TENORM Brine Treated Roads Study (2016 – 2017)

DIVISION OF WATER QUALITY
BUREAU OF CLEAN WATER
DEPARTMENT OF ENVIRONMENTAL PROTECTION
COMMONWEALTH OF PENNSYLVANIA

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INTRODUCTION

In 2016, the Pennsylvania Department of Environmental Protection (DEP) published a comprehensive evaluation of the oil and gas production process as it relates to Technologically Enhanced Naturally Occurring Radioactive Materials (TENORMs) (DEP 2016). This comprehensive study was designed to trace TENORMs through the entire oil and gas production process, surveying everything from equipment used and facilities to drill cuttings, produced fluids, and end uses. The 2016 comprehensive study primarily focused on worker exposure and environmental impacts, including wastewater discharges to Pennsylvania surface waters and residual impacts on land uses (DEP 2016). The 2016 comprehensive study, as well as a case study published by DEP Water Quality Division (WQD) staff in 2013 (DEP 2013), have effectively shown wastewater discharges do elevate TENORMs above background levels in sediment near and directly downstream of discharge locations. Because wastewater discharges are point sources of pollution, TENORMs are easily traced via methods described in the 2016 comprehensive evaluation (DEP 2016) and the WQD 2013 case study (DEP 2013). Nonpoint source TENORMs pollution to surface waters, such as oil and gas brine waste used to treat dirt roads, is not clearly defined in research and is harder to source track.

TENORMs are a classification of radiological elements (e.g., uranium, thorium, potassium, radium) which have been technologically concentrated in a solution or medium above levels occurring naturally. For example, during the conventional oil and gas production process, extraction of oil and gas brings to the surface both petroleum and water contained within the geologic formations drilled. The formation water is further processed to separate the water from the oil and gas hydrocarbons; the remaining water is called produced water. This produced water typically contains high concentrations of salts, sulfates, and naturally occurring radiological material (NORM), as determined by the geological formation's chemical make-up (USEPA 2018; USGS 2018; Veil et al. 2004). Due to the high salinity, these produced waters are commonly referred to as brine, which are managed as a wastewater by treatment, deep well injection, and recycling, as a few examples.

Until recently, brine produced from the oil and gas industry and the associated treated brines have historically been re-used as dust suppressants and road stabilizers on secondary road systems in Pennsylvania. While beneficial to road systems, application of oil and gas brines to road systems has the potential to negatively impact environmental health. Oil and gas brines and associated wastewater streams have the potential to carry TENORMs extracted and concentrated during oil and gas production and processing. When oil and gas brines are applied to road systems, TENORMs may migrate from application areas into surface waters and streambed sediments, potentially contaminating streams and impacting water quality. Radium is a known carcinogen and is a TENORM of particular interest because certain isotopes have drinking water standards. Tasker et al. (2018) showed that while radium does sorb to sediment particles and is retained, to a degree, in roadbed materials, radium can be leached from roads treated with oil and gas wastewaters to the surrounding environments through runoff. Tasker et al. (2018) began to characterize the mobility of TENORMs associated with road application of oil and gas wastewaters through the environment, but there is a need to further characterize the mobility of these TENORMs across a broad spectrum of landscapes to include air, land, and surface water.

In 2015, the DEP WQD began investigating TENORMs in Pennsylvania's surface waters near roads treated with oil and gas brines. The goal of this investigation was to define areas of brine road applications and to delineate stream locations potentially impacted by TENORMs associated with the brine applications. Sites were visited in winter 2016 and again through spring and summer 2017. Water and sediment were collected to determine if streams adjacent to brine-treated roads had elevated concentrations of TENORMs. This report presents the physiochemical and radiological characteristics of these water and sediment samples and discusses some of the key uncertainties involved with environmental radiological sampling and analyses. The data presented in this report is provided as an investigative study.

SITE LOCATIONS

Historical Road Spreading of Oil and Gas Brines in Pennsylvania

The target area for this study was northwestern Pennsylvania, where – until recently – secondary roads were frequently treated with oil and gas brine wastewaters, primarily for dust suppression and road stabilization purposes during typically drier months. This recycling of oil and gas wastewaters appeals to dirt and gravel road maintenance planners as there is little cost associated with its application. Historically, road spreading of oil and gas brines occurred most intensely from late April to early October. A review of records from 2008 to 2015 show that Erie, Crawford, Clarion, Jefferson, Venango, and Warren counties reported the highest number of roads treated with brine and the most instances of brine application (Figure 1).

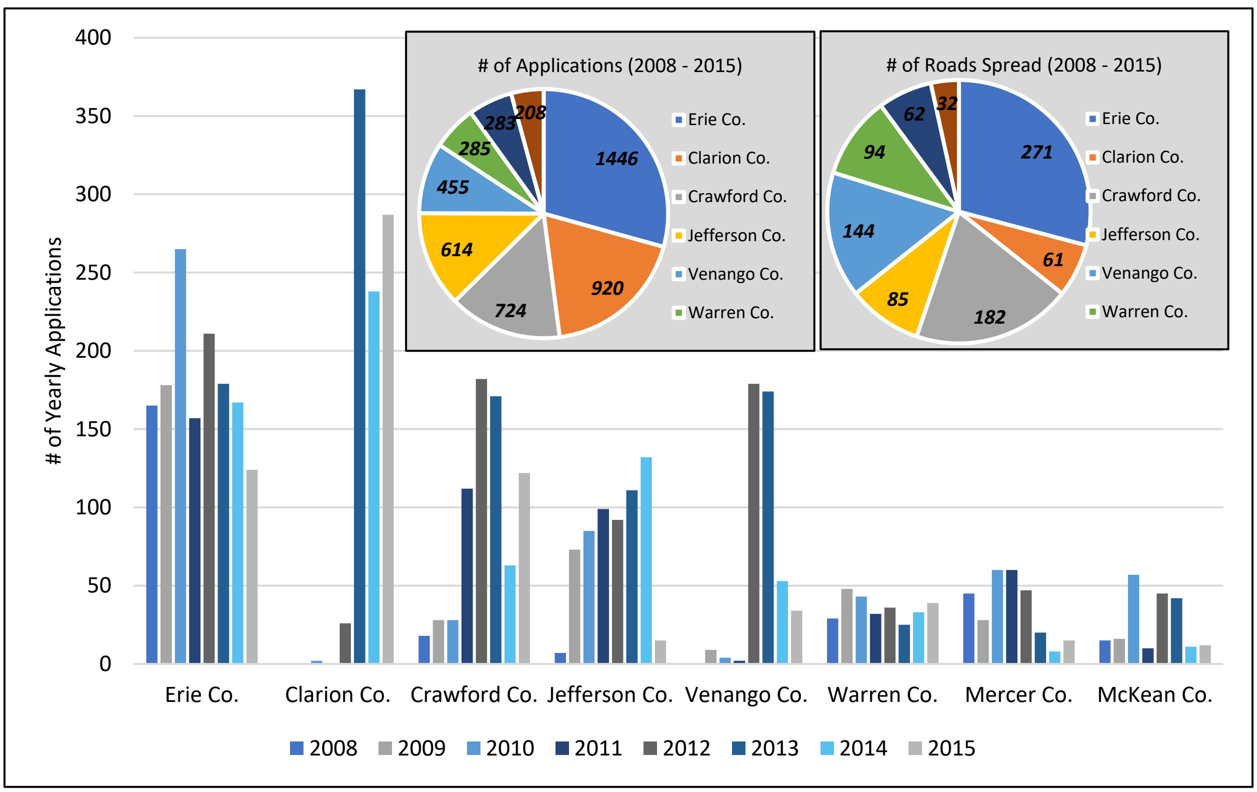

Figure 1. Road spreading of oil and gas brine in northwestern Pennsylvania, 2008 to 2015. Records provided by DEP Office of Oil and Gas Management.

Site Selection

For this investigation, brine road spreading data reported by municipalities to the DEP Office of Oil and Gas Management from 2015 were used to determine sampling sites in 2016. Areas determined to have the most instances of brine spreading in 2015 were: Venango, Amity, and Concord townships in Erie County; Plum, Jackson, and Oakland townships in Venango County; and Limestone and Redbank townships in Clarion County. Final road spreading reports from 2016 were reviewed to determine additional sites for 2017 sampling. The counties and townships with the most instances of brine spreading were similar between the 2015 and 2016 reports; however, based on the 2016 road spreading reports, in 2017 sampling sites were added in Union Township, Erie County and Athens Township, Crawford County. Sites were selected based on proximity of the road to a stream through a Geographic Information System (GIS) reconnaissance exercise. Roads targeted for sampling either crossed the stream or paralleled the stream closely (Table 1; Figure 2).

Table 1. Sampling locations and sediment sampling technique.

