FINAL REPORT

AIR DISPERSION MODELLING SOLID WASTE FACILITIES IN THE YUKON

Prepared for:

EBA Engineering Consultants Ltd.
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Whitehorse, YT Y1A 2V3

Prepared by:

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EXECUTIVE SUMMARY

SENES Consultants Limited (SENES) was retained by EBA Engineering Consultants Limited (EBA) on behalf of the Government of Yukon to conduct air dispersion modelling for Solid Waste Facilities (SWF) in the Yukon. Fifteen of these SWFs use burning vessels and one uses open burning of wastes in a trench. Air dispersion modelling was undertaken at six representative facilities to determine appropriate set-back distances for residential development around these facilities.

The CALMET/CALPUFF modelling system was used to assess the maximum potential concentrations that will occur only once per year from the six chosen SWFs at Beaver Creek, Carcross, Johnson's Crossing, Pelly Crossing, Ross River and Tagish. CALMET/CALPUFF, the regulatory model in Newfoundland and Labrador, is an accepted model in British Columbia and is the US Regulatory model for long-range transport. CALPUFF works very well in complex terrain as is the case in most of the Yukon.

The EPA Document "Evaluation of Emissions from the Burning of Household Waste in Barrels" was used as the source of airborne contaminant emission factors. This is a comprehensive study of emission factors that is the industry standard for evaluating garbage burning.

Contaminant emission rates were estimated based on the number of users per SWF, an estimate of waste production per person and relevant emission factors for the open burning of household waste were obtained from the EPA Document "Evaluation of Emissions from the Burning of Household Waste in Barrels" (US EPA 1997a, 1997b). Based on supplied information it was assumed, for modelling purposes, that the solid waste was burned once per week and each burn lasted 8 hours.

As the Government of Yukon does not have air quality standards, it was necessary for the purposes of this study to determine suitable assessment criteria for contaminants. Most of the assessment criteria were derived from Ontario's Air Pollution – Local Air Quality Regulation (O.Reg. 419/05). Other assessment criteria were obtained from a jurisdictional scan of air quality standards published by the Ontario Ministry of the Environment (MOE 2008). Most of the Ontario based assessment criteria are incremental criteria, i.e., background concentrations are not considered. For contaminants that are not listed in the above two references, toxicity information from National Institute for Occupational Safety and Health's database (NIOSH 2005) was considered.

The FReSH based Non-hydrostatic Mesoscale Model (NMM) system was used to develop meteorology in a series of refining steps starting with 32 km resolution initialization fields and refining to 8 km resolution over the entire Yukon and area, nesting down to 2 km domains

around the six selected site. This refined data was further refined down to 100 m resolution for each site using CALMET. This produces very representative meteorology for each site.

For each of the six selected sites, a CALPUFF modelling domain of 10 km by 10 km centered on the solid waste burning site was used. An evenly spaced 100 m modelling receptor grid was used to determine the maximum concentrations and the extent of the sites' impacts. Based on Government of Yukon supplied mapping and verification using Google Earth™, nearby residences were identified and representative discrete receptors were selected so that results could be presented in tabular format.

A screening method was developed to prioritize contaminants that have higher emission rates with respect to their assessment criteria. For each contaminant, the ratio between the emission factor and assessment criterion was calculated as a measure of that contaminant's priority rank. The top five contaminants that were modeled and assessed were (in order of priority):

- PM_{10} (particulate matter smaller than 10 microns in diameter);
- Total Polychlorinated dibenzodioxins and polychlorinated dibenzofurans **(**PCDD/PCDF) - single Toxic Equivalent (TEQ) of dioxins and furans;
- HCN – Hydrogen cyanide;
- Total Polychlorinated biphenyls **(**PCB);
- $PM_{2.5}$ (particulate matter smaller than 2.5 microns in diameter).

The results presented are the maximum values found from the modelling outside of the property line of the SWFs. Grid points within the property line were excluded to eliminate overpredictions due to the model's limitation in close proximity to the source.

The concentrations reported in this study are maximum 24 hour average incremental concentrations that occur only once per year assuming burning durations of 8 hours, once a week. No background air quality concentrations exist for the sites studied. Most of the assessment criteria used are incremental.

The reported predicted maximum concentrations occur only once per year at each receptor. For every other day, the concentrations will be lower. Model results indicated that concentrations would to drop off quickly with distance.

At Carcross, the assessment criteria for PM_{10}, PCDD/PCDF and HCN were exceeded outside of the facility property line. For PM_{10}, the set-back distance at which the assessment criterion would be met is 900 m from the centre of the SWF.

At Tagish, exceedance of PM_{10} was modelled outside of the property line with a set-back distance of 400 m from the centre of the SWF.

No other exceedances were observed for other contaminant at the other modelled sites excluding background concentrations). Modelling indicated that there are no exceedances of any assessment criteria at any of the representative receptors for the SWFs assessed, with predicted maximum concentrations well below respective criteria at receptor locations. Predicted PM_{10} concentrations for a receptor at Carcross are at 50% of the PM_{10} 24 hr average criterion. All other contaminants at all other receptors are at lower percentages of their respective criteria.

Care should be taken in applying the results of this study to other sites. Terrain and land use were observed to have large impacts on the local meteorology near each of the six selected sites, as demonstrated through wind roses. This emphasizes the importance of obtaining representative meteorology for the prediction of maximum concentrations, and for establishing set-back distances based on these concentrations. Due to these uncertainties, the set-back distances determined in this study should be multiplied by some “safety” factor to ensure that impacts are minimized.

Overall, based on the assumptions made in this report, the modelling shows that currently the maximum 24 hr average concentrations of all contaminants considered in this study are below the respective criteria derived from North American jurisdictions at all identified residential areas for all six selected SWFs.

Emissions of chlorinated contaminants such as PCDD/PCDF and PCB, could be reduced by source separation of chlorinated plastics such as polyvinyl chloride (PVC). PCDD/PCDF and PCB cannot be formed without a source of chlorine in the burned waste. Removing other toxic materials such as paints, glues, batteries, electronic equipment, etc. from the material to be burned would also reduce emissions of toxic compounds.

To minimize exposure of users when taking their refuse to the SWF, it is recommended that these facilities be closed to the public during hours when a burn is underway.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

Abbreviation/Acronym	Description
AAQC	Ambient Air Quality Criteria
AP-42	U.S. EPA Compilation of Air Pollution Emission Factors Version 5 – Volume 1: Stationary Point and Area Sources –AP-42.
CALMET	Meteorological preprocessor for CALPUFF
CALPUFF	Air dispersion model
CCME	Canadian Council of Ministers of the Environment
CWS	Canada Wide Standard
DTC	Developmental Testbed Center
EC	Environment Canada
FReSH	SENES proprietary weather forecasting system
HCN	Hydrogen Cyanide
MOE	Ontario Ministry of the Environment
NAAQO	National Ambient Air Quality Objectives
NAD	North American Datum
NCEP	National Centers for Environmental Prediction
NIOSH	National Institute for Occupational Safety and Health
NMM	Non-hydrostatic Mesoscale Model
NOAA	National Oceanic and Atmospheric Administration
O. Reg.	Ontario Regulation
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated biphenyls
PCDD/PCDF	Polychlorinated dibenzodioxins and polychlorinated dibenzofurans
PM	Particulate Matter
PM_{10}	Particulate Matter less than 10 microns in diameter – inhalable
$PM_{2.5}$	Particulate Matter less than 2.5 microns in diameter – respirable
POI	Point of Impingement
PRIME	Plume Rise Model Enhancement
SWF	Sold Waste Facility
TEQ:	Toxic Equivalent
U.S.EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VOC	Volatile Organic Compound
WRF	Weather Research and Forecasting

1. INTRODUCTION

SENES Consultants Limited (SENES) was retained by EBA Engineering Consultants Limited (EBA) on behalf of the Government of Yukon to conduct air dispersion modelling for solid waste facilities in the Yukon. EBA is currently completing a review of Solid Waste Facilities (SWF) the Yukon. Fifteen of these SWFs use burning vessels and one uses open burning of wastes in a trench. Air dispersion modelling was undertaken at these facilities to determine an appropriate set-back distance for residential development around these facilities. Six representative facilities were chosen to be modelled in order to develop the modelling approach in an efficient, timely and cost-effective manner. Figure 1-1 presents the location of the six chosen facilities (blue dots) and the other SWFs that are not part of this study (red dots).

FIGURE 1-1 – LOCATIONS OF SOLID WASTE FACILITIES

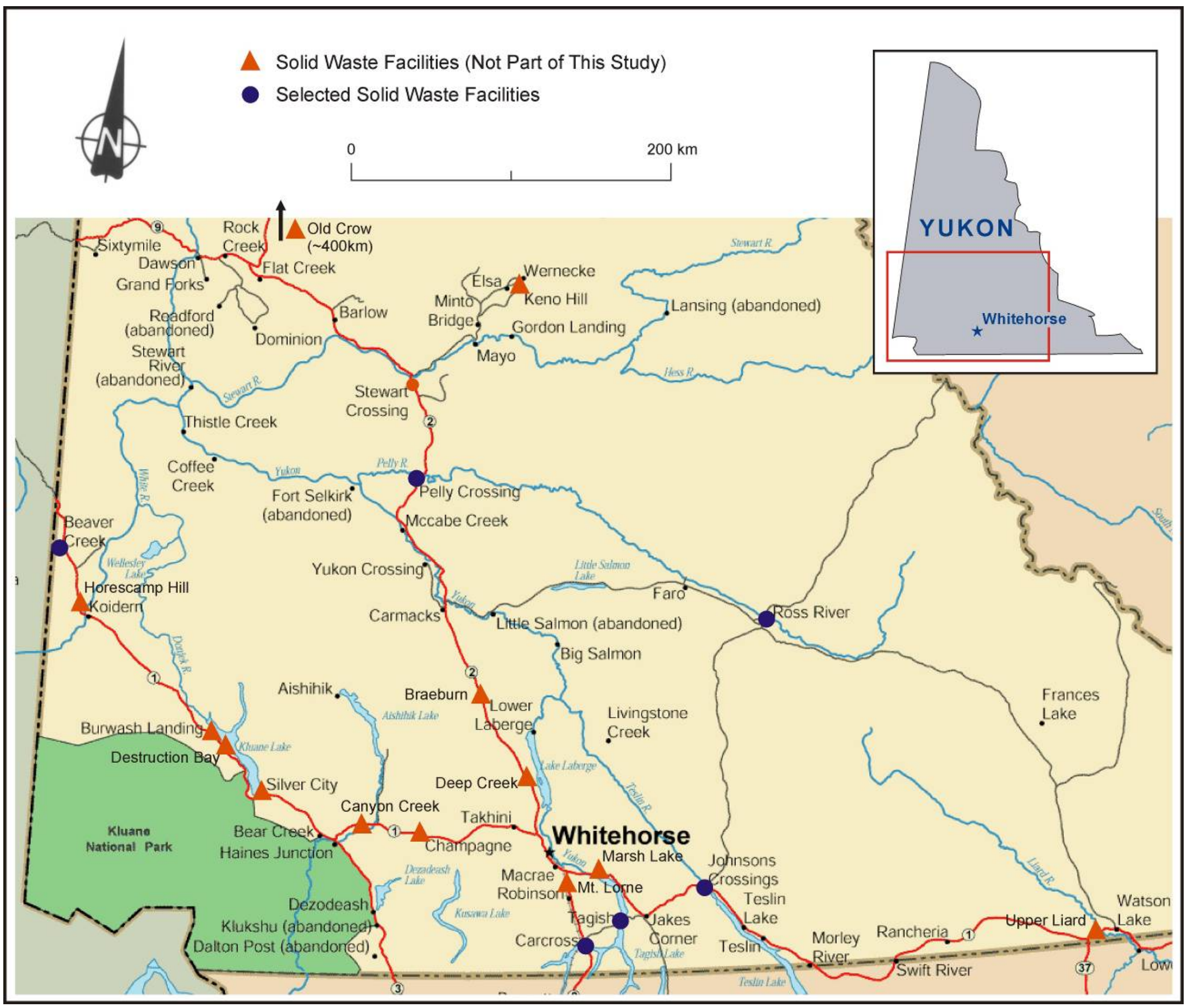


Table 1-1 contains the names of all SWFs and their latitude and longitude coordinates (in degrees). The six chosen SWFs are shown in shaded rows.

TABLE 1-1 - COORDINATES OF SOLID WASTE FACILITIES

Solid Waste Facility	Longitude – West (°)	Latitude (°)
Beaver Creek	149.8333	62.4167
Braeburn	165.7667	61.4333
Burwash Landing	138.8667	61.3000
Canyon Creek	137.1500	60.8333
Carcross	134.6667	60.1833
Champagne	136.4500	60.7833
Deep Creek	135.2333	61.0833
Destruction Bay Metals	138.8500	61.2833
Horsecamp Hill	140.5864	62.0550
Johnson's Crossing	133.2833	60.4833
Keno City	135.3167	63.9000
Marsh Lake	134.4333	60.5667
Mt. Lorne	134.8667	60.4833
Old Crow	139.8333	67.5833
Pelly Crossing	136.6000	62.7833
Ross River	132.3500	61.9667
Silver City	138.3333	61.0333
Stewart Crossing	136.6667	63.3333
Tagish	134.2833	60.2667
Upper Liard	128.9167	60.0500

The rationale for the selection of these six sites is as follows:

Beaver Creek located near the Alaska/Yukon border, Beaver Creek was selected due to the long distance from Haines Junction (i.e. the closest incorporated community), which likely indicated that a change in practices would represent higher operational costs in comparison to other facilities. As such, an air dispersion assessment would provide key information in evaluating the possibility of change.

The **Carcross** site represents the worst case scenario setting with respect to topography and distance to sensitive receptors. Additionally, residents in Carcross have been very adamant in the past in their opposition to the burning of wastes, making their community a primary candidate to evaluate for change.

Johnson's Crossing is a small facility close to Whitehorse and a likely candidate to be converted into a transfer station due to its location between Whitehorse and Teslin. Additionally, the air dispersion modeling results were of interest for this facility to provide a comparison between smaller and larger population bases in relation to emissions generated by wastes.

Pelly Crossing is a larger community representative of a more northern geographic location, and the largest unincorporated community north of Carmacks. Air dispersion modeling at this location was thought to be indicative of the emissions to be expected with smaller communities that are also located in the north.

Ross River was selected as an example of a larger community that could potentially function on its own if the nearest incorporated community (i.e. Faro) was unwilling to accept the community's waste. In order to examine the viability of waste alternatives available, air dispersion modeling provides key information for the decision making process.

The rationale behind the selection of **Tagish** in this modeling process is similar to that of Carcross. Tagish is a larger unincorporated community in relatively close proximity to Whitehorse and is also strongly opposed to the burning of wastes in the Yukon.

Figure 1-2 presents some photos illustrating styles of burning vessels used at these SWFs.

FIGURE 1-2 - EXAMPLES OF BURNING VESSEL CONFIGURATIONS

Tagish — Burwash Landing — Silver City

There are several challenges involved in completing such an evaluation, which decrease the level of certainty associated with the assessment. Specifically, these include:

- the varied nature of the burning operations in terms of type and quantities of waste burned, intermittent nature of the burning operations, and the type of vessels or trenches used (Figure 1-2);
- the geographic extent and topographic complexity of the terrain where these facilities are located ;

- the lack of representative meteorological monitoring data available for input to a dispersion model; and
- the uncertainty in estimating the emission rates for the many types of pollutants that are emitted to the air hinder an accurate source characterization of each facility's impacts.

The CALMET/CALPUFF modelling system was used to assess the maximum potential concentrations that will occur only once per year from the six chosen SWFs at Beaver Creek, Carcross, Johnson's Crossing, Pelly Crossing, Ross River and Tagish. CALMET/CALPUFF is the regulatory model in Newfoundland and Labrador, is an accepted model in British Columbia and is the US Regulatory model for long-range transport. CALPUFF works very well in complex terrain as is the case in most of the Yukon.

The EPA Document "Evaluation of Emissions from the Burning of Household Waste in Barrels" (US EPA 1997a, 1997b) was used as the source of airborne contaminant emission factors. This is a comprehensive study of emission factors that is the industry standard for evaluating garbage burning.

1.1 ASSESSMENT CRITERIA

As the Government of Yukon does not have air quality standards, it was necessary for the purposes of this study to determine suitable assessment criteria for contaminants. Most of the assessment criteria were derived from Ontario's Air Pollution – Local Air Quality Regulation (O.Reg. 419/05). Other assessment criteria were obtained from a jurisdictional scan of air quality standards published by the Ontario Ministry of the Environment (MOE 2008). Most of the Ontario-based assessment criteria are incremental criteria, i.e. background concentrations are not considered. For contaminants that are not listed in the above two references, toxicity information from National Institute for Occupational Safety and Health's database (NIOSH 2005) was considered. These assessment criteria are listed in Table 1-2.

The Canada wide standard for $PM_{2.5}$ of 25 $\mu g/m^3$ based on the 98^{th} percentile over a three year average becomes effective in 2010. However, since $PM_{2.5}$ is a contaminant of much interest and epidemiological studies of exposure to $PM_{2.5}$ have not identified a level below which no adverse health effects can be expected to occur, the potential adverse effects due to $PM_{2.5}$ were evaluated in terms of whether the open burning of wastes could result in measurable impacts (i.e., incremental increases in ambient $PM_{2.5}$ concentrations greater than 1 $\mu g/m^3$)[1]. This approach results in the use of a very conservative assessment criteria for $PM_{2.5}$.

[1] The accuracy of $PM_{2.5}$ monitoring equipment is such that an increase in $PM_{2.5}$ concentration of less than 1 $\mu g/m^3$ on a 24-hour average basis would be undetectable (i.e., it would fall within the noise level of the monitoring equipment).

TABLE 1-2 – CONTAMINANT ASSESSMENT CRITERIA

Contaminant	24hr Average Assessment Criteria (µg/m^3)	Reference
benzene	95.7	NIOSH TWA divided by 100, multiplied by 3
acetone	11880	MOE O.Reg.419/05
styrene	400	MOE O.Reg.419/05
naphthalene	22.5	MOE O.Reg.419/05
phenol	30	MOE O.Reg.419/05
dichlorobenzenes	95	MOE O.Reg.419/05, assumed same as 1,4 dichlororbenzene
trichlorobenzenes	400	MOE O.Reg. 419/05, assumed same as 1,2,4 trichlorobenzene
tetrachlorobenzenes	1	MOE Jurisdictional Scan 1,2,4,5-Tetrachlorobenzene
pentachlorobenzene	3	MOE Jurisdictional Scan Pentachlorobenzene
hexachlorobenzene	0.011	MOE Jurisdictional Scan Hexachlorobenzene
acenaphthylene	3.5	MOE Jurisdictional Scan Acenaphthylene
phenanthrene	3	NIOSH REL TWA is 0.1 mg/m3 (coal tar pitch volatiles)
aldehydes&ketones	500	MOE O.Reg.419/05, assumed same as Acetaldehyde
total PCDD/PCDF	0.000005	MOE O.Reg.419/05 (TEQ)
total PCB	0.15	MOE O.Reg.419/05
PM_{10}	50	MOE Ambient Air Quality Criteria (AAQC)
$PM_{2.5}$	1	Measureable incremental level
hydrogen chloride (HCl)	20	MOE O.Reg.419/05
hydrogen cyanide (HCN)	8	MOE O.Reg.419/05
copper (Cu)	50	MOE O.Reg.419/05
nickel (Ni)	2	MOE O.Reg.419/05
zinc (Zn)	120	MOE O.Reg.419/05
lead (Pb)	0.5	MOE O.Reg.419/05
magnesium (Mg)	120	MOE O.Reg.419/05 as Magnesium Oxide
aluminum (Al)	120	MOE O.Reg.419/05 as Aluminum Oxide
selenium (Se)	10	MOE Guideline
barium (Ba)	10	MOE Guideline water soluble fraction
beryllium (Be)	0.01	MOE O.Reg.419/05
silver (Ag)	1	MOE O.Reg.419/05
cadmium (Cd)	0.15	NIOSH TWA divided by 100, multiplied by 2
arsenic (As)	0.3	MOE Guideline
chromium (Cr)	1.5	MOE Guideline as Di and Tri valent forms
mercury (Hg)	2	MOE O.Reg.419/05

2. ATMOSPHERIC EMISSIONS

2.1 METHODS

This study considers the number of users of each community SWF to estimate the generated waste that is burned at each site. Relevant emission factors for the open burning of household waste were obtained from the EPA Document "Evaluation of Emissions from the Burning of Household Waste in Barrels" (US EPA 1997a, 1997b). However, in this document the emission factors for dioxins and furans were based on individual species, while the MOE O.Reg. 419/05 criterion is based on a single Toxic Equivalent (TEQ) factor. A TEQ emission factor for Dioxins and Furans was provided by Environment Canada (Environment Canada 2009). Based on supplied information, it was assumed, for modelling purposes, that the burning of waste occurs once a week and that the burn lasts 8 hours.

