Ontario

Groundwater Hydrochemistry, Water Isotope and Manual Water Level Data for the Early Silurian Carbonates of the Niagara Escarpment Cuesta

Support Document

Ontario Geological Survey
Miscellaneous Release—Data 390

by

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2021

Users of OGS products should be aware that Indigenous communities may have Aboriginal or treaty rights or other interests that overlap with areas of mineral potential and exploration.

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INTRODUCTION

This document provides background information and context supporting the digital data release, Miscellaneous Release—Data 390 (MRD 390). The data release comprises the hydrochemical, isotopic and manual water level data for a groundwater sampling event conducted in the Early Silurian carbonates of the Niagara Escarpment cuesta during the summer of 2016. The groundwater sampling and monitoring was conducted in 3 different well types: an OGS network of Flexible Liner Underground Technologies Ltd. (FLUTe™) multidepth wells, Provincial Groundwater Monitoring Network (PGMN) wells and carefully selected domestic wells. This data release represents the final phase of a multiphase groundwater mapping project. Additional work phases and findings are described in Brunton et al. (2007), Brunton (2009), Brunton et al. (2011), Brunton and Brintnell (2011), Lee et al. (2011), Priebe, Brunton and Lee (2012), Brunton et al. (2012), Priebe and Brunton (2016), Priebe, Neville and Rudolph (2017), Priebe, Neville and Brunton (2017), Priebe et al. (2018) and Priebe (2019). The data published here were collected in support of an OGS-funded PhD thesis, which contains data interpretation and analyses (Priebe 2019). Hydrochemistry data from a FLUTe™ well network sampling campaign in 2011 and 2012 were published previously by Priebe and Lee (2016). The study area comprises the Michigan Basin portion of the Niagara Escarpment cuesta of southern Ontario and is bounded by the Bruce Peninsula to the north, the erosional edge of the Niagara Escarpment cuesta to the east, the edge of the Michigan Basin to the south-southeast and the subcrop boundary of the Late Silurian Salina Group to the west (*see* Figure 1).

This data set contains analyses for 69 groundwater samples from 36 stations. The stations consist of 12 FLUTe™ multidepth wells with 3 to 6 sampling ports each, 5 PGMN wells and 19 domestic wells (*see* Figure 1). The average charge balance error (absolute value) is 4% with a standard deviation of ± 3%, demonstrating the reliability of major ion analyses. A field quality assurance–quality control (QA–QC) program was undertaken to support an evaluation of analytical accuracy and precision. The QA–QC program consisted of the collection of 1 blank, 4 duplicate pairs and 6 standards, representing 10% of the total number of samples submitted for analysis. Duplicates provided by the laboratory as part of their in-house QA were also used to assess precision, with the number of laboratory duplicates varying by analytical method. To further ensure confidence in the data set, key parameters, such as major ions, were analyzed by 2 separate analytical methods to assist with the identification of systematic errors or those associated with sample sequencing problems. Data with the best accuracy and precision are published here. Evaluation of the data set via the QA–QC measures provides confidence in its reliability. To enable such an evaluation by clients, accuracy and precision plots (*see* Appendix) and the data used to create them (*see* All_data_2016.xlsx) have been provided. The groundwater sampling protocols, sample handling, field measurements and analytical methods used here are those of the OGS Ambient Groundwater Geochemistry Program described in the following sections of this support document and in greatest detail by Hamilton and Brauneder (2008), Hamilton (2015) and Hamilton et al. (*in prep*.).

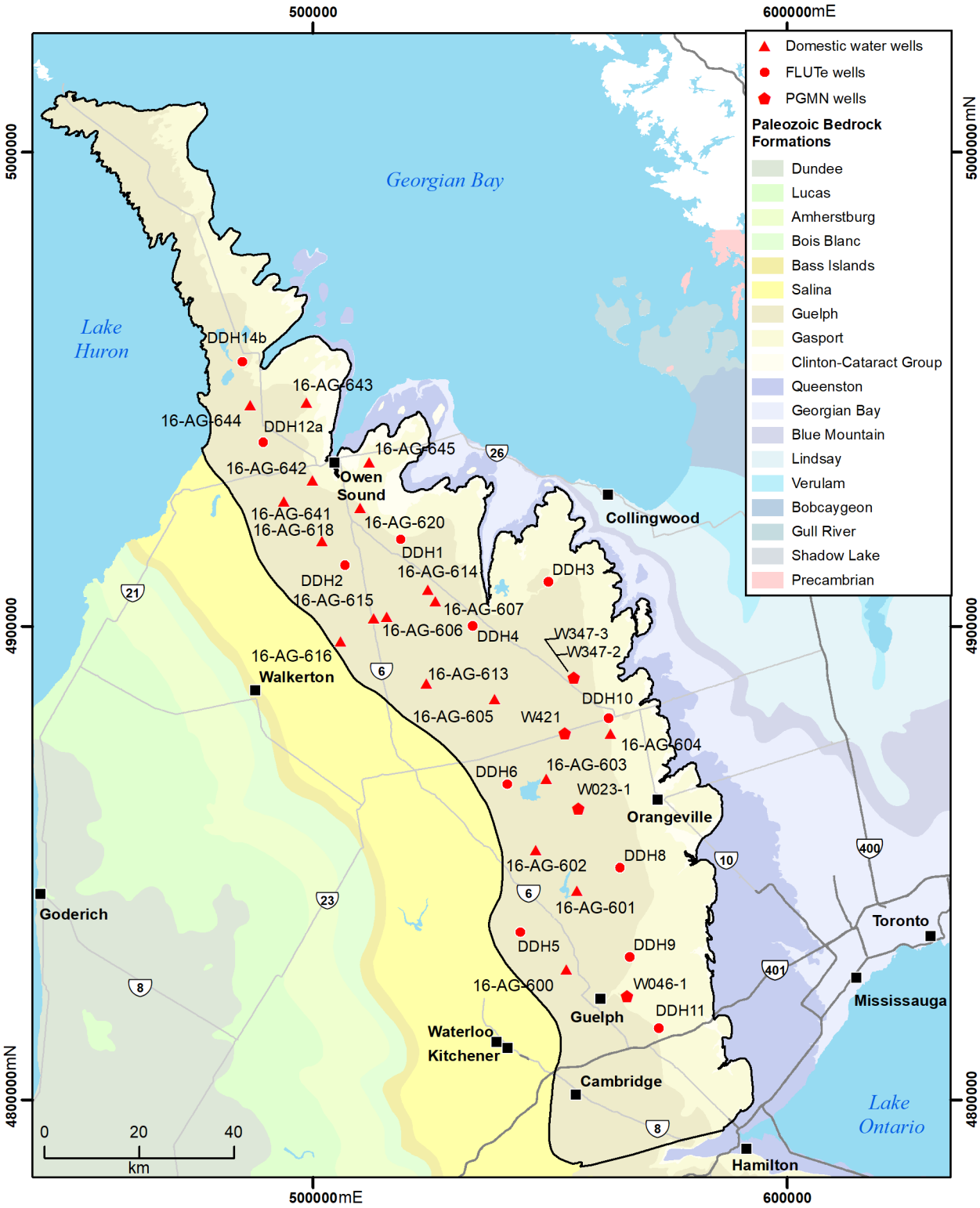

Figure 1. Study area showing groundwater sampling locations overlying the Paleozoic bedrock map of southern Ontario of Armstrong and Dodge (2007). Paleozoic bedrock units are formations unless otherwise stated. Well locations are symbolized to represent well type and each location is labelled with its Station identification.

Contents

The data of MRD 390 are organized into the following files:

- **All_data_2016.xlsx:** this Microsoft® Excel® for Office 360 file contains manual water level, hydrochemistry and isotope data as well as station and sample details.
- **MRD_390_Support Document.pdf**: This document briefly describes the study and provides a description of data collection and analytical methods. Also included in this document are
  - **Figure 1**: A location map showing groundwater sampling and monitoring locations.
  - **Table 1**: A summary table containing a list of the fields contained within the Microsoft® Excel® file, the units and detection limits for each parameter and hyperlinks to the QC plots in the Appendix.
  - **Appendix**: QC plots. Accuracy and precision plots provided for analytical parameters and some field parameters. These can be accessed via the hyperlinks in Table 1 or directly in the Appendix.

Table 1. List of parameters, detection limits and units. **Note:** Quality Control Plots column contains hyperlinks to the QC plots in the Appendix.

Parameter	Units	Detection Limit	Quality Control Plots
Sample			
Station			
Easting	m, 17N, NAD83	±100 m	
Northing	m, 17N, NAD83	±100 m	
Latitude	Dec° WGS 84	±100 m	
Longitude	Dec° WGS 84	±100 m	
Elevation	Metres above sea level		
Geologic Formation at well screen			
Field_QC			
Well_type	Drilled domestic, FLUTe™, PGMN		
MECP Well ID			
Year_drilled			
Well Depth	Metres below ground surface.		
Static Water Level	Metres below ground surface.		
Sample date			
Water_clarity			
Water_colour			
Water_smell			
	Field and Aggregate Parameters		
Temperature	ºC	0.1	
Dissolved Oxygen	% saturation	0.1	
Conductivity	µS/cm	1	
Total Dissolved Solids (TDS)	mg/L		
pH		0.01	

Parameter	Units	Detection Limit	Quality Control Plots
ORP levelled	mV	0.1	
H_2S	mg/L	0.01	
DIC	mg/L	1.09	QC_DIC
DOC	mg/L	1.14	QC_DOC
Total_Coliform	cfu/100 mL	0	
Fecal_Coliform	cfu/100 mL	0	
	Major Parameters and Trace Anions		
Ca	mg/L	0.001	QC_Ca
Mg	mg/L	0.0003	QC_Mg
Na	mg/L	0.0034	QC_Na
K	mg/L	0.13	QC_K
HCO_3^-	mg/L	10	
SO_4^{2-}	mg/L	0.05	QC_SO_4^{2-}
Cl^-	mg/L	0.04	QC_Cl^-
Br	mg/L	0.02	QC_Br
F^-	mg/L	0.01	QC_F^-
PO_4^{3-}	mg/L	0.04	QC_PO_4^-
B	µg/L	5.6	QC_B
Fe	µg/L	0.93	QC_Fe
Iodide	µg/L	5	QC_Iodide
Sr	µg/L	0.24	QC_Sr
Si	µg/L	29	QC_Si
Langelier SI	dimensionless		
	Nitrogen Parameters		
NO_3^-	mg/L	0.006	QC_NO_3^-
NO_2^-	mg/L	0.003	QC_NO_2^-
Organic_N	mg/L	0.05	
TKN	as N mg/L	0.05	QC_TKN
NH_3+ NH_4^+	as N mg/L	0.04	QC_NH_3+ NH_4^+
	Dissolved Gases		
CH_4(aq)	ppmv	0.0001	QC_CH_4(aq)
Insitu CH_4	% saturation		
CO_2(aq)	ppmv	0.0001	QC_CO_2(aq)
Insitu CO_2	% saturation		
	Trace Metals		
Ag	µg/L	0.005	QC_Ag
Al	µg/L	5	QC_Al
As	µg/L	0.03	QC_As
Ba	µg/L	1.2	QC_Ba
Cd	µg/L	0.01	QC_Cd
Ce	µg/L	0.002	QC_Ce
Co	µg/L	0.005	QC_Co
Cr	µg/L	0.02	QC_Cr

Parameter	Units	Detection Limit	Quality Control Plots
Cs	µg/L	0.0005	QC_Cs
Cu	µg/L	0.2	QC_Cu
Dy	µg/L	0.001	QC_Dy
Er	µg/L	0.001	QC_Er
Eu	µg/L	0.0004	QC_Eu
Gd	µg/L	0.001	QC_Gd
Hf	µg/L	0.004	QC_Hf
Ho	µg/L	0.0001	QC_Ho
La	µg/L	0.001	QC_La
Li	µg/L	0.01	QC_Li
Lu	µg/L	0.0001	QC_Lu
Mn	µg/L	3	QC_Mn
Mo	µg/L	0.01	QC_Mo
Nb	µg/L	0.001	QC_Nb
Nd	µg/L	0.003	QC_Nd
Ni	µg/L	0.1	QC_Ni
Pb	µg/L	0.002	QC_Pb
Pr	µg/L	0.0004	QC_Pr
Rb	µg/L	0.005	QC_Rb
Sb	µg/L	0.01	QC_Sb
Se	µg/L	0.2	QC_Se
Sm	µg/L	0.001	QC_Sm
Tb	µg/L	0.0001	QC_Tb
Th	µg/L	0.001	QC_Th
Ti	µg/L	0.1	QC_Ti
Tl	µg/L	0.001	QC_Tl
Tm	µg/L	0.0001	QC_Tm
U	µg/L	0.0002	QC_U
V	µg/L	0.003	QC_V
W	µg/L	0.01	QC_W
Y	µg/L	0.0005	QC_Y
Yb	µg/L	0.001	QC_Yb
Zn	µg/L	0.81	QC_Zn
LREEs sum (Gd+Tb+Dy+Ho+Er+Tm+Yb+Lu)	µg/L		
HREEs sum (La+Ce+Pr+Nd+Sm+Eu)	µg/L		
	Isotopes		
$\delta^{18}O$	‰ VSMOW		QC_18O
$\delta\ ^{2}H$	‰ VSMOW		QC_2H
Tritium	Tritium units		QC_Tritium

Abbreviations*: cfu – colony-forming unit; DIC – dissolved inorganic carbon; DOC – dissolved organic carbon; HREE – heavy rare earth elements; Langelier SI – Langelier saturation index; L – litre; LREE – light rare earth elements; µS/cm – microsiemens per centimetre; mg – milligram; mV – millivolt; MECP –Ministry of the Environment, Conservation and Parks; NAD83 – North American Datum 1983; ORP – oxidation-reduction potential; ppmv – parts per million per volume; TKN – total Kjeldahl nitrogen; VSMOW – Vienna Standard Mean Ocean Water; WGS 84 – World Geodetic Survey 1984.*

Field Measurements and Sampling Techniques

The 3 types of wells sampled for this program—FLUTe™ multidepth, PGMN and domestic—require different sampling methodologies. The FLUTe™ multidepth wells consist of a flexible liner that is sealed against the borehole by an excess of head (standing water) contained within it. Each sampling port is located within a spacer on the exterior of the liner, against the rock borehole wall (Cherry, Parker and Keller 2007). These ports are hydraulically separated from each other by the over-pressured liner pressed against the borehole wall. Groundwater samples are collected from FLUTe™ wells by injecting pressurized nitrogen gas into a tube leading to the sampling port, which displaces the sample to surface. Backflow and gas-sample contact are limited, with a series of check valves along the sampling tube, as described on the FLUTe™ website (www.flut.com/water-flute). The PGMN wells were sampled with a stainless-steel submersible pump. Many PGMN wells have dedicated submersible pumps, but those that do not were sampled with a travelling submersible pump that was decontaminated with bleach between sample sites. Domestic well sampling was conducted to fill in spatial data gaps within the study area. The selection of domestic wells for sampling was restricted to wells with an associated Ministry of Environment, Conservation and Parks water well record, with a preference for recently installed (past 10 years), deep bedrock wells. Groundwater samples from domestic wells were collected from the existing pump and plumbing infrastructure, and the sample taken from a point in the plumbing system where raw, untreated water could be collected. The collection of raw, untreated water was confirmed by inspecting the plumbing inside the home prior to sampling.

For every groundwater sample, physical characteristics of the water, such as colour, gas exsolution, odour and clarity, were reported. In addition to these qualitative observations, a multiparameter instrument equipped with a flow-through cell was used to measure temperature, dissolved oxygen, pH, electrical conductivity and oxidation-reduction potential (ORP) in the field. These parameters were measured continuously and logged during purging. To ensure the sample represented aquifer conditions and not standing water in the well casing, purging was conducted until parameter stabilization was achieved. In many cases, not all parameters achieved stability before sampling. For example, ORP does not stabilize when waters from different aquifers or zones are mixing. Temperature and conductivity stabilization provides the most reliable indication that the well is adequately purged. Logged field parameters from the multiparameter instrument were then plotted and the most representative values were selected for publication.

The multiparameter instrument was calibrated daily for pH and weekly for electrical conductivity with daily accuracy checks. The temperature probe was not calibrated, per manufacture recommendation, because of the demonstrated long-holding factory calibration. The optical-sensor dissolved oxygen probe was checked daily and calibrated weekly. During the 2016 field season, calibration of the ORP probe, a platinum electrode with an internally referenced silver-silver chloride half-cell, was conducted once with Zobell solution at the beginning of the field season and checked every few weeks. The ORP data published here were levelled to correct for problems related to calibration errors and probe polarization, which are common occurrences with the use of such reference electrodes. The levelling comprised a scaling and linear transformation of ORP data by batch, using as a reference, the observed ORP response to high oxygen and high H_2S samples within each batch. The objective was to improve the continuity and comparability of ORP among batches. Batches are defined as blocks of data measured by the same instrument across an entire field season, or parts of field seasons if the instrument was calibrated or otherwise adjusted. This empirical "levelled ORP" was determined for the entire OGS Ambient Groundwater Geochemistry data set, comprising 3925 ORP readings collected from 2007–2014 (Hamilton 2015) and from 2015–2018 (Hamilton, *in prep.*). Dissolved oxygen and H_2S were selected to represent the empirical ORP range because they are commonly observed, the probe adequately responds to them and they are close to the oxidizing and reducing ends of the redox spectrum in natural

groundwaters. A batch of data represents the field ORP measurements collected from a single instrument for a field season or between calibrations within a field season. Each field measured ORP value was transformed with:

$$ORP_{levelled} = ORP_{\widetilde{H2S}} + \left\{ (ORP_{meas} - Batch_ORP_{\widetilde{H2S}}) \times \left(\frac{ORP_{\widetilde{O2}-\widetilde{H2S}}}{Batch_ORP_{\widetilde{O2}} - Batch_ORP_{\widetilde{H2S}}} \right) \right\}$$

Where

$ORP_{levelled}$ is the transformed ORP value,

$ORP_{\widetilde{H2S}}$ is the median ORP value for the entire data set for samples with significant quantities of H_2S (> 0.2 mg/L)

ORP_{meas} is the uncorrected field-measured ORP value,

$Batch_ORP_{\widetilde{H2S}}$ is the median ORP value for a batch of data for samples with significant quantities of H_2S (> 0.2 mg/L) and,

$Batch_ORP_{\widetilde{O2}}$ is the median ORP value for a batch of data for samples with significant quantities of O_2 (> 10% saturation),

$ORP_{\widetilde{O2}-\widetilde{H2S}}$ is the difference between the median high and low ORP values for the entire data set.

Sample collection and preservation protocols followed those of Hamilton (2015). Samples collected for metals and anions were filtered on-site using a 0.45 micron Millipore® Durapore polyvinylidene fluoride membrane filter and rubber-free polypropylene syringe. Samples for metals analyses were acidified to 1% with J.T.Baker™ Ultrapure HNO_3 or Fisher Chemical™-brand equivalent samples for Hg were acidified to 2% with Fisher Chemical™ Optima™-grade Ultrapure HCl. All other samples were unacidified. Upon collection, all samples were kept in field coolers until the end of the sampling day, when they were transferred to a refrigerator. Samples collected for bacteria and nutrients were shipped to the laboratory within 24 hours of collection to meet laboratory prescribed sample holding times.

Bicarbonate, hydrogen sulphide and iodide are unstable in a sample bottle, with concentrations modifying en route to the laboratory. Because of their instability and lack of suitable preservation methods, these parameters were measured in the field. Bicarbonate concentrations were calculated from alkalinity, which was determined in the field using the digital titration method of the HACH Digital Titrator 16900-01 kit. This is a fixed end-point method using bromocresol green-methyl red as the colour indicator. Hydrogen sulphide was measured in the field using the HACH model 2238-01 methylene-blue test kit. The test kit requires that a methylene blue spiked sample be matched to a colour spectrum, providing a 0.01 ppm detection limit. A comparison of this method with several laboratory analyses was done by Hamilton (2015), with results showing that the field method provides better accuracy and precision than common laboratory analytical methods, particularly at hydrogen sulphide concentrations below 5 ppm.

Iodide analyses were conducted in the field within 3 days of sample collection using an Orion 4-Star portable pH/ISE meter and an Orion 9453BN Iodide Ion Selective Electrode (ISE). Samples collected for iodide analysis were treated with 2 ml of a saturated nickel acetate solution to precipitate dissolved sulphide, which would otherwise interfere with the ISE measurement of iodide. This is approximately 10 times the amount of nickel required to precipitate the dissolved sulphide in 60 mL of a solution with 100 mg/L dissolved sulphide. The ISE was calibrated prior to each use.

Dissolved methane (CH_4) and carbon dioxide (CO_2) were also analyzed in the field. Samples for dissolved gases consisted of 600 ml of groundwater collected in a 1.15 L bottle to allow for a headspace. Once capped, sample bottles were left to equilibrate with ambient atmospheric temperatures. Within

24 hours of sample collection, CH_4, CO_2 and O_2 concentrations in the headspace were measured with an Eagle multigas meter. The Eagle multigas meter is equipped with an infrared CO_2 sensor (range 0.01 to 5%), an electrochemical O_2 sensor (range 0.1 to 40%) and 2 CH_4 sensors; a high-level infrared sensor (range 0.5 – 100% CH_4) and a low-level combustible gas catalytic sensor (range 5 ppm to 50 000 ppm, as CH_4). Calibration or an accuracy check of the sensors was performed prior to measuring headspace concentrations. In-situ concentrations of dissolved gases in groundwater were then estimated by converting measured headspace gas concentrations to dissolved gas concentrations using Henry's Law and then adjusting these values to in-situ conditions using static water level, well depth and groundwater temperature. A complete description of this approach with calculations is provided in McIntosh et al. (2014).

Laboratory Analytical Methods

The majority of the parameters published here were analyzed at the OGS Geoscience Laboratories in Sudbury, Ontario. The laboratory instruments used were the inductively coupled plasma mass spectrometer (ICP-MS), the inductively coupled plasma atomic emission spectrometer (ICP-AES), ion chromatography (IC) system and atomic fluorescence spectrometer (for Hg analysis only). Samples were sent to commercial laboratory SGS Analytical Laboratories for several time-sensitive analyses: dissolved organic carbon, dissolved inorganic carbon, nitrogen parameters (NO_{3-}, NO_{2-}, NH_3, TKN and organic nitrogen) and bacteria (total and fecal coliform).

Water stable isotopes analyses were performed by Isotope Tracer Technologies in Waterloo, Ontario. These analyses were performed using a Picarro® L2120-I Isotopic Water Analyzer with a precision and accuracy of ±0.2‰ δ18O and ± 1.0‰ δD VSMOW. Tritium analyses were performed by the University of Waterloo's Environmental Isotopes Laboratory using liquid scintillation counting after enrichment to achieve a detection limit of 0.8 tritium units with ± 1σ of 0.3 tritium units.

Quality Control

Quality assurance was built into this data set with the insertion of blind QC samples, comprising 10% of the total number submitted to the laboratory. The type and frequency of control sample submissions facilitates an assessment of accuracy and precision for each element and compound reported. Blind duplicate pairs (4) were collected to enable the evaluation of analytical precision. These pairs are plotted with laboratory duplicate pairs to assess precision, shown within a 10% difference envelope (*see* Appendix). To evaluate analytical accuracy, blind standards and blanks were included with the sample submissions. The standards used were SLRS-5 and SLRS-6, CANMET certified reference materials, and 2 internal standards (BLK-1 and BLK-2) for which the values were established in a multilaboratory "round-robin" exercise (Burnham, Schroeder and Hamilton 2012). Where certified reference or internal standards did not represent the anticipated full range of potential concentrations of key parameters, the standards were spiked. Internal standard BLK-1 was spiked with fluoride, ammonia and nitrate to achieve concentrations of 7 mg/L, 5 mg/L and 5 mg/L respectively.