Station	Sediment Sampling Technique	Location	County	Township
1FC	Single composite (LDB)	UNT 54061 to French Creek (Mouth) Lat: 42.01926 Long: -79.76768	Erie	Venango
2FC	Complete composite (LDB and RDB)	UNT 54061 to French Creek (UPS) Lat: 42.04526 Long: -79.77159	Erie	Venango
1LFR	Single composite (LDB)	UNT 53252 to Little Federal Run Lat: 41.77146 Long: -79.87203	Crawford	Athens
1WB	Complete composite (LDB and RDB)	UNT 53493 to West Branch French Creek Lat: 42.07378 Long: -79.83508	Erie	Venango
2WB	Complete composite (LDB and RDB)	UNT 53906 to West Branch French Creek Lat: 42.02956 Long: -79.83675	Erie	Venango
AR	Single composite (RDB)	Alder Run Lat: 41.96325 Long: -79.83424	Erie	Amity
EBMC	Complete composite (LDB and RDB)	East Branch Muddy Creek Lat: 41.71847 Long: -79.85191	Crawford	Athens
EBSC	Single composite (RDB)	East Branch Sugar Creek Lat: 41.52007 Long: -79.82958	Venango	Oakland
HR	Single composite (LDB)	Hubble Run Lat: 41.99680 Long: -79.80453	Erie	Amity
LSC	Complete composite (LDB and RDB)	Little Sugar Creek (DWS) Lat: 41.53728 Long: -79.80166	Venango	Plum
PC	Single composite (RDB)	Pine Creek Lat: 41.03276 Long: -79.25872	Clarion	Redbank
PNYC	Single composite (LDB)	Piney Creek Lat: 41.13208 Long: -79.34552	Clarion	Limestone
PRC	Single composite (RDB)	Prather Creek Lat: 41.56422 Long: -79.77673	Venango	Plum
SC	Single composite (LDB)	Sugar Creek Lat: 41.51403 Long: -79.86206	Venango	Jackson
LSC_1	Complete composite (LDB and RDB)	Little Sugar Creek (UPS) Lat: 41.58746 Long: -79.79927	Venango	Plum
3FC	Complete composite (LDB and RDB)	UNT 53817 to French Creek Lat: 41.94430 Long: -79.86264	Erie	Amity
HORT	Complete composite (LDB and RDB)	Horton Run Lat: 41.88753 Long: -79.87462	Erie	Union
PRC_1	Complete composite (LDB and RDB)	UNT 51767 to Prather Creek Lat: 41.59171 Long: -79.77407	Venango	Plum

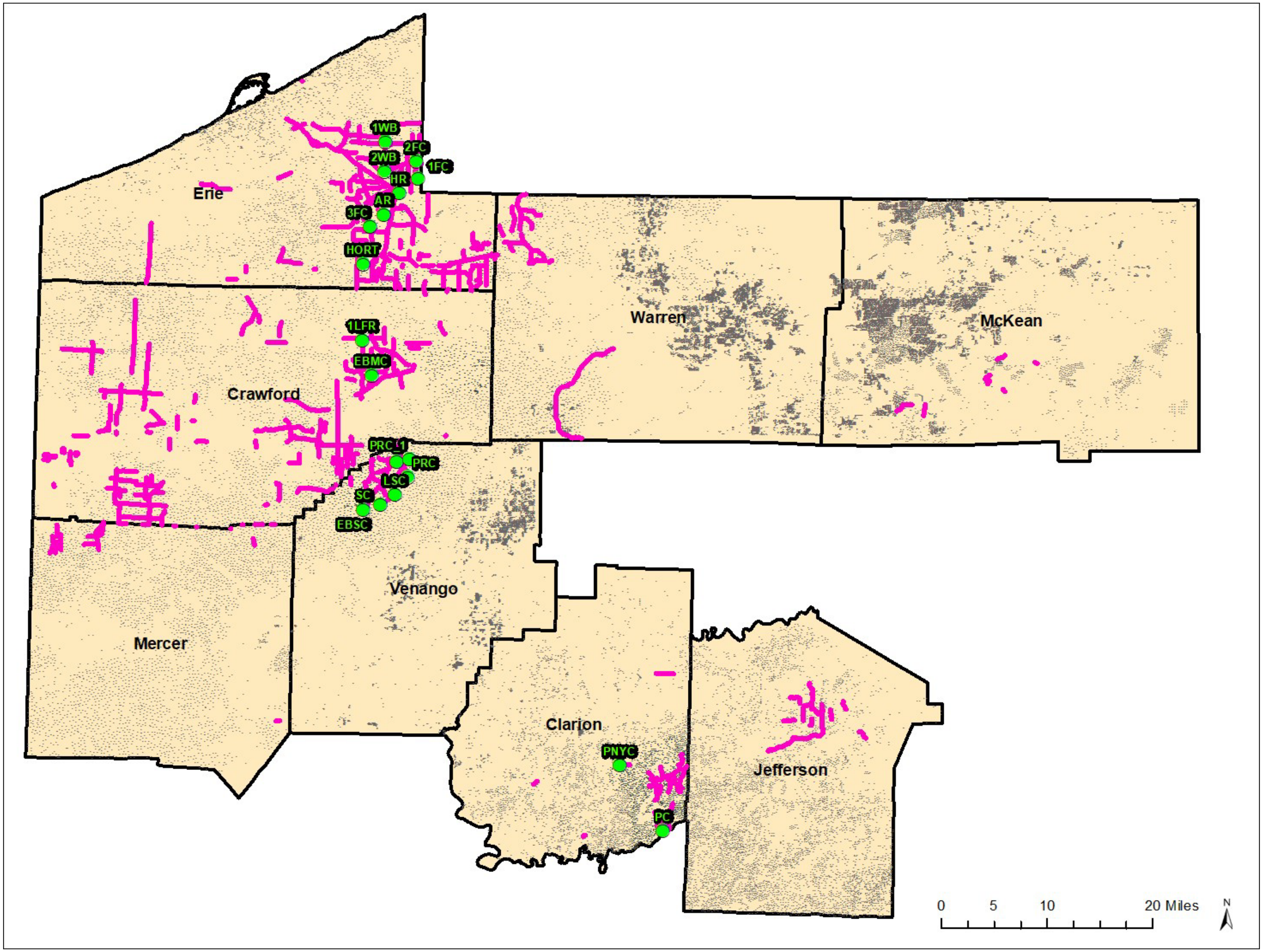

Figure 2. Sampling locations (labeled green dots), brine-treated roads reported in 2015 and 2016 (pink lines), and active or proposed oil and gas wells (gray dots; darker areas indicate areas with high concentrations of wells).

DATA COLLECTION AND ANALYSIS PROTOCOLS

Data collection for this investigation was designed to characterize seasonal accumulation effects and runoff impacts of brine road spreading on nearby streams. Baseline data was collected in February and March of 2016 at a select number of sites. These samples represent conditions before the beginning of the most intense period of brine spreading (i.e., late April to early October). In 2017, samples were collected in early spring (i.e., May), mid-summer (i.e., July) and late summer (i.e., August) to study the accumulation effect of dry-season treatment of dirt and gravel roads. Sample design also targeted one major storm event within the active brine spreading time frame. These targeted stormwater samples were collected in July 2017 at select sites. A total of 18 sites were sampled with variable sampling schedules (Table 2). Water and sediment samples were collected at all locations. Samples from 2016 were only analyzed for certain radionuclide constituents (Table 3); samples from 2017 were also analyzed for general chemistry, metal, and nutrient parameters (Table 4).

Table 2. Data collection schedule.

Station	Feb/Mar	May	Jul	Aug
1FC	3/1/2016	5/3/2017*	7/13/2017*	8/30/2017*
2FC	-	5/3/2017	7/13/2017	8/30/2017
1LFR	-	5/4/2017*	7/12/2017	8/30/2017
1WB	3/1/2016	5/4/2017*	7/13/2017*	8/30/2017*
2WB	3/1/2016	5/3/2017	7/13/2017	8/30/2017
AR	3/1/2016	5/4/2017	7/13/2017	8/30/2017
EBMC	-	5/2/2017	7/12/2017	8/29/2017
EBSC	2/29/2016	5/1/2017	7/12/2017	8/29/2017*
HR	-	5/3/2017	7/13/2017	8/30/2017┼
LSC	-	5/1/2017	7/12/2017	8/29/2017*
PC	2/29/2016	5/1/2017	7/21/2017	8/29/2017
PNYC	2/29/2016	5/1/2017*	7/19/2017*	8/29/2017*
PRC	2/29/2016	5/1/2017	7/12/2017	8/29/2017
SC	2/29/2016	5/4/2017	7/12/2017	8/29/2017
LSC_1	-	-	7/12/2017	8/29/2017
3FC	-	5/3/2017	-	-
HORT	-	-	7/19/2017	-
PRC_1	-	-	7/12/2017	-

Yellow highlight indicates stormwater sample collections
* Used in validation re-analysis (See **DISCUSSION** subsection **Validation**)
┼ Ultra-Pure Blank water also collected, analyzed, and used in validation re-analysis (See **DISCUSSION** subsection **Validation**)

Each sampling day, background radioactivity was recorded using a Ludlum Ratemeter/Scaler Model 2221, probe 44-10 at least once per day. Background readings were usually taken at the first sample site visited. Additional background radioactivity readings were taken at other sites some sampling days if the distance between sample sites was large (i.e., more than 30 miles). The ratemeter/scaler was set away from the stream at a higher elevation directly on top of exposed soil for 10 minutes, at which time a background level was recorded in counts per minute (cpm).

Water samples for radiological analyses were collected as a 4-L cubitainer grab samples, collected mid-channel, mid-depth. These water samples were delivered to DEP's Bureau of

Laboratories (BOL) and analyzed under Standard Analysis Code (SAC) RAD 61 using EPA 901.1 and 900.0 methodologies (see Table 3 for list of analytes). General chemistry water samples were collected according to DEP's *Chemical Data Collection Protocols* (Shull and Lookenbill 2018) and analyzed under BOL's SAC 046 (see Table 4 for list of analytes and methodologies).

Sediment was collected as either a single streamside sample from the left descending bank (LDB) or right descending bank (RDB) or as a complete composite sample (LDB and RDB) depending on the stream site's location relative to the treated road (Table 1). In either situation, about 1000 grams of sediment limited to the top 1 to 6 centimeters of surficial sediment was collected. Each sample was homogenized in a metal bowl with a metal trowel. Before transferring the sediment to a doubled plastic bag for transport to BOL, the sediment was scanned with the Ludlum Ratemeter/Scaler Model 2221, probe 44-10 to get initial field screening cpm. The sample was delivered to BOL and analyzed using Department of Energy (DOE) 4.5.2.3 methodology under SAC RAD 35 (see Table 3 for list of analytes).

Table 3. Radiological Standard Analysis Codes (SAC) analyte list.