2.2 CONTAMINANT EMISSION RATES

The Government of Yukon's estimate of waste production is 2 kg per person per day for the communities considered in this study (Government of Yukon 2009). The number of users and the associated waste generation rates are listed in Table 2-1. As can be seen, the number of users varies from a low of 35 at Johnson's Crossing to a maximum of 430 at Carcross. The emission factors (in mg of contaminant per kg of waste burned) were multiplied by the number of users and the estimated waste production per person to calculate the emission rates, which were assumed to be emitted over an 8 hour burn period (9:00 a.m. to 5:00 p.m.) once a week, for entry into the dispersion model. These emission rates are listed in Table 2-2

TABLE 2-1 – NUMBER OF USERS AND WASTE PRODUCTION RATES

Solid Waste Facility	Number of Users	Waste Production (kg/day)
Beaver Creek	130	260
Carcross	430	860
Johnson's Crossing	35	70
Pelly Crossing	300	150
Ross River	380	190
Tagish	280	140

TABLE 2-2 - CONTAMINANT EMISSION RATES DURING 8 HR BURN

Contaminant	Emission Factor (mg/kg of Waste)	8 Hr Average Emission Rates (g/s)					
		Beaver Creek	Carcross	Johnson's Crossing	Pelly Crossing	Ross River	Tagish
benzene	1.24E+03	7.84E-02	2.59E-01	2.11E-02	1.81E-01	2.29E-01	1.69E-01
acetone	9.40E+02	5.94E-02	1.96E-01	1.60E-02	1.37E-01	1.74E-01	1.28E-01
styrene	7.40E+02	4.68E-02	1.55E-01	1.26E-02	1.08E-01	1.37E-01	1.01E-01
naphthalene	4.80E+01	3.03E-03	1.00E-02	8.17E-04	7.00E-03	8.87E-03	6.53E-03
phenol	1.40E+02	8.85E-03	2.93E-02	2.38E-03	2.04E-02	2.59E-02	1.91E-02
dichlorobenzenes	1.60E-01	1.01E-05	3.34E-05	2.72E-06	2.33E-05	2.96E-05	2.18E-05
trichlorobenzenes	1.10E-01	6.95E-06	2.30E-05	1.87E-06	1.60E-05	2.03E-05	1.50E-05
tetrachlorobenzenes	7.40E-02	4.68E-06	1.55E-05	1.26E-06	1.08E-05	1.37E-05	1.01E-05
pentachlorobenzene	5.30E-02	3.35E-06	1.11E-05	9.02E-07	7.73E-06	9.79E-06	7.21E-06
hexachlorobenzene	2.20E-02	1.39E-06	4.60E-06	3.74E-07	3.21E-06	4.06E-06	2.99E-06
acenaphthylene	1.10E+01	6.95E-04	2.30E-03	1.87E-04	1.60E-03	2.03E-03	1.50E-03
phenanthrene	7.30E+00	4.61E-04	1.53E-03	1.24E-04	1.06E-03	1.35E-03	9.94E-04
aldehydes & ketones	2.80E+03	1.77E-01	5.85E-01	4.76E-02	4.08E-01	5.17E-01	3.81E-01
total PCDD/PCDF	4.83E-04	3.05E-08	1.01E-07	8.22E-09	7.04E-08	8.92E-08	6.57E-08
total PCB	2.86E+00	1.81E-04	5.98E-04	4.87E-05	4.17E-04	5.28E-04	3.89E-04
PM_{10}	1.90E+04	1.20E+00	3.97E+00	3.23E-01	2.77E+00	3.51E+00	2.59E+00
$PM_{2.5}$	1.74E+01	1.10E-03	3.64E-03	2.96E-04	2.54E-03	3.21E-03	2.37E-03
hydrogen chloride (HCl)	2.84E+02	1.79E-02	5.94E-02	4.83E-03	4.14E-02	5.25E-02	3.87E-02
hydrogen cyanide (HCN)	4.68E+02	2.96E-02	9.78E-02	7.96E-03	6.83E-02	8.65E-02	6.37E-02
copper (Cu)	2.16E+00	1.37E-04	4.52E-04	3.68E-05	3.16E-04	4.00E-04	2.95E-04
nickel (Ni)	2.50E-01	1.58E-05	5.23E-05	4.25E-06	3.65E-05	4.62E-05	3.40E-05
zinc (Zn)	9.11E-01	5.76E-05	1.90E-04	1.55E-05	1.33E-04	1.68E-04	1.24E-04
lead (Pb)	7.52E-01	4.75E-05	1.57E-04	1.28E-05	1.10E-04	1.39E-04	1.02E-04
magnesium (Mg)	3.19E+00	2.02E-04	6.67E-04	5.43E-05	4.65E-04	5.89E-04	4.34E-04
aluminum (Al)	4.78E+00	3.02E-04	9.98E-04	8.13E-05	6.97E-04	8.82E-04	6.50E-04
selenium (Se)	1.42E+00	9.00E-05	2.98E-04	2.42E-05	2.08E-04	2.63E-04	1.94E-04
barium (Ba)	1.24E+00	7.85E-05	2.60E-04	2.11E-05	1.81E-04	2.29E-04	1.69E-04
beryllium (Be)	5.70E-02	3.60E-06	1.19E-05	9.70E-07	8.31E-06	1.05E-05	7.76E-06
silver (Ag)	6.80E-02	4.30E-06	1.42E-05	1.16E-06	9.92E-06	1.26E-05	9.26E-06
cadmium (Cd)	2.39E-01	1.51E-05	5.00E-05	4.07E-06	3.49E-05	4.41E-05	3.25E-05
arsenic (As)	4.33E+00	2.74E-04	9.05E-04	7.37E-05	6.31E-04	8.00E-04	5.89E-04
chromium (Cr)	2.28E-01	1.44E-05	4.77E-05	3.88E-06	3.33E-05	4.21E-05	3.10E-05
mercury (Hg)	8.10E-02	5.12E-06	1.69E-05	1.38E-06	1.18E-05	1.50E-05	1.10E-05

Note: Emission factors obtained from US EPA 1997a/b, except total PCDD/PCDF from Environment Canada 2009

3. MODELLING METHODS

3.1 GENERAL

The CALMET/CALPUFF modelling system was used to conduct the dispersion modelling analysis. For this study, the modelling was undertaken using Version 6.326 (level 080709) of the CALMET and Version 6.262 (level 080725) of the CALPUFF models. CALMET is a meteorological model that produces hourly, three dimensional gridded wind fields from available meteorological, terrain and land use data. CALPUFF is a non-steady state puff dispersion model that utilizes the CALMET wind fields and accounts for spatial changes in meteorology, variable surface conditions, and plume interactions with terrain. CALPUFF can handle both simple and complex terrain.

CALMET develops hourly wind and temperature fields on a three-dimensional gridded modelling domain incorporating the effects of terrain on wind flow and produces the two-dimensional meteorological fields such as mixing heights, surface characteristics and dispersion properties. The three-dimensional wind field can be developed by CALMET using observations from several meteorological monitoring stations in the vicinity of the emission source. If there are no suitable surface monitoring stations available for the area, CALMET has the option to import prognostic wind field data produced by a weather model. Since the representative meteorological data for dispersion modelling were not available for most of the Yukon communities in question, SENES used a prognostic weather model to develop suitable meteorological data for the analysis.

3.2 PREPARATION OF METEOROLOGY

The prognostic weather model that SENES used is the Non-hydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system developed by the National Oceanic and Atmospheric Administration (NOAA) and National Centers for Environmental Prediction (NCEP) in the United States. The current release is Version 3. The WRF-NMM model is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and can efficiently run on available parallel computing platforms. The WRF-NMM is suitable for use in a broad range of applications across scales ranging from meters to thousands of kilometres, including:

- real-time numerical weather prediction;
- forecast research;
- parameterization research;
- coupled-model applications; and,
- teaching.

The NOAA/NCEP and the Developmental Testbed Center (DTC) are currently maintaining and supporting the WRF-NMM portion of the overall WRF code (Version 3) that includes:

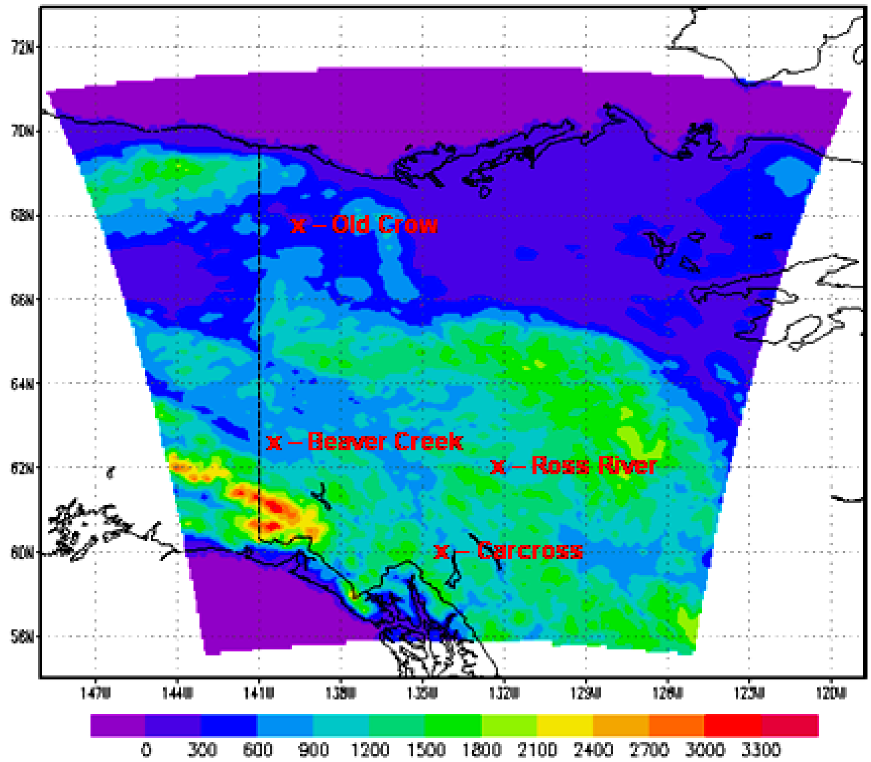
- WRF Software Framework;
- WRF Preprocessing System (WPS);
- WRF-NMM dynamic solver, including one-way and two-way nesting;
- Numerous physics packages contributed by WRF partners and the research community; and,
- Post-processing utilities and scripts for producing images in several graphics programs.

The SENES approach to developing meteorological data for each of the Yukon communities was to use the WRF-NMM model in the hindcasting mode. Hindcasting uses large scale analysis fields for North America that are generated by NWP centers in the U.S. The analysis fields are the real observed data, pre-processed to balance all physical forces into 3-dimensional meteorological fields that can be used for boundary conditions for high resolution simulations. In hindcasting mode, the analysis fields from NCEP every 6 hours are used for boundary conditions and a higher resolution 'forecast' is made using a full weather model (WRF-NMM) for a 24-hour period each day. The analysis field boundary conditions nudge the forecast in the direction of the observations. Such nudging occurs at the domain boundaries, so that the model physics can generate the finer scale circulations within the area of interest.

SENES has encompassed the WRF-NMM model into a practical, operational and proprietary system referred to as the FReSH Forecasting System. FReSH has been developed, tested and used by SENES for many different applications over the past seven years. FReSH uses the full capability of WRF-NMM (without any coding changes), but has additional access to model output parameters such that derived parameters and statistics can be used for detailed analysis. FReSH is a stand-alone computer model with three main modules – the first collects the required starting data from NCEP, the second is the state-of-the-science weather model (WRF-NMM), and the third formats the output data to meet the needs of a particular application.

The FReSH model was initialized with 32 km by 32 km NCEP data and run with a horizontal resolution of 8 km by 8 km over the area depicted in Figure 3-1.

FIGURE 3-1 - TERRAIN DATA FOR 8 KM BY 8 KM FRESH MODELLING DOMAIN



Note: Scale is in meters

This meteorological data was refined by "nesting" downward over the areas shown in Figure 3-2 to a fine horizontal resolution of 2 km by 2 km. This data was further refined by CALMET down to a horizontal grid spacing of 100 m by 100 m for each of the six 10 km by 10 km CALMET modelling domains centered over the six studied sites (Figure 3-2). This approach significantly improves the representation of meteorological conditions over the area of complex terrain or valleys where the SWFs are located, compared to the alternative of creating fields based on just one surface and one upper air observation station.

FIGURE 3-2 – FINE RESOLUTION (2 KM BY 2 KM) FRESH MODELLING DOMAINS

Running the FReSH model is a computer intensive operation. The large 8 km by 8 km FReSH model run took approximately 1 hr of computer time per day of simulation (~15 days). The 2 km by 2 km FReSH run that was used for Carcross, Johnson's Crossing and Tagish run took approximately 90 days of computer time. Each of the three smaller 2 km by 2 km FReSH runs for Beaver Creek, Pelly Crossing and Ross River took approximately 30 days of computer time. All of the runs were broken down over multiple computers to allow runs to be completed in a timely manner.

3.3 CALMET

The CALMET model was used to develop the year 2008 data set of hourly wind fields for use by the CALPUFF dispersion model. The CALMET model was run for a large modeling domain of 10 km in both the east-west and north-south directions with a grid spacing of 100 m. The same approach was taken for all six assessed sites.

The output from the CALMET model was used to capture the regional flow and complex terrain winds and as input into the CALPUFF air dispersion calculations. The mixing heights in "A Mixing Heights Study for North America (1987 – 1991)" (SENES 1997) from Whitehorse Airport were reviewed to insure that the top of the grid is well above the climatological mixing height (1675 m). Guidance from the CALMET User's manual in terms of gradually increasing layer depth with height was followed and the ten vertical layers used are shown in Table 3-1.

TABLE 3-1 - CALMET WIND FIELD LAYER HEIGHTS

Vertical Height of Layer (m)	Layer Height of Top (m)	Notes
20	20	10-meter meteorology
30	50	25-meter meteorology
25	75	
25	100	
100	200	
300	500	
500	1000	
500	1500	
500	2000	
1300	3300	

The CALMET model requires as input, a control file that defines the wind field grid parameters and model option switches, meteorological data, land use data and terrain data. A description of the data used for each site in this analysis is provided below.

Terrain

Terrain data for the modelling domain were processed through the TERREL CALMET pre-processor and prepared for the CALMET GEO file through MAKEGEO pre-processors. The terrain processing program TERREL, which is provided with the CALMET/CALPUFF modelling system, was designed to process Canadian DEM formats for the map scale 1:250,000 (~90 m resolution) from the Geomatics Web page (http://www.geobase.ca/geobase/en/data/cded).

Land Use

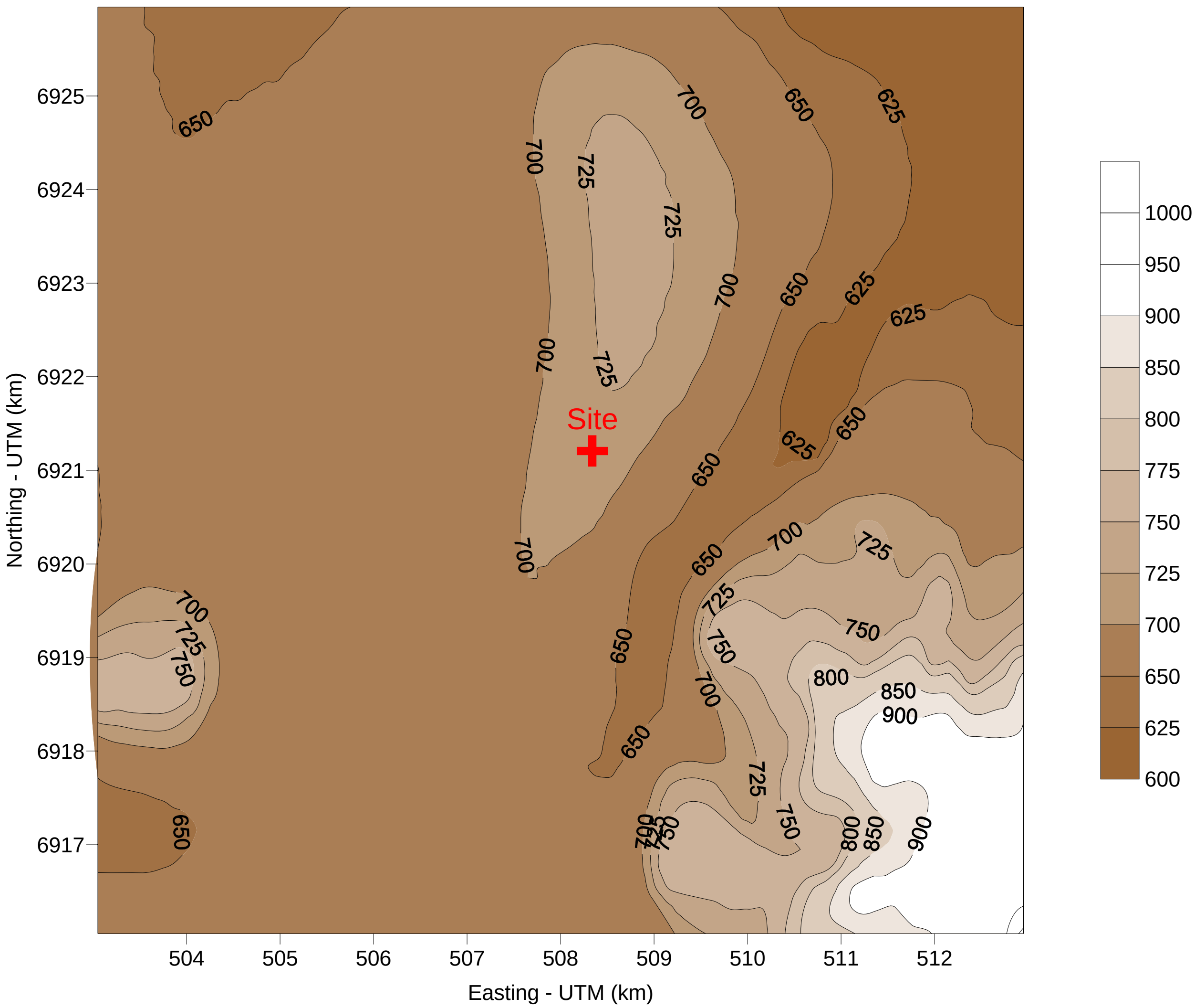
There is a lack of digital land use information for the study area. Data was generated based on Government of Yukon provided site maps and Google Earth™ maps. In this study, the CALMET model was applied on two sets of land use data. During the winter when the ground is covered by snow the land use category of 90 (Perennial Snow Cover) was used for the land. The site and the nearby local communities were not changed to urban as they are not highly urbanized areas. The rivers and lakes were set to land use category 51 (small water bodies). The terrain file was used as the starting point to prepare the land use file.