The Appendix contains composite plots of precision and accuracy for each analytical parameter. The top plot shows duplicate pairs against the 10% difference envelope. The bottom plot displays the sampling results in analytical sequence as well as the results for blind standards plotted against their certified ranges. The plots in the Appendix provide a visual tool for quickly assessing the accuracy and precision of the published data.

Acknowledgments

The sampling methods and QA/QC program employed in this project were developed by Dr. Stewart Hamilton. I am grateful for the time he took to share his knowledge and expertise. The preparation of this publication was greatly supported by the diligent data management and programming of Julie Chartrand and the drafting of Julien Bonin. The project is indebted to the geological mapping of Frank Brunton, which forms the foundation of this work. Finally, many thanks are extended to the OGS for funding the PhD thesis for which these data were collected.

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Appendix

Quality Control Plots

This appendix contains quality control plots for the following parameters. Table 1 in the report provides convenient hyperlinks to each QC plot.

Field and Aggregate Parameters
DIC, DOC

Major Parameters and Trace Anions
Ca, Mg, Na, K, SO_4^{2-}, Cl^-, Br, F^-, PO_4^-, B, Fe, Iodide, Sr, Si

Nitrogen Parameters
NO_3^-, NO_2^-, TKN, NH_3+ NH_4^+

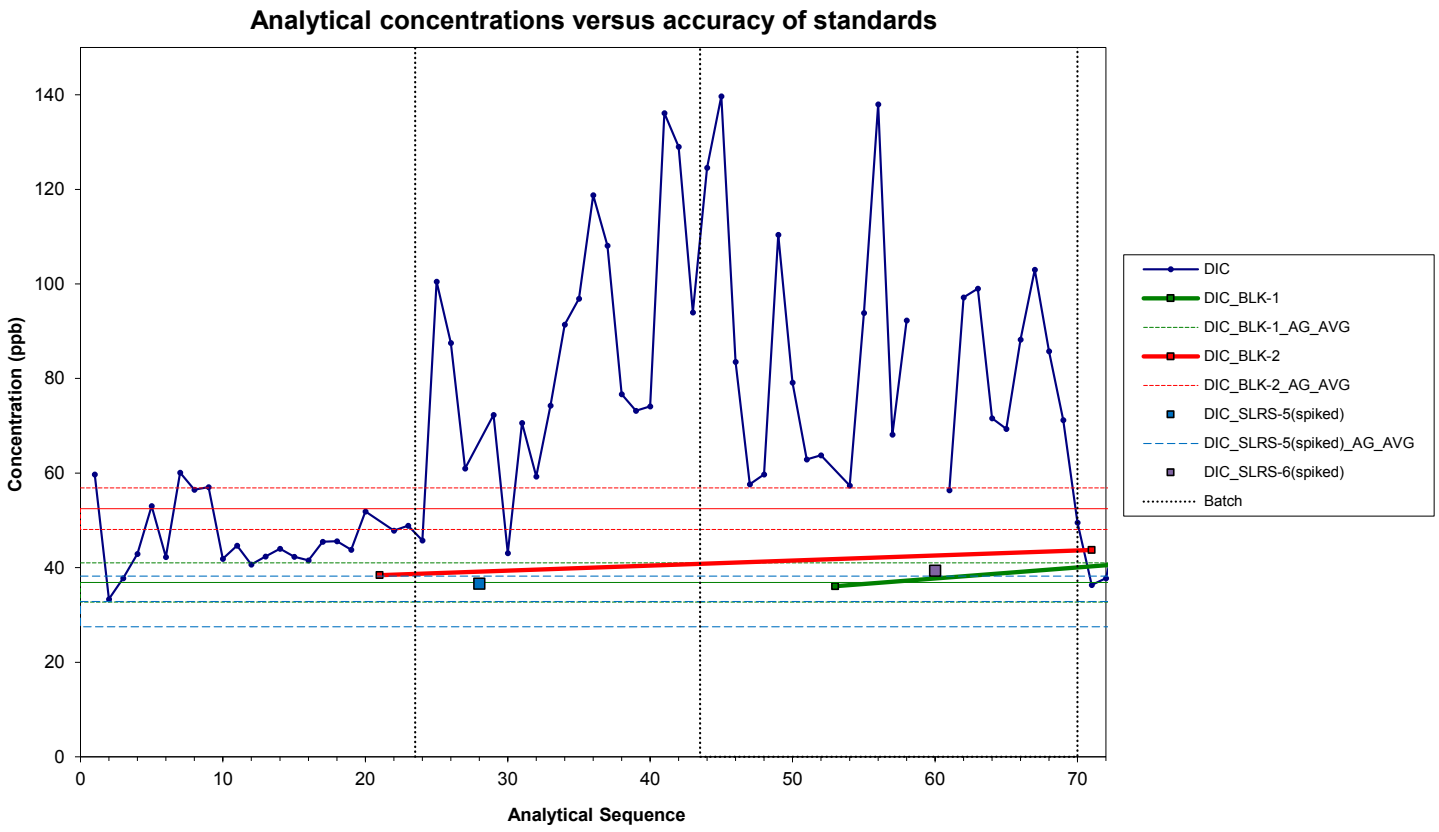
Dissolved Gases
CH_4(aq), CO_2(aq)

Trace Metals
Ag, Al, As, Ba, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Gd, Hf, Ho, La, Li, Lu, Mn, Mo, Nb, Nd, Ni, Pb, Pr, Rb, Sb, Se, Sm, Tb, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn

Isotopes
$\delta^{18}O$, $\delta\ ^2H$, Tritium

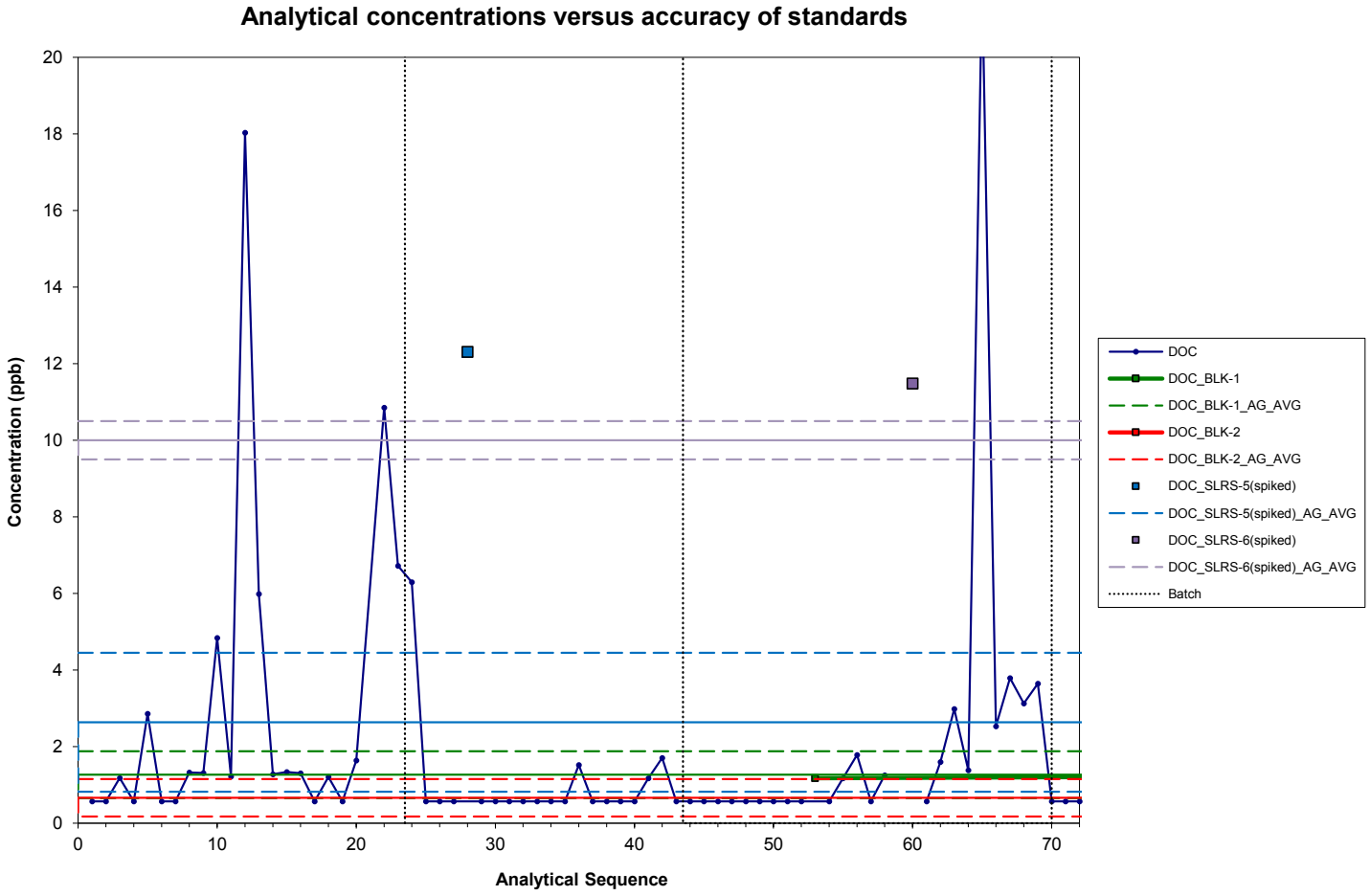
BACK TO TABLE 1

Quality-control plots: dissolved inorganic carbon (DIC) analyses



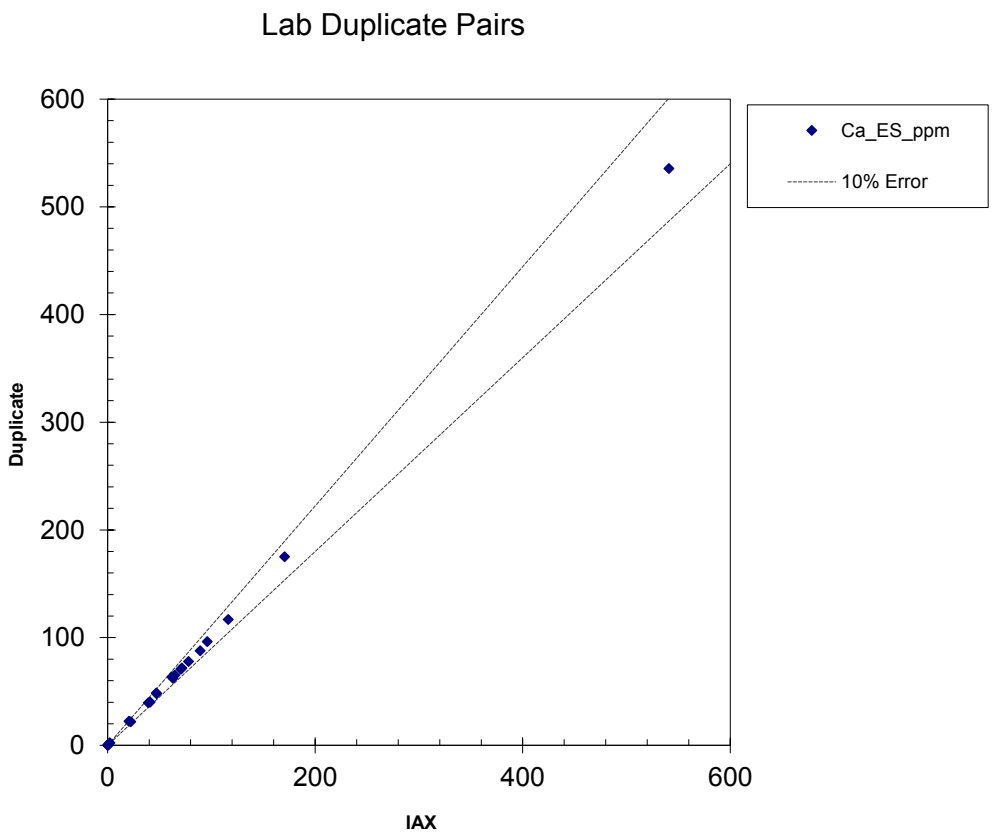
BACK TO TABLE 1

Quality-control plots: dissolved organic carbon (DOC) analyses

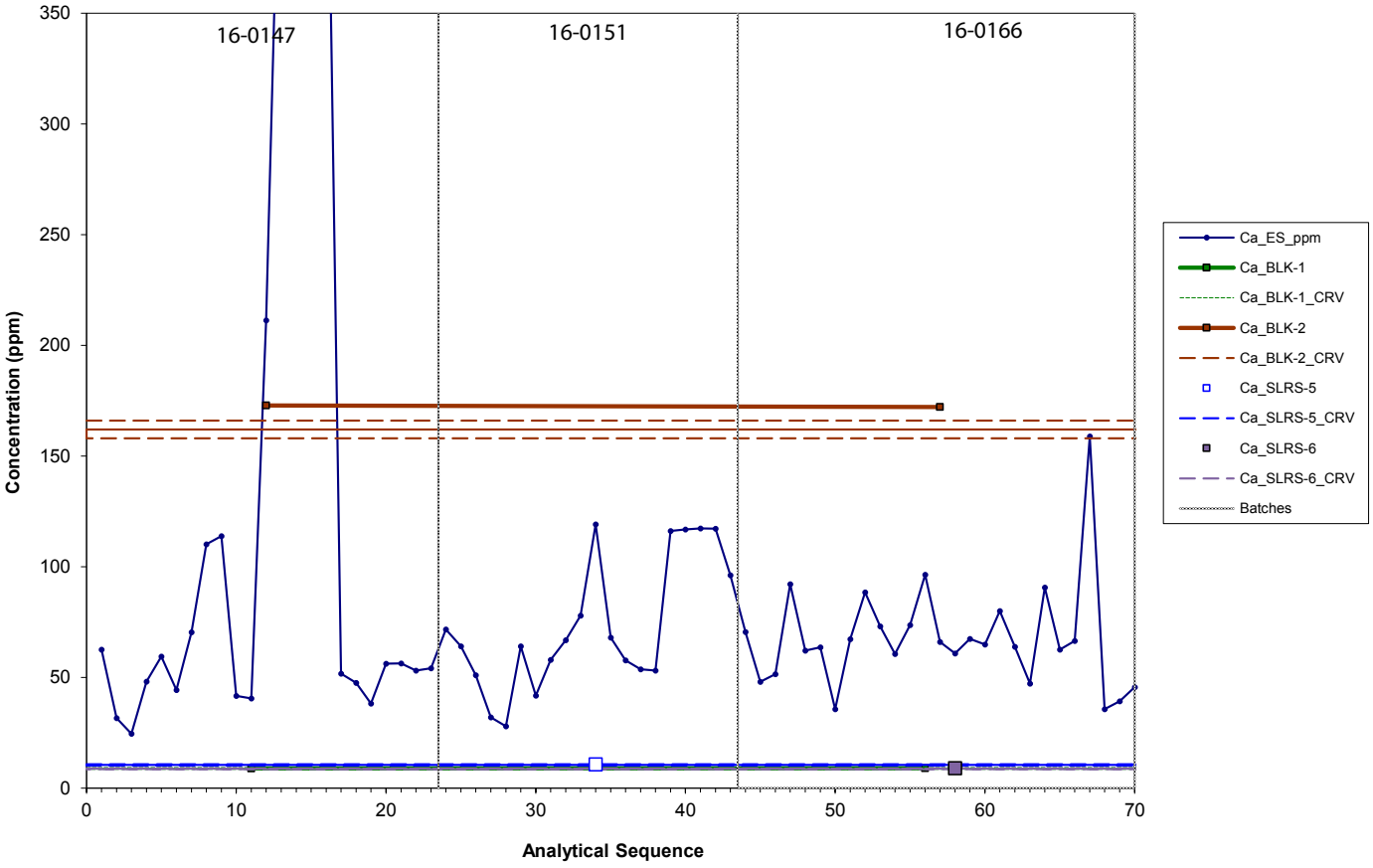


BACK TO TABLE 1

Quality-control plots: Calcium (Ca) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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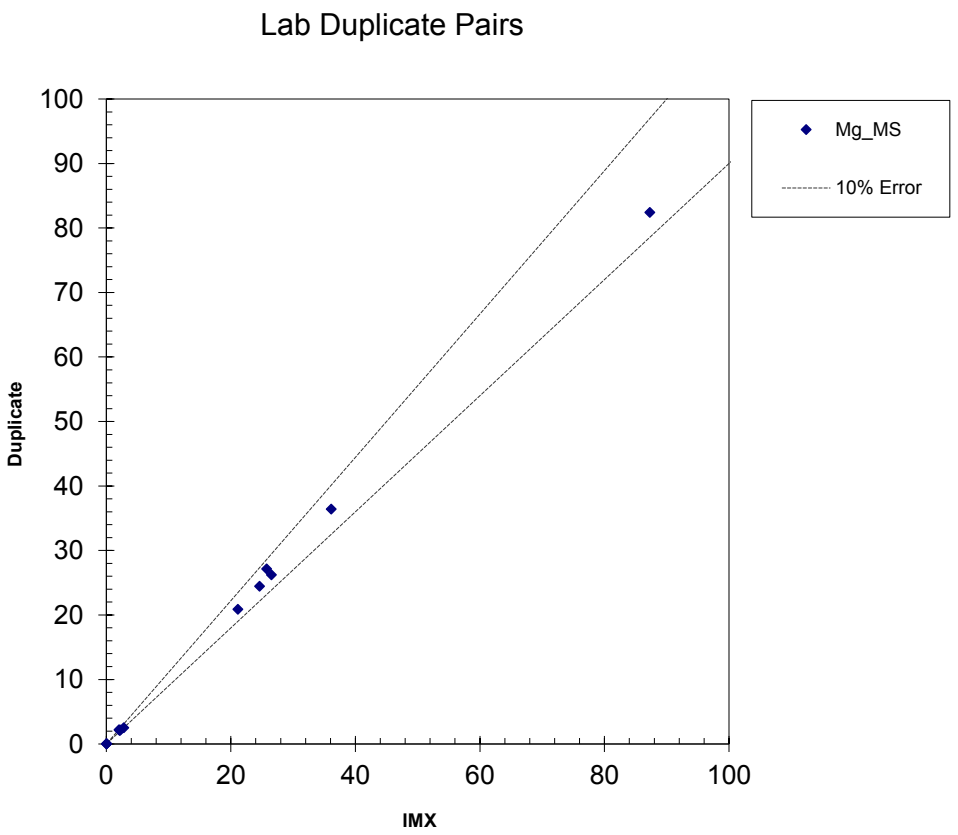
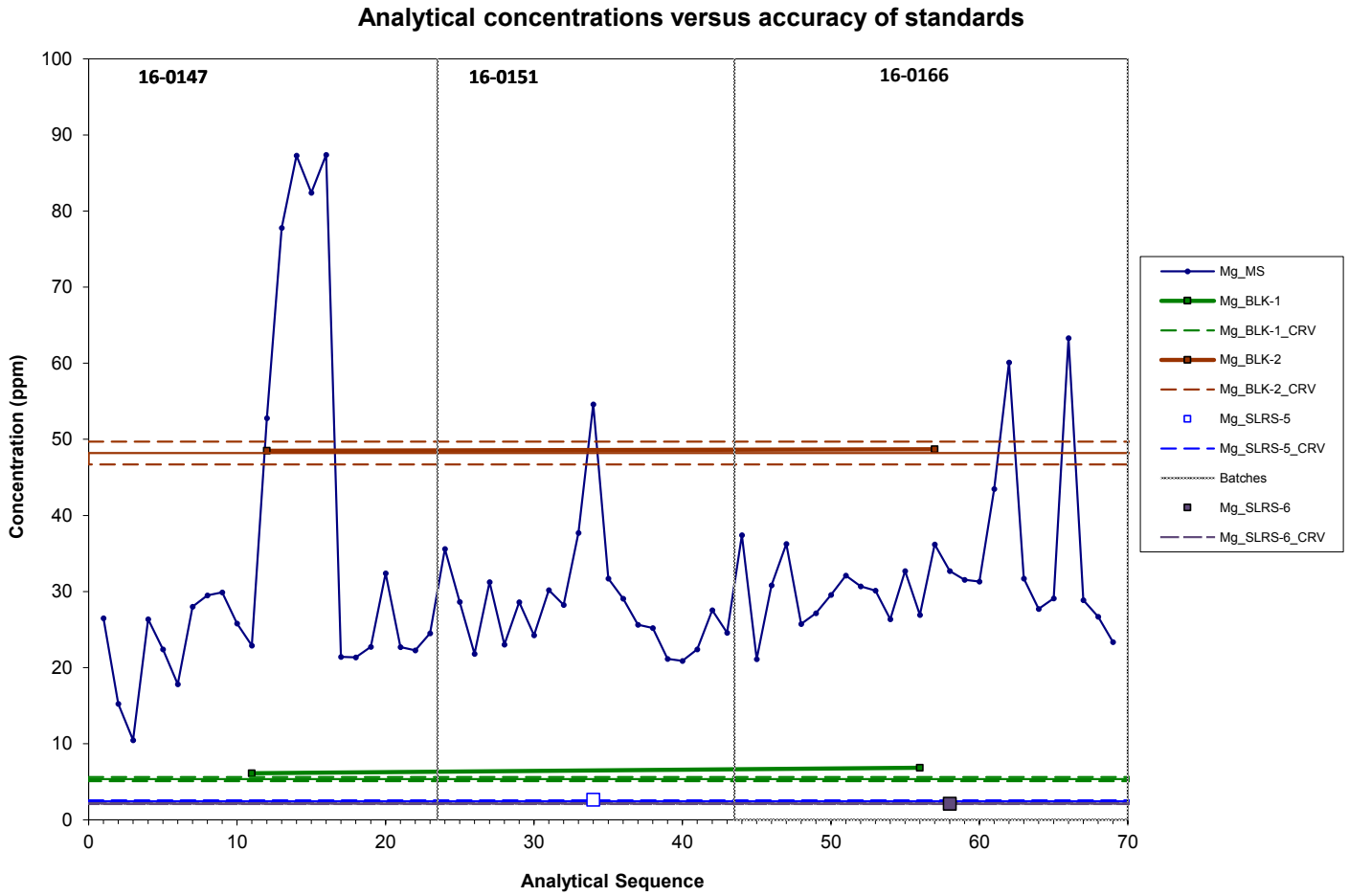
Quality-control plots: Magnesium (Mg) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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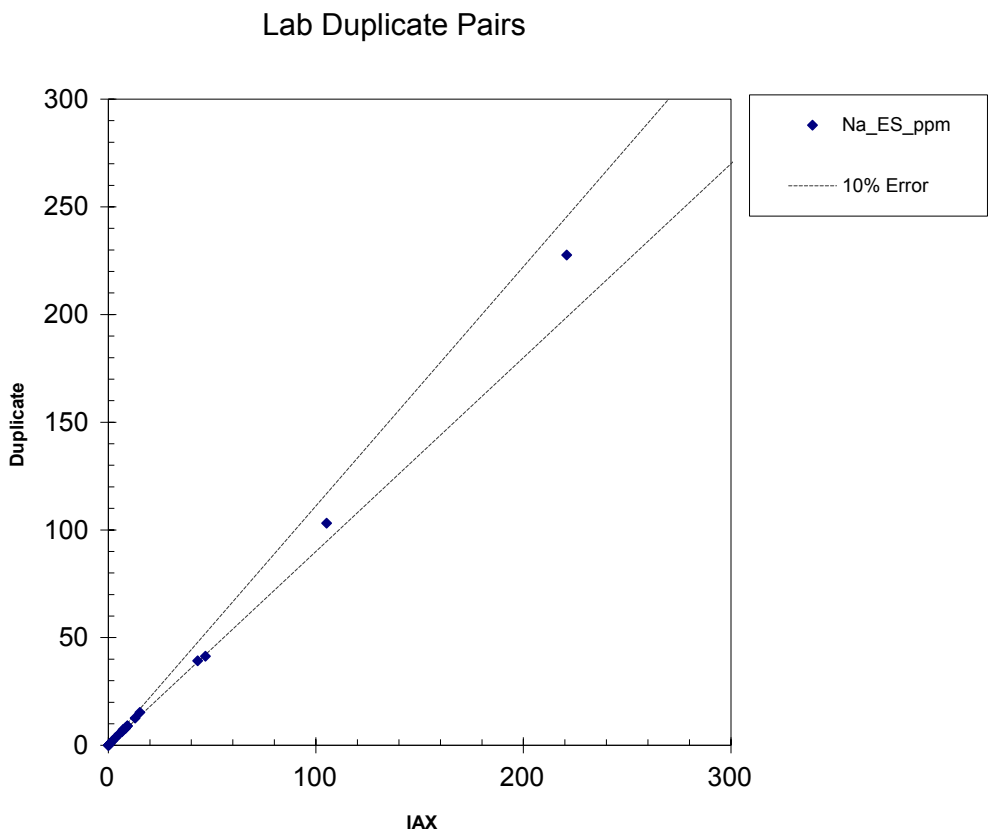
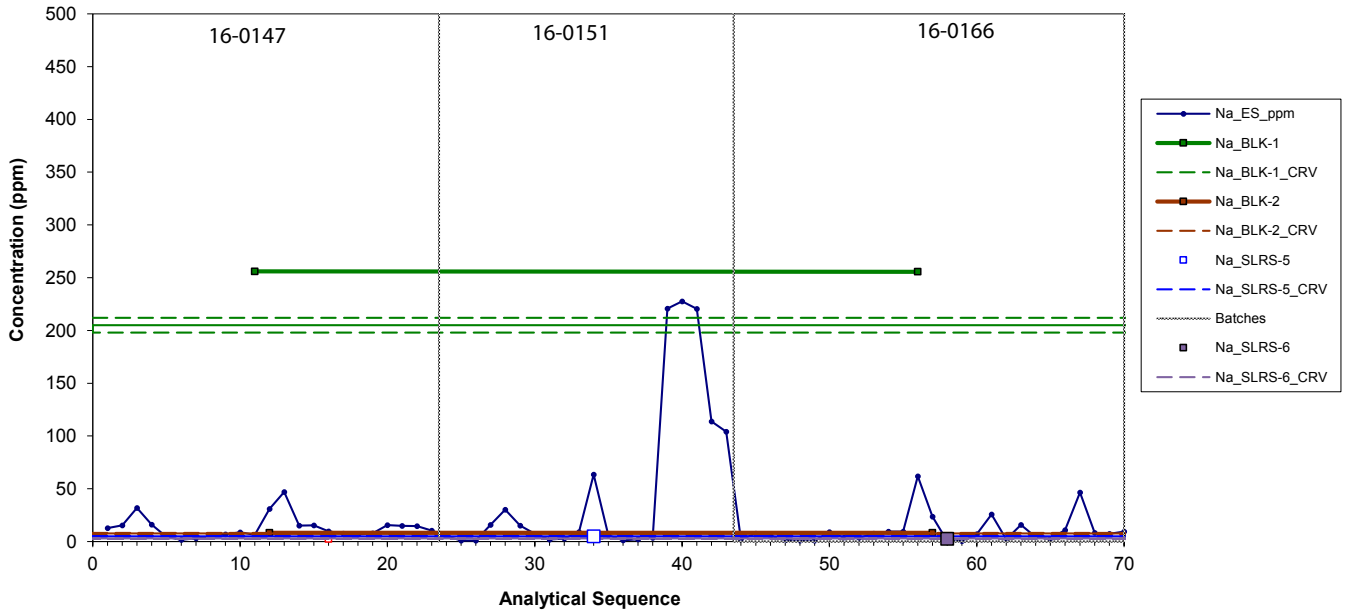
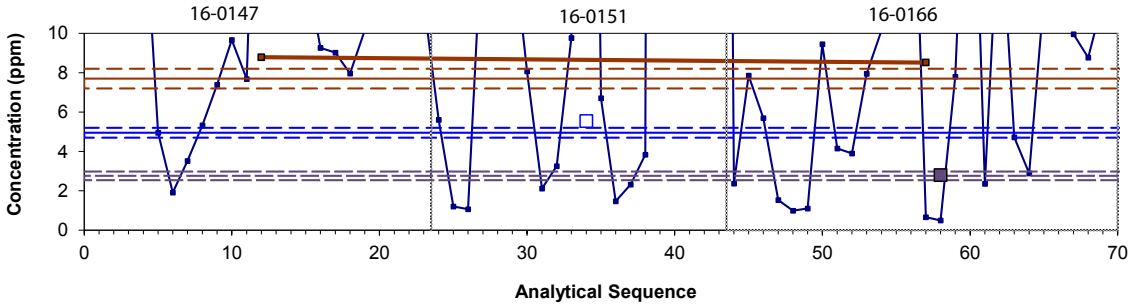
Quality-control plots: Sodium (Na) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards





