WRITTEN EVIDENCE OF THE CITY OF VANCOUVER **APPENDIX 52**
Levelton Consultants Ltd. Report
"Air Quality Impacts from Simulated Oil Spills in Burrard Inlet & English Bay"

LEVELTON

Metro Vancouver

Air Quality Impacts from Simulated Oil Spills in Burrard Inlet & English Bay

Air Quality Dispersion Modelling Report

Submitted by:
LEVELTON CONSULTANTS LTD.

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OQM | Organizational Quality Management Program

DISCLAIMER

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EXECUTIVE SUMMARY

Levelton Consultants Ltd. (Levelton) understands that Metro Vancouver and other intervenor(s) have identified gaps in the oil spill modelling work conducted by Trans Mountain Pipeline ULC (Trans Mountain) in their filings to the National Energy Board (NEB) for the Trans Mountain Expansion Project (the Project). Metro Vancouver has worked in collaboration with other intervenor(s) who have developed an oil spill trajectory model for the Burrard Inlet area and English Bay. Levelton was retained by Metro Vancouver to characterize air contaminant emissions based on the output of the oil spill trajectory model, and conduct air dispersion modelling using the CALPUFF model which predicts ambient air concentrations of various air contaminants. This report details the methodology used to characterize the emissions and conduct air dispersion modelling based on Levelton's investigations to date in collaboration with Metro Vancouver and Genwest Systems Inc. (Genwest), and presents the results as compared to relevant ambient air quality objectives and emergency health-based benchmarks.

The assessment methodology utilized a number of computer models. The General NOAA Operational Modelling Environment (GNOME) model from the United States Department of Commerce, Office of Response and Restoration Emergency Response Division was used to characterize the geographic extents of potential oil spill scenarios. Geographic Information System (GIS) routines were used to process GNOME output into an air dispersion model ready input format. Crude oil emission evaporation rates for various pseudo-components were derived from the oil evaporation subroutines (OilWx) used within the Response Options Calculator (ROC) model from Genwest. Information generated from GIS and OilWx was used as input parameters into the CALPUFF air dispersion modelling system to predict air contaminant concentrations from various pseudo-components from each of the simulated scenarios.

A total of four spill locations were modelled in this study considering an instantaneous spill of either 8,000 cubic metres (m^3) or 16,000 m^3 depending on the location as outlined below:

1) **English Bay**: (Latitude: 49.289444, Longitude: -123.199722)
   16,000 m^3 Instantaneous Spill
2) **First Narrows Bridge:** (Latitude: 49.315409, Longitude: -123.138569)
   16,000 m^3 Instantaneous Spill
3) **Second Narrows Bridge:** (Latitude: 49.295371, Longitude: -123.024432)
   16,000 m^3 Instantaneous Spill
4) **Westridge Terminal**: (Latitude: 49.291089, Longitude: -122.950338)
   8,000 m^3 Instantaneous Spill

In order to capture a range of possible tidal and meteorological conditions possible during a spill, a total of 12 unique time periods for each of the four spill locations were modelled for a total of 48 scenarios. This assessment is not meant to be comprehensive of all possible tidal and meteorological combinations that may be present during a potential oil spill, but rather the assessment is intended to show potential impacts of a limited set of tidal and meteorological conditions selected using specific screening criteria.

For spill locations, based on the maximum predicted one-hour benzene results, the population exposed was calculated to provide context around the dispersion modelling results. The population exposed was calculated using 2011 census block level population data from Statistics Canada to determine the number of people living within the maximum predicted one-hour benzene concentration contours corresponding

to the acute inhalation exposure limit and health exposure guidelines. Also based on the maximum predicted one-hour benzene results, an analysis was conducted to determine the total land use area within the maximum predicted one-hour benzene concentration contours corresponding to acute inhalation exposure limit and health exposure guidelines, and the current land use percentages within each of these concentration bands was determined to gain a further understanding of the potential areas affected.

Results from the air quality modelling assessment were compared to acute inhalation exposure limits and the Protective Action Criteria (PAC) from the US Department of Energy Emergency Management Issues Special Interest Group (DOE EMI SIG). The PAC was used as an additional health exposure guideline, in order to predict the potential health effects to the general public if they were exposed to a particular hazardous chemical if a spill were to occur.

The PAC is a hierarchy-based system that is comprised of three common public exposure guideline systems, in the order of preference: Acute Exposure Guideline Levels (AEGLs), Emergency Response Planning Guidelines (ERPGs), and Temporary Emergency Exposure Limits (TEELs).

PAC have three tiers of exposure limits for each chemical (PAC-1, PAC-2, and PAC-3), and each successive tier is associated with an increasingly severe effect that involves a higher level of exposure. The DOE EMI SIG defines the PAC tiers as threshold levels as follows[1]:

- "PAC-1: Mild, transient health effects.
- PAC-2: Irreversible or other serious health effects that could impair the ability to take protective action.
- PAC-3: Life-threating health effects."

The following conclusions have been drawn regarding potential impacts from the air emissions associated with the simulated oil spills considered in this assessment:

- The study area was not large enough to capture the full extent of the potential impacts and only a few spill locations and meteorological conditions were considered. If the study area was larger and a greater number of possible spill locations and meteorological conditions were considered, the results would indicate a greater population affected and likely indicate higher concentrations than reported herein.
- There are predicted exceedances for the majority of pseudo-components, modelled as surrogate chemicals, of acute inhalation, PAC-1, or PAC-2 exposure thresholds.
- There are predicted exceedances for i-butane, n-pentane and n-hexane, modelled as surrogate chemicals, of PAC-3 exposure thresholds over water.

[1] *United States Department of Energy, 2012. Protection Action Criteria (PAC): Chemicals with AEGLs, ERPGs, & TEELs. Rev. 27, February 2012.*

- There are no predicted exceedances for any pseudo-components, modelled as surrogate chemicals, of PAC-3 exposure thresholds over land areas.

- There are predicted benzene PAC-2 exceedances over water and land areas, however, not in areas where people live according to the Statistics Canada census data (2011). The exceedances of the benzene PAC-2 levels have been predicted for areas where people may be present including Stanley Park, Lions Gate Bridge, Second Narrows Bridge and over water. Note this analysis was only conducted for benzene.

- The Texas Commission on Environmental Quality (TCEQ) acute inhalation exposure benzene limit was exceeded in large areas of the study domain affecting a range of 133,100 to 1,077,700 people within the model domain for the different spill locations and scenarios considered. Note that the acute inhalation exposure limit contour extends beyond the model domain for all spill locations and therefore these are likely underestimates of the potential population affected.

- The PAC-1 threshold for benzene was exceeded in areas affecting for a range of 2,600 to 31,400 people within the model domain for the different spill locations and scenarios considered.

- The acute inhalation exposure limit was exceeded for benzene in an area covering from 75 km^2 to 580 km^2 within the model domain for the different spill locations and scenarios considered.

- The PAC-1 threshold was exceeded for benzene in an area covering from 7 km^2 to 42 km^2 within the model domain for the different spill locations and scenarios considered.

- The maximum predicted one-hour benzene concentrations decrease below the PAC-1 threshold six hours after an oil spill, yet are still above the acute inhalation exposure limit, for all spill locations and scenarios considered.

- The maximum predicted one-hour i-butane concentrations decrease below the PAC-1/PAC-2 threshold two hours after an oil spill, and are below the acute inhalation exposure limit by the fifth hour, for all spill locations and scenarios considered.

- The maximum predicted one-hour concentrations for benzene and i-butane from an oil spill is during the first hour following an oil spill. Therefore, the greatest human health risk from benzene and i-butane is likely to occur during the first hour following an oil spill based on the simulated scenarios considered.

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1 INTRODUCTION

Levelton Consultants Ltd. (Levelton) understands that Metro Vancouver and other intervenor(s) have identified gaps in the oil spill modelling work conducted by Trans Mountain Pipeline ULC (Trans Mountain) in their filings to the National Energy Board (NEB) for the Trans Mountain Expansion Project (the Project). Metro Vancouver has worked in collaboration with other intervenor(s) who have developed an oil spill trajectory model for the Burrard Inlet area and English Bay. Levelton was retained by Metro Vancouver to characterize air contaminant emissions based on the output of the oil spill trajectory model, and conduct air dispersion modelling using the CALPUFF model which predicts ambient air concentrations of the various air contaminants. This report details the methodology used to characterize the emissions and conduct air dispersion modelling based on Levelton's investigations to date in collaboration with Metro Vancouver and Genwest Systems Inc. (Genwest), and presents the results as compared to relevant ambient air quality objectives and health-based benchmarks.

2 METHODOLOGY

The assessment methodology utilized a number of computer models. The General NOAA Operational Modelling Environment (GNOME) model from the United States Department of Commerce, Office of Response and Restoration Emergency Response Division was used to characterize the geographic extents of potential oil spill scenarios. Geographic Information System (GIS) routines were used to process GNOME output into an air dispersion model ready input format. Crude oil emission evaporation rates for various pseudo-components were derived from the oil evaporation subroutines (OilWx) used within the Response Options Calculator (ROC) model from Genwest. Information generated from GIS and OilWx was used as input parameters into the CALPUFF air dispersion modelling system to predict air contaminant concentrations from various pseudo-components from the simulated scenarios.

A total of four spill locations were modelled in this study at the following locations: Westridge Terminal, First Narrows Bridge, Second Narrows Bridge, and English Bay (Anchorage 8). Further details are provided in Section 2.1.

This assessment is not meant to be comprehensive of all possible tidal and meteorological combinations that may be present during a potential oil spill, but rather the assessment is intended to show potential impacts of a limited set of tidal and meteorological conditions selected using specific screening criteria. The worst case has likely not been captured as it is dependent on a number of variables, including: tidal conditions, meteorological conditions, and oil evaporation rates. However, a sensitivity analysis was conducted in an attempt to capture periods with poor dispersion characteristics, which is described in detail in Section 2.5.

A flowchart outlining the air quality assessment methodology is shown below in Figure 2-1.

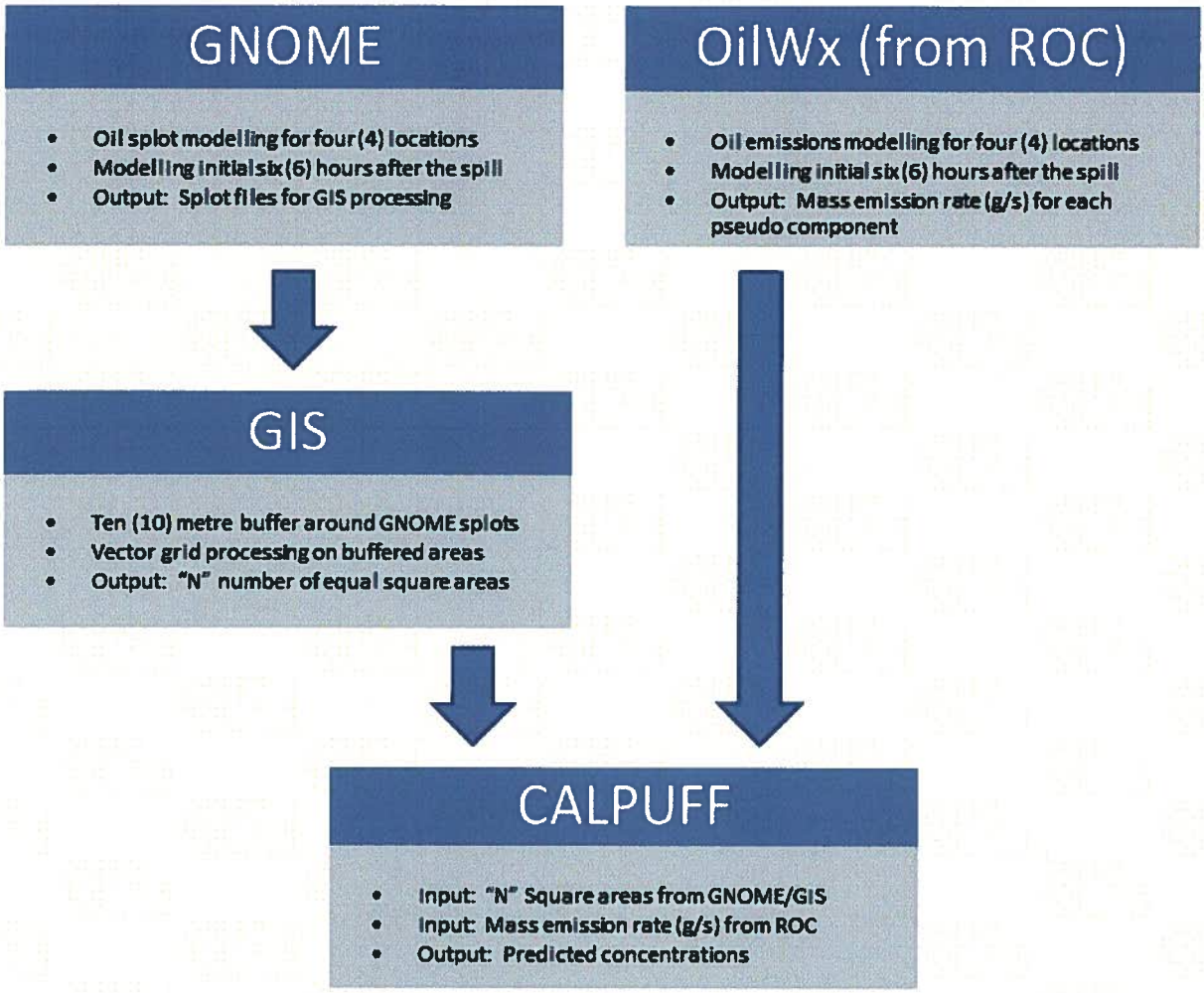

Figure 2-1 Air Quality Assessment Methodology Flowchart

2.1 GNOME Modelling

GNOME modelling was conducted by Metro Vancouver and the output was provided to Levelton in the form of ArcGIS Personal Geodatabase files (.mdb). The potential spill locations, spill volumes, and other GNOME modelling options align with the spill scenarios considered by the other intervenor(s) in their own evaluations.

A total of four spill locations were modelled by Metro Vancouver considering an instantaneous spill of either 8,000 cubic metres (m^3) or 16,000 m^3 depending on the location as outlined below:

1) **English Bay at Anchorage 8**: (Latitude: 49.289444, Longitude: -123.199722)

   16,000 m^3 Instantaneous Spill

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   16,000 m^3 Instantaneous Spill

4) **Westridge Terminal:** (Latitude: 49.291089, Longitude: -122.950338)

   8,000 m^3 Instantaneous Spill

In an attempt to capture a range of possible tidal and meteorological conditions possible during a spill, a total of 12 unique start times for each of the four spill locations were modelled by Metro Vancouver for a total of 48 scenarios. The start times were selected by Levelton to reflect periods of poor dispersion characteristics, further explained in Section 2.5 below. The resulting outputs for each of the locations and time periods were provided to Levelton.

Additionally, it was determined from preliminary investigation with ROC and CALPUFF that a period of the first six hours following a spill are the most important with respect to potential impacts and should be considered in the air quality dispersion model. Modelling the first six hours will provide a reasonable estimate of the potential impacts following an oil spill considering an instantaneous release.

2.2 GIS Processing

Each GNOME simulation described in Section 2.1 were modelled for consecutive hours one through six following a potential oil spill, and an ArcGIS associated personal geodatabase (.mdb) for each hour was generated and processed with the following procedure.

Each ArcGIS associated personal geodatabase file (.mdb) contained the location of every oil splot modelled in GNOME. This file was imported into GIS, and then a 10 metre (m) buffer was placed around every oil splot. Then, a vector grid consisting of 100 m by 100 m grid cells was overlaid which encompassed the entire oil spill area. Each vector grid cell containing a buffered oil splot area was noted and the coordinates of these grid cells was tabulated for further processing by CALPUFF.

Overall, the GNOME oil spill output was rasterized into square grid cells for input into CALPUFF. This was necessary as CALPUFF can only handle four sided polygons, and it is recommended to keep the aspect ratio of the area sources to one to one (1:1) and have the size of the areas less than that of the CALMET grid resolution.

Figure 2-2 through Figure 2-4 below illustrates an example of converting GNOME output into CALPUFF input data.

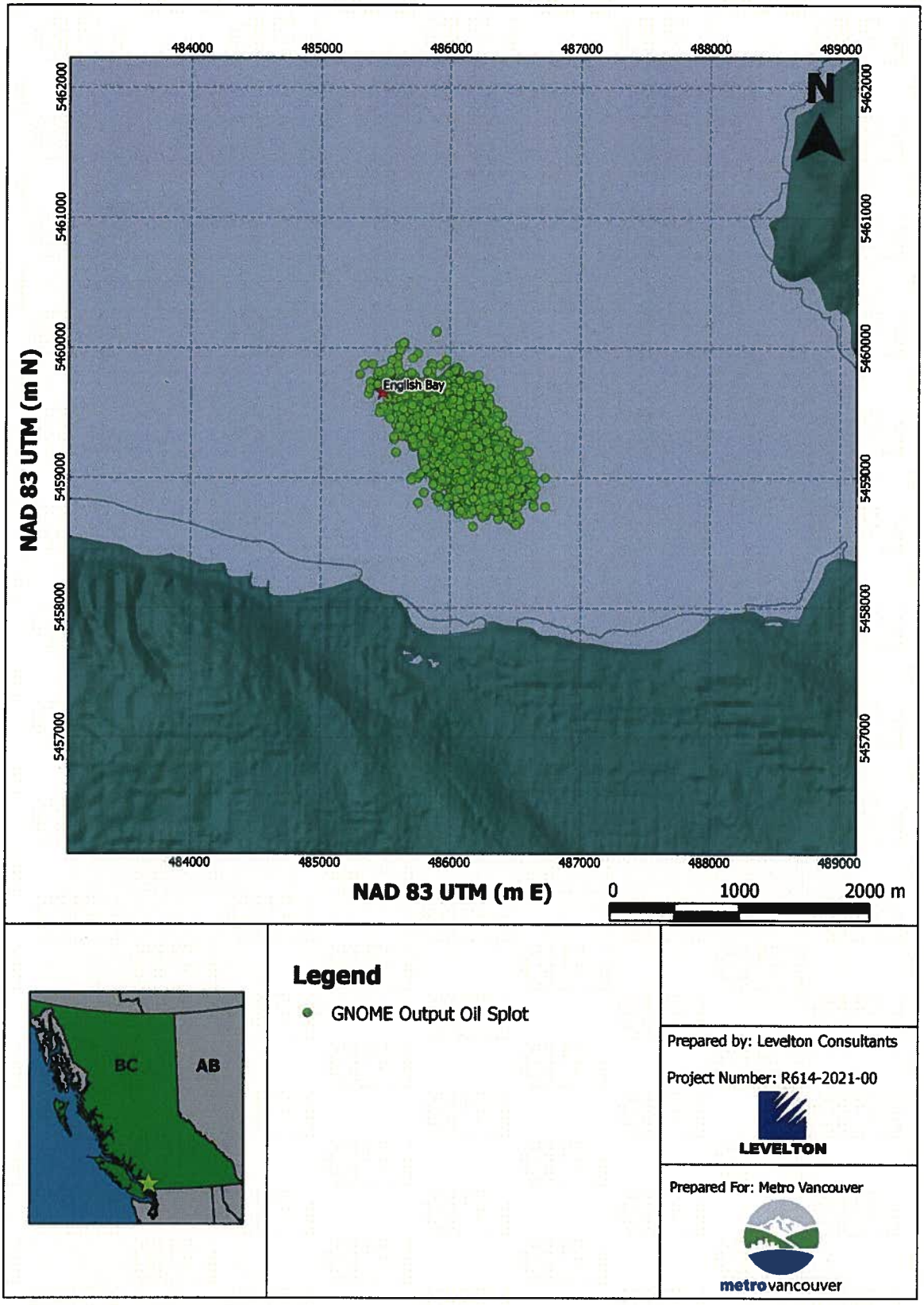

Figure 2-2 Example GNOME Output Data for the English Bay (Anchorage 8) Spill Location

