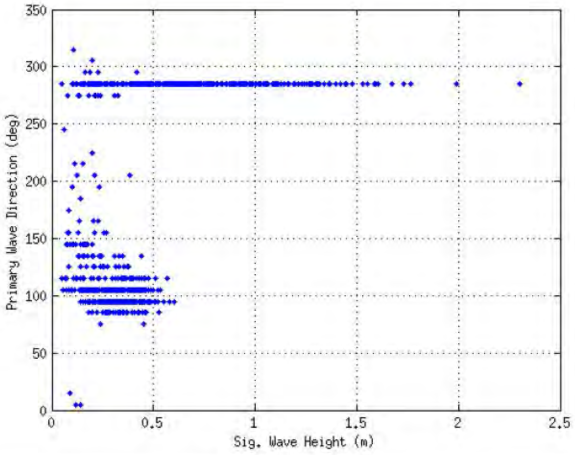


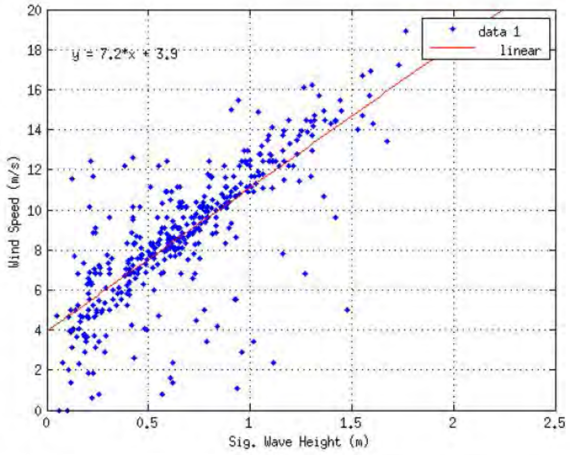


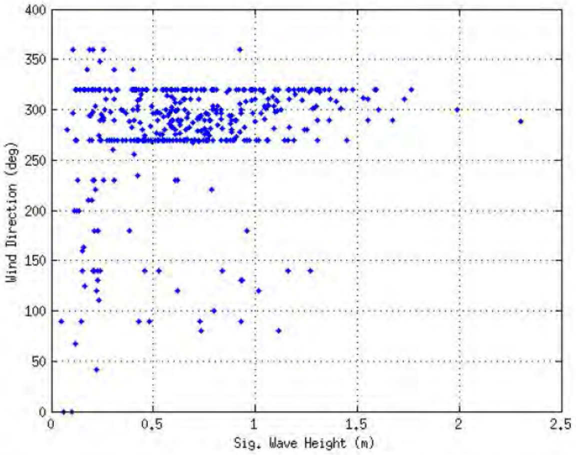
2.2 OVERLAND WAVE MODEL BOUNDARY CONDITIONS – ZONE 2



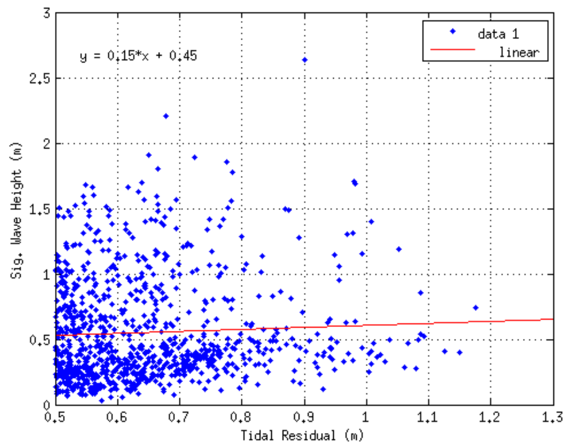


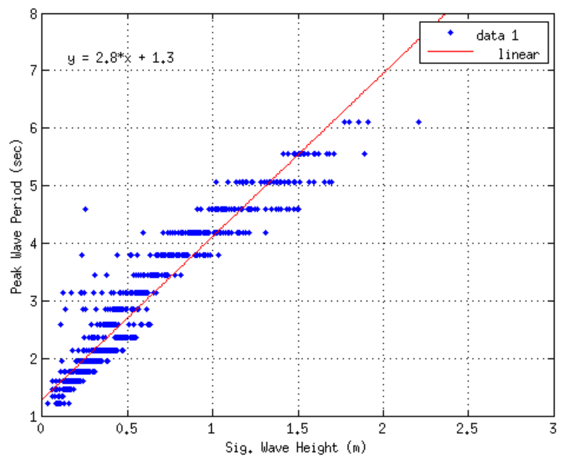

Primary Wave Direction (deg)
350
300
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
Sig. Wave Height (m)

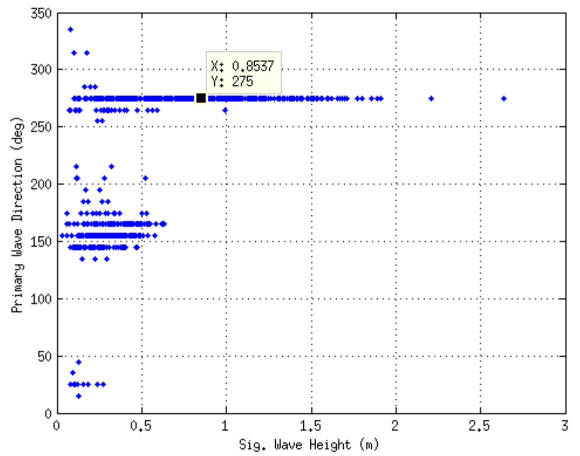

y = 7.2*x + 3.9
data 1
linear
Wind Speed (m/s)
20
18
16
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
Sig. Wave Height (m)

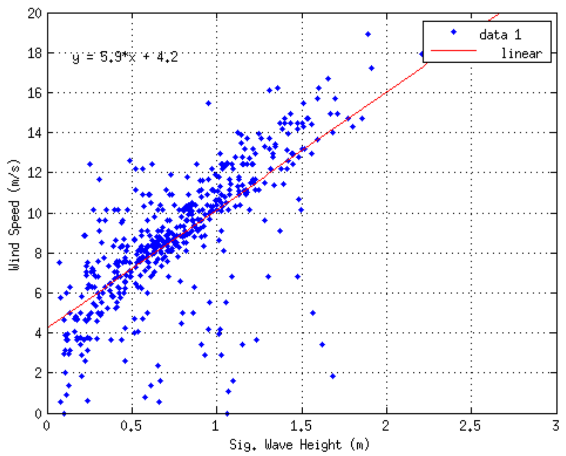

Wind Direction (deg)
400
350
300
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
Sig. Wave Height (m)

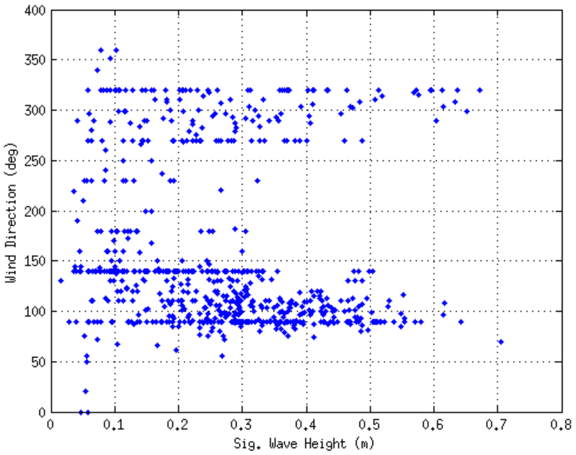
2.3 OVERLAND WAVE MODEL BOUNDARY CONDITIONS – ZONE 3



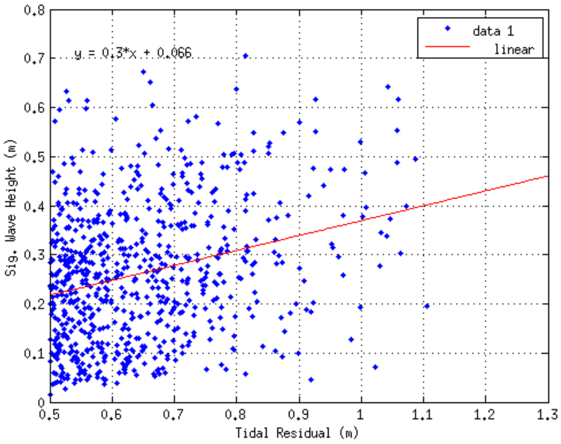


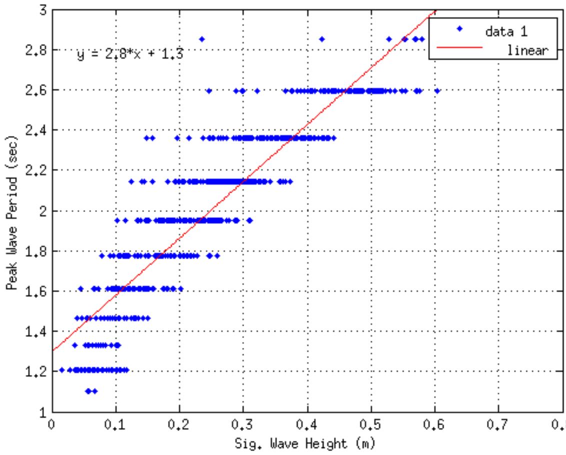


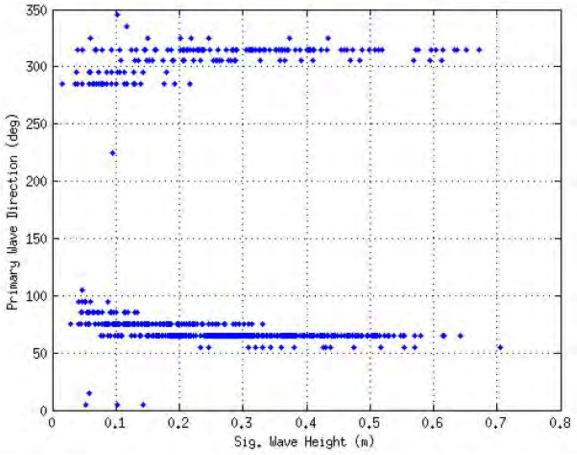


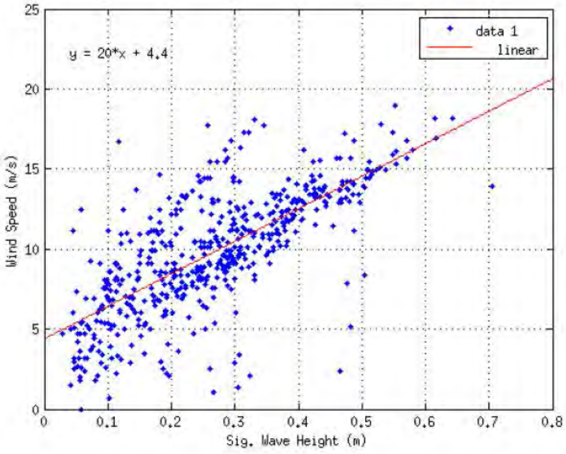


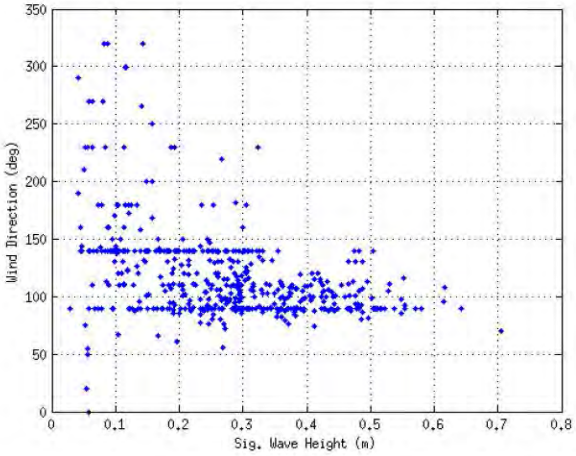
2.4 OVERLAND WAVE MODEL BOUNDARY CONDITIONS – ZONE 4-1 (WIND/WAVES FROM NE)



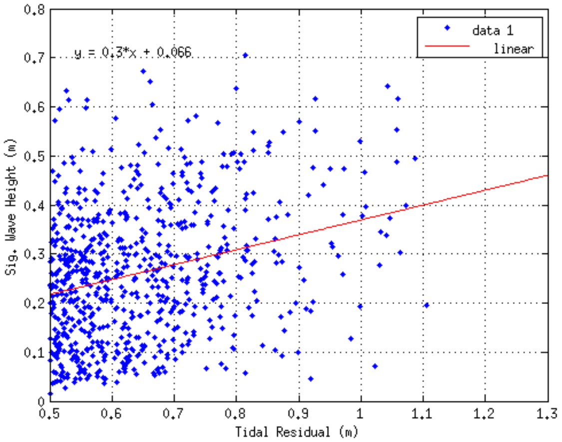


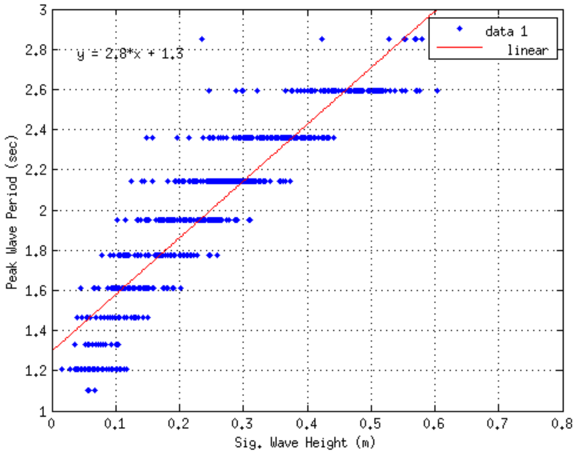

Primary Wave Direction (deg)
Sig. Wave Height (m)
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

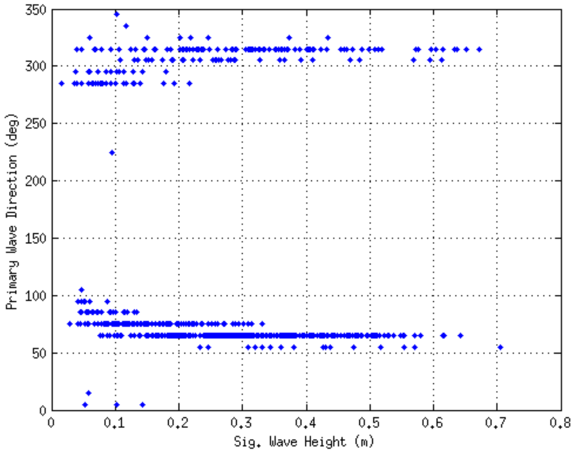

Wind Speed (m/s)
Sig. Wave Height (m)
y = 20*x + 4.4
data 1
linear
0
5
10
15
20
25
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

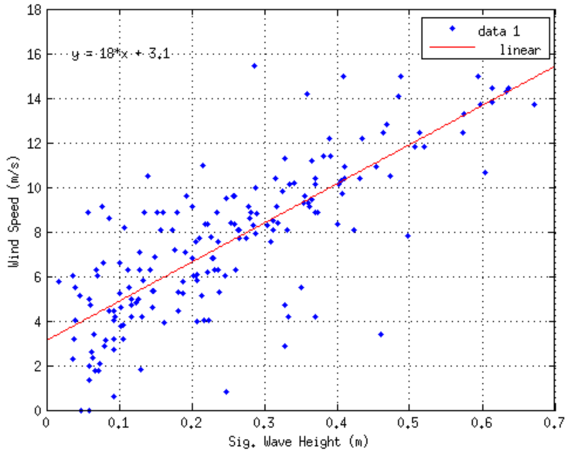

Wind Direction (deg)
Sig. Wave Height (m)
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

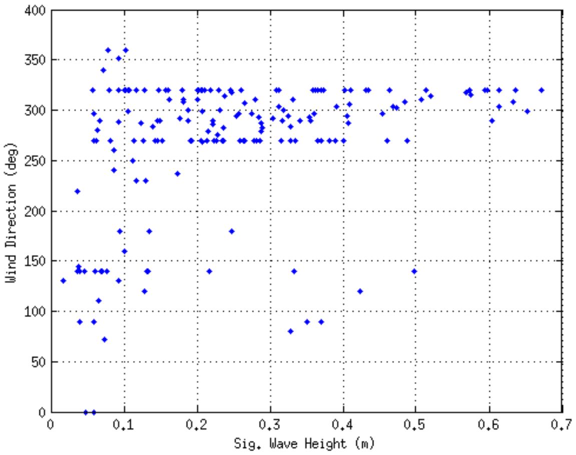
2.5 OVERLAND WAVE MODEL BOUNDARY CONDITIONS – ZONE 4-2 (WIND/WAVES FROM NW)











3 WAVE MODEL SETUP

This section details the specifics of the setup of the wave modelling software used for the coastal hind-cast and for the overland wave modelling. For both tasks, Version 40.91 of the SWAN wave modelling software [5] was used in unstructured mode.

3.1 THE COASTAL HIND-CAST

The general configuration of the wave model and boundary conditions is described in **Section 4.5.5**. The specifics of the model setup are:

Grid Type:	Unstructured
Coordinate Type:	Spherical
Direction Convention:	Nautical
Direction Discretization:	0-360 degrees, 10 degree spacing
Frequency Discretization:	0.0521-1.0 Hz, 31 intervals with logarithmic spacing
Computation Stationarity:	Non-stationary, 1hr time-step
Wave boundary conditions:	None
Wind boundary conditions:	Non-stationary, spatially constant, 1hr time-step
Water level boundary conditions:	Non-stationary, spatially constant, 1hr time-step
Core physics:	Generation 3, with *KOMEN* wave growth.
Optional physics:	Breaking, Friction
Numerics:	STOPC, DABS=0.005 DREL=0.01 CURVAT=0.005 NPNTS=95.0 NONSTAT MXITNS=4

Other options not specified here were left as defaults.

3.2 OVERLAND WAVE MODELLING

The general configuration of the wave model and boundary conditions is described in **Section 4.5.5**. The specifics of the model setup are:

Grid Type:	Unstructured
Coordinate Type:	Cartesian
Direction Convention:	Nautical
Direction Discretization:	0-360 degrees, 10 degree spacing
Frequency Discretization:	0.0521-1.0 Hz, 31 intervals with logarithmic spacing
Computation Stationarity:	Stationary
Wave boundary conditions:	Stationary, specified with Hs, Tp, Dp and $\cos^2$ spreading
Wind boundary conditions:	Stationary, spatially constant
Water level boundary conditions:	Stationary, spatially variable
Core physics:	Generation 3, with *KOMEN* wave growth.
Optional physics:	Diffraction, Breaking, Friction, Triads
Numerics:	STOPC, DABS=0.005 DREL=0.02 CURVAT=0.005 NPTS=98.0 STAT 100 CSIGMA CFL=0.5 CTHETA CFL=0.5

Other options not specified here were left as defaults.

ANNEX C

WAVE MEASUREMENTS AND OCEAN MODEL VALIDATION

1 INTRODUCTION

During the course of the City of Vancouver Coastal Flood Risk Assessment, the absence of wave measurements in Burrard Inlet was identified as a significant data gap. Wave measurements were needed to validate the numerical wave modelling executed as part of this project.

Discussions between NHC, the City of Vancouver and Port Metro Vancouver (PMV) concluded that wave sensors should be deployed at strategic locations in Burrard Inlet to fill the aforementioned data gap. A number of technologies were considered including a buoy-style sensor, an Acoustic Doppler Current Profiler (ADCP) and a bottom mounted pressure sensor. The cost and navigation nuisance precluded the use of a buoy-style sensor. The cost of renting an ADCP was also prohibitive. PMV already owned two bottom mounted pressure-based wave sensors manufactured by RBR. These sensors appeared to be an ideal, low-cost option for gathering the desired wave data and so were selected for this work.

The objective in siting these sensors was to:

- locate them close to high value assets of interest (Kitsilano, False Creek, Downtown), while staying as away from frequent boat traffic as possible.
- ensure that, given the 3.3 m tidal range, the sensors would always stay wetted and out of the surf zone.
- avoid proximity to geographic or civil features that would create highly localized variations in the wave field (wave focusing or shadowing).

Two sites were selected for deployment of these sensors: one off Kitsilano Beach, and the other on Burnaby Shoal (see **Figure 1**). Both are located at sites having a water depth of about 10 m.

The sensors were deployed from November 25, 2013 to May 8, 2014 and serviced monthly.

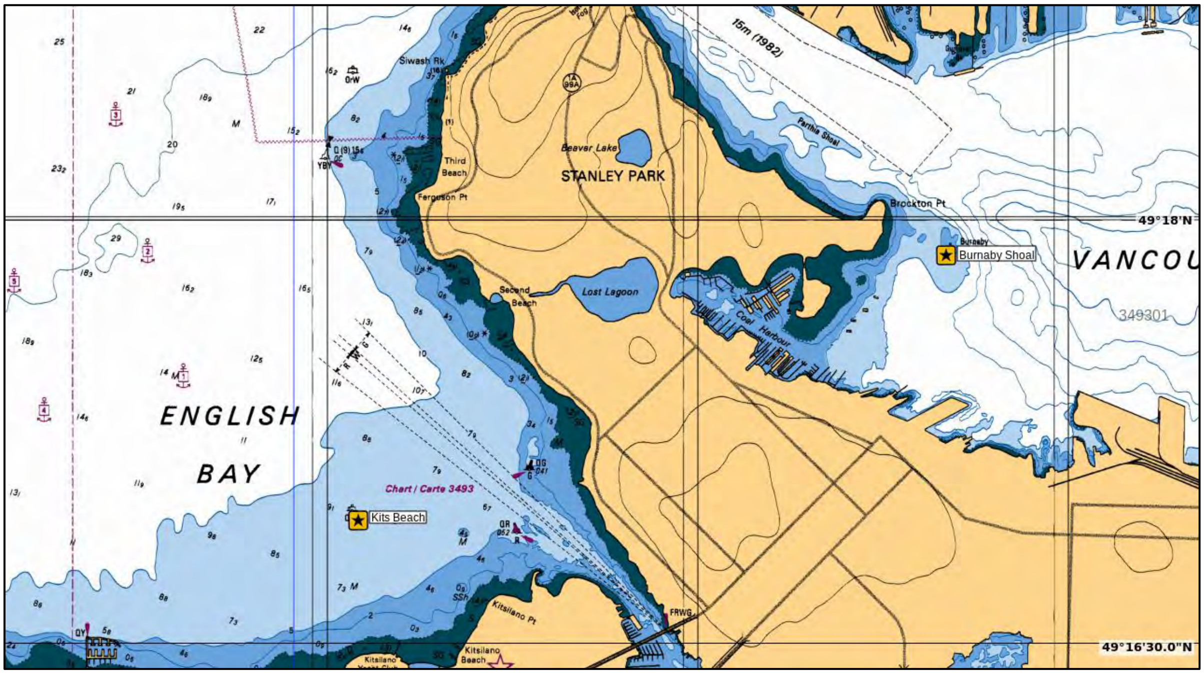


Figure 1. **Chart image showing location of Kits Beach and Burnaby Shoal wave sensors (marked with black/yellow star).**

2 THE RBR WAVE SENSOR

The RBR Wave Sensor is a bottom mounted pressure-based wave sensor. As a wave passes over the sensor, the height of the column of water above the sensor increases, and this causes an increase in pressure through the water column. The RBR Wave Sensor records the pressure, and from that, measurement can infer the passing of waves. The sensor accuracy is approximately ±0.1 m (pressure).

The RBR Sensor has limited battery life and data storage. For this reason, it was necessary to service the sensors each month to replace the batteries and recover the data. The sensors were deployed without a dedicated surface float. A timer was used to release a recovery float at the end of the deployment period. In this way, the sensors could be recovered for servicing.

The downloaded spectral wave data was post processed and time-varying parametric values (significant wave height, peak wave period, maximum wave height, etc.) were obtained. This data was to be used to validate the results of the wave hind-cast model developed for the City of Vancouver Coastal Flood Risk Assessment project.

Figure 2. Wave sensor (black tube at right), with cinder block anchors and timed float (blue tube at left).

3 THE SWAN WAVE MODEL

The computational wave model used in this project is based on the industry standard SWAN spectral wave modelling software. The model covers the entire Strait of Georgia and is forced with measured winds from a number of sources. The model performance is excellent when compared to measurements made at Halibut Bank and acceptable when compared to measurements made at Point Grey. Further details on the wave model are provided in the City of Vancouver Coastal Flood Risk Assessment Final Report.

The model was run over the deployment period of the sensors with driving winds sourced from the Halibut Bank Buoy and the Entrance Island Lighthouse. Both parametric and spectral wave data were output at the locations of the wave sensors.

4 SPECTRAL DESCRIPTION OF WAVES

Before discussing the measurements and model results, it is helpful to review some of the basics of the spectral description of waves. Ocean waves in the real world typically do not follow a regular sinusoidal pattern. There is a quality of randomness to the waves that can range from small ripples on a predominant swell to completely confused wind seas. For this reason, it can be difficult to identify a height and a period corresponding to the sea conditions. With wave measurements, this difficulty is overcome by describing the waves in the frequency domain.

In the spectral description of waves, a short time series of water elevation measurements (say 15 min) is converted into the frequency domain using a Fourier Transform. The Fourier Transform approximates the elevation signal as the sum of a large number of sinusoidal waves, each with a frequency, amplitude and phase. The frequency and amplitude information of each of the sinusoidal wave components can then be used to generate a wave spectrum. **Figure 3** below gives a pictorial representation of this process.

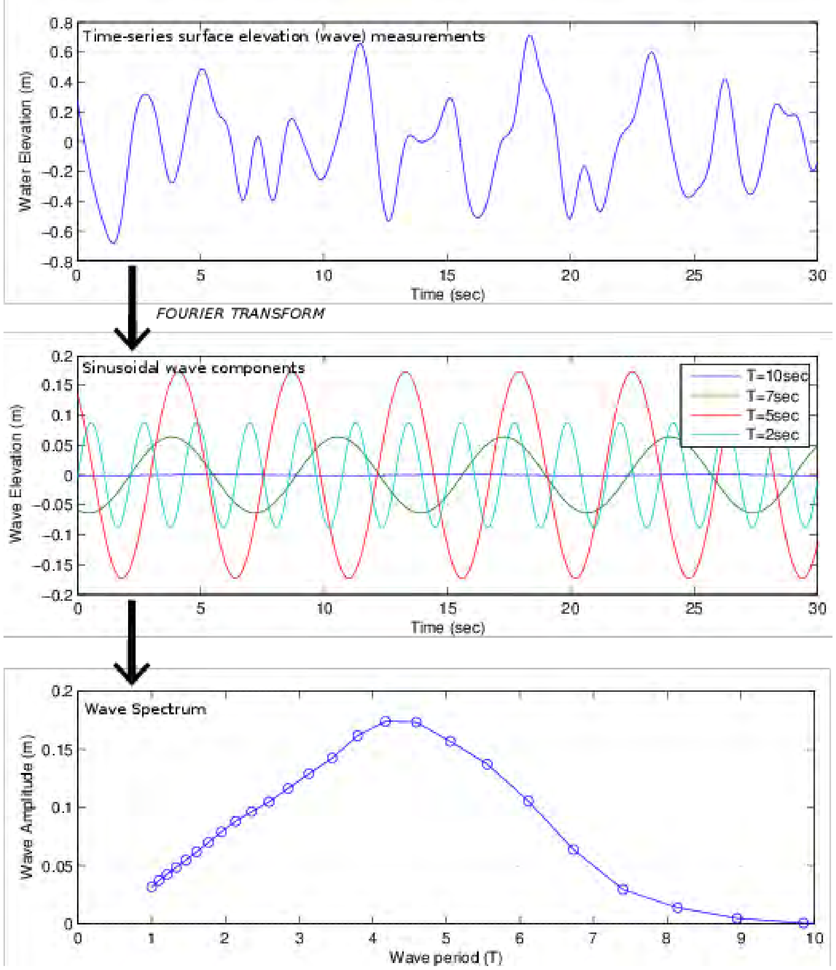


Figure 3. **Schematic showing conversion of time-series wave data into spectral (frequency domain) representation of waves using Fourier Transform. Note that the middle plot does not show all the wave components.**

Wave parameters are derived from the wave spectrum. Two of the most commonly used parameters are significant wave height (H_{m0}) and peak wave period (T_p). Significant wave height is proportional to the area under the wave amplitude spectrum. Peak wave period is the period corresponding to the maximum amplitude in the wave amplitude spectrum (in the case of **Figure 3**, about 4 seconds). The wave spectrum is more commonly quantified in terms of variance density. In this case, significant wave height is defined as:

$$\mathrm{m0} = 4\sqrt{\sum_{\mathrm{i}} \mathrm{S_i}\Delta \mathrm{f_i}}$$

where S is variance density in m_2/Hz and Δf is the frequency band-width.

5 MODEL-MEASUREMENT COMPARISON

Initial comparisons between the wave measurements and the model estimates and showed correlation, but significant discrepancy. The model appeared to over-predict significant wave height during both calm and stormy conditions. **Figure 4** shows the model and measured significant wave height at Kitsilano Beach through the first two weeks of January 2014.

Comparison of wave periods suggested that there were some issues with the measured data. At Kitsilano Beach, the measured wave period was frequently greater than 20 seconds (about 15% of the time), and sometimes greater than 100 seconds (about 2% of the time). Given the fetch[1] limitations of the Strait of Georgia, the largest possible peak wave period should be about 9 seconds. Furthermore, these unusually large wave periods tended to occur when the seas were calm.

Further scrutiny of the H_{m0} data measured at Kitsilano Beach also pointed to issues. Only 10% of the time was the significant wave height measured as greater than 10 cm (calm). Only 0.5% of the time was the significant wave height measured as greater than 20 cm (smooth).

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[1] 'Fetch' is the horizontal distance the wind blows over open water.

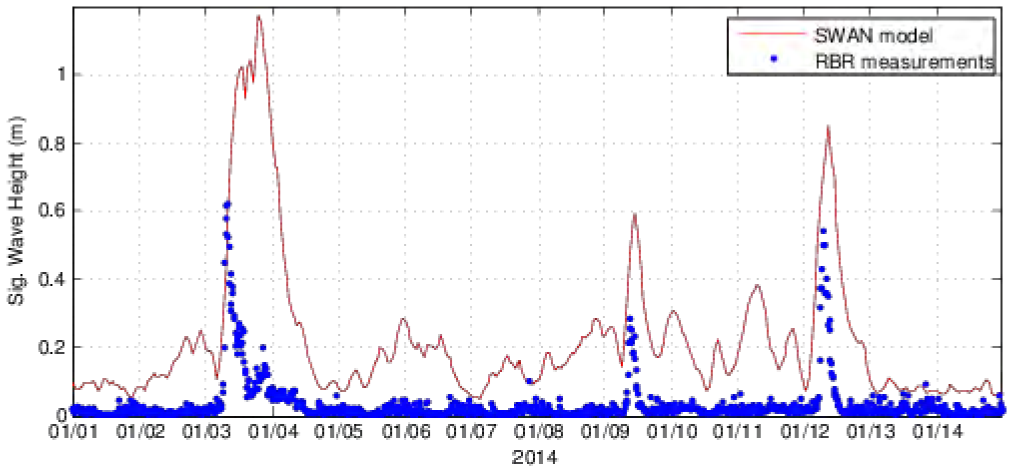


Figure 4. **Modelled and measured significant wave height at Kitsilano Beach during first two weeks of January 2014.**

At this point, it was evident that there were some issues with the wave measurements. A review of the RBR wave sensor's technical documentation gave no indication of what these could be. It was only after reading a scientific paper detailing the operation of the RBR sensor that the cause was positively identified [1].

6 LIMITATIONS OF RBR WAVE SENSOR

The limitations of the RBR wave sensor stem from limitations common to all pressure-based wave sensors. The deeper the water, the more difficult it is to detect the pressure of short wavelength waves. This happens because the pressure fluctuations that occur with a passing wave are attenuated with depth. **Figure 5** shows a graph of the variation in attenuation factor with depth and wave period (from [1]). An attenuation factor of 1.0 indicates that there is no attenuation of the pressure signal; an attenuation factor of 0.1 indicates that the signal amplitude is only 10% of the full-strength signal.

The RBR wave sensor works by first transforming the time sequence of pressure measurements into its frequency components using Fourier analysis. Each frequency component is then multiplied by a gain equal to the inverse of the attenuation at that frequency. This action is limited to attenuations <1/20 to avoid injecting noise into the reconstruction. This limitation effectively sets a high frequency (short period) limit on the resolvable range of frequencies. This limit depends on the depth of the deployment. For the 12 m depth deployment at Kitsilano Beach, the high frequency limit is about 3.5 seconds. This means that waves with a period less than 3.5 seconds are effectively not recorded.

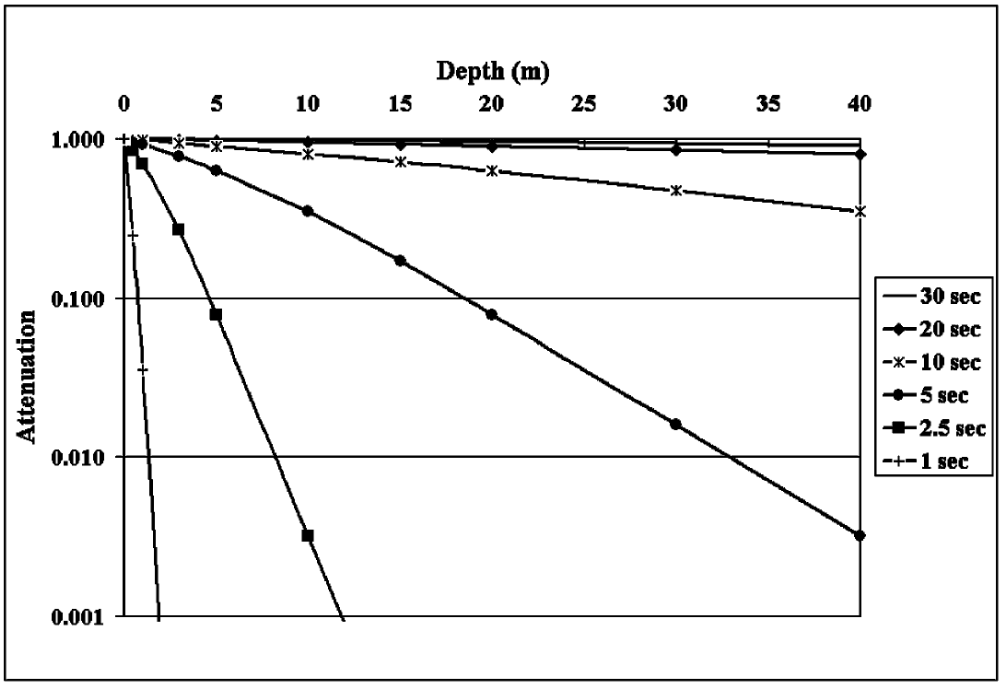


Figure 5. Graph showing variation of attenuation factor with depth and wave period (from [1]).

In deployments exposed to open ocean waves, this limitation may be acceptable as the waves with the most energy would be of longer period (approximately 8-12 seconds). But, the Strait of Georgia is a semi-enclosed basin, which is not exposed to open-ocean waves. Almost all wave energy is generated locally, and given the fetch limitations, waves tend to be short in period (1-6 seconds). For this range of waves, the 3.5-second period limitation of the RBR results in significant underestimation of wave parameters.

As mentioned previously, the significant wave height is proportional to the area under the wave amplitude spectrum. It follows that if the RBR sensor is effectively not recording a portion of the spectrum, the computed significant wave height will be underestimated. **Figure 6** shows a wave amplitude spectrum for a relatively large sea at Kitsilano Beach (H_{m0}=1.4 m). The grey area in the figure shows the region not captured by the RBR wave sensor, approximately one-third of the energy in the spectrum. During smaller seas, even greater portions of the wave spectrum would fall into the grey region not captured by the sensor. This illustrates why there was a prevailing large bias in significant wave heights between the model results and the measurements made with the RBR sensor.

[redacted]

Figure 6. Wave amplitude spectrum with grey area showing region not captured by the RBR sensor.

7 QUALITATIVE MODEL VALIDATION

To facilitate comparison of the measure and modelled wave data, the modelled data was adjusted. The failing of the wave data measured with the RBR wave sensor is that it was unable to capture the high frequency portion of the wave spectrum. By neglecting the same portion of the modelled wave spectrum, the resultant wave parameters become equivalent to the RBR measured parameters. The difficulty with this approach is that the details of the wave spectrum are more difficult to model correctly than the integral wave parameters (i.e. H_{m0}), and therefore, the comparison of the adjusted wave parameters is likely to be poorer than if we were able to compare the un-adjusted wave parameters. However, within the limitations of the recorded data, this approach enabled qualitative validation of the model results.

Kitsilano Beach

Of the two wave sensor sites, Kitsilano Beach is the more energetic location. This means that the wave conditions are more likely to be resolved using the RBR wave sensor. Though the Kitsilano Beach wave sensor was deployed over the same period as the Burnaby Shoal device, data is limited to November 25, 2013 through February 12, 2014 as after that time the sensor became clogged with sediment.

Figure 7 below shows a comparison of the significant wave height measured by the RBR sensor and the adjusted modelled significant wave height. A much better agreement is seen here between the measured and modelled values. A tabulated list of maximum significant wave height values for a number of wave events at Kitsilano Beach is provided in **Table 1**. Only events exceeding a significant wave height of about 0.15 m are listed. This threshold was selected in view of the sensor's accuracy of ±0.1 m.

The agreement in maximum significant wave height in each of the events listed in **Table 1** is reasonable. While there is insufficient data to produce any quantitative measures of model accuracy, the larger wave events tend to be more accurate. This is a desirable result as the focus of the hind-cast was on large events.

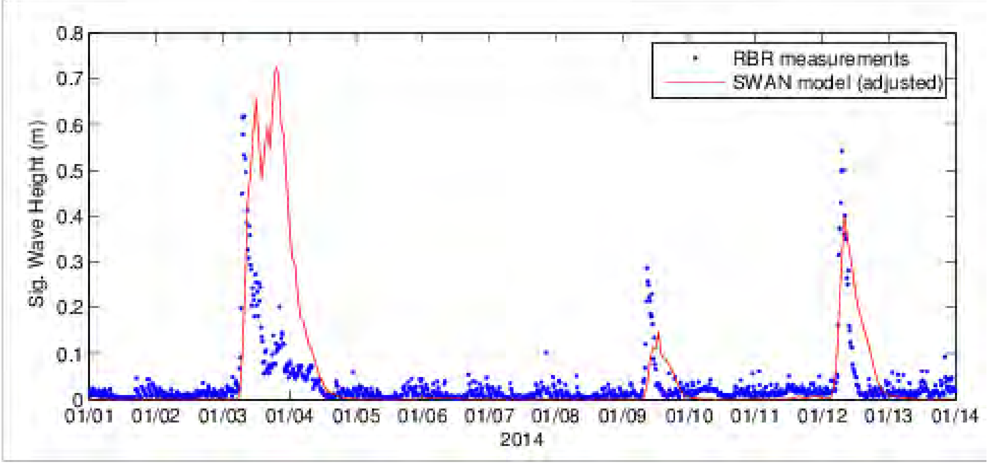


Figure 7. **Adjusted modelled significant wave height and measured significant wave height at Kitsilano Beach during first two weeks of January 2014.**

Table 1. **Comparison of maximum measured and adjusted modelled significant wave height for wave events at Kitsilano Beach.**

Kitsilano Beach			
Date	**Wind**	**RBR Measured H_{m0} (m)**	**Adjusted Modelled H_{m0} (m)**
02/12/2014	11.9 m/s from 310°	0.13	0.33
18/12/2014	13.3 m/s from 310°	0.13	0.50
03/01/2014	14.5 m/s from 310°	0.62	0.72
09/01/2014	12.8 m/s from 305°	0.28	0.15
12/01/2014	11.5 m/s from 310°	0.54	0.40
30/01/2014	9.9 m/s from 300°	0.34	0.12

Burnaby Shoal

Burnaby Shoal is located within Vancouver Harbour. The primary exposure at this location is to waves generated locally within the Harbour. This means that wave heights are typically very small (<0.5 m) and wave periods very short (<3 seconds). As a result, typically all of the wave energy at this location is beyond the 3.5 second cut-off period of the RBR wave sensor.

Figure 8 shows a comparison of the significant wave height measured by the RBR sensor and the adjusted modelled significant wave height. During the January 3rd events, a reasonable match is observed, but during events on January 10th and 11th, the model significantly overestimates significant wave height. A tabulated list of maximum significant wave height values for a number of wave events at Burnaby Shoal is given in **Table 2**. For selecting events at this location, it was more difficult to adhere to the 0.15 m significant wave height threshold.

The agreement in maximum significant wave height in each of the events listed in **Table 2** is reasonable for weather systems from the northwest. For weather systems from the east, the model predicts larger wave heights. This is likely due to differences in wind strength between the Strait of Georgia and Burrard Inlet. The winds driving the wave model were sourced from the Halibut Bank Weather Buoy and the Entrance Island Lightstation, representing conditions in the open Strait of Georgia. In the Inner Harbour, winds tend to be smaller in magnitude than the open Strait of Georgia and, in some conditions, will have a different direction.

While these results suggest systematic bias in the model within Vancouver Harbour for some weather systems, this bias is positive and preferable to a negative bias from a hazard point of view.

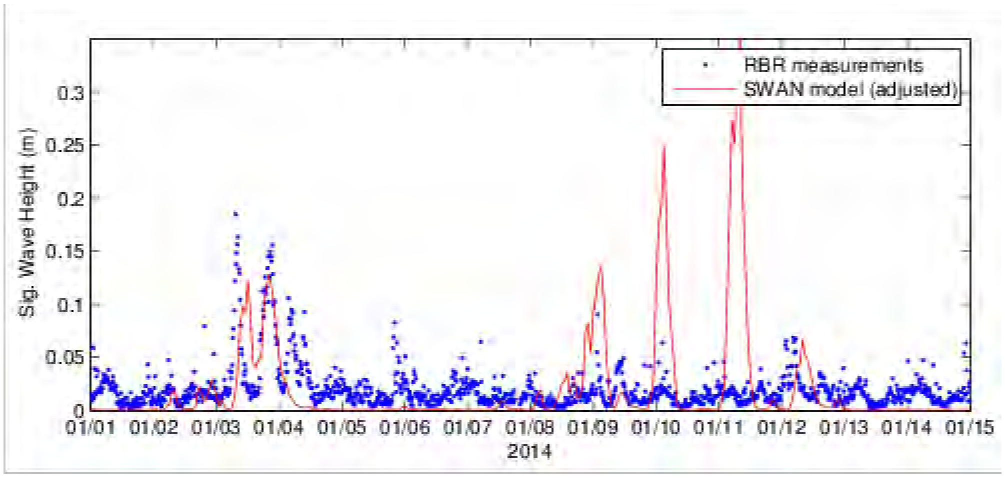


Figure 8. **Adjusted modelled significant wave height and measured significant wave height at Burnaby Shoal during first two weeks of January 2014.**

Table 2. **Comparison of maximum measured and adjusted modelled significant wave height for wave events at Burnaby Shoal.**

		Burnaby Shoal	
Date	**Wind**	**RBR Measured H_{m0} (m)**	**Adjusted Modelled H_{m0} (m)**
03/01/2014 AM	14.5 m/s from 300°	0.18	0.12
03/01/2014 PM	13.8 m/s from 310°	0.16	0.13
09/01/2014	12.8 m/s from 300°	0.09	0.13
10/01/2014	13.4 m/s from 90°	0.06	0.24
11/01/2014	14.5 m/s from 95°	0.05	0.35
12/02/2014	13.5 m/s from 100°	0.04	0.35
14/02/2014	16.2 m/s from 125°	0.06	0.17
18/02/2014	12.6 m/s from 100°	0.06	0.20
20/02/2014	12.5 m/s from 310°	0.13	0.14
21/02/2014	11.7 m/s from 305°	0.08	0.14

8 QUALITATIVE MODEL VALIDATION

During the course of the City of Vancouver Coastal Flood Risk Assessment, a lack of wave measurements in Burrard Inlet were identified as a significant data gap. Wave measurements were needed to validate the numerical wave modelling that was executed as part of this project. PMV already owned two bottom mounted pressure-based wave sensors manufactured by RBR. These sensors appeared to be an ideal, low-cost option for gathering the wave data needed for model validation.

Two sites were selected for deployment of these sensors; one off of Kitsilano Beach and the other at Burnaby Shoal (see **Figure 1**). Both are about located at sites having a water depth of 10 m. These sites were selected based on proximity to high value assets and appropriate depth given the 3.3 m tidal range. The sensors were deployed from November 25, 2013 to May 8, 2014 and serviced monthly.

An unforeseen problem with using pressure-based wave sensors at these locations was that these sensors have difficulty detecting the high frequency waves that are typical in the Strait of Georgia. The RBR wave sensors have a high frequency cut-off beyond which the sensors effectively cannot detect the waves. For the 12 metre-deep deployments, the corresponding cut-off period was approximately 3.5 seconds. For most deployments, this cut-off is considered to be acceptable. However, the Strait of Georgia is a semi-enclosed basin and almost all wave energy is generated locally, and given the fetch limitations, waves tend to be short in period (1-6 seconds). For this range of waves, the 3.5 second period limitation of the RBR sensor results in significant underestimation of wave parameters.

When comparing the measured and modelled significant wave height, issues with the RBR wave sensor measurements were apparent. The modelled wave height was consistently much larger than the measured value, and there were many erroneous wave period measurements ranging up to 100 seconds.

To facilitate comparison of the measured and modelled wave data, the modelled data was adjusted. The shortcoming of the wave data measured with the RBR wave sensor is that it does not capture the high frequency portion of the wave spectrum. By neglecting the same portion of the modelled wave spectrum, the resultant wave parameters become equivalent to the RBR measured values. Unfortunately, with this adjustment, most records become essentially zero leaving only a few particularly energetic events in the record. However, within the limitations of the recorded data, this approach enabled qualitative validation of the model results.

For the Kitsilano Beach wave sensor location, the adjusted significant wave heights show reasonable agreement with the RBR sensor measurements. Kitsilano is the more energetic of the two locations, so several moderate events were available for validation. The larger wave events tended to show better agreement between the model and measurements. This is a desirable result as the focus of the hind-cast was on large events.

At Burnaby Shoal, the wave events were typically of lower energy, and so, more difficult to capture. The adjusted model significant wave height agrees reasonably well with the RBR measurements for weather systems from the north-west. For weather systems from the east, the model predicts larger wave heights than the measurements. This is likely due to differences in wind strength between the Strait of Georgia and Burrard Inlet. The winds driving the wave model during the validation period were sourced from the Halibut Bank Weather Buoy and the Entrance Island Light station. These winds represent the conditions in the open Strait of Georgia. In the Inner Harbour, winds tend to be smaller in magnitude than the open Strait of Georgia and, in some conditions, will have a different direction. While these results suggest systematic bias in the model within Vancouver Harbour for some weather systems, this bias is positive and preferable to a negative bias from a hazard point of view.

Further work may be done to improve the wave model by including spatially-variable winds. The difficulty with including spatially-variable winds is a lack of available data. Currently, there are several dozen wind measurements stations throughout the Strait of Georgia. If data from these stations was available throughout the hind-cast period, it might suffice for the creation of spatially- and temporally-varying wind fields. However, many of these stations have been in operation for only a few years.

Alternatively, numerical climate re-analyses might provide the necessary wind field data in the future. Similar work by Environment Canada on the Atlantic Coast has produced a highly accurate wind and wave climatology for the Atlantic Provinces (the MSC50 hind-cast). Unfortunately, complex topography and bathymetry of the Strait of Georgia requires a very high resolution model to capture the spatial variation in wind and wave conditions. Currently, available long-term climate re-analyses do not contain sufficient resolution to merit their use.

Until such a time when better wind data becomes available, the wave hind-cast performed for the City of Vancouver Coastal Flood Risk Assessment represents a best estimate of historical wave conditions. This hind-cast has been validated throughout the Strait of Georgia: quantitatively to wave measurements at Halibut Bank, Point Grey and West Vancouver, and qualitatively to wave measurements at Kitsilano Beach. Within Vancouver Harbour, qualitative comparison of the model results to measurements at Burnaby Shoal suggest the model performs well for weather systems from the north-west but over estimates wave heights for weather systems from the east.

9 BIBLIOGRAPHY

[1] D T Gibbons, G Jones, E Siegel, A Hay, and F Johnson, "Performance of a New Submersible Tide-Wave Recorder," in *OCEANS. Proceedings of MTS/IEEE* , Washington, D.C., 2005, pp. 1057 - 1060 Vol. 2.

ANNEX D

OVERLAND MODEL DEVELOPMENT

1 HYDRAULIC MODELLING – BURRARD INLET

When modelling future coastal flood risk, an inundation model is typically used to simulate the potential flooding inland. To do this, an open boundary is established offshore and forced by a water level time series of extreme water levels with an associated probability of exceedance (return period). Correctly resolving the total water level in a coastal inundation model is crucial and has been documented by many as the greatest source of uncertainty in coastal inundation models. To address the spatial variability along the City's shoreline and to help find an appropriate balance between the mesh resolution and computation time, the study area was split into four overland zones.

Figure 1 shows the overland modelling area delimited into zones considered to be in hydraulic isolation from each other due to high ground or other constraining features. At the selected boundaries (blue lines in **Figure 1**), the interaction of flow between the zones is expected to be minimal or non-existent. Similarly, at the selected upland zone boundaries (red lines in **Figure 1**), there is limited or no interaction of flow between zones (this will be discussed in a later section). It is also assumed that the City would raise an East-West road for emergency response, thereby providing artificial upland boundaries between Zone 2 and Zone 4.

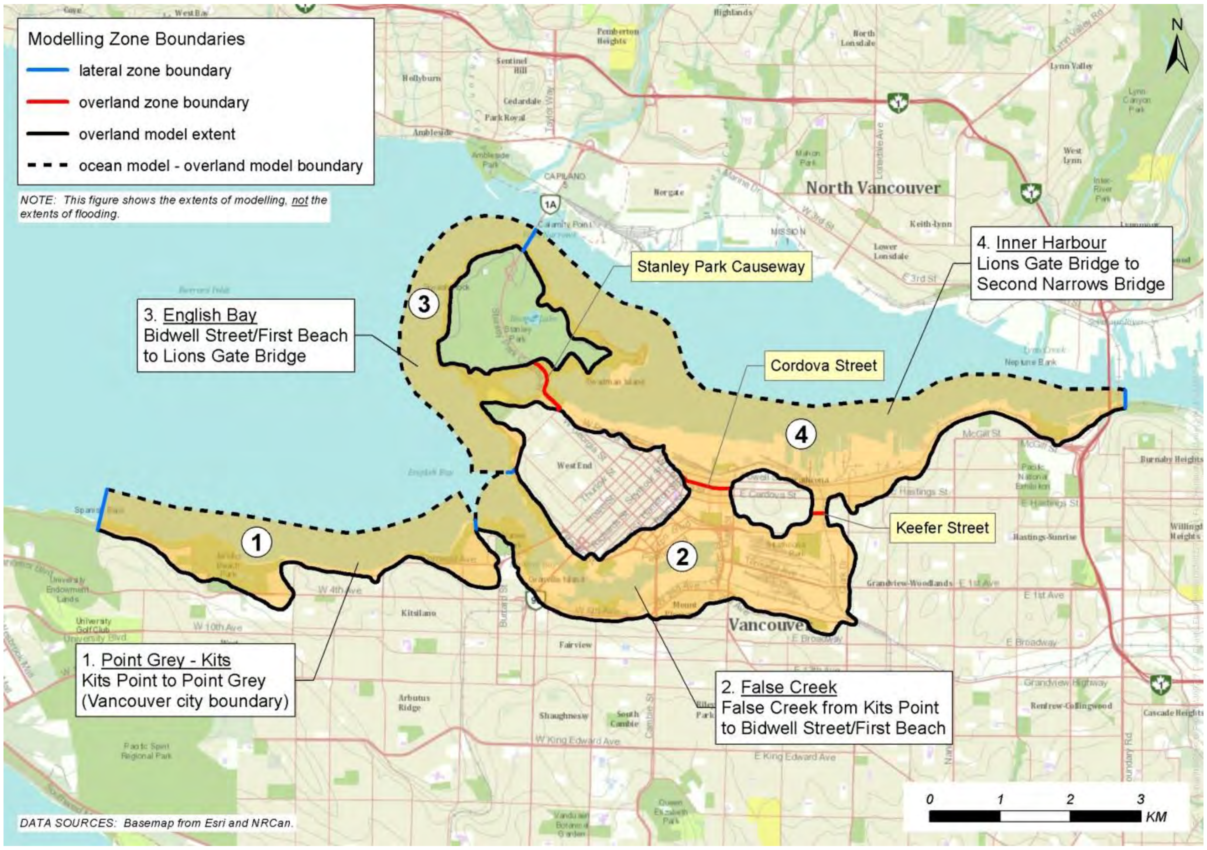


Figure 1. Flood modelling zones in Burrard Inlet.

2 BACKGROUND ON URBAN FLOOD MODELLING

2.1 BUILDINGS

In urban settings, buildings typically act as obstacles and alter the propagation of flood waters. Physical modelling experiments (LaRocque et al 2013) have demonstrated that:

1) Topography is the primary reason for the overall distribution of flow whereas buildings redistribute the flow locally within flooded areas (comparison of simulations with and without buildings).
2) Closely spaced buildings act like a single obstacle to the flow.
3) Zones of low velocities and recirculation occurred at some locations between the buildings.
4) Houses and buildings closest to the source of flooding act as a first barrier to slow down flow and increase water level on the “upstream” side of flooded areas.

When modelling an urban zone, there are four main approaches to represent buildings. First, the “building-hole” method consists of removing the buildings from the mesh by setting the exterior building walls as solid boundaries (building interior is not included in the mesh and therefore never gets wet). A second option is to include the area corresponding to the building interior in the mesh and to set the elevation of those elements at the elevation of the roof. Third, the “roughness upscaling” method assigns a high bed friction value within the building elements to represent the additional resistance from buildings on the flow (bed elevations of building elements are set to adjacent ground elevation). Finally, a porosity value can be set to simulate the flow between the buildings.

During the initial stages of a flood, building walls act as impervious obstacles, modifying and deflecting flow paths but as flooding progresses, water usually enters buildings (Dottori et al, 2013). Work completed by Mignot and Paquier (2003) found that representing buildings using the first two approaches (solid boundaries or roof elevations) produced very similar results to those of a physical model while the third approach (bed friction) allowed water to flow “through” the buildings. Allowing water to flow “through” the buildings resulted in significant differences in the modelled water levels and flow velocities but according to Brown et al. (2007) small differences in the overall inundation extents (~2%) and flood volume (~3%).

2.2 MESH RESOLUTION

Another important consideration in modelling urban environments is the mesh refinement since urban areas are characterised by structures of varying dimensions and size as well as differing separation distances. In scientific literature, the optimal grid scale for urban environments is still under discussion. Previous modelling work has shown (Soares-Frazao and Zech, 2008) that a mesh with about 10 cells over the width of a street allows for an accurate representation of the complex two-dimensional wave structure observed in a physical model, but that even a coarser mesh (2 or 5 cells over the width of a street) gives a good idea of the mean water level. Mignot and Paquier

(2003) found that mesh refinement produced some local differences in water depth and velocity but had no impact on the global results. Brown et al. (2007) argue that a mesh resolution of ~10 m is sufficient to capture the main effects of buildings on flow and Fewtrell et al. (2008) recommend selecting a node spacing of 1 to 2 times the most frequent minimum separation distance between buildings.

2.3 TOPOGRAPHY

An accurate description of the topography is essential for an urban 2D flood model. The advances and increasing availability of airborn laser altimetry (LiDAR) surveys have allowed collection of detailed topographic data required for urban inundation modelling (submetre horizontal scale with 5 to 15 cm accuracy in elevation).

2.4 ROUGHNESS PARAMETERS

Roughness parameters are used to represent the flow resistance due to various sources of energy loss. Roughness parameters should be within a physically realistic range and be consistent throughout the study area (Smith et al., 2012). Difficulties arise when trying to characterise a specific landuse type as limited guidance is currently available for the selection of roughness coefficients for urban areas. Caution is recommended if using empirically determined values from literature that were derived for natural rivers.

Roughness coefficients should be treated as calibration parameters and adjusted to simulate observed flood conditions. Although others have found that varying the coefficient of friction in both urban and rural areas had an influence on the modelling results, the impact was less significant than the impact of topography and varying the wave overtopping rates and the tidal water levels at the model boundary (Lewis et al., 2011; Smith et al., 2012; Dottori et al., 2013; Brown et al., 2007). Changes to roughness parameters have also been found to have a greater impact on flow velocities and arrival times than on water depths and inundation extents.

3 SUB-MESH DEVELOPMENT

The City of Vancouver overland model mesh extents are shown in **Figure 2**. A detailed sub-mesh was generated for each of the four zones and was, in turn, incorporated in the larger mesh.

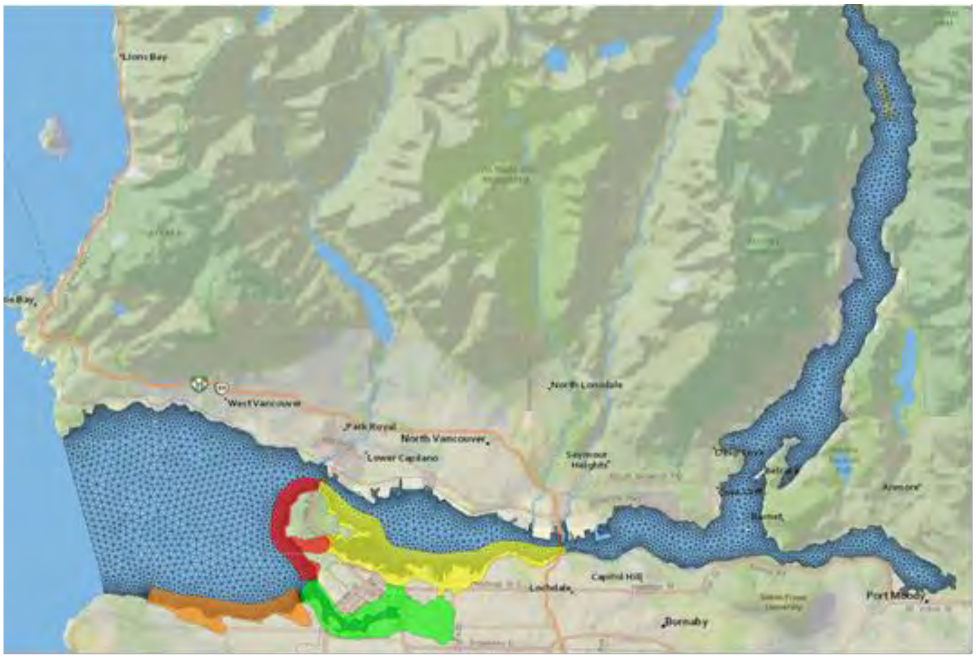


Figure 2. **Overland model extents with detailed sub-mesh areas for each zone shown in different colours.**

3.1 BUILDINGS

Building footprint data was available for the City of Vancouver, which lead to the selection of the “building-hole” method to represent the effect of buildings in the model. To model buildings using the “building-hole” method, buildings are removed from the mesh by setting the exterior building walls as solid boundaries.

Buildings with a separation distance of less than 5 m were merged together using a generalisation algorithm. The minimum separation distance to the nearest building was calculated in GIS using the original building dataset (prior to generalisation). Frequency distribution plots of the minimum separation distance for each building are shown in the following plots and summarized in **Table 1**. Note that the separation distance is given for each building therefore the narrow space between two adjacent buildings is included twice. Frequency distributions of the distance between a building and its closest neighbour are plotted in **Figure 3**.

Table 1. **Number of buildings and separation distances.**

Zone	No. of Buildings	No. Buildings with Separation Distance	
		0 to 5 m	> 5 m
1	685	543	142
2	816	348	468
3	22	11	11

4	408	173	235
All	1931	1075	856

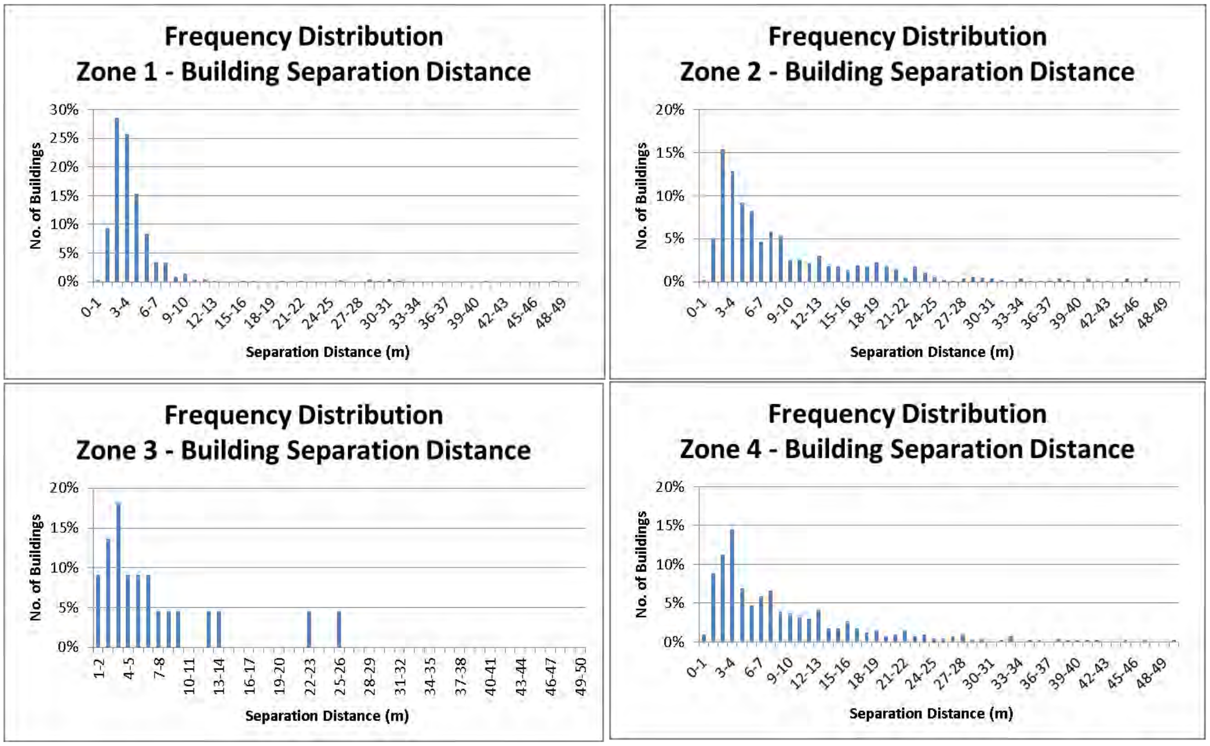


Figure 3. **Frequency distribution plots of the distance between a building and its closest neighbour for each of the four modelling zones.**

The values above indicate that Zone 1 will have the greatest impact from the generalization of all buildings located less than 5 m apart. This is most noticeable at Kitsilano Point and near Jericho Beach where rows of closely spaced houses were merged together. Considering the fences, garages, and dense garden vegetation around and between the houses in these residential areas, it is reasonable to assume that limited water would actually flow between the houses. Sensitivity tests were done to investigate the impact of the building generalization and will be discussed in a subsequent section of this Annex.

