APPENDIX G

SUMMARY OF UPLAND SOIL CHARACTERISTICS IN THE STUDY AREA

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ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
AOI	area of interest
B.C.	British Columbia
BERA	Baseline ecological risk assessment
bgs	below ground surface
BSB	Black Sand Beach
COPC	chemical of potential concern
CSR	Contaminated Sites Regulations
DEM	Digital Elevation Model
DOI	U.S. Department of Interior
Ecology	Washington State Department of Ecology
Eco-SSL	ecological soil screening level
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
FEMA	Federal Emergency Management Agency
GIS	geographic information system
ICP-MS	inductively coupled plasma–mass spectrometry
IDW	inverse distance weighting
IJC	International Joint Commission
K_d	soil-water partition coefficient
K_{OC}	organic carbon/water partition coefficient
Le Roi smelter	Le Roi/Northport Smelter
NAVD-88	North American Vertical Datum 1988
NCDC	National Climatic Data Center
NGVD-29	National Geodetic Vertical Datum 1929
NPRI	National Pollutant Release Inventory (database)
NURE-HSSR	National Uranium Resource Evaluation-Hydrogeochemical and Stream Sediment Reconnaissance

RI/FS	remedial investigation and feasibility study
RM	river mile
RMS	root-mean-square
SALM	Strong Acid Leachable Metals
Site	Upper Columbia River site
SO_2	sulfur dioxide
TCAI	Teck Cominco American Incorporated
TCM	Teck Cominco Metals, Inc.
Teck Trail Operations	Teck Metals Ltd.
U.S.	United States
UCR	Upper Columbia River
USBR	U.S. Bureau of Reclamation
USCGS	U.S. Coastal and Geodetic Survey
USGS	U.S. Geological Survey
WDFW	Washington State Department of Fish and Wildlife

UNITS OF MEASURE

cfs	cubic feet per second
cm	centimeters
ft	feet
km	kilometers
m	meters
m^3/s	cubic meters per second
mg/kg	milligrams per kilogram
mm	millimeters
L/kg	liter per kilogram
L^3/T	flow (volume divided by time)
L/T	velocity (length divided by time)
L^2	area (length squared)

1 INTRODUCTION

The following appendix is intended to help identify and delineate soils contamination associated with the Upper Columbia River (UCR) Remedial Investigation/Feasibility Study (RI/FS). In general, and as identified within the site conceptual model, soil contamination may result from three distinct processes. The first is from atmospheric point source emissions (e.g., smelter stacks), the second from hydrologic transport and deposition (i.e., floodplains), and finally the third from exposed euphotic sediments subject to wind erosion. Each of the above-listed processes are individually evaluated, a detailed description of analyses completed, and associated results are presented within the following sections.

The studies evaluated in this appendix are historical and were not necessarily conducted for the UCR RI/FS and baseline ecological risk assessment (BERA) and may not meet the current standards of practice and/or the data quality requirements necessary for completion of the BERA. However, for purposes of this BERA Work Plan, the data and analyses are assumed to be adequate to assist in identifying data gaps and describing general site characteristics, but may not be acceptable for use in future deliverables in their current form.

As the BERA progresses, the quality of the existing data, data analysis procedures, and suitability for inclusion in the BERA will be assessed according to procedures that will be reviewed and approved by the U.S. Environmental Protection Agency (EPA). In addition, clear explanations of the data used in evaluations, evaluation methodology, and statistical analysis documentation will be provided in future documents

2 SMELTER STACK EMISSIONS

The extent of the smelter aerial deposition from stacks was evaluated through an analysis of existing soil data and was designed to help address the following: 1) Is there evidence that smelter stack aerial emissions have resulted in elevated concentrations of metals in soils, and 2) what is the spatial extent within the United States (U.S.) of any such effects? Results of this analysis are presented and discussed below.

2.1 HISTORY OF SMELTER EMISSIONS

Two large smelters have operated in the vicinity of the Site; the Trail smelter owned and operated by Teck Metals Ltd. (Teck Trail Operations) located in Trail, British Columbia (B.C.), and the former Le Roi/Northport Smelter located in Northport, Washington. Information on historical operations and aerial emissions for each of these facilities is summarized in the following sections.

2.1.1 Teck Trail Operations

The Teck Trail facility is located approximately 10 river miles north of the U.S.-Canada border in Trail, B.C. Currently, the facility is one of the largest integrated zinc-lead smelting complexes in the world, producing approximately 3 percent of the global demand for refined zinc (USEPA 2008).

Ore smelting operations began at Trail in 1896 with the establishment of a copper-gold smelter (USEPA 2008). Within 10 years, operations evolved to include the use of blast furnaces and ore roasters, and by 1916, the facility was one of only two zinc refineries in the world and Canada's first copper refinery. By 1925, the facility consisted of a complex of structures housing a lead plant, an electrolytic zinc plant, a copper smelter, a copper refinery, a silver and gold refinery, sulfuric acid plant, a foundry, a machine shop, and a copper-rod mill. Copper smelting ceased in 1931. Since 1951, expansion of on-site zinc and lead operations has made the facility one of the largest lead-zinc smelters in the world. In addition to lead and zinc, the facility generates a wide range of products that serve as building blocks for other industries. These include, but are not necessarily limited to, cadmium, indium, germanium, gold, silver, bismuth, copper, sulfur, sulfuric acid, sulfur dioxide (SO_2), and granular and crystallized ammonium sulfate (i.e., fertilizer).

Atmospheric sulfur emissions were historically a significant component of facility emissions in the early years (USEPA 2008). In response to these emissions, SO_2 control measures were established at the facility in 1928. These control measures included the installation of control measures (e.g., Cottrell filters) at point sources such as stacks and the installation and continuous monitoring of a weather station (USEPA 2008). Subsequent development and modernization at the Trail facility led to further reductions in emissions (USEPA 2008).

Arsenic, cadmium, copper, lead, and zinc are characteristic of current and past aerial emissions of metals and may serve as tracers of hazardous chemicals in aerial emissions from the Trail facility. Although SO_2 is more toxic to plants than are metals, effects attenuate quickly after emissions are controlled. Because of the attenuation of effects from SO_2 due to natural processes and large decreases in SO_2 emissions since the first decades of the 20th century, and because metals in aerial emissions are expected to represent the greatest potential risk to ecological receptors and human health, the historical data regarding plant injury from SO_2 are not expected to be indicative of the locations of present day residual risks from emissions. The heavier metal particulates generally deposit in a smaller area than gaseous pollutants such as SO_2 (Zanini and Bonifacio 1991), particularly in mountainous terrain that characterizes the Trail vicinity and much of the Site. Metal particulate distribution patterns from past emissions likely would be similar today, if the height of the smelter stack and velocity of emissions are similar. The shorter stacks from the early part of the 20th century would have generated a different pattern, likely depositing particulates closer to the smelter. A summary of the loading of the indicator metals from the Trail facility air emissions over the 1994 to 2005 period, as reported to the Canadian National Pollutant Release Inventory (NPRI) database, is provided in Table 1.

2.1.2 Le Roi Smelter

The Le Roi/Northport Smelter (Le Roi smelter) was formerly located approximately 7 river miles downstream of the U.S.-Canada border in Northport, Washington (USEPA 2008). Copper, lead, and silver ore smelting operations occurred intermittently from 1896 to 1922, with peak processing reaching approximately 500 tons of ore per day by 1908, when it was one of the largest smelters on the West Coast (USEPA 2003). Economic pressure led to the closure of the smelter in 1922. During its operation, emissions from the smelter containing elevated concentrations of metals and SO_2 were released into the surrounding area (USEPA 2003).

The initial smelter operations were crude, and involved releases of "large quantities" of pollutants (E&E 2002). Tellurium ore was processed by heap roasting, which vaporized the tellurium and released SO_2 into the air (E&E 2002). Lead smelting conducted at the site starting in 1914 resulted in the release of approximately 30 tons of sulfur per day. Stack filters were added sometime later (E&E 2002).

Information on aerial emissions from the Le Roi smelter is limited. A soil removal action was conducted on the property and the town of Northport by the U.S. Environmental Protection Agency (EPA) in 2004 (Weston 2005). The remedial action consisted of the removal of 10,500 tons of contaminated soil from surrounding residential properties and the excavation of 10,280 tons of contaminated soil from the smelter property (Weston 2005). As of July 5, 2007, a "no further action" decision had not been granted by the Washington State Department of Ecology (Ecology), and this site remains on Ecology's Confirmed and Suspected Contaminated Sites List (Ecology 2007a, b).

2.2 AERIAL TRANSPORT

Wind speeds and directions near the Trail smelter were evaluated to support the analysis and interpretation of soil data with respect to likely particulate deposition from smelter emissions. Because of the location of the Trail facility and the surrounding topographic conditions, local meteorological conditions are likely to have played a significant role in determining the direction, elevation, and the horizontal and vertical dispersion of the emission plume from the Trail facility, subsequently affecting the distribution and magnitude of the dry and wet depositions of chemicals presented in the dispersion plume. The available data on wind speed and direction were used to assist in the application of soil data interpolation methods.

After reviewing the topographic condition, the proximity to the Trail facility, and the availability of hourly meteorological records in six nearby meteorological stations, the Warfield station was determined to be the most representative of meteorological conditions at and around the Trail facility. The Warfield meteorological station is located approximately 1.6 miles west of the Trail facility. The longitude of the station is 117° 44′ W and the latitude is 49° 6′ N. The elevation of the station is 566.90 m. Because there is a small hill located between the Warfield station and Trail, small differences may exist between the micrometeorological conditions at Warfield and at Trail.

Hourly meteorological data parameters (e.g., temperature, wind speed, wind direction, pressure, visibility) collected from Warfield station for 2002 to 2004 were downloaded from the Environment Canada meteorological network,[1] and the data files in monthly format were evaluated for completeness and then compiled into yearly format.

Hourly wind data were analyzed and categorized by direction, using eight divisions (Table 2). The most frequently measured wind direction at Trail was from north–northwest to south–southeast (315 to 360 degrees). The wind direction with the next highest frequency was from east–northeast to west–southwest (135 to 180 degrees). During the period 2002 to 2004, 27 and 19 percent of the monitored hourly wind data fell into these two ranges, respectively.

The wind distribution patterns represented by the Warfield meteorological station are for surface winds observed near the Trail facility. The surface winds are strongly affected by the local topographic conditions, particularly the orientation of the Columbia River valley (Ferguson 1998). However, at the upper level, winds may show different trends. A

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[1] http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

comprehensive study (Ferguson 1998) found that the seasonal upper-level flow pattern includes frequent southerly (i.e., coming from the south) or northerly (i.e., coming from the north) flow over the Columbia River basin. Northerly winds are common during winter in this area. Spring upper-level winds are highly variable with mean directions between southwest and west–southwest. A similar wind distribution occurs during summer. In autumn, prevailing winds begin to shift back to westerly.

2.3 TRAIL SMELTER ECOLOGICAL RISK ASSESSMENT

An ecological risk assessment (ERA) was recently conducted by Teck to determine impacts of past, present, or future emissions from the Trail smelter on terrestrial and aquatic plants and animals in the area (Cantox 2003; Golder 2005a; Intrinsik 2007). Based on analysis of the spatial distributions of metals in soil in the vicinity of the Trail facility, Cantox (2003) concluded that soil concentrations of antimony, arsenic, cadmium, copper, lead, mercury, and zinc were related, at least in part, to smelter activity.

The size of the initial area of interest (AOI) around the smelter was very large (approximately 80,000 hectares), containing mountainous terrain with elevations ranging from 400 to 1,800 m above sea level) (Cantox 2003; Golder 2005a, 2007). The initial AOI for the terrestrial ERA extended along the Columbia River valley from the U.S.-Canada border north to Castlegar, and was approximately defined by the 2,100 m contour at the west boundary, and the 1,200 m contour at the east boundary (*i.e.*, the "height of land" on both sides of the river valley); (Golder, 2005a).The terrestrial AOI was subsequently reduced to an area of 32,755 hectares based on a comparison of soil sampling results to Contaminated Sites Regulations (CSR); the northernmost portion of the AOI was eliminated based on the presence of relatively low chemical concentrations (Golder 2005a).

3 APPROACH

The major elements of the approach used to evaluate the spatial extent of aerial deposition of metals from smelter stacks are

- Inclusion of all surface soil data that are either known or likely to be influenced by aerial deposition (based on proximity) and all surface soil data in the U.S. near the study area that is not known to be influenced by other sources
- Use of standard quantitative methods to estimate by interpolation the concentrations of metals in surface soil between sampling locations
- Comparison of the measured and interpolated concentrations in soil to screening concentrations for ecological effects.

The approach included an effort to evaluate the distribution of soil data with respect to wind conditions in the vicinity of the smelter. Ultimately, however, the two fundamental questions posed at the beginning of this section—1) is there evidence that smelter stack aerial emissions have resulted in elevated concentrations of metals in soils? and 2) what is the spatial extent within the U.S. of any such effects?—were addressed by examining the spatial distribution of soil metal concentrations in the vicinity of the U.S.-Canada border.

3.1 DATA SETS

Several different investigations have produced data sets that are relevant to determining whether the boundaries of aerial deposition cross from Canada into the U.S. The overall spatial area evaluated lay between latitudes of 48.6 and 49.7 degrees north, and longitudes of 117.36 and 118.51 degrees west. Data from these data sets were used only if they were known not to be influenced by sources other than the Trail facility (with the exception stated below of historical soils from around the Le Roi smelter), and only if the data had not been rejected as a result of data quality review. The data sets included in this analysis include the following:

- Ecological risk analysis of the Trail smelter, including data collected from the U.S. (Golder 2005a; Enns 2007)
- Waneta hydroelectric expansion project, offsite samples (Golder 2005b)
- Le Roi smelter removal action, outer area samples (Weston 2005)
- National Uranium Resource Evaluation-Hydrogeochemical and Stream Sediment Reconnaissance (NURE-HSSR) soil samples (USGS 2007).

Each of these studies is described in more detail below. All sampling locations from these studies are shown in Map 1.

3.1.1 Trail Smelter ERA

Soil samples were collected in 2001, 2002, 2004, and 2005 as part of the terrestrial ERA (Cantox 2003; Golder 2005a). Sampling in 2001 was conducted throughout the original AOI, an area of approximately 82,000 hectares in the vicinity of Trail and Castlegar, B.C. Samples were collected in 2002 from a smaller area (32,755 hectares) within the original area to fill remaining data gaps. Another round of soil sampling occurred in 2004 in association with the collection of forage plant samples (Golder 2005a). The soil samples generally consisted of composites of five subsamples collected within 10 m of a central sampling point. The sample interval for each subsample was 0 to 15 cm below ground surface (bgs). The subsamples from one in every 10 locations were kept as discrete samples. Following collection, the sample material was sieved, and the <2 mm grain size fraction was submitted for metals analysis. One in 10 samples was further split into subsamples for quality assurance and quality control purposes.

In addition to the extensive soil collection in Canada, 10 soil samples were also collected from northeastern Washington State in 2005 as part of the biomonitoring program. These samples were analyzed for arsenic, cadmium, and lead.

Soil samples were analyzed for metals at Cantest Laboratories in Burnaby, B.C., in accordance with the B.C. Ministry of Environment, Lands and Parks, "Strong Acid Leachable Metals (SALM) in Soil, Version 1.0" method, either by inductively coupled argon plasma spectroscopy or inductively coupled plasma–mass spectrometry (ICP–MS) depending on the method detection limits specified in the SALM manual (BCMELP 2001). Soil samples were analyzed for arsenic, cadmium, selenium, silver, and thallium by ICP–MS, and for mercury by cold vapor atomic absorption spectrophotometry. Soil samples were also analyzed by sequential extraction, using a modification of the Tessier et al. (1979) method. Based on the methods used for these analyses, the data are assumed to be of adequate quality for the aerial deposition qualitative assessment.

3.1.2 Waneta Expansion Project

In preparation for construction of a power plant expansion at the existing Waneta Dam on the Pend Oreille River in B.C., the Waneta Expansion Power Corporation investigated sediment and upland soil contamination in their project area (Golder 2005b).

Surface and subsurface soil samples collected in May and June 2005 as part of the upland investigations were selected for this evaluation (Golder 2005b). The selected samples were collected from areas where "fallout" from the Trail smelter was listed as a potential source of contamination. Surface samples were collected to depths up to 15 cm bgs. Selected test pit samples were collected from depth intervals of either 0.8 to 1.0 m bgs or 1.8 to 2.0 m bgs.

Soil sampling was conducted in accordance with Golder's field protocols (Golder 2005b). The samples were analyzed by Cantest Laboratories for concentrations of metals, and various organic constituents. Samples analyzed for metals include two duplicate soil samples collected for quality assurance and quality control purposes.

3.1.3 Le Roi Smelter Removal Action

A Comprehensive Environmental Response, Compensation, and Liability Act removal action was conducted in 2004 at the Le Roi smelter in Northport, Washington, under the direction of EPA Region 10 (Weston 2005). A total of 346 soil samples were collected and analyzed for arsenic, cadmium, copper, and lead.

Sample analyses were carried out following the EPA Statement of Work 5.3, and a quality assurance review of the laboratory results was conducted as part of the remedial program (Weston 2005). The analyses met acceptability standards for precision, accuracy, representativeness, comparability, and completeness.

The Le Roi data set includes samples from locations that were subsequently remediated and that are therefore not representative of current conditions. Those samples were retained for this analysis to allow a clearer visualization of the historical (and recent, through 2004) influence of the Le Roi smelter, to aid in determining whether there has been a mingling of the aerial deposition areas from the Le Roi and Trail smelters.

3.1.4 NURE-HSSR

The NURE-HSSR program was a nationwide survey of the elemental composition of soils and sediments that was conducted to assess the location of potential deposits of uranium and other strategic minerals. Sampling and analysis was conducted by four national laboratories during the 1970s and 1980s. In the Pacific Northwest, sampling and analysis was conducted primarily by the Savannah River Laboratory, with some samples collected and processed by the Lawrence Livermore Laboratory.

A subset of the NURE-HSSR soil data near the study area was included in the data set used to evaluate aerial deposition. The NURE-HSSR program did not collect soil data throughout the entire area adjacent to the entire U.S.-Canada border. However, the only NURE-HSSR soil data available to be included in this analysis was considerably west (and south) of the Trail facility. During the NURE-HSSR field program, the location of each sample was described, and those descriptions included an indication of whether or not each sampling location was potentially influenced by municipal, agricultural, industrial, mining, or other (unspecified) anthropogenic activity. Samples that were described as potentially influenced by anthropogenic activity were excluded from the data set used to characterize the extent of aerial deposition, because of the potential for confounding effects. Documentation of the field and laboratory methods following the NURE-HSSR program were reviewed to assess the usability of these data. It is important to note that the use of the NURE-HSSR data within this analysis was only to provide an upper bound on soil chemical concentrations, and facilitate mapping (i.e., interpolation) of potential soil chemical concentrations; it is acknowledged that the NURE data may not be sufficient to determine background concentrations.

3.2 INTERPOLATION METHODS

To assist in visualizing overall spatial trends in concentrations, and to assist in determining the spatial location of the boundary of aerial deposition, two spatial interpolation methods were used to estimate metal concentrations at locations between the sampling points. The two methods used were kriging and inverse distance weighting (IDW). Kriging is a method that can incorporate the effect of site-specific nonlinear changes in the variability of concentrations with distance, and provide a measure of the uncertainty of each interpolated value (Myers 1997). IDW is a method that uses a simple power function to represent the relative contributions of measured values at various distances to the estimated value at an interpolated point. These interpolation methods, particularly kriging, assume spherical distributions of contaminates around each actual sample point. This assumption is an oversimplification, given the nature of the river valley and mountains in the area, resulting in uncertainties associated with the modeled output. However, the intent of the exercise is to provide a general area within which initial soil sampling could be conducted, and it is not intended to be an accurate depiction of the aerial deposition zone.

3.2.1 Kriging

Interpolation by kriging relies upon a variance-distance relationship that is based on site-specific data. This relationship is derived by computing the variance between each pair of data points in the data set and fitting a nonlinear function to the variances and corresponding distances between the pairs of points. The plot of variance against distance is called a variogram or semivariogram.[2] Typically (or ideally) the variance between nearby measurements is relatively small, and the variance increases with distance up to a certain point at which the variance becomes constant—this is the distance where there is no common influence acting on the locations sampled. The function that is fitted to the variance–distance relationship is used to estimate the relative influence of measured values at various distances from a point to be interpolated. The shape of this function, or the underlying distribution of data, is also used to identify the maximum distance at which concentrations covary to any extent. The statistical methods used to represent the variance–distance relationship allow not just the estimation of

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[2] The latter term is sometimes used because in practice, the squared difference between the values of each pair of points is used rather than the variance.

concentrations at an interpolated point, but also the estimation of the uncertainty of the interpolated concentration. An interpolated surface produced by kriging always matches measured data at the point of measurements (i.e., is an exact interpolation method), but the influence of a measured concentration on nearby interpolated values is determined by the shape of the function fitted to the variance–distance relationship.

The validity of the computational methods used in kriging depends on the underlying data set meeting several statistical assumptions. Several specialized variations of the kriging method incorporate slightly different assumptions. The basic assumption underlying all kriging methods is that the data set exhibits stationarity, that is, that the mean and variance of concentration values are constant over the entire area. Two specialized kriging methods were applied to the soil data, ordinary kriging, which assumes that only the measured values surrounding a point to be interpolated all have a common mean, and universal kriging, which assumes that there is an overall linear spatial trend in the data. As noted in the discussion of results, several different subsets of the soil data around the Trail smelter were used during evaluation of different interpolation approaches. Ordinary kriging was used for most of these analyses, and universal kriging was used with spatially limited subsets of the data near the Trail facility that had a strong linear spatial trend. Although the assumption of a constant mean is modified in each of these two specialized methods, the assumption of uniform variance remains. The assumption of constant variance is most likely to be satisfied if a single source or process is responsible for the observed data. When different sources or transport mechanisms are active, the data may not meet this assumption.

The release and transport mechanisms that are responsible for the distribution of metals in soil are not necessarily uniform in all directions. Aerial transport, for example, may transport stack emissions primarily in a single direction, producing a relatively elongated area of influence. This variation with direction, or anisotropy, can be accounted for during the development of the variogram and its application to estimate interpolated concentrations, and can help account for any systematic differences in variance between the lateral and longitudinal directions of transport.

Kriging was carried out using Surfer (Golden Software, Golden, Colorado) and ArcGIS Geostatistical Analyst (ESRI, Redlands, California).

3.2.2 Inverse Distance Weighting

The IDW method is mathematically much simpler than kriging, and merely represents the influence of a measured point on an interpolated point as an inverse power function of distance. The weight, or influence, of distant points on an interpolated value diminishes according to the power function. Large power values give little weight to distant points, and smaller power values give greater weight to those points. If the function that best fits a variogram is a power function, then IDW and kriging can give very similar results. Like kriging, IDW is an exact interpolation method. The spatial extent of the influence of a measured concentration is determined by the power selected. The power to be used with IDW can be estimated using an optimization method that involves successively removing each measured value from a data set, and choosing the power that minimizes the error between measured and predicted values. In practice, software tools allow other aspects of the IDW method to be modified in ways that improve the accuracy of interpolations. These variations of the method include anisotropic selection of neighboring data points around a point to be interpolated, and dynamic variation of the search distance for neighbors to achieve a specified number of data points around each point to be interpolated.

IDW interpolation was carried out using ArcGIS Geostatistical Analyst software.

3.3 THRESHOLDS FOR AERIAL DEPOSITION DETECTION

Determination of the spatial extent of aerial deposition depends on the application of some rule or criterion to determine the boundary of elevated concentrations. For the purpose of this evaluation, two types of threshold values were used

- EPA ecological soil screening levels (Eco-SSLs; USEPA 2005a through d, 2007a,b)
- An upper bound on regional soil conditions (i.e., the NURE-HSSR).

The Eco-SSLs are conservative screening values designed to be protective of ecological receptors that contact soil or ingest biota that live in or on soil. The intended purpose of the Eco-SSL values is to identify chemicals of potential concern that warrant further evaluation in a baseline ERA (USEPA 2005a through d, 2007a,b). Eco-SSL values for most metals are receptor-specific; for any given metal, there may be separate Eco-SSL values for plants, soil invertebrates, birds, and mammals. The Eco-SSL values used for this analysis are shown in Table 3. Also illustrated within Table 3 are the upper bounds on concentrations of arsenic, cadmium, copper, lead, and zinc as determined from the NURE-HSSR data.

For the analysis conducted herein, an exceedance of any receptor-specific Eco-SSL value, and exceedance of the NURE-HSSR upper tolerance limit (i.e. 90 percent coverage, 95 percent confidence), was considered to represent an "elevated" concentration. Identification of the aerial deposition boundary was based not only on the magnitude of concentration values but also on the contiguity of elevated values. Because of the possible influence of other sources (specifically, past mining operations throughout the general area), elevated concentrations were considered indicative of aerial deposition only if they were contiguous with other elevated concentrations between the smelter and the point of measurement. Isolated elevated concentrations were generally not considered indicative of the extent of aerial deposition.

There are two features of the site that may complicate identification of the spatial location of aerial emissions from the Trail smelter. The first of these is riverine transport of smelter waste, because the valley of the Columbia River tends to channel winds as well as water, elevated metal concentrations that are observed immediately adjacent to the river may be present as a result of either aerial or fluvial transport and is evaluated further within this appendix (i.e., floodplains). The second of these is the presence of other sources, and the former Le Roi smelter in particular. Although a removal action has been completed in the area of the former Le Roi smelter in Northport, residual elevated concentrations may nonetheless exist in the vicinity. If unaccounted for, both of these complicating factors will tend to increase the apparent spatial extent of the aerial emission boundary. Neither of these factors has been accounted for in this analysis (primarily because of the difficulty of making any quantitative assessment with available data) with the consequence that this analysis is likely to represent a conservative estimate of the extent of aerial deposition from the Trail smelter.

4 RESULTS

Kriging and IDW methods were evaluated using soil data from the vicinity of Trail and around the study area, and an interpolation method selected for these site-specific data. The evaluation steps and the results of the final interpolations are described in the following sections.

4.1 APPLICATION OF INTERPOLATION METHODS

Because of the kriging method's ability to estimate the uncertainty associated with interpolated values, kriging was initially applied to estimate the extent of aerial deposition. In practice, the feasibility of applying kriging to the UCR soil data depends on the statistical characteristics of the data used; in particular, adherence to the assumption of stationarity. Variograms, error plots (predicted vs. observed concentrations), and visual examination of interpolated data for anomalies were used to evaluate kriging using different data subsets and assumptions.

The spatial density of soil samples is higher near the Trail facility than near and south of the U.S.-Canada border, and concentration ranges are greater and spatial trends are also clearer closer to the facility. Because of these characteristics, and the presumably stronger association between smelter emissions and soil metals closer to the facility (Cantox 2003), the Trail ERA soil data were initially selected as the preferred data set for the development of variograms specific to the metals of interest and the effects of aerial emissions. The initial approach taken to develop kriging parameters was to use the Trail ERA data to develop variograms, with the intent of using those variograms throughout the potential area of deposition. Although other sources (including natural background) and transport mechanisms are expected to dominate the effects of the smelter closer to the edge of the aerial deposition boundary, and thus change the variance–distance relationships, variograms specific to the Trail ERA soil data are expected to provide a good initial estimate of the boundary.

Metal concentrations in soil near the Trail facility (Trail ERA data) are highly variable, despite the presence of well-defined maxima of concentrations of several metals close to the facility. The result of this variability is that variance–distance relationships are not well defined, and do not allow accurate fitting of functions to represent these relationships. This variability is illustrated by the variogram for lead in Trail ERA soil data, as shown in Figure 1. Variograms for other metals are similar. The figure includes an example of a variance–distance function (spherical model) fitted to these data. Because concentrations are highly variable even over relatively short distances, neither this model nor any other accurately represents the spatial variation in concentrations. Despite the fact that kriging is an exact interpolation method, the interpolated surfaces produced using such models show a high proportion of cases in which interpolated concentrations differ from measured concentrations over very short distances.

Because the entire soil data set near the smelter did not exhibit clear variance–distance relationships, several different subsets of soil data and variations of the kriging method were applied to determine if better relationships could be developed. These variations included

- Evaluation of data only from slopes that face upwind toward the predominant wind direction (310 to 360 degrees), based on the possibility that aerial deposition was more systematic on slopes where the wind impinged
- Evaluation of data only from slopes that face downwind, away from the predominant wind direction (130 to 180 degrees), based on the possibility that aerial deposition was more systematic in the lee, where wind is stilled
- Separate evaluation of data from within and without the valley of the Columbia River, based on the possibility that aerial transport differs with these topographical features
- Use of universal kriging for data south of the smelter, where variations in concentrations could reasonably be modeled as including an overall spatial trend
- Use of anisotropic search distances with the long axis aligned with the predominant wind direction (north–northwest to south–southeast).

These refinements resulted in little or no overall improvement in the kriging results. The use of an anisotropic search radius produced an improvement in the variance–distance relationships, but resulted in larger discrepancies between observed and predicted values at greater distances from the Trail facility.

The difficulty in identifying accurate variance–distance relationships in the Trail ERA data is potentially caused by a combination of factors, including

- Spatial and temporal variations in wind transport resulting from topographic variation in the vicinity of the smelter
- Historical variation in smelter emissions
- Relict floodplain deposits in soils near the Columbia River
- Post-deposition remobilization of soil by wind, water, or human activity.

Because the data for the areas closest to the smelter—and presumably most strongly influenced by aerial emissions—did not allow optimal kriging parameters to be identified, data from the area near the U.S.-Canada border was used instead for parameter estimation. Although data are sparser in this location, these are the data that are most directly relevant to determining whether, or by how much, aerial deposition has influenced U.S. soil.

Both universal kriging (in addition to ordinary kriging) and anisotropic search distances were evaluated using the data near the U.S.-Canada border. The long axis of the anisotropic search distances was varied in 15-degree increments throughout a total of 360 degrees. As with the larger data set around the Trail facility, improvements in the variograms were found when anisotropic search distances were used (particularly with the long axis oriented approximately northeast to southwest), but substantial prediction errors nevertheless occurred throughout the data set. Use of universal kriging did not improve predictive accuracy relative to ordinary kriging.

As a result of the inability to obtain well-defined variograms and kriging parameters with good predictive accuracy, the inverse distance weighting method was evaluated using the data set near the U.S.-Canada border. ArcGIS Geostatistical Analyst was used to compute an "optimum" power for the IDW method using a cross-validation method. For all metals of interest, the optimum power was found to be 1.0. This power value indicates that measured values that are far from the point to be interpolated should have the same weight as measured values that are close to the point to be interpolated. In effect, this indicates that there is no systematic spatial structure to the data. This is the same conclusion that is implied by variograms that show little curvature and high variance at all distances (e.g., Figure 1).

Given the absence of spatial structure, interpolation was carried out with the goal of propagating measured values to surrounding areas without direct measurements. This improves the ability to visualize the distribution of measured values, but (owing to the absence of any systematic spatial structure) does not necessarily provide accurate estimates of concentrations at locations between the measured points. To achieve this goal, IDW was used for the interpolation method. IDW was chosen because the data do not support kriging, and the accuracy of IDW is equivalent to kriging in the absence of spatial structure (Kravchenko 2003). A power of 2 was used so that interpolated values are most strongly influenced by the nearest measured value (Mueller et al. 2005). Search distances were 2,000 ft for interpolations conducted over the entire area of potential smelter impacts (i.e., including Trail and areas to the north), and 1,000 ft for interpolations over the smaller area near the U.S.-Canada border. A minimum of three and a maximum of five neighboring measured values were used for each interpolation. The grid spacing for interpolation was approximately 97 ft throughout the focus area near the border. The interpolated surfaces (concentration values) were trimmed spatially at a distance beyond the outermost points of the data set at a distance approximately equal to the average distance between points in the data set.

4.2 AERIAL DEPOSITION IDENTIFICATION

Surface soil concentrations of arsenic, cadmium, copper, lead, mercury, and zinc were mapped using the interpolation method described above. Maps were produced for both a large extent that includes the Trail facility and areas northward, and a small extent that is focused on the area around the U.S.-Canada border (mercury and zinc were not measured in U.S. soil samples near the border, and so only the former maps are included for these metals). The concentration values produced by interpolation were subdivided into discrete categories using breakpoints corresponding to the threshold values shown in Table 3. For the purpose of assessing whether aerial deposition influenced soil concentrations within the U.S., two criteria applied were

- Concentrations in the U.S. must be above the NURE-HSSR upper bound condition and above at least one Eco-SSL value to be considered elevated to a level of potential concern.
- Areas of elevated concentrations in the U.S. must be contiguous with equivalent or higher concentrations back to the Trail facility. The possibility that topographic conditions affect aerial transport and deposition, the possibility of other sources in the general area, and the uncertain accuracy of the interpolation method used are all considered when interpreting contiguity.

4.2.1 Arsenic

Concentrations of arsenic in soil around the Trail facility, and in the vicinity of the U.S.-Canada border, are shown in Maps 2 and 3, respectively. Arsenic concentrations are highest near the Trail facility and decrease with increasing distance from the facility. Elevated concentrations generally follow the Columbia River valley, both north and south of the facility.

Concentrations at the U.S.-Canada border, and in U.S. soils adjacent to and south of the border, are lowest than the lowest Eco-SSL and also generally within the range of the NURE_HSSR data. Although there are several samples with relatively elevated concentrations within the U.S., these samples are not contiguous with equivalently elevated concentrations farther north in Canada. Furthermore, those elevated samples are not in the Columbia River valley, which appears to channel aerial transport south of the Trail facility. Consequently, the extent of aerially deposited arsenic from the Trail facility does not appear to extend into the U.S.

4.2.2 Cadmium

Concentrations of cadmium in soil around the Trail facility, and in the vicinity of the U.S.-Canada border, are shown in Maps 4 and 5, respectively. The general pattern of concentrations is similar to that for arsenic, with the highest concentrations near the Trail facility and some elevated concentrations extending along the Columbia River valley both north and south of the facility.

Concentrations in the region of the U.S.-Canada border are above the lowest Eco-SSL values (mammal and avian) but generally below the NURE-HSSR upper bound. These same conditions occur north of Castlegar (Canada), an area eliminated from the AOI for the Trail smelter ERA based on comparison to Canadian soil screening levels (Golder 2005a). In the region of the U.S.-Canada border, concentrations above the range of background conditions, and contiguous with elevated concentrations near the Trail facility, are found in Canadian soils almost to the boundary. There are several samples in the U.S. that also have concentrations above the range of background, but these are not contiguous with the elevated concentrations in Canada. Consequently, the boundary of aerially deposited cadmium from the Trail facility does not appear to extend into the U.S.

4.2.3 Copper

Concentrations of copper in soil around the Trail facility, and in the vicinity of the U.S.-Canada border, are shown in Maps 6 and 7, respectively. Elevated concentrations of copper are found around the Trail facility and also around the former Le Roi smelter. Copper concentrations at the U.S.-Canada border, and to a considerable distance on either side, are below all of the Eco-SSL values and within the range of NURE-HSSR data. Consequently, there is no indication that the aerial extent of elevated copper concentrations extends from the Trail facility into the U.S.

4.2.4 Lead

Concentrations of lead in soil are shown in Maps 8 through 10. These show, respectively, the area around the Trail facility, the area around the U.S.-Canada border, and the area south of Northport. Elevated concentrations of lead are found around the Trail facility and around the former Le Roi smelter in Northport, Washington. As with other metals, elevated lead associated with the Trail facility is distributed both north and south along the Columbia River. Concentrations above some or all Eco-SSL values and above the NURE-HSSR upper bound, and contiguous with the higher concentrations around the Trail facility, are found in the region between the U.S.-Canada border and Northport. Soil lead concentrations south of Northport (Map 10) are generally within the range of background, though above the lowest (avian) Eco-SSL. Farther south of the region shown in Map 10 there are some additional samples with elevated concentrations, but these are not contiguous with the area of elevated concentrations between the U.S.-Canada border and Northport. Concentrations to the west of Northport are above the range of NURE-HSSR data and above both avian and mammalian Eco-SSLs. The limited amount of data available in this direction does not allow a bound to these elevated concentrations to be established, however.

The distribution of lead in U.S. soils between the U.S.-Canada border and Northport meets the criteria for identification of an area of aerial deposition influenced by the Trail facility. These elevated concentrations are also contiguous with the elevated concentrations around the Le Roi facility. Because copper was one of the primary metals smelted in Northport (USEPA 2003) but copper was not a product of the Trail facility, ratios of lead to copper in soil samples were evaluated to determine whether they would provide better discrimination between the areas influenced by the two smelters. Interpolation of the spatial distribution of the ratio of lead to copper (Map 11) shows a local minimum between the border and Northport, similar to that observed for lead alone. However, the statistical distribution of this ratio does not show clear evidence of two different populations, or sources that might be characteristic of the different smelters (Figure 2).

4.2.5 Mercury

Concentrations of mercury in soil around the Trail facility, south to the U.S.-Canada border, are shown in Map 12. There are no Eco-SSL values for mercury; however, Sanei et al. (2007) estimated the upper limit of background concentrations of mercury for British Columbia soils. The 95th percentile of this background concentration distribution was 0.07 (mg/kg, and is the qualitative threshold value employed in Map 12.

Although mercury concentrations are elevated in the vicinity of the Trail facility, concentrations decrease relatively rapidly over distance. Concentrations equivalent to the upper bound on background conditions as defined by Sanei et al. (2007) are reached in Canada between the Trail facility and the U.S.-Canada border.

4.2.6 Zinc

Concentrations of zinc in soil around the Trail facility are shown in Map 13. Zinc was not measured in samples collected during the Le Roi smelter investigation or in samples collected from the U.S. for the Trail ERA. Consequently, there are no zinc data for U.S. soils adjacent to the U.S.-Canada border.

Concentrations of zinc in soil are highest near the Trail facility and decrease with increasing distance from the facility. As with other metals, elevated concentrations generally follow the Columbia River valley, both north and south of the facility. Concentrations higher than the NURE-HSSR upper bound, and higher than both avian and mammal Eco-SSL values extend to and across the border in a relatively narrow region around the Columbia River. Although there are no zinc measurements in adjacent U.S. soil, the spatial pattern of elevated zinc concentrations strongly suggests that elevated concentrations also could be found in at least a limited region of U.S. soils near the border. Available data are not sufficient, however, to define the boundary of this area.

5 SUMMARY – SMELTER STACK EMISSIONS

The spatial distributions of arsenic, cadmium, copper, lead, mercury, and zinc in surface soil have been evaluated to assess whether U.S. soils in or adjacent to the RI/FS study area are potentially impacted by aerial deposition of metals from the Trail facility. The presence of a potential impact was evaluated by having an elevated concentration that is above the NURE-HSSR upper bound conditions, higher than at least one Eco-SSL, and spatially contiguous with similar or higher concentrations.

The spatial pattern of lead and zinc concentrations indicate that the extent of aerial deposition of these two metals crosses the U.S.-Canada border into the U.S. Lead concentrations are elevated within the area from the U.S.-Canada border to just south of Northport, Washington. Lead from the Le Roi smelter is probably mixed with lead from the Trail smelter within this area, but available data are not sufficient to allow these the two sources to be distinguished. South of Northport, elevated lead concentrations drop to levels below the NURE-HSSR upper bound. Unbounded elevated concentrations of lead are present to the west of Northport, and there are insufficient data in this region to establish the complete extent.

Zinc concentrations are elevated in Canadian soils near the Columbia River up to the U.S.-Canada border. Zinc was not measured in the available soil samples on the U.S. side of the border, and the presence and spatial extent of elevated concentrations in U.S. soil cannot be definitively determined. Based on the overall spatial distribution of zinc in Canadian soils adjacent to the border, elevated concentrations are likely to also exist in U.S. soil.

6 FLOODPLAINS - HYDROLOGIC TRANSPORT

The extent of potential soil contamination resulting from water-borne contaminant transport and deposition onto relict floodplains was evaluated using a number of geographic information system (GIS) and hydraulic analysis tools. These include ArcGIS 9.2 (ESRI 2005), HEC-GeoRAS 4.0 (USACE 2005), and HEC-RAS 4.0 (USACE 2006). As part of this evaluation, the geostatistical method outlined within the modified RI/FS work plan (USEPA 2008) was refined using site-specific data. The following sections present a summary of the above-listed analyses with the primary intent of helping to identify and define areas of potential soil contamination resulting from this process.

7 REFINED BATHYMETRIC DATA GEOSTATISTICAL ANALYSES

Water depth measurements (soundings) from the 1947 to 1949 surveys conducted by the U.S. Coastal and Geodetic Survey (USCGS 1950) were analyzed in conjunction with Digital Elevation Model (DEM) data for the surrounding upland area and river shoreline data (defined by the 1,290 ft full pool level for the Lake Roosevelt impoundment). The full data set contains 121,919 soundings from the U.S.-Canada border to Grand Coulee Dam. With the exception of the area immediately downstream of the U.S.-Canada border, bathymetric soundings for the UCR are very detailed. The average distance between any sounding and its nearest neighbor is less than 30 m (100 ft) and the maximum distance between two adjacent soundings is approximately 420 m (1,400 ft).

To facilitate the evaluation of river cross-sectional characteristics, the soundings data were converted to elevations and divided into 12 subsets (passes). These subsets were selected so that each had approximately 10,000 to 15,000 soundings with a well-defined orientation (direction) along the river valley to account for any difference in elevations as a function of direction (i.e., anisotropy). There was a small area of overlap between each subset to minimize the potential for abrupt elevation differences along the edges between subsets. A map displaying the locations of the 12 data subsets used in the analyses are presented in Map 14.

A continuous bed elevation surface was initially generated by kriging with a single parameter set globally optimized to reduce the overall error of elevation estimates. To refine the bathymetric surface, the kriging was then performed using different sets of parameters locally optimized to minimize error for each subset. Kriging and associated GIS operations were performed using ArcGIS 9.2 (ESRI 2005) with the Spatial Analyst and Geostatistical Analyst Extensions. To perform the kriging calculations, parameters for the semi-variogram and the interpolation neighborhood must be specified. The semi-variogram expresses how the differences between measured values changes with distance in any direction. The interpolation neighborhood expresses how data points are used when interpolating a value at a location. Descriptions of all kriging parameters and terms (e.g., lag size, sill, range, anisotropy, etc.) are provided by ESRI (2005).

For each data subset, the root-mean-square (RMS) error of bed elevation cross validation calculations was minimized by adjusting the semi-variogram model type, major range, minor range, anisotropy direction, and sill. The lag size and number of lags were set to 30 m and 100 m, respectively, for all 12 passes. Spherical and exponential model types were tested for each pass and the best fitting semi-variogram determined by trial-and-error. All analyses used an eight sector search with the maximum and minimum number neighbors to include in the analysis adjusted to minimize the RMS error. Two search radius options were tested 1) the default, which is based on the semi-variogram major range, minor range, and anisotropy direction, and 2) a large search radius (4,500 m). In most cases the large search radius reduced the RMS error in comparison to the default search radius. The exceptions were passes 1, 2 and 7B, where smaller or anisotropic search radii produced smaller RMS errors. Values for all kriging parameters and resulting cross validation errors are summarized in Table 4.

Kriging results for each of the twelve soundings passes (inside the "full pool" shoreline) and the DEM from the U.S. Geological Survey (USGS) National Elevation Dataset (outside the shoreline) were mosaiced together. A display of the refined bathymetric surface and surrounding upland elevations for the UCR is presented in Map 15. Close-up displays of the bathymetric surface in areas near Northport, Marcus Flats, and Inchelium are presented in Maps 16, 17, and 18, respectively.

It should be noted that the refined bathymetric surface is based on the 1947 through 1949 USCGS soundings in combination with the USGS DEM for the area. Uncertainties in elevations from these sources exist. For example, it is possible that bed elevations have changed in response to changing flows, sediment inputs, or other factors in the 60 years that have passed since the USCGS data were collected. Additional interpolation uncertainties also exist. Islands and seasonally emergent rocks are not well represented in the interpolated bathymetric surface. The raw soundings data do not indicate the locations or depths of such features because the survey boat could not traverse those areas. An example of this is shown in Maps 15 through 19. Such unreported areas end up being treated as if they are submerged when bed elevations are interpolated because all points in the immediate area are submerged. This also contributes to the uncertainty in estimated channel depths and cross-sectional areas.

8 1-D HYDRAULIC ANALYSES

One-dimensional hydraulic analyses were performed using HEC-RAS 4.0 (USACE 2006) software. River channel and floodplain geometry for the analyses was generated from the refined bathymetric surface using the HEC-GeoRAS 4.1 (USACE 2005) extension to ArcGIS. A total of 417 cross-sections with a typical spacing of 500 to 750 m (1,600 to 2,500 ft) were defined and exported from ArcGIS using HEC-GeoRAS and read into the geometry editor in HEC-RAS. These include several cross-sections to facilitate comparisons to field data in the area just downstream of Northport. Within HEC-RAS, 7,164 additional cross-sections were interpolated to ensure proper computation of water surface elevations. The resulting total number of defined and interpolated cross-sections used in HEC-RAS was 7,581.

For these analyses, flow in the UCR was assumed to be subcritical. For subcritical flow, water surface elevations and corresponding energy (head) losses are calculated starting at the downstream limits of the system and proceed upstream (i.e., from Grand Coulee Dam to the U.S.-Canada border). The primary hydraulic calibration variable is the flow resistance coefficient (Manning n). Flow resistance was calibrated by comparing computed water surface elevations to measurements.

Flow resistance and head loss due to momentum changes are expected to vary along the river as a consequence of differences in bed materials (grain sizes run from fine sand to boulders), channel bends, and cross-section constrictions, and expansions. To account for possible spatial differences in flow resistance and head loss, the base Manning n value used for straight sections of the river was increased by 50 percent around bends[3]. Other than modifying Manning n at bends, no further spatial differences in roughness parameterization were evaluated because of the limited spatial extent of the field data.

Data for calibration included 90 flow and stage measurements at the border collected between 1997 and 2006 by the USGS, three water surface elevation measurements reported by Survey Solutions, Inc. during a December 2006, topographic survey of Black Sand Beach (BSB), and nine Acoustic Doppler Current Profiler (ADCP) measurements provided by the Washington

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[3] The 50 percent increase in Manning n around bends is a relatively large adjustment and is intended to account for changes in cross section shape and the shifting location of the river thalweg as well as any changes in flow alignment along a bend. Because of the number of bends along the UCR, this adjustment was applied to approximately 50 percent of the total channel length. It is worth noting that the adjustment for bends could be reduced to a more typical value of 15 percent for "appreciable meandering" as described by Chow (1959) by increasing the Manning n value that is applied to straight sections of the channel. Considering both the number of bends and straight sections of the channel, the overall (distance weighted) Manning n value that yielded the minimum RMS error at the border gage was 0.0419. This overall Manning n is in the mid- to moderately-high range of values for natural streams (Chow 1959) and is consistent with values applied in upstream portions of the Columbia River (NHC 2007).

State Department of Fish and Wildlife (WDFW)[4]. It should be noted that these data focus on the upper 20 km (12 miles) of the UCR.

The vertical datum for BSB water surface elevation measurements differs from values reported by the USGS. As a result, and for consistency, BSB elevation measurements were adjusted to the USGS vertical datum. Although the vertical datum for each data source differs, there is no way to determine if either is "correct". Given this uncertainty, the USGS datum was chosen based on the assumption that stage data reported at Grand Coulee Dam and all flow, stage, and supporting bathymetry data at the U.S.–Canada Border reported by the USGS have a consistent datum. Therefore, BSB values were first converted from the North American Vertical Datum-1988 (NAVD-88) to the National Geodetic Vertical Datum-1929 (NGVD-29). Once converted to NGVD-29, the difference between the elevations reported for the 100 ft mark on the staff gage immediately north of BSB and the elevation of the 100 ft mark from the survey was calculated and added to the BSB water surface elevation measurements as a correction. Values for the datum adjustments are given in Table 5.

Due to the relatively large number of measurements for the USGS border gage (and the limited data elsewhere); HEC-RAS was calibrated by minimizing the RMS error of calculated water surface elevations at the U.S.-Canada border. Despite uncertainties regarding the consistent application of the vertical datum for different measurements, water surface elevation is the most robust parameter for calibration because it is not expected to vary as widely with location as do velocity or cross-sectional area. Velocity and cross-sectional area are less suitable for calibration because the channel cross-section is not uniform. Even for nearly identical water surface elevations, nearby locations can have appreciably different cross-sectional areas and velocities.

During calibration, Manning n for each cross-section was scaled using a fixed multiplier until the RMS error for computed water surface elevations at the border was minimized (Figure 3). An initial Manning n of 0.034 was used for straight sections of the channel and was varied from approximately 0.030 to 0.036. As previously noted, Manning n for bends was 50 percent larger than for the straight channel value. The Manning n value that yielded the minimum RMS error for calculated water surface elevations was 0.0337 for straight channels and 0.0506 for bends. The minimum RMS error in calculated water surface elevations at the border was approximately 0.15 meters.

Calculated water surface elevation, velocity, and cross-sectional area at the U.S.-Canada border, BSB, and below Northport were compared to field measurements to confirm the appropriateness of subsequent hydraulic calculations (Figures 4 through 9). In these figures the one-to-one line of perfect agreement is shown as well as linear regression estimates for

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[4] ADCP measurements were collected at three locations south of Northport on three separate days in July 2006. During each collection activity the daily stage (reservoir pool level) at Grand Coulee Dam was also recorded.

calculated versus measured values assuming both non-zero (green) and zero (red) intercepts (a non-zero intercept is an indicator of a systematic difference between calculated and measured values as are significant deviations from the 1:1 line of perfect correspondence). Additional statistics describing the results are also presented on the figures.

For Figure 4, it should be noted that the adjusted BSB water surface elevation measurements are plotted along with other measurements for the U.S.-Canada border. However, BSB measurements were not included in the statistical summary. For Figure 9, it should be noted that data reported for the ADCP transects south of Northport did not include values that could be directly related to water surface elevation. However, the data did include a maximum depth measurement along each transect. This value was compared to the profile depth calculated by HEC-RAS as the water surface elevation minus the minimum channel bed elevation along the respective cross-section.

As previously noted, the overall RMS error of calculated water surface elevations at the border is approximately 0.15 m. Corresponding differences between calculated and measured velocities and cross-sectional areas at the border are larger. These differences are very likely the result of uncertainty or error of bed surface elevations. As previously noted, the density of soundings from the 1947 through 1949 USCGS bathymetric survey is fairly sparse in the area of the border gage (refer to Map 19). The cross-section defined from the kriged bathymetric surface is considerably larger than the area defined by USGS measurements collected to define the stage-discharge relationship at the border gage (Figure 10). These additional measurements from the USGS could be added to the bathymetric surface calculation to better define channel bed elevations in this section of the channel. Calculated velocities differ from measured values as a simply reflection of continuity (conservation of mass) for steady flow

$$Q = VA$$

Where:

Q = flow (L^3/T)
V = velocity (L/T)
A = area (L^2).

Given typical water surface elevations of 395 to 400 m (1,295 to 1,315 ft) at the border, more accurate bathymetry at this location would result in an improved (smaller) cross-sectional area, and (by continuity) larger velocities. However, it is worth noting that improvements to the representation of the river cross-section at the border are not expected to materially alter (or improve) the overall analysis because the head loss along the entire river is not influenced by conditions at this one cross section.

Although some differences attributable to uncertainties in the vertical datum may exist, channel geometry downstream of Northport appear to be more accurately represented by the kriged bathymetric surface based on the 1947 to 1949 USCGS soundings. Calculated velocities are in good agreement with field ADCP measurements. There does appear to be a consistent bias of approximately 10 percent toward lower velocities and higher cross-sectional areas and depths. Some of these differences may be attributable to uncertainty in the ADCP measurements because transects and associated measurements did not necessarily measure river conditions from bank-to-bank. Nonetheless, calculated values are well within the accuracy of the ADCP measurements given the uncertainty of the underlying bathymetric surface.

Calculated water surface profiles for a range of flow and dam operating conditions are show in Figures 11 through 17 (the label for each profile lists the day, flow, and water level condition). It is worth noting that calculated water surface elevations have an abrupt change at the Little Dalles (Figure 18). This location is historically a known constriction to flow as noted by the International Joint Commission (IJC) International Columbia River Board of Control Order of Approval (IJC 1941). Uncertainties or error associated with the bathymetric surface may impact the calculated head loss through this section of the UCR for some flow conditions.

The assumption that flow is always subcritical and steady may also limit the extent to which calculated water surfaces can match measured conditions. The UCR includes several sites locations where riffles can occur (e.g., refer to Figure 19). Under conditions that cause riffles, the river flow may approach or become supercritical. In addition, unsteady flow conditions occur as a function of upstream flow and pool level regulation as water is stored or withdrawn from the reservoir. The more variable flow is in the system, the less likely steady flow hydraulic calculations will reproduce any given set of measurements.

9 FLOODPLAIN DELINEATION

The areal extent within the UCR for a range of flood conditions was estimated using the previously described 'calibrated' HEC-RAS application. Given changes in upstream flow regulation that began in 1973, flood magnitudes were separately considered for the pre-1973 (pre-regulation) and post-1973 (regulated) periods. Water surface extents were developed for seven different flow conditions in descending order of magnitude. These included

1. The projected 1-in-500-year flood based on pre-1973 flows
2. The projected 1-in-100-year flow based on pre-1973 flows
3. The maximum recorded pre-1973 flood (June 1948)
4. The projected 1-in-500-year flood based on post-1973 flow data
5. The projected 1-in-100-year flood based on post-1973 flow data
6. The maximum recorded post-1973 flood (June, 1997)
7. The average daily flow based on post-1973 flow data.

Reported annual peak flow data were used to calculate summary statistics (i.e., mean, standard deviation, and skewness) for the pre- and post-1973 periods. This information was then used to construct frequency distributions that represent the likelihood of a discharge as a function of recurrence interval (exceedence probability). The standard procedure to determine the recurrence interval associated with a certain flow event involves fitting stream flow measurements to a probability distribution that is used to extrapolate conditions for the upper tail of the distribution. The choice of the probability distribution to use for this extrapolation requires careful consideration of how well a distribution fits the upper tail of the data, as well as the length of the annual flood record. The five probability distributions evaluated for this flood frequency analysis were

- Normal distribution
- Log-Normal distribution
- Gumbel distribution
- Log-Pearson Type III distribution
- Flow Duration Curve approach (Julien 2002).

Flood magnitude estimates for the seven flow conditions examined using the above-listed probability distributions are presented in Table 6. The appropriateness of any distribution to estimate flood magnitudes depends on the underlying distribution of data, and whether the flood record is long enough to reliably estimate larger, less frequent floods. For the UCR, flood records for pre- and post-1973 periods are relative short (approximately 30 years). In general, limitations of a short flood record can be counteracted by using a distribution that yields a more conservative (i.e., larger) estimate when extrapolating flows for large floods.

As described by the U.S. Interagency Advisory Committee on Water Data (USGS 1982), the Log-Pearson Type III distribution is the recommended approach for flood frequency analysis. However, flood estimates for the 100- and 500-year flood events based on the Log-Pearson Type III distribution are smaller than estimates based on the Type 1 Extreme Value (Gumbel distribution, see Table 6). Given that the short record used for the analysis might not have been sufficiently long to accurately estimate 100- and 500-year flood events, a more conservative approach is appropriate. Therefore, flood magnitude estimates based on the Gumbel distribution were chosen over the other techniques.

The Gumbel distribution (Gumbel 1958) is a two parameter (i.e., mode and a scaling factor) distribution with a constant skewness of 1.139. The scaling factor is essentially a function of the number of data points in the sample and the sample standard deviation. The extreme value distribution approach assumes that the relationship between the flows of any particular flood event is linearly related to the reduced variate used in the distribution. It is worth noting that for events with large recurrence intervals, the reduced variate can be assumed to equal the natural log of the recurrence interval. The procedure used for the frequency analysis was adapted from standard procedures used by the USGS (Riggs 1968; USGS 1982). The fit of the Gumbel distribution to measured annual peak flows and extrapolated to the 1-in-100- and 1-in-500-year recurrence intervals for both the pre- and post-1973 periods are shown in Figure 20.

Estimated (or measured) flows for the seven specified flood conditions were entered into HEC-RAS and water surface elevations were calculated. These results were exported from HEC-RAS and imported into ArcGIS for further analysis using the HEC-GeoRAS extension. Floodplains for each of the seven flood conditions were then delineated. The accuracy of the water surface and floodplain extent calculations was assessed by graphical comparison to floodplain limits for the UCR published by the Federal Emergency Management Agency (FEMA). The calculated flood extent for the estimated post-1973, 1-in-100-year flow was compared to the FEMA 1-in-100-year floodplain. Calculated flood extents are in very close agreement with the published FEMA flood zones. Comparisons of the 1-in-100-year calculated and FEMA floodplain extents for the areas around Northport, Marcus Flats, and Inchelium are presented in Maps 20 through 22. Given the potential for differences in channel bathymetry, flow resistance parameterization, and the flow condition used to represent the post-1973, 1-in-100-year flood, the very close correspondence between these two independent analyses floodplains suggests that UCR HEC-RAS water surface calculations provide a reasonable basis to estimate flood extents for other flood conditions.

As previously noted a primary goal of this analysis analyses was to identify relict floodplain areas along the UCR and help identify areas of potential soil contamination. For this analysis, a relict floodplain is defined as an area that may have been subjected to flooding under past flow conditions but that is not expected to be flooded under present flow and pool level management controls. Three flow conditions are relevant to the analysis—1) the average daily post-1973 flow at low pool; 2) the average daily post-1973 flow at high pool; and 3) the maximum reported pre-1973 flow. The water surface extent for the average daily post-1973 flow at low pool defines the minimum area that is expected to be under water at all times (i.e., areas that are always flooded). In continuously flooded areas, sample collection activities would typically need to be conducted from a boat (i.e., sediment sampling). The water surface extent for the average daily post-1973 flow at high pool defines the area that is expected to be periodically flooded (i.e., areas that are sometimes flooded) during the year. In periodically flooded areas, sample collection activities could be performed from a boat when wet or by ground crews when dry. The maximum reported pre-1973 flow was 15,577 m^3/s (550,100 cfs) occurring on June 12, 1948 and as such, defines the largest area where flooding may have occurred. The area between high pool floodplain and the maximum pre-1973 floodplain represents the relict floodplain. In relict floodplain areas, there is a potential for historical contamination to exist beyond present-day floodplain limits. Sample collection activities in these areas could only be performed by ground crews (i.e., soil sampling).

A map showing calculated floodplain extents for daily average flow conditions as well as the historical (relict) floodplain maximum extents from the U.S.-Canada border to Grand Coulee Dam is presented in Map 23. Detailed views of floodplain extents for the areas around Northport, Marcus Flats, and Inchelium are presented in Maps 24 through 26, respectively. These results indicate that in most locations the pre-1973 maximum floodplain was no larger than the present-day floodplain extent at high pool. However, in a few locations (e.g., the area around the Deep Creek near Northport) the relict floodplain is larger than the present-day floodplain. Based of this analysis, relict floodplain areas exist upstream of Little Dalles (approximately USGS river mile [RM] 729). Downstream of Little Dalles, historical floodplain areas are expected to be inundated by Lake Roosevelt.

10 EXPOSED SEDIMENTS - WIND EROSION

The potential for soil contamination resulting from exposed sediments subjected to wind erosion (i.e., wind-borne dusts) along the shorelines of Lake Roosevelt was evaluated.

10.1 WIND-BLOWN SEDIMENTS

Sediments along the banks of Lake Roosevelt become exposed and dry out during the drawn-down period (January – July). This allows smaller particles to be suspended by the wind and blown onto the shores. Over sufficiently long time-frames, some of the chemicals of potential concern (COPCs) that are elevated in the sediments could build up in soils to levels that may pose risk to terrestrial ecosystems. To evaluate whether this has occurred, locations with the highest probability of enrichment by wind-blown sediments will be selected for soil sampling. This section describes the process for selection of the Marcus Flats and Seven Bays areas on the east side of the UCR as the most probable locations for soil contamination from wind-blown sediments.

The process of selection of locations for soil sampling to evaluate whether soil enrichment from wind-blown sediment has occurred is based on the analysis of three factors–wind (velocity, direction and frequency); concentrations of selected COPCs in bank sediments; and percent of fines (small particles) in the sediments. It is assumed that areas where the wind blows with most frequency and highest velocity in a direction that takes particles towards shore have a high probability of suspending and blowing sediments. This will be enhanced in areas with the highest amount of small particles, as lower threshold velocities are required for picking up and moving smaller sized particles. Soil enrichment will be highest in areas where there are elevated concentrations of COPCs that have physical/chemical properties that result in binding to soil and very slow leaching processes. Therefore, where these three data sets intersect (i.e., maximum winds, highest percent fines, and highest concentrations of critical COPCs) will be the area(s) of greatest probability of exposure. The process for evaluation of each of these three factors is described herein. This analysis was conducted only for RM 597 (Grand Coulee Dam) to RM 707 (above Marcus Flats), as this is the region affected by the annual drawdown of Lake Roosevelt and has exposed sediments with significant percent fine particles.

10.1.1 Generation of Wind Roses and Wind Velocity Plots

Site-specific meteorological data are a critical component for evaluating and estimating the distribution of wind-suspended sediment emissions because the emission rate and the direction of dust plume movement are driven by the wind speed and direction at the original location of the wind-suspended sediment. To understand the distribution of wind speed and direction along the UCR, a systematic analysis of the site-specific meteorological data files was performed.

10.1.1.1 Data Sources

Site-specific meteorological data along the UCR have been collected by two major programs. One was operated by USGS as part of the air quality monitoring study for 2002 to 2006, and includes four stations on the UCR. The other is the AgriMet program operated by U.S. Bureau of Reclamation (USBR), Department of Interior (DOI). The current AgriMet network consists of more than 70 agricultural weather stations located throughout the Pacific Northwest; 3 stations are set up along the UCR. Additionally, limited site specific meteorological data were collected by Teck during 1994 to 1995 joint sampling periods with Washington Department of Ecology. The location of the meteorological station was in Northport, Washington.

USGS

The hourly meteorological data files for 2002 to 2006 recorded by USGS were collected from Seven Bays, Inchelium, Marcus Flats, and Kettle Falls. Hourly; wind speed, wind direction, temperature, and precipitation were recorded. The meteorological station locations were located from several hundred feet to 1 mile away from the river. Because of the technical challenges encountered in the early sampling period (e.g., 2002) and the follow up years, data gaps exist, with a variety of hourly averages missing from the data set. For these reasons, USGS Kettle Falls data were not used in this analysis; data collected by AgriMet at Kettle Falls was used instead.

AgriMet

Files providing hourly meteorological data for 2002 through 2008 at the Grand Coulee Dam, Seven Bays, and Kettle Falls were directly downloaded from the DOI AgriMet website. The AgriMet meteorological stations are located on the bank of the UCR. When compared with the USGS meteorological station locations, the AgriMet station locations were much closer to the river and better represent conditions potentially affecting euphotic sediments in the UCR. Therefore, AgriMet data are given preference over USGS data. The AgriMet meteorological files provide observations of wind speed and standard deviation, wind direction, hourly precipitation data, temperature, and other parameters. More importantly, the AgriMet data files also contain the 15-minute peak wind gust data, which can be further used to estimate the suspension of fine sediments by wind should more detailed analyses be required in the future.

Data Processing

The following meteorological data sets for the periods indicated were processed for generating wind roses and wind speed plots for both annual and UCR drawdown periods

- Marcus Flats—USGS operation (2003 to 2005)
- Kettle Falls—AgriMet Operation (2007 to 2008)
- Inchelium—USGS Operation (2003 to 2005)
- Seven Bays—USGS Operation (2003 to 2005)
- Seven Bays—AgriMet Operation (2003 to 2008)
- Grand Coulee—AgriMet Operation (2007 to 2008).

Data Gap Filling

To efficiently identify the hours with the missing meteorological parameters, a computer program was written to process the large amounts of hourly meteorological data in the data files obtained from USGS and AgriMet. The software contains algorithms for both locating data gaps and estimating the missing hourly data values. Values to estimate missing data were calculated following U.S. EPA's technical guidance in *Procedures for Substituting Values for Missing Meteorological Data for Use in Regulatory Air Quality Model* (USEPA 1992). The processed meteorological files were used for generating wind roses for both annual and UCR drawdown periods, and the windspeed plots.

Data Format Conversion

To meet the stringent requirements on data format for wind rose and wind plot generation, hourly meteorological data files were converted into a specific format (i.e., National Climatic Data Center [NCDC] CD-144 format). The format adjustment and conversion process includes

- Standard template set up in Excel based on NCDC format specifications
- Site-specific meteorological data transfer to the template and format adjustment
- Surrogate data filling for fields that are not used in wind rose generation yet necessary for meeting format requirements
- QA/QC of the meteorological files
- Conversion of the meteorological files from Excel to CD-144 format (in ASCII).

To generate the wind roses for both the annual and drawdown periods, respectively, the meteorological files were set up with two types of time windows

- Hour 01, January 1—Hour 24, December 31 (annual)
- Hour 01, January 1—Hour 24, June 30 (drawdown period).

Wind Rose and Wind Plot Generation

By using the converted hourly meteorological data files and the proprietary computer software WRPLOT View (Lake Environmental 2009) and R for Windows (v. 2.9.0; R Development Core Team 2009), wind roses were generated for the UCR drawdown periods, and windspeed patterns were plotted.

The WRPLOT program was run for the selected years, and the generated wind roses are presented in Map 27 for the drawdown period (January through June).

For the windspeed plots, both the annual and drawdown period are presented in the same graph for a given year, with the drawdown period covered with light shadow (Figures 21 through 26).

10.1.2 Sediment Grain Size

The Project database of sediment COPC concentrations includes data on grain size. The database was queried to extract percent fines (<63 mm) and percent particles <75 mm diameter from the years 1996 – present meeting Category 1 or 2 data quality criteria. This time-frame is consistent with the definition of the baseline dataset used in the Human Health Risk Assessment Work Plan. Fine-grained sediments refer to those measured by USGS which were defined by <63 um diameter. The distribution of these particles by river mile is shown in Figures 27 and 28.

Examination of Figure 28 identifies the area between Inchelium and Seven Bays as having the highest percentage of fine particles. There does not appear to be significant differences between the left and right bank, although the left bank has a higher peak near Seven Bays. Based on this analysis, the area just north of Seven Bays (i.e., at the confluence of the Spokane River) would be selected as a location that has a higher probability of the presence of particles in sizes mostly likely to be blown by the wind. This area has relatively flat topographically as well.

10.1.3 Sediment COPC concentrations

Elevated soil concentrations of COPCs from wind-blown sediments that are deposited in a particular location will occur if 1) there are elevated concentrations in the sediments themselves and 2) the COPC remains in the surface soil and is not leached through into deeper soils. The first parameter was examined through identifying and plotting sediment concentrations by river mile, averaged for each five miles (Figures 29 and 30 for metals and Figures 31 and 32 for organic COPCs). The chemicals selected for analysis are those with high K_d (inorganics, Table 7) or high organic carbon/water partition coefficient (K_{oc}) (organics, Table 8). These properties refer to the partitioning of the chemical onto soil particles or into water (i.e., the ratio particulate:water concentrations). Therefore, those with higher soil-water partition coefficient

(K_d) or K_{oc} are most likely to bind to soil particles and persist in the upper soil horizons, rather than being leached through soil porewater into deeper substrates.

For inorganics, lead, cadmium, nickel and zinc were chosen as metals with relatively high K_d values and potentially elevated sediment concentrations. Note that elements such as chromium and iron have extremely high K_d values and, as a consequence, have naturally high levels in soils. Therefore, these COPCs would not make good markers for wind-blown dust measurements. A similar analysis using K_{oc} for the organic COPCs was conducted, although the results were uninteresting because all reported concentrations were actually the detection limits (i.e., no elevated concentrations to report). This is reflected in the essentially straight lines plotted in Figures 31 and 32.

Therefore, the analysis of areas most likely to have high COPC concentrations of materials that will remain in the soil sufficiently long to accumulate to potentially toxic levels was restricted to the inorganic COPCs. This analysis shows highest concentrations at Marcus Flats with another minor peak around Seven Bays.

10.1.4 Results

Combining the information derived from the analysis of wind conditions (velocity, direction, and frequency), COPC concentrations in bank sediments, and percent fine particulates in sediments indicates that the most likely area of wind-blown sediment dispersal with the highest potential for enriching soils with COPCs is at Marcus Flats and Seven Bays.

Marcus Flats has the highest COPC concentrations and slightly elevated percent fines. It is windy, but not as windy as at Seven Bays, where winds blow with greater frequency but perhaps less velocity. Furthermore Marcus Flats has a large area of exposed sediments during the critical drawdown period between April and July.

Seven Bays also is open with large amounts of exposed sediments during the drawdown. Winds are frequent in this area, blowing from multiple directions but often blowing towards shore. Sediment concentrations of COPCs are not as high in this area as they are at Marcus Flats, but the percent fine particles may be higher.

Therefore, Marcus Flats and Seven Bays on the left bank (east side) of the river represent the reasonable worst case scenario for enrichment of soils by COPCs in wind-blown sediments. Soil sampling in these areas will provide confirmatory data about whether or not this possibility is realized.

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FIGURES

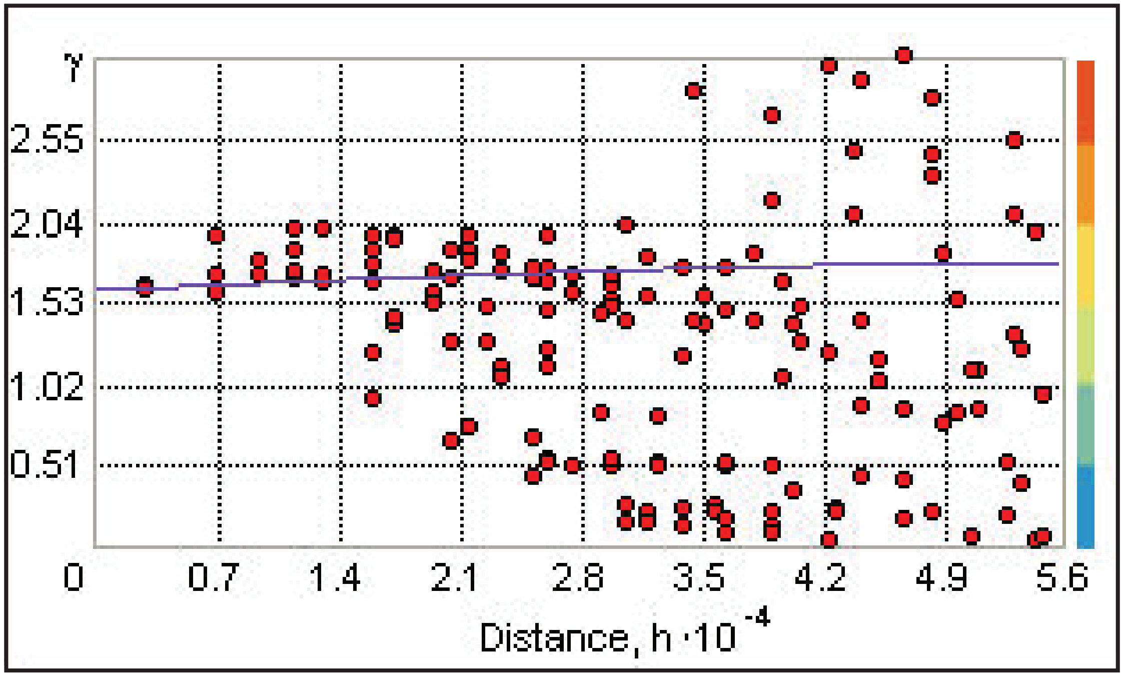


Figure 1. Variogram for Lead in Trail ERA Surface Soil Data

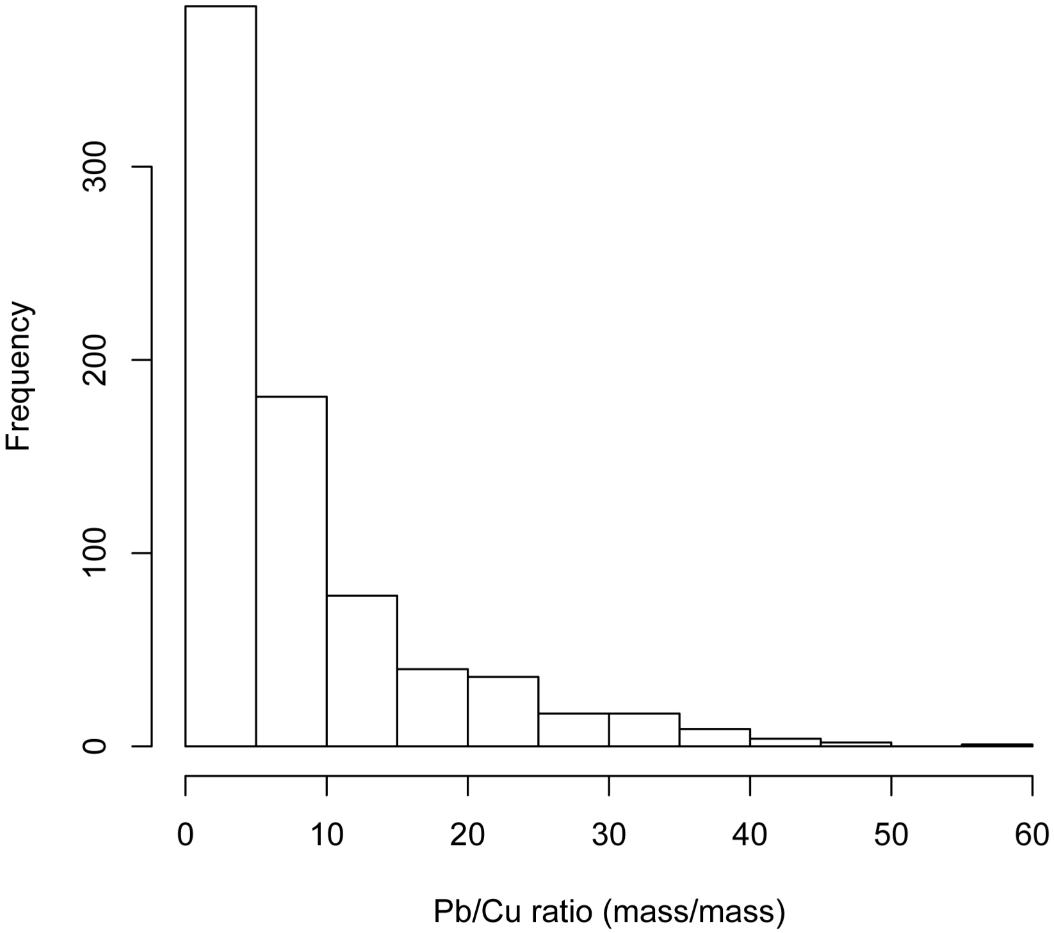


Figure 2. Statistical Distribution of Lead to Copper Ratios in Soil

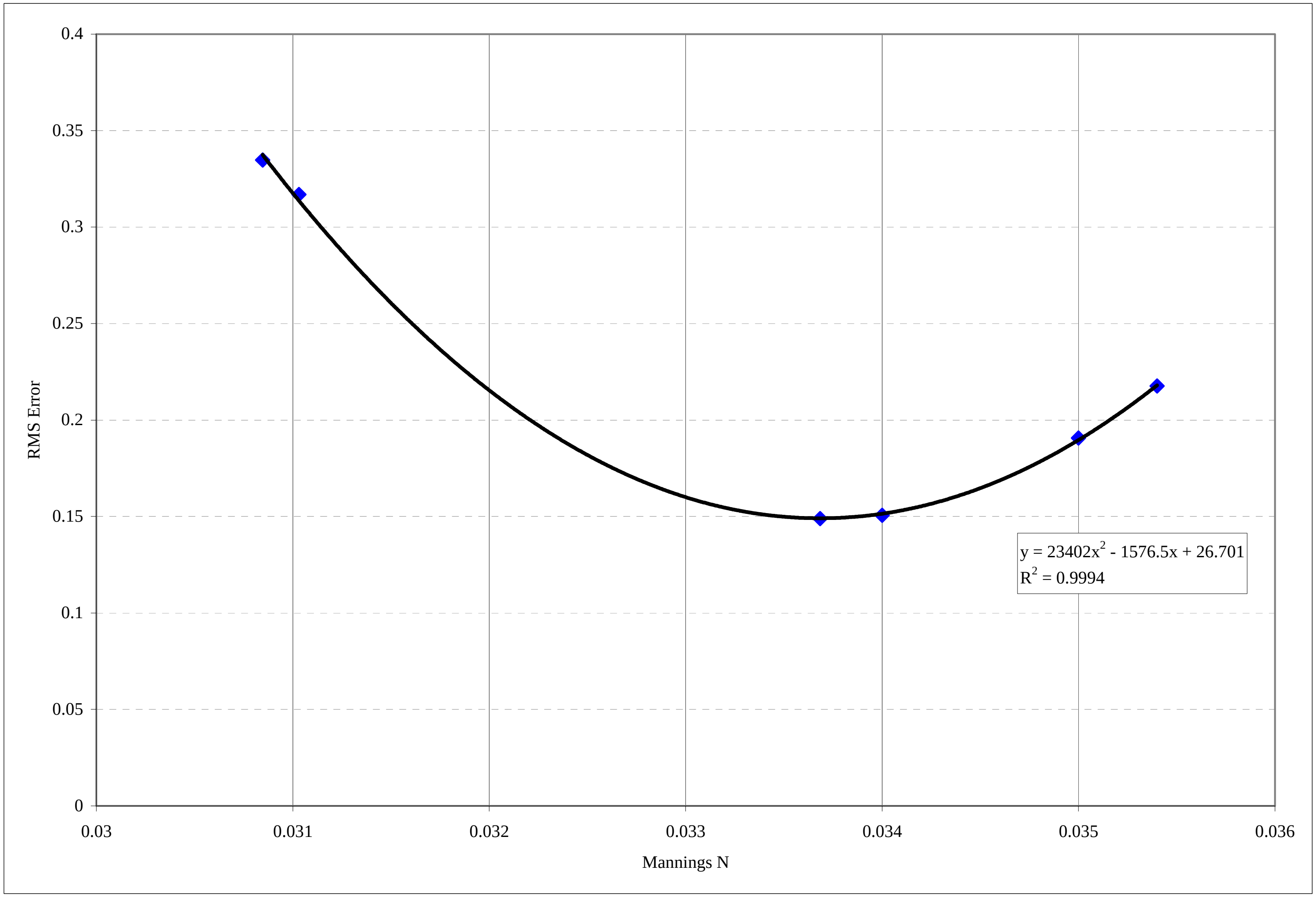
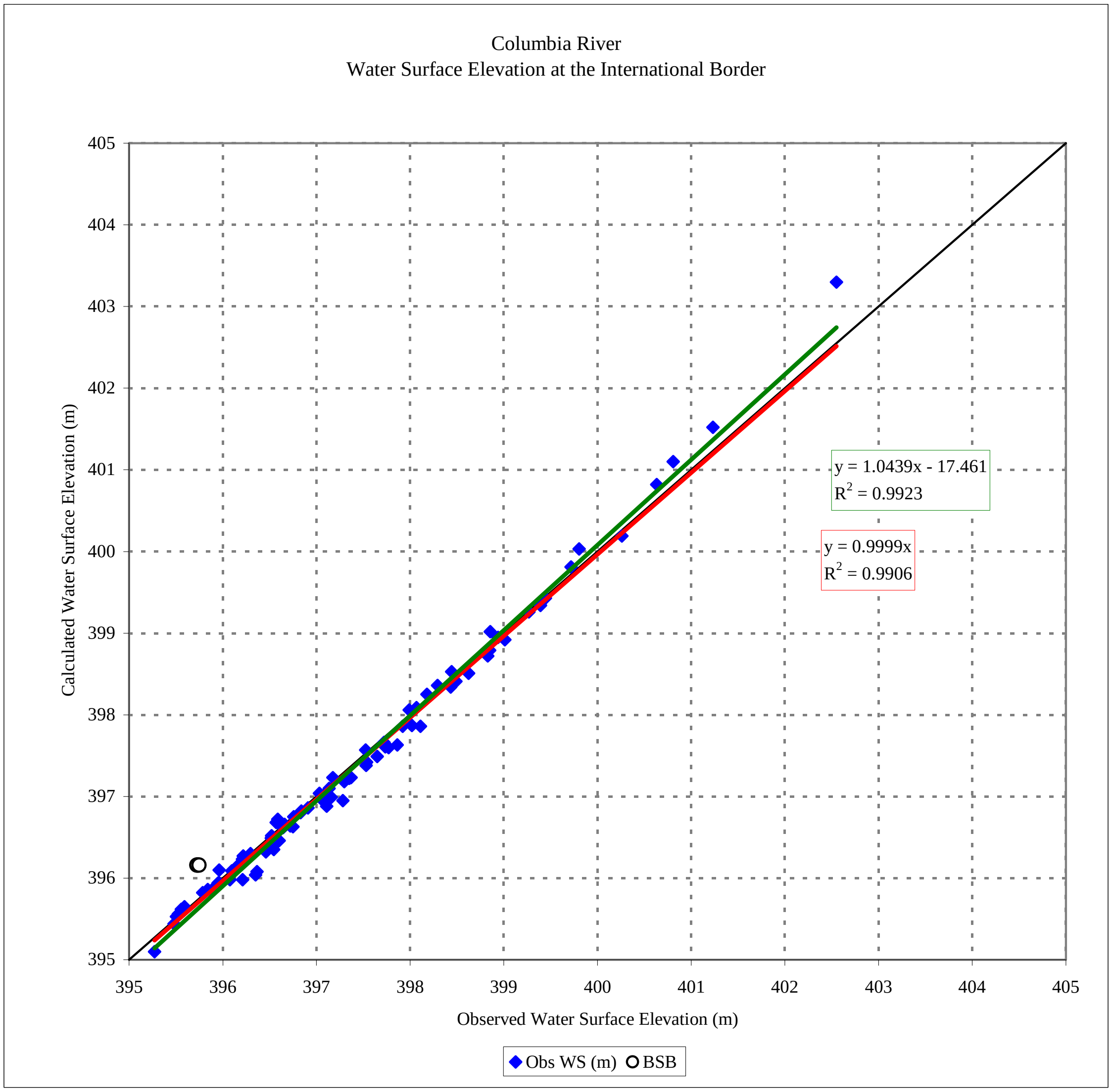


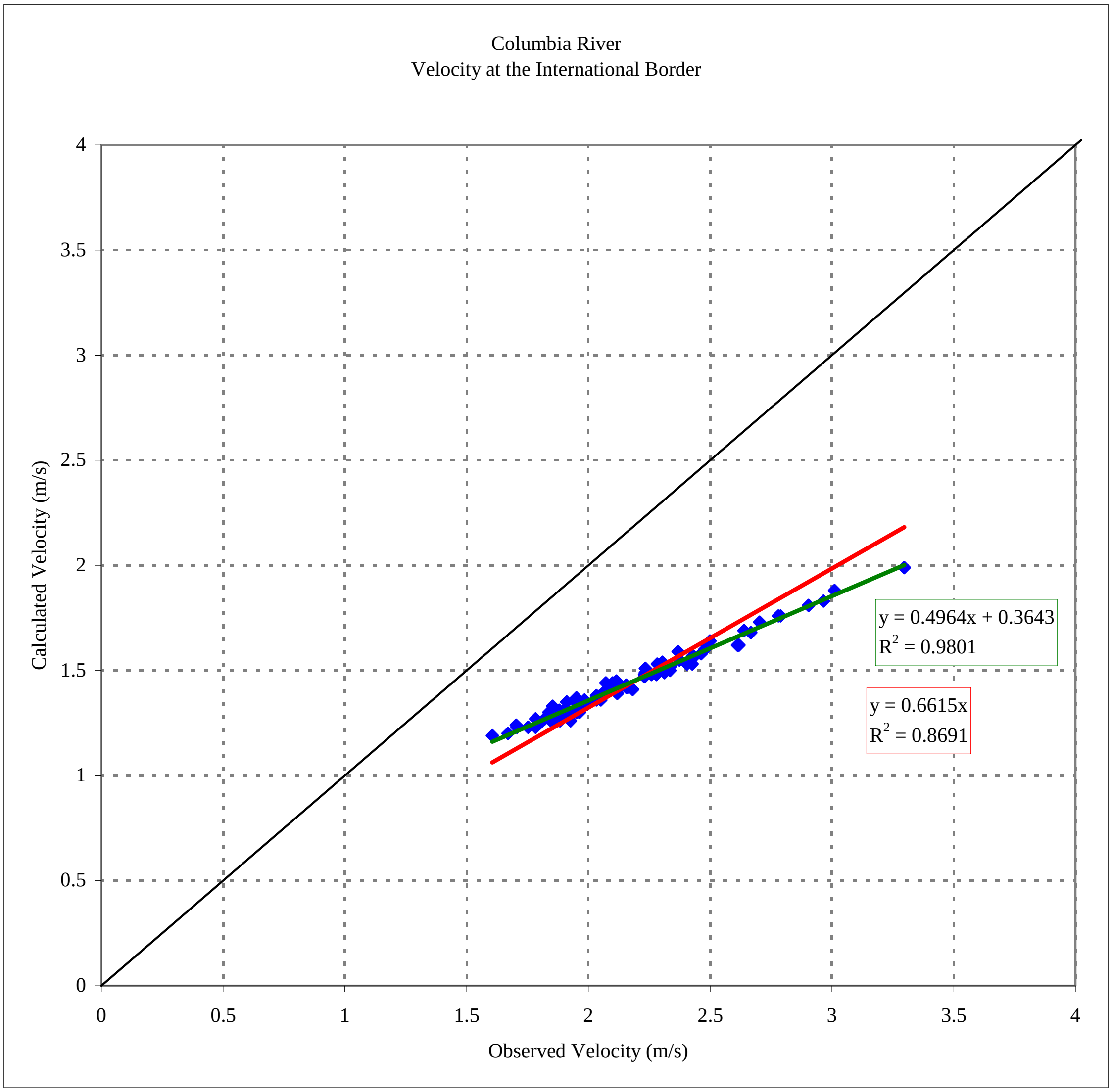
Figure 3. Optimization of Manning n: RMS Error (in meters)
Versus Manning n for Straight Sections of the Channel



Mean Error =	-0.03 (m)	RMS Error =	0.15 (m)
Maximum Error =	0.75064 (m)		
Minimum Error =	-0.332416 (m)		

Note: regression equations are shown for cases where the intercept of the regression is assumed to be zero (red) or allowed to be non-zero (green).

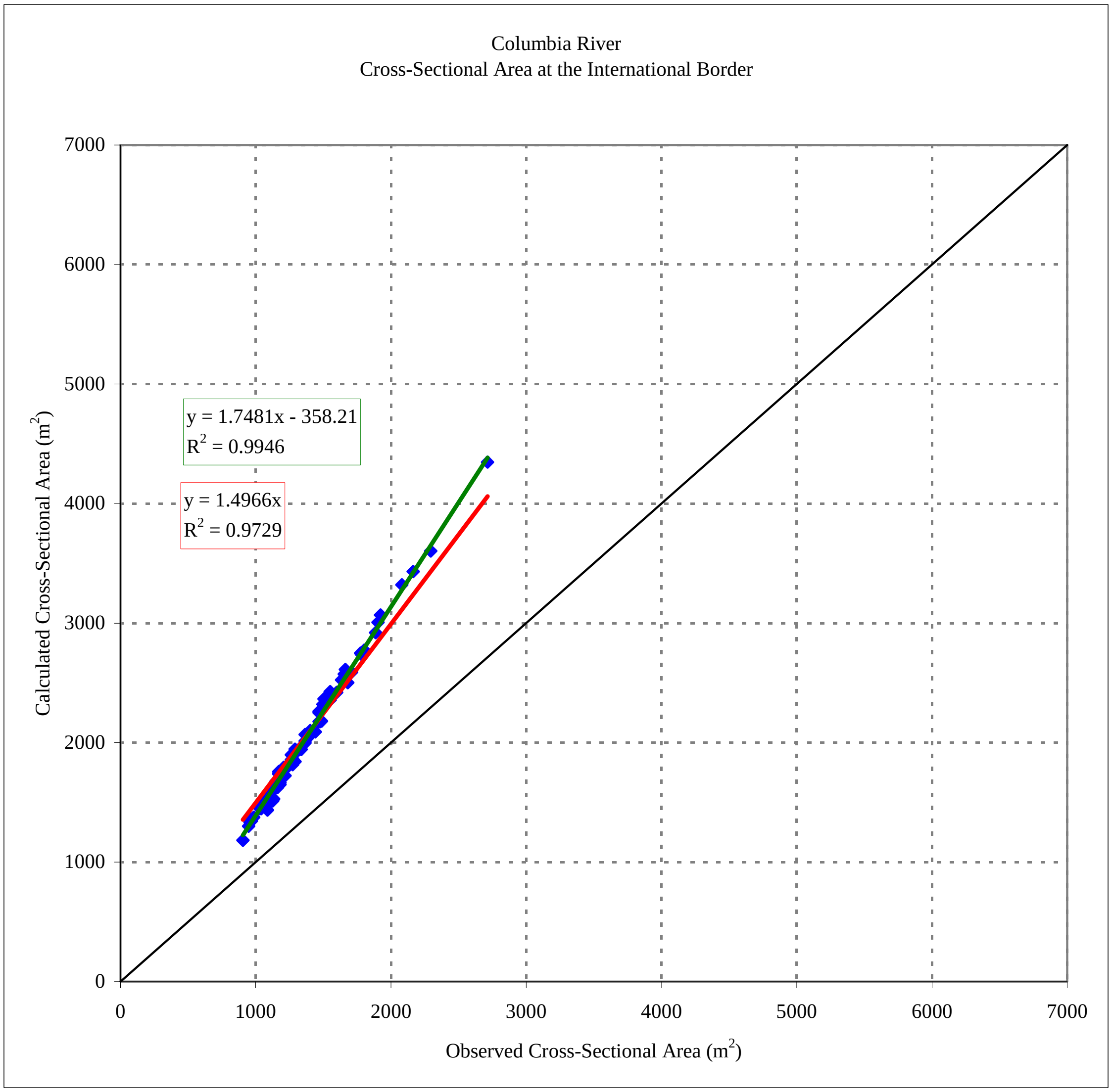
Figure 4. Calculated Versus Measured Water Surface Elevation at the U.S.–Canada Border and Including Measurements at Black Sand Beach



Mean Error =	-0.72 (m/s)		RMS Error =	0.74 (m/s)
Maximum Error =	-0.416296 (m/s)			
Minimum Error =	-1.307936 (m/s)			

Note: regression equations are shown for cases where the intercept of the regression is assumed to be zero (red) or allowed to be non-zero (green).

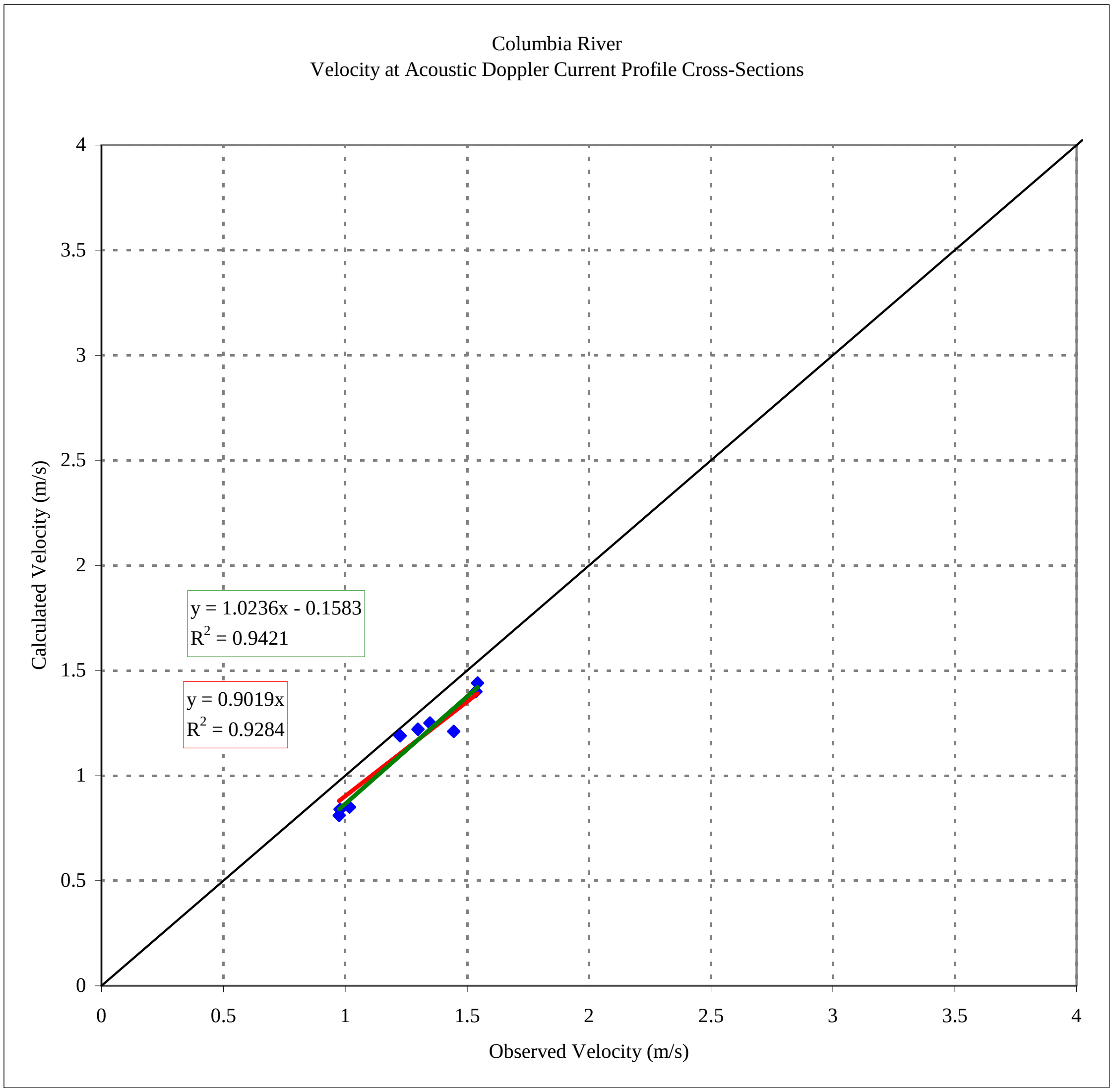
Figure 5. Calculated Versus Measured Velocity at the U.S.-Canada Border



Mean Error =	650.59 (m^2)	RMS Error =	694.59 (m^2)
Maximum Error =	1634.04123 (m^2)		
Minimum Error =	276.49536 (m^2)		

Note: regression equations are shown for cases where the intercept of the regression is assumed to be zero (red) or allowed to be non-zero (green).

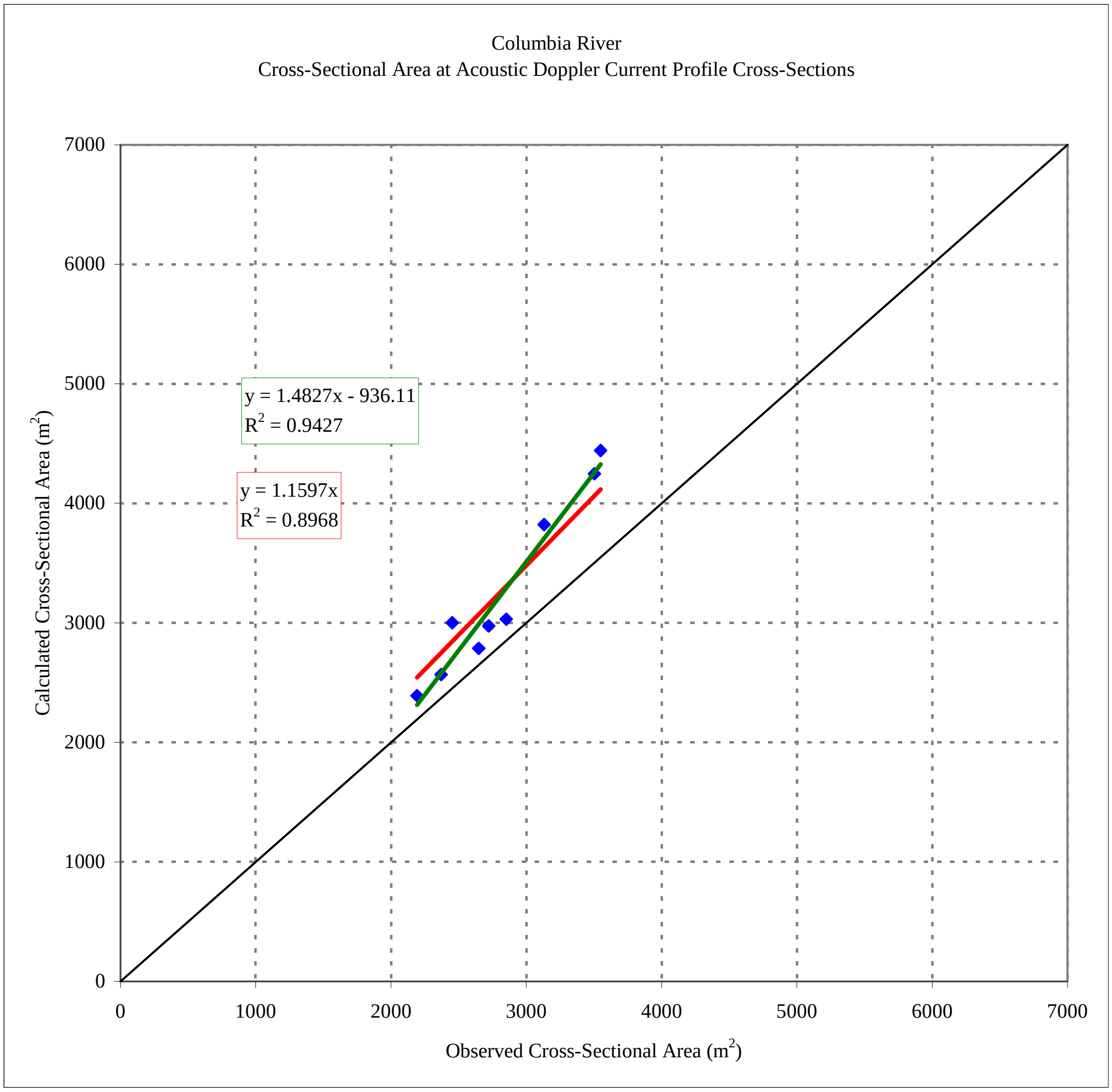
Figure 6. Calculated Versus Measured Cross-Section Area at the U.S.-Canada Border



Mean Error =	-0.13	(m/s)	RMS Error =	0.14 (m/s)
Maximum Error =	-0.035296	(m/s)		
Minimum Error =	-0.234752	(m/s)		

Note: regression equations are shown for cases where the intercept of the regression is assumed to be zero (red) or allowed to be non-zero (green).

Figure 7. Calculated Versus Measured
Velocity at ADCP Transects near Northport



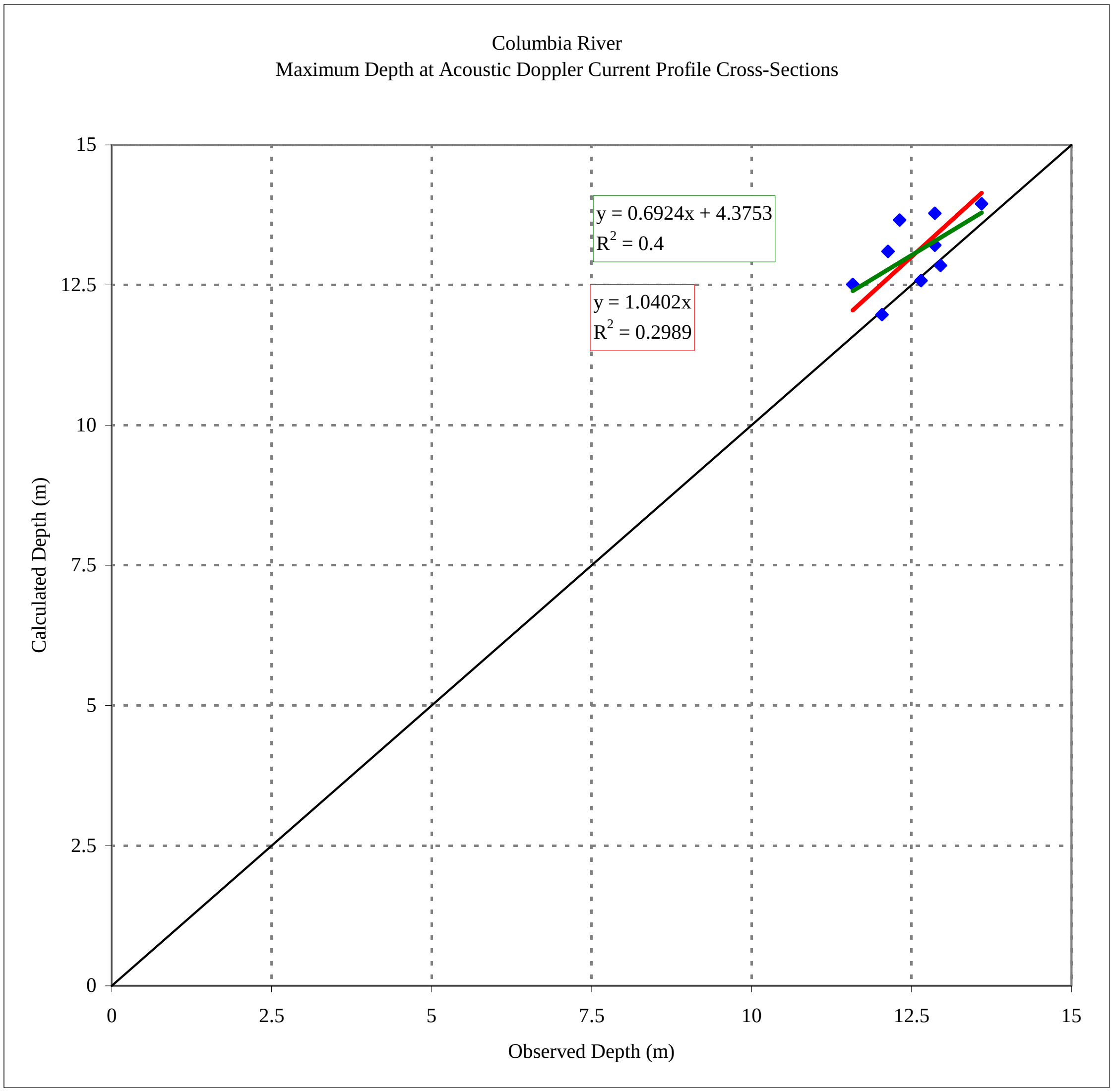
Columbia River
Cross-Sectional Area at Acoustic Doppler Current Profile Cross-Sections

Mean Error = 427.20 (m^2)
Maximum Error = 892.833872 (m^2)
Minimum Error = 138.75336 (m^2)

RMS Error = 508.42 (m^2)

Note: regression equations are shown for cases where the intercept of the regression is assumed to be zero (red) or allowed to be non-zero (green).

Figure 8. Calculated Versus Measured Cross-Section Area at ADCP Transects near Northport



Mean Error =	0.51 (m)		RMS Error =	0.72 (m)
Maximum Error =	1.34608 (m)			
Minimum Error =	-0.104 (m)			

Note: regression equations are shown for cases where the intercept of the regression is assumed to be zero (red) or allowed to be non-zero (green).

Figure 9. Calculated Versus Measured Maximum Depth at ADCP Transects near Northport

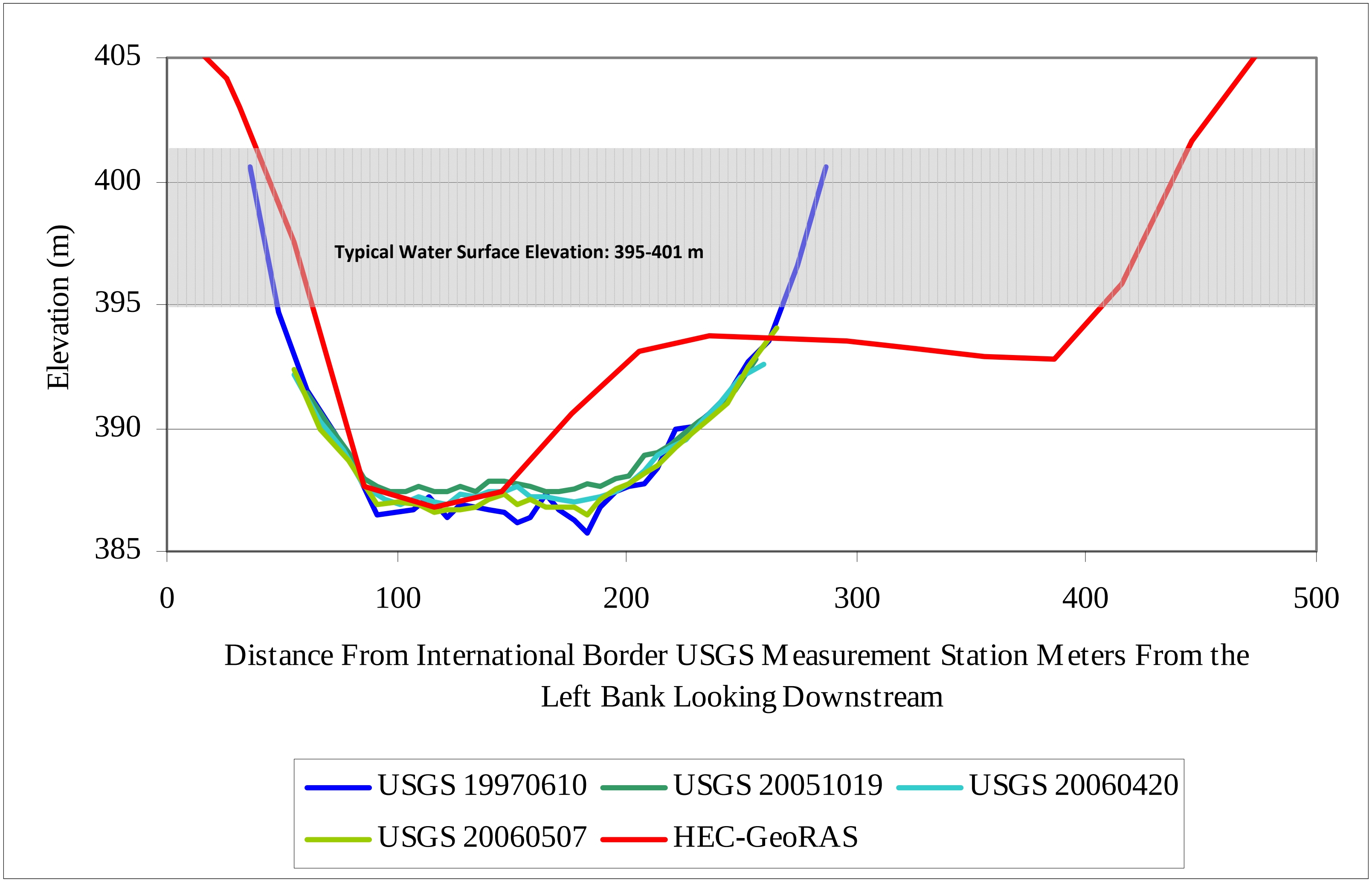
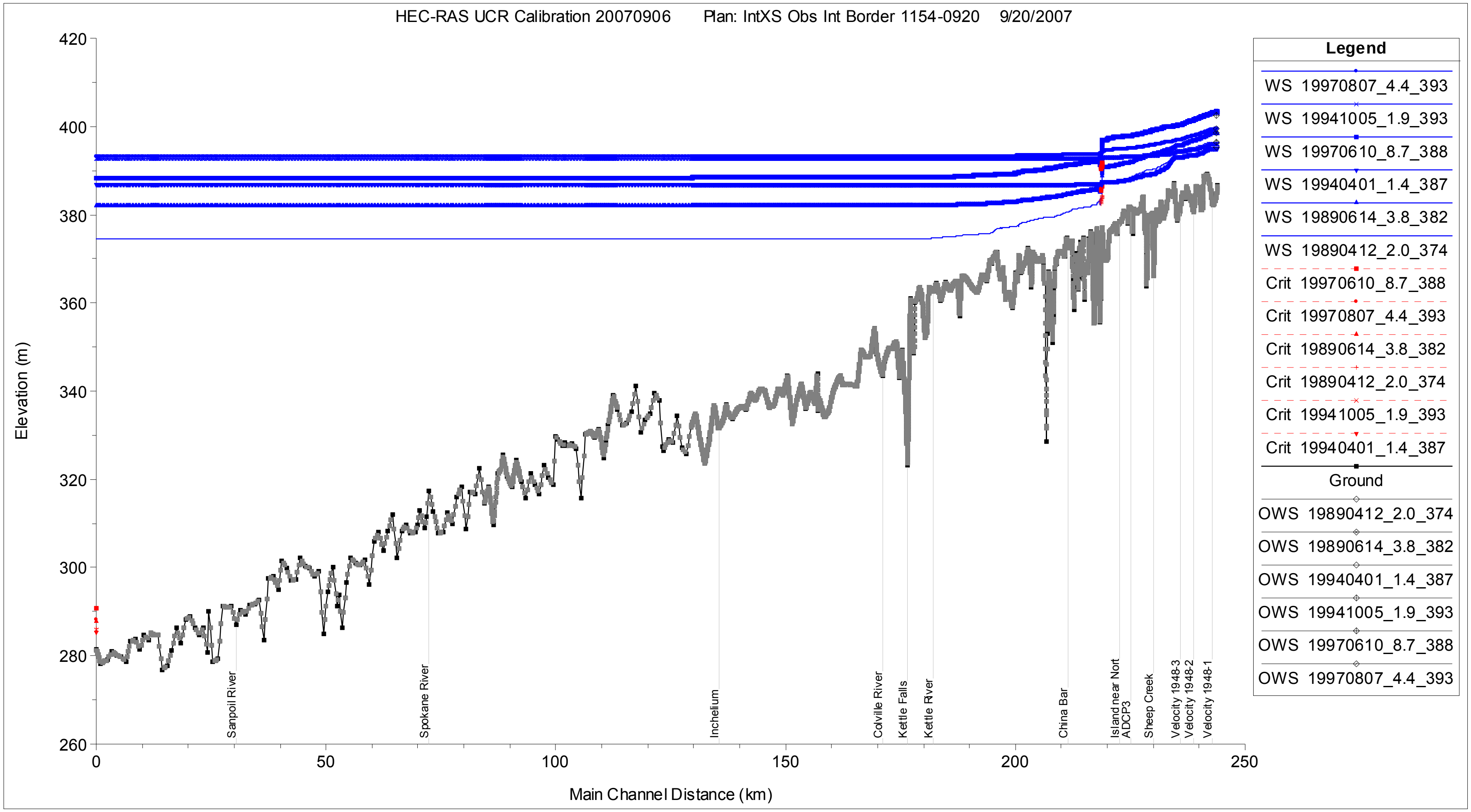
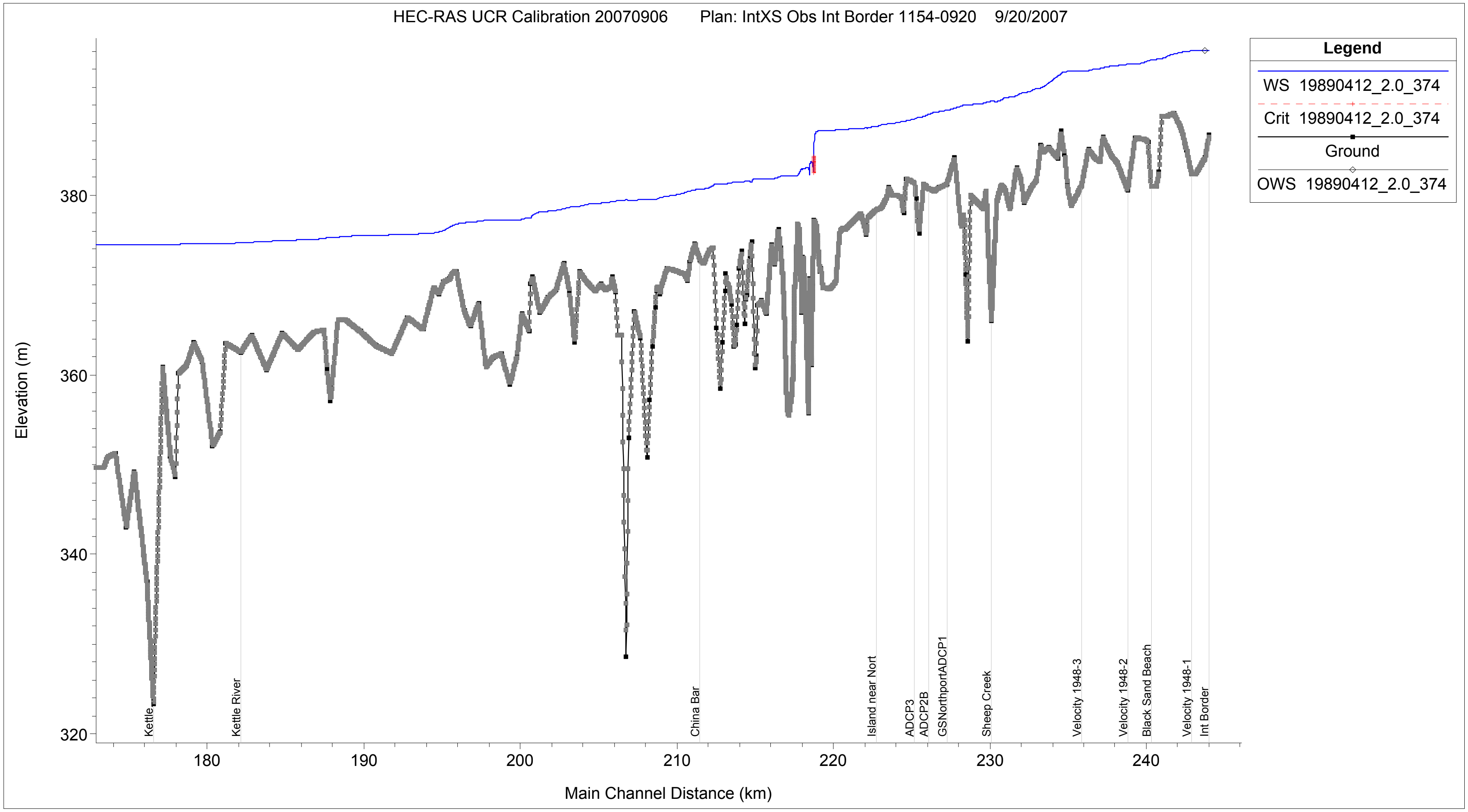


Figure 10. Interpolated (HEC-GeoRAS based on kriged bathymetric surface) Versus Measured Cross-Section Area at the U.S.-Canada Border



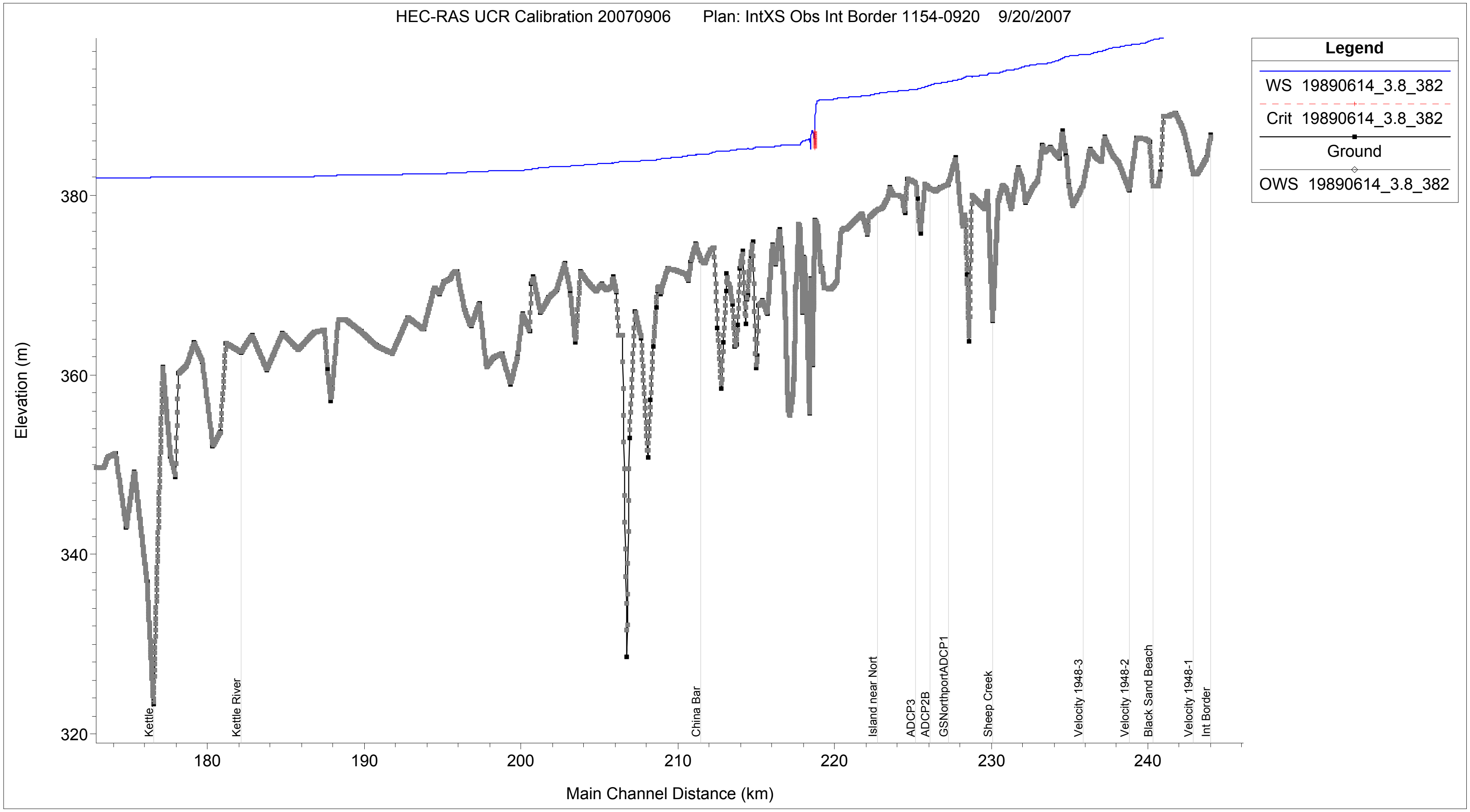
Note: Profile labels detail the date (in YYYYMMDD format), the upstream flow condition (in 1000 m^3/s), and the downstream water level (m) at Grand Coulee Dam.

Figure 11. Calculated Water Surfaces for the Full Spatial Extent of UCR HEC-RAS Hydraulic Analyses



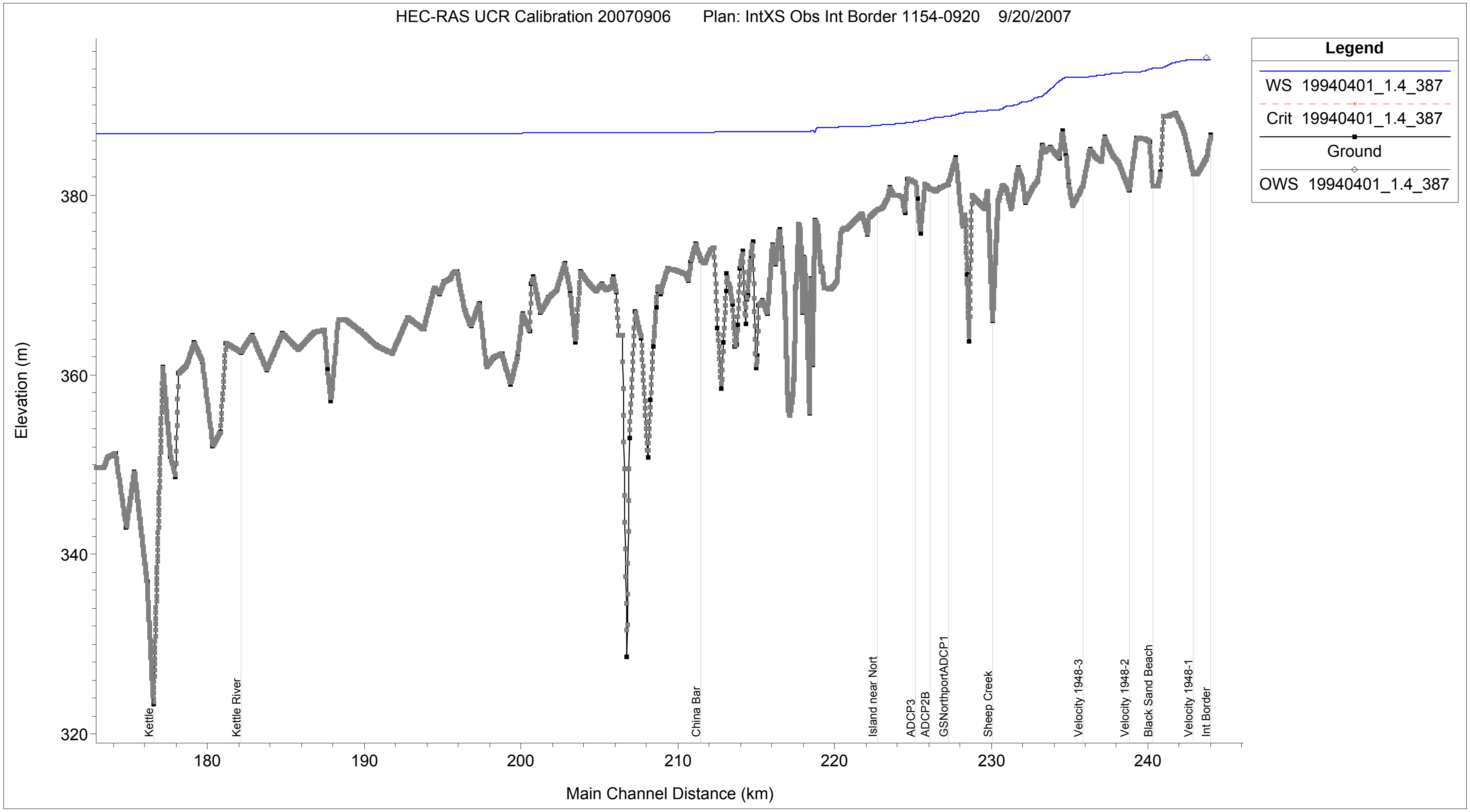
Note: Profile labels detail the date (in YYYYMMDD format), the upstream flow condition (in 1000 m^3/s), and the downstream water level (m) at Grand Coulee Dam.

Figure 12. Calculated Water Surface for the Lowest Dam Elevation and Flow Conditions at the U.S.-Canada Border, April 12, 1989



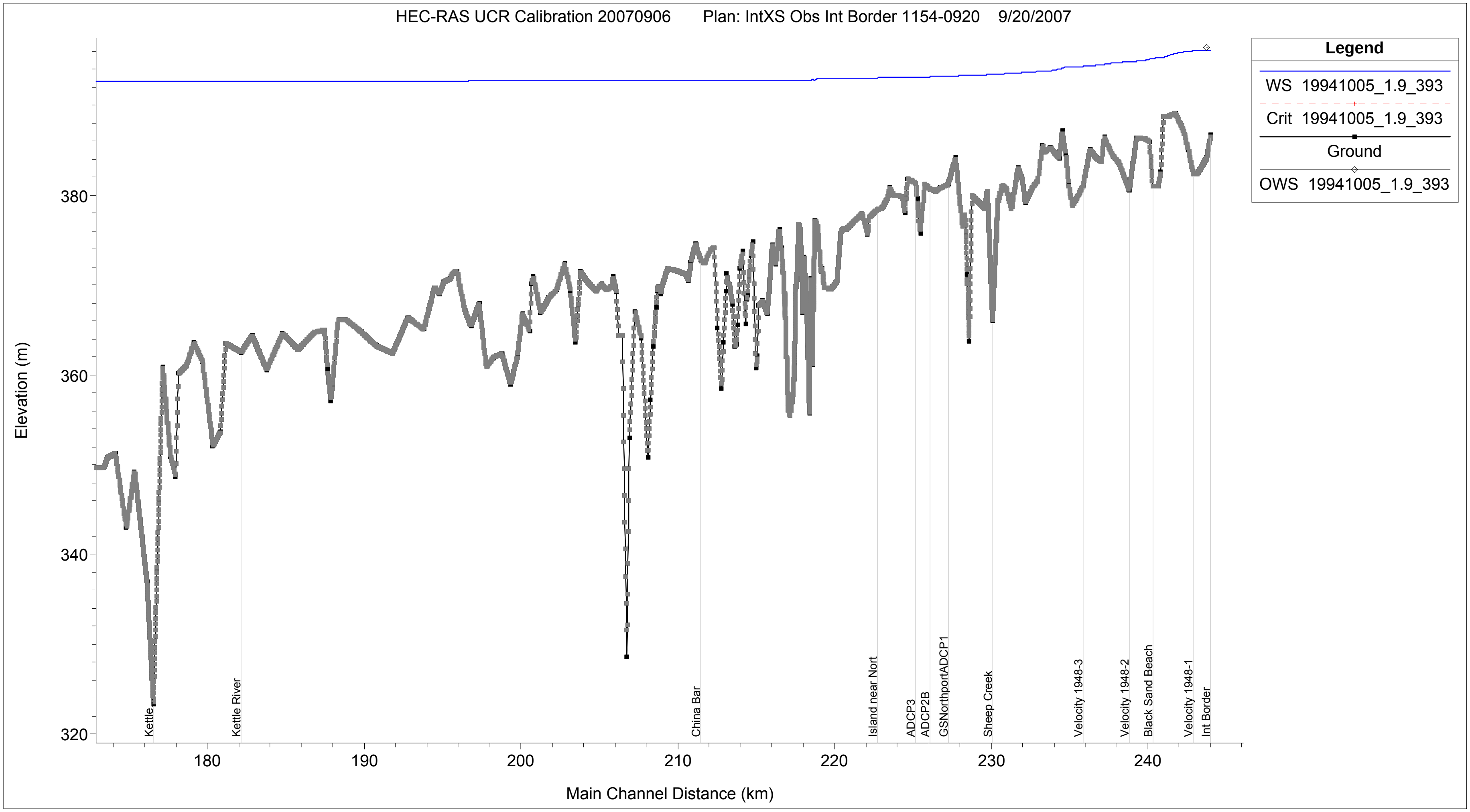
Note: Profile labels detail the date (in YYYYMMDD format), the upstream flow condition (in 1000 m^3/s), and the downstream water level (m) at Grand Coulee Dam.

Figure 13. Calculated Water Surface for the Highest Dam Elevation and Flow Conditions at the U.S.-Canada Border, June 14, 1989



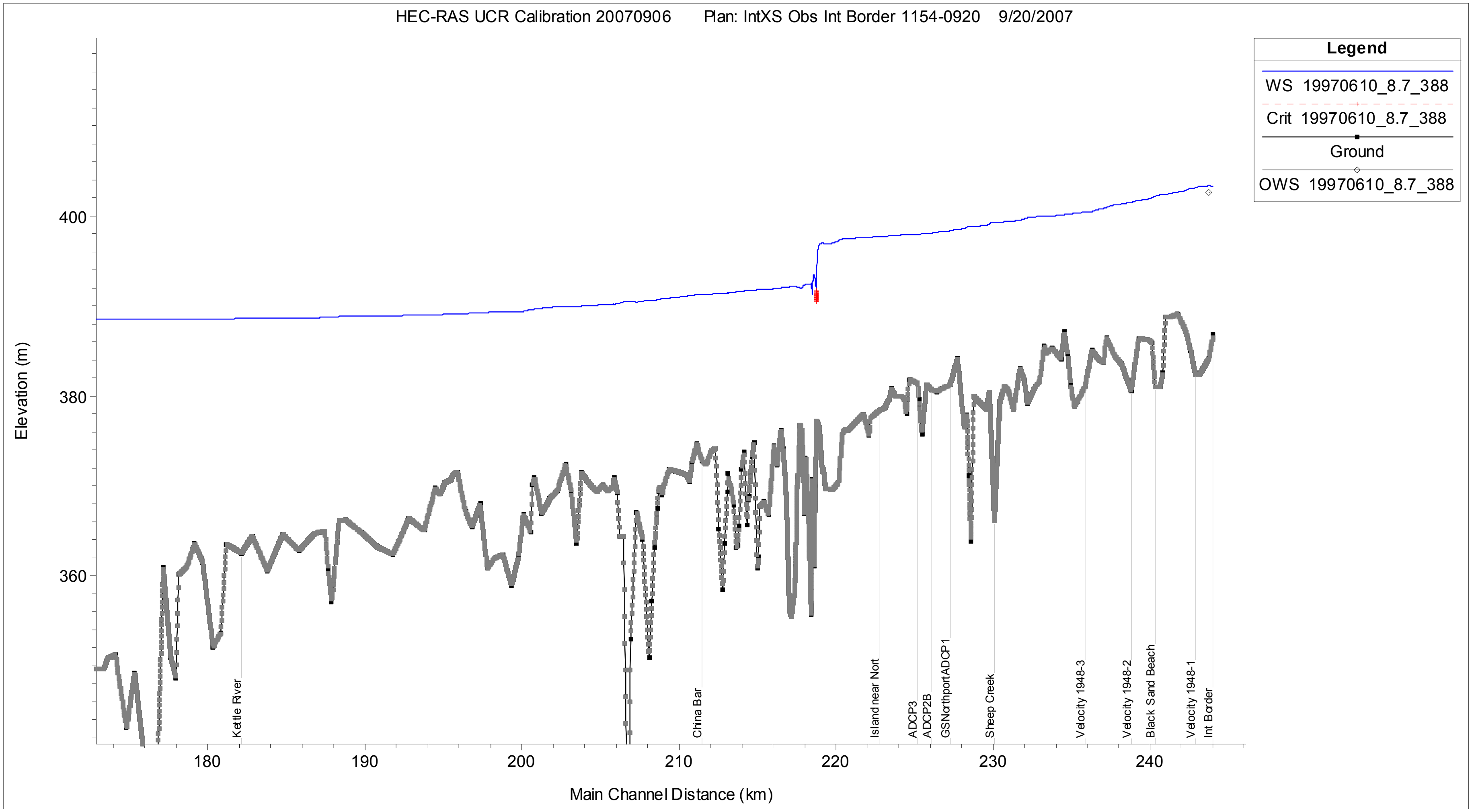
Note: Profile labels detail the date (in YYYYMMDD format), the upstream flow condition (in 1000 m^3/s), and the downstream water level (m) at Grand Coulee Dam.