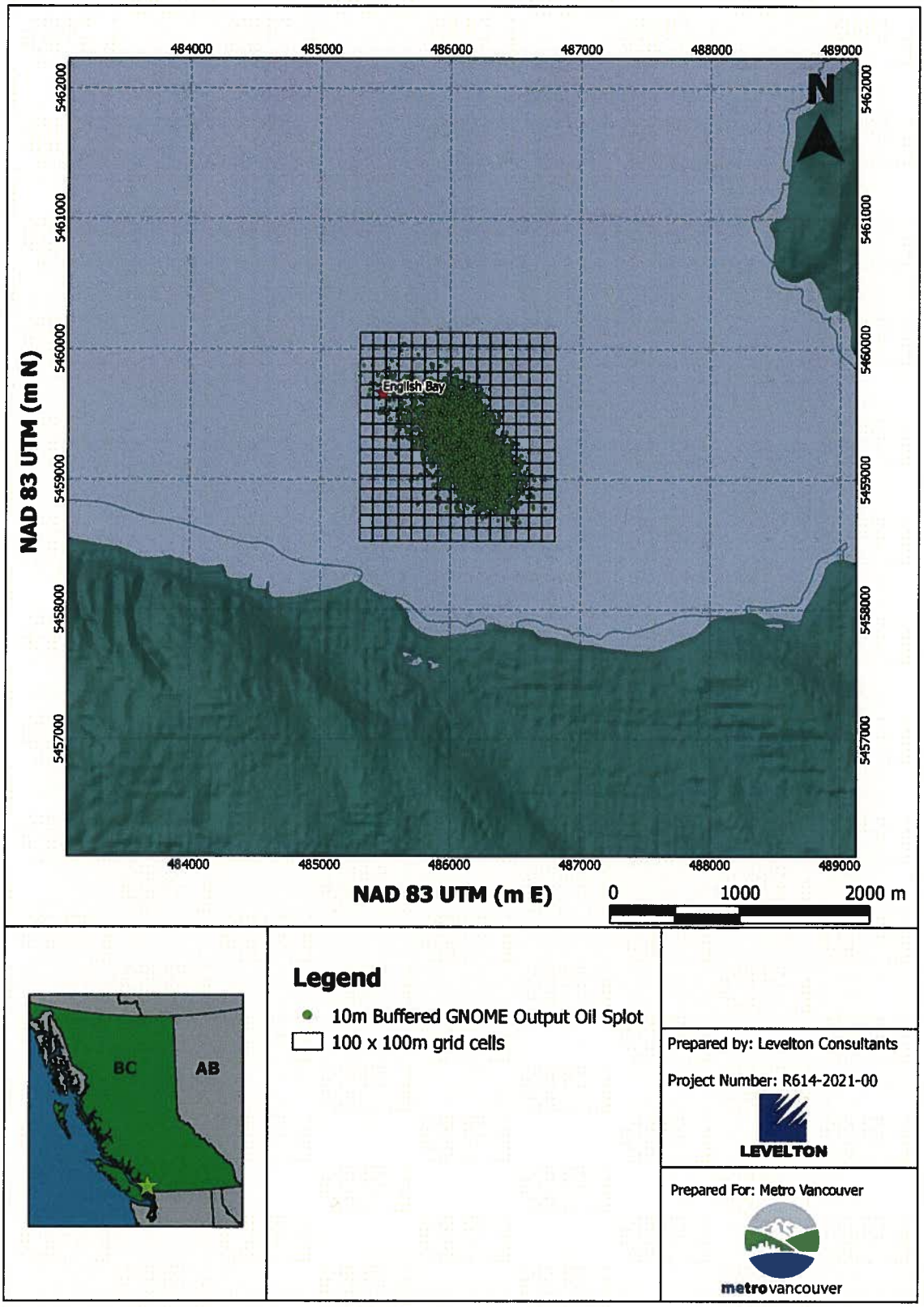

Figure 2-3 **Example 10 Metre Buffered GNOME Output Data with an Overlaid Vector Grid for the English Bay (Anchorage 8) Spill Location**

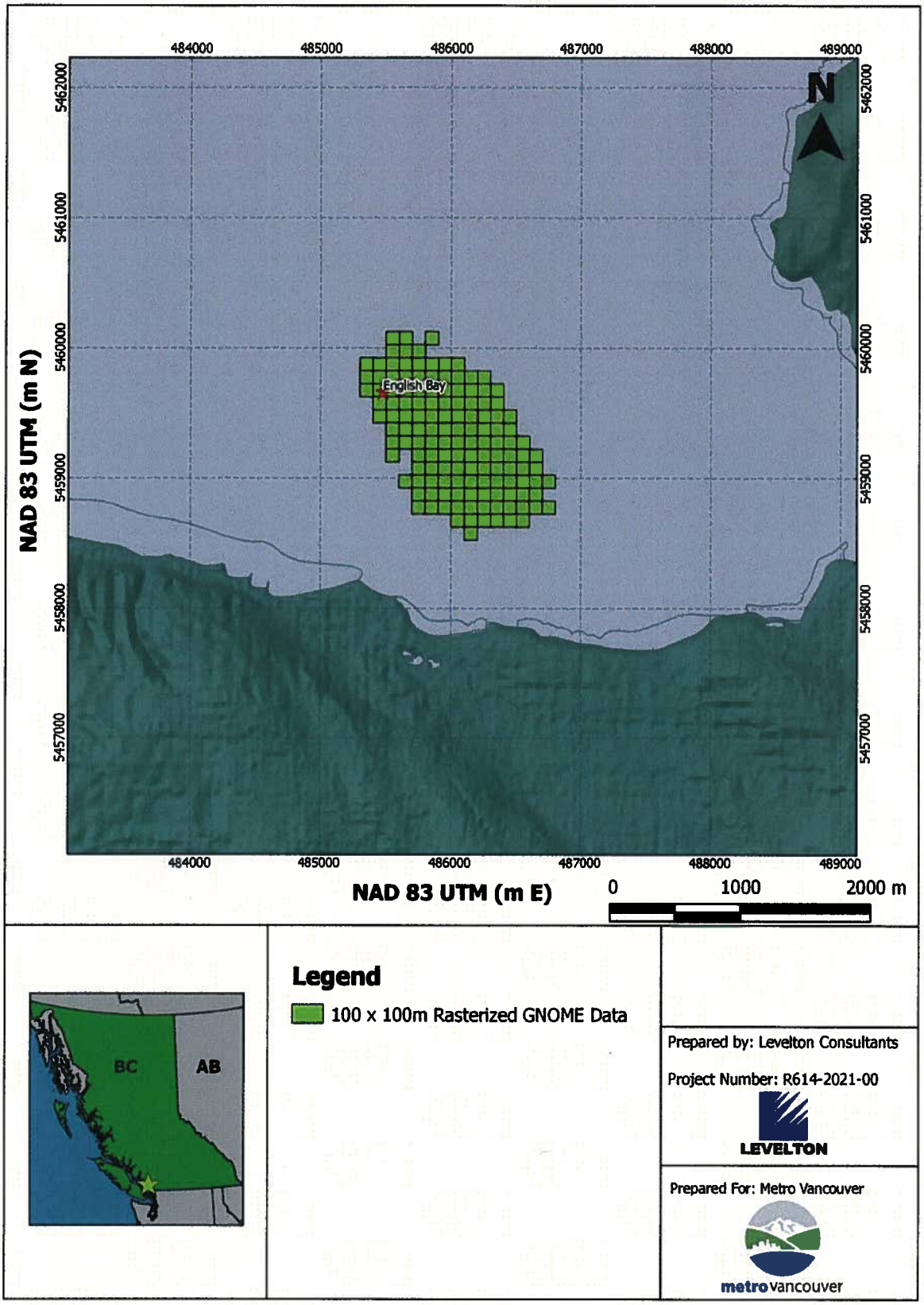

Figure 2-4 Example Rastorized GNOME Output for the English Bay (Anchorage 8) Spill Location

2.3 OILWX (FROM ROC) MODELLING

As crude oil is a mixture of a wide variety of primarily hydrocarbon constituents, it is represented within the ROC model using 15 pseudo-components, which are components with varying boiling points in order to simulate the complete crude oil distillation curve. The evaporative emissions from a potential oil spill were calculated using the ROC oil weathering subroutines (OilWx)[2] within the ROC model because OilWx has the capability to output the weathering emissions of individual pseudo-components representing the crude oil.

Oil spill emissions from Cold Lake Blend crude oil was modelled in this assessment, which is bitumen from the Cold Lake area diluted with condensate. Detailed information regarding the Cold Lake Blend was obtained from www.crudemonitor.ca, a producer-funded program providing open access crude quality data. Details regarding the spill characteristics modelled are shown below in Table 2-1.

Table 2-1 Cold Lake Blend Crude Oil Characteristics

Parameter	Value	Data Source
Density (kg/m^3)	928.28	Historical Average of www.crudemonitor.ca
Gravity (°API)	20.80	Historical Average of www.crudemonitor.ca
Viscosity (cS)	206	Defaults for Cold Lake Blend in ROC
Reference Viscosity Temperature (°C)	16	Defaults for Cold Lake Blend in ROC

In terms of potential short term air quality impacts associated with marine oil spills, the pseudo-components that are of greatest concern are generally the components with lower boiling points as these will be the most volatile components. Each of the pseudo-components was represented by a single surrogate chemical, which was modelled in CALPUFF and compared directly to corresponding ambient air quality objectives and/or human health exposure thresholds. The use of surrogate chemicals is consistent with the approach taken with the Human Health Risk Assessment (HHRA) conducted by Intrinsik[3] as additional supplemental information for the Project application, where Intrinsik associated surrogate chemicals with the pseudo-components modelled by Tetra Tech EBA[4]. A listing of the speciated components for Cold Lake Blend crude oil has been obtained from the available crude oil speciation data on www.crudemonitor.ca, and each of these components was assigned a surrogate chemical and corresponding chemical properties. In order to prepare a distillation curve for OilWx, the boiling points of the surrogate chemicals were sorted in ascending order and the cut percentage of these surrogate chemicals, representing pseudo-components modelled in OilWx, was interpolated from available cut point percentages provided on www.crudemonitor.ca for the Cold Lake Blend crude oil. The data from 371 test samples for Cold Lake Blend crude oil ranging from January 7, 2001 (Sample CL-587) to January 7, 2015 (Sample CL(H)-609) was used in this analysis. Three additional pseudo-components from the cut point data were added as the last components to fill out a complete distillation curve. Surrogate chemicals were not associated with these last three pseudo-components.

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[2] *Galt, J.A., Oil Weathering Technical Documentation and Recommended Use Strategies – DRAFT, Genwest. Retrieved from: http://www.genwest.com/DRAFT%20ROC%20TechnicalDocumentation.pdf January, 2015.*

[3] *Intrinsik, 2014. Human Health Risk Assessment of Facility and Marine Spill Scenarios Technical Report for the Trans Mountain Pipeline ULC Trans Mountain Expansion Project. SPEP-NEB-TERA-00006. June 2014.*

[4] *Tetra Tech EBA, 2013. Trans Mountain Pipeline ULC. Modelling the Fate and Behaviour of Marine Oil Spills for the Trans Mountain Expansion Project. EBA File: V13203022. November 2013.*

Table 2-2 below indicates the pseudo-components/surrogate chemicals modelled in OilWx and Figure 2-5 indicates a comparison between distillation curves prepared with conventional cut percentage (%) data available on www.crudemonitor.ca and the speciated pseudo-components.

Table 2-2 Pseudo-Component and Surrogate Chemical List

Pseudo-Component Number	Component from www.crudemonitor.ca	Cumulative Cut (%)	Boiling Point (°C)	Surrogate Chemical
1	C3-	0.042	-42.22	n-Propane
2	Butanes	1.60	-11.67	i-Butane
3	Pentanes	4.04	36.11	n-Pentane
4	Hexanes	6.37	68.89	n-hexane
5	Benzene	7.45	80.00	Benzene
6	Heptanes	9.24	98.33	n-Heptane
7	Toluene	10.35	111.11	Toluene
8	Octane	11.37	125.56	n-Octane
9	Ethyl Benzene	12.12	136.11	Ethyl-Benzene
10	Xylenes (-m,-o,-p)	12.29	138.50	Xylenes (-m,-o,-p)
11	Nonanes	13.14	150.56	Nonane
12	Decanes	17.88	217.78	Naphthalene
13	40% Cut Point	40.00	398.77	-
14	60% Cut Point	60.00	533.85	-
15	80% Cut Point	80.00	672.93	-

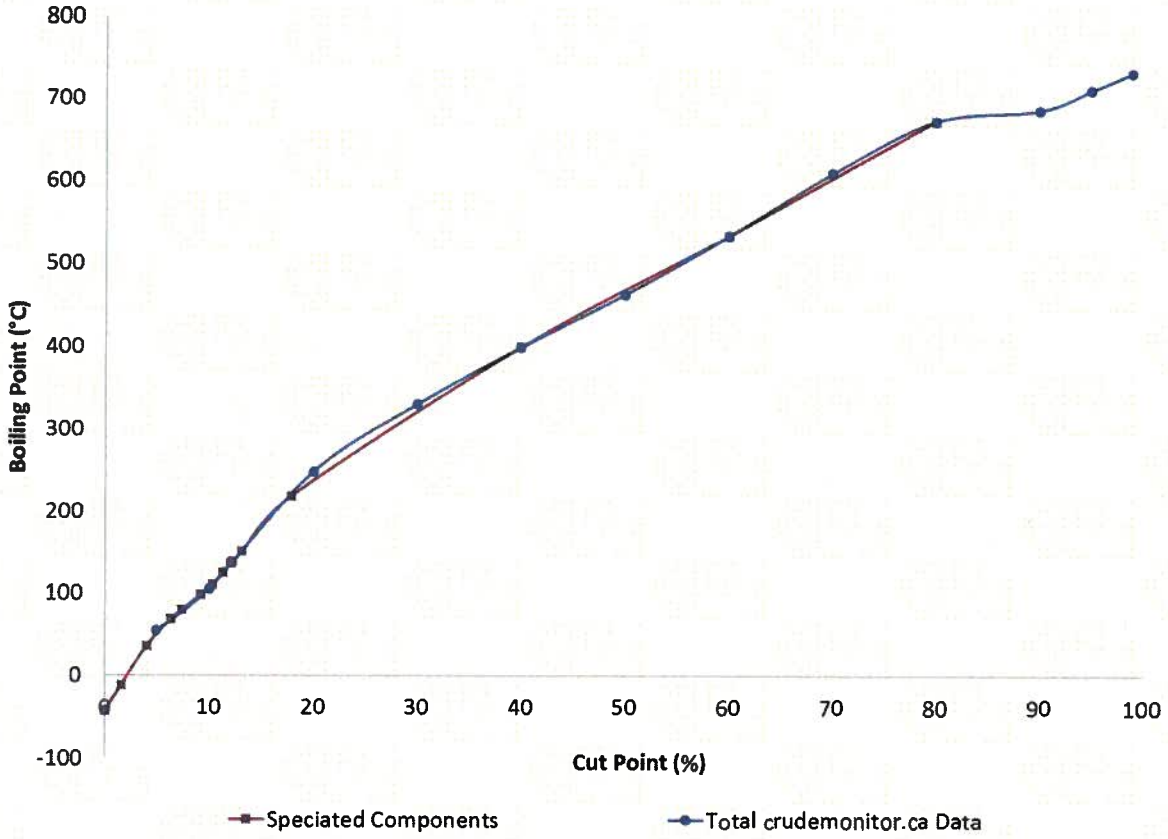

Figure 2-5 Distillation Curve Comparing the Speciated Pseudo-Components and Cut Point Percentages Provided on www.crudemonitor.ca

Other than the crude oil characteristics, the main variables have an impact on oil spill evaporative characteristics are the ambient wind speed and water temperature. Wind speeds were determined from CALMET output provided by Metro Vancouver, and the water temperatures were gathered from the Halibut Bank buoy operated by Environment Canada. These wind speeds and water temperatures were assumed to be representative in the modelled oil spill locations.

A sensitivity analysis was conducted using ROC in order to understand the importance of wind speed and water temperature on oil evaporation rates (Figure 2-6 and Figure 2-7). The sensitivity shows that the percentage of oil evaporated over time is greater with increasing water temperature and wind speed. As the amount of oil evaporated can vary substantially based on these two environmental parameters, emissions from the OilWx modelling used the hourly wind speed and water temperatures associated with the corresponding time frame of each oil spill simulation rather than attempt to come up with an average emission factor.

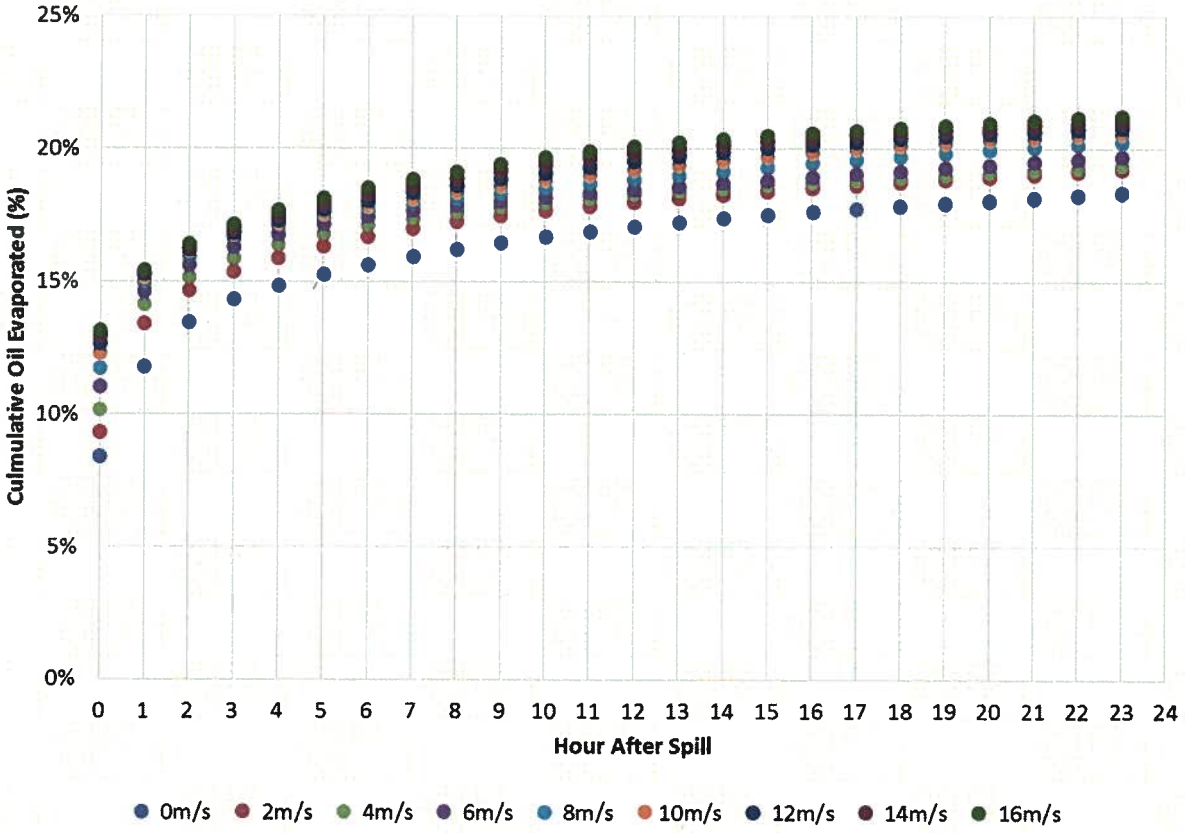

Figure 2-6 **ROC Evaporation Curves with Varying Wind Speed and a Constant Water Temperature of 12°C for an Oil Spill of 16,000 m³**

