ONTARIO POWER GENERATION

Report

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ENVIRONMENTAL RISK ASSESSMENT REPORT FOR PICKERING NUCLEAR

Environmental Risk Assessment Report For Pickering Nuclear

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Environmental Risk Assessment Report for Pickering Nuclear

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Environmental Risk Assessment Report for Pickering Nuclear

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LIST OF ACRONYMS AND SYMBOLS

ACRONYMS

AAQC	ambient air quality criteria
ALARA	as low as reasonably achievable
APS	Auxiliary Power System
BAF	bioaccumulation factor
BCF	bioconcentration factor
BC MOE	British Columbia Ministry of the Environment
BOD	biochemical oxygen demand
BTEX	benzene, toluene, ethylbenzene, and xylenes
BV	benchmark value
CCME	Canadian Council of Ministers of the Environment
CCW	condenser cooling water
CNSC	Canadian Nuclear Safety Commission
CofA	certificate of approval
COD	chemical oxygen demand
COG	CANDU Owners Group
COPC	contaminant of potential concern
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	catch per unit effort
CSA	Canadian Standards Association
CSP	Conventional Safety Program
CTU	Combustion Turbine Units
DC	dose coefficient
DOC	dissolved organic carbon
DRL	derived release limit
DRPD	Durham Region Planning Department
DWSP	Drinking Water Surveillance Program
EA	environmental assessment
EC/HC	Environment Canada/Health Canada
EcoRA	ecological risk assessment
ELC	Ecological Land Classification
EMP	environmental monitoring program
ERA	environmental risk assessment
ESA	Environmentally Sensitive Area
ESDM	Emissions Summary and Dispersion Modelling
ESL	effects screening limits
EV	exposure values
FDS	fish diversion system
GLFC	Great Lakes Fishery Commission

HHRA	human health risk assessment
HQ	hazard quotient
HTS	heat transport system
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
ILCR	incremental lifetime cancer risk
ILW	intermediate level waste
JSL	jurisdictional screening levels
LCV	lowest chronic value
LLW	low level waste
LOAEL	Lowest Observable Adverse Effect Level
LOEC	lowest observed effect concentration
LOEL	lowest observed effect level
LSA	local study area
MAL	maximum allowable limit
MDL	Method Detection Limit
MISA	Municipal Industrial Strategy for Abatement
MOE	Ontario Ministry of Environment
MTE	maximum temperature for embryos
MWAT	maximum weekly average water temperatures
NEW	nuclear energy worker
NOEC	no observed effect concentration
NOAEL	No Observable Adverse Effect Level
NPDES	National Pollutant Discharge Elimination System
NPRI	National Pollution Release Inventory
NSCA	Nuclear Safety and Control Act
NURP	Nationwide Urban Runoff Program
NWTP	New Water Treatment Plant
ODS	Ozone Depleting Substances
OMNR	Ontario Ministry of Natural Resources
OPG	Ontario Power Generation
QA	quality assurance
PAH	polycyclic aromatic hydrocarbon
PARTS	Pickering A Return to Service
PCB	polychlorinated biphenyl
PESC	Pacific Environmental Science Centre
PHC	polyhalogenated compound
PN	Pickering Nuclear
PNGS	Pickering Nuclear Generating Station
POI	point of impingement
PRA	probabilistic risk assessment
PWMF	Pickering Waste Management Facility

PWQO	provincial water quality objective
QSAR	Quantitative Structure-Activity Relationship
RBE	relative biological effectiveness
REMP	radiological environmental monitoring program
RLWMS	Radioactive Liquid Waste Management System
RPP	Radiation Protection Plan
RSA	regional study area
SARO	Species at Risk in Ontario
SCV	secondary chronic value
SSA	site study area
STDM	short-term daily average temperatures
TAB	Turbine Auxiliary Bay
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TF	transfer factor
TLV	threshold limit value
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TRC	total residual chlorine
TRCA	Toronto and Region Conservation Authority
TRV	toxicity reference value
TSD	technical support document
TSS	total suspended solids
UF	uncertainty factor
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UPP	Upgrading Plant Pickering
US EPA	United States Environmental Protection Agency
VBRS	Vacuum Building Ramp Sump
VEC	valued ecosystem component
WHO	World Health Organization
WPCP	Water Pollution Control Plant
WSP	Water Supply Plant
WWMF	Western Waste Management Facility

SYMBOLS

Human Non-radiological Parameters

C_{air}	=	air concentration (µg/m^3).
C	=	concentration of contaminant in drinking water (mg/L)
IR	=	receptor intake rate (L/d)
RAF_{GIT}	=	absorption factor from the gastrointestinal tract (unitless)
D_2	=	days per week exposed•(7 days)$^{-1}$ (d/d)
D_3	=	weeks per year exposed•(52 weeks)$^{-1}$ (wk/wk)

D_4	=	total years exposed to site (years) (for carcinogens only)
BW	=	body weight (kg)
C_{foodi}	=	concentration of contaminant in food i (mg/kg)
IR_{foodi}	=	receptor ingestion rate for food i (kg/d)
RAF_{GITi}	=	relative absorption factor from the gastrointestinal tract for contaminant i (unitless)
D_i	=	days per year during which consumption of food i will occur (d/a)
LE	=	life expectancy (years) (for carcinogens only)
P_{01}	=	transfer parameter from source emission to air

Environmental Partitioning Parameters

$C_{s(fw)}$	=	concentration in sediment (Bq/kg fw)
C_w	=	concentration in water (Bq/L)
ρ_w	=	density of water (1 kg/L)
θ	=	sediment porosity (unitless)
K_d	=	distribution coefficient (L/kg solid)
ρ_s	=	density of solids (kg/L)
$C_{s(dw)}$	=	concentration in sediment (Bq/kg dw)
f_{dw}	=	dry weight fraction of sediment (unitless).

Ecological Radiological Dose Parameters

D_{int}	=	internal radiation dose (µGy/d)
D_{ext}	=	external radiation dose (µGy/d)
DC_{int}	=	internal dose coefficient ((µGy/d)/(Bq/kg))
DC_{ext}	=	external dose coefficient ((µGy/d)/(Bq/kg))
$DC_{ext,w}$	=	external dose coefficient (in water)
$DC_{ext,s}$	=	external dose coefficient (in soil) ((µGy/d)/(Bq/kg))
$DC_{ext,ss}$	=	external dose coefficient (on soil surface) (µGy/d)/(Bq/kg))
C_m	=	media concentration (Bq/L or Bq/kg)
C_f	=	average concentration in food (Bq/kg fw)
C_w	=	water concentration (Bq/L)
C_s	=	soil/sediment concentration (Bq/kg fw)
C_t	=	whole body tissue concentration (Bq/kg fw)
C_x	=	concentration in the ingested item x (Bq/kg fw)
OF_w	=	occupancy factor in water
OF_{ws}	=	occupancy factor at water surface
OF_s	=	occupancy factor in soil/sediment
OF_{ss}	=	occupancy factor at soil/sediment surface
BAF	=	bioaccumulation factor (L/kg or kg/kg)
BMF	=	biomagnification factor (unitless)
I_x	=	ingestion rate of item x (kg fw/d)
TF	=	ingestion transfer factor (d/kg)
DW_a	=	dry/fresh weight ratio for animal products (kg-dw/kg-fw)

$1\text{-}DW_a$	=	water content of the animal (L water /kg-fw)
$1\text{-}DW_p$	=	water content of the plant/food (L water /kg-fw plant)
BAF_{a_HTO}	=	aquatic animal BAFs for tritium (L/kg-fw)
BAF_{p_HTO}	=	plant BAF for tritium (L/kg-fw)
P_{air_plant}	=	transfer from air to plant (m^3/kg-fw)
P_{air_spw}	=	transfer from air to soil pore water (m^3/L)
θ	=	volumetric moisture content of soil (m_3 water/m_3 soil)
p_b	=	bulk density of the soil (kg/m^3)
k_{af}	=	fraction of food from contaminated sources
k_{aw}	=	fraction of water from contaminated sources (assumed to be 1)
$f_{w\text{-}w}$	=	fraction of the animal water intake derived from direct ingestion of water
$f_{w\text{-}pw}$	=	fraction of the animal water intake derived from water in the plant feed
$f_{w\text{-}dw}$	=	fraction of the animal water intake that results from the metabolic decomposition of the organic matter in the feed
ID_p	=	isotopic discrimination factor for plant metabolism
$P_{HTOwater\_animal}$	=	transfer of HTO to animals through water ingestion (L/kg-fw)
$P_{HTOfood\_animal}$	=	transfer of HTO to animals through food ingestion
$P_{HTOsoil\_plant}$	=	transfer of HTO from soil to plant
S_a	=	stable carbon content in the aquatic animal/invertebrate/plant (gC/kg-fw)
S_w	=	mass of stable carbon in the dissolved inorganic phase in water (gC/L)
S_a	=	stable carbon content in the animal (gC/kg-fw)
S_p	=	stable carbon content in the food (gC/kg-fw)
$BAFa_{C14}$	=	C14 BAF for aquatic animals, invertebrates, and plants (L/kg-fw)
$P_{C14food\_animal}$	=	transfer of C-14 from food to animals

Ecological Non-Radiological Parameters

C_x	=	concentration in the ingested item (x) (mg/kg)
D_{ing}	=	dose from ingestion pathway (mg/kg body weight/day)
I_x	=	ingestion rate of item x (kg/day)
W	=	body weight of consumer (kg fw)
ΔT	=	change in temperature (ºC)

Executive Summary

The Canadian Standards Association (CSA) recently completed its N288.6 standard on environmental risk assessment (ERA) for Class I nuclear facilities (CSA, 2012). The standard calls for both human health risk assessment (HHRA) and ecological risk assessment (EcoRA), for both radiological and non-radiological contaminants and physical stressors.

A multi-tiered EcoRA was performed from 1999 to 2002 (SENES, 1999; 2000; 2001; 2002) to assess the overall ecological effect of operations at the Pickering Nuclear (PN) site and to support regulatory compliance. In the first phase an issue-based Environmental Review was completed and submitted to the Canadian Nuclear Safety Commission (CNSC - then the Atomic Energy Control Board). The CNSC recommended that a desktop EcoRA be performed to identify any effects the Pickering Nuclear Generating Station (PNGS) has on the valued ecosystem components (VECs). SENES then completed a multi-tiered risk assessment in response to CNSC recommendations. Although the focus of the risk assessment was on ecological receptors, some human receptors were evaluated as well. In 2007, to support the Pickering B Refurbishment and Continued Operations Environmental Assessment, the ecological risk assessment was updated and a human health assessment was performed (SENES, 2007a, 2007b).

This ERA document provides an integrated EcoRA and HHRA that follows recently published CSA N288.6-12 guidance, and provides an update to the existing ERA using recent monitoring data from the five-year period 2007 to 2011.

The overall goals of this ERA were:

- To update the ERA in general accordance with the CSA N288.6-12 Standard.
- To provide focus for the environmental monitoring program on relevant contaminants of potential concern (COPCs), media, and ecological and human receptors.

The specific objectives of this ERA, consistent with CSA N288.6-12, were:

- To evaluate the risk to relevant human and ecological receptors resulting from exposure to contaminants and stressors related to the PN site and its activities.
- To recommend potential further monitoring or assessment as needed based on the results of the ERA.

Human Health Risk Assessment (HHRA)

Predicted exposures to sources from PNGS A and PNGS B were evaluated on the basis of toxicological effects from non-carcinogenic COPCs, potential cancer risk from carcinogens,

and potential radiation exposure from radionuclides. Potential effects were evaluated based on data from 2007 to 2011, where available, and older site data as appropriate.

Human Receptors

Human receptors evaluated included off-site members of the public, specifically those critical groups used for dose calculations in the OPG Annual REMP Reports, including:

- C2 Correctional Institution;
- Local Residents;
- Local Farms;
- Local Dairy Farms;
- Sport Fishers; and
- Off-site Industrial/Commercial Workers.

These six critical groups were appropriate for the exposure assessment for both radiological and non-radiological COPCs.

On-site receptors were not addressed in the HHRA, since human exposures on the site are kept within safe levels through OPG's Conventional Safety Program (CSP) and Radiation Protection Program (RPP).

Screening of COPCs for Human Health

Predicted concentrations of non-radiological COPCs in air during the 2007 to 2011 period were compared to air quality benchmarks as discussed in Section 3.1.2.1. Based on the screening, hydrazine was carried forward for further quantitative assessment in the HHRA.

The surface water screening is based on measurements of non-radiological COPCs discharged from 2007 to 2011 into the CCW discharge channel, as well as lake water measurements collected in 2006. Based on the screening for human health, hydrazine and morpholine were carried forward for further quantitative assessment in the HHRA.

Human exposure to COPCs from on-site groundwater was not evaluated since there are no complete exposure pathways for human receptors to site groundwater. There is potential for site groundwater to migrate to surface water (Lake Ontario). Groundwater flux from the site into Lake Ontario is likely to be small based on the estimated groundwater velocity and influence of site infrastructure (Wardrop, 1998); therefore, any COPCs in groundwater that reach the lake are subject to considerable dilution before they can migrate with surface water to a point of water intake for human consumption. The atmospheric release of tritium from the PNGS has an influence on tritium concentrations in groundwater on and off-site. On-site groundwater is not considered potable. Off-site drinking water wells are influenced by the atmospheric tritium plume and this is taken into account in the public dose calculations as part of the annual REMP.

Non-radiological COPCs were not assessed in soil, since there are no complete human exposure pathways for site soil. Additionally, human exposure to COPCs from off-site soil is unlikely, since the results of the air screening presented in Section 3.1.2.1 show acceptable concentrations for air COPCs that could deposit on soil.

The radionuclides selected for use in Derived Release Limit (DRL) calculations were considered appropriate for assessment in the HHRA. The limiting radionuclides (i.e., the radionuclide with the most restrictive DRL) for particulates in air and for gross beta/gamma in water were used to represent all radionuclides in each grouping. Although the 2011 DRLs (OPG, 2011a,b) indicate that P-32 is the limiting gross beta/gamma radionuclide in water, annual human doses for the 2007 to 2011 REMPs used Cs-137 to represent gross beta/gamma radionuclides in water based on Cs-137 being the limiting gross beta/gamma radionuclide in water in previous DRL calculations. The 2011 DRLs were not implemented into the PNGS licence until 2013. Using Cs-137 to represent 2007 to 2011 doses is considered appropriate since site-specific data exists for fish and sediment and the 2011 DRL for Cs-137 is only marginally higher than the DRL for P-32, based on the Sport Fisher. A separate assessment using P-32 as the limiting gross beta/gamma radionuclide in water has been performed and the results included in the ERA report. In soil, Cs-134, Cs-137, and Co-60 were included as COPCs, based on available measured data and in order to address potential concern about deposition of particulate activity.

All noise levels at the PNGS are compliant with relevant noise standards. Therefore, no physical stressors related to human health were carried forward in the HHRA.

Results of HHRA

Non-radiological HHRA

The complete exposure pathways that were assessed in the non-radiological HHRA included:

- Inhalation (hydrazine) for all six human receptor groups;
- Water ingestion (hydrazine and morpholine) for the Urban Resident, Correctional Institution, and Industrial/Commercial Worker; and
- Fish ingestion (hydrazine and morpholine) for the Sport Fisher.

Potential risks to human receptors were characterized quantitatively in terms of Hazard Quotients (HQs) for non-carcinogens (morpholine) and Incremental Lifetime Cancer Risks (ILCRs) for potential carcinogens (hydrazine).

No risks to the urban resident, commercial/industrial worker, and correctional institution are expected due to exposure to morpholine in drinking water - all HQs were less than the target of 0.2.

Exposure to hydrazine for the urban resident, correctional institution, and industrial/commercial worker through water ingestion (Ajax WSP) is above the cancer risk target (ILCR) of 10^{-6}. Maximum hydrazine concentrations are based on measured data from 2007 to 2011 at the effluent discharge point into the CCW discharge channel. However, all lake water samples collected from both the PNGS A and PNGS B discharge channels show hydrazine concentrations less than the Method Detection Limit (MDL) of 0.005 mg/L, indicating that rapid mixing occurs. Using the measured lake water concentration (<0.005 mg/L and applying a dilution factor of 8 to the Ajax WSP) as a more realistic mean concentration, the risk to the urban resident and correctional institution still exceeds the 10^{-6} cancer risk target; however, the risk is only slightly above Health Canada's target cancer risk of 10^{-5}. A range of cancer risk between 1 in 10,000 and 1 in 1,000,000 is generally considered acceptable (Health Canada, 2004). As all lake water samples for hydrazine were below the detection limit of 0.005 mg/L, the lake water concentration is likely even lower; therefore, the risk estimated is conservative.

With respect to the sport fisher, risks from morpholine through fish ingestion are below the target of 0.2 for non-cancer risk, indicating that no increased risk from fish ingestion is expected. Exposure to hydrazine for the sport fisher through fish ingestion is above the cancer risk target of 10^{-6}. However, hydrazine is expected to degrade quickly in the environment. At a pH of 8 (representative of the typical pH observed in Lake Ontario near the PNGS), the chemical half-life of hydrazine ranges from 0.6 to 1.31 days (EC/HC, 2011). Therefore, it is uncertain if hydrazine would be available for uptake by fish at the concentrations used in the calculations. The risk estimated is conservative.

The estimated range in risk to the urban resident and the commercial/industrial worker from inhalation of hydrazine is above the cancer risk target (ILCR) of 10^{-6}. These risk estimates are likely very conservative. In the Pickering B EA, SENES (2007d) estimated the risk due to hydrazine inhalation at the Bay Ridges Neighbourhood and Liverpool Road Subdivision. These receptors are part of the collective "Urban Resident". The risk estimates were below the cancer risk target of 10^{-6}.

Although the hydrazine emission rates used were comparable to the emission rates used in the 2007 EA, the differences in the results are likely due to model differences. In SENES (2007d), the air concentrations at the Bay Ridges Neighbourhood and Liverpool Road Subdivision were estimated using AERMOD. For the current risk assessment, dispersion factors were determined from dispersion modelling in IMPACT based on release rates and meteorological data, consistent with those dispersion factors used in the annual public

radiological dose calculations. At distances greater than 1 km, there is a two-fold uncertainty around the predictions of the sector-averaged Gaussian model used in IMPACT (Hart, 2008). At all distances, the Gaussian air model in IMPACT on average, overpredicts air concentrations by approximately a factor of 1.5 (Hart, 2008); however, modeled air concentrations from IMPACT are still considered appropriate as a conservative estimate. Air concentrations from AERMOD may be more representative of true air concentrations. Overall, the hydrazine inhalation risks to the urban resident and the industrial/commercial worker presented in this risk assessment are considered conservative. The mean risk estimates presented exceed the cancer risk target of 10^{-6} by a factor of 2, but are consistent with the 10^{-6} target considering the uncertainty in the IMPACT model. Therefore, risks at these receptor locations, and at receptor locations farther away from the site, due to inhalation of hydrazine are considered acceptable.

Radiological HHRA

For exposure of human receptors to radiological COPCs, the relevant exposure pathways and human receptors (critical groups) were those presented in the annual OPG REMP reports. Radiological dose calculations followed the methodology outlined in CSA N288.1-08. Table ES-1 presents a summary of the maximum dose to the critical group from 2007 to 2011. The annual dose during this five year period ranged from 0.9 to 4.1 µSv and the critical group was either the industrial/commercial worker (adult) or the urban resident (adult/10 year old). The dominant pathways and radionuclides that contribute significantly to the total dose are inhalation of HTO and external exposure to noble gases.

Over the five year period (2007-2011), the public dose estimates for the critical group (industrial/commercial worker or the urban resident) are between 0.1 and 0.4% of the regulatory public dose limit of 1 mSv/year and approximately 0.1% of the Canadian background radiation. Since the critical groups receive the highest dose from the PNGS, the demonstration that they are protected implies that other receptor groups near the PNGS are also protected.

Facility releases are considered to be adequately controlled, and further optimization of PNGS operations is not required. Nevertheless, the ALARA principle is applied at PNGS to reduce emissions as much as is reasonably possible.

Since the dose estimates are a small fraction of the regulatory public dose limit and natural background exposure, no discernable health effects are anticipated due to exposure of potential groups to radioactive releases from the PNGS.

Table ES-1: Summary of Annual Dose to Critical Group from 2007 to 2011

Year	Critical Group	Effective Dose (µSv)	Percentage of Regulatory Limit (%)	Percentage of Canadian Background Radiation (%)
2007	Industrial/Commercial (adult)	2.6	0.3	0.1
2008	Industrial/Commercial (adult)	4.1	0.4	0.3
2009	Industrial/Commercial (adult)	1.8	0.2	0.1
2010	Urban Resident (adult)	1.0	0.1	0.1
2011	Urban Resident (adult, 10 yr old child)	0.9	0.1	0.1

Ecological Risk Assessment (EcoRA)

Valued Ecosystem Components

Representative organisms or VECs were selected for dose and risk analysis because they are known to exist on the site, and are representative of major taxonomic groups or have a special importance or value. From the list of VECs, a focused group of organisms were chosen, referred to as indicator species, as shown in Table ES-2. These indicator species were characterized in a generic and conservative manner to collectively represent exposure to the main stressors from facility operations. Protection of indicator species implies other species are also protected. Indicator species from the 2000 (SENES 2000) and 2007 (SENES 2007a) ERAs, along with their rationale, were reviewed and assessed based on the criteria listed in Table 7.1 of CSA N288.6 (2012), to arrive at appropriate species for this assessment. The indicator species used are summarized in the table below.

Table ES-2: Summary of Indicator Species Assessed for the EcoRA

Class	Indicator Species
Fish	Alewife
	Smallmouth Bass
	Northern Pike
	Brown Bullhead
	Round Whitefish
	White Sucker
	Lake Trout
	Walleye
	American Eel
Aquatic Plants	Narrow-leaved cattail

Class	Indicator Species
Aquatic Invertebrates	Benthic Invertebrates
Amphibians and Reptiles	Northern Leopard Frog
	Midland Painted Turtle
Aquatic Birds	Trumpeter Swan
	Ring-Billed Gull
	Common tern
	Bufflehead
Aquatic Mammals	Muskrat
Terrestrial Plants	Chokecherry
	New England aster
	Eastern hemlock
	Red ash
	Sandbar willow
Terrestrial Invertebrates	Earthworms
Terrestrial Birds	Red-winged blackbird
	Red-tailed hawk
Terrestrial Mammals	Red Fox
	Meadow Vole

Screening of COPCs for Ecological Assessment

For the majority of COPCs the air pathway is a minor exposure pathway relative to soil and food ingestion exposure for ecological receptors. However, for gases that do not partition to soil, such as NO_x and SO_x, air concentrations dominate the exposure pathway to terrestrial biota. Additionally, hydrazine and morpholine in air do not partition well to soil. Estimated property line concentrations for NO_x and SO_x from 2007 to 2011 were below relevant air quality standards and are not likely to have potential effects on ecological receptors located at the property line. The closest area within the PN site with significant ecological populations is Alex Robertson Park. Property line concentrations of NO_x and SO_x would be protective of any ecological receptors at Alex Robertson Park, since the property line dispersion factor for the air CofA is based on worst case meteorological conditions. Since Alex Robertson Park is not located downwind of the predominant wind direction, the air concentrations at the park are expected to be less than the maximum property line concentrations. Property line concentrations for hydrazine and morpholine

were below relevant no effect levels for terrestrial biota, since no air quality standards are available for these chemicals.

The surface water screening is based on measurements of non-radiological COPCs discharged from 2007 to 2011 into the CCW discharge channel, as well as lake water measurements collected in 2006. Based on the EcoRA screening of measured values against water quality guidelines and background lake water concentrations, hydrazine, morpholine, total residual chlorine (TRC), cadmium, and copper were carried forward for further quantitative assessment in the EcoRA.

Surface water monitoring in ditches at the East Landfill was performed in 2008, 2010, and in 2012, and is no longer required as part of OPG's Perpetual Care Program. Based on sulphate concentrations in the ditches exceeding the BC MOE water quality guideline, sulphate was carried forward for further assessment in the EcoRA, in order to confirm the conclusion that the East Landfill does not pose a potential concern to the environment.

The most recent on-site soil monitoring data are from 1999. Based on the screening conducted for soil against MOE or CCME soil quality guidelines, and background concentrations where guidelines were lacking, arsenic, cadmium, copper, lead, strontium, thallium, and zinc were carried forward for further quantitative assessment in the EcoRA.

Ecological exposure to COPCs from on-site groundwater was not evaluated since there are no complete exposure pathways for ecological receptors to site groundwater. The ecological receptors that are most likely to be exposed to COPCs migrating with groundwater are those that reside in zones of groundwater discharge in Lake Ontario. The risks to ecological receptors in the groundwater discharge zone are primarily from tritium, and are considered to be low as long as levels in the groundwater and the point of discharge in the shoreline remain below $3x10^6$ Bq/L (EcoMetrix, 2012). Based on groundwater data from 2008 to 2012, tritium concentrations in the zones of groundwater discharge in Lake Ontario are well below $3x10^6$ Bq/L.

The radionuclides considered for use in Derived Release Limit (DRL) calculations were also considered for possible assessment in the EcoRA. The limiting radionuclides (i.e., the radionuclide with the highest dose per unit release) for particulates in air and for gross beta/gamma in water were used to represent all radionuclides in each grouping. Different from the HHRA, Co-60 was selected to represent gross beta/gamma emissions in water, since Co-60 is the limiting radionuclide among beta/gamma emitters for aquatic biota, and therefore provides a conservative estimate of radiological dose (see Appendix C). In soil, Cs-134, Cs-137, and Co-60 were included as COPCs, based on available measured data. Noble gases (predominantly Ar-41) were also included as COPCs for the EcoRA because they are the main contributors to air immersion dose.

Thermal stressors and entrainment and impingement were carried forward for assessment in the EcoRA since they are widely recognized as being of primary concern in nuclear power plants, as recommended by CSA N288.6-12. Other physical stressors such as noise, wildlife strikes with vehicles, bird/bat strikes on buildings, shoreline alteration and lake filling, terrestrial landscape alteration and land use, and sedimentation screened out and were not carried forward for further assessment in the EcoRA.

Results of the EcoRA

Non-radiological EcoRA

The potential for ecological effects was assessed by comparing exposure levels to toxicological benchmarks, and characterized quantitatively in terms of Hazard Quotients (HQs). A HQ greater than 1 indicates a need to more closely assess the risk to the concerned VEC.

Outfall

Maximum concentrations near the outfall exceed the benchmark for cadmium for benthic invertebrates, the benchmarks for TRC for fishes and invertebrates, and the benchmarks for hydrazine for fishes and invertebrates. The maximum hydrazine concentration at the outfall exceeds the benchmark for both fish and benthic invertebrates, and the mean hydrazine concentration at the outfall exceeds the benchmark for benthic invertebrates. The maximum cadmium concentration estimated at the outfall is 0.9 µg/L, which is only slightly higher than the hardness-adjusted lowest chronic value (LCV). Since the average outfall concentration is below the benchmark, impairment of the invertebrate community due to cadmium is unlikely.

The maximum morpholine, hydrazine and TRC concentrations are based on the maximum values reported in OPG's CofA monitoring reports at the point of discharge. Lake water samples taken close to the point of discharge are much lower, indicating that rapid mixing occurs in the lake. It is not expected that concentrations of morpholine, hydrazine and TRC in the effluent will remain at these high levels for chronic exposure durations. Mean measured concentrations are more representative of chronic exposure levels since biota are unlikely to reside in the discharge pipes and effluent concentrations are not expected to remain at elevated levels for chronic exposure.

There are no exceedances of TRC benchmarks based on the mean concentrations; hence, effects are not expected. The mean measured concentration of hydrazine based on lake water measurements result in a HQ of less than 1 for fish, and a HQ of 1.2 for benthic invertebrates. Effects on fish are not expected. Although the HQ for benthic invertebrates is greater than one, this exceedance is minimal, and effects are not likely to be significant.

Overall, the risk to fish at the outfall is low, and fish are not expected to experience any adverse effects due to the liquid effluents from PNGS operations.

Frenchman's Bay

Predicted maximum concentrations of hydrazine at Frenchman's Bay exceed benchmarks for aquatic plants and invertebrates, while predicted average concentrations exceed aquatic plant benchmarks. Maximum concentrations exceed TRC benchmarks for all aquatic biota, and the cadmium benchmark for benthic invertebrates. Hydrazine was not an issue in the 2000 ERA because the aquatic plant benchmark was higher (0.4 mg/L, based on a 48-hour EC_{50} for green algae). The benchmark used for this assessment is an algal EC_{50} from the data set used to derive the Federal Water Quality Guideline (a 72-hour EC_{50} of 0.012 mg/L for algal growth). The exceedances of this benchmark suggest that the concentration of hydrazine may occasionally inhibit the growth of aquatic plants at Frenchman's Bay. Effects of hydrazine on benthic invertebrate communities were not assessed in the 2000 ERA. It is unlikely that effects will be significant for aquatic plant communities in Frenchman's Bay, because the dilution factor estimates exposure at the mouth of the Bay, whereas the wetlands are at the north end of the Bay and the benchmarks are only slightly exceeded at the mouth. Additionally, the maximum hydrazine concentration at Frenchman's Bay was estimated from the maximum effluent measurement at the outfall; therefore, the concentration used is very conservative. There were no toxicity data for hydrazine for birds, as discussed in Section 4.3.1. Hydrazine is not expected to be of concern for birds due to the low risk of food chain bioaccumulation.

The maximum cadmium concentration estimated at Frenchman's Bay of 0.3 µg/L, is less than the hardness-adjusted LCV for benthic invertebrates (Chapman et al (ND) summarized in US EPA, 2001). Therefore, minimal potential effects are expected for the reproduction of benthic invertebrates at Frenchman's Bay due to cadmium concentrations. The maximum chlorine concentration at Frenchman's Bay is estimated from a CofA maximum, whereas an estimate based on the mean concentration in effluent is more representative of chronic exposure at the Bay. Since the latter concentration does not exceed the TRC benchmark, no effects on aquatic receptors due to TRC in Frenchman's Bay are expected.

Pickering Site

The HQ target of 1 was exceeded for copper for the meadow vole for copper, lead and zinc for the red-winged blackbird; and for lead and zinc for red-tailed hawk, when exposure to maximum concentrations was assumed. However, these receptors, with the exception of the meadow vole, are mobile and are unlikely to be exposed to the maximum concentrations for the entire year. There are no exceedances for mammals or birds exposed to average concentrations in soil, therefore adverse effects are not expected. The higher HQ value for copper for the meadow vole is driven by maximum concentrations in terrestrial plants. The maximum copper concentration in the plant is localized to one

sampling location (see paragraph below). Therefore any effects on the meadow vole due to copper intake are limited to one area.

Copper, lead, and zinc maximum exposure concentrations exceed benchmark values for earthworms. Lead and thallium were not assessed as COPCs for soil in the 2000 ERA (SENES 2000), but copper and zinc exceed benchmarks for earthworms. In the current assessment, maximum concentrations of arsenic, cadmium, copper, lead, thallium and zinc exceed benchmark values for terrestrial plants. In the 2000 ERA, copper and zinc exceed benchmarks, whereas arsenic, cadmium lead, and thallium were not assessed. The potential effects on plants due to exposure to arsenic, cadmium, copper, lead and zinc are expected to be limited to certain areas at the PN site, as the toxicological benchmarks for these COPCs were exceeded at only 2 of 39 sampling locations at the PN site.

The thallium benchmarks for terrestrial plants was exceeded at five sampling locations. Thallium is adsorbed into plants by their roots and highest concentrations occur at the seedling stage. Effects on plants through root uptake include discoloration, necroses and litterfall (CCME, 1999b). At the five locations with high thallium concentrations, terrestrial plants may potentially experience slightly retarded root growth and reduced plant height. However based on the limited extent of these elevated thallium concentrations, detrimental effects on terrestrial plant communities at the site are not expected.

There were no data to determine strontium benchmarks for terrestrial plants and birds. Strontium competes with calcium but it does not have a toxic effect on bone in chicks. A study (cited in Skoryna, 1981) found that there were no deleterious effects on chicks until very high doses were given. This dose is reported to be much higher than the benchmark value used to assess strontium effects on mammals. If the benchmark values for birds were set the same as mammals, which could be interpreted as a NOAEL, there would be no exceedances. Since no data were available for terrestrial plants, there are uncertainties associated with the effects assessment, but it is unlikely that there would be adverse effects on these receptors due to strontium.

East Landfill

The maximum sulphate concentration observed in Ditch 6 in the East Landfill was 328 mg/L, which exceeds the benchmark of 100 mg/L from the BC MOE. However, in April 2013 the BC MOE published an update to the sulphate water quality guideline based on a number of toxicity studies linking sulphate toxicity to water hardness. The revised BC guideline states that if natural hardness is greater than 250 mg/L site-specific toxicity testing on several species should be conducted, since the combination of high water hardness and sulphate levels may cause osmotic stress on the organism, likely related to high levels of TDS. The highest hardness level observed on site was 752 mg/L in 2010 from Ditch 6, with a sulphate concentration of 328 mg/L. Although there is uncertainty in the sulphate benchmark at hardness levels above 250 mg/L, the observed sulphate concentration in

Ditch 6 is well below the LC_{20} for trout of 857 mg/L at a hardness of 250 mg/L (BC MOE, 2013) as well as the LC_{25} for *C. dubia* of 425 mg/L at a hardness of 320 mg/L (Elphick et al., 2011). The maximum sulphate in Ditch 6 is below these effect levels as well as below the sulphate guideline at the maximum hardness. Based on these observations, sulphate levels in Ditch 6 are not likely of concern.

Although high hardness can be an indicator for high TDS, there are no TDS data for the ditches from the east landfill; therefore, there is uncertainty surrounding potential toxicity effects from TDS in that area.

Radiological EcoRA

Radiation dose benchmarks of 400 µGy/h (9.6 mGy/d) and 100 µGy/h (2.4 mGy/d) (UNSCEAR, 2008) were selected for the assessment of effects on aquatic biota and terrestrial biota, respectively, as recommended in the CSA N288.6-12 standard (CSA 2012).

Outfall

There were no exceedances of the 9.6 mGy/d radiation dose benchmark for the fish at the PNGS outfall location.

Frenchman's Bay

There were no exceedances of the aquatic radiation dose benchmark (9.6 mGy/d) for any aquatic receptors at Frenchman's Bay.

Pickering Site

The total radiological dose benchmark of 2.4 mGy/d was exceeded for the earthworm and red-winged blackbird based on the maximum tritium concentration in site soil. The area where such high exposure occurs is localized and close to the reactor buildings, and therefore earthworm populations on the site as a whole are not expected to be affected. The exceedance for the blackbird is driven by the ingestion of maximally exposed earthworms. Since the blackbird is mobile and unlikely to be exposed to maximum concentrations, the mean dose is more representative of the red-winged blackbird, and does not exceed the dose benchmark.

Thermal Effects

Cooper (2013) evaluated lake temperatures in the vicinity of the Pickering B discharge using 2011-2012 data provided by OPG from thermal dataloggers placed on the substrate. Temperature results at locations in the thermal plume and in reference areas (Thickson Point and Bonnie Brae Point) were compared to thermal criteria for 15 fish species and HQ

values were calculated for relevant time periods for each species at each location. Thermal criteria relevant to spawning and embryo-larval periods, and juvenile and adult stages were presented for weekly and daily averaging periods (MWAT and STDM criteria).

An HQ above 1 is indicative of potential adverse effects from the thermal plume. HQs were presented for the highest temperature location in the plume area, and in the reference area. For fish spawning and embryo-larval development, the highest HQs were marginally above 1 in the plume, but usually very similar in the reference. Round whitefish is the only species for which HQ was higher in the plume for all life stages. It is also the species with the highest HQ in each life stage category, but the highest HQ (for spawning) is only 2.83 as compared to 2.0 in the reference area.

Cooper (2013) addressed round whitefish further by calculating ΔT for the lake station nearest the Pickering B discharge, during the January to April period of embryo-larval development, and compared this value to a ΔT benchmark for round whitefish embryo-larval development. The ΔT was calculated relative to an ambient value representing the average of weekly averages at all Bonnie Brae and Thickson Point stations. The ΔT at station P1 near the discharge never exceeded a conservative benchmark of 3^{o}C.

Based on the MWAT, STDM and ΔT results relevant to fish spawning and embryo-larval development, Cooper (2013) concluded that there is no evidence of adverse impacts on fish caused by the thermal plume.

For fish growth (juvenile and adult), the highest HQs were marginally above 1 in the plume for lake trout, rainbow trout, white sucker and threespine stickleback, but were less than or equal to reference values for all these species. Therefore, it is unlikely that there are any effects arising from the thermal plume in the lake for juvenile or adult stages of any fish species.

Entrainment and Impingement

In October 2008, OPG was ordered by the CNSC to reduce fish impingement at the Pickering station by 80%, relative to the baseline, and to reduce fish entrainment by 60%. In order to reduce impingement, OPG installed a barrier net in October 2009. Entrainment cannot be practically reduced, but equivalent ecological benefit was realized by undertaking fish stocking and coastal wetland habitat enhancement programs (OPG, 2012e).

Biomass reduction calculated from fish abundance surveys both inside and outside the FDS indicate that impingement was reduced by 88 and 85% in 2010 and 2011. These reductions in impinged biomass are considered to meet or exceed the 80% reduction target.

The FDS only reduces the impingement component of fish losses at the Pickering cooling water intake. The entrainment losses will be similar to those reported prior to FDS

installation. The impact of entrainment losses, in terms of production foregone, is an order of magnitude less than the impact of impingement losses.

The combined losses after FDS installation have not been calculated in terms of adult equivalents or production foregone. However, combined losses prior to the FDS installation, considering adult equivalents and production foregone, were found to be very small relative to commercial and recreational harvests (Golder, 2007g; SENES, 2008). Losses that were of little ecological consequence before the FDS will be smaller and even less consequential now that the FDS is in operation.

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1.0 INTRODUCTION

1.1 Background

The *Nuclear Safety and Control Act* (NSCA) mandates the Canadian Nuclear Safety Commission (CNSC) to regulate the nuclear industry in a manner that prevents unreasonable risk to the environment and makes adequate provision for environmental protection, in conformity with international obligations. This mandate is reflected in the General Nuclear Safety and Control Regulations under the NSCA, and in the CNSC (2001) Regulatory Policy on Protection of the Environment. This policy indicates that licence applicants will be required to "demonstrate through performance assessments, monitoring, or other evidence, that their provisions to protect the environment are adequate".

The Canadian Standards Association (CSA) has recently completed its N288.6 standard on environmental risk assessment (ERA) for Class I nuclear facilities (CSA, 2012). The standard calls for both ecological risk assessment (EcoRA) and human health risk assessment (HHRA), for both radiological and non-radiological contaminants and physical stressors. The CSA has recently completed its N288.4 (2010) and N288.5 (2011) standards on environmental monitoring programs (EMP) and effluent monitoring programs. These standards recommend that effluent and environmental programs are designed, in part, to address risk issues identified by ERA. These programs can also inform the ERA by providing information on effluent concentrations and loadings, and by providing environmental data to assist in model calibration and validation.

A multi-tiered EcoRA was performed from 1999 to 2002 (SENES, 1999; 2000; 2001; 2002) to assess the overall ecological effect of operations at the Pickering Nuclear (PN) site and to support regulatory compliance. In the first phase an issue-based Environmental Review was completed and submitted to the CNSC (then the Atomic Energy Control Board). The CNSC recommended that a desktop EcoRA be performed to identify any effects the Pickering Nuclear Generating Station (PNGS) has on the valued ecosystem components (VECs). SENES then completed a multi-tiered risk assessment in response to CNSC recommendations. Although the focus of the risk assessment was on ecological receptors, some human receptors were evaluated as well. In 2007 to support the Pickering B Refurbishment and Continued Operations Environmental Assessment the ecological risk assessment was updated and a human health assessment was performed (SENES, 2007a, 2007b).

This ERA document provides an integrated EcoRA and HHRA that follows the recently published CSA N288.6-12 guidance, and provides an update to the existing ERA using recent monitoring data from the five-year period 2007 to 2011. This risk assessment is not a probabilistic risk assessment (PRA). A PRA is not required by the CSA N288.6-12 standard. Therefore, uncertainty discussions presented in this risk assessment are qualitative and semi-quantitative.

1.2 Goals, Objectives and Scope

The overall goals of this ERA are:

- To update the ERA in general accordance with the CSA N288.6-12 Standard.
- To provide focus for the environmental monitoring program on relevant contaminants of potential concern (COPCs), media, and ecological and human receptors.

The specific objectives of this ERA, consistent with CSA N288.6-12 are:

- To evaluate the risk to relevant human and ecological receptors resulting from exposure to contaminants and stressors related to the PN site and its activities.
- To recommend potential further monitoring or assessment as needed based on the results of the ERA.

The scope of the ERA encompasses normal operations at PNGS during the operations phase of the facility. It does not include decommissioning and does not address acute or high-level exposures resulting from accidents. The scope looks at the potential effects of releases from the facility on the human and ecological environment, as well as physical stressors.

Spatial boundaries define the geographical extent(s) over which likely or potential environmental effects will be considered. The spatial scale for humans includes identified human receptors (potential critical groups) within 20 km of the PN site, which is part of the local study area (LSA) and part of the regional study area (RSA). Consistent with the 2007 Pickering B Refurbishment for Continued Operation Environmental Assessment (EA), the LSA is composed of an area which lies outside of the site study area (SSA) and extends approximately 10 km from PNGS. It is defined as an area which includes lands within the city of Pickering, the town of Ajax, and the eastern part of the City of Toronto (Scarborough). This study area also includes a portion of Lake Ontario abutting the property and used by those communities for activities such as recreation and community water supply and waste water discharge. The RSA extends beyond the LSA and extends approximately 20 km, to the Darlington Nuclear Generating Station in the east (i.e., the eastern boundary of the Region of Durham), to the eastern part of the City of Toronto (Scarborough) in the west, and including the municipalities in the Regional Municipality of Durham north of the PNGS site.

The spatial scale for ecological receptors includes receptors on-site and within the immediate site boundary (SSA) and the near-field receiving waters. Consistent with the 2007 Pickering B Refurbishment for Continued Operation EA, the SSA includes the facilities, buildings and infrastructure at the PNGS facility and the area within the 914 metre exclusion zone for the site which encompasses both land surface and part of the Lake Ontario water surface.

1.3 Quality Assurance and Quality Control

The ERA makes extensive use of environmental monitoring data. These data are derived from chemical and radiochemical analyses of samples collected from effluent streams and environmental media around the PN site. The samples are collected by Ontario Power Generation (OPG) staff and analyzed by qualified performing laboratories under the EMP, such as the Health Physics Laboratory. The Radiological Environmental Monitoring Program (REMP) has its own quality assurance (QA) program that encompasses activities such as sample collection, laboratory analysis, laboratory quality control, and external laboratory comparison (OPG, 2007).

Throughout the planning and preparation of the ERA, EcoMetrix staff worked under the EcoMetrix Quality Management System which is ISO 9001:2008 certified by NSF International (EcoMetrix, 2013). All work was internally reviewed and verified prior to submission to OPG. Reviews included verification of data and calculations, as well as review of report content. OPG comments have been dispositioned by EcoMetrix and addressed as appropriate by report revisions. The review process has been documented through a paper trail of review comments and dispositions.

1.4 Organization of Report

The main sections of the ERA report, generally consistent with the suggested table of contents in CSA N288.6 (2012), are as follows:

- Section 2.0: Site Description
- Section 3.0: Human Health Risk Assessment
- Section 4.0: Ecological Risk Assessment
- Section 5.0: Conclusions and Recommendations
- Section 6.0: References

2.0 SITE DESCRIPTION

2.1 Engineered Site Facilities

An overview of each facility/operation and its releases is described in this section. Quantitative releases from the facilities/operations in both liquid and gaseous effluent are discussed in the Problem Formulation in Section 3.1.2 and Appendix A.

2.1.1 Site Overview

The PN site comprises approximately 240 hectares and accommodates two CANDU generating stations, PNGS-A and PNGS-B. Units 1 to 4 are located on the PNGS-A side, with Units 2 and 3 being permanently shut down, and Units 5 to 8 are on the PNGS-B side. Power from the generating stations is delivered to the southern Ontario electrical grid. An overview of the facilities on the PN site is presented in Figure 2.1.

Report

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Title: PICKERING B SAFETY REPORT - PART 1

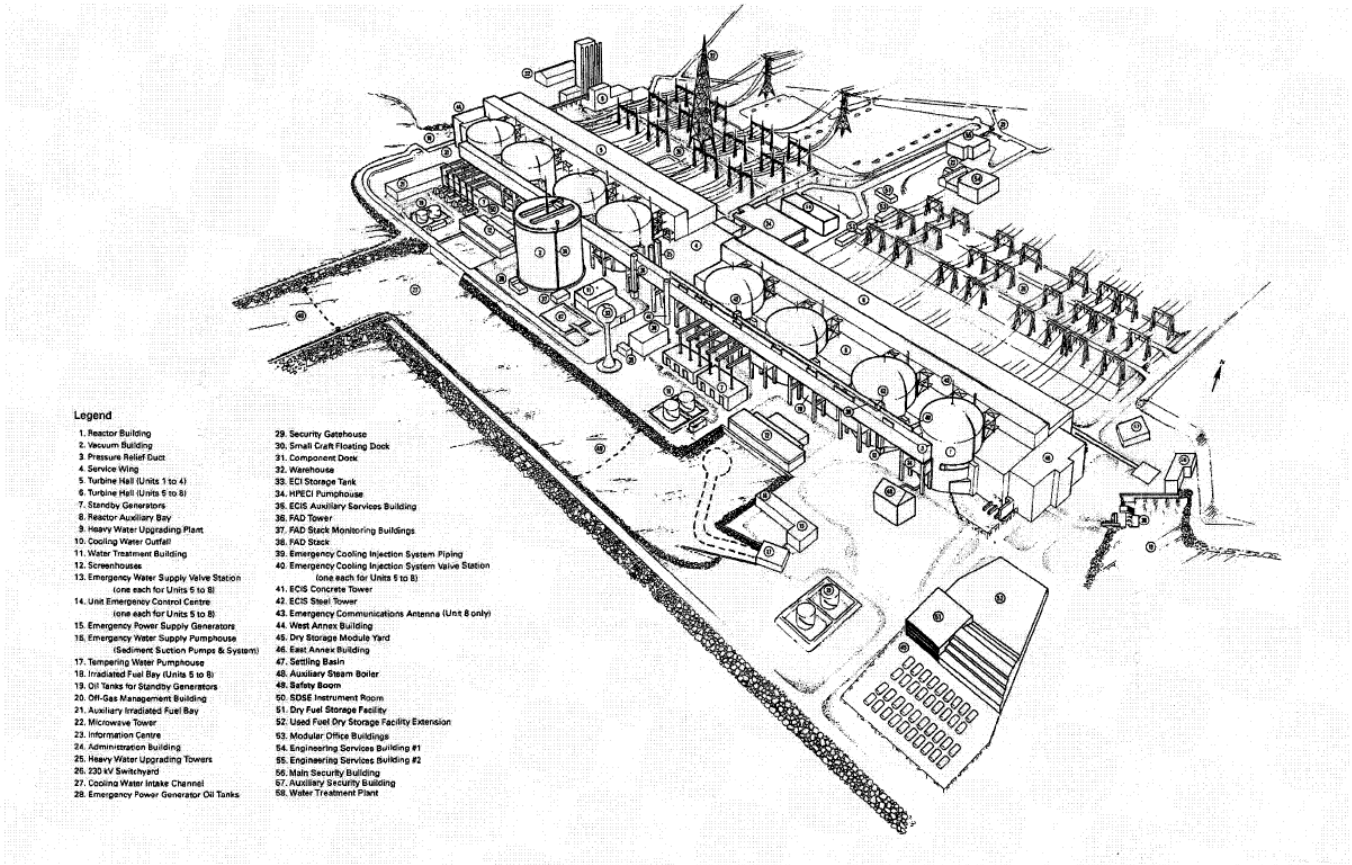

Figure 1-2: Pickering Generating Station

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Figure 2.1: Pickering Generating Station (OPG, 2009a)

PNGS-A and PNGS-B share the overall PN site as well as many services and facilities.

The principal PN buildings and a brief discussion of their purpose are described below:

- Reactor buildings – these buildings contain the reactors, control mechanisms, fuelling machines, heat transport system, steam generators, and auxiliary equipment. To the south of each reactor is an emergency control center located under the pressure relief duct.
    - The heat transport system circulates pressurized heavy water through the reactor fuel channels to remove the heat produced from nuclear fission. This heat is then transferred to light water in the steam generators. The chemistry of the coolant heavy water is controlled through filtering, ion exchange, and chemical addition (see Table 2.1).
    - Twelve steam generators per reactor transfer heat from the heavy water to light water. Steam flows through the main steam piping to the turbines in the powerhouse. The concentration of dissolved solids in the light water is controlled by boiler blowdown.
    - When make-up water is required in the steam and feedwater system it is supplied from the demineralized water storage tanks from the New Water Treatment Plant. Feedwater pH and oxygen concentrations are controlled by hydrazine and morpholine addition.
    - Each unit has a turbine/generator set with auxiliary systems. Pipes transport steam from the boilers to the turbine and have steam reject valves. The reject valves discharge steam to the atmosphere when the turbine is unavailable to accept steam.
    - Each unit has a low-pressure service water system that is supplied by pumps from the powerhouse. Water within the low-pressure service water system is treated by chlorination to protect against zebra mussel infestation.
- Reactor auxiliary bay – these buildings cover the full length of Units 1 through 4 and Units 5 through 8. These buildings house auxiliary systems and the irradiated fuel bays. Used fuel initially stored in the irradiated fuel bays for ten years to allow for cooling, are transferred to dry storage containers for processing and dry storage at the Pickering Waste Management Facility (PWMF). Ventilation and filtration are implemented in the irradiated fuel bays to remove fission products should the fuel be inadvertently damaged during handling. Filters, ion exchange columns, and heat exchangers are used to maintain optical clarity and remove radionuclides from the water. Makeup water is provided from the demineralized water system.

- Powerhouse – this building includes the turbine hall and turbine auxiliary bay. Within the turbine hall are the turbines/generators. Also within the powerhouse are the steam and feedwater systems and much of the electrical distribution system.

- Screenhouses – these buildings contain screenhouses and intake ducts for condenser circulating water and service water for the PN units. The screenhouse consists of screens to remove algae, fish, and other debris from the water. After the water is used in the condensers the condenser cooling water (CCW) is discharged into covered ducts north of the powerhouse and returned to the lake via the discharge channel. Two CCW pumps per reactor pump water to the condensers.

- Standby and emergency electric generators – standby power is available from independent gas turbine generators. The standby generators are run on No. 2 fuel oil (i.e., distillate oil) that is stored just south of the generators. The fuel oil is stored within dyked areas that would contain the oil in the event of spillage or tank rupture. Separate from the standby generators are seismically qualified emergency power generators that can supply emergency power. Fuel oil for these emergency generators is located to the east of these generators and is stored in storage tanks within a dyked area.

- Containment structures and pressure relief duct – a negative pressure containment envelope is maintained within the PN reactor buildings, the pressure relief duct, and the vacuum building.

- East Annex building – this building is a two story steel frame building used for the storage of new fuel, service equipment, and tooling.

- West Annex building – this building supports fuel channel inspection, environmental qualifications and lay-up support personnel.

- Electrical transmission facilities – each unit generator has one main output transformer and supplies power to the 230 kV electrical grid through the switchyard.

- Emergency water supply pumphouse – this building contains pumps and water supply equipment that can provide emergency water to various PN systems if normal water supply becomes unavailable.

- Sediment suction system pumphouse – this system serves to limit the accumulation of sediment in plant systems. Large pumps from within this pumphouse move the sediment laden water to the PNGS-B outfall. This sediment laden water mixes with the CCW prior to discharge to the lake.

- Oil and chemical storage building – this building provides storage and dispensing facilities for bulk oils and combustible, toxic, corrosive, and reactive chemicals. The building is located between the PNGS-B powerhouse and the switchyard.

- Auxiliary steam boiler – this building provides a backup supply of heating steam for PN.

- Administration, Engineering Services, and Main Security buildings – these buildings are the offices and support services for station staff.

- High pressure emergency coolant injection facilities – the high pressure emergency coolant injection system consists of a 780 m^3 elevated water storage tank, a pumphouse with high pressure pumps, and an auxiliary services building.

- New Water Treatment Plant (NWTP) – the water treatment plant demineralizes lake water prior to use in feedwater and other water systems requiring demineralized water at PN. The water treatment plant uses filters, ultra-violet sterilization, reverse osmosis, and ion-exchange columns with a design flow rate of 66 L/s.

- Neutralization Sump – this is no longer in use. When in use this sump discharges on a daily batch basis. The sump collects liquid waste from the water treatment plant settling pond, sand filters, and regeneration streams of the ion exchange columns. Water is monitored and, if required, neutralized with chemicals prior to discharge to Lake Ontario. The water is filtered to remove suspended solids and discharged west of the West Annex.

- Auxiliary irradiated fuel bay – this facility provides underwater storage for used fuel from PNGS A and for cobalt-60 from PNGS B.

- Heavy water upgrading plant and towers – these facilities purify and upgrade heavy water from the moderator and heat transport systems.

- Pickering Nuclear Information Centre – this building provides information exhibits relating to electricity generation and use with a focus on nuclear power and the environment.

- East Complex – this is an area consisting of several different types of operations. Included in the East Complex are technical and field support offices, warehousing, maintenance garages, machine shops, a chemical storage building, parking areas, material storage, a combustion-turbine unit standby power system, access roads, and drainage ditches. At the east end of the East Complex is the Southeast Inert Fill Area and a wetland. The combustion-turbine standby power system uses fuel oil that is stored on-site in storage tanks within dyked areas.

- Pickering Waste Management Facility – the PWMF is divided into two facilities, the PWMF I, and PWMF II. PWMF I is used for dry storage of used fuel bundles. It has a dry storage container processing building, two storage buildings for the dry storage containers, and an area for dry storage modules. PWMF II is an area of two storage buildings. The dry storage modules are large cylindrical casks of reinforced

concrete with carbon steel inner and outer liners. The dry storage modules also store used reactor components from the PNGS-A reactors, in addition to the used fuel bundles.

2.1.1.1 Site Drainage

The site water balance is presented in Figure 2.2. The water balance includes a number of the water systems across the PN site including the inactive drainage system, active drainage system, domestic sewage system, stormwater system, intake, discharge, and other systems.

On-site drainage consists of inactive drainage, active drainage, sewage system, and stormwater drainage. These drainage systems are briefly discussed below.

- Inactive drainage system – collects drainage from floor drains and utility drains from the turbine hall, turbine auxiliary bay, and foundation drains. Water from these sources is collected in a sump and is pumped to a holding pond where it is sampled as it is discharged to the lake. If necessary, this water is dechlorinated with sodium bisulphite.

- Active drainage system - liquid waste is segregated according to the degree of contamination and is directed to the receiving tanks of the radioactive liquid waste management system. Sources of the active liquid waste include reactor building floor drains, reactor auxiliary bay floor drains, irradiated fuel bay drainage, and spent ion exchange resin slurrying water. The waste can be treated using filters and ion exchange columns. After treatment the waste is sampled and chemically analyzed to ensure it is not toxic and that radioactivity levels are sufficiently low. Radioactivity monitors on the discharge piping automatically stop discharge flow if the detected activity is above prescribed limits.

- Domestic Sewage system – domestic sewage is collected throughout PN and is discharged into the Regional Municipality of Durham sewage mains. Sewage waste is sampled and analyzed on a regular basis for radioactivity (tritium and gross beta).

- Station stormwater drainage - stormwater is discharged directly to Lake Ontario at different locations. The switchyard drainage system directs stormwater to catchment basins and discharges it via the CCW outfall to Lake Ontario.

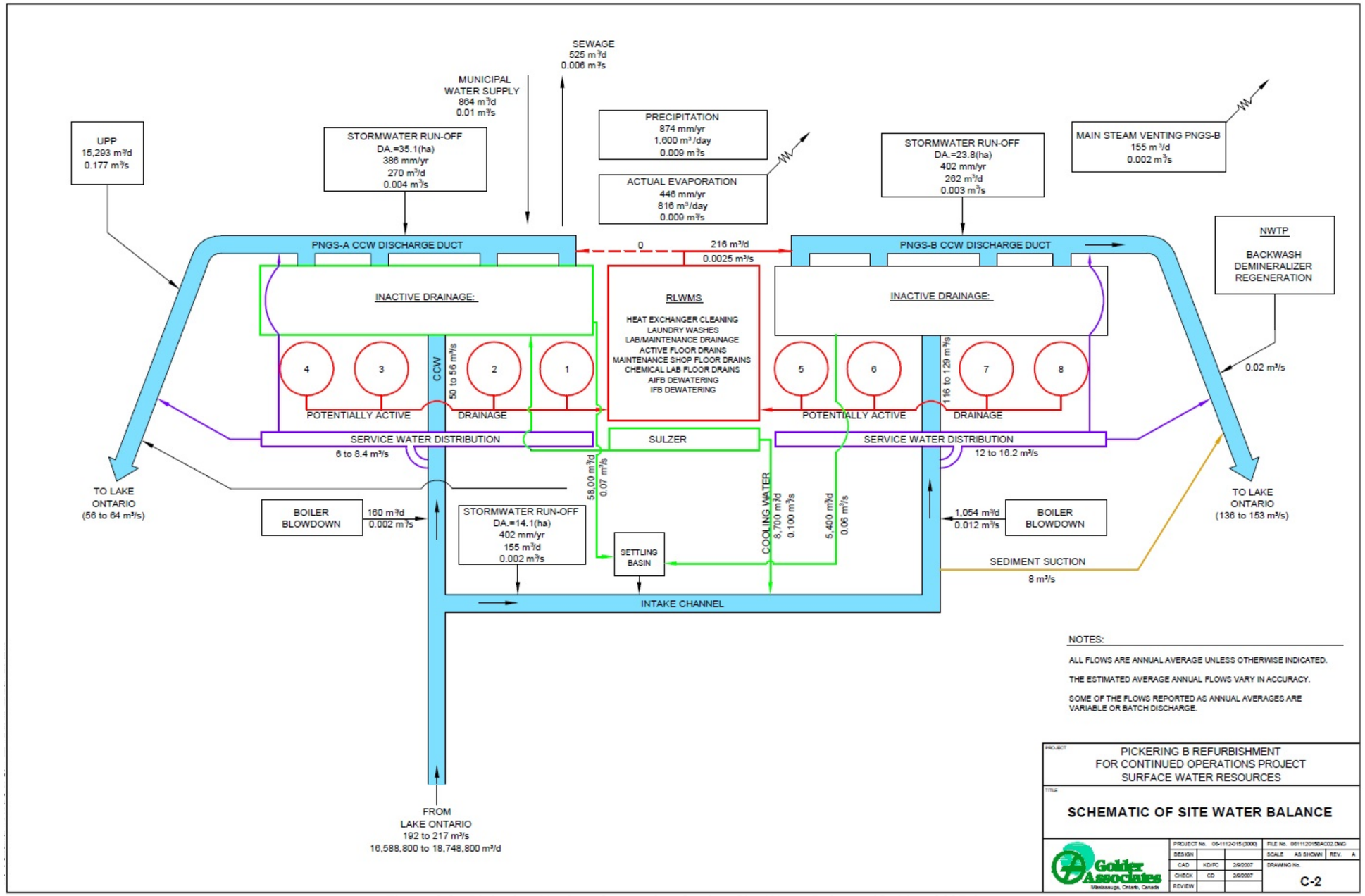


Figure 2.2: Pickering Nuclear Generating Station Site Water Balance (Golder, 2007a)

2.1.1.2 Heating and Ventilation

The heating systems are designed to provide comfort to individuals working in the plant and to maintain equipment. Steam, electricity, and hot water are used for heating and hot water from the domestic water system is used for humidification. Ventilation and air conditioning systems control temperature, moisture, and atmospheric conditions as required for employees and plant equipment. Exhaust from areas that may contain radioactive materials are filtered and monitored prior to discharge.

2.1.2 Materials Management

The PN site has a multitude of systems that are designed to manage both radioactive and non-radioactive materials. The main radioactive material managed at the PN site is heavy water.

The heavy water management system is used to minimize heavy water losses from the heat transport system and moderator system. Pumps and piping systems are preferentially used for storage and transfer. Leakage is diverted to collection systems, and air dryers are used to extract and collect heavy water from the reactor building atmosphere.

Additional heavy water management systems include processes to remove impurities from heavy water using ion exchange, filtration, and oil/water separation. The upgrading process removes light water from the heavy water. In addition, to recover heavy water vapour losses, each reactor building area has vapour recovery circuits designed to dry the atmosphere in areas that are subjected to the leakage of heavy water. Water collected from these systems is sent to the heavy water cleanup and upgrading systems.

A brief summary of the use(s) and the associated management methods for non-radioactive chemicals used across the site are presented in Table 2.1.

Table 2.1: Non-Radioactive Chemical Usage and Disposal

Chemical	Use	Disposal
Boric acid	Reactivity control in the moderator system	Removed by ion exchange in the moderator purification system
Gadolinium nitrate	Reactivity control in the moderator system	Removed by ion exchange in the moderator purification system
Helium gas	A cover gas preventing the ingress of air for the moderator, liquid zone controllers, and the heavy water storage tank.	Periodically purged to reactor building exhaust
Oxygen gas	Added to combine with deuterium gas to maintain pressure	Consumed and emitted with building exhaust

Chemical	Use	Disposal
Hydrogen gas	Added to remove oxygen gas from the heat transport system (HTS) and to cool generators	Consumed in the HTS and vented to the reactor building exhaust. Vented to the atmosphere from the main generators
Hydrazine	Removes oxygen and used for pH control in the emergency coolant injection system, boiler feedwater, condensate feedwater, recirculating cooling water system, and end shield cooling water.	Consumed, but residual may be discharged to the atmosphere or to the lake.
Lithium hydroxide	Controls pH in the HTS, end shield cooling system, and the recirculating cooling water system.	Consumed when pH is corrected.
Ion exchange resins	Used for pH control and removal of impurities in the moderator system, irradiated fuel bay, auxiliary fuel bay, liquid zone control, heat transport system, end shield cooling system, and the recirculating cooling water system.	The resin is temporarily held within spent resin tanks and is placed in interim storage at the Western Waste Management Facility (WWMF) at the Bruce site.
Ion exchange resins (Sulphite)	Removes oxygen gas in the stator cooling water system.	Disposed as waste by licensed contractors based on analysis.
Sulphuric acid	Used in production of demineralized water.	Consumed during usage.
Sodium metabisulphite	Used in production of demineralized water and to de-chlorinate effluent.	Consumed during usage.
Anti-scalant	Used in production of demineralized water.	Consumed during usage.
Sodium hypochlorite	Used in production of demineralized water and zebra mussel control in the low pressure service water.	Consumed during usage in demineralized water production. When applied for zebra mussel control, it is consumed and the residual is discharged to Lake Ontario.
Carbon dioxide gas	Used in the annulus gas system as a carrier gas and in the generators as a purging gas	Vented from the annulus gas system to the reactor building exhaust and vented to the atmosphere from the generators.

Chemical	Use	Disposal
Morpholine	pH and corrosion control in the boiler feedwater and in the condensate feedwater	Partly consumed in its usage and the balance is lost to atmospheric discharge and boiler blowdown
Sulphur hexafluoride	Leak detection in the CCW system.	Released to Lake Ontario in small volumes
Distillate oil (fuel/diesel)	Fuel in the standby generator, emergency power generators, and the auxiliary power system.	Consumed and results in waste gases including CO_2, NO_x, SO_2, etc.
Lubricating oil and seal oil	Lubrication and sealing of the turbine system and the generator system	Reused and removed by licensed contractor.
Insulating oil	Transformer cooling in the main output and service transformers.	Removed by licensed contractor.
Ethylene glycol	Air conditioners in the battery rooms.	The ethylene glycol is removed by licensed contractors.
Reolube Turbo fluid 46	Hydraulic fluid for turbine governor valves in the turbine governors.	Reused or placed into drums for disposal by licensed contractors.

2.1.2.1 Waste Management

Waste produced on-site includes used fuel, radioactive solid waste, radioactive liquid waste, radioactive gaseous waste, and non-radioactive solid, liquid, and gaseous waste.

2.1.2.1.1 Used Fuel

Used fuel bundles are stored in the irradiated fuel bay for at least 10 years and then transferred to dry storage containers for storage in the PWMF.

2.1.2.1.2 Radioactive Solid Waste

Radioactive Solid Wastes include both intermediate and low level wastes. Low Level Waste (LLW) is defined as waste with contact radiation fields of less than 10 mSv/h at 30 cm. LLW is made of maintenance wastes from day-to-day reactor operations including cleaning materials, personal protective equipment, contaminated metal parts, metal sweepings, and miscellaneous items. LLWs are categorized as incinerable, compactable, or as non-processible.

The majority of incinerable LLW is collected in plastic bags, packed into shipping containers and transportation packages, and shipped off-site for incineration at the WWMF at the Bruce site. LLW may be briefly stored at the Service Wing of the Waste Handling Facility prior to shipping off-site.

Compactable LLW, including light gauge metals, welding rods, metal cans, insulation, metallic air filters, air hoses, small cables, and other assorted wastes, is collected in plastic bags and temporarily stored in the solid radioactive waste management area before being shipped to the WWMF where it is compacted and stored.

Non-processible LLW includes lathe turnings and metal filings, heavy gauge metal and components, floor sweepings, glass, and larger electrical cables. This waste is packaged and shipped to the WWMF.

Intermediate Level Waste (ILW) is defined as waste with dose rates greater than 10 mSv/h. Materials categorized as ILW include spent ion exchange resins, disposable filters, and other non-processible radioactive wastes.

The spent ion exchange resins are slurried from the purification systems to spent resin storage tanks. Spent resin is then slurried to a disposable liner and transported in bulk de-watered form to the WWMF on the Bruce site. Low level resin/charcoal generated from the Active Liquid Waste System is transferred into totes and sent to WWMF as well.

After their removal, radioactive disposable filters are placed within shielding flasks and are transferred to the in-station flask lay-down area in the PNGS A Turbine Loading Bay, where they are then placed within the Radioactive Filter Transportation Package and shipped to the off-site WWMF for storage.

Non-processible radioactive waste that is classified as ILW is packed in appropriate sized containers in the solid radioactive waste management area for shipment to the WWMF.

2.1.2.1.3 Radioactive Liquid Waste

Select systems within the PNGS have the potential to release radioactive substances via liquid effluents. Liquid effluent radionuclides include tritium, carbon-14, gross alpha and gross beta-gamma. Gross beta-gamma is a gross measure of radioactivity and is inclusive of all non-volatile radionuclides in effluent including cesium-137, cesium-134, strontium-90, cobalt-60, etc.

The radioactive liquid waste management system (RLWMS) is shared between PNGS A and B. This system receives and treats the aqueous waste streams from the active drainage systems. A simplified flow diagram of the RLWMS is shown in Figure 2.3.

Potentially radioactive effluents with chemical contaminants are directed through a purification system that is then directed to dedicated discharge tanks. The purification system removes some of the gross beta-gamma activity from the water from activated suspended solids or dissolved radionuclides. The discharge is sampled for radiological and chemical parameters and discharge is only completed if required specifications are met. All discharges from the RLWMS must be non-toxic as directed by the Provincial Municipal Industrial Strategy for Abatement (MISA) regulations. Radioactivity monitors on the

discharge piping automatically stop discharge flow if the detected activity is above specified limits. Treated wastes are discharged to Lake Ontario through the CCW discharge ducts and the PNGS A and PNGS B discharge channels.

Select types of non-aqueous radioactive liquids including lubricating oils and liquid scintillation cocktails are transported to the WWMF for incineration. Other non-aqueous radioactive liquids are solidified and sent to the WWMF as non-processible drummed waste. Low activity chemical wastes are collected and shipped to licensed third party facilities for treatment. Where it is necessary, secondary wastes from third party treatment, including incinerator ash, are returned to OPG for storage at the WWMF.

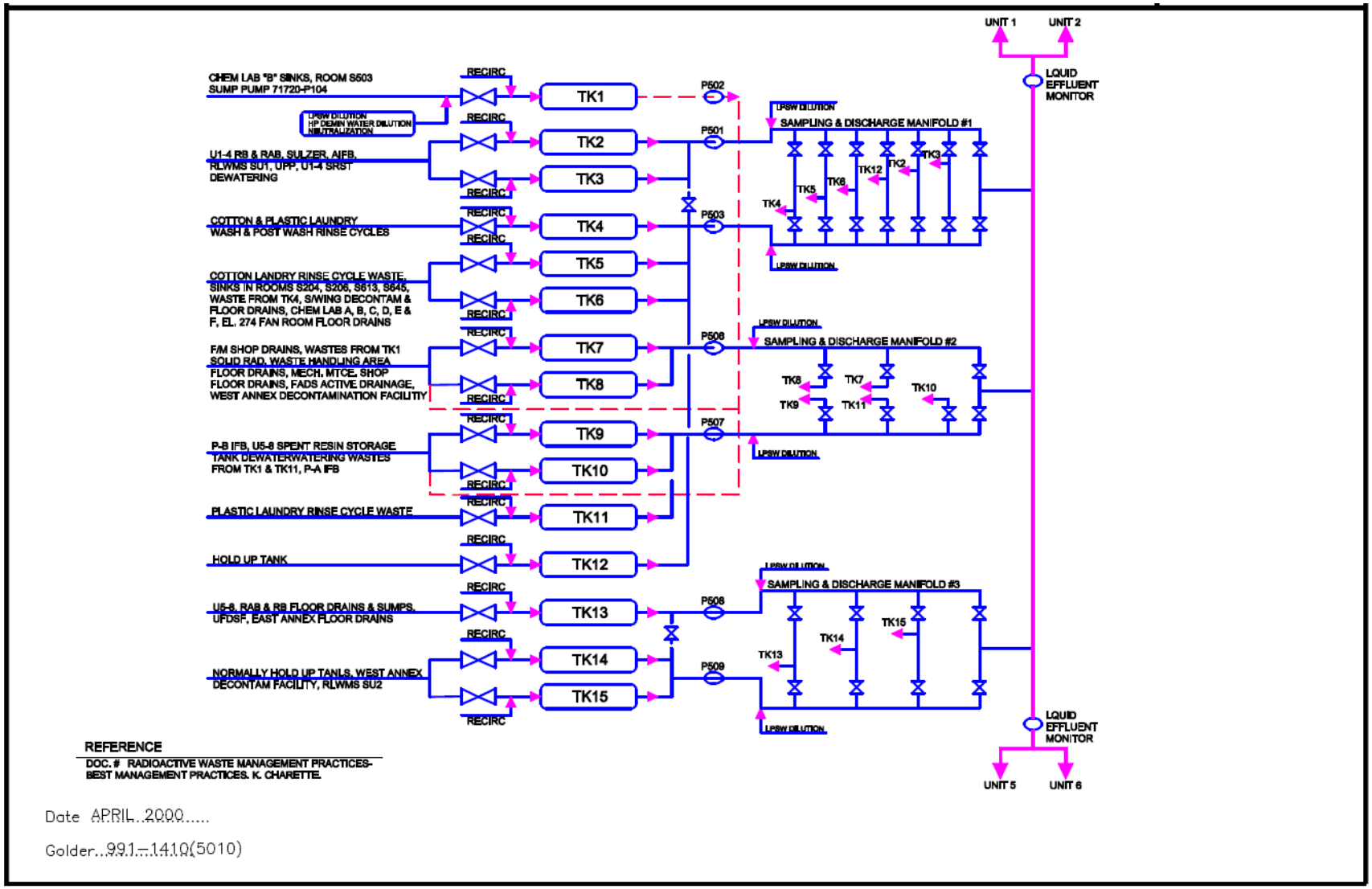


Figure 2.3: Simplified Radioactive Liquid Waste Management System Flow Diagram (OPG, 2000)

2.1.2.1.4 Radioactive Gaseous Waste

Sources of airborne radioactive emissions include the air exhaust from the reactor buildings, the air exhaust from the reactor auxiliary bay, ventilation from the auxiliary irradiated fuel bay, ventilation from the Upgrading Plant Pickering (UPP), Sulzers, and the used fuel dry storage facility.

Tritium, which is produced in the heavy water system, is released to the reactor building and environment in the form of tritiated water vapour. Tritium can also be released into the atmosphere through steam generator tube leaks and leakage from the heat transport system.

Gaseous wastes from potentially active areas are monitored for radioactivity before atmospheric release. When radioactive particulates and radioiodine may be present, gases from active ventilation stacks are filtered through absolute and charcoal filters prior to release.

The primary source of particulate emissions is the heat transport system where solid radionuclides originate from within the fuel bundles or from corrosion of system components. Additional radioactive particulate emissions include cesium-137 and cobalt-60 which primarily originate from the heat transport system where they are formed in the fuel bundles or from corrosion of the system components. Carbon-14 is released from the moderator cover gas system and the annulus gas system through the reactor building stack. The ventilation exhaust stacks are monitored for particulate and gaseous carbon-14 activity where necessary.

Argon-41, a noble gas, can be released in the reactor building ventilation due to leaks and purges from the annulus gas system, moderator cover gas system, the helium sub-system of the liquid zone control system, and the calandria vault air. Xenon-133 can be released when there are minor defects in the Zircaloy-4 cladding of the fuel tubes. The radioactive noble gases cannot be effectively filtered but strict quality control in fuel elements results in low noble gas emissions. Radioactive iodine isotopes are formed by fission and can escape through defects in fuel bundles. Monitors to detect noble gas and iodine are in place where appropriate.

Radioactive gaseous emissions are modelled, for the purpose of public dose calculations, as two virtual sources: one from PNGS A and one from PNGS B.

2.1.2.1.5 Non-Radioactive Solid Waste

Non-radioactive wastes are re-used or recycled where feasible. Hazardous wastes are handled in accordance with regulations and are shipped off site to licensed disposal facilities. Non-hazardous solid wastes are disposed in an off-site landfill if landfill requirements are satisfied.

2.1.2.1.6 Non-Radioactive Liquid Waste

Aqueous liquid effluent, except for domestic sewage and stormwater drainage, from PNGS is discharged into the CCW system (intake forebay or discharge duct/channel). The stormwater drainage is directed to Lake Ontario, and domestic sewage is directed to the York-Durham Water Pollution Control Plant (WPCP).

Non-radioactive liquid emissions are controlled in accordance with the provincial Certificates of Approval (CofA) requirements, and with the MISA program under O. Reg. 215/95 (Effluent Monitoring and Effluent Limits – Electric Power Generation Sector).

Under O. Reg 215/95 PN monitors the control points in use for MISA Compliance monitoring. Two of these control points have never been established and have not had discharges. Monitored parameters at the control points include: aluminum, iron, pH, acute lethality/toxicity, chronic lethality/toxicity, phosphorus, oil and grease, total suspended solids, and zinc. The control points and the parameters monitored at each point are presented in Table 2.2 (OPG, 2012a).

Table 2.2: MISA Monitoring Requirements

Control Point	MISA Monitoring Requirements
Radioactive Liquid Waste Management System –A	Phosphorus Total Suspended Solids Zinc Iron Oil and Grease pH Chronic and Acute Lethality/Toxicity
Radioactive Liquid Waste Management System – B	
Water Treatment Plant Neutralizing Sump[1]	Total Suspended Solids Aluminum Iron pH Chronic and Acute Lethality/Toxicity
New Water Treatment Plant discharge	
Oily Water Separator – A[1]	pH Oil and Grease
Unit 1 Building Effluent[1]	pH Total Suspended Solids (Monitoring Only) Oil and Grease (Monitoring Only) Chronic and Acute Lethality/Toxicity
Unit 2 Building Effluent[1]	
Unit 3 Building Effluent[1]	
Unit 4 Building Effluent[1]	
Unit 5 Building Effluent[1]	
Unit 6 Building Effluent[1]	
Unit 7 Building Effluent[1]	
Unit 8 Building Effluent[1]	
Unit 1-8 Combined Building Effluent	

Note:
[1] denotes an inactive system

2.1.2.1.7 Non-Radioactive Gaseous Emissions

Non-radioactive gaseous emissions are controlled in accordance with provincial CofA requirements. An Emissions Summary and Dispersion Modelling (ESDM) report is used to document and maintain compliance with O.Reg. 419/05 (Air Pollution – Local Air Quality) and forms the basis for the site's Basic Comprehensive Certificate of Approval (CofA No. 9090-6SBGEH).

The PN site is expected to have non-radioactive gaseous emissions including the products of fuel combustion, particulate matter, and volatiles. The ESDM and CofA list maximum point of impingement concentrations for significant contaminants (Golder, 2011). Contaminant concentrations are determined based on the calculated emission rates and the output from the approved dispersion model in compliance with O.Reg. 419/05.

The locations of the air emissions sources used in the 2011 ESDM are presented in Figure 2.4. In the ESDM report the facility was modelled with six virtual air emission sources and

two point sources. The facilities and contaminants associated with each virtual source are presented in Table 2.3.

As identified in Figure 2.4 virtual source one (VS1) encapsulates much of the PN facility located south of the switchyards and north of the forebay while VS2 through VS6 and point sources 7 and 8 (PS7 and PS8) only contain emissions from single sources.

Table 2.3: Modelled Sources and Associated Contaminants

Source Identification	Operations/Facilities at Source	Expected Contaminants
Virtual Source 1 (VS1)	Standby Gas Turbines	Products of distillate oil combustion
	Auxiliary Steam Boiler	
	Side Steam Venting Systems	Water conditioning chemicals
	Service Wing	Volatile chemicals
	Fuel Storage Tanks	Fuel oil vapour
	Gas Cylinders	Argon, carbon dioxide, carbon monoxide, deuterium, helium, hydrogen, methane, nitrogen, and sulphur hexafluoride
	Mobile Small Combustion Sources	Products of gasoline and diesel combustion
	Sodium Hypochlorite Storage Tanks	Sodium hypochlorite
	Pressure Relief Ducts	Ethylene gas
	Diesel Generators	Products of diesel combustion
	Diesel Powered Fire Pumps	Products of diesel combustion
Virtual Source 2 (VS2)	Transportation and Work Equipment Garage Exhaust Extraction System	Products of gasoline and diesel combustion
Virtual Source 3 (VS3)	Carpentry Shop Baghouse	Particulate matter
Virtual Source 4 (VS4)	East Complex Garage	Volatile chemicals and products of gasoline and diesel combustion
Virtual Source 5 (VS5)	Auxiliary Diesel Generators	Products of diesel combustion
Virtual Source 6 (VS6)		
Point Source 7 (PS7)	Combustion Turbine Units	Products of distillate combustion
Point Source 8 (PS8)		

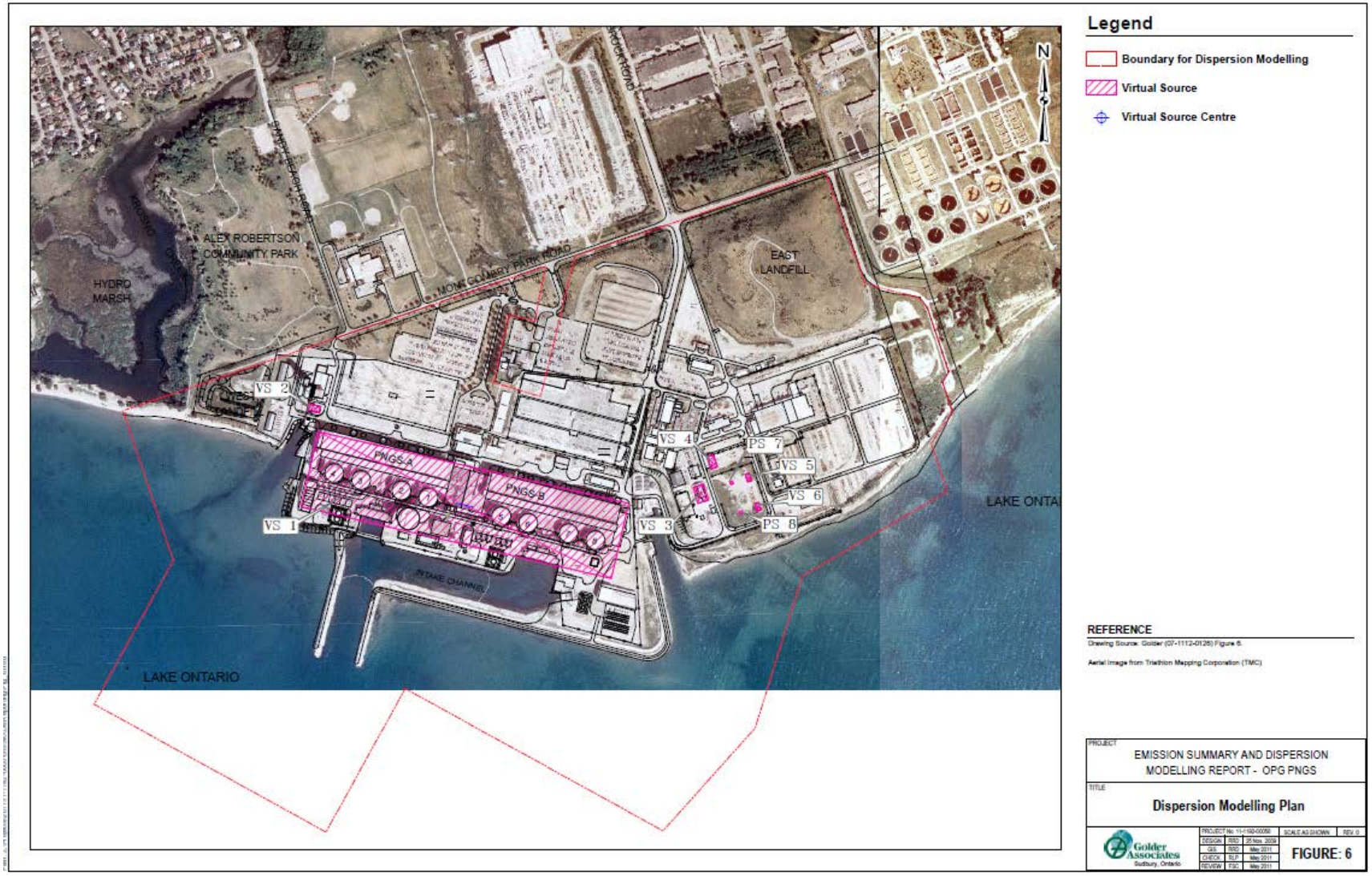


Figure 2.4: Non-radiological Air Emissions Sources (Golder, 2011)

2.2 Description of the Natural and Physical Environment

PNGS-A and PNGS-B are located on the PN site in the City of Pickering, within the Regional Municipality of Durham, Ontario, on the north shore of Lake Ontario at Moore Point. The site is about 32 km east-northeast of downtown Toronto and 21 km southwest of Oshawa at latitude 43° 49′ N and longitude 79° 04′ W.

This section will describe the natural and physical environment according to the spatial scale defined in Section 1.2. This includes parts of the SSA, LSA, and RSA, as defined in Section 1.2.

This section will briefly describe meteorology and climate, site geology, hydrogeology, hydrology, vegetation communities, aquatic communities, human land use, and population distribution with a focus on PNGS site conditions. More detailed information can be obtained from the following Technical Support Documents for the Pickering B Refurbishment for Continued Operation EA:

- NK30-REP-07701-00007 “Surface Water Resources” (Golder, 2007a);
- NK30-REP-07701-00008 “Aquatic Environment” (Golder, 2007b);
- NK30-REP-07701-00009 “Terrestrial Environment” (Golder, 2007c);
- NK30-REP-07701-00006 “Geology, Hydrogeology and Seismicity” (Golder, 2007d);
- NK30-REP-07701-00015 “Human Health” (SENES, 2007b);
- NK30-REP-07701-00004 “Radiation and Radioactivity” (SENES, 2007c); and
- NK30-REP-07701-00003 “Atmospheric Environment” (SENES, 2007d).

2.2.1 Meteorology and Climate

The PNGS is located in southern Ontario on the north shore of Lake Ontario. It displays a humid continental climate with four distinct seasons. In Southern Ontario, the climate is highly modified by the influence of the Great Lakes which results in uniform precipitation amounts year-round, delayed spring and autumn, and moderated temperatures in winter and summer (Environment Canada, 1997). Meteorological data were collected from stations within the site, local and regional areas.

2.2.1.1 Temperature

Local temperature data are collected at the PN meteorological station at a height of 10 metres above ground level. The local temperature data from the PNGS meteorological station for the period of 1996 to 2000 are summarized in Table 2.4. Figure 2.5 presents minimum, mean and maximum monthly values for the period. Winter mean monthly temperatures, December to March, are below 0°C. Summer mean monthly temperatures, June to September, are typically above 15°C. The mean annual temperature is 8.1°C.

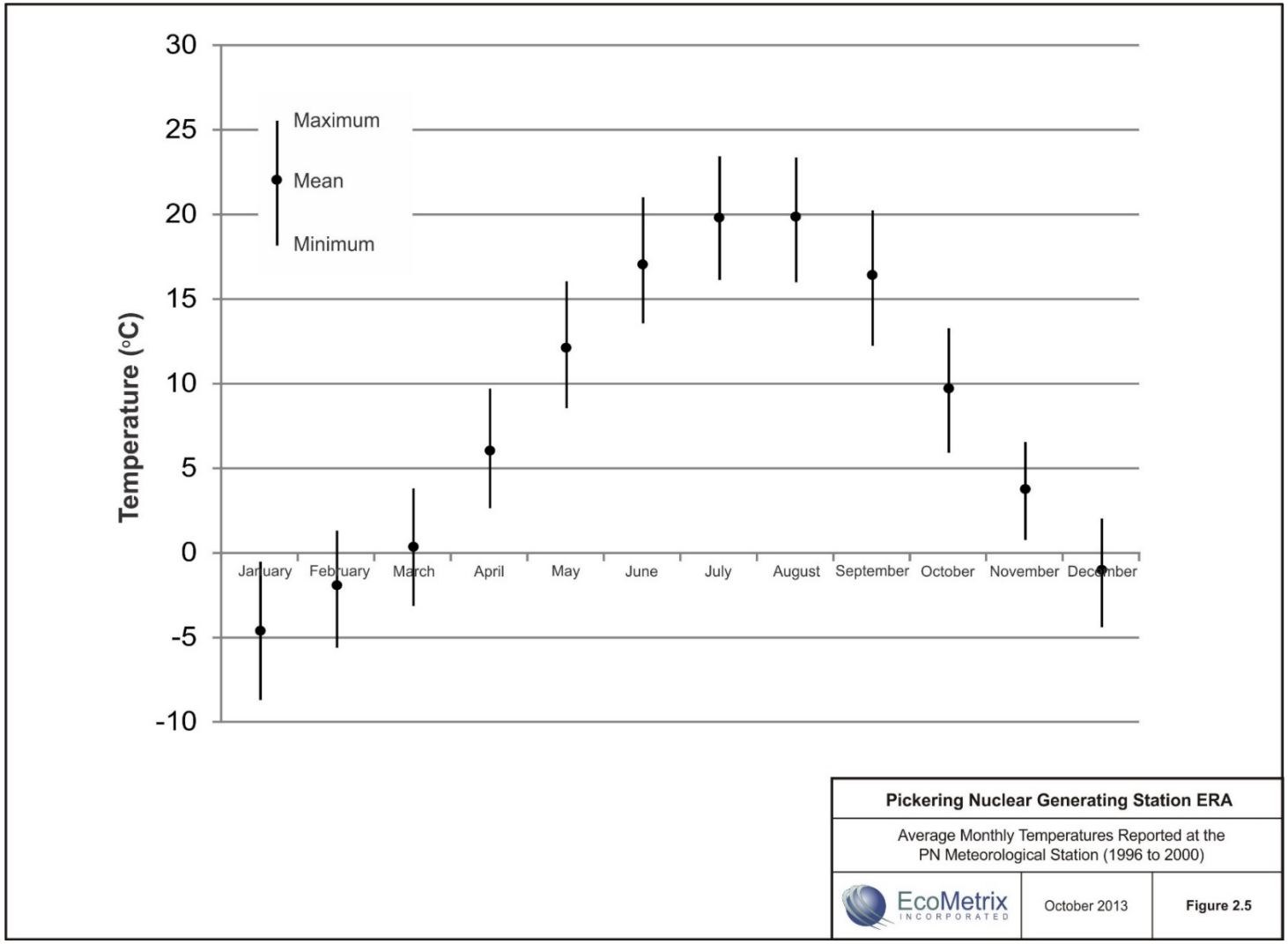


Figure 2.5: Average Monthly Temperatures Reported at the PNGS Meteorological Station (1996-2000)

Table 2.4 summarizes temperature data for two regional meteorological stations near the PNGS: Pearson International Airport (TOR) (1981 to 2010) and Oshawa WPCP (OSH) (1981 to 2006) (Government of Canada, 2013), along with temperature data from 1996 to 2000 from the PNGS meteorological station (at the 10 m elevation). The meteorological data collected from the PNGS meteorological station are generally consistent with the regional temperature normals.

