Appendix B. Background Information

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B. Background Information

The following information is provided to assist the reader in understanding this report. Included in this Appendix is information on scientific notation; units of measure, radioactivity, and radiological dose; chemical and elemental nomenclature; understanding data tables and data uncertainty; understanding graphs; and an explanation of select mathematical symbols. Definitions of technical terms can be found in Appendix A.

B.1 Public Reading Rooms

University of Washington Government Publications Division Suzzallo & Allen Libraries P.O. Box 352900 Seattle, WA 98195-2900 (206) 543-4164 http://www.lib.washington.edu/gmm/collections/govpubs	Portland State University Government Information Branford Price Millar Library 1875 SW Park Ave Portland, OR 97207-1151 (503) 725-4542 https://library.pdx.edu/research/government-information-maps/
Washington State University, Tri-Cities US DOE Public Reading Room Consolidated Information Center, Rm 101-L 2770 University Drive Richland, WA 99352 (509) 372-7443 http://reading-room.labworks.org	Gonzaga University, Foley Center East 502 Boone Spokane, WA 99258-0001 (509) 313-3847 https://www.gonzaga.edu/academics/libraries/foley-library
Hanford Health Info Archive (through Washington State Archives): https://www.sos.wa.gov/archives/	

B.2 Scientific Notation

Scientific notation is used to express very large or very small numbers. For example, the number 1 billion could be written as 1,000,000,000 or, under using scientific (E notation), 1×10^9 or 1.0E+09. Translating from scientific notation to a more traditional number requires moving the decimal point either left or right from its current location. If a value given is 2.0×10^3 (or 2.0E+03), the decimal point should be moved three places to the **right** so that the number would then read 2,000. If the value given is 2.0×10^5 (or 2.0E-05), the decimal point should be moved five places to the **left** so that the result would be 0.00002.

B.3 Units of Measure

The primary units of measure used in this report follow the International System of Units and are metric. Table B-1 summarizes and defines the terms and corresponding symbols (metric and non-metric). A conversion table is provided in Table B-2.

Table B-1. Units of Measure.

Symbol	Name
Temperature	
°C	degree Celsius
°F	degree Fahrenheit
Time	
d	day
hr	hour
min	minute
sec	second
yr	year
Rate	
cfs (or ft^3/sec)	cubic feet per second
cpm	counts per minute
gpm	gallon per minute
mph	mile per hour
mR/hr	milliroentgen per hour
mrem/yr	millirem per year
Volume	
cm^3	cubic centimeter
ft^3	cubic foot
gal	gallon
L	liter
m^3	cubic meter
mL	milliliter (1×10^{-3} L)
yd^3	cubic yard

Symbol	Name
Concentration	
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
Length	
cm	centimeter (1×10^{-2} m)
ft	foot
in.	inch
km	kilometer (1×10^{3} m)
m	meter
mi	mile
mm	millimeter (1×10^{-3} m)
µm	micrometer (1×10^{-6} m)
Area	
ha	hectare (1×10^{4} m^2)
km^2	square kilometer
mi^2	square mile
ft^2	square foot
Mass	
g	gram
kg	kilogram (1×10^{3} g)
mg	milligram (1×10^{-3} g)
µg	microgram (1×10^{-6} g)
lb	pound

Table B-2. Conversion Table.

Multiply	By	To Obtain
cm	0.394	in.
m	3.28	ft
km	0.621	mi
kg	2.205	lb
L	0.2642	gal
m^2	10.76	ft^2
ha	2.47	acre
km^2	0.386	mi^2
m^3	35.31	ft^3
m^3	1.308	yd^3
pCi	1,000	nCi
µCi/mL	109	pCi/L
Ci/m^3	1012	pCi/m^3
mCi/cm^3	1015	pCi/m^3
nCi/m^2	1.0	mCi/km^2
Ci	3.7×10^{10}	Bq
pCi	0.037	Bq
rad	0.01	Gy