It should also be noted that many of the buildings are located near the upland boundaries (**Figure 4** to **Figure 7**) and will not be within the flood extents for the modelled scenarios.

3.2 MESH RESOLUTION

For the generation of the four detailed sub-mesh, breaklines were added to guide the placement of nodes to ensure elements were aligned with the shoreline, edge of streets, edge of parking lots, and other topographic features. Buildings were removed from the mesh using building footprints provided by the City of Vancouver. Mesh elements inland were generated based on a node spacing specification of 5 m. This distance was selected as a compromise between the opposite requirements of maintaining reasonable computational times and providing a sufficiently detailed representation of the study area. A node spacing of 5 m corresponds to two elements over the average width of a street and one element over the mean building separation distance.

Table 2 summarises the number of nodes and elements included in each mesh while the mesh for each zone is shown in **Figure 4** to **Figure 7**.

Table 2. Mesh geometry for the overland model.

Zone	Node Count	Element Count
1	85,248	160,430
2	182,602	338,921
3	76,242	148,278
4	232,285	448,985

Figure 4. **Zone 1 sub-mesh.**

Figure 5. Zone 2 sub-mesh.

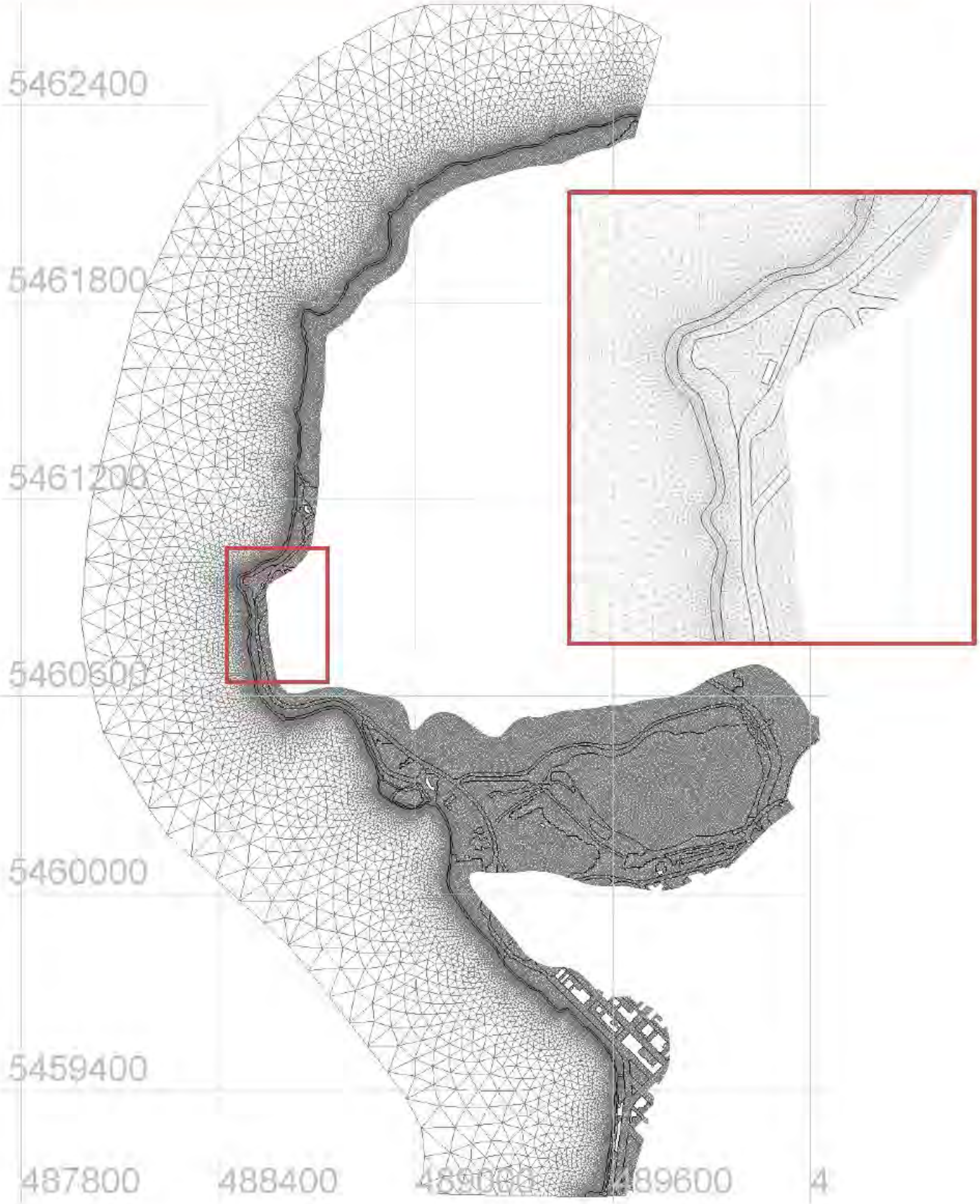


Figure 6. Zone 3 sub-mesh.

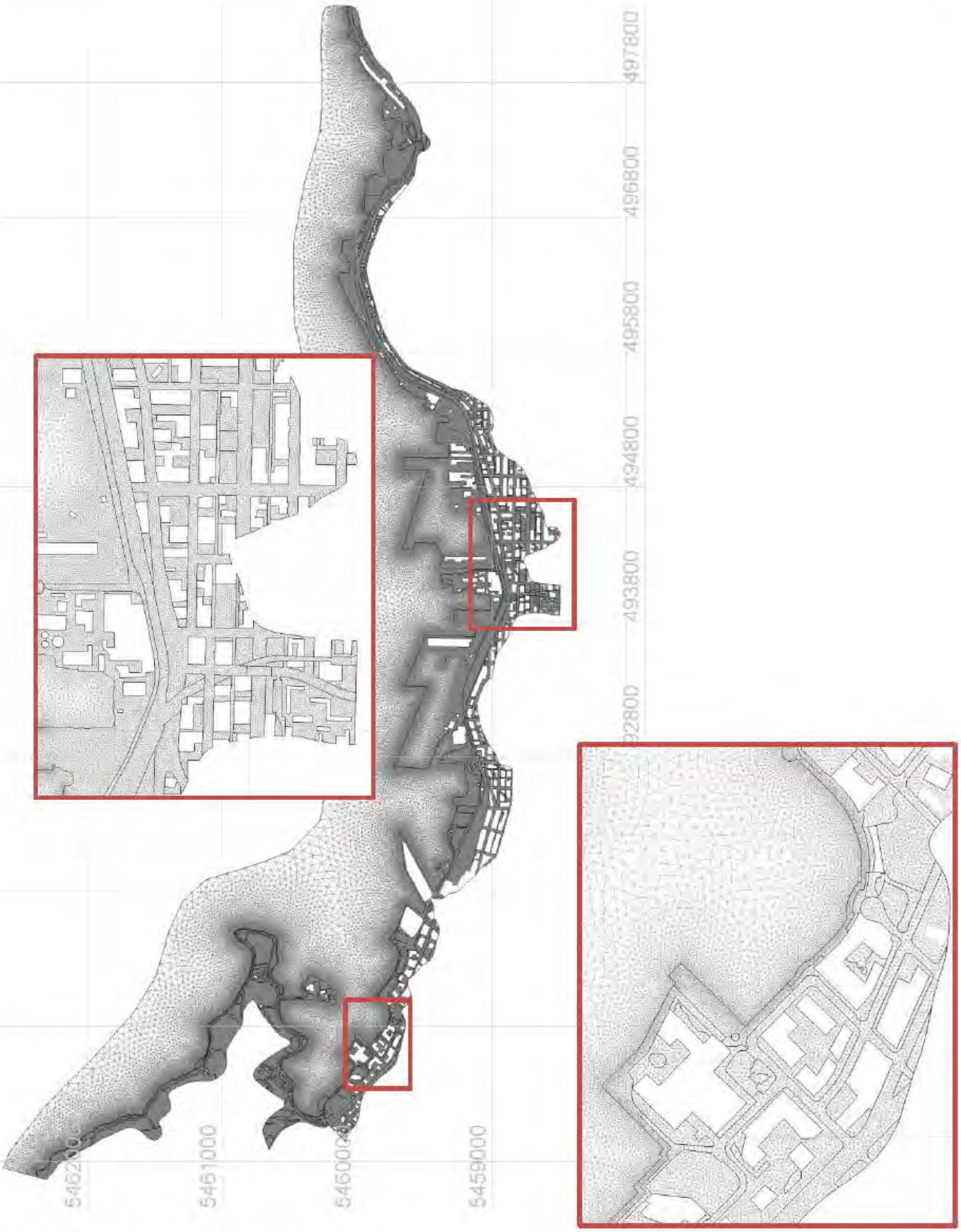
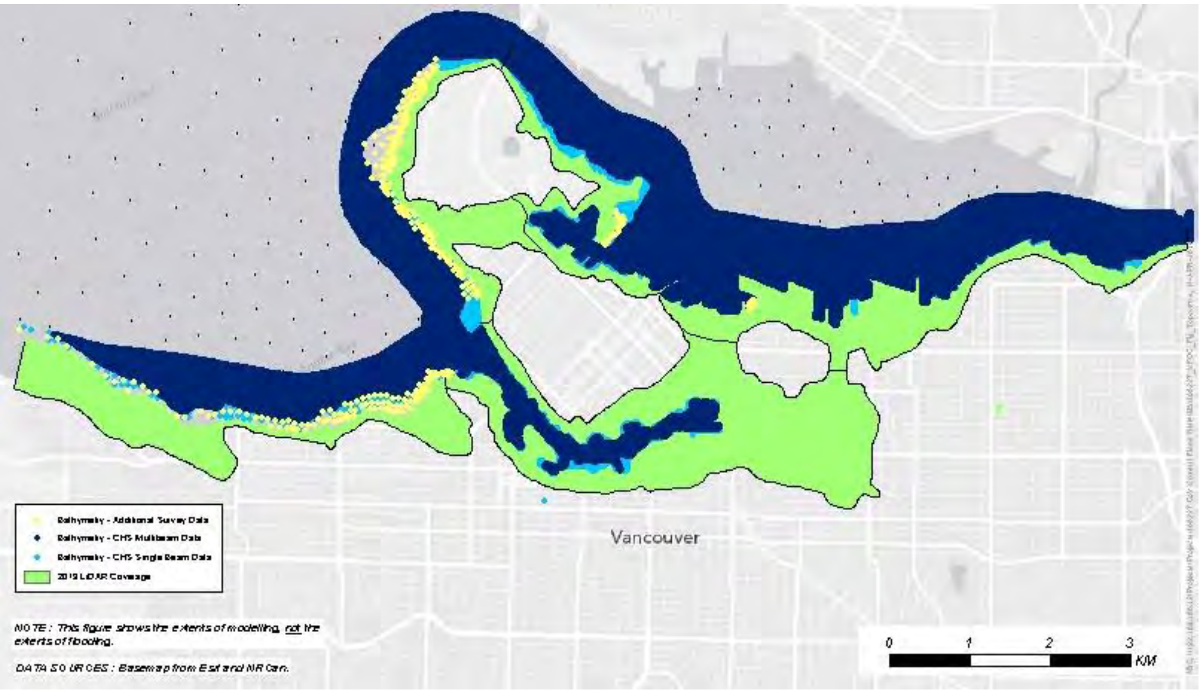


Figure 7. Zone 4 sub-mesh.

3.3 TOPOGRAPHY/BATHYMETRY

Bottom elevations used in the model were obtained from a combination of sources (**Figure 8**). LiDAR data flown in 2013 covered the overland areas and portions of the offshore environment. The LiDAR data was used to generate a digital terrain model (DTM), representing the bare earth without building or vegetation. The DTM was checked to ensure that all bridges and elevated road sections that would form artificial obstacles to flood propagation had been removed. Bathymetry for offshore areas was compiled from single-beam and multi-beam surveys conducted by the Canadian Hydrographic Service.

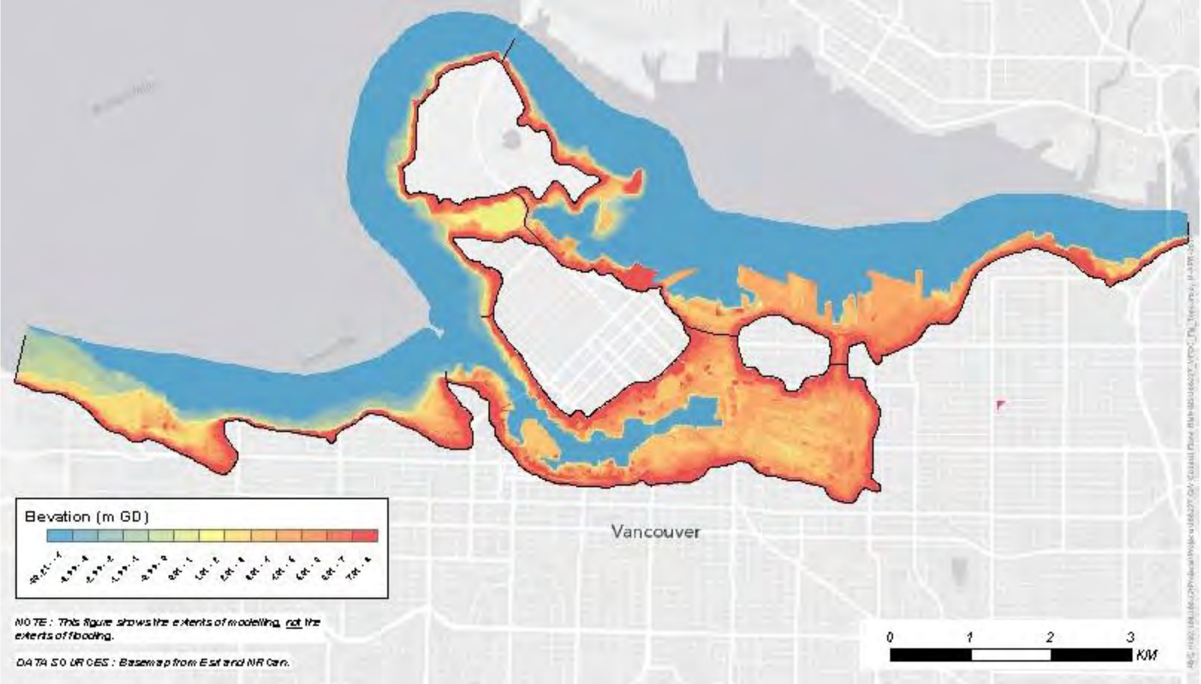


NOTE: This figure shows the extents of modelling, not the extents of flooding.

DATA SOURCES: Basemap from Esri and NRCan.

Figure 8. Coverage of topographic and bathymetric datasets.

The combined elevation data is shown in **Figure 9** while the Zone 2 mesh is shown in **Figure 10** as an example of a mesh with interpolated elevations.



NOTE: This figure shows the extents of modelling, not the extents of flooding.

DATA SOURCES: Basemap from Esri and NRCan.

Figure 9. **Elevations (m GD) from digital terrain model (DTM) interpolated to model mesh.**

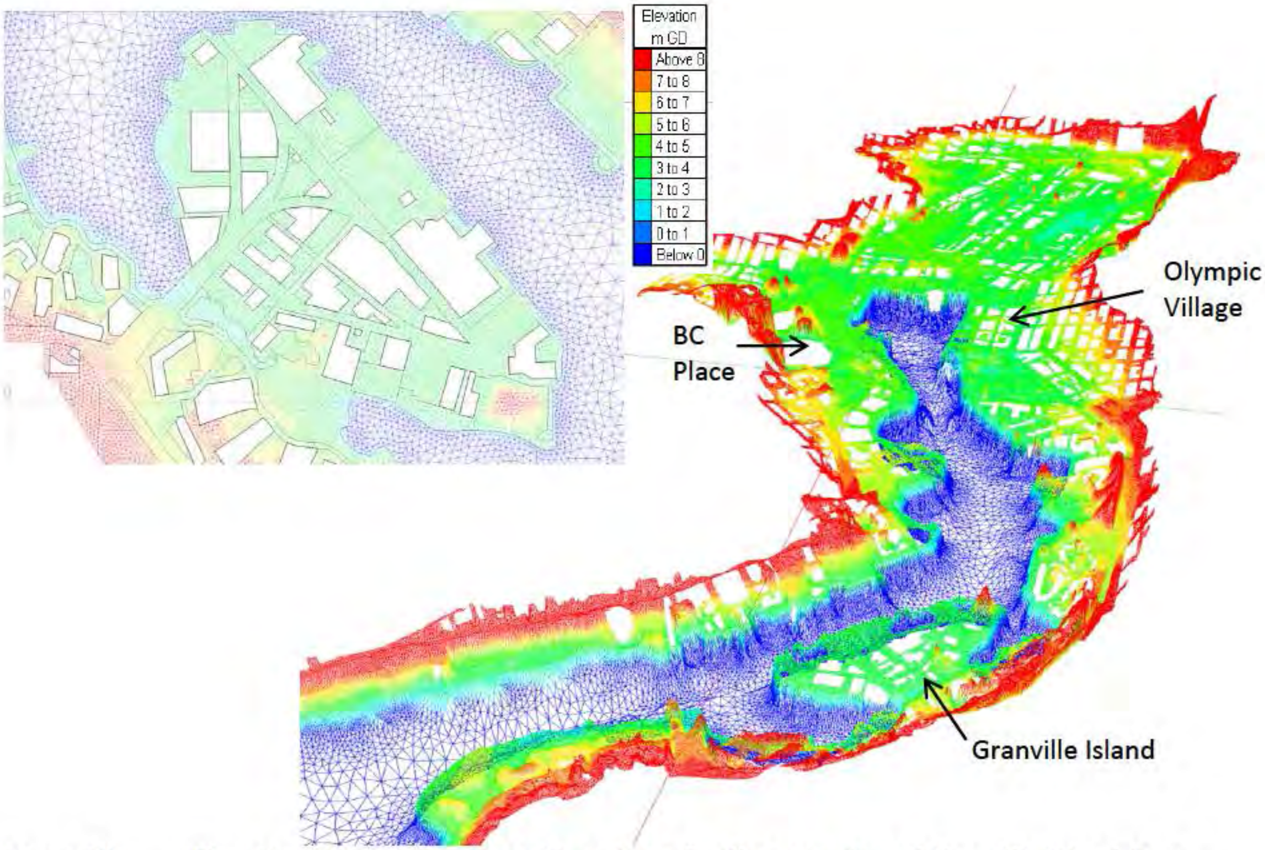


Figure 10. **Elevations interpolated onto Zone 2 mesh. Close-up view of Granville Island (top left) and 3D view looking East towards False Creek flats.**

3.4 ROUGHNESS PARAMETERS

Roughness coefficients (Manning's n value) represent the flow resistance due to various sources of energy loss. These parameters should be within a physically realistic range and be consistent throughout the study area. Difficulties can arise when trying to characterise a specific landuse type. For example, a garden can include trees, walls, fences, concrete paths, ponds, grass, etc. Limited guidance is currently available in the literature for the selection of a roughness coefficient for urban areas. However, the model results are relatively insensitive to changes in roughness values. The model domain was classified into the following categories based on the 2011 landuse data and 2013 tree canopy data provided by the City. **Table 3** summarises the assigned roughness values that were modified from those used in Brown et al. (2007) for urban areas. **Figure 11** includes a spatial representation of the roughness values specified for the overland area.

Table 3. **Summary of landuse classes and associated roughness values (adapted from Brown et al., 2007).**

Land Type	Manning’s n
Open and Undeveloped Lots Roads, Paved Areas, Paths	0.016
Offshore	0.024
Transportation Corridor, Communication & Utility Commercial Industrial	0.025
Institutional Residential – Apartment, Commercial/Mixed	0.030
Recreation and Protected Natural Areas (Some Institutional, Open and undeveloped)	0.035
Residential – House (SFR/Duplex/Townhouse)	0.050
Water	0.001
Densely Forested Area	0.09
Buildings	N/A

NOTE: This figure shows the extents of modelling, *not* the extents of flooding.

DATA SOURCES: Basemap from Esri and NRCan.

Figure 11. Roughness coefficients assigned to the mesh based on landuse classes.

4 MODEL CALIBRATION AND VALIDATION

Calibration and validation are standard steps in the model development process. These steps consist of comparing observations from historic flood events with the model's ability to simulate those events. Unlike records of fluvial flooding, comprehensive data sets are rare for coastal flood events because these latter events tend to occur rapidly with little warning and most often in the winter. Potential sources of data on flood extents include ground and aerial photographs, newspapers with empirical evidence and first hand descriptions from witnesses. Water depths, wrack marks (debris or other temporary evidence left behind that record the location of the flood water) and measurements of flow velocity or flow rates are sources of hydraulic data.

With sufficient data, model parameters can be adjusted to achieve better agreement with observations (calibration) before validating the model by simulating a second independent event. This process provides confidence in the model's ability to predict other events of similar magnitude. Ideally, models should be verified against all the variables of interest: flood extent, water depth, velocity field, time of occurrence, duration of event.

4.1 DECEMBER 2012 KING TIDE

The recent King Tide that occurred on December 17, 2012 was well-documented with inundation extents captured in numerous photos and videos along the City's shoreline. Flood extents were identified on the photos and videos and digitized in GIS. Locations of all available photos and videos are shown in **Figure 12**.

The flood extents simulated by the model for the December 2012 tides were then compared with the observations. **Figure 13** through **Figure 20** show comparisons between the modelled and observed flood extents. In general, the comparisons showed good agreement between modelled and observed flood extents. **Table 4** summarises the agreement for the locations where observed flood extents were documented.

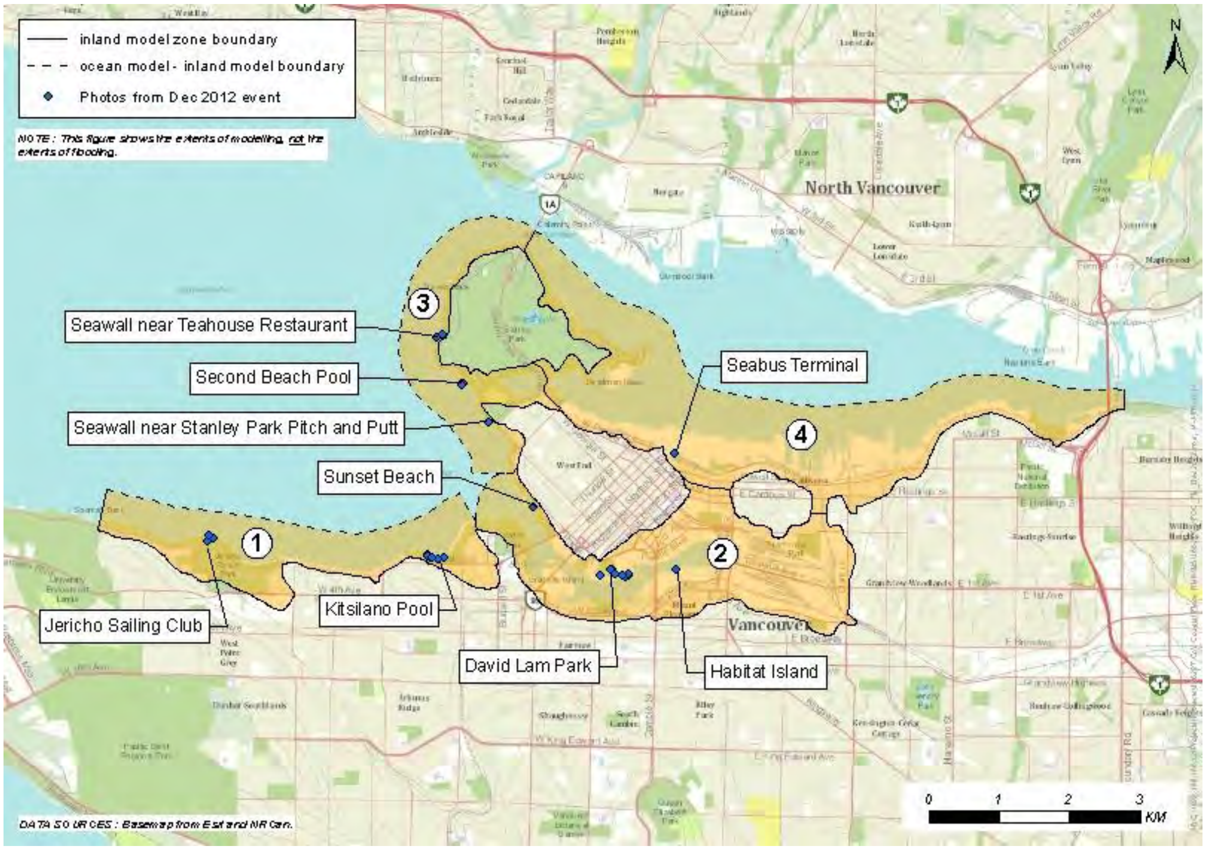


Figure 12. Locations of photos showing flood extents on December 17, 2012.

Table 4. Summary of agreement between observed and simulated flood extents (Dec 17, 2012).

Location	Zone	Agreement
Kitsilano Beach	1	Excellent
Kitsilano Pool	1	Excellent
Jericho Sailing Club	1	Poor
West of Jericho Sailing Club	1	Poor

David Lam Park	2	Good
Sunset Beach	2	Good
Habitat Island	2	Good
Seawall near Stanley Park Pitch and Putt	3	Fair
Second Beach Pool	3	Excellent
Seawall near Teahouse Restaurant in Stanley Park	3	Excellent
PMV parking lot (near SeaBus terminal)	4	Poor

At Jericho Sailing Club (**Figure 14**), the agreement is not as good. The model shows larger inundation extents and roughly 0.2 m more water than what can be deduced from photos. There are two possible explanations for the difference in water levels. First, the large pier that extends out from the point was not included in the model and would likely provide some sheltering. Secondly, the water level applied at the Zone 1 boundary was constant and likely more representative of the wave setup conditions at Kitsilano Beach than those in the shallower waters near Jericho beach.

At the Port Metro Vancouver parking lot located near the SeaBus terminal, the model over-predicted the inundation extents. Ground elevations were surveyed by PMV along the edge of the parking lot at the shoreline. The surveyed ground elevations are 5 to 20 cm higher than the nearest points captured in the 2013 LiDAR. The difference between observed and modelled flood extents would seem to indicate that the LiDAR elevations are lower than reality, at least along the edge of the parking lot. However, it is also likely that the modelled water level reaching the shoreline at that location is higher than it was on December 2012. Another possible explanation is that the photo does not show the flood extents corresponding to the peak water level (photo had no timestamp).

It should be emphasized that although the model showed a reasonable ability to simulate the December 17, 2012 flooding, this event is of a much lower magnitude (peak water level of 2.66 m GD) than the five future scenarios selected by the City. In December 2012, the flooding occurred within a narrow band with a maximum distance of 15 m to 30 m from the shoreline. Hence, the validation process does not provide much confidence in the model's ability to simulate the overland flooding (water depths and flow velocities) during future coastal flood events when water will flow along streets and between buildings.

Figure 13. **Comparison of observed and simulated flood extents at Kitsilano Pool and Beach for December 17, 2012.**

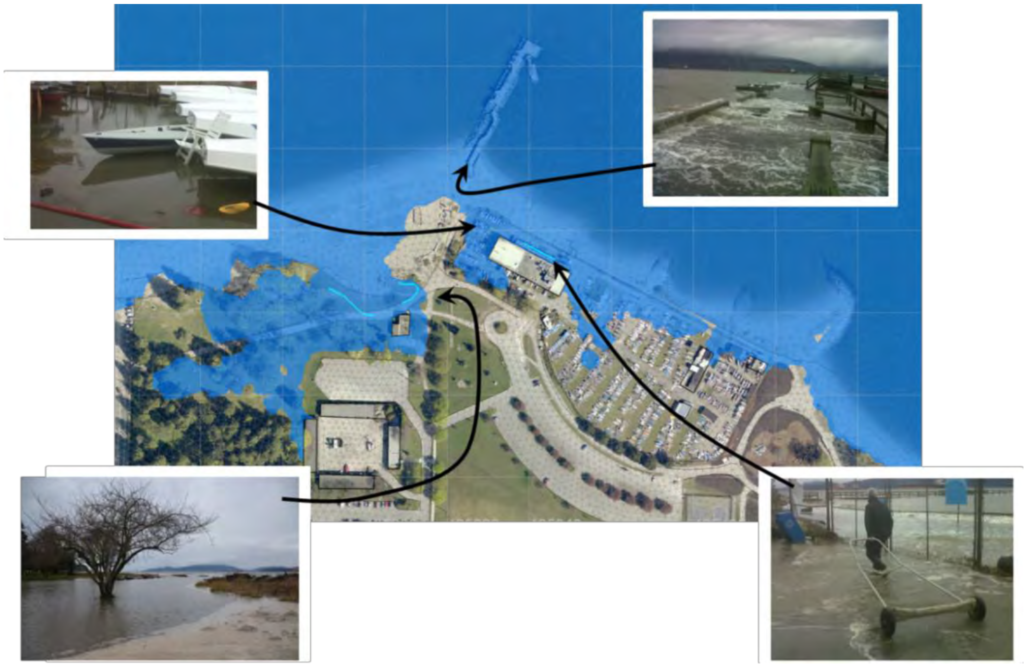


Figure 14. **Comparison of observed and simulated flood extents at Jericho Sailing Club for December 17, 2012.**

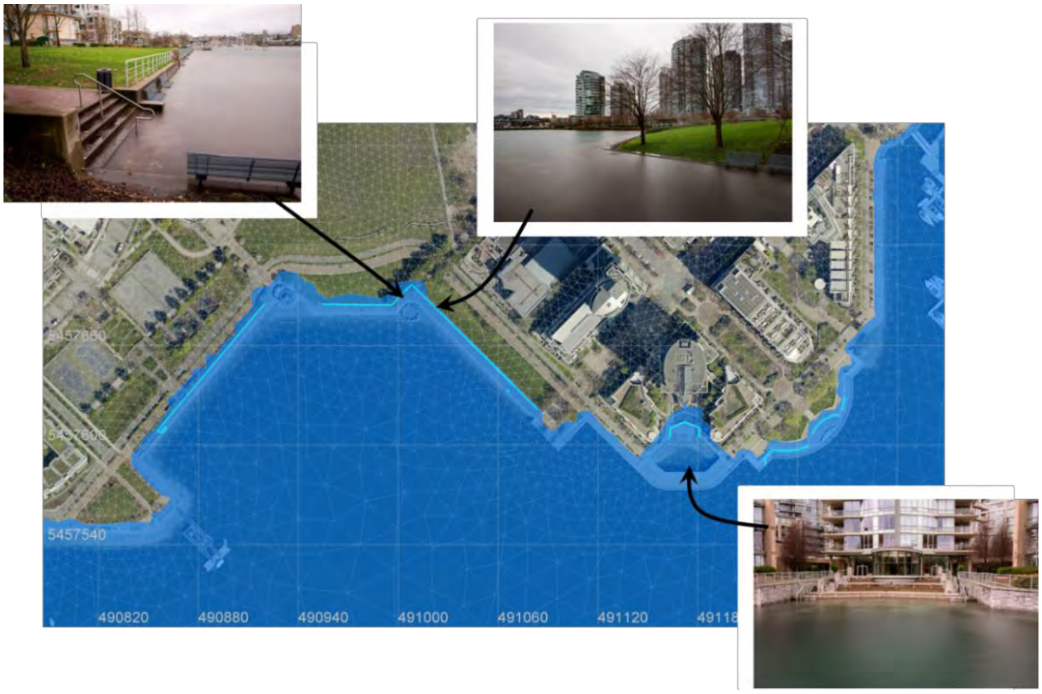


Figure 15. Comparison of observed and simulated flood extents at David Lam Park for December 17, 2012.

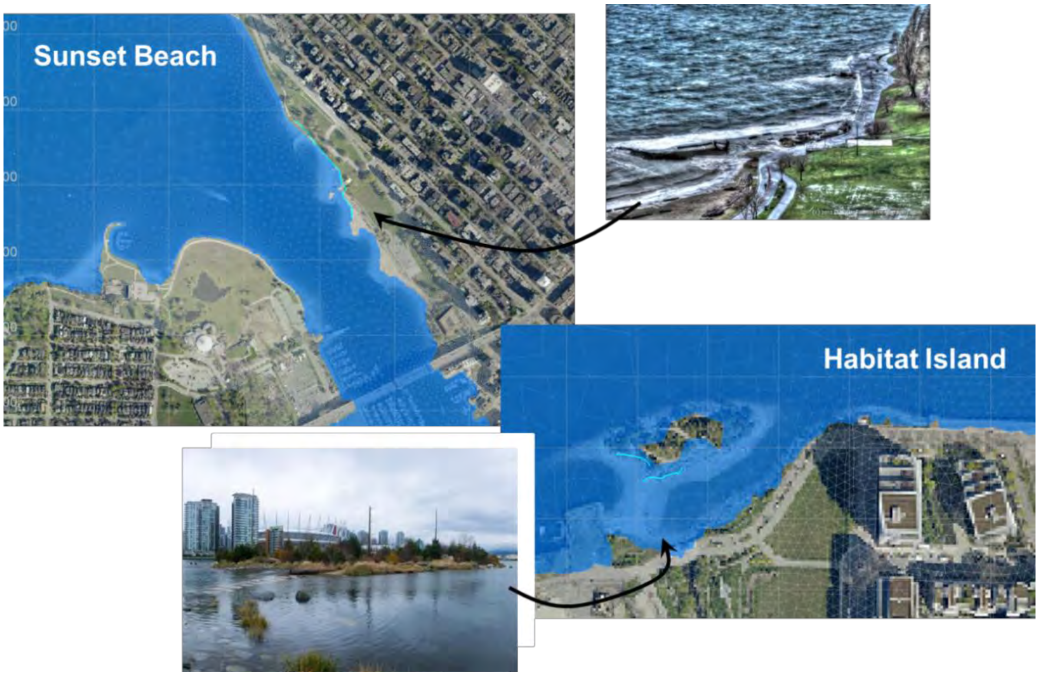


Figure 16. Comparison of observed and simulated flood extents at Sunset Beach and Habitat Island for December 17, 2012.

Figure 17. **Comparison of observed and simulated flood extents along the seawall near Stanley Park Pitch and Putt for December 17, 2012.**

Figure 18. **Comparison of observed and simulated flood extents along the seawall near Second Beach Pool for December 17, 2012.**

Figure 19. **Comparison of observed and simulated flood extents along Stanley Park seawall near the Teahouse Restaurant for December 17, 2012.**

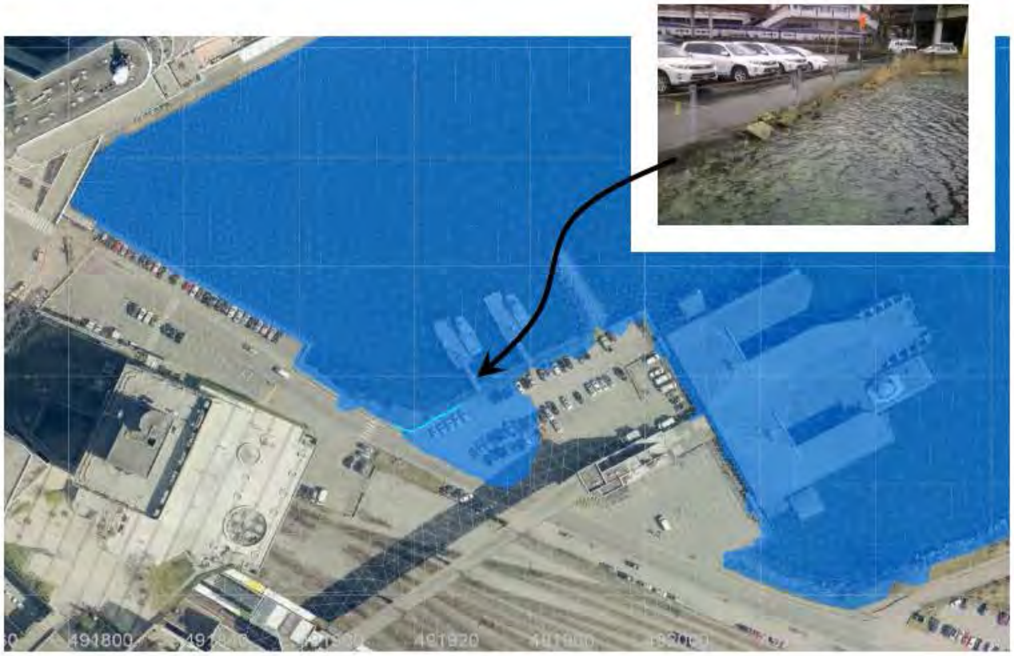


Figure 20. **Comparison of observed and simulated flood extents near SeaBus terminal for December 17, 2012. (Note: the SeaBus terminal and other floating structures were not included in the model).**

5 SIMULATION OF SELECTED SCENARIOS

The five scenarios selected during the October 17, 2013 Technical Advisory Group meeting are summarised in **Table 5**. The last column in the table lists the shoreline water level provided from the coastal modelling analysis. These are the values that were specified as a tidally-varying boundary condition to the overland model (**Figure 21**).

Table 5. Selected modelling scenarios and total water levels for Burrard Inlet.

Scenario	Year	SLR	Return Period	Method	Shoreline Water Level (m GD)
1	2013	0.0 m	1/500		2.97
2	2100	0.6 m	1/500	Joint	3.57
3	2100	1.0 m	1/500	Joint	3.97
4	2100	1.0 m	1/10,000	Joint	4.18
5	2200	2.0 m	1/10,000	Joint	5.18

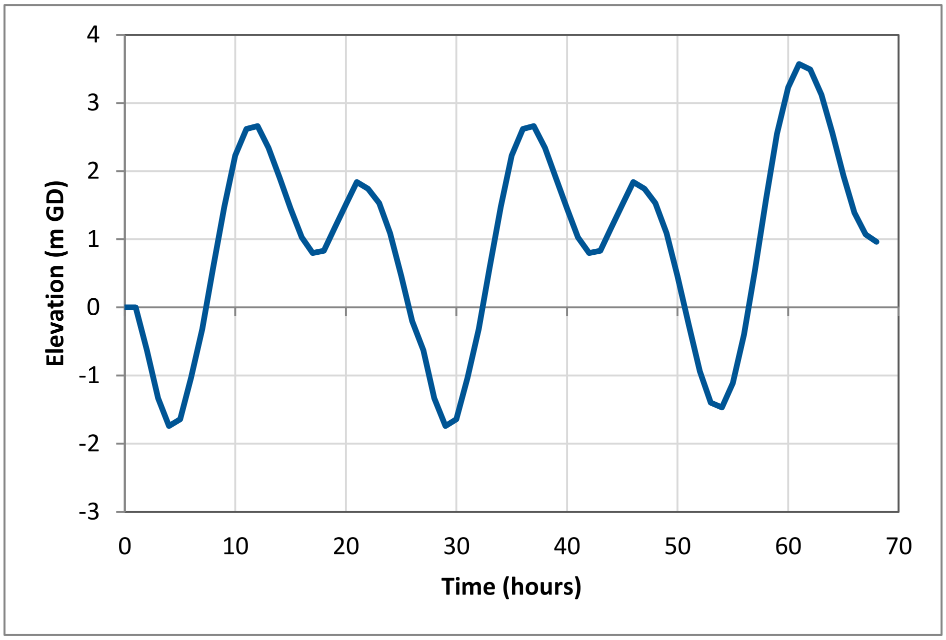


Figure 21. Sample tidal cycle used as forcing for overland model (Scenario 2).

The timeseries were imposed as boundary conditions to the overland flood model. The resulting simulated water depths were post-processed in GIS and are shown on the maps presented in Section 7 of the report.

5.1 FLOOD PROPAGATION

The period of time from the onset of flooding until the maximum inundation was analysed. This duration provides an indication of the rate of flooding or in other words, the propagation of the flood wave overland. In open areas, the flood wave generally travels at a speed of 0.2 m/s or less. In confined locations – between buildings, along streets, alleys and paths – the flood wave generally travels at speeds between 0.2 m/s and 0.6 m/s with speeds occasionally exceeding 1 m/s at some locations. No data are available to verify the modelled flow velocities and given the associated uncertainty, should only be used as approximate values.

Table 6 summarises the simulated time to reach peak inundation extents for each of the scenarios. As the severity of the flooding scenario increases, the onset of flooding occurs earlier relative to the peak tide, and in some locations the flood wave continues to propagate inland after the tide offshore has started to recede.

Table 6. Simulated time to peak of flooding at selected locations in Zone 1 and Zone 2.

	Time to Peak (hr:mm)			
	Zone 1		Zone 2	
Scenario	**Jericho**	**Kits Beach**	**Granville Island**	**Science World**
1	2:50	2:00	N/A	N/A
2	2:20	2:30	1:20	1:10
3	2:30	3:15	1:50	1:45
4	2:45	4:00	2:10	2:30
5	3:30	4:30	3:10	4:20

During a coastal flood event, the stormwater system plays an important role in the receding of flood water especially in low-lying areas. No comment can be made on the duration of the flooding as the stormwater system was not represented in the overland flood model.

6 SENSITIVITY ANALYSES

Without any observed data corresponding to flooding from peak tides greater than those documented in December 2012, it is impossible to evaluate the model's ability to accurately predict flooding for Scenarios 1 through 5. In order to gauge the model's sensitivity to various input parameters and to help interpret the model results, sensitivity tests were performed.

6.1 BUILDING GENERALISATION

First, a sensitivity test was done to investigate the impact of generalizing buildings by merging those with a separation distance of less than 5 m. This test was done in the Kitsilano Beach area where the merging of rows of closely spaced houses was expected to have the greatest impact on the simulated flooding. **Figure 22** shows the two meshes that were used for the sensitivity test.

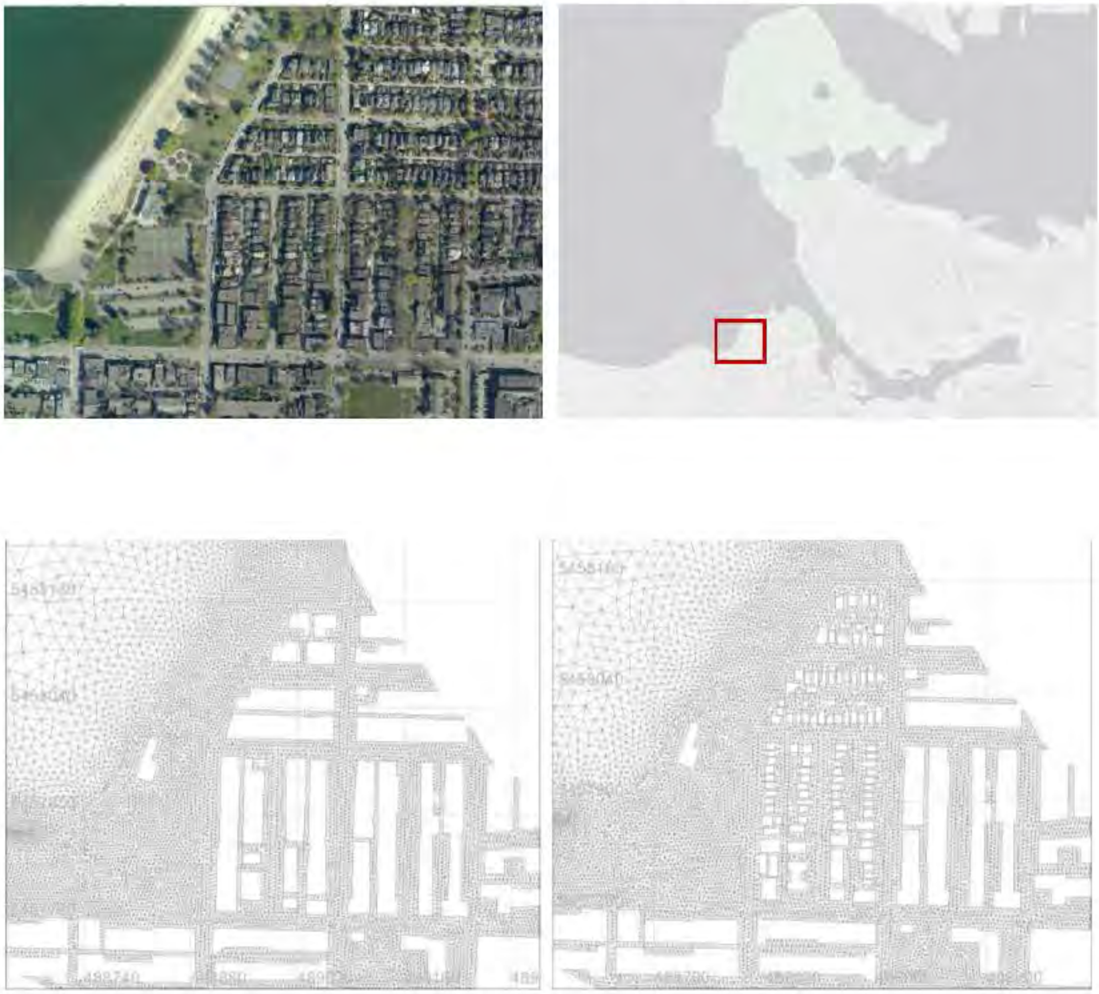


Figure 22. **Impact of generalising buildings in model mesh investigated in Kitsilano Beach area (top right panel). Houses are shown in the 2013 ortho (top left) while the mesh with generalised buildings (bottom left) can be compared with the finer mesh (bottom right).**

The simulated maximum flood extents for Scenario 3 are shown in **Figure 23** for both meshes. The darker blue inundation extents were computed with the mesh used for this study (generalized buildings) while the lighter blue extents were computed with the finer mesh that included the original building footprint (no generalization).

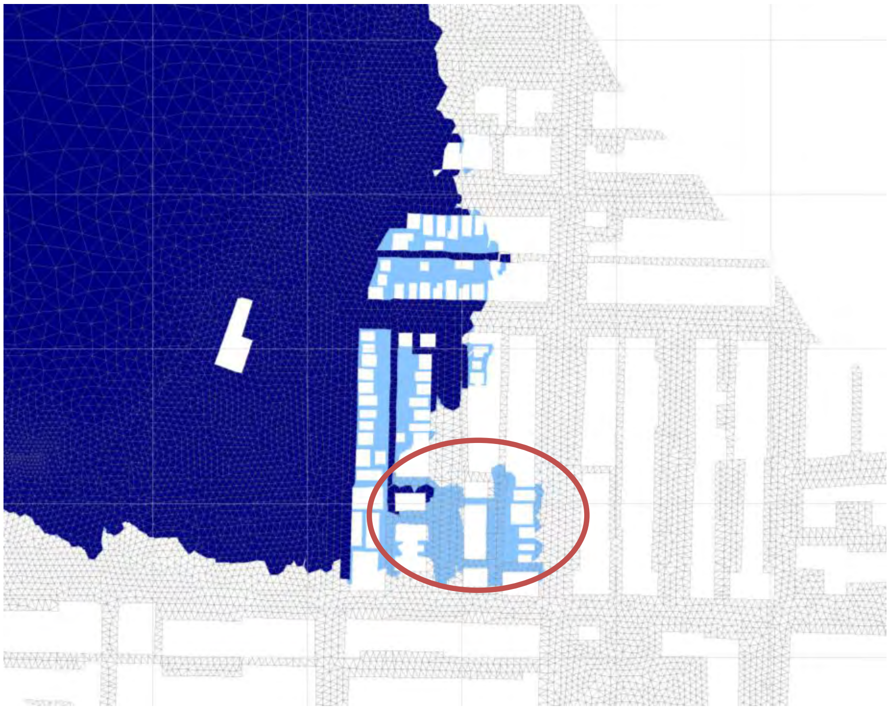


Figure 23. Comparison of modelled flood extents for mesh with generalized buildings (dark blue) and mesh with original building footprints (light blue).

The modelled flood extents are almost identical except in the area circled in **Figure 23**. The gaps between houses that are included in the finer mesh allow the flood water to extend further inland where the merged rows of houses are parallel to the shoreline. It should be noted that the gaps included in the finer mesh are generally wider than the actual spacing between the houses and that a more accurate representation of the houses would be some intermediate mesh with smaller gaps. That being said, the generalization of the buildings is only expected to have an impact on the modelled flood extents in areas such as this one where closely spaced buildings are oriented perpendicular to the direction of flow. It is expected that the generalisation of buildings would have an impact on the modelled flow velocities.

6.2 PEAK WATER LEVEL

The peak water level specified as a boundary condition in the model has an inherent degree of uncertainty associated with it. To verify the influence of this input on the modelled flooding, Scenario 3 was simulated with the peak water level adjusted by ± 0.1 m and ± 0.2 m. The sensitivity of the modelled inundation extents to input peak water levels is shown in **Figure 24**.

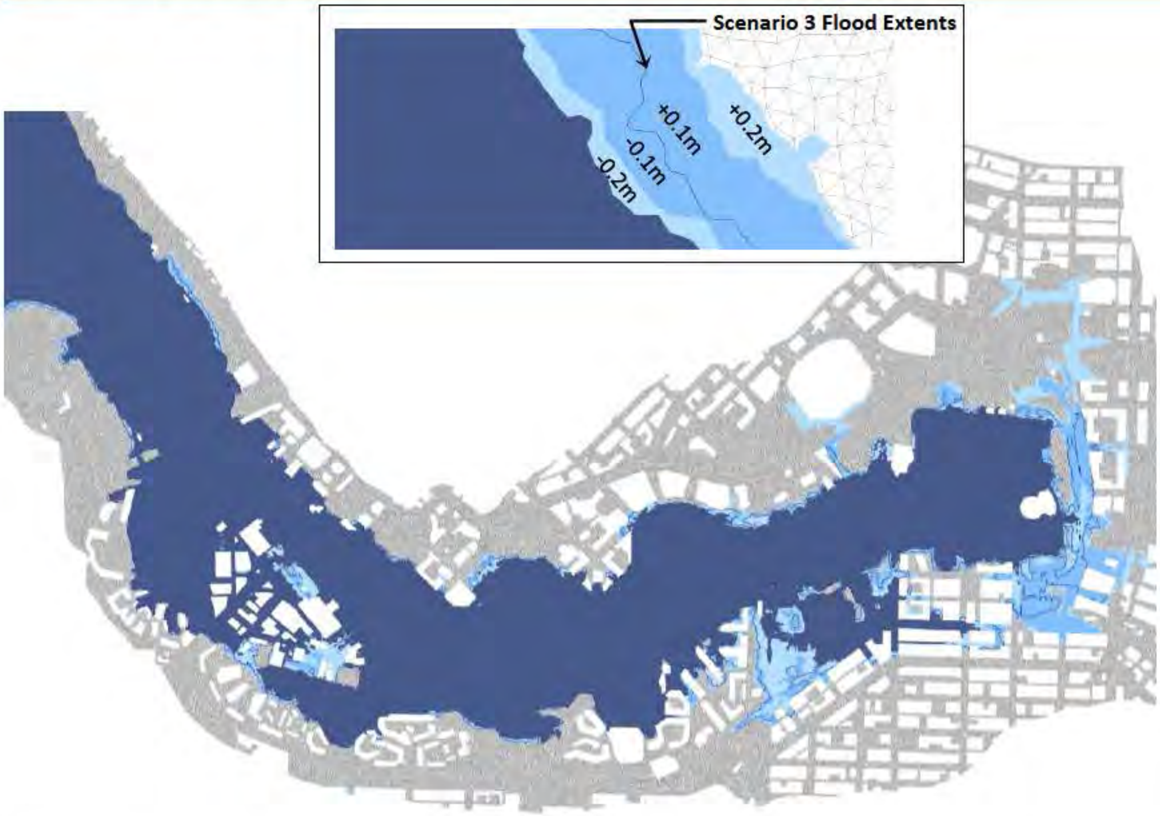


Figure 24. **Sensitivity of modelled flood extents to uncertainty in peak water levels under Scenario 3 in Zone 2.**

Where the flood extents end in flat and/or gently sloping areas, varying the peak water level causes significant changes in the inundation extents and flood volume. In areas where the flood extents abut against a steeper slope, there is little change in the inundation extents but the depth of flooding will vary. Areas that are flat and/or gently sloping such as Jericho Beach, Kitsilano Beach, Granville Island, False Creek flats, Lost Lagoon, Gastown, the Port lands are most susceptible to changes in inundation extents as a result of changes in peak water levels.

6.3 ROUGHNESS COEFFICIENTS

Finally, tests were done to quantify the sensitivity of the model output to change in roughness values.

Roughness parameters are used to represent the flow resistance due to various sources of energy loss. Difficulties arise when trying to characterise a specific landuse type as limited guidance is currently available for the selection of roughness coefficients for urban areas. The roughness values assigned to the mesh elements were adjusted by ± 20% and ± 40% to reflect the possible range of uncertainty. As shown in **Figure 25**, varying the roughness values had limited effect on the modelled flood extents. However, varying the roughness did have an impact on the modelled flow velocities and the time to peak.

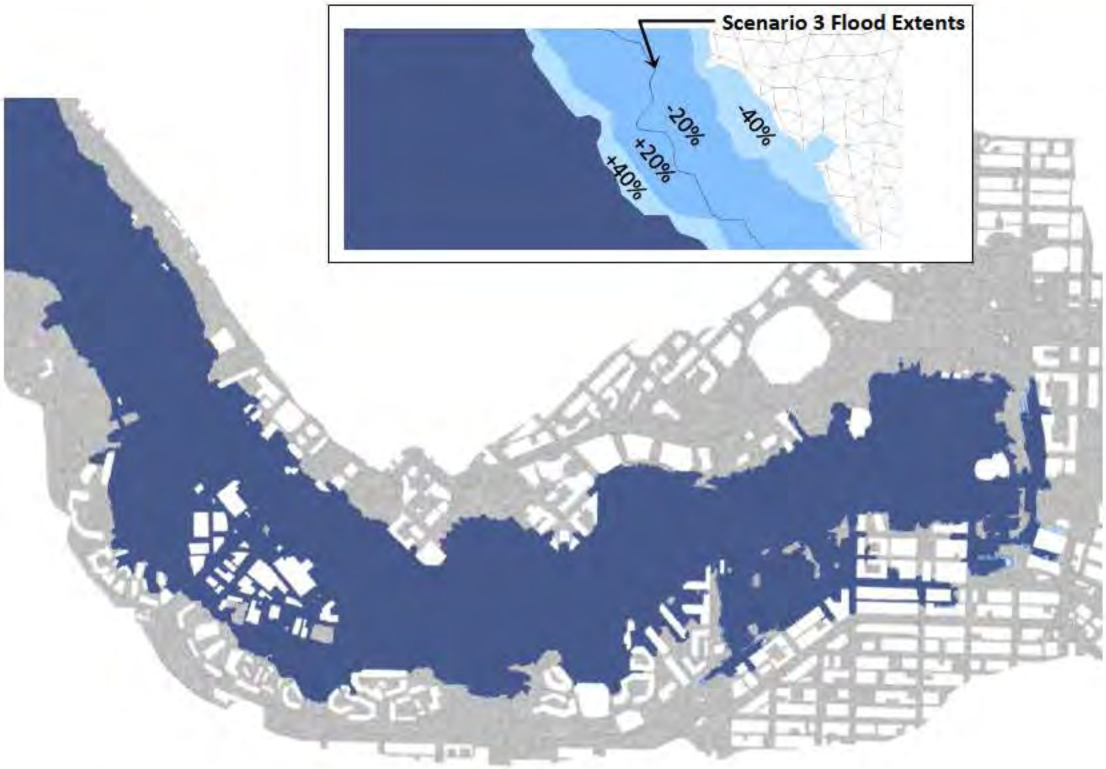


Figure 25. **Sensitivity of modelled flood extents to changes in roughness coefficients, Scenario 3 in Zone 2.**

One additional test was done where the roughness parameters corresponding to smoother surfaces (n < 0.024) were decreased by 20% and the roughness parameters of rougher surfaces (n > 0.024) were increased by 20%. This was done to investigate the effects of decreased energy losses along roads and higher energy losses on the adjacent properties. Results show virtually no change in modelled flood extents.

7 MODEL LIMITATIONS

The accuracy of water levels and other output data is limited by the following:

- For mesh development, a generalization algorithm was used to merge closely spaced buildings (<5 m apart) that would likely act as a single obstacle to the flow. Buildings were removed from the model mesh and building outlines represented by solid boundaries. No roughness value was assigned to these internal boundaries.
- Model roughness values were assigned based on typical landuse classes to represent the flow resistance due to various sources of energy loss. The accuracy of the model output is

limited by the reliability of the water level data used for calibrating the model. Limited data was available at select locations but did not extend more than 15 m from the shoreline.

- The accuracy of model output is limited by the accuracy of the DEM. Data from LiDAR, surveyed in 2013, was used to create a Digital Elevation Model (DEM) for the City of Vancouver; the DEM surface was edited to remove buildings and temporary features. The DEM surface was also modified to include (1) the Powell Street Overpass, currently under construction, and (2) modifications to Pacific Boulevard and Griffiths Way planned as part of the removal of the Georgia Viaduct.
- Changes to ground elevations, landuse or buildings from those included in the model will affect the flood levels and render site-specific information obsolete. The modelled flood levels are based on ground conditions at the time of the surveys (and some anticipated future landuse and building layouts).
- The model geometry was kept constant at all flows although variations (erosion, subsidence, or future constructions) may occur before or during a flood. Irregularities or blockages caused by fences, walls, hedges, vehicles, boats, or other barriers are difficult to characterize and were not represented in the model.
- The modelling does not take into account all flood defences which may be in place now or in the future.
- The accuracy of the model boundary conditions and model parameters will affect the accuracy of the modelling results.
- Other sources of water (i.e. precipitation, groundwater, or sewer surcharge) and complex interactions between subsurface drainage networks and structures (i.e. SkyTrain infrastructure, underground parking, conduits, etc.) were not considered and can affect flood levels locally.

The model limitations and uncertainties should be considered when making decisions based on the model results.

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ANNEX E

VULNERABILITY ASSESSMENT

Flood Vulnerability: What's in the way?

City of Vancouver Vulnerability Assessment

6/16/2014
Arlington Group Planning + Architecture

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Context

The City of Vancouver has a long and prevailing relationship with water. It has a dynamic and complex shoreline that is home to a large residential population, waterfront parks and beaches, water dependent industry and commerce, road and rail connections, and tourist attractions. Civic leaders, businesses, community associations and residents have been debating the most appropriate forms of land use for years. Striking a balance between sound real estate decisions, healthy community initiatives and sustainable development with the impending climate change impacts will be vital for maintaining Vancouver's renowned liveability.

Climate change impacts anticipated in Vancouver include more intense rainstorms, stronger winds, more frequent floods and rising sea levels. Adapting to these impacts will require a mix of policy, planning and technical responses and a thorough understanding of the consequences of coastal flood hazards. The City of Vancouver began the process by publishing the Climate Change Adaptation Strategy in the summer of 2012, which called for a coastal flood risk assessment for the city.

This document forms a part of the first phase of the Coastal Flood Risk Assessment (CFRA) as demonstrated in Figure 1. This work along with detailed hazard mapping and a preliminary consequence assessment will be used in order to develop the technical, policy and planning tools necessary to create a robust and resilient approach to manage flood risk (Phase 2).

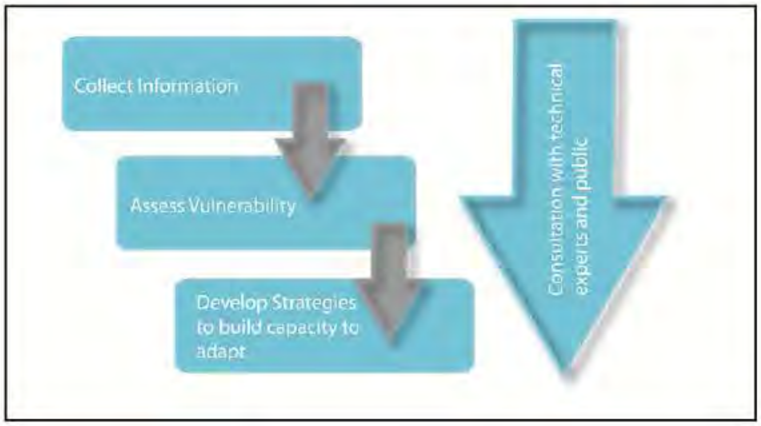

Figure 1 - Steps to a Coastal Flood Risk Assessment

In mid-February 2014, a diverse range of stakeholders were invited to a discussion and feedback session about the current and future coastal flood hazard areas within the City of Vancouver. The overall objective of the session was to identify and expand on the city's vulnerabilities, including, but not limited to, the assets, services and populations that would be in the way during a potential flood, how vulnerable they are to flooding, and what sort of impact this will have on the City of Vancouver (additional workshop details and documentation are available in Appendix A). This report expands on the information obtained from the workshop and develops a deeper understanding of the potential consequences of a coastal flood event.