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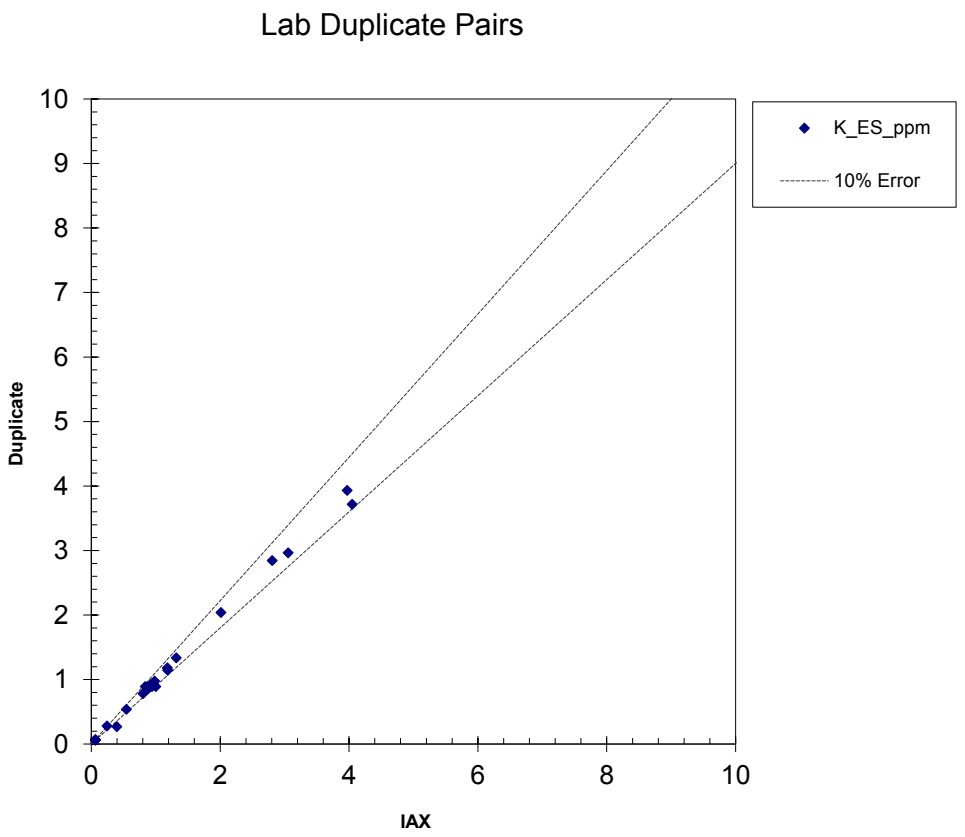
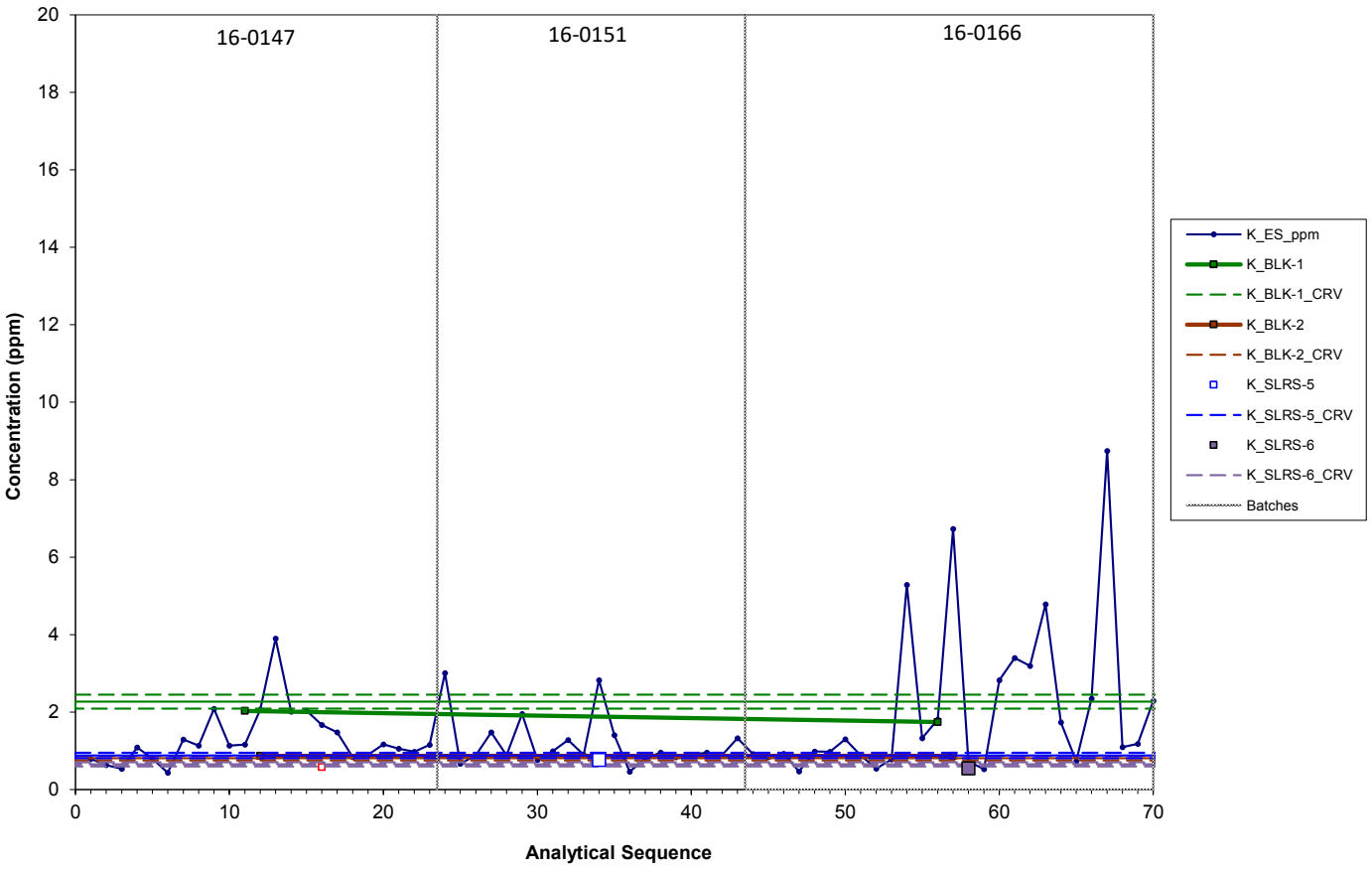
Quality-control plots: Potassium (K) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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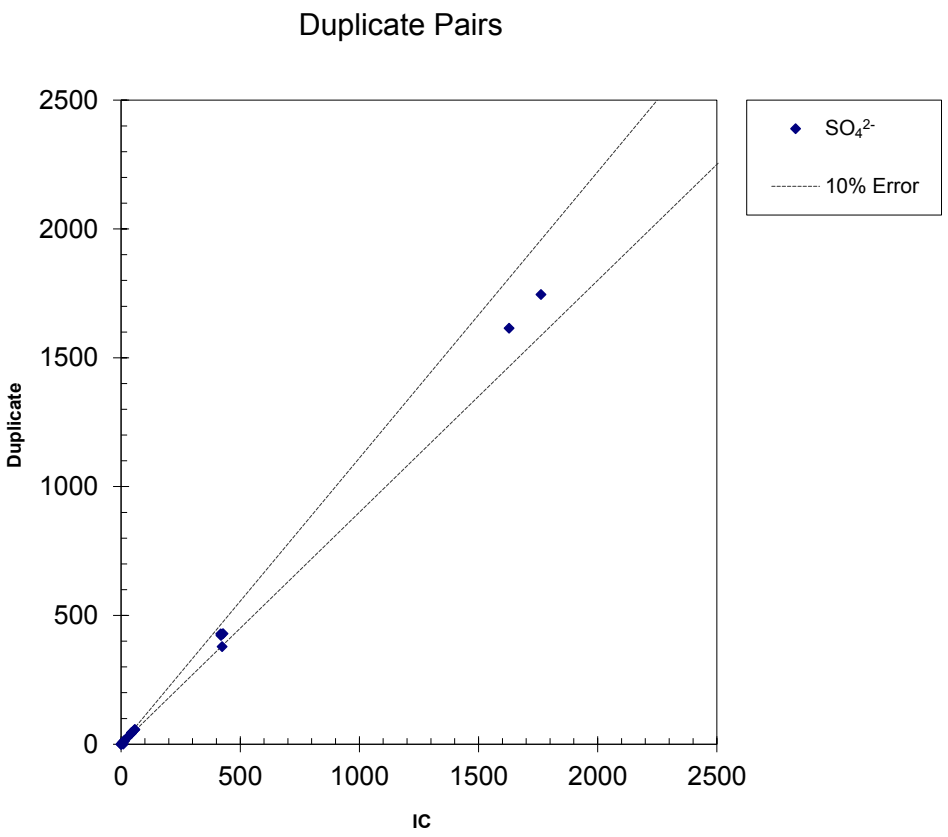
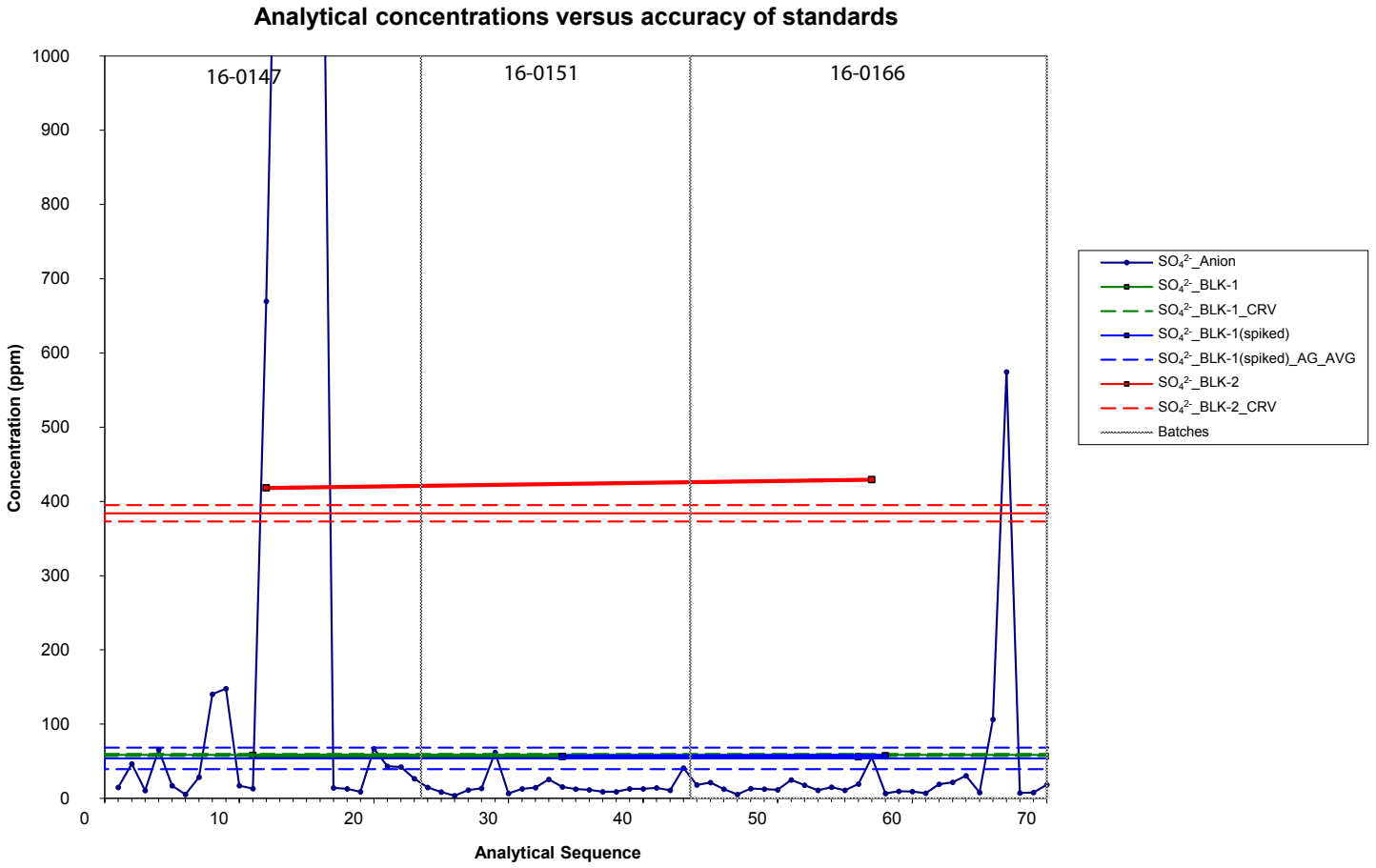
Quality-control plots: sulphate (SO_4^{2-}) analyses using ion chromatography (IC)





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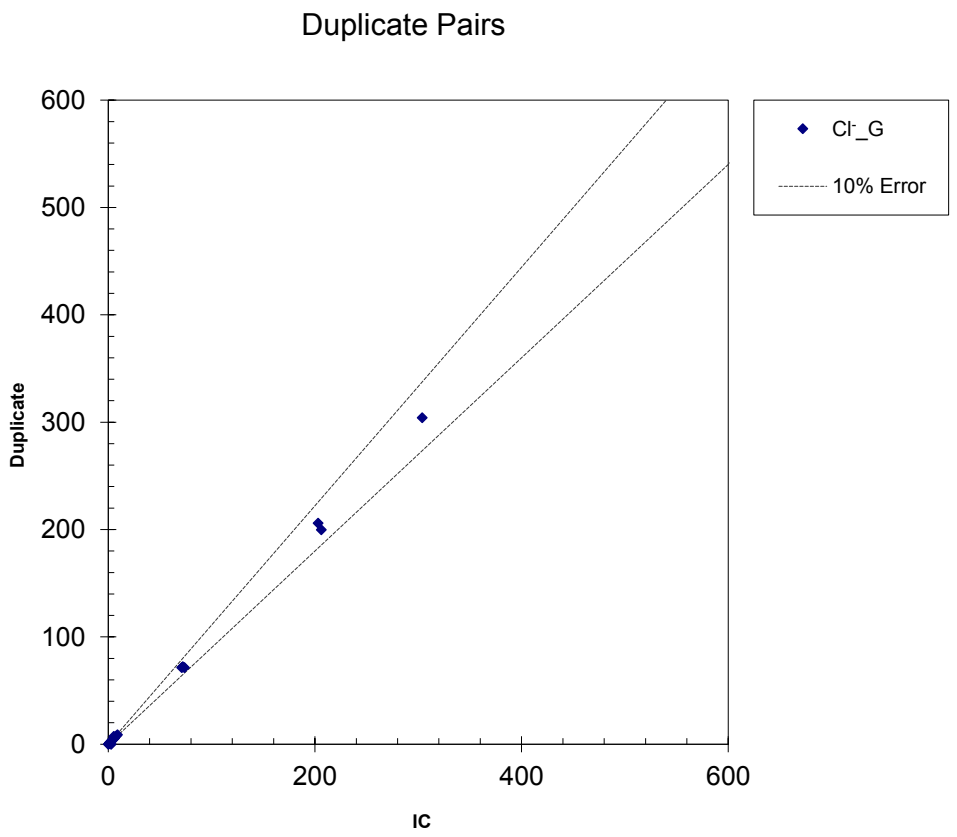
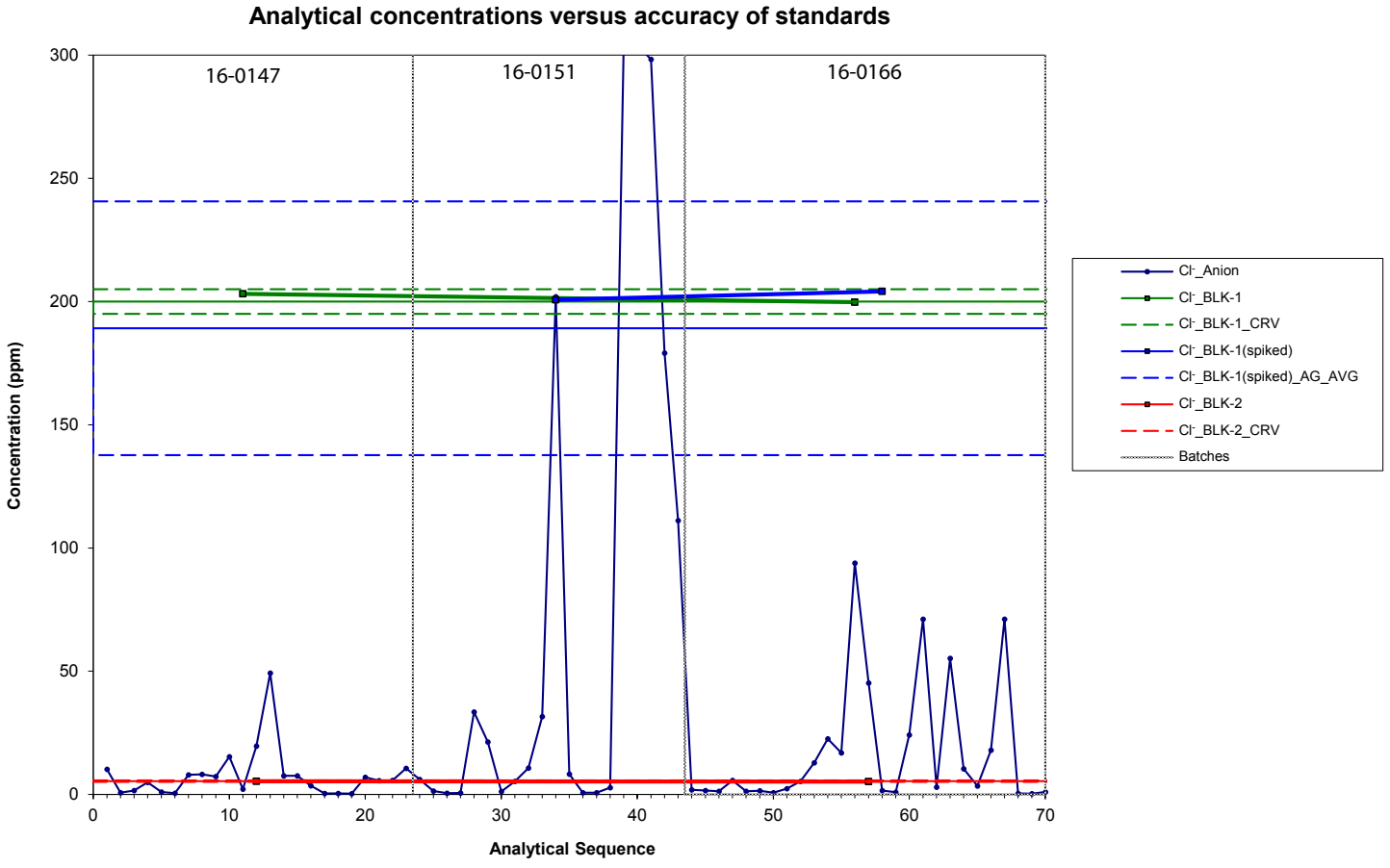
Quality-control plots: Chlorine (Cl^-) analyses using ion chromatography (IC)