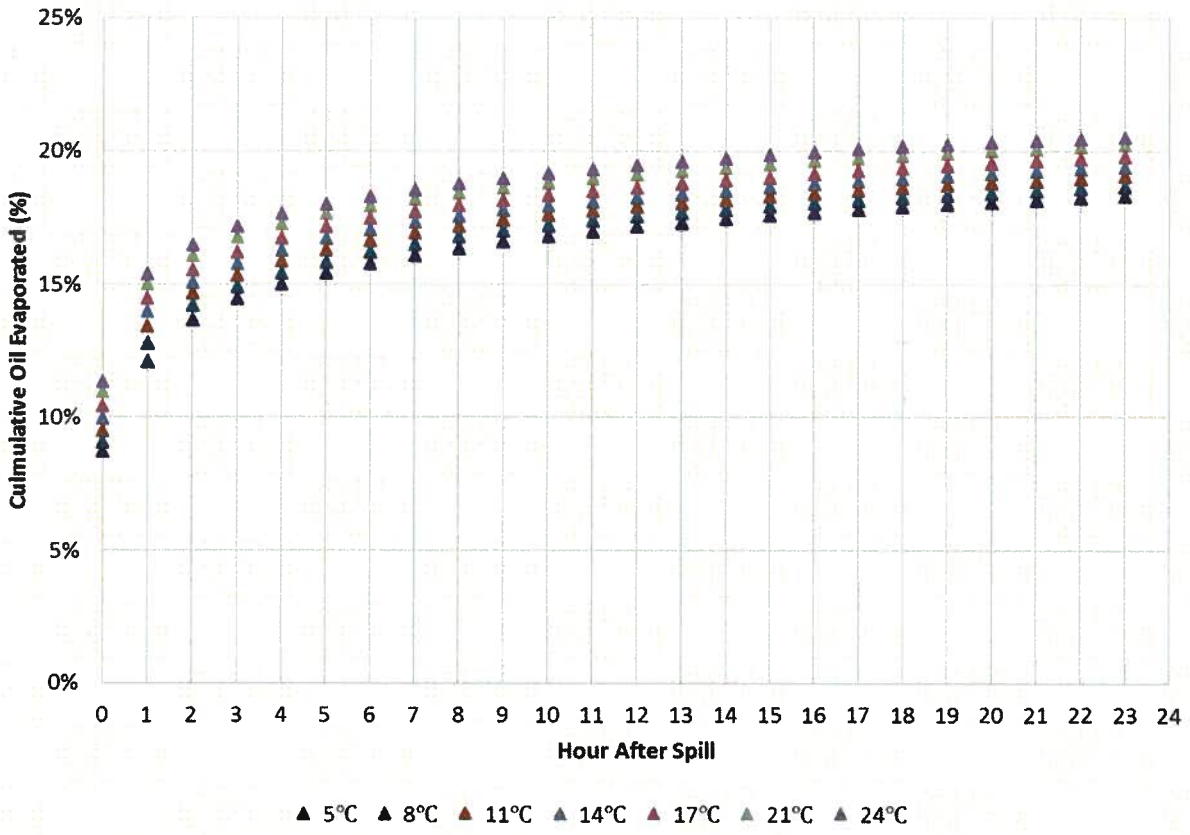

Figure 2-7 ROC Evaporation Curves with Varying Water Temperature and a Constant Wind Speed of 3 m/s for an Oil Spill of 16,000 m^3

2.4 CALPUFF Air Dispersion Modelling

The CALPUFF air dispersion model was used to predict ambient air concentrations of the pseudo-components from a potential marine oil spill. Detailed three-dimensional meteorological fields were produced by the diagnostic computer model CALMET, based on prognostic meteorological data, surface weather data, digital land use data, and terrain data. The CALMET output required for this assessment was provided to Levelton by Metro Vancouver. The three-dimensional fields produced by CALMET were used by CALPUFF (version 6.42), a three-dimensional, multi-species, non-steady state Gaussian puff dispersion model that can simulate the effects of time and space varying meteorological conditions on pollutant transport. Finally, post-processing utilities CALSUM (version 1.4), CALPOST (version 6.221), CALMAX (version 1.1), and CALRANK (version 1.1) were used to post-process and summarize the modelling output data from CALPUFF.

The CALMET output data provided by Metro Vancouver covers a 30 km (east-west) by 24 km (north-south) domain, for the period of January 1, 2005 to December 31, 2005. The CALMET data was characterized using a 250 m grid resolution and 10 vertical layers. The CALPUFF computational domain was nested 1 km within the CALMET domain on all sides to create a 28 km (east-west) by 22 km (north-south) domain. Receptors were placed within the entire CALPUFF modelling domain with a uniform distribution at 250 m, for a total of 10057 receptors. A 1.5 m receptor height was used to simulate the average height of human air intake for predicting concentrations. Figure 2-8 shows the geographic extent of the CALPUFF and CALMET domains, and Figure 2-9 indicates the location of the receptors.

Each oil spill simulation modelled in GNOME was run in CALPUFF using the corresponding time period and meteorology. A total of 15 pseudo-components were modelled with the mass emission rates determined by OilWx, and the location and number of area sources from the GIS processing output. The results were pro-rated for each pseudo-component using a uniform mass flux ($g/m^2/s$) calculated by the mass emission rate from OilWx divided by the total area of the area sources from the GIS processing output. The pseudo-component emissions were conservatively assumed to not be limited by the available surface area of the oil spill.

Each of the 48 CALPUFF modelling scenarios (12 spill start times for four locations) consisted of six hourly time steps associated with the first six hours of a potential spill. Given that the extent of the oil spill area changes with time, the six time steps included different emission source areas as individual CALMET input files. A variable emissions input file was used with each of the six CALPUFF input files which represents each of the six hours after the spill. The results from each of the individual CALPUFF runs were then combined using CALSUM for each oil spill release scenario. Table 2-3 below indicates the relevant dispersion modelling parameters used in the variable emissions files.

Table 2-3 Variable Emissions File Parameters

Description	CALPUFF Input Parameter	Value
Effective Height (m) of the Emissions Above the Ground	HT	0
Elevation of Ground (m) above Mean Sea Level	ELEV	0
Temperature (°K)	TEMPK	CALMET Hourly Ambient Temperature
Effective Rise Velocity (m/s)	WEFF	0
Effective Radius (m) for Rise Calculation	REFF	0
Initial Vertical Spread (m)	SIGZ	0

The maximum predicted concentration for any given receptor, from all scenarios at each location, were processed using CALMAX to determine the maximum predicted concentration at each receptor, and CALPOST was used to develop tables and contour plots of maximum predicted concentrations for pseudo-components, or surrogate chemicals. All other standard CALPUFF model input options follow the guidance outlined in the *Guidelines for Air Quality Dispersion Modelling in British Columbia*[5].

[5] *British Columbia Ministry of Environment, 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Victoria, British Columbia, March 2008.*

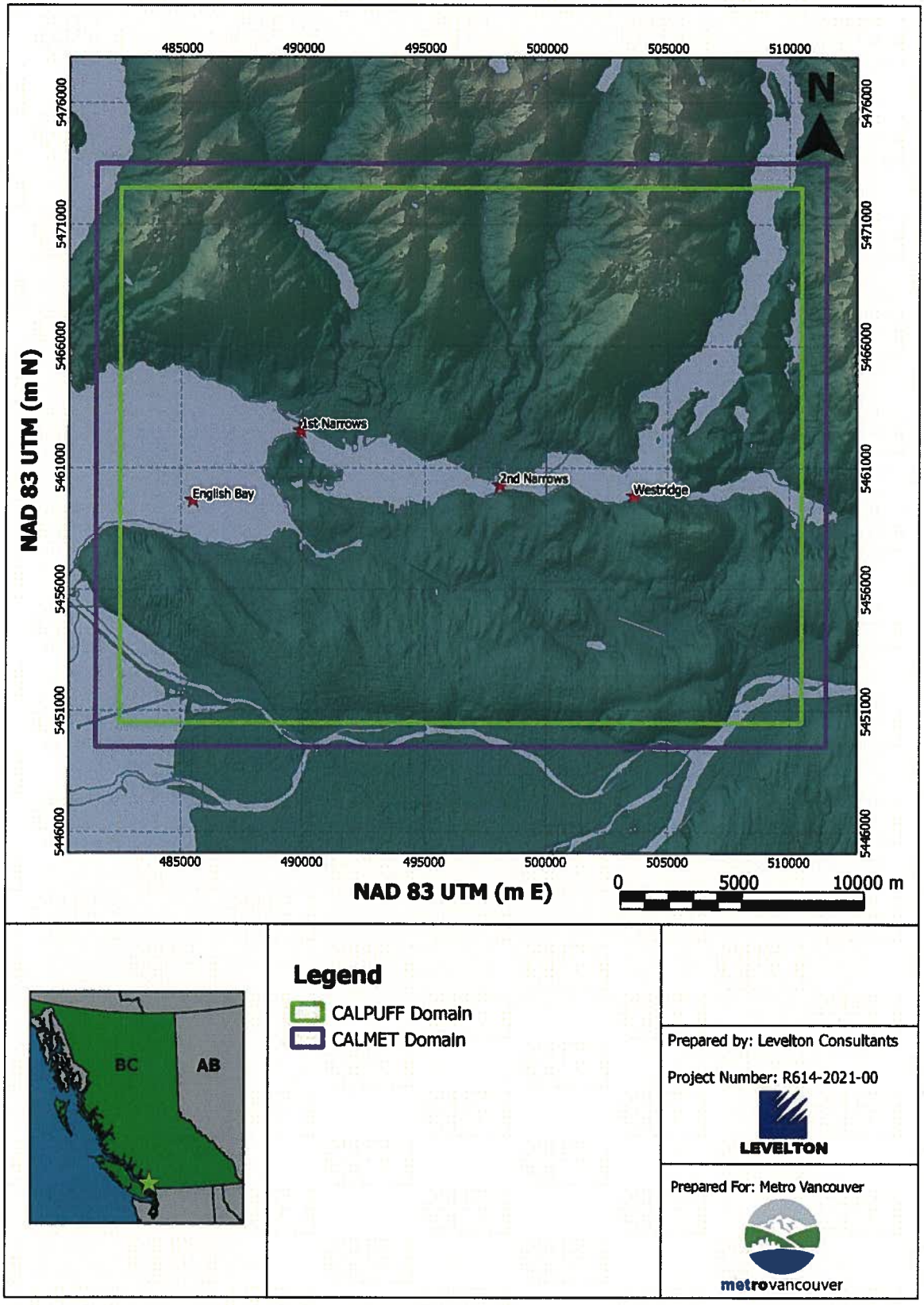

Figure 2-8 CALPUFF and CALMET Modelling Domains

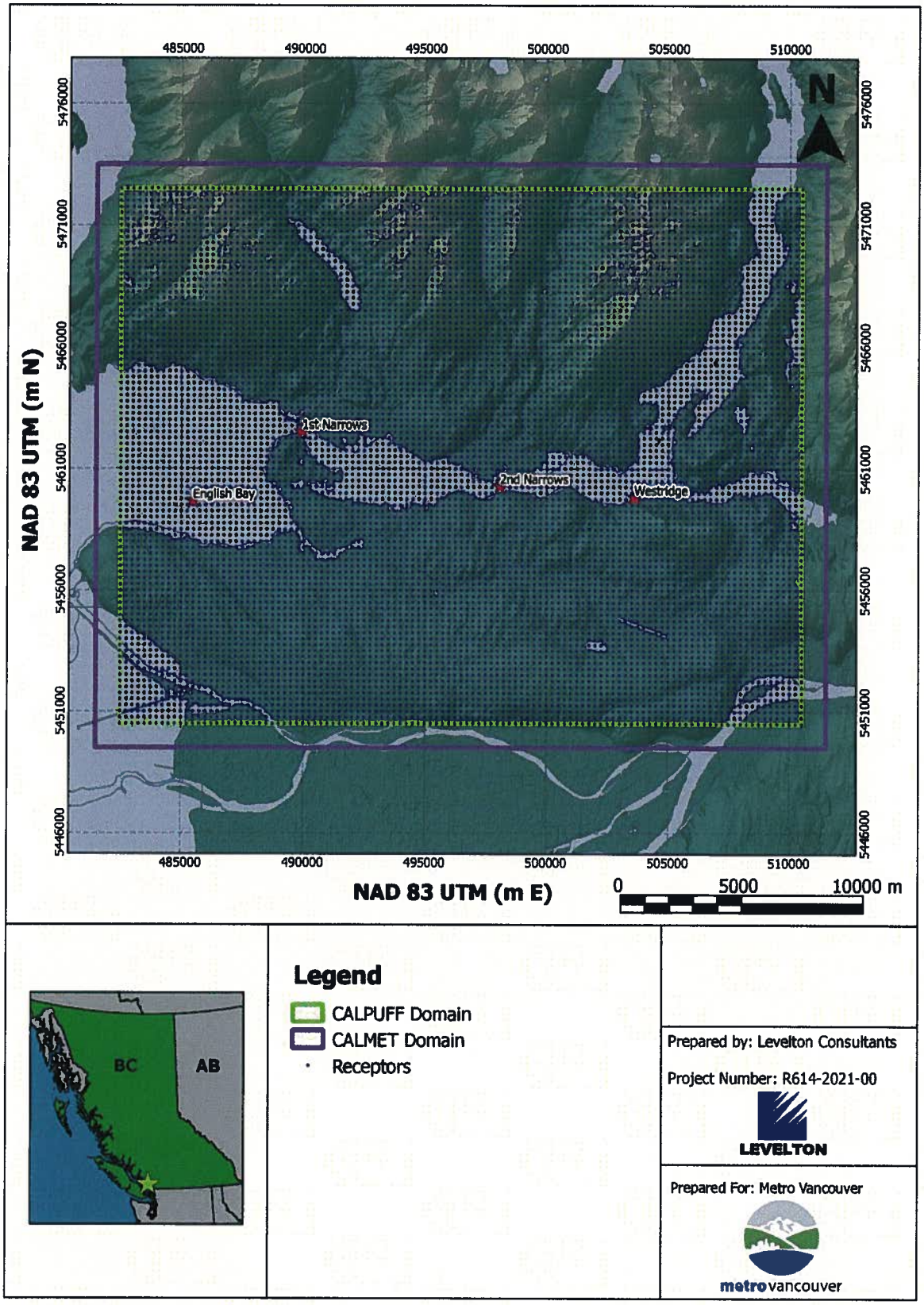

Figure 2-9 CALPUFF and CALMET Modelling Domains and Receptor Locations

2.5 TIME PERIODS MODELLED

This assessment was not intended to be comprehensive but rather an attempt at demonstrating some potential effects of a possible oil spill. In order to select time periods to be modelled, periods of poor dispersion were selected based on a dispersion sensitivity analysis.

The dispersion sensitivity analysis consisted of running CALPUFF with four 250 m by 250 m fixed area sources at each potential spill location, with a unit emissions flux (1 g/m^2/s) as shown in Figure 2-10. The results of this sensitivity analysis were examined to determine periods of poor dispersion (i.e. hours in the year when the highest one-hour averaging period concentration occurs without considering causality) in order to select the oil spill starting release times. Figure 2-11 indicates the receptor grid used in this analysis which represents the receptors over land on the South Shore of English Bay and Burrard Inlet in Metro Vancouver, in order to isolate worst-case meteorological conditions that could affect the greatest populations.

The hours that resulted in the twelve highest maximum predicted concentrations for each spill location were determined and are shown below in Table 2-4. These results were used to define the twelve meteorological scenarios for each four spill locations and their respective starting time in GNOME, OilWx, and CALPUFF.

Table 2-4 Starting Times (Month/Day/Hour) Run in GNOME/OilWx/CALPUFF

Location	English Bay (Anchorage 8)											
Scenario	1	2	3	4	5	6	7	8	9	10	11	12
Month	7	11	4	9	11	10	7	12	4	11	10	9
Day	1	2	29	19	1	29	13	7	9	2	20	20
Hour	20	4	19	22	4	5	1	4	20	5	1	1
Location	First Narrows											
Scenario	1	2	3	4	5	6	7	8	9	10	11	12
Month	7	8	11	4	3	4	11	6	1	5	6	5
Day	30	22	11	14	27	17	14	1	11	5	9	23
Hour	1	1	6	0	5	20	2	2	20	2	22	2
Location	Second Narrows											
Scenario	1	2	3	4	5	6	7	8	9	10	11	12
Month	9	1	3	10	12	1	9	2	10	11	3	7
Day	2	5	10	18	16	3	24	17	18	18	9	16
Hour	1	2	21	19	16	22	5	6	6	6	19	20
Location	Westridge Terminal											
Scenario	1	2	3	4	5	6	7	8	9	10	11	12
Month	1	11	1	9	4	12	5	6	1	12	11	2
Day	9	5	9	22	7	1	8	25	28	1	13	7
Hour	5	20	4	18	4	18	4	20	19	3	21	2