Multiply	By	To Obtain
in.	2.54	cm
ft	0.305	m
mi	1.61	km
lb	0.454	kg
gal	3.785	L
ft^2	0.093	m^2
acre	0.405	ha
mi^2	2.59	km^2
ft^3	0.0283	m^3
yd^3	0.7646	m^3
nCi	0.001	pCi
pCi/L	10-9	µCi/mL
pCi/m^3	10-12	Ci/m^3
pCi/m^3	10-15	mCi/cm^3
mCi/km^2	1.0	nCi/m^2
Bq	2.7×10^{-11}	Ci
Bq	27	pCi
Gy	100	rad

Multiply	By	To Obtain
rem	0.01	Sv
ppm	1,000	ppb
°C	(°C × 9/5) + 32	°F
oz	28.349	g
ton	0.9078	tonne

Multiply	By	To Obtain
Sv	100	rem
ppb	0.001	ppm
°F	(°F -32) ÷ 9/5	°C
g	0.035	oz
tonne	1.1	ton

B.4 Radioactivity Units

Much of this report provides data on levels of radioactivity in various environmental media. Radioactivity in this report is usually discussed in units of **curies** (**Ci**), with conversions to **becquerels** (**Bq**), the International System of Units measure (Table B-3). The curie is the basic unit used to describe the amount of activity present, and activities are generally expressed in terms of curies per mass or volume (e.g., pCi/L). One curie is equivalent to 37 billion disintegrations per second or is a quantity of any radionuclide that decays at the rate of 37 billion disintegrations per second. One becquerel is equivalent to one disintegration per second. Nuclear disintegrations produce spontaneous emissions of alpha or beta particles, gamma radiation, or combinations of these. Table B-4 includes selected conversions from curies to bequerels.

Table B.3. Radioactivity Unit Conversions.

aCi 27	fCi 1	fCi 27	pCi 1	pCi 27	nCi 1	nCi 27	µCi 1	µCi 27	mCi 1	mCi 27	Ci 1	Ci 27	kCi 1
1 µBq	37 µBq	1 mBq	37 mBq	1 Bq	37 Bq	1 kBq	37 kBq	1 MBq	37 MBq	1 GBq	37 GBq	1 TBq	37 TBq

New unit of quantity = Becquerel (Bq) (formerly curie [Ci]) (1 Ci = 3.7×10^{10} dps).
1 Becquerel = 1 disintegratios/sec (dps).

Table B-4. Radioactivity Units.

Symbol	Name		Symbol	Name
Ci	curie		Bq	becquerel (2.7×10^{-11} Ci)
mCi	millicurie (1×10^{-3} Ci)		mBq	millibecquerel (1×10^{-3} Bq)
µCi	microcurie (1×10^{-6} Ci)		kBq	kilobecquerel (1×10^{3} Bq)
nCi	nanocurie (1×10^{-9} Ci)		MBq	megabecquerel (1×10^{6} Bq)
pCi	picocurie (1×10^{-12} Ci)		GBq	gigabecquerel (1×10^{9} Bq)
fCi	femtocurie (1×10^{-15} Ci)		TBq	terabecquerel (1×10^{12} Bq)
aCi	attocurie (1×10^{-18} Ci)			

B.5 Radiological Dose Limits

Regulatory dose limits, both public and occupational regulatory dose limits, are set by federal (i.e., U.S. Environmental Protection Agency [EPA], U.S. Nuclear Regulatory Commission [NRC], and

U.S. Department of Energy [DOE]) and state agencies to limit cancer risk (Table B-5). Other radiation dose limits are applied to limit other potential biological effects with workers' skin and lens of the eye.

Table B-5. Radioactivity Dose Limits.

Annual Radiation Dose Limits	Agency
Radiation Worker - 5,000 mrem	NRC, occupationally exposed
General Public - 100 mrem	NRC, member of the public
General Public - 25 mrem	NRC, D&D all pathways
General Public - 10 mrem	EPA, air pathway
General Public - 4 mrem	EPA, drinking water pathway
D& D = decontamination and decommissioning.	

B.6 Radiological Dose Limits for Non-human Biota

Regulatory dose limits for non-human biota are set by DOE (Table B-6).

Table B-6. Radioactivity Dose Limits for Non-human Biota.