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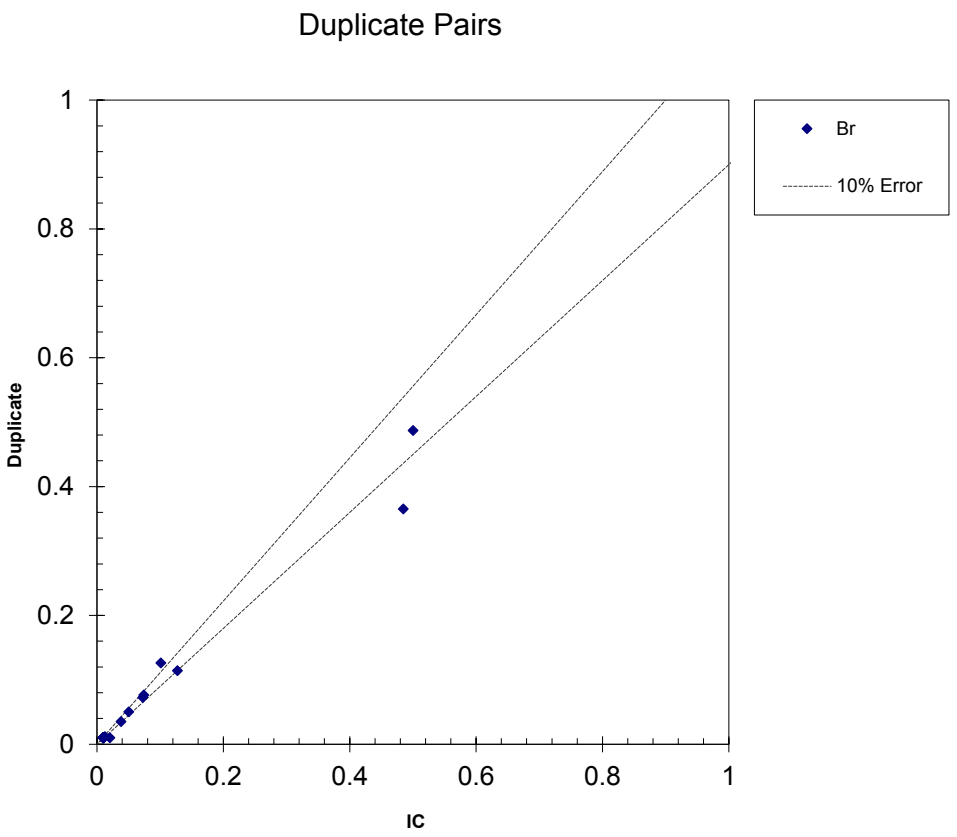
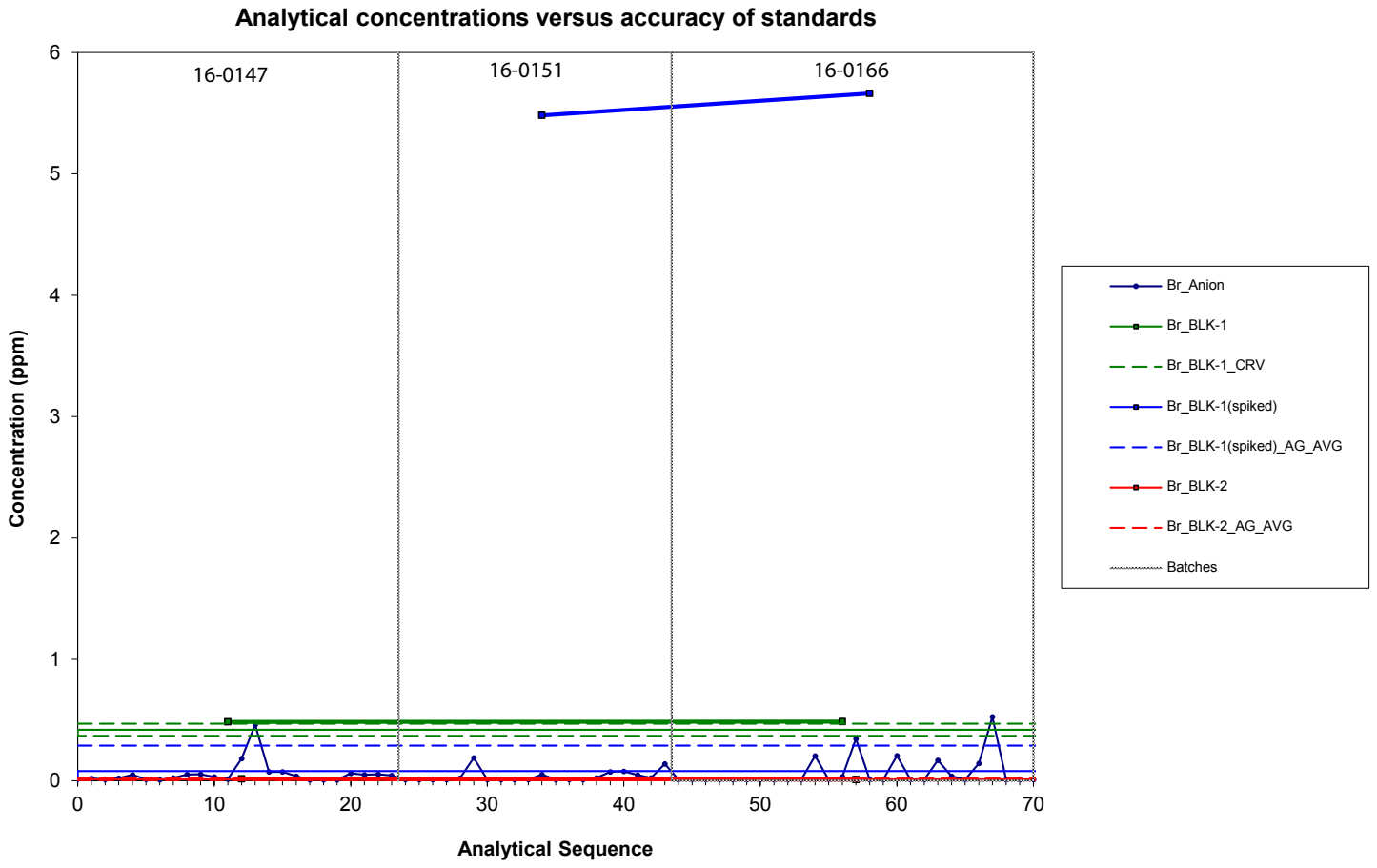
Quality-control plots: Bromine (Br) analyses using ion chromatography (IC)





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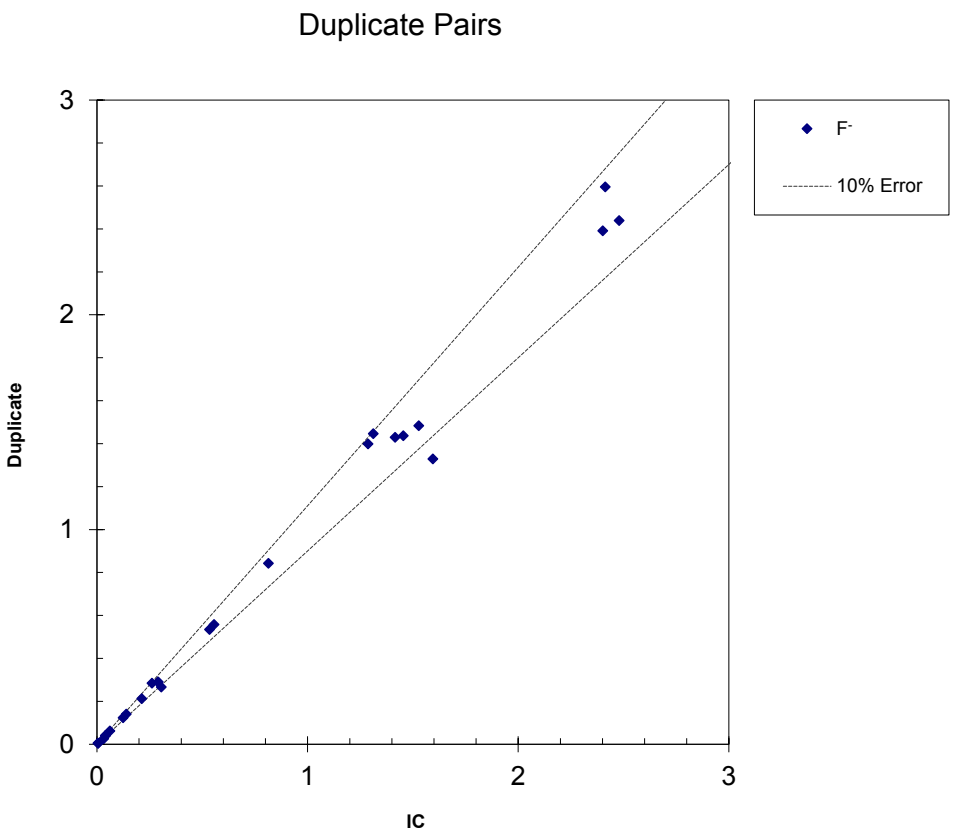
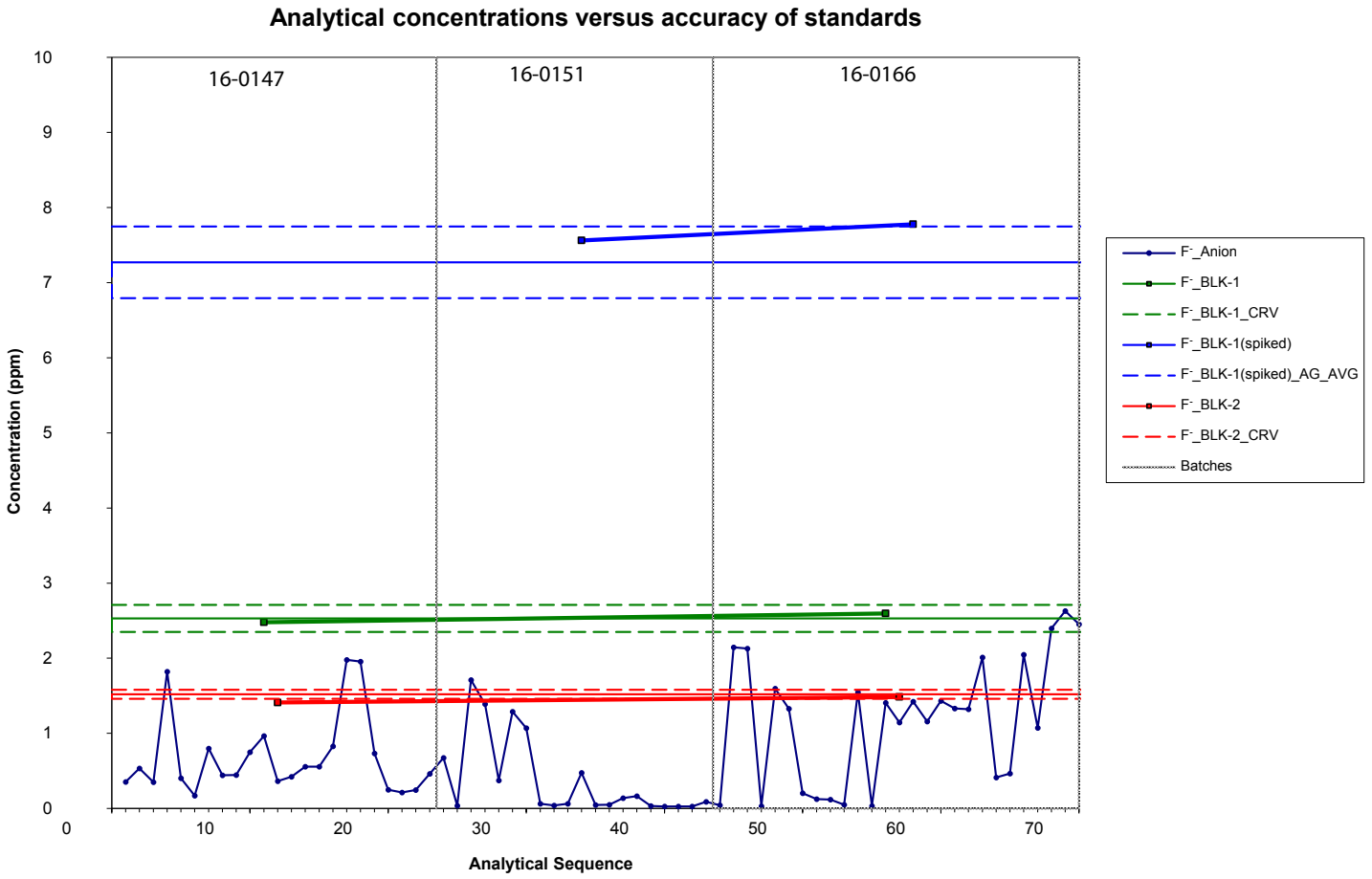
Quality-control plots: Fluoride (F^-) analyses using ion chromatography (IC)





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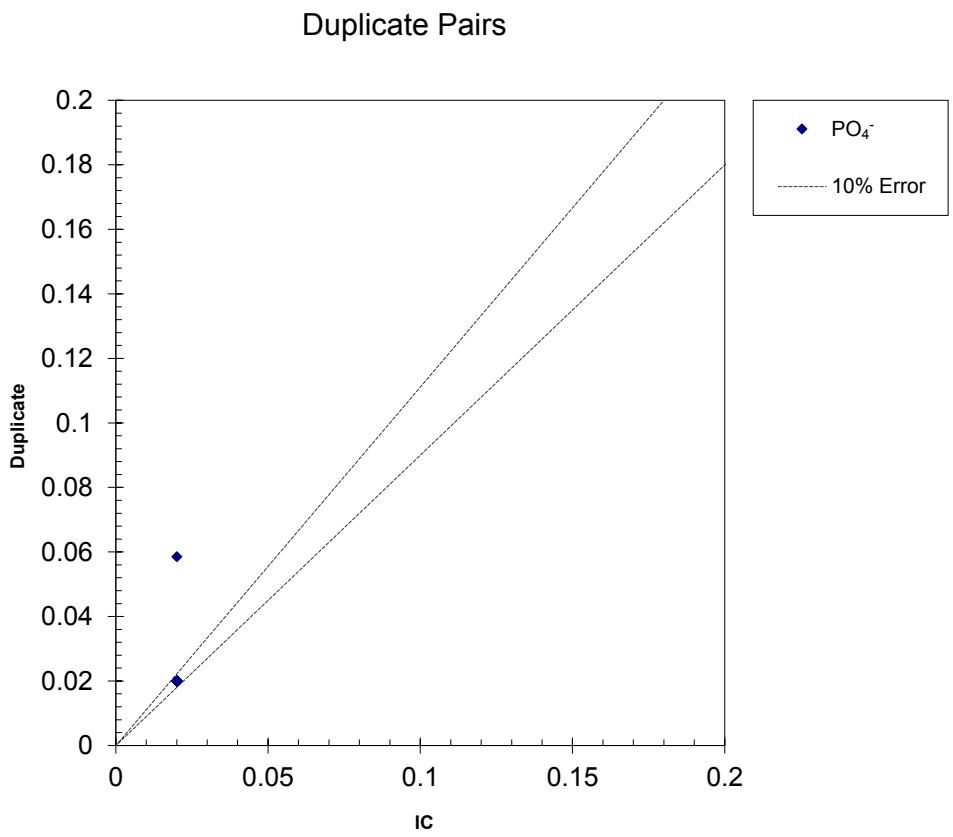
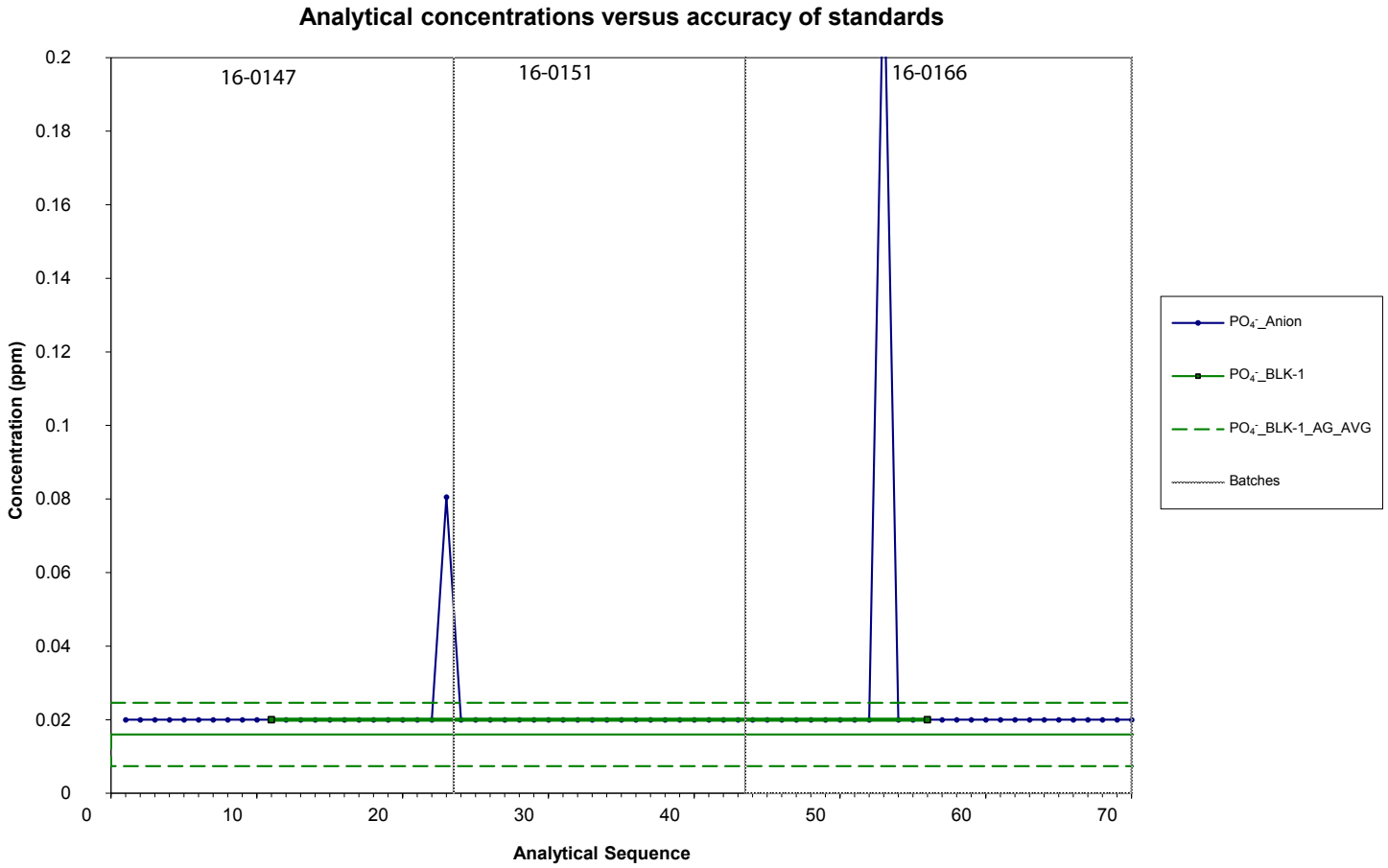
Quality-control plots: Phosphate (PO_4^-) analyses