RAD 61 (Water) ***EPA 901.1 and 900.0****	**RAD 35 (Sediment)** ***DOE 4.5.2.3***
Actinium 228 Water	Actinium 228
Bismuth 212 Water	Bismuth 212
Gross Alpha Activity*	Bismuth 214
Gross Beta Activity*	Lead 212
Lead 212 Water	Lead 214
Lead 214 Water	Potassium 40
Potassium 40 Water	Radium 226 by Gamma
Radium 226 Water by Gamma	Radium 228 by Gamma
Radium 228 Water by Gamma	Thorium 232 Solid by Gamma
Thorium 232 Water by Gamma	Uranium 235
Uranium 235 Water by Gamma	Uranium 238
Uranium 38 Water by Gamma	

Table 4. General Chemistry SAC 046 analyte list.

SAC 046	Method
Specific Conductivity @ 25.0 C	SM 2510B
Biochemical Oxygen Demand Inhibited 5 Day	SM 5210B
pH, Lab (Electrometric)	SM 4500H-B
Alkalinity Total as $CaCO_3$ (Titrimetric)	SM 2320B
Total Suspended Solids	USGS I-3765
Ammonia Total as Nitrogen	EPA 350.1
Nitrate & Nitrite, Total as Nitrogen	EPA 353.2
Phosphorus, Total as P	EPA 365.1
Hardness Total (Calculated)	SM 2340 B
Calcium, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Magnesium, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Sodium, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Chloride by Ion Chromatograph	EPA 300.0
Sulfate by Ion Chromatograph	EPA 300.0
Arsenic, Total by Trace Elements in Waters & Wastes by ICPMS	EPA 200.8
Barium, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Boron, Total	EPA 200.7
Iron, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Manganese, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Strontium, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Zinc, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Aluminum, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Lithium, Total by Trace Elements in Waters & Wastes by ICP	EPA 200.7
Selenium, Total by Trace Elements in Waters & Wastes by ICPMS	EPA 200.8
Total Dissolved Solids @ 180C by USGS-I-1750	USGS I-1750
Bromide, by Ion Chromatography	EPA 300.1 B
Osmotic Pressure, MOS/KG	BOL 3003

RESULTS

Water Quality

Generally, physiochemical water quality did not vary much across sites or across sample collection events. Water quality sample results were generally consistent with surface water quality in the region, except for stations PC and PNYC, which showed consistently high concentrations of magnesium, manganese, sodium, strontium, sulfate, hardness, specific conductance and total dissolved solids (TDS) relative to other sites. These high concentrations of metals indicate that these two streams may be impacted by abandoned mine drainage (AMD). A review of current aquatic life use assessments shows the stream reach in which the PNYC station was situated as being impaired by metals associated with AMD. Station AR had consistently high concentrations of sulfate, nitrate and nitrite, alkalinity, hardness, and TDS. May samples collected at stations EBMC, LSC, PC, PNYC and PRC had a higher than average Carbonaceous Biological Oxygen Demand (CBOD); the highest CBOD recorded was 8.8 mg/L at station PRC. August collections at station SC yielded higher iron, nitrate and nitrite, and TDS concentrations than other collections at this site. Aluminum, iron, manganese, zinc, nitrate and nitrite, phosphorus, and total suspended solids (TSS) concentrations were higher in stormwater samples at most sites. Otherwise each site's chemical analyses reflected expected values given land use and field findings (see Appendix A, Table A1 for full water quality physiochemical sample results).

Table 5. Water quality physiochemical sample analysis summary. n = number of detections; ND = number of non-detections or detections below the minimum detectable limit. Maximum values **bolded** and highlighted yellow indicate stormwater samples.

PARMETER	UNITS	Average	n	ND	Max	Max Site	Min	Min Site
ALUMINUM T	ug/L	1099	20	27	**4767**	LSC	213	1FC
ARSENIC	ug/L	4.65	5	42	6.43	EBMC	3	AR
BARIUM T	ug/L	32	47	0	64	AR	10	2FC
BORON T	ug/L	ND	0	47	ND	-	ND	-
BROMIDE	ug/L	44.61	23	24	107.7	PC	27.11	HR
CALCIUM T	mg/L	27.8	47	0	82.1	PC	6.6	LSC
CHLORIDE T	mg/L	7	47	0	18	PC	1	2FC
IRON T	ug/L	845	47	0	**5516**	PRC	67	2WB
LITHIUM T	ug/L	ND	0	47	ND	-	ND	-
MAGNESIUM T	mg/L	6.8	47	0	33.6	PNYC	1.8	LSC, 2FC
MANGANESE T	ug/L	105	43	4	439	PNYC	12	1WB
MOLYBDENUM T	ug/L	ND	0	47	ND	-	ND	-
SELENIUM T	ug/L	ND	0	47	ND	-	ND	-
SODIUM T	mg/L	5.689	47	0	21.607	PNYC	1.180	2FC
STRONTIUM T	ug/L	75	47	0	344	PNYC	24	2FC, SC
SULFATE T	mg/L	30.76	47	0	297	PNYC	3.43	2FC
ZINC T	ug/L	13	10	37	**23**	PRC	10	1FC
AMMONIA T	mg/L	0.07	34	13	**0.27**	HR	0.02	AR
NITRATE & NITRITE T	mg/L	0.41	45	2	**1.07**	LSC_1	0.09	2FC
PHOSPHORUS T	mg/L	0.046	42	5	**0.165**	PRC	0.01	PRC
ALKALINITY	mg/L	67.1	47	0	172.8	2WB	16	LSC
CBOD	mg/L	1.8	47	0	8.8	PRC	0.3	2FC
HARDNESS T	mg/L	98	47	0	335	PNYC	24	LSC
OSMOTIC PRESSURE	mosm/kg	3	22	25	6	PC, PNYC	1	Multiple
pH	pH units	7.8	47	0	8.6	AR	7.2	2WB, LSC_1
SPECIFIC COND	umhos/cm	213.0	47	0	713	PNYC	63.5	LSC
TDS	mg/L	144	47	0	522	PNYC	54	2FC
TSS	mg/L	37	15	32	**130**	PRC	6	1LFR
FIELD MEASURMENTS								
Temperature	°C	15.9	47	0	22.9	HR	7.9	2FC
Specific Cond	umhos/cm	216.0	47	0	726	PNYC	64.8	LSC
pH	pH units	7.56	47	0	8.74	AR	6.73	1WB
Dissolved Oxygen (DO)	mg/L	9.19	47	0	15.07	AR	3.57	2WB
DO % Saturation	%	92.3	47	0	164.3	AR	34.9	2WB

Radiological Results

Radiological analyses for many samples produced results that were less than the relevant methodological detectable limit. These very low concentrations made it necessary to interpret the radiological analysis results with caution. A complete list of results can be found in Appendix A, Table A2. Furthermore, the radiological analyses used in this study presents complexities associated with interpretation. Interpretation of data is based off of half-life, activity levels and the rate of detection for each parent radionuclide and progeny radionuclides. Proper laboratory procedures are followed to ensure parent and progeny activities are at equilibrium. This equilibrium allows a valid interpretation of the parent concentration utilizing the progeny concentration that is more reliably detectable. Furthermore, any value observed for a parent analyte that is outside the range of associated progeny analyte concentrations is likely a result of some interference with the specific gamma ray energy used for identification. One scenario is the interference between Ra-226 and U-235; both are naturally occurring and have nearly identical gamma energy which analytical software could misinterpret. Additional interpretation complexities are specific to analytical methods and software interpretation of gamma spectroscopy outputs. For example, if Ra-228 and Ac-228 are present, the software used in the analysis infers the presence of Th-232, and while the Th-232 result is likely accurately reported because the sample should be in equilibrium with its decay chain, this Th-232 result is only accurate to the extent of equipment and software capabilities.

Radiological water sample results showed little to no radioactivity; most of the time, the analytes being tested (see Table 3) were below the Minimum Detectable Activity (MDA) or interference was identified in the analytical report. Ac-228, Pb-212, Pb-214, and Bi-214 were the only analytes that were detected with confidence and not reported from the inference of surrogate signals; however, U-238 and Ra-226 were detected in a few instances but results are interpreted with caution as both are very difficult to detect at low concentrations using gamma spectroscopy. Ac-228 had the highest concentrations at sites PC and PNYC – 16 pCi/L and 21 pCi/L, respectively – but its parent compound, Th-232, was not detected with certainty as it was qualified in the lab-generated report. Bi-214 had its highest concentration at site 1FC – 22 pCi/L – but, its parent compound, U-238, was not detected above the MDA. Gross alpha and gross beta activity were identified in a handful of samples, results which can likely be attributed to the presence of radioactive species naturally abundant in the environment, U-235 and K-40 (DEP 2016).

Initial scans on each sediment sample did not show radioactivity counts to be above the background levels recorded. The highest sediment count rate was observed at station AR at 7,657 cpm, which was below the background of 7,758 cpm. Radiological analysis results of sediment samples (Table 7) were indicative of normal ranges for background soils (Table 8). The highest concentrations of radiological analytes in sediment samples were detected in the March 2016 sample from PNYC, the July and August 2017 samples from AR, the one sample from HORT (July 2017), and the 2017 samples from PC, particularly the August 2017 sample; the lowest concentrations were observed at sites EBSC, LSC, LSC_1, PRC, PRC_1, and 1LFR (Table 8).

Table 7. Summary statistics for SAC RAD 35 sediment results. Calculated values provided incorporate those concentrations inferred by spectra and reported. n = number of detections; ND = number of non-detections, or detections below the MDA.