Figure 14. Lowest Upstream Flow with Observed U.S.-Canada Border Elevation



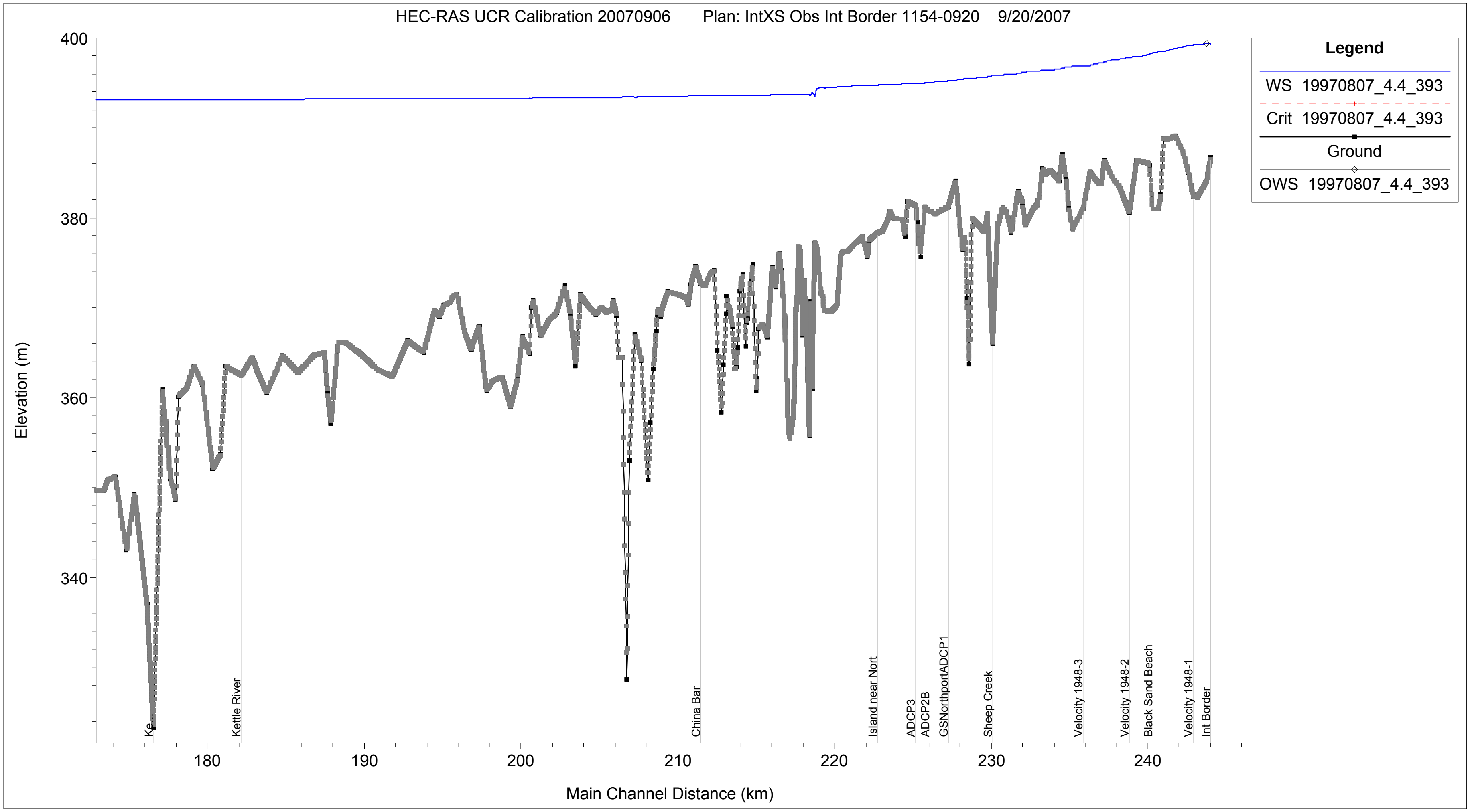
Note: Profile labels detail the date (in YYYYMMDD format), the upstream flow condition (in 1000 m^3/s), and the downstream water level (m) at Grand Coulee Dam.

Figure 15. High Dam Elevation with Low Upstream Flow and Observed U.S.-Canada Border Elevation



Note: Profile labels detail the date (in YYYYMMDD format), the upstream flow condition (in 1000 m^3/s), and the downstream water level (m) at Grand Coulee Dam.

Figure 16. Highest Upstream Flow with Observed U.S.-Canada Border Elevation



Note: Profile labels detail the date (in YYYYMMDD format), the upstream flow condition (in 1000 m^3/s), and the downstream water level (m) at Grand Coulee Dam.

Figure 17. High Dam Elevation with High Upstream Flow and Observed U.S.-Canada Border Elevation

Figure 18. Aerial Photograph Identifying the Location of the Little Dalles Constriction Along the Upper Columbia River

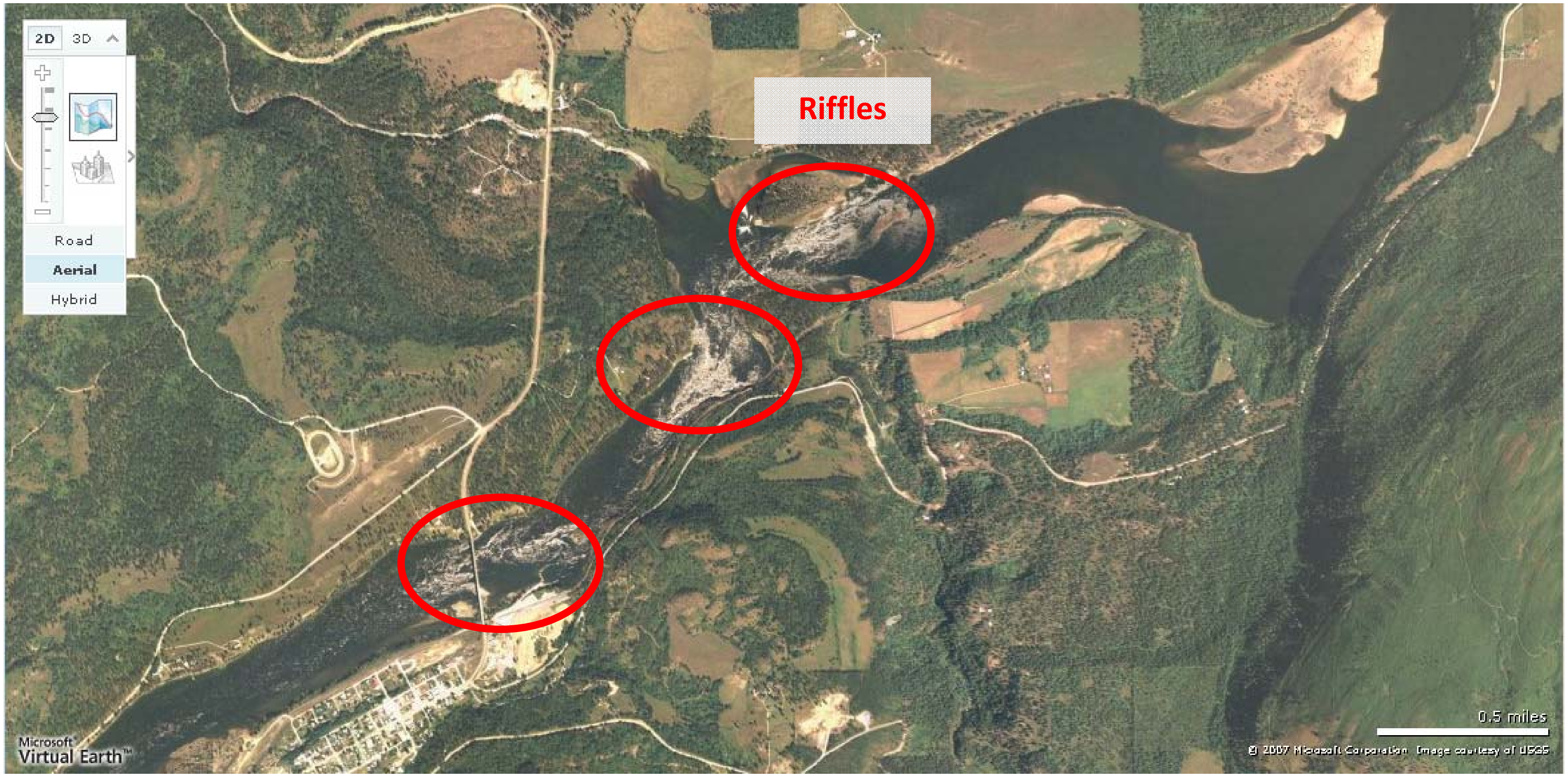


Figure 19. Aerial Photograph Identifying the Location of the Riffles Along the Upper Columbia River near Northport

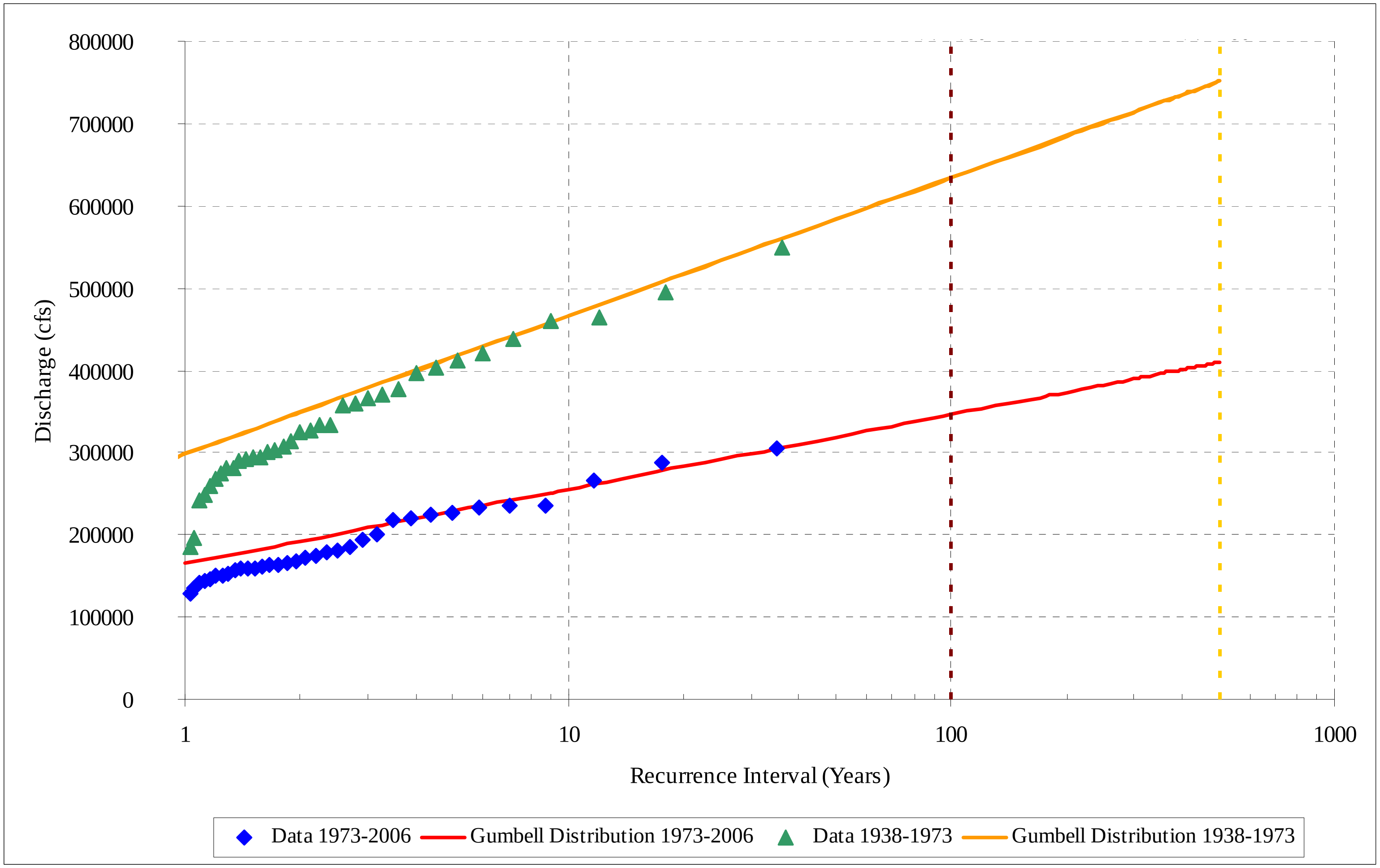


Figure 20. Estimated Flood Magnitude vs. Recurrence Interval for the Upper Columbia River: Gumbel Distribution

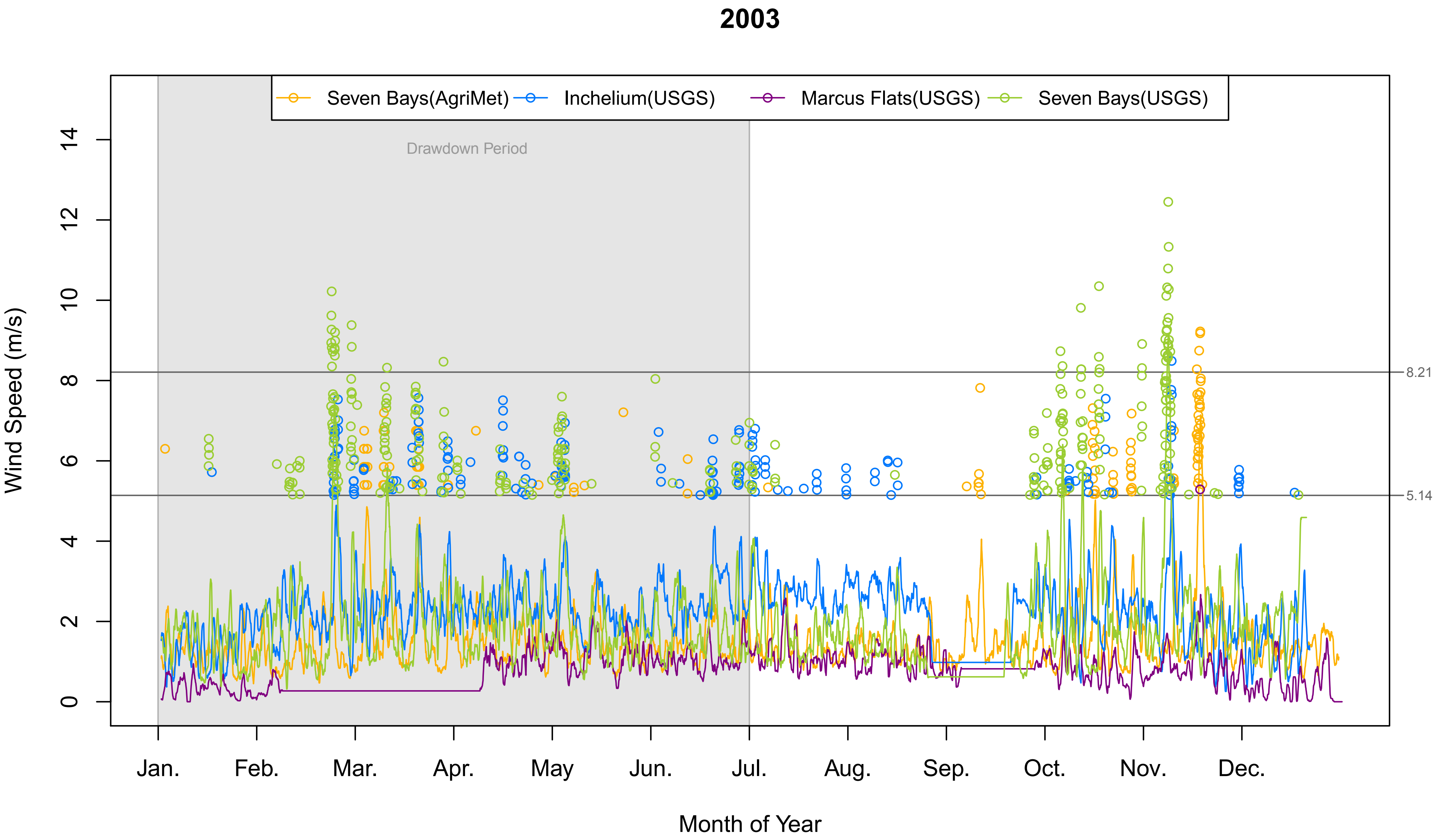


Figure 21. Wind Speed Data for 2003 from UCR Monitoring Stations
Hourly wind speed > 5.14 m/s shown as individual points; continuous line represents 24−h rolling average wind speed at each station.

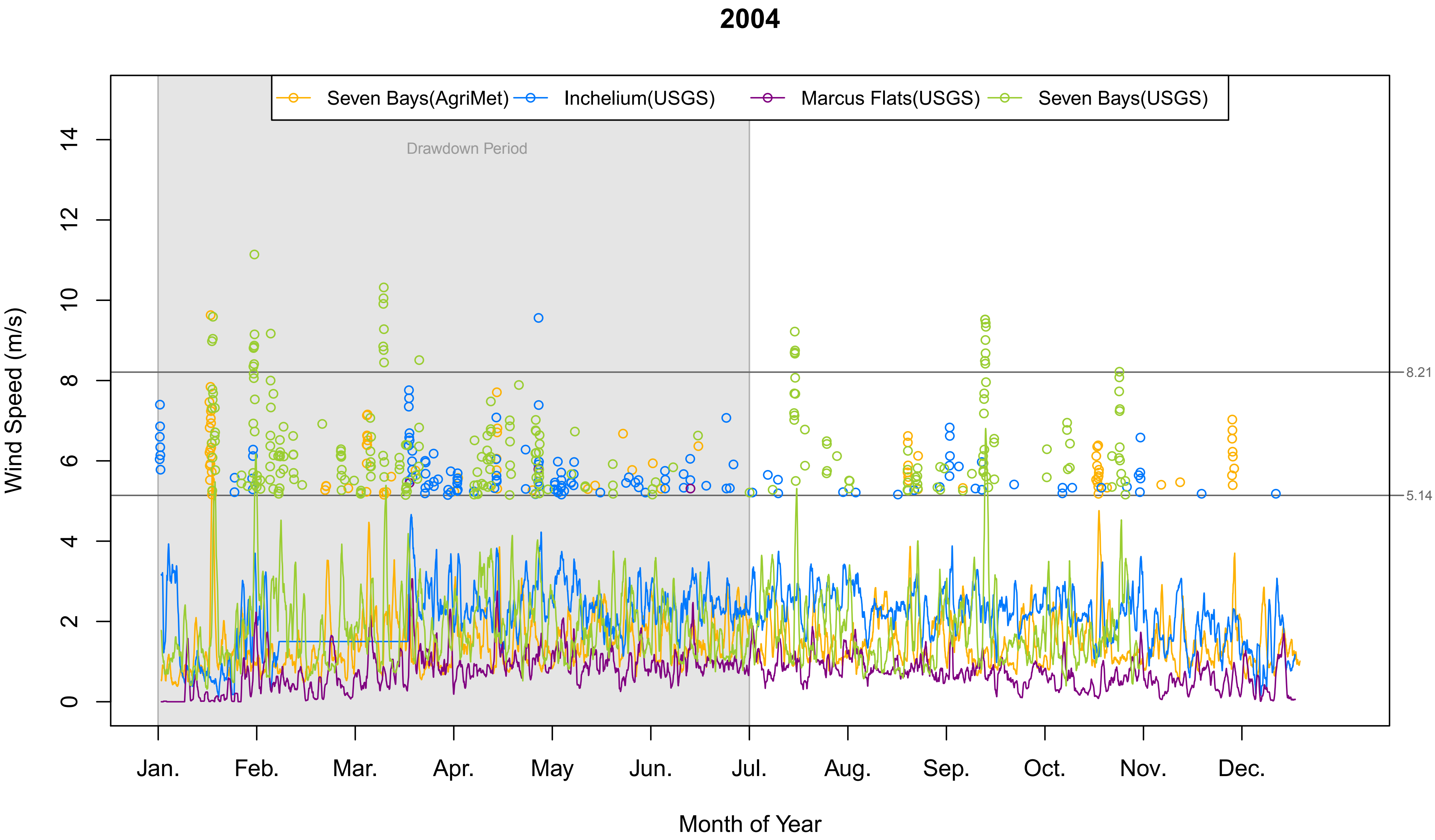


Figure 22. Wind Speed Data for 2004 from UCR Monitoring Stations
Hourly wind speed > 5.14 m/s shown as individual points; continuous line represents 24−h rolling average wind speed at each station.

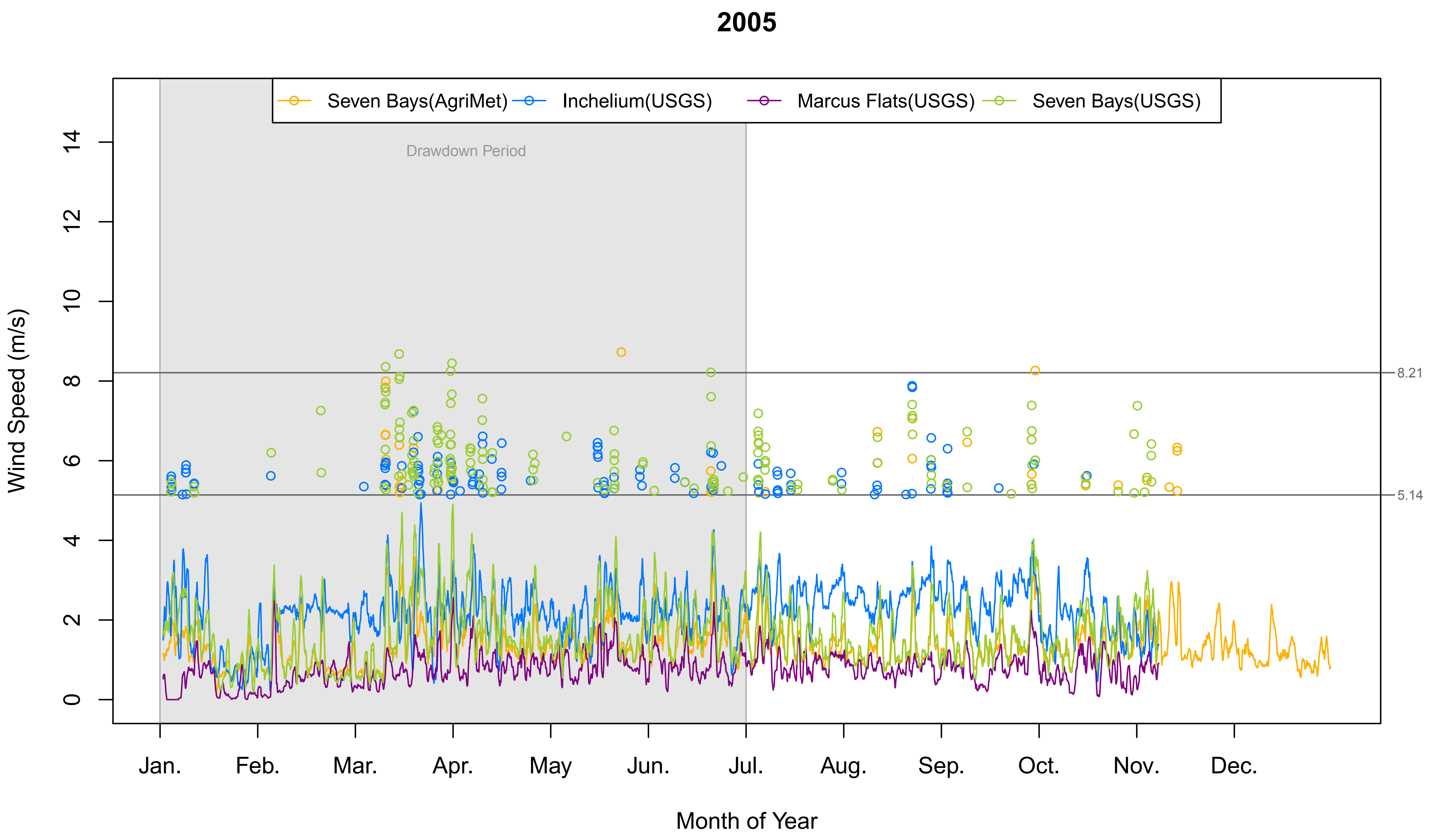


Figure 23. Wind Speed Data for 2005 from UCR Monitoring Stations
Hourly wind speed > 5.14 m/s shown as individual points; continuous line represents 24−h rolling average wind speed at each station.

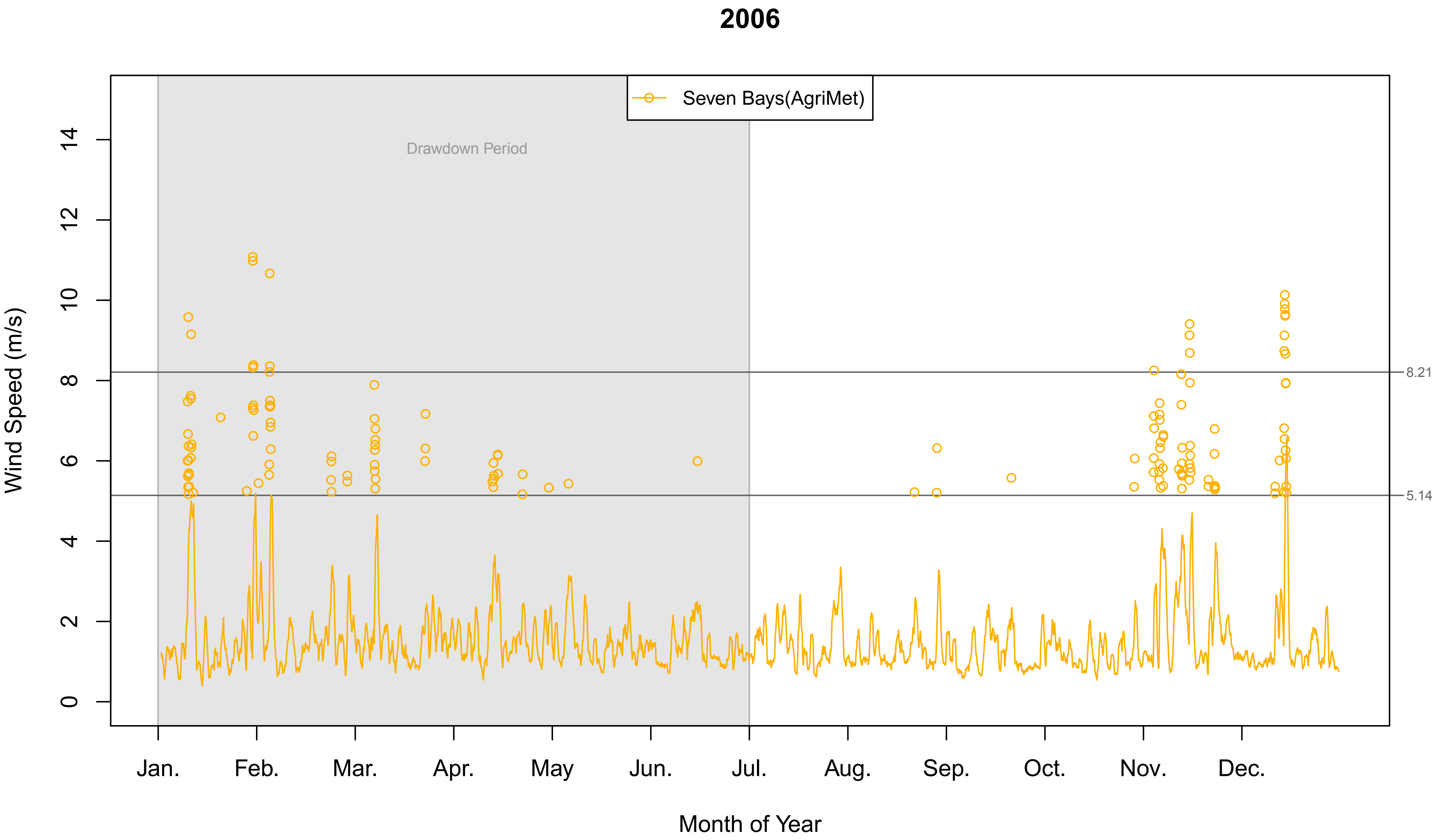


Figure 24. Wind Speed Data for 2006 from UCR Monitoring Stations
Hourly wind speed > 5.14 m/s shown as individual points; continuous line represents 24−h rolling average wind speed at each station.

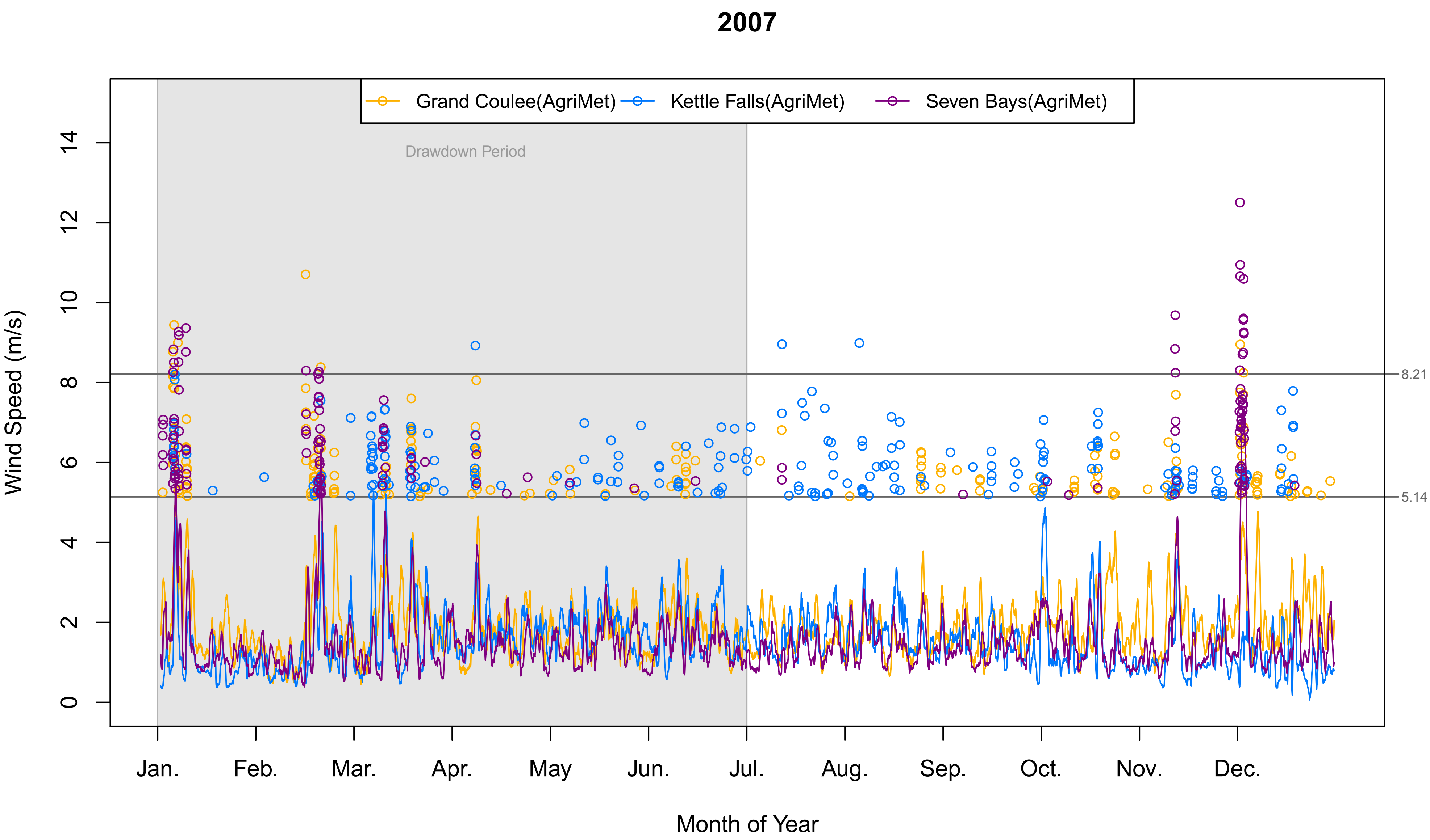


Figure 25. Wind Speed Data for 2007 from UCR Monitoring Stations
Hourly wind speed > 5.14 m/s shown as individual points; continuous line represents 24−h rolling average wind speed at each station.

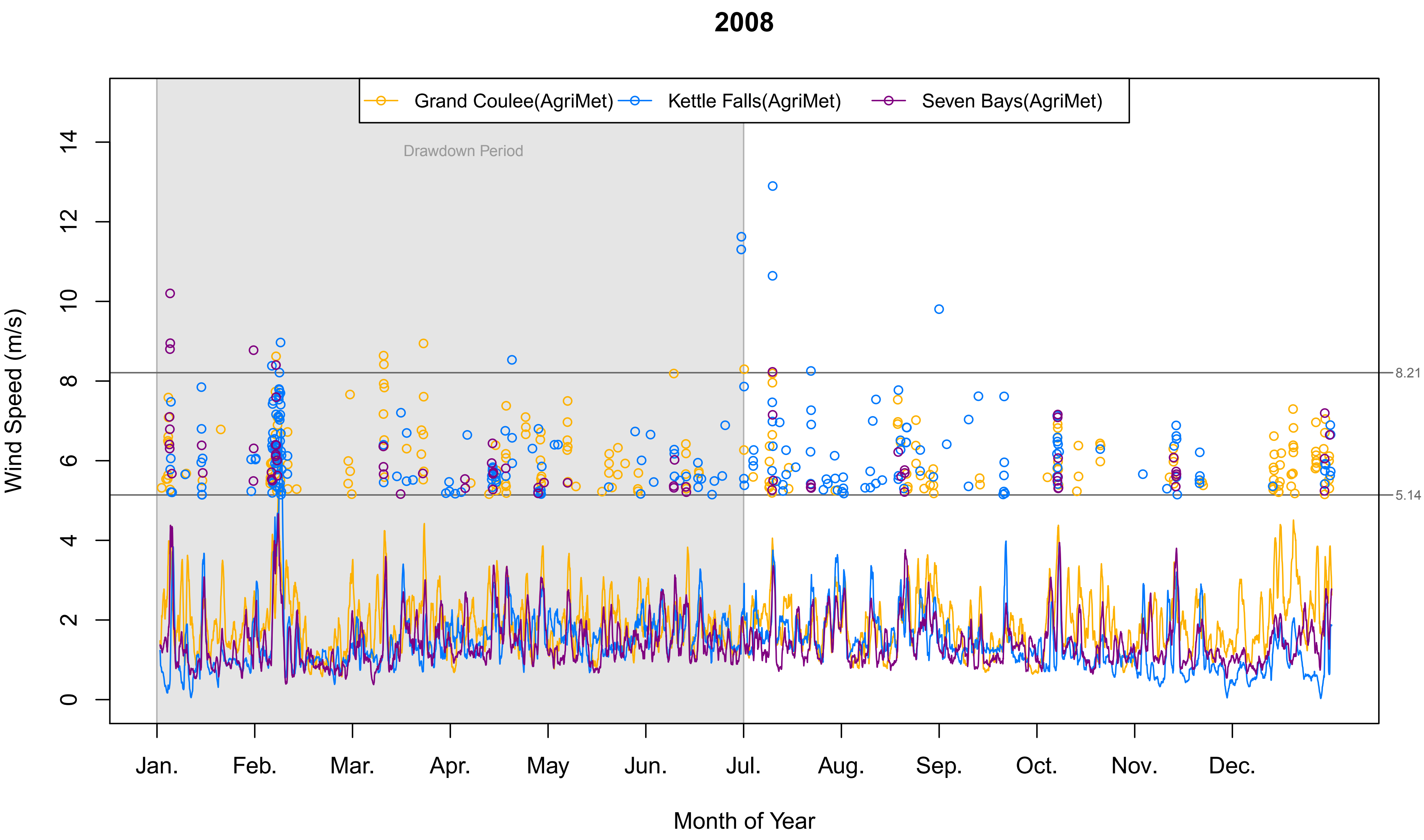


Figure 26. Wind Speed Data for 2008 from UCR Monitoring Stations
Hourly wind speed > 5.14 m/s shown as individual points; continuous line represents 24−h rolling average wind speed at each station.

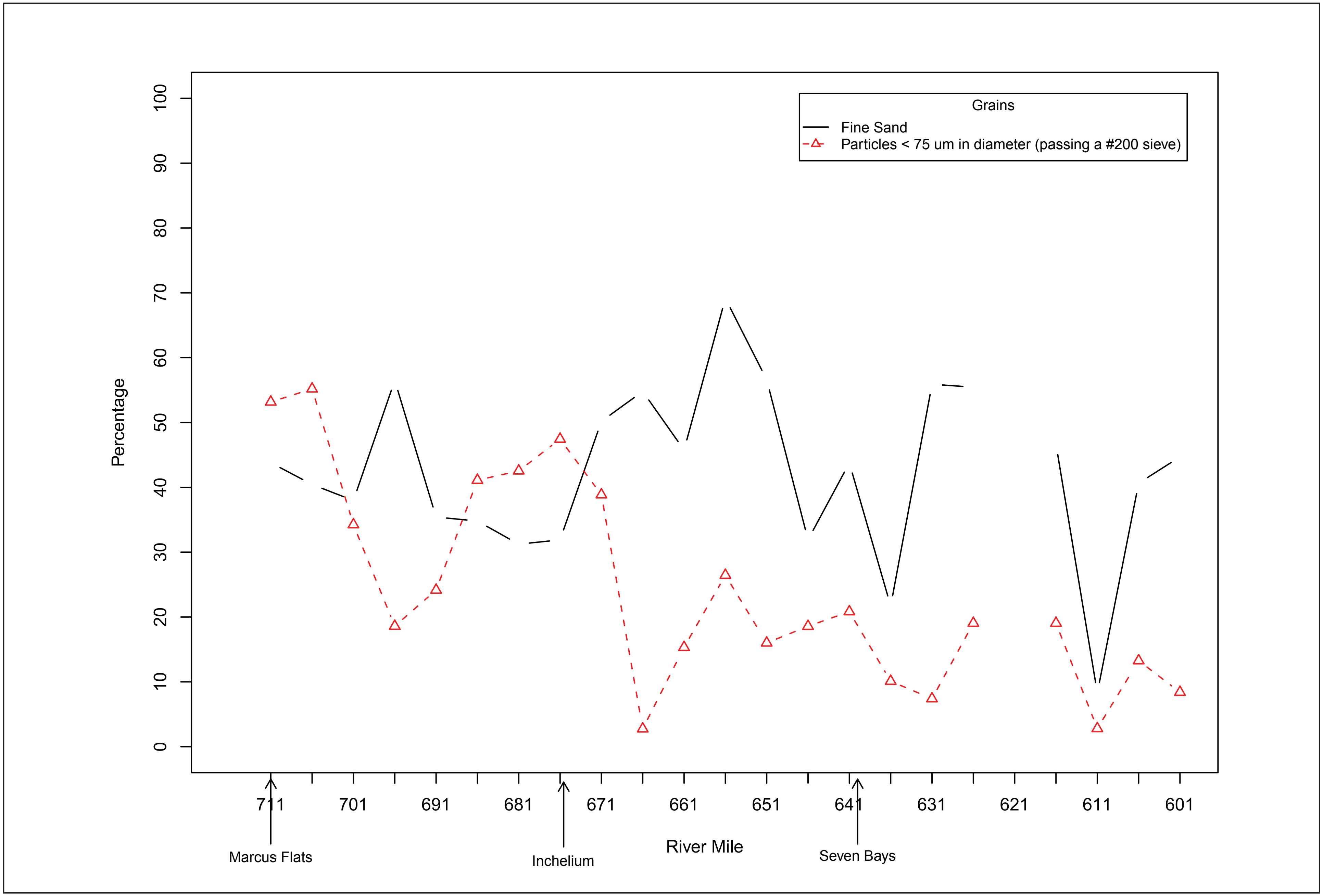


Figure 27. Selected Grainsize Percentages in Right Bank Sediments

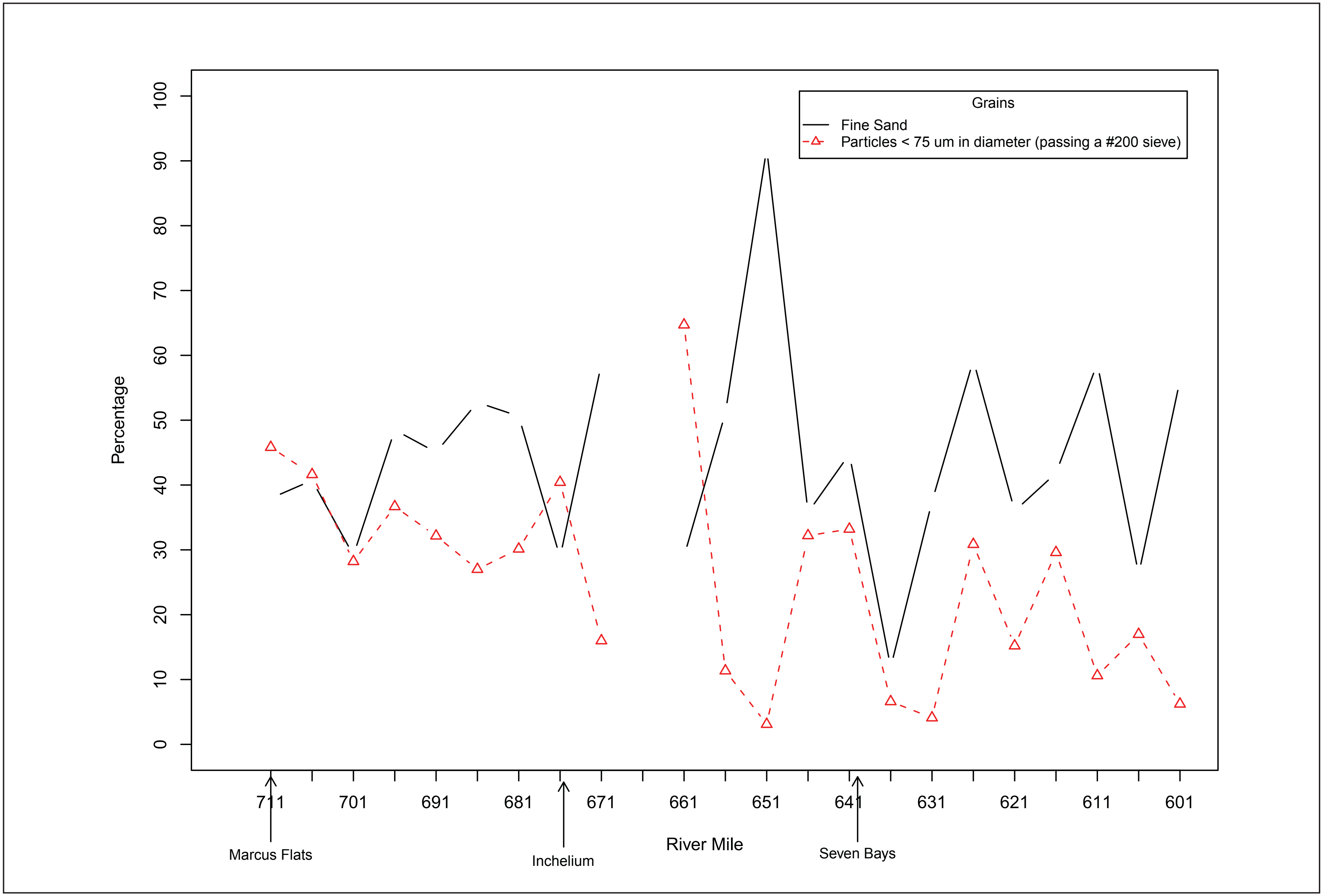


Figure 28. Selected Grainsize Percentages in Left Bank Sediments

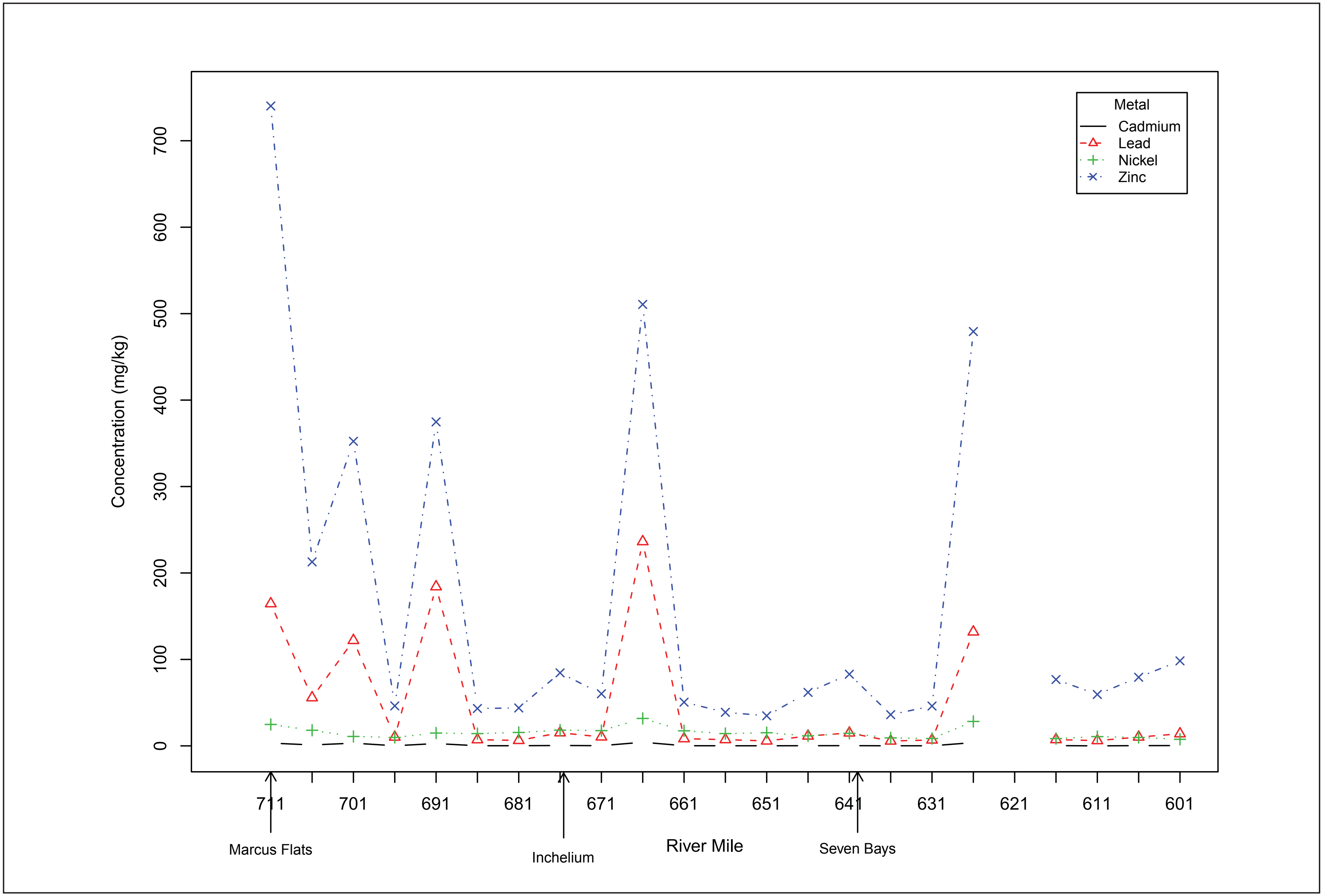


Figure 29. Selected Metals Concentrations in Right Bank Sediments

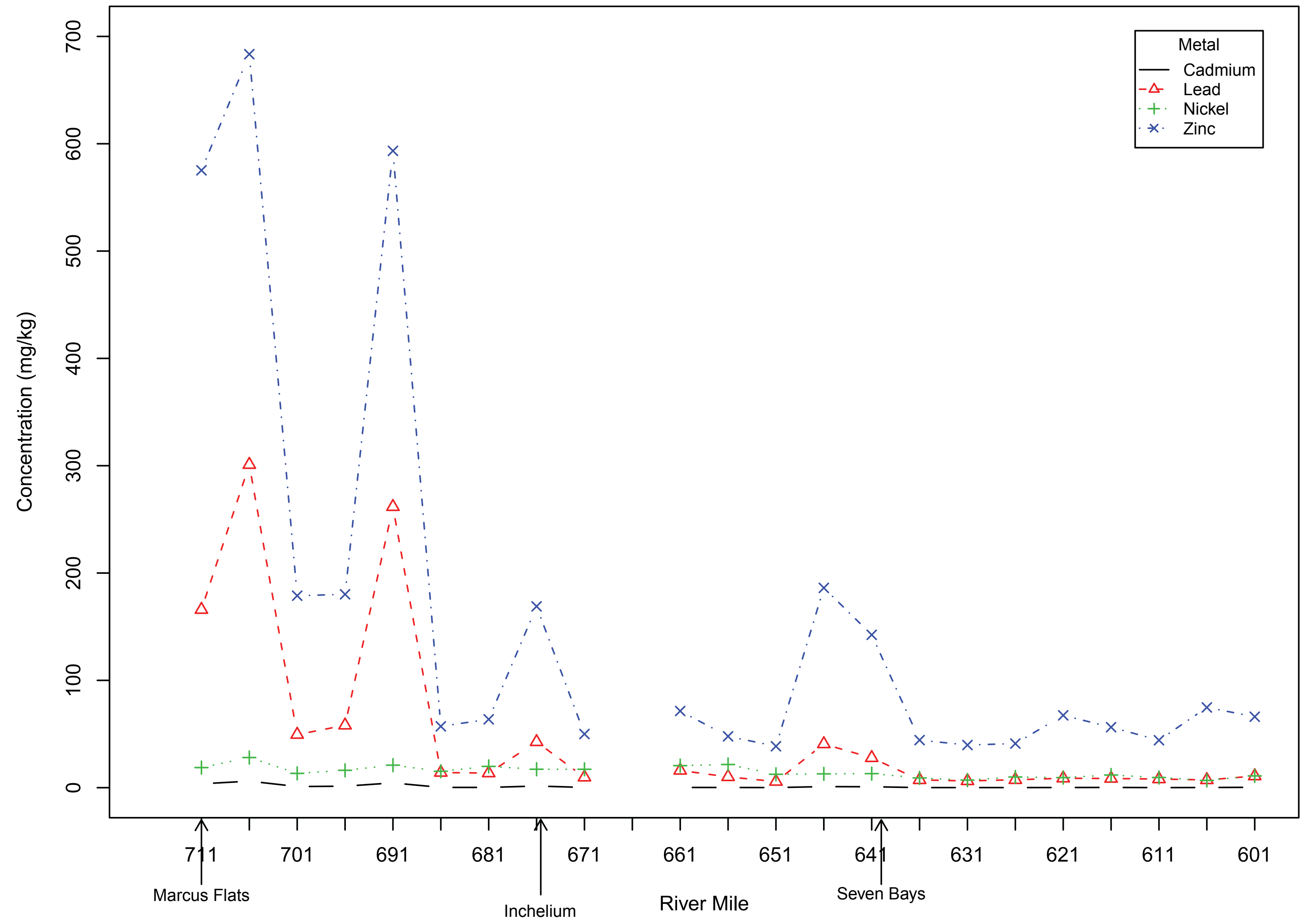


Figure 30. Selected Metals Concentrations in Left Bank Sediments

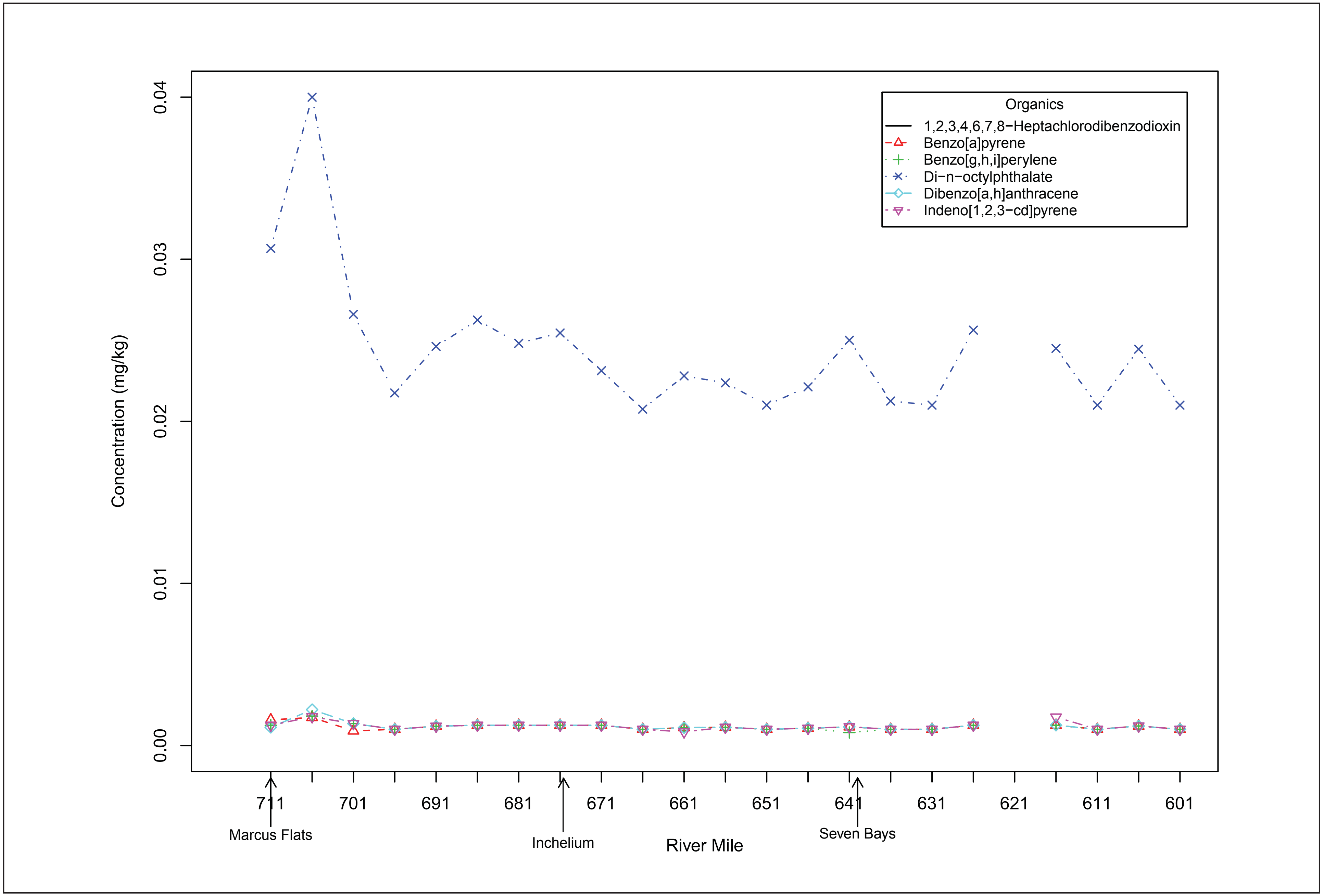


Figure 31. Selected Organics Concentrations in Right Bank Sediments

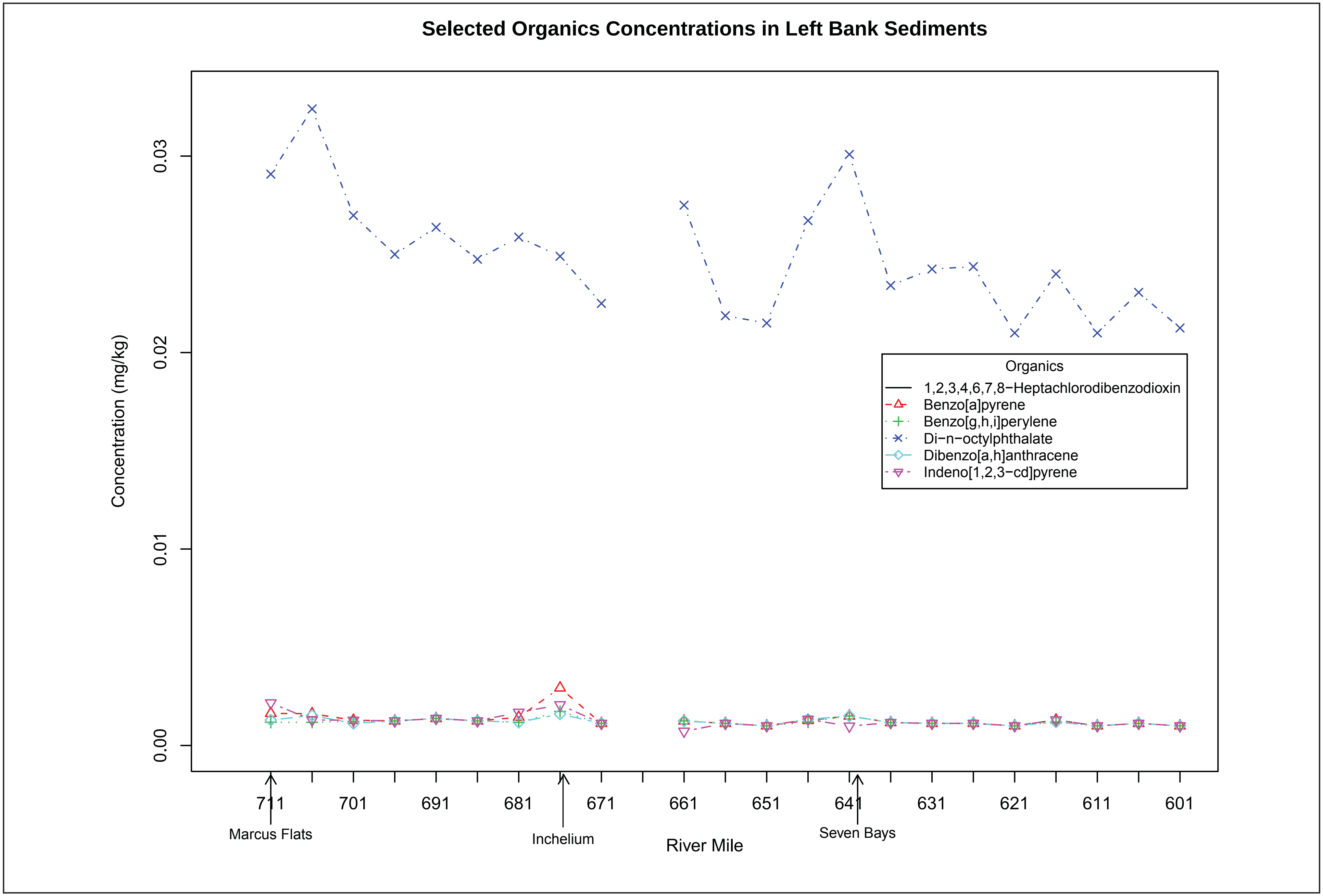


Figure 32. Selected Organics Concentrations in Left Bank Sediments

TABLES

Table 1. Summary of On-Site Releases at the Trail Facility as Reported to the National Pollutant Release Inventory (NPRI) Database

Medium	Release	Quantity (tonnes)												
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Arsenic														
Air	Stack or Point Releases	7.1	14.2	14.94	7.2	3.6	1.22	1.94	1.86	1.22	0.94	0.82	0.70	0.70
	Storage or Handling Releases	0	0	0	0	0	0	0	0	0	0	0.001	0.001	0.002
	Fugitive Releases	0	0	0	0	0	0	0	0	0	0	0.040	0.032	0.033
	Spills	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Non-Point Releases	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total =	7.1	14.2	14.9	7.2	3.6	1.2	1.9	1.9	1.2	0.9	0.9	0.7	0.7
Cadmium														
Air	Stack or Point Releases	3.4	4.5	4.94	6.28	1.19	0.345	0.6	0.25	0.1	0.10	0.12	0.13	0.14
	Storage or Handling Releases	0	0	0	0	0	0	0	0	0	0	0.0007	0.0007	0.0007
	Fugitive Releases	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0.01
	Spills	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Non-Point Releases	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total =	3.4	4.5	4.9	6.3	1.2	0.3	0.6	0.3	0.1	0.1	0.1	0.1	0.2
Copper														
Air	Stack or Point Releases	0.6	3.2	0.51	0.38	0.369	0.24	0.34	0.31	0.16	0.16	0.15	0.69	0.1
	Storage or Handling Releases	0	0	0	0	0	0	0	0	0	0	0.008	0.008	0.008
	Fugitive Releases	0	0	0	0	0	0	0	0	0	0	0.052	0.035	0.027
	Spills	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Non-Point Releases	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total =	0.6	3.2	0.5	0.4	0.4	0.2	0.3	0.3	0.2	0.2	0.2	0.7	0.1
Lead														
Air	Stack or Point Releases	83	97	102.75	126.5	38.12	9.76	17.04	6.68	4.34	2.2	1.97	4.94	1.82
	Storage or Handling Releases	0	0	0	0	0	0	0	0	0	0	0.04	0.05	0.03
	Fugitive Releases	0	0	0	0	0	0	0	0	0	0	0.77	0.73	0.66
	Spills	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Non-Point Releases	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total =	83.0	97.0	102.8	126.5	38.1	9.8	17.0	6.7	4.3	2.2	2.8	5.7	2.5
Zinc														
Air	Stack or Point Releases	35	22	103.75	244.41	111.1	139.4	147.4	138.7	100.33	116.48	124.2	121.22	97.66
	Storage or Handling Releases	0	0	0	0	0	0	0	0	0	0	0.154	0.156	0.15
	Fugitive Releases	0	0	0	0	0	0	0	0	0	0	1.029	0.545	0.429
	Spills	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Non-Point Releases	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total =	35.0	22.0	103.8	244.4	111.1	139.4	147.4	138.7	100.3	116.5	125.4	121.9	98.2

Note:

Established in 1992 and legislated under the Canadian Environmental Protection Act, 1999 (CEPA 1999), the NPRI requires companies to report information on releases and transfers of pollutants to the Government of Canada on an annual basis. CEPA (1999) is designed to protect the environment and human health and to promote sustainable development. Empty cells indicate that no reporting requirements were required at the respective time frame and substance.

Table 2. Summary of 2002-2004 Wind Distribution for Meteorological Data Collected from Warfield, B.C., Canada
(Station Location: Longitude: 117° 44' W; Latitude: 49° 6' N; 'Elevation: 566.90 m)

Wind Direction (deg.)		2002			2003			2004		
From	To	Number of Hours within This Range	Total Hours w/ Collected Data	Annual Percentage	Number of Hours within This Range	Total Hours w/ Collected Data	Annual Percentage	Number of Hours within This Range	Total Hours w/ Collected Data	Annual Percentage
0	45	902	8747	10%	774.5	8735	9%	851.5	8308	10%
45	90	232	8747	3%	199.5	8735	2%	168.5	8308	2%
90	135	496.5	8747	6%	478	8735	5%	437	8308	5%
135	180	1465.5	8747	17%	1633	8735	19%	1622	8308	20%
180	225	1151	8747	13%	1187	8735	14%	989.5	8308	12%
225	270	860	8747	10%	903	8735	10%	705.5	8308	8%
270	315	1251.5	8747	14%	1247.5	8735	14%	1178.5	8308	14%
315	360	2386.5	8747	27%	2311.5	8735	26%	2334.5	8308	28%

Table 3. 95th Percentiles and Tolerance Limits for Soil Samples, with Comparative Data

			Eco-SSL Values			
Analyte	Units	NURE Data[a]	Plants	Soil Invertebrates	Birds	Mammals
Arsenic	mg/kg	10	18		43	46
Cadmium	mg/kg	3.6	32		0.77	0.36
Copper	mg/kg	29	70	80	29	49
Lead	mg/kg	49.4	120		11	56
Zinc	mg/kg	110	160	120	46	79

[a] Source: USGS (2007)

Table 4. Kriging Parameters Optimized for each Pass (data subset)

Parameter	Pass												All
	1	2	3	4	5	6	7	7B	8	9	9B	10	
Number of Soundings	11,877	16,644	10,857	13,272	14,838	8,184	18,274	7,388	11,024	9,025	7,981	14,344	
Model Type	Sph	Sph	Exp	Exp	Sph	Exp	Sph	Sph	Sph	Sph	Sph	Sph	
Major Range (m)	499.7	500	2400	2400	1000	3000	800	660	646.2	850	800	975	
Minor Range (m)	319.1	375	1284.8	536.7	733.3	2800	568.7	566.4	-	750	750	925	
Anisotropy Direction (degrees)	49.6	15	20.9	350.5	23	41	10	55	-	86.7	4.1	79	
Sill	47.71	75	260	220	475	850	475	340	905.66	1208.56	793.16	1260.47	
Anisotropy	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	
Maximum Number of Neighbors	15	10	20	10	25	20	20	20	25	25	25	20	
Minimum Number of Neighbors	1	2	2	1	2	4	2	2	5	5	5	2	
Search Angle (degrees)	49.6	n/a (0.0)	n/a (0.0)	n/a (0.0)	n/a (0.0)	n/a (0.0)	n/a (0.0)	55	n/a (0.0)	n/a (0.0)	n/a (0.0)	n/a (0.0)	
Major Search Axis	1600	2500	4500	4500	4500	4500	4500	660	4500	4500	4500	4500	
Minor Search Axis	999	2500	4500	4500	4500	4500	4500	566.4	4500	4500	4500	4500	
Search Sectors	Eight	Eight	Eight	Eight	Eight	Eight	Eight	Eight	Eight	Eight	Eight	Eight	
Number Of Lags	100	100	100	100	100	100	100	100	100	100	35	100	
Lag Size	30	30	30	30	30	30	30	30	30	30	30	30	
Local Parameter Cross Validation													
Mean Error	0.003	0.009	0.016	0.005	0.022	0.012	0.002	0.035	0.011	0.018	0.017	0.01	0.014
Root-Mean-Square Error (m)	2.029	2.138	2.387	2.382	3.162	2.84	3.067	3.116	4.471	4.449	3.618	3.576	3.076
Average Standard Error (m)	2.26	2.981	4.152	4.35	5.527	5.351	5.887	5.498	8.627	8.906	7.091	8.385	5.992
Mean Standardized Error (m)	-0.0001	0.0015	0.0019	0.001	0.0023	0.0013	0.0004	0.0034	0.0009	0.0013	0.0014	0.0007	0.001
Root-Mean-Square Standardized Error (m)	0.905	0.731	0.596	0.567	0.594	0.544	0.531	0.588	0.537	0.518	0.535	0.448	0.528

Notes:

Sph = spherical
Exp = exponential

Table 5. Black Sand Beach Survey Vertical Datum Adjustments

		Elevation			
Points	Value	NAVD-88 (ft)	NGVD-29 (ft)	NAVD-88 (m)	NGVD-29 (m)
100 ft Mark	Survey	1302.9	1298.83	397.12	395.88
	USGS		1300		396.24
	Difference		1.17		0.36
Water Surface Elevation	Survey	1301.24	1297.17	396.62	395.38
		1301.2	1297.13	396.61	395.37
		1301.28	1297.21	396.63	395.39
	Adjusted		1298.34		395.73
			1298.3		395.72
			1298.39		395.75

Table 6. Estimated and Measured Flows for UCR Floodplain Delineation (m^3/s)

Distribution Type	Pre-1973			Post-1973			
	1-in-500	1-in-100	Peak Flow	1-in-500	1-in-100	Peak Flow	Average
Normal Distribution	16,300	15,000		8,900	8,200		
Log-Normal Distribution	18,700	16,400		9,700	8,600		
Type I Extreme Value (Gumbel) Distribution	21,267	17,948		11,600	9,809		
Log-Pearson Type III Distribution	18,000	16,033		11,500	9,600		
Flow Duration Curve Approach (Julien 2002)	14,045	13,196		10,845	9,656		
Measured			15,577			8,637	2,762

Table 7. Physical Chemical Properties

Analyte	CAS#	Kd (cm^^{3}/g)	Ref
Chromium (III)	16065-83-1	1800000.00	EPA SSG
Thorium	7440-29-1	150000.00	Baes
Zirconium	7440-67-7	3000.00	Baes
Aluminum	7429-90-5	1500.00	Baes
Gallium	7440-55-3	1500.00	Baes
Indium	7440-74-6	1500.00	Baes
Cesium	7440-46-2	1000.00	Baes
Scandium	7440-20-2	1000.00	Baes
Titanium	7440-32-6	1000.00	Baes
Vanadium	7440-62-2	1000.00	Baes
Lead	7439-92-1	900.00	Baes
Cerium	7440-45-1	850.00	Baes
Beryllium	7440-41-7	790.00	EPA SSG
Dysprosium	7429-91-6	650.00	Baes
Erbium	7440-52-0	650.00	Baes
Europium	7440-53-1	650.00	Baes
Gadolinium	7440-54-2	650.00	Baes
Holmium	7440-60-0	650.00	Baes
Lanthanum	7439-91-0	650.00	Baes
Lutetium	7439-94-3	650.00	Baes
Neodymium	7440-00-8	650.00	Baes
Praseodymium	7440-10-0	650.00	Baes
Samarium	7440-19-9	650.00	Baes
Tantalum	7440-25-7	650.00	Baes
Terbium	7440-27-9	650.00	Baes
Thulium	7440-30-4	650.00	Baes
Ytterbium	7440-64-4	650.00	Baes
Yttrium	7440-65-5	500.00	Baes
Uranium	7440-61-1	450.00	Baes
Niobium	7440-03-1	350.00	Baes
Lithium	7439-93-2	300.00	Baes
Tellurium	13494-80-9	300.00	Baes
Tin	7440-31-5	250.00	Baes
Bismuth	7440-69-9	200.00	Baes
Fluoride	7782-41-4	150.00	Baes
Tungsten	7440-33-7	150.00	Baes
Sodium	7440-23-5	100.00	Baes
Cadmium	7440-43-9	75.00	EPA SSG
Thallium	7440-28-0	71.00	EPA SSG
Manganese	7439-96-5	65.00	Baes
Nickel	7440-02-0	65.00	EPA SSG
Zinc	7440-66-6	62.00	EPA SSG
Rubidium	7440-17-7	60.00	Baes
Mercury	7439-97-6	52.00	EPA SSG
Antimony	7440-36-0	45.00	Baes
Cobalt	7440-48-4	45.00	Baes
Barium	7440-39-3	41.00	EPA SSG
Copper	7440-50-8	35.00	Baes
Strontium	7440-24-6	35.00	Baes
Silicon (Silica)	7440-21-3	30.00	Baes
Arsenic	7440-38-2	29.00	EPA SSG

Table 7. Physical Chemical Properties

Analyte	CAS#	Kd (cm^^{3}/g)	Ref
Germanium	7440-56-4	25.00	Baes
Gold	7440-57-5	25.00	Baes
Iron	7439-89-6	25.00	Baes
Molybdenum	7439-98-7	20.00	Baes
Silver	7440-22-4	8.30	EPA SSG
Sulfur (Sulfate)	7704-34-9	7.50	Baes
Potassium	7440-09-7	5.50	Baes
Selenium	7782-49-2	5.00	EPA SSG
Magnesium	7439-95-4	4.50	Baes
Calcium	7440-70-2	4.00	Baes
Phosphorous	7723-14-0	3.50	Baes
Boron	7440-42-8	3.00	Baes
Chloride	7782-50-5	0.25	Baes

Notes:

Log K_{ow} - Octanol-water partition coefficient, the ratio of the concentration of a chemical in octanol and in water at equilibrium and at a specified temperature. Octanol is an organic solvent that is used as a surrogate for natural organic matter (e.g., lipids). Also, a Log Kow $\geq$ 4.0 is indicative of a bioaccumulative compound. Values obtained from the Hazardous Substances DataBank (HSDB) (http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB) or Oak Ridge National Laboratory Risk Assessment Information System (http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=csf).

K_{oc} - Organic Carbon Partition Coefficient (L/kg). Values obtained from Oak Ridge National Laboratory Risk Assessment Information System (http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=csf).

K_d - from: Baes et al. (1984)

Table 8. Organic COPCs Sorted by K_{oc}

Analyte	CAS#	K_{oc} (L/kg)	Log K_{ow}
Benzo(ghi)perylene	191-24-2	2.68E+06	6.63E+00
Indeno[1,2,3-cd]pyrene	193-39-5	2.68E+06	6.70E+00
Dibenzo(a,h)anthracene	53-70-3	2.62E+06	6.75E+00
Octachlorodibenzodioxin	3268-87-9	1.19E+06	8.20E+00
Benzo(b)fluoranthene	205-99-2	8.03E+05	5.78E+00
Benzo(a)pyrene	50-32-8	7.87E+05	6.13E+00
Benzo(k)fluoranthene	207-08-9	7.87E+05	6.11E+00
1,2,3,4,6,7,8-Heptachlorodibenzodioxin	37871-00-4	7.03E+05	8.20E+00
Octachlorodibenzofuran	39001-02-0	6.57E+05	8.60E+00
1,2,3,4,7,8-Hexachlorodibenzodioxin	--	4.17E+05	8.21E+00
1,2,3,6,7,8-Hexachlorodibenzodioxin	57653-85-7	4.17E+05	8.21E+00
1,2,3,7,8,9-Hexachlorodibenzodioxin	19408-74-3	4.17E+05	8.21E+00
1,2,3,4,6,7,8-Heptachlorodibenzofuran	38998-75-3	3.89E+05	7.92E+00
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	3.89E+05	7.92E+00
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	36088-22-9	2.57E+05	6.30E+00
1,2,3,4,7,8-Hexachlorodibenzofuran	55684-94-1	2.36E+05	7.58E+00
Chrysene	218-01-9	2.36E+05	5.81E+00
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	2.31E+05	7.92E+00
2,3,4,6,7,8-Hexachlorodibenzofuran	60851-34-5	2.31E+05	7.92E+00
Benzo(a)anthracene	56-55-3	2.31E+05	5.76E+00
2,4'-DDT	789-02-6	2.25E+05	6.79E+00
4,4'-DDT	50-29-3	2.20E+05	6.91E+00
Aroclor 1260	11096-82-5	2.07E+05	8.27E+00
Di-n-octylphthalate	117-84-0	1.96E+05	8.10E+00
bis(2-Ethylhexyl)phthalate	117-81-7	1.65E+05	7.60E+00
2,4'-DDD	53-19-0	1.56E+05	5.87E+00
4,4'-DDD	72-54-8	1.53E+05	6.02E+00
4,4'-DDE	72-55-9	1.53E+05	6.51E+00
2,3,7,8-Tetrachlorodibenzodioxin	1746-01-6	1.46E+05	6.80E+00
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	1.37E+05	6.79E+00
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	1.37E+05	6.92E+00
Aldrin	309-00-2	1.06E+05	6.50E+00
Toxaphene	8001-35-2	9.93E+04	5.78E+00
alpha-Chlordane (cis-)	12789-03-6	8.67E+04	6.16E+00
gamma-Chlordane (trans-)	12789-03-6	8.67E+04	6.16E+00
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	8.10E+04	6.53E+00
Aroclor 1254	11097-69-1	7.56E+04	6.79E+00
Fluoranthene	206-44-0	7.09E+04	5.16E+00
Pyrene	129-00-0	6.94E+04	4.88E+00
Heptachlor	76-44-8	5.24E+04	6.10E+00
Aroclor 1242	53469-21-9	4.48E+04	6.29E+00
Aroclor 1248	12672-29-6	4.39E+04	6.34E+00
Methoxychlor	72-43-5	4.26E+04	5.08E+00
Endosulfan sulfate	1031-07-8	3.23E+04	3.66E+00
Aroclor 1016	12674-11-2	2.71E+04	5.62E+00
Endosulfan I	115-29-7	2.20E+04	3.83E+00
Endosulfan II	115-29-7	2.20E+04	3.83E+00
Phenanthrene	85-01-8	2.08E+04	4.46E+00
Anthracene	120-12-7	2.04E+04	4.45E+00
Fluorene	86-73-7	1.13E+04	4.18E+00
Carbazole	86-74-8	1.13E+04	3.72E+00

Table 8. Organic COPCs Sorted by K_{oc}

Analyte	CAS#	K_{oc} (L/kg)	Log K_{ow}
Dibenzofuran	132-64-9	1.13E+04	4.12E+00
Endrin aldehyde	7421-93-4	1.08E+04	4.80E+00
Dieldrin	60-57-1	1.06E+04	5.40E+00
Endrin	72-20-8	1.06E+04	5.20E+00
Aroclor 1221	11104-28-2	1.03E+04	4.53E+00
Aroclor 1232	11141-16-5	1.03E+04	4.53E+00
Butyl benzyl phthalate	85-68-7	9.36E+03	4.73E+00
3,3'-Dichlorobenzidine	91-94-1	7.49E+03	3.51E+00
1,1'-Biphenyl	92-52-4	6.25E+03	3.98E+00
N-Nitrosodiphenylamine	86-30-6	6.15E+03	3.13E+00
Acenaphthene	83-32-9	6.12E+03	3.92E+00
Acenaphthylene	208-96-8	6.12E+03	3.94E+00
Heptachlor epoxide	1024-57-3	5.26E+03	4.98E+00
alpha-BHC	319-84-6	3.38E+03	3.80E+00
beta-BHC	319-85-7	3.38E+03	3.78E+00
delta-BHC	319-86-8	3.38E+03	4.14E+00
gamma-BHC (Lindane)	58-89-9	3.38E+03	3.72E+00
Hexachlorobenzene	118-74-1	3.38E+03	5.73E+00
Pentachlorophenol	87-86-5	3.38E+03	5.12E+00
2-Methylnaphthalene	91-57-6	2.98E+03	3.86E+00
Naphthalene	91-20-3	1.84E+03	3.30E+00
Hexachlorocyclopentadiene	77-47-4	1.67E+03	5.04E+00
Di-n-butyl phthalate	84-74-2	1.46E+03	4.50E+00
2,4,5-Trichlorophenol	95-95-4	1.19E+03	3.72E+00
2,4,6-Trichlorophenol	88-06-2	1.19E+03	3.69E+00
Hexachlorobutadiene	87-68-3	9.94E+02	4.78E+00
1,2,4-Trichlorobenzene	120-82-1	7.18E+02	4.02E+00
2,4-Dichlorophenol	120-83-2	7.18E+02	3.06E+00
2,4-Dimethylphenol	105-67-9	7.18E+02	2.30E+00
4,6-Dinitro-2-methylphenol	534-52-1	6.02E+02	2.13E+00
N-Nitrosodi-n-propylamine	621-64-7	4.85E+02	1.36E+00
1,2-Dichlorobenzene	95-50-1	4.43E+02	3.43E+00
2-Chlorophenol	95-57-8	4.43E+02	2.15E+00
2-Methylphenol (o-cresol)	95-48-7	4.43E+02	1.95E+00
1,3-Dichlorobenzene	541-73-1	4.34E+02	3.53E+00
1,4-Dichlorobenzene	106-46-7	4.34E+02	3.44E+00
4-Methylphenol (p-cresol)	106-44-5	4.34E+02	1.94E+00
2,6-Dinitrotoluene	606-20-2	3.71E+02	2.10E+00
2,4-Dinitrophenol	51-28-5	3.64E+02	1.67E+00
2,4-Dinitrotoluene	121-14-2	3.64E+02	1.98E+00
2-Nitrophenol	88-75-5	3.16E+02	1.79E+00
4-Nitrophenol	100-02-7	3.09E+02	1.91E+00
Phenol	108-95-2	2.68E+02	1.46E+00
Atrazine	1912-24-9	2.30E+02	2.61E+00
Hexachloroethane	67-72-1	2.25E+02	4.14E+00
Nitrobenzene	98-95-3	1.91E+02	1.85E+00
Diethyl phthalate	84-66-2	1.26E+02	2.42E+00
Isophorone	78-59-1	5.83E+01	1.70E+00
Caprolactam	105-60-2	5.74E+01	6.60E-01
2-Nitroaniline	88-74-4	5.27E+01	1.85E+00
3-Nitroaniline	99-09-2	5.16E+01	1.37E+00

Table 8. Organic COPCs Sorted by K_{oc}

Analyte	CAS#	K_{oc} (L/kg)	Log K_{ow}
4-Nitroaniline	100-01-6	5.16E+01	1.39E+00
Acetophenone	98-86-2	4.62E+01	1.58E+00
Dimethyl phthalate	131-11-3	3.71E+01	1.60E+00
Benzaldehyde	100-52-7	3.27E+01	1.48E+00
Benzyl alcohol	100-51-6	1.57E+01	1.10E+00
Bis(2-chloroethyl)ether	111-44-4	1.50E+01	1.29E+00
Benzoic acid	65-85-0	1.45E+01	1.87E+00
bis(2-Chloroethoxy)methane	111-91-1	2.77E+00	1.30E+00
Total PBDEs	--		5.87-8.9
2,4'-DDE	--		6.51
cis-Nonachlor	3734-49-4		6.20
trans-Nonachlor	3734-49-4		6.20
Oxychlordane	27304-13-8		6.16
Endrin ketone	53494-70-5		5.20
4-Bromophenyl-phenylether	101-55-3		4.94
4-Chlorophenyl-phenyl ether	7005-72-3		4.08
2-Chloronaphthalene	91-58-7		3.90
4-Chloro-3-methylphenol	59-50-7		3.10
2,2'-oxybis(1-Chloropropane)	108-60-1		2.48
4-Chloroaniline	106-47-8		1.83

Notes:

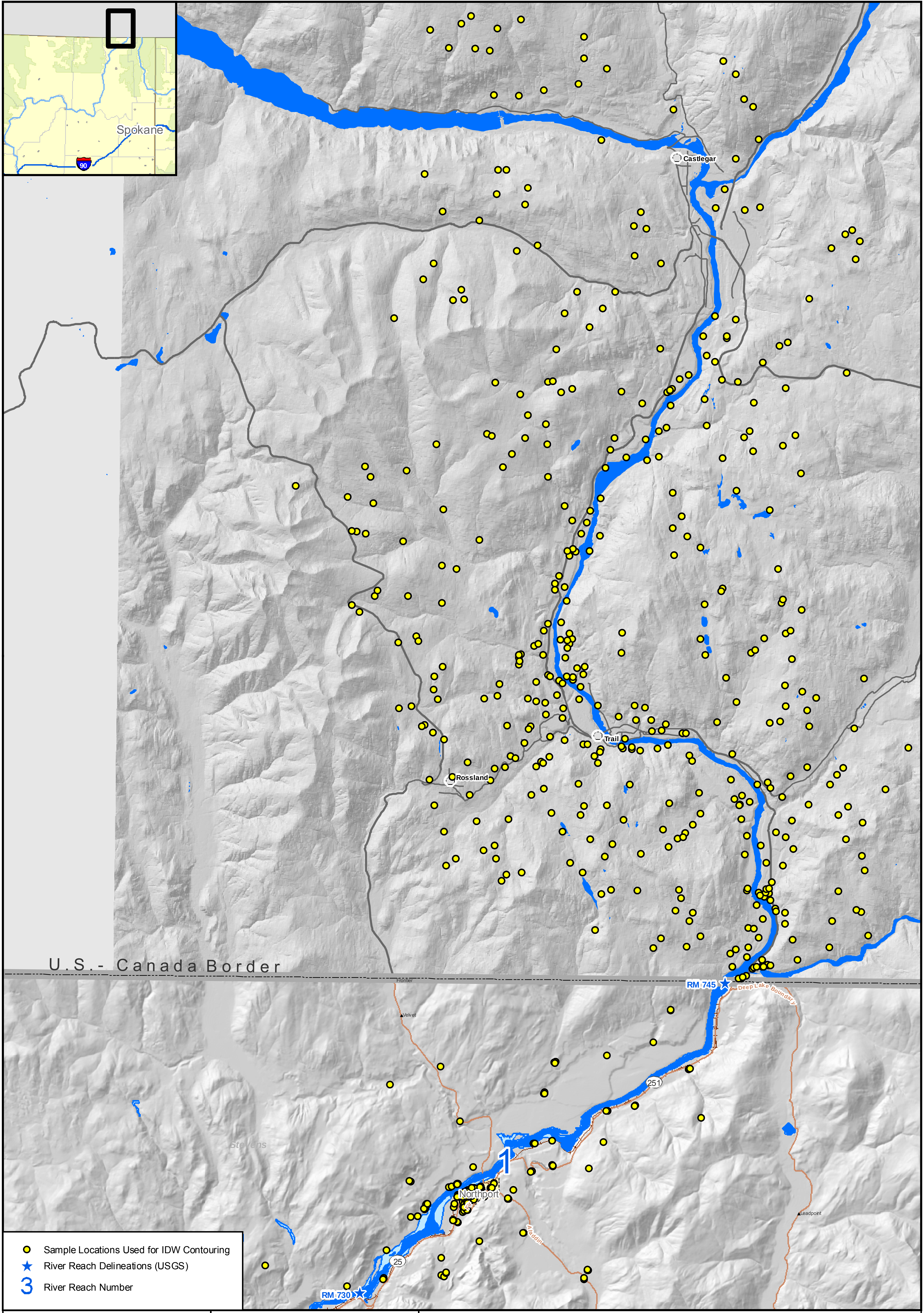
Log K_{ow} - Octanol-water partition coefficient, the ratio of the concentration of a chemical in octanol and in water at equilibrium and at a specified temperature. Octanol is an organic solvent that is used as a surrogate for natural organic matter (e.g., lipids). Also, a Log $K_{ow} \geq$ 4.0 is indicative of a bioaccumulative compound. Values obtained from the Hazardous Substances DataBank (HSDB) (http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB) or Oak Ridge National Laboratory Risk Assessment Information System (http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=csf).

K_{oc} - Organic Carbon Partition Coefficient (L/kg). Values obtained from Oak Ridge National Laboratory Risk Assessment Information System (http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=csf).

K_d - from: Baes et al. (1984)

MAPS

\\Mi\gis\mi\C306_UCR_Teck-Cominco\t0407\st01\IDW_LocOverview_lg_03102008.mxd JP @ 03-10-2008



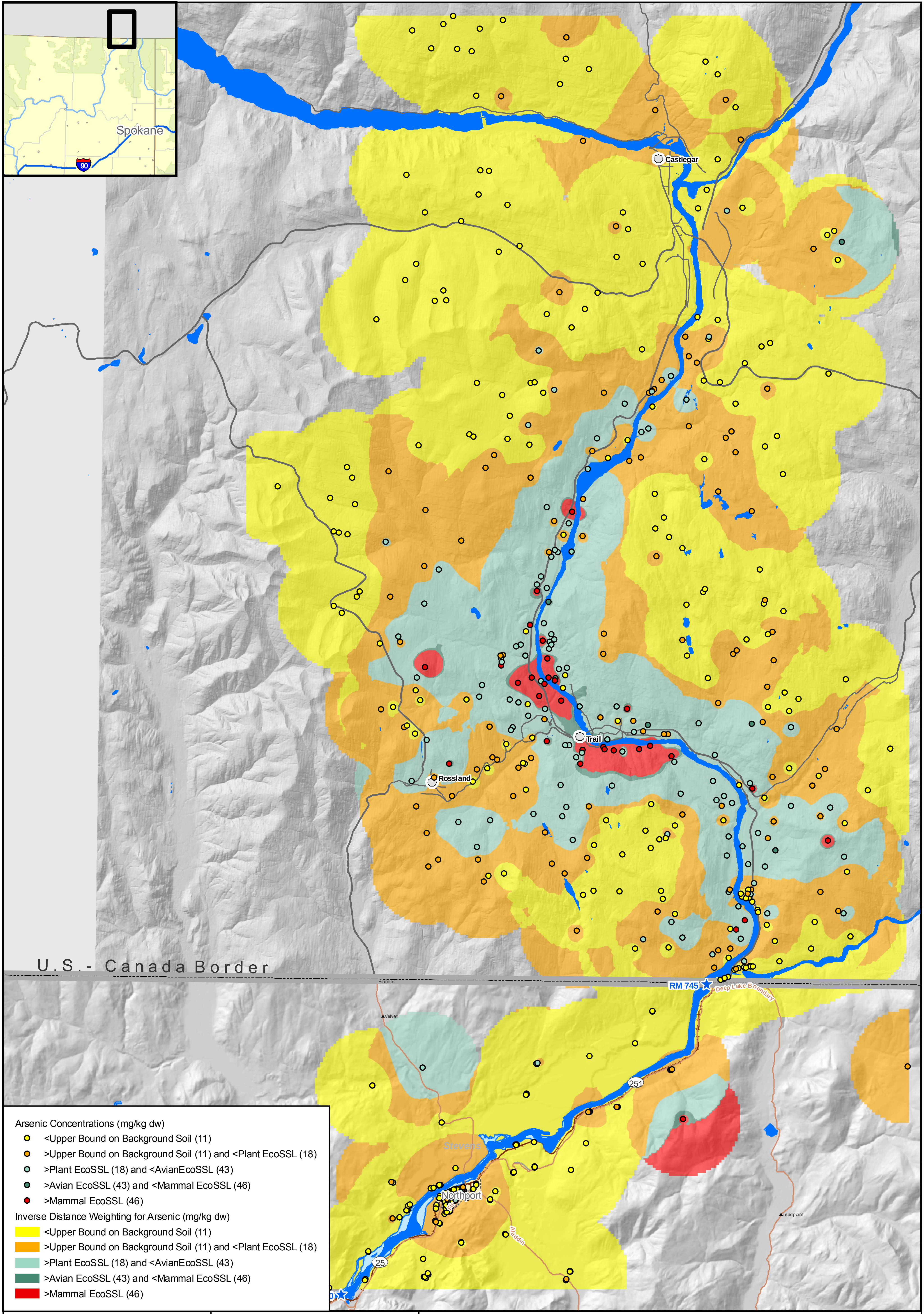
Exponent Parametrix

Km
0 1 2
Miles
0 1 2
N

Map 1. All Soil Sample Locations Used for the Footprint Evaluation

Upper Columbia River, WA

`\\Mi\gis\mi\C306_UCR_Teck-Cominco\t0407\st01\IDW_09182008\IDW_Arsenic_09182008.mxd JP @ 09-18-2008`



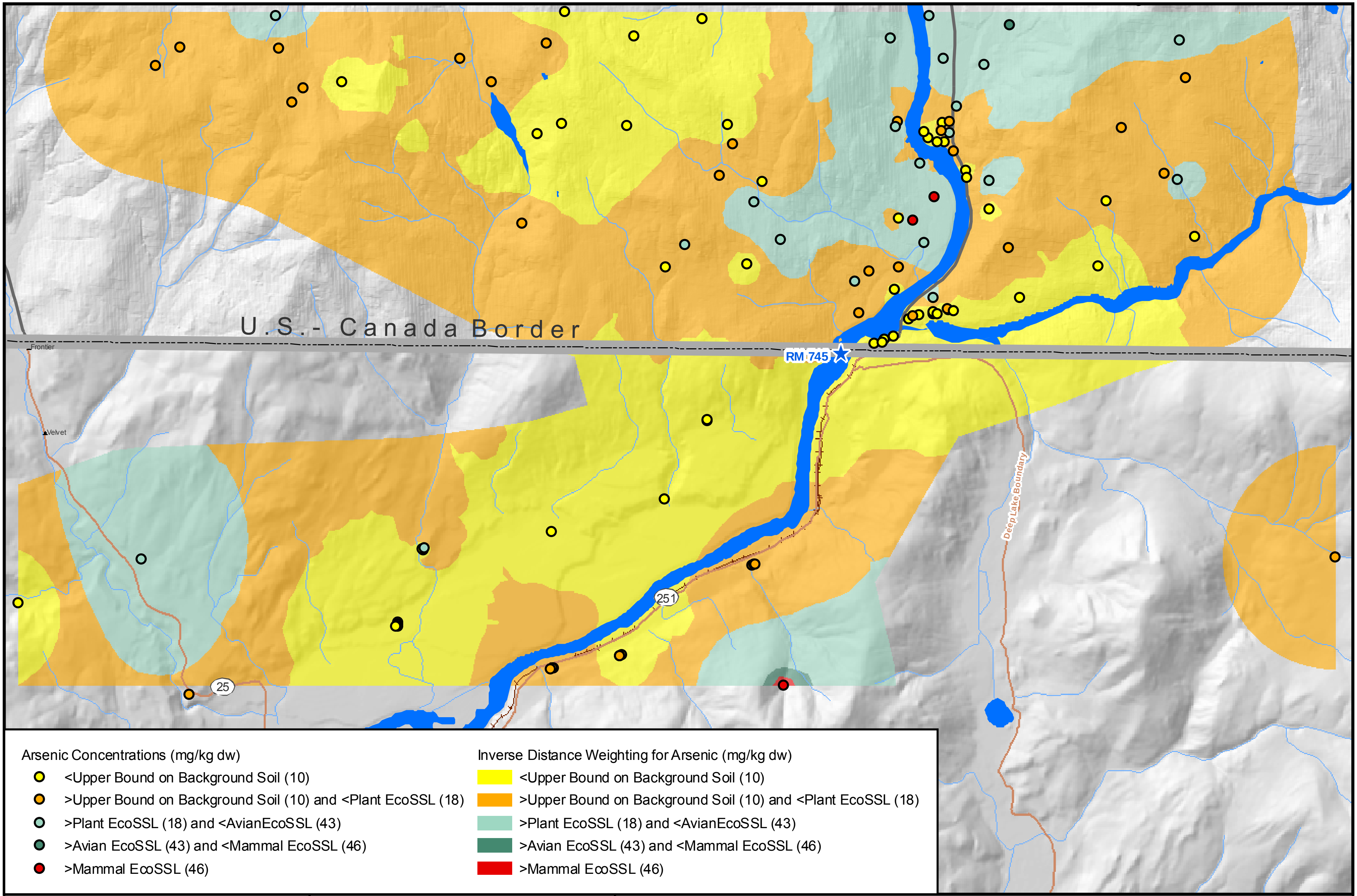
Exponent Parametrix

Km
0 1 2
Miles
0 1 2

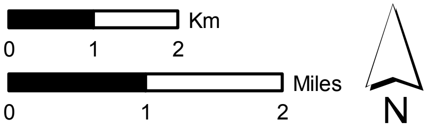
N

Map 2. Soil Arsenic Concentrations in the Vicinity of the Trail Facility and Adjacent U.S. Soils

Upper Columbia River, WA



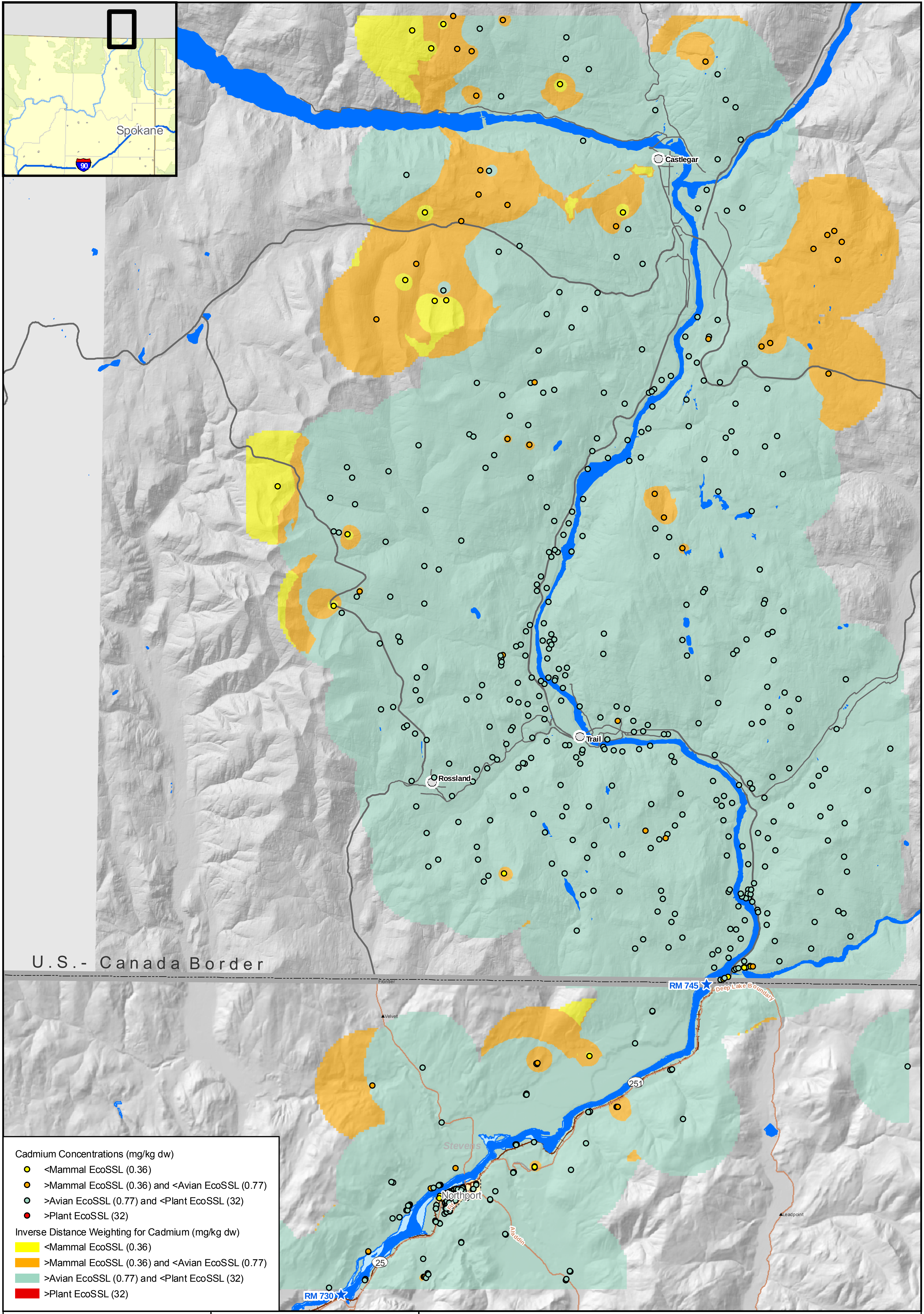
Exponent Parametrix



Map 3. Soil Arsenic Concentrations in the Area of the U.S. - Canada Border

Upper Columbia River, WA

\\Mi\gis\mi\C306_UCR_Teck-Cominco\t0407\st01\IDW_09182008\IDW_Cadmium_2_09182008.mxd JP @ 09-18-2008

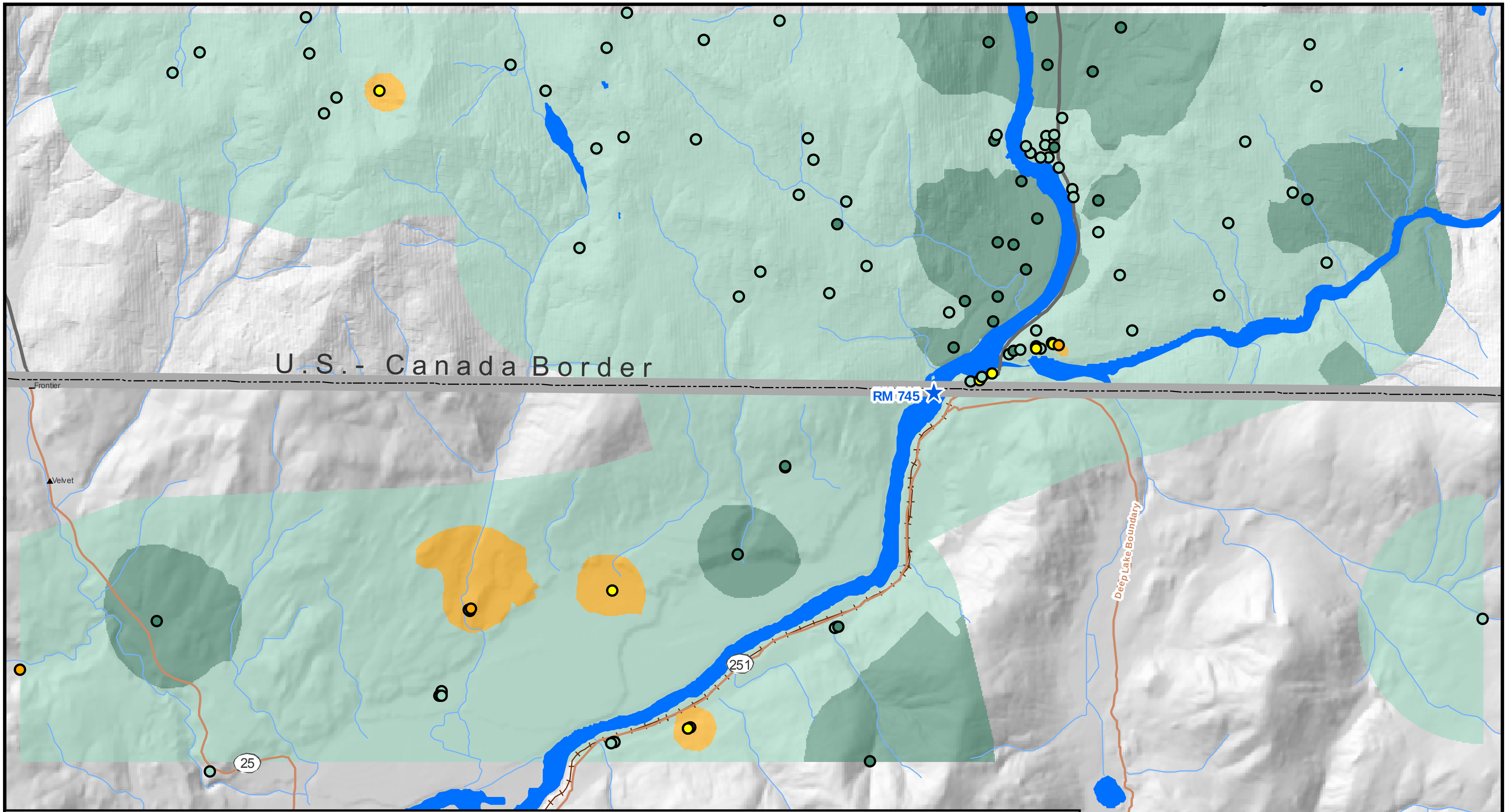


Exponent Parametrix

Map 4. **Soil Cadmium Concentrations in the Vicinity of the Trail Facility and Adjacent U.S. Soils**

Upper Columbia River, WA

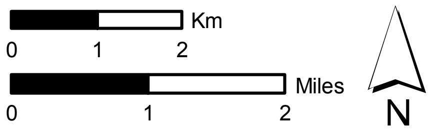
\\Mi\gis\mi\C306_UCR_Teck-Cominco\t0407\st01\IDW_Cadmium_sm_03072008.mxd JP @ 03-07-2008



Cadmium Concentrations (mg/kg dw)
- ● <Mammal EcoSSL (0.36)
- ● >Mammal EcoSSL (0.36) and <Avian EcoSSL (0.77)
- ● >Avian EcoSSL (0.77) and <Upper Bound on Background Soil (3.6)
- ● >Upper Bound on Background Soil (3.6) and <Plant EcoSSL (32)
- ● >Plant EcoSSL (32)

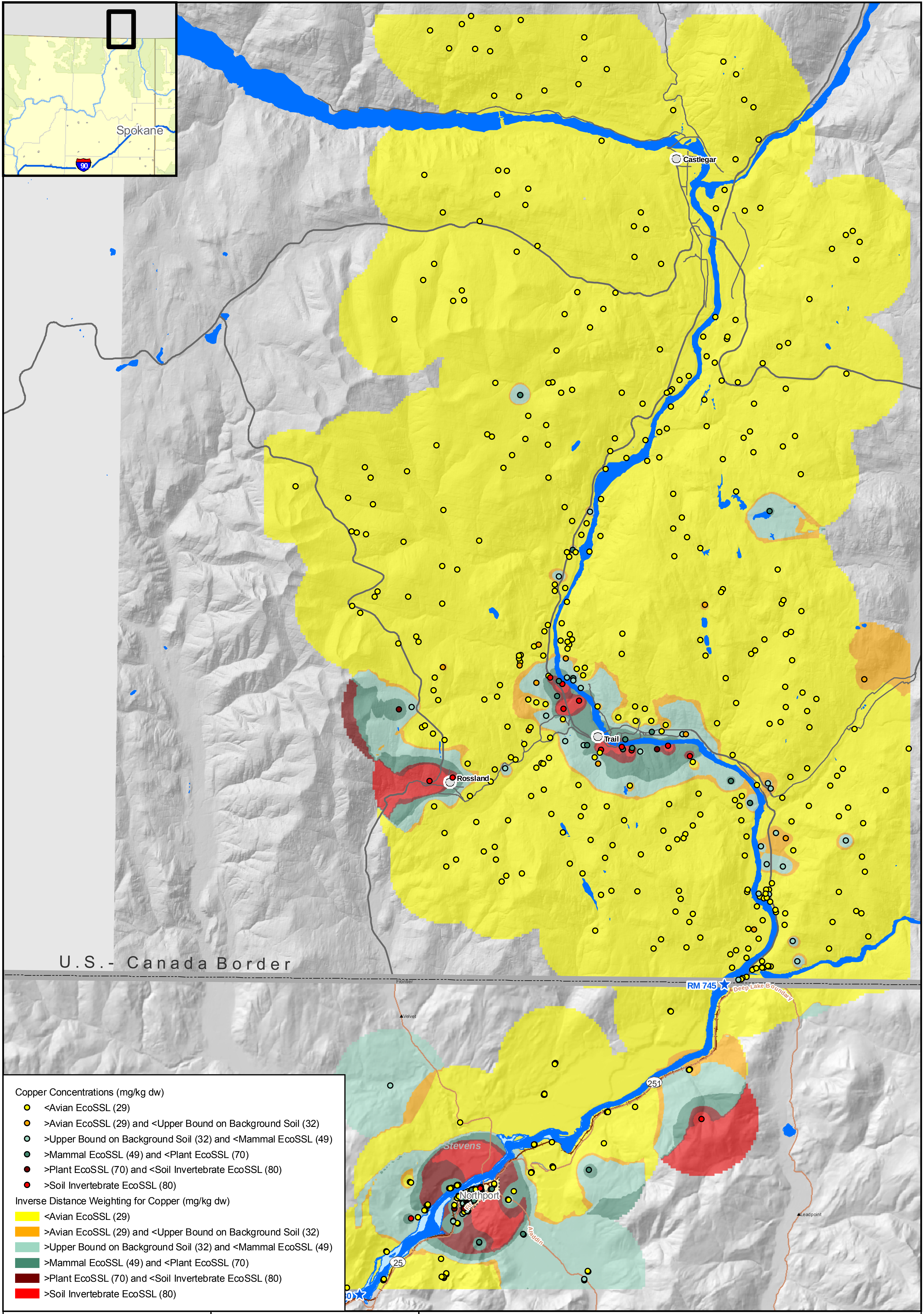
Inverse Distance Weighting for Cadmium (mg/kg dw)
- 🟨 <Mammal EcoSSL (0.36)
- 🟧 >Mammal EcoSSL (0.36) and <Avian EcoSSL (0.77)
- 🟩 >Avian EcoSSL (0.77) and <Upper Bound on Background Soil (3.6)
- 🟩 >Upper Bound on Background Soil (3.6) and <Plant EcoSSL (32)
- 🟥 >Plant EcoSSL (32)

Exponent Parametrix



Map 5. Soil Cadmium Concentrations in the Area of the U.S. - Canada Border

Upper Columbia River, WA



Exponent Parametrix

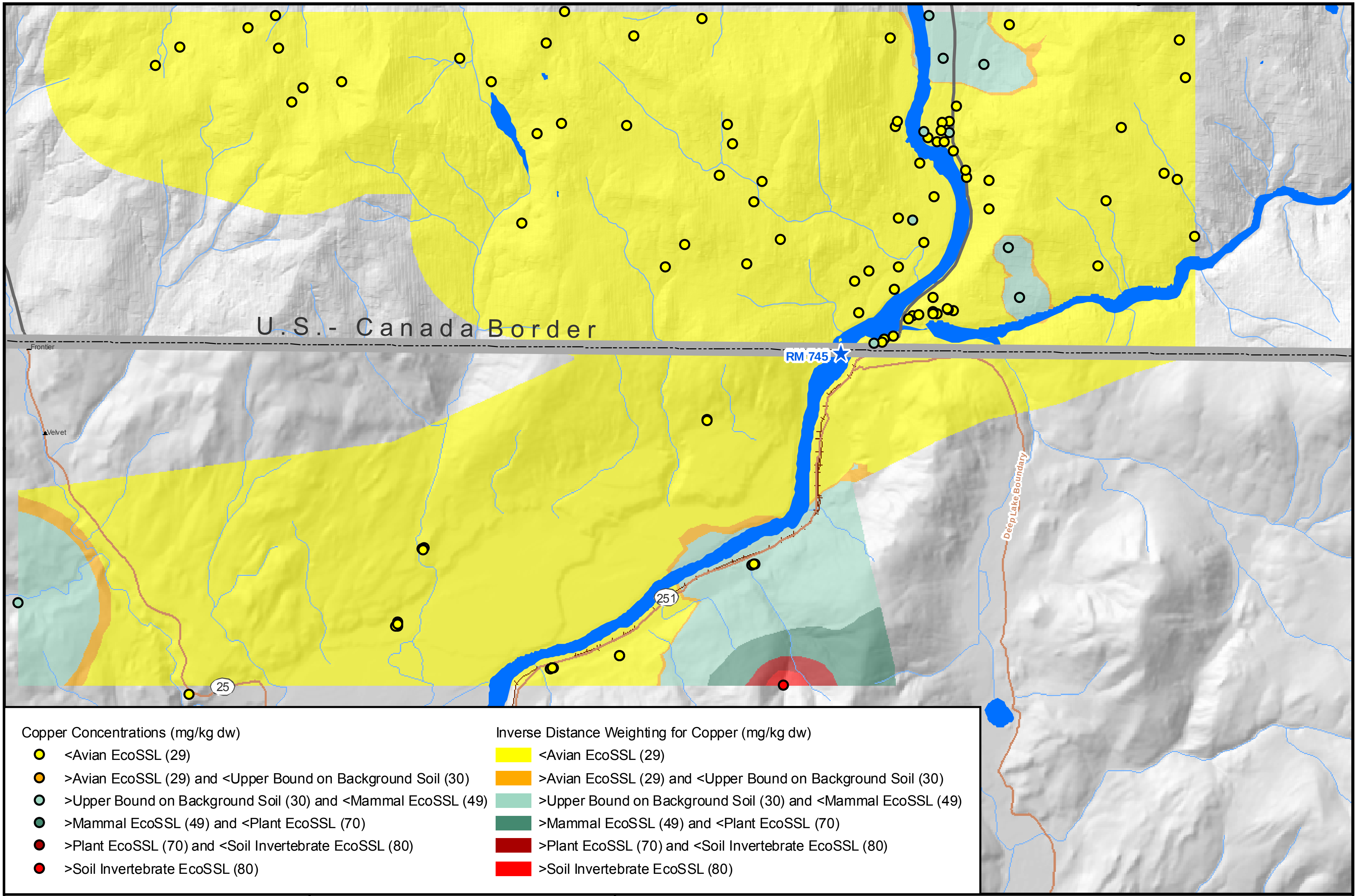
Km
0 1 2
Miles
0 1 2

N

Map 6. **Soil Copper Concentrations in the Vicinity of the Trail Facility and Adjacent U.S. Soils**

Upper Columbia River, WA

\\Mi\gis\mi\C306_UCR_Teck-Cominco\t0407\st01\IDW_Copper_sm_03072008.mxd JP @ 03-07-2008



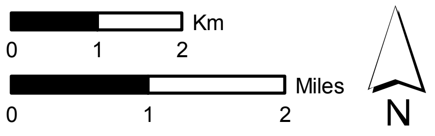
Copper Concentrations (mg/kg dw)

- ● <Avian EcoSSL (29)
- ● >Avian EcoSSL (29) and <Upper Bound on Background Soil (30)
- ● >Upper Bound on Background Soil (30) and <Mammal EcoSSL (49)
- ● >Mammal EcoSSL (49) and <Plant EcoSSL (70)
- ● >Plant EcoSSL (70) and <Soil Invertebrate EcoSSL (80)
- ● >Soil Invertebrate EcoSSL (80)

Inverse Distance Weighting for Copper (mg/kg dw)

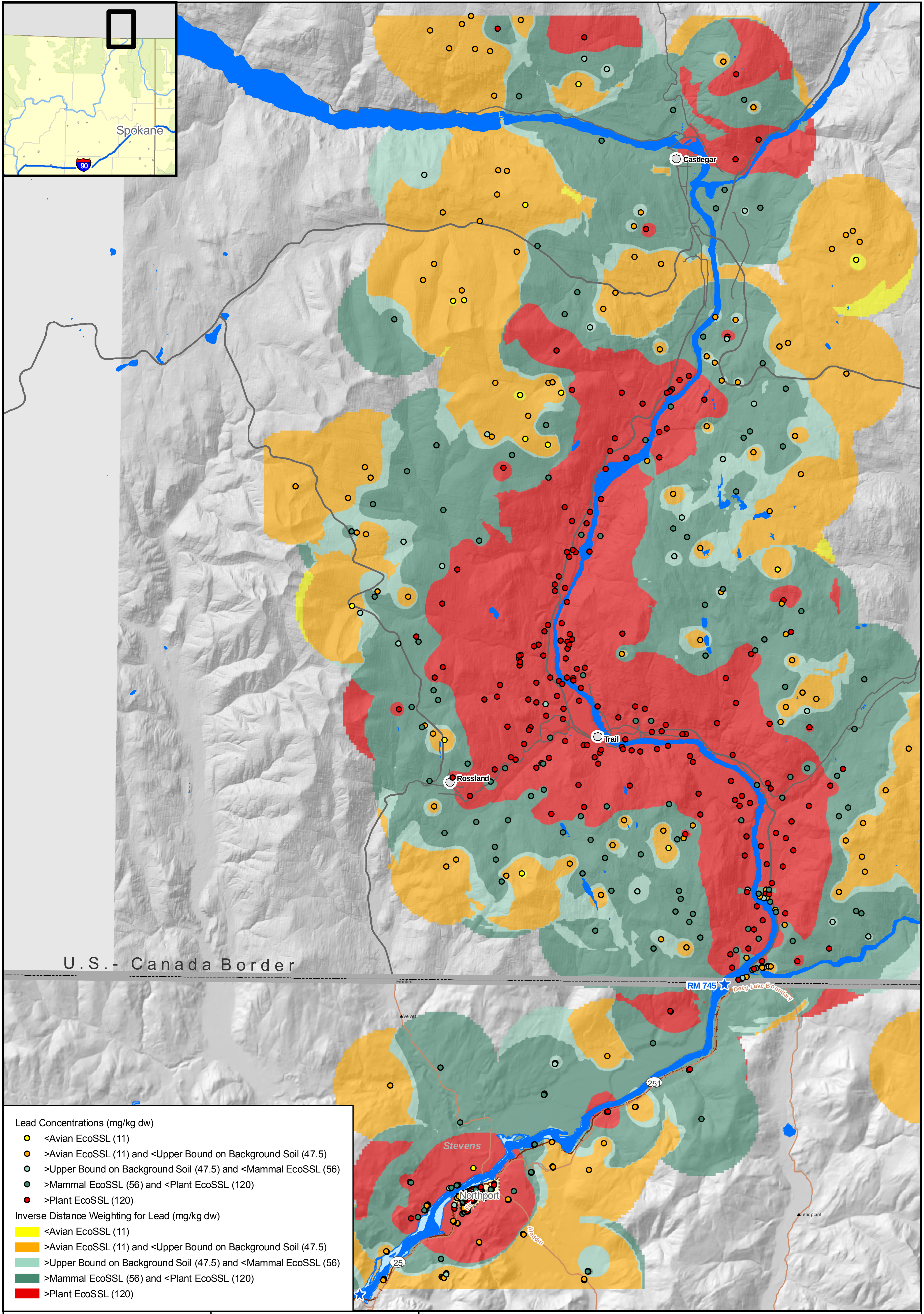
- 🟨 <Avian EcoSSL (29)
- 🟧 >Avian EcoSSL (29) and <Upper Bound on Background Soil (30)
- 🟩 >Upper Bound on Background Soil (30) and <Mammal EcoSSL (49)
- 🟩 >Mammal EcoSSL (49) and <Plant EcoSSL (70)
- 🟥 >Plant EcoSSL (70) and <Soil Invertebrate EcoSSL (80)
- 🟥 >Soil Invertebrate EcoSSL (80)

Exponent Parametrix



Map 7. Soil Copper Concentrations in the Area of the U.S. - Canada Border

Upper Columbia River, WA



Exponent Parametrix

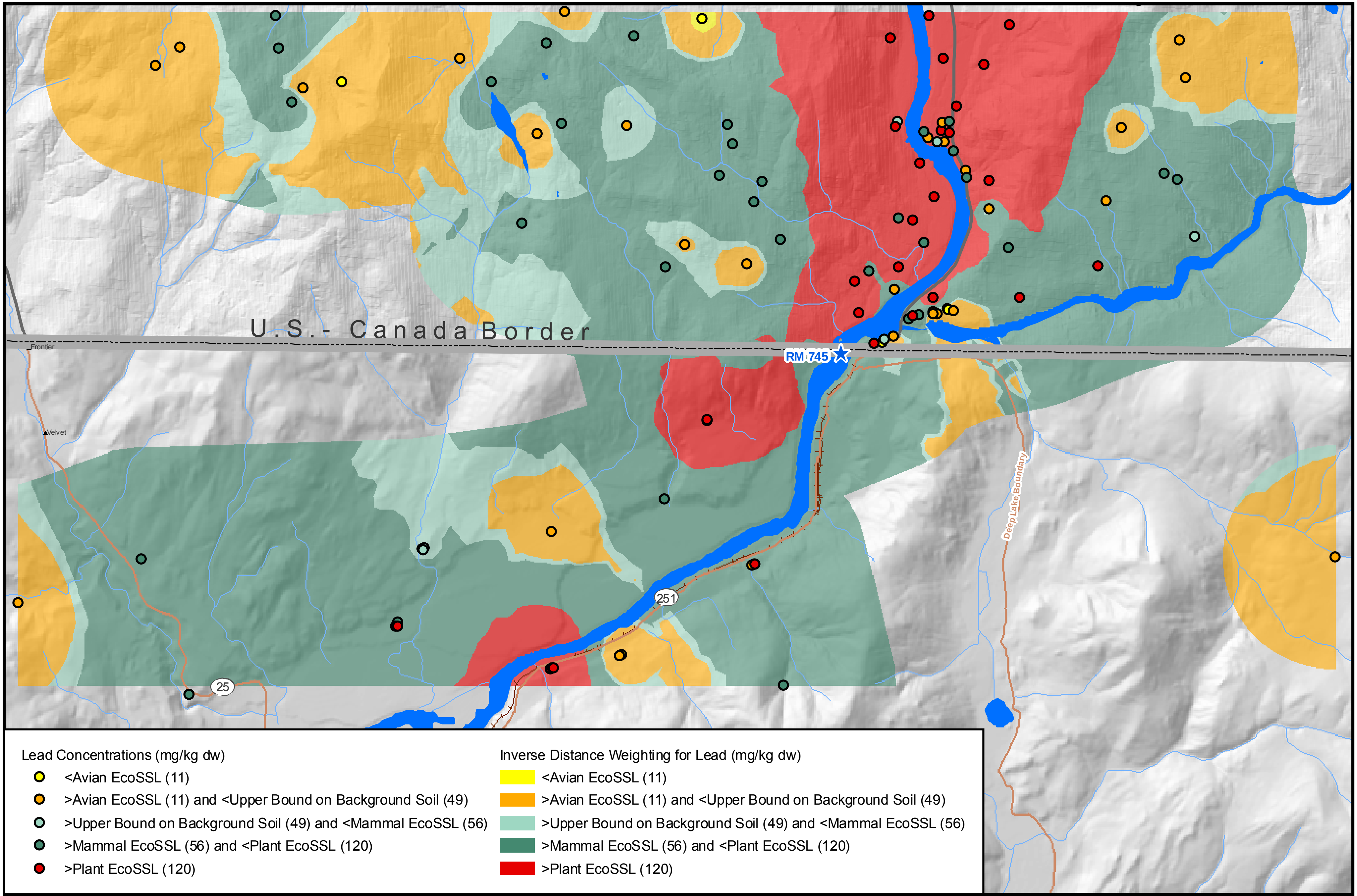
Km
0 1 2

Miles
0 1 2

N

Map 8. **Soil Lead Concentrations in the Vicinity of the Trail Facility and Adjacent U.S. Soils**

Upper Columbia River, WA



Exponent Parametrix

Km
0 1 2

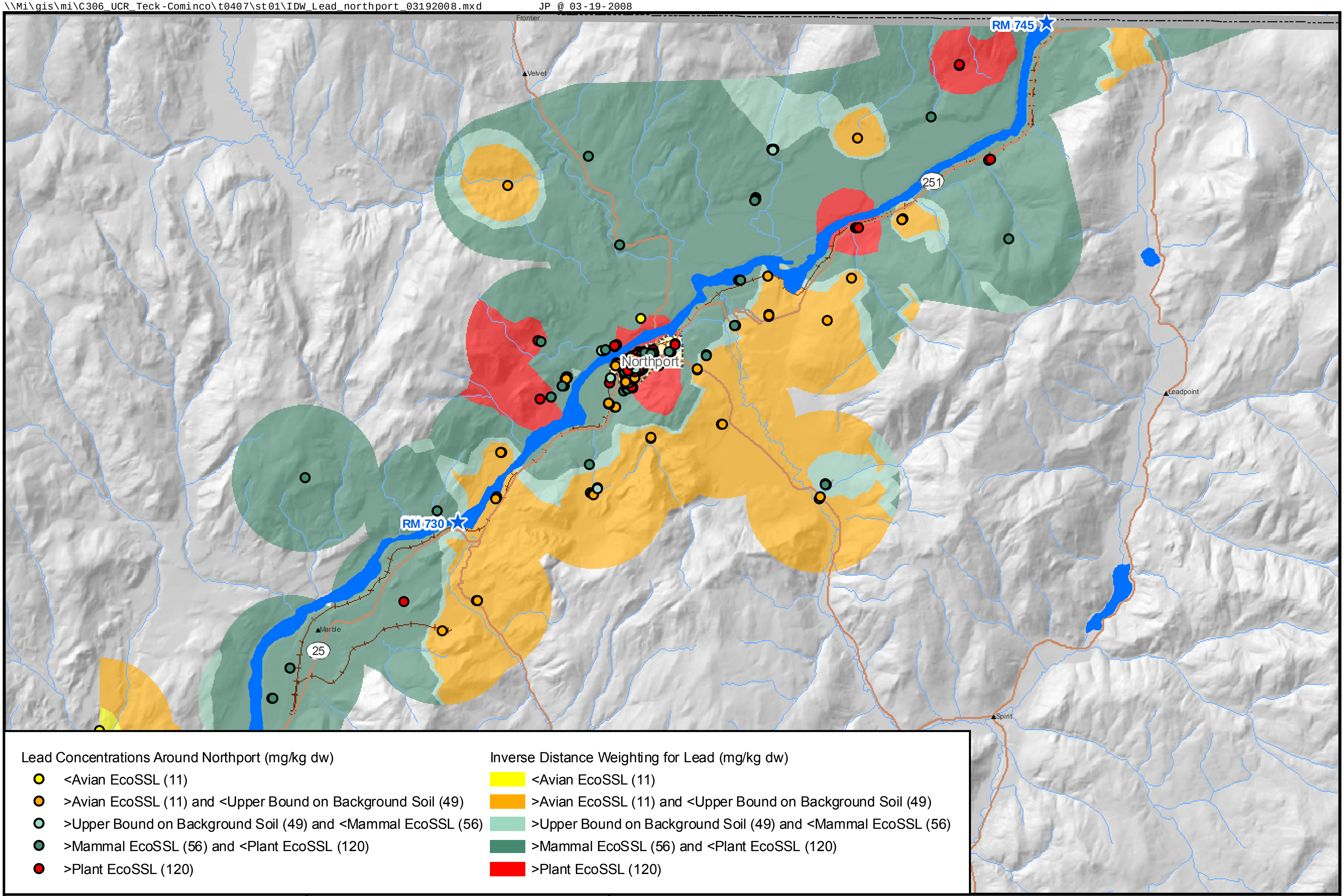
Miles
0 1 2

N

Map 9. Soil Lead Concentrations in the Area of the U.S. - Canada Border

Upper Columbia River, WA

\\Mi\gis\mi\C306_UCR_Teck-Cominco\t0407\st01\IDW_Lead_northport_03192008.mxd JP @ 03-19-2008



Lead Concentrations Around Northport (mg/kg dw)

● <Avian EcoSSL (11)
● >Avian EcoSSL (11) and <Upper Bound on Background Soil (49)
● >Upper Bound on Background Soil (49) and <Mammal EcoSSL (56)
● >Mammal EcoSSL (56) and <Plant EcoSSL (120)
● >Plant EcoSSL (120)

Inverse Distance Weighting for Lead (mg/kg dw)

🟨 <Avian EcoSSL (11)
🟧 >Avian EcoSSL (11) and <Upper Bound on Background Soil (49)
🟩 >Upper Bound on Background Soil (49) and <Mammal EcoSSL (56)
🟩 >Mammal EcoSSL (56) and <Plant EcoSSL (120)
🟥 >Plant EcoSSL (120)

Exponent Parametrix

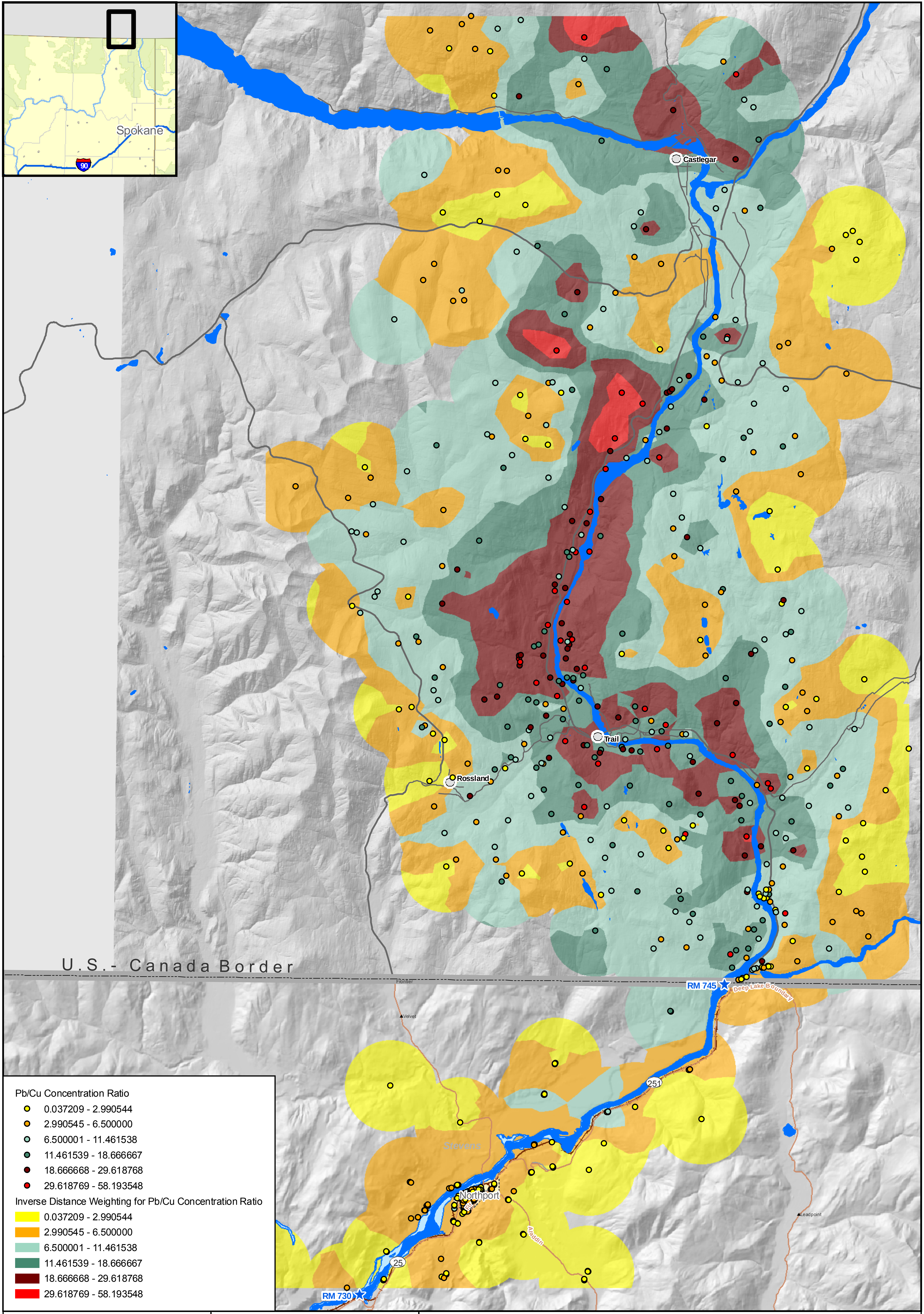
Km
0 1 2

Miles
0 1 2

N

Map 10. Soil Lead Concentrations in the Area South of Northport, Washington

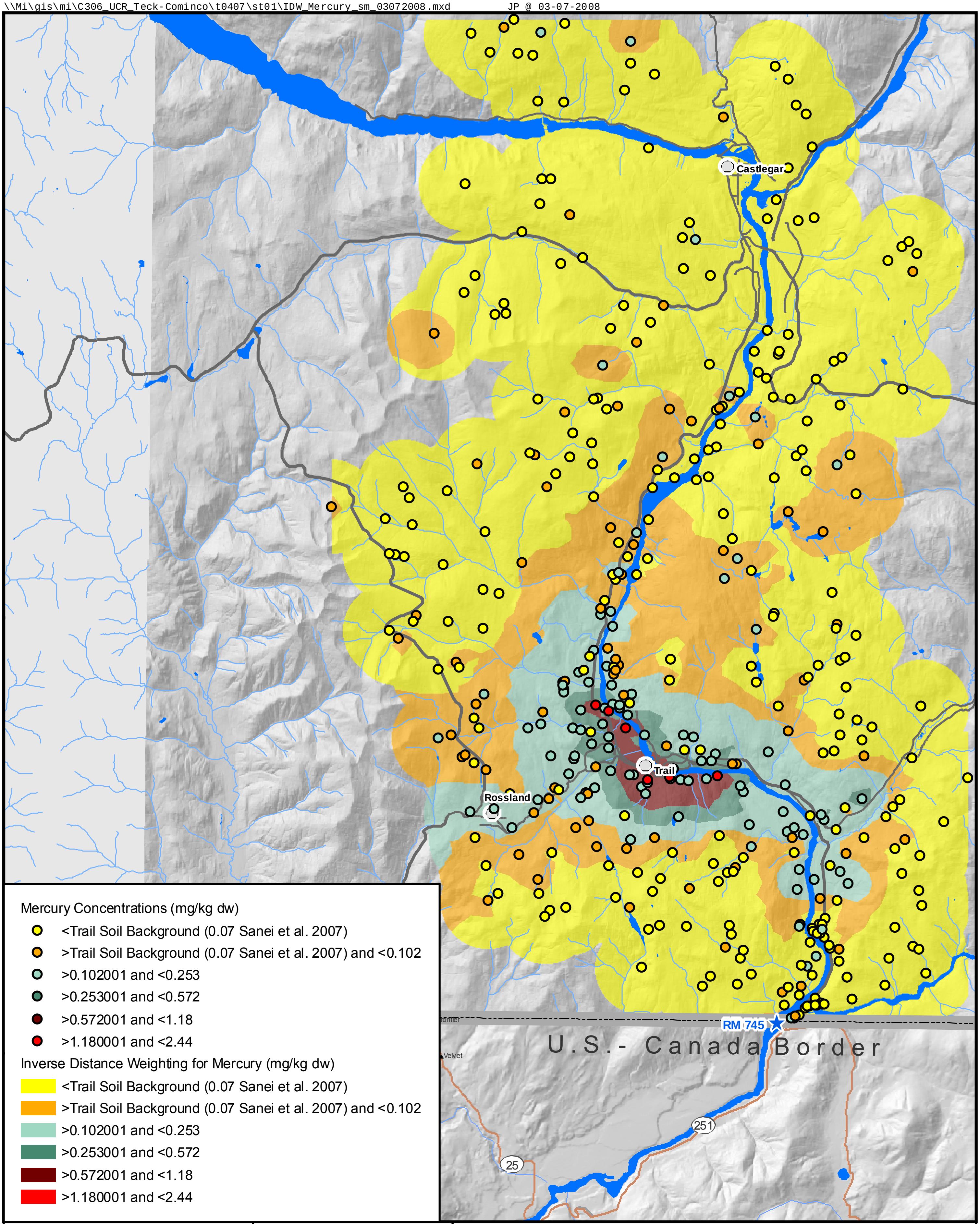
Upper Columbia River, WA



Exponent Parametrix

Map 11. **Spatial Distribution of Lead to Copper Ratios in Soil Between Trail and Northport**

Upper Columbia River, WA

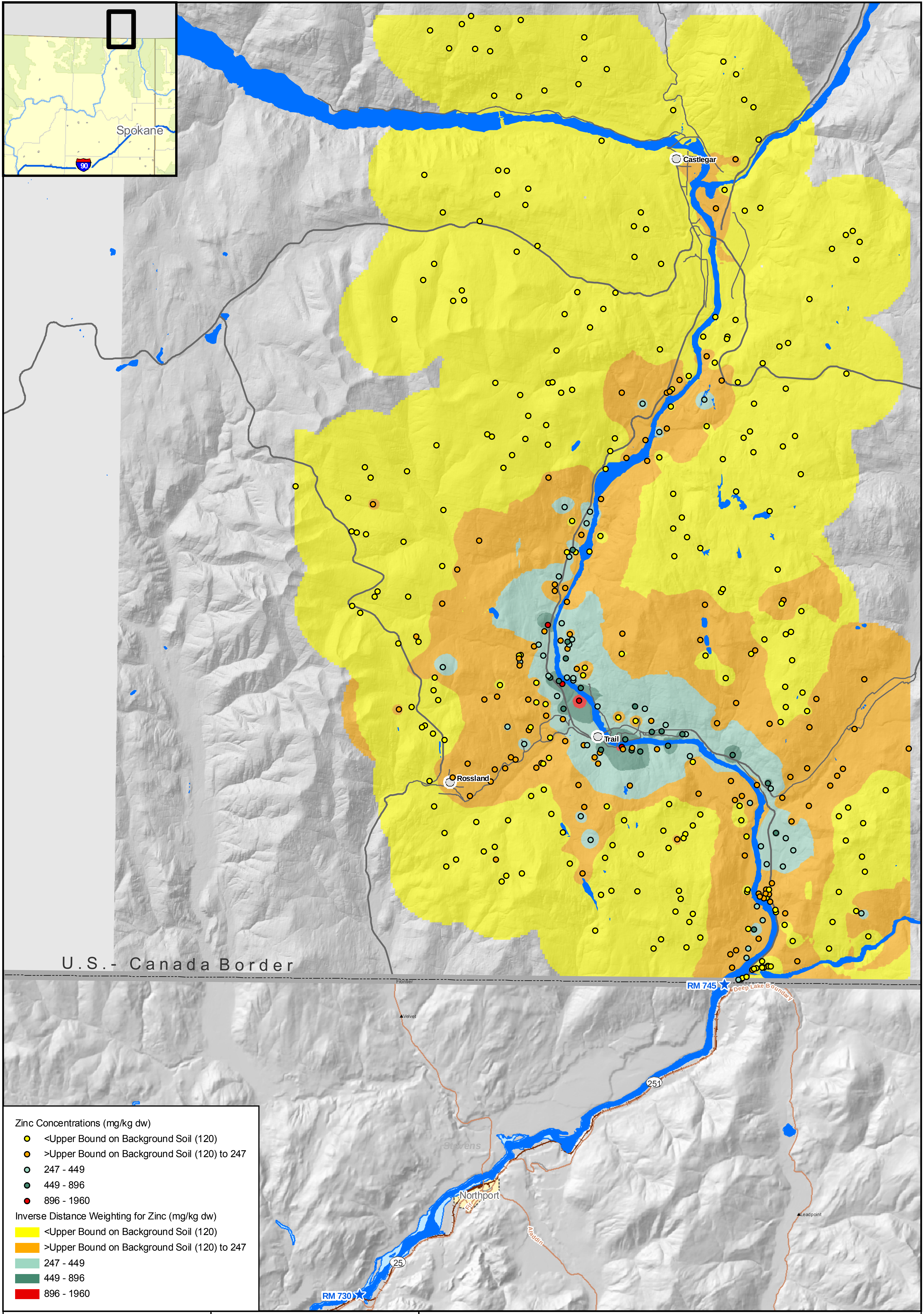


Exponent **Parametrix**

Map 12. **Soil Mercury Concentrations in the Vicinity of the Trail Facility and the U.S. - Canada Border**

Upper Columbia River, WA

\\Mi\gis\mi\C306_UCR_Teck-Cominco\t0407\st01\IDW_09182008\IDW_Zinc_09182008.mxd JP @ 09-18-2008



Zinc Concentrations (mg/kg dw)
- ● <Upper Bound on Background Soil (120)
- ● >Upper Bound on Background Soil (120) to 247
- ● 247 - 449
- ● 449 - 896
- ● 896 - 1960

Inverse Distance Weighting for Zinc (mg/kg dw)
- 🟨 <Upper Bound on Background Soil (120)
- 🟧 >Upper Bound on Background Soil (120) to 247
- 🟩 247 - 449
- 🟩 449 - 896
- 🟥 896 - 1960

Exponent Parametrix

Km
0 1 2

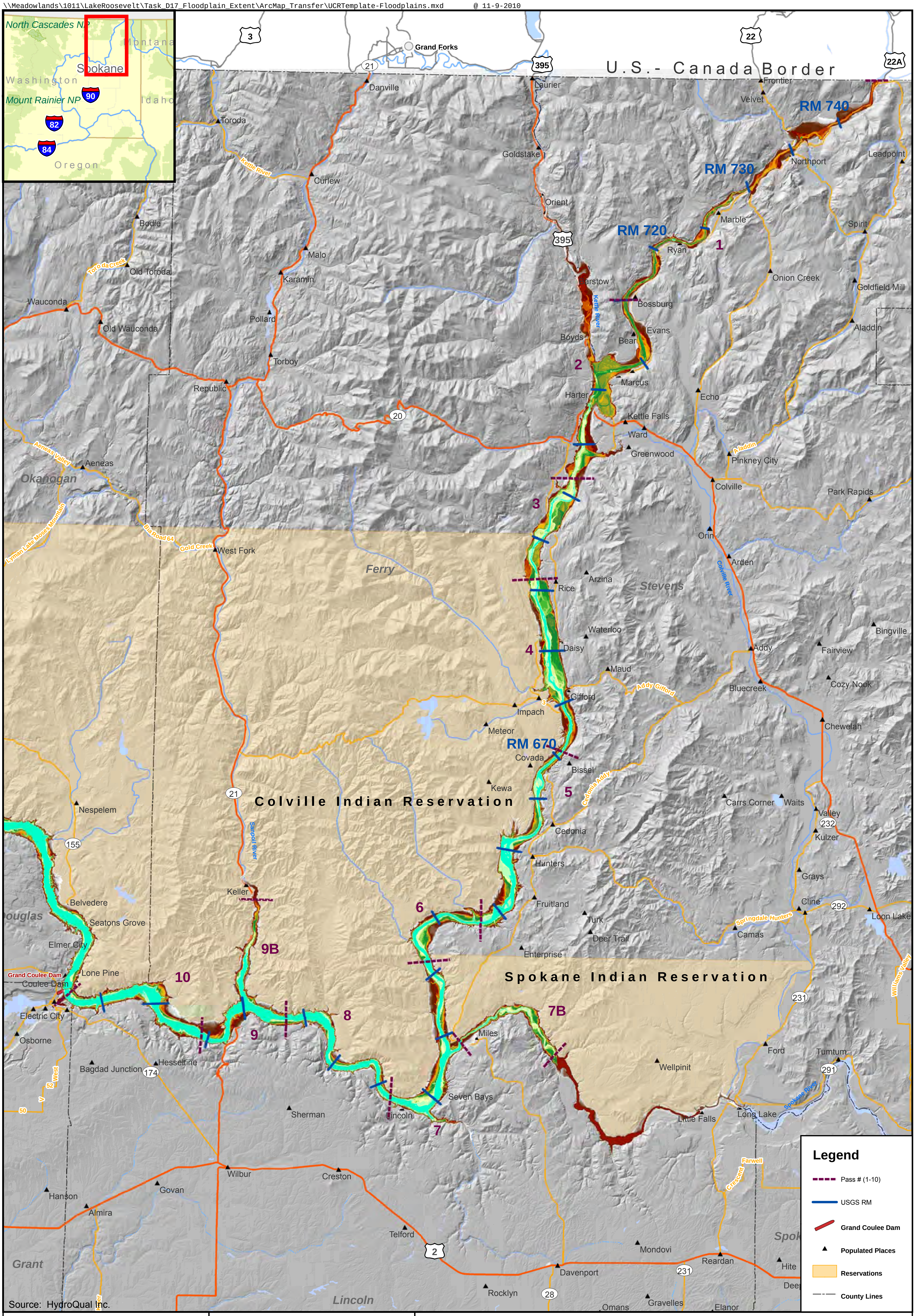
Miles
0 1 2

N

Map 13. **Spatial Distribution of Zinc in Soil Between Trail and Northport**

Upper Columbia River, WA

\\Meadowlands\1011\LakeRoosevelt\Task_D17_Floodplain_Extent\ArcMap_Transfer\UCRTemplate-Floodplains.mxd @ 11-9-2010

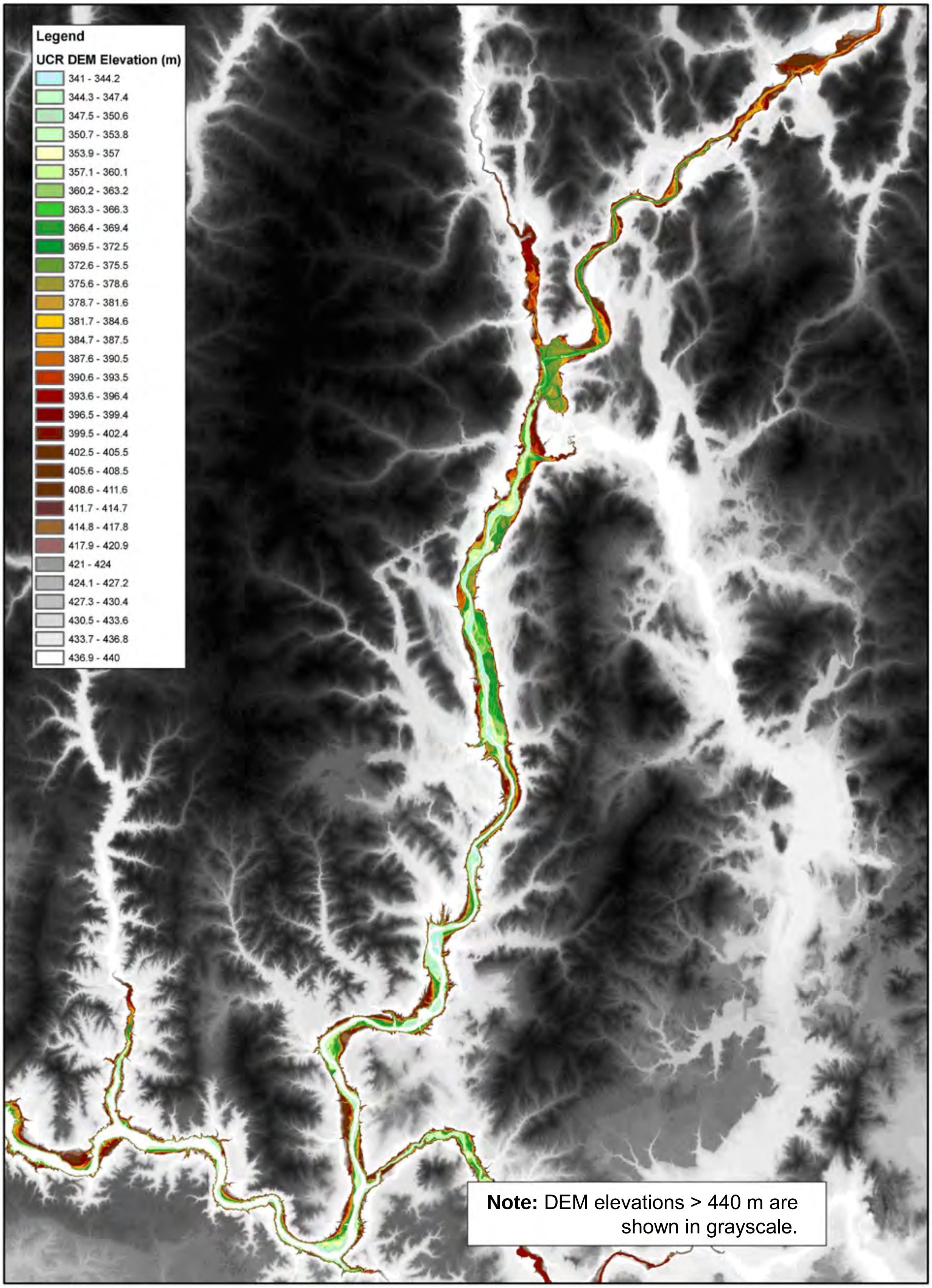


Source: HydroQual Inc.