Table 2.4: Temperature Normals near Pickering Nuclear

Month	Daily Mean (°C)			Mean Daily Maximum (°C)			Mean Daily Minimum (°C)		
	TOR[1]	OSH[2]	PNGS[3]	TOR[1]	OSH[2]	PNGS[3]	TOR[1]	OSH[2]	PNGS[3]
January	-5.49	-4.76	-4.61	-1.51	-1.06	-0.54	-9.44	-8.45	-8.69
February	-4.54	-3.61	-1.93	-0.35	0.06	1.29	-8.7	-7.28	-5.60
March	0.06	0.37	0.34	4.62	4.24	3.79	-4.49	-3.51	-3.13
April	7.06	6.62	6.02	12.21	10.76	9.69	1.86	2.46	2.64
May	13.12	12.3	12.11	18.79	16.89	16.03	7.41	7.68	8.56
June	18.6	17.57	17.03	24.19	22.26	21.01	12.95	12.85	13.58
July	21.45	20.55	19.80	27.06	25.13	23.43	15.79	15.93	16.13
August	20.55	19.97	19.85	26.01	24.26	23.36	15.05	15.64	16.00
September	16.2	15.94	16.41	21.61	20.16	20.22	10.75	11.69	12.25
October	9.5	9.47	9.71	14.31	13.32	13.28	4.63	5.57	5.93
November	3.72	4.21	3.76	7.59	7.38	6.53	-0.17	1.02	0.78
December	-2.18	-1.18	-1.01	1.41	2.07	2.02	-5.76	-4.43	-4.37
Year	8.17	8.12	8.12	-	-	-	-	-	-

Notes:

[1] Toronto Pearson International Airport, 1981-2010 (Government of Canada, 2013)

[2] Oshawa WPCP, 1981-2006 (Government of Canada, 2013).

[3] Pickering Nuclear Generating Station, 1996-2000.

2.2.1.2 Precipitation

Local precipitation data are not available from the PN site. Local precipitation data were obtained for the Frenchman's Bay Climate Station, located a few kilometers west of PNGS in Pickering for the period of 1971 to 2000. Climate normals for the Frenchman's Bay Climate Station for the period of 1971 to 2000 provide the best available precipitation data for the local study area at this time (Government of Canada, 2013). Precipitation, rain and snow fall data for 1971 to 2000 are summarized in Table 2.5. The data demonstrate that precipitation is fairly consistent throughout the year with slightly more precipitation in the second half of the year. The Frenchman's Bay station reports an average annual precipitation of approximately 879 mm of which less than 15% is snowfall. Monthly precipitation averages range from approximately 49 mm in February to approximately 84 mm in September.

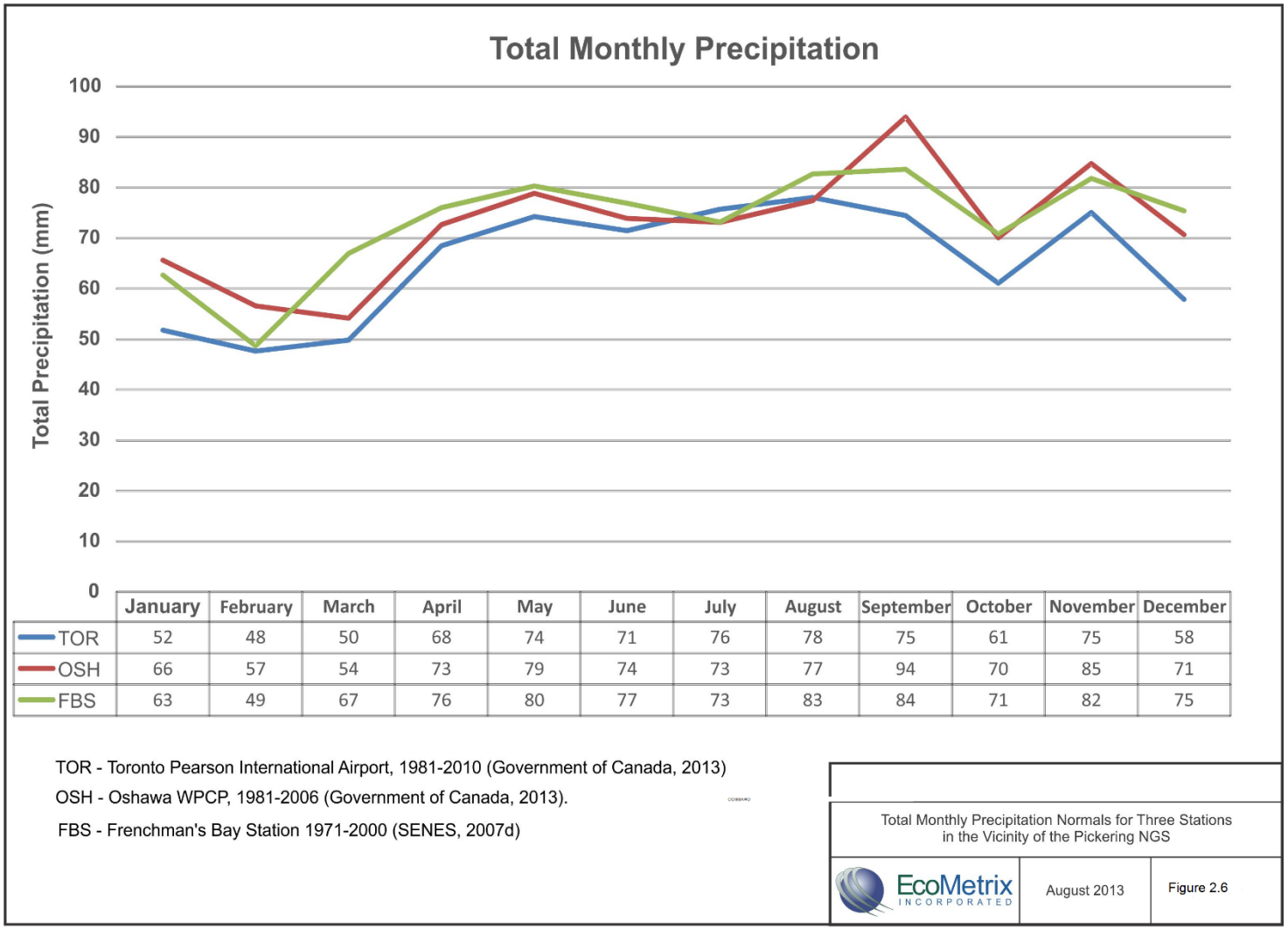
Total monthly precipitation normals for the local study area are compared to the most recent regional precipitation normals (1981 to 2010), for the Pearson International Airport (TOR) and Oshawa WPCP (OSH) (Government of Canada, 2013). The TOR is located approximately 35 km west – south – west of the PN site, and the OSH is located approximately 30 km north-east of the PN site. The data sets for the local and regional meteorological station overlap for the period from 1981 to 2000. Table 2.5 shows that monthly precipitation within the local study period tends to follow the regional monthly precipitation trends.

Table 2.5: Precipitation in the Local Study Area[1] (1971 – 2000) (Government of Canada, 2013)

Month	Monthly Averages			Daily Extremes		
	Precipitation (mm)	Rain (mm)	Snow (cm)	Precipitation (mm)	Rain (mm)	Snow (cm)
January	62.7	35.4	27.4	45.6	45.6	28
February	48.7	30.6	18.1	39.3	39.3	21.3
March	67	47.7	19.3	48.5	46	21.6
April	76	69.8	6.1	40.8	40.8	21
May	80.3	80.3	0	61.4	61.4	0.6
June	76.9	76.9	0	74.7	74.7	0
July	73.2	73.2	0	84.8	84.8	0
August	82.7	82.7	0	71.6	71.6	0
September	83.6	83.6	0	71.4	71.4	0
October	70.8	70.5	0.3	61.6	61.6	9.7
November	81.8	73.7	8.1	48	48	15.8
December	75.4	49.2	26.3	42.7	42	31.8
Annual Total	879	773.4	105.6	-	-	-

Note:

[1] Frenchman's Bay Station



	January	February	March	April	May	June	July	August	September	October	November	December
TOR	52	48	50	68	74	71	76	78	75	61	75	58
OSH	66	57	54	73	79	74	73	77	94	70	85	71
FBS	63	49	67	76	80	77	73	83	84	71	82	75

Figure 2.6: Comparison of Total Monthly Precipitation for the Local Study Area (1971 – 2000) with Monthly Precipitation Normals for two Regional Meteorological Stations (Government of Canada, 2013)

2.2.1.3 Wind

Historical local wind data, from 1996 to 2000, were available from the on-site PNGS meteorological tower at an elevation of 10 m from ground level (OPG, 2011 a, b). The data are summarized as a windrose in Figure 2.7. The most recent consecutive five-year period of reliable data is 1996 to 2000 (OPG, 2010a). A review of five reference Environment Canada meteorological stations demonstrated consistency in average wind patterns from 1996 through 2008 (ORTECH Power, 2008 cited in OPG, 2011 a, b). Therefore, the 5-year average meteorological data from 1996 to 2000 is expected to be representative of current average meteorological conditions. During this period, calm winds, less than 2 m/s, were reported approximately 34% of the time while winds with measured speeds from 2 to 3 m/s and 3 to 4 m/s were observed approximately 20% of the time for both speed categories (OPG, 2011 a, b) .

The prevailing winds for the 1996 to 2000 period were from the north-westerly quarter (N, NNW, NW and WNW) approximately 35% of the time, the south-southwest approximately 10% of the time, and the east (7% of the time).

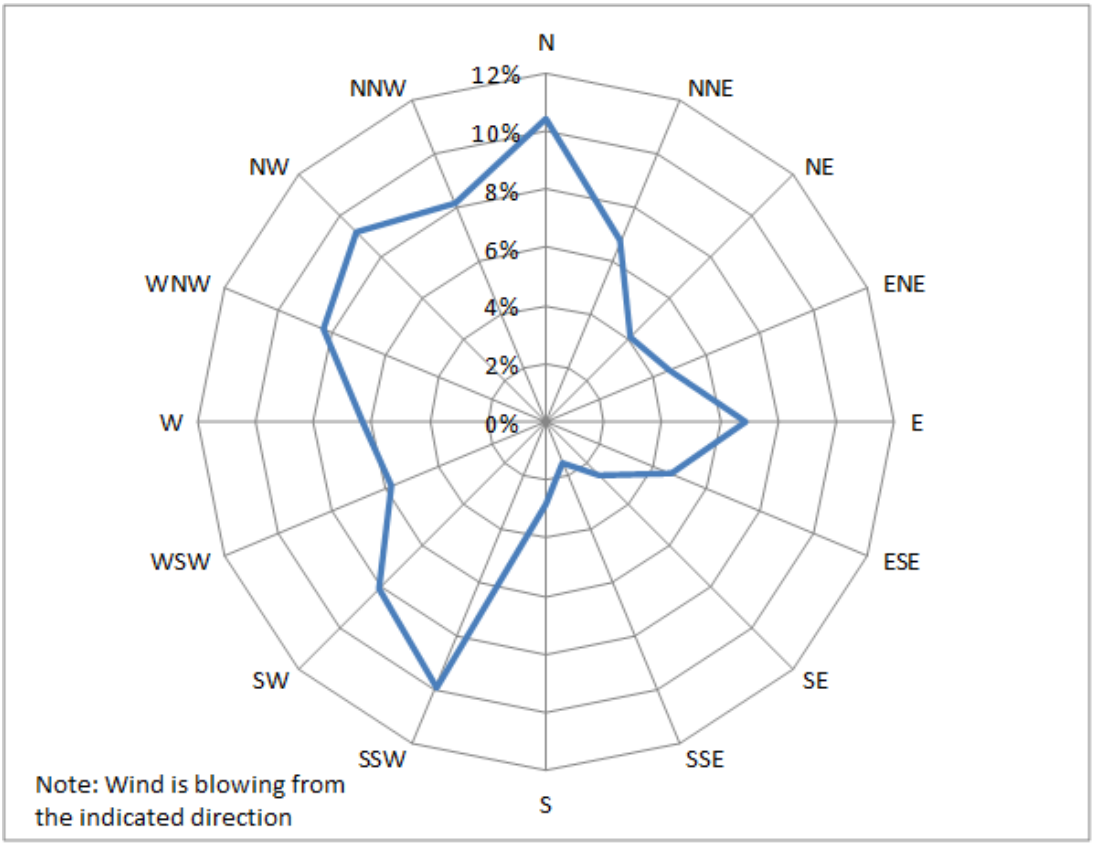


Figure 2.7: 1996 - 2000 Annual Average Windrose at 10m Tower (OPG, 2011b)

2.2.2 Geology

A substantial body of information has been collected at the PN site through work carried out during previous investigations, including geological drilling investigations, monitoring well installations and sampling. These data have been summarized in the Pickering B Refurbishment Environmental Assessment (EA) (SENES, 2007e) and a more detailed discussion is provided in Golder (2007d). The following sections provide an overview of the regional and local bedrock and surficial geology, and a summary of bedrock and surficial geology for the PN site and offshore.

2.2.2.1 Bedrock

On a regional scale, the PN site is underlain by Ordovician age sedimentary rocks composed of nearly flat-lying shales and limestones that dip gently (1%) southward, characteristic of the north shore of Lake Ontario. The relatively undeformed Ordovician sequence lies uncomfortably upon gneiss crystalline Precambrian rocks that form the basement complex. The stratigraphic sequence of the Ordovician shales that underlie the PN site, in descending order, include Blue Mountain Formation shale, the thin Whitby Formation shaly limestone and shale overlying the thick limestone sequence composed of the Lindsay, Verulam, Bobcaygeon and Gull River Formations. The combined limestone sequence has a thickness of approximately 180 m. The clastic sediments of the comparatively thin (12 m) Shadow Lake Formation underlie the limestone sequence and occur on the Precambrian basement complex (Golder, 2007d).

The bedrock beneath the site has been investigated by numerous geotechnical and hydrogeological investigations including over 500 boreholes drilled over the past 45 years (Golder, 2007d). A cross section of the subsurface conditions beneath the PN site and offshore is presented in Figure 2.8. In general, the bedrock surface is encountered at depths of approximately 10 m to 20 m below the surface with localized areas of low bedrock topography. The surface slopes southward from elevations of 68 metres above sea level (masl) at the north of the site to elevations of approximately 47 masl approximately 1.5 km offshore in Lake Ontario. The Blue Mountain Formation grey shale sequence and the underlying Whitby Formation black shale are approximately 10 to 20 m thick and 5 to 7 m thick, respectively.

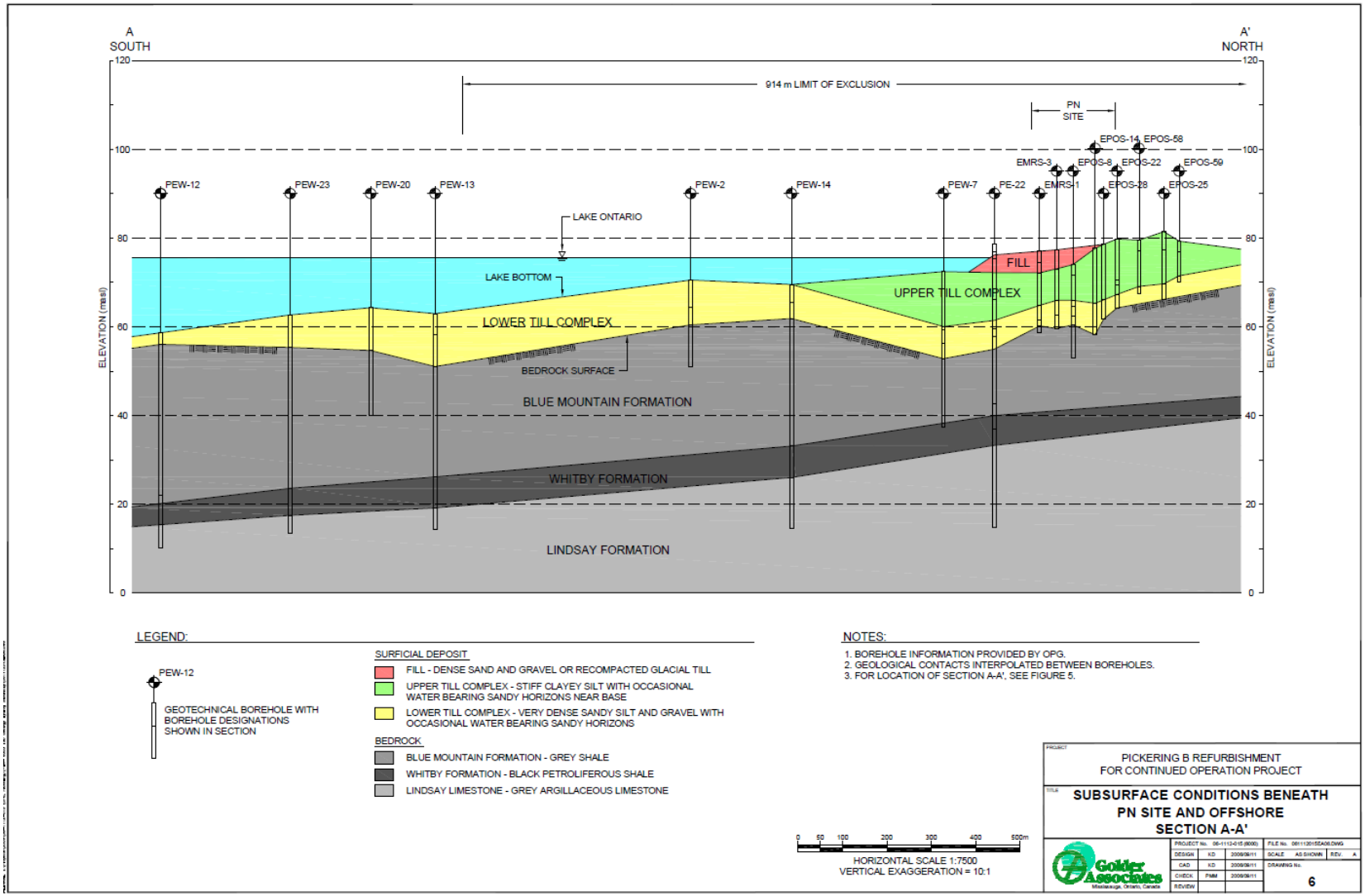


Figure 2.8: Subsurface Conditions Beneath the PN Site and Offshore Section A-A' (Golder, 2007d)

2.2.2.2 Surficial Geology

The Oak Ridges Moraine is situated approximately 20 km to 30 km inland from the north shore of Lake Ontario. It forms the regional height of land separating the Trent System and Lake Simcoe drainage to the north from Lake Ontario drainage to the south. The moraine is composed of thick deposits of glacial till and sand and gravel that are associated with hummocky terrain at the surface. Regionally, the north shore of Lake Ontario is largely underlain by glacial till and glaciolacustrine deposits of clayey silt to silty clay composition. The deposits are exposed in bluffs along the lakeshore and in stream valleys throughout the area. Locally, the surficial geology predominantly comprises glacial till, or glaciolacustrine silts and clays overlying the till, which forms drumlin ridges oriented approximately northwest-southeast.

Investigations conducted in advance of the construction of the PNGS A and B facilities indicate that the pre-construction subsoils in the area of the existing plant generally consisted of glacial silt and sand tills up to 24 m thick overlying shale bedrock. The glacial till deposit was found to consist of an upper, more recent soil complex, comprising compact to dense sandy silt with some clay and gravel, overlying an older sandy and gravelly clay till. The elevation of the upper and lower soil complexes were found to range from about 67 masl to 79 masl and 56 masl to 67 masl, respectively, within the main PNGS A and B structures area. Water bearing layers and lenses of interglacial silt, sand and gravel have been encountered at the base of the upper soil complex and interbedded within the lower complex. Therefore the soil sequence overlying the bedrock beneath the PN site can be subdivided into three main layers comprising construction fill, an Upper Till Complex and a Lower Till Complex overlying bedrock (Golder, 2007d) as illustrated in Figure 2.8.

The fill material consists of either, sand and gravel backfill that was placed for foundations, or recompacted clayey silt placed in the reclamation areas. The fill material underlies most of the PN site areas south of the former Lake Ontario shoreline. Structures such as the Reactor Buildings and Reactor Auxiliary Buildings were placed on 3 m to 6 m of compacted granular fill.

2.2.3 Hydrogeology

On a regional scale, the permeable layers of sands, or sand and gravels buried within and between low permeability till deposits constitute aquifers that support groundwater flow. The tills typically have low permeability due to their fine granularity and behave as aquitards, restricting infiltration and the recharge of water to the permeable layers. The bedrock deposits of shale and limestone that underlie the surficial deposits also have low permeability, except for some weathered zones and open fractures. The exposed areas of sand and gravel within the Oak Ridge Moraine are a significant regional source of groundwater recharge from precipitation. Once recharged, the direction of groundwater flow in the buried sand and gravel deposits generally parallels that of surface streams, flowing away from the height of land formed by the moraine toward adjacent areas to the

north and south. Some of the groundwater recharged in the Oak Ridge Moraine subsequently discharges into stream beds providing baseflow that maintains the streams during the dry periods of the year when there is little or no surface runoff. The regional direction of groundwater flow south of the Oak Ridge Moraine is southward toward Lake Ontario and generally parallel to the land slope.

Previous hydrogeological investigations (CH2M Gore and Storrie, 2000; CH2M Hill, 2005a; Golder, 2003; Golder, 2007d) have indicated that there are approximately 8 hydrostatigraphic units, or zones of geological material with similar hydraulic characteristics, present below the PN site. Within these units, there are four main groundwater flow systems. The shallow overburden groundwater is found in the shallow, more permeable overburden layers of fill, organic clayey silt to silty clay and brown sandy to clayey silt till (HUs 1 through 5). The intermediate overburden groundwater unit is a grey clayey silt to silt clay till (HU 6). A dense, grey sandy silt till forms the deep overburden groundwater flow system (HU 7) while the shale bedrock comprises the fourth unit (HU 8). More detail is provided in the above listed references regarding the specific HUs, including geological cross-sections.

Groundwater elevations are typically measured by OPG quarterly. The results of historic site investigations and monitoring have provided an understanding of the groundwater flow system below the PN site. Groundwater contour maps for spring 2011 are shown in Figure 2.9 and Figure 2.10 for the shallow and intermediate groundwater systems.

The primary feature of the shallow groundwater regime is the East Landfill (Figure 2.9). This area represents a groundwater recharge area, with radial flow outward from the landfill area. A groundwater divide appears to be present along the northern portion of the PN site that generally runs parallel to Montgomery Park Road (CH2M Gore and Storrie, 2000). Southerly groundwater flow is towards the station buildings and Lake Ontario, but is influenced by the Turbine Auxiliary Bay (TAB) till foundation drain system that acts as a hydraulic sink for the shallow groundwater. Subsurface infrastructure also influences the shallow flow, and includes a sump at the base of a ramp to the east of the Vacuum Building (Figure 2.9) that also acts as a local hydraulic sink and results in a small groundwater divide between the reactor buildings and Lake Ontario. Groundwater elevation monitoring over the past few years has indicated that there is generally no significant seasonal change in the shallow groundwater flow directions.

The intermediate groundwater flow system is similar to the shallow system, with the East Landfill acting as a recharge area. The TAB drains and VB Ramp Sump (VBRS) create artificial hydraulic sinks similar to that observed in the shallow groundwater system causing limited groundwater flow towards the lake south of the Reactor buildings.

Due to a limited number of wells located within the deep overburden and shallow bedrock, the deeper groundwater flow systems are less well defined, but the limited data indicate flow towards Lake Ontario with some influence of the TAB foundation drains. The data also

show that the shallow bedrock is typically not influenced by non-nuclear COPCs or by tritium.

In general, vertical flow between the flow systems is downward in the overburden and upward in the bedrock, as would be expected for regional groundwater discharge to Lake Ontario. However, the local flow is partially influenced by pumping from the TAB foundation drains and VBRS. Measured flow into the TAB foundation drains is on the order of about 25 and 77 m^3/day for PNGS A and PNGS B, respectively (CH2M Gore and Storrie, 2000).

Estimated lateral flow velocities in groundwater across the site range from 0.3 to 11 m/y (CH2M Gore and Storrie, 2000).

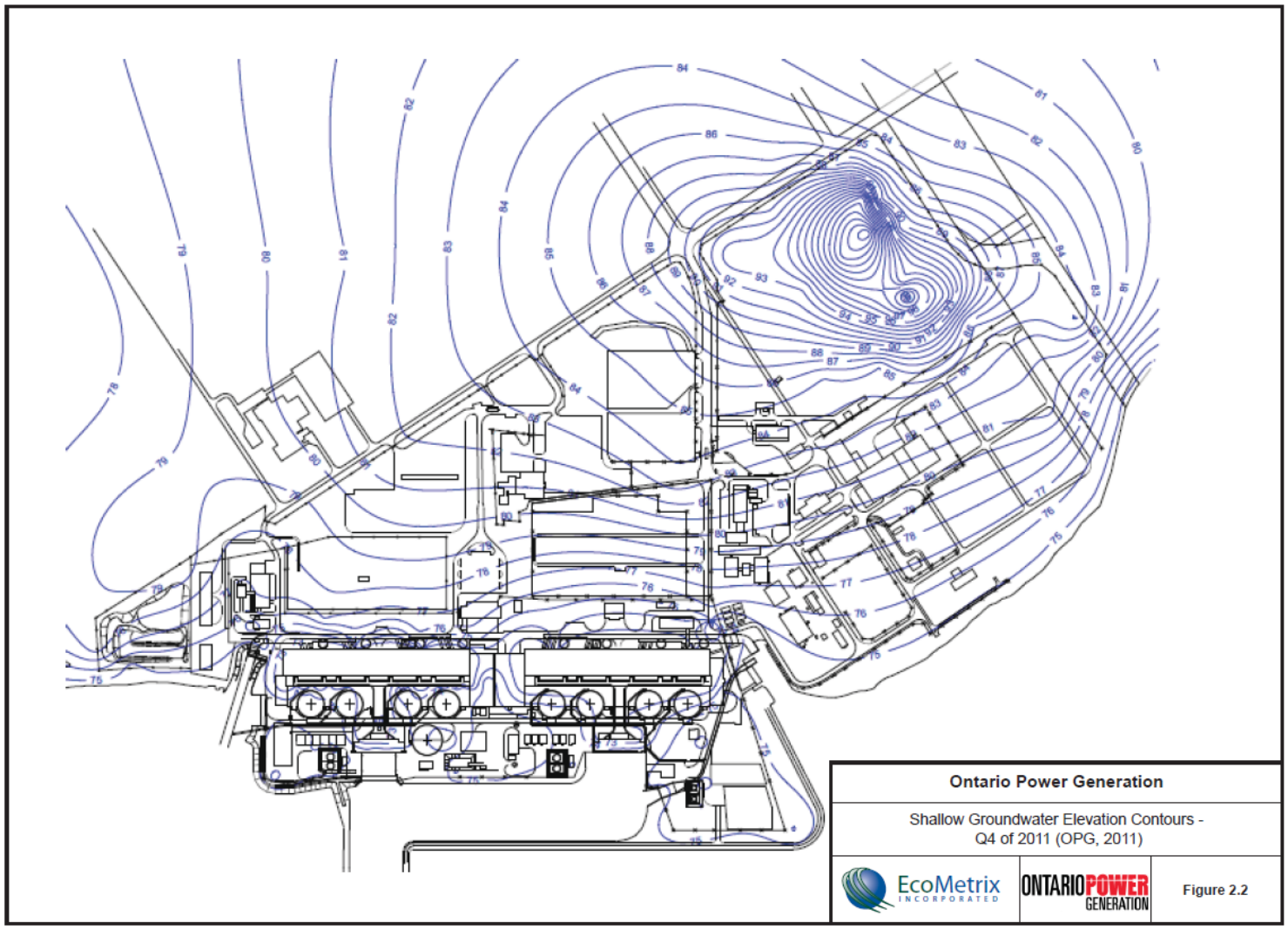


Figure 2.9: Site Groundwater Flow Conditions – Shallow Groundwater Elevation Contours (OPG, 2011c)

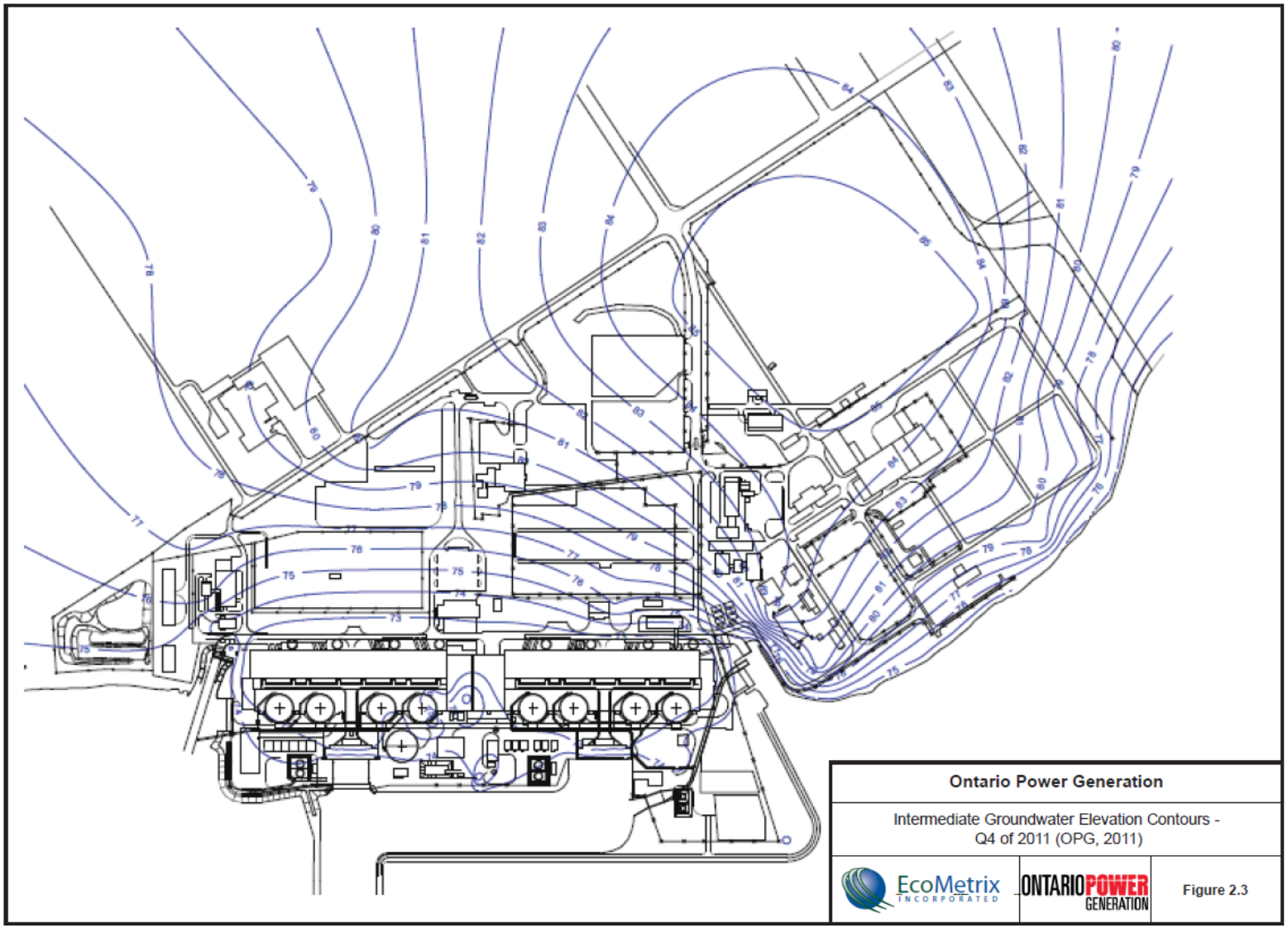


Figure 2.10: Site Groundwater Flow Conditions – Intermediate Groundwater Elevation Contours (OPG, 2011c)

2.2.4 Hydrology

2.2.4.1 Lake-wide Circulation and Nearshore Currents

The PN site is situated on the north shore of Lake Ontario. Lake-wide circulation in Lake Ontario is primarily driven by wind and by seasonal temperature effects. The nearshore region currents tend to be driven by brief patterns of strong winds exerting stress at the water surface. The nearshore current typically has a breadth of about 7 km in spring and as much as 10 km in summer and fall (Golder, 2007a).

Table 2.6 shows the frequency of lake current flowing toward each direction and the maximum speed that occurred in each direction for the monitoring period from 2007 to 2011 inclusive. Table 2.7 shows the depth averaged lake current direction and speeds for the same period. During the 5-year period including 2007 to 2011, the average easterly and westerly current speeds were 17.5 cm/s and 11.5 cm/s respectively.

Table 2.6 Lake Current Data from 2007 to 2011 (OPG, 2013a)

Direction "To"	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Easterly	Westerly
Total Number of Measured Hours	0	12	146	2862	9050	3015	1167	698	803	1099	2466	8105	1835	236	22	2	15073	12642
Percent of Total Measured Hours	0.0%	0.0%	0.5%	9.1%	28.7%	9.6%	3.7%	2.2%	2.5%	3.5%	7.8%	25.7%	5.8%	0.7%	0.1%	0.0%	47.8%	40.1%
Average Speed (cm/s)	N/A	4.3	9.2	21.3	19.1	13.8	10.1	7.8	7.3	7.8	9.2	12.3	10.7	6.3	4.3	3.5	17.5	11.5
Maximum Speed (cm/s)	N/A	7.1	34.9	57.8	48.7	38.7	27.7	43.0	20.7	35.1	38.9	61.6	60.8	29.6	11.6	3.6	57.8	61.6

Notes:
Easterly direction includes NE, ENE, E, and ESE.
Westerly direction includes SW, WSW, W, and WNW.
Extended periods where data were not available: Jan - Oct 2007, Jun – Sep 2008, Oct – Dec 2009.

Table 2.7: Current Speed and Direction from 2007 to 2011 (OPG 2013)

	Depth averaged direction Deg from N	Depth averaged speed - All cm/s	Depth averaged speed - E cm/s	Depth averaged speed - W cm/s
Jan	136.5	17.5	21.1	11.6
Feb	145.1	17.4	21.9	11.2
Mar	165.1	13.9	16.2	12.9
Apr	174.7	12.4	16.6	9.9
May	174.0	10.5	13.4	9.0
Jun	155.0	10.2	11.8	10.3
Jul	186.8	10.3	13.4	9.8
Aug	194.1	13.7	19.3	12.8
Sep	180.1	14.6	16.2	13.4
Oct	157.6	16.0	19.2	13.2
Nov	169.6	15.0	20.3	10.7
Dec	135.4	18.5	21.1	13.2
Average of monthly averages		14.2	17.5	11.5

Notes:
Easterly direction (E) includes NE, ENE, E, and ESE.
Westerly direction (W) includes SW, WSW, W, and WNW.
Extended periods where data were not available: Jan - Oct 2007, Jun – Sep 2008, Oct – Dec 2009.

Nearshore lake currents are affected by the existing operation of the PNGS-A and PNGS-B. Some localized effects are observed near water intake and water discharge points. Water velocities in the vicinity of intake groynes are directed toward the plants and a zone of in-flowing water is evident around the intake. With four units running at PNGS B and two units running at PNGS A, typical water withdraw between the intake groynes and into the plant via the intake channel is estimated at 190 m^3/s based on rated condenser CCW pump capacities and service water demand (SENES, 2007e).

Golder (2000, cited in Golder 2007a) estimated that with four units running at PNGS B and PNGS A in layup, the zone of influence due to in-flowing water extends approximately 600 m offshore. Water discharged from the PNGS A and PNGS B discharge channels is released as a fast-flowing jet or momentum plume of water. Current velocities in the jet are gradually dissipated by shear and mixing with lake water as the jet moves offshore to deeper water. The jet current velocities are also influenced by the speed and direction of the nearshore lake currents. The discharge jets from PNGS A and PNGS B extend offshore at the western and eastern ends of the station respectively (see Section 2.1.1.1). Burchat (1990, cited in Golder 2007a) found that with four units running at PNGS B and PNGS A in layup, the effect of the jet under normal nearshore currents extends up to 600 m

offshore. Under current conditions (six units operating), it is expected that the zone of influence and effect of the jet extends farther.

2.2.4.2 Lake Water Temperature

Lake Ontario is generally classified as a dimictic lake because it undergoes a complete cycle of isothermal and vertically stratified conditions in a year. The thermal structure generally depends on the season because of large annual variation in surface heat fluxes. In spring and early summer, heating of the lake surface gradually results in potential formation of thermal stratification conditions, with warmer water at the surface layer and cooler water in the bottom layer. Since nearshore water is heated up more rapidly than offshore water in spring, the depth of the thermocline in shallow water near the shore is greater than the depth of the thermocline in deep water offshore. As deeper water becomes stratified, the thermal bar (i.e., the temperature gradients on the same horizontal plane) moves progressively farther offshore, and it disappears when most of the lake is stratified sometime in June. The lake water is isothermal in fall and winter, or sometimes very weakly stratified in winter. In summer, the nearshore vertical temperature profile demonstrates a stable temperature stratification with warmer water in the surface layer and cooler water in the bottom layer. The depth of the summer thermocline ranges from 5 m to 10 m.

Table 2.8 presents monthly water temperature statistics based on monitoring data from 1970 to 1988 for three representative water depths of 1 to 2 m (surface), 8 m and 12 m at an ambient location off PNGS. These data indicate that the ambient water temperature is lowest in February and peak in August. The year-to-year variation in monthly mean temperatures is larger in the summer months than in the winter months and is similar at different depths.

Table 2.8: Nearshore Mean Monthly Ambient Temperatures (°C) off of PNGS for the 1970-1988 Period (Golder, 2007a)

Month	Nearshore Surface Temperature (1970-1988)	12-m Depth Temperature (1972-1988)
January	1.6	2.2
February	1.2	1.8
March	2.4	2.3
April	5.3	3.9
May	7.5	5.8
June	10.1	7.4
July	12.9	8.7
August	17.3	13.5
September	14.5	12.0
October	9.9	8.5
November	6.0	5.9
December	3.0	4.3

Between 1986 and 1988, 12 synoptic thermal plume surveys and in-situ water temperature measurements, six during warm weather conditions and six during cold weather conditions, were conducted (Burchat ,1990, cited in Golder, 2007a). Warm weather conditions refer to ambient lake water temperatures greater than 4°C and occur in spring, summer, and fall. Cold weather conditions refer to ambient lake water temperatures less than 4°C and occur only in winter. The study was designed to determine the combined effect of both the PNGS-A and -B on the aquatic environment with five to seven units in operation. Details of the study are provided in Golder (2007a).

Under warm weather conditions, the thermal plume from the PN site is warmer than the ambient lake water and is therefore buoyant. The historical data showed that the depth of the thermal plumes under warm weather conditions was 1 to 2 m and that the thermal plumes flowed in the direction of the prevailing wind. The thermal plumes under warm weather conditions extended mostly to the west. Under cold weather conditions the thermal plume is initially buoyant because its water temperature is warmer than the ambient lake water. Because water is most dense at 4°C, the buoyant plume temperature decreases under cold weather conditions to a level at which its density is greater than that of the ambient surface water thereby resulting in reduced buoyancy. During calm winter days with insufficient vertical mixing, which are rare in Lake Ontario, the plume would tend to sink and travel beneath the ambient water. During the 12 synoptic surveys, the thermal plumes under cold weather conditions extended mostly along the shore and to the east.

Historic data indicate that winter plumes were generally larger in extent than summer plumes. The historical data indicated that the area of combined PNGS A and B thermal plumes based on a criterion of 2°C above the ambient water temperature ranged from 150 to 800 ha at the water surface regardless of warm or cold weather conditions, and from 50 to 300 ha at the bottom during cold weather conditions. Results of numerical modelling for winter plumes are presented in Golder (2007b).

In 2006 and 2007, a series of anchored buoys, each with temperature loggers at three depths, were set in the vicinity of PNGS A and B to monitor water temperature during normal operations and algae events (Ager *et al.,* 2008). Water temperature contours corresponding to algal events for October 2006 and August - October 2007 were summarized in the report. The results of the field study indicated that PNGS B was the dominant thermal discharge plume because of its greater discharge volume and higher discharge temperature differential. PNGS A had minimal effects on thermal plumes throughout the study period, because of reduced discharge temperatures and volumes at this Station. The temporal changes observed in the temperature isopleths at the three depth contours were consistent with the development of an elastic floating thermal plume, following a variable initial period of vertical mixing in the vicinity of the PNGS B discharge. The development of the floating thermal plume resulted from temperature related differences in the density of the discharge and lake water layers.

The greatest extent of the surface plumes (based on a 10°C differential between the ambient temperatures and PN intake temperature) for 2006 were roughly 33,000 m^2, and 40,000 m^2 during October 11-12 and October 27-28 events, respectively. The greatest extent of the surface plumes for 2007 were roughly 53,000 m^2, 34,000 m^2 and 63,000 m^2 during August 21-29, October 9-10, and October 26 -28 events, respectively. Thermal plumes at the middle and bottom contours were more localized. Table 2.9 provides the estimated areas of the surface, middle and bottom thermal plumes where the temperature was greater than 10°C above the PN B intake temperature observed during the 2006 – 2007 algal events.

Table 2.9: Estimated Area of the Surface, Middle and Bottom Thermal Plumes (10°C above the PN B Intake Temperature) during Algal Events Observed in 2006 and 2007

Event		Temperature Contour	
Year	Date	10°C above the PN B Intake Temperature	
		Depth	Maximum Area (m^2)
2006	October 11-12	Surface	33,425
		Middle	9,750
		Bottom	8,325
2006	October 27-28	Surface	40,800
		Middle	13,325
		Bottom	12,850
2007	August 21-29	Surface	53,475
		Middle	24,000
		Bottom	3,300
2007	October 9-10	Surface	33,975
		Middle	20,100
		Bottom	125
2007	October 26-28	Surface	62,625
		Middle	24,175
		Bottom	11,375

Source:

Tables 9 to 14, Ager *et al.*, 2008.

2.2.4.3 Surface Drainage

Lake Ontario is the farthest downstream of the five Great Lakes. It is the smallest in surface area but is substantially larger in volume, 1,640 km^3, than Lake Erie, which is located immediately upstream and empties into Lake Ontario via the Niagara River. The land area draining directly to Lake Ontario is approximately 64,030 km^2. The Niagara River

constitutes the single most significant inflow to Lake Ontario. The natural outlet from Lake Ontario is the St. Lawrence River.

The Lake Ontario watershed boundary in the region of the PN site is defined by a topographic high corresponding to the Oak Ridges Moraine which forms the watershed divide between Lake Ontario and Georgian Bay. From west to east, the main drainages to Lake Ontario within the region, include Don River, Highland Creek, Rouge River, Petticoat Creek, Frenchman's Bay, Duffins Creek, Carruthers Creek, Lynde Creek, Oshawa Creek, and Harmony Creek and Farewell Creek watersheds.

The PN site is surrounded by two major watersheds: the Rouge River watershed to the west and the Duffins Creek watershed to the east, as shown in Figure 2.11. Two smaller watersheds are located between the Rouge River watershed and the PN site. These are the Petticoat Creek watershed and the watershed draining to Frenchman's Bay, which are 26 km^2 and 22 km^2, respectively. The watershed draining to what has been referred to as the "Hydro Marsh", located directly west of the PN site (see Figure 2.12), includes flow from Krosno Creek which has a watershed of 0.7 km^2 and is a tributary of Frenchman's Bay. Krosno Creek also drains 0.14 km^2 of Hydro One's central maintenance and storage areas north of Montgomery Road.

Drainage in the PN site is a mix of ephemeral swales, ditches, culverts and storm sewers. Stormwater runoff from the PN site is collected by the stormwater drainage system and directed through drainage pathways south to Lake Ontario. No major watercourses traverse the SSA and no waterbody other than a small (0.5 ha) isolated wetland known as the Southeast Wetland is located in the SSA. This small isolated wetland, which lies in the southeast corner of the PNGS property at the foot of Montgomery Park Road was once farmland and was created during the construction of PNGS as a result of landfilling activities. The Southeast Wetland receives drainage from the area around the former construction landfill within the SSA, and at best remains seasonally wet. Figure 2.12 provides a site plan for the PN site including the location of Hydro Marsh, the Southeast Wetland Area, PNGS A and B discharges and the PNGS water intake channel. In addition, there is a small manmade ephemeral pond in Alex Robertson Park.

Figure 2.13 presents the catchment areas for the PN site.

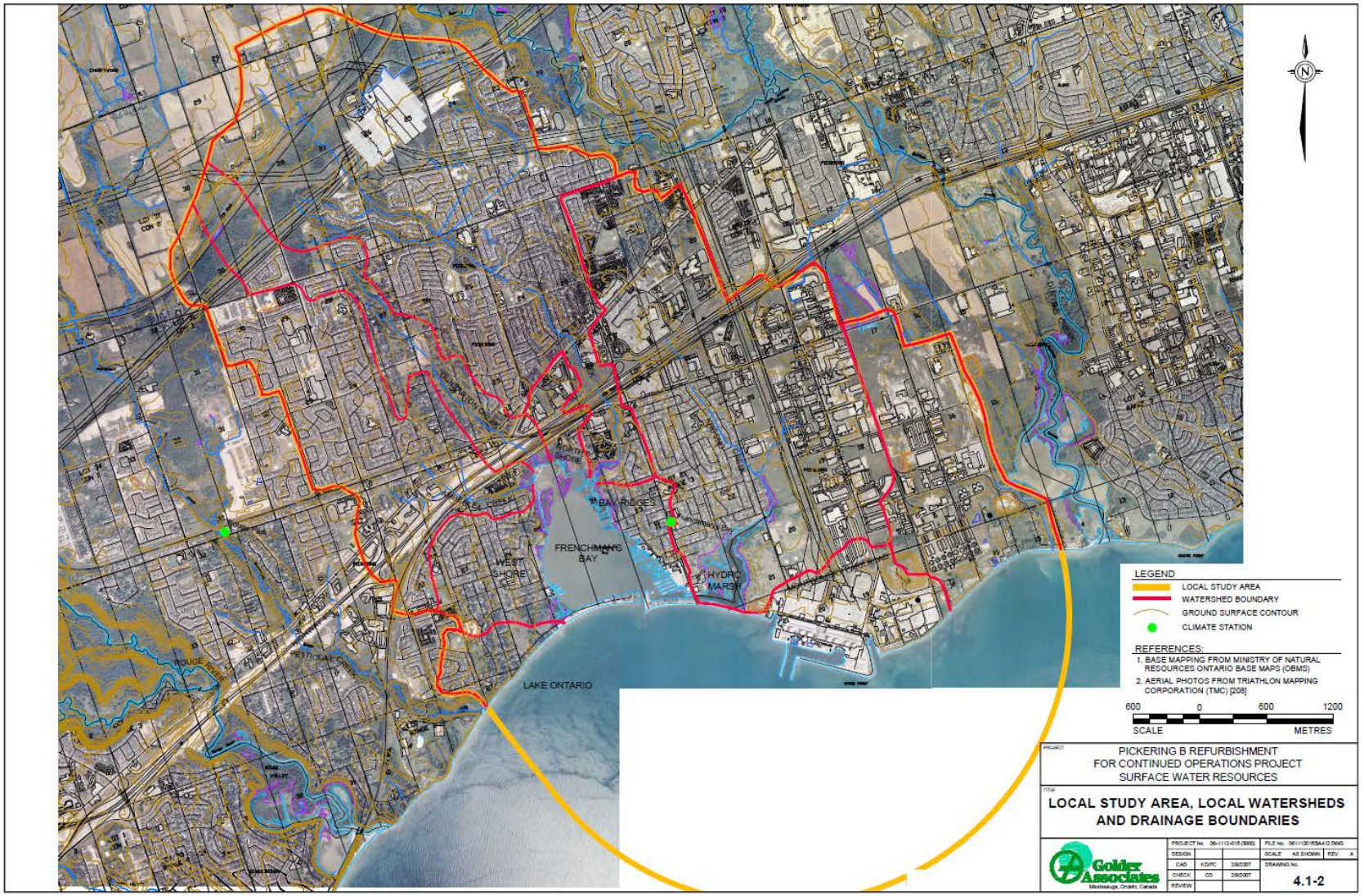


Figure 2.11: Local Study Area for Surface Water Resources, Local Watersheds and Drainage Boundaries (Golder, 2007a)

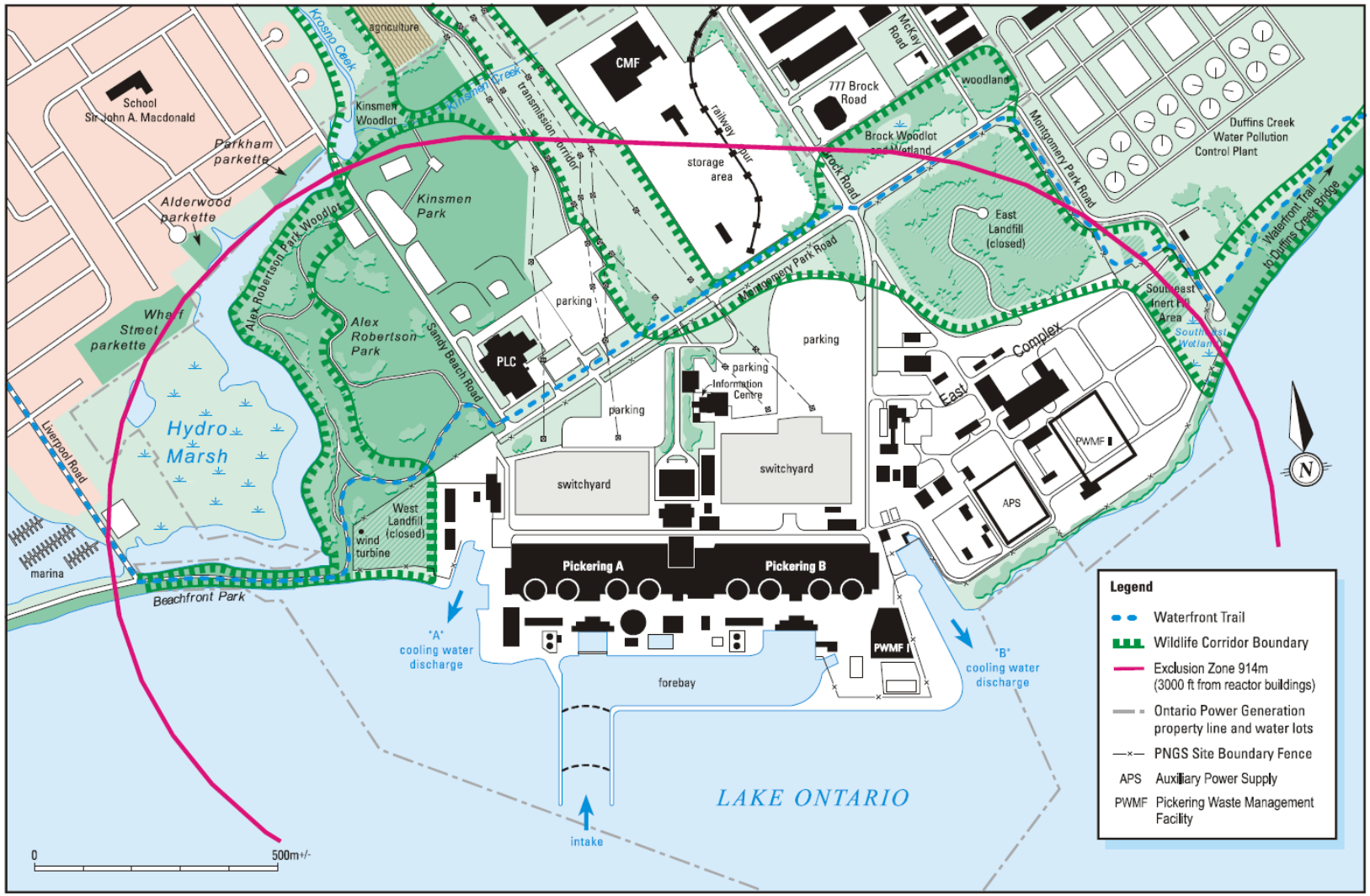


Figure 2.12: PN Site Plan (Golder, 2007a)

Figure 2.13: Catchment Areas for the Pickering Nuclear Generation Station

2.2.5 Vegetation Communities

This section provides a brief overview of regional vegetation communities and summarizes existing vegetation communities located in the SSA, LSA, and RSA. The site, local and regional vegetation communities and other components of the terrestrial environment are described in greater detail in Golder (2007c).

In 2009, Toronto and Region Conservation Authority (TRCA) biologists were contracted to establish a local monitoring project on PN property (OPG, 2011d). The OPG Terrestrial Long-Term Monitoring Project follows the conservation authority's regional monitoring protocol in forest, wetland and meadow habitat types on site. Monitoring will be conducted annually for a 5-year period which began in 2009. The purpose of the inventory is to detect changes and trends in the flora and fauna communities over time. A summary list of flora and fauna documented at the PN site is completed annually. A summary analysis and report will be completed after 5 years of data collection. Monitoring results for 2009, 2010 and 2011 were available at the time of this report. Species lists are provided in Golder (2007c) and OPG (2012b).

Much of the RSA has been cultivated over the past century. Accordingly, the dominant vegetation cover related to agricultural use, including cash crops and pasture land. Other natural vegetation features are associated with valley lowlands associated with rivers and creeks, and the Lake Ontario shoreline environment. The flora of the RSA generally falls into the Niagara section of the Deciduous Forest Region (Rowe, 1972 as cited in Golder, 2007c). Dominant tree species in the natural forest areas in the vicinity of the PN site include: beech, sugar maple, basswood, red maple, white oak and bur oak. The coastal wetlands, located between the permanent, deep water of the lake and the dry uplands area, contain a mix of plant communities. Examples of vegetation communities in coastal wetlands include treed and thicket swamps, wet grass and sedge meadows, and emergent marshes that contain plants such as cattails and bulrushes. Coastal wetlands often contain interspersed pockets of open water that support submerged and floating leafed plants such as pondweeds and waterlilies.

Vegetation communities within and in the vicinity of the PN site are identified in Figure 2.14. The vegetation communities were identified based on the Ontario Ministry of Natural Resources (OMNR) Ecological Land Classification (ELC) for Southern Ontario (Lee *et al*., 1998, cited in Golder, 2007c). The vegetation communities are classified into four terrestrial communities (#1 to #4), six wetland communities (#5 to #10), one open water community (#11) and four cultural communities (#12 to #14). As shown in the figure, the portion of the PN site south of Montgomery Park Road is largely dedicated to industrial use while most of the PN site north of Montgomery Park Road is vegetated. The vegetated lands north of Montgomery Park Road are occupied by public parkland, athletic fields and a transmission corridor.

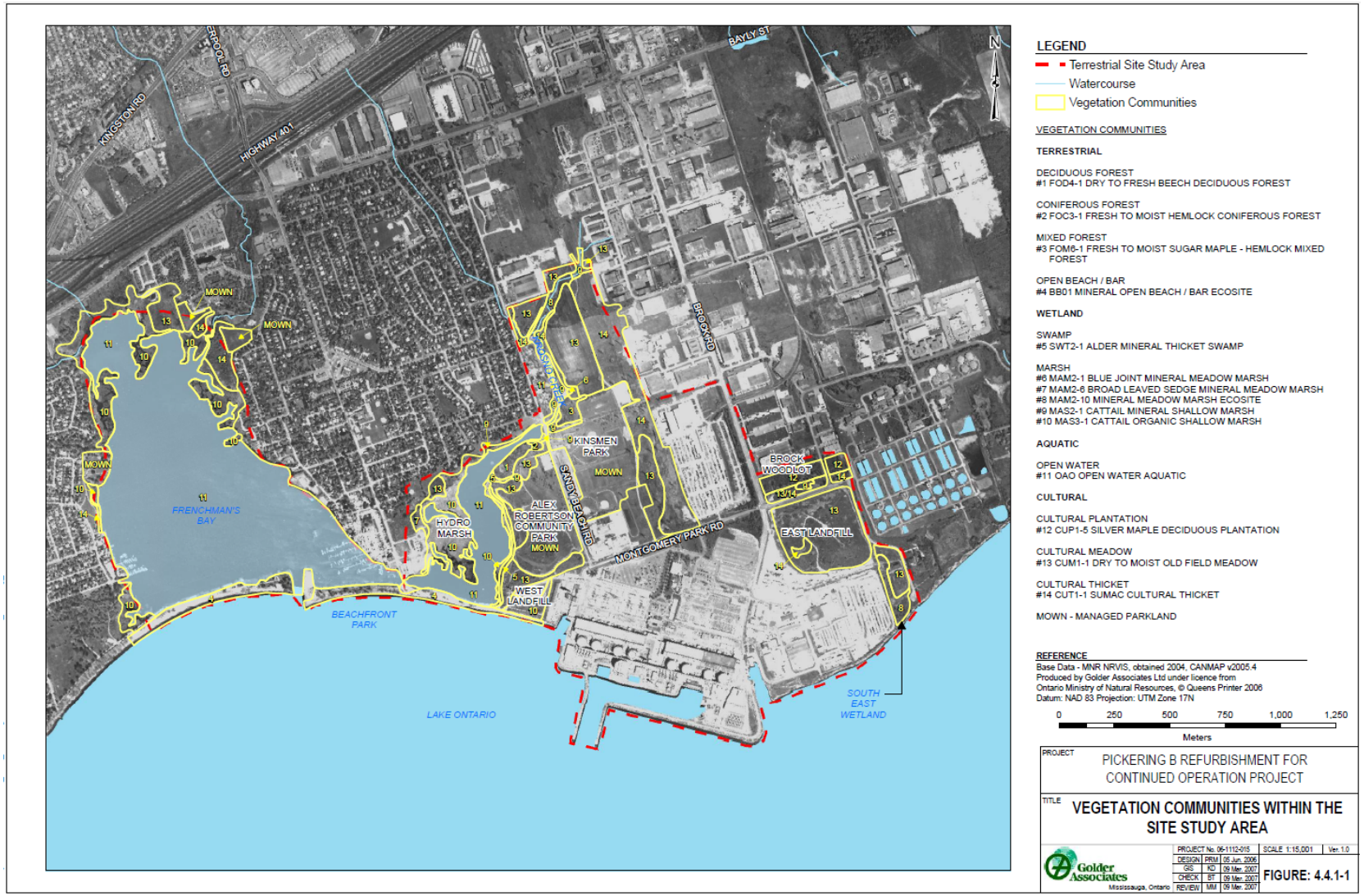


Figure 2.14: Vegetation Communities Within and in the Vicinity of the PNGS Site (Golder, 2007c)

2.2.5.1 Terrestrial Vegetation Communities

The terrestrial vegetation systems are upland areas where the water table is normally below the substrate surface. Four terrestrial community types were identified in the vicinity of PNGS, including deciduous, coniferous, and mixed forest areas, and an open beach/bar.

The forest communities are small independent areas (less than 2 ha) located along Krosno Creek upstream of Hydro Marsh. They include a 1.57 ha remnant deciduous forested area at the north end of Alex Robertson Park, a 0.25 ha coniferous forest community located within the Alex Robertson Woodlot and a 1.07 ha remnant mixed forest area located just north of Kinsmen Park. The three forest communities generally consist of mature trees which form a closed canopy and result in a poorly defined shrub layer. Open canopy conditions are present in the south end of the deciduous forest community of Alex Robertson Park resulting in an abundant shrub layer. Two butternut trees (designated as a nationally endangered species by COSEWIC, provincially endangered by COSSARO and protected under Ontario's *Endangered Species Act*) are present along the north edge of the Mixed Forest lot north of Kinsmen Park.

The open beach/bar is confined along the Lake Ontario shoreline, east and west of the mouth of Frenchman's Bay. This vegetation community is confined to an area near the water level that is generally subject to active shoreline processes including periodic high water levels, wave action, erosion, deposition and ice scour. The southern portions of this community, adjacent to the lake, generally support sparse vegetation cover. The vegetation cover increases in the central and northern portions of this community where wave action and ice scour occur less frequently. The structure of this vegetation community generally consists of old field vegetation and tree and shrub regeneration. The north part of the eastern bar adjacent to Hydro Marsh is protected for naturalization. A habitat restoration area has been established north of the boardwalk on the eastern bar. This area has been planted with species historically found on beaches of the Great Lakes.

2.2.5.2 Wetland Vegetation Communities

Wetland vegetation systems include areas where water levels fluctuate and are less than 2 m in depth. One swamp thicket area and five marsh areas were identified within and in the vicinity of the PN site.

The swamp thicket area is a narrow linear community located along the east margin of Hydro Marsh and forms a riparian interface between Hydro Marsh and the lower slope area of Alex Robertson Park. The vegetation is dominated by shrubs, especially speckled alder. The lower slope area of this community, where a drier soil regime is present, supports shrubs, including raspberry and elderberry, and planted trees, including silver maple and cottonwood.

The marsh communities are classified by vegetation and environmental characteristics, such as duration of flooding, substrate type, disturbance and available nutrients. Marsh

communities around Frenchman's Bay, Hydro Marsh and in the West Landfill area of PNGS grow on organic substrates, while the marsh communities in the upper section of Krosno Creek and the eastern portion of the PN site grow on mineral materials substrates. Three of the marsh communities are classified as meadow marshes indicating that the wetland-terrestrial interface is seasonally inundated with water and usually dominated by grasses or forbes. Two marsh communities are classified as shallow marshes, indicating that the water table rarely drops below the substrate surface and the vegetation community is composed primarily of broad-leafed or narrow-leafed emergent species. The wetland communities associated with the central and western portions of Hydro Marsh and the central and northern portions of Frenchman's Bay are organic shallow marshes dominated by dense stands of broad-leaf cattail and narrow-leaf cattail. The Southeast Wetland situated at the eastern shoreline of the PN site is classified as a mineral meadow marsh ecosite. The Southeast Wetland is on a poorly drained mineral soil that receives runoff from adjacent lands from the west and north, as well as stormwater drainage through a culvert under the southern end of the Montgomery Park Road. The vegetation community is dominated by common reed, but includes pockets of dense shrub growth and sporadic tree growth.

2.2.5.3 Open Water Vegetation Community

Open water vegetation communities are generally aquatic communities in which the permanent water is generally deeper than 2 m and the total vegetation cover is greater than 25%. An open water vegetation community occupies the majority of Frenchman's Bay and the main channel associated with the lower reaches of Krosno Creek and Hydro Marsh. In Hydro Marsh, most of the open water is less than 0.5 m deep and substrates in the upstream areas can be exposed depending on the water level in Lake Ontario. Aquatic vegetation is sparse and is limited to isolated pockets of floating duckweed species.

2.2.5.4 Cultural Vegetation Communities

Cultural vegetation communities originate from, or are maintained by anthropogenic influences and culturally based disturbances. They often contain a large proportion of non-native species. In addition to large areas of mown parkland located in the Alex Robertson Park and the Kinsmen Park, three cultural community types were identified within or in the vicinity of the PNGS site, including a cultural plantation, a cultural meadows and cultural thicket.

The 2.3 ha forested area located north of Montgomery Park Road and east of Brock Road, the Brock Woodlot, is classified as a Silver Maple Deciduous Plantation. The woodlot consists of rows of silver maple, white ash, black locust and eastern cottonwood, oriented in an east-west direction. Fifteen bird nesting boxes were installed in the plantation in 2004 to provide nesting opportunities and trees and branches resulting from selective thinning activities conducted in 2004 were left on the woodlot floor to provide brush pile habitat for small animals.

Cultural meadows are open vegetation communities that support less than 25% tree cover and less than 25% shrub cover. These communities develop in areas that have not been subjected to mowing practices and typically represent an early stage of natural succession. This vegetation type is the most common community type at the PN site. Cultural meadow vegetation occurs throughout the East and West Landfill Sites, adjacent to the Southeast Wetland, along portions of the hydro corridor, along the south side of the Brock Woodlot and in areas of Alex Robertson Park that have been allowed to naturalize.

Cultural thickets are characterized by tree cover less than 10% and tall shrub cover greater than 25%. These communities represent a more advanced state of natural regeneration than cultural meadow areas. Within the PN site, cultural thicket vegetation is most predominant along the east side of the hydro corridor. These communities consist of old field meadow species and thicket vegetation that has been allowed to naturalize for some time. Shrubs are densely arranged in most areas, and openings within the thicket vegetation is dominated by herbaceous species typical of cultural meadow communities.

2.2.5.5 Vegetation Species at Risk

A list of the plant species that have been recorded at the PNGS site, along with their regional federal and provincial conservation status ranking, is provided in Golder (2007c) and OPG (2012b). The list includes observations from the 2009 to 2011 inventories as well as earlier referenced observations for the area. Four plant species (Table 2.10) with a provincial rarity ranking of critically imperiled (S1), imperiled (S2) or vulnerable (S3) threatened or endangered were recorded at the PNGS site.

Table 2.10: Plant Species at Risk Observed within the PNGS Site Area (OPG, 2012b)

Scientific Name	Common Name	Federal Ranking	Provincial Ranking	Year Last Observed
Juglans cinerea	Butternut	Endangered	Endangered	2011
Lespedeza virginica	Slender bush-clover	Endangered	Endangered	2000
Gymnocladus dioicus	Kentucky coffee-tree	Threatened	Threatened	2000
Morus rubra	Red mulberry	Endangered	Endangered	2000

Note:

The Provincial Species at Risk in Ontario List and Federal List of Wildlife Species at Risk are frequently revised.

2.2.5.6 Wildlife Habitat

Wildlife habitat is associated with the vegetation communities and natural and developed areas found within. This section summarizes the potential use of different vegetation communities by wildlife species that have been recorded at the PN site. Detailed description of wildlife communities and species recorded at the PN site and their use of the different habitats is provided in Golder (2007c). Documentation of wildlife communities and species derived from historical records, wildlife mortality survey work conducted for the

PNGS A Return to Service Environmental Assessment and associated follow-up and monitoring undertaken from 2004 to 2006 were reviewed (Golder, 2007c). In summary, three amphibian species, seven reptile species, 247 bird species and 23 mammal species have been reported to occur within or in the vicinity of the PN site.

Terrestrial animal species at risk that have been recorded at the PN site, along with their federal and provincial ranking, are listed in OPG (2012b). The list includes observations from the 2009 to 2011 inventories as well as earlier referenced observations for the area. Three reptile species, eight bird species and one insect species at risk (Table 2.11) with a provincial ranking of threatened or special concern were recorded at the PN site.

Table 2.11: Terrestrial Animal Species at Risk Observed within the PNGS Site Area (OPG, 2012b)

Scientific Name	Common Name	Federal Ranking	Provincial Ranking	Year Last Observed
Amphibians and Reptiles				
Chelydra serpentina	Snapping Turtle	Special Concern	Special Concern	2009
Emydoidea blandingii	Blanding's Turtle	Threatened	Threatened	2006
Graptemys geographica	Northern Map Turtle	Special Concern	Special Concern	2006
Birds				
Chaetura pelagica	Chimney Swift	Threatened	Threatened	2008
Chlidonias niger	Black Tern	-	Special Concern	2008
Chordeiles minor	Common Nighthawk	Threatened	Special Concern	2010
Dolichonyx oryzivorus	Bobolink	Threatened	Threatened	2006
Falco peregrinus	Peregrin Falcon	Special Concern	Threatened	2010
Haliaeetus leucocephalus	Bald Eagle	-	Special Concern	2007
Hirundo rustica	Barn Swallow	-	Threatened	2011
Insects				
Denaus plexippus	Monarch	Special Concern	Special Concern	2011

Note:
The Provincial Species at Risk in Ontario List and Federal List of Wildlife Species at Risk are frequently revised.

Wetlands

Marsh and swamp habitat is found both in Frenchman's Bay Marsh and Hydro Marsh and extends to a limited degree in Krosno Creek upstream of Sandy Beach Road. A small marsh habitat also occurs in the naturalized area to the south of East Landfill (referred to as the southeast wetland) and along the south edge of the West Landfill. Frenchman's Bay and Hydro Marsh contain a large area of open shallow water surrounded by a cattail perimeter. The open water portion of the marsh does not contain submergent vegetation so

this portion is used primarily by gulls, ducks, geese and swans for limited foraging for items such as insects, while the perimeter areas are used by a variety of bird species for nesting and foraging. Birds that may use the perimeter areas include red-winged blackbird and black-crowned night heron. The open water and perimeter areas are used by aquatic mammals, such as muskrat, amphibians (American toad, green frog and northern leopard frog) and reptiles (snapping turtle, midland painted turtle, northern map turtle, Blanding's turtle, red-eared slider, eastern garter snake, Dekay's brownsnake).

Woodland

Woodland refers to a treed community having 35% to 60% cover by coniferous or deciduous trees. Woodland habitat within the PN site is generally limited to the Brock Woodlot and Alex Robertson Woodlot, as well as the wooded area along the east edge of Krosno Creek. Woodland habitat is used for nesting foraging and roosting by resident and migratory bird species. Small mammals will also use these sites for shelter, foraging and reproduction.

Shrubland

Shrubland habitat occurs at the edge of the woodland habitat areas and in areas where trees and shrubs have been permitted to grow at coverage percentages <35% to 60%. Shrubland habitat is located at the south edge of the Brock Woodlot and along the west side of Alex Robertson Community Park adjacent to the Hydro Marsh and its woodland areas. Shrubland habitat also occurs in the beach/bar, Alder Mineral Thicket Swamp, Broad-leaved Sedge Mineral Meadow Marsh, Mineral Meadow Marsh Ecosite and the Sumac Cultural Thicket communities show on Figure 2.14. This transitional habitat between field and forest is used by a combination of field and woodland bird species that prefer dense shrub cover for nesting and foraging and by small mammals for shelter, foraging and reproduction.

Open Grassland

Open grassland includes those open areas that are either natural or seeded and then left in a relatively natural state. Open grassland habitat is available in the cultural meadow vegetation of the East and West Landfills, adjacent to the Southeast Wetland, along portions of the hydro corridor, along the south side of the Brock Woodlot and in areas of Alex Robertson Park that have been allowed to naturalize. Open grassland can provide habitat for species that prefer grassland and prairies. It will be used by birds for nesting, foraging and shelter, and small mammals for shelter, foraging and reproduction.

Parkland

Parkland is those habitats that are managed for recreational or aesthetic purposes. Parkland habitat includes portions of Kinsmen Park, Alex Robertson Community Park, and the various areas of maintained lawn. While habitat is limited in this area due to the lack of

vegetation cover and diversity, certain species, such as swallows, nighthawks, swifts and bats, will make use of the open area to forage.

Shoreline and Open Water Habitat

Shoreline habitat consists of the Open Beach/Bar community shown in Figure 2.14. This area provides a small amount of habitat for loafing and foraging by waterbirds, particularly wading birds and geese. The open water portions of the PN site are also used by waterbirds for resting and foraging, and provide feeding opportunities for resident species such as ducks, gulls, terns and swans.

Pickering Nuclear Built Environment

The PN site includes buildings and man-made structures that provide habitat for wildlife. Buildings provide habitat suitable for common urban bird species and rodents that are tolerant of noise and activity associated with the daily operations of the station. Habitat conditions within the envelope of the generating station buildings are typically marginal due to the lack of cover, shelter and food. The taller buildings and their auxiliary structures provide opportunity for raptors and other species to scan for food sources and provides roosting opportunities for other species such as doves and sparrows. The black-crowned night-heron, which is classified as a vulnerable species in the province, is commonly observed roosting on cables across the PNGS B discharge channel. Much of the PN built environment occurs within fenced areas, restricting the movement of larger mammals within this area; however, white-tailed deer and red fox are occasionally recorded within the fenced areas. Red fox den sites are located within the fenced area.

The constructed shoreline, where the station meets Lake Ontario, consists of large areas of armourstone. These areas provide loafing opportunities for gulls and small mammals that inhabit rock crevices and small vegetated areas that have opportunistically grown up along the shoreline.

The PN intake forebay and PNGS A and B discharge channels provide both loafing and foraging habitat for a variety of waterbird species. These areas remain ice-free throughout the winter and offer shelter from Lake Ontario during inclement weather. In the case of the discharge channels, the warmer discharge water provides unique opportunities for fish and invertebrates, resulting in concentrated foraging opportunities.

2.2.6 Aquatic Communities

This section describes existing aquatic communities focusing on the SSA and LSA (Figure 2.15 and Figure 2.16), as these two areas encompass the larger area in which direct effects of the PNGS may be measurable. The RSA, which encompasses areas of Lake Ontario outside of the LSA, is discussed in terms of regional fish and invertebrate populations that migrate into the SSA and LSA. More detailed descriptions of site, local and regional aquatic environments and the aquatic communities therein are provided in Golder (2007b).

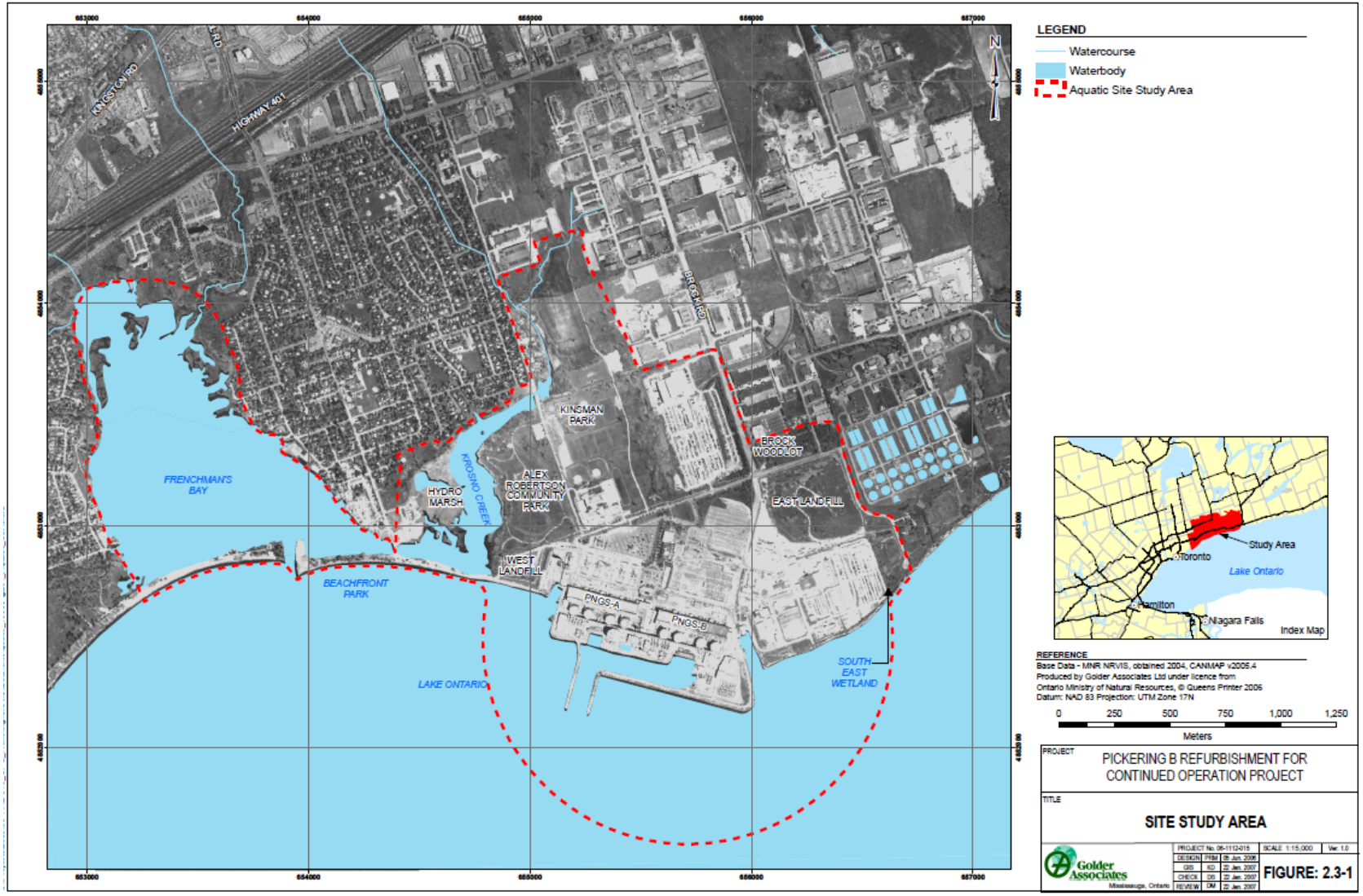


Figure 2.15: Aquatic Site Study Area (Golder, 2007b)

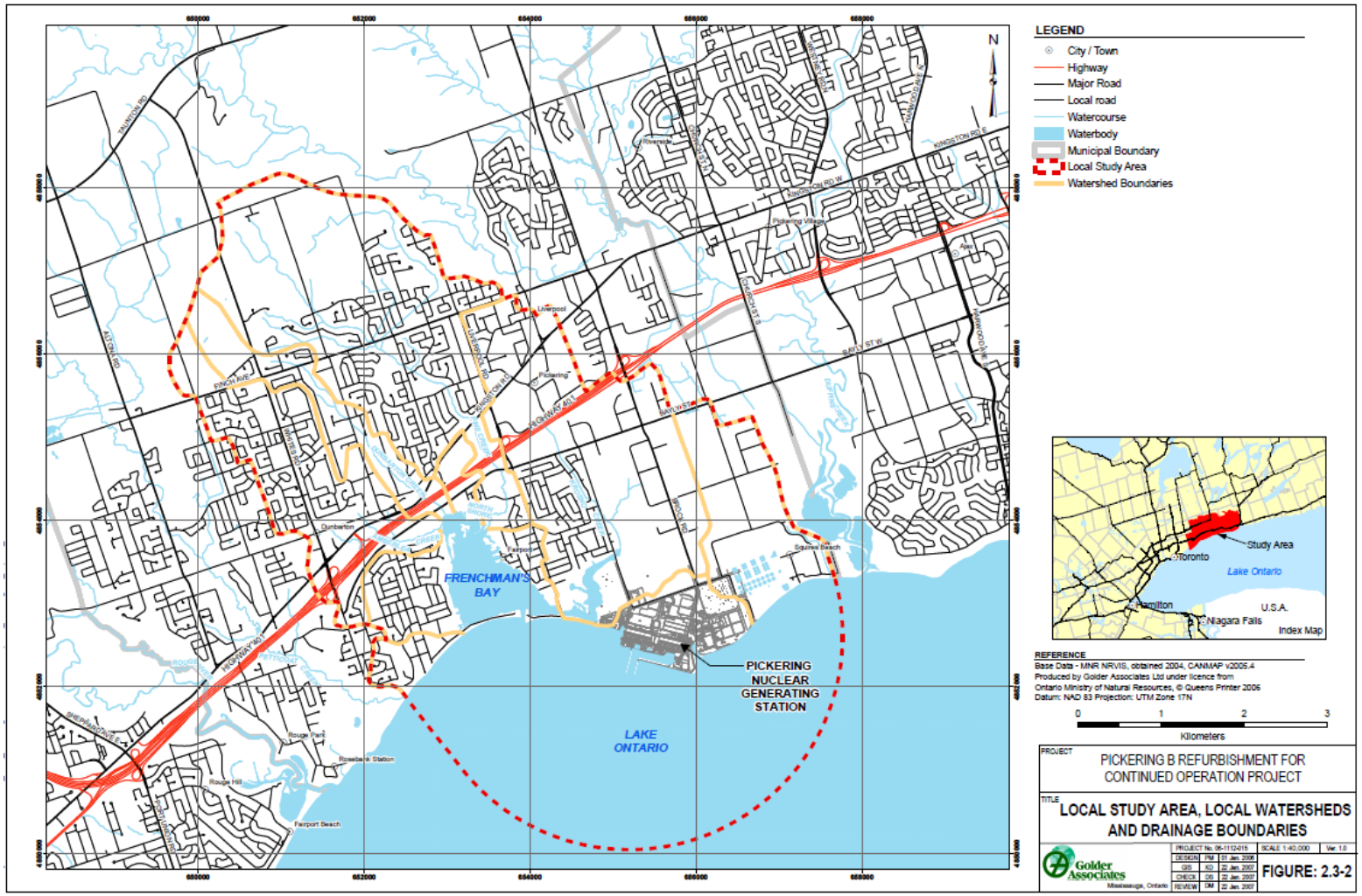


Figure 2.16: Aquatic Local Study Area (Golder, 2007b)

2.2.6.1 Periphyton, Phytoplankton and Zooplankton Communities

Plankton communities in the vicinity of the PNGS are highly variable and have undergone significant changes over the past 30 years that are not related to PNGS A and B activities. For example, changes to nutrient loadings, fluctuating populations of pelagic planktivores, colonization by the filter feeding zebra mussel and introduction of exotic zooplankton predators have altered the plankton community structure of Lake Ontario. Therefore, the use of historical information, prior to the mid-1970s, in describing current conditions may be of limited use based on the ecosystem changes in Lake Ontario.

Since the 1970s, phytoplankton biomass has declined in Lake Ontario presumably due to phosphorus reduction programs and the colonization of zebra mussels (Environment Canada *et al*., 1998). Diatoms dominate the overall phytoplankton community in diversity and biomass. In summer, during stable stratified conditions, phytoplankton communities in Lake Ontario shift away from diatoms to include substantial contributions to biomass by chlorophytes, cyanophytes and dinoflagellates (Barbiero and Tuchman, 2001). Decreases in the densities of several major algal groups, including diatoms, chlorophytes and cryptophytes, have contributed to the overall decrease in algal density observed in nearshore algal communities along the northshore of Lake Ontario (Winter *et al*., 2012).

The zooplankton community in Lake Ontario is dominated by a small number of species and the current community composition appears to have been stable since the 1960s (Barbiero *et al*., 2001, Lampman, 1999). The total crustacean densities and species richness are generally higher during the summer than in the spring. Structuring of the zooplankton community is affected by the intense planktivory particularly by alewives. Dominant zooplankton groups include crustaceans, primarily cyclopod copepods, along with cladocerans, *Bosmin*a and *Daphnia* (Barbiero *et al*., 2001).

Periphyton is benthic algal material. The periphyton community near PNGS-A and -B are dominated by the filamentous algae *Cladophora glomerata* that grows attached to solid substrata and forms dense growths that are periodically detached by waves and wash ashore. *Cladophora* growth is limited by availability of phosphorous and light penetration (substratum availability). Phosphorous reduction programs in Lake Ontario initially resulted in a reduction in *Cladophora* productivity. However, habitat availability for *Cladophora* and overall productivity have increased since the 1990s, due to reduced algal growth and colonization of the lake by filter feeding zebra and quagga mussels which have reduced water turbidity and offset reductions (Higgins *et al.*, 2008, Auer *et al.*, 2010).

2.2.6.2 Benthic Invertebrates

The benthic community of the north shore of Lake Ontario is characteristic of the unstable, relatively severe conditions typical of the exposed coast. Small crustaceans (especially the benthic amphipod, *Diporeia* spp.*)* and worms (oligochaetes) have historically dominated the open water benthic communities of Lake Ontario. Benthic community studies conducted

from 1976 to 1978, indicated that the community was dominated by oligochaetes and chironomids, and contained significant numbers of amphipods, molluscs and ostracods (Lush 1981, cited in Golder 2007b). Representatives of the more environmentally sensitive groups such as Ephemeroptera and Trichoptera were rare. Most of the dominant taxa had higher abundances at sites within or close to the PNGS A thermal plume than at reference sites. Diversity was generally higher in the spring/fall than in the summer/winter seasons. The diversity of the invertebrate community at sites with a depth of 6 and 10 m were influenced by the thermal plume and diversity was significantly lower than for the reference sites. This observation was attributed to an increase in the relative abundance of certain species and not to a reduction in species numbers. No differences in diversity were noted at the 1 m sites, presumably due to the exposed conditions that masked plume effects. Gastropods and bivalves had low relative abundances due to wave abrasion and/or unsuitable substrates at shallow locations. Appearance of chironomid, amphipod and oligochaete increased in the vicinity of the discharge channels (1 m sites) where the algae, *Cladophora*, was present.

More recently, zebra mussels and quagga mussels have colonized the nearshore areas in the vicinity of PNGS and are now very abundant. Benthic organisms which have possibly been negatively affected by zebra and quagga mussels' colonization in nearshore areas of the lake include *Dipoteia* spp., oligochaetes, sphaerid clams, and unionid clams (Golder 2007b).

2.2.6.3 Fisheries

More than 90 species of fish are known to inhabit Lake Ontario. Almost all of these species make use of nearshore waters of the lake for spawning, rearing, feeding, and migrations. Many of these species rely on habitats contained within coastal marshes, embayments and estuaries. Examples of these habitats within the SSA and LSA include Hydro Marsh, Frenchman's Bay and the Mouths of the Rouge River and Duffins Creek.

Fish species at risk that have been recorded at the PN site, along with their federal and provincial ranking, are listed in OPG (2012b). The list includes observations from the 2009 to 2011 inventories as well as earlier referenced observations for the area. Three fish species at risk (Table 2.12) with a provincial ranking of threatened, endangered or extirpated were recorded at the PN site. Atlantic Salmon were observed within the area as recently as 2010. The Atlantic Salmon Lake Ontario Population is listed as extirpated federally and provincially. Atlantic Salmon found in Lake Ontario are likely individuals from the Atlantic Salmon stocking program and are not considered individuals of the native Lake Ontario Population.

Table 2.12: Fish Species at Risk Observed within the PNGS Site Area (OPG, 2012b)

Scientific Name	Common Name	Federal Ranking	Provincial Ranking	Year Last Observed
Fish				
Acipenser fulvescens	Lake Sturgeon	Threatened	Threatened	2005
Anguilla rostrata	American Eel	Threatened	Endangered	2011
Salmo salar	Atlantic Salmon *	Extirpated	Extirpated	2010

Notes:

The Provincial Species at Risk in Ontario List and Federal List of Wildlife Species at Risk are frequently revised.

* Atlantic Salmon (Lake Ontario Population) is listed as extirpated. Atlantic salmon found in Lake Ontario are likely individuals from the Atlantic Salmon stocking program and are not considered individuals of the native Lake Ontario Population.

The fish community may be divided into resident and migratory species. Migratory species are only seasonally present in the Lake Ontario nearshore, these include pelagic fishes such as Rainbow Smelt, Alewife and Brown Trout which make seasonal spawning migrations into the nearshore zone, including entering the discharge channels and the intake forebay of PNGS; and inshore fishes which occupy coastal marshes and river mouth habitats and enter the nearshore zone when water temperature and velocity conditions are favourable. Table 2.13 lists resident and migratory fish species selected to represent the fish community in the site and local study areas.

Table 2.13: Common and Scientific Names of Resident and Migratory Fish Species at PNGS (Golder, 2007b)

Resident Fish Species		Migratory Fish Species	
Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
Longnose Gar	*Lepisosteus osseus*	Sea Lamprey	*Petromyzon marinus*
Bowfin	*Amia calva*	Lake Sturgeon	*Acipenser fulvescens*
American Eel	*Anguilla rostrata*	Alewife	*Alosa pseudoharengus*
Gizzard Shad	*Dorosoma cepedianum*	Lake Chub	*Couesius plumbeus*
Goldfish	*Carassius auratus*	Emerald Shiner	*Notropis atherinoides*
Common Carp	*Cyprinus carpio*	Spottail Shiner	*N. hudsonius*
Common Shiner	*Luxilus cornutus*	Longnose Sucker	*Catostomus catostomus*
Golden Shiner	*Notemigonus crysoleucas*	White Sucker	*C. Commersoni*
Mimic Shiner	*N. Volucellus*	Redhorse Sucker	*moxostoma spp.*
Bluntnose Minnow	*Pimephales notatus*	Rainbow Smelt	*Osmerus mordax*
Fathead Minnon	*P. promelas*	Lake Herring	*Coregonus artedi*
Longnose Dace	*Rhinizchethys cataractae*	Lake Whitefish	*C. clipeaformis*
Quillback	*Carpiodes cyprinus*	Pink Salmon	*Oncorhynchus gorbuscha*
Black Bullhead	*Amejurus melas*	Coho Salmon	*O. kisutch*
Brown Bullhead	*A. nebulosus*	Rainbow Trout	*O. mykiss*

Resident Fish Species		Migratory Fish Species	
Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
Channel Catfish	*Ictalurus punctatus*	Chinook Salmon	*O. tshawytscha*
Stonecat	*Noturus flavus*	Round Whitefish	*Prosopium cylindraceum*
Northern Pike	*Esox lucius*	Atlantic Salmon	*Salmo salar*
Trout-perch	*Percopsis omiscomaycus*	Brown Trout	*Salmo trutta*
Brook Silverside	*Labidesthes sicculus*	Brook Trout	*Salvelinus fontinalis*
Brook Stickleback	*Culaea inconstans*	Splake	*S. fontinalis X S. namaycush*
White Perch	*Morone americana*	Lake Trout	*S. namaycush*
White Bass	*M. chrysops*	Threespine Stickleback	*Gasterosteus aculeatus*
Rock Bass	*Ambloplites rupestris*	Mooneye	*Hiodon tergisus*
Pumpkinseed	*Lepomis gibbosus*		
Bluegill	*L. macrochirus*		
Smallmouth Bass	*Micropterus dolomieu*		
Largemouth Bass	*M. salmodies*		
White Crappie	*Pomoxis annularis*		
Black Crappie	*P. nigromaculatus*		
Johnny Darter	*Etheostoma nigrum*		
Yellow Perch	*Perca flavescens*		
Logperch	*Percina caprodes*		
Walleye	*Sander vitreus*		
Freshwater Drum	*Aplodinotus grunniens*		
Slimy Sculpin	*Cotius cognatus*		
Mottles Culpin	*C. bairdi*		

Note:
Data derived from LGL Limited, 1992; Toronto and Region Conservation Authority, 1999; Golder Associates, 2000, as cited in Golder, 2007b.