Scope

Preliminary mapping of the potential effects of coastal flood hazards on the City of Vancouver has identified several areas of concern. As Figure 2 illustrates, the areas under analysis for the Burrard Inlet portion this part of the Coastal Flood Risk Assessment (CFRA) include Kitsilano Beach, False Creek, English Bay, Stanley Park and along the Inner Harbour east to the Second Narrows Bridge. The North Arm of the Fraser River is analyzed separately, and found in **Annex G – Fraser River High Level Strategy**.

Figure 2 - Vancouver CFRA study areas

Coastal flood hazard events will vary by tides, storm components (including storm surge, wind and wave effects) and future sea level rise. Most coastal flood hazard events occur periodically, differing only in the time between events (otherwise known as frequency or return period) and scale of event. The December 2012 storm, a recent event for many Vancouver residents, had a return period of about 50 years from Point Grey to Kitsilano and a 15 year return period for False Creek. However the high King Tide[1] itself (without the storm surge and wind effects) occurs about every 3 years. In comparison, Hurricane Katrina, which devastated New Orleans in 2005, is said to have a return period between 21 and 23 years[2], while Superstorm Sandy was on the recurrence interval of 700 years[3].

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[1] King Tides (also known as perigean spring tides) are extreme high tide events that occur when the sun and moon's gravitation forces reinforce one another at times of the year when the moon is closest to the earth. They happen twice a year, but they are typically more dramatic during the winter. (Livesmartbc.ca)

[2] For return period of 23 years (http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf) and for 21 years (http://onlinelibrary.wiley.com/doi/10.1029/2005GL025452/abstract)

[3] Recurrence interval of 700 years: http://pubs.giss.nasa.gov/abs/ha07610g.html

For Vancouver, five future coastal flood scenarios were selected in consultation with a technical advisory group. The scenarios selected ensure that as many different possibilities and time frames would be analyzed. The 5 Scenarios are:

- Scenario 1 – Year 2013, Probability 1:500 year event;
- Scenario 2 – Year 2100, SLR 0.5 m, Probability 1:500 year event;
- Scenario 3 – Year 2100, SLR 1 m, Probability 1:500 year event;
- Scenario 4 – Year 2100, SLR 1 m, Probability 1:10,00 year event;
- Scenario 5 – Year 2200, SLR 2 m, Probability 1:10,000 year event.

For the purposes of the Vulnerability Assessment, Scenario 3 – in the same order of magnitude as Superstorm Sandy on the East Coast of the United States – has been used. Scenario 3 is based on two key criteria: a 500 year-event (i.e. annual probability of .002 or 0.2%) and sea level rise of one metre, anticipated by the year 2100.

Knowing the approximate extent of coastal flood hazard events in Vancouver supports the importance of integrating flood-receptive designs into land use and community development planning. Knowing what is in the way is vital, as is appreciating the possible ramifications, to working towards flood risk and flood impact minimization. By conducting a Vulnerability Assessment, the degree of community assets and neighbourhoods vulnerable to coastal flood events can begin to be established. From there, existing assets (including the protection and relocation of residents) can be protected, relocated or created anew, as determined by their level of susceptibility to flood levels and importance to vulnerable populations during a flood event.

Vulnerability

Vulnerability refers to the degree to which a system (or element) is susceptible, or unable to cope with the adverse effects of climate change, including variability and extremes. It is a function of exposure, sensitivity (degree to which it may be affected) and adaptive capacity and involves many forms, including at household (or individual), social, institutional, economic, physical, environmental and place levels (Jha et al, 2012).

Social vulnerability is the product of social inequalities as well as location inequalities, including community characteristics and the built environment (Cutter, 2003). The elevation above and/or proximity to a hazard – in this case, a coastal flood event – is an important factor in determining the resiliency of a community. Social vulnerability is an important part of the CFRA but it can be difficult to assess, let alone quantify (Cutter, 2003).

To appropriately assess vulnerability, both geographic and social considerations need to be taken into account to determine what may be harmed by flooding, in other words the *elements at risk* (e.g. people, houses, buildings or the environment). Infrastructure and assets can include the building stock, critical infrastructure, transportation routes, and utilities within a community or region. Other miscellaneous items can include the quality and access to parks and recreational space, cultural spaces (outside of the building stock component), and high value habitat (including agricultural potential) (February 14th workshop, 2014). In regards to social vulnerability, no fully agreed upon set of indicators exist and these vary considerably from one city to another (Cutter, 2003). Strongly correlated variables include the following (Cutter, 2013 and Jha et al, 2012):

- Socioeconomic status, gender, age, race and ethnicity
- Value, quality and density of residential properties
- Presence of renters and transient populations
- Commercial and industrial development
- Occupation, education, family structure and expected population growth
- Medical services and health status, social dependence and special needs populations

People and buildings (including their contents) are often of primary concern in a flood event; however a flood event often acts as a catalyst, or initiates a chain of cascading events, resulting in many secondary or tertiary effects. These effects can occur on an economic, social and community level.

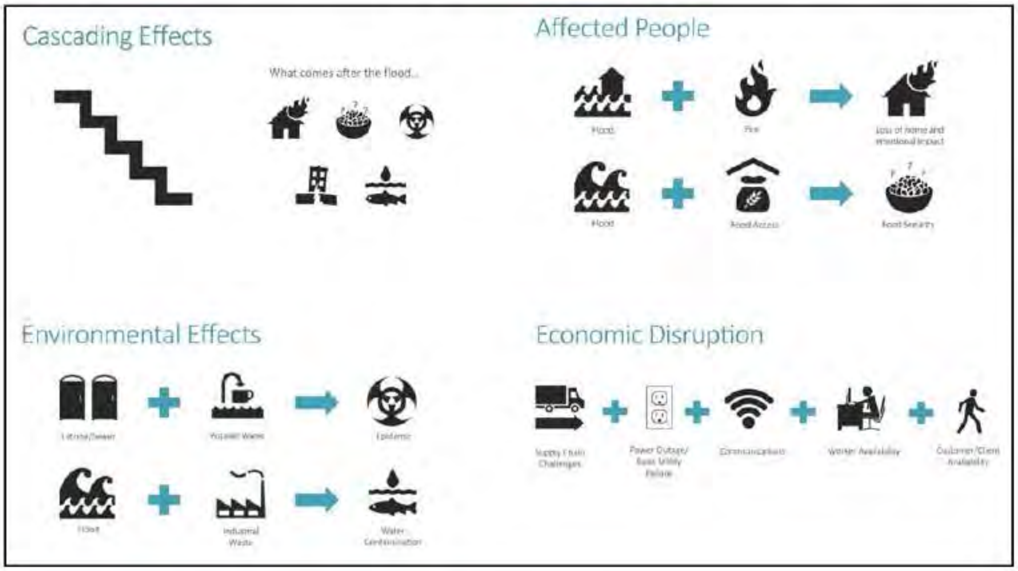

Figure 3 - Cascading effects (February 14th workshop, 2014)

What's in the Way

Identifying the coastal flood hazard and its potential impact on people, property and infrastructure is a key introductory step to considering mitigation measures.

Local Economy

Business and economic activities provide an important socio-economic role in a community. Businesses provide goods and services throughout the community/region, provide tax revenues to the local government and employment opportunities for residents (Zhang et al, 2009). When business activity is negatively impacted, local businesses and economic activity can anticipate disruption (Tierney, 2006). Disruption, or even simply temporary failure, of parts of the local economy can result in job/employment loss, population displacement, lost tax revenue, supply-chain difficulties, customer/client decline, and the inability of employees to get to work will restrict a community's ability to recover from an event (Tierney, 2006 and Web et al 2000, 2002). Historically, 'recovery' has been defined as the 'return to pre-disaster conditions' (Chang & Rose, 2012, pg. 172) but there is now recognition that an economy may stabilize at a "new normal" (Chang & Rose, 2012).

The value, quality and density of commercial and industrial land uses and buildings can provide an indicator to the economic health and potential resiliency of a community in the event of a disaster (Cutter, 2003). Certain types of businesses and sectors may recover more easily than others (Table 1).

Table 1 - Overview of business sector by recovery

Businesses that may recover more easily	**Businesses that may face additional challenges**
Larger businesses	Smaller Businesses • May "occupy more physically vulnerable structures, have less access to insurance and other means of finance,[and] lack redundancy in facility location" (Chang & Rose, 2012, page 173)
Businesses serving a regional or international market	Locally-oriented businesses
Businesses with multiple location or part of a franchise chain	Wholesale and retail businesses
Manufacturing and construction companies • In general, reconstruction post-event can provide significant economic stimulus. Construction and related industries may anticipate significant opportunities post-event. (Chang & Rose, 2012 and Chang, 2010).	
Sources: Chang & Falit-Baiamonte, 2002, Chang & Rose, 2012, Web et al, 2000, 2002) and Zhang et al, 2009	

Businesses with less physical damage to property (including contents and equipment) and those with less disruption to their infrastructure and utilities (including electricity, water, sewer, fuel sources, telecommunication lines and transportation routes) are more likely to recover quickly (Chang & Falit-Baiamonte, 2002 and Web et al, 2000, 2002). Businesses with less physical damage, but that are located in heavily damaged areas, may face recovery challenges (Chang & Rose, 2012). The restoration of strategic infrastructure (electricity is of particular importance) is imperative for business recovery (Chang & Rose, 2012) as the less time a business is closed, the higher the probability of recovery (Webb et al, 2002).

Figure 4 demonstrates elements at risk (both in and out of the flood zone) within the City of Vancouver CFRA study zones. To capture the transportation linkages, SkyTrain stations, train and bus stations and gas stations were included. Given the importance of the service sector to the City of Vancouver, major restaurants, tourist destinations and hotels were incorporated (including key commercial/retail areas within the City). Water-dependent industries were also added.

In comparison, Figure 5 demonstrates how a Scenario 3 (including freeboard) coastal flood event would interact with economic-related land uses (commercial, industrial and Port Metro Vancouver lands). Both Figure 4 and Figure 5 illustrate the SkyTrain, rail and key truck routes and how they may impact the adjacent commercial and industrial activities given a coastal flood event. Appendix B provides the Hot Spot Map methodology while Appendix C provides additional information on the data sources and notable elements included on the Hot Spot Map as well as detailed maps demonstrating each of the CFRA study areas.

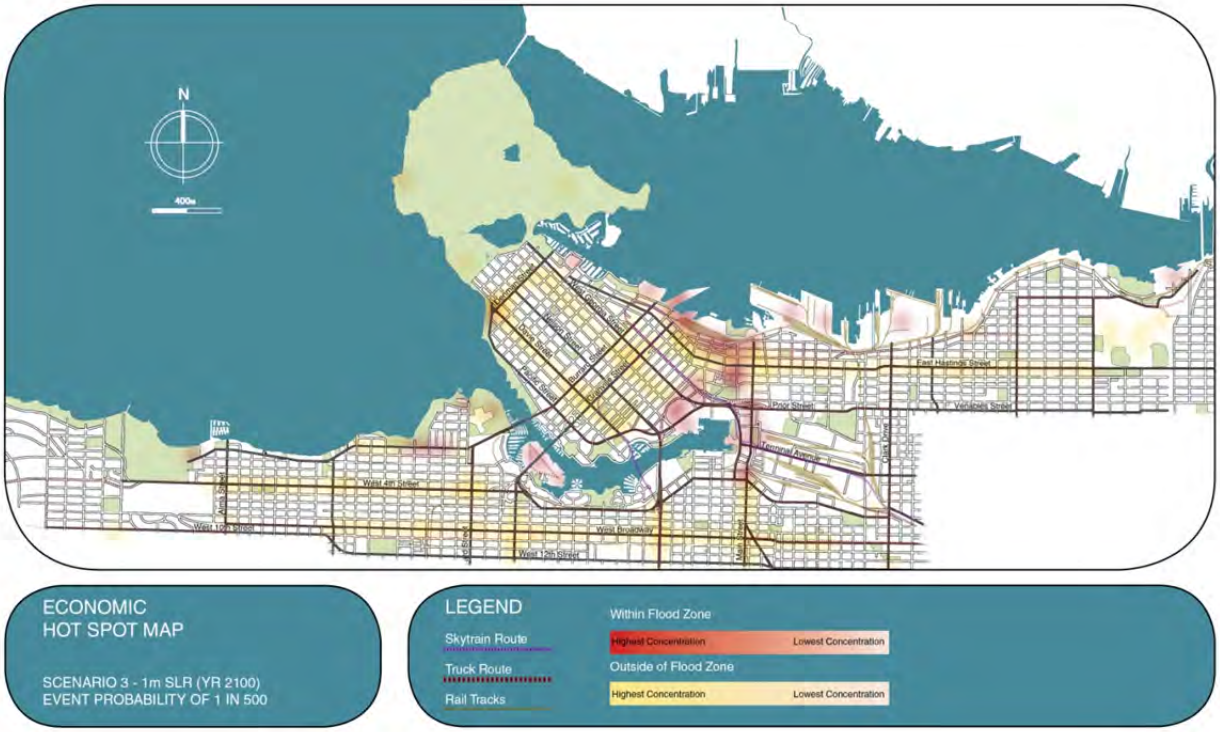

Figure 4 - Economic Hot Spot Map

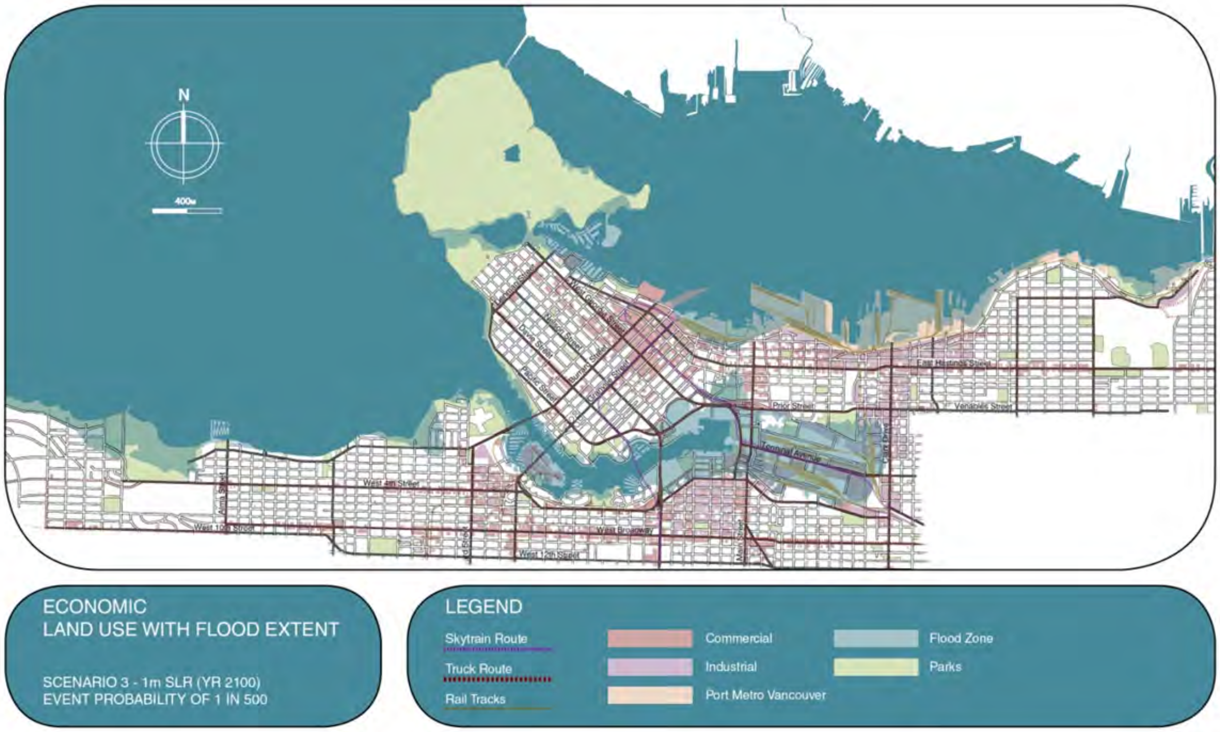

Figure 5 - Economic Land Use Map with Flood Extent

Land Use

Under a Scenario 3 coastal flood event (including freeboard[4]) conditions, 3.97% [5]of the City of Vancouver's land would be inundated. The land uses with highest amount of inundation – when taking into account the entire City of Vancouver land area – are:

- *Recreation and Protected Natural Areas* (1,621,441 m^2, 1.39%) followed by
- *Port Uplands* (1,018,113 m^2, 0.88%),
- *Transportation Corridor and Utilities* (710,038 m^2, 0.61%) and
- *Industrial* (373,647 m^2, 0.32%).

These four types of land uses represent over 80% of all land uses in the City subject to inundation. Other land uses consist of *Commercial* (285,247 m^2, 0.25%), *Open and Undeveloped* (295,562 m^2, 0.25%) and *Residential*[6] (262,827 m^2, 0.23%). Appendix D provides the area (m^2) and percentages (%) by land use for all five CFRA scenarios, as well as the 2009 City of Vancouver Land Use Map with flood extent.

Land uses that are considered most flood-compatible are summarized in Table 2.

Table 2 - Overview of most flood-compatible land uses

Flood-compatible land uses	
Water-based recreation	Lifeguard and coastguard stations
Ship/Marine based industries	Defence facilities
Docks, marinas and wharves	Navigation facilities
Amenity open space, recreation space, nature conservation and biodiversity	Water and Sewage transmission infrastructure and pumping stations
Adapted from: Flood risk vulnerability classification, CLG 2006	

Land uses that are considered most vulnerable to a flood hazard event include essential transport infrastructure, strategic utility infrastructure, electric generating stations, emergency services, residential dwellings with basement suites, and uses requiring storage or process of hazardous substances (CLG, 2006). The complete classification of land uses is available in Appendix E.

Port Metro Vancouver

Port Metro Vancouver is Canada's largest port, and the 4th largest tonnage port in North America. The Port handles over $172.4 billion (CAD) of cargo annually, 19% of Canada's total trade (by value), $9.7 billion in direct GDP, and $6.1 billion in wages. The direct economic impact of the Port is summarized in Table 3.

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[4] Freeboard of 0.6 m has been used. This concept attempts to provide a safety margin including errors in calculation.

[5] Data supplied by NHC. This does not include flooding along Fraser River.

[6] *Residential* includes all 5 Categories: Residential – Commercial/Mixed; Residential – High-rise Apartment; Residential – Low-rise Apartment; Residential Single Detached & Duplex; and Residential – Townhouse.

Table 3 - Port Metro Vancouver direct economic impact

Geographic Area	**Jobs**	**Person Years**	**Wages**	**GDP**	**Output**
Vancouver	13,900	12,200	$780 Million	$1,120 Million	$2,840 Million
Metro Vancouver (including City of Vancouver)	35,100	32,300	$2,090 Million	$3,020 Million	$7,450 Million
Source: PMV Economic Impact Study, 2013					

The continuing operations of the Port generates over $1,270 million annually in government tax revenues with $754 million for the Federal Government, $400 million provincially ($336 million in B.C., $22 million in Alberta, $14 million in Ontario, nearly $9 million in Manitoba, approx. $12 million in Quebec and nearly $7 million in Saskatchewan), and $116 million to port municipalities ($110 million in property taxes and $6 million in payments-in-lieu of property taxes) (PMV Economic Impact Study, 2013).

PMV consists of 28 major marine cargo terminals, however only seven are within this part of the CFRA study area. Terminals and associated business sectors, as of December 2013 (draft PMV Land Use Plan, 2013), that can anticipate coastal flood impacts include:

Bulk Terminals

- Alliance Grain Terminal – handles grain, specialty crop and grain feed.
- Cascadia – grain terminal which handles wheat, durum, canola, barley, rye, oats and by-products.
- Lantic Inc. (Rogers Sugar) – a leading refiner, processor, distributor and marketer of Rogers Sugar brand products in Western Canada. The terminal handles bulk raw sugar imports.
- Pacific Elevators (operated by Viterra) – handles canola, flax, peas and various bulk manufactured agri-forage and by-products.
- West Coast Reduction – handles fat and oil products.

Container Terminals

- Centerm – operates six gantry cranes on two berths, on-dock rail facilities and an advanced operating system that tracks cargo in real time.
- Vanterm (operated by TSI Terminal Systems Inc.) – handles containerized cargo, project cargo and bulk oils from adjacent West Coast Reduction facility.

In addition, PMV is the home-port for the Vancouver-Alaska cruise industry, and has two cruise related facilities:

- Canada Place

- Ballantyne Pier (adjacent to Centerm)
    - It is expected to close in October 2014 and be re-purposed for other uses (draft PMV Land Use Plan, 2013).

The Port and Canadian trade imports and exports are expected to substantially increase. Major container terminals, such as Centerm and Vanterm, will be expected to expand to accommodate the increased container volumes (draft PMV Land Use Plan, 2013). PMV is cognisant that climate change, including sea level rise, may significantly affect port operations and infrastructure. PMV is working with local stakeholders (including the Fraser Basin Council, First Nations and local, provincial and federal governments) to develop a Business Plan for a Regional Flood Management Strategy for the Lower Mainland, as well as participating on the Joint Program Committee for Integrated Flood Hazard Management (draft PMV Land Use Plan, 2013). Furthermore, PMV has an infrastructure asset management program designed to maximize the long-term use of assets in a cost-effective manner to reduce the risk of negative financial, safety and environmental events (draft PMV Land Use Plan, 2013).

Cascading effects from disruption of Port activities may include (but are not limited to):

- Number of jobs (including higher-earning wage positions) along Burrard Inlet. Positions may shift from the south shore of Burrard Inlet to other areas within the region.
- Temporary (or "nuisance") inundation of port lands may result (but not limited to) in:
    - Export and international trade delays
    - Import and service delays of consumer goods locally, regionally and across the province.
    - Re-distribution of intermodal transportation routes – truck, CN, CP and BNSF routes will need to re-route to accommodate for the change in capacity.
- Port and port-dependent businesses rely heavily on road and rail infrastructure for transporting products, delays (either from actual inundation of port lands or just the proximity of inundated lands) will disrupt local and regional transportation, which can result in (but is not limited to):
    - Cargo disruptions in bulk commodities and intermodal shipping
    - Export delays in grain, meat, lumber, coal
        - Four week delay in meat exports alone is equal to 9,000 tonnes of beef and $28M of exports.
        - Over three week delay could require mills and plants as far away as Alberta to shut down, if the product cannot be exported (or if they don't have a contingency plan in place)
- PMV has a limited land supply – concern over lack of existing space for "off-dock" container storage may be exacerbated with a sea level rise and/or a coastal flood event.

Other Industrial Areas

Most industrial sectors are dependent on transportation infrastructure – in particular, efficient road networks – for moving people and goods (Industrial Areas Study, 2007). Automotive, apparel manufacturing, food and beverage production, retail, warehouse/distribution and wholesale/commercial services sectors require unimpeded access (Industrial Areas Study, 2007). Apparel, food and beverage production/processing and catering, and light manufacturing sectors tend to benefit from proximity to local area suppliers (Industrial Areas Study, 2007).

Powell Street Industrial Area

Immediately south of PMV land is the Powell Street Industrial Area – bounded by Heatley Avenue to the west, Semlin Drive to the east, and Hastings Street to the south – which was intended to accommodate heavy- and water- dependent industries (Industrial Areas Study, 2007). Few industrial sectors within the area are directly dependent on the PMV or receive direct benefit from their proximity to the Port (Industrial Areas Study, 2007). However, a few sectors (including apparel and light manufacturing and assembly sectors) do ship via the Port's container terminals (Industrial Areas Study, 2007). The area is not well connected to the rail network.

In 1990, the stretch along Hastings Street between Heatley Avenue and Semlin Drive was designated as "let go" (CoV Industrial Lands Policies, 1995). Today, it is intended that the area will move forward by incorporating more mixed-use development, including new social housing developments and local retail and services for both the new residents and existing Strathcona community (DTES LAP, 2014). Light industrial opportunities are to be kept along Hastings Street, where feasible (DTES LAP, 2014).

The area is not anticipated to flood during a Scenario 3 coastal flood event.

The Flats and Great Northern Way

Whereas the majority of the Industrial land along Burrard Inlet is part of Port Metro Vancouver, there is also significant industrial-approved space in False Creek Flats. While the neighbourhood planning process continues for the area, significant development is already underway south of the existing BNSF rail line.

A new Emily Carr University will be the centre of an arts-and-tech enclave at the Great Northern Way campus by 2017, bringing 1,800 students and staff to the area. Art galleries previously found in the South Granville neighbourhood have moved to the area. Light industrial uses, such as breweries, are already in the region and rough plans are in place to create space for high-tech industries and green jobs (Kerry Gold, 2014). The headquarters of Mountain Equipment Co-op (MEC) is also expected to move to a new location on a former Albion Fisheries property in 2014, which would be a large (112,000 sq. ft.) building (Kerry Gold, 2014).

Two condo developments are approved/in-progress (Canvas and Meccanica) and student rental housing and a hotel development are in the planning stages (Kerry Gold, 2014).

This area has potential to remain largely industrial- or commercial-oriented without many large residential developments. The existing buildings at the Great Northern Way campus appear to be built at an elevation primarily above the modelled level plus freeboard. With appropriate flood protection measures along the base, the buildings may be able to withstand damage during a flood event. Buildings anticipated to be constructed on the site will need to be built at appropriate elevations and/or with adequate flood proofing measures. Similarly, the new MEC building under construction (expected to open in the summer of 2014) is situated just outside of the flood zone.

The BNSF rail line just north of the MEC site may be inundated in a coastal flood event in addition to adjacent blocks along Great Northern Way. All the local roads running south of Great Northern Way are anticipated to remain free of floodwaters and should remain accessible. Vernon Drive is at the eastern extent of the flood zone. Clark Drive is the first accessible north-south arterial road that may remain usable.

Concerns include whether or not the existing regulatory framework (Vancouver Building Bylaw and Development Permit requirements) will be sufficient to ensure that the industrial and commercial uses of the area (particularly for those focused on IT and Green-oriented development) will be able to withstand a major coastal flood event and resulting business disruption (February 14th workshop, 2014).

Commercial Areas

In addition to industrial areas, select commercial areas may be impacted in a flood event. Certain commercial areas may need to relocate if reconstruction or loss of business revenues become too costly. As these areas largely consist of service-oriented employment, the total number of service-oriented jobs in the city would not necessarily decrease but they could be redistributed to different neighbourhoods (in comparison to Port or Industrial related jobs which would be more difficult to relocate) (February 14th workshop, 2014).

Gastown

Established in 1867 and arguably the 'original Vancouver', Gastown (under the Gastown Business Improvement Association) consists of 100 commercial buildings, with approximately 500 businesses ranging from art galleries, restaurants, boutique shops, and new media companies. Nearly every building has heritage value, and the neighbourhood itself was designated a National Historic site in 2009 (as well as "4th Most Stylish Neighbourhood in the World" in 2012). It is viewed as a hotbed for independent businesses and creative talent in the areas of fashion, food, and design. (Gastown BIA website). Gastown also hosts a significant post-secondary presence with the following institutions: SFU's School for Contemporary Arts, SFU Woodward's, Vancouver Community College, and Vancouver Film School.

Chinatown

Vancouver's Chinatown is the second largest in North America and one of Vancouver's oldest neighbourhoods (BizMap, 2009). Chinatown consists primarily of retail trade, followed by professional, administrative and support services, and accommodation and food services with over 400 businesses (draft DTES LAP, 2014). It is an important cultural and tourist destination as well as providing specialty Asian goods and services. Both the Chinatown Business Improvement Association and Chinatown Merchants Association work to support local economic interests. Notable retail areas include Pender Street and the local network of lanes and courtyards.

Davie and Denman

The commercial and retail area in the West End should remain free of flood waters. Any potential impacts would be due to proximity or secondary effects (e.g. if a large portion of West End residents are displaced for a significant period of time). The Vancouver Seawall, discussed in detail in a following section, will see an increase in service disruptions. The Davie and Denman neighbourhood may see additional secondary effects from the service disruption.

Granville Island

Granville Island is the product of a 1970s industrial renewal project and under the administration of the Canada Mortgage and Housing Corporation (CMHC). Granville Island now hosts an internationally renowned public market, marina, boutique hotel, Emily Carr University of Art and Design (until 2016), Arts Umbrella, False Creek Community Theatre, various Performing Arts Theatres, art galleries, and many shopping opportunities. In addition, Granville Island is serviced by False Creek Ferries and Aquabus which provide ferry service to various Downtown Vancouver locations, including Yaletown, South False Creek, Vanier Park, and the West End. Granville Island generates over $130 million of economic activity annually, has over 275 businesses and provides over 2,500 jobs. It is very much a tourist destination, but also a key entertainment district for locals and tourists alike.

With rising sea levels and increasing frequency and strength of storms, access to Granville Island and the capacity for economic activity will be at grave risk. Significant planning and engagement is required to be able to adequately address these coastal hazards. As the majority of businesses on Granville Island will be responsible for their flood recovery costs, they have a vested interest in collectively developing a flood mitigation program. Significant amounts of protective infrastructure will need to be built to adequately protect Granville Island in its present form; however, the existing relationship that visitors experience with the water would be disrupted. The marinas and ferry service would likely be disrupted, at the very least during significant storm and flood events. On-going, ‘nuisance’ infrastructure repairs are to be expected, due to potential debris damage and storm surge effects. Over time, the built environment of Granville Island can evolve to incorporate water into the urban design, and though it would be costly, the long term economic benefits may make that worthwhile. Otherwise, businesses may need to make contingency plans on what to do, should Granville Island no longer be safe for operation.

Possible consequences of a major flood event:

- If Granville Island remains:
  - Modification of built form (buildings, urban design, etc.) required
  - Increase in construction and related industries
  - Depending on new designs, potential increase in area for commercial and community activities (as a method of off-setting structural protection and construction costs)
- If Granville Island relocates:
  - Impact on Vancouver’s reputation – loss of major tourist and community activity hub
  - Loss of economic and property tax revenue
  - Will need to deconstruct the island/find appropriate uses for the future flood-prone space
- In the event of a flood event:
  - Service disruption
  - Structural damage
  - Boat debris post-coastal flood event (February 14th workshop, 2014)
  - Post-coastal flood event clean-up costs (February 14th workshop, 2014)

Cornwall Avenue

This small commercial area in Kitsilano will suffer negative impacts from a coastal flood event. Blocks around Cornwall, bounded by Arbutus Street to the west and Maple Street to the east, can anticipate floodwaters. Commercial activity on the south side of Cornwall Avenue west of Arbutus may avoid direct impact, but can expect effects due to floodwater proximity. The same applies to the commercial area east of Maple Street. This commercial area is dependent on local residents as well as those who visit the recreational space (courts, parks and beach) year-round.

West 4th and West Broadway

These commercial areas are anticipated to remain clear of floodwaters and are unlikely to have negative impacts due to a coastal flood event – they may even see short-term gains post-flood event.

Tourism Industry

Over nine million people visit Metro Vancouver every year. Vancouver was named the Top Destination in Canada in Trip Advisor's 2012 Travelers' Choice awards, and has been award the title "Most Liveable City" eight times since 2002 (hellobc.com). A snapshot of the economic impact from tourism, not including the sections discussed above, in Greater Vancouver includes:

- Total expenditure of $1,260,000,000 in 2012. The average visitor spent 35% of their expenditures on accommodation, 28% on restaurant and store food and beverage purchases, 17% on retail, 9% on private transportation, 9% on recreation and entertainment, and 2% on public transportation. Downtown Vancouver has 71 properties (12,523 rooms[7]) with an additional 17 properties (1,399 rooms) outside of the Downtown Areas (Tourism Vancouver, 2012).
- The meeting and convention industry represented expenditures of $518,000,000 in 2012 and involved 6,035 jobs. The average delegation stays for 4.3 days and spends $230 daily (Tourism Vancouver, 2012).
- The Cruise ship industry had 191 sailings valued at $167,000,000 in 2012. Nearly 2,000 jobs (part-time and full-time) are generated by initial cruise ship passenger spending, with $58,000,000 in wages and salaries. The total number of cruise ship passengers who spent time in Metro Vancouver was 541,000. Expenditures were $97,000,000 in 2012 (Tourism Vancouver, 2012).
- Select Museums and Attractions
    - **Vancouver Maritime Museum**
      Over 62,000 people visited the Museum (and adjacent Heritage Harbour) in 2012 – including over 100 school classes and community groups – highlighting the importance of their unique location, relationship with water, and place for dialogue about the ocean and waterways. The Vancouver Maritime Museum has extensive connections with other marine/nautical related partners and associations, including as a centre for the promotion of science and technology of maritime industries. The Museum is primarily funded by Public funds – City of Vancouver and the Province of BC (45% of revenues) – but does see sizable revenue from Donations (16%), Admissions (11.5%), BC Art Council (6%), Public and School Programs (5%) and Other Revenue sources, including Moorage, (15%) (Vancouver Maritime Museum Annual Report, 2012).

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[7] Does not include seasonal rooms, hostels, bed & breakfasts, long-term accommodations or time shares.

- **HR MacMillan Space Center and Museum of Vancouver**
  These two facilities in Vanier Park were the 16th and 20th largest tourist attractions in Metro Vancouver in 2013 (BIV). The HR MacMillan Space Centre had 96,000 visitors in 2013. Total operating revenues were $656,977 in 2012. (Source: 2012 Annual General Report) The Museum of Vancouver (MoV) had 75,000 visitors in addition to over 177 thousand "online connections" in 2013. The MoV brought in over $2 million in revenues in 2012 (2012 Annual Report).

- **Bard on the Beach**
  Adjacent to the Museum of Vancouver/HR MacMillan Space Centre is the home to Canada's largest not-for-profit professional Shakespeare Festival, Bard on the Beach. Bard on the Beach is the 18th largest tourist attraction in Metro Vancouver (BIV). Entering its 25th year in 2014, "Bard Village" has settled in to their space in Vanier Park, along the water, with the completion of a custom-built main stage in 2011, and renovations to the secondary Douglas Campbell Studio Stage in the works. Bard on the Beach has grown from 6,000 patrons in 1990 to over 89,000 patrons in 2013 with a budget (2013) of about $4 million. In addition to their 200+ performances, Bard on the Beach hosts community outreach initiatives (e.g. Young Shakespeare Workshops) during the summer.

- **Science World at TELUS World of Science**
  Science World is the fourth largest tourist attraction in Metro Vancouver (BIV). In the 2012 fiscal year, Science World welcomed over 530,000 visitors and program participants through its doors. Customer admission and membership revenues alone brought in $6.5 million, for a total of $10.7 million in revenues (Annual Report, 2012). The Science World dome is a unique contribution to the Vancouver skyline.

- **Festivals**
  Vancouver is host to many festivals throughout the year. Being temporary events, they can largely be re-located to venues outside of the flood zone, as necessary. A few, such as the many hosted on Granville Island and the Vancouver Folk Music Festival in Kitsilano, may encounter relocation and advertising challenges.

Most major hotel locations are outside of the flood zone. The Westin Bayshore Hotel may require on-site mitigation measures but the Granville Island Hotel and the Hostelling International-Vancouver Jericho Beach will require significant structural protection/floodproofing or relocation. For the other hotels, most impacts will be secondary or tertiary in nature (including increased demand for accommodation but also disrupted supply chains). The meeting and convention industry may incur a post-flood impact in terms of loss of business and/or operation disruption.

Notwithstanding the impact to Gastown, Chinatown, Granville Island, and other areas noted above, the selected attractions also demonstrate the extent of impact given a Scenario 3 coastal flood event:

- **Vancouver Maritime Museum**
  The capacity of the Vancouver Maritime Museum to meet its mandate and mission at its

present location will be threatened. Storage, including archived materials, and exhibition space will be at risk of damage and destruction (February 14th workshop, 2014). With appropriate discourse with the City and other public donors, mitigation measures may be put in place. The construction of protective infrastructure measures, floodproofing the building, or a full relocation of the Museum are possibilities. Given the topical nature of the Museum, it could be worthwhile exploring initiatives between the Museum and the City that could highlight the significance of sea level rise and the impacts of coastal flood events while also protecting the Museum.

- **HR MacMillan Space Center, Museum of Vancouver and Bard on the Beach**
  With the custom-built stage, it is now more difficult and costly to move the Bard Village to higher ground. Mitigation measures would require protective structural measures or an alternate location.

- **Science World at Telus World of Science**
  Under a Scenario 3 coastal flood event, most of the area surrounding Science World (with the exception of the Ken Spencer Science Park, completed in 2012) will flood. To combat expected sea levels and flood events into the future, additional building repairs and renovations will be required to maintain the building's operational capacity. Being an iconic symbol of Vancouver, relocation would need to be carefully weighed.

Without appropriate mitigation measures (whether relocation or structural upgrades with flood protection) over the coming decades; the City may see a loss of tourism revenue from these sources. Fortunately, there is time and the capacity to mitigate much of the vulnerability.

Public Transportation

Public transit routes and service will also be affected. Hard infrastructure damage has been discussed above.

Buses

Bus service is the most resilient aspect of the transportation system as it can be rerouted around inundated areas. Vehicles in the affected areas at the time of inundation may suffer damages. In the wake of a coastal flood event, additional bus capacity may be required to compensate for service reductions and/or obstructions to other modes of transportation.

Rapid Transit

Skytrain service (including Expo, Millennium and Canada Lines) will be impacted by a coastal flood event. Sections of underground track and service tunnels in the Downtown core, particularly in the vicinity of Waterfront Station, are presumed to flood (February 14th workshop, 2014). While the specific circumstances of flooding are as of yet unknown, several possibilities exist on how service will be affected.

- Service west of Commercial-Broadway station (on Expo and Millennium Lines) may cease.
- Service north of Broadway-City Hall station (on Canada Line) may experience service interruptions.

- Service connections between the functioning stations (Broadway-City Hall; Commercial-Broadway) and the Downtown core will need to be provided should key electrical and mechanical equipment of the Skytrain and Canada Line become damaged.

Waterfront Station and Vancouver Harbour

The Helicopter Pad and Float Plane Terminals at Vancouver Harbour may see service interruptions and operational challenges in additional to storm debris damage in a coastal flood event. Access to and from Downtown Vancouver will be impacted by the operability of the North Vancouver SeaBus terminal, which is equally afflicted. Depending on the nature of the event, the terminals may become inoperable.

Vancouver's commuter rail service, the West Coast Express, may experience service disruption. With enough warning, the trains can be moved out of the flood hazard areas thereby saving them from damage by floodwater or debris, as well as from causing damage to their surroundings. In addition, Port Metro Vancouver's two cruise ship terminals, two container terminals and five bulk terminals on the south shore of Burrard Inlet, as well as the CP Railyard and lines will experience operational challenges in moving people and goods.

Having the transit system in downtown Vancouver partially or completely shut down by a coastal flood event will consequently affect the accessibility, mobility and evacuation of people from flooded areas.

Infrastructure

Coastal flood hazard impacts on local infrastructure can have multifarious effects – commonly categorized between direct (such as damage or loss of structural integrity) and indirect (such as loss of functionality and service). These range from mere inconvenience to compromised structural integrity to destruction (Peck et al, 2011). Assessing infrastructural resiliency to flood damage, given the area inundated, length of inundation, depth and velocity of water, is crucial. Also essential is the current and expected condition of the infrastructure and how that will affect its resiliency during a flood event. In this case, infrastructure consists of the transportation infrastructure, critical infrastructure, flood protection structures, sanitary and storm networks and the drinking water distribution network.

There are three types of infrastructure impacts: loss of functionality, loss of equipment and loss of structure.

- Loss of function refers to the degree to which the infrastructure has lost its functionality – the degree to which the infrastructure no longer functions at an acceptable level, relative to original design, as a result of flooding (Peck et al, 2011).
- Loss of equipment refers to loss of contents, or of the non-structural components of the infrastructure, due to the coastal flood impact (Peck et al, 2011).
- Loss of structure refers to the degree to which the structural integrity of the infrastructure is compromised due to the coastal flood impact. Factors will include the flood depth and flood velocity, condition of the infrastructure, as well as its age and adaptive capacity.

Each of these impacts will include an economic loss component – in other words, the potential monetary damage incurred as a result of a flood event. Conceptualizing the potential economic and monetary damage provides valuable information to prioritize protection (Peck et al, 2011). An attempt to capture the economic impact through the use of Hazus was undertaken in the CFRA Consequence Assessment report (Annex F).

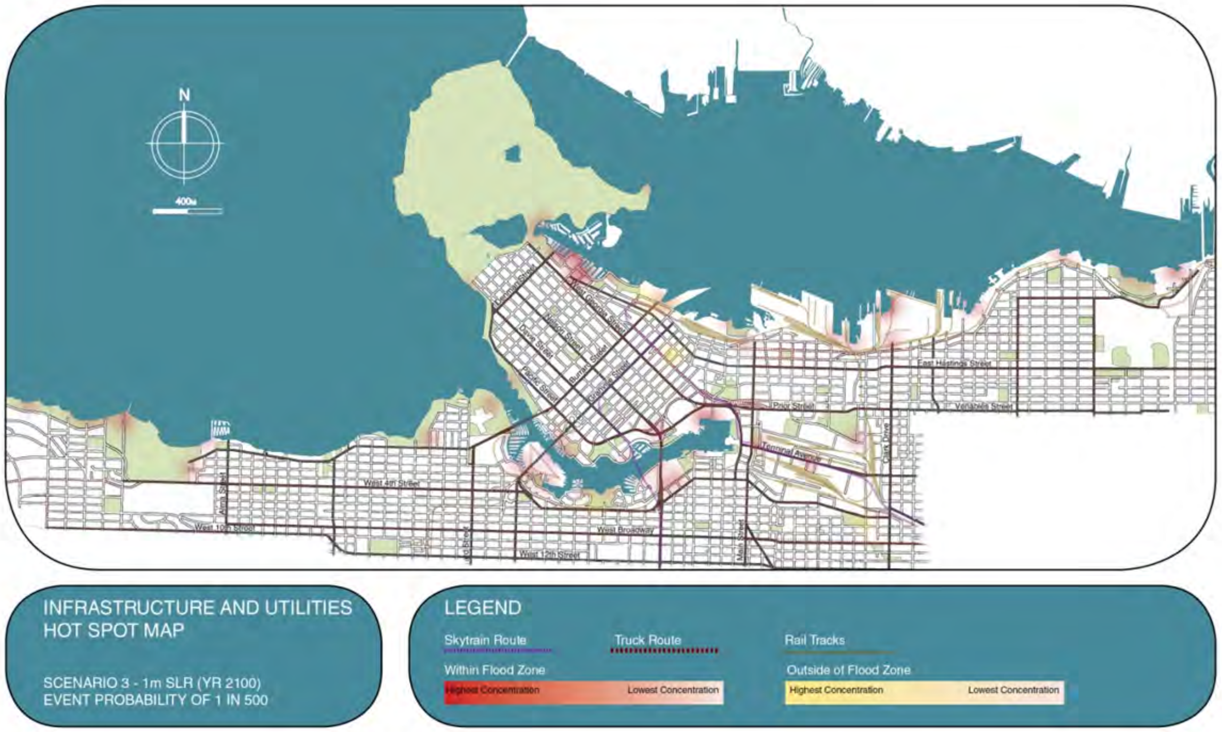

Figure 6 - Infrastructure and Utilities Hot Spot Map

Appendix F provides additional information on the data sources on the Hot Spot Map as well as detailed maps demonstrating each of the CFRA study areas.

Transportation Infrastructure

Transportation infrastructure – namely roads and bridges – are needed to move people, goods and services around the region. In a flood event, they become critical for aiding in evacuation, emergency and rescue services. Inundated roads and bridge accesses and supports run the risk of washout, rutting and damage from loose debris as well as seeing a reduction in their overall design life (and likely requiring repair earlier than planned) (Peck et al, 2011). The extent of damage is a function of the nature of the construction materials, and the depth and velocity of water.

Roads and bridges suffer a complete loss of functionality once inundated, as well posing a threat to human health by hampering access by emergency services. Additionally, flood debris may further exacerbate the damage to surrounding elements such as railings and streetlights. In terms of costs, there will be the economic impact as local business access is restricted (resulting in a loss of revenue) and the minimum replacement and/or repair costs for rehabilitating the infrastructure (Peck et al, 2011).

Under Scenario 3 conditions, the on-ramps and access points for the three main bridges servicing the Downtown core of Vancouver are anticipated to remain free of floodwaters. However, the roads running under the supports for the Burrard, Granville and Cambie street bridges will be inundated. Additional north-south traffic routes, including Quebec Street, Main Street and Clark Drive, will see disruption. Main Street and Clark Drive play an important role in servicing the Port and are recognized as important truck routes within the City of Vancouver.

In terms of east-west connections, parts of Pacific Street and Cornwall Avenue will be inoperable, as well as significant portions of Prior Street and Terminal Avenue. The key east-west connector streets of the Downtown core (West Georgia, Nelson and Davie streets) are anticipated to remain clear of flood waters.

Critical Facilities and Infrastructure

Critical facilities and infrastructure include buildings that provide essential or emergency services. Critical facilities and infrastructure are at risk of structural damage and equipment damage in a flood event. The building envelope may be compromised and any equipment left below the inundation level may be lost. Functionality may be affected due to the proximity to the floodwaters. Critical facilities are considered to have a loss of function when they are inundated but also when all possible access routes are blocked due to flooding (Peck et al, 2011).

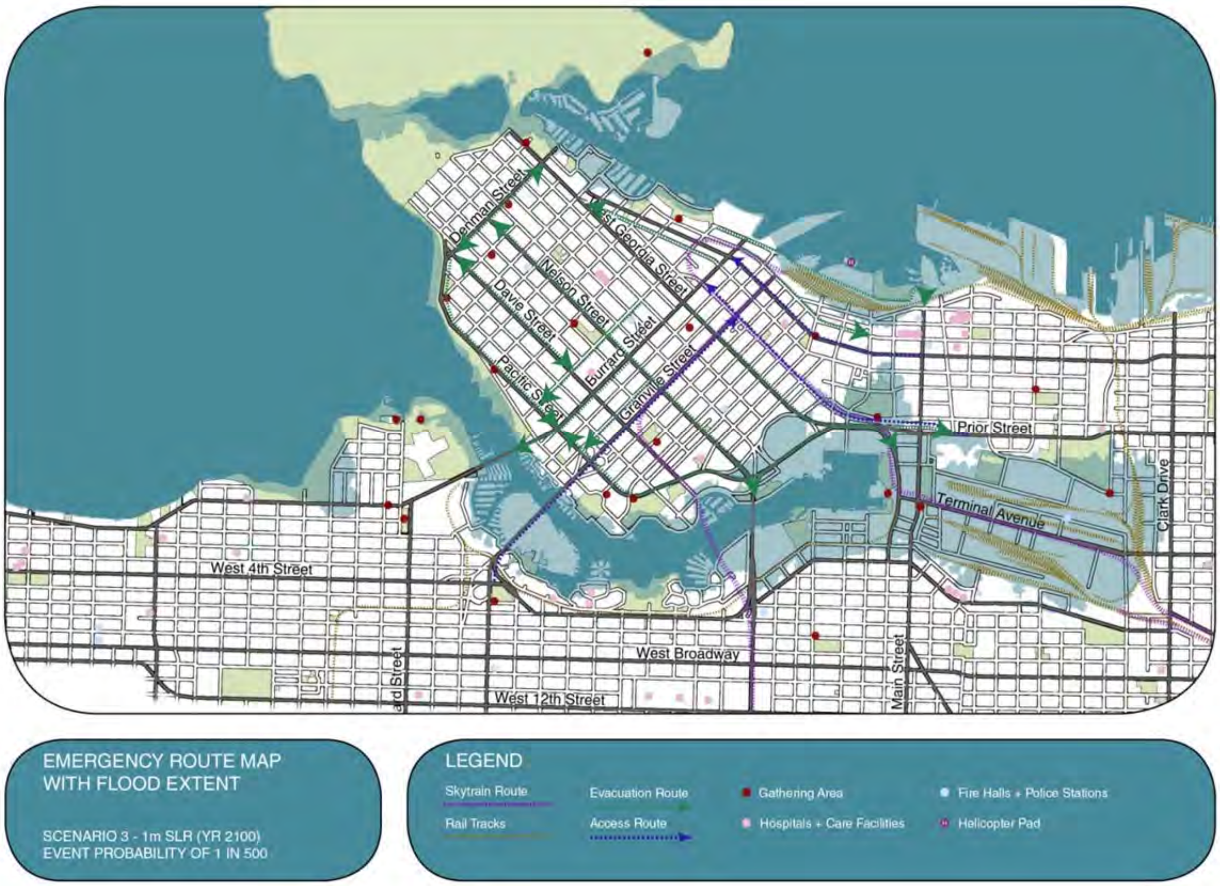

Figure 7 - Emergency Planning Map with Scenario 3 Flood Extent (Downtown Vancouver)

<u>Hospitals</u>

In a flood event, hospitals must have multiple access routes for evacuation purposes. Ambulances and emergency service vehicles will need to be able to reach the hospital. Even if the hospital itself does not flood, staff and patient access to the hospital may be impacted. If staff access is stymied, building operations will be affected. A coastal flood event may increase the demand for services and hospitals need to be prepared to deal with an increased influx of patients, including those from other hospitals and care facilities that may need to evacuate (Peck et al, 2011).

St Paul's Hospital is outside of the flood zone but may encounter impacted infrastructure and restricted access. Given its proximity to flooded areas, a spike in patient inflow should be expected. Vancouver General Hospital is also outside of the flood zone, and may be able to handle the patient overflow from St. Paul's. Smaller care facilities in proximity of the flood zone may not be operable.

<u>Fire, Police and Emergency Management Services (EMS)</u>

Akin to hospitals, fire, police and EMS infrastructure will lose functionality if access routes are restricted by flood waters. Operations may be impacted if the flooding impacts personnel access or safety.

Additionally, an increase in demand for these services can be expected during a coastal flood event (Peck et al, 2011).

In the event of an emergency, the City of Vancouver designates the gyms in their 23 community centers as emergency shelters. Several emergency shelter locations may not be operational in a coastal flood event due to their proximity to floodwaters. In addition numerous gathering locations are within the flood zone. Two are near Vanier Park, two are near Science World, and five are located along the water (including the West End, Stanley Park, Lost Lagoon, and Coal Harbour).

The City of Vancouver and the Vancouver Police Department have created the VECTOR (Vancouver Emergency Community Telecommunications Organization) partnership. VECTOR communication stations are intended to be set up at each shelter in order to provide emergency backup communication services for the City in the event of a disaster. Therefore, in addition to reduced shelter capacity, emergency communications capacity may be reduced.

Three evacuation routes will be impeded by the flood zone or directly impacted by coastal flood waters. Two of the three access routes may be unusable in a Scenario 3 flood event. Evacuation and access routes are considered essential transport infrastructure; any reduction in capacity and serviceability will increase the vulnerability of the affected neighbourhoods and populations. Emergency evacuation and planning for the Downtown and Inner Harbour zones may need to be reviewed by the City and Emergency Response personnel.

One police work yard is within the flood zone, with three Fire and/or Police stations in close proximity to the flood zone. Six gathering areas are within the flood zone and three are in close proximity. The gathering areas can easily be moved to more safe locations. The stations in close proximity to flooding will likely see an increased demand for their services in the event of a flood. For example with Main Street inundated, there may be reduced accessibility and increased response time in that area.

Strategic Infrastructure

Power stations and primary substations – any strategic utility infrastructure – in a flood hazard areas will be extremely vulnerable. Without building adaptive capacity and resiliency into the system, the provision of electricity, water and heat may fail. Redundancy, or back-up service capacity, has arguably been built into the system within Vancouver.

Currently, only B.C. Hydro's Murrin Substation, located between Main Street and Andy Livingstone Park, is at risk in a coastal flood event. Cathedral Square, Dal Grauer, Sperling and the new Vancouver City Centre Transmission (VCCT) Substations are outside of the forecasted coastal flood event with storm surge. Underground cables connect VCCT to Sperling and Cathedral Square, and Cathedral Square to Murrin.

There are 40 storm lines and 10 combined sewer overflow lines running through these wage pump stations lie in or near the flood zone with outfalls in Burrard Inlet/False Creek. This infrastructure, whether pumped or gravity fed, may be sensitive to damage and disruption in a coastal flood event.

For the False Creek region, the Neighbourhood Energy Utility (NEU) provides strategic infrastructure, including heat and hot water via a district heating system to Southeast False Creek. Service is expected to expand to the Great Northern Way Campus and Northeast False Creek[8] (including Chinatown) (NEU Correspondence, 2014). At the present, NEU infrastructure includes energy plants, distribution piping and energy transfer stations (ETS). In a coastal flood event, the energy plant would shut down (severing all connected residents[9] from heat and hot water) until replacement parts could be ordered and installed (NEU Correspondence, 2014). A service disruption of several weeks could be experienced. The ETS's would be damaged but operable in manual mode by the utility provider. The distribution piping is waterproofed, with additional controls in place should water damage occur (NEU Correspondence, 2014).

Also of note is that False Creek Flats and Waterfront are being explored as potential locations for a Low Carbon Plant[10] to service the Downtown core.

Sanitary Sewers, Stormwater and Water Distribution Systems

The water distribution system consists of a network of pressurized pipes and the stormwater system consists of a network of sewers, outfalls, manholes and stormwater management facilities. Stormwater management will be affected in a flood event – the system could become overwhelmed where the pipe network may be unable to handle the increased volume of water (causing back-up and flooding of manholes and inlets along roads and lanes) (Peck et al, 2011). Combined sewer systems (CSOs) may backup with sewage and cause damage to buildings and if the management facilities are overwhelmed with floodwaters no storage or treatment, services will be available (Peck et al, 2011).

Water and sewage transmission infrastructure (including pumping stations) are considered water-compatible development opportunities and can become more resilient when renovation and retrofitting is called for (Jha et al, 2012). Sewer and water infrastructure are now managed on a 100-year replacement cycle (CoV Capital Plan, 2012) with new infrastructure assets to be built as part of development projects. The City aims to eliminate the untreated sanitary sewage flowing into Burrard Inlet, English Bay, False Creek or the Fraser River by 2050 (Capital Strategic Outlook, 2011). The CFRA study areas are identified as already having separated sewer and stormwater lines (with 22 stormwater outfalls[11]); however, CSO lines still run to the waters. The sewer and water systems, as of 2011, are considered in 'average' condition (Capital Strategic Outlook, 2011).

Flood Control Structures

The flood control structures used within this part of the CFRA study area primarily consist of the Vancouver Seawall and retaining walls around Stanley Park. The seawall is considered in 'average'

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[8] A Steam to Hot Water Converter Station (converts steam from Central heat to hot water for circulation to all connected Neighbourhood Energy buildings) is expected to be the energy plant-equivalent for Northeast False Creek (NEU Correspondence, 2014).

[9] Expected to be 16,000 residents at full build-out.

[10] By a partner utility.

[11] 17 in False Creek, 6 in English Bay and 59 along the Inner Harbour.

condition (Capital Strategic Outlook, 2011). In addition, the north side of English Bay contains a series of groynes, used principally to impede the migration of sand, rather than as a flood protection measure.

Buildings

With development occurring throughout the False Creek Flats as well as the continued occupation of buildings along the coastline, a coastal flood event has the potential to have a major impact on residential and business properties. The foundation, age, structure type and condition of the buildings play an important role in how resilient Vancouver's building stock is to a flood event (Peck et al, 2011).

Community, Culture and Recreation

Community

Demographics

For the purposes of this section, the CFRA is considered to be within the boundaries of twenty-five census tracts set out by Census Canada. These census tracts (CTs) have been selected as all experience some inundation in a Scenario 3 coastal flood event. The entire CT may not see inundation; therefore the demographic analysis is taken as a representation of the people and dwellings affected in a coastal flood event as well as those in close proximity to a coastal flood event. Specifically, the Strathcona and Downtown neighbourhoods have been broken down into sub-areas to highlight the neighbourhoods which may see broader inundation across the census tract. In comparison, the level of inundation expected in the Hastings-Sunrise/Grandview-Woodlands area is quite low.

Table 4 - CFRA Neighbourhood breakdown by Census Tract

Neighbourhood	Census Tracts	Level of inundation
Hastings-Sunrise/Grandview-Woodlands	9330053.01 9330055.02 9330056.01	Mainly coastal, along the border with PMV lands.
Strathcona		Some flooding in the DTES, but Chinatown and North and South False Creek Flats could be significantly inundated.
DTES	9330058.00	
Chinatown	9330057.01	
North False Creek Flats	9330057.02	
South False Creek Flats	9330050.03	
Downtown		Primarily restricted to shoreline flooding, with the exception of the lagoon between the Downtown core and Stanley Park.
Gastown	9330059.06	
Coal Harbour	9330059.11	
	9330066.00	
	9330067.02	
Stanley Park	9330068.00	
West End	9330062.00	
	9330061.00	
	9330060.01	
	9330060.02	
Yaletown	9330059.07	
	9330059.08	

Fairview		
Fairview/Mount Pleasant	9330049.01	Each tract sees considerable flooding, including Granville Island and the residential buildings along the south side of False Creek.
Tract with Granville Island	9330049.02	
Fairview/Kitsilano	9330048.00	
Kitsilano	9330047.02 9330047.01 9330045.01	Primarily limited to beach flooding, with the exception of the Kitsilano Beach corner.
West Point Grey	9330044.00	Flooding largely offset by topographic change, with the exception of flooding in Jericho Beach Park.

The data sources are the 2011 Canadian Census and National Household Survey and all analyses are restricted in sample size and accuracy by the methodology implemented by the Federal government. Appendix G provides further details on the census tracts and demographic data used for the CFRA study area.

According to the 2011 Census, the CFRA study area had 127,919 people residing in 29,222 private dwellings (StatsCan, 2012).[12] The City of Vancouver had a population of 603,502, and 286,742 private dwellings. The CFRA study area represents 21% of the population within the City of Vancouver and 11% of the private dwellings. The number of people in an area does not necessarily inhibit evacuation, damage levels or recovery rates, providing enough redundancy has been incorporated into the system for evacuation and relief assistance planning.

Within the CFRA study area 8% of the population is under 14 years of age, 80% is between 15 and 64 years, and 13% is above 65 years of age. Table 5 documents the percentages for population under the age of 14 within the different neighbourhoods that comprise the CFRA. West Point Grey (13%) and Hastings-Sunrise/Grandview Woodlands CT (12%) have the highest percentage of people under the age of 14. The rest of the CFRA neighbourhoods remained under 11%. In comparison, the City of Vancouver population breakdown was 12% aged 14 and under, 75% between 15 and 64, and 14% over the age of 65. The CFRA study area has a lower proportion of children than the City at large. However, the CFRA study area is representative of the City for seniors. Both the elderly (indicated by the census data of 65 and above) and the young (14 and under) are vulnerable in a disaster. Additional assistance may be required to assist in the evacuation of vulnerable populations, such as specific evacuation and transportation plans.

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[12] The latest BC Stats population for the City of Vancouver is 640,915 (January 2014). Although not as current, 2011 census data has been used in this section as it includes extensive demographic information including geographic breakdown by neighbourhood.

Table 5 - CFRA Neighbourhoods and percentage population for 14 and under

Neighbourhood (Census Tracts within CFRA study area)	Population 0-14 years	Total Population[13]	Percentage
Hastings-Sunrise/Grandview-Woodlands	1,765	14,605	12%
Strathcona	1,220	13,250	9%
DTES	Data unavailable	Data unavailable	
Chinatown	335	3,195	10%
North False Creek Flats	535	5,050	11%
South False Creek Flats	350	4,975	7%
Downtown	3,225	58,220	6%
Gastown	185	6,500	3%
Coal Harbour	1,125	18,610	6%
Stanley Park	185	4,830	4%
West End	590	16,680	4%
Yaletown	1,140	11,600	10%
Fairview	1,680	21,340	8%
Fairview/Mount Pleasant	615	8,180	8%
Granville Island	555	5,790	10%
Fairview/Kitsilano	510	7,370	7%
Kitsilano	770	12,210	6%
West Point Grey	585	4,525	13%

Census data reports the following percentages for population aged 65 and above within sections of the neighbourhoods in the CFRA. Specific CTs with the highest percentage of people over 65 include Chinatown (26%), Fairview CT (which includes Granville Island, 25%), North False Creek Flats (20%), and West Point Grey (20%). Seniors in the rest of the CFRA neighbourhood CTs comprised less than 15% of population.

Table 6 - CFRA Neighbourhoods and percentage population for 65+

Neighbourhood (Census Tracts within CFRA study area)	Population 65+ years	Total Population[14]	Percentage
Hastings-Sunrise/Grandview-Woodlands	1,930	14,605	13%
Strathcona	2,225	13,250	9%
DTES	Data unavailable	Data unavailable	Data unavailable
Chinatown	840	3,195	26%
North False Creek Flats	1,005	5,050	20%
South False Creek Flats	380	4,975	8%
Downtown	6,830	58,220	12%
Gastown	845	6,500	13%

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[13] Data from Statistics Canada. May include rounding and a slightly different total than listed population totals.
[14] Data from Statistics Canada. May include rounding and a slightly different total than listed population totals.