Exponent **Parametrix**

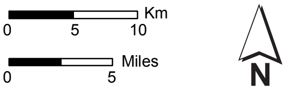
Map 14. Locations of Data Subsets Used to Generate the Refined Bathymetric Surface for the Upper Columbia River

Upper Columbia River, WA



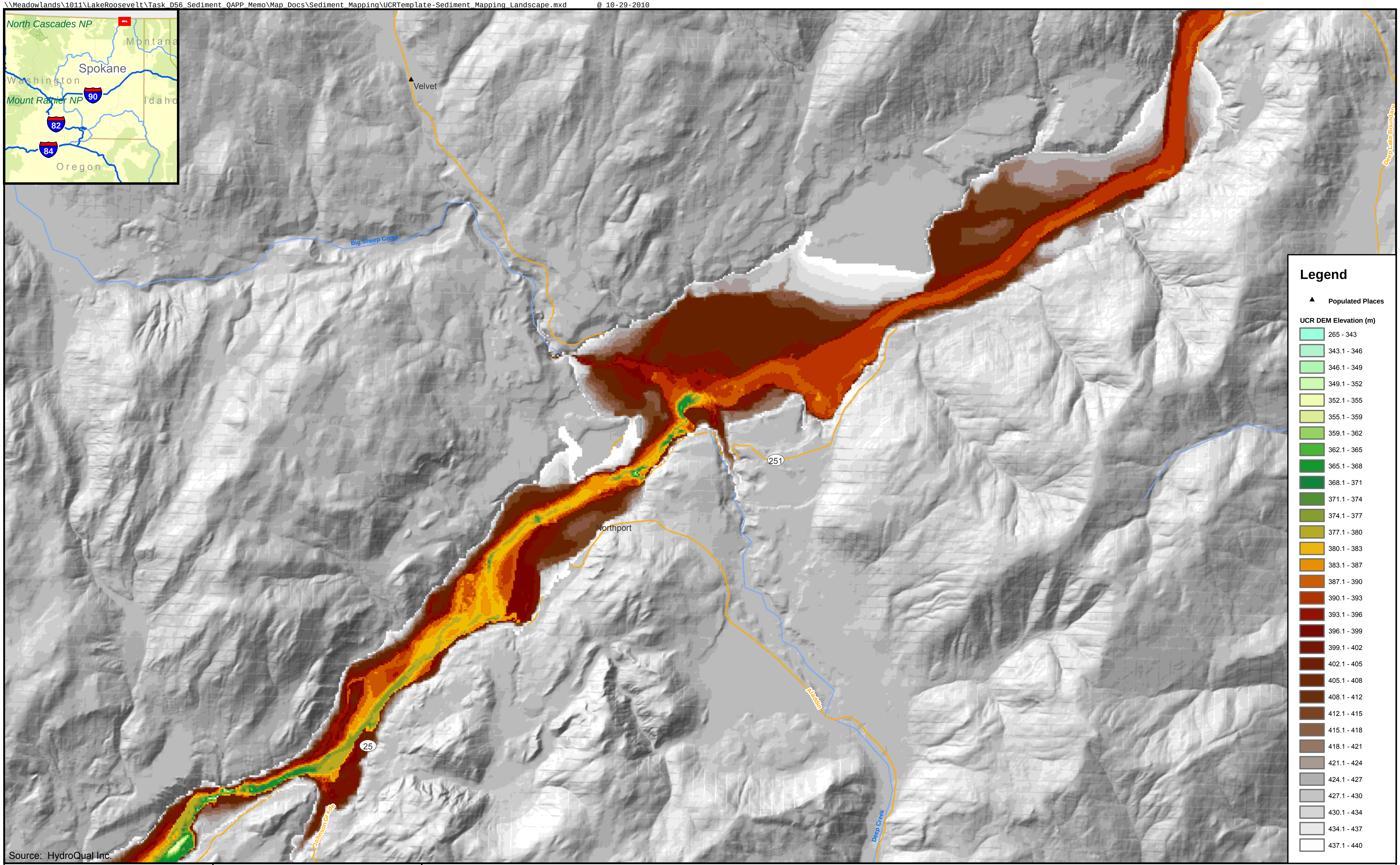
Note: DEM elevations > 440 m are shown in grayscale.

Exponent Parametrix



Map 15. **Refined Bathymetric Surface for the Upper Columbia River: U.S. - Canada Border to Grand Coulee Dam**

Upper Columbia River, WA



Source: HydroQual Inc.

Exponent Parametrix

Map 16. **Refined Bathymetric Surface for the Upper Columbia River near Northport**

Upper Columbia River, WA

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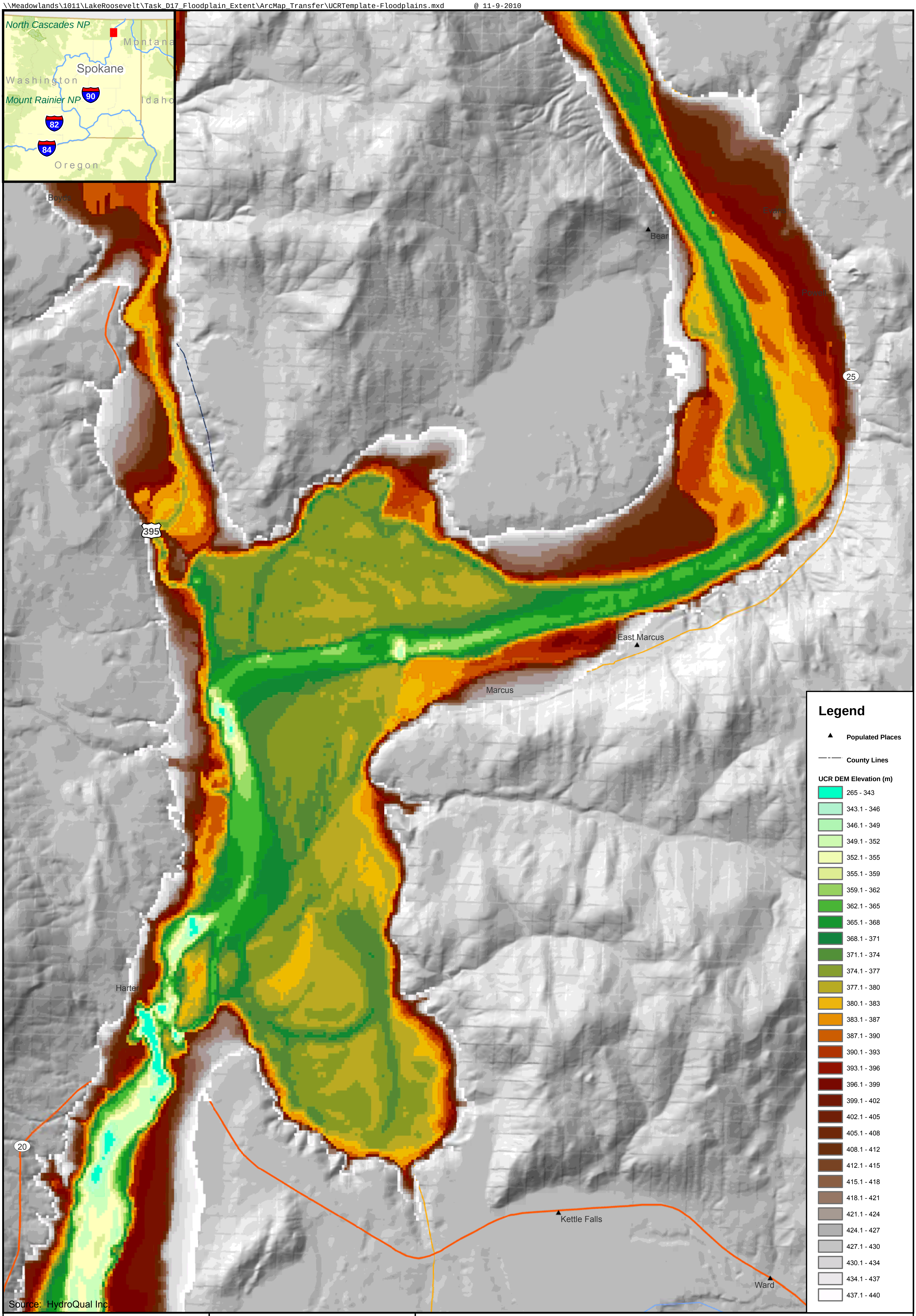
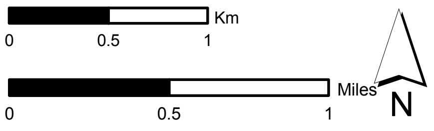


Source: HydroQual Inc.

Exponent **Parametrix**



Map 17. **Refined Bathymetric Surface for the Upper Columbia River near Marcus Flats**

Upper Columbia River, WA

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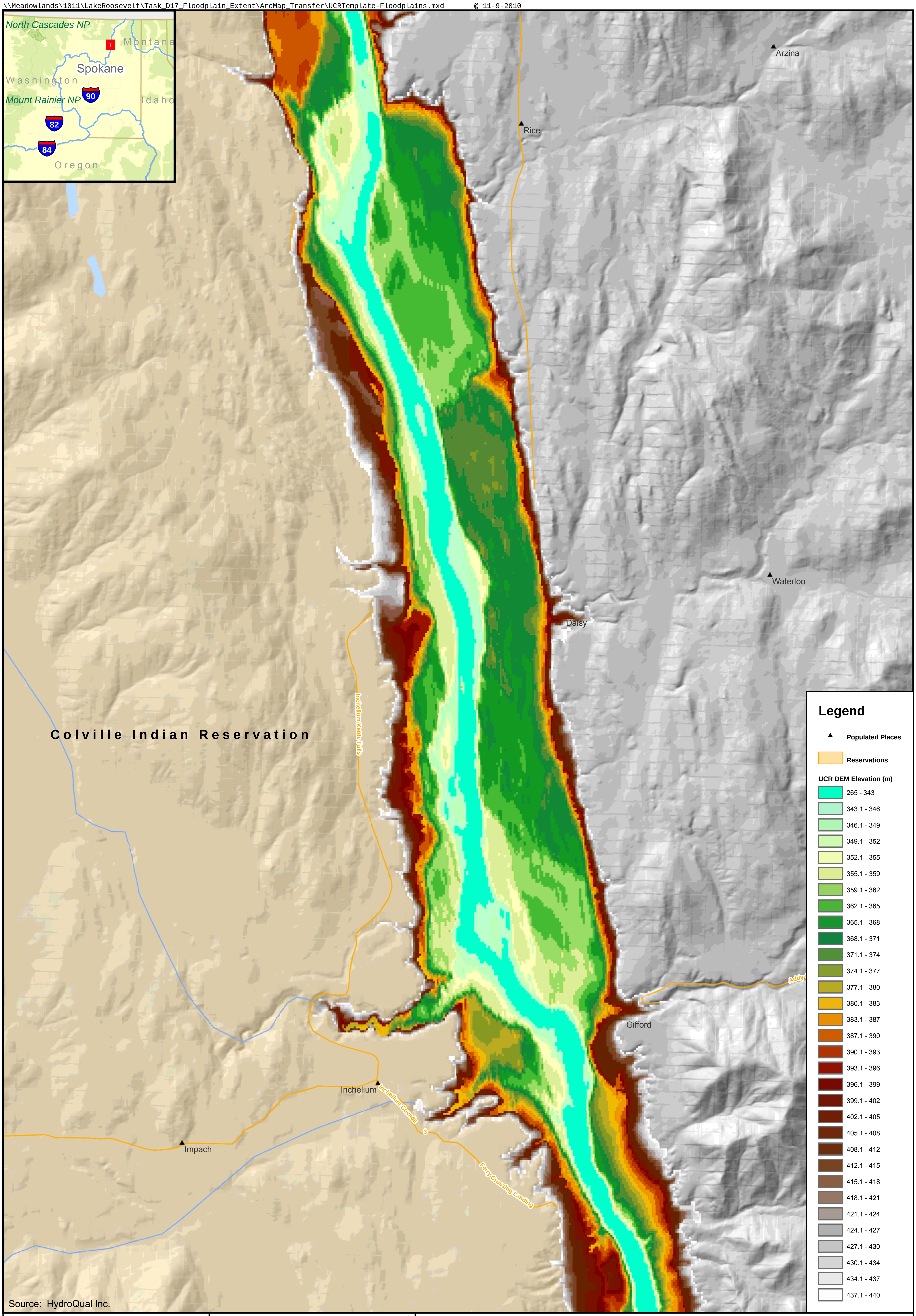
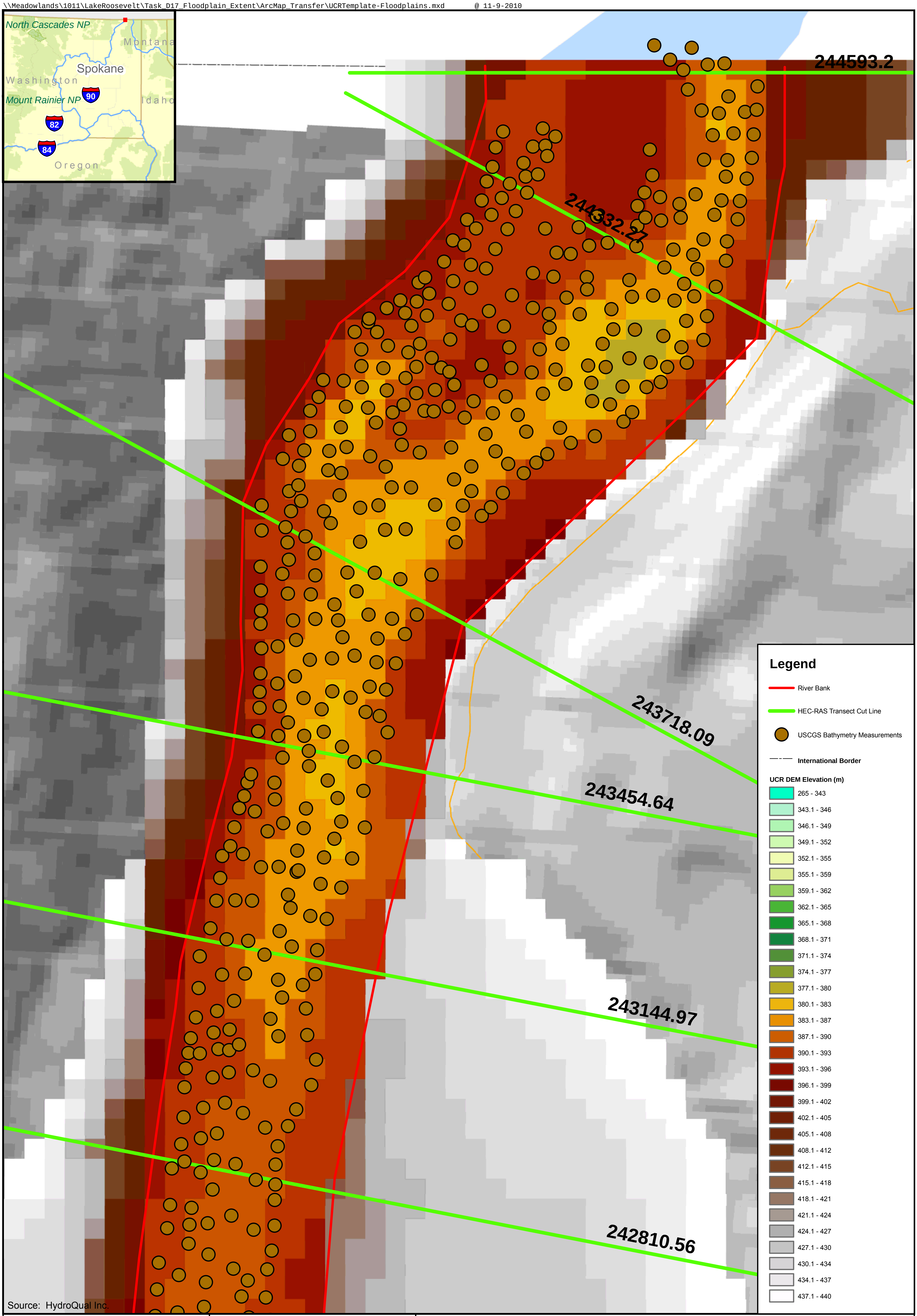


Source: HydroQual Inc.

Exponent **Parametrix**

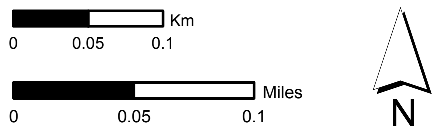
Map 18. **Refined Bathymetric Surface for the Upper Columbia River near Inchelium**

Upper Columbia River, WA



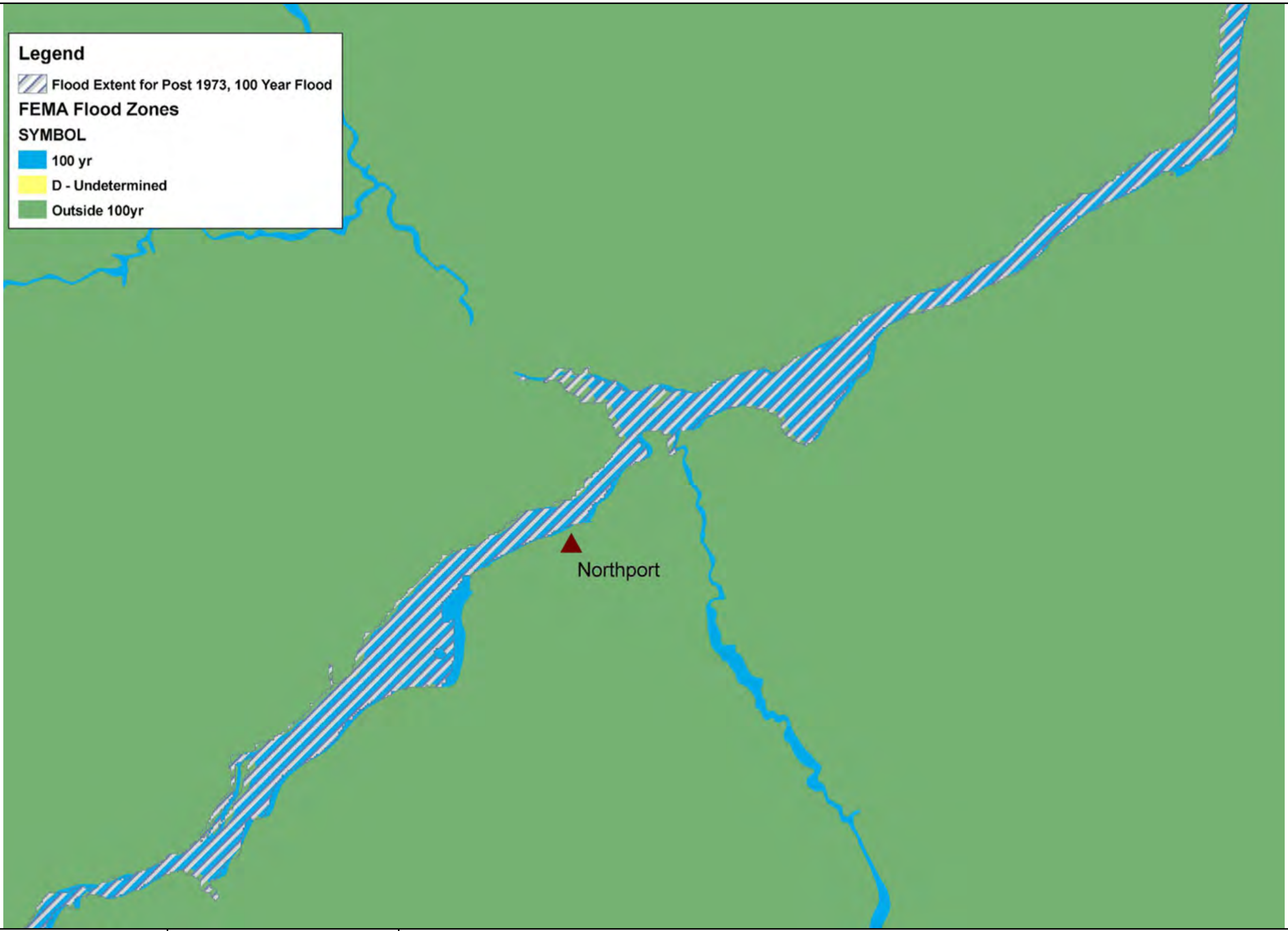
Source: HydroQual Inc.

Exponent **Parametrix**



Map 19. **Density of 1947-1949 USCGS Soundings near the U.S. - Canada Border**

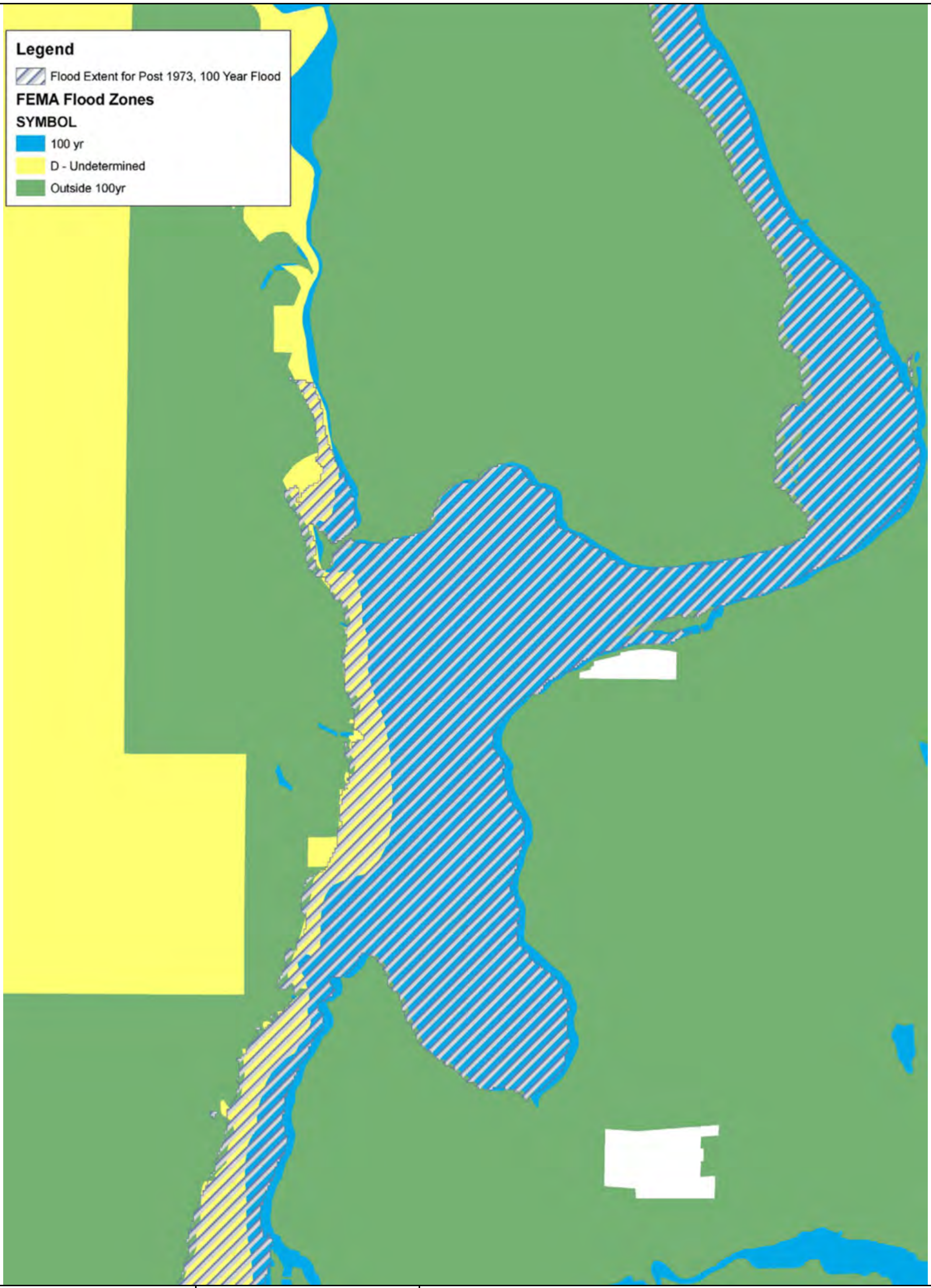
Upper Columbia River, WA



Exponent Parametrix

Map 20. **Comparison of Calculated and FEMA Floodplains for the 1-in-100-Year (post-1973) Flood Area near Northport**

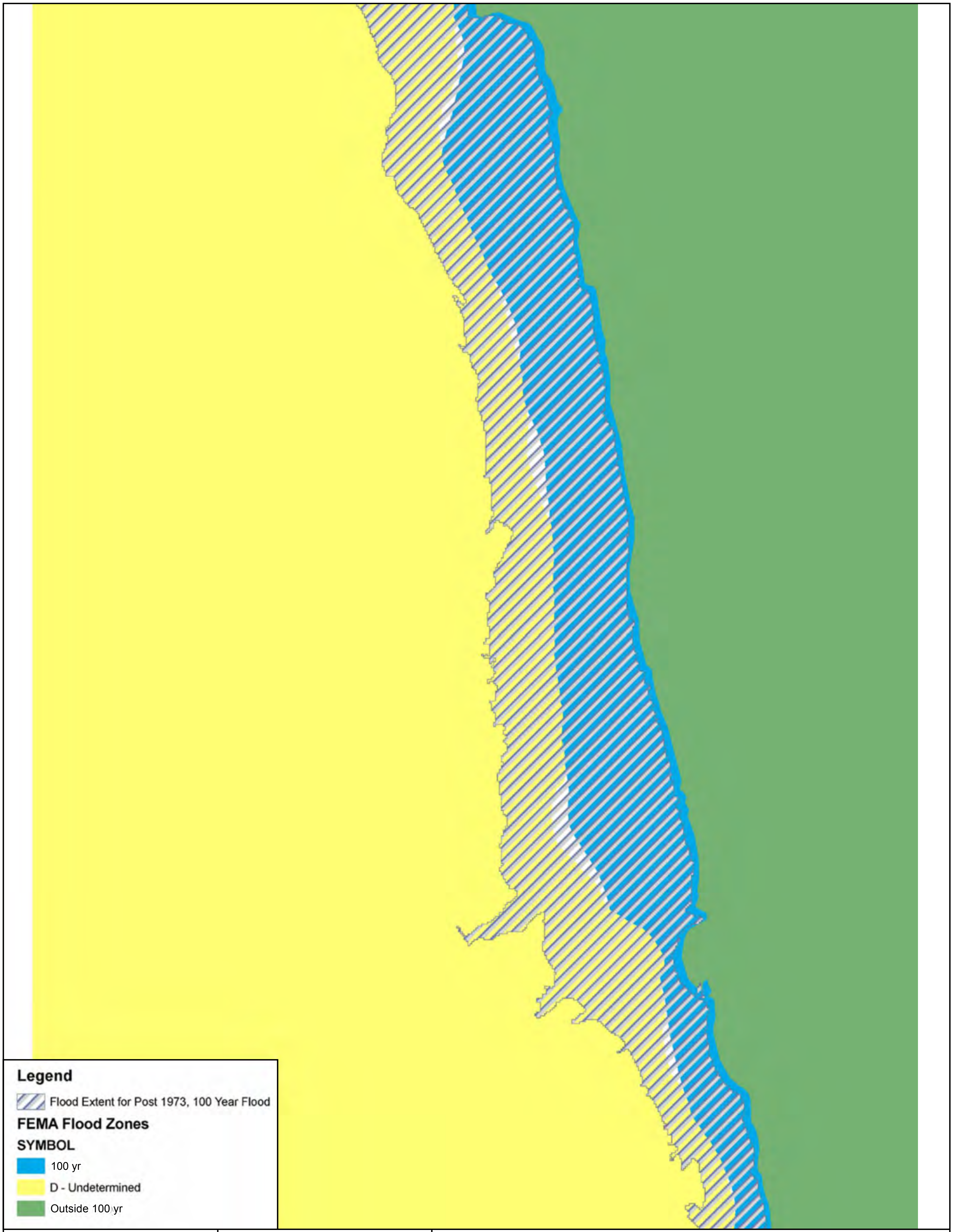
Upper Columbia River, WA



Exponent Parametrix

Map 21. **Comparison of Calculated and FEMA Floodplains for the 1-in-100-Year (post-1973) Flood Area near Marcus Flats**

Upper Columbia River, WA

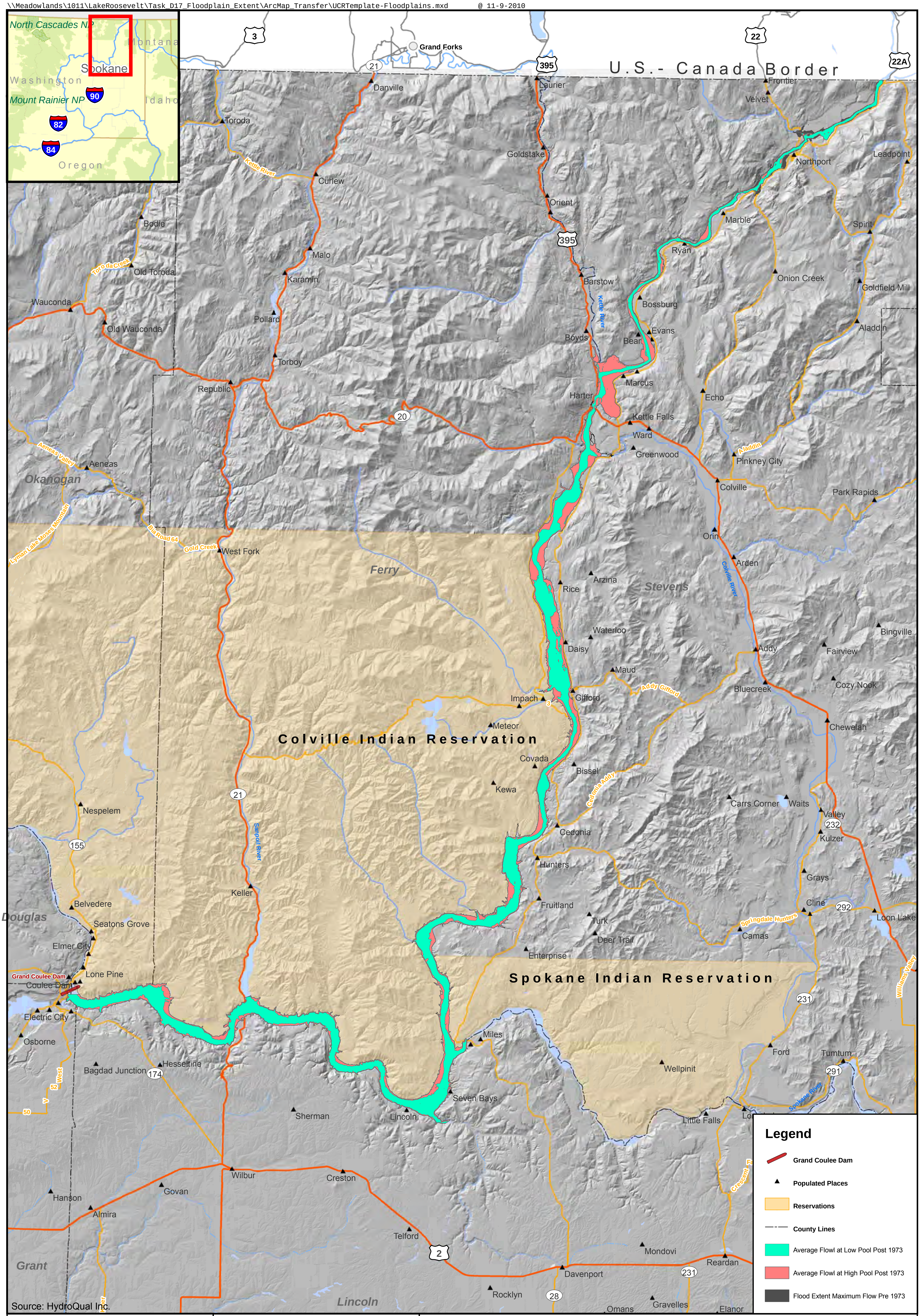


Exponent Parametrix

Map 22. **Comparison of Calculated and FEMA Floodplains for the 1-in-100-Year (post-1973) Flood Area near Inchelium**

Upper Columbia River, WA

\\Meadowlands\1011\LakeRoosevelt\Task_D17_Floodplain_Extent\ArcMap_Transfer\UCRTemplate-Floodplains.mxd @ 11-9-2010



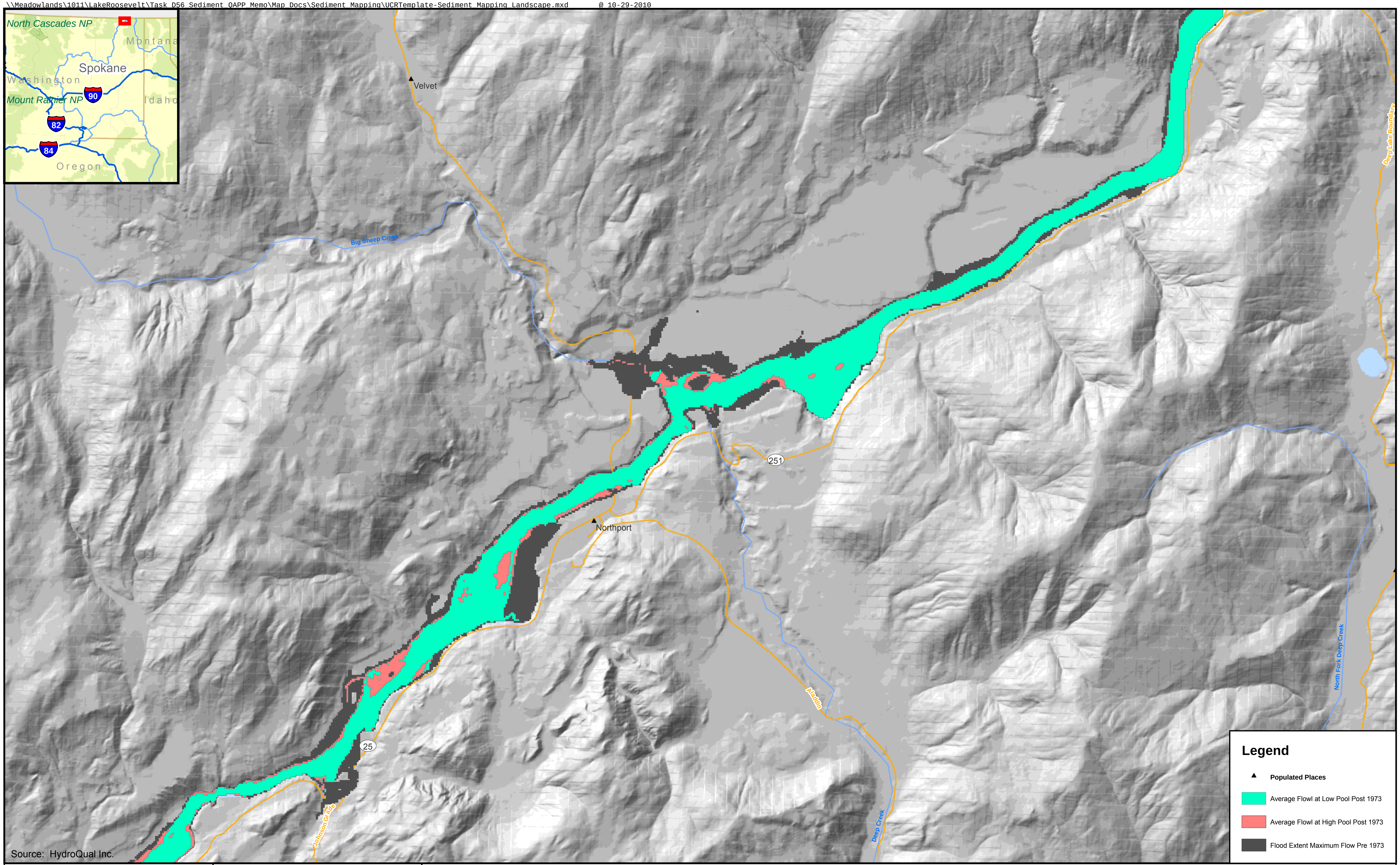
Legend

- Grand Coulee Dam
- ▲ Populated Places
- 🟨 Reservations
- — · — County Lines
- 🟩 Average Flowl at Low Pool Post 1973
- 🟥 Average Flowl at High Pool Post 1973
- ■ Flood Extent Maximum Flow Pre 1973

Exponent **Parametrix**

Map 23. Calculated Floodplains for Post-1973 Average Daily Flow and Pre-1973 Maximum Flow Conditions from the U.S. - Canada Border to Grand Coulee Dam

Upper Columbia River, WA



Source: HydroQual Inc.

Exponent Parametrix

Km
0 0.5 1

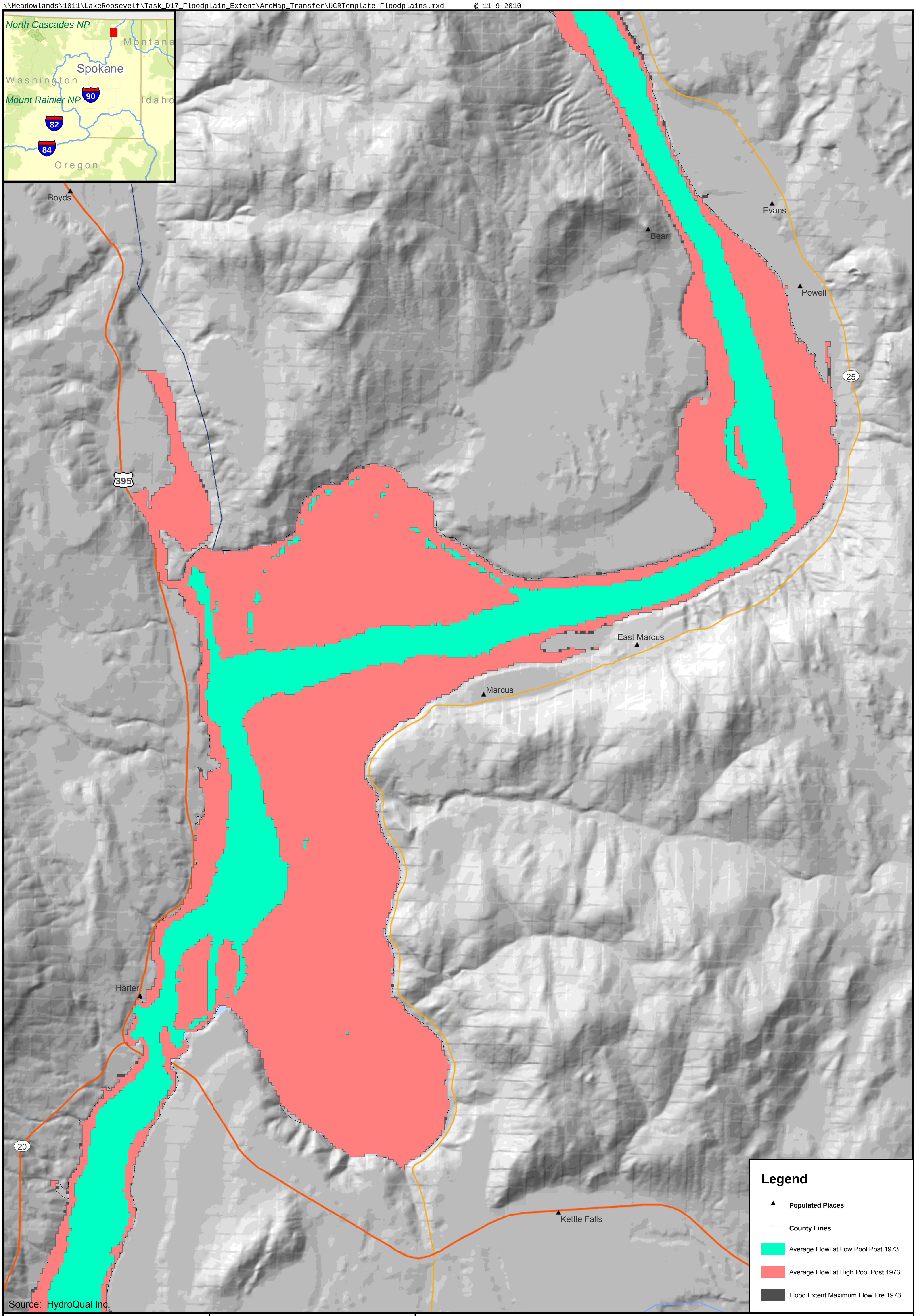
Miles
0 0.5 1

N

Map 24. Calculated Floodplains for Post-1973 Average Daily Flow and Pre-1973 Maximum Flow Conditions Area near Northport

Upper Columbia River, WA

\\Meadowlands\1011\LakeRoosevelt\Task_D17_Floodplain_Extent\ArcMap_Transfer\UCRTemplate-Floodplains.mxd @ 11-9-2010



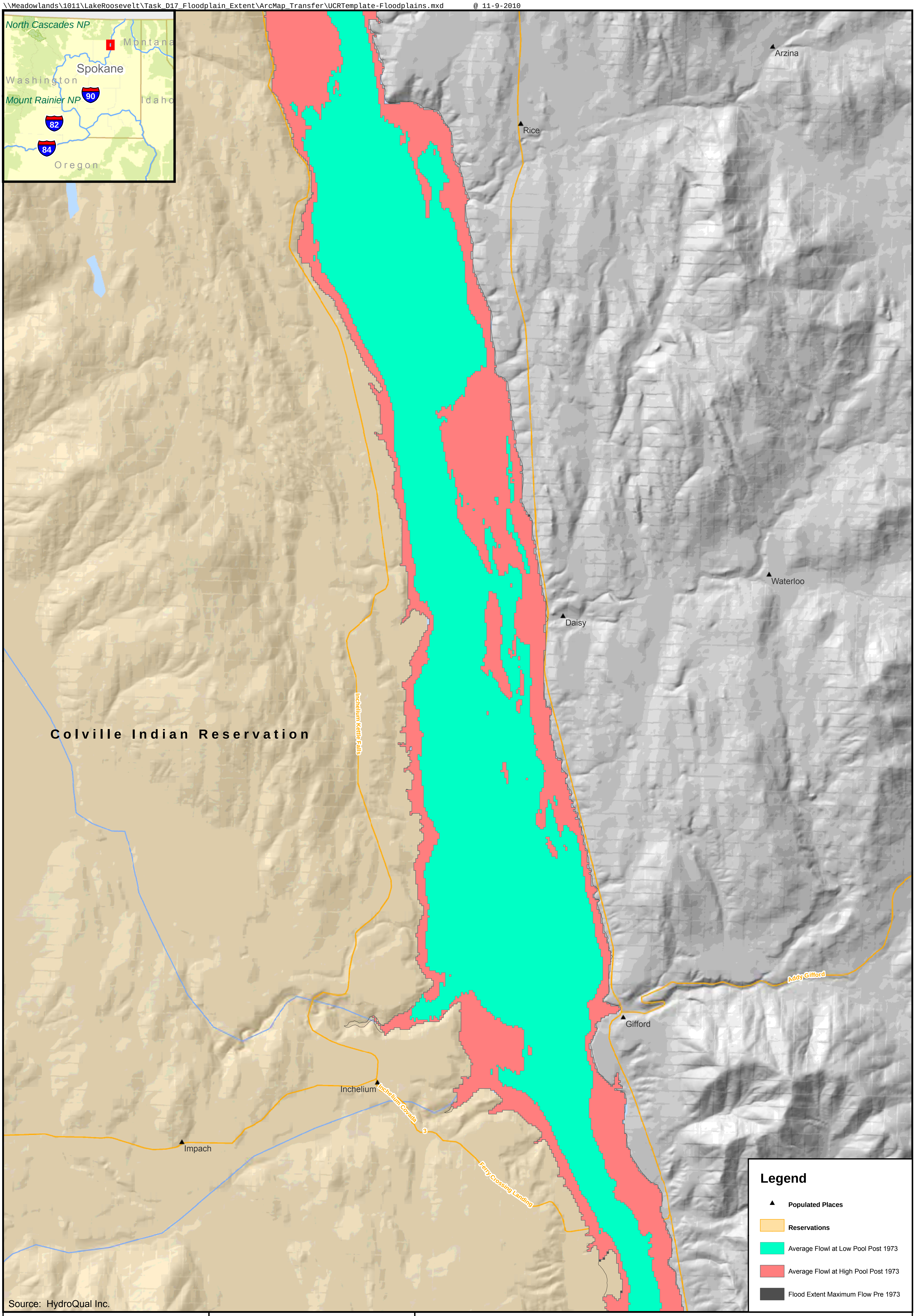
Source: HydroQual Inc.

Exponent **Parametrix**

Map 25. Calculated Floodplains for Post-1973 Average Daily Flow and Pre-1973 Maximum Flow Conditions Area near Marcus Flats

Upper Columbia River, WA

\\Meadowlands\1011\LakeRoosevelt\Task_D17_Floodplain_Extent\ArcMap_Transfer\UCRTemplate-Floodplains.mxd @ 11-9-2010



Source: HydroQual Inc.

Exponent Parametrix

Km
0 0.5 1

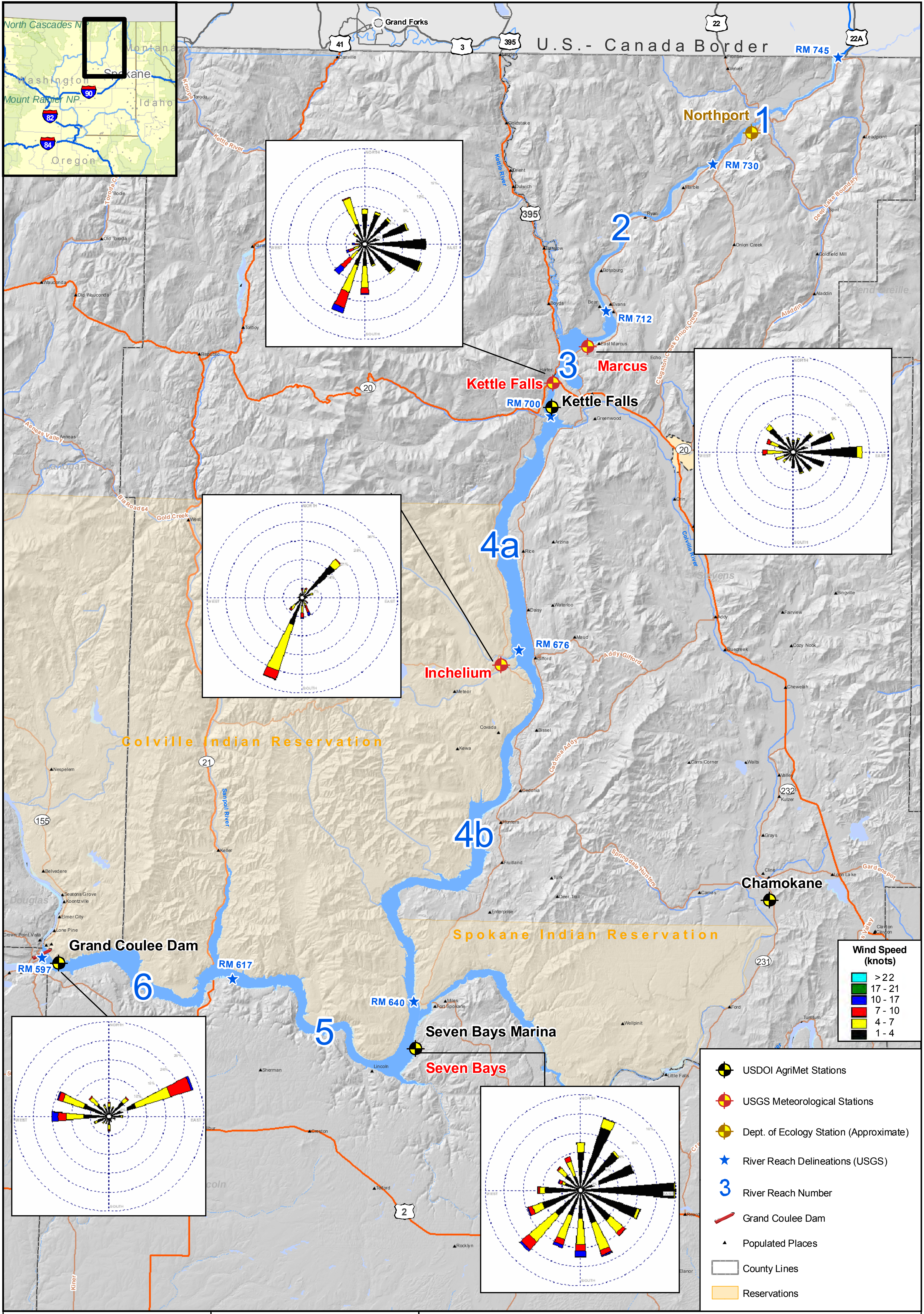
Miles
0 0.5 1

N

Map 26. **Calculated Floodplains for Post-1973 Average Daily Flow and Pre-1973 Maximum Flow Conditions Area near Inchelium**

Upper Columbia River, WA

\\192.168.2.11\gis\mi\C503_0401\MetStations_wGraphics_Drawdown_07022009.mxd JP @ 07-07-2009



Exponent Parametrix

Km
0 5 10

Miles
0 5 10

N

Map 27. **Wind Distribution Along UCR During Drawdown Period**

Upper Columbia River, WA

APPENDIX H

BACKGROUND SEDIMENT AND SOIL CHEMISTRY

CONTENTS

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ACRONYMS AND ABBREVIATIONS

BERA	baseline ecological risk assessment
COPC	chemical of potential concern
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ERDA	Energy Research and Development Administration
Lake Roosevelt	Franklin D. Roosevelt Lake
NURE-HSSR	National Uranium Resource Evaluation Hydrogeochemical and Stream Sediment Reconnaissance
RGS	Regional Geochemistry Survey
RI/FS	remedial investigation and feasibility study
Teck	Teck American Incorporated
UCR	Upper Columbia River
U.S.	United States
USGS	U.S. Geological Survey
UTL	upper tolerance limit
$UTL_{95,95}$	upper 95 percent confidence limit on the 95th percentile of the upper tolerance limit

UNITS OF MEASURE

km	kilometer(s)
mg/kg	milligrams per kilogram
mm	millimeter(s)
ppm	parts per million

1 INTRODUCTION

U.S. Environmental Protection Agency (EPA) guidance incorporates the evaluation of reference or background conditions[1] as part of the conduct of risk assessments (USEPA 1989, 1997). Data used for this background analysis are taken from regional studies in the same overall area as the Site; the characterization of background sediment and soil concentrations uses statistics and methods recommended by USEPA (1992, 2002, 2006).

The studies evaluated in this appendix are historical and were not necessarily conducted for the UCR RI/FS and baseline ecological risk assessment (BERA) and may not meet the current standards of practice and/or the data quality requirements necessary for completion of the BERA. However, for purposes of this BERA Work Plan, the data and analyses are assumed to be adequate to assist in identifying data gaps and describing general site characteristics, but may not be acceptable for use in future deliverables in their current form.

As the BERA progresses, the quality of the existing data, data analysis procedures, and suitability for inclusion in the BERA will be assessed according to procedures that will be reviewed and approved by the EPA. In addition, clear explanations of the data used in evaluations, evaluation methodology, and statistical analysis documentation will be provided in future documents

1.1 BACKGROUND AND OBJECTIVES

Characteristics of sediment and soils in the Upper Columbia River (UCR) may be strongly influenced by local geological conditions. Chemicals of potential concern (COPCs) initially developed for the UCR Remedial Investigation/Feasibility Study (RI/FS) include a number of exotic metals that have been measured at least once in the study area; but that have no known relationship to any specific sources. Sediment and soil data collected by investigators in the Columbia Basin watershed but outside the river itself also include many of these exotic metals.

The purpose of this appendix is to identify and describe available sediment and soil data, for the purpose of characterizing background conditions, which, if required during the ecological risk assessment (ERA) process, and per EPA guidance (USEPA 1989, 1997); will facilitate comparisons of individual chemical measurements from within the Site and help inform risk-based management decisions. The distribution of concentrations for each COPC in the background data set is characterized by an upper tolerance limit

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[1] Ecological risk assessment guidance (USEPA 1997) specifies that site-specific measurement endpoints are to be compared to reference, where "*[r]eference data are baseline values or characteristics that should represent the site in the absence of contaminants released from the site.*" Human health risk assessment guidance (USEPA 1989) specifies that background data are to be used to distinguish site-related contamination from naturally occurring or non-site-related conditions, and that "*[b]ackground samples are collected at or near the hazardous waste site in areas not influenced by site contamination.*" Thus, although different terms are used in ecological and human health risk assessment guidance, both refer to conditions that are equivalent to a site but for the presence of contamination. These conditions are referred to as background conditions in this appendix.

(UTL), as recommended by USEPA (1992, 2002, 2006). The following sections describe how background UTLs were calculated for sediments and soils.

2 SEDIMENT BACKGROUND CONDITIONS

The characterization of background conditions takes several things into account

- The data sets to be used
- The appropriate spatial extent to use
- The representativeness of available data within the spatial extent of the study area
- UTL statistics that are appropriate and feasible to compute with the data set.

Evaluation of the representativeness of the data used to characterize background required the analysis and comparison of several alternative methods of selecting and grouping data.

2.1 DATA SETS FOR BACKGROUND SEDIMENT CHARACTERIZATION

Several studies have measured COPC concentrations in sediments in the vicinity of the UCR but not within the area of the Columbia River proper or its floodplain. The following studies include data that are useful for characterizing regional background conditions:

- National Uranium Resource Evaluation Hydrogeochemical and Stream Sediment Reconnaissance (NURE-HSSR; soil samples from 1,824 locations and sediment samples from 4,578 locations, United States [U.S.] only) (USGS 2004).
- Regional Geochemistry Survey (RGS; 8,446 sediment locations, Canada only) (BC MEMPR 2007).

Each of these studies is briefly described in the following sections.

2.1.1.1 National Uranium Resource Evaluation—Hydrogeochemical and Stream Sediment Reconnaissance

The NURE-HSSR program, a nationwide survey of the elemental composition of soils and sediments, was conducted to assess the location of potential deposits of uranium and other strategic minerals in the U.S. Sampling and analysis was conducted by four national laboratories during the 1970s and 1980s. In the Pacific Northwest, sampling and analysis was conducted primarily by the Savannah River Laboratory, with some samples collected and processed by the Lawrence Livermore Laboratory. NURE-HSSR data were obtained from U.S. Geological Survey (USGS 2004).

During the NURE-HSSR program, sediment was collected from numerous small streams within and near the study area. The location of each sample was described, and those descriptions included an indication of whether or not each sampling location was potentially influenced by municipal, agricultural, industrial, mining, or other (unspecified) anthropogenic activity. All samples that were described as potentially influenced by anthropogenic activity were excluded from the data set used to characterize background conditions.

Documentation of the field and laboratory methods followed during the NURE-HSSR program was reviewed to assess to usability of these data. The field and analytical methods used to collect and analyze the NURE-HSSR data were reviewed by an analytical chemist, relying on published descriptions of the methods (Bolivar 1980; Puchlik 1977; Steinborn 1977). The quality assurance program included the following elements:

- Standardized sampling procedures
- Use of qualified personnel in the field with senior oversight provided
- Contracted sampling teams were visited at random by laboratory personnel throughout the duration of the sample collection effort
- A minimum of 5 percent of sites were revisited to check accuracy of locations on topographic maps and to collect quality assurance samples
- Field quality assurance samples included field replicates and field splits that were submitted to the laboratories as blind samples
- Synthetic standards were made to check instrument performance
- Standardized geologic materials were analyzed to ensure consistency of analyses over time
- Selected samples were also analyzed by both emission spectroscopy and activation analysis to evaluate the comparability of the different methods used
- An inter-laboratory quality assurance program was administered by the Energy Research and Development Administration (ERDA)-Ames Laboratory which consisted of
  - Sending several standardized sediments and solutions to the participating laboratories as blind samples on a routine basis
  - Compiling the analytical results for these performance standards and reporting them to the ERDA-Grand Junction Office.

Given the comprehensive nature of the quality assurance program, the overall monitoring of data quality by ERDA-Ames Laboratory, and the standard methods used for analysis, the quality of data generated by the NURE-HSSR program is considered acceptable for determining background concentrations. The 0.5 to 1.0 mm fraction of each sample was analyzed by neutron activation analysis, a sensitive method that effectively quantifies the total amount of each element in a sample. However, it should be noted that samples collected during Phase I of the RI/FS are of different grain sizes, creating an inconsistency that introduces potential bias into any comparisons that might be made between the two datasets. Overall, the quality assurance measures implemented during the NURE-HSSR field and laboratory programs followed the standards of good laboratory practice, and the data are considered usable for the purpose of evaluating background conditions.

Mercury and silver values in the original NURE-HSSR data source span a very wide range of concentrations. Mercury data are reported in units of ppm (or equivalently, mg/kg), but the magnitude of the values are generally in the hundreds, much higher than is to be expected of background sediment, and much higher than the mercury values in other data sets (specifically, RGS and Phase 1 data). Although historical use of mercury for gold mining may be responsible for some occurrences of high mercury concentrations in the area, the extensive elevation of mercury values raises some uncertainty about the accuracy of mercury values in the NURE-HSSR data set. Silver values in the NURE-HSSR data set seem to conform to a well-defined distribution, but with a large number of observations several orders of magnitude above the apparent mean of the underlying distribution. The presence of silver ores and mining activities in the region may be responsible for this bimodal distribution, but the nature of the distribution raises some potential concerns about the suitability of these data to characterize background conditions. As a result of the unusual distributions of mercury and silver values in the NURE-HSSR data set, these data were not used for background characterization. The distribution of background concentrations for mercury and silver are therefore based only on data from the RGS data set. All of the data that were extracted and used for background characterization have been uploaded into the project database.

2.1.2 Regional Geochemistry Survey

The RGS program measured concentrations of elements in sediments of British Columbia from the late 1970s through 2005. The overall scope of this program was similar to that of the NURE-HSSR program. RGS data were obtained from the British Columbia Ministry of Energy, Mines, and Petroleum Resources (BC MEMPR 2007).

A subset of the RGS data set surrounding the upstream (Canadian) portions of the Columbia River was included in the data set used to evaluate regional background sediment. This subset included measurements between approximately latitudes 49 and 52 degrees north, and 115.3 and 120.6 degrees west. All samples within the area corresponding to the approximate limits of the possible influence of aerial emissions from the Trail facility were excluded from the assessment of background. Quality assurance procedures followed by the RGS program were consistent with good laboratory practices, and the data are considered usable for the purpose of evaluating background conditions.

2.2 SPATIAL EXTENT FOR BACKGROUND CHARACTERIZATION

The following spatial constraints were applied to data used for background sediment characterization:

- Only data from sampling locations within the UCR watershed were used, because data from outside the watershed may not be representative of sediments found in the UCR itself. The UCR watershed boundary was identified as described below.
- Sampling locations within the 100-year floodplain were excluded because they could be influenced by river-borne materials.
- Sampling locations within a buffer zone around the Trail smelter were excluded because they could be influenced by aerial deposition of smelter materials.

For the portion of the upper Columbia River watershed located in the U.S., hydrologic unit polygons were compared to the overall extent of the Columbia River watershed boundary defined by the Interior Columbia Basin Ecosystem Management Project (ICBEMP 2008), and all corresponding polygons were exported as a single data set. For the portion of the Columbia River watershed located in Canada, polygons (BC Government 2008) were compared to the overall extent of the Columbia River watershed boundary (ICBEMP 2008) and exported as a single data set. The U.S. and Canadian data sets were merged to produce an overall watershed boundary.

To ensure that the possible effect of aerial emissions was eliminated from the background data set, several alternative sizes of buffers around the Trail smelter were evaluated. Because the spatial extent of aerial deposition has not been strictly defined by other data analyses, buffer sizes from 10 to 80 km in radius were used (Map 1). The criterion for selection of a buffer size for use in the background characterization was that it should be the smallest buffer size at which background concentrations stabilize for smelter-associated metals (cadmium, copper, lead, and zinc). Because a UTL is to be ultimately used to characterize the background distribution, and because the UTL is sensitive to both the mean and the variance of a data distribution, the UTL of the background data at each buffer size was used to assess the stability of the background data set. Therefore, the buffer size to be used is the smallest one at which the UTL of background data becomes essentially constant for smelter-associated metals.

The buffer zone ultimately used for background characterization should not be interpreted as an indicator of the spatial extent of aerial emissions from the Trail smelter. Circular buffer zones were evaluated, whereas the pattern of aerial deposition around the smelter is most likely not circular as a result of non-uniform wind directions and speeds. The buffer zone may also have effectively included other sources, particularly including the Le Roi smelter in Northport, Washington. Consequently, the evaluation process that was applied provides confidence that sediments from outside the buffer are not affected by the Trail smelter, but does not indicate that all of the sediments inside the buffer are affected by the smelter.

2.3 REPRESENTATIVENESS OF DATA WITHIN THE BACKGROUND EXTENT

Locations sampled by the NURE-HSSR and RGS programs appear to be neither uniformly nor randomly located throughout the extent of interest (Map 2). Because samples were collected where sediment was found, intrinsic variations in the distribution of sediments are likely to have affected the distribution of sampling locations. Nevertheless, there are smaller areas within the overall extent of NURE-HSSR sampling with a higher-than-ordinary spatial density of samples. The spatial variation of the sampling density is therefore of potential concern for the evaluation of representative background conditions. To address the variation in sampling density, the overall area was subdivided into blocks of 1, 2, 5, and 10 km in width and height, and data averaged within each block. Variation in the UTL at each block size was evaluated to determine whether variations in the spatial density of sampling were affecting the calculated values of the UTL. UTLs for the complete original data set, without block averaging, were also computed for comparison to the results for various block sizes.

2.3.1 Distributions by Analyte and Data Set

Concentrations of elements reported within the NURE-HSSR and RGS data sets are very similar in overall range, central tendency (median), and characteristic over-dispersion (relative to a normal or lognormal distribution). Aluminum, potassium, and terbium are the only elements for which there is a fairly large difference between the data sets; concentrations in the NURE-HSSR data set are higher in all cases. Detailed depictions of the distributions of the pooled sediment data sets are shown in Figures 1 through 46. In general, concentrations are not normally distributed, even after log transformation of the data. Therefore, a distribution-free method is appropriate to calculate tolerance limits.

2.4 UTL STATISTICS FOR BACKGROUND CHARACTERIZATION

USEPA (2006) guidance for the use of an upper tolerance limit states

> *Upper Tolerance Limits (UTLs) are frequently recommended to characterize the upper tail of a distribution. A percentile is chosen and a confidence interval is constructed around that value. …. When attempting to characterize the upper tail of a distribution, a large percentile is chosen, 95th or 99th, and a confidence interval with a high confidence level, say 95%, is constructed about that percentile.*

In accordance with the above-referenced guidance, the target UTL for characterization of background sediment is the upper 95 percent confidence limit on the 95th percentile ($UTL_{95,95}$). This can be expressed as 95 percent coverage (the percentile) with 95 percent confidence (the confidence limit). Tolerance limits were calculated as described in Hahn and Meeker (1991), using a method that does not rely on assumptions about the form of the data distribution. Detection frequencies were at or near 100 percent for most elements; only a few of the exotic elements had detection frequencies below 80 percent (dysprosium [66 percent], niobium [74 percent], selenium [64 percent], strontium [73 percent], tellurium [78 percent], tungsten [79 percent], and yttrium [63 percent]). During block averaging of sediment COPC concentrations, undetected values were taken at one-half of the reported detection limit. Because of the high detection frequencies, large number of data points, and use of a distribution-free method for calculating the UTL, the small fraction of undetected data is not expected to have any effect on the calculated UTLs (Helsel 2005).

2.5 SUMMARY OF BACKGROUND SEDIMENT CHARACTERIZATION APPROACH

The characterization of local background sediment conditions for the UCR study area incorporated the following considerations:

- The NURE-HSSR and RGS data sets were used
- The spatial extent evaluated was within the watershed, outside of the floodplain, and outside of a buffer zone around the Trail smelter
- The effect of averaging over block sizes of 1, 2, 5, and 10 km was evaluated
- The 95th upper confidence limit about the 95th percentile was selected as a target UTL.

2.6 APPLICATION OF THE BACKGROUND SEDIMENT CHARACTERIZATION APPROACH

Both the block sizes (for averaging) and the buffer zone sizes need to be evaluated before an appropriate set of UTLs for background sediment can be obtained. Block sizes were evaluated first, and buffer sizes evaluated second, as described in the following sections.

2.6.1 Block Sizes

The effect of block size was first evaluated using an irregular buffer zone around the smelter that was defined based on initial smelter footprint analyses. This irregular buffer zone corresponds to a radius of approximately 60 km south of the smelter. Because this distance is consistent with the buffer radius ultimately selected for background characterization, no re-evaluation of block sizes was considered necessary following the buffer size analysis. The $UTL_{95,95}$ was calculated for each of the 1, 2, 5, and 10 km block sizes. Results showing these UTLs for different block sizes for a variety of sediment chemical, and including sample sizes, are shown in Figures 47 through 97. UTL values are generally equivalent whether calculated using point data or block sizes of 1 or 2 km. UTLs for 5 km block sizes are generally a little smaller (sometimes a little larger), and UTLs for 10 km block sizes show a greater deviation.

A decrease in UTLs at larger block sizes is not surprising, because the averaging process may reduce the variance of the distribution of values. However, the averaging process also reduces the number of samples used to compute the variance, which will tend to cause the variance, and thus the UTL, to increase. A decrease in the UTL is to be expected when most of the variation occurs over relatively small spatial scales (comparable to the size of a block), and an increase in the UTL is to be expected when most of the variation occurs over relatively large spatial scales (i.e., samples within a block are similar to one another, but blocks differ one from another). The latter condition could be associated with variations in regional geology over the study area (i.e., differing nature of the sediment parent material). To understand whether background sediment chemical concentrations are controlled by regional geology, and therefore whether geology needs to be taken into account when developing UTLs for background sediment, geological data in the U.S. portion of the overall spatial extent was evaluated. Regional geological formations were summarized into general categories (Map 3) as described in an attachment to this Appendix. The distribution of sediment chemistry measurements by geological category, for some of the chemicals showing an increase in UTL at the 10 km block size, are shown in Figures 98 through 106. Background sediment chemical concentrations vary somewhat among these geological types. However, the sample sizes are small for some analytes (as a consequence of the fact that only regional geology data for the U.S. was used, whereas background data from both the U.S. and Canada were used to calculate the UTLs). In addition, equivalent variations in concentrations are seen for analytes with UTLs that decrease with increasing block size. Therefore, regional geology is not clearly responsible for the few cases where the UTL of background sediment increases with block size, and consideration of geological variations within the UCR watershed is considered to be unnecessary for the calculation of UTLs of background sediment.

2.6.2 Upper Tolerance Limits

The number of data points available for each element following averaging by 5 km blocks was sufficient to allow calculation of the $UTL_{95,95}$ for all analytes. In addition, the upper tolerance limits for 90 percent coverage with 95 percent confidence (the $UTL_{95,90}$) were evaluated for sediment.

2.6.3 Buffer Sizes

UTLs ($UTL_{95,95}$) were calculated for all analytes in the background data set for various buffer radii. The results for all radii and all analytes are shown in graphic form in Figure 107. Chemicals that are expected to be associated with the Trail smelter, and to have high concentrations close to the smelter, are expected to cause an elevation of the UTL at small buffer sizes. The distance at which the UTL stabilizes (i.e., becomes constant) is taken to be the buffer size at which the Trail smelter is no longer affecting the calculation of background conditions. Many elements show no trend with buffer size. For example, aluminum, vanadium, and manganese, all indicative of crustal material, show no trends with distance from the Trail smelter. Even iron, which is a component of granulated slag, shows no spatial trend in these sediment samples (note that no samples were included from within the floodplain of the Columbia River, thereby presumably eliminating most, if any, potential influence of granulated slag, even at small distances from the Trail smelter). Some elements that are not associated with smelter operations show some variation, including trends both up and down, with distance from the smelter. Among the metals most directly associated with Trail smelter operations, the following variations with buffer size are observed:

- Cadmium—There is no trend
- Lead—UTL values decrease with distance from the smelter, reaching a constant value at a buffer size of 50 km
- Mercury—There is no trend
- Zinc—UTL values decrease with distance from the smelter, reaching a constant value at a buffer size of 50 km.

A distance of 50 km was therefore taken to be the most appropriate buffer size. The UTL of the background distribution was then calculated using only samples that are more than 50 km from the smelter.

2.6.4 Summary

Based on the results of the evaluations of block sizes, tolerance limits, and buffer sizes, background sediment conditions were calculated for 5 km block sizes, a 50 km buffer around the smelter and two sets of tolerance limits–the upper 95 percent confidence limit on both the 95th and the 90th percentiles. The former UTL is considered the most appropriate representation of the limit of background conditions, and the latter is to be used for comparisons between background values for sediment and soil.

2.7 UPPER TOLERANCE LIMITS OF ELEMENTS IN BACKGROUND SEDIMENT

The calculated UTLs ($UTL_{95,95}$) for background sediment data, selected as described previously, are shown in Table 1. This table includes the 90th and 95th percentiles of the distribution, as well as the 95 percent upper tolerance limit on each of those percentiles. The number of samples and the detection frequency for each analyte are also shown. Detection frequencies were at or near 100 percent for most elements; only a few of the exotic elements had detection frequencies below 80 percent. When calculating the UCLs in Table 1, undetected values were included at one-half of the reported detection limit. Because of the high detection frequencies, large number of data points, and use of a distribution-free method for calculating the UTL, undetected data are not expected to have any effect on the calculated UTLs. The last column in Table 1 contains the $UTL_{95,95}$ values that will, if necessary, be used to evaluate site sediment data per EPA guidance (USEPA 1989, 1997). The $UTL_{95,95}$ is typically only slightly higher than the 95th percentile. This is a reflection of the large sample size (often, N > 2,000) that is available for most constituents.

3 SOIL BACKGROUND CONDITIONS

3.1 DATA SETS FOR BACKGROUND SOIL CHARACTERIZATION

In addition to the NURE-HSSR (1,824 soil locations) data set as detailed in Section 2 of this appendix, several other studies have measured COPC concentrations in soils in the vicinity of the UCR. The data sets produced by these studies and providing the basis for estimating regional background soil concentrations of COPCs include

- Holmgren et al. Washington State samples (79 soil locations) (Holmgren et al. 1993)
- Burt et al. Washington State samples (1 soil location) (Burt et al. 2003)
- Le Roi Smelter Removal Action (6 outer area soil locations only) (Weston 2005)
- Soil samples collected within the U.S. as part of the Teck American Incorporated (Teck) ecological risk analysis biomonitoring program (3 locations) (Golder 2005; Enns 2007).

Data from the above-listed studies that were collected within the boundaries of the aquatic study area, within the boundaries of the pre-1973 100-year floodplain, or within the apparent extent of the Trail facility depositional footprint (from south of Northport to the border) were excluded from the analysis of background conditions[2]. Table 2 summarize the number of measurements of each analyte that are included in the background soil data set. Each of these studies is briefly described in the following sections.

3.1.1 Holmgren et al.

Holmgren et al. (1993) collected surface soil from 3,045 agricultural soils in the U.S., analyzing the samples for cadmium, copper, lead, nickel, and zinc. The purpose of the study was to characterize background soil chemistry in agricultural areas, and sampling sites were selected to represent normal agricultural practices, uninfluenced by any known nonagricultural sources of cadmium and lead. Three locations from the Holmgren et al. (1993) study were sampled within the spatial extent used to select regional background data. These samples were located to the south of the study area.

Soil sample analyses were conducted using strong acid digestion, and analysis of standard reference materials and spiked sediments demonstrated complete recovery of the target metals. Based on the results of quality control sample analyses and the reporting of these data in a peer-reviewed publication, the data of Holmgren et al. (1993) are considered usable for the purpose of evaluating background soil conditions.

The data collected by Holmgren et al. (1993) are available online at http://soils.usda.gov/survey/geochemistry/gen_description.html and have been loaded into the project database.

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[2] Offsite data from the Waneta Hydroelectric Expansion Project are potentially relevant, but are within the area of possible influence of the Trail facility, and so were not included in this analysis.

3.1.2 Burt et al.

Burt et al. (2003) collected surface soil from throughout the U.S., analyzing the samples for trace metals and other major elements. The single Washington State sample that is included in this analysis is located to the south of the study area, near the town of Ritzville.

Burt et al. (2003) analyzed surface soil sample fractions of less than 2 mm diameter using standard methods, producing results corresponding to total concentrations of each analyte. Analytical methods included the analysis of quality control samples. Based on the results of these analyses and the reporting of these data in a peer-reviewed publication, the data of Burt et al. (2003) are considered usable for the purpose of evaluating background soil conditions. Burt et al. (2003) data are available online at http://soils.usda.gov/survey/geochemistry/ gen_description.html.

3.1.3 Le Roi Smelter Removal Action

A Comprehensive Environmental Response, Compensation, and Liability Act removal action was conducted in 2004 at the Le Roi smelter in Northport, Washington, under the direction of EPA Region 10 (Weston 2005). During Phase 2 sampling in May 2004, samples were collected on public lands at varying distances from the former smelter site ("Outer Area" or "OA" samples). The OA samples were analyzed for arsenic, cadmium, copper, and lead.

Sample analyses were carried out following the EPA Statement of Work 5.3, and a quality assurance review of the laboratory results was conducted as part of the remedial program (Weston 2005). The analyses met acceptability standards for precision, accuracy, representativeness, comparability, and completeness.

The OA samples were spatially within or beyond the band of samples around Northport that were designated for no action. A total of 17 OA samples were collected, but location coordinates were available for only 11 of these, and only data for those 11 OA samples were loaded into the project database and used for the characterization of background soil. One of the OA samples was found to have an arsenic concentration above the removal action level (Weston 2005), and that sample was not included among those used for this analysis.

3.1.4 TECK ERA SAMPLES

As part of the biomonitoring program for the Teck wide area ERA (Golder 2005), 10 soil samples were collected in northeastern Washington State during 2005. Three of these were within the overall area used to select regional background samples for soil characterization. Two of these were near the Columbia River between Northport and Marcus Flats, and the third was near the international border east of the study area. The samples were analyzed for arsenic, cadmium, and lead.

3.2 DATA SUMMARIZATION METHODS

As was completed for sediment samples (refer to Section 2 of this Appendix for details) soil data selection criteria applied were as follows:

- Data were excluded if they were within the spatial extent of the aquatic study area, the pre-1973 100-year floodplain, or the potential area of influence of aerial emissions from the Trail facility.
- Data were excluded if they were potentially influenced by agricultural, industrial, mining, power generation, sewage, urban, or other (unspecified) anthropogenic influences, based on information included in the data set. It is important to note that although agricultural soils from the Holmgren et al. (1993) data set were included in the background data set, those 'agricultural' samples were specifically selected to represent background conditions, whereas the character of agricultural influences on NURE-HSSR samples is unknown.
- Only surface sediment samples were included.
- Only measurements reported on a dry weight basis were included.

Data were summarized to produce a single value for each analyte and each sampling location by averaging across laboratory replicates, field splits, and field replicates as necessary. Undetected measurements were taken at half the detection limit. The treatment of undetected measurements has no effect on tolerance limits because detection frequencies are high for all analytes and the highest detection limits are well below the highest detected values (Table 3).

As was the case for sediment samples, because the distribution of concentrations in soil are non-normal even after log transformation (as illustrated in the next section), a distribution-free method (Hahn and Meeker 1991) was used to calculate the upper tolerance limit (the upper 95th percent confidence limit on the 95th percentile) for all analytes with at least 10 measurements in the background data set. There were only 13 measurements of cadmium in soil, insufficient to calculate a tolerance limit directly, so a sample of size 400 (comparable to most other common metals in soil) was bootstrapped using the Gaussian parameters of the log-transformed cadmium distribution, and the tolerance limit calculated on this bootstrapped data set.

3.3 DISTRIBUTIONS BY METAL AND DATA SET

The relative distributions of the background soil concentrations for chemicals that were measured in more than one study are shown in the box-and-whisker plots of Figures 108 through 124. In these figures, the box extends from the 25th to the 75th percentile, with the median shown within the box. The whiskers extend to 1.5 times the inter-quartile distance (Cleveland 1993). Both untransformed and log-transformed concentrations are shown in the figure for each chemical.

The NURE-HSSR data set has the largest range, as is to be expected because the number of samples in this data set is considerably larger than in the other data sets, and the range of a distribution ordinarily increases with sample size (Sokal and Rohlf 1981). For many metals, the NURE-HSSR data set includes numerous observations above and below the whiskers of the box plot, indicating that the data set is non-normal with relatively long tails. Concentrations of metals in other data sets are generally within the range of the NURE-HSSR data. There are some differences between the data sets for some metals, which may reflect differences in sampling or analysis methods, or locations within the overall region, but these differences are not systematic, nor large relative to the overall range of data. Because the NURE-HSSR data set has a relatively large number of measurements, it will have the greatest influence on the tolerance limits. Because the other data sets are generally consistent with the NURE-HSSR data, all the data for each analyte was pooled for further analysis. Differences among data sets appear to be most pronounced for cadmium, perhaps in part because there is no large data set (i.e., NURE-HSSR) to provide context for the others. Because of the relatively limited number of measurements for cadmium, and because of no known intrinsic differences in representativeness among the data sets, the cadmium data were also pooled.

More detailed depictions of the distributions of the pooled soil data sets are shown in Figures 125 through 166. In general, concentrations are not normally distributed, even after log transformation of the data. Therefore, a distribution-free method was used to calculate tolerance limits, as performed for sediment data. Unlike most other metals, the distribution of cadmium can be treated as normal after log transformation (p = 0.29 for the Shapiro-Wilk test), which is an important feature of this distribution because the sample size is too low to directly calculate a tolerance limit. The mean and standard deviation of the log transformed cadmium data were used to bootstrap (Manly 2001) a larger sample for which a tolerance limit could be calculated using the same method that was applied to other analytes.

3.4 CHARACTERIZATION OF THE RANGE OF BACKGROUND CONCENTRATIONS

Calculated tolerance limits for the regional soil evaluated here are shown in Table 4. Also included in this table are the 95th percentile values for these data and the results of some other assessments of regional or western U.S. background soil characteristics. This table allows comparison of the background soil data in the immediate vicinity of the study area to other potentially relevant data sets. These data sets are

- Background soil samples collected from north of the Trail facility as part of the ecological risk assessment investigation (Sanei et al. 2007). The 95th percentile of this data set is reported, and these values can be contrasted directly with the 95th percentiles of the regional data assessed here.
- Background soil data for the western U.S. that was compiled and assessed as part of EPA’s development of ecological soil screening criteria (USEPA 2003). The 95th percentile of this data set is reported, and these values can be contrasted directly with the 95th percentiles of the regional data assessed here.
- Background soil concentrations for the Spokane basin that were measured by the Washington State Department of Ecology (Ecology 1994). The 90th percentile of this data set is reported, and these values would be expected to be a little lower than the 95th percentiles of the regional data assessed here.

Comparison of the equivalent (or nearly equivalent) percentiles among these data sets indicates that the site-specific regional background data set evaluated here is comparable to the other data sets. Of the analytes that can be compared among the data sets, the 95th percentile of the local regional background is lower than all the other values for arsenic, barium (only one other value), and silver (only one other value); higher than all the other values for beryllium, cadmium, chromium, cobalt (only one other value), iron, manganese, selenium (only one other value), and vanadium (only one other value); and within the range of the other values for aluminum, copper, lead, nickel, and zinc. Of these data sets, the only systematic variation is that of the Spokane basin data from Ecology, which is consistently lower than all of the other data sets—although, as previously mentioned, expected because a lower percentile of the distribution is available.

Based on the acceptable quality of the regional data sets evaluated here, the general comparability of concentrations across those data sets, and comparability of 95th percentile values between the pooled data from those data sets and from other summaries of western U.S. soil background data, the tolerance limits calculated here appear to be representative of the upper bound of background soil concentrations in the immediate vicinity of the study area. As additional data become available during the soil sampling program, the background calculations will be revisited in consultation with EPA.

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APPENDIX H – ATTACHMENT 1

GEOLOGICAL CATEGORIES

GEOLOGICAL CATEGORIES

The purpose of this attachment is to develop a generalized map of the Upper Columbia River (UCR) that groups specific geologic formations together based upon broad lithologic categories for which average chemical constituent information are available. These categories are expressed in the corollary study as the ratio of iron to aluminum, meaning that the map will give its user an approximate understanding of the spatial distribution of iron vs. aluminum.

Fe/Al Ratios

Fe/Al ratios were provided by Mihai Aldea of Integral Consulting Inc., and constituted the original sediment categorization framework. Adjustments to the categories had to be made in order to give ratios for the new necessary categories. The original data were as follows:

CRB	Ultramafic	Basalt	Low-Ca Granite	High-Ca Granite	Shale	Sandstone	Carbonate Rocks
0.98	8.00	1.04	0.37	0.19	0.59	0.40	0.75

Source: Faure (1991)

Because there is little chemical difference between intrusive and extrusive igneous rocks, or metamorphic rocks and their protoliths, the specific categories were generalized. To arrive at one number for felsic rocks, the Low-Ca Granite ratio and the High-Ca Granite ratio were averaged. The average of felsic rocks and mafic rocks then became the ratio assigned to the new category "Intermediate." Finally, "Undifferentiated Sediments" were given as a ratio of the average of the three types of sedimentary rocks. The ratios for the final categories are as follows:

	Category								
	CRB	Ultramafic	Mafic	Intermediate	Felsic	Undifferentiated Sediment	Silty Sediment	Sandy Sediment	Carbonate Sediment
Ratio	0.98	8.00	1.04	0.66	0.28	0.58	0.59	0.40	0.75

The descriptions of the formations in the UCR area were taken from the metadata file "X_Distinct_Lith_forShape." This file was generated from data available on the Washington State Division of Geology and Earth Resources web site. These metadata supplied information for both the rock type and lithology of the formation. The following describes how the numerous formations were distilled into individual categories.

Columbia River Basalt. Any member of the Columbia River Basalt Group.

Ultramafic. Any rock that was described as ultramafic or ultrabasic, or included those terms in its description.

Mafic. This category includes all mafic igneous rocks, specifically anything that is described as mafic, basic, alkalic or alkaline, basalt, gabbro, or amphibolite.

Intermediate. This is a broad category that includes igneous rocks that are intrusive or extrusive in nature and are of an intermediate composition, as well as any metamorphic rocks that had a protolith in the intermediate igneous series. In addition, any metamorphic or igneous rock that did not have a specific lithology listed, or was listed as "undivided" was put into this category as it must be assumed that the unspecified lithologies are diverse, and thus chemically would average out into the intermediate zone. The boundaries of this category were set wide, so anything that is not specifically a mafic rock or protolith or a felsic rock or protolith falls into this category. Descriptors and lithologies include intermediate, mixed, undivided, hybrid, mesocratic, andesite/andesitic, diorite/dioritic, granodiorite/ granodioritic, quartz diorite, monzonite, migmatite, dacite, and tonalite.

Felsic. This category includes any rock, igneous or metamorphic, that is felsic in composition. Granite is assumed to be the protolith where gneiss or orthogneiss are the only available information. Explosive volcanic products are assumed to be derived predominantly from felsic, gaseous magma bodies and are thus also placed in this category. Descriptors and lithologies include granite/granitic, acidic, quartz monzonite, syenite, pegmatite, rhyolite, trachyte, volcaniclastic, tuffs, tuff breccias, gneiss, and orthogneiss.

Undifferentiated Sediments. Sediments or metamorphic protoliths that are clearly sediments but cannot be further categorized are now listed as "undifferentiated sediments." In addition, if undifferentiated sediments and undifferentiated igneous/metamorphics are listed together they are listed under sediments. In the absence of further definition, descriptors and lithologies include tectonic breccia, marine metasedimentary, continental sedimentary deposits, paragneiss, undivided glaciolacustrine and outburst flood deposits, peat, tectonic zone, and calc-silicate.

Fine-Grained Sediments/Protoliths. This category includes shale, silt-dominated deposits, and metamorphic rocks where shale is the protolith. Descriptors and lithologies include argillite, phyllite, schist, glaciolacustrine deposits, lacustrine, and loess.

Coarse-Grained Sediments/Protoliths. This category includes sandstone, sand-dominated deposits, clastic and conglomerate deposits, and metamorphic rocks where sandstone is the protolith. Descriptors and lithologies include quartzite, wacke, conglomerate, alluvium, dune sand, artificial fill, gravel, sand, glacial outwash, glacial till, glacial drift, and mass-wasting deposits.

Carbonates. This category includes carbonate rocks, and metamorphic rocks where limestone or another carbonate is the protolith. Descriptors and lithologies include metacarbonate and marble.

REFERENCE

Faure, G. 1991. *Principles and applications of inorganic geochemistry*. Chapter 10. Chemical differentiation of the earth. Macmillan Publishing, NY. pp. 164-1655.

FIGURES

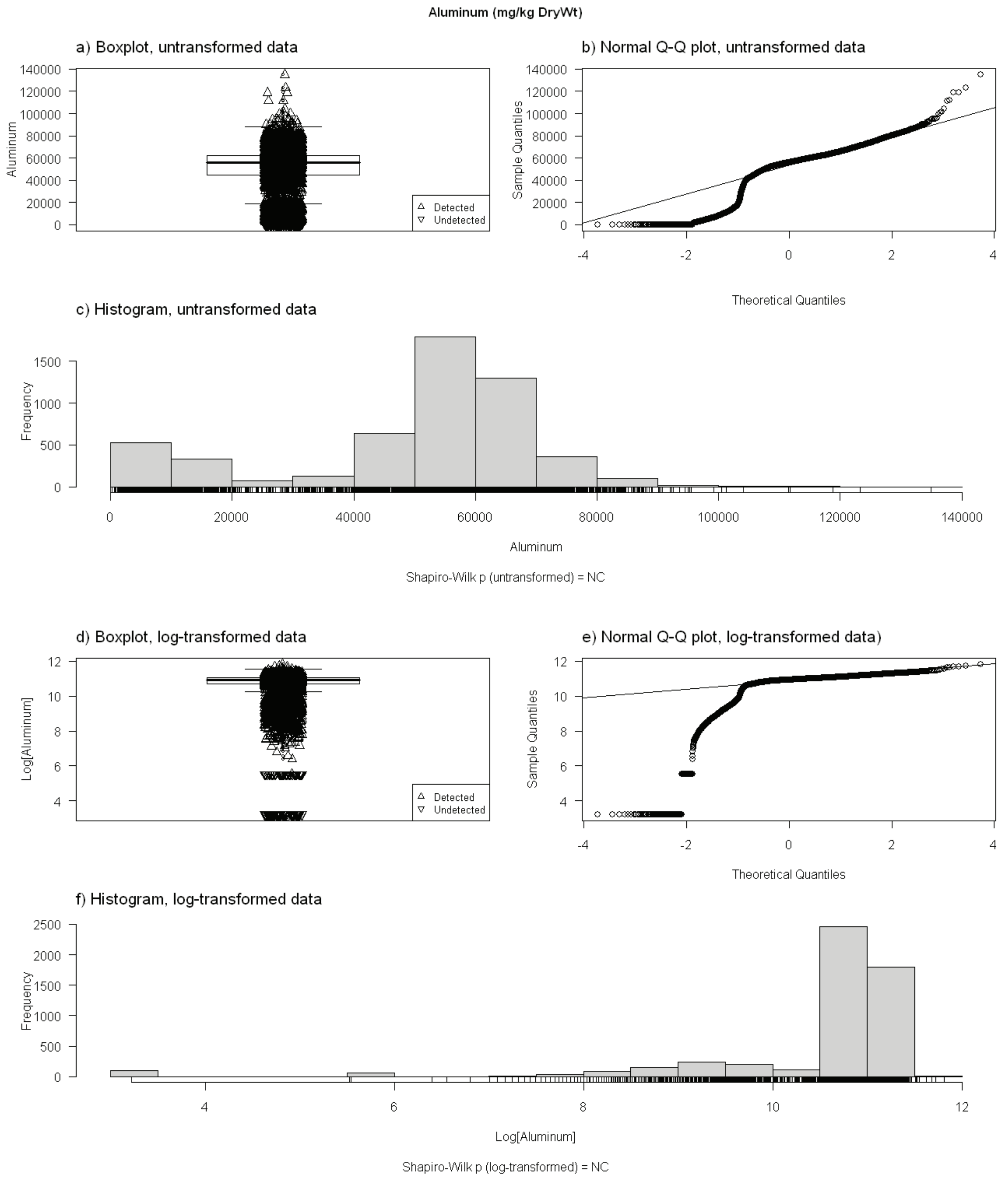


Figure 1. Distribution of All Background Concentrations of Aluminum in Sediment

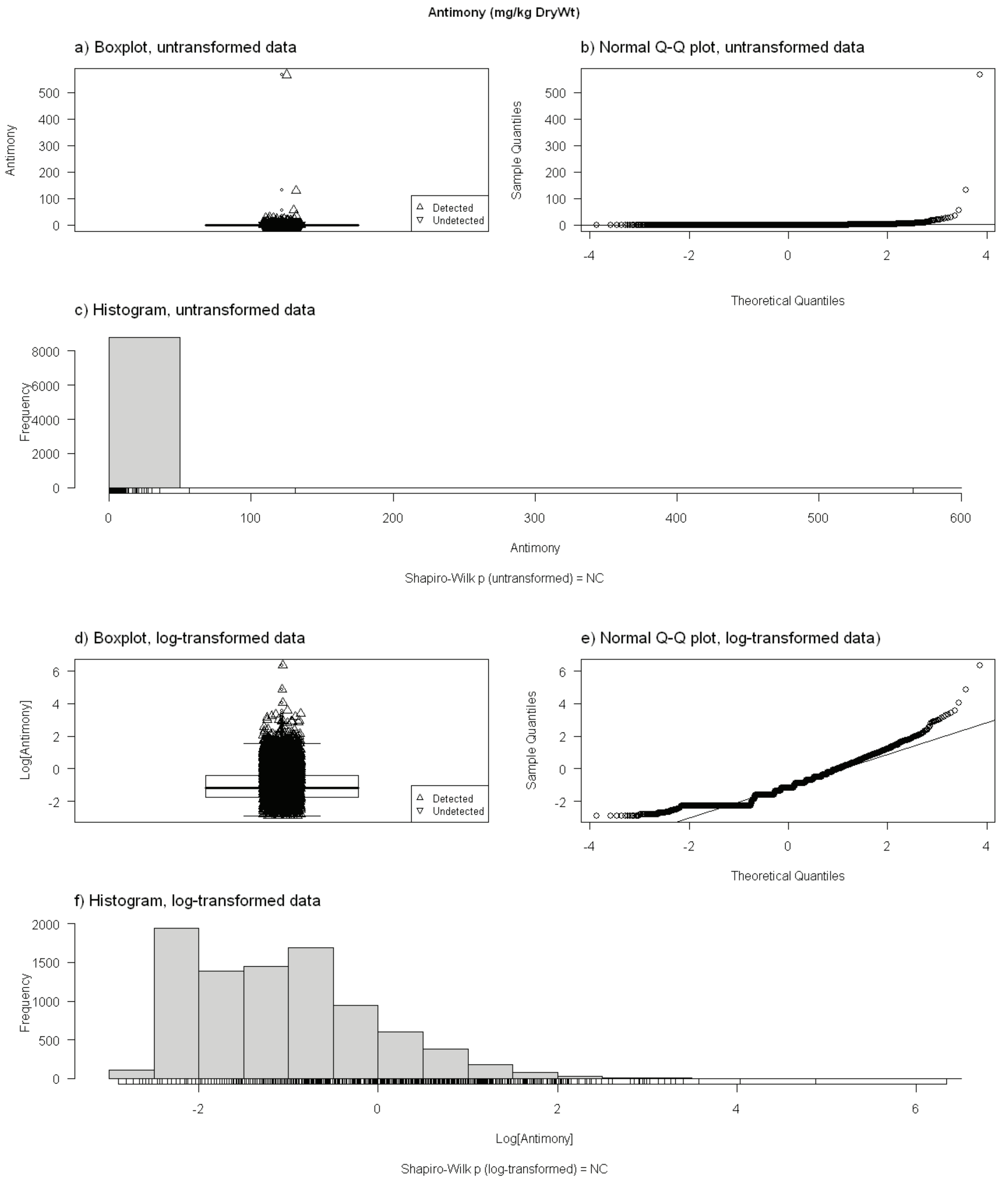
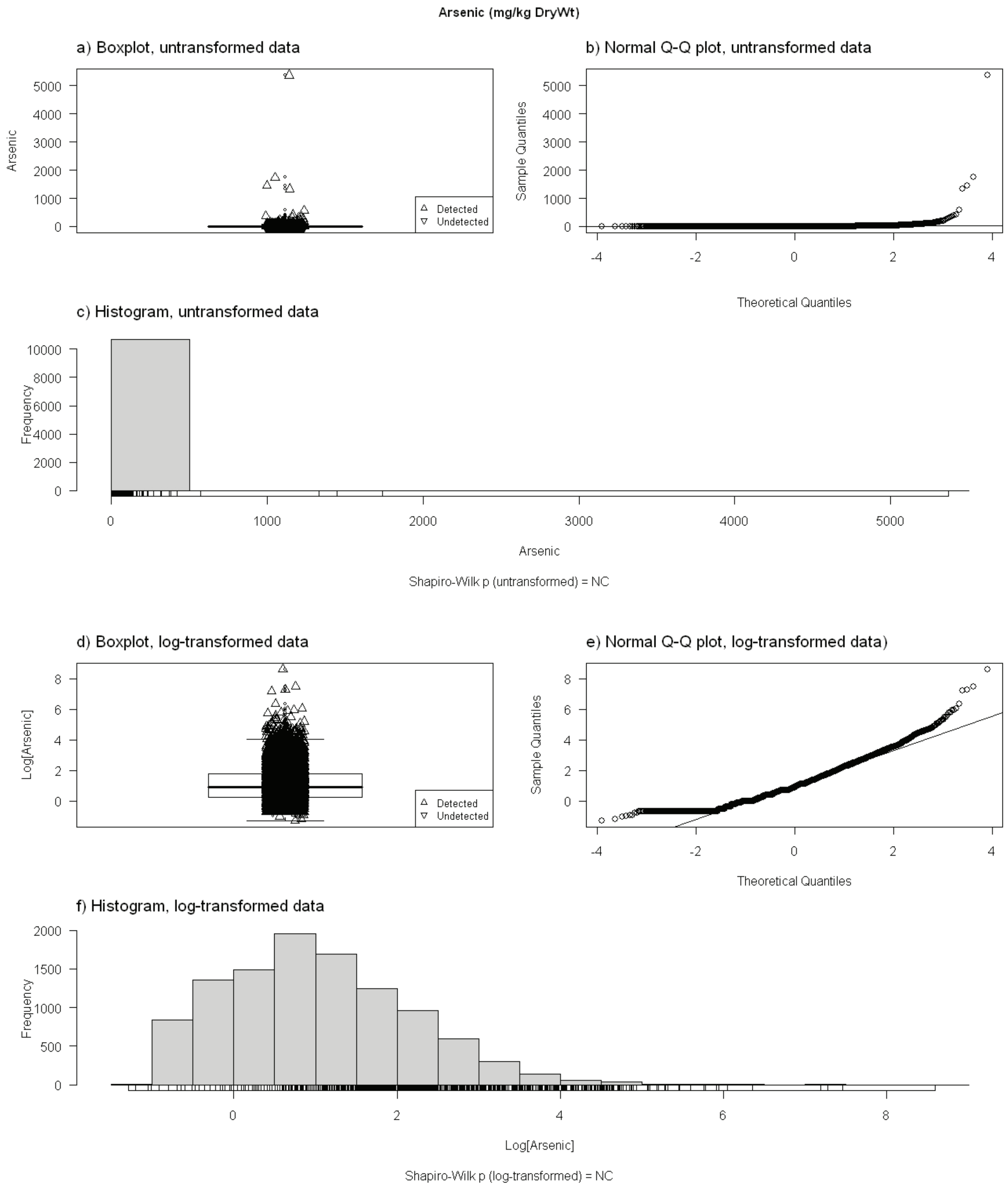


Figure 2. Distribution of All Background Concentrations of Antimony in Sediment



Shapiro-Wilk p (untransformed) = NC

Shapiro-Wilk p (log-transformed) = NC

Figure 3. Distribution of All Background Concentrations of Arsenic in Sediment

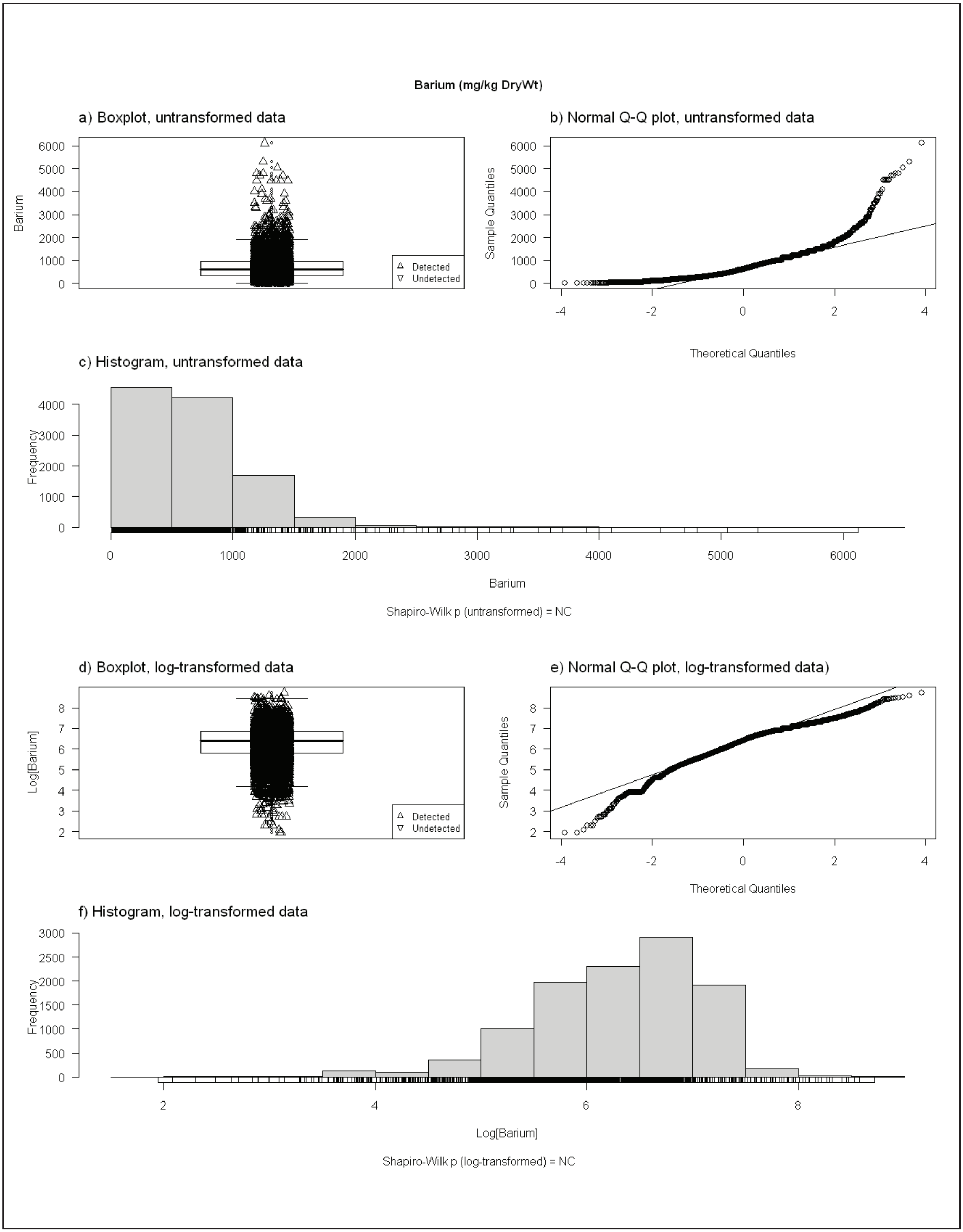


Figure 4. Distribution of All Background Concentrations of Barium in Sediment

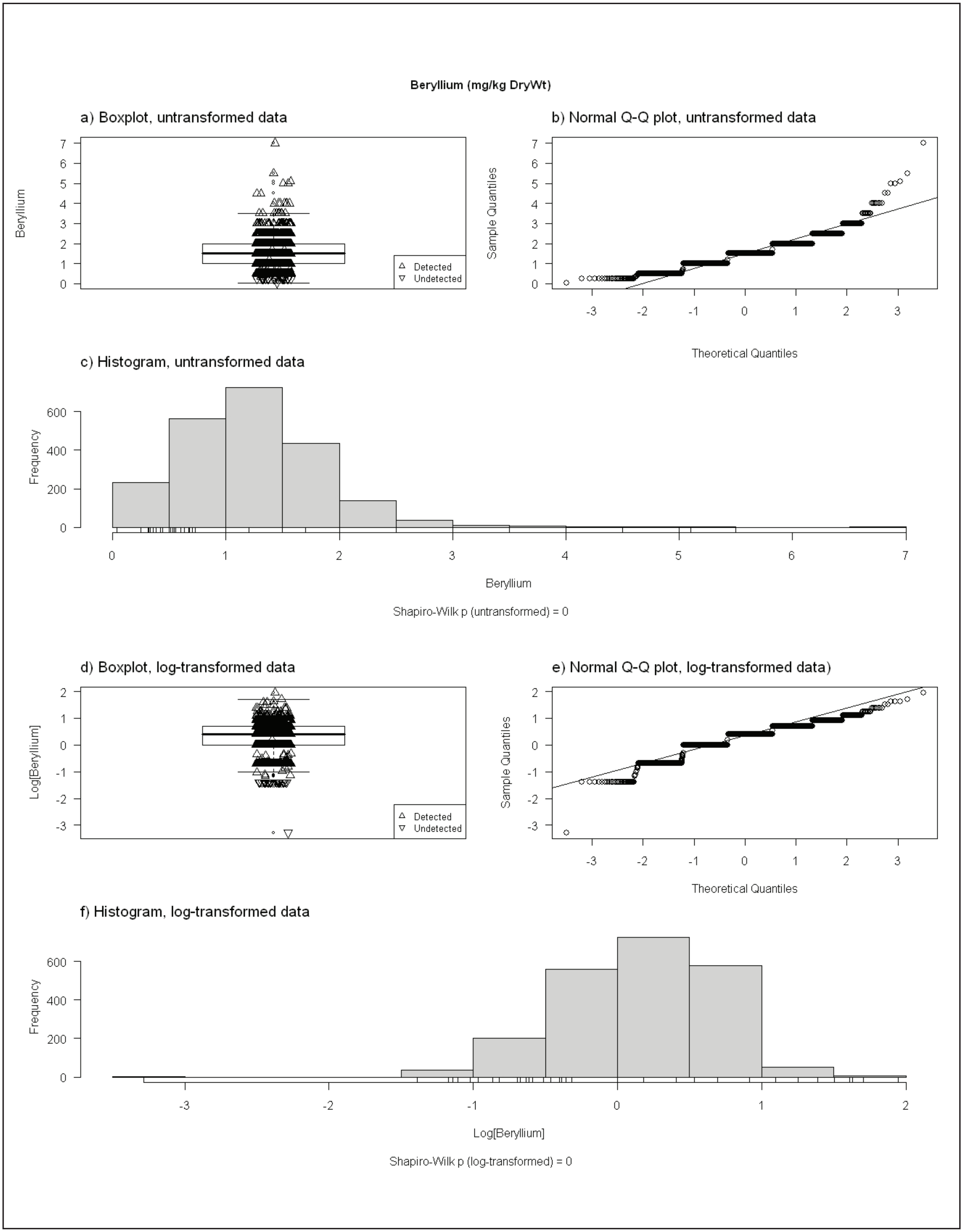


Figure 5. Distribution of All Background Concentrations of Beryllium in Sediment

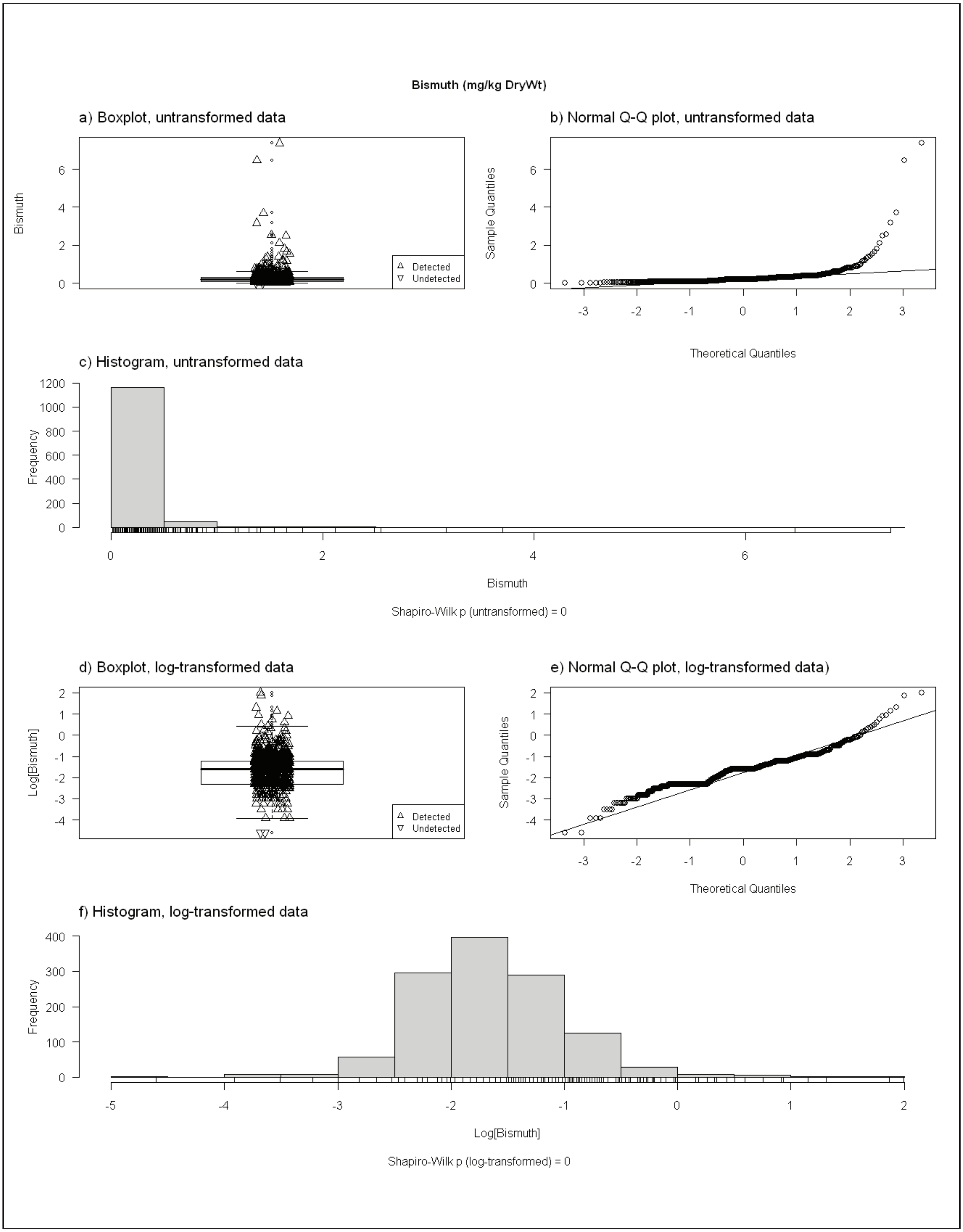
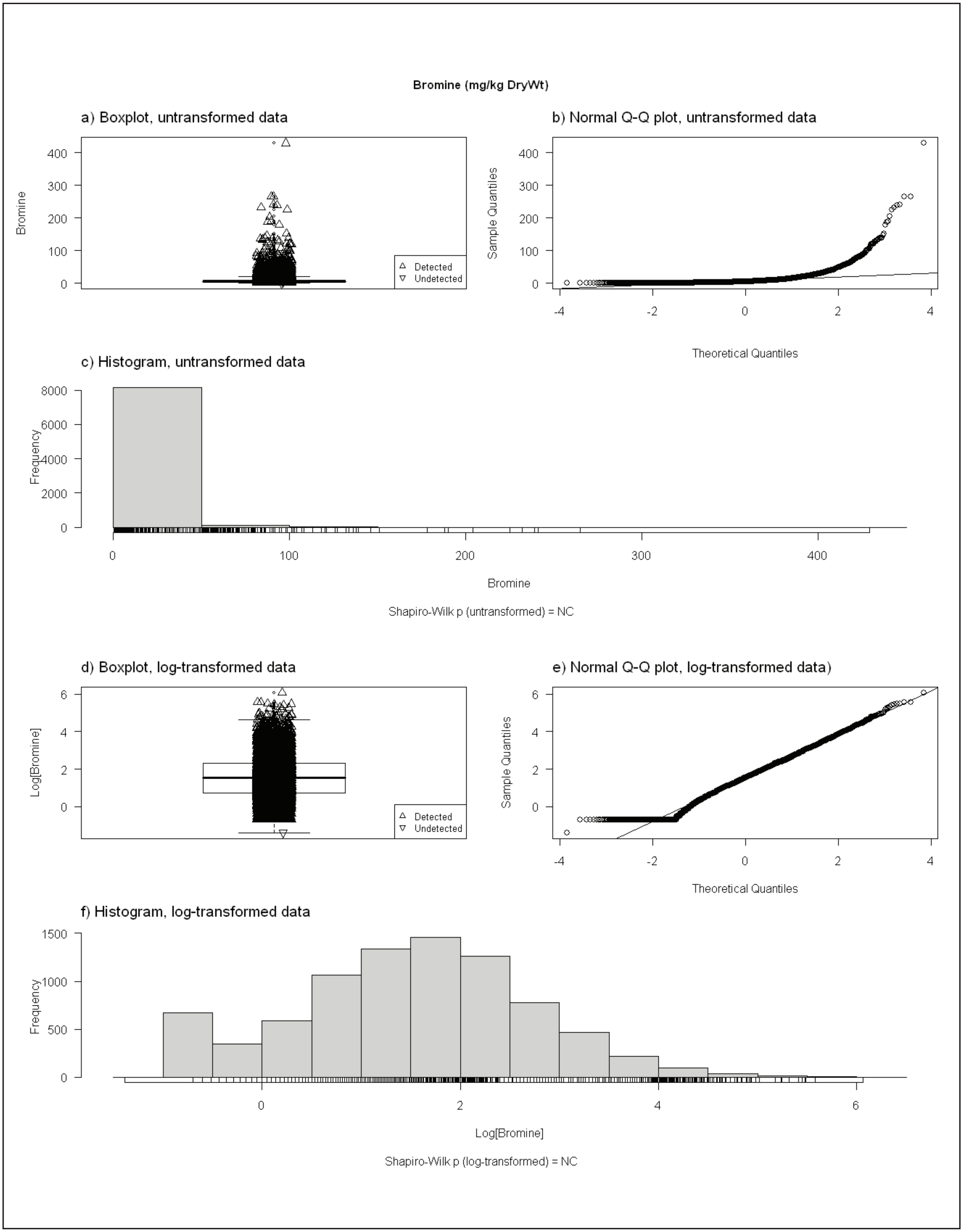