Spawning and Rearing Habitats

On a local level, the exposed shoreline of Lake Ontario provides rocky substrates for lake trout and round whitefish spawning in the shallow nearshore waters east of PNGS-A and -B. Both east and west of PNGS, the Lake Ontario nearshore areas support broadcast spawning by emerald shiner. Juvenile habitat for lake trout, round whitefish and emerald shiner exist both east and west of PNGS as well. The Rouge River mouth and Duffins Creek contains spawning and juvenile habitats for northern pike, smallmouth bass and emerald shiner and juvenile habitat for white sucker. Frenchman's Bay may provide spawning and juvenile habitat for smallmouth bass, northern pike, white sucker and emerald shiner.

Spawning habitat for smallmouth bass, northern pike and emerald shiner exists within the SSA. Smallmouth bass spawning and nest-building occur within the PNGS-A and -B

discharge channels. The shoreline is a high energy habitat, due to the effects of Lake Ontario wave action and fish species are not likely to use it as spawning habitat with the possible exception of emerald shiner. Northern pike and emerald shiner may use Hydro Marsh as spawning habitat. The SSA also provides rearing habitats for immature stages of some species, such as smallmouth bass (PNGS A and B discharge channels, the armoured shoreline, and Hydro Marsh), round whitefish (PNGS A discharge channel and the armoured shoreline), white sucker (PNGS A and B discharge channels) and emerald shiner (the armoured shoreline).

Foraging Habitats

Foraging opportunities may be seasonal and dependant on local conditions. For example, lake trout can only forage in the nearshore zone when colder water temperatures exist due to the season or to wind-driven upwellings of colder lake water. Coldwater species such as lake trout and round whitefish, winter in Lake Ontario and are not likely to feed within the river mouth and marsh habitats. Warm and coolwater species such as smallmouth bass, northern pike, walleye, white sucker and emerald shiner, likely use the mouth of the Rouge River, Duffins Creek rivermouth/ marsh habitat, and Frenchman's Bay as foraging habitat.

Each of the habitats within the SSA provide foraging habitats for at least some fish species. Impingement monitoring suggests that large numbers of emerald shiners, alewife, smelt, round goby and juvenile gizzard shad occupy the intake forebay. Piscivores, such as smallmouth bass, northern pike, walleye and lake trout have also been observed and may feed on these schools of baitfish. Round whitefish and white sucker may feed on bottom dwelling invertebrates associated with aquatic vegetation and the variety of substrates found within the forebay. The armoured shoreline may provide foraging habitat for many fish species including northern pike, walleye and lake trout which are attracted to schools of small planktonivorous fishes such as the emerald shiner that are common in the shallows along the breakwalls. Smallmouth bass may use the protective cover and foraging opportunities provided in the spaces among the armour, and white sucker and round whitefish may feed on benthic invertebrates in the shallow water adjacent to the armoured shoreline.

Migration and Overwinterings

Walleye, lake trout, round whitefish, white sucker and emerald shiner may follow the shoreline on regional or local migrations to and from deeper water. Smallmouth bass and northern pike are more closely associated with coastal marshes and embayments but may migrate between those habitats by following the Lake Ontario shoreline. Migrations into Duffins Creek mouth may include spawning runs of northern pike, suckers and brown trout in the spring and introduced pacific salmon in the fall, movements between protected warmwater habitats, seasonal foraging movements and movements in response to wind-driven water temperature changes. Smallmouth bass, northern pike, white sucker and

emerald shiner migrate into, between or among the sheltered warmwater habitats along the shores of Lake Ontario, including the Duffins Creek mouth.

Winter habitats for walleye, lake trout, round whitefish, white sucker and emerald shiner are found in the nearshore waters of Lake Ontario in the LSA. White suckers are tolerant of a wide range of water temperatures and are year-round inhabitants of the nearshore zone, and lake trout and round whitefish occupy nearshore areas when temperatures permit, throughout the year. Overwintering habitats may exist in Duffins Creek for smallmouth bass, northern pike and emerald shiner and in Frenchman's Bay for smallmouth bass, northern pike, walleye, white sucker and emerald shiner. Walleye and white sucker may also migrate to Duffins Creek during the winter. Walleye are attracted by the thermal plume(s) during winter. Smallmouth bass and northern pike are more likely to overwinter within coastal marshes and, possibly, in the PNGS discharge and intake channels. Emerald shiner makes an offshore shift with the onset of winter, but is present in the nearshore zone at other times of the year.

2.2.7 Human Land Use

Aspects of regional, local and site human land uses have been presented in the Pickering B Refurbishment EA (SENES, 2007e) and the Human Health Technical Supporting Document (TSD) (SENES, 2007b). In this section, current land uses, agricultural production, water supply and recreational fishing are summarized.

2.2.7.1 Review of Durham Region and City of Pickering Land Use

PNGS is located in the Region of Durham, City of Pickering, on the north shore of Lake Ontario. It is approximately 21 km west southwest of Oshawa and approximately 32 km east of downtown Toronto. The Region of Durham and the City of Pickering have both urban and rural land uses. In general, the urban uses in the Region of Durham parallel the shoreline of Lake Ontario in the communities of Pickering, Ajax, Whitby, Oshawa and Clarington. The rural uses are in the northern portion of the municipality in the communities of Brock, Scugog and Uxbridge. The urban land uses in the City of Pickering, including residential, commercial and employment, are generally located south of 3rd Concession along Lake Ontario. The rural uses, including agricultural uses and rural hamlets, are generally located north of 3rd Concession.

PNGS is part of the Brock Industrial Neighbourhood, in the City of Pickering, immediately east of the Bay Bridges Neighbourhood, south of Highway 401, west of the Town of Ajax and north of Lake Ontario. The land use surrounding PNGS is largely urban, including industrial, residential and parkland. Duffins Creek WPCP is located to the east of the PN Site, and several marinas are located to the west of the PN Site along Lake Ontario. Frenchman's Bay and Hydro Marsh (class 2 wetlands) are located approximately 1.5 km to the west and Duffins Creek Marsh (class 3 wetland/ environmentally significant area/ area of natural and scientific interest) is located approximately 2.5 km to the east.

PNGS is approximately 240 ha in size with a continuous landscaped buffer paralleling all adjacent municipal roads. PNGS is fenced and access is restricted and controlled by OPG. There is a 914 m exclusion zone around PNGS. This exclusion zone limits the type of uses that can occur within its confines. The exclusion zone is predominantly owned by OPG. These lands are primarily used for industrial purposes related to electricity generation. Two public outdoor recreation parks, Alex Robertson Community Park and Kinsmen Park, are located approximately 600 m northwest of PNGS A, on lands leased by the City of Pickering.

2.2.7.2 Agricultural Production

An inventory of Ontario agricultural data was completed for the 2012 Pickering Nuclear Radiological Environmental Monitoring Program (OPG, 2013a) site specific survey using data from the 2011 Census of Agriculture conducted by Statistics Canada. The total area of land used for fruits, vegetables and potatoes in Ontario was estimated at 80,444 ha (804 km^2). Of that, 24.6% is used for fruit production, 56.6% is used for vegetable production and 18.8% is used for potato production. Assuming that agricultural production is uniform across Ontario, the total land used for fruit, vegetable and potato production within a 30 km radius semi-circle centered at PN was estimated to be 348 km^2, 800 km^2 and 266 km^2, respectively. Fruit, vegetable and potatoes production from within the 30 km radius semi-circle was estimated to be 4.1×10^8 kg, 2.1×10^9 kg and 5.1×10^8 kg, respectively.

In 2012, there were six commercial dairy farms operating within 20 km of the PNGS (OPG, 2013a).

2.2.7.3 Water Supply

Water supplies from four municipal water supply plants (WSP) are included in the PN REMP: the Ajax and Whitby WSPs situated east of PNGS, and J.F. Horgan and R.C. Harris WSPs situated southwest of PNGS. The water intake for the Ajax WSP located approximately 6.5 km east of the PN site is the nearest to of the four WSPs to the PN site. All four WSPs obtain their water from Lake Ontario. The water supply for the City of Pickering and the Town of Ajax is provided primarily from the Ajax WSP which services a population of almost 200,000. The more rural areas of Durham are supplied by individual water supply systems from either surface water intakes or ground water wells. The F.J. Horgan WSP services Scarborough and sells water to the York Region. The R.C. Harris WSP services eastern and central Toronto and also sells water to the York Region.

Table 2.14 summarizes the offshore distance and depth of the WSP intakes, WSP capacities, populations served and distance of the intakes from the PN site for each of the PN REMP WSPs, recommended for use in public dose calculations (OPG, 2013a).

Table 2.14: Water Supply Plant Information (OPG, 2013a)

	Distance of Intake from Shore (m)	Intake Depth (m)	Capacity (m^3/day)	Population Served	Estimated Distance of Intakes from PN (km)
R.C. Harris WSP	2,300	15	950,000	1,500,000	21.7 km SW
F.J. Horgan WSP	3,200	9	800,000	2,000,000	11.3 km SW
Ajax WSP	2,500	13.5	163,500	198,025	6.5 km E
Whitby WSP	1,710	15	118,000	121,455	12.3 km ENE

Note:
Ajax WSP's intake pipe is at a depth of 18 m, however the water is drawn in from an intake crib that is 13.5 m below the lake surface.

2.2.7.4 Recreational Fishing

Recreational fishing near the PN property is popular among local residents, but is not a widespread activity among people living in the study area. Results from a recreational fisheries survey undertaken by OPG in the fall of 1999 indicated that most recreation fishing activity nearest the PN property was shore angling rather than boat angling (SENES, 2007e). Of the shore angling sites, Frenchman's Bay was the most popular. At PNGS, smallmouth bass is targeted the most. At Frenchman's Bay salmon and trout were most commonly targeted but largemouth bass and common carp were most commonly caught. At the Rouge River, west of the PN site, the most prevalent catch was common carp.

2.2.8 Population Distribution

The majority of residents in Durham region live in urban areas. Over 90% of the population in Pickering, Ajax, Oshawa and Whitby reside in urban areas, whereas, the townships of Brock, Scugog and Uxbridge represent the greatest percentage of the rural population in Durham. Urban/rural population trends for Durham indicate this trend will continue into 2031 (DRPD, 2009).

Based on 2006 census data, Durham's population distribution clearly depicts the Boom (40 to 59 year range), Bust (30 to 39 year range), and Echo (15 to 29 year range) generations. Children under the age of 15 comprised 20.5% of the population in 2006, while young persons (aged 15-24), adults (aged 25-64) and older adults (aged 65+) comprised 14%, 55% and 10.7%, respectively (DRPD, 2009).

A population of approximately 2.2 million reside within a 30 km radius of the PN site, based on 2011 census data shown in Table 2.15 (OPG, 2013a). The bulk of this population (approximately 80% or 1.8 million) resides west of the PN site, in the southwest to north-north-west sectors, while approximately 20% (0.4 million) reside east of the PN site in the north to east-north-east sectors. Areas south and east of the PN site (south-south-west to east) are occupied by Lake Ontario. Approximately 0.2% of this population (3,359) reside within a 0 to 2 km radius of the PN site, 11% of this population (243,281) reside within a 0

to 10 km radius, and 26% (564,820 individuals) reside within a 0 to 16 km radius of the PN site.

Table 2.15: Population Distribution Surrounding PN Based on 2011 Census Data (OPG, 2013a)

Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-2 km	5	5	0	0	0	0	0	0	0	0	0	0	560	940	1,793	56	3,359
2-4 km	10	0	2,690	1,496	0	0	0	0	0	0	0	2,355	4,503	4,121	6,352	4,012	25,539
4-6 km	8,143	5,483	11,665	3,232	0	0	0	0	0	0	2,385	3,915	9,353	13,235	10,731	10,725	78,867
6-8 km	22,512	11,928	9,679	1,064	0	0	0	0	0	0	10,810	9,655	7,221	4,500	453	3,816	81,638
8-10 km	16,709	4,844	414	54	0	0	0	0	0	0	6,465	24,334	630	296	90	42	53,878
10-12 km	4,637	5,829	11,062	0	0	0	0	0	0	0	19,941	18,523	8,482	74	211	40	68,799
12-14 km	462	14,553	13,993	0	0	0	0	0	0	0	21,984	38,925	23,650	928	134	354	114,983
14-16 km	196	18,722	18,849	56	0	0	0	0	0	0	35,872	36,617	15,693	11,514	97	141	137,757
16-22 km	1,847	34,072	98,426	11,353	0	0	0	0	0	0	138,004	184,391	145,949	78,161	965	1,643	694,811
22-30 km	1,957	4,593	66,172	1,302	0	0	0	0	0	0	388,842	300,412	140,683	11,202	26,097	1,729	942,989
Total	56,478	100,029	232,950	18,557	0	0	0	0	0	0	624,303	619,127	356,724	124,971	46,923	22,558	2,202,620

3.0 HUMAN HEALTH RISK ASSESSMENT

3.1 Problem Formulation

3.1.1 Receptor Selection and Characterization

3.1.1.1 Receptor Selection

Human receptors are defined as on-site workers, contractors and visitors, as well as off-site members of the public.

3.1.1.1.1 On-site Non-Nuclear Energy Workers

On-site workers, contractors, and visitors are potentially exposed to environmental contaminants, both chemical and radiological, but these exposures are considered and controlled through the Conventional Safety Program (CSP) and the Radiation Protection Program (RPP), and are not considered in the HHRA, as discussed below.

The CSP is designed to ensure the protection of employees, contractors and visiting members of the public. The program outlines a systems approach used to manage risks associated with activities, products and services of OPG Nuclear operations. Contractors are required to maintain a level of safety equivalent to OPG staff while working at an OPG workplace. Work at OPG is subject to safe work planning requirements where safety hazards are identified and mitigating measures are planned for the work through Pre-Job Briefings. Routine or planned work is governed by approved procedures and operating instructions (OPG, N-PROG-HR-0004 R003).

The RPP is designed to ensure that doses for employees, contractors and visiting members of the public are below regulatory limits, and as low as reasonably achievable, social and economic factors being taken into account (ALARA). Employee radiation doses are monitored to ensure they do not exceed exposure control levels that are below regulatory limits. Doses to visitors and contractors are also monitored. Only workers classified as Nuclear Energy Workers (NEWs) may perform radioactive work. Visitors are limited to non-radioactive work and escorted by a qualified NEW. Personal information is collected for the purposes of dose reporting (OPG, N-PROG-RA-0013 R007)

Persons who are located on-site at a nuclear facility (within the exclusion zone) but who are not classified as NEWs are subject to the same dose limits as members of the general public (1 mSv/y). To verify that the doses to these non-NEW personnel indeed are within limits to the general public, a program to measure the airborne tritium and ambient gamma levels was undertaken. The results indicate that workers not routinely monitored are not exposed to radiation levels that could potentially lead to doses greater than that allowed to members of the general public (Surette, 2010).

Because human exposures on the site are kept within safe levels through the CSP and RPP, on-site receptors are not addressed further in the HHRA. The focus of the HHRA is on off-site members of the public.

3.1.1.1.2 Members of the Public

Off-site members of the public are potentially exposed to low levels of airborne or waterborne contaminants. The potentially most affected off-site members of the public are defined as "critical groups". Critical groups are defined through the site specific survey and used for dose calculations in the OPG Annual REMP Reports. The most recent site specific survey was completed in 2012 (OPG, 2013a), and concludes that the six potential critical groups identified in the 2006 site specific survey are still appropriate; however, the 2012 survey provides some updated critical group characteristics. The six potential critical groups are:

- C2 Correctional Institution
- Local Residents
- Local Farms
- Local Dairy Farms
- Sport Fishers
- Off-site Industrial/Commercial Workers

These six critical groups are appropriate for the exposure assessment for both radiological and non-radiological COPCs.

3.1.1.2 Receptor Characterization

The critical group receptor characteristics used for exposure assessment are described in Appendix E of the 2011 REMP Report (OPG, 2012c) and are presented below.

- The **C2** potential critical group consists of inhabitants at a correctional institute, located approximately 3 km NNE of the PN Site. The C2 group obtains drinking water from the Ajax WSP and does not consume locally produced fruits or vegetables. The C2 resident is conservatively assumed to be at this location 100 percent of the time over at least one year.

- The **Industrial/Commercial** potential critical group consists of adult workers whose work location is close to the nuclear site. Members of this group are typically at this location about 23% of the time. They consume water from the Ajax WSP. The closest location for this group is about 1 km NNE of the site.

- The **Urban Residents** potential critical group consists of Pickering and Ajax area residents which surround the PN Site (e.g., Fairport, Fairport Beach, Rosebank, Liverpool, Pickering Village, etc.). The members of this group mostly consume water from the Ajax WSP and also consume a diet composed in part of locally grown produce and an insignificant component of locally caught fish. Members of this

potential critical group are also externally exposed to beach sand at local beaches (Beachpoint Promenade, Liverpool Rd. Beach or Squires Beach).

- The **Farm** potential critical group consists of residents of agricultural farms (but not dairy farms) within a 10 km radius of the PN Site. Members of this group obtain most of their water supply from wells but also a portion from the Ajax WSP. Members of this potential critical group consume locally grown produce and animal products. They are also externally exposed to beach sand at local beaches (Beachpoint Promenade, Liverpool Rd. Beach or Squires Beach).

- The **Dairy Farm** potential critical group consists of residents of dairy farms within a 20 km radius of the PN Site. This group obtains most of their water supply from local wells. They also consume locally grown fruit and vegetables and locally produced animal products, including fresh cow's milk. Members of this potential critical group are also externally exposed to beach sand at local beaches (Beachpoint Promenade, Liverpool Rd. Beach or Squires Beach).

- The **Sport Fisher** potential critical group is comprised of non-commercial individuals fishing near the PN site outfalls, 0.5 km S of the PN site. Members of this group were conservatively assumed to obtain their entire amount of fish for consumption from the vicinity of the PN site and spend 1% of their time at the outfall location where atmospheric exposure occurs.

The receptors that are closest to the facility are the Sport Fisher, the Urban Resident, and the Industrial/Commercial Worker. Within each critical group three different age classes are defined: 0-5 years (infant), 6-15 years (child), and 16-70 years (adult), consistent with CSA N288.1-08 (CSA, 2008). Site-specific receptor data were used for the exposure assessment, where available. Otherwise, default receptor characteristics such as body weight, inhalation rates, ingestion rates etc. were obtained from sources as outlined in CSA N288.6-12. The radiological HHRA presents doses already reported in REMP reports from 2007 to 2011, using site-specific data from the 2006 site-specific survey (OPG, 2006a). For the non-radiological HHRA, site-specific data from the 2012 site-specific survey were used (OPG, 2013a).

As recommended by N288.6, human health radiological risk assessments should follow the guidance of CSA N288.1-08. With the exception of the drinking water intake rate for the 1 year old infant, the intake rates are the mean intake rates from CSA N288.1-08. As discussed in OPG (2010b), the drinking water intake rate for a 1 year old infant is 0 kg/yr since the 1 year old is assumed to only drink cow's milk.

3.1.2 Selection of Chemical, Radiological, and Other Stressors

3.1.2.1 Air

The main sources of atmospheric emissions result from boiler chemical emissions and fuel combustion. Boiler treatment chemicals including hydrazine, morpholine and degradation

products are used within the feedwater system to prevent corrosion in the boilers. These chemicals are released to the atmosphere through controlled boiler venting. Combustion emissions result from the Standby Gas Turbines, Auxiliary Power System (APS) Combustion Turbine Units (CTU), APS Diesel Generators and minor sources. These systems release carbon monoxide, nitrogen oxides, sulphur dioxide, suspended particulate matter, trace VOCs, and PAHs.

The Air CofAs from 2007 to 2011 and the ESDM Reports, prepared to support the application for a CofA, from 2007, 2009, and 2011 were assessed to aid in COPC selection. The ESDM reports present the estimated atmospheric emissions of COPCs from the PNGS. They use dispersion modelling to predict the maximum concentration at the property line point-of-impingement (POI) for each COPC, by using a dispersion factor of 9.9755 µg/m³ at the property line for each 1 g/s emission of a contaminant (Golder, 2011). The ½ hour POI concentrations were first compared against ½ hour Ontario Ministry of Environment (MOE) POI limits, where available. Where such criteria were not available, COPCs were screened against jurisdictional screening levels (JSLs). Comparison against the ½-hour POI standards is appropriate as these limits are generally set at a factor of 15 times greater than the annual Ambient Air Quality Criteria (AAQC), based on MOE's conversion equation between averaging periods (MOE, 2009a).

For substances without POI limits or JSLs, annual concentrations were estimated from the ½ hour POI concentrations using the MOE averaging conversion equation, and compared against compound-specific long-term effects screening limits (ESLs) obtained from the Texas Commission on Environmental Quality (TCEQ, 2013). Long-term ESLs are appropriate for annual averaging periods and are based on data for health effects, odour, and effects on vegetation.

With the exception of ammonia and hydrazine, no modelled exceedances were observed from 2007 to 2011, as shown in Appendix A (Table A.1). The maximum ½ hour POI concentration (678 µg/m³) for ammonia was observed in 2007 and 2008, where the interim POI limit was 3600 µg/m^3. In 2009 the POI limit decreased to 300 µg/m³. Since 2009 the atmospheric emissions of ammonia also decreased and are below the current POI limit; therefore, ammonia is not carried forward as a COPC. During the 2007 to 2011 period, ammonia concentrations have been below their limits at the time.

There is no POI limit or JSL for hydrazine; however, the estimated annual concentration of hydrazine exceeds the long-term ESL (TCEQ, 2013) and is therefore carried forward in the HHRA. This result is consistent with previous risk assessments, where hydrazine was carried forward as a COPC requiring further assessment for human health since it is a suspected human carcinogen.

3.1.2.1.1 Results from Pickering B Refurbishment Environmental Assessment

The results discussed above are consistent with the conclusions of the Pickering B Refurbishment EA. SENES (2007d) modelled the atmospheric dispersion of COPCs released from the PNGS at 19 specific receptor groups (see Figure 3.1). The closest

sensitive receptors to the site are R1-R8 (Bay Ridges neighbourhood) and R19 (Liverpool Road Sub-Division).

In the Pickering B Refurbishment EA, emission estimates were taken from the 2006 air CofA. The maximum 24-hour concentrations for each COPC at the nearest residential locations were compared against the MOE 24-hour AAQC. The maximum annual concentrations were compared against annual AAQCs. For substances without annual AAQCs, the MOE ½-hour POI standard was divided by 15 – the ½-hour POI standards are set at a factor of 15 times greater than the annual AAQC. For substances with no ½-hour POI criteria, the annual concentration was compared to generally available criteria such as toxicological data from material safety data sheets, as previously derived in the Pickering A Return to Service (PARTS) EA. The results of the screening showed that the predicted annual concentration for all non-carcinogenic COPCs expected to be released from the boiler chemicals is less than 1% of the criteria at the nearest receptors. Although hydrazine was below the criteria, the Pickering B EA carried forward hydrazine as a COPC requiring further assessment for human health since it is a suspected human carcinogen. The predicted annual concentrations of COPCs released from fuel combustion (on and off-site roads) are less than 15% of the criteria at the nearest receptors.

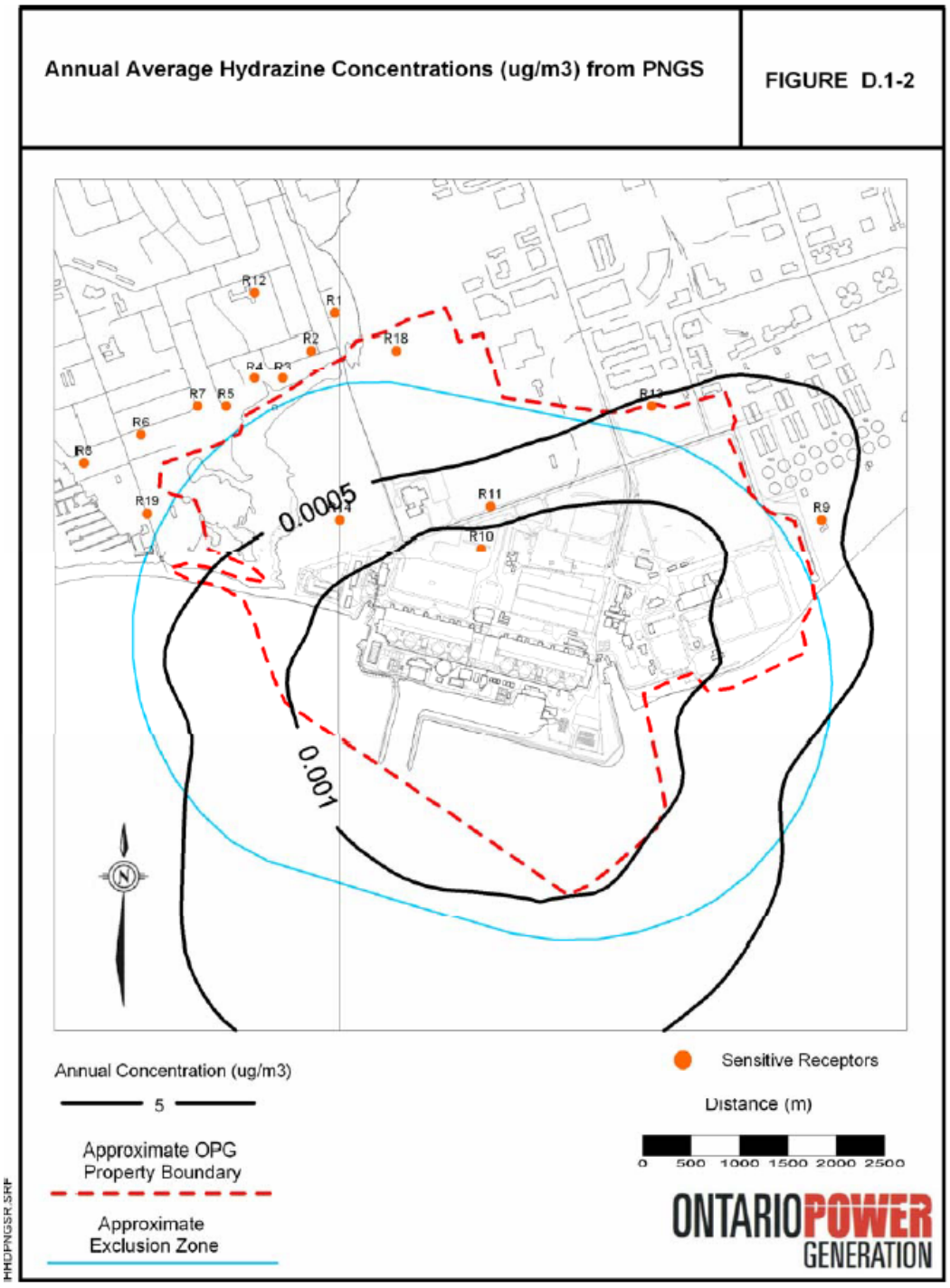


Figure 3.1: Air Quality Sensitive Receptors Locations (SENES, 2007d)

Table 3.1: Estimated Annual Average Boiler Chemical Concentrations at the Nearest Residential Receptors (SENES, 2007d)

Chemical	MOE Annual AAQC[1]	Derived Annual Standard[2]	Maximum Concentration at Residences Using AERMOD			
			Bay Ridges Neighbourhood (R1)		Liverpool Road Sub-Division (R19)	
	µg/m^3	µg/m^3	µg/m^3	% of AAQC	µg/m^3	% of AAQC
Hydrazine	-	0.067	2.70E-04	0.40%	3.30E-04	0.5%
Ammonia	-	100	5.26E-02	0.05%	5.99E-02	0.1%
Morpholine	-	1775	8.82E-02	0.005%	1.07E-01	0.01%
Hydroquinone	-	46	1.00E-05	0.00002%	1.00E-05	0.00002%
Methylamine	-	146	5.58E-03	0.004%	6.66E-03	0.005%
Ethanolamine	-	266	5.69E-03	0.002%	6.77E-03	0.003%
2-2(aminoethoxyl) ethanol	-	32	8.80E-04	0.003%	1.04E-03	0.003%
Acetic Acid	-	571	1.81E-03	0.0003%	2.16E-03	0.0004%
Glycolic Acid	-	-	4.00E-05	-	4.00E-05	-
Formic Acid	-	215	5.00E-04	0.0002%	6.10E-04	0.0003%

Notes:
[1] Ref: MOE 2005
[2] For carcinogenic parameters, the MOE generally sets the ½-hour POI standard at a factor of 15 times higher than the annual AAQC. In the absence of MOE ½-hour POI criteria, hydrazine was derived using a factor of 15 annual to its ½ hour "allowable limit". Ammonia derived using US EPA IRIS database. No occupational exposure values were available for glycolic acid. The remaining contaminants (which are not suspected human health carcinogens) were derived using occupational exposure values (8 hour threshold limit value (TLV)/8760*2000/10) corrected for the number of hours of exposure in the year and a safety factor of 10. TLVs are generally based on available toxicological data.

Table 3.2: Estimated Annual Average Conventional Pollutant Concentrations at the Nearest Residential Receptors (SENES, 2007d)

Chemical	MOE Annual AAQC[1]	Maximum Concentration at Residences Using AERMOD Due to PN Operations and Local Traffic				Background Concentration
		Bay Ridges Neighbourhood (R1)		Liverpool Road Sub-Division (R19)		
	µg/m^3	µg/m^3	% of AAQC	µg/m^3	% of AAQC	µg/m^3
NO_2	100	2.47	2.47%	0.35	0.35%	44
SO_2	55	0.11	0.20%	0.11	0.21%	12
CO	-	17.91	-	1.18	-	1495
SPM	60	7.63	12.72%	0.46	0.76%	44
$PM_{2.5}$	-	0.40	-	0.03	-	9
Acrolein	0.02	0.0007	3.5%	0.0001	0.5%	-

Notes:
[1] Ref. MOE 2005
AAQC for NO_2 is a federal Maximum Allowable Limit (MAL), as there is no annual MOE AAQC for NO_2
No Acrolein annual MOE Standard, so IRIS reference concentration used for comparison (US EPA, 2007)

3.1.2.1.2 Ozone Depleting Substances

OPG reports any spills of ozone depleting substances (ODSs) including refrigerants (R-123, R-11, R-134, and R-22) greater than 100 kg to the Ontario MOE, under O.Reg 675.98. Spills from federal equipment ranging from 10 to 100 kg are reported to Environment Canada under the Federal Halocarbon Regulations (SOR/2003-289). A summary of the refrigerants released from 2005 to 2011 is presented in Table 3.3, as reported in the biannual halocarbon release reports submitted to Environment Canada.

Table 3.3: Ozone Depleting Substances (Refrigerants) Released from 2005-2011

Year	R-123 (kg)	R-11 (kg)	R-134 (kg)	R-22 (kg)
2005	29	0	0	0
2006	0	0	0	59
2007	242	131	0	0
2008	70	97.1	60.5	0
2009	138	0	0	0
2010	151	0	0	0
2011	0	0	0	0

3.1.2.2 Surface Water

The surface water screening is based on measurements of COPCs discharged from 2007 to 2011 into the CCW discharge channel, as well as lake water measurements collected in 2006. The screening based on effluent discharge is presented below. The screening based on lake water measurements is presented in Section 3.1.2.2.1. Monitoring locations are presented in Figure 3.2.

Information from 2007 to 2011 on the concentration of COPCs discharged in liquid effluents into the environment was available from PNGS CofAs, MISA reports, and National Pollution Release Inventory (NPRI) reports. This information was assessed to aid in COPC selection.

As shown in Figure 2.2, all effluent except for sewage and stormwater is discharged into the CCW. As such, the final station discharge released from the CCW was assessed as the compliance point. As part of the CofA requirements, the effluent is sampled and analyzed for unionized ammonia, hydrazine, morpholine, pH, and total residual chlorine (TRC). For each COPC, the maximum concentration in the effluent from 2007 to 2011 was screened against its provincial water quality objective (PWQO), Canadian Council of Ministers of the Environment (CCME) water quality guideline, or a federal or provincial drinking water quality guideline. Drinking water guidelines were used as the preferred benchmarks, where available, as they are more relevant to human health than the PWQO or CCME water quality guidelines.

Hydrazine does not have a PWQO or a CCME water quality guideline, or a drinking water quality guideline. However, the U.S. Environmental Protection Agency (US EPA) estimated

that a hydrazine concentration of 0.01 µg/L would result in a cancer risk level of $1x10^{-6}$ (EC/HC, 2011).

As shown in Table A.2 in Appendix A, the maximum concentrations for morpholine and TRC have exceeded the PWQO during the 2007 to 2011 period. In 2011 the reported maximum morpholine concentration from Pickering B was 0.168 mg/L. This number was later retracted since it was determined through a third-party review that the elevated concentrations were suspect and due to mislabeling or sample contamination during analysis (OPG, 2012d). Irrespective of this particular event, there were still instances where the morpholine concentration at the final discharge exceeded the PWQO. Although TRC exceeded the PWQO during the 2007 to 2011 period, it does not exceed the Health Canada drinking water range of 0.04 to 2.0 mg/L. Although Health Canada has not set a drinking water limit, at these concentrations, taste and odour related to chlorine or its by-products are generally within the range of acceptability for most consumers (Health Canada, 2009). The WHO reports that at a residual chlorine concentration of 0.6 mg/L some sensitive individuals could have an aversion to the taste. The WHO has set a drinking water limit for chlorine of 5 mg/L, based on a 1992 study by the US National Toxicology Program on rodents; however, no adverse health effects were observed (WHO, 2011). Based on the above discussion, TRC has not been carried forward for further quantitative assessment in the HHRA.

Since hydrazine does not have a benchmark (PWQO or CCME water quality guideline), hydrazine is carried forward for further quantitative assessment along with morpholine.

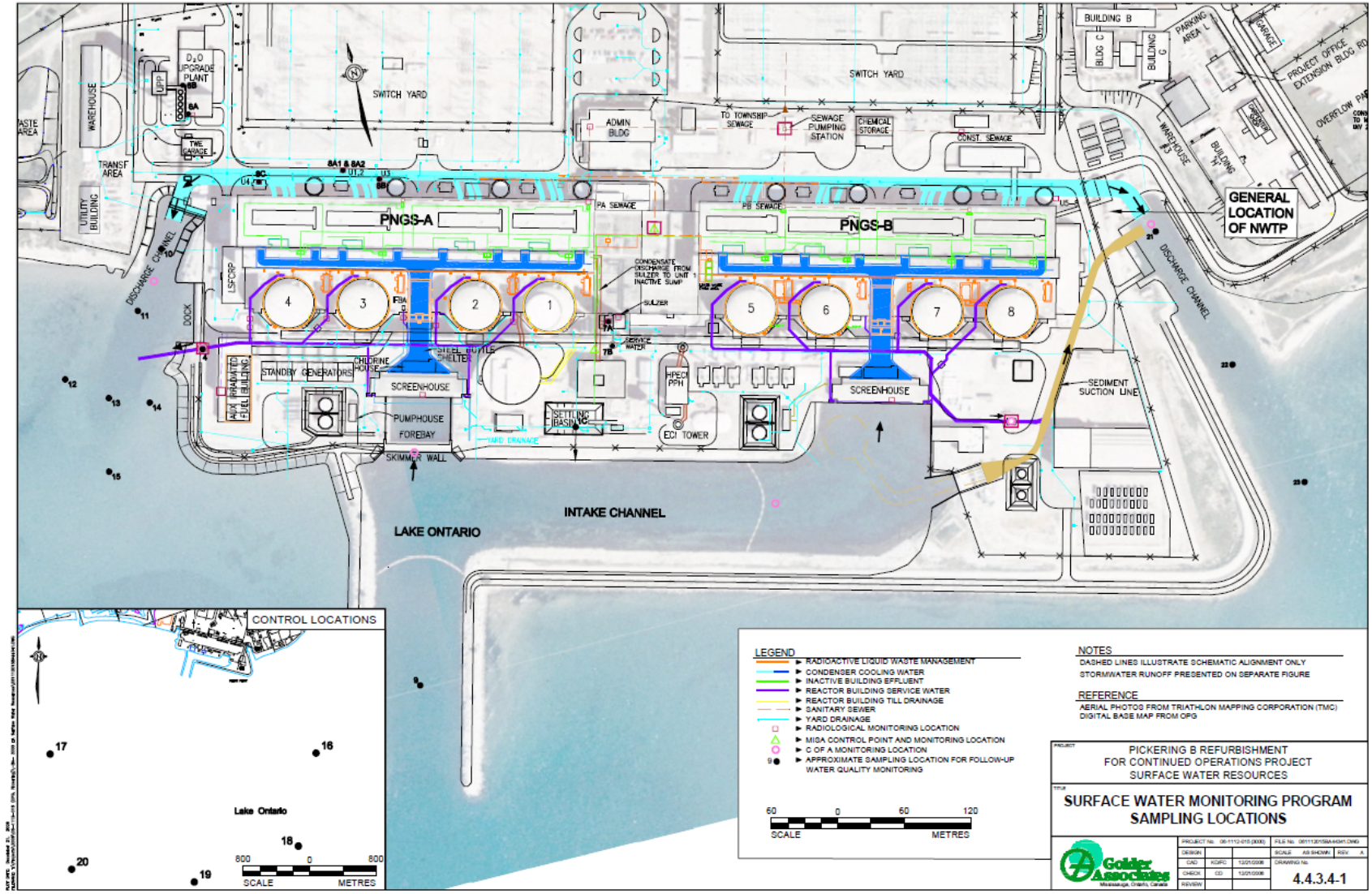


Figure 3.2: Surface Water Monitoring Program Sampling Locations (Golder, 2007a)

Effluent monitoring is required under the MISA program. As part of the MISA program, COPCs for monitoring were identified for the RLWMS effluent, WTP neutralization sumps and the inactive drainage system (Table 3.4).

Table 3.4: Water Quality Parameters Monitored under MISA

Description	MISA Control Point	Parameter
Radioactive Liquid Waste Management System (RLWMS) A, B	200, 3700	Phosphorus TSS Zinc Iron Oil and Grease pH Acute and Chronic Lethality/Toxicity
New/Old Water Treatment Plant (NWTP)	3100, 4400	TSS Aluminum Iron pH Acute and Chronic Lethality/Toxicity
Oil Water Separator – A	3600	pH Oil and Grease
Building Effluent Units 1, 2, 3, 4, 5, 6, 7, 8 Unit 1-8 Combined Effluent	0100, 0300 to 0900 4600	TSS Oil and Grease Acute Lethality/Toxicity

Note:
The Old Water Treatment Plant, Oil Water Separator –A, and the individual unit building effluents control points are no longer in use.

For MISA monitoring parameters not measured in the CCW (phosphorus, TSS, zinc, iron, oil and grease, and aluminum), Golder (2007a) conducted mixing calculations to compare expected concentrations of COPCs in the CCW based on effluent discharge to the CCW from the RLWMS and the NWTP. Mixing calculations were based on a worst case scenario, assuming effluent was discharged at the MISA limits. This is conservative, since exceedances of MISA limits have not been observed for the majority of the COPCs over the past 10 years (2001-2011). Mixing calculations have been updated based on a CCW flow rate for PNGS B of 116 m^3/s (OPG, P-FORM-10937) and assumes two CCW pumps per unit operating.

Since none of the MISA monitoring parameters (except for pH) for the RLWMS are measured in the CCW duct after mixing, mixing calculations for the RLWMS discharge to the CCW duct were calculated based on the maximum concentrations of the RLWMS discharge allowed under MISA. The calculated CCW concentrations were compared against the PWQOs and were found to be well below these limits. The concentration in the CCW was calculated according to the following equation:

$$\text{Conc. in CCW} = \frac{\text{Conc. in RLWMS effluent} \cdot \text{Effl. flow rate} + \text{Intake Conc.} \cdot \text{CCW flow rate}}{\text{CCW flow rate}}$$

The maximum RLWMS discharge flow rate was assumed to be 0.0126 m^3/s and the CCW flow rate was assumed to be 116 m^3/s (Golder, 2007a).

For the NWTP discharge to the CCW, the concentration in the CCW was calculated according to the following equation:

$$\text{Conc. in CCW} = \frac{\text{Conc. in NWTP effluent} \cdot \text{Effl. flow rate} + \text{Intake Conc.} \cdot \text{CCW flow rate}}{\text{CCW flow rate}}$$

The maximum NWTP discharge flow rate was assumed to be 0.02 m^3/s and the CCW flow rate was assumed to be 116 m^3/s (Golder, 2007a). The calculated CCW concentrations were compared against the PWQOs and were found to be well below these limits.

Based on MISA reports from 2007 to 2011, with the exception of total suspended solids (TSS) and one *Daphnia magna* acute toxicity failure, no exceedances of MISA limits have been observed. Therefore based on mixing calculations, no PWQO exceedances in the CCW discharge are expected for the MISA parameters, as shown in Table 3.5. Exceedances of TSS in December 2009 and March 2010 were related to unusually high lake water solids due to adverse weather conditions. Changes in plant operations during storm events have been implemented to prevent reoccurrence (OPG, 2011e). The toxicity failure in 2009 was due to higher metal content and elevated hardness in the ALW system. The sampling and surveillance program associated with the discharges from the ALW system have been improved to address this failure (OPG, 2010c).

Table 3.5: Summary of CCW Mixing Calculations for RLWMS and NWTP

Parameter	Units	Intake Conc. (Golder, 2007a)	MISA Limit at Effluent Discharge	Max Conc. in CCW	PWQO
RLWMS A, B					
Phosphorus	mg/L	<0.01	1	<0.01	0.02
TSS	mg/L	<2	73	<2	N/A
Zinc	mg/L	0.01	1	0.010	0.03
Iron	mg/L	0.025	9	0.026	0.3
Oil and Grease	mg/L	<1	36	<1	Narrative
NWTP					
Aluminum	mg/L	0.004	13	0.0056	0.075
TSS	mg/L	<2	70	<2	N/A
Iron	mg/L	0.0025	2.5	0.0253	0.3

3.1.2.2.1 Lake Water Sampling

The most recent lake water data in the vicinity of the PNGS were collected in 2006 to quantify the concentration of COPCs in the PNGS A and PNGS-B CCW discharge channels. Water quality samples were collected from a number of locations (see locations 9, 10, 11, 12, 13, 14, 15, 21, 22, and 23 on Figure 3.2) in the PNGS A and PNGS B discharge channels and analyzed for chlorine, pH, temperature, conductivity, total dissolved solids (TDS), alkalinity, TSS, turbidity, oil and grease, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total phosphorus, morpholine, hydrazine, total ammonia, total hardness, tritium, and metals (Golder, 2007a;e). Golder (2007a) compared surface water quality samples in the PNGS B CCW discharge channel against PWQOs. Exceedances were observed for morpholine and cadmium. In the 2007 Pickering B EA, parameters without PWQOs were not assessed.

For the current HHRA, a screening was performed, where maximum observed lake water concentrations near PNGS A and PNGS B were screened against PWQOs, and drinking water quality guidelines. Drinking water guidelines were used as the preferred benchmarks, where available, as they are more relevant to human health than the PWQO or CCME water quality guidelines. Where no guideline existed, concentrations were compared against 95th percentile of background concentrations of COPCs in untreated Lake Ontario water measured from 2005 to 2009 as part of the Drinking Water Surveillance Program (DWSP) by the Ontario MOE. The data were limited to raw water samples from water treatment plants located in Cobourg, Whitby, Oshawa, Toronto (F.J. Horgan, R.L. Clark, R.C. Harris, and Island), Oakville, and South Peel (Lakeview and Lorne Park),

For parameters not part of the DWSP, 95th percentile of background data obtained from the Cobourg area were used, identified as the RSA in the Darlington EA (Golder, 2009). As a last resort, where background lake water concentrations from the RSA were not available, background concentrations were obtained from the area including Darlington Provincial Park and Port Darlington, defined as the LSA in the Darlington EA.

For a number of COPCs (bismuth, cesium, thorium, and tin), the maximum measured lake water concentration was below the detection limit; however, environmental water quality guidelines were not available and the detection limit exceeded background concentrations. Since all lake water samples obtained for these metals were below the detection limit and are not expected to be related to emissions from the Pickering site, these metals are not carried forward for further quantitative assessment.

For some COPCs without environmental water quality guidelines (calcium, magnesium, potassium, and strontium), the maximum measured PNGS lake water concentration marginally exceeded – between 3 and 11% – the 95th percentile of Lake Ontario background concentration. Differences of less than 20% are typically not statistically discernible or measurable in the field or laboratory (Suter *et al.*, 1995; Suter, 1996). Since

the measured concentrations differed from background by less than 20%, these metals are not carried forward for further quantitative assessment.

Based on the lake water screening presented in Appendix A (Table A.3), hydrazine and morpholine are carried forward for further quantitative assessment in the HHRA.

3.1.2.3 Stormwater

Stormwater runoff from the PN site is collected by the stormwater drainage system and directed through drainage pathways south to Lake Ontario. Surface drainage around the PNGS is comprised of 19 catchments, as shown in Figure 3.3. A brief discussion of the drainage pattern is presented below (Golder, 2007a):

- Catchments 1 and 2 discharge to the PNGS A discharge channel;
- Runoff from Catchment 3 is collected by catchbasins, directed to a subsurface yard drainage network and discharged directly to Lake Ontario via a submerged outfall;
- Runoff from Catchments 4 and 5 is collected by catchbasins, directed to a subsurface yard drainage network and discharged to the intake channel via submerged outfalls;
- Runoff from Catchment 7 is collected by a system of catchbasins and subsurface drains and discharged to the PNGS B discharge channel;
- Runoff from Catchment 8 is directed through culverts and ditches and discharged to the PNGS B discharge channel;
- Catchments 6 and 9 each drain through a pipe into the PNGS B discharge channel; and
- Catchments 10 through 16A drain directly to the Lake Ontario shoreline. The discharge points are approximately 6 m to 10 m above the Lake Ontario water level.

From 1990 to 1991 stormwater was monitored to compare water quality of the station stormwater drainage and the effluent streams. This monitoring was part of a larger effluent monitoring campaign of all point source effluents in response to the promulgation of MISA. It was determined that monitoring of stormwater was not required through MISA since it did not contain industrial wastewater and it had acceptable water quality (Golder, 2007c). Follow-up stormwater monitoring occurred in 1995-6, 2000-1, and 2006 to verify that concentrations of COPCs in site stormwater are not likely to have an adverse effect on the environment (Gray, 2002; Golder, 2007f).

In 2000-1, stormwater was monitored during four rainfall events over a period of one year, from fourteen sampling stations around the PN site. Elevated concentrations above the Durham Region Sewer Use By-Law Limits for stormwater discharges and the US EPA (1995) National Pollutant Discharge Elimination System (NPDES) values were observed for TSS and some metals including aluminum, copper, lead and zinc. Tritium concentrations in stormwater were consistent with measured tritium concentrations in precipitation on the site. Cs-134, Cs-137, and Co-60 were not detected in stormwater. Elevated sodium levels

were observed likely due to de-icing activities using road salts. One failed toxicity test was observed (in MH 211); however, the mortalities may have been associated with low mineral hardness and elevated total metals concentrations; no conclusive evidence was found (Gray, 2002).

In 2006, stormwater was monitored during four rainfall events between September and November, at six locations around the PN site (concentrated near PNGS A). Stormwater results were compared to Durham Region Sewer Use By-Law Limits for stormwater discharges, US EPA (1983, 1995) typical urban runoff values Nationwide Urban Runoff Program (NURP) and NPDES values. Exceedances of some of these limits were observed for TSS, nitrate, phosphorous, and zinc. These concentrations and exceedances are generally consistent with those reported in 1997 and the 2002 follow-up study. Consistent with the 2002 study, elevated sodium levels were observed likely due to de-icing activities using road salts. Toxicity testing was conducted in 2006 (in MH 211), and only one of the four samples passed. This is consistent with the 2002 results; however the 2002 study concluded that there is no evidence that toxicity is associated with contaminants from site activities (Gray, 2002).

Overall, the conclusions from the 1997, 2002, and 2006 studies indicate that stormwater quality has not resulted in any unexpected or adverse effects on the environment. Follow-up monitoring is complete and no further stormwater quality monitoring is planned at PNGS.

To confirm the conclusion from the stormwater monitoring programs that stormwater quality has not resulted in any adverse effects on the environment, a screening of stormwater quality against water quality guidelines was conducted (Appendix A, Table A.4 and Table A.5). The stormwater quality screening focused on stormwater discharged to the PNGS A and PNGS B discharge channels (Catchments 1, 2, 6, 7, 8, and 9), and stormwater discharged directly to Lake Ontario (Catchments 3 and 10-16A). Stormwater discharged into the intake channel (Catchments 4 and 5) was not included in the assessment as that stormwater is redirected into the station.

PNGS A and B Discharge Channels

Stormwater monitoring data from the 2002 and 2006 studies from each relevant catchment were compiled to determine the maximum concentration potentially released to the PNGS A and PNGS B discharge channels. More recent stormwater data have not been collected. Dilution calculations were performed to determine the concentration in the discharge channel for each of the monitored parameters. The stormwater runoff to the PNGS A and PNGS B discharge channels is 0.004 and 0.003 m^3/s, respectively (Golder, 2007a). The flowrate in PNGS A and PNGS B discharge channels is 48 m^3/s and 116 m^3/s, respectively (OPG, P-FORM-10936; P-FORM-10937) and assumes two CCW pumps per unit operating.

Runoff to Lake Ontario

Stormwater monitoring data from the 2002 and 2006 studies from Catchments 10-16A located east of the station and data from Catchment 3 located west of the station were assessed separately. The flow in the wave zone in Lake Ontario was determined based on the assumption that the wave zone extends out to 150 m east of the station and 120 m west of the station and is well mixed over a depth of 2 m (based on the Canadian Hydrographic Service nautical map of the area). The current speed was taken as the average of the easterly and westerly current speeds from Table 2.6 above (0.15 m/s). Therefore, lake flow to the east and west of the station is 22.5 m^3/s and 18 m^3/s, respectively.

Dilution calculations were performed to determine the concentrations of COPCs in the wave zone at the shoreline of Lake Ontario. Stormwater runoff flowrate was available for each of the four stormwater events monitored in 2002 – based on the runoff volume and event duration (Gray, 2002). The maximum loading rate was determined from monitoring data and stormwater runoff. The maximum concentration in the lake was then estimated from the maximum loading rate and lake flow along the shoreline.

Overall Conclusion

The final concentration in each of the discharge channels, and in the lake, resulting from stormwater runoff was compared to water quality guidelines – PWQO, CCME, and Lake Ontario background. The screening tables are presented in Appendix A (Tables A.4 to Table A.7). The results of the screening assessment are in agreement with the conclusions of the previous stormwater monitoring programs that stormwater is not toxic; therefore, stormwater is not discussed further in this ERA.

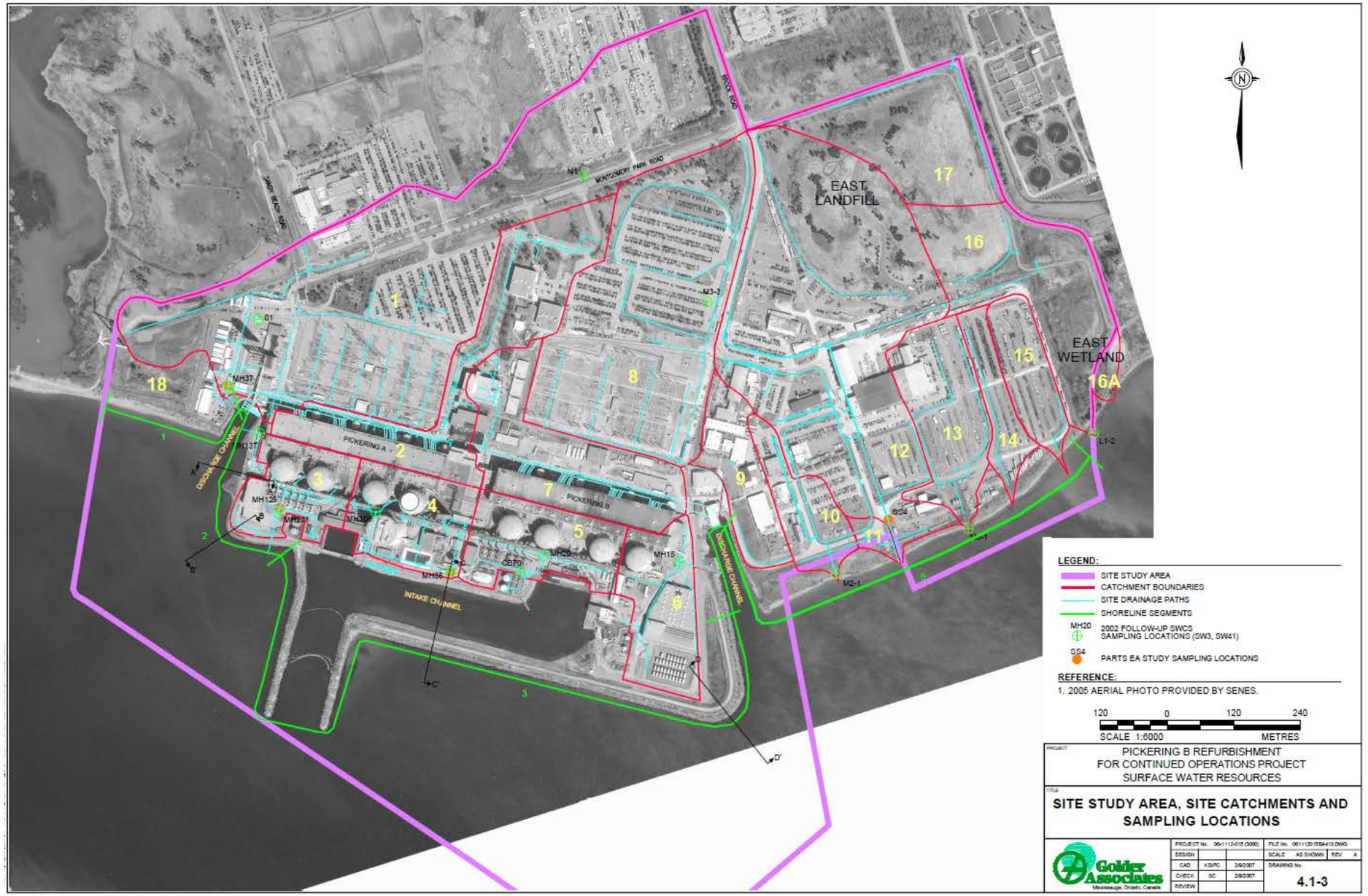


Figure 3.3: Catchments in the PNGS Site Study Area (Golder 2007a)

3.1.2.4 Radiological Emissions

Airborne and waterborne radioactive emissions from the years 2007 to 2011 were analyzed and compared against baseline emissions as defined in the Refurbishment and Continued Operation of Pickering B Nuclear Generating Station Environmental Assessment (SENES, 2007e)). For PNGS A, baseline emissions were from 2005. For PNGS B, baseline emissions were based on the rationale provided in Table 4.6-2 of SENES (2007e). Emissions from the five year period 2007 to 2011 are within the range of baseline emissions (see Table 3.6, Table 3.7, and Figure 3.4), with the exception of gross beta-gamma in water.

Since 2008, PN HTO airborne emissions have continued to trend downwards as a result of improvements in leak management, reliability and operation of vapour recovery dryers, and reduction of HTO source terms (OPG, 2012c). Since 2007, airborne C-14 emissions have been trending down. In April 2008, the calandria tube that leaked CO_2 from the annulus gas into the Unit 7 moderator system, was replaced, reducing emissions to pre-2005 levels.

In 2008 and 2009, HTO waterborne emissions were slightly elevated, but 2011 levels returned to levels observed prior to 2008. Increased emissions in 2008 were from a heavy water leak in a Unit 1 shutdown cooling heat exchanger. Increased emissions in 2009 were from a Unit 1 boiler tube leak. HTO waterborne emissions were slightly higher in 2011 than in 2010 because all units were shutdown in 2010 for the duration of the Vacuum Building Outage.

In 2009 and 2010, gross beta waterborne emissions were elevated compared to previous years; however, a third-party review of station in-house investigations confirmed that the increase was due to anomalous samples of high activity (OPG, 2012c). In 2011, gross beta waterborne emissions from PNGS A decreased to levels observed prior to 2009. Gross beta waterborne emissions from PNGS B appear to be approximately one order of magnitude greater from 2007 to 2011 when compared to baseline levels. As indicated by OPG, this increase is due to improved reporting practices in 2007 which include emissions from boiler blowdown (A. Brown, personal communication, November 21, 2012). This change is unlikely to result in noticeable changes to public dose as gross beta makes up a small component of the dose. More discussion is provided in Section 3.2.6.1.

Table 3.6: Radioactive Emissions from PNGS-A

	Parameter	Baseline	Year					Average (2007-2011)
			2007	2008	2009	2010	2011	
Air	HTO (Bq/yr)	2.35E+14	2.76E+14	5.29E+14	4.39E+14	2.80E+14	2.12E+14	3.47E+14
	Noble Gases (Bq-MeV/yr)	1.18E+14	7.96E+13	1.06E+14	2.08E+14	1.51E+14	9.93E+13	1.29E+14
	I-131 (Bq/yr)	6.13E+07	4.06E+07	2.83E+07	2.32E+07	2.14E+07	1.48E+07	2.57E+07
	Part. (Bq/yr)	1.15E+08	7.03E+07	6.67E+07	6.89E+07	5.26E+07	8.18E+06	5.33E+07
	C-14 (Bq/yr)	2.13E+12	9.36E+11	1.35E+12	1.18E+12	2.15E+12	1.04E+12	1.33E+12
Water	HTO (Bq/yr)	8.20E+13	6.09E+13	2.50E+14	1.51E+14	1.02E+14	1.12E+14	1.35E+14
	B-G* (Bq/yr)	2.27E+09	5.04E+09	1.68E+10	1.78E+10	2.72E+10	5.13E+09	1.44E+10

Note:

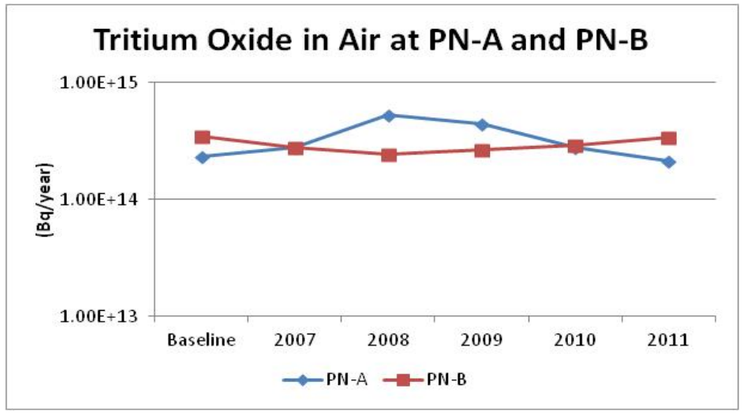
* B-G = beta-gamma

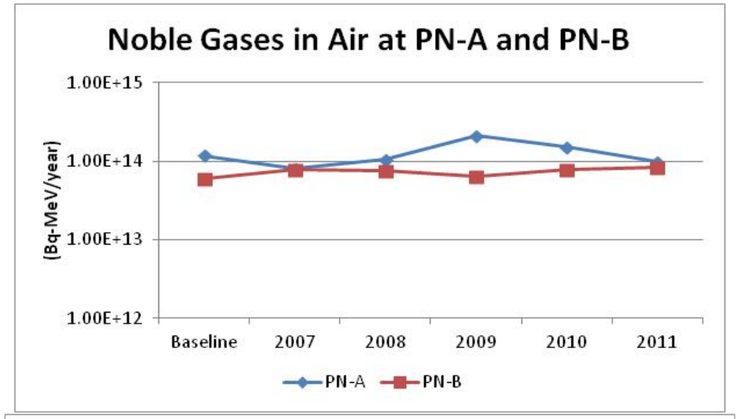
Table 3.7: Radioactive Emissions from PNGS-B

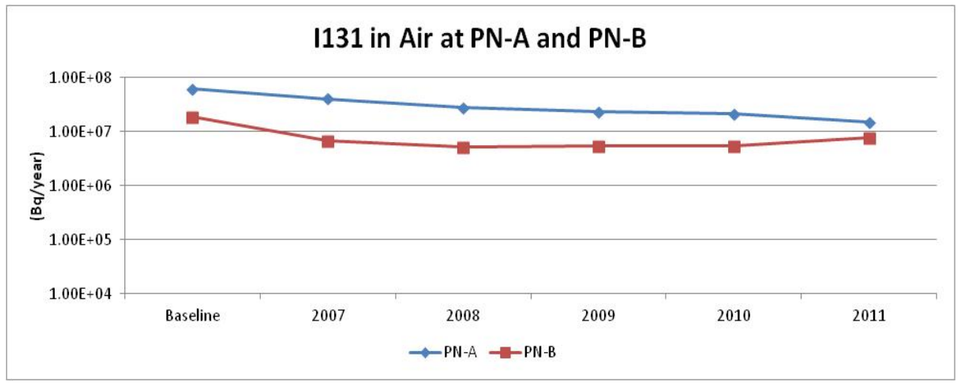
	Parameter	Baseline	Year					Average (2007-2011)
			2007	2008	2009	2010	2011*	
Air	HTO (Bq/yr)	3.45E+14	2.77E+14	2.44E+14	2.64E+14	2.89E+14	3.41E+14	2.83E+14
	Noble Gases (Bq-MeV/yr)	5.92E+13	7.70E+13	7.53E+13	6.36E+13	7.78E+13	8.32E+13	7.54E+13
	I-131 (Bq/yr)	1.85E+07	6.83E+06	5.17E+06	5.47E+06	5.42E+06	7.85E+06	6.15E+06
	Part. (Bq/yr)	6.67E+06	3.53E+06	4.00E+06	6.66E+06	2.86E+06	3.60E+06	4.13E+06
	C-14 (Bq/yr)	2.13E+12	1.10E+13	5.57E+12	1.32E+12	9.20E+11	7.67E+11	3.92E+12
Water	HTO (Bq/yr)	8.20E+13	1.92E+14	2.00E+14	2.45E+14	1.55E+14	1.95E+14	1.97E+14
	B-G (Bq/yr)	2.27E+09	3.23E+10	1.70E+10	7.68E+10	1.72E+11	1.37E+10	6.23E+10
	C-14 (Bq/yr)	7.80E+09	7.84E+09	3.71E+09	4.43E+09	3.57E+09	1.06E+09*	4.12E+09

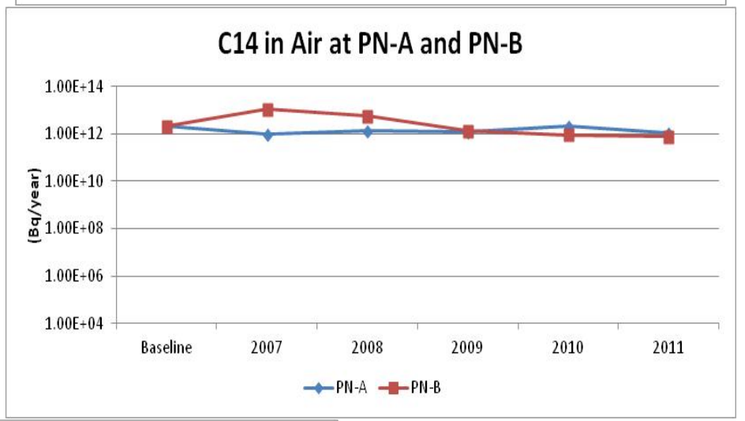
Note:

* Values were not available for October, November and December of 2011, so the annual average is based on data from January to September.









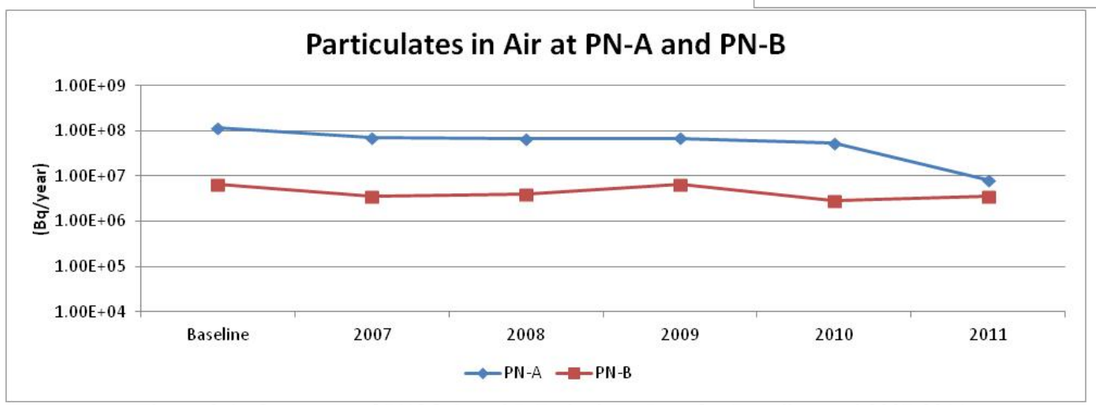


Figure 3.4: Summary of PNGS A and B Emissions Data for Baseline and 2007-2011

The Radiation and Radioactivity TSD (SENES, 2007c) identified a number of radionuclides released to air and water that should be carried forward for the dose assessment. The 2011 Derived Release Limits (DRL) Report for PNGS A and B presents the same effluent release groups for air and water, with the exception of including gross alpha for both air and water (OPG, 2011a,b).

The DRLs for the effluent release groups were calculated based on the selection of the radionuclide with the most restrictive DRL, according to the process outlined in the CANDU Owners Group (COG) DRL Guidance document (Hart, 2008). Radionuclides were eliminated from groupings based on the following criteria for inclusion:

- Radionuclides are regularly present in the effluent; and
- Radionuclides represent no less than 1% of the total radioactivity present.

Based on these criteria, the radionuclides selected for use in DRL calculations were considered appropriate for carrying forward in the risk assessment. The limiting radionuclides (i.e., the radionuclide with the most restrictive DRL) for particulates in air and for gross beta/gamma in water were used to represent all radionuclides in each grouping. The 2011 DRLs (OPG, 2011a,b) indicate that P-32 is the limiting gross beta/gamma radionuclide in water. The 2011 DRLs were not implemented into the PNGS' licence until 2013, therefore the annual dose calculations for the REMP from 2007 to 2011 (as presented in the annual REMP reports and in this HHRA) used Cs-137 to represent gross beta/gamma radionuclides in water based on Cs-137 being the limiting gross beta/gamma radionuclide in water in previous DRL calculations. Using Cs-137 to represent 2007 to 2011 doses is considered appropriate since site-specific data exists for fish and sediment and the 2011 DRL for Cs-137 is only marginally higher than the DRL for P-32, for the Sport Fisher.

Category	Radiological COPC
Air	H-3, noble gases, C-14, I (mixed fission products), particulates (P-32, S-35, Sc-46, Cr-51, Mn-54, Fe-59, Co-60, Zn-65, Sr-89, Sr-90 (Y-90), Zr-95, Nb-95, Ru-106, Sn-113, Sb-124, Sb-125, Cs-134, Cs-137, Ce-144, Gd-153, Ba-140, La-140, Tb-160, Hg-203, Th-234)
Surface water	H-3, C-14, Gross Beta/Gamma (P-32, S-35, Sc-46, Cr-51, Mn-54, Fe-55, Fe-59, Co-60, Sr-90 (Y-90), Zr-95, Nb-95, Ru-106, Sn-113, Sb-124, Sb-125, I-131, Cs-137, Eu-154, Gd-153, Tb-160, Zn-65)

Gross alpha radionuclides do not need to be carried forward for the risk assessment. The level of airborne and waterborne gross alpha emissions from OPG nuclear facilities has been considered to be negligible (OPG, 2005). This position is supported by determination of alpha activity in the heat transport water and estimates of the maximum probable emission levels under normal and abnormal operating conditions. The airborne exhaust

systems at PN contain HEPA filters which continuously filter particulate from the airborne effluents, thus capturing the alpha emitting particles, resulting in negligible emissions. This was confirmed through a COG (2003) study which analyzed alpha activities on air filters and determined they were at or below the detection limit in the milliBequerel range. A study on monthly gross alpha waterborne emissions was performed to establish an appropriate monitoring methodology (OPG, 2006b). Gross alpha concentrations at PN RLWMS are at Method Detection Limit (MDL) and their emissions are at a very small fraction of the monthly DRL.

3.1.2.5 Soil Radiological and Non-Radiological COPCs

The Radiation and Radioactivity TSD (SENES, 2007c) identified Cs-134, Cs-137, Co-60, and K-40 as relevant COPCs for soil and sediment. However, K-40 is environmentally abundant and not associated with station operations. The cesium and cobalt isotopes are included as COPCs in order to address potential concern about deposition of particulate activity. Only Cs-134 and Co-60 are specific to reactor operations, and these are typically not detected in REMP monitoring of either soil or sediment around the facility (OPG, 2012c).

The full screening for non-radiological COPCs for soil is presented in Section 4.1.3. The lack of complete human exposure pathways for site soil indicates that there is no need for inclusion of these pathways in the HHRA. Human exposure to COPCs from off-site soil is unlikely, since the results of the air screening presented in Section 3.1.2.1 show acceptable concentrations for air COPCs that could deposit on soil.

3.1.2.6 Groundwater Radiological and Non-Radiological COPCs

In September 2012, EcoMetrix prepared a report for OPG on PNGS Groundwater Monitoring Program Design (EcoMetrix, 2012). In this document, EcoMetrix recommended that tritium, PAHs, PHCs, BTEX compounds, and inorganics (chloride, iron and sodium) be included in the monitoring program. The selection of COPCs was based on analyzing groundwater data from 2007 to 2011 and comparing against appropriate screening concentrations as well as considering COPCs that were included in past assessments and studies.

Pinchin (2010) concluded that off-site recreational receptors would not be exposed to COPCs such as PAHs, PHCs, and BTEX compounds migrating from groundwater to surface water. This conclusion was based on site groundwater flow direction and data in groundwater monitoring wells closest to the intake channel which showed acceptable concentrations of COPCs. Pinchin (2010) concluded that COPCs from the standby generators are not migrating from groundwater to surface water in the intake channel at unacceptable concentrations. Additionally, a recreational resident would not be allowed to swim in the intake channel, and any exposure to recreational users farther away following discharge would be minimal due to massive dilution of the small groundwater flow.

There is potential for site groundwater to migrate to surface water (Lake Ontario). Groundwater flux from the site into Lake Ontario is likely to be small based on the estimated groundwater velocity and influence of site infrastructure (Wardrop, 1998); therefore, any COPCs in groundwater that reach the lake are subject to considerable dilution before they can migrate with surface water to a point of water intake for human consumption. The nearest water intake at Ajax is approximately 5 km east of the Pickering Nuclear site and is not at any risk due to constituents in groundwater on the site.

Although COPCs have been identified through the screening assessment in EcoMetrix (2012), the lack of complete exposure pathways for site groundwater to the public indicates that there is no need for inclusion of these pathways in the HHRA.

The atmospheric release of tritium from the PNGS has an influence on tritium concentrations in groundwater on and off-site. On-site groundwater is not considered potable. Off-site drinking water wells are influenced by the atmospheric tritium plume and this is taken into account in the public dose calculations as part of the annual REMP.

3.1.2.7 Noise

Noise is the only physical stressor mentioned in N288.6 as a potential human stressor, and is the only physical stressor associated with PNGS that is of potential concern to humans. Other physical stressors relevant to ecological receptors are discussed in Section 4.1.3.5). Noise at the PNGS originates from the following sources:

- West Annex Active Ventilation System;
- Standby gas turbine generating sets for both PNGS A and B;
- Emergency power supply generators;
- Auxiliary steam boiler;
- Switchyard hum and breakers;
- East Annex Active Ventilation System;
- Powerhouse ventilators;
- Steam venting;
- Emergency signals; and
- Auxiliary Power Supply.

Noise resulting from steam venting and emergency signals were not included in the noise assessment (SENES, 2007d). The closest residential communities to the PNGS are located in the Bay Ridges Neighbourhood (northwest of the facility), and in the Liverpool Road Subdivision (west of the facility). The closest receptor to the east was a correctional residence (now an office for the WPCP). The predicted noise levels at the PNGS (Table 3.8) are compliant with NPC-205 (SENES, 2007d). Therefore, noise is not carried forward as a COPC in the HHRA.

Table 3.8: Predicted Sound Levels at Nearby Receptors from PN Site Operations and Local Traffic (SENES, 2007d)

Scenario	Noise Emission Scenario	Name	Receptor Sound Pressure Level (dBA)
1a	Existing Conditions	R1 - 1443 Parkham Crescent	63.2
		R9 - Office for WPCP	45.8
		R19 - Liverpool Road Sub-Division	52.9
2a	Refurbishment Phase	R1 - 1443 Parkham Crescent	63.7
		R9 - Office for WPCP	47
		R19 - Liverpool Road Sub-Division	53.1

Notes:
Noise Emission Scenario #1 is without the construction equipment
Noise Emissions Scenario #2 is with the construction equipment

3.1.2.8 Summary of COPC Selection for the HHRA

Table 3.9 summarizes the radiological and non-radiological COPCs that are carried forward to the exposure assessment in the HHRA.

Table 3.9: Summary of COPCs Selected for the HHRA

Category	Radiological COPC	Hazardous COPC
Air	H-3, noble gases, C-14, I (mixed fission products), particulates (P-32, S-35, Sc-46, Cr-51, Mn-54, Fe-59, Co-60, Zn-65, Sr-89, Sr-90 (Y-90), Zr-95, Nb-95, Ru-106, Sn-113, Sb-124, Sb-125, Cs-134, Cs-137, Ce-144, Gd-153, Ba-140, La-140, Tb-160, Hg-203, Th-234)	hydrazine
Surface water	H-3, C-14, Gross Beta/Gamma (P-32, S-35, Sc-46, Cr-51, Mn-54, Fe-55, Fe-59, Co-60, Sr-90 (Y-90), Zr-95, Nb-95, Ru-106, Sn-113, Sb-124, Sb-125, I-131, Cs-137, Eu-154, Gd-153, Tb-160, Zn-65)	hydrazine morpholine
Groundwater	None	None
Stormwater	None	None
Soil	Cs-134, Cs-137, Co-60	None
Noise	None	

3.1.3 Selection of Exposure Pathways

For exposure of human receptors to non-radiological COPCs the potential exposure pathways include:

- ingestion of water;
- dermal contact with water;
- inhalation;
- incidental ingestion of dust (inhalation), soils and sediment;
- dermal contact with soils and sediment; and
- ingestion of food.

Not all exposure pathways are considered complete. A complete exposure pathway consists of a contaminant source, release mechanism, transport mechanism within the relevant environmental medium (or media), point of exposure and exposure route to a receptor. Based on the COPC screening presented in Section 3.1.2, the complete exposure pathways for exposure of relevant human receptors to non-radiological COPCs generally include inhalation and ingestion, and are summarized in Table 3.10.

Hydrazine does not partition well into other environmental compartments. The environmental partitioning of hydrazine was modeled and described in EC/HC (2011). The modeling results show that when hydrazine is released to surface water (alkaline hardwater), it will remain almost entirely in the water (99.9% in water, 0.02% in sediment). Similarly when hydrazine is released to air, it will remain almost entirely in air (90% in air, 9.6% in water, 0.51% in soil, and 0.01% in sediment). When morpholine is released to surface water, modelling shows that it will remain almost entirely in water (96.1% water, 3.9% air) and that in general it prefers to distribute to the water compartment (ECHA, 2008). As such, for hydrazine, the relevant exposure pathways for humans are inhalation and ingestion (water and fish). For morpholine, the relevant exposure pathways for humans are ingestion (water and fish).

For exposure of human receptors to radiological COPCs, the relevant exposure pathways include:

- inhalation of air and external exposure to air;
- ingestion of water and external exposure to water;
- incidental ingestion of soil and sediment
- external exposure to soil and sediment; and
- ingestion of food.

The complete exposure pathways, as defined in OPG's REMP, for exposure of relevant human receptors to radiological COPCs are summarized in Table 3.11.

Although COPCs have been identified in the screening for groundwater, there are no operable groundwater exposure pathways for humans. EcoMetrix (2012) indicated that there are no groundwater supply wells downgradient of potential source areas of COPCs; therefore, human consumption of contaminated groundwater is not a relevant pathway and is not a concern. Additionally, Pinchin (2010) concluded that although there is potential for site groundwater to migrate to Lake Ontario where a human receptor could be exposed through dermal contact and/or ingestion, off-site recreational receptors would not likely be exposed to COPCs migrating from groundwater to surface water at unacceptable concentrations, as discussed in Section 3.1.2.6.

Off-site drinking water wells are influenced by the atmospheric tritium plume and this is taken into account in the public dose calculations as part of the annual REMP.

Table 3.10: Complete Exposure Pathways for Relevant Receptors for Exposure to Non-Radiological COPCs

Location	Receptor	Exposure Pathway	Environmental Media
Outfall (500m S)	Sport Fisher	Inhalation	Air
		Ingestion	Aquatic animals (fish)
0.9 km NE	Industrial/Commercial Worker	Inhalation	Air
		Ingestion	Water (Ajax WSP)
1.2 km WNW	Urban Resident	Inhalation	Air
		Ingestion	Water (Ajax WSP)
3.1 km NNE	Correctional Institution	Inhalation	Air
		Ingestion	Water (Ajax WSP)
6.9 km NE	Farm	Inhalation	Air
10.25 km NE	Dairy Farm	Inhalation	Air

Table 3.11: Complete Exposure Pathways for Relevant Receptors for Exposure to Radiological COPCs

Receptor	Exposure Pathway	Environmental Media
Sport Fisher	Inhalation	Air
	Ingestion	Aquatic animals (fish)
	External	Air
Industrial/Commercial Worker(1)	Inhalation	Air
	Ingestion	Water Soil Sediment Aquatic animals Terrestrial plants Terrestrial animals
	External	Air Water Soil Sediment
Urban Resident	Inhalation	Air
	Ingestion	Water Soil Sediment Aquatic animals Terrestrial plants Terrestrial animals
	External	Air Water Soil Sediment
Correctional Institution	Inhalation	Air
	Ingestion	Water Soil
	External	Air Water Soil

Receptor	Exposure Pathway	Environmental Media
Farm	Inhalation	Air
	Ingestion	Water Soil Sediment Aquatic animals Terrestrial plants Terrestrial animals
	External	Air Water Soil Sediment
Dairy Farm	Inhalation	Air
	Ingestion	Water Soil Sediment Terrestrial plants Terrestrial animals
	External	Air Water Soil Sediment

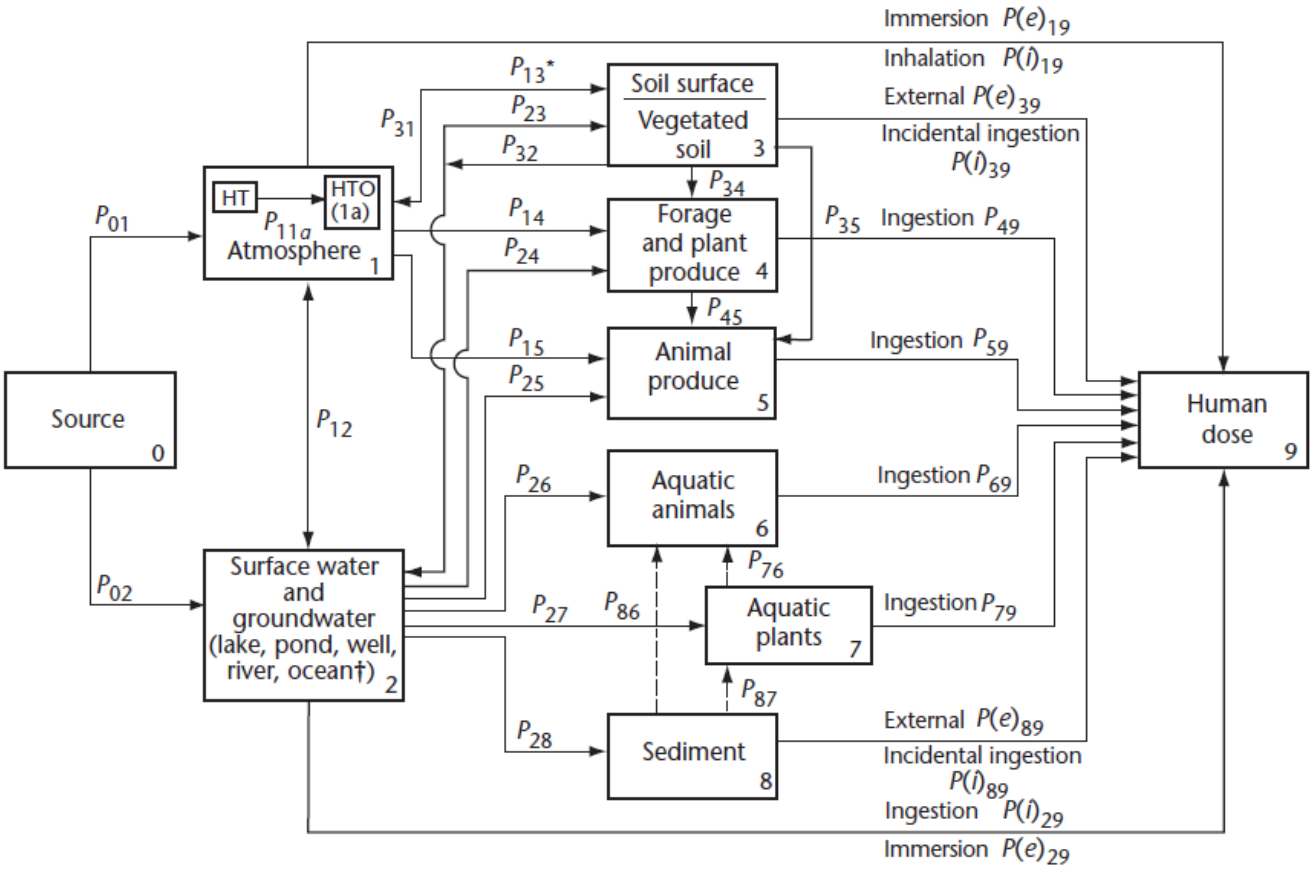
Note:

(1) A small fraction of Industrial/Commercial workers are also urban residents; therefore, the ingestion pathway is included to account for when the worker is at home.

3.1.4 Human Health Conceptual Model

The conceptual model illustrates how receptors are exposed to COPCs. It represents the relationship between the source and receptors by identifying the source of contaminants, receptor locations and the exposure pathways to be considered in the assessment for each receptor. Exposure pathways represent the various routes by which radionuclides and/or chemicals may enter the body of the receptor, or (for radionuclides) how they may exert effects from outside the body.

A generic conceptual model, taken from CSA N288.1 (2008) is shown in Figure 3.5, and is applied to human receptors around PNGS. This represents the exposure pathways from source to receptor. It is appropriate for radiological and non-radiological COPCs, except that, for non-radionuclides, external and immersion pathways represent dermal exposure.



*Includes transfer factors P_{13area}, P_{13mass}, and P_{13spw}.
†For ocean water, pathways P_{23}, P_{24}, P_{25}, and $P(i)_{29}$ are not used.

Notes:

(1) *The broken lines represent pathways that are not explicitly considered in the model, or are considered only in special circumstances.*

(2) *Factors include multiple transfers where appropriate.*

Figure 3.5: Generic Conceptual Model for Human Receptors (CSA, 2008)

3.2 Exposure Assessment

3.2.1 Exposure Locations

The exposure location is the location where the receptor comes into contact with the COPC or stressor. For both the radiological and non-radiological exposure assessment the relevant human receptors are the potential critical groups defined by the REMP, as discussed in Section 3.1.1.1. Table 3.12 and Figure 3.6 present the locations of these receptors. The approximate distance from the PNGS is an average of the distance from PNGS A and PNGS B (OPG, 2011d,e). The exposure assessment looked at all six receptors, as reported in the REMP, where appropriate. For the non-radiological exposure assessment, the farm and dairy farm critical groups were not assessed for water ingestion since they obtain the majority of their water intake from waterwells, and not the Ajax WSP.

Table 3.12: Distance and Wind Sector of Potential Critical Groups

Potential Critical Group	Approximate Distance from PNGS-A and B (km)	Wind Sector (Direction TO)	Transfer Parameter from source to air, P_{01} (s/m^3)(3)
Farm	6.9	NE	7.0E-08
Dairy Farm	10.25	NNE	4.4E-08
Urban Resident	1.35	WNW	6.9E-07
Industrial/Commercial	0.95	NNE	1.8E-06
Sport Fisher(1)	0.5	S	7.1E-06
Correctional Institution(2)	3.1	NNE	2.9E-07

Notes:
(1) The Fisher group is located 500m south, offshore of PN site.
(2) The Correctional Institution is the Kennedy Youth House located 3.1 km NE of PNGS A
(3) Transfer parameter (P_{01}) is an average of P_{01} for PNGS A and P_{01} for PNGS B

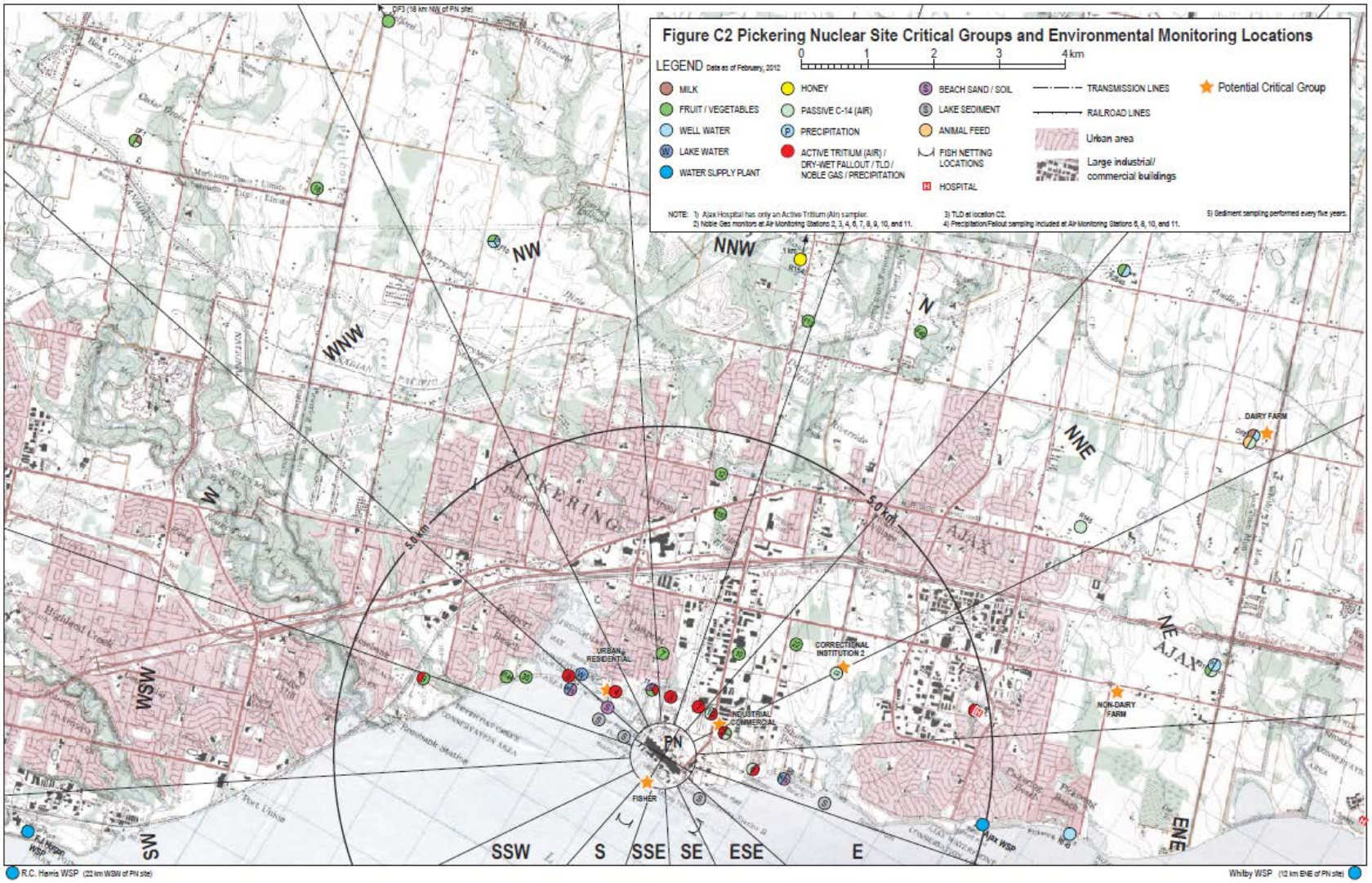


Figure 3.6: Locations of Human Receptors – Potential Critical Groups (OPG, 2012c)

3.2.2 Exposure Duration and Frequency

Full-time residency was assumed for the correctional institute resident, urban resident, farm resident, and dairy farm resident. For the industrial/commercial worker and the sport fisher a residency of 23% and 1% was assumed, respectively (OPG, 2012c).

3.2.3 Exposure and Dose Calculations

3.2.3.1 Radiological Dose Calculations

Radiological dose calculations follow the equations presented in CSA N288.1-08 (2008), which are not reproduced in this report.

3.2.3.2 Non-Radiological Exposure and Dose Calculations

In performing the exposure assessment for inhalation of hydrazine, only the air concentration was used since the incremental lifetime cancer risk (ILCR) is estimated from an air exposure concentration times a unit risk. Therefore, inhalation rates and body weights for receptors are not used. The air exposure concentrations were expressed in units of $\mu g/m^3$ factoring in the exposure frequency.

$$\text{Exposure Concentration } (\mu g/m^3) = C_{air} \bullet \text{Fraction of time exposed}$$

where,

C_{air} = air concentration ($\mu g/m^3$).