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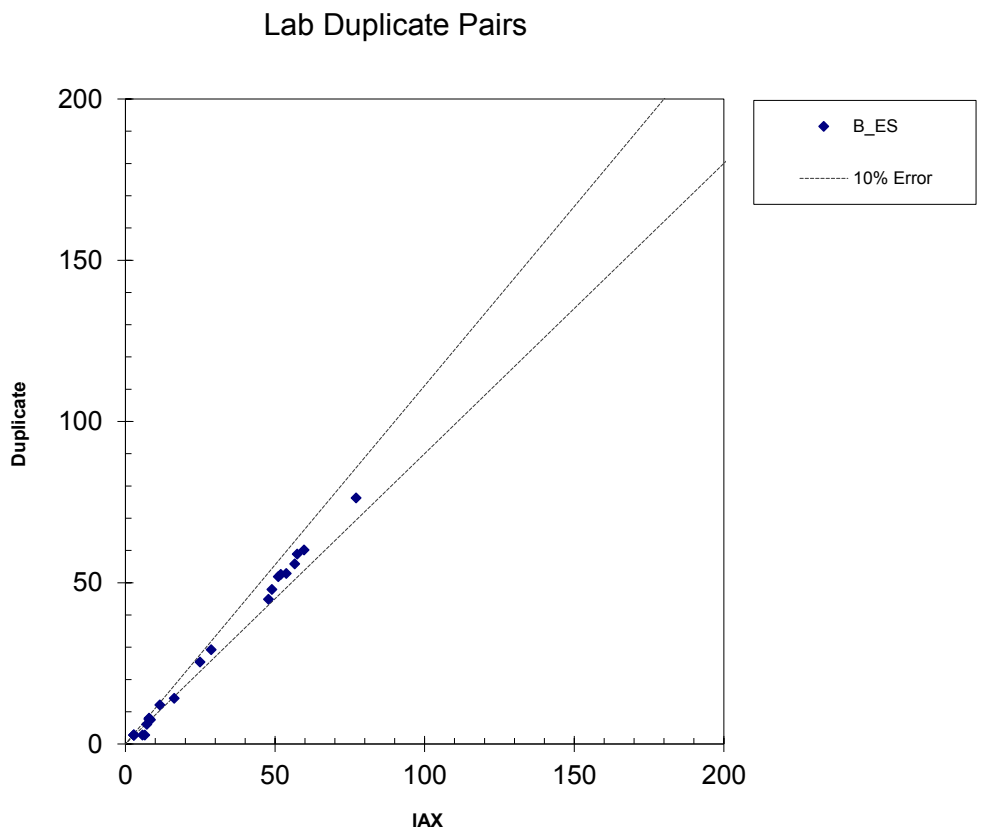
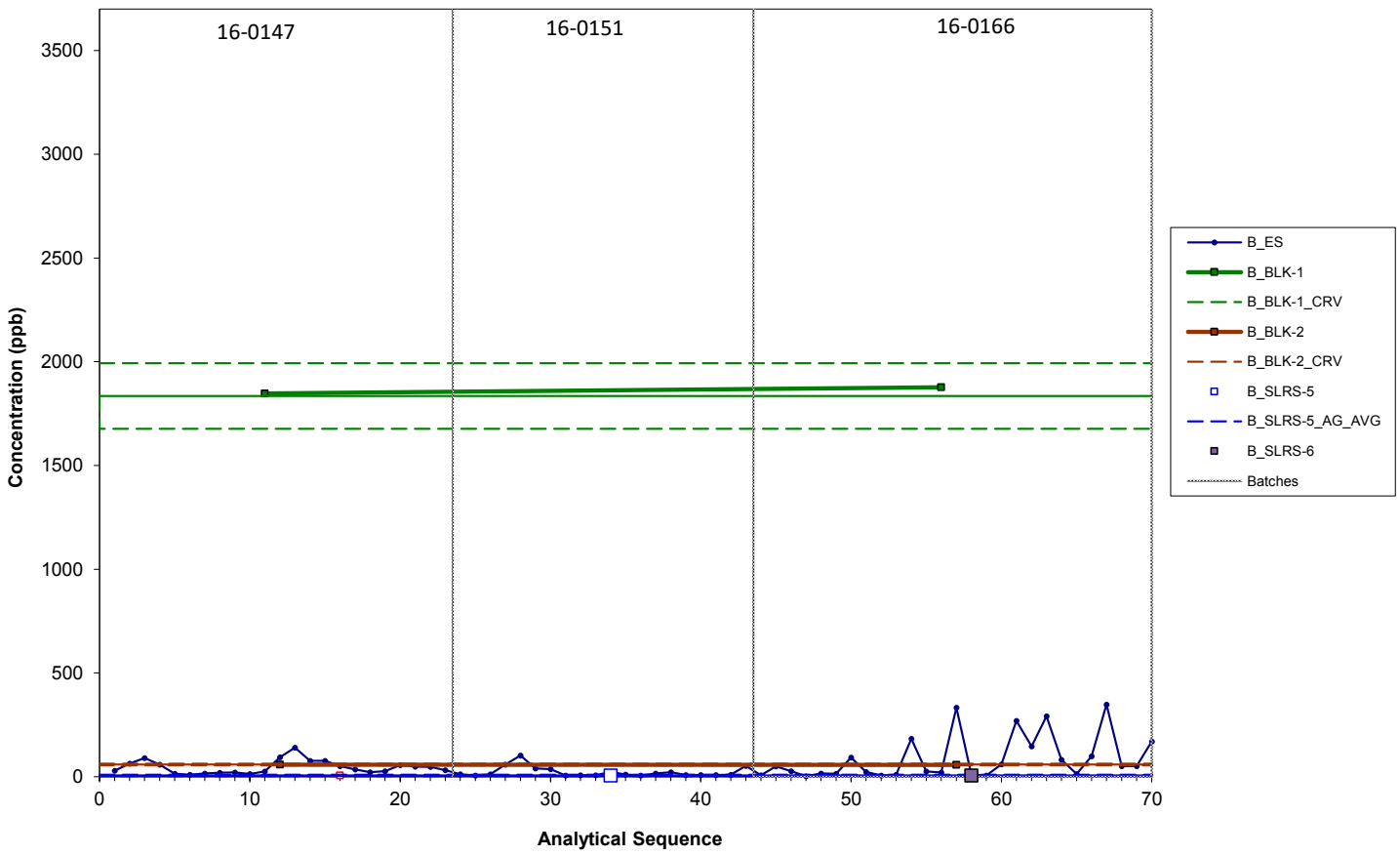
Quality-control plots: Boron (B) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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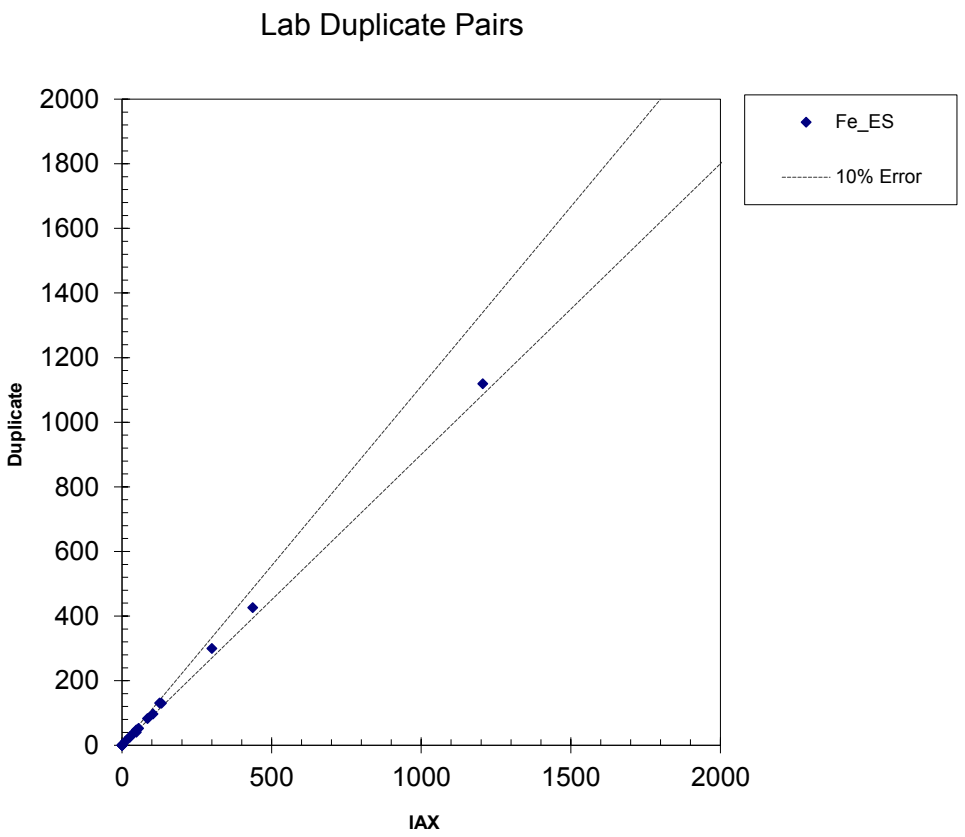
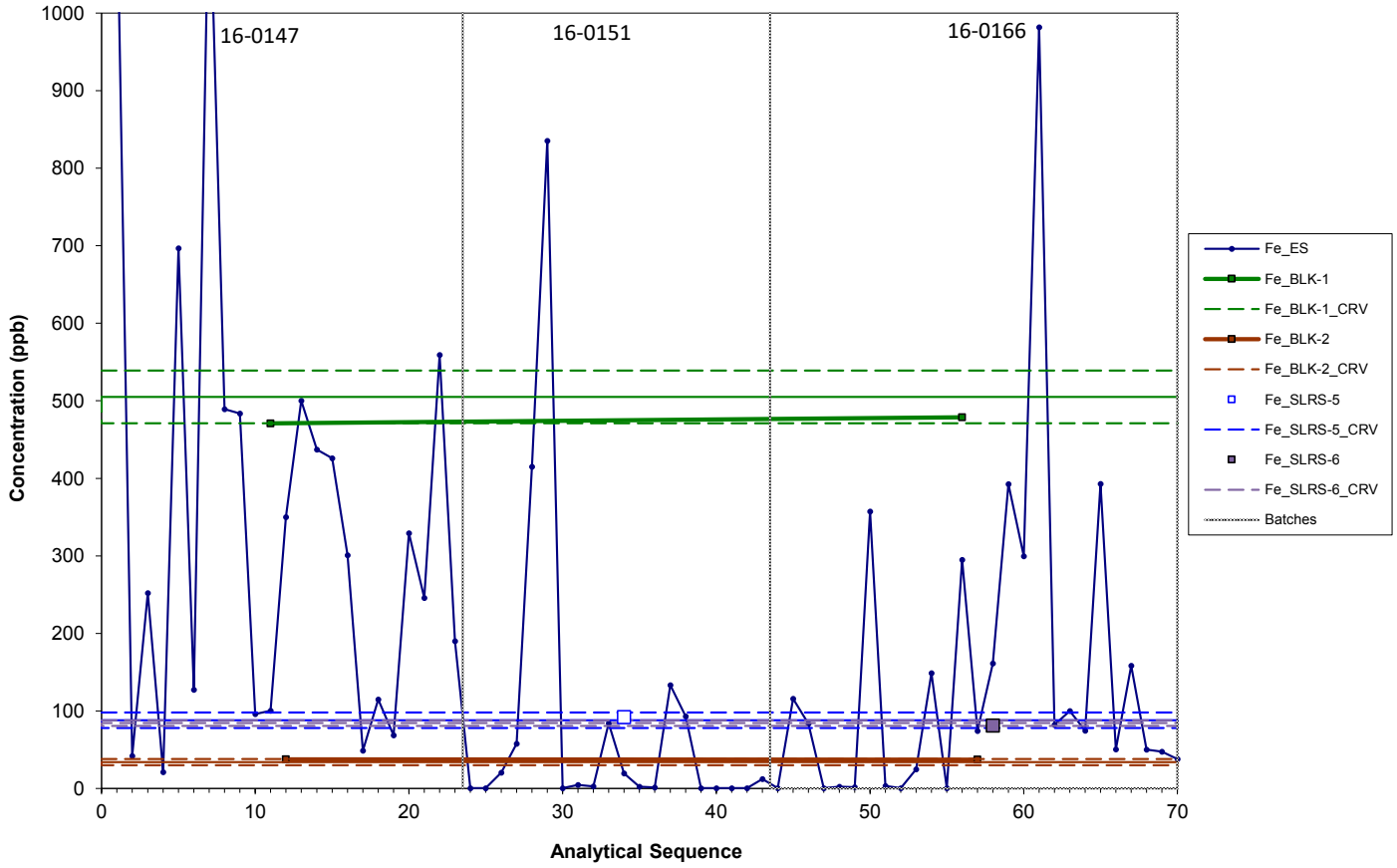
Quality-control plots: Iron (Fe) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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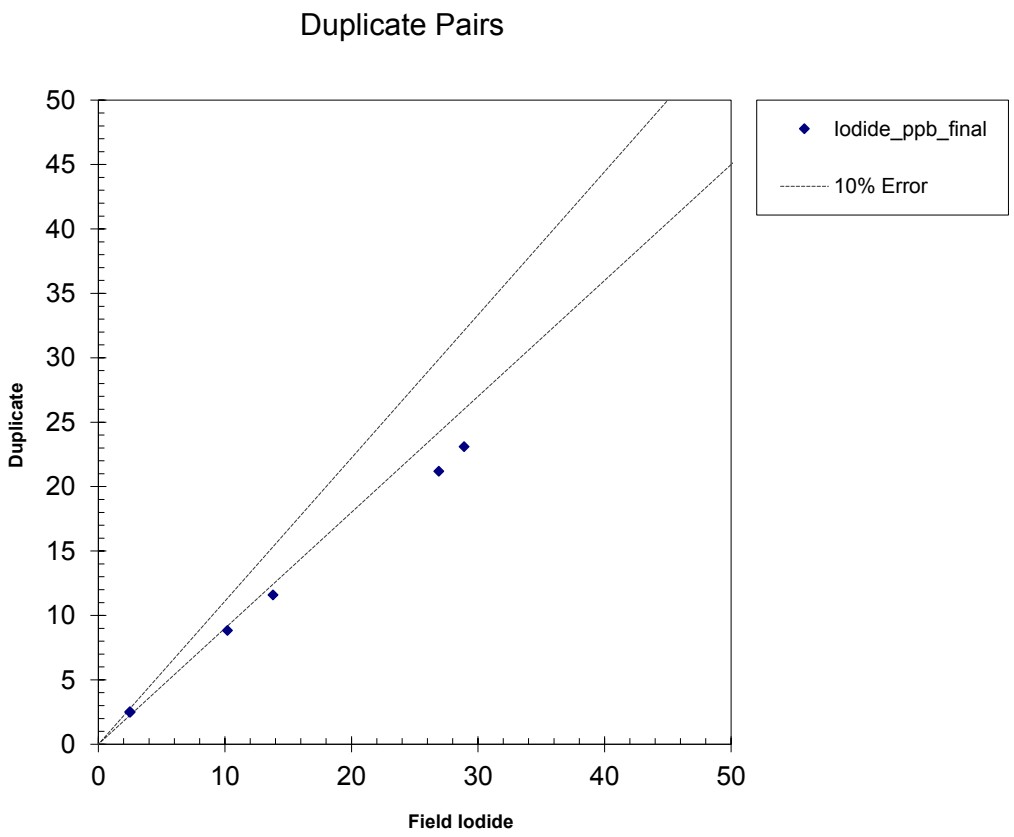
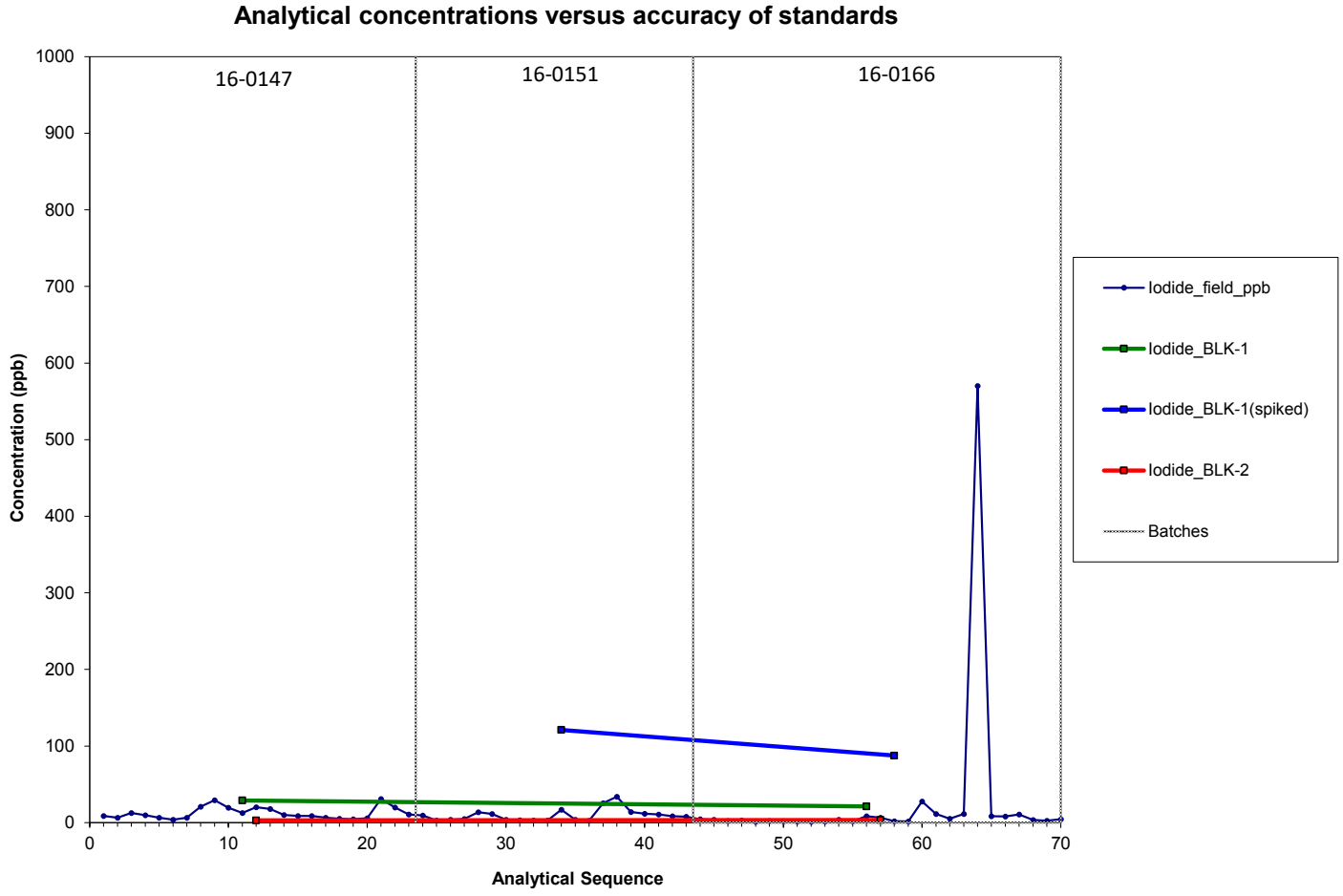
Quality-control plots: iodide analyses