Daily Radiation Dose Limits	Agency
Aquatic Animal - 1 rad	DOE
Riparian Animal – 0.1 rad	DOE
Terrestrial Plant - 1 rad	DOE
Terrestrial Animal – 0.1 rad.	DOE

B.7 Radiological Dose Units

Radiological dose in this report is usually written in terms of total effective dose (equivalent) and reported numerically in units of millirem (mrem), with the metric units millisievert (mSv) or microsievert (µSv) following in parenthesis or footnoted.

Millirem (millisievert) is a term that relates a given amount of absorbed radiation energy to its biological effectiveness or risk to humans. For perspective, a dose of 1 mrem (10 µSv) would have a biological effect roughly the same as received from 1 day's exposure to natural background radiation. An acute (short-term) dose to the whole body of 100 rem (1 mSv) would likely cause temporary radiation sickness in some exposed individuals. An acute dose of over 500 rem (5 mSv) would soon result in death in approximately 50% of those exposed. Exposure to lower amounts of radiation (10 mrem [100 µSv] or less) produces no immediate observable effects, but long-term delayed effects are possible. The average person in the United States receives an annual dose from exposure to naturally produced radiation of approximately 310 mrem (3.1 mSv; National Council on Radiation Protection and Measurements 2009).

Medical and dental X-rays and air travel add to this total. Table B-6 includes selected conversions from rem to sievert.

Table B-7. Radiological Dose Units Conversions.

µSv 0.01	µSv 0.1	µSv 1	µSv 10	µSv 100	mSv 1	mSv 10	mSv 100	Sv 1
1 µrem	10 µrem	100 µrem	1 mrem	10 mrem	100 mrem	1 rem	10 rem	100 rem
Unit of absorbed dose – Gray (Gy; formerly rad); unit of dose equivalent – sievert (Sv; formerly rem). Table also converts Gy to rad.								

Also used in this report is the term **rad**, with the corresponding unit **gray** (**Gy**) in parenthesis or footnoted. The rad (gray) is a measure of the energy absorbed by any material, whereas a rem relates to both the amount of radiation energy absorbed by humans and its consequence. The gray can be converted to rad by multiplying by 100. The conversions in Table B-6 also can be used to convert grays to rads. Dose to non-human biota is calculated in rads and compared to the limits in Table B-6.

The **roentgen (R)** is a measure of exposure to electromagnetic radiation (i.e., gamma and x-radiation). One roentgen is equivalent to a charge release of 258 microcoulombs per kilogram of air. The names and symbols for units of radiation dose used in this report are listed in Table B-7.

Table B-8. Radiation Dose or Exposure Units.

Symbol	Name
rad	rad (10 milligray [mGy])
mrad	millirad (1×10^{-3} rad)
mrem	millirem (1×10^{-3} rem)
µrem	microrem (1×10^{-6} rem)
Sv	sievert (100 rem)
mSv	millisievert (1×10^{-3} Sv)
µSv	microsievert (1×10^{-6} Sv)
nSv	nanosievert (1×10^{-9} Sv)
R	roentgen
mR	milliroentgen (1×10^{-3} R)
µR	microroentgen (1×10^{-6} R)
Gy	gray (100 rad)
mGy	milligray (1×10^{-3} rad)

Additional information on radiation and dose terminology can be found in Appendix A. A list of the radionuclides discussed in this report, their symbols, and their half-lives are included in Table B-8.

Table B-9. Radionuclides and Half-Lives.

