ONTARIO POWER GENERATION

Report

Public Information	
Document Number: **W-REP-03443-00006**	Usage Classification: **Information**
Sheet Number: **N/A**	Revision: **R000**

Title:
2021 Results of Environmental Monitoring Program for Nuclear Sustainability Services – Western Facility and Radioactive Waste Operations Site 1

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W-REP-03443-00006

2022-08-05

Order Number: N/A
Other Reference Number:

Public Information

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2021 RESULTS OF ENVIRONMENTAL MONITORING PROGRAM FOR NUCLEAR SUSTAINABILITY SERVICES - WESTERN FACILITY AND RADIOACTIVE WASTE OPERATIONS SITE 1

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Ref. 22-3006
5 August 2022

2021 RESULTS OF ENVIRONMENTAL MONITORING PROGRAM FOR NUCLEAR SUSTAINABILITY SERVICES - WESTERN FACILITY AND RADIOACTIVE WASTE OPERATIONS SITE 1

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EXECUTIVE SUMMARY

Ontario Power Generation (OPG) maintains an environmental monitoring program (EMP) at the Nuclear Sustainability Services - Western Facility (NSS-W), formerly known as the Western Waste Management Facility. The detailed design of the NSS-W EMP was developed in 2012 in accordance with the Canadian Standards Association (CSA) N288.4-10 Environmental Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills. The 2021 program was implemented according to the recommended 2012 design and 2019 updates. The program scope encompasses protection of both the public and the environment from nuclear substances, hazardous substances, and physical stressors resulting from the operation of the NSS-W and Radioactive Waste Operations Site (RWOS 1).

The EMP is designed to satisfy the following four primary objectives of CSA N288.4-10:

1. Support assessment of the impact on human health and the environment of contaminants and physical stressors of concern resulting from operation of OPG nuclear facilities.

2. Demonstrate compliance with limits on the concentration and/or intensity of contaminants and physical stressors in the environment or their effect on the environment.

3. Demonstrate the effectiveness of containment and effluent control and provide public assurance of the effectiveness of containment and effluent control, independent of effluent monitoring.

4. Verify the predictions made by the Environmental Risk Assessments (ERAs), refine the models used, and reduce the uncertainty in the predictions made by these assessments and models.

The 2021 program results contained in this report include concentrations of radionuclides in air, water and groundwater as well as ambient dose measurements from the vicinity of the NSS-W and RWOS 1 sites. The relative contribution by NSS-W and RWOS 1 to public dose was assessed through comparison with effluents from the Bruce A and B Generating Stations. For C-14 emissions, dose to a hypothetical receptor at the NSS-W property boundary was calculated using available data.

Operation of NSS-W resulted in extremely low public dose, well within regulatory limits. The potential exposure of non-Nuclear Energy Workers (NEW) to gamma radiation near NSS-W facilities was shown to be low and well below the derived dose rate limit. OPG continued to meet its commitment to keep its impact on tritium levels at nearby Water Supply Plants (WSPs) below 100 Bq/L on an annual average basis.

Bedrock aquifer groundwater sampling indicated that there were no significant increasing trends in radioactivity and no significant releases of radioactivity to groundwater travelling offsite.

Previously elevated tritium levels in one area of the Middle Sand Aquifer (MSA) near the Low Level Storage Buildings (LLSB) have steadily decreased since 2017.

Tritium sampling in precipitation and passive air sampling of C-14 have been conducted. Tritium levels in precipitation are not elevated compared to the background. C-14 activity in air is mainly contributed by the in-ground containers on the NSS-W. No adverse effects to workers, the public and the environment are expected due to these emissions.

There is currently no indication of unacceptable levels of radioactivity leaving the site either in air, surface water or groundwater.

Overall, the results of the 2021 NSS-W environmental monitoring program indicate confirmation of adequate protection of the public, workers and environment.

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1.0 Introduction

Ontario Power Generation (OPG) owns and operates the Nuclear Sustainability Services — Western Facility (NSS-W), formerly known as the Western Waste Management Facility. To ensure activities at OPG facilities are conducted in a manner that minimizes any potential adverse impact on the public and natural environment, OPG has established an Environmental Management System (EMS) that is consistent with the Canadian Nuclear Safety Commission (CNSC) Regulatory Document – 2.9.1: Environmental Protection: Environmental Protection Policies, Program and Procedures [1]. Additionally, the OPG EMS is registered to the International Organization for Standardization (ISO) 14001 Environmental Management Systems standard.

As part of this program, each OPG Class 1 Nuclear Generating Station and Facility has an Environmental Monitoring Program (EMP), which identifies the contaminants and physical stressors which require monitoring. It also conducts monitoring in the environment surrounding the facility.

In 2012, OPG developed a detailed design for an EMP to monitor the NSS-W. It was developed in accordance with the guidance of the Canadian Standards Association (CSA) N288.4-10 standard, "Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills" [2].

This report provides the results of the WMMF EMP for 2021. The report has been prepared in compliance with Clause 11.1 of CSA N288.4-10 [2], as shown in Table 1.1.

Table 1.1: Concordance Table with Reporting Requirements in CSA N288.4-10

CSA N288.4-10 Clause 11.1.2	Section in EMP Report
The report shall include	
a) the results of the EMP, including	
i) measurements of the monitored hazardous and/or nuclear substances, physical stressors, and physical and biological parameters, including their statistical analyses (i.e., assessments of changes through time and space);	Section 2.3
ii) radiation doses calculated as doses to receptors where this is required;	Section 3.0
iii) an assessment of the EMP results compared with the performance indicator targets; and	Section 2.3 and 3.0

CSA N288.4-10 Clause 11.1.2	Section in EMP Report
iv) documentation and justification of any deviations from field sampling, and analytical, and data management procedures;	Section 4.3
b) a summary and assessment of the field and laboratory QA/QC results, including any nonconformances	Section 4.1
c) a summary of the audit and review results and subsequent corrective actions	Section 4.2
d) a summary of any proposed modifications to the EMP	Section 6.0
e) documentation, assessment, and review of any supplementary studies that have been initiated, completed, or both.	Section 2.2.5 and 2.3.4

1.1 Program Objectives

The objectives of the NSS-W EMP are to [3]:

1. Demonstrate that the radiological risk to the public due to the operation of the NSS-W is low and well within the regulatory public dose limit.
2. Measure external gamma dose at the perimeter of the NSS-W and RWOS 1 to confirm compliance with the operating limit of 0.5 µSv/h.
3. Monitor groundwater to confirm the effectiveness of containment of in-ground storage structures at the NSS-W and the RWOS 1.
4. Monitor HTO in precipitation to provide data for the purpose of establishing the source of HTO in on-site groundwater (from rainfall or from leaks/spills) and for trend analysis for tritium in precipitation.
5. Monitor the railway ditch water for tritium levels to assess remedial measures taken to reduce tritium in the NSS-W MSA groundwater.
6. Monitor water and sediment for radionuclides and non-radioactive contaminants in the wetland east of the NSS-W to confirm no ecological impact from the east site drainage discharge.
7. Demonstrate that NSS-W waterborne emissions comply with OPG's commitment to keep tritium concentrations at nearby WSPs below 100 Bq/L on an annual average basis.
8. Update the estimated fugitive tritium and C-14 emissions from the site and determine if additional monitoring and reporting is warranted.

1.2 Overview of the Nuclear Sustainability Services - Western Facility

The NSS-W is located on the Bruce nuclear site along the east shore of Lake Huron, approximately 18 km north of Kincardine and 17 km southwest of Port Elgin (Figure 1.1). Although not located within the NSS-W facility boundaries, the former Spent Solvent Treatment Facility (SSTF) and RWOS 1 are also located on the Bruce nuclear site (Figure 1.2) and are owned and operated by OPG. The SSTF has not accepted spent solvent since 2003 and was decommissioned in 2019 and the CNSC licence has been removed. The RWOS 1 has not received waste since 1976 and remaining storage structures are in caretaking mode [7].

The Bruce nuclear site also hosts Bruce Nuclear Generating Station A (Bruce NGS-A) and Bruce Nuclear Generating Station B (Bruce NGS-B), the Central Maintenance Facility (CMLF), Central Storage Facility (CSF) and other nuclear facilities and related infrastructures (Figure 1.2). Kinectrics North Facility is located 3 km from the Bruce site. Its main function is the decontamination and refurbishment of large nuclear reactor tools and equipment. The Bruce nuclear site occupies an area of 932 hectares (2,300 acres) within the Municipality of Kincardine, County of Bruce, and Province of Ontario. Land use in the immediate vicinity is primarily agricultural, recreational and rural residential. Surrounding the Bruce nuclear site is a mixture of rural agricultural land, former gravel pits, fragmented woodlands, streams and wetlands. Recreational land use includes Inverhuron Park and cottages in the hamlet of Inverhuron (south of Bruce nuclear site) and Baie du Doré/Scott Point Area (north of Bruce nuclear site).

The NSS-W is owned and operated by OPG and has been in operation since 1974. It is a Class 1B nuclear facility for the storage of low and intermediate level (L&ILW) radioactive waste and used fuel. The NSS-W consists of the L&ILW Management Area and the Used Fuel Management Area. The L&ILW Management area includes the Low-Level Storage Buildings (LLSBs), a Steam Generator Storage Building (SGSB), a Retube Waste Container Storage Building (RWCSB), a Waste Volume Reduction Building (WVRB), and a Transportation Package Maintenance Building (TPMB). In-ground structures include In-ground Containers (ICs), trenches and tile holes, while above-ground structures in this area include the Quadricells. The Used Fuel Management Area includes a Used Fuel Dry Storage Container Processing Building and four Used Fuel Dry Storage Buildings. The layout of the NSS-W is illustrated in Figure 1.3.

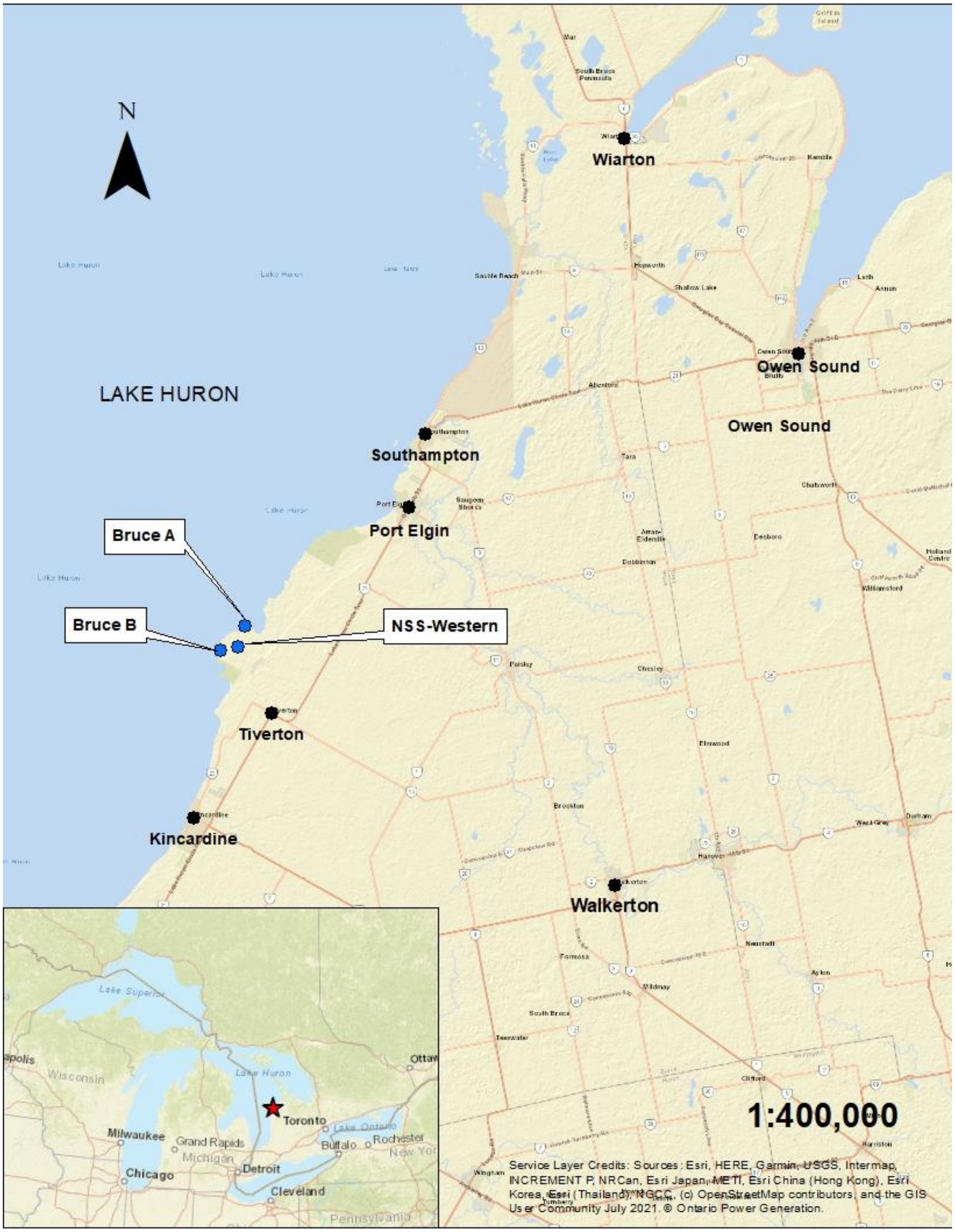

Figure 1.1: Location of Nuclear Sustainability Services - Western Facility

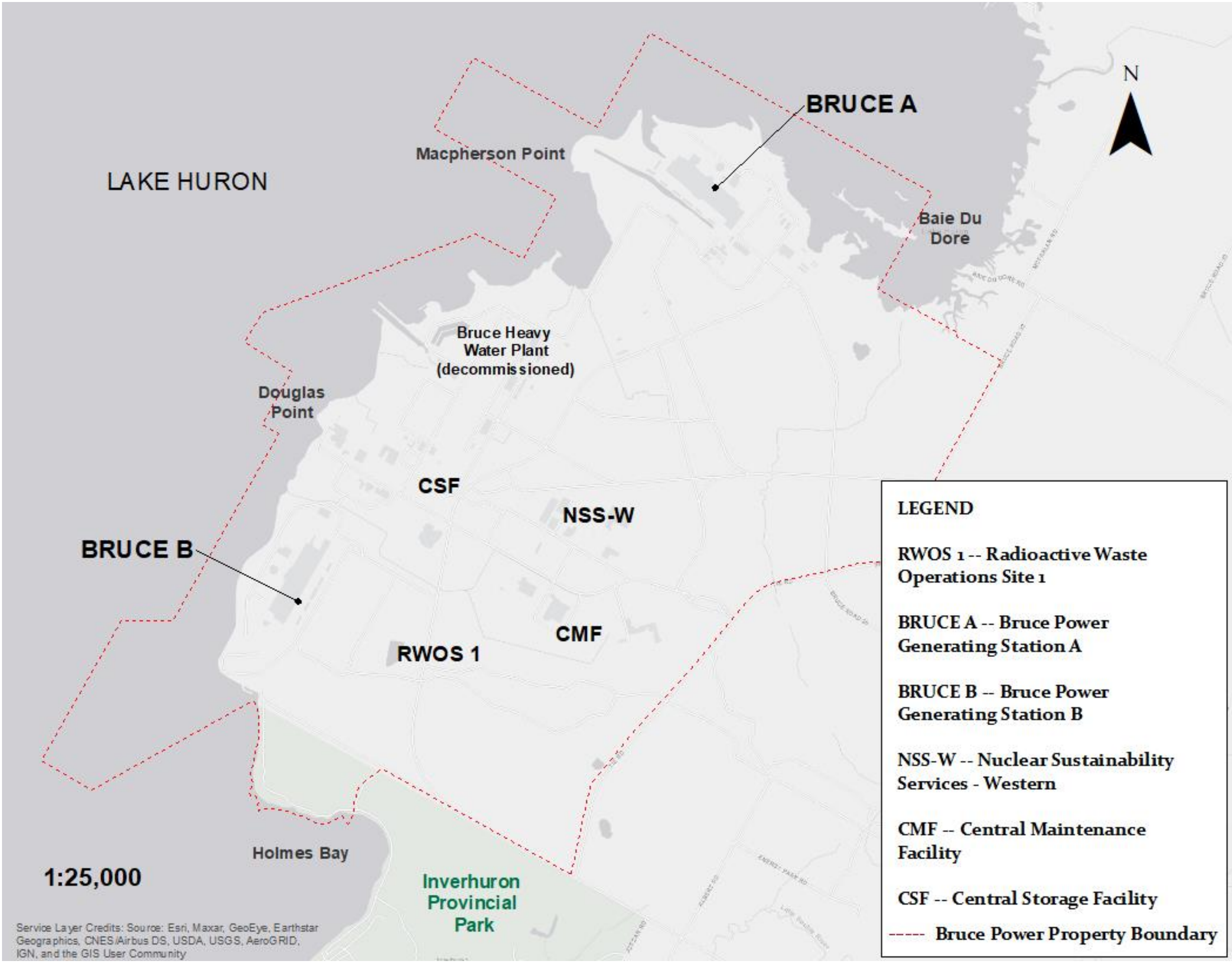

Figure 1.2: Location of Facilities on Bruce Nuclear Site

Figure 1.3: NSS-W Aerial View

2.0 Environmental Monitoring Program

2.1 Design of EMP

Radiation protection, effluent monitoring, and environmental monitoring have taken place at the NSS-W for many years. Results of the environmental monitoring are reported in the NSS-W Quarterly Operation Reports (QORs) to the CNSC. Current EMP elements that were reported in the QORs are TLD gamma doses, groundwater monitoring results and groundwater trend graphs. Prior to the issue of N288.4-10 a separate EMP for the NSS-W was not needed because the previous version of the standard, N288.4-M90 only addressed the radioactivity in the environment outside the boundary of the facility. The Bruce site radioactive environmental monitoring program fulfilled this former requirement. CSA N288.4-10 [2], has an expanded scope for environmental monitoring which includes radioactivity, non-radioactive contaminants, human health, non-human biota, physical stressors and the areas of the environment within the facility boundaries. Thus, an EMP for the NSS-W was designed according to the guidance provided in this standard. The detailed design of this EMP was completed in June 2012 [4] and monitoring has been ongoing based on this design.