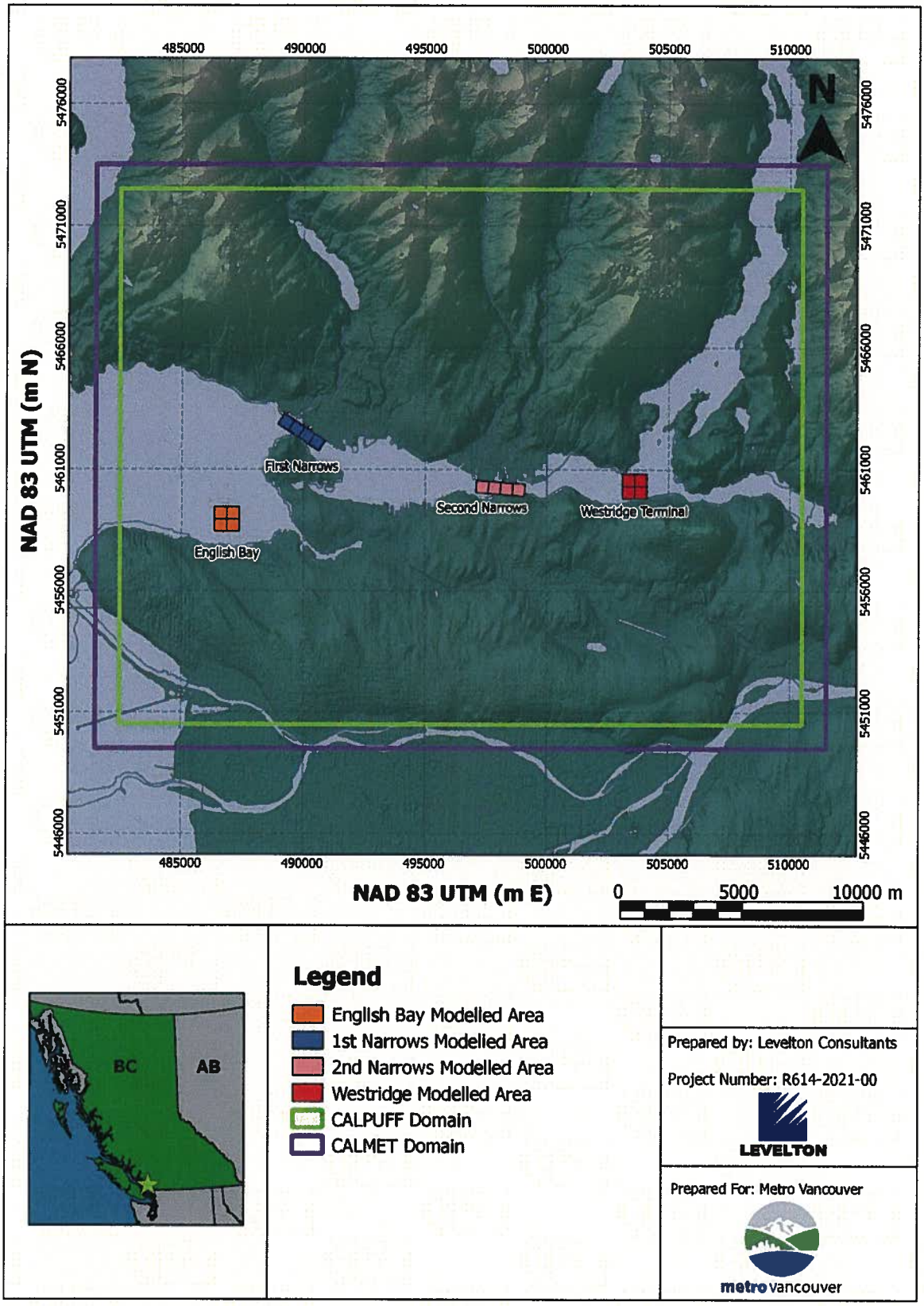

Figure 2-10 CALPUFF Uniform Emission Area Sources

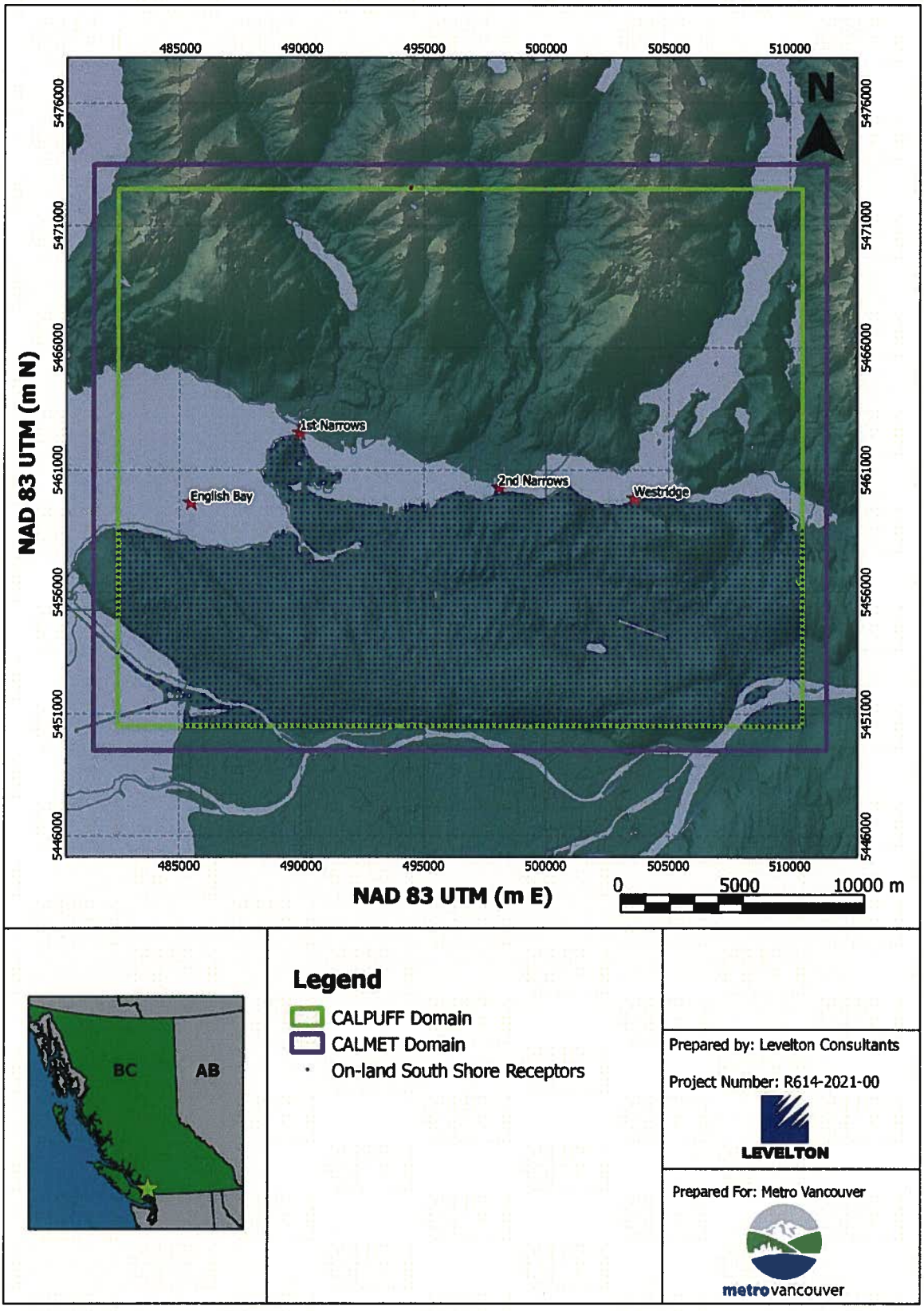

Figure 2-11 South Shore On-land Receptors Used with the CALPUFF Uniform Emission Sources

2.6 LIMITATIONS

Inherently, all air quality modelling assessments will have limitations associated primarily with the emissions characterization and the air dispersion modelling. Air dispersion modelling requires a number of assumptions and simplifications in order to provide an approximation of complex atmospheric processes. However, air dispersion models have been shown to reasonably and reliably predict maximum concentrations occurring sometime within the modelling domain, typically with a range of 10 - 40%[6] of the observed maximum concentration.

This assessment is not meant to be comprehensive of all possible tidal and meteorological combinations and conditions, and likely does not capture the worst-case impacts. In order to determine the worst-case impacts one would need to perform a more comprehensive assessment that considered all possible combinations of oil spill trajectories, oil spill emissions, and meteorological conditions. In addition, only the first six hours of emissions following a spill were considered as the focus of this study was on the most volatile compounds. Longer timeframes may be required to provide a better determination of impacts from the less volatile compounds.

In this study, attempts were made to select a few meteorological conditions that were thought to have the greatest impact on air dispersion model predictions associated with a marine crude oil spill. The meteorological conditions were chosen that resulted in maximum predicted concentrations on the South Shore of English Bay and the Burrard Inlet. It is unknown what maximum predicted concentrations would result if southerly winds pushed the plume to the North Shore as these conditions were not considered in the assessment. The study area was also not large enough to capture the entire effects of some exceedances, such as the acute inhalation exposure limits and in certain instances PAC thresholds levels.

Furthermore, only four spill locations were considered in this assessment, three of which were located in the middle of water. In an event of a spill occurring closer to land, this could likely result in higher maximum predicted concentrations for the on-land receptors.

3 AMBIENT AIR QUALITY OBJECTIVES, ACUTE INHALATION EXPOSURE LIMITS, AND OTHER HEALTH EXPOSURE GUIDELINES

Since there are no ambient air quality objectives for the chemicals of interest in British Columbia, a literature search for exposure limits from a number of scientific and regulatory authorities was conducted. A listing of the acute inhalation exposure limits for one-hour averaging periods was investigated and shown in Table 3-1 below. The majority of the table was populated from the acute inhalation exposure limits used in the HHRA conducted by Intrinsik[3] as additional supplemental information for the Trans Mountain application to the NEB, as they conducted an assessment on available exposure limits based on relevance, scientific robustness, and technical defensibility. In addition, acute inhalation exposure limits were added for n-hexane, n-octane, and nonane. The acute inhalation exposure limits originated from the following US authorities: Texas Commission on Environmental Quality (TCEQ), Agency for Toxic Substances and Disease Registry (ATSDR), and the American Conference of Governmental Industrial Hygienists (ACGIH).

[6] *United States Environmental Protection Agency. 2005. Part III. Environmental Protection Agency 40 CFR Part 51. Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule. November 9, 2005.*

Table 3-1 Acute Inhalation Exposure Limits

Surrogate Chemical	Acute Inhalation Exposure Limit (µg/m³)	Authority
n-Propane	-	-
i-Butane	78,000	TCEQ[7]
n-Pentane	200,000	TCEQ[8]
n-Hexane	6,200	TCEQ[9]
Benzene	580	TCEQ[10]
n-Heptane	-	-
Toluene	15,000	TCEQ[11]
n-Octane	-	-
Ethyl-Benzene	21,700	ATSDR[12]
Xylenes (-m,-o,-p)	7,400	TCEQ[13]
Nonane	10,500	TCEQ[14]
Naphthalene	2,000	ACGIH[15]

In addition to the acute inhalation exposure thresholds, the US Department of Energy Emergency Management Issues Special Interest Group (DOE EMI SIG) Protective Action Criteria (PAC) were used as an additional health exposure guideline, in order to estimate the relative health risks to the general public if they were exposed to a particular hazardous chemical in an emergency release scenario.

The PAC is a hierarchy-based system that is comprised of three common public exposure guideline systems, in the order of preference:

- Acute Exposure Guideline Levels (AEGLs);
- Emergency Response Planning Guidelines (ERPGs); and,

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[7] *Texas Commission on Environmental Quality, 2012. n-Butane and Isobutane. CAS Registry Number: n-Butane: 106-97-8, Isobutane: 75-28-5. Development Support Document, Final, July 31, 2012. Prepared by: Jong Song Lee, Toxicology Division.*

[8] *Texas Commission on Environmental Quality, 2011. Pentane, All Isomers. CAS Registry Numbers: n-Pentane: 109-66-0, Isopentene: 78-78-4, Neopentane: 463-82-1. Development Support Document, Final, July 29, 2011. Prepared by: Jong-Song Lee, Toxicology Division.*

[9] *Texas Commission on Environmental Quality, 2007. n-Hexane, CAS Registry Number: 110-54-3. Development Support Document, Final, Pentane, All Isomers. CAS Registry Number: n-Hexane: 110-54-3. Development Support Document, Final, October 15, 2007. Prepared by: Bernard J. Kadlubar, Toxicology Section.*

[10] *Texas Commission on Environmental Quality, 2007. Benzene, CAS Registry Number: 71-43-2. Development Support Document, Final, October 15, 2007. Prepared by: Joseph T. Haney, Toxicology Section.*

[11] *Texas Commission on Environmental Quality, 2008. Toluene, CAS Registry Number: 108-88-3. Development Support Document, Final, April 15, 2008. Prepared by: Manuel Reyna and Jong-Song Lee, Toxicology Division.*

[12] *Agency for Toxic Substances and Disease Registry, 2010. Toxicological Profile for Ethylbenzene. Atlanta, GA: US Department of Health and Human Services, Public Health Service.*

[13] *Texas Commission on Environmental Quality, 2009. Xylenes. CAS Registry Numbers: Xylene mixture: 1330-20-7, m-Xylene: 108-38-3, o-Xylene: 95-47-6, p-Xylene: 106-42-3. Development Support Document, Final, February 13, 2009. Prepared by: Manuel Reyna and Jong-Song Lee, Toxicology Division.*

[14] *Texas Commission on Environmental Quality, 2014. March 2014 Effects Screening Levels, March 17, 2014.*

[15] *America Conference of Governmental Industrial Hygienists. 2013. TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati, OH.*

- Temporary Emergency Exposure Limits (TEELs).

PAC have three tiers of exposure limits for each chemical (PAC-1, PAC-2, and PAC-3), and each successive tier is associated with an increasingly severe effect that involves a higher level of exposure. The DOE EMI SIG defines the PAC tiers as threshold levels as follows[16]:

- "PAC-1: Mild, transient health effects.
- PAC-2: Irreversible or other serious health effects that could impair the ability to take protective action.
- PAC-3: Life-threating health effects."

PAC levels for the surrogate chemicals modelled in this analysis are shown below in Table 3-2, incorporating the latest AEGL compilation from October, 2014[17]. Values have been converted from ppm to µg/m^3 using the ideal gas law and standard ambient conditions (25 °C, 101.325 kPa). The PAC levels in ppm sourced from AEGL levels mirror those used by Intrinsik[3] for the same chemicals studied, with the exception of the latest AEGL compilation levels from October, 2014[17] incorporated for Toluene.

Table 3-2 Protective Action Criteria Exposure Levels

Surrogate Chemical	PAC-1[16,17] (ppm)	PAC-2[16,17] (ppm)	PAC-3[16,17] (ppm)	PAC-1 (µg/m^3)	PAC-2 (µg/m^3)	PAC-3 (µg/m^3)	Source
n-Propane	5,500	17,000	33,000	9,914,000	30,643,273	59,484,001	AEGL
i-Butane	800	800	4,000	1,899,826	1,899,826	9,499,129	TEEL
n-Pentane	120	610	15,000	354,133	1,800,175	44,266,593	TEEL
n-Hexane	300	2,900	8,600	1,057,003	10,217,694	30,300,749	TEEL (PAC-1), AEGL (PAC-2/3)
Benzene	52	800	4,000	166,019	2,554,137	12,770,687	AEGL
n-Heptane	440	440	5,000	1,802,055	1,802,055	20,477,898	TEEL
Toluene	67	760	3,700	252,221	2,108,120	13,928,649	AEGL
n-Octane	300	385	5,000	1,400,345	1,797,109	23,339,081	TEEL
Ethyl-Benzene	33	1,100	1,800	143,247	4,774,906	7,813,483	AEGL
Xylenes (-m,-o,-p)	130	920	2,500	564,307	3,993,558	10,852,059	AEGL
Nonane	200	200	200	1,048,828	1,048,828	1,048,828	TEEL
Naphthalene	15	15	500	78,601	78,601	2,620,026	TEEL

[16] *United States Department of Energy, 2012. Protection Action Criteria (PAC): Chemicals with AEGLs, ERPGs, & TEELs. Rev. 27, February 2012.*

[17] *United States Environmental Protection Agency, 2014. Final AEGLs (162). October 3, 2014.*

4 DISPERSION MODELLING RESULTS

A summary of model results for a potential worst case oil spill are shown in this section for four spill locations. The following subsections present results in tables showing the maximum predicted concentration from all receptors and on-land receptors only. The on-land receptors are shown separately, as it is more likely that potentially exposed human populations would reside on-land. The receptors considered for the maximum predicted on-land concentration analyses are shown in Figure 4-1.

In addition, for each spill location, the maximum predicted concentrations at each receptor from the 12 meteorological scenarios have been analyzed to represent the potential spatial distribution for four spill locations. In a standard modelling assessment, typically at minimum a year of meteorology would be assessed in this manner. Therefore, for each location, 12 of 8760 possible meteorological scenarios in a year have been analyzed which may not capture worst-case impacts. Rather, the maximum predicted concentration plots are presented to illustrate the potential spatial extents from an oil spill given the limited meteorology considered in the assessment.

Of the 15 pseudo-components modelled, pseudo-component number five associated with surrogate chemical benzene, was of particular interest as it had the greatest ratio of emission rate to the acute inhalation exposure limit. Thus, the following figures and subsequent analysis mainly focus on the maximum predicted concentrations of benzene.

For spill locations, based on the maximum predicted one-hour benzene results, the population exposed was calculated to provide context around the dispersion modelling results. The population exposed was calculated using 2011 census block level population data from Statistics Canada to determine the number of people living within the maximum predicted one-hour benzene concentration contours corresponding to acute inhalation exposure limits and PAC threshold levels.

Lastly, also based on the maximum predicted one-hour benzene results, an analysis was conducted to determine the total land use area within the maximum predicted one-hour benzene concentration contours corresponding to acute inhalation exposure limits and PAC threshold levels, and the current land use percentages within each of these concentration bands was determined to gain a further understanding of the potential areas affected.

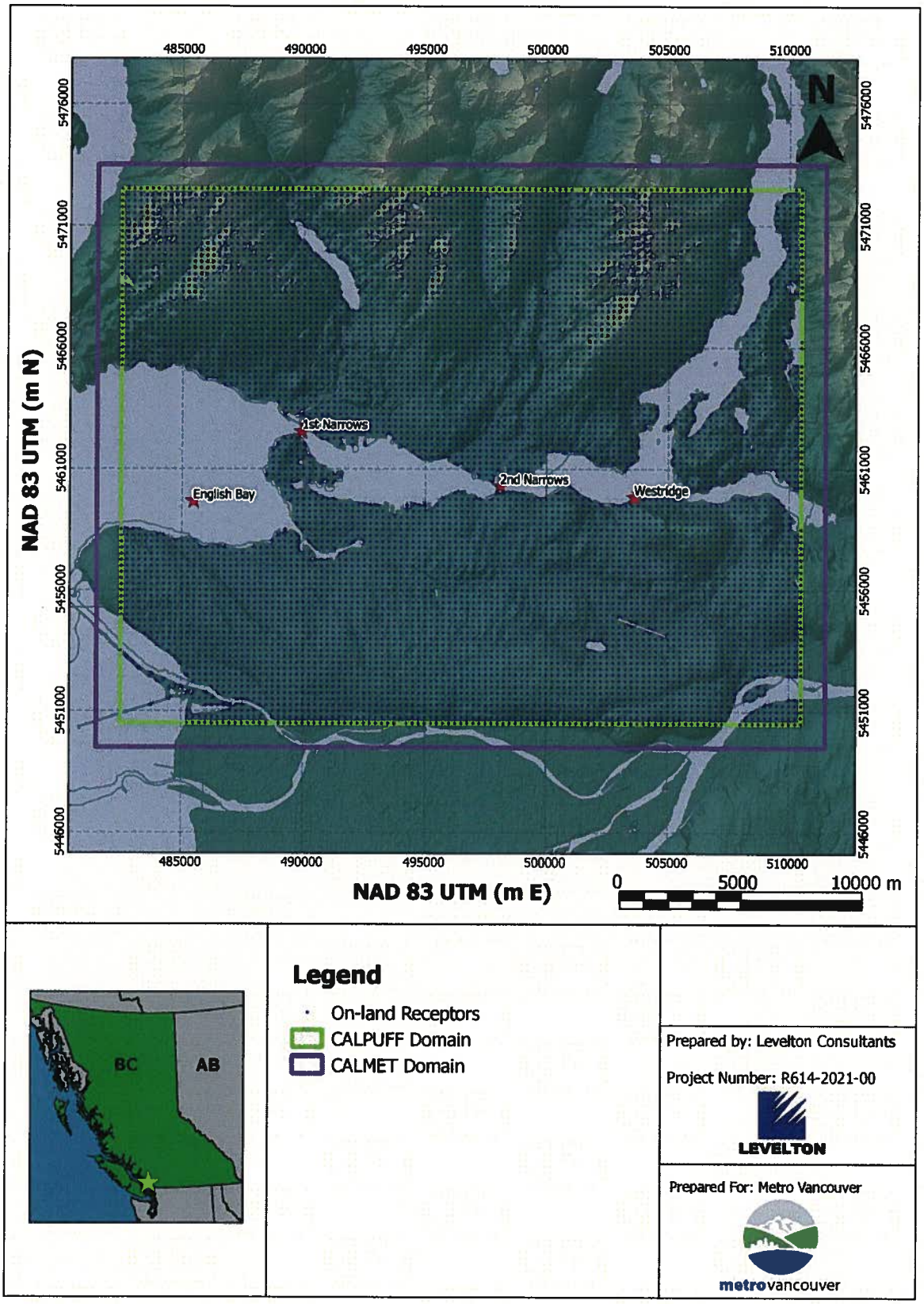

Figure 4-1 On-Land Receptors Considered

4.1 ENGLISH BAY (ANCHORAGE 8) RESULTS

The maximum predicted concentrations from the English Bay (Anchorage 8) meteorological scenarios are shown in Table 4-1. There are predicted exceedances of either the acute inhalation, PAC-1, or PAC-2 exposure limits for all surrogate chemicals modelled with the exception of n-propane when considering the maximum predicted concentrations.

The maximum predicted one-hour contour plot of benzene is shown in Figure 4-2 indicating the contours of the acute inhalation, PAC-1, and PAC-2 exposure limits. Contours for the acute inhalation exposure limit and PAC-1 extend beyond the CALPUFF modelling domain, therefore the analysis was based on the contour areas within the CALPUFF modelling domain. The corresponding land use categories within the respective contours can be seen in Figure 4-3 below. Figure 4-4 indicates the predicted exposed population (based on 2011 census data) for the acute inhalation, PAC-1, and PAC-2 benzene contours, while Figure 4-5 classifies the land use categories within these contours. It should be noted that the predicted exposed population does not account for people at work (e.g. office workers in downtown, businesses near Burrard Inlet and English Bay), transiting (e.g. on bridges, Seabus or roads) or performing recreational activities (e.g. in Stanley Park or beaches).

Figure 4-4 illustrates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain affected 133,100 and 400 people, respectively. Figure 4-5 indicates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain covers an area of 75 km^2 and 7 km^2, respectively.