PARMETER	UNITS	Average	n	ND	Max	Max Site	Min	Min Site
Thorium 232	**pCi/g**	0.541	45	11	0.936	AR	0.235	EBSC
Radium 228	**pCi/g**	0.530	46	10	0.936	AR	0.037	PRC
Actinium 228	**pCi/g**	0.542	52	4	1.170	PNYC	0.235	EBSC
Lead 212	**pCi/g**	0.524	55	1	1.260	AR	0.191	PRC
Bismuth 212	**pCi/g**	0.562	55	1	1.080	PNYC	0.230	PRC
Uranium 238	**pCi/g**	0.797	38	18	2.430	PNYC	0.363	1FC
Radium 226	**pCi/g**	1.023	52	4	1.930	AR	0.348	SC
Lead 214	**pCi/g**	0.502	53	3	1.010	PNYC	0.223	PRC_1
Bismuth 214	**pCi/g**	0.470	53	3	1.320	PNYC	0.206	LSC_1
Uranium 235	**pCi/g**	0.073	25	31	0.178	PNYC	0.034	LSC_1
Potassium 40	**pCi/g**	7.344	53	3	12	HORT	3.470	PRC
Field Counts	**pCi/g**	5771	54	2	7657	AR	4622	PNYC
BACKGROUND Counts	**cpm**	7141.6	55	1	9890.4	HORT	6271.7	1LFR

Table 8. Natural Background Radioactivity Values for U.S. Soil (UNSCEAR 2000).

Material	U-238 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)	K-40 (pCi/g)
Soil (Average)	0.95	1.1	0.95	10
Soil (Minimum)	0.11	0.22	0.11	2.7
Soil (Maximum)	3.8	4.3	3.5	19

Radiological Qualitative Analysis

Although the large proportion of results below the relevant MDA precludes analysis of patterns across sites or over time for most radiological water sample results (Table A2), the water sample results for Pb-212 provided enough reportable data for some such analysis. Pb-212 concentrations in all water samples collected in March 2016 were below the MDA (Table A2). Relatively high Pb-212 concentrations in water were observed in the August 2017 samples at most sites, except EBSC and PNYC (Table A2). Relatively high concentrations of other radiological analytes were also detected in August 2017 samples, such as U-235 in samples from 2FC, 1LFR, and LSC. Pb-212 water sample concentrations in targeted stormwater samples were relatively high at some sites (i.e., 1LFR, EBMC, EBSC, LSC, LSC_1, PRC, PRC_1) but relatively low at other sites (i.e., 1FC, 1WB, 2FC, 2WB, AR, HR) (Table A2).

The highest concentrations of gross beta activity in water samples were observed in targeted stormwater samples from most sites – 1FC, 1LFR, 1WB, 2WB, AR, EBMC, EBSC, HR, LSC, PRC, and LSC_1 – but the highest concentrations of gross beta activity in water samples from two sites – PC and PNYC – were observed in the August 2017 samples (Table A2).

While the qualitative analysis of sediment data incorporates inferred values, the information gives opportunity to describe accumulative effects at these sites. Comparisons were made before brine spreading (i.e., the March 2016 samples) and after brine spreading (i.e., the 2017 samples) at nine sites. At sites 1FC, 1WB, AR, and SC, sediment concentrations of several radionuclides were slightly higher after brine spreading than before brine spreading (Table A2).

At sites 2WB, EBSC, PC, and PRC, little to no change in sediment concentrations of most radionuclides was observed before and after the brine spreading period (Table A2). Site PNYC had sediment radionuclide concentrations slightly lower after brine spreading than what was observed before brine spreading (Table A2).

Sediment data from 2017 shows that the radionuclides of interest generally did not accumulate substantially over the course of the study, although slight increases in concentrations of some radionuclides over time were observed at 1FC, 2WB, LSC, LSC_1, and PC (Table A2); site AR had a more noticeable increase in radionuclide concentrations over time (Table A2). Pb-212 sediment results provided the most data for interpretation. Sediment concentrations of Pb-212 at site AR were 0.451 pCi/g in the May 2017 sample with increases to 1.26 pCi/g in the July 2017 and 0.881 pCi/g in the August 2017 sample (Table A2). Otherwise, concentrations of radionuclides in sediment samples show only small variations at each site over the course of the study.

Brine Specific Results

DEP's Northwest District Oil and Gas Office receives notification from brine spreading operators of an operator's intent to apply prior to spreading, and the operator also provides a chemical analysis of the brine used for the treatment of roads as described in DEP's fact sheet, *Roadspreading of Brine for Dust Control and Road Stabilization* (DEP 2011). The suite of analytes analyzed in these brine samples include sodium, calcium, magnesium, chloride, and TDS. Some operators additionally analyzed brine samples for barium, benzene, e-benzene, iron, lead, sulfate, toluene, and xylene. Data from brine analyses submitted to DEP from 2012 to 2016 indicate that the concentrations of most analytes in the brines (Table 9) were one to two orders of magnitude greater than the concentrations found in the stream water samples in this study (Table 5, Table A1).

Table 9. Brine sample chemistry data reported by operators (2012-2016). Averages, maximums and minimum values representative of samples from operators within the sampled area of this investigation.

	Units	Sodium	Calcium	Magnesium	Chloride	TDS
Average	mg/L	36,423	18,773	47,905	174,278	311,342
Maximum	mg/L	73,500	41,600	784,876	344,000	387,000
Minimum	mg/L	6,000	2,601	205	39,100	82,970

Independently from this DEP investigation, sampling and analyses of oil and gas wastewater brines to be spread on roads in 14 townships in northwestern Pennsylvania during the summer of 2017 was conducted by Tasker et al. (2018). Tasker et al. (2018) analyzed the brines for inorganic constituents including TDS, Cl, Br, Na, K, Mg, Ca, Sr, Ba, Fe, Ra-226, and Ra-228. The brines analyzed by Tasker et al. (2018) came directly from storage tanks in some of the same townships where this DEP investigation was conducted. Focusing on the radionuclide analytes, the analyses of Tasker et al. (2018) show Ra-226 concentrations ranging between 50.6 pCi/L and 1,220 pCi/L with an average of 439.1 pCi/L, and Ra-228 concentrations ranging between 8 pCi/L and 1,760 pCi/L with an average of 719 pCi/L (Table 10). For a complete description of sampling and analysis methodologies and a more complete discussion of these results see Tasker et al. (2018).

Table 10. Summary of Tasker et al. (2018) inorganic chemistry analyses.

	TDS (mg/L)	Cl (mg/L)	Br (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)
Average	256,136	155,629	1,758	53,756	2,013	3,569
Median	293,000	183,000	1,950	58,150	1,895	3,110
Max	356,000	211,000	2,970	79,000	4,710	9,150
Min	48,900	28,100	314	4,890	45.5	699
	Ca (mg/L)	**Sr (mg/L)**	**Ba (mg/L)**	**Ra-226 (pCi/L)**	**Ra-228 (pCi/L)**	**Fe (mg/L)**
Average	28,626	1,339	5.585	439.1	719	159
Median	31,700	1,270	4.120	505.5	464	120
Max	40,100	4,310	22	1,220	1,760	638
Min	3,370	32	0.656	50.6	8	2

Only brines from conventional oil and gas wells can be used as a dust suppressant for roads in Pennsylvania. Data shows that Ra-226 concentrations in unconventional produced waters are, on average, approximately 20 times greater than in conventional produced waters (Table 11). The Ra-226 average concentrations reported in Table 11 are fairly similar to the average Ra-226 concentration reported by Tasker et al. (2018), suggesting that the brines sampled by Tasker et al. (2018) were in fact brines from conventional oil and gas wells.

Table 11. Conventional versus unconventional produced water radium isotope concentrations (Figure 3-7 in DEP 2016).

Production	Filtered Samples	No. of Samples	Average Ra-226 (pCi/L)	Average Ra-228 (pCi/L)	Ratio of Ra-226/Ra-228
Conventional	No	4	336	295	1.14
Unconventional	No	9	8,340	986	8.46
Conventional	Yes	4	334	288	1.16
Unconventional	Yes	9	8,220	985	8.35

DISCUSSION

The sampling conducted for this investigation largely showed little to no radiological activity above background levels in water or sediment samples collected from streams near sites where oil and gas brines were applied to roads. Somewhat elevated concentrations of some radionuclides were detected in the streambed sediment samples collected for this investigation and some samples suggest the potential for runoff impacts to streams near brine road application sites, but follow-up sampling would be needed to further investigate these observations. Water sampling conducted for this investigation also showed concentrations of physiochemical parameters and certain radionuclides in streams near sites of road application of oil and gas brines well below the concentrations of those analytes in brine samples as documented by DEP (2016) and Tasker et al. (2018).

Limitations

During this investigation, some limitations existed with sampling design and sample collection. While sites were selected based on historical road spreading records, brine application schedules were often unknown until operators reported intent to apply to DEP’s Northwest District Oil and Gas Office, which sometimes occurred as little as 24 hours in advance of brine application, making sample collection scheduling difficult. Therefore, sites were selected based on the analysis of historic records as indicated in the Site Selection section of this report. The other limiting factor to consider is weather. Northwestern Pennsylvania experienced a relatively wet year in 2017, with the rainfall total for the year approaching 50 inches, 20 inches of which occurred during the typically dry season months of May to September (NOAA 2018). The relatively wet conditions in northwestern Pennsylvania during 2017 may have resulted in relatively little road application of oil and gas brines compared to other years, which could have influenced the results of the sampling conducted for this investigation.

Another limitation of this investigation related to the use of the ratemeter/scaler. The use of a ratemeter/scaler in radiological sampling can be very beneficial to source tracking, particularly in areas of known or high radiological contamination. This technique often leads to targeting sample collection at defined hotspots. Because no radiologically contaminated hotspots were detected during this investigation, the use of the ratemeter to source track radiological contamination did not prove useful in this investigation. Since environmental conditions indicated no hotspots to track pathways by which radioactivity may have been conveyed to the stream and streambed sediments, this investigation targeted stream sample locations based solely on proximity to brine-treated roads and hydrological drainage patterns.