2.1.1 Facilities included in EMP

NSS-W operates under a Class IB Nuclear Facility Licence. Although the EMP design report primarily addresses the NSS-W, including all waste storage, waste processing, transportation equipment maintenance, and used fuel dry storage facilities, it also currently includes RWOS 1. Most of the radiological waste was recovered from RWOS 1 and stored at the NSS-W. The RWOS 1 is in caretaking mode. Other OPG facilities on the Bruce nuclear site include the conventional landfill and four (4) construction landfills. These were excluded from the EMP design as they are either regulated by the Ontario Ministry of the Environment, Conservation and Parks (MECP) or were not considered to present any significant risk [4].

2.1.2 Environmental Risk Assessment

The NSS-W ERA assesses potential human health and ecological risks from exposure to radiological contaminants, conventional contaminants, and physical stressors present in the environment as a result of site operations. The ERA helps to identify which monitoring to include in the NSS-W EMP. Subsequently EMP data are used to update the ERA on a regular time interval, with the data being used to refine models, test predictions of the last ERA and further enhance the understanding of potential risk from the site.

The most recent NSS-W ERA was completed in 2021 [6] in accordance with the requirements of CSA N288.6-12, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills [8]. The ERA provided the following recommendations for monitoring:

- The current quarterly monitoring of tritium within the South Railway Ditch (SRD) as part of the EMP program is appropriate and should be continued.

- Hazard quotients above 1 were observed in the surface water at the SRD for a number of metals, which is consistent with observations from past monitoring and may be attributed to the existence of a former rail line within the ditch for some metals, and to naturally elevated water concentrations for iron and manganese. Additional monitoring is recommended prior to the next ERA to confirm that conditions in the SRD remain unchanged.

- It was previously recommended that the supplementary precipitation study be repeated in 2020-21 to support the 2021 ERA update. However, based on analysis presented in the 2021 ERA, the precipitation monitoring program is not interpreted to provide additional insight into the NSS-W inputs to precipitation since the results indicated that tritium is most likely attributed to the operation of Bruce A and Bruce B, and the location and elevation of the precipitation samples are not expected to capture the tritium off-gassing processes occurring at the LLSBs. Therefore, future precipitation monitoring can be discontinued.

- The source of inputs to the wetland is sufficiently understood; therefore, ongoing monitoring of the wetland is not necessary at this time. However, additional wetland monitoring is recommended to support the next ERA update to determine if conditions are stable or have changed.

- The source of C-14 concentrations in vegetation near IC-18 is understood. Therefore, it is recommended that routine air monitoring should continue as part of the EMP design to determine fugitive C-14 emissions, but additional investigations into C-14 in air and vegetation are not required. Future consideration of C-14 in vegetation can be modelled using the specific activity model, as modelled concentrations in vegetation are expected to correlate well with measured air concentrations.

- Adverse effects to benthic invertebrates at the community level are not expected within the SRD and the West Ditch. Considering that dioxins and furans are not expected to cause adverse effects at the community level at either the West Ditch and SRD, remediation is not warranted. Remediation efforts that involve disturbing the sediment within the SRD and West Ditch are not recommended. Samples of benthic invertebrates can be collected and analyzed for dioxins and furans in a supplementary study to reduce uncertainty in risk characterization for the next ERA update.

2.1.3 Other Inputs

The EMP design was also based on other inputs in addition to risk factors identified in the ERA, such as ongoing confirmation of containment of radioactivity in the NSS-W storage structures, contamination of groundwater, and confirmation of predictions in the ERAs.

2.2 EMP Sampling Plan

The EMP sampling plan outlines the parameters monitored, the monitoring locations, the sample types, and the frequency of collection. Samples collected, analyses performed, and interpretation of the data support the EMP objectives as follows:

2.2.1 Public Radiological Dose Estimation

A direct determination of public radiological dose based on environmental monitoring of nuclear substances released from NSS-W operations is not feasible. Environmental media around the Bruce nuclear site (e.g., air, soil, plant and animal food products, water, beach sand) contain radionuclides which are released from all nuclear facilities on the site operated by OPG, Bruce Power and Canadian Nuclear Laboratories (CNL); that is the NSS-W, Bruce NGS-A, Bruce NGS-B, CMF, CSF, and Douglas Point Waste Facility (DPWF). Most of these radionuclides are common to all facilities and for the most part, one cannot determine the level of contributions in environmental media from each specific source by means of environmental measurements and laboratory analyses. Most of the radioactivity monitored in the environment is tritium, C-14 and beta/gamma emitters, all of which are released to some extent in airborne and waterborne effluents by all Bruce nuclear site facilities. Bruce Power conducts a full EMP, including radiological monitoring [9]. Estimation of public radiological dose resulting from NSS-W operations is achieved by estimating the NSS-W contribution to the Bruce Power public radiological dose calculation by comparing the relative levels of monitored radiological emissions. See Section 3.1 for the results of this assessment.

2.2.2 Tritium Levels at Water Supply Plants

OPG has a commitment to the government of Ontario to control waterborne emissions of tritium from its facilities to levels that will keep tritium concentrations at nearby WSPs below 100 Bq/L on an annual average basis. Confirmation that OPG is keeping its commitment is achieved by estimating NSS-W's relative contribution to Bruce Power's results of monitoring tritium in the Southampton and Kincardine WSPs, using measured waterborne tritium emissions. See Section 3.2 for the results of this assessment.

2.2.3 Direct Gamma and Skyshine Dose

Direct gamma and skyshine doses result from radioactivity in the waste storage facilities fall off rather quickly with distance. The NSS-W storage facilities are located reasonably far from the Bruce nuclear site perimeter, and gamma dose from the NSS-W is not a significant contributor to the radiological dose of the general public. However, external gamma doses near the storage facilities are monitored to ensure that potential non-NEWs working in proximity of the NSS-W are adequately protected. In order to protect non-NEWs near the NSS-W site, the storage facilities have a gamma dose limit of 0.5 µSv/h at the fence line. This ensures that a non-NEW at a nearby location over the course of a normal work year would not be exposed to more than the non-NEW regulatory dose limit of 1 mSv/a.

Environmental TLDs were placed at a number of locations around the perimeters of the NSS-W and RWOS 1 to measure direct gamma doses. There are 36 TLDs at the NSS-W (16 around the Used Fuel Dry Storage Facility (UFDSF) and 20 around the rest of the NSS-W). There are seven (7) TLDs around RWOS 1. The specific locations are shown in Figure 2.1 and Figure 2.2. The TLDs were replaced every quarter and shipped to the OPG Whitby Health Physics laboratory (HPL) for analysis. Preparation, shipping, deployment and analysis of the TLDs are described in the EGM System Overview [10]. See sections 2.3.2 and 3.3 for results of TLD measurements. Data can also be found in the quarterly reports (see [11], [12], [13], and [14].

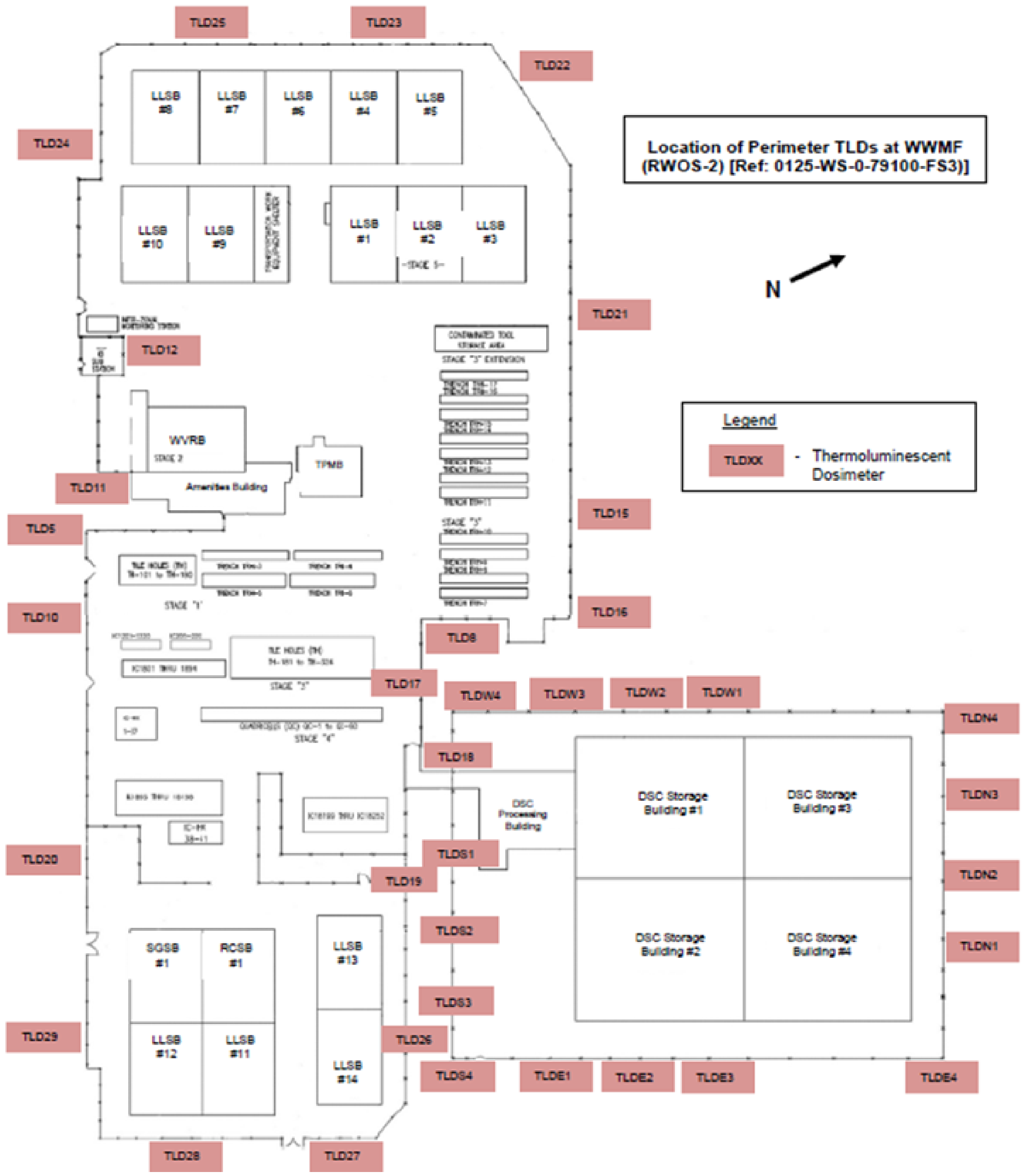

Figure 2.1: Location of TLDs at NSS-W

Source: NSS-W Quarterly Operations Report [11]

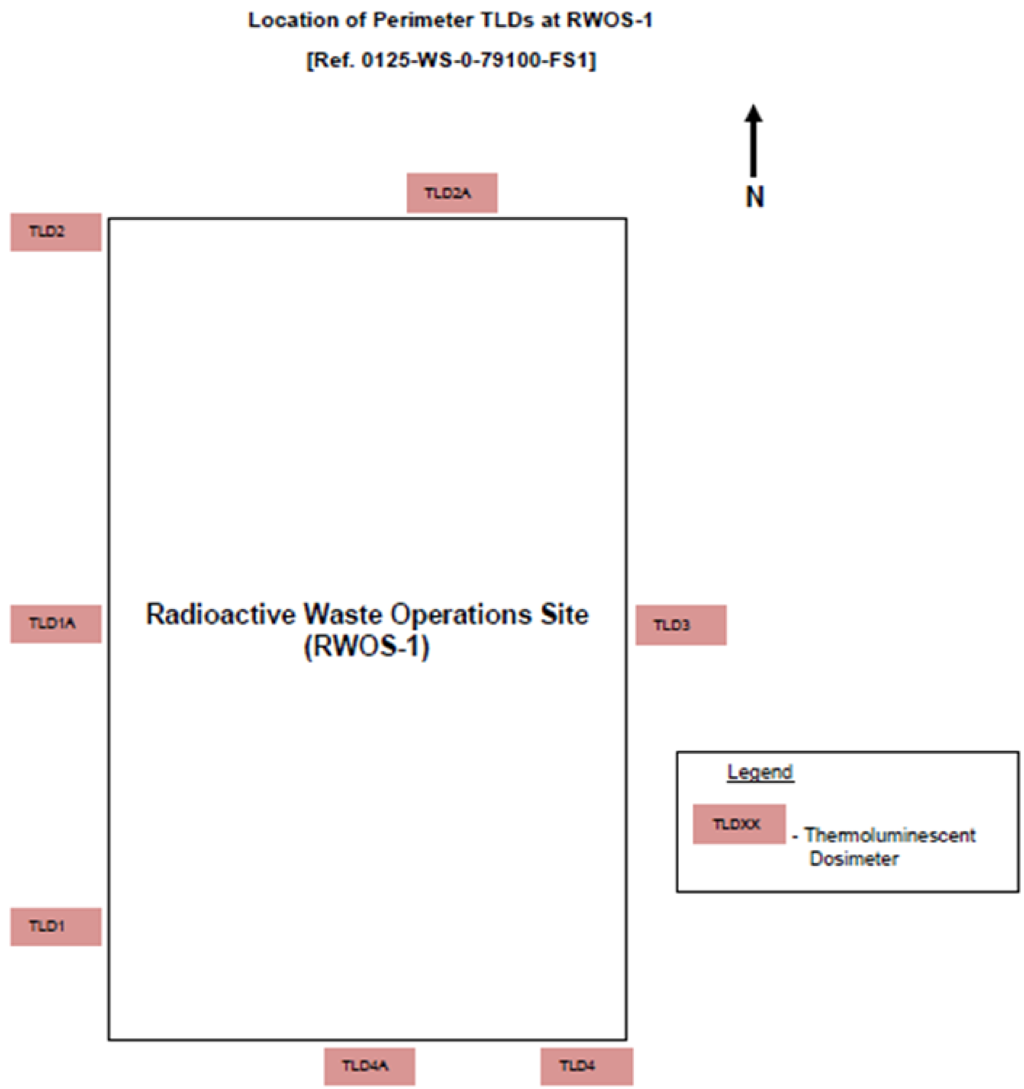

Figure 2.2: Locations of TLDs at RWOS 1

Source: NSS-W Quarterly Operations Report [11]

2.2.4 Confirmation of Containment Integrity of In-ground Storage Structures

In-ground storage structures are monitored in different ways. The trenches and tile holes have an engineered subsurface drainage system, and any radioactivity released from these structures to water in the subsurface drainage system is routinely reported in the monitored waterborne effluents. IC-12s and IC-18s have an accessible space outside the IC walls that is routinely checked for any water accumulation and radioactivity, thus providing a primary check of containment. As an additional barrier to ensure effective storage structure containment, groundwater around the NSS-W and RWOS 1 is routinely sampled. The sampling wells are proper, sealed groundwater sampling wells, but are called water sampling holes (WSHs). The WSHs are placed to detect a potential loss of containment in storage structures and any movement of radioactivity in groundwater from the NSS-W. The specific locations of the WSHs at the NSS-W are shown in Figure 2.3, and the locations of those at RWOS 1 are shown in Figure 2.4.

Both the shallower Middle Sand Aquifer (MSA) and the deeper bedrock aquifer are monitored. Detailed procedures are followed for proper monitoring of the groundwater wells [15].

The MSA is generally localized to the NSS-W but is hydraulically connected to the bedrock aquifer. Groundwater from the MSA generally leaves the NSS-W site via the bedrock aquifer. However, it appears that due to excavations and backfill material associated with the installation of a Stormceptor in the mid-2000s, some groundwater from the MSA discharges to the South Railway Ditch (near the north-western area of the NSS-W). For a more detailed description of groundwater flow within and outside of the NSS-W, see the EMP design report [4]. A source term assessment and groundwater monitoring network design enhancement was completed in 2016 at the NSS-W. The specific locations of the WSHs at the NSS-W are shown in Figure 2.3, and the locations of those at RWOS 1 are shown in Figure 2.4

Section 2.3.3 provides the WSHs monitored in 2021 for tritium, gross beta or C-14 at both RWOS 1 and the NSS-W. Most wells at RWOS 1 and the NSS-W are monitored quarterly, however some wells are monitored once per year. The frequency of sampling and analysis for tritium and gross beta activity in WSH 231 is currently monthly. The higher frequency addresses the elevated tritium activity in WSH 231.

There are no specific targets or limits for radioactivity in groundwater at the NSS-W or RWOS 1. However, OPG has committed to notify the CNSC if tritium levels at WSH 231 exceed 60,000 Bq/L [7]. In general, the radioactivity in each WSH is examined to see if there is an increasing trend over time that may indicate a loss of integrity of a storage structure. In the case of WSH 231, where elevated tritium in the MSA has been identified for some time, remedial measures such as pumpouts of water from LLSB electrical manhole sumps were initiated starting in February 2010. WSH 231 data were examined for a decreasing trend from February 2010 onward to determine how effective the remedial measures have been in reducing tritium concentrations. See Section 2.3.3 and Appendix C for results of groundwater monitoring.

Figure 2.3: Monitoring Well Network at the NSS-W

Figure 2.4: Monitoring Well Network at the RWOS 1

2.2.5 Water and Sediment in South Railway Ditch, Wetland and Grassed Swale (Supplementary Study)

The EMP design report recommended a supplementary study to monitor water and sediment quality in the grassed swale and wetland at the east side of the NSS-W to verify ERA predictions of no significant adverse effects. In 2013, samples of water and sediment were taken in the South Railway Ditch just north of the UFDSF (upstream of the grassed swale and wetland), in the grassed swale/wetland close to the stormwater discharge point from the east side of the NSS-W site, and at the east end of the railway ditch, east of the NSS-W site downstream of the wetland. Samples were taken in spring, summer and fall. Water and sediment samples were analyzed for metals (metal scan) and gamma emitters (gamma scan). Water samples were also analyzed for HTO, C-14 and gamma emitters. The 2016 NSS-W ERA concluded that there was no risk to biota, with the exception of benthic invertebrates, due to exceedances of copper and zinc sediment TRVs. Copper and zinc are not associated with NSS-W operations [16]. However, zinc levels in the South Railway Ditch and NSS-W drainage measured as part of a groundwater monitoring well network assessment in 2016 were above what was assessed in the ERA and suggest that the zinc concentrations in the South Railway Ditch are influenced by the NSS-W drainage system [6].