Table 4-1 Maximum Predicted Concentrations and Maximum Predicted On-Land Concentrations for an English Bay Spill

Surrogate Chemical	Acute Inhalation Exposure ($\mu g/m^3$)	PAC-1 ($\mu g/m^3$)	PAC-2 ($\mu g/m^3$)	PAC-3 ($\mu g/m^3$)	Maximum Predicted Concentrations ($\mu g/m^3$)	Maximum Predicted On-land Concentrations ($\mu g/m^3$)
n-Propane	-	9,914,000	30,643,273	59,484,001	381,000	83,072
i-Butane	78,000	1,899,826	1,899,826	9,499,129	9,392,400	2,047,900
n-Pentane	200,000	354,133	1,800,175	44,266,593	29,875,000	6,513,800
n-Hexane	6,200	1,057,003	10,217,694	30,300,749	24,251,000	4,315,600
Benzene	580	166,019	2,554,137	12,770,687	9,604,700	1,677,200
n-Heptane	-	1,802,055	1,802,055	20,477,898	12,152,000	2,122,000
Toluene	15,000	252,221	2,108,120	13,928,649	4,908,500	950,280
n-Octane	-	1,400,345	1,797,109	23,339,081	2,849,600	664, 260
Ethyl-Benzene	21,700	143,247	4,774,906	7,813,483	1,305,400	384,400
Xylenes (-m,-o,-p)	7,400	564,307	3,993,558	10,852,059	228,710	77,319
Nonane	10,500	1,048,828	1,048,828	1,048,828	849,030	322,630
Naphthalene	2,000	78,601	78,601	2,620,026	795,970	384,650

Legend			
	Acute Inhalation Exposure Limit Exceedance		PAC-2 Exceedance
	PAC-1 Exceedance		PAC-3 Exceedance

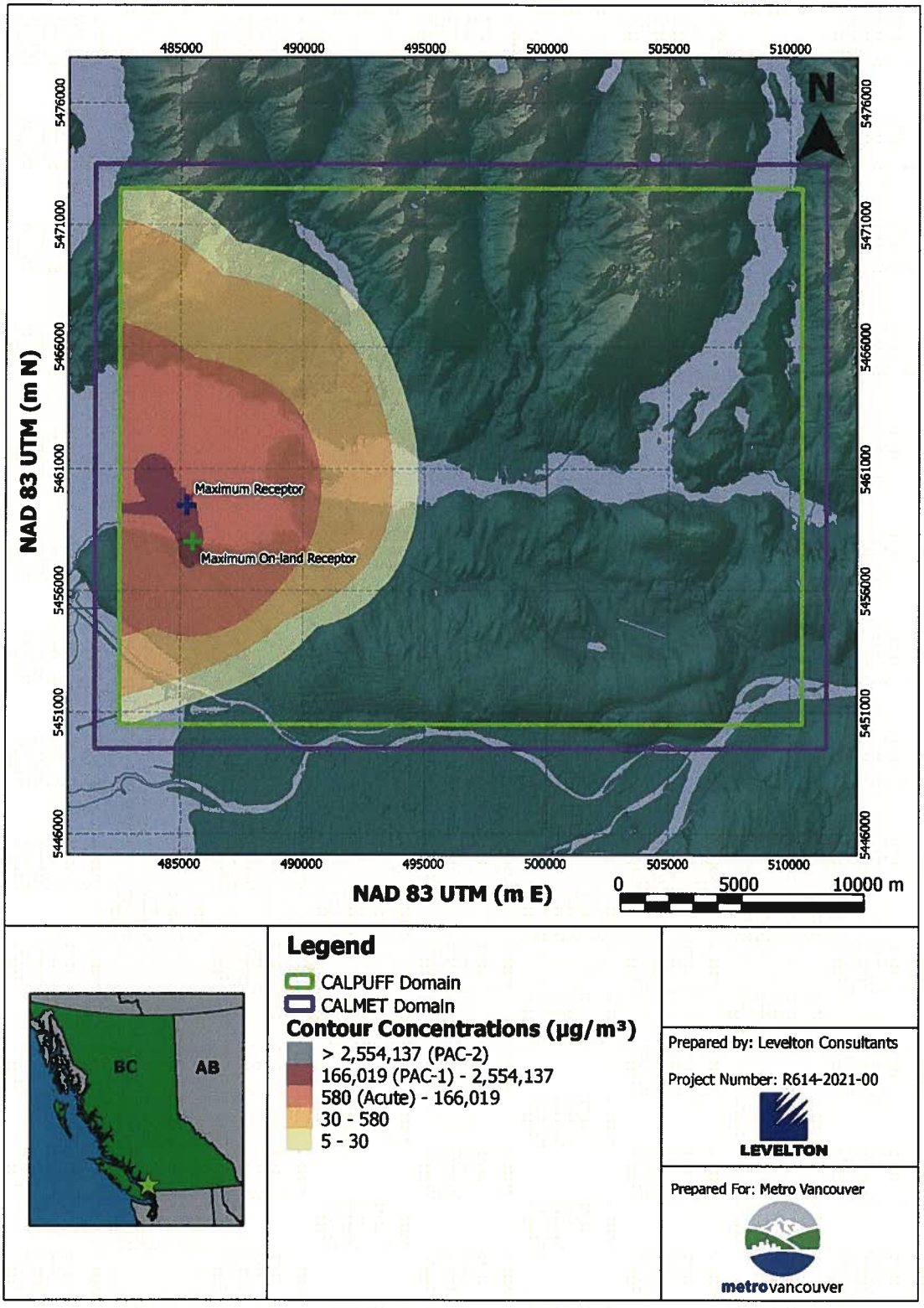

Figure 4-2 **Acute Inhalation, PAC-1, and PAC-2 Exposure Levels Contour for Benzene for an English Bay Spill**

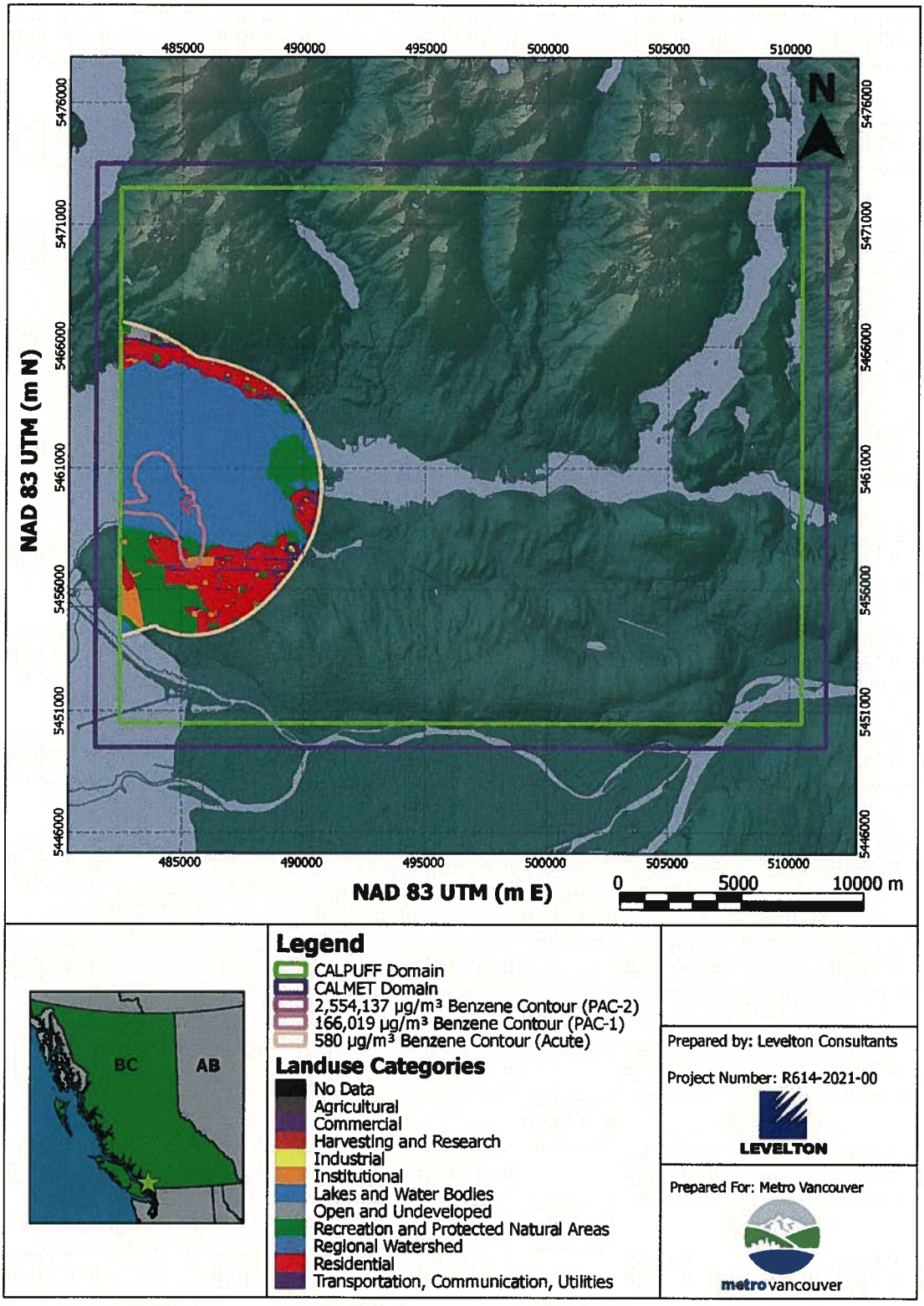

Figure 4-3 **Land Use Area and Percentage Breakdown within the Acute Inhalation, PAC-1, and PAC-2 Exposure Levels for Benzene for an English Bay Spill**

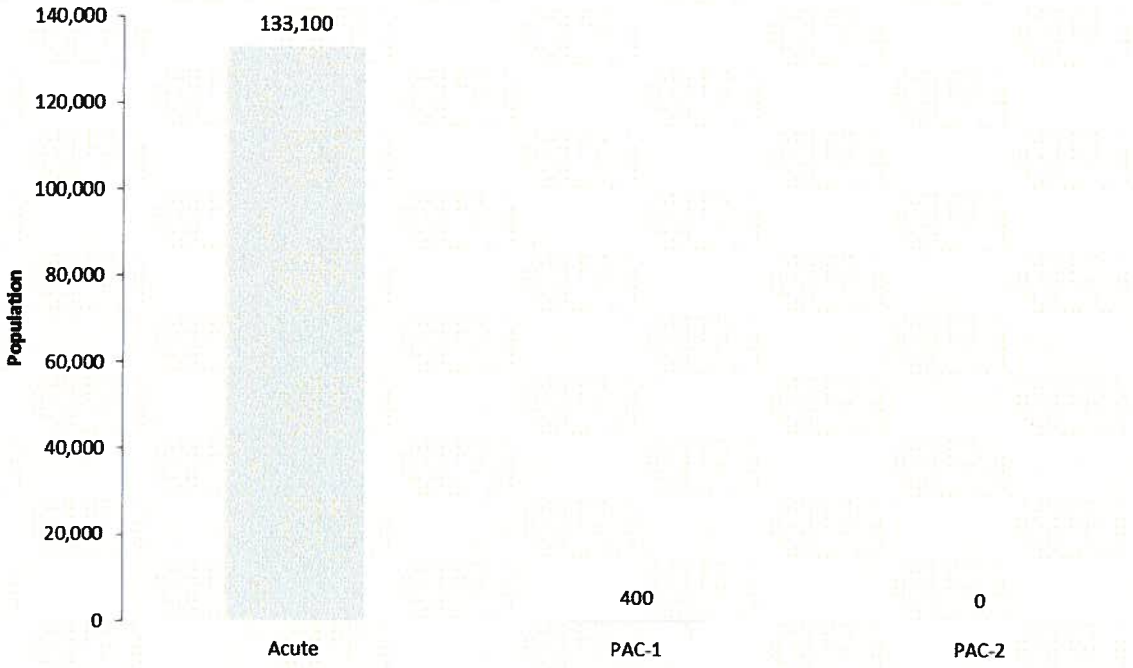

Figure 4-4 **Population in the Model Domain within Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for an English Bay Spill**

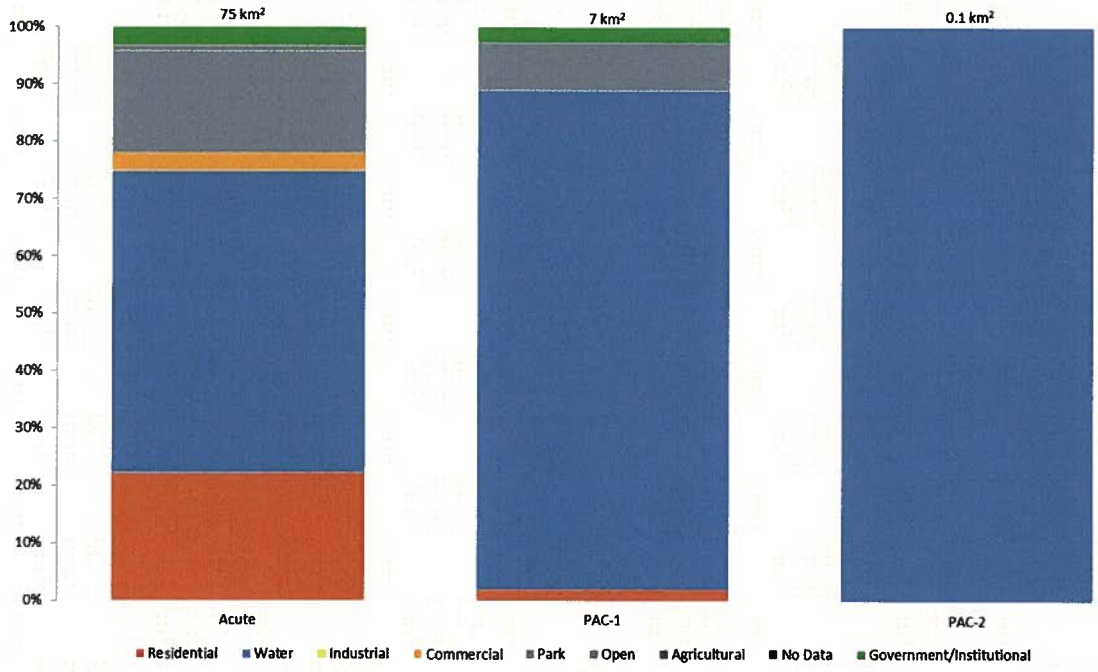

Figure 4-5 **Land Use Area and Percentage Breakdown in the Model Domain within Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for an English Bay Spill**

4.2 First Narrows Results

The maximum predicted concentrations from the First Narrows meteorological scenarios are shown below in Table 4-2. There are predicted exceedances of either the acute inhalation, PAC-1, or PAC-2 exposure limits for the all surrogate chemicals modelled, with the exception of n-propane when considering the maximum predicted concentrations. There are also predicted exceedances of the PAC-3 exposure limit for i-butane when considering the maximum predicted concentrations.

The maximum predicted one-hour contour plot of benzene is shown in Figure 4-6 below indicating the contours of the acute inhalation, PAC-1, and PAC-2 exposure limits. Contours for the acute inhalation exposure limit and PAC-1 extend beyond the CALPUFF modelling domain, therefore the analysis was based on the contour areas within the CALPUFF modelling domain. The corresponding land use categories within the respective contours can be seen in Figure 4-7 below. Figure 4-8 indicates the predicted exposed population (based on 2011 census data) for the acute inhalation, PAC-1, and PAC-2 benzene contours, while Figure 4-9 classifies the land use categories within these contours. It should be noted that the predicted exposed population does not account for people at work (e.g. office workers in downtown, businesses near Burrard Inlet and English Bay), transiting (e.g. on bridges, Seabus or roads) or performing recreational activities (e.g. in Stanley Park or beaches).

Figure 4-8 illustrates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain affected 1,050,300 and 31,200 people, respectively. Figure 4-9 indicates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain covers an area of 580 km^2 and 32 km^2, respectively.

Table 4-2 Maximum Predicted Concentrations and Maximum Predicted On-Land Concentrations for a First Narrows Spill

Surrogate Chemical	Acute Inhalation Exposure ($\mu g/m^3$)	PAC-1 ($\mu g/m^3$)	PAC-2 ($\mu g/m^3$)	PAC-3 ($\mu g/m^3$)	Maximum Predicted Concentrations ($\mu g/m^3$)	Maximum Predicted On-land Concentrations ($\mu g/m^3$)
n-Propane	-	9,914,000	30,643,273	59,484,001	567,840	307,960
i-Butane	78,000	1,899,826	1,899,826	9,499,129	14,028,000	7,626,500
n-Pentane	200,000	354,133	1,800,175	44,266,593	44,100,000	24,135,000
n-hexane	6,200	1,057,003	10,217,694	30,300,749	28,513,000	15,591,000
Benzene	580	166,019	2,554,137	12,770,687	9,092,600	4,503,500
n-Heptane	-	1,802,055	1,802,055	20,477,898	10,123,000	4,764,200
Toluene	15,000	252,221	2,108,120	13,928,649	3,929,300	1,703,900
n-Octane	-	1,400,345	1,797,109	23,339,081	2,761,100	921, 940
Ethyl-Benzene	21,700	143,247	4,774,906	7,813,483	1,406,400	404,010
Xylenes (-m,-o,-p)	7,400	564,307	3,993,558	10,852,059	256,230	69,507
Nonane	10,500	1,048,828	1,048,828	1,048,828	984,190	253,890
Naphthalene	2,000	78,601	78,601	2,620,026	1,011,800	228,220

Legend			
	Acute Inhalation Exposure Limit Exceedance		PAC-2 Exceedance
	PAC-1 Exceedance		PAC-3 Exceedance

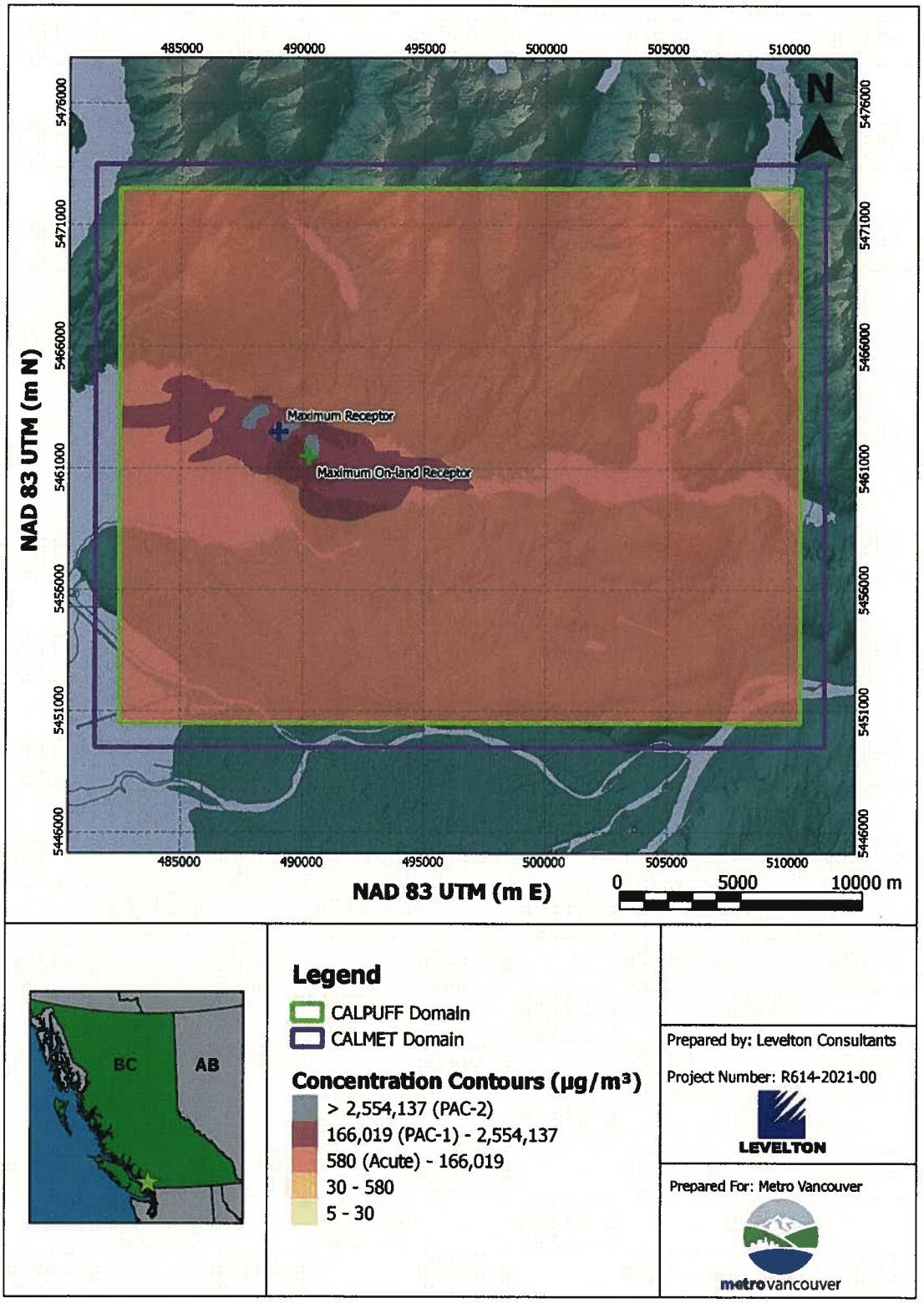

Figure 4-6 **Acute Inhalation, PAC-1, and PAC-2 Exposure Level Contours for Benzene for a First Narrows Spill**