Coal Harbour	1,440	18,610	8%
Stanley Park	675	4,830	14%
West End	2,400	16,680	14%
Yaletown	1,470	11,600	13%
Fairview	2,880	21,340	14%
Fairview/Mount Pleasant	620	8,180	7%
Granville Island	1,435	5,790	25%
Fairview/Kitsilano	825	7,370	11%
Kitsilano	1,410	12,210	12%
West Point Grey	905	4,525	20%

Within the CFRA, there were 28,530 census families which included 16,805 married couples (59% of the census families in the CFRA), 7,780 common-law couple families (27%), and 3,980 lone-parent families (14%). Of the lone-parent families, 80% were female-lone parent families and 20% were male lone-parent families. The number of census families in the City of Vancouver was 151, 330 (68% of the census families were married couples in 2011, 16% were common-law-couples and 16% were lone-parent families). The CFRA neighbourhood CTs represent 19% of the City of Vancouver's census families.

Families with adequate resources to prepare and absorb impacts are relatively robust in the event of a coastal flood event. Adequate resources are often measured as a function of income, employment, social dependency (i.e. government transfer payments) and education. As single-parent families may face increased challenges, such as limited finances and/or balancing income-generating activities with family care, (Cutter, 2003), the CFRA study area census data highlights the neighbourhoods with the highest proportion: Downtown (35%, primarily because of Coal Harbour (13%) and Yaletown (11%)), Hastings-Sunrise/Grandview-Woodlands (19%), and Fairview (18%).

There were 69,325 private households within the CFRA study area in 2011, representing 26% of the 264,575 private households found in the City of Vancouver overall. The types of households are provided in Table 7.

Table 7 - Number of Private Households by Type[15]

Household Type	**CFRA study zone**[16]		**Vancouver**	
	Number	**Percentage (within CFRA Study Zone)**	**Number**	**Percentage**[17] **(within Vancouver)**
Couple-family with household children 24 and under at home	6,325	9%	48,990	19%

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[15] Data Source: GeoSearch 2011, by Arlington Group

[16] Data Source: GeoSearch 2011, by Arlington Group

[17] Of total number of private households

Couple-family household without children 24 and under at home	17,575	25%	64,710	24%
Lone-parent family household	3,795	5%	21,580	8%
One-person households	35,600	51%	101,205	38%
Other	6,030	9%	28,085	11%
Total	69,325		264,575	

A third of Vancouver's one-person households are within the CFRA study area, who in turn comprise just over 50% of the private households within the CFRA. Couples without children under 24 at home are the second most significant group at 25%. Families with three members or more tend to be located outside of the CFRA study area. The average family size within the CFRA study is 1.7. This is well below the City of Vancouver average of 2.2.

In terms of the types of occupied dwellings, there are 69,326 private dwellings occupied by the usual residents[18] (Table 8). Specific details on the number and types of building stock to suffer damage or inundation are provided separately in the Consequence Assessment.

Table 8 - Number of Private Dwellings by Building Stock

Occupied private dwelling CFRA Building Stock	**Census Count Number (CFRA)**	**Percentage within CFRA Study zone**	**Census Count Number (City of Vancouver)**	**Percentage within City of Vancouver**
Single Detached Houses	2,730	3.94%	47,535	18%
Semi Detached houses	835	1.20%	3,995	1.5%
Row Houses	1,900	2.74%	9,045	3.4%
Apartments or flats in a duplex	2,505	3.61%	45,845	17%
Apartments in a building with fewer than 5 storeys	24,635	35.54%	87,425	33%
Apartments in a building with 5+ storeys	35,700	51.50%	70,265	27%
Other[19] Dwellings	130	0.19%	455	0.2%
Total	69,326		264,570	

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[18] In general, the usual place of residence is the dwelling in Canada in which a person lives most of the time.

[19] Includes other single-attached houses, mobile homes and other movable dwellings such as houseboats and railroad cars.

Of the 70,660 private households in the CFRA study area neighbourhood CTs, 38% are owned and 63% are tenant households (Table 9). Of the tenant households, 18% are subsidized housing. The City of Vancouver has 263.590 private households, of which 48% are owned and 52% are tenant households where 14% are in subsidized housing. CFRA neighbourhoods with the highest number of owner households include Downtown (43%), Hastings-Sunrise/Grandview-Woodlands and Kitsilano (both at 11%). Strathcona, a neighbourhood that may experience the bulk of the inundation in a Scenario 3 coastal flood event, has only 8% of owner households.

The highest proportion of tenant households are in Downtown (51%), followed by Strathcona and Fairview (both at 14%) and Kitsilano (10%). The neighbourhood with the highest percentage of tenant households in subsidized housing is the Downtown (47%) where the sub-areas range from 77% in the DTES to 14% in South False Creek Flats. Outside of the Downtown, the highest sub-area is Gastown (45%) with subsequent neighbourhoods being West Point Grey, Hastings-Sunrise/Grandview-Woodlands and Fairview (31%, 20% and 17%, respectively). As the West Point Grey CT includes significant topographic changes, a lower number of subsidized tenant households than the 250 in Point Grey may be vulnerable to a coastal flood event compared to Fairview. Subsidized tenant housing stock rehabilitation and recovery may be contingent on cooperation and collaboration with the Province, potentially reducing the availability of subsidized housing post-coastal flood event.

Table 9 - CFRA Census Tract Shelter Costs

Neighbourhood	Number of owner households in non-farm, non-reserve private Dwellings (within CFRA)	% (within CFRA study area)	Number of tenant households in non-farm, non-reserve private dwellings (within CFRA)	% (within CFRA study area)	% of tenant households in subsidized housing (within each neighbourhood)
Hastings-Sunrise/ Grandview-Woodlands	2,900	11%	3,890	9%	20%
Strathcona	2,080	8%	6,355	14%	47%
DTES	85	0.32%	1,460	3%	77%
Chinatown	80	0.3%	1,420	3%	55%
North False Creek Flats	630	2.4%	1,590	4%	51%
South False Creek Flats	1,285	4.85%	1,885	4%	14%
Downtown	11,520	43%	22,630	51%	11%
Gastown	780	3%	2,380	5%	45%
Coal Harbour	4,255	16%	6,035	14%	8%
Stanley Park	680	3%	2,695	6%	1.3%

West End	2,135	8%	9,265	21%	8%
Yaletown	3,670	14%	2,255	5%	13%
Fairview	5,985	23%	6,250	14%	17%
Fairview/ Mount Pleasant	2,450	9%	2,225	5%	2.7%
Granville Island	1,545	6%	1,570	4%	5%
Fairview/ Kitsilano	1,215	8%	2,455	6%	0%
Kitsilano	2,810	11%	4,560	10%	3%
West Point Grey	1,215	5%	810	2%	31%
Total	26,510	38%	44,495	63%	18%

Within the CFRA study area, 61% of owner households have a mortgage and 31% of owner households spend 30% or more on shelter costs. The average monthly shelter costs for owned dwellings range from $963 (West End) to $1,924 (Gastown) and the average value of dwellings range from $377,750 (South False Creek Flats) to $2,007,661 (West Point Grey). The City of Vancouver has 52% of owner households with a mortgage, with 29% spending more than 30% on household shelter costs. The average monthly shelter cost for an owned dwelling in the City of Vancouver is $1,462 and the average value of a dwelling is $929,049.

Just under half (48%) of tenant households within the CFRA are spending 30% or more of their household income on shelter costs. The average monthly shelter costs for rented dwellings in the CFRA ranges from $521 (DTES) to $1,646 (Coal Harbour). Similarly, 46% of the tenant households in the City of Vancouver are spending 30% or more on shelter costs. The average monthly amount for a rented dwelling in the City of Vancouver is $1,089. Households with shelter costs exceeding 30% of total income will have limited financial resources to absorb the unexpected impact of a coastal flood event.

It is uncertain if renters or owners would be more vulnerable given a coastal flood event, given Vancouver’s unique real estate environment. In general, tenant households are considered to be more transient with fewer financial resources than property owners. Home owners, particularly owners of higher value properties, may be more motivated to reduce their vulnerability on the grounds that they are thought to protect their greater financial assets during a flood event. However, in the Vancouver context, the level of disposable income and shelter cost will likely be a stronger indicator on potential vulnerability than traditional tenant vs. home-ownership. In addition, there is an important distinction between single-family compared to strata property owners. Of note is that strata corporations predominate in the CFRA neighbourhoods and they are eligible for and typically obtain overland flood insurance, whereas single family home owners and tenants cannot obtain such insurance. As a result, single family owners may or may not have more financial resources but they have greater vulnerability insofar as they cannot obtain overland flood insurance. Both homeowner and tenant households may be eligible for disaster financial assistance[20] provided by the Province.

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[20] With some exceptions, and providing the Province has recognized the coastal flood event as a disaster eligible under the disaster financial assistance program.

In terms of the homeless population in the City of Vancouver, Table 10 to Table 13 have been compiled via the 2014 Metro Vancouver Homeless Count.

Table 10 - Number of Homeless Populations in the City of Vancouver

Homeless Population by Type	**Unsheltered**	**Sheltered (Emergency Facilities/Shelters)**	**Sheltered (No Fixed Address)**	**Total**
Total homeless population (Vancouver)	538	1,136	124	1,136
	Unsheltered	**Sheltered**		**Total**
Total homeless aboriginal people (Vancouver)	239	178		417
Total homeless youth under 25 (Vancouver)	141	116		257

As of the 2014 Social Impact Assessment for the DTES, there were 731 homeless people in the DTES – 83% of these in shelters and 17% on the street. Within the CFRA study area neighbourhood CTs, 3.18% state an Aboriginal Identity and 1.69% are a Registered or Treaty Indian. The City of Vancouver overall has a slightly lower rate of aboriginal identity at 2%, with 1% as a Registered or Treaty Indian. Treaty or Registered Indian involvement may require communication with the Federal Government.

For the CFRA study area neighbourhood CTs, the labour force participation rate is 72%, the employment rate is 67% and the unemployment rate is 7%. The City of Vancouver's participation rate is 67%, employment rate is 63% and the unemployment rate is the same at 7%. Participation and employment rates (above 65%) are consistent between each neighbourhood. The Strathcona neighbourhood has the highest unemployment rate at 11%, with Chinatown (16%) and the DTES (14%) being the highest sub-regions and most vulnerable, under this indicator.

Table 11 - CFRA Neighbourhood CTs by Labour Force Status

Neighbourhood	**Participation Rate**	**Employment Rate**	**Unemployment Rate**
Hastings-Sunrise/Grandview-Woodlands	**69%**	**63%**	**9%**
Strathcona	**68%**	**61%**	**11%**
DTES	36%	30%	14%
Chinatown	38%	32%	16%
North False Creek Flats	59%	51%	13%
South False Creek Flats	79%	72%	8%

Downtown	**73%**	**68%**	**6%**
Gastown	71%	63%	11%
Coal Harbour	71%	66%	7%
Stanley Park	76%	71%	6%
West End	75%	71%	5%
Yaletown	71%	67%	5%
Fairview	**78%**	**74%**	**6%**
Fairview/Mount Pleasant	83%	77%	7%
Granville Island	66%	61%	7%
Fairview/Kitsilano	81%	79%	4%
Kitsilano	**78%**	**73%**	**4%**
West Point Grey	**61%**	**57%**	**6%**
Overall	**72%**	**67%**	**7%**

Of the employed workforce within the CFRA study area over the age of 15, 84% are employees and 16% are self-employed. The City of Vancouver workforce as a whole consists of 86% employees and 14% that are self-employed. Those that are self-employed may be more vulnerable after a coastal flood event, as supply chain and related economic disruptions may be felt more immediately than those who are employed. Also, self-employed persons may have fewer resources to support them in the event of a disruption.

Within the CFRA study area neighbourhood CTs, 39% of those with a usual place of work travel by vehicle (e.g. car or truck) as the driver and 2% by vehicle as a passenger. Public transit is used by 28%, followed by walking with 24%. Bike (6%) and Other (2%) are less popular modes of transportation. The City at large has 48% as a driver of a vehicle, 8% as a passenger in a vehicle, 30% by public transit, 13% walked and 1% as Other. Appropriate transportation evacuation plans will need to be prepared to accommodate this modal split.

Average income in the CFRA study area ranges from $ 19,311 (Chinatown) and $20,738 (DTES) to $78,710 (Yaletown) and $86,505 (West Point Grey). Average income in the City of Vancouver is $43,058. Those earning under $50,000 comprise approximately 70% of the income for both the CFRA (67%) and the City of Vancouver (73%).

Table 12 - Income of Individuals in 2010

Income Bracket (for population 15 and over)	CFRA (persons)	CFRA (income distribution)	City (persons)	City (income distribution)
Without Income	3,750		24,580	
With Income (total)	108,475		494,395	
Under $5,000	11,965	11%	65,700	13%
$5,000 - $9,999	5,945	5%	32,160	7%
$10,000 - $14,999	10,530	11%	50,565	12%
$15,000 - $19,999	10,065	10%	49,060	10%
$$20,000 - $29,000	12,315	11%	60,870	12%
$30,000 - $39,000	10,140	9%	51,345	10%
$40,000 - $49,000	10,865	10%	46,645	9%

The percentage of income from market sources (consisting of Employment income (wages and salaries, and self-employment income), investment income, retirement pensions, superannuation and annuities) ranges from 58% and 63 % (Chinatown and DTES, respectively) to 97% (Coal Harbour) in the CFRA study area neighbourhood CTs. The percentage of income from government transfer payments (which include Canada Pension Plan benefits, Old Age Security pensions and Guaranteed Income Supplements, Employment Insurance benefits, child benefits and other income from government sources) range from 3% (Coal Harbour) to 37% and 42% (DTES and Chinatown, respectively). For the City overall, 92% is from market sources and 8% from government transfer payments. Government transfer payments remain an indicator for social dependency, which may increase an individual or family's vulnerability in a coastal flood event.

Within the CFRA study area, the majority (77%) have not changed place of residence within the last year. Of the 23% who have changed their place of residence within the last year, 13% were not migrants, 10% were migrants (63% were internal migrants – 63% of which are intraprovincial, and 36% interprovincial – and 36% external migrants)). For the City of Vancouver, 82% have not moved in the last year. Of the 18% who responded that they moved their place of residence, 61% were non-migrants, 39% were migrants (58% were internal migrants – 67% intraprovincial, 33%% interprovincial – and 42% external migrants).

Within the CFRA, in terms of immigration, 60% of the population responded as a non-immigrant. Of the 34% who responded to being an immigrant, 19% (or approximately 7,900 people) immigrated between 2006 and 2011. In comparison, the City of Vancouver had 52% of the population respond as a non-immigrant and 44% as an immigrant. Of the 44%, 16% (approximately 22,970 people) immigrated between 2006 and 2011. An individual or family may be more robust with stronger social networks, and those new to an area may not have as developed social networks for the necessary level of support.

Within the CFRA study area neighbourhood CTs, English is the mother tongue for 63% of residents, French 2% and a non-official language 32% (of which 0.45% represents an Aboriginal language as a mother tongue). In Vancouver, 52% of the population reported English as their mother tongue. The remainder reported French (2%) or a non-official language (47%) as their mother tongue. Those who have no knowledge of either official language consist of 4% of the CFRA study area neighbourhood population, and 5.6% city-wide. Hazard-preparedness information, warning systems and evacuation notices need to be accessible for all residents, in multiple media formats and languages.

Table 13 - CFRA Study Area Language Characteristics

Neighbourhood	Mother Tongue – English	Mother Tongue – non-official language	Knowledge of official languages – neither French nor English
Hastings-Sunrise/Grandview-Woodlands	**7%**	**4%**	**1%**

Strathcona	**6%**	**4%**	**2%**
DTES	Data unavailable	Data unavailable	Data unavailable
Chinatown	0.88%	1%	0.75%
North False Creek Flats	2%	2%	0.72%
South False Creek Flats	3%	1%	0.07%
Downtown	**28%**	**17%**	**1%**
Gastown	3%	1%	0.3%
Coal Harbour	7%	7%	0.48%
Stanley Park	3%	1%	0.04%
West End	3%	4%	0.16%
Yaletown	5%	4%	50.28%
Fairview	**13%**	**4%**	**0.22%**
Fairview/Mount Pleasant	5%	2%	0.09%
Granville Island	3%	1%	0.05%
Fairview/Kitsilano	5%	1%	0.07%
Kitsilano	**8%**	**2%**	**0.4%**
West Point Grey	**3%**	**1%**	**0.8%**
CFRA Area Overall	**63%**	**32%**	**4%**

A lack of English knowledge or proficiency is not necessarily an indicator of vulnerability but is of interest due to the potential inability of people to understand emergency communications, indicating a need for translating emergency related materials, both before and after a coastal flood event.

In terms of education, viewed as a function in determining robustness, the CFRA study area neighbourhood CTs have a high proportion of residents with a post-secondary certificate, diploma or degree (71%). The remaining 29% is split between High School diploma or equivalent (20%) and no certificate or degree (9%, or 10,455 individuals). The City of Vancouver has a slightly lower, but still high, percentage of people with a post-secondary certificate, diploma, or degree (63%). Residents with a high school diploma or equivalent report in at 23%% and without a certificate at 14%.

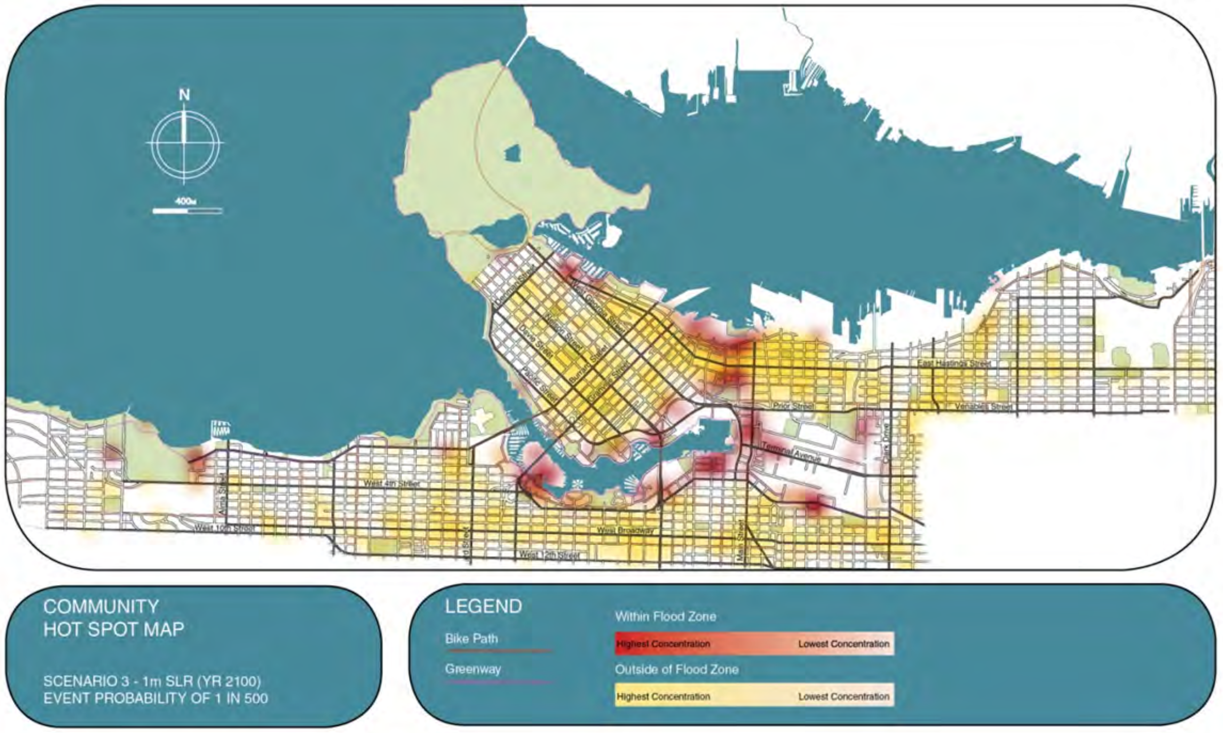

Figure 8 - Community Hot Spot Map

Appendix H provides additional information on the data sources and notable elements included on the Hot Spot Map as well as magnified shots of the CFRA study area.

Community and Seniors Centres

It is important for back-up gathering and emergency location sites to serve as a place of refuge in an emergency. Some community and other associated centres may be at risk of inundation in a coastal flood event. Under a Scenario 3 coastal flood event, the West Point Grey, False Creek, Creekside and Coal Harbour Community Centres may be in the flood zone. The Yaletown Roundhouse Community Centre and Carnegie Centre may be in close proximity to the flood zone. All of these community centres may experience service disruption, loss of equipment and contents, and potentially compromised structural integrity. Brock House Society buildings can be anticipated to flood as well. Relocation or floodproofing measures will be required.

Non-market Housing, Homeless Shelters and Free and Low Cost Meals

In the actual flood zone, there are comparatively few non-market housing developments, homeless shelters and free and low cost meal locations at risk. Approximately 80 non-market developments may be at risk which includes those on or near the water along the south and east sides of False Creek (around Moberly Road and the Olympic Village, and the developments along Main Street) and in the Downtown Eastside (DTES). Most of the homeless shelters and free and low cost meal locations at risk are along Carrall Street, near the DTES.

Downtown Eastside (DTES)

The DTES is one of Vancouver's oldest neighbourhoods and one of Canada's most hard affected urban neighbourhoods (Hastings-Crossing BIA). However, it is also home to over 2,800 businesses, in a diverse range of sectors, including technology, design, restaurants and cafés, retail, and social enterprises, and has about 19,500 people working within the area.

The informal economy[21] is strong in the DTES, and is "essential" for many people to meet their basic needs (draft DTES SIA, 2014). Further to the importance of the informal economy to the DTES is the role that volunteer positions play. In 2012, 29 city-funded organizations in the DTES employed 1,075 volunteers who contributed over 100,000 hours to community work (draft DTES SIA, 2014). Volunteer positions often provide food and training in return for the hours worked (draft DTES SIA, 2014).

From the DTES Social Impact Assessment of Spring 2014, it can be determined that two 'livelihood' related assets are clearly within the flood zone (Crab Park and The Dugout), four within a health-concern related proximity to the flood waters (Insite, Pantages Theatre and Newtown Bakery) and seven within general vicinity of the floodwaters (Gallery Gachet, Portland Hotel Society, Pigeon Park, DNC Street and Fair Market, Enterprising Women Making Art, DTES Women's Centre, and Washington Hotel).

In terms of identified health and social services, two identified community assets are within the flood zone (The Dugout and Dr. Sun Yat-Sen Classical Chinese Garden). However, the most commonly identified asset in this category is the Carnegie Community Centre, located about half a block away from potential flood waters. Three identified assets also in proximity to potential flood waters include Insite, Health Contact Centre and the Portland Community Clinic. The DTES has 14 shelters, only one of which may be in the flood zone in the vicinity of Carrall and Abbott Streets.

Housing is a significant determinant for health and well-being. A lack of basic sanitation, heating/ventilation and the presence of vermin prior to an environmental hazard may increase the impact on the local community. Currently, there are an estimated 15,300 housing units in the DTES (draft DTES SIA, 2014). Housing options range from Single Room Occupancy (SRO) hotels, self-contained apartments, single family houses, condominiums and supportive housing units, with the average occupancy rate being 1.4 persons per unit (draft DTES SIA, 2014).

SRO's are an important component of the DTES housing stock, in particular for individuals on income assistance or a fixed income (draft DTES SIA, 2014). In 2013, there were approximately 4,000 private SRO units in the DTES, 1,500 non-market ones (operated by a non-profit or government agency) most of which are not self-contained, and 5,200 social housing units (draft DTES SIA, 2014).

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[21] Informal economy in the DTES can include binning, street vending, panhandling, bartering or the sex trade.

Table 14 - DTES Housing Mix (2013)

Housing Type	**2013**
Social Housing – SROs	1,500
Social Housing – Units	5,200
Private Rental SROs	4,000
Other Market Housing*	4,600
Total	15,300

** Includes a variety of housing types including single family homes, duplexes and market rental housing.*

Source: draft DTES SIA, 2014

Culture and Recreation

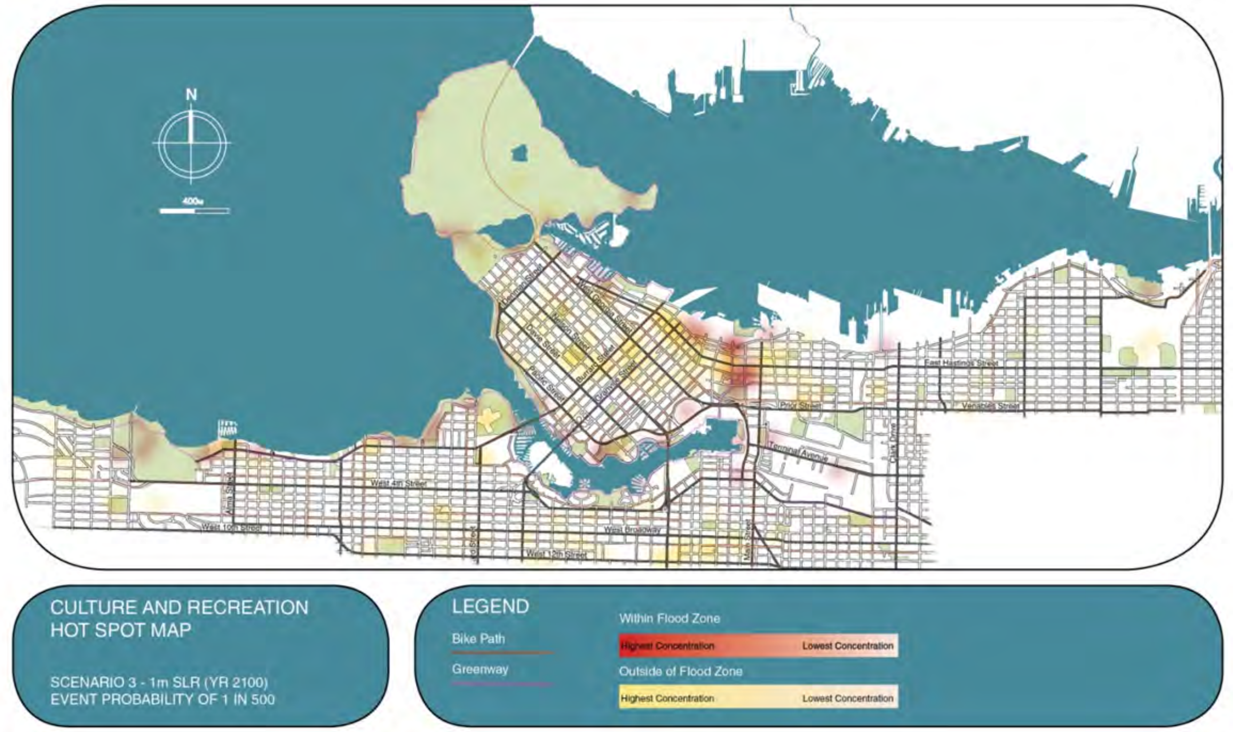

Figure 9 - Culture and Recreation Hot Spot Map

Appendix I provides additional information on the data sources and notable elements included on the Hot Spot Map as well as magnified shots of the CFRA study area.

Heritage and Historic Sites

This section includes cultural destinations (such as Siwash Rock), Heritage 'A' sites and historic districts found within the City of Vancouver. Major museums and galleries have been included above under Economy (see: Tourism) given the explicit revenue numbers available.

It is extremely difficult to effectively and accurately capture the economic or financial impact of the loss of heritage, includngits emotional and symbolic value. Vancouver's heritage includes:

- Chinatown – is one of the oldest and largest Chinatowns in the country, and is one of the earliest established communities in Vancouver. It was designated as a National Historic site in June 2010 (HistoricPlaces.ca)
- Gastown – represents an early Western Canadian city, with buildings from between 1886 and 1914. It also illustrates the rise of the activist heritage movement that emerged in urban centres, around 1970, that wanted to protect the historic fabric of cities. It was designated as a National Historic site in 2009 (HistoricPlaces.ca).

- Heritage A sites - represent the best examples of a style or type of building. It may be associated with a person or event of significance, or early pattern of development." (Vancouver Heritage Registrar, 2013).
- Cultural destinations – as represented by Siwash Rock and Yakdzi Myth, Wakias, Nhe-is-bik (Totems, Petroglyphs, Canoes) in Stanley Park. They are documented as Landscape Resources (Monuments) by the Vancouver Heritage Registrar.

Both Chinatown and Gastown are at risk of flooding, incurring the loss of heritage buildings and of history itself. These neighbourhoods would see structural damage, including unique architectural styles, as well as reduced function and loss of building contents. Furthermore, several Heritage 'A' site buildings would be at risk in a flood event. Relocation (such as with the Hastings Mill House) or transfer of heritage potential are options to consider with each private building owner.

Parks & Green Space

Nestled along the ocean, Vancouver is known for its exceptional scenery and access to nature. Access to parks and green spaces has been the focus of many studies that demonstrate a positive relationship to overall health. In addition to providing health benefits, well-designed park and green spaces can reduce potential flood impacts (as well as diminishing the urban heat island effect and lowering CO_2 emissions) by dissipating wave and tidal energy as it reaches the shoreline as well as trapping sediment and reducing erosion (Sea Level Rise Adaptation Primer, 2013). Unfortunately, existing green space (including high-value habitat areas) may experience coastal squeeze[22] and other ecological impacts with rising sea levels.

Most of Vancouver's coastline in the CFRA study area (the major exception being along the Inner Harbour) is bordered by park or recreational space. In order to maintain access and use of this space, strategies that allow the urban landscape to adapt and regenerate after a flood event will be important (Michael Van Valkenburgh, 2014). Avoiding the use of saline intolerant plants, reducing salt levels in the soils post-flood event and working to incorporate (and locate) appropriate vegetation is one part of the process (Michael Van Valkenburgh, 2014).

Recreation

Vancouver has many recreational opportunities along the waterfront, ranging from swimming, picnicking, kayak and canoe rentals to community tennis courts to marinas. Many of the concerns in this category are similar to that of basic infrastructure and buildings – they may suffer a loss of functionality, loss of contents and loss of structural integrity. There will be an economic impact for the businesses and organizations (including the City of Vancouver) running the recreation amenities. Post-flood effects include damage of debris and blockage (February 14th workshop, 2014). Items (including smaller items such as netting and balls to bigger boats in the marinas) may become scattered throughout the waters and shore. Kitsilano Pool may suffer salt water inundation and/or damage in a flood, most sports fields will need landscaping and care to be serviceable post-flood. Topics to be determined include the financial cost of and responsibility for the clean-up (February 14th workshop, 2014).

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[22] Effect of shoreline retreat located between rising sea levels and the built environment.

Vancouver Seawall

Spanning 22 km from Kitsilano, through False Creek, the West End, Stanley Park, Coal Harbour to Downtown Vancouver, the Vancouver Seawall has been iconic for decades. However, it was built for a different set of sea levels and storm intensities. Looking ahead, Vancouver will need to consider the best way to maintain the seawall given the rising cost implications. In 2011, $6.4 million went into upgrades for a 340-metre stretch along English Bay and for 470 m in Stanley Park[23.] In 2012, the seawall was periodically closed due to the impacts of high tides, strong winds, and flooding events[24]. Both cost and frequency of service disruptions can be expected to rise.

Cascading effects:

- Expensive to continually repair and upgrade, including service disruptions, would provide construction job opportunities
- Impact Vancouver's reputation and tourism – countless restaurants and businesses rely on the existence of the seawall for their clientele.
- Impact Vancouver's standard of 'liveability' if the extent of bike and pedestrian paths is reduced.

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[23] http://actionplan.gc.ca/en/news/backgrounder-creating-jobs-and-improving-vancouver-infrastructure

[24] http://www.huffingtonpost.ca/2012/12/17/stanley-park-seawall-closed-storm-surge_n_2317328.html

Conclusions

Typically, vulnerability assessments primarily focus on socio-economic considerations, in order to capture the potential for adverse economic, social, and environmental impacts. The results of a coastal flood vulnerability assessment can then be applied to urban development planning and initiatives. Urban development plans should not proceed unless the flood risk and expected impacts can be managed to an acceptable level. Effective management techniques can include the use of on-and off-site measures that regulate land use and the conditions of land use through landuse plans, zoning, enforceable policies and regulation that provide necessary instruction for individuals, organizations, businesses and government. This will enable interested parties to determine which types of development, when and where they can take place and under what conditions, including costs.

The following observations have been made about vulnerability in the City of Vancouver, given the feedback received from the February 14th Workshop, a literature review and an analysis of a Scenario 3 coastal flood event:

Emergency Management

- Most hospital and care facilities are outside of the flood zone. Those in proximity to the flood zone, and in particular those within the Downtown core, can expect to see increased patient inflows in the event of a coastal flood event.
    - St Paul's Hospital is outside of the flood zone but may encounter impacted infrastructure and restricted access. Given its proximity to flooded areas, a spike in patient inflow should be expected.
    - Vancouver General Hospital is also outside of the flood zone, and may be able to handle the patient overflow from St. Paul's.
    - Smaller care facilities in proximity of the flood zone may not be able be operational (e.g. Moberly Road on the south side of False Creek west of Cambie Street and near Main and Hastings Street in the Downtown Eastside).

- Most evacuation and access routes are expected to remain relatively clear of inundation in a flood event. Routes particularly at risk of inundation include the north-south corridor along Main Street and Pacific Boulevard. All bridge on-ramps are expected to remain clear of floodwaters.
- Three evacuation routes (along West Georgia Street to either Prior Street or Terminal Avenue, Nelson Street to the Cambie Street Bridge, and Pacific Street to Burrard Street Bridge) will be impeded by the flood zone or directly impacted by coastal flood waters. The first two evacuation routes will be unusable in a Scenario 3 flood event. Evacuation and access routes are considered essential transport infrastructure; any reduction in capacity and serviceability will increase the vulnerability of the affected neighbourhoods and populations.
- One police work yard is within the flood zone, with three Fire and/or Police stations in close proximity to the flood zone.

- Current planned Gathering Areas within the Downtown core have not been selected with a coastal flood event in mind. Several existing sites will be inundated. The following Gathering Areas should be moved to locations with a reduced flood risk
    - Vanier Park sites
    - Science World and Terminal Avenue
    - BC Place Stadium
    - Coal Harbour (not fully inundated, but extremely close to flood waters)
- Emergency evacuation and planning for the Downtown and Inner Harbour zones may need to be reviewed by the City and Emergency Response personnel.

Infrastructure

- Mapped infrastructure is expected to be relatively resilient in the event of a coastal flood. Risk of damage increases with aging infrastructure.
    - Roads and bridges suffer a complete loss of functionality if inundated. Bridge on-ramps should remain free of floodwaters; however the collector and adjacent roads under the Burrard, Granville and Cambie Street Bridges will be inundated.
    - North-south traffic routes, including Quebec Street, Main Street and Clark Drive, will see disruption. Main Street and Clark Drive play an important role in servicing the Port and are recognized as important truck routes within the City of Vancouver.
    - In terms of east-west connections, parts of Pacific Street and Cornwall Avenue will be inoperable, as well as significant portions of Prior Street and Terminal Ave. The key east-west connector streets of the Downtown core (West Georgia, Nelson and Davie streets) are anticipated to remain clear of flood waters.
    - Neighbourhood Energy Utility assets are relatively new with waterproofed piping. Future capacity build-out can incorporate appropriate flood-proofing techniques.
- Uncertainties exist as to how existing combined sewer overflows, storm sewer overflows and sanitary sewer overflows will fare in a flood event outside of the False Creek Area.

Economy

- Extensive Port Metro Vancouver (PMV) lands along Burrard Inlet will be inundated. Structural measures will need to be undertaken to maintain operation during a coastal flood event. PMV may be able to offset temporary service disruptions by increased reliance on Deltaport.
- Commercial Services (includes major restaurants, shops, hotels and tourist destinations) within the flood zone will be impacted. Service jobs (particularly local restaurants and retail shops) may be more resilient as they can shift between neighbourhoods. Larger projects (hotels and iconic tourist destinations) may be more challenging, from both a logistics and cost perspective, to relocate (or protect). Areas at risk include:

        - Cornwall Avenue and Vanier Park tourist attractions (Museum of Vancouver, HR MacMillan Space Centre, Vancouver Archives, Vancouver Maritime Museum and Bard on the Beach)
        - Granville Island (plethora of local artisans and businesses, as well as entertainment venues)
        - Terminal Avenue/Science World area
        - English Bay and local restaurants/shops in the area
        - Waterfront Station (as a transportation hub) and Gastown (entertainment, shops and restaurants)

Culture and Recreation

- Coastal recreation-oriented public spaces will flood.
    - Many parks and public green space are at risk of inundation; however, with flood-tolerant landscaping and design, the resiliency of the parks and green space after a flood event can increase.
    - Pools, rinks and playing fields are more likely to suffer structural and functional damage during and after a coastal flood event, incurring significant reconstruction and rehabilitation costs.
- Many museums, archives, cultural destinations and historic buildings/sites are at risk of flooding.
    - At greatest risk are the buildings in Gastown and Chinatown, which have historical and cultural significance.
    - Structural and functional damage may be expected, as well as a loss of contents and equipment (non-fixed items may be able to removed, but larger items and specialized pieces of equipment may not be).

Community

- Census data and the national household survey (NHS) provide the following insights to the census tracts[25] (CTs) in the CFRA study area:
    - West Point Grey and Hastings-Sunrise/Grandview Woodlands CTs have the highest percentage of people under the age of 14.
    - Chinatown, Fairview, North False Creek Flats and West Point Grey report the highest percentage of people over the age of 65.
    - One-third of Vancouver's one-person households are within the CFRA study area, who in turn comprise just over 50% of the private households in the study area.

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[25] Please see Appendix G for Census Tract breakdown by CFRA neighbourhood

    - Two-thirds of the private households are tenant households, of which 18% is subsidized housing.
    - One third of owner households and approximately 50% of tenant households are spending 30% or more of their household income on shelter costs.
    - Government transfer payments as a source of income, and indicator of social dependence, range from 3% in Coal Harbour to 42% in Chinatown.
- At a higher level, the City's social services (including homeless shelters, community amenities and education opportunities) are not particularly vulnerable in a flood event. The vast majority of services are provided outside of the flood zone. However, a few pockets do contain at-risk services. With proper planning and relocation, this vulnerability can be reduced, if not eliminated. Areas at risk include:
    - Carrall Street Corridor (between Water Street to the north and Keefer Street to the south).
    - Designated school sites at International Village and Southeast False Creek.
    - Existing and proposed daycare/childcare facilities at Olympic Village and near Terminal Avenue.
    - Existing social housing in along Moberly Road (south side of False Creek, west of Cambie Street).
    - Granville Island amenities.
- In terms of the Downtown Eastside, the area between Carrall Street and Main Street is most at risk. Although this represents a small proportion of the DTES and limited flood depths, significant secondary impacts may be felt due to the high number of private and non-market SRO's, non-market housing, and training/livelihood related sites nearby. Sites of significance that may be impacted include:
    - Crab Park and The Dugout (drop-in centre at 59 Powell Street) – anticipated inundation.
    - Insite, Pantages Theatre, Newtown Bakery, Pigeon Park and Portland Housing Society – anticipated service disruption.
    - DTES Women's Centre and Carnegie Community Centre – anticipated increase in demand for services.

Glossary

Adaptation	In human systems, adaptation is the process of adjustment to actual or expected climate change and its effects, in order to moderate harm or exploit beneficial opportunities. With respect to sea level rise, adaptation refers to action taken to prepare for its occurrence.
Adaptation Planning	Refers to the process of how a community identifies ways in which it may be impacted by climate change, and how it develops a plan to address the negative consequences.
CFRA	Coastal Flood Risk Assessment
Coastal Hazards	Naturally occurring events that pose a threat to the health or life of people, property and/or the environment in coastal areas. Types of coastal hazards include storm surges, coastal flooding and shoreline erosion.
Coastal Squeeze	Effect of shoreline retreat located between rising sea levels and hard structural protection such as dikes. Coastal habitats that are unable to migrate landward are squeezed between the rising sea and hard defences. This reduces the adaptive capacity and the extent of intertidal and sub-tidal habitats including saltwater marshes.
Elements at risk	Refers to those things that may be harmed by flooding (e.g. people, houses, buildings or the environment).
Flood Hazards	The features of flooding that have adverse impacts on elements at risk such as the depth of water, speed of flow, duration, and water quality.
Hazus	A standardized methodology using Geographic Information System technology to estimate potential physical, economic and social impacts from floods and other natural disasters. It was developed by the Federal Emergency Management Agency in the USA and is being adapted for use in Canada by Natural Resources Canada.
Likelihood (probability)	A general concept relating to the chance of an event occurring. Likelihood of flooding is generally expressed as a probability (or frequency) of a flood of a given magnitude or severity occurring or being exceeded in any given year. It is based on the average frequency estimated, measured or extrapolated from records over a large number of years and is usually expressed as the chance of a particular flood level being exceeded in any one year.

PMV	Port Metro Vancouver
Resilience	The capacities to anticipate, prepare for, respond to, and recover from the effects of sea level rise with minimum damage to social well-being, the economy and the environment.
Risk	The likelihood of a negative event occurring (e.g. flooding due to sea level rise) combined with the magnitude of the potential consequences.
	Risk = Likelihood (Probability) x Consequence
Vulnerability	Refers to the degree to which a system is susceptible to, or unable to cope with the adverse effects of climate change, including variability and extremes. It is a function of exposure, sensitivity, and adaptive capacity.
	Vulnerability = Exposure x Sensitivity x Adaptive Capacity
Exposure	Refers to the state of the elements at risk of being exposed to contact with something – such as a coastal flood event.
Sensitivity	The degree to which the elements at risk are affected.
Adaptive Capacity	The ability to adapt in the face of potential flood hazards and risks.

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Appendices

Appendix A – February 14th Workshop Documentation

Flood Vulnerability: What is in the way?
February 14th, 2014
Creekside Community Centre

Workshop Notes:

Table 1 – False Creek

Guiding Question:
What is the issue that concerns you the most about potential sea level rise?

- The kids and any vulnerable elementary schools
- Professional concern
- The entire study area [False Creek] and relevant best practices and the effects of the railway in the area
- Everything
- People displacement

Breakout Session 1
What's in the way?

- Forecasting helps

Breakout Session 2
What are the cascading effects and long-term impacts from flooding in your area?

Post-It Paper

- Two-parent Families and fall-out effects on:
  - children and childcare
  - mortgages
  - Economy
- Mortgages
  - Amount/$
  - Basement suits and supplementary mortgage income
- Shelters are gone
  - BC Place will be compromised (given the scenario on the maps)
  - See New Orleans, for what that can imply
  - Secondary gathering sites? Community Centres?
- Areas will be cut off
  - Strathcona
- Sanitation

    - Flushing
    - Additional capacity
- Environment of Industrial Contamination
    - Environmental Issues
        - Health
        - Food Security and Supply chain
            - (See map for Purple bits) → Produce Depot, Food Banks
        - Animal shelters
    - Every place the water touches will be affected
        - Till after the public health check
            - Time consuming → economic effects
            - Seniors and Co-op Housing → How will they be affected?
            - Strathcona has high density
- Tunnels between buildings Downtown
    - Already flood

Round table Discussion

What is the most "burning issue" that was raised today?

- Real estate and tourism → driven by views.
- Will feel a large impact if Granville Island is removed → from both real estate and tourism perspective.
- Shelter issue
- Industry is a bigger issue than schools
- Importance of education and public awareness
    - Ready for event?
    - How prepared for a flood?
    - How to be pro-active?
- Dealing with time horizons and cost bearing.
- Dialogue on how to 'fix' before it's actually broken
- We did it to ourselves
- Rainfall distribution a major impact
- Displacement of vulnerable people and concern over shelter
- Importance of not discussing climate change or the 1/10000 year event concept for frequency. Equate it to "Katrina" or "Sandy" – something that people can understand.
- An intense rainfall of 150mm cost 1B$ for 500K people
- Technical insulation

Table 2 – False Creek

Guiding Question:

What is the issue that concerns you the most about potential sea level rise?

- Social Impact
- Schools that are in the flood zone as they are low structures
- Flooding in general

- For people to care about future proofing long-term and not just short term, short-sighted
- Buildings that have parkades with the electrical systems below

Breakout Session 1

What's in the way?

- 2 new schools being built (one French school, one not built yet) near Olympic village area
- International School in International Village
- Daycare facilities: Citygate, Creekside
- Co-op housing
- Senior facilities
- Social Services
- Shelters, other social services for high risk populations (United We Can moved recently)
- 6 million in new development (4 million residential of that is residential)
- Planned ice rink
- Affordable housing and also new planned towers (but they are already building up in accordance to the building bylaw
- Dr. Sun Yat-Sen Gardens
- General distribution for railroad and port
- Train Station/Bus Station – port activity stalls if railyard floods, there are unknown materials @ railyard
- Some are already city-owned property such as National Yards, Animal Shelter, Evans yard, property endowment fund, 4 million square feet and most are single story
- Arts & Cultural assets (Emily Carr)
- Marinas – docks might breakaway and block other areas
- Hazardous Waste in Industrial Area – there is storage for waste
- Concern about what is at the bottom of False Creek
- Refrigeration plant with Ammonia off the viaduct
- Utilities (such as NEU) – if flooded it would be out but still contained – can't just dry it out, needs to be rebuilt (electrical)
- Schools – during a disaster the community would normally go to schools for help and refuge but the school is not being built in a way to help others, only to help the children (to evacuate and keep safe) – no recovery capability so then the building can't serve as a refuge for the community.
- Not enough refuge – If BC place has no power to help the community then there will be issues
- Bridge scour – problems for water to drain away
- The industrial area – the damaged assets would go back into false creek
- SkyTrain tunnel – no service
- The unknowns are hazardous materials, cars from dealerships will be floating away

Breakout Session 2

What are the cascading effects and long-term impacts from flooding in your area?

- Affected people (loss of home, lack of food),

- Loss of business, displacement of vulnerable people, rehoming, where will they get food? Every store could be empty within 8 hours and not get back up for 72 hours
- Environmental effects
- Economic disruptions – might take too long to drain
- Small businesses
- Ports will have no movement – or everything slows and starts bottle-necking.
- No games! Morale in the City goes down (hopefully will bounce back like the rodeo in Calgary)
- Environmental cleanup – who will pay? Feds? Province? City? – will get stuck in a log jam of responsibility between the sectors.
- How do you dispose of the debris? Recycling? Landfill?
- no mobility between North Shore and Vancouver - transportation will be affected
- Rebuilding in areas that have been flooded before may change what will be built in the future – might be all structural change, should we rebuild in this area? Change it to a park?
- Re-thinking land use, re-review of the area, density of people
- Value of property
- Granville Island (biggest tourist area in Canada) – will people come back? How much money will we lose, and what about the old structures
- Green job zones – IT companies moving in: do they have proper backup? Do they have a plan in case of a disaster (most do)
- Will people get paid? Some have insurance, some don't.

From Post-it Notes:

- Families will have to take care of their kids at home
  - Economic impact
- Lose income
  - Cultural assets linked to tourism
- Business disruption
- Morale
- Port → slow down rail access to Port
- How do you dispose of debris?
- Transportation disruption → business impacts
- Catalyst for re-think
- As in Develop – wait to see big flood
- Real Estate Impacts – GDP
- Granville Island – Tourism & Long Term $
- Environmental clean up costs
- Levels of Gov't jurisdiction for clean up
- Displacement ALREADY vulnerable
- Distribution not manufacturing
- Insurance costs → will take time to workout

Round table Discussion

What is the most "burning issue" that was raised today?

- Planning process in industrial area. Do you preserve industrial lands or turn it residential, etc.?
- Rational places to put things like Firehalls & other City infrastructure

- Social Aspect – we need a social plan – response and pre-planning
- Does emergency management think about only earthquakes or also flood
- Impacts to surrounding areas – workers that travel to Vancouver for work
- Long term thinking:
    - Real Estate – short-sightedness of how these buildings are built (developers, do they care about more than esthetics than safety?)
    - Think and plan for more than 5 to 10 years, show long-term
- Sustainability aspect – what are we doing to prevent these catastrophic events?

Table 3 – Kitsilano Beach, followed by False Creek

Guiding Question:
What is the issue that concerns you the most about potential sea level rise?

- What do we have to do to floodproof?
- How can we protect the infrastructure we have in vulnerable areas?
- We keep putting people and infrastructure in the areas of highest risk.

Breakout Session 1
What's in the way?

- Major Metro Vancouver sewage pump station that serves UBC
- City sewage pump station
- Several combined sewage outfalls
- Parks works yard (Jericho)
- Community centre (Jericho)
- Marina (Jericho)
- Relatively small residential development except westerly part of Kits Point
- Transmission lines may or may not be affected (underground lines should not be affected, overhead transmission poles may need to be shored up, no substations are nearby but impacts from other transmission stations could occur depending on redundancy)
- People's expectation of a connection (positive) to water
- Erosion potential along cliffs (north of Point Grey Road)
- Kitsilano Pool and other park facilities
- Few, if any, roads should be impacted
- The group consensus was that the impacts of Scenario 4 on zone 1 would be relatively modest compared to the other zones

False Creek

- Several combined sewage outfalls
- Several storm outfalls
- Several marinas in False Creek
- All of Granville Island including post-secondary school and community centre
- BC Place and Rogers Arena (potential mass refuges)

Breakout Session 2 (comments applied primarily to False Creek)

What are the cascading effects and long-term impacts from flooding in your area?

- Real Estate Values will go down
- Insurability (increasing rates, shortfall between property values and disaster financial assistance)
- Withdrawal of affluence from waterfront
- $ not being spent along coast
- Railway disruption
  - Derailments
  - Distribution Networks (includes ships of goods and food to Vancouver, export grain terminals will be out of service if rail access is not available)
  - Will rolling stock be able to be moved in time?
- Contamination of False Creek
- Change in psychology of people who currently want to live on water
- We will be able to adapt
  - Land use changes
  - Move HVAC equipment and electrical service panels from basements to higher elevation
- Loss of value (tax base)
- The new waterfront may not be attractive → cost of redesign
- Thinking of building needs to change
- Displacement of people will affect small areas but with high density
  - Olympic Village and Downtown South
- Lower density residential areas will also be impacted as basement suites are very common
- Freighters at anchor could be washed onto shore
- Marine industry will be heavily impacted
- Rising water tables could affect development
- Should viaducts be demolished if their vulnerability to an extreme event is low?

Round table Discussion

What is the most "burning issue" that was raised today?

- Reconstruction of port facilities to address sea level rise will face huge infrastructure costs. These will have national impacts due to the Port of Vancouver's important role in import/export trade.
- Should we keep our Business as Usual approach of mitigating the effects of sea level rise? Should 'managed retreat' be considered and what are the implications?
- Many of our expectations will need to change. We can make everything work but changes will include the siting of facilities, their size, and infrastructure requirements.
- We will have to change our thinking because our assumption of sea level being constant will not be the same in the future.
- The consequences of sea level rise are not all negative. Although costs will increase, we have the opportunity to rebuild better and more resilient development in the future.

Table 4 – Kitsilano Beach

Guiding Question:

What is the issue that concerns you the most about potential sea level rise?

- Loss of infrastructure and capabilities
- CSOs
    - ability to discharge to sea
- Storm events
    - Impact on people and businesses on individual level (cascading effects)
- Fraser Valley
    - Power outages/holistic P.O.V
- Infrastructure Planning for CoV
    - Engineering solutions vs. policy
    - Urban design of solutions

Breakout Session 1

What's in the way?

- Kitsilano Yacht club
- Jericho Sailing Centre
- Jericho Hostel
- Housing, predominantly single-family residences
- Jericho Beach Park, Locarno Beach Park, Kitsilano Beach Park
- Kitsilano Pool
- Northwest Marine Drive
- Jericho Arts Centre
- West Point Grey Community Centre
- Aberthau Cultural Centre (West 2nd Avenue and Trimble Street)
- Vancouver Maritime Museum

5 most vulnerable – nuisance flooding

- Northwest Marine Drive
- Jericho Hostel
- Jericho Sailing Centre, Kitsilano Yacht Club
- Vancouver Maritime Museum
- The Boathouse Restaurant
- Kits Pool
- Aquabus docks

5 most vulnerable – catastrophic flooding

- Commercial land-use along Cornwall Avenue
- Ability to discharge sewers at English Bay outfall
- Power outages of homes, but can restrict power outages to smaller geographical area
- Areas not flooded (e.g. Belmont Ave) but affected if other areas have sewers backed-up. Will result in contamination issues.

- No defined emergency routes or disaster response routes in Kitsilano Beach area (nearest route is along 41st, so far away and on high ground)
- Henry Hudson Elementary School near Cornwall Ave, but could evacuate out of flood zone fast
- If water along W 4th Avenue, would simply close it.

50yr, 100yr outlook

- Could raise Northwest Marine Dr., would be improvement.
- No expectation of development in this area in future, keep as is because of flooding concerns.
- Managed retreat would be an option here.
- Suggest not connecting seawall (would need fill). Instead, do a boardwalk
  - But is the city obligated to protect homes along the waterfront?
- Seawall pathway along Kitsilano Beach – planned for upgrades going forward. Suggest raising now.

Breakout Session 2

What are the cascading effects and long-term impacts from flooding in your area?

(* top 5)

- If nuisance flooding (flood after flood), business owners might decide to pack up *
- Lose recreation facilities – private (sailing club?) and public (park, seawall) *
- Loss of cultural facilities – Maritime Museum – loss of archives *
- Small number of jobs affected/lost *
  - But minimum wage jobs in service industry (vs. manufacturing jobs at higher wages – whose employees can relocate)
  - Likely, only a handful of management positions would be affected
- Small number of residents leaving the area
- Sewage contamination *
  - But these people can move to hotels (but places stress on hotels)
- Cascading effects don't extend very far
- Not hitting any major thoroughfares
- Transportation routes outside City are shutdown
  - Richmond, YVR and Cape Horn Interchange → would compromise the ability to get resources into the area
- Here (Kits-Jericho Shoreline) is manageable but compounded by other areas of Vancouver's issues
- Home-based businesses may be affected, but are relatively mobile
- Upgrades may be demanded by residents because of huge tax base
- Personal insurance of homeowners can go up
- Changes to building code in long-term
- Real estate values

Round table Discussion

What is the most "burning issue" that was raised today?

- Change zoning bylaws, disallow construction in these areas; don't make it worse.
- Land use planning
    - Consider mitigation and response if there are people still living here.
- Collective approach to designing areas
- Will there be flood insurance?
    - Disaster Financial Assistance will continue.
- Plan has to be adaptable, future generations need to be able to easily implement
    - Plan for what you know now, and revisit every 20 years, etc.
- Develop with new constraints – FCL's, building codes
    - In this area, people do tear down and rebuild
- Retreat is an option here (compared to downtown core)

Table 5 – Inner Harbour

Guiding Question:
What is the issue that concerns you the most about potential sea level rise?

- Cost of mitigation vs. cost of abandoning
- Ecological cost/shoreline resilience
- Infrastructure changes to adapt
    - Long term plans
- Have to be getting stuff right
- Looking at ecological values
    - Avoid hard engineering/more adaptive
    - Communication of SLR to clients and public

Breakout Session 1
What's in the way?

- Number of CSR
- Sewer pump station – critical
    - Fails
    - Contamination issues
    - Subterranean
- Port
    - Cranes may have operational levels with 1m SLR
    - Oil tanks, other industrial contaminants in area
        - May be a database with Port regarding contaminant items
- Social services and low income on fringe
- Potential for industrial items/desires to start to float/contaminate
- Crab Park/Columbia St.
    - Larger areas of (contaminate) fill
        - Could be susceptible to high ground water levels due to SLR
- Bad soils near seabus
- "basically a 1m SLR wipes out the port"
- Sent website with infrastructure

- Flood a pump station you got a problem
- Water infrastructure is okay
- DFPS – may be in flood zone (should check)

Breakout Session 2

What are the cascading effects and long-term impacts from flooding in your area?

- How long would Port Facilities be out of operation?
- If main sewer pump station is out, what happens? Can it be adapted?
- There will be debris from entire harbour – would affect ingress/egress from area.
- Massive Western Canada/National impact
    - Send/receive goods
    - KEY ITEM
- Significant environment/human health issue – near vulnerable populations
    - If sewer pump station goes down
- If you lose power nearby high rises outside of flood zone will lose power which affects access and liveability
- West Coast Express will be affected
- Christchurch Experience
    - Up and back running in a few days
- Port – does have emergency plans, however limited access points
- Coastal and Emergency Services (fireboats) are at risk
    - Could be affected by floating debris
- Contamination by oil/hazardous materials
- Proximity to vulnerable populations which would be affected by Ports need to address flooding
    - Could be conflicts
- Hydro is making the downtown electrical system redundant
    - But sill concerns that there may be impacts
- Long term impact on Cruise Ship business if Port can't get up and running
    - Could miss a season
- All major hotels/tourist infrastructure in vulnerable areas near Seabus
- Reclaimed land
    - If you lose it there is a "letters pass" that allows Port to 'claim' land further inland to rebuild
- Corridor from Strathcona Okay. Road based transportation okay.
- Port has right to expropriate given distance from High Water Mark which be affected by Sea Level Rise

Round table Discussion

What is the most "burning issue" that was raised today?

- Soil Contamination
    - Would this affect response
- Infrastructure to protect City would need to be built on Port land, which will need good communication between City and the Port.

Table 6 – Inner Harbour, followed by joining other tables

Guiding Question:
What is the issue that concerns you the most about potential sea level rise?

- Social impacts of a changing landscape
- Financing for future adaptation
- No concerns
- Apathy

Additional Notes:

Neighbourhood Energy wasn't able to make the presentation, and provided the following in advance of the workshop:

Neighbourhood Energy Infrastructure = **Energy Plant** + **Distribution Piping** + **Energy Transfer Stations** (ETS)

Southeast False Creek

Currently, NE infrastructure is located in Southeast False Creek (plant under the Cambie bridge, piping under 1rst Ave, ETS's in the P1 level of connected buildings) as it connects to more and more buildings down there, with plans to extend service to the Great Northern Way Campus.

In a flood event:

- **energy plant** would shut down. This would eliminate heat and hot water to all connected residents (16,000 at full build-out) until such time that replacement equipment could be ordered and installed (on the order of several weeks). There would not be a health/safety concern with this plant shutting down – no hazardous materials leaking, etc.
- **distribution piping** is the most resilient infrastructure available. It is waterproof, with detection and other controls in place, should they incur water damage.
- **ETS's** would be damaged (electrical controls shut down), but operable in manual mode by the utility (COV).

Northeast False Creek

NEFC is slightly different. It is under development, so no NE Infrastructure is currently in place. 3 buildings will host a **Steam to Hot Water Converter Station** (in their P1) which will convert steam from Central Heat to hot water for circulation to all other connected NEFC buildings (eventually extending to Chinatown as well). The StHW is for all intents and purposes like an Energy Plant; therefore measures should be put in place to flood-proof these rooms as much as possible (We've heard of 'submarine doors' used in River District's plant) as they would shut down in a flood event. Distribution piping is likely to go along the realigned Pacific Ave. For ETSs, while damage is likely, it may be overkill to flood-proof these rooms, as we’re not sure a building would do that for a typical boiler room…would they?

Low Carbon Plant

The partner utility for the downtown is required to switch Central Heat to a low carbon fuel source. They are currently exploring sites for a large centralized low carbon plant in either the False Creek Flats or the waterfront. In either case, such a plant would be partially below the flood plain. Technology is likely to be biomass, therefore certain to shut down in a flood event. Flood proofing is important for this large piece of infrastructure.

Appendix B – Hot Spot Map Methodology

The Graphic Designer took the collected data (detailed below) and plotted them on a base map of the City of Vancouver (sourced from VanMap). Each dot – representing an individual item per category – was mapped with a circle with a radius of approximately one half of a City of Vancouver block.

To determine the concentration of items, circle opacity was dropped to 50%, and then overlaid with the Scenario 3 flood extent. If the item was within the flood zone it was coloured red; outside of the flood zone, yellow. The higher the concentration of items is reflected by a darker colour. Dark red indicates five or more items are in proximity and at risk of inundation. The layers were then smoothed via Gaussian blur, for improved visualization while maintaining accuracy.

Appendix C – Economic Hot Spot Map Details

The following pages demonstrate the data, hot spot, land use and magnified hot spot and land use maps for the Economic section.