In 2020 and 2021, to support the 2021 NSS-W ERA update, the supplementary study was repeated, and surface water and sediment samples were collected from the South Railway Ditch, wetland and Grassed Swale for radionuclides and metals (see the 2021 NSS-W ERA update for details on the sampling [6]).

2.2.6 Water in South Railway Ditch

South Railway Ditch has been monitored routinely for tritium since 2010 and was also monitored in 2013 as part of the NSS-W EMP supplementary studies [7], and in 2020 and 2021 as part of the NSS-W ERA update [6]. The results provided no firm conclusions about changes in tritium in the South Railway Ditch as compared with tritium levels measured in WSH 231 over the same period. Quarterly routine monitoring of the ditch continues at four locations (WOD1, WOD2, WOD4 and WOD5). The continued quarterly monitoring in the SRD and the groundwater wells should provide a better understanding of any trends in tritium moving forward.

2.2.7 HTO in Precipitation

The EMP design report recommended a supplementary study to investigate maximum tritium concentrations in precipitation on the NSS-W site in order to compare these levels to those in groundwater and to determine if tritium in precipitation may be a source of elevated tritium in groundwater [4]. This supplementary study was completed in July 2014. The results suggested that tritium levels in precipitation were too low to account for increased tritium at WSH 231, but may account for tritium levels at other near-surface sampling locations. The study also concluded that there was no significant decrease in tritium concentration between the NSS-W and RWOS 1 or between the NSS-W perimeter and the incinerator. It was concluded that elevated tritium concentrations in the precipitation are mainly a result of emissions from the Bruce Nuclear Generating Station [6].

Routine precipitation monitoring has continued at the NSS-W and two reference locations. Samples were taken at four locations at the corners of the NSS-W at the site boundary (WS1-4). This design is intended to detect any increased concentrations that may occur close to the incinerator and the WVRB ventilation exhausts. One reference location is at RWOS 1 (WS-B), and the second reference location is south of the Bruce A Switchyard, 700m north of the NSS-W (WS-A). Sampling locations are shown in Figure 2.5. Precipitation was collected continuously with rain gauges and was analyzed for HTO.

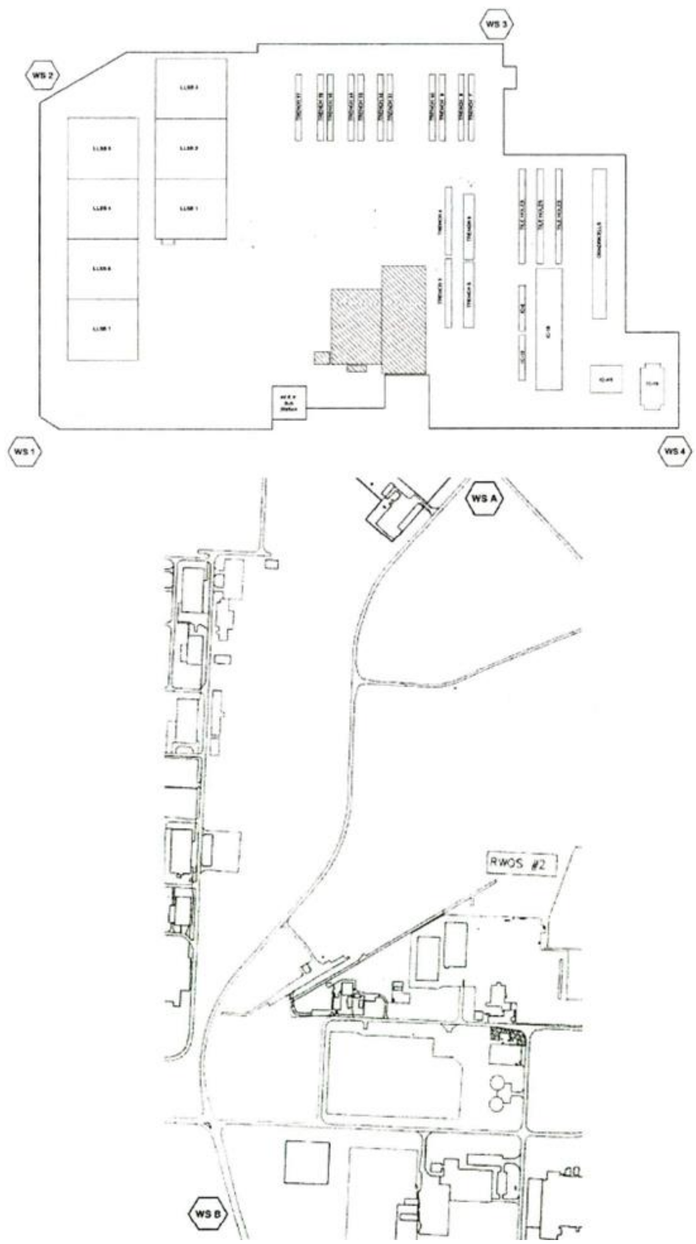

Figure 2.5: Sampling Locations for Routine Precipitation HTO Monitoring

2.2.8 Fugitive Emissions of C-14

Elevated C-14 in air on the NSS-W site was identified in the 2013 EMP Report [7] and an integration into routine sampling was recommended. Bruce Power nuclear site passive C-14 samplers are shown in Figure 2.6: C-14 Passive Monitor Locations Across the NSS-W/Bruce Power Site

In 2020 and 2021, passive sampler results from Bruce Power indicated higher levels than provincial background locations. The highest concentrations were localized at NSS-W. Measured C-14 levels were near provincial background levels at the site boundary [8].

The C-14 passive samplers consist of mixed soda lime pellets to absorb CO_2 from air at a controlled rate. The CO_2 is released from the pellets in the laboratory by titration with acid, then collected and analyzed by liquid scintillation counting for C-14 content. Twenty samplers are positioned around the area of the NSS-W for passive monitoring (Figure 2.7). The samples are collected and analyzed quarterly.

As a result of a review of the effluent monitoring program in 2018, elevated concentrations of C-14 were detected at the NSS-W. Their source was traced to the spent resin storage area, specifically the in-ground containers (IC-12s and IC-18s). The fugitive emissions reassessment was designed to update the estimated fugitive tritium and C-14 emissions from the site and determine if additional monitoring and reporting is warranted. Sampling for this assessment was completed in 2019. During this assessment air samples were also collected from 67 ICs. An assessment of the fugitive C-14 emissions from the ICs was based on the measured levels of C-14 in the IC air and the previously measured volumes of air released from the ICs due to wind pumping. The assessment concluded that, with an estimated emission rate of 6.7E+10 Bq/week, performance monitoring of C-14 is required for ICs, as the emission estimate is >0.05% of the DRL. OPG has reviewed the estimating methodology and is working with the contractor to further refine the prediction instrument. Both environmental and health physics monitoring support that there is no significant impact on workers, the public, or the environment.

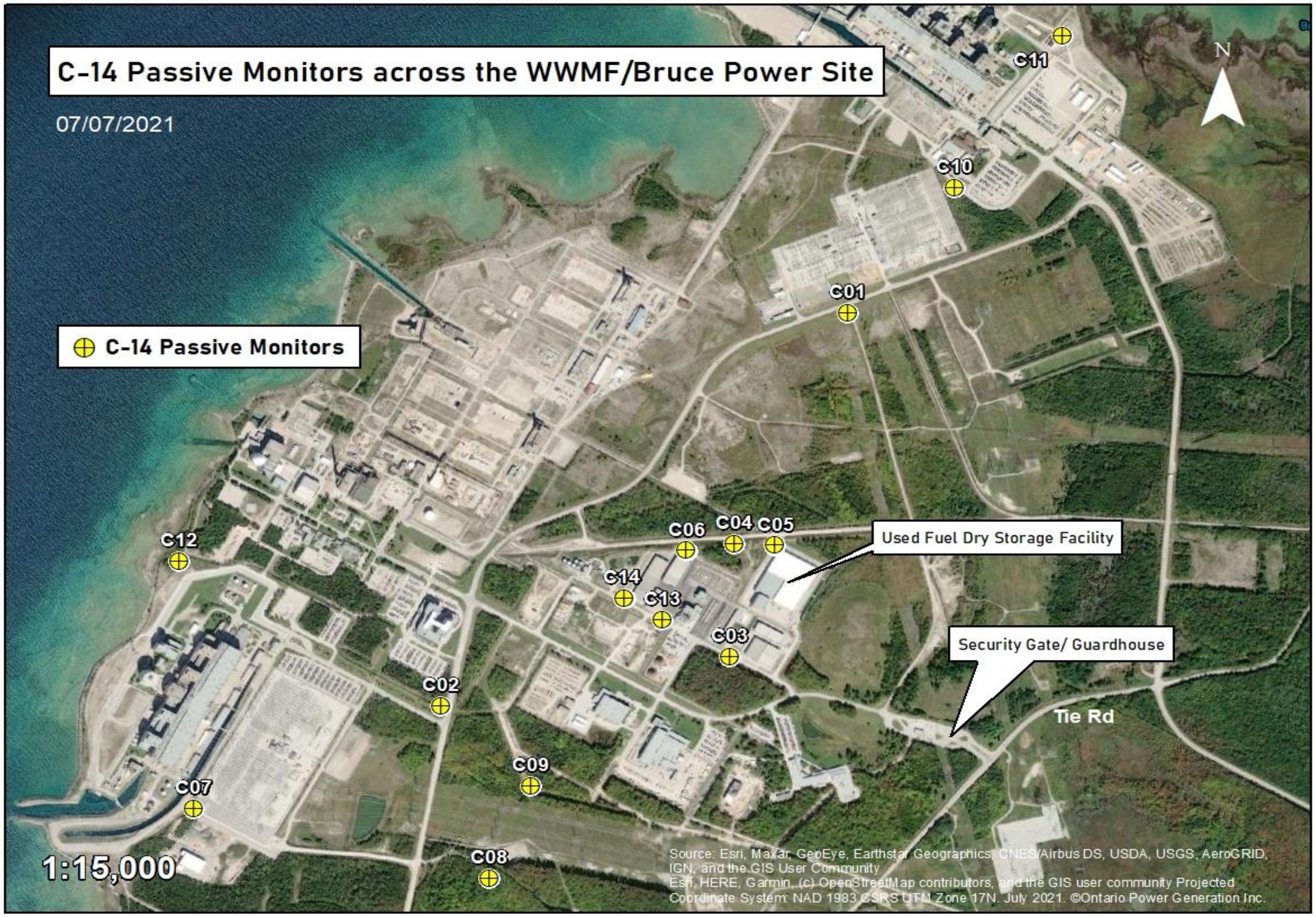

Figure 2.6: C-14 Passive Monitor Locations Across the NSS-W/Bruce Power Site

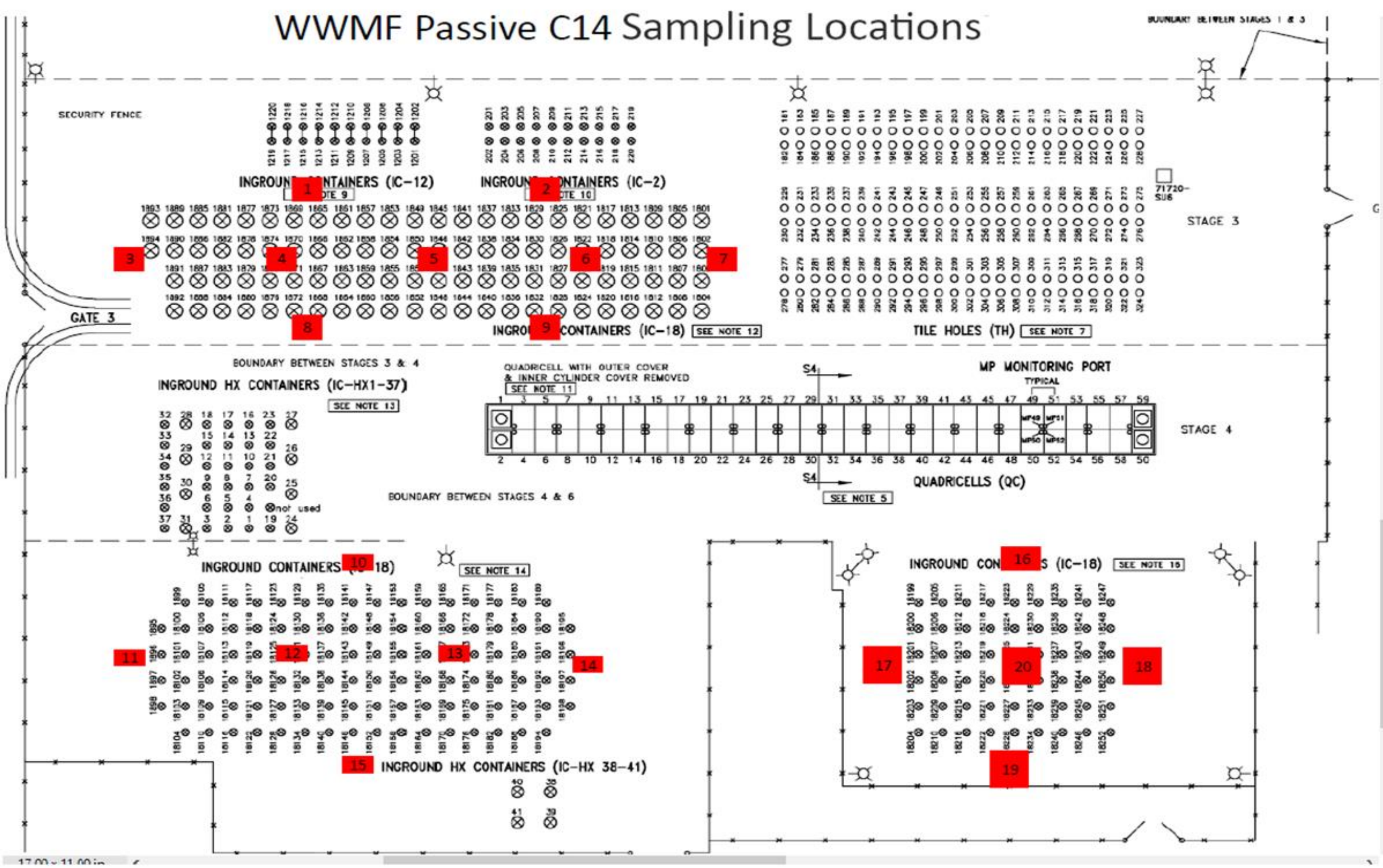

Figure 2.7: Sampling Locations at the Passive Air Samplers at the NSS-W

2.3 EMP Results

This section contains the 2021 results of the EMP for the NSS-W and RWOS 1. Sampling methods, analyses, and QA/QC measures are identified.

2.3.1 Reporting Data and Uncertainties

Descriptive statistics such as means and standard deviations were calculated in Excel unless the dataset contained non-detects with values specified. Statistical analysis for trends were performed using the Microsoft Excel Real Statistics package [17].

Radionuclide concentrations and radiation levels in the environment are low and at times below levels which can be detected by routine analytical techniques. In these situations, the analytical result is reported as being below the detection limit (Ld).

Lc: The critical level is the level (relative to background) below which a quantity cannot reliably be measured. More specifically, the critical level is the largest value of the quantity for which the probability of a wrong conclusion that a quantity is present exceeds a specified probability [18]. The EMP uses a probability of 5%. For the EMP, Lc is approximately equal to half of the Ld.

Ld: The detection limit is the level (relative to background) above which a quantity can confidently be measured. More specifically, the detection limit is the smallest value of the quantity for which the probability of a wrong conclusion that the quantity is not present does not exceed a specified probability [18]. The EMP uses a probability of 5%.

When reporting the analytical data, the following conventions are used:

- Where a measured value is below the analytical Ld but above the Lc, the measured value is reported in bold type.
- Where a measured value is below the Lc, then "< Lc" is reported without an uncertainty measure.
- Where a measured value is censored at the Ld, it is reported as "< Ld". This is the case for gamma spectrometer results, noble gas data, and conventional contaminants.
- For a dataset comprised of a single measured value, the associated uncertainty is the laboratory analytical uncertainty for that particular sample.
- For a dataset without any data censored at the Ld, the arithmetic mean is reported and associated uncertainty is two times the standard deviation of the dataset.
- For a dataset containing some data censored at the Ld, the Kaplan-Meier (KM) estimation method is used. The KM mean is reported and associated uncertainty is two times the KM standard deviation of the dataset. An asterisk "*" is used to identify these datasets.
- For a dataset that consists entirely of data censored at the Ld, the average is reported as "<Ld" without an uncertainty measure.

- For a dataset that consists entirely of data below the Lc (with no censored data), the average is reported as "< Lc" without an uncertainty measure.

2.3.2 Gamma Radiation Dose Monitoring Results

The Harshaw Environmental TLD System was used to measure the direct gamma and skyshine doses around the perimeters of the NSS-W and RWOS 1.

The dosimeters are changed quarterly and shipped to the OPG HPL for readout. For QC, transport dosimeters always accompany the field dosimeters on the trip to and from the field locations, in order to monitor and account for extraneous radiation dose received in transit. Additional information on the TLDs and the readout procedure can be found in the EGM System Overview [19].

The 2021 TLD gamma dose results are shown in Table 2.1. Results are given as air kerma rates (µGy/h). All quarterly results and annual average results at RWOS 1 and the NSS-W, including the UFDS area, are well below the derived dose rate limit of 0.5 µGy/h. A graphical representation of the 2021 results is shown in Figure 2.8.