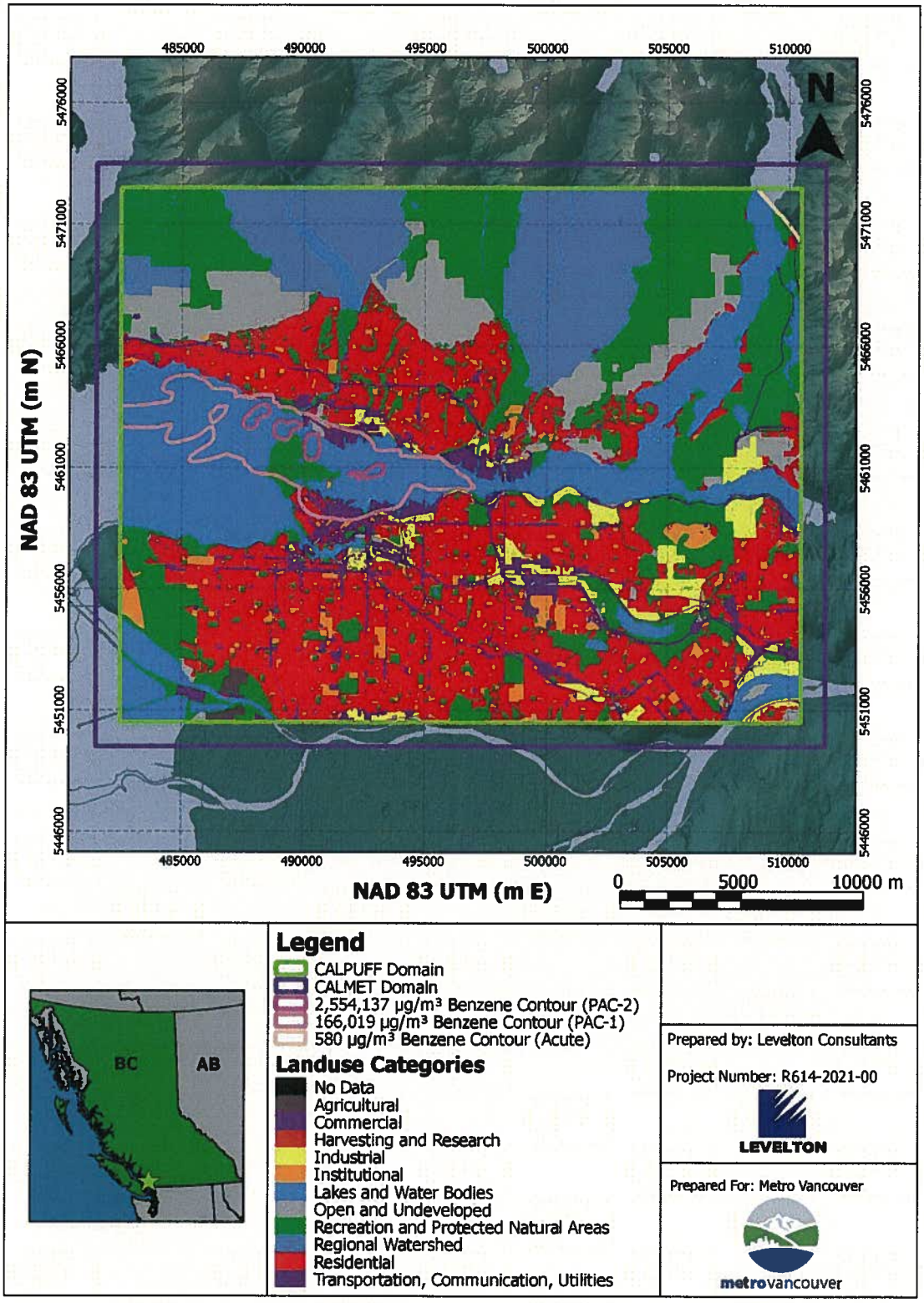

Figure 4-7 **Land Use Area and Percentage Breakdown within the Acute Inhalation, PAC-1, and PAC-2 Exposure Levels for Benzene for a First Narrows Spill**

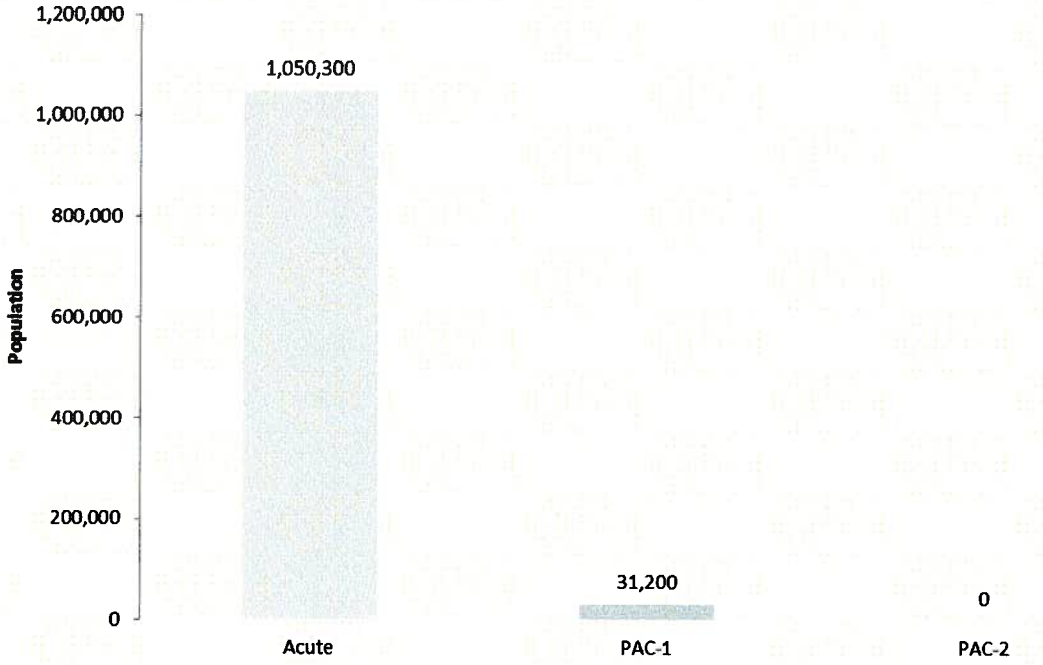

Figure 4-8 **Population in the Model Domain within Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for a First Narrows Spill**

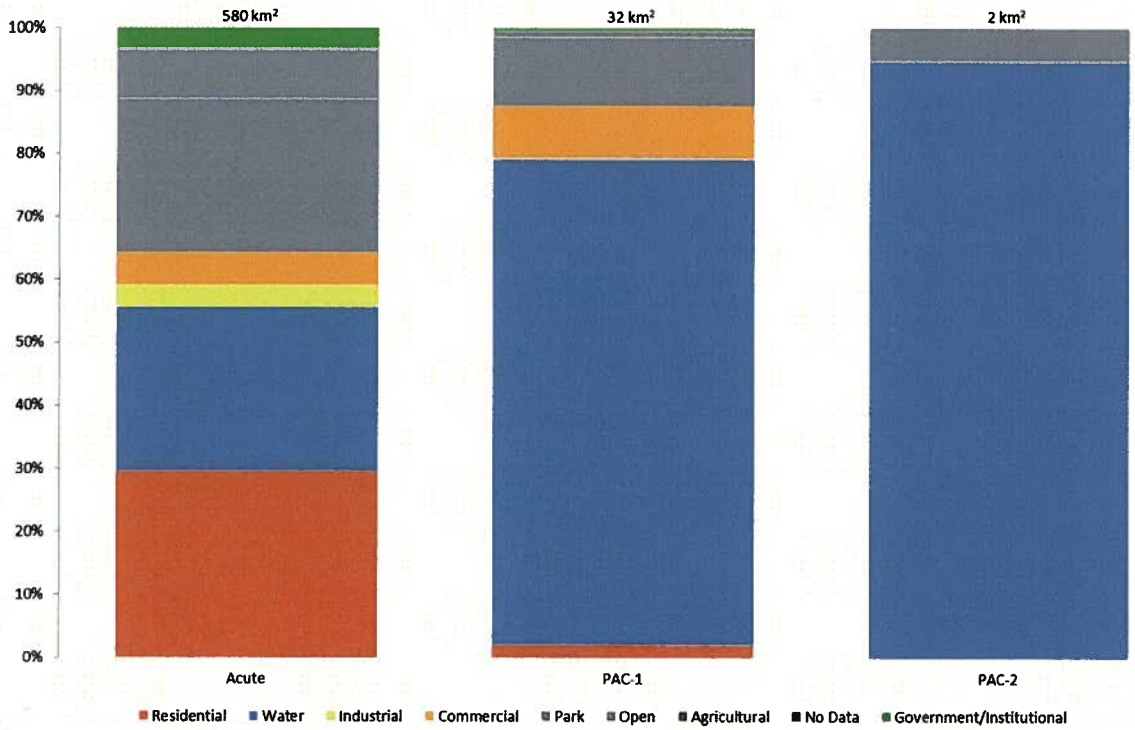

Figure 4-9 **Land Use Area and Percentage Breakdown in the Model Domain within Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for a First Narrows Spill**

4.3 SECOND NARROWS RESULTS

The maximum predicted concentrations from the First Narrows meteorological scenarios are shown below in Table 4-3. There are predicted exceedances of either the acute inhalation, PAC-1, or PAC-2 exposure limits for the all surrogate chemicals modelled with the exception of n-propane when considering the maximum predicted concentrations. There are also predicted exceedances of the PAC-3 exposure limits for i-butane, n-pentane and n-hexane when considering the maximum predicted concentrations.

The maximum predicted one-hour contour plot of benzene is shown in Figure 4-10 indicating the contours of the acute inhalation, PAC-1, and PAC-2 exposure limits. Exceedances of the acute inhalation exposure limit are predicted over the entire CALPUFF modelling domain. The corresponding land use categories within the respective contours can be seen in Figure 4-11 below. Figure 4-12 indicates the predicted exposed population (based on 2011 census data) for the acute inhalation, PAC-1, and PAC-2 benzene contours, while Figure 4-13 classifies the land use categories within these contours. It should be noted that the predicted exposed population does not account for people at work (e.g. office workers in downtown, businesses near Burrard Inlet and English Bay), transiting (e.g. on bridges, Seabus or roads) or performing recreational activities (e.g. in Stanley Park or beaches).

Figure 4-12 illustrates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain affected 1,050,100 and 31,400 people, respectively. Figure 4-13 indicates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain covers an area of 573 km^2 and 42 km^2, respectively.

Table 4-3 Maximum Predicted Concentrations and Maximum Predicted On-Land Concentrations for a Second Narrows Spill

Surrogate Chemical	Acute Inhalation Exposure ($\mu g/m^3$)	PAC-1 ($\mu g/m^3$)	PAC-2 ($\mu g/m^3$)	PAC-3 ($\mu g/m^3$)	Maximum Predicted Concentrations ($\mu g/m^3$)	Maximum Predicted On-land Concentrations ($\mu g/m^3$)
n-Propane	-	9,914,000	30,643,273	59,484,001	696,140	194,860
i-Butane	78,000	1,899,826	1,899,826	9,499,129	17,161,000	4,822,700
n-Pentane	200,000	354,133	1,800,175	44,266,593	54,489,000	15,241,000
n-hexane	6,200	1,057,003	10,217,694	30,300,749	33,644,000	10,142,000
Benzene	580	166,019	2,554,137	12,770,687	9,385,300	3,182,300
n-Heptane	-	1,802,055	1,802,055	20,477,898	9,792,500	3,508,000
Toluene	15,000	252,221	2,108,120	13,928,649	3,441,900	1,293,400
n-Octane	-	1,400,345	1,797,109	23,339,081	1,842,200	715,560
Ethyl-Benzene	21,700	143,247	4,774,906	7,813,483	803,760	319,160
Xylenes (-m,-o,-p)	7,400	564,307	3,993,558	10,852,059	137,680	55,365
Nonane	10,500	1,048,828	1,048,828	1,048,828	501,260	210,540
Naphthalene	2,000	78,601	78,601	2,620,026	440,180	214,890

Legend			
	Acute Inhalation Exposure Limit Exceedance		PAC-2 Exceedance
	PAC-1 Exceedance		PAC-3 Exceedance

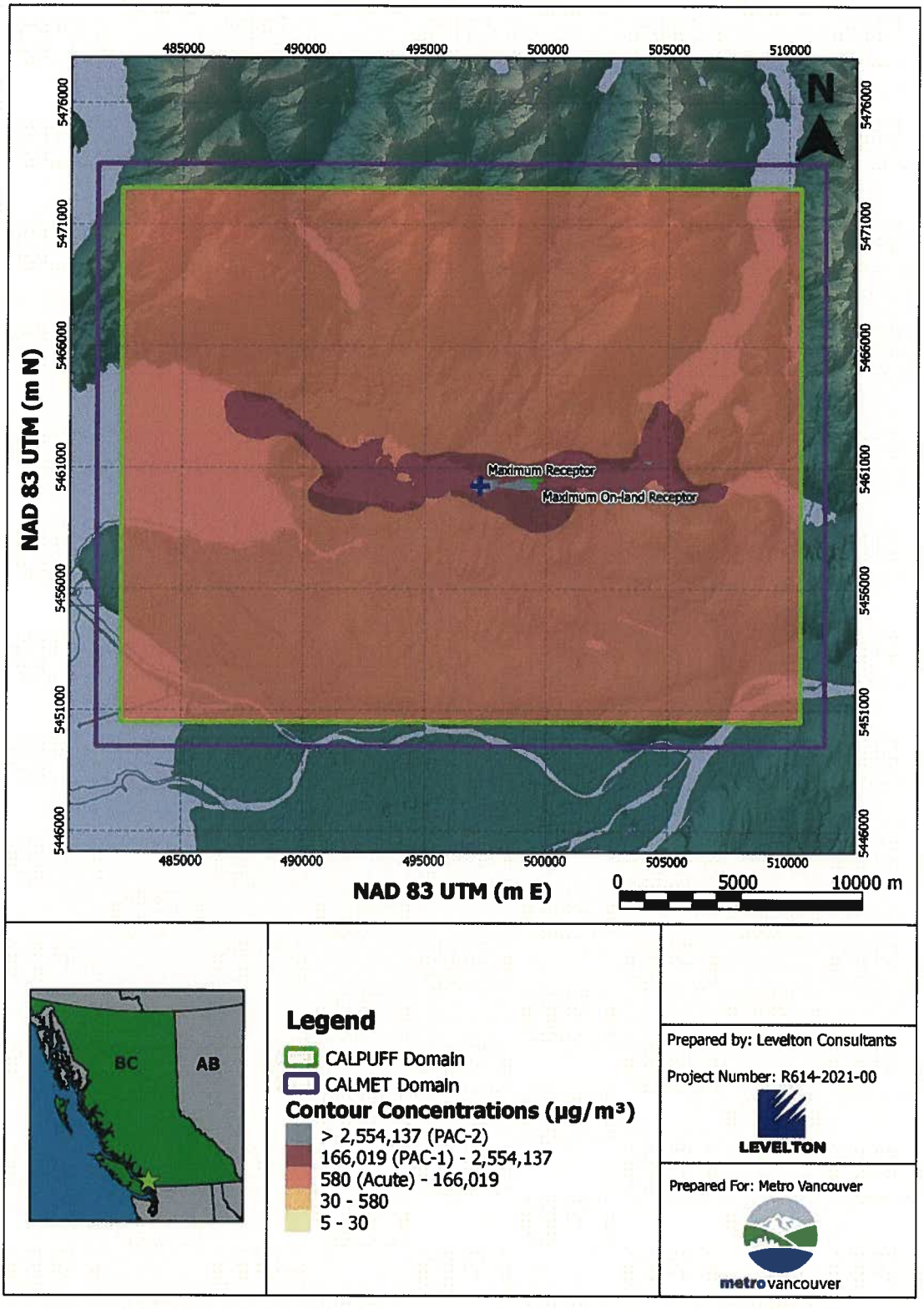

Figure 4-10 **Acute Inhalation, PAC-1, and PAC-2 Exposure Level Contours for Benzene for a Second Narrows Spill**

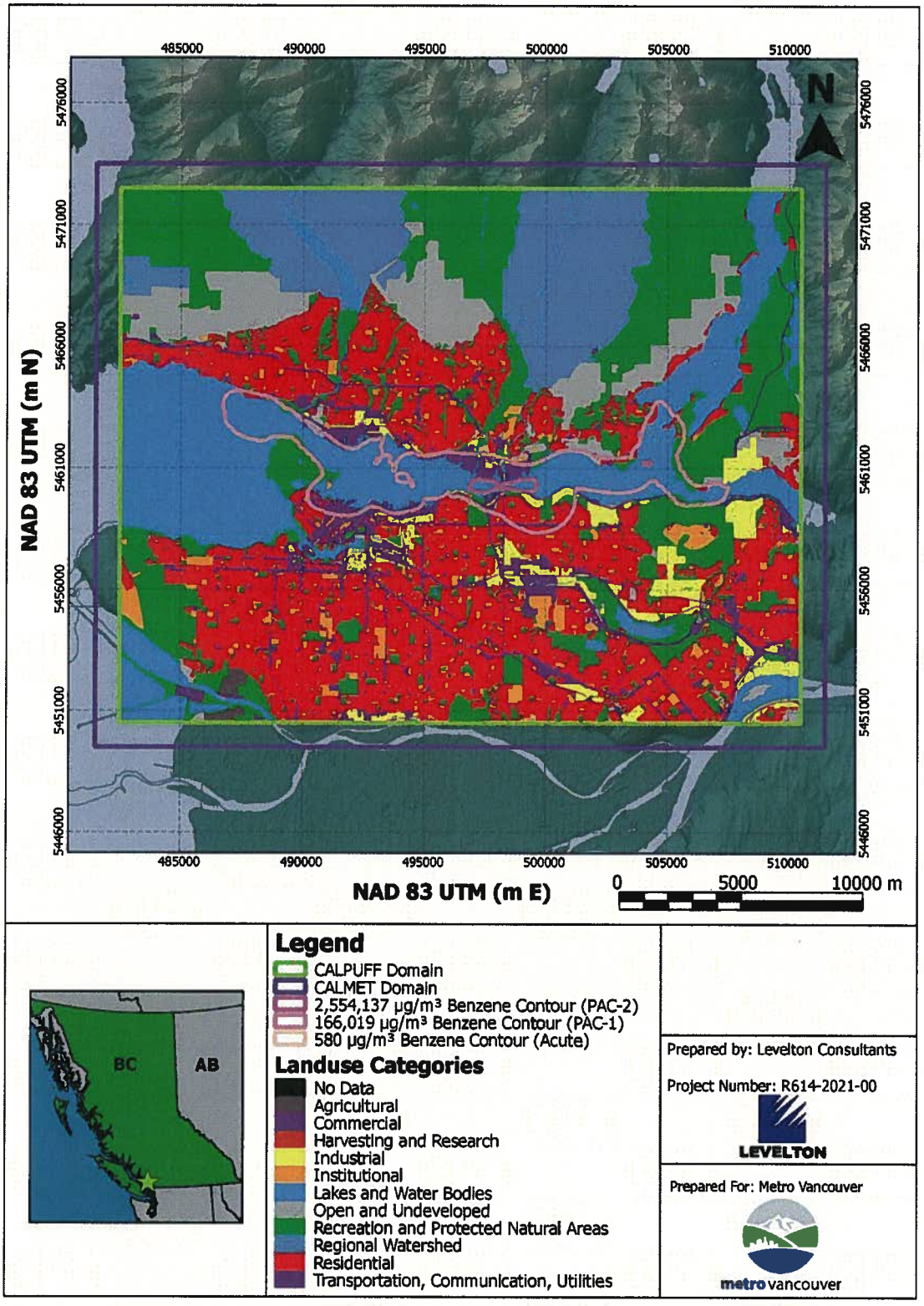

Figure 4-11 Land Use Area and Percentage Breakdown within the Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for a Second Narrows Spill