Symbol	Radionuclide	Half-Life	Symbol	Radionuclide	Half-Life	Symbol	Radionuclide	Half-Life
^{3}H	tritium	12.35 yr	^{103}Ru	ruthenium-103	39.28 d	U	natural uranium	~4.5 × 10^{9} [(a)]
^{7}Be	beryllium-7	53.3 d	^{106}Ru	ruthenium-106	368.2 d	^{233}U	uranium-233	1.585 × 10^{5} yr
^{14}C	carbon-14	5,730 yr	^{113}Sn	tin-113	115.1 d	^{234}U	uranium-234	2.445 × 10^{5} yr
^{40}K	potassium-40	1.28 × 10^{9} yr	^{125}Sb	antimony-125	2.77 yr	^{235}U	uranium-235	7.038 × 10^{8} yr
^{51}Cr	chromium-51	27.704 d	^{129}I	iodine-129	1.57 × 10^{7} yr	^{237}Np	neptunium-237	2.14 × 10^{6} yr
^{54}Mn	manganese-54	312.5 d	^{131}I	iodine-131	8.04 d	^{238}U	uranium-238	4.468 × 10^{9} yr
^{55}Fe	iron-55	2.7 yr	^{134}Cs	cesium-134	2.062 yr	^{238}Pu	plutonium-238	87.74 yr
^{59}Fe	iron-59	44.529 d	^{137}Cs	cesium-137	30.0 yr	^{239}Pu	plutonium-239	2.4065 × 10^{4} yr
^{59}Ni	nickel-59	7.5 × 10^{4} yr	^{137}mBa	barium-137m	2.552 min	^{240}Pu	plutonium-240	6.537 × 10^{3} yr
^{60}Co	cobalt-60	5.271 yr	^{152}Eu	europium-152	13.33 yr	^{241}Pu	plutonium-241	14.4 yr
^{63}Ni	nickel-63	96 yr	^{154}Eu	europium-154	8.8 yr	^{242}Pu	plutonium-242	3.763 × 10^{5} yr
^{65}Zn	zinc-65	243.9 d	^{155}Eu	europium-155	4.96 yr	^{241}Am	americium-241	432.2 yr
^{85}Kr	krypton-85	10.72 yr	^{212}Pb	lead-212	10.64 hr	^{243}Am	americium-243	7,380 yr
^{90}Sr	strontium-90	29.12 yr	^{220}Rn	radon-220	55.6 sec	^{243}Cm	curium-243	28.5 yr
^{90}Y	yttrium-90	64.0 hr	^{222}Rn	radon-222	3.8235 d	^{244}Cm	curium-244	18.11 yr
^{95}Zr	zirconium-95	63.98 d	^{232}Th	thorium-232	1.405 × 10^{10} yr	^{245}Cm	curium-245	8,500 yr
^{99}Tc	technetium-99	2.13 × 10^{5} yr						

NOTE: Natural uranium is a mixture dominated by uranium-238; thus, the half-life is approximately 4.5 × 10^{9} years.

B.8 Chemical and Elemental Nomenclature

Many of the chemical contaminants discussed in this report are listed in Table B-9, along with their chemical (or elemental) names and their corresponding symbols.

Table B-10. Elemental and Chemical Constituent Nomenclature.

Symbol	Constituent	Symbol	Constituent
Ag	silver	K	potassium
Al	aluminum	LiF	lithium fluoride
As	arsenic	Mg	magnesium
B	boron	Mn	manganese
Ba	barium	Mo	molybdenum
Be	beryllium	NH_3	ammonia
Br	bromine	NH_4^+	ammonium
C	carbon	N	nitrogen
Ca	calcium	Na	sodium
CaF_2	calcium fluoride	Ni	nickel
CCl_4	carbon tetrachloride	NO_2^-	nitrite
Cd	cadmium	NO_3^-	nitrate
$CHCl_3$	trichloromethane	Pb	lead
Cl^-	chloride	PO_4^{-3}	phosphate
CN^-	cyanide	P	phosphorus
Cr^{+6}	chromium (hexavalent)	Sb	antimony
Cr	chromium (total)	Se	selenium
CO_3^{-2}	carbonate	Si	silicon
Co	cobalt	Sr	strontium
Cu	copper	SO_4^{-2}	sulfate
F^-	fluoride	Ti	titanium
Fe	iron	Tl	thallium
HCO_3^-	bicarbonate	V	vanadium
Hg	mercury		

B.9 Understanding the Data Tables

Some degree of variability or uncertainty is associated with all analytical measurements. This uncertainty is the consequence of random or systematic inaccuracies related to collecting, preparing, and analyzing the samples. These inaccuracies could include errors associated with reading or recording the result, handling or processing the sample, calibrating the counting instrument, and numerical rounding. With radionuclides, inaccuracies also can result from the randomness of radioactive decay. In this report, the uncertainties used include standard deviation, total propagated analytical uncertainty, and standard error of the mean.