Information is presented at the six selected sites in alphabetical order.

3.3.1 CALMET – Beaver Creek

The Beaver Creek terrain data used by CALMET is shown in Figure 3-3. Higher elevations may be seen to the southeast of the site.

FIGURE 3-3 – BEAVER CREEK TERRAIN DATA

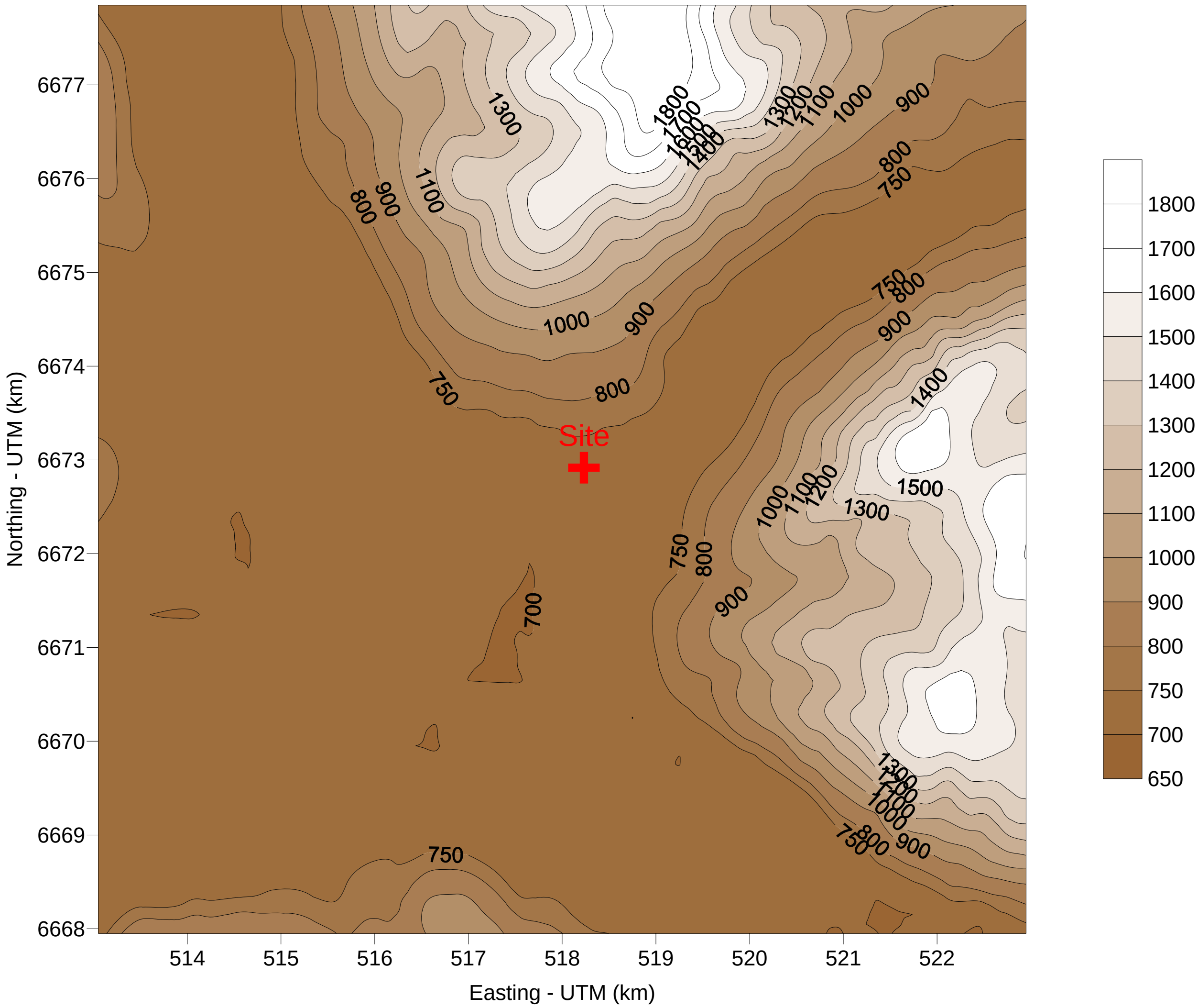


Note: Elevations are given in metres above Mean Sea Level

3.3.2 CALMET – Carcross

Figure 3-4 presents the Carcross terrain data used by CALMET. There are areas of higher elevations both to the north and the east/southeast.

FIGURE 3-4 - CARCROSS TERRAIN DATA

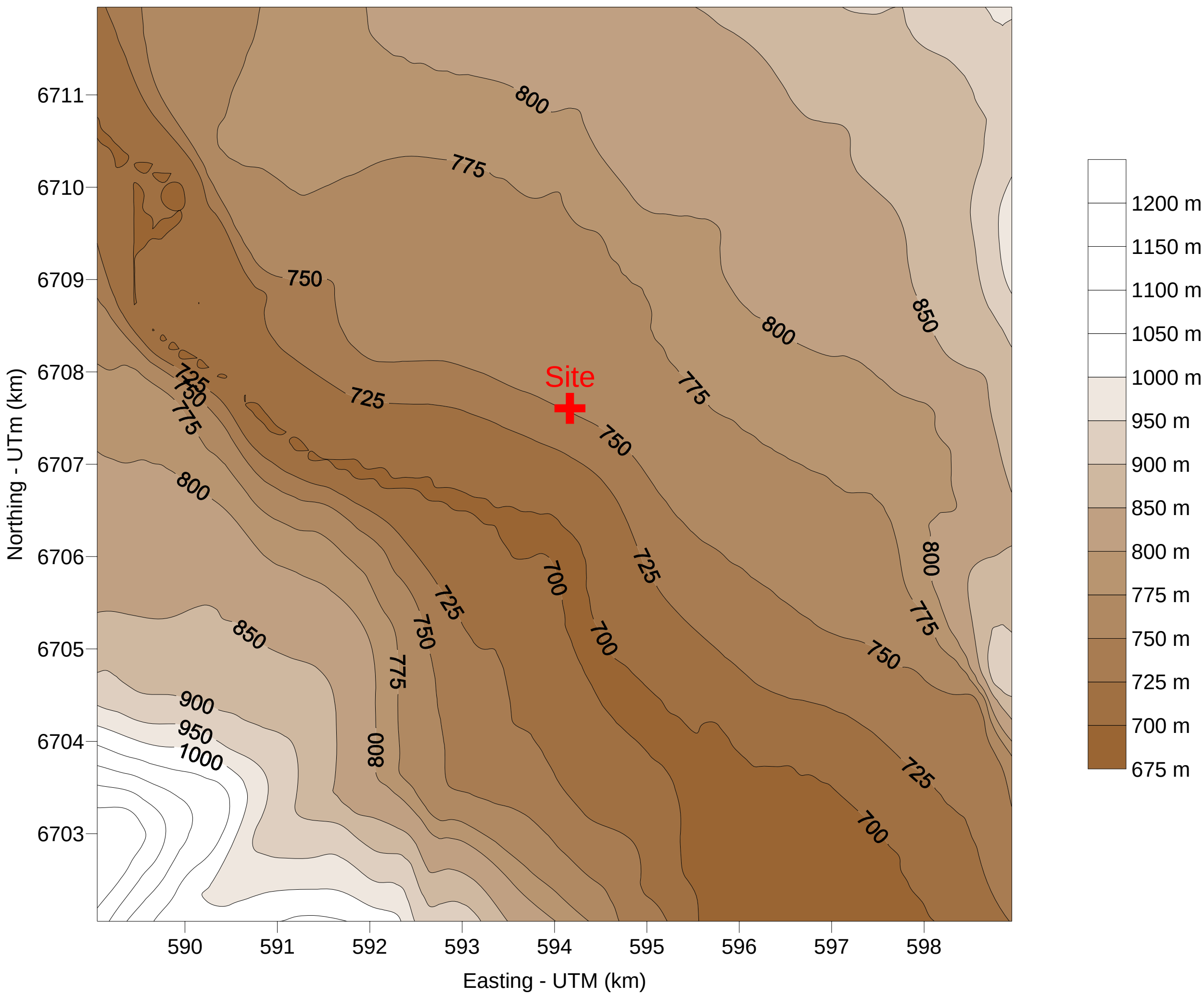


Note: Elevations are shown in metres above Mean Sea Level

3.3.3 CALMET – Johnson's Crossing

The terrain data around Johnson's Crossing used by CALMET is shown in Figure 3-5. The solid waste burning site is located within a northwest – southeast river valley.

FIGURE 3-5– JOHNSON'S CROSSING TERRAIN DATA

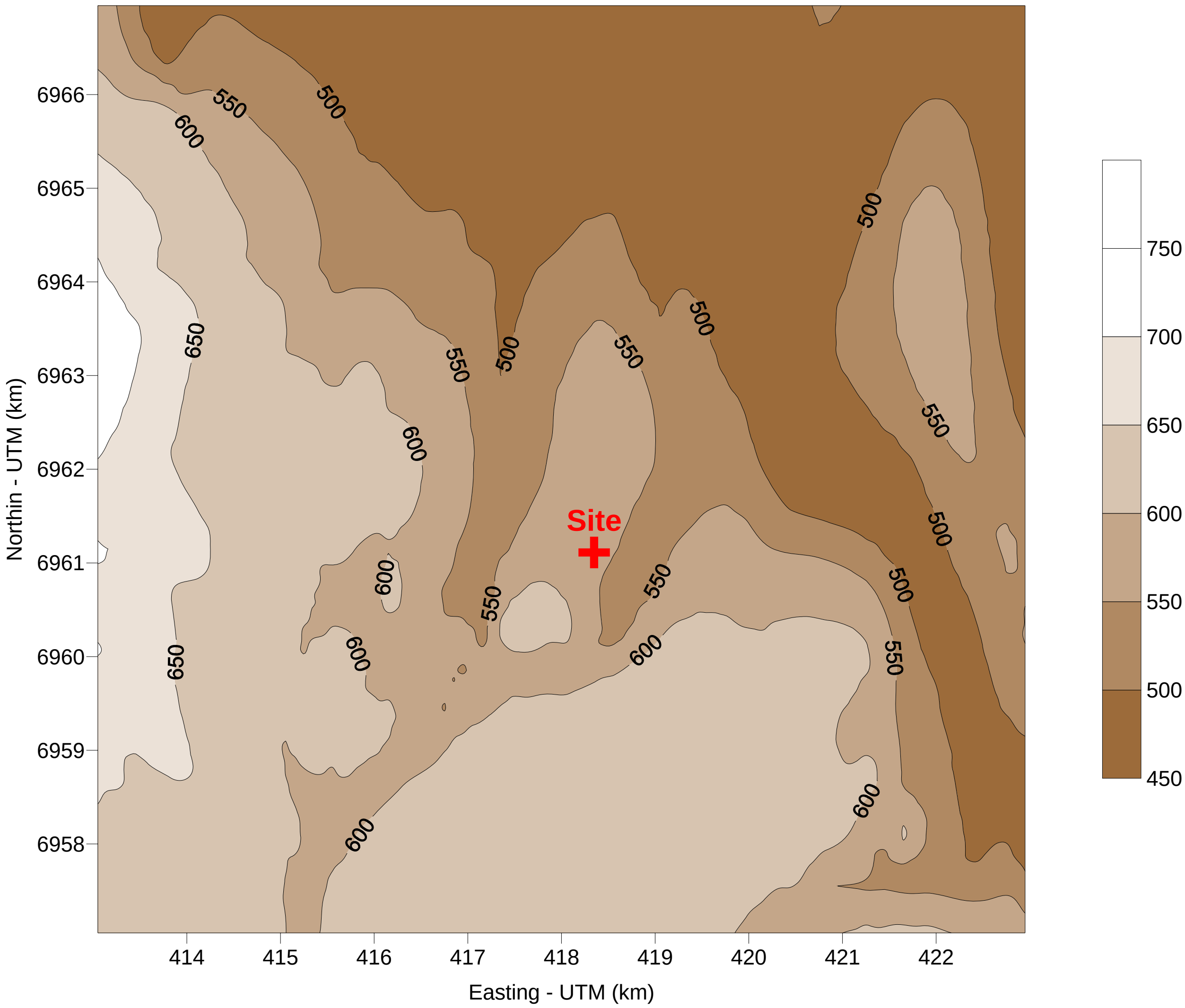


Note: Elevations are shown in metres above Mean Sea Level

3.3.4 CALMET – Pelly Crossing

Figure 3-6 presents the terrain data near Pelly Crossing site.

FIGURE 3-6 – PELLY CROSSING TERRAIN DATA

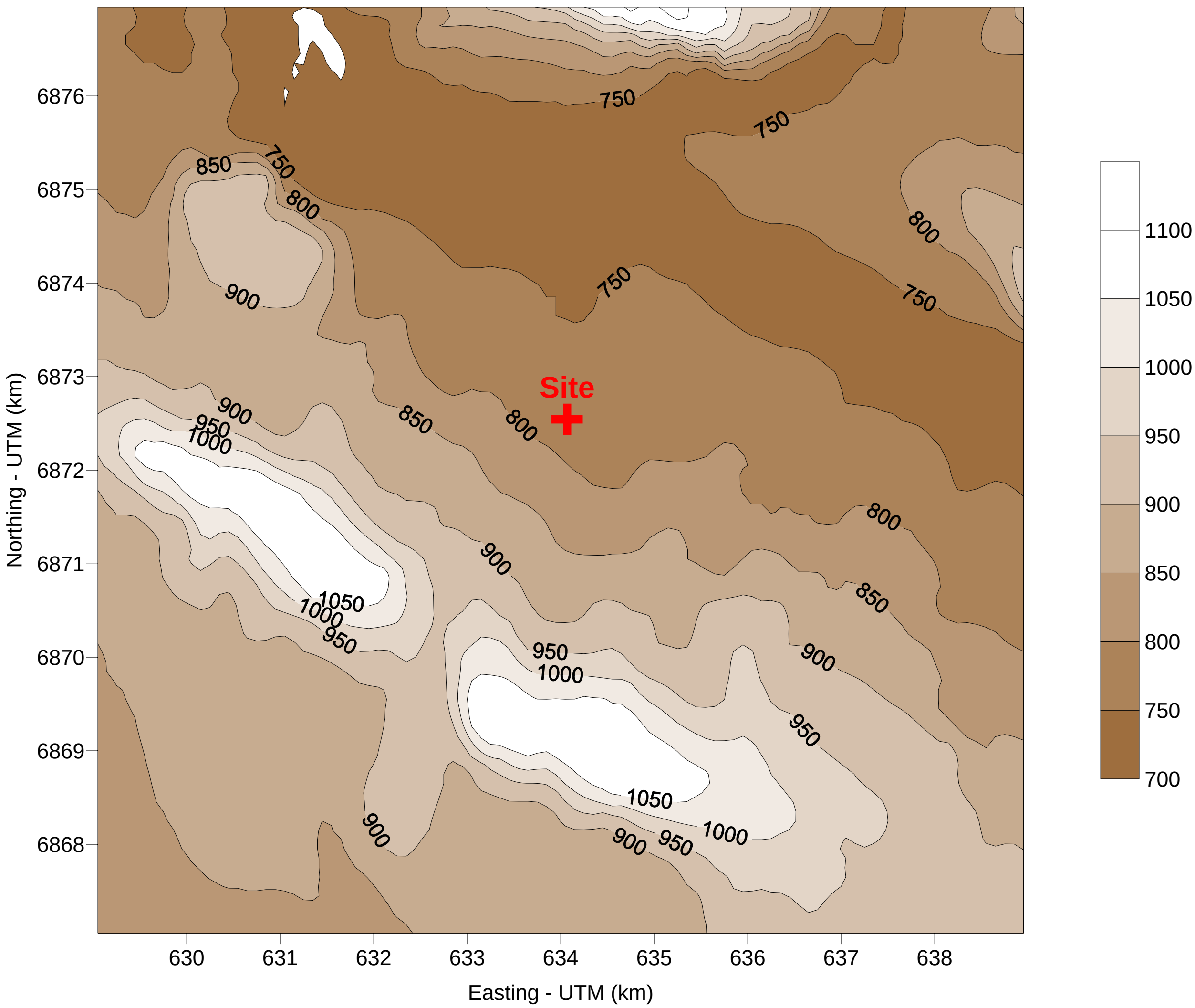


Note: Elevations are shown in metres above Mean Sea Level

3.3.5 CALMET – Ross River

Figure 3-7 shows the terrain data near the Ross River site which is located on the slopes of a northwest – southeast running valley.

FIGURE 3-7 – ROSS RIVER TERRAIN DATA

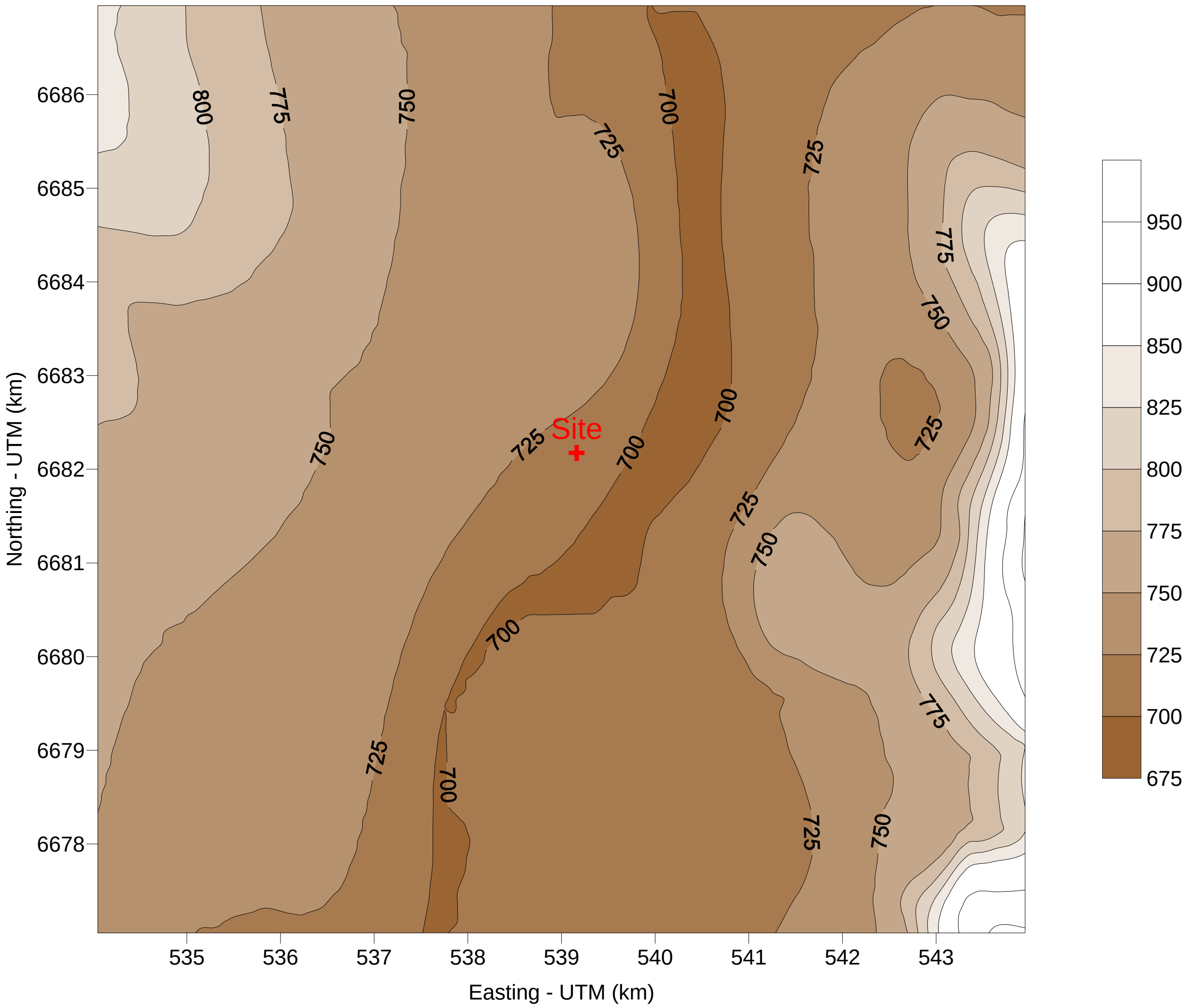


Note: Elevations are shown in metres above Mean Sea Level

3.3.6 CALMET – Tagish

Figure 3-8 presents the terrain data from around Tagish which is located in a roughly north - south running river valley.