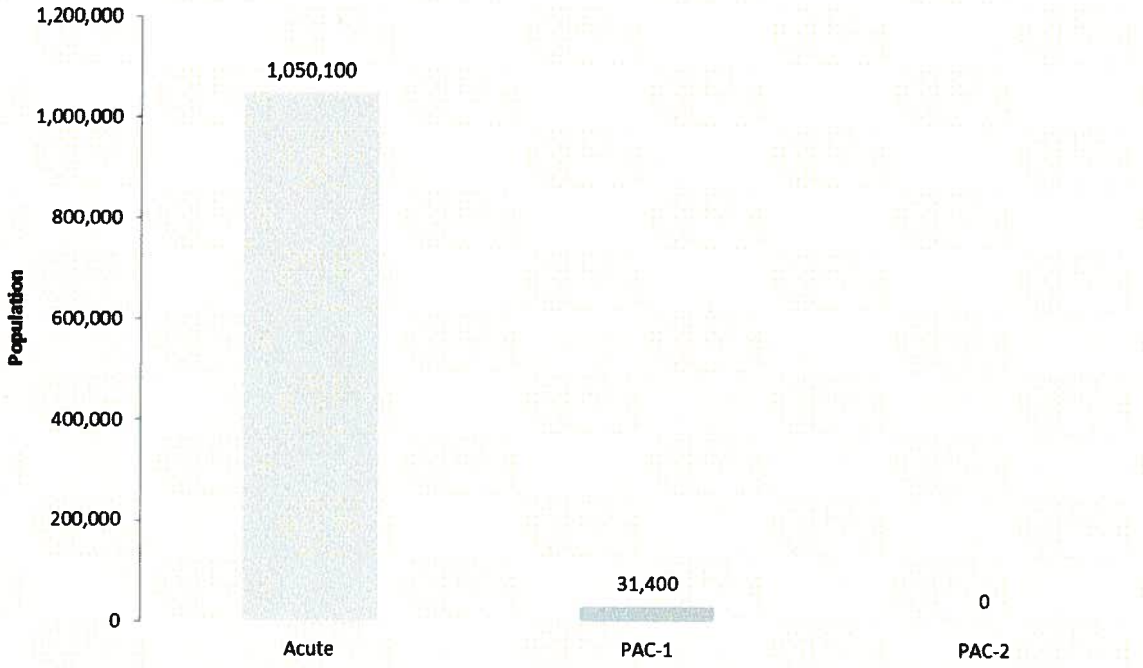

Figure 4-12 **Population in the Model Domain within Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for a Second Narrows Spill**

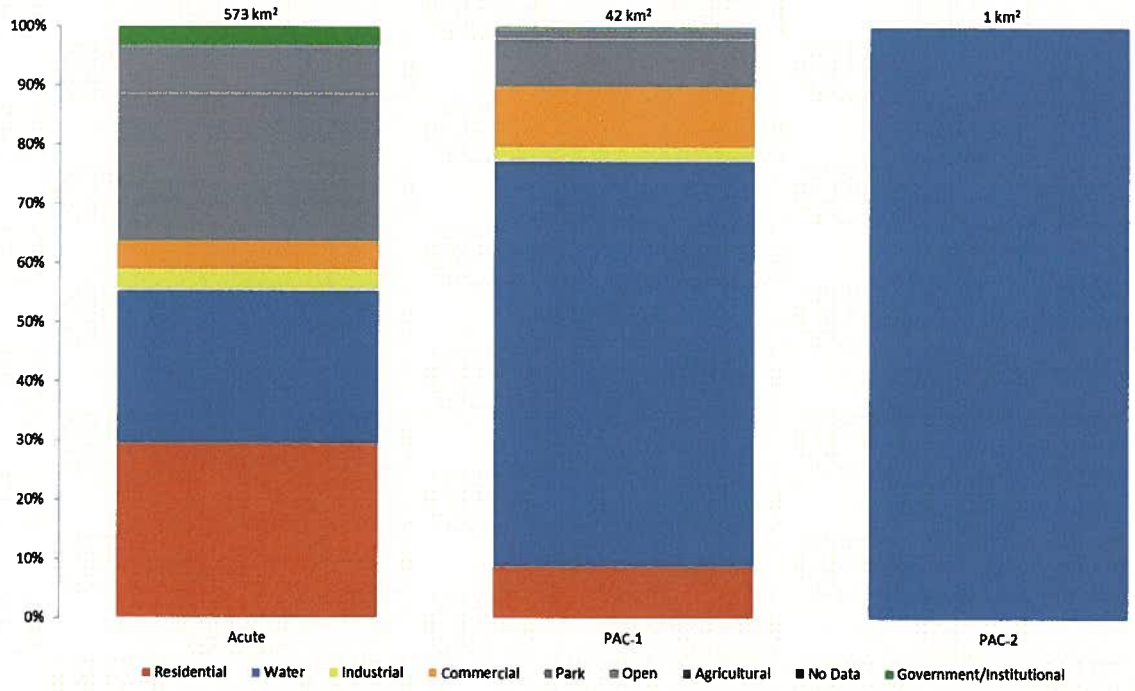

Figure 4-13 **Land Use Area and Percentage Breakdown in the Model Domain within Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for a Second Narrows Spill**

4.4 WESTRIDGE TERMINAL RESULTS

The maximum predicted concentrations from the Westridge Terminal meteorological scenarios are shown below in Table 4-4. There are exceedances of either the acute inhalation, PAC-1, or PAC-2 exposure limits for all surrogate chemicals modelled when considering the maximum predicted concentrations, with the exception of n-propane and n-octane.

The maximum predicted one-hour contour plot of benzene is shown in Figure 4-14 below indicating the contours of the acute inhalation, PAC-1, and PAC-2 exposure limits. Contours for the acute inhalation exposure limit extend beyond the CALPUFF modelling domain, therefore the analysis was based on the contour areas within the CALPUFF modelling domain. The corresponding land use categories within the respective contours can be seen in Figure 4-15 below. Figure 4-16 indicates the predicted exposed population (based on 2011 census data) for the acute inhalation, PAC-1, and PAC-2 benzene contours, while Figure 4-17 classifies the land use categories within these contours. It should be noted that the predicted exposed population does not account for people at work (e.g. office workers in downtown, businesses near Burrard Inlet and English Bay), transiting (e.g. on bridges, Seabus or roads) or performing recreational activities (e.g. in Stanley Park or beaches).

Figure 4-16 illustrates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain affected 1,077,700 and 2,600 people, respectively. Figure 4-17 indicates that the benzene acute inhalation exposure threshold and PAC-1 contour within the CALPUFF modelling domain covers an area of 570 km^2 and 14 km^2, respectively.

Table 4-4 Maximum Predicted Concentrations and Maximum Predicted On-Land Concentrations for a Westridge Terminal Spill

Surrogate Chemical	Acute Inhalation Exposure ($\mu g/m^3$)	PAC-1 ($\mu g/m^3$)	PAC-2 ($\mu g/m^3$)	PAC-3 ($\mu g/m^3$)	Maximum Predicted Concentrations ($\mu g/m^3$)	Maximum Predicted On-land Concentrations ($\mu g/m^3$)
n-Propane	-	9,914,000	30,643,273	59,484,001	264,450	264,450
i-Butane	78,000	1,899,826	1,899,826	9,499,129	6,514,700	6,514,700
n-Pentane	200,000	354,133	1,800,175	44,266,593	20,704,000	20,704,000
n-hexane	6,200	1,057,003	10,217,694	30,300,749	13,802,000	13,802,000
Benzene	580	166,019	2,554,137	12,770,687	4,057,900	4,057,900
n-Heptane	-	1,802,055	1,802,055	20,477,898	4,322,900	4,322,900
Toluene	15,000	252,221	2,108,120	13,928,649	1,615,900	1,545,900
n-Octane	-	1,400,345	1,797,109	23,339,081	900,120	839,180
Ethyl-Benzene	21,700	143,247	4,774,906	7,813,483	404,570	366,590
Xylenes (-m,-o,-p)	7,400	564,307	3,993,558	10,852,059	70,262	62,939
Nonane	10,500	1,048,828	1,048,828	1,048,828	259,740	229,670
Naphthalene	2,000	78,601	78,601	2,620,026	242,980	203,170

Legend			
	Acute Inhalation Exposure Limit Exceedance		PAC-2 Exceedance
	PAC-1 Exceedance		PAC-3 Exceedance

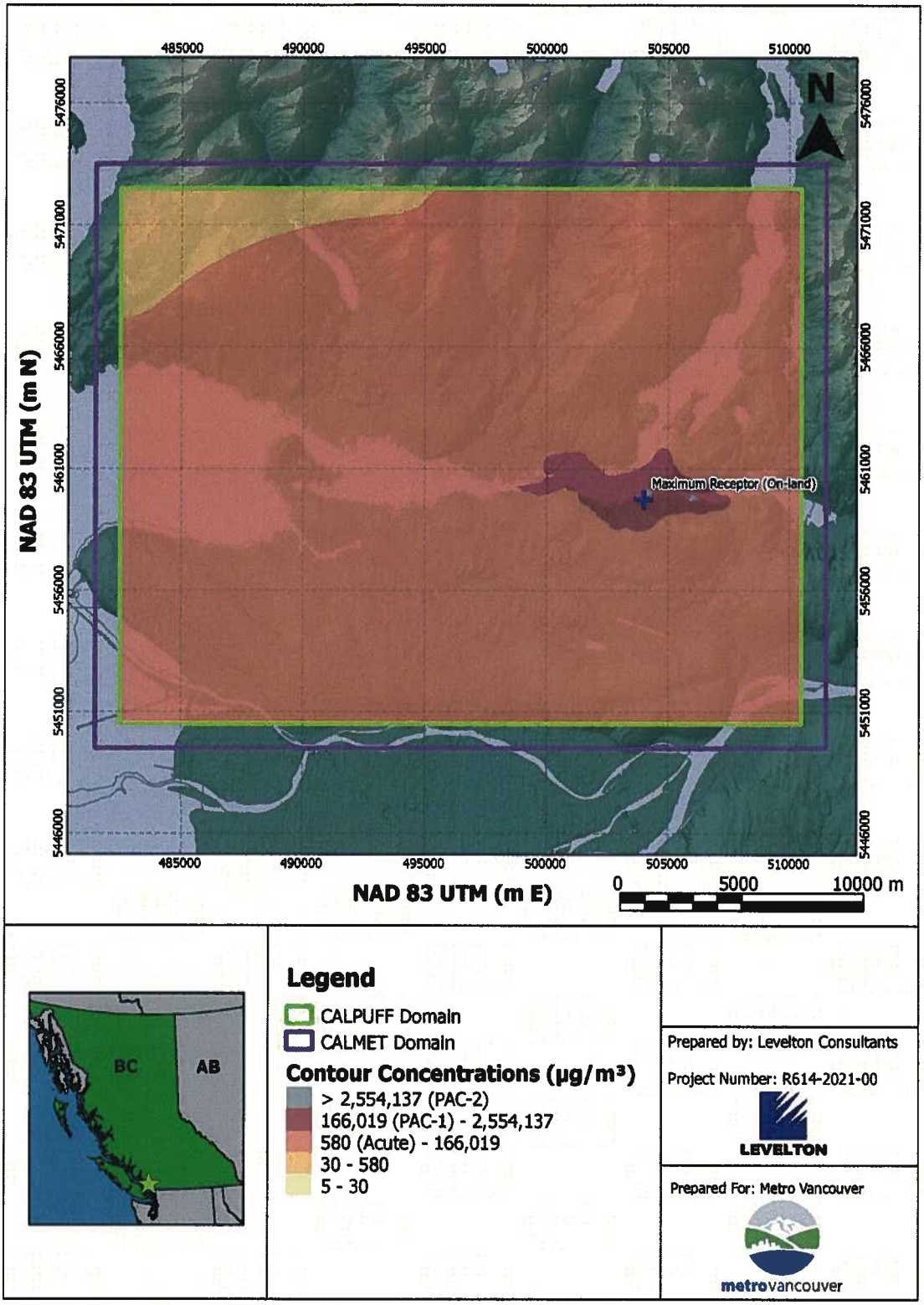

Figure 4-14 **Acute Inhalation, PAC-1, and PAC-2 Exposure Level Contours for Benzene for a Westridge Terminal Spill**

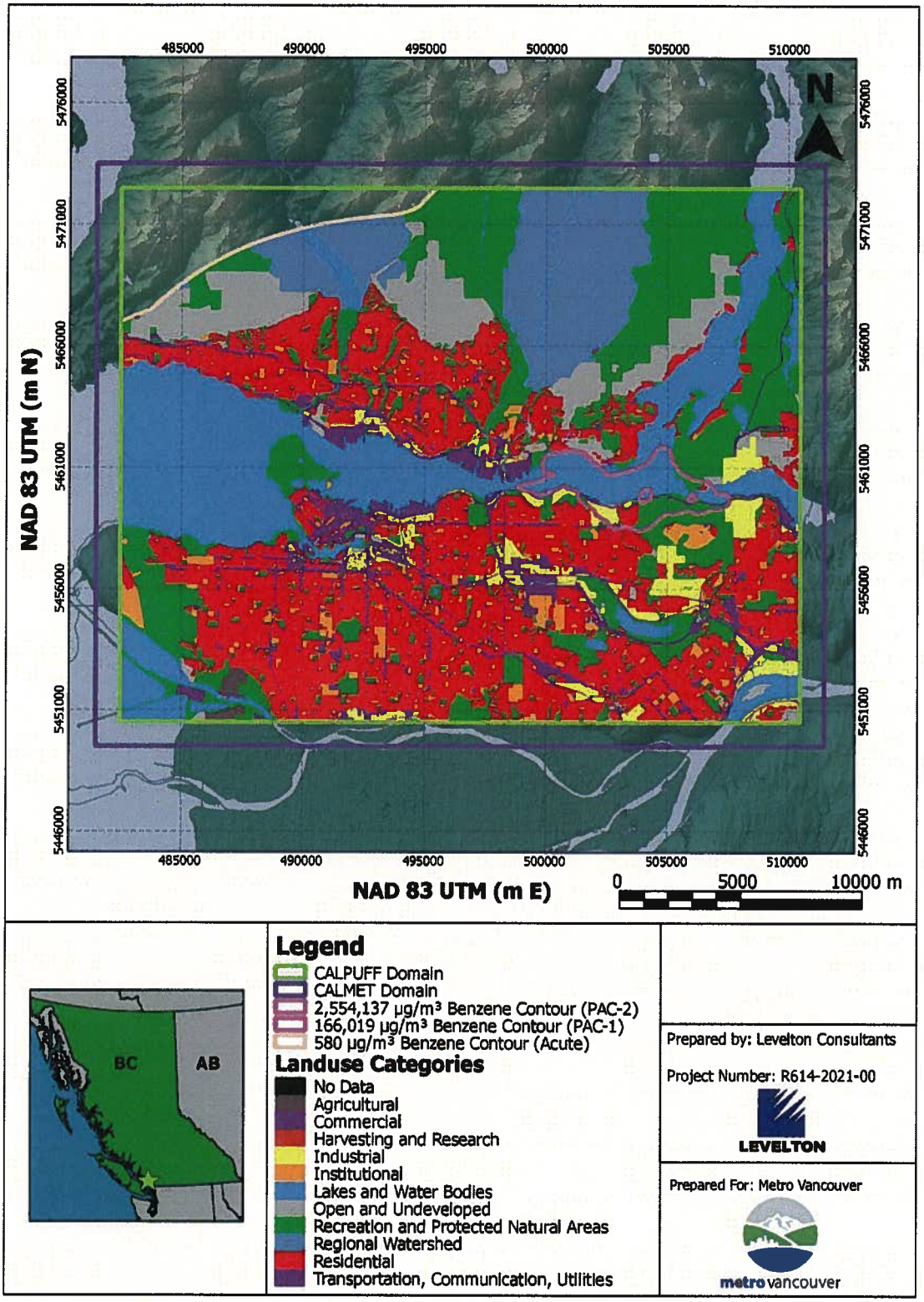

Figure 4-15 Land Use Area and Percentage Breakdown within the Acute Inhalation, PAC-1, or PAC-2 Exposure Levels for Benzene for a Westridge Terminal Spill

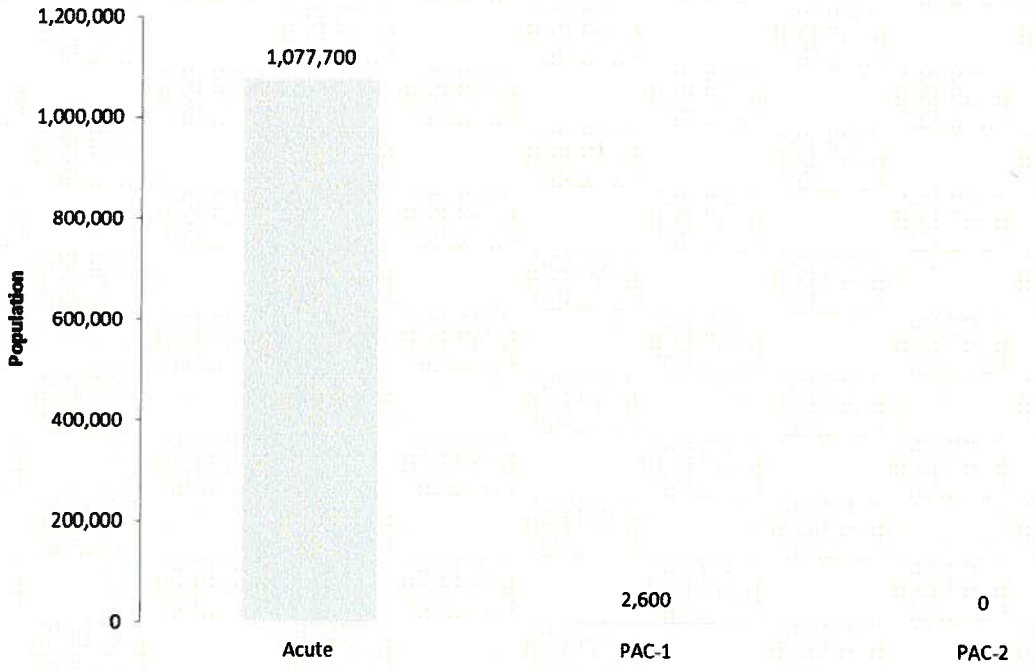

Figure 4-16 **Population in the Model Domain within the Acute Inhalation, PAC-1, and PAC-2 Exposure Levels for Benzene for a Westridge Terminal Spill**

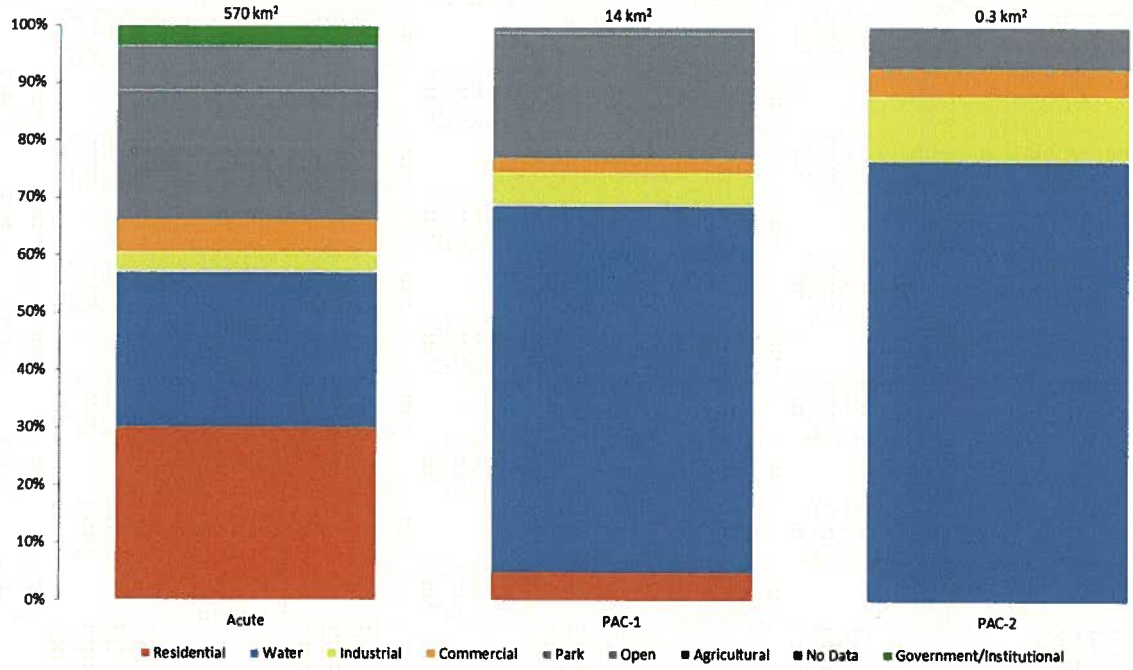

Figure 4-17 **Land Use Area and Percentage Breakdown in the Model Domain within the Acute Inhalation, PAC-1, and PAC-2 Exposure Levels for Benzene for a Westridge Terminal Spill**

4.5 TIME SERIES PLOT FOR BENZENE AND I-BUTANE - ALL LOCATIONS

In order to gain a better understanding of how the maximum predicted hourly concentrations change over time, time series of the maximum predicted benzene and i-butane concentrations versus hour after an oil spill are shown in Figure 4-18 through Figure 4-21. For each spill location, the marker represents the average of the maxima from the 12 meteorological scenarios, the top bar indicates the highest of the maxima from the 12 meteorological scenarios, and the bottom bar indicates the lowest of the maxima from the 12 meteorological scenarios.