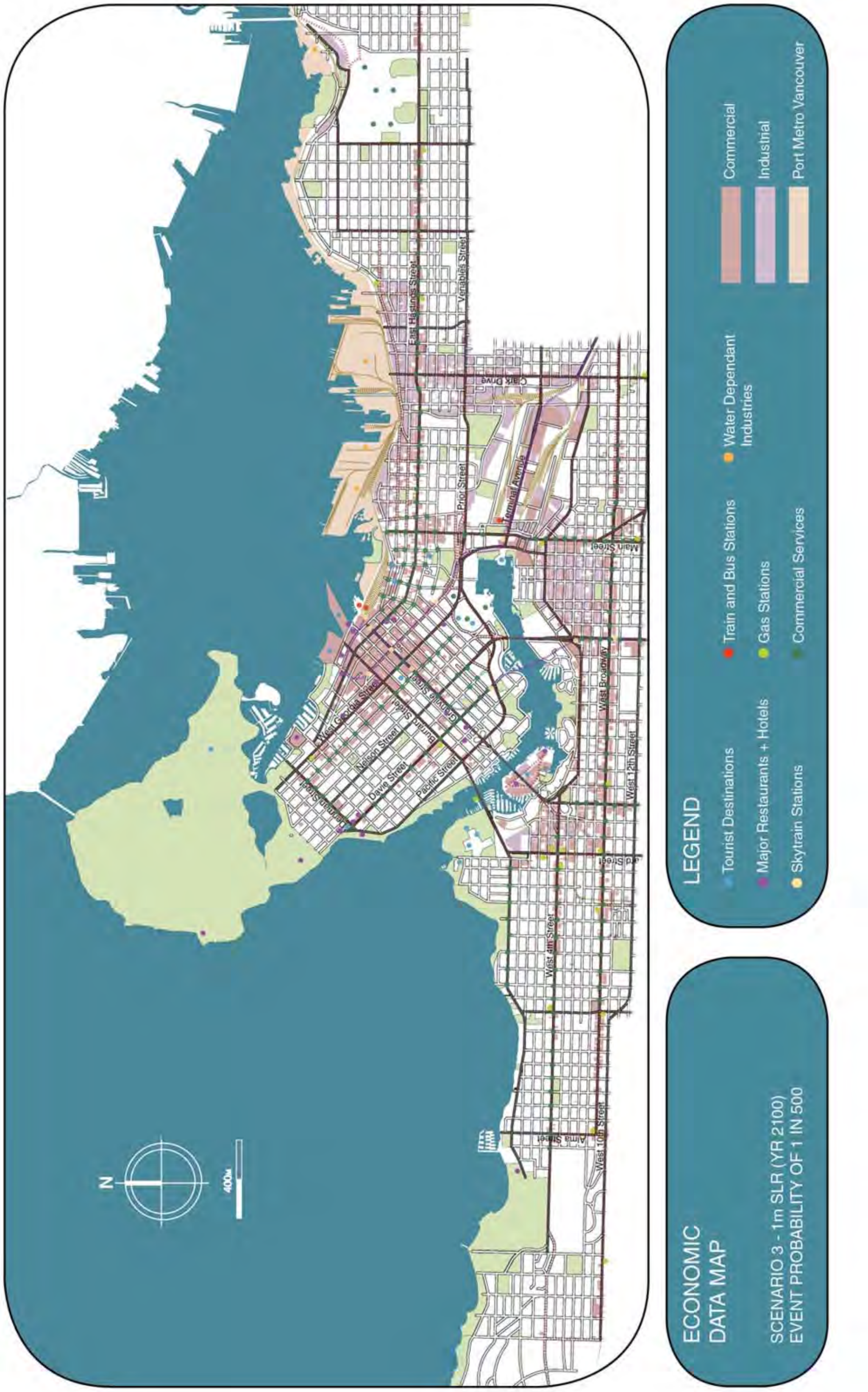


Figure 10 - Economic Data Map

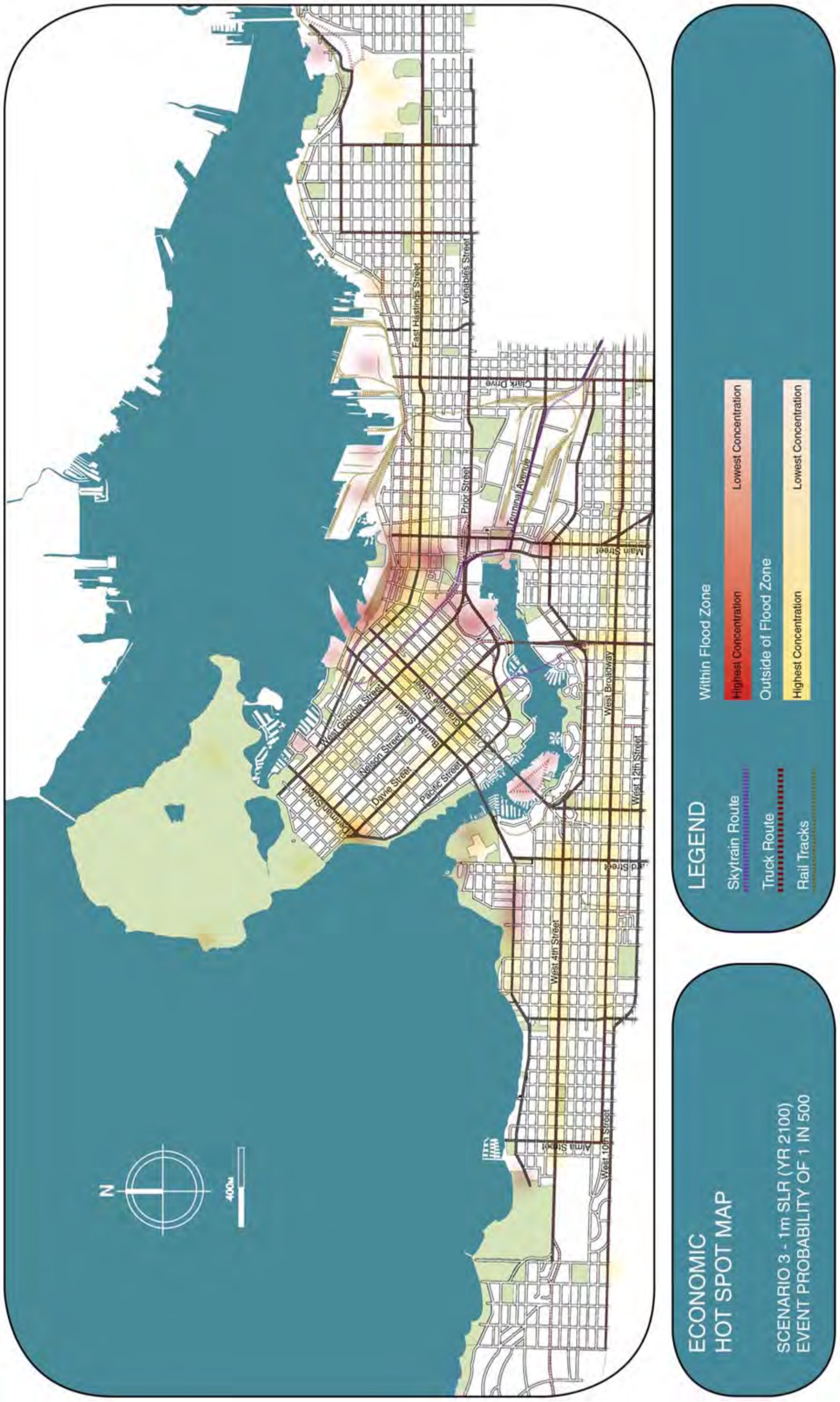


Figure 11- Economic Hot Spot Map

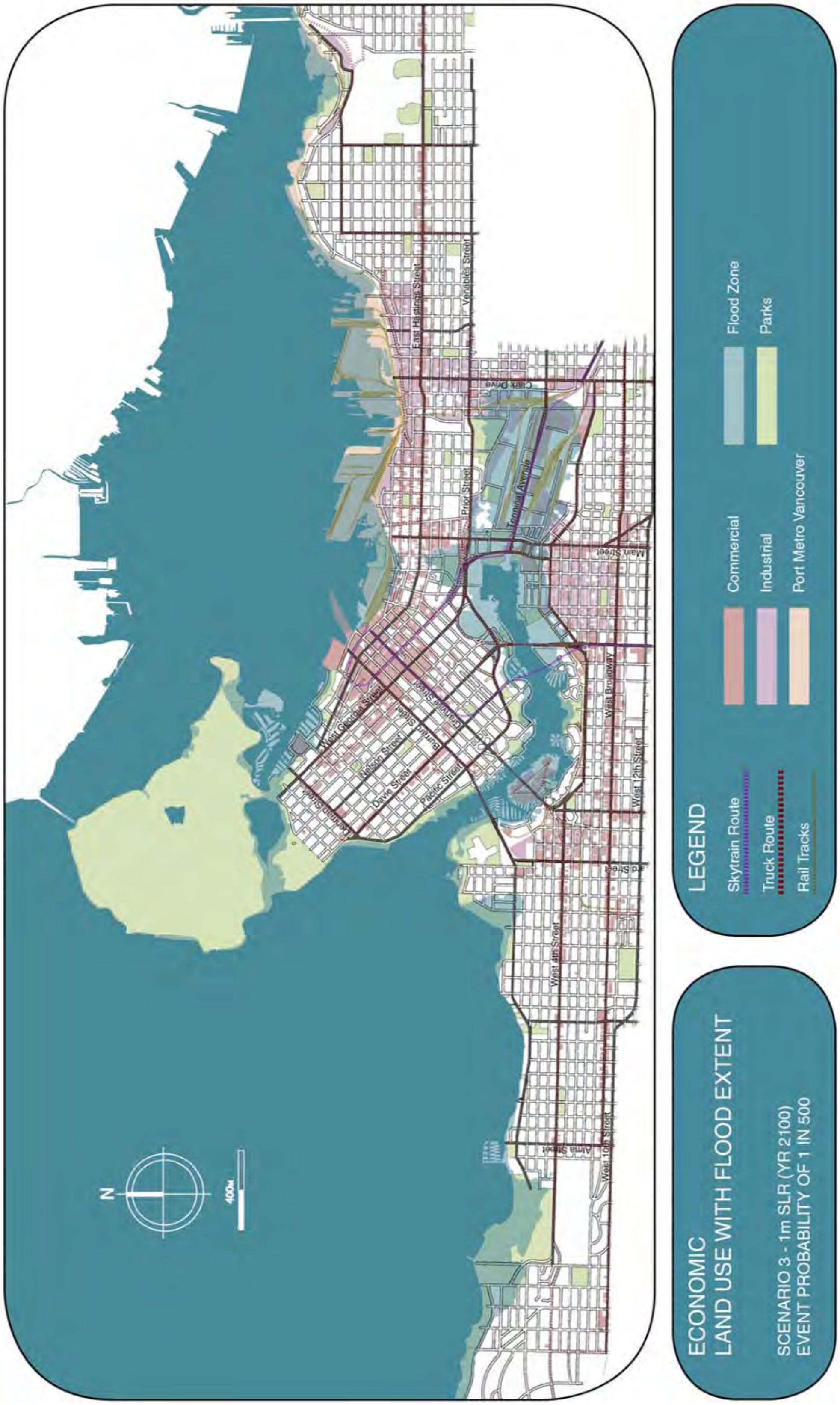


Figure 12 - Economic Land Use Map with Flood Extent

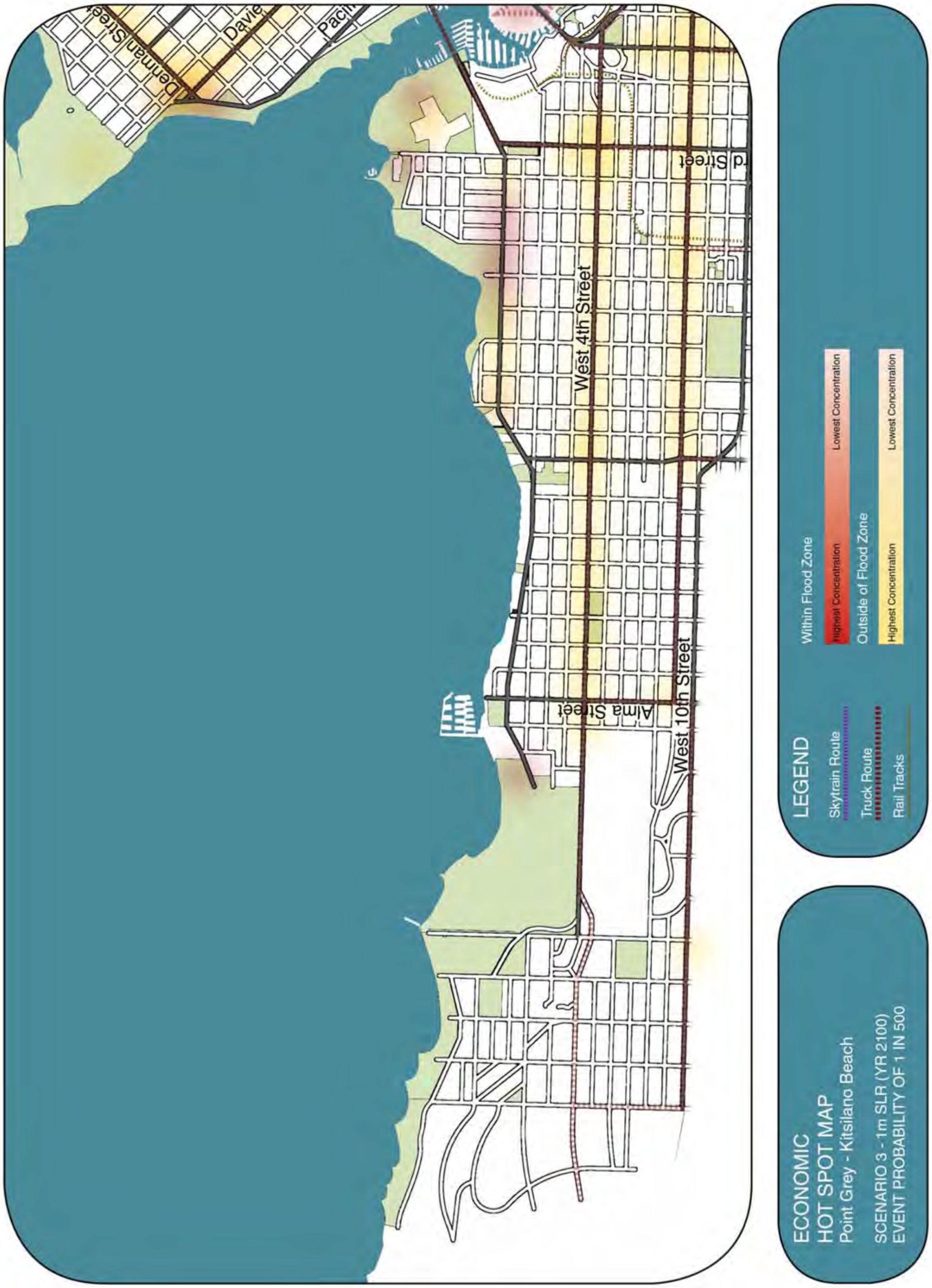


Figure 13 - Economic Hot Spot Map (Point Grey - Kitsilano)

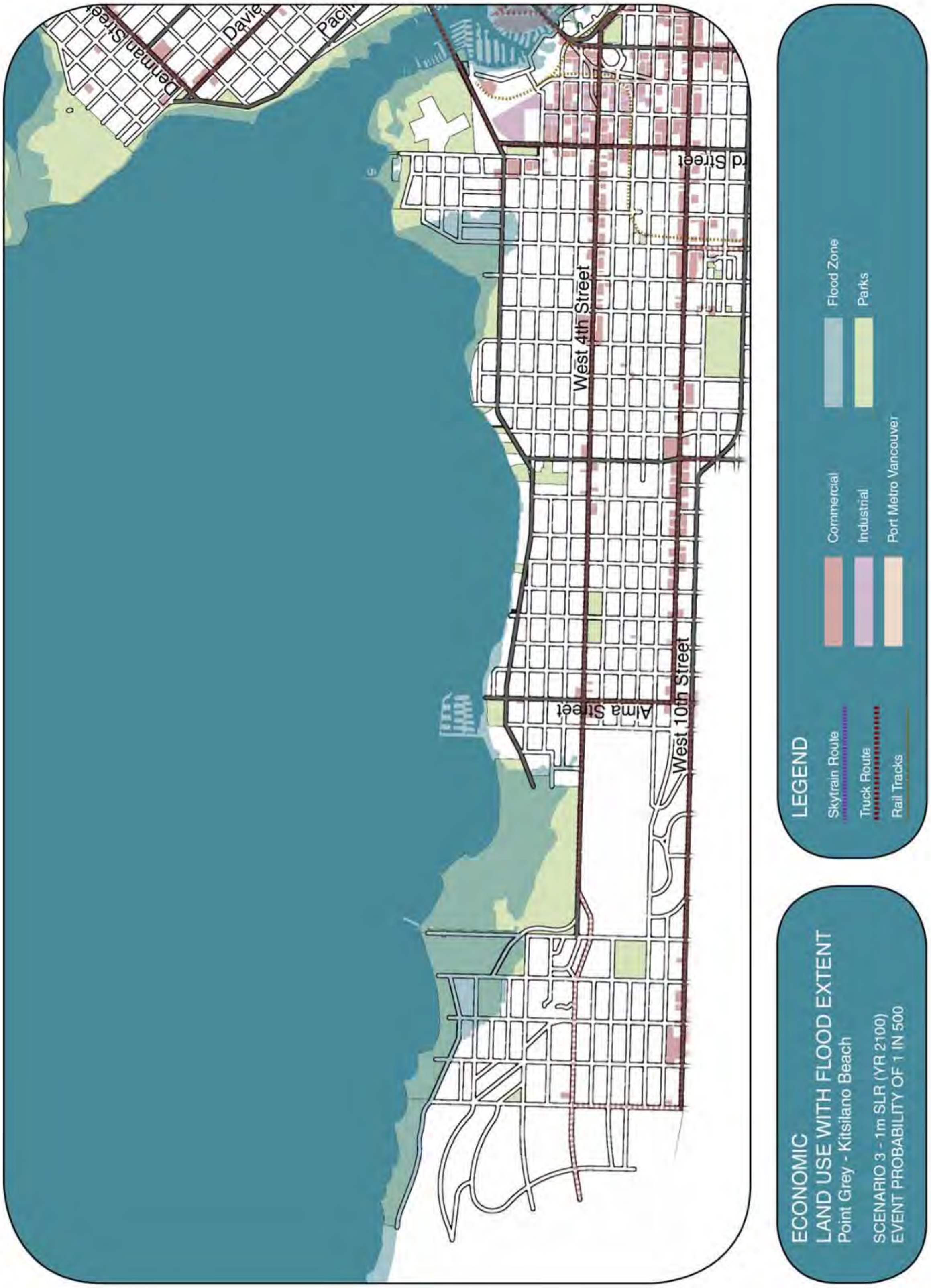


Figure 14 - Economic Land Use Map with Flood Extent (Point Grey - Kitsilano)

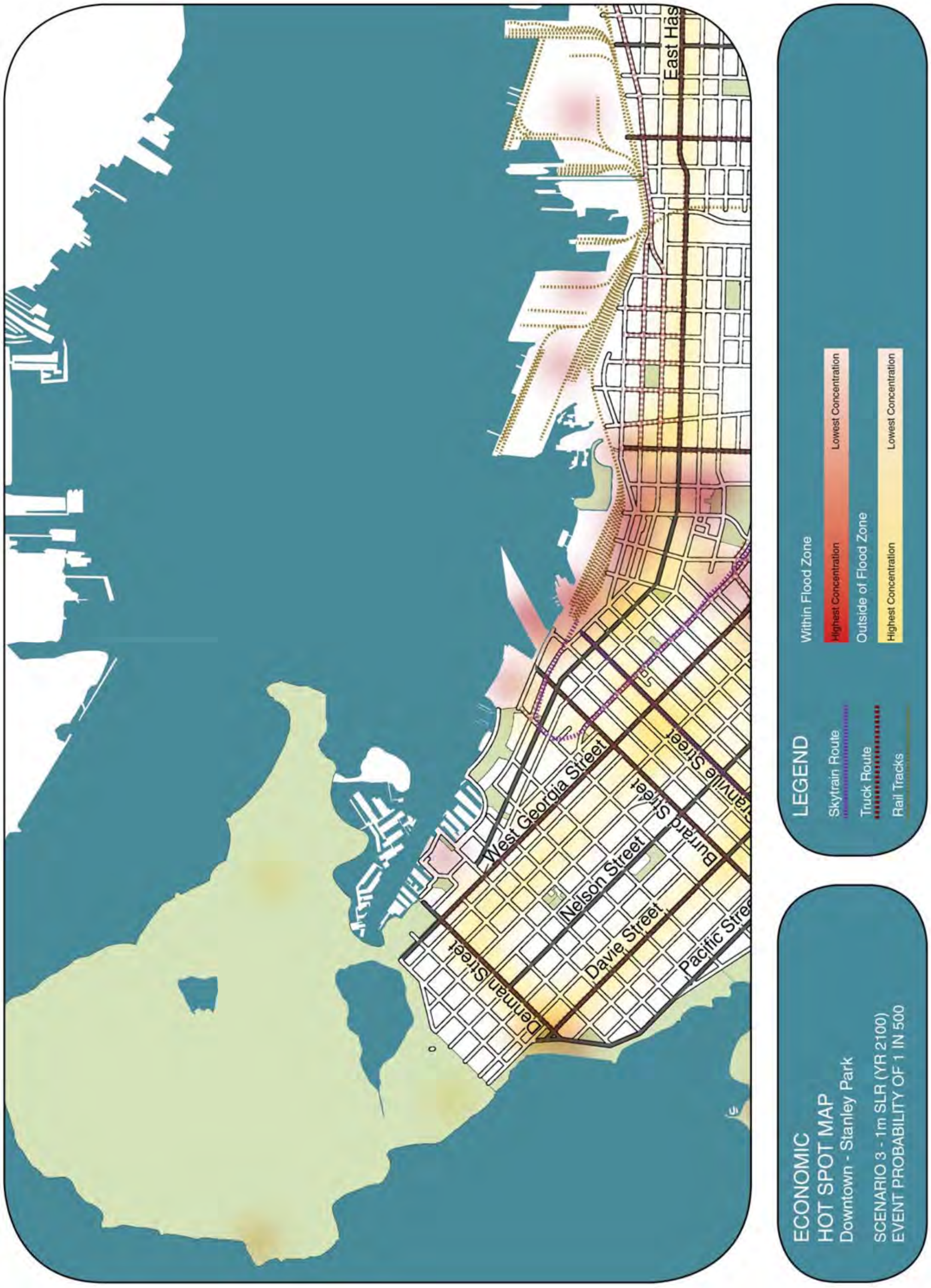


Figure 15 - Economic Hot Spot Map (Downtown - Stanley Park)

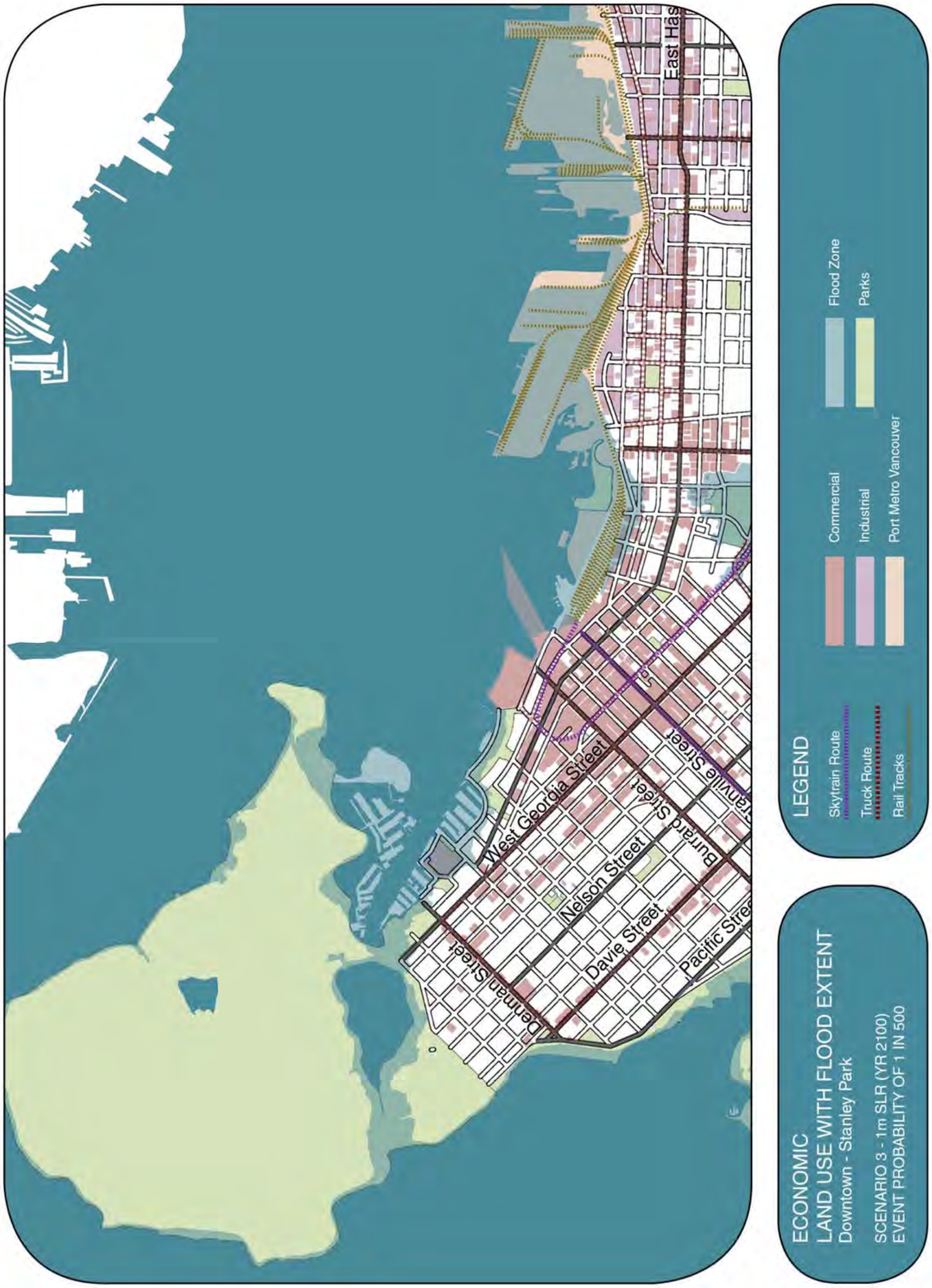


Figure 16 - Economic Land Use Map with Flood Extent (Downtown - Stanley Park)

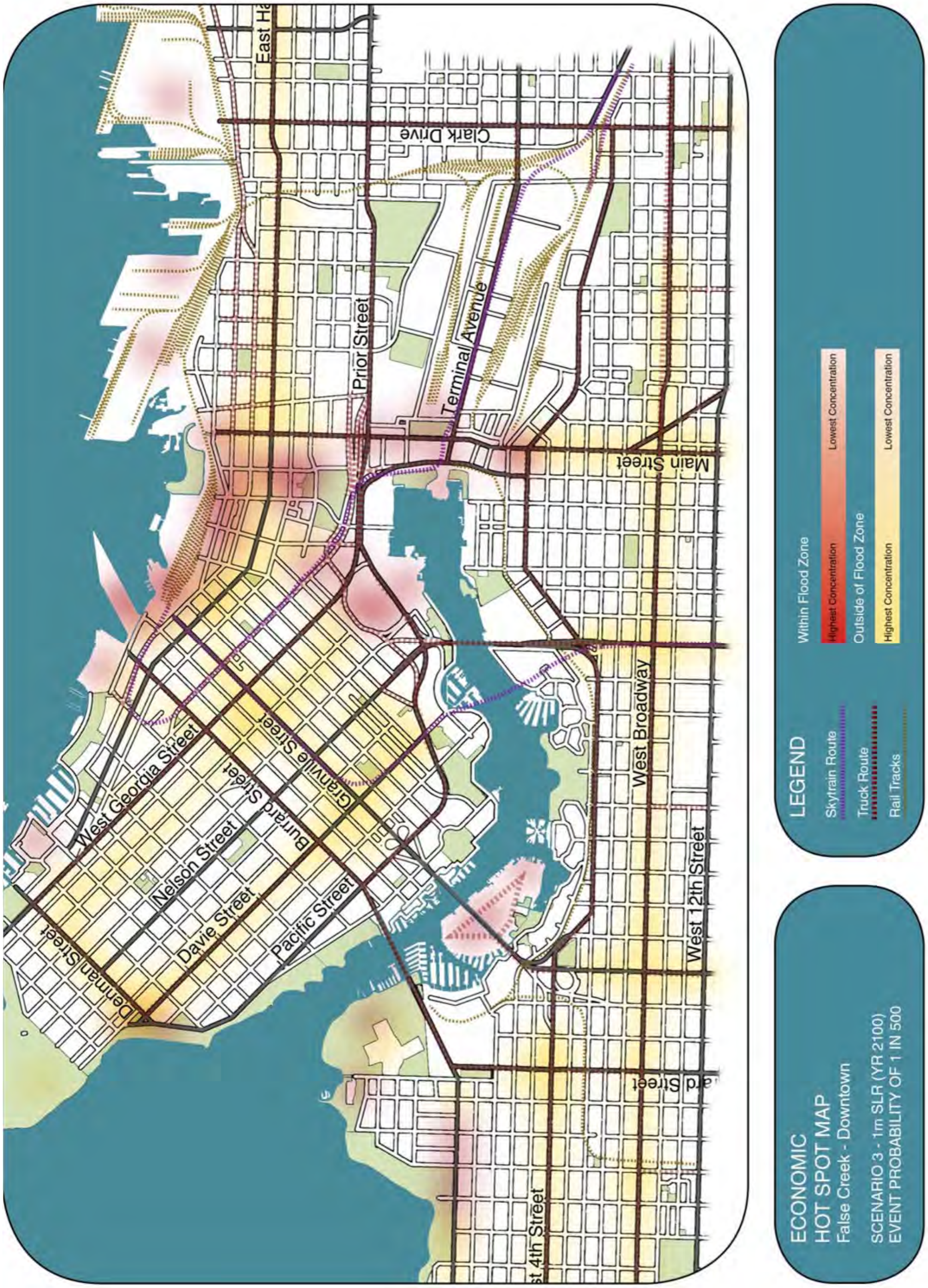


Figure 17 - Economic Hot Spot Map (False Creek - Downtown)

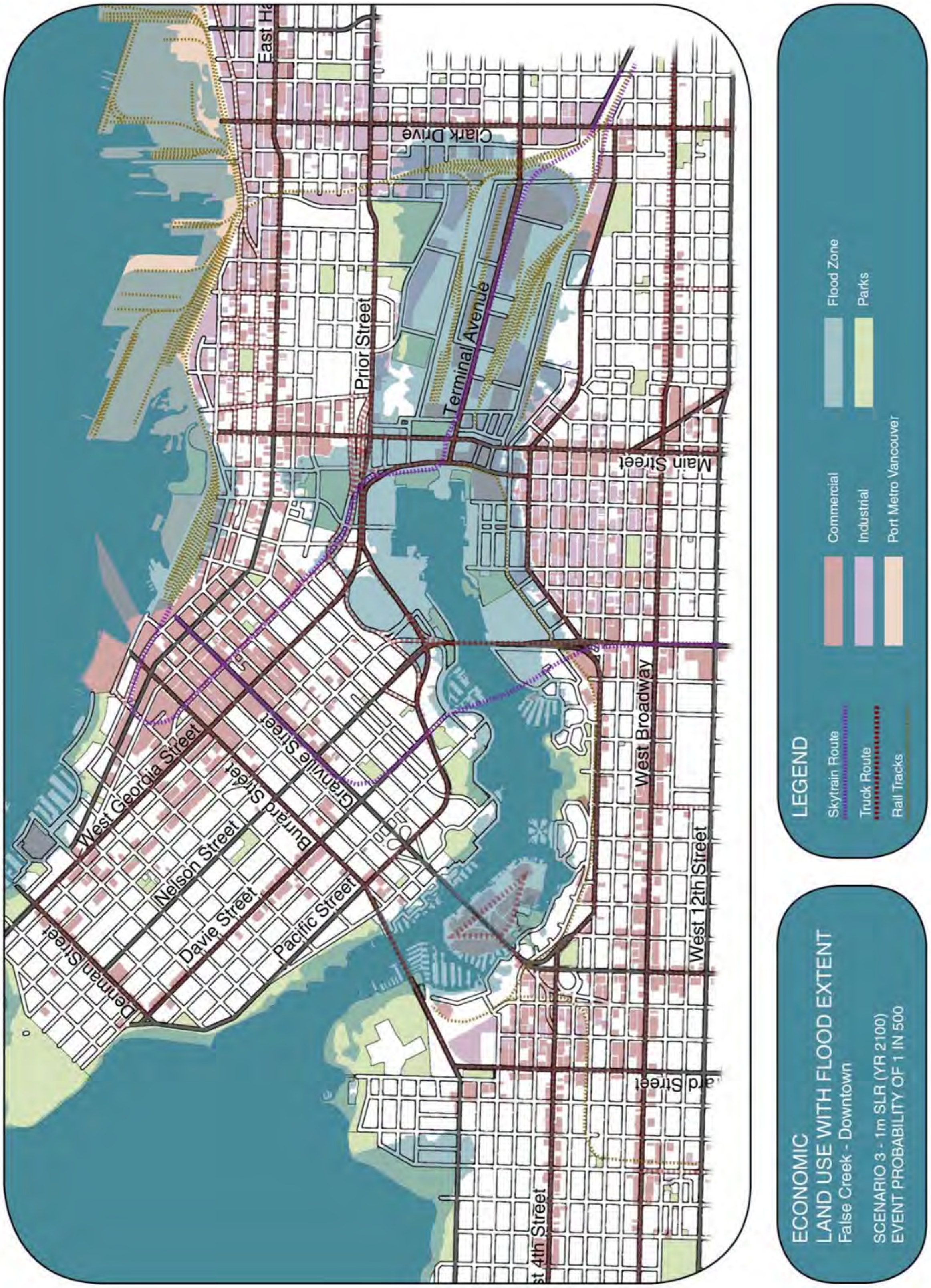


Figure 18 - Economic Land Use Map with Flood Extent (False Creek – Downtown)

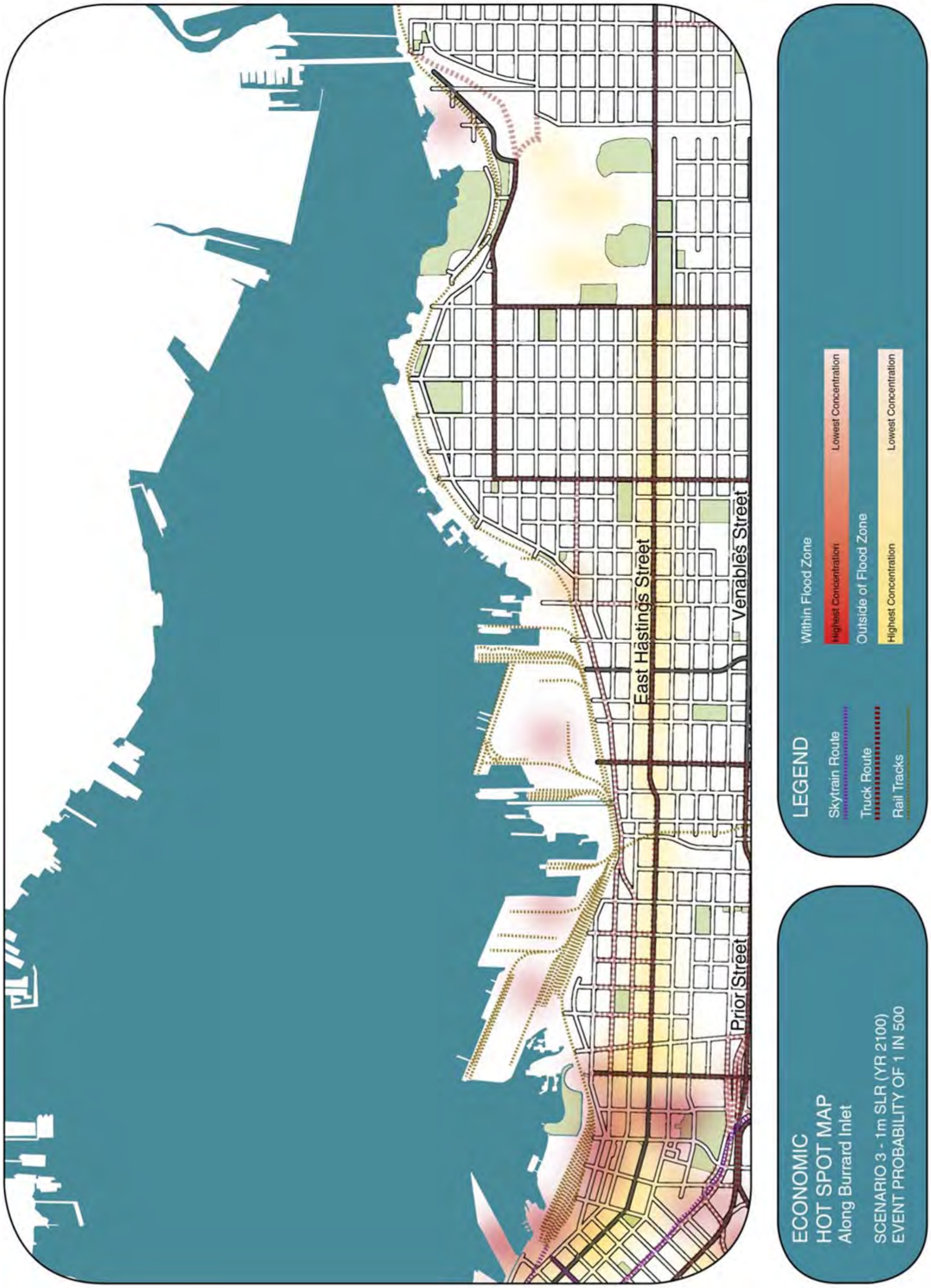


Figure 19 - Economic Hot Spot Map (Along Burrard Inlet)

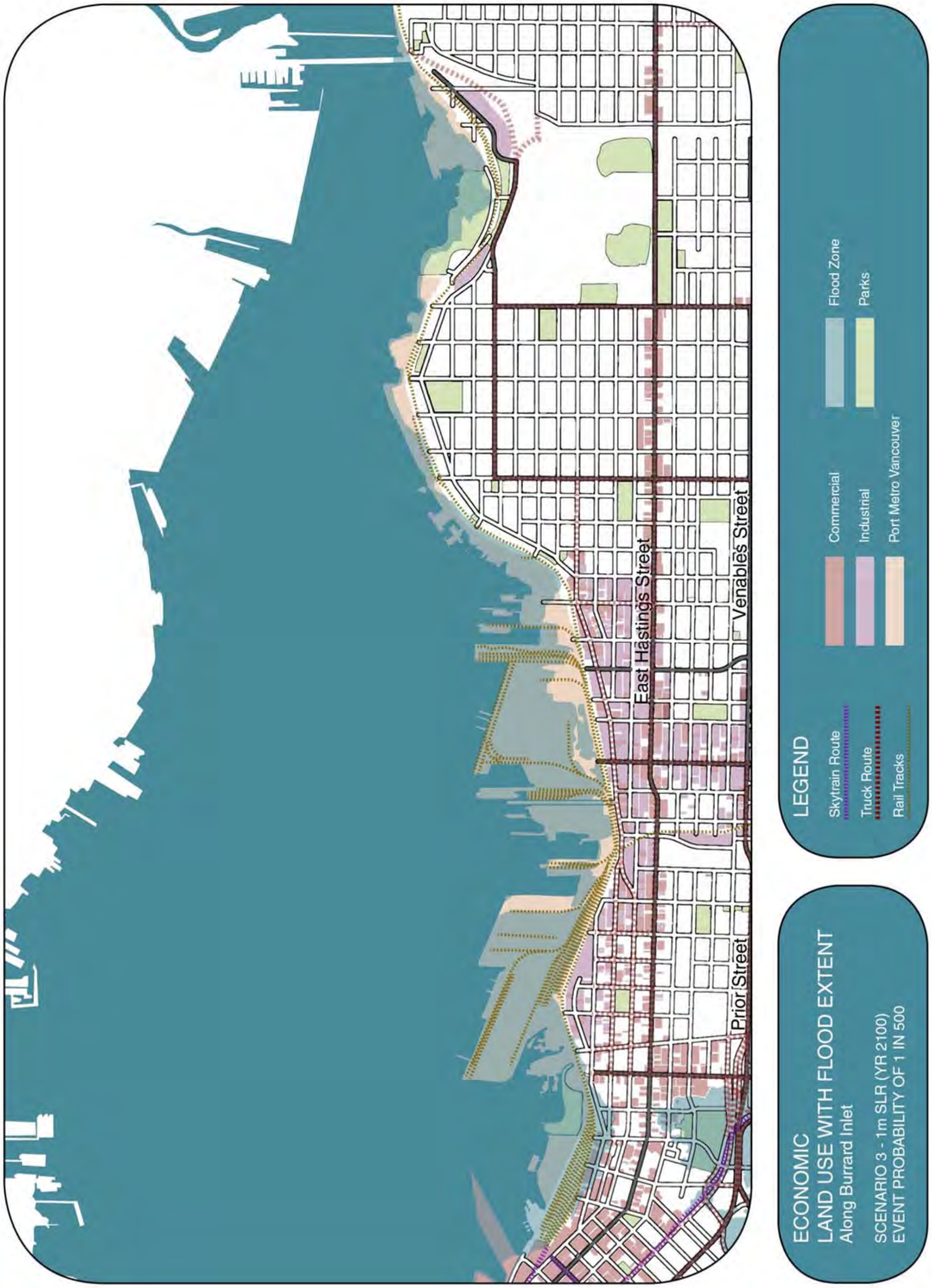


Figure 20 - Economic Land Use with Flood Extent (Along Burrard Inlet)

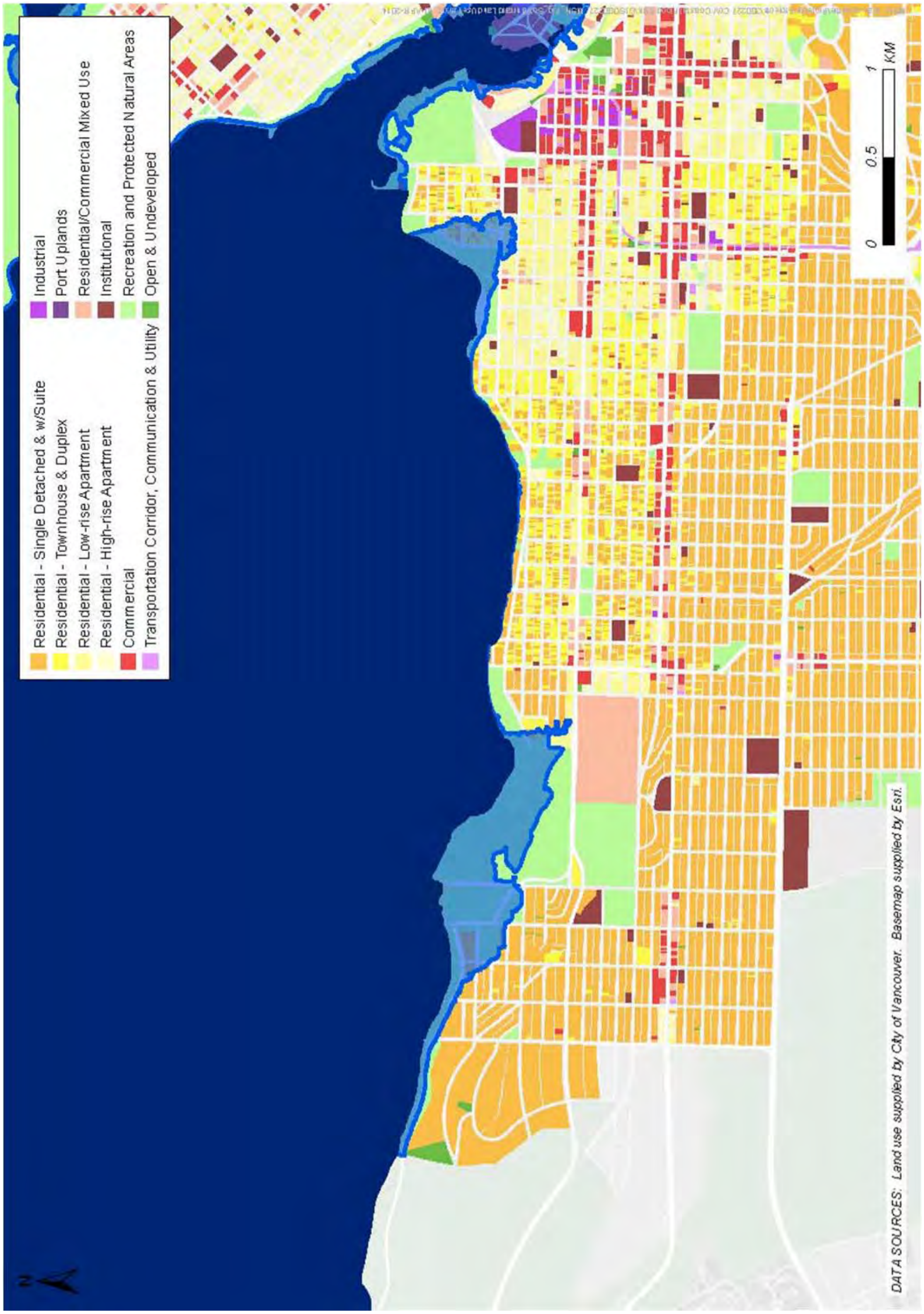
Table 15 - List of categories, sources and items in the Economic Hot Spot Maps

Category	Source	Additional Mapped Items	Items in Flood Zone
Truck Routes Train Tracks SkyTrain Routes (on Base Map)	VanMap		
SkyTrain Stations Truck Stations key Terminals	Google	Pacific Central Station Seabus Terminal West Coast Express Terminal	Pacific Central Station Seabus Terminal West Coast Express Terminal
Key Port Metro Vancouver Locations	Workshop Google	1 dot on each major 'pier' and building on PMV Lands	All PMV land
Industrial Uses	Workshop	Produce distribution (4 bldgs), City Works Yard, Fire Training, Fuel Station, Parks Works Yard, VSB Works Yard, Brewery, Waste/Recycling Tow Yard, Police Training, Roger's Sugar, Alliance Grain Terminals, Viterra Grain Terminal	Produce distribution (4 bldgs), City Works Yard, Fire Training, Fuel Station, Parks Works, VSB Works, Brewery, Waste/Recycling Tow Yard, Police Training, Roger's Sugar, Alliance Grain Terminals, Viterra Grain Terminal
Gas Stations	Google	Stanley Park Chevron, Davie St Esso, False Creek Fuels (water), Burrard PetroCanada, Burrard Esso, Burrard Chevron, W 4th PetroCanada, W Broadway Shell, W Broadway Esso, W Broadway Esso @ Hemlock, Macdonald Chevron, Macdonald Petro Canada, Alma Chevron, W 10th Shell, E 2nd Shell @ Main, E 12th Super Save Gas, Victoria Drive Shell, Powell Street Mohawk, E Hastings Petro Canada,	False Creek Fuels (in water), E 2nd Shell @ Main, Powell Street Mohawk (not quite, but just on verge of being in flood zone),

Electric Vehicle Charging Stations	Open Data Catalogue	900 Denman St, 455 West 10th Ave, 480 Broughton St, 2083 Alma St, 1040 W Pender St, 999 Canada Place Way, 701 W Georgia St, 845 Avison Way, 555 Seymour St, Beach @ Cardero, Beach @ Broughton, Beach @ Bute, 1055 Eveleigh St, 1100 Granville St, 911 Mainland St, 775 Hamilton St, 890 W 12th Ave, 1580 W Broadway, Main Street Chevron,	999 Canada Place Way 480 Broughton St, Very near the Flood Line: Beach @ Cardero, Beach @ Broughton, Beach @ Bute,
Helicopter Pad	Google	East of SeaBus Terminal	Helicopter pad is in flood zone
SkyTrain Stations	VanMap	Waterfront Station, Chinatown Station, Science World Station	Waterfront Station, Chinatown Station, Science World Station
Key Tourism Locations	Workshop Google	Vancouver Maritime Museum, Museum of Vancouver, HR MacMillan Space Centre, Science World, BC Sports Hall of Fame, Vancouver Police Museum, Chinese Cultural Centre of Greater Vancouver, Vancouver Art Gallery, Bard on the Beach, Aquarium, Granville Island, BC Place, Canada Place old, Canada Place new, English Bay Laughing Corner, Gastown Clock, Blood Alley	Chinese Cultural Centre, Science World, BC Sports Hall of Fame, Vancouver Maritime Museum, Bard on the Beach Granville Island, BC Place, Canada Place old, Canada Place new, Gastown Clock, Blood Alley Near Flood Zone: Museum of Vancouver HR MacMillan Space Centre

Commercial zones Business Improvement Associations*	VanMap		Water Street & Gastown
Major Restaurants	Google	Teahouse Stanley Park, Fish House, Cactus Club English Bay, Bridges Granville Island, Brock House	Cactus Club English Bay, Bridges Granville Island, Brock House Near Flood Zone: Teahouse Stanley Park
Major Hotels	Google	Westin Bayshore, Marriott Pinnacle, Hyatt Regency, Pan Pacific, Granville Island Hotel, Sandman, Fairmont Waterfront, Fairmont Pacific Rim, Ramada Limited Downtown, Delta Vancouver, Georgia Hotel, Sylvia Hotel, English Bay hotel, Best Western plus Sands, Quality Hotel Downtown, Best Western Plus Downtown, Holiday Inn & Suites	Westin Bayshore, Pan Pacific, Granville Island Hotel, Sandman, Near Flood Zone: Fairmont Waterfront Silvia Hotel
Hospitals and Care Facilities	VanMap layer layers 'Hospital' and 'Licenced and Registered Care Facilities'		2 locations in SE False Creek, 3 near Terminal, and 1 in kits are in or near the flood zone.

Appendix D – Land Use Map Details



DATA SOURCES: Land use supplied by City of Vancouver. Basemap supplied by Esri.

Figure 21 - City of Vancouver Land Use Map with Scenario 3 Flood Extent (Point Grey to Kitsilano)

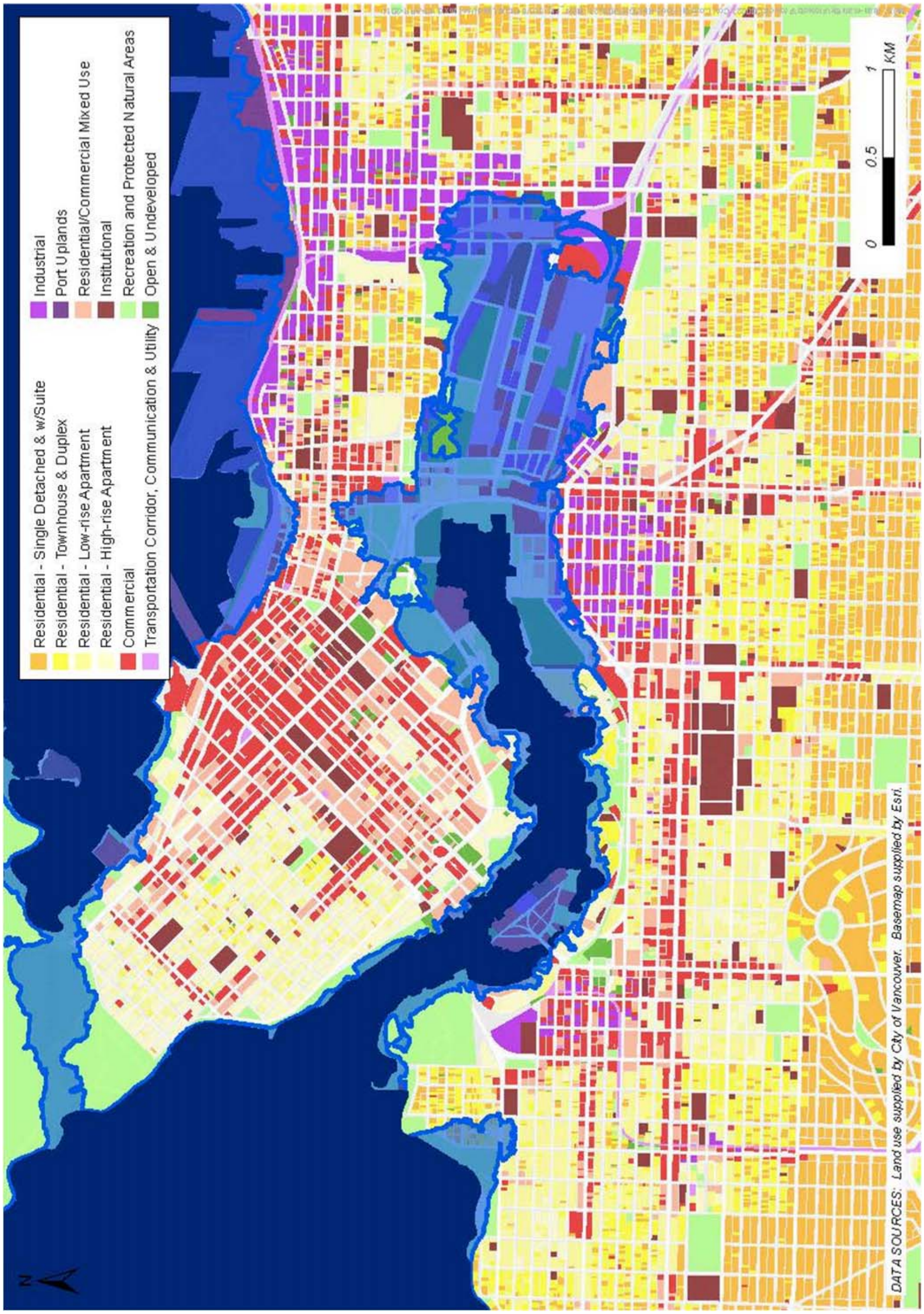
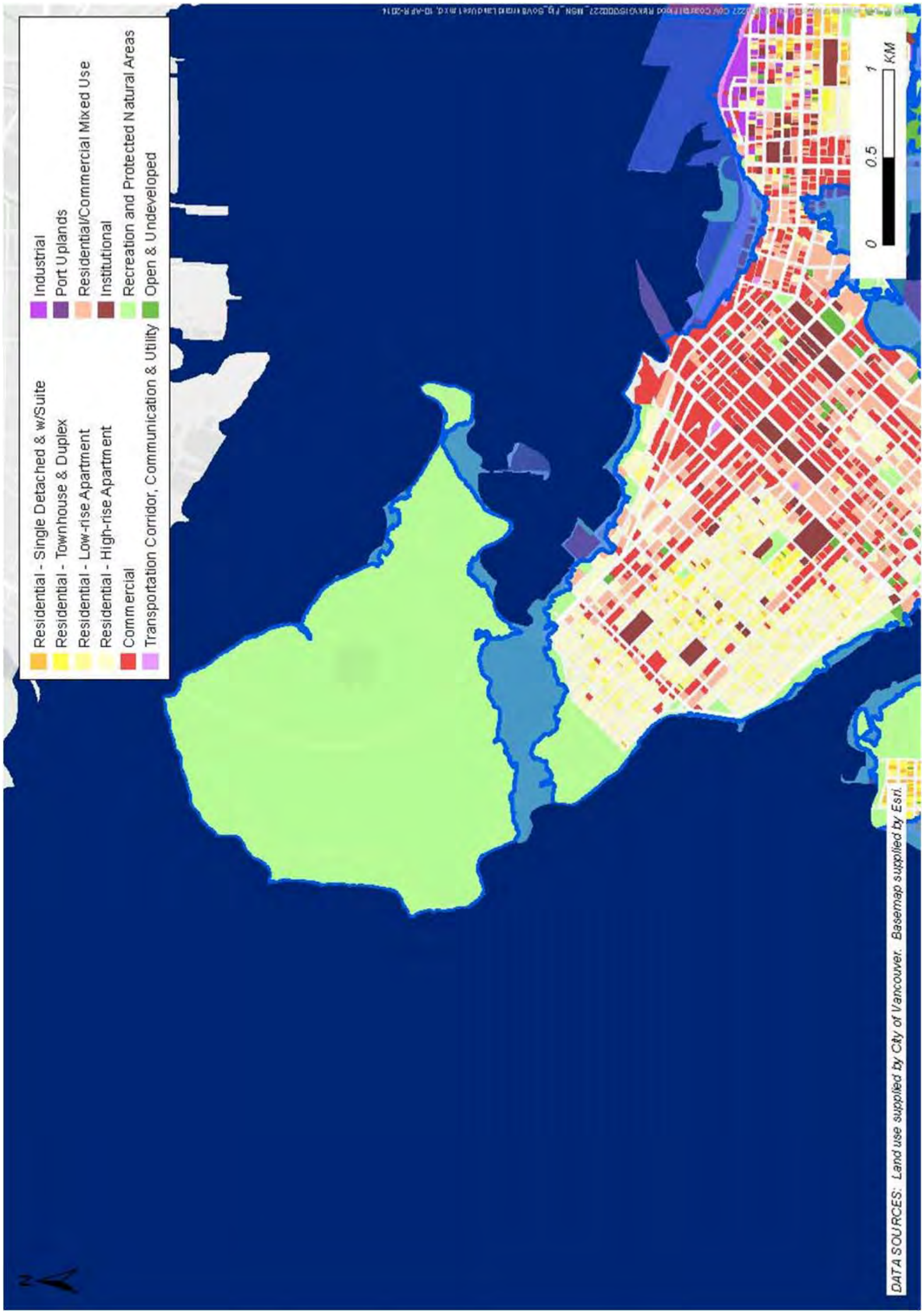


Figure 22 - City of Vancouver Land Use Map with Scenario 3 Flood Extent (False Creek - Downtown)



DATA SOURCES: Land use supplied by City of Vancouver. Basemap supplied by Esri.