The ingestion dose from exposure to hydrazine and morpholine in drinking water was calculated according to the following equation, consistent with CSA N288.6 (2012):

$$\text{Dose (mg/kg-d)} = C \bullet IR \bullet RAF_{GIT} \bullet D_2 \bullet D_3 \bullet D_4 / (BW \bullet LE)$$

where,

C	=	concentration of contaminant in drinking water (mg/L)
IR	=	receptor intake rate (L/d)
RAF_{GIT}	=	absorption factor from the gastrointestinal tract (unitless)
D_2	=	days per week exposed•$(7 \text{ days})^{-1}$ (d/d)
D_3	=	weeks per year exposed•$(52 \text{ weeks})^{-1}$ (wk/wk)
D_4	=	total years exposed to site (years) (for carcinogens only)
BW	=	body weight (kg)
LE	=	life expectancy (years) (for carcinogens only).

The ingestion dose from exposure to hydrazine and morpholine in fish was calculated according to the following equation, consistent with CSA N288.6 (2012):

$$\text{Dose (mg/kg-d)} = [\Sigma\ (C_{food\ i} \bullet IR_{food\ i} \bullet RAF_{GITi} \bullet D_i)] \bullet D_4/(BW \bullet 365 \bullet LE)$$

where,

C_{foodi} = concentration of contaminant in food i (mg/kg)
IR_{foodi} = receptor ingestion rate for food i (kg/d)
RAF_{GITi} = relative absorption factor from the gastrointestinal tract for contaminant i (unitless)
D_i = days per year during which consumption of food i will occur (d/a)
D_4 = total years exposed to site (years) (for carcinogens only)
BW = body weight (kg)
365 = total days per year (constant) (d/a)
LE = life expectancy (years) (for carcinogens only)

3.2.4 Exposure Factors

3.2.4.1 Radiological Exposure Factors

For the radiological dose calculations the exposure factors (e.g., intake rates, occupancy and shielding factors, etc.) are generally those used in CSA N288.1-08. The intake rates for ingestion and inhalation are the mean intake rates provided in CSA N288.1-08 (2008) and Hart (2008) with the exception of the drinking water intake rate for a 1 year old infant. The drinking water intake rate for the 1 year old infant differs from that recommended in CSA N288.1-08 since the PNGS infant is assumed to drink only cow's milk (and not water and infant formula) (OPG, 2010b). Table 3.13 summarizes the exposure factors used in the radiological dose calculations.

Table 3.13: Human Exposure Factors for Radiological Dose Calculations

Exposure Factor	Units[4]	Infant 1 year	Child 10 year	Adult
Inhalation rate	m^3/a	1830	5660	5950
Inhalation occupancy factor	NA	1.0	1.0	1.0
Incidental soil ingestion rates	g dw/d	0.04	0.04	0.01
Incidental ingestion of sediment	g dw/d	0.04	0.04	0.01
Drinking water intake rates[1] Aquatic animal intake rates[2] Terrestrial animal intake rates Terrestrial plant intake rates	L/a kg/a kg/a kg/a	0 0.58 249 120.5	262.8 1.97 234 275.1	511 4.6 256.6 465.9
Outdoor occupancy factor	NA	0.2	0.2	0.2
Indoor plume shielding factor (effective dose)	NA	0.5	0.5	0.5

Exposure Factor	Units[4]	Infant 1 year	Child 10 year	Adult
Indoor plume shielding factor (skin dose and pure beta emitters)	NA	1.0	1.0	1.0
Indoor groundshine shielding factor (gamma emitters)[3]	NA	0.2	0.2	0.2
Groundshine shielding factor (uneven surface shielding)	NA	0.5	0.5	0.5
Beach swim occupancy factor	NA	0	0.014	0.014
Bathing occupancy factor	NA	0.014	0.014	0.014
Pool swim occupancy factor (WSP fill)	NA	0	0.028	0.028
Pool swim occupancy factor (Well water fill)	NA	0	0.014	0.014
Skin area	m^2	0.72	1.46	2.19
Dilution factor for shoreline sediments	NA	1.0	1.0	1.0
Shore Width factor (lake)	NA	0.3	0.3	0.3
Shoreline occupancy factor	NA	0.02	0.02	0.02
No. days/a soil ingested	d/a	135	135	135
No. days/a sediment ingested	d/a	45	45	45

Notes:

(1) The infant water intake rate is the difference between the water intake and milk intake rate given in CSA N288.1-08 factoring in the water content of milk.

(2) Excludes shellfish due to fresh water environment at PNGS. Shellfish are a marine environment food product.

(3) For effective and skin dose. For essentially pure beta emitters, this shielding factor is zero.

(4) dw used in specification of units indicates dry weight.

3.2.4.2 Non-Radiological Exposure Factors

For non-radiological dose calculations, exposure factors are generally those from Health Canada PQRA guidance (2004, 2010), as recommended by Clause 6.3.5 of CSA N288.6-12 (2012). Table 3.14 summarizes the exposure factors used in the non-radiological dose calculations.

Based on the results of the screening, the human exposure assessment was performed for the inhalation pathway for hydrazine, and the drinking water and fish ingestion pathways for hydrazine and morpholine. Hydrazine is released into the atmosphere through boiler steam releases and venting. Hydrazine and morpholine are discharged into the aquatic environment through boiler blowdown and flushing to the intake forebay. Hydrazine is added to the feedwater for oxygen removal and morpholine is added to the feedwater for pH control. Boiler blowdown is generally continuous and intermittent at PNGS B, and intermittent at PNGS A. For this assessment it was assumed that hydrazine is released to the aquatic environment continuously.

Since the relevant exposure pathway for the Sport Fisher is through fish ingestion, the fish tissue concentration for the relevant COPCs was estimated using bioaccumulation factors (BAFs), as discussed below.

Limited data exist on the bioaccumulation of hydrazine in aquatic organisms. Slonim and Gisclard (1976) derived a bioconcentration factor (BCF) of 288 L/kg based on a hydrazine concentration (144 mg/kg) estimated in guppies after four days exposure to hard water at a hydrazine concentration of 0.5 mg/L. According to Environment Canada and Health Canada (EC/HC, 2011) there are limitations and uncertainties associated with this study. Hydrazine was not measured in the fish, but was estimated from measurements in water, assuming that the slightly greater loss from water over 4 days, when fish were in the water, was due to uptake into the fish. Hydrazine bioaccumulation in fish was not directly measured. Since the same study showed higher rates of hydrazine degradation due to fish excretia in water, it is not clear that any hydrazine uptake into fish actually occurred. As well, a hydrazine concentration of 0.5 mg/L can generate ecotoxicity; therefore, there is uncertainty around the BCF of 288 L/kg. According to the *Persistence and Bioaccumulation Regulations* under the *Canadian Environmental Protection Act*, hydrazine would not be considered a substance that bioaccumulates since its BAF (or BCF) is less than 5000 and its $\log K_{ow}$ is less than 5 ($\log K_{ow}$ of -2.07 (EC/HC, 2011)).

Considering the large uncertainty surrounding the Slonim and Gisclard (1976) study, the published BCF from that study was not used for the quantitative evaluation of hydrazine. Quantitative Structure-Activity Relationship (QSAR) models are available to estimate bioconcentration factors for chemicals using correlations between BCFs and hydrophobicity ($\log K_{ow}$), where experimental data on bioaccumulation are lacking (European Commission, 2006). Meylan et al. 1999 (as cited in European Commission, 2006) recommends an improved model that suggests using a logBCF of 0.5 for all non-ionic compounds with $\log K_{ow} < 1$. Therefore, a logBCF of 0.5 was used to represent bioaccumulation of hydrazine in fish.

No data exist on the bioaccumulation of morpholine in aquatic organisms; however, bioaccumulation is not expected based on its low octanol-water partition coefficient ($\log K_{ow}$ of -2.55) (BUA, 1991 as cited in WHO, 1996). According to the *Persistence and Bioaccumulation Regulations* under the *Canadian Environmental Protection Act*, a substance is considered to bioaccumulate if its BAF≥5000, or its BCF≥5000, or if the $\log K_{ow} \geq 5$ (if neither the BAF nor the BCF can be determined). Similar to hydrazine, a logBCF of 0.5 was used to represent bioaccumulation of morpholine in fish, based on the recommended QSAR models discussed above (Meylan et al. 1999; as cited in European Commission, 2006).

Table 3.14: Human Exposure Factors for Non-Radiological Dose Calculations

Parameter	Units	Urban Resident		Commercial/ Industrial Worker	Sport Fisher		Reference
		Toddler	Adult	Adult	Toddler	Adult	
Drinking Water Intake Rate	L/d	0.6	1.5	1.5	N/A	N/A	HC, 2010
Fish Ingestion Rate	kg/day	N/A	N/A	N/A	0.056	0.111	HC, 2004
Days per Week/7 (D2)	d/d	1	1	1	N/A	N/A	OPG, 2013a
Weeks per Year/52 (D3)	wk/wk	1	1	0.23	N/A	N/A	OPG, 2013a
Years Exposed (D4)	years	N/A	30	30	N/A	30	HC, 2004
D_{fish}	d/yr	N/A	N/A	N/A	365	365	OPG, 2013a
Body Weight	kg	16.5	70.7	70.7	16.5	70.7	HC, 2010
Life Expectancy	years	N/A	70	70	N/A	70	
$RAF_{GIThydrazine}$		1	1	1	1	1	conservative assumption
$RAF_{GITmorpholine}$		1	1	1	1	1	conservative assumption

Note:
Characteristics of the Urban Resident are also applicable to the Correctional Institution

3.2.5 Models

OPG uses IMPACT™ version 5.4.0 (IMPACT) to calculate its annual public radiological doses using a mixture of environmental monitoring data and emissions data. IMPACT represents the method of dose calculation presented in CSA N288.1-08 (2008). Where environmental monitoring data were lacking, the concentration of radionuclides in air was determined from the sector-averaged Gaussian plume atmospheric dispersion model in IMPACT, based on the release rates from the PNGS. Table 3.15 shows a summary of which radionuclides and pathways were modelled and where measured data were used.

IMPACT has not been used for the non-radiological exposure assessment; however, atmospheric dispersion factors from IMPACT from source to receptor have been used to estimate the hydrazine concentration in air at each critical group location.

Table 3.15: Radionuclide and Pathway Data Used in the Dose Calculations (OPG, 2010b)

Pathway	Radionuclide	Modeled [1]	Measured
Air Inhalation	HTO	✓ (Fisher)	✓
	HTO	✓[2]	
	C-14	✓[2]	✓
	I(mfp)	✓[2]	
	Co-60	✓[2]	
Air External Exposure	Noble Gas		✓[3]
	C-14	✓[2]	✓
	I(mfp)	✓[2]	
	Co-60	✓[2]	
Soil External Exposure	HTO	✓	
	C-14	✓	
	I(mfp)	✓	
	Cs-137 + Co-60	✓	
Sand External Exposure	HTO	✓	
	C-14	✓	
	I(mfp)	✓	
	Cs-137 +		✓
Water External Exposure (Lakes, WSPs, Wells)	HTO	✓ (wells)	✓
	C-14	✓	
	I(mfp)	✓	
	Cs-137 +	✓	
Terrestrial Animals Ingestion	HTO	✓	✓ (milk)
	C-14	✓	✓ (milk)
	I(mfp)	✓	
	Cs-137 + Co-60	✓	
	OBT	✓[4]	
Terrestrial Plants Ingestion	HTO		✓
	C-14		✓
	I(mfp)	✓	
	Cs-137 + Co-60	✓	
	OBT	✓[4]	
Aquatic Animals Ingestion	HTO		✓
	C-14		✓
	I(mfp)	✓	

Pathway	Radionuclide	Modeled (1)	Measured
	Cs-137 +		✓
	OBT	✓(4)	
Sand and Soil Incidental Ingestion	HTO	✓	
	C-14	✓	
	I(mfp)	✓	
	Cs-137 + Co-60	✓	✓ (sand)
Water Ingestion (WSPs, Wells)	HTO		✓
	C-14	✓	
	I(mfp)	✓	
	Cs-137 +	✓	

Notes:
"+" indicates that contributions from progeny are included.
(1) Modeling is based on emissions or from local air measurements where they are available
(2) Concentrations are modeled from emissions and adjusted using empirical K_a determined for each critical group location
(3) Doses are measured directly at the site boundary and adjusted to critical group locations using the ratio of modeled air dispersion factors for the boundary monitor and critical group
(4) OBT dose is modeled from HTO concentration in terrestrial plants, terrestrial animals, or fish respectively.

3.2.6 Exposure Point Concentrations and Doses

3.2.6.1 Radiological Exposure Point Concentrations and Doses

For the radiological exposure assessment, exposure point concentrations are either based on measured data from the annual REMP or modelled from emissions data, as described in Table 3.15 and in OPG (2010b). Additionally, when measurement averages or other calculations are performed, they are calculated using actual results obtained even if they are below the critical level (OPG, 2010). As mentioned above, OPG uses IMPACT™ version 5.4.0 (IMPACT) to calculate its annual public doses using a mixture of environmental monitoring data and emissions data. Table 3.16 presents a summary of the maximum dose to the critical group from 2007 to 2011. The annual dose during this five year period ranged from 0.9 to 4.1 µSv and the critical group was either the industrial/commercial worker (adult) or the urban resident (adult/10 year old). The dominant pathways and radionuclides that contribute significantly to the total dose are inhalation of HTO and external exposure to noble gases.

The increase in annual dose from 2.6 µSv to 4.1 µSv in 2008, to the same critical group (Industrial/Commercial – Adult), is due to increased tritium and noble gas emissions from PNGS, and in particular, increased generation from Pickering A. The decrease in annual dose from 4.1 µSv to 1.8 µSv in 2009 to the same critical group is primarily due to a reduction in dose from HTO inhalation based on implementation of model parameters specified by CSA N288.1-08 (2008). The decrease in annual dose from 1.8 µSv to 1.0 µSv in 2010 is primarily due to a reduction in HTO emissions to air, discontinuation of passive

tritium-in-air samplers, which historically had higher results than the active samplers, and lower dose from noble gas as the result of a correction made to the building shielding factor to align with CSA N288.1-08 (2008).

In 2010 the critical group that received the highest dose switched from the Industrial/Commercial Worker to the Urban Resident. This change results from adjustments made to the characteristics of the Urban Resident to account for the portion of residents who work within 5 km of PNGS, resulting in increased dose from noble gases.

Although gross beta waterborne emissions from PNGS B over the 2007 to 2011 time period were approximately one order of magnitude greater than baseline levels (as shown in Table 3.7) this has not significantly impacted the annual public dose. Exposure to gross beta/gamma (represented by Cs-137 in the model) makes up a small component of the dose when compared to HTO inhalation and external exposure to noble gases. However, over the five year period beta/gamma emissions were highest in 2010. During 2010, annual dose from exposure to beta/gamma (Cs-137) primarily from water ingestion and external exposure to soil was approximately 20% of the total annual dose to the urban resident, whereas in 2011 dose from beta/gamma (Cs-137) from water ingestion and external exposure to soil contributed less than 2% of the total annual dose to the urban resident. This is conservative, as drinking water is used to irrigate the soil in the IMPACT model; therefore an increase in beta/gamma emissions in 2010 correlates with a greater external dose from soil. As of 2011 beta/gamma emissions have decreased to baseline levels (as shown in Table 3.6 and Table 3.7; therefore, the contribution of beta/gamma to the total dose is expected to remain low.

Table 3.16: Summary of Dose to Critical Group from 2007 to 2011

Year	Critical Group	Effective Dose (µSv)	Percentage of Regulatory Limit (%)	Percentage of Canadian Background Radiation (%)
2007	Industrial/Commercial (adult)	2.6	0.3	0.1
2008	Industrial/Commercial (adult)	4.1	0.4	0.3
2009	Industrial/Commercial (adult)	1.8	0.2	0.1
2010	Urban Resident (adult)	1.0	0.1	0.1
2011	Urban Resident (adult, 10 yr old child)	0.9	0.1	0.1

3.2.6.1.1 Radiological Doses using P-32 to Represent Gross Beta/Gamma in Water

Since the 2011 DRLs (implemented in 2013) indicate that P-32 is the limiting gross beta/gamma radionuclide in water, the annual dose calculations for 2011 and 2012 were recalculated using IMPACT 5.4.0 assuming all gross beta/gamma waterborne emissions were P-32 instead of Cs-137. In the existing public dose calculations, OPG uses measured

site-specific Cs-137 data for fish and sediment as dictator sources. For the updated scenarios, emissions of P-32 were modelled from source to receptor and did not incorporate any site-specific data, since none is available for P-32. The full results are presented in Appendix E, and a summary is provided here.

Using P-32 instead of Cs-137 to represent gross beta/gamma radionuclides in water, results in the Sport Fisher (adult) becoming the critical group for both 2011 and 2012 instead of the Urban Resident (adult), as shown in Table 3.17. The main pathway affected by the change from Cs-137 to P-32 is the aquatic animal ingestion pathway. The dose resulting from exposure to P-32 from fish ingestion is approximately three orders of magnitude higher than from exposure to Cs-137 through fish ingestion. This dose increase results from modelling P-32 in water followed by uptake in fish, instead of using measured site-specific fish tissue data for Cs-137 – there is no measured site-specific data for P-32.

Table 3.17: Comparison of Effective Dose to Potential Critical Groups Using P-32 and Cs-137 to Represent Gross Beta/Gamma in Water

Year	Potential Critical Group	Total Effective Dose with P-32 (µSv)	Total Effective Dose with Cs-137 (µSv)
2011	Farm	0.394	0.344
	Dairy Farm	0.354	0.355
	Urban Resident	0.931	0.948
	Industrial/Commercial	0.837	0.839
	Sport Fisher	1.45	0.363
	Correctional Institution	0.797	0.797
2012	Farm	0.407	0.342
	Dairy Farm	0.257	0.258
	Urban Resident	1.05	1.08
	Industrial/Commercial	0.828	0.830
	Sport Fisher	1.78	0.227
	Correctional Institution	0.786	0.787

3.2.6.2 Non-Radiological Exposure Point Concentrations and Doses

The exposure point concentrations are based on the screening conducted during problem formulation. For waterborne non-radiological COPCs, data were screened based on a number of data sources: CCW data from MISA and CofA from 2007 to 2011 and Lake Ontario water samples collected at the PNGS from 2006. The overall maximum and mean concentration from all of these sources was used for the exposure assessment. Since a large portion of the dataset for hydrazine and morpholine were non-detects, concentrations at the detection limit were incorporated into the mean concentration for hydrazine and morpholine.

For the human receptors that obtain drinking water from the Ajax WSP, a dilution factor between the PNGS outfall and the Ajax WSP of 8 was used, based on CSA N288.1 methodology (OPG, 2011a). Additionally, the release of hydrazine to the aquatic environment is assumed to occur continuously. The dose to the Sport Fisher due to ingestion of fish exposed to hydrazine and morpholine reflects this continuous release.

For airborne non-radiological COPCs, the air concentrations at the PNGS were estimated based on hydrazine emission rates from the facility and available dispersion factors to the locations of the closest human receptors (Urban Resident, Sport Fisher, and Industrial/Commercial Worker). The transfer parameters (P_{01}) from source emission to air are presented in Table 3.12. The transfer parameter presented is an average of P_{01} for PNGS A and P_{01} for PNGS B (OPG, 2011d,e). The model is conservative as it does not account for degradation of hydrazine in air between source and receptor. The exposure point concentrations for hydrazine in air are shown in Table 3.17. The maximum annual hydrazine concentration in air is based on the maximum ½ hour POI emission rate from the 2007 to 2011 air CofAs, averaged over the year. The maximum ½ hour POI is based on the assumption of 1 reactor start-up (2 hour vent) and 3 reactors in normal operations. The annual average hydrazine concentration in air is based on the annual emission rate presented in the Atmospheric Environment TSD for the Pickering B Refurbishment EA (SENES, 2007d), and assumes that each reactor vents 2 times per year (2 hours per vent). For both scenarios the reactor was assumed to operate at an 80% capacity factor (SENES, 2007d). Under normal operations, the emission rates for boiler chemicals such as hydrazine are significantly lower than during start-up (SENES, 2007d). The emission rates applied reflect emissions during start-up and are therefore conservative.

A summary of the dose to receptors from exposure to hydrazine and morpholine in water through ingestion and from exposure to hydrazine in air through inhalation is presented in Table 3.19, Table 3.20, and Table 3.21.

Table 3.18: Summary of Exposure Point Concentrations for Relevant Receptors, Pathways and Non-Radiological COPCs

Location	Receptor	Media	COPC	Units	Mean Annual Conc.	Max Annual Conc.	Notes
Outfall (500m S)	Sport Fisher	Air	Hydrazine	$\mu g/m^3$	0.011	0.044	emission rate*dispersion factor
		Water (fish ingestion)	Hydrazine	mg/L	< 0.00496	0.08	CCW (2007 to 2011 emissions data – Appendix A), Lake Water Sampling (2006)
			Morpholine	mg/L	< 0.00133	0.012	CCW (2007 to 2011 emissions data – Appendix A) , Lake Water Sampling (2006)
Ajax WSP	Industrial/Commercial Worker Urban Resident Correctional Institution	Water (ingestion)	Hydrazine	mg/L	< 0.00062	0.01	CCW/dilution factor
			Morpholine	mg/L	< 0.00017	0.0015	CCW/dilution factor
0.95 km NNE	Industrial/Commercial Worker	Air	Hydrazine	$\mu g/m^3$	0.0029	0.011	emission rate*dispersion factor
1.35 km WNW	Urban Resident	Air	Hydrazine	$\mu g/m^3$	0.0011	0.0043	emission rate*dispersion factor
3.1 km NNE	Correctional Institution	Air	Hydrazine	$\mu g/m^3$	0.00047	0.0018	emission rate*dispersion factor
6.9 km NE	Farm	Air	Hydrazine	$\mu g/m^3$	0.00011	0.00044	emission rate*dispersion factor
10.25 km NNE	Dairy Farm	Air	Hydrazine	$\mu g/m^3$	0.00007	0.00028	emission rate*dispersion factor

Notes:
Max ½ hour emission rate = 0.097 g/s (Appendix A, Table A.1)
Annual mean emission rate = 0.00163 g/s (SENES, 2007d, Table 3.2-1 and Table 3.2-2)
Dispersion factors are provided in Table 3.12.
Dilution factor = 8 (OPG, 2011a)

Table 3.19: Dose to Urban Resident and Commercial/Industrial Worker from Water Ingestion

COPC	Water Conc. From Ajax WSP (mg/L)		Urban Resident/ Correctional Institution Mean Dose (mg/kg-d)		Commercial/ Industrial Worker Mean Dose (mg/kg-d)	Urban Resident/ Correctional Institution Max Dose (mg/kg-d)		Commercial/ Industrial Worker Max Dose (mg/kg-d)
	Mean	Max	Toddler	Adult	Adult	Toddler	Adult	Adult
Hydrazine	0.00062	0.01	N/A	5.64E-06	1.30E-06	N/A	9.09E-05	2.09E-05
Morpholine	0.000166	0.0015	6.05E-06	3.53E-06	8.12E-07	5.45E-05	3.18E-05	7.32E-06

Notes:
The dose to the urban resident is also applicable to the correctional institution.
For carcinogenic substances only exposure to adult receptors is needed (HC, 2010). The toddler dose is not limiting and was not calculated.

Table 3.20: Dose to Sport Fisher due to Fish Ingestion

	Water Conc. From Outfall (mg/L)		BAF (L/kg fw)	Fish Tissue Conc. (mg/kg fw)		Sport Fisher Mean Dose (mg/kg-d)		Sport Fisher Max Dose (mg/kg-d)	
COPC	Mean	Max		Mean	Max	Toddler	Adult	Toddler	Adult
Hydrazine	0.00496	0.08	3.16	0.0157	0.2528	N/A	1.05E-05	N/A	1.70E-04
Morpholine	0.00133	0.012	3.16	0.0042	0.0379	1.43E-05	6.61E-06	1.29E-04	5.95E-05

Notes:
The BAF is from Meylan et al. 1999 (as cited in European Commission, 2006) that suggests using a logBCF of 0.5 for all non-ionic compounds with $\log K_{ow} < 1$.
For carcinogenic substances only exposure to adult receptors is needed (HC, 2010). The toddler dose is not limiting and was not calculated.

Table 3.21: Dose to Receptors due to Hydrazine Inhalation

Receptor	Fraction of Time Exposed	Mean Dose ($\mu g/m^3$)	Max Dose ($\mu g/m^3$)
Urban Resident	1	3.85E-04	1.48E-03
Industrial/Commercial	0.23	2.25E-04	8.70E-04
Fisher	0.01	3.94E-05	1.52E-04
Correctional Institution	1	1.61E-04	6.23E-04
Farm	1	3.90E-05	1.51E-04
Dairy Farm	1	2.47E-05	9.53E-05

Note:
Includes 80% reactor capacity assumption

3.2.7 Uncertainties in the Exposure Assessment

Table 3.22 summarizes the major uncertainties in the exposure assessment.

Table 3.22: Summary of Major Uncertainties in the Exposure Assessment

Risk Assessment Assumption	Justification	Over/Under Estimate Risk?
Water concentration for hydrazine and morpholine at Ajax WSP is pre-treatment, and is modeled from liquid releases	No information on concentration of relevant COPCs post WSP treatment, dilution factor available from PNGS to Ajax WSP	Overestimate
Air concentrations at receptor locations estimated using dispersion factors (not measured) from OPG (2011a,b)	Dispersion factors are available.	Overestimate
Mixed beta-gamma emissions to air (particulate) are represented by Co-60 and mixed beta-gamma emissions to water are represented by Cs-137.	These radionuclides are the radionuclides with the most limiting dose based on DRL calculation.	Overestimate
DRLs being implemented in 2013 indicate P-32 is the limiting beta-gamma radionuclide in water, not Cs-137.	This ERA focuses on 2007 to 2011 data; however dose from P-32 is provided in Appendix E.	Underestimate
BAF for hydrazine is based on QSAR model and not measured bioaccumulation data.	Limited information exists on bioaccumulation of hydrazine, although it is expected to be low. Only one study (Slonim and Gisclard, 1976) exists on hydrazine bioaccumulation, and there is large uncertainty surrounding the methods and results.	Neither (value is best estimate)

Risk Assessment Assumption	Justification	Over/Under Estimate Risk?
BAF for morpholine is based on QSAR model and not measured bioaccumulation data.	No information in literature regarding morpholine BAF, although it is not expected to bioaccumulate.	Neither (value is best estimate)
Biodegradation of hydrazine was not taken into account	Conservative assumption	Overestimate

3.3 Toxicity Assessment

3.3.1 Toxicological Reference Values (TRVs)

Boiler treatment chemicals including hydrazine, morpholine and degradation products are used within the feedwater system to prevent corrosion in the boilers. Hydrazine is specifically used in the PNGS as an oxygen reduction agent and morpholine is used for pH control. A summary of the TRVs selected for hydrazine and morpholine are presented in Table 3.23 and discussed below. Examples of TRVs include slope factors and unit risks for carcinogens, and reference doses, tolerable daily intake, or acceptable daily intake for non-carcinogens. TRVs are used in the risk characterization to determine ILCRs and Hazard Quotients (HQs), as discussed in Section 3.4

Hydrazine is classified by the International Agency for Research on Cancer (IARC) and the US EPA as a Group 2B carcinogen – probable human carcinogen; and by the European Commission as Category 2 for carcinogenicity – should be regarded as if it is carcinogenic to man. There is evidence of hydrazine's carcinogenicity in experimental animals, but insufficient evidence in humans. Studies showed tumor induction in mice, rats and hamsters following administration of hydrazine orally or via inhalation (EC/HC, 2011).

The inhalation unit risk for hydrazine is 4.9×10^{-3} $(\mu g/m^3)^{-1}$ and was derived by the US EPA based on a 1981 study by MacEwan et al. of nasal cavity tumors in rats exposed to hydrazine via inhalation (US EPA, 1991). The US EPA (1991) has derived an oral slope factor of 3.0 $(mg/kg\text{-}day)^{-1}$ based on a 1970 study by Biancifiori on liver cancer in mice exposed to hydrazine sulphate orally.

Morpholine is not carcinogenic or teratogenic; however, morpholine can be nitrosated to n-nitrosomorpholine which is carcinogenic. Health Canada (2002) has derived an acceptable daily intake of 0.48 mg/kg/d based on a No Observable Adverse Effect Level (NOAEL) from a chronic oral toxicity study conducted by Shibata et al. (1987) in rats and mice, with the inclusion of uncertainty factors (UFs). Specifically, a UF of 10 was used for the inter-species differences between mice and humans, and a second UF of 10 was used for the intra-species differences between humans. Additionally, a UF of 2 was included to

reflect the deficiencies in the toxicological database (J. Rotstein, personal communication, December 27, 2013).

Table 3.23: Selected Human Toxicity Reference Values for Non-Radiological Risk Assessment

COPC	TRV Type	Value	Units	Reference
Hydrazine	Oral Slope Factor	3	$(mg/kg/d)^{-1}$	IRIS US EPA, 2001 (as cited in US EPA, 2009)
	Inhalation Unit Risk	4.90E-03	$(\mu g/m^3)^{-1}$	IRIS US EPA, 2001 (as cited in US EPA, 2009)
Morpholine	Acceptable Daily Intake	0.48	mg/kg/d	HC, 2002

3.3.2 Radiation Dose Limits and Targets

The public dose limit for radiation protection is 1 mSv/yr, as described in the Radiation Protection Regulations under the *Nuclear Safety and Control Act*. This limit is defined as an incremental dose. It is set at a fraction of natural background exposure to radiation. Public doses arising from licensed facilities are compared to the public dose limit and higher doses are considered unacceptable.

3.3.3 Uncertainties in the Toxicity Assessment

The oral slope factors are developed as conservative upper-bound estimates of the increase in carcinogenic risks due to lifetime exposure to the COPC. The unit risk is the upper bound of the increase in carcinogenic risk estimated for continuous lifetime exposure to a chemical at a concentration of 1 $\mu g/m^3$ in air. Unit risks and slope factors are used to estimate an upper bound probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen. The unit risk and the slope factor are based on the assumption of a linear low-dose response. This is considered conservative. The acceptable daily intake for morpholine incorporates several UFs. Specifically, a UF of 10 was used for the inter-species differences between mice and humans, and a second UF of 10 was used for the intra-species differences between humans. Additionally, a UF of 2 was included to reflect the deficiencies in the toxicological database (J. Rotstein, personal communication, December 27, 2013). These factors are intended to provide a conservative toxicity reference value. Risk Characterization

3.3.4 Risk Estimation

In order to characterize potential risks quantitatively, the results of the exposure and toxicity assessments were used to estimate HQs and ILCRs for each receptor. HQs were estimated for non-carcinogenic substances using a threshold TRV as follows:

Hazard Quotient = Estimated Exposure / Toxicity Reference Value

These HQs were compared to a target value of 0.2, as recommended by Clause 6.5.2.6 in CSA N288.6-12.

For carcinogenic substances, the estimated exposure was multiplied by the appropriate non-threshold TRV, either a slope factor or a unit risk, to derive a conservative estimate of the potential ILCR, as follows:

ILCR = Estimated Exposure x Cancer Slope Factor

Or, in the case of airborne contaminants:

ILCR = Estimated Exposure x Cancer Unit Risk

The estimated ILCRs were compared to a target cancer risk of 1 in 1,000,000 or 10^{-6}, as recommended by Clause 6.5.2.4 in CSA N288.6-12. This level is consistent with the acceptable risk level used by the Ontario MOE (2011) and the US EPA (2005). At this risk level, health impacts are considered to be negligible. Other agencies, such as Health Canada use a target cancer risk of 1 in 100,000 or 10^{-5}. However, a range of cancer risk between 1 in 10,000 and 1 in 1,000,000 is generally considered acceptable (Health Canada, 2004).

A summary of the HQs and ILCRs are presented in Table 3.24.

For radionuclides, the total dose is compared to the public dose limit of 1 mSv/yr as discussed in Section 3.3.2 above.

Table 3.24: Risk Estimates for Exposure to COPCs

Receptor	Pathway	Type	COPC	Mean Risk	Max Risk	Benchmark
Urban Resident	Inhalation	Cancer Risk	hydrazine	1.88E-06	7.27E-06	1.00E-06
	Water Ingestion	Cancer Risk	hydrazine	1.69E-05	2.73E-04	1.00E-06
	Water Ingestion	HQ	morpholine	1.26E-05	1.14E-04	0.2
Commercial/ Industrial Worker	Inhalation	Cancer Risk	hydrazine	1.10E-06	4.26E-06	1.00E-06
	Water Ingestion	Cancer Risk	hydrazine	3.89E-06	6.27E-05	1.00E-06
	Water Ingestion	HQ	morpholine	1.69E-06	1.52E-05	0.2
Sport Fisher	Inhalation	Cancer Risk	hydrazine	1.93E-07	7.45E-07	1.00E-06
	Fish Ingestion	Cancer Risk	hydrazine	3.16E-05	5.10E-04	1.00E-06
	Fish Ingestion	HQ	morpholine	2.98E-05	2.68E-04	0.2
Correctional Institution	Inhalation	Cancer Risk	hydrazine	7.91E-07	3.05E-06	1.00E-06
	Water Ingestion	Cancer Risk	hydrazine	1.69E-05	2.73E-04	1.00E-06
	Water Ingestion	HQ	Morpholine	1.26E-05	1.14E-04	0.2
Farm	Inhalation	Cancer Risk	hydrazine	1.91E-07	7.39E-07	1.00E-06
Dairy Farm	Inhalation	Cancer Risk	hydrazine	1.21E-07	4.67E-07	1.00E-06

Note:
Grey shading indicates when the risk exceeds the associated benchmark

3.3.5 Discussion of Chemical and Radiation Effects

3.3.5.1 Effects Monitoring Evidence

Two studies of health indicators in Durham Region (Durham Region Health Department, 1996, 2007) compared the incidence of cancer deaths and birth defects for Durham Region, and for municipalities within Durham Region including Ajax-Pickering, Oshawa-Whitby, Clarington, and North Durham against the same statistics for the Province of Ontario. In the 1996 study, Halton Region and Northumberland were used for comparison purposes and in the 2007 study Halton Region and Simcoe County were used for comparison against

Durham Region. Both studies found no evidence that any emissions from CANDU stations at PNGS or Darlington Nuclear Generating Station had any adverse health effects on nearby residents.

3.3.5.2 Likelihood of Effects

A summary of the HQs and ILCRs are presented in Table 3.24. As shown in the table, risks from morpholine for the urban resident, correctional institution and industrial/commercial worker through water ingestion are below the target of 0.2 for non-cancer risk, indicating that no increased risk from water ingestion is expected.

Exposure to hydrazine for the urban resident, correctional institution, and industrial/commercial worker through water ingestion (Ajax WSP) is above the cancer risk target of 10^{-6}. Maximum hydrazine concentrations are based on measured data from 2007 to 2011 at the point of discharge to the CCW. However, all lake water samples collected from both the PNGS A and PNGS B discharge channels show hydrazine concentrations <0.005 mg/L in the lake, indicating that rapid mixing occurs. Using the measured lake water concentration (and applying a dilution factor of 8 to the Ajax WSP), the risk to the urban resident and correctional institution still exceeds the 10^{-6} cancer risk target; however, the risk is only slightly above Health Canada's target cancer risk of 10^{-5}. A range of cancer risk between 1 in 10,000 and 1 in 1,000,000 is generally considered acceptable (Health Canada, 2004). As all lake water samples for hydrazine were below the detection limit of 0.005 mg/L, the lake water concentration is likely even lower; therefore, the risk estimated is conservative.

With respect to the sport fisher, risks from morpholine through fish ingestion are below the target of 0.2 for non-cancer risk, indicating that no increased risk from fish ingestion is expected. Exposure to hydrazine for the sport fisher through fish ingestion is above the cancer risk target of 10^{-6}. However, hydrazine is expected to degrade quickly in the environment. At a pH of 8 (representative of the typical pH observed in Lake Ontario near the PNGS), the chemical half-life of hydrazine ranges from 0.6 to 1.31 days (EC/HC, 2011). Therefore, it is uncertain if hydrazine would be available for uptake by fish at the concentrations used in the calculations. The risk estimated is conservative.

As seen in Table 3.24, the estimated range of risk to the urban resident and the commercial/industrial worker from inhalation of hydrazine is above the cancer risk target of 10^{-6}. These risk estimates are likely very conservative. In the Pickering B EA, SENES (2007d) estimated the risk due to hydrazine inhalation at the Bay Ridges Neighbourhood and Liverpool Road Subdivision. These receptors are part of the collective "Urban Resident". The risk estimates were 4.5×10^{-7} at the Bay Ridges Neighbourhood and 5.5×10^{-7} at the Liverpool Road Subdivision, all below the cancer risk target of 10^{-6}.

Although the hydrazine emission rates used were comparable to the emission rates used in the 2007 EA, the differences in the results are likely due to model differences. In SENES

(2007d), the air concentrations at the Bay Ridges Neighbourhood and Liverpool Road Subdivision were estimated using AERMOD. For the current risk assessment, the air concentrations at receptor locations were estimated using the dispersion factors used for the derived release limits and annual REMP dose calculations. These dispersion factors are determined from dispersion modeling in IMPACT based on release rates and meteorological data. The Gaussian air model in IMPACT on average, overpredicts air concentrations by approximately a factor of 1.5 (Hart, 2008); however, modeled air concentrations from IMPACT are still considered appropriate as a conservative assessment.

The uncertainties associated with the air model in IMPACT are discussed in more detail in Section 3.3.6. The estimated dispersion factor from the facility source to the urban resident in AERMOD is approximately 5.2×10^{-8} s/m^3, whereas the estimated dispersion factor to the urban resident in IMPACT is approximately 6.9×10^{-7} s/m^3. Overall, the hydrazine inhalation risks to the urban resident and the industrial/commercial worker presented in this risk assessment are considered conservative. The mean risk estimates presented are more realistic and exceed the cancer risk benchmark by a factor of 2, but are consistent with the 10^{-6} target considering the uncertainty in the IMPACT model. Therefore, risks at these receptor locations due to inhalation of hydrazine are considered acceptable.

3.3.5.3 Radiation Effects

The public dose estimates for the critical group (industrial/commercial worker or the urban resident) are between 0.1 and 0.4% of the regulatory public dose limit of 1 mSv/year and approximately 0.1% of the Canadian background radiation. Since the critical group receives the highest dose from the PNGS, demonstration that they are protected implies that other receptor groups near the PNGS are also protected.

Facility releases are considered to be adequately controlled, and further optimization of PNGS operations is not required. Nevertheless, the ALARA principle is applied at PNGS to reduce emissions as low as reasonably possible.

Since the dose estimates are a small fraction of the public dose limit and natural background exposure, no discernable health effects are anticipated due to exposure of potential groups to radioactive releases from the PNGS.

3.3.6 Uncertainties in the Risk Characterization

There is inherent uncertainty in the air model in IMPACT that is used by OPG to estimate atmospheric dispersion factors to the critical group locations. Uncertainty in the air predictions arises from the following assumptions made in the model (Hart, 2008):

- The activity in the plume has a normal distribution in the vertical plane.

- The effects of building-induced turbulence on the effective release height and plume spread have been generalized, while data suggest that effects of building wakes vary substantially depending upon the geometry of the buildings and their orientation with respect to wind direction.

- A given set of meteorological and release conditions leads to a unique air concentration, where in reality measured concentrations can vary by a factor of 2 under identical conditions.

At distances greater than 1 km, there is a two-fold uncertainty around the predictions of the sector-averaged Gaussian model used in IMPACT (Hart, 2008). At all distances, the Gaussian air model in IMPACT on average, overpredicts air concentrations by approximately a factor of 1.5 (Hart, 2008).Considering the combined uncertainties in the exposure assessments and the target values, it is reasonable that the overall risks presented are conservative estimates. In some cases where an ILCR above the target cancer risk (10^{-6}) was estimated, for a given COPC, potential field monitoring may be appropriate to clarify media concentrations.

A PRA to quantify uncertainty in the risk estimate has not been performed and is not considered necessary, since it is not likely to provide a better basis for risk management/decision making. According to CSA N288.6 (2012), a qualitative or semi-quantitative evaluation of uncertainty is considered sufficient for evaluation of uncertainty.

4.0 ECOLOGICAL RISK ASSESSMENT

4.1 Problem Formulation

4.1.1 Receptor (VEC) Selection and Characterization

4.1.1.1 Receptor (VEC) Selection

It is an impractical task to assess the effect of radiological emissions on all the species of biota within the natural ecosystem at the Pickering site. Therefore, a select group of organisms are chosen for dose and risk analysis. These organisms are selected because they are known to exist on the site, and are representative of major taxonomic groups or have a special importance or value. The representative organisms are also known as VECs. From this list of VECs, a focused group of organisms are chosen, referred to as indicator species. These indicator species are characterized in a generic and conservative manner to collectively represent exposure to the main stressors from facility operations.

Indicator species were selected in previous ecological assessments for the PNGS in 2000 (SENES, 2000) and 2007 (SENES, 2007a). For the 2000 ERA, indicator species were selected based on a review of biota found on or near the site, and multi-stakeholder input. In 2007, the VEC and indicator species list was revised, with rationale provided. The indicator species from the two ERAs, along with their rationale, and recent data regarding biota, flora and fauna were reviewed and assessed based on the criteria listed in Table 7.1 of CSA N288.6 (2012).

Table 4.1 presents the indicator assessment based on the CSA criteria. Other than the American Eel, none of the ecological receptors have a conservation status in the Species at Risk registry, or Species at Risk in Ontario (SARO) list. The American Eel (*Anguilla rostrata*) is listed as endangered in the SARO list, and threatened in the COSEWIC list. The only other species that has a history of concern is the Trumpeter Swan. The presence of breeding Trumpeter Swans is a criterion to confirm that an area is a Significant Wildlife Habitat, according to Ontario's Ministry of Natural Resources.

Indicator species were selected as receptors for the conceptual model based on the criteria in Table 4.1. Species were selected to represent each major plant and animal group, reflecting the main ecological exposure pathways, feeding habits and habitats at or around the site. Then the list of receptors was reduced based on evaluation against the remaining criteria, using the previous rationales and other literature resources. Species that were ecologically similar to other species and could be represented by another species, were not included in the assessment to reduce redundancy in the exposure calculations. For example, the alewife and emerald shiner are similar across all criteria, and could be assessed interchangeably. However, according to impingement reports, the alewife is the dominant species impinged at PN, so it was chosen to be a receptor. Any effects on the alewife are considered representative of those for the emerald shiner. Further description

regarding the chosen VECs, such as habitat and feeding habits, are provided in Appendix B.

Table 4.2 shows the VECs chosen for assessment. Six types of fish were chosen as VECs to represent the fish species likely to be influenced by the operation of PNGS. However, due to the limited species-specific exposure factor and toxicity data available, risks to fish are estimated by assessing the fish in two categories (bottom-dwelling fish and other fish) for the radiological assessment, and as one category of fish for the non-radiological assessment. The same methodology was applied for terrestrial plants, where all the types of terrestrial plants were assessed by class and the most representative factor was applied and used.

Fish species are used as surrogates for amphibians because the sensitive life stages for amphibians and reptiles (i.e., egg and tadpole) are aquatic and similar to the sensitive life stages for fish. During the tadpole stage, tadpoles and fish have similar exposure pathways (e.g., absorption through skin, similar feeding habits). In addition, exposure factor and toxicity data for amphibians and reptiles are limited. Therefore, the fish species in the assessment are expected to provide a reasonably good surrogate for, and protection of, amphibians and reptiles such as frogs during the sensitive tadpole stage.

Table 4.1: Criteria to Select Ecological Receptors

Class/ Community/ Individual	Indicator Species	Major Plant or Animal Group	Facility or Stakeholder Importance	Socio-economic Significance	Availability of Information	Exposed to and/or Sensitive to Stressor	Potential to Evaluate Population Effects
Fish	**Alewife**	P, F	PN			W, TH, IM, NR	
	Smallmouth Bass	P, PR	PN	SF	EER	W, R, NR, TH, IM	EER
	Northern Pike	P, PR, FF	PN	SF	EER	W, R, NR, TH, IM	EER
	Brown Bullhead	B	EW, PN		EER	W, R, NR, TH, IM	
	Round Whitefish	P, B, O	PN	CF	EER	W, R, NR, TH, IM	EER
	White Sucker	P, B	EW, PN		EER	W, R, NR, TH, IM	
	Emerald Shiner	P, F	PN			W, TH, IM, NR	
	Lake Trout	P, PR, FF	PN	CF, SF		W, TH	
	Walleye	P, PR	PN	CF, SF		W, TH	
	American Eel	P, B, AI	PN	E		W, TH, IM, NR	
Aquatic Plants	**Narrow-leaved cattail**	Aquatic Plant	PN		EER	W, NR, R	
Aquatic Invertebrates	**Benthic Invertebrates**	Aquatic Invertebrate	PN		EER	W, NR, R	
Terrestrial Invertebrates	**Earthworms**	Terrestrial Invertebrate	PN			A, NR, R	
Amphibians and Reptiles	**Northern Leopard Frog**	Amphibian	PN			A, W, NR, R	

Class/ Community/ Individual	Indicator Species	Major Plant or Animal Group	Facility or Stakeholder Importance	Socio-economic Significance	Availability of Information	Exposed to and/or Sensitive to Stressor	Potential to Evaluate Population Effects
	Midland Painted Turtle	Reptile	PN			A, W	
Birds	Lesser Scaup	AQ, AP, AI			EER	EER	
	Double-Crested Cormorant	AQ, FF	PN		EER	EER	
	Trumpeter Swan	AQ, AP	RG, EW, PN		EER	BR, NE, NR, NO	EER
	Ring-Billed Gull	TR, AQ, FF, IN, MM	PN		EER	RA	
	Great Horned Owl	TR, MM, BB	PN		EER	R, A	
	Black-crowned night heron	AQ, FF	PN				
	Common tern	AQ, FF, IN	PN			R, NR, BR, NE	
	Grey catbird	TR, IN	PN			A, NE, R, NR, NO	
	Bufflehead	AQ, AI, FF	PN			WC, SC, M, TH	
	Red-winged blackbird	TR, IN, SE	PN			R, A, BR, NR, NO	
	Red-tailed hawk	TR, MM, IN, BB	PN			BR, NR, NO	
Mammals	**Muskrat**	AM, AP, FF	PN		EER	NR	EER
	Red Fox	TM, MM, BB, V	PN		EER	HM	EER
	Meadow Vole	TM, V	EW, PN		EER	AC	
	Woodchuck	TM, V	PN			NR, NO	
Terrestrial Plants	**Pines**	Coniferous	EW, PN		EER	NR	EER
	Chokecherry	Shrub	PN			NR	
	New England aster	Herbaceous perennial	PN			NR	
	Eastern hemlock	Coniferous	PN			NR	
	Red ash	Deciduous	PN			NR	
	Sandbar willow	Shrub	PN			NR	

A – Affected by airborne emissions
AI – Aquatic Invertebrate in Diet
AM – Aquatic Mammal
AP – Aquatic Plants in Diet
AQ – Aquatic Bird
B – Benthic Invertebrates in Diet
BB – Birds in Diet
BR – Breeds within the area
CF – Commercial Fish
E – Endangered (Provincially)
EER – Identified as fulfilling requirement in EER (2000)
EW – Identified in a scientific workshop for the 2000 ERA, included participants from OPG, CNSC, MOE, and consultants

F – Forage
FF – Fish in Diet
HM – Sensitive to human activities
IM – Impingement Concern
IN – Insects in Diet
MM – Mammals in Diet
M – Migratory
NE – Nests in the area
NO – Sensitive to noise disturbance
NR – Sensitive to Non-Radioactive emissions
O – Omnivore
P – Pelagic
PN – Present on site

PR – Predator
RG – Identified by the regulator (CNSC)
R – Sensitive to Radioactive emissions
SC – Exposed to sediment contamination
SE – Seeds in Diet
SF – Sport Fish
TH – Sensitive to thermal emissions
TM – Terrestrial Mammal
TR – Terrestrial Bird
V – Vegetation in Diet

W – Affected by waterborne emissions
WC – Exposed to water contamination

Species names in bold are chosen as indicator species for assessment.

Table 4.2: Summary of VECs and Representative Assessment Biota

Class	Assessment Biota	VEC
Fish	Fish	Brown Bullhead[1]
		Alewife
		Smallmouth Bass
		Northern Pike
		Round Whitefish[1]
		White Sucker[1]
		Lake Trout
		Walleye
		American Eel[1]
Amphibians and Reptiles		Northern Leopard Frog
		Midland Painted Turtle
Aquatic Plants	Aquatic Plants	Narrow-leaved cattail
Aquatic Invertebrates	Aquatic Invertebrates	Benthic Invertebrates
Aquatic Birds	Trumpeter Swan	Trumpeter Swan
	Ring-Billed Gull	Ring-Billed Gull
	Common tern	Common tern
	Bufflehead	Bufflehead
Aquatic Mammals	Muskrat	Muskrat
Terrestrial Plants	Terrestrial Plants	Chokecherry
		New England aster
		Eastern hemlock
		Red ash
		Sandbar willow
Terrestrial Invertebrates	Terrestrial Invertebrates	Earthworms
Terrestrial Birds	Red-winged blackbird	Red-winged blackbird
	Red-tailed hawk	Red-tailed hawk
Terrestrial Mammals	Red Fox	Red Fox
	Meadow Vole	Meadow Vole

Note:
[1] Assessed as a bottom-feeding fish in radiological assessment

4.1.1.2 Receptor (VEC) characterization

Receptor profiles in Appendix B describe the habitat and the feeding habits of the selected receptor species. The receptor species were assigned to assessment locations on the site based on habitat features at each location and where the receptor is likely to be found. Receptor locations for assessment purposes are discussed in Section 4.1.5.

For mammals and birds, dietary assumptions were made based on the described feeding habits. Diets were simplified to represent the main food chain pathways without trying to capture their full taxonomic complexity. For example, muskrats are assumed to eat aquatic plants. The dietary assumptions for bird and mammal receptors are detailed in Table 4.6.

Species-specific exposure parameters, including bioaccumulation factors, food and water ingestion rates, transfer factors and body weights, are described Section 4.2.3.4.

4.1.2 Assessment and Measurement Endpoints

Assessment endpoints are attributes of the receptors that we wish to protect in our environmental programs (Suter *et al.*, 1993). The purpose of an environmental assessment is to evaluate whether these environmental protection goals are being achieved or are likely to be achieved. The assessment endpoint for all receptors in this ecological risk assessment is population abundance. The environmental protection goal is to maintain population abundance for the majority of species, and thereby maintain ecosystem function. The purpose of the ecological risk assessment is to evaluate whether this is likely to be achieved.

Population abundance will not be directly measured or predicted quantitatively in this ecological risk assessment. Forecasting stressor effects on population abundance requires development and parameterization of a population model which incorporates understanding of stressor effects and compensatory mechanisms. This understanding requires years of population study, which is beyond the scope of the EcoRA at present.

Measurement endpoints are typically utilized to evaluate whether environmental protection goals are likely to be achieved. These are endpoints such as reproduction, growth and survival that are logically related to maintenance of population abundance, but are more easily inferred from COPC concentration and dose. In this EcoRA, possible effects of COPCs on survival or reproduction will be inferred or predicted by comparison of estimated doses to benchmark doses that have been associated with such effects in the literature. The benchmark values used are presented in Section 4.3.

4.1.3 Selection of Chemical, Radiological, and Other Stressors

4.1.3.1 Chemical Stressors

4.1.3.1.1 Air

Section 3.1.2.1 describes the atmospheric releases due to the operations at the PN site. Inhalation exposures to biota are usually minor compared to the soil and food ingestion pathways, and can be ignored for most substances, except for substances that do not partition to soil (CSA, 2012). These substances include gases such as nitrogen oxides and sulphur dioxide. For these substances, air concentrations dominate the exposure pathway to terrestrial biota. As discussed in Section 3.1.2.1, the main source of these gases is fuel combustion. The maximum concentrations at the property line POI for NO_x and SO_x were predicted using estimated atmospheric emissions and a dispersion factor. The ½ hour POI concentrations were converted to concentrations with averaging periods comparable to the relevant MOE AAQC. The AAQCs are developed to be protective of health and the environment. The 24-hr NO_x concentration at the property line is 163 µg/m^3, compared to the 24-hr AAQC of 200 µg/m^3. The annual SO_2 concentration at the property line is 28 µg/m^3 compared to the annual AAQC of 55 µg/m^3. The concentrations at the property line are well below the AAQC, therefore NO_x and SO_x are not likely to have potential effects on ecological receptors located at the property line.

The closest area within the PN site with significant ecological populations is Alex Robertson Park. Based on REMP reports from 2007 to 2011, the dispersion factor (based on air emissions and measured data in the environment) to Alex Roberson Park ranged from 9.10×10^{-8} s/m^3 to 2.00×10^{-7} s/m^3. This factor is an order of magnitude less than the value from Golder (2011) used to calculate the maximum POI concentration at the property line. The dispersion factor for the property line is meant to estimate the worst case concentration along the property line. Since Alex Robertson Park is not located downwind of the predominant wind direction, the air concentrations at the park are expected to be less than the maximum property line concentration, as shown by the differences in dispersion factors. Since the NO_x and SO_x concentrations do not exceed AAQCs at the property line, biota at Alex Robertson Park are not expected to experience adverse effects from exposure to these COPCs, since the concentrations at Alex Robertson Park are expected to be lower than those predicted for the property line. NO_x and SO_x are not discussed further in the EcoRA.

Hydrazine and morpholine are released to the air through atmospheric boiler emissions, as described in Section 3.1.2.1. The releases due to boiler venting were compared against acute toxicity benchmarks. The benchmarks considered were Lowest Observable Adverse Effect Levels (LOAELs) converted to NOAELs by applying a safety factor of 10. This conversion factor has been used to derive the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 1999a), and is the most conservative factor cited in Suter *et al.* (1993). The maximum half-hour POI concentrations were 0.968 µg/m^3 and

299.3 µg/m^3 for hydrazine and morpholine, respectively (Appendix A, Table A.1). These concentrations did not exceed the toxicity benchmarks, which are 10,600 µg/m^3 for hydrazine (EC/HC, 2011) and 780,000 µg/m^3 for morpholine (WHO, 1996). Therefore, hydrazine and morpholine were not carried forward for further assessment.

4.1.3.1.2 Surface Water

The surface water screening is based on measurements of COPCs discharged from 2007 to 2011 into the CCW discharge channel, as well as lake water measurements collected in 2006. The station effluent from the CCW discharge channel is discussed in Section 3.1.2.2 and the screening based on effluent discharge is presented in Table A.8.

As discussed in the COPC screening for the HHRA (Section 3.1.2.2), a surface water monitoring program was conducted in 2006 to quantify the concentration of COPCs in the PNGS A and PNGS B CCW discharge channels (Golder, 2007a;e). For the current assessment, an additional screening was performed (Appendix A, Table A.9), where maximum observed lake water concentrations were screened against the lowest of PWQO or CCME water quality guidelines (or guidelines from other jurisdictions such as British Columbia MOE where Ontario or CCME values were not available), as well as 95th percentile of Lake Ontario background values from the DWSP (MOE, 2013), where no guideline existed. For parameters not part of the DWSP, 95th percentile of background data obtained from the Cobourg area were used, identified as the RSA in the Darlington EA (Golder, 2009). Where background lake water concentrations from the RSA were not available, background concentrations were obtained from the area including Darlington Provincial Park and Port Darlington, defined as the LSA in the Darlington EA. For some parameters (e.g., beryllium), 95th percentile of background data did not exist; therefore the minimum background concentration was used.

Toxicity benchmarks were also used where environmental quality guidelines were lacking. As recommended by Clause 7.2.5.3.2 in CSA N288.6, screening criteria should represent no-effect levels. Toxicity benchmarks were generally obtained from Suter and Tsao (1996), modified from Borgmann *et al.* (2005), and modified from EC/HC (2011). These benchmarks represented secondary chronic values (SCV), modified LC_{50}s (acute to chronic, and 50% to no-effect), and modified no-effect concentrations (acute to chronic). A chronic no-effect concentration of 2.6 µg/L has been suggested for hydrazine in fresh water, based on an acute toxicity threshold with a safety factor (EC/HC, 2011).

For a number of COPCs, the maximum measured lake water concentration was below the detection limit; however, the detection limit exceeded background concentrations or environmental quality guidelines. Therefore, toxicity benchmarks were used to clarify risk. For manganese, strontium and tin, toxicity benchmarks (SCVs) from Suter and Tsao (1996) were used. SCVs are considered NOECs and are appropriate for screening. Limited toxicity data exists for bismuth, cesium, and thorium. For these metals, Borgmann *et al.* (2005) presents acute LC_{50} values. Borgmann *et al.* (2005) performed acute toxicity tests

with *Hyalella azteca* for 63 metals in hard and soft water. Acute LC_{50}s were converted to chronic EC_{20}s (using a conversion factor of 10 (EC/HC, 2003)) for bismuth, cesium, and thorium, for use in the Pickering ERA screening assessment. Chronic EC_{20}s were then converted to NOECs by incorporating a safety factor of 10. Although the detection limits for bismuth and thorium are above their respective NOECs, the detection limits are below their respective chronic EC_{20}s. Additionally, for these metals, all lake water samples obtained were below the detection limit and are not expected to be related to emissions from the Pickering site.

For some COPCs without environmental water quality guidelines (barium, calcium, and potassium), the maximum measured PNGS lake water concentration marginally exceeded – between 3 and 4% – the 95th percentile of Lake Ontario background concentration. Differences of less than 20% are typically not statistically discernible or measurable in the field or laboratory (Suter *et al*., 1995; Suter, 1996). Since the measured concentrations differed from background by less than 20%, these metals are not carried forward for further quantitative assessment.

Overall, based on the screening conducted for lake water the following COPCs are carried forward for the EcoRA: hydrazine, morpholine, TRC, copper, and cadmium.

4.1.3.1.3 Stormwater

Stormwater runoff from the PN site is collected by the stormwater drainage system and directed through drainage pathways south to Lake Ontario. Surface drainage around the PNGS is comprised of 19 catchments, as discussed in Section 3.1.2.3. The point of discharge concentrations were compared against the water quality guidelines (PWQO, CCME, Lake Ontario Background) protective of ecological endpoints, and none of the measured contaminants exceeded the guidelines (see Appendix A, Tables A.4 to Table A.7). Therefore, stormwater is not discussed further in this ERA.

4.1.3.1.4 East Landfill Surface Water

Bi-annual surface water sampling is conducted at the East Landfill as part of PN's East Landfill Perpetual Care Program. Every two years from 1996 to 2013, PN must conduct a visual inspection, surface water and groundwater sampling, and report the results to the MOE. The mandatory analytical parameters monitored in this surface water program include: alkalinity, BOD (5-day), calcium, copper, dissolved organic carbon (DOC), hardness, pH, phenols, sulphate, TSS, total phosphorous and zinc. In 2000, OPG voluntarily added mercury to the program based on recommendations made following an environmental site assessment conducted on the landfill areas that suggested that 180,000 L of waste oil may have been deposited in the landfill between 1997 and 1982 (OPG, 2011f). In 2012, OPG discontinued the voluntary analysis of mercury since mercury levels were below the detection limit over a four to six year period (OPG, 2013b). In the 2009-2010 report (OPG, 2011f), in addition to the program parameters analytical results for

a wide range of metals were presented; however in 2012 only the required parameters were sampled (OPG, 2013b). The locations for the sampling program including seepage and ditch points are shown in Figure 4.1.

For the purpose of this EcoRA, 2008, 2010, and 2012 sample concentrations were compared against the lowest of the PWQO or CCME water quality guidelines, where available (Table A.10, Table A.11 and Table A.12). Where no PWQO or CCME guideline was available data were obtained from other jurisdictions such as British Columbia MOE or from MacDonald (1999). Where no water quality guideline was found, toxicity benchmarks were used to clarify risk according to the same process described in the surface water screening discussed previously. For the assessment of east landfill surface water only, parameters without guidelines (potassium, silicon, and total sulphur) have not been carried forward given that these are substances of minimal concern with presumably small flows to the lake, and are not part of the east landfill surface water monitoring program.

Ditch 4 and Ditch 6 are the final surface water discharge points from the east landfill into Lake Ontario, with the majority of the effluent coming from Ditch 6. Ditches 1, 2A, 3, and 5 are located upgradient of the discharge points for Ditch 4 and Ditch 6. Trigger levels developed by OPG, in consultation with the MOE have been established for copper (0.15 mg/L) and zinc (0.9 mg/L) at the sampling locations for Ditch 4 and Ditch 6 (OPG, 2011f). These levels are 30 times the PWQO. Data from 2008 through 2012 indicate no exceedances of trigger levels. Data from 2008 and 2012 for Ditch 4 and Ditch 6 also indicate no exceedances of water quality guidelines for copper and zinc, as shown in Tables A.10, A.11, and A.12.

In 2010 and 2012, Ditch 4 was not sampled, due to accessibility and safety concerns. Based on data from Ditch 6 from 2008 to 2012, the COPCs that exceed screening benchmarks are phosphorous and sulphate.

Although observed phosphorus concentrations in Ditch 4 and Ditch 6 from 2008 to 2012 exceed the provincial guideline for nuisance algal growth, phosphorus in its chemically combined forms is not toxic to aquatic life (MOEE, 1979). These combined forms, such as phosphate, are the expected forms on the site, and in most surface waters. Both MOE (MOEE, 1994) and CCME (1999a) water quality guidelines for total phosphorus focus on its potential effects in enhancing algal growth. The implications of exceeding the phosphorus guideline in Ditch 4 and Ditch 6 are possible enhancement of algal growth and associated aquatic community effects, which are not uncommon in drainage ditches.

No PWQO or CCME water quality guideline was available for sulphate. Based on sulphate concentration in the ditches exceeding the BC MOE water quality guideline, sulphate has been carried forward for further assessment in the EcoRA, in order to confirm the conclusion that the East Landfill does not pose a potential concern to the environment.

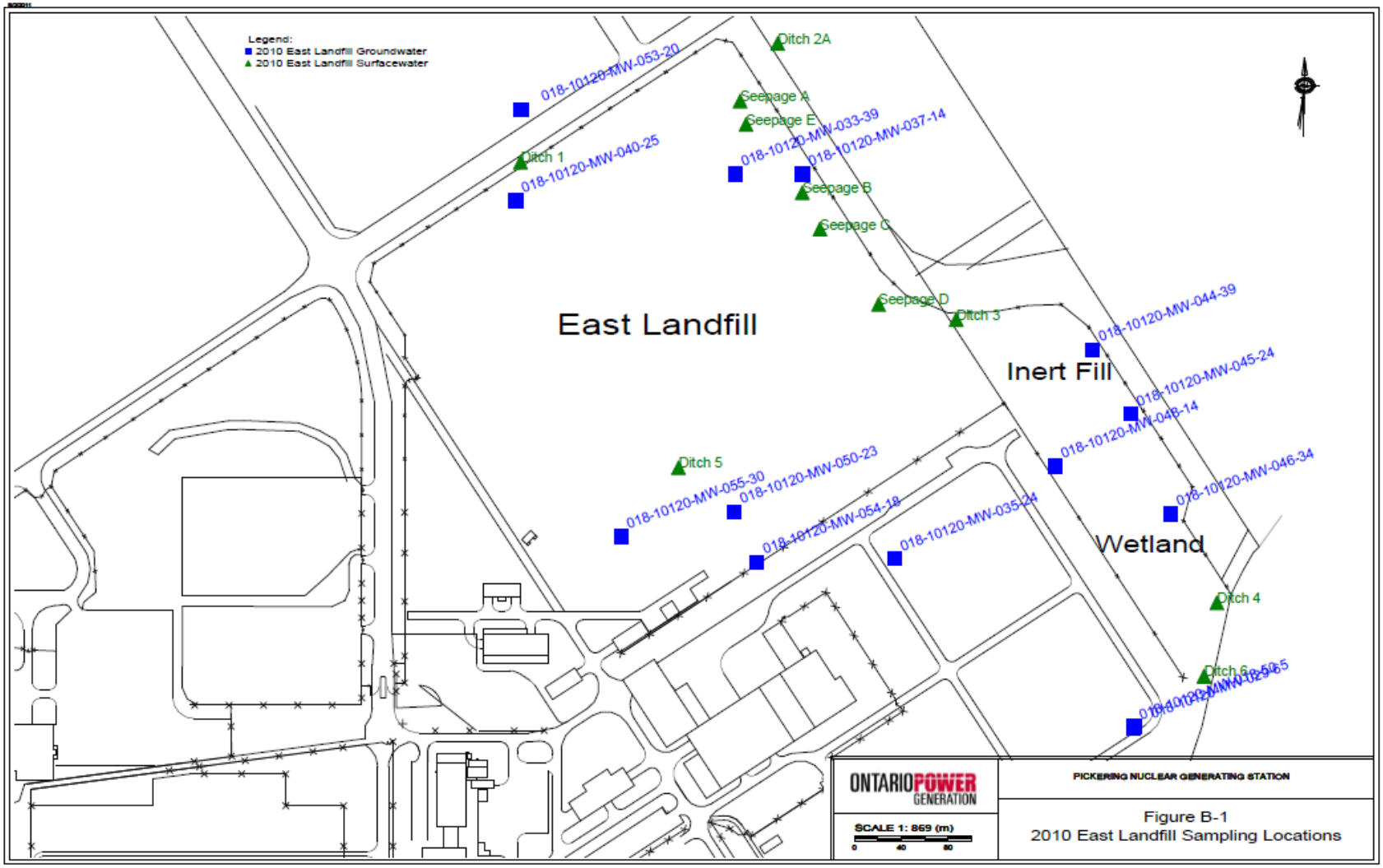


Figure 4.1: Surface Water Sampling Points for the East Landfill Perpetual Care Program (OPG, 2011f)

4.1.3.1.5 Soil

A site-wide soil monitoring program to characterize soil quality at the PN site was conducted in 1999 by CH2M Gore & Storrie Ltd. and was summarized in the Geology Hydrogeology and Seismicity TSD (Golder, 2007d). A total of 220 soil samples were collected for analysis. The results of the soil analysis were compared against the Ontario Ministry of Environment's Guidelines for Use at Contaminated Site in Ontario (1997), and were used in the Phase (ii) Ecological Risk Assessment (SENES, 2000). In the Phase (ii) ERA assessment, PCBs, TPH, copper, zinc and boron screened through as COPCs for soil.

Since the original 1999 soil characterization study was completed, the Ontario MOE has updated O.Reg 153/04 and issued new soil quality standards (MOE, 2011). Soil samples from the site-wide soil monitoring program taken from a depth of 0 to 1.5 m (approximately 5 feet) were compared against updated screening criteria. This depth is appropriate for the terrestrial receptors assessed in the EcoRA. The most stringent industrial value between the MOE (2011) standard (Table 3 standards for soil samples obtained greater than 30 m from a waterbody, and Table 9 standards for soil samples obtained within 30 m of a waterbody) and the CCME soil quality guideline was selected as the screening criteria, for comparison against the maximum soil concentration. A number of field investigations and grain size analysis conducted during Phase II Environmental Site Assessments at various locations on the PN site (CH2M Hill, 2005b-d, 2006), classified the soil texture at Pickering as coarse. The screening tables are shown in Appendix A in Table A.13 and Table A.14.

For parameters without MOE or CCME guidelines, maximum concentrations were compared against background concentrations. Background concentrations were obtained from the 98th percentile of the Ontario Typical Range (OTR_{98}; MOEE, 1993), or average crustal abundance (Faure, 1998), and Kjølholt et al *(*2003).

For acrylonitrile, the detection limit exceeded the US EPA screening level. Efroymson (1997a) provides a soil screening benchmark based on toxicity of acrylonitrile to soil microorganisms of 1000 mg/kg - a LOAEL based on observed reduced soil respiration. A NOAEL of 100 mg/kg was estimated by applying a safety factor of 10 to the LOAEL. Since the detection limit (<0.15 mg/kg) is significantly less than the NOAEL and acrylonitrile is not expected to be related to emissions from the Pickering site, acrylonitrile is not carried forward in the EcoRA.

For calcium, although the maximum concentration on-site (340,000 mg/kg) exceeds the background concentration (OTR_{98} and average crustal abundance), Faure (1998) presents a range of background concentrations in different rock types. The calcium concentration ranges from 5,100 to 302,300 mg/kg from low-Ca rocks to carbonate rocks. Calcium concentrations in PNGS site soil range from 5,800 to 340,000 mg/kg, which generally fall within the range in Faure (1998). Additionally, calcium is not expected to be related to facility releases.

For the sample locations within 30 m of a waterbody, the detection limit of antimony (<2.5 mg/kg) exceeded the MOE (2011) Table 9 standard. The Table 9 standard for antimony is based on Ontario background; however, the MOE presents component values for protection of plant and soil organisms and mammals for antimony. These values are generally lowest observed effect levels (LOEL). Applying a safety factor of 10 to the MOE LOELs provides a NOAEL of 5 mg/kg for protection of plants and soil organisms and 150 mg/kg for protection of mammals. The detection limit of antimony is below these NOAELs.

Based on the screening conducted for soil, the following COPCs are carried forward in the risk assessment: arsenic, cadmium, copper, lead, strontium, thallium, and zinc.

4.1.3.2 Radiological Stressors

The Radiation and Radioactivity TSD (SENES, 2007c) identified a number of radionuclides released to water that should be carried forward for the dose assessment. The 2011 DRL Report for Pickering A and B (OPG, 2011d,e) presents the same effluent release groups for water, with the exception of including gross alpha.

The DRLs for the effluent release groups were calculated based on the selection of the radionuclide with the most restrictive DRL, according to the process outlined in the COG DRL Guidance document. Radionuclides were eliminated from groupings based on the following criteria for inclusion:

- Radionuclides are regularly present in the effluent; and
- Radionuclides represent no less than 1% of the total radioactivity present.

Based on these criteria, DRLs were calculated for tritium oxide (HTO), C-14, and gross beta/gamma (P-32, S-35, Sc-46, Cr-51, Mn-54, Fe-55, Fe-59, Co-60, Sr-90 (Y-90), Zr-95, Nb-95, Ru-106, Sn-113, Sb-124, Sb-125, I-131, Cs-137, Eu-154, Gd-153, Tb-160, Zn-65). The radionuclides considered for use in DRL calculations were also considered for possible assessment in the EcoRA. The limiting radionuclides (i.e., the radionuclide with the highest dose per unit release) for particulates in air and for gross beta/gamma in water were used to represent all radionuclides in each grouping. Different from the HHRA, Co-60 was chosen to represent gross beta/gamma emissions in water, since Co-60 is the limiting radionuclide among beta/gamma emitters for aquatic biota, and therefore provides a conservative estimation of radiological dose (see Appendix C).

As discussed in Section 3.1.2.4, gross beta waterborne emissions from Pickering A decreased in 2011 to levels observed prior to 2009. Gross beta waterborne emissions from Pickering B were approximately one order of magnitude greater from 2007 to 2011 when compared to baseline levels. Implications for dose to aquatic biota are discussed in Section 4.4.2.

Gross alpha radionuclides do not need to be carried forward for the risk assessment. The level of airborne and waterborne gross alpha emissions from OPG nuclear facilities has been considered to be negligible (OPG, 2005). This position is supported by determination of alpha activity in the heat transport water and estimates of the maximum probable emission levels under normal and abnormal operating conditions. The airborne exhaust systems at PN contain HEPA filters which continuously filter particulate from the airborne effluents, thus capturing the alpha emitting particles, resulting in negligible emissions. This was confirmed through a COG (2003) study which analyzed alpha activities on air filters and determined they were at or below the detection limit in the milliBequerel range. A study on monthly gross alpha waterborne emissions was performed to establish an appropriate monitoring methodology (OPG, 2006b). Gross alpha concentrations at PN RLWMS are at MDL and their emissions are at a very small fraction of the monthly DRL.

Ar-41 is the predominant radionuclide measured in noble gas around the Pickering site. The number of operating days of Pickering Units 1 and 4 is related to emissions of Ar-41. Since 2003, an increasing trend of Ar-41 emissions has been observed, and is the result of Unit 4 returning to service, and Unit 1 returning to service in 2005. In 2011, repairs were performed to reduce air ingress via Unit 4 calandria vault dryers, reducing Ar-41 levels at the site boundary, compared to 2010 (OPG, 2012c). Ar-41 emissions have been evaluated for human receptors through the annual REMP reports. The dose to non-human biota from exposure to noble gases (predominantly Ar-41) is presented in the exposure assessment.

The Radiation and Radioactivity TSD (SENES, 2007c) identified Cs-134, Cs-137, Co-60, and K-40 as relevant COPCs for soil and sediment. However, K-40 is environmentally abundant and not associated with station operations. The Cs and Co isotopes are included as COPCs in order to address potential concern about deposition of particulate activity. Only Cs-134 and Co-60 are specific to reactor operations, and these are typically not detected in REMP monitoring of either soil or sediment around the facility.

4.1.3.3 Groundwater Radiological and Non-Radiological COPCs

In September 2012, EcoMetrix prepared a report for OPG on PNGS Groundwater Monitoring Program Design (EcoMetrix, 2012). In this document, EcoMetrix recommended that tritium, PAHs, PHCs, BTEX compounds, and inorganics (chloride, iron and sodium) be included in the monitoring program. The selection of COPCs was based on analyzing groundwater data from 2007 to 2011 and comparing against appropriate screening concentrations as well as considering COPCs that were included in past assessments and studies. Although COPCs have been identified through the screening assessment in EcoMetrix (2012), the lack of complete ecological exposure pathways for site groundwater indicates that there is no need for inclusion of these pathways in the EcoRA. In addition, due to the direction of groundwater flow at the site, there is no exposure pathway between offsite terrestrial biota and groundwater exposed to activities due to the operation of the PNGS. Groundwater at the site flows towards Lake Ontario, and the effects on aquatic biota are assessed there.

4.1.3.4 Noise

Noise levels at the PNGS can potentially cause disturbance to wildlife. The Pickering B EA Terrestrial Environment TSD (Golder, 2007c) concluded that, although some wildlife may be forced to leave their habitat due to noise levels, most wildlife in the area are likely accustomed to noise levels associated with an urban environment. Exposure of non-human biota to noise levels from the PNGS is not discussed further.

4.1.3.5 Physical Stressors

Physical stressors are not subject to a formal screening process; however, CSA N288.6 (2012) recommends carrying forward thermal stressors and entrainment and impingement for assessment in the ERA since they are widely recognized as being of primary concern at nuclear power plants. One of the notable concerns is related to the algae events, which in turn, cause CCW temperature difference exceedances. The 24 hour temperature difference limit in the CofA for PNGS is 11ºC. When the algae events cause pumps to be turned off, the temperature of the water being released at the outfall is a higher temperature than normal, when the pumps are in operation. These algae events have caused the temperature difference to exceed the CofA limit, ranging from 11.5ºC (in 2009) to 12.6ºC (in 2010). The increase in temperature difference is 0.5ºC to 1.6ºC. The effect of this thermal plume was carried forward and assessed.

The EA conducted for the Pickering B refurbishment and continual operation assessed the likelihood of environmental effects on the terrestrial land use and land scape. The terrestrial environment TSD (Golder, 2007c) concluded that there would be no changes to vegetation communities and species, wildlife habitat, wildlife communities and species (with the exception of wildlife strikes and lake water temperature and circulation), and natural heritage systems, due to the operation of the PNGS. The aquatic environment TSD (Golder, 2007b) concluded that the only project interactions between the PNGS continued operation and the aquatic biota and habitat were due to the lake water temperature and circulation. There were no effects related to sedimentation, shoreline alterations or lake filling. During the period from 2007 to 2011, there were no physical activities conducted that had any measureable effects on wildlife habitat.

Wildlife strikes with vehicles and bird/bat strikes on buildings are other physical stressors typically addressed in an ERA. These physical stressors have been previously addressed in the 2007 Pickering B EA. Monitoring of wildlife mortality from vehicle strikes has been performed on the Pickering site as part of the PARTS EA Follow-Up and Monitoring Program. In 2006, 27 mortalities in 24 observation days were observed, which corresponds to 1.08 individual mortalities per observation day. Prior to Pickering A restart, 23 mortalities were observed in 27 days, which corresponds to 0.9 mortalities per observation day. Mortality rates have been fairly consistent over the years where data were collected. The species most commonly struck include the eastern grey squirrel, eastern cottontail, and European starling. Some species identified as VECs have been struck. None of the

species recorded as mortalities are considered species of concern. All of the VECs that have been recorded as mortalities are abundant in the area. Based on this observation, the EA states that no population level effects are expected to result from the loss of a few individuals at the low rate of mortality currently observed (Golder, 2007c).

The Terrestrial Environment TSD (Golder, 2007c) identifies a number of bird species (water and land) as VECs. From 2007 to 2011, 9 bird strikes on buildings were recorded through voluntary reporting in Station Condition Records. However, numbers may be higher since this is through voluntary reporting. Data on bird and bat strikes against station buildings is limited; however, it is assumed that the rate is consistent with the number impinged on the wind turbine located on the shoreline next to Pickering. Since the number of birds and bats impinged on the wind turbine is low (4 birds and 8 bats over 1 calendar year) and there are a large number of birds and bats in the area, the EA states that no population level effects are expected to result from the loss of a few individuals. There are uncertainties associated with the assumed comparability of strike rates between the wind turbine and buildings, but the strike rates for buildings are unlikely to be substantially higher, and the rate for the wind turbine is of little consequence, so a similar finding for building strikes is reasonable.

According to the discussion above, wildlife strikes with vehicles and bird and bat strikes on buildings, and other physical stressors, with the exception of thermal plume and impingement/entrainment do not need to be carried forward for further consideration in the ERA.

4.1.3.6 Summary of COPC Selection for the EcoRA

Table 4.3 summarizes the radiological and non-radiological COPCs that are carried forward to the exposure assessment in the EcoRA.

Table 4.3: Summary of COPCs Selected for the Ecological Risk Assessment

Category	Radiological COPC	Hazardous COPC
Air	Noble gases (represented by Ar-41)	None
Surface water	H-3, C-14, Gross beta-gamma (represented by Co-60), Cs-134, Cs-137	Hydrazine, Morpholine, TRC, Cadmium, Copper Sulphate (East Landfill Only)
Groundwater	None	None
Stormwater	None	None
Soil	H-3, Cs-134, Cs-137, Co-60	As, Cd, Cu, Pb, Sr, Tl, Zn
Noise	None	
Physical Stressors	impingement/entrainment	
	thermal plume	

4.1.4 Selection of Exposure Pathways

Exposure pathways include the routes of contaminant dispersion from the source to receptor location and the routes of contaminant transport through the food chain to the receptor organism. Both are considered, as appropriate to the species and location, using measured concentrations of COPCs wherever such data exist, and estimating concentrations where measured values are not available.

For fish, frog and aquatic plants, contact with water and contaminant uptake from water via bioaccumulation represents the main exposure pathway. For soil invertebrates and terrestrial plants, the main exposure pathway is through contact with soil and contaminant uptake from soil via bioaccumulation. The dominant exposure pathways for birds, mammals and turtles is through the uptake of contaminants via the ingestion of water, incidental ingestion of soil or sediment, and ingestion of food.

Airborne COPCs partition to soil and plants, and ingestion pathways dominate over inhalation and air immersion for most COPCs. The latter pathways will be omitted for ecological receptors in this assessment, except for noble gases, where these pathways are expected to be important.

4.1.5 Ecological Conceptual Model

The conceptual model illustrates how receptors are exposed to COPCs. It represents the relationship between the source and receptors by identifying the source of contaminants, receptor locations and the exposure pathways to be considered in the assessment for each receptor. Exposure pathways represent the various routes by which radionuclides and/or chemicals may enter the body of the receptor, or (for radionuclides) how they may exert effects from outside the body. Table 4.4 summarizes the relevant exposure pathways for each type of ecological receptor. The conceptual model for the EcoRA is illustrated in Figure 4.2 and Figure 4.3. For completeness, the air exposure pathway is shown, but can usually be ignored since it is usually minor compared to the soil or sediment ingestion exposure (CSA, 2012). Exposures to noble gases in air can be important, since air is the dominant pathway in this case. In addition, the figures incorporate generalizations where for the ease of representation, some VECS are grouped together by category. For example, all the pelagic fish, regardless of size and habits, are shown to be consumed by the tern and the bufflehead, although their diets would consist of differing types of fish.

Although COPCs have been identified in the screening for groundwater, there are no operable groundwater exposure pathways for ecological receptors. The ecological receptors that are most likely to be exposed to COPCs migrating with groundwater are those that reside in zones of groundwater discharge in Lake Ontario. These receptors include benthic invertebrates living in or on shoreline sediments, and possibly shoreline vegetation with roots near the water table that may be exposed to groundwater when the water table is high. Most on-site ecological receptors are not likely exposed to

groundwater, since the depth to groundwater on-site is at least 2 metres (Golder, 2007d). The risks to ecological receptors in the groundwater discharge zone are primarily from tritium, and are considered to be low as long as levels in the groundwater and the point of discharge in the shoreline remain below 3×10^6 Bq/L (EcoMetrix, 2012). Based on groundwater data from 2008 to 2012 the only locations where tritium in groundwater exceeds 3×10^6 Bq/L are around Unit 1 in PNGS A and one well in PNGS B. Groundwater in the Unit 1 area migrates towards either the IFB A, VBRS and TAB foundation drains, which are monitored. Groundwater from PNGS B flows to the TAB foundation drains, which is a hydraulic sink and a monitored pathway (EcoMetrix, 2012). Groundwater originating from these sources is monitored and not discharged directly to Lake Ontario. Additionally, relevant ecological receptors are located in the nearshore zones of Lake Ontario in the groundwater discharge area and not on-site.

The previous ERA assessed aquatic biota for non-radiological exposure at the Hydro Marsh. Historically, this location was assessed because there was a pipeline which discharged CCW from PNGS through a fish farm to the Hydro Marsh. This pipeline was disconnected in 1997, and follow-up field studies have shown there is no accumulation of radionuclides in the marsh, and contaminant accumulation patterns do not correlate with effluent from the PN site (SENES, 2007a). Without the pipeline, it is unlikely that the PNGS has an influence on the water and sediment quality at the Hydro Marsh. The marsh is considered not exposed to the PNGS operations because it is separated from Lake Ontario by a barrier beach, and receives water inflow from Krosno Creek and municipal storm sewers.

Frenchman's Bay is a provincially significant wetland, is designated an Environmentally Sensitive Area (ESA) by the TRCA, and is an Aquatic Biology Core Area. Frenchman's Bay is a habitat for wetland vegetation, mainly cattails, aquatic invertebrates, fish, and wildlife. Frenchman's Bay is Hydro Marsh's link to Lake Ontario, and water from the lake enters the system when the water level rises in Lake Ontario (Golder, 2007b). Therefore, Frenchman's Bay is more likely to be impacted by non-radiological and radiological waterborne discharges from PNGS operations, and provides a habitat for all the indicator species identified in Table 4.4. This includes the habitat for the red-winged blackbirds that use the wetland as a source of food and nesting habitat, primarily among the cattails (SENES, 2007a). The wetland is located in the northern section of the bay. However, biota are assessed at the mouth of the bay where sediment data were collected, and where waterborne emissions from PNGS will have the greatest impact. This is a conservative assumption, since water concentrations would be more diluted at the wetland. In addition, although the Hydro Marsh experiences airborne deposition from atmospheric emissions from PNGS, tritium in air concentrations from the REMP reports show that the difference in dispersion factors between Hydro Marsh and Frenchman's Bay is minor. Therefore, Frenchman's Bay is a suitable location to assess riparian and aquatic receptors.

All the avian receptors to be assessed are migratory, and are likely to reside at the PN site for half of the year. However, for the exposure assessment, their occupancy at the site is assumed to be for the whole year.

Fish are abundant in the discharge channel, which provides a spawning habitat for smallmouth bass. There is also very sparse vegetation cover along the discharge channel (Golder, 2007b). Due to the prevalence of fish at the discharge channel, fish are assessed at the outfall.

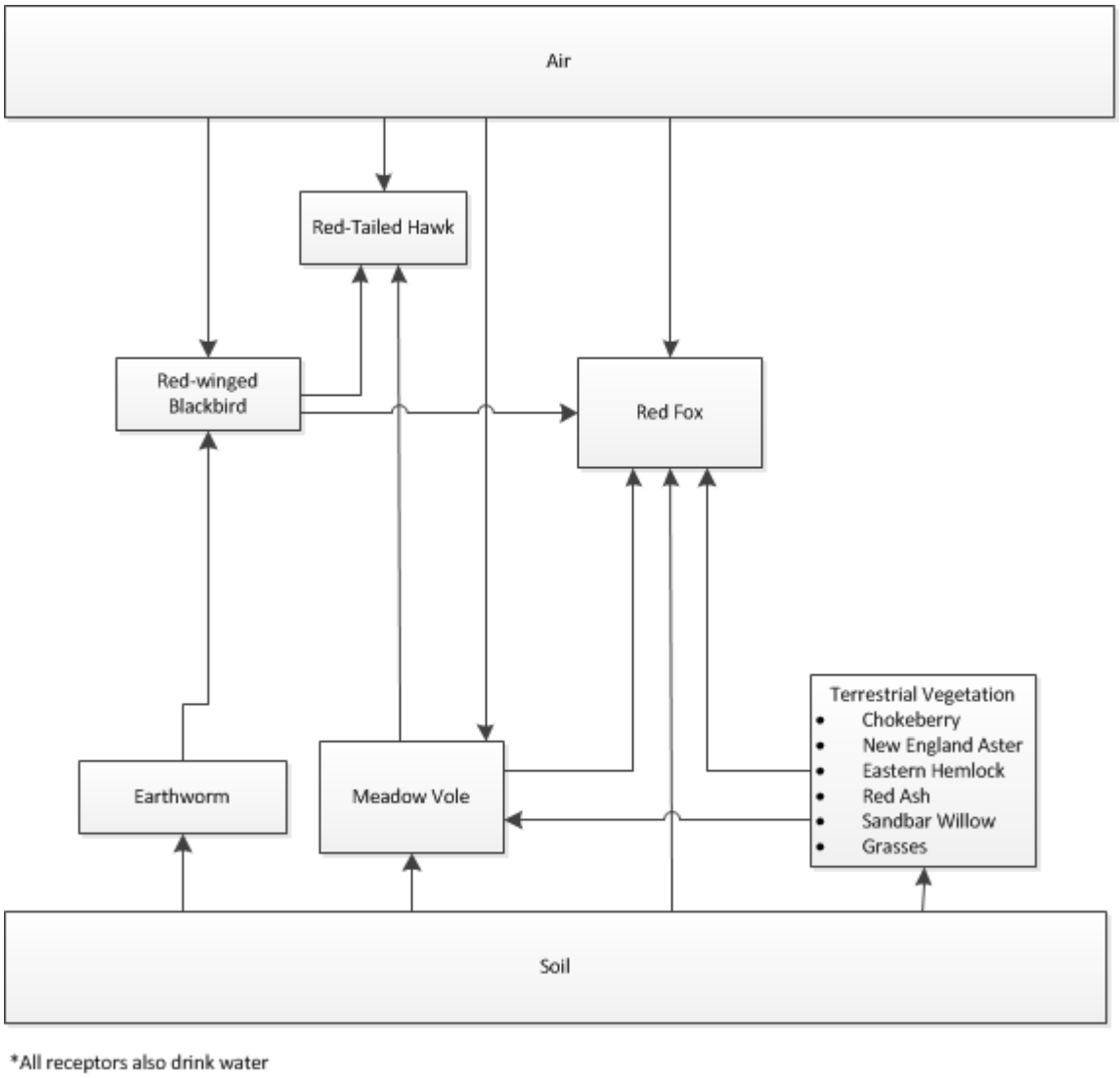
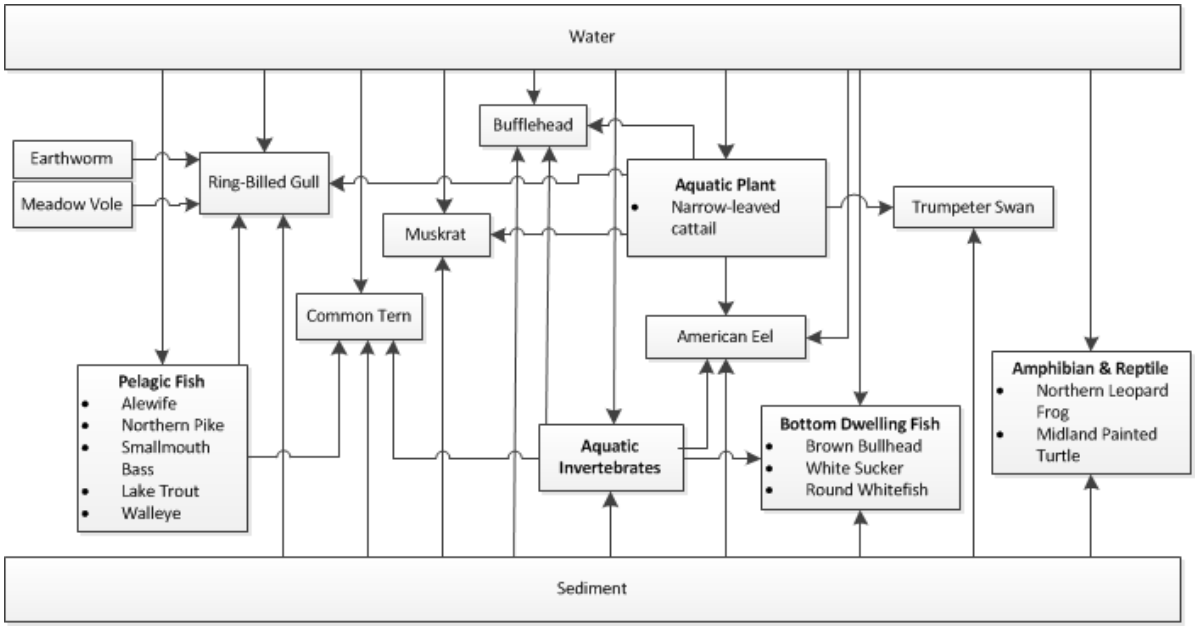


Figure 4.2: Conceptual Model for the Terrestrial Environment



Note:
Waterbirds and aquatic mammals (i.e., muskrat) are exposed to air immersion which is not shown in the figure.