A final limitation of this study was the relatively high proportion of sample results, particularly for the water samples, reported as below the relevant MDA level, which limited the type and extent of data analyses in this investigation. In an attempt to address this limitation, a subset of samples collected for this investigation was re-analyzed using laboratory methodologies with better measurement resolution; a discussion of this validation process and data is provided below.

Validation

A subset of 13 water samples was used as a validation dataset. These samples were re-analyzed by BOL using EPA 903.1 and Brooks and Blanchard Methodologies for Ra-226 and Ra-228 respectively, under SAC RAD92. These methodologies use radiochemistry instead of gamma spectroscopy to analyze specifically for Ra-226 and Ra-228, and these methodologies have better analytical sensitivities, allowing for measurement in samples with lower concentrations of target analytes. Table 12 summarizes and compares the results obtained using the gamma spectroscopic and radiochemical analytical methods. Of those results provided in the initial gamma spectroscopic analyses, Ra-226 and Ra-228 were either reported as much higher than expected or had an inference value reported that was also higher than expected. Compared to the gamma spectroscopic results, the radiochemistry validation data showed notably lower Ra-226 and Ra-228 concentrations: the radiochemistry validation results for Ra-226 and Ra-228 combined ranged from 0.045 pCi/L to 0.998 pCi/L compared with the gamma spectroscopic results which ranged from 48 pCi/L to 739 pCi/L (Table 11). The results of this data validation exercise strongly suggest that concentrations of at least some radionuclides reported in Appendix A, Table A2, which were determined by gamma spectroscopic analyses, are likely substantially higher than concentrations that would have resulted from more sensitive radiochemical analyses, particularly for samples where concentrations were reported with no qualifier (i.e. interference was not detected). This additional precautionary disclaimer can be made for samples at sites 1FC, 2FC, 1LFR, 2WB, AR, EBMC, EBSC, LSC, PC, PRC, SC, LSC_1, and HORT. For all the samples included in the validation dataset, the results of the radiochemical analyses were well below EPA's drinking water Maximum Contaminant Level for Ra-226 + Ra-228 of 5 pCi/L.

Table 12. Validation data set comparison. All results in pCi/L.

Site	Date	Parameter	METHOD	
			Gamma Spectroscopy	Radiochemistry[1]
1FC	Jul-17	Ra-228	4	<MDA
		Ra-226	78	<MDA
	Aug-17	Ra-228	<MDA	<MDA
		Ra-226	106	0.062
2FC	Aug-17	Ra-228	<MDA	<MDA
		Ra-226	739	<MDA
1LFR	May-17	Ra-228	<MDA	<MDA
		Ra-226	260	0.089
1WB	May-17	Ra-228	102	<MDA
		Ra-226	122	<MDA
	Jul-17	Ra-228	<MDA	<MDA
		Ra-226	162	0.045
	Aug-17	Ra-228	<MDA	<MDA
		Ra-226	218	<MDA
EBSC	Aug-17	Ra-228	<MDA	<MDA
		Ra-226	196	<MDA
LSC	Aug-17	Ra-228	<MDA	<MDA
		Ra-226	712	<MDA
PNYC	May-17	Ra-228	<MDA	0.944
		Ra-226	92	0.054
	Jul-17	Ra-228	26	<MDA
		Ra-226	107	0.041
	Aug-17	Ra-228	<MDA	<MDA
		Ra-226	217	0.066
BLANK (HR)	Aug-17	Ra-228	<MDA	<MDA
		Ra-226	148	<MDA

[1] Radiochemistry analyses were conducted outside of the RAD92 sample holding times; results here are provided for comparison only

Interference detected during BOL analysis

SUMMARY

While the stream sampling and review of historical brine road spreading records conducted for this investigation did not document widespread or pronounced impacts of road application of oil and gas brines on the chemical or radiological composition of waters or sediments in streams near road application sites in northwestern Pennsylvania, results of this study did suggest some potential for road application of oil and gas brines to increase concentrations of certain chemical and radiological constituents in streams near road application sites, particularly in streambed sediments. More specifically, the streambed sediment samples collected for this investigation show higher concentrations of certain radionuclides at some sites, which may result from migration of materials from brine-treated roads to streambeds. Furthermore, radiological analysis of water and sediment samples collected from streams near brine road application sites for this investigation suggest little impact associated with stormwater runoff from brine-treated roads, although weather conditions and limitations on sample collection scheduling may have prevented robust assessment of stormwater runoff impacts.

This investigation documented concentrations of targeted chemical and radiological constituents in streams near oil and gas brine road application sites well below concentrations in samples of brines documented in previous studies (DEP 2016; Tasker et al. 2018), which suggests that uncontrolled brine spills may present a more substantial acute risk to streams than road spreading. However, further investigations are needed to assess potential long-term, accumulative effects of brine road spreading on nearby streams and to better characterize the stormwater runoff response.

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APPENDIX A:

Tables A1 and A2

Table A1. SAC 046 chemistry sample results. Dates bolded represent stormwater samples.

PARMETER	UNITS	1FC			2FC			1LFR			1WB		
		May-17	***Jul-17***	Aug-17	May-17	***Jul-17***	Aug-17	May-17	***Jul-17***	Aug-17	May-17	***Jul-17***	Aug-17
ALUMINUM T	ug/L	< 200	213	< 200	< 200	428	236	372	627	< 200	< 200	323	232
ARSENIC	ug/L	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
BARIUM T	ug/L	13	19	25	10	18	23	15	24	29	23	30	43
BORON T	ug/L	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200
BROMIDE	ug/L	< 25	< 25	40.27	< 25	29.46	29.72	< 25	34.95	38.7	< 25	34.25	< 25
CALCIUM T	mg/L	16.1	20.4	37.9	9.9	13.1	25.6	15.2	23.1	39.4	23.3	24.1	36
CHLORIDE T	mg/L	2	2	4	1	2	2	5	7	7	8	12	5
IRON T	ug/L	104	287	96	118	624	337	971	1771	867	96	456	463
LITHIUM T	ug/L	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25
MAGNESIUM T	mg/L	2.9	3.7	6.7	1.8	2.5	4.3	2.9	4.5	9.4	3.7	4	5.6
MANGANESE T	ug/L	< 10	16	18	< 10	25	36	92	224	395	12	39	223
MOLYBDENUM T	ug/L	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70
SELENIUM T	ug/L	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7
SODIUM T	mg/L	1.774	2.306	3.435	1.18	1.668	2.397	4.6	5.794	4.62	7.066	10.674	4.468
STRONTIUM T	ug/L	38	50	87	24	34	59	37	53	74	48	58	80
SULFATE T	mg/L	4.66	4.06	6.19	4.43	3.43	5.52	4.88	4.46	7.49	5.04	4.16	8.04
ZINC T	ug/L	10	< 10	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
AMMONIA T	mg/L	< 0.02	< 0.02	0.05	< 0.02	0.03	0.05	0.03	0.07	0.12	< 0.02	0.05	0.07
NITRATE & NITRITE T	mg/L	0.15	0.22	< 0.05	0.09	0.2	0.12	0.34	0.9	0.14	0.22	0.2	0.27
PHOSPHORUS T	mg/L	< 0.01	< 0.01	0.014	0.012	0.013	0.018	0.044	0.076	0.042	0.022	0.042	0.036
ALKALINITY	mg/L	47.6	62.8	116.4	28.4	41.2	75.4	49.2	69	127.2	67.6	77.6	104.2
CBOD	mg/L	1	0.7	1.1	0.3	0.7	0.9	1.5	1.9	1.5	0.9	1.5	1.3
HARDNESS T	mg/L	52	66	122	32	43	82	50	76	137	74	77	113
OSMOTIC PRESSURE	mosm/kg	< 1	NA	2	< 1	< 1	1	NA	NA	2	1	NA	3
pH	pH units	7.9	7.7	8.2	7.6	7.7	7.6	7.7	7.4	7.7	8	8	7.8
SPECIFIC COND	umhos/cm	104.9	137.4	240	65.4	93.4	159.7	125.9	173	275	169.2	206	233
TDS	mg/L	74	88	140	54	74	92	96	120	176	98	124	136
TSS	mg/L	< 5	< 5	< 5	< 5	20	< 5	6	10	< 5	< 5	8	10
FIELD READINGS													
Temperature	°C	8.5	19.1	15.7	7.9	18.4	15.3	11.9	21.6	17.2	8.3	18.7	14.9
Specific Cond	umhos/cm	105.8	139.1	244.4	65.6	94.3	161.5	128	176.6	278.1	169.8	205	236.8
pH	pH units	7.81	7.21	7.97	7.5	6.78	7.41	7.4	7.24	7.49	7.68	6.73	7.29
Dis Oxygen (DO)	mg/L	11.33	8.74	8.99	11.19	8.45	7.79	9.22	7.41	6.08	10.88	8.35	6.06
DO % Saturation	%	96.8	94.5	90.6	94.3	90	77.8	85.3	84.1	63.2	92.6	89.6	60

Table A1 (continued). SAC 046 chemistry sample results. Dates bolded represent stormwater samples.