B.10 Standard Deviation

The standard deviation (SD) of sample data relates to the variation around the mean of a set of individual sample results. If analytical results follow a bell-shaped curve (or a normal statistical distribution), then 95% of the time an independent sample would fall within the mean plus or minus two times the standard deviation (or mean±2 SD).

B.11 Total Propagated Analytical Uncertainty

For samples that are prepared or manipulated in the laboratory prior to counting (counting the rate of radioactive emissions from a sample), the total propagated analytical uncertainty includes both the counting uncertainty and the uncertainty associated with sample preparation and chemical separations. For samples that are not manipulated (e.g., ashed, dried, or chemically treated) in the laboratory before counting, the total propagated analytical uncertainty only accounts for the uncertainty associated with counting the sample. The uncertainty associated with samples that are analyzed but not counted (e.g., chemical or water quality measurements) includes only the analytical process uncertainty. In this situation, the total propagated analytical uncertainty may be assumed the nominal detection limit.

B.12 Standard Error of the Mean

Just as individual values are accompanied by uncertainty, the mean is accompanied by an associated standard error (SE). The standard error is calculated from the SD and the number of samples. As the number of samples increases the SE decreases, therefore uncertainty in the mean is reduced. The mean plus or minus two times the standard error of the mean would include approximately 95% of the means estimated from that same population.

B.13 Median, Maximum, and Minimum Values

Median, maximum, and minimum values are reported in some sections of this report. A median value is the middle value of an odd numbered set and the average of the two central values in an even numbered set. For example, the median value in the following series of numbers — 1, 2, 3, 3, 4, 5, 5, 5, 6 is 4. The maximum value would be 6 and the minimum value would be 1. Figure B-1 provides a graphical representation of median, maximum, and minimum values. The upper line is the maximum value, the center dot is the median value, and the lower line is the minimum value.