All TLD locations were analyzed for any statistically significant trends in the last five years (2017 – 2021) at the 95% significance level using the Mann-Kendall Test [17]. Most locations did not show any appreciable changes or trends that would warrant further investigation. Only four (4) TLD locations showed statistically significant trends from 2017 to 2021 (TLDs 19, 24, 25 and 28). TLD 19 increased from 0.059 µGy/h in Q1 of 2017, to 0.083 µGy/h in Q4 of 2021 ($p=0.017$). TLD 24 increased from 0.065 µGy/h in Q1 of 2017, to 0.085 µGy/h in Q4 of 2021 ($p=0.012$). TLD 25 at the Western Low and Intermediate Level Waste Storage Facility (WLILWSF) increased from 0.059 µGy/h in Q1 of 2017 to 0.094 µGy/h in Q4 of 2021 ($p=0.0006$). TLD 28 decreased from 0.108 µGy/h in Q1 of 2017 to 0.096 µGy/h in Q4 of 2021 ($p<0.0068$) (Figure 2.8).

Table 2.1: 2021 TLD Average Air Kerma Rates

TLD - Average Air Kerma Rates (µGy/h)						
TLD Location	**Q1**	**Q2**	**Q3**	**Q4**	**Annual Average**	**2*SD[(3)]**
RWOS 1						
1	0.048	0.047	0.050	0.066	0.053	0.018
1A	0.050	0.052	0.053	0.064	0.055	0.013
2	0.052	0.051	0.053	0.065	0.055	0.013
2A	0.048	0.053	0.054	0.068	0.056	0.017
3	0.044	0.050	0.050	0.060	0.051	0.013
4	0.044	0.048	0.049	0.062	0.051	0.016
4A	0.048	0.047	0.049	0.061	0.051	0.013
WLILWSF[(1)]						
5	0.048	0.047	0.050	0.066	0.053	0.018
8	0.057	0.058	0.059	0.074	0.062	0.016
10	0.049	0.050	0.051	0.063	0.053	0.013
11	0.054	0.056	0.068	0.117	0.074	0.059
12	0.066	0.059	0.056	0.071	0.063	0.014
15	0.058	0.058	0.060	0.072	0.062	0.013
16	0.062	0.062	0.065	0.081	0.068	0.018
17	0.057	0.059	0.058	0.076	0.063	0.018
18	0.059	0.063	0.064	0.075	0.065	0.014
19	0.075	0.061	0.067	0.083	0.072	0.019
20	0.053	0.054	0.061	0.080	0.062	0.025
21	0.053	0.055	0.055	0.068	0.058	0.014
22	0.053	0.054	0.054	0.069	0.058	0.015
23	0.069	0.067	0.067	0.078	0.070	0.011
24	0.073	0.071	0.071	0.085	0.075	0.013
25	0.077	0.071	0.078	0.094	0.080	0.020
26	0.067	0.074	0.078	0.093	0.078	0.022
27	0.064	0.070	0.075	0.086	0.074	0.019
28	0.081	0.081	0.087	0.096	0.086	0.014
29	0.057	0.059	0.072	0.082	0.068	0.023
UFDSF[(2)]						
DFSN-1	0.082	0.081	0.078	0.092	0.083	0.012
DFSN-2	0.091	0.088	0.083	0.103	0.091	0.017
DFSN-3	0.079	0.081	0.080	0.091	0.083	0.011
DFSN-4	0.061	0.061	0.059	0.074	0.064	0.014
DFSS-1	0.067	0.068	0.070	0.081	0.072	0.013
DFSS-2	0.064	0.067	0.071	0.086	0.072	0.020

TLD - Average Air Kerma Rates (µGy/h)						
TLD Location	**Q1**	**Q2**	**Q3**	**Q4**	**Annual Average**	**2*SD(3)**
DFSS-3	0.067	0.069	0.075	0.087	0.075	0.018
DFSS-4	0.060	0.060	0.064	0.081	0.066	0.020
DFSE-1	0.063	0.066	0.070	0.077	0.069	0.012
DFSE-2	0.084	0.083	0.085	0.096	0.087	0.012
DFSE-3	0.083	0.083	0.080	0.097	0.086	0.015
DFSE-4	0.060	0.059	0.058	0.074	0.063	0.015
DFSW-1	0.084	0.087	0.083	0.098	0.088	0.014
DFSW-2	0.080	0.078	0.078	0.095	0.083	0.016
DFSW-3	0.076	0.075	0.077	0.092	0.080	0.016
DFSW-4	0.058	0.058	0.060	0.071	0.062	0.012

1) WLILWSF: Western Low and Intermediate Level Waste Storage Facility
2) WUFDSF: Western Used Fuel Dry Storage Facility
3) Uncertainty in annual average is given as ± 2 standard deviations.
   Ld = 0.7 µGy.

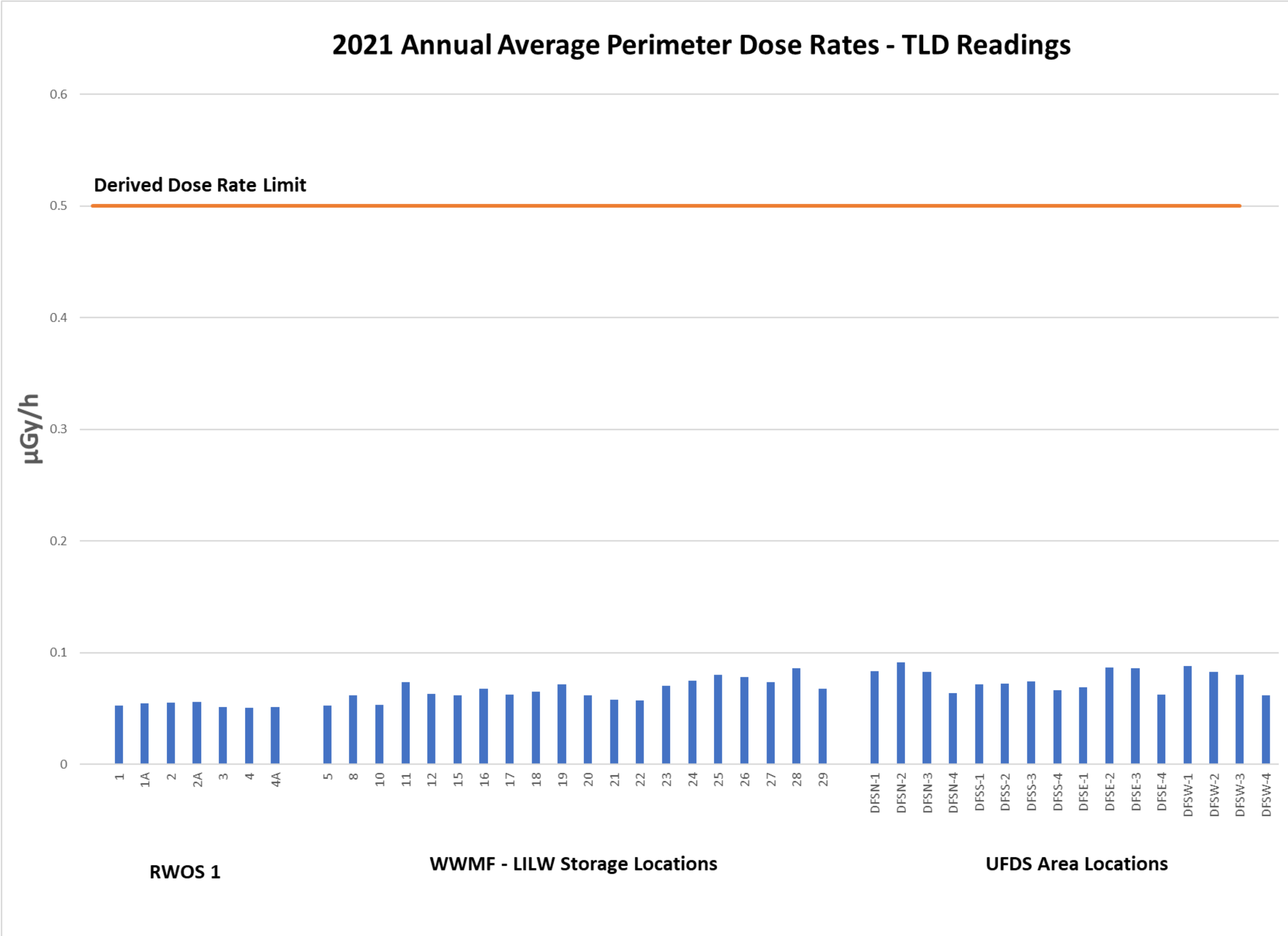

Figure 2.8: 2021 TLD Results

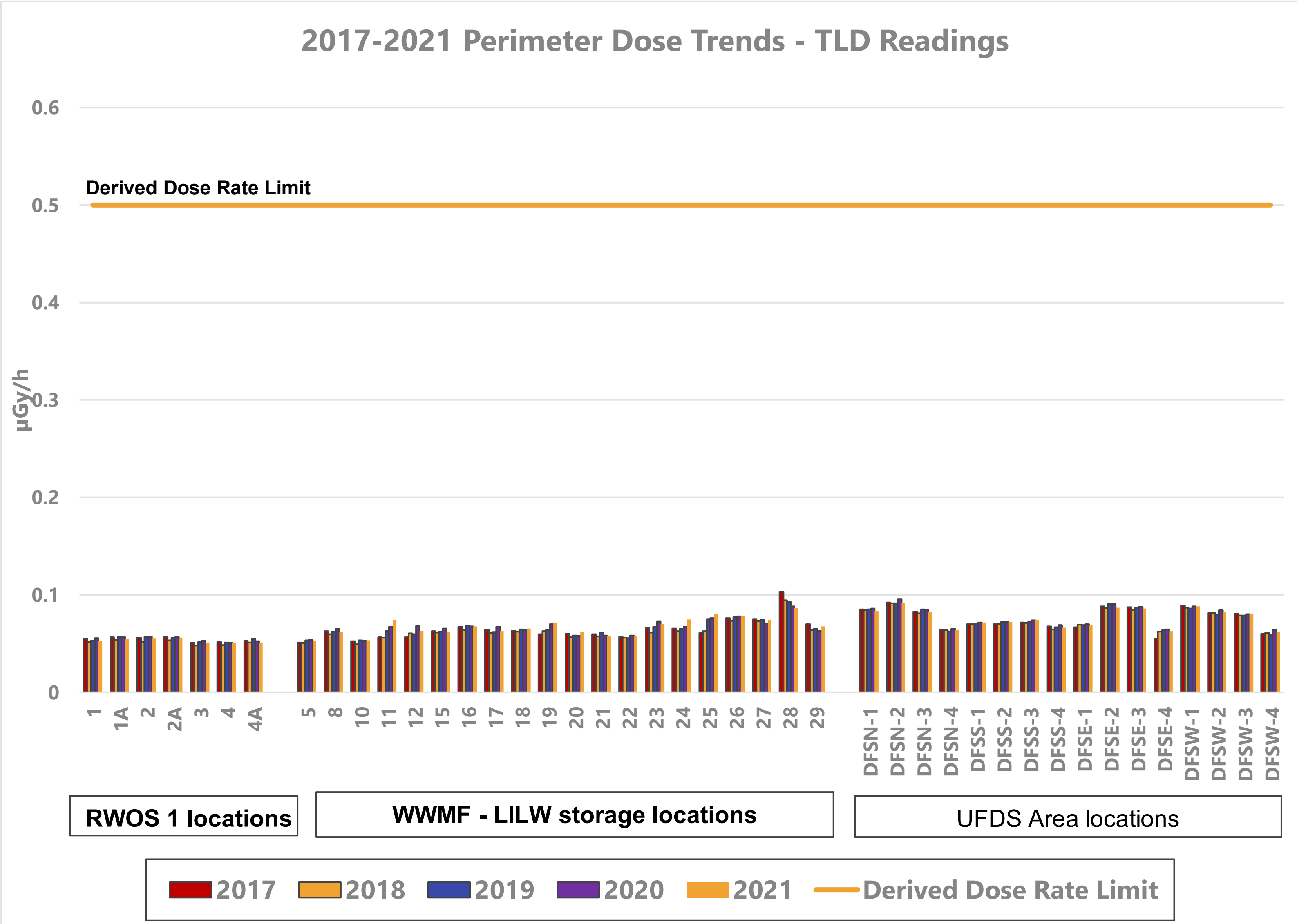

Figure 2.9: 2017-2021-TLD Results

2.3.3 Groundwater Monitoring Results

Of the 40 wells monitored in 2021 at the NSS-W in the bedrock and the MSA, 20 wells are monitored for tritium and gross β activity quarterly and 20 are monitored annually. WSH 224 is monitored for tritium, gross β activity and C-14 annually. WSH 226 is monitored for tritium and gross β activity quarterly and for C-14 monthly. Monitoring of WSH US6 was discontinued in 2017. Analysis results for all wells sampled on a quarterly basis are shown in Table 2.2. Wells that are monitored annually are shown in Table 2.3. Table 2.4 shows the monthly results from WSH 231. At RWOS 1 the bedrock aquifer is monitored for tritium and gross β activity quarterly in seven wells and two surface water locations (Ditch N, Ditch S), shown in Table 2.2 and Table 2.5 respectively. All of these wells are also monitored quarterly for C-14.

In 2021, 8 of the 9 RWOS 1 wells and 35 of the 40 NSS-W wells measured had annual average tritium concentrations in groundwater below 500 Bq/L. Wells with tritium concentrations higher than 500 Bq/L include WSH 20S (639 Bq/L), WSH 229 (1,260 Bq/L), WSH 230 (591 Bq/L), WSH 253 (21,600 Bq/L), WSH 255 (2,540 Bq/L) and WSH 282 (550 Bq/L). Tritium in WSH 231, which characterizes the MSA, averaged 12,532 Bq/L over the year, and never exceeded the level of 60,000 Bq/L at which OPG has committed to notify the CNSC [7]. A negative trend was identified for tritium concentrations at WSH 231 ($p<0.001$), indicating that tritium is steadily decreasing at this station over time. The highest tritium concentrations were measured at WSH 253, located close to WSH 231 with an annual average of 21,600 Bq/L. Monitoring of this well started in 2017 and no statistically significant trend was identified. The 2021 tritium concentrations in groundwater for all WSHs are shown in Figure 2.10.

Annual average gross β levels in RWOS 1 groundwater averaged 0.09 Bq/L, and ranged from 0.07 Bq/L at WSH 20S and WSH 124 to 0.11 Bq/L at WSH 122. Annual gross β levels in NSS-W groundwater averaged 0.27 Bq/L and ranged from 0.08 Bq/L at station WSH 230, to 1.38 Bq/L at station WSH 269. Higher gross β levels at station WSH 269 was consistent with past values at this location and is still low, such that further investigation is not warranted. The 2021 gross β in groundwater results for all WSHs are shown in Figure 2.11: 2021

Historic data for tritium and gross β activity in the WSHs of both sites from 2017 to 2021 was analyzed for the presence of statistically significant trends over this 5-year period. The Mann-Kendall Test was used for trend analysis and tested for evidence of a statistical increasing or decreasing trend at the 95% confidence level. The results of the trend analyses for tritium in the NSS-W wells indicated that WSH 229, WSH 230 and WSH 264 showed an increasing trend. Of the remaining NSS-W wells, thirteen had a decreasing tritium trend (WSH 226, WSH 228, WSH 231, WSH 238, WSH 240, WSH 251, WSH 260, WSH 263, WSH 265, WSH 270, WSH 282, WSH 283, WSH 284) and the remainder had no statistically significant trend. There were eight wells with statistically significant trends for gross β. All of these were decreasing trends (WSH 228, WSH 230, WSH 231, WSH 253, WSH 255, WSH 265, WSH 269, WSH 286).

From 2017 to 2021, one RWOS 1 groundwater well showed a significant trend in tritium levels, with Ditch S decreasing over time ($p=0.0011$) (Note that Ditch S is considered a surface water sample). Conversely, significant trends in gross β levels were identified at all RWOS 1 wells, with all stations decreasing over time.

These results indicate that there are no elevated radionuclide concentrations in groundwater leaving the NSS-W in the bedrock aquifer. However, the localized elevated tritium in WSH 231 and WSH 253 indicate that there was a path from a source of elevated tritium concentration to groundwater in the MSA. There have been investigations to determine the source, which point to tritiated water vapour from waste stored in the LLSBs [5]. Remedial actions have been taken since 2007, which included resealing of select LLSB sumps and regular pump-outs of Electrical Manholes to prevent downgradient migration of tritiated groundwater. Additionally, the tritium inventory in this area continues to decrease due to decay and off-gassing. As stated above, tritium levels in WSH 231 showed a statistically significant decreasing trend over the 2017 to 2021 time period ($p<0.01$). WSH 231 and the neighbouring WSH 253 annual averages over this period are plotted in Figure 2.12.