Figure 4.3: Conceptual Model for the Aquatic Environment

Table 4.4: Complete Exposure Pathways for All Selected Indicator Species

Class/ Community/ Individual	Location	Indicator Species	Exposure Pathways	Environmental Media
Fish	Outfall Frenchman's Bay	Alewife	Direct Contact	Water
		Smallmouth Bass	Direct Contact	Water
		Northern Pike	Direct Contact	Water
		Brown Bullhead	Direct Contact	Water Sediment
		Round Whitefish	Direct Contact	Water Sediment
		White Sucker	Direct Contact	Water Sediment
		Lake Trout	Direct Contact	Water
		Walleye	Direct Contact	Water
		American Eel	Direct Contact	Water Sediment
Aquatic Plants	Frenchman's Bay	Narrow-leaved cattail	Direct Contact	Water
Aquatic Invertebrates	Outfall Frenchman's Bay	Benthic Invertebrates	Direct Contact	Sediment
Amphibians and Reptiles	Frenchman's Bay	Northern Leopard Frog	Direct Contact	Water Sediment
		Midland Painted Turtle	Direct Contact	Water Sediment
Aquatic Birds	Frenchman's Bay	Trumpeter Swan	Immersion	Air

Class/ Community/ Individual	Location	Indicator Species	Exposure Pathways	Environmental Media
			Ingestion	Water Sediment Aquatic Plant
		Ring-Billed Gull	Immersion	Air
			Ingestion	Water Sediment Aquatic Plant Fish Earthworm Mammals
		Common tern	Immersion	Air
			Ingestion	Water Sediment Aquatic Invertebrate Fish
		Bufflehead	Immersion	Air
			Ingestion	Water Sediment Aquatic Invertebrate Aquatic Plants
Aquatic Mammals	Frenchman's Bay	Muskrat	Immersion	Air
			Ingestion	Water Sediment Aquatic Plant
Terrestrial Plants	Pickering Nuclear site	Chokecherry	Direct Contact	Soil
			Immersion	Air
		New England aster	Direct Contact	Soil
			Immersion	Air
		Eastern hemlock	Direct Contact	Soil
			Immersion	Air
		Red ash	Direct Contact	Soil
			Immersion	Air
		Sandbar willow	Direct Contact	Soil
			Immersion	Air
Terrestrial Invertebrates	Pickering Nuclear site	Earthworms	Direct Contact	Soil
Terrestrial Birds	Pickering Nuclear site	Red-winged blackbird	Immersion	Air
			Ingestion	Insects Soil Water
		Red-tailed hawk	Immersion	Air
			Ingestion	Birds Mammals Soil Water
Terrestrial Mammals	Pickering Nuclear site	Red Fox	Immersion	Air
			Ingestion	Soil Terrestrial Vegetation Mammals Birds Water
		Meadow Vole	Immersion	Air
			Ingestion	Soil Terrestrial Vegetation Water

For organism losses by entrainment/impingement, the conceptual model illustrated in CSA N288.6 (2012) is appropriate. This conceptual model (Figure 4.4) represents the relationship between the individual losses and possible population or community effects.

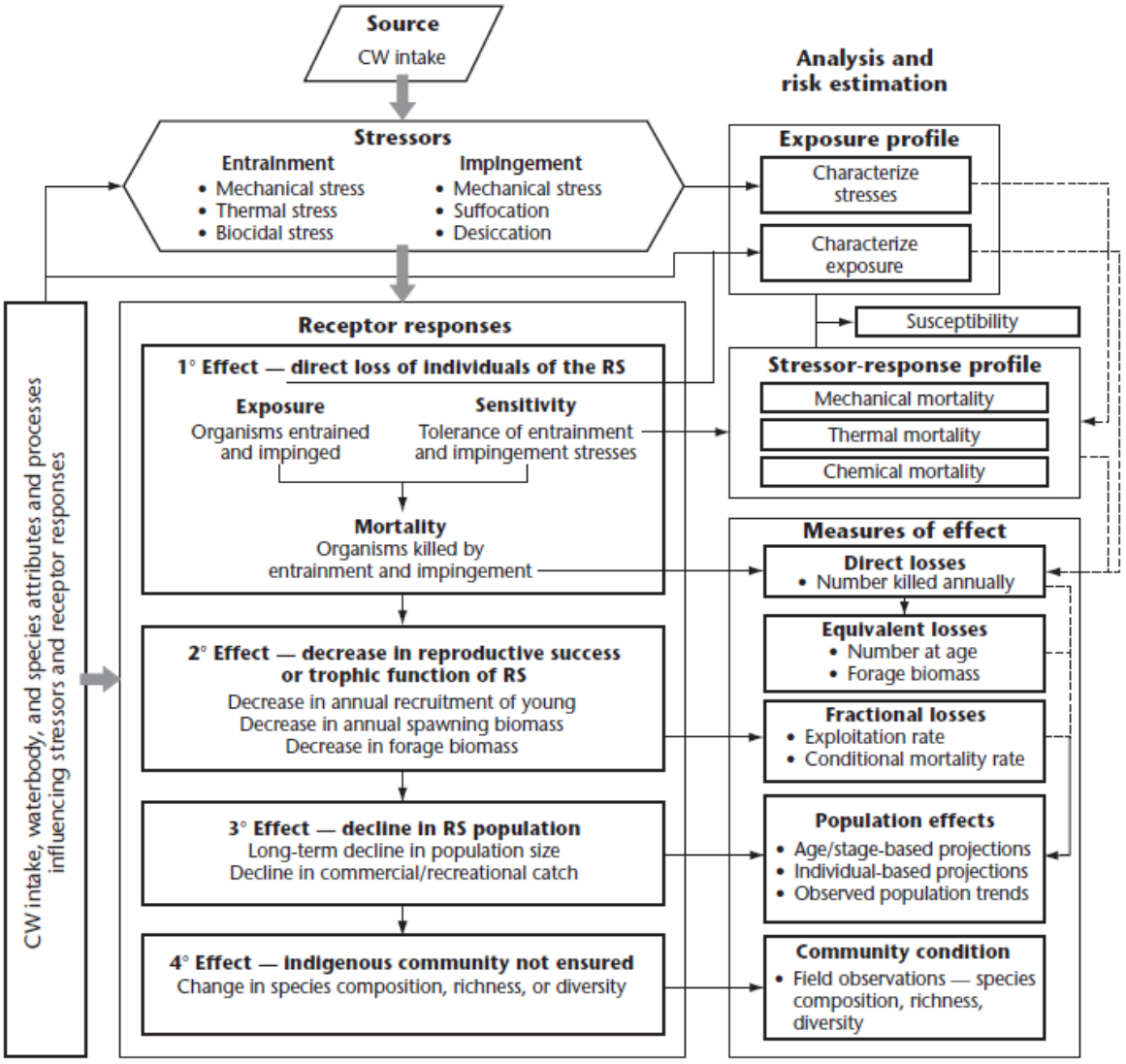


Figure 4.4: Generic Conceptual Model for Relationships between Individual Endpoints and Population/Community Endpoints (CSA, 2012)

4.2 Exposure Assessment

4.2.1 Exposure Points

Measured concentrations of COPCs for the various media at the receptor locations listed in Table 4.4 were generally available, with the exception of water concentrations in Frenchman's Bay. Water concentrations in Frenchman's Bay were estimated using a conservative dilution factor. The exposure concentrations at the exposure locations are further described in Section 4.2.5. The concentrations came from a variety of OPG documents including:

- P-REP-07010-10008 "Ecological Risk Assessment of Pickering Nuclear Phase (ii) Summary and Supporting Document" (SENES, 2000);
- P-REP-07010-10009 "Tier 2 Ecological Risk Assessment of Pickering Nuclear, Phase (iii) Summary and Supporting Document" (SENES, 2001);
- NK30-REP-07701-00007 "Surface Water Resources Technical Support Document" (Golder, 2007a);
- NK30-REP-07701-0006 "Geology, Hydrogeology and Seismicity Technical Support Document" (Golder, 2007b);
- OPG Annual REMP reports (years 2007 to 2011); and
- COG reports.

4.2.2 Exposure Averaging

4.2.2.1 Exposure Averaging

When multiple measurements and samples were available for a given COPC in a particular medium at an assessed exposure location, the arithmetic average as well as maximum concentrations were calculated based on the available data. Birds and mammals are likely to experience something close to average concentrations as they move around the area. However, for less mobile organisms such as plants and invertebrates, both average and upper limit concentrations represent exposures that would be experienced by some organisms on a long term basis.

4.2.2.2 Environmental Partitioning

Water:sediment partitioning was estimated as described below in activity units:

$$C_{s(fw)} = \frac{\theta \cdot C_w \cdot \rho_w + (1-\theta) \cdot C_w \cdot K_d \cdot \rho_s}{\theta \cdot \rho_w + (1-\theta) \cdot \rho_s}$$

$$C_{s(dw)} = C_{s(fw)} / f_{dw}$$

$$f_{dw} = \frac{(1-\theta)\cdot\rho_s}{\theta\cdot\rho_w + (1-\theta)\cdot\rho_s}$$

where,

$C_{s(fw)}$ = concentration in sediment (Bq/kg FW)
C_w = concentration in water (Bq/L)
ρ_w = density of water (1 kg/L)
θ = sediment porosity (unitless)
K_d = distribution coefficient (L/kg solid)
ρ_s = density of solids (kg/L)
$C_{s(dw)}$ = concentration in sediment (Bq/kg DW)
f_{dw} = dry weight fraction of sediment (unitless).

The sediment distribution coefficients (K_d) used in the environmental partitioning calculations are listed in Table 4.5. For COPCs that do not have a sediment K_d in CSA (2008) or IAEA (2010), the soil K_d found in IAEA (2010) was used. The soil K_d is multiplied by a factor of 10 to take into account the typically higher water content (water filled porosity) in sediment and greater available particle surface area for adsorption. The sediment porosity and sediment density at the PN site is assumed to be 0.1 and 1.5 kg/L (for sand) respectively (CSA, 2008).

Table 4.5: Sediment Distribution Coefficients

COPC	Distribution Coefficient (K_d) (L/kg dw)	Reference
Tritium	0	CSA, 2008
Carbon-14	50	CSA, 2008
Cobalt-60	43,000	IAEA, 2010
Cesium-134	9,500	IAEA, 2010
Cesium-137	9,500	IAEA, 2010
Arsenic	10	CSA, 2008
Cadmium	1,500	IAEA, 2010 (soil value x 10)
Chlorine (TRC)	17	CSA, 2008
Copper	2,700	IAEA, 2010 (soil value x 10)
Hydrazine	0	See text below
Lead	2,200	IAEA, 2010 (soil value x 10)
Morpholine	0	See text below
Strontium	190	IAEA, 2010
Thallium	3,900,000	NCRP, 1996 (soil value x 10)
Zinc	500	IAEA, 2010

The environmental partitioning of hydrazine was modeled and described in EC/HC (2011). The modeling results show that when hydrazine is released to surface water, it will remain almost entirely in the water (99.9% in water, 0.02% in sediment). Based on these results, the partitioning of hydrazine from water to sediment is negligible as the K_d is 0 L/kg dw. Due to morpholine's solubility in water, when it is released into the environment, it moves with soil moisture and water, and does not sorb to sediment or organic matter (Lewis *et al.* as cited in Poupin *et al.* 1998). Therefore, the K_d for morpholine for this assessment is 0 L/kg dw. Sulphate is assessed qualitatively and does not require a K_d.

4.2.3 Exposure and Dose Calculations

Exposure and dose calculations for each COPC were performed for the indicator species and receptor locations outlined in the ecological conceptual model (Section 4.1.5).

4.2.3.1 Radiological Dose Calculations

The radiation doses for the aquatic biota were estimated using the methods outlined in CSA N288.6-12 (2012). The dose for each radionuclide is comprised of an internal dose component, and an external dose component, which is driven by water and sediment. The aquatic biota dose was calculated using the following equations:

$$D_{int} = DC_{int} \cdot C_t$$

$$D_{ext} = DC_{ext} \cdot [(OF_w + 0.5 \cdot OF_{ws} + 0.5 \cdot OF_{ss}) \cdot C_w + (OF_s + 0.5 \cdot OF_{ss}) \cdot C_s]$$

where,

D_{int} = internal radiation dose (µGy/d)
D_{ext} = external radiation dose (µGy/d)
DC_{int} = internal dose conversion factor ((µGy/d)/(Bq/kg))
DC_{ext} = external dose coefficient ((µGy/d)/(Bq/kg))
C_t = whole body tissue concentration (Bq/kg fw)
C_w = water concentration (Bq/L)
C_s = sediment concentration (Bq/kg fw)
OF_w = occupancy factor in water
OF_{ws} = occupancy factor at water surface
OF_{ss} = occupancy factor at sediment surface
OF_s = occupancy factor in sediment

For aquatic biota that has both an on soil and a water external dose coefficient, such as the muskrat and waterbirds, the external dose component was calculated as follows:

$$D_{ext} = DC_{ext,w} \cdot OF_w \cdot C_w + DC_{ext,s} \cdot OF_{ss} \cdot C_s$$

where,

$DC_{ext,w}$ = external dose coefficient (in water)
$DC_{ext,s}$ = external dose coefficient (on soil)
C_w = water concentration (Bq/L)
C_s = sediment concentration (Bq/kg fw)
OF_w = occupancy factor in water
OF_{ss} = occupancy factor on soil surface

The radiation dose to terrestrial biota is estimated using a method similar to that for aquatic biota, except the external dose component is driven by soil rather than water and sediment. The equations used to estimate radiation dose are:

$$D_{int} = DC_{int} \cdot C_t$$

$$D_{ext} = DC_{ext,s} \cdot OF_s \cdot C_s + DC_{ext,ss} \cdot OF_{ss} \cdot C_s$$

where,

DC_{int} = internal dose coefficient ((µGy/d)/(Bq/kg))
$DC_{ext,s}$ = external dose coefficient (in soil) ((µGy/d)/(Bq/kg))
$DC_{ext,ss}$ = external dose coefficient (on soil surface) (µGy/d)/(Bq/kg))
C_t = whole body tissue concentration (Bq/kg fw)
C_s = soil concentration (Bq/kg dw)
OF_s = occupancy factor in soil
OF_{ss} = occupancy factor at soil surface

The total radiation dose to biota is the sum of the internal and external dose components for each radionuclide ($D_{int} + D_{ext}$). External exposure through the air immersion and inhalation pathway are considered to be minor compared to the ingestion pathway, and were ignored, with the exception of noble gases (CSA, 2012). The external dose due to Ar-41 was assessed for the terrestrial biota by directly applying the absorbed dose value from the air kerma presented in OPG's annual REMP reports. The dose coefficients and occupancy factors used in the radiological dose estimation are provided in Section 4.2.3.4.

4.2.3.2 Non-Radiological Dose Calculations

The non-radiological dose (D_{ing}) for mammals and birds was estimated using the methods described in CSA (2012), and are as follows:

$$D_{ing} = \Sigma\, C_x \cdot I_x / W$$

where,

C_x = concentration in the ingested item (x) (mg/kg)
I_x = ingestion rate of item x (kg/day)

W = body weight of consumer (kg fw)

For receptors that drink from contaminated water, such as the muskrat drinking from Frenchman's Bay, the drinking water component was considered. The concentrations in the water and the ingestion rate were in units of volume. In addition, for receptors that have incidental contaminated soil or sediment ingestion, this pathway was considered on a dry weight basis. Other ingested items (foods) were considered on a fresh weight basis. As with the radiological dose calculations, inhalation exposure is considered minor compared to the ingestion exposure, and was ignored (CSA, 2012).

4.2.3.3 Tissue Concentration Calculations

The tissue concentrations (C_t) for plants, invertebrates or fish were derived using bioaccumulation factors (BAFs), as per CSA (2012) as follows:

$$C_t = C_m \cdot BAF$$

where,

C_t = whole body tissue concentration (Bq/kg fw)
C_m = media concentration (Bq/L or Bq/kg)
BAF = bioaccumulation factor (L/kg or kg/kg)

For birds and mammals, tissue concentrations were estimated using transfer factors (TFs), or biomagnification factors (BMFs) and the concentrations in their food, as follows:

$$C_t = \Sigma\, C_x \cdot I_x \cdot TF = C_f \cdot BMF$$

where,

C_x = concentration in the ingested item x (Bq/kg fw)
I_x = ingestion rate of item x (kg fw/d)
TF = ingestion transfer factor (d/kg)
C_f = average concentration in food (Bq/kg fw)
BMF = biomagnification factor (unitless)

The BMF is equivalent to the total food intake rate times the transfer factor:

$$BMF = \Sigma\, I_x \cdot TF$$

The BAFs, TFs and ingestion rates used for the calculation of tissue concentrations in biota are further described in Section 4.2.3.4.

4.2.3.4 Exposure Factors

There are several COPC- and biota-specific exposure factors required for the dose calculations discussed in Section 4.2.3. These parameters include intake rates, body weights, occupancy factors, BAFs, TFs, and dose coefficients (DCs).

4.2.3.4.1 Body Weight and Intake Rates

The body weight and intake rates are required for the calculation of exposure to birds and mammals. The body weights and total feed intake rates were taken from the previous ERA (SENES, 2000), where the assumptions and values were considered to be applicable. For receptors not assessed in the previous ERA, body weights were found in literature, and feed intake rates were proportioned to body weight using allometric equations from the US EPA (US EPA, 1993). The water intake and inhalation rates were determined using allometric equations for all birds and mammals. The incidental ingestion of soil and sediment was estimated based on the feed intake. The incidental ingestion varied from 2% to 10.4% of dry weight food intake depending on the biota. The values are summarized in Table 4.6.

Table 4.6: Bird and Mammal Body Weights and Intake Rates

Receptor	Body weight	Total Feed Intake		Dietary Components	Feed Type Fraction	Feed Intake		% Moisture[1]	Intake of Soil/ Sediment[2]	Total Soil/ Sediment	Water Intake	Inhalation
	kg	kg/d dw	kg/d fw			kg/d dw	kg/d fw		%	kg DW/d	kg/d	m^3/d
Trumpeter Swan	11.0	0.347	1.386	aquatic plants	1	**0.347**	1.386	75%	3.3%	1.14E-02	0.294	2.591
Ring-Billed Gull	0.700	0.050	0.193	aquatic plant	0.2	**0.010**	0.040	75%	3.3%	1.64E-03	0.046	0.311
				fish	0.6	**0.030**	0.120	75%				
				soil invert	0.1	**0.005**	0.017	70%				
				small mammals	0.1	**0.005**	0.017	70%				
Common Tern	0.125[3]	0.015	0.060	fish	0.9	**0.014**	0.054	75%	2%	3.01E-04	0.015	0.082
				aquatic invert	0.1	**0.002**	0.006	75%				
Bufflehead	0.473[4]	0.045	0.179	aquatic plant	0.1	0.004	**0.018**	75%	10.4%	4.65E-03	0.036	0.230
				aquatic invert	0.9	0.040	**0.161**	75%				
Muskrat	1.18	0.088	0.353	aquatic plant	1.0	0.088	**0.353**	75%	3.3%	2.91E-03	0.114	0.621
Red-winged blackbird	0.055[5]	0.009	0.029	soil invert	1	**0.009**	0.029	70%	7.3%	6.39E-04	0.008	0.044
Red-tailed hawk	1.22	0.066	0.221	birds	0.27	**0.018**	0.060	70%	3.3%	2.19E-03	0.068	0.478
				small mammals	0.73	**0.048**	0.162	70%				
Red fox	4.54	0.030	0.109	small mammals	0.5	0.016	**0.054**	70%	2.8%	8.45E-04	0.386	1.831
				waterfowl	0.3	0.010	**0.033**	70%				
				vegetation	0.2	0.004	**0.022**	81%				
Meadow Vole	0.034	0.002	0.011	vegetation	1	0.002	**0.011**	81%	2.4%	5.02E-05	0.005	0.036

Notes:
Data is from SENES (2000), unless otherwise indicated
[1] CSA, 2008
[2] Beyer *et al*., 1994
[3] Cuthbert *et al.,* 2003
[4] NatureServe, 2013
[5] Ministry of the Environment, 2009

4.2.3.4.2 Occupancy Factors

The fraction of time the biota resides in the PN site area, as discussed in Section 4.2.2, is assumed to be one. An occupancy factor is defined as the fraction of time the receptor species spends in or on various media. The occupancy factors, where available, are those in the previous ERA (SENES 2000, SENES 2001). For new biota, the occupancy factors are based on the experience and judgement of the risk assessor and the known behaviour of the receptor. The occupancy factors used in the radiological dose estimation are given in Table 4.7, and are applied to the equations discussed in Section 4.2.3.1.

Table 4.7: Receptor Occupancy Factors

Aquatic Biota	OF_s	OF_{ss}	OF_w	Terrestrial Biota	OF_s	OF_{ss}
Bottom Dwelling Fish		0.5	0.5	Terrestrial Plant		1
Other Fish			1	Earthworm	1	
Amphibians		0.5	0.5	Red-winged blackbird		1
Benthic Invertebrates	1			Red-tailed hawk		1
Aquatic Plants			1	Meadow Vole		1
Waterbirds		0.5	0.5	Red Fox	0.2	0.8
Muskrat		0.5	0.5			

Notes:
OF_s = occupancy factor in soil/sediment
OF_{ss} = occupancy factor on soil/sediment surface
OF_w = occupancy factor in water

4.2.3.4.3 Bioaccumulation Factors

Bioaccumulation factors relate the COPCs in the environmental media to the concentration in the receptor. Since tissue concentrations were not available for the receptors at the PN site, BAFs were used to calculate COPC concentrations in plant, invertebrate and fish tissues. These factors vary throughout the literature. For the exposure assessment, BAFs were taken from CSA (2008), IAEA (2010) and literature sources, including those suggested in CSA N288.6 (2012). The BAFs used in the assessment are presented in Table 4.8 and Table 4.9. Bioaccumulation factors for tritium and carbon-14 are calculated using the specific activity model, which is discussed in Section 4.2.3.4.6 and 4.2.3.4.7. As discussed in Section 3.2.4 of the HHRA, the fish BAF for hydrazine and morpholine is based on a QSAR model by Meylan et al. 1999 (as cited in European Commission, 2006). There are no other hydrazine and morpholine BAFs available for other aquatic biota.

Table 4.8: Bioaccumulation Factors (BAFs) for Fish, Amphibians, Aquatic Invertebrates, and Aquatic Plants (L/kg fw)

COPC	Fish	Amphibian	Aquatic Invertebrate	Aquatic Plant
Cobalt-60	5.40E+01[1]	5.40E+01[1]	1.10E+02[5]	7.90E+02[5]
Cesium-134	3.50E+03[1]	3.50E+03[1]	9.90E+01[5]	2.20E+02[5]
Cesium-137	3.50E+03[1]	3.50E+03[1]	9.90E+01[5]	2.20E+02[5]
Hydrazine	3.16E+00[2]	nd	nd	nd
Morpholine	3.16E+00[2]	nd	nd	nd
Cadmium	1.40E+02[3]	1.40E+02[3]	1.00E+02[4]	1.90E+04[4]
Chlorine (TRC)	9.50E+01[4]	9.50E+01[4]	1.60E+02[4]	5.00E+01[4]
Copper	2.70E+02[4]	2.70E+02[4]	4.20E+01[4]	3.00E+03[4]

Notes:
nd = no data available
[1] CSA, 2008
[2] European Commission, 2006
[3] Sheppard *et al.,* 2010
[4] IAEA, 2010
[5] Geomean of values (where available) from Thompson *et al.,* 1972; IAEA, 2010; Bird and Schwartz, 1996; IJC 1997; Yankovich, 2005; Wang *et al.*, 1993; and Sheppard *et al.,* 2010.

Table 4.9: Bioaccumulation Factors (BAFs) for Soil Invertebrates and Terrestrial Plants (kg-dw/kg-fw)

COPC	Soil Invertebrate	Terrestrial Plant
Cobalt-60	2.80E-02[1]	8.93E-03[4]
Cesium-134	1.30E-03[1]	1.01E-02[5]
Cesium-137	1.30E-03[1]	1.01E-02[4]
Arsenic	4.43E-02[1]	4.75E-02[4]
Cadmium	2.30E+00[1]	3.99E-02[5]
Copper	1.40E-01[1]	1.52E-01[5]
Lead	9.21E-02[1]	4.37E-03[5]
Strontium	8.97E-03[2]	1.65E-01[4]
Thallium	2.34E-02[3]	1.43E-02[6]
Zinc	7.45E-01[1]	2.47E-01[4]

Notes:
[1] Sample *et al*., 1998
[2] Beresford *et al*., 2008
[3] Mean of arthopod values converted to fw, from USACHPPM, 2004
[4] CSA, 2008
[5] IAEA, 2010
[6] Geomean of leaves and stems values converted to fw, from Madejon *et al.*, 2007

4.2.3.4.4 Transfer Factors

Transfer factors represent the fraction of daily COPC intake transferred to the tissue of birds and mammals. Ingestion transfer factors are COPC and biota-specific. Transfer factors from feed to tissue for agricultural livestock are available in CSA (2008). An allometric equation (transfer proportional to a -3/4 power of body weight) (CSA, 2012), was applied to transfer factors available for beef, rabbit and poultry, to estimate the transfer factors for the bird and mammal receptors. The derived transfer factors are presented in Table 4.10 and Table 4.11. The transfer factors for tritium and carbon-14 were derived using specific activity methods, which are discussed in Section 4.2.3.4.6 and 4.2.3.4.7.

Table 4.10: Transfer Factors for Waterbirds and Muskrat (d/kg fw)

COPC	Trumpeter Swan	Ring-Billed Gull	Common Tern	Bufflehead	Muskrat
Cobalt-60	3.34E-01	2.64E+00	9.60E+00	3.54E+00	2.47E-01
Cesium-134	1.23E+00	9.67E+00	3.52E+01	1. 30E+01	3.97E+00
Cesium-137	1.23E+00	9.67E+00	3.52E+01	1.30E+01	3.97E+00
Cadmium	4.73E-01	3.74E+00	1.36E+01	5.01E+00	6.23E-01
Chlorine (TRC)	4.87E-01	3.85E+00	1.40E+01	5.16E+00	3.04E+00
Copper	8.09E-02	6.38E-01	2.32E+00	8.56E-01	7.36E-01

Notes:
There were no data available to determine transfer factors for hydrazine and morpholine
Radionuclide transfer factors were derived from rabbit and poultry transfer factors from CSA (2008)
Cadmium transfer factors were derived from beef and poultry transfer factors from IAEA (2010)

Table 4.11: Transfer Factors for Terrestrial Birds and Mammals (d/kg fw)

COPC	Red-winged blackbird	Red-tailed hawk	Meadow Vole	Red fox
Cobalt-60	1.79E+01	1.73E+00	3.54E+00	8.96E-02
Cesium-134	6.56E+01	6.36E+00	5.69E+01	1.44E+00
Cesium-137	6.56E+01	6.36E+00	5.69E+01	1.44E+00
Arsenic	0.00E+00	N/A	3.08E+01	N/A
Cadmium	2.53E+01	N/A	8.92E+00	N/A
Copper	4.33E+00	N/A	1.05E+01	N/A
Lead	6.03E+00	N/A	1.08E+00	N/A
Strontium	2.98E-01	N/A	2.00E+00	N/A
Thallium	2.63E+01	N/A	5.19E+00	N/A
Zinc	7.01E+00	N/A	2.46E+02	N/A

Notes:
Transfer factors for non-radionuclides were not required for red-tailed hawk and red fox, since tissue concentrations were not required for the exposure calculation.
Radionuclide transfer factors were derived from rabbit and poultry transfer factors from CSA (2008)
Arsenic transfer factors were derived from beef and poultry (CSA, 2008)
Cadmium, lead (for mammals), strontium and zinc transfer factors were derived from beef and poultry (IAEA, 2010)
Copper, lead (for birds), and thallium transfer factors were derived from beef and poultry (Sheppard, 2009)

4.2.3.4.5 Dose Coefficients

Radiation dose coefficients (DCs) used for terrestrial and aquatic biota are shown in Table 4.12. These DCs were taken from ICRP (2008) and the ERICA Tool (2011). The surrogate species from these sources were selected to represent the indicator species, considering similarities in body size and likely external exposure media. The DC values for tritium in both sources (ICRP, 2008 and ERICA Tool, 2011) do not incorporate radiation quality factors for relative biological effectiveness (RBE). Therefore, the “low beta” components of the DCs were multiplied by 2 (as per CSA N288.6-12) in order to represent its greater relative effectiveness.

Table 4.12: Dose Coefficients of Surrogate Receptors Used for Radiological Exposure Calculations

Radionuclide	Earthworm		Shrub		Insect Larvae		Vascular Plant	
	Internal DC (µGy/d)/(Bq/kg)	External DC (in soil) (µGy/d)/(Bq/kg)	Internal DC (µGy/d)/(Bq/kg)	External DC (µGy/d)/(Bq/kg)	Internal DC (µGy/d)/(Bq/kg)	External DC (µGy/d)/(Bq/kg)	Internal DC (µGy/d)/(Bq/kg)	External DC (µGy/d)/(Bq/kg)
Tritium	1.38E-04	0.00E+00	9.90E-05	0.00E+00	9.90E-05	5.76E-12	9.90E-05	4.32E-08
Carbon-14	6.80E-04	0.00E+00	6.72E-04	0.00E+00	6.72E-04	1.97E-05	6.48E-04	2.64E-05
Cobalt-60	1.80E-03	3.10E-02	1.78E-03	1.08E-02	1.25E-03	3.36E-02	1.25E-03	3.36E-02
Cesium-134	2.60E-03	2.00E-02	6.96E-03	2.40E-03	1.73E-03	2.21E-02	1.66E-03	2.21E-02
Cesium-137	3.40E-03	7.30E-03	3.36E-03	2.64E-03	2.35E-03	8.88E-03	2.35E-03	8.88E-03

Radionuclide	Rat			Trout	
	Internal DC (µGy/d)/(Bq/kg)	External DC (on soil) (µGy/d)/(Bq/kg)	External DC (in soil) (µGy/d)/(Bq/kg)	Internal DC (µGy/d)/(Bq/kg)	External DC (in water) (µGy/d)/(Bq/kg)
Tritium	1.38E-04	0.00E+00	0.00E+00	1.38E-04	8.50E-12
Carbon-14	6.80E-04	0.00E+00	0.00E+00	6.80E-04	4.40E-07
Cobalt-60	4.00E-03	1.20E-02	2.90E-02	5.10E-03	3.10E-02
Cesium-134	4.10E-03	7.40E-03	1.90E-02	4.90E-03	1.90E-02
Cesium-137	4.10E-03	2.70E-03	6.80E-02	4.40E-03	6.80E-03

Radionuclide	Tadpole		Duck		
	Internal DC (µGy/d)/(Bq/kg)	External DC (in water) (µGy/d)/(Bq/kg)	Internal DC (µGy/d)/(Bq/kg)	External DC (on soil) (µGy/d)/(Bq/kg)	External DC (in water) (µGy/d)/(Bq/kg)
Tritium	1.38E-04	3.20E-10	1.38E-04	0.00E+00	8.50E-12
Carbon-14	6.80E-04	5.50E-06	6.80E-04	0.00E+00	4.30E-07
Cobalt-60	1.50E-03	3.40E-02	5.70E-03	1.10E-02	3.00E-02
Cesium-134	2.30E-03	2.20E-02	5.30E-03	7.00E-03	1.90E-02
Cesium-137	3.20E-03	8.10E-03	4.50E-03	2.60E-03	6.70E-03

Notes:
Earthworm, rat, trout, tadpole and duck DCs from ICRP (2008)
Shrub, insect larvae and vascular plant DCs from ERICA Tool (Brown *et al*. 2008)
Shrub is the surrogate species for all terrestrial plants, insect larvae used for benthic invertebrates, vascular plants for aquatic plants, rat for mammals, and duck for all birds.
Noble gases are assessed using measured values from OPG's REMP and does not require DCs.

4.2.3.4.6 Specific Activity Model for Tritium

For tritium and C-14, tissue concentrations were calculated using specific activity models, as recommended in Clause 7.3.4.3.7 of CSA N288.6 (2012). Aquatic BAFs for tritium assume that the specific activity in the aqueous component of the aquatic animal or plant is the same as the specific activity in the water. BAFs are used to calculate tritium concentrations in plant, invertebrate and fish tissues. Therefore the BAF (L/kg-fw) is:

$$BAF_{a\_HTO} = 1\text{-}DW_a$$

or

$$BAF_{p\_HTO} = 1\text{-}DW_p$$

where,

$1\text{-}DW_a$ = water content of the animal (L water /kg-fw)
$1\text{-}DW_p$ = water content of the plant (L water /kg-fw plant)

The transfer of HTO from soil to plant is based on the ratio of the transfer of HTO from air to plant and the transfer of HTO from air to soil pore water, and is calculated as follows:

$$P_{HTOsoil\ plant} = \frac{P_{air\ plant} \cdot \rho_b}{P_{air\_spw} \cdot 1000 \cdot \theta}$$

where,

P_{air_plant} = transfer from air to plant (m^3/kg-fw) (50.1 m^3/kg-fw from Table A.5a CSA, 2008)
P_{air_spw} = transfer from air to soil pore water (m^3/L) (43.48 m3/L from Clause 6.5.4.2 CSA, 2008)
θ = volumetric moisture content of soil (m_3 water/m_3 soil) (0.3 from Clause 6.3.4.3 CSA, 2008)
p_b = bulk density of the soil (kg/m^3) (1400 kg/m^3 for clay from CSA, 2008)

The HTO BAF for terrestrial invertebrates was obtained from Beresford (2008). All HTO BAFs, which are derived from a specific activity model, are summarized in Table 4.13.

For HTO, the majority of the tritium taken into the animal is from water ingestion and food consumption. Soil ingestion dose from tritium is negligible. The transfer of HTO to animals (L/kg-fw) through water ingestion was determined using the specific activity model from CSA N288.1 (2008), and is calculated as follows:

$$P_{HTOwater\_animal} = k_{aw} \cdot f_{w\text{-}w} \cdot (1\text{-}DW_a)$$

where,

k_{aw} = fraction of water from contaminated sources (assumed to be 1)
f_{w-w} = fraction of the animal water intake derived from direct ingestion of water (0.5 from CSA N288.1-08)
DW_a = dry/fresh weight ratio for animal products (kg-dw/kg-fw) (0.3 from CSA N288.1-08)

The transfer of HTO to animals through food ingestion was also determined using the specific activity model from CSA N288.1 (2008), and is calculated as follows:

$$P_{HTOfood\_animal} = k_{af} \cdot (f_{w-pw} + IDp \cdot f_{w-dw} \cdot (1-DW_a)/(1-DW_p)$$

where,

k_{af} = fraction of food from contaminated sources (assumed to be 1)
f_{w-pw} = fraction of the animal water intake derived from water in the plant feed
f_{w-dw} = fraction of the animal water intake that results from the metabolic decomposition of the organic matter in the feed
ID_p = isotopic discrimination factor for plant metabolism (assumed to be 1)
$1-DW_a$ = water content of the animal product (L water/kg-fw)
$1-DW_p$ = water content of the plant/food (L water/kg-fw plant)

For each receptor, the water content of the total diet (DW_p) was determined based on the weighted average of the water content of the individual food items in the receptor's diet. For example, the red fox's diet consists of 50% small mammals, 30% waterfowl and 20% vegetation. The combined DW_p for the red fox was the weighted average of the dry weight fraction for small mammals, waterfowl, and vegetation.

A summary of the input parameters is provided in Table 4.14 and a summary of the transfer factors for HTO are provided in Table 4.16.

Table 4.13: Summary of BAFs for Tritium and Carbon-14

Receptor	Units	H-3	C-14	References
Fish	L/kg fw	7.50E-01	5.70E+03	As discussed in text
Aquatic Plant	L/kg fw	7.50E-01	5.90E+03	As discussed in text
Aquatic Invertebrate	L/kg fw	7.50E-01	5.20E+03	As discussed in text
Amphibian	L/kg fw	7.50E-01	5.70E+03	As discussed in text
Terrestrial Plant	kg-dw/kg-fw	5.38E+00	N/A	As discussed in text
Terrestrial Invertebrate	kg-dw/kg-fw	1.50E+02	N/A	Beresford (2008)

4.2.3.4.7 Specific Activity Model for Carbon-14

Aquatic BAFs for C-14 assume that the C-14 to stable carbon ratio in aquatic animals is equal to the ratio in dissolved inorganic carbon in the water. Therefore the BAF (L/kg-fw) for aquatic animals, invertebrates, and plants is calculated as follows:

$$BAFa_{C14} = S_a/S_w$$

where,

S_a = stable carbon content in the aquatic animal/invertebrate/plant (gC/kg-fw)
S_w = mass of stable carbon in the dissolved inorganic phase in water (gC/L)

S_w is 0.0213 gC/L, consistent with CSA N288.1 (2008). For fish the stable carbon content is 122 gC/kg-fw, for freshwater invertebrates the stable carbon content for marine crustaceans (111 gC/kg-fw) was considered appropriate, and for aquatic plants the stable carbon content for terrestrial plants (500 gC/kg-dw) was considered appropriate (CSA N288.1, 2008).

C-14 is not a soil COPC in the EcoRA therefore the transfer from soil to plant and soil to terrestrial invertebrate is not needed.

For C-14, food consumption contributes to the majority of the carbon ingested by the animal, compared to inhalation, water and soil ingestion. The transfer of C-14 from food to animals was determined using a specific activity model consistent with IAEA (2010) and with that presented in the draft CSA N288.1 2014 update.

$$P_{C14food\_animal} = k_{af} \cdot S_a/S_p$$

where,

S_a = stable carbon content in the animal (gC/kg-fw)
S_p = stable carbon content in the food (gC/kg-fw)

The stable carbon content in the animal was obtained from IAEA (2010). The beef value was applied for all mammals and the poultry value was applied for all birds. For each receptor, the carbon content of the total diet (S_p) was determined based on the weighted average of the carbon content of the individual food items in the receptor's diet. A summary of the input parameters is provided in Table 4.14 and Table 4.15, and a summary of the transfer factor for C-14 is provided in Table 4.16.

Table 4.14: Input Parameters for Specific Activity Calculations for Tritium and Carbon-14

Receptor	f_{w_pw}	f_{w_dw}	DW_p (kg-dw/kg-fw)	S_a (gC/kg-fw)	S_p (gC/kg-fw)
Trumpeter Swan	0.65	0.121	0.25	240	125
Ring-Billed Gull	0.65	0.121	0.26	240	129.3
Common Tern	0.65	0.121	0.25	240	120.9
Bufflehead	0.65	0.121	0.25	240	112.4
Muskrat	0.509	0.071	0.25	200	124.4
Red-winged blackbird	0.65	0.121	0.3	240	111
Red-tailed hawk	0.65	0.121	0.3	240	210.8
Red fox	0.509	0.071	0.278	200	191
Meadow Vole	0.509	0.071	0.19	200	95

Notes:
f_{w_pw} and f_{w_dw} are from Hart and Burt (2013) for fresh feed (rabbit was used for mammals and Canada goose was used for birds).
S_a is from IAEA (2010) where beef was used for mammals and hen was used for birds.

Table 4.15: Stable Carbon Content for Food Types

Food Type	Stable Carbon Content (gC/kg-fw)	Reference
aquatic plants	125	Zach and Sheppard 1992 (adjusted to fw)
fish	122	CSA 2008 (Table 21)
insects/earthworms	111	CSA 2008 (Table 21)
small mammals	200	IAEA 2010 (Table 67)
benthos	111	CSA 2008 (Table 21)
birds	240	IAEA 2010 (Table 67)
vegetation	95	Zach and Sheppard 1992 (adjusted to fw)

Table 4.16: Summary of Transfer Factors for Tritium and Carbon-14

Receptor	$P_{HTOwater\_animal}$ (L/kg-fw)	$P_{HTOfood\_animal}$ (unitless)	$P_{C14food\_animal}$ (unitless)
Trumpeter Swan	0.35	0.70	1.92
Ring-Billed Gull	0.35	0.71	1.86
Common Tern	0.35	0.70	1.99
Bufflehead	0.35	0.70	2.14
Muskrat	0.35	0.53	1.61
Red-winged blackbird	0.35	0.75	2.16
Red-tailed hawk	0.35	0.75	1.14
Red fox	0.35	0.55	1.05
Meadow Vole	0.35	0.49	2.11

4.2.4 Dispersion Models

Measured data were used to characterize soil, water or sediment concentrations for the exposure assessment. Dispersion factors for relevant air COPCs at Alex Robertson Park were estimated based on air emissions and measured data in the environment. No dispersion models were used for the EcoRA.

4.2.5 Exposure Point Concentrations and Doses

4.2.5.1 Exposure Point Concentrations

The concentration and doses used for the exposure evaluation are listed in Table 4.17. The exposure values are based on monitoring and measurements at the PN site. There are media-specific concentrations used for the various receptors and receptor locations.

Table 4.17: Exposure Values for the PNGS Exposure Assessment

Location	Media	Receptors	COPC	Units	Maximum Concentration	Mean Concentration	Notes
Radionuclides							
Outfall	Water	Fish Aquatic invertebrates Aquatic bird	H-3 C-14 Gross β/γ represented by Co-60	Bq/L	2.61E+02 5.73E-01 1.07E-02	8.48E+01 2.01E-02 1.45E-03	Values based on the effluent concentration from most exposed discharge based on monthly effluent and CCW flow rates from 2007 to 2011. H-3: Discharge A C-14 and Gross β/γ: Discharge B
	Sediment	Fish Aquatic invertebrates Aquatic bird	C-14 Gross β/γ represented by Co-60	Bq/kg dw	1.14E+03 < 5.00E-01	3.67E+02 < 2.88E-01	REMP report 2006-2009: Discharge B Max and average of "B" Discharge – A,B, C, D from 2006-2009
	Air	Aquatic bird	Noble gases (Ar-41)	µGy/d	1.04E-02	4.25E-03	Air Kerma Rates 2006-2011 REMP for Ar-41 for on-site locations (P2, P3, P4, P6, P7, P10, P11)

Location	Media	Receptors	COPC	Units	Maximum Concentration	Mean Concentration	Notes
Frenchman's Bay	Water	Fish Aquatic invertebrate Aquatic birds Amphibians Aquatic mammals Aquatic plants	H-3 C-14 Gross β/γ represented by Co-60	Bq/L	4.99E+01 1.91E-01 3.57E-03	3.38E+01 6.70E-03 4.83E-04	H-3 from REMP Reports 2007-2011 Concentration in outfall water divided by the dilution factor of 3
	Sediment	Fish Aquatic invertebrate Aquatic birds Amphibians Aquatic mammals Aquatic plants	C-14 Co-60 Cs-134 Cs-137	Bq/g	1.47E-02 6.00E-03 < 3.00E-03 2.20E-02	1.00E-02 < 1.54E-03 < 1.18E-03 1.16E-02	COG report results (Table 3.1, Hart and Peterson, 2013)
	Air	Aquatic birds Aquatic mammals	Noble gases (Ar-41)	µGy/d	1.47E-03	1.30E-03	Air Kerma Rates 2006-2011 REMP for Ar-41 for Frenchman's Bay (P8)

Location	Media	Receptors	COPC	Units	Maximum Concentration	Mean Concentration	Notes
PN Site	Water	Terrestrial plants Terrestrial birds Terrestrial mammals	H-3 Co-60	Bq/L	2.61E+02 1.07E-02	8.48E+01 1.45E-03	Concentrations are those from the outfall
	Soil	Terrestrial plants Terrestrial birds Terrestrial mammals	H-3 Co-60 Cs-134 Cs-137	Bq/kg dw	4.09E+05 4.52E+02 1.85E+01 1.85E+01	1.14E+05 2.60E-01 < 4.57E+00 < 4.57E+00	Tritium in Groundwater Report (1999-2000) 1999 Soil Sampling Co-60 mean from REMP 2007-2011
	Air	Terrestrial plants Terrestrial birds Terrestrial mammals	Noble gases (Ar-41)	µGy/d	1.04E-02	4.25E-3	Air Kerma Rates 2006-2011 REMP for Ar-41
Non-Radionuclides							
Outfall	Water	Fish Aquatic invertebrates Aquatic bird	Hydrazine Morpholine Cadmium Copper TRC	mg/L	8.00E-02 1.20E-02 9.00E-04 5.40E-03 3.00E-02	< 4.96E-03 < 1.33E-03 <1.10E-04 1.48E-03 < 2.19E-03	CCW (2007 to 2011 emissions data – Appendix A) Lake Water Sampling Program Results (2006)

Location	Media	Receptors	COPC	Units	Maximum Concentration	Mean Concentration	Notes
	Sediment	Fish Aquatic invertebrates Aquatic bird	Hydrazine Morpholine Cadmium Copper TRC	mg/kg fw	0.00E+00 0.00E+00 1.26E+00 1.36E+01 4.75E-01	0.00E+00 0.00E+00 1.53E-01 3.71E+00 3.46E-02	Estimated using water:sediment partitioning (see Section 4.2.2.2)
Frenchman's Bay	Water	Aquatic invertebrate Aquatic birds Amphibians Aquatic mammals Aquatic plants	Hydrazine Morpholine Cadmium Copper TRC	mg/L	2.67E-02 4.00E-03 3.00E-04 1.80E-03 1.00E-02	1.65E-03 4.44E-04 < 3.65E-05 4.92E-04 7.29E-04	Concentration in outfall water divided by the dilution factor of 3
	Sediment	Aquatic invertebrate Aquatic birds Amphibians Aquatic mammals Aquatic plants	Hydrazine Morpholine Cadmium Copper TRC	mg/kg fw	0.00E+00 0.00E+00 4.19E-01 4.52E+00 1.58E-01	0.00E+00 0.00E+00 5.10E-02 1.24E+00 1.15E-02	Estimated using water:sediment partitioning (see Section 4.2.2.2)

Location	Media	Receptors	COPC	Units	Maximum Concentration	Mean Concentration	Notes
PN Site	Water	Terrestrial plants Terrestrial birds Terrestrial mammals	Arsenic Cadmium Copper Lead Strontium Thallium Zinc	mg/L	< 1.00E-03 9.00E-04 2.30E-03 < 1.00E-04 2.20E-01 < 1.00E-04 1.25E-02	< 1.00E-03 < 1.00E-04 1.40E-03 < 1.00E-04 1.87E-01 < 1.00E-04 3.87E-03	Lake Water Sampling Program Results (2006)
	Soil	Terrestrial plants Terrestrial birds Terrestrial mammals	Arsenic Cadmium Copper Lead Strontium Thallium Zinc	mg/kg dw	4.82E+01 1.20E+01 8.75E+02 7.85E+02 4.50E+02 5.21E+00 3.02E+03	< 2.44E+00 < 4.87E-01 3.44E+01 < 4.14E+01 1.97E+01 < 8.24E-01 1.34E+02	1999 Soil Sampling

Information from 2007 to 2011 on the radiological contaminants discharged in liquid effluents into the environment was available from the PNGS REMP Reports (OPG 2008, OPG 2009b, OPG 2010d, OPG 2011g and OPG 2012c). The contaminants are reported as HTO, C-14 and gross beta/gamma. The gross beta/gamma radionuclide with the most restrictive DRL for aquatic biota, Co-60, was chosen to represent the gross beta/gamma emissions in the risk calculations (see Appendix C). The aquatic biota at the outfall is assumed to be exposed to radionuclide concentrations equal to the effluent discharge concentration.

Water concentrations at Frenchman's Bay were unavailable for both radionuclide and non-radionuclide COPCs, with the exception of tritium. Therefore, a dilution factor was applied to the outfall values to estimate the concentrations at Frenchman's Bay. A dilution factor from the PNGS Discharge B to Frenchman's Bay was estimated using the equation and parameter values (Table 4.18) in CSA N288.1 (2008). The dilution factor of 3 applied to estimate the water concentrations in Frenchman's Bay was calculated for the mouth of the Bay. Since the wetland is farther north in Frenchman's Bay, where exchange with the lake is limited, this dilution factor is conservative. For tritium, measured data at Frenchman's Bay were used from 2007 to 2011 from the annual REMP reports.

Table 4.18: Parameter Values for Determining the Dilution Factor for Frenchman's Bay

Parameter	Units	Value	Reference
Average water depth in the reach occupied by the plume (d)	m	10	Table F.3 (CSA 2008)
Annual average effluent recirculation factor (β)	unitless	2	Table F.5 (CSA 2008)
Proportionality coefficient used to derive the lateral dispersion coefficient (κ)	unitless	3.39E-7	Table F.3 (CSA 2008)
Annual average volumetric discharge rate of liquid effluent (Q_v)	L/s	9.57E+4	Emission data from OPG
Annual average current speed in the direction towards the point of interest (U_c)	m/s	0.1	Table F.4 to west (CSA 2008)
Initial dilution at the point of discharge (D_o)	unitless	1	Table F.3 (CSA 2008)
Distance between the source and the point of interest (x)	m	1500	Golder 2007b

A groundwater and soil sampling study was conducted in 1999 for a full suite of organic, inorganic and radiological parameters. Since then, the monitoring program has been restricted to target parameters of concern. The data from the 1999 study is presented in the Geology, Hydrogeology and Seismicity TSD (Golder, 2007d) and was assessed in the Tier 2 ERA (SENES, 2001). Using the data presented in the TSD, maximum and arithmetic mean concentrations were determined for the COPC concentrations in soil at the PN site. The Tier 2 ERA (SENES, 2001) reported that in 1999 there were issues with Co-60

contamination on the bottles used for sampling, and presented a different maximum Co-60 concentration. The Co-60 concentration presented in the Tier 2 ERA was used as the maximum concentration. A mean value for Co-60 in soil was taken from the open area/unirrigated reported values for P11 from the 2007 to 2011 REMP reports.

In instances where there were non-detects in the dataset and they were not predominant, they were replaced with one-half MDL value, and a mean value determined. However, when more than 50% of the dataset was comprised of non-detects, there is no method to provide a reliable estimate of the mean (CSA, 2012). To be conservative, in these instances the detection limit was considered to be a measured value and used in the dataset to calculate the mean, overestimating the concentrations likely found at the location.

4.2.5.2 Exposure Doses

The exposure concentrations in Section 4.2.5.1, along with the exposure factors in Section 4.2.3.4, were applied to the equations in Section 4.2.3 to estimate the radiological dose to all biota and non-radiological dose to birds and mammals. The estimated doses are presented in Table 4.19 to Table 4.23.

Table 4.19: Estimated Radiation Dose for Fish at the Outfall (mGy/d)

COPC		Fish	Bottom Dwelling Fish	Benthic Invertebrate	Ring-Billed Gull
H-3	max	2.70E-05	2.70E-05	1.93E-05	6.10E-01
	mean	8.79E-06	8.79E-06	6.30E-06	1.70E-01
C-14	max	2.22E-03	2.22E-03	2.02E-03	2.76E-03
	mean	7.79E-05	7.79E-05	7.70E-05	9.67E-05
Co-60	max	3.28E-06	6.80E-06	1.71E-05	8.87E-06
	mean	4.44E-07	2.51E-06	9.19E-06	5.20E-06
Ar-41	max	-	-	-	1.04E-05
	mean	-	-	-	4.25E-06
Total Dose	max	2.25E-03	2.25E-03	2.06E-03	6.13E-01
	mean	8.71E-05	8.92E-05	9.25E-05	1.70E-01

Table 4.20: Estimated Radiation Dose for Aquatic Biota at Frenchman's Bay (mGy/d)

COPC		Fish	Bottom Dwelling Fish	Frog	Benthic Invertebrate	Cattails	Muskrat	Trumpeter Swan	Bufflehead	Common Tern	Ring-Billed Gull
H-3	max	5.17E-06	5.17E-06	5.17E-06	3.71E-06	3.71E-06	5.15E-06	6.02E-06	6.02E-06	6.02E-06	6.10E-01
	mean	3.50E-06	3.50E-06	3.50E-06	2.51E-06	2.51E-06	3.49E-06	4.08E-06	4.08E-06	4.08E-06	1.70E-01
C-14	max	7.40E-04	7.40E-04	7.40E-04	6.67E-04	7.30E-04	1.23E-03	1.47E-03	1.46E-03	1.46E-03	1.11E-03
	mean	2.60E-05	2.60E-05	2.60E-05	2.34E-05	2.56E-05	4.30E-05	5.16E-05	5.13E-05	5.11E-05	3.89E-05
Co-60	max	1.09E-06	1.11E-06	4.28E-07	6.78E-07	3.64E-06	1.48E-06	7.53E-06	2.38E-06	7.87E-07	5.34E-06
	mean	1.48E-07	1.55E-07	6.36E-08	1.14E-07	4.92E-07	2.05E-07	1.02E-06	3.26E-07	1.10E-07	3.52E-07
Cs-134	max	5.42E-09	1.87E-08	1.79E-08	6.17E-08	1.23E-10	1.05E-08	1.06E-08	1.12E-08	2.11E-08	1.82E-07
	mean	2.13E-09	7.35E-09	7.04E-09	2.43E-08	4.82E-11	4.12E-09	4.18E-09	4.39E-09	8.32E-09	4.74E-08
Cs-137	max	3.57E-07	7.05E-07	6.74E-07	1.82E-06	1.22E-08	3.10E-07	3.19E-07	3.53E-07	9.74E-07	9.70E-07

COPC		Fish	Bottom Dwelling Fish	Frog	Benthic Invertebrate	Cattails	Muskrat	Trumpeter Swan	Bufflehead	Common Tern	Ring-Billed Gull
	mean	1.88E-08	3.71E-08	3.55E-08	9.60E-08	6.42E-10	1.63E-08	1.68E-08	1.86E-08	5.13E-08	1.01E-07
Ar-41	max	-	-	-	-	-	1.47E-06	1.47E-06	1.47E-06	1.47E-06	1.47E-06
	mean	-	-	-	-	-	1.30E-06	1.30E-06	1.30E-06	1.30E-06	1.30E-06
Total Dose	max	7.47E-04	7.47E-04	7.47E-04	6.74E-04	7.38E-04	1.23E-03	1.49E-03	1.47E-03	1.47E-03	6.11E-01
	mean	2.96E-05	2.97E-05	2.96E-05	2.62E-05	2.86E-05	4.80E-05	5.80E-05	5.70E-05	5.66E-05	1.70E-01

Table 4.21: Estimated Non-Radiological Dose for Aquatic Birds and Mammals at PN Outfall and Frenchman's Bay (mg/kg·d)

COPC		PN Outfall	Frenchman's Bay				
		Ring-Billed Gull	Muskrat	Trumpeter Swan	Bufflehead	Common Tern	Ring-Billed Gull
Cadmium	max	1.00E+00	1.71E+00	7.19E-01	2.30E-01	5.48E-04	9.88E-01
	mean	4.80E-02	2.08E-01	8.75E-02	2.81E-02	6.68E-05	4.60E-02
Chlorine (TRC)	max	7.27E-01	1.51-01	6.34E-02	5.66E-01	1.29E-02	2.42E-01
	mean	5.30E-02	1.10E-02	4.62E-03	4.13E-02	9.44E-04	1.77E-02
Copper	max	3.88E+00	1.63E+00	6.86E-01	2.78E-01	5.97E-03	3.69E+00
	mean	2.91E-01	4.46E-01	1.87E-01	7.60E-02	1.63E-03	2.39E-01
Hydrazine	max	4.85E-02[1]	2.60E-03[1]	7.13E-04[1]	2.01E-03[1]	1.05E-03[1]	1.62E-02[1]
	mean	3.01E-03[1]	1.61E-04[1]	4.42E-05[1]	1.25-04[1]	6.49E-05[1]	1.00E-03[1]
Morpholine	max	7.27E-03[1]	3.90E-04[1]	1.07E-04[1]	3.02E-04[1]	1.57E-04[1]	2.41E-03[1]
	mean	8.07E-04[1]	4.32E-05[1]	1.19E-05[1]	3.35E-05[1]	1.74E-05[1]	2.69E-04[1]

[1] Doses calculated only account for ingestion of water, sediment and fish/frog ingestion (as applicable) due to the lack of information on tissue concentrations of hydrazine and morpholine in other foods.

Table 4.22: Estimated Radiation Doses for Terrestrial Biota at the PN Site (mGy/d)

COPC		Earthworm	Terrestrial Plant	Meadow Vole	Red-winged blackbird	Red Fox	Red-Tailed Hawk
H-3	max	8.49E+00	2.18E-01	1.49E-01	6.34E+00	7.42E-02	1.36E+00
	mean	2.37E+00	6.09E-02	4.16E-02	1.77E+00	2.07E-02	3.80E-01
Co-60	max	1.40E-02	4.89E-03	5.42E-03	5.04E-03	6.96E-03	4.99E-03
	mean	8.07E-06	2.81E-06	3.12E-06	2.90E-06	4.00E-06	2.87E-06
Cs-134	max	3.70E-04	4.57E-05	1.38E-04	1.34E-04	1.80E-04	1.33E-04
	mean	9.14E-05	1.13E-05	3.40E-05	3.31E-05	4.45E-05	3.30E-05
Cs-137	max	1.36E-04	4.95E-05	5.06E-05	5.32E-05	2.92E-04	5.20E-05
	mean	3.35E-05	1.22E-05	1.25E-05	1.31E-05	7.21E-05	1.28E-05
Ar-41	max	-	1.04E-05	1.04E-05	1.04E-05	1.04E-05	1.04E-05
	mean	-	4.25E-06	4.25E-06	4.25E-06	4.25E-06	4.25E-06
Total Dose	max	8.50E+00	2.23E-01	1.54E-01	6.35E+00	8.17E-02	1.36E+00
	mean	2.37E+00	6.09E-02	4.16E-02	1.77E+00	2.08E-02	3.80E-01

Table 4.23: Estimated Non-Radiological Dose for Terrestrial Birds and Mammals at the PN Site (mg/kg·d)

COPC		Meadow Vole	Red-winged blackbird	Red Fox	Red-Tailed Hawk
Arsenic	max	8.17E-01	1.71E+00	3.02E-02	2.77E+00
	mean	4.15E-02	8.66E-02	1.61E-03	1.37E-01
Cadmium	max	1.74E-01	1.49E+01	7.32E-03	1.67E+00
	mean	7.06E-03	6.05E-01	4.50E-04	6.77E-02
Copper	max	4.46E+01	7.61E+01	9.89E-01	4.92E+01
	mean	1.76E+00	2.99E+00	3.92E-02	1.94E+00
Lead	max	2.28E+00	4.79E+01	1.64E-01	4.41E+01
	mean	1.20E-01	2.53E+00	8.64E-03	2.32E+00

COPC		Meadow Vole	Red-winged blackbird	Red Fox	Red-Tailed Hawk
Strontium	max	2.49E+01	7.47E+00	4.79E-01	2.49E+01
	mean	1.09E+01	3.29E+00	2.18E-01	1.09E+01
Thallium	max	3.20E-02	1.26E-01	1.41E-02	2.96E-01
	mean	5.08E-03	2.00E-02	1.29E-02	4.69E-02
Zinc	max	2.47E+02	1.24E+03	2.87E+01	1.90E+02
	mean	1.09E+01	5.48E+01	1.27E+00	8.39E+00

4.2.6 Uncertainties in the Exposure Assessment

Uncertainties in the exposure assessment include the representativeness of media concentrations used in the assessment at each location. Mean concentrations of COPCs were used for each location and media, where possible, and are considered to be representative for all mobile receptors. Maximum concentrations found in various sources were also used as an upper bound on exposure. These values are, by definition, not representative for mobile organisms that can move around the site, effectively averaging their exposure concentrations. In addition, migratory birds were assumed to reside in the area 100% of the time, which further increases their exposure concentrations. Maximum values are representative for exposures of any sessile organisms that reside at the location of the maximum value. The on-site soil data is from 1999. The results of the 1999 study do not account for the spills, contamination, and cleanup activities performed on site since 1999. Therefore, this soil data may not be reflective of current site conditions. However, spills are reported by OPG every three years, and these spill reports provide insight to the management of spills at the site. From 2008 to 2010, Pickering had a total of 9 reportable spills and the highest frequency of spills was from the HVAC/Chiller units, which are prone to the release of refrigerants. In 2011, many of the spills are related to leaking refrigerant, oil, fuel oil, hydraulic fluid, and antifreeze. The majority of the spills were cleaned up immediately, preventing release into the environment. In general, the majority of the spills that have occurred at PNGS and that are reported through the spills program are localized spills that are cleaned up immediately through use of absorbent spill pads or other absorbent materials (OPG, 2011h). These types of spills do not have the potential for long-lasting effects that could change the nature of the facility effluents and resulting risks to receptors. The spill reports indicate that OPG manages spills well, and therefore it is unlikely the results would deviate greatly from the soil concentrations from the 1999-2000 program.

Partition coefficients were used to estimate COPC concentrations in media that were not measured (i.e., sediment concentration estimated from a water concentration). Uncertainties in organism exposure arise from these estimated concentrations and from the use of BAFs to calculate uptake into tissues. In some cases, BAFs for a species of interest were unavailable, and surrogate values were used, e.g., fish values used for frog. The partition coefficients and BAFs used for the exposure assessment were not site-specific, and were taken from reputable sources and are considered to be representative of the conditions found at the site.

Dilution factors were used in estimating water concentrations in Frenchman's Bay due to PNGS effluent releases to Lake Ontario. These are based on the equation and assumptions discussed in Section 4.2.5.1. The dilution factor calculated does not account for the small size of the inlet to Frenchman's Bay. Therefore, COPC concentrations found in Frenchman's Bay due to effluent releases from the PNGS are expected to be lower than those presented.

Wildlife exposure factors, such as intake rates and diets, are a potential source of uncertainty. Reputable sources are used for these factors and are considered to be representative of the organisms assessed.

Dose coefficients were obtained from reputable sources for reference organisms, but have not been derived specifically for all the organisms assessed. Dose coefficients for surrogate organisms were often used. They were selected with attention to similar body size and exposure habits, and are believed to adequately represent the organism assessed. Dose coefficients for each receptor were not adjusted for body size and dimensions.

Radiation doses were calculated due to gross beta/gamma at the outfall which was represented by cobalt-60, based on the limiting radionuclide among beta/gamma emitters for aquatic biota (Appendix C). It is likely that this is a conservative estimate, and if the total gross beta/gamma effluent release was further characterized, the dose effects attributed to this release would be reduced.

4.3 Effects Assessment

The potential for ecological effects from COPC exposure at each location (Section 4.2) was assessed by comparing the exposure levels to toxicological, radiation, and thermal benchmarks. These benchmarks values (BVs) are taken from literature and are compared to the exposure values (EVs) to determine the potential for adverse ecological effects.

4.3.1 Toxicological Benchmarks

For hydrazine, the aquatic toxicity benchmark values were taken from the Federal Environmental Quality Guidelines (EC, 2013). Morpholine aquatic toxicity benchmark values were taken from WHO (1996). Since the benchmarks for hydrazine (EC, 2013) and morpholine (WHO, 1996) are acute, they were converted to chronic benchmarks by dividing by a factor of 10 (CCME, 1999a; Suter *et al.*, 1993). Chronic benchmarks are appropriate for hydrazine and morpholine, as exposure is based on a continuous release.

All aquatic benchmarks are summarized in Table 4.24.

Sulphate is assessed separately in Section 4.4.2.2.4. Therefore, toxicological benchmarks for sulphate are not presented in Table 4.23.

Terrestrial plant and invertebrate benchmarks are based on soil concentrations. The values are Canadian soil quality guidelines (soil contact values) (CCME, 1999a), provincial soil quality guidelines (plant and soil organism values) (MOE, 2011) or Lowest Observable Effect Concentration (LOEC) soil concentrations from Efroymson et al. (1997a,b). The Effroymson values are specific to either earthworms (1997a) or plants (1997b) but are conservative screening levels. Where an Effroymson value was higher than the more stringent of the CCME or MOE guideline values, which occurred only for earthworms, the

Effroymson value was used as the benchmark, because it was specific to the terrestrial invertebrate indicator species (earthworm) selected for the EcoRA.

However, if the Effroymson value was lower than the more stringent of the CCME or MOE guideline values, then the more stringent guideline value was used as a benchmark, because these guidelines are considered by the responsible authorities to be adequately protective of plants and soil organisms.

In the case of thallium, an earthworm specific value was taken from CCME data, because Effroymson (1997a) does not provide a thallium value. The CCME and MOE guideline for thallium of 1.4 mg/kg soil is based on a study by McCool (1933, cited in CCME 1999b) on various plants. In a study by Environment Canada (cited in CCME, 1999b), the earthworm NOEC was 12 mg/kg and the lowest observed effect concentration (LOEC) for earthworm mortality was 27 mg/kg. Since the study was earthworm specific, a benchmark of 27 mg/kg for earthworms is applicable for thallium.

There were no guidelines available for strontium, and no values were provided by Effroymson (1997a,b). A WHO (2010) report on strontium cites an effect level for invertebrates of 10,600 mg/kg. This effect level is used as a benchmark for the terrestrial invertebrates.

The terrestrial plant and invertebrate benchmarks are summarized in Table 4.25.

The benchmark values for birds and mammals (aquatic and terrestrial) are based on doses. The benchmark doses used are the LOAEL values from Sample *et al.* (1996), EC/HC (2011) for hydrazine, and WHO (1996) for morpholine. There were no data available for the toxicity of hydrazine, morpholine, strontium or thallium for birds. Hydrazine and morpholine are concerns in the aquatic environment, but due to their rapid degradation in the aquatic system and low octanol-water partition coefficient, the bioaccumulation of hydrazine and morpholine in the food chain is unlikely (EC/HC, 2011). The mammal and bird benchmarks used are summarized in Table 4.26 and Table 4.27, respectively.

Table 4.24: Toxicological Benchmarks for Aquatic Receptors

COPC	Receptor	Water TRV (mg/L)	Endpoint	Test Species	Reference
Cadmium	Fish and Frog	1.70E-03	LCV	Early life stage test on brook trout (*Salvelinus fontinalis*)	Sauter *et al.*, 1976 (cited in Suter and Tsao, 1996)
	Aquatic Plant	2.00E-03	LCV (LOEC)	Growth of *Asterionella formosa*	Conway, 1977 (cited in Suter and Tsao, 1996)
	Aquatic Invertebrate	1.50E-04	LCV	Reproduction for *Daphnia magna*	Chapman *et al.*, n.d. (cited in Suter and Tsao, 1996)

COPC	Receptor	Water TRV (mg/L)	Endpoint	Test Species	Reference
Chlorine (TRC)	Fish and Frog	5.90E-03	96h LC_{50} converted to EC_{20}	Rainbow trout (*O. mykiss*)	Fisher *et al.*1999 (cited in CCME, 1999a)
	Aquatic Plant	5.00E-03	LAV converted to EC_{20}	Growth of *Myriophyllum spicatum*	Watkins and Hammerschlag, 1984 (cited in CCME 1999a)
	Aquatic Invertebrate	3.20E-03	48h LC_{50} converted to EC_{20}	*Daphnia magna*	Fisher *et al.*1999 (cited in CCME, 1999a)
Copper	Fish and Frog	3.80E+00	LCV	Early life stage test on brook trout (*Salvelinus fontinalis*)	Sauter *et al.*, 1976 (cited in Suter and Tsao, 1996)
	Aquatic Plant	1.00E+00	LCV	Growth of *Chlorella pyrenoidosa*	Steeman-Nielsen and Wium-Anderson,1970 (cited in Suter and Tsao, 1996)
	Aquatic Invertebrate	6.07E+00	LCV	*Gammarus pseudolimnaeus*	Arthur and Leonard, 1970, (cited in Suter and Tsao, 1996)
Hydrazine	Fish and Frog	6.1E-02	LC_{50} (96 hour) converted to chronic	Common guppy (*Lebistes rericulatus*)	Slonim 1977 (cited in EC, 2013)
	Aquatic Plant	1.20E-03	EC_{50} (72 hour) converted to chronic	Growth of algae (*Pseudokirchneriella subcapitata)*	Scherfig et al., 1977 (cited in EC, 2013)
	Aquatic Invertebrate	4.00E-03	LC_{50} (48 hour) converted to chronic	Amphipod (*Hyalella azteca*)	Fisher *et al.*, (cited in EC, 2013)
Morpholine	Fish and Frog	1.80E+01	LC_{50} (96 hour) converted to chronic	Mortality Rainbow trout (*Oncorhynchus mykiss*) (low hardness)	WHO,1996
	Aquatic Plant	2.80E+00	EC_{50} (96 hour) converted to chronic	Impairment/mortality Algae (*Selenastrum capricornutum*)	WHO, 1996
	Aquatic Invertebrate	1.00E+01	EC_{50} (24 hour static) converted to chronic	*Daphnia magna*	WHO, 1996

Table 4.25: Toxicological Benchmarks for Soil for Terrestrial Invertebrates and Plants

COPC	Soil Invertebrate (mg/kg)	Reference	Terrestrial Plant (mg/kg)	Reference
Arsenic	6.00E+01	Efroymson, 1997a	1.70E+01	CCME, 1999a
Cadmium	2.00E+01	Efroymson, 1997a	1.00E+01	CCME, 1999a
Copper	6.30E+01	CCME, 1999a	6.30E+01	CCME, 1999a
Lead	5.00E+02	Efroymson, 1997a	2.50E+02	MOE, 2011
Strontium	1.06E+04	WHO, 2010	nd	-
Thallium	2.70E+01	CCME, 1999b	1.40E+00	CCME, 1999a
Zinc	2.00E+02	Efroymson, 1997a	2.00E+02	CCME, 1999a

Note:
nd = no data available

Table 4.26: Selected Toxicity Reference Values for Mammals (Aquatic and Terrestrial)

COPC	Mammal LOAEL (mg/kg-d)	Test Species	Endpoint	Test Duration	Reference
Arsenic	1.26E+00	mouse	reproduction	3 generations	Schroeder and Mitchner, 1971 (cited in Sample *et al.*, 1996)
Cadmium	1.00E+01	rat	reproduction	6 weeks	Sutou *et al.*, 1980 (cited in Sample *et al.*, 1996)
Chlorine (TRC)	5.00E+01	rat	body weight	92 days	Furukawa *et al.*, 1980 (cited in HHA, 2010)
Copper	1.54E+01	mink	reproduction	375 days	Aulerich *et al.*, 1982 (cited in Sample *et al.*, 1996)
Lead	8.00E+01	rat	reproduction	3 generations	Azar *et al.*, 1973 (cited in Sample *et al.*, 1996)
Strontium	2.63E+01[a]	rat	body weight, bone changes	3 years	Skoryna, 1981 (cited in Sample *et al.*, 1996)
Thallium	7.40E-02	rat	reproduction	60 days	Formigli et al.,1986 (cited in Sample *et al.*, 1996)
Zinc	3.20E+02	rat	reproduction	days 1-16 of gestation	Schlicker and Cox, 1968 (cited in Sample *et al.*, 1996)
Hydrazine	1.87E+00	mouse	lung tumour	110-120 weeks	Roe *et al.*, 1967; Toth, 1969, 1972 (cited in EC/HC, 2011)
Morpholine	9.00E+00	guinea pig	mortality	30 days	WHO, 1996

Notes:
nd = no data available
The TRV for strontium is a NOAEL. No adverse effects were observed at any strontium dosage level.
The TRV for morpholine is a chronic EC_{20} value, converted from an acute LD_{50} using a factor of 10.

Table 4.27: Selected Toxicity Reference Values for Birds

COPC	Bird LOAEL (mg/kg-d)	Test Species	Endpoint	Test Duration	Reference
Arsenic	1.28E+01	mallard duck	mortality	128 days	USFWS, 1964 (cited in Sample *et al.*, 1996)
Cadmium	2.00E+01	mallard duck	reproduction	90 days	White and Finley, 1978 (cited in Sample *et al.*, 1996)
Chlorine (TRC)	nd	-	-	-	-
Copper	6.17E+01	1 day old chicks	growth, mortality	10 weeks	Mehring *et al.*, 1960 (cited in Sample *et al.*, 1996)
Lead	1.13E+01	Japanese quail	reproduction	12 weeks	Edens *et al.,* 1976 (cited in Sample *et al.*, 1996)
Strontium	nd	-	-	-	-
Thallium	nd	-	-	-	-
Zinc	1.31E+02	white leghorn hens	reproduction	44 weeks	Stahl *et al.*, 1990 (cited in Sample *et al.*, 1996)
Hydrazine	nd	-	-	-	-
Morpholine	nd	-	-	-	-

Note:
nd = no data available

4.3.2 Radiation Benchmarks

Radiation dose benchmarks of 400 µGy/h (9.6 mGy/d) and 100 µGy/h (2.4 mGy/d) (UNSCEAR, 2008) were selected for the PN assessment of effects on aquatic biota and terrestrial biota, respectively, as recommended in the CSA N288.6-12 standard (CSA, 2012). This is a total dose benchmark, therefore the dose to biota due to each radionuclide of concern is summed to compare against this benchmark.

The aquatic biota dose benchmark of 10 mGy/d was initially developed by the NCRP (1991) and was recommended by the IAEA (1992) which concluded that limiting the dose rate to individuals in an aquatic population to a maximum of 10 mGy/d would provide adequate protection for the population. Later reviews by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (1996, 2008) have supported this recommendation.

For terrestrial biota, a level of 1 mGy/d has been widely used as an acceptable level based on IAEA (1992) and UNSCEAR (1996). More recently, UNSCEAR (2008) has supported a slightly higher exposure level of 100 µGy/h (2.4 mGy/d) as the threshold for effects of population significance in terrestrial organisms. UNSCEAR (2008) updated its review of radiation effects on natural biota, and noted that the 0.04 mGy/h (1 mGy/d) exposure produced no effect in the most sensitive mammalian study (with dogs), while 0.18 mGy/h produced eventual sterility. Therefore, UNSCEAR chose an intermediate exposure level of

0.1 mGy/h (2.4 mGy/d) as the threshold for effects of population significance in terrestrial organisms. UNSCEAR concluded that lower dose rates to the most highly exposed individuals would be unlikely to have significant effects on most terrestrial communities.

It is recognized that the selection of reference dose levels is a topic of ongoing debate. For example, the CNSC has recommended dose limit values of 0.6 mGy/d for fish, 3 mGy/d for aquatic plants (algae and macrophytes), 6 mGy/d for benthic invertebrates (aquatic invertebrates and zooplankton in this assessment), and 3 mGy/d for terrestrial animals and plants (Bird *et al.,* 2002; EC/HC, 2003). The dose limit value for fish was based on a reproductive effects study in carp in a Chernobyl cooling pond with a history of higher exposures (Makeyeva *et al.,* 1995). A value of 0.6 mGy/d was found to be in the range where both effects and no effects were observed. The aquatic plant benchmark was based on information related to terrestrial plants (conifers), which are considered to be sensitive to the effects of radiation. Reproductive effects in polychaete worms were used to derive the dose limit for benthic invertebrates.

The International Commission on Radiological Protection (ICRP) (2008) has suggested "derived consideration levels" as a range of dose rates reflecting a range in potential for effect, for each of several taxonomic groups. The ICRP states that the ranges of dose rates they provide are preliminary and need to be revised as more data become available.

Considering the history and discussions surrounding the selection of radiation benchmarks, 400 µGy/h (9.6 mGy/d) and 100 µGy/h (2.4 mGy/d) (UNSCEAR, 2008) were selected for the assessment of effects on aquatic biota and terrestrial biota, respectively. These benchmarks were recommended in CSA N288.6 (2012), and are appropriate for this assessment.

4.3.3 Thermal Benchmarks

Golder (2007b) compiled thermal criteria relevant to fish spawning and embryo-larval development, based on review of thermal effects literature (e.g., Wismer and Christie, 1987). These benchmarks (Table 4.32) included optimum and upper lethal temperatures, as well as maximum weekly average water temperatures (MWAT) criteria for interpretation of maximum weekly average temperatures. The latter represent an upper bound of temperature suitable for spawning (embryos) and larval development under chronic exposure conditions. Golder (2007b) also compiled criteria relevant to summer growth of juvenile and adult fish, including MWAT criteria (Table 4.36). MWAT criteria were defined for two warm water fish species (smallmouth bass and emerald shiner) and two cold water species (round whitefish and lake trout), which were selected as representative species for assessment of thermal effects.

OPG (2010b) developed thermal criteria based on laboratory incubation studies for egg survival of the round whitefish. The round whitefish is the most temperature sensitive species of all the fall and winter spawners; therefore, it is protective of all other species.

These criteria represent 1 hr, 24 hr and 7 day maximum temperature for embryos (MTE) and are presented in Table 4.33 in Section 4.4.3.1. These criteria were extensively reviewed and commented upon by the CNSC and Environment Canada, who agreed that they are adequate (i.e., conservative) for a screening level.

Cooper (2013) compiled thermal criteria relevant to fish spawning and embryo-larval development, as well as criteria relevant to summer growth of juvenile and adult fish, from literature sources such as Wismer and Christie, 1987. These benchmarks (Table 4.34 and Table 4.36) included preferred and upper non-lethal temperatures, as well as MWAT criteria for interpretation of maximum weekly average temperatures, and 24 hr criteria for interpretation of maximum short-term daily average temperatures (STDM). These criteria were defined for 15 species found in the vicinity of the Pickering station.

Cooper (2013) also considered the possible effects of "periodic rise" in temperature on round whitefish spawning near the discharge, using a ΔT benchmark of 3ºC. This was based on a threshold ΔT value of 5°C associated with increased embryo mortality in laboratory studies (SENES, 2013).

4.3.4 Uncertainties in the Effects Assessment

Toxicological benchmarks used in the risk assessment were selected from sources recommended in the CSA N288.6 (2012) standard, and other reputable sources. These BVs represent the low end of threshold effect levels in literature for each receptor category. BVs for the test species were not adjusted for body weight and were considered directly applicable to the wildlife species. The BVs are considered to be conservatively representative of the effect threshold for the COPC for the receptor of interest. There is uncertainty because most species of interest have not been tested to determine their effect thresholds. Nevertheless, it is expected that few species will be much more sensitive than indicated by the selected benchmark values.

Also, toxicological benchmarks are not available for certain COPCs (e.g., thallium for terrestrial birds), therefore no quantitative assessment was carried out. Without the benchmark value, it is difficult to determine potential effects for these biota. However, areas with elevated levels of these COPCs are limited; therefore, these uncertainties are unlikely to have major effects on the overall conclusions of the risk assessment.

Radiation dose benchmarks for biota are a topic of ongoing debate. Uncertainties exist related to some low values that have been suggested based on field studies around Chernobyl. The radiation dose benchmarks chosen follow UNSCEAR (2008) and CSA N288.6-12 (2012) in giving more credence to values based on controlled laboratory studies and demonstrated low levels of effect.

Thermal benchmarks represent a variety of species, life stages and endpoints, and vary among literature sources. Selected values vary among literature sources and have varied somewhat among studies of thermal effects at the Pickering station.

4.4 Risk Characterization

4.4.1 Risk Estimation

Ecological risk is estimated by dividing the EV (Section 4.2.5) by the BV (Section 4.3) for a given COPC and receptor species, yielding a HQ. When the EV for an organism at a site exceeds the BV (HQ > 1), a potential for adverse ecological effects is inferred. A summary of the radiation doses to each receptor by COPC is presented in Table 4.28, and a summary of non-radiological HQs is presented in Table 4.29 and Table 4.30.

Table 4.28: Summary of Radiation Dose Estimates for Biota at the Pickering Site (mGy/d)

COPC	H-3		C-14		Co-60		Cs-134		Cs-137		Ar-41		Total Dose	
	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean
PN Outfall														
Fish	2.70E-05	8.79E-06	2.22E-03	7.79E-05	3.28E-06	4.44E-07	-	-	-	-	-	-	2.25E-03	8.71E-05
Bottom Dwelling Fish	2.70E-05	8.79E-06	2.22E-03	7.79E-05	6.80E-06	2.51E-06	-	-	-	-	-	-	2.25E-03	8.92E-05
Benthic Invertebrate	1.93E-05	6.30E-06	2.02E-03	7.70E-05	1.71E-05	9.19E-06	-	-	-	-	-	-	2.06E-03	9.25E-05
Ring-Billed Gull	6.10E-01	1.70E-01	2.76E-03	9.67E-05	8.87E-06	5.20E-06	-	-	-	-	1.04E-05	4.25E-06	6.13E-01	1.70E-01
Frenchman's Bay														
Fish	5.17E-06	3.50E-06	7.40E-04	2.60E-05	1.09E-06	1.48E-07	5.42E-09	2.13E-09	3.57E-07	1.88E-08	-	-	7.47E-04	2.96E-05
Bottom Dwelling Fish	5.17E-06	3.50E-06	7.40E-04	2.60E-05	1.11E-06	1.55E-07	1.87E-08	7.35E-09	7.05E-07	3.71E-08	-	-	7.47E-04	2.97E-05
Frog	5.17E-06	3.50E-06	7.40E-04	2.60E-05	4.28E-07	6.36E-08	1.79E-08	7.04E-09	6.74E-07	3.55E-08	-	-	7.47E-04	2.96E-05
Benthic Invertebrate	3.71E-06	2.51E-06	6.67E-04	2.34E-05	6.78E-07	1.14E-07	6.17E-08	2.43E-08	1.82E-06	9.60E-08	-	-	6.74E-04	2.62E-05
Cattails	3.71E-06	2.51E-06	7.30E-04	2.56E-05	3.64E-06	4.92E-07	1.23E-10	4.82E-11	1.22E-08	6.42E-10	-	-	7.38E-04	2.86E-05
Muskrat	5.15E-06	3.49E-06	1.23E-03	4.30E-05	1.48E-06	2.05E-07	1.05E-08	4.12E-09	3.10E-07	1.63E-08	1.47E-06	1.30E-06	1.23E-03	4.80E-05
Trumpeter Swan	6.02E-06	4.08E-06	1.47E-03	5.16E-05	7.53E-06	1.02E-06	1.06E-08	4.18E-09	3.19E-07	1.68E-08	1.47E-06	1.30E-06	1.49E-03	5.80E-05
Bufflehead	6.02E-06	4.08E-06	1.46E-03	5.13E-05	2.38E-06	3.26E-07	1.12E-08	4.39E-09	3.53E-07	1.86E-08	1.47E-06	1.30E-06	1.47E-03	5.70E-05
Common Tern	6.02E-06	4.08E-06	1.46E-03	5.11E-05	7.87E-07	1.10E-07	2.11E-08	8.32E-09	9.74E-07	5.13E-08	1.47E-06	1.30E-06	1.47E-03	5.66E-05
Ring-Billed Gull	6.10E-01	1.70E-01	1.11E-03	3.89E-05	5.34E-06	3.52E-07	1.82E-07	4.74E-08	9.70E-07	1.01E-07	1.47E-06	1.30E-06	6.11E-01	1.70E-01
PN Site														
Earthworm	**8.49E+00**	2.37E+00	-	-	1.40E-02	8.07E-06	3.70E-04	9.14E-05	1.36E-04	3.35E-05	-	-	**8.50E+00**	2.37E+00
Terrestrial Plant	2.18E-01	6.09E-02	-	-	4.89E-03	2.81E-06	4.57E-05	1.13E-05	4.95E-05	1.22E-05	1.04E-05	4.25E-06	2.23E-01	6.09E-02
Meadow Vole	1.49E-01	4.16E-02	-	-	5.42E-03	3.12E-06	1.38E-04	3.40E-05	5.06E-05	1.25E-05	1.04E-05	4.25E-06	1.54E-01	4.16E-02
Red-winged blackbird	**6.34E+00**	1.77E+00	-	-	5.04E-03	2.90E-06	1.34E-04	3.31E-05	5.32E-05	1.31E-05	1.04E-05	4.25E-06	**6.35E+00**	1.77E+00
Red Fox	7.42E-02	2.07E-02	-	-	6.96E-03	4.00E-06	1.80E-04	4.45E-05	2.92E-04	7.21E-05	1.04E-05	4.25E-06	8.17E-02	2.08E-02
Red-Tailed Hawk	1.36E+00	3.80E-01	-	-	4.99E-03	2.87E-06	1.33E-04	3.30E-05	5.20E-05	1.28E-05	1.04E-05	4.25E-06	1.36E+00	3.80E-01

Note:
Bold and shaded values exceed the aquatic benchmark of 9.6 mGy/d or the terrestrial benchmark of 2.4 mGy/d.

Table 4.29: Non-Radiological Hazard Quotients for Terrestrial Biota

Receptor	Arsenic		Cadmium		Copper		Lead		Strontium		Thallium		Zinc	
	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean
Earthworm	0.8	0.0	0.6	0.0	**13.9**	0.5	**1.6**	0.1	0.0	0.0	0.2	0.0	**15.1**	0.7
Terrestrial Plant	**2.8**	0.1	**1.2**	0.0	**13.9**	0.5	**3.1**	0.2	nd	nd	**3.7**	0.6	**15.1**	0.7
Meadow Vole	0.6	0.0	0.0	0.0	**2.9**	0.1	0.0	0.0	0.1	0.0	0.4	0.1	0.8	0.0
Red-winged blackbird	0.1	0.0	0.7	0.0	**1.2**	0.0	**4.2**	0.2	nd	nd	nd	nd	**9.5**	0.4
Red Fox	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.0
Red-Tailed Hawk	0.2	0.0	0.1	0.0	0.8	0.0	**3.9**	0.2	nd	nd	nd	nd	**1.4**	0.1

Notes:
Bold and shaded values indicate a HQ > 1
nd denotes that no data were available

Table 4.30: Non-Radiological Hazard Quotients for Aquatic Biota

Receptors	Cadmium		Chlorine (TRC)		Copper		Hydrazine		Morpholine	
	max	mean	max	mean	max	mean	max	mean	max	mean
PN Outfall										
Fish	0.5	0.1	**5.1**	0.4	0.0	0.0	**1.3**	0.1	0.0	0.0
Benthic Invertebrate	**6.0**	0.7	**9.4**	0.7	0.0	0.0	**20.0**	**1.2**	0.0	0.0
Ring-Billed Gull	0.1	0.0	nd	nd	0.1	0.0	nd	nd	nd	nd
Frenchman's Bay										
Fish	0.2	0.0	**1.7**	0.1	0.0	0.0	0.4	0.0	0.0	0.0
Frog (Tadpole)	0.2	0.0	**1.7**	0.1	0.0	0.0	0.4	0.0	0.0	0.0
Benthic Invertebrate	**2.0**	0.2	**3.1**	0.2	0.0	0.0	**6.7**	0.4	0.0	0.0
Aquatic Plant	0.2	0.0	**2.0**	0.1	0.0	0.0	**22.2**	**1.4**	0.0	0.0
Muskrat	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Trumpeter Swan	0.0	0.0	nd	nd	0.0	0.0	nd	nd	nd	nd
Bufflehead	0.0	0.0	nd	nd	0.0	0.0	nd	nd	nd	nd
Common Tern	0.0	0.0	nd	nd	0.0	0.0	nd	nd	nd	nd
Ring-Billed Gull	0.0	0.0	nd	nd	0.1	0.0	nd	nd	nd	nd

Notes:
Bold and shaded values indicate a HQ > 1
nd denotes that no data were available

4.4.2 Discussion of Chemical and Radiation Effects

4.4.2.1 Effects Monitoring Evidence

Data used for the problem formulations, screening and ecological risk assessment were taken from the most recent environmental studies conducted at the PN site. These sources include the recent monitoring reports from the East Landfill, annual REMP reports, annual compliance reports, and the 2007 EA and its associated TSDs. No additional data are available to what is presented at this time to clarify potential effects at the site.

4.4.2.2 Likelihood of Effects

4.4.2.2.1 Outfall

There are no exceedances of the 9.6 mGy/d radiation benchmark for the fish at the outfall location. Gross beta waterborne emissions from Pickering B were approximately one order of magnitude greater from 2007 to 2011 than baseline levels. This increase in gross beta emissions may result in higher doses to aquatic biota, especially to those in the residing in and on sediment. However, the radiation dose to aquatic biota is mainly driven by carbon-14, therefore this increase of waterborne gross beta emissions are not likely to lead to noticeable changes to the aquatic biota radiological dose.

Maximum concentrations near the outfall exceeded the benchmark for cadmium for benthic invertebrates, the benchmarks for total residual chlorine (TRC) for fishes and invertebrates, and the benchmarks for hydrazine for fishes and invertebrates. The maximum hydrazine concentration at the outfall exceeds the benchmark for both fish and benthic invertebrates, and the mean hydrazine concentration at the outfall exceeds the benchmark for benthic invertebrates.

The toxicity of cadmium varies with the hardness of water. The benchmark used to assess the effects on benthic invertebrates (0.15 µg/L) was based on a hardness of 53 mg/L. The average hardness of the lake water samples taken at the site was 121 mg/L. In the same study, two other tests were completed at hardness of 103 mg/L and 209 mg/L. These tests found that the lowest chronic value (LCV) for reproduction were 0.21 µg/L and 0.44 µg/L respectively (Chapman *et al.* (ND) summarized in US EPA, 2001). The maximum cadmium concentration estimated at the outfall is 0.9 µg/L, which is only slightly higher than the LCV at the highest hardness for this study. Since the average outfall concentration is below the benchmark, impairment of the invertebrate community due to cadmium is unlikely.