Figure 6. Distribution of All Background Concentrations of Bismuth in Sediment


Bromine (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = NC

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = NC

Figure 7. Distribution of All Background Concentrations of Bromine in Sediment

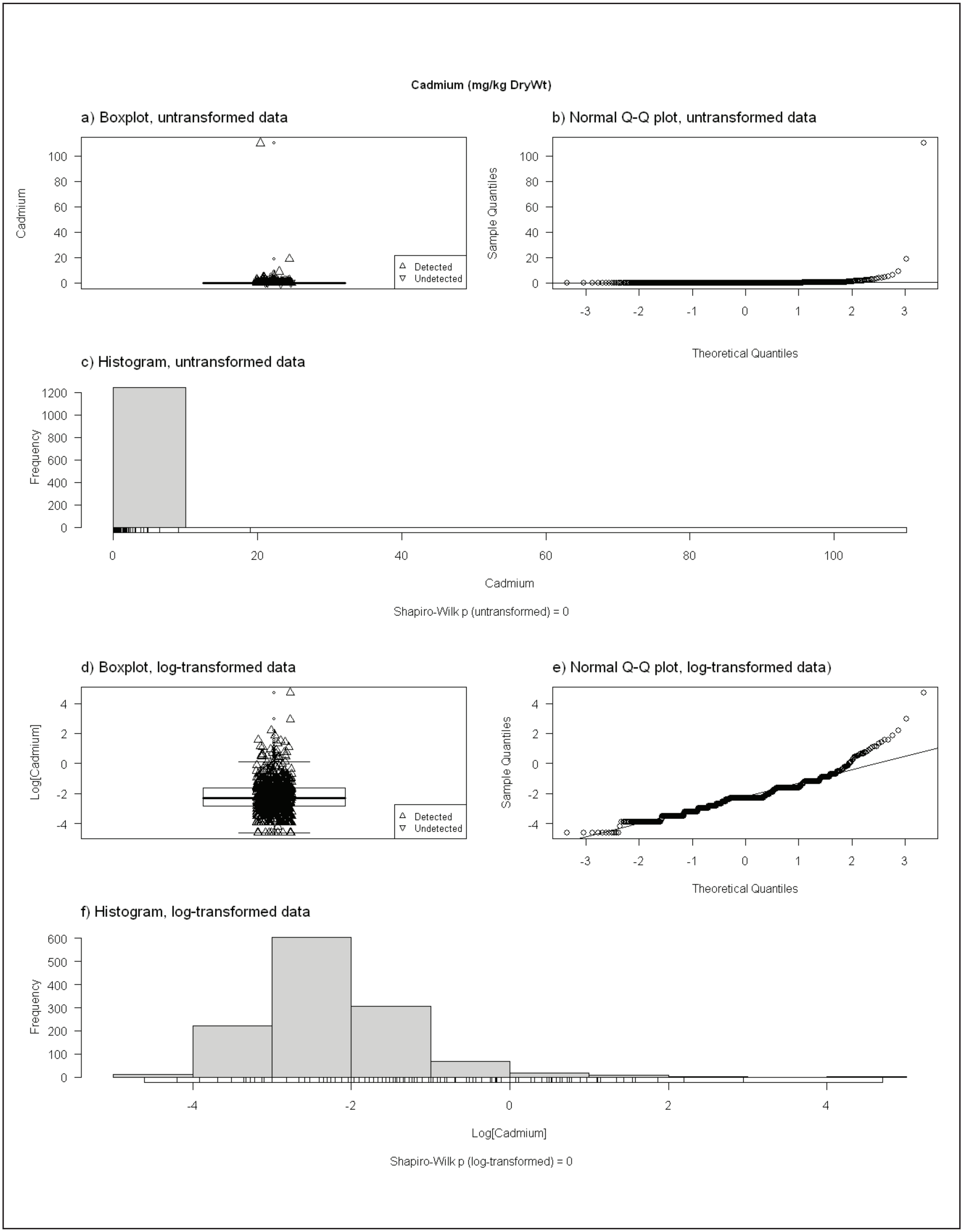
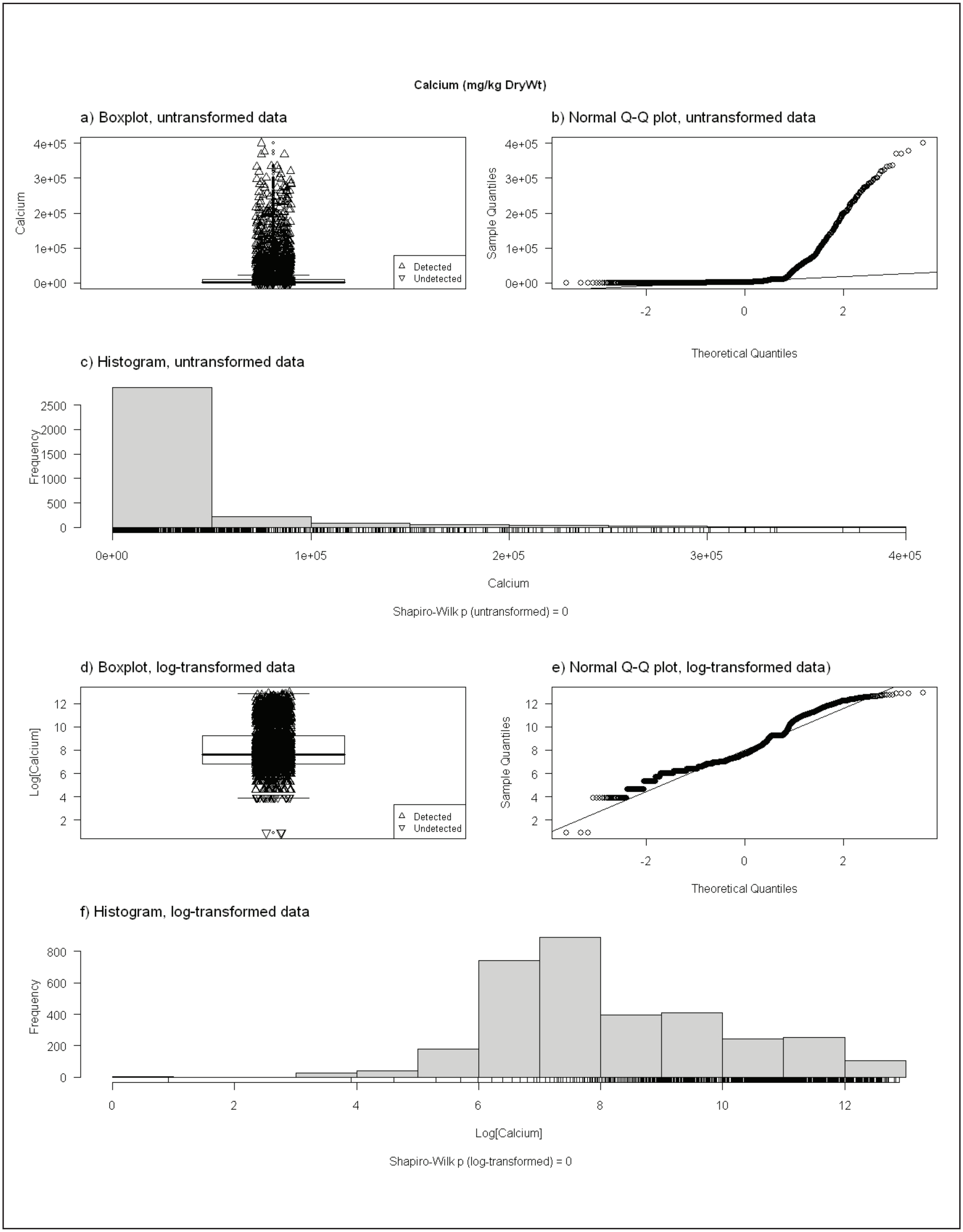


Figure 8. Distribution of All Background Concentrations of Cadmium in Sediment



Calcium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 9. Distribution of All Background Concentrations of Calcium in Sediment

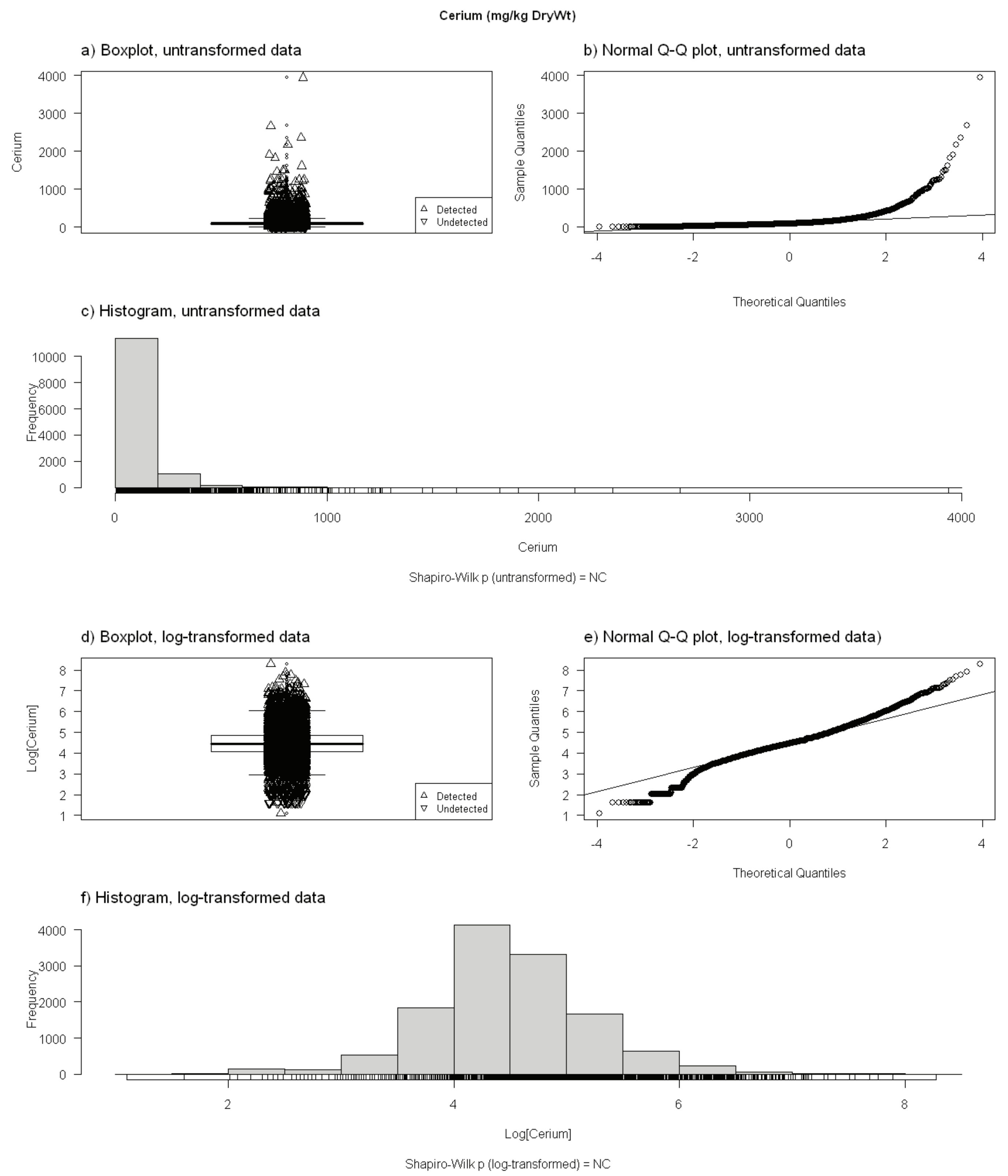


Figure 10. Distribution of All Background Concentrations of Cerium in Sediment

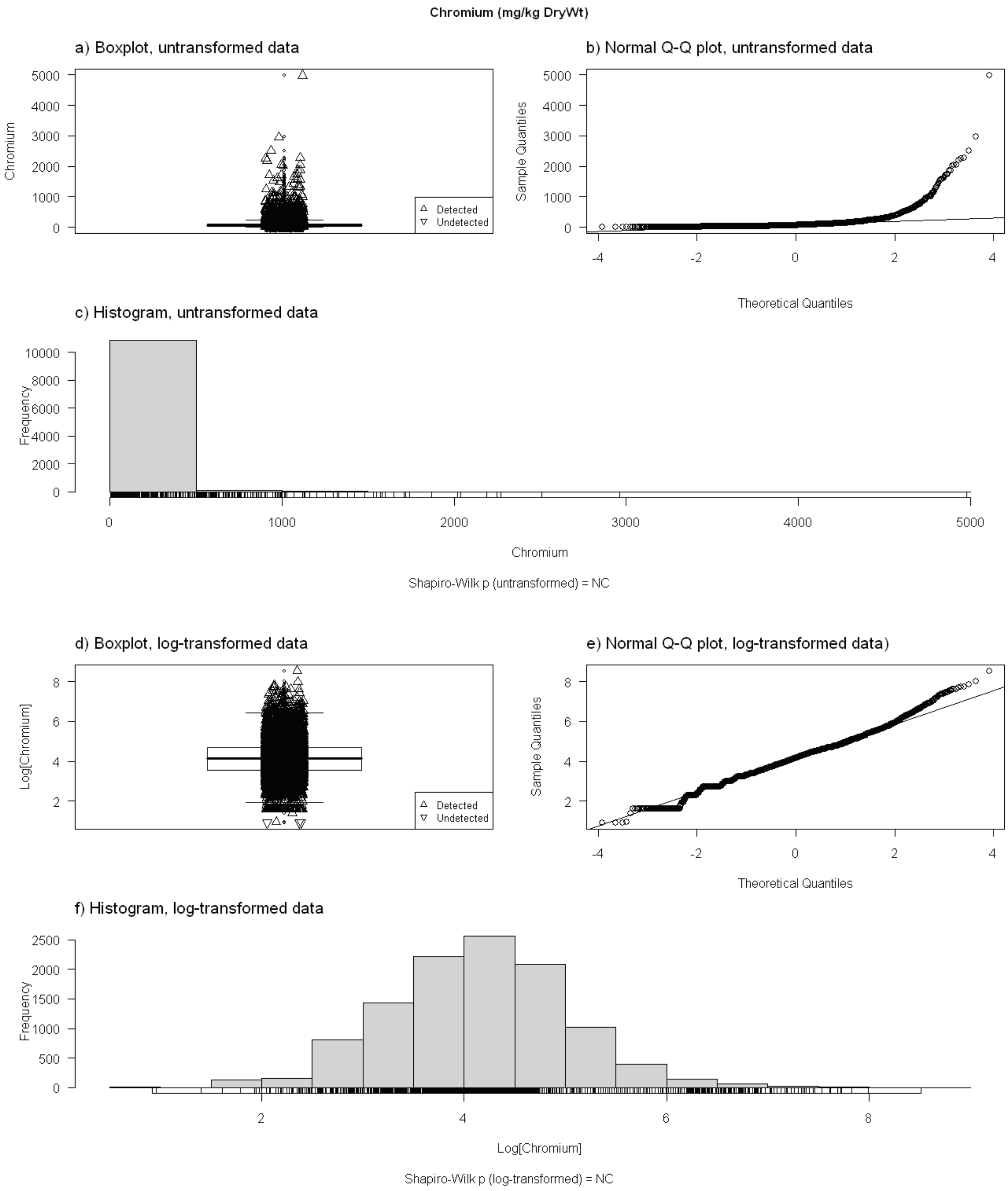


Figure 11. Distribution of All Background Concentrations of Chromium in Sediment

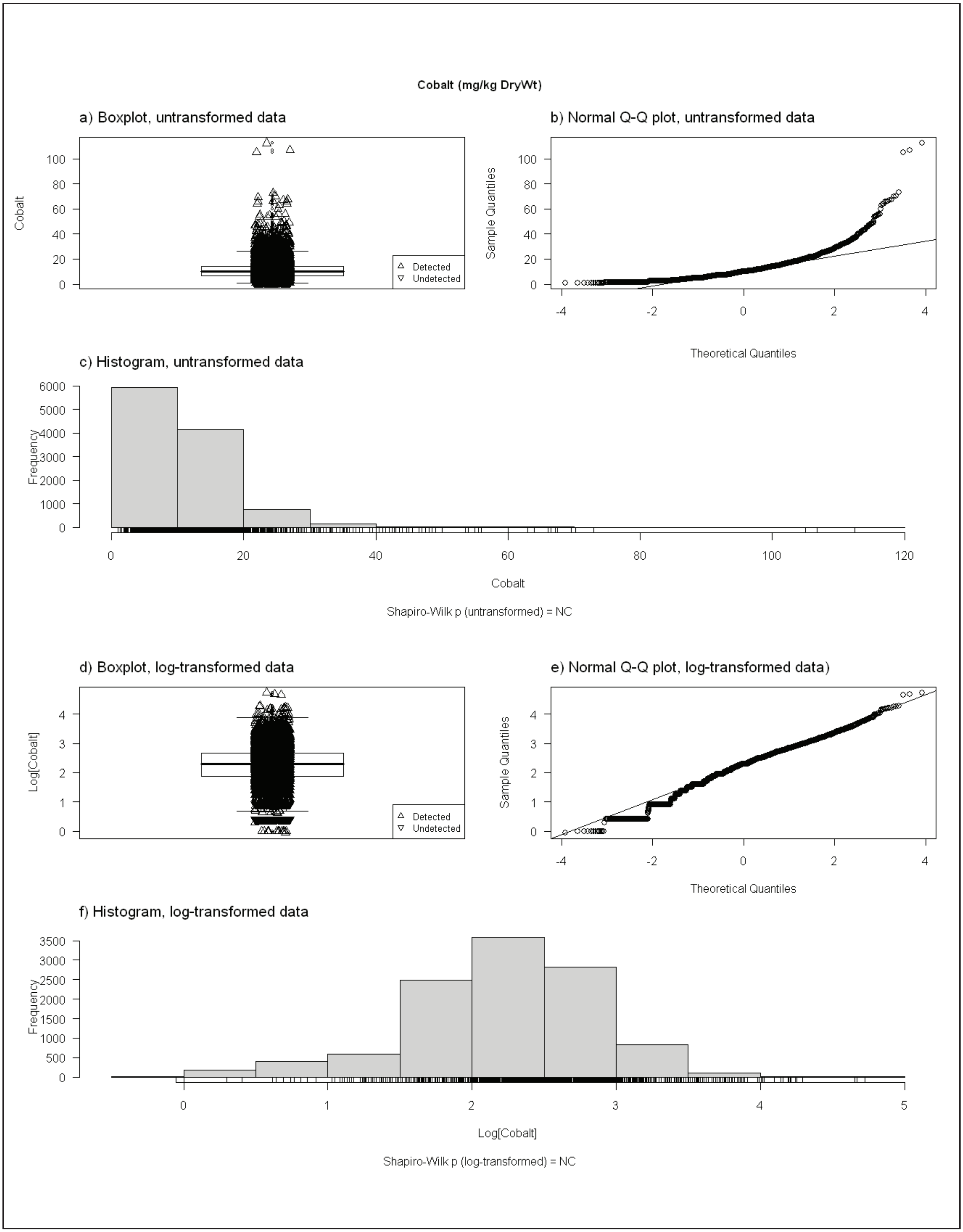


Figure 12. Distribution of All Background Concentrations of Colbalt in Sediment

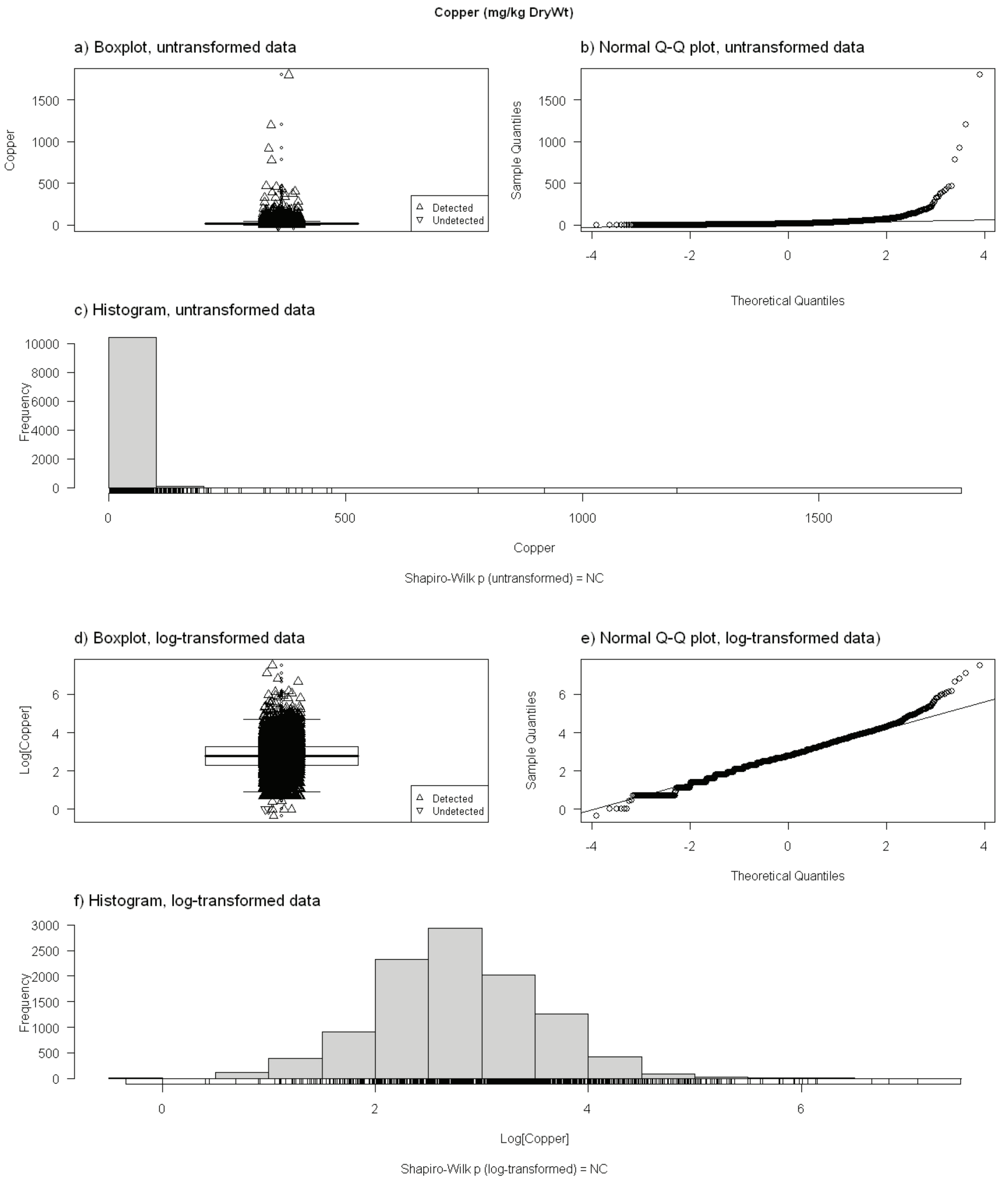


Figure 13. Distribution of All Background Concentrations of Copper in Sediment

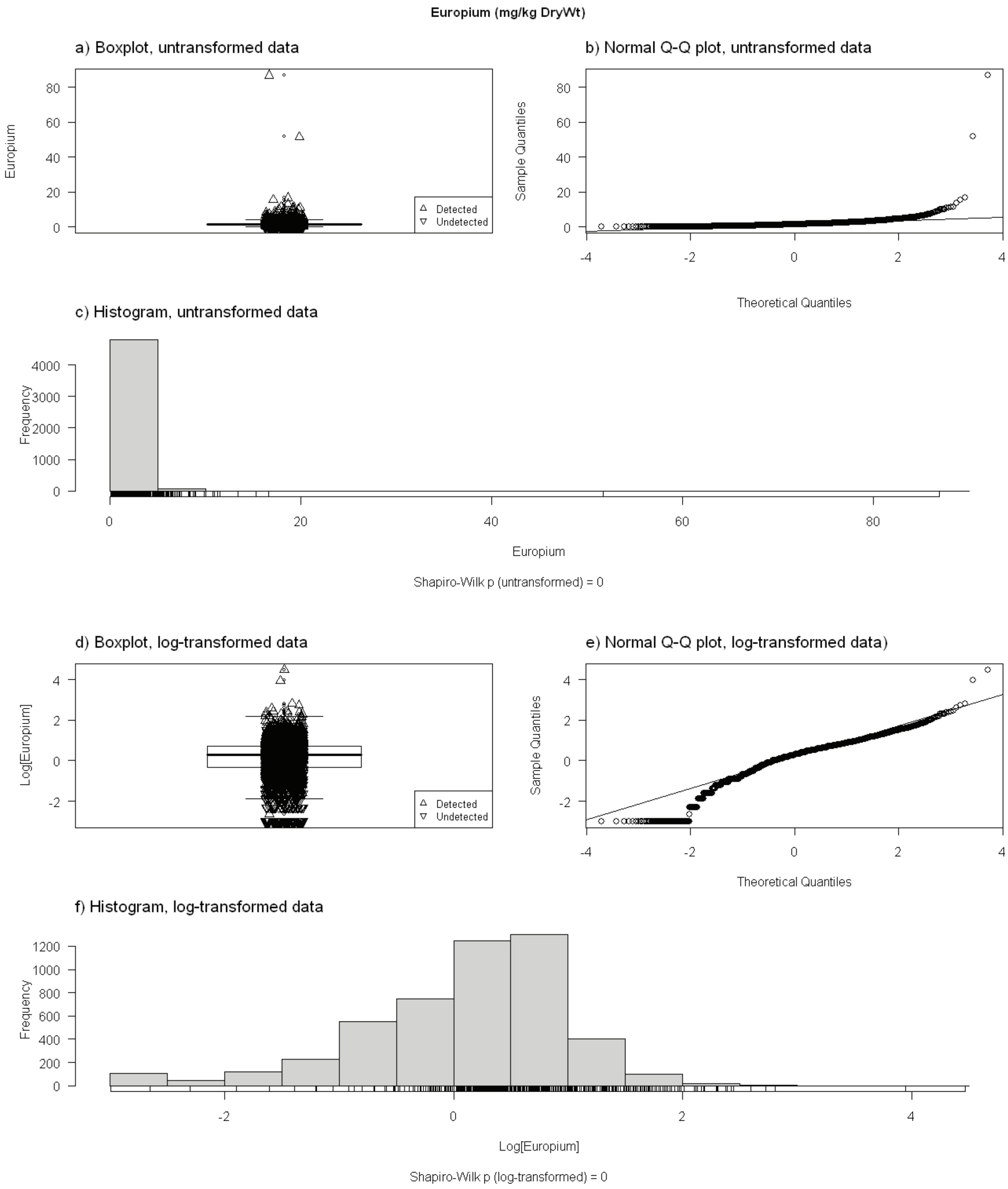


Figure 14. Distribution of All Background Concentrations of Europium in Sediment

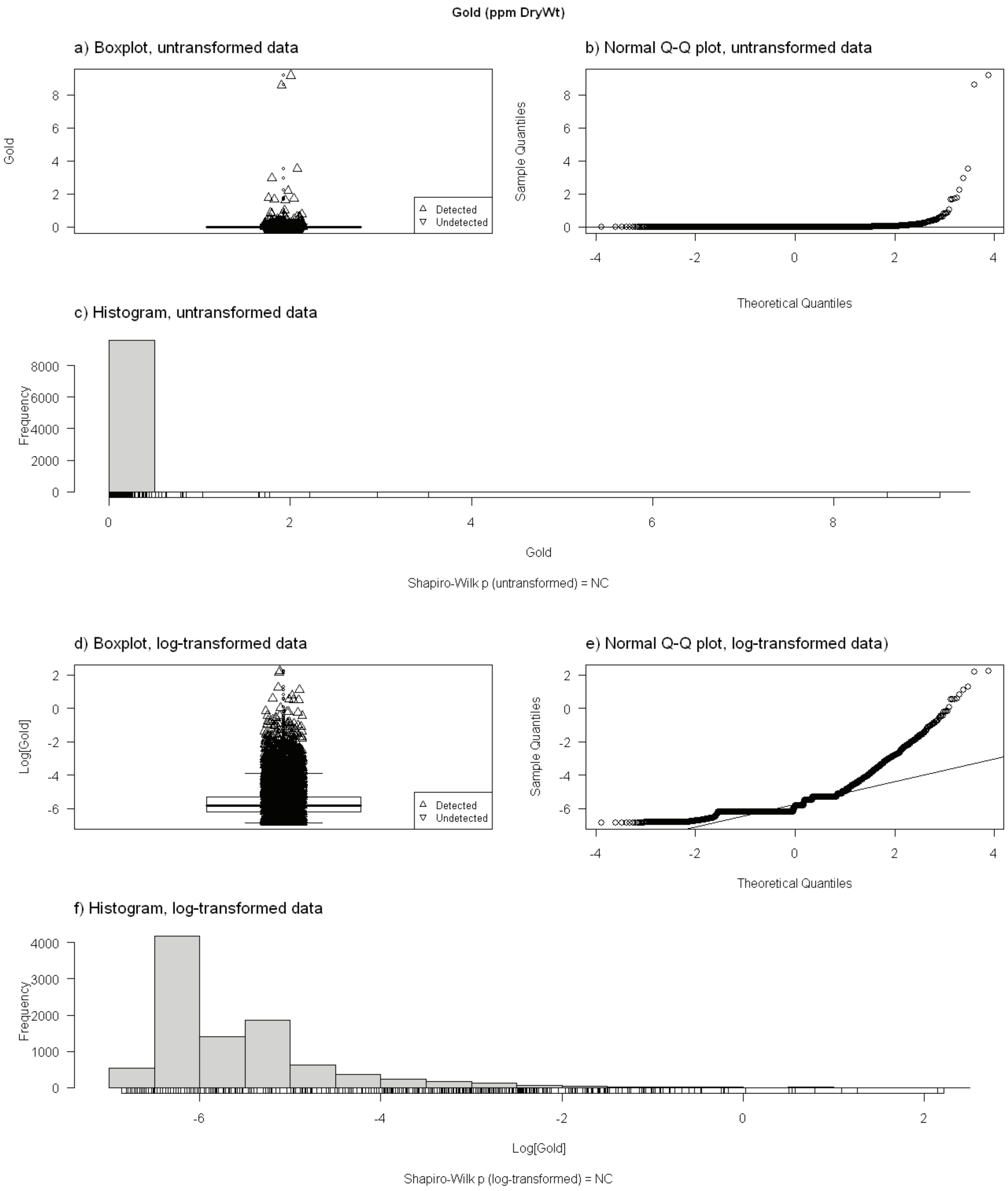
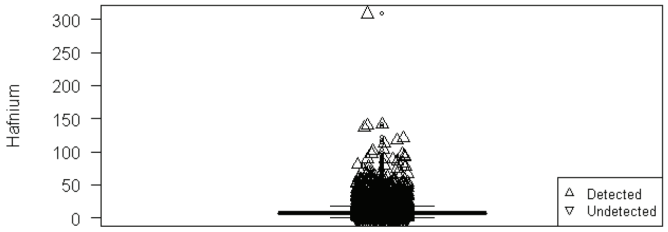


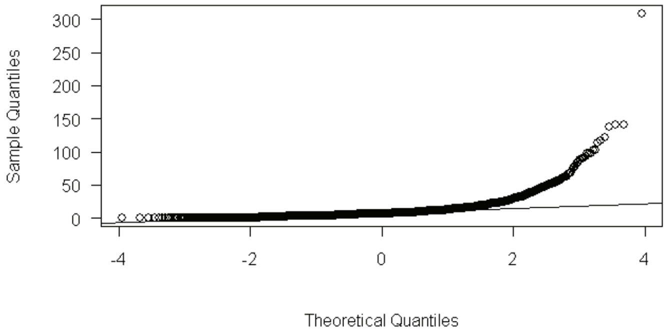
Figure 15. Distribution of All Background Concentrations of Gold in Sediment

Hafnium (mg/kg DryWt)

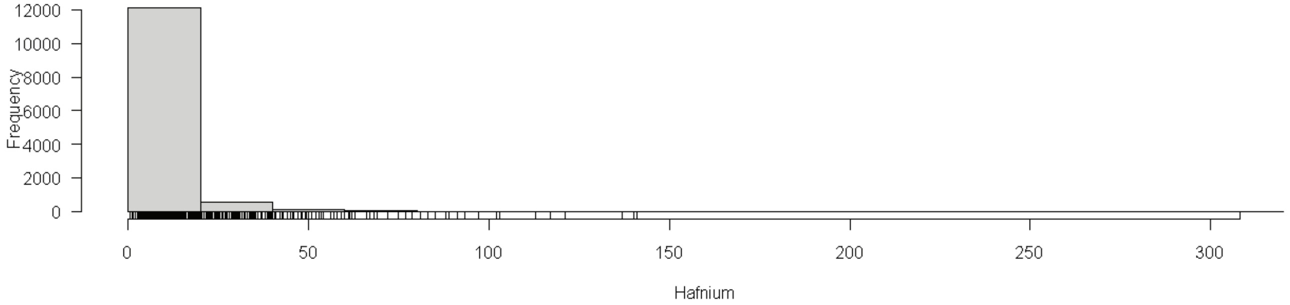
a) Boxplot, untransformed data



b) Normal Q-Q plot, untransformed data

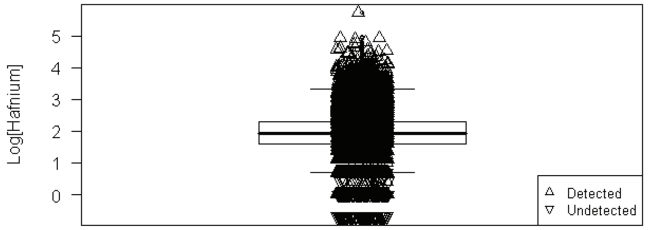


c) Histogram, untransformed data

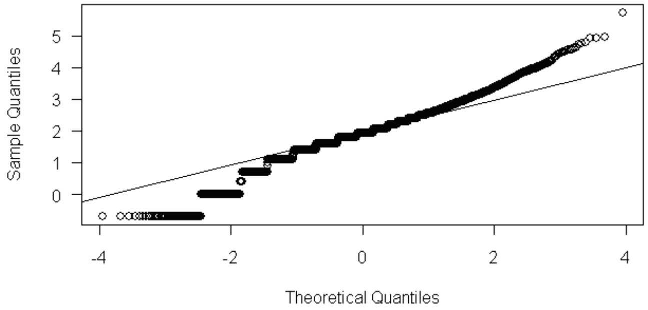


Shapiro-Wilk p (untransformed) = NC

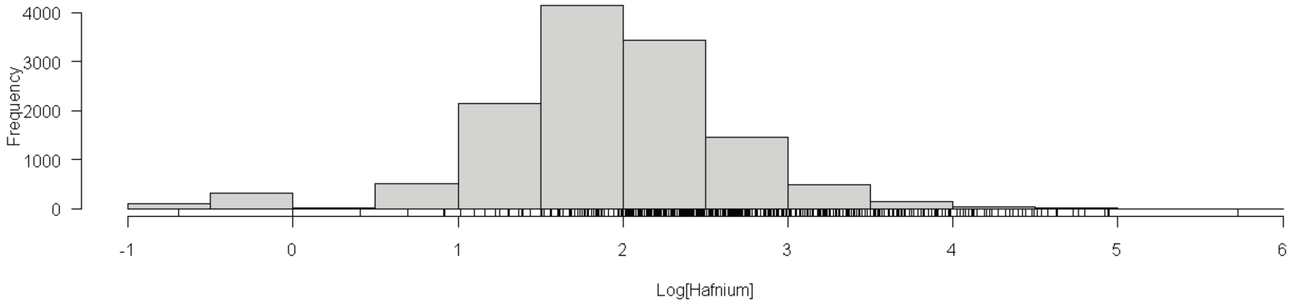
d) Boxplot, log-transformed data



e) Normal Q-Q plot, log-transformed data)



f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = NC

Figure 16. Distribution of All Background Concentrations of Hafnium in Sediment

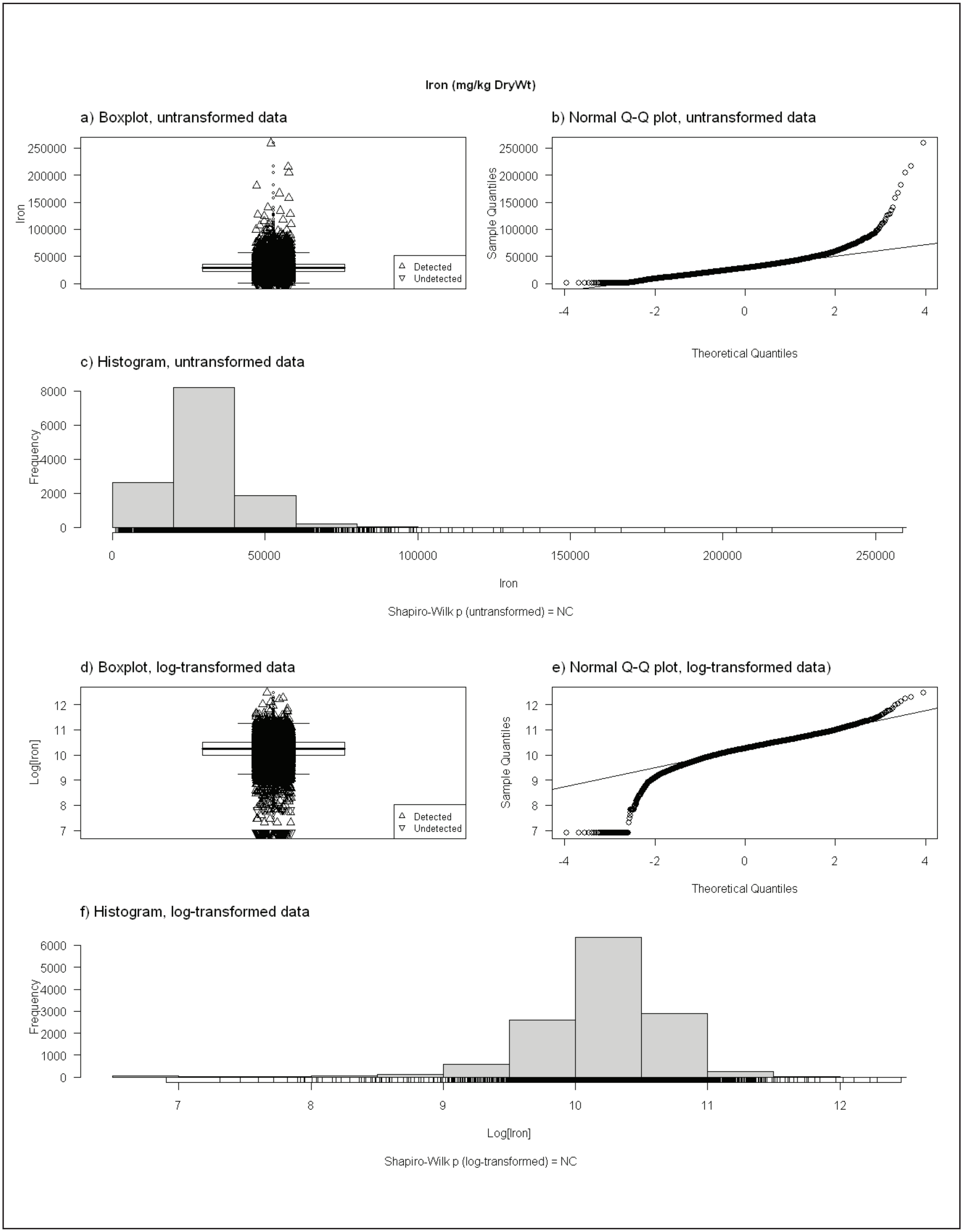


Figure 17. Distribution of All Background Concentrations of Iron in Sediment

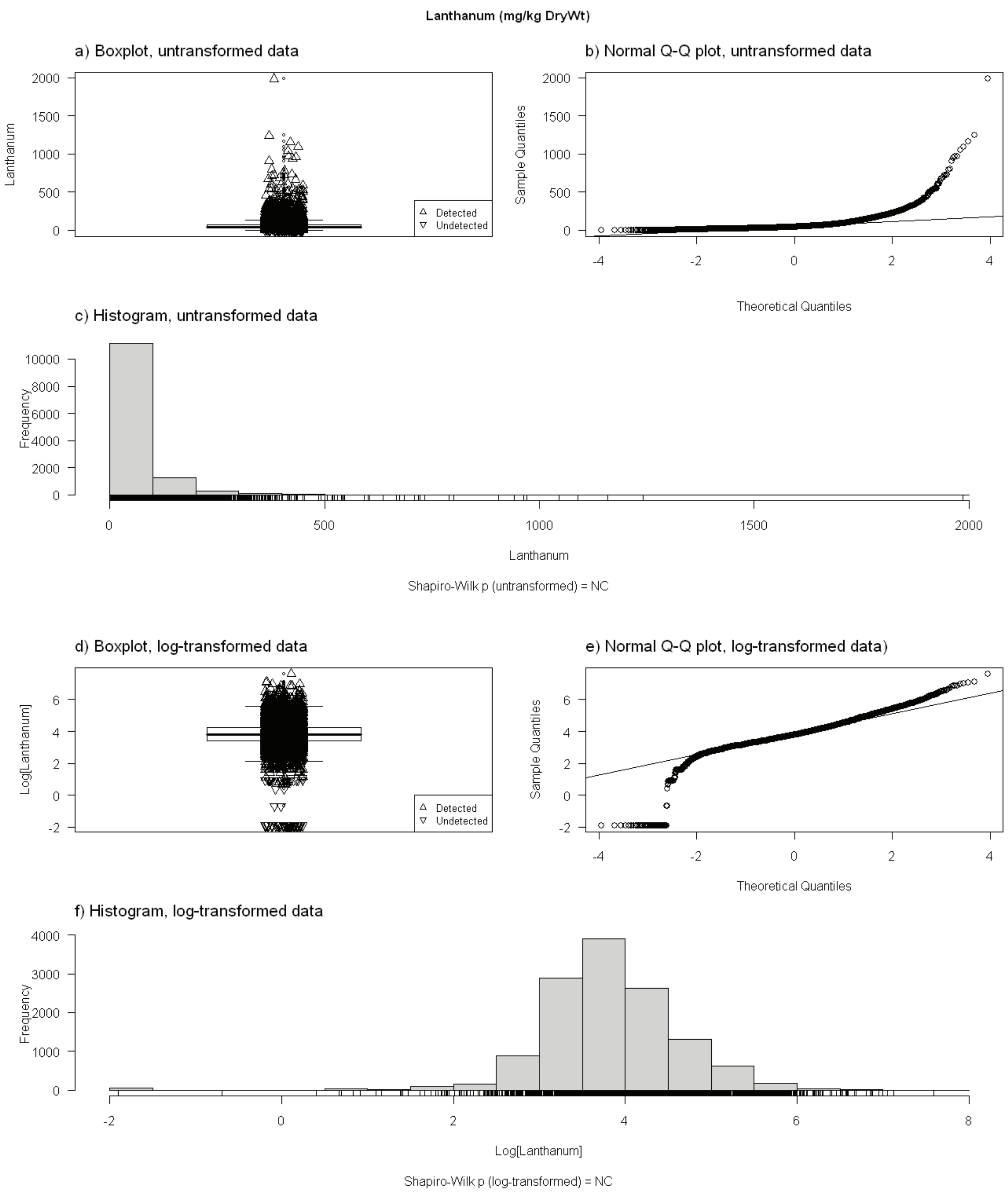
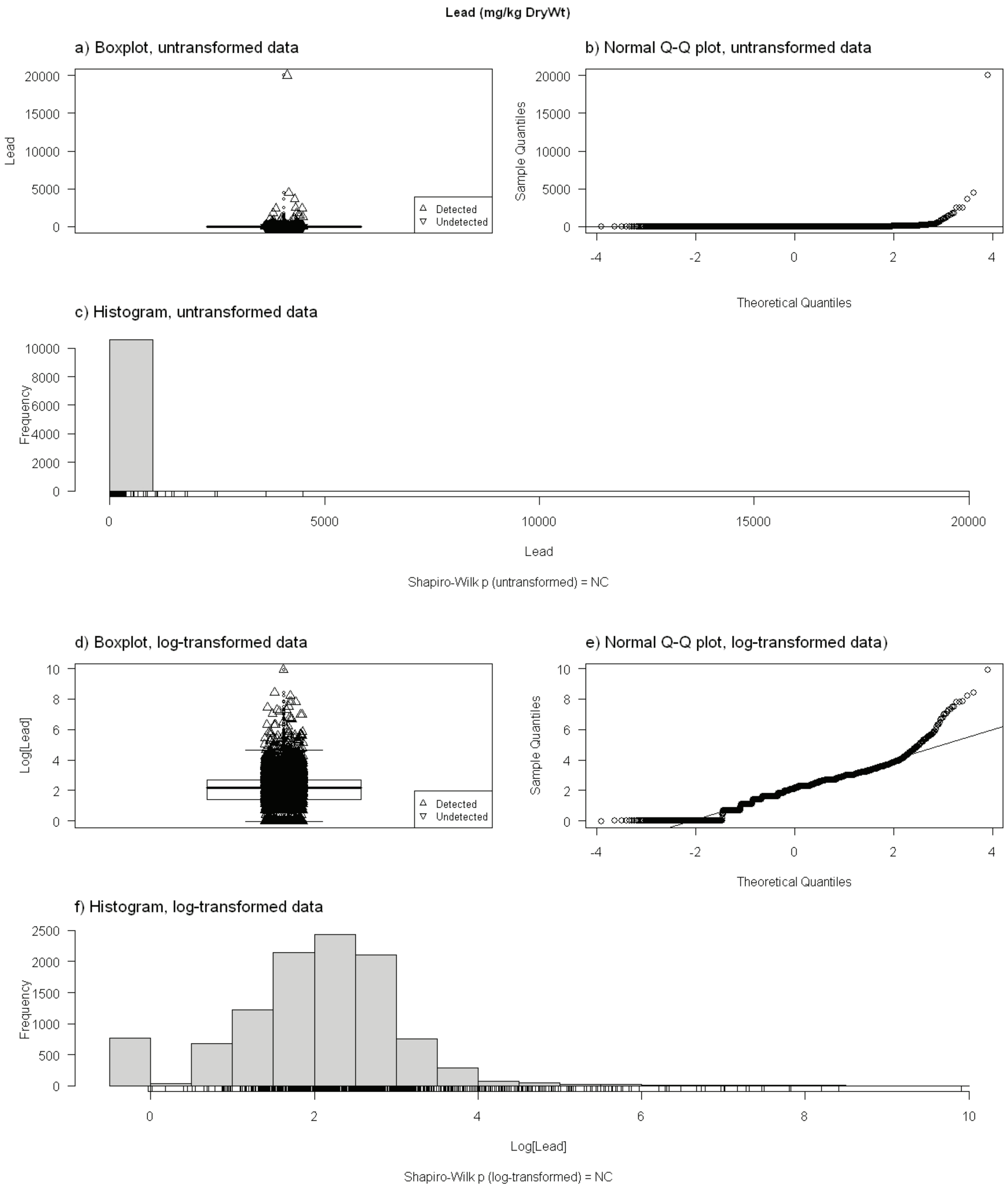


Figure 18. Distribution of All Background Concentrations of Lanthanum in Sediment


Lead (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = NC

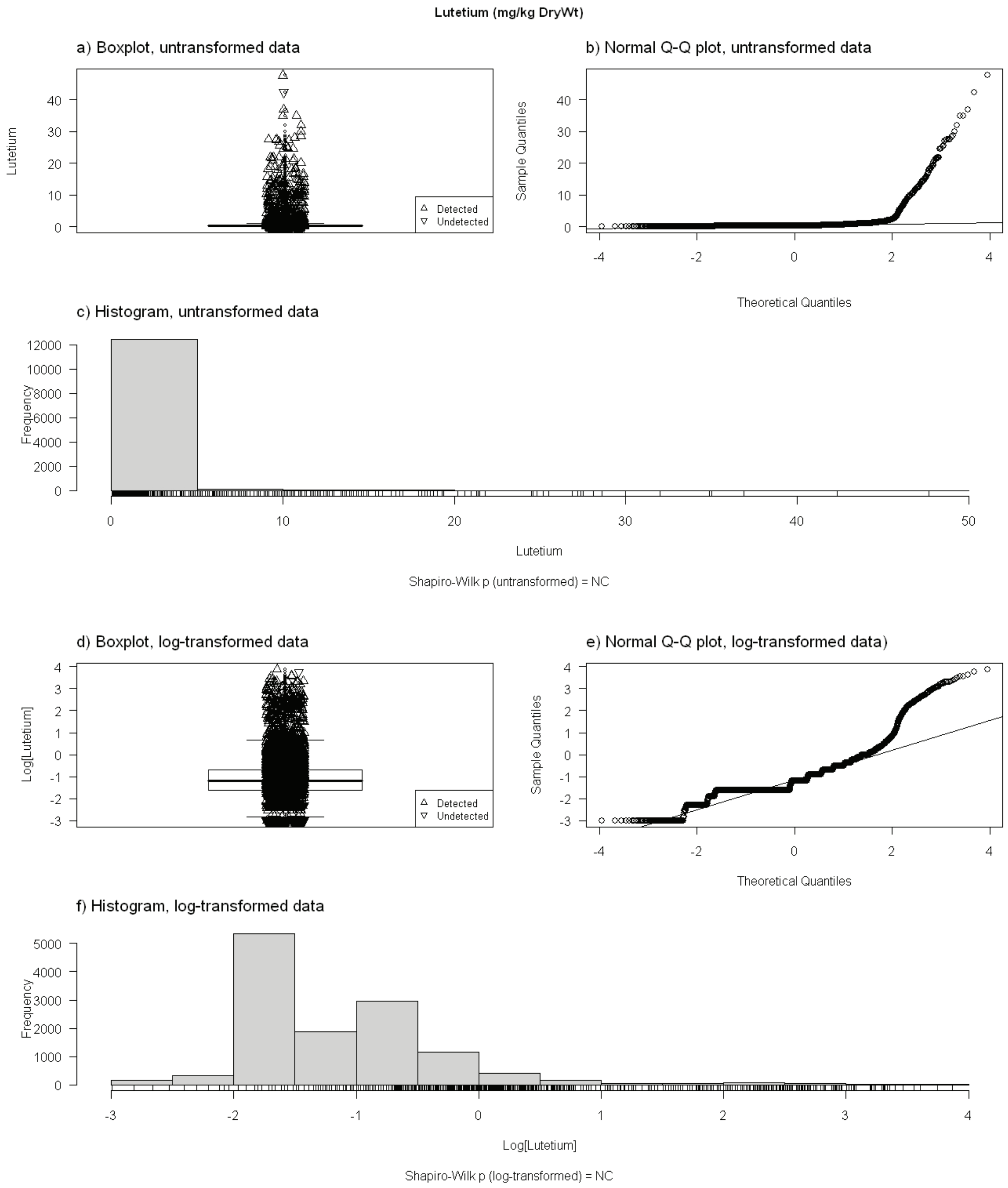
d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = NC

Figure 19. Distribution of All Background Concentrations of Lead in Sediment



Lutetium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = NC

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = NC

Figure 20. Distribution of All Background Concentrations of Lutetium in Sediment

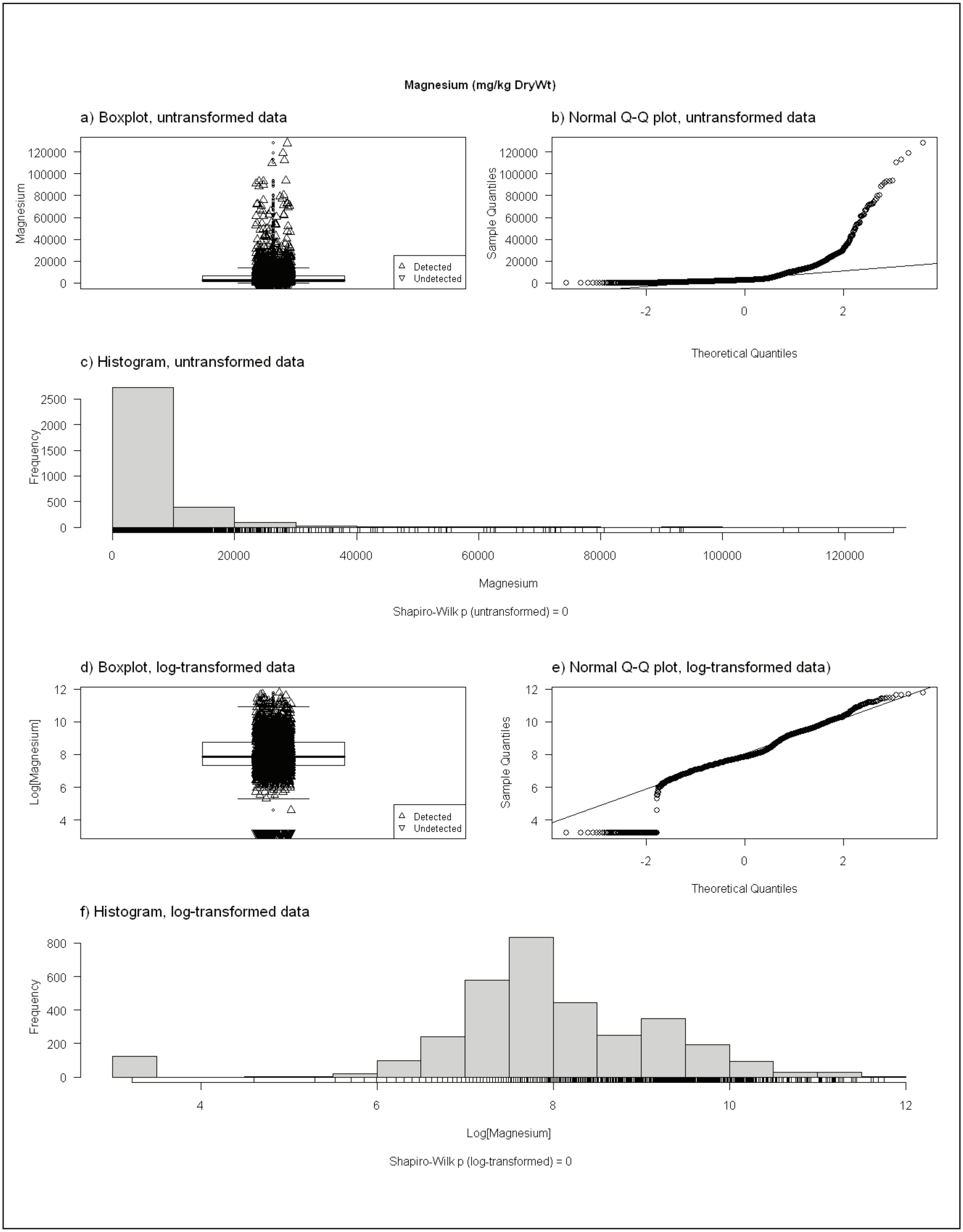


Figure 21. Distribution of All Background
Concentrations of Magnesium in Sediment

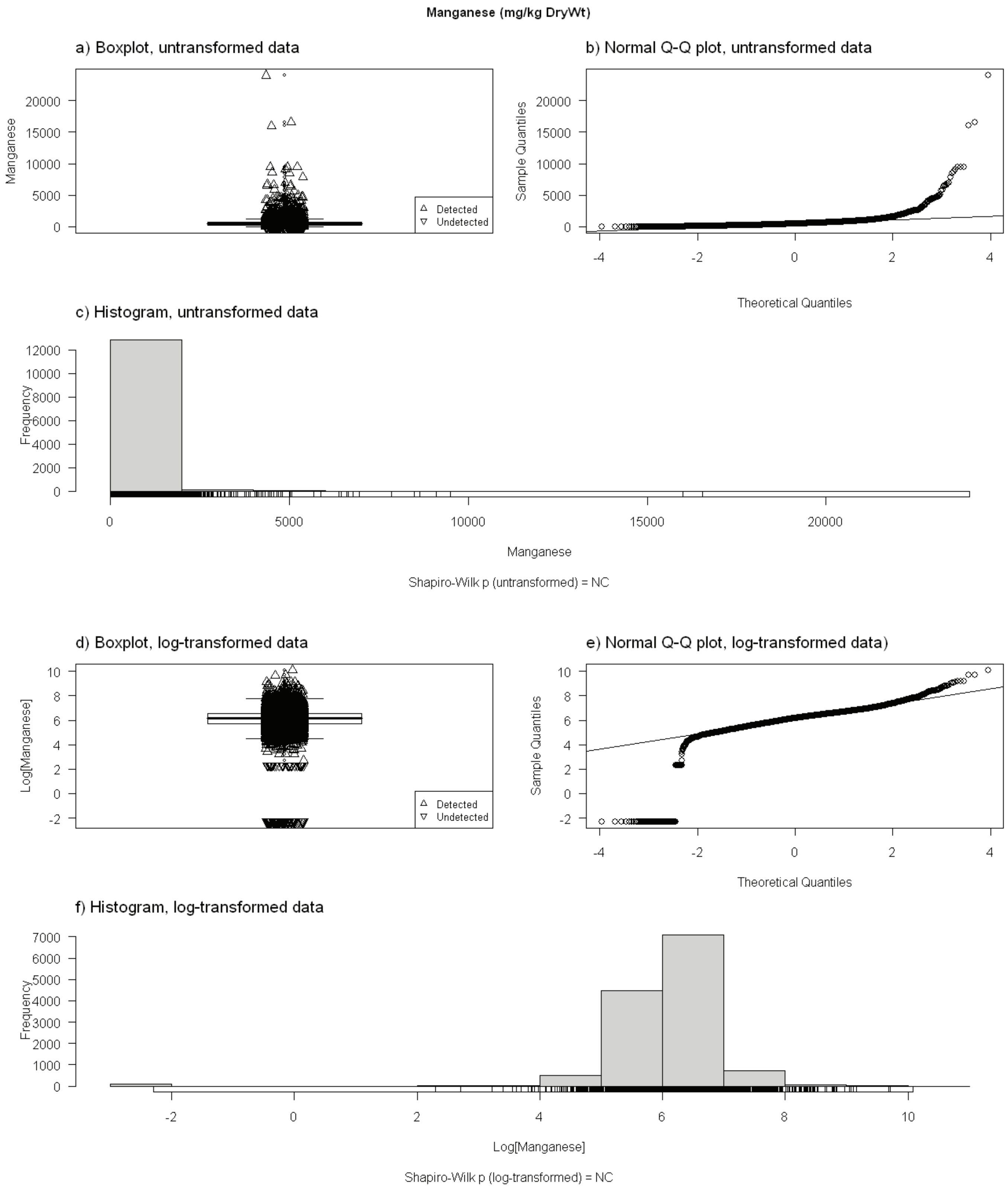
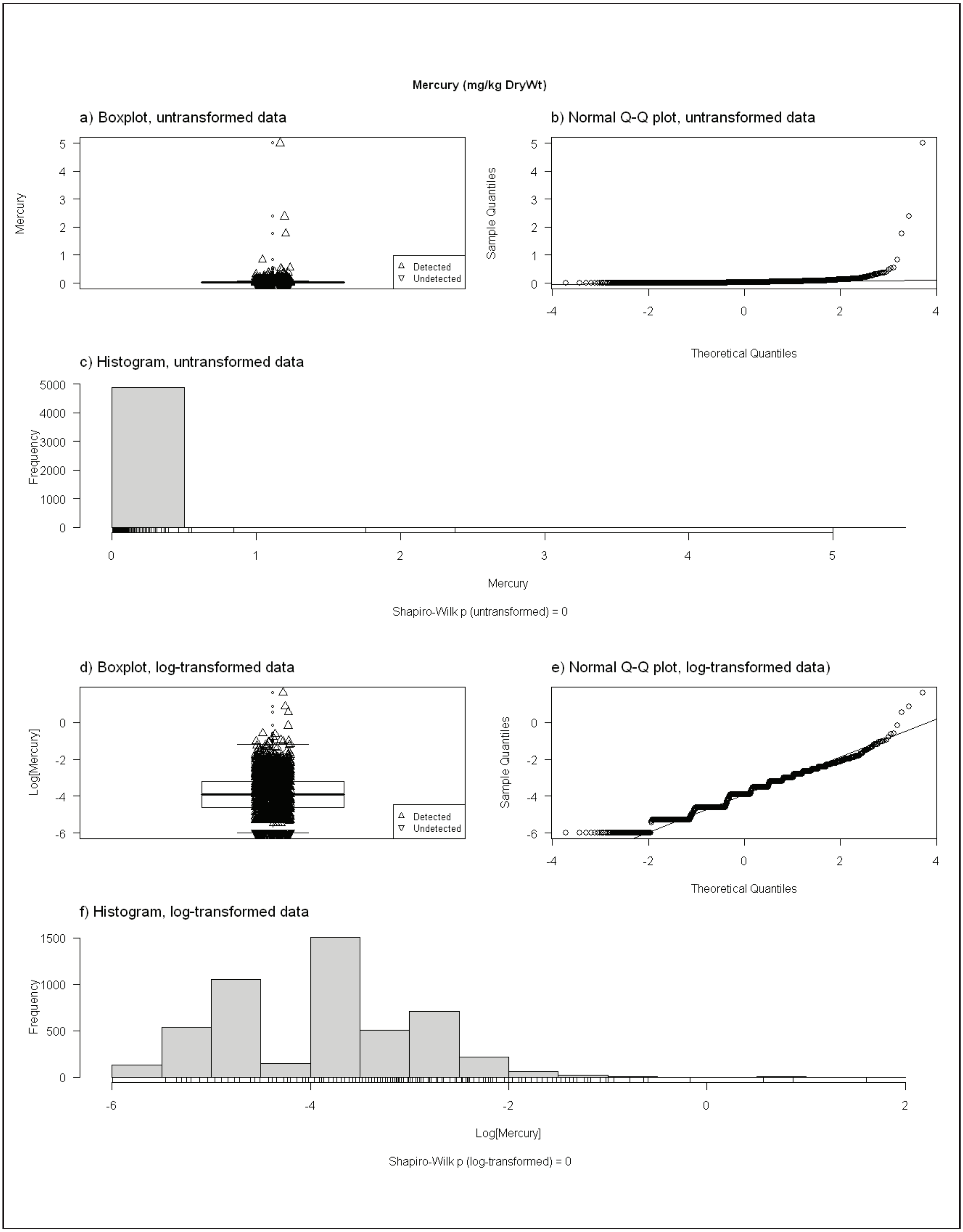


Figure 22. Distribution of All Background Concentrations of Manganese in Sediment



Mercury (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 23. Distribution of All Background
Concentrations of Mercury in Sediment

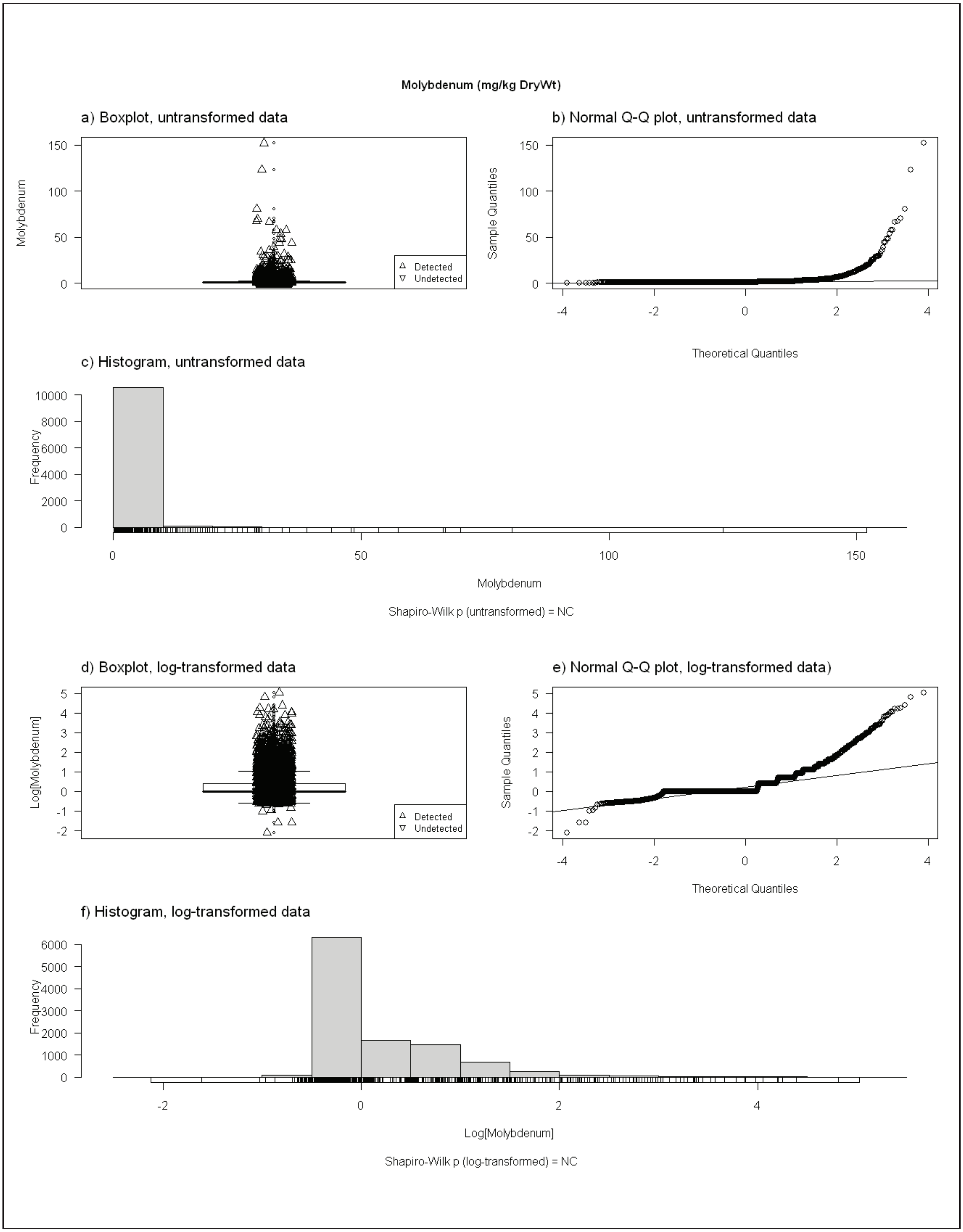


Figure 24. Distribution of All Background Concentrations of Molybdenum in Sediment

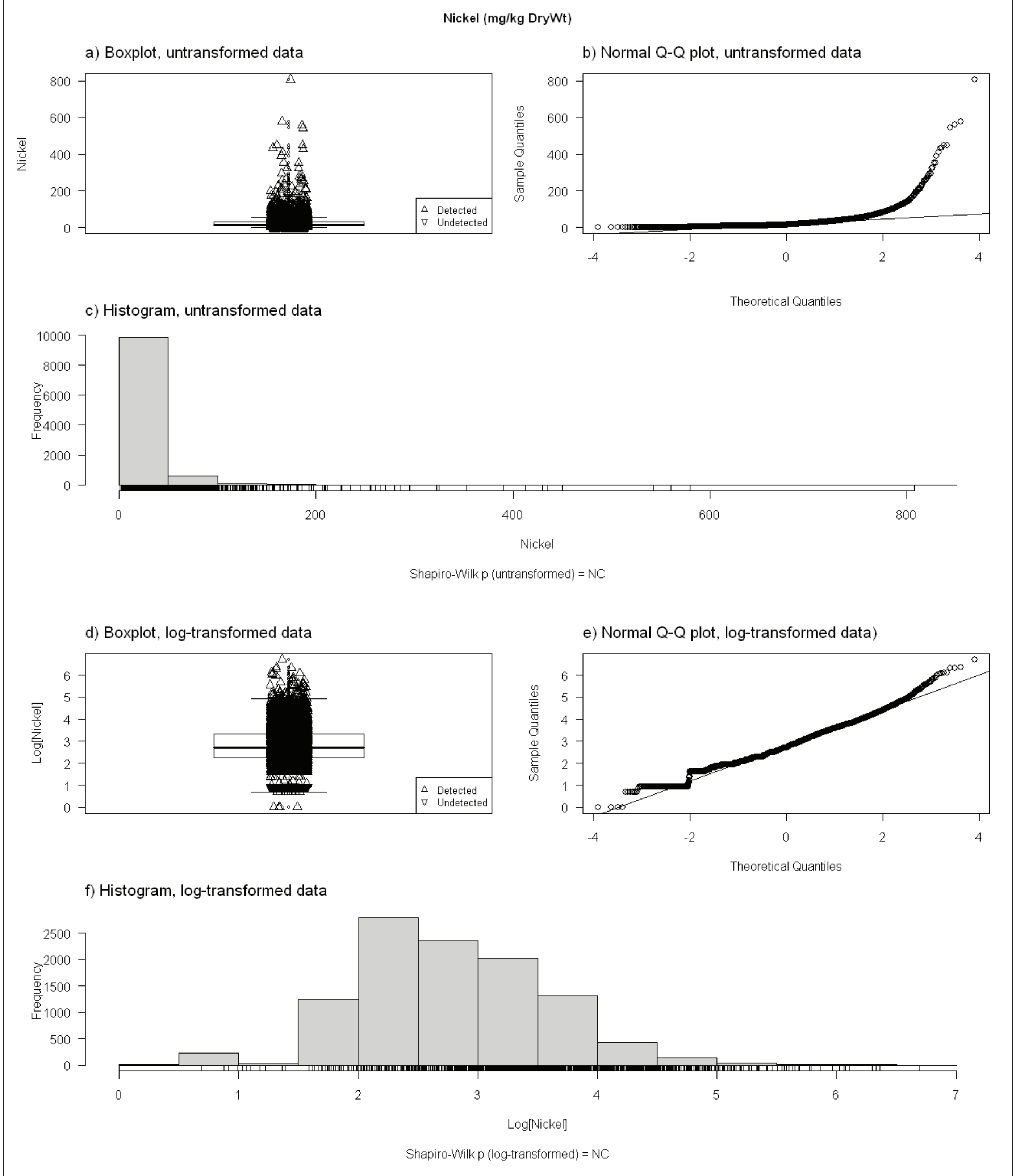


Figure 25. Distribution of All Background Concentrations of Nickel in Sediment

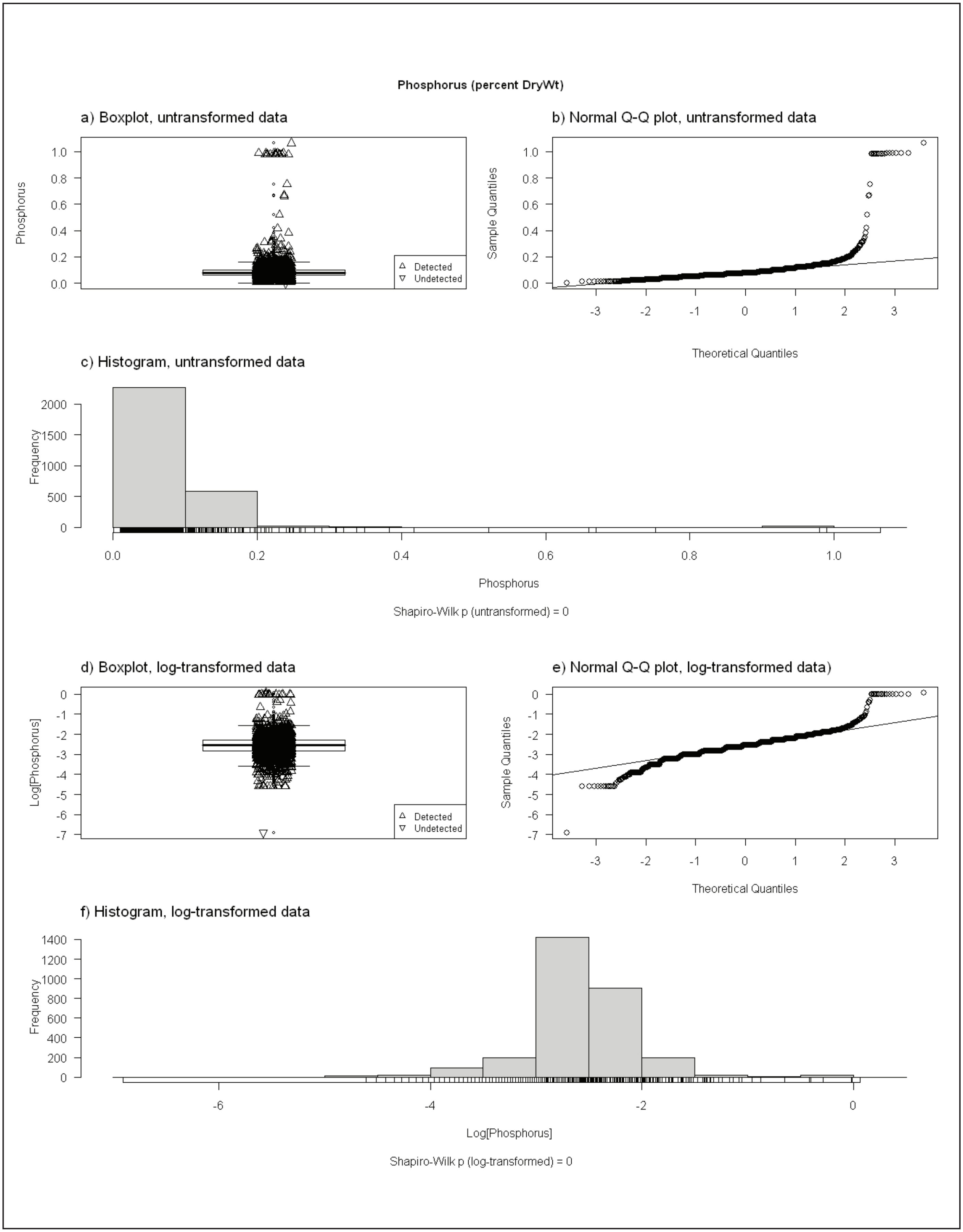


Figure 26. Distribution of All Background Concentrations of Phosphorus in Sediment

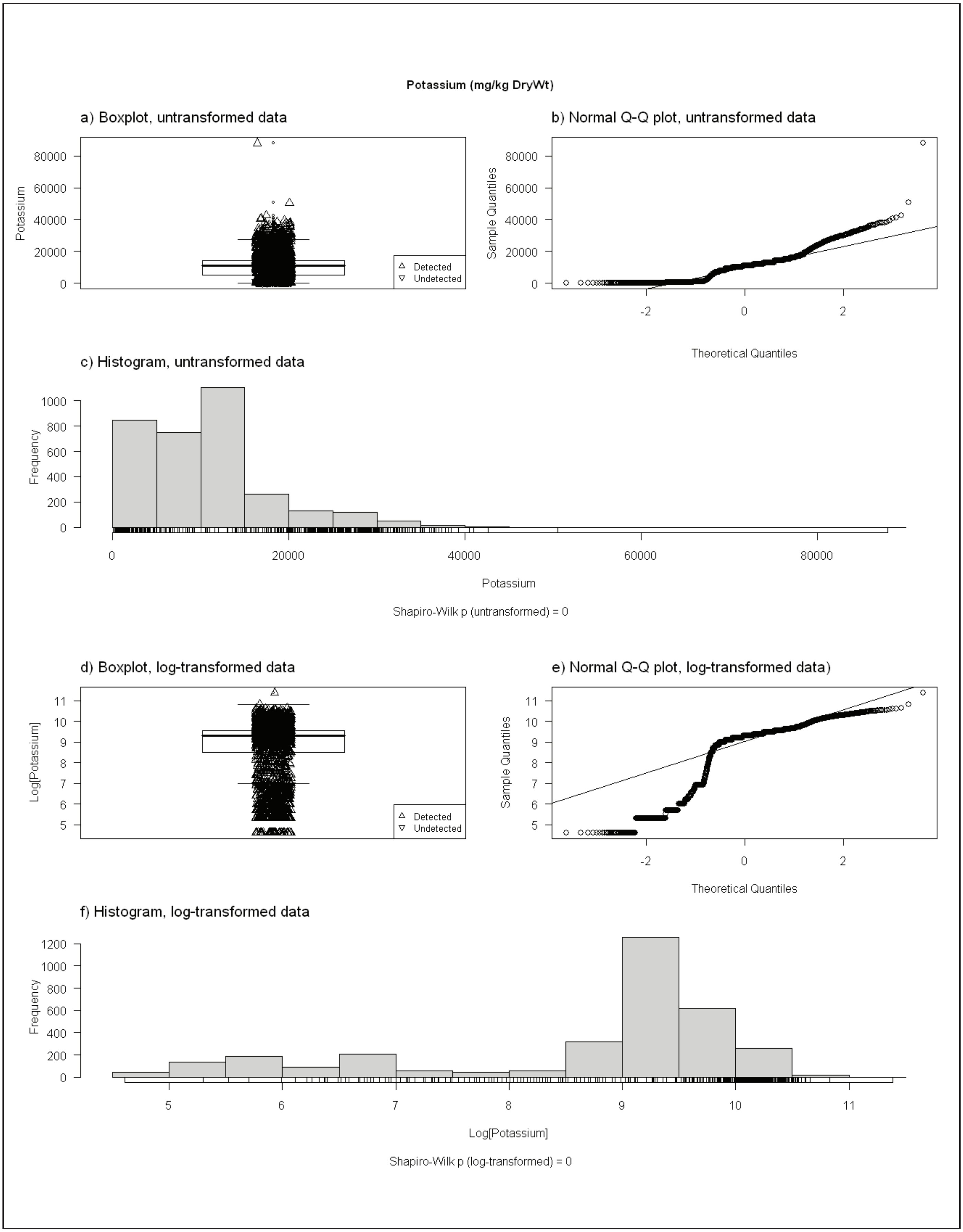
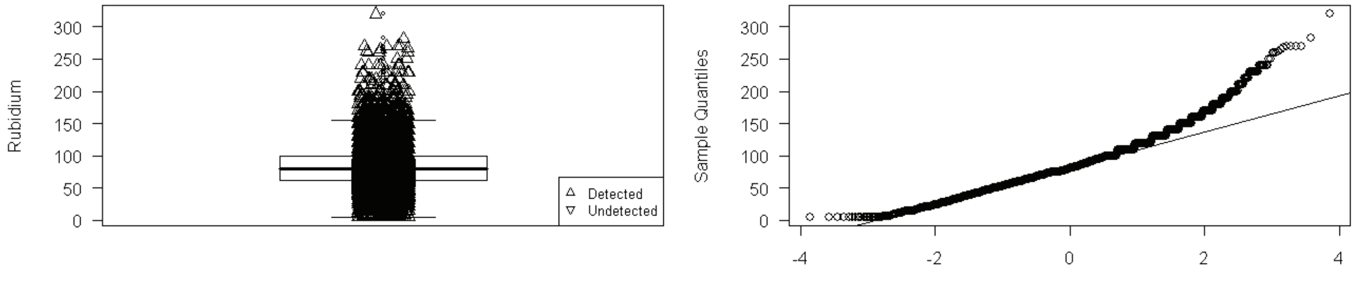


Figure 27. Distribution of All Background Concentrations of Potassium in Sediment

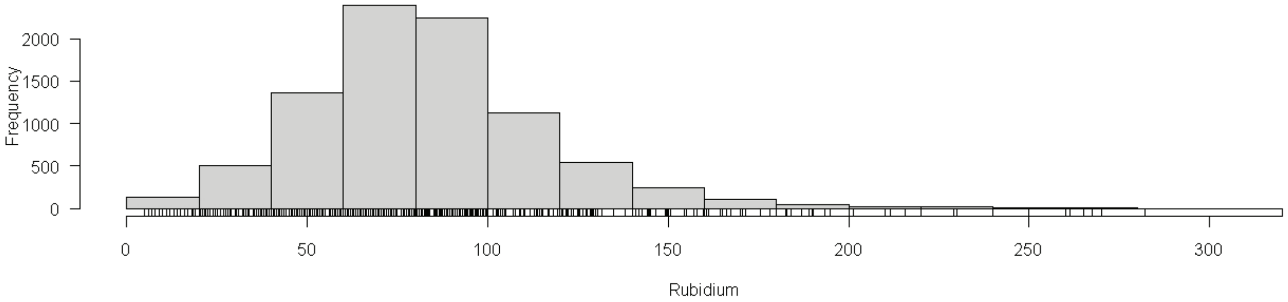
Rubidium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data



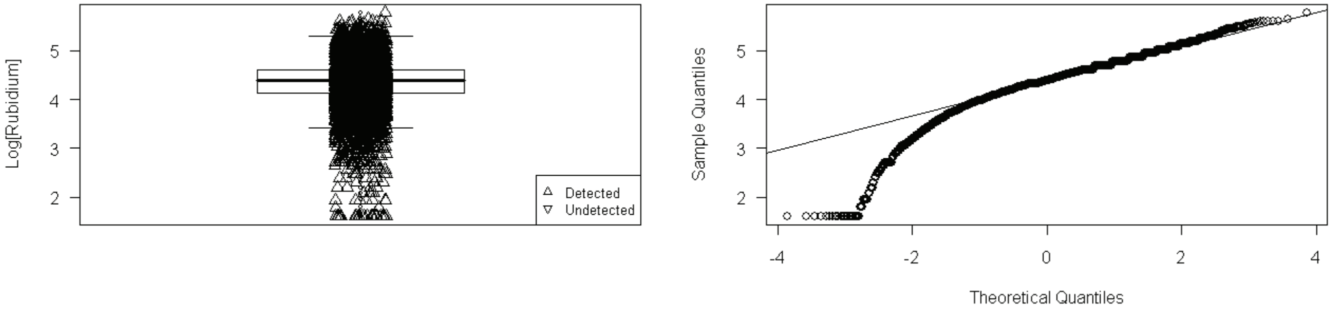
c) Histogram, untransformed data



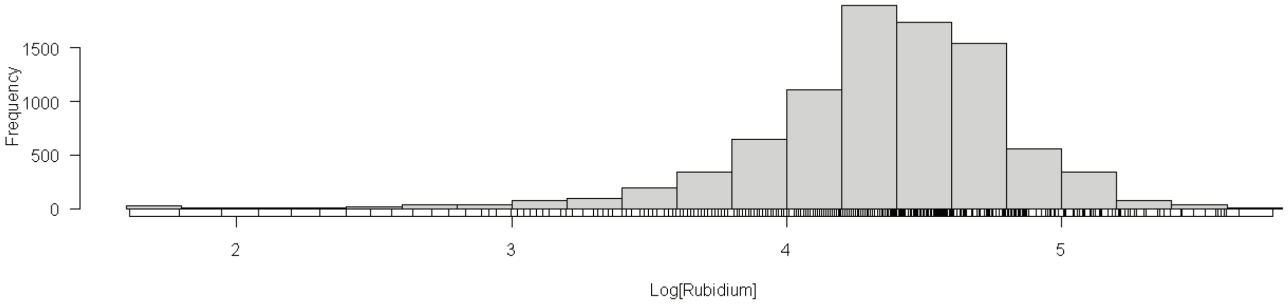
Shapiro-Wilk p (untransformed) = NC

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)



f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = NC

Figure 28. Distribution of All Background Concentrations of Rubidium in Sediment

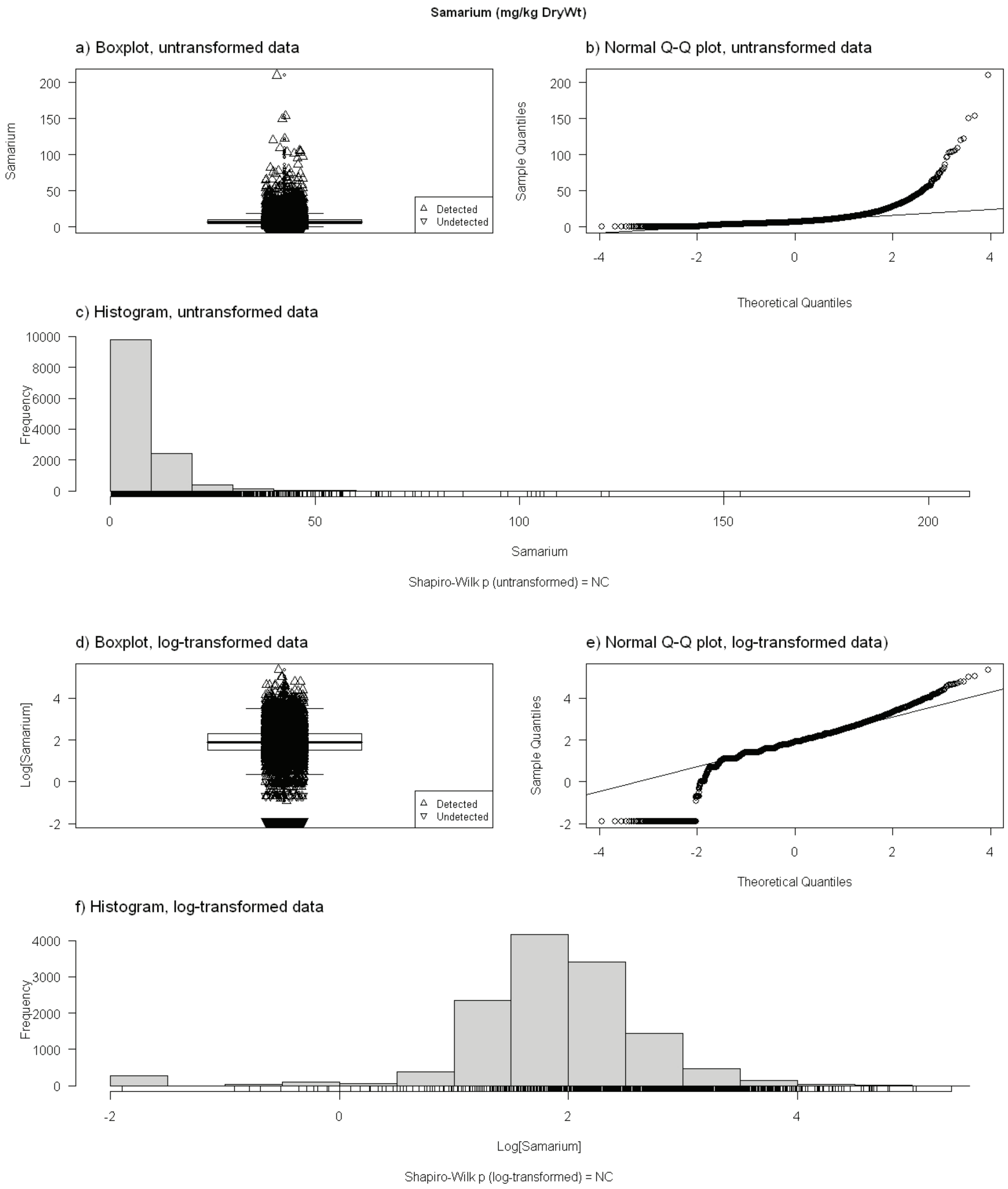


Figure 29. Distribution of All Background Concentrations of Samarium in Sediment

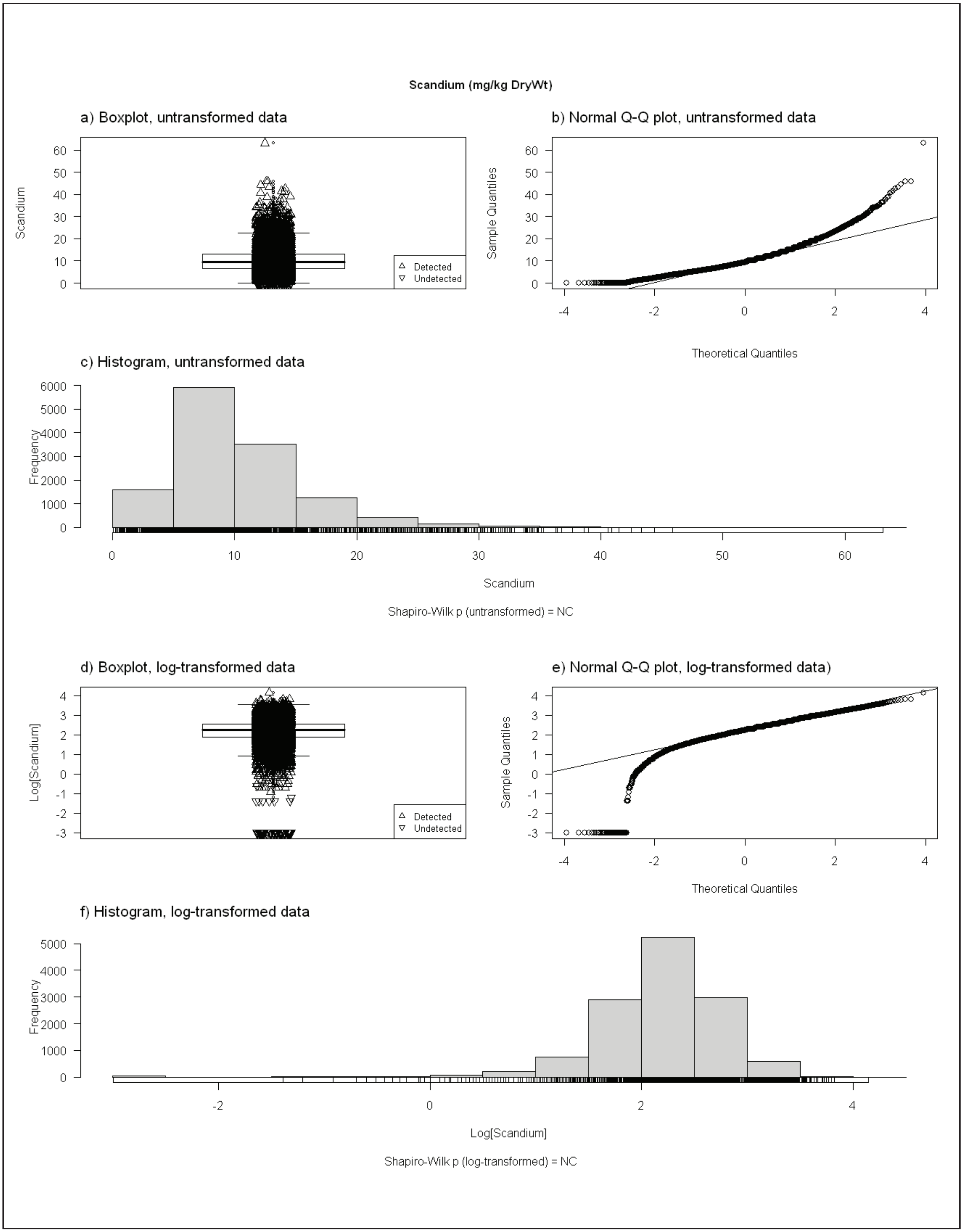
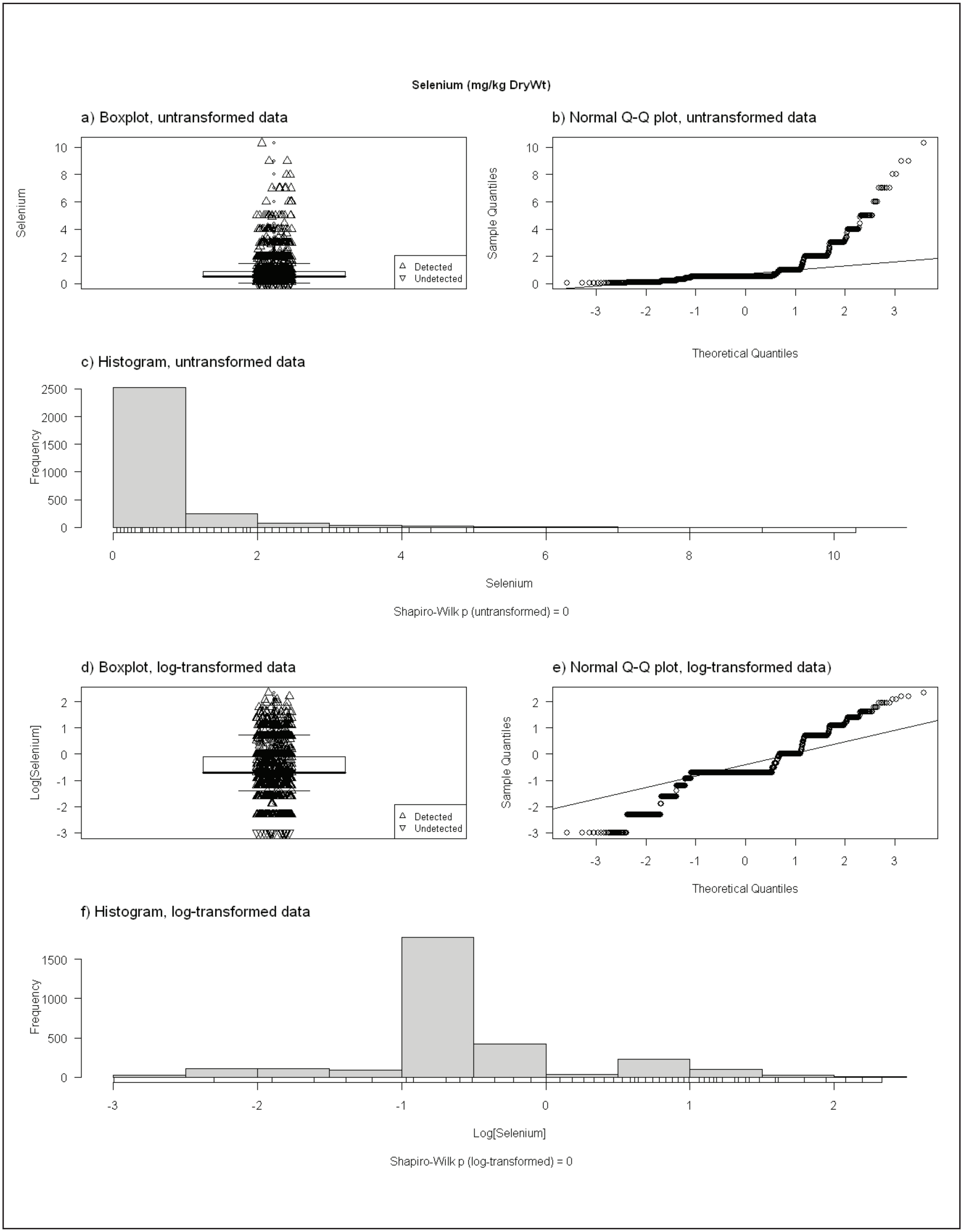


Figure 30. Distribution of All Background Concentrations of Scandium in Sediment



Selenium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 31. Distribution of All Background Concentrations of Selenium in Sediment

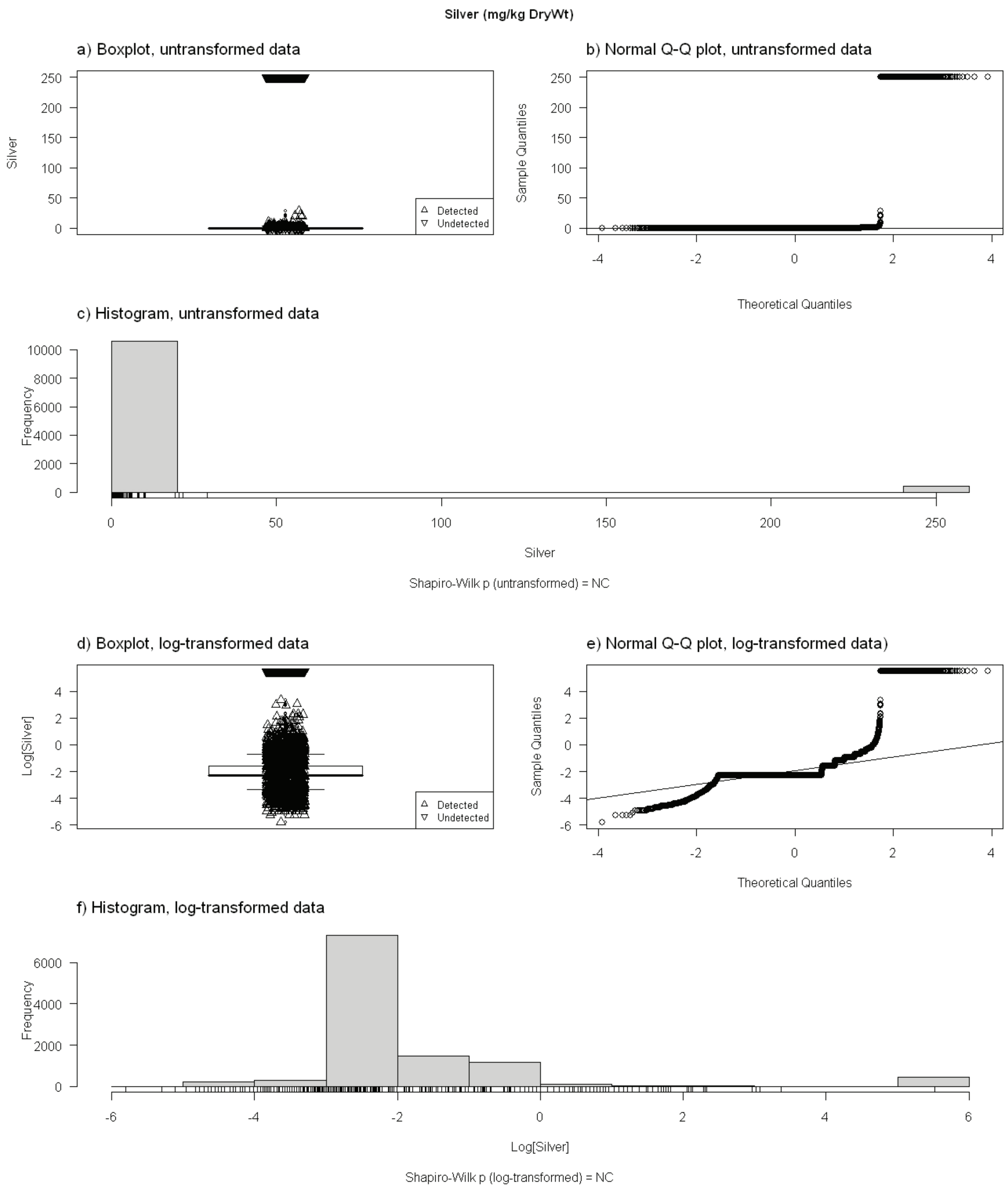


Figure 32. Distribution of All Background Concentrations of Silver in Sediment

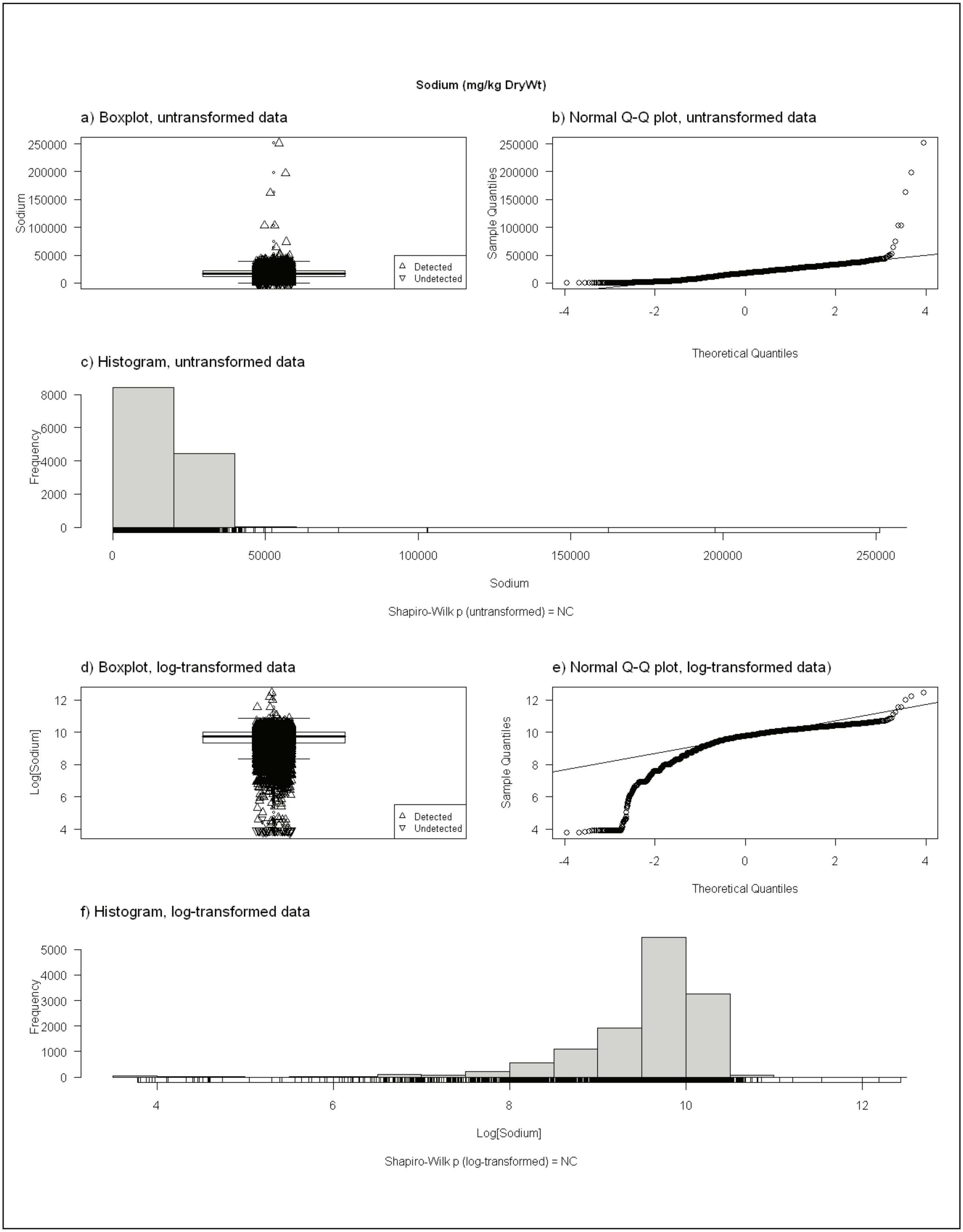


Figure 33. Distribution of All Background
Concentrations of Sodium in Sediment

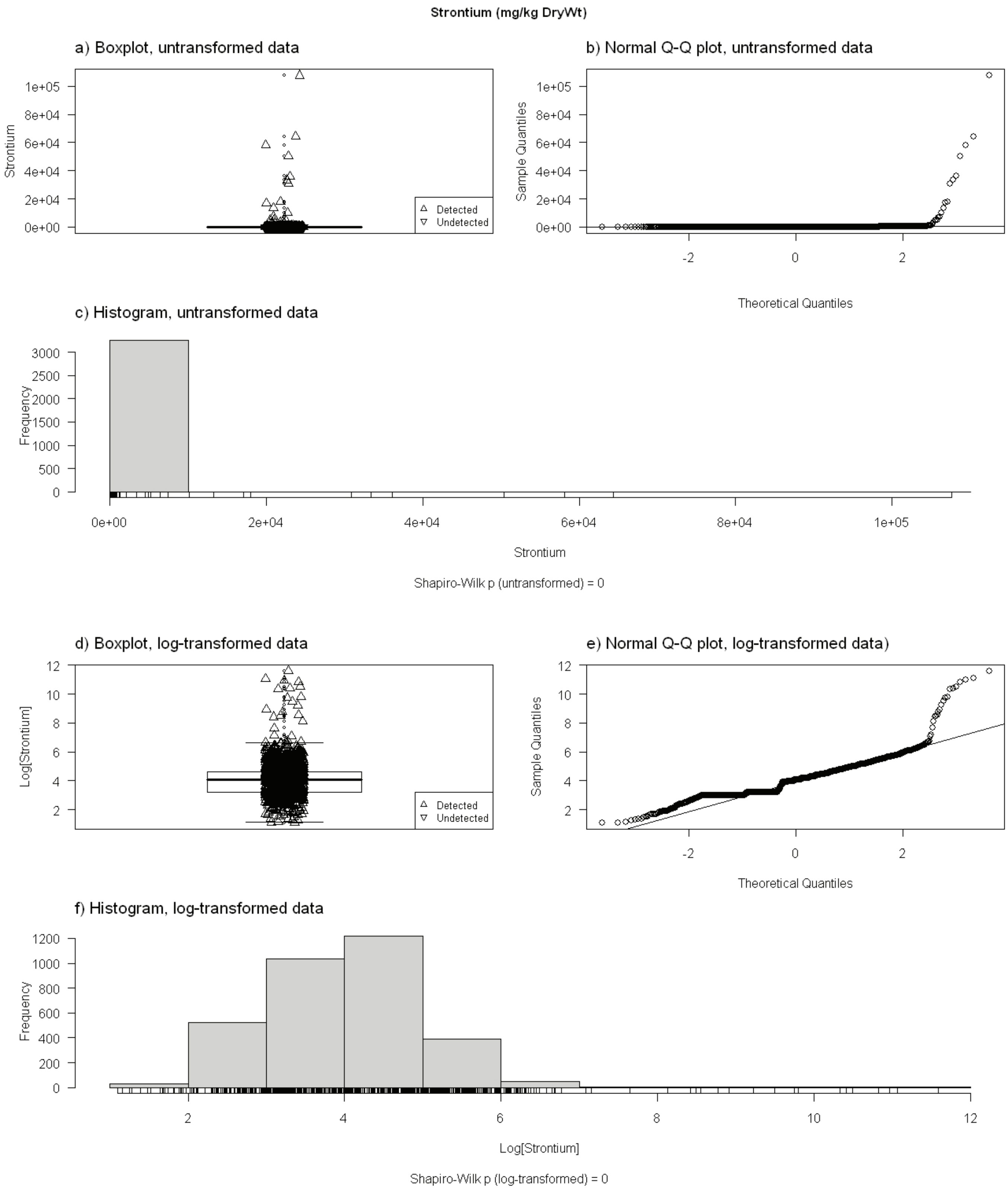


Figure 34. Distribution of All Background Concentrations of Strontium in Sediment

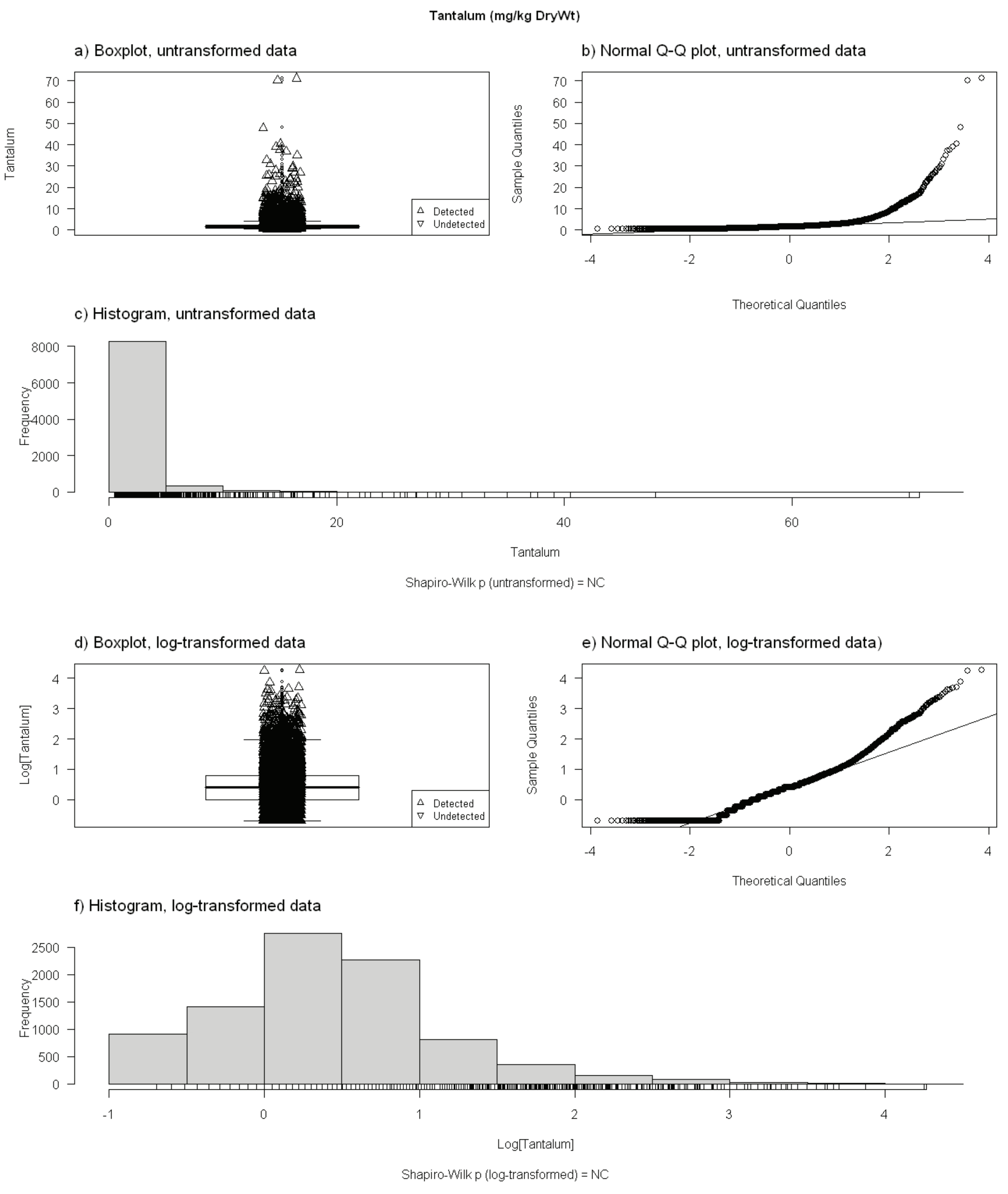
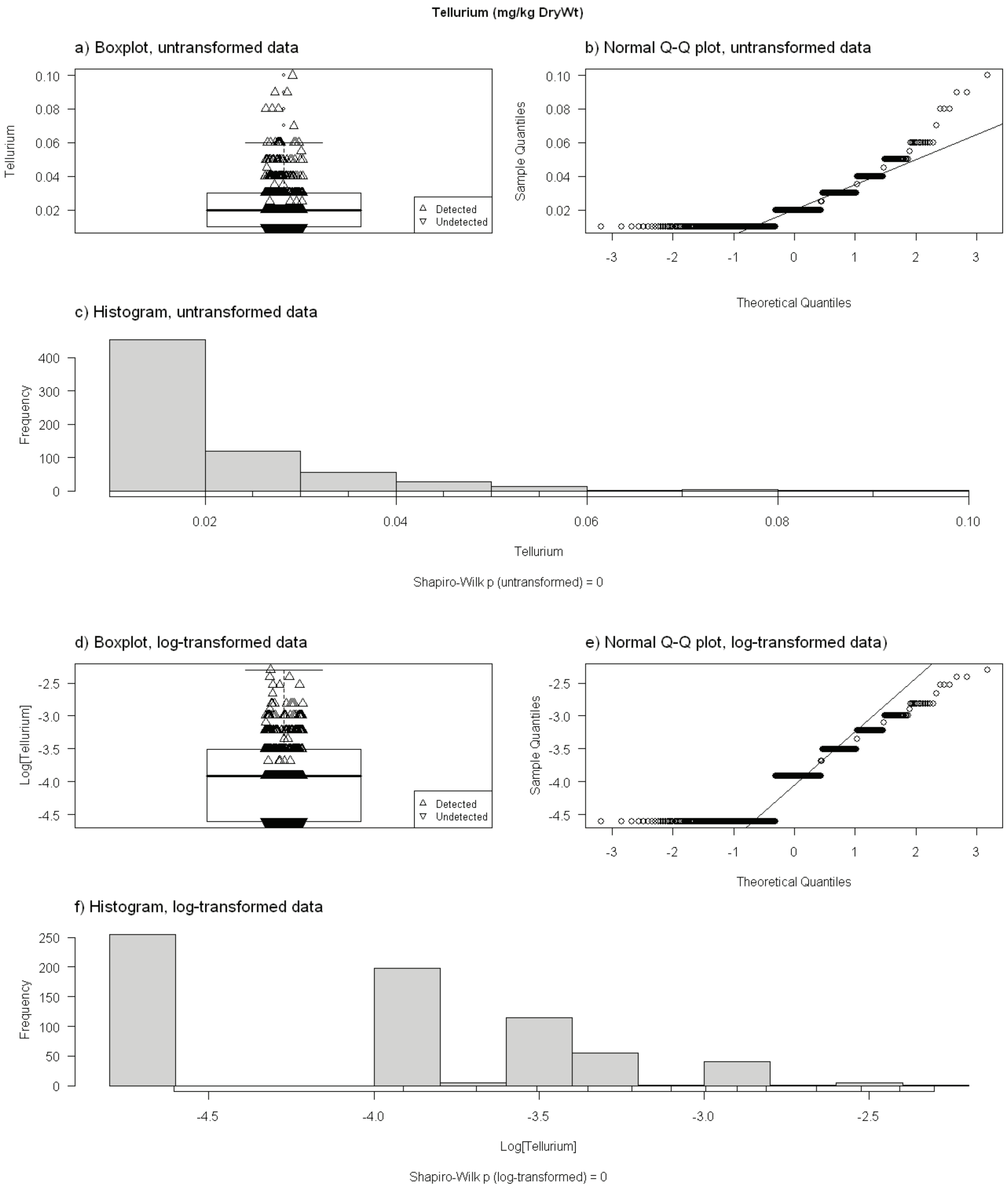


Figure 35. Distribution of All Background Concentrations of Tantalum in Sediment



Tellurium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 36. Distribution of All Background Concentrations of Tellurium in Sediment

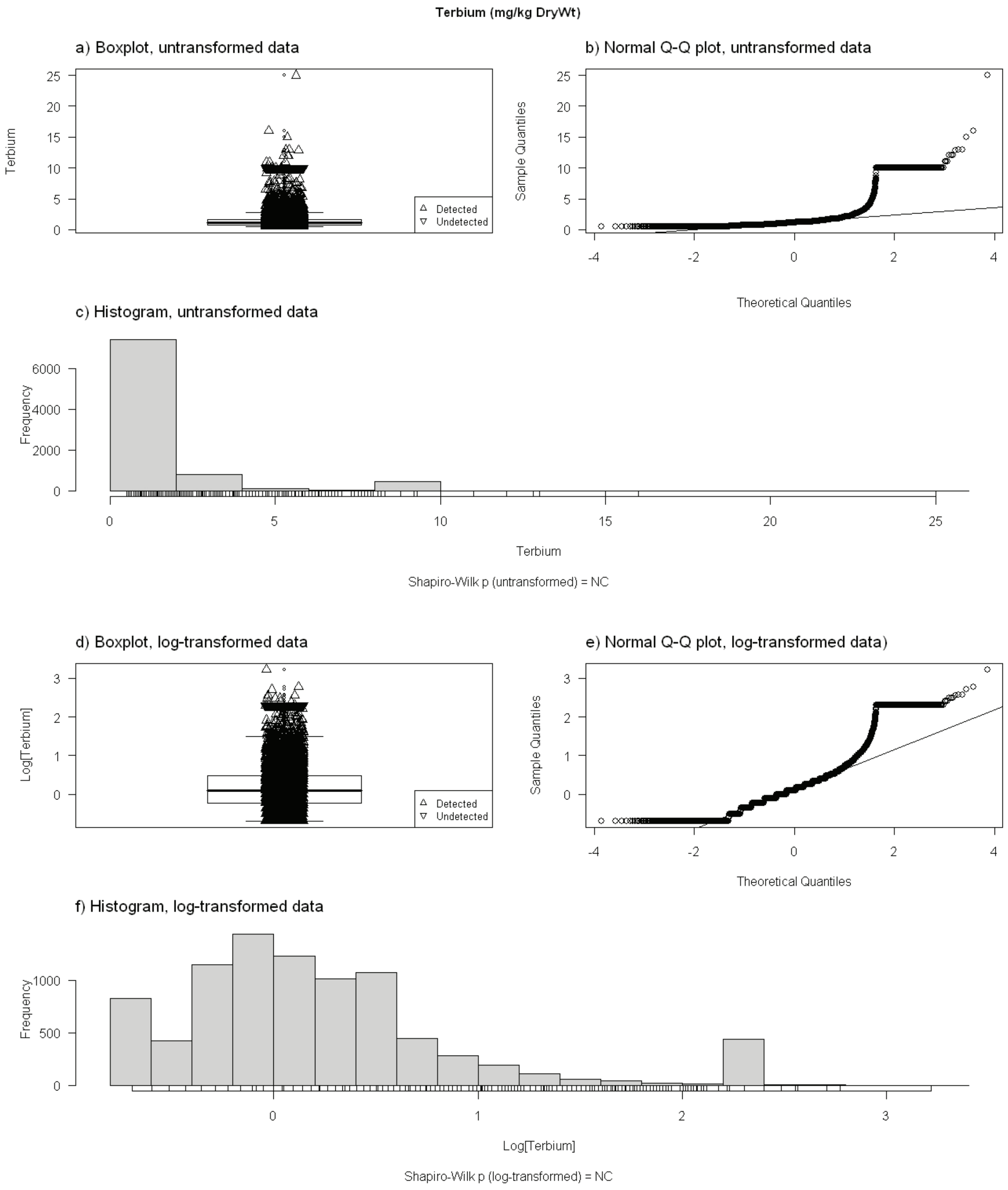
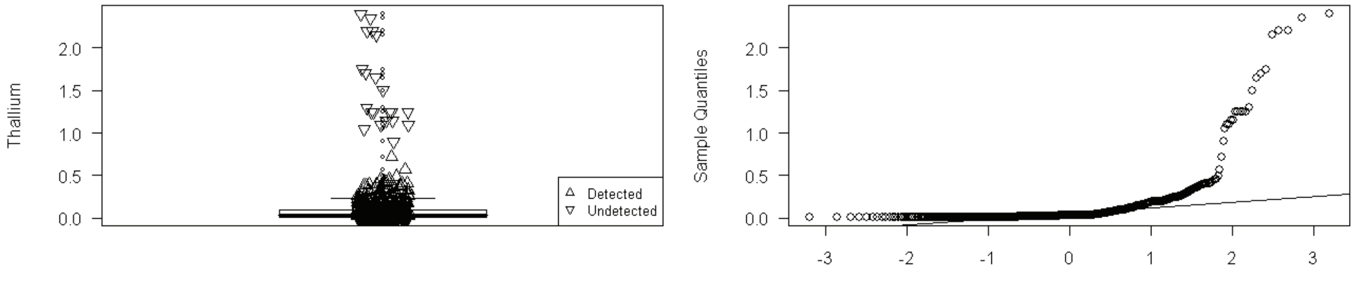


Figure 37. Distribution of All Background
Concentrations of Terbium in Sediment

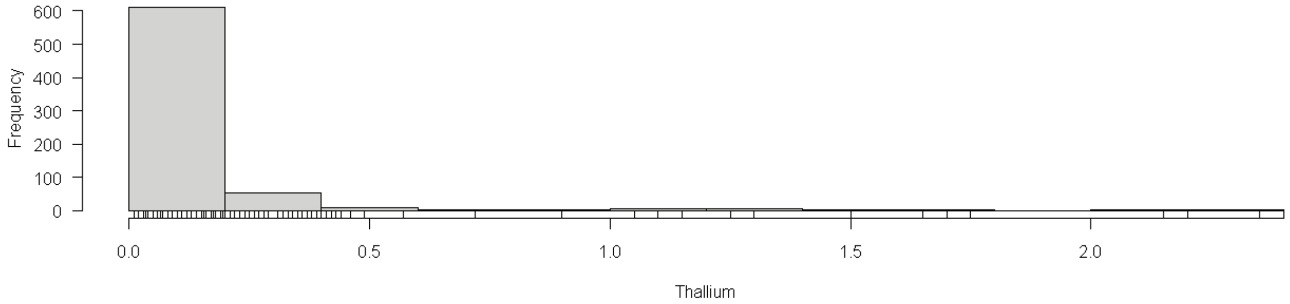
Thallium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data