Table 2.2: 2021 Groundwater Monitoring Results (Bq/L)

	Q1			Q2			Q3			Q4			Annual Average				
WSH	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Uncertainty (2)	Gross β	Uncertainty (2)	C-14 (3)
RWOS 1																	
122	1.63E+02	0.13	**0.1**	1.95E+02	**0.07**	0.137	9.92E+01	**0.06**	**0.1**	8.86E+01	0.18	**0.1**	1.36E+02	1.02E+02	0.11	0.11	0.14
123	3.03E+02	0.11	**0.1**	7.14E+02	**0.07**	0.219	2.94E+02	0.07	**0.1**	5.09E+02	0.08	**0.1**	4.55E+02	3.98E+02	0.08	0.04	0.22
20S	2.10E+02	**0.08**	**0.1**	2.43E+02	**0.07**	0.192	1.88E+03	**0.06**	1.02	2.23E+02	0.07	**0.1**	6.39E+02	1.65E+03	0.07	0.02	1.02
124	1.24E+02	0.08	**0.11**	1.45E+02	0.07	**0.1**	2.56E+02	**0.07**	**0.1**	1.55E+02	**0.07**	**0.1**	1.70E+02	1.18E+02	0.07	0.01	0.11
125	1.25E+02	0.12	0.13	1.29E+02	**0.07**	**0.1**	1.34E+02	0.08	**0.1**	1.26E+02	0.12	**0.1**	1.29E+02	8.08E+00	0.10	0.05	0.13
126	1.12E+02	**0.08**	**0.1**	1.54E+02	**0.07**	**0.1**	1.54E+02	**0.08**	**0.1**	1.18E+02	0.15	**0.1**	1.34E+02	4.55E+01	0.10	0.07	0.10
127	7.93E+01	**0.07**	**0.1**	8.83E+01	**0.07**	**0.1**	9.47E+01	**0.06**	**0.1**	7.72E+01	0.11	0.35	8.49E+01	1.63E+01	0.08	0.04	0.35
NSS-W																	
226	**9.86E+00**	0.16	0.1	**8.29E+00**	**0.09**	**0.1**	**9.22E+00**	0.15	**0.1**	**9.75E+00**	0.12	**0.1**	9.28E+00	1.43E+00	0.13	0.06	0.10
228	1.68E+02	**0.07**	**0.1**	1.62E+02	0.18	**0.1**	1.60E+02	0.07	**0.1**	1.56E+02	0.07	**0.1**	1.62E+02	1.00E+01	0.10	0.11	0.10
229	1.65E+03	0.14	0.16	1.34E+03	0.24	0.2	9.06E+02	0.11	0.376	1.15E+03	0.09	**0.1**	1.26E+03	6.28E+02	0.14	0.13	0.38
230	5.70E+02	0.10	**0.1**	6.07E+02	0.11	**0.1**	5.88E+02	**0.07**	**0.1**	5.98E+02	**0.06**	**0.1**	5.91E+02	3.17E+01	0.08	0.05	0.10
240	**9.41E+00**	**0.07**	**0.1**	**1.03E+01**	0.08	**0.1**	**8.98E+00**	0.08	**0.1**	**1.67E-01**	0.12	**0.1**	7.21E+00	9.46E+00	0.09	0.04	0.10
242	4.65E+01	0.23	N/A	5.93E+01	0.10	N/A	5.63E+01	0.10	N/A	4.96E+01	0.20	N/A	5.29E+01	1.18E+01	0.16	0.13	0.00
243	3.60E+02	0.22	**0.1**	3.12E+02	0.09	**0.1**	2.85E+02	0.21	**0.1**	3.41E+02	0.20	**0.12**	3.25E+02	6.58E+01	0.18	0.12	0.12
253	2.23E+04	0.17	N/A	2.86E+04	0.10	N/A	1.42E+04	**0.08**	N/A	2.13E+04	0.22	N/A	2.16E+04	1.18E+04	0.14	0.14	0.00
255	2.04E+03	0.25	N/A	1.62E+03	0.06	N/A	3.16E+03	0.08	N/A	3.34E+03	0.17	N/A	2.54E+03	1.68E+03	0.14	0.18	0.00
264	3.67E+01	0.11	**0.1**	4.02E+01	**0.09**	**0.1**	5.41E+01	0.11	**0.1**	4.70E+01	0.16	**0.12**	4.45E+01	1.54E+01	0.12	0.06	0.12
265	4.15E+02	0.23	0.14	4.25E+02	**0.12**	0.255	3.87E+02	**0.22**	0.24	3.04E+02	0.18	**0.1**	3.83E+02	1.10E+02	0.19	0.10	0.26
269	3.36E+02	**2.36**	N/A	3.67E+02	**2.51**	N/A	2.74E+02	**0.34**	N/A	2.65E+02	0.30	N/A	3.11E+02	9.83E+01	1.38	2.45	0.00
282	5.46E+02	0.46	**0.1**	5.65E+02	0.23	**0.1**	5.68E+02	0.39	0.142	5.19E+02	0.54	0.18	5.50E+02	4.51E+01	0.41	0.26	0.18
283	1.14E+02	0.48	**0.1**	1.10E+02	0.36	**0.1**	9.98E+01	0.36	**0.1**	9.91E+01	0.55	**0.1**	1.06E+02	1.49E+01	0.44	0.19	0.10
284	3.72E+02	0.29	**0.1**	3.48E+02	0.18	**0.1**	3.72E+02	0.50	**0.1**	3.35E+02	0.50	**0.1**	3.57E+02	3.65E+01	0.37	0.31	0.10
285	2.73E+02	0.19	**0.2**	2.54E+02	0.25	**0.1**	3.07E+02	0.15	0.104	3.81E+02	0.24	**0.1**	3.04E+02	1.11E+02	0.21	0.10	0.20
286	2.99E+02	0.21	**0.1**	2.60E+02	0.32	**0.1**	2.45E+02	0.24	**0.1**	2.82E+02	0.39	**0.1**	2.72E+02	4.76E+01	0.29	0.16	0.10
287	2.90E+02	0.28	**0.1**	2.86E+02	0.35	**0.1**	3.17E+02	0.19	**0.1**	2.84E+02	0.35	**0.1**	2.94E+02	3.07E+01	0.29	0.16	0.10

All measured values for HTO and Gross β are assumed to be uncensored. As such, no Kaplan–Meier mean calculations were necessary

(1) 0.10 Bq/L is the assumed minimum detectable limit for C-14

(2) Uncertainty is presented as ±2 standard deviations

(3) For C-14 the annual maximum is shown

(4) Discharge Ditch S and N are sampled monthly, thus each duplicate row depicts month 1-4, 5-8 and 9-12, respectively

Bolded values indicate measurements under the detection limit

Values in grey are an average of two samples taken within a quarter

Table 2.3: Annual Tritium, Gross β and C-14 in Yearly Monitored Groundwater Wells (Bq/L)

	Q3 (Bq/L)		
WSH	**HTO**	**Gross β**	**C-14**
NSS-W			
224	5.34E+01	0.07	**0.1**
232	**4.94E+00**	0.08	**0.1**
237	**9.47E+00**	0.37	**0.1**
238	**9.29E+00**	1.08	**0.1**
239	**9.20E+00**	0.61	**0.1**
244	6.09E+01	0.07	N/A
246	9.66E+00	0.16	N/A
248	9.80E+00	0.23	N/A
249	1.83E+01	0.28	N/A
251	1.70E+03	0.07	N/A
257	2.51E+03	0.19	N/A
259	8.97E+02	**2.19**	N/A
260	1.09E+01	0.09	N/A
263	6.59E+01	0.08	N/A
268	**9.81E+00**	0.05	N/A
270	**8.33E+00**	0.07	N/A
271	**8.39E+00**	0.14	N/A
272	2.45E+02	0.07	N/A
278	6.99E+01	0.49	N/A
279	1.06E+02	0.41	N/A

Bolded values indicate measurements under the detection limit.

Table 2.4: Monthly Tritium and Gross β Concentration in WSH 231 (Bq/L)

Date	HTO	Gross β
2021-01-19	1.09E+04	0.11
2021-02-19	1.29E+04	0.19
2021-03-19	1.22E+04	**0.09**
2021-04-26	1.78E+04	0.16
2021-05-17	1.63E+04	**0.21**
2021-06-16	1.56E+04	0.14
2021-07-19	1.17E+04	0.17
2021-08-17	1.27E+04	**0.07**
2021-09-22	1.12E+04	0.12
2021-10-18	9.31E+03	0.19
2021-11-25	9.98E+03	**0.08**
2021-12-20	9.79E+03	**0.09**
annual average	1.25E+04	0.13

Bolded values indicate measurements under the detection limit.

Table 2.5: 2021 Groundwater Monitoring Results RWOS 1 Surface Water (Bq/L)

Date	Discharge Ditch (N)		Discharge Ditch (S)	
	HTO	Gross β	HTO	Gross β
2021-01-06	2.50E+02	0.09	9.69E+01	0.09
2021-02-10	2.27E+02	0.11	1.19E+02	**0.09**
2021-03-10	2.30E+02	0.09	1.21E+02	0.09
2021-04-06	1.63E+02	**0.06**	2.05E+02	**0.07**
2021-05-02	1.80E+02	0.10	2.89E+02	0.07
2021-06-03	2.08E+02	0.11	2.32E+02	0.11
2021-07-11	2.14E+02	0.07	1.17E+02	0.09
2021-08-12	1.97E+02	0.18	1.09E+02	0.15
2021-09-13	1.89E+02	0.19	8.66E+01	0.17
2021-10-05	1.99E+02	0.11	9.38E+01	0.18
2021-11-05	1.17E+02	0.12	1.17E+02	0.15
Annual Average	1.95E+02	0.11	1.43E+02	0.11

Bolded values indicate measurements under the detection limit.

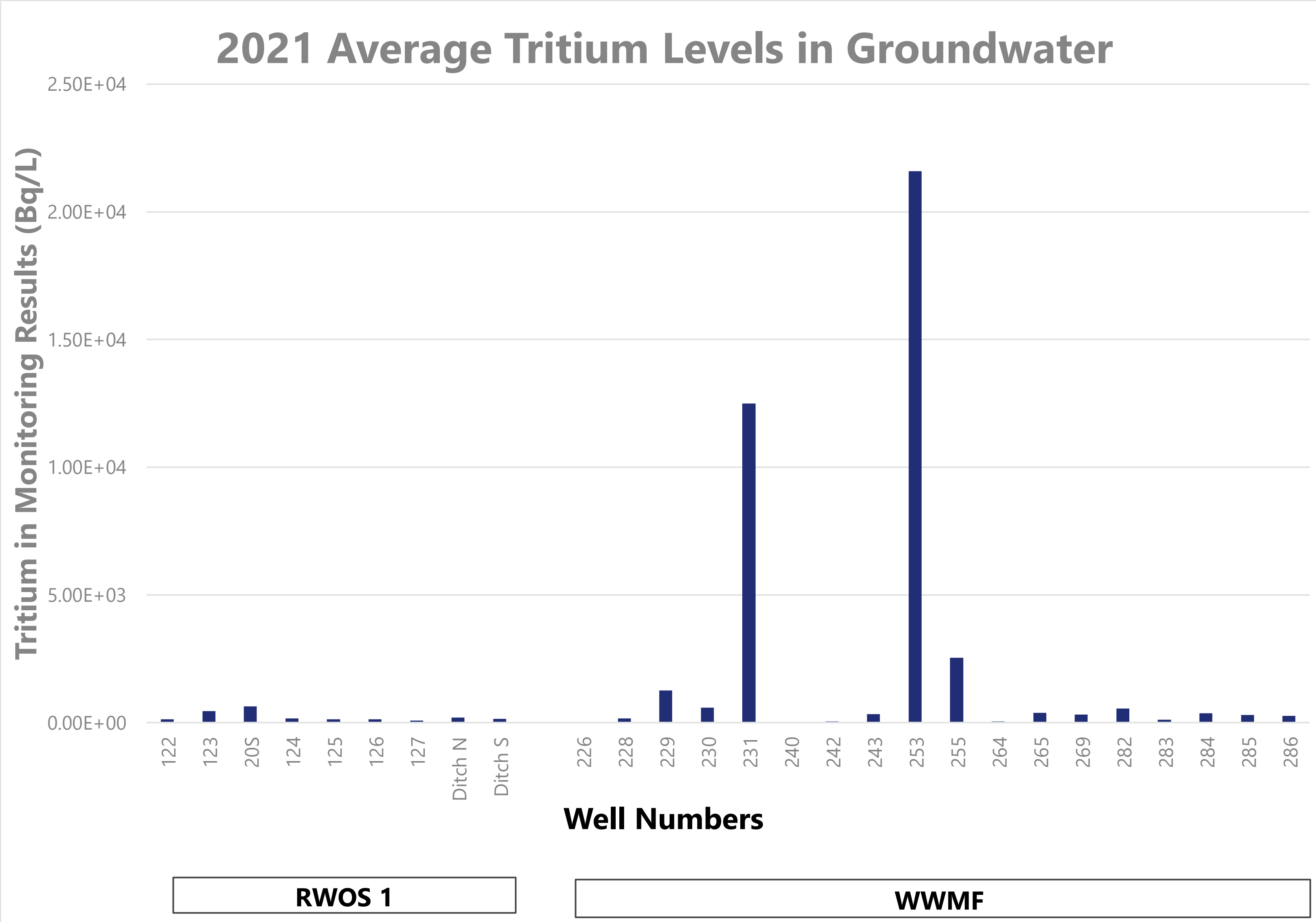

Figure 2.10: 2021 Average Annual Tritium Levels in Groundwater Monitoring Wells

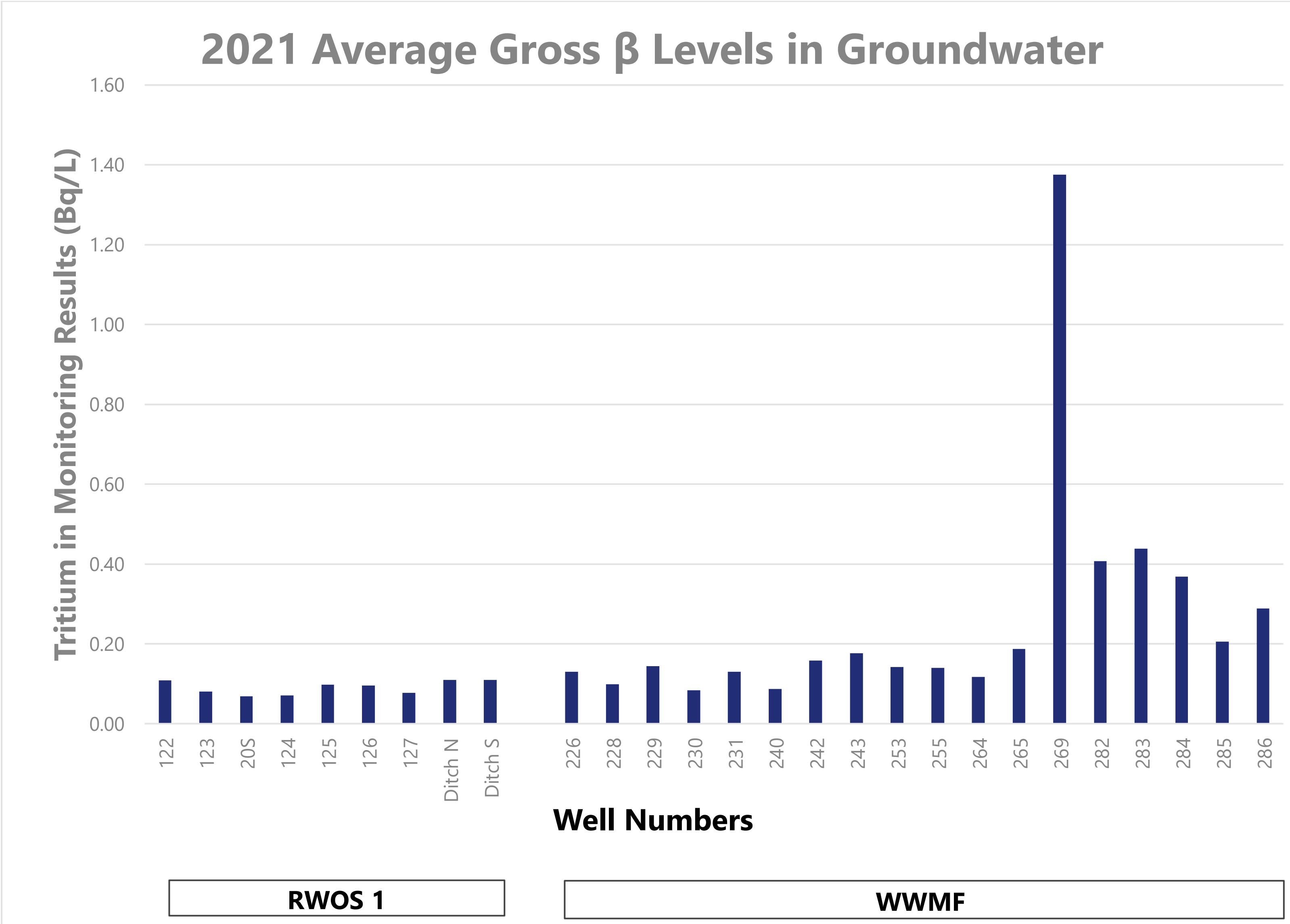

Figure 2.11: 2021 Average Annual Gross ß Concentration in Groundwater Monitoring Wells

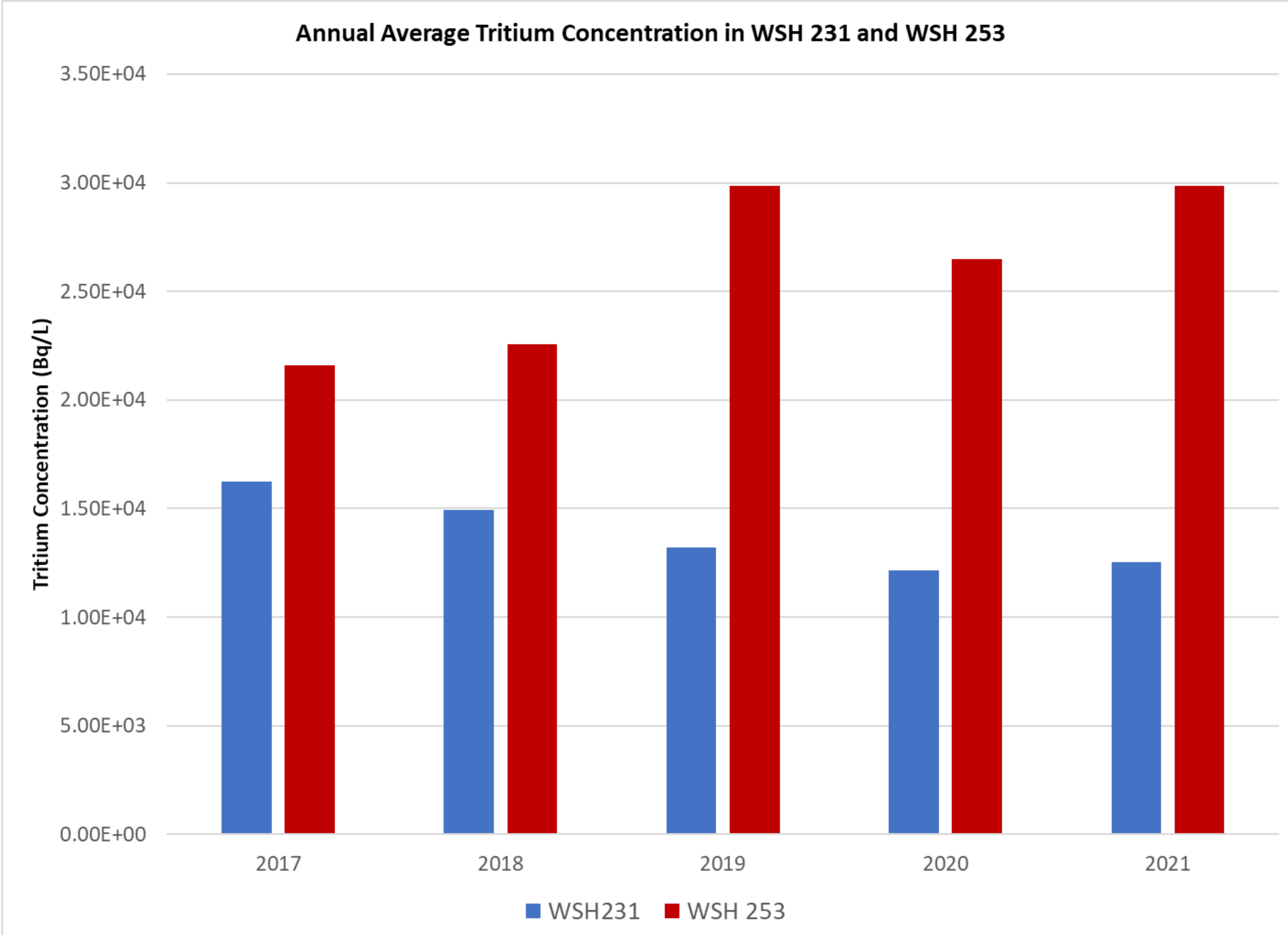

Figure 2.12: Annual Average Concentration of Tritium in Groundwater at Well WSH 231 and WSH 253

2.3.4 Water and Sediment in South Railway Ditch, Grassed Swale, and Wetland (Supplementary Study)

Surface water samples were collected in 2020-2021 in the fall, winter, spring, and summer and analyzed for metals and inorganic parameters, dioxins and furans, C-14, tritium and gamma scan. Sediment samples were collected in 2020-2021 in the fall, spring, and summer and analyzed for metals, moisture, total organic carbon (TOC), dioxins and furans, C-14 and gamma scan. Cattails were also collected in the fall from the South Railway Ditch and wetland and analyzed for C-14, moisture, and metals. Analytical results are presented in Appendix F of the 2021 NSS-W ERA [6].