The maximum morpholine, hydrazine and TRC concentrations are based on the maximum value reported in OPG's CofA at the point of discharge. Lake water samples taken close to the point of discharge are much lower, thus liquid effluents from PNGS are mixed rapidly in Lake Ontario. Therefore mean measured concentrations are more representative of chronic exposure since it is unlikely that biota would reside in the discharge pipes and

concentrations in the effluent are not expected to remain at these high levels for chronic exposure.

Mean measured concentrations of TRC are more representative of chronic exposure levels arising from the release of chlorinated water at CCW. There are no exceedances of TRC benchmarks based on mean concentrations, hence, effects are not expected.

The mean measured concentration of hydrazine based on lake water measurements result in a HQ of less than 1 for fish, and a HQ of 1.2 for benthic invertebrates. Effects on fish are not expected. Although the HQ for benthic invertebrates is greater than one, this exceedance is minimal, and effects are not likely to be significant.

4.4.2.2.2 Frenchman's Bay

There are no exceedances of the aquatic radiation benchmark for any aquatic receptors at Frenchman's Bay.

Predicted maximum concentrations of hydrazine at Frenchman's Bay exceed benchmarks for aquatic plants and invertebrates, while predicted average concentrations exceeded aquatic plant benchmarks. Maximum concentrations exceed TRC benchmarks for all aquatic biota, and the cadmium benchmark for benthic invertebrates. Hydrazine was not an issue in the 2000 ERA (SENES, 2000) because the aquatic plant benchmark was higher (0.4 mg/L, based on a 48-hour EC_{50} for green algae). The benchmark used for this assessment is an algal EC_{50} from the data set used to derive the Federal Water Quality Guideline (a 72-hour EC_{50} of 0.012 mg/L for algal growth). The exceedances of this benchmark suggest that the concentration of hydrazine may occasionally inhibit the growth of aquatic plants at Frenchman's Bay. Effects of hydrazine on benthic invertebrate communities were not assessed in the 2000 ERA. It is unlikely that effects will be significant for aquatic plant communities in Frenchman's Bay, because the dilution factor estimates exposure at the mouth of the Bay, whereas the wetlands are at the north end of the Bay, and because the benchmarks are only slightly exceeded at the mouth. Additionally, the maximum hydrazine concentration at Frenchman's Bay was estimated from the maximum effluent measurement at the outfall; therefore, the concentration used is very conservative. There were no toxicity data for hydrazine for birds, as discussed in Section 4.3.1. Hydrazine is not expected to be of concern for birds due to the low risk of food chain bioaccumulation.

Based on the discussion of cadmium toxicity in Section 4.4.2.2.1, the LCVs for reproduction were 0.21 µg/L and 0.44 µg/L, hardness values that bound the lake water hardness. The maximum cadmium concentration estimated at Frenchman's Bay is 0.3 µg/L. Therefore, minimal potential effects are expected for the reproduction of benthic invertebrates at Frenchman's Bay due to cadmium concentrations. The maximum chlorine concentration is estimated from a CofA maximum, whereas the estimate based on the mean concentration in effluent is more representative of chronic exposure at Frenchman's Bay. Since the latter

concentration does not exceed the TRC benchmark, no effects on aquatic receptors due to TRC in Frenchman's Bay are expected.

4.4.2.2.3 Pickering Nuclear Site

The total radiological dose benchmark was exceeded by the earthworm and red-winged blackbird based on the maximum tritium concentration in site soil. The area where such high exposure occurs is localized and close to the reactor buildings, and therefore earthworm populations on the site as a whole are not expected to be affected. The exceedance for the blackbird is driven by the ingestion of maximally exposed earthworms. Since the blackbird is mobile and unlikely to be exposed to maximum concentrations, the mean dose is more representative for the red-winged blackbird and does not exceed the dose benchmark.

In general, soils on site that exceed benchmark concentrations are very localized, suggesting the influence of former spills rather than deposition from atmospheric sources. As such, COPC accumulation in soil over time is not expected. Instead, the range of concentrations should be reduced as affected areas are identified and cleaned up. Any clean-up since 2000 would not be reflected in the 1999 soil data used. Therefore, the assessment is conservative.

The HQ target of 1 was exceeded for copper for the meadow vole for copper; lead and zinc for the red-winged blackbird; and for lead and zinc for red-tailed hawk when exposure to maximum concentrations was assumed. However, these receptors, with the exception of the meadow vole, are mobile and are unlikely to be exposed to the maximum concentrations for the entire year. There are no exceedances for mammals or birds exposed to average concentrations in soil, therefore adverse effects are not expected. The higher HQ value for copper for the meadow vole is driven by maximum concentrations in terrestrial plants. The maximum copper concentration in the plant is localized to one sampling location (see paragraph below). Therefore any effects on the meadow vole due to copper intake are limited to one area.

Copper, lead, and zinc maximum exposure concentrations exceeded benchmark values for earthworms. Lead and thallium were not assessed as COPCs for soil in the 2000 ERA (SENES, 2000), but copper and zinc exceeded benchmarks for earthworms. In the current assessment, maximum concentrations of arsenic, cadmium, copper, lead, thallium and zinc exceeded benchmark values for terrestrial plants. In the 2000 ERA, copper and zinc exceeded benchmarks, whereas arsenic, cadmium lead, and thallium were not assessed. The potential effects on plants due to exposure to arsenic, cadmium, copper, lead and zinc are expected to be limited to certain areas at the PN site. The toxicological benchmarks for these COPCs were exceeded at only 2 out of the 39 sampling locations at the PN site. Arsenic, copper, and zinc benchmarks were exceeded at GMS-MW-32 (south west of the East Landfill), and lead and zinc benchmarks were exceeded at GMS-MW-13

(north of the intake channel, just south of the Old Water Treatment Plant). All locations are shown on Figure 16 in Golder (2007d).

The thallium benchmark for terrestrial plants was exceeded at five sampling locations (GMS-MW-28, -29, -31, -32, all located on the eastern portion of the site and GMS-MW-38, located in Parking Area A at Montgomery Road). Thallium is adsorbed into plants by their roots and highest concentrations occur at the seedling stage. Effects on plants through root uptake include discoloration, necroses and litterfall (CCME, 1999b). At the five locations of high thallium concentrations, terrestrial plants may potentially experience slightly retarded root growth and reduced plant height. However based on the limited extent of these elevated thallium concentrations, detrimental effects on terrestrial plant communities at the site are not expected. There were no toxicity data available to assess risk of birds from exposure to thallium.

There were no data to determine strontium benchmarks for terrestrial plants and birds. Strontium competes with calcium but it does not have a toxic effect on bone in chicks. A study (cited in Skoryna, 1981) found that there were no deleterious effects on chicks until very high doses were given. This dose is reported to be much higher than the benchmark value used to assess strontium effects on mammals. If the benchmark for birds were set to the same values as mammals, which could be interpreted as a NOAEL, there would be no exceedances. Since there were no data available for terrestrial plants, there are uncertainties associated with the effects assessment, but it is unlikely that there would be adverse effects on these receptors due to strontium.

4.4.2.2.4 East Landfill

The screening benchmark for sulphate (100 mg/L) is the British Columbia Ministry of the Environment (BC MOE) short-term maximum water quality guideline from 2000 for the protection of freshwater aquatic life. At that time not enough toxicity data existed to propose a long-term 30 day average guideline. The 100 mg/L value was based on an acute toxicity test for *H. azteca* of 205 mg/L (96-hour LC_{50}), and incorporates a safety factor of 2. However, in April 2013 the BC MOE published an update to the sulphate water quality guideline based on a number of toxicity studies linking sulphate toxicity to water hardness, as discussed below.

Elphick et al. (2011) performed chronic toxicity tests on nine test organisms over four levels of water hardness (40, 80, 160, and 320 mg/L). For most test organisms, Elphick et al. (2011) observed a decrease in toxicity to test organisms as hardness increased. However, at a hardness of 320 mg/L, *C. dubia* showed increased sensitivity when compared to the test at 160 mg/L. Elphick et al. (2011) concluded that at higher hardness levels (greater than 250 mg/L), osmotic stress could be related to total dissolved solids and not elevated sulphate concentrations.

Pacific Environmental Science Centre (PESC) conducted chronic toxicity tests on seven test organisms over three levels of water hardness (50, 100, and 150 mg/L) and also found decreasing sulphate toxicity with increasing water hardness. Dr. Chris Kennedy repeated the rainbow trout test under soft water conditions to clarify concerns with control mortality, and also found lowered sulphate toxicity when hardness increased up to 250 mg/L (BC MOE, 2013).

BC MOE has set updated sulphate guidelines (see Table 4.31 and Figure 4.5) based on 21-d rainbow trout embryo to alevin life stage LC_{20} data at different levels of hardness from the Kennedy study and incorporating a safety factor of 2 (BC MOE, 2013). BC MOE sets guidelines using the critical value approach – using the lowest toxicity test result and applying a safety factor.

Table 4.31: Sulphate Water Quality Guidelines based on Water Hardness

Water Hardness (mg/L)	Sulphate Guideline (mg/L)
Very soft (0-30)	128
Soft to moderately soft (31-75)	218
Moderately soft/hard to hard (76-180)	309
Very hard (181-250)	429
>250	Need to determine based on site water

The BC guideline states that if natural hardness is greater than 250 mg/L site-specific toxicity testing on several species should be conducted, since the combination of high water hardness and sulphate levels may cause osmotic stress on the organism, likely related to high levels of TDS. The highest hardness level observed on site was 752 mg/L in 2010 from Ditch 6, with a sulphate concentration of 328 mg/L. Although there is uncertainty in the sulphate benchmark at hardness levels above 250 mg/L, the observed sulphate concentration in Ditch 6 is well below the LC_{20} for trout of 857 mg/L at a hardness of 250 mg/L (BC MOE, 2013) as well as the LC_{25} for *C. dubia* of 425 mg/L at a hardness of 320 mg/L (Elphick et al., 2011). The maximum sulphate in Ditch 6 is below these effect levels as well as below the sulphate guideline at the maximum hardness. Based on these observations, sulphate levels in Ditch 6 are not likely of concern.

Although high hardness can be an indicator for high TDS, there are no TDS data for the ditches from the east landfill; therefore, there is uncertainty surrounding potential toxicity effects from TDS in that area.

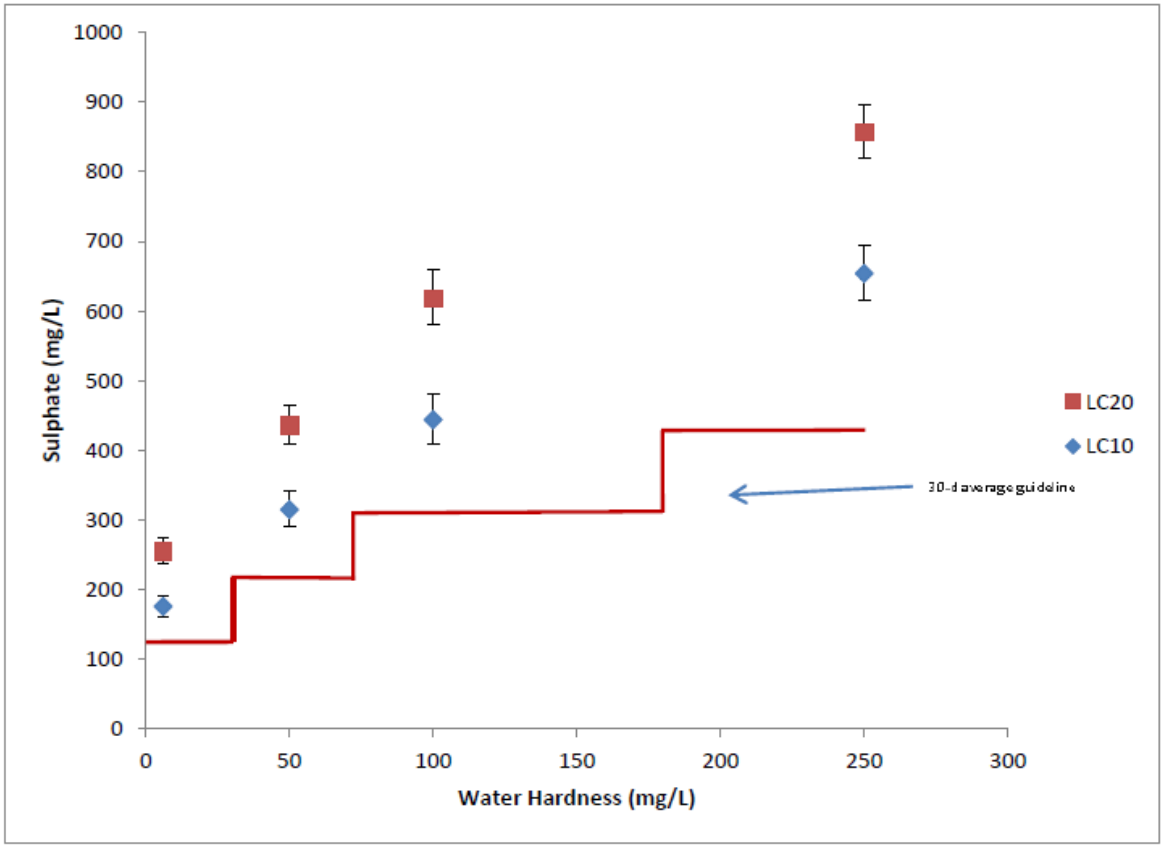


Figure 4.5: Relationship between Sulphate Toxicity and Water Hardness (BC MOE, 2013)

4.4.3 Thermal Effects

4.4.3.1 Thermal Plume Effects on Fish Spawning and Larvae

The potential effects of the thermal plume on fish spawning and larvae were evaluated in the Aquatic Environment Technical Support Document for the EA for the refurbishment and continued operation of the Pickering B nuclear generation station (Golder, 2007b). The thermal regime as influenced by the existing plume was determined by numerical modelling which described the seasonal and spatial variation in water temperature. The modelled MWATs were compared to MWAT criteria representing an upper bound of temperature suitable for spawning (embryos) and larval development under chronic exposure conditions. MWAT criteria were defined for two warm water fish species (smallmouth bass and emerald shiner) and two cold water species (round whitefish and lake trout) (Golder, 2007b, Table A2.5-1). These species were selected based on local abundance and identified potential for thermal plume effects. While some other fish species (white sucker, walleye, northern pike) are common in the area, they are transient or do not have susceptible life history stages. The MWAT criteria for spawning and larval development are considered here (Table 4.32). Thermal effects on fish growth over the summer are considered in Section 4.4.3.2.

Table 4.32: Thermal Criteria Relevant to Spawning and Larval Development of Selected Fish Species (Golder, 2007b)

Fish Species	Life Stage	Optimum Temp (°C)	Upper Lethal Temp (°C)	MWAT for Spawning & Larvae (°C)	Relevant Timeframe
Smallmouth bass	Spawning	18	37	24.3	mid-Apr-May
	Larvae	21	33	25	mid-Apr-May
Round whitefish	Spawning	2-5	5.4	4.5	mid-Nov-Dec
	Larvae	3-4.5	10	5	mid-Nov-Apr
Emerald shiner	Spawning	24	29	27	mid-Apr-May
	Larvae	24	29	27	mid-Apr-May
Lake trout	Spawning	-	14.8	10	December
	Larvae	-	14.8	10	Dec- Apr

The cold water species (round whitefish and lake trout) spawn on shoals and rocky substrates located in the shallow nearshore waters east of the Pickering nuclear generating station. Round whitefish spawn in mid-November to December. Lake trout spawn in December. The larval periods for both species extend into April.

Golder (2007b, Table A3.1-1) found that modelled MWATs for the October-December period generally exceeded MWAT criteria for round whitefish spawning and larval development, but this is mainly due to October and early November temperatures prior to the spawning season. Modelled values for the January to March period were generally below the MWAT criteria at most lake locations, indicating suitable temperatures for spawning and larval development. At two lake locations near the outfall, the criteria were generally exceeded near the water surface (average up to 5 and 4.9°C), but generally not exceeded near the bottom. Findings were similar for lake trout, with only occasional exceedence of MWAT criteria, only in near surface waters, at one lake location near the outfall.

Among the warm water species, smallmouth bass spawn primarily within the intake and discharge channels which are the primary local habitat for all life stages. The emerald shiners prefer nearshore areas with substrate structure. Spawning and larval development occur primarily around the armoured break wall and intake channel, and may also include portions of the discharge channel. The spawning and larval periods for both species extend from mid-April through May.

Golder (2007b, Table A3.1-1) found that modelled MWATs for the April to June period occasionally exceeded MWAT criteria for smallmouth bass in the discharge channel (up to 27°C) and reached but did not exceed the MWAT criteria for emerald shiners. Temperatures in the lake near the outfall and in the intake channel did not exceed MWAT criteria for either species. Thermal conditions are therefore suitable for spawning and larval development of these species in and around the discharge.

Follow-up monitoring of water temperatures on the round whitefish spawning beds was completed over the December through April period in 2009-2010 (OPG, 2010e). Near surface and bottom dataloggers were placed at 16 locations in the spawning area east of the PNGS, and at 7 locations in each of two reference spawning areas (Thickson Point and Bonnie Brae Point). The data were compared to highly conservative criteria for hourly, daily and weekly average temperature, for three phases of the spawning and developmental period, based on experimental data from Griffiths (1980) (Table 4.33). These criteria were associated with embryo-larval survival rates of 76 to 98%. For each temperature endpoint for each developmental period the frequency of temperature observations exceeding the applicable criterion was noted, and compared between Pickering and reference locations. The frequency of exceeding criteria differed significantly among locations, and was higher in the Pickering area than in either reference location.

Table 4.33: Thermal Criteria for Round Whitefish Embryo-larval Periods

Period	HI		STDM		MWAT	
	°C	% Survival	°C	% Survival	°C	% Survival
Dec 1 - Jan 5	6.8	84	6	80	3.8	91
Jan 6 - Mar 8	6.8	98	6	98	6	98
Mar 9 - Apr 17	6.5	92	6	76	4	98

Note:
HI - 1 hour average; STDM - 24 hour average; MWAT - 7 day rolling average based on experimental data from Griffiths (1980)

In general, the follow-up monitoring results for weekly average temperature confirmed the earlier modelled MWATs, but the measured temperatures exceeded the lower MWAT criteria for both early and late developmental periods, more frequently and over a larger spatial area. However, the stringent criteria were also exceeded in reference areas. Furthermore, the reference areas have higher whitefish usage based on adult catch per unit effort (CPUE). Overall, it was concluded that the thermal plume represents a potential but small risk to round whitefish spawning and larval development. These conclusions are consistent with the EA predictions that the thermal plume would cause some exceedances of MWAT criteria; however, the minor adverse effect is considered not significant.

Cooper (2013) evaluated lake temperatures in the vicinity of the Pickering B discharge using 2011-2012 data provided by OPG from thermal dataloggers placed on the substrate. Temperature results at locations in the thermal plume and in reference areas (Thickson Point and Bonnie Brae Point) were compared to thermal criteria for 15 species and HQ values were calculated for relevant time periods for each species at each location. The thermal criteria relevant to spawning and embryo-larval periods are listed in Table 4.34 for all species that exceeded criteria at any location.

Table 4.34: Thermal Criteria Relevant to Spawning and Embryo-Larval Development of Selected Fish Species (Cooper, 2013)

Lake Trout

Stage	Pref	Upper	MWAT	STDM
Spawning	10.6		9	
Egg	5.5			10
Larvae	10			

Common Carp

Stage	Pref	Upper	MWAT	STDM
Spawning	25.8		21	
Egg	20.8			34.5
Larvae	21.9			37.6

Rainbow Trout

Stage	Pref	Upper	MWAT	STDM
Spawning	7.1		9	
Egg	7.9			13.7
Larvae	15.9			

Freshwater Drum

Stage	Pref	Upper	MWAT	STDM
Spawning	20.9		21	
Egg	24			26
Larvae	24			

Round Whitefish

Stage	Pref	Upper	MWAT	STDM
Spawning	3.5		3	
Egg	2.3		4.6	6.3
Larvae	2.2		4.6	

Smallmouth Bass

Stage	Pref	Upper	MWAT	STDM
Spawning	18		17	
Egg	21			28.3
Larvae				

Walleye

Stage	Pref	Upper	MWAT	STDM
Spawning	7.9		8.5	
Egg	8.4			20
Larvae	15.6	24		

Yellow Perch

Stage	Pref	Upper	MWAT	STDM
Spawning	10.1		12	20
Egg	11			22
Larvae	18.5	35.6	25.5	36.2

White Sucker

Stage	Pref	Upper	MWAT	STDM
Spawning	19.5		10	24.1
Egg	15.2			24.1
Larvae	23.8	30	28	30

Threespine Stickleback

Stage	Pref	Upper	MWAT	STDM
Spawning	12.5		19	
Egg				20
Larvae	19			

Notes:
Pref=preferred temperature, Upper=upper non-lethal temperature, MWAT=maximum weekly average temperature, STDM= maximum short-term daily average temperature

Hazard quotients were calculated by taking the measured MWAT or STDM at each location, for the seasonal period relevant to each species, and dividing by the MWAT or STDM criterion. In addition, Cooper (2013) calculated HQ_{UP} from the measured MWAT values, for mobile life stages only, to identify locations that would likely be avoided due to elevated temperature. HQ_{UP} was calculated as:

$$HQ_{UP} = (T_{MWAT} - T_{PREF}) / (T_{UPPER} - T_{PREF})$$

This formulation produces a negative HQ whenever weekly average temperature is less than the preferred temperature for the life stage. Such negative values are not indicative of adverse effects from the thermal plume and are not relevant to the risk assessment.

Table 4.35 presents the HQ values for all species that had HQ values above 1, indicative of potential adverse effects from the thermal plume. The HQ is shown for the highest temperature location in the plume area, and in the reference area. These highest HQs were marginally above 1 in the plume, but usually very similar in the reference. Round whitefish is the only species for which HQ was higher in the plume for all life stages. It is also the species with the highest HQ in each life stage category, but the highest HQ (for spawning) is only 2.83 as compared to 2.0 in the reference area.

Cooper (2013) addressed round whitefish further by calculating ΔT for the lake station nearest the Pickering B discharge, during the January to April period of embryo-larval development, and comparing this value to a ΔT benchmark for round whitefish embryo-larval development. The ΔT was calculated relative to an ambient value representing the average of weekly averages at all Bonnie Brae and Thickson Point stations. The ΔT at station P1 near the discharge never exceeded a conservative benchmark of 3^{o}C.

Based on the MWAT, STDM and ΔT results relevant to fish spawning and embryo-larval development, Cooper (2013) concluded that there is no evidence or adverse impacts on fish caused by the thermal plume.

Table 4.35: Thermal Hazard Quotients Relevant to Spawning and Embryo-Larval Development of Selected Fish Species in Lake Ontario near the Pickering B Discharge (Cooper, 2013)

Lake Trout	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**2.33**			**2.33**	
Egg			**1.28**			**1.06**
Larvae						

Common Carp	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**1.07**			**1.08**	
Egg			0.69			0.69
Larvae			0.53			0.51

Rainbow Trout	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		0.99			0.99	
Egg			**1.39**			**1.51**
Larvae						

Freshwater Drum	Plume B			Referenc Reference (BR)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**1.07**		**1.08**		
Egg			0.92			0.92
Larvae						

Round Whitefish	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**2.83**			**2**	
Egg		**1.91**	**1.62**		**1.74**	**1.43**
Larvae		**1.93**			**1.78**	

Smallmouth Bass	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**1.08**			**1.14**	
Egg			0.67			0.73
Larvae						

Walleye	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**1.05**			0.96	
Egg			0.89			0.91
Larvae	0.14			0.21		

Yellow Perch	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**1.4**	0.89		**1.45**	0.91
Egg			0.86			0.94
Larvae	0.1		0.6	0.09		0.61

White Sucker	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**1.69**	0.79		**1.93**	0.86
Egg			0.9			0.92
Larvae	neg	0.81	0.8	neg	0.81	0.8

Threespine Stickleback	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Spawning		**1.19**			**1.2**	
Egg			**1.2**			**1.2**
Larvae						

Notes:
The HQ shown represents the highest temperature location in each area.
"neg" indicates that HQ_{UP} as calculated by Cooper is negative

4.4.3.2 Thermal Plume Effects on Fish Growth over the Summer

The potential effects of the thermal plume on fish growth were evaluated in the Aquatic Environment Technical Support Document for the EA for the refurbishment and continued operation of the Pickering B nuclear generating station (Golder, 2007b). The thermal regime as influenced by the existing plume was determined by numerical modelling which described the seasonal and spatial variation in water temperature. The modelled MWATs were compared to MWAT criteria representing an upper bound of temperature suitable for growth under chronic exposure conditions. MWAT criteria were defined for two warm water fish species (smallmouth bass and emerald shiner) and two cold water species (round whitefish and lake trout) (Golder, 2007b, Table A2.5-1). These species were selected based on local abundance and identified potential for thermal plume effects. While some other fish species (white sucker, walleye, northern pike) are common in the area, they are transient or do not have susceptible life history stages. The MWAT criteria for juveniles and adults are considered here (Table 4.36). Thermal effects on spawning and larval development are considered in Section 4.4.3.1.

Table 4.36: Thermal Criteria Relevant to Summer Growth and Mortality of Selected Fish Species (Golder, 2007b)

Fish Species	Life Stage	Optimum Temp (°C)	Upper Lethal Temp (°C)	MWAT for Growth Temp (°C)	Nearshore Timeframe
Smallmouth bass	Adult	21	36	29, 33	all year
	Juvenile	28.5	35	29	all year
Round whitefish	Adult	15	26.7	18.9	mid-Nov-Dec
	Juvenile	17, 18.5	26.7	20.2, 21.2	mid-Nov-Dec
Emerald shiner	Adult	25	42	30	all year
	Juvenile	23	35	30	all year
Lake trout	Adult	12	21.5	19.4	mid-Nov-Apr
	Juvenile	12	21.5	19.4	mid-Nov-Apr

The cold water species avoid the Lake Ontario nearshore during the summer period, and are thus not exposed to the thermal plume at this time. For example, round whitefish are potentially exposed from mid-November to early December and lake trout are potentially exposed from mid-November to April. Golder (2007b, Table A3.1-1) found that modelled MWATs did not exceed criteria for growth of juveniles and adults of round whitefish and lake trout at the time that they are present in the nearshore area.

The warm water species are potentially exposed to the thermal plume during the summer growth period when water temperatures are highest. The discharge and intake channels have been identified as the primary habitat areas for the smallmouth bass in the area. The modelled MWATs marginally exceeded the criteria for growth of juveniles and adults occasionally at one lake location near the Pickering B discharge over the July to September

period (e.g., up to 29.93°C vs criterion of 29°C for smallmouth bass) and only in the near surface water. Deeper water at the same location did not exceed the criterion. Residing mainly near the bottom, these fish would likely not be exposed to temperatures that are adverse for growth.

In the discharge channel, the modelled MWATs were as high as 34°C over the July to September period, which exceeds the MWAT criteria for growth of juveniles and adults for both smallmouth bass (29°C) and emerald shiner (30°C). However, the average modelled MWAT over this period was 25°C, well below the MWAT criteria. The upper lethal temperatures for these species were not exceeded. Thus, there could be occasional times when growth is affected in the discharge channel, or fish may move out of the discharge channel at these times.

Algal growth events during the late summer and fall occasionally require the cooling water intake pumps to be shut off which results in a slightly increased discharge temperature. Kinectrics (2008) observed one six-day algae event in August 2007 (21-27 August) and one two-day algae event in October 2007 (9-10 October). The daily temperature increment in the Pickering B discharge was 6.9 to 12.8°C over 21-27 August, and 8.6°C for the October event. The daily discharge temperatures (28.6 to 31.2°C for the August event and 29.3°C for the October event), were slightly above MWAT criteria, but are not comparable to MWAT criteria. Weekly average temperatures are appropriate for this comparison, and did not exceed the MWAT criteria. Surveillance in the discharge channel and lake during these periods did not find any evidence of fish mortality associated with the increased temperatures; nor did the observed temperatures exceed upper lethal temperatures for the species that would be present. Both smallmouth and largemouth bass use the discharge for spawning, but spawning is completed by July, and therefore is not subject to thermal effects due to algal events. Similarly, alewife spawning in the lake nearshore zone is complete by July. Thus, algal events have not produced mortality and have had no adverse effects on spawning.

Hourly temperature values for influent and effluent, and ΔT values, were measured through the year in 2008, 2009, 2010 and 2011, and daily average values were calculated for comparison to a CofA ΔT limit of $^{+}11$°C. Only the Pickering B discharge exceeded this ΔT limit, usually as a result of a temporary pump shutoff to clear away material such as algae or frazil ice. The number of algal events per year has ranged from 1 to 7; the events typically last 1 or 2 days. During these events, effluent temperature has usually increased by a few degrees, but only during August and September events has the daily average temperature exceeded the MWAT criterion for smallmouth bass (29°C). Weekly average temperatures during these events rarely exceed the criterion. One event in August 2010 produced a daily average temperature of 39°C, above the upper lethal temperature for smallmouth bass. However, no fish mortality has been observed in association with any of these events.

In summary, algal events have the potential to slightly increase water temperatures in the discharge channel, and water temperatures near the surface in the lake near the discharge, for short periods of time. These brief and occasional changes in thermal regime due to algal events would not be expected to have any substantial effect on the suitability of nearshore waters for growth of the fish species that reside there at the time of these events.

Cooper (2013) evaluated lake temperatures in the vicinity of the Pickering B discharge using 2011-2012 data provided by OPG from thermal dataloggers placed on the substrate. Temperature results at locations in the thermal plume and in reference areas (Thickson Point and Bonnie Brae Point) were compared to thermal criteria for 15 species and HQ values were calculated for relevant time periods for each species at each location. The thermal criteria relevant to juvenile and adult stages are listed in Table 4.37 for all species that exceeded criteria for any life stage at any location.

Table 4.37: Thermal Criteria Relevant to Juvenile and Adult Stages of Selected Fish Species (Cooper, 2013)

Lake Trout

Stage	Pref	Upper	MWAT	STDM
Juvenile	11	15.5	19.4	21.5
Adult	11.9	14		23.5

Common Carp

Stage	Pref	Upper	MWAT	STDM
Juvenile	32	33.6	34	38.3
Adult	27.6	36.6		39

Rainbow Trout

Stage	Pref	Upper	MWAT	STDM
Juvenile	19	22.8	18.3	29
Adult	17.3	20.5	19	20.8

Freshwater Drum

Stage	Pref	Upper	MWAT	STDM
Juvenile	26.5		25.6	33
Adult	22.1	30		34

Round Whitefish

Stage	Pref	Upper	MWAT	STDM
Juvenile	15			
Adult	16.3	23.3		

Smallmouth Bass

Stage	Pref	Upper	MWAT	STDM
Juvenile	23.6	32.3	32.5	35
Adult	30.5	33	31	32

Walleye

Stage	Pref	Upper	MWAT	STDM
Juvenile	19.3		25	28.5
Adult	21.7		25	

Yellow Perch

Stage	Pref	Upper	MWAT	STDM
Juvenile	16.6	29.8	29	31.2
Adult	15.6			35

White Sucker

Stage	Pref	Upper	MWAT	STDM
Juvenile	24.4		28	35.6
Adult	20.5	21.7	28	31.6

Threespine Stickleback

Stage	Pref	Upper	MWAT	STDM
Juvenile	15.4		22.4	28.5
Adult	6			

Notes:
Pref=preferred temperature, Upper=upper non-lethal temperature, MWAT=maximum weekly average temperature, STDM= maximum short-term daily average temperature

HQs were calculated by taking the measured MWAT or STDM at each location, for the seasonal period relevant to each species, and dividing by the MWAT or STDM criterion. In addition, Cooper (2013) calculated HQ_{UP} from the measured MWAT values, to identify

locations that would likely be avoided due to elevated temperature. Cooper's (2013) formulation produces a negative HQ_{UP} whenever weekly average temperature is less than the preferred temperature for the life stage (see Section 4.4.3.1). Such negative values are not indicative of adverse effects from the thermal plume and are not relevant to the risk assessment.

Table 4.38 presents the HQ values for juvenile and adult stages for all species that had HQ values above 1 at any life stage. The HQ is shown for the highest temperature location in the plume area, and in the reference area. The highest HQs were marginally above 1 in the plume for lake trout, rainbow trout, white sucker and threespine stickleback, but were less than or equal to reference values for all these species. Therefore, it is unlikely that there are any effects arising from the thermal plume in the lake for juvenile or adult stages of any fish species.

Table 4.38: Thermal Hazard Quotients Relevant to Juveniles and Adults of Selected Fish Species in Lake Ontario near the Pickering B Discharge (Cooper, 2013).

Lake Trout	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile	**2.57**	**1.16**	**1.11**	**2.61**	**1.16**	**1.11**
Adult	**5.07**		**1.02**	**5.17**		**1.02**

Common Carp	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile	neg	0.55	0.52	neg	0.54	0.5
Adult	neg		0.61	neg		0.61

Rainbow Trout	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile	0.93	**1.23**	0.82	0.99	**1.24**	0.82
Adult	**1.64**	**1.19**	**1.15**	**1.7**	**1.2**	**1.15**

Freshwater Drum	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile		0.88	0.72		0.89	0.72
Adult	0.06		0.7	0.08		0.7

Round Whitefish	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile						
Adult	0.36			0.3		

Smallmouth Bass	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile	neg	0.69	0.68	neg	0.7	0.68
Adult	neg	0.73	0.75	neg	0.73	0.75

Walleye	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile		0.9	0.84		0.91	0.84
Adult		0.9			0.91	

Yellow Perch	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile	0.45	0.88	0.77	0.47	0.89	0.77
Adult		0.78	0.68		0.78	0.68

White Sucker	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile		0.81	0.67		0.81	0.67
Adult	**1.71**	0.81	0.76	**1.87**	0.81	0.76

Threespine Stickleback	Plume B			Reference (BB)		
Stage	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}	HQ_{UP}	HQ_{MWAT}	HQ_{STDM}
Juvenile		**1.01**	0.84		**1.02**	0.84
Adult						

Notes:
The HQ shown represents the highest temperature location in each area.
"neg" indicates that HQ_{UP} as calculated by Cooper is negative

4.4.3.3 Thermal Plume Contribution to Winter Cold Shock

During an outage, thermal additions to receiving water can be rapidly curtailed, such that water temperature declines more rapidly than fish are able to acclimate to lower temperatures (Coutant, 1977). In this event, water temperature may fall below the lower lethal temperature, and fish mortality may occur. In theory, heat shock can also occur when water is rapidly warmed, but temperature rise during start-up seldom occurs at a sufficient rate to cause heat shock.

Fish are most susceptible to cold shock in the winter months (Wismer and Christie, 1987), whereas outages usually occur in spring and fall when demand for power is low. Fish are least susceptible to cold shock in spring and fall. Therefore, cold shock is not a likely occurrence during most outages.

SENES (2001) addressed the potential for cold shock at the PNGS. From October 1999 to January 2001, at a monitoring location near the Pickering B discharge, winter water temperatures were typically 10^{o}C, or ambient 4^{o}C with an increment of 6^{o}C (SENES, 2001, Figures 8.2-2 and 8.2-4). Coutant (1977) indicates a lower lethal temperature of about 2^{o}C at acclimation temperatures up to 14^{o}C (SENES, 2001, Figure 8.1-1). Thus, a drop from the nearfield plume temperature of 10^{o}C to an ambient temperature of 4^{o}C would be unlikely to induce cold shock. However, the possibility of lower ambient temperatures in winter, and a drop below the lower lethal temperature during a winter outage, is acknowledged.

SENES (2001) notes that natural upwellings in the Lake Ontario nearshore can reduce nearshore water temperature by as much as 10^{o}C in a few hours, resulting in natural cold shock events over a relatively large area. Given that a winter outage during a particularly cold period is a rare event, and that any cold shock effects of an outage would be localized near the plume outfall, such events must represent a small contribution to cold shock risk for fish populations.

4.4.4 Entrainment/Impingement

Fish impingement sampling was conducted at the PNGS from September 2003 to September 2004. Fish egg/larvae entrainment sampling was conducted from mid-March through December 2006. Subsequently, in October 2008, OPG was ordered by the CNSC to reduce fish impingement at the Pickering station by 80%, relative to the baseline, and to reduce fish entrainment by 60%. In order to reduce impingement, OPG installed a fish diversion system (FDS), in October 2009. Entrainment cannot be practically reduced, but equivalent ecological benefit was realized by undertaking fish stocking and coastal wetland habitat enhancement programs (OPG, 2012e).

4.4.4.1 Evaluation of Impingement in 2003/04 and Entrainment 2006

Fish impingement occurs at the combined cooling water intake for PNGS A and B. Fish were collected on a regular basis from the traveling screen bins in 2003/04 (Golder, 2007g). The most abundant species, in decreasing order of relative abundance, were alewife (42.9%), threespine stickleback (37.9%), emerald shiner (9.1%), rainbow smelt (3.4%) and brown bullhead (2.7%). A total of 36 species were represented in the collections.

Actual numbers of each species were scaled up for times not sampled to obtain annual numbers. The annual numbers were scaled up to account for less than full design flow at the time of sampling. Then juvenile numbers were scaled down to account for natural rates of survival to age 1. Impingement losses were expressed as age 1 equivalents. Finally, the biomass production foregone as a result of impingement losses was calculated. The results as presented by Golder (2007b) are summarized in the fish impingement row of Table 4.39.

Table 4.39: Entrainment/Impingement at PNGS before the FDS (Golder, 2007g)

	Actual	Annual	Annual (max flow)	Age-1 Equivalents	Production Foregone (kg)
Fish Impingement	380,590	706,941	831,505	561,484	5,695.6[b]
Larval Entrainment	53	11,209,435	11,388,876	455,373[a]	163.3[a]
Egg Entrainment	347	50,575,743	51,994,686	-	-

Notes:

[a] combined egg and larvae contributions

[b] includes 3,251.7 kg forage fish, equivalent to 81.9 kg sport fish

Fish eggs and larvae that pass through the screens are entrained with the cooling water. They were sampled in 2006 from March to December (Golder, 2007g) through a hose from the intake, approximately 50 m from the west intake groyne and 1.5 m above the substrate. The species represented, in decreasing order of relative abundance were common carp (48.36%), alewife (34.91%), round goby (16.51%) and freshwater drum (0.22%). A total of four species were represented.

Actual numbers of eggs and larvae were adjusted for times not sampled to obtain annual numbers, and these were scaled up to represent full design flow conditions as described above. The combined egg and larval entrainment losses were expressed as age-1 equivalents, and the biomass production foregone as a result of these losses was calculated. The results as presented by Golder (2007b) are shown in the bottom two rows of Table 4.39.

SENES (2008) analyzed the Golder (2007b) E/I data independently, using slightly different life history assumptions and more realistic methods, focusing on the 15 most common

species. Most importantly, while Golder assumed all adult fish were age-1, SENES used their likely ages based on length and weight data. Their results are shown in Table 4.40.

Table 4.40: Entrainment/Impingement at PNGS before the FDS (SENES, 2008)

Fish Species	Annual (max flow)	Age-1 Equivalents	Production Foregone (kg)
Alewife	356,722	295,632	5,557
Brown Bullhead	22,483	11,455	1,184
Brown Trout	604	696	270
Chinook Salmon	182	289	51
Coho Salmon	9	14	2
Emerald Shiner	75,481	90,713	83
Lake Trout	149	80	11
Northern Pike	144	146	747
Rainbow Smelt	28,078	22,920	830
Round Whitefish	133	189	40
Smallmouth Bass	180	164	28
Threespine Stickleback	314,773	173,956	154
Walleye	1,263	492	350
White Sucker	2,431	1,754	121
Yellow Perch	832	891	5
Total	**803,464**	**599,391**	**9,434**

The numbers of fish lost to entrainment and impingement represent a very small fraction of lake-wide populations, as discussed by Golder (2007b). For example, the alewife losses represent less than 0.2 % of the lake-wide population. The brown bullhead losses represent 1% of the commercial harvest in Lake Ontario. The losses of emerald shiner represent an amount that would produce approximately 3 kg of sport fish biomass. The lake trout losses represent 0.1% of the catch by fishing boats in Lake Ontario. The northern pike losses represent 4% of the commercial harvest from Canadian waters of Lake Ontario. The losses of round whitefish represent an amount that would produce approximately 0.14 kg of sport fish biomass. The smallmouth bass losses represent 0.13% of the angler harvest in eastern Lake Ontario. The losses of threespine stickleback, represent an amount that would produce approximately 7 kg of sport fish biomass. The walleye losses represent 0.2 to 0.3% of the amount harvested annually by anglers in Lake Ontario. It is unlikely that the losses at the Pickering station have any appreciable effect on the success of Lake Ontario fish populations.

4.4.4.2 Impingement Reduced by the Fish Diversion Structure

A FDS consisting of a barrier net around the Pickering cooling water intake was installed in October, 2009. It is maintained in place from April through November. It is removed during the winter months because water conditions are unsafe for divers who must maintain the nets free of algae and other debris.

Studies of FDS performance were undertaken in 2010 and 2011. Performance was evaluated in terms of the reduction in impinged fish biomass, on an annual basis, and during the period of FDS operation (OPG, 2011i, 2012f). Table 4.41 summarizes the results.

Table 4.41: Impinged Biomass and Percent Reduction in 2010 and 2011 (OPG, 2012f)

						FDS Period Only	
Fish Species	**2003/04 Biomass (kg)**	**2010 Biomass (kg)**	**2011 Biomass (kg)**	**2010 Reduction (%)**	**2011 Reduction (%)**	**2010 Reduction (%)**	**2011 Reduction (%)**
Freshwater Drum	4,803.38	128.94	204.08	97.32	95.75	99.42	98.35
Brown Bullhead	3,287.22	48.74	45.98	98.52	98.60	99.37	99.32
Alewife	3,134.61	2,591.86	1,912.12	17.31	39.00	19.36	47.7
Carp	2,621.71	347.21	462.49	86.76	82.36	94.07	94.07
Gizzard Shad	1,702.01	393.09	327.21	76.90	80.78	78.12	76.64
Salmonids	717.79	260.5	449.65	63.71	37.36	71.93	36.31
Walleye	617.8	27.8	0	95.50	100.00	98.9	100
White Sucker	608.25	77.87	94.92	87.20	84.39	86.22	90.66
Threespine Stickleback	279	0.6	0.3	99.78	99.89	99.95	99.97
Emerald Shiner	135.95	23.67	4.07	82.59	97.01	79.49	96.37
Smallmouth Bass	84.2	11.2	17.79	86.70	78.87	96.71	92.99
Northern Pike	66.93	51.19	120.43	23.52	-79.93	100	38.25
Rainbow Smelt	41.7	124.5	132.52	-198.56	-217.79	-153.69	-141.56
American Eel	38.51	0.51	12.3	98.68	68.06	98.69	90.34
Yellow Perch	16.6	15.3	18.05	7.83	-8.73	16.34	28.33
Sea Lamprey	4.43	36.07	14.7	-714.22	-231.83	-651.1	-216.04
Round Goby	0	287.5	155.62	NA	NA	NA	NA
Other Species	39.58	189.99	54.8	-246.70	27.78	77.81	46.77
Total Biomass	**18,214.88**	**4,616.50**	**4,011.80**	**74.66**	**77.98**	**77.81**	**82.76**
mg / m^3 Flow	**4.35**	**0.95**	**0.84**	**78.82**	**80.62**	**80.93**	**84.83**

For many fish species there have been substantial reductions in the biomass lost to impingement since the installation of the FDS. For a few species, such as rainbow smelt,

the biomass lost to impingement has increased relative to the baseline year (2003/04). The baseline year was a time of unusually low abundance of rainbow smelt. Both rainbow smelt and alewife have been increasing in abundance in the lake (GLFC, 2010 and 2011). The round goby was not impinged in the baseline year, thus a reduction in goby impingement cannot be calculated. This is an invasive species that has recently extended its range into the Pickering area and may still be undergoing rapid population growth here.

In order to estimate a percent reduction in fish impingement that is not influenced by the arbitrary selection of a baseline year, OPG conducted hydroacoustic and gill netting surveys to estimate fish abundance inside and outside the FDS net face. Using these data it was possible to predict the fish biomass that would have been impinged in each year if the FDS was not deployed. The impinged biomass in 2010 and 2011 was then compared to that which would have been impinged in the absence of the FDS. Using this method, the reduction in impinged biomass was estimated at 88% in 2010 and 85% in 2011 (OPG, 2012f). These results suggest greater FDS efficiency than that illustrated in Table 4.41.

Overall, biomass lost to impingement was reduced relative to baseline by 75 and 78% on an annual basis for 2010 and 2011, and by 78 and 83% when calculated only for the period of FDS operation. Biomass per unit of CCW flow was reduced by 79 and 81% on an annual basis for 2010 and 2011, and by 81 and 85% when calculated only for the period of FDS operation. Biomass reduction calculated from fish abundance surveys inside and outside the FDS indicate that impingement was reduced by 88 and 85% in 2010 and 2011. These reductions in impinged biomass are considered to meet or exceed the 80% reduction target.

The FDS only reduces the impingement component of fish losses at the Pickering cooling water intake. The entrainment losses will be similar to those reported prior to FDS installation. The impact of entrainment losses, in terms of production foregone, is an order of magnitude less than the impact of impingement losses (Table 4.40).

The combined losses after FDS installation have not been calculated in terms of adult equivalents or production foregone. However, the combined losses prior to the FDS installation, considering adult equivalents and production foregone, were found to be very small relative to commercial and recreational harvests (Golder, 2007g; SENES, 2008). Losses that were of little ecological consequence before the FDS will be smaller and even less consequential now that the FDS is in operation.

4.4.5 Uncertainties in the Risk Characterization

There are uncertainties associated with the components contributing to the overall risk assessment. This includes receptor exposure factors, such as transfer factors, intake rates and bioaccumulation factors, partition coefficients, dose coefficients and averaging assumptions (discussed in Section 4.2.6), as well as benchmarks values used to determine risk of potential effects (discussed in Section 4.3.4).

Overall, considering uncertainties in the exposure assessments and the benchmark values, it is reasonable to consider that HQs above 1 for a COPC, receptor and location are indicative of a potential for adverse effects. However it does not necessarily imply adverse effects. In some cases, field studies may be appropriate to clarify whether effects are occurring.

A PRA to quantify uncertainty in the risk estimate has not been performed and is not considered necessary, since it is not likely to provide a better basis for risk management/decision making. According to CSA N288.6 (2012), a qualitative or semi-quantitative evaluation of uncertainty is considered sufficient for evaluation of uncertainty.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Conclusions of Human Health Risk Assessment (HHRA)

5.1.1.1 Non-Radiological HHRA

Potential risks to human receptors were characterized quantitatively in terms of Hazard Quotients (HQs) for non-carcinogens (morpholine) and Incremental Lifetime Cancer Risks (ILCRs) for potential carcinogens (hydrazine).

No risks to the urban resident, commercial/industrial worker, and correctional institution are expected due to exposure to morpholine in drinking water - all HQs were less than the target of 0.2.

Exposure to hydrazine for the urban resident, correctional institution, and industrial/commercial worker through water ingestion (Ajax WSP) is above the cancer risk target (ILCR) of 10^{-6}. Maximum hydrazine concentrations are based on measured data from 2007 to 2011 at the effluent discharge point into the CCW discharge channel. However, all lake water samples collected from both the PNGS A and PNGS B discharge channels show hydrazine concentrations <0.005 mg/L, indicating that rapid mixing occurs. Using the measured lake water concentration (<0.005 mg/L and applying a dilution factor of 8 to the Ajax WSP) as a more realistic mean concentration, the risk to the urban resident and correctional institution still exceeds the 10^{-6} cancer risk target; however, the risk is only slightly above Health Canada's target cancer risk of 10^{-5}. A range of cancer risk between 1 in 10,000 and 1 in 1,000,000 is generally considered acceptable (Health Canada, 2004). As all lake water samples for hydrazine were below the detection limit of 0.005 mg/L, the lake water concentration is likely even lower; therefore, the risk estimated is conservative.

With respect to the sport fisher, risks from morpholine through fish ingestion are below the target of 0.2 for non-cancer risk, indicating that no increased risk from fish ingestion is expected. Exposure to hydrazine for the sport fisher through fish ingestion is above the cancer risk target of 10^{-6}. However, hydrazine is expected to degrade quickly in the environment. At a pH of 8 (representative of the typical pH observed in Lake Ontario near the PNGS), the chemical half-life of hydrazine ranges from 0.6 to 1.31 days (EC/HC, 2011). Therefore, it is uncertain if hydrazine would be available for uptake by fish at the concentrations used in the calculations. The risk estimated is conservative.

The estimated range in risk to the urban resident and the commercial/industrial worker from inhalation of hydrazine is above the cancer risk target (ILCR) of 10^{-6}. These risk estimates are likely very conservative. In the Pickering B EA, SENES (2007d) estimated the risk due to hydrazine inhalation at the Bay Ridges Neighbourhood and Liverpool Road Subdivision.

These receptors are part of the collective “Urban Resident”. The risk estimates were below the cancer risk target of 10^{-6}.

Although the hydrazine emission rates used were comparable to the emission rates used in the 2007 EA, the differences in the results are likely due to model differences. In SENES (2007d), the air concentrations at the Bay Ridges Neighbourhood and Liverpool Road Subdivision were estimated using AERMOD. For the current risk assessment, dispersion factors were determined from dispersion modelling in IMPACT based on release rates and meteorological data, consistent with those dispersion factors used in the annual public radiological dose calculations. At distances greater than 1 km, there is a two-fold uncertainty around the predictions of the sector-averaged Gaussian model used in IMPACT (Hart, 2008). At all distances, the Gaussian air model in IMPACT on average, overpredicts air concentrations by approximately a factor of 1.5 (Hart, 2008); however, modeled air concentrations from IMPACT are still considered appropriate as a conservative estimate. Air concentrations from AERMOD may be more representative of true air concentrations. Overall, the hydrazine inhalation risks to the urban resident and the industrial/commercial worker presented in this risk assessment are considered conservative. The mean risk estimates presented exceed the cancer risk target of 10^{-6} by a factor of 2, but are consistent with the 10^{-6} target considering the uncertainty in the IMPACT model. Therefore, risks at these receptor locations, and at receptor locations farther away from the site, due to inhalation of hydrazine are considered acceptable

5.1.1.2 Radiological HHRA

For exposure of human receptors to radiological COPCs, the relevant exposure pathways and human receptors (critical groups) were those presented in the annual OPG REMP reports. Radiological dose calculations followed the methodology outlined in CSA N288.1-08. Table 5.1 presents a summary of the maximum dose to the critical group from 2007 to 2011. The annual dose during this five year period ranged from 0.9 to 4.1 µSv and the critical group was either the industrial/commercial worker (adult) or the urban resident (adult/10 year old). The dominant pathways and radionuclides that contribute significantly to the total dose are inhalation of HTO and external exposure to noble gases.

Over the five year period (2007-2011), the public dose estimates for the critical group (industrial/commercial worker or the urban resident) are between 0.1 and 0.4% of the regulatory public dose limit of 1 mSv/year and approximately 0.1% of the Canadian background radiation. Since the critical group receives the highest dose from the PNGS, the demonstration that they are protected implies that other receptor groups near the PNGS are also protected.

Facility releases are considered to be adequately controlled, and further optimization of PNGS operations is not required. Nevertheless, the ALARA principle is applied at PNGS to reduce emissions as much as is reasonably possible.

Since the dose estimates are a small fraction of the regulatory public dose limit and natural background exposure, no discernable health effects are anticipated due to exposure of potential groups to radioactive releases from the PNGS.

Table 5.1: Summary of Annual Dose to Critical Group from 2007 to 2011

Year	Critical Group	Effective Dose (µSv)	Percentage of Regulatory Limit (%)	Percentage of Canadian Background Radiation (%)
2007	Industrial/Commercial (adult)	2.6	0.3	0.1
2008	Industrial/Commercial (adult)	4.1	0.4	0.3
2009	Industrial/Commercial (adult)	1.8	0.2	0.1
2010	Urban Resident (adult)	1.0	0.1	0.1
2011	Urban Resident (adult, 10 yr old child)	0.9	0.1	0.1

5.1.2 Results of Ecological Risk Assessment (EcoRA)

5.1.2.1 Non-radiological EcoRA

The potential for ecological effects was assessed by comparing exposure levels to toxicological benchmarks, and characterized quantitatively in terms of Hazard Quotients (HQs). A HQ greater than 1 indicates a need to more closely assess the risk to the concerned VEC.

Outfall

Maximum concentrations near the outfall exceed the benchmark for cadmium for benthic invertebrates, the benchmarks for total residual chlorine (TRC) for fishes and invertebrates, and the benchmarks for hydrazine for fishes and invertebrates. The maximum hydrazine concentration at the outfall exceeds the benchmark for both fish and benthic invertebrates, and the mean hydrazine concentration at the outfall exceeds the benchmark for benthic invertebrates. The maximum cadmium concentration estimated at the outfall is 0.9 µg/L, which is only slightly higher than the LCV at the highest hardness in Chapman et al. (ND) as summarized in US EPA (2001). Since the average outfall concentration is below the benchmark, impairment of the invertebrate community due to cadmium is unlikely.

The maximum morpholine, hydrazine and TRC concentrations are based on the maximum values reported in OPG's CofA at the point of discharge. Lake water samples taken close to the point of discharge are much lower, indicating that rapid mixing occurs in the lake. It is not expected that concentrations of morpholine, hydrazine and TRC in the effluent will remain at these high levels for chronic exposure durations. Mean measured concentrations are more representative of chronic exposure levels since biota are unlikely to reside in the

discharge pipes and effluent concentrations are not expected to remain at elevated levels for chronic exposure.

There are no exceedances of TRC benchmarks based on the mean concentrations; hence, effects are not expected. The mean measured concentration of hydrazine based on lake water measurements result in a HQ of less than 1 for fish, and a HQ of 1.2 for benthic invertebrates. Effects on fish are not expected. Although the HQ for benthic invertebrates are greater than one, this exceedance is minimal, and effects are not likely to be significant.

Overall, the risk to fish at the outfall is low, and fish are not expected to experience any adverse effects due to the liquid effluents from PNGS operations.

Frenchman's Bay

Predicted maximum concentrations of hydrazine at Frenchman's Bay exceeded benchmarks for aquatic plants and invertebrates, while predicted average concentrations exceeded aquatic plant benchmarks. Maximum concentrations exceeded TRC benchmarks for all aquatic biota, and the cadmium benchmark for benthic invertebrates. Hydrazine was not an issue in the 2000 ERA because the aquatic plant benchmark was higher (0.4 mg/L, based on a 48-hour EC_{50} for green algae). The benchmark used for this assessment is an algal EC_{50} from the data set used to derive the Federal Water Quality Guideline (a 72-hour EC_{50} of 0.012 mg/L for algal growth). The exceedances of this benchmark suggest that the concentration of hydrazine may occasionally inhibit the growth of aquatic plants at Frenchman's Bay. Effects of hydrazine on benthic invertebrate communities were not assessed in the 2000 ERA. It is unlikely that effects will be significant for aquatic plant communities in Frenchman's Bay, because the dilution factor estimates exposure at the mouth of the Bay, whereas the wetlands are at the north end of the Bay and the benchmarks are only slightly exceeded at the mouth. Additionally, the maximum hydrazine concentration at Frenchman's Bay was estimated from the maximum effluent measurement at the outfall; therefore, the concentration used is very conservative. There were no toxicity data for hydrazine for birds, as discussed in Section 4.3.1. Hydrazine is not expected to be of concern for birds due to the low risk of food chain bioaccumulation.

The maximum cadmium concentration estimated at Frenchman's Bay of 0.3 µg/L. The LCVs for reproduction for benthic invertebrates were 0.21 µg/L and 0.44 µg/L, hardness values that bound the lake water hardness (Chapman et al (ND) summarized in US EPA, 2001). Therefore, minimal potential effects are expected for the reproduction of benthic invertebrates at Frenchman's Bay due to cadmium concentrations. The maximum chlorine concentration at Frenchman's Bay is estimated from a CofA maximum, whereas an estimate based on the mean concentration in effluent is more representative of chronic exposure at the Bay. Since the latter concentration does not exceed the TRC benchmark, no effects on aquatic receptors due to TRC in Frenchman's Bay are expected.

Pickering Site

The HQ target of 1 was exceeded for copper for the meadow vole for copper; lead and zinc for the red-winged blackbird; and for lead and zinc for red-tailed hawk, when exposure to maximum concentrations was assumed. However, these receptors, with the exception of the meadow vole, are mobile and are unlikely to be exposed to the maximum concentrations for the entire year. There are no exceedances for mammals or birds exposed to average concentrations in soil, therefore adverse effects are not expected. The higher HQ value for copper for the meadow vole is driven by maximum concentrations in terrestrial plants. The maximum copper concentration in the plant is localized to one sampling location (see paragraph below). Therefore any effects on the meadow vole due to copper intake are limited to one area.

Copper, lead, and zinc maximum exposure concentrations exceeded benchmark values for earthworms. Lead and thallium were not assessed as COPCs for soil in the 2000 ERA (SENES 2000), but copper and zinc exceeded benchmarks for earthworms. In the current assessment, maximum concentrations of arsenic, cadmium, copper, lead, thallium and zinc exceeded benchmark values for terrestrial plants. In the 2000 ERA, copper and zinc exceeded benchmarks, whereas arsenic, cadmium lead, and thallium were not assessed. The potential effects on plants due to exposure to arsenic, cadmium, copper, lead and zinc are expected to be limited to certain areas at the PN site, as the toxicological benchmarks for these COPCs were exceeded at only 2 of 39 sampling locations at the PN site.

The thallium benchmarks for terrestrial plants was exceeded at five sampling locations. Thallium is adsorbed into plants by their roots and highest concentrations occur at the seedling stage. Effects on plants through root uptake include discoloration, necroses and litterfall (CCME 1999b). At the five locations with high thallium concentrations, terrestrial plants may potentially experience slightly retarded root growth and reduced plant height. However based on the limited extent of these elevated thallium concentrations, detrimental effects on terrestrial plant communities at the site are not expected. There were no toxicity data available to assess risk of birds from exposure to thallium.

There were no data to determine strontium benchmarks for terrestrial plants and birds. Strontium competes with calcium but it does not have a toxic effect on bone in chicks. A study (cited in Skoryna, 1981) found that there were no deleterious effects on chicks until very high doses were given. This dose is reported to be much higher than the benchmark value used to assess strontium effects on mammals. If the benchmark values for birds were set the same as mammals, which could be interpreted as a NOAEL, there would be no exceedances. Since no data were available for terrestrial plants, there are uncertainties associated with the effects assessment, but it is unlikely that there would be adverse effects on these receptors due to strontium.

East Landfill

The maximum sulphate concentration observed in Ditch 6 in the East Landfill was 328 mg/L, which exceeds the benchmark of 100 mg/L from the BC MOE. However, in April 2013 the BC MOE published an update to the sulphate water quality guideline based on a number of toxicity studies linking sulphate toxicity to water hardness. The revised BC guideline states that if natural hardness is greater than 250 mg/L site-specific toxicity testing on several species should be conducted, since the combination of high water hardness and sulphate levels may cause osmotic stress on the organism, likely related to high levels of TDS. The highest hardness level observed on site was 752 mg/L in 2010 from Ditch 6, with a sulphate concentration of 328 mg/L. Although there is uncertainty in the sulphate benchmark at hardness levels above 250 mg/L, the observed sulphate concentration in Ditch 6 is well below the LC_{20} for trout of 857 mg/L at a hardness of 250 mg/L (BC MOE, 2013) as well as the LC_{25} for *C. dubia* of 425 mg/L at a hardness of 320 mg/L (Elphick et al., 2011). The maximum sulphate in Ditch 6 is below these effect levels as well as below the sulphate guideline at the maximum hardness. Based on these observations, sulphate levels in Ditch 6 are not likely of concern.

Although high hardness can be an indicator for high TDS, there are no TDS data for the ditches from the east landfill; therefore, there is uncertainty surrounding potential toxicity effects from TDS in that area.

5.1.2.2 Radiological EcoRA

Radiation dose benchmarks of 400 µGy/h (9.6 mGy/d) and 100 µGy/h (2.4 mGy/d) (UNSCEAR, 2008) were selected for the assessment of effects on aquatic biota and terrestrial biota, respectively, as recommended in the CSA N288.6-12 standard (CSA, 2012).

Outfall

There were no exceedances of the 9.6 mGy/d radiation dose benchmark for the fish at the PNGS outfall location.

Frenchman's Bay

There were no exceedances of the aquatic radiation dose benchmark (9.6 mGy/d) for any aquatic receptors at Frenchman's Bay.

Pickering Site

The total radiological dose benchmark of 2.4 mGy/d was exceeded for the earthworm and red-winged blackbird based on the maximum tritium concentration in site soil. The area where such high exposure occurs is localized and close to the reactor buildings; therefore, earthworm populations on the site as a whole are not expected to be affected. The

exceedance for the blackbird is driven by the ingestion of maximally exposed earthworms. Since the blackbird is mobile and unlikely to be exposed to maximum concentrations, the mean dose is more representative of the red-winged blackbird, and does not exceed the dose benchmark.

5.1.2.3 Thermal, Entrainment, and Impingement Effects

Thermal Effects

Cooper (2013) evaluated lake temperatures in the vicinity of the Pickering B discharge using 2011-2012 data provided by OPG from thermal dataloggers placed on the substrate. Temperature results at locations in the thermal plume and in reference areas (Thickson Point and Bonnie Brae Point) were compared to thermal criteria for 15 fish species and HQ values were calculated for relevant time periods for each species at each location. Thermal criteria relevant to spawning and embryo-larval periods, and juvenile and adult stages were presented for weekly and daily averaging periods (MWAT and STDM criteria).

An HQ above 1 is indicative of potential adverse effects from the thermal plume. HQs were presented for the highest temperature location in the plume area, and in the reference area. For fish spawning and embryo-larval development, the highest HQs were marginally above 1 in the plume, but usually very similar in the reference. Round whitefish is the only species for which HQ was higher in the plume for all life stages. It is also the species with the highest HQ in each life stage category, but the highest HQ (for spawning) is only 2.83 as compared to 2.0 in the reference area.

Cooper (2013) addressed round whitefish further by calculating ΔT for the lake station nearest the Pickering B discharge, during the January to April period of embryo-larval development, and compared this value to a ΔT benchmark for round whitefish embryo-larval development. The ΔT was calculated relative to an ambient value representing the average of weekly averages at all Bonnie Brae and Thickson Point stations. The ΔT at station P1 near the discharge never exceeded a conservative benchmark of 3^{o}C.

Based on the MWAT, STDM and ΔT results relevant to fish spawning and embryo-larval development, Cooper (2013) concluded that there is no evidence of adverse impacts on fish caused by the thermal plume.

For fish growth (juvenile and adult), the highest HQs were marginally above 1 in the plume for lake trout, rainbow trout, white sucker and threespine stickleback, but were less than or equal to reference values for all these species. Therefore, it is unlikely that there are any effects arising from the thermal plume in the lake for juvenile or adult stages of any fish species.

Entrainment and Impingement

In October 2008, OPG was ordered by the CNSC to reduce fish impingement at the Pickering station by 80%, relative to the baseline, and to reduce fish entrainment by 60%. In order to reduce impingement, OPG installed a barrier net in October 2009. Entrainment cannot be practically reduced, but equivalent ecological benefit was realized by undertaking fish stocking and coastal wetland habitat enhancement programs (OPG, 2012e).

Overall, biomass lost to impingement was reduced relative to baseline (2003/4) by 75 and 78% on an annual basis for 2010 and 2011, and by 78 and 83% when calculated only for the period of FDS operation. Biomass per unit of CCW flow was reduced by 79 and 81% on an annual basis for 2010 and 2011, and by 81 and 85% when calculated only for the period of FDS operation. Biomass reduction calculated from fish abundance surveys both inside and outside the FDS indicate that impingement was reduced by 88 and 85% in 2010 and 2011. These reductions in impinged biomass are considered to meet or exceed the 80% reduction target.

The FDS only reduces the impingement component of fish losses at the Pickering cooling water intake. The entrainment losses will be similar to those reported prior to FDS installation. The impact of entrainment losses, in terms of production foregone, is an order of magnitude less than the impact of impingement losses.

The combined losses after FDS installation have not been calculated in terms of adult equivalents or production foregone. However, the combined losses prior to the FDS installation, considering adult equivalents and production foregone, were found to be very small relative to commercial and recreational harvests (Golder, 2007g; SENES, 2008). Losses that were of little ecological consequence before the FDS will be smaller and even less consequential now that the FDS is in operation.

5.2 Recommendations for the Monitoring Program

In the few instances where radiation or chemical doses were predicted to exceed benchmarks, it is recommended that OPG confirm exposure conditions, and proceed either to monitor for the effects relevant to benchmark exceedance, or to evaluate options for risk management if the need for risk management is clear. The confirmation of exposure may involve refinement of exposure estimates from existing data, or obtaining new monitoring data where exposures were based on predicted concentrations.

- In order to clarify risk in future human and ecological assessments, the following specific recommendations for monitoring are provided:
    - The Pickering site soil data is from 1999 and may not reflect current conditions on-site, including any remediation that may have occurred.

  - An updated soil monitoring program on-site, focused on areas with historically elevated concentrations of tritium, will help reduce uncertainty regarding tritium concentrations used in dose calculations for ecological receptors. It is recommended to resample problem areas to confirm if there are high soil concentrations – based on data from 2000 the highest concentrations were observed in close proximity to Units 1 and 2. The objective of this program would be to better understand why concentrations are elevated (i.e., is it from roof drains). This would be considered a supplementary one-time study and would only be part of the monitoring program until the objective is achieved.

  - Additionally, a number of metals in soil exceeded ecological benchmarks for earthworms (Cu, Pb, Tl, Zn) and terrestrial plants (As, Cd, Cu, Pb, Tl, Zn). An updated PN site soil monitoring program, focused on areas with historically elevated concentrations, would clarify if concentrations have changed due to site remediation activities, or potentially if elevated concentrations are due to local background. The program would focus on the area south west of the East Landfill, the eastern portion of the PN site, the vicinity of Parking Area A, and north of the intake channel just south of the Old Water Treatment plant, as indicated in Section 4.4.2.2.3. This would be considered a supplementary one-time study and would only be part of the monitoring program until the objective is achieved.

- Lake water samples collected along the PNGS discharge channels, analyzed using a lower detection limit for hydrazine, would help reduce the uncertainty surrounding human exposure to hydrazine through drinking water. If a lower detection limit is not feasible, a realistic estimate of the expected concentration in the discharge channel should be made based on concentrations in the blowdown. This would be considered a supplementary one-time study and would only be part of the monitoring program until the objective is achieved.

- Since site-specific data exists for fish and sediment, Cs-137 should continue to be used to represent gross beta/gamma radionuclides for human dose calculations. P-32 measurements in fish (and potentially sediment) should be obtained, if possible. Initially, this would be considered a supplementary one-time study. If and when measurements confirm that P-32 is the main dose contributor for the critical receptor, then it may be appropriate to switch from Cs-137 to P-32. If the monitoring program switches from C-137 to P-32, these measurements should be incorporated into the annual monitoring program.

In order to reduce uncertainty in future human and ecological assessments, the following specific recommendations for monitoring are provided:

- The Frenchman's Bay wetland is located in the northern section of the bay; however, in the EcoRa biota were assessed at the mouth of the bay where sediment data were collected, and where waterborne emissions from PNGS will have the greatest impact. Sampling of sediment and water in the northern section of the bay for the COPCs identified in Table 4.17 of the EcoRA could be performed to reduce uncertainty. Initially, this would be considered a supplementary one-time study; however, depending on the results may be incorporated into the annual monitoring program.

- The only exposure pathway for receptors at Hydro Marsh is through airborne deposition of tritium from atmospheric emissions from PNGS. Sampling of water at Hydro Marsh could be performed to confirm that effects from tritium deposition in the marsh are minor. This would be considered a supplementary one-time study and would only be part of the monitoring program until the objective is achieved.

5.3 Risk Management Recommendations

No risk management recommendations are made at this time.

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Appendix A Screening Tables Used for the HHRA and EcoRA

Table A.1: Non-Radiological Screening of Air COPCs for Human Health

Contaminant	CAS No.	Aggregate Emission Rate (g/s)									Max 1/2 Hour POI Concentration (ug/m^3)[a]	1/2 hour Limit (ug/m^3)	Limiting Effect	Regulation Schedule No.	% of Limit	Annual Concentration (ug/m^3)	Derived Annual Criteria (ug/m^3)	Reference for Derived Annual Criteria	Carried Forward as COPC?
		2007	2008	2009-1	2009-2	2010-1	2010-2	2011-1	2011-2	Max (g/s)									
2-(2-aminoethoxy) ethanol	929-06-6	5.50E-02	ND	ND	ND	5.50E-02	5.50E-02	5.50E-02	5.50E-02	5.50E-02	0.549	5.56E-01		Previously approved limit	98.68	0.036	38	TCEQ, 2013	No
Acetic Acid	64-19-7	ND	ND	ND	ND	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.33E-01	3.322	25000	Odour	Schedule 2	0.01	N/A	N/A	N/A	No
Acetone	67-64-1	ND	ND	ND	ND	3.36E-02	3.36E-02	3.36E-02	3.36E-02	3.36E-02	0.335	3.56E+04	Health	Schedule 2	0.00	N/A	N/A	N/A	No
Ammonia	7664-41-7	6.80E+01	6.80E+01	2.12E+01	2.12E+01	2.12E+01	2.12E+01	2.12E+01	2.12E+01	6.80E+01	678.334	300	Health	Schedule 2	226.11	N/A	N/A	N/A	No (based on rationale in Section 3.1.2 of ERA Report
Ammonium Hydroxide	1336-21-6	ND	ND	ND	ND	2.14E-03	2.14E-03	2.14E-03	2.14E-03	2.14E-03	0.021	3.00E+02		JSL	0.01	N/A	N/A	N/A	No
Amyl Alcohol	71-41-0	ND	ND	ND	ND	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	0.001	1.11E-03		Previously approved limit in CofA	96.16	6.92E-05	73	TCEQ, 2013	No
Butyl acetate, n	123-86-4	1.43E+00	1.43E+00	1.43E+00	1.43E+00	ND	ND	ND	ND	1.43E+00	14.265	735	Health	POI	1.94	N/A	N/A	N/A	No
Carbon monoxide	630-08-0	2.75E+01	2.70E+01	1.49E+01	2.58E+01	1.48E+01	2.47E+01	1.48E+01	2.47E+01	2.75E+01	274.326	6000	Health	Schedule 2	4.57	N/A	N/A	N/A	No
Deuterium	7782-39-0	ND	ND	ND	ND	3.17E-07	3.17E-07	3.17E-07	3.17E-07	3.17E-07	3.16E-06	3.00E-01		De minimus	0.00	N/A	N/A	N/A	No
Ethanolamine	141-43-5	1.10E+00	ND	ND	ND	1.10E+00	1.10E+00	1.10E+00	1.10E+00	1.10E+00	10.973	1.11E+01		Previously approved limit in CofA	98.86	0.711	7.50	TCEQ, 2013	No
Ethylene	74-85-1	9.53E-02	9.53E-02	9.53E-02	9.53E-02	9.53E-02	9.53E-02	9.53E-02	9.53E-02	9.53E-02	0.951	0.96		Previously approved limit in CofA	99.03	0.062	34	TCEQ, 2013	No
Ethylene glycol butyl ether	111-76-2	5.50E-01	5.50E-01	5.50E-01	5.50E-01	ND	ND	ND	ND	5.50E-01	5.487	350	Odour	POI	1.57	N/A	N/A	N/A	No
Formic Acid	64-18-6	ND	ND	ND	ND	2.40E-01	2.40E-01	2.40E-01	2.40E-01	2.40E-01	2.394	1.50E+03	Health	Schedule 2	0.16	N/A	N/A	N/A	No
Fuel Oil No. 2	68476-30-2	ND	ND	ND	ND	2.80E-01	2.80E-01	2.80E-01	2.80E-01	2.80E-01	2.793	1.20E+03		JSL	0.23	N/A	N/A	N/A	No
Glycolic Acid	79-14-1	ND	ND	ND	ND	8.90E-03	8.90E-03	8.90E-03	8.90E-03	8.90E-03	0.089	0.171		Previously approved limit in CofA	51.92	0.006	2	TCEQ, 2013	No
Hexamethylene diiso-cyanate (HDI) monomer	822-06-0	1.34E-03	1.34E-03	1.34E-03	1.34E-03	ND	ND	ND	ND	1.34E-03	0.013	0.1	Health	Schedule 2	13.37	N/A	N/A	N/A	No
Hexane	110-54-3	ND	7.01E-03	ND	ND	7.01E-03	7.01E-03	7.01E-03	7.01E-03	7.01E-03	0.070	2.25E+04	Health	Schedule 2	0.00	N/A	N/A	N/A	No
Hydrazine	302-01-2	7.70E-02	9.70E-02	9.70E-02	9.70E-02	7.70E-02	7.70E-02	7.70E-02	7.70E-02	9.70E-02	0.968	9.72E-01		Previously approved limit in CofA	99.55	0.063	0.01	TCEQ, 2013	**Yes**
Hydrogen Chloride	7647-01-0	ND	ND	ND	ND	2.14E-02	2.14E-02	2.14E-02	2.14E-02	2.14E-02	0.213	60	Health	Schedule 2	0.36	N/A	N/A	N/A	No
Hydroquinone	123-31-9	ND	ND	ND	ND	8.90E-03	8.90E-03	8.90E-03	8.90E-03	8.90E-03	0.089	8.99E-02		Previously approved limit in CofA	98.76	0.006	1	TCEQ, 2013	No
Isobutyl acetate	110-19-0	1.76E+00	1.76E+00	1.76E+00	1.76E+00	ND	ND	ND	ND	1.76E+00	17.557	1200	Odour	POI	1.46	N/A	N/A	N/A	No
Isopropyl Alcohol	67-63-0	ND	ND	ND	ND	2.14E-03	2.14E-03	2.14E-03	2.14E-03	2.14E-03	0.021	2.20E+04	Health	Schedule 2	0.00	N/A	N/A	N/A	No
Methane	74-82-8	ND	ND	ND	ND	1.61E-03	1.61E-03	1.61E-03	1.61E-03	1.61E-03	0.016	3.00E-01		De minimus	5.35	N/A	N/A	N/A	No
Methanol	67-56-1	ND	ND	ND	ND	6.73E-02	6.73E-02	6.73E-02	6.73E-02	6.73E-02	0.671	1.20E+04	Health	Schedule 2	0.01	N/A	N/A	N/A	No
Methyl Ethyl Ketone	78-93-3	ND	ND	4.40E+00	4.40E+00	ND	ND	ND	ND	4.40E+00	43.892	3000	Health	Schedule 2	1.46	N/A	N/A	N/A	No
Methyl isobutyl ketone	108-10-1	5.50E-01	ND	ND	ND	ND	ND	ND	ND	5.50E-01	5.487	1200		Schedule 2	0.46	N/A	N/A	N/A	No
Methylamine	74-89-5	1.40E-01	1.40E-01	1.40E-01	1.40E-01	1.40E-01	1.40E-01	1.40E-01	1.40E-01	1.40E-01	1.397	25	Odour	Schedule 2	5.59	N/A	N/A	N/A	No
Methylene Chloride	75-09-2	ND	ND	ND	ND	2.25E-01	2.25E-01	2.25E-01	2.25E-01	2.25E-01	2.244	6.60E+02	Health	Schedule 2	0.34	N/A	N/A	N/A	No
Mineral Spirits	N/A	ND	ND	4.68E+00	4.68E+00	2.14E-03	2.14E-03	2.14E-03	2.14E-03	4.68E+00	46.685	3000	Odour	Schedule 2	1.56	N/A	N/A	N/A	No
Morpholine	110-91-8	3.00E+01	3.00E+01	3.00E+01	3.00E+01	3.00E+01	3.00E+01	3.00E+01	3.00E+01	3.00E+01	299.265	48		JSL	623.47	N/A	N/A	N/A	No
Nitric Acid	7697-37-2	ND	ND	ND	ND	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	0.107	100	Corrosion	Schedule 2	0.11	N/A	N/A	N/A	No
Nitrogen oxides	10102-44-0	9.74E+01	9.74E+01	5.44E+01	9.13E+01	5.29E+01	8.53E+01	5.29E+01	8.53E+01	9.74E+01	482.000	500	Health	Schedule 2	96.40	N/A	N/A	N/A	No
Particulate matter	N/A	4.09E+01	4.09E+01	9.68E-01	4.08E+01	9.54E-01	4.04E+01	9.54E-01	4.04E+01	4.09E+01	25.400	100	Visibility	Schedule 2	25.40	N/A	N/A	N/A	No
Phosphoric Acid (as P2O5)	7664-38-2	ND	ND	ND	ND	2.14E-03	2.14E-03	2.14E-03	2.14E-03	2.14E-03	0.021	100	Particulate	Schedule 2 (2013)	0.02	N/A	N/A	N/A	No
Polyethylene glycol ether	84133-50-6	8.65E-01	8.65E-01	8.65E-01	8.65E-01	8.65E-01	8.65E-01	8.65E-01	8.65E-01	8.65E-01	8.629	8.69		Previously approved limit in CofA	99.30	0.559	100	TCEQ, 2013	No
Sodium hypochlorite	7681-52-9	1.19E+00	1.19E+00	1.19E+00	1.19E+00	1.19E+00	1.19E+00	1.19E+00	1.19E+00	1.19E+00	11.871	12.1		Previously approved limit in CofA	98.11	0.770	5	TCEQ, 2013	No
Sulphur dioxide	7446-09-5	4.37E+01	4.35E+01	3.36E+01	4.26E+01	3.34E+01	4.21E+01	3.34E+01	4.21E+01	4.37E+01	435.929	830	Health	Schedule 2	52.52	N/A	N/A	N/A	No
Sulphur Hexafluoride	2551-62-4	ND	ND	ND	ND	3.46E-03	3.46E-03	3.46E-03	3.46E-03	3.46E-03	0.035	1.80E+06	Health	POI	0.00	N/A	N/A	N/A	No
Sulphuric Acid	7664-93-9	ND	8.55E-03	8.55E-03	8.55E-03	8.55E-03	8.55E-03	8.55E-03	8.55E-03	8.55E-03	0.085	15	Health	Schedule 2 (2013)	0.57	N/A	N/A	N/A	No
Toluene	108-88-3	3.30E+00	3.30E+00	3.30E+00	3.30E+00	6.41E-05	6.41E-05	6.41E-05	6.41E-05	3.30E+00	32.919	2.00E+03	Odour	Schedule 2	1.65	N/A	N/A	N/A	No
Toluene diisocyanate	584-84-9	1.65E-02	1.65E-02	1.65E-02	1.65E-02	ND	ND	ND	ND	1.65E-02	0.165	0.6	Health	Schedule 2	27.43	N/A	N/A	N/A	No
Total hydrocarbons	N/A	5.48E+00	5.48E+00	2.96E-01	5.20E+00	2.73E-01	5.18E+00	2.73E-01	5.18E+00	5.48E+00	9.360	9.03		Previously approved limit in CofA	103.65	0.607	5	TCEQ, 2013 (hydrocarbon resin)	No
Trimethylbenzene, 1,2,4-	95-63-6	3.06E+00	3.06E+00	3.06E+00	3.06E+00	2.95E+00	2.95E+00	2.95E+00	2.95E+00	3.06E+00	30.525	660	Odour	Schedule 2 (2013)	4.63	N/A	N/A	N/A	No
Trimethylbenzene, 1,3,5-	108-67-8	ND	1.10E-01	1.10E-01	1.10E-01	ND	ND	ND	ND	1.10E-01	1.097	6600	Upper Risk Threshold	Schedule 5	0.02	N/A	N/A	N/A	No
Xylenes	1330-20-7	3.30E+00	3.30E+00	3.30E+00	3.30E+00	2.14E-04	2.14E-04	2.14E-04	2.14E-04	3.30E+00	32.919	2200	Health	Schedule 2	1.50	N/A	N/A	N/A	No

Notes:
ND = No Data, N/A = Not Applicable

[a.] Concentration estimated based dispersion factor at property line of 9.9755 µg/m^3 (Golder, 2011).

Table A.2: Human Health Screening of Non-Radiological Final Station Effluent from Condenser Cooling Water

Parameters	Unit	PWQO	Canadian DWQG (HC, 2012)	CofA Limit	Selected Benchmark	PA					PB					Max Conc.	Carried forward as COPC?
						Annual Range (2007)	Annual Range (2008)	Annual Range (2009)	Annual Range (2010)	Annual Range (2011)	Annual Range (2007)	Annual Range (2008)	Annual Range (2009)	Annual Range (2010)	Annual Range (2011)		
Unionized Ammonia	mg/L	0.02	None required	0.02	0.02	<0.01- 0.014	<0.01	<0.01- 0.02	<0.01- 0.01	<0.001- 0.011	<0.01- 0.01	<0.01-0.015	<0.01- 0.013	<0.01- 0.02	<0.01- 0.02	0.02	No
Hydrazine	mg/L	-	-	0.1	-	<0.003 - 0.012	0.003-0.0175	<0.003 - 0.037	<0.003 - 0.067	<0.002 - 0.006	<0.003 - 0.009	0.003-0.0183	<0.003 - 0.08	<0.003 - 0.048	<0.002 - 0.005	0.08	Yes
Morpholine	mg/L	0.004[a]	-	0.02	0.004[a]	0.001 - 0.0016	<0.001-0.003	0.001 - 0.002	0.001 - 0.003	0.001 - 0.004	0.001 - 0.003	<0.001-0.007	0.001 - 0.004	0.001 - 0.012	0.001 - 0.168[c]	0.012	Yes
pH	pH units	6.5 - 8.5	6.5 - 8.5	6.0 - 9.5	6.5 - 8.5	7.7 - 8.7	7.7 - 8.3	7.7 - 8.7	7.8 - 8.3	7.9 - 8.3	7.7 - 8.5	8 - 8.5	8 - 8.4	7.8 - 8.3	7.9 - 8.4	8.7	No
TRC	mg/L	0.002	0.04-2.0[b]	0.01	0.04-2.0[b]	<0.001 - 0.03	<0.006-0.01	<0.008 - 0.01	<0.001 - 0.01	<0.001 - 0.016	<0.001 - 0.0036	<0.006	<0.008 - 0.009	<0.001 - 0.004	<0.001 - 0.004	0.03	No

Notes:

[a] Interim PWQO is conservatively derived based on limited information; no scientific criteria document.

[b] No limit set, but at these concentrations, taste and odour related to chlorine or its by-products are generally within the range of acceptability for most consumers, according to Health Canada.

[c] This elevated number was retracted since it was determined through a third-party review that the elevated concentrations were suspect and due to mislabeling or sample contamination during analysis

Table A.3: Non-Radiological Screening of Lake Water COPCs for Human Health

Parameter	Units	PWQO	Interim PWQO	Canadian Drinking Water Quality Guidelines (HC, 2012)[3]	MOE GW1 Component Value (MOE, 2011)[4]	95th Percentile DWSP Background (MOE, 2013)	Background Lake Ontario (OPG, 2009)	Selected Benchmark	Max Observed 2006 Lake Water (Golder, 2007c,e)	Carried Forward as COPC?	Notes
Alkalinity (as CaCO3)	ppm	Variable				98.065	97.5	98.065	92.6	No	
Ammonia (Total)	ppm					0.0664	0.03	-	0.117	-	
Ammonia (unionized)	ppm	0.02					0.002	0.02	0.0192	No	
BOD	ppm							-	8.1	-	
COD	ppm					2.2	6	-	13	-	
Conductivity (Specific)	mS/m						30	-	30.1	-	
Conductivity (Specific, In-situ)	mS/m							-	35.5	-	
Hardness (as CaCO3)	ppm			None required		126.75	145	-	133	-	
Oil and Grease	ppm	Narrative						-	<1	-	
pH	pH Units	6.5-8.5					8.8	6.5-8.5	8.5	No	
pH (in-situ)	pH Units	6.5-8.5					8.5	6.5-8.5	8.5	No	
Temperature (in situ)	C						21.5	-	31.4	-	
TDS	ppm			<500	500		185	<500	515	No	Aesthetic objective exceeded
TRC (in situ)	ppm	0.002		0.04- 2.0[5]			0.001	0.04- 2.0[5]	0.005	No	
TOC	ppm						2.6	-	6.2	-	
TSS	ppm						4.4	4.4	3.7	No	
Turbidity	NTU			5			1.6	5	1.85	No	
Hydrazine	ppm						0.0025	0.0025	<0.005	**Yes**	
Morpholine	ppm		0.004				0.0005	0.004	0.0044	**Yes**	
Tritium	Bq/L	7000						7000	203.5	No	
Aluminum	ppm	0.075		0.1		0.1655	0.45	0.1	0.029	No	
Aluminum (filtered)	ppm		0.075				0.013	0.075	0.029	No	
Antimony	ppm		0.02	0.006	0.006	0.000882	0.0005	0.006	<0.001	No	
Arsenic	ppm	0.1	0.005	0.01	0.025	0.0012	0.001	0.01	<0.001	No	
Barium	ppm			1	1	0.02608	0.03	1	0.027	No	
Beryllium	ppm	1.1			0.004	0.00001	0.0005	0.004	<0.001	No	
Bismuth	ppm						0.0005	0.0005	<0.001	No	Not carried forward because all values are non-detect, but DL > limit
Boron	ppm		0.2 [(1)]	5	5	0.028225	0.07	5	0.032	No	
Cadmium	ppm	0.0002	0.0005	0.005	0.005	0.00003	0.00005	0.005	0.0009	No	
Calcium	ppm					35.75	41.5	35.75	36.9	No	Exceeds background by <20% (Suter et al., 1995; Suter, 1996)
Cesium	ppm						0.00005	0.00005	<0.0001	No	Not carried forward because all values are non-detect, but DL > limit
Chromium	ppm	0.0089			0.05	0.0021	0.002	0.05	0.0034	No	
Chromium (hexavalent)	ppm	0.001		0.05	0.025		0.0025	0.025	<0.01	No	
Cobalt	ppm	0.0009			0.003	0.000164	0.0002	0.003	<0.0001	No	Not carried forward because all values are non-detect, but DL > limit
Copper	ppm	0.005	0.005	1	1	0.08095	0.0013	1	0.0054	No	
Iron	ppm	0.3		0.3	0.3	0.14525	0.04	0.3	0.111	No	
Lead	ppm	0.025	0.005	0.01	0.01	0.000635	0.0005	0.01	0.001	No	
Lithium	ppm						0.004	0.004	0.003	No	
Magnesium	ppm					9.1625	10	9.1625 10.9		No	Exceeds background by <20% (Suter et al., 1995; Suter, 1996)
Manganese	ppm	1[(2)]		0.05	0.05	0.0122	0.0024	0.05	0.0062	No	
Mercury (filtered)	ppm	0.0002		0.001	0.001		0.00005	0.001	<0.0001	No	
Molybdenum	ppm		0.04		0.07	0.0014625	0.0014	0.07	0.0015	No	
Nickel	ppm	0.025			0.1	0.00165	0.0009	0.1	<0.0001	No	
Phosphorus	ppm		0.02			0.0298	0.0084	0.02	0.021	No	Not a human health concern
Potassium	ppm					1.8	1.9	1.8	1.86	No	Exceeds background by <20% (Suter et al., 1995; Suter, 1996)
Selenium	ppm	0.1		0.01	0.01	0.001	0.0005	0.01	<0.001	No	
Silver	ppm	0.0001		none required	0.1	0.00002	0.00005	0.1	<0.0001	No	
Sodium	ppm			≤200	20	21.3	17	≤200	15.8	No	
Strontium	ppm					0.193	0.21	0.193	0.21	No	Exceeds background by <20% (Suter et al., 1995; Suter, 1996)
Thallium	ppm		0.0003		0.002	0.0000425	0.00005	0.002	<0.0001	No	
Thorium	ppm						0.00005	0.00005	<0.0001	No	Not carried forward because all values are non-detect, but DL > limit
Tin	ppm						0.00005	0.00005	<0.0001	No	Not carried forward because all values are non-detect, but DL > limit
Titanium	ppm					0.003275	0.0016	0.003275	<0.0001	No	
Tungsten	ppm		0.03				0.00015	0.03	<0.0001	No	
Uranium	ppm		0.005 [(1)]	0.02	0.02	0.0004	0.0005	0.02	0.0004	No	
Vanadium	ppm		0.006		0.0062	0.00077	0.0007	0.0062	<0.0001	No	
Zinc	ppm	0.03	0.02	≤5	5	0.00835	0.0047	≤5	0.0125	No	
Zirconium	ppm		0.004				0.00005	0.004	0.0121	No	One value exceeds interim PWQO, but duplicate and all other values are <0.0001mg/L. This value is suspect.

[1] Interim PWQO was set based on readily available information and was not peer reviewed; the CCME guideline is used in preference.

[2] BC MOE (2001) for hardness of 100 mg/L (Ambient Water Quality Guidelines for Manganese. Overview Report. British Columbia Ministry of the Environment

[3] Health Canada (HC). 2012. Guidelines for Canadian Drinking Water Quality- Summary Table. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

[4] Ontario Ministry of the Environment (MOE). 2011. Rationale for the Development of Soil and Ground Water Standards for Use at Contaminated Sites in Ontario. Standards Development Branch. April.