Figure 23 - City of Vancouver Land Use Map with Scenario 3 Flood Extent (Downtown - Stanley Park)

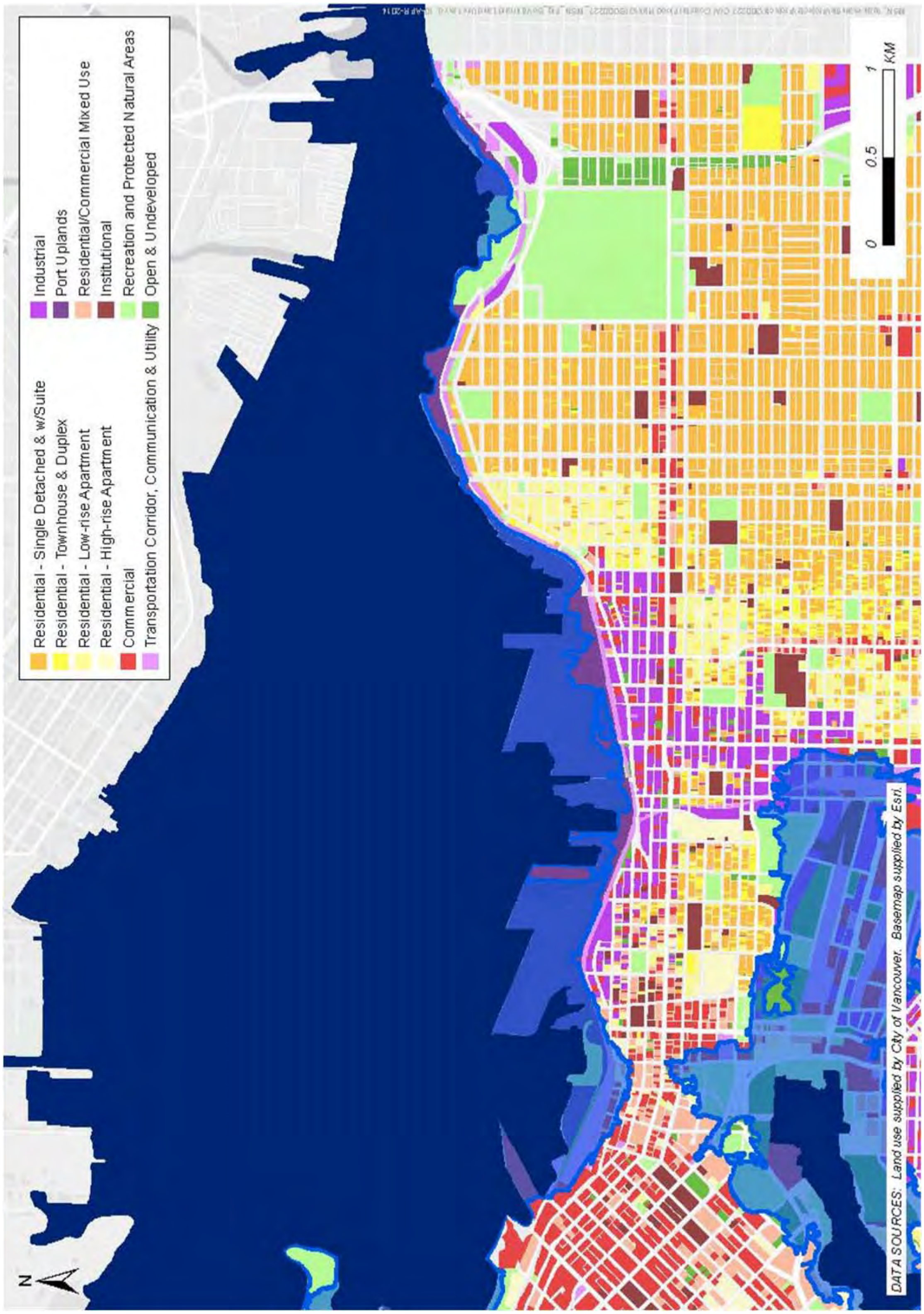


Figure 24 - City of Vancouver Land Use Map with Scenario 3 Flood Extent (Along Burrard Inlet)

Table 16 - Summary of Land Use Area (m^2) within Flood Extent, by Flood Scenario

	Area (m^2)				
	Without Freeboard				
LAND CLASS	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Commercial	22,811	46,618	127,624	152,455	311,880
Industrial	2,311	26,719	69,860	80,608	430,046
Institutional	5,371	26,519	46,632	48,960	69,474
Open and Undeveloped	11,822	17,565	58,037	93,819	348,288
Port Uplands	109,778	149,924	237,142	449,983	1,142,917
Recreation and Protected Natural Areas	364,953	907,905	1,162,824	1,263,182	1,771,296
Residential - Commercial/Mixed	3,815	12,806	27,706	34,723	123,585
Residential - High-rise Apartment	238	3,997	12,685	23,112	75,561
Residential - Low-rise Apartment	450	8,032	25,684	32,507	72,967
Residential - Single Detached & Duplex	16,815	29,096	35,206	39,149	60,010
Residential - Townhouse	868	2,228	6,749	8,852	24,375
Total Residential	22,186	56,158	108,030	138,343	356,498
Transportation Corridor, Communication & Utility	13,205	82,767	158,591	171,026	771,875
	Area (m^2)				
	With Freeboard				
LAND CLASS	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Commercial	99,636	217,681	285,247	298,512	381,043
Industrial	41,808	234,547	373,647	395,802	584,348
Institutional	34,260	50,087	55,349	60,992	77,874
Open and Undeveloped	19,446	192,095	295,262	342,025	365,138
Port Uplands	162,881	542,211	1,018,113	1,103,475	1,210,637
Recreation and Protected Natural Areas	960,253	1,443,455	1,621,441	1,707,641	2,005,091
Residential - Commercial/Mixed	13,202	52,109	80,596	100,895	182,123
Residential - High-rise Apartment	3,554	36,914	67,446	74,830	127,188
Residential - Low-rise Apartment	8,140	34,192	53,742	60,404	106,361

Residential - Single Detached & Duplex	29,020	38,620	44,597	50,586	71,728
Residential - Townhouse	1,958	10,007	16,446	19,033	42,060
Total Residential	55,874	171,843	262,827	305,747	529,460
Transportation Corridor, Communication & Utility	97,449	565,385	710,038	731,541	867,971
From GIS Burrard Inlet Modelling Zones 1, 2, 3 and 4					

Table 17 - Summary of Land Use Area (%) within Flood Extents, by Flood Scenario

	Area (%)				
	Without Freeboard				
LAND CLASS	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Commercial	0.0196%	0.0400%	0.1096%	0.1310%	0.2679%
Industrial	0.0020%	0.0230%	0.0600%	0.0692%	0.3694%
Institutional	0.0046%	0.0228%	0.0401%	0.0421%	0.0597%
Open and Undeveloped	0.0102%	0.0151%	0.0499%	0.0806%	0.2992%
Port Uplands	0.0943%	0.1288%	0.2037%	0.3865%	0.9818%
Recreation and Protected Natural Areas	0.3135%	0.7799%	0.9989%	1.0851%	1.5216%
Residential - Commercial/Mixed	0.0033%	0.0110%	0.0238%	0.0298%	0.1062%
Residential - High-rise Apartment	0.0002%	0.0034%	0.0109%	0.0199%	0.0649%
Residential - Low-rise Apartment	0.0004%	0.0069%	0.0221%	0.0279%	0.0627%
Residential - Single Detached & Duplex	0.0144%	0.0250%	0.0302%	0.0336%	0.0515%
Residential - Townhouse	0.0007%	0.0019%	0.0058%	0.0076%	0.0209%
Total Residential	0.0191%	0.0482%	0.0928%	0.1188%	0.3062%
Transportation Corridor, Communication & Utility	0.0113%	0.0711%	0.1362%	0.1469%	0.6631%
Total	0.4746%	1.1289%	1.6912%	2.0603%	4.4689%
	Area (%)				
	With Freeboard				
LAND CLASS	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Commercial	0.0856%	0.1870%	0.2450%	0.2564%	0.3273%
Industrial	0.0359%	0.2015%	0.3210%	0.3400%	0.5020%
Institutional	0.0294%	0.0430%	0.0475%	0.0524%	0.0669%
Open and Undeveloped	0.0167%	0.1650%	0.2536%	0.2938%	0.3137%

Port Uplands	0.1399%	0.4658%	0.8746%	0.9479%	1.0400%
Recreation and Protected Natural Areas	0.8249%	1.2400%	1.3929%	1.4669%	1.7224%
Residential - Commercial/Mixed	0.0113%	0.0448%	0.0692%	0.0867%	0.1564%
Residential - High-rise Apartment	0.0031%	0.0317%	0.0579%	0.0643%	0.1093%
Residential - Low-rise Apartment	0.0070%	0.0294%	0.0462%	0.0519%	0.0914%
Residential - Single Detached & Duplex	0.0249%	0.0332%	0.0383%	0.0435%	0.0616%
Residential - Townhouse	0.0017%	0.0086%	0.0141%	0.0164%	0.0361%
Total Residential	0.0480%	0.1476%	0.2258%	0.2626%	0.4548%
Transportation Corridor, Communication & Utility	0.0837%	0.4857%	0.6099%	0.6284%	0.7456%
Total	1.2641%	2.9355%	3.9703%	4.2485%	5.1726%
From GIS Burrard Inlet Modelling Zones 1, 2, 3 and 4 Percentages are calculated on the assumption that the Total City of Vancouver above water area is 116,411,709 m^2 (11,641.17 hectares)					

Appendix E – Land Use Classification by Flood Risk

Table 18 - Land Use Classification by Flood Risk

Essential Infrastructure	Essential transport infrastructure (including mass evacuation routes) crossing area at risk, and strategic utility infrastructure, including electricity generating power stations and grid and primary substations.
Highly Vulnerable	Police stations, ambulance stations, fire stations and command centers and telecommunications installations required to be operational during flooding. Emergency dispersal points. Basement dwellings. Caravans, mobile homes and park homes intended for permanent residential use. Installations requiring hazardous substances consent.
More Vulnerable	Hospitals. Residential institutions such as residential care homes, children's homes, social services homes, prisons and hostels. Buildings used for: dwelling houses; student halls of residence; drinking establishments; nightclubs and hotels. Non-residential uses for health services, nurseries and educational establishments. Landfill and sites used for waste management facilities for hazardous waste. Sites used for holiday or short-let caravans and camping, subject to a specific warning and evacuation plan.
Less Vulnerable	Buildings used for: shops; financial, professional and other services; restaurants and cafes; offices; general industry; storage and distribution; non-residential institutions not included in 'more vulnerable'; and assembly and leisure. Land and buildings used for agriculture and forestry. Waste treatment (except landfill and hazardous waste facilities) Minerals working and processing (except for sand and gravel working). Water treatment plants. Sewage treatment plants (if adequate pollution control measures are in place).
Water-Compatible Development	Flood control infrastructure. Water transmission infrastructure and pumping stations. Sewage transmission infrastructure and pumping stations. Sand and gravel workings. Docks, marinas and wharves. Navigation facilities. Defense installations. Ship building, repairing and dismantling, dockside fish processing and refrigeration, and compatible activities requiring a waterside location. Water-based recreation (excluding sleeping accommodation). Lifeguard and coastguard stations. Amenity open space, nature conservation and biodiversity, outdoor sports and recreation and essential facilities such as changing rooms. Essential ancillary sleeping or residential accommodation for staff required by uses in this category, subject to a specific warning and evacuation plan.

Source: Flood risk vulnerability classification, CLG 2006, pg. 320 of UN Document (Title)

Appendix F – Infrastructure and Utilities Hot Spot Map Details

The following pages demonstrate the data, hot spot and magnified hot spot maps for infrastructure and utilities.

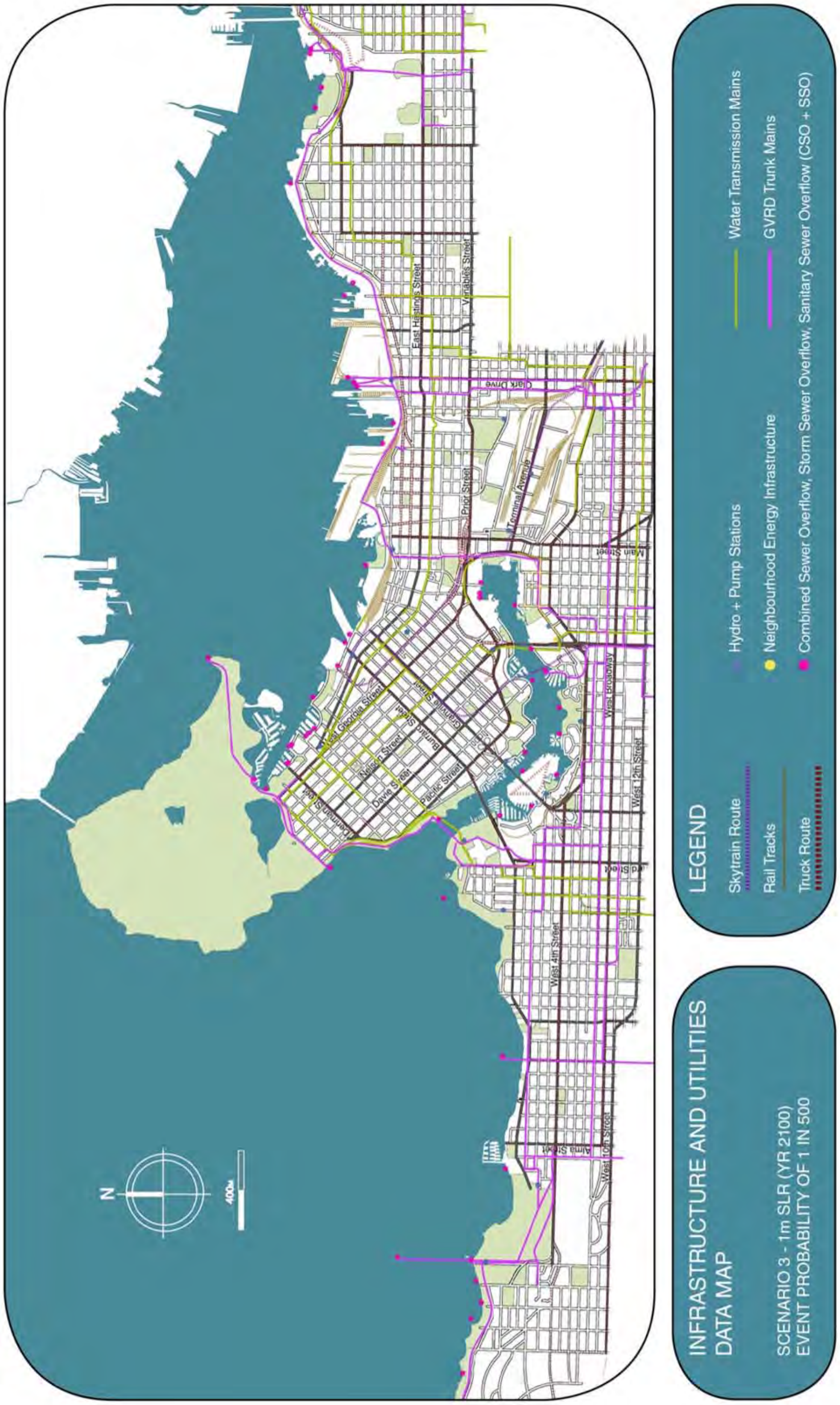


Figure 25 - Infrastructure and Utilities Data Map

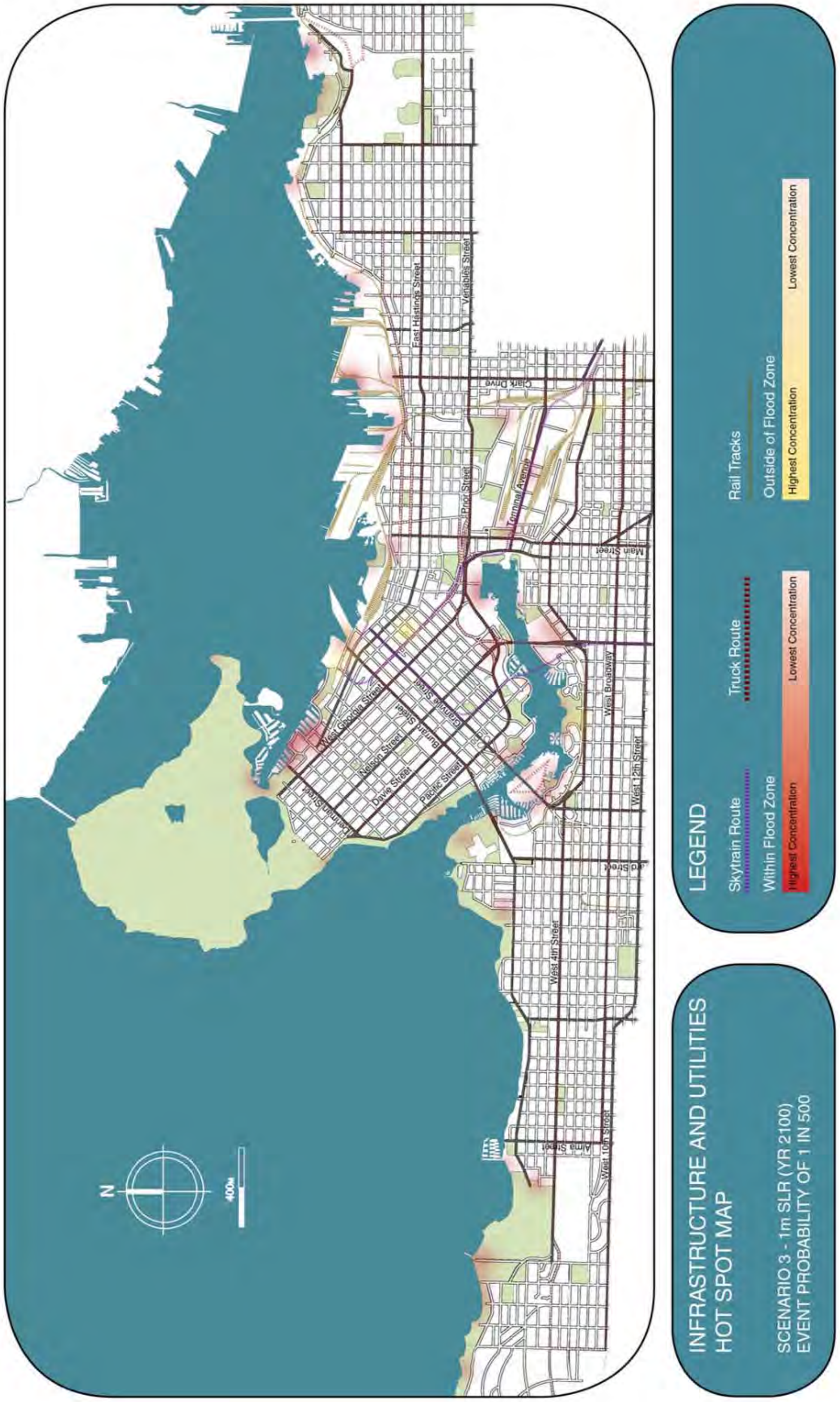


Figure 26 - Infrastructure and Utilities Hot Spot Map

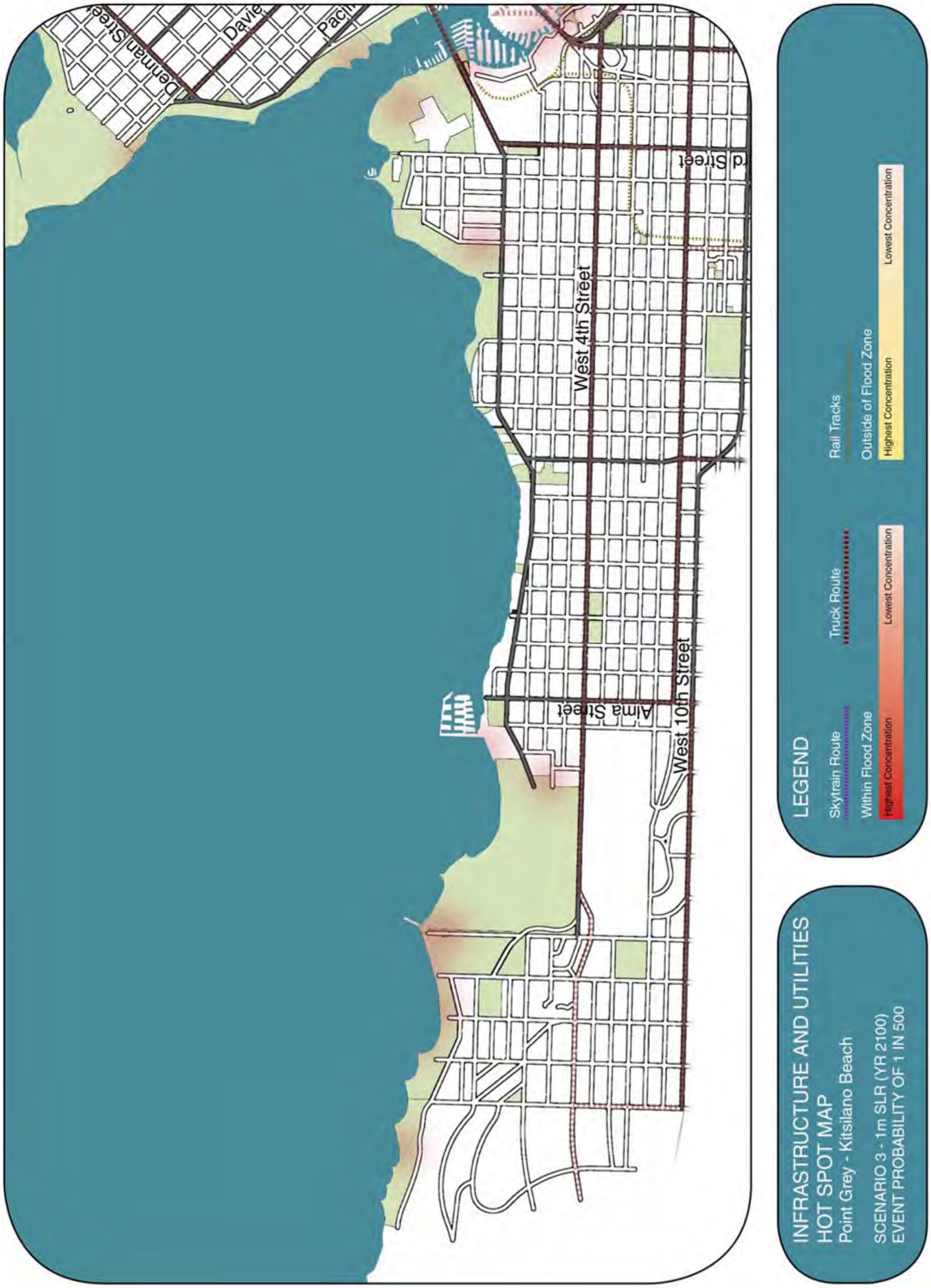


Figure 27 - Infrastructure and Utilities Hot Spot Map (Point Grey - Kitsilano)

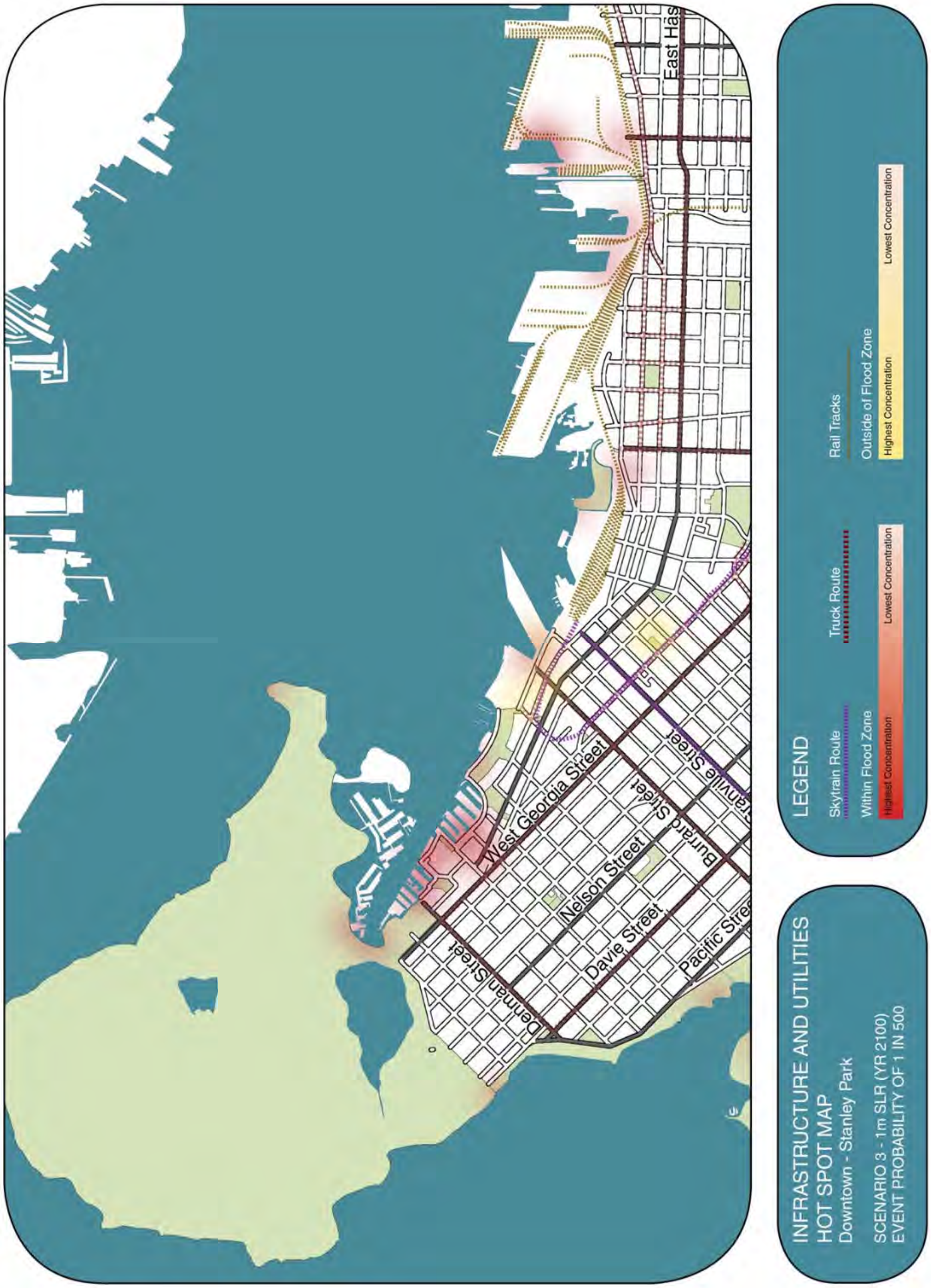


Figure 28 - Infrastructure and Utilities Hot Spot Map (Downtown - Stanley Park)

Figure 29 - Infrastructure and Utilities Hot Spot Map (False Creek - Downtown)

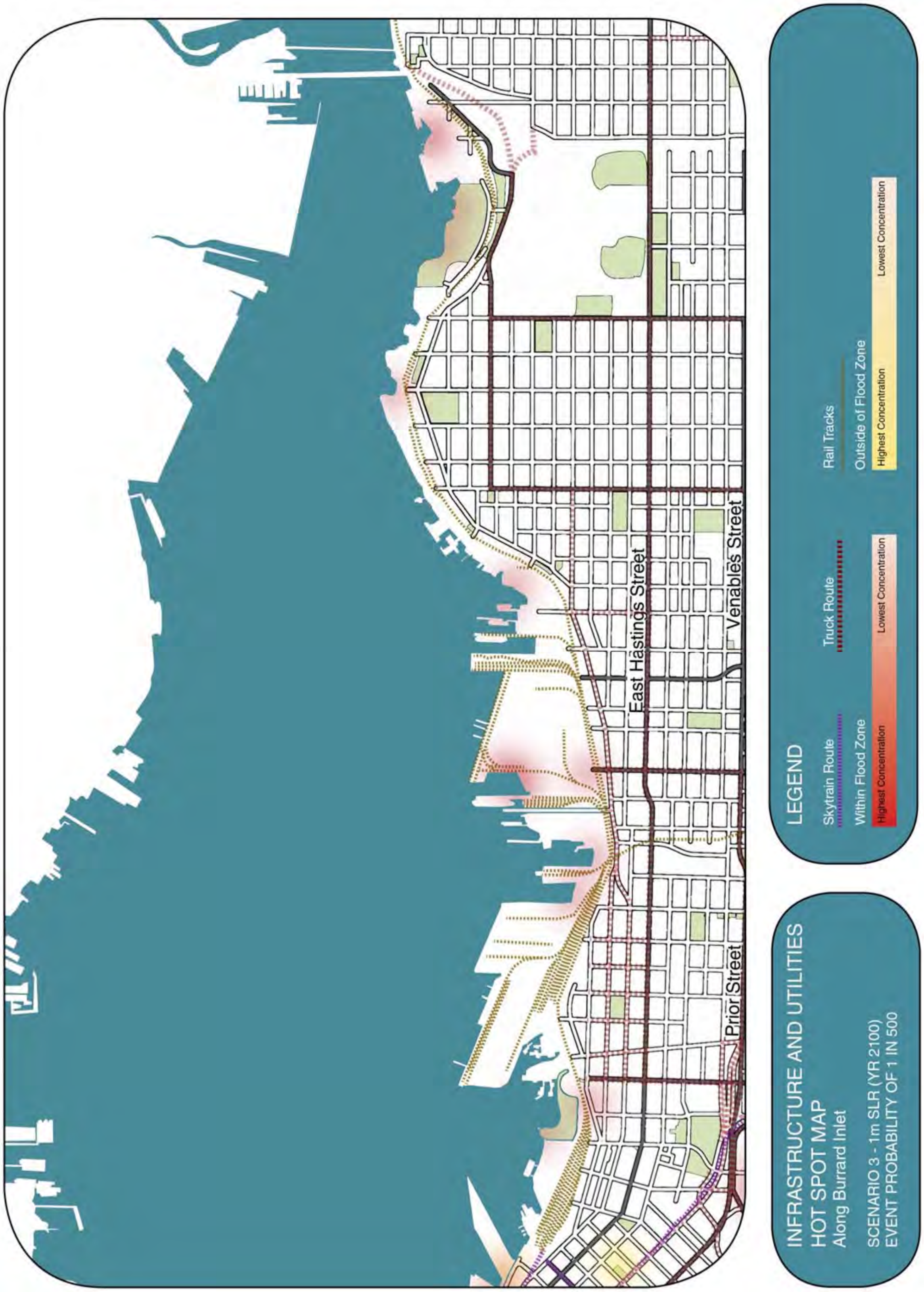


Figure 30 - Infrastructure and Utilities Hot Spot Map (Along Burrard Inlet)

Table 19- Summary of Authorized Discharges plotted on Hot Spot Maps

Name	Waste Type	Plant Type	Treatment
Ocean Construction Supplies Ltd	Storm	A ready-mix plant that discharges storm water.	Infiltration pond
Rogers Sugar Ltd.	Cooling, process	A sugar refinery (240,000 tonnes of sugar per year) that discharges effluent from cooling waters from non-contact steam turbine oil coolers and storm water to the Burrard Inlet.	Submerged outfall
Rogers Sugar Ltd.	Cooling, process	A sugar refinery (240,000 tonnes of sugar per year) that discharges effluent from cooling water condensates and condensates from liquid sugar operations and storm water to Burrard Inlet.	Submerged outfall
Rogers Sugar Ltd.	--	A sugar refinery (240,000) tonnes of sugar per year) that discharges effluent from condenser cooling water and condensates from direct contact barometric condensers associated with evaporators and vacuum pans combined with cooling water to Burrard inlet.	Submerged outfall
LaFarge Canada Inc.	Storm	A ready-mix concrete batch plant that discharges truck wash water, batch plant wash water and storm water.	Filtration bed, pH treatment system
Univar Canada Ltd.	Storm	A bulk chemical loading facility that discharges effluent	Neutralization
Neptune Bulk Terminals (Canada) Ltd.	Process, storm	A bulk loading and storage facility that discharges effluent from the coal loading and storage area.	Settlings ponds, flocculation
Canada Place Corporation	--	A hotel and convention centre that discharges effluent of cooling water.	Outfall
West Coast Reduction Ltd.	Storm, process	An animal and fish by-product reduction and rendering plant that discharges effluent storm water discharge from a grease interceptor and a sampling manhole.	Oil & grease interceptors

Table 20 - Combined Sewer Overflows plotted on Hot Spot Maps

Name	Owner	Location	Annual Overflow (m ^{3})
False Creek – Crowe St. East	CoV	CoV	92,300
False Creek – Heather St.	MV	CoV	3,652,000
English Bay – Balaclava St.	MV	CoV	2,456,000
English Bay – English Bay	MV	CoV	152,000
English Bay – Alma - Discovery	MV	CoV	-

Inner Harbour – Brockton Point	MV	CoV	129,000
Inner Harbour – Cassiar St. East	MV	CoV	9,328,000
Inner Harbour – Cassiar St. North	MV	CoV	-
Inner Harbour – Clark Drive 1	MV	CoV	3,148,000
Inner Harbour – Clark Drive 2	MV	CoV	-
Inner Harbour – Vernon Relief Outfall	MV	CoV	-
Inner Harbour – Harbour West	CoV	CoV	-
Inner Harbour – Slocan	CoV	CoV	566
Inner Harbour – Victoria Drive	CoV	CoV	1,020,000

Appendix G – Demographic Details

Table 21 - Neighbourhoods broken down by Census Tract

Neighbourhood	Census Tracts	Level of inundation
Hastings-Sunrise/Grandview-Woodlands*	9330053.01 9330055.02 9330056.01	Mainly coastal, along the border with PMV lands.
Strathcona		Some flooding in the DTES, but Chinatown and North and South False Creek Flats could be significantly inundated.
DTES	9330058.00	
Chinatown	9330057.01	
North False Creek Flats	9330057.02	
South False Creek Flats	9330050.03	
Downtown		Primarily restricted to shoreline flooding, with the exception of the lagoon between the Downtown core and Stanley Park.
Gastown	9330059.06	
Coal Harbour	9330059.11 9330066.00 9330067.02	
Stanley Park	9330068.00	
West End	9330062.00 9330061.00 9330060.01 9330060.02	
Yaletown	9330059.07 9330059.08	
Fairview		Each tract sees considerable flooding, including Granville Island and the residential buildings along the south side of False Creek.
Fairview/Mount Pleasant	9330049.01	
Tract with Granville Island	9330049.02	
Fairview/Kitsilano	9330048.00	
Kitsilano	9330047.02 9330047.01 9330045.01	Primarily limited to beach flooding, with the exception of the Kitsilano Beach corner.
West Point Grey	9330044.00	Flooding largely offset by topographic change, with the exception of flooding in Jericho Beach Park.

* Census Tract 9330053.02 (Hastings Sunrise, along Boundary Road and Burrard Inlet) was kept out of the Demographic analysis, as while it was within the CFRA study area, the entire residential component of the Census Tract is not vulnerable to coastal storm events.

Appendix H – Community Hot Spot Map Details

The following pages demonstrate the data, hot spot and magnified hot spot maps for Community.

Figure 31 - Community Data Map

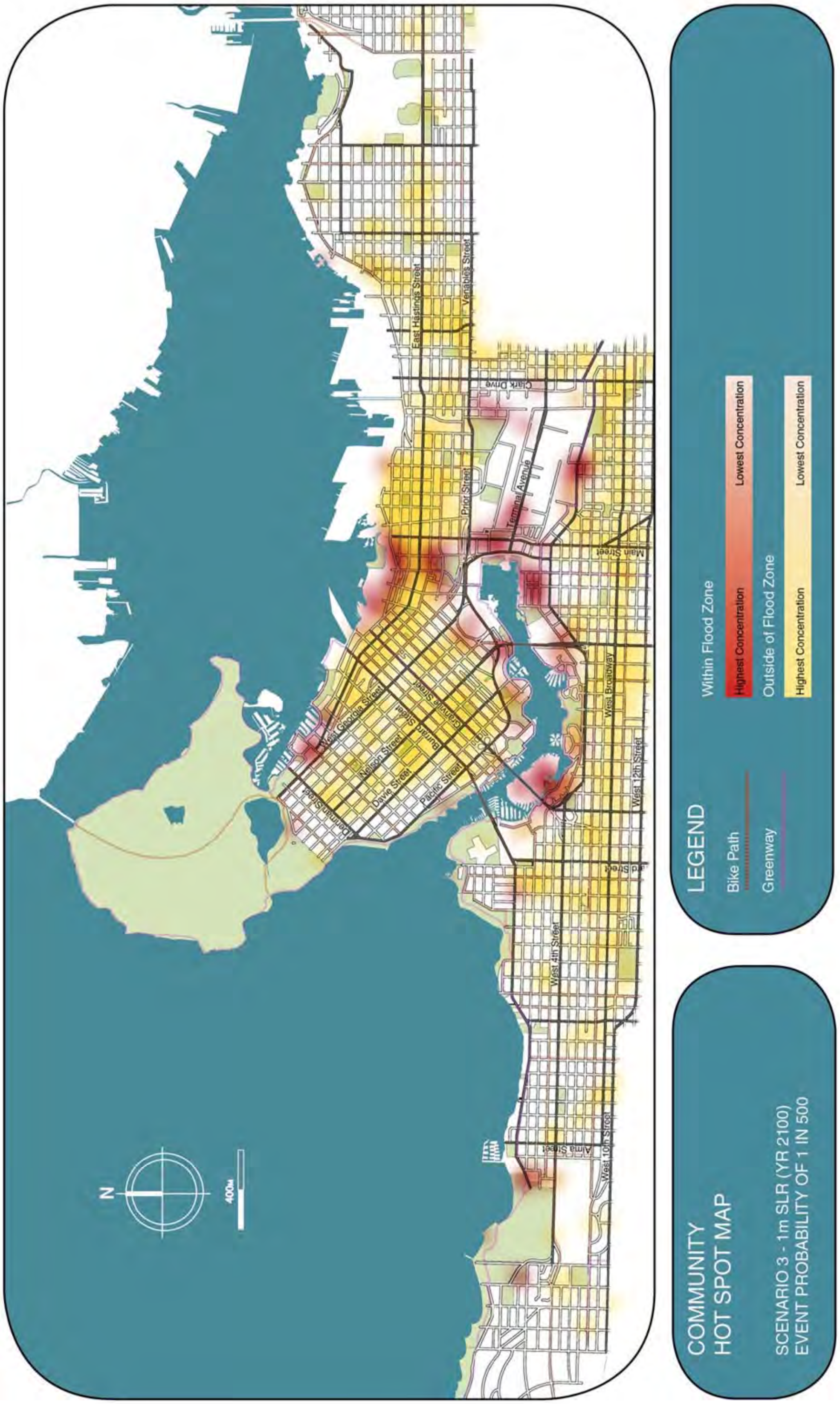


Figure 32 - Community Hot Spot Map

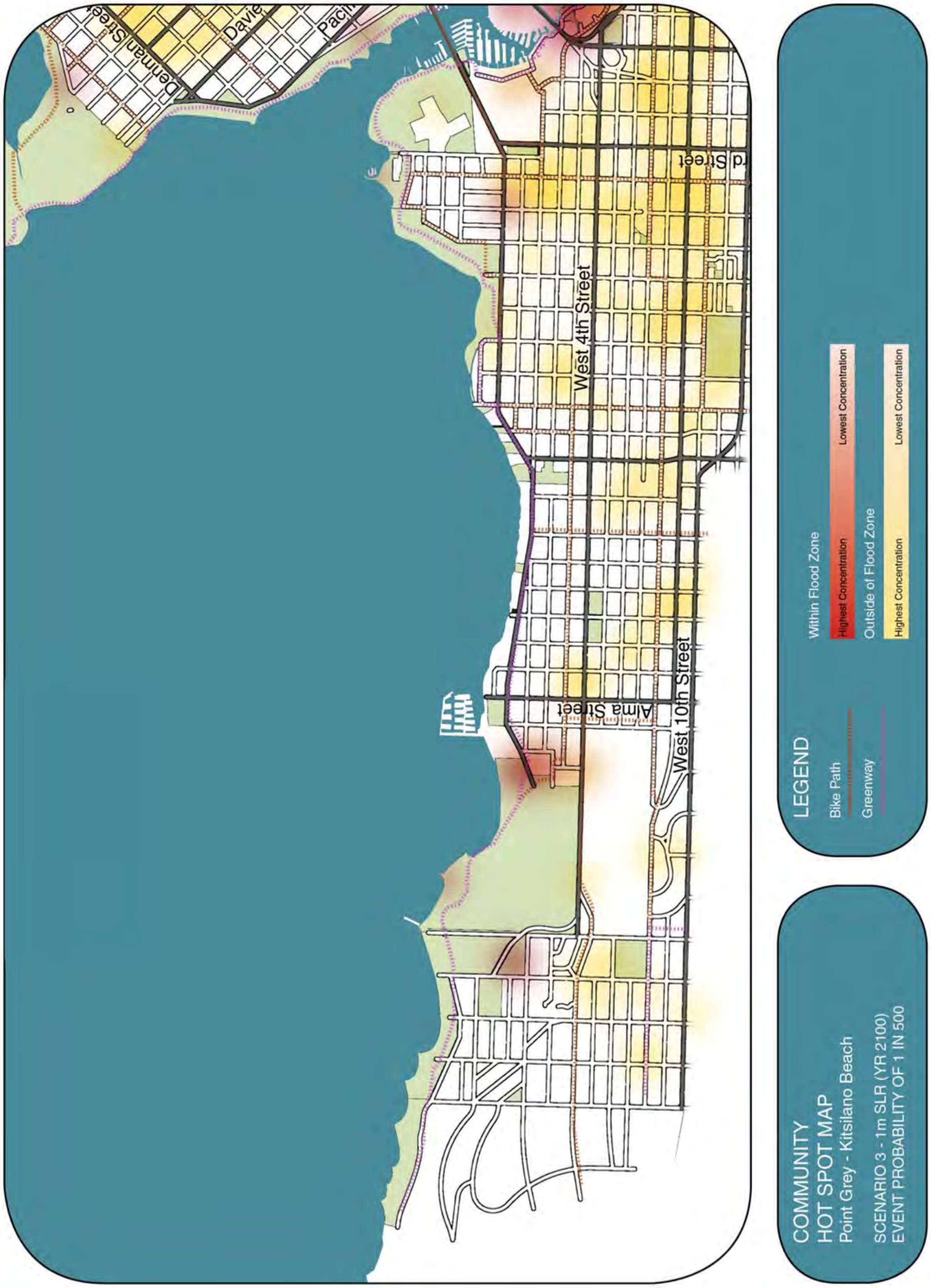


Figure 33 - Community Hot Spot Map (Point Grey - Kitsilano)

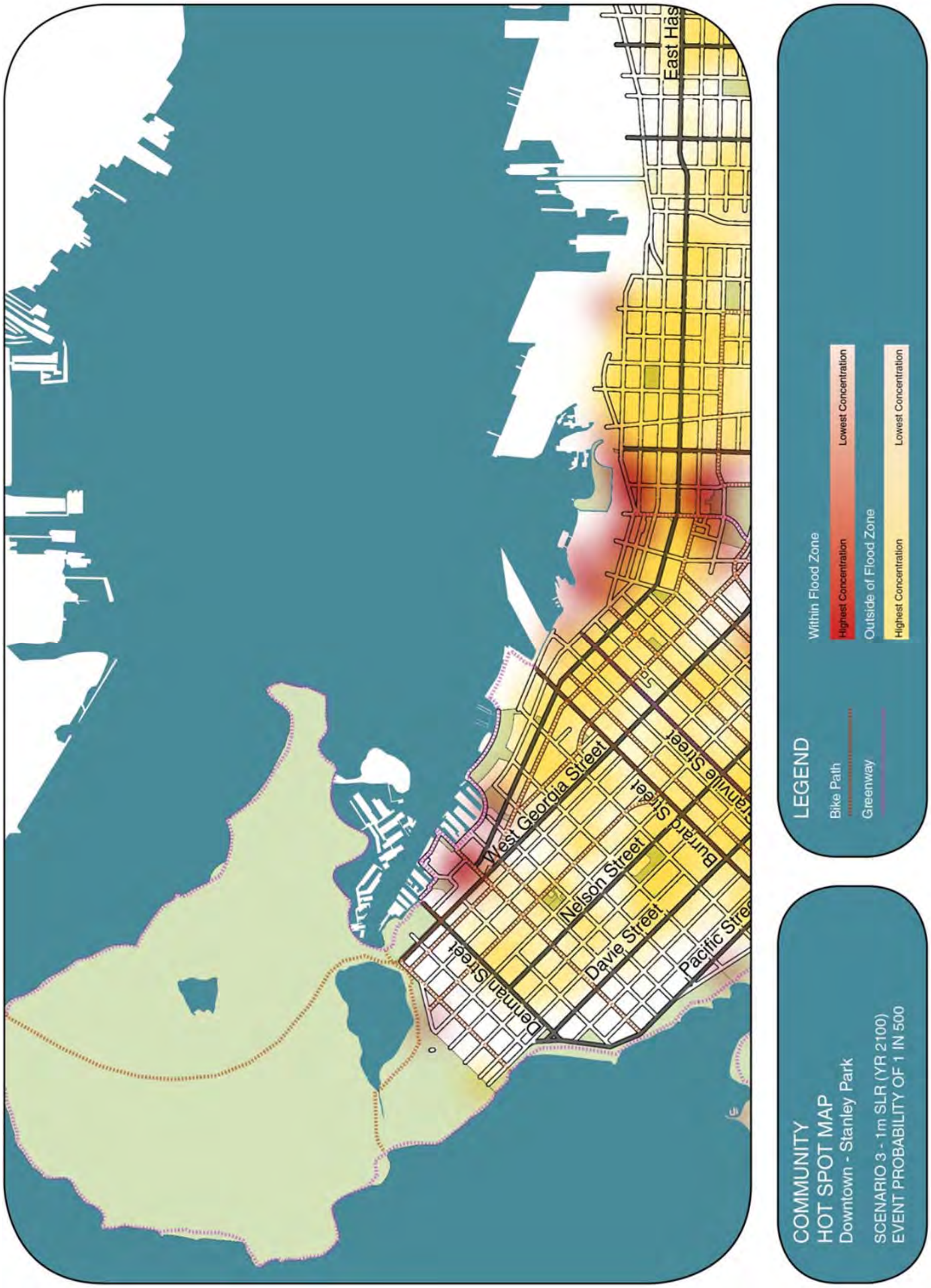


Figure 34 - Community Hot Spot Map (Downtown - Stanley Park)

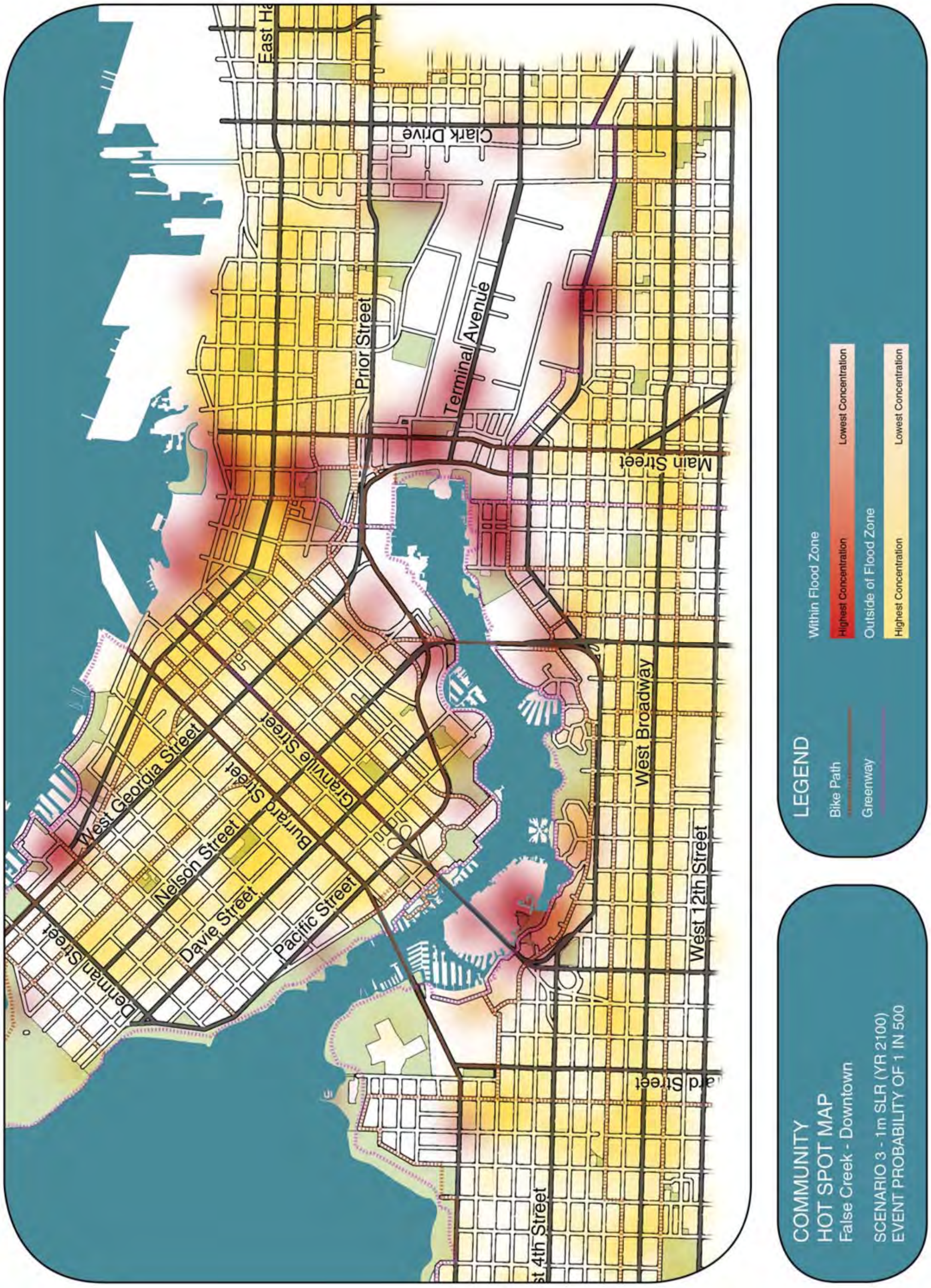


Figure 35 - Community Hot Spot Map (False Creek - Downtown)

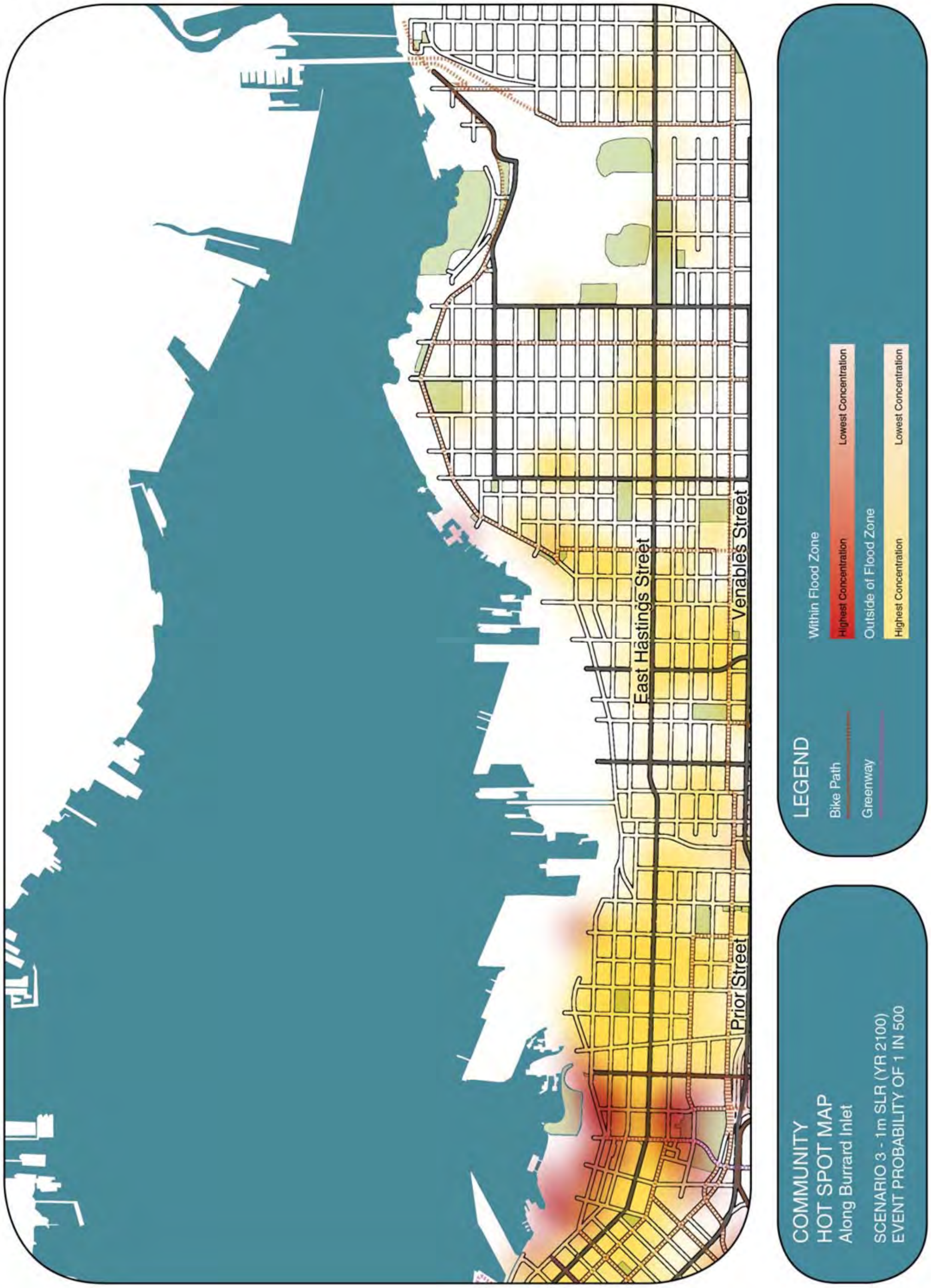


Figure 36 - Community Hot Spot Map (Along Burrard Inlet)

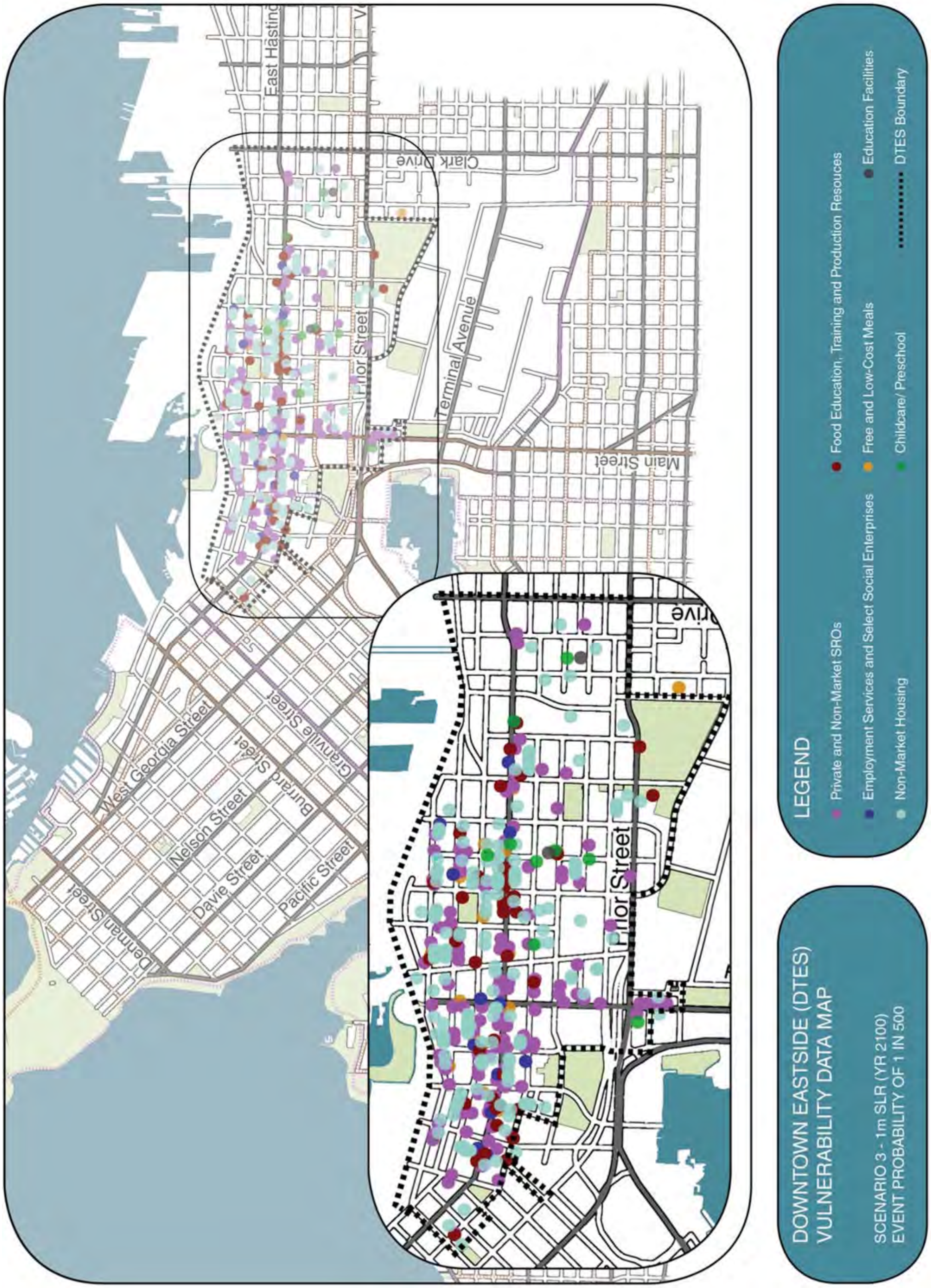


Figure 37 - Downtown Eastside (DTES) Data Map

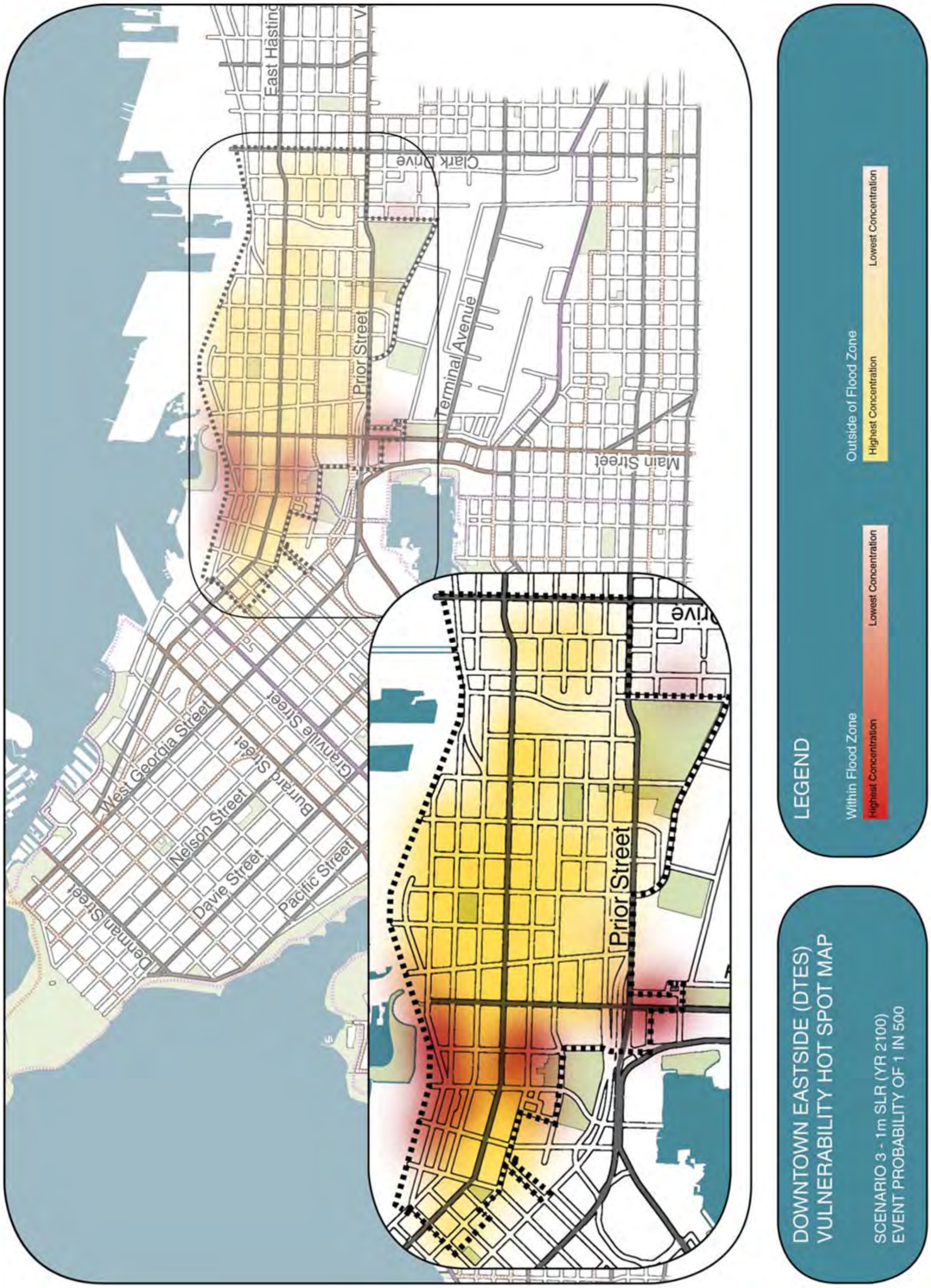


Figure 38 - Downtown Eastside (DTES) Hot Spot Map

Table 22- List of categories, sources, and items in the flood zone of Community Hot Spot Maps

Item	**Source**	**Additional Mapped Items**	**In the Flood Zone**
Community Hot Spot Map			
Community Centres (C.C.)	VanMaps – Community Centres	1607 E Hastings St	West Point Grey C.C., False Creek C.C. Creekside C.C. Coal Harbour C.C. Near Flood Zone: Roundhouse C.C. Carnegie Centre
Seniors Centres	Google	Brock House Society, Crossreach Broadway, Tapestry at Arbutus Walk, Senior's Friendship Centre South Granville, 411 Seniors Care Society, Britannia Senior's Activity Centre, Second Mile Society E Hastings St, Grace Seniors Home Pender Street, Second Mile Society Seymour Street, Central City Lodge, West End Seniors Association Denman, West End Seniors Association Barclay St	411 Seniors Centre Society, Brock House Society
Food Shelters	Workshop		Foodbank is in flood zone.
Homeless Shelters	Map provided by NHC	Gathering Place 609 Helmcken St, St James Community Service Society 625 Powell Street, St Marks 1805 Larch Street	
Non Market Housing	OpenData Catalogue		About 80 directly affected
Social Services	CoV Provided Map		About 55 Directly affected.

Childcare Preschool	CoV Provided Map	As per map. Added: YMCA Childgate Care Centre, Citygate 2,	Hudson Out of School Care, West 4th @Wallace St (no name) False Creek out of School Care, Creekview Tiny Tots, False Creek YMCA Child Care, SE False Creek Development, Reach for the Stars Montessori, YMCA Childgate Care Centre, Citygate 2, Immigrant Services Society day care, George St @ Parker (no name), International Village, Quayside C.C. City, Dorothy Lam Childrens' Centre, Pooh Corner Day Care Centre, Bayshore, Near Flood Zone: Family Montessori Preschool (within 1 block) Beatty @ Robson (no name - within 1 block) Homer Street
Schools Education	VanMaps	VanMap shows Elementary and Secondary. Added: Pattison Highschool 981 Nelson St, BCIT downtown, VCC downtown, VCC Broadway, Great Northern Way Campus: UBC, SFU, Emily Carr, BCIT, Arts Umbrella Granville Island, Pacific Culinary School Granville Island. Included VSB Works Yd.	Elsie Roy Elementary, Arts Umbrella, Pacific Culinary Arts, Emily Carr Granville Island, All of Great Northern Way campus (BCIT, Emily Carr, UBC, SFU), VSB, VSB Works Yard, Near Flood Zone: False Creek Elementary Henry Hudson Elementary (within 1 block),
Libraries	VanMaps	As per map layer "Libraries"	Near Flood Zone: Carnegie Library (within 1 blk)

Appendix I – Culture and Recreation Hot Spot Map Details

The following pages demonstrate the data, hot spot and magnified hot spot maps for Culture and Recreation.