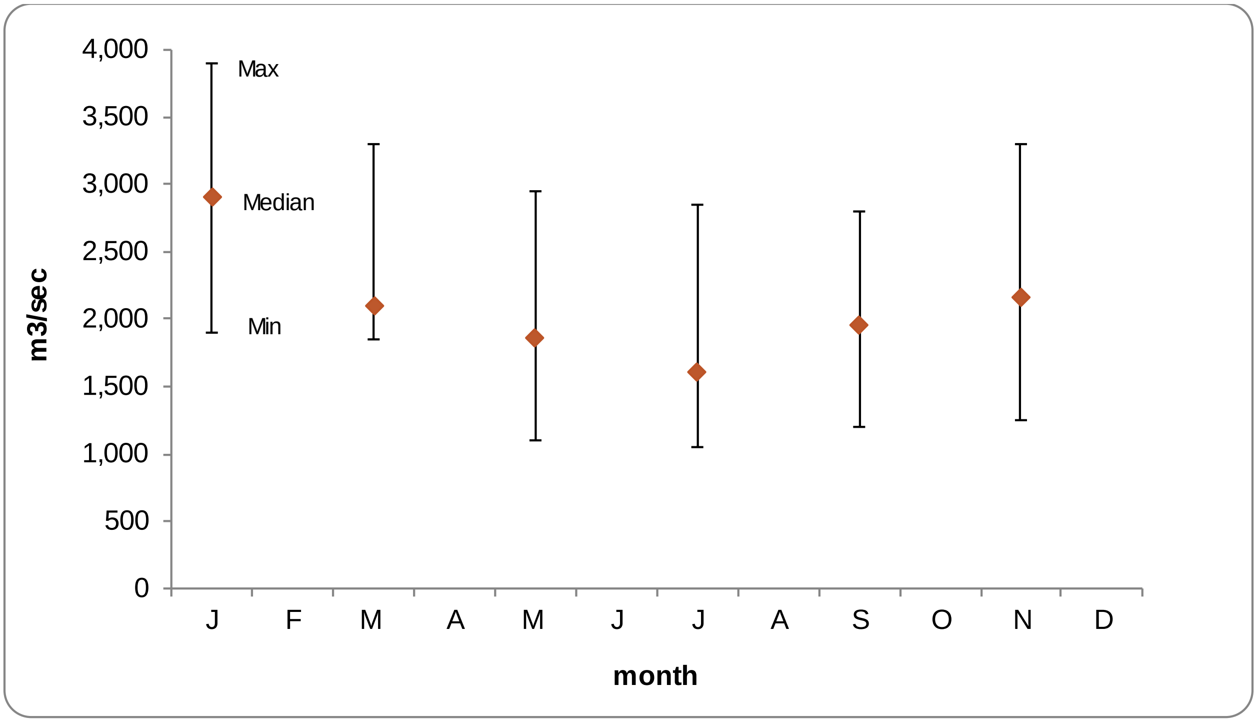

Figure B-1. Maximum, Median, and Minimum Values Graphical Representation.

B.14 Negative Concentrations

Instruments used in the laboratory to measure radioactivity in Hanford Site environmental samples are sensitive enough to measure natural, or background, radiation along with any contaminant radiation in a sample. To obtain a true measure of the contaminant level in a sample, the background radiation level must be subtracted from the total amount of radioactivity measured by an instrument during sample analysis. Backgrounds are determined with empty detectors and represent and average background decay rate. Because of the randomness of radioactive emissions (including backgrounds), the very low activities of some contaminants, , it is possible that the average background value used is larger than the actual contaminant measurement result. When the larger background measurement is subtracted from the smaller contaminant measurement, a negative result is generated. The negative results are reported because they are essential when conducting statistical evaluations of the data.

B.15 Greater Than (>) or Less Than (<) Symbols

Greater than (>) or less than (<) symbols are used to indicate that the actual value may either be larger than the number given or smaller than the number given. For example, >0.09 would indicate that the actual value is greater than 0.09. A symbol pointed in the opposite direction (<0.09) would indicate that the number is less than the value presented. A symbol used with an underscore (≤ or ≥) indicates that the actual value is less than or equal to or greater than or equal to the number given, respectively.

B.16 Understanding Graphs

Graphs are useful when comparing numbers collected at several locations or at one location over time. Graphs often make it easy to visualize differences in data where they exist. However, careful consideration should be given to the scale (linear or logarithmic) and units.

Some of the data graphed in this report may be plotted using logarithmic or compressed scales. Logarithmic scales are useful when plotting two or more numbers that differ greatly in size or are very close together. For example, a sample with a concentration of 5 g/L would get lost at the bottom of the graph if plotted on a linear scale with a sample having a concentration of 1,000 g/L (Figure B-2). A logarithmic plot of these same two numbers allows the reader to see both data points clearly (Figure B-3). Each scale has its benefits in presenting information. Note that the linear scale often has a natural minimum value of zero for the y-axis. Zero and negative values cannot be plotted on logarithmic scale plots and the analyst much select an appropriate minimum value for the y-axis.