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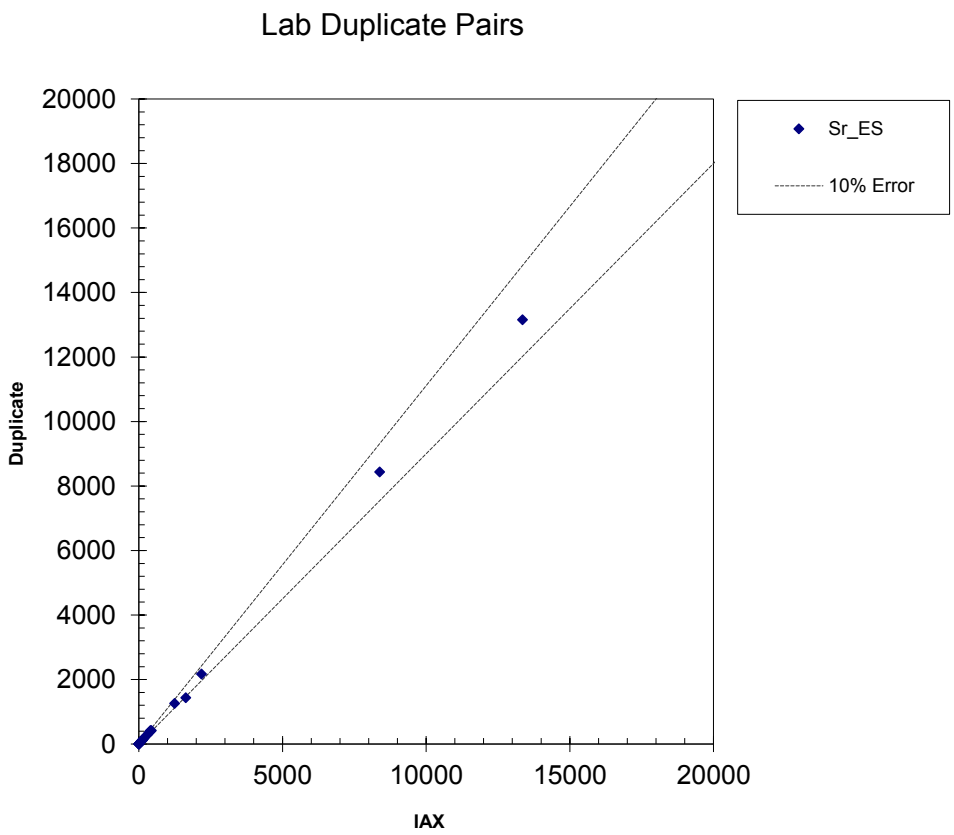
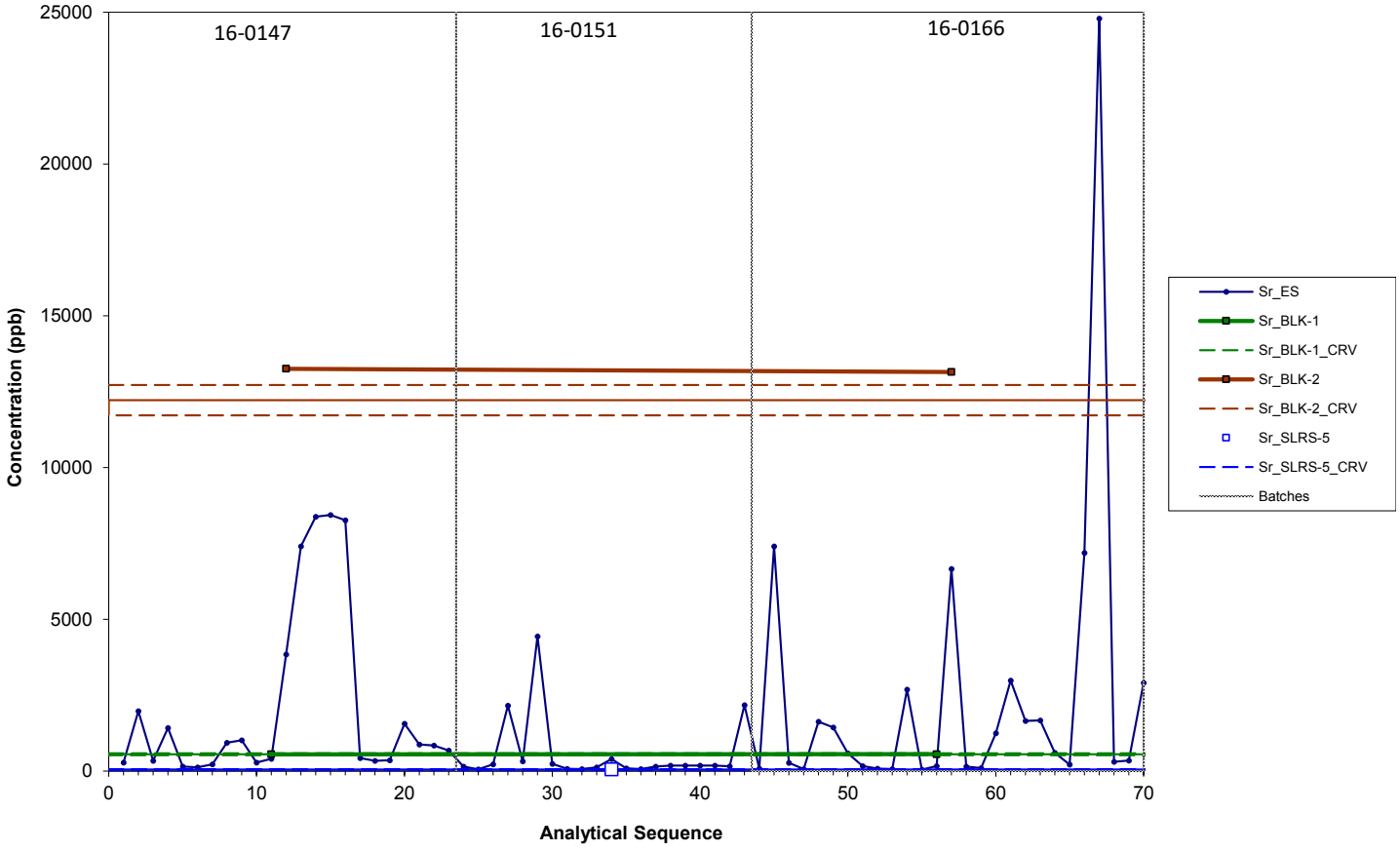
Quality-control plots: Strontium (Sr) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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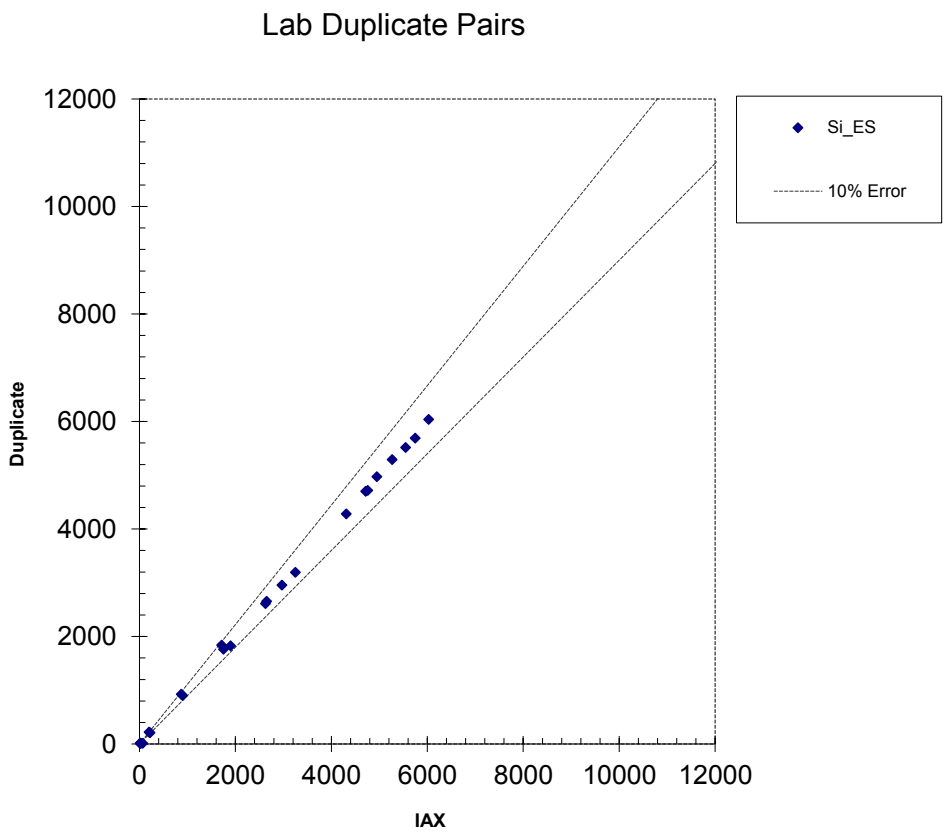
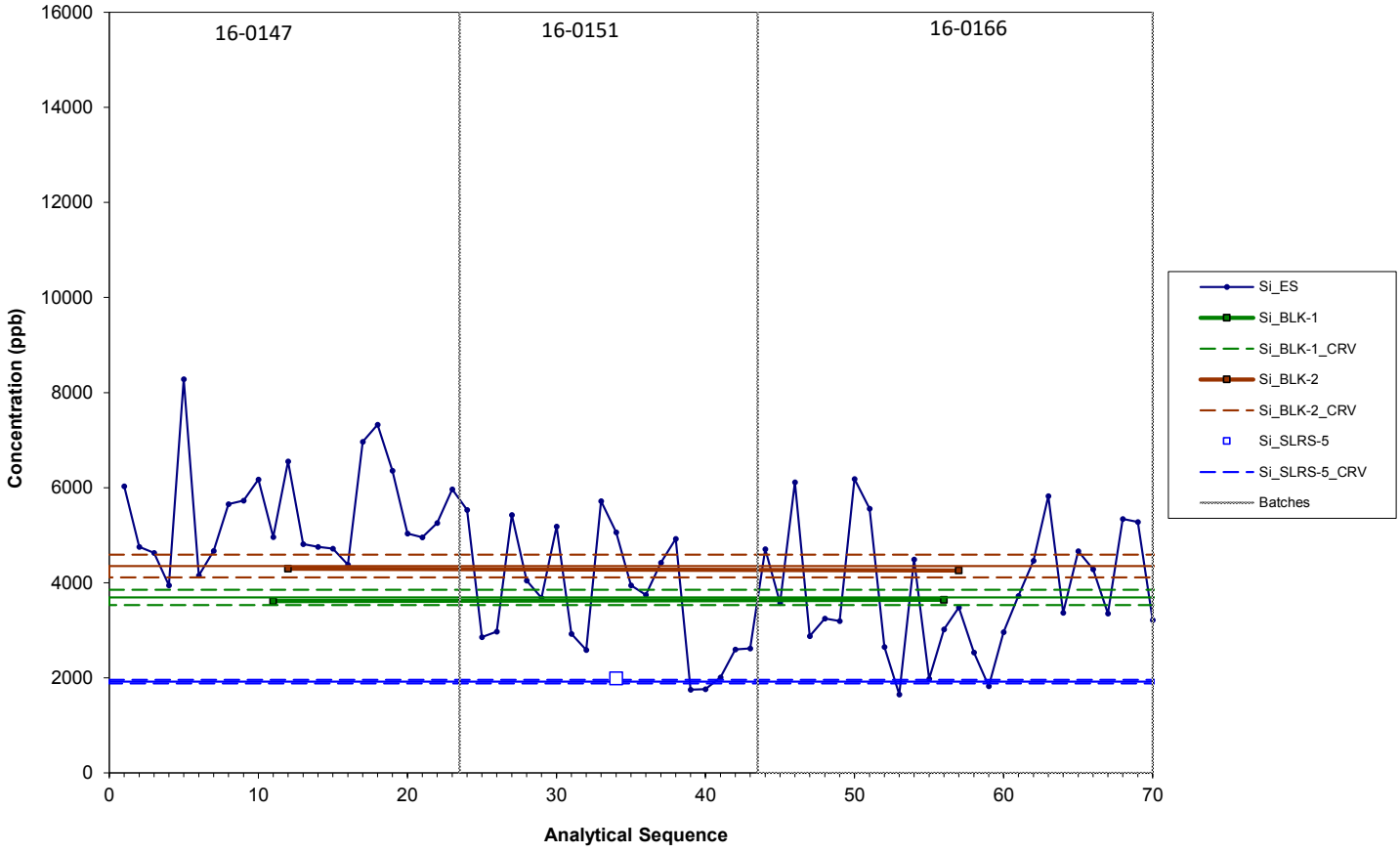
Quality-control plots: Silicon (Si) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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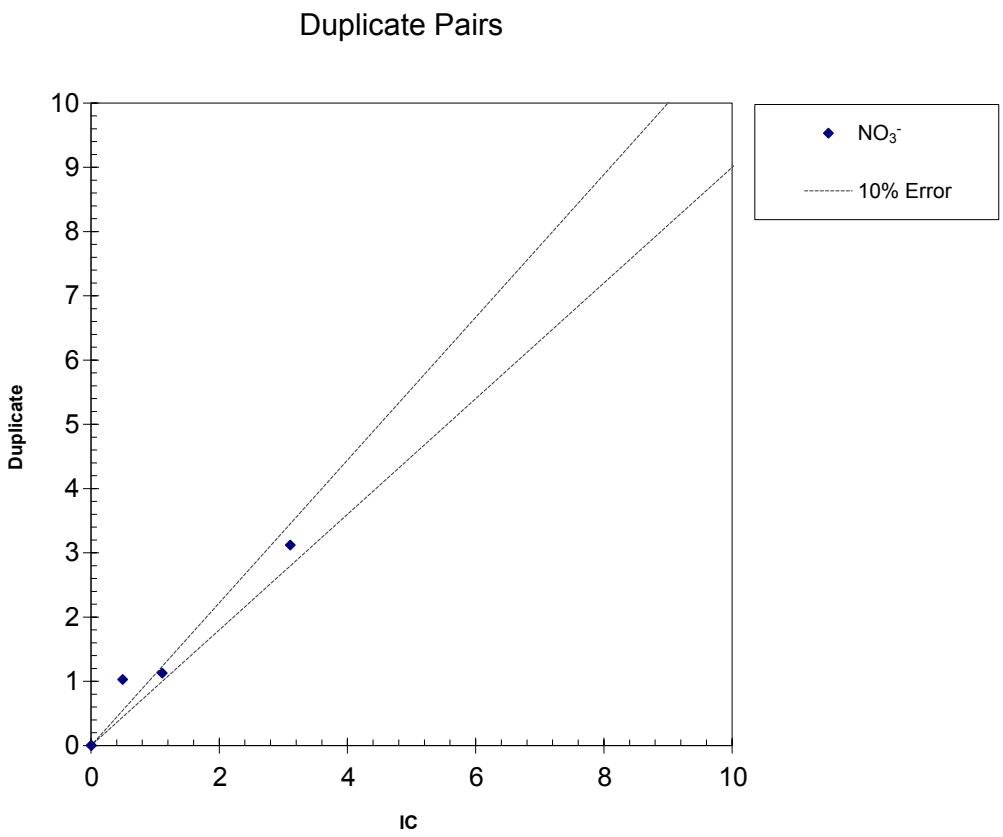
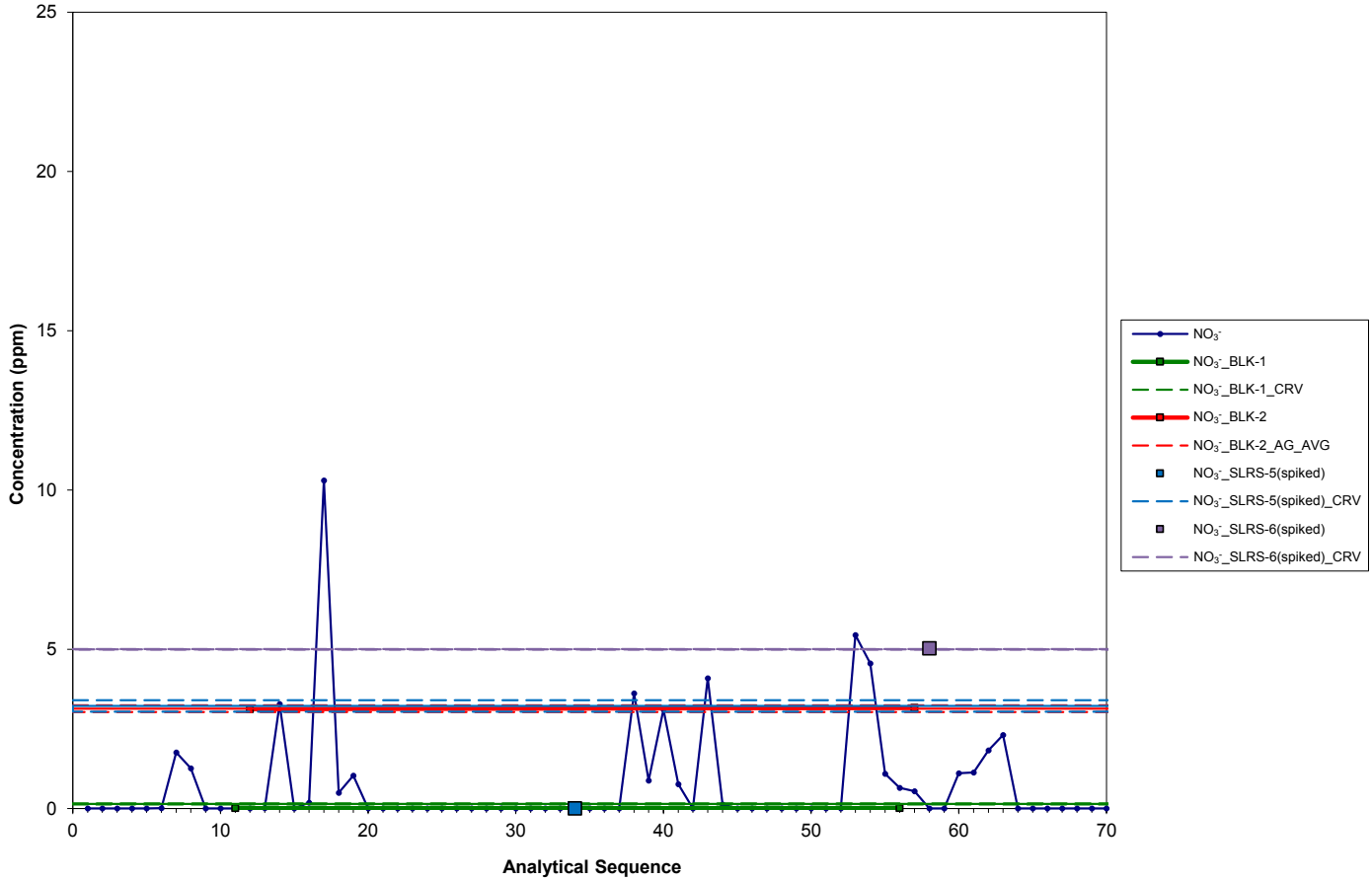
Quality-control plots: Nitrate (NO_3^-) analyses



Analytical concentrations versus accuracy of standards



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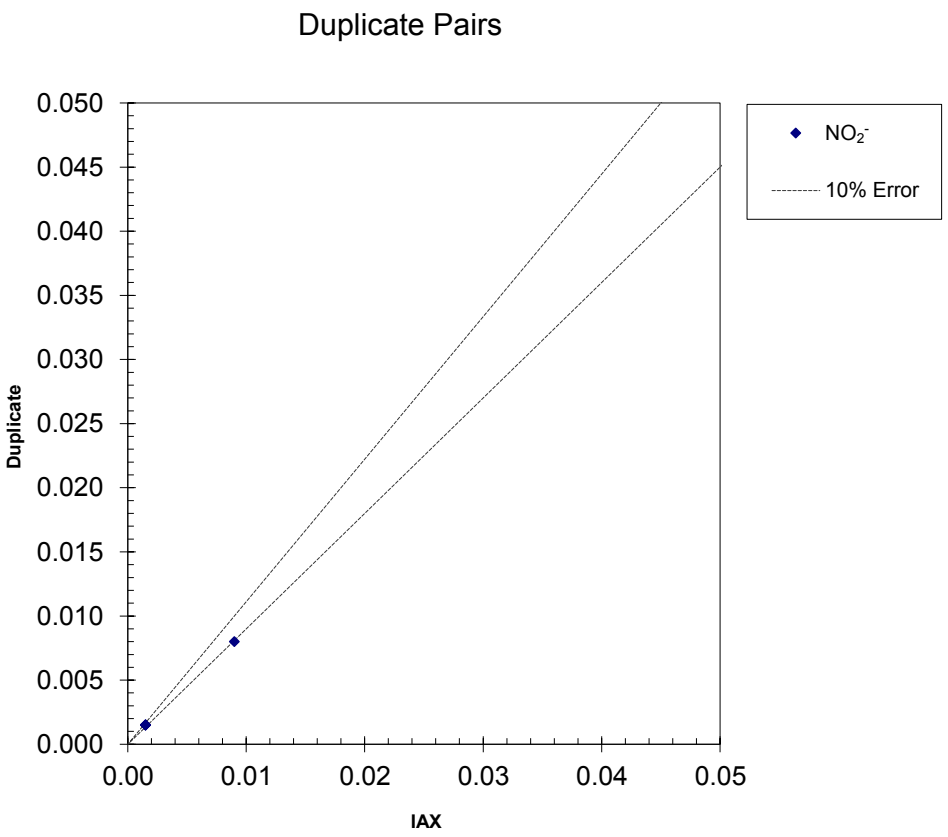
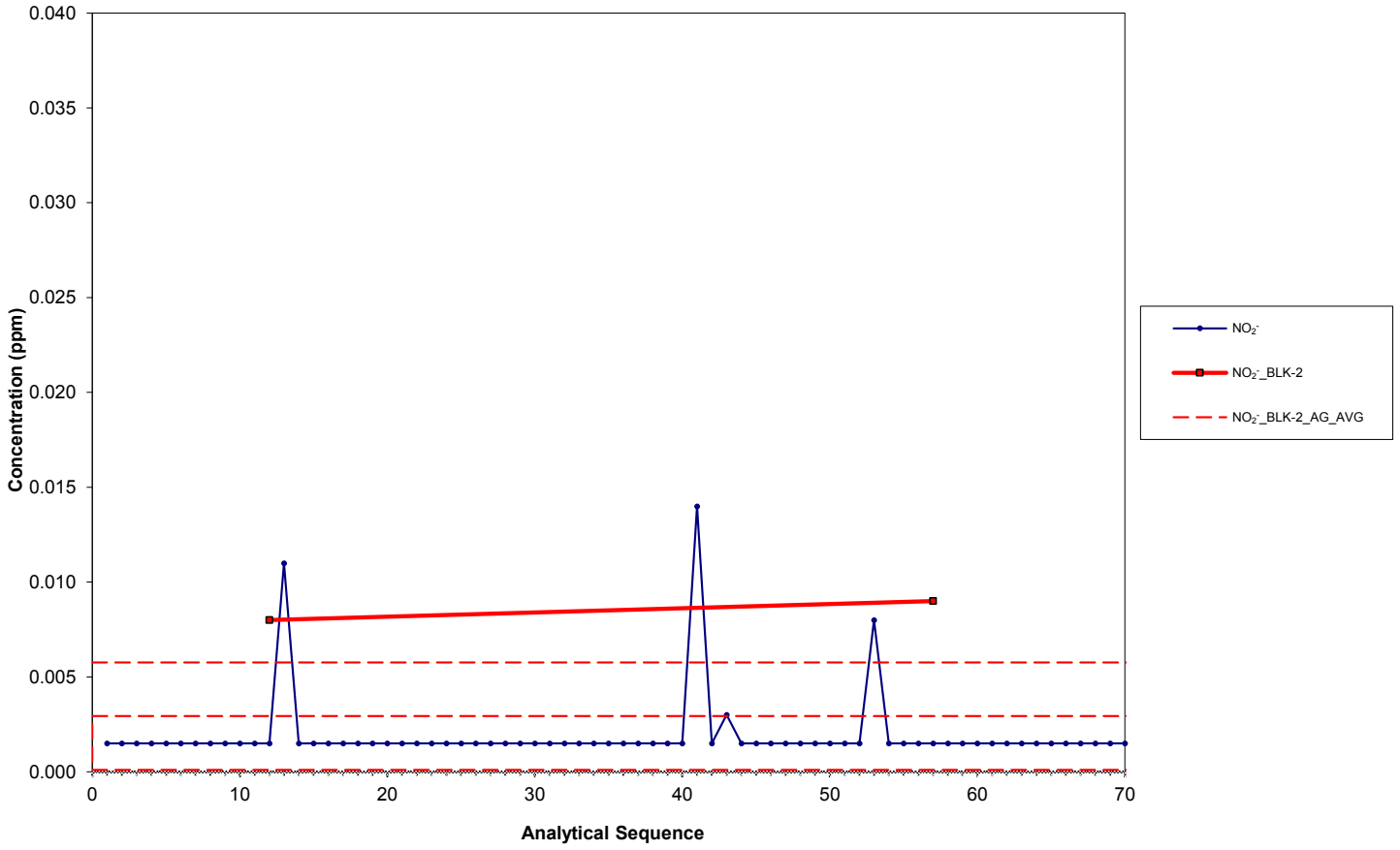
Quality-control plots: Nitrite (NO_2^-) analyses



Analytical concentrations versus accuracy of standards



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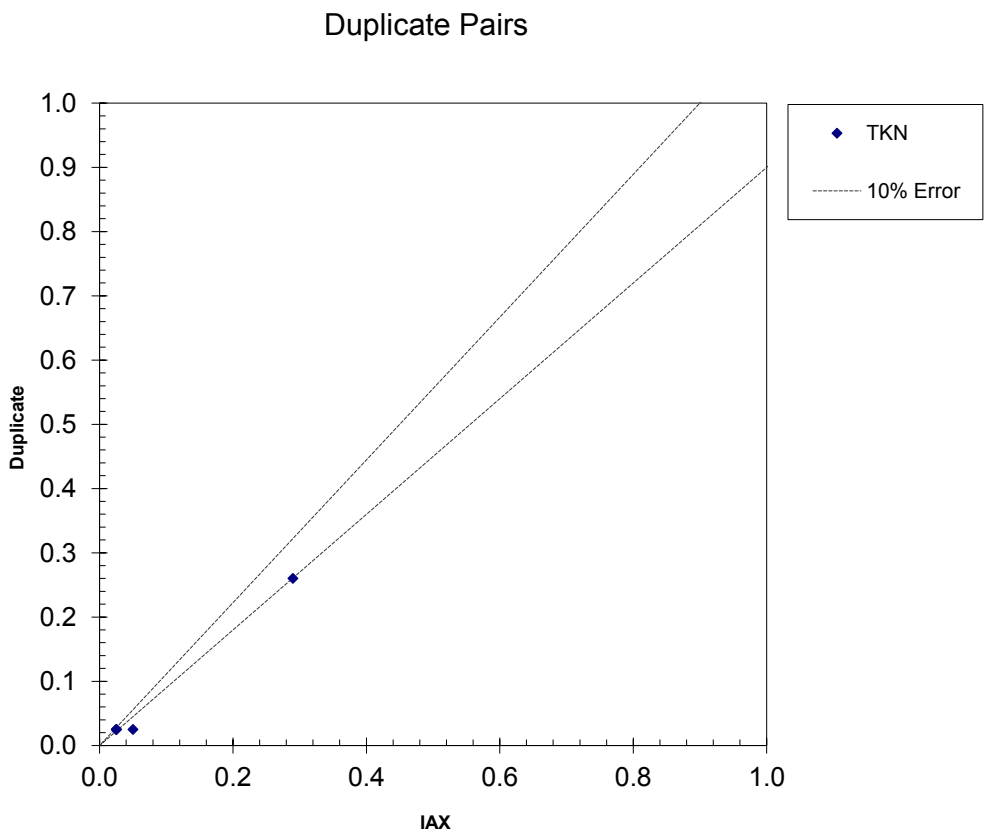
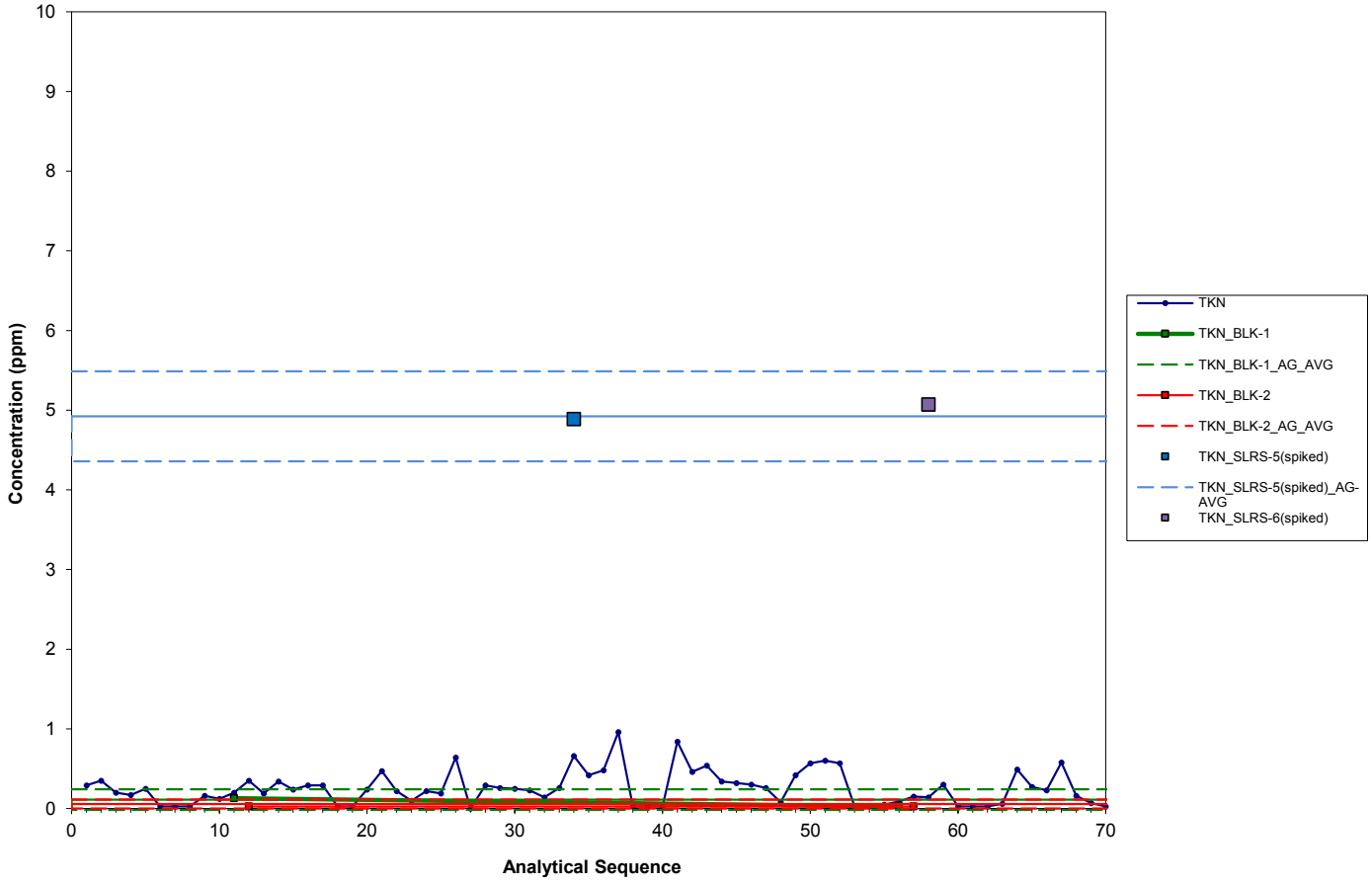
Quality-control plots: total nitrogen by Kjeidahl (TKN) analyses