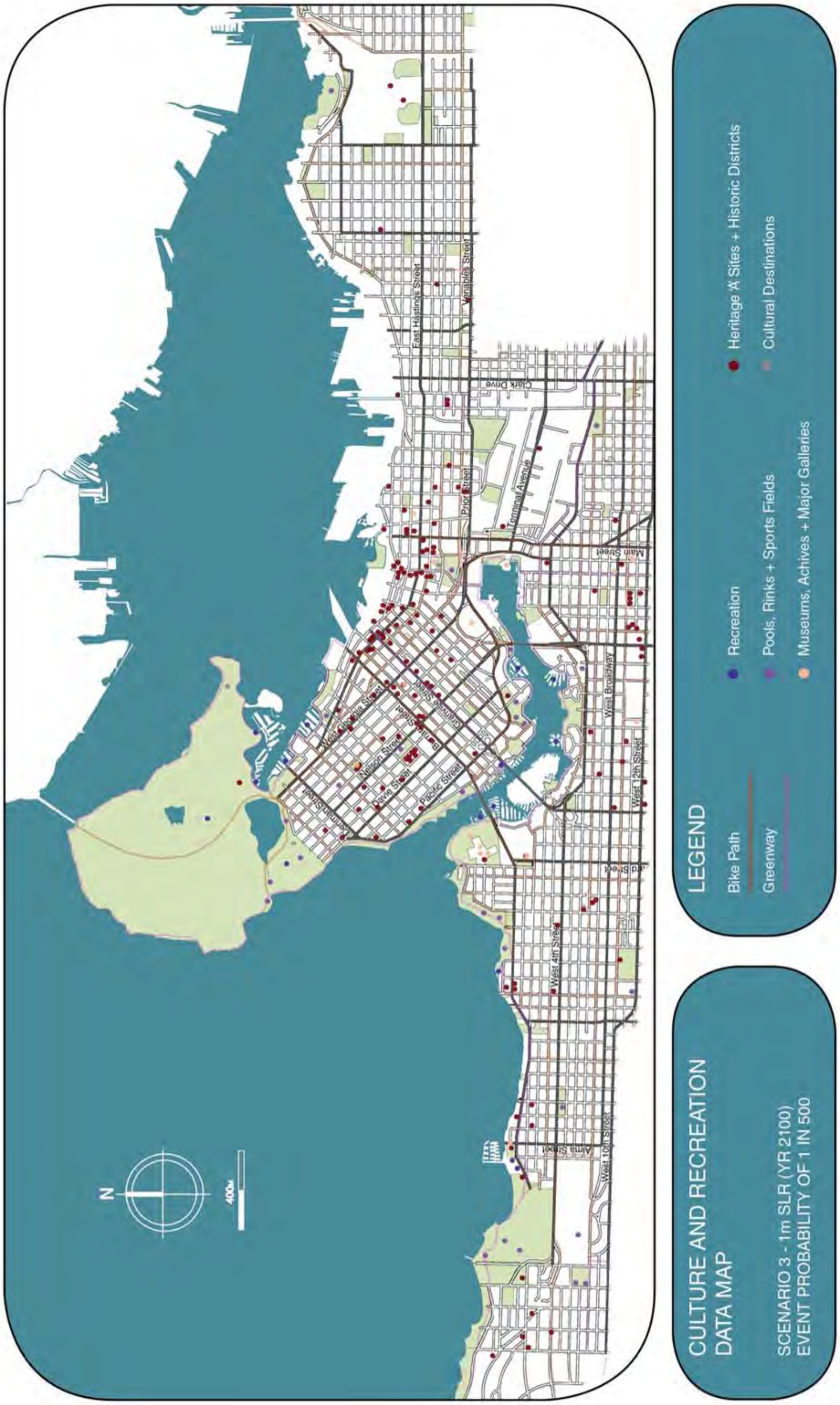


Figure 39 - Culture and Recreation Data Map

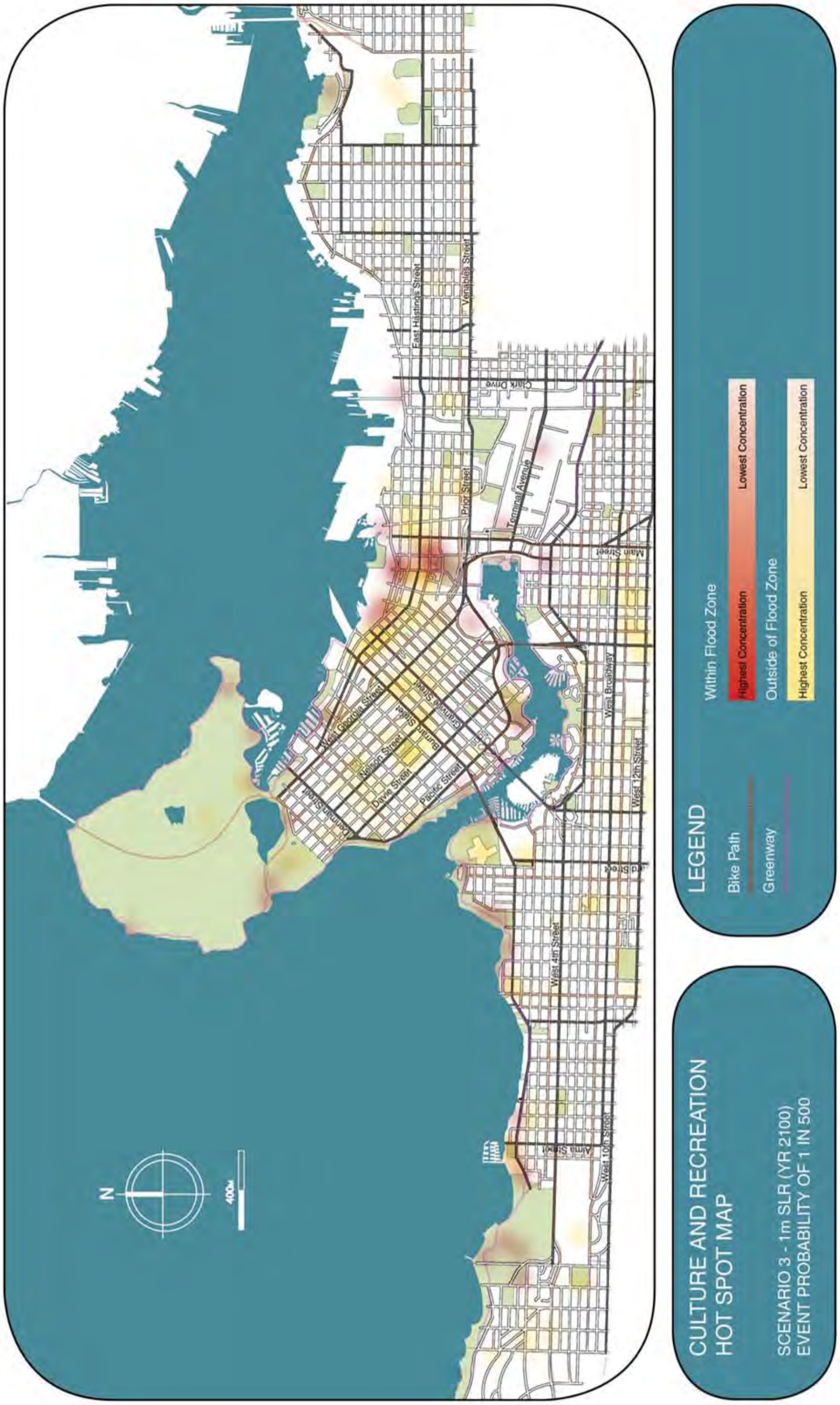


Figure 40 - Culture and Recreation Hot Spot Map

Figure 41 - Culture and Recreation Hot Spot Map (Point Grey - Kitsilano)

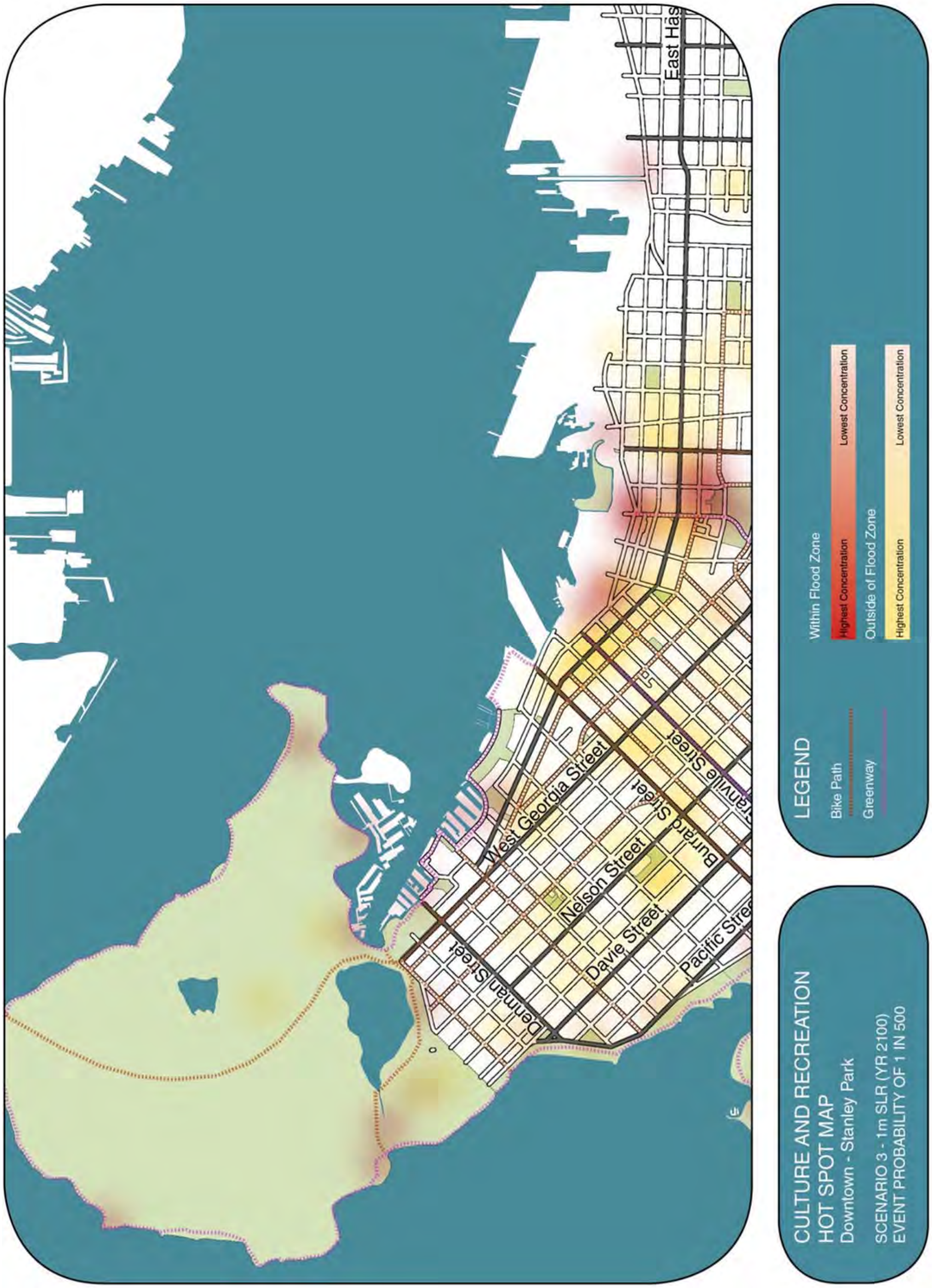


Figure 42 - Culture and Recreation Hot Spot Map (Downtown - Stanley Park)

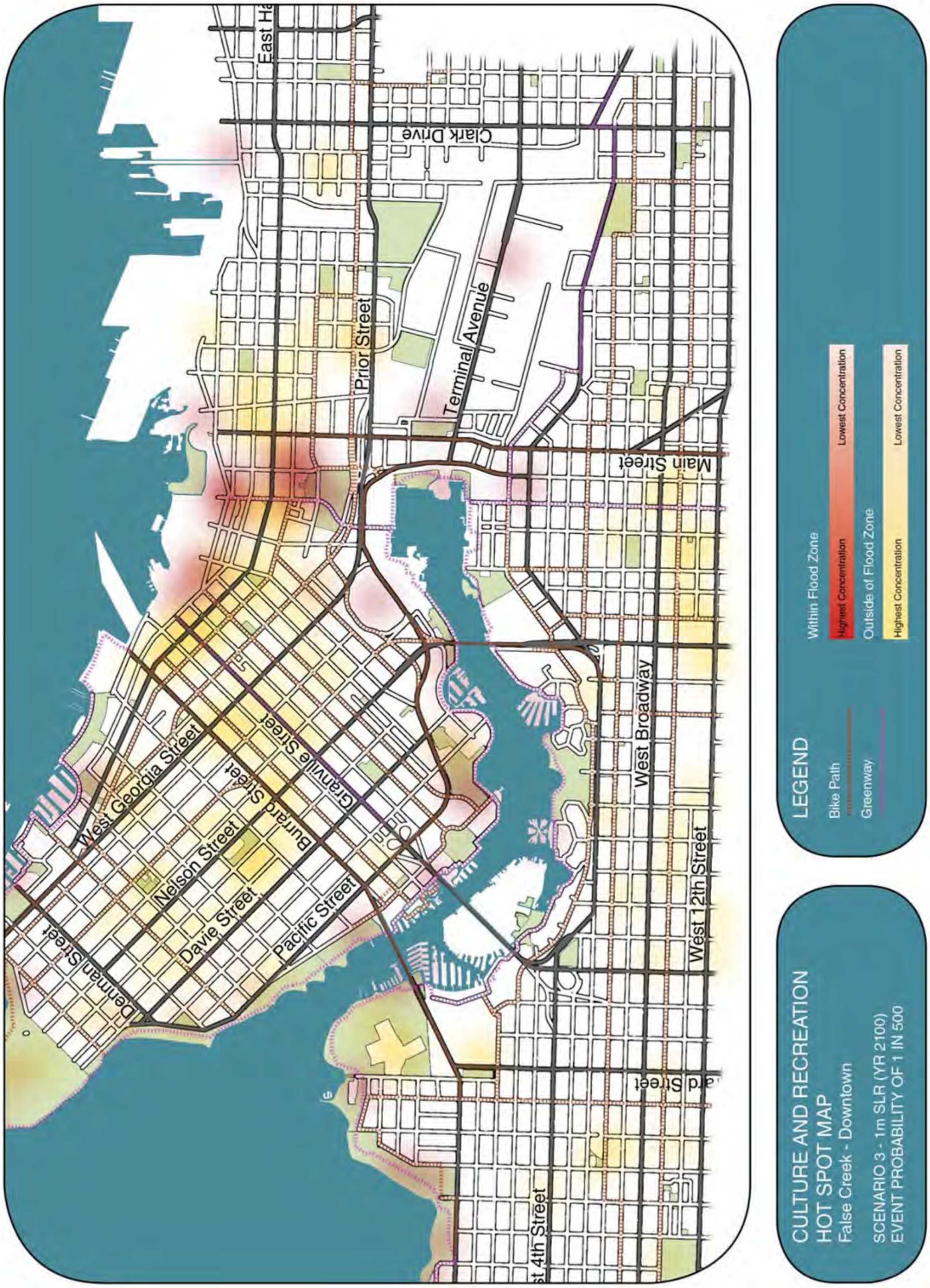


Figure 43 - Culture and Recreation Hot Spot Map (False Creek - Downtown)

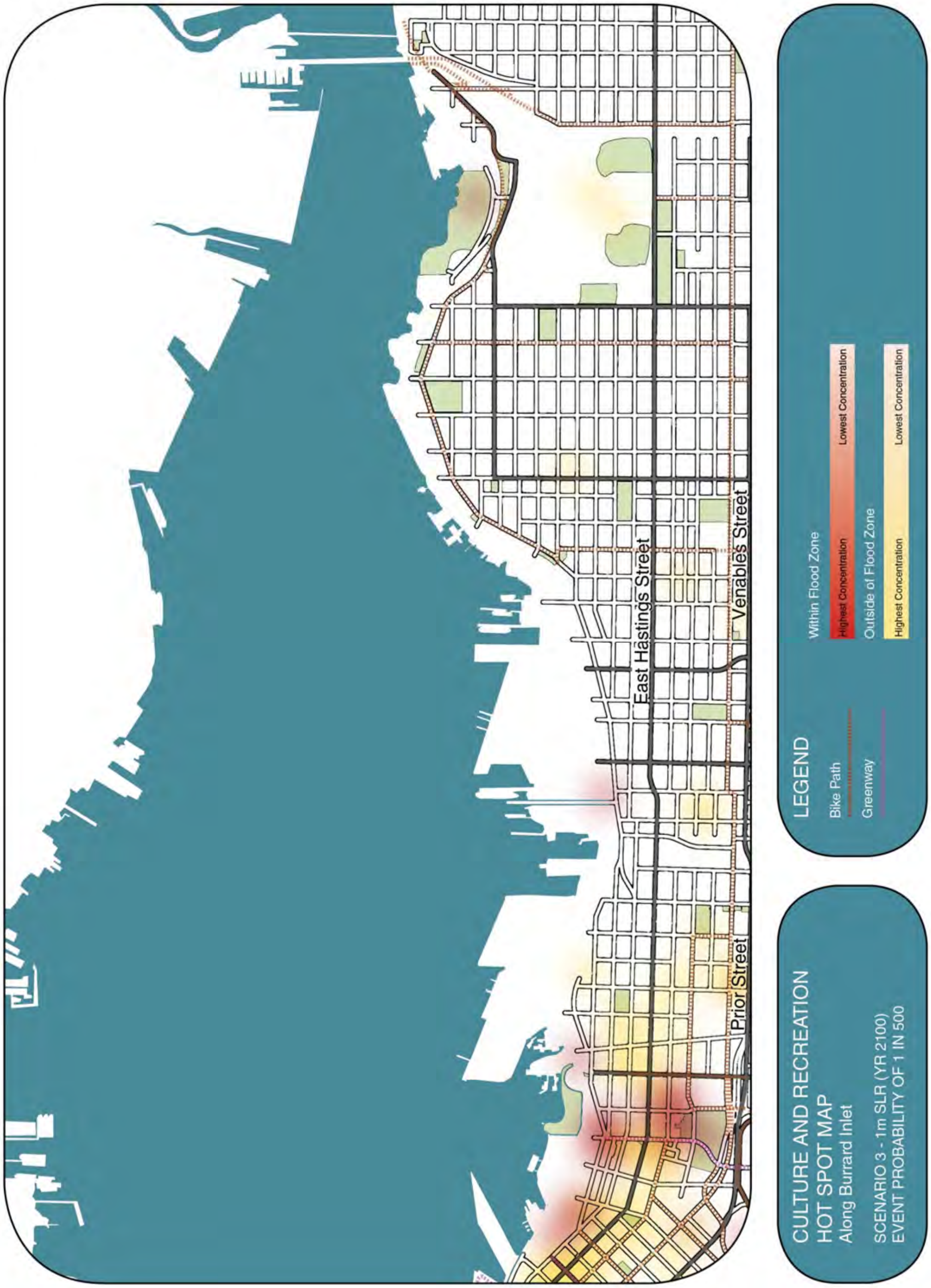


Figure 44 - Culture and Recreation Hot Spot Map (Along Burrard Inlet)

Table 23- List of categories, sources, and items in the flood zone for Culture and Recreational Hot Spot Maps

Item	Source	Additional Mapped Items	In the Flood Zone
Culture and Recreation Hot Spot Map			
Courts, Playgrounds and Pools	Google	Trimble Park playground, Trimble Park Tennis Court, Cooper's Park Playground, David Lam Park Playground, David Lam Park Tennis Court, Kitsilano Pool, Aquatic Centre, Second Beach Pool, West End Tennis Courts, Kitsilano Beach Tennis Courts, McBride Park Tennis Courts, Jericho Beach Public Tennis Courts, Connaught Park Tennis Courts, SE False Creek Tennis Courts, Andy Livingstone Field, Nelson Park Playground, Ceperley Playground, Coal Harbour Playground, China Creek Park Playground, David Lam Park Basketball Court, Kitsilano Beach basketball courts, Windsurf Adventure Watersports (Jericho) Jericho Park Rugby Field, Jericho Hill Athletic Field,	Ceperley Playground (Stanley Park), Second Beach Pool, Lost Lagoon Tennis Courts, Coal Harbour Playground, New Brighton Pool, Andy Livingstone Fields, Cooper's Park Playground, David Lam basketball court, David Lam Tennis Courts, David Lam Playground, Aquatic Centre, Kits pool, Kitsilano Beach tennis courts, Kitsilano Beach basketball courts, Jericho Beach tennis courts, Jericho rugby field, Jericho Hill Athletic Field

		Stanley Park Tennis Courts, Lost Lagoon Tennis Courts, New Brighton Park Pool	
Recreation	Google	Stanley Park Waterpark, Royal Vancouver Yacht Club, Royal Vancouver Yacht Club (Point Grey), Vancouver Rowing Club, Kitsilano Yacht Club, False Creek Yacht Club, Vanier Boat Ramps, Burrard Civic Marina, Spruce Harbour Marina, Heather Civic Marina, Quayside Marina, Coal Harbour Marina, Bayshore West Marina, Stanley Park Pitch and Putt, Jericho Tennis Club	Kitsilano Yacht Club, Vanier Boat Ramps, Burrard Civic Marina, Spruce Harbour Marina, Heather Civic Marina, Quayside Marina, Bayshore West Marina, Royal Vancouver Yacht Club, Vancouver Rowing Club, Coal Harbour Marina Near Flood Zone: Jericho Tennis Club Royal Vancouver Yacht Club (Point Grey) False Creek Yacht Club Stanley Park Pitch n Putt
Heritage 'A' Sites[26]	Heritage Register - Class 'A'	See full list below.	Brock House - 4397 W 2nd Ave, 3875 Point Grey Road, 1631 Dunbar St, 29 E 2nd Ave, CN Station - 1150 Station Street, 750 Terminal, Sam Kee Building - 2-14 W Pender, Ming Wo Building - 23 E Pender, Chinese Benev. Association - 104-108 E Pender, Chinese School 121-125 E Pender, Chin Wing Chun Society - 158-160 E Pender, 412 Columbia Street, CPR Station - 601 W Cordova, Greenshields Buildings, East Half - 339-341 Water Street, Greenshields Buildings, West

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[26] Category A: The site represents the best examples of a style or type of building. It may be associated with a person or event of significance, or early pattern of development.

			Half - 345-347 Water ST, Terminus Hotel - 36 Water Street, 1 Alexander Street, 53 Powell Street, 1 Gaolers Mews, Alhambra Hotel - 203-221 Carrall Street, Flying Angel Mission - 401 E Waterfront, 123 Rogers Street, Near Flood Zone: 1571 Alma 2590 Point Grey Road, 800 Jackson (1 block away), 814 Jackson (1 block away), 620 Beatty (within 1 block), Yaletown Roundhouse - 181 Roundhouse Mews (within 1 block), 1311 Beach Ave (within 1 block), 1386 Nicola St (within 1 block), Bandstand - 1755 Beach Ave, 1154 Gilford ST (within 1 block), 611 Alexander (within 1 block),
Historic Districts	Google	Gastown (Gassy Jack Statue) and Chinatown (Chinatown Gate)	Both will be partially flooded.
Museums Vancouver Archives Major Art Galleries	Google	Old Hastings Mill store Museum, Vancouver Maritime Museum, Vancouver Archives, Museum of Vancouver, HR MacMillan Space Centre, Seaforth Highlanders Regimental Museum, British Columbia Museum of Medicine, 15th Field Artillery Regiment Museum, William Boyd Museum	BC Sports Hall of Fame (in BC Place), Chinese Cultural Centre of Greater Vancouver Museum and Archives, Science World, Bard on the Beach, Maritime Museum, Old Hastings Mill store Museum Near Flood Zone: Vancouver Archives, HR MacMillan Space Centre, Museum of Vancouver

		of Pathology, Societe D'Histoire Des Franco-Colombiens, Ukraine Museum of Canada, Science World, BC Sports Hall of Fame, Vancouver Police Museum, Chinese Cultural Centre of Greater Vancouver Museum and Archives, Vancouver Art Gallery, Roedde House Museum, Bard on the Beach	
Cultural Destinations	Google	Siwash Rock, Stanley Park Totem Poles	Siwash Rock, Stanley Park Totem Poles

Table 24 - Complete list of Heritage Category 'A' Sites mapped in CFRA Study Area

HERITAGE A LIST:	
1704 E. 1st	4755 Belmont D.H. Copp house
3410 W 1st	1100 Bidwell Lord Roberts School
2033-2035 E 2nd	2300 Birch James England house
97 E 2nd (Opal Steel)	1484-1490 W Broadway Dick building
4686 W 2nd	2425 Brunswick
4397 W 2nd	355 Burrard Marine building
4629 W 2nd	690 Burrard Christ Church Cathedral
2556 W 3rd	750 Burrard former library
2199 W 4th Bank of Commerce	944 Burrard substation
101 W 7th Quebec Manor	969 Burrard First Baptist
1017 W 2nd	1081 Burrard St Paul’s
2028 W 7th	1650 Burrard Seaforth Armory
132 W 10th	884 Bute
2015 W 8th	203-221 Carrall
144 W 10th	425 Carrall
150 w 10th	868 Cassiar
366 w 10th	1100 Chestnut museum and planetarium,
1096 w 10th	1631 Collingwood
2390 w 10th	1120 Comox

3846 w 10th	1122 Comox
104 w 11th	1160 Comox
356 w 11th	1164 Comox
453 w 12th City Hall	1170 Comox
501 w 12th	1963 Comox
555 w 12th	238 E Cordova
1306 w 12th	303 E Cordova
1440 w 12th	309 E Cordova
2588 Alder	8-36 W Cordova
1-7 Alexander	301 W Cordova
601-617 Alexander	321 W Cordova
2200 Arbutus	601W Cordova CPR station
1114 Barclay O Canada house	2575 Cornwall
1415 Barclay Roedde house	1523 Davie
1447 Barclay manor	1631 Dunbar
1311 Beach Tudor manor	1710 Dunbar
1755 Beach Haywood bandstand	2449 Dundas
2099 Beach Park Board offices	1975 Ferndale
620 Beatty drill hall	800w Georgia Art Gallery
4585 Bellevue Kania castle	900w Georgia Hotel Vancouver
1075 W Georgia Macmillan Bloedel building	401 Main Carnegie Hall
1201 Georgia Banff apartments	2025 Napier St Fancies
1333 W Georgia Westcoast Energy	989 Nelson BC Hydro
1154 Gilford Sylvia hotel	1012 Nelson St Andrews Wesley
525-529 Gore Nationalist League building	1001 Nicola fire hall 6
1750 Grant	1386 Nicola
470 Granville Rogers building	23 E Pender
674 Granville The Bay	104 E Pender
734 Granville Vancouver block	121 E Pender Chinese school
838 Granville commodore	158 E Pender
884 Granville Orpheum theatre	451 E Pender
916 Granville vogue	500 E Pender
688 Hamilton Queen Elizabeth theatre	2-14 W Pender
847 Hamilton	98 W Pender Sun tower
100 E Hastings	250 W Pender
2901 E Hastings	330 Permanent bldg.
2901 E Hastings livestock building	640 W Pender Bank of Montreal
1 W Hastings Merchants Bank	1285 W Pender Evergreen bldg.
198 W Hastings province	1125 Pendrell
207 W Hastings Dominion building	1173 Pendrell
580 Bank of Toronto	1401 Pendrell

675 Bank	2530 Point Grey
686 Bank of Commerce	2590 Point Grey
757 Sinclair Customs building	3875 Point Grey Brock house
757 former post office (717)	41 Powell Europe hotel
757 Winch building (739)	390 Powell New World hotel
848 W Hastings Ceperley Rounsfell bldg.	2525 Quebec
850 W Hastings	432 Richards
915 W Hastings Vancouver club	646 Richards
651-671 Heatley Ballantyne pier shed 1	Rogers NFT BC Sugar
1380 Hornby Leslie house	181 Roundhouse Mews CPR Roundhouse
451 Howe	800 Smithe Law Courts and Robson Square
800 Jackson	1150 Station CN station
814 Jackson	750 Terminal packers
720 Jervis Abbott house	1875 Tolmie
1130 Jervis St Paul’s church	549 Union
1130 Keefer Seymour school 1	1020 Victoria
1130 Keefer Seymour school 2	36 Water Terminus hotel
339 Water Greenshield building east half	401 W Waterfront Flying Angel mission
345 Water west half	2646 Yukon
350 Water Holland block	

ANNEX F

CONSEQUENCE ASSESSMENT

City of Vancouver
Coastal Flood Risk Assessment
Consequence Assessment: Final Report

December 2014

ebbwater
CONSULTING

Executive Summary

Flood risk assessment is becoming widely used around the world as a decision-making tool for government. Risk assessment allows decision makers to look at the consequences of flooding to their community rather than just knowing where the hazard zones are. Flood risk assessment takes flood management to the next level; it requires information from a flood hazard assessment, such as the expected depth and direction of flow, as well as information about the assets and people that are vulnerable to flooding. By combining these two data sets, potential losses (economic, social, and environmental) due to flooding can be identified. Knowing where a community's vulnerabilities lie during a flood is imperative for good flood planning, flood damage mitigation and for emergency management.

Hazus, a model initiated by the U.S. Federal Emergency Management Agency (FEMA) in 1992, is a standardized methodology for the calculation of potential losses from natural hazards and is widely used across the United States. It was recently adopted in Canada by Natural Resources Canada. The flood module for this program is in Beta release, and the City of Vancouver (the City) is the first major user of the program in the country. Hazus, like most risk assessment tools, calculates only direct tangible and some indirect tangible damages and losses, providing a significant amount of information about damages and losses to buildings in particular. Damage and loss results are calculated based on an asset inventory – what's on the floodplain – and the hazard itself – where and how deep the water is. This information is then combined with damage and loss curves from the Hazus database to produce hazard and site specific consequence information.

The modelling showed significant anticipated impacts to buildings and people for coastal flood events in the present-day, and increasingly in the future. In the present day, a 500-year (0.2% chance of occurring in a given year) event would result in 1700 displaced households and almost 500 damaged buildings. The same storm event with 1 m of sea level rise, would incur dramatically more impacts: 4000 displaced households with over 800 damaged buildings. The majority of the damaged buildings are residential but there are also a significant number of industrial buildings impacted, particularly along the Fraser River. The Hazus model estimated that the debris generated from the 1:500 storm event with 1 m of sea level rise would fill 4,500 trucks—enough to cause a significant waste management concern for the City and the region.

The Hazus model was also used to estimate direct damage costs. However, due to difficulties in adapting a U.S. tool to Vancouver, the resulting costs were considered unreliable. Further, while the Hazus model can provide direct damage estimates, there are a significant number of more intangible or less directly calculable impacts that are not calculated by Hazus. An example of a significant indirect cost for flooding in Vancouver would be the economic impacts resulting from disruption to an electrical distribution facility or a major transit station. While Hazus is clearly a useful tool for evaluating the potential consequences of a flood, further work is needed to refine the model for use in the Canadian context.

For context, a review was done of the damages incurred in southern Alberta as a result of the 2013 flood. The total cost of that event is now estimated to be $7B. An estimated 4,000 businesses and 2,000 homes were directly impacted in Calgary alone. More than $50 million was spent on emergency response by the City. While the flood in southern Alberta is not directly transferrable to Vancouver as it was caused by river flooding, rather than a coastal event, the costs do illustrate the widespread impacts of a major flood event. Similarly, a 2013 flood event in Toronto caused nearly $1B in damages and disrupted transportation into and out of the city. Hurricane Sandy—the most significant coastal flood event in North America to date--caused an estimated $20B in damages in New York City.

As coastal cities grapple with climate change and sea level rise in particular, there is an urgent need to begin planning for adaptation and mitigation that will reduce our risk to coastal floods in future. This need far outweighs the risk of moving ahead with imperfect information. As practitioners, we need to recognize that we are not going to get the risk calculation perfectly right, or perhaps even close, but that we can use the best available tools and data to make informed decisions. These decisions will hopefully increase our resiliency to coastal flooding in a changing climate.

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TABLES

1. Introduction

Photo 1: Stratafied by Jason Dunc Photo ©
False Creek, December 2012

Flood risk assessment is becoming widely used around the world as a decision-making tool for government. Risk assessment allows decision makers to look at the consequences of flooding to their community rather than just knowing where the hazard zones are. Flood risk assessment takes flood management to the next level; it requires information from a flood hazard assessment, such as the expected depth and direction of flow, as well as information about the assets and people that are vulnerable to flooding. By combining these two data sets, potential losses (economic, social, and environmental) due to flooding can be identified. Knowing where a community's vulnerabilities lie during a flood is imperative for good flood planning, flood damage mitigation and for emergency management.

This report outlines the need, methods and results of a flood consequence assessment completed for the City of Vancouver, and is part of a much larger project that looked at the flood hazard and flood vulnerabilities from a coastal flood event in a changing climate. This report has been prepared by Ebbwater Consulting, with inputs from the City of Vancouver. The original scope of work for this portion of the project involved the curation of input data for Hazus modelling, provision of support to the City in their Hazus modelling and final reporting the results of the Hazus modelling. As the project evolved, it became clear that the beta version of Hazus Canada would not provide as much information as anticipated, and that some of the results might not be as robust as desired. Therefore, the project evolved to provide information on the methods and results for the Hazus modelling, but also provides additional information on the gaps to the process.

The second section of the report provides an overview of flood risk planning, and the need to look at more than just hazard and losses. This is followed by a section that describes flood impact typologies and methods of assessing impact. Section 4.0 provides an overview of impacts anticipated in the City of Vancouver and details the methods used to assess the impacts. This is followed in Section 5.0 by the results of the consequence modelling using Hazus. Challenges, gaps and next steps to developing a comprehensive flood risk assessment are described in Section 6.0. The final section (7.0) provides some insight on how this report and the Hazus results can be used to inform the second phase of work, when mitigation and adaptation options will be considered.

2. Flood Risk – Why and What?

The identity of Vancouver is intertwined with its position on the coast; iconic images of the City nearly always include shoreline. The coastal and riverine floodplains are centres of commercial, social, economic and ecologic activity, and as such they are home to City, regional, provincial and national assets. These assets are subject to damage when floods occur.

Given that we use our floodplains for a range of commercial, social, economic and environmental purposes, we need to acknowledge and plan for flooding in a way that improves the resilience of our built form and encourages safety and well-being for our communities. As the City looks to the future and a changing climate, sea level rise (SLR) in particular, the need to understand the potential impacts of coastal flooding is crucial for decision-making (Figure 1). We can't manage and reduce our risk until we know what it is.

Figure 1: Flood risk planning process

Flood risk assessment is widely considered to be the best tool to make decisions that will mitigate flood impacts over time (European Comission 2003; Jha, Bloch, and Lamond 2012), and is being used around the world (Australia (Queensland Reconstruction Authority 2013); New Zealand (Rouse 2012), Japan, Netherlands and the United States (US Army Corps of Engineers et al. 2011); and the UK (Environment Agency 2009)) as countries and cities grapple with increasing flood risk in a changing climate. A true flood risk assessment is invaluable for decision-making as it considers flood consequences for a range of potential events and time-scales; this is particularly useful when considering long-term investments in adaptation.

Flood risk is a function of both the likelihood of an event occurring and the consequences of that event occurring (Figure 2). Flood consequence is defined as a function of flood hazard - where water will go - and vulnerability - what's in the way.

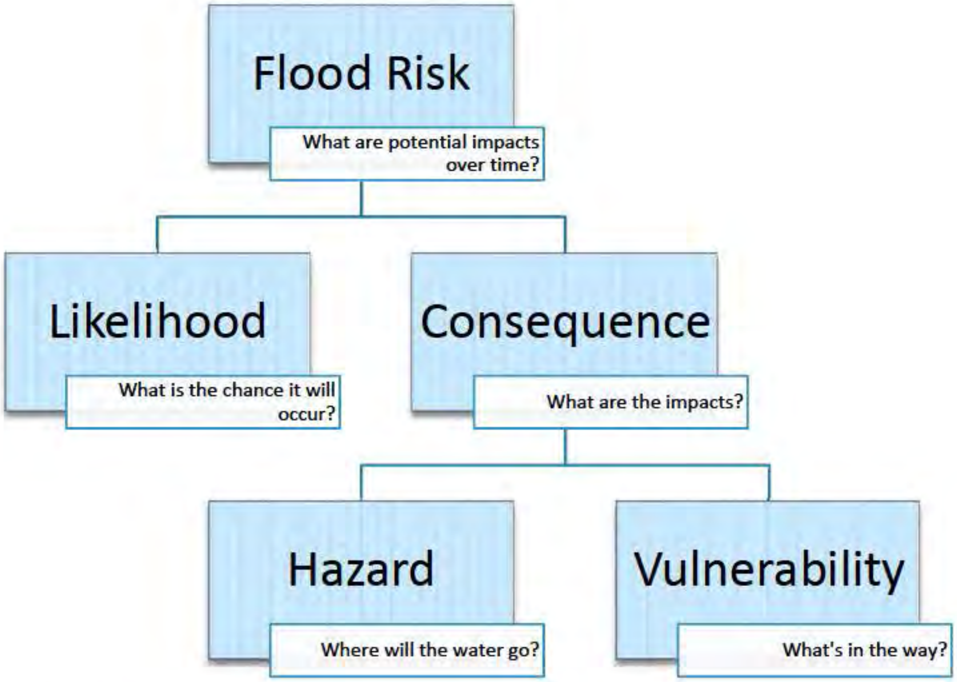

Figure 2: Flood Risk as a Function of Hazard, Likelihood and Vulnerability (after (Queensland Reconstruction Authority 2013))

As discussed above, risk is a function of both likelihood and consequence (Figure 3), which helps decision-makers consider and compare both a high likelihood, low consequence event and a low likelihood, high consequence event on an equal footing (Figure 4). This becomes particularly important as we look across long time-horizons. A nuisance flood that occurs annually over several decades may in fact be more impactful than a catastrophic flood that occurs just once. A risk assessment can be used to compare both the impacts and the potential benefits of mitigation options for the whole spectrum of nuisance to catastrophic events.

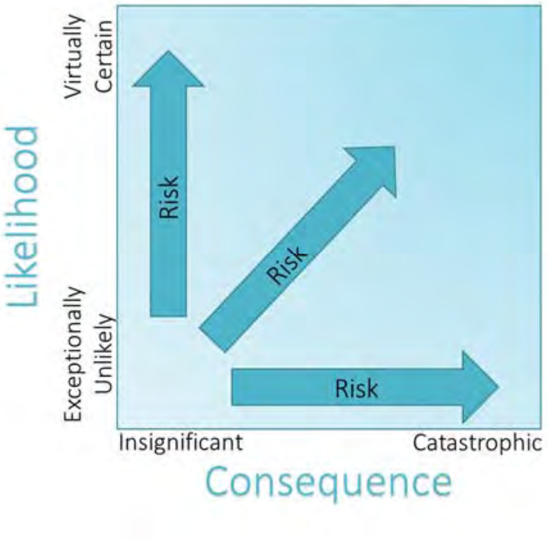

Figure 3: Risk as a function of likelihood and consequence

Figure 4: Nuisance and catastrophic flooding

Obviously the aim of any flood management strategy is to reduce the risk from flooding by either reducing the hazard (for example in the extreme instance, by redirecting a river) or the vulnerability (for example, by removing people or assets from the floodplain). The amount of effort and resources dedicated to reducing the risk is dependent on the community risk tolerance. Where **acceptable risks** are those that are broadly acceptable to the public and no further effort to reduce the risk is warranted. Whereas, **unacceptable risks** are those that should be mitigated if at all possible. The line between acceptable and unacceptable risks is termed **risk tolerance** (Figure 5). Risk tolerance will vary across many dimensions such as time, place and person. For example, the Netherlands with its history of catastrophic flooding, has a low societal risk tolerance to flooding and therefore invests €Billions annually to maintain and improve its flood protection systems (Glas 2010). In contrast, many regions are now moving to a new model for flood mitigation based on the premise of “living with floods” (Ad Hoc Committee of ICFM6 2014), where efforts are focused on increasing resilience and recovering faster from floods (i.e. a high risk tolerance).

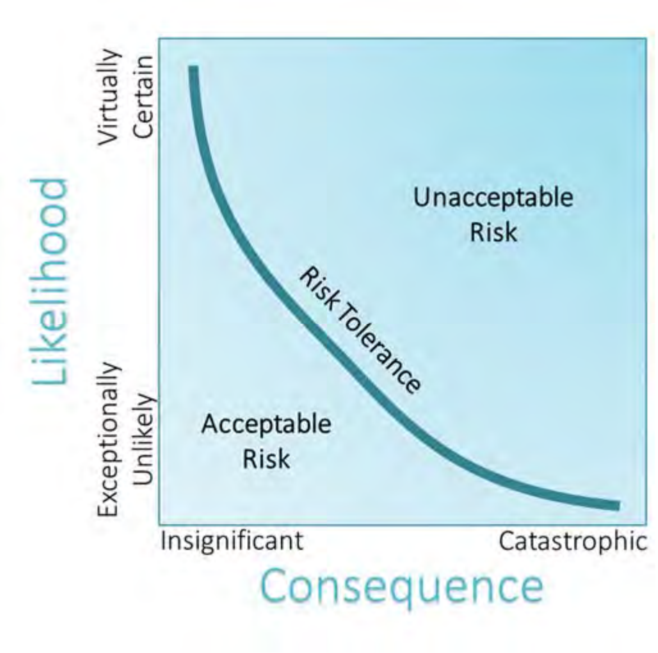

Figure 5: Risk tolerance

In summary, a true flood risk assessment, one that looks at flood impacts over time, is an invaluable tool for decision makers. It can be used to understand and mitigate present and future flood damages, to create flood management strategies that are both cost-effective and community supported, and to help plan for long-term financial investments in flood mitigation.

Limitations to Flood Risk Approach

A true flood risk assessment requires a significant amount of data, resources and expertise; as the likelihood, hazard and consequences all need to be defined. The limitations associated with likelihood and hazard are described in the main body of the Coastal Flood Risk Assessment report and the limitations and constraints of a flood consequence assessment as they relate to the City of Vancouver are described below.

Furthermore, there is no established international standards or best practices for flood risk assessment (Meyer et al. 2013). This means that it is difficult to compare flood risks across different communities or countries, and that methods and standards be developed for each risk assessment at a considerable cost. However, this also means that communities can develop risk assessments that truly consider the priorities of their communities. For the City of Vancouver CFRA, considerable effort has been taken to identify community priorities and vulnerabilities, and although not all of these could be included directly into the flood consequence assessment they are being considered and acknowledged.

3. Flood Consequences or Impacts

Water on a floodplain itself is not a problem. The impacts of flooding occur when water interacts with natural and human environments in a negative sense, causing damage, disruption and occasionally death. Flood impacts are varied, and can be described in many ways.

Flood Impact Typologies

The source-pathway-receptor model is a common method of looking a flood risk, where the impacts are defined by the 'receptors' or elements at risk on a floodplain (Frank Messner et al. 2006; RIBA n.d.). These include people, buildings/infrastructure, natural environments and the economies that link them (Figure 6). These groupings are one means of considering and organising flood impacts for practical reporting, however it must be noted that there are many linkages and common elements between these groups.

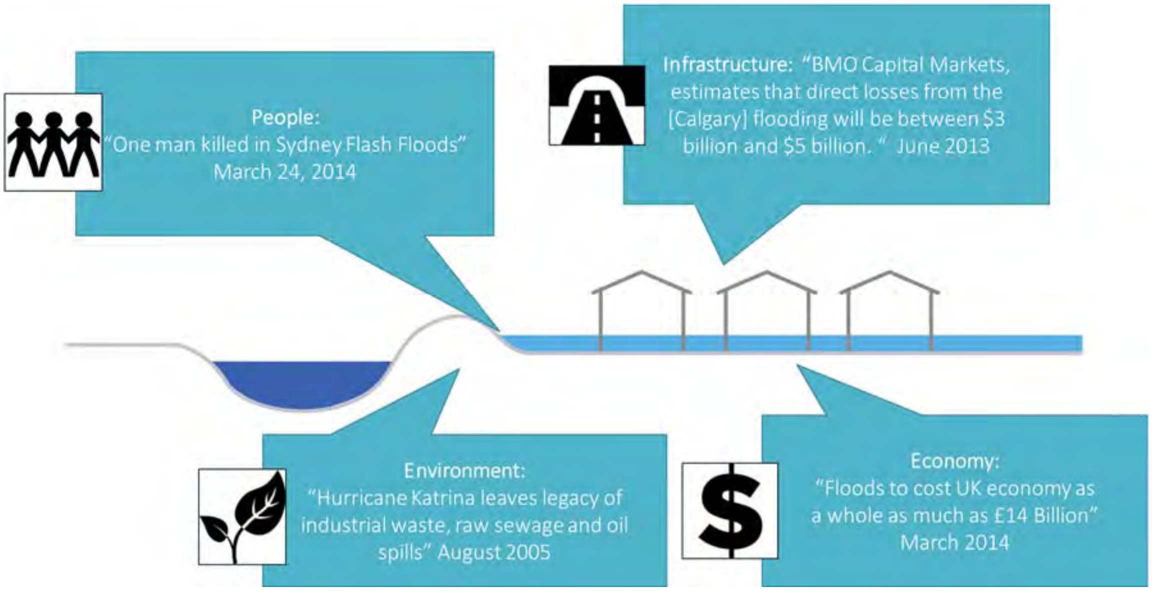

Figure 6: Flood impacts by receptor

Direct and Indirect Flood Impacts

Flood impacts can be further divided into direct and indirect impacts. **Direct** impacts describe all harm that relates to the immediate physical contact of water to people, infrastructure and the environment. Examples include damages to buildings, impacts to building contents and other assets, damage to the environment and loss of human life. Whereas, **indirect** impacts are those caused by the disruption of the physical and economic links in the region as well as the costs associated with the emergency response to a flood. For example, businesses losses because of interruption of normal activities, or costs associated with traffic disruption when roads are impassable.

Flood Impacts by Tangibility

The effect of a flood on the environment, human or community health, or the loss of life are difficult to quantify, and are therefore considered to be **intangible** impacts. Whereas, the

tangible dollar losses from a damaged building or ruined inventory in a warehouse are more easily calculated. This does not mean that tangible losses are more important than intangibles, just that they are easier to quantify and assess. However, the inclusion of intangible impacts is desirable for the development of a robust flood risk assessment (Frank Messner et al. 2006). Table 1 provides examples of direct/indirect and tangible/intangible impact typologies.

Table 1: Examples of flood impact typologies

Form of Damage/Measurement	Tangible	Intangible
Direct	• Building damage • Infrastructure damage • Content/Inventory damage	• Loss of life • Health effects • Loss of habitat and environment
Indirect	• Loss of industrial production • Traffic disruption • Emergency response costs	• Inconvenience of post-flood recovery • Increased vulnerability of survivors

Source: (Frank Messner et al. 2006)

Calculating Flood Impacts

Estimates of potential flood impacts are an essential piece of a flood risk assessment (see Figure 2). A general approach to estimating flood impacts is to first assess potential flood damages to the various elements at risk: people, infrastructure, environment and the economy. Infrastructure damage is by far the easiest to quantify (it is a direct tangible impact), and is commonly calculated as a percent of damage to a structure. This in turn is translated into a cost or loss by considering the amount of money or other resources required to repair, rebuild, replace or move the damaged structure (Figure 7). Similar, although more subtle, calculations can be made to look at damages and losses to people, the environment and the economy; these calculations tend to be more difficult as the impacts are either indirect or intangible. At present, the tools to calculate the indirect or intangible impacts are not well-developed in the field of flood risk management (F Messner and Meyer 2006; J. A. E. Veldhuis 2011).

Figure 7: Estimating flood impacts

Direct Damages

The estimation of flood damages to the various receptor groups (people, infrastructure, environment and the economy) is a complex process that involves a large number of hydraulic, engineering and socio-economic factors. The estimation of economic flood damages is gaining importance in the world of flood management as flood risk assessment is adopted as the preferred method for flood planning around the world. Despite the efforts made to date on the calculation of flood damages, it is known that there are many gaps still (B. Merz et al. 2010b). This is in part because of limitations in available data and knowledge about flood damage mechanisms. As a further constraint, the models and information available are not considered robust, as unfortunately, flood damage model validation is rarely performed (B Merz et al. 2010a).

The lack of progress in the estimation of flood damages is due in part to the many parameters that contribute to flood damages. These include water depth (McBean, Fortin, and Gorrie 1986; US Army Corps of Engineers 1997), velocity (Kelman and Spence 2004; H. Kreibich et al. 2009; Middelmann-Fernandes 2010), wave action ((Nadal et al. 2010), flood duration (FEMA 2005), and contamination, sediment or debris load (Middelmann-Fernandes 2010; Nadal et al. 2010). Furthermore, building construction type and age can influence damage (Zhai, Fukuzono, and Ikeda 2005). Further examples of less tangible factors, such as warning time and human behaviour can be found in the literature. Despite the enormous number of factors that play a role in building damages only flood depth has been widely studied and used in flood risk assessment (Kelman and Spence 2004; Merz et al. 2010b; Messner et al. 2007; Middelmann-Fernandes 2010). In the last couple of years alternatives to this approach have been explored such as the use of data-mined multi-variate damage models, which are derived from large datasets of damaged buildings (B. Merz, Kreibich, and Lall 2013). For the moment, this approach is the domain of researchers and has not yet been widely applied as a tool for flood damage estimation.

Depth-Damage Curves

The most common and internationally accepted method of estimation for direct flood damage to infrastructure is the application of depth-damage curves (Figure 8). Damage to a building is based on stage elevation (i.e. water depth) as a percentage damage or as a loss to the structure or contents. Depth-damage curves are generally developed from empirical data following a flood event; these curves are based on data from a specific location and flood event and are therefore not easily transferable. Or, as an alternative synthetic depth-damage curves from on a broader base of information have also been developed; these tend to be more transferable and more accurate at an aggregate level, but less robust when considering single building losses (McBean, Fortin, and Gorrie 1986; Middelmann-Fernandes 2010). Further discussion on depth-damage curves as they apply to the City of Vancouver is presented in Section 6 of this annex.

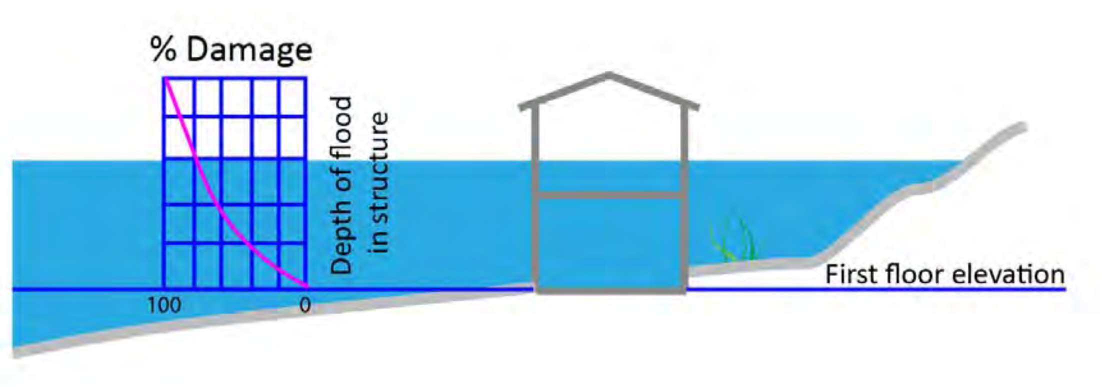

Figure 8: Schematic representation of a depth-damage curve (after (Nastev and Todorov 2013)**)**

Direct Losses

Direct damage estimates are useful for planning and mitigation projects, however, losses – often dollar losses - can be a more effective tool for communication. Therefore, losses are often calculated as a function of damage and asset values. Commonly direct losses are monetary representations of the cost to repair or rebuild. Direct losses may also be calculated for social indicators, specifically loss of life.

Economic losses from building damages

Most flood consequence models use flood damage information in conjunction with value information for floodplain assets to derive a loss. For example, a $150,000 residence, which has 10% damage will be reported as a $15,000 loss, other losses for the contents of the building may also be added to the total loss calculation. Loss calculations are therefore highly dependent on the damage curves and on the assessed values of the building stock.

Social losses

Social losses from flooding are for the most part indirect or intangible and as such are rarely calculated; the exception is loss of life (Aboelata and Bowles 2007). However, loss of life directly attributable to flooding in Canada is rare, and for Vancouver where the flood mechanisms (coastal storm event and Fraser River freshet flooding) mean that there is warning and response time, loss of life is even less likely. Loss of life is more relevant for cases of sudden dam or dike failure. Should Vancouver change course, and promote diking as an instrument for flood protection, then loss-of-life will need to be considered as a risk.

Summary

Impacts from a flood event are broad and many of the impacts are not easily calculated. Furthermore, when impacts are calculated they have considerable uncertainty. However, there is still significant value in making best estimates of flood impacts and consequences in order to make informed decisions for flood mitigation.

4. Flood Impacts in the City of Vancouver: Methods

If we revisit the definition of flood consequence; it is a function of both the flood hazard and the vulnerability of the elements in the way of the flood (Figure 9). For the City of Vancouver, detailed hazard mapping has been developed as a major component of phase 1 of the CFRA project and is presented in Chapter 7 of the main report. Furthermore, key vulnerabilities have been fleshed out as a part of the same project and are presented in Chapter 8 of the main report and are summarised again below. Concurrent to this, the City of Vancouver has developed a database of buildings on the floodplain in CDMS (Comprehensive Data Management System); a sub-component of the Hazus model, which was used to estimated flood consequences. This section provides an overview of the methods used to estimate flood consequences.

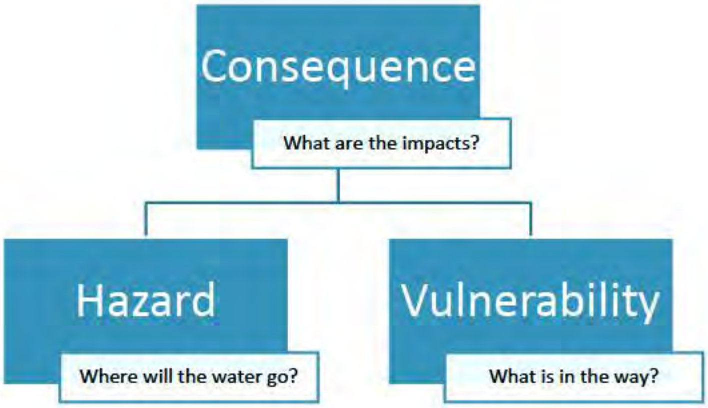

Figure 9: Flood consequence as a function of hazard and vulnerability

Identified Vulnerabilities in the City of Vancouver

On the completion of the hazard assessment, with knowledge of what areas of the city might be under water in future, the project team conducted a high level vulnerability assessment to look at elements at risk on the floodplains (see detail in Annex E: Vulnerability). This effort involved reviewing the current land uses, available literature and reporting and most importantly conducting a stakeholder workshop. Several dozen diverse stakeholders were invited to illicit a list of "what's in the way" and "what do we care about" on the City's floodplains. A summary of key vulnerabilities is listed in Table 2.

There is significant diversity in the identified elements; they straddle the various receptor types of infrastructure, economy, people and environment. Many of the elements are indirect impacts (e.g. economic losses from the closure of tourist destinations), and many were intangible (e.g. the potential loss of heritage and cultural sites). Indirect and cascading impacts were also considered, but are not presented here for brevity (see Annex E).

Table 2: Summary of identified vulnerabilities to coastal flooding

Infrastructure	*Economy*	*People (Community)*	*People (Recreation and Culture)*	*Environment*
▪ Major rail lines ▪ Rapid transit tunnels ▪ Electricity substations and transmission lines ▪ Water and sewer pump stations, overflows and pipes ▪ Neighbourhood energy infrastructure ▪ City yards, fire halls and police stations ▪ Commercial and residential towers ▪ Commercial and residential low-rise buildings, some with basement suites ▪ Industrial buildings	▪ Transport hubs (train stations and yards, bus station, rapid transit stations) ▪ Port ▪ Tourist destinations (parks, beaches, major restaurants, hotels and hostels, cruise ship terminal, parks, beaches, Granville Island) ▪ Commercial service centres ▪ Industrial zones including "green jobs zone" and produce depots ▪ Water dependant industry including marinas ▪ High-value real estate	▪ Community centres ▪ Homeless shelters ▪ Non-market housing ▪ Emergency shelters and mass refuges ▪ Seniors housing and day-centres ▪ Childcare and pre-schools ▪ Schools and educational facilities (including libraries) ▪ Food banks ▪ Social service centres ▪ Animal shelters	▪ Pools, rinks, sports fields ▪ Museums and archives ▪ Galleries and cultural destinations ▪ Heritage sites	▪ Ecological value of shoreline areas ▪ Potential contamination from hazardous waste storage and infill soils ▪ Parks and beaches

Calculating Flood Consequences for the City

An ideal consequence assessment for the City of Vancouver would look at valuing all of the elements at risk identified in Table 2. However, there are many obstacles to this. The following model (Figure 10) is proposed to help understand the potential gaps in the process:

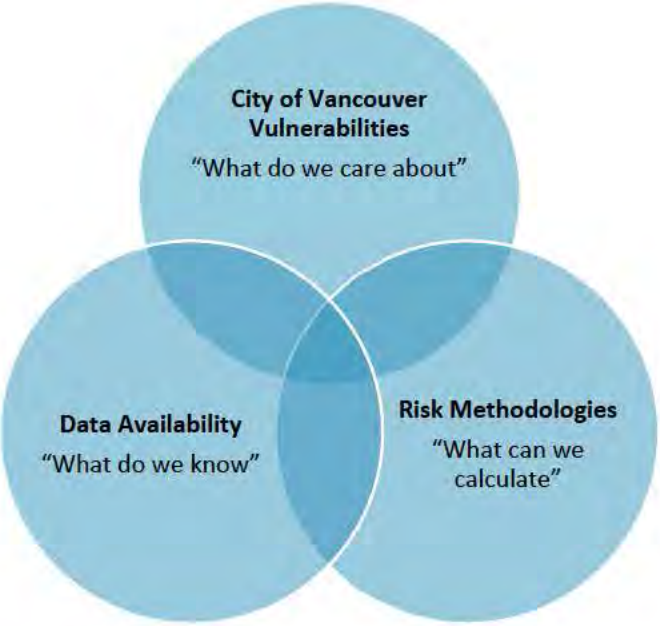

Figure 10: Model to provide consequence assessment data for CFRA.

An overview of risk methodologies was provided in Section 2.0 and 3.0. There are many limitations to what can be valued and assessed, either because the impacts are intangible, or because there is only limited or outdated science available to calculate the direct impacts. Furthermore, even if there is a standard method to calculate a flood impact, there might not be high-quality data available for the City of Vancouver. This is a new type of process, and the City hasn't had cause before to collect flood-mitigation specific data, for example the first-floor elevation of buildings within the floodplain. Some of the challenges and gaps to the process of developing a comprehensive risk assessment that looks at impacts to people, infrastructure, the economy and the environment along with some potential next steps are presented in detail in Section 6.0. There are however, some elements that are at the nexus of vulnerabilities, data availability and risk methodologies (Figure 10). These are primarily flood impacts associated with building damages and short-term impacts to people. For this project, we employed Hazus, a flood consequence tool to calculate these impacts.

Flood Consequence: Hazus Model

Hazus, a model initiated by FEMA in 1992, is a standardized methodology for the calculation of potential losses from natural hazards and is widely used across the United States. It was designed as a planning level tool for local governments and agencies to develop emergency management and mitigation plans (Department of Homeland Security. Federal Emergency Management Agency 2009a). Natural Resources Canada began adapting Hazus for use in Canada in 2011 (Nastev and Todorov 2013). The earthquake module was the initial focus of the effort; the addition of the flood module for Canada is still in the infancy stage, with the model currently in beta release. The Canadian version of Hazus is solidly based on the US version and it is our understanding that for the flood module is virtually unchanged (Hastings 2014).

Hazus, like most risk assessment tools, calculates only direct tangible and some indirect tangible damages and losses, providing a significant amount of information about damages and losses to buildings in particular. It also provides limited loss information pertaining to people as well as indirect economic losses. Most of the calculations are done based on large scale classifications of building stock and demographics, but there is also the opportunity to refine this information with user-defined facility (UDF) information on buildings and critical infrastructure. Both approaches have been applied for the City of Vancouver consequence assessment.

Damage and loss results are calculated based on an asset inventory – what's on the floodplain – and the hazard itself – where and how deep the water is. This information is then combined with damage and loss curves from the Hazus database to produce hazard and site specific consequence information (Figure 11).

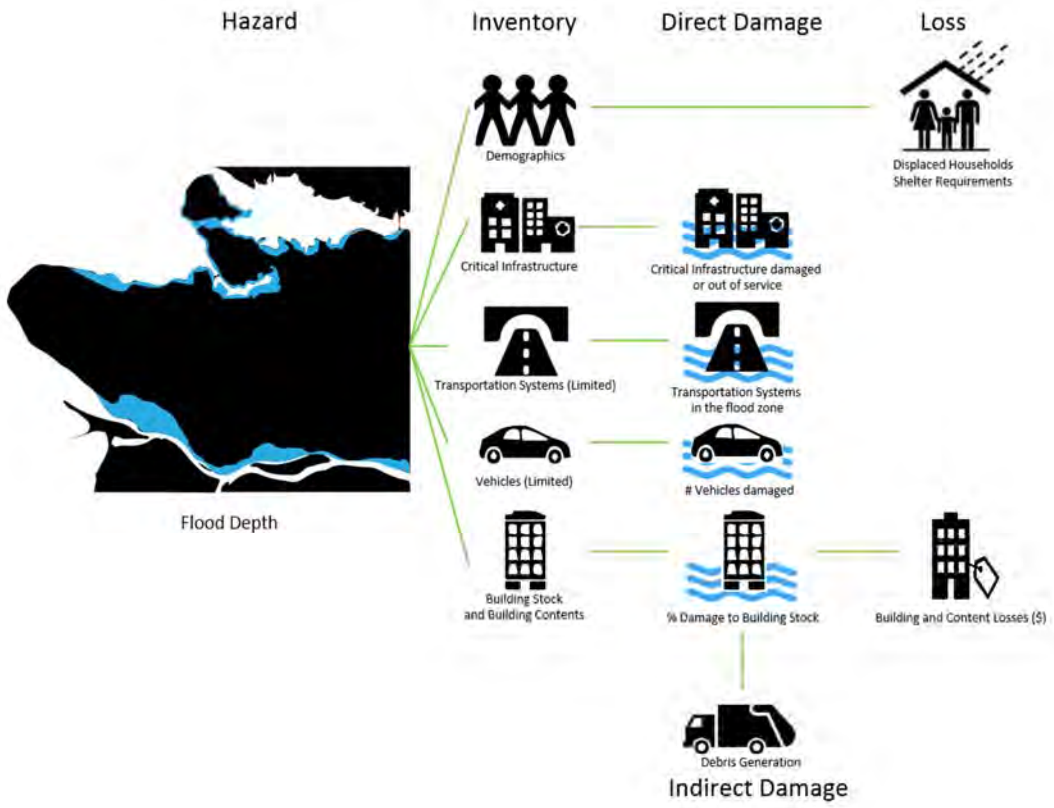

Figure 11: Hazus Structure (adapted from (Department of Homeland Security. Federal Emergency Management Agency 2009b)

General Approach for City of Vancouver Hazus Model Development

Hazard Input

Much of the first phase of work for the Vancouver CFRA was focused on developing detailed hazard mapping for the City of Vancouver. The methods and results of this are presented in the main report. Only minor changes to the results from the overland model were required to create the input for the Hazus model. Hazus requires the input of a flood-depth grid, which spatially describes how deep the water is; this was easily developed by subtracting the flood elevations from the digital elevation model of the City. All five hazard scenarios were used in the Hazus modelling (Table 3); although given the uncertainty associated with a year 2200 scenario, results for this scenario are not presented.