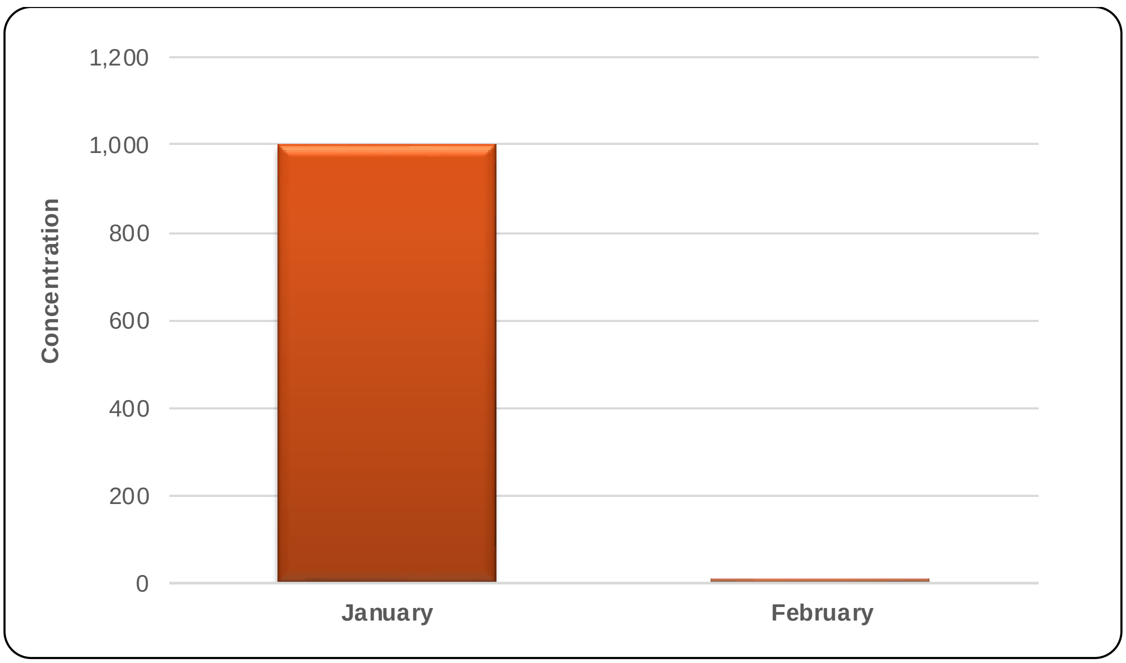

Figure B-2. Data Plotted Using a Linear Scale.

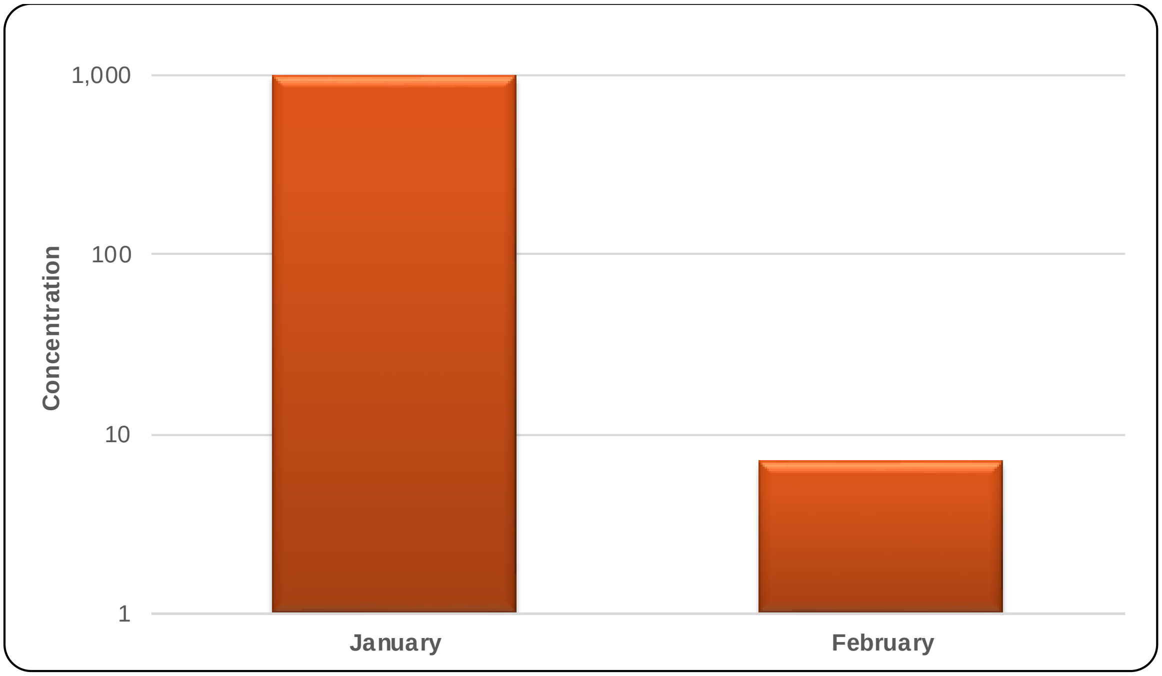

Figure B-3. Data Plotted Using a Logarithmic Scale.