Based on the results of the data collected, the following conclusions were made in the 2021 NSS-W ERA.

<u>South Railway Ditch (including Grassed Swale)</u>

Fish and herpetofauna in the South Railway Ditch are not at toxicological risk from NSS-W operations. Cattails may be exposed to concentrations of iron, nickel and zinc above their toxicity reference values; however, the cattail population as a whole is not expected to be at risk in the South Railway Ditch.

Some individual benthic invertebrates may be impacted due to exposure for a number of metals in water and sediment and concentrations above the applicable toxicity reference values; however, the benthic invertebrate community as a whole is not expected to be at risk in the South Railway Ditch.

<u>Wetland</u>

The wetland receives drainage from multiple sources, including the South Railway Ditch, Grassed Swale and Construction Landfill 1. The majority of concentrations of constituents was higher in the South Railway Ditch than in the wetland indicating that concentrations are largely originating from the South Railway Ditch prior to discharge into the wetland. However, elevated concentrations of strontium were observed in the wetland that were not observed in the South Railway Ditch. While the maximum strontium concentration in surface water in the wetland may be an outlier, it is possible that the location where the maximum strontium concentration was measured is representative of one of the other sources that discharge into the wetland, i.e., the Construction Landfill 1. Strontium levels in the wetland will be monitored as part of the next ERA update to determine if this finding represents a trend.

2.3.5 Water in South Railway Ditch

Tritium concentrations in the South Railway Ditch were measured five times in 2021. The mean annual concentrations at each location are shown in Table 2.6. All locations were analyzed for statistically significant trends at the 95% significance level using the Mann-Kendall Test. Using measured tritium concentrations from 2017 to 2021 no statistically significant trends were detected (Figure 2.13).

Table 2.6: Mean Annual Tritium Concentration in 2021 at Railway Ditch

	HTO (Bq/L)	Uncertainty *
WOD1	2.25E+02	1.32E+02
WOD2	6.08E+02	3.96E+02
WOD4	7.80E+02	4.48E+02
WOD5	7.88E+02	5.00E+02

*Uncertainty is given as ± 2 standard deviations.

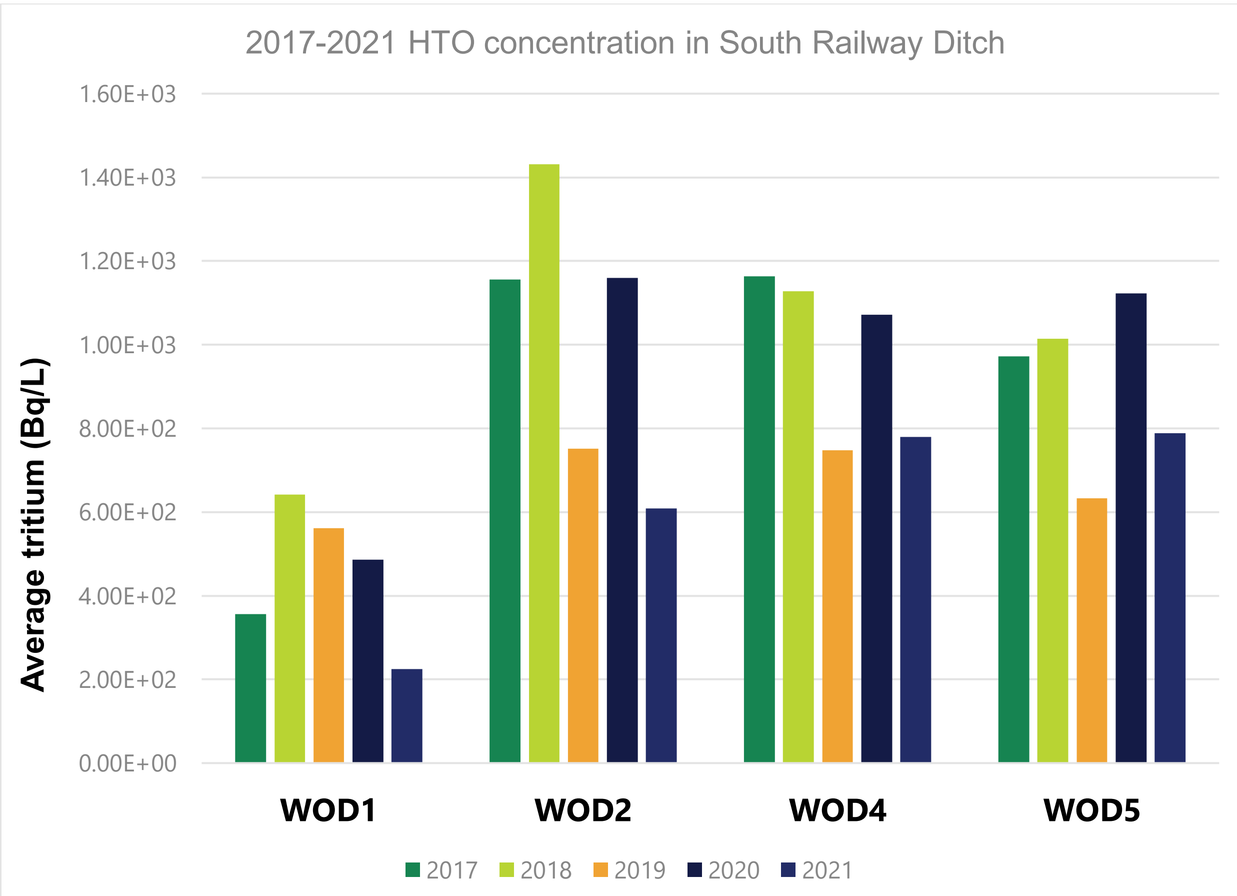

Figure 2.13: 2017-2021 Average Annual Tritium at Surface Water Sampling Locations in South Railway Ditch

2.3.6 HTO in Precipitation

Ten precipitation samples were collected in 2021 from four locations at the perimeter of the NSS-W (WS1-4) and two reference locations (WS-A and WS-B) and were analyzed for tritium concentrations. The average tritium concentration in 2021 was 384 Bq/L in the samples from WS1-4 and 363 Bq/L at the reference locations. The Mann-Kendall Test for the last 5 years showed no statistically significant trend in either the NSS-W or the reference locations (Figure 2.14).

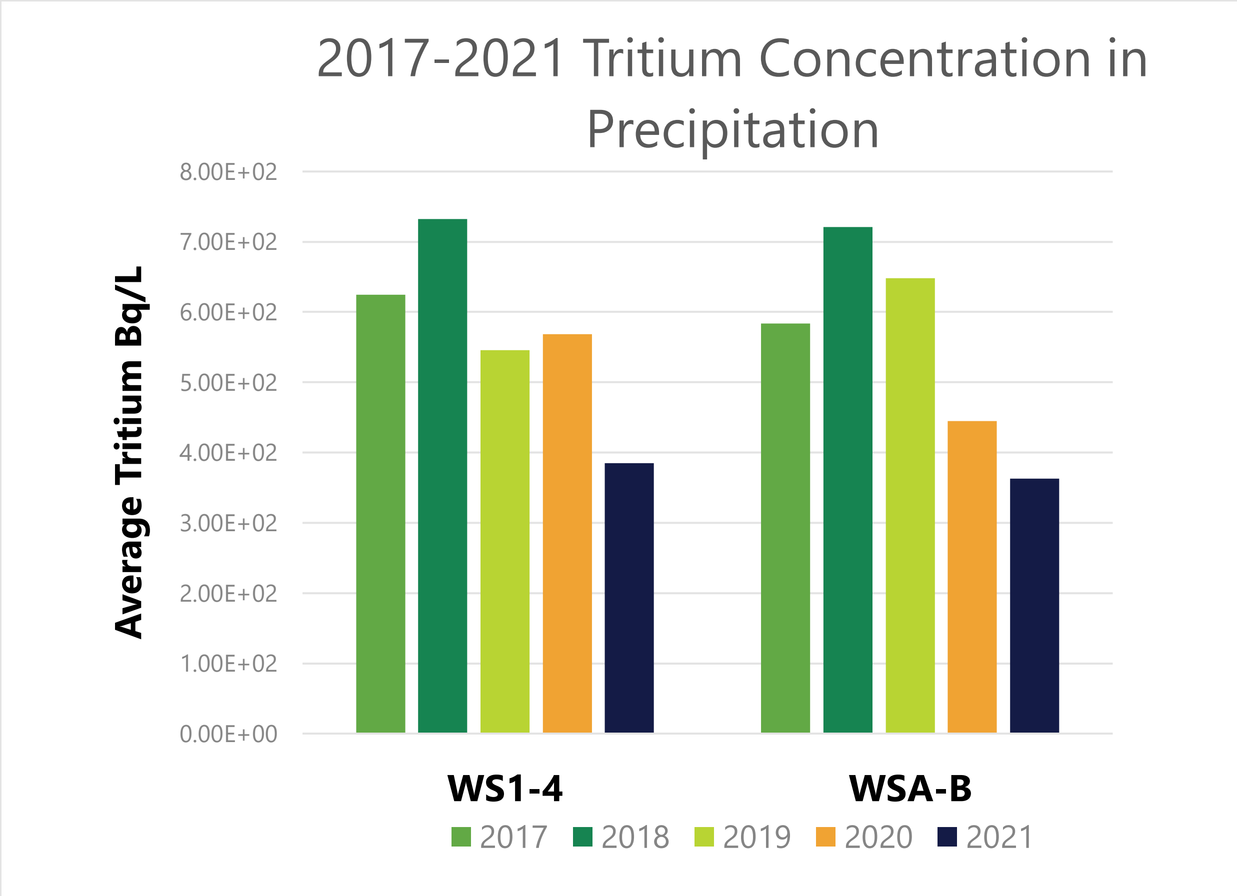

Figure 2.14: Average Annual Tritium Concentration in Precipitation Samples

2.3.7 Passive Carbon-14 Sampling

Twenty passive monitors are used to determine C-14 in air at the NSS-W on a quarterly basis. Quarterly and annual results from the passive monitors are shown in Table 2.7. Figure 2.15 shows all quarterly measurements from 2020 and 2021. No statistically significant trends were noted with the Mann-Kendall Test based on the quarterly data from 2020 and 2021.

The elevated concentrations of C-14 are attributed to spent moderator ion exchange (IX) resin stored in the IC-12s and IC-18s and those are investigated separately. As a result, C-14 concentration in air is highest in Area 1 (samplers 1-9) where IC-12s and IC-2s are located, and in Area 2 at the location of the IC-18s. The highest concentration in Area 2 is noted for sampler #12 located at the center of the IC-18s (Figure 2.7).

Elevated concentrations of C-14 close to the IC-18s are confirmed. Figure 2.16 shows C-14 concentrations from the Bruce Power passive air sampler located closest to the IC-18s (i.e., B#3, Figure 2.16) and one representing background (i.e., B#13, Figure 2.16) for comparison. A trend analysis using the quarterly data over the time period 2017-2021 shows a statistically significant increasing trend for both B#3 ($p=0.032$) and B#13 ($p=0.030$).

Table 2.7: 2021 C-14 Passive Air Sampling Results

Location	Q1 (Bq C-14 /kgC)	Q2 (Bq C-14 /kgC)	Q3 (Bq C-14 /kgC)	Q4 (Bq C-14 /kgC)	Annual Average (Bq C-14 /kgC)	Uncertainty (Bq C-14 /kgC)	Annual Average (Bq/m^3)	Uncertainty (Bq/m^3)
			Area 1: Phase I-III				**Area 1: Phase I-III**	
#1	1.01E+05	1.13E+05	2.48E+04	5.27E+04	7.29E+04	8.26E+04	1.60E+01	1.82E+01
#2	1.53E+05	1.11E+05	1.35E+05	7.55E+04	1.19E+05	6.70E+04	2.61E+01	1.47E+01
#3	1.73E+05	9.27E+04	3.64E+04	9.25E+04	9.87E+04	1.12E+05	2.17E+01	2.47E+01
#4	1.35E+05	7.55E+05	6.00E+04	6.30E+04	2.53E+05	6.73E+05	5.57E+01	1.48E+02
#5	1.76E+05	9.89E+04	2.89E+05	7.21E+04	1.59E+05	1.94E+05	3.50E+01	4.28E+01
#6	2.00E+05	1.53E+05	2.48E+05	2.04E+05	2.01E+05	7.77E+04	4.43E+01	1.71E+01
#7	2.32E+05	1.51E+05	2.18E+05	1.68E+05	1.92E+05	7.77E+04	4.23E+01	1.71E+01
#8	1.51E+05	1.06E+05	5.07E+04	7.06E+04	9.46E+04	8.80E+04	2.08E+01	1.94E+01
#9	3.06E+05	1.88E+05	2.22E+05	1.59E+05	2.19E+05	1.27E+05	4.81E+01	2.80E+01
			Area 2: Stage 6				**Area 2: Stage 6**	
#10	2.75E+05	1.10E+05	5.61E+04	2.03E+05	1.61E+05	1.94E+05	3.54E+01	4.28E+01
#11	1.23E+05	1.23E+05	1.04E+05	1.51E+05	1.25E+05	3.87E+04	2.76E+01	8.52E+00
#12	4.70E+05	3.75E+05	2.06E+05	5.21E+05	3.93E+05	2.77E+05	8.65E+01	6.10E+01
#13	8.42E+04	5.64E+04	1.54E+04	5.36E+04	5.24E+04	5.65E+04	1.15E+01	1.24E+01
#14	4.16E+04	1.73E+04	5.87E+03	2.18E+04	2.16E+04	2.98E+04	4.76E+00	6.56E+00
#15	8.25E+04		5.53E+04	1.59E+05	9.89E+04	1.08E+05	2.18E+01	2.37E+01
			Area 3: Batch 5				**Area 3: Batch 5**	
#16	1.34E+04	6.18E+03	4.73E+03	1.09E+04	8.80E+03	8.08E+03	1.94E+00	1.78E+00
#17	6.84E+03	3.96E+03	7.79E+03	1.49E+04	8.37E+03	9.29E+03	1.84E+00	2.04E+00
#18	7.32E+03	3.65E+03	2.59E+03	4.46E+03	4.51E+03	4.05E+03	9.91E-01	8.92E-01
#19	5.60E+03	3.68E+03	2.45E+03	3.74E+03	3.87E+03	2.60E+03	8.51E-01	5.72E-01
#20	5.74E+03	3.30E+03	2.44E+03	3.76E+03	3.81E+03	2.80E+03	8.38E-01	6.15E-01

*Uncertainty is given as ±2 standard deviations.