Analytical concentrations versus accuracy of standards



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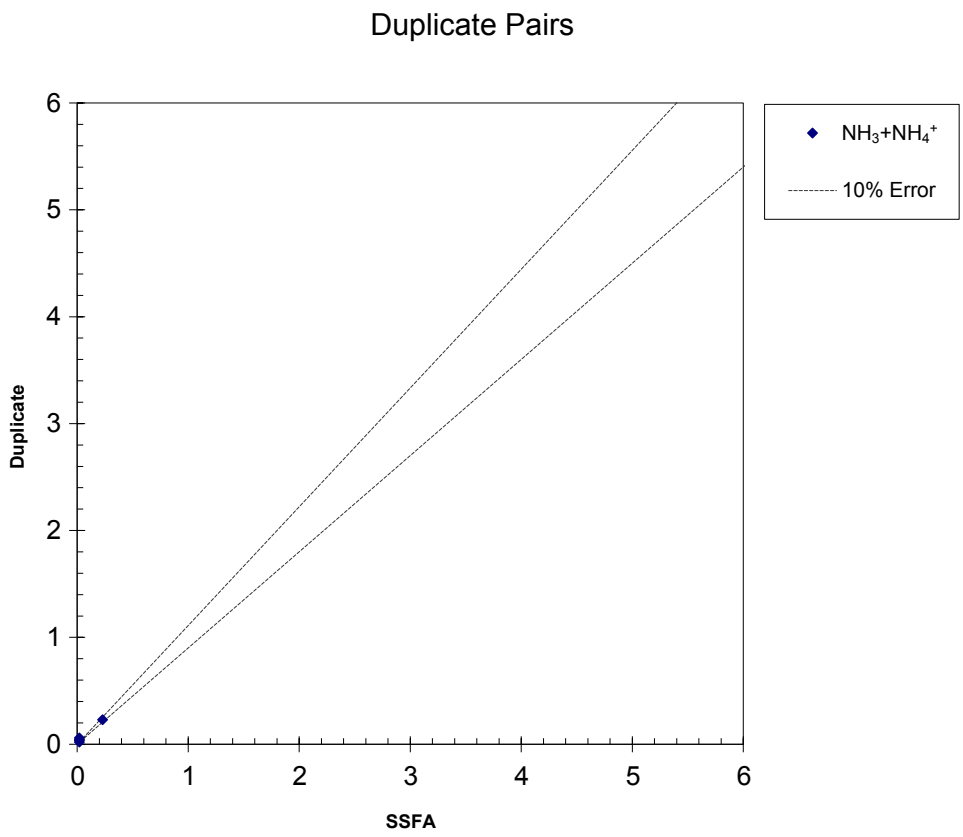
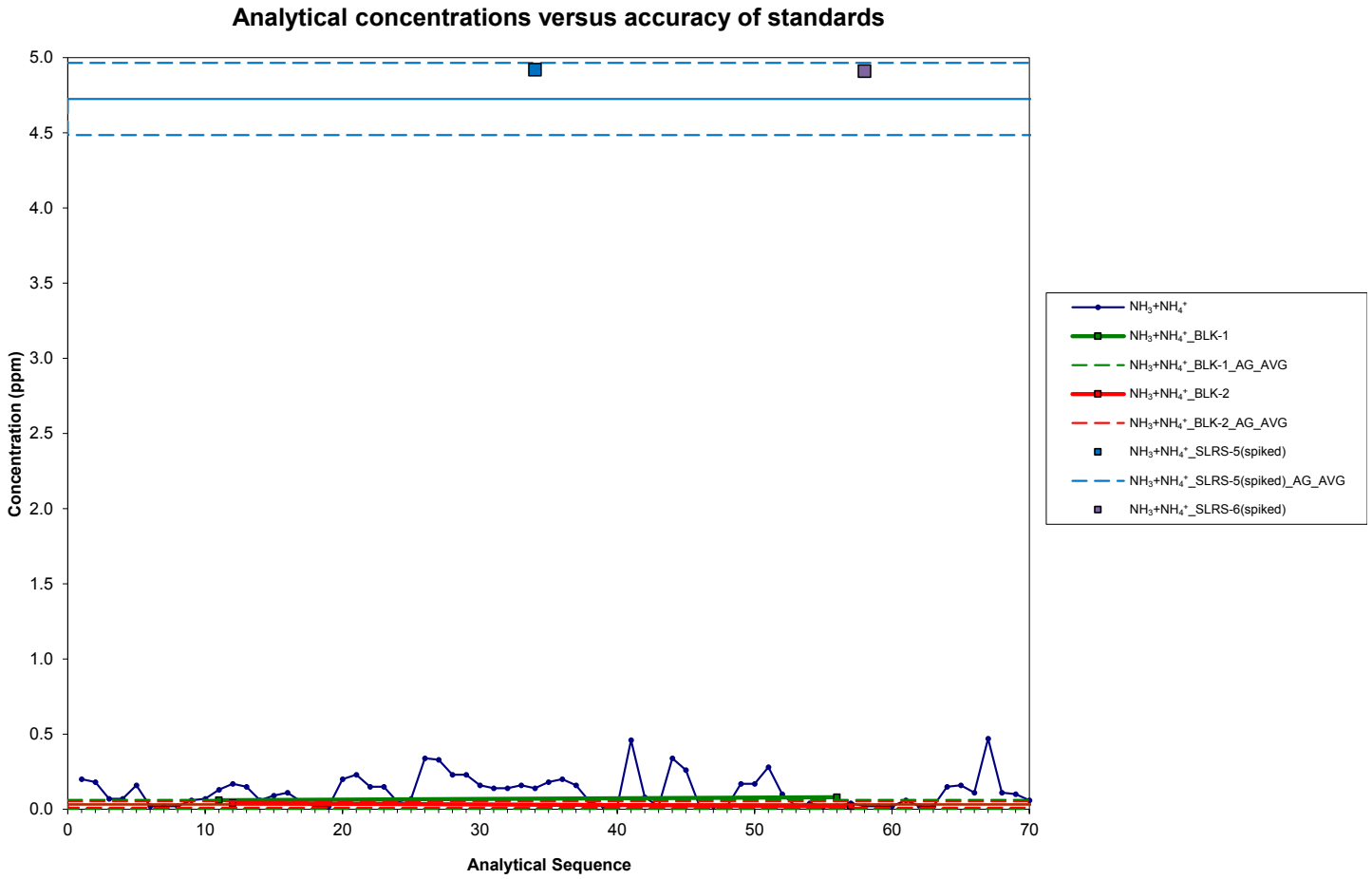
Quality-control plots: NH_3+NH_4^+ analyses





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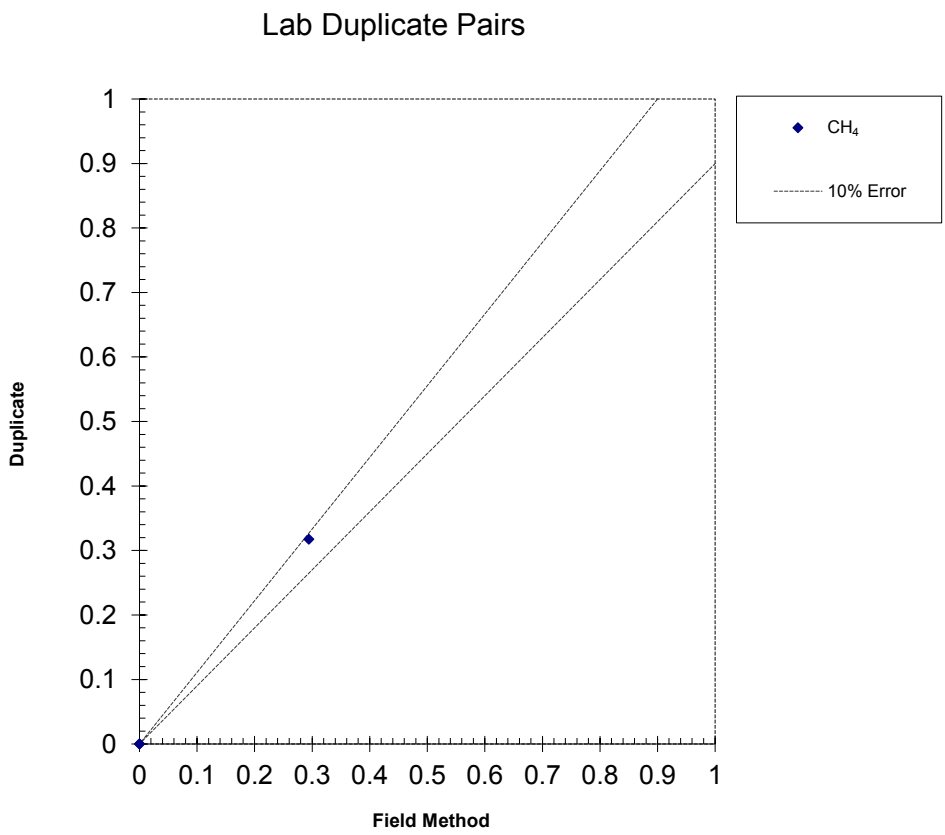
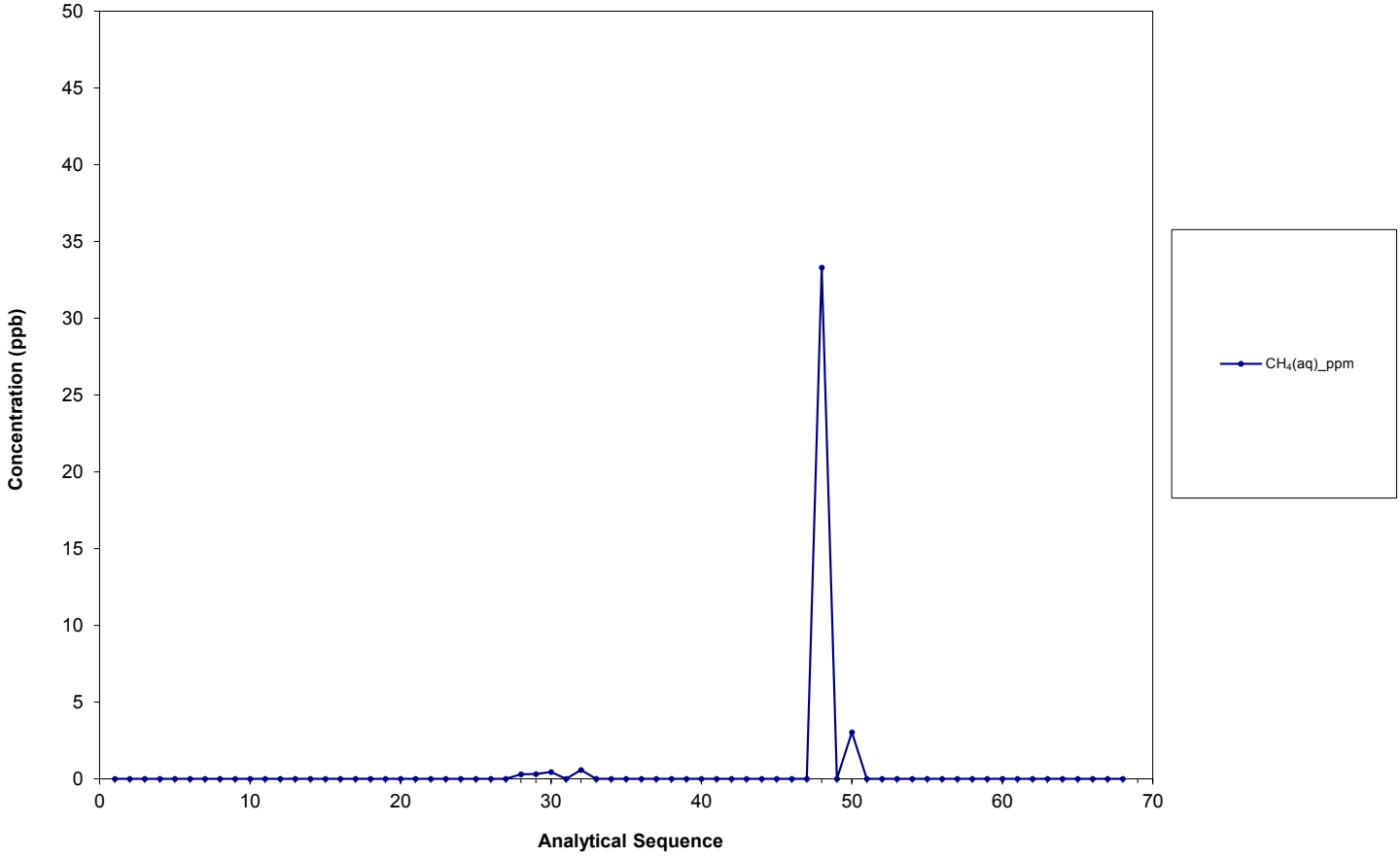
Quality-control plots:Dissolved CH_4 (aq) ppmv_ calculated



Analytical concentrations versus accuracy of standards



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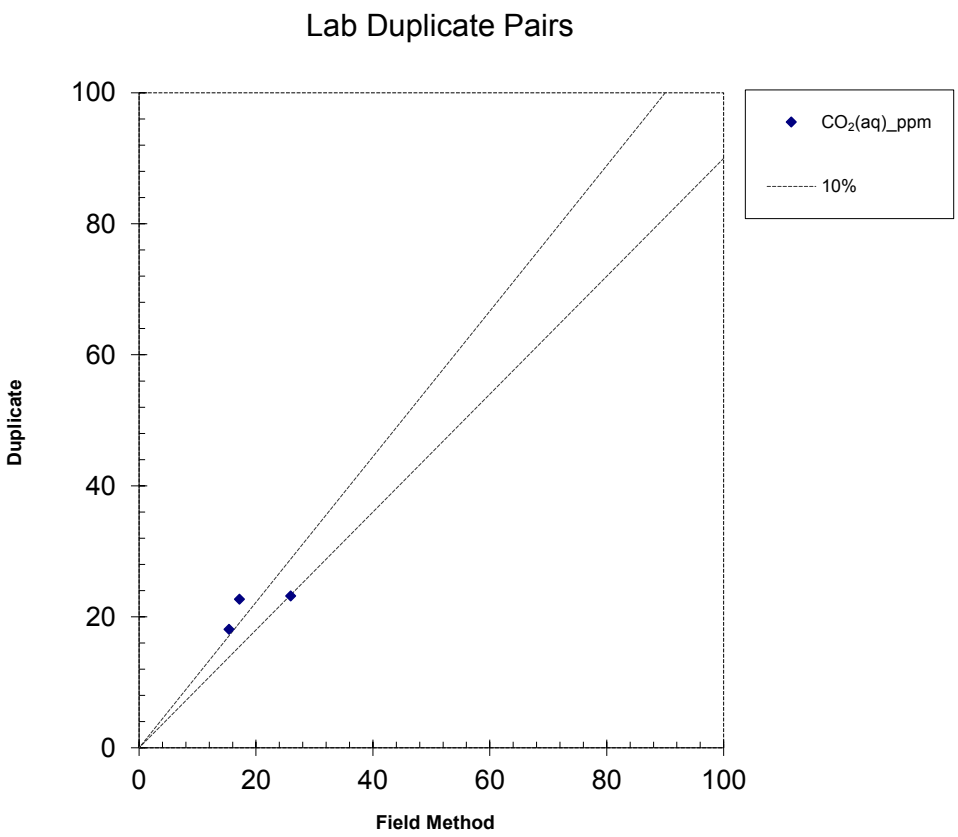
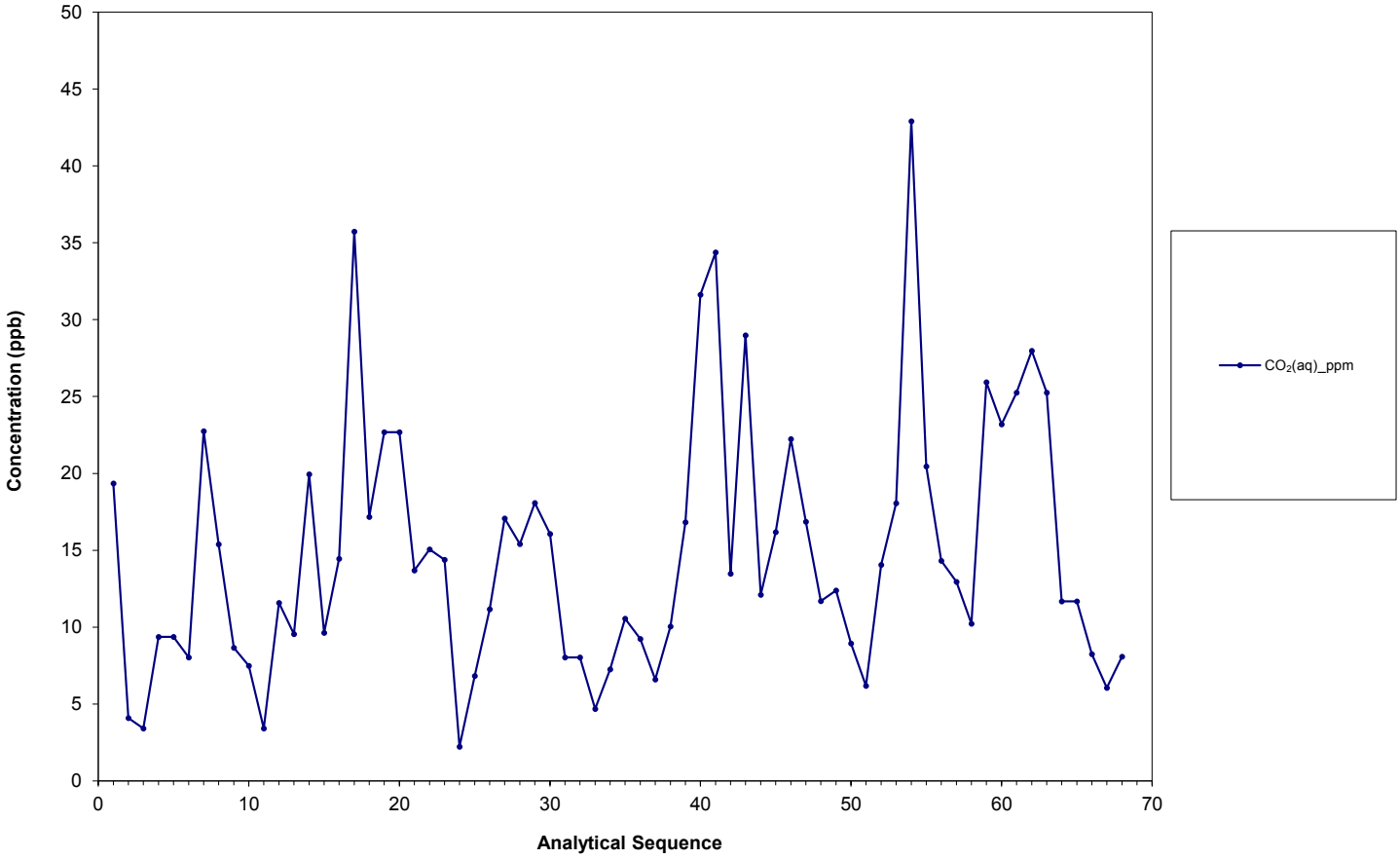
Quality-control plots: Dissolved CO_2 (aq) ppmv_ calculated