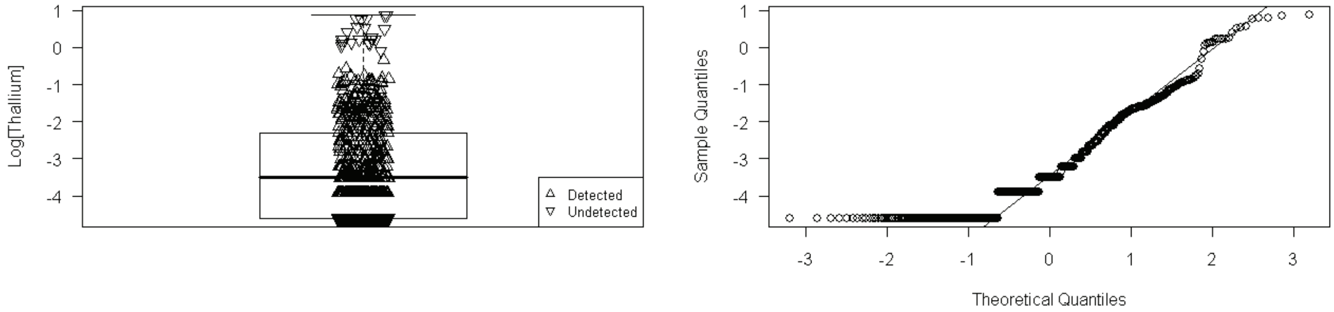
c) Histogram, untransformed data



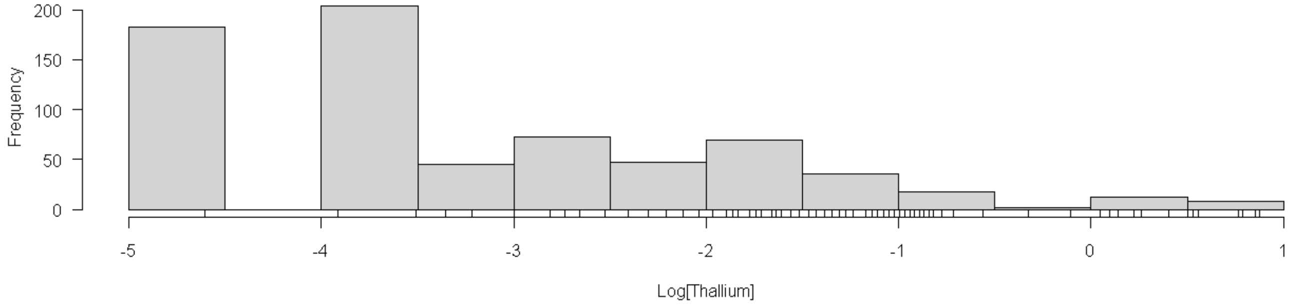
Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)



f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = 0

Figure 38. Distribution of All Background
Concentrations of Thallium in Sediment

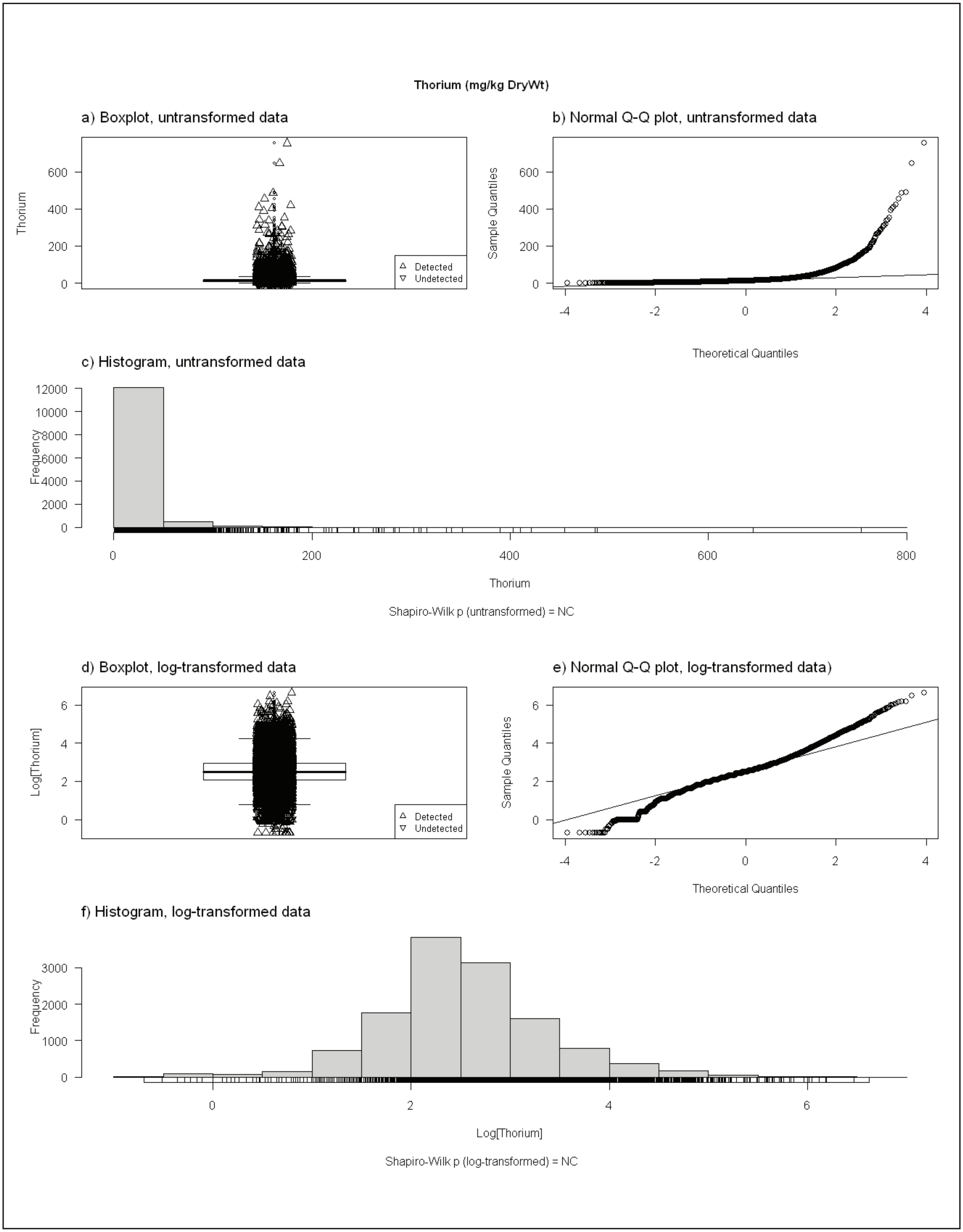


Figure 39. Distribution of All Background Concentrations of Thorium in Sediment

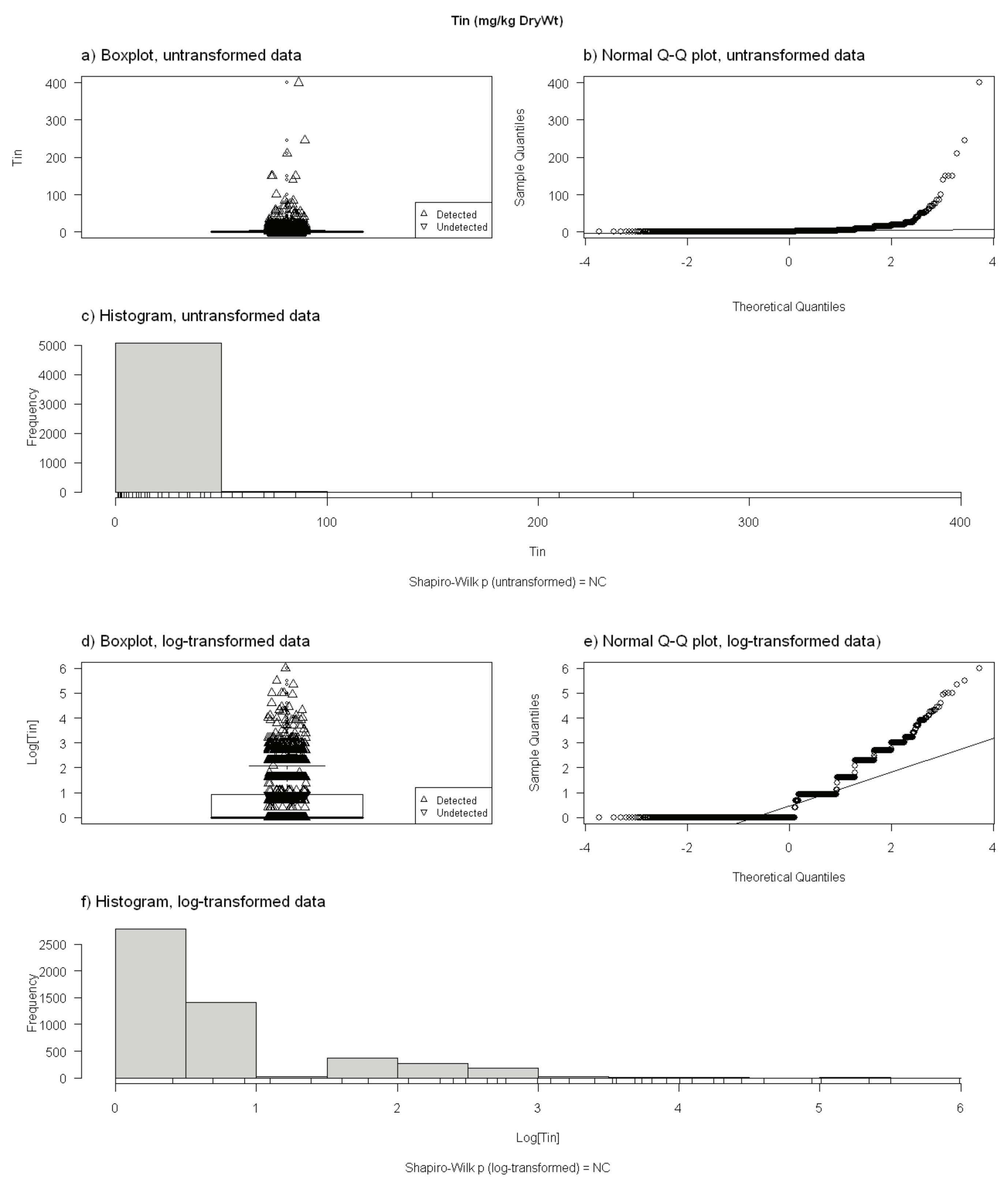


Figure 40. Distribution of All Background Concentrations of Tin in Sediment

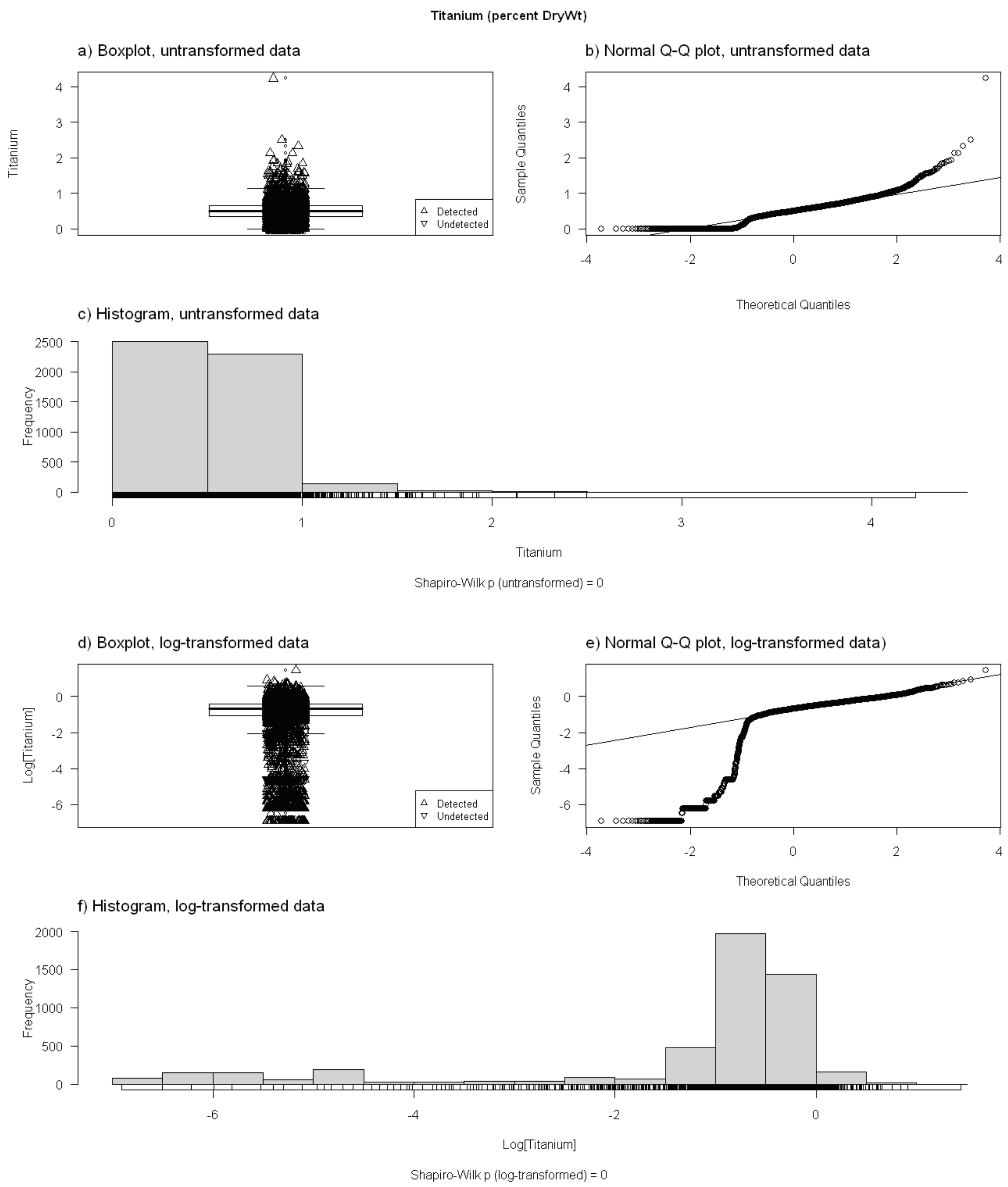


Figure 41. Distribution of All Background Concentrations of Titanium in Sediment

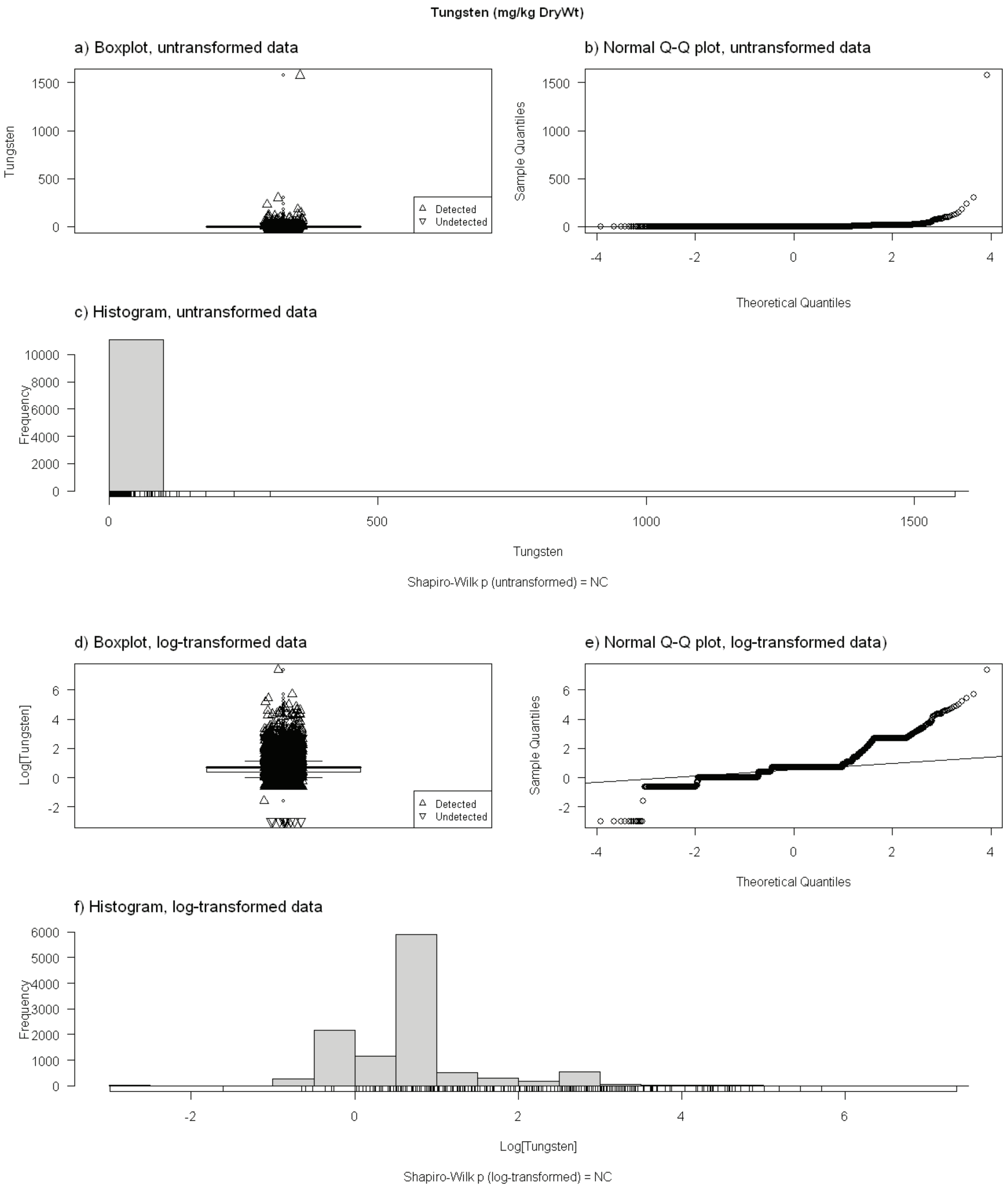


Figure 42. Distribution of All Background Concentrations of Tungsten in Sediment

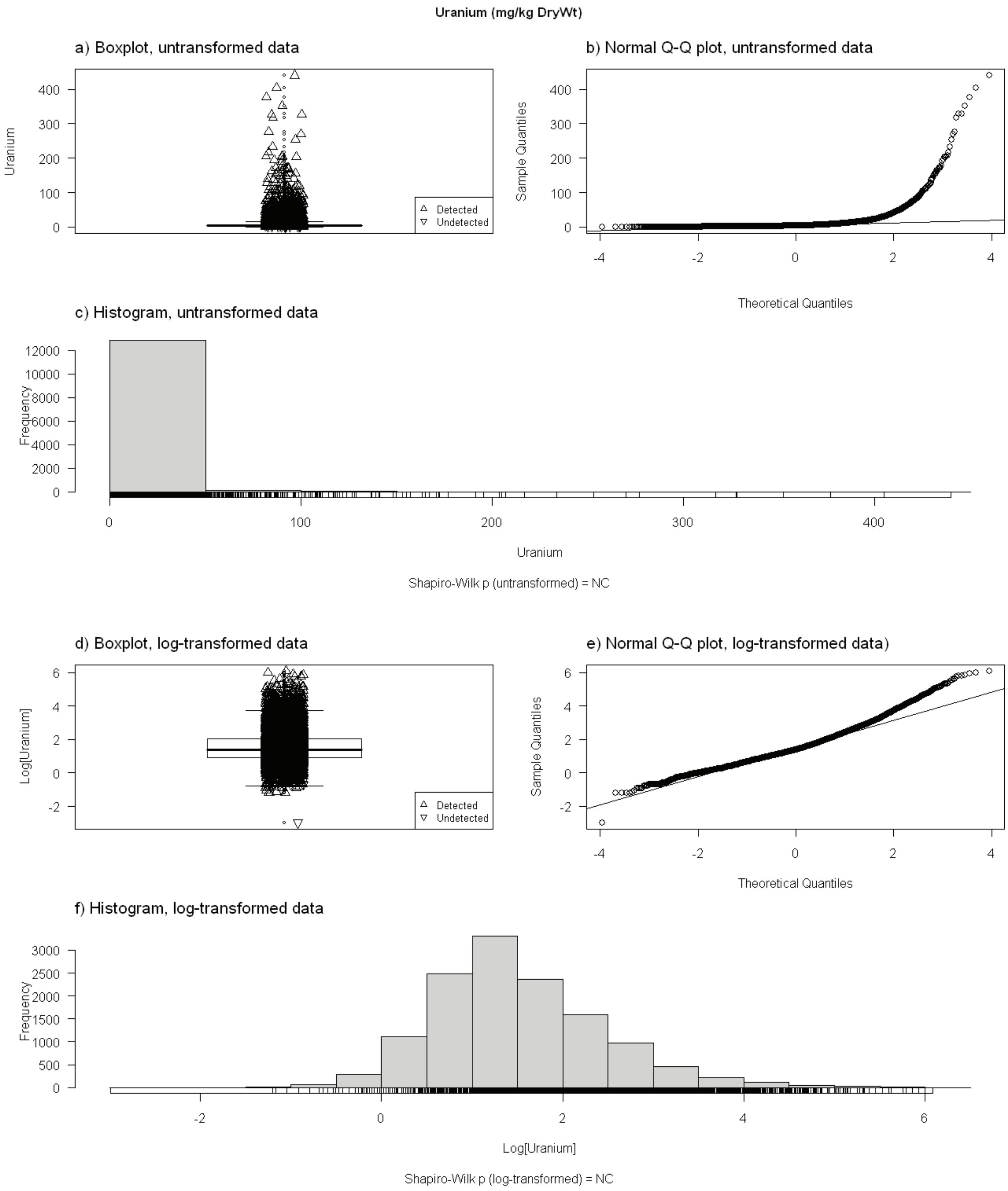


Figure 43. Distribution of All Background Concentrations of Uranium in Sediment

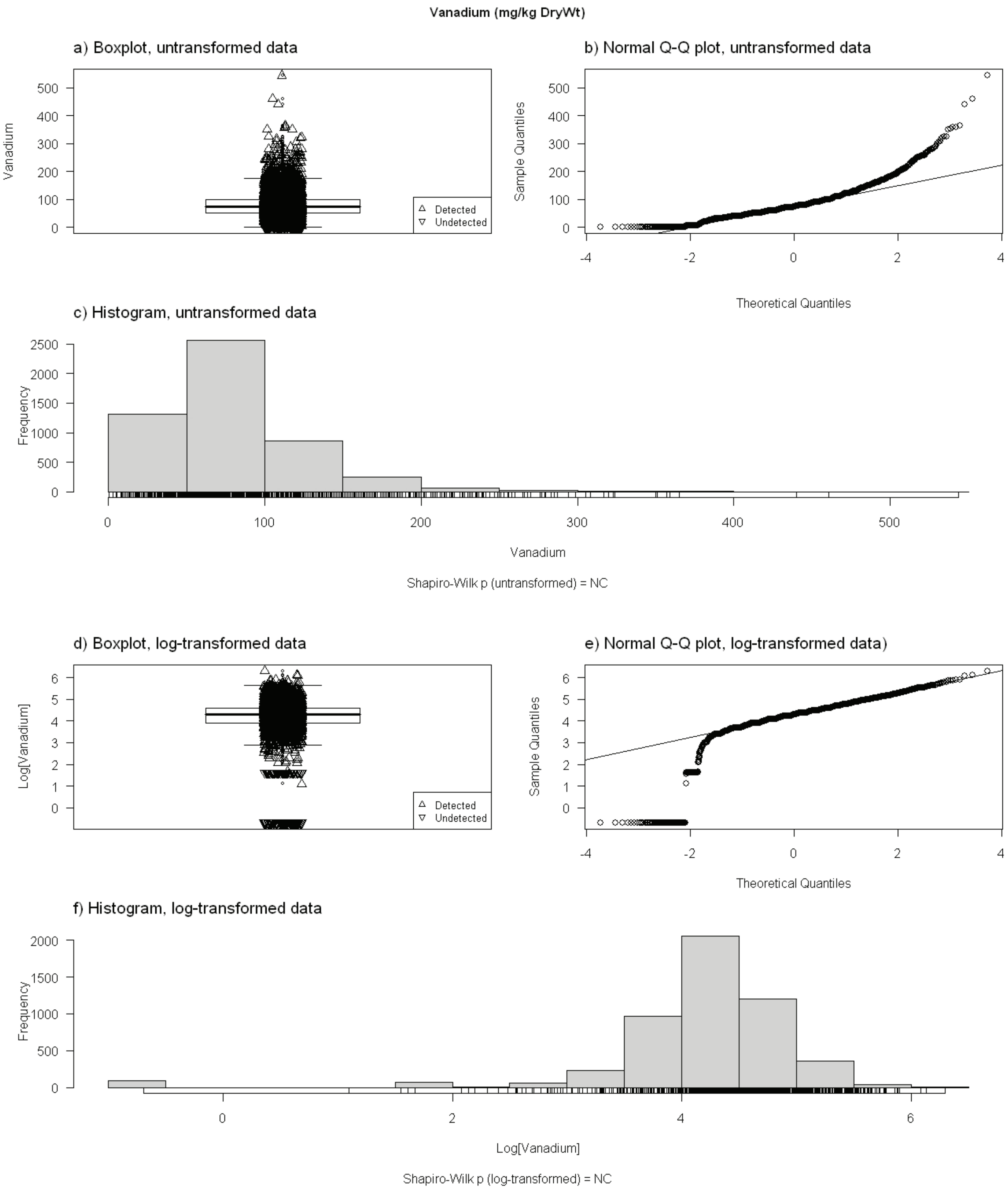


Figure 44. Distribution of All Background
Concentrations of Vanadium in Sediment

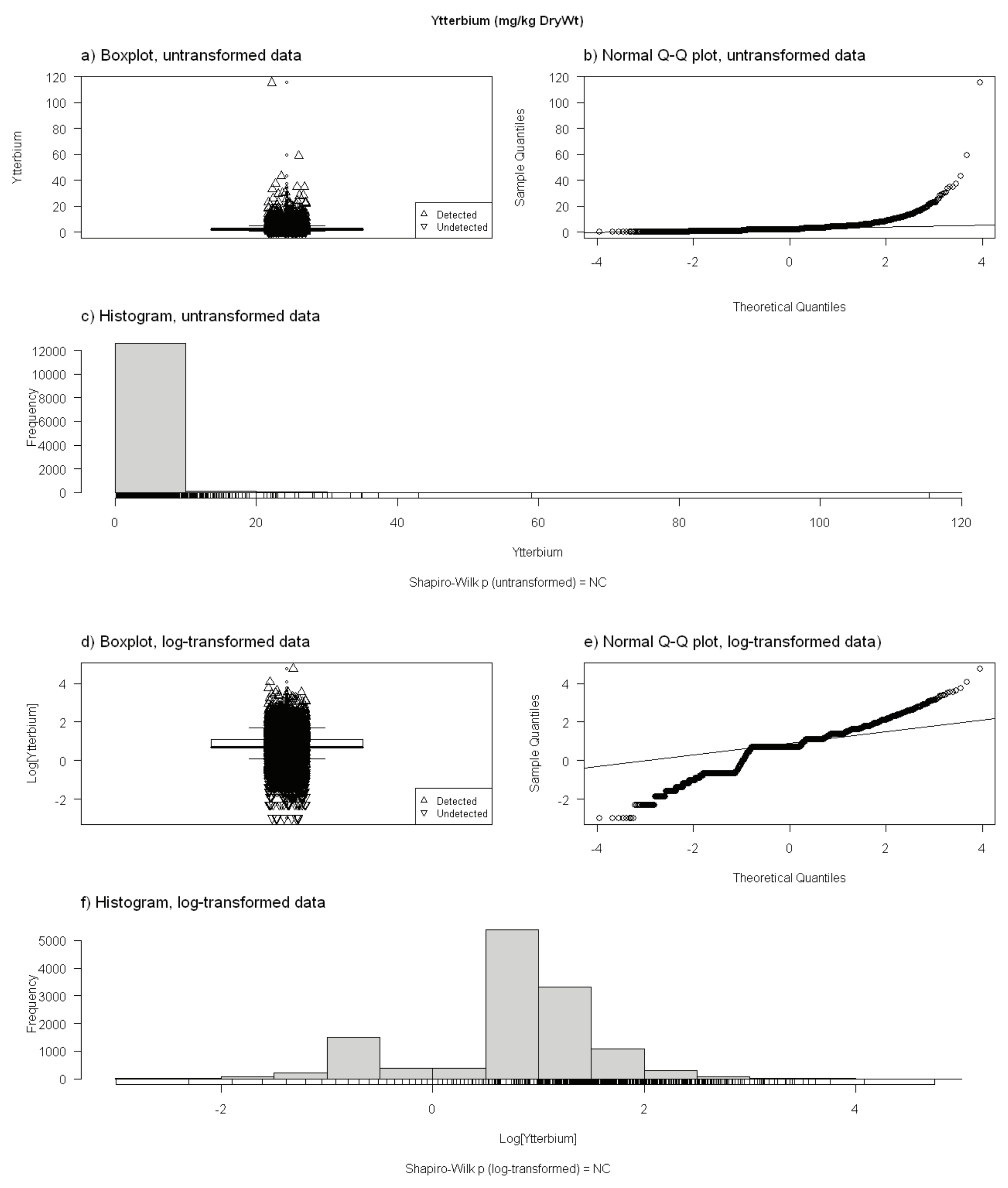
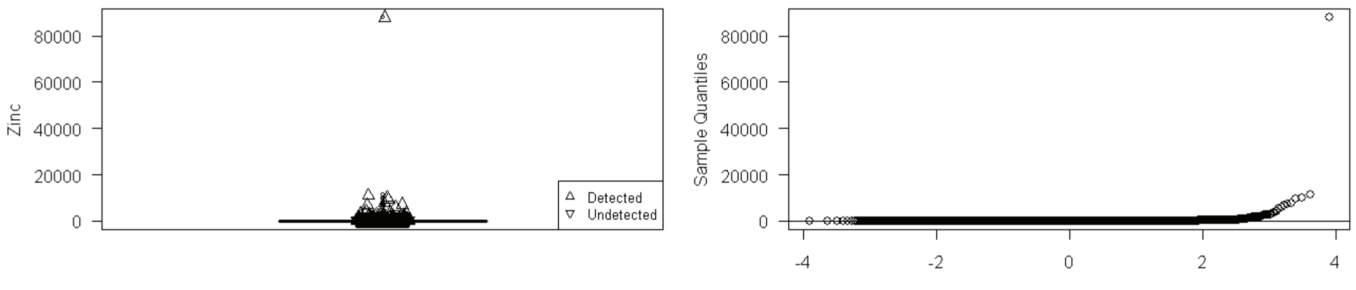


Figure 45. Distribution of All Background Concentrations of Ytterbium in Sediment

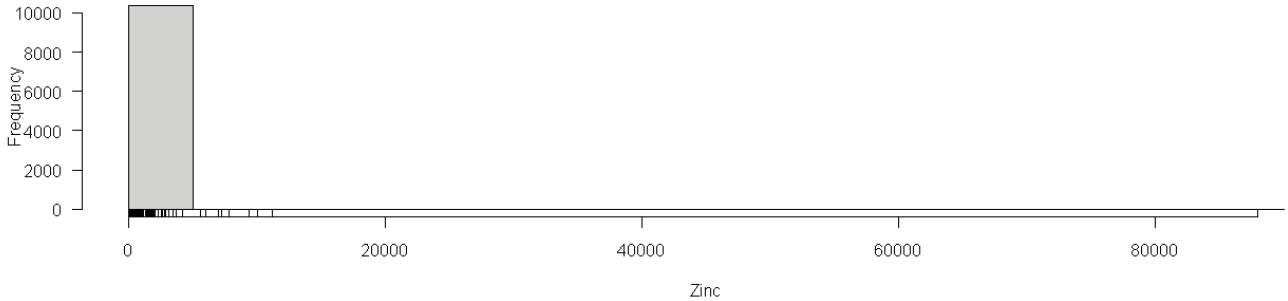
Zinc (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data



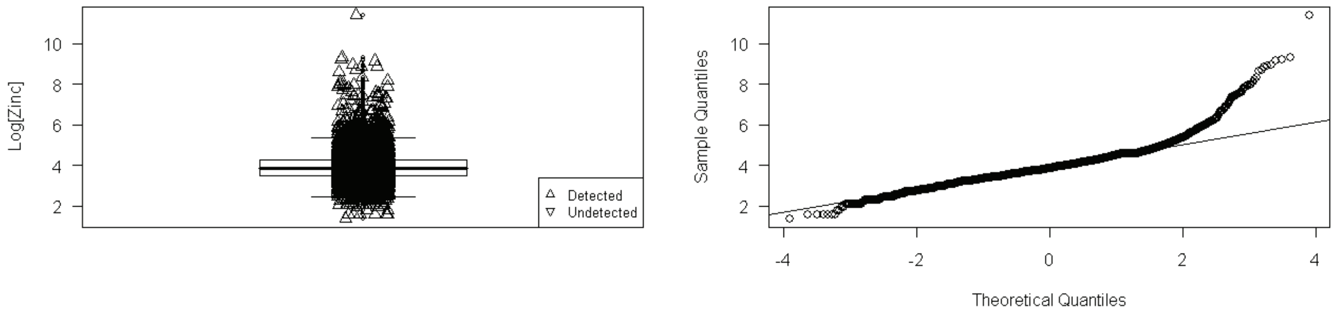
c) Histogram, untransformed data



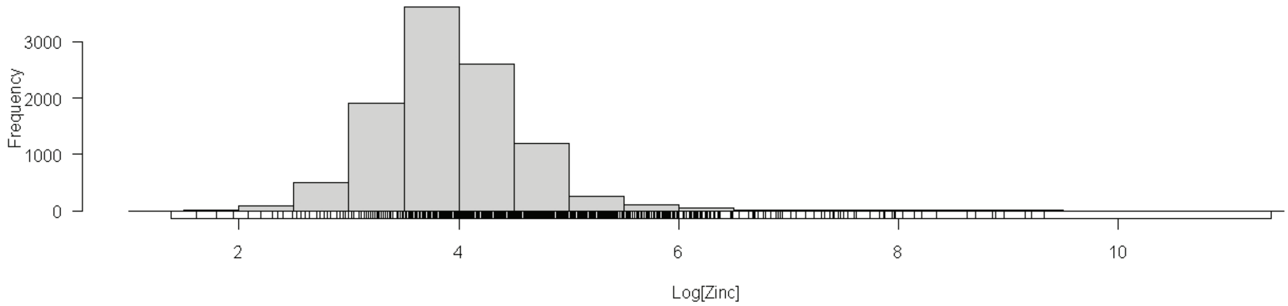
Shapiro-Wilk p (untransformed) = NC

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)



f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = NC

Figure 46. Distribution of All Background Concentrations of Zinc in Sediment

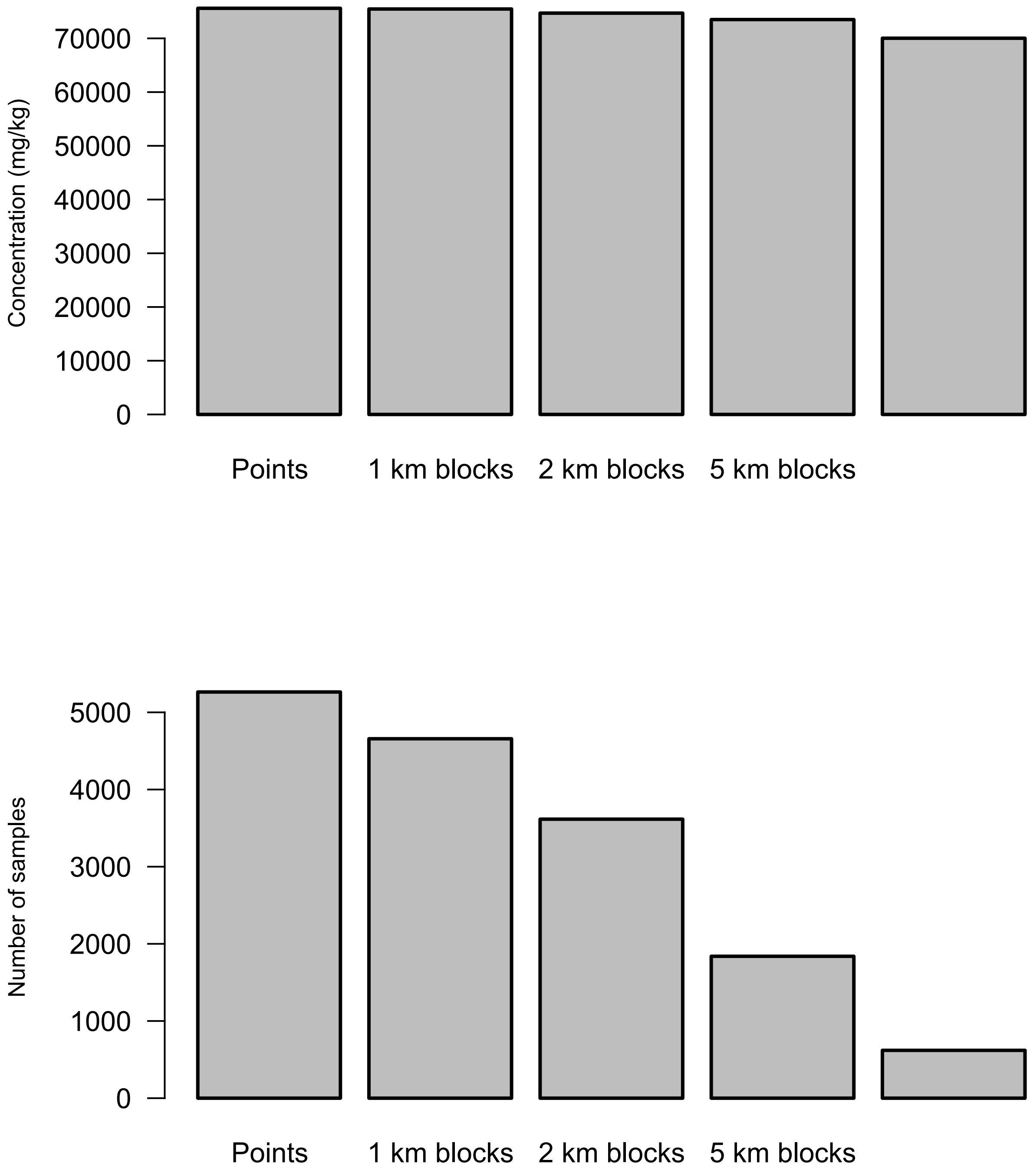


Figure 47. Variation in Aluminum Concentration and Number of Samples by Size of Block Used for Averaging

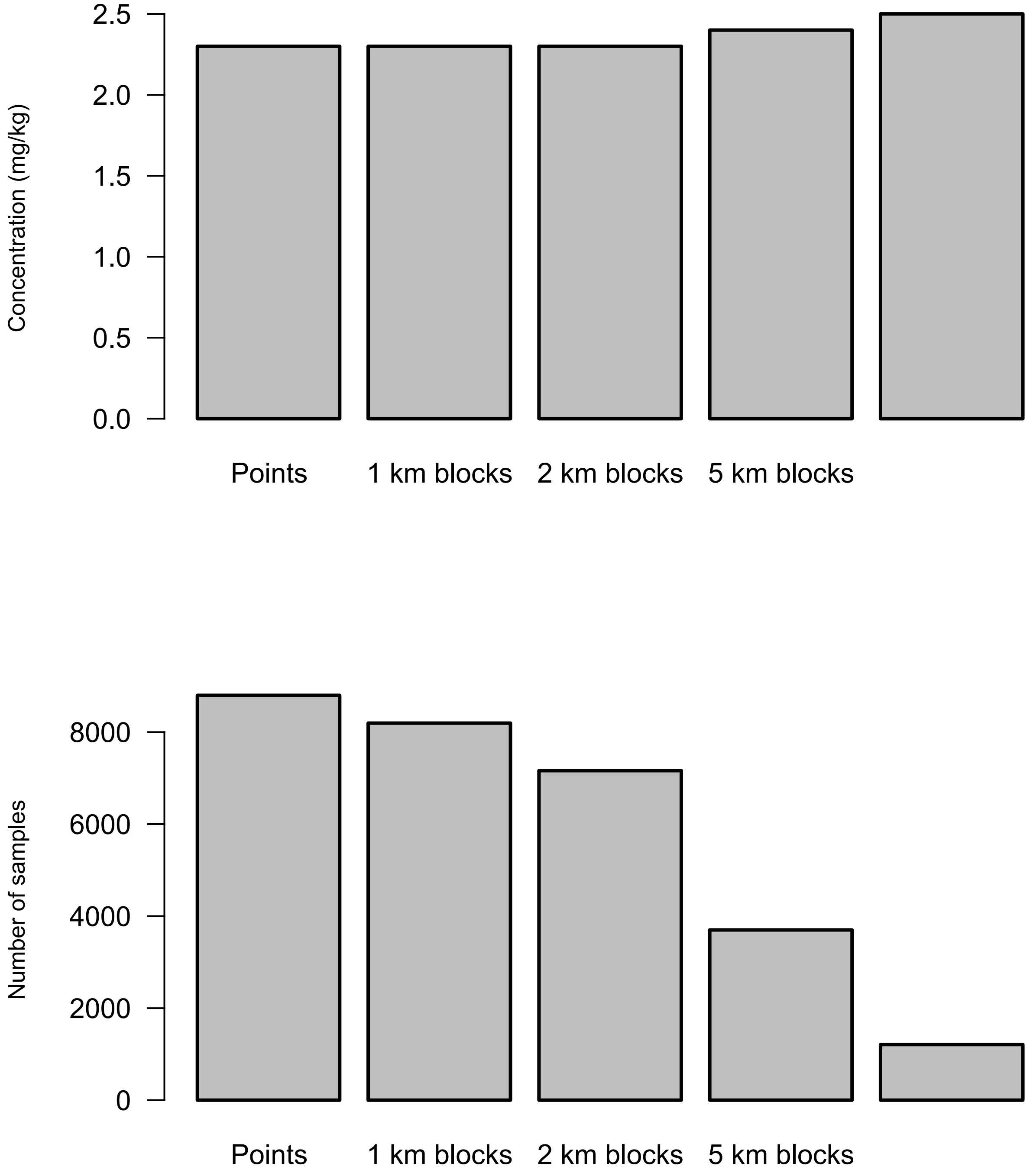


Figure 48. Variation in Antimony Concentration and Number of Samples by Size of Block Used for Averaging

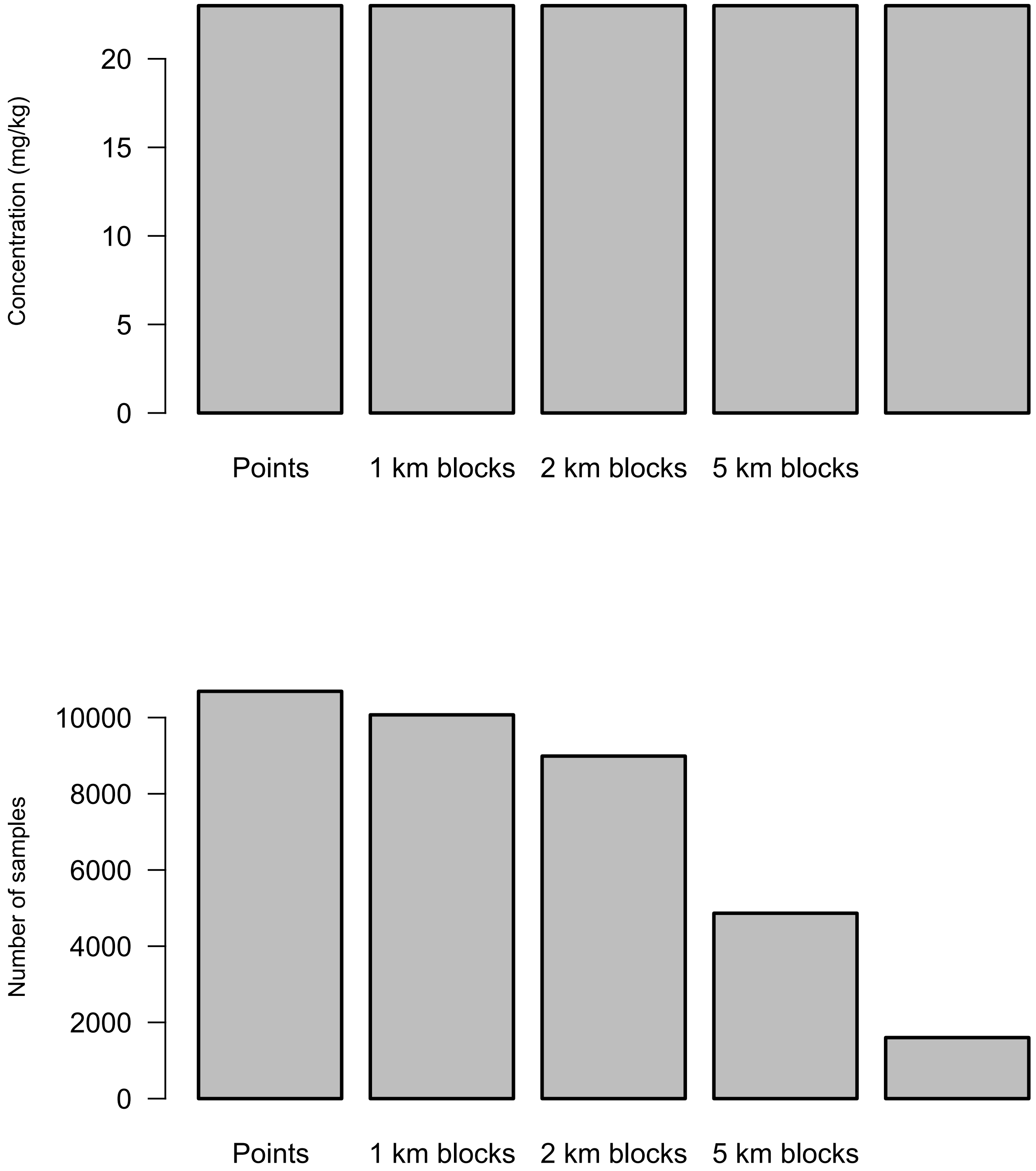


Figure 49. Variation in Arsenic Concentration and Number of Samples by Size of Block Used for Averaging

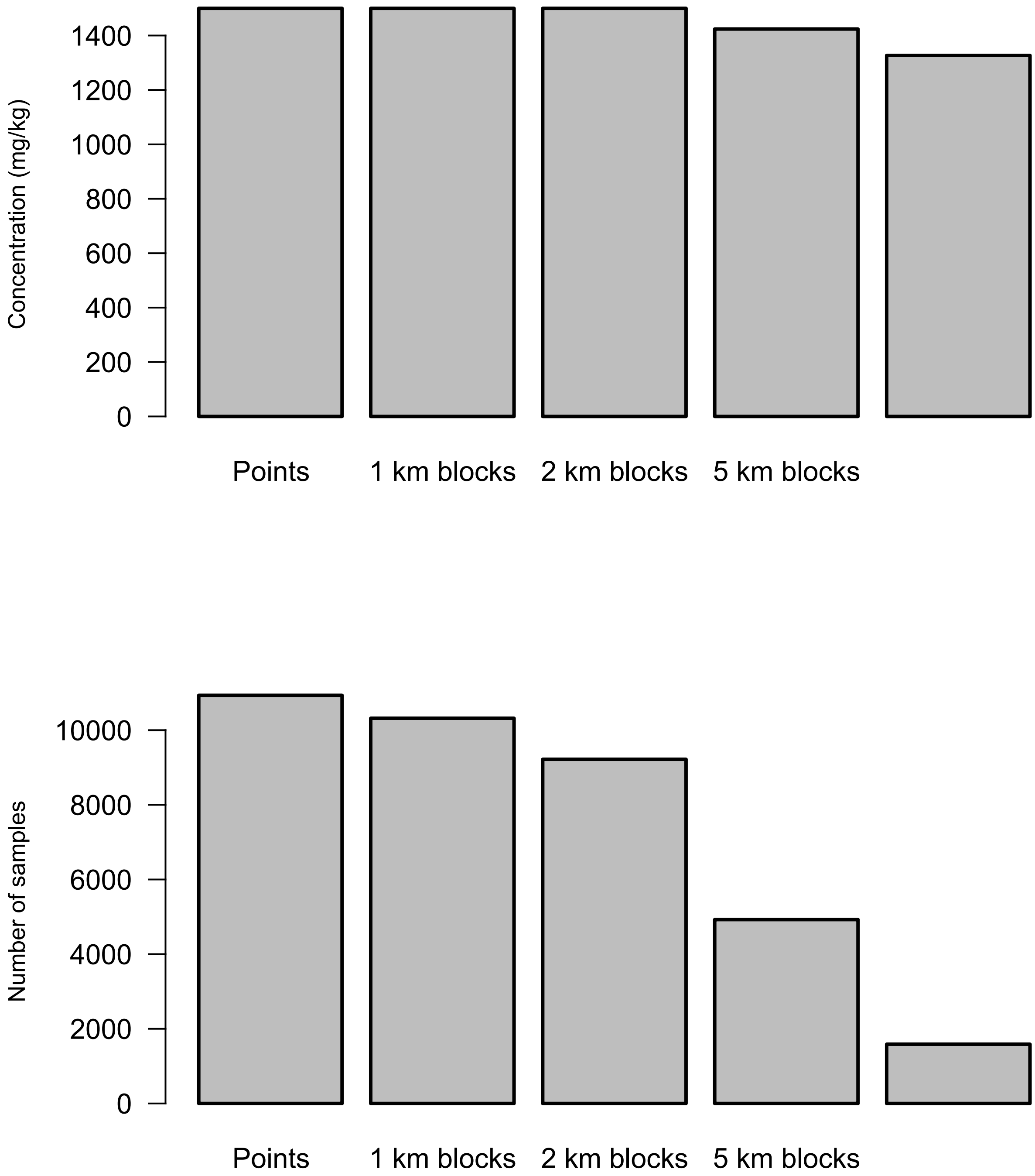


Figure 50. Variation in Barium Concentration and Number of Samples by Size of Block Used for Averaging

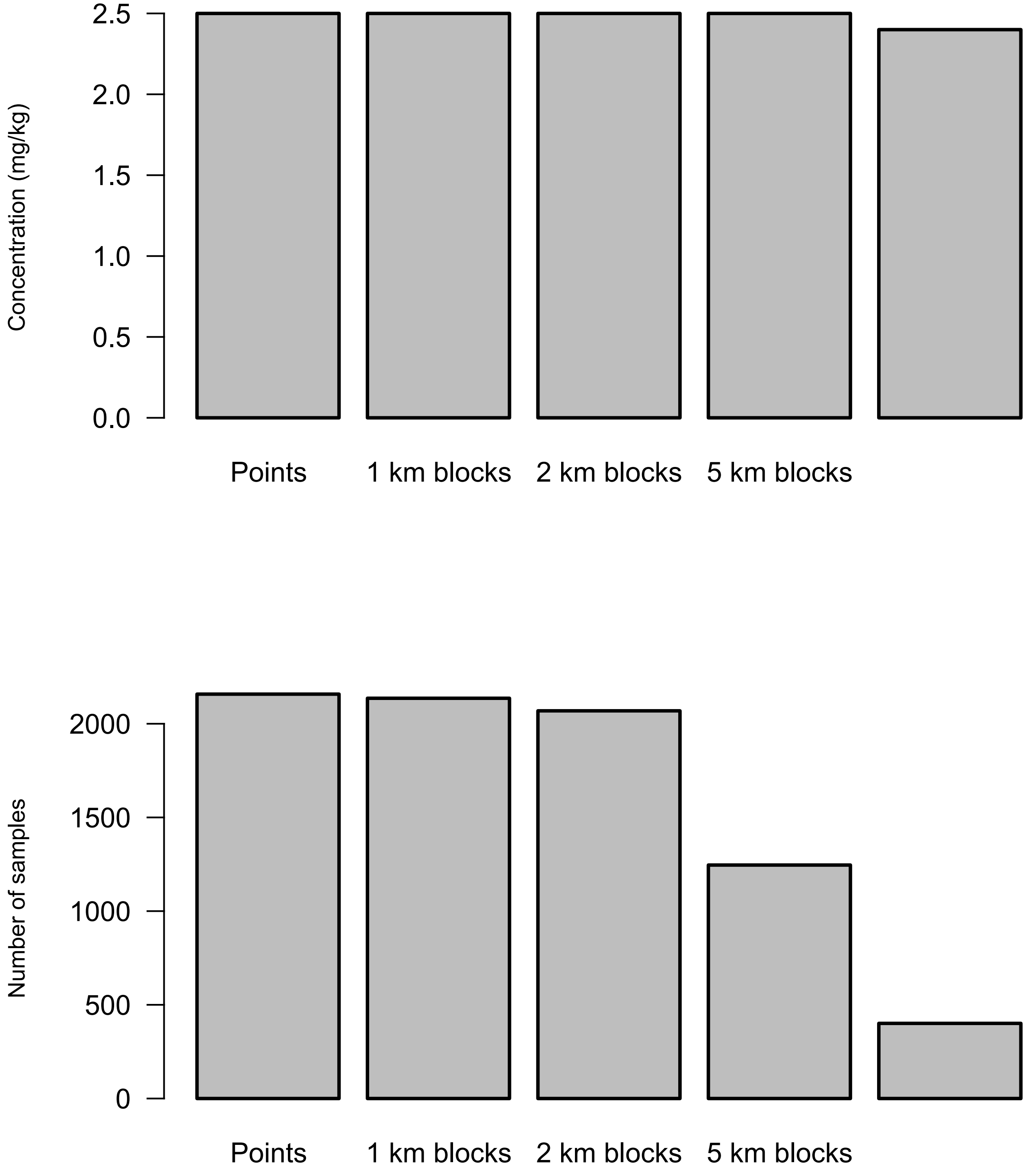


Figure 51. Variation in Beryllium Concentration and Number of Samples by Size of Block Used for Averaging

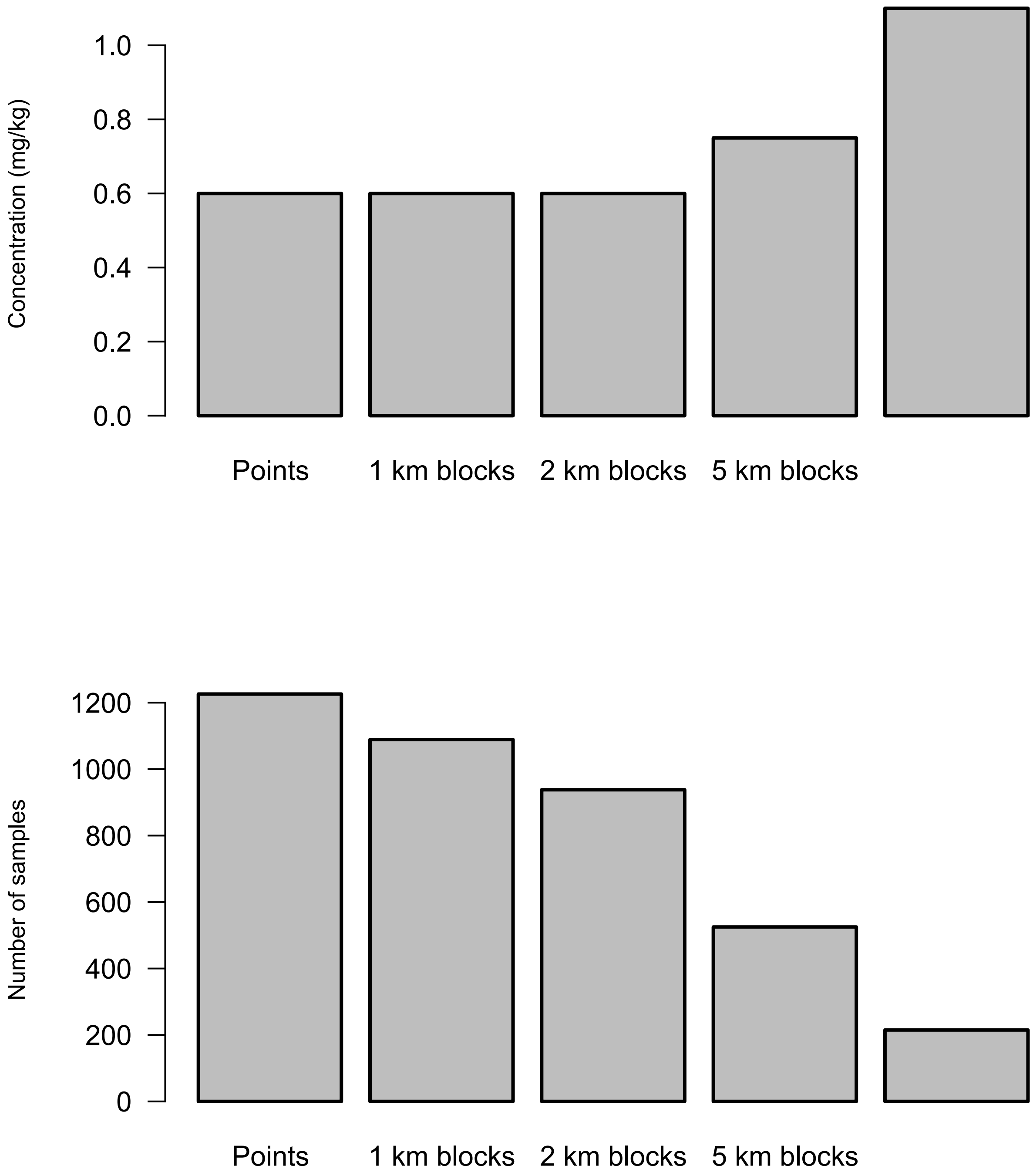


Figure 52. Variation in Bismuth Concentration and Number of Samples by Size of Block Used for Averaging

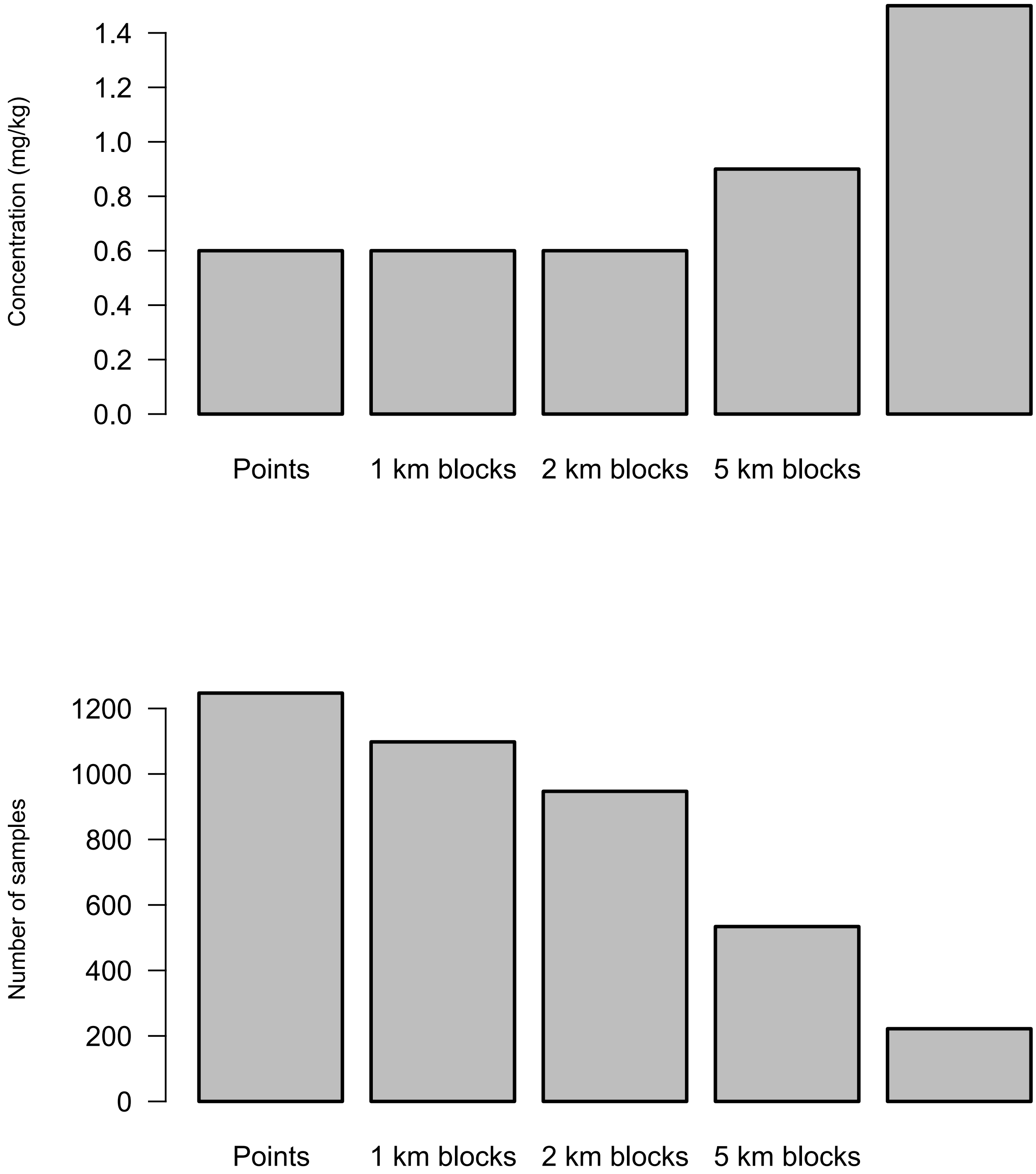


Figure 53. Variation in Cadmium Concentration and Number of Samples by Size of Block Used for Averaging

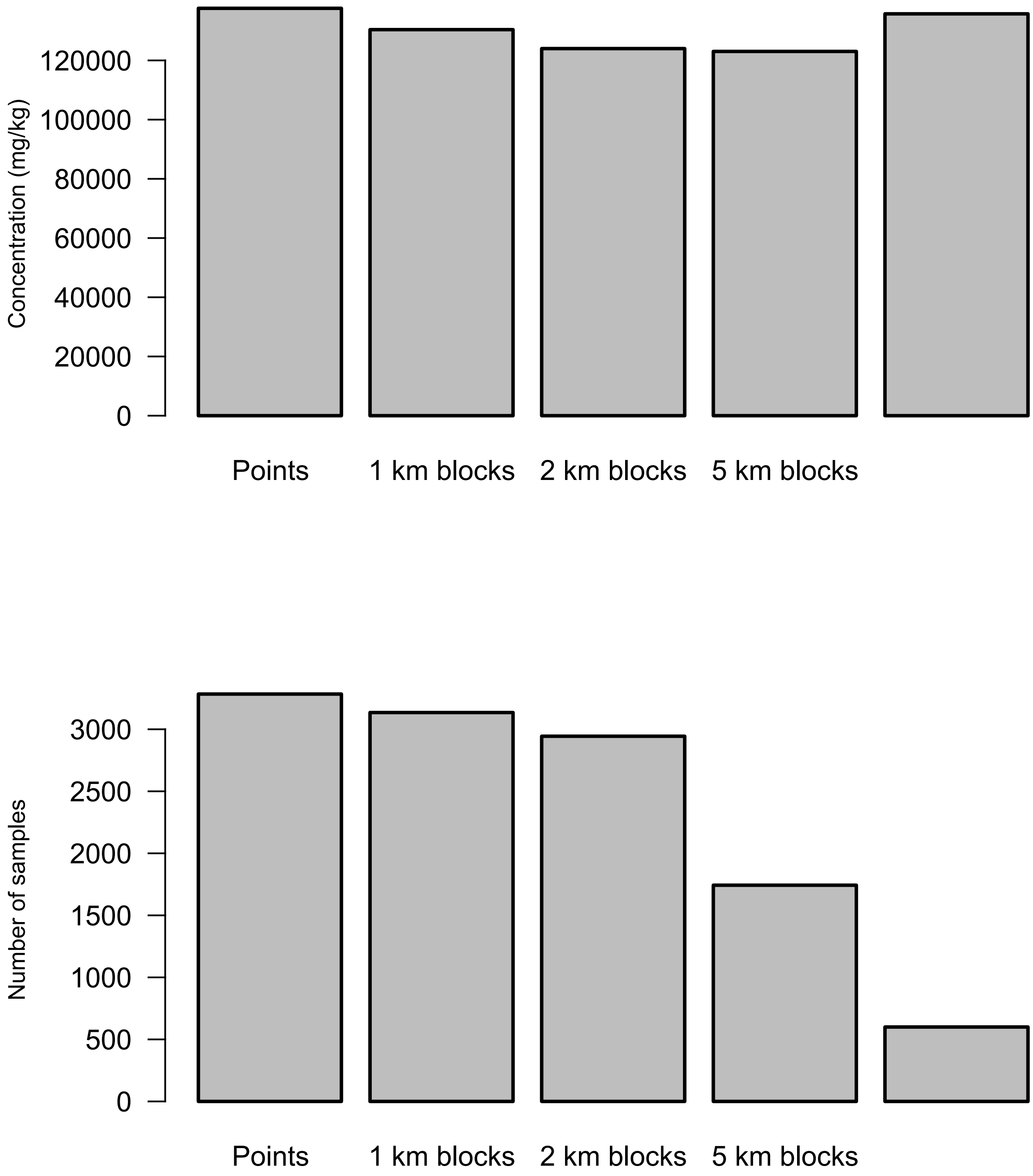


Figure 54. Variation in Calcium Concentration and Number of Samples by Size of Block Used for Averaging

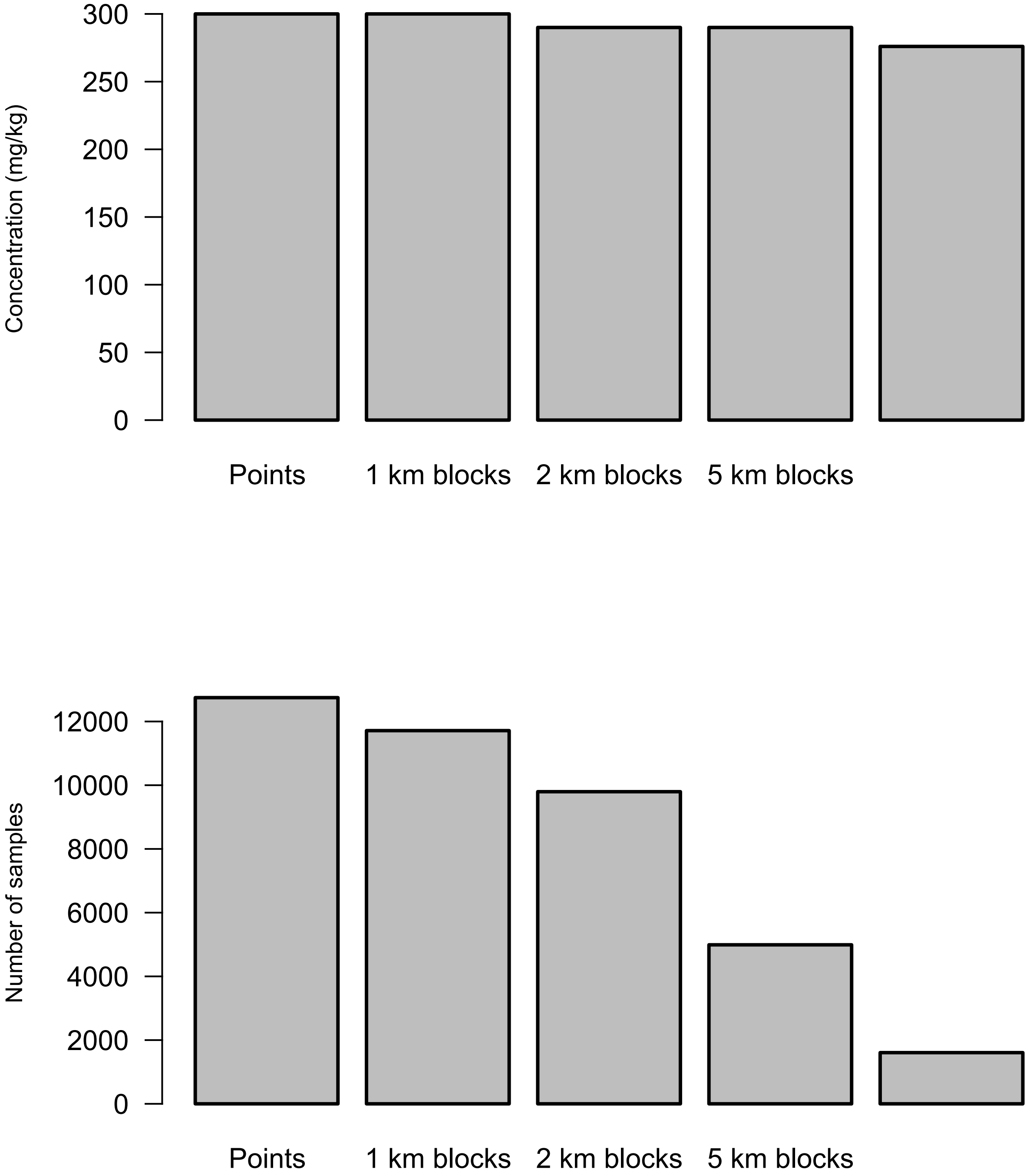


Figure 55. Variation in Cerium Concentration and Number of Samples
by Size of Block Used for Averaging

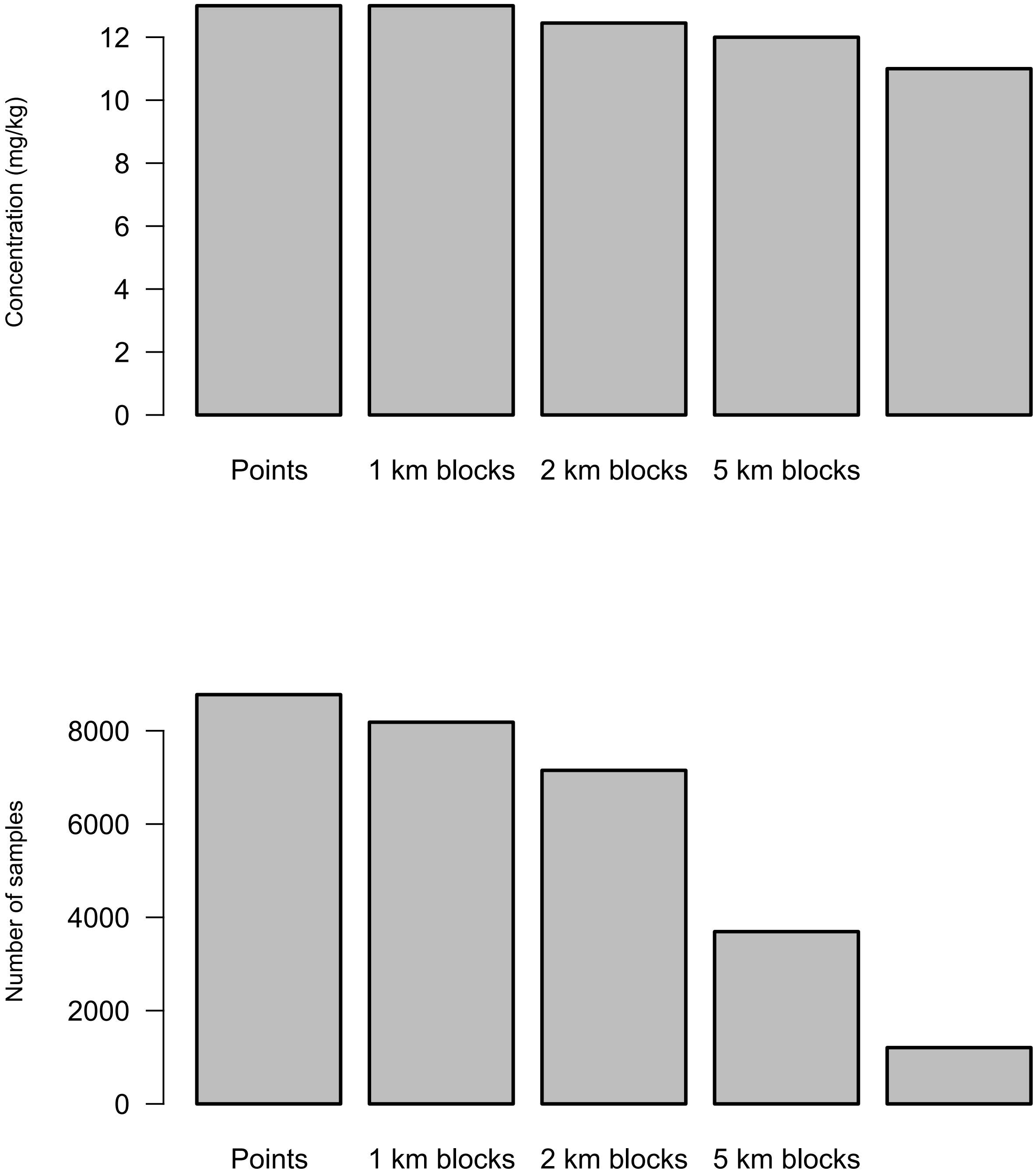


Figure 56. Variation in Cesium Concentration and Number of Samples
by Size of Block Used for Averaging

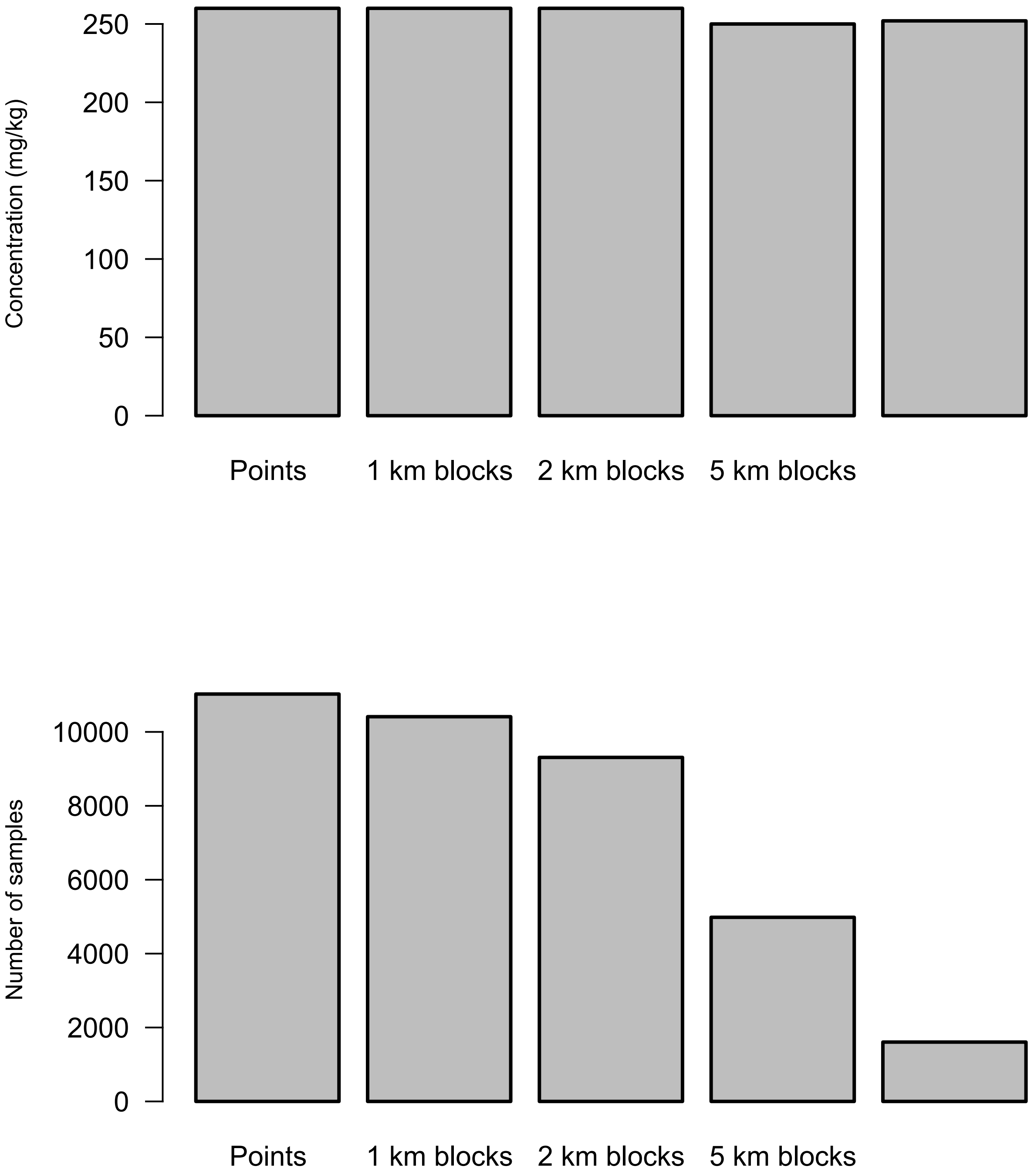


Figure 57. Variation in Chromium Concentration and Number of Samples by Size of Block Used for Averaging

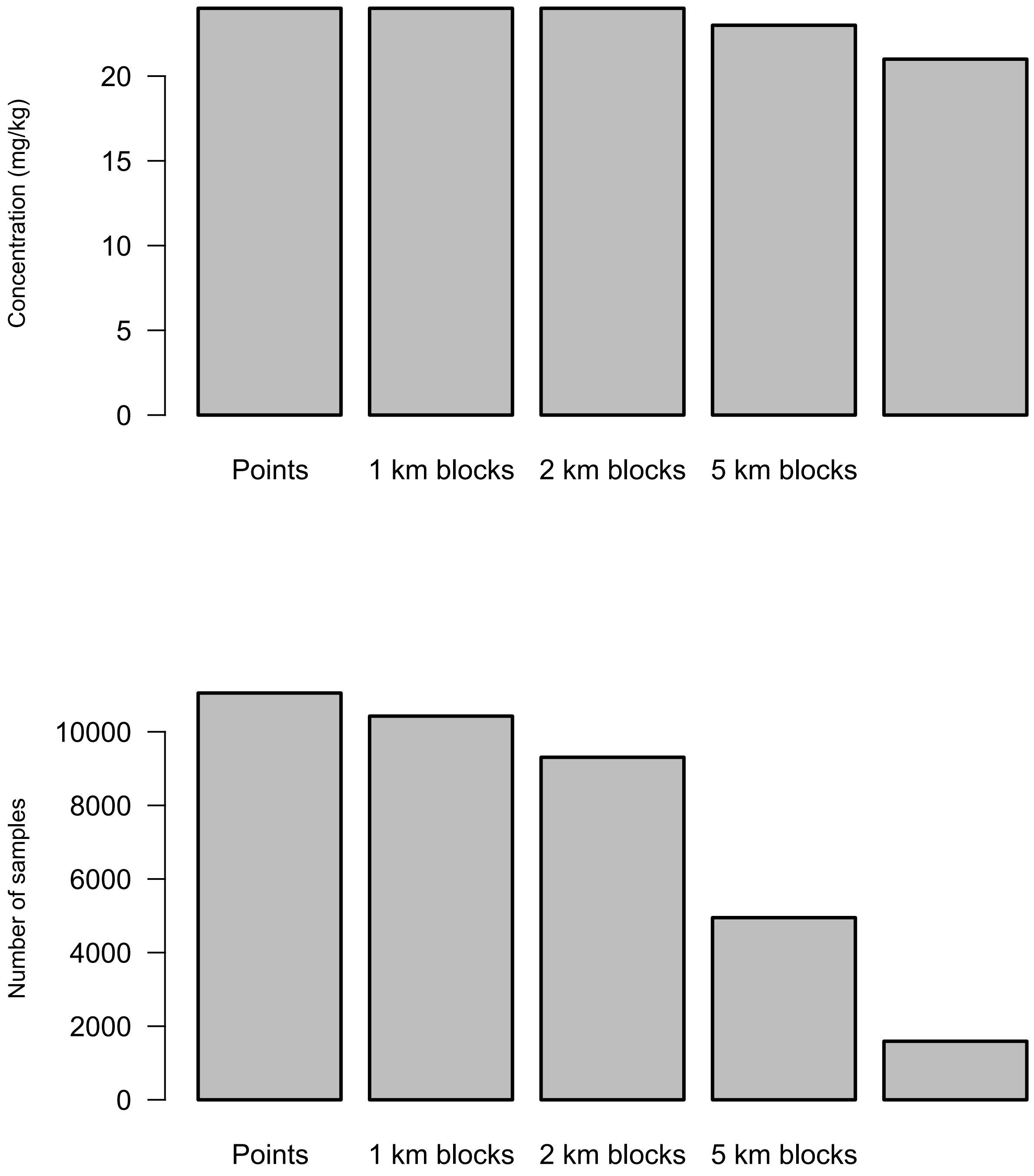
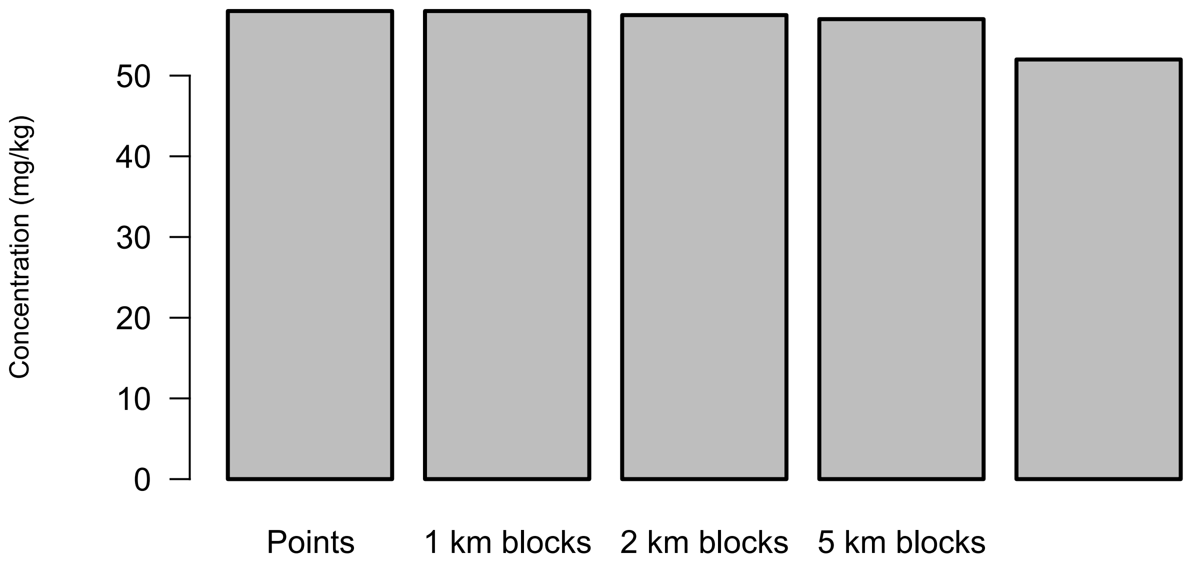


Figure 58. Variation in Cobalt Concentration and Number of Samples
by Size of Block Used for Averaging



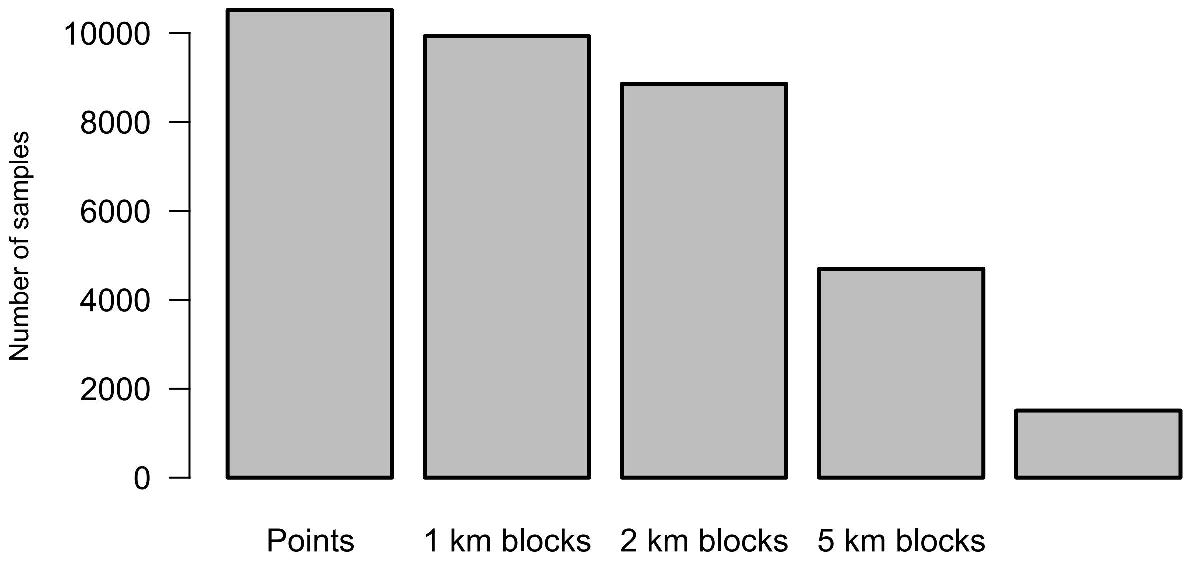


Figure 59. Variation in Copper Concentration and Number of Samples by Size of Block Used for Averaging

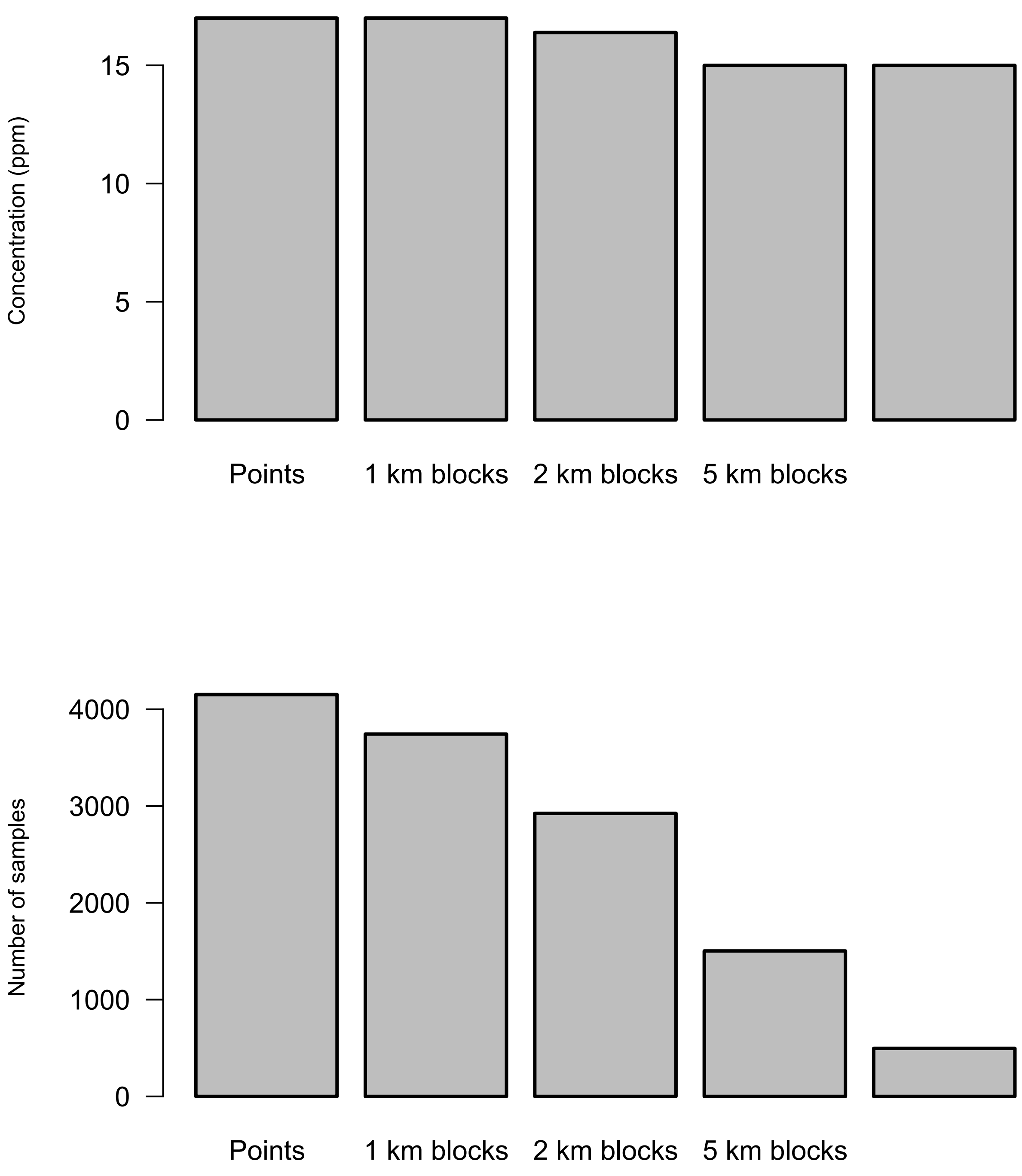


Figure 60. Variation in Dysprosium Concentration and Number of Samples by Size of Block Used for Averaging

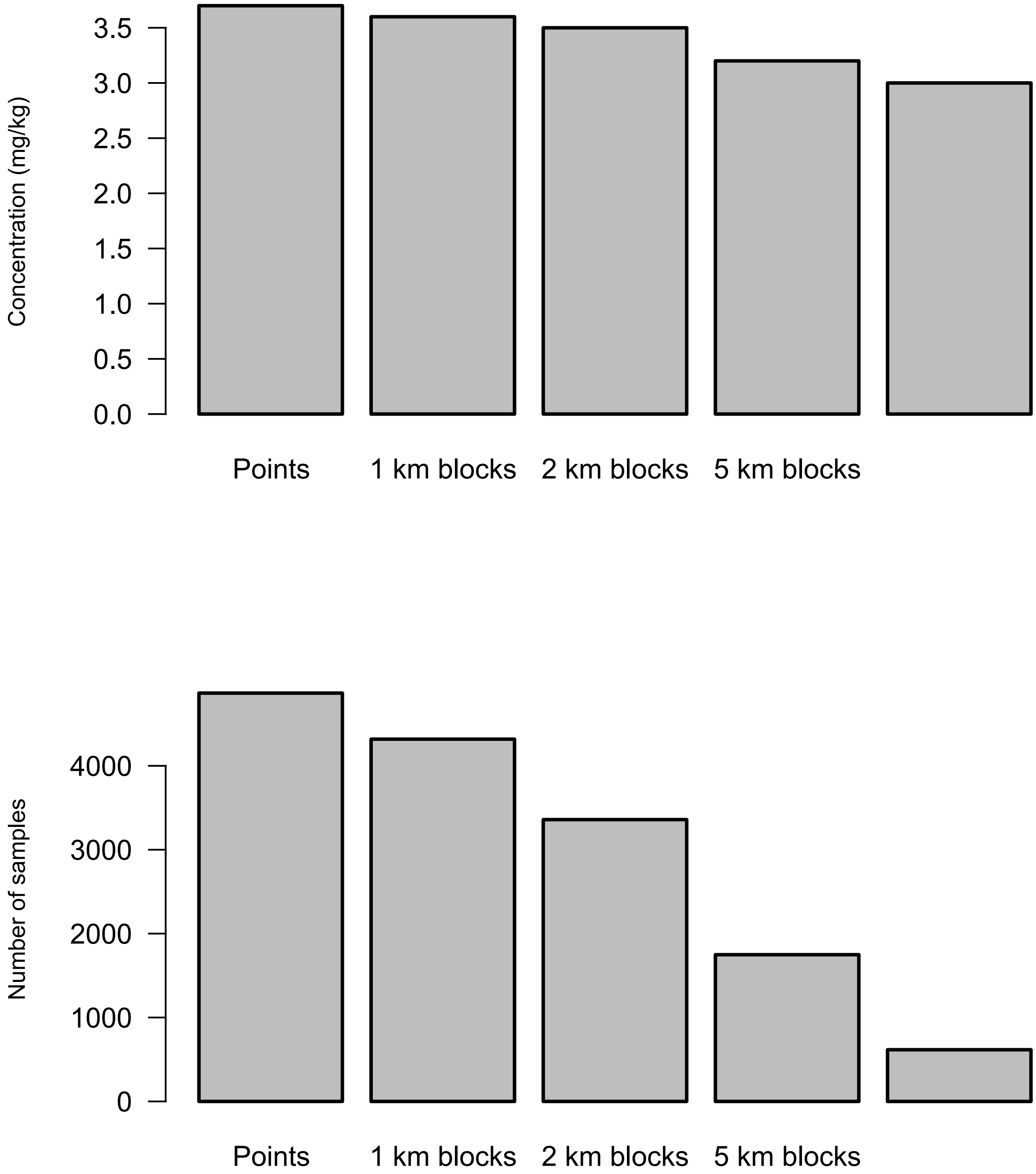


Figure 61. Variation in Europium Concentration and Number of Samples by Size of Block Used for Averaging

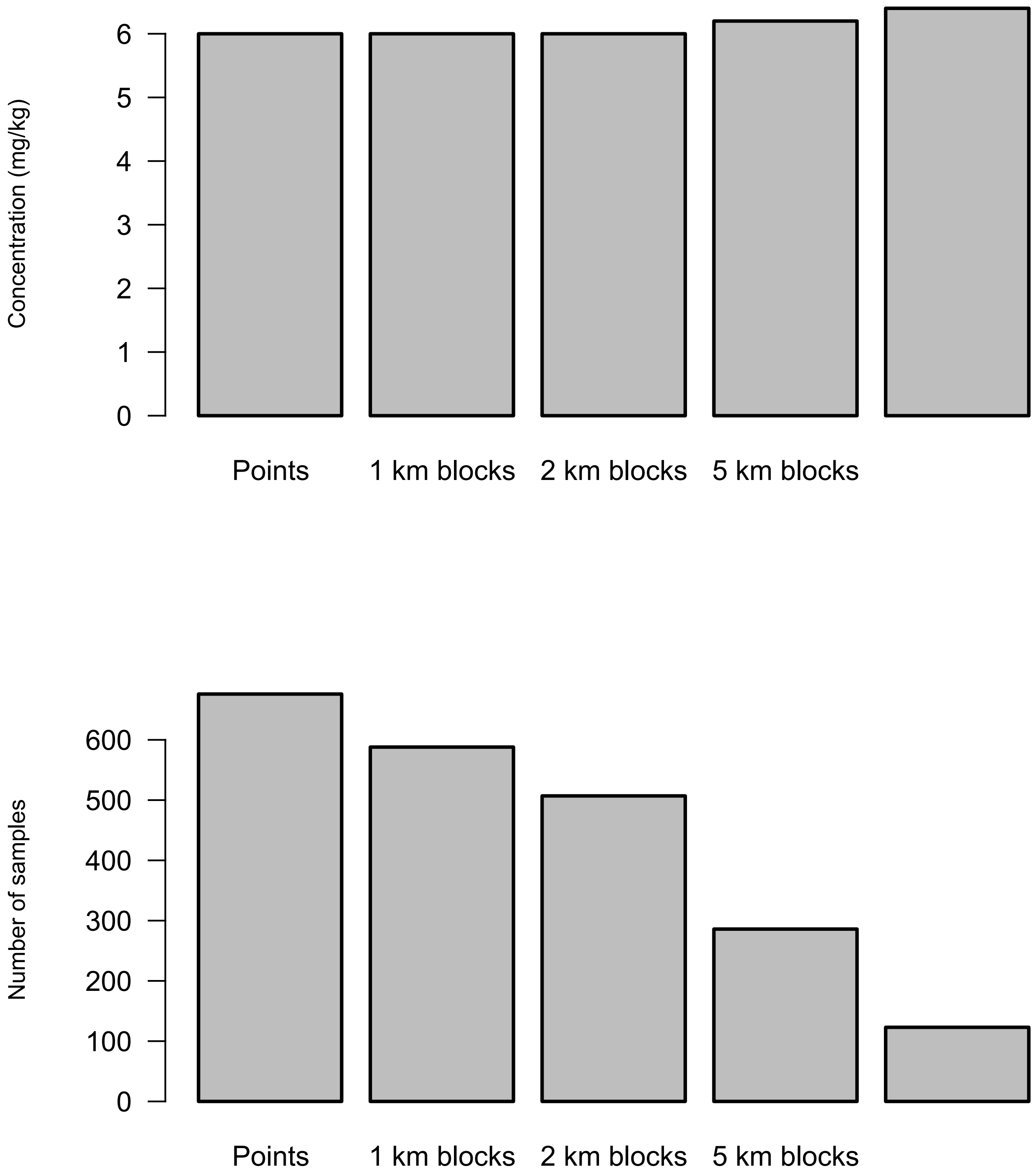


Figure 62. Variation in Gallium Concentration and Number of Samples by Size of Block Used for Averaging

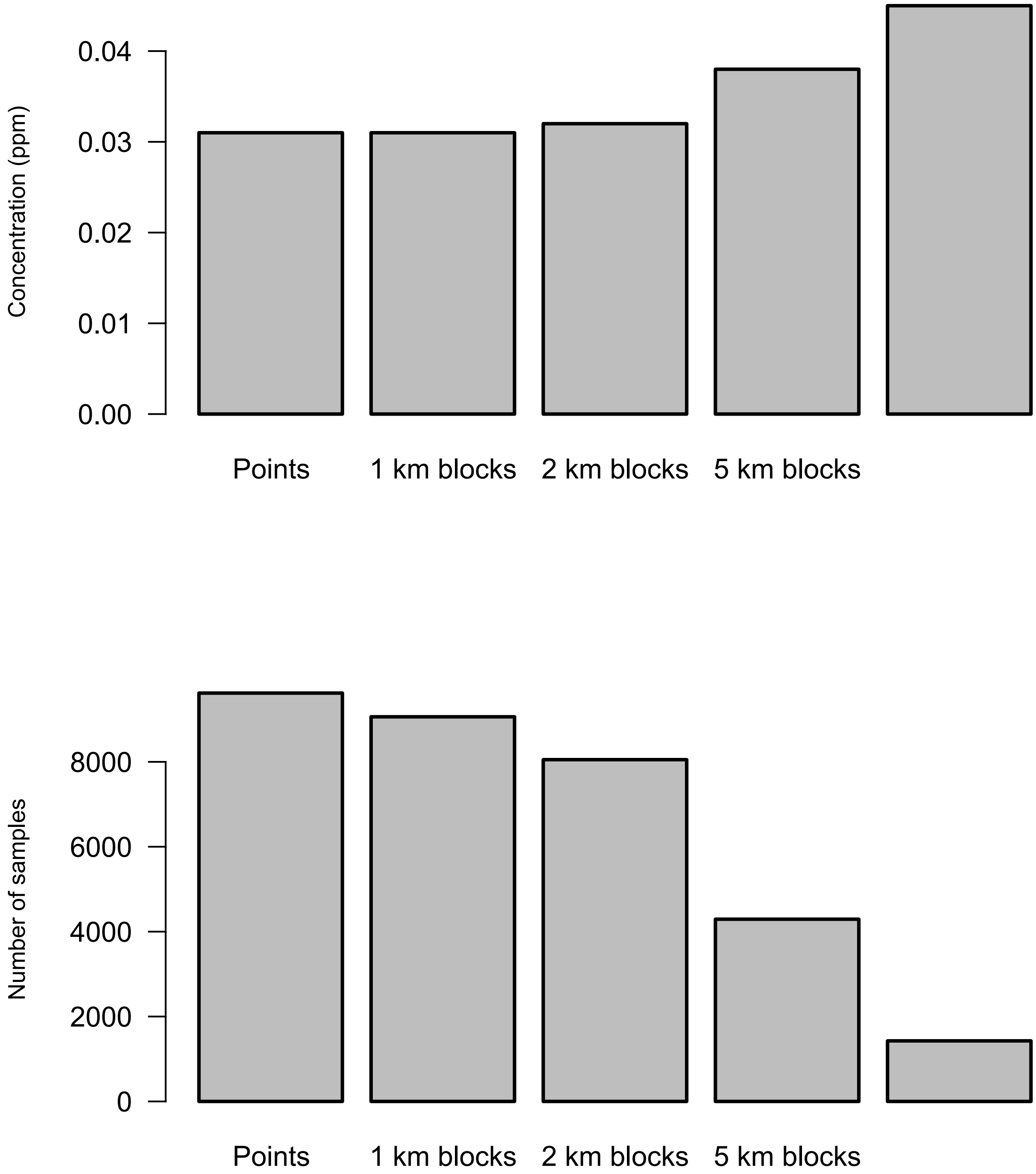


Figure 63. Variation in Gold Concentration and Number of Samples
by Size of Block Used for Averaging

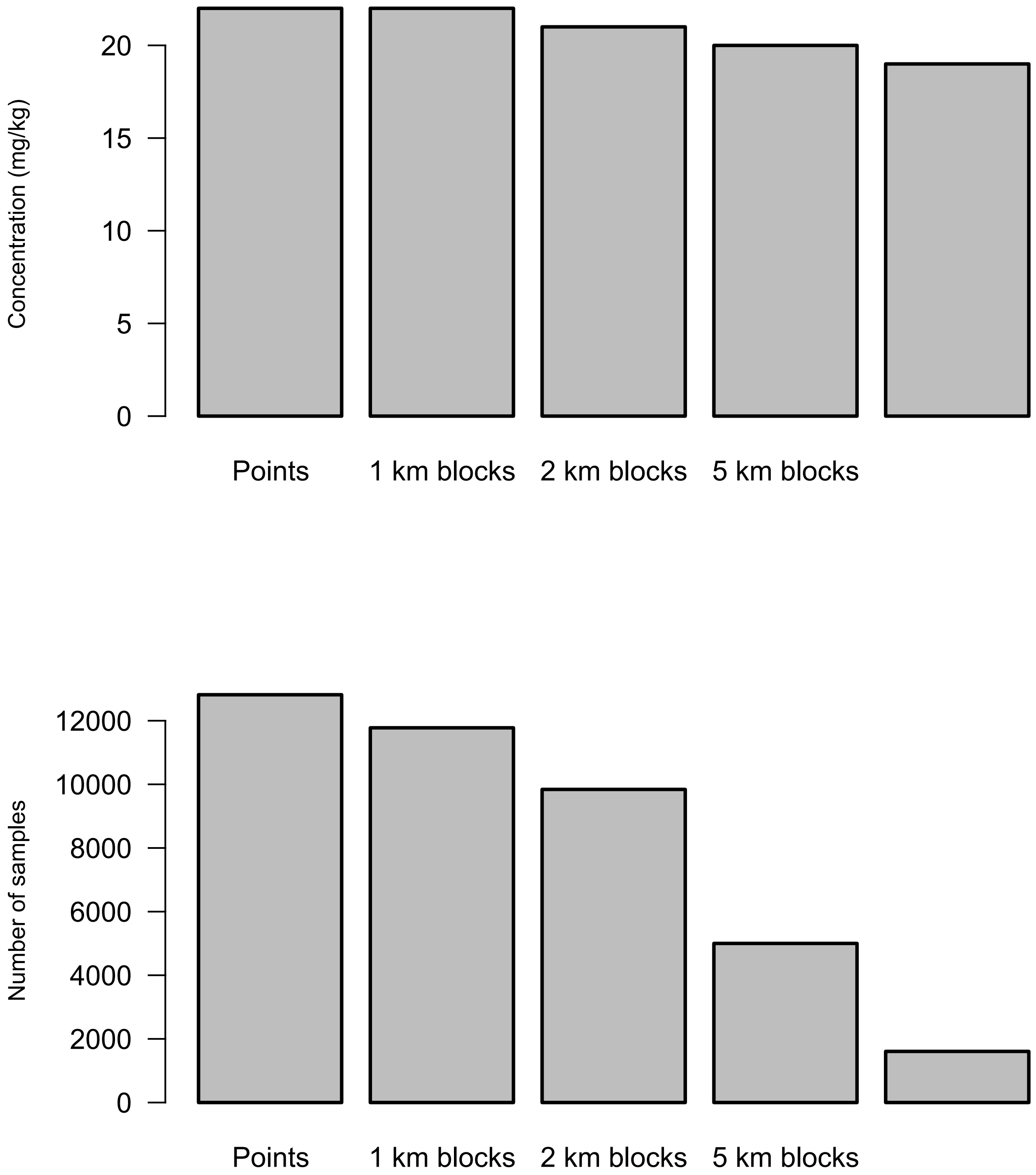


Figure 64. Variation in Hafnium Concentration and Number of Samples by Size of Block Used for Averaging

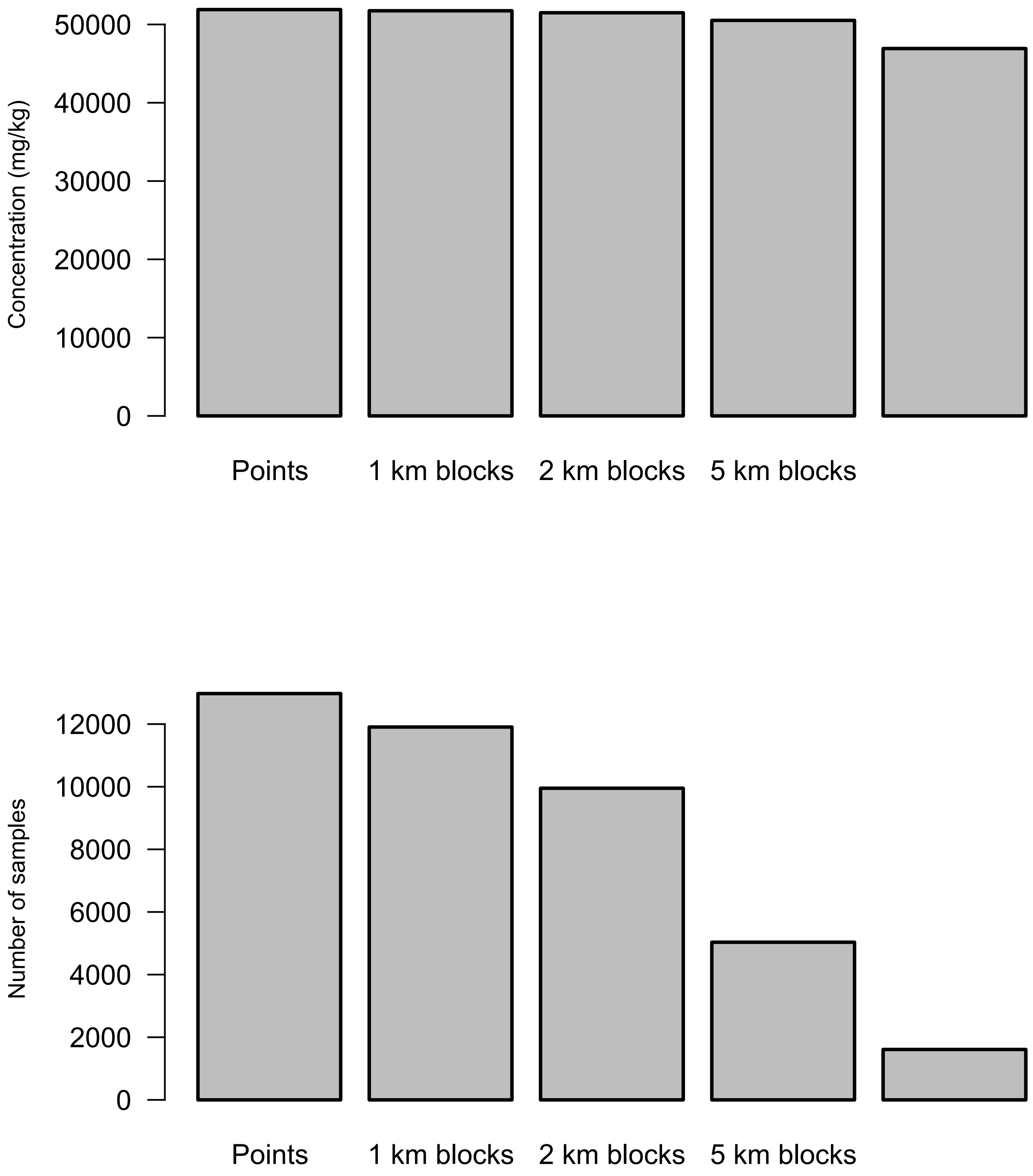


Figure 65. Variation in Iron Concentration and Number of Samples by Size of Block Used for Averaging

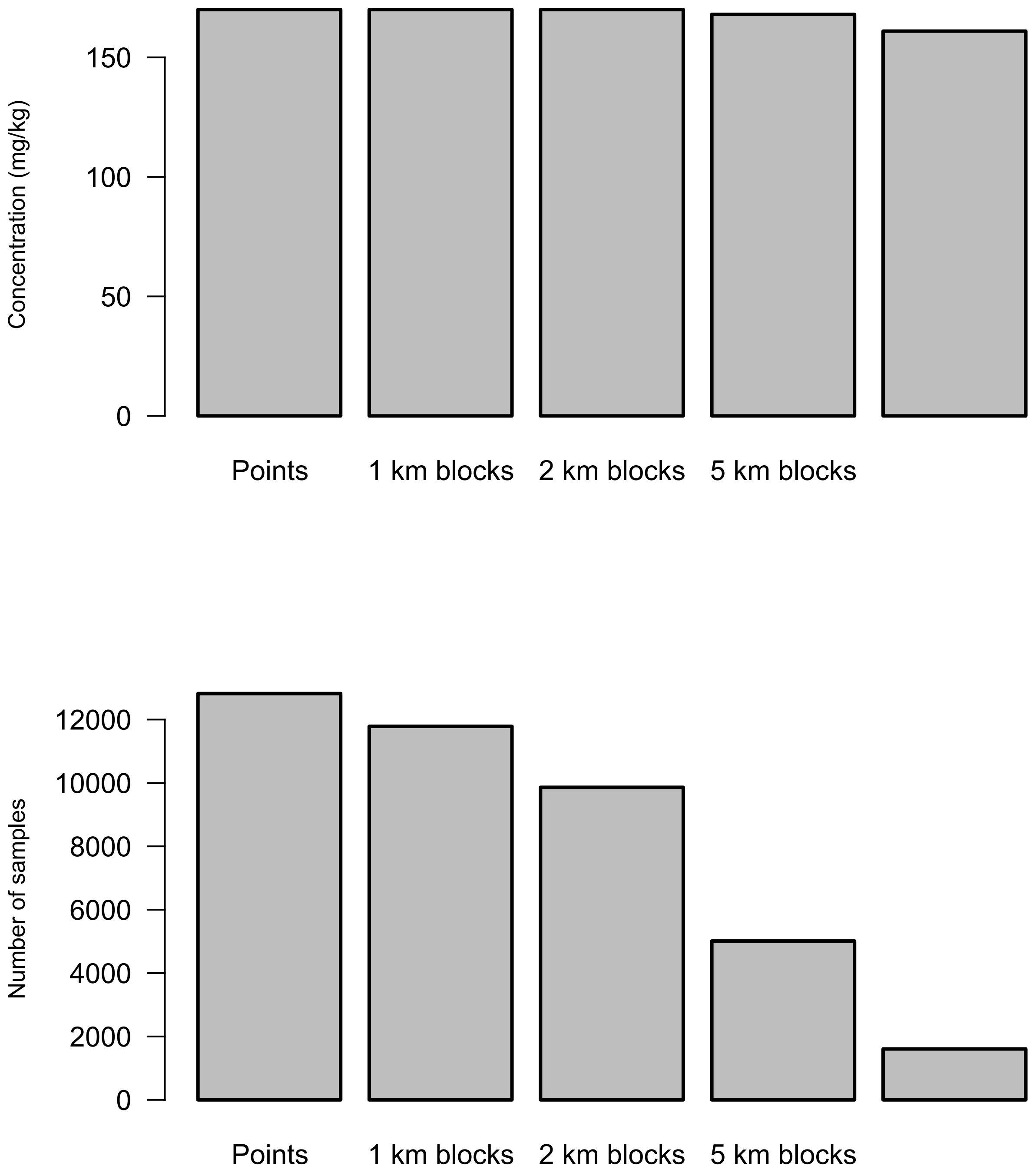
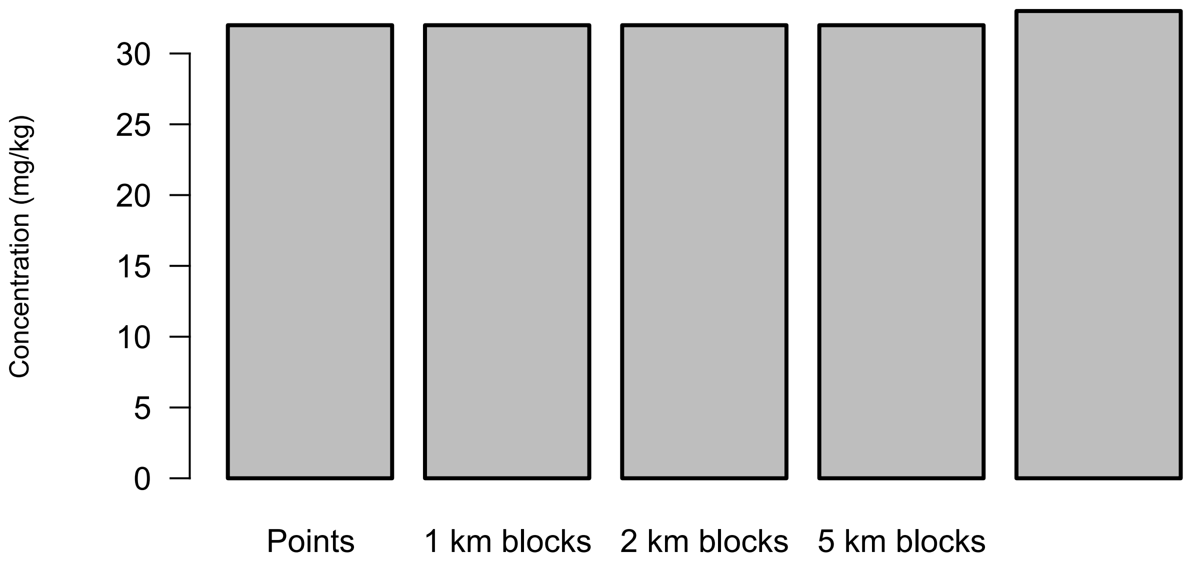


Figure 66. Variation in Lanthanum Concentration and Number of Samples by Size of Block Used for Averaging



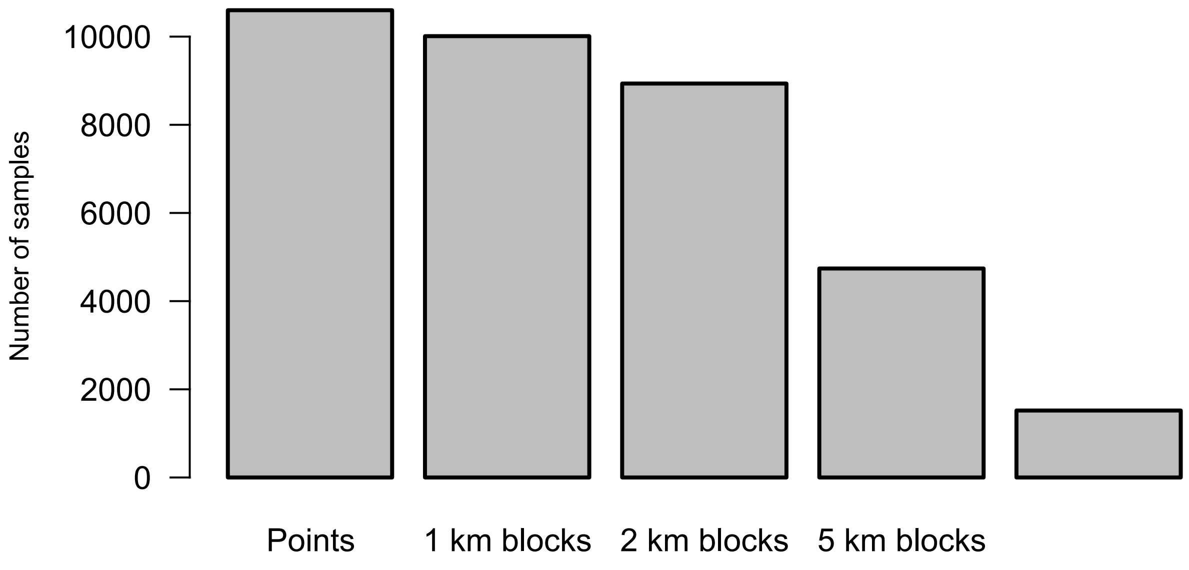


Figure 67. Variation in Lead Concentration and Number of Samples by Size of Block Used for Averaging

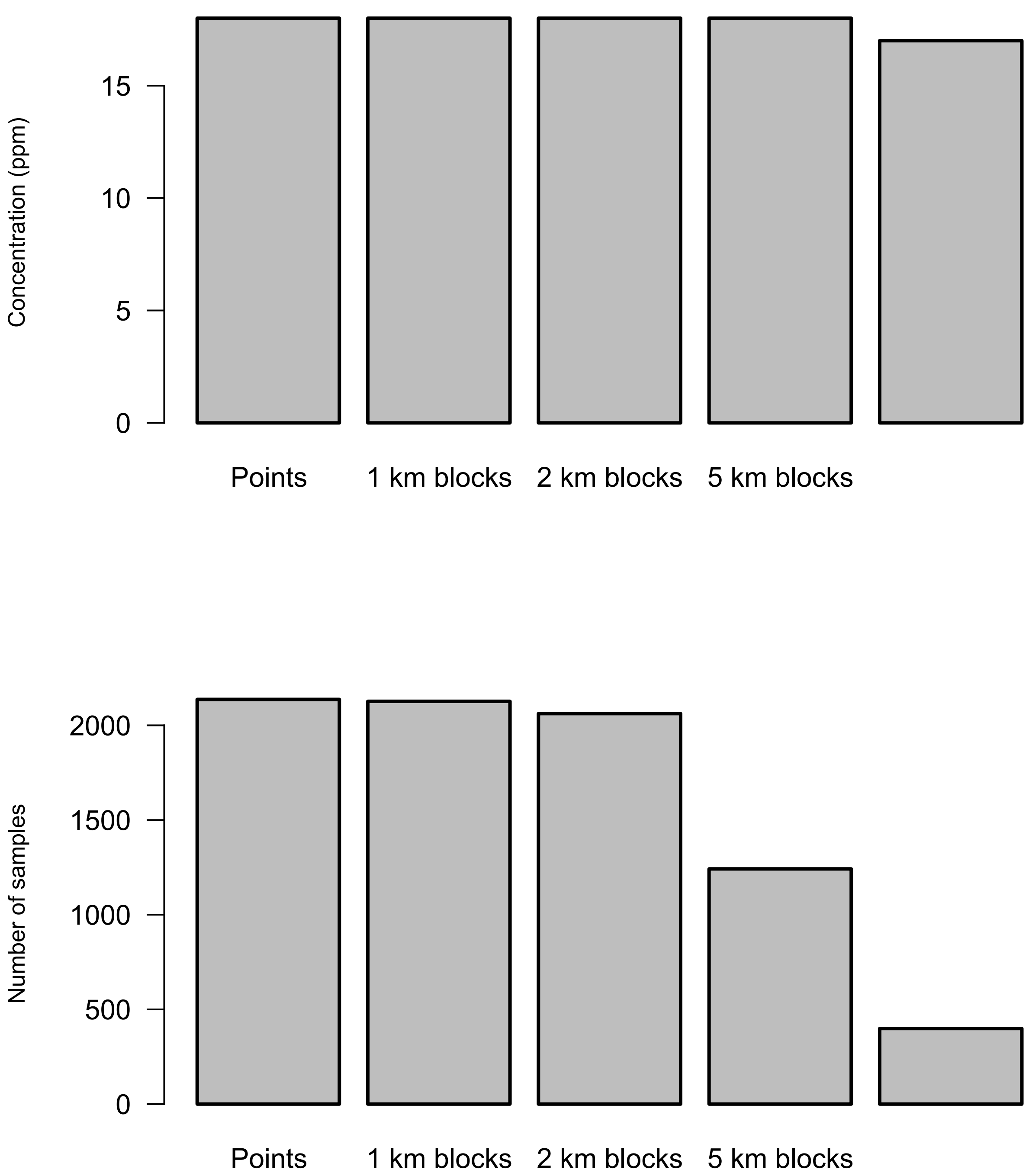


Figure 68. Variation in Lithium Concentration and Number of Samples by Size of Block Used for Averaging

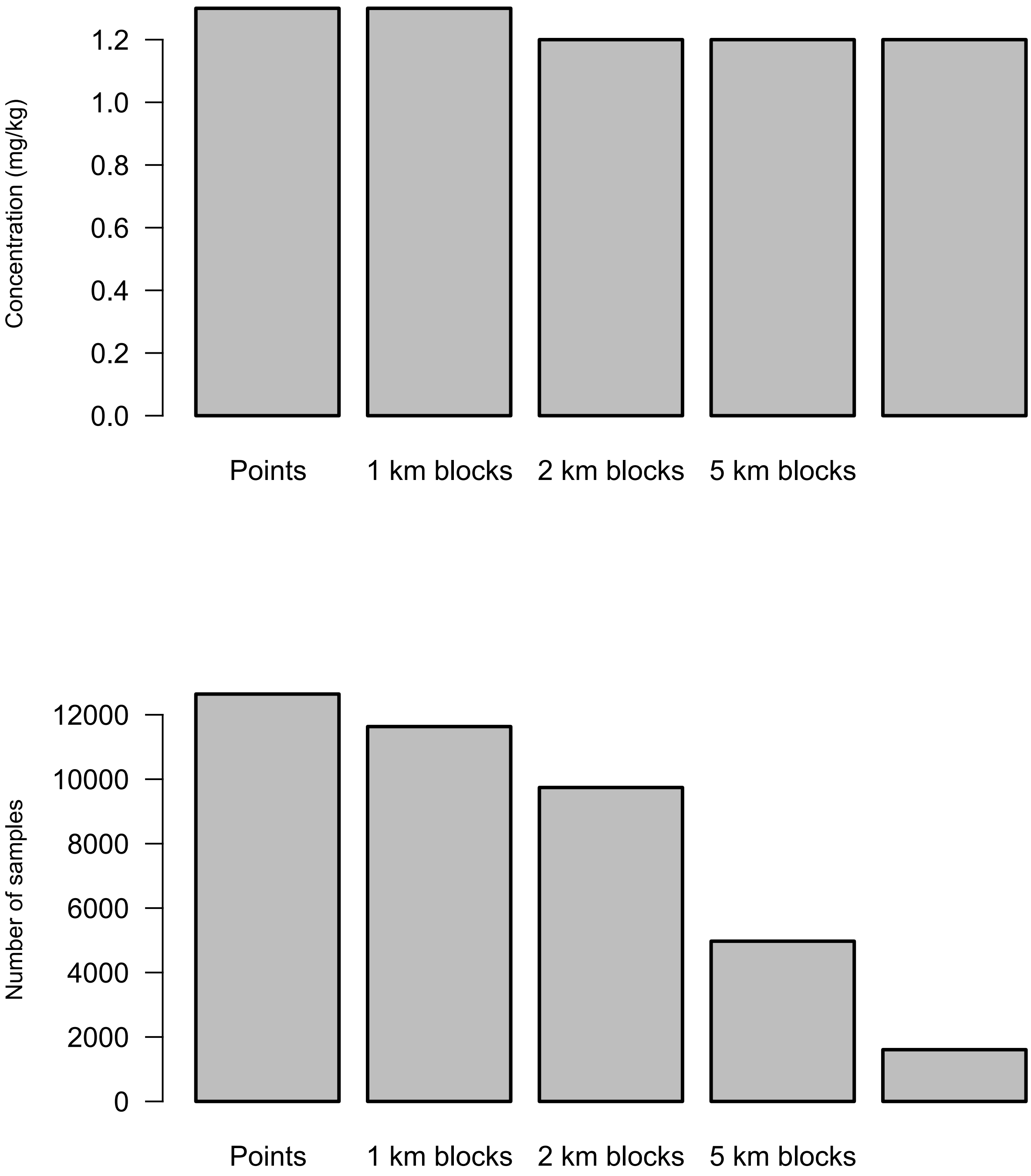
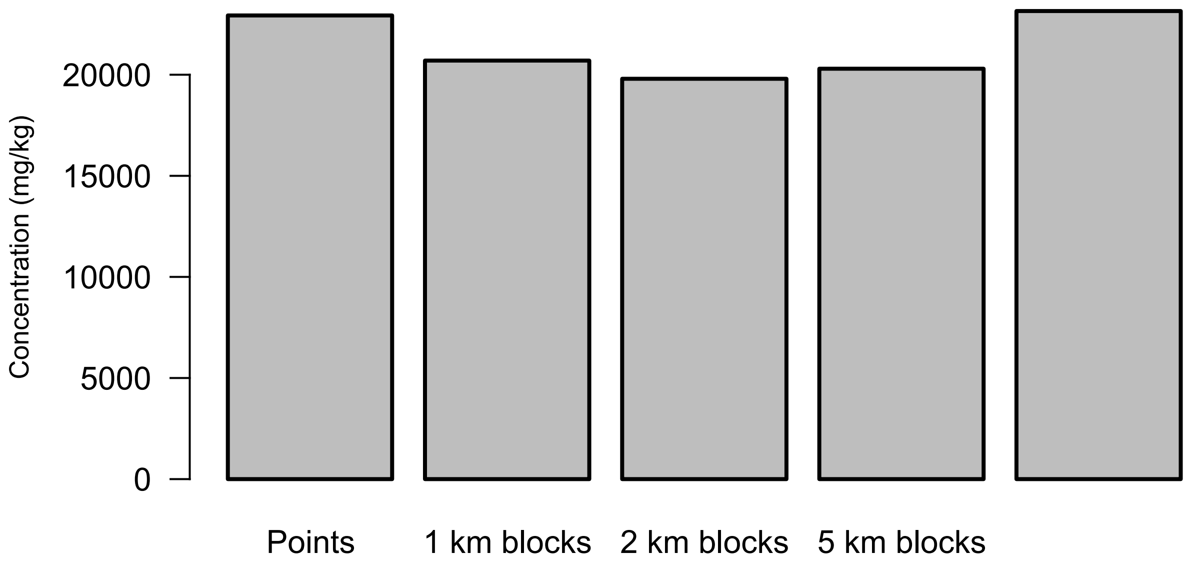


Figure 69. Variation in Lutetium Concentration and Number of Samples by Size of Block Used for Averaging



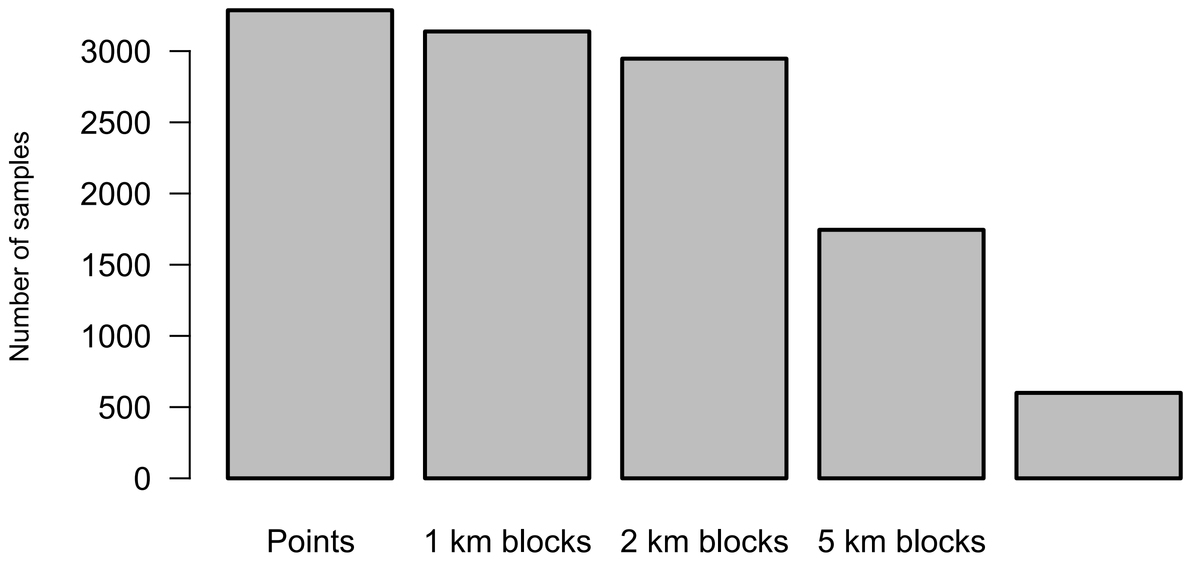


Figure 70. Variation in Magnesium Concentration and Number of Samples by Size of Block Used for Averaging

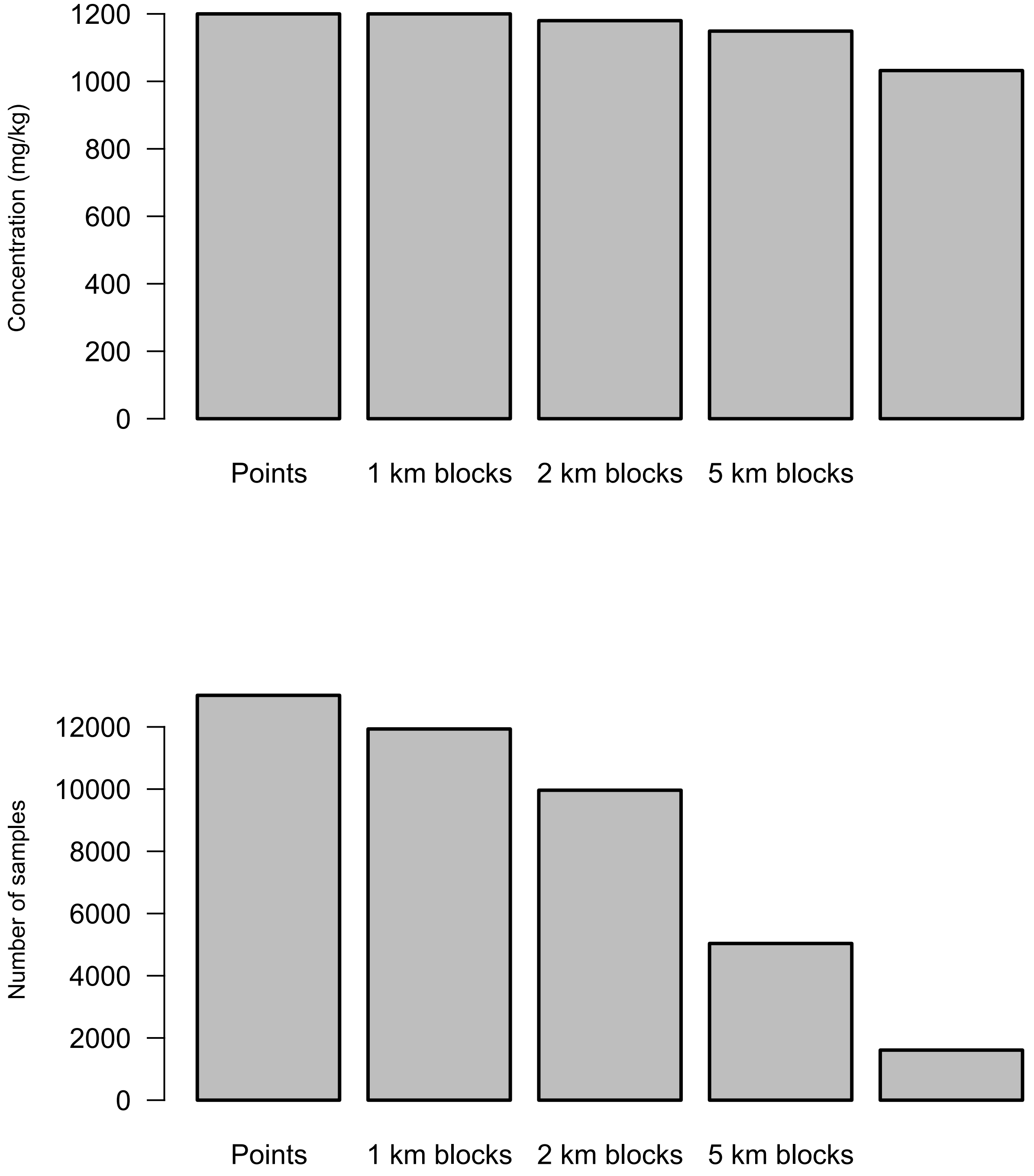


Figure 71. Variation in Manganese Concentration and Number of Samples by Size of Block Used for Averaging

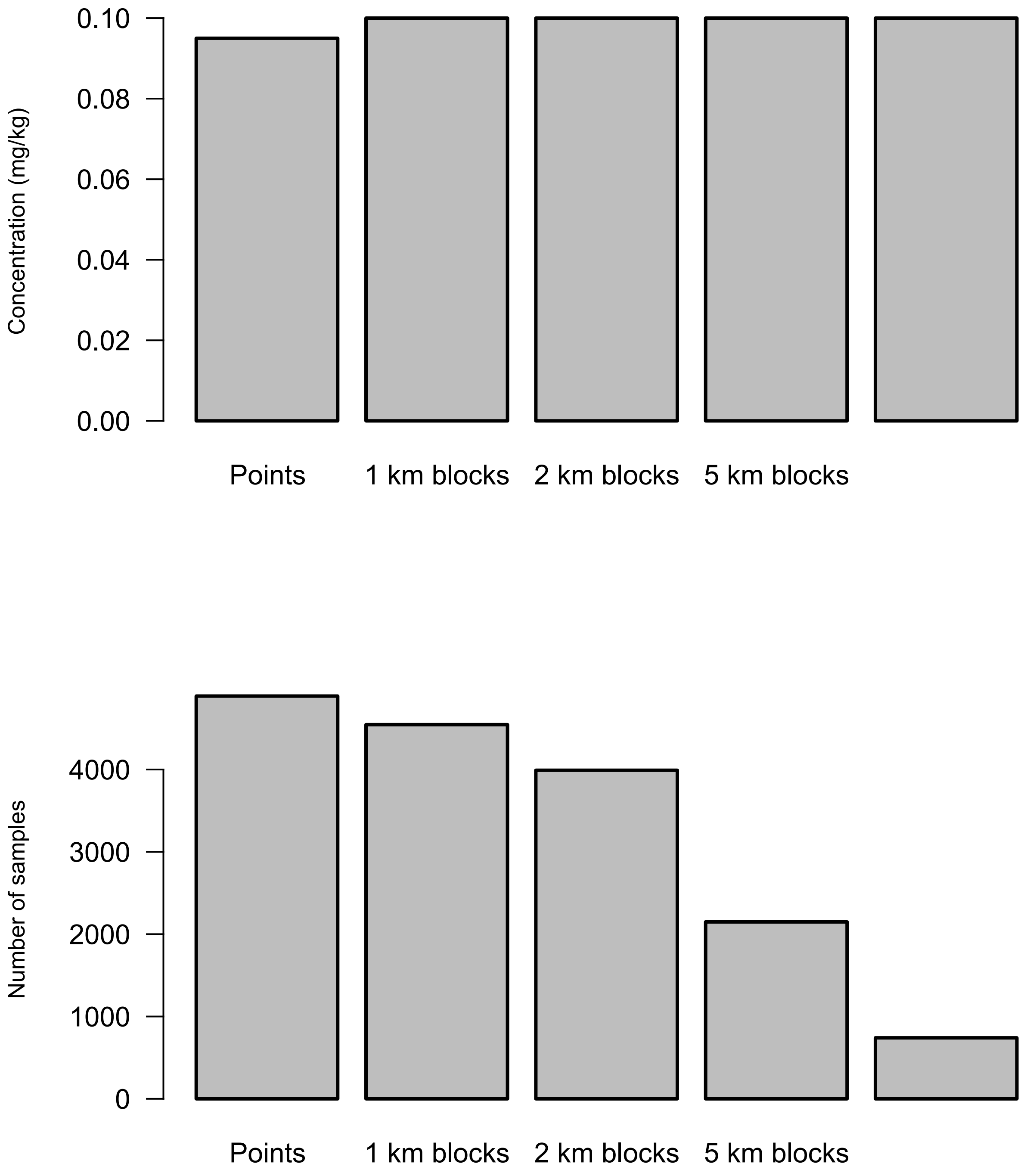


Figure 72. Variation in Mercury Concentration and Number of Samples
by Size of Block Used for Averaging

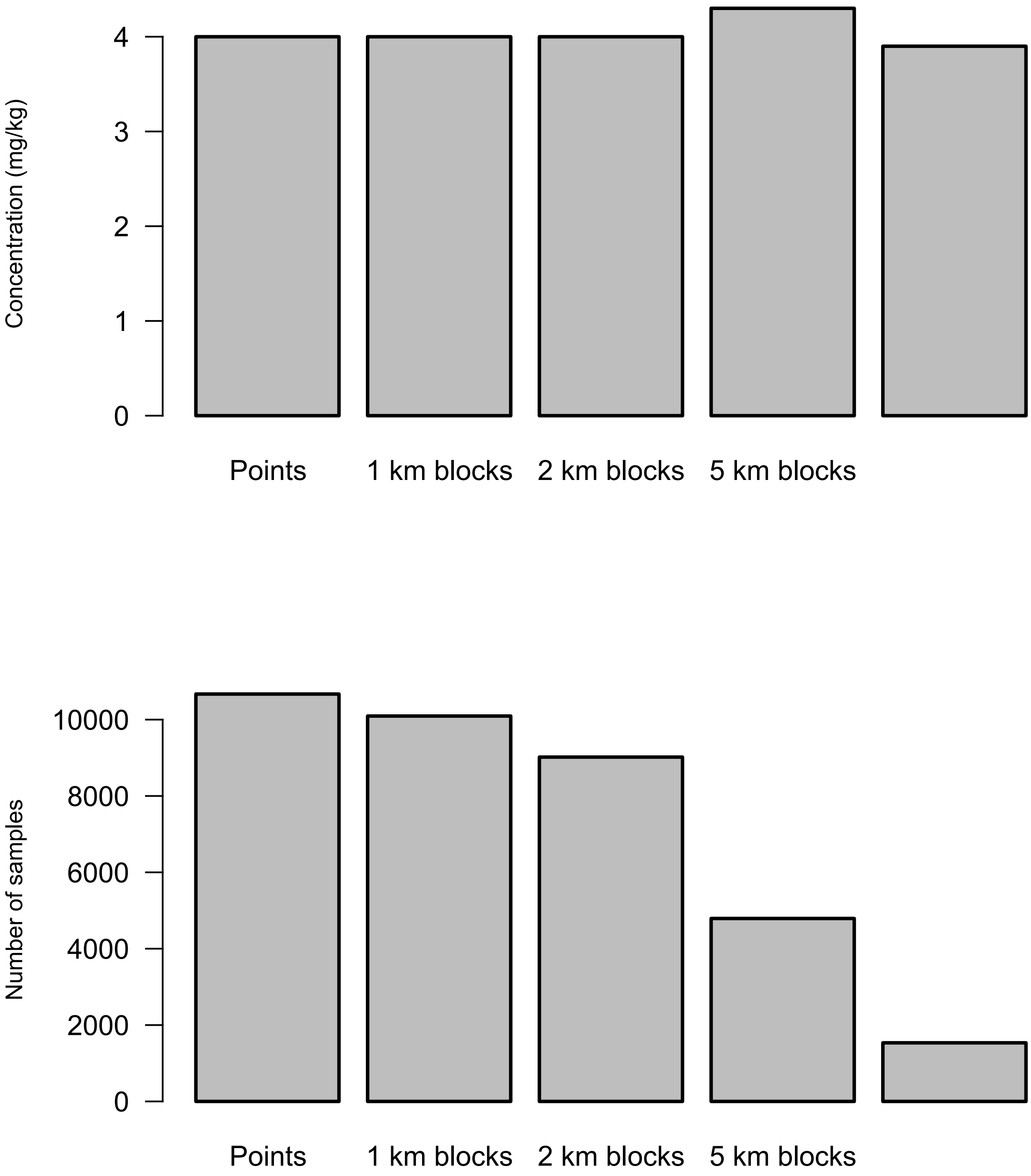


Figure 73. Variation in Molybdenum Concentration and Number of Samples by Size of Block Used for Averaging