FIGURE 3-8 – TAGISH TERRAIN DATA



Note: Elevations are shown in metres above Mean Sea Level

3.3.7 CALMET Generated Meteorology

3.3.7.1 Meteorological Observations

Table 3-2 presents a list of the closest meteorological stations to each of the six selected sites. Except for Beaver Creek, the nearest meteorological station is located some distance away from the site and would not be suitable for use for modelling of these sites as there are many local terrain features that would "steer" the winds in the neighbourhood of the site. Data from the Beaver Creek site was examined and it appears that there were problems with the equipment (e.g., possibly frozen) during the winter as the wind direction did not change. Several of these sites had data for daytime hours only and there was generally much missing data and not suitable for modelling purposes.

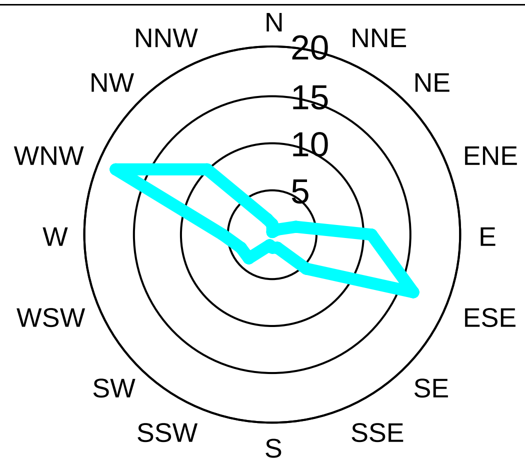
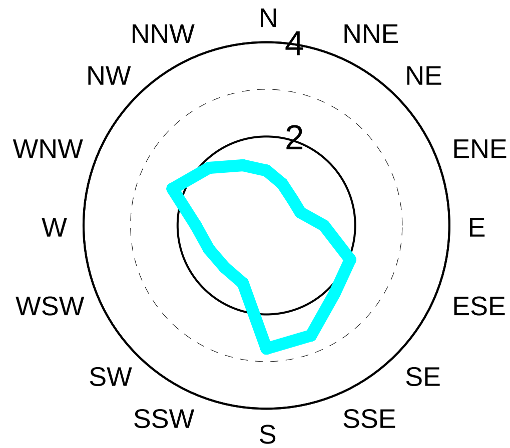
TABLE 3-2 - CLOSEST METEOROLOGICAL STATIONS TO THE WASTE SITES

Yukon Waste Sites	UTM Zone	Distance (km)	Meteorological Station
Beaver Creek	Zone 7	2.1	Beaver Creek
Carcross	Zone 8	63.1	Whitehorse
Johnson's Crossing	Zone 8	46.0	Teslin
Pelly Crossing	Zone 8	76.9	Carmacs
Ross River	Zone 8	60.2	Faro
Tagish	Zone 8	65.9	Whitehorse

3.3.7.2 CALMET Meteorological Results

Wind roses were prepared by extracting CALMET generated meteorological data at each of the six selected sites (Figure 3-9 to Figure 3-14). It can be seen that there are very different wind patterns at each of the six sites due to the local influence of terrain and land use. For example, Figure 3-11 for Johnson's Crossing shows the very strong influence of the river valley. Note that wind roses show the direction the wind is blowing from.

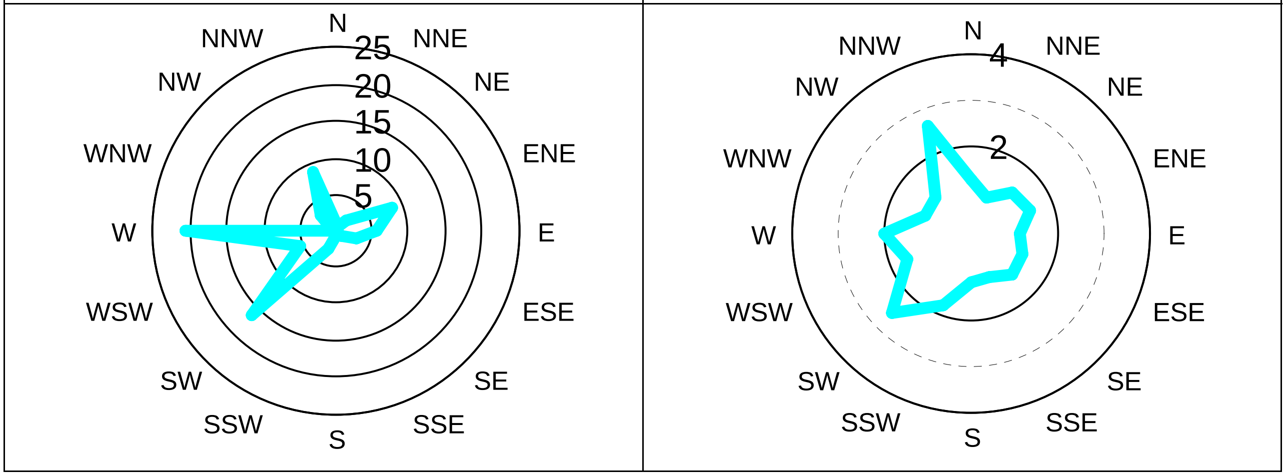
FIGURE 3-9 - WIND ROSE BEAVER CREEK – CALMET GENERATED

Wind Direction Frequency (%)	Average Wind Speed (m/s)
	

Note: Percent Calms = 13.0%
Wind is shown as direction wind blows from

FIGURE 3-10 - WIND ROSE CARCROSS – CALMET GENERATED

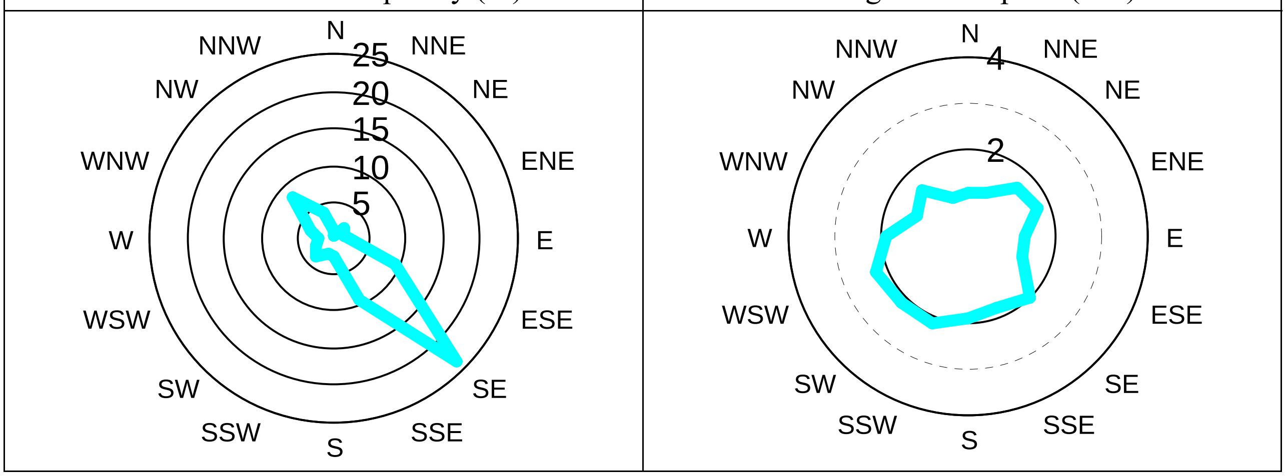
Wind Direction Frequency (%)	Average Wind Speed (m/s)



Note: Percent Calms = 16.2%
Wind is shown as direction wind blows <u>from</u>

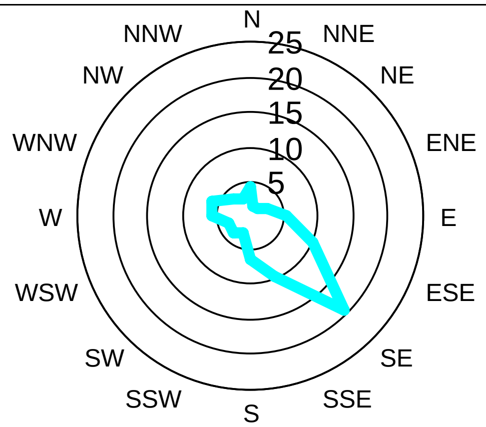
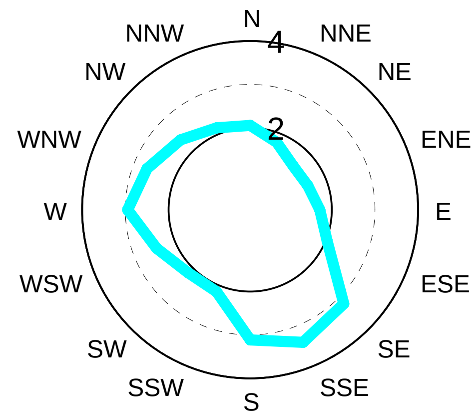
FIGURE 3-11 - WIND ROSE JOHNSON'S CROSSING – CALMET GENERATED

Wind Direction Frequency (%)	Average Wind Speed (m/s)



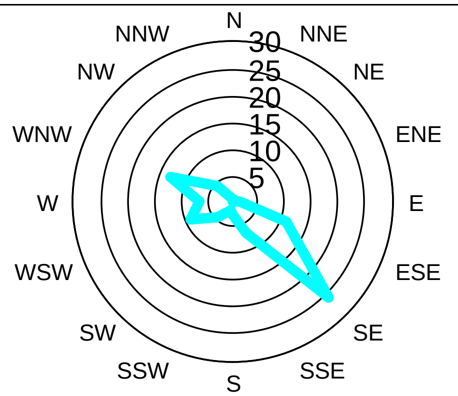
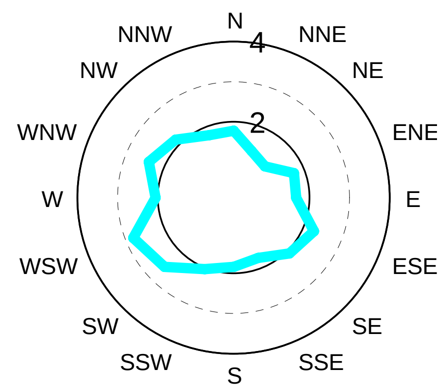
Note: Percent Calms = 18.4%
Wind is shown as direction wind blows <u>from</u>

FIGURE 3-12 - WIND ROSE PELLY CROSSING – CALMET GENERATED

Wind Direction Frequency (%)	Average Wind Speed (m/s)
	

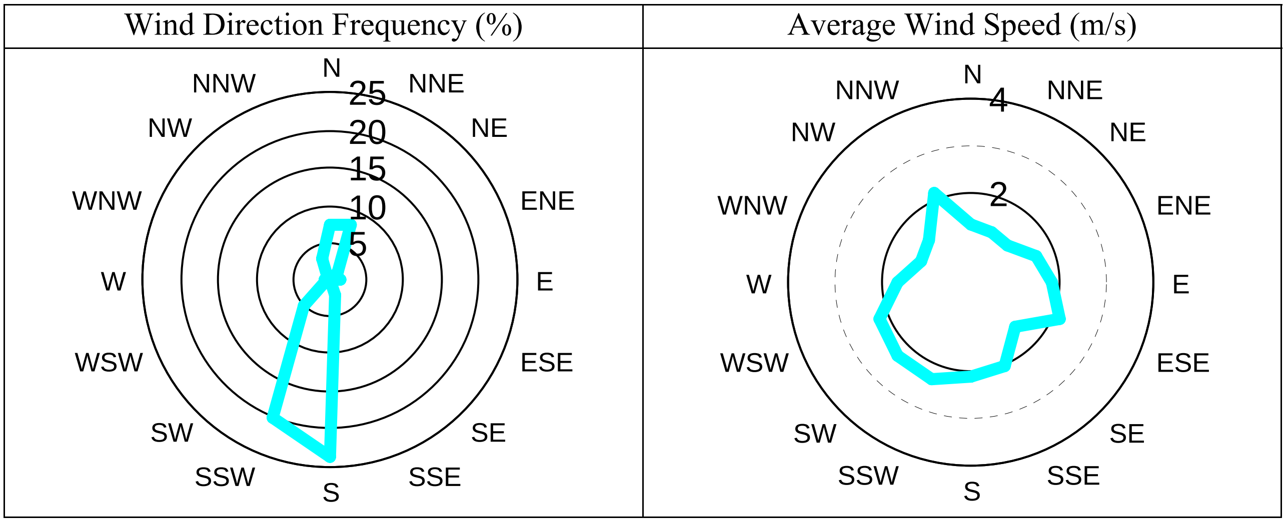
Note: Percent Calms = 7.2%
Wind is shown as direction wind blows <u>from</u>

FIGURE 3-13 - WIND ROSE ROSS RIVER – CALMET GENERATED

Wind Direction Frequency (%)	Average Wind Speed (m/s)
	

Note: Percent Calms = 8.4%
Wind is shown as direction wind blows <u>from</u>

FIGURE 3-14 - WIND ROSE TAGISH – CALMET GENERATED



Note: Percent Calms = 19.9%
Wind is shown as direction wind blows from

3.4 CALPUFF MODELLING

3.4.1 Modelling Domains and Grids

For each of the six selected sites a CALPUFF modelling domain of 10 km by 10 km centered on the solid waste burning site was used. An evenly spaced 100 m modelling receptor grid was used to determine the maximum concentrations and the extent of the sites' impacts. Based on supplied mapping and verification using Google Earth™, nearby residences were identified and representative discrete receptors were selected so that results could be presented in tabular format. Note that all coordinates used in this report are based on UTM (meters or kilometres) NAD 83 Zone 8, except for Beaver Creek which is located in Zone 7.

Based on supplied mapping, the extents or property lines of the six SWF were estimated. If the supplied maps gave no clear indication of the size of the property a minimum size of 400 m x 400 m was assumed. All modelling receptors within the assumed property boundary were removed to eliminate overpredictions due to limitations of the model in close proximity to the source.

Figure 3-15 through Figure 3-20 presents the discrete receptors used at each of the six sites on supplied base maps. Note that the Pelly Crossing site map did not show any locations readily identifiable as residences; therefore, discrete receptors were chosen at distances of 1000 m, 2000 m and 3000 m in both directions along the Yukon Highway Nº 2.