[5] No limit set, but at these concentrations, taste and odour related to chlorine or its by-products are generally within the range of acceptability for most consumers, according to Health Canada.

Table A.4: Non-Radiological Screening of Stormwater COPCs for Human and Ecological Health - PNGS A

		Catchment 1												Catchment 2								Max Conc. at Discharge	Final Conc. In CCW	PWQO	Interim PWQO	CCME Protection of Aquatic Life	95th Percentile DWSP Background (MOE, 2013)	Selected Benchmark	Carried Forward in Risk Assessment?
	Station ID	MH37 (2002)				MH 149 (2006)[formerly MH37]				O1 (2002)				MH137 (2002)				MH132A (2006) formerly MH137											
	Units	Q1	Q2	Q3	Q4	Sep-02	Oct-17	Oct-27	Nov-16	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Sep-02	Oct-17	Oct-27	Nov-16								
Radionuclides																													
Co-60	Bq/L	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	< 1.2	<1.00E-04						No
Cs-137	Bq/L	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	< 1.2	<1.00E-04	50				50	No
Cs-134	Bq/L	<1	<1.1	<1.1	<1.2	<0.37	<1.11	<0.74	<0.555	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	< 1.2	<1.00E-04						No
H3	Bq/L	1998	233.1	814	192.4	255	648	407	244	555	118.4	925	273.8	148	210.9	74	555	85	74	74	233	1998	0.1665	7000				7000	No
C-14	Bq/L	<0.111	<0.111	<0.111	<0.111	0.005	<0.111	<0.003	<0.111	<0.111	<0.111	<0.111	<0.111	<0.111	0.148	<0.111	<0.111	<0.003	<0.111	<0.003	<0.111	0.148	1.233E-05						No
Organic Compounds																													
PCB	ppb	<0.1	<0.1	0.1	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.05	<0.05	<0.05	<0.05	0.1	8.333E-06	0.001				0.001	No
C5-C10	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	< 0.1	<8.33E-06	0.75 [3]				0.75 (3)	No
C10-C24	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	< 0.1	<8.33E-06	0.15 [3]				0.15 (3)	No
C24-C50	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	8.333E-06	0.5 [3]				0.5 (3)	No
Oil in Water	ppm	<1.0	1.4	N/A	<1	<1	<1	<1	2	<1.0	<1.0	N/A	1	<1.0	<1.0	N/A	1	<1	<1	<1	<1	2	0.0001667						-
General																													
Alkalinity (as CaCO3)	N/A	N/A	N/A	N/A	N/A	93.8	81.7	71	75.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	91.5	92.8	103	94.3	103	0.0085833	Variable			98.065	98.065	No
Nitrate (as N)	N/A	N/A	N/A	N/A	N/A	2.86	2.55	2.24	2.08	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.63	2.3	2.72	2.66	2.86	0.0002383			2.93		2.93	No
Nitrite (as N)	N/A	N/A	N/A	N/A	N/A	<0.01	0.041	<0.01	<0.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.01	<0.01	<0.01	<0.01	0.041	3.417E-06			0.06		0.06	No
Toxicity	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A								-
Hardness	mg CaCO3/L	N/A	N/A	N/A	N/A	152	113	94.8	108	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	126	120	133	114	152	0.0126667				126.75	126.75	No
TSS	ppm	2	7	14.09	6	41.5	26.5	18.5	34.9	<2.0	6	38.32	23	<2.0	2	0.8	5	42	3.22	133	7.62	133	0.0110833				4.4 [4]	4.4 [4]	No
Phosphorous	ppm	0.015	0.093	0.032	0.09	0.0862	0.046	0.0286	0.0839	0.023	0.107	0.055	0.22	0.04	0.013	0.01	0.17	0.0558	0.0102	0.021	0.0196	0.22	1.833E-05	0.02				0.02	No
pH		7.94	8.01	7.78	6.75	7.64	7.83	7.48	7.59	7.99	7.79	7.74	6.96	7.83	8	7.84	7.04	8.09	8.14	7.59	7.57	8.14		6.5-8.5				6.5-8.5	No
Conductivity	mS/m	245	60	73.8	43	80.1	28.1	555	31.8	291	67	78	66.7	36	30.2	31.2	42.5	21.3	28.4	328	29.9	555	0.04625					-	-
Metals																													
Aluminum	ppm	<0.01	0.459	0.142	0.109	0.259	0.234	0.169	0.532	<0.01	0.449	0.135	0.071	<0.01	0.026	<0.01	0.845	0.197	0.0147	0.0739	0.0169	0.845	7.042E-05			0.1		0.1	No
Antimony	ppm	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	< 0.005	<4.17E-07		0.02			0.02	No
Arsenic	ppm	<0.005	<0.005	<0.005	<0.005	<.0001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<.0001	<0.001	<0.001	<0.001	< 0.005	<4.17E-07	0.1	0.005	0.005		0.005	No
Barium	ppm	0.069	0.016	0.026	0.027	0.0285	0.0221	0.019	0.022	0.075	0.012	0.026	0.02	0.022	0.021	0.02	0.027	0.026	0.0228	0.0259	0.021	0.075	6.25E-06				0.026	0.02608	No
Beryllium	ppm	<0.002	<0.002	<0.002	<0.002	<0.0001	<0.001	<0.001	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.0001	<0.001	<0.001	<0.001	< 0.002	<1.67E-07	1.1				1.1	No
Boron	ppm	<0.025	<0.025	<0.025	0.028	0.0233	0.0146	0.00627	0.00944	<0.025	0.026	0.028	<0.025	<0.025	0.03	<0.025	<0.025	0.0283	0.0225	0.0256	0.023	0.03	0.0000025		0.2 [1]	1.5			1.5	No
Cadmium	ppm	<0.001	<0.002	<0.002	<0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.002	<0.002	<0.002	<0.001	<0.002	<0.002	<0.002	<0.0001	<0.0001	<0.0001	<0.0001	< 0.002	<1.67E-07	0.0002	0.0005	0.000033		0.000033	No
Chromium	ppm	<0.001	<0.01	<0.01	<0.01	0.00613	0.00473	0.00296	0.0033	<0.001	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.01	0.00144	0.00116	0.000619	0.00096	0.00613	5.108E-07	0.0089		0.0089		0.0089	No
Cobalt	ppm	<0.002	<0.01	<0.01	<0.01	0.000449	0.00034	0.000276	0.00064	<0.002	<0.1	<0.01	<0.01	<0.002	<0.01	<0.01	<0.01	0.000287	0.00015	0.00017	0.00016	0.000639	5.325E-08	0.0009				0.0009	No
Copper	ppm	0.005	<0.01	<0.01	<0.01	0.00836	0.00334	0.00252	0.00397	<0.005	<0.01	<0.01	0.011	0.005	<0.01	<0.01	<0.01	0.00204	0.00123	0.00154	0.00211	0.011	9.167E-07	0.005	0.005	0.002		0.002	No
Iron	ppm	0.152	0.574	0.358	0.581	0.543	0.403	0.26	0.52	0.089	0.686	0.44	1.618	0.094	0.165	0.145	0.755	0.374	0.0247	0.121	0.0312	1.618	0.0001348	0.3		0.3		0.3	No
Lead	ppm	<0.005	<0.01	N/A	<0.01	0.00404	0.00381	0.00321	0.00886	<0.005	<0.01	<0.01	<0.01	<0.005	<0.01	N/A	<0.01	0.000622	0.00013	0.000245	0.00098	0.00886	7.383E-07	0.025	0.005	0.001-0.007		0.001-0.007	No
Manganese	ppm	0.046	0.039	0.023	<0.01	0.0618	0.0253	0.0238	0.0879	0.047	0.058	0.168	0.081	0.002	<0.01	<0.01	0.065	0.0266	0.00135	0.00775	0.00302	0.168	0.000014	1 [2]				1(2)	No
Molybdenum	ppm	<0.002	<0.01	<0.01	<0.01	0.0011	0.00073	0.000518	0.00028	<0.002	<0.01	<0.01	<0.01	<0.002	<0.01	<0.01	<0.01	0.00126	0.00129	0.00128	0.00116	0.00129	1.075E-07		0.04	0.073			0.04	No
Nickel	ppm	<0.002	<0.01	<0.01	<0.01	<0.0001	0.00184	0.00151	0.00259	<0.002	<0.01	<0.01	<0.01	0.003	<0.01	<0.01	<0.01	<0.0001	0.00153	0.00207	0.00195	0.003	2.5E-07	0.025		0.025-0.15		0.025	No
Selenium	ppm	<0.005	<0.005	<0.005	<0.005	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0001	<0.001	<0.001	<0.001	< 0.005	<4.17E-07	0.1		0.001		0.001	No
Silver	ppm	<0.0001	<0.001	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.01	0.0001	0.0001	<0.0001	<0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	8.333E-09	0.0001		0.0001		0.0001	No
Sodium	ppm	313	52	78.334	26.4	0.174	91.2	68.7	33.9	350	60	105.34	96.8	26	12.2	10.388	174	13.9	12.8	15.2	13.9	350	0.0291667				21.3	21.3	No
Thallium	ppm	<0.002	<0.01	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.002	<0.01	0.0001	0.0001	<0.002	<0.01	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	8.333E-09		0.0003	0.0008		0.0008	No
Uranium	ppm	0.0009	<0.2	<0.02	0.0004	0.000288	0.00026	0.000241	0.00018	0.0014	<0.2	<0.02	0.0002	0.0004	<0.2	<0.02	0.0002	0.00038	0.00035	0.000402	0.00035	0.0014	1.167E-07		0.005 [1]	0.015		0.005 (1)	No
Vanadium	ppm	<0.001	<0.02	0.046	<0.02	0.00265	0.00178	0.00139	0.00206	<0.001	<0.02	0.027	<0.02	0.003	<0.02	<0.005	<0.02	0.00107	0.0007	0.000577	0.00053	0.046	3.833E-06		0.006			0.006	No
Zinc	ppm	0.059	0.049	N/A	0.005	0.0926	0.0363	0.0329	0.0655	0.035	0.038	N/A	0.009	0.032	<0.005	N/A	0.145	0.00494	0.00196	0.00274	0.0124	0.145	1.208E-05	0.03	0.02	0.03		0.02	No
Zirconium	ppm	<0.002	<0.01	0.0002	N/A	0.000149	0.00019	0.000157	0.00016	<0.002	<0.01	0.0002	N/A	<0.002	<0.01	0.0003	N/A	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	2.5E-08		0.004			0.004	No
Mercury (filtered)	ppm	N/A	N/A	N/A	N/A	<0.0001	<0.0001	<0.0001	<0.0001	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0001	<8.33E-09	0.0002		0.000026		0.000026	No

[1] Interim PWQO was set based on readily available information and was not peer reviewed; the CCME guideline is used in preference.

[2] BC MOE (2001) for hardness of 100 mg/L (Ambient Water Quality Guidelines for Manganese. Overview Report. British Columbia Ministry of the Environment

[3] MOE (2011) Table 3 for non-potable groundwater

[4] Background Lake Ontario (OPG, 2009)

Table A.5: Non-Radiological Screening of Stormwater COPCs for Human and Ecological Health - PNGS B

	Station ID	Catchment 6				Catchment 8								Max Conc. at Discharge		Final Conc. In CCW	PWQO	Interim PWQO	CCME Protection of Aquatic Life	95th Percentile DWSP Background (MOE, 2013)	Selected Benchmark	Carried Forward in Risk Assessment?
		MH15 (2002)				M3-3 (2002)				M3-3 (2006)												
	Units	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Sep-02	Oct-17	Oct-27	Nov-16									
Radionuclides																						
Co-60	Bq/L	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	<	1.2	<3.10E-05						No
Cs-137	Bq/L	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	<	1.2	<3.10E-05	50				50	No
Cs-134	Bq/L	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<0.37	<0.37	<0.74	<0.555	<	1.2	<3.10E-05						No
H3	Bq/L	6660	2072	10175	2427.2	148	18.5	185	173.9	100	292	85	133		10175	2.63E-01	7000				7000	No
C-14	Bq/L	<0.111	<0.111	<0.111	0.148	<0.111	<0.111	0.185	<0.111	<0.003	<0.111	<0.003	<0.111		0.185	4.78E-06						No
Organic Compounds																						
PCB	ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.05	<0.05	<0.05	<0.05		0.1	2.59E-06	0.001				0.001	No
C5-C10	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<	0.1	<3.00E-06	0.75 [3]				0.75 (3)	No
C10-C24	ppm	<0.1	<0,	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<	0.1	<3.00E-06	0.15 [3]				0.15 (3)	No
C24-C50	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1		0.1	2.59E-06	0.5 [3]				0.5 (3)	No
Oil in Water	ppm	<1.0	<1.0	N/A	3	1.6	<1.0	N/A	4	<1	<1	<1	<1		4	1.03E-04						-
General																						
Alkalinity (as CaCO3)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	71	119.5	56	61.5		119.5	3.09E-03	Variable			98.065	98.065	No
Nitrate (as N)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.34	2.57	2.56	2.78		2.78	7.19E-05			2.93		2.93	No
Nitrite (as N)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.01	0.059	<0.01	0.036		0.059	1.53E-06			0.06		0.06	No
Toxicity	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A						-
Hardness	mg CaCO3/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	142	114	65.4	85		142	3.67E-03				126.75	126.75	No
TSS	ppm	9	74	11	21	42	34	103.61	52	15.8	27.5	65.4	36.3		103.61	2.68E-03				4.4 [4]	4.4 [4]	No
Phosphorous	ppm	0.033	0.288	0.086	0.21	0.087	0.057	0.023	0.14	0.05	0.027	0.0258	0.0391		0.288	7.45E-06	0.02				0.02	No
pH		8	8.04	7.89	7.34	7.64	8.28	7.82	7.08	7.63	7.81	7.58	7.54		8.28		6.5-8.5				6.5-8.5	No
Conductivity	mS/m	98	23.2	4.5	74.5	207	15.1	144	343	164	221	582	62.2		582	1.51E-02					-	-
Metals																						
Aluminum	ppm	0.06	1.718	0.13	0.44	0.59	0.356	0.282	0.551	0.167	0.139	0.147	0.232		1.718	4.44E-05			0.1		0.1	No
Antimony	ppm	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<	0.005	<1.29E-07		0.02			0.02	No
Arsenic	ppm	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0001	0.00206	0.00121	0.00102		0.00206	5.33E-08	0.1	0.005	0.005		0.005	No
Barium	ppm	0.049	0.04	0.01	0.019	0.035	0.028	0.014	0.046	0.0321	0.035	0.0136	0.0152		0.049	1.27E-06				0.026	0.02608	No
Beryllium	ppm	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.0001	<0.001	<0.001	<0.001	<	0.002	<5.17E-08	1.1				1.1	No
Boron	ppm	0.06	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.0172	0.00325	0.00477	0.0123		0.06	1.55E-06		0.2 [1]	1.5		1.5	No
Cadmium	ppm	<0.001	<0.002	<0.002	<0.002	<0.001	<0.002	<0.002	<0.002	<0.0001	<0.0001	<0.0001	<0.0001	<	0.002	<5.17E-08	0.0002	0.0005	0.000033		0.000033	No
Chromium	ppm	<0.001	<0.01	<0.01	<0.01	0.005	<0.01	<0.01	<0.01	0.012	0.0125	0.00414	0.00574		0.0125	3.23E-07	0.0089		0.0089		0.0089	No
Cobalt	ppm	<0.002	<0.01	<0.01	<0.01	<0.002	<0.01	<0.01	<0.01	0.00026	0.00028	0.000225	0.000312		0.000312	8.07E-09	0.0009				0.0009	No
Copper	ppm	<0.005	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.013	0.00476	0.00368	0.00304	0.00387		0.013	3.36E-07	0.005	0.005	0.002		0.002	No
Iron	ppm	0.148	3.125	0.204	0.388	1	0.622	0.436	0.712	0.249	0.213	0.194	0.225		3.125	8.08E-05	0.3		0.3		0.3	No
Lead	ppm	<0.005	<0.01	N/A	<0.01	0.007	0.01	<0.01	0.014	0.0027	0.00343	0.00287	0.00638		0.014	3.62E-07	0.025	0.005	0.001-0.007		0.001-0.007	No
Manganese	ppm	0.008	0.095	0.017	0.035	0.134	0.047	0.032	0.097	0.041	0.0311	0.0198	0.033		0.134	3.47E-06	1 [2]				1(2)	No
Molybdenum	ppm	<0.002	<0.01	<0.01	<0.01	<0.002	<0.01	<0.01	<0.01	0.00082	0.00084	0.000463	0.000913		0.000913	2.36E-08		0.04	0.073		0.04	No
Nickel	ppm	<0.002	<0.01	<0.01	<0.01	0.003	0.01	<0.01	<0.01	<0.0001	0.00172	0.0013	0.00177		0.01	2.59E-07	0.025		0.025-0.15		0.025	No
Selenium	ppm	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0001	<0.001	<0.001	<0.001	<	0.005	<1.29E-07	0.1		0.001		0.001	No
Silver	ppm	<0.0001	<0.0001	0.0001	0.0001	<0.0001	<0.01	0.0001	0.0001	0.00042	<0.0001	<0.0001	<0.0001		0.000417	1.08E-08	0.0001		0.0001		0.0001	No
Sodium	ppm	84	17.8	9.07	116	318	15.3	59.032	635	0.422	313	136	88.8		635	1.64E-02				21.3	21.3	No
Thallium	ppm	<0.002	<0.01	0.0001	0.0001	<0.002	<0.01	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001		0.0001	2.59E-09		0.0003	0.0008		0.0008	No
Uranium	ppm	0.0005	<0.2	<0.02	0.0001	0.0003	<0.2	<0.02	0.0002	0.00018	0.00028	0.000146	0.000171		0.0005	1.29E-08		0.005 [1]	0.015		0.005 (1)	No
Vanadium	ppm	0.003	<0.02	0.097	<0.02	0.004	<0.02	0.034	<0.02	0.00501	0.00455	0.00197	0.00237		0.097	2.51E-06		0.006			0.006	No
Zinc	ppm	0.16	0.166	N/A	0.415	0.155	0.068	N/A	0.146	0.0262	0.0312	0.0225	0.0371		0.415	1.07E-05	0.03	0.02	0.03		0.02	No
Zirconium	ppm	<0.002	<0.01	0.0001	N/A	<0.002	<0.01	0.0001	N/A	0.00022	0.00031	0.000167	0.000191		0.000307	7.94E-09		0.004			0.004	No
Mercury (filtered)	ppm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.0001	<0.0001	<0.0001	<0.0001	<	0.0001	<2.59E-09	0.0002		0.000026		0.000026	No

[1] Interim PWQO was set based on readily available information and was not peer reviewed; the CCME guideline is used in preference.

[2] BC MOE (2001) for hardness of 100 mg/L (Ambient Water Quality Guidelines for Manganese. Overview Report. British Columbia Ministry of the Environment

[3] MOE (2011) Table 3 for non-potable groundwater

[4] Background Lake Ontario (OPG, 2009)

Table A.6: Non-Radiological Screening of Stormwater COPCs for Human and Ecological Health - Lake Water East

		Concentration													Loadings																
	Station ID	Catchment 10 M2-1 (2002)				Catchment 13 M5-1 (2002)				Catchment 16A L1-2 (2002)					Catchment 10 M2-1 (2002)				Catchment 13 M5-1 (2002)				Catchment 16A L1-2 (2002)				Max Loading		Final Conc. in Lake	PWQO	Interim PWQO	CCME Protection of Aquatic Life	95th Percentile DWSP Background (MOE, 2013)	Selected Benchmark	Carried Forward in Risk Assessment?
	Units	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Units	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4		Units							
Radionuclides																																			
Co-60	Bq/L	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	Bq/s	<12.84	<31.77	<29.3	<16.79	<12.55	<31.02	<28.58	<16.4	<0.83	<3.31	<3.45	<1.95	<31.77	Bq/L	<1.41E-03						No
Cs-137	Bq/L	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	Bq/s	<12.84	<31.77	<29.3	<16.79	<12.55	<31.02	<28.58	<16.4	<0.83	<3.31	<3.45	<1.95	<31.77	Bq/L	<1.41E-03	50				50	No
Cs-134	Bq/L	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	Bq/s	<12.84	<31.77	<29.3	<16.79	<12.55	<31.02	<28.58	<16.4	<0.83	<3.31	<3.45	<1.95	<31.77	Bq/L	<1.41E-03						No
H3	Bq/L	407	48.1	111	229.4	199.8	18.5	74	177.6	296	99.9	74	296	Bq/s	4752.5	1389.3	2956.1	3209.4	2279.0	521.8	1922.8	2427.0	222.9	300.8	232.3	480.2	4752.5	Bq/L	2.11E-01	7000				7000	No
C-14	Bq/L	<0.111	<0.111	<0.111	0.185	<0.111	<0.111	<0.111	<0.111	<0.111	0.148	<0.111	<0.111	Bq/s	<1.3	<3.21	<2.96	2.59	<1.27	<3.13	<2.88	<1.52	<0.08	0.45	<0.35	<0.18	<3.21	Bq/L	<1.42E-04						No
Organic Compounds																																			
PCB	ppb	<0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	ug/s	<1.17	<2.89	2.66	1.40	<1.14	<2.82	<2.6	1.37	<0.08	<0.3	<0.31	0.16	<2.89	ppb	<1.28E-04	0.001				0.001	No
C5-C10	ppm	<0.1	<0.1	<0.1	<0.1	N/A	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	mg/s	<1.17	<2.89	<2.66	<1.4	N/A	<2.82	<2.6	<1.37	<0.08	<0.3	<0.31	<0.16	<2.89	ppm	<1.28E-04	0.75 [3]				0.75 (3)	No
C10-C24	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	mg/s	<1.17	<2.89	<2.66	<1.4	<1.14	<2.82	<2.6	<1.37	<0.08	<0.3	<0.31	<0.16	<2.89	ppm	<1.28E-04	0.15 [3]				0.15 (3)	No
C24-C50	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	mg/s	<1.17	<2.89	<2.66	<1.4	<1.14	<2.82	<2.6	<1.37	<0.08	<0.3	<0.31	<0.16	<2.89	ppm	<1.28E-04	0.5 [3]				0.5 (3)	No
Oil in Water	ppm	<1.0	<1.0	N/A	<1.0	1.2	<1.0	N/A	1	<1.0	<1.0	N/A	<1.0	mg/s	<11.68	<28.88	N/A	<13.99	13.69	<28.2	N/A	13.67	<0.75	<3.01	N/A	<1.62	<28.88	ppm	<1.28E-03						-
General																																			
Alkalinity (as CaCO3)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A	Variable			98.065	98.065	No
Nitrate (as N)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A			2.93		2.93	No
Nitrite (as N)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A			0.06		0.06	No
Toxicity	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		-	N/A						-
Hardness	mg CaCO3/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	mg/s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		mg CaCO3/L	N/A				126.75	126.75	No
TSS	ppm	57	73	103.61	44	19	52	38.32	194	11	25	12.62	3	mg/s	665.6	2108.5	2759.3	615.6	216.7	1466.5	995.7	2651.1	8.3	75.3	39.6	4.9	2759.3	ppm	1.23E-01				4.4 [4]	4.4 [4]	No
Phosphorous	ppm	0.082	0.147	0.124	0.12	0.027	0.054	0.058	0.18	0.032	0.083	0.265	0.09	mg/s	1.0	4.2	3.3	1.7	0.3	1.5	1.5	2.5	0.0	0.2	0.8	0.1	4.2	ppm	1.89E-04	0.02				0.02	No
pH		7.84	7.76	7.77	7.38	7.85	8.34	7.88	7.02	7.97	7.94	7.29	7.27		-	-	-	-	-	-	-	-	-	-	-	-	-		-	6.5-8.5				6.5-8.5	No
Conductivity	mS/m	404	34	44	12	82	8.8	29	200	178	55	123	108		4717.5	982.0	1171.8	167.9	935.3	248.2	753.5	2733.1	134.0	165.6	386.1	175.2	4717.5	mS/m	2.10E-01					-	-
Metals																																			
Aluminum	ppm	0.33	0.701	1.032	0.545	0.124	0.469	0.481	0.586	0.26	0.403	0.232	0.071	mg/s	3.85	20.25	27.48	7.62	1.41	13.23	12.50	8.01	0.20	1.21	0.73	0.12	27.5	ppm	1.22E-03			0.1		0.1	No
Antimony	ppm	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	mg/s	<0.058	<0.144	<0.133	<0.07	<0.057	<0.141	<0.13	<0.068	<0.004	<0.015	<0.016	<0.008	<0.144	ppm	<6.42E-06		0.02			0.02	No
Arsenic	ppm	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	mg/s	<0.058	<0.144	<0.133	<0.07	<0.057	<0.141	<0.13	<0.068	<0.004	<0.015	<0.016	<0.008	<0.144	ppm	<6.42E-06	0.1	0.005	0.005		0.005	No
Barium	ppm	0.118	0.028	0.027	0.016	0.047	0.012	0.028	0.042	0.051	0.023	0.043	0.043	mg/s	1.38	0.81	0.72	0.22	0.54	0.34	0.73	0.57	0.04	0.07	0.13	0.07	1.38	ppm	6.12E-05				0.026	0.02608	No
Beryllium	ppm	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	mg/s	<0.023	<0.058	<0.053	<0.028	<0.023	<0.056	<0.052	<0.027	<0.002	<0.006	<0.006	<0.003	<0.058	ppm	<2.57E-06	1.1				1.1	No
Boron	ppm	0.08	0.032	0.041	<0.025	0.073	<0.025	0.027	0.066	0.06	0.06	0.074	0.072	mg/s	0.93	0.92	1.09	0.35	0.83	0.71	0.70	0.90	0.05	0.18	0.23	0.12	1.09	ppm	4.85E-05		0.2 [1]	1.5		1.5	No
Cadmium	ppm	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.002	<0.002	<0.002	mg/s	<0.012	<0.058	<0.053	<0.028	<0.023	<0.056	<0.052	<0.027	<0.001	<0.006	<0.006	<0.003	<0.058	ppm	<2.57E-06	0.0002	0.0005	0.000033		0.000033	No
Chromium	ppm	0.002	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.015	mg/s	0.02	<0.29	<0.27	<0.14	<0.11	<0.28	<0.26	0.14	<0.01	<0.03	<0.03	0.02	<0.289	ppm	<1.28E-05	0.0089		0.0089		0.0089	No
Cobalt	ppm	<0.002	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.002	<0.01	<0.01	<0.01	mg/s	<0.023	<0.29	<0.27	<0.14	<0.11	<0.28	<0.26	<0.14	<0.002	<0.03	<0.03	<0.02	<0.289	ppm	<1.28E-05	0.0009				0.0009	No
Copper	ppm	0.01	0.024	0.016	<0.01	<0.01	<0.01	<0.01	0.011	0.006	<0.01	<0.01	<0.01	mg/s	0.12	0.69	0.43	0.14	0.11	0.28	0.26	0.15	0.00	0.03	0.03	0.02	0.69	ppm	3.08E-05	0.005	0.005	0.002		0.002	No
Iron	ppm	1.39	1.554	1.901	0.617	0.653	0.753	0.693	1.618	0.527	0.814	0.736	0.513	mg/s	16.23	44.88	50.63	8.63	7.45	21.24	18.01	22.11	0.40	2.45	2.31	0.83	50.63	ppm	2.25E-03	0.3		0.3		0.3	No
Lead	ppm	<0.005	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.005	0.01	<0.01	<0.01	mg/s	<0.058	0.29	<0.27	<0.14	<0.11	0.28	<0.26	<0.14	<0.004	0.03	<0.03	<0.02	0.29	ppm	1.28E-05	0.025	0.005	0.001-0.007		0.001-0.007	No
Manganese	ppm	0.436	0.099	0.065	0.059	0.012	0.045	0.028	0.14	0.042	0.035	0.018	0.011	mg/s	5.09	2.86	1.73	0.83	0.14	1.27	0.73	1.91	0.03	0.11	0.06	0.02	5.09	ppm	2.26E-04	1 [2]				1(2)	No
Molybdenum	ppm	<0.002	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.002	<0.01	<0.01	<0.01	mg/s	<0.023	<0.29	<0.27	<0.14	<0.11	<0.28	<0.26	<0.14	<0.002	<0.03	<0.03	<0.02	<0.289	ppm	<1.28E-05		0.04	0.073		0.04	No
Nickel	ppm	0.004	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.002	0.01	<0.01	<0.01	mg/s	0.05	0.29	<0.27	<0.14	<0.11	0.28	<0.26	<0.14	<0.002	0.03	<0.03	<0.02	0.29	ppm	1.28E-05	0.025		0.025-0.15		0.025	No
Selenium	ppm	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	mg/s	<0.058	<0.144	<0.133	<0.07	<0.057	<0.141	<0.13	<0.068	<0.004	<0.015	<0.016	<0.008	<0.144	ppm	<6.42E-06	0.1		0.001		0.001	No
Silver	ppm	0.0003	<0.01	0.0001	0.0001	<0.01	<0.01	0.0001	0.0001	<0.0001	<0.01	0.0001	0.0001	mg/s	0.0035	<0.29	0.0027	0.0014	<0.11	<0.28	0.0026	0.0014	<0.0001	<0.03	0.0003	0.0002	<0.289	ppm	<1.28E-05	0.0001		0.0001		0.0001	No
Sodium	ppm	570	31.2	41	4.19	12.7	0.49	2.819	363	111	23.5	19.495	36.6	mg/s	6655.83	901.16	1091.91	58.62	144.86	13.82	73.25	4960.50	83.57	70.76	61.19	59.37	6655.83	ppm	2.96E-01				21.3	21.3	No
Thallium	ppm	<0.002	<0.01	0.001	0.0001	<0.01	<0.01	0.0001	0.0001	<0.002	<0.01	0.0001	0.0001	mg/s	<0.023	<0.29	0.027	0.001	<0.11	<0.28	0.003	0.001	<0.002	<0.03	0.000	0.000	<0.289	ppm	<1.28E-05		0.0003	0.0008		0.0008	No
Uranium	ppm	0.001	<0.2	<0.02	0.0002	<0.2	<0.2	<0.02	0.0002	0.0034	<0.2	<0.02	0.0029	mg/s	0.012	<5.78	<0.53	0.003	<2.28	<5.64	<0.52	0.003	0.003	<0.6	<0.06	0.005	<5.777	ppm	<2.57E-04		0.005 [1]	0.015		0.005 (1)	No
Vanadium	ppm	<0.001	<0.02	0.084	<0.02	<0.02	<0.02	0.048	<0.02	0.004	<0.02	0.011	<0.02	mg/s	<0.012	<0.58	2.237	<0.28	<0.23	<0.56	1.247	<0.27	0.003	<0.06	0.035	<0.03	2.24	ppm	9.94E-05		0.006			0.006	No
Zinc	ppm	0.37	0.164	N/A	0.092	0.373	0.054	N/A	0.134	0.009	0.011	N/A	0.005	mg/s	4.320	4.737	N/A	1.287	4.255	1.523	N/A	1.831	0.007	0.033	N/A	0.008	4.74	ppm	2.11E-04	0.03	0.02	0.03		0.02	No
Zirconium	ppm	<0.002	<0.01	0.0003	N/A	<0.01	<0.01	0.0002	N/A	<0.002	<0.01	0.0008	N/A	mg/s	<0.023	<0.29	0.008	N/A	<0.11	<0.28	0.005	N/A	<0.002	<0.03	0.003	N/A	<0.289	ppm	<1.28E-05		0.004			0.004	No
Mercury (filtered)	ppm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	mg/s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ppm	N/A	0.0002		0.000026		0.000026	No

[1] Interim PWQO was set based on readily available information and was not peer reviewed; the CCME guideline is used in preference.
[2] BC MOE (2001) for hardness of 100 mg/L (Ambient Water Quality Guidelines for Manganese. Overview Report. British Columbia Ministry of the Environment
[3] MOE (2011) Table 3 for non-potable groundwater
[4] Background Lake Ontario (OPG, 2009)

Table A.7: Non-Radiological Screening of Stormwater COPCs for Human and Ecological Health - Lake Water West

	Concentration									Loadings														
	Station ID	Catchment 3								Catchment 3														
		MH 129/211 (2006)				MH 129/211 (2002)					MH 129/211 (2006)				MH 129/211 (2002)				Max Loading		Final Conc. in Lake	PWQO	Interim PWQO	CCME Protection of Aquatic Life	95th Percentile DWSP Background (MOE, 2013)	Selected Benchmark	Carried Forward in Risk Assessment?
	Units	Sep-02	Oct-17	Oct-27	Nov-16	Q1	Q2	Q3	Q4	Units	Sep-02	Oct-17	Oct-27	Nov-16	Q1	Q2	Q3	Q4		Units						
Radionuclides																										
Co-60	Bq/L	<0.37	<0.37	<0.74	<0.74	<1.1	<1.1	<1.1	<1.2	Bq/s	<3.58	<8.44	<15.0	<7.63	<10.65	<25.09	<22.29	<12.37	<25.09	Bq/L	<1.39E-03						No
Cs-137	Bq/L	<0.37	<0.37	5.55	20	<1.1	<1.1	<1.1	<1.2	Bq/s	<3.58	<8.44	112.46	206.14	<10.65	<25.09	<22.29	<12.37	206.14	Bq/L	1.15E-02	50				50	No
Cs-134	Bq/L	<0.37	8.51	<0.74	<0.74	<1.1	<1.1	<1.1	<1.2	Bq/s	<3.58	194.12	<15.0	<7.63	<10.65	<25.09	<22.29	<12.37	194.12	Bq/L	1.08E-02						No
H3	Bq/L	9660	11433	7252	7992	14060	7770	8140	14430	Bq/s	93564	260799	146954	82373	136181	177242	164948	148729	260799	Bq/L	1.45E+01	7000				7000	No
C-14	Bq/L	0.007	0.148	<0.003	<0.111	<0.111	<0.111	<0.111	<0.111	Bq/s	0.068	3.376	<0.06	<1.14	<1.08	<2.53	<2.25	<1.14	3.38	Bq/L	1.88E-04						No
Organic Compounds																										
PCB	ppb	<0.05	<0.05	<0.05	<0.05	<0.1	0.1	0.1	<0.1	ug/s	<0.48	<1.14	<1.01	<0.52	<0.97	2.28	2.03	<1.03	2.28	ppb	1.27E-04	0.001				0.001	No
C5-C10	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	mg/s	<0.97	<2.28	<2.03	<1.03	<0.97	<2.28	<2.03	<1.03	<2.28	ppm	<1.27E-04	0.75 [3]				0.75 (3)	No
C10-C24	ppm	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	mg/s	<0.97	<2.28	<2.03	1.03	<0.97	<2.28	<2.03	<1.03	<2.28	ppm	<1.27E-04	0.15 [3]				0.15 (3)	No
C24-C50	ppm	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.17	<0.1	mg/s	<0.97	<2.28	<2.03	1.03	<0.97	<2.28	3.44	<1.03	3.44	ppm	1.91E-04	0.5 [3]				0.5 (3)	No
Oil in Water	ppm	<1.0	<1.0	<1.0	1.7	2.7	1	N/A	2	mg/s	<9.69	<22.81	<20.26	17.52	26.15	22.81	N/A	20.61	26.15	ppm	1.45E-03						-
General																										
Alkalinity (as CaCO3)		94.7	47.8	40	36.6	N/A	N/A	N/A	N/A		917.2	1090.4	810.6	377.2	N/A	N/A	N/A	N/A	1090		6.06E-02	Variable			98.065	98.065	No
Nitrate (as N)		5.39	3.4	3.35	3.05	N/A	N/A	N/A	N/A		52.2	77.6	67.9	31.4	N/A	N/A	N/A	N/A	78		4.31E-03			2.93		2.93	No
Nitrite (as N)		0.822	0.099	0.114	0.055	N/A	N/A	N/A	N/A		8.0	2.3	2.3	0.6	N/A	N/A	N/A	N/A	8		4.42E-04			0.06		0.06	No
Toxicity	-	pass	fail	fail	fail	pass	pass	fail	pass		-	-	-	-	-	-	-	-	-	-	N/A						-
Hardness	mg CaCO3/L	84.7	56.1	44.2	37.1	194.5	30.7	36.5	58	mg/s	820	1280	896	382	1884	700	740	598	1884	mg CaCO3/L	1.05E-01				126.75	126.75	No
TSS	ppm	19.2	23.1	13.5	74.3	58	2	3.64	13	mg/s	186	527	274	766	562	46	74	134	766	ppm	4.25E-02				4.4 [4]	4.4 [4]	No
Phosphorous	ppm	0.199	0.105	0.0805	0.0769	0.27	0.057	0.042	0.168	mg/s	2	2	2	1	3	1	1	2	3	ppm	1.45E-04	0.02				0.02	No
pH		7.59	7.81	7.26	7.64	7.71	7.52	7.65	6.75		-	-	-	-	-	-	-	-	-		N/A	6.5-8.5				6.5-8.5	No
Conductivity	mS/m	46.6	12.5	110	8.6	185	7.24	9.6	68.5		451	285	2229	89	1792	165	195	706	2229	mS/m	1.24E-01					-	-
Metals																										
Aluminum	ppm	0.159	0.167	0.136	0.158	0.054	0.092	0.084	0.32	mg/s	1.5	3.8	2.8	1.6	0.5	2.1	1.7	3.3	3.8	ppm	2.12E-04			0.1		0.1	No
Antimony	ppm	0.00127	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	mg/s	0.012	<0.02	<0.02	<0.01	<0.05	<0.11	<0.1	<0.05	<0.114	ppm	<6.34E-06		0.02			0.02	No
Arsenic	ppm	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	mg/s	<0.001	<0.02	<0.02	<0.01	<0.05	<0.11	<0.1	<0.05	<0.114	ppm	<6.34E-06	0.1	0.005	0.005		0.005	No
Barium	ppm	0.055	0.0367	0.0219	0.0139	0.073	0.006	0.009	0.02	mg/s	0.533	0.837	0.444	0.143	0.707	0.137	0.182	0.206	0.837	ppm	4.65E-05				0.026	0.02608	No
Beryllium	ppm	<0.0001	<0.001	<0.001	<0.001	<0.002	<0.002	<0.002	<0.002	mg/s	<0.001	<0.023	<0.02	<0.01	<0.019	<0.046	<0.041	<0.021	<0.046	ppm	<2.53E-06	1.1				1.1	No
Boron	ppm	0.057	0.023	0.0148	0.00832	<0.025	<0.025	<0.025	<0.025	mg/s	0.552	0.525	0.300	0.086	<0.242	<0.57	<0.507	<0.258	<0.57	ppm	<3.17E-05		0.2 [1]	1.5		1.5	No
Cadmium	ppm	0.00039	0.00043	0.000383	0.00043	<0.001	<0.002	<0.002	<0.002	mg/s	0.004	0.010	0.008	0.004	<0.01	<0.046	<0.041	<0.021	<0.046	ppm	<2.53E-06	0.0002	0.0005	0.000033		0.000033	No
Chromium	ppm	0.00359	0.00194	0.00076	0.00085	<0.001	<0.01	<0.01	<0.01	mg/s	0.035	0.044	0.015	0.009	<0.01	<0.228	<0.203	<0.103	<0.228	ppm	<1.27E-05	0.0089		0.0089		0.0089	No
Cobalt	ppm	0.00046	0.00033	0.000232	0.00028	<0.002	<0.01	<0.01	<0.01	mg/s	0.004	0.007	0.005	0.003	<0.019	<0.228	<0.203	<0.103	<0.228	ppm	<1.27E-05	0.0009				0.0009	No
Copper	ppm	0.0154	0.0108	0.00631	0.00601	0.021	<0.01	<0.01	0.011	mg/s	0.149	0.246	0.128	0.062	0.203	<0.228	<0.203	0.113	0.246	ppm	1.37E-05	0.005	0.005	0.002		0.002	No
Iron	ppm	0.329	0.282	0.16	0.166	2.67	0.09	0.14	0.44	mg/s	3.187	6.433	3.242	1.711	25.861	2.053	2.837	4.535	25.861	ppm	1.44E-03	0.3		0.3		0.3	No
Lead	ppm	0.0143	0.00303	0.00171	0.00338	0.007	<0.01	N/A	<0.01	mg/s	0.139	0.069	0.035	0.035	0.068	<0.228	N/A	<0.103	<0.228	ppm	<1.27E-05	0.025	0.005	0.001-0.007		0.001-0.007	No
Manganese	ppm	0.0658	0.021	0.0111	0.0156	0.009	<0.01	<0.01	0.027	mg/s	0.637	0.479	0.225	0.161	0.087	<0.228	<0.203	0.278	0.637	ppm	3.54E-05	1 [2]				1(2)	No
Molybdenum	ppm	0.00206	0.00108	0.000474	0.00029	<0.002	<0.01	<0.01	<0.01	mg/s	0.020	0.025	0.010	0.003	<0.019	<0.228	<0.203	<0.103	<0.228	ppm	<1.27E-05		0.04	0.073		0.04	No
Nickel	ppm	<0.0001	0.0021	0.00139	0.00129	0.003	<0.01	<0.01	<0.01	mg/s	0.001	0.048	0.028	0.013	0.029	<0.228	<0.203	<0.103	<0.228	ppm	<1.27E-05	0.025		0.025-0.15		0.025	No
Selenium	ppm	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	mg/s	<0.001	<0.023	<0.02	<0.01	<0.048	<0.114	<0.101	<0.052	<0.114	ppm	<6.34E-06	0.1		0.001		0.001	No
Silver	ppm	0.00022	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.001	mg/s	0.002	<0.002	<0.002	<0.001	<0.001	<0.002	0.002	0.010	0.010	ppm	5.73E-07	0.0001		0.0001		0.0001	No
Sodium	ppm	0.097	6.55	4.22	2.95	258	2.3	1.4	104.8	mg/s	0.940	149.413	85.514	30.405	2498.904	52.466	28.369	1080.168	2498.904	ppm	1.39E-01				21.3	21.3	No
Thallium	ppm	<0.0001	<0.0001	<0.0001	<0.0001	<0.002	<0.01	0.0001	0.0001	mg/s	<0.001	<0.002	<0.002	<0.001	<0.019	<0.228	0.002	0.001	<0.228	ppm	<1.27E-05		0.0003	0.0008		0.0008	No
Uranium	ppm	0.00027	<0.0001	<0.0001	<0.0001	0.0004	<0.2	0.0001	0.0001	mg/s	0.003	<0.002	<0.002	<0.001	0.004	<4.562	0.002	0.001	<4.562	ppm	<2.53E-04		0.005 [1]	0.015		0.005 (1)	No
Vanadium	ppm	0.0031	0.0012	0.000691	0.0009	<0.001	<0.02	<0.02	<0.02	mg/s	0.030	0.027	0.014	0.009	<0.01	<0.456	<0.405	<0.206	<0.456	ppm	<2.53E-05		0.006			0.006	No
Zinc	ppm	0.219	0.338	0.319	0.254	0.6	0.175	0.268	0.837	mg/s	2.121	7.710	6.464	2.618	5.811	3.992	5.431	8.627	8.627	ppm	4.79E-04	0.03	0.02	0.03		0.02	No
Zirconium	ppm	<0.0001	0.00013	0.000129	<0.0001	<0.002	<0.01	N/A	N/A	mg/s	<0.001	0.003	0.003	<0.001	<0.019	<0.228	N/A	N/A	<0.228	ppm	<1.27E-05		0.004			0.004	No
Mercury (filtered)	ppm	<0.0001	<0.0001	<0.0001	<0.0001	N/A	N/A	N/A	N/A	mg/s	<0.001	<0.002	<0.002	<0.001	N/A	N/A	N/A	N/A	<0.002	ppm	<1.27E-07	0.0002		0.000026		0.000026	No

[1] Interim PWQO was set based on readily available information and was not peer reviewed; the CCME guideline is used in preference.

[2] BC MOE (2001) for hardness of 100 mg/L (Ambient Water Quality Guidelines for Manganese. Overview Report. British Columbia Ministry of the Environment

[3] MOE (2011) Table 3 for non-potable groundwater

[4] Background Lake Ontario (OPG, 2009)

Table A.8: Ecological Screening of Non-Radiological Final Station Effluent from Condenser Cooling Water

Parameters	Unit	PWQO	CCME Protection of Aquatic Life	Toxicity Benchmark	CofA Limit	Selected Benchmark	PA					PB					Max Conc.	Carried forward as COPC?
							Annual Range (2007)	Annual Range (2008)	Annual Range (2009)	Annual Range (2010)	Annual Range (2011)	Annual Range (2007)	Annual Range (2008)	Annual Range (2009)	Annual Range (2010)	Annual Range (2011)		
Unionized Ammonia	mg/L	0.02	0.019		0.02	0.02	<0.01- 0.014	<0.01	<0.01- 0.02	<0.01- 0.01	<0.001- 0.011	<0.01- 0.01	<0.01-0.015	<0.01- 0.013	<0.01- 0.02	<0.01- 0.02	0.02	No
Hydrazine	mg/L	-	-	0.0026[b]	0.1	0.0026[b]	<0.003 - 0.012	0.003-0.0175	<0.003 - 0.037	<0.003 - 0.067	<0.002 - 0.00	<0.003 - 0.009	0.003-0.0183	<0.003 - 0.08	<0.003 - 0.048	0.002 - 0.0	0.08	Yes
Morpholine	mg/L	0.004[a]	-		0.02	0.004[a]	0.001 - 0.0016	<0.001-0.003	0.001 - 0.002	0.001 - 0.003	0.001 - 0.004	0.001 - 0.003	<0.001-0.007	0.001 - 0.004	0.001 - 0.012	001 - 0.16	0.012	Yes
pH	pH units	6.5 - 8.5	6.5-9.0		6.0 - 9.5	6.5 - 8.5	7.7 - 8.7	7.7 - 8.3	7.7 - 8.7	7.8 - 8.3	7.9 - 8.3	7.7 - 8.5	8 - 8.5	8 - 8.4	7.8 - 8.3	7.9 - 8.4	8.7	No
TRC	mg/L	0.002	-		0.01	0.002	<0.001 - 0.03	<0.006-0.01	<0.008 - 0.01	<0.001 - 0.01	<0.001 - 0.01	<0.001 - 0.003	<0.006	<0.008 - 0.009	<0.001 - 0.004	.001 - 0.0	0.03	Yes

Notes:

[a] Interim PWQO is conservatively derived based on limited information; no scientific criteria document.

[b] Toxicity benchmark from EC, 2010 (modified to chronic no effect concentration)

[c] This elevated number was retracted since it was determined through a third-party review that the elevated concentrations were suspect and due to mislabeling or sample contamination during analysis

Table A.9: Non-Radiological Screening of Lake Water COPCs for Ecological Assessment

Parameter	Units	PWQO	Interim PWQO	CCME Protection of Aquatic Life	95th Percentile DWSP Background (MOE, 2013)	Background Lake Ontario (OPG, 2009)	Toxicity Benchmark	Notes	Selected Benchmark	Max Observed 2006 Lake Water (Golder, 2007a,e)	Carried Forward as COPC?
Alkalinity (as CaCO3)	ppm	Variable			98.065	97.5			98.065	92.6	No
Ammonia (Total)	ppm				0.0664	0.03			-	0.117	-
Ammonia (unionized)	ppm	0.02		0.019		0.002			0.019	0.0192	No (Marginally exceeds CCME but less than PWQO)
BOD	ppm								-	8.1	-
COD	ppm				2.2	6			-	13	-
Conductivity (Specific)	mS/m					30			-	30.1	-
Conductivity (Specific, In-situ)	mS/m								-	35.5	-
Hardness (as CaCO3)	ppm				126.75	145			-	133	No
Oil and Grease	ppm	Narrative							-	<1	-
pH	pH Units	6.5-8.5		6.5-9.0		8.8			6.5-8.5	8.5	No
pH (in-situ)	pH Units	6.5-8.5				8.5			6.5-8.5	8.5	No
Temperature (in situ)	C					21.5			21.5	31.4	**Yes**
TDS	ppm					185			-	515	-
TRC (in situ)	ppm	0.002				0.001			0.002	0.005	**Yes**
TOC	ppm					2.6			-	6.2	-
TSS	ppm					4.4			4.4	3.7	No
Turbidity	NTU					1.6			-	1.85	-
Hydrazine	ppm					0.0025	0.0026	Toxicity benchmark from EC/HC, 2011 (modified to chronic no effect concentration)	0.0026	<0.005	**Yes**
Morpholine	ppm		0.004			0.0005			0.004	0.0044	**Yes**
Tritium	Bq/L	7000							7000	203.5	No
Aluminum	ppm	0.075		0.1	0.1655	0.45			0.075	0.029	No
Aluminum (filtered)	ppm		0.075			0.013			0.075	0.029	No
Antimony	ppm		0.02		0.000882	0.0005			0.02	<0.001	No
Arsenic	ppm	0.1	0.005	0.005	0.0012	0.001			0.005	<0.001	No
Barium	ppm				0.02608	0.03			0.02608	0.027	No (Exceeds background by <20% (Suter *et al* ., 1995; Suter, 1996)
Beryllium	ppm	1.1			0.00001	0.0005			1.1	<0.001	No
Bismuth	ppm					0.0005	0.00025	Toxicity benchmark is modified from Borgmann *et al.* (2005)	0.00025	<0.001	No (DL exceeds NOEC, but not EC20)
Boron	ppm		0.2 [(1)]	1.5	0.028225	0.07			1.5	0.032	No
Cadmium	ppm	0.0002	0.0005	0.000033	0.00003	0.00005	-		0.00003	0.0009	**Yes**
Calcium	ppm				35.75	41.5			35.75	36.9	No (Exceeds background by <20% (Suter *et al* ., 1995; Suter, 1996)
Cesium	ppm					0.00005	0.01	Toxicity benchmark is modified from Borgmann *et al.* (2005)	0.01	<0.0001	No
Chromium	ppm	0.0089		0.0089	0.0021	0.002			0.0089	0.0034	No
Chromium (hexavalent)	ppm	0.001		0.001		0.0025	-		0.001	<0.01	No (Not carried forward because all values are non-detect, but DL > limit)
Cobalt	ppm	0.0009			0.000164	0.0002			0.0009	<0.0001	No
Copper	ppm	0.005	0.005	0.002	0.08095	0.0013			0.002	0.0054	**Yes**
Iron	ppm	0.3		0.3	0.14525	0.04			0.3	0.111	No
Lead	ppm	0.025	0.005	0.001-0.007	0.000635	0.0005			0.001-0.007	0.001	No
Lithium	ppm					0.004			0.004	0.003	No
Magnesium	ppm				9.1625	10			9.1625	10.9	No
Manganese	ppm	1 [(2)]			0.0122	0.0024			1 [(2)]	0.0062	No
Mercury (filtered)	ppm	0.0002		0.000026		0.00005			0.000026	<0.0001	No (Not carried forward because all values are non-detect, DL > CCME limit, but DL < PWQO)
Molybdenum	ppm		0.04	0.073	0.0014625	0.0014			0.04	0.0015	No
Nickel	ppm	0.025		0.025-0.15	0.00165	0.0009			0.025	<0.0001	No
Phosphorus	ppm		0.02	Guidance Framework	0.0298	0.0084			0.02	0.021	No (Not a toxicity issue)
Potassium	ppm				1.8	1.9			1.8	1.86	No (Exceeds background by <20% (Suter et al., 1995; Suter, 1996)
Selenium	ppm	0.1		0.001	0.001	0.0005			0.001	<0.001	No
Silver	ppm	0.0001		0.0001	0.00002	0.00005			0.0001	<0.0001	No
Sodium	ppm				21.3	17			21.3	15.8	No
Strontium	ppm				0.193	0.21	1.5	Toxicity benchmark is SCV (Suter and Tsao, 1996)	1.5	0.21	No
Thallium	ppm		0.0003 [(1)]	0.0008	0.0000425	0.00005			0.0008	<0.0001	No
Thorium	ppm					0.00005	0.000052	Toxicity benchmark is modified from Borgmann et al. (2005)	0.000052	<0.0001	No (DL exceeds NOEC, but not EC20)
Tin	ppm					0.00005	0.073	Toxicity benchmark is SCV (Suter and Tsao, 1996)	0.073	<0.0001	No
Titanium	ppm				0.003275	0.0016			0.003275	<0.0001	No
Tungsten	ppm		0.03			0.00015			0.03	<0.0001	No
Uranium	ppm		0.005 [(1)]	0.015	0.0004	0.0005			0.015	0.0004	No
Vanadium	ppm		0.006		0.00077	0.0007			0.006	<0.0001	No
Zinc	ppm	0.03	0.02	0.03	0.00835	0.0047			0.03	0.0125	No
Zirconium	ppm		0.004			0.00005			0.004	0.0121	No (One value exceeds interim PWQO, but duplicate and all other values are <0.0001mg/L. This value is suspect.)

[1] Interim PWQO was set based on readily available information and was not peer reviewed; the CCME guideline is used in preference.
[2] BC MOE (2001) for hardness of 100 mg/L (Ambient Water Quality Guidelines for Manganese, Overview Report, British Columbia Ministry of the Environment

Table A.10: Non-Radiological Screening of Ditch Landfill COPCs for Ecological Assessment - 2008

Parameter	Units	PWQO	Interim PWQO	CCME	Other Jurisdiction (MacDonald, 1999)	Selected Benchmark	Ditch 1	Ditch 3	Ditch 4	Ditch 5	Ditch 6	Seepage B	Seepage C	Seepage E	Carried Forward as COPC?
Alkalinity (as CaCO3)	ppm	Variable					315	342	248	629	318	671	837	600	-
BOD	ppm						< 2	< 2	< 2	< 2	< 2	8	15	5	-
DOC	ppm						45	6	7	11	6	8.3	15	10	-
Hardness (as CaCO3)	ppm						636	822	432	716	577	741	829	644	-
pH	pH Units	6.5-8.5					7.84	7.84	8.03	7.21	8.11	6.74	6.65	6.74	-
TSS	ppm						4590	18	16	499	3.2	13.5	81	32	-
Calcium	ppm			1000 (livestock)		1000 (livestock)	132	164	130	153	120	158	170	147	No
Copper	ppm	0.005	0.005	0.004		0.004	0.0016	0.0027	0.0017	0.0020	0.0020	0.0007	0.0015	0.0015	No
Mercury (filtered)	ppm	0.0002		0.000026		0.000026	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.0001	<0.0001	<0.0001	No (All values are non-detect, DL > CCME limit, but DL < PWQO)
Phosphorus	ppm		0.02			0.02	2.11	0.05	0.06	0.15	0.05	0.50	0.16	0.12	No (exceeds PWQO but not considered toxicity issue)
Zinc	ppm	0.03	0.02	0.03		0.02	0.0056	0.0065	0.0021	0.0120	0.0025	0.0035	0.0276	0.0318	No (only concerned with Ditch 4/6)
Phenol	ppm		0.005	0.004		0.004	< 0.001	< 0.001	< 0.001	0.002	< 0.001	0.006	0.011	0.0025	No (only concerned with Ditch 4/6)
Sulphate	ppm				100 [(1)]	100 [(1)]	379.00	562.00	186.00	181.00	300.00	175.00	170.00	152.00	**Yes**

[1] BC MOE (2000) Ambient Water Quality Guidelines for Sulphate. Overview Report. British Columbia Ministry of the Environment

Table A.11: Non-Radiological Screening of Ditch Landfill COPCs for Ecological Assessment - 2010

Parameter	Units	PWQO	Interim PWQO	CCME	Other Jurisdiction (MacDonald, 1999)	Toxicity Benchmark	Selected Benchmark	Ditch 1	Ditch 3	Ditch 5	Ditch 6	Seepage B	Seepage C	Seepage E	Carried Forward as COPC?	Notes
Alkalinity (as CaCO3)	mg/L	Variable						462	202	920	217	929	1080	832	-	
BOD	mg/L							8	13	22	7	31	42	20	-	
DOC	mg/L							5	6	15	6	11	18	14	-	
Hardness (as CaCO3)	mg/L							879	1270	1010	752	883	1060	981	-	
pH	pH Units	6.5-8.5						7	8	7	8	7	7	7	-	
TSS	mg/L							363	100	121	25	92	329	929	-	
Aluminum	mg/L		0.075	0.1			0.075	0.001	0.001	0.001	0.001	0.138	1.010	3.120	No - only concerned with Ditch 4/6	
Antimony	mg/L		0.02				0.02	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	No	
Arsenic	mg/L	0.1	0.005	0.005			0.005	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001	No	
Barium	mg/L				1-5		1-5	0.038	0.032	0.153	0.064	0.264	0.324	0.323	No	
Beryllium	mg/L	1.1					1.1	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	No	
Bismuth	mg/L					0.0025	0.0025	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	No	Toxicity benchmark is modified from Borgmann *et al.* (2005)
Boron	mg/L		0.2 [1]	1.5			1.5	0.1	0.1	0.8	0.1	0.6	0.8	0.4	No	
Cadmium	mg/L	0.0002	0.0005	0.00024			0.0002	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0003	No	
Calcium	mg/L			1000 (livestock)			1000	268.0	354.0	278.0	229.0	248.0	269.0	309.0	No	
Cesium	mg/L					0.01	0.01	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	No	Toxicity benchmark is modified from Borgmann *et al.* (2005)
Chromium	mg/L	0.0089		0.0089			0.0089	0.005	0.004	0.005	0.005	0.008	0.013	0.008	No - only concerned with Ditch 6	
Cobalt	mg/L	0.0009					0.0009	0.002	0.0004	0.001	0.0003	0.001	0.001	0.004	No - only concerned with Ditch 6	
Copper	mg/L	0.005	0.005	0.004			0.004	0.002	0.003	0.003	0.003	0.001	0.003	0.014	No - only concerned with Ditch 6	
Iron	mg/L	0.3		0.3			0.3	0.01	< 0.005	< 0.005	< 0.005	15.7	26.5	31.7	No - only concerned with Ditch 6	
Lead	mg/L	0.025	0.005	0.001-0.007			0.005	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0003	0.002	0.011	No - only concerned with Ditch 6	
Lithium	mg/L				0.067		0.067	< 0.001	0.002	0.004	0.003	0.007	0.013	0.005	No	
Magnesium	mg/L				600 (livestock)		600 (livestock)	61.1	102.0	70.2	56.3	54.4	89.0	48.7	No	
Manganese	mg/L				1 [2]		1	2.61	0.01	0.8	0.0	0.6	0.6	0.9	No - only concerned with Ditch 6	
Mercury	mg/L	0.0002		0.000026			0.000026	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.0001	< 0.0001	<0.0001	No	Not carried forward because all values are non-detect, but DL > CCME limit, <PWQO
Molybdenum	mg/L		0.04	0.073			0.04	0.001	0.001	0.0002	0.001	< 0.0001	0.0001	0.0001	No	
Nickel	mg/L	0.025		0.025-0.15			0.025	0.002	0.002	0.001	0.002	0.001	0.003	0.006	No	
Phosphorus	mg/L		0.02				0.02	0.1	0.2	0.3	0.04	0.3	0.4	0.7	No	Exceeds PWQO, but not considered a toxicity issue
Potassium	mg/L						-	1.7	3.1	8.3	4.5	7.8	15.5	6.0	No - substance of minimal concern	
Selenium	mg/L	0.1		0.001			0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001	0.002	0.001	No - only concerned with Ditch 6	
Silver	mg/L	0.0001		0.0001			0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	No	
Sodium	mg/L					68000	68000	18.0	19.2	46.4	84.6	22.2	68.1	21.3	No	Toxicity benchmark is modified LCV (Suter and Tsao, 1996)
Strontium	mg/L					1.5	1.5	0.6	1.2	1.0	1.4	1.9	2.4	1.4	No - only concerned with Ditch 6	Toxicity benchmark based on SCV (Suter and Tsao, 1996)
Thallium	mg/L		0.0003	0.0008			0.0003	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	No	
Thorium	mg/L					0.000052	0.000052	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0003	No (DL exceeds NOEC but not EC20)	Toxicity benchmark is modified from Borgmann *et al.* (2005)
Tin	mg/L					0.073	0.073	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	No	Toxicity benchmark based on SCV (Suter and Tsao, 1996)
Titanium	mg/L				0.01		0.01	0.009	0.018	0.002	0.008	0.010	0.038	0.059	No	
Tungsten	mg/L		0.03				0.03	0.0001	< 0.0001	0.0004	< 0.0001	0.002	0.001	0.0005	No	
Uranium	mg/L		0.005 [1]	0.015			0.015	0.002	0.006	0.0004	0.003	0.0002	0.001	0.001	No	
Vanadium	mg/L		0.006				0.006	< 0.0001	< 0.0001	< 0.0001	0.001	0.001	0.004	0.015	No - only concerned with Ditch 6	
Zinc	mg/L	0.03	0.02	0.03			0.02	0.008	0.016	0.004	0.007	0.008	0.027	0.061	No - only concerned with Ditch 6	
Zirconium	mg/L		0.004				0.004	0.0002	0.0002	0.0002	0.0002	0.001	0.001	0.002	No	
Phenol	mg/L		0.005	0.004			0.004	< 0.002	< 0.002	< 0.002	< 0.002	<0.002	0.021	0.013	No - only concerned with Ditch 6	
Sulphate	mg/L				100 [3]		100 [3]	411.0	830.0	82.2	328.0	24.7	47.9	81.9	**Yes**	
Silicon	mg/L						-	6.5	3.8	12.9	3.8	13.3	15.7	14.3	No - substance of minimal concern	
Total Sulphur	mg/L						-	148.0	315.0	33.5	118.0	9.2	81.3	29.2	No - substance of minimal concern	

[1] Interim PWQO was set based on readily available information and was not peer reviewed; the CCME guideline is used in preference.

[2] BC MOE (2001) for hardness of 100 mg/L (Ambient Water Quality Guidelines for Manganese. Overview Report. British Columbia Ministry of the Environment

[3] BC MOE (2000) Ambient Water Quality Guidelines for Sulphate. Overview Report. British Columbia Ministry of the Environment

Table A.12: Non-Radiological Screening of Ditch Landfill COPCs for Ecological Assessment - 2012

Parameter	Units	PWQO	Interim PWQO	CCME	Other Jurisdiction (MacDonald, 1999)	Selected Benchmark	Ditch 1	Ditch 3	Ditch 5	Ditch 6	Seepage B	Seepage C	Seepage E	Carried Forward as COPC?
Alkalinity (as CaCO3)	ppm	Variable					362	202	364	364	927	1070	790	-
BOD	ppm						13.3	13	4.65	< 2	12	9	12	-
DOC	ppm						9	6	7	10	12.0	17	12	-
Hardness (as CaCO3)	ppm						847	1270	459	587	855	933	810	-
pH	pH Units	6.5-8.5					7.61	7.54	7.14	7.75	6.69	6.77	6.72	-
TSS	ppm						63	100	88	5.5	87.7	20	48	-
Calcium	ppm			1000 (livestock)		1000 (livestock)	238	354	129	168	243	224	249	No
Copper	ppm	0.005	0.005	0.004		0.004	<0.01	0.0030	<0.01	<0.01	<0.01	<0.01	<0.01	No (DL changed in 2012)
Phosphorus	ppm		0.02			0.02	<0.2	0.17	<0.2	<0.2	0.90	6.40	<0.2	No (exceeds PWQO but not considered toxicity issue)
Zinc	ppm	0.03	0.02	0.03		0.02	<0.005	0.0160	<0.005	<0.005	<0.005	<0.005	<0.005	No
Phenol	ppm		0.005	0.004		0.004	<0.002	<0.002	<0.002	<0.002	<0.2	<0.2	<0.002	No
Sulphate	ppm				100 [(1)]	100 [(1)]	623.00	830.00	132.00	245.00	87.70	6.40	45.20	**Yes**

[1] BC MOE (2000) Ambient Water Quality Guidelines for Sulphate. Overview Report. British Columbia Ministry of the Environment

Table A.13: Screening of Soil COPCs for Locations Greater than 30 m from Water for Ecological Assessment

Parameter	Detection Limit	Units	MOE 2011 (Table 3 - Industrial)	CCME SQG (Industrial)	OTR98	Average Crustal Abundance	US EPA Region 5 RCRA	Selected Benchmark	Max Soil Conc.	Carried Foward in Risk Assessment?
Acetone	0.05, 0.105, 0.15	ppm	16					16	<0.15	No
Acrolein	1	ppm					5.27	5.27	<1	No
Acrylonitrile	0.15	ppm					0.0239	0.0239	<0.15	No (based on toxicity rationale provided in Section 4.1.3.1.4)
Aluminum	1	ppm			27000	84000		27000-84000	49000	No (within range of crustal abundance)
Antimony	1	ppm	40	40				40	5.9	No
Arsenic	2.5, 1	ppm	18					18	48.2	**Yes**
Barium	0.5	ppm	670	2000				670	172.7	No
Benzene	0.002 to 0.005	ppm	0.32	0.03				0.03	<0.005	No
Beryllium	0.2 to 0.5	ppm	8					8	1.8	No
Bismuth	0.5 to 1	ppm			0.1-13[a]	0.6		0.1-13[a]	<2.5	No (within range of crustal abundance)
Boron	2.5	ppm	120					120	11	No
Bromodichloromethane	0.01	ppm	18					18	<0.01	No
Bromoform	0.002	ppm	0.61					0.61	<0.02	No
Bromomethane	0.003 to 0.02	ppm	0.05					0.05	<0.02	No
Bulk Density(free fall)		lbs/cu ft						-		No
Cadmium	0.1	ppm	1.9	22				1.9	2.1	**Yes**
Calcium	0.01	ppm			58000	53000		53000-58000	295000	No (based on toxicity rationale provided in Section 4.1.3.1.4)
Calcium	1	ppm			58000	53000		53000-58000	340000	No (based on toxicity rationale provided in Section 4.1.3.1.4)
Carbon Tetrachloride	0.002 to 0.1	ppm	0.21	50				0.21	<0.01	No
Chlorobenzene	0.002 to 0.005	ppm	2.4	10				2.4	<0.005	No
Chlorodibromomethane	0.002 to 0.01	ppm	13					13	<0.01	No
Chloroethane	0.002 to 0.01	ppm	0.032					0.032	<0.01	No
Chloroethylvinyl ether 2-	0.1	ppm						-	<0.1	
Chloroform	0.002 to 0.02	ppm	0.47	50				0.47	<0.01	No
Chloromethane	0.003 to 0.02	ppm					10.4	10.4	<0.02	No
Chromium	0.5	ppm	160	87				87	39.6	No
Dichloroethylene cis-1,2-	0.002 to 0.01	ppm	55					55	<0.01	No
Dichloropropene cis-1,3-	0.002 to 0.005	ppm	0.18					0.18	<0.005	No
60Co		pCi/kg						-	770000	**Yes**
Cobalt	0.5	ppm	80	300				80	60.9	No
Copper	0.5	ppm	230	91				91	875	**Yes**
134Cs	<50	pCi/kg						-	<500	**Yes**
137Cs	<50	pCi/kg						-	<500	**Yes**
Dichlorobenzene 1,2-	0.001 to 0.01	ppm	6.8	10				6.8	<0.01	No
Dichlorobenzene 1,3-	0.002	ppm	9.6	10				9.6	<0.01	No
Dichlorobenzene 1,4-	0.002 to 0.01	ppm	0.2	10				0.2	<0.01	No
Dichloroethane 1,1-	0.002 to 0.01	ppm	17	50				17	<0.01	No
Dichloroethane 1,2-	0.01	ppm	0.05	50				0.05	<0.01	No
Dichloroethylene 1,1-	0.002	ppm	0.064	50				0.064	<0.0024	No
Dichloromethane	0.003	ppm		50				50	-	No
Dichloromethane	0.01	ppm		50				50	<0.01	No
Dichloropropane 1,2-	0.002 to 0.01	ppm	0.16	50				0.16	<0.01	No
Ethylbenzene	0.002 to 0.005	ppm	9.5	0.082				0.082	<0.005	No
Ethylene dibromide	0.002 to 0.005	ppm	0.05					0.05	<0.005	No
Extractable Hydrocarbons (C10-24)	10 to 100	ppm	230					230	<10 - <100	No
3H		pCi/kg						-	11064000	**Yes**
Hexanone,-2	0.025	ppm						N/A	-	No
Iron	0.5	ppm			33000	71000		33000-71000	48400	No (within range of crustal abundance)
Lead	0.005 to 0.5	ppm	120	600				120	194.2	**Yes**
m/p-Xylene	0.002 to 0.005	ppm	26	11				11	<0.005	No
Magnesium	0.002 to 0.2	ppm			16000	32000		16000-32000	17500	No (within range of crustal abundance)
Manganese	0.5	ppm				1400		1400	648	No
Methyl ethyl ketone	0.008 to 0.15	ppm	70					70	<0.15	No
Methyl Isobutyl Ketone	0.025 to 0.07	ppm	31					31	<0.07**	No
Methyl-t-Butyl Ether	0.015 to 0.002	ppm	11					11	<0.015**	No
Molybdenum	0.005 to 3	ppm	40	40				40	13.2	No
Nickel	0.005 to 5	ppm	270	50				50	30.3	No
o-Xylene	0.002 to 0.005	ppm	26	11				11	<0.005	No
PCB	0.1	ppm	55	33				33	0.06	No
pH		units						-	10.18	-
Potassium	0.01 to 1	ppm			5000	9000		5000-9000	5520	No (within range of crustal abundance)
Purgeable Hydrocarbons (C5-10)	0.2 to 0.5	ppm	55					55	<0.5**	No
Selenium	0.005 to 2.5	ppm	5.5	2.9				2.9	0.2	No
Silver	0.25 to 0.5	ppm	40	40				40	<1	No
Sodium	0.5	ppm	NA		910	23000		910-23000	2840	No (within range of crustal abundance)
Specific gravity(25C)		unitless						N/A	-	-
Strontium	0.5	ppm			78	260		78-260	450	**Yes**
Styrene	0.002 to 0.01	ppm	34	50				34	<0.01	No
Tetrachloroethane 1,1,1,2-	0.002 to 0.01	ppm	0.087	0.6				0.087	<0.01	No
Tetrachloroethane 1,1,2,2-	0.002 to 0.01	ppm	0.05					0.05	<0.01	No
Tetrachloroethylene	0.002 to 0.01	ppm	4.5					4.5	<0.01	No
Thallium	0.5	ppm	3.3	1				1	5.21	**Yes**
Tin	1	ppm		300				300	<2.5	No
Titanium	0.005 to 0.5	ppm			4800	5300		4800-5300	903	No
Toluene	0.002 to 0.005	ppm	68	0.37				0.37	0.069	No
trans-1,2-Dichloroethylene	0.002 to 0.01	ppm	55					55	<0.01	No
trans-1,3-Dichloropropene	0.002 to 0.005	ppm	0.18					0.18	<0.005	No
Trichloroethane 1,1,1-	0.002 to 0.01	ppm	6.1	50				6.1	<0.01	No
Trichloroethane 1,1,2-	0.02	ppm	0.05	50				0.05	<0.02	No
Trichloroethylene	0.002 to 0.01	ppm	0.91	0.01				0.01	<0.01	No
Trichlorofluoromethane	0.004 to 0.02	ppm	4					4	<0.02	No
Vanadium	0.005 to 0.5	ppm	86	130				86	34.5	No
Vinyl Chloride		ppm	0.032					0.032	<0.003	No
Zinc	0.005 to 0.5	ppm	340	360				340	3022	**Yes**
Zirconium	0.5	ppm				100		100	13	No

Table A.14: Screening of Soil COPCs for Locations Less than 30 m from Water for Ecological Assessment

Parameter	Detection Limit	Units	MOE 2011 (Table 9)	CCME SQG (industrial)	OTR98	Average Crustal Abundance	US EPA Region 5 RCRA	Selected Benchmark	Sample *et al.* 1996 Table 12	Max Soil Conc.	Carried Foward in Risk Assessment?
Acetone	0.05, 0.105, 0.15	ppm	0.5					0.5		<0.15	No
Acrolein	1	ppm					5.27	5.27		<1	No
Acrylonitrile	0.15	ppm					0.0239	0.0239		<0.15	No (based on toxicity rationale provided in Section 4.1.3.1.4)
Aluminum	1	ppm			27000	84000		27000-84000	1.93	10400	No (within range of crustal abundance)
Antimony	1	ppm	1.3	40				1.3		<2.5	No
Arsenic	2.5, 1	ppm	18					18		7.4	No
Barium	0.5	ppm	220	2000				220		70	No
Benzene	0.002 to 0.005	ppm	0.02	0.03				0.02		<0.005	No
Beryllium	0.2 to 0.5	ppm	2.5					2.5		0	No
Bismuth	0.5 to 1	ppm			0.1-13[a]	0.6		0.1-13[a]		<2.5	No (within range of crustal abundance)
Boron	2.5	ppm	36					36		9	No
Bromodichloromethane	0.01	ppm	0.05					0.05		<0.01	No
Bromoform	0.002	ppm	0.05					0.05		<0.02	No
Bromomethane	0.003 to 0.02	ppm	0.05					0.05		<0.02	No
Bulk Density(free fall)		lbs/cu ft						-			No
Cadmium	0.1	ppm	1.2	22				1.2		0.2	No
Calcium	0.01	ppm			58000	53000		53000-58000		295000	No (based on toxicity rationale provided in Section 4.1.3.1.4)
Calcium	1	ppm			58000	53000		53000-58000		295000	No (based on toxicity rationale provided in Section 4.1.3.1.4)
Carbon Tetrachloride	0.002 to 0.1	ppm	0.05	50				0.05		<0.01	No
Chlorobenzene	0.002 to 0.005	ppm	0.05	10				0.05		<0.005	No
Chlorodibromomethane	0.002 to 0.01	ppm	0.05					0.05		<0.01	No
Chloroethane	0.002 to 0.01	ppm	0.02					0.02		<0.01	No
Chloroethylvinyl ether 2-	0.1	ppm						-		<0.1	
Chloroform	0.002 to 0.02	ppm	0.05	50				0.05		<0.01	No
Chloromethane	0.003 to 0.02	ppm					10.4	10.4		<0.02	No
Chromium	0.5	ppm	70	87				70		16	No
Dichloroethylene cis-1,2-	0.002 to 0.01	ppm	0.05					0.05		<0.01	No
Dichloropropene cis-1,3-	0.002 to 0.005	ppm	0.05					0.05		<0.005	No
60Co		pCi/kg						-		7300	**Yes**
Cobalt	0.5	ppm	22	300				22		9.6	No
Copper	0.5	ppm	92	91				91		19.9	No
134Cs	<50	pCi/kg						-		<500	**Yes**
137Cs	<50	pCi/kg						-		<500	**Yes**
Dichlorobenzene 1,2-	0.001 to 0.01	ppm	0.05	10				0.05		<0.01	No
Dichlorobenzene 1,3-	0.002	ppm	0.05	10				0.05		<0.01	No
Dichlorobenzene 1,4-	0.002 to 0.01	ppm	0.05	10				0.05		<0.01	No
Dichloroethane 1,1-	0.002 to 0.01	ppm	0.05	50				0.05		<0.01	No
Dichloroethane 1,2-	0.01	ppm	0.05	50				0.05		<0.01	No
Dichloroethylene 1,1-	0.002	ppm	0.05	50				0.05		<0.0024	No
Dichloromethane	0.003	ppm		50				50		-	No
Dichloromethane	0.01	ppm		50				50		<0.01	No
Dichloropropane 1,2-	0.002 to 0.01	ppm	0.05	50				0.05		<0.01	No
Ethylbenzene	0.002 to 0.005	ppm	0.05	0.082				0.05		<0.005	No
Ethylene dibromide	0.002 to 0.005	ppm	0.05					0.05		<0.005	No
Extractable Hydrocarbons (C10-24)	10 to 100	ppm	10					10		<10 - <100	No
Hexanone,-2	0.025	ppm						N/A		-	No
Iron	0.5	ppm			33000	71000		33000-71000		21300	No (within range of crustal abundance)
Lead	0.005 to 0.5	ppm	120	600				120		7.7	No
m/p-Xylene	0.002 to 0.005	ppm	0.05	11				0.05		<0.005	No
Magnesium	0.002 to 0.2	ppm			16000	32000		16000-32000	1000	9500	No (within range of crustal abundance)
Manganese	0.5	ppm				1400		1400	88	648	No
Methyl ethyl ketone	0.008 to 0.15	ppm	0.5					0.5		<0.15	No
Methyl Isobutyl Ketone	0.025 to 0.07	ppm	0.5					0.5		<0.07**	No
Methyl-t-Butyl Ether	0.015 to 0.002	ppm	0.05					0.05		<0.015**	No
Molybdenum	0.005 to 3	ppm	2	40				2		1.47	No
Nickel	0.005 to 5	ppm	82	50				50		21.9	No
o-Xylene	0.002 to 0.005	ppm	0.05	11				0.05		<0.005	No
PCB	0.1	ppm	0.3	33				0.3		0	No
pH		units						-		9.21	-
Potassium	0.01 to 1	ppm			5000	9000		5000-9000		2400	No (within range of crustal abundance)
Purgeable Hydrocarbons (C5-10)	0.2 to 0.5	ppm	25					25		<0.5**	No
Selenium	0.005 to 2.5	ppm	1.5	2.9				1.5		0	No
Silver	0.25 to 0.5	ppm	0.5	40				0.5		<1	No
Sodium	0.5	ppm	NA		910	23000		910-23000		800	No (within range of crustal abundance)
Specific gravity(25C)		unitless						N/A		-	-
Strontium	0.5	ppm			78	260		78-260	263	395	**Yes**
Styrene	0.002 to 0.01	ppm	0.05	50				0.05		<0.01	No
Tetrachloroethane 1,1,1,2-	0.002 to 0.01	ppm	0.05	0.6				0.05		<0.01	No
Tetrachloroethane 1,1,2,2-	0.002 to 0.01	ppm	0.05					0.05		<0.01	No
Tetrachloroethylene	0.002 to 0.01	ppm	0.05					0.05		<0.01	No
Thallium	0.5	ppm	1	1				1		3.4	**Yes**
Tin	1	ppm		300				300		<2.5	No
Titanium	0.005 to 0.5	ppm			4800	5300		4800-5300		171	No
Toluene	0.002 to 0.005	ppm	0.2	0.37				0.2		0	No
trans-1,2-Dichloroethylene	0.002 to 0.01	ppm	0.05					0.05		<0.01	No
trans-1,3-Dichloropropene	0.002 to 0.005	ppm	0.05					0.05		<0.005	No
Trichloroethane 1,1,1-	0.002 to 0.01	ppm	0.05	50				0.05		<0.01	No
Trichloroethane 1,1,2-	0.02	ppm	0.05	50				0.05		<0.02	No
Trichloroethylene	0.002 to 0.01	ppm	0.05	0.01				0.01		<0.01	No
Trichlorofluoromethane	0.004 to 0.02	ppm	0.25					0.25		<0.02	No
Vanadium	0.005 to 0.5	ppm	86	130				86		15.4	No
Vinyl Chloride		ppm	0.02					0.02		<0.003	No
Zinc	0.005 to 0.5	ppm	290	360				290		41.8	No
Zirconium	0.5	ppm				100		100		8.8	No

Appendix B Ecological Receptor Profiles

One of the key considerations, which defines the scope of a risk assessment, is the selection of ecological receptors. In selecting ecological receptors it is important to identify plants and animals that are likely to be most exposed to the effects of the project. As it is not possible to evaluate all ecological species at a site, representative VECs are generally selected based on several criteria as discussed in Section 4.1.1 of the main report.

This appendix details the aquatic and terrestrial ecological receptors (groups or species) selected for the assessment.

B.1 Aquatic Biota

B.1.1 Benthic Invertebrates

Benthic invertebrates live and feed within sediments and provide a sediment to fish pathway link and between aquatic and terrestrial ecosystems. Many species feed on decaying organic matter and thereby form an important link between the decomposer and primary consumer levels. Small crustaceans such as the benthic amphipod *Diporeia* spp. and worms (oligochaetes) have historically dominated the open water benthic communities of Lake Ontario. Representatives of the more environmentally sensitive groups such as Ephemeroptera and Trichoptera are generally rare. Most of the dominant taxa had higher abundances at sites within or close to the thermal plumes than at reference sites. In shallow areas, gastropods and bivalves have low relative abundances presumably due to wave abrasion and/or unsuitable substrates at shallow locations. Appearance of chironomid, amphipod and oligochaete increased in the shallows (1-m depth) in the vicinity of the discharge channels where the algae, *Cladophora*, are present.

Aquatic invertebrates are represented by the generic benthos in the ecological model.

B.1.2 Aquatic Plants

B.1.2.1 Narrow-leaved cattail

The Narrow-leaved Cattail (*Typha angustifolia*) is a native emergent wetland species, growing to over 1 m tall. It is commonly found in the northern hemisphere in marshes, ponds, and ditches (Newmaster *et al.*, 1997). Cattail are a good source of material for nest building. Cattails are used by the red-winged blackbird and muskrat for nesting, and as feed for the muskrat.

Narrow-leaved cattail was observed during flora inventories within the PN site as recently as 2011 (OPG, 2012f).

B.1.3 Amphibians and Reptiles

Amphibians (class: Amphibia) typically inhabit a wide variety of habitats with most species bridging terrestrial and aquatic ecosystems during their life cycle. Common animals within the class include frogs and salamanders. Amphibians rely on surface water for reproduction as larvae are typically born in water. The young generally undergo metamorphosis from larva with gills to an adult air-breathing form with lungs. With their complex reproductive needs and permeable skins, amphibians are often used as ecological indicators.

Reptiles (class: Reptilia) are cold blooded animals with scales or scutes rather than fur and feathers like mammals and birds. Common animals within the class include turtles, snakes and lizards. Most reptiles are oviparous (egg-laying) but do not require water bodies in which to breed.

B.1.3.1 Northern Leopard Frog

The northern leopard frog (*Lithobates pipiens*) is a medium sized, semi terrestrial frog (family: Ranidae). Breeding typically occurs in permanent and semi-permanent shallow, open wetlands that are typically no deeper than 2.0 m in depth, are neutral pH and lack fish (COSEWIC, 2009). The eggs hatch within a period of 9 days and metamorphosis occurs approximately 60 to 90 days after hatching. During the tadpole stage, which is a sensitive life stage, the exposure of tadpoles and fish to constituents of potential concern (COPCs) is expected to be similar (i.e., gills for breathing, absorption through skin, similar feeding habits).

Northern Leopard frog was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.3.2 Midland Painted Turtle

Midland painted turtle (*Chrysemys picta marginata*) is the most common turtle species in Ontario. There are three sub-species of the midland painted turtle, two of which are found in Ontario. Painted turtles inhabits waterbodies, such as ponds and marshes that provide abundant basking sites and aquatic vegetation. Northern populations of painted turtles may take up to five years to reach sexual maturity. Reproducing females lay eggs in May to early July. Nests are dug in loamy or sandy soils in sunny areas. Hatchlings may emerge in the fall but may overwinter in the nest and emerge the following spring. Painted turtles are opportunistic feeders and eat algae, invertebrates, fish, frogs, carrion and vegetation.

Midland painted turtle was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4 Fish

B.1.4.1 Alewife

Alewife (*Alosa pseudoharengus*) is a member of the herring family. Alewife are found in Lake Ontario, although there is debate as to whether the alewife population found in Lake Ontario is native or introduced. In its native range, alewives are anadromous, they are quite capable of completing its life cycle in freshwater environments. Adult alewife average about 6 to 7 inches in length in the freshwater variety. Alewives live for about 6 to 7 years and usually begin to reproduce around two years of age. Alewife spawn once a year from late April to early June. Females randomly deposit 10,000 to 12,000 eggs. In less than a week, the young alewives hatch and begin feeding primarily on zooplankton. In the fall, the young alewives make their way back to the sea or into the deep waters of freshwater lakes or rivers. Adult alewives feed on zooplankton, aquatic insects, and small fish (Indiana DNR, n.d.).

Alewife was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4.2 Smallmouth Bass

Smallmouth bass (*Micropterus dolomieui*), also called the black bass (or largemouth bass), is found in southern Ontario as far north as Cochrane and west to the Manitoba border. It prefers rocky lakes and rivers. Smallmouth bass concentrate around shoreline rocks and points as well as offshore shoals, often in deep water. Adults have an average weight of 1 to 1.4 kg. Sexual maturity is generally attained in males in their third to fifth year and in females in their fourth to sixth year. Smallmouth bass spawn in June. Females may lay up to 21,100 eggs. After spawning, the males guard the nest. Larval and young smallmouth bass feed on suspended zooplankton then on small insects and crustaceans following dispersal from nesting territories. Adults eat aquatic insects, large crustaceans, and small fish (Funnell, 2012). Smallmouth bass is a good natural indicator of a healthy environment

Smallmouth bass was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4.3 Northern Pike

Northern pike (*Esox lucius*) is a freshwater species found throughout the northern hemisphere. Pike are found in sluggish streams and shallow, weedy places in lakes, as well as in cold, clear, rocky waters. Pike can grow to large sizes, but typically are 46 to 76 cm in length and weigh 0.9-2.3 kg (DFO, 2013a). Pike reproduce in areas with rich submersible vegetation nearby. Pike are known to spawn in spring when the water temperature first reaches 9°C. After mating, males tend to stay in the area for a few extra weeks. Pike are typically solitary ambush predators. Young pike feed on small invertebrates and quickly move on to bigger prey. When the body length is 4 to 8 cm they start feeding on small fish.

Northern pike was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4.4 Brown Bullhead

Brown bullhead (*Ameriurus nebulosus*) is a medium sized member of the catfish family. Brown bullhead are found in both fresh and brackish waters. They generally inhabit lakes, ponds, impoundments, and low-gradient streams, with shallow water and muddy bottoms. This warm water species is a benthic dweller. It can tolerate lower oxygen levels and higher water temperatures than most other fish species. Brown bullheads do not migrate seasonally or to breed. Brown bullheads average 230 to 305 mm in length. A typical adult weighs approximately 454 g but may reach as much as 1.8 kg. Brown bullheads spawn in the late spring. One or both parents excavate a shallow nest in mud or sandy substrate near the cover of logs, rocks, or vegetation, in water less than 0.6 m deep. Bullheads lay between 2,000 and 10,000 eggs in an adhesive cluster. Both parents guard the eggs and aerate them by fanning, physically stirring them up, and taking them into the mouth and spitting them back out. Larvae stay within the nest under the protection of the parents for their first week. After leaving the nest larvae remain in dense schools until they reach approximately 50 mm. Brown bullheads are opportunistic nocturnal bottom feeders, consuming a variety of plant, animal, and detrital foods. Juveniles are primarily carnivorous, and feed mostly on invertebrates, as well as eggs and larvae of other fish. Leeches, mollusks, fish eggs, and frogs are also common foods of adults. Brown bullheads are able to digest and utilize filamentous algae and may consume large amounts of this food source (US EPA, n.d.).

Brown Bullhead was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4.5 Round Whitefish

The round whitefish (*Prosopium cylindraceum*) is a coldwater lake fish. Spawning migrations may be undertaken by some round whitefish populations. Adults typically weigh between 454 g and 1360 g. Spawning occurs along lake and stream shorelines in late fall or early winter in southern Canada over gravel shoals or river mouths. Round whitefish are shallow water bottom feeders. Females lay and average of 5,000 to 12,000 eggs. Round whitefish hatch as sac fry in March to May and remain on the bottom, seeking shelter in rubble and boulders. Older juveniles, age 1 and 2, live in the same areas as adults but in shallower water and tend to move into deeper and faster water as they grow. Round whitefish eat a variety of invertebrates including mayfly larvae, chironomid larvae, small mollusks, crustaceans, fish, and fish eggs. Fish in lakes may eat more molluscs and small crustaceans than those in rivers (DFO, 2007; IF&W, 2001).

Round whitefish was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4.6 White Sucker

White sucker (*Catostomus commersonni*) is a freshwater fish found in lakes and streams across North America. It is a bottom feeding fish that resides mainly in shallow, warm waters. The white sucker spawns in spring, April or May, in moderate to swift riffles, in gravelly and stony areas, when the water temperature is above 4°C. Spawning may also take place in the shallow water of lakes. Females randomly scatter 30,000 to 130,000 eggs over the spawning grounds. Fry (1.2 cm in length) feed primarily on plankton and other small free-floating invertebrates. When the white sucker reaches a length of about 1.6 to 1.8 cm, it begins bottom feeding. White suckers are preyed upon by birds, fishes, lamprey and mammals. In this assessment, white suckers are assumed to spend half of their time at the sediment surface and the other half immersed in the water (Ontario Fish Species, n.d.).

White sucker was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4.7 Lake Trout

Lake trout (*Salvelinus namaycush*) is a freshwater char. Lake trout mainly reside in deep lakes in northern North America where the water is cold and oxygen-rich. In spring, lake trout are widely dispersed in the shallow waters of their habitat but, as soon as the water warms they migrate to deeper and colder water. Adults are generally 38 to 52 cm in length and have an average weight of 4.5 kg. In general, lake trout spawn on rocky reefs or shoals in the fall. Spawning takes place at night during which the eggs are scattered over the rocky bottom. The eggs remain among the rocks for weeks and hatch the following spring. Within a month or so after hatching, the young lake trout usually seek deeper water and are thought to be reclusive, plankton feeders during their first few years of life. The lake trout's diet varies depending on the season; in the summer months they become more planktivorous and during the cooler months, they become piscivorous (DFO, 2013b).