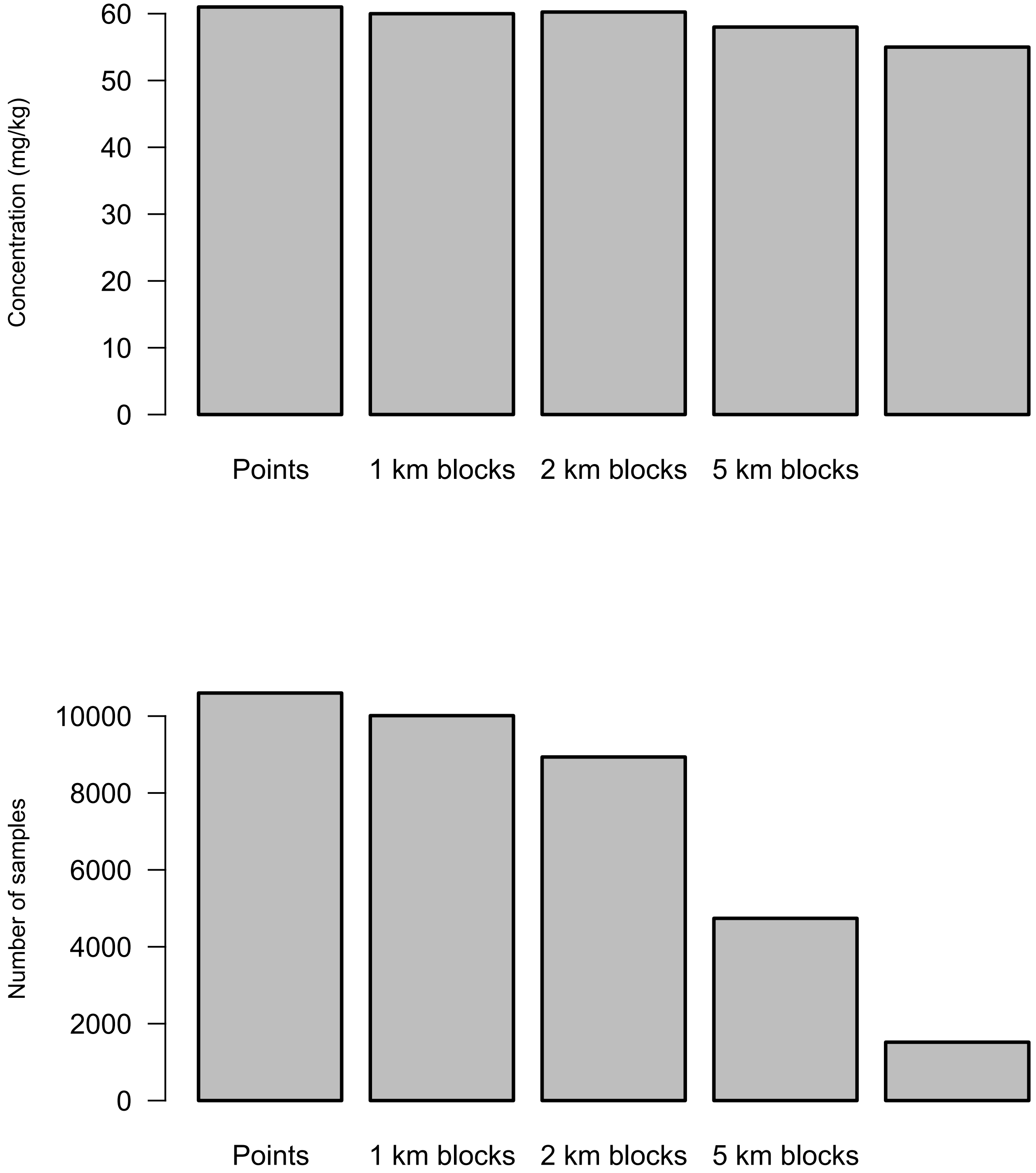


Figure 74. Variation in Nickel Concentration and Number of Samples by Size of Block Used for Averaging

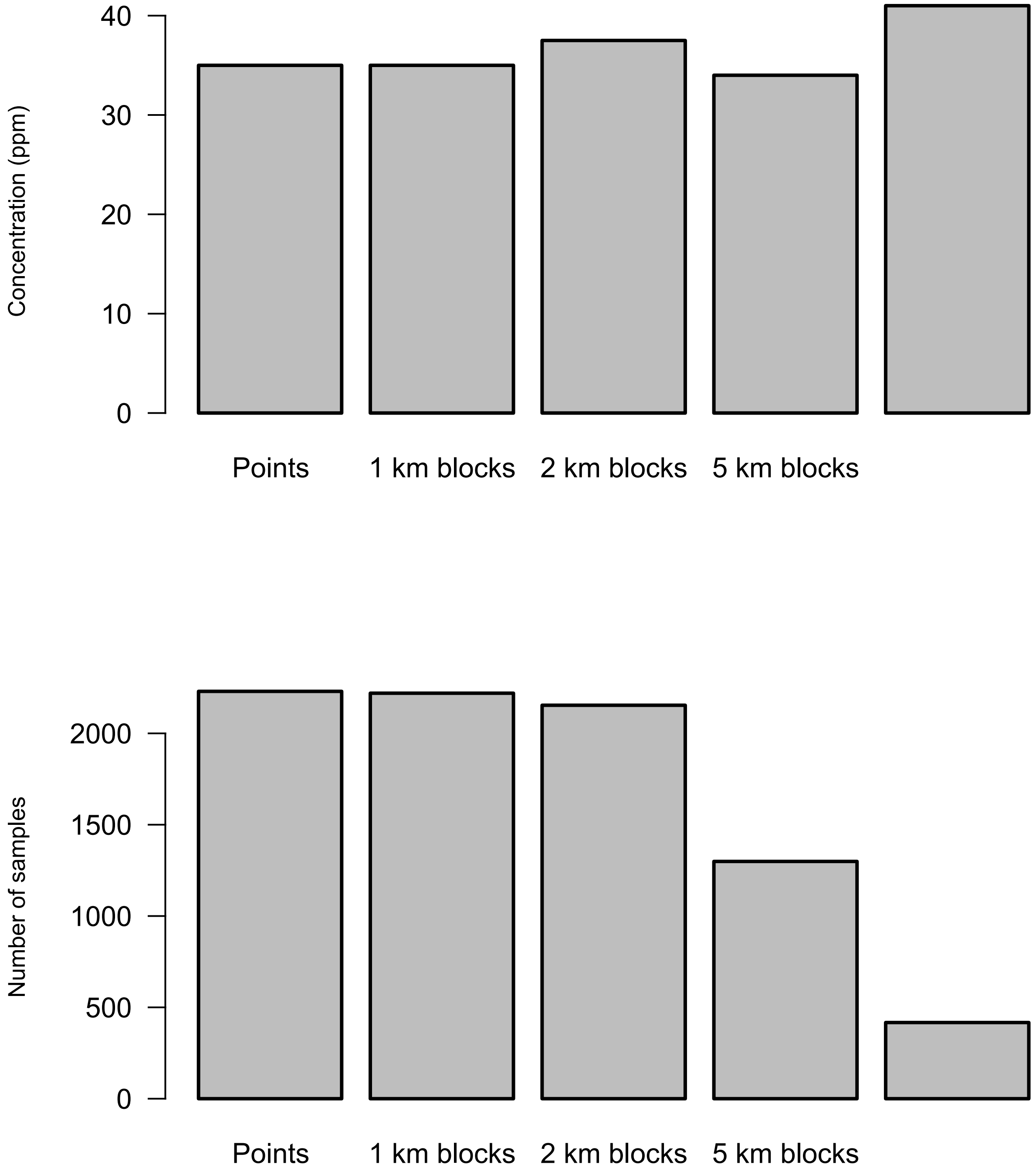


Figure 75. Variation in Niobium Concentration and Number of Samples
by Size of Block Used for Averaging

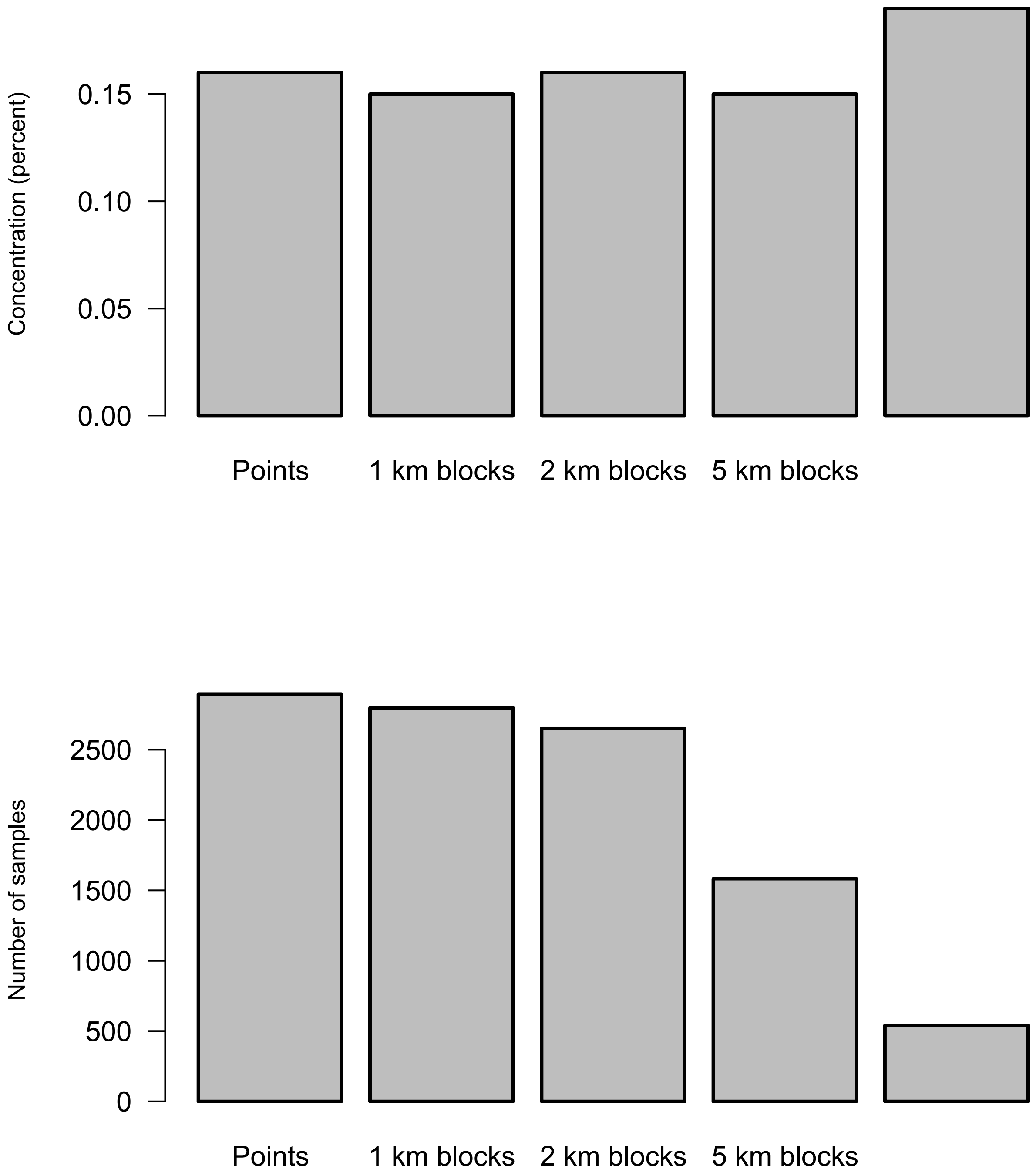


Figure 76. Variation in Phosphorus Concentration and Number of Samples by Size of Block Used for Averaging

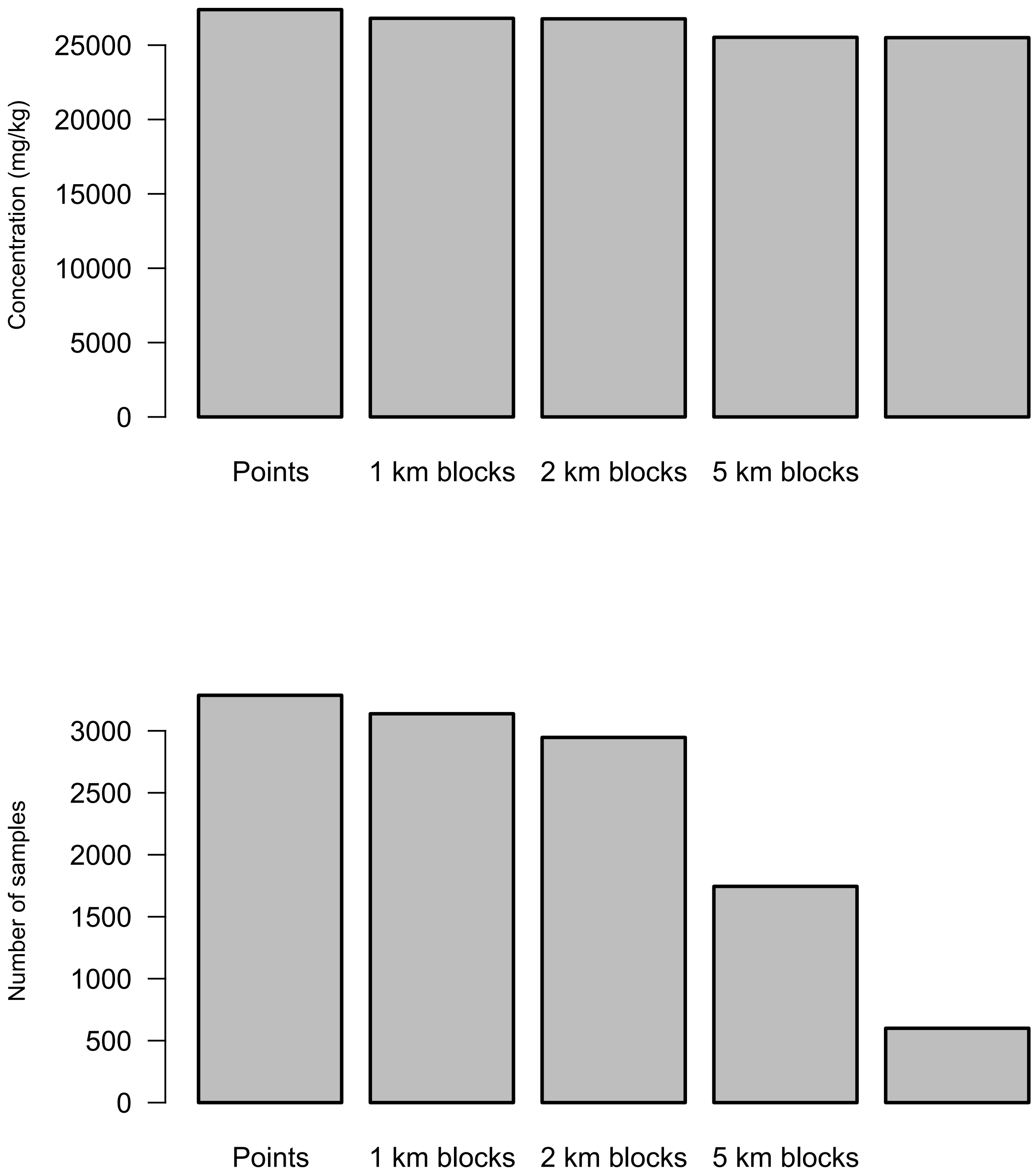


Figure 77. Variation in Potassium Concentration and Number of Samples by Size of Block Used for Averaging

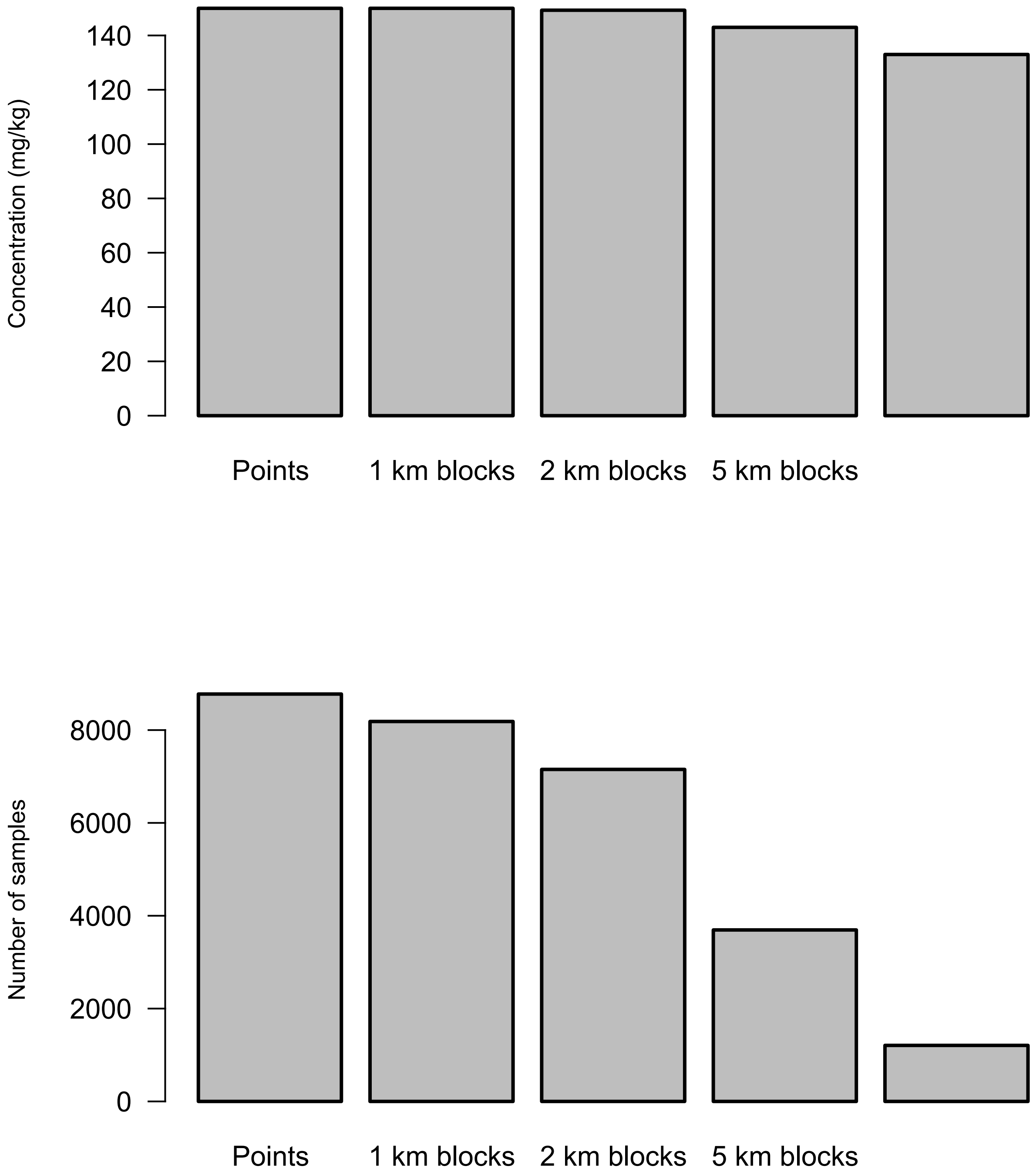


Figure 78. Variation in Rubidium Concentration and Number of Samples by Size of Block Used for Averaging

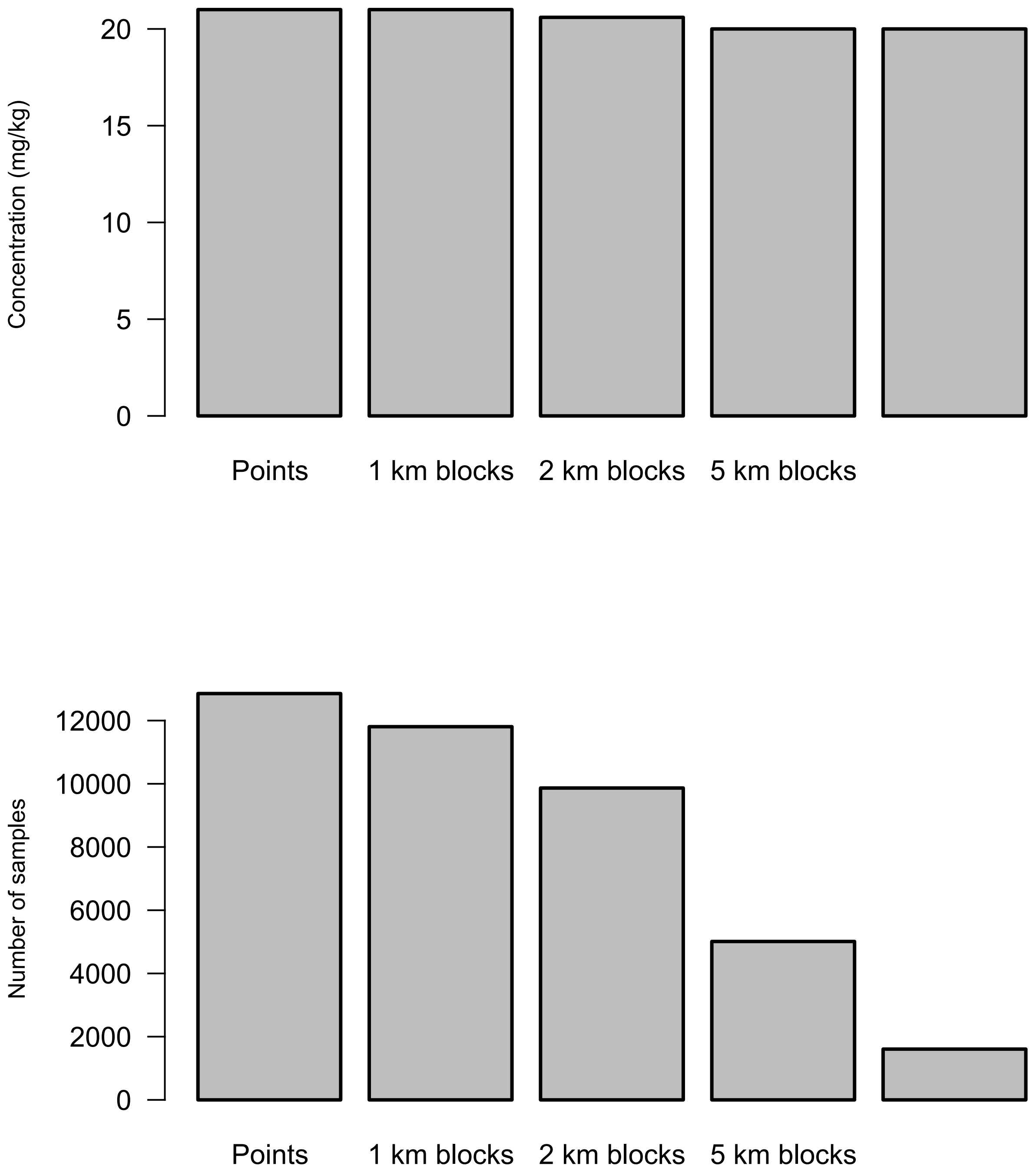


Figure 79. Variation in Samarium Concentration and Number of Samples
by Size of Block Used for Averaging

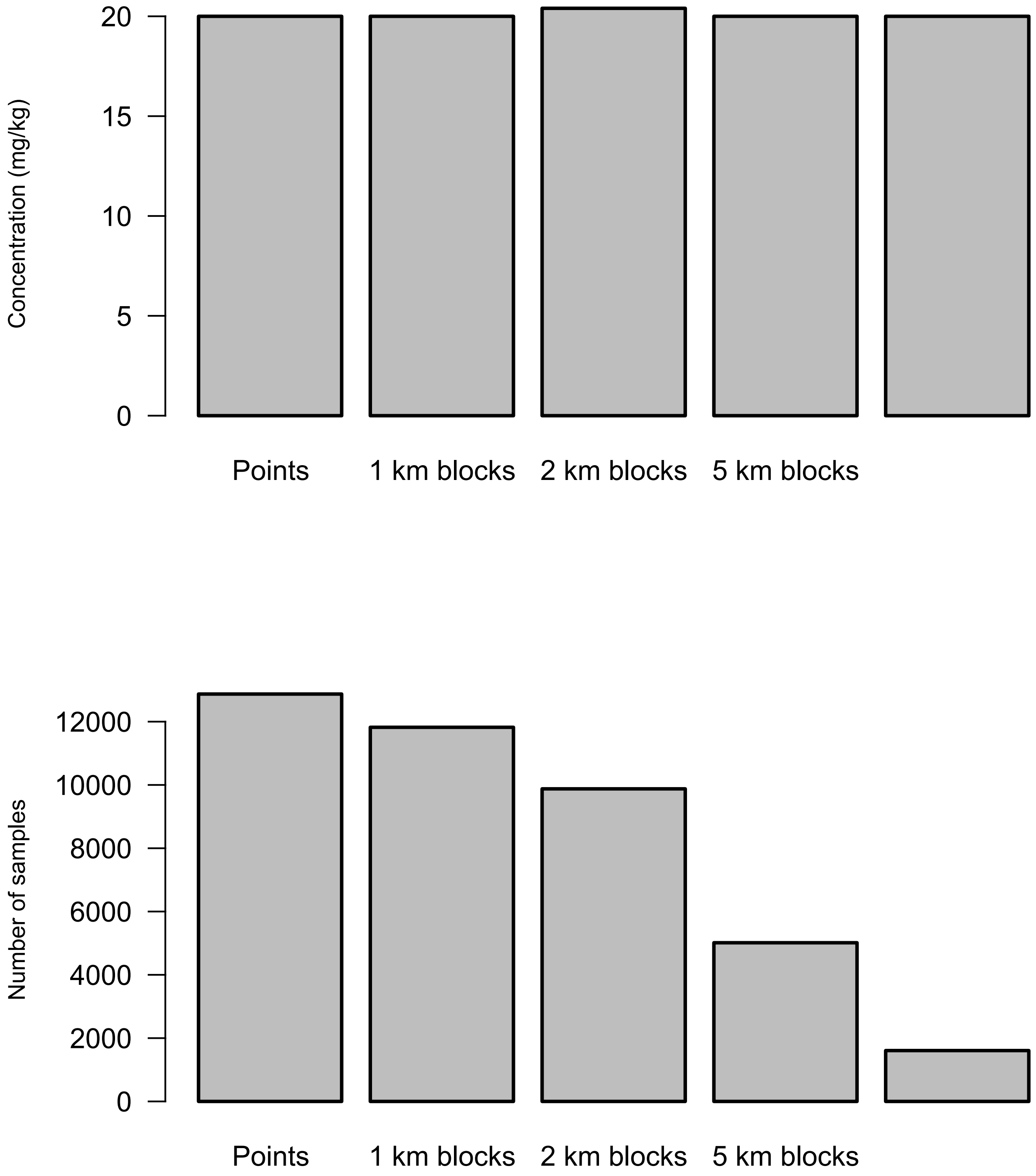


Figure 80. Variation in Scandium Concentration and Number of Samples by Size of Block Used for Averaging

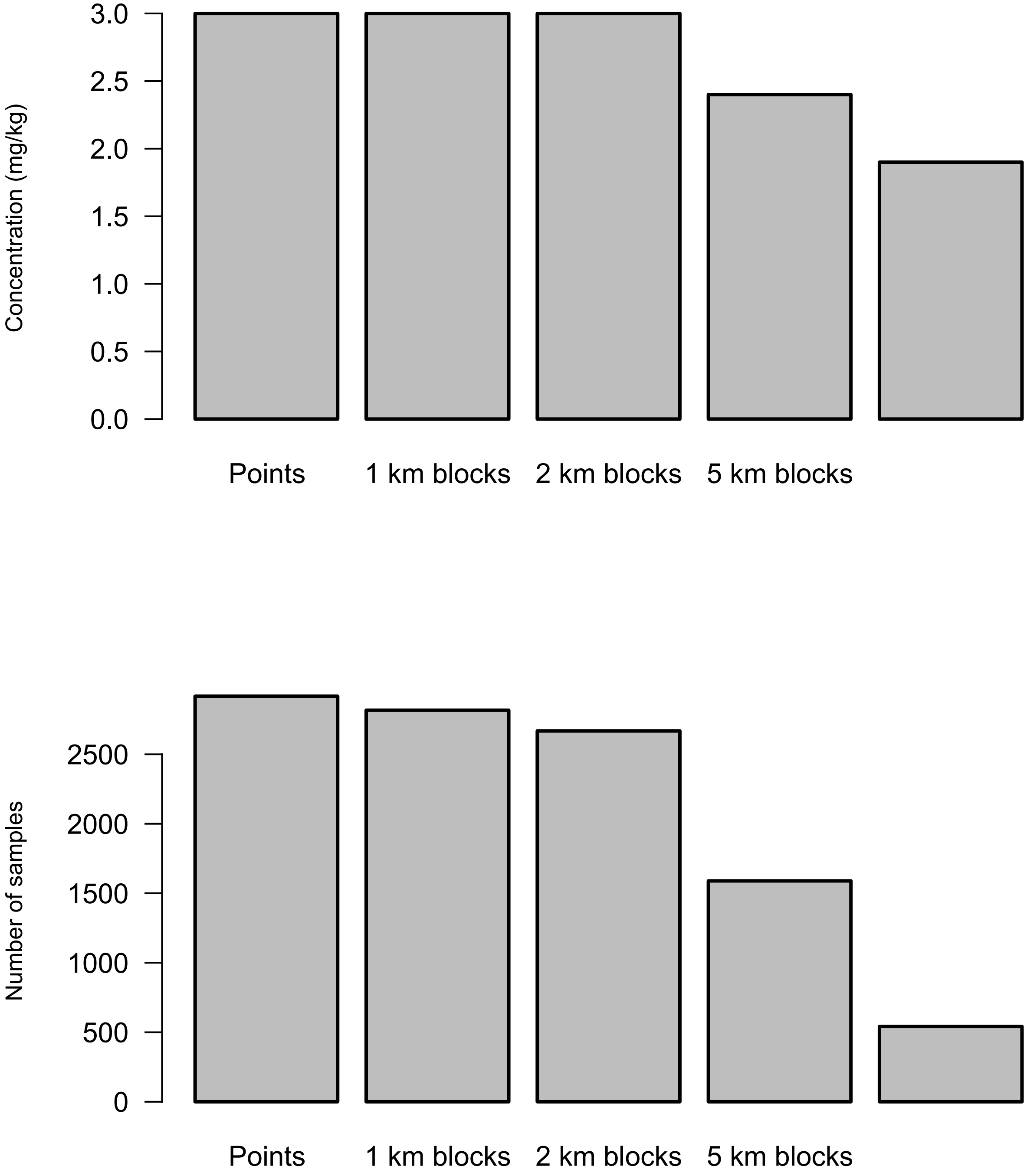


Figure 81. Variation in Selenium Concentration and Number of Samples by Size of Block Used for Averaging

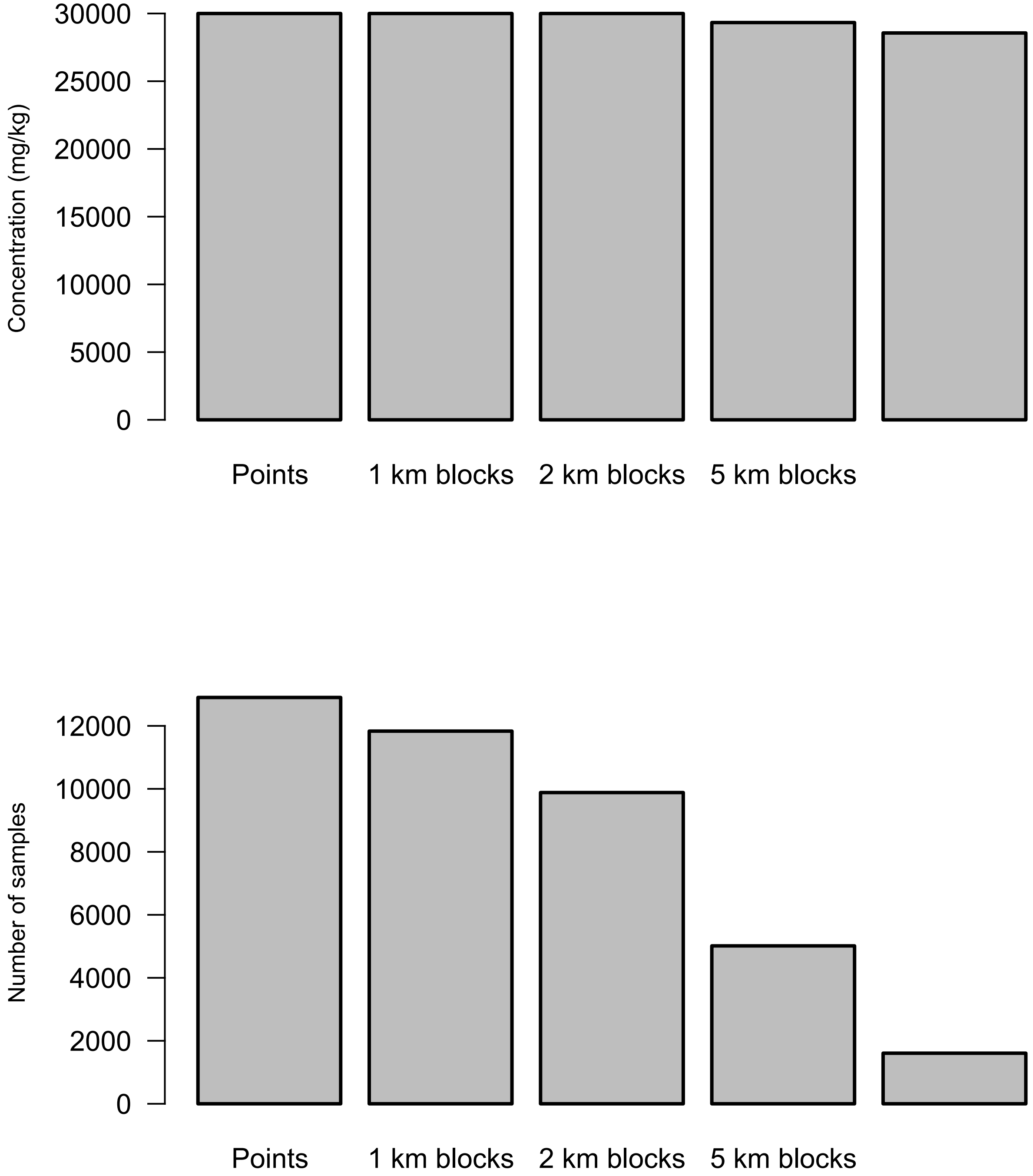


Figure 82. Variation in Sodium Concentration and Number of Samples by Size of Block Used for Averaging

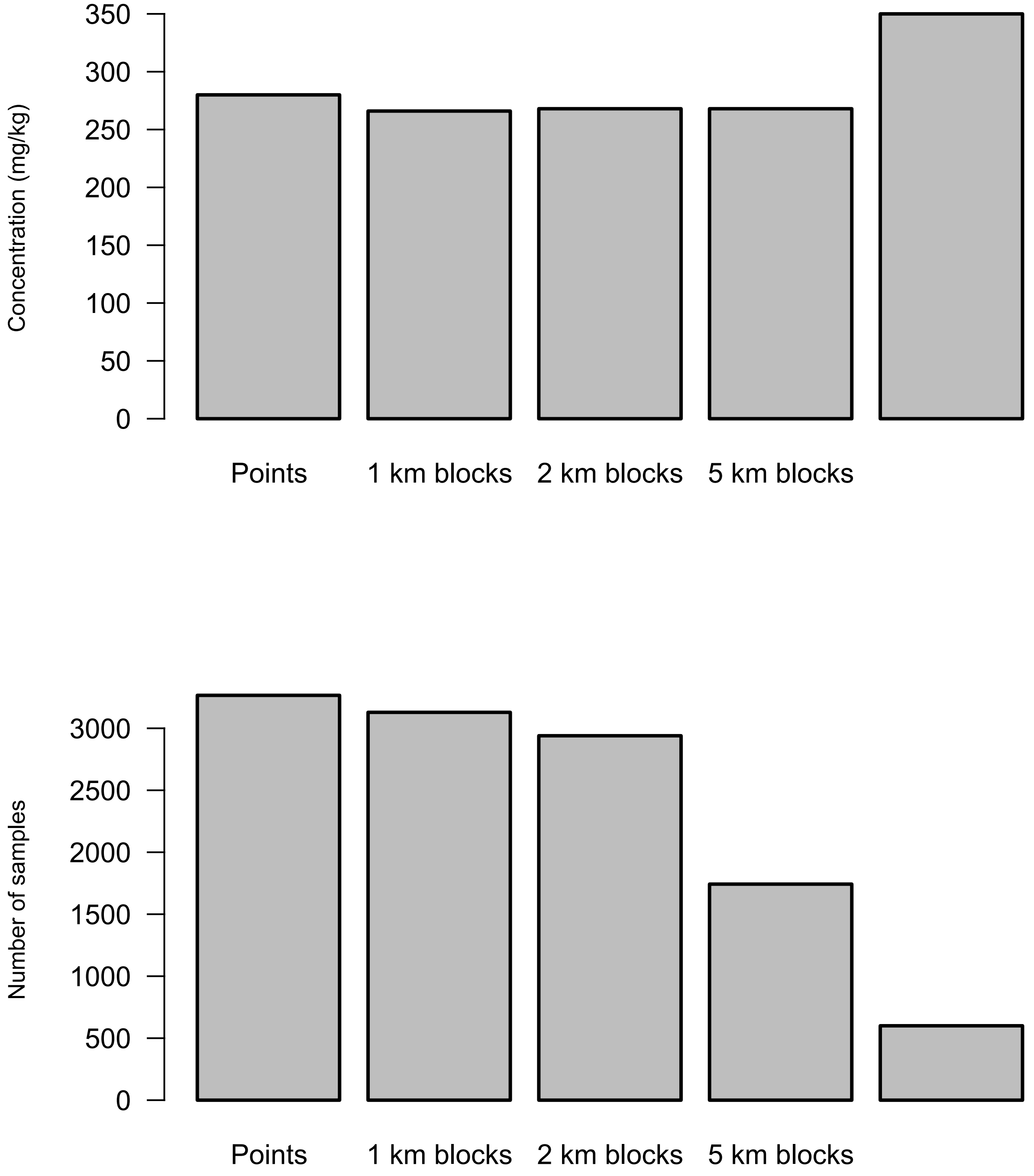


Figure 83. Variation in Strontium Concentration and Number of Samples by Size of Block Used for Averaging

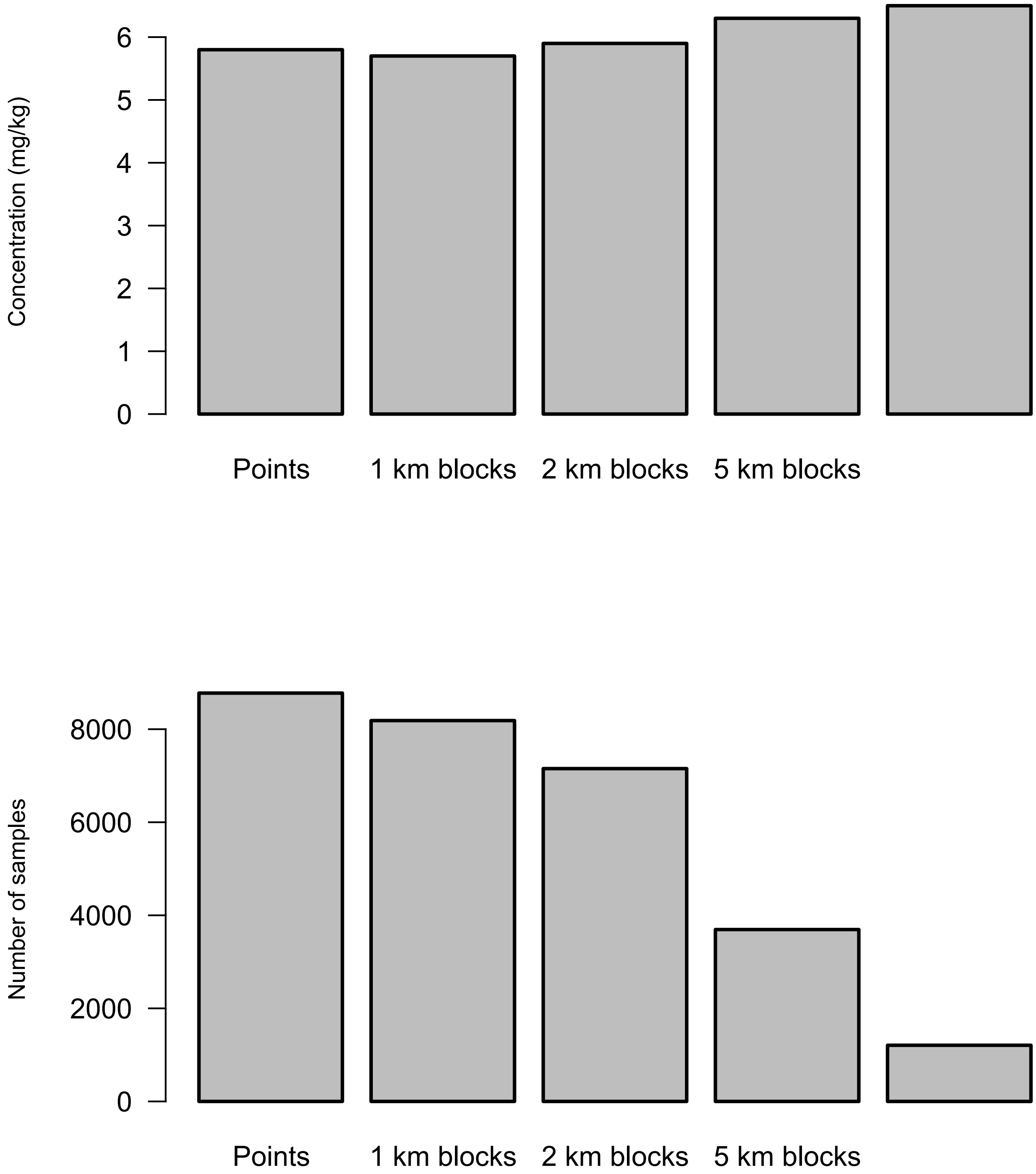


Figure 84. Variation in Tantalum Concentration and Number of Samples by Size of Block Used for Averaging

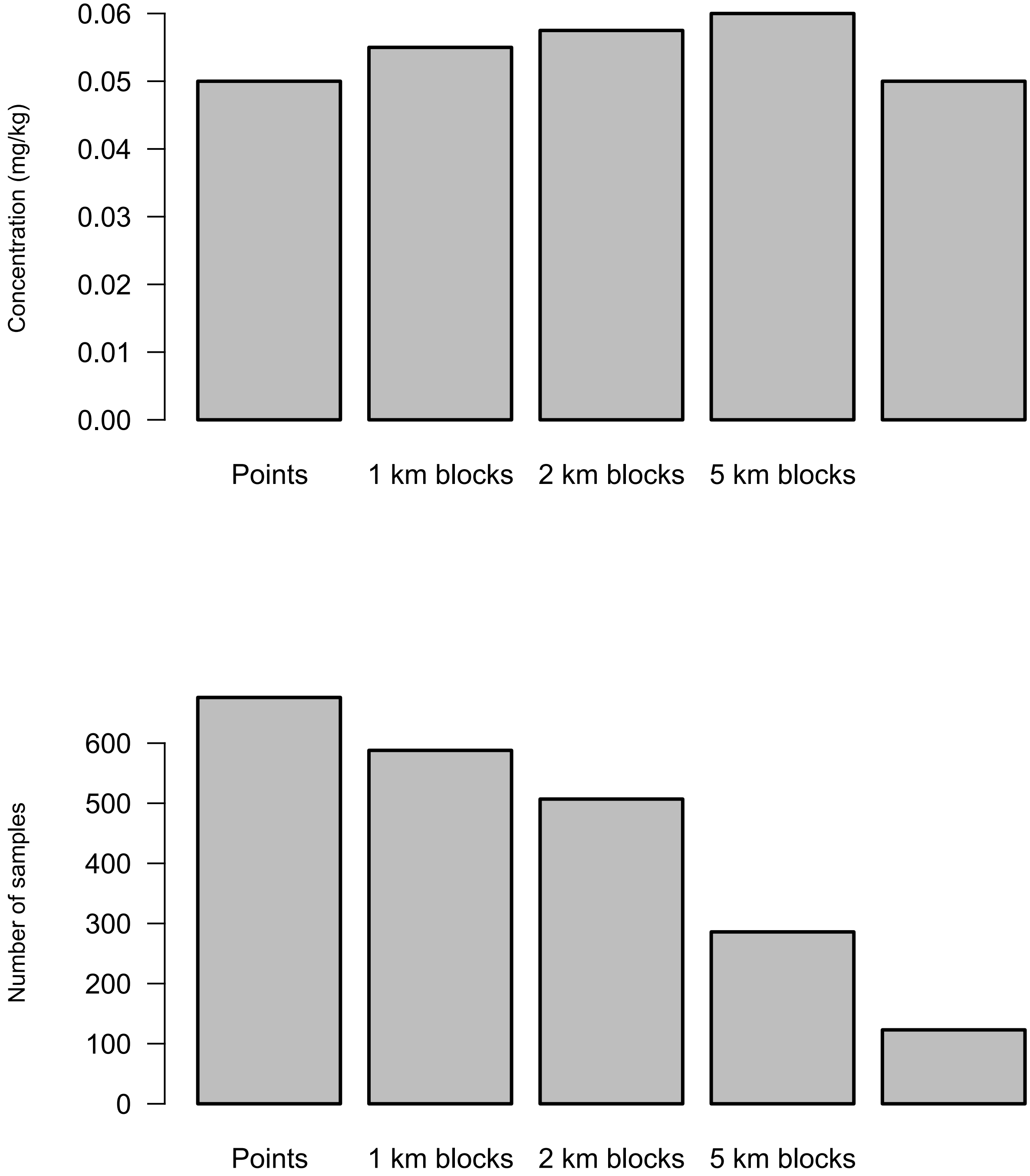
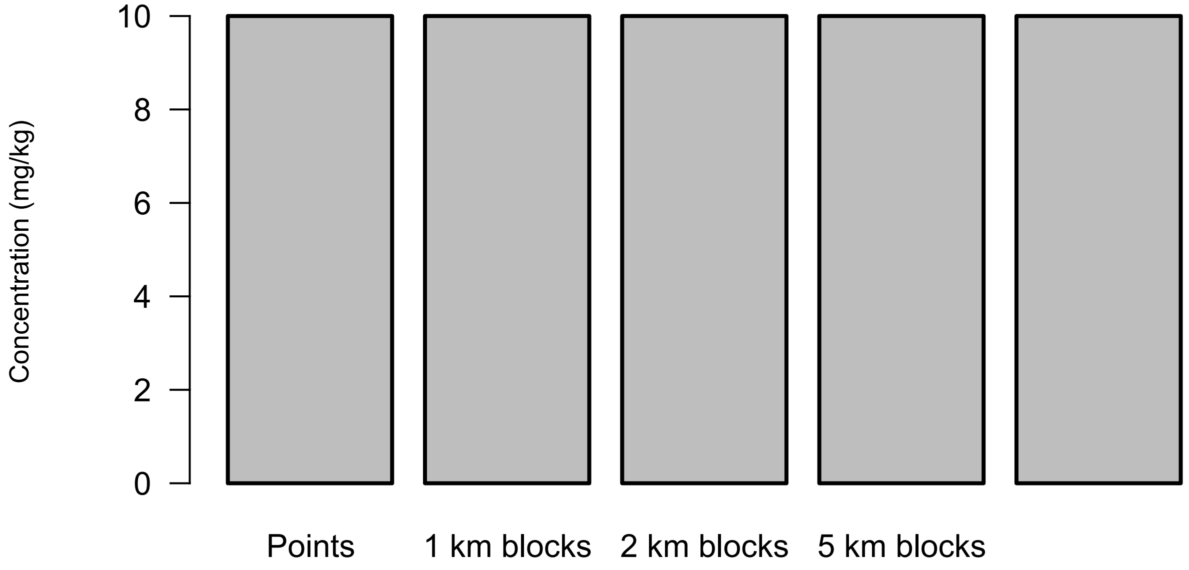


Figure 85. Variation in Tellurium Concentration and Number of Samples by Size of Block Used for Averaging



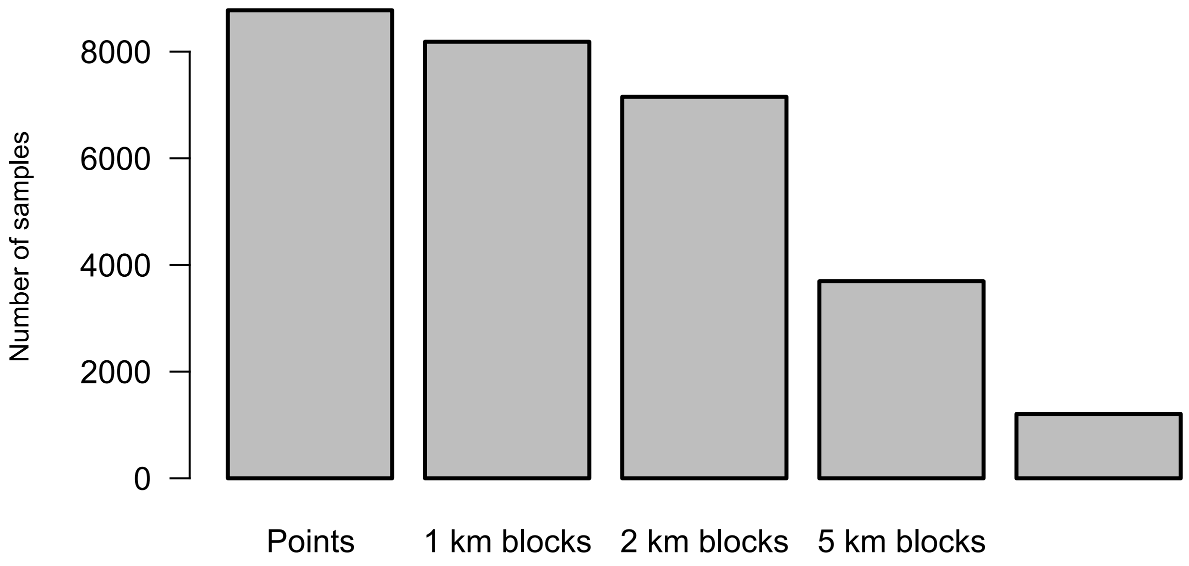


Figure 86. Variation in Terbium Concentration and Number of Samples by Size of Block Used for Averaging

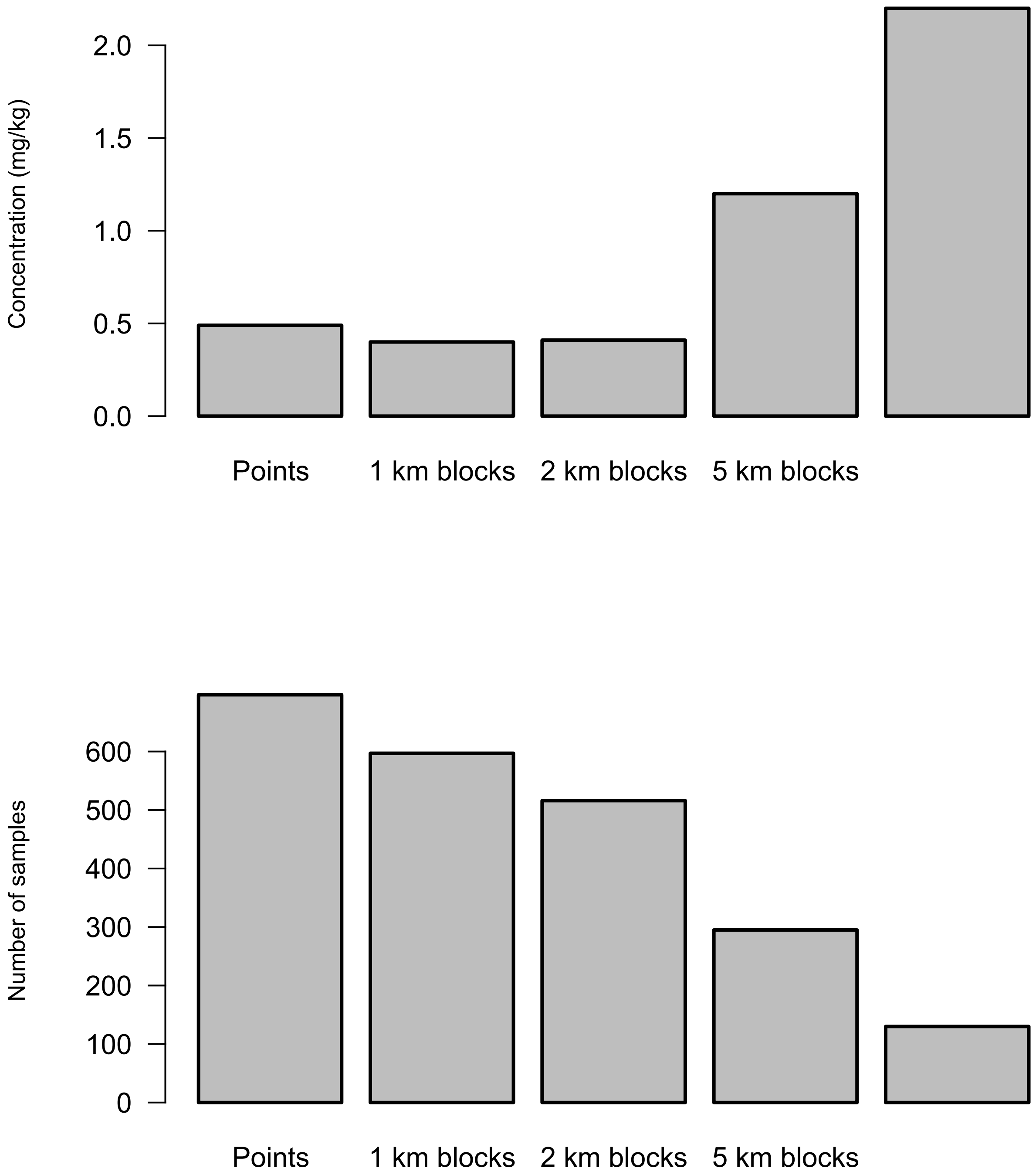


Figure 87. Variation in Thallium Concentration and Number of Samples by Size of Block Used for Averaging

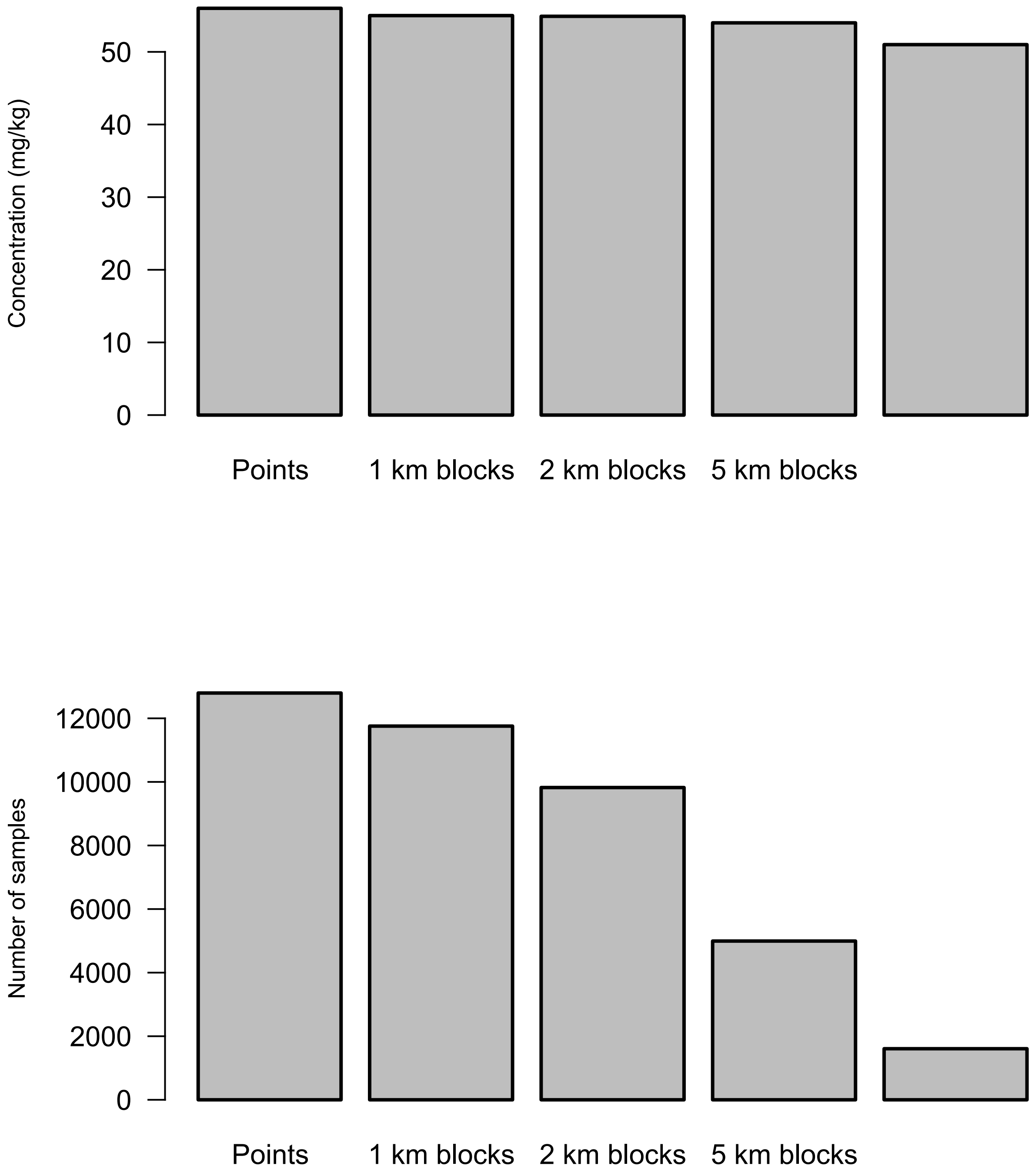


Figure 88. Variation in Thorium Concentration and Number of Samples by Size of Block Used for Averaging

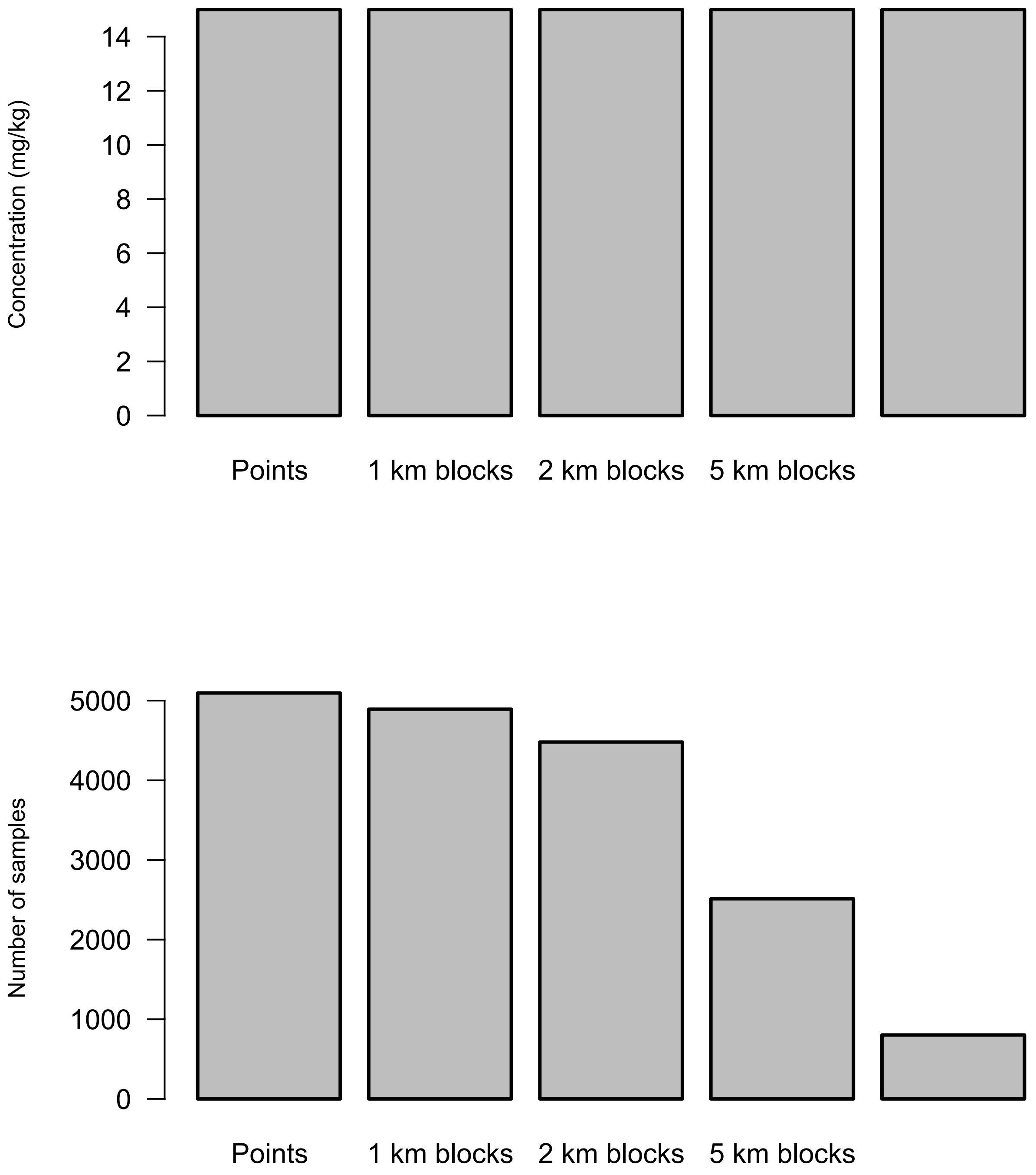


Figure 89. Variation in Tin Concentration and Number of Samples by Size of Block Used for Averaging

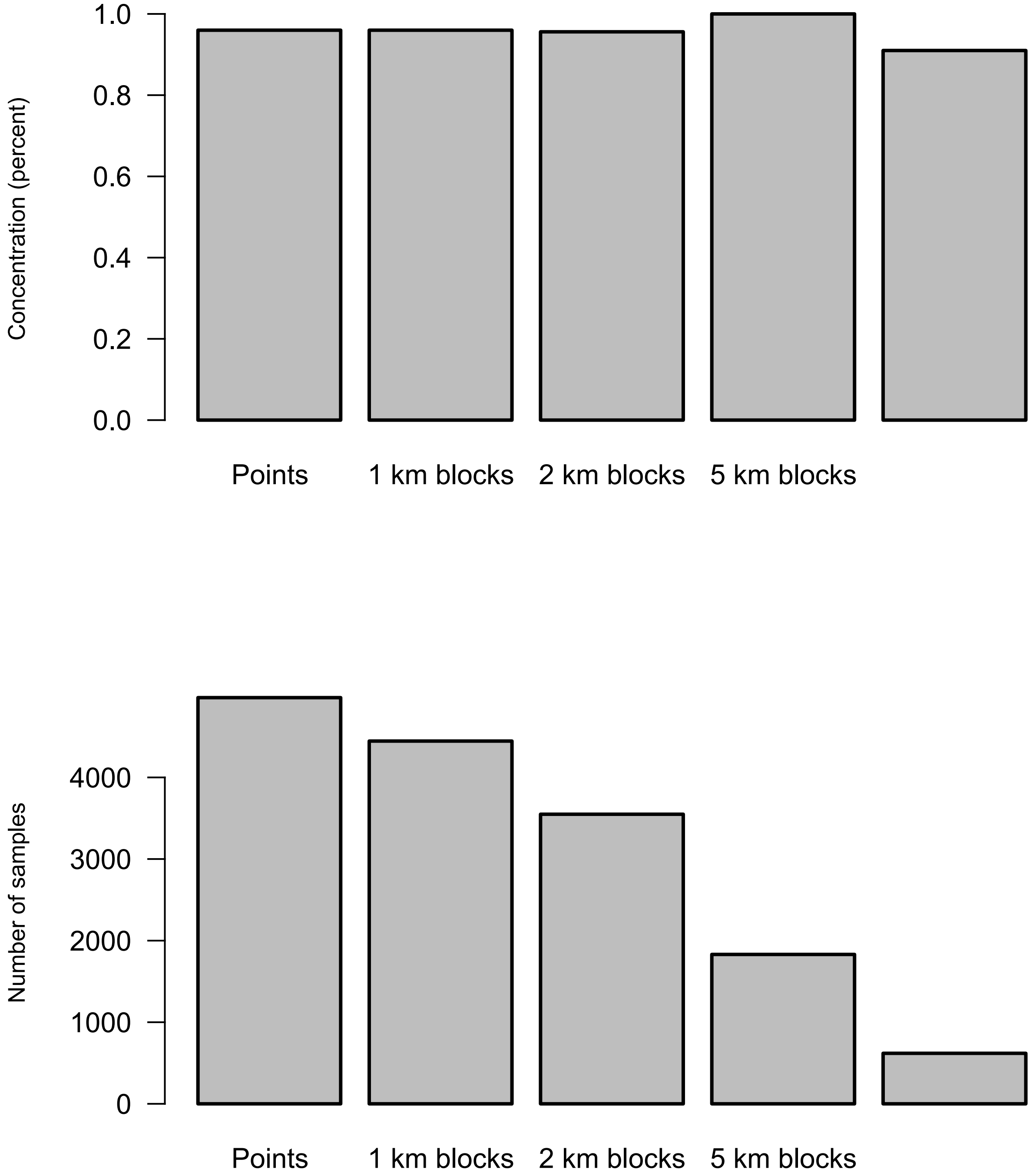


Figure 90. Variation in Titanium Concentration and Number of Samples by Size of Block Used for Averaging

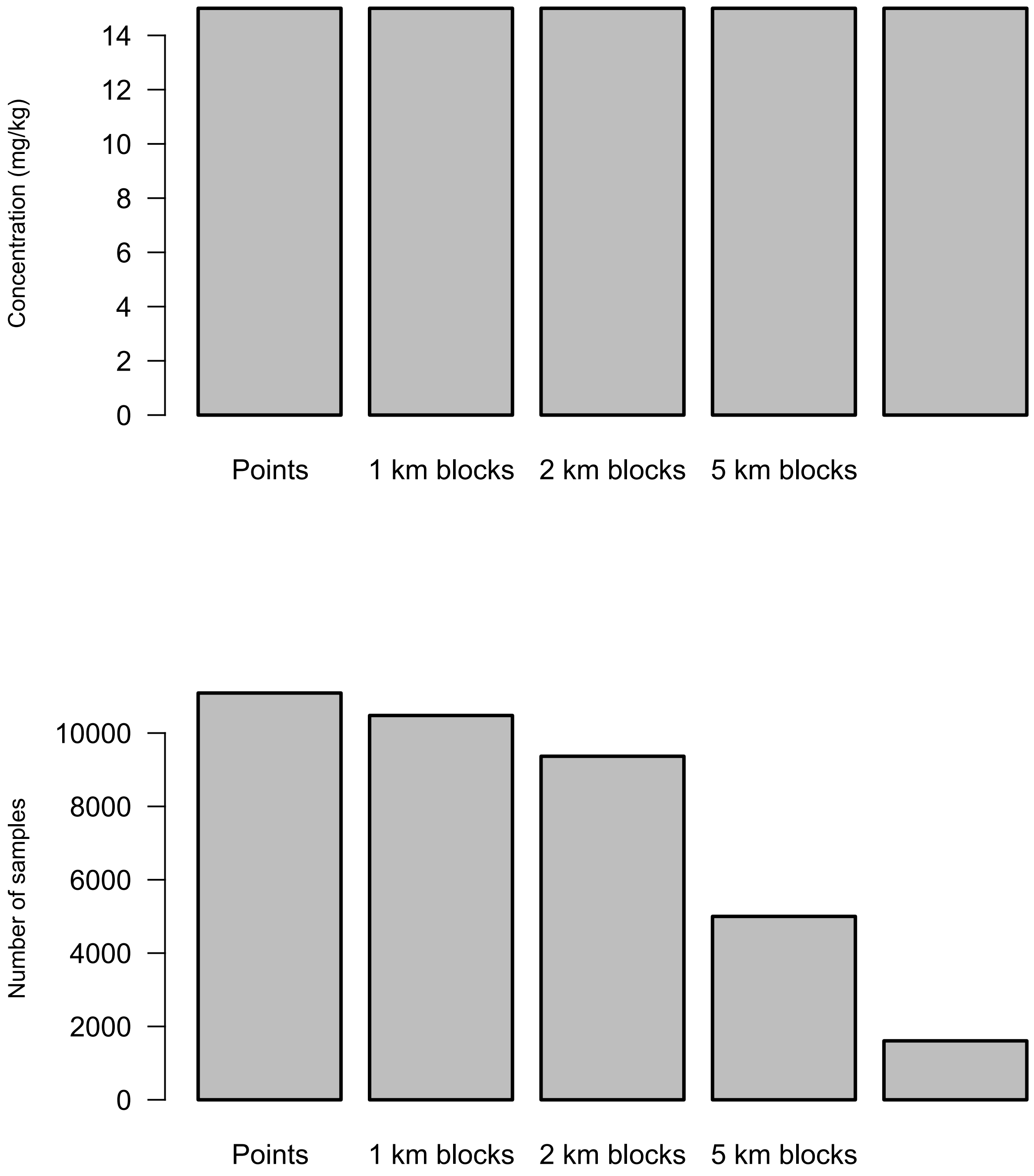


Figure 91. Variation in Tungsten Concentration and Number of Samples by Size of Block Used for Averaging

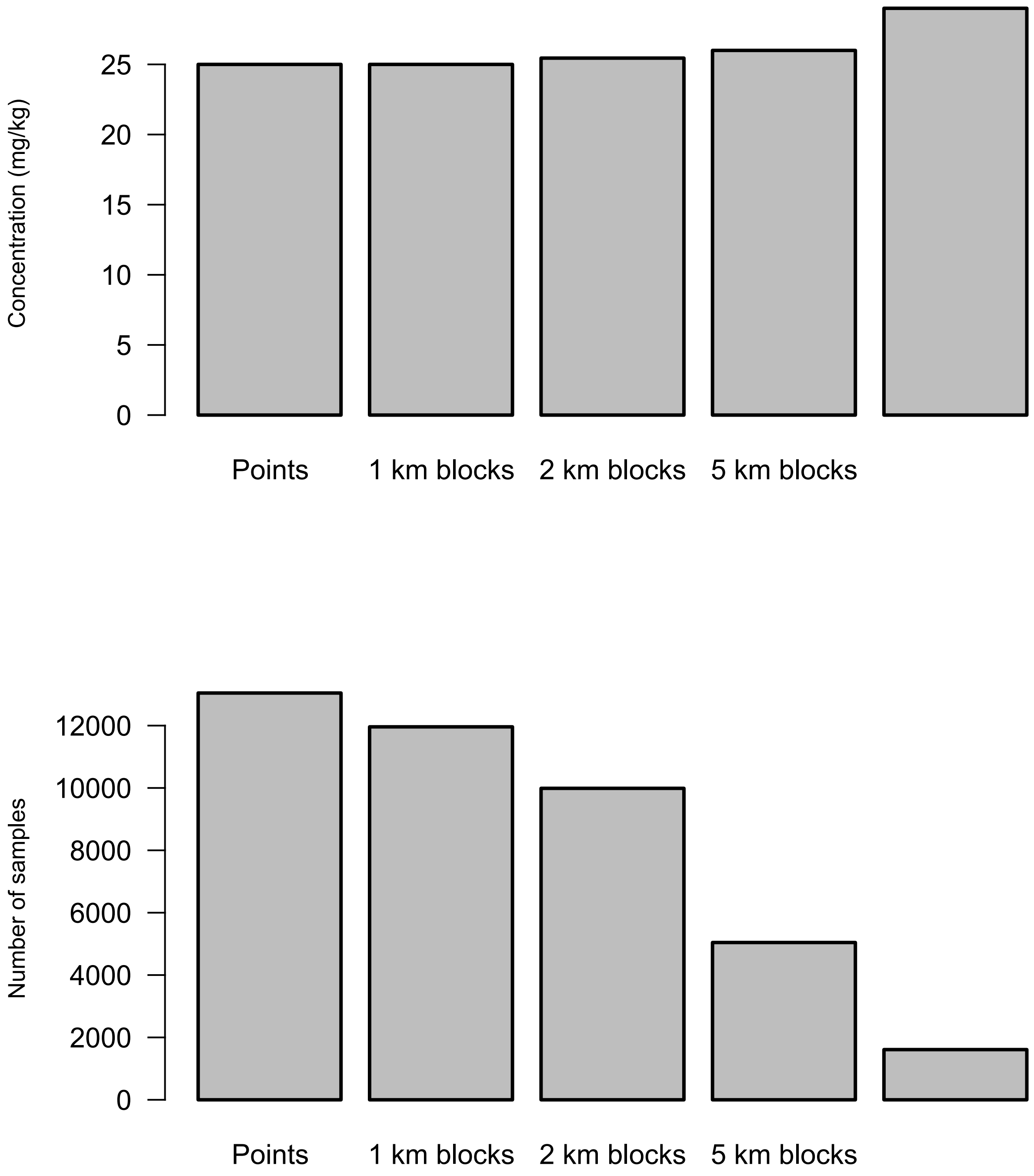


Figure 92. Variation in Uranium Concentration and Number of Samples by Size of Block Used for Averaging

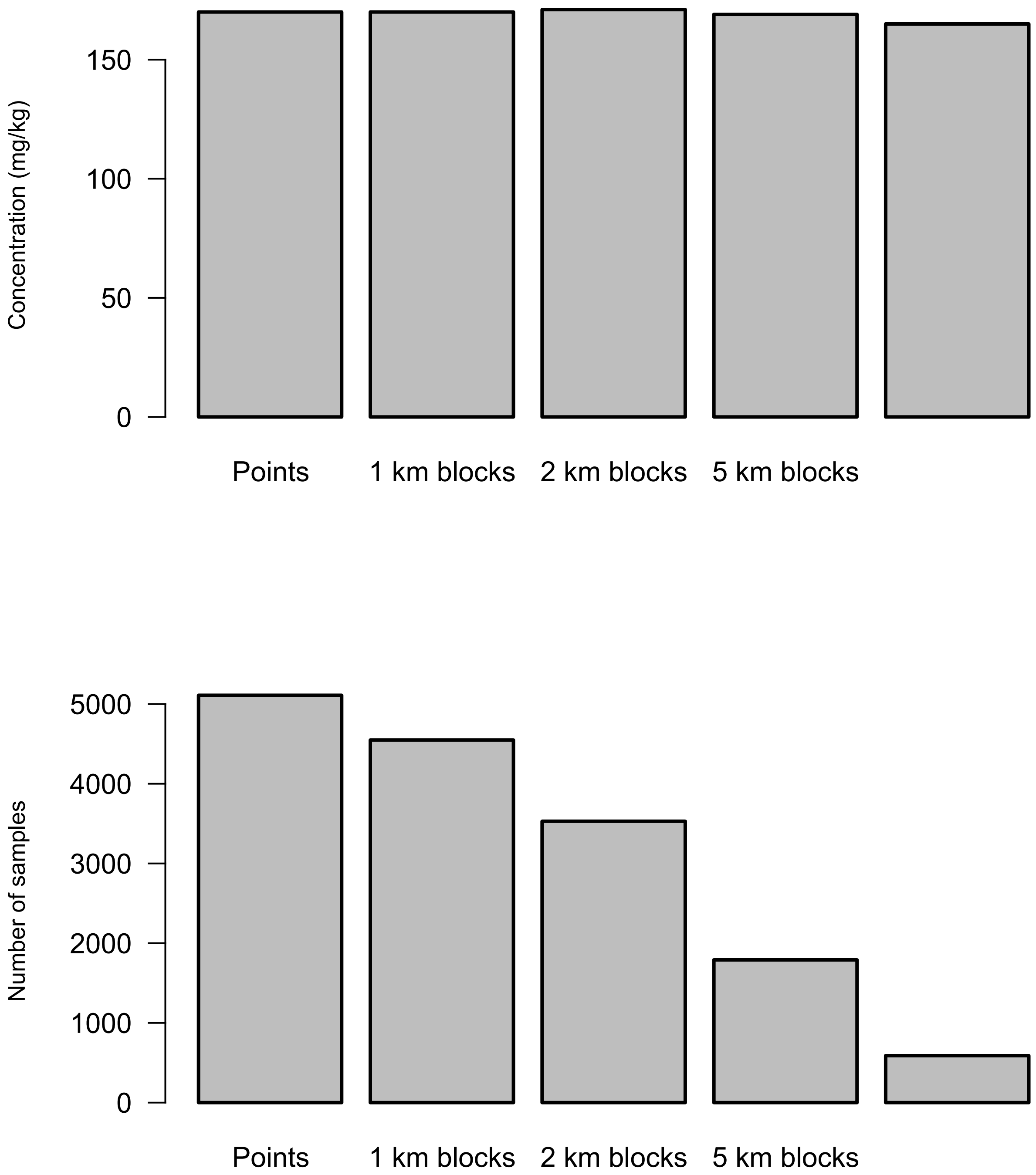


Figure 93. Variation in Vanadium Concentration and Number of Samples by Size of Block Used for Averaging

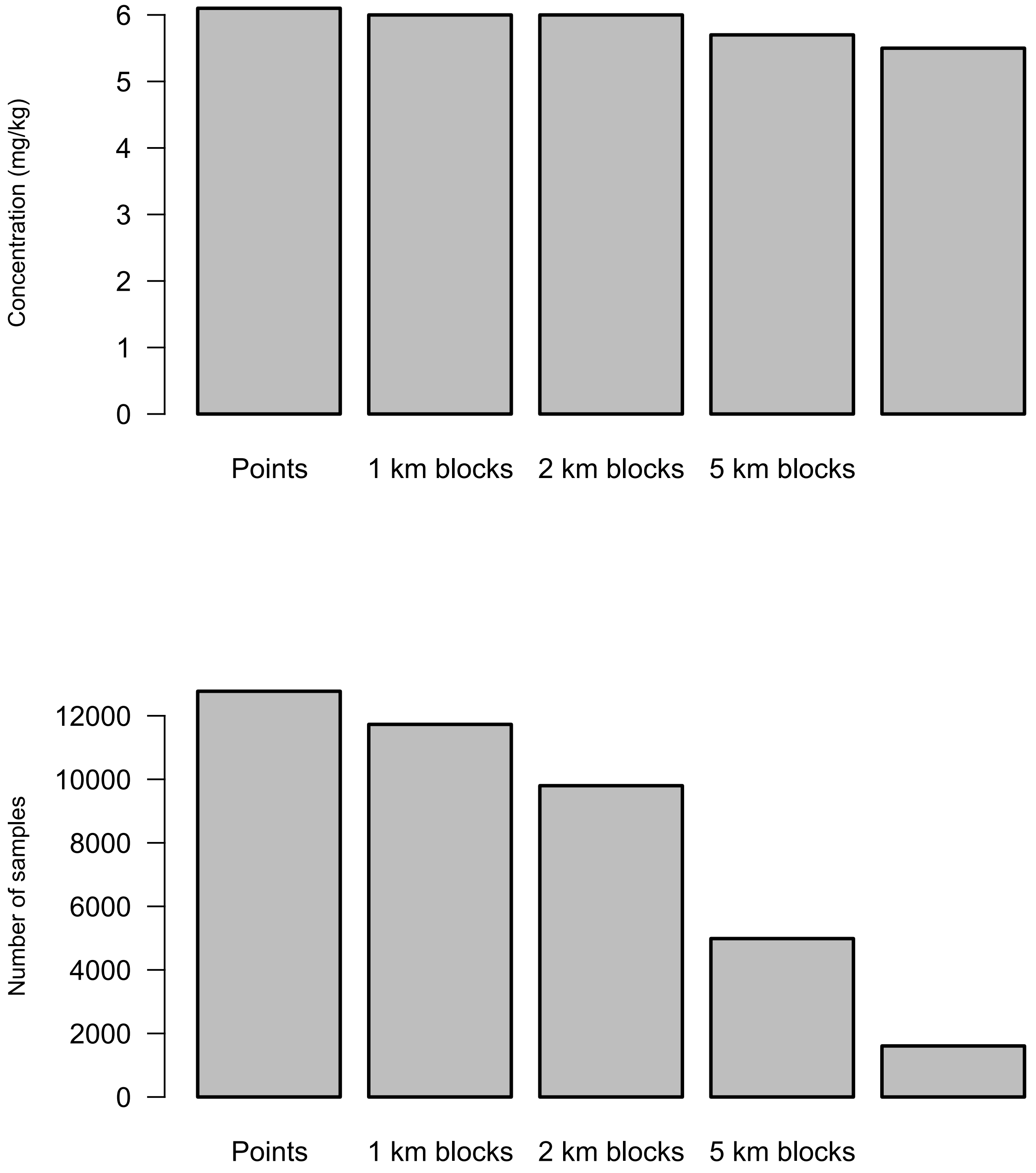


Figure 94. Variation in Ytterbium Concentration and Number of Samples by Size of Block Used for Averaging

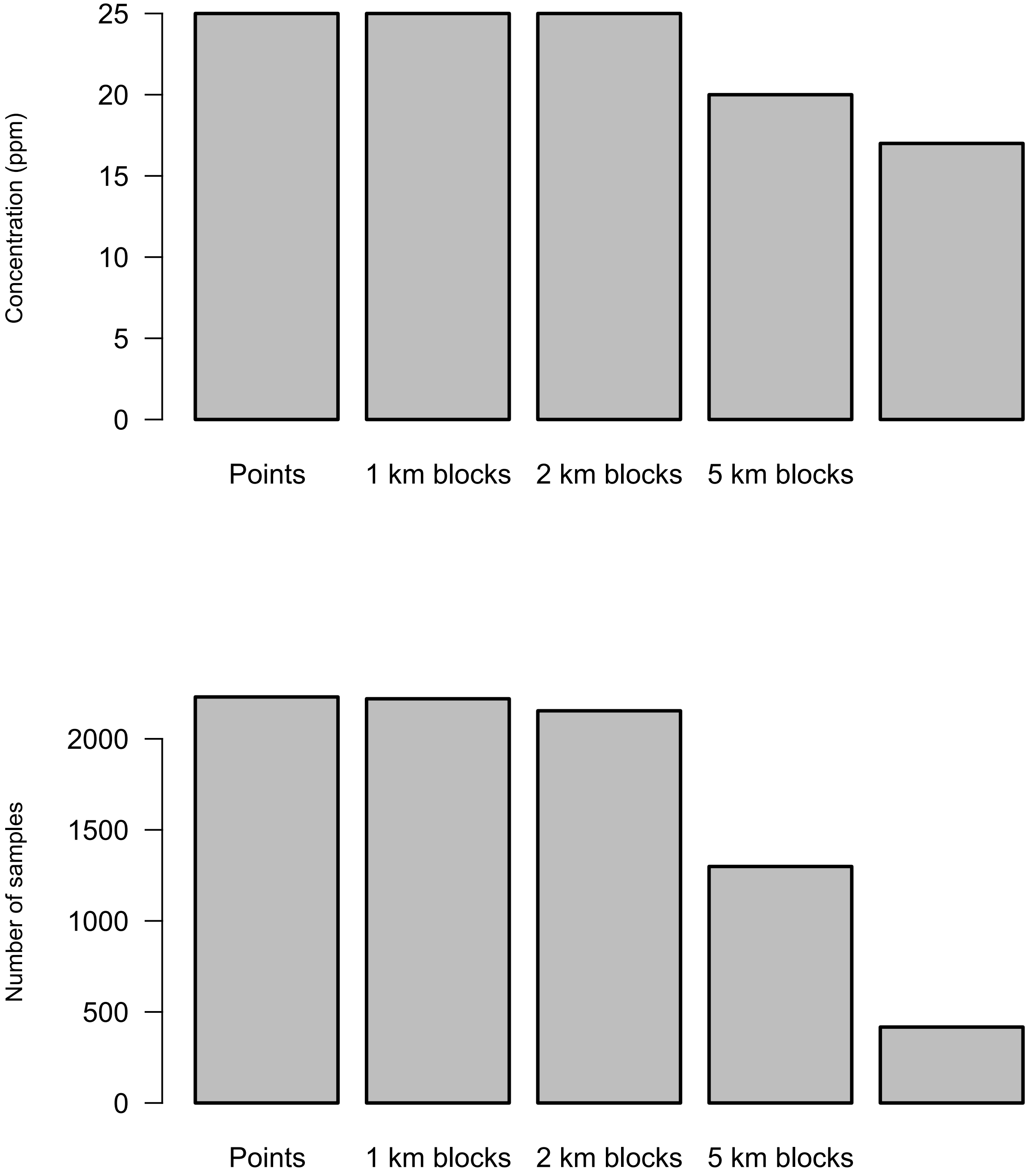


Figure 95. Variation in Yttrium Concentration and Number of Samples by Size of Block Used for Averaging

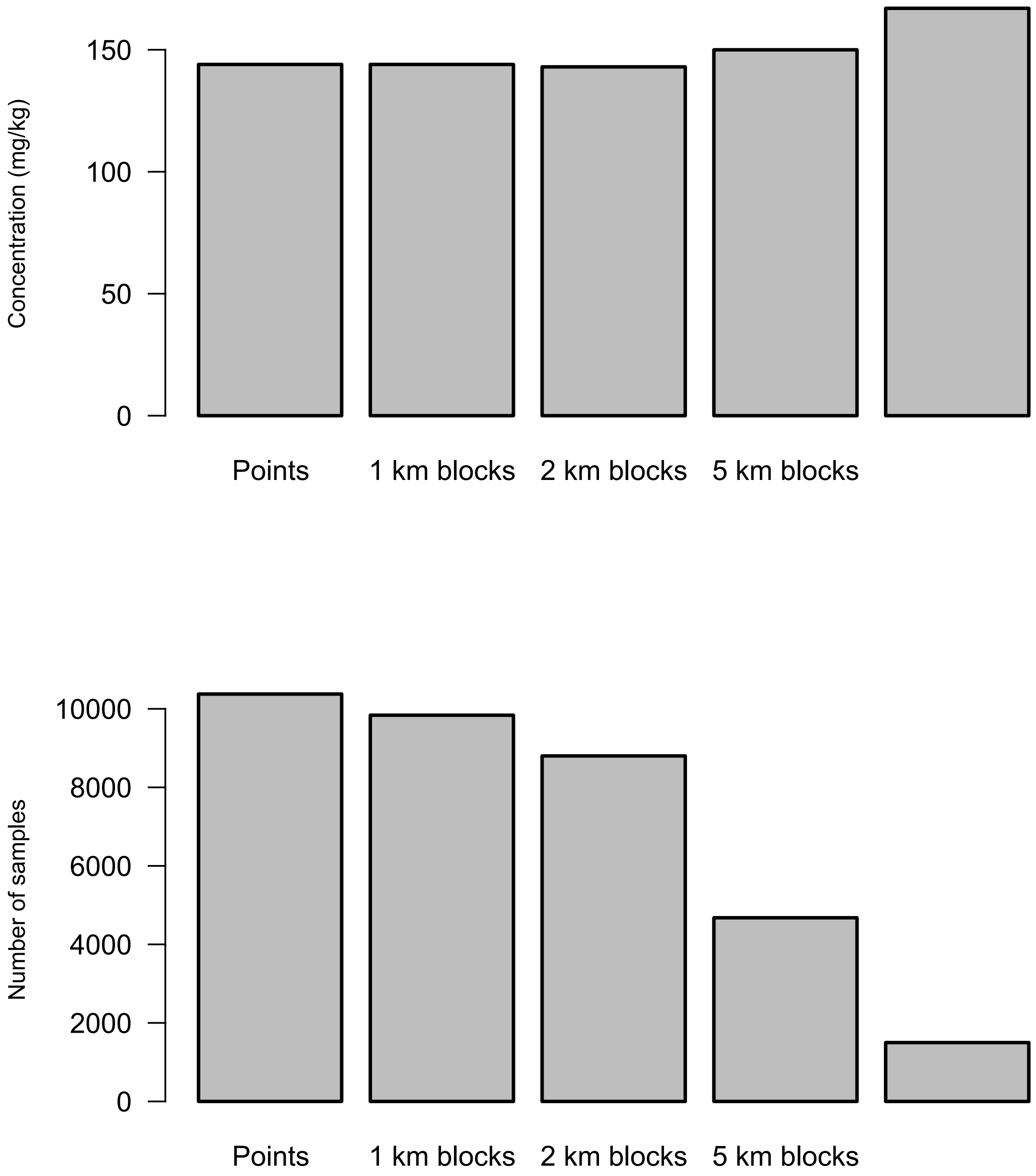


Figure 96. Variation in Zinc Concentration and Number of Samples by Size of Block Used for Averaging

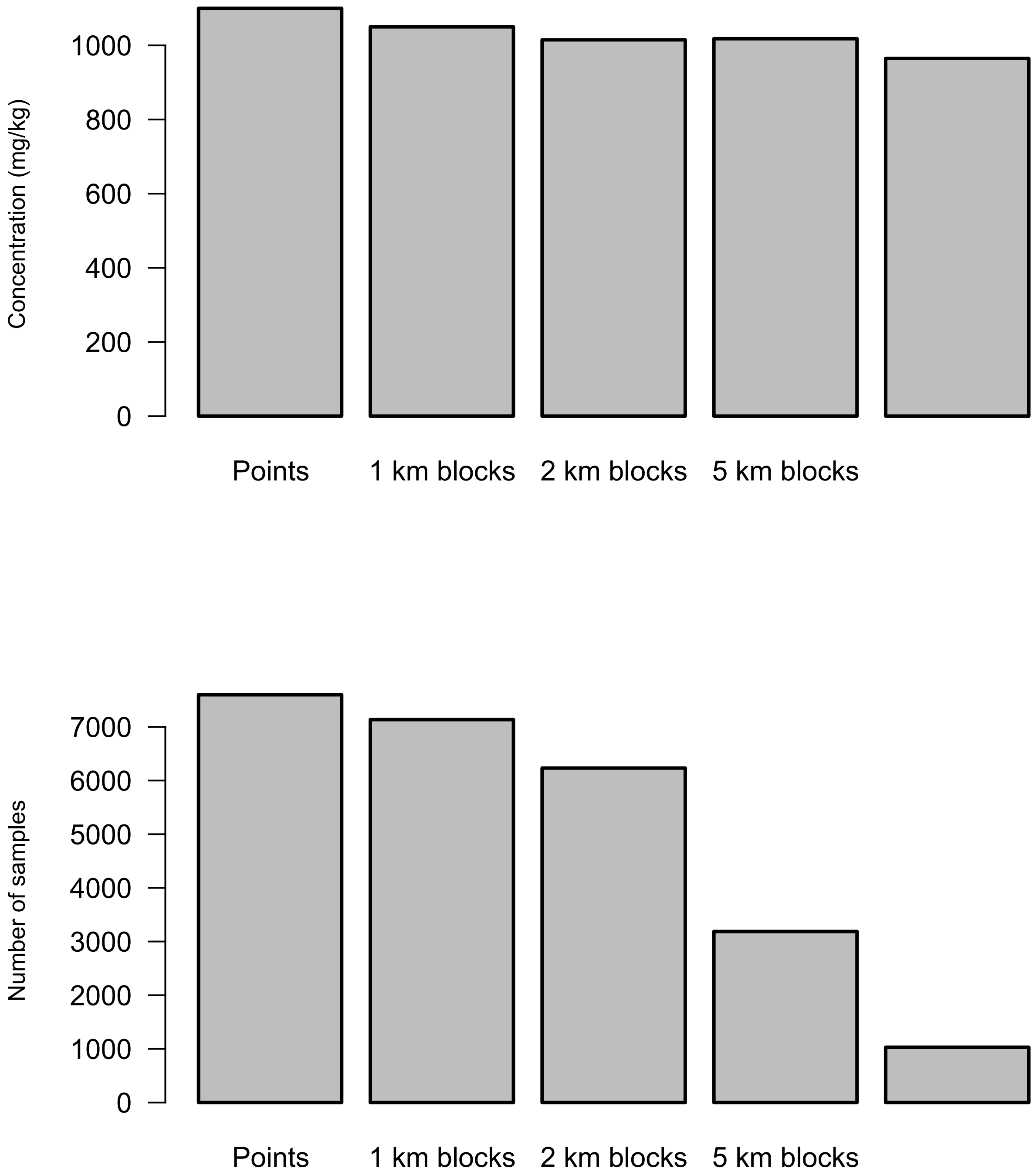


Figure 97. Variation in Zirconium Concentration and Number of Samples by Size of Block Used for Averaging

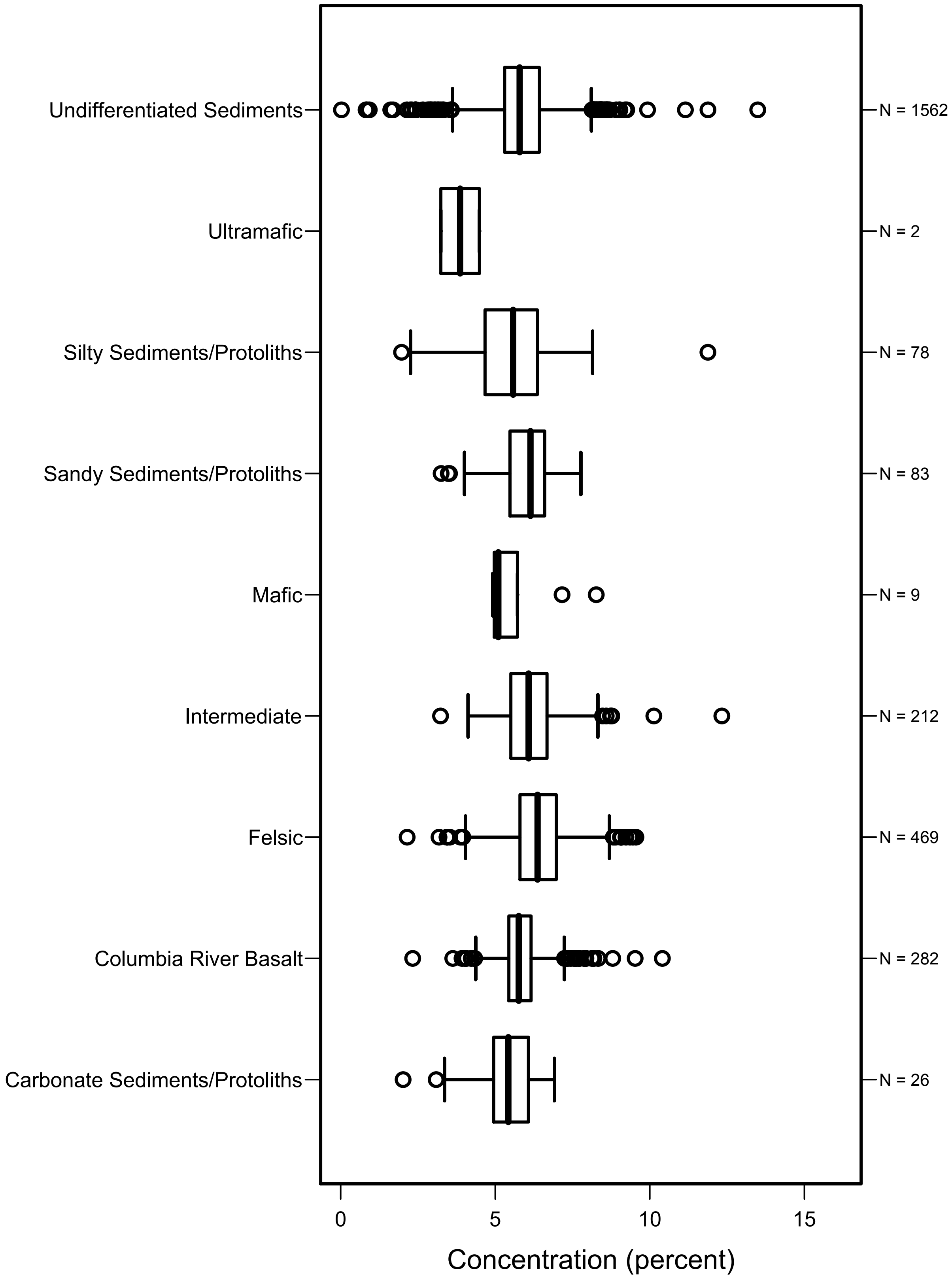


Figure 98. Variation of Background Aluminum With Geology

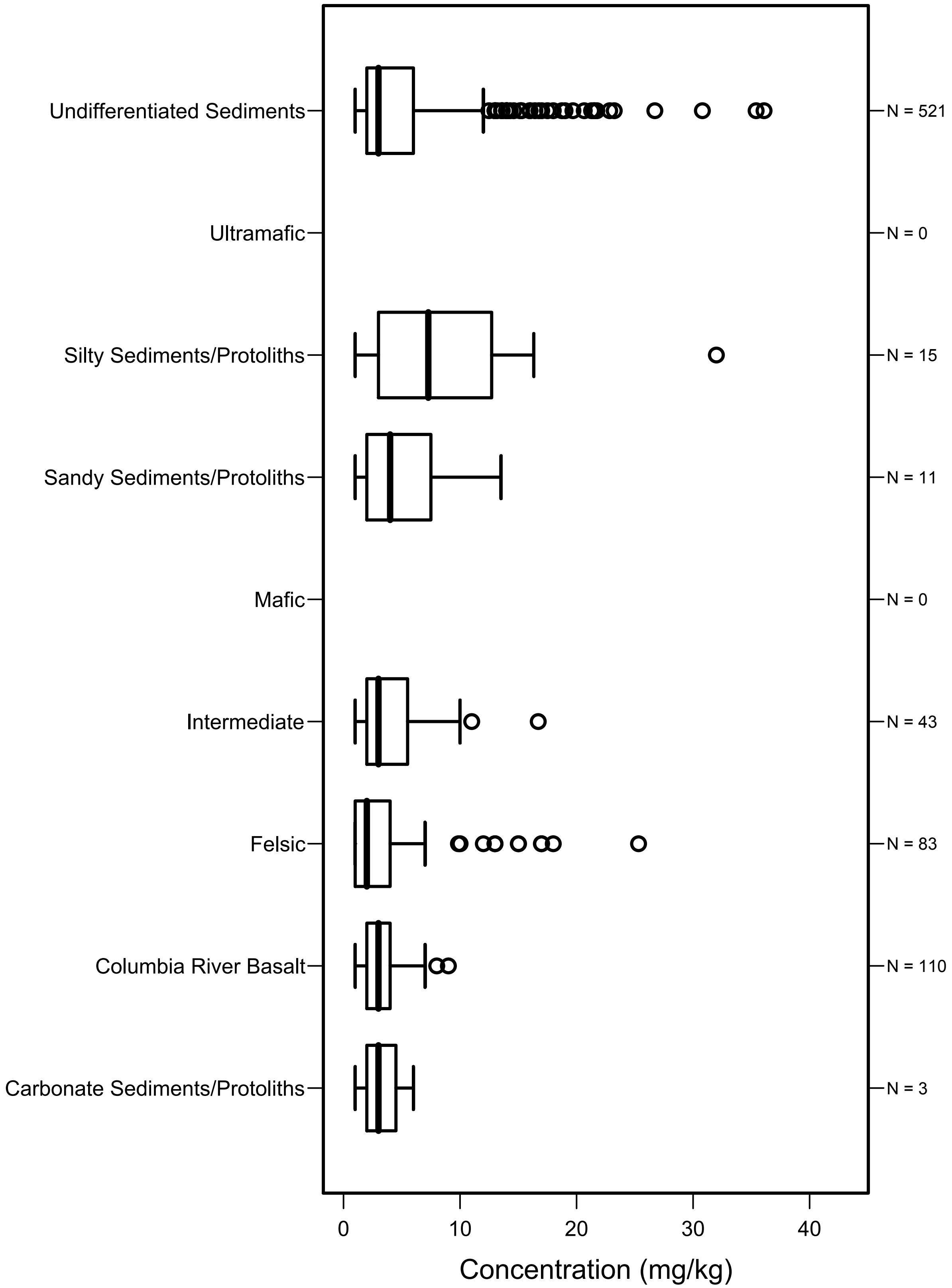


Figure 99. Variation of Background Arsenic
With Geology

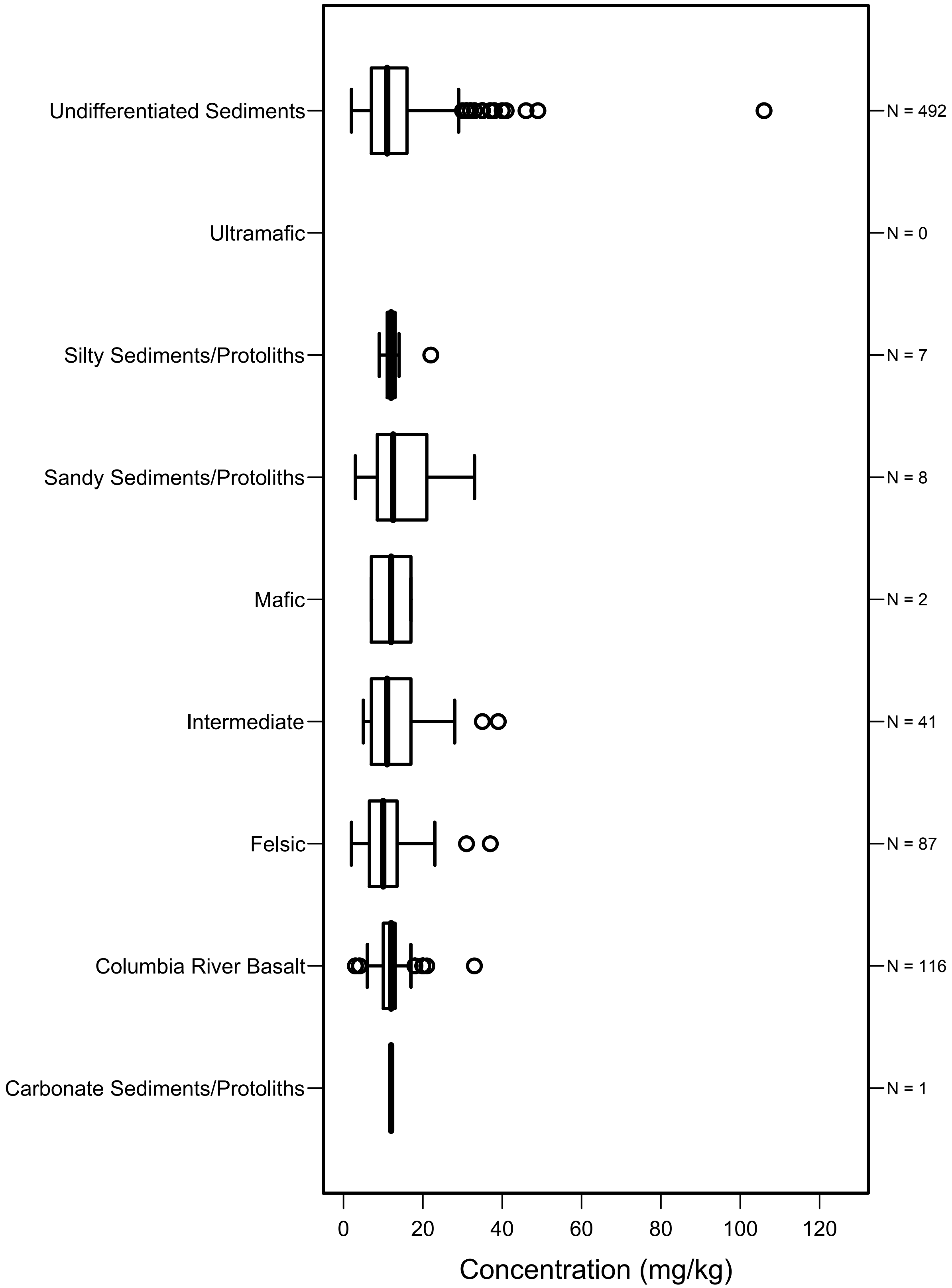


Figure 100. Variation of Background Copper With Geology

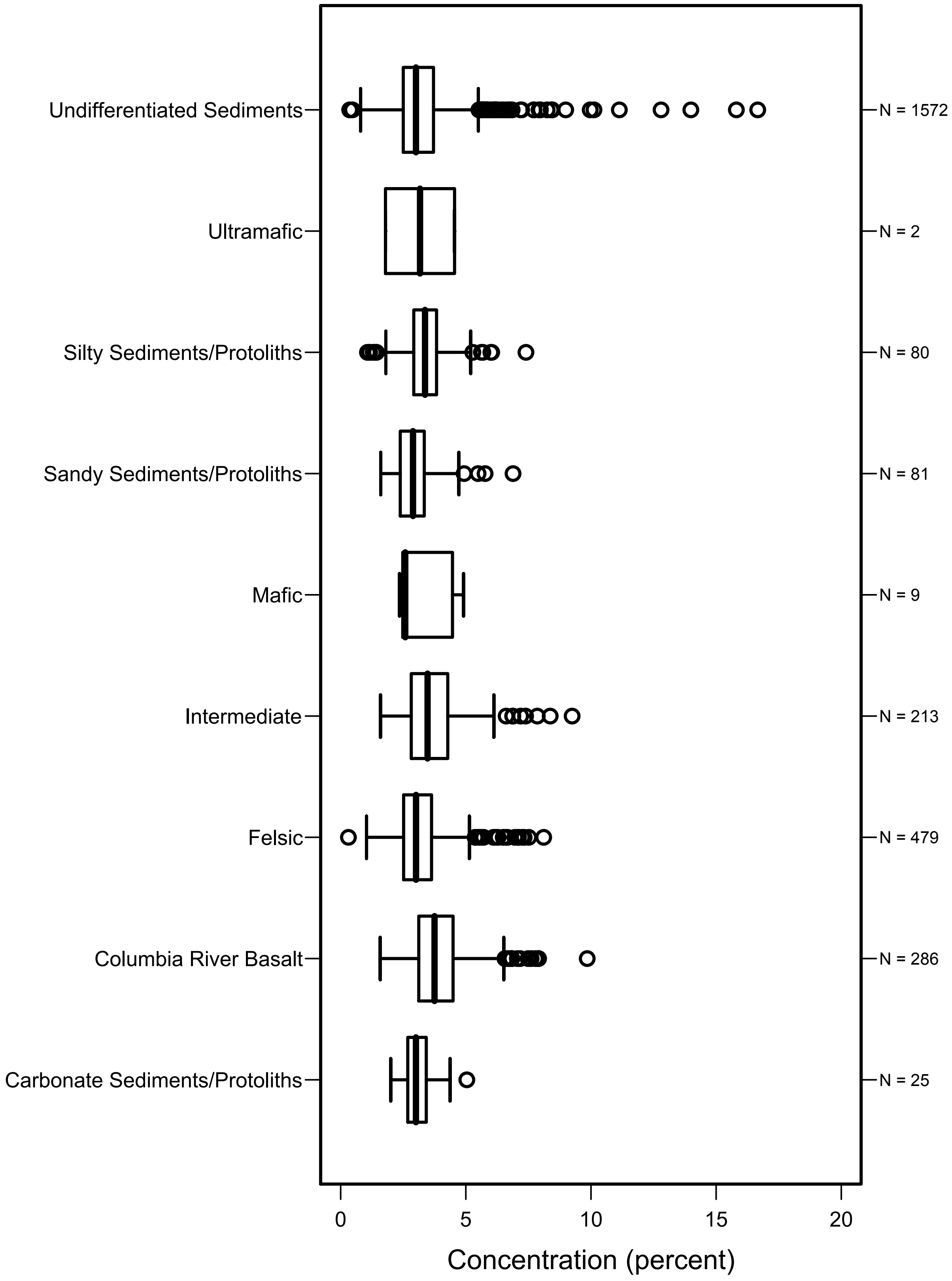


Figure 101. Variation of Background Iron With Geology

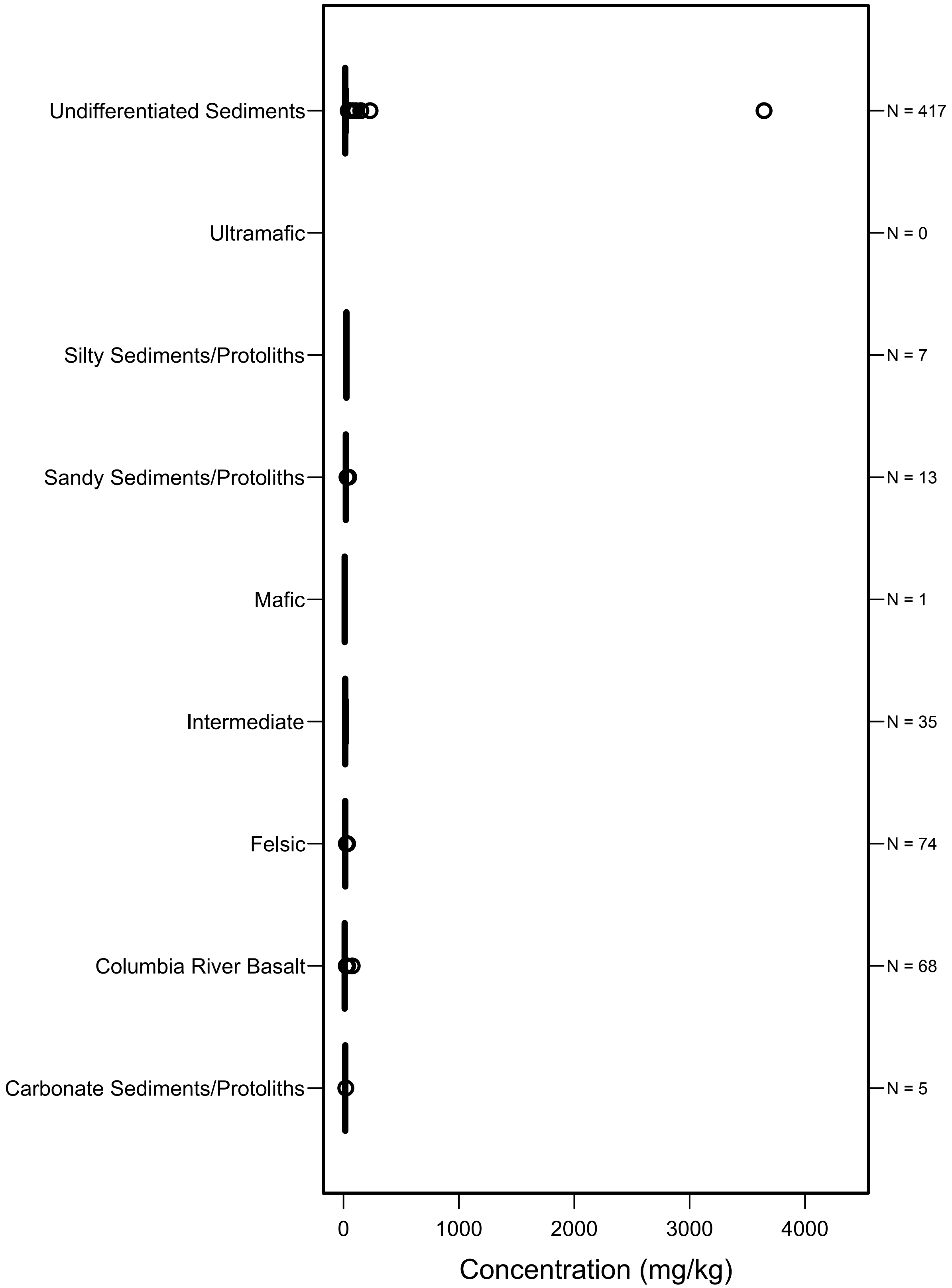


Figure 102. Variation of Background Lead With Geology

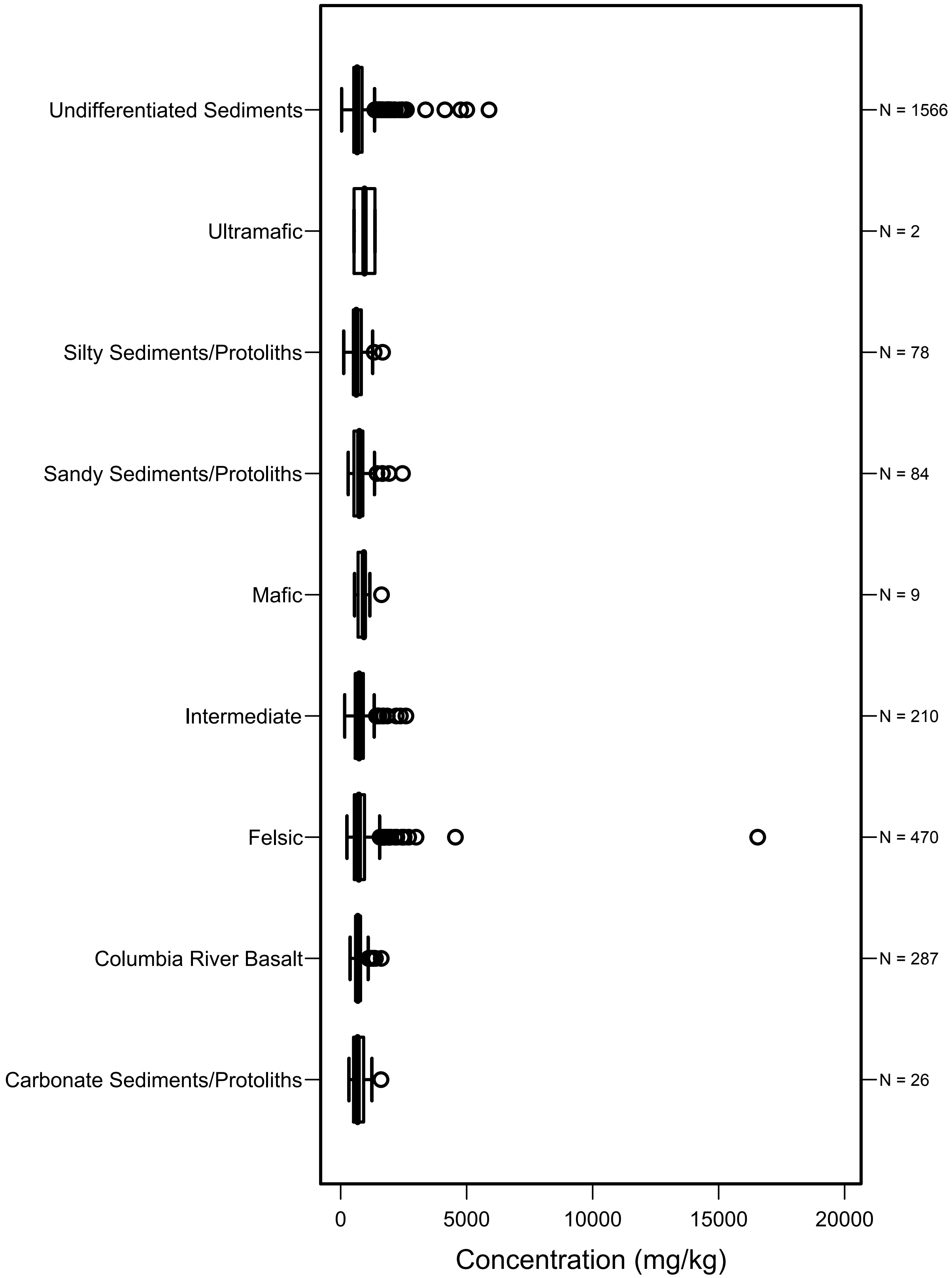


Figure 103. Variation of Background Manganese With Geology

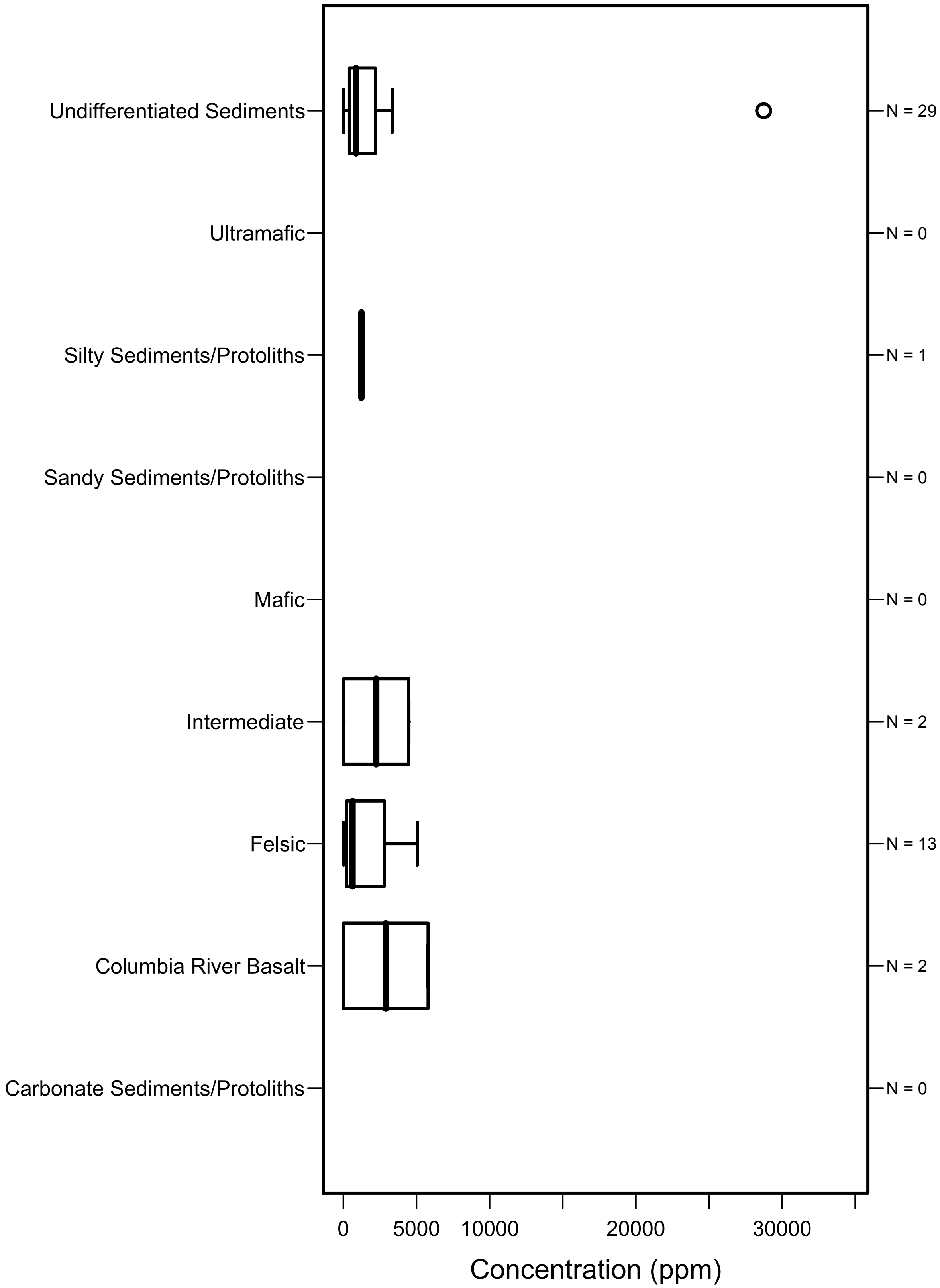


Figure 104. Variation of Background Mercury
With Geology

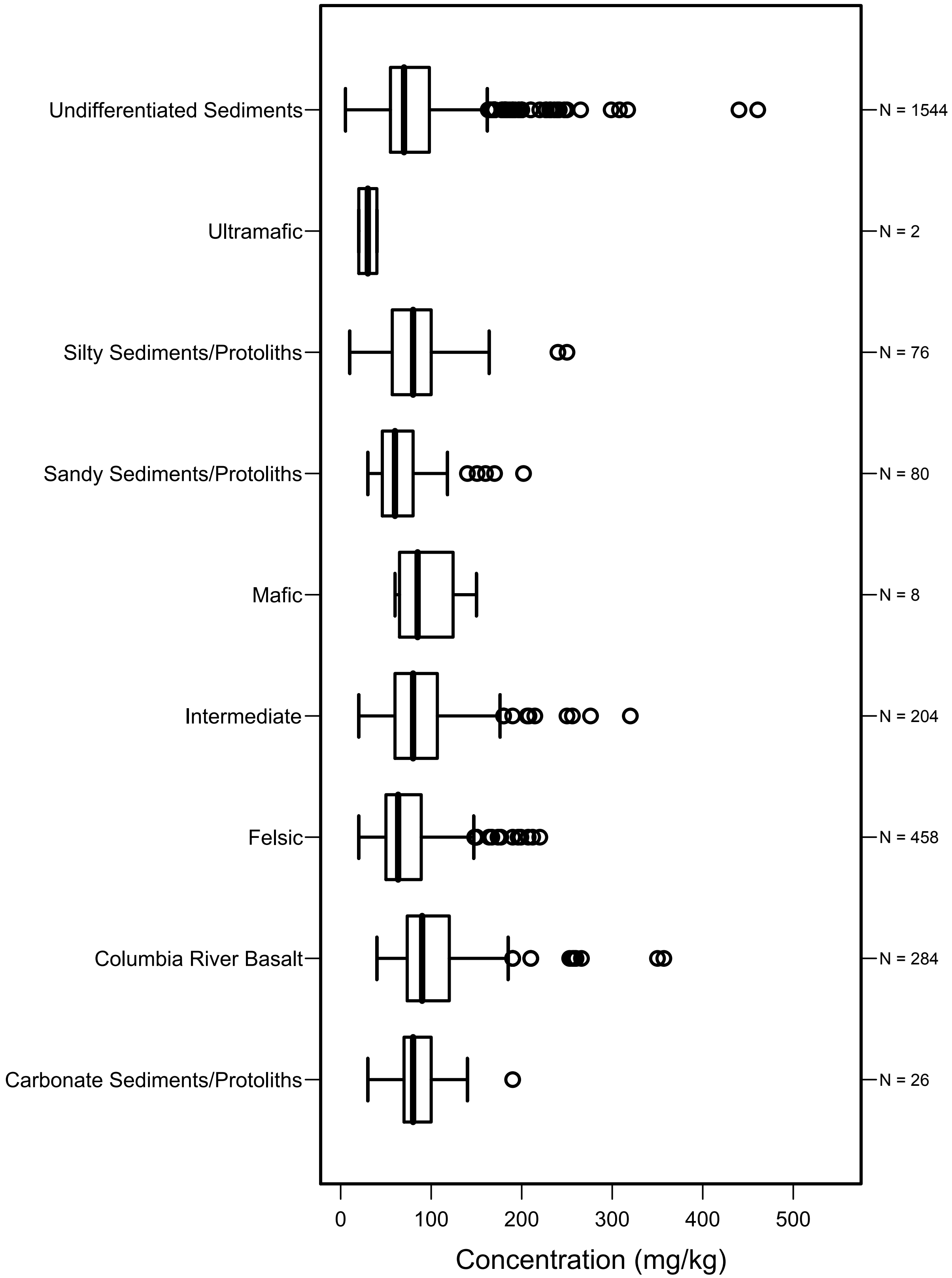


Figure 105. Variation of Background Vanadium With Geology

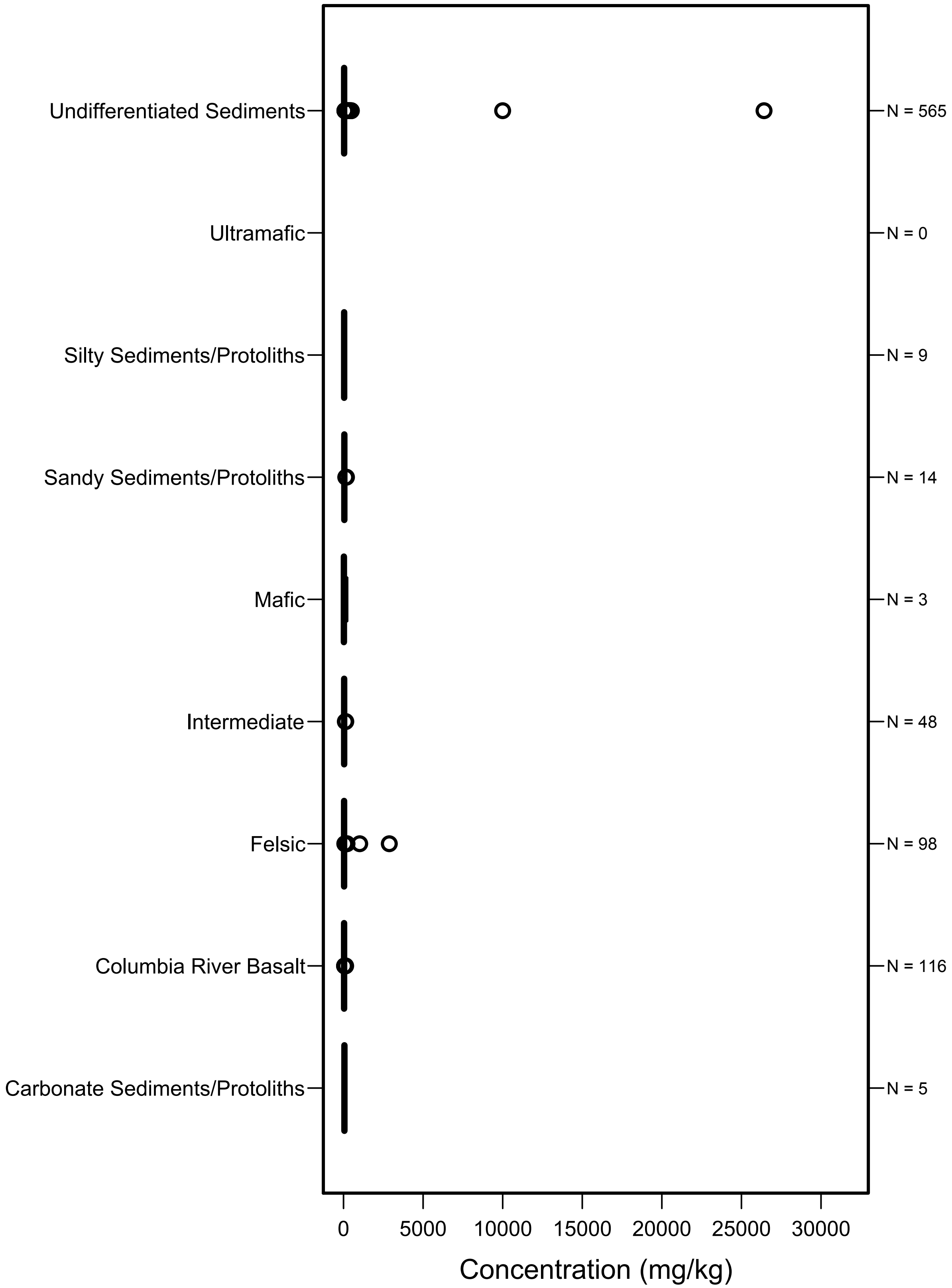


Figure 106. Variation of Background Zinc
With Geology

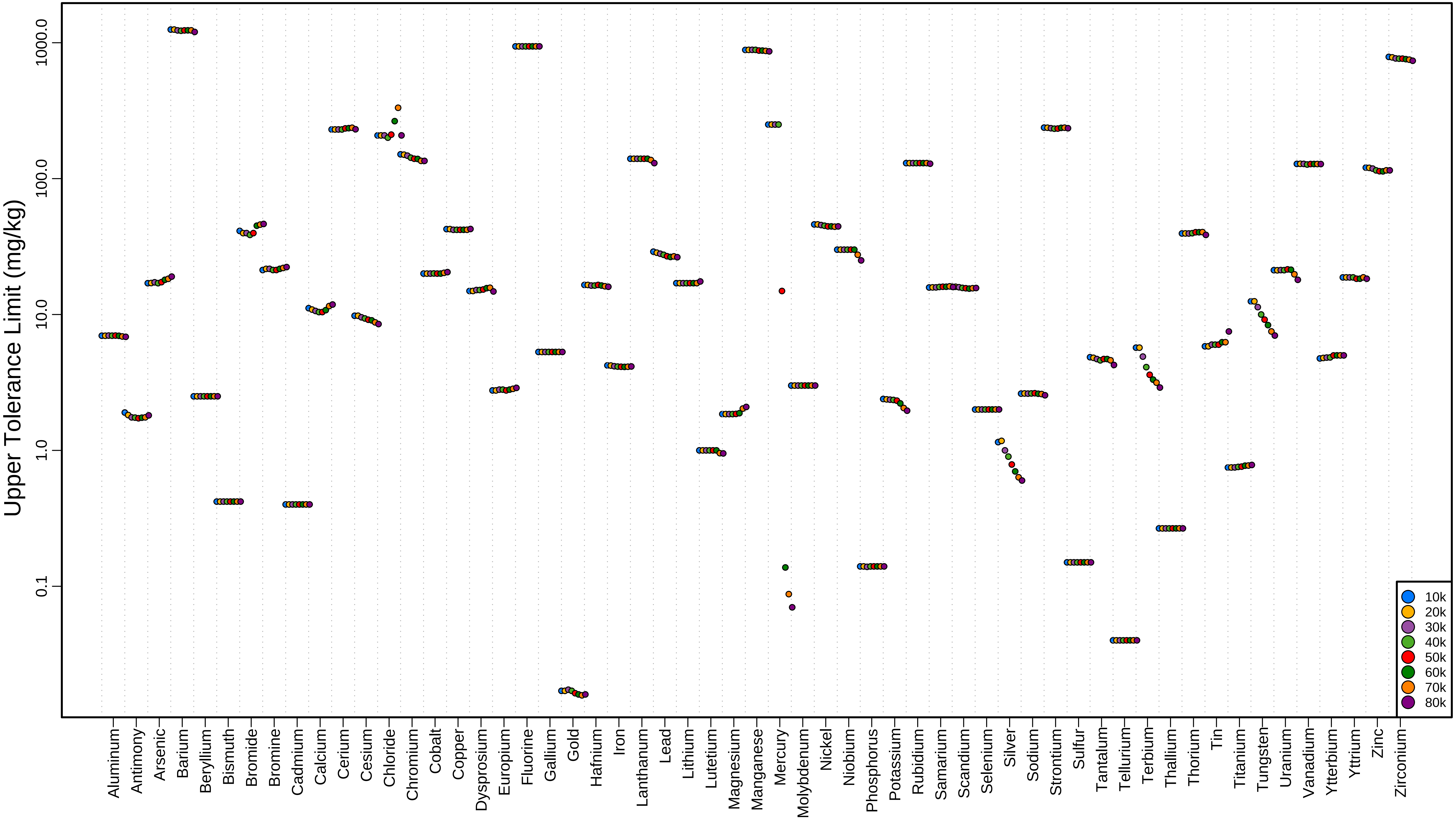


Figure 107. Upper Tolerance Limit of Background Sediment Data as a Function of Exclusion Zone Radius