The mean (average) and median (defined earlier) values seen in graphics in this report have vertical lines extending above and below the data point. When used with a value, these lines (called error bars) indicate the amount of uncertainty (standard deviation, total propagated analytical uncertainty, or standard error of the mean) in the reported value. The error bars in this report represent a 95% chance that the value is between the upper and lower ends of the error bar and a 5% chance that the true value is either lower or higher than the error bar.[1] For example, in Figure B-4, the first plotted value is 2.0 ± 1.1, so there is a 95% chance that the true value is between 0.9 and 3.1, a 2.5% chance that it is less than 0.9, and a 2.5% chance that it is greater than 3.1. Error bars are computed statistically, employing all of the information used to generate the value. These bars provide a quick, visual indication that one value may be statistically similar to or different from another value. If the error bars of two or more values overlap, as is the case with values 1 and 3 and values 2 and 3, the values may be statistically similar. If the error bars do not overlap (values 1 and 2), the values may be statistically different. Values that appear to be very different visually (e.g., 2 and 3) may actually be quite similar when compared statistically.

1 Assuming the data are normally distributed.

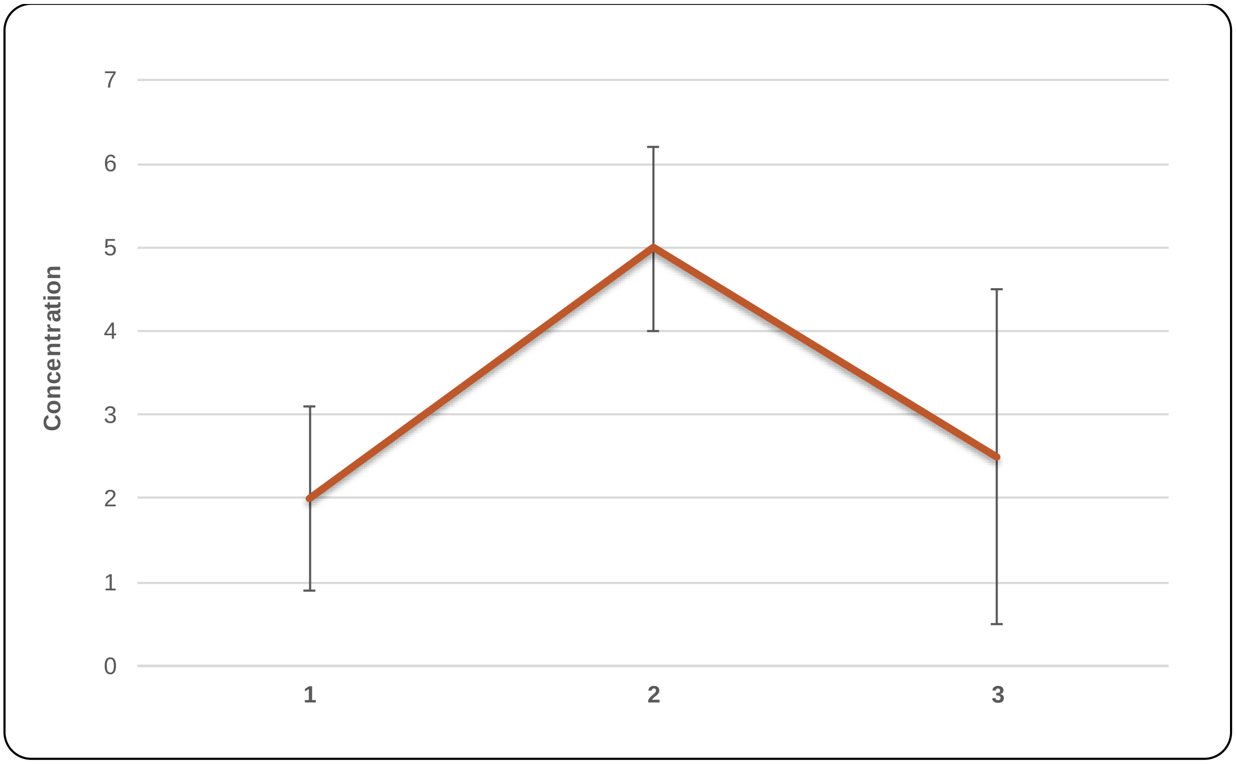

Figure B-4. Data with Error Bars Plotted Using a Linear Scale.