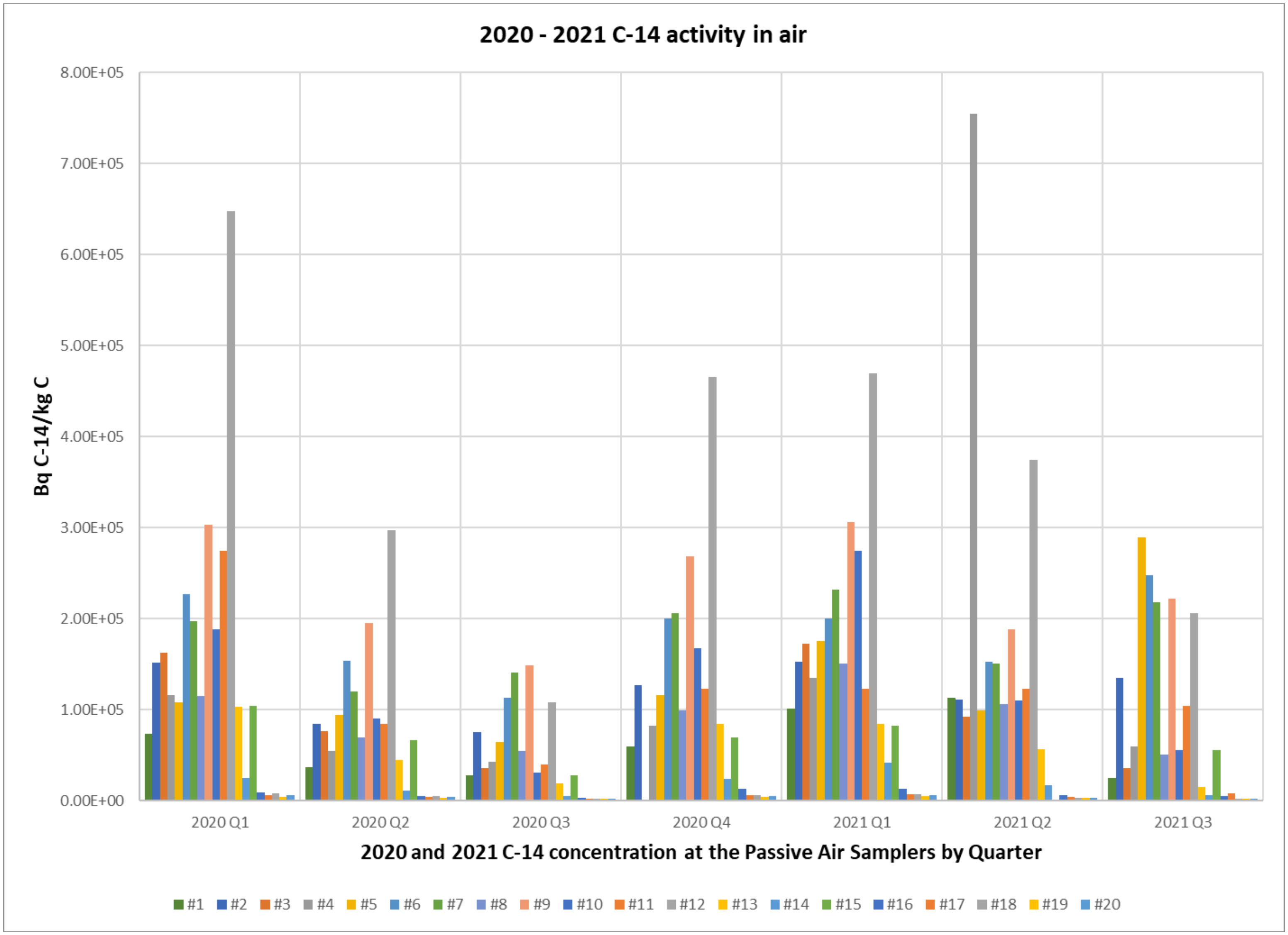

Figure 2.15: 2020 and 2021 C-14 concentration at the Passive Air Samplers by Quarter

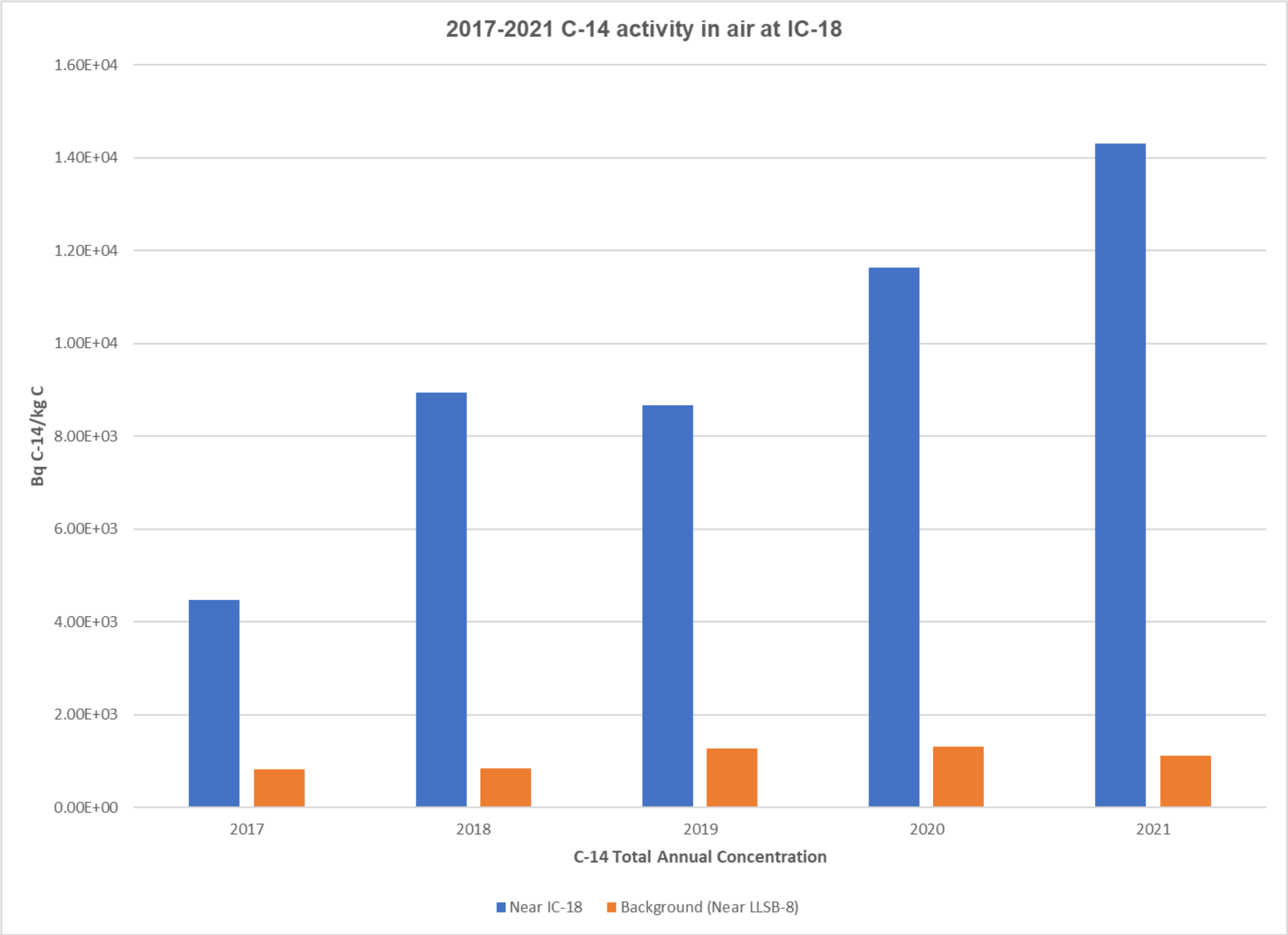

Figure 2.16: 2017-2021 C-14 Average Annual Concentration at NSS-W for Samplers B#3 (Near IC-18) and B#13 (Background)

3.0 Radiological Dose to the Public

One NSS-W EMP objective is to demonstrate that the radiological risk to the public from the operation of NSS-W is low and any potential dose to the public is well below the regulatory dose limit of 1 mSv/a. Non-NEWs on site may be exposed to direct/in-direct radiation from NSS-W facilities or RWOS 1. The regulatory dose limit for these workers is the same as for members of the public. OPG has also committed to keeping levels of tritium in drinking water, due to operation of OPG facilities, below 100 Bq/L on an annual average basis at nearby WSPs.

3.1 Public Radiological Dose Estimation Results

As discussed in Section 2.2.1, the calculated public radiological dose based on measurements of radioactivity in environmental media outside the Bruce nuclear site is the result of public exposure to the combined emissions of all facilities on the Bruce nuclear site.

3.1.1 Basis for Calculation of Dose to Members of the Public

Bruce Power calculates the public radiological dose to the various surrounding population groups most likely to receive the highest doses. These groups are referred to as the potential critical groups. The methodology used follows the guidance provided in CSA N288.1-14 [20]. Public dose is calculated using mostly measured concentrations of radionuclides in the environment, exposure pathways for the identified potential critical groups, and critical group characteristics. Important pathways and group characteristics were determined by a pathways analysis and a site specific survey. Further information on how Bruce Power determines public dose can be found in Bruce Power's annual environmental report [9].

3.1.2 Public Dose from NSS-W Operations

Bruce Power reported the annual public dose to be 1.6 µSv in 2021 based on results from their 2021 EMP [9]. This is approximately three orders of magnitude below the public dose limit of 1 mSv/a. The public dose arising from NSS-W operations is a small fraction of the 1.6 µSv value since NSS-W radiological emissions are no more than 1.7% of the combined site emissions (Table 3.1). Thus, the dose to members of the public from NSS-W operations is well below the regulatory limit.

3.2 Tritium Levels at Nearby Water Supply Plants

The WSPs influenced by NSS-W emissions are the same as those monitored by Bruce Power in their EMP, that is, the Kincardine WSP and the Southampton WSP. For 2021, Bruce Power reported that the annual average tritium in drinking water at these WSPs was 5.45 Bq/L at the Kincardine WSP and 12.4 Bq/L at the Southampton WSP [9]. These are well below the Ontario Drinking Water Standard for tritium of 7,000 Bq/L, and also meet OPG's commitment to keep these levels below 100 Bq/L on an annual average basis.

3.3 Direct Gamma Radiation Exposure

The NSS-W facilities, including the UFDS facility and RWOS 1 are relatively far from the Bruce nuclear site boundaries. Gamma radiation and skyshine from the NSS-W facilities is attenuated to a very large degree at and beyond the site boundaries and does not contribute significantly to public dose. The gamma dose and skyshine were measured at the RWOS 1 and NSS-W facility boundaries (see Section 2.3.2) to ensure that non-NEWs did not receive doses in excess of the regulatory limit. The TLD measurements for 2021 showed that doses at all locations around the facility boundaries were around 0.1 µGy/h, compared to the derived dose rate limit of 0.5 µGy/h.

3.4 Radiation Dose from C-14 in Air

Dose related to C-14 emissions is expected to be negligible for human and non-human receptors. Using average C-14 concentration in air at the IC-18s (Figure 2.16) from 2021 of 1.43E+04 Bq/kgC, the dose in a worst-case scenario to a non-NEW worker at the fence line of the NSS-W can be estimated. In the case of 8-hour occupancy year-round, the expected dose due to C-14 inhalation is estimated to be 0.05 µSv/a. This is well below the public dose limit of 1,000 µSv/a.

Sampling close to the IC-18s found that the concentration of C-14 in grass is comparable to the concentration in air on a Bq/kgC basis. From this, the dose to non-human biota (grasses) in the immediate vicinity of the C-14 emission was estimated. Calculated dose rates to grasses were determined to be 9.72E-04 mGy/day, well below the terrestrial dose benchmark of 2.4 mGy/day [21] [8].

3.5 Discussion of Results

All direct and indirect estimations of radiological dose to members of the public, including non-NEWs on-site, produced results well below regulatory limits. Additionally, the tritium levels at WSPs were well below the OPG commitment level of 100 Bq/L. These results indicate that the NSS-W is meeting its EMP objectives in these areas.

Table 3.1: Radiological Emissions from Bruce Nuclear Site Facilities (Bq/year)

	Bruce A	Bruce B	CMF	CSF	NSS-W[(d)]	CNL	Kinectrics KI[(c)]	Total	%NSS-W[(b)]
					Airborne Emissions (Bq/year)				
Tritium Oxide	8.1E+14	4.2E+14	1.6E+10	9.1E+10	2.16E+13	2.57E+11	1.24E+11	1.3E+15	1.7%
Noble gas	8.6E+13	3.4E+13	N/A	N/A	N/A	N/A	N/A	1.2E+14	N/A
I-131	3.1E+05	0.0E+00	0.0E+00	N/A	1.05E+03	N/A	N/A	3.1E+05	0.34%
Particulate Gamma	2.9E+06	5.7E+06	2.2E+04[(a)]	7.5E+02	2.72E+03	N/A	N/A	8.6E+06	0.032%
Particulate Gross Beta	N/A	N/A	N/A	N/A	N/A	7.58E+04	N/A	7.6E+04	N/A
Particulate-Gross Alpha	2.7E+04	3.5E+04	1.2E+03	N/A	N/A	N/A	N/A	6.3E+04	N/A
C-14	1.7E+12	9.5E+11	N/A	N/A	5.63E+09	N/A	N/A	2.7E+12	0.21%
					Waterborne Emissions (Bq/year)				
Tritium Oxide	2.8E+14	9.1E+14	-	-	N/A[(d)]	2.30E+10	N/A	1.2E+15	N/A
C-14	6.9E+08	2.6E+09	-	-	N/A[(d)]	N/A	N/A	3.3E+09	N/A
Gross β/ γ	2.7E+09	2.1E+09	-	-	N/A[(d)]	N/A	N/A	4.8E+09	N/A
Gross β	N/A	N/A	-	-	N/A[(d)]	2.97E+07	N/A	3.0E+07	N/A
Gross α	<Ld	<Ld	-	-	N/A[(d)]	N/A	N/A	0.00E+00	N/A

a) Naturally occurring radionuclide material detected in gamma spectrum analysis is not reported.

b) %Gross β = NSS-W Gross β/(total Gross β/ γ + NSS-W Gross β)

c) This is the net airborne emission from KI North Facility for the period of December 31, 2020 to December 29, 2021. There were no waterborne emissions in 2021 for Kinectrics KI

d) Beginning in January 2021, waterborne emissions from the NSS-W are no longer reported under the effluent monitoring program since surface discharge is stormwater and subsurface discharge is groundwater. Effluent from the NSS-W is not released into the stormwater system – any tritium in stormwater is from atmospheric deposition.

<Ld = less than limit of detection

4.0 Quality Assurance and Performance

The NSS-W EMP design report recommends that a QA/QC program for the NSS-W EMP be implemented and that it should be based on OPG's existing EMP QA manual (for Darlington and Pickering EMPs) [18], with adjustments for the specific characteristics of the NSS-W site and operations. The program would encompass all activities including field sample collection, laboratory analysis, laboratory quality control, and external laboratory intercomparison. The objectives would include ensuring that EMP samples are representative, and their analytical results are accurate, as well as complying with procedures and program quality requirements. This section provides an overview of quality assurance activities.

4.1 Laboratory Quality Assurance and Quality Control

The OPG HPL has a QA/QC program that includes measurement of environmental TLDs. The system uses TLD-100H LiF dosimeters capable of measuring gamma dose down to ambient environmental levels. These are suitable for the intended purpose. Part of the QA program is to read out eight dosimeters every quarter that were irradiated to known environmental exposures by the National Research Council Canada and achieve a mean relative bias less than ±30% and a coefficient of variation less than 0.35. In addition, the sum of the mean relative bias (as a fraction) and the coefficient of variation is required to be less than 0.50. For 2021, the OPG EGM system met these accuracy and precision requirements. Results of its HPL QA testing for 2021 were satisfactory and are documented in its annual QA report [22].

The OPG HPL has a commitment to perform a minimum of one annual independent audit of the quality system used for dosimetry and environmental measurement services. These may not always be related to the EMPs. In 2021, an HPL QA audit was conducted on the Alpha/Beta Analysis in Water and the Lifecycle of the Automatic Thermoluminescent dosimeter (ATLD).

The Alpha/Beta Analysis in Water audit identified two recommendations and two findings. The two recommendations and finding 1 are being addressed through AR 28248302, 'Actions from Self Assessment RF21-000626-SA 2021 Health Physics Laboratory Quality Assurance Internal audit – Alpha/Beta Analysis in Water'. Finding 2 is being addressed through AR 28248303, 'Actions from Self Assessment RF21-000233-SA 2021 Health Physics Laboratory Quality Assurance Audit – Lifecycle of ATLD'. There were no significant non-conformances affecting quality of results, recommendations represent opportunities for improvement or clarity of areas where further review is warranted.

The Lifecycle of ATLD audit identified two good practices, two strengths, nine recommendations and two findings. The nine recommendations and two findings are being addressed through AR 28248303, 'Actions from Self Assessment RF21-000233-SA 2021 Health Physics Laboratory Quality Assurance Audit – Lifecycle of ATLD'. There were no significant non-conformances affecting quality of results, recommendations represent opportunities for improvement or clarity of areas where further review is warranted.

The MECP performed audits of the HPL in February and August, 2021. There were no non-compliant findings for either audit. Overall, the inspection rating for both audits was 100% [22].

The Canadian Association for Laboratory Accreditation performed an audit at the HPL (Whitby) in November 2021. Two adverse conditions were found and documented. Both findings were minor corrections to lab procedures for clarification. These documents were revised accordingly.

The Canadian Nuclear Safety Commission (CNSC) completed a field inspection on March 5, 2021 and no adverse conditions were found.

Environmental tritium and gross β analysis in water samples are performed for the NSS-W by the Bruce Power Health Physics laboratory. The Bruce Power Health Physics Lab operates a comprehensive QA program in accordance with ISO 14001, which includes quality control samples, blank/background samples, process control samples and externally generated proficiency testing samples. QA/QC results for testing relevant to the groundwater, surface water, and precipitation sample analyses, that is, HTO and gross β activity in water, met all requirements, including accuracy and precision requirements as per external laboratory testing. Bruce Power Health Physics Lab had one audit in 2021, performed by the internal Audit department [9]. Bruce Power's compliance with ISO 14001 and the CSA N288.4, N288.5 and N288.7 standards was verified through internal independent oversight audits. Opportunities for improvement and any identified gaps are being addressed and do not impact overall conformance to ISO 14001 or the N288 series standards [9].

Kinectrics performs C-14 analysis for the NSS-W. The Kinectrics laboratory operates a comprehensive QA program which includes proficiency testing for C-14 analysis using a service provided by the National Research Council Canada (NRC). Kinectrics is accredited by The Standards Council of Canada for radiochemical tests, including C-14 in water [23].

4.2 Program Quality Assurance

EMP program QA generally includes self-assessments and audits as per the requirements of CSA N288.4-10 [2]. There were no assessments or audits of the EMP program in 2021.

4.2.1 Self-assessments

Performance Assessment

Self-assessment COE22-000106-SA was completed for the 2020 EMP Annual Performance Assessment. The assessment confirmed that all EMP design objectives were met and the results of the 2020 NSS-W EMP indicated adequate protection of the public, workers, and the environment. No necessary revisions to the NSS-W EMP were identified.