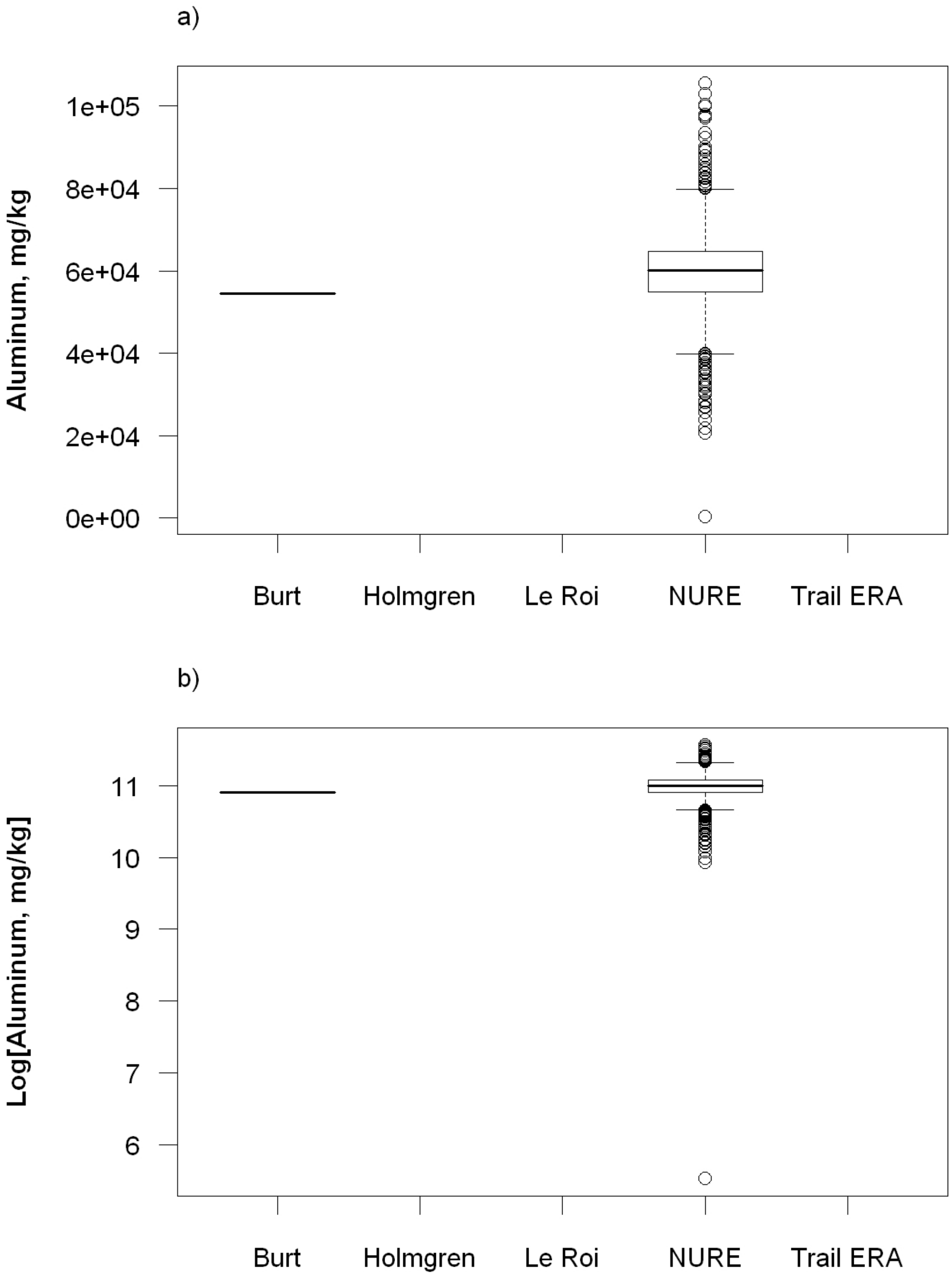


Figure 108. Distribution of Background Soil Aluminum Concentrations in Different Studies

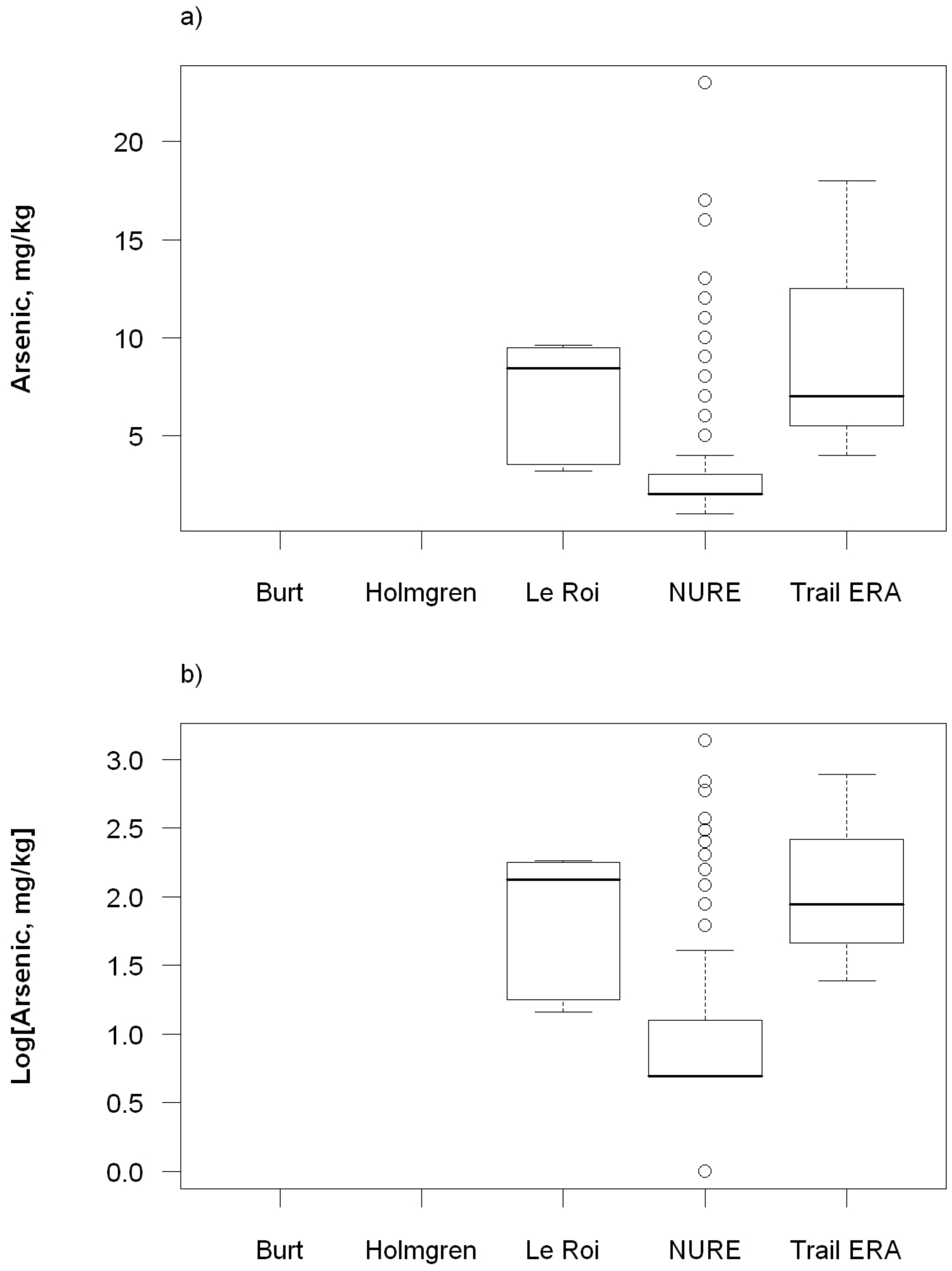


Figure 109. Distribution of Background Soil Arsenic Concentrations in Different Studies

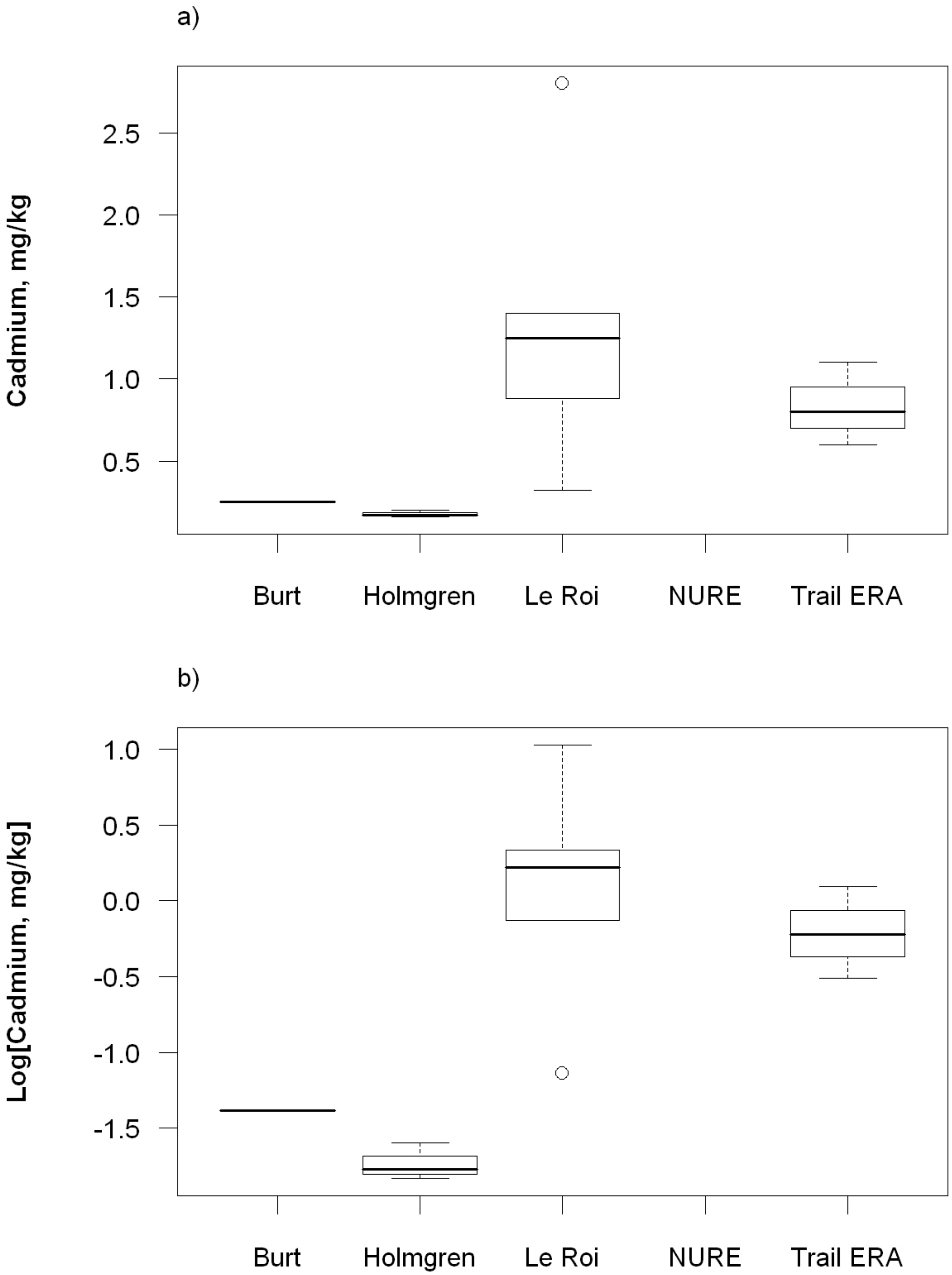


Figure 110. Distribution of Background Soil Cadmium Concentrations in Different Studies

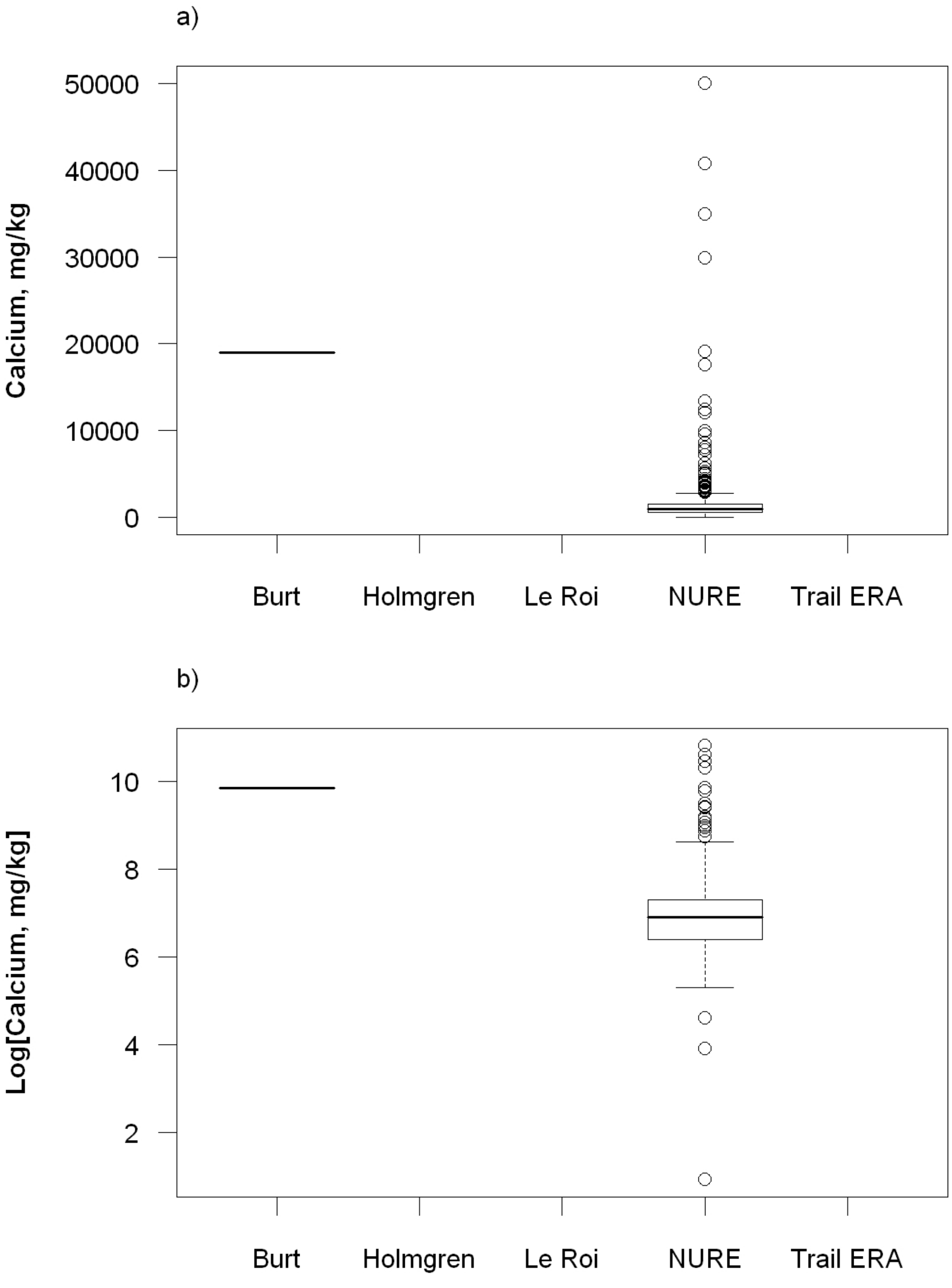


Figure 111. Distribution of Background Soil Calcium Concentrations in Different Studies

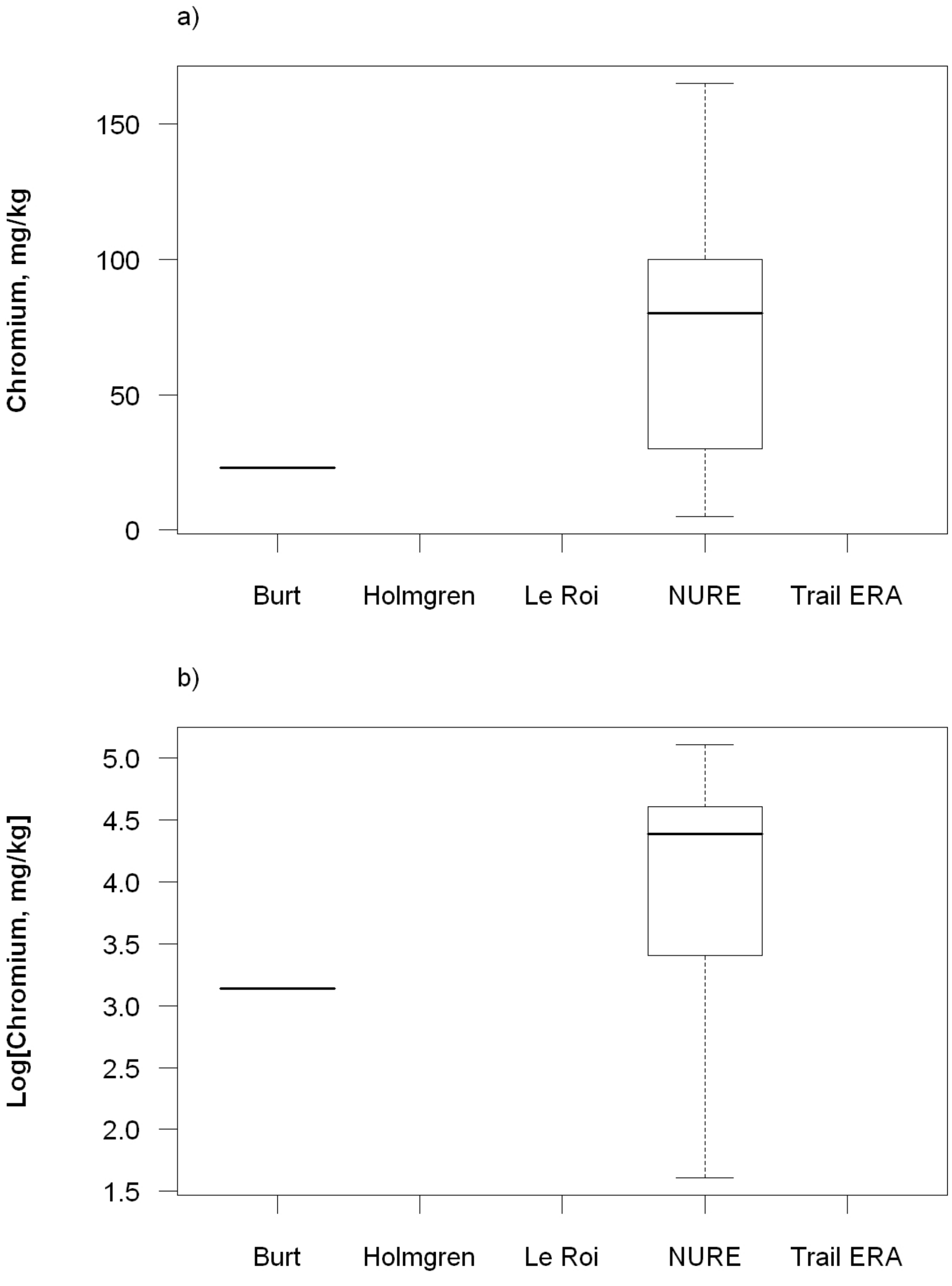


Figure 112. Distribution of Background Soil Chromium Concentrations in Different Studies

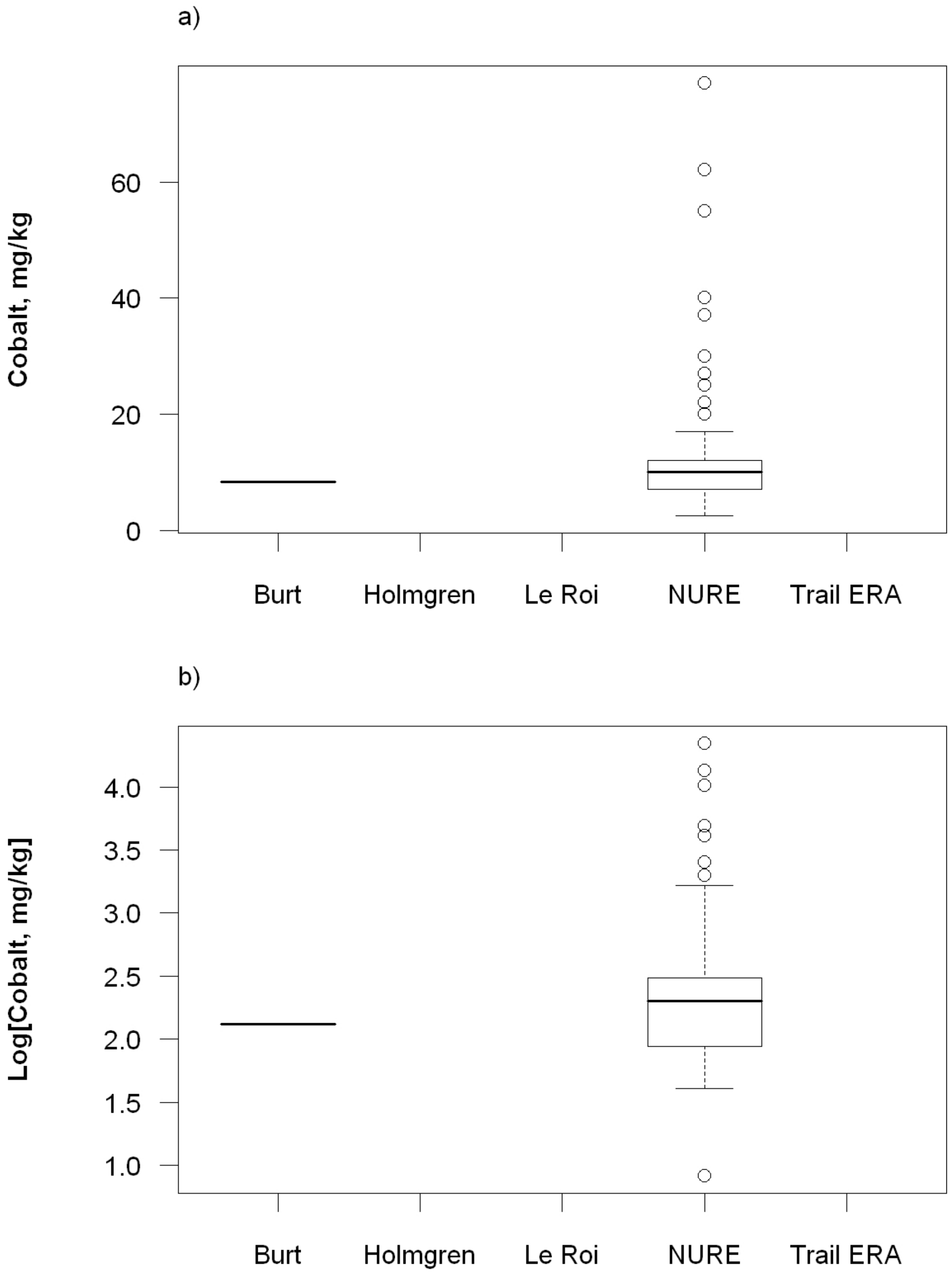


Figure 113. Distribution of Background Soil
Cobalt Concentrations in Different Studies

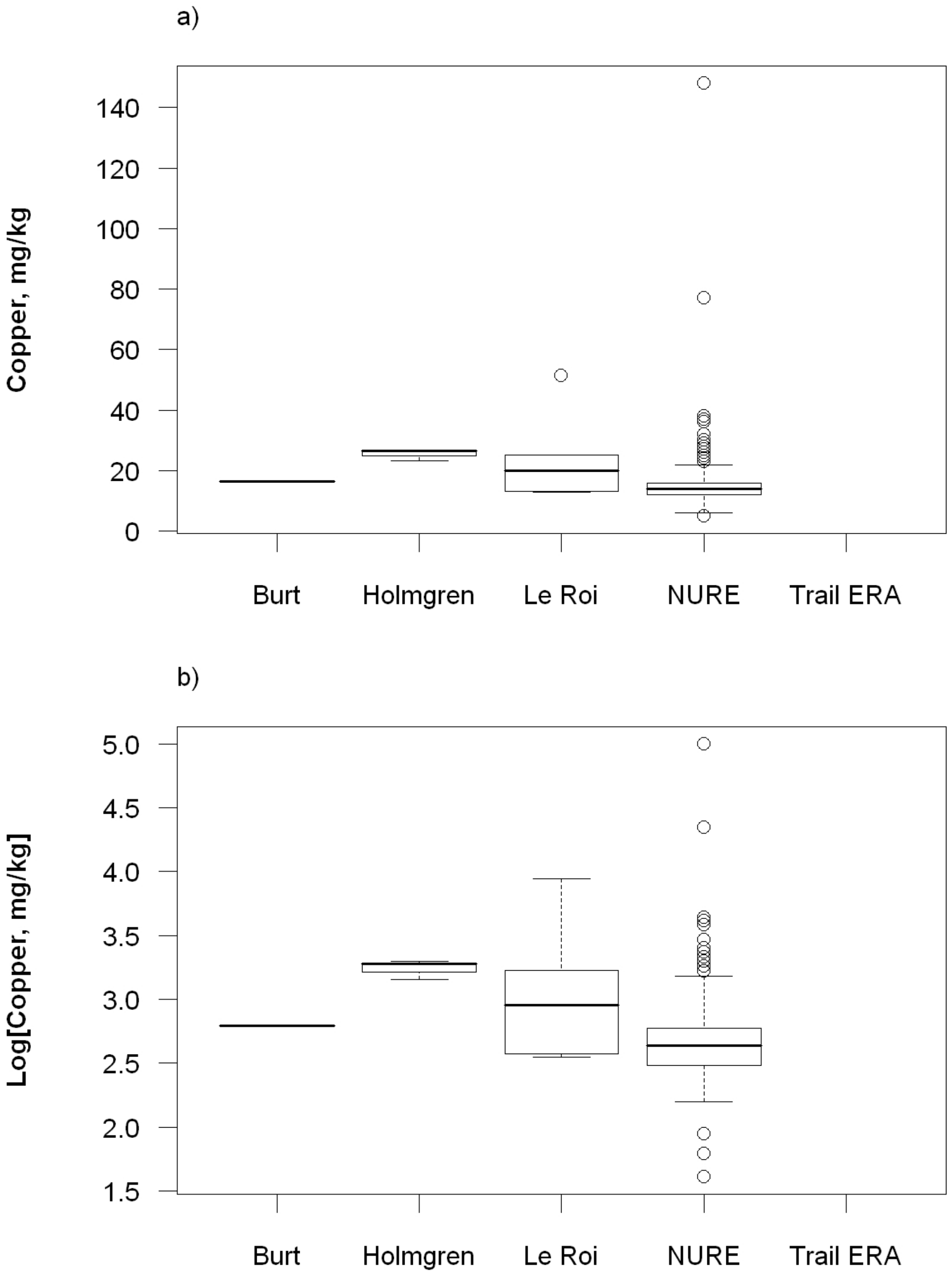


Figure 114. Distribution of Background Soil Copper Concentrations in Different Studies

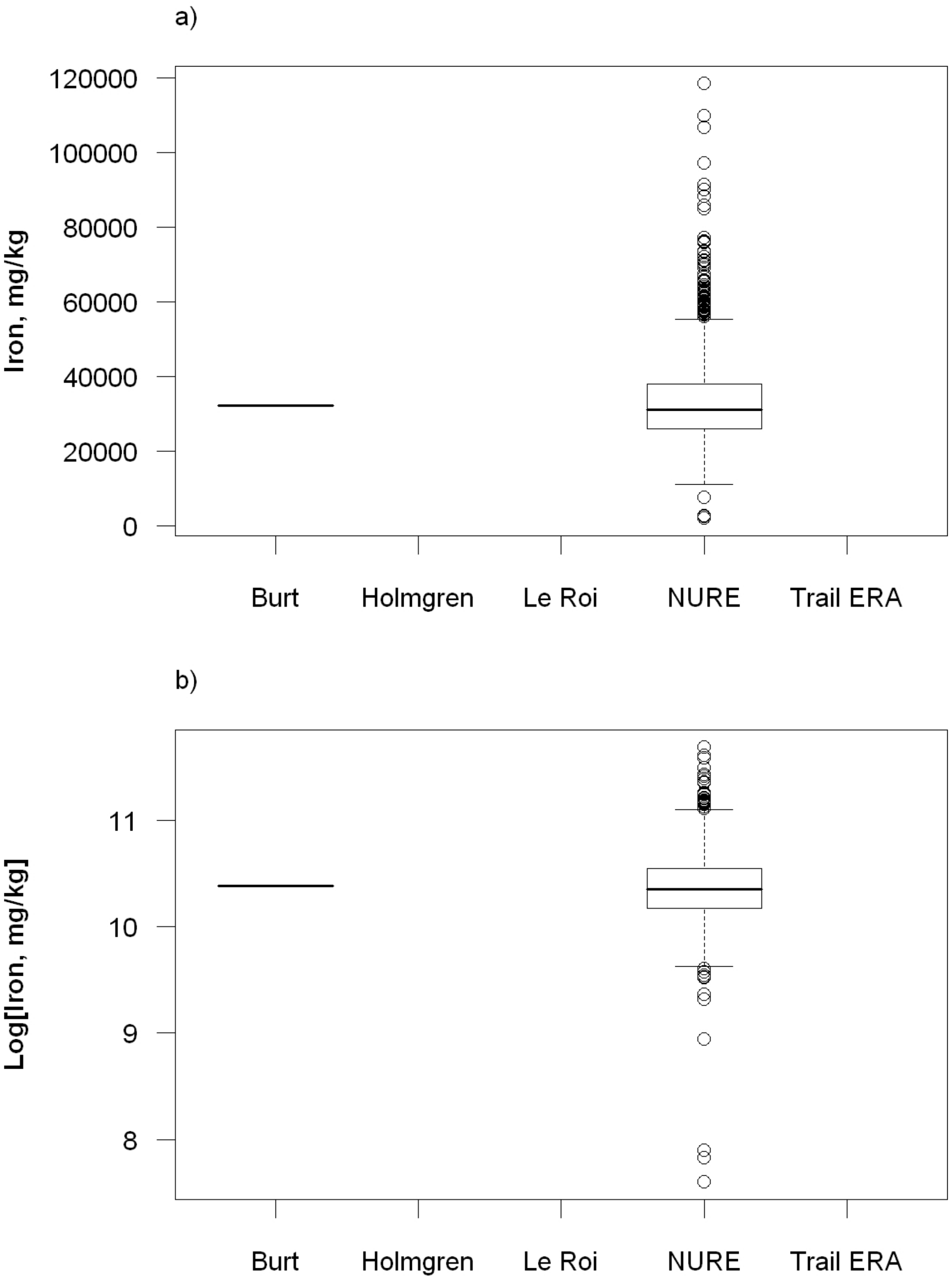


Figure 115. Distribution of Background Soil Iron Concentrations in Different Studies

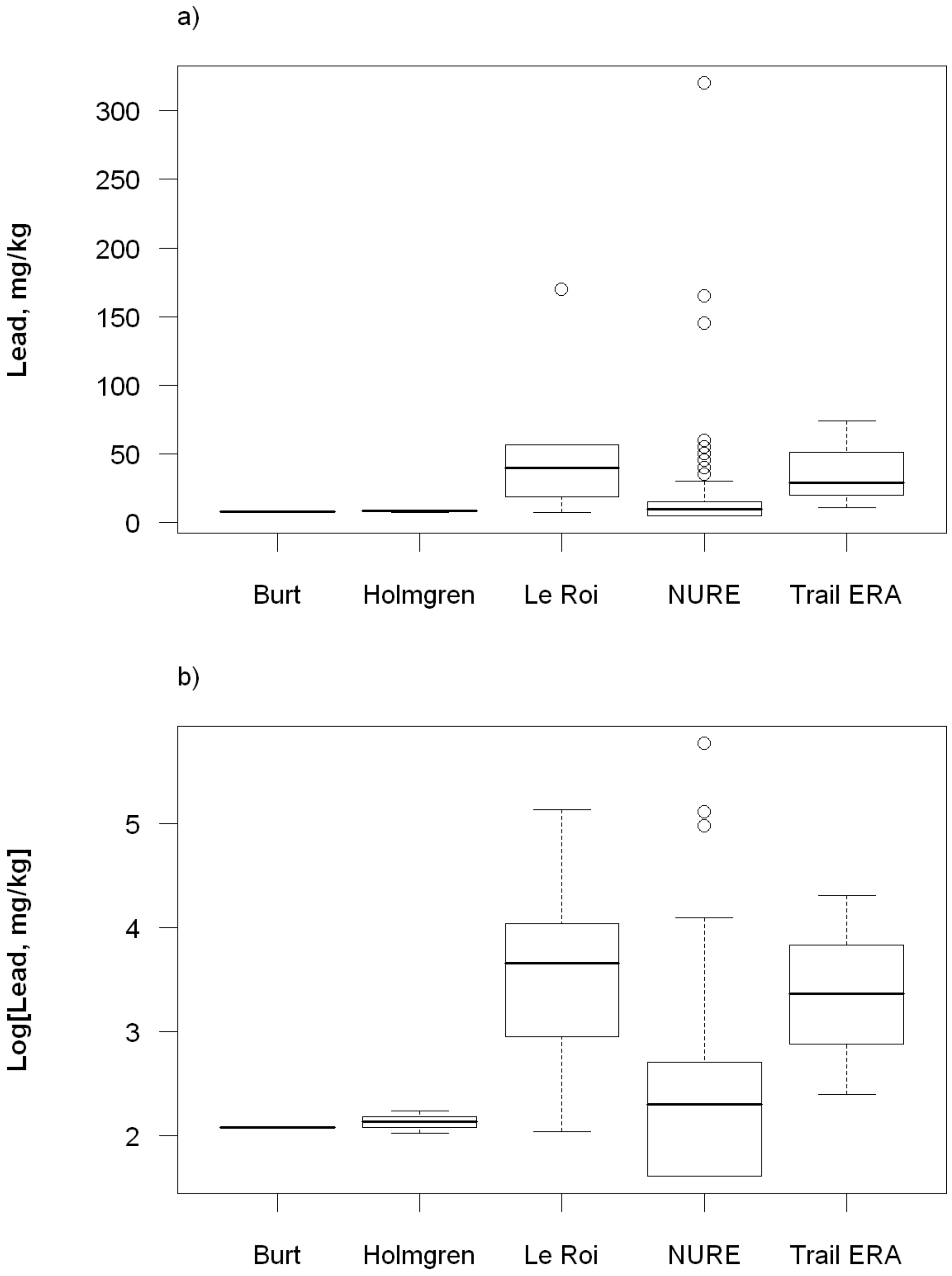


Figure 116. Distribution of Background Soil Lead Concentrations in Different Studies

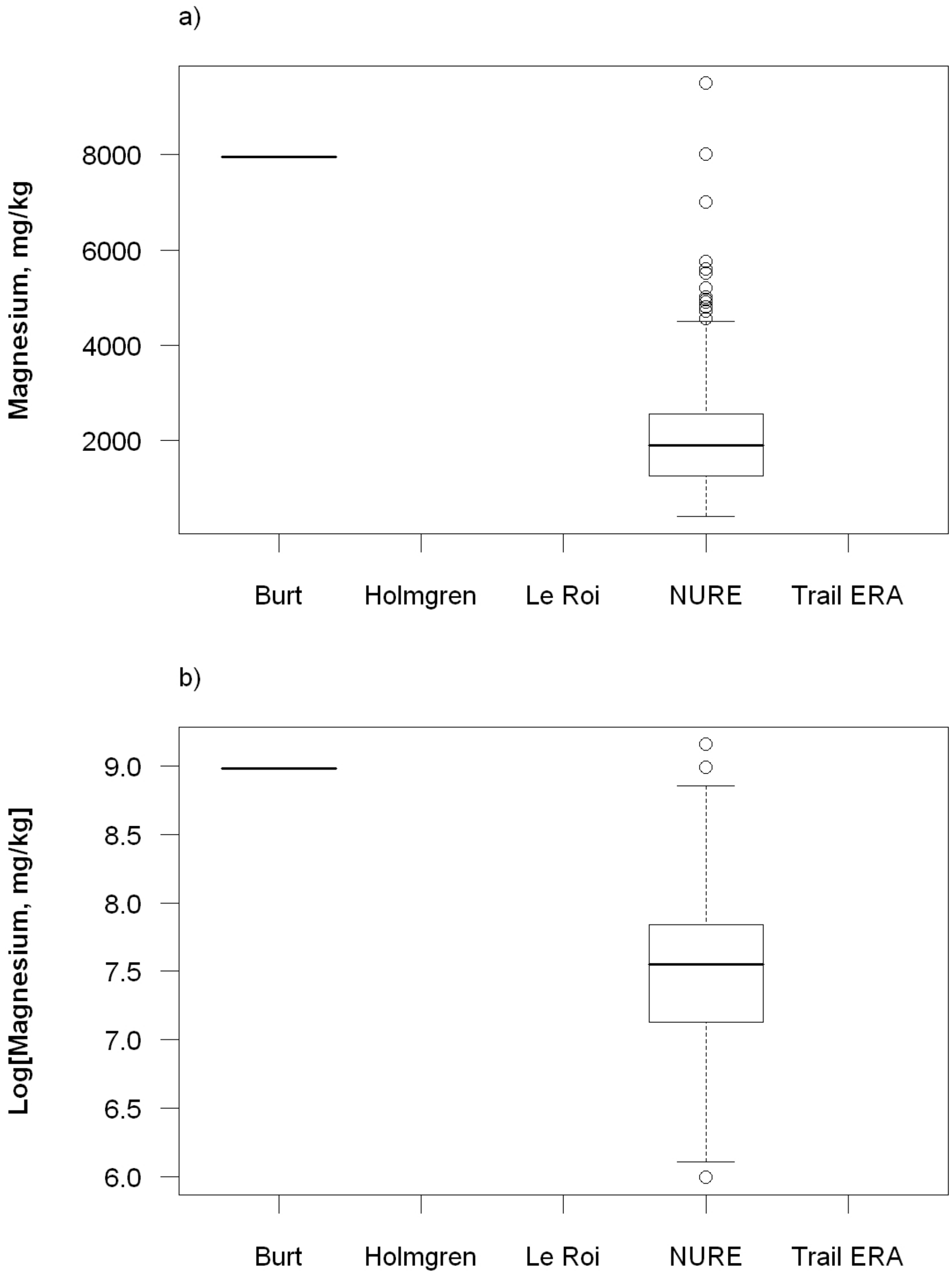


Figure 117. Distribution of Background Soil Magnesium Concentrations in Different Studies

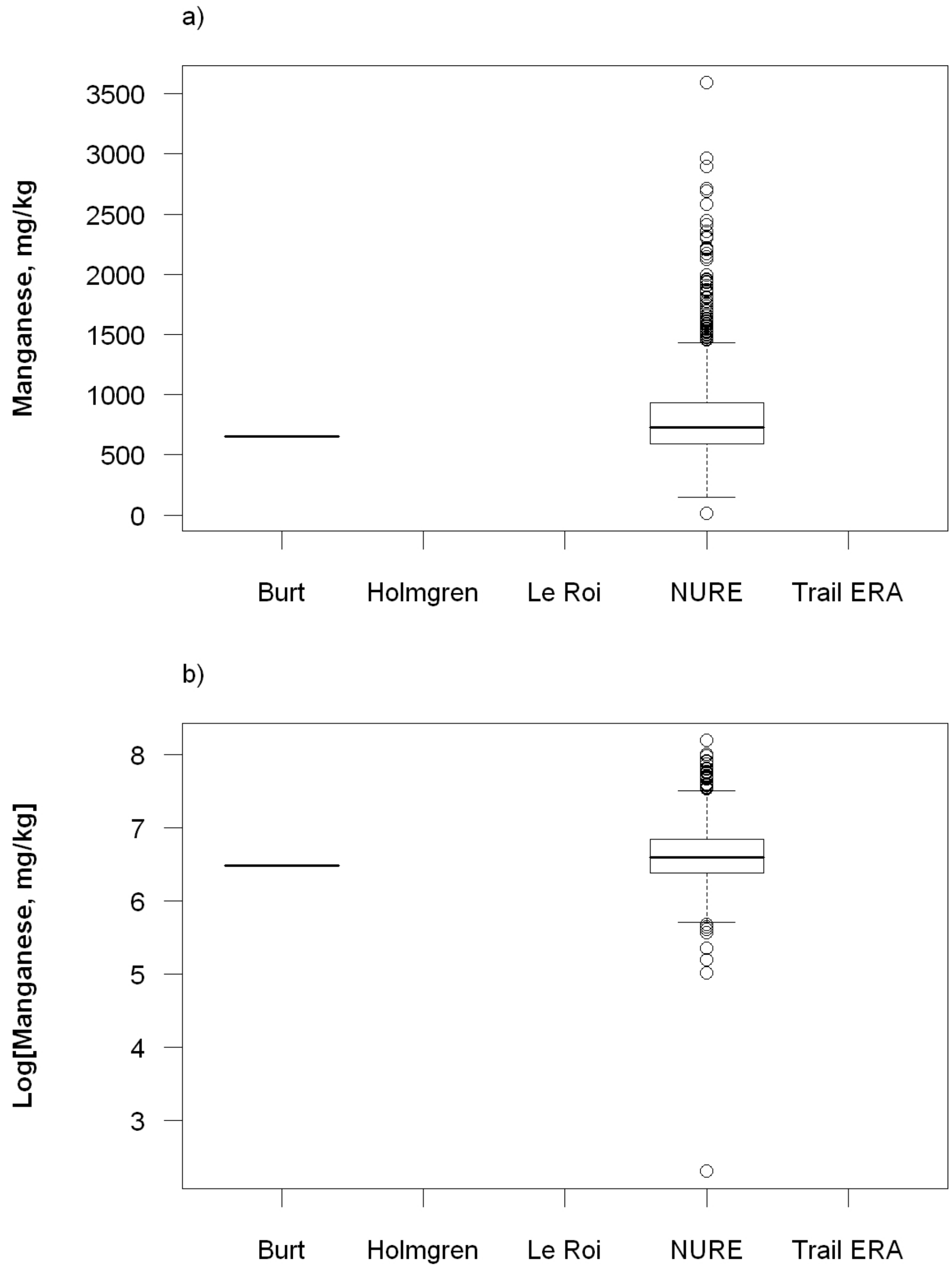


Figure 118. Distribution of Background Soil Manganese Concentrations in Different Studies

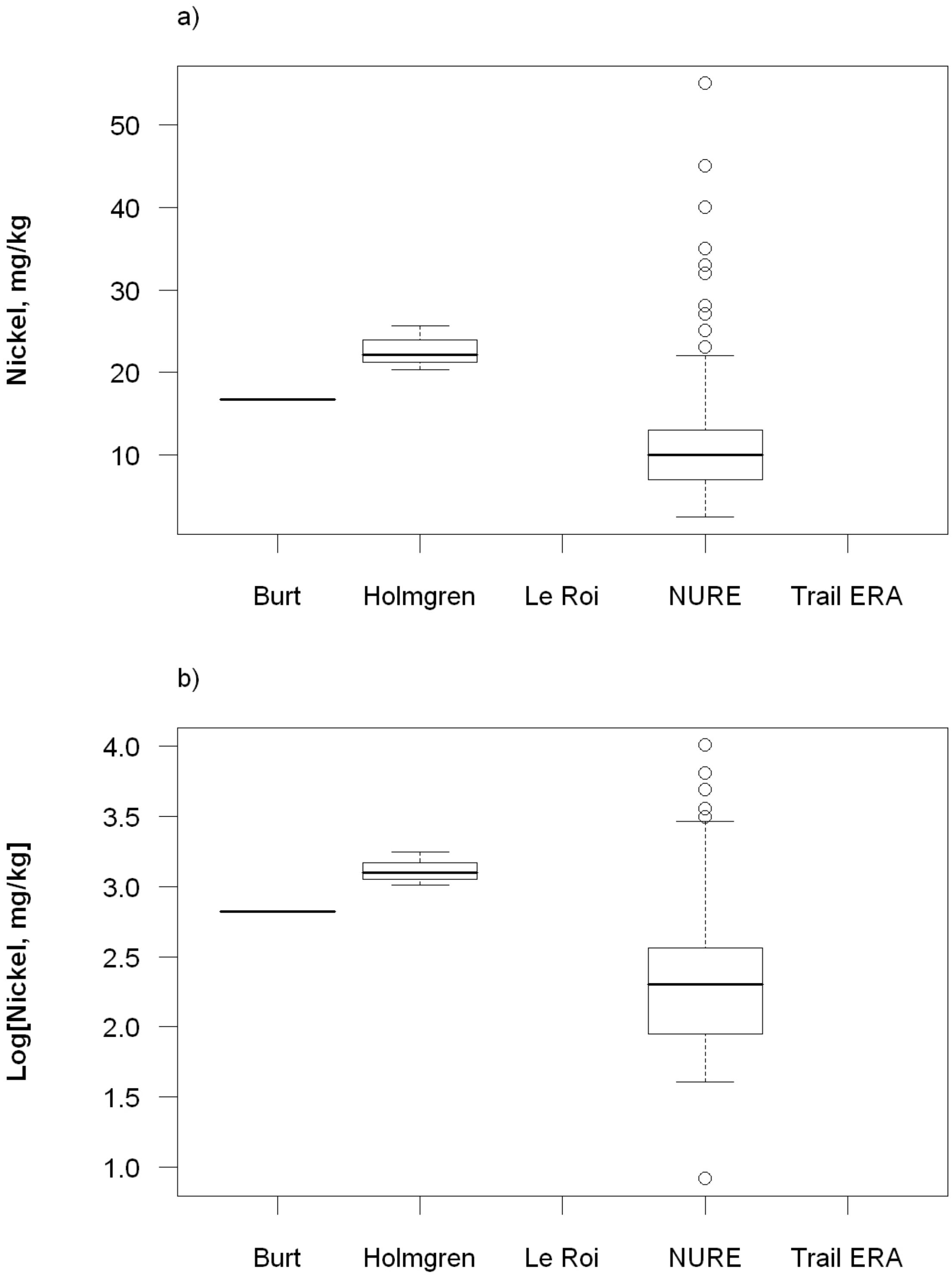


Figure 119. Distribution of Background Soil Nickel Concentrations in Different Studies

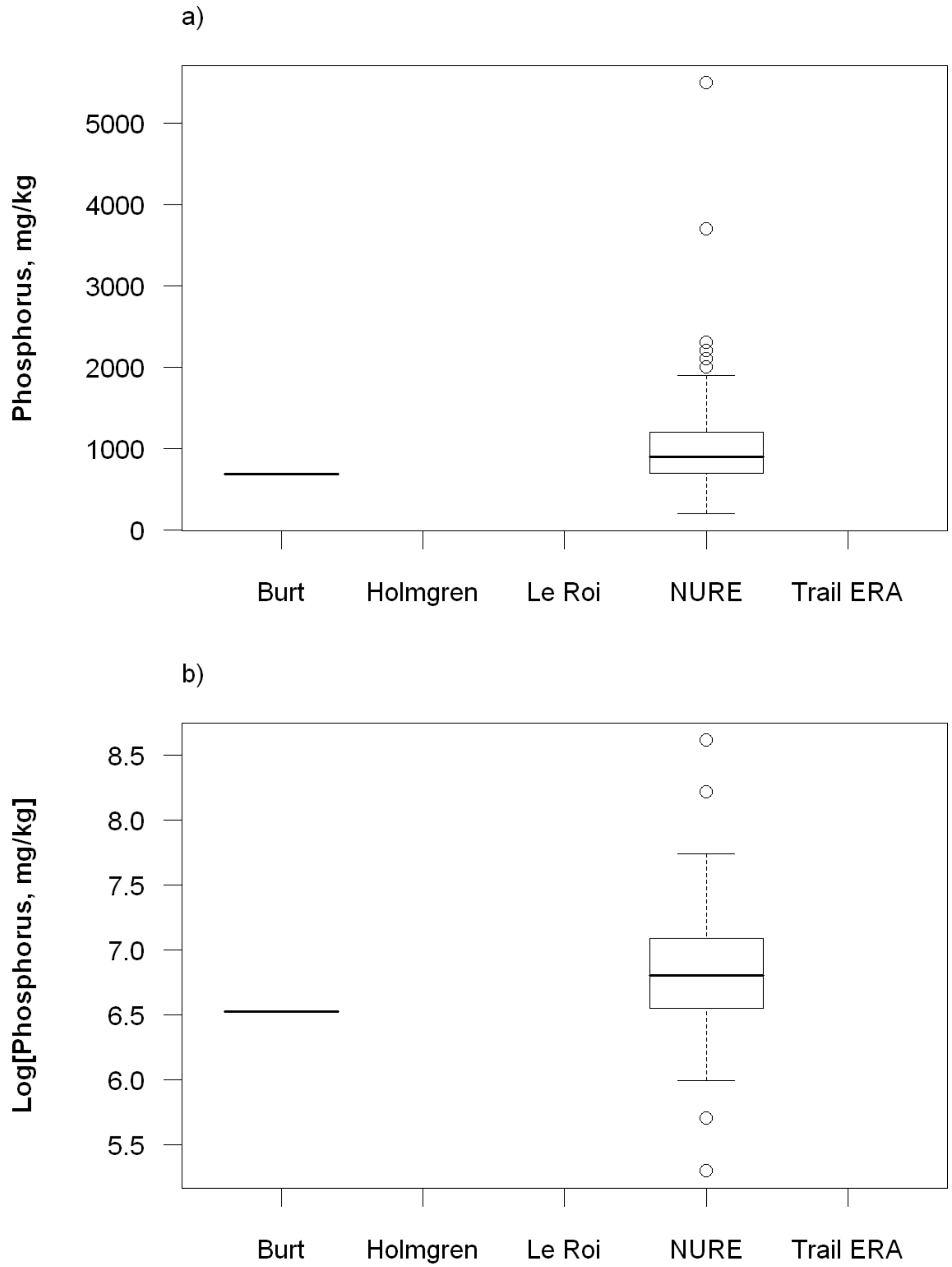


Figure 120. Distribution of Background Soil
Phosphorus Concentrations in Different Studies

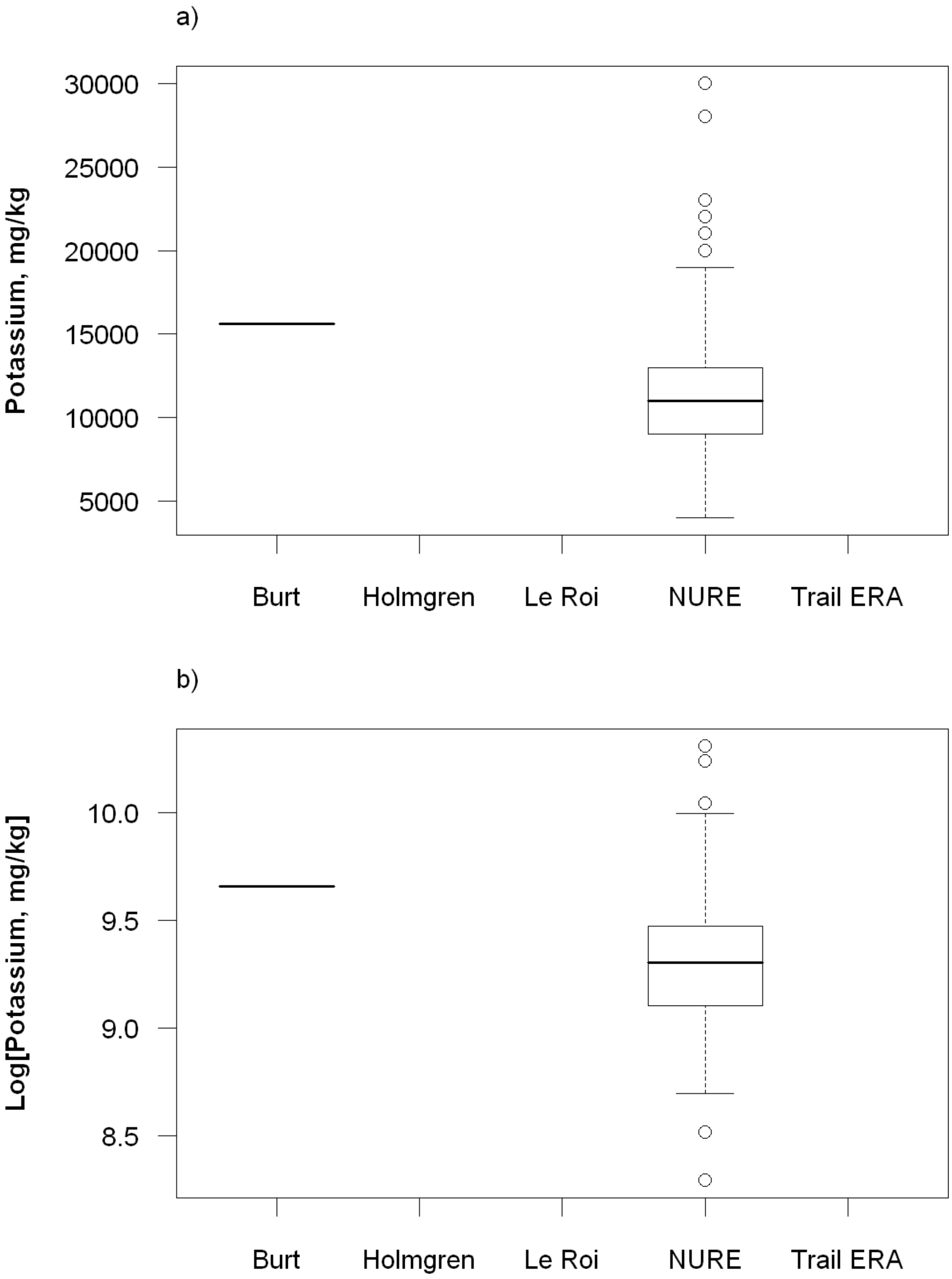


Figure 121. Distribution of Background Soil Potassium Concentrations in Different Studies

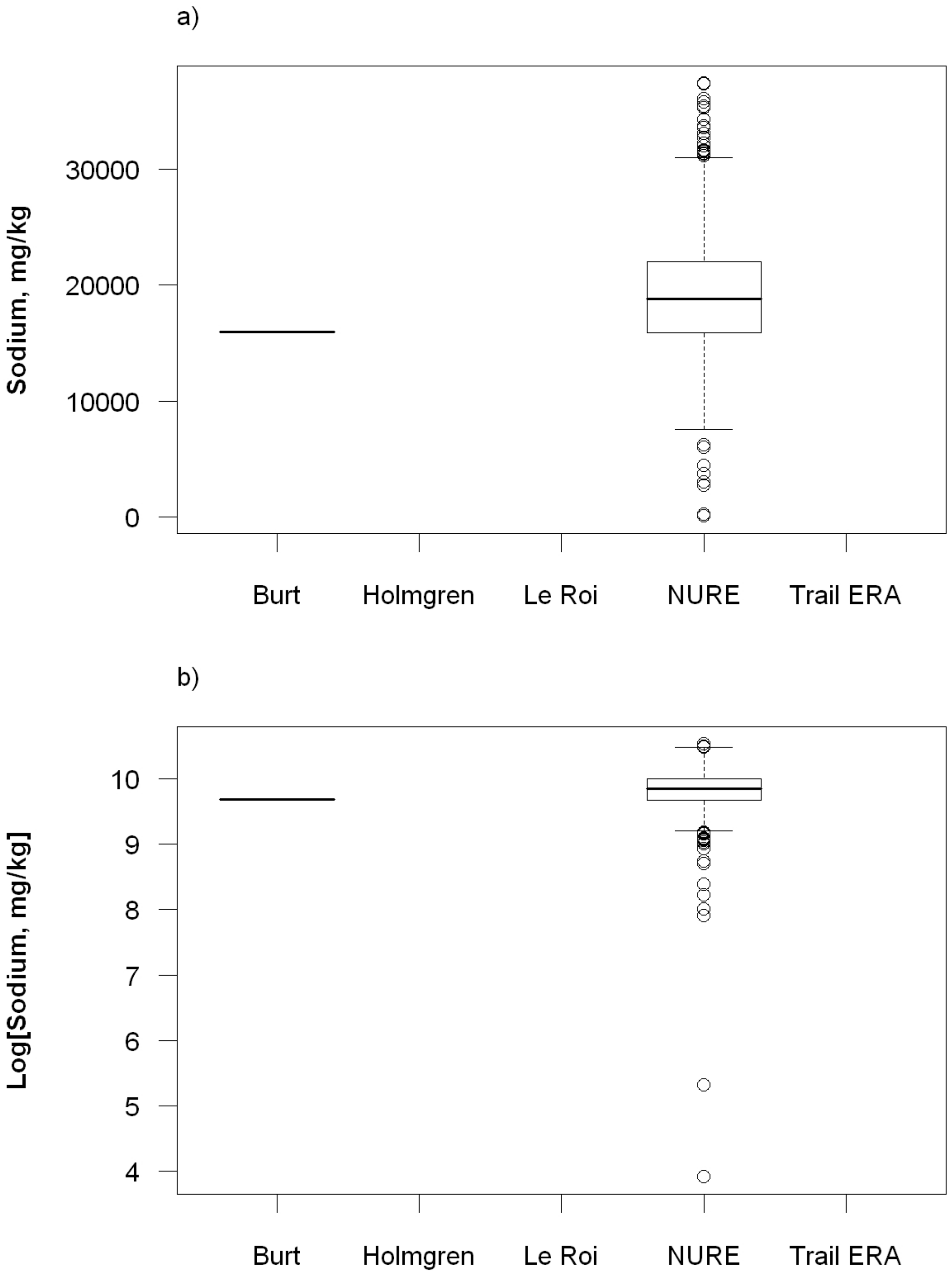


Figure 122. Distribution of Background Soil Sodium Concentrations in Different Studies

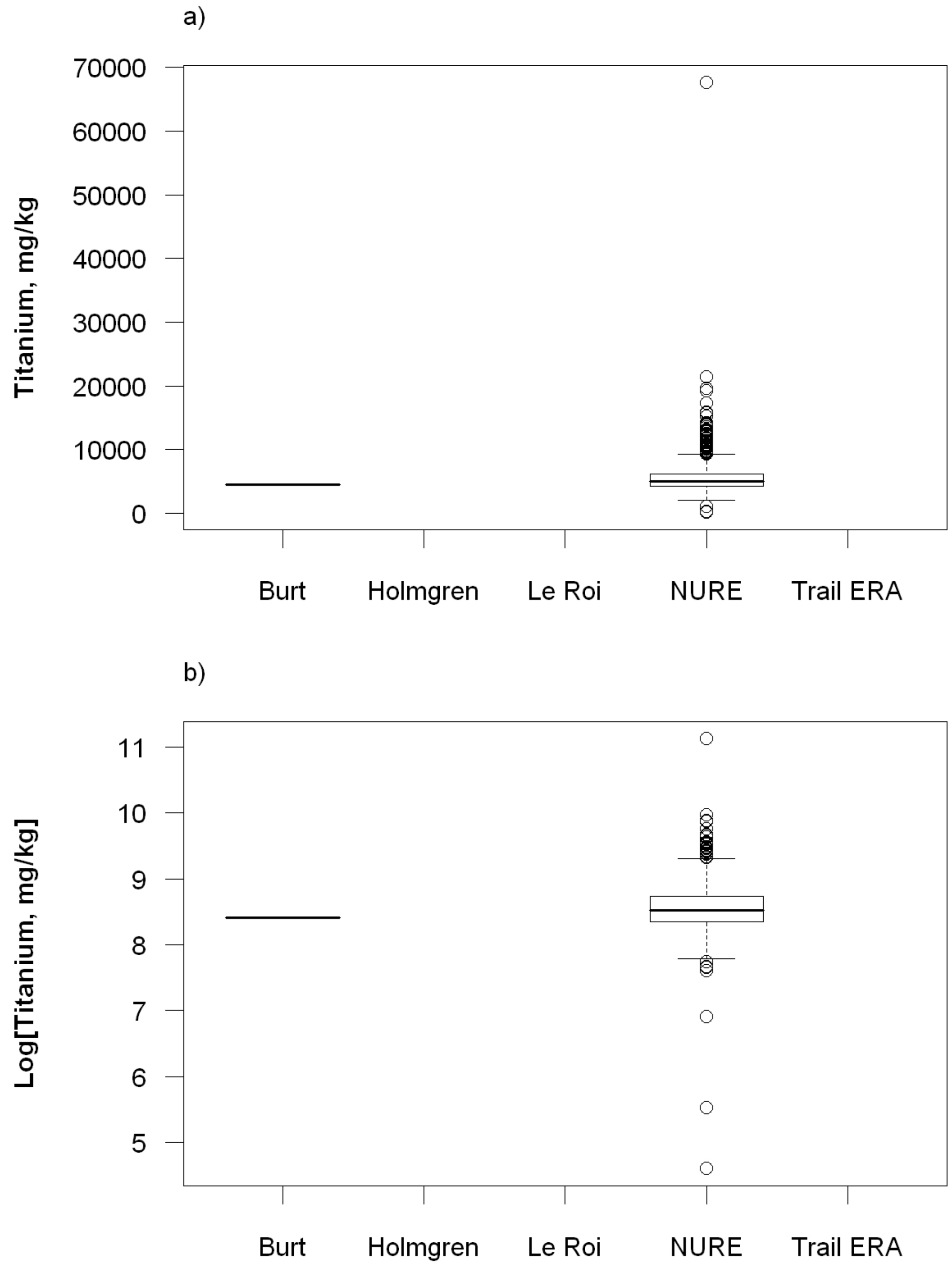


Figure 123. Distribution of Background Soil Titanium Concentrations in Different Studies

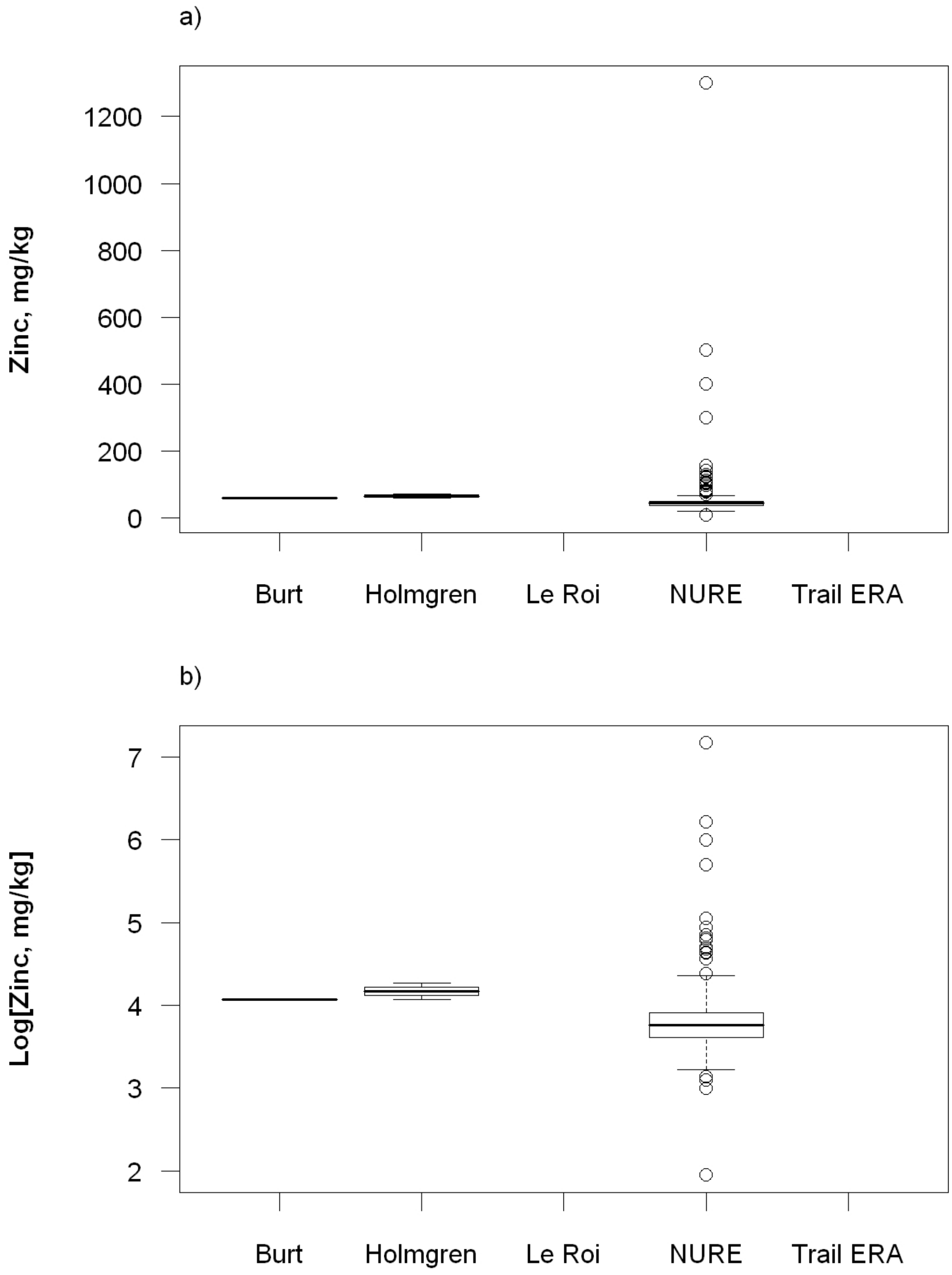


Figure 124. Distribution of Background Soil Zinc Concentrations in Different Studies

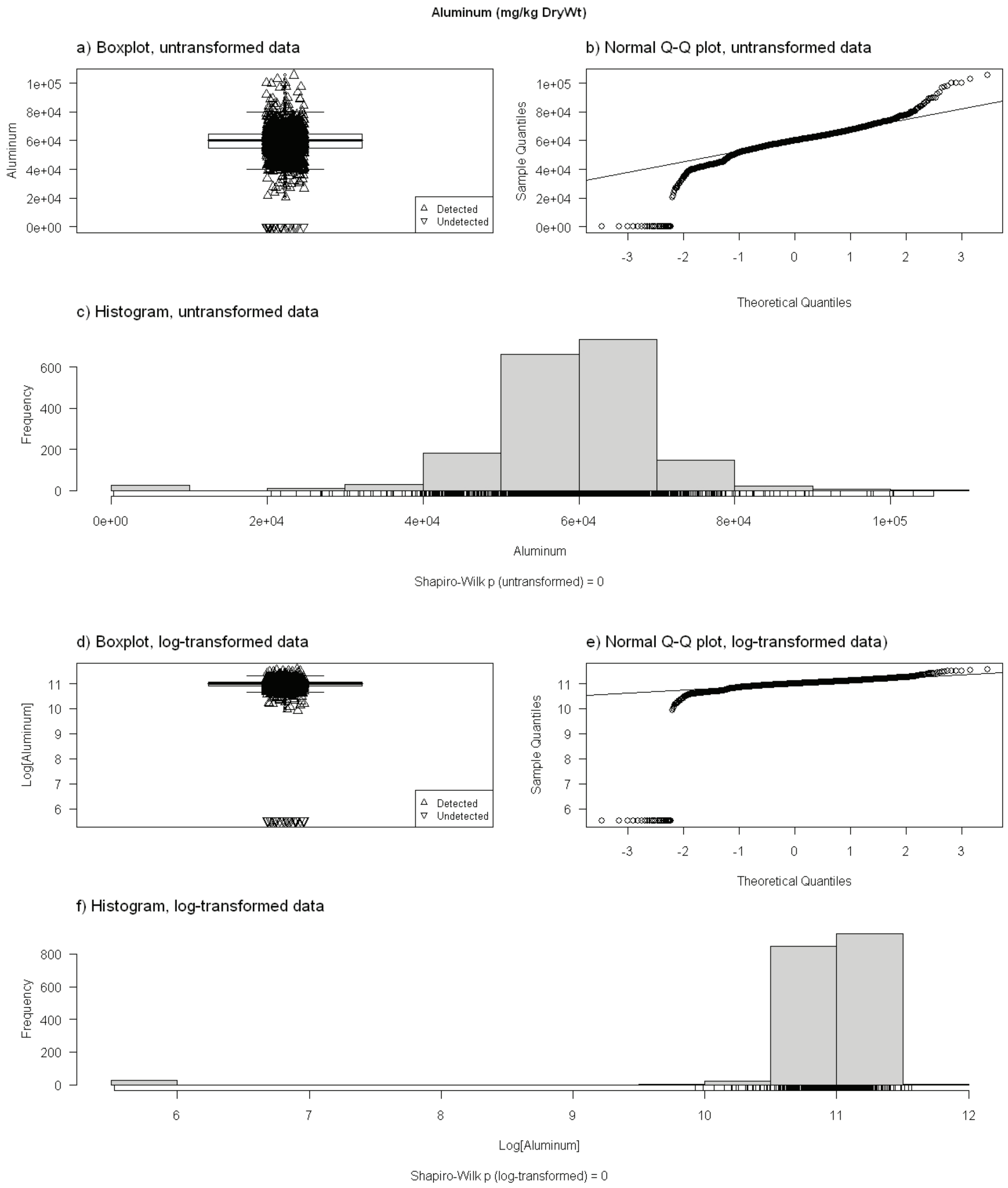
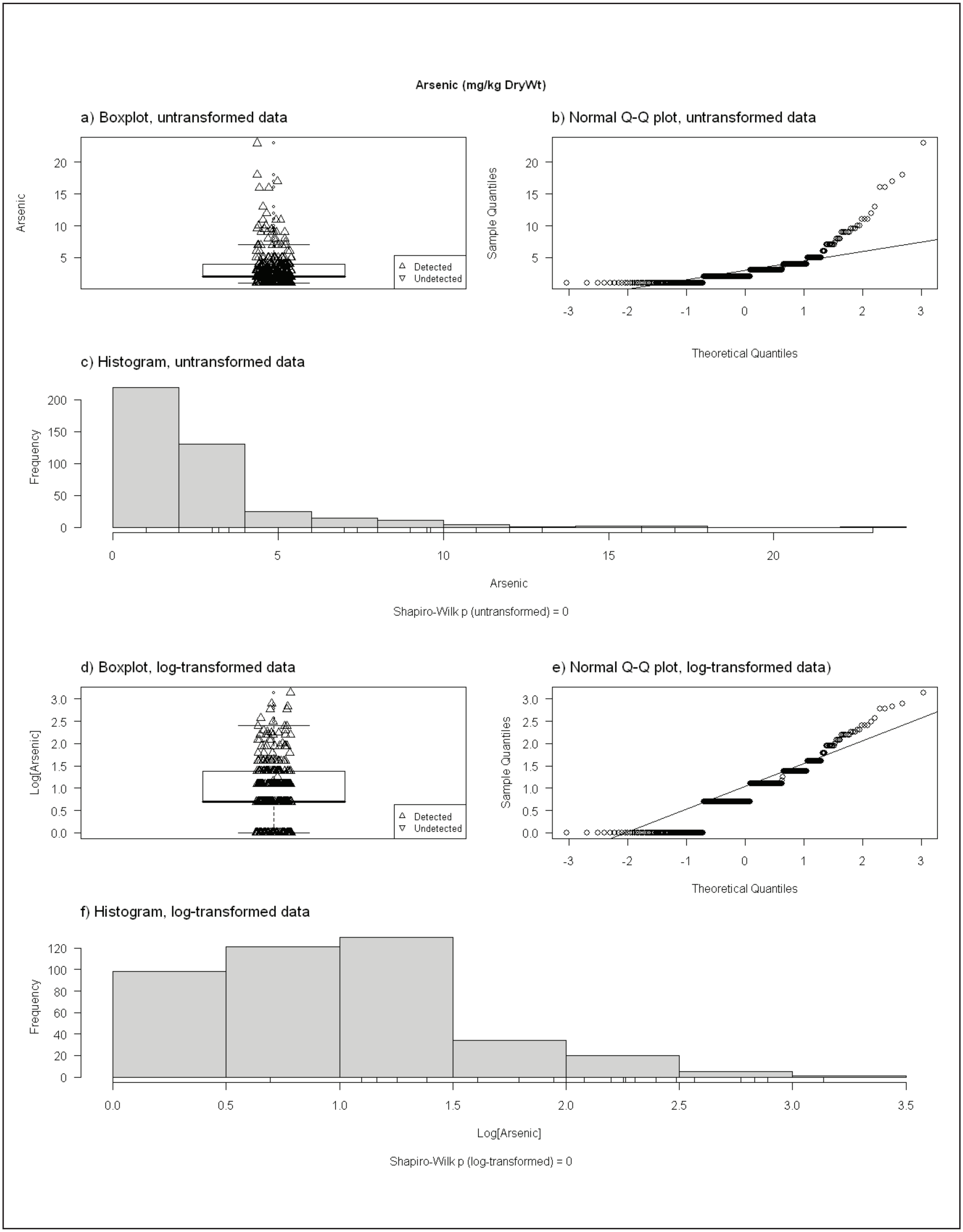


Figure 125. Distribution of All Background Concentrations of Aluminum in Soil


Arsenic (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 126. Distribution of All Background Concentrations of Arsenic in Soil

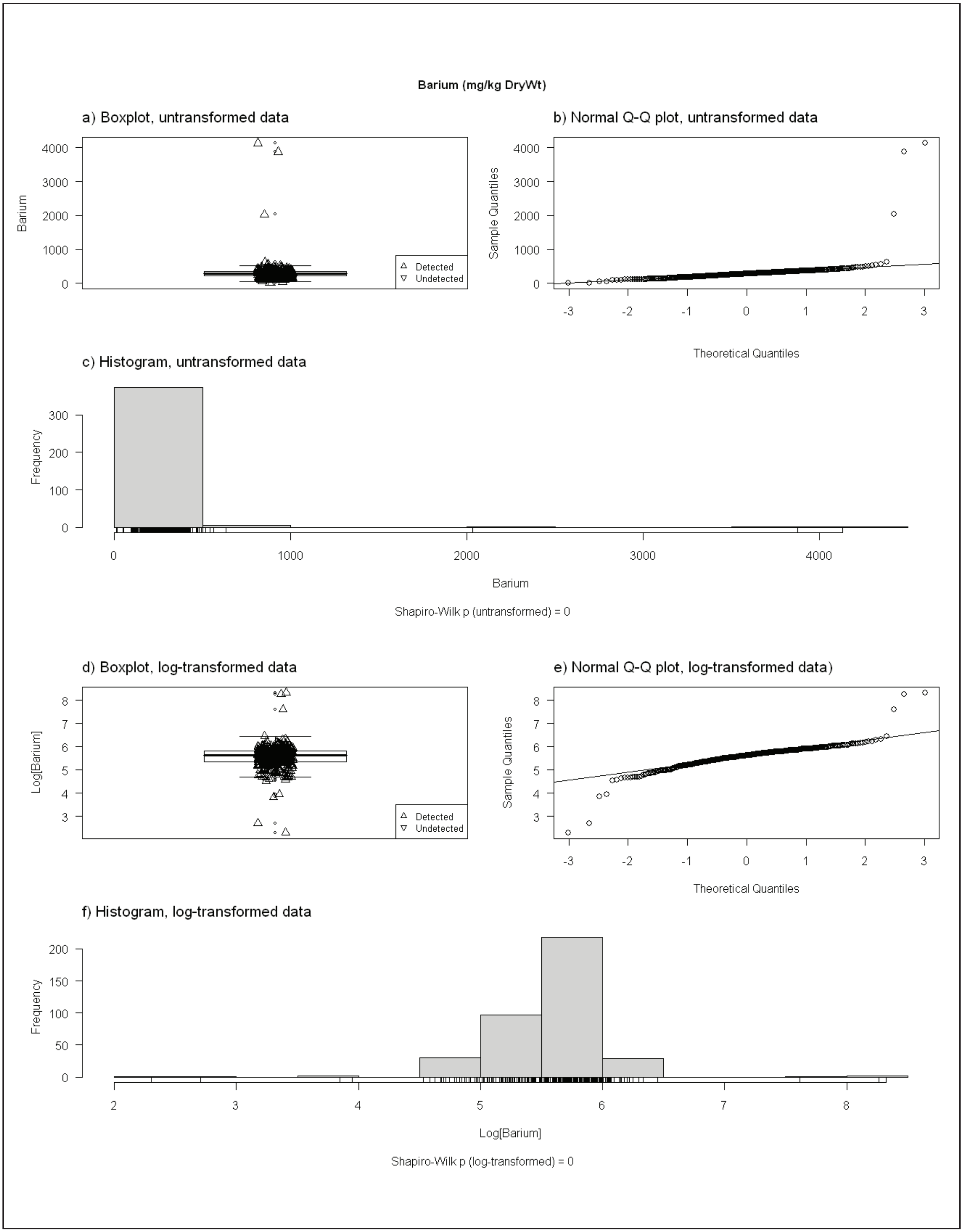


Figure 127. Distribution of All Background Concentrations of Barium in Soil

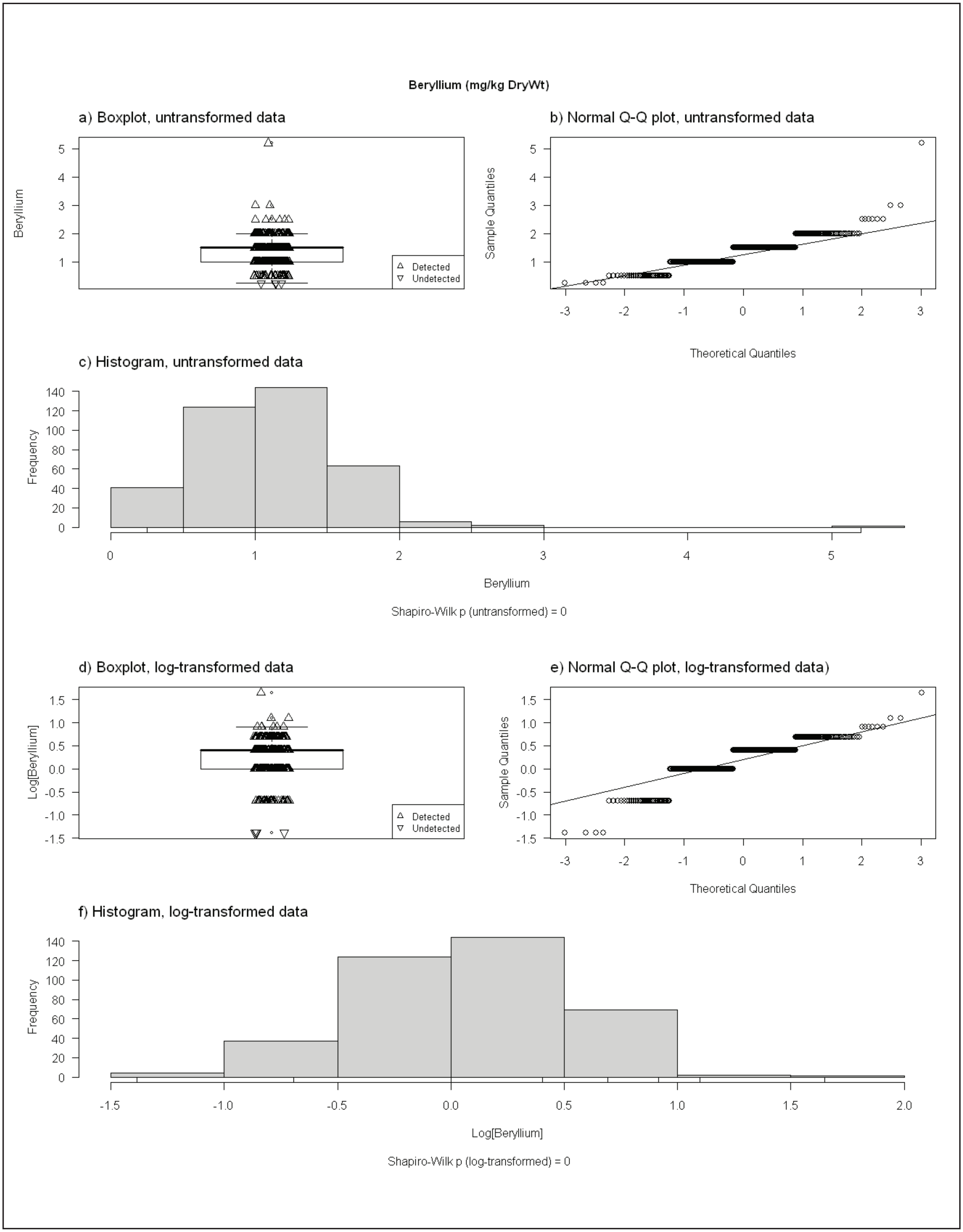


Figure 128. Distribution of All Background Concentrations of Beryllium in Soil

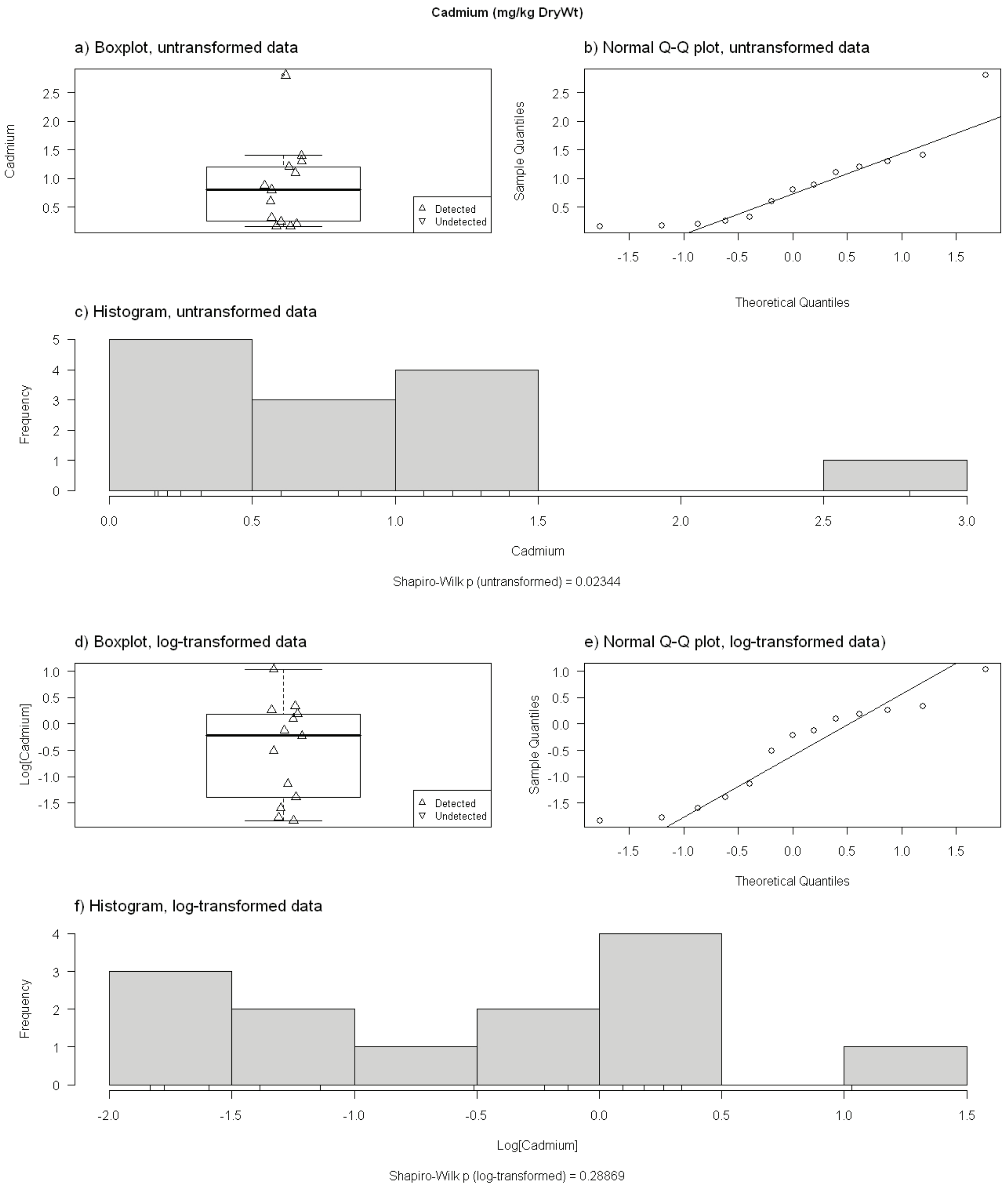


Figure 129. Distribution of All Background Concentrations of Cadmium in Soil

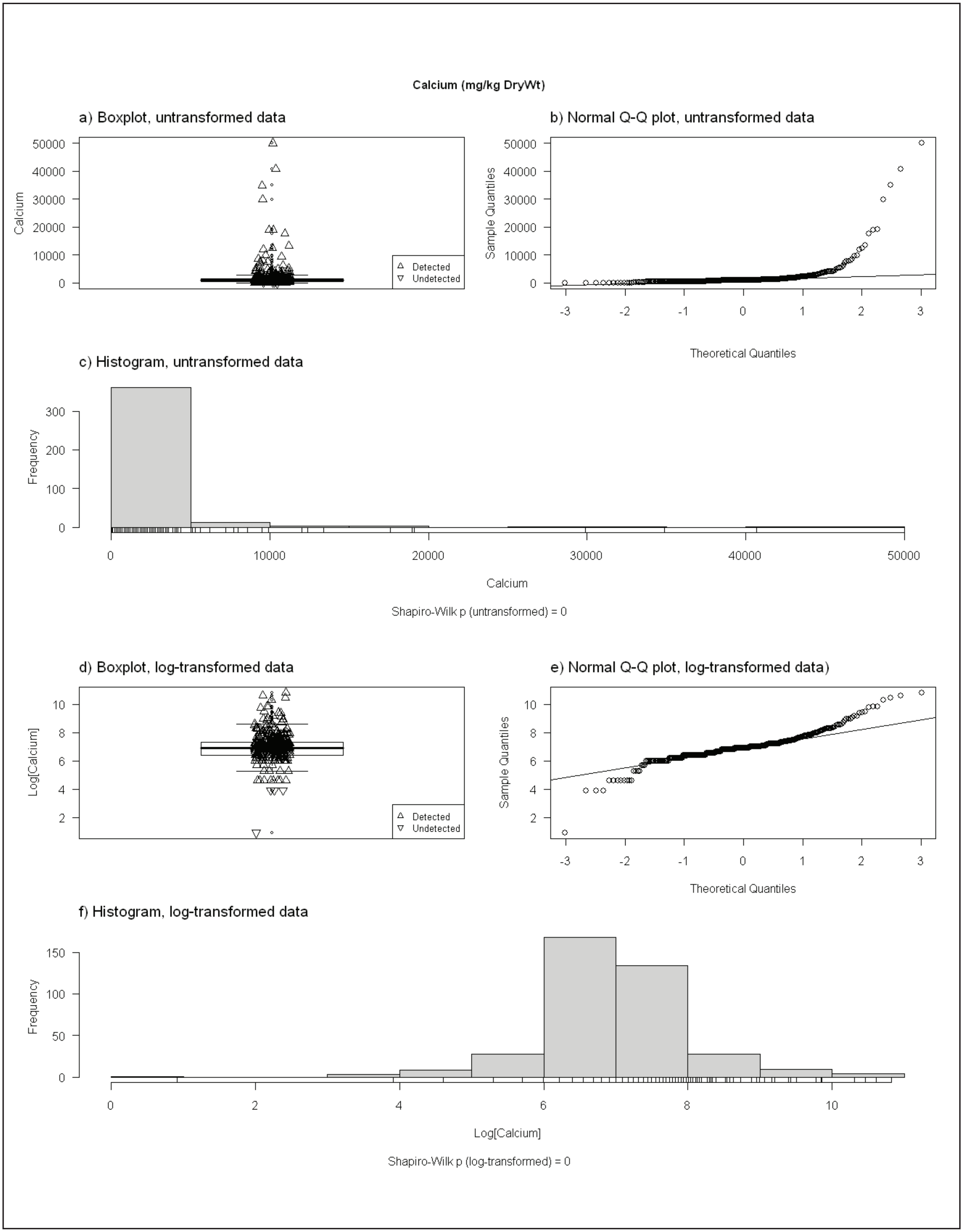


Figure 130. Distribution of All Background Concentrations of Calcium in Soil

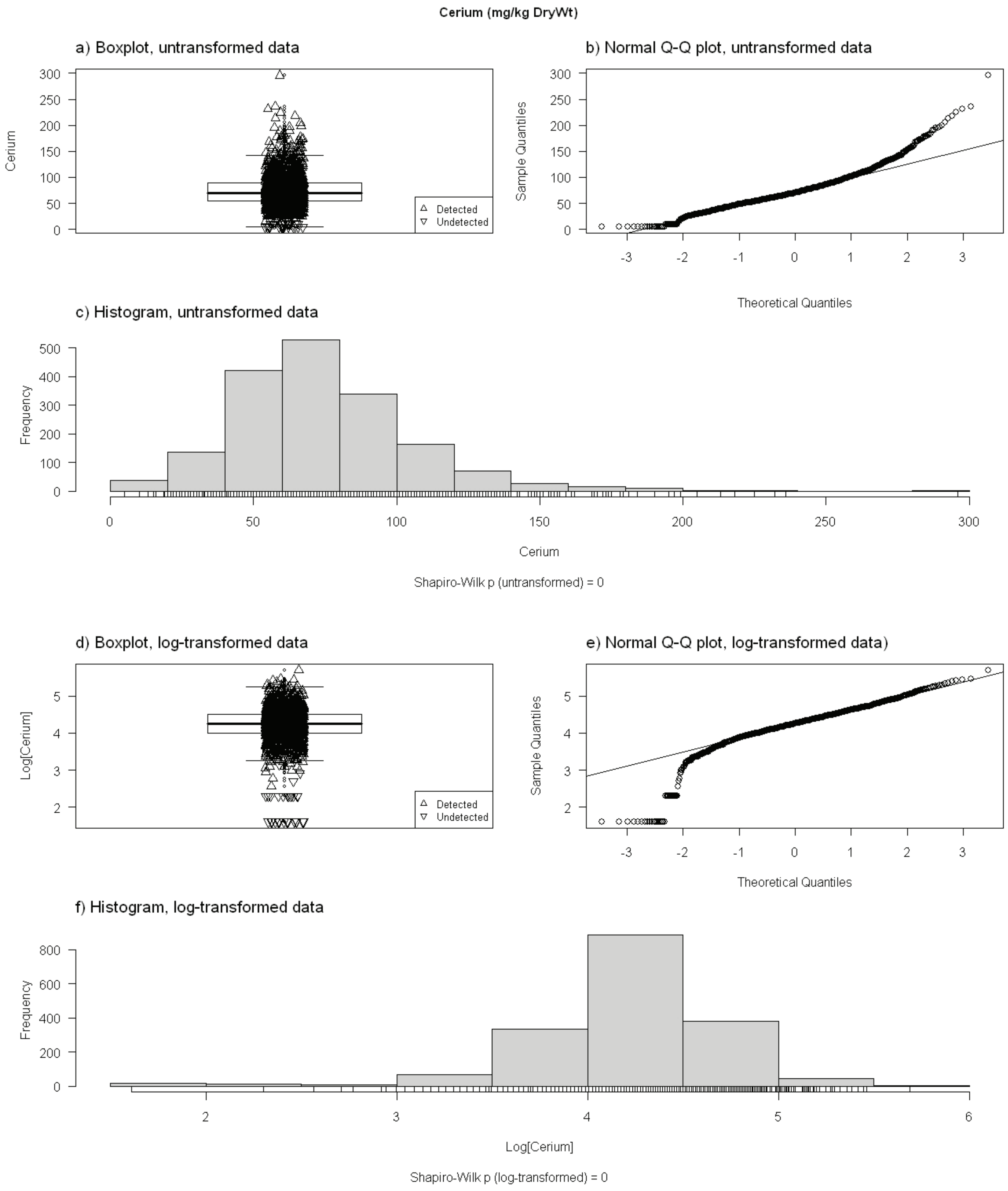


Figure 131. Distribution of All Background Concentrations of Cerium in Soil

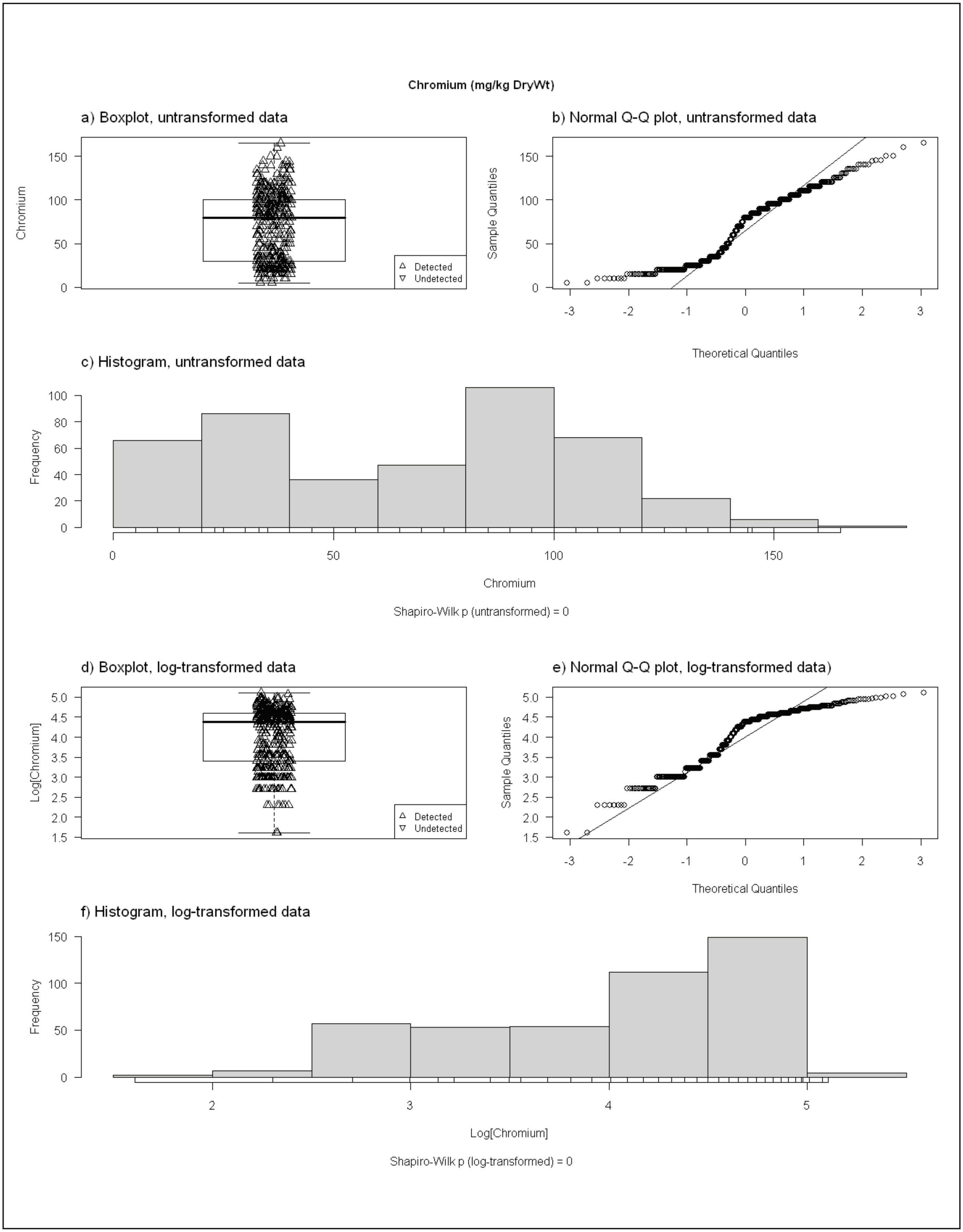
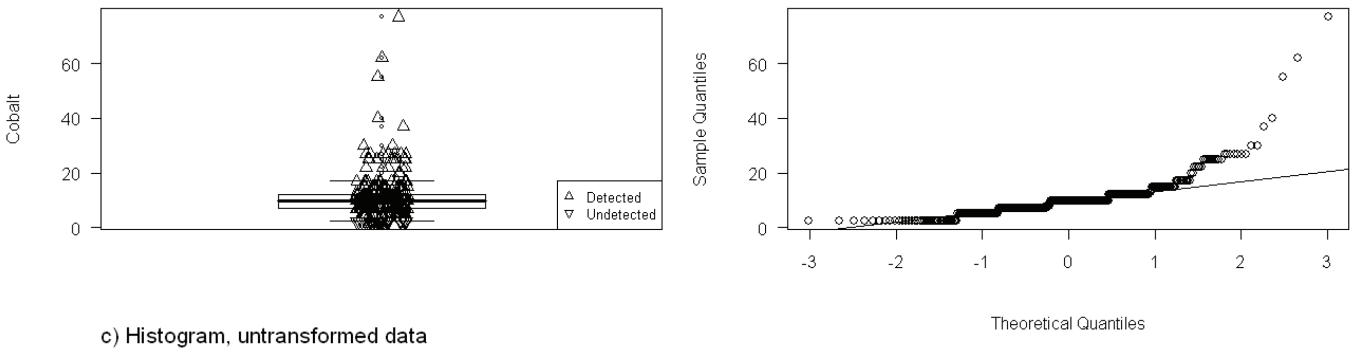


Figure 132. Distribution of All Background Concentrations of Chromium in Soil

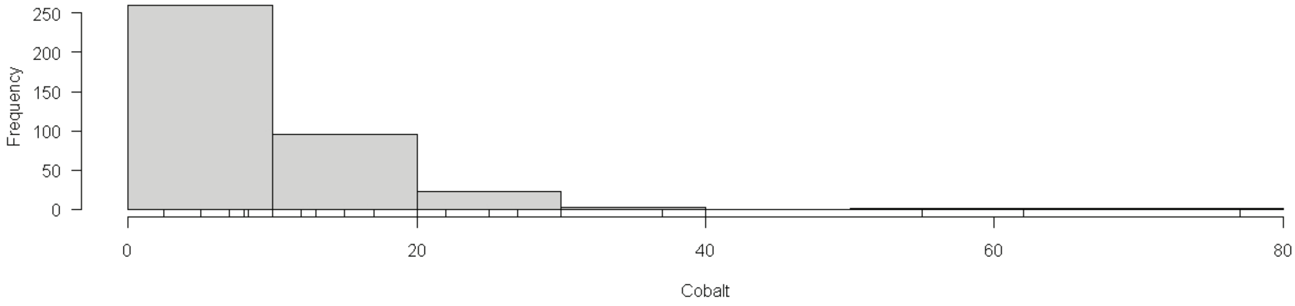
Cobalt (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data



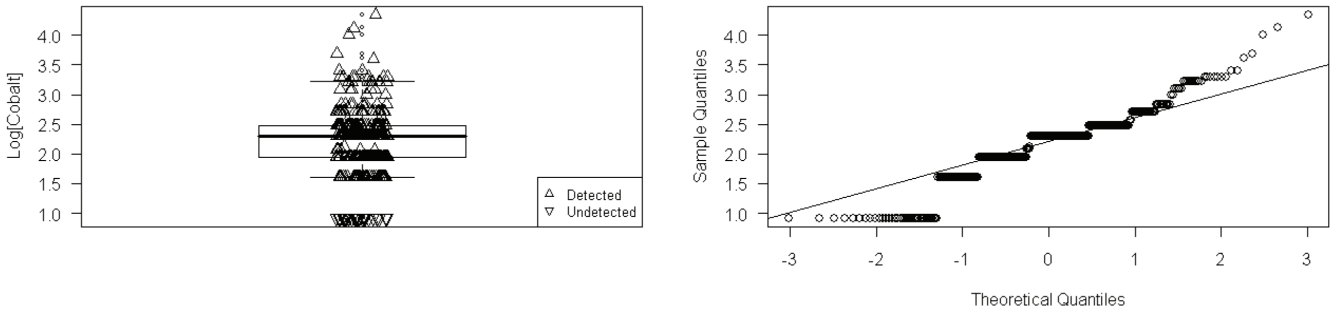
c) Histogram, untransformed data



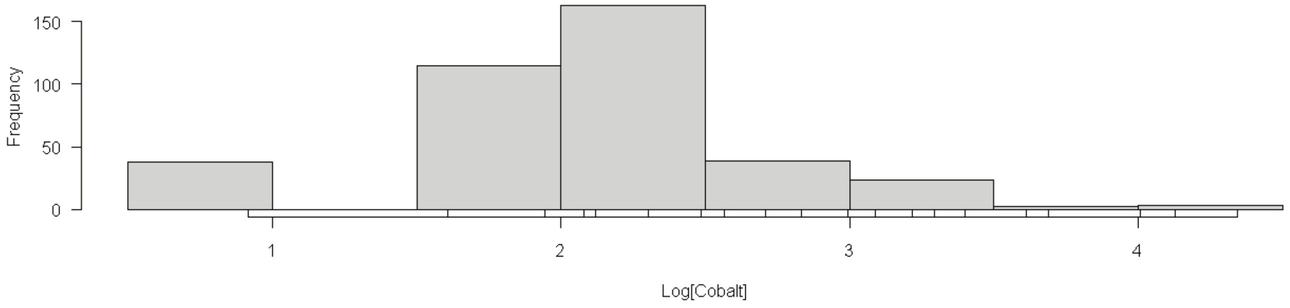
Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)



f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = 0

Figure 133. Distribution of All Background Concentrations of Cobalt in Soil

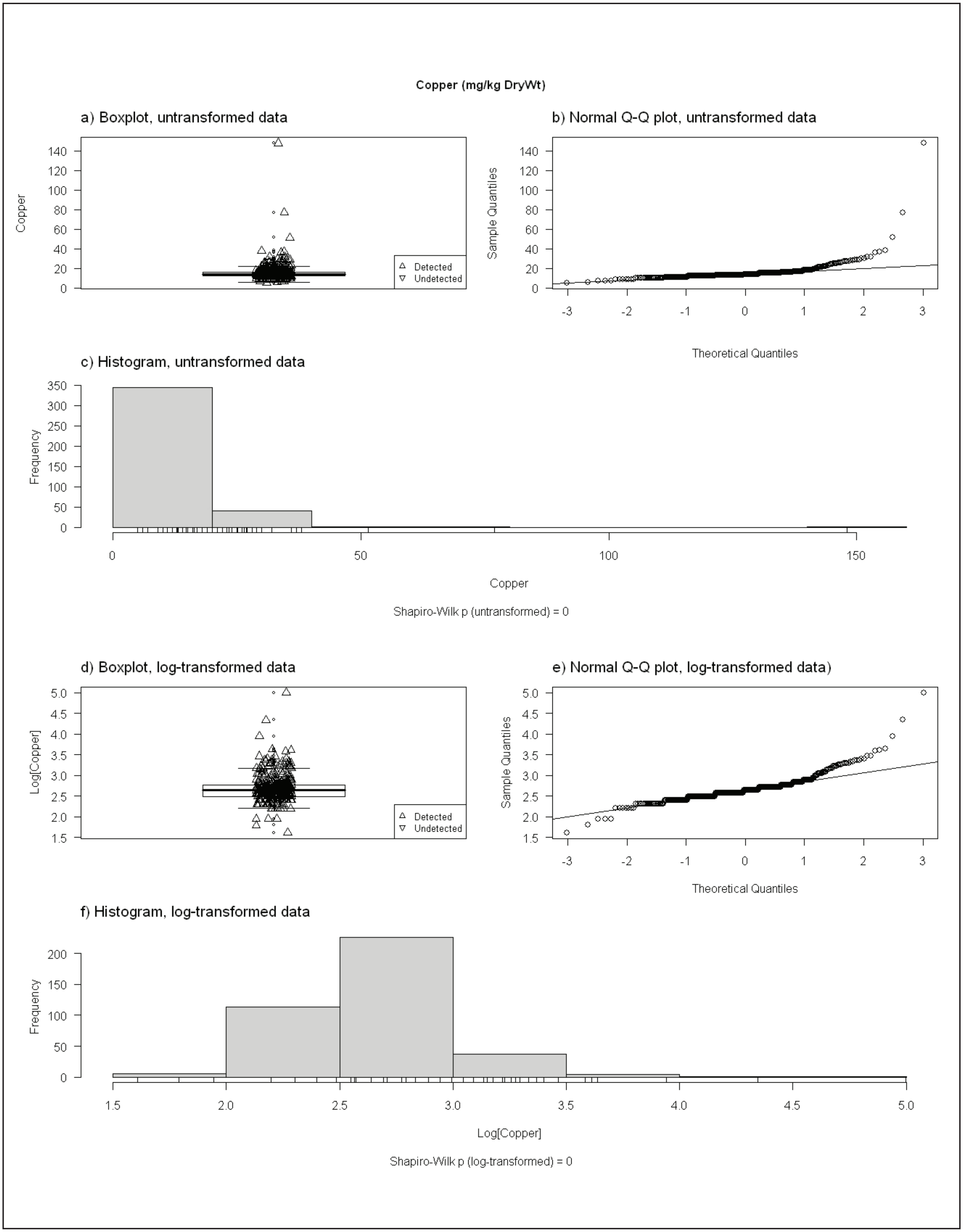


Figure 134. Distribution of All Background Concentrations of Copper in Soil

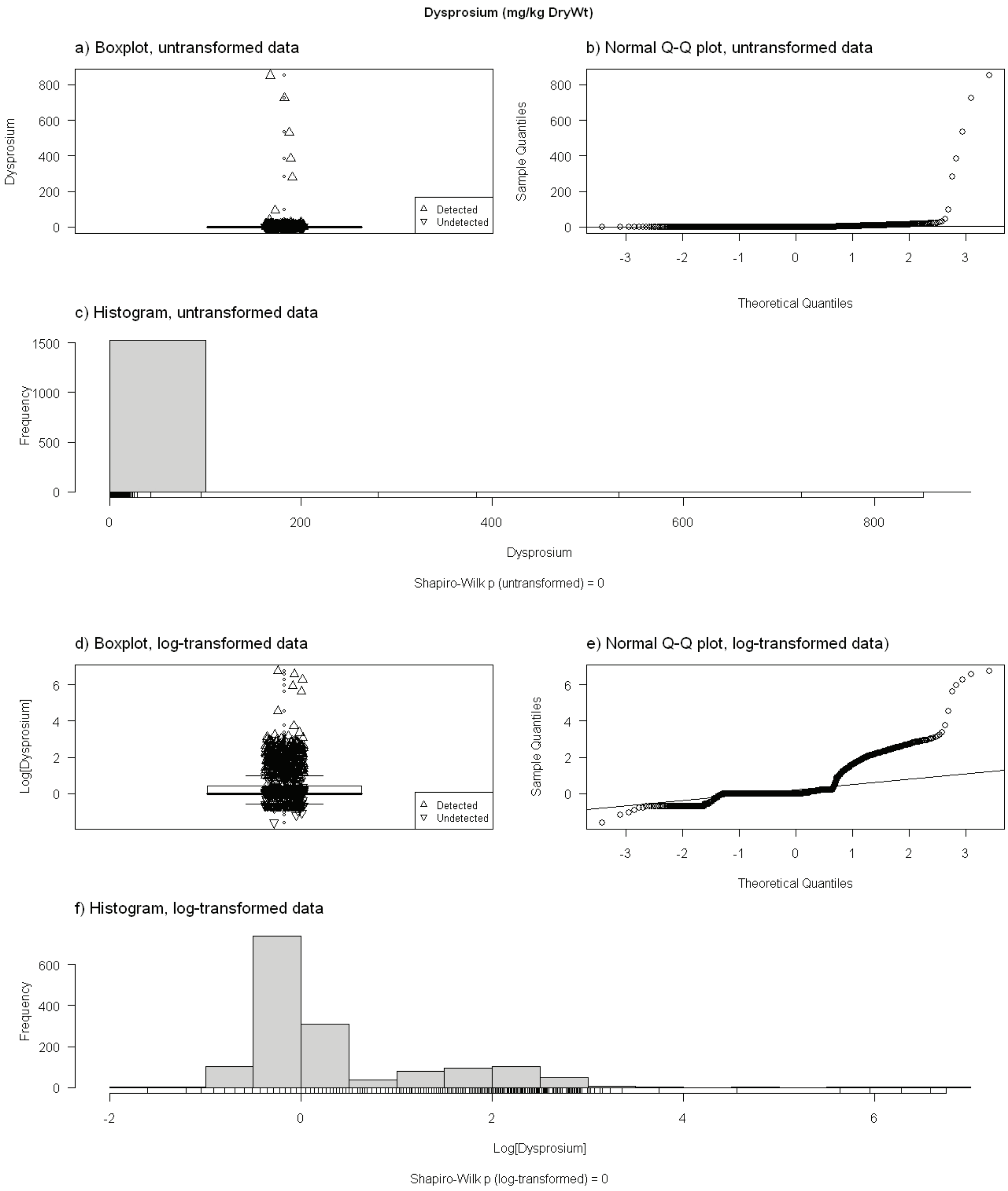
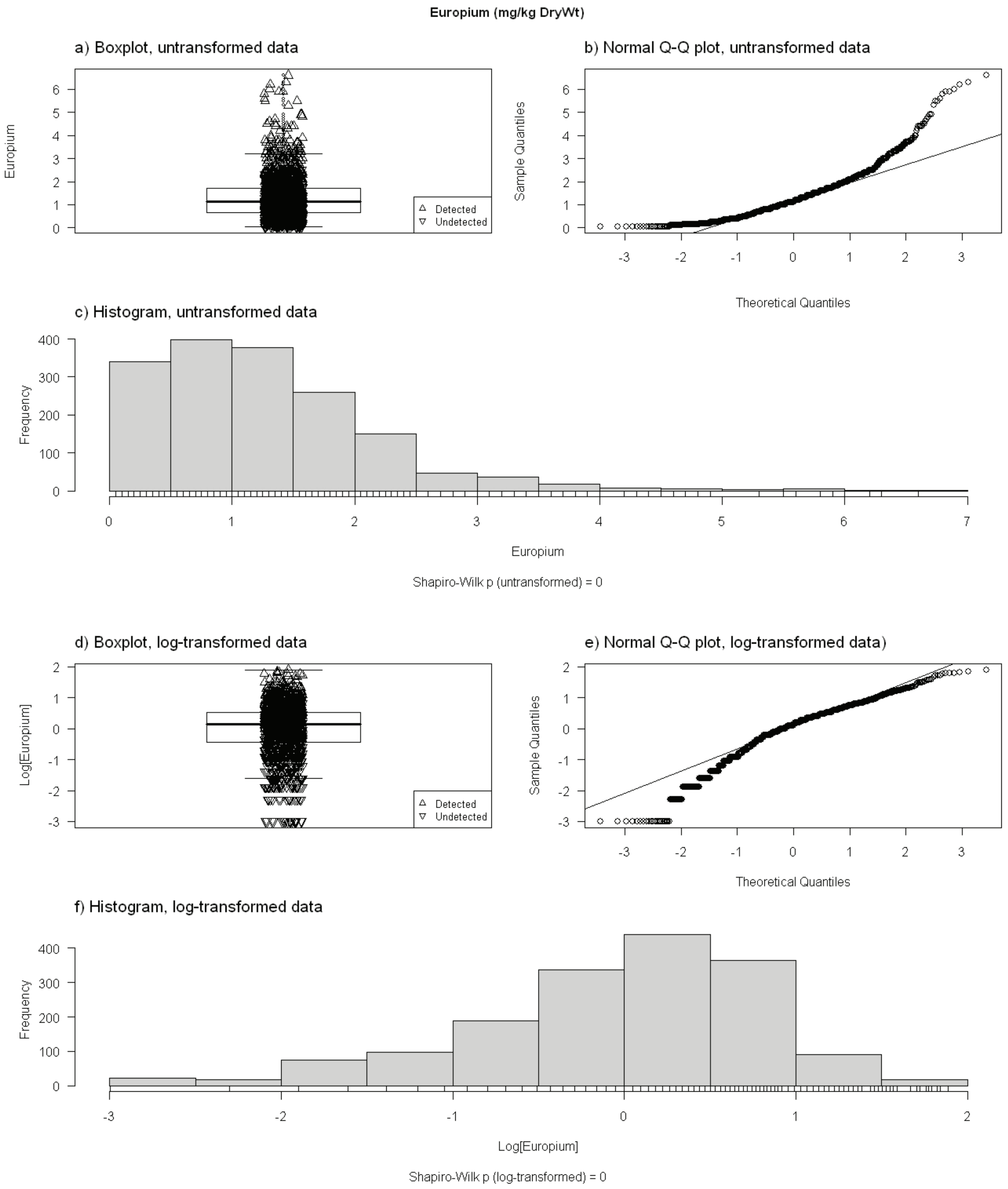


Figure 135. Distribution of All Background Concentrations of Dysprosium in Soil


Europium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 136. Distribution of All Background Concentrations of Europium in Soil

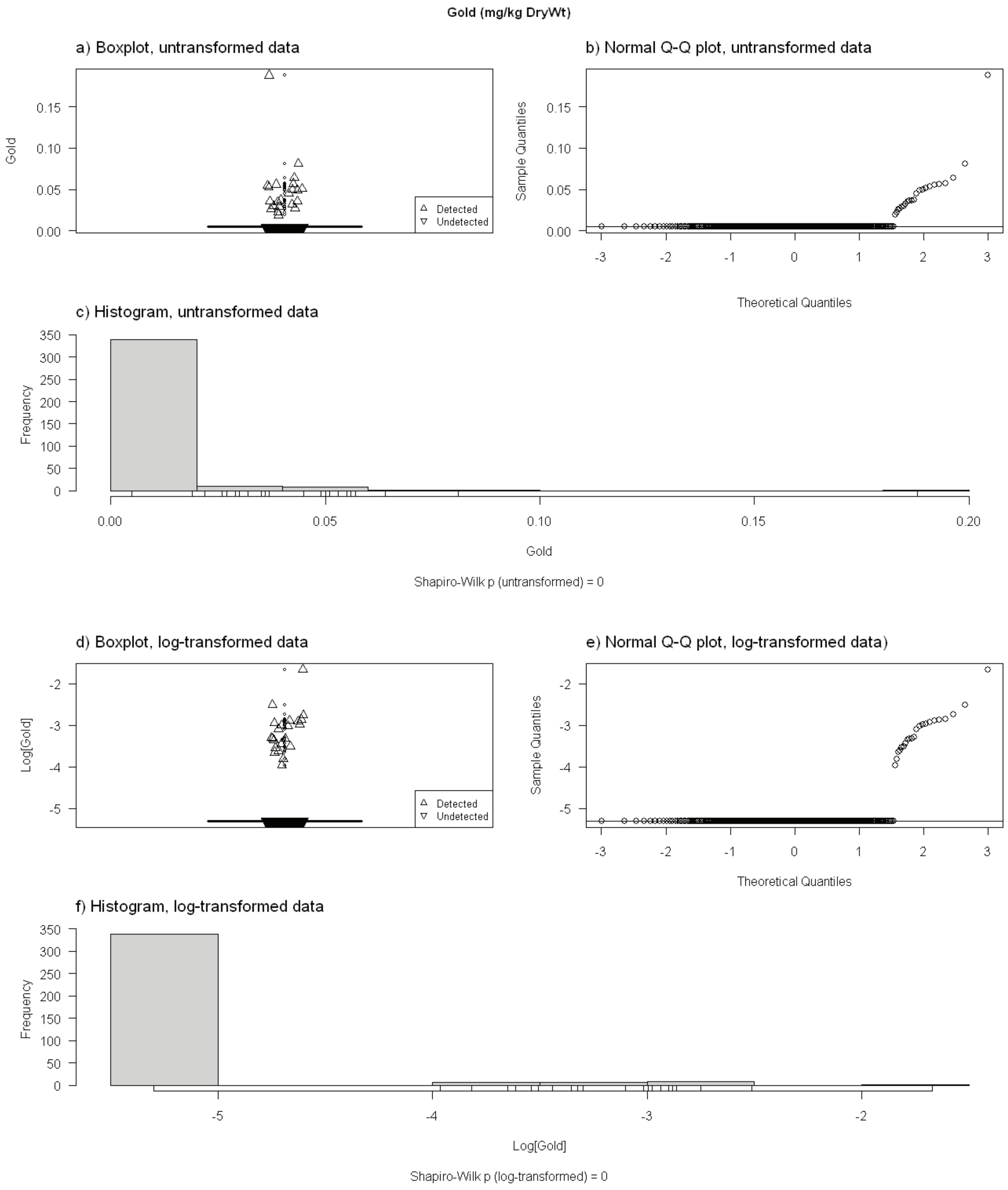


Figure 137. Distribution of All Background Concentrations of Gold in Soil

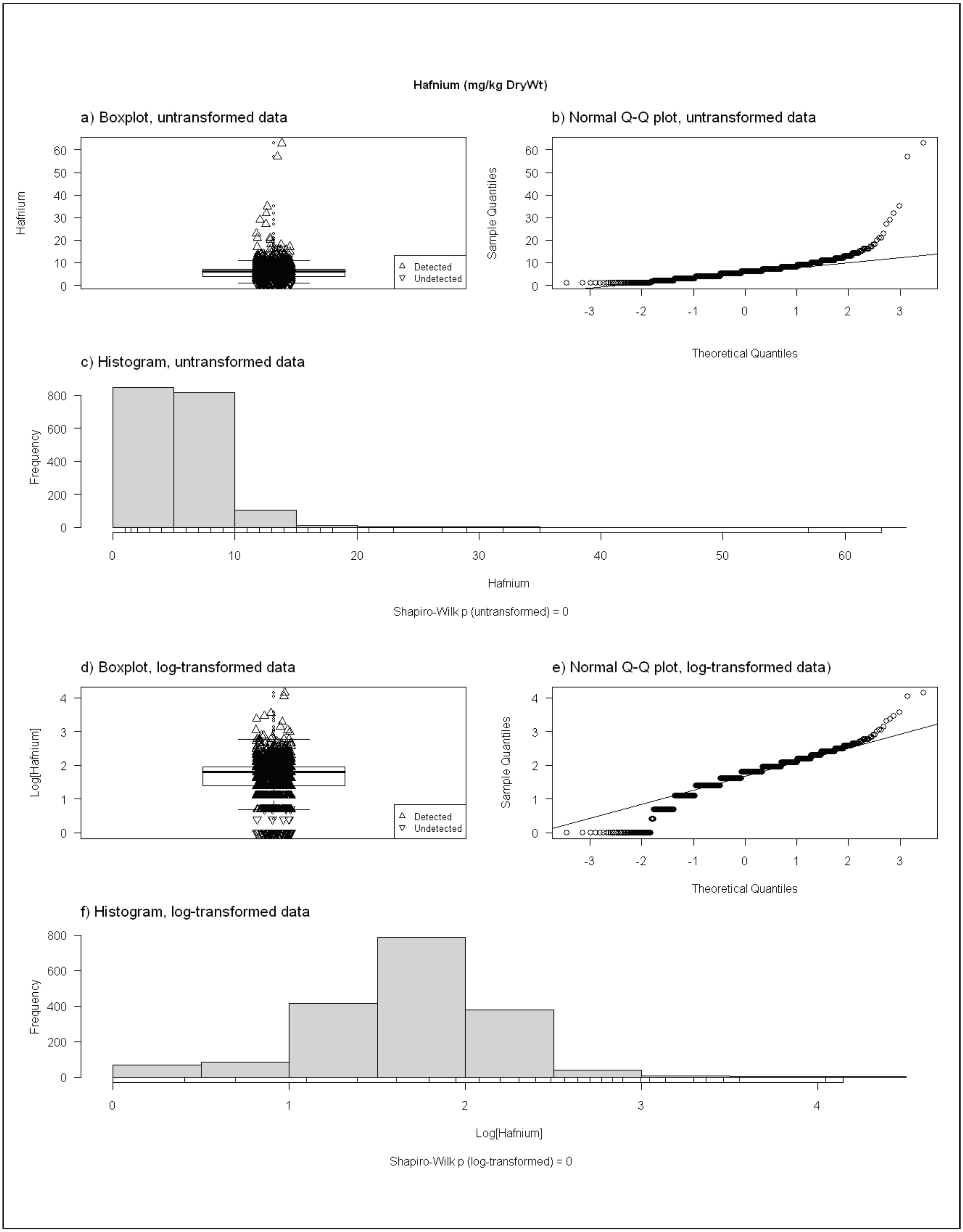


Figure 138. Distribution of All Background Concentrations of Hafnium in Soil

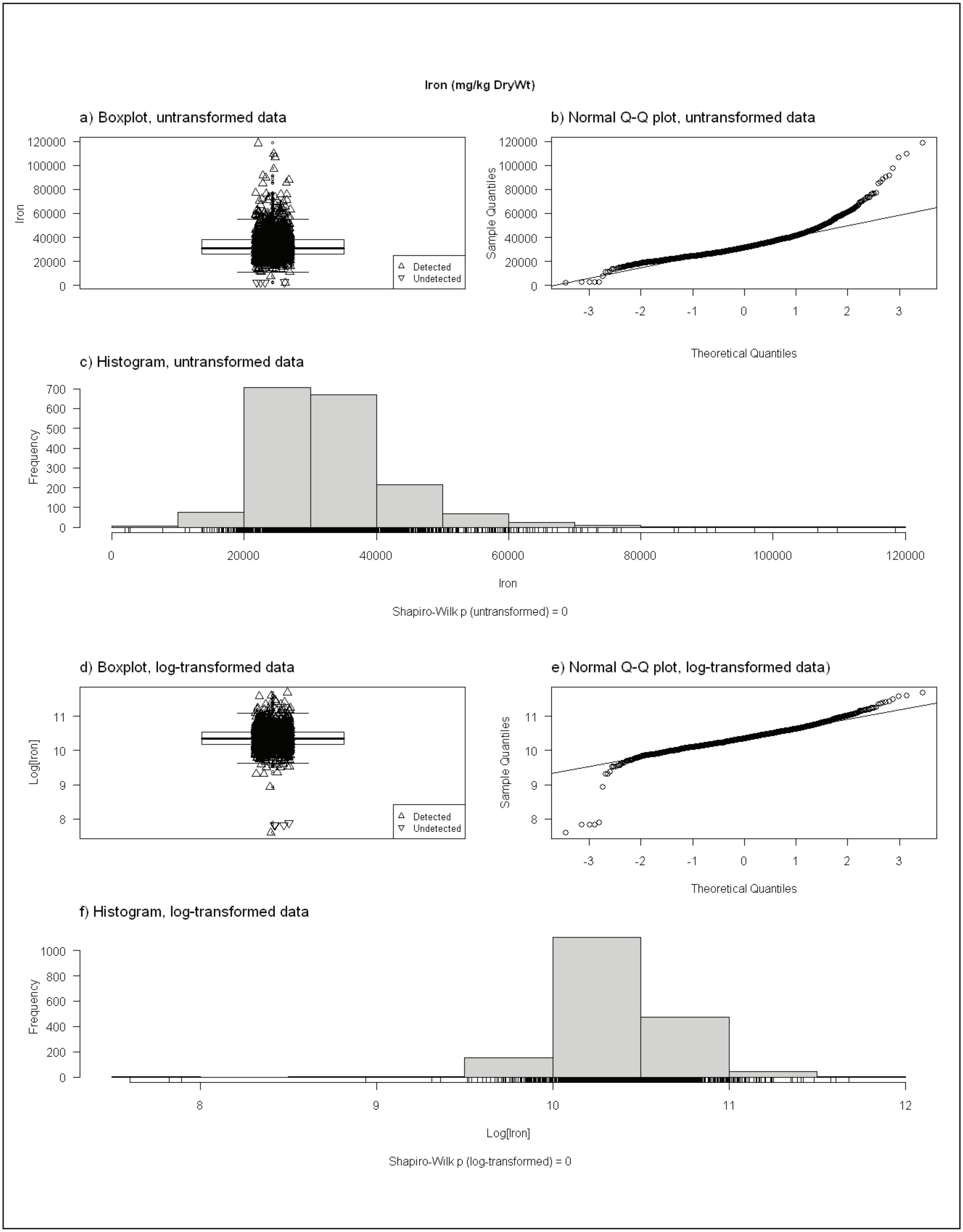


Figure 139. Distribution of All Background Concentrations of Iron in Soil

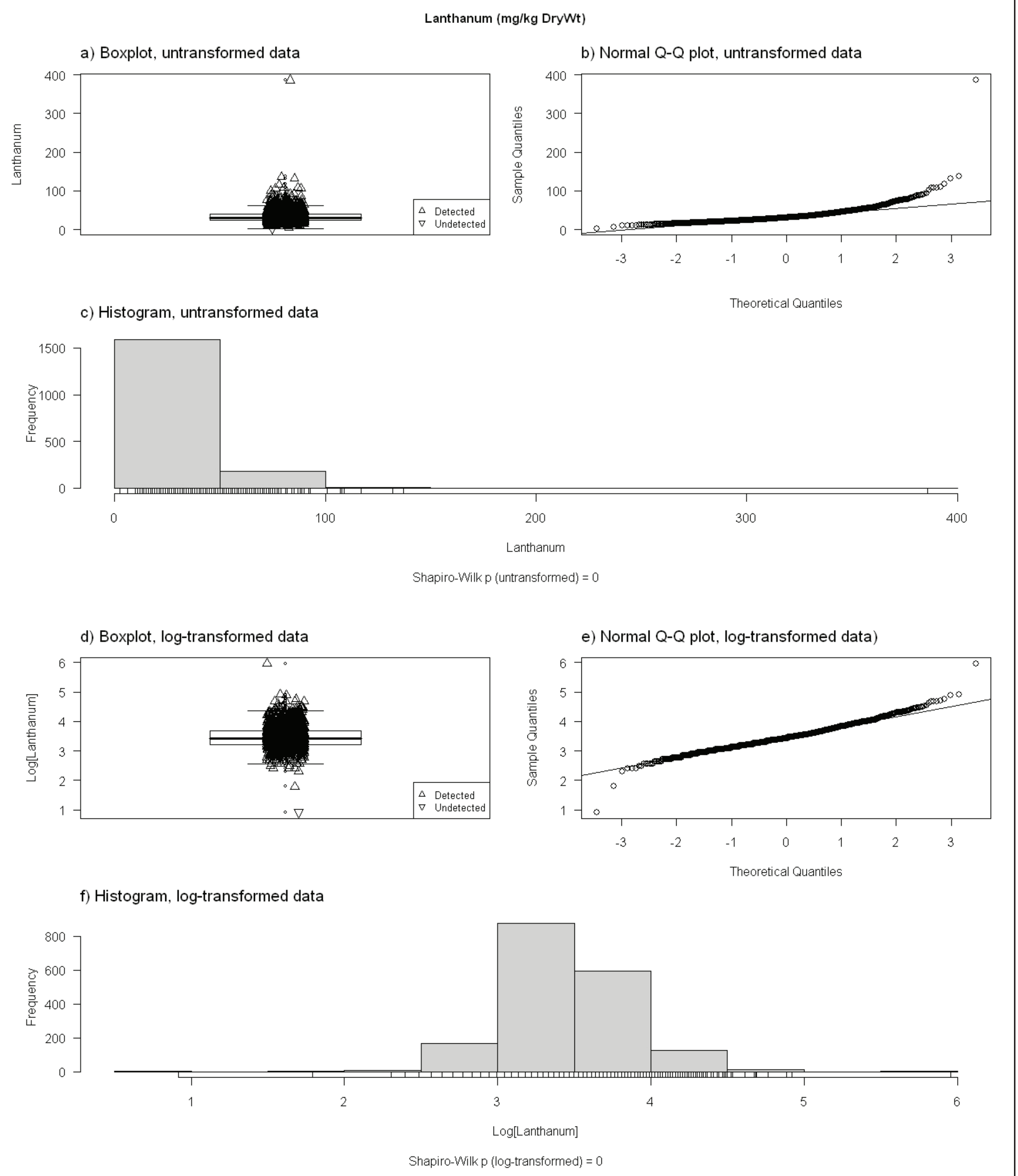


Figure 140. Distribution of All Background Concentrations of Lanthanum in Soil

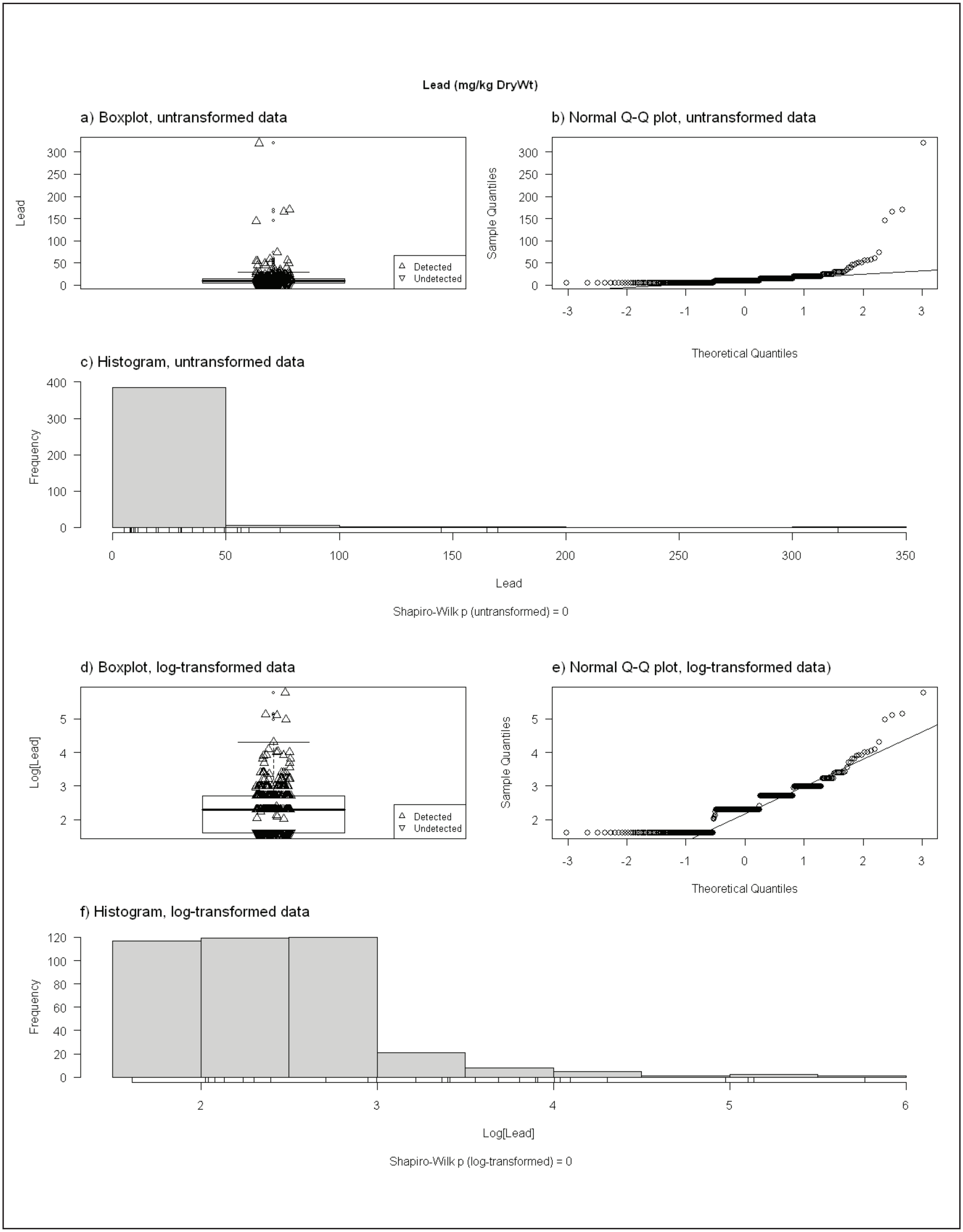


Figure 141. Distribution of All Background Concentrations of Lead in Soil

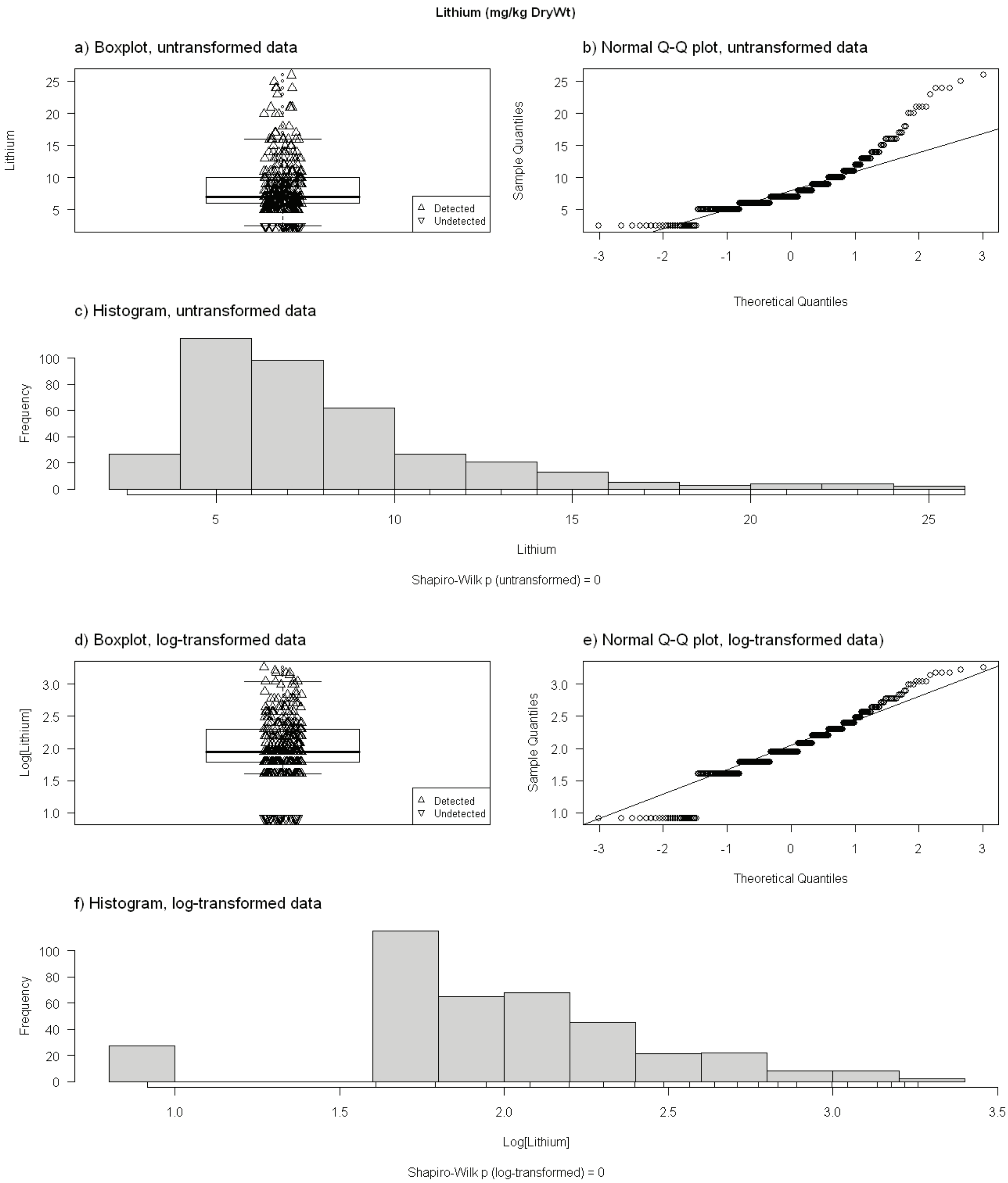


Figure 142. Distribution of All Background Concentrations of Lithium in Soil

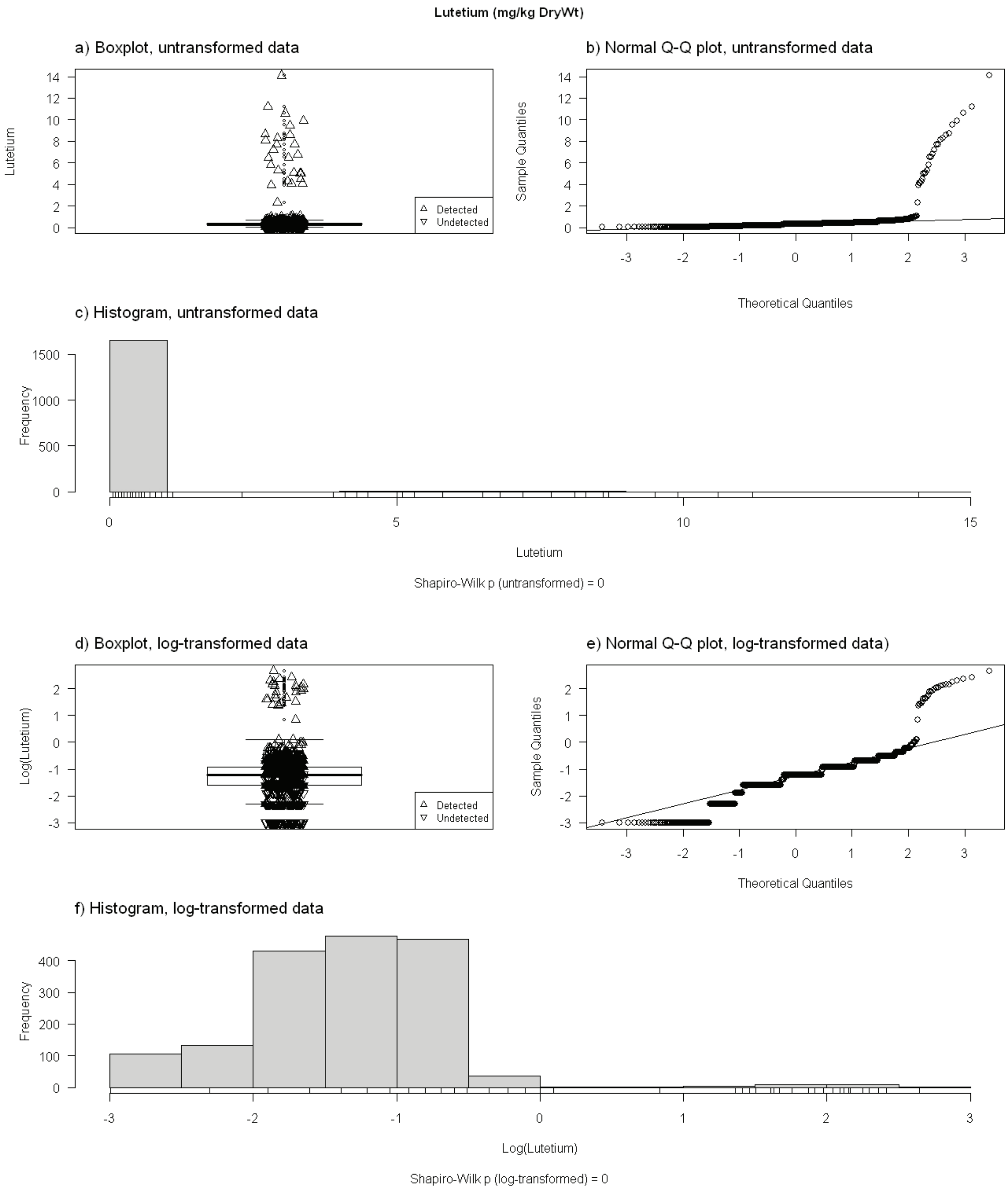
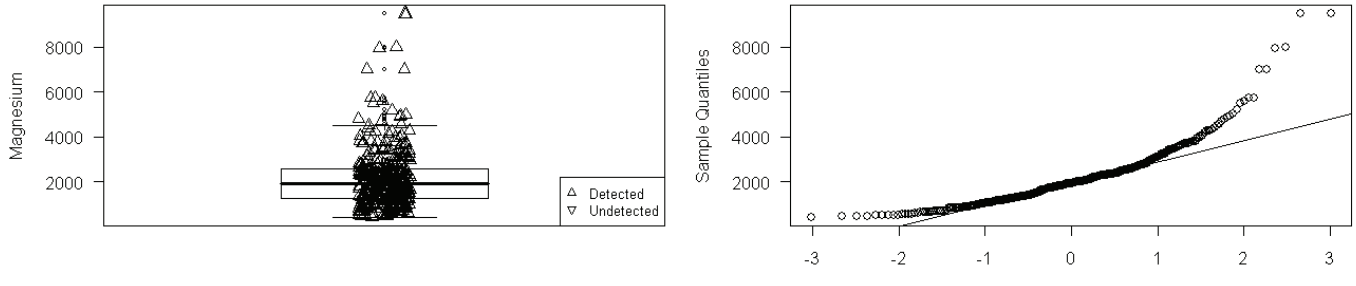