Analytical concentrations versus accuracy of standards



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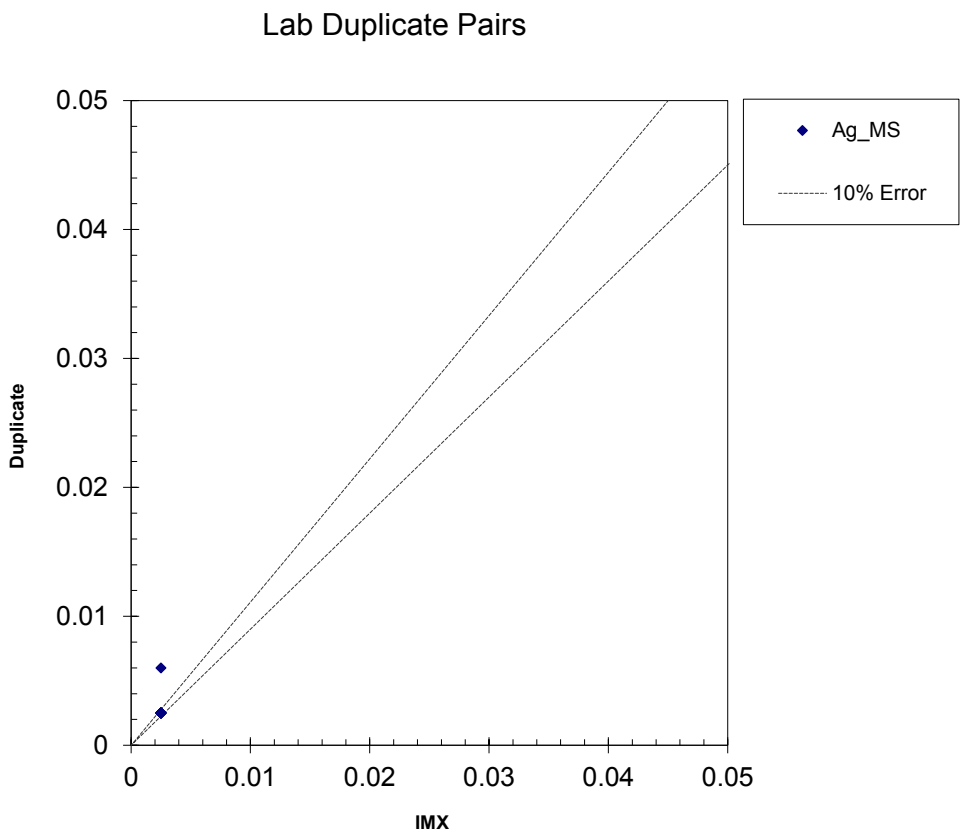
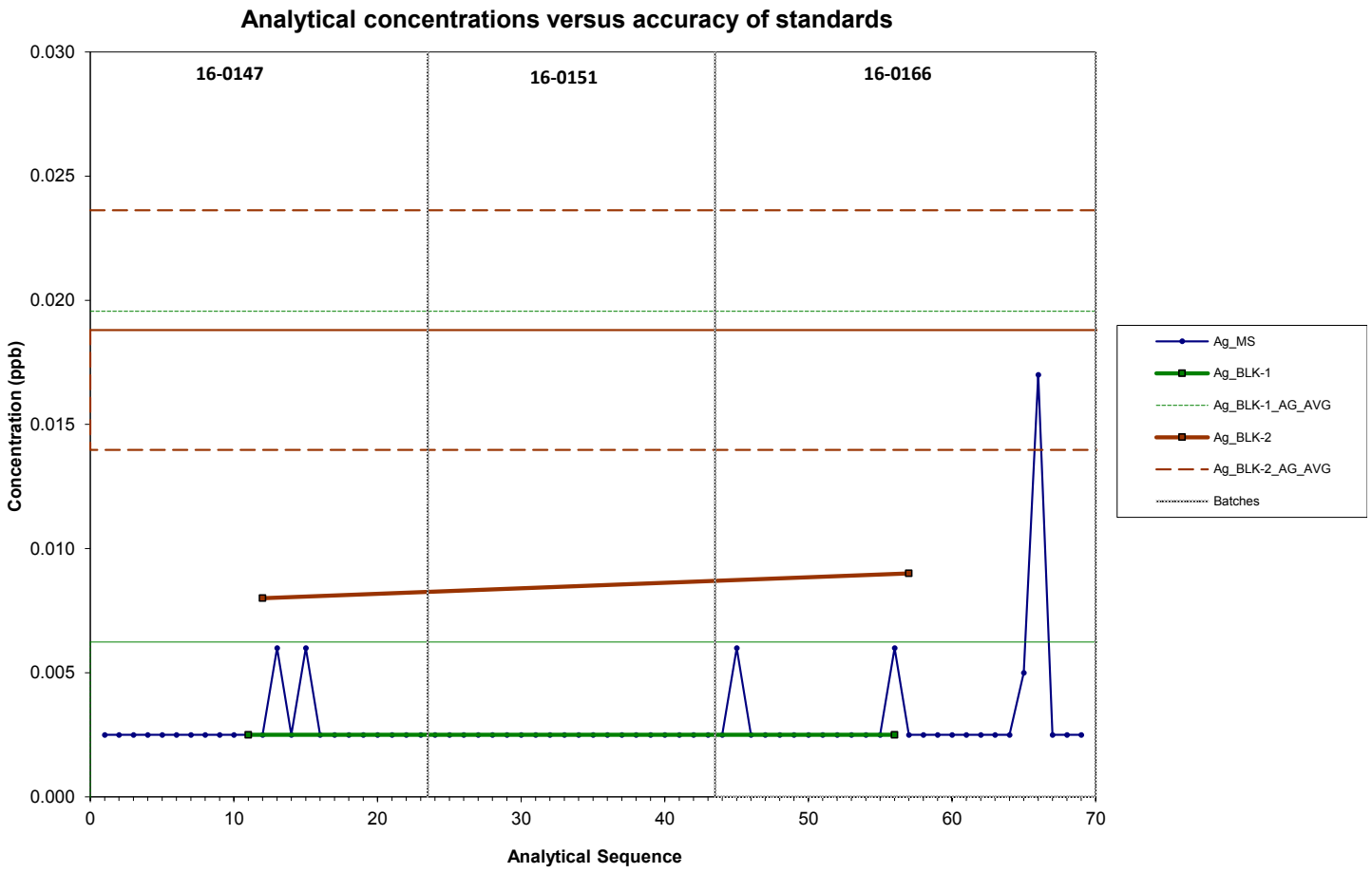
Quality-control plots: Silver (Ag) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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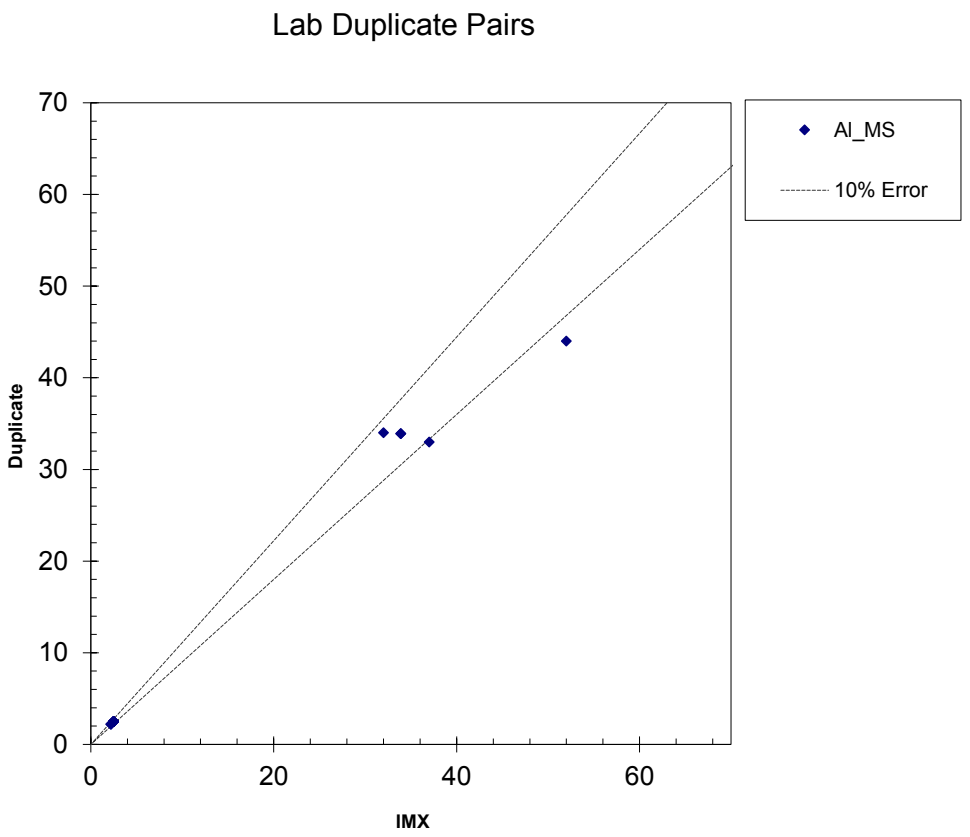
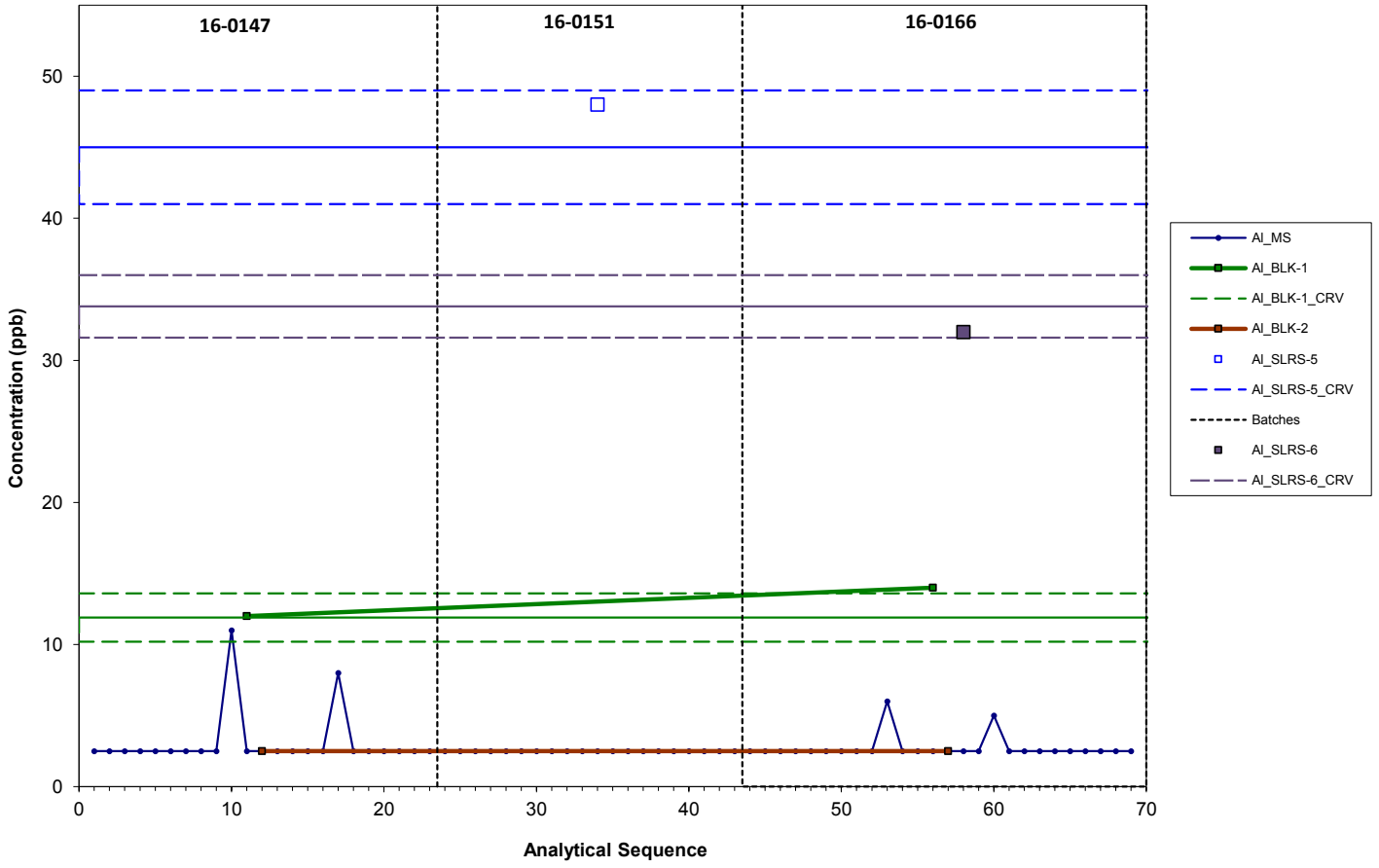
Quality-control plots: Aluminum (Al) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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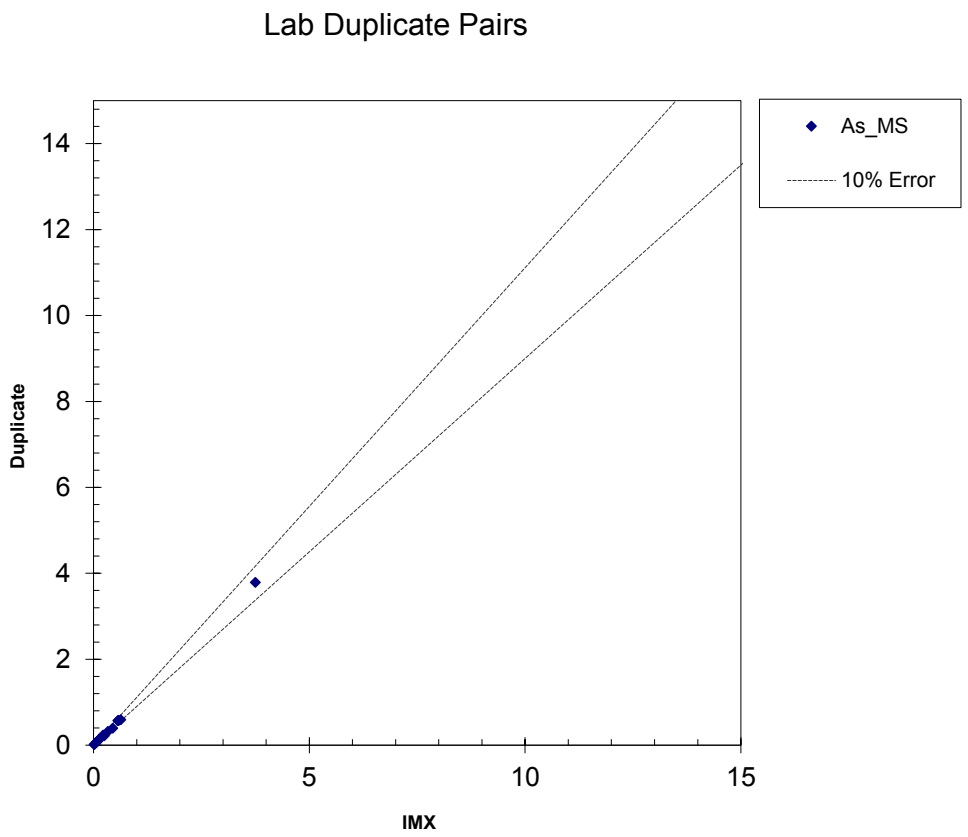
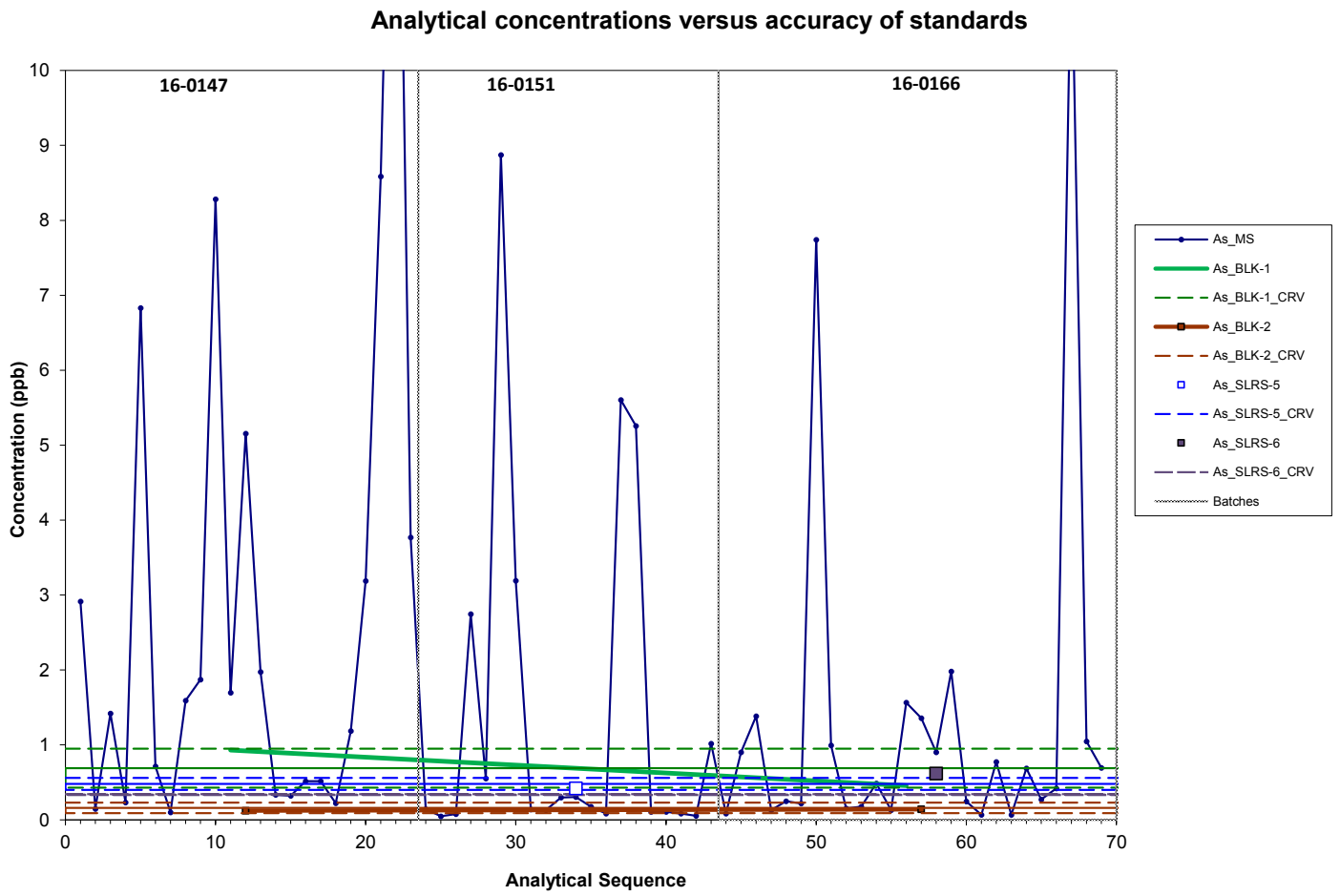
Quality-control plots: Arsenic (As) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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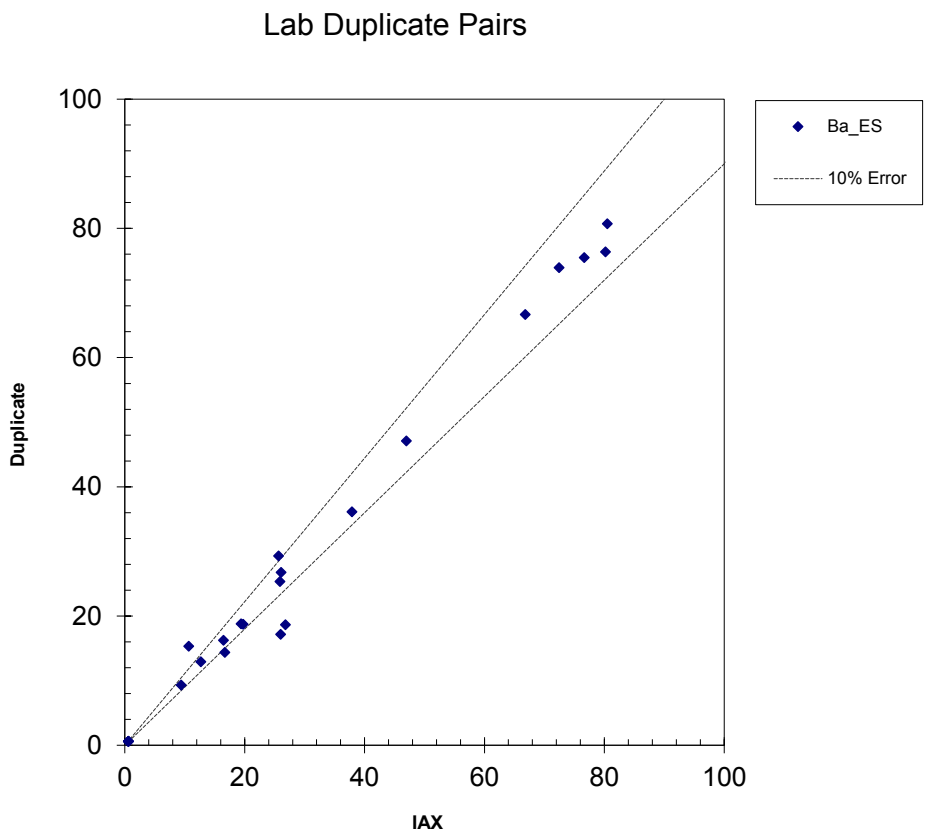
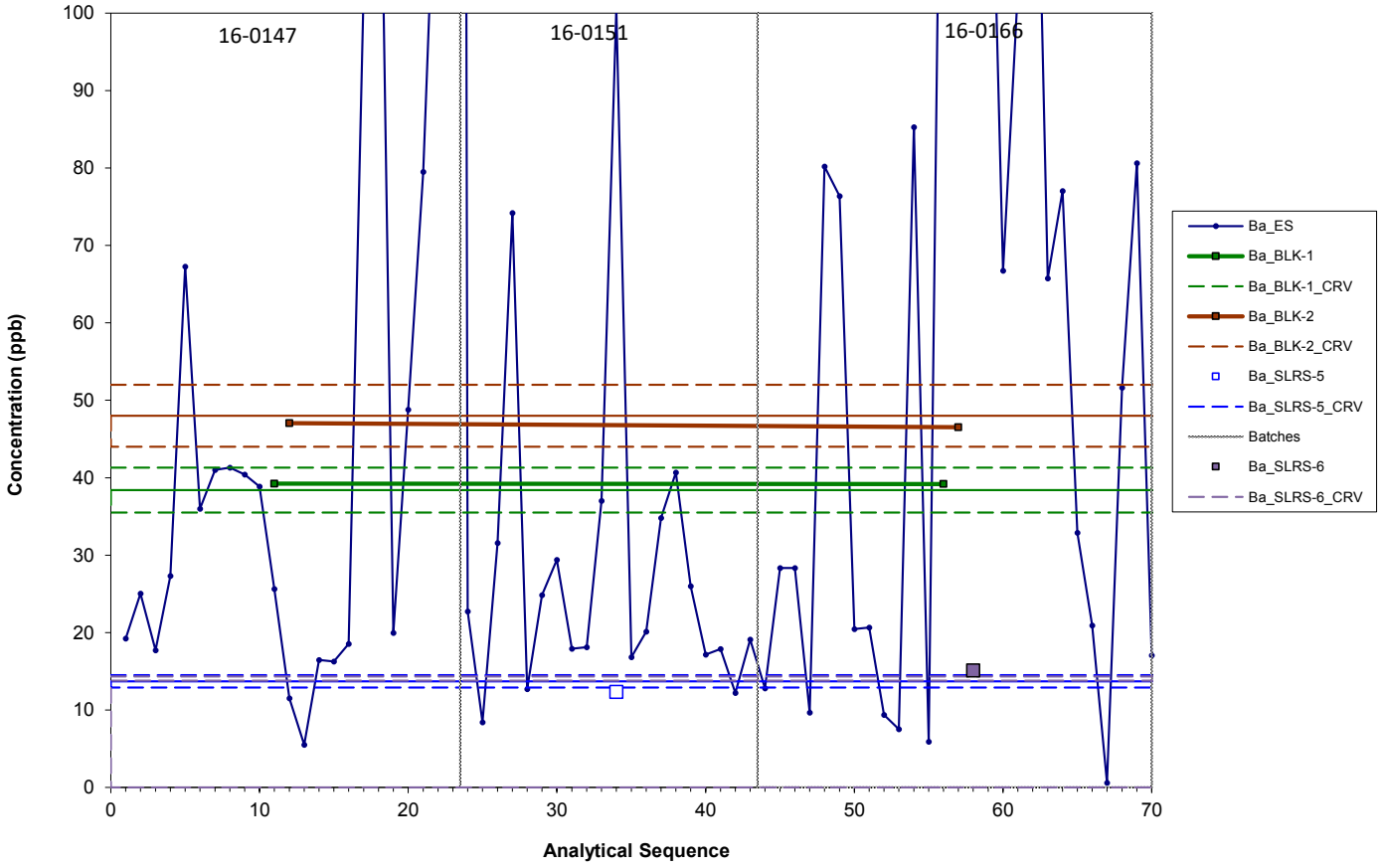
Quality-control plots: Barium (Ba) analyses using inductively coupled emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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