FIGURE 3-15 – SITE AND DISCRETE RECEPTORS FOR BEAVER CREEK

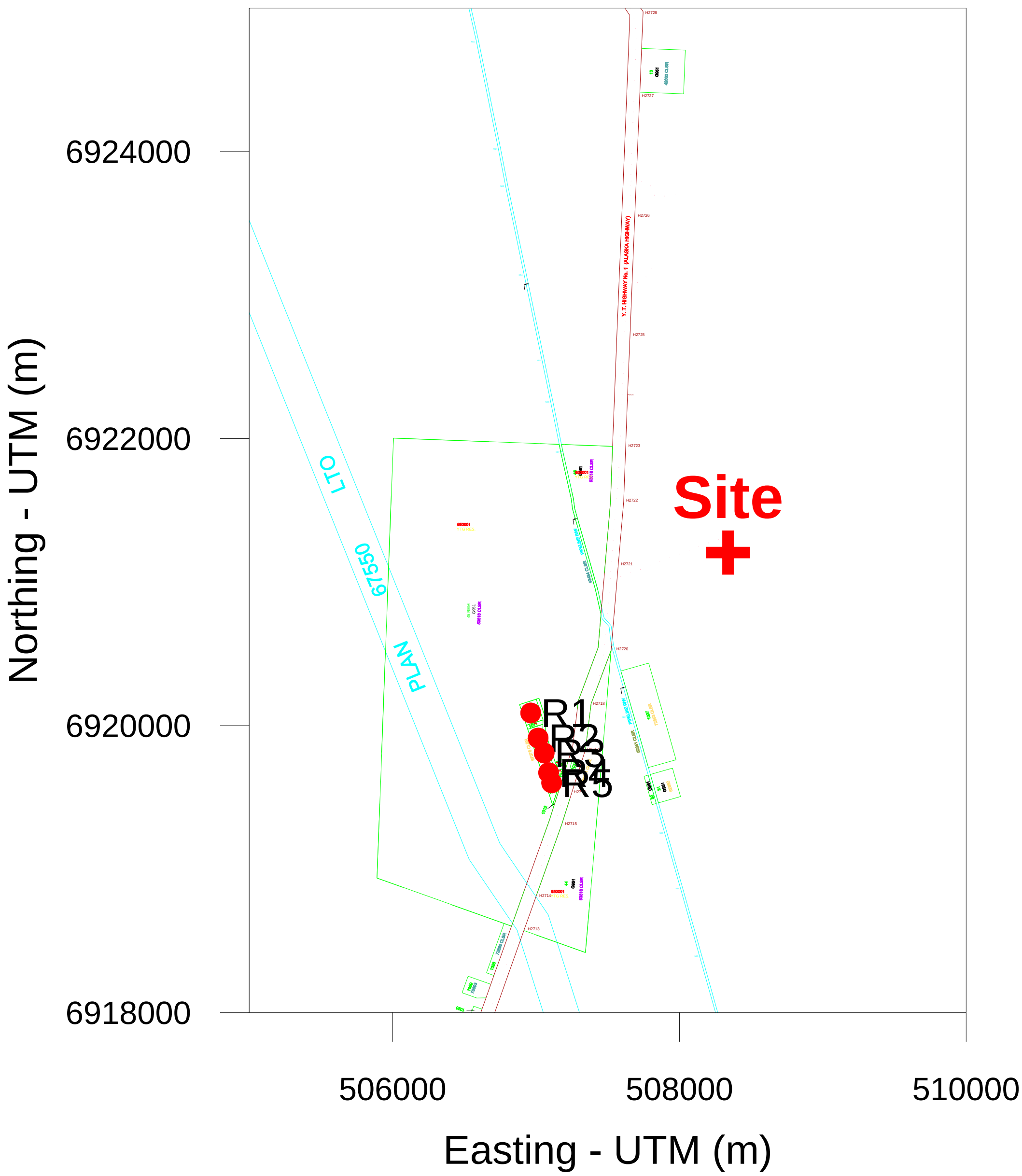


FIGURE 3-16 – SITE AND DISCRETE RECEPTORS FOR CARCROSS

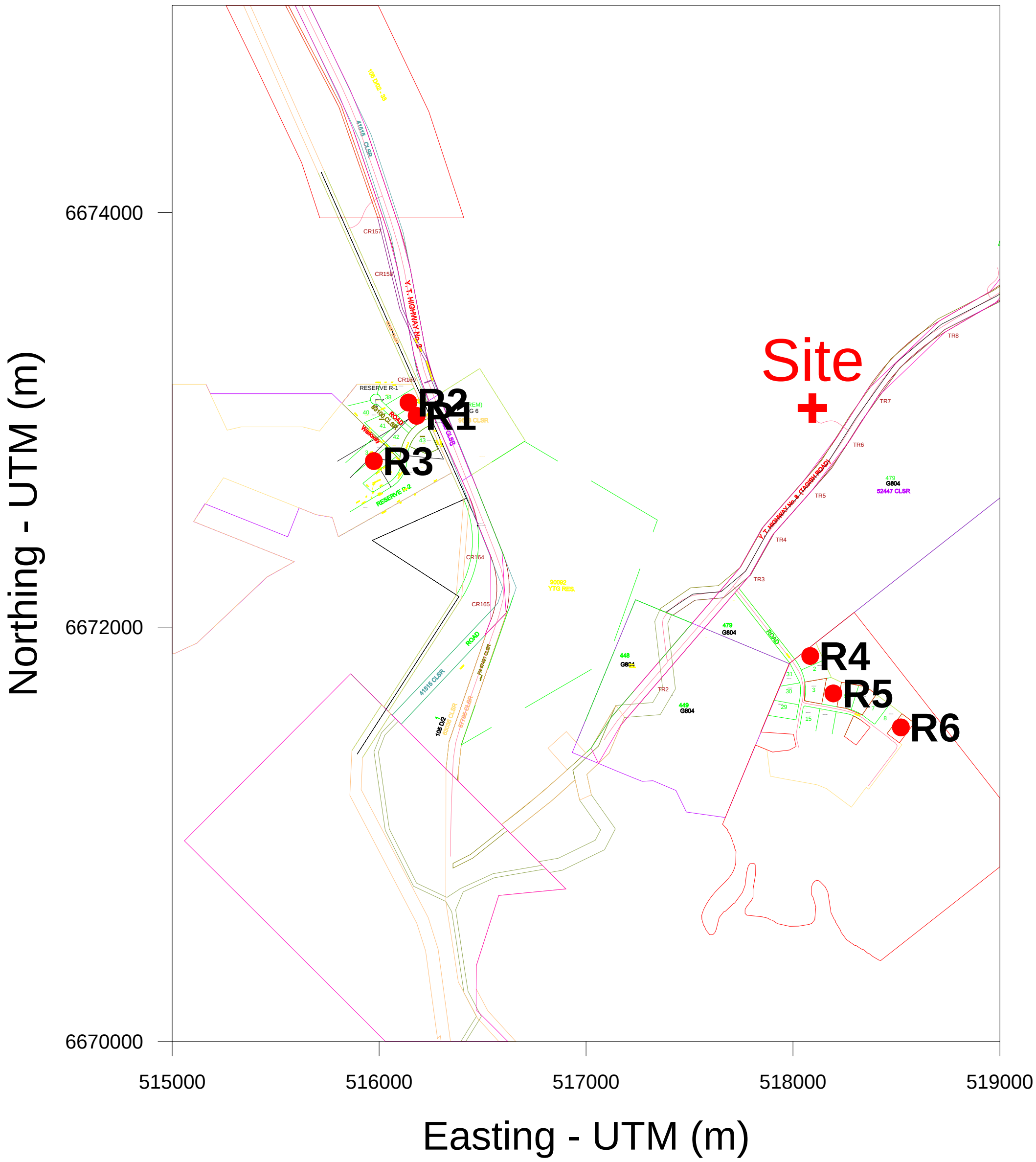


FIGURE 3-17 – SITE AND DISCRETE RECEPTORS FOR JOHNSON'S CROSSING

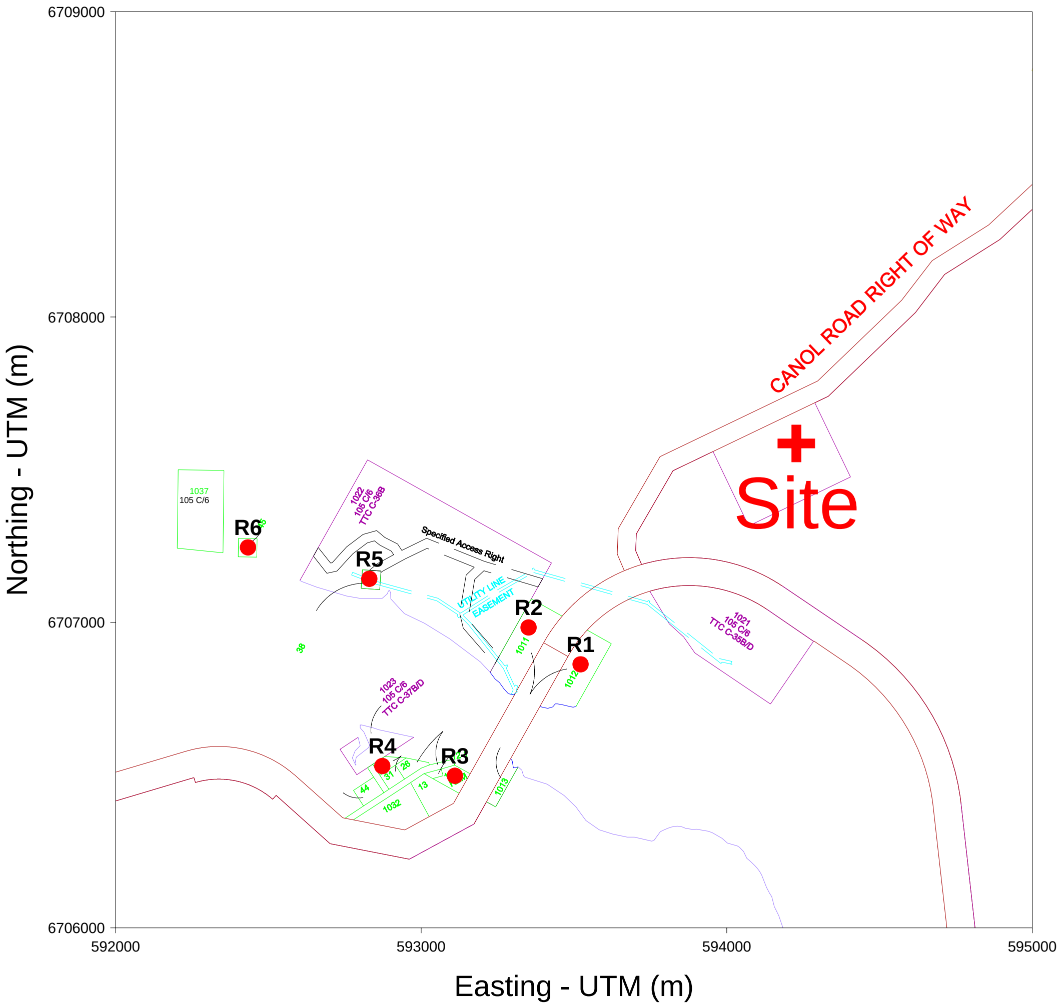


FIGURE 3-18 – SITE AND DISCRETE RECEPTORS FOR PELLY CROSSING

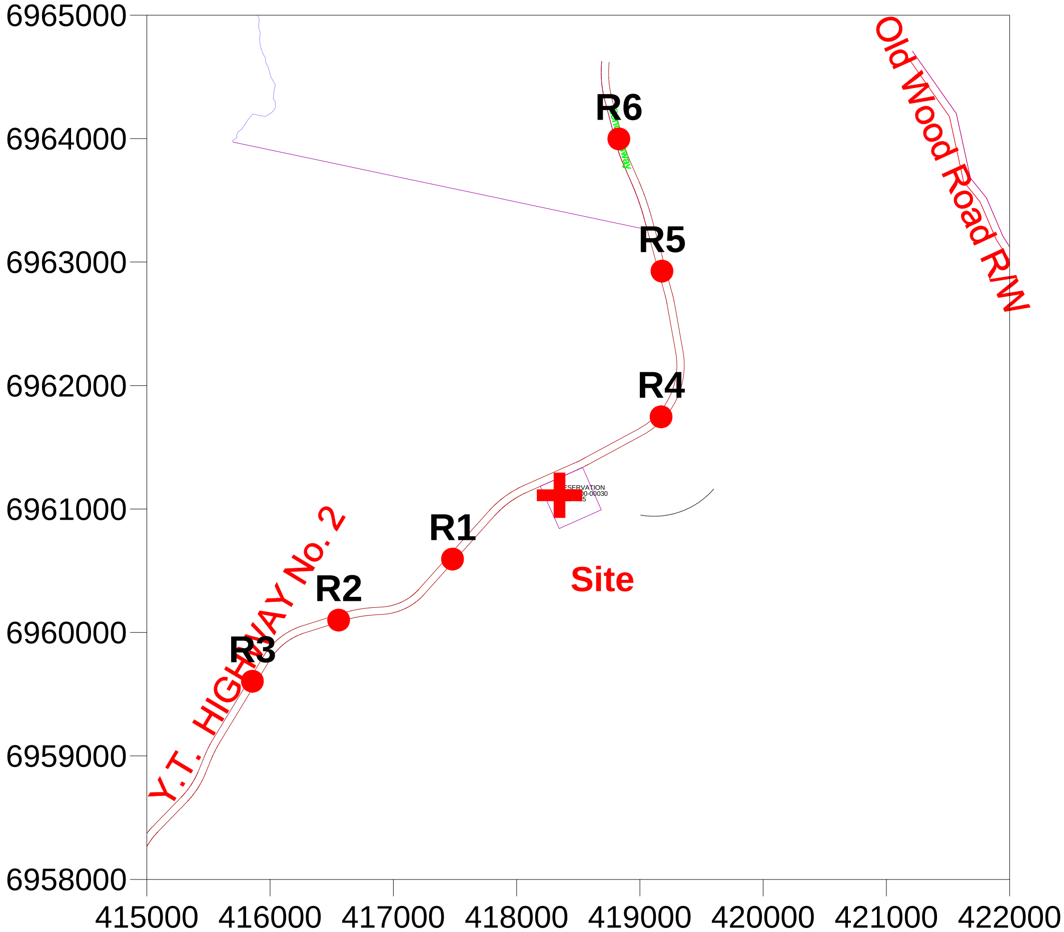


FIGURE 3-19 – SITE AND DISCRETE RECEPTORS FOR ROSS RIVER

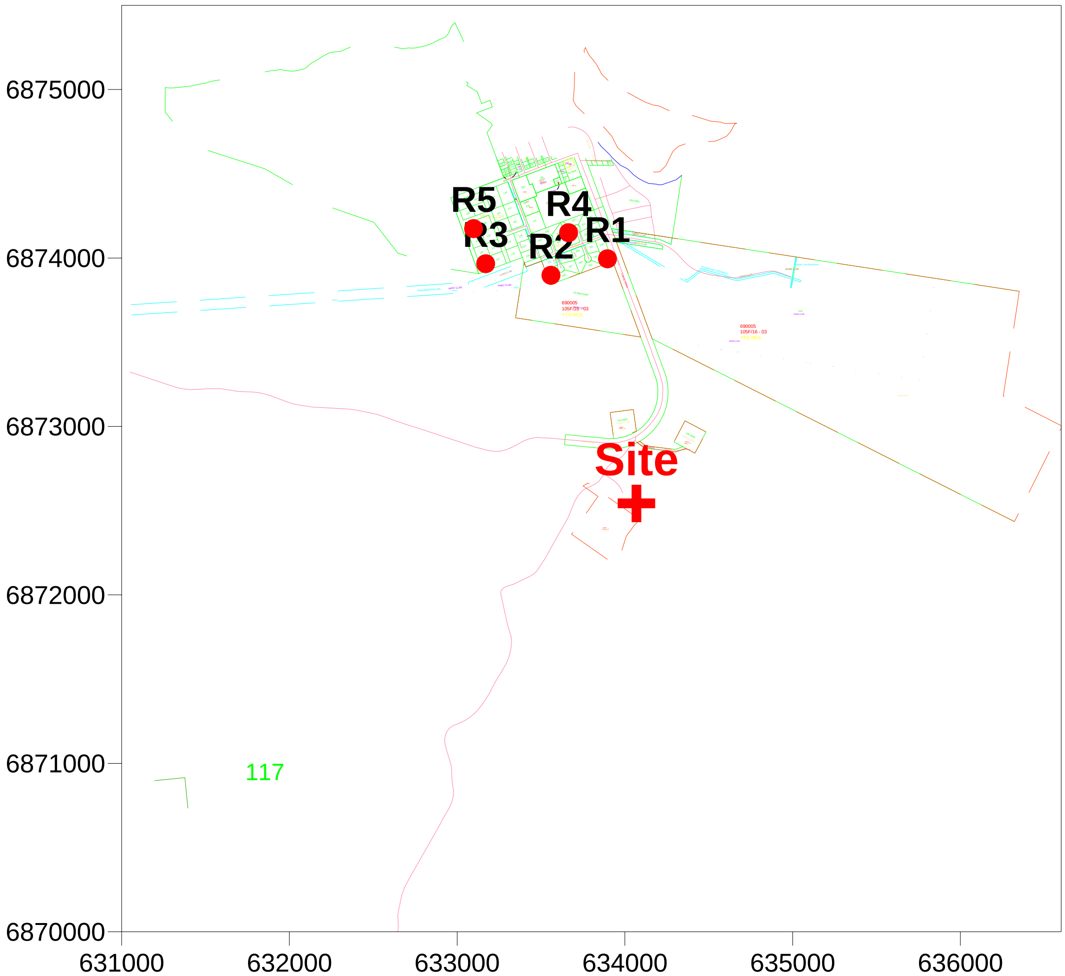
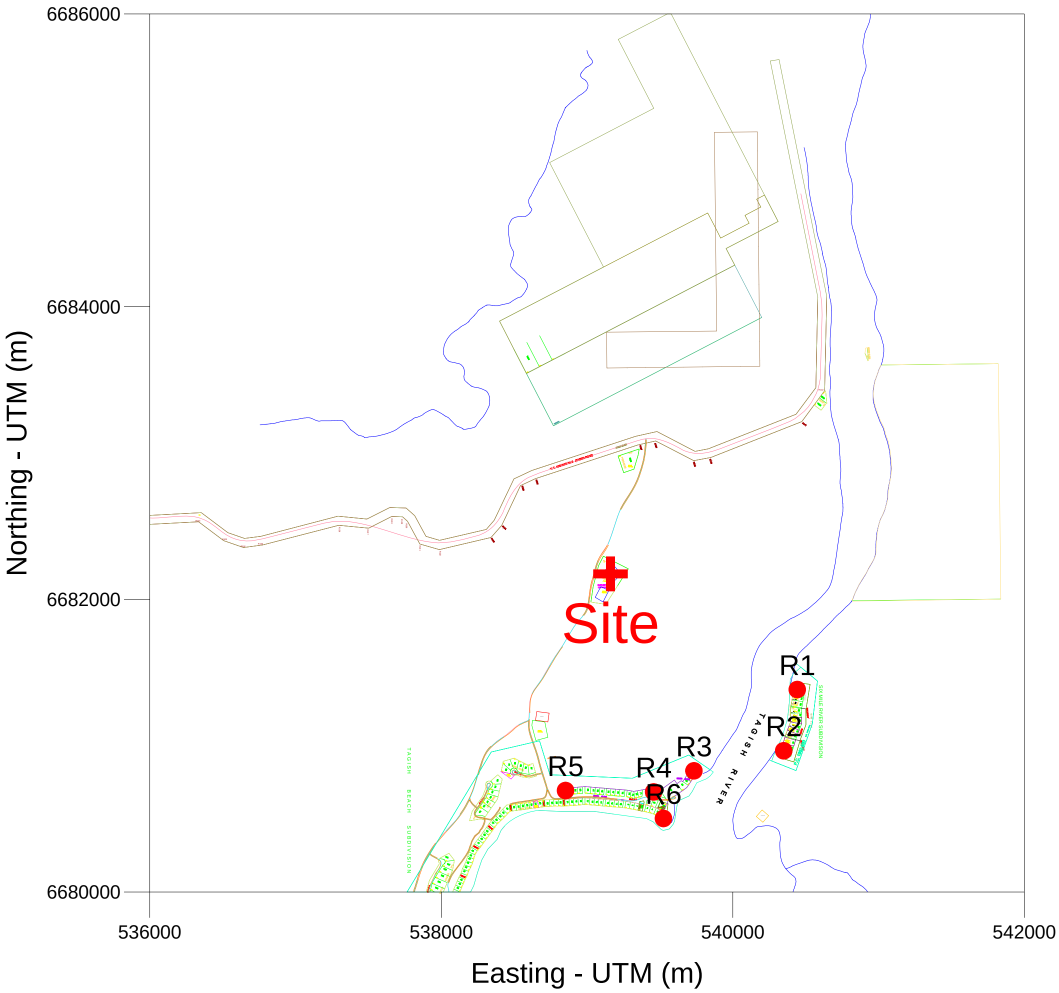


FIGURE 3-20 – SITE AND DISCRETE RECEPTORS FOR TAGISH



3.5 SELECTION OF CONTAMINANTS

It would not be practical to model all of the 34 contaminants identified in Table 1-2. A screening method was developed to prioritize contaminants that have higher emission rates with respect to their assessment criteria. For each contaminant, the ratio between the emission factor and assessment criterion was calculated as a measure of that contaminant's priority rank. Contaminants with a higher ratio have a higher emission rate compared to their respective criteria and thus have a greater potential to approach or exceed that criterion. Table 3-3 presents in descending order of the ratio of emission factor divided by criteria, the contaminants, their emission factor, applicable criteria and the ratio emission factor divided by criteria. It can be seen that there is a very wide range of ratios.

TABLE 3-3 – CONTAMINANT PRIORITY RANKING

Contaminant	Emission Factor (mg/kg waste)	24hr Average Assessment Criteria (µg/m^3)	Ratio of Emission Factor Divided by Assessment Criteria
PM_{10}	19000	50	380
total PCDD/PCDF	0.000483	0.000005	97
hydrogen cyanide (HCN)	468	8	59
total PCB	2.86	0.15	19
$PM_{2.5}$	17.4	1	17
arsenic (As)	4.329	0.3	14
hydrogen chloride (HCl)	284	20	14
benzene	1240	95.7	13
beryllium (Be)	0.057	0.01	6
aldehydes & ketones	2800	500	6
phenol	140	30	5
acenaphthylene	11	3.5	3
phenanthrene	7.3	3	2
naphthalene	48	22.5	2
hexachlorobenzene	0.022	0.011	2
styrene	740	400	1.9
cadmium (Cd)	0.239	0.15	1.6
lead (Pb)	0.752	0.5	1.5
chromium (Cr)	0.228	1.5	0.2
selenium (Se)	1.424	10	0.1
nickel (Ni)	0.25	2	0.1
barium (Ba)	1.242	10	0.1
acetone	940	11880	0.08
tetrachlorobenzenes	0.074	1	0.07
silver (Ag)	0.068	1	0.07
copper (Cu)	2.164	50	0.04
mercury (Hg)	0.081	2	0.04
aluminum (Al)	4.776	120	0.04
manganese (Mg)	3.189	120	0.03
pentachlorobenzene	0.053	3	0.02
zinc (Zn)	0.911	120	0.008
dichlorobenzenes	0.16	95	0.002
trichlorobenzenes	0.11	400	0.0003

For the purposes of this study, the five contaminants with the highest ratios (as shaded in Table 3-3) were considered for further analysis.

4. MODELLING RESULTS

4.1 GENERAL

The results presented are the maximum values found from the modelling outside of the property line of the SWFs. Grid points within the property line were excluded to eliminate overpredicted concentrations that could occur in close proximity of the source due to the limitations of the model. From the mapping supplied, it was not possible to positively identify the property lines for Beaver Creek and Ross River. In these cases a generic 400 m by 400 m metre site was assumed for the purposes of eliminating grid points within the SWF itself.

Predicted concentrations and most of the derived assessment criteria reported in this study are incremental. No known background air quality concentrations exist for the sites studied.

The concentrations reported in this section are maximum 24 hour average concentrations. The model determines the 24 hour average concentration at each of the approximately 10,000 modelled receptors for each of the 366 days in the year 2008. For each site, these maximum concentrations are presented graphically as isopleths (lines of equal concentration) and in a tabular format at a selection of nearby existing residences. Note that these maximum concentrations cannot occur at the same time all over the mapped area. For example, if the wind is blowing generally from the east on May 1 towards a specific receptor giving rise to a maximum 24 hour average concentration, then none of the contaminants being emitted from the site will impact receptors upwind of the site on that day. For those upwind receptors, the maximum 24 hour average will occur on another day. The reported maximum 24 hr average concentrations occur only once per year at each receptor. For every other day, the concentrations will be lower.