Table 3: Summary of hazard scenarios used as input to Hazus

Scenarios	Year	Sea Level Rise	Return Period
1	2013	-	1/500
2	2100	0.6 m	1/500
3	2100	1.0 m	1/500
4	2100	1.0 m	1/10,000
5	2200	2.0 m	1/10,000

Asset Inventory

Hazus requires asset information that describes what elements are on the floodplain, which is used in combination with the hazard information to produce consequences. There are two broad categories of data that are required: information on people and information on building stock. Calculations related to people are made using the default database supplied with the program, whereas, building stock information can be either be based on the default database or can be developed at a building-specific level and input manually. Details on the approaches used for the City of Vancouver modelling are provided below.

Demographic Data

Demographic calculations are based on the default asset inventory that is contained within provincial databases supplied with Hazus Canada. For the flood module, the asset inventory for residential buildings is based on 2011 census Canada data and is provided at the dissemination block level (Ulmi et al. 2014, Hastings 2014).

Economic Data

Business interruption calculations are based on business and commercial data that is supplied with Hazus Canada. For the beta version, the data was developed from a Dunn and Bradstreet database and then parceled to dissemination blocks based on Natural Resources Canada algorithms (Hastings 2014). These have not yet been validated; business interruption results are presented in this report, but should be considered as a starting point and not as robust final values.

Essential Facilities

The Hazus model reports damage to essential facilities which are defined in Hazus as including fire stations, hospitals, police stations and schools. These were incorporated into the asset inventory based on City of Vancouver datasets. It should be noted that essential facilities, as defined by Hazus, are not the same as critical infrastructure and do not include facilities such as electrical distribution stations, water or wastewater facilities, or transit hubs.

User-Defined Facilities

The basic mantra of numerical modelling of any kind is that model outputs are only as good as the inputs. For flood risk modelling this is no different, and therefore for this project considerable effort was put into ensuring that the building stock inventory correctly reflected the built environment of Vancouver. Recent studies comparing an object-oriented approach versus an aggregate approach to flood damage modelling shows significantly better results using as fine as scale as possible for building information (Jongman et al. 2012a). The primary advantage of this approach is that more precise water depths can be applied to individual buildings, for example near the margins of the floodplain a single house may be shown to be under 50 cm of water, where it's slightly upslope neighbour is dry. The damage to these two buildings will be correctly reflected in the results. Whereas, if an aggregate approach is taken – then assumptions are generalised across large areas (a city block for example); average water depths are applied to all the buildings, and in the above example, both buildings would have assumed shallow-depth flooding with minimum associated losses; in this case the aggregate approach would likely produce lower total losses than for the object-oriented approach. Second, the object-oriented approach means that individual building types are reflected in the inputs and the outputs. For example, a wood structure built on grade will show more damage than its concrete neighbour. In the aggregate case, basic algorithms that define the average number of wood versus concrete home in a census block are used, and at present these are based on the original US curves and are not representative of Vancouver.

A UDF asset database is an option in Hazus, where individual buildings, single-family homes for example, are input into the model individually. This is an example of an object-oriented type model. The City of Vancouver GIS department developed the UDF database of buildings; their basic approach is described in Figure 12, and detailed below.

Figure 12: Summary of UDF Database Development Process

1. **Locate Building Footprints**: Initially, an older, 2009, LiDAR-based dataset of building footprints was used. In order to update footprint information to reflect new development and demolitions, the City development permit database was used to identify changes, and new footprints were developed from orthophotos. The building footprints were also used in the development of the hydraulic model mesh.

2. **Building Size and Class**: Building size was derived directly from the footprint information, and building class was determined from a combination of pictometry images, Google Streetview, zoning and generalized land-use.
3. **Structural Information**: Base elevation was determined from LiDAR for lands neighbouring the footprint. First storey height and presence/absence of a basement was then determined as function of the base elevation, pictometry, oblique images, Google Streetview and familiarity with generalized land use. Building construction type was established in a similar manner.
4. **Value Information**: Building value (not land value) information was determined using BCAssessment data. Internal data was available for the City of Vancouver ratepayers, the City of Vancouver municipal buildings. Additional assessment data was provided by PortMetroVancouver and by CMHC for buildings on Granville Island.

For each building within the database there is a significant amount of information that is required (building size, class, location, construction type, elevation, value, etc.), and it was not possible to develop a completely comprehensive database. Overall 95% of the buildings within the largest flood plain extent (Scenario 5, Year 2200, 10,000-Year storm) were included in the final database (Table 4). The major gap is for buildings on Granville Island, where only about half the buildings had complete information.

Table 4: Percent completion of building asset inventory

Study Region[1]	Total Footprints	Complete Data	Coverage
Fraser River	711	697	98%
False Creek	117	91	78%
Burrard Inlet West	116	111	95%
Burrard Inlet North	67	59	88%
Stanley Park	2	1	50%
Total	1013	959	95%

As the project moves into Phase 2, and the team researches mitigation and adaption options, there may be an opportunity to continue to refine the Hazus inventory.

Damage and Loss Curve Selection

For this early phase of work, and given the infancy of Hazus as a tool in Canada the team elected to use the default loss and damage curves from Hazus in the initial runs. We recognise that some of these curves are not appropriate, either because they are outdated (most of the curves in Hazus were developed in the 1980s), or because they are not suited to Vancouver's built

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[1] Study regions refer to the flood zones from the hazard modelling. The Hazus model was also run at a zone scale for computational reasons, although results are presented at a city-scale.

environment (the curves were primarily developed using data from floods in the mid-west US, where communities are more suburban). Concerns with the use of some of the curves are outlined in Section 6 in this annex along with recommendations on next steps to improve the Hazus results.

However, it should be noted that Hazus is a well-respected tool for flood risk assessment, and that there are few alternatives out there. This is also the tool that has been adopted by the Federal government, who have invested considerable resources to populate the inventory database, especially the demographic information. The use of alternate tools, mostly European, would require the same level of scrutiny to ensure that the algorithms would be appropriate for Vancouver, and additionally would require significant effort to populate the models with demographic and census information. It is therefore recommended that the City continue with Hazus as a flood risk assessment tool, but that the known limitations be clearly described in any reporting.

5. Flood Impacts in the City of Vancouver: Results of Hazus Modelling

The City of Vancouver ran the Hazus model as described in Section 4 for each of the hazard scenarios described in Table 3. The following documents the results of these runs. Some results are not presented in full due to concerns about the robustness of the results (see Sections 4 and 6). Careful consideration of the results presentation has been made to ensure that the results are useable and can be used to make decisions regarding adaptation options, despite the uncertainties. Because of many uncertainties associated with understanding the built-form of Vancouver in the distant future, no results are presented here for Scenario 5. The presentation formats have been developed based on conversations with the City of Vancouver, with other users of Hazus (FEMA Region X and FEMA Region IV) and with Natural Resources Canada.

People

Hazus reports both the number of displaced households and the expected number of people who will seek shelter at public shelters. The number of displaced households is calculated as a function of the number of housing units in or near to the inundated area. Shelter needs are calculated as a function of the number of the displaced households, the number of people within the household and their perceived need for public shelters; wealthier families are assumed to be less likely to seek shelter in a public shelter for example. The results of these scenarios are presented in Table 5, Figure 13 and Figure 14. Spatial results for displaced households are shown in Figure 15. The demographic outputs from Hazus are based on the default census-based inputs, and are therefore most accurate when considered at the aggregate scale. Consequently, the figures show large areas of impact because whole census dissemination areas are considered, whereas the later figures of building damages show individual building damages and therefore the impact area looks smaller. However, all figures can be viewed at a high-level to explore relative differences across the City; they should not be directly compared to each other.

Table 5: Hazus results for social losses

Scenario	Description	Number Displaced Households	Number of People Who Will Seek Shelter
1	0 m SLR, 500-Year Storm	1700	5000
2	0.6 m SLR, 500-Year Storm	2700	8000
3	1 m SLR, 500-Year Storm	4000	11900
4	1 m SLR, 10,000-Year Storm	4800	14300

Figure 13: Hazus results: number of displaced households

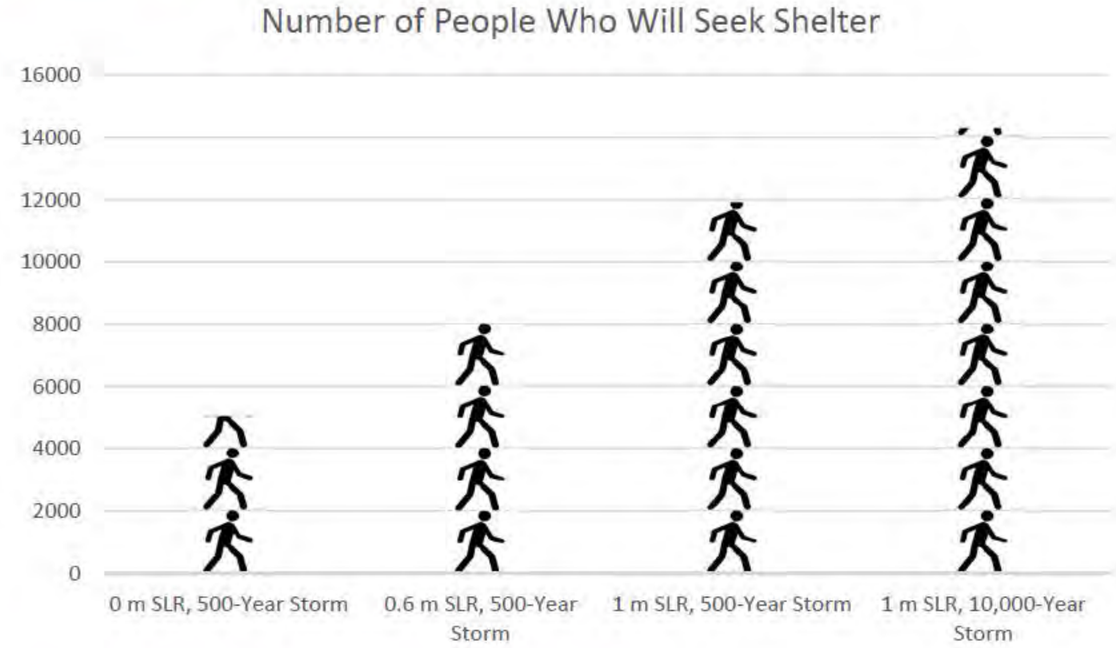


Figure 14: Hazus results: number of people who will seek shelter

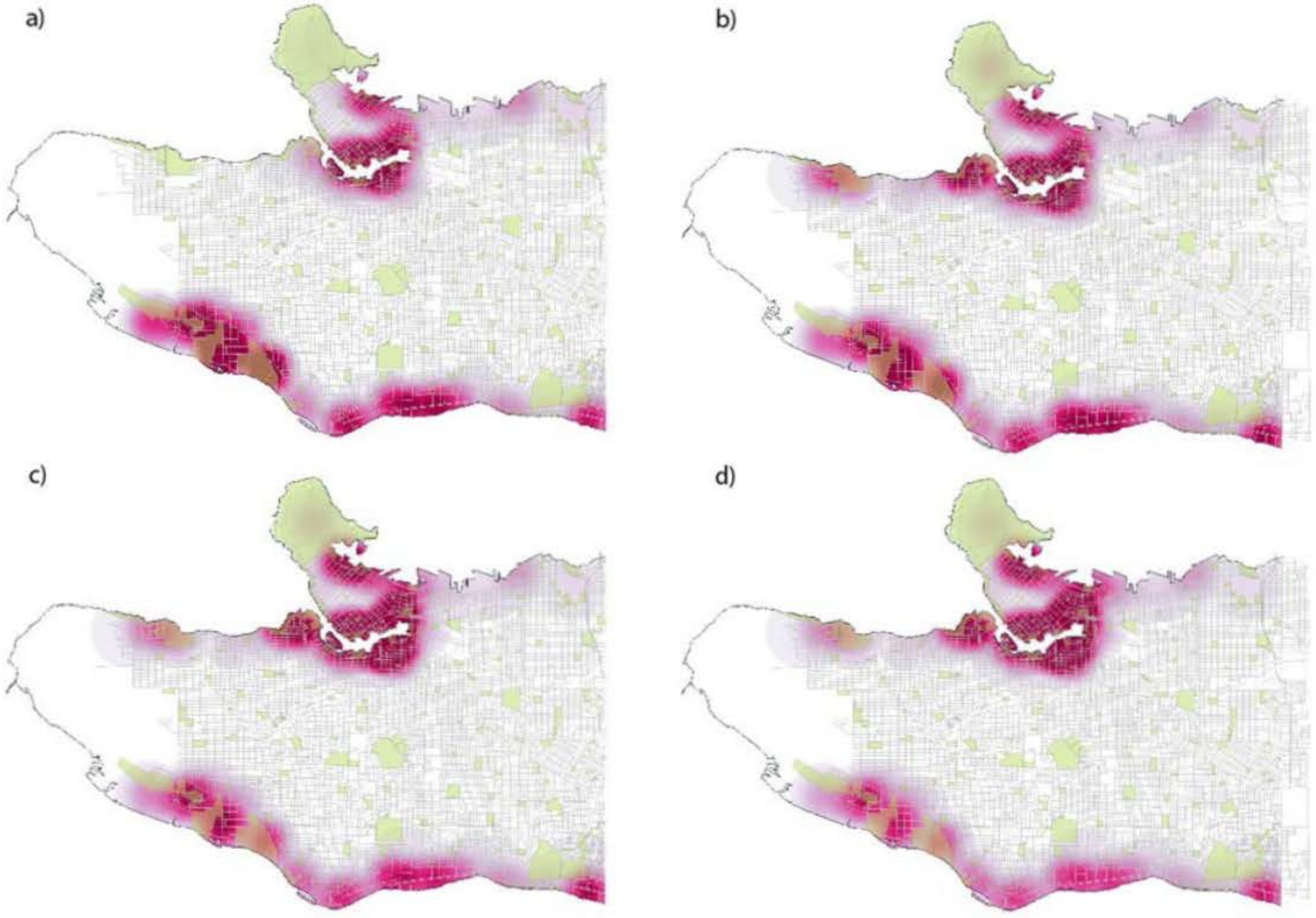


Figure 15: Map of displaced households for (a)* 0m SLR, 500-Yr storm (b) 0.6 m SLR, 500-Yr storm (c) 1 m SLR, 500-Yr storm (d) 1m SLR, 10000-Yr storm
*Data missing for Jericho and Kits point available for scenario (a)

The Hazus results show that significant impacts will be felt directly by the residents of Vancouver if a flood event were to occur, even in the present-day, when 1,700 homes would likely require evacuation for a short period of time. Many of these homes are in the False Creek area, where there is a relatively dense residential community, and a significant number of non-market housing units. There is a steady increase in the number of displaced households with worsening flood events, with 4,800 homes evacuated under a severe storm scenario with 1 m of SLR (Scenario 4).

Infrastructure (Building Stock)

Hazus provides many outputs that relate to building structures. And, for this project, the City of Vancouver employed a user-defined (UDF) approach to the building asset inventory. This effectively means that as much as possible, the attributes of each individual building in the floodplain was incorporated into the model. This approach is preferred to the default census block approach as it provides building specific outputs. A summary of the methods and limitations to this approach are provided above.

Building Damages

The total number of damaged buildings is shown in Table 6, with the breakdown by level of damage in Figure 16 and the breakdown by occupancy type in Figure 17. Spatial representation of building damages is shown in Figure 18.

Table 6: Hazus results for building damages

Scenario	Description	Total Number of Damaged Buildings
1	0 m SLR, 500-Year Storm	484
2	0.6 m SLR, 500-Year Storm	666
3	1 m SLR, 500-Year Storm	817
4	1 m SLR, 10,000-Year Storm	862

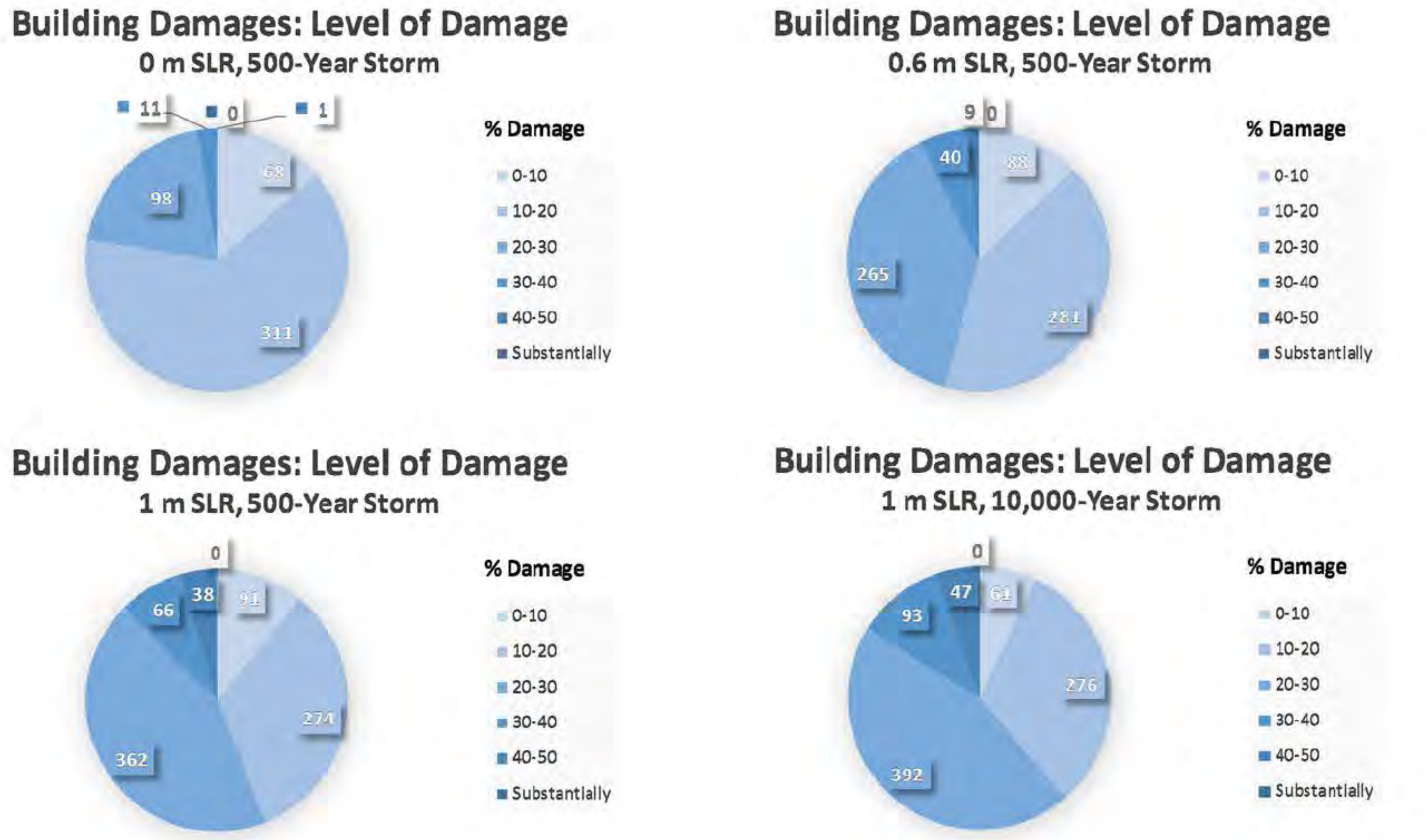
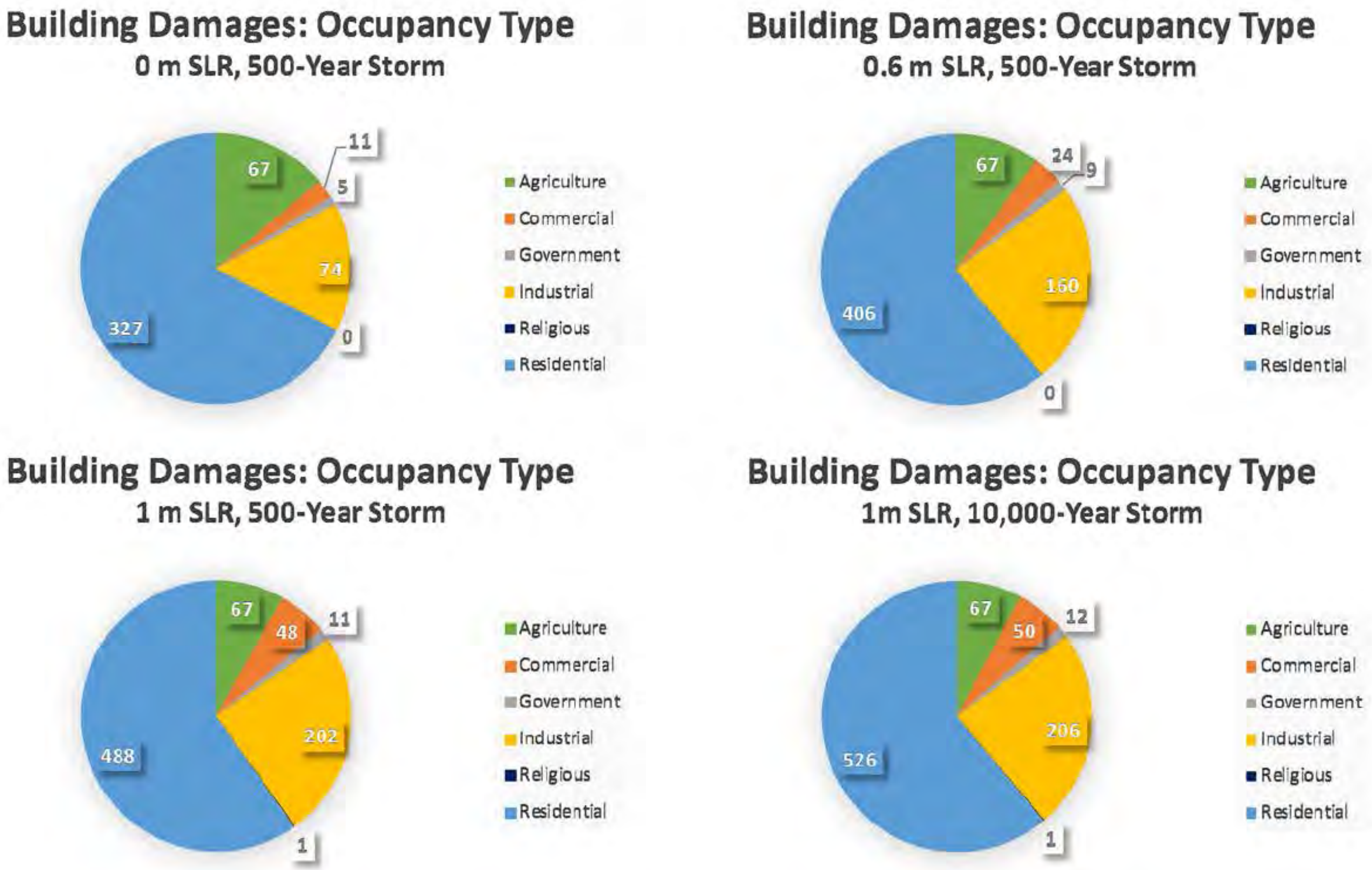


Figure 16: Building damages as total and % damage for (a) 0m SLR, 500-Yr storm (b) 0.6m SLR, 500-Yr storm (c) 1m SLR, 5



Building Damages: Occupancy Type
0 m SLR, 500-Year Storm

Building Damages: Occupancy Type
0.6 m SLR, 500-Year Storm

Building Damages: Occupancy Type
1 m SLR, 500-Year Storm

Building Damages: Occupancy Type
1m SLR, 10,000-Year Storm

Figure 17: Building damages by occupancy type for (a) 0m SLR, 500-Yr storm (b) 0.6m SLR, 500-Yr storm (c) 1m SLR, 500-Yr storm (d) 1m SLR, 10,000-Yr storm

Figure 18: Map of building damages as total and % damage for (a) 0m SLR, 500-Yr storm (b) 0.6m SLR, 500-Yr storm (c) 1m 500-Yr storm (d) 1m SLR, 10,000-Yr stor

There is a significant number of anticipated building damages as a result of coastal flooding in the City of Vancouver, with almost 500 damaged buildings assuming a 500-year storm with present-day sea level conditions. The number of damaged buildings increases with the severity of the storm and flood event, with 860 damaged buildings under scenario 4. Another important consideration is the level of damage that is incurred under the various scenarios. For scenario 1, the present-day, more than three-quarters of buildings suffer minimal damages (< 20% damage), which correlates to a building "getting its feet wet" and requiring the replacement of floors, carpets, lower drywall, etc. but no major renovations. However, under the same storm scenario with 1 m of sea level rise (scenario 3) there are significantly more damaged buildings, and each of these buildings suffers more damage. 38 buildings in this scenario are shown to have damage approaching the 50% mark, which is generally considered to be the "write-off" point.

When looking at building damage by sector, it is clear that the majority of buildings at risk are residential homes; this is true through all scenarios. Significant industrial building damage is also expected through all scenarios; the industrial buildings are primarily located in the Fraser River floodplain, with some additional buildings, especially for the larger flood events, along the Burrard Inlet foreshore.

Building Losses

Hazus also provides estimates of dollar costs and losses for building stock damage. Although estimates have been calculated, due to concerns about the robustness of the data, actual dollar costs are not included in this report. Relative losses across geographic space, across landuses and between hazard scenarios are presented below.

Dollar losses are divided into three categories:

Building Loss: This is the expected cost to repair or replace the building structure. It is calculated based on the building (not land) value and the amount of damage it would incur. The damage is a function of the depth of water and the type of structure (residential, commercial, etc., wood, concrete, etc. and storeys, basement, etc.).

Content Loss: Contents are defined as furniture and other equipment that is not integrated with the structure. Content value is estimated from the building value and varies between 50% and 200% depending on the class of use. For example, residential contents are assumed to be 50% the value of the building, whereas some industrial contents are assumed to have a value of 150% the value of the building. Content losses are calculated as a function of the content value and a depth-damage curve that varies with building class.

Inventory Loss: Inventory losses are ascribed to all non-residential building classes (industrial, commercial, agricultural, etc.). Inventory value is calculated as a function of the building size (in sq.ft), the building class and algorithms that define annual sales volumes for various industries. As for building and contents, losses are calculated as a function of the inventory value and a % damage.

Losses for the various scenarios are summarised in Figure 19 through Figure 21.

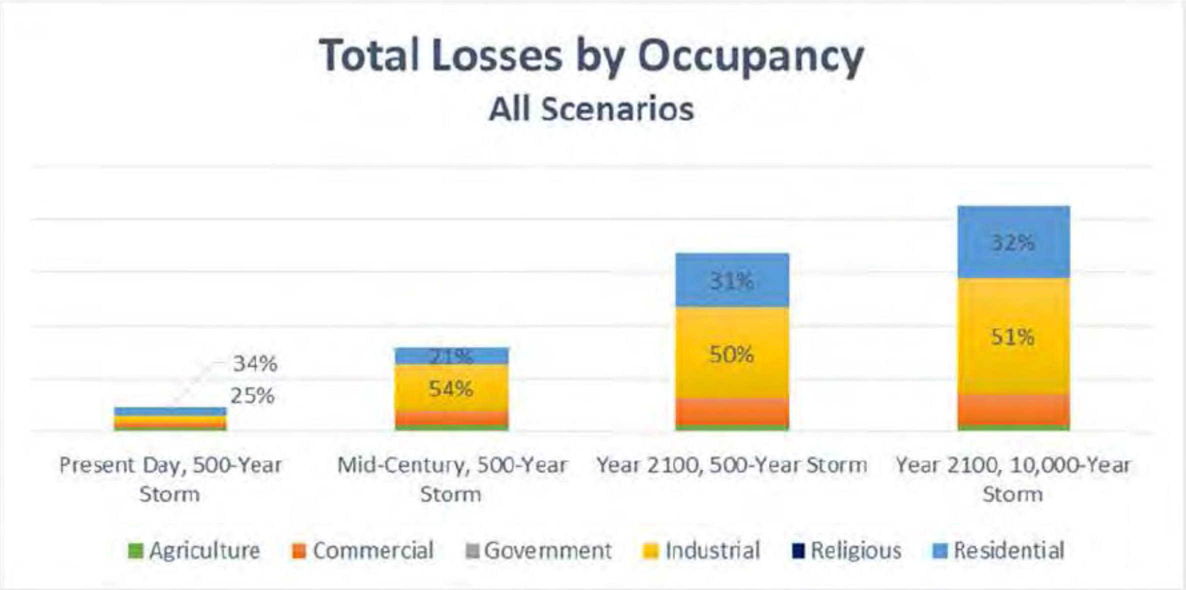


Figure 19: Total losses by occupancy (land use) for all scenarios

Figure 20: Total infrastructure and content losses for all scenarios

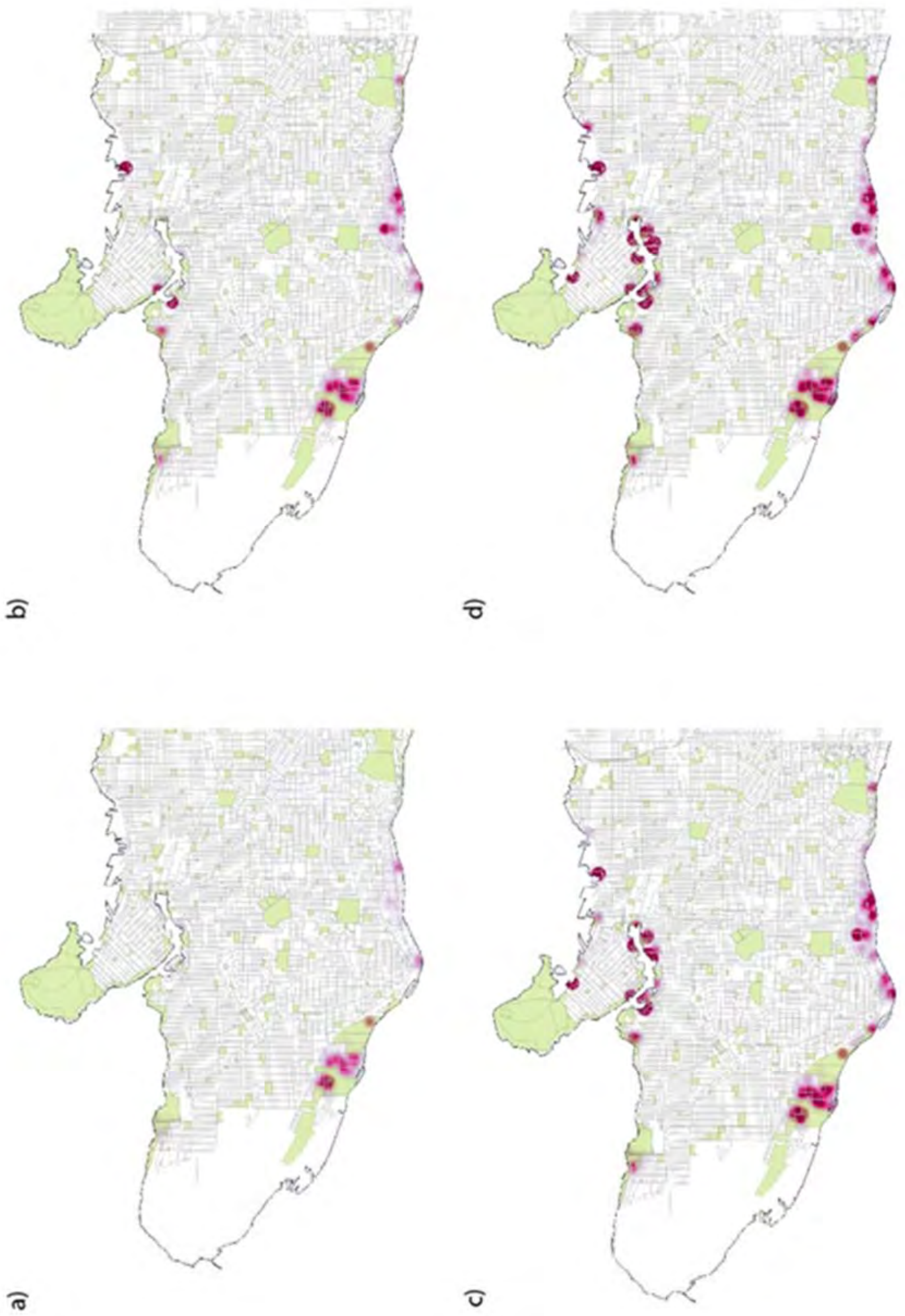


Figure 21: Map of building losses for (a) 0m SLR, 500-Yr storm (b) 0.6m SLR, 500-Yr storm (c) 1m SLR, 500-Yr storm (d) 1m SLR, 10000-Yr storm

Figure 22: Map of total losses for (a) 0m SLR, 500-Yr storm (b) 0.6m SLR, 500-Yr storm (c) 1m SLR, 500-Yr storm (d) 1m SLR, 10000-Yr storm

The results show that there is significant losses expected from building damage as a result of coastal flooding. Even under present-day sea level conditions large losses are anticipated. A significant proportion of the losses are ascribed to content and inventory damages; this is not surprising given the large number of industrial buildings that are inundated (see Figure 17); industrial and commercial content and inventory losses are presumed to be a larger percentage of the building value than for residential buildings. Spatially, the Fraser River floodplain is shown to have significant losses in both the residential Southlands area and in the industrial lands further east in the present day and in the future. Granville Island is another significant hotspot for building losses, particularly under the 1 m SLR scenarios.

The calculated losses for building stock damages are large, and certainly warrant thought with regards to mitigation and adaptation on their own. These are however, only a very small proportion of the direct losses that would be expected from a flood event. For example, municipal infrastructure (other than community centres) is not accounted for in the Hazus analysis. Further description of some of the losses not accounted for are found in Section 3 of this annex.

Recent Estimates of Damage Costs from Flood Events

To provide some context to the City of Vancouver in terms of what might be expected in terms of damage costs, research into recent Canadian flood events was conducted. Specifically, the City of Calgary event of 2013 was examined.

In June 2013, Southern Alberta received significant rainfall which resulted in swollen rivers across large swaths of the province. Some of the largest impacts were seen in the City of Calgary, where the downtown core was impacted by overflows from the Bow and Elbow Rivers. There is no publically available audit of this event, however with the support of the City of Calgary, some information has been provided to create context for the City of Vancouver (Table 7).

Table 7: Summary of Available Loss Estimates for the City of Calgary 2013 Flood

Loss Type	Description
Damage to residential properties	1. 1,939 of approximately 450,000 residential properties in the City of Calgary were identified as having experienced a reduction in assessed value due to the flood (City of Calgary n.d.) 2. Building and content losses estimated for 100-year flood plain (smaller than extent of 2013 flood) of $787M (Hatch Mott MacDonald 2014)
Business impacts	1. Business loss estimate of $302M from the Conference Board of Canada (not-inclusive of major utilities) (Hatch Mott MacDonald 2014). 2. Approximately 4000 businesses were impacted; approximately 3980 reopened (City of Calgary n.d.)
City infrastructure impacts	1. $445M of identified infrastructure repair costs from 209 separate infrastructure projects (City of Calgary n.d.)

Emergency response costs	1. $55M was spent on the emergency response effort (Panel, Flood, and June 2014).

Although useful, the City of Calgary impacts are not directly transferable to the City of Vancouver. First the areal extent of damage, 20.2 km^2 (Slaney 2014) is larger than the 12.8 km^2 inundation area for Scenario 3 in this report. Second, the City of Calgary experienced prolonged (multiple-day) riverine flooding, whereas the City of Vancouver is exposed to a coastal flood hazard, which is potentially more damaging in the short-term due to wave action, but is less prolonged. Regardless, it can be assumed that a coastal flood event in Vancouver would result in widespread and significant damage costs.

Essential Facilities

The Hazus model reports damage to essential facilities, which it defines as fire stations, hospitals, police stations and schools. This is simply based on the location of essential facilities within the floodplain. There are no essential facilities within the flood extents of Scenarios 1 through 4. The largest scenario (Scenario 5), which consists of 2 m of sea level rise and a significant, 10,000-year storm, results in moderate damage to one school and loss-of-use of another school in the Kitsilano neighbourhood. The lack of infrastructure damage reported by Hazus is largely a function of the limitations of the software. It only considers fire stations, hospitals, police stations and schools as essential infrastructure. There are many other critical infrastructure elements that would be at risk: pump stations, power substations, etc. Many of these are documented in Section 8 of the main report.

Business Interruption Losses

Business interruption costs are calculated by Hazus. These are losses associated with the inability to operate a business due to damage sustained during a flood. Business interruption costs also include temporary living expenses for people displaced from their homes. It does not consider the long-term economic impacts from a flood event. The algorithms used for these calculations are based on U.S. economic data, primarily for manufacturing based industries. This does not reflect the City of Vancouver well; the results are likely gross-underestimates of business disruption costs and are therefore not presented here. Further work into the economic models underpinning Hazus (or an alternative model) needs to be completed before business losses could be considered robust enough to report.

Induced Damage Debris Generation

Photo 2: Calgary Sun image of debris generation in Calgary, June 2013

Hazus estimates the amount of debris that will be generated by a flood. Debris generation can be a significant impact of a flood; this was evident in the 2013 Calgary flood event when debris piled up outside buildings in the immediate aftermath of the flood. The City has recently reported that 24,000 loads[2] of waste were received by City landfills following the flood event (City of Calgary 2014). The model calculates debris quantities based on damages to buildings and on construction type and includes finishes (drywall, insulation, etc.), structural components (wood, brick, etc.) and foundation materials (concrete, rebar, etc.). Debris is reported in tons and as the number of truckloads required to remove the materials. Truckloads of generated debris for the various

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[2] Loads are not defined by the City of Calgary, but are assumed to be equivalent to the truckloads calculated by Hazus.

scenarios is presented in Figure 23. The modelling shows that there will be significant debris generated as a result of a flood event, even in the present-day. This would pose a significant waste management problem for the City and Metro Vancouver.

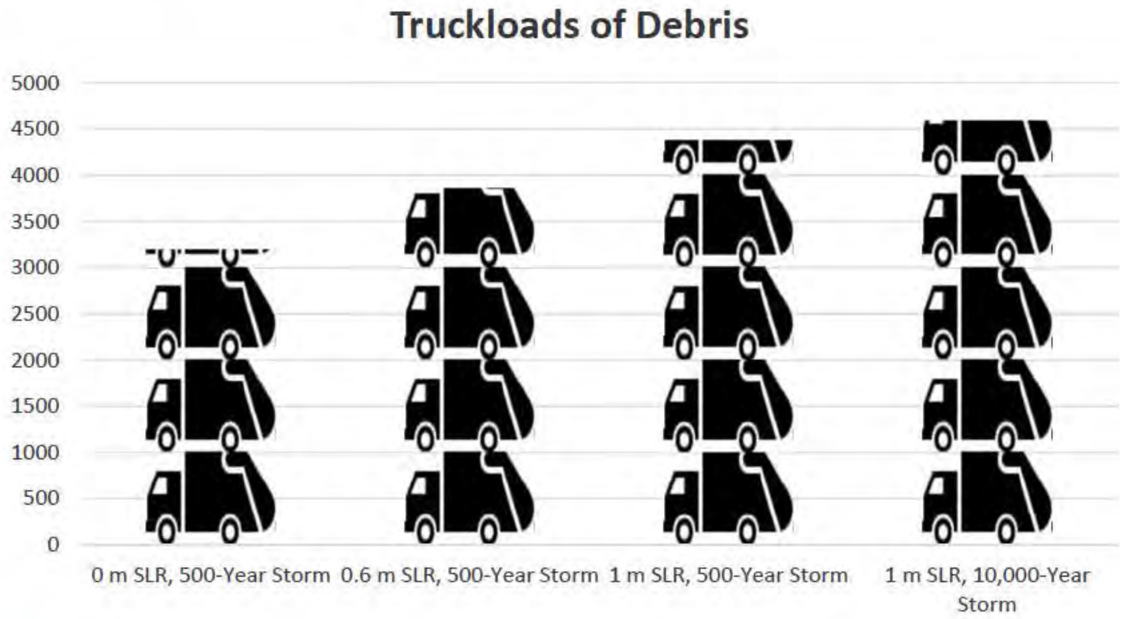

Figure 23: Truckloads of debris generated

Building Scale Impacts

Over the course of the consequence assessment it became clear that there were limitations to the results from the Hazus modelling. As such, alternative approaches to presenting flood consequences were considered. Specifically, building scale impacts using some of the Hazus results along with visualization tools were completed. Potential future impacts to the Jericho Sailing Centre are presented below as an example of what might be expected along the whole Vancouver coastline. The sailing centre was selected as the pilot site because it is an iconic city-owned building that has great value to the citizens of Vancouver beyond the value of the structure itself.

Jericho Sailing Centre

The Jericho Sailing Centre is a well-known community hub located at the tip of Discovery Street on Jericho Beach on Vancouver's west side (Figure 24). It is run by non-profit association with a mandate to provide low cost, highly accessible ocean recreation for small, naturally powered craft. The building itself houses the association offices, a small bar/restaurant and storage facilities for the many association craft. It is a well-regarded and well-used facility; with more than 20,000 people-visits in 2013 (JCSA 2014).

Its location on the waterfront obviously serves its purpose, providing access to the ocean for sailors. However, this also puts the building and the association in a vulnerable location with regards to ocean flooding, especially under rising sea levels.

Figure 24: Jericho Sailing Centre location

The building-scale analysis from Hazus provides some insight into expected damages and losses to the building structure in future. Select results are presented in Table 8, and Figure 25

Table 8: Hazus results for Jericho Sailing Centre

Scenario	Description	Depth of Flooding (m)	% Damage to Building	Building Losses ($Mil)	Total Losses ($Mil)
1	0 m SLR, 500-Year Storm	0.4	9	0.6	3.5
2	0.6 m SLR, 500-Year Storm	1.0	12	0.8	4.8
3	1 m SLR, 500-Year Storm	1.4	15	0.9	5.6
4	1 m SLR, 1000-Year Storm	1.6	16	1.0	5.9

Figure 25: Image of Jericho Sailing Centre under present-day and future (1 m SLR, 500-Year Storm) conditions[3],[4]

If we look beyond the dollar losses that might be incurred by the centre it is clear that given its heavy use by a large diverse community of sailors, this disruption or even potential loss of this

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[3] Stephen Hui Image, Georgia Straight, February 24th, 2012.

[4] Visualisations made using CanVis3, a flood visualization tool developed by NOAA in the US.

facility would have a strong impact on the residents of Vancouver. There is the obvious direct tangible impacts of damage (and potential loss) of the building, but there are also strong intangible indirect impacts that would be expected through the loss of a recreational amenity, and the community that uses the facility.

The impacts to the sailing centre presented above provide a good example of the variety of impacts that might be expected to the city as a whole.

Summary of Hazus Results

The Hazus modelling, although limited in scope relative to the larger scale of impacts expected from a flood event, does provide some excellent insight into expected damages and losses that might be experienced by the City of Vancouver. In particular, it shows that that a coastal flood event will have a big impact on people, first and foremost, displacing thousands of families in the short term, and causing disruption to hundreds of families while their residences are cleaned and repaired post-disaster. The results also show that a significant number of businesses—particularly industry along the Fraser River—will be impacted, both by direct damage to buildings as well as loss of inventory. The damage costs calculated by Hazus were not considered reliable at this time as the model has not been calibrated or validated for Canada. However, based on the damages incurred in other recent flood events, it is reasonable to expect that the costs of a major coastal flood in Vancouver would be widespread and significant.

6. Challenges, Resources and Next Steps

The City of Vancouver is an early-adopter in its use of a flood risk assessment to inform policy. This of course creates many challenges some of which may be overcome in time, but some of which are insurmountable and must therefore be recognised as a limitation to the process. The goal of this section of the consequence report is to outline some of the challenges to complete a flood consequence and risk assessment for the City, with some specific challenges resulting from being the first major user of Hazus Canada. Resources and recommendations for each of the identified challenges are also laid out as appropriate.

Intangibility of Flood Impacts and Damages

As discussed in Section 3, flood impacts can be either tangible or intangible. The intangible impacts being essentially non-quantifiable. Obviously, this poses a problem when the intangible impacts may be equally important and valid.

Background

As we transition from a period of flood planning and damage mitigation based on a standards based approach to a more holistic risk based approach to flood mitigation, there has been a significant increase in the knowledge base around flood impacts. As discussed in Section 3 of this annex, the impacts of flooding are widespread and affect people, infrastructure, the economy and the environment. Flood damage estimation has traditionally been the domain of engineers and as such as focussed on economic valuation of infrastructure and building losses, leaving a large gap in knowledge (F Messner and Meyer 2006). This gap has increasingly been acknowledged, but there is still very limited validated research available, and tools to look at intangible impacts are large undeveloped. It is however known that when damages are monetised buildings become priorities for flood mitigation, whereas when damage is expressed as the number of people affected by a flood (through stress or inconvenience) that road flooding (and resultant damage and closures) become a mitigation priority (J. A. E. Veldhuis 2011). The metrics chosen to look a flood damage can deeply impact the result and subsequent planning decisions.

Proposed Next Steps

The non-inclusion of intangible impacts will impact the City of Vancouver consequence assessment. We need to recognise that the results presented to date as a weakness of the current process. There is promising new research into methods that take intangible effects into consideration including the revealed preferences method, stated preferences method, benefit or value transfer methods, hedonic pricing, replacement cost method and choice modelling of life satisfaction (Meyer et al. 2013). We anticipate that the Structured-Decision-Making process proposed for the second phase of work will be able to tease out some of the intangible impacts and include them in decision making.

Uncertainty in Model Input

Background

Model results can only be as good as the input data. For the purposes of this study, there are two main input datasets. First, the hazard information in the form of flood-depth grids for various events and second, the asset information describing the elements at risk on the floodplains. The hazard modelling is based on the best available science and modelling techniques. It is, like all models, subject to some error; it is however not to be improved upon using existing data and techniques. The asset information is less robust. This is primarily because the available data to describe floodplain assets was not developed with flood damage in mind. For example, detailed information on foundation-types or elevations of first floors is generally not available. Significant efforts have been made by the City to ensure that the database used for the project is as accurate and complete as possible. However, many proxies and expert judgements were used to develop the database (see Section 4).

Proposed Next Steps

At this time, no changes or updates to the hazard modelling are recommended. And, in the short-term no changes are suggested for the UDF database other than the inclusion of missing buildings as data becomes available.

In the longer-term, it is recommended that the City put systems in place to collect relevant information. For example, for all new buildings and significant renovations within the 2m SLR, 10,000-Year floodplain relevant information should be stored within the city systems. This includes first floor elevations, the presence/absence of a basement, structure material (wood, concrete, masonry, etc.), and any floodproofing measures.

Uncertainty and Sensitivity in Stage-Damage Curves

Stage-damage curves are a key component of Hazus modelling and flood consequence modelling in general. Research has shown that along with information about the assets that depth-damage curves are the most important source of uncertainty in consequence modelling (P. Bubeck et al. 2011; Jongman et al. 2012a) , and can affect the end results by a factor of 2 (Moel and Aerts 2010). It is therefore extremely important that care and attention is paid to the applicability and robustness of the stage-damage curves used in the Hazus modelling for the City of Vancouver.

Background

Specific issues with the default curves currently applied in the model include: the transferability of stage-damage curves, errors in stage-damage curves for shallow depths of flood, the omission of velocity and waves from the default curves. More details are provided below.

Transferability of Stage-Damage Curves

It is well known that stage-damage curves are inherently uncertain, but continue to be used as they are the best available tool for flood consequence assessments. One major issue is the paucity of available stage-damage curves, there are only half a dozen or so publically available datasets. And as such, these datasets tend to be broadly used without full consideration of the applicability and transferability of these functions to a new geographical region. Recent research has shown that stage-damage curves aren't directly transferable, and that care should be taken to at least select curves from related regions with similar flood and building characteristics (Cammerer, Thieken, and Lammel 2013).

Uncertainty in use of Stage-Damage Curves for Shallow Depths

Furthermore, it is also known that available stage-damage curves are not applicable for shallow flood depths, and tend to underestimate damages and losses (Bruno Merz and Thieken 2009; J. a E. ten Veldhuis and Clemens 2010). For the City of Vancouver scenarios, large swaths of land are shown to have relatively shallow depths of flooding, and would therefore be subject to this error.

Information Gap for Stage-Damage Curves for Industry and Commercial Sector

A large portion of the flood hazard areas in the City of Vancouver are industrial zones, and therefore many industries are at risk. There is very limited information available on stage-damage functions for industry, this is mostly due to the variation in industry (Booysen, Viljoen, and Villiers 1999). Inventory (content) losses in Hazus are generally assumed to be 100% the value of the building (Department of Homeland Security. Federal Emergency Management Agency 2009b: Table 14.6). This may be true of some traditional manufacturing businesses, but is unlikely to reflect the potential losses from a high-tech industrial plant. Research has shown that the only reliable way to estimate losses from industrial areas is to establish on a case-by-case basis what is housed in industrial buildings on the floodplain; a large amount of effort. Similarly, there is limited information on commercial losses – Hazus uses the same approach for both industry and commerce and assumes the damage of inventory is directly correlated to the value of the building. Some research has recently been conducted on commercial losses (Heidi Kreibich et al. 2010), which again shows that considerable effort should be taken to look at local circumstances.

Omission of Velocity from Damage Curves

Velocity is known to be a key factor in the damage of buildings in a flood, however few empirical databases exist that describe expected damages under a combination of depths and velocities (Kelman and Spence 2004; Middelmann-Fernandes 2010). And, no velocity is used in the default Hazus curves at this time. H. Kreibich et al. 2009 suggests that this may not be an oversimplification for damage to buildings, although road damage is highly sensitive to velocity. Road damage is not at this time considered in Hazus (see below). Very new research into velocity-induced damages is being conducted in Europe (Nadal et al. 2010) and may eventually be incorporated into Hazus. In the meantime, it is important to consider that damage estimates from Hazus are likely underestimates.

Robustness of Wave Damage in Curves

Similar to velocity, intuitively it makes sense that waves would damage buildings more than slack water. Hazus does have a coastal damage feature enabled, however the relative difference in the damage curves for a riverine versus a coastal zone is negligible. This is a known problem with Hazus that has been recognised by the developers. For example, based on recent validations the coastal damage functions are incorrect, only estimating 33% of the actual loss – especially for high rise buildings such as those found in False Creek (Todorov 2013). Mapping for this project has shown that only a few areas (Kits Point and Jericho) would be subjected to significant waves.

Lack of understanding of surge flood damages vs slow-rise riverine flood damages

As alluded to above, the majority of research into flood damages has been conducted for instances of riverine flooding, where the mechanism of flooding tends to be slower and lower-energy than for coastal flooding. Recent studies have shown that the time-to-peak plays a significant role in flood damages (Nadal et al. 2010). For example damage resulting from a coastal storm surge, tsunami, or dike breach could be 40% higher than for the same building with the same depth of water from a slowly increasing river flood.

Proposed Next Steps

Clearly, there are many uncertainties associated with the use of the default depth-damage curves in Hazus. However, this is the best available information at this time. In order to move this project forward the following recommendations are made:

Recommended for Phase 2 work

1. Hazus Canada is the best available tool for flood consequence assessment in Canada today. It does however have many fallibilities, many of which have been identified in this report. At this time, we recommend that the results from the Hazus modelling be used as a basis for going forward with flood mitigation planning (Phase 2). But, that the results be viewed at an aggregate, big picture scale, for relative comparisons of damage. It should not be used for detailed cost-benefit assessments at this time.

Recommended near-term work if funds are available

2. Natural Resources Canada is now aware of the issues with the default stage-discharge currently used in the Canadian version of the program. We recommend that the City of Vancouver work with Natural Resources Canada and other stakeholders to complete a comprehensive review of the curves in the program, and, to in the first instance, update the information with more appropriate curves from non-US flood damage databases. Many of the major issues with the curves have already been identified in this document, which can be used as a starting point for this research. Possible alternative damage databases include:

Table 9: Alternate databases for depth-damage curves

Model/Database	Origin	References
FLEMO	Germany	(P. Bubeck et al. 2011; Jongman et al. 2012a; Heidi Kreibich et al. 2010; B. Merz, Kreibich, and Lall 2013; B. Merz et al. 2010b; Bruno Merz, Thieken, and Kreibich 2011; Bruno Merz and Thieken 2009; Moel and Aerts 2010; Seifert et al. 2009; Thieken et al. 2008)
HOWAS	Germany	(Jongman et al. 2012b; Frank Messner et al. 2006;

		Meyer et al. 2013)
ANUFlood	Australia	(Middelmann-Fernandes 2010)
Multi-Coloured Manual	UK	http://www.mcm-online.co.uk/
“Standard Method”	Netherlands	(Philip Bubeck 2007; Jonkman et al. 2008)
FDRP Era (1970s and 1980s) Curves	Canada	(McBean, Fortin, and Gorrie 1986)
Red River Curves from 1997 event	Canada (Manitoba)	(KGS 2000)
Saint–Laurent Valley Curves	Canada (Québec)	(Doyon et al. 2004)

Recommended long-term work if funds are available

1. Canada has recently experienced several damaging floods: Calgary and Toronto 2013 and Richelieu 2011 for example. It may be possible to pursue the development of Canadian-specific curves from these events with appropriate research partners. Potential partners include Natural Resources Canada, Alberta Environment and Sustainable Resource Development, Public Safety Canada, the Institute for Catastrophic Loss Reduction at Western University and the insurance industry.
2. The City should create a fund, so that should a coastal flood event occur in Vancouver, the City can properly document the event hazard, damages and losses. This potential dataset would be invaluable to future flood consequence and risk research in the City.

Gap in Infrastructure Damage and Losses

Background

It is anticipated that city infrastructure would be subjected to significant damage and loss under a flood event. This includes roads, sewers, street furniture, etc. This represents not only direct dollar losses from repairs or replacement, but would also create significant social and economic losses as large swaths of the city might be without services or access for a period of time. Causing both inconvenience and more direct economic losses from loss of business. At present, the Canadian Hazus flood model does not ‘damage’ infrastructure; it only reports the value of infrastructure in the flood region. At present there is very limited information or tools available to estimate infrastructure damage. FEMA has acknowledged that there is a lack of data and has proposed changes to the Hazus model in future to better reflect the impacts of losing infrastructure (critical infrastructure and lifelines in particular) (Department of Homeland Security. Federal Emergency Management Agency 2009b).

Next Steps

The present model does not properly calculate damages and losses to infrastructure, but there are no robust methodologies or tools available to do this type of work. It may be possible to leverage information from neighbouring Alberta, Calgary specifically, who recently experienced a large flooding event. Information regarding the cost-to-repair municipal infrastructure from the 2013 flood event could be used as a proxy to estimate damages to the City of Vancouver; some information from Calgary is presented in this report.

Gap in business interruption costs

Background

Hazus provides basic estimates of business interruption costs. However, based on recent discussions with the Natural Resources Canada and UBC SCARP research team that has developed a Hazus model for earthquake damage and consequence for the District of North Vancouver, the direct results from Hazus are thought to be a gross underestimation. Best practices for business disruption costs general require applying sector-specific reference values (e.g. the loss of added value per employee per day) (Meyer et al. 2013). This type of approach is being applied in the District of North Vancouver

Proposed Next Steps

A similar methodology as described above could be explored and eventually applied to the City of Vancouver. This could potentially be an excellent project for a student.

Uncertainty in Social Losses

Background

Social losses are generally considered to be intangible and are therefore difficult to calculate. Hazus does produce some social loss information based on demographics – including estimates of displaced households and of the number of people who will seek shelter. The sheltering needs are based on displaced population (with some factors for income and age). Unfortunately, the income distribution that drives sheltering (higher income, young people are assumed to be more able to shelter themselves) is based on older US statistics, where someone with an annual income of $35,000 is considered high income. This does not reflect reality in Vancouver. And therefore we anticipate that the sheltering needs calculated by Hazus will be too low. At this time the income spread is hard-wired into the code and we are not able to adjust it.

Proposed Next Steps

At present, we propose to use the social loss results from Hazus in a general sense, mostly to describe geographic variations – for example, that more people will seek shelter from the False Creek area than from Southlands. Second, we suggest that the City continue to work with Natural Resources Canada to update the Hazus algorithms to better reflect the demographics of Canada and Vancouver in particular.

Environmental Losses

Background

As outlined in the vulnerability annex, many of the potential impacts that Vancouverites care about are environmental damages and losses. Unfortunately, these are not modelled in Hazus, nor are there methods for environmental losses readily available in the literature. This is for two reasons: first, that to date environmental damages have not been considered a priority, and second, they are largely intangible.

Next Steps

As the project moves into Phase 2, we recommend that further research into best management practices in this area be conducted. In the meantime we recognise that environmental losses are a gap in the results. As for the other intangible damages and losses, the structured decision making process proposed for Phase 2 should help with the consideration of environmental trade-offs in any flood mitigation projects.

Summary

If we revisit the gap model presented in Section 4 using the information presented in the challenges, resources and next steps section, city priority vulnerabilities can be grouped according to the potential for their future valuation (Table 10).

Table 10: Summary of identified vulnerabilities to coastal flooding by ability to quantify

Impact	Elements at Risk
Quantified and Presented	▪ Fire halls and police stations ▪ Commercial and residential low-rise buildings, some with basement suites ▪ Industrial buildings ▪ High-value real estate
Quantifiable with minimal effort (within Phase 2 timeline)	▪ Water and sewer pump stations, overflows and pipes ▪ Neighbourhood energy infrastructure ▪ City yards
Quantifiable with moderate effort (requires additional data or refined methodology)	▪ Major rail lines ▪ Rapid transit tunnels ▪ Electricity substations and transmission lines ▪ Commercial and residential towers ▪ Port ▪ Commercial service centres ▪ Industrial "green jobs zone" and produce depots
Quantifiable with substantial effort	▪ Transport hubs (train station and yards, bus station, rapid transit) ▪ Tourist destinations (parks, beaches, major restaurants, hotels and hostels, cruise ship terminal, parks, beaches, Granville Island) ▪ Water-dependent industries (marinas, etc.) ▪ Potential contamination from hazardous waste storage and infill soils ▪ Non-market housing ▪ Seniors housing and day-centres ▪ Childcare and pre-schools ▪ Schools and educational facilities (including libraries)
Intangible	▪ Community centres ▪ Homeless shelters ▪ Emergency shelters and mass refuges

	▪ Food banks ▪ Social service centres ▪ Animal shelters ▪ Pools, rinks, sports fields ▪ Museums and archives ▪ Galleries and cultural destinations ▪ Heritage sites ▪ Ecological value of shoreline areas ▪ Parks and beaches

As the City moves to Phase 2 there is some opportunity to improve on the consequence assessment, especially by adding some of the quantifiable elements to the existing assessment. Furthermore, the structured-decision-making process proposed for the Phase 2 should help with the consideration of the many hard to quantify or intangible elements.

7. Conclusion

Over the course of the project, the team has recognized the many uncertainties and gaps in the process of developing a CFRA for a modern, dense, vibrant, urban city such as Vancouver. Especially when considering the long planning horizons required to prepare for and adapt to sea level rise. This annex highlights the many obstacles and gaps in the assessment, but also alludes to the inherent value of the process and results:

Increased knowledge of hazards: Up until the development of hazard mapping for this project, the City of Vancouver lacked detailed floodplain maps. These provide high value to the city as they inform the current standards-based policies (e.g. flood construction levels). Furthermore, the hydrodynamic model results includes depths and velocities, which can be used for emergency management mapping.

Increased knowledge of relative difference between hazard scenarios: One of the goals of this project was to look at the changes to the floodplain extents and depths over time with sea level rise. The inundation mapping clearly shows regions of the City that are currently ‘safe’ from coastal flooding, but that will ‘tip’ in future and become floodplains.

Increased knowledge of vulnerabilities: The project included an assessment of vulnerable assets on the existing and future floodplains. Understanding the elements at risk will inform future planning and policy.

Increase in city engagement and capacity: Many dozens of people were involved in the project. Each interaction with the stakeholders has hopefully resulted in increased awareness in the issues of climate change, and the need to prepare for and adapt for its impacts. Numerous maps (hazards, vulnerability hotspots, consequence hotspots) and other visual aids have been developed for this project that will continue to aid in engagement and education, which will hopefully lead to action.

Increased understanding of gaps: The process of documenting the gaps and uncertainties associated with a CFRA will help the project team as it moves forward. Some of the gaps will be filled in time, others will merely be identified and acknowledged.

As coastal cities grapple with climate change and sea level rise in particular, there is an urgent need to begin planning for adaptation and mitigation that will reduce our risk to coastal floods in future. This need far outweighs the risk of moving ahead with imperfect information. As practitioners, we need to recognize that we are not going to get the risk calculation perfectly right, or perhaps even close, but that we can use the best available tools and data to make informed decisions. These decisions will hopefully increase our resiliency to coastal flooding in a changing climate.

Options for the future

The first phase of work for the City of Vancouver CFRA focussed on establishing coastal flood hazard, vulnerabilities and consequences in the present day in into the future. This is the grounding information that will inform the second phase of work, which has the objective of providing adaptation and mitigation options to the City.

As yet, we don't know what these options are, and what will be the preferred route for the City of Vancouver. However, we can learn from other communities who are already working on improving the resilience of floodplain communities. Figure 26, from the Queensland (Australia) Reconstruction Authority, shows the process and tools that jurisdiction is using to increase floodplain resilience, in the wake of devastating floods in 2011.

Figure 26: Example of flood management process and options for floodplain resilience (Queensland Reconstruction Authority 2013)

The many tools that were developed as part of the CFRA Phase 1 project will directly inform the second phase of work. And, even though they are acknowledged as being far from perfect, if used carefully, they can be used to make informed and good policy and planning decisions for the City of Vancouver.

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