Figure 143. Distribution of All Background Concentrations of Lutetium in Soil

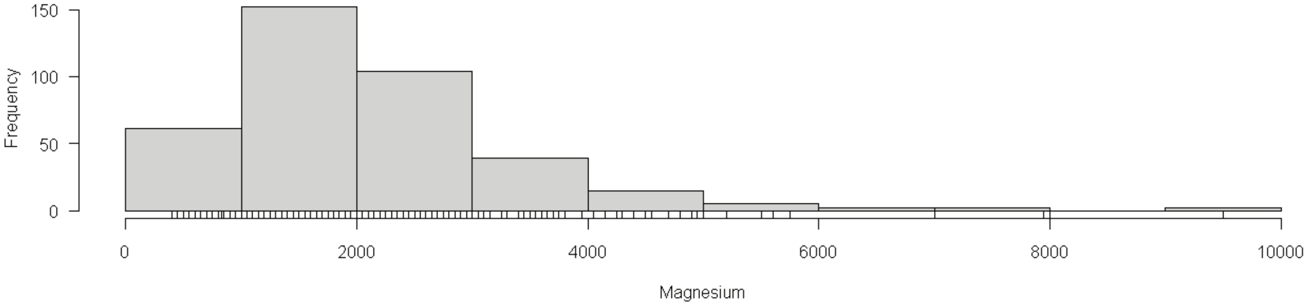
Magnesium (mg/kg DryWt)



a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

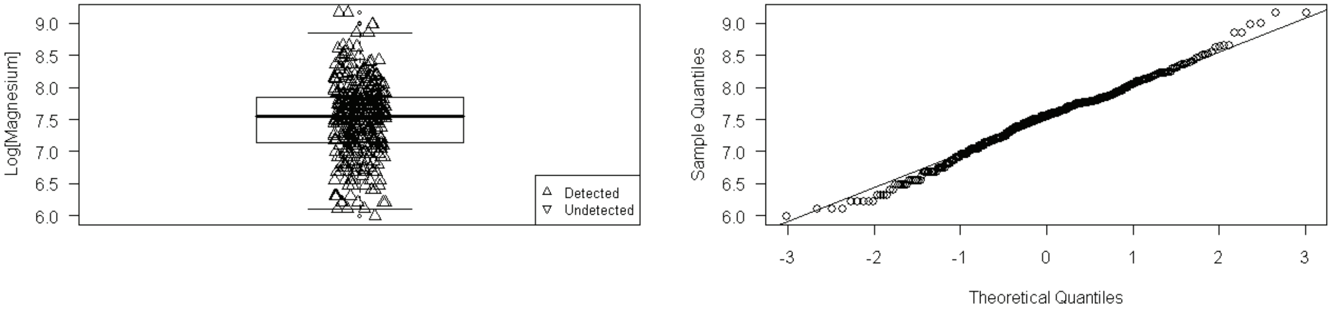
c) Histogram, untransformed data



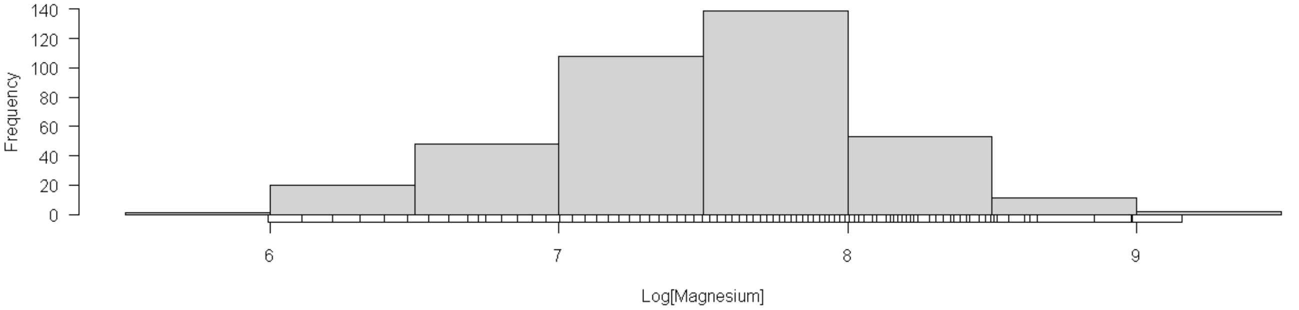
Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)



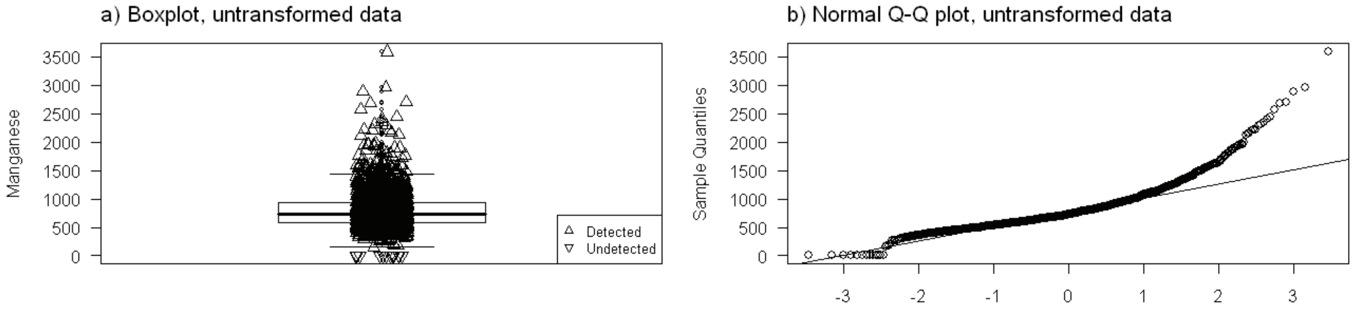
f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = 0.02638

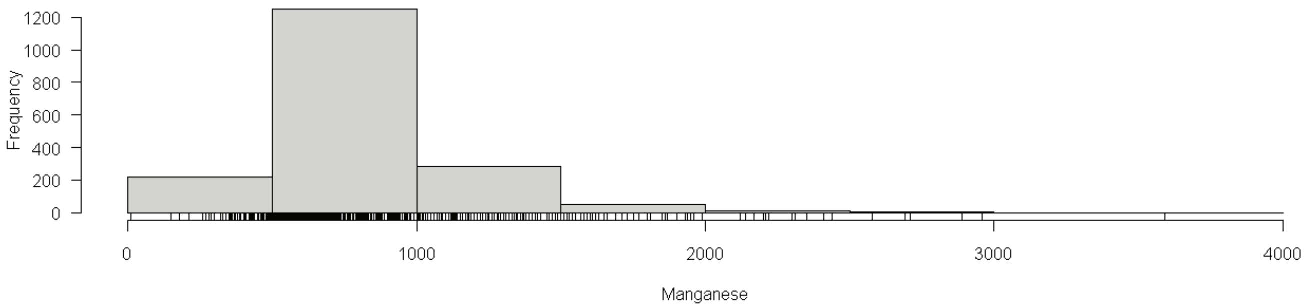
Figure 144. Distribution of All Background Concentrations of Magnesium in Soil

Manganese (mg/kg DryWt)

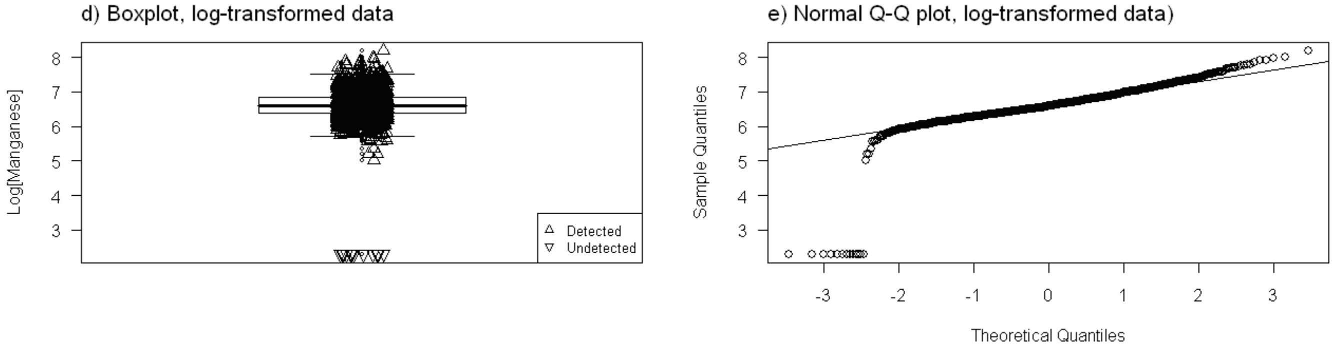

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

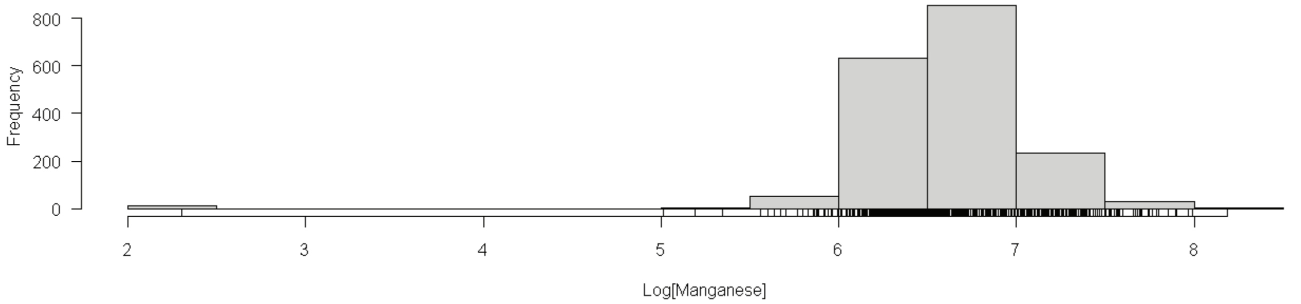


Shapiro-Wilk p (untransformed) = 0


d) Boxplot, log-transformed data

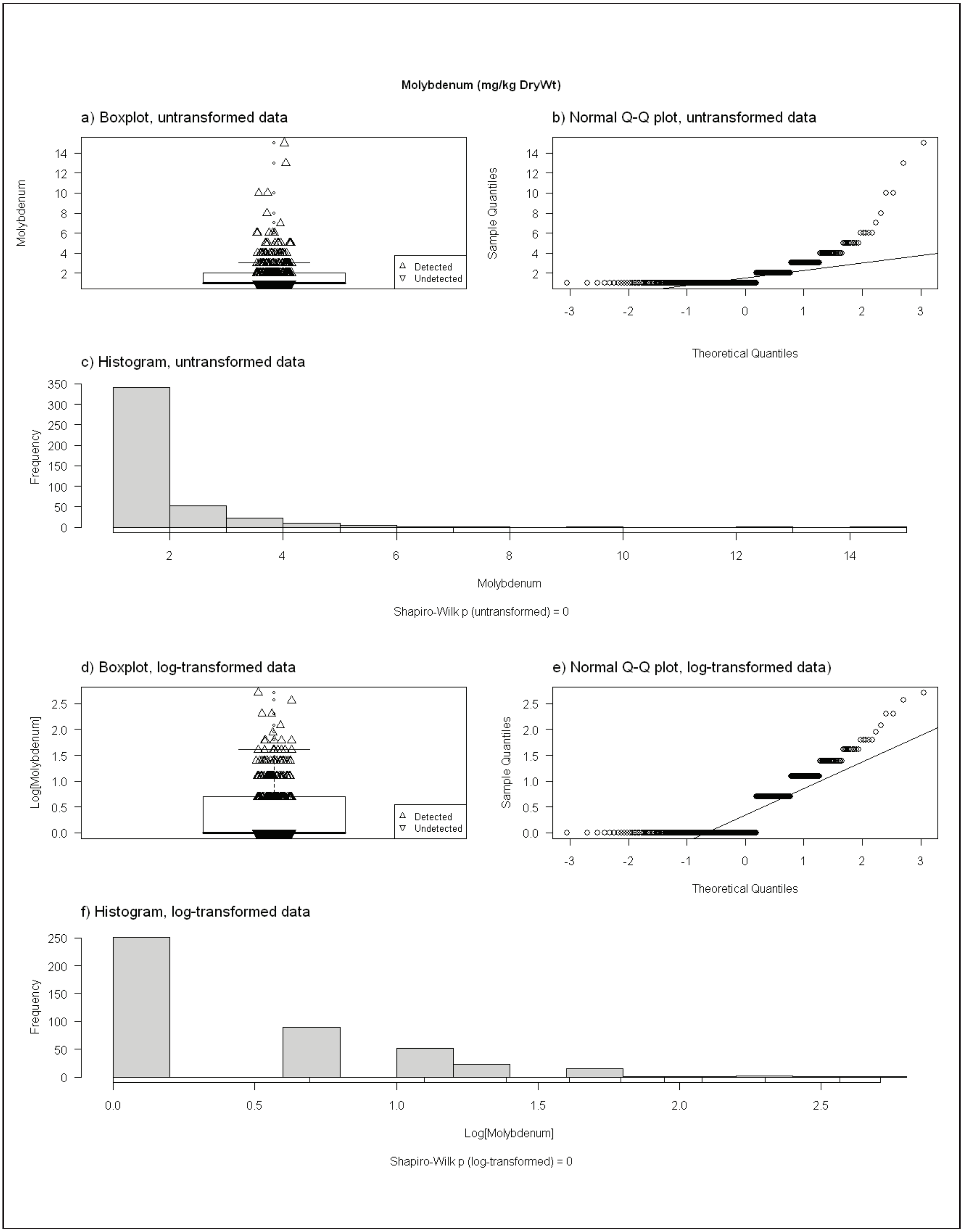
e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = 0

Figure 145. Distribution of All Background Concentrations of Manganese in Soil



Shapiro-Wilk p (untransformed) = 0

Shapiro-Wilk p (log-transformed) = 0

Figure 146. Distribution of All Background Concentrations of Molybdenum in Soil

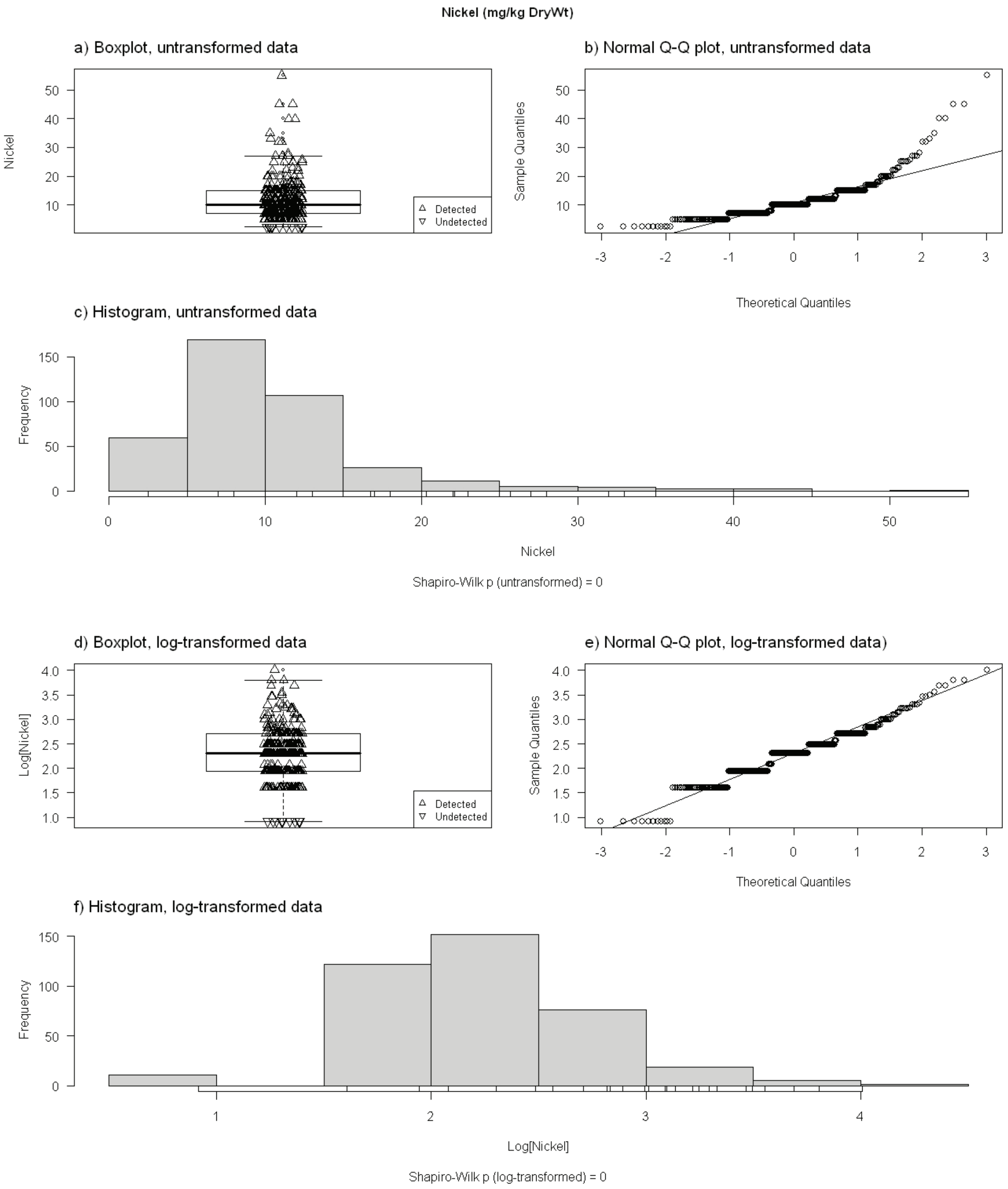


Figure 147. Distribution of All Background Concentrations of Nickel in Soil

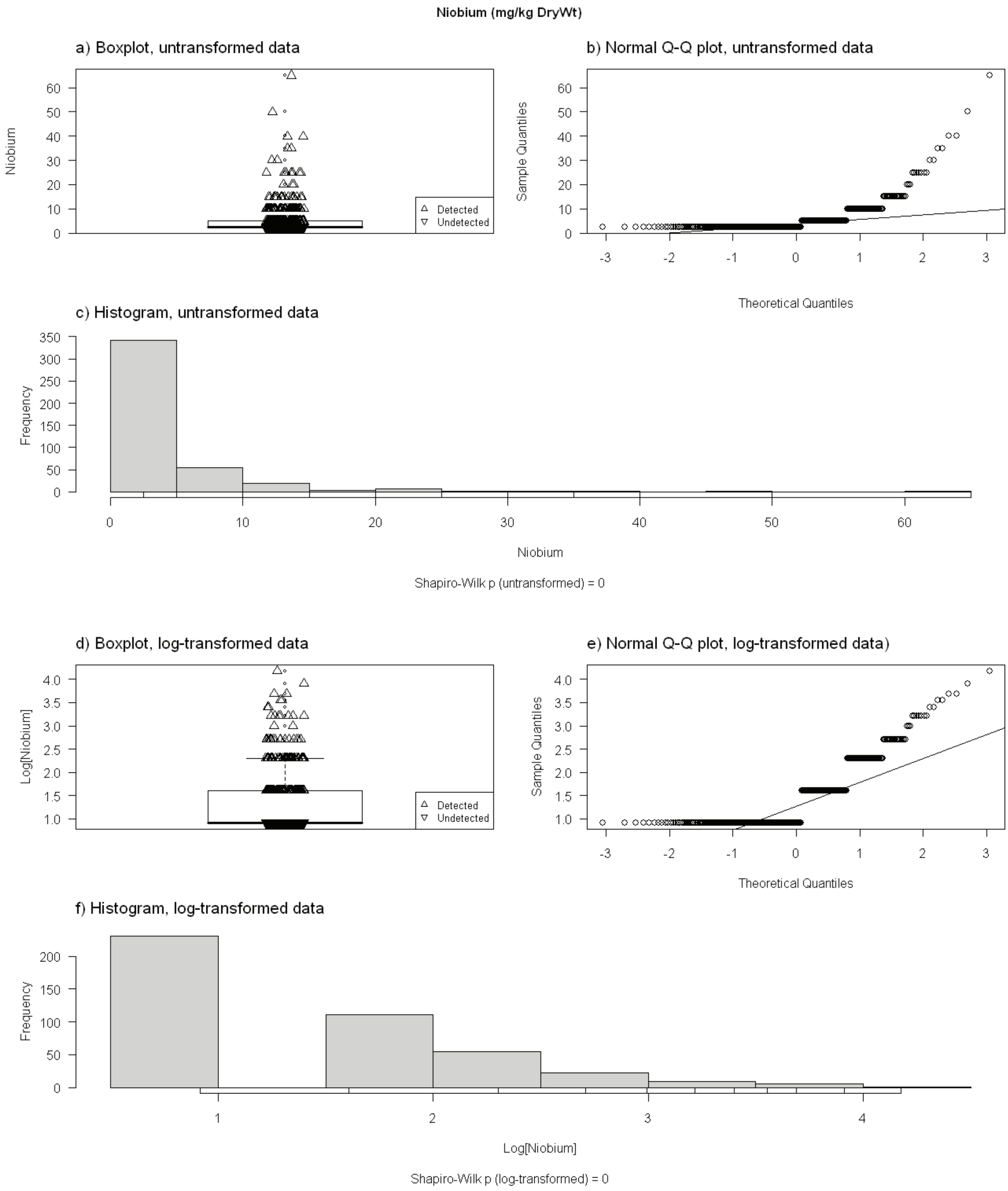
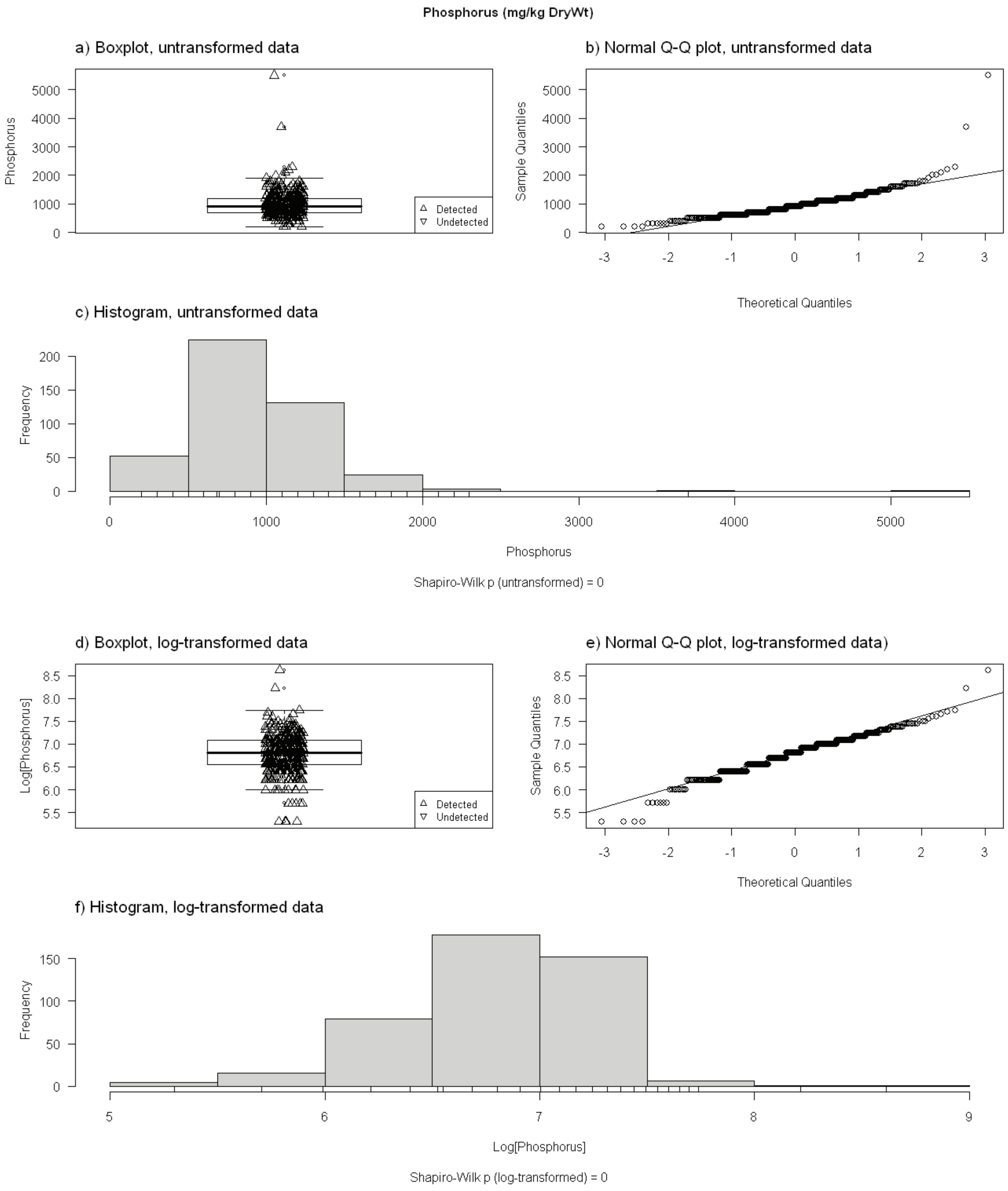


Figure 148. Distribution of All Background Concentrations of Niobium in Soil



Shapiro-Wilk p (untransformed) = 0

Shapiro-Wilk p (log-transformed) = 0

Figure 149. Distribution of All Background Concentrations of Phosphorus in Soil

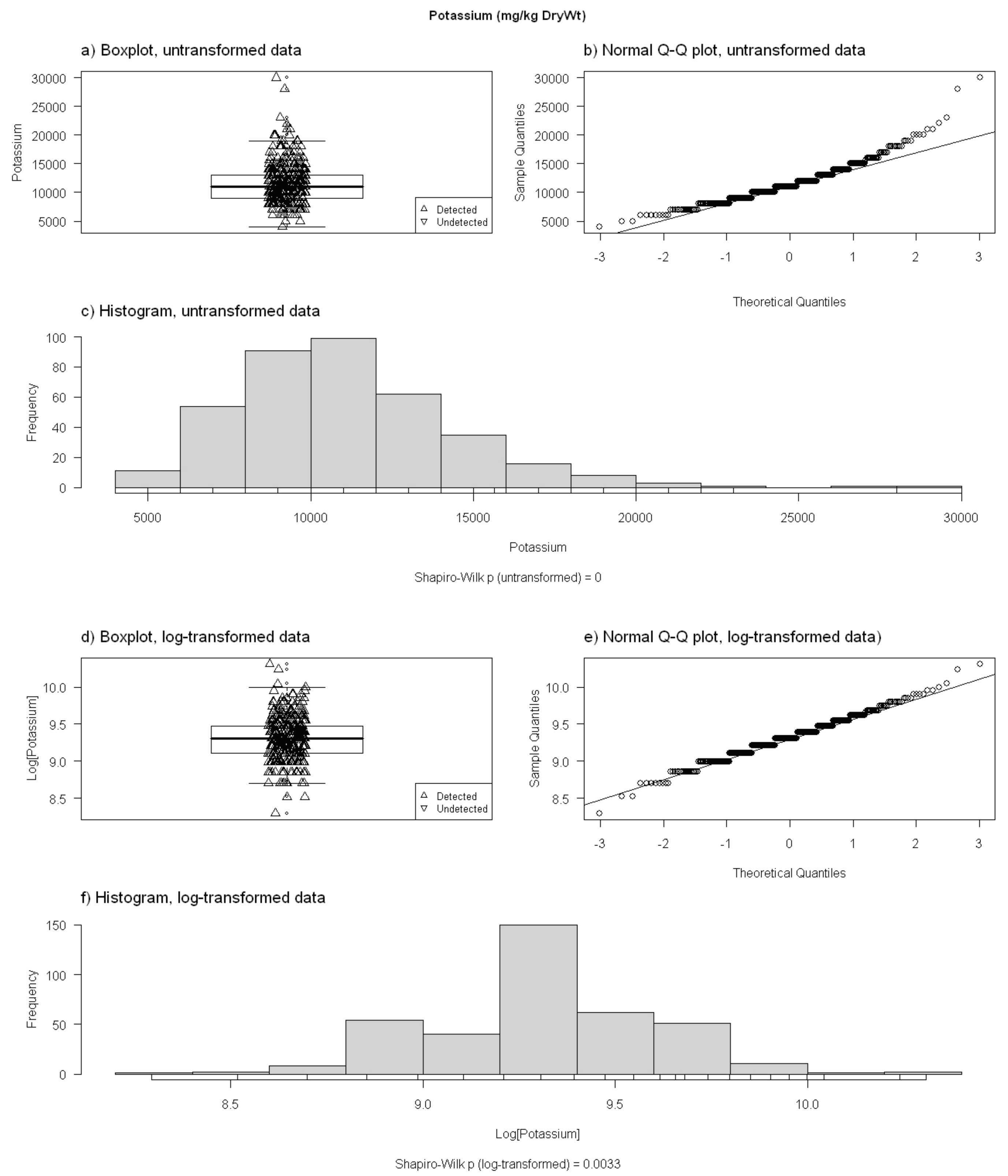


Figure 150. Distribution of All Background Concentrations of Potassium in Soil

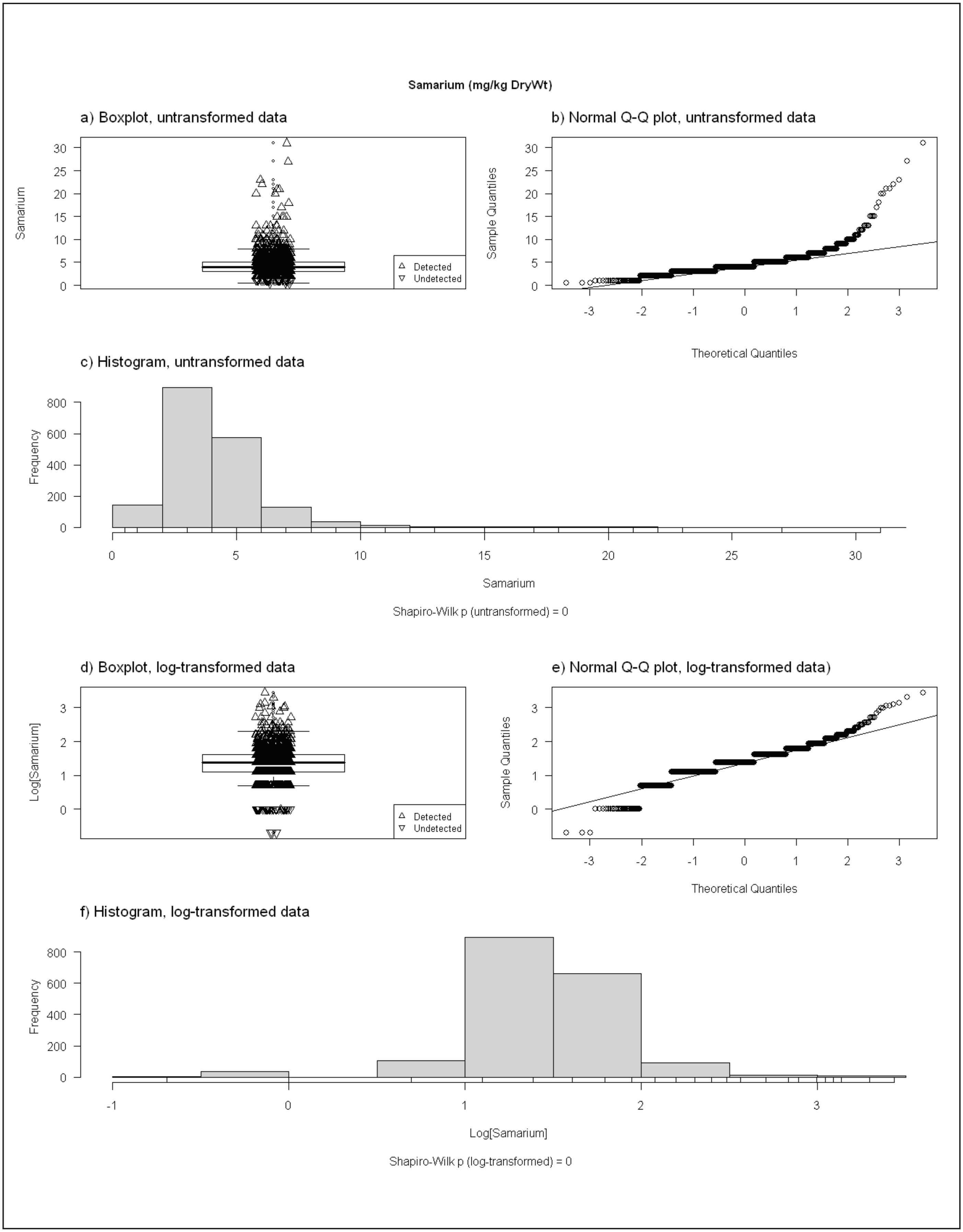


Figure 151. Distribution of All Background Concentrations of Samarium in Soil

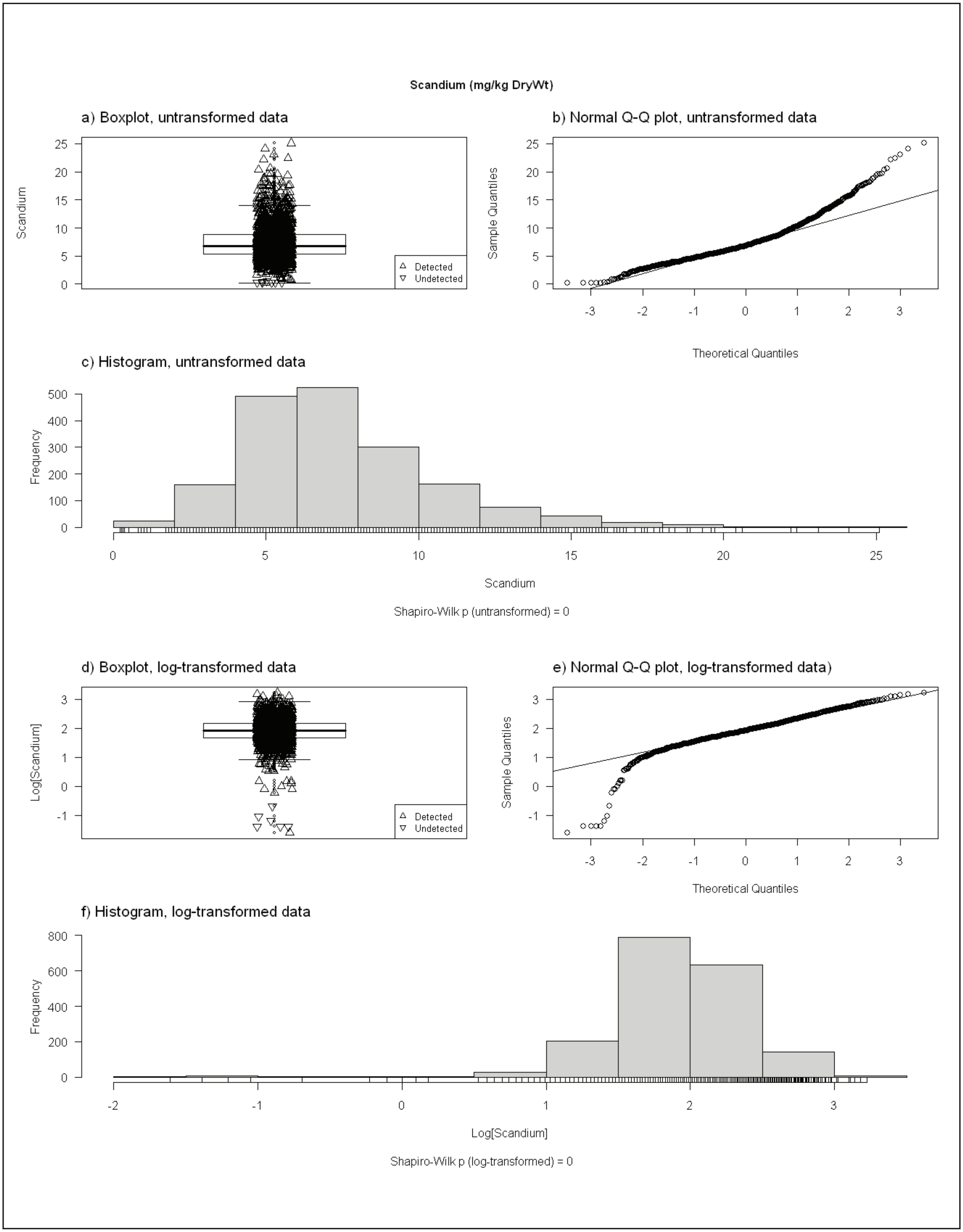
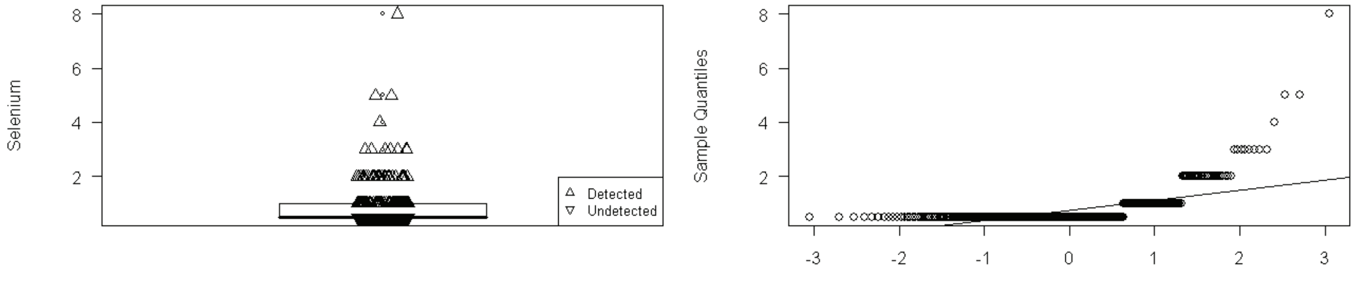


Figure 152. Distribution of All Background Concentrations of Scandium in Soil

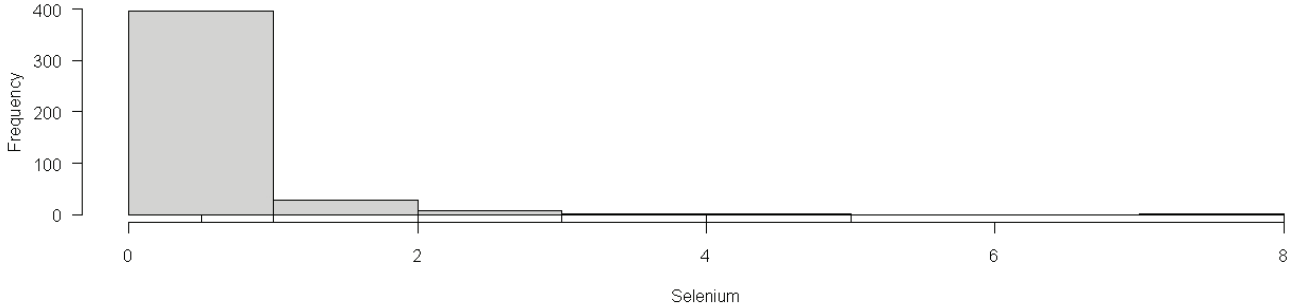
Selenium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data



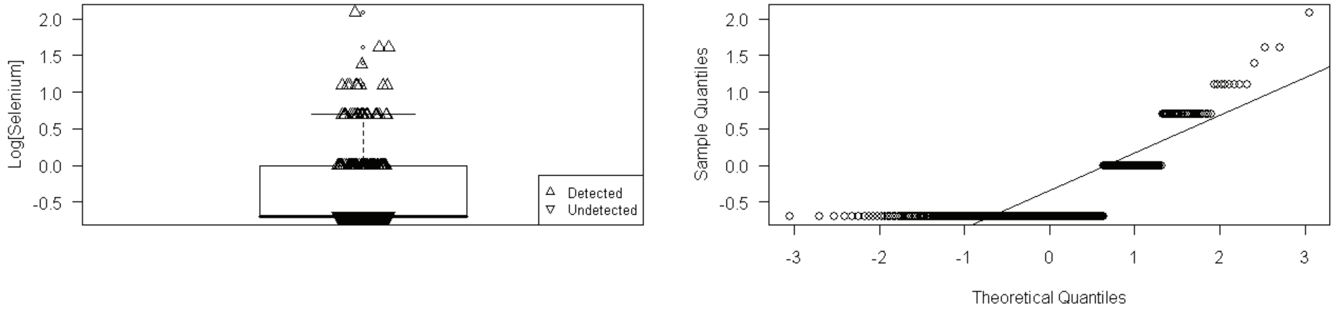
c) Histogram, untransformed data



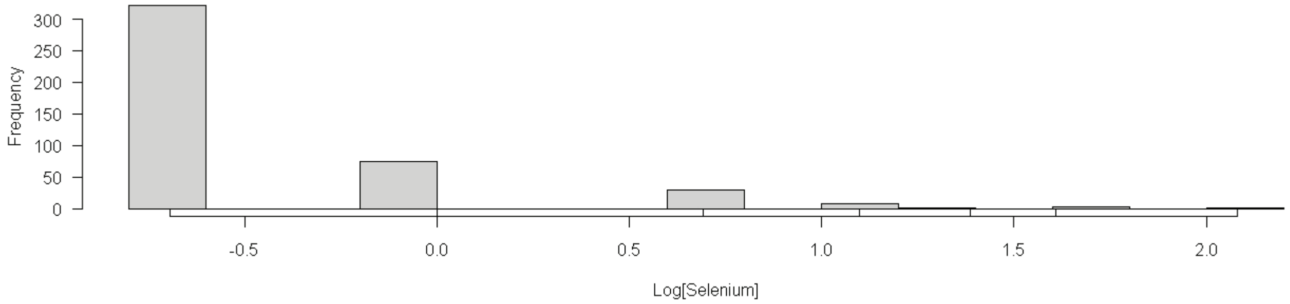
Shapiro-Wilk p (untransformed) = 0

d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)



f) Histogram, log-transformed data



Shapiro-Wilk p (log-transformed) = 0

Figure 153. Distribution of All Background Concentrations of Selenium in Soil

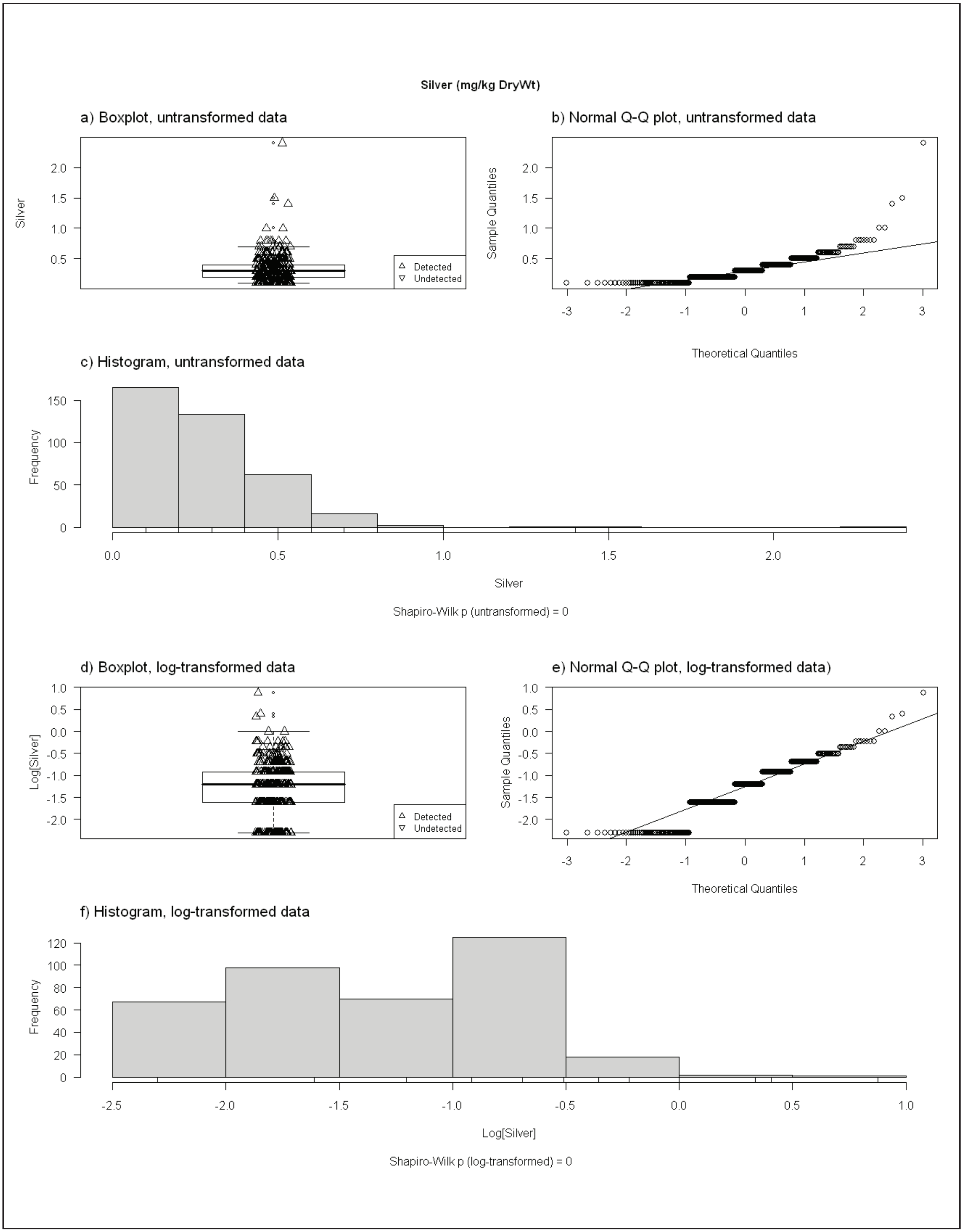
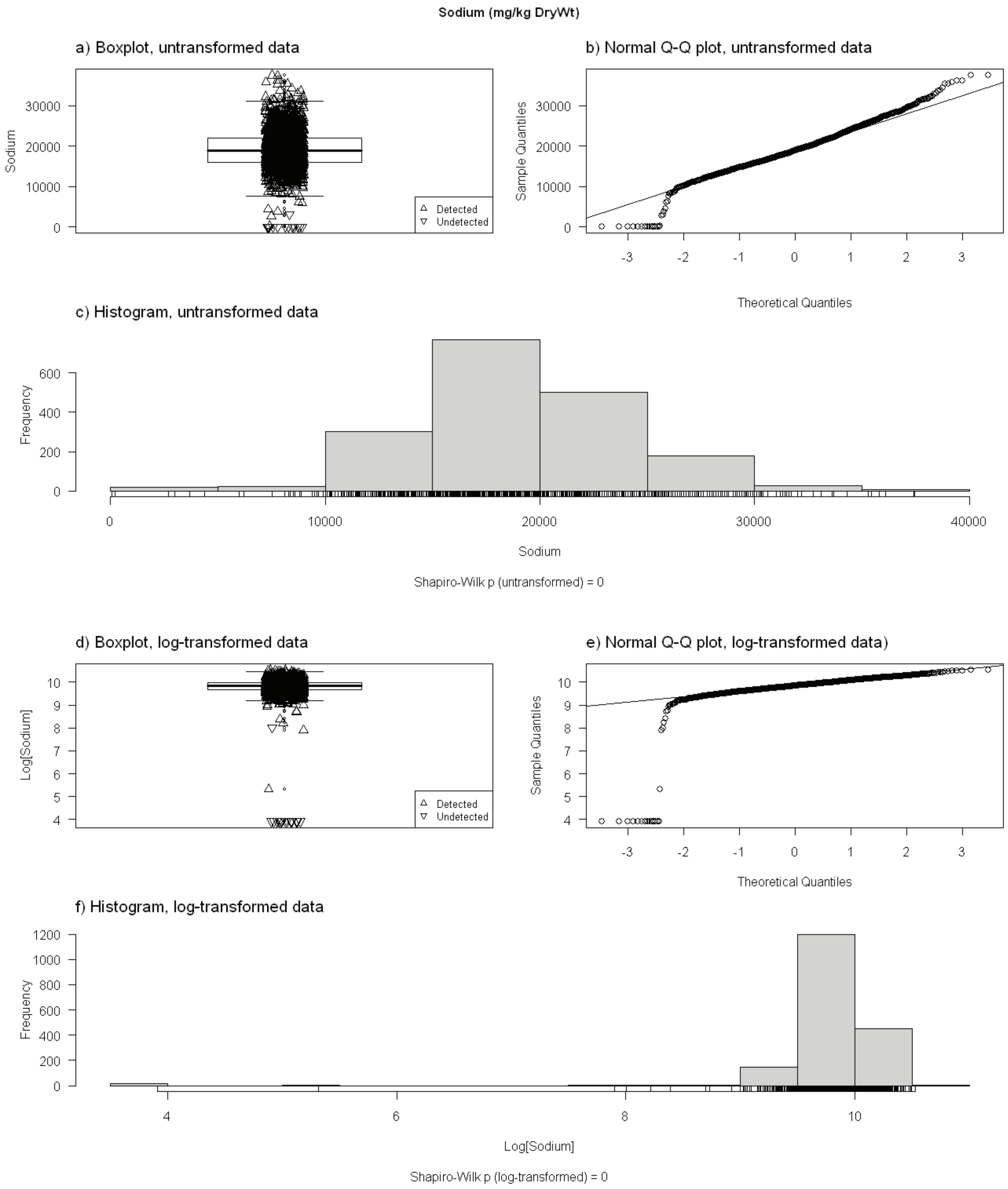


Figure 154. Distribution of All Background Concentrations of Silver in Soil


Sodium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

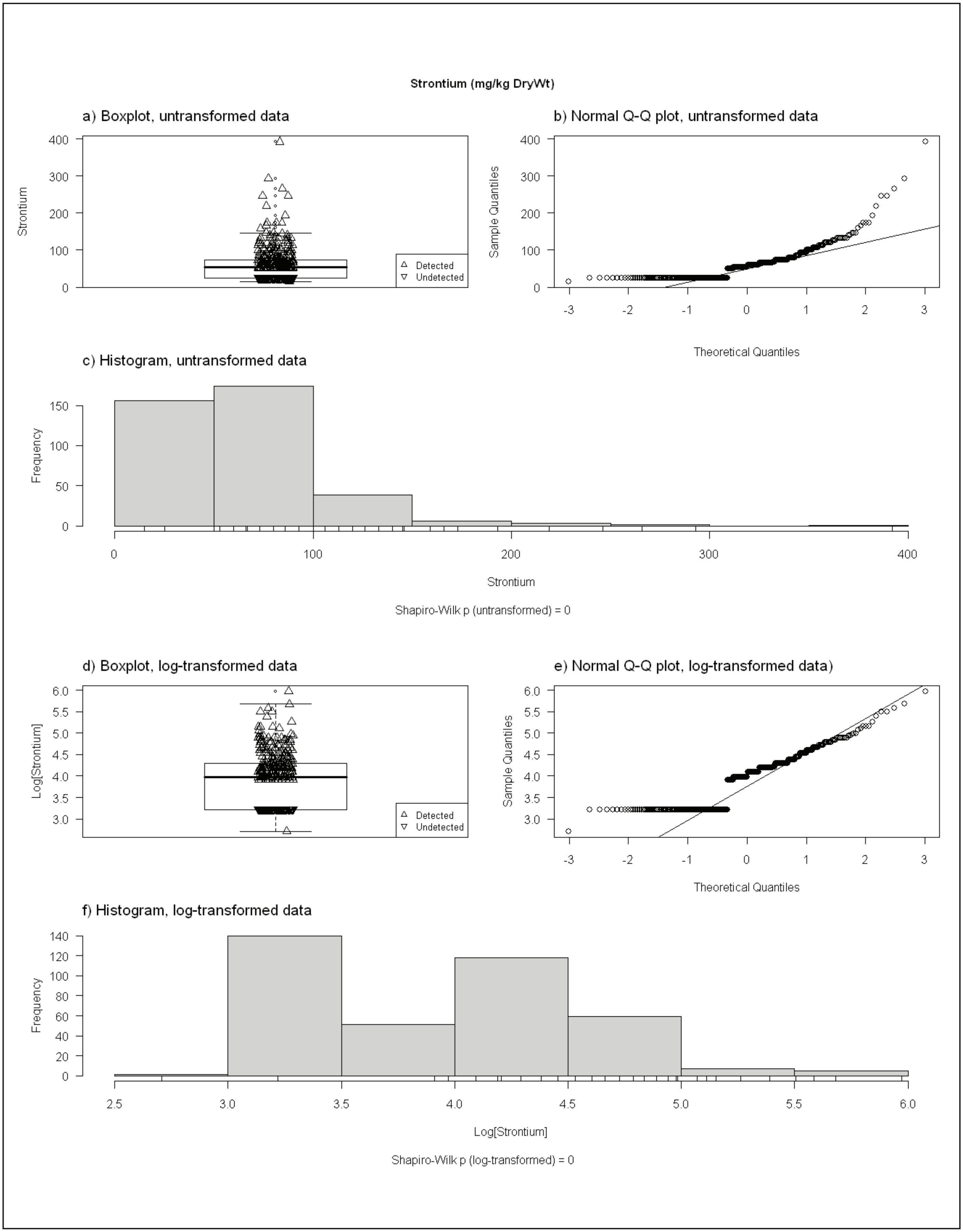
d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 155. Distribution of All Background Concentrations of Sodium in Soil



Strontium (mg/kg DryWt)

a) Boxplot, untransformed data

b) Normal Q-Q plot, untransformed data

c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0

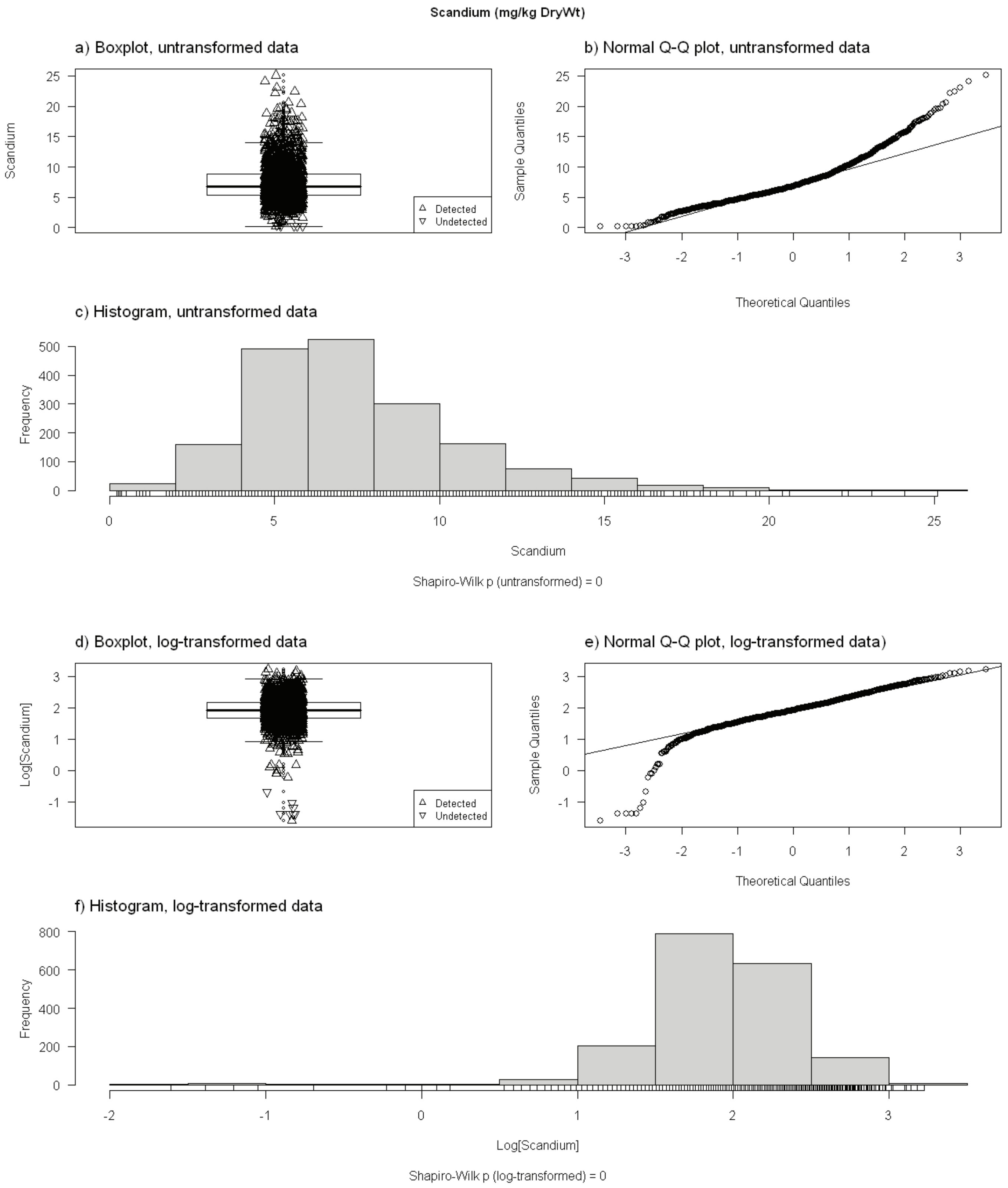
d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)

f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 156. Distribution of All Background Concentrations of Strontium in Soil



Shapiro-Wilk p (untransformed) = 0

Shapiro-Wilk p (log-transformed) = 0

Figure 157. Distribution of All Background Concentrations of Scandium in Soil

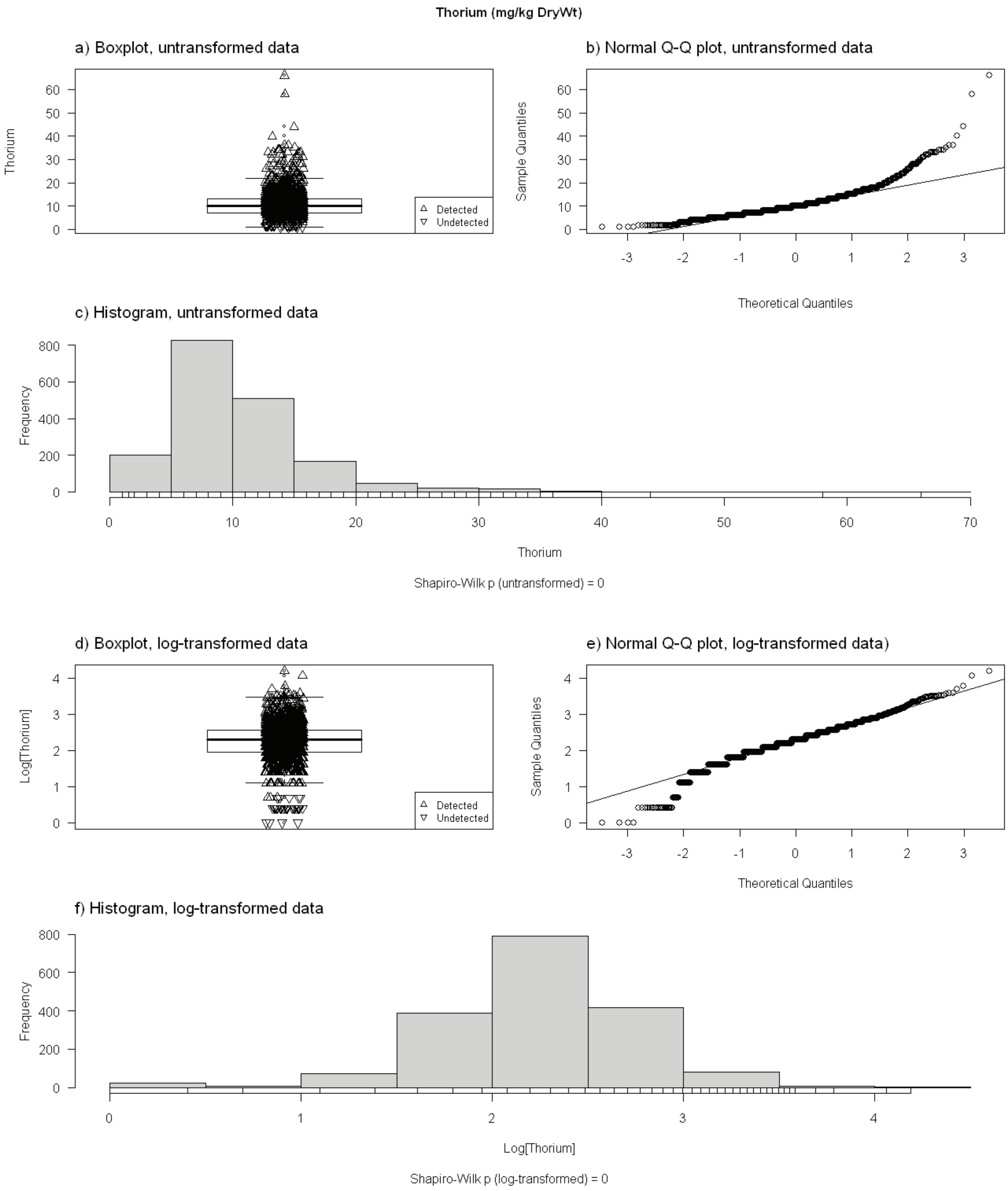


Figure 158. Distribution of All Background Concentrations of Thorium in Soil

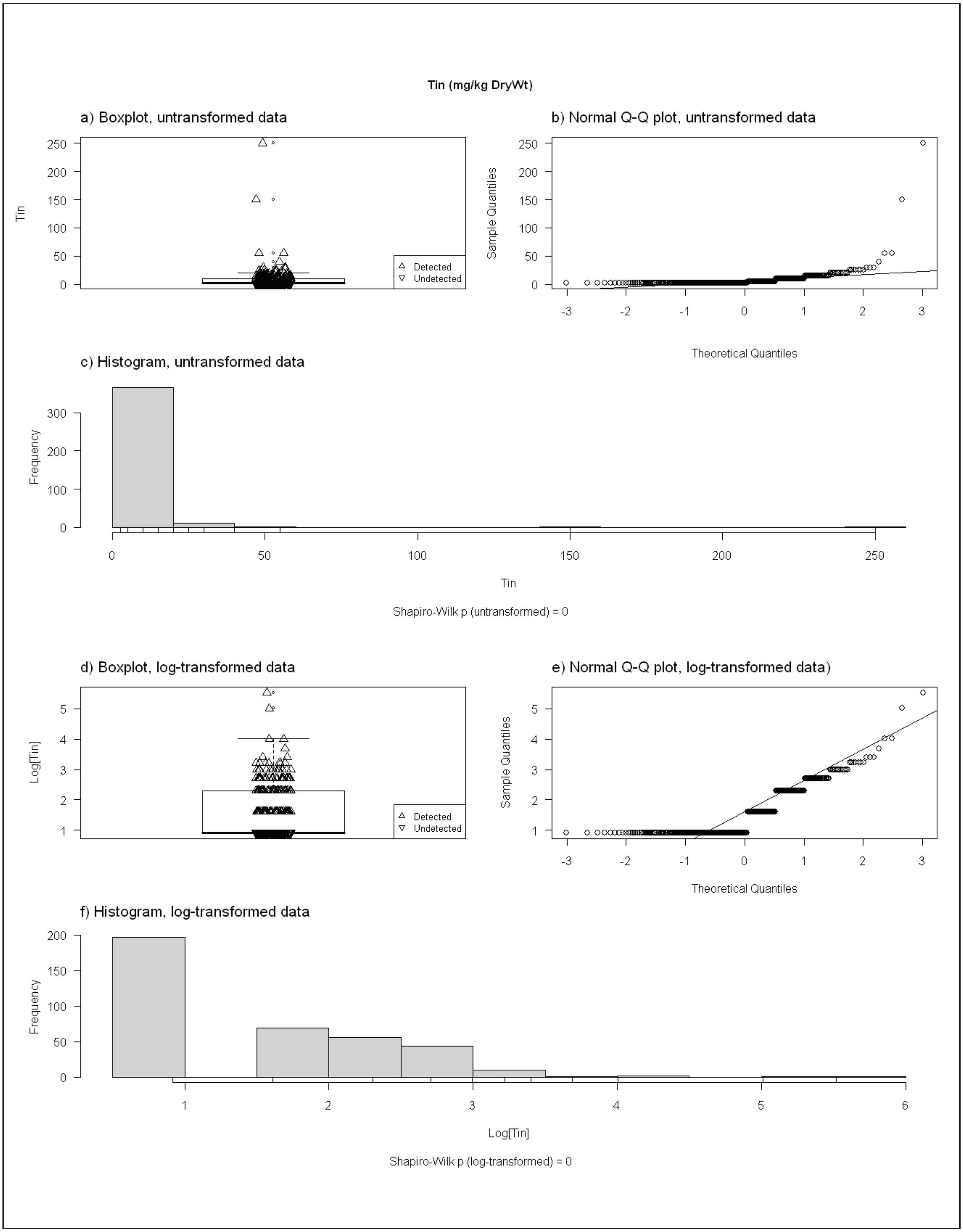


Figure 159. Distribution of All Background Concentrations of Tin in Soil

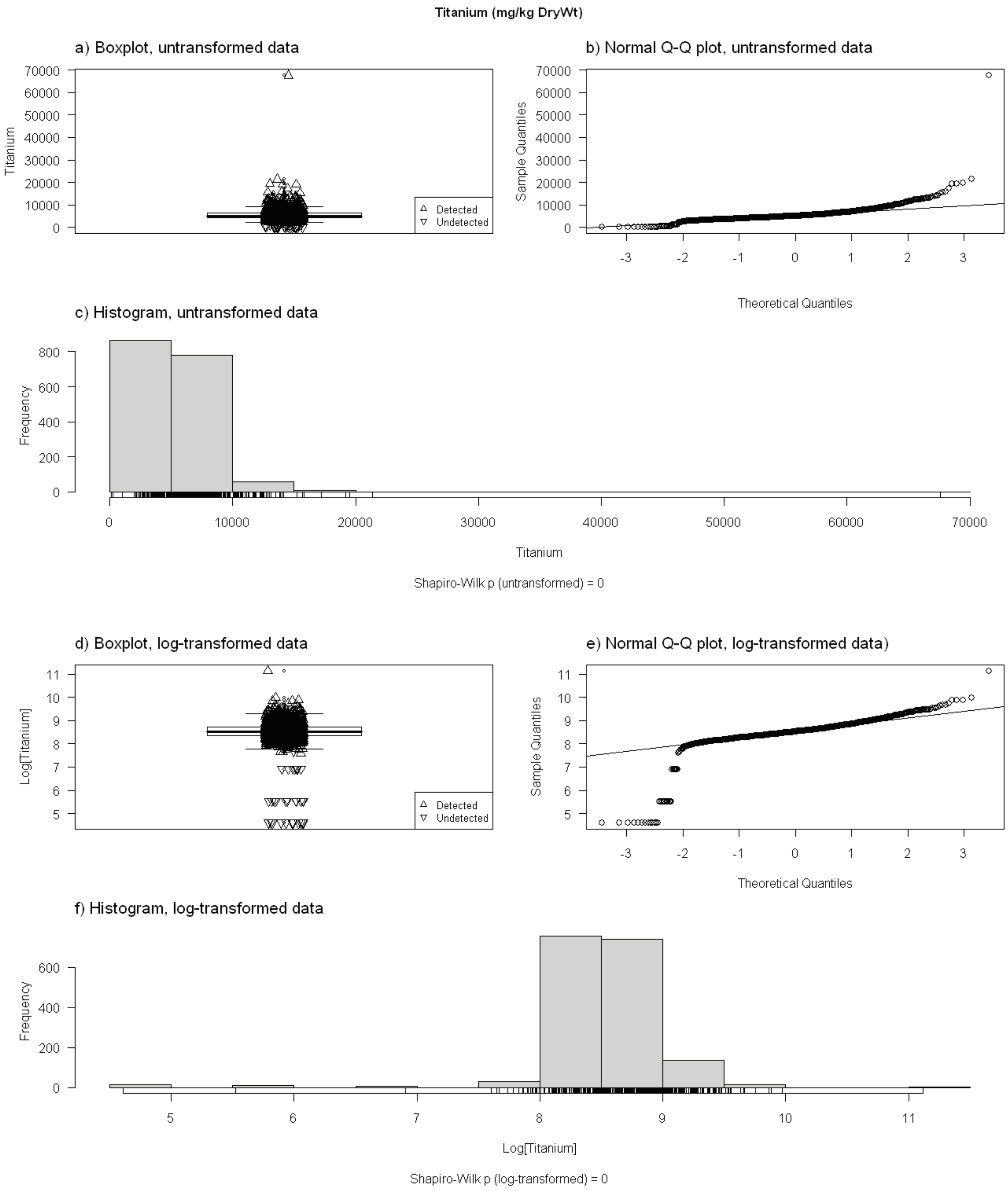


Figure 160. Distribution of All Background Concentrations of Titanium in Soil

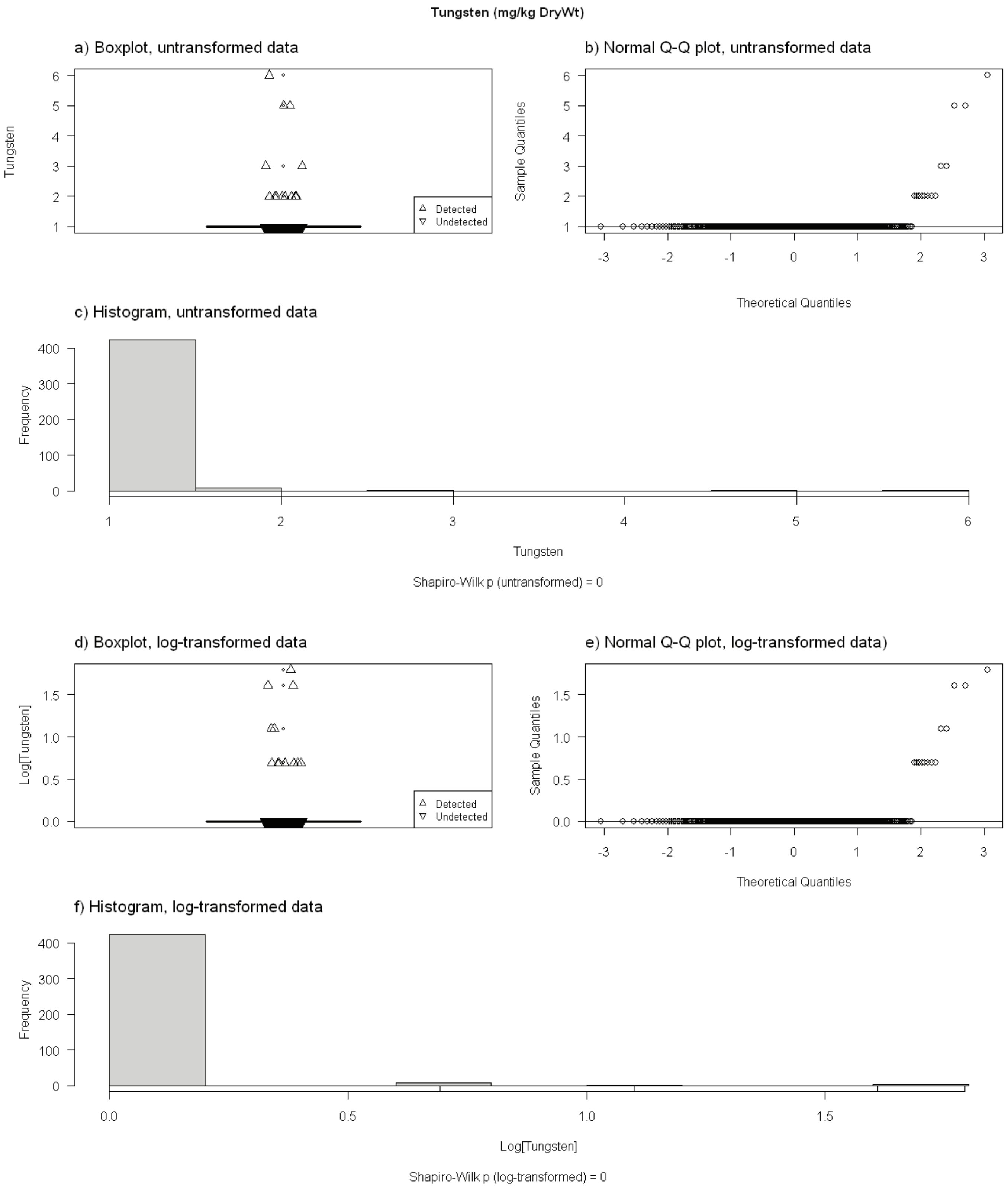


Figure 161. Distribution of All Background Concentrations of Tungsten in Soil

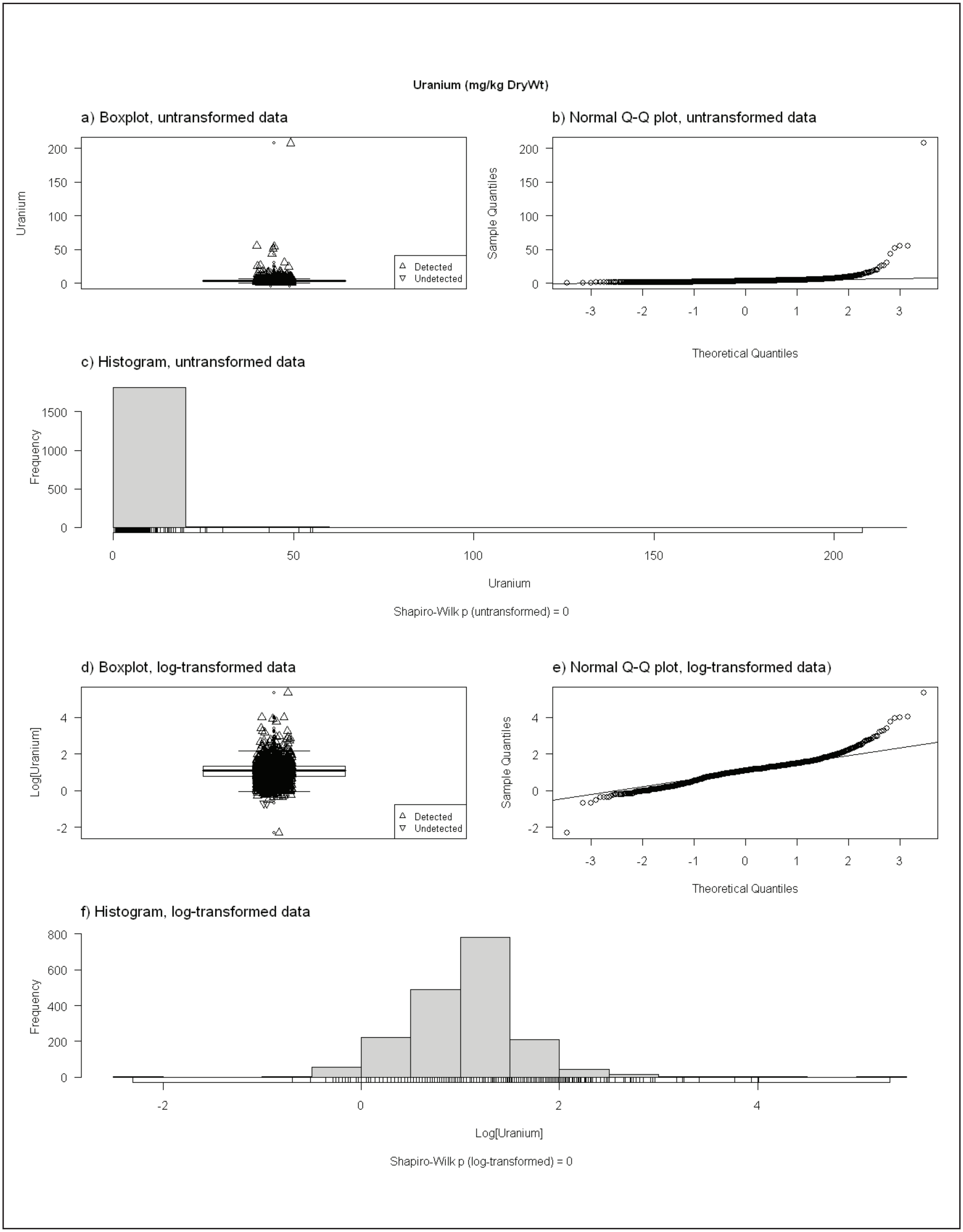
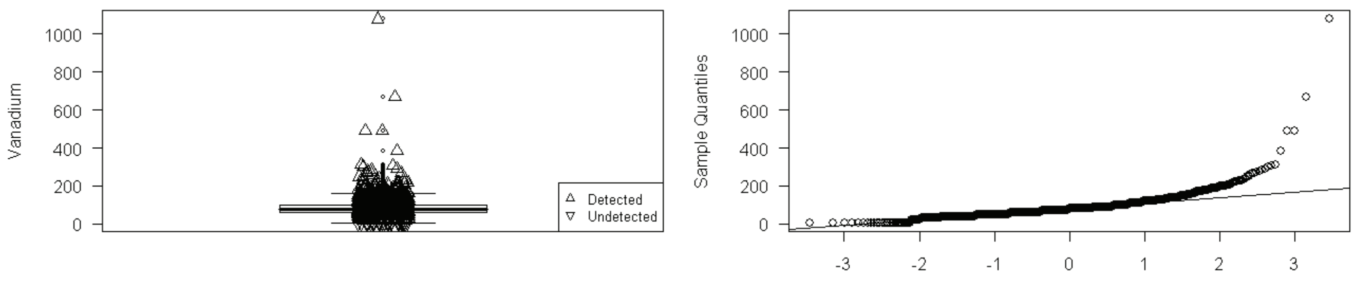
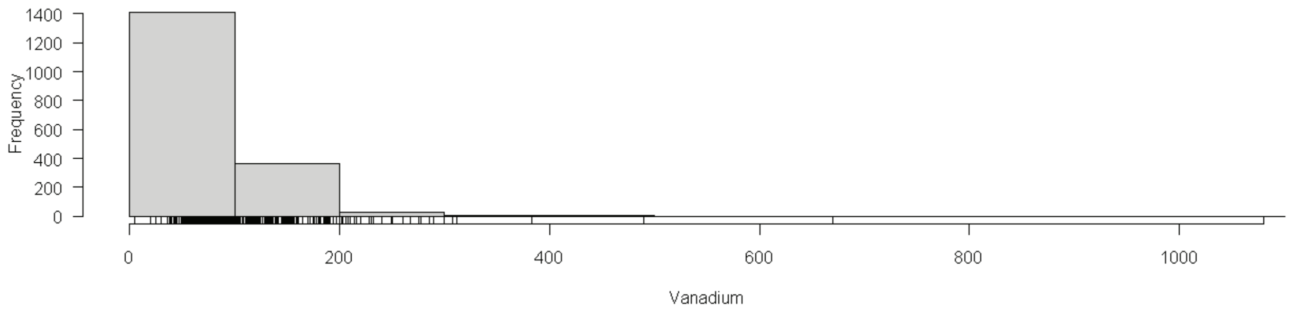


Figure 162. Distribution of All Background Concentrations of Uranium in Soil

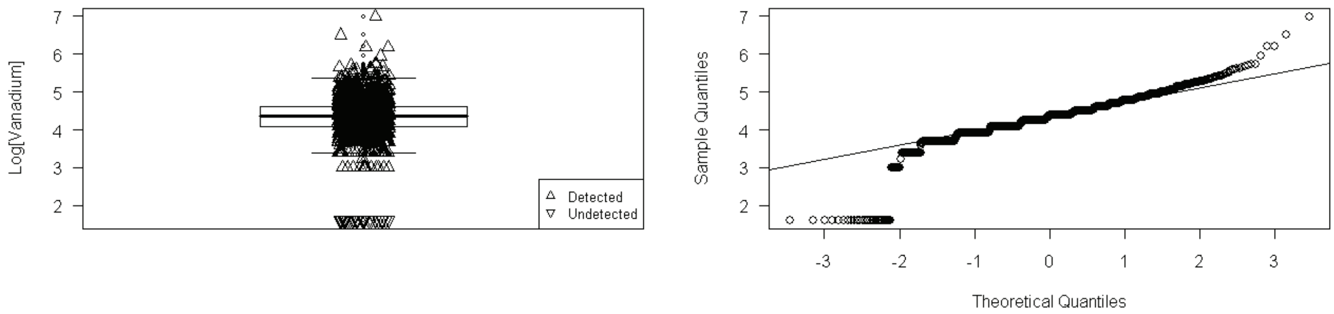
Vanadium (mg/kg DryWt)


a) Boxplot, untransformed data

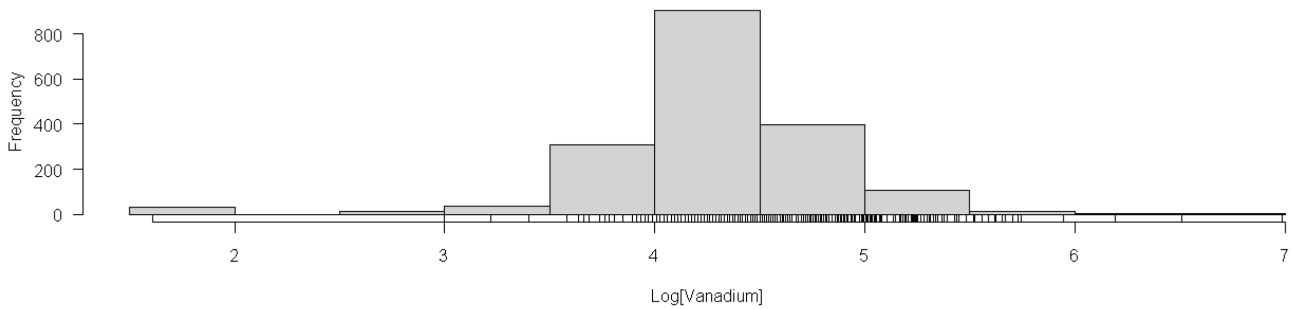
b) Normal Q-Q plot, untransformed data


c) Histogram, untransformed data

Shapiro-Wilk p (untransformed) = 0


d) Boxplot, log-transformed data

e) Normal Q-Q plot, log-transformed data)


f) Histogram, log-transformed data

Shapiro-Wilk p (log-transformed) = 0

Figure 163. Distribution of All Background Concentrations of Vanadium in Soil

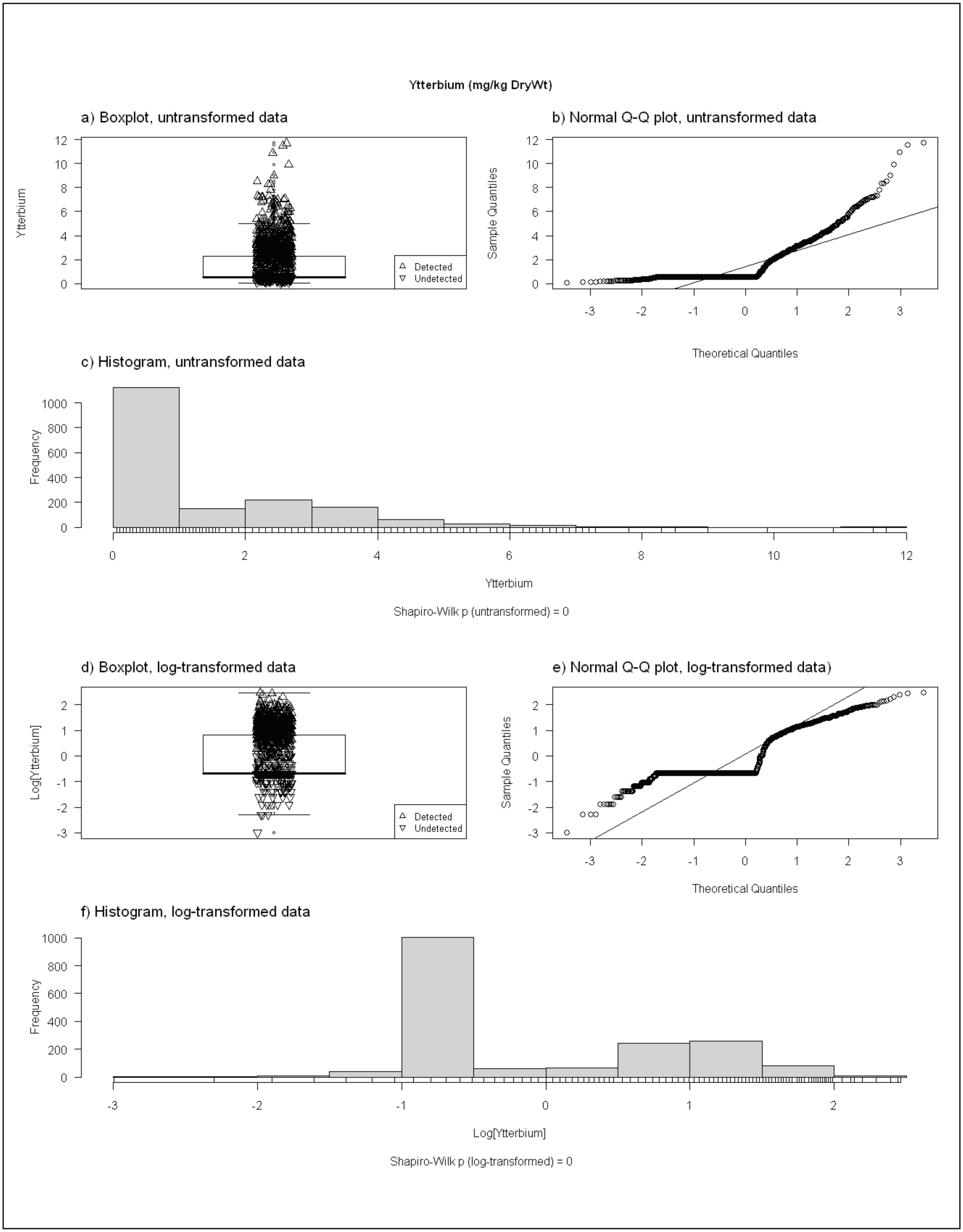


Figure 164. Distribution of All Background Concentrations of Ytterbium in Soil

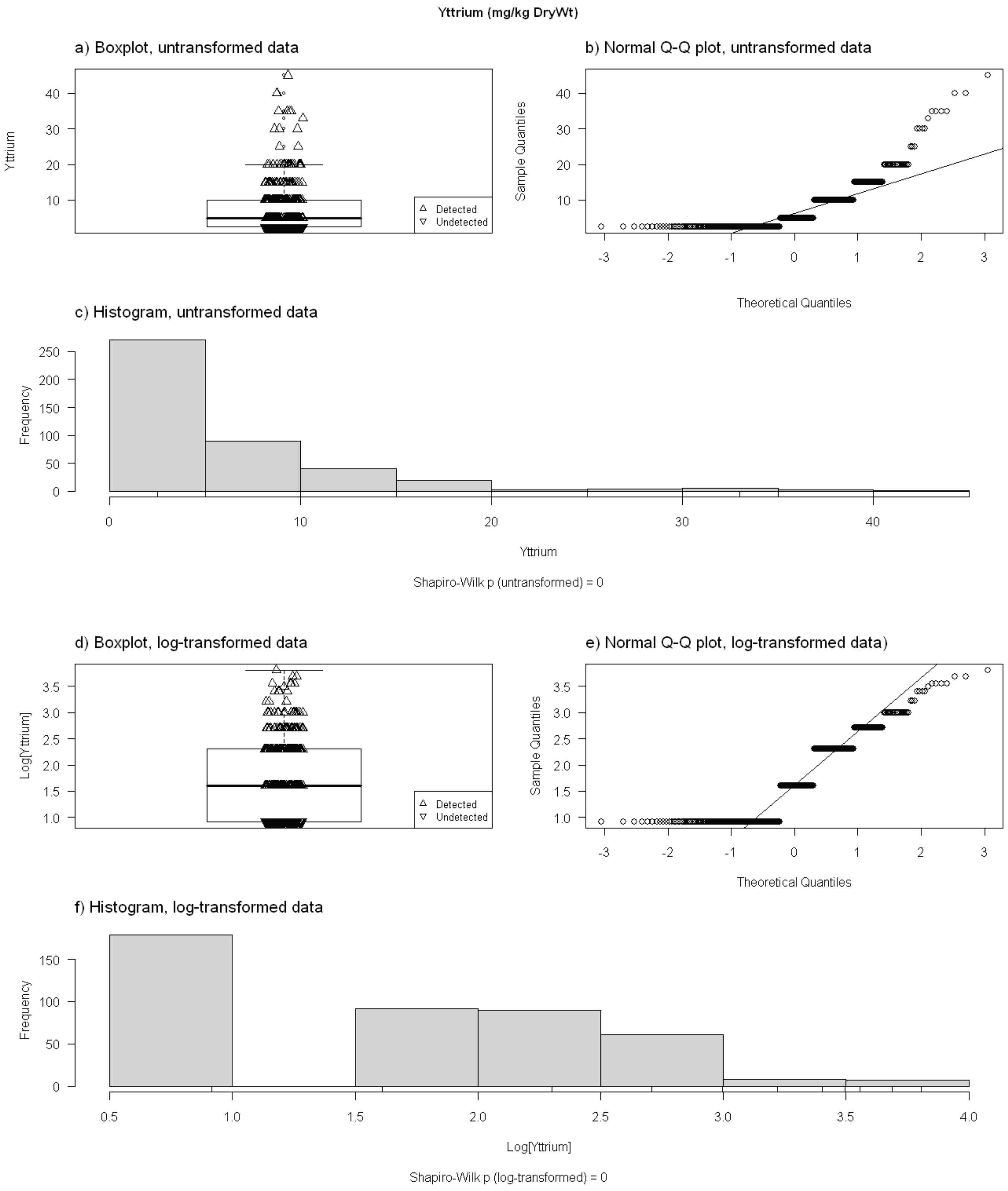


Figure 165. Distribution of All Background Concentrations of Yttrium in Soil

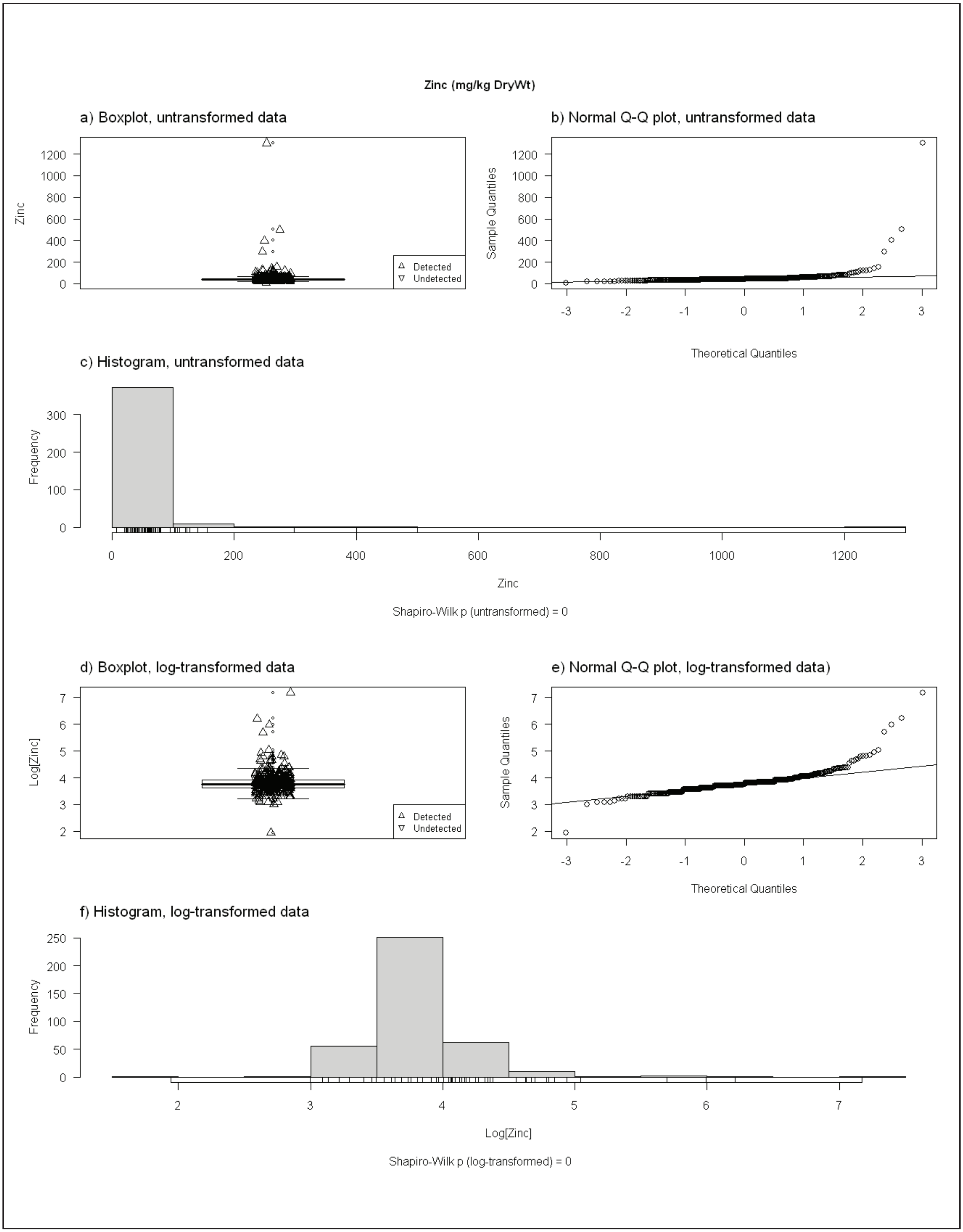


Figure 166. Distribution of All Background Concentrations of Zinc in Soil

MAPS

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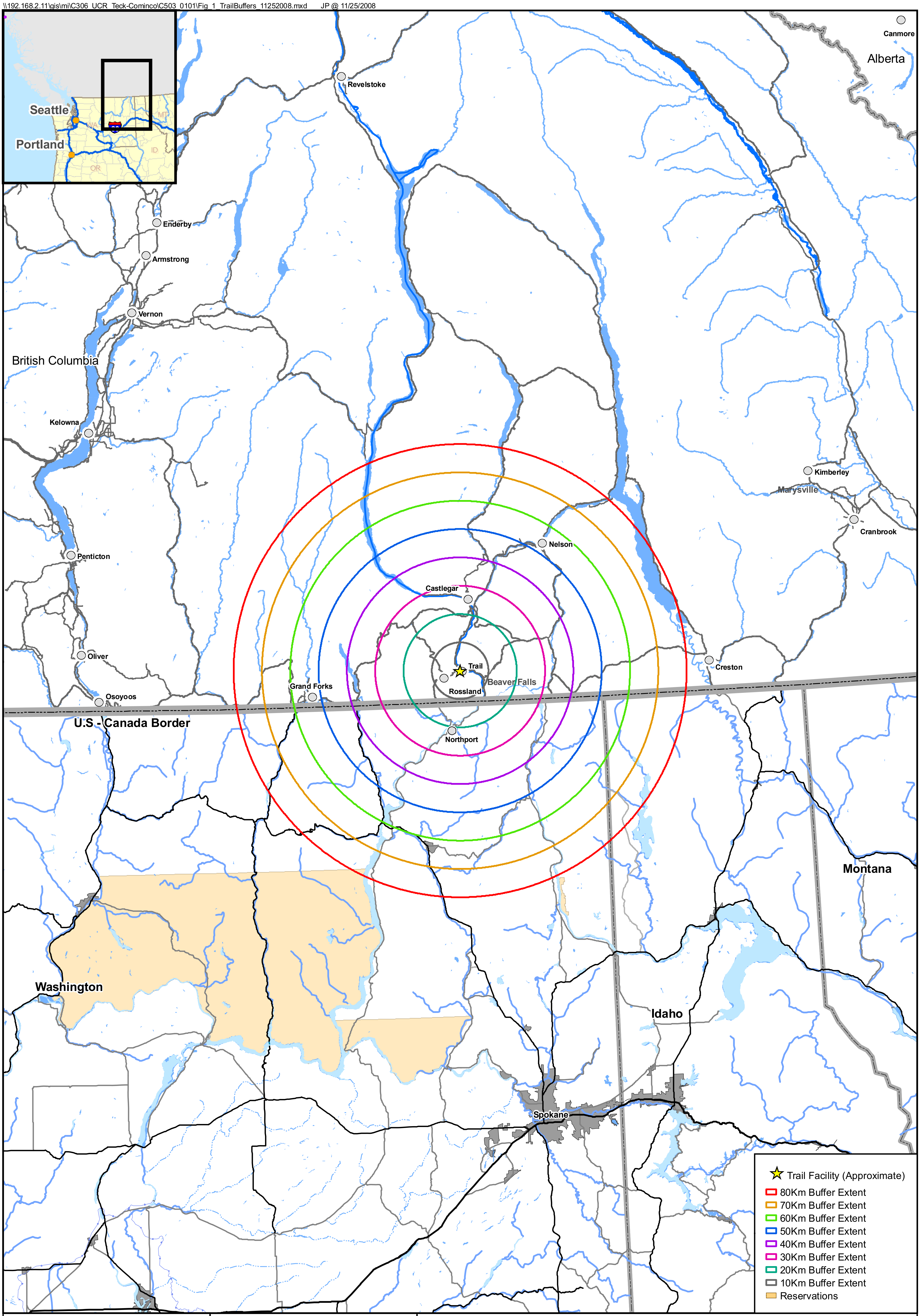


Integral **Parametrix**

Km
0 10 20

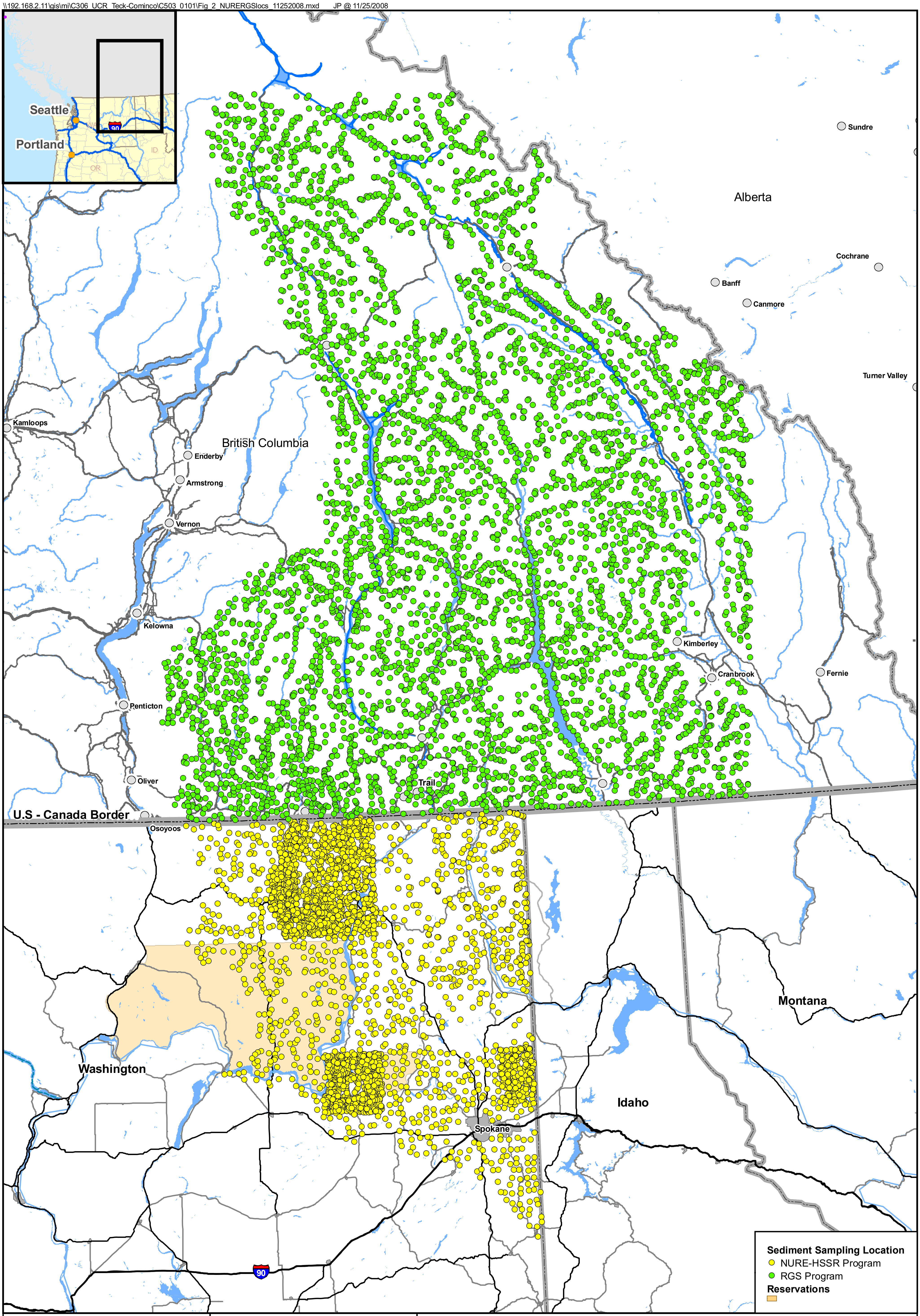
Miles
0 10 20

N

Map 1. **Buffer Zones Around the Trail Smelter for Evaluation of Background Sediment and Soil**

Upper Columbia River, WA

\\192.168.2.11\gis\mi\C306_UCR_Teck-Cominco\C503_0101\Fig_2_NURERGSlocs_11252008.mxd JP @ 11/25/2008



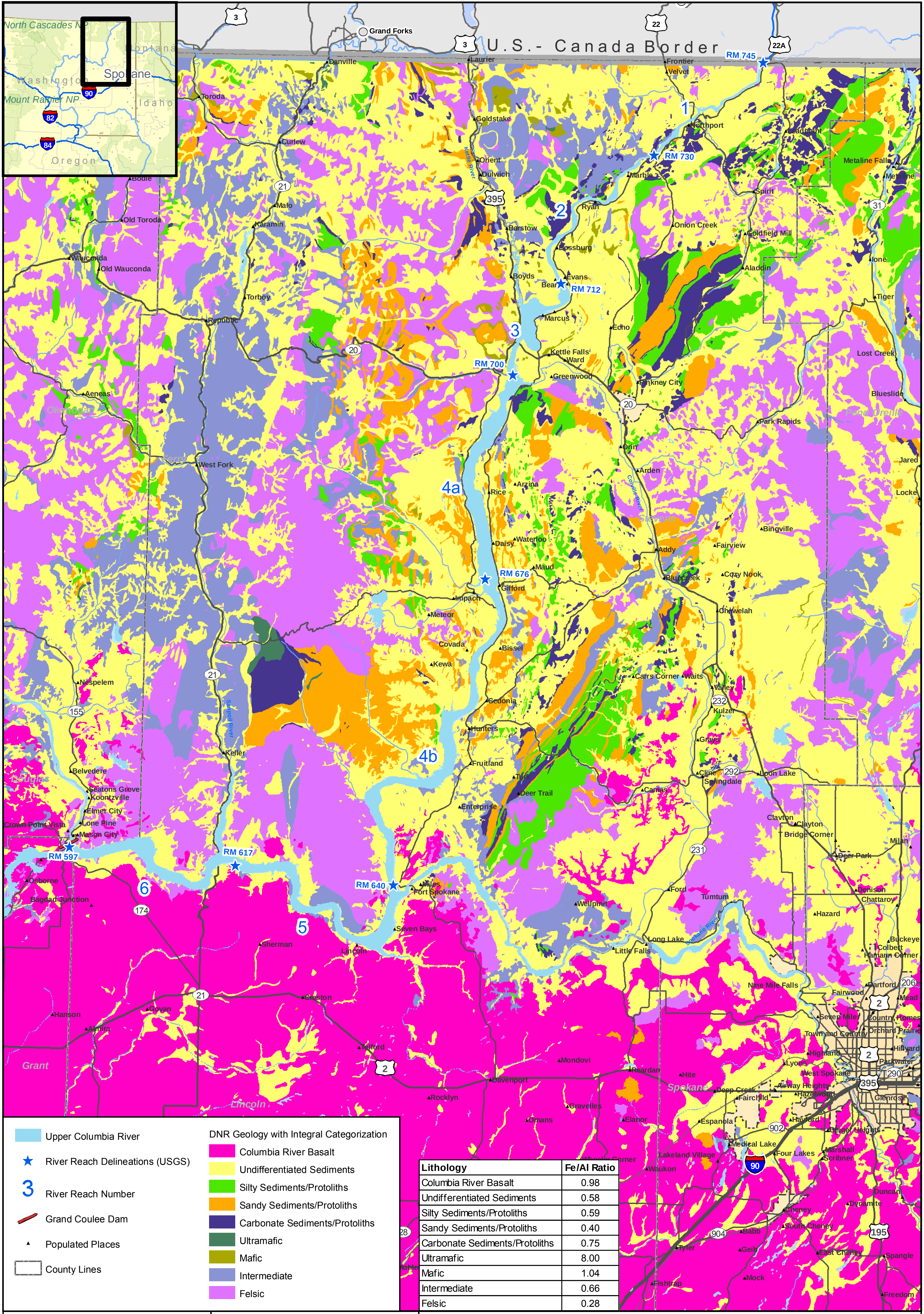
Integral **Parametrix**

Km
0 15 30
Miles
0 15 30
N

Map 2. **Sediment Sampling Locations for the NURE-HSSR and RGS Programs**

Upper Columbia River, WA

\\Mi\gis\mi\C306_UCR_Teck-Cominco\C503_0101\Fig_54_Geology_11252008.mxd JP @ 11-25-2008



Lithology	Fe/Al Ratio
Columbia River Basalt	0.98
Undifferentiated Sediments	0.58
Silty Sediments/Protoliths	0.59
Sandy Sediments/Protoliths	0.40
Carbonate Sediments/Protoliths	0.75
Ultramafic	8.00
Mafic	1.04
Intermediate	0.66
Felsic	0.28

Integral **Parametrix**

Km 0 5 10

Miles 0 5 10

N

Map 3. **UCR Geology**

Upper Columbia River, WA

TABLES

Table 1. Upper Tolerance Limits for 5 km Blocks and a Buffer Size of 50 km

Class	Chemical	Units	Number of Samples	Detection Frequency	90th Percentile	95% UCL on the 90th Percentile	95th Percentile	95% UCL on the 95th Percentile
Metals	Aluminum	mg/kg	931	97.0%	68,100	70,200	73,700	75,200
Metals	Antimony	mg/kg	2178	95.7%	1.6	1.7	2.4	2.8
Metals	Arsenic	mg/kg	2595	96.1%	16	17	25	28
Metals	Barium	mg/kg	2644	99.3%	1,200	1,230	1,410	1,500
Metals	Beryllium	mg/kg	479	99.8%	2.5	2.5	2.5	3.0
Metals	Bismuth	mg/kg	512	100.0%	0.40	0.42	0.57	0.75
Metals	Cadmium	mg/kg	518	99.8%	0.30	0.40	0.57	0.90
Metals	Calcium	mg/kg	901	93.7%	78,200	104,000	149,000	162,000
Metals	Cesium	mg/kg	2175	97.0%	8.6	9.2	12	14
Metals	Chromium	mg/kg	2644	98.6%	132	140	180	190
Metals	Cobalt	mg/kg	2659	96.1%	20	20	23	24
Metals	Copper	mg/kg	2467	100.0%	40	42	50	54
Metals	Europium	mg/kg	921	84.5%	2.5	2.8	3.1	3.3
Metals	Gallium	mg/kg	273	100.0%	5.0	5.3	5.4	5.8
Metals	Gold	mg/kg	2275	90.7%	0.014	0.016	0.032	0.038
Metals	Hafnium	mg/kg	2669	99.4%	16	17	20	21
Metals	Iron	mg/kg	2687	99.6%	40,500	41,200	46,100	47,500
Metals	Lead	mg/kg	2509	97.0%	25	27	35	40
Metals	Lithium	mg/kg	478	93.5%	15	17	18	21
Metals	Lutetium	mg/kg	2667	97.4%	0.9	1.0	1.2	1.4
Metals	Magnesium	mg/kg	902	96.8%	15,600	18,600	25,300	31,200
Metals	Manganese	mg/kg	2688	99.1%	850	876	1,030	1,090
Metals	Mercury	mg/kg	1782	92.3%	0.11	11	250	250
Metals	Molybdenum	mg/kg	2508	89.2%	2.8	3.0	4.3	4.6
Metals	Nickel	mg/kg	2509	98.6%	43	45	54	58
Metals	Niobium	mg/kg	478	75.1%	27	30	33	40
Metals	Potassium	mg/kg	902	96.7%	21,000	23,500	27,100	28,900
Metals	Rubidium	mg/kg	2175	95.9%	129	130	145	150
Metals	Samarium	mg/kg	2671	97.7%	15.4	16.0	19.7	20.8
Metals	Scandium	mg/kg	2671	99.7%	15.0	15.6	17.9	18.3
Metals	Selenium	mg/kg	752	64.0%	1.7	2.0	2.0	2.5

Table 1. Upper Tolerance Limits for 5 km Blocks and a Buffer Size of 50 km

Class	Chemical	Units	Number of Samples	Detection Frequency	90th Percentile	95% UCL on the 90th Percentile	95th Percentile	95% UCL on the 95th Percentile
Metals	Silver	mg/kg	2659	94.1%	0.6	0.8	250	250
Metals	Sodium	mg/kg	2673	99.9%	26,000	26,300	28,600	29,000
Metals	Strontium	mg/kg	901	71.6%	209	233	286	334
Metals	Tantalum	mg/kg	2175	96.5%	4.2	4.6	6.4	7.5
Metals	Tellurium	mg/kg	273	77.7%	0.037	0.040	0.045	0.058
Metals	Terbium	mg/kg	2175	93.8%	3.1	3.6	10.0	10.0
Metals	Thallium	mg/kg	279	84.6%	0.23	0.30	0.31	0.53
Metals	Tin	mg/kg	1670	86.8%	5.0	6.0	10.0	11.8
Metals	Titanium	percent	926	97.0%	0.7	0.8	0.84	0.87
Metals	Tungsten	mg/kg	2656	78.8%	7.5	9.2	15.0	15.0
Metals	Vanadium	mg/kg	897	97.1%	123	128	141	152
Metals	Yttrium	mg/kg	478	62.3%	15.0	18.3	20.0	22.5
Metals	Zinc	mg/kg	2398	94.6%	105	113	149	171
Metals	Zirconium	mg/kg	1759	100.0%	717	763	968	1,060
Nutrients	Phosphorus	percent	750	100.0%	0.13	0.14	0.15	0.18
PhysChem	Sulfur	percent	273	95.2%	0.13	0.15	0.16	0.20
Halogens	Bromide ion	mg/kg	155	73.5%	28	40	41	60
Halogens	Bromine	mg/kg	2020	100.0%	19	21	28	32
Halogens	Chloride ion	mg/kg	155	20.6%	153	209	215	362
Halogens	Fluorine	mg/kg	512	100.0%	843	940	1,040	1,100
Actinides	Thorium	mg/kg	2670	99.7%	37	40	55	60
Actinides	Uranium	mg/kg	2689	100.0%	20	22	31	36
Lanthanide	Cerium	mg/kg	2669	99.6%	222	234	293	310
Lanthanide	Dysprosium	mg/kg	641	66.8%	14	16	20	25
Lanthanide	Lanthanum	mg/kg	2671	99.7%	130	140	173	186
Lanthanide	Ytterbium	mg/kg	2668	93.9%	4.7	5.0	6.0	6.5

Table 2. Number of Background Soil Measurements, by Study and Analyte

	Study					
Analyte	Burt et al. (2003)	Holmgren et al. (1993)	Le Roi (2005)	NURE	Trail ERA	N
Aluminum	1			1,824		1,825
Arsenic			6	400	3	409
Barium				381		381
Beryllium				381		381
Cadmium	1	3	6		3	13
Calcium	1			382		383
Cerium				1,753		1,753
Chromium	1			437		438
Cobalt	1			382		383
Copper	1	3	6	377		387
Dysprosium				1,530		1,530
Europium				1,652		1,652
Gold				360		360
Hafnium				1,787		1,787
Iron	1			1,785		1,786
Lanthanum				1,780		1,780
Lead	1	3	6	381	3	394
Lithium				381		381
Lutetium				1,681		1,681
Magnesium	1			381		382
Manganese	1			1,822		1,823
Molybdenum				437		437
Nickel	1	3		382		386
Niobium				434		434
Phosphorus	1			435		436
Potassium	1			381		382
Samarium				1,804		1,804
Scandium				1,818		1,818
Selenium				437		437
Silica	1					1
Silver				381		381
Sodium	1			1,823		1,824
Strontium				381		381
Sulfur					3	3
Thorium				1,791		1,791
Tin				381		381
Titanium	1			1,711		1,712
Tungsten				437		437
Uranium				1,824		1,824
Vanadium				1,813		1,813
Ytterbium				1,781		1,781
Yttrium				437		437
Zinc	1	3		382		386
Zirconium	1					1

Table 3. Detection Frequencies in Background Soil Samples

Analyte	Units	Total Measurements	Maximum Detected Value	Maximum Undetected Value	Number Detected	Detection Frequency
Aluminum	mg/kg	1,825	105,500	250	1,800	98.6%
Arsenic	mg/kg	409	23.0	NA	409	100.0%
Barium	mg/kg	381	4,133	NA	381	100.0%
Beryllium	mg/kg	381	5.20	0.250	377	99.0%
Cadmium	mg/kg	13	2.80	NA	13	100.0%
Calcium	mg/kg	383	50,000	50.0	379	99.0%
Cerium	mg/kg	1,753	296	40.5	1,713	97.7%
Chromium	mg/kg	438	165	NA	438	100.0%
Cobalt	mg/kg	383	77.0	2.50	345	90.1%
Copper	mg/kg	387	148	NA	387	100.0%
Dysprosium	mg/kg	1,530	851	3.15	378	24.7%
Europium	mg/kg	1,652	6.60	3.20	775	46.9%
Gold	mg/kg	360	0.188	0.0050	22	6.1%
Hafnium	mg/kg	1,787	63	2.00	1,714	95.9%
Iron	mg/kg	1,786	118,466	2,687	1,782	99.8%
Lanthanum	mg/kg	1,780	386	2.50	1,779	99.9%
Lead	mg/kg	394	320	5.00	277	70.3%
Lithium	mg/kg	381	26.0	2.50	354	92.9%
Lutetium	mg/kg	1,681	14.1	0.550	1,288	76.6%
Magnesium	mg/kg	382	9,500	NA	382	100.0%
Manganese	mg/kg	1,823	3,590	10.0	1,810	99.3%
Molybdenum	mg/kg	437	15.0	1.00	186	42.6%
Nickel	mg/kg	386	55.0	2.50	375	97.2%
Niobium	mg/kg	434	65.0	2.50	203	46.8%
Phosphorus	mg/kg	436	5,500	NA	436	100.0%
Potassium	mg/kg	382	30,000	NA	382	100.0%
Samarium	mg/kg	1,804	31.0	1.00	1,767	97.9%
Scandium	mg/kg	1,818	25.1	0.500	1,811	99.6%
Selenium	mg/kg	437	8.00	0.500	115	26.3%
Silver	mg/kg	381	2.40	NA	381	100.0%
Sodium	mg/kg	1,824	37,447	3,000	1,809	99.2%
Strontium	mg/kg	381	392	25.0	241	63.3%
Thorium	mg/kg	1,791	66.0	2.00	1,761	98.3%
Tin	mg/kg	381	250	2.50	184	48.3%
Titanium	mg/kg	1,712	67,600	2,138	1,680	98.1%
Tungsten	mg/kg	437	6.00	1.00	13	3.0%
Uranium	mg/kg	1,824	208	0.500	1,822	99.9%
Vanadium	mg/kg	1,813	1,080	5.00	1,782	98.3%
Ytterbium	mg/kg	1,781	11.7	1.55	642	36.0%
Yttrium	mg/kg	437	45.0	2.50	258	59.0%
Zinc	mg/kg	386	1,300	NA	386	100.0%
Zirconium	mg/kg	1	101	NA	1	100.0%

Table 4. 95th Percentiles and Tolerance Limits for Soil Samples, with Comparative Data

		Regional Soil Data		Trail Background Data[b]	Western U.S. Background[c]	Ecology Spokane Basin[d]
Analyte	Units	95th Percentile	Tolerance Limit[a]	95th Percentile	95th Percentile	90th Percentile
Aluminum	mg/kg	73,453	74,546		90,000	21,376
Arsenic	mg/kg	8.6	10	19.7	10	9.34 / 20.8[e]
Barium	mg/kg	430	472		800	
Beryllium	mg/kg	2.0	2.0		1.5	0.84
Cadmium	mg/kg	1.96	3.6[f]	1.67	1.0	0.72
Calcium	mg/kg	5300	9900			
Cerium	mg/kg	131	136			
Chromium	mg/kg	126	135		120	17.8
Cobalt	mg/kg	25	27		16	
Copper	mg/kg	26.3	29	51.5	40	21.6
Dysprosium	mg/kg	11	12.6			
Europium	mg/kg	3	3.2			
Gold	mg/kg	0.0271	0.049			
Hafnium	mg/kg	11	12			
Iron	mg/kg	52,083	55,200		50,000	25,026
Lanthanum	mg/kg	59	64			
Lead	mg/kg	30	49.4	37.9	40	14.9
Lithium	mg/kg	16	20			
Lutetium	mg/kg	0.6	0.6			
Magnesium	mg/kg	4,298	5,200			
Manganese	mg/kg	1,410	1,500		1,100	663
Mercury	mg/kg	ND	ND	0.07		0.02
Molybdenum	mg/kg	4.0	5.0			
Nickel	mg/kg	23	27		35	16.2
Niobium	mg/kg	15	25			
Phosphorus	mg/kg	1,600	1,700			
Potassium	mg/kg	18,000	19,000			
Samarium	mg/kg	8.0	8.0			
Scandium	mg/kg	13.7	14.3			
Selenium	mg/kg	2.0	2.0		0.7	

Table 4. 95th Percentiles and Tolerance Limits for Soil Samples, with Comparative Data

Analyte	Units	Regional Soil Data 95th Percentile	Regional Soil Data Tolerance Limit[a]	Trail Background Data[b] 95th Percentile	Western U.S. Background[c] 95th Percentile	Ecology Spokane Basin[d] 90th Percentile
Silver	mg/kg	0.7	0.8		0.8	
Sodium	mg/kg	27,400	28,013			
Strontium	mg/kg	133	166			
Thorium	mg/kg	20.5	22			
Tin	mg/kg	20	25			
Titanium	mg/kg	9,400	10,033			
Tungsten	mg/kg	1.0	2.0			
Uranium	mg/kg	6.5	7.1			
Vanadium	mg/kg	160	170		150	
Ytterbium	mg/kg	4.4	4.8			
Yttrium	mg/kg	20	25			
Zinc	mg/kg	77.8	110	168	120	66.4
Zirconium	mg/kg	101	NC			

Notes:

ND = no data

NC = not calculated (insufficient data)

[a] The upper 95% confidence limit on the 95th percentile

[b] Sanei et al. (2007)

[c] USEPA (2003)

[d] Ecology (1994)

[e] Values for atomic absorption and inductively coupled plasma spectroscopic methods, respectively

[f] Calculated using a bootstrapped data set (see text)