For modelling purposes, it was assumed that the eight hours of waste burning was occurring every day of the year. This is to ensure that the worst meteorological conditions would be captured in the modelling.

4.2 SUMMARY OF RESULTS

Model results show that the highest model concentrations relative to their applicable assessment criteria are for PM_{10} and total PCDD/PCDF, followed by HCN, total PCB and $PM_{2.5}$. These results are consistent with the relative ratios of emission factors and criteria shown in Table 3-3.

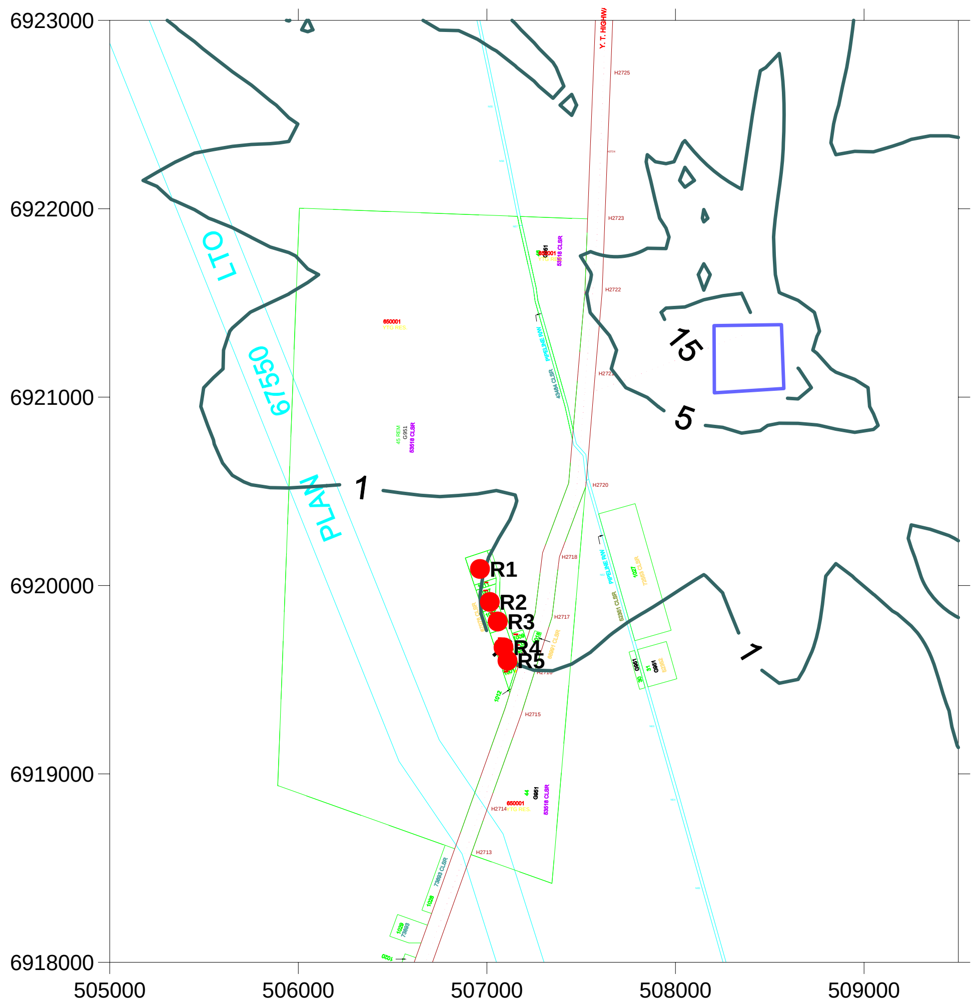
Model results indicate that there are no exceedances of any assessment criteria at any of the representative receptors for the SWFs assessed, with predicted maximum concentrations well below respective criteria at receptor locations. Predicted PM_{10} concentrations for a receptor at Carcross are at 50% of the PM_{10} 24 hr average criterion. All other contaminants at all other receptors are at lower percentages of their respective criteria. Further, there were no modelled exceedances of criteria at any off-site locations for PCBs and $PM_{2.5}$. For some sites, exceedances of criteria at off-site locations were noted for PM_{10}, total PCDD/PCDF and, on one occasion, for HCN. As such, while tabular results are provided for all contaminants assessed, PM_{10} and total PCDD/PCDF are the focus of discussions for the site-specific results presented in the following sections. HCN is also discussed for the single site where the criterion is exceeded.

4.2.1 Beaver Creek Results

No assessment criteria were modelled to be exceeded at this site.

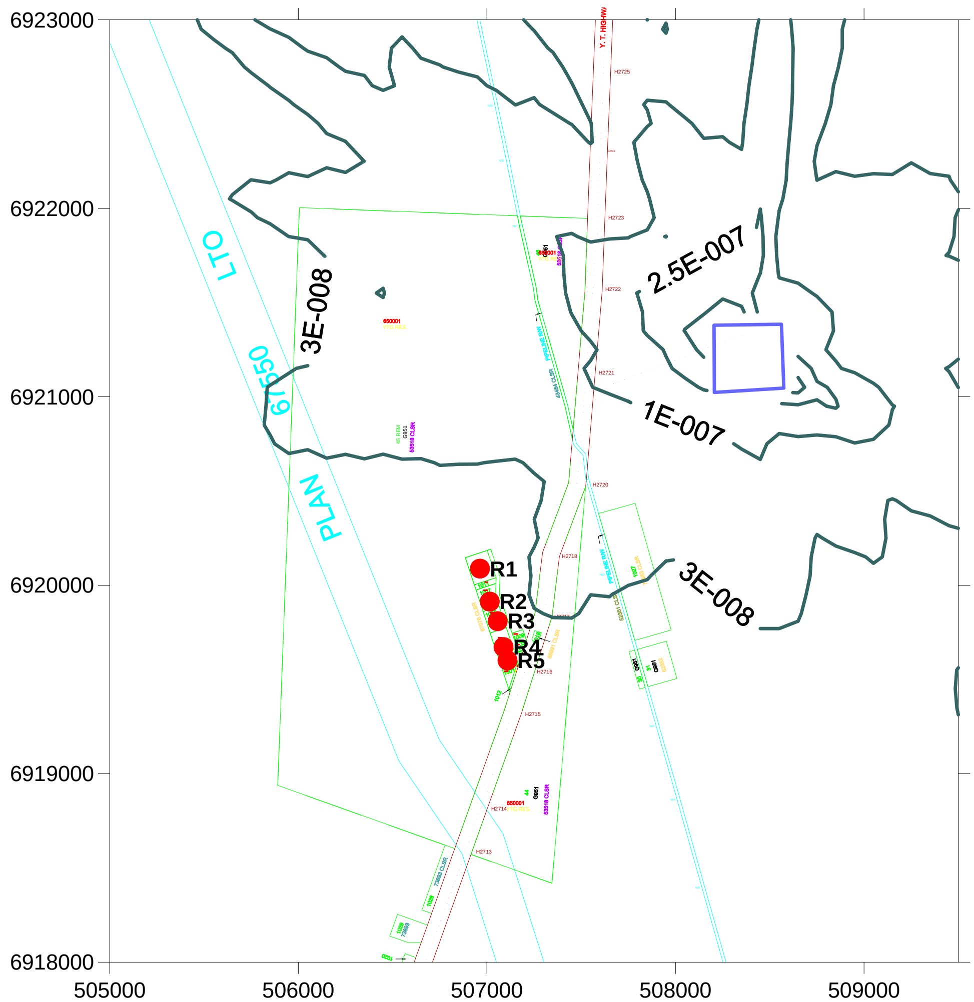
Figure 4-1 presents the maximum 24 hr average PM_{10} concentration isopleths and Figure 4-2 presents the maximum 24 hr average PCDD/PCDF concentration isopleths. Table 4-1 presents the maximum 24 hr average concentration at nearby residences and the maximum concentration outside of the property line for the five priority contaminants. As shown in Table 4-1, the maximum model 24 hr PM_{10} concentration is ~83% of the assessment criterion within close proximity of the SWF.

FIGURE 4-1 – BEAVER CREEK MAXIMUM 24 HR AVERAGE PM_{10} ISOPLETHS



Note: Isopleths are in units of μg/m³

FIGURE 4-2 – BEAVER CREEK MAXIMUM 24 HR AVERAGE PCDD/PCDF ISOPLETHS



Note: Isopleths are in units of µg/m³

TABLE 4-1 – BEAVER CREEK MAXIMUM 24 HR AVERAGE CONCENTRATIONS

Receptors	PM_{10}	PCDD/PCDF	HCN	PCB	$PM_{2.5}$
R1	1.0	2.5E-08	2.4E-02	1.5E-04	8.9E-04
R2	1.1	2.7E-08	2.6E-02	1.6E-04	9.6E-04
R3	1.1	2.7E-08	2.6E-02	1.6E-04	9.8E-04
R4	1.0	2.6E-08	2.5E-02	1.5E-04	9.4E-04
R5	1.0	2.5E-08	2.5E-02	1.5E-04	9.1E-04
Max outside property line	41.4	1.1E-06	2.1	0.013	0.077
Assessment Criteria	50	5.0E-6	8	15	1

4.2.2 Carcross Results

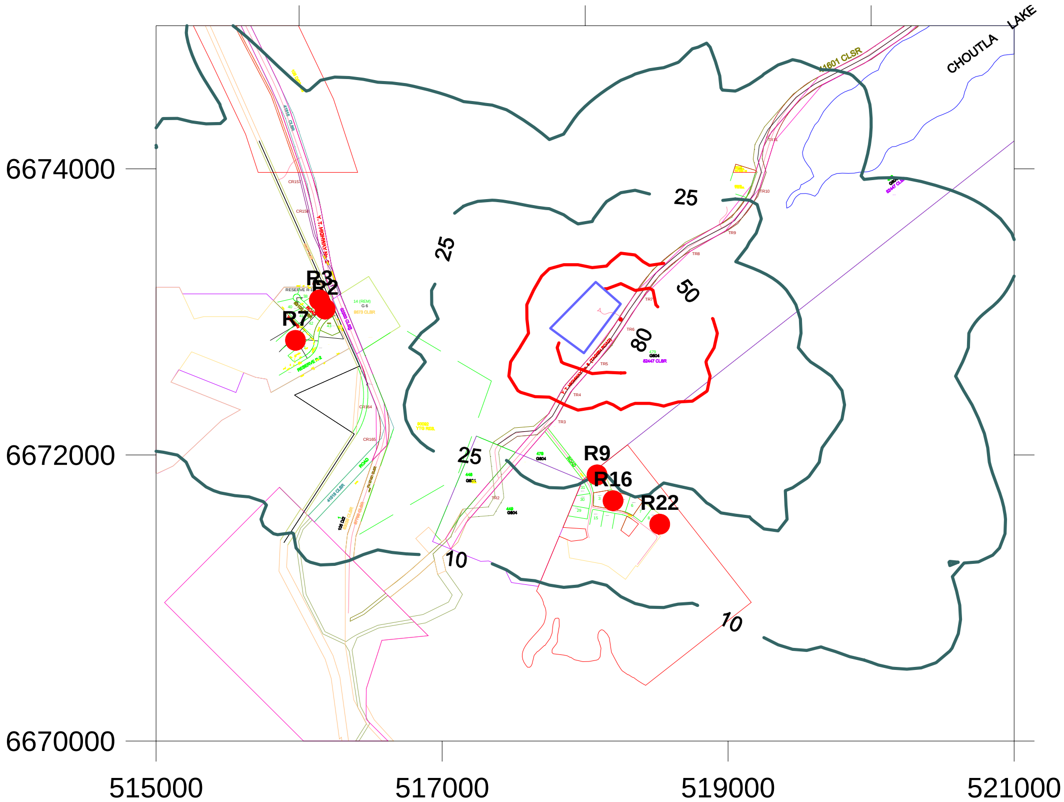
Carcross has the largest number of users (420) amongst the six representative sites modelled and, as such, would be expected to have the greatest impacts of the six sites selected. Table 4-2 shows that maximum modelled concentrations of PM_{10}, PCDD/PCDF and HCN are above their respective criteria outside of the property boundary.

Figure 4-3 shows that the maximum 24 hr average PM_{10} concentration is above the assessment criterion of 50 $\mu g/m^3$ (red isopleth) out to a distance of about 900 metres from the centre of the site. The maximum concentration outside of the property line is 830% of the 24 hr average PM_{10} assessment criteria (Table 4-2). The modelled 24 hr average PM_{10} concentrations decrease to a maximum of 50% of the assessment criterion at the distance of the nearest identified residences (Table 4-2).

The maximum 24 hr average PCDD/PCDF concentration isopleths in Figure 4-4 show a small area outside of the property boundary out to a distance of approximately 240 m from the centre of the site where the assessment criterion of 5E-06 $\mu g/m^3$ is modelled to be exceeded. At the nearby receptors the maximum 24 hr average concentration of PCDD/PCDF is approximately 10% of the assessment criteria.

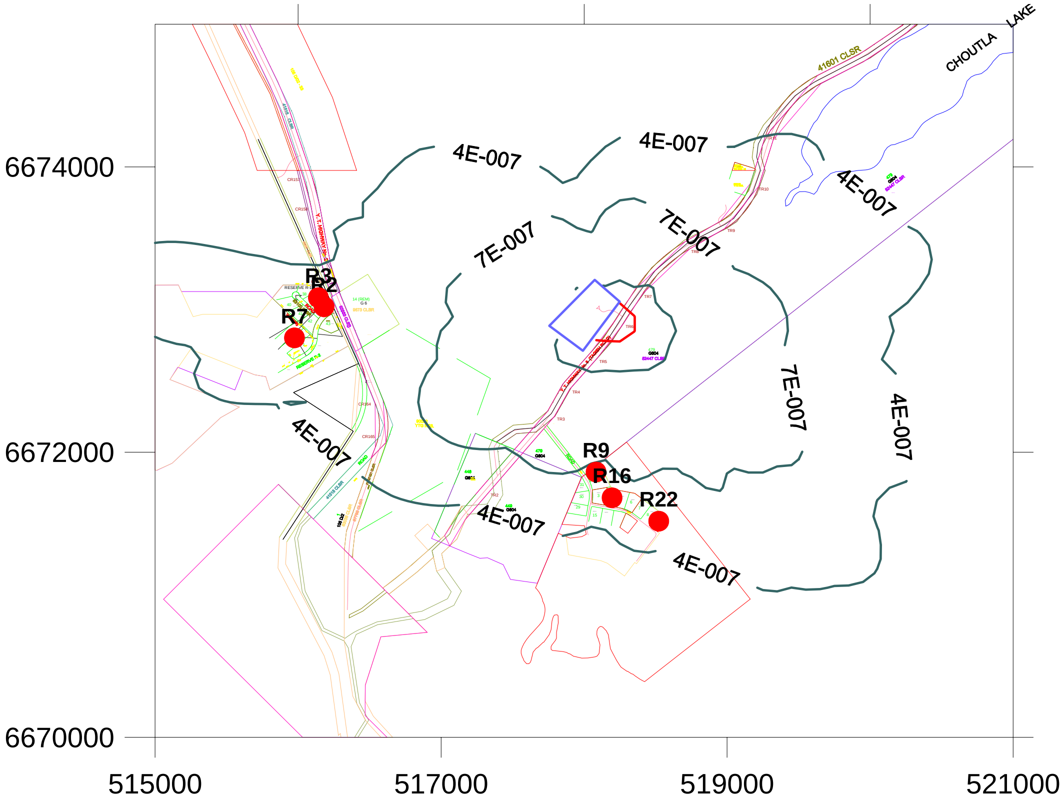
Table 4-2 shows that the maximum 24 hr average concentration of HCN is only slightly above the assessment criterion of 8 $\mu g/m^3$ and is within criterion at a distance of approximately 180 m from the centre of the site. Maximum concentrations of HCN are well below the criterion at nearby receptors. The shaded cells in Table 4-2 are above their respective criteria.

FIGURE 4-3 – CARCROSS MAXIMUM 24 HR AVERAGE PM_{10} ISOPLETHS



Note: Isopleths are in units of µg/m³

FIGURE 4-4 – CARCROSS MAXIMUM 24 HR AVERAGE PCDD/PCDF ISOPLETHS



Note: Isopleths are in units of µg/m³

TABLE 4-2 – CARCROSS MAXIMUM 24 HR AVERAGE CONCENTRATIONS

Receptors	PM_{10}	PCDD/PCDF	HCN	PCB	$PM_{2.5}$
R1	19	4.9E-07	0.47	2.9E-03	1.8E-02
R3	20	5.0E-07	0.48	3.0E-03	1.8E-02
R7	18	4.7E-07	0.45	2.8E-03	1.7E-02
R9	25	6.3E-07	0.61	3.7E-03	2.3E-02
R16	22	5.5E-07	0.54	3.3E-03	2.0E-02
R22	20	5.0E-07	0.48	3.0E-03	1.8E-02
Max outside property line	415	1.1E-05	10.2	0.063	0.38
Assessment Criteria	50	5.0E-6	8	15	1

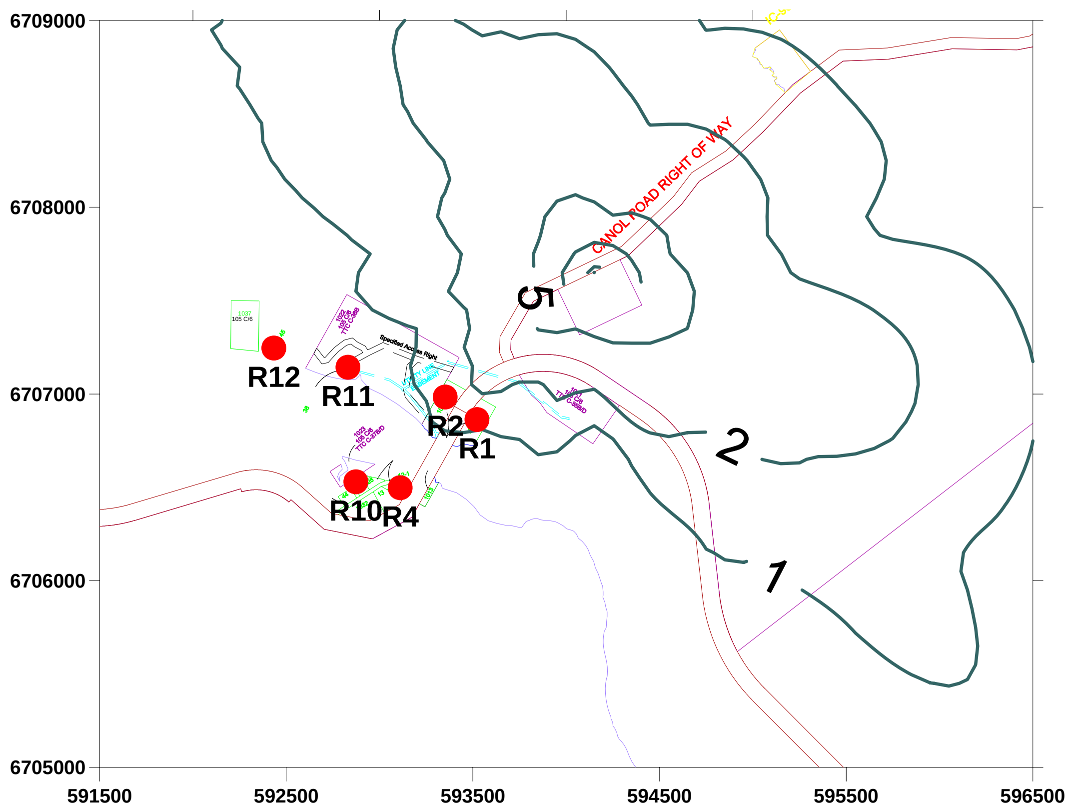
Note: Shaded cells are above respective criterion

4.2.3 Johnson's Crossing Results

No exceedances of any of the modelled contaminants were predicted to occur anywhere outside of the property line at Johnson's Crossing.