4.3 Program Performance

4.3.1 Sample Unavailability

Table D.1 (Appendix D) provides a summary of samples collected, the monitoring period and deviations from the Plan during the 2021 EMP, for all media.

TLD deployment and analysis and groundwater sampling and analysis are done on a planned schedule. All data were examined to determine the unavailability for 2021. Unavailability is the fraction of the total planned samples that were missed or produced invalid results. The NSS-W does not currently have unavailability targets for EMP samples.

A total of 172 TLD samples were planned for 2021, consisting of quarterly samples at seven locations at RWOS 1, quarterly samples at 20 locations at the NSS-W/LILW storage area, and quarterly samples at 16 locations at the NSS-W/UFDSF. All 172 results were obtained and valid, producing an overall unavailability of 0%.

A total of 60 samples were collected for the 2021 tritium monitoring in precipitation, consisting of six samples on 10 sampling dates. All 60 results were valid, producing a total unavailability of 0%.

Table E.1 (Appendix E) shows the numbers of planned and actual samples and analyses for the groundwater and ditch surface water monitoring components of the EMP, and the unavailability for these. The 2021 groundwater monitoring plan collected 385 of the planned 385 samples and had an overall unavailability of 0.0%.

A total of 80 C-14 samples were planned for 2021, consisting of quarterly samples at 20 locations at NSS-W. 79 of the 80 results were obtained and valid (see Table 2.7), producing an overall unavailability of 1.25%.

5.0 Overall Summary of EMP

An EMP detailed design was developed for the NSS-W in 2012 [4] with updates made in 2019 [3]. The design recommended in the detailed EMP design report was followed in 2021. The primary objectives of the EMP concerning public and worker safety and demonstrating containment of radioactivity were met in 2021. Operation of the NSS-W resulted in extremely low public dose, well below regulatory limits. The potential exposure of non-NEWs near NSS-W facilities to gamma radiation and skyshine was low and well within the derived dose rate limit. Concentrations of tritium at nearby WSPs were below 100 Bq/L on an annual average basis (Objectives 1 and 7).

Measurements of TLDs around the NSS-W and RWOS 1 (Objective 2) are well below the derived dose rate limit of 0.5 µGy/h. Despite an increasing trend in three locations, no TLD exceeded 0.13 µGy/h and no effects are expected due to this exposure.

Bedrock aquifer groundwater sampling (Objective 3) indicated that there were no significant releases of radioactivity to groundwater travelling offsite. Three wells at the NSS-W showed statistically significant increasing trends in tritium, however they remain well below the level of 60,000 Bq/L at which OPG has committed to notify the CNSC. Of these wells that show an increasing trend, WSH 230 (annual average 591 Bq/L) and WSH 229 (annual average 1,260 Bq/L) had concentrations above 500 Bq/L.

Previously elevated tritium levels in one area of the MSA have steadily decreased since 2009. Remedial measures taken to reduce tritium in groundwater have been effective. A statistically significant decrease in tritium concentrations in groundwater at WSH 231 was identified for the period 2017 to 2021. Comparing to the Ontario Drinking Water Quality Standards for tritium (7,000 Bq/L) and gross β activity (1 Bq/L), there is currently no evidence of unacceptable levels of radioactivity leaving the site either in surface water or groundwater. The groundwater monitoring program has been updated to meet CSA N288.7 and implementation was initiated in 2022. Moving forward, groundwater results will be reported in a separate monitoring report that is compliant with CSA N288.7.

Monitoring of HTO in precipitation (Objective 4) is incorporated in the routine sampling program. Precipitation samples are taken at four locations around the NSS-W and at two reference locations as precipitation events allow. The supplementary study conducted in 2013 concluded that the HTO concentration was not correlated with operation of the incinerator and was too low to account for elevated levels in MSA wells. No statistically significant trend for 2017 – 2021 was observed.

Monitoring in the South Railway Ditch (Objective 5) is completed as part of routine sampling. Surface water in the South Railway Ditch is monitored quarterly. The supplementary study conducted in 2013, concluded that the NSS-W runoff/groundwater has a negligible influence on tritium concentrations and found no statistically significant trends. No statistically significant trends were observed in the monitored locations for 2017-2021.

Sediment and water in the SRD, wetland, and grassed swale areas of the NSS-W (Objective 6) were monitored in a supplementary study conducted in 2013-2014 and used in the 2016 ERA [16]. Sediment and water samples were also collected in the SRD, wetland, and grassed swale areas in 2020-2021 to support the NSS-W ERA update. The 2021 NSS-W ERA concluded no risk to the majority of aquatic biota due to exposure to metals and radionuclides. Risk was identified to benthic invertebrates in the SRD due to exposure to nickel and zinc in water and multiple constituents in sediment. The wetland was assessed with the SRD and grassed swale since the wetland receives drainage from multiple sources including the SRD, grassed swale, and a construction landfill. Elevated concentrations of strontium in the wetland appear to be coming from another source other than the SRD, such as a construction landfill. Strontium will be monitored in the wetland as part of the next ERA update to determine if this is an emerging trend.

Increasing C-14 concentration in air at the NSS-W has been attributed to moderator exchange resin stored in Area 1. A fugitive emissions reassessment has been completed to address this finding. OPG has reviewed the estimating methodology and is working with the contractor to further refine the prediction instrument. Scrubbers were installed in select ICs in 2021 with additional scrubbers to be installed in the 2022 to reduce the amount of fugitive emissions to help mitigate this trend. Despite these emissions, both environmental and health physics monitoring support that there is no significant impact on workers, the public, or the environment.

Overall, the results of the 2021 NSS-W EMP indicate confirmation of adequate protection of the public, the workers and the environment.

6.0 Outlook for EMP

Ongoing implementation of the EMP design will be continued. Some additional work to address existing areas of uncertainty will also be planned. Areas that will be addressed are:

- NSS-W and RWOS 1 groundwater monitoring: the development of a groundwater protection program and groundwater monitoring program compliant with CSA N288.7 is complete and implementation has been initiated. Future reporting on the results of the groundwater monitoring program will be reported outside of this EMP Report, in a CSA N288.7 compliant report.
- Precipitation: Routine and supplementary monitoring concluded that tritium in precipitation is not the likely source of tritium in groundwater. Tritium concentrations measured in precipitation between the background and the monitoring locations at the NSS-W are very similar which is an indication that the tritium is most likely attributed to the operation of Bruce A and B and not capturing local sources. The 2021 NSS-W ERA concluded as well that no additional precipitation monitoring at the NSS-W site is warranted.
- Surface Water: The South Railway Ditch routine and supplementary studies indicated little impact from the NSS-W, and tritium concentrations in WOD5 are trending downwards. The routine tritium sampling in the South Railway Ditch will continue. A supplementary study to collect water and sediment data for non-radionuclides was completed in 2020-21 in support of the 2021 NSS-W ERA update and should be completed prior to the next ERA update.
- Wetland sampling: The East Wetland was sampled in 2020-21 as part of a repeat of supplementary studies to support the 2021 NSS-W ERA. Similar to the South Railway Ditch, the supplementary study of the wetland should be completed prior to the next ERA update.
- C-14 monitoring in air: To be continued as currently implemented with a focus on the upward trend close to IC-18. Scrubbers were installed in select ICs in 2021 with additional scrubbers to be installed in the 2022. Subsequent results should indicate if this mitigation is sufficient to address the recently observed upward trend.

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Appendix A Radiological Units and Conversions

Absorbed Dose

1 gray (Gy)	=	1 joule/kg

Effective Dose

1 sievert (Sv)	=	100 rem
1 millisievert (mSv)	=	100 millirem (mrem)
1 microsievert (µSv)	=	0.1 millirem (mrem)

Quantity of Radionuclide

1 becquerel (Bq)	=	1 disintegration per second
1 curie (Ci)	=	3.7×10^{10} Bq
1 mCi/(km^2·month)	=	37 Bq/(m^2·month)

Appendix B Glossary of Acronyms and Symbols

Radionuclides and Units of Measure

C-14	Carbon-14
HTO	Tritium Oxide
Gross α	Gross Alpha
Gross β	Gross Beta
µGy	microgray
µSv	microsievert
Bq	becquerel
Gy	Gray
kg	kilogram
L	Litre
mGy	milligray
mSv	millisievert
Sv	Sievert

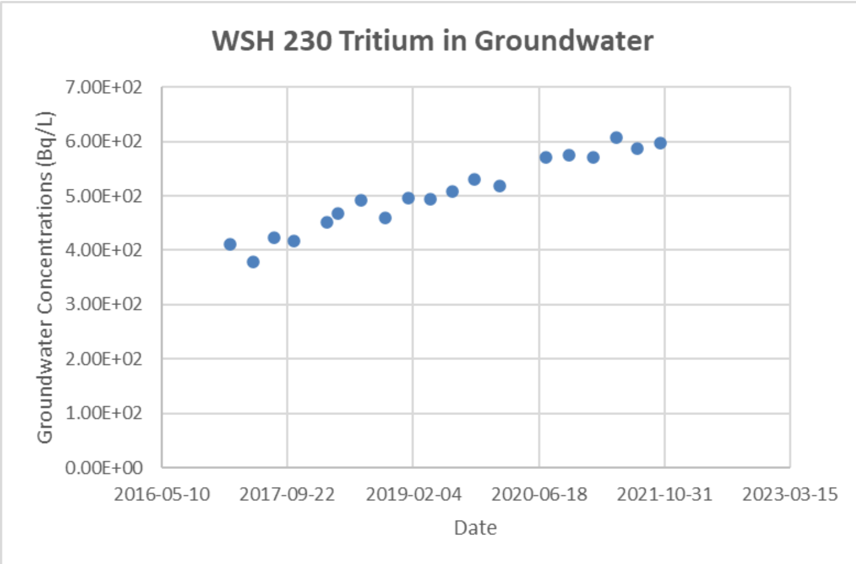
Acronyms and Abbreviations

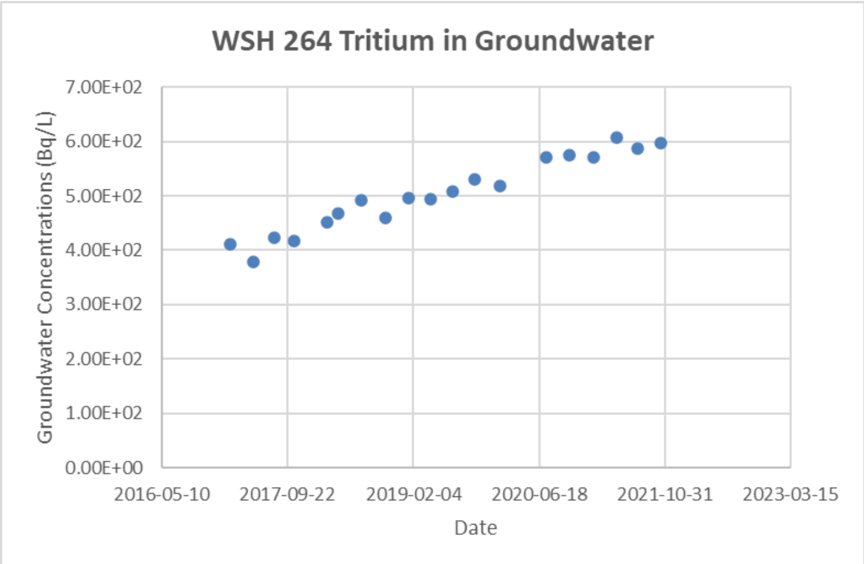
AECL	Atomic Energy of Canada Limited
CMF	Central Maintenance Facility
CNSC	Canadian Nuclear Safety Commission
CNL	Canadian Nuclear Laboratories
CSA	Canadian Standards Association
CSF	Central Storage Facility
DN	Darlington Nuclear
EGM	Environmental Gamma Monitors
EMP	Environmental Monitoring Program
EPA	Environmental Protection Agency
ERA	Environmental Risk Assessment
HPL	OPG Health Physics Laboratory
IAEA	International Atomic Energy Agency
ICs	In-ground storage containers
IC-12	12 m^3 capacity ICs
IC-18	18 m^3 capacity ICs
ISO	International Organization for Standardization
Lc	Critical Level
Ld	Limit of Detection
LILW	Low and Intermediate Level Waste
LLSB	Low Level Storage Building
MSA	Middle Sand Aquifer
NRC	National Research Council of Canada

NEW	Nuclear Energy Worker
NSS-W	Nuclear Sustainability Services - Western Facility
OPG	Ontario Power Generation
QA	Quality Assurance
QC	Quality Control
QOR	NSS-W Quarterly Operations Report
RWOS 1	Radioactive Waste Operations Site 1
SSTF	Spent Solvent Treatment Facility
TLD	thermo luminescent dosimeter
TPMB	Transportation Maintenance Building
UFDSF	Used Fuel Dry Storage Facility
WSH	Water Sampling Hole
WSP	Water Supply Plant
WVRB	Waste Volume Reduction Building

Appendix C Tritium in Groundwater 2017-2021

This appendix contains the plots of tritium with statistically significant increases over the 5-year period 2017-2021. All datasets were analyzed for the presence of statistically significant trends using the Mann-Kendall test in the Microsoft Excel Real Statistics package. The results of the trend analyses are reported in Section 2.3.3.





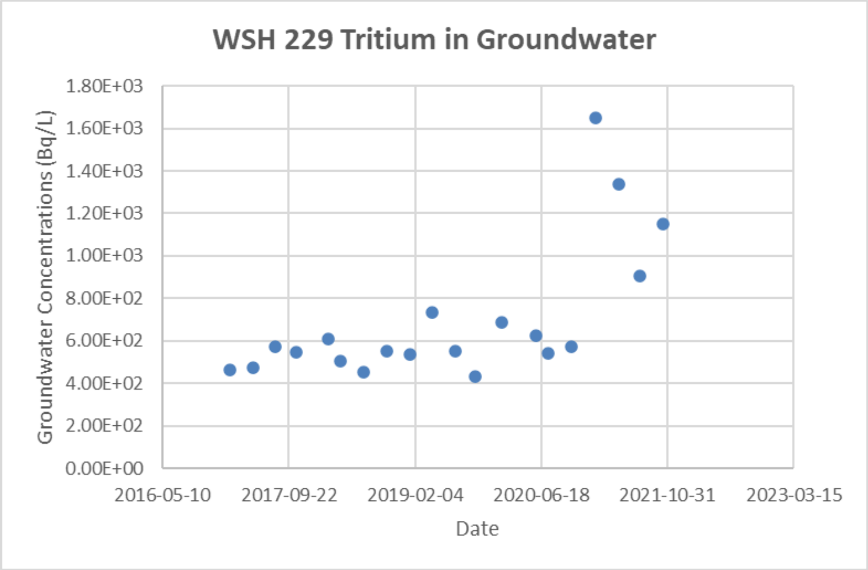


Figure C.1: Measured Tritium in Groundwater Wells with Significant Trends

Appendix D Summary of Samples Collected

Table D.1: Summary of Samples Collected, Monitoring Period and Deviation from the Plan during the 2021 EMP

Sampling Program	Monitoring Results Presented in EMP (all raw data)	Monitoring Period	Deviations from Monitoring Period	Assessment Period
Gamma Radiation Monitoring	Yes	4 quarters of 2021	No	2021, trend analysis: 2017 - 2021
Groundwater Monitoring	Yes	2021 (4 quarters, WSH monitored monthly)	No	2021, trend analysis: 2017 - 2021
SRD	Yes – (presented average and 2 sigma for each measurement station consistent with the 2020 EMP). Raw data is not provided in the EMP Report.	2021	No	2021, trend analysis 2017 - 2021
Precipitation	Yes – (presented average and 2 sigma for each measurement station consistent with the 2020 EMP). Raw data is not presented in the EMP Report.	2021	No	2021, trend analysis 2017 - 2021
C-14 in air	Yes	2021	No (79 of the 80 planned samples were obtained)	2021, trend analysis 2017 - 2021

Appendix E Groundwater and Ditch Surface Sample Unavailability

Table E.2: 2021 Planned and Actual Samples and Analyses for Groundwater and Ditch Surface Water at NSS-W

	Planned Samples														
	HTO				Gross β				C-14				Total	Total	%
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Planned	Actual	Unavailability
	RWOS 1														
122	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
123	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
20S	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
124	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
125	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
126	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
127	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
	NSS-W														
226	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
228	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
229	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
230	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
231	3	3	3	3	3	3	3	3					24	24	0.0
240	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
242	1	1	1	1	1	1	1	1					8	8	0.0
243	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
253	1	1	1	1	1	1	1	1					8	8	0.0
255	1	1	1	1	1	1	1	1					8	8	0.0
264	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
265	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
269	1	1	1	1	1	1	1	1					8	8	0.0
282	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0

	Planned Samples														
	HTO				Gross β				C-14				Total	Total	%
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Planned	Actual	Unavailability
283	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0
284	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0
285	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0
286	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0
287	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0
	NSS-W Annual monitoring														
224			1				1				1		3	3	0.0
232			1				1				1		3	3	0.0
237			1				1				1		3	3	0.0
238			1				1				1		3	3	0.0
239			1				1				1		3	3	0.0
244			1				1						2	2	0.0
246			1				1						2	2	0.0
248			1				1						2	2	0.0
249			1				1						2	2	0.0
251			1				1						2	2	0.0
257			1				1						2	2	0.0
259			1				1						2	2	0.0
260			1				1						2	2	0.0
263			1				1						2	2	0.0
268			1				1						2	2	0.0
270			1				1						2	2	0.0
271			1				1						2	2	0.0
272			1				1						2	2	0.0
278			1				1						2	2	0.0
279			1				1						2	2	0.0
	Railway Ditch														

	Planned Samples												Total Planned	Total Actual	% Unavailability
	HTO				Gross β				C-14						
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
WOD1	1	1	1	1	1	1	1	1					8	8	0.0
WOD2	1	1	1	1	1	1	1	1					8	8	0.0
WOD4	1	1	1	1	1	1	1	1					8	8	0.0
WOD5	1	1	1	1	1	1	1	1					8	8	0.0