Figure 4-18 illustrates that in the first hour after an oil spill the maximum predicted benzene concentrations from each spill location considered exceeds PAC-2. In each successive hour after an oil spill the maximum predicted concentrations decrease, and by the sixth hour the maximum predicted concentrations from each spill location considered are below PAC-1, yet still above the acute inhalation exposure limit. Figure 4-19 illustrates a similar trend for the maximum predicted benzene concentrations when considering the on-land receptors. Although the maximum predicted concentrations are lower in magnitude, by the sixth hour the maximum predicted concentrations from each spill location considered remain above the acute inhalation exposure limit.

Figure 4-20 illustrates that in the first hour after an oil spill the maximum predicted i-butane concentrations from each spill location considered exceeds PAC-2 at English Bay (Anchorage 8) and Westridge Terminal, and PAC-3 at First Narrows and Second Narrows. In each successive hour after an oil spill the maximum predicted concentrations decrease, by the second hour the maximum predicted i-butane concentrations are below PAC-1/PAC-2, and by the fifth hour the maximum predicted i-butane concentrations are below the acute inhalation exposure limit. Figure 4-21 illustrates a similar trend for the maximum predicted i-butane concentrations when considering on-land receptors, which drop below PAC-1/PAC-2 by the second hour and below the acute inhalation exposure limit by the fifth hour after an oil spill.

From Figure 4-18 through Figure 4-21, it can be seen that the maximum predicted concentrations for benzene and i-butane occur in the first hour following an oil spill. Therefore, the greatest human health risk from benzene and i-butane is likely to occur during the first hour following an oil spill based on the simulated scenarios considered.

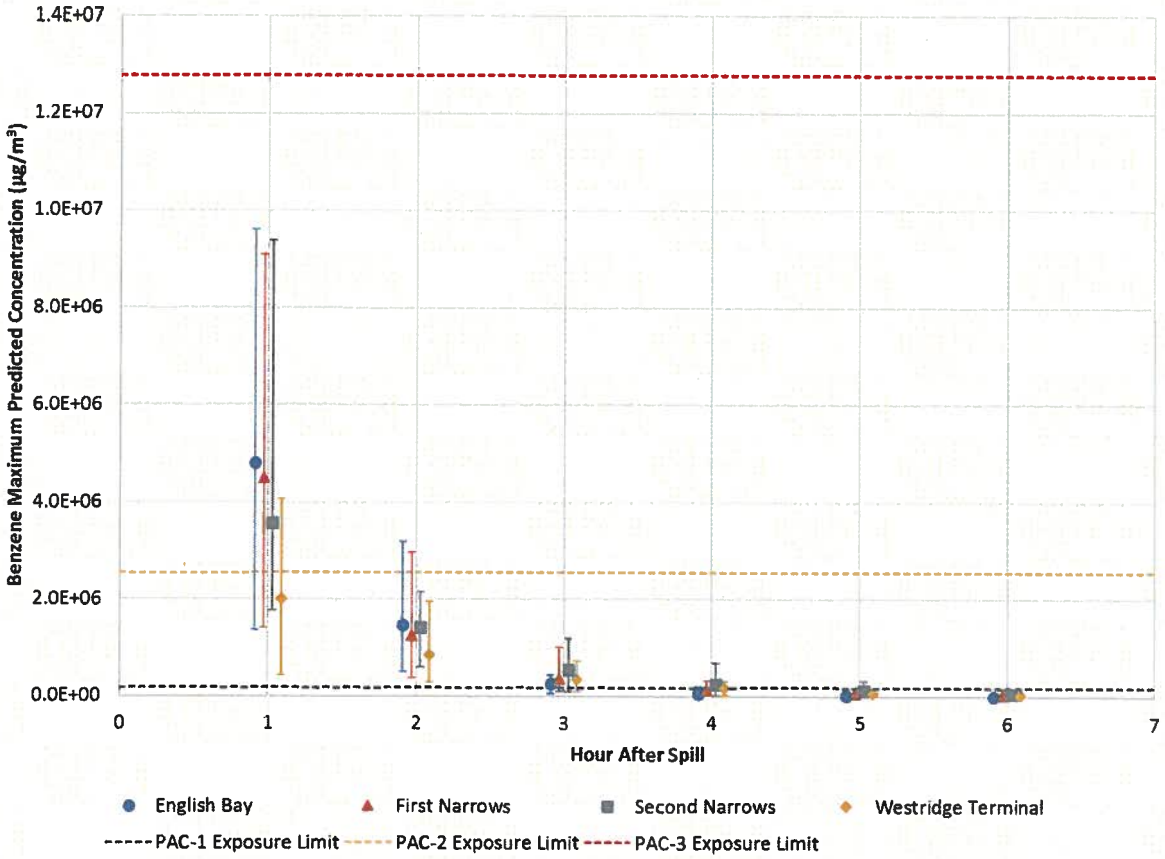

Figure 4-18 Benzene Maximum Predicted Concentration Time Series, All Receptors

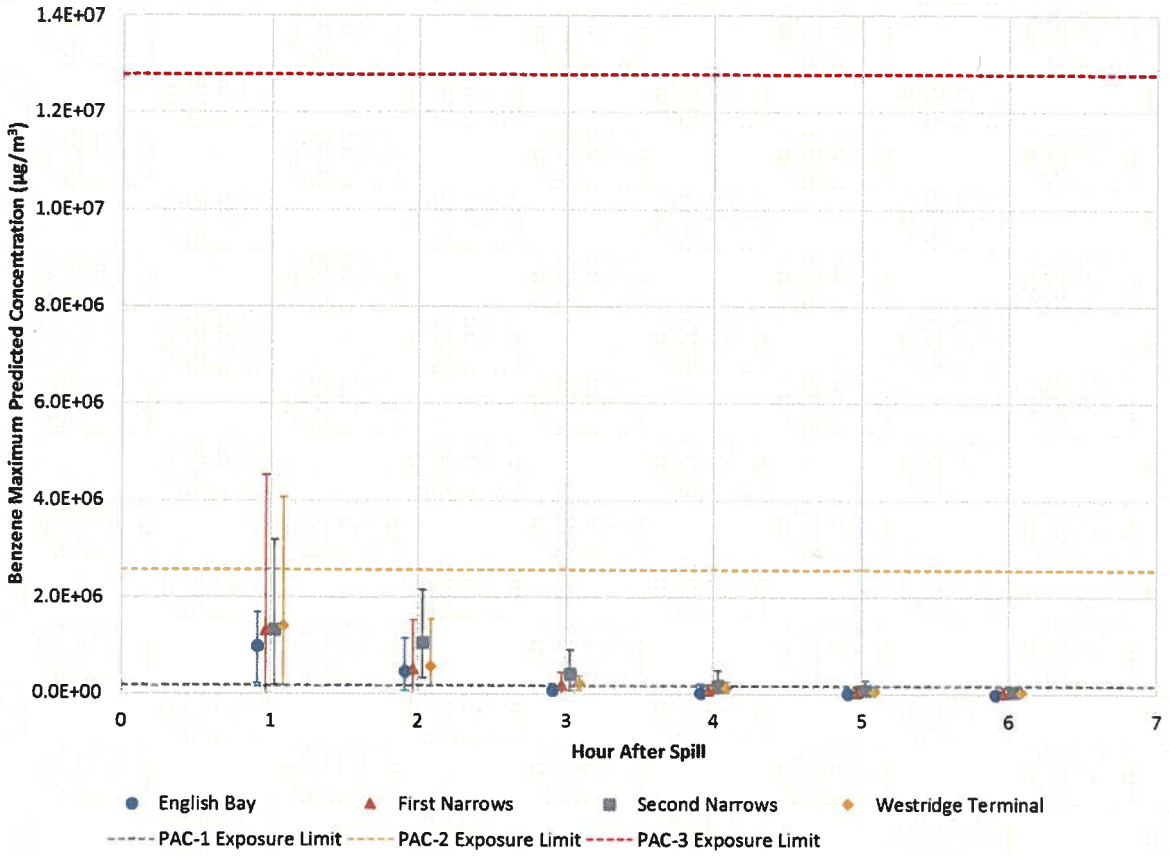

Figure 4-19 Benzene Maximum Predicted Concentration Time Series, On-Land Receptors

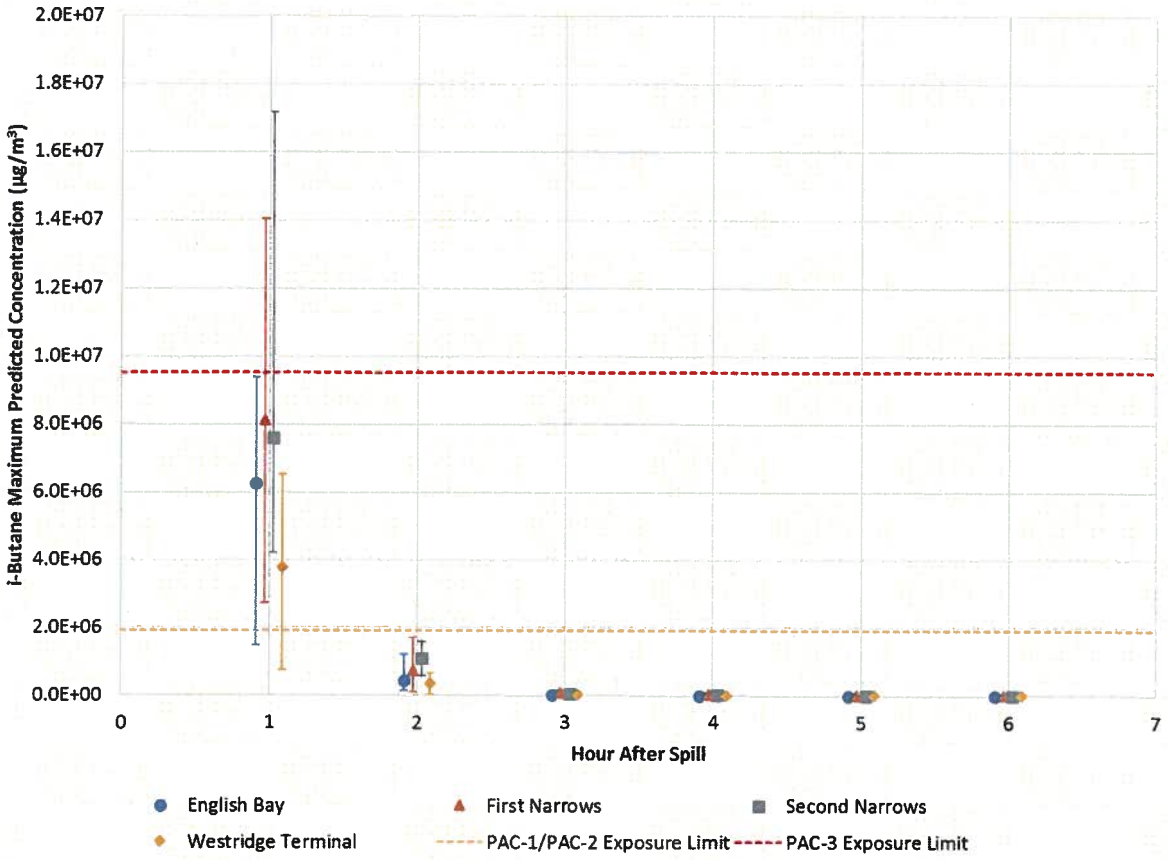

Figure 4-20 i-Butane Maximum Predicted Concentration Time Series, All Receptors

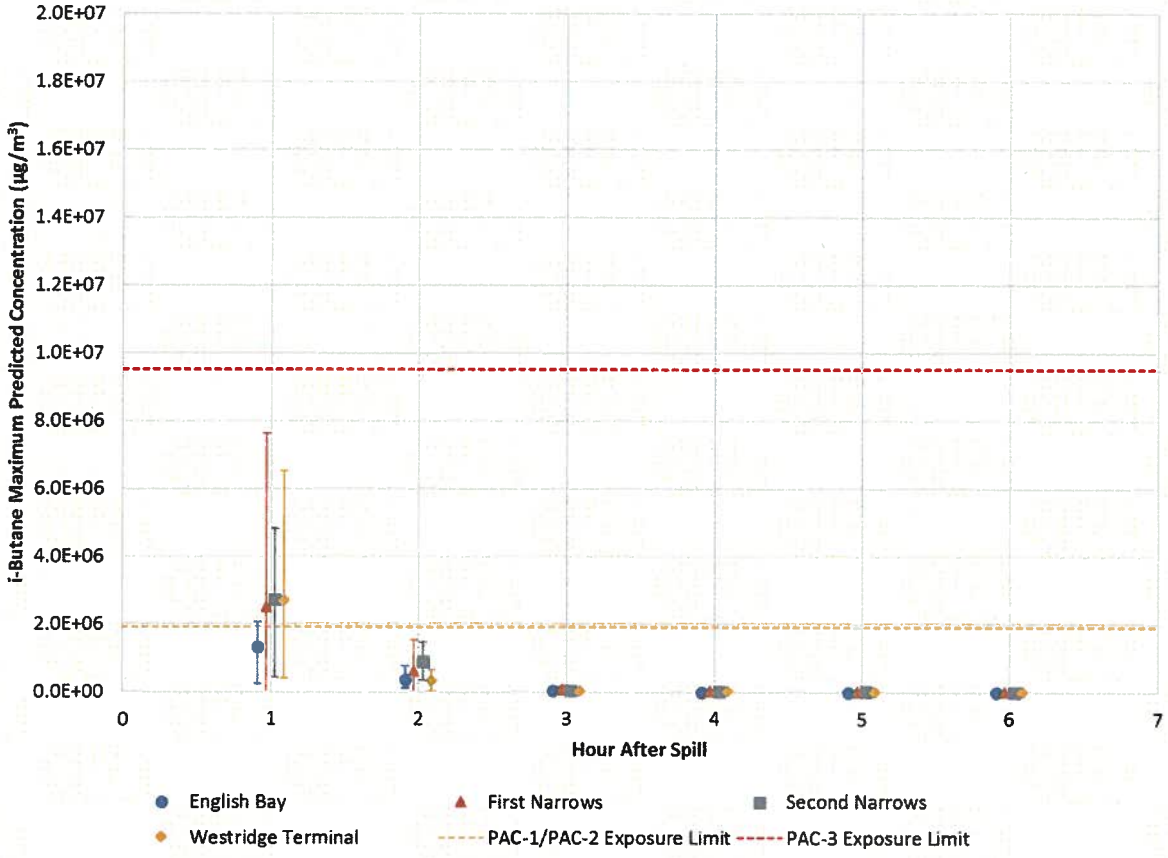

Figure 4-21 i-Butane Maximum Predicted Concentration Time Series, On-Land Receptors

5 CONCLUSIONS

Based on the air quality modelling assessment for an oil spill of Cold Lake Blend crude oil at English Bay (Anchorage 8), First Narrows, Second Narrows, and Westridge Terminal locations, the following conclusions have been drawn regarding potential impacts from the air emissions associated with the simulated oil spills:

- The study area was not large enough to capture the full extent of the potential impacts and only a few spill locations and meteorological conditions were considered. If the study area was larger and a greater number of possible spill locations and meteorological conditions were considered, the results would indicate a greater population affected and likely indicate higher concentrations than reported herein.
- There are predicted exceedances for the majority of pseudo-components, modelled as surrogate chemicals, of acute inhalation, PAC-1, or PAC-2 exposure thresholds.
- There are predicted exceedances for i-butane, n-pentane and n-hexane, modelled as surrogate chemicals, of PAC-3 exposure thresholds over water.
- There are no predicted exceedances for any pseudo-components, modelled as surrogate chemicals, of PAC-3 exposure thresholds over land areas.
- There are predicted benzene PAC-2 exceedances over water and land areas, however, not in areas where people live according to the Statistics Canada census data (2011). The exceedances of the benzene PAC-2 levels have been predicted for areas where people may be present including Stanley Park, Lions Gate Bridge, Second Narrows Bridge and over water. Note this analysis was only conducted for benzene.
- The Texas Commission on Environmental Quality (TCEQ) acute inhalation exposure benzene limit was exceeded in large areas of the study domain affecting a range of 133,100 to 1,077,700 people within the model domain for the different spill locations and scenarios considered. Note that the acute inhalation exposure limit contour extends beyond the model domain for all spill locations and therefore these are likely underestimates of the potential population affected.
- The PAC-1 threshold for benzene was exceeded in areas affecting for a range of 2,600 to 31,400 people within the model domain for the different spill locations and scenarios considered.
- The acute inhalation exposure limit was exceeded for benzene in an area covering from 75 km^2 to 580 km^2 within the model domain for the different spill locations and scenarios considered.
- The PAC-1 threshold was exceeded for benzene in an area covering from 7 km^2 to 42 km^2 within the model domain for the different spill locations and scenarios considered.
- The maximum predicted one-hour benzene concentrations decrease below the PAC-1 threshold six hours after an oil spill, yet are still above the acute inhalation exposure limit, for all spill locations and scenarios considered.

- The maximum predicted one-hour i-butane concentrations decrease below the PAC-1/PAC-2 threshold two hours after an oil spill, and are below the acute inhalation exposure limit by the fifth hour, for all spill locations and scenarios considered.

- The maximum predicted one-hour concentrations for benzene and i-butane from an oil spill is during the first hour following an oil spill. Therefore, the greatest human health risk from benzene and i-butane is likely to occur during the first hour following an oil spill based on the simulated scenarios considered.