PARMETER	UNITS	2WB			AR			EBMC			EBSC		
		May-17	***Jul-17***	Aug-17	May-17	***Jul-17***	Aug-17	May-17	***Jul-17***	Aug-17	May-17	***Jul-17***	Aug-17
ALUMINUM T	ug/L	< 200	2560	< 200	< 200	< 200	< 200	958	1510	< 200	< 200	1412	< 200
ARSENIC	ug/L	< 3	< 3	< 3	< 3	< 3	3	6.43	3.88	< 3	< 3	< 3	< 3
BARIUM T	ug/L	22	43	30	37	59	64	18	28	37	19	36	29
BORON T	ug/L	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200
BROMIDE	ug/L	< 25	27.34	30.16	30.22	42.67	48.1	< 25	< 25	< 25	< 25	< 25	40.88
CALCIUM T	mg/L	28.2	46.7	61.7	35.8	46.5	50.2	11.9	15.3	39.6	7.6	6.9	14.8
CHLORIDE T	mg/L	3	4	5	4	6	8	2	3	4	6	4	10
IRON T	ug/L	177	2766	67	334	446	337	1467	2834	398	346	2248	501
LITHIUM T	ug/L	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25
MAGNESIUM T	mg/L	4.8	7.3	8.6	6.2	8.8	10.6	2.5	3.1	7.1	2	1.9	4
MANGANESE T	ug/L	< 10	157	25	65	125	116	68	176	126	21	108	43
MOLYBDENUM T	ug/L	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70
SELENIUM T	ug/L	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7
SODIUM T	mg/L	2.544	4.722	4.283	3.636	4.541	5.292	2.219	4.252	3.578	4.296	3.438	8.393
STRONTIUM T	ug/L	56	87	102	64	85	92	31	37	75	29	30	61
SULFATE T	mg/L	4.76	6.38	5.86	9.52	13.41	17.09	4.8	4.57	12.02	7.6	5.31	8.73
ZINC T	ug/L	< 10	15	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	11	< 10
AMMONIA T	mg/L	< 0.02	0.03	0.07	0.02	0.06	0.07	0.03	0.05	0.06	< 0.02	< 0.02	0.06
NITRATE & NITRITE T	mg/L	0.49	1.05	0.76	0.84	0.84	0.34	0.39	0.92	0.16	0.19	0.36	0.12
PHOSPHORUS T	mg/L	0.016	0.109	0.012	0.034	0.08	0.043	0.059	0.141	0.023	0.018	0.086	0.012
ALKALINITY	mg/L	83.6	142.6	172.8	100.2	142	143.8	37.8	43.6	115.8	22.2	16.8	47.6
CBOD	mg/L	0.4	1.4	1	0.9	0.6	2.2	1.4	2.6	1.3	8.6	2.4	1.2
HARDNESS T	mg/L	90	147	189	115	152	169	40	51	128	27	25	53
OSMOTIC PRESSURE	mosm/kg	1	3	4	2	4	3	NA	< 1	1	< 1	NA	< 1
pH	pH units	7.8	7.2	7.6	8.1	7.9	8.6	7.7	7.4	8.2	7.7	7.3	8
SPECIFIC COND	umhos/cm	176.4	301	357	227	317	319	93.5	114.6	254	79.4	67	146
TDS	mg/L	118	170	204	140	182	196	78	112	160	66	60	100
TSS	mg/L	< 5	82	< 5	< 5	< 5	< 5	10	52	< 5	< 5	42	< 5
FIELD READINGS													
Temperature	°C	8.5	15.7	14.3	10.2	19.7	19.5	12.7	20.7	16.7	15.1	17.7	17.6
Specific Cond	umhos/cm	179.3	302.3	356.6	229.1	322.2	327.7	93.1	116.1	260.3	80.4	68.6	149.2
pH	pH units	7.69	6.81	7.36	8.02	7.58	8.74	7.41	7.27	8.03	7.7	6.97	8.01
Dis Oxygen (DO)	mg/L	10.85	6.06	3.57	11.46	8.92	15.07	9.35	7.77	9.61	10.13	8.85	10.33
DO % Saturation	%	92.9	61.2	34.9	102.2	90.8	164.3	88	86.6	98.8	100.7	92.8	108.2

Table A1 (continued). SAC 046 chemistry sample results. Dates bolded represent stormwater samples. NA = Test was cancelled by laboratory.

PARMETER	UNITS	HR			LSC			PC			PNYC		
		May-17	***Jul-17***	Aug-17	May-17	***Jul-17***	Aug-17	May-17	*Jul-17*	Aug-17	May-17	*Jul-17*	Aug-17
ALUMINUM T	ug/L	< 200	239	< 200	< 200	4767	< 200	221	< 200	< 200	< 200	< 200	< 200
ARSENIC	ug/L	< 3	4.49	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
BARIUM T	ug/L	28	58	46	20	44	30	29	36	50	40	48	52
BORON T	ug/L	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200
BROMIDE	ug/L	< 25	27.11	< 25	< 25	< 25	44.62	59.97	NA	107.7	< 25	NA	91.69
CALCIUM T	mg/L	23.9	43	35.6	7.8	6.6	15.5	37.5	61.8	82.1	38.4	53.2	78.8
CHLORIDE T	mg/L	6	10	11	6	5	10	11	13	18	9	12	16
IRON T	ug/L	646	838	551	314	3291	382	337	254	107	231	225	268
LITHIUM T	ug/L	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25
MAGNESIUM T	mg/L	4.3	8.6	6.5	2	1.8	4.1	12.9	21.9	27.6	17.2	24	33.6
MANGANESE T	ug/L	92	138	92	20	158	40	157	58	38	439	208	197
MOLYBDENUM T	ug/L	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70
SELENIUM T	ug/L	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7
SODIUM T	mg/L	4.452	7.176	6.648	4.275	4.825	8.43	6.587	9.908	14.328	7.814	13.678	21.607
STRONTIUM T	ug/L	45	80	69	29	28	61	140	221	295	154	214	344
SULFATE T	mg/L	6.38	13.5	26.24	7.52	5.22	8.9	108	163	213	166	197	297
ZINC T	ug/L	< 10	< 10	< 10	< 10	13	< 10	11	< 10	< 10	11	< 10	14
AMMONIA T	mg/L	0.02	0.27	0.08	< 0.02	< 0.02	0.07	< 0.02	0.03	0.08	< 0.02	0.05	0.08
NITRATE & NITRITE T	mg/L	0.22	0.44	< 0.05	0.21	0.37	0.19	0.27	0.49	0.22	0.41	0.83	0.44
PHOSPHORUS T	mg/L	0.035	0.047	0.033	0.017	0.123	0.013	0.016	0.022	0.015	< 0.01	0.015	< 0.01
ALKALINITY	mg/L	67.6	126	84.2	22.8	16	49.8	51.4	79	103.4	26.2	35.4	47
CBOD	mg/L	0.8	0.7	1.5	4.2	2.2	1.2	4.4	0.9	1.1	3.9	1	1.2
HARDNESS T	mg/L	77	143	116	28	24	55	147	245	319	167	232	335
OSMOTIC PRESSURE	mosm/kg	NA	3	2	< 1	< 1	< 1	2	3	6	2	3	6
pH	pH units	7.6	8	8	7.7	7.2	8	7.8	8.2	8.2	7.5	7.5	7.7
SPECIFIC COND	umhos/cm	162.9	302	256	81.7	63.5	151.9	353	513	657	413	507	713
TDS	mg/L	104	174	162	62	66	100	246	332	460	286	352	522
TSS	mg/L	< 5	< 5	< 5	< 5	78	< 5	< 5	< 5	< 5	< 5	< 5	< 5
FIELD READINGS													
Temperature	°C	9.4	22.9	18.5	15	17.7	17	15.6	20.8	15.3	16	19.8	15.7
Specific Cond	umhos/cm	162.4	307.2	259.7	83.3	64.8	156	360.1	526	670	421.8	519	726
pH	pH units	7.56	7.91	7.94	7.62	7	7.93	7.74	7.97	7.99	7.41	7.29	7.59
Dis Oxygen (DO)	mg/L	9.88	9.24	9.34	9.86	8.85	10.27	9.35	8.63	9.33	9.24	8.93	8.8
DO % Saturation	%	86.4	107.7	99.6	97.7	93	106.3	93.9	96.6	93.2	93.7	97.9	88.7

Table A1 (continued). SAC 046 chemistry sample results. Dates bolded represent stormwater samples.

PARMETER	UNITS	PRC			SC			3FC	HORT	LSC_1		PRC_1
		May-17	***Jul-17***	Aug-17	May-17	*Jul-17*	Aug-17	May-17	*Jul-17*	***Jul-17***	Aug-17	***Jul-17***
ALUMINUM T	ug/L	281	3128	< 200	939	933	< 200	< 200	< 200	1434	< 200	1159
ARSENIC	ug/L	< 3	5.45	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
BARIUM T	ug/L	24	57	46	20	24	23	20	22	31	16	28
BORON T	ug/L	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200
BROMIDE	ug/L	< 25	37.64	67.22	< 25	< 25	< 25	< 25	NA	29.62	< 25	< 25
CALCIUM T	mg/L	7.2	8.3	18.5	9.2	12.2	33.1	18	36.5	9.6	12.8	8.9
CHLORIDE T	mg/L	5	6	10	3	4	7	8	10	5	9	3
IRON T	ug/L	464	5516	398	1339	1631	87	593	200	1761	200	1952
LITHIUM T	ug/L	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25
MAGNESIUM T	mg/L	1.9	2.1	4.5	2.1	2.5	6.2	3.1	6.3	2.4	3.6	2.7
MANGANESE T	ug/L	27	283	35	68	86	< 10	45	41	75	17	106
MOLYBDENUM T	ug/L	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70	< 70
SELENIUM T	ug/L	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7
SODIUM T	mg/L	3.75	4.656	10.39	2.572	3.334	5.707	6.015	7.804	3.434	5.686	3.149
STRONTIUM T	ug/L	29	34	80	24	31	59	41	82	32	37	28
SULFATE T	mg/L	7.22	4.54	9.55	5.62	5.53	11.29	4.24	5.17	5.25	8.79	4.32
ZINC T	ug/L	< 10	23	< 10	12	< 10	< 10	< 10	< 10	< 10	< 10	< 10
AMMONIA T	mg/L	< 0.02	0.02	0.05	< 0.02	0.06	0.19	0.04	0.04	0.12	0.06	0.09
NITRATE & NITRITE T	mg/L	0.16	0.33	0.11	0.41	0.5	1.03	0.16	0.28	1.07	0.59	0.56
PHOSPHORUS T	mg/L	0.027	0.165	0.01	0.072	0.069	< 0.01	0.059	0.025	0.103	0.017	0.116
ALKALINITY	mg/L	21.6	21	63	26.8	33.6	92.2	53.4	110	24	35.4	27.6
CBOD	mg/L	8.8	2.7	1.2	1.1	1.7	1.2	2	0.9	2.5	1.1	2.3
HARDNESS T	mg/L	26	30	65	31	41	108	58	117	34	47	33
OSMOTIC PRESSURE	mosm/kg	< 1	NA	< 1	NA	< 1	2	< 1	2	NA	< 1	< 1
pH	pH units	7.5	7.3	8	7.5	7.6	8.4	7.9	8.1	7.2	8	7.4
SPECIFIC COND	umhos/cm	73.6	70.8	175.6	78.6	93.5	233	139.3	251	86.6	123.6	78.9
TDS	mg/L	62	74	116	68	76	144	92	148	86	92	84
TSS	mg/L	< 5	130	< 5	28	24	< 5	< 5	< 5	20	< 5	28
FIELD READINGS												
Temperature	°C	14.8	18.1	16.4	12	17.6	15.6	10.5	18	18.2	15.2	19.4
Specific Cond	umhos/cm	69.2	72.7	178	79.7	95.4	235.7	140.4	238.5	88.1	127.8	80.6
pH	pH units	7.6	7.08	7.91	7.31	7.07	8.34	7.93	7.61	7.19	7.94	7.06
Dis Oxygen (DO)	mg/L	9.72	8.69	9.65	9.62	8.65	10.16	11.03	8.13	8.98	10.55	8.34
DO % Saturation	%	96	92	98.6	89.3	90.7	102	98.9	85.9	95.3	105	90.7