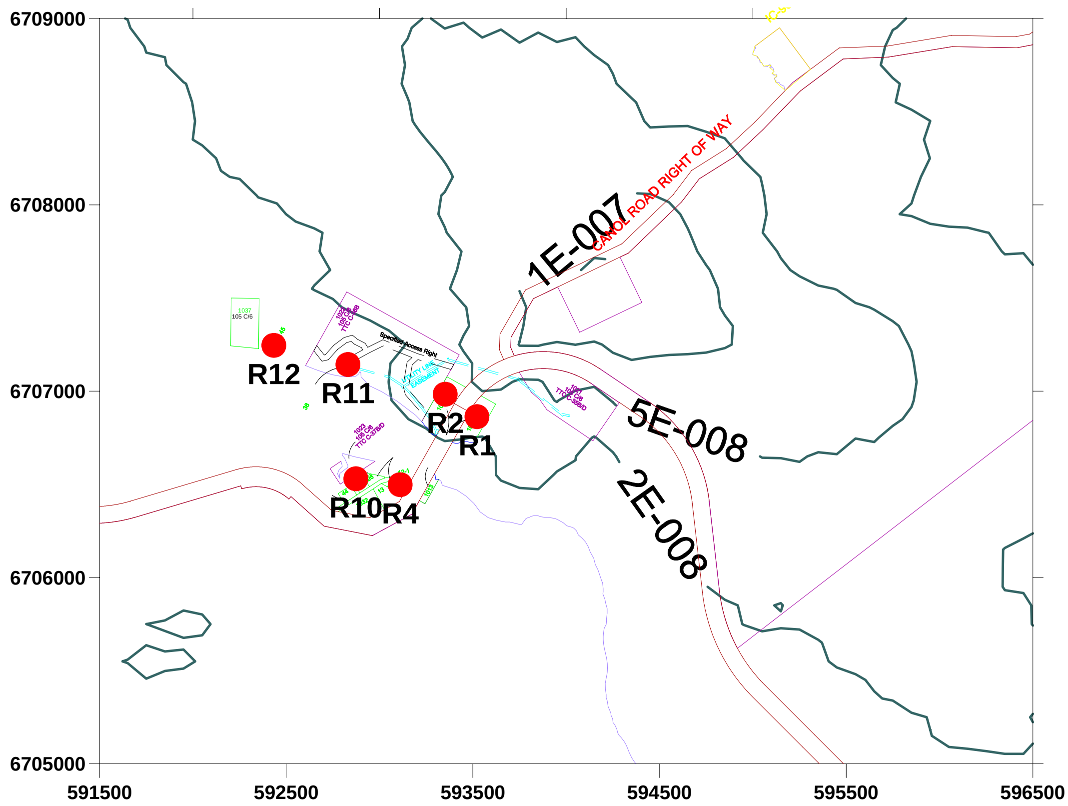
Figure 4-5 and Figure 4-6 present the maximum 24 hr average concentration isopleths for PM_{10} and PCDD/PCDF, respectively. The tabular results are contained in Table 4-3. The maximum 24 hr average PM_{10} concentration outside of the property line is 60% of the criteria but only ~3% at the nearest identified receptor.

FIGURE 4-5 – JOHNSON'S CROSSING MAXIMUM 24 HR AVERAGE PM_{10} ISOPLETHS



Note: Isopleths in units of µg/m³

FIGURE 4-6 – JOHNSON'S CROSSING MAXIMUM 24 HR AVERAGE PCDD/PCDF ISOPLETHS



Note: Isopleths in units of µg/m^3

TABLE 4-3 – JOHNSON'S CROSSING MAXIMUM 24 HR AVERAGE CONCENTRATIONS

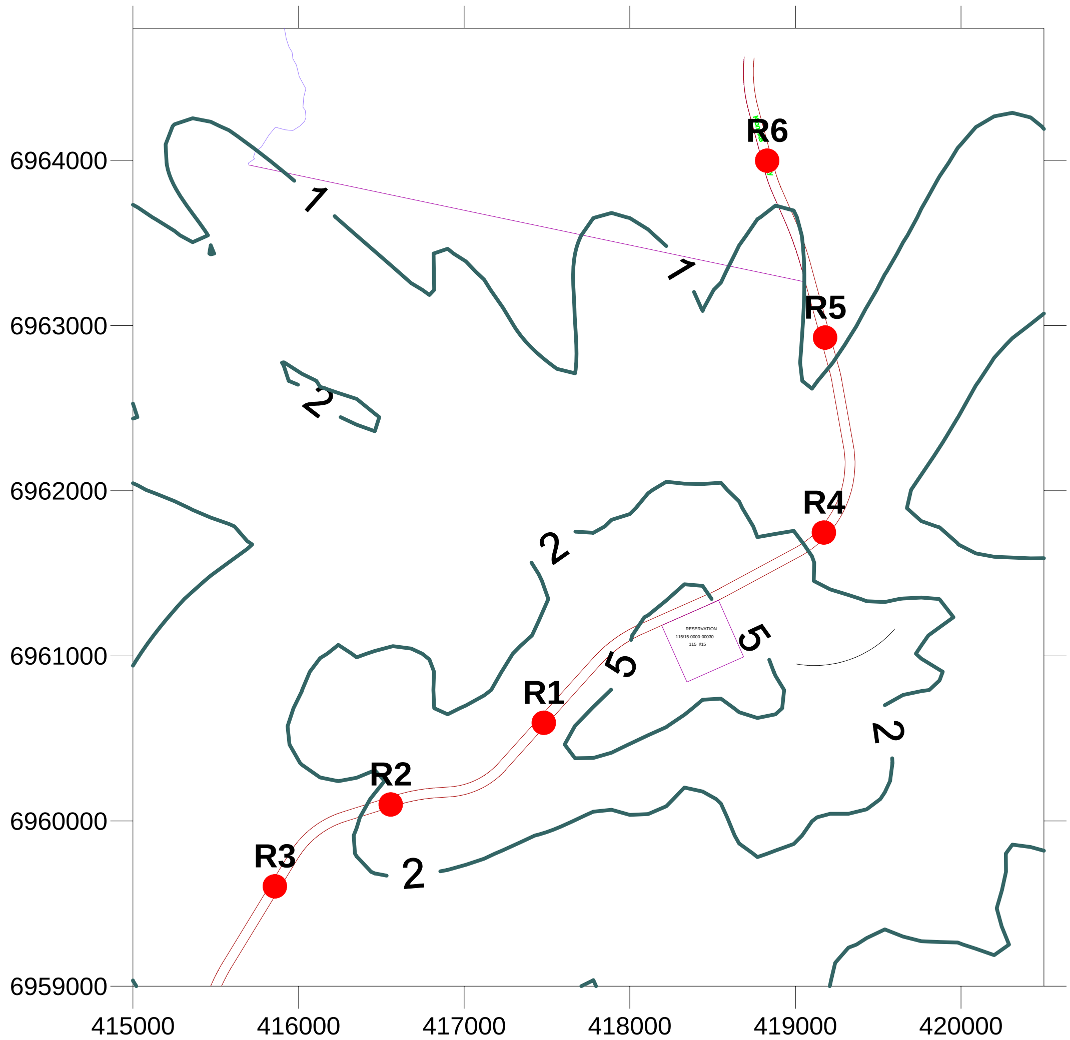
Receptors	PM_{10}	PCDD/PCDF	HCN	PCB	$PM_{2.5}$
R1	1.3	2.5E-06	3.1E-02	1.9E-04	1.2E-03
R2	1.4	2.7E-06	3.4E-02	2.1E-04	1.3E-03
R4	0.5	1.1E-06	1.3E-02	8.1E-05	4.9E-04
R10	0.6	1.2E-06	1.4E-02	8.7E-05	5.3E-04
R11	0.5	9.2E-07	1.1E-02	6.9E-05	4.2E-04
R12	0.3	6.7E-07	8.3E-03	5.1E-05	3.1E-04
Max outside property line	30	7.7E-07	0.74	0.0046	0.028
Assessment Criteria	50	5.0E-6	8	15	1

4.2.4 Pelly Crossing Results

No exceedances of any of the modelled contaminants were modelled anywhere outside of the property line at Pelly Crossing.

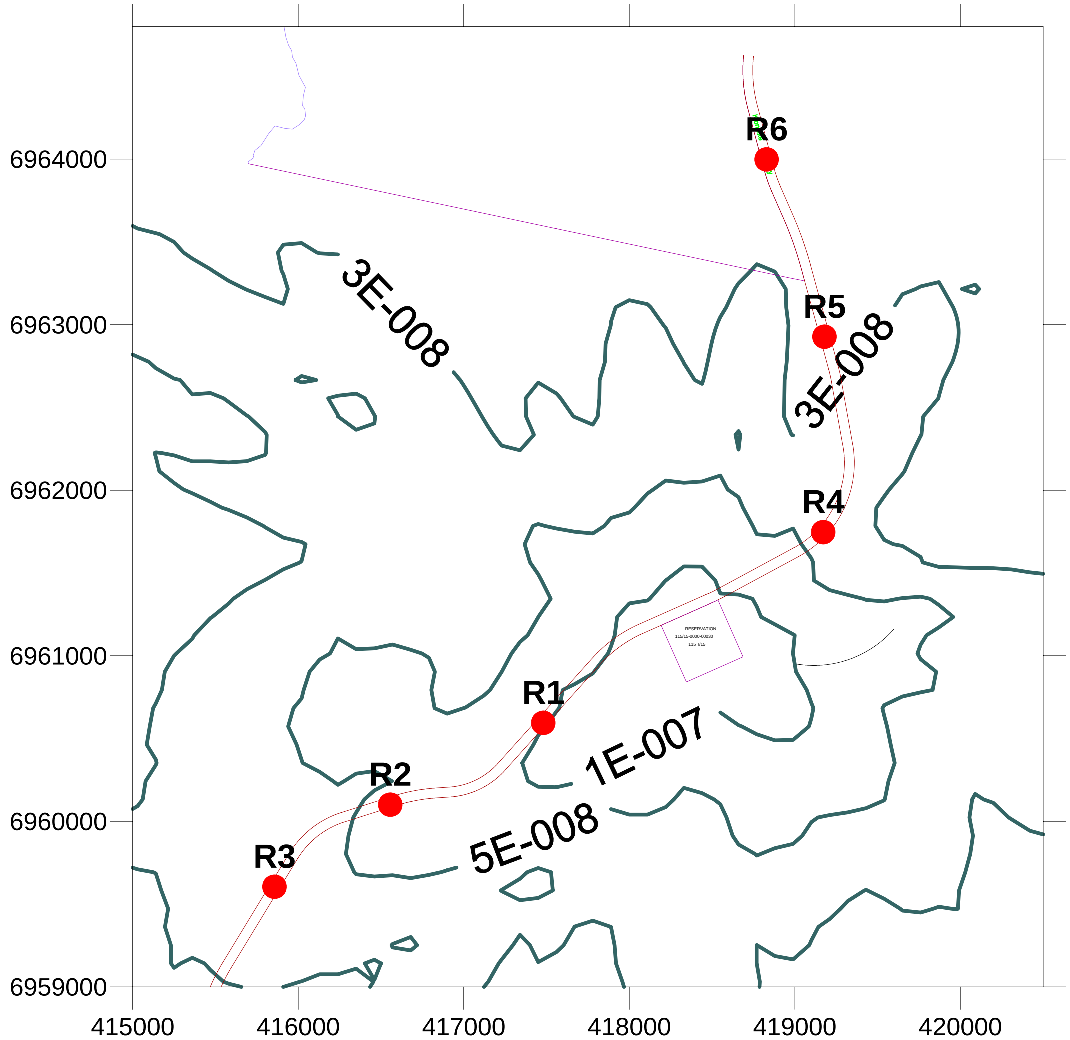
Figure 4-7 and Figure 4-8 present the maximum 24 hr average concentration isopleths for PM_{10} and PCDD/PCDF, respectively. The tabular results are contained in Table 4-4. The maximum 24 hr average PM_{10} concentration outside of the property line is 18% of the criteria but only ~7% at the most impacted receptor.

FIGURE 4-7 – PELLY CROSSING MAXIMUM 24 HR AVERAGE PM_{10} ISOPLETHS



Note: Isopleths in units of μg/m³

FIGURE 4-8 – PELLY CROSSING MAXIMUM 24 HR AVERAGE PCDD/PCDF ISOPLETHS



Note: Isopleths in units of μg/m³

TABLE 4-4 – PELLY CROSSING MAXIMUM 24 HR AVERAGE CONCENTRATIONS

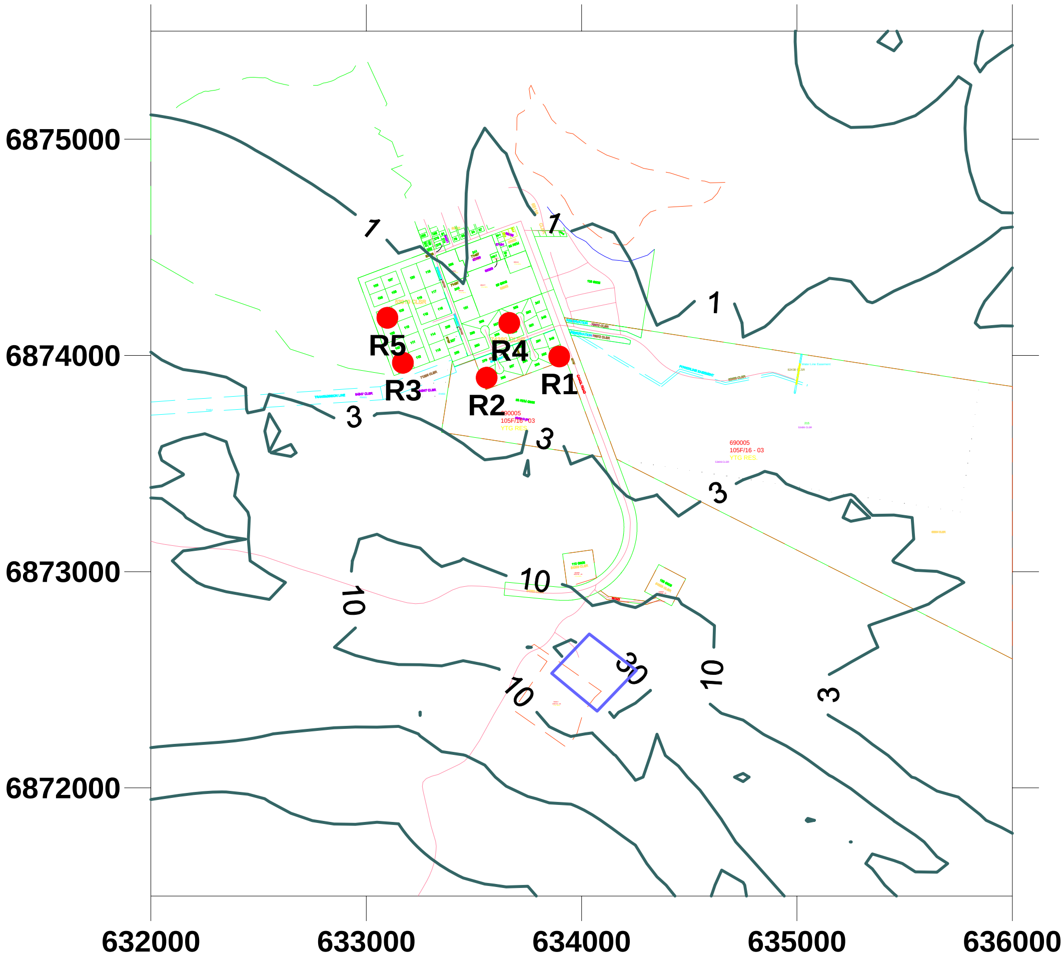
Receptors	PM_{10}	PCDD/PCDF	HCN	PCB	$PM_{2.5}$
R1	3.8	9.7E-08	9.5E-02	5.8E-04	3.5E-03
R2	2.2	5.4E-08	5.4E-02	3.3E-04	2.0E-03
R3	1.6	4.1E-08	4.1E-02	2.5E-04	1.5E-03
R4	1.7	4.3E-08	4.3E-02	2.6E-04	1.6E-03
R5	0.84	2.1E-08	2.1E-02	1.3E-04	7.7E-04
R6	0.84	2.1E-08	2.1E-02	1.3E-04	7.7E-04
Max outside property line	9.3	2.4E-07	0.23	0.0014	0.0085
Assessment Criteria	50	5.0E-6	8	15	1

4.2.5 Ross River Results

No exceedances of any of the modelled contaminants were predicted to occur anywhere outside of the property line at Ross River.

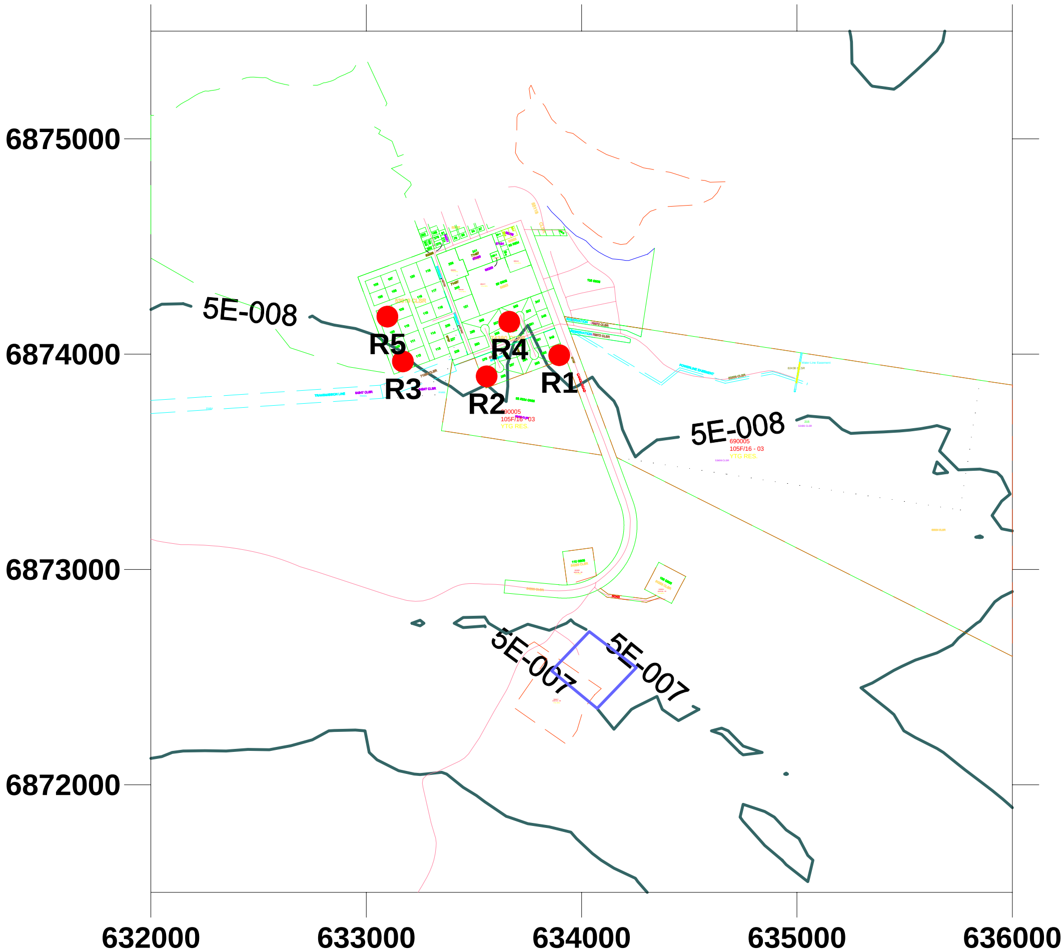
The graphical results are presented in Figure 4-9 for PM_{10} and Figure 4-10 for PCDD/PCDF respectively. The tabular results are contained in Table 4-5. The maximum 24 hr average PM_{10} concentration outside of the property line is 97% of the criteria but only ~4% at the nearest identified receptor.