Lake trout was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.4.8 Walleye

Walleye (*Sander vitreus*) is the largest member of the perch family. The walleye is native to the freshwaters of North America. The walleye is a cool-water species that prefers turbid waters in either large, shallow lakes or rivers. Adults are generally 33 to 51 cm in length, with an average weight of 0.45 to 1.4 kg. Walleye spawn in the spring or early summer. Adults migrate to the rocky areas in white water below impassable falls and dams in rivers, or boulder to coarse-gravel shoals of lakes. Spawning takes place at night and the eggs fall into crevices in the rocky substrate. The eggs hatch in 12 to 18 days and by 10 to 15 days after hatching, the young disperse into the upper levels of open water. As the walleye increases in size, its diet shifts from invertebrates to fishes (DFO, 2013c).

Walleye was observed during aquatic inventories within the PN site as recently as 2010 (OPG, 2012).

B.1.4.9 American Eel

The American eel (*Anguilla rostrata*) is a freshwater species found on the eastern coast of North America, and enter Ontario through the St. Lawrence River and Lake Ontario. The eel has a snake-like body and a dorsal fin that extends from half-way down the length of its back to the underside of its body. At maturity, eel range from 75 to 100 centimetres (cm) in length and weigh one to three kilograms. American eels have a complex life cycle, which begins with breeding in the Sargasso Sea in the Atlantic Ocean. Young eels migrate to inland streams where they proceed to feed and mature in freshwater bodies for 10 to 25 years, before returning to the Sargasso Sea to spawn. The majority of American eels found in Ontario are large, highly fecund (egg-laden) females. The eel is an important indicator of ecosystem health, and is a top predator. The American eel is designated an endangered species and is protected under the Provincial *Endangered Species Act, 2007*. The American eel is designated as "threatened" under COSEWIC.

American eel was observed during aquatic inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.5 Aquatic Birds

Birds are mobile receptors that will forage from a large home range. During breeding and rearing of young, the home range is often reduced.

B.1.5.1 Trumpeter Swan

The trumpeter swan (*Cygnus buccinator*) is a large bird with white feathers and black legs and feet. Adult males weigh an average of 12 kg. The female is slightly smaller, averaging 10 kg. Trumpeter Swans are found in Canada year round. In winter they congregate in areas where water does not freeze and food is available. Breeding birds select nest sites that are surrounded by water from 10 cm to several metres in depth. They frequently construct their nests on old beaver houses and dams or emergent vegetation even before a site is completely free of ice. Most nests are used year after year, usually by the same pair. A female produces an average of 5 or 6 eggs which she incubates for about 32 days until they hatch. The cygnets grow from approximately 300 g at hatching to approximately 7 kg at fledging. During summer, trumpeters feed on leaves, tubers, and roots of aquatic plants at depths up to 1 m, which they reach by dipping their heads and necks, or by up-ending. The cygnets, or young, feed predominately on insects and other invertebrates for the first few weeks of life but may start feeding on plants before they are two weeks old (EC & CWF, 2013).

Trumpeter swan was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.5.2 Ring-Billed Gull

The ring-billed gull (*Larus delawarensis*) is a medium-sized gull, measuring 45 cm from bill to tail, having a 50-cm wingspan and weighing about 0.7 kg. The ring-billed gull is probably the most numerous gull in North America. Ring-billed Gulls nest in colonies of hundreds or thousands of pairs. A small percentage of Canadian ring-billed gulls winter on the Great Lakes, usually near open water on lakes Erie and Ontario and the Niagara River. Breeding colonies arrive in Eastern Canada in late February or early March. They lay a clutch of three eggs beginning in April in the Great Lakes area. Ring-billed Gulls incubate their eggs for approximately 25 to 27 days until they hatch. The young generally fledge five to six weeks later. The diet of Ring-billed Gulls is variable. These gulls are opportunistic feeders that readily switch from one type of food to another. During the spawning season they will feed primarily on smelt; after a rain they seek out earthworms; during farmers' ploughing and harvesting seasons they feed on insect larvae and mice. At other times of the year they will feed on carrion, flying insects, and the young of other birds, especially small ducklings (EC & CWF, 2013).

Ring-billed gull was observed during terrestrial inventories within the PN site as recently as 2009 (OPG, 2012).

B.1.5.3 Common Tern

The common tern (*Sterna hirundo*) has a circumpolar range and is strongly migratory. It winters in coastal tropical and subtropical areas and breeds in the northern part of its range. Adults have an average length of 31 to 38 cm and an average weight of 93 to 200 g. Common terns arrive on northern breeding grounds from late April through mid-May (The Cornell Lab of Ornithology, n.d.(a)). They nest on any flat, poorly vegetated surface close to water. The female lays 1 to 4 eggs. The eggs hatch in around 21 or 22 days and the chicks fledge in 22 to 28 days. Like most terns, this species feeds by plunge-diving for fish. However, it is an opportunistic feeder and molluscs, crustaceans and other invertebrate prey may form a significant part of the diet in some areas (BTO, 2013).

Common tern was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.1.5.4 Bufflehead

The Bufflehead (*Bucephala albeola*) is Canada's smallest diving duck. Males average 450 g in weight and females about 340 g. During migration they may carry up to an additional 115 g of fat. Their breeding habitat is small ponds, usually in wooded areas. They are not gregarious and typically occur in groups of 10 birds or fewer. Their summer breeding range is north and west of the Great Lakes. Their Canadian overwinter range includes the west coast and favoured spots around Lake Ontario and the southern coasts of New Brunswick and Nova Scotia. Buffleheads nest in tree cavities. The female lays a clutch of 7 to 11 eggs. Hatching occurs about 30 days later and ducklings remain in the

nest only 24 to 36 hours before being lead to the nearest waterbody. The young may be eaten by pike or other predators. The Buffleheads' main foods are arthropods, mostly insect larvae in freshwater and small crustaceans, such as shrimps, crabs, amphipods, in salt water. In fall they eat many seeds of aquatic plants, and in winter they take small marine snails or freshwater clams in their respective habitats (EC & CWF, 2013).

Bufflehead was observed during terrestrial inventories within the PN site as recently as 2008 (OPG, 2012).

B.1.6 Aquatic Mammals

B.1.6.1 Muskrat

The muskrat (*Ondatra zibethicus*) is a large rodent, measuring approximately 50 cm from tip of the nose to tail, and weighing on average 1 kg. Muskrats exist all over North America, from the Arctic Ocean in the north to the Gulf of Mexico in the south, from the Pacific Ocean in the west to the Atlantic Ocean in the east. Muskrats prefer freshwater marshes, marshy areas of lakes, and slow-moving streams. The preferred water depth in these areas is 1 to 2 m, deep enough not to freeze fully during the winter but shallow enough to allow aquatic vegetation to grow. Muskrats nest in compact mounds of partially dried and decayed plant material such as cattails bulrushes. In winter, muskrats generally occupy lodges that they build through burrowing underneath their mounds (EC & CWF, 2013).

Muskrats mainly feed on aquatic plants such as cattails, bulrushes, horsetails, or pondweeds; however, they prefer cattails. When aquatic plants are unavailable, muskrats are also known to feed on fish, frogs, and clams. Breeding generally occurs in March, April, or May. Birth of the litter usually occurs within 1 month of mating and usually contains 5 to 10 young. Breeding can occur multiple times throughout the season (EC & CWF, 2013).

Muskrat was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.2 Terrestrial Biota

B.2.1 Earthworms

Earthworms live in soil, and depending on the species they either move vertically or horizontally in different soil layers. Earthworms acquire their nutrition through the organic matter in soil as well as the decomposing remains of other animals. They can devour one third of their own body weight per day.

B.2.2 Terrestrial Plants

B.2.2.1 Pines

Various pines have been observed during terrestrial inventories within the PN site between 2008 and 2011. White Pine and Scots Pine were observed as recently as 2011. Austrian Pine was observed as recently as 2008 (OPG, 2012).

B.2.2.2 Chokecherry

Chokecherry (*Prunus virginiana ssp. virginiana*) is a small tree or shrub growing to approximately 8 m, and are native to North America (Ontario Trees & Shrubs, n.d.). Chokecherries are a food source for birds.

Chokecherry was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.2.2.3 New England Aster

New England Aster (*Symphyotrichum novae-angliae* formerly *Aster novae-angliae*) is a flowering herbaceous perennial plant, growing up to approximately 2 m. It is native to the majority of North America east of the Rocky Mountains, with the exception of parts of the southern United States and far northern Canada (USDA, 2003).

New England Aster was observed during terrestrial inventories within the PN site as recently as 2008 (OPG, 2012).

B.2.2.4 Eastern Hemlock

Eastern Hemlock (*Tsuga canadensis*) is a coniferous tree, growing up to 30 m. It is native to eastern North America. In Canada, the Eastern Hemlock is found from New Brunswick and Nova Scotia to southern Quebec and Ontario (USDA, 2002a).

Eastern Hemlock was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.2.2.5 Red Ash

Red Ash (*Fraxinus pennsylvanica*) is a medium sized deciduous tree, growing up to 12 to 25 m tall and 60 cm diameter trunk. The Red Ash is native to eastern and central North America, and occurs throughout southern and eastern Ontario (Northern Ontario Plant Database, 2013).

Red Ash was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.2.2.6 Sandbar Willow

Sandbar Willow (*Salix exigua*) is a deciduous shrub, growing up to 4 to 7 m. The Sandbar Willow is native to North America, primarily in the west. Sandbar Willow provides wood and shelter for a number of birds (USDA, 2002b).

Sandbar Willow was observed during terrestrial inventories within the PN site as recently as 2008 (OPG, 2012).

B.2.3 Terrestrial Birds

B.2.3.1 Red-winged Blackbird

The red-winged blackbird (*Agelaius phoeniceus*) is one of the most abundant birds across North America. Adults are approximately 17 to 23 cm in length and weigh 32 to 77 g. Red-winged blackbirds breed in wetlands across. They winter in southern British Columbia, extreme southern Ontario, Nova Scotia and rarely in southern Quebec. Red-winged Blackbirds roost in flocks in all months of the year. In summer small numbers roost in the wetlands where the birds breed. Winter flocks can be congregations of several million birds, including other blackbird species and starlings. Each morning the roosts spread out, traveling as far as 50 miles to feed, then re-forming at night. Red-winged Blackbirds build their nests low among vertical shoots of marsh vegetation, shrubs, or trees. Females lay a clutch of 2 to 4 eggs. The eggs hatch within 11 to 13 days, and the young fledge approximately 11 to 14 days later. Red-winged Blackbirds eat mainly insects in the summer and seeds, including corn and wheat, in the winter. Sometimes they feed by probing at the bases of aquatic plants with their bills, prying them open to get at insects hidden inside. In fall and winter they eat weedy seeds such as ragweed and cocklebur as well as native sunflowers and waste grains (EC & CWF, 2013).

Red-winged blackbird was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.2.3.2 Red-tailed Hawk

The red-tailed hawk (*Buteo jamaicensis*) is likely the most common hawk in North America. Adult males average 45 to 56 cm in length and weigh and average of 690 to 1300 g. Adult females are somewhat larges, averaging 19.7 to 25.6 cm in length and weighing 900 to 1460 g. Red-tailed Hawks occupy just about every type of open habitat on the continent. They typically put their nests in the crowns of tall trees, cliff ledge or on artificial structures such as window ledges and billboard platforms. Females typically lay 1 to 5 eggs. The eggs are incubated for about 28 to 35 days and the young fledge in about 42 to 46 days. Mammals make up the bulk of most Red-tailed Hawk meals. They prey upon voles, mice, wood rats, rabbits, snowshoe hares, jackrabbits, and ground squirrels. The hawks also eat birds, snakes and carrion. Individual prey items can weigh anywhere from less than an ounce to more than 5 pounds (The Cornell Lab of Ornithology, n.d.(b)).

Red-tailed hawk was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.2.4 Terrestrial Mammals

B.2.4.1 Red Fox

The red fox (*Vulpes vulpes*) is a small mammal, ranges in length between 90 to 112 cm, and weighs approximately 4.54 kg (US EPA, 1993). Red foxes are found throughout Canada in all provinces and territories. They generally occupy a home range between 4 to 8 km^2 and reside in a main underground den and one or more other burrows within their home range. The tunnels are up to 10 m long and lead to a chamber 1 to 3 m below surface. Foxes breed between late December and mid-March, and pups are born from March through May, with litter sizes ranging from 1 to 10. Pup-rearing is the primary focus of the red fox during spring and early summer. Their diet is predominantly small mammals such as mice and voles, but they also eat insects, fruits, berries, seeds and nuts. Their diet varies with the seasons, eating mainly small mammals in fall and winter, nesting waterfowl in the spring, and insects and berries in the summer (EC & CWF, 2013).

Red fox was observed during terrestrial inventories within the PN site as recently as 2011 (OPG, 2012).

B.2.4.2 Meadow Vole

The meadow vole (*Microtus pennsylvanicus*) is a small herbivorous rodent, measuring 8.9 to 13 cm from head to tail, and weighing between 0.02 to 0.04 kg. The meadow vole is found across Canada, Alaska and the northern United States. They can be found mainly in meadows, lowland fields, grassy marshes, and along rivers and lakes. They are also occasionally found in flooded marshes, high grasslands near water, and orchards or open woodland if grassy (US EPA, 1993).

The meadow vole breeds throughout the year, but breeding peaks from April to October. Gestation lasts approximately 21 days, with litter sizes ranging from 1 to 9 (NatureServe, 2012). Meadow voles mainly feed on shoots, grass, and bark. Voles are prey for hawks and owls as well as several mammalian predators such as short-tailed shrews, badgers, and foxes (US EPA, 1993).

Meadow vole was observed during terrestrial inventories within the PN site earlier than 2006 (OPG, 2012; Golder, 2007).

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Appendix C Limiting Gross Beta/Gamma Radionuclides for Ecological Receptors

Beta and gamma emissions from PNGS are measured as a gross value, rather than by individual radionuclide. In 2003, a study by the Candu Owners Group (COG, 2003) sought to characterize the effluent from the nuclear power stations. However, it is difficult to assign percentages of gross beta/gamma effluent to individual radionuclides using the information available. Without a thorough understanding of the proportions of radionuclides in composition of the gross beta gamma emissions, it is conservative to choose on radionuclide to be representative of the gross value. In addition, it would be impractical to assess twenty-two radionuclides when one can be chosen to conservatively represent their effects.

To choose the representative radionuclide, a derived release limit was calculated for beta and gamma radionuclides in the PNGS emission. Since beta/gamma is not a concern in the air pathway for ecological receptors, only the liquid effluents were considered. Derived release limits (DRLs) are calculated to represent the release rate that would cause the aquatic biota in the outfall to receive a dose equal to the aquatic radiation benchmark (9.4 mGy/d) due to releases of a radionuclide to surface water during normal operations in a year.

The radionuclides considered in the determination of the DRLs for gross beta-gamma in water were taken from OPG (2010a and 2010b). The list is as follows: ^{32}P, ^{35}S, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{59}Fe, ^{60}Co, ^{90}Sr (^{90}Y), ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{113}Sn, ^{124}Sb, ^{125}Sb, ^{131}I, ^{137}Cs, ^{154}Eu, ^{153}Gd, ^{160}Tb, ^{65}Zn.

Four receptors were chosen to representative of those that may be exposed to the effluent at the outfall of the PNGS: fish, bottom-dwelling fish, snail and invertebrate. These receptors were chosen represent the effect on both water and sediment concentrations since they have varied occupancy factors (in water, on sediment and in sediment). The occupancy factors of each receptor are summarized in Table C.1.

Table C.1: Occupancy Factors Assumptions for the Aquatic Biota

Aquatic Biota	OF_s	OF_{ss}	OF_w
Fish			1
Bottom Dwelling Fish		0.25	0.75
Snail	0.5	0.5	
Benthic Invertebrates	1		

C.1 Methodology

Radiation dose to aquatic biota due to the release of waterborne effluents is determined as per CSA N288.6 (2012). The total radiation dose to biota is the sum of the internal and external dose components for each radionuclide ($D_{int} + D_{ext}$).

$$D_{int} = DC_{int} C_t$$
$$D_{ext} = DC_{ext}[(OF_w+0.5OF_{ws}+0.5OF_{ss})C_w + (OF_s+0.5OF_{ss})C_s]$$

where:

D_{int}	=	internal radiation dose (µGy/d)
D_{ext}	=	external radiation dose (µGy/d)
DC_{int}	=	internal dose coefficient ((µGy/d)/(Bq/kg))
DC_{ext}	=	external dose coefficient ((µGy/d)/(Bq/kg))
C_t	=	whole body tissue concentration (Bq/kg fw)
C_w	=	water concentration (Bq/L)
C_s	=	sediment concentration (Bq/kg fw)
OF_w	=	occupancy factor in water
OF_{ws}	=	occupancy factor at water surface
OF_{ss}	=	occupancy factor at sediment surface
OF_s	=	occupancy factor in sediment

The tissue concentrations (C_t) for the aquatic biota were derived using bioaccumulation factors (BAFs), as follows:

$$C_t = C_m \, BAF$$

where:

C_t	=	whole body tissue concentration (Bq/kg fw)
C_m	=	media concentration (Bq/L or Bq/kg)
BAF	=	bioaccumulation factor (L/kg or kg/kg)

By setting the total dose to 9.4 mGy/d, the dose equation above can rearranged to solve for concentration in water or sediment. The relationship between water concentration and sediment concentration is:

$$C_{s(fw)} = \frac{\theta \, C_w \, \rho_w + (1-\theta) \, C_w \, K_d \, \rho_s}{\theta \, \rho_w + (1-\theta) \, \rho_s}$$

$$C_{s(dw)} = C_{s(fw)} / f_{dw}$$
$$f_{dw} = \frac{(1-\theta) \, \rho_s}{\theta \, \rho_w + (1-\theta) \, \rho_s}$$

where:

$C_{s(fw)}$	=	concentration in sediment (Bq/kg FW)
C_w	=	concentration in water (Bq/L)
ρ_w	=	density of water (1 kg/L)
θ	=	sediment porosity (unitless)
K_d	=	distribution coefficient (L/kg solid)
ρ_s	=	density of solids (kg/L)

$C_{s(dw)}$ = concentration in sediment (Bq/kg DW)
f_{dw} = dry weight fraction of sediment (unitless)

The water concentration calculated from the benchmark dose is converted into a DRL by multiplying the water concentration by the average annual release rate (i.e., CCW flow rate). The release rate was assumed to be the average of the annual average flow rates from 2007 to 2011 (3.02E+12 L/y).

C.2 Assumptions and Parameters

Bioaccumulation factors (BAFs) relate the COPCs in the environmental media to the concentration in the receptor. The BAFs used in to determine tissue concentration were taken from CSA (2008) and IAEA (2010). These values are summarized in Table C.2.

Table C.2: Bioaccumulation Factors (BAFs) for Aquatic Biota (L/kg fw)

Radionuclide	Fish & Bottom-Dwelling Fish	Snail & Benthic Invertebrate
Co-60	54	110
Cr-51	55	390
Cs-137	3500	99
Eu-154	130	600
Fe-55	240	2800
Fe-59	240	2800
Gd-153	30	1000
I-131	6	10
Mn-54	240	690
Nb-95	300	100
P-32	26000	21000
Ru-106	55	11
S-35	800	100
Sb-124	37	81
Sb-125	37	81
Sc-46	190	1500
Sn-113	3000	590
Sr-90	2	240
Tb-160	410	1000
Y-90	20	1000
Zn-65	5000	1800
Zr-95	7	3000

Notes:
[1] Values from CSA (2008) except Eu-154, Ru-106, Sb-124, Sb-125, Sc-46 and Tb-160 from IAEA (2010)
[2] Values from IAEA (2010)

Radiation dose coefficients (DCs) for the aquatic biota are shown in Table C.3. These DCs were taken from ICRP (2008) and the ERICA Tool (2011). Surrogate species were used were selected to represent the receptors. The ICRP (2008) Trout was used to represent all fish, the ERICA Tool (2011) gastropod and insect larvae were used for the snail and benthic invertebrate, respectively.

Table C.3: Radiation dose coefficients (DCs) for aquatic biota [(µGy/d)/(Bq/kg)]

Radionuclide	All Fish		Snail		Benthic Invertebrate	
	Internal DC	External DC	Internal DC	External DC	Internal DC	External DC
Co-60	5.10E-03	3.10E-02	1.90E-03	3.36E-02	1.90E-03	3.36E-02
Cr-51	1.30E-04	3.80E-04	nd	nd	nd	nd
Cs-137	4.40E-03	6.80E-03	3.36E-03	7.92E-03	3.36E-03	7.92E-03
Eu-154	6.00E-03	1.50E-02	4.08E-03	1.70E-02	4.08E-03	1.70E-02
Fe-55	nd	nd	nd	nd	nd	nd
Fe-59	nd	nd	nd	nd	nd	nd
Gd-153	nd	nd	nd	nd	nd	nd
I-131	3.30E-03	4.60E-03	2.64E-03	5.28E-03	2.64E-03	5.28E-03
Mn-54	1.50E-03	1.00E-02	3.12E-04	1.13E-02	3.12E-04	1.13E-02
Nb-95	1.90E-03	9.30E-03	8.16E-04	1.03E-02	8.16E-04	1.03E-02
P-32	9.40E-03	2.60E-04	8.16E-03	1.49E-03	8.16E-03	1.49E-03
Ru-106	1.90E-02	3.80E-03	1.32E-02	9.36E-03	1.32E-02	9.36E-03
S-35	6.80E-04	4.60E-07	6.72E-04	2.88E-06	6.72E-04	2.88E-06
Sb-124	8.00E-03	2.20E-02	5.04E-03	2.64E-02	5.04E-03	2.64E-02
Sb-125	2.20E-03	5.10E-03	1.51E-03	5.76E-03	1.51E-03	5.76E-03
Sc-46	nd	nd	nd	nd	nd	nd
Sn-113	nd	nd	nd	nd	nd	nd
Sr-90	1.50E-02	5.60E-04	1.27E-02	2.88E-03	1.27E-02	2.88E-03
Tb-160	nd	nd	nd	nd	nd	nd
Y-90	nd	nd	nd	nd	nd	nd
Zn-65	1.10E-03	7.10E-03	nd	nd	nd	nd
Zr-95	2.90E-03	9.00E-03	1.80E-03	1.01E-02	1.80E-03	1.01E-02

Note:
nd indicates that no data were available for the radionuclide and receptor

The sediment distribution coefficients (K_d) used in the environmental partitioning calculations are listed in Table C.4. For COPCs that do not have a sediment K_d in CSA 2008 or IAEA 2010, the soil K_d found in IAEA 2010 was used. The sediment porosity and sediment density at the PN site is assumed to be 0.1 and 1.5 kg/L (for sand) respectively (CSA 2008).

Table C.4: Sediment Distribution Coefficients (L/kg dw)

Radionuclide	Distribution Coefficient (K_d)	Reference
Co-60	4.30E+04	IAEA 2010
Cr-51	6.70E+02	CSA 2008
Cs-137	9.50E+03	IAEA 2010
Eu-154	5.00E+02	IAEA 2010
Fe-55	5.00E+03	IAEA 2010
Fe-59	5.00E+03	IAEA 2010
Gd-153	9.90E+02	CSA 2008
I-131	4.40E+03	IAEA 2010
Mn-54	1.30E+05	IAEA 2010
Nb-95	1.60E+03	CSA 2008
P-32	9.00E+01	CSA 2008
Ru-106	3.20E+04	IAEA 2010
S-35	1.10E+02	CSA 2008
Sb-124	5.00E+03	IAEA 2010
Sb-125	5.00E+03	IAEA 2010
Sc-46	1.40E+03	CSA 2008
Sn-113	1.30E+03	CSA 2008
Sr-90	1.90E+02	IAEA 2010
Tb-160	9.90E+02	CSA 2008
Y-90	1.70E+03	CSA 2008
Zn-65	5.00E+02	IAEA 2010
Zr-95	1.00E+03	IAEA 2010

C.3 Results

Table C.5 summarizes the DRLs per radionuclide for each aquatic receptor. Some of the radionuclides do not have DRLs due to insufficient information for appropriate dose coefficients. This is an uncertainty, since these missing radionuclides may yield a lower limit. However, it is not expected to be an issue. The lowest release limit is for Mn-54 for invertebrates (2.12E+13 Bq/y). Mn-54 is released in very small quantities from PNGS, which are less than detection limits (COG, 2003), so it is not an appropriate representative of the gross beta/gamma component of the effluent released. The next limiting radionuclide is Co-60 for invertebrates (2.15E+13 Bq/y). Cobalt-60 is released at measureable amounts from PNGS and due to its low DRL, it will be used to represent gross beta/gamma emissions.

Table C.5: Derived Release Limits per Radionuclide (Bq/y)

Radionuclide	Fish	Bottom Dwelling Fish	Snail	Invertebrate
Co-60	9.45E+16	1.86E+14	2.87E+13	2.15E+13
Cr-51	4.05E+18	7.81E+17		
Cs-137	1.86E+15	1.26E+15	5.48E+14	4.12E+14
Eu-154	3.71E+16	1.74E+16	3.45E+15	2.79E+15
Fe-55	-	-	-	-
Fe-59	-	-	-	-
Gd-153	-	-	-	-
I-131	1.44E+18	1.22E+16	1.78E+15	1.34E+15
Mn-54	7.91E+16	1.91E+14	2.83E+13	2.12E+13
Nb-95	5.08E+16	1.25E+16	2.49E+15	1.87E+15
P-32	1.18E+14	1.19E+14	1.69E+14	1.69E+14
Ru-106	2.75E+16	1.91E+15	1.38E+14	1.04E+14
S-35	5.33E+16	5.33E+16	4.30E+17	4.29E+17
Sb-124	7.14E+16	2.21E+15	3.13E+14	2.35E+14
Sb-125	3.56E+17	9.49E+15	1.43E+15	1.08E+15
Sc-46	-	-	-	-
Sn-113	-	-	-	-
Sr-90	9.66E+17	6.76E+17	8.43E+15	8.13E+15
Tb-160	-	-	-	-
Y-90	-	-	-	-
Zn-65	3.42E+15	4.89E+15	-	-
Zr-95	1.43E+18	2.69E+16	2.33E+15	1.96E+15

Note:
Shaded cells refer to the lowest estimated DRLs per aquatic receptor.

C.4 References

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Appendix D Sample Calculations

Table D.1: Sample Calculation-Urban Resident (Toddler) Exposure and Risk to Morpholine

		Morpholine		
Environmental Media Concentration				
Water Concentration	A	1.66E-04	mg/L	Table 3.18
Human Exposure Factors (Toddler)				
Drinking Water Intake	B	0.6	L/d	Table 3.14
Days per Week/7 (D2)	C	1	d/d	Table 3.14
Weeks per Year/52 (D3)	D	1	wk/wk	Table 3.14
Body Weight	E	16.5	kg	Table 3.14
RAF_{GITi}	F	1	unitless	Table 3.14
TRV (Acceptable Daily Intake)	G	0.48	mg/kg d	Table 3.23
Human Dose and ILCR				
Ingestion Dose	H = (A*B*C*D*F)/E	6.05E-06	mg/kg d	Calculation
HQ	I = H/G	1.26E-05	unitless	Calculation

Table D.2: Sample Calculation-Sport Fisher Exposure and Risk to Hydrazine

Environmental Media Concentration		Hydrazine		
Water Concentration	A	4.96E-03	mg/L	Table 3.18
Fish Concentration				
Bioaccumulation Factor (BAF)	B	3.16	L/kg fw	Table 3.20
Tissue Concentration	C=A*B	0.02	mg/kg fw	Calculation
Human Exposure Factors (Adult)				
Fish Ingestion	D	0.111	kg/d	Table 3.14
Years Exposed (D4)	E	30	years	Table 3.14
D_{fish} (days in which consumption occurs)	F	365	d/yr	Table 3.14
Body Weight	G	70.7	kg	Table 3.14
Life Expectancy	H	70	years	Table 3.14
RAF_{GITi}	I	1	unitless	Table 3.14
TRV (Oral Slope Factor)	J	3	$(mg/kg\ d)^{-1}$	Table 3.23
Human Dose and ILCR				
Ingestion Dose	K = (C*D*F*I*E)/G*365*H	1.05E-05	mg/kg d	Calculation
ILCR	L = K*J	3.16E-05	unitless	Calculation

Table D.3: Sample Calculation-Trumpeter Swan Dose and Risk Calculations for Cadmium

Environmental Media Concentration		Cadmium		
Water Concentration	A	3.65E-05	mg/L	Table 4.17
Water-Sediment Partitioning Coefficient	B	1.50E+03	L/kg dw	Table 4.5
Sediment Concentration (dry weight)	C = A*B	5.48E-02	mg/kg dw	Calculation
Aquatic Plant Concentration				
Bioaccumulation Factor (BAF)	D	1.90E+04	L/kg fw	Table 4.8
Tissue Concentration	E = A*D	6.94E-01	mg/kg fw	Calculation
Trumpeter Swan Exposure Factors				
Water Intake	F	2.94E-01	kg/d	Table 4.6
Sediment Intake	G	1.14E-02	kg dw/d	Table 4.6
Aquatic Plant Intake	H	1.39E+00	kg/d fw	Table 4.6
Body Weight	I	11	kg	Table 4.6
Toxicological Benchmark	J	2.00E+01	mg/kg d	Table 4.27
Trumpeter Swan Dose and HQ				
Ingestion Dose	K = (F*A+G*C+H*E)/I	8.75E-02	mg/kg d	Calculation
Hazard Quotient	L = K/J	0.004	unitless	Calculation

Table D.4: Sample Calculation-Trumpeter Swan Radiological Dose for Cobalt-60

Environmental Media Concentration		Cobalt-60		
Water Concentration (Co-60)	A	4.83E-04	Bq/L	Table 4.17
Sediment Concentration (dw)	B	1.54E-03	Bq/kg dw	Table 4.17
Sediment Porosity	C	0.1	unitless	Section 4.2.2.2
Sediment Density	D	1.50E+00	kg/L	Section 4.2.2.2
Density of Water	E	1.00E+00	kg/L	Section 4.2.2.2
Dry Weight Fraction of Sediment	F = (1-C)*D/(C*E+(1-C)*D)	9.31E-01	kg dw/ kg fw	Calculation
Sediment Concentration (fw)	G = B*F	1.43E-03	Bq/kg fw	Calculation
Aquatic Plant Concentration				
Bioaccumulation Factor (BAF)	H	7.90E+02	L/kg fw	Table 4.8
Tissue Concentration	I = A*H	3.82E-01	Bq/kg fw	Calculation
Trumpeter Swan Exposure Factors				
Water Intake	J	0.294	kg/d	Table 4.6
Sediment Intake	K	1.14E-02	kg dw/d	Table 4.6
Aquatic Plant Intake	L	1.386	kg/d fw	Table 4.6
Occupancy Factor on Sediment Surface	M	0.5	unitless	Table 4.7
Occupancy Factor in Water	N	0.5	unitless	Table 4.7
Transfer Factor	O	3.34E-01	d/kg fw	Table 4.10
Internal Dose Coefficient	P	5.70E-03	(µGy/day)/(Bq/kg)	Table 4.12
External Dose Coefficient on Sediment	Q	1.10E-02	(µGy/day)/(Bq/kg)	Table 4.12
External Dose Coefficient in Water	R	3.00E-02	(µGy/day)/(Bq/kg)	Table 4.12
Trumpeter Swan Dose				
Tissue Concentration	S = O*(J*A+K*B+L*I)	1.77E-01	Bq/kg fw	Calculation
Internal Dose	T = P*S	1.01E-03	µGy/d	Calculation
External Dose	U = (Q*M*G)+(R*N*A)	1.51E-05	µGy/d	Calculation
Total Radiological Dose	V = T + U	1.02E-03	µGy/d	Calculation

Table D.5: Sample Calculation-Meadow Vole Dose and Risk Calculations for Cadmium

Environmental Media Concentration		Cadmium		
Water Concentration	A	1.00E-04	mg/L	Table 4.17
Soil Concentration	B	4.87E-01	mg/kg dw	Table 4.17
Terrestrial Plant Concentration				
Bioaccumulation Factor (BAF)	C	3.99E-02	kg dw/kg fw	Table 4.9
Tissue Concentration	D = B*C	2.13E-03	mg/kg fw	Calculation
Vole Exposure Factors				
Water Intake	E	4.70E-03	kg/d	Table 4.6
Soil Intake	F	5.02E-05	kg dw/d	Table 4.6
Terrestrial Plant Intake	G	1.10E-02	kg/d fw	Table 4.6
Body Weight	H	0.0338	kg	Table 4.6
Toxicological Benchmark	I	1.00E+01	mg/kg d	Table 4.26
Vole Dose and HQ				
Ingestion Dose	J = (E*A+F*B+G*D)/H	7.06E-03	mg/kg d	Calculation
Hazard Quotient	K = J/I	0.0001	unitless	Calculation

Table D.6: Sample Calculation-Meadow Vole Radiological Dose for Cobalt-60

Environmental Media Concentration		Cobalt-60		
Water Concentration (Outfall)	A	1.45E-03	Bq/L	Table 4.17
Soil Concentration	B	2.60E-01	Bq/kg dw	Table 4.17
Terrestrial Plant Concentration				
Bioaccumulation Factor (BAF)	C	8.93E-03	L/kg fw	Table 4.9
Tissue Concentration	D = B*C	2.32E-03	Bq/kg fw	Calculation
Vole Exposure Factors				
Water Intake	E	4.70E-03	kg/d	Table 4.6
Soil Intake	F	5.02E-05	kg dw/d	Table 4.6
Terrestrial Plant Intake	G	1.10E-02	kg/d fw	Table 4.6
Occupancy Factor on Soil Surface	H	1	unitless	Table 4.7
Transfer Factor	I	3.54E+00	d/kgFW	Table 4.10
Internal Dose Coefficient	J	4.00E-03	(µGy/day)/(Bq/kg)	Table 4.12
External Dose Coefficient on Soil	K	1.20E-02	(µGy/day)/(Bq/kg)	Table 4.12
Vole Dose				
Tissue Concentration	L = I*(E*A+F*B+G*D)	1.61E-04	Bq/kg fw	Calculation
Internal Dose	M = J*L	6.42E-07	µGy/d	Calculation
External Dose	N = K*H*B	3.12E-03	µGy/d	Calculation
Total Dose	O = M+N	3.12E-03	µGy/d	Calculation

Appendix E P-32 Dose Assessment for 2011 and 2012

MEMO

To:	Cammie Cheng, OPG	From:	Rina Parker Witty Lai Don Hart
Ref:	**P-32 Dose Assessment for 2011 and 2012**	Date:	9 October 2013

INTRODUCTION

In 2011, OPG calculated new Derived Release Limits (DRLs) for the Pickering Nuclear site, in order to meet the methodology and parameters presented in CSA N288.1-08 (2008), and to incorporate changes in locations and characteristics of nearby members of the public. The 2011 DRLs (OPG, 2011a,b) indicate that P-32 is the limiting gross beta/gamma radionuclide in water – based on the Sport Fisher as the limiting critical group. Previously, Cs-137 was considered the limiting gross beta/gamma radionuclide in water. The annual dose calculations for the REMP (as presented in the annual REMP reports) currently use Cs-137 to represent gross beta/gamma radionuclides in water based on Cs-137 being the limiting gross beta/gamma radionuclide in water in previous DRL calculations. OPG has requested that EcoMetrix calculate the annual public dose to all potential critical groups for 2011 and 2012 using P-32 to represent gross beta/gamma in water instead of Cs-137.

METHODOLOGY

EcoMetrix re-ran the 2011 and 2012 IMPACT 5.4.0 scenario files assuming all gross beta/gamma waterborne emissions were P-32 instead of Cs-137. In the existing public dose calculations, OPG uses measured site-specific Cs-137 data for fish and sediment as dictator sources. For the updated scenarios, EcoMetrix modelled emissions of P-32 from source to receptor and did not incorporate any site-specific data, since none is available for P-32.

All changes to IMPACT 5.4.0 scenario files were reviewed and verified in accordance with EcoMetrix' Quality Management System.

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RESULTS

The full results of the re-assessment for both 2011 and 2012 are presented in Tables A.1 to A.12. They show that the main pathway affected by the change from Cs-137 to P-32 is the aquatic animal ingestion pathway. In general (with the exception of sediment ingestion in 2012), the dose resulting from Cs-137 exposure is higher than from P-32 exposure for other pathways (see Table B.1 and B.2). However, the dose resulting from exposure to P-32 from fish ingestion is approximately 3 orders of magnitude higher than from exposure to Cs-137 through fish ingestion. This dose increase results from modelling P-32 in water followed by uptake in fish, instead of using measured site-specific fish tissue data for Cs-137. The summary of dose to the Sport Fisher from the aquatic animal ingestion pathway is shown in Table 1. For comparison purposes, the aquatic animal ingestion dose from modelling Cs-137 from emissions has been presented. The dose from modelled Cs-137 is more comparable to P-32 than the measured Cs-137 data.

In terms of total dose, the only critical group to have an increase in total dose is the Sport Fisher, as shown in the attached tables. For all other critical groups, the total dose decreases marginally when switching from Cs-137 to P-32. This is consistent with the 2011 DRLs, where P-32 has been assigned the limiting gross beta/gamma radionuclide as a direct result of the Sport Fisher as the limiting critical group. Changing from Cs-137 to P-32 would result in the Sport Fisher (adult) becoming the critical group for both 2011 and 2012 instead of the Urban Resident (adult). Dose tables for 2011 and 2012 for all critical groups are attached at the end of this memo.

Table 1: Summary of Radiological Dose to Sport Fisher due to Fish Ingestion (2011-2012)

Sport Fisher	Radionuclide	2012 Aquatic Animals Dose (µSv/a)	2011 Aquatic Animals Dose (µSv/a)
Adult	Cs-137+ (measured)	0	4.15E-03
	Cs-137+ (modelled)	1.07E+00	8.19E-01
	P-32 (modelled)	1.46E+00	1.12E+00
Child-10y	Cs-137+ (measured)	0	1.37E-03
	Cs-137+ (modelled)	3.51E-01	2.70E-01
	P-32 (modelled)	1.38E+00	1.06E+00
Infant-1y	Cs-137+ (measured)	0	4.83E-04
	Cs-137+ (modelled)	1.24E-01	9.54E-02
	P-32 (modelled)	1.46E+00	1.12E+00

Note:
In 2012, the Cs-137 concentration measured in fish tissue was less than background concentrations; therefore no dose was attributed to fish ingestion from Cs-137.

Overall, it seems appropriate for OPG to continue using Cs-137 to represent gross beta/gamma radionuclides since site-specific data exists for fish and sediment. OPG should plan to obtain P-32 measurements in fish (and potentially sediment), if possible. If and when measurements confirm that P-32 is the main dose contributor for the critical receptor, then it may be appropriate to switch from Cs-137 to P-32, at least for the Sport Fisher.

REFERENCES

Canadian Standards Association (CSA). 2008. Guidelines for calculating derived release limits for radioactive material in airborne and liquid effluents for normal operation of nuclear facilities. CSA N288.1-08.

Ontario Power Generation (OPG). 2011a. Derived Release Limits and Environmental Action Levels for Pickering Nuclear Generating Station A. Report No. NA44-REP-03482-00001. January – DRAFT.

Ontario Power Generation (OPG). 2011b. Derived Release Limits and Environmental Action Levels for Pickering Nuclear Generating Station B. Report No. NK30-REP-03482-00001. January – DRAFT

Appendix A – Tables of Public Doses by Radionuclide, Pathway and Age Group for Pickering Nuclear Critical Groups (2011-2012)

Table A.1: Pickering Nuclear - Farm Critical Group Doses - 2011

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	0.00E+00	0.00E+00	2.48E-06	4.29E-10	3.02E-13	5.64E-12	4.32E-09	2.76E-10	0.00E+00	8.16E-04	6.95E-02	3.69E-02	1.07E-01
	Co-60	uSv/a	4.77E-07	1.81E-08	4.26E-09	5.12E-10	2.19E-10	2.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.49E-06	1.43E-07	2.29E-04
	P-32	uSv/a	0.00E+00	0.00E+00	8.34E-05	8.09E-07	7.78E-12	2.35E-07	2.71E-07	6.87E-06	0.00E+00	5.29E-02	3.57E-06	1.07E-07	5.30E-02
	HTO	uSv/a	6.69E-02	0.00E+00	9.44E-02	1.63E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.23E-05	1.66E-02	3.25E-03	1.83E-01
	NobleGases	uSv/a	0.00E+00	4.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.24E-05	2.51E-03	2.05E-03	4.58E-03
	I (mfp)	uSv/a	2.93E-06	2.09E-07	2.05E-08	9.45E-11	1.47E-11	6.41E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.92E-05	1.69E-05	6.99E-05
	Total	uSv/a	6.69E-02	4.58E-02	9.45E-02	1.63E-03	2.42E-10	2.27E-04	2.75E-07	6.87E-06	0.00E+00	5.38E-02	8.87E-02	4.22E-02	3.94E-01
Child-10y	C-14	uSv/a	0.00E+00	0.00E+00	1.76E-06	4.29E-10	1.67E-12	5.64E-12	2.38E-08	2.76E-10	0.00E+00	4.82E-04	5.14E-02	2.35E-02	7.54E-02
	Co-60	uSv/a	6.81E-07	1.81E-08	7.09E-09	5.12E-10	2.83E-09	2.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.03E-06	2.39E-07	2.31E-04
	P-32	uSv/a	0.00E+00	0.00E+00	9.48E-05	8.09E-07	6.87E-11	2.35E-07	2.39E-06	6.87E-06	0.00E+00	5.01E-02	4.13E-06	1.09E-07	5.02E-02
	HTO	uSv/a	7.96E-02	0.00E+00	6.07E-02	1.36E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-05	1.11E-02	1.79E-03	1.55E-01
	NobleGases	uSv/a	0.00E+00	4.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-05	1.91E-03	1.22E-03	3.14E-03
	I (mfp)	uSv/a	6.65E-06	2.09E-07	2.49E-08	9.45E-11	1.39E-10	6.41E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.79E-05	2.61E-05	9.15E-05
	Total	uSv/a	7.96E-02	4.58E-02	6.08E-02	1.36E-03	3.04E-09	2.27E-04	2.42E-06	6.87E-06	0.00E+00	5.06E-02	6.45E-02	2.65E-02	3.29E-01
Infant_1y	C-14	uSv/a	0.00E+00	0.00E+00	0.00E+00	7.47E-12	3.34E-12	5.64E-12	4.77E-08	2.76E-10	0.00E+00	2.84E-04	4.61E-02	1.80E-02	6.44E-02
	Co-60	uSv/a	4.99E-07	2.35E-08	0.00E+00	6.66E-10	6.94E-09	2.94E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.88E-06	2.44E-07	2.99E-04
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	1.36E-08	2.46E-10	2.35E-07	8.57E-06	6.87E-06	0.00E+00	5.28E-02	6.75E-06	1.57E-07	5.28E-02
	HTO	uSv/a	5.45E-02	0.00E+00	0.00E+00	3.34E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.75E-05	1.07E-02	1.67E-03	6.72E-02
	NobleGases	uSv/a	0.00E+00	5.60E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.60E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.99E-06	1.70E-03	1.11E-03	2.82E-03
	I (mfp)	uSv/a	7.77E-06	2.71E-07	0.00E+00	1.23E-10	4.86E-10	8.33E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.98E-05	4.30E-05	1.32E-04
	Total	uSv/a	5.45E-02	5.60E-02	0.00E+00	3.34E-04	7.68E-09	2.95E-04	8.62E-06	6.87E-06	0.00E+00	5.31E-02	5.86E-02	2.08E-02	2.44E-01

Table A.2: Pickering Nuclear - Dairy Farm Critical Group Doses - 2011

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	0.00E+00	0.00E+00	3.09E-07	4.21E-10	0.00E+00	0.00E+00	4.32E-09	2.76E-10	0.00E+00	0.00E+00	4.21E-02	8.08E-02	1.23E-01
	Co-60	uSv/a	3.86E-07	1.47E-08	0.00E+00	1.38E-10	2.11E-10	2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.17E-06	4.59E-07	2.22E-04
	P-32	uSv/a	0.00E+00	0.00E+00	1.04E-05	7.95E-07	0.00E+00	0.00E+00	2.71E-07	6.87E-06	0.00E+00	0.00E+00	0.00E+00	5.22E-09	1.83E-05
	HTO	uSv/a	6.06E-02	0.00E+00	8.74E-02	1.55E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-02	2.05E-02	1.82E-01
	NobleGases	uSv/a	0.00E+00	3.97E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.97E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	6.52E-03	8.52E-03
	I (mfp)	uSv/a	2.43E-06	1.35E-07	0.00E+00	2.22E-11	1.22E-11	5.39E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.13E-05	5.66E-05	3.10E-06
	Total	uSv/a	6.06E-02	3.97E-02	8.74E-02	1.55E-03	2.23E-10	2.20E-04	2.75E-07	6.87E-06	0.00E+00	0.00E+00	5.64E-02	1.08E-01	3.54E-01
Child-10y	C-14	uSv/a	0.00E+00	0.00E+00	2.19E-07	4.21E-10	0.00E+00	0.00E+00	2.38E-08	2.76E-10	0.00E+00	0.00E+00	3.09E-02	6.99E-02	1.01E-01
	Co-60	uSv/a	5.51E-07	1.47E-08	0.00E+00	1.38E-10	2.74E-09	2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-06	1.14E-06	2.24E-04
	P-32	uSv/a	0.00E+00	0.00E+00	1.18E-05	7.95E-07	0.00E+00	0.00E+00	2.39E-06	6.87E-06	0.00E+00	0.00E+00	0.00E+00	4.44E-09	2.18E-05
	HTO	uSv/a	7.20E-02	0.00E+00	5.62E-02	1.29E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.17E-03	2.32E-02	1.61E-01
	NobleGases	uSv/a	0.00E+00	3.97E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.97E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E-03	5.69E-03	7.22E-03
	I (mfp)	uSv/a	5.54E-06	1.35E-07	0.00E+00	2.22E-11	1.16E-10	5.39E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.85E-05	1.14E-04	1.69E-04
	Total	uSv/a	7.20E-02	3.97E-02	5.62E-02	1.29E-03	2.86E-09	2.20E-04	2.42E-06	6.87E-06	0.00E+00	0.00E+00	4.07E-02	9.89E-02	3.09E-01
Infant_1y	C-14	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.77E-08	2.76E-10	0.00E+00	0.00E+00	2.33E-02	1.07E-01	1.30E-01
	Co-60	uSv/a	4.04E-07	1.90E-08	0.00E+00	1.79E-10	6.71E-09	2.85E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.26E-06	2.61E-06	2.91E-04
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.57E-06	6.87E-06	0.00E+00	0.00E+00	0.00E+00	1.19E-08	1.55E-05
	HTO	uSv/a	4.94E-02	0.00E+00	0.00E+00	2.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.53E-03	5.21E-02	1.08E-01
	NobleGases	uSv/a	0.00E+00	4.83E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.83E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	9.48E-03	1.07E-02
	I (mfp)	uSv/a	6.48E-06	1.75E-07	0.00E+00	2.89E-11	4.05E-10	7.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.48E-05	3.99E-04	4.71E-04
	Total	uSv/a	4.94E-02	4.83E-02	0.00E+00	2.50E-04	7.12E-09	2.86E-04	8.62E-06	6.87E-06	0.00E+00	0.00E+00	3.11E-02	1.69E-01	2.98E-01

Table A.3: Pickering Nuclear - Industrial/Commercial Critical Group Doses - 2011

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	6.55E-04	7.53E-07	3.62E-06	3.51E-11	2.05E-13	3.82E-12	2.66E-10	1.70E-11	0.00E+00	7.47E-07	1.34E-03	4.59E-07	2.00E-03
	Co-60	uSv/a	3.54E-06	1.34E-07	3.47E-296	1.21E-11	1.82E-10	1.89E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-07	7.05E-12	1.93E-04
	P-32	uSv/a	0.00E+00	0.00E+00	1.22E-04	6.56E-08	5.27E-12	1.59E-07	1.67E-08	4.23E-07	0.00E+00	4.85E-05	1.80E-07	2.50E-12	1.71E-04
	HTO	uSv/a	4.97E-01	0.00E+00	1.21E-02	1.18E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.78E-08	7.15E-04	1.18E-07	5.10E-01
	NobleGases	uSv/a	0.00E+00	3.25E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.25E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.05E-08	1.12E-04	7.02E-08	1.12E-04
	I (mfp)	uSv/a	2.18E-05	1.55E-06	0.00E+00	1.09E-12	5.87E-12	2.61E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-06	2.36E-09	2.54E-05
	Total	uSv/a	4.98E-01	3.25E-01	1.22E-02	1.18E-04	1.93E-10	1.89E-04	1.69E-08	4.23E-07	0.00E+00	4.93E-05	2.17E-03	6.50E-07	8.37E-01

Note:

A fraction of Industrial/Commercial workers reside close to PN. The 2011 REMP adjusts the dose for this critical group to account for the exposure at work and at home. The same adjustment factors were applied to determine the P-32 dose.

Table A.4: Pickering Nuclear - Correctional Institute (C2) Critical Group Doses - 2011

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	3.28E-04	3.77E-07	1.29E-05	3.86E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.41E-04
	Co-60	uSv/a	2.83E-06	1.07E-07	0.00E+00	0.00E+00	1.49E-09	1.55E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-03
	P-32	uSv/a	0.00E+00	0.00E+00	4.32E-04	7.05E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.32E-04
	HTO	uSv/a	4.41E-01	0.00E+00	4.29E-02	2.70E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.84E-01
	NobleGases	uSv/a	0.00E+00	2.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.43E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	I (mfp)	uSv/a	1.80E-05	1.22E-06	0.00E+00	0.00E+00	8.95E-11	4.03E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.33E-05
	Total	uSv/a	4.41E-01	2.43E-01	4.33E-02	2.70E-04	1.58E-09	1.55E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.30E-01
Child-10y	C-14	uSv/a	4.68E-04	3.77E-07	9.12E-06	3.86E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.77E-04
	Co-60	uSv/a	4.04E-06	1.07E-07	0.00E+00	0.00E+00	1.93E-08	1.55E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-03
	P-32	uSv/a	0.00E+00	0.00E+00	4.91E-04	7.05E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04
	HTO	uSv/a	5.24E-01	0.00E+00	2.76E-02	2.25E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.52E-01
	NobleGases	uSv/a	0.00E+00	2.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.43E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	I (mfp)	uSv/a	4.08E-05	1.22E-06	0.00E+00	0.00E+00	8.45E-10	4.03E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.61E-05
	Total	uSv/a	5.25E-01	2.43E-01	2.81E-02	2.25E-04	2.01E-08	1.55E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.97E-01

Table A.5: Pickering Nuclear - Fisher Critical Group Doses - 2011

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	3.10E-04	3.56E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E-02	0.00E+00	0.00E+00	1.76E-02
	Co-60	uSv/a	1.68E-06	6.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E-06
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	0.00E+00	0.00E+00	1.12E+00
	HTO	uSv/a	2.37E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03	0.00E+00	0.00E+00	2.38E-01
	NobleGases	uSv/a	0.00E+00	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.89E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.76E-04	0.00E+00	0.00E+00	4.76E-04
	I (mfp)	uSv/a	1.03E-05	6.77E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-05
	Total	uSv/a	2.37E-01	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E+00	0.00E+00	0.00E+00	1.45E+00
Child-10y	C-14	uSv/a	4.42E-04	3.56E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-02	0.00E+00	0.00E+00	1.06E-02
	Co-60	uSv/a	2.40E-06	6.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.46E-06
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E+00	0.00E+00	0.00E+00	1.06E+00
	HTO	uSv/a	2.81E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.94E-04	0.00E+00	0.00E+00	2.82E-01
	NobleGases	uSv/a	0.00E+00	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.89E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-04	0.00E+00	0.00E+00	2.79E-04
	I (mfp)	uSv/a	2.35E-05	6.77E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-05
	Total	uSv/a	2.81E-01	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+00	0.00E+00	0.00E+00	1.42E+00
Infant_1y	C-14	uSv/a	3.02E-04	3.56E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.03E-03	0.00E+00	0.00E+00	6.33E-03
	Co-60	uSv/a	1.76E-06	8.28E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E-06
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	0.00E+00	0.00E+00	1.12E+00
	HTO	uSv/a	1.93E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.71E-04	0.00E+00	0.00E+00	1.93E-01
	NobleGases	uSv/a	0.00E+00	8.48E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.48E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-04	0.00E+00	0.00E+00	1.70E-04
	I (mfp)	uSv/a	2.74E-05	8.81E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-05
	Total	uSv/a	1.93E-01	8.48E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E+00	0.00E+00	0.00E+00	1.41E+00

Table A.6: Pickering Nuclear - Urban Resident Critical Group Doses - 2011

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	6.29E-04	7.23E-07	1.09E-05	5.49E-10	3.20E-12	5.97E-11	4.16E-09	2.66E-10	0.00E+00	1.17E-05	2.09E-02	7.17E-06	2.16E-02
	Co-60	uSv/a	3.46E-06	1.31E-07	5.42E-295	1.89E-10	2.85E-09	2.95E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E-06	1.10E-10	2.96E-03
	P-32	uSv/a	0.00E+00	0.00E+00	3.61E-04	1.03E-06	8.24E-11	2.49E-06	2.61E-07	6.62E-06	0.00E+00	7.58E-04	2.82E-06	3.91E-11	1.13E-03
	HTO	uSv/a	4.68E-01	0.00E+00	3.71E-02	1.84E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.48E-07	1.12E-02	1.84E-06	5.18E-01
	NobleGases	uSv/a	0.00E+00	3.85E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.21E-07	1.74E-03	1.10E-06	1.74E-03
	I (mfp)	uSv/a	2.12E-05	1.67E-06	0.00E+00	1.71E-11	9.18E-11	4.08E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	3.69E-08	5.47E-05
	Total	uSv/a	4.69E-01	3.85E-01	3.75E-02	1.84E-03	3.03E-09	2.96E-03	2.65E-07	6.62E-06	0.00E+00	7.70E-04	3.39E-02	1.01E-05	9.31E-01
Child-10y	C-14	uSv/a	7.85E-04	6.32E-07	7.64E-06	5.70E-10	1.84E-11	6.20E-11	2.38E-08	2.76E-10	0.00E+00	7.17E-06	1.60E-02	8.95E-06	1.68E-02
	Co-60	uSv/a	4.33E-06	1.15E-07	9.37E-295	1.97E-10	3.82E-08	3.06E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.24E-06	3.33E-10	3.07E-03
	P-32	uSv/a	0.00E+00	0.00E+00	4.07E-04	1.07E-06	7.56E-10	2.59E-06	2.39E-06	6.87E-06	0.00E+00	7.44E-04	3.36E-06	6.70E-11	1.17E-03
	HTO	uSv/a	4.85E-01	0.00E+00	2.37E-02	1.59E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.16E-07	7.73E-03	1.26E-06	5.18E-01
	NobleGases	uSv/a	0.00E+00	3.49E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.49E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.96E-07	1.38E-03	7.57E-07	1.38E-03
	I (mfp)	uSv/a	4.22E-05	1.49E-06	0.00E+00	1.78E-11	9.01E-10	4.24E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.38E-05	8.24E-08	8.18E-05
	Total	uSv/a	4.86E-01	3.49E-01	2.41E-02	1.59E-03	3.99E-08	3.07E-03	2.42E-06	6.87E-06	0.00E+00	7.52E-04	2.52E-02	1.10E-05	8.90E-01
Infant_1y	C-14	uSv/a	5.36E-04	6.32E-07	0.00E+00	3.87E-11	3.67E-11	6.20E-11	4.77E-08	2.76E-10	0.00E+00	4.22E-06	1.30E-02	1.86E-05	1.36E-02
	Co-60	uSv/a	3.18E-06	1.50E-07	0.00E+00	2.56E-10	9.38E-08	3.98E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E-06	8.63E-10	3.99E-03
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	6.90E-08	2.71E-09	2.59E-06	8.57E-06	6.87E-06	0.00E+00	7.85E-04	4.96E-06	2.27E-10	8.08E-04
	HTO	uSv/a	3.32E-01	0.00E+00	0.00E+00	3.13E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-07	6.91E-03	1.80E-06	3.39E-01
	NobleGases	uSv/a	0.00E+00	4.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E-07	1.15E-03	9.30E-07	1.15E-03
	I (mfp)	uSv/a	4.93E-05	1.94E-06	0.00E+00	2.31E-11	3.15E-09	5.51E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E-05	3.06E-07	1.03E-04
	Total	uSv/a	3.33E-01	4.26E-01	0.00E+00	3.13E-04	9.97E-08	3.99E-03	8.62E-06	6.87E-06	0.00E+00	7.90E-04	2.11E-02	2.16E-05	7.85E-01

Note:

A fraction of Adult Urban Residents work within 5 km of PN. The 2011 REMP adjusts the dose for this critical group to account for the exposure at work and at home. The same adjustment factors were applied to determine the P-32 dose.

Table A.7: Pickering Nuclear - Farm Critical Group Doses - 2012

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	8.58E-05	9.86E-08	1.43E-05	2.02E-09	1.63E-12	3.04E-11	2.01E-08	1.29E-09	0.00E+00	3.73E-04	5.65E-02	2.64E-02	8.34E-02
	Co-60	uSv/a	3.64E-07	1.38E-08	3.25E-09	3.90E-10	1.67E-10	1.73E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-06	1.09E-07	1.75E-04
	P-32	uSv/a	0.00E+00	0.00E+00	1.43E-04	1.19E-06	1.33E-11	4.01E-07	3.99E-07	1.01E-05	0.00E+00	6.89E-02	6.10E-06	1.83E-07	6.90E-02
	HTO	uSv/a	7.21E-02	0.00E+00	7.99E-02	1.49E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.16E-05	2.10E-02	3.37E-03	1.78E-01
	NobleGases	uSv/a	0.00E+00	7.16E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.16E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.79E-05	3.12E-03	2.12E-03	5.26E-03
	I (mfp)	uSv/a	2.40E-06	1.67E-07	1.68E-08	7.70E-11	1.21E-11	5.22E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.03E-05	1.38E-05	5.72E-05
	Total	uSv/a	7.22E-02	7.16E-02	8.01E-02	1.49E-03	1.94E-10	1.74E-04	4.19E-07	1.01E-05	0.00E+00	6.93E-02	8.07E-02	3.19E-02	4.07E-01
Child-10y	C-14	uSv/a	1.22E-04	9.86E-08	1.02E-05	2.02E-09	8.99E-12	3.04E-11	1.11E-07	1.29E-09	0.00E+00	2.21E-04	4.18E-02	1.69E-02	5.91E-02
	Co-60	uSv/a	5.19E-07	1.38E-08	5.40E-09	3.90E-10	2.15E-09	1.73E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E-06	1.82E-07	1.77E-04
	P-32	uSv/a	0.00E+00	0.00E+00	1.62E-04	1.19E-06	1.17E-10	4.01E-07	3.52E-06	1.01E-05	0.00E+00	6.51E-02	7.06E-06	1.87E-07	6.53E-02
	HTO	uSv/a	8.58E-02	0.00E+00	5.14E-02	1.24E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.23E-05	1.41E-02	1.86E-03	1.54E-01
	NobleGases	uSv/a	0.00E+00	7.16E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.16E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.05E-05	2.38E-03	1.26E-03	3.65E-03
	I (mfp)	uSv/a	5.44E-06	1.67E-07	2.05E-08	7.70E-11	1.14E-10	5.22E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.75E-05	2.14E-05	7.50E-05
	Total	uSv/a	8.59E-02	7.16E-02	5.16E-02	1.24E-03	2.39E-09	1.74E-04	3.63E-06	1.01E-05	0.00E+00	6.54E-02	5.83E-02	2.00E-02	3.54E-01
Infant_1y	C-14	uSv/a	8.35E-05	9.86E-08	0.00E+00	4.49E-11	1.80E-11	3.04E-11	2.22E-07	1.29E-09	0.00E+00	1.30E-04	3.84E-02	1.29E-02	5.15E-02
	Co-60	uSv/a	3.80E-07	1.79E-08	0.00E+00	5.07E-10	5.29E-09	2.24E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.96E-06	1.86E-07	2.28E-04
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	2.32E-08	4.21E-10	4.01E-07	1.26E-05	1.01E-05	0.00E+00	6.87E-02	1.15E-05	2.69E-07	6.88E-02
	HTO	uSv/a	5.88E-02	0.00E+00	0.00E+00	3.42E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E-05	1.41E-02	1.74E-03	7.50E-02
	NobleGases	uSv/a	0.00E+00	8.73E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.73E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E-06	2.19E-03	1.15E-03	3.35E-03
	I (mfp)	uSv/a	6.36E-06	2.16E-07	0.00E+00	1.00E-10	3.99E-10	6.79E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.55E-05	3.53E-05	1.08E-04
	Total	uSv/a	5.89E-02	8.73E-02	0.00E+00	3.42E-04	6.13E-09	2.25E-04	1.28E-05	1.01E-05	0.00E+00	6.89E-02	5.48E-02	1.58E-02	2.86E-01

Table A.8: Pickering Nuclear - Dairy Farm Critical Group Doses - 2012

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	0.00E+00	0.00E+00	1.43E-05	1.96E-09	0.00E+00	0.00E+00	2.01E-08	1.29E-09	0.00E+00	0.00E+00	6.85E-03	2.40E-02	3.09E-02
	Co-60	uSv/a	2.88E-07	1.09E-08	0.00E+00	1.03E-10	1.58E-10	1.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-06	3.43E-07	1.65E-04
	P-32	uSv/a	0.00E+00	0.00E+00	1.77E-05	1.17E-06	0.00E+00	0.00E+00	3.99E-07	1.01E-05	0.00E+00	0.00E+00	0.00E+00	8.92E-09	2.94E-05
	HTO	uSv/a	5.84E-02	0.00E+00	8.89E-02	1.37E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.19E-03	1.74E-02	1.73E-01
	NobleGases	uSv/a	0.00E+00	4.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E-03	5.47E-03	6.64E-03
	I (mfp)	uSv/a	1.85E-06	9.55E-08	0.00E+00	1.66E-11	9.42E-12	4.04E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.18E-05	4.37E-05	7.78E-05
	Total	uSv/a	5.84E-02	4.58E-02	8.89E-02	1.37E-03	1.67E-10	1.63E-04	4.19E-07	1.01E-05	0.00E+00	0.00E+00	1.52E-02	4.69E-02	2.57E-01
Child-10y	C-14	uSv/a	0.00E+00	0.00E+00	1.18E-06	1.96E-09	0.00E+00	0.00E+00	1.11E-07	1.29E-09	0.00E+00	0.00E+00	5.03E-03	3.15E-02	3.65E-02
	Co-60	uSv/a	4.11E-07	1.09E-08	0.00E+00	1.03E-10	2.04E-09	1.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.61E-06	8.51E-07	1.67E-04
	P-32	uSv/a	0.00E+00	0.00E+00	2.01E-05	1.17E-06	0.00E+00	0.00E+00	3.52E-06	1.01E-05	0.00E+00	0.00E+00	0.00E+00	7.59E-09	3.49E-05
	HTO	uSv/a	6.94E-02	0.00E+00	5.71E-02	1.14E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.79E-03	1.98E-02	1.52E-01
	NobleGases	uSv/a	0.00E+00	4.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.98E-04	4.80E-03	5.70E-03
	I (mfp)	uSv/a	4.22E-06	9.55E-08	0.00E+00	1.66E-11	8.90E-11	4.04E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.74E-05	8.77E-05	1.30E-04
	Total	uSv/a	6.94E-02	4.58E-02	5.71E-02	1.14E-03	2.13E-09	1.63E-04	3.63E-06	1.01E-05	0.00E+00	0.00E+00	1.08E-02	5.62E-02	2.41E-01
Infant_1y	C-14	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.22E-07	1.29E-09	0.00E+00	0.00E+00	3.80E-03	6.80E-02	7.18E-02
	Co-60	uSv/a	3.02E-07	1.42E-08	0.00E+00	1.34E-10	5.01E-09	2.12E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.43E-06	1.95E-06	2.17E-04
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E-05	1.01E-05	0.00E+00	0.00E+00	0.00E+00	2.03E-08	2.28E-05
	HTO	uSv/a	4.76E-02	0.00E+00	0.00E+00	2.41E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.83E-03	4.47E-02	9.64E-02
	NobleGases	uSv/a	0.00E+00	5.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.58E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.91E-04	8.12E-03	8.81E-03
	I (mfp)	uSv/a	4.94E-06	1.24E-07	0.00E+00	2.16E-11	3.12E-10	5.25E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.99E-05	3.08E-04	3.63E-04
	Total	uSv/a	4.76E-02	5.58E-02	0.00E+00	2.41E-04	5.32E-09	2.13E-04	1.28E-05	1.01E-05	0.00E+00	0.00E+00	8.37E-03	1.21E-01	2.33E-01

Table A.9: Pickering Nuclear - Industrial/Commercial Critical Group Doses - 2012

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	7.27E-04	8.36E-07	1.43E-05	1.70E-10	1.10E-12	2.06E-11	1.24E-09	7.93E-11	0.00E+00	3.42E-07	1.71E-03	3.24E-07	2.45E-03
	Co-60	uSv/a	2.25E-06	8.53E-08	2.23E-296	7.81E-12	1.17E-10	1.22E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.03E-08	5.37E-12	1.24E-04
	P-32	uSv/a	0.00E+00	0.00E+00	2.08E-04	1.01E-07	9.00E-12	2.72E-07	2.45E-08	6.23E-07	0.00E+00	6.31E-05	3.08E-07	4.28E-12	2.72E-04
	HTO	uSv/a	4.47E-01	0.00E+00	8.33E-03	9.16E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.81E-08	1.21E-03	1.29E-07	4.57E-01
	NobleGases	uSv/a	0.00E+00	3.68E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.68E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-08	1.93E-04	7.62E-08	1.93E-04
	I (mfp)	uSv/a	1.49E-05	1.08E-06	0.00E+00	7.62E-13	4.11E-12	1.82E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-06	1.94E-09	1.74E-05
	Total	uSv/a	4.48E-01	3.68E-01	8.55E-03	9.17E-05	1.31E-10	1.22E-04	2.58E-08	6.23E-07	0.00E+00	6.35E-05	3.11E-03	5.31E-07	8.28E-01

Note:

A fraction of Industrial/Commercial workers reside close to PN. The 2012 REMP adjusts the dose for this critical group to account for the exposure at work and at home. The same adjustment factors were applied to determine the P-32 dose.

Table A.10: Pickering Nuclear - Correctional Institute (C2) Critical Group Doses - 2012

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	7.58E-04	8.72E-07	1.43E-05	2.08E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.73E-04
	Co-60	uSv/a	1.99E-06	7.54E-08	0.00E+00	0.00E+00	1.05E-09	1.09E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-03
	P-32	uSv/a	0.00E+00	0.00E+00	7.38E-04	1.20E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.39E-04
	HTO	uSv/a	4.03E-01	0.00E+00	2.94E-02	1.85E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.33E-01
	NobleGases	uSv/a	0.00E+00	2.85E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.85E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	I (mfp)	uSv/a	1.30E-05	8.73E-07	0.00E+00	0.00E+00	6.51E-11	2.91E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E-05
	Total	uSv/a	4.04E-01	2.85E-01	3.02E-02	1.85E-04	1.12E-09	1.09E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.20E-01
Child-10y	C-14	uSv/a	1.08E-03	8.72E-07	4.91E-05	2.08E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-03
	Co-60	uSv/a	2.84E-06	7.54E-08	0.00E+00	0.00E+00	1.36E-08	1.09E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-03
	P-32	uSv/a	0.00E+00	0.00E+00	8.39E-04	1.20E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.39E-04
	HTO	uSv/a	4.79E-01	0.00E+00	1.89E-02	1.54E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.98E-01
	NobleGases	uSv/a	0.00E+00	2.85E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.85E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	I (mfp)	uSv/a	2.96E-05	8.73E-07	0.00E+00	0.00E+00	6.15E-10	2.91E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.34E-05
	Total	uSv/a	4.80E-01	2.85E-01	1.98E-02	1.54E-04	1.42E-08	1.09E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.86E-01

Table A.11: Pickering Nuclear - Fisher Critical Group Doses - 2012

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	3.10E-04	3.56E-07	1.43E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.93E-03	0.00E+00	0.00E+00	8.25E-03
	Co-60	uSv/a	1.68E-06	6.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E-06
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00	0.00E+00	1.46E+00
	HTO	uSv/a	2.37E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.83E-04	0.00E+00	0.00E+00	2.38E-01
	NobleGases	uSv/a	0.00E+00	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.89E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.79E-04	0.00E+00	0.00E+00	3.79E-04
	I (mfp)	uSv/a	1.03E-05	6.77E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-05
	Total	uSv/a	2.37E-01	6.89E-02	1.43E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.47E+00	0.00E+00	0.00E+00	1.78E+00
Child-10y	C-14	uSv/a	4.42E-04	3.56E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.68E-03	0.00E+00	0.00E+00	5.12E-03
	Co-60	uSv/a	2.40E-06	6.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.46E-06
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+00	0.00E+00	0.00E+00	1.38E+00
	HTO	uSv/a	2.81E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.73E-04	0.00E+00	0.00E+00	2.81E-01
	NobleGases	uSv/a	0.00E+00	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.89E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.22E-04	0.00E+00	0.00E+00	2.22E-04
	I (mfp)	uSv/a	2.35E-05	6.77E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-05
	Total	uSv/a	2.81E-01	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E+00	0.00E+00	0.00E+00	1.74E+00
Infant_1y	C-14	uSv/a	3.02E-04	3.56E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.76E-03	0.00E+00	0.00E+00	3.06E-03
	Co-60	uSv/a	1.76E-06	8.28E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E-06
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00	0.00E+00	1.46E+00
	HTO	uSv/a	1.93E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.95E-04	0.00E+00	0.00E+00	1.93E-01
	NobleGases	uSv/a	0.00E+00	8.48E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.48E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-04	0.00E+00	0.00E+00	1.35E-04
	I (mfp)	uSv/a	2.74E-05	8.81E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-05
	Total	uSv/a	1.93E-01	8.48E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00	0.00E+00	1.74E+00

Table A.12: Pickering Nuclear - Urban Resident Critical Group Doses - 2012

Human Type	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	6.21E-04	7.14E-07	1.43E-05	2.66E-09	1.73E-11	3.22E-10	1.94E-08	1.24E-09	0.00E+00	5.35E-06	2.68E-02	5.07E-06	2.74E-02
	Co-60	uSv/a	2.23E-06	8.44E-08	3.49E-295	1.22E-10	1.83E-09	1.90E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E-06	8.40E-11	1.90E-03
	P-32	uSv/a	0.00E+00	0.00E+00	6.18E-04	1.57E-06	1.41E-10	4.25E-06	3.84E-07	9.75E-06	0.00E+00	9.86E-04	4.81E-06	6.69E-11	1.62E-03
	HTO	uSv/a	4.42E-01	0.00E+00	2.57E-02	1.43E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.95E-07	1.89E-02	2.01E-06	4.88E-01
	NobleGases	uSv/a	0.00E+00	5.29E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.29E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.56E-07	3.02E-03	1.19E-06	3.02E-03
	I (mfp)	uSv/a	1.48E-05	1.17E-06	0.00E+00	1.19E-11	6.42E-11	2.84E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.96E-05	3.03E-08	3.84E-05
	Total	uSv/a	4.43E-01	5.29E-01	2.63E-02	1.43E-03	2.05E-09	1.91E-03	4.03E-07	9.75E-06	0.00E+00	9.92E-04	4.87E-02	8.30E-06	1.05E+00
Child-10y	C-14	uSv/a	7.56E-04	6.09E-07	4.08E-05	2.76E-09	9.89E-11	3.34E-10	1.11E-07	1.29E-09	0.00E+00	3.28E-06	2.04E-02	6.62E-06	2.12E-02
	Co-60	uSv/a	2.79E-06	7.42E-08	6.04E-295	1.27E-10	2.46E-08	1.97E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-06	2.54E-10	1.97E-03
	P-32	uSv/a	0.00E+00	0.00E+00	6.96E-04	1.63E-06	1.29E-09	4.42E-06	3.52E-06	1.01E-05	0.00E+00	9.68E-04	5.73E-06	1.14E-10	1.69E-03
	HTO	uSv/a	4.62E-01	0.00E+00	1.64E-02	1.24E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.31E-07	1.31E-02	1.39E-06	4.93E-01
	NobleGases	uSv/a	0.00E+00	4.93E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.56E-07	2.40E-03	8.25E-07	2.40E-03
	I (mfp)	uSv/a	2.95E-05	1.05E-06	0.00E+00	1.24E-11	6.30E-10	2.95E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-05	6.76E-08	5.74E-05
	Total	uSv/a	4.63E-01	4.93E-01	1.71E-02	1.24E-03	2.66E-08	1.98E-03	3.63E-06	1.01E-05	0.00E+00	9.72E-04	3.59E-02	8.90E-06	1.01E+00
Infant_1y	C-14	uSv/a	5.16E-04	6.09E-07	0.00E+00	2.05E-10	1.98E-10	3.34E-10	2.22E-07	1.29E-09	0.00E+00	1.93E-06	1.65E-02	1.41E-05	1.70E-02
	Co-60	uSv/a	2.05E-06	9.65E-08	0.00E+00	1.65E-10	6.05E-08	2.57E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.99E-06	6.58E-10	2.57E-03
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	1.18E-07	4.63E-09	4.42E-06	1.26E-05	1.01E-05	0.00E+00	1.02E-03	8.47E-06	3.88E-10	1.06E-03
	HTO	uSv/a	3.17E-01	0.00E+00	0.00E+00	2.36E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.07E-07	1.09E-02	2.02E-06	3.28E-01
	NobleGases	uSv/a	0.00E+00	6.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.46E-08	1.90E-03	1.02E-06	1.90E-03
	I (mfp)	uSv/a	3.44E-05	1.36E-06	0.00E+00	1.61E-11	2.21E-09	3.84E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.24E-05	2.51E-07	7.23E-05
	Total	uSv/a	3.18E-01	6.00E-01	0.00E+00	2.36E-04	6.75E-08	2.58E-03	1.28E-05	1.01E-05	0.00E+00	1.02E-03	2.93E-02	1.74E-05	9.51E-01

Note:

A fraction of Adult Urban Residents work within 5 km of PN. The 2012 REMP adjusts the dose for this critical group to account for the exposure at work and at home. The same adjustment factors were applied to determine the P-32 dose.

Appendix B – Comparison Tables of P-23 and Cs-137 for All Pathways and Age Groups for Pickering Nuclear Critical Groups (2011-2012)

Table B.1: 2012 Comparison of P-32 and Cs-137 for All Pathways and All Critical Groups

Receptor	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Farm															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	7.97E-04	1.03E-04	3.73E-08	2.44E-03	1.17E-06	5.93E-04	0.00E+00	0.00E+00	7.43E-05	1.12E-05	4.02E-03
	P-32	uSv/a	0.00E+00	0.00E+00	1.43E-04	1.19E-06	1.33E-11	4.01E-07	3.99E-07	1.01E-05	0.00E+00	6.89E-02	6.10E-06	1.83E-07	6.90E-02
	Difference	uSv/a	0.00E+00	0.00E+00	-6.54E-04	-1.02E-04	-3.73E-08	-2.44E-03	-7.71E-07	-5.83E-04	0.00E+00	6.89E-02	-6.82E-05	-1.10E-05	6.50E-02
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	3.15E-04	1.03E-04	1.15E-07	2.44E-03	3.60E-06	5.93E-04	0.00E+00	0.00E+00	3.02E-05	3.79E-06	3.49E-03
	P-32	uSv/a	0.00E+00	0.00E+00	1.62E-04	1.19E-06	1.17E-10	4.01E-07	3.52E-06	1.01E-05	0.00E+00	6.51E-02	7.06E-06	1.87E-07	6.53E-02
	Difference	uSv/a	0.00E+00	0.00E+00	-1.53E-04	-1.02E-04	-1.15E-07	-2.44E-03	-7.97E-08	-5.83E-04	0.00E+00	6.51E-02	-2.31E-05	-3.60E-06	6.18E-02
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	2.68E-06	1.38E-07	3.18E-03	4.32E-06	7.70E-04	0.00E+00	0.00E+00	1.64E-05	1.76E-06	3.98E-03
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	2.32E-08	4.21E-10	4.01E-07	1.26E-05	1.01E-05	0.00E+00	6.87E-02	1.15E-05	2.69E-07	6.88E-02
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	-2.66E-06	-1.38E-07	-3.18E-03	8.30E-06	-7.60E-04	0.00E+00	6.87E-02	-4.87E-06	-1.49E-06	6.48E-02
Dairy Farm															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	9.91E-05	1.01E-04	0.00E+00	0.00E+00	1.17E-06	5.93E-04	0.00E+00	0.00E+00	0.00E+00	4.66E-07	7.95E-04
	P-32	uSv/a	0.00E+00	0.00E+00	1.77E-05	1.17E-06	0.00E+00	0.00E+00	3.99E-07	1.01E-05	0.00E+00	0.00E+00	0.00E+00	8.92E-09	2.94E-05
	Difference	uSv/a	0.00E+00	0.00E+00	-8.14E-05	-9.98E-05	0.00E+00	0.00E+00	-7.71E-07	-5.83E-04	0.00E+00	0.00E+00	0.00E+00	-4.57E-07	-7.65E-04
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	3.92E-05	1.01E-04	0.00E+00	0.00E+00	3.60E-06	5.93E-04	0.00E+00	0.00E+00	0.00E+00	1.38E-07	7.37E-04
	P-32	uSv/a	0.00E+00	0.00E+00	2.01E-05	1.17E-06	0.00E+00	0.00E+00	3.52E-06	1.01E-05	0.00E+00	0.00E+00	0.00E+00	7.59E-09	3.49E-05
	Difference	uSv/a	0.00E+00	0.00E+00	-1.91E-05	-9.98E-05	0.00E+00	0.00E+00	-7.97E-08	-5.83E-04	0.00E+00	0.00E+00	0.00E+00	-1.30E-07	-7.02E-04
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.32E-06	7.70E-04	0.00E+00	0.00E+00	0.00E+00	1.24E-07	4.44E-06
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E-05	1.01E-05	0.00E+00	0.00E+00	0.00E+00	2.03E-08	2.28E-05
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.30E-06	-7.60E-04	0.00E+00	0.00E+00	0.00E+00	-1.04E-07	1.83E-05
Industrial/Commercial															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	1.16E-03	8.72E-06	2.53E-08	1.65E-03	7.21E-08	3.65E-05	0.00E+00	0.00E+00	3.79E-06	8.60E-11	2.86E-03
	P-32	uSv/a	0.00E+00	0.00E+00	2.08E-04	1.01E-07	9.00E-12	2.72E-07	2.45E-08	6.23E-07	0.00E+00	6.31E-05	3.08E-07	4.28E-12	2.72E-04
	Difference	uSv/a	0.00E+00	0.00E+00	-9.52E-04	-8.62E-06	-2.53E-08	-1.65E-03	-4.76E-08	-3.59E-05	0.00E+00	6.31E-05	-3.48E-06	-8.17E-11	-2.59E-03
Correctional Institute															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	4.13E-03	1.07E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.14E-03
	P-32	uSv/a	0.00E+00	0.00E+00	7.38E-04	1.20E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.39E-04
	Difference	uSv/a	0.00E+00	0.00E+00	-3.39E-03	-1.06E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.40E-03
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	1.63E-03	1.07E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-03
	P-32	uSv/a	0.00E+00	0.00E+00	8.39E-04	1.20E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.39E-04
	Difference	uSv/a	0.00E+00	0.00E+00	-7.91E-04	-1.06E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.02E-04
Sport Fisher															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00	0.00E+00	1.46E+00
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00	0.00E+00	1.46E+00
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+00	0.00E+00	0.00E+00	1.38E+00
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+00	0.00E+00	0.00E+00	1.38E+00
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00	0.00E+00	1.46E+00
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00	0.00E+00	1.46E+00
Urban Resident															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	3.45E-03	1.36E-04	3.95E-07	2.58E-02	1.13E-06	5.71E-04	0.00E+00	0.00E+00	5.92E-05	1.34E-09	3.00E-02
	P-32	uSv/a	0.00E+00	0.00E+00	6.18E-04	1.57E-06	1.41E-10	4.25E-06	3.84E-07	9.75E-06	0.00E+00	9.86E-04	4.81E-06	6.69E-11	1.66E-03
	Difference	uSv/a	0.00E+00	0.00E+00	-2.83E-03	-1.34E-04	-3.95E-07	-2.58E-02	-7.46E-07	-5.61E-04	0.00E+00	9.86E-04	-5.44E-05	-1.27E-09	-2.84E-02
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	1.36E-03	1.42E-04	1.26E-06	2.68E-02	3.60E-06	5.93E-04	0.00E+00	0.00E+00	2.48E-05	5.19E-10	2.89E-02
	P-32	uSv/a	0.00E+00	0.00E+00	6.96E-04	1.63E-06	1.29E-09	4.42E-06	3.52E-06	1.01E-05	0.00E+00	9.68E-04	5.73E-06	1.14E-10	1.69E-03
	Difference	uSv/a	0.00E+00	0.00E+00	-6.64E-04	-1.40E-04	-1.26E-06	-2.68E-02	-7.97E-08	-5.83E-04	0.00E+00	9.68E-04	-1.91E-05	-4.05E-10	-2.72E-02
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	1.36E-05	1.52E-06	3.49E-02	4.32E-06	7.70E-04	0.00E+00	0.00E+00	1.22E-05	3.68E-10	3.57E-02
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	1.18E-07	4.63E-09	4.42E-06	1.26E-05	1.01E-05	0.00E+00	1.02E-03	8.47E-06	3.88E-10	1.06E-03
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	-1.35E-05	-1.52E-06	-3.49E-02	8.30E-06	-7.60E-04	0.00E+00	1.02E-03	-3.73E-06	2.05E-11	-3.46E-02

Table B.2: 2011 Comparison of P-32 and Cs-137 for All Pathways and All Critical Groups

Receptor	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Farm															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	4.69E-04	6.96E-05	2.19E-08	1.43E-03	2.60E-06	1.32E-03	0.00E+00	1.95E-04	4.37E-05	6.57E-06	3.54E-03
	P-32	uSv/a	0.00E+00	0.00E+00	8.34E-05	8.09E-07	7.78E-12	2.35E-07	2.71E-07	6.87E-06	0.00E+00	5.29E-02	3.57E-06	1.07E-07	5.30E-02
	Difference	uSv/a	0.00E+00	0.00E+00	-3.86E-04	-6.88E-05	-2.19E-08	-1.43E-03	-2.33E-06	-1.31E-03	0.00E+00	5.27E-02	-4.01E-05	-6.46E-06	4.95E-02
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	1.85E-04	6.96E-05	6.75E-08	1.43E-03	8.01E-06	1.32E-03	0.00E+00	6.44E-05	1.78E-05	2.23E-06	3.10E-03
	P-32	uSv/a	0.00E+00	0.00E+00	9.48E-05	8.09E-07	6.87E-11	2.35E-07	2.39E-06	6.87E-06	0.00E+00	5.01E-02	4.13E-06	1.09E-07	5.02E-02
	Difference	uSv/a	0.00E+00	0.00E+00	-9.02E-05	-6.88E-05	-6.74E-08	-1.43E-03	-5.62E-06	-1.31E-03	0.00E+00	5.00E-02	-1.37E-05	-2.12E-06	4.71E-02
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	1.58E-06	8.10E-08	1.87E-03	9.61E-06	1.71E-03	0.00E+00	2.27E-05	9.62E-06	1.04E-06	3.62E-03
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	1.36E-08	2.46E-10	2.35E-07	8.57E-06	6.87E-06	0.00E+00	5.28E-02	6.75E-06	1.57E-07	5.28E-02
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	-1.57E-06	-8.08E-08	-1.87E-03	-1.04E-06	-1.70E-03	0.00E+00	5.28E-02	-2.87E-06	-8.83E-07	4.92E-02
Dairy Farm															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	5.83E-05	6.84E-05	0.00E+00	0.00E+00	2.60E-06	1.32E-03	0.00E+00	0.00E+00	0.00E+00	2.74E-07	1.45E-03
	P-32	uSv/a	0.00E+00	0.00E+00	1.04E-05	7.95E-07	0.00E+00	0.00E+00	2.71E-07	6.87E-06	0.00E+00	0.00E+00	0.00E+00	5.22E-09	1.83E-05
	Difference	uSv/a	0.00E+00	0.00E+00	-4.79E-05	-6.76E-05	0.00E+00	0.00E+00	-2.33E-06	-1.31E-03	0.00E+00	0.00E+00	0.00E+00	-2.69E-07	-1.43E-03
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	2.31E-05	6.84E-05	0.00E+00	0.00E+00	8.01E-06	1.32E-03	0.00E+00	0.00E+00	0.00E+00	8.13E-08	1.42E-03
	P-32	uSv/a	0.00E+00	0.00E+00	1.18E-05	7.95E-07	0.00E+00	0.00E+00	2.39E-06	6.87E-06	0.00E+00	0.00E+00	0.00E+00	4.44E-09	2.18E-05
	Difference	uSv/a	0.00E+00	0.00E+00	-1.13E-05	-6.76E-05	0.00E+00	0.00E+00	-5.62E-06	-1.31E-03	0.00E+00	0.00E+00	0.00E+00	-7.69E-08	-1.40E-03
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.61E-06	1.71E-03	0.00E+00	0.00E+00	0.00E+00	7.26E-08	1.72E-03
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.57E-06	6.87E-06	0.00E+00	0.00E+00	0.00E+00	1.19E-08	1.55E-05
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.04E-06	-1.70E-03	0.00E+00	0.00E+00	0.00E+00	-6.07E-08	-1.70E-03
Industrial/Commercial															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	6.83E-04	5.69E-06	1.49E-08	9.71E-04	1.60E-07	8.12E-05	0.00E+00	1.79E-07	2.23E-06	5.06E-11	1.74E-03
	P-32	uSv/a	0.00E+00	0.00E+00	1.22E-04	6.56E-08	5.27E-12	1.59E-07	1.67E-08	4.23E-07	0.00E+00	4.85E-05	1.80E-07	2.50E-12	1.71E-04
	Difference	uSv/a	0.00E+00	0.00E+00	-5.61E-04	-5.62E-06	-1.49E-08	-9.71E-04	-1.43E-07	-8.08E-05	0.00E+00	4.83E-05	-2.05E-06	-4.81E-11	-1.57E-03
Correctional Institute															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	2.43E-03	6.27E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.44E-03
	P-32	uSv/a	0.00E+00	0.00E+00	4.32E-04	7.05E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.32E-04
	Difference	uSv/a	0.00E+00	0.00E+00	-2.00E-03	-6.20E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.00E-03
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	9.61E-04	6.27E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.67E-04
	P-32	uSv/a	0.00E+00	0.00E+00	4.91E-04	7.05E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04
	Difference	uSv/a	0.00E+00	0.00E+00	-4.70E-04	-6.20E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.76E-04
Sport Fisher															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.15E-03	0.00E+00	0.00E+00	4.15E-03
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	0.00E+00	0.00E+00	1.12E+00
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	0.00E+00	0.00E+00	1.12E+00
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.37E-03	0.00E+00	0.00E+00	1.37E-03
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E+00	0.00E+00	0.00E+00	1.06E+00
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E+00	0.00E+00	0.00E+00	1.06E+00
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.83E-04	0.00E+00	0.00E+00	4.83E-04
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	0.00E+00	0.00E+00	1.12E+00
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	0.00E+00	0.00E+00	1.12E+00
Urban Resident															
Adult	Cs-137	uSv/a	0.00E+00	0.00E+00	2.03E-03	8.90E-05	2.32E-07	1.52E-02	2.51E-06	1.27E-03	0.00E+00	2.80E-06	3.48E-05	7.91E-10	1.86E-02
	P-32	uSv/a	0.00E+00	0.00E+00	3.61E-04	1.03E-06	8.24E-11	2.49E-06	2.61E-07	6.62E-06	0.00E+00	7.58E-04	2.82E-06	3.91E-11	1.16E-03
	Difference	uSv/a	0.00E+00	0.00E+00	-1.67E-03	-8.80E-05	-2.32E-07	-1.52E-02	-2.25E-06	-1.26E-03	0.00E+00	7.55E-04	-3.20E-05	-7.52E-10	-1.75E-02
Child-10y	Cs-137	uSv/a	0.00E+00	0.00E+00	7.97E-04	9.24E-05	7.43E-07	1.58E-02	8.01E-06	1.32E-03	0.00E+00	9.57E-07	1.46E-05	3.05E-10	1.80E-02
	P-32	uSv/a	0.00E+00	0.00E+00	4.07E-04	1.07E-06	7.56E-10	2.59E-06	2.39E-06	6.87E-06	0.00E+00	7.44E-04	3.36E-06	6.70E-11	1.17E-03
	Difference	uSv/a	0.00E+00	0.00E+00	-3.90E-04	-9.13E-05	-7.42E-07	-1.58E-02	-5.62E-06	-1.31E-03	0.00E+00	7.43E-04	-1.12E-05	-2.38E-10	-1.69E-02
Infant_1y	Cs-137	uSv/a	0.00E+00	0.00E+00	0.00E+00	8.00E-06	8.91E-07	2.05E-02	9.61E-06	1.71E-03	0.00E+00	3.38E-07	7.16E-06	2.17E-10	2.22E-02
	P-32	uSv/a	0.00E+00	0.00E+00	0.00E+00	6.90E-08	2.71E-09	2.59E-06	8.57E-06	6.87E-06	0.00E+00	7.85E-04	4.96E-06	2.27E-10	8.08E-04
	Difference	uSv/a	0.00E+00	0.00E+00	0.00E+00	-7.93E-06	-8.88E-07	-2.05E-02	-1.04E-06	-1.70E-03	0.00E+00	7.85E-04	-2.20E-06	1.04E-11	-2.14E-02