Table A2. Water, reported in pCi/L, and sediment (highlighted yellow), reported in pCi/g, radiological sample results. Field and background sediment counts reported in counts per minute (CPM). Dates bolded represent stormwater samples.

PARAMETER		1FC				2FC			1LFR			1WB			
		Mar-16	May-17	**Jul-17**	Aug-17	May-17	**Jul-17**	Aug-17	May-17	**Jul-17**	Aug-17	Mar-16	May-17	**Jul-17**	Aug-17
	Gross Alpha	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	Gross Beta	<MDA	<MDA	1.58	<MDA	<MDA	<MDA	<MDA	<MDA	3.028	1.26	<MDA	1.661	2.006	<MDA
Throium 232 - Decay Series	**THORIUM 232**	<MDA	<MDA	4	<MDA	18	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	102	<MDA	<MDA
	RADIUM 228	<MDA	<MDA	4	<MDA	18	11	<MDA	<MDA	<MDA	<MDA	<MDA	102	<MDA	<MDA
	ACTINIUM 228	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	LEAD 212	<MDA	<MDA	4	13	14	6	9	16	19	15	<MDA	9	<MDA	8
	BISMUTH 212	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	Thorium 232	<MDA	0.455	0.692	<MDA	0.709	0.714	0.695	0.476	0.516	0.371	<MDA	0.606	0.596	0.618
	RADIUM 228	<MDA	0.455	0.692	<MDA	0.709	0.714	0.695	0.476	0.516	0.371	<MDA	0.606	0.596	0.618
	Actinium 228	0.384	0.455	0.692	<MDA	0.709	0.714	0.695	0.476	0.516	0.371	0.336	0.606	0.596	0.618
	Lead 212	0.276	0.488	0.666	0.696	0.763	0.671	0.674	0.58	0.462	0.36	0.293	0.626	0.606	0.625
	Bismuth 212	0.545	0.506	0.678	0.737	0.721	0.691	0.706	0.476	0.481	0.431	0.567	0.62	0.648	0.617
Uranium 238 - Decay Series	**URANIUM 238**	<MDA	<MDA	304	<MDA	274	<MDA	***1140***	***204***	<MDA	900	<MDA	134	<MDA	<MDA
	RADIUM 226	<MDA	155	***78***	106	187	67	***739***	260	164	730	<MDA	122	162	218
	LEAD 214	<MDA	<MDA	<MDA	15	<MDA	<MDA	<MDA	<MDA	<MDA	15	<MDA	16	<MDA	<MDA
	BISMUTH 214	<MDA	<MDA	<MDA	22	<MDA	<MDA	<MDA	12	<MDA	<MDA	<MDA	16	10	<MDA
	Uranium 238	<MDA	0.363	0.732	0.642	0.608	0.608	1.32	<MDA	0.655	1.04	<MDA	0.74	0.53	<MDA
	Radium 226	0.803	0.919	1.69	1.08	1.08	1.23	1.43	0.908	0.876	0.958	<MDA	1.1	1.17	1.38
	Lead 214	0.351	0.44	0.563	0.582	0.582	0.574	0.612	<MDA	0.468	0.357	<MDA	0.616	0.581	0.59
	Bismuth 214	0.386	0.386	0.515	<MDA	0.51	0.571	0.56	0.419	0.415	0.335	<MDA	0.532	0.504	0.533
	URANIUM 235	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	48	<MDA	<MDA	47	<MDA	<MDA	<MDA	<MDA
	POTASSIUM 40	48	<MDA	10	99	60	<MDA	<MDA	129	<MDA	<MDA	<MDA	110	<MDA	<MDA
	Uranium 235	<MDA	<MDA	0.072	<MDA	<MDA	0.079	<MDA	<MDA	0.056	0.062	<MDA	<MDA	0.075	0.088
	Potassium 40	9.97	8.88	9.78	<MDA	11.2	10.5	10.5	5.88	9.04	8.41	5.3	10.2	9.95	10.5
	Field Counts	6372	5642	6668	6603	5697	6683	6946	5360	5156	5997	6358	5670	6665	6562
	BACKGROUND Counts	6914.8	6616.7	7758	8103.4	6616.7	7758	8103.4	6294.9	6271.7	8103.4	6914.8	6616.7	7758	8103.4

<MDA; MDA = Minimum Detectable Activity is the minimum sample value that can be detected with 95% confidence

Interference detected during BOL analysis. Values reported here as inferred isotopic activity.

Further investigation required to interpret results (See **DISCUSSION** subsection *Validation*)

Table A2 (continued). Water, reported in pCi/L, and sediment (highlighted yellow), reported in pCi/g, radiological sample results. Field and background sediment counts reported in counts per minute (CPM). Dates bolded represent stormwater samples.

	PARAMETER	2WB				AR				EBMC			EBSC			
		Mar-16	May-17	**Jul-17**	Aug-17	Mar-16	May-17	**Jul-17**	Aug-17	May-17	**Jul-17**	Aug-17	Mar-16	May-17	**Jul-17**	Aug-17
	Gross Alpha	<MDA	<MDA	2.491	2.171	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	1.8184	<MDA	<MDA	<MDA	<MDA
	Gross Beta	<MDA	1.185	4.52	1.472	<MDA	<MDA	3.803	1.712	2.31	3.732	<MDA	<MDA	<MDA	2.44	<MDA
Throium 232 - Decay Series	**THORIUM 232**	<MDA	15	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	22	<MDA	<MDA	<MDA	<MDA	<MDA
	RADIUM 228	<MDA	15	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	22	<MDA	<MDA	<MDA	<MDA	<MDA
	ACTINIUM 228	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	LEAD 212	<MDA	13	5	15	<MDA	13	4	10	5	19	17	<MDA	<MDA	12	<MDA
	BISMUTH 212	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	Thorium 232	<MDA	0.545	0.533	0.622	<MDA	0.506	0.936	0.895	0.655	0.701	0.421	<MDA	0.237	0.3	0.235
	RADIUM 228	<MDA	0.545	0.533	0.622	<MDA	0.506	0.936	0.895	0.655	0.701	0.421	<MDA	0.237	0.3	0.235
	Actinium 228	0.505	0.545	0.533	0.622	0.481	0.506	0.936	0.895	0.655	0.704	0.421	0.28	0.237	0.3	0.235
	Lead 212	0.31	0.526	0.557	0.671	0.469	0.451	1.26	0.881	0.622	0.716	0.514	0.203	0.241	0.332	0.228
	Bismuth 212	0.608	0.508	0.571	0.587	0.716	0.498	0.889	1.03	0.704	0.571	0.426	0.369	0.259	0.281	0.28
Uranium 238 - Decay Series	**URANIUM 238**	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	*112*	<MDA	<MDA	<MDA	<MDA	<MDA	170	<MDA	*231*
	RADIUM 226	100	119	48	*158*	<MDA	173	84	239	100	174	*158*	<MDA	199	190	196
	LEAD 214	5	12	<MDA	21	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	18
	BISMUTH 214	4	12	<MDA	17	<MDA	<MDA	<MDA	19	<MDA	11	<MDA	<MDA	<MDA	<MDA	20
	Uranium 238	1.33	<MDA	0.593	0.908	1.67	<MDA	<MDA	<MDA	1.11	0.771	<MDA	0.524	<MDA	0.372	<MDA
	Radium 226	1.42	0.992	1.01	1.2	<MDA	1.05	1.93	1.65	1.48	1.27	0.772	0.638	0.491	0.567	0.436
	Lead 214	0.405	0.488	0.477	0.618	0.55	0.497	0.947	0.871	0.619	0.684	0.42	0.272	0.241	0.26	0.233
	Bismuth 214	0.516	0.453	0.432	0.556	0.567	0.449	0.817	0.772	0.565	0.595	0.371	0.297	0.213	0.246	0.215
	URANIUM 235	<MDA	<MDA	<MDA	<MDA	2	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	POTASSIUM 40	41	96	<MDA	96	28	<MDA	25	<MDA	<MDA	50	51	23	<MDA	110	<MDA
	Uranium 235	<MDA	0.064	<MDA	<MDA	0.093	0.067	0.123	<MDA	<MDA	0.082	<MDA	<MDA	<MDA	<MDA	<MDA
	Potassium 40	9.71	10.4	<MDA	9.25	8.89	9.04	11.5	9.7	8.36	7.93	7.22	5.33	3.52	4.17	3.65
	Field Counts	5367	6463	7521	6302	6306	5698	7657	6627	5822	5455	6086	--*	4840	5196	5482
	BACKGROUND Counts	6914.8	6616.7	7758	8103.4	6914.8	6616.7	7758	8103.4	6294.9	6271.7	6851.4	7577	6957.9	6367.1	6851.4

<MDA; MDA = Minimum Detectable Activity is the minimum sample value that can be detected with 95% confidence

*Sediment Field Counts not recorded.