FIGURE 4-9 – ROSS RIVER MAXIMUM 24 HR AVERAGE PM_{10} ISOPLETHS



Note: Isopleths in units of µg/m³

FIGURE 4-10 – ROSS RIVER MAXIMUM 24 HR AVERAGE PCDD/PCDF ISOPLETHS



Note: Isopleths in units of µg/m^3

TABLE 4-5 – ROSS RIVER MAXIMUM 24 HR AVERAGE CONCENTRATIONS

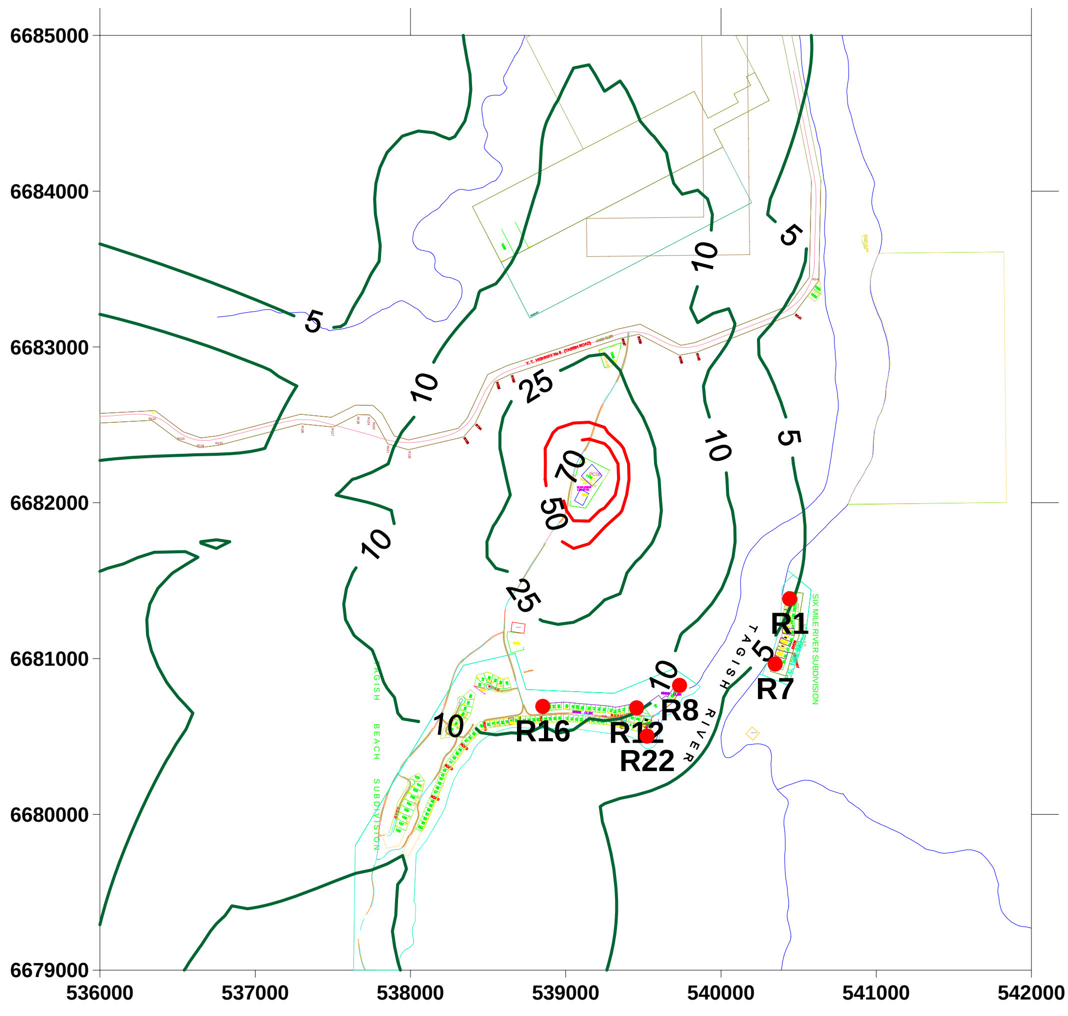
Receptors	PM_{10}	PCDD/PCDF	HCN	PCB	$PM_{2.5}$
R1	1.6	4.1E-08	4.0E-02	2.5E-04	1.5E-03
R3	1.7	4.3E-08	4.2E-02	2.5E-04	1.5E-03
R5	2.1	5.4E-08	5.2E-02	3.2E-04	1.9E-03
R6	1.9	4.9E-08	4.7E-02	2.9E-04	1.8E-03
R7	1.7	4.2E-08	4.1E-02	2.5E-04	1.5E-03
Max outside property line	48.6	1.2E-06	1.2	0.007	0.044
Assessment Criteria	50	5.0E-6	8	15	1

4.2.6 Tagish Results

Figure 4-11 shows that the maximum 24 hr average PM_{10} concentration is above the assessment criterion of 50 µg/m^3 (red isopleth) out to a distance of about 420 metres from the centre of the site. The maximum concentration outside of the property line is ~260% of the 24 hr average PM_{10} assessment criteria (shaded cell of Table 4-6). The modelled 24 hr average PM_{10} concentrations decrease to a maximum of approximately 24% of the assessment criterion at the distance of the nearest identified residences (Table 4-6).

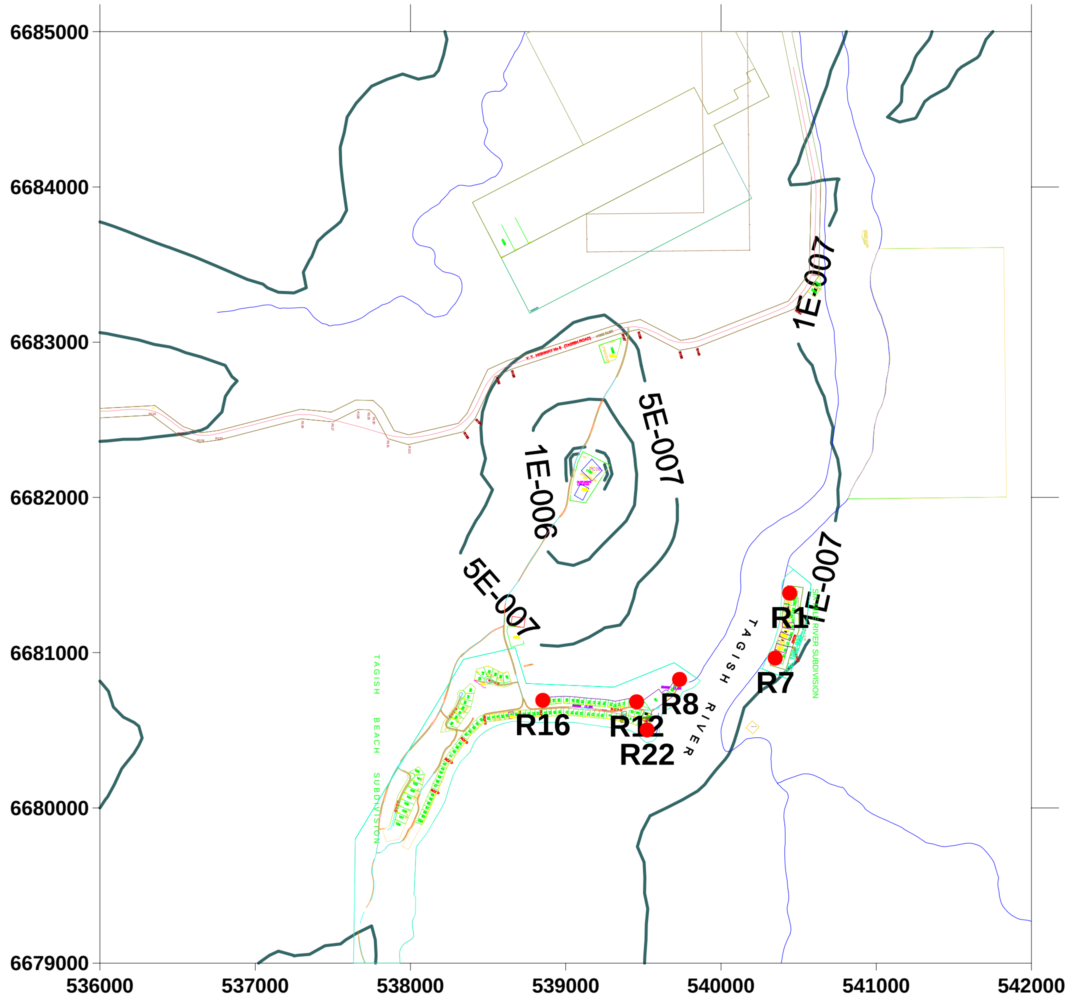
None of the other contaminants showed any exceedances anywhere outside of the property line at Tagish. Figure 4-12 presents the maximum 24 hr average PCDD/PCDF concentration isopleths.

FIGURE 4-11 – TAGISH MAXIMUM 24 HR AVERAGE PM_{10} ISOPLETHS



Note: Isopleths in units of µg/m^3

FIGURE 4-12 – TAGISH MAXIMUM 24 HR AVERAGE PCDD/PCDF ISOPLETHS



Note: Isopleths in units of µg/m³

TABLE 4-6 – TAGISH MAXIMUM 24 HR AVERAGE CONCENTRATIONS

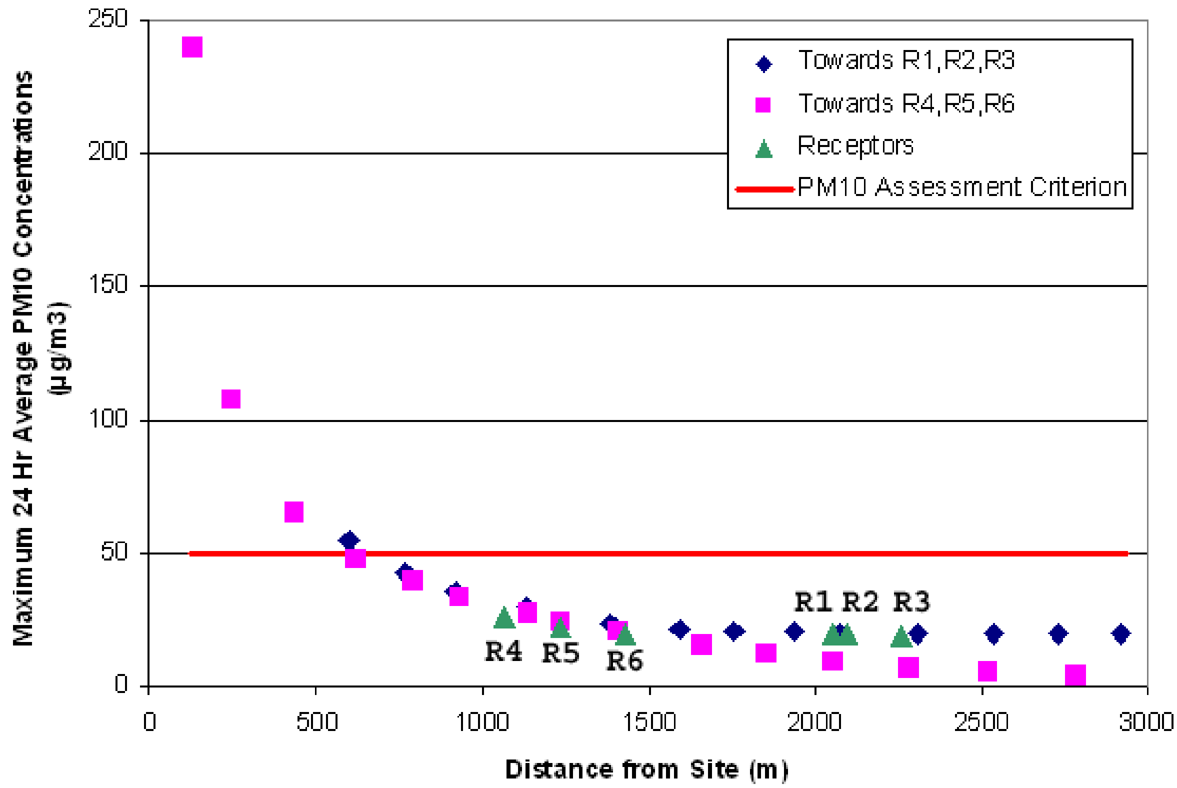
Receptors	PM_{10}	PCDD/PCDF	HCN	PCB	$PM_{2.5}$
R1	5.2	1.3E-07	1.3E-01	7.7E-04	4.7E-03
R7	4.3	1.1E-07	1.1E-01	6.5E-04	4.0E-03
R8	8.3	2.1E-07	2.0E-01	1.2E-03	7.6E-03
R12	1.0	2.6E-07	2.5E-01	1.5E-03	9.3E-03
R16	12.0	3.0E-07	2.9E-01	1.8E-03	1.1E-02
R22	7.7	2.0E-07	1.9E-01	1.2E-03	7.0E-03
Max outside property line	132	3.3E-06	3.25	0.02	0.12
Assessment Criteria	50	5.0E-6	8	15	1

5. DETERMINATION OF RESIDENTIAL SET-BACK DISTANCES

5.1 DECREASE IN MAXIMUM CONCENTRATION WITH DISTANCE FROM SITE

The maximum 24 hr average concentrations drop off quickly with distance. For the Carcross site, the maximum 24 hr average PM_{10} concentrations were plotted against distance from the site in. Figure 5-1 shows two sets of data: one set in the direction of receptors R1, R2 and R3 and one set towards receptors R4, R5 and R6. The 24 hr average PM_{10} assessment criterion of 50 µg/m^3 is shown as a red line. It can be seen that the maximum 24 hr average PM_{10} concentration drops exponentially from an absolute maximum of ~240 µg/m^3 at a distance of ~200 m from the burning source to the PM_{10} assessment criteria at a distance of ~600 m from the site for the directions chosen. The concentrations drop to approximately half of the assessment criteria at a distance of ~1,000 m from the burning site. The difference in dispersion for the two directions is a function of local terrain, land use and meteorology.

FIGURE 5-1 – DECREASE IN MAXIMUM CONCENTRATION WITH DISTANCE



5.2 RESIDENTIAL SET-BACK DISTANCES

The required residential set-back distances were determined for the contaminants that exceeded their assessment criteria based on the maximum distance from the centre of the SWF where the assessment criteria is met. Table 5-1 presents the residential set-back distances determined. The table shows that for Carcross, residential development should not be allowed closer than 900 m from the centre of the SWF based on the results from PM_{10}.

TABLE 5-1 – RESIDENTIAL SET-BACK DISTANCES

Solid Waste Facility	Number of Users	Residential Set-Back Distance Based on PM_{10} (m)	Residential Set-Back Distance Based on PCDD/PCDF (m)	Residential Set-Back Distance Based on HCN (m)
Beaver Creek	130	- (1)	-	-
Carcross	430	900	240	180
Johnson's Crossing	35	-	-	-
Pelly Crossing	300	-	-	-
Ross River	380	-	-	-
Tagish	280	400	-	-

Note: (1) "-" indicates that no set-back is required to meet the respective criterion.

Table 5-1 also shows that the residential set-back distance is not only a function of the number of users as both Ross River and Pelly Crossing have more users and thus more emissions than Tagish, but show no exceedances. The dispersion is a function of the meteorology, the terrain and the land use around each individual site.

5.3 UNCERTAINTY

There are several sources of uncertainty in this report that include:

- Amount of waste generated per person per day;
- Applicability of emission factors collected in US to waste generated in Northern Canada due to differences in wastes disposed and ambient temperatures during burning;
- Recycling efforts will change not only quantity but characteristics of waste to be burned;
- Rate of emissions may depend on characteristics of container used to burn waste;
- Duration of burn was assumed to be 8 hrs every week; and
- Uncertainties in meteorology and CALPUFF model dispersion algorithms.

This study examined 24 hour average concentration against assessment criteria that are generally health-based. There may be nuisance effects (odour, visual opacity, etc.) on a short term basis with the use of the set-backs determined in this study.

Due to these uncertainties, the residential set-back distances determined in this study should be multiplied by some “safety” factor to ensure that impacts are minimized.

5.4 ON-SITE CONCENTRATIONS

To avoid overpredictions of concentrations on-site due to limitations of the modelling program, on-site receptors were removed. However, for the duration of a burn, concentrations within the property line are higher than off-site concentrations. Therefore, to prevent unnecessary exposure to high concentrations of contaminants, it is recommended that the SWF be made inaccessible to public when the burning of material is underway.

6. CONCLUSIONS

The six SWFs of Beaver Creek, Carcross, Johnson's Crossing, Pelly Crossing, Ross River and Tagish were selected for this study. The number of users of these sites ranged from 35 for Johnson's Crossing to 430 for Carcross.

Contaminant emission rates were estimated based on the number of users per SWF, an estimate of waste production per person and relevant emission factors for the open burning of household waste were obtained from the EPA Document "Evaluation of Emissions from the Burning of Household Waste in Barrels" (US EPA 1997a, 1997b). Based on supplied information it was assumed, for modelling purposes, that the solid waste was burned once per week and each burn lasted 8 hours.

Site specific meteorology was generated for each of the six SWFs studied as meteorology varies from site to site.

CALPUFF air dispersion modelling determined maximum 24 hr average concentrations around each site for the following five key contaminants, selected based on ratios of emission rates to air quality criteria (in order of priority):

- PM_{10} (particulate matter smaller than 10 microns in diameter)
- Total Polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/PCDF) - single Toxic Equivalent (TEQ) of dioxins and furans
- HCN – Hydrogen cyanide
- Total Polychlorinated biphenyls (PCB)
- $PM_{2.5}$ (particulate matter smaller than 2.5 microns in diameter)

The reported predicted maximum concentrations occur only once per year at each receptor. For every other day, the concentrations will be lower. Concentrations were observed to drop off quickly with distance.

At Carcross, exceedance of PM_{10}, PCDD/PCDF and HCN were modelled outside of the property line. For PM_{10} the set-back distance to stay below the assessment criteria is 900 m from the centre of the SWF. Note that this set—back distance only considers emission impacts due to waste burning, irrespective of background PM_{10} concentrations from other sources.

At Tagish, exceedance of PM_{10} was modelled outside of the property line with a set-back distance to stay below the assessment criteria of 400 m from the centre of the SWF.

No other exceedances were observed for other contaminant at the other modelled sites excluding background concentrations). Modelling indicated that there are no exceedances of any assessment criteria at any of the representative receptors for the SWFs assessed, with predicted maximum concentrations well below respective criteria at receptor locations. Predicted PM_{10} concentrations for a receptor at Carcross are at 50% of the PM_{10} 24 hr average criterion. All other contaminants at all other receptors are at lower percentages of their respective criteria.

Care should be taken in applying the results of this study to other sites not modelled in this study. Terrain and land use were observed to have large impacts on the local meteorology near each of the six selected sites as demonstrated through wind roses. This emphasizes the importance of obtaining representative meteorology for the prediction of maximum concentrations and for establishing set-back distances based on these concentrations.

Due to these uncertainties, the set-back distances determined in this study should be multiplied by some “safety” factor to ensure that impacts are minimized.

Overall, based on the assumptions made in this report, the modelling shows that currently the maximum 24 hr average concentrations of all contaminants considered in this study are below the respective criteria derived from North American jurisdictions at all identified residential areas for all six selected SWFs.

Emissions of chlorinated contaminants such as PCDD/PCDF and PCB, could be reduced by source separation of chlorinated plastics such as polyvinyl chloride (PVC). PCDD/PCDF and PCB cannot be formed without a source of chlorine in the burned waste. Removing other toxic materials such as paints, glues, batteries, electronic equipment, etc. from the material to be burned would also reduce emissions of toxic compounds.

In addition, to limit short-term exposure to high concentration of contaminants that are generated at these burn sites, it is recommended that these areas be fenced off and inaccessible to public when the burning of material is underway.

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