Interference detected during BOL analysis. Values reported here as inferred isotopic activity.

Further investigation required to interpret results (See **DISCUSSION** subsection *Validation*)

Table A2 (continued). Water, reported in pCi/L, and sediment (highlighted yellow), reported in pCi/g, radiological sample results. Field and background sediment counts reported in counts per minute (CPM). Dates bolded represent stormwater samples.

PARAMETER		HR			LSC			PC				PNYC			
		May-17	**Jul-17**	Aug-17	May-17	**Jul-17**	Aug-17	Mar-16	May-17	Jul-17	Aug-17	Mar-16	May-17	Jul-17	Aug-17
	Gross Alpha	<MDA	4.408	<MDA	<MDA	2.484	<MDA	<MDA	<MDA	<MDA	6.212	<MDA	<MDA	<MDA	10.517
	Gross Beta	<MDA	4.282	1.489	1.24	4.39	<MDA	<MDA	<MDA	<MDA	6.22	<MDA	1.362	2.342	8.726
Throium 232 - Decay Series	**THORIUM 232**	<MDA	<MDA	<MDA	5	<MDA	<MDA	<MDA	<MDA	16	<MDA	<MDA	<MDA	26	<MDA
	RADIUM 228	<MDA	<MDA	<MDA	5	<MDA	<MDA	<MDA	<MDA	16	<MDA	<MDA	<MDA	26	<MDA
	ACTINIUM 228	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	16	<MDA	<MDA	<MDA	21	<MDA
	LEAD 212	10	5	25	5	14	14	<MDA	<MDA	10	18	<MDA	9	13	<MDA
	BISMUTH 212	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	Thorium 232	0.709	0.699	0.795	0.261	0.296	0.343	<MDA	0.727	0.768	0.798	<MDA	0.441	0.495	0.531
	RADIUM 228	0.709	0.699	0.795	0.261	0.296	0.343	<MDA	0.727	0.768	0.798	<MDA	0.441	0.495	0.531
	Actinium 228	0.709	0.699	0.795	0.261	0.296	0.343	0.646	0.727	0.769	0.798	1.17	0.441	0.495	0.531
	Lead 212	0.769	0.789	0.724	0.243	0.282	0.322	0.391	0.669	0.652	0.753	0.86	0.406	0.445	0.446
	Bismuth 212	0.812	0.837	0.799	0.273	0.331	0.385	0.656	0.748	0.745	0.805	1.08	0.401	0.497	0.521
Uranium 238 - Decay Series	**URANIUM 238**	<MDA	385	269	<MDA	<MDA	*1230*	<MDA	<MDA	<MDA	<MDA	<MDA	307	<MDA	<MDA
	RADIUM 226	114	234	220	44	<MDA	712	<MDA	<MDA	*85*	<MDA	<MDA	92	107	217
	LEAD 214	19	<MDA	16	3	<MDA	<MDA	<MDA	<MDA	9	15	<MDA	<MDA	<MDA	19
	BISMUTH 214	17	<MDA	<MDA	4	<MDA	19	<MDA	<MDA	<MDA	17	<MDA	4	7	<MDA
	Uranium 238	0.824	1.01	0.581	<MDA	0.671	0.783	<MDA	0.66	1.03	0.702	2.43	0.446	0.584	0.645
	Radium 226	1.16	1.43	1.35	0.504	0.832	0.922	1.34	1.32	1.53	1.45	<MDA	0.864	0.964	0.961
	Lead 214	0.634	0.673	0.688	0.231	0.282	0.289	0.488	0.739	0.709	0.806	1.01	0.532	0.478	0.502
	Bismuth 214	0.586	0.587	0.62	0.207	0.269	0.264	0.663	0.649	0.669	0.697	1.32	0.469	0.447	0.464
	URANIUM 235	<MDA	15	<MDA	3	<MDA	46	<MDA	5	<MDA	<MDA	<MDA	6	<MDA	<MDA
	POTASSIUM 40	<MDA	<MDA	165	27	<MDA	<MDA	42	62	73	1430	<MDA	39	128	74
	Uranium 235	<MDA	0.092	<MDA	<MDA	0.054	0.059	<MDA	0.085	0.098	<MDA	0.178	0.056	0.062	<MDA
	Potassium 40	9.98	8.81	9.88	3.71	4.07	4.15	7.22	6.75	6.11	5.95	10.3	3.66	4.42	4.17
	Field Counts	5484	5333	7169	4718	4882	5135	5231	5457	5994	5963	4972	4622	4948	4883
	BACKGROUND Counts	6616.7	7758	8103.4	6957.9	6367.1	6851.4	7656	6758.2	7042.6	7494.6	7656	6758.2	7042.6	7494.6

<MDA; MDA = Minimum Detectable Activity is the minimum sample value that can be detected with 95% confidence

Interference detected during BOL analysis. Values reported here as inferred isotopic activity.

Further investigation required to interpret results (See **DISCUSSION** subsection *Validation*)

Table A2 (continued). Water, reported in pCi/L, and sediment (highlighted yellow), reported in pCi/g, radiological sample results. Field and background sediment counts reported in counts per minute (CPM). Dates bolded represent stormwater samples.

	PARAMETER	PRC				SC				LSC_1		3FC	HORT	PRC_1
		Mar-16	May-17	**Jul-17**	Aug-17	Mar-16	May-17	Jul-17	Aug-17	**Jul-17**	Aug-17	May-17	Jul-17	**Jul-17**
	Gross Alpha	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA*	<MDA	1.643	<MDA	<MDA	<MDA	<MDA
	Gross Beta	<MDA	1.145	4.977	<MDA	<MDA	1.62	1.433	<MDA	3.169	<MDA	<MDA	1.681	3.642
Throium 232 - Decay Series	**THORIUM 232**	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	13
	RADIUM 228	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	13
	ACTINIUM 228	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	LEAD 212	<MDA	<MDA	9	12	<MDA	<MDA	18	11	18	13	15	15	12
	BISMUTH 212	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	Thorium 232	<MDA	0.292	<MDA	0.255	<MDA	0.587	0.634	0.435	0.272	0.375	0.571	0.722	0.288
	RADIUM 228	0.037	0.292	<MDA	0.255	<MDA	0.587	0.634	0.435	0.272	0.375	0.571	0.722	0.288
	Actinium 228	<MDA	0.292	<MDA	0.255	0.423	0.587	0.634	0.435	0.272	0.375	0.571	0.722	0.288
	Lead 212	0.191	0.28	0.445	0.268	0.353	0.522	0.602	0.553	0.3	0.328	0.562	0.876	0.281
	Bismuth 212	0.368	0.261	0.493	0.23	0.466	0.604	0.582	0.454	0.364	0.396	0.613	0.701	0.311
Uranium 238 - Decay Series	**URANIUM 238**	<MDA	237	***307***	<MDA	<MDA	***91***	214	<MDA	***167***	<MDA	<MDA	232	136
	RADIUM 226	<MDA	101	<MDA	141	<MDA	59	130	192	136	204	166	***153***	102
	LEAD 214	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	14
	BISMUTH 214	<MDA	<MDA	<MDA	20	<MDA	<MDA	<MDA	10	15	11	<MDA	<MDA	12
	Uranium 238	0.809	0.454	0.615	0.387	<MDA	1.04	0.675	<MDA	<MDA	<MDA	0.605	<MDA	0.807
	Radium 226	0.714	0.534	0.806	0.453	0.348	1.02	1.08	0.877	0.533	0.7	0.924	1.38	0.47
	Lead 214	0.263	0.28	0.372	0.256	0.374	0.526	0.567	0.418	0.24	0.332	0.541	0.617	0.223
	Bismuth 214	0.301	0.258	0.327	0.219	0.465	0.47	0.474	0.376	0.206	0.305	0.474	0.558	0.212
	URANIUM 235	<MDA	6	<MDA	<MDA	<MDA	4	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA
	POTASSIUM 40	25	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	<MDA	43	<MDA	<MDA	100
	Uranium 235	<MDA	0.035	<MDA	<MDA	0.042	0.066	0.07	<MDA	0.034	0.045	<MDA	<MDA	<MDA
	Potassium 40	4.91	3.83	5.9	3.47	6.96	7.55	7.54	5.93	4.12	5.26	9.52	12	4.25
	Field Counts	5483	5473	4883	5075	7241	4871	4903	5276	5803	5288	5252	7298	5193
	BACKGROUND Counts	7577	6957.9	6367.1	6851.4	7577	6294.9	6683.2	6851.4	6367.1	6851.4	6616.7	9890.4	6367.1

<MDA; MDA = Minimum Detectable Activity is the minimum sample value that can be detected with 95% confidence

Interference detected during BOL analysis. Values reported here as inferred isotopic activity.

Further investigation required to interpret results (See **DISCUSSION** subsection *Validation*)

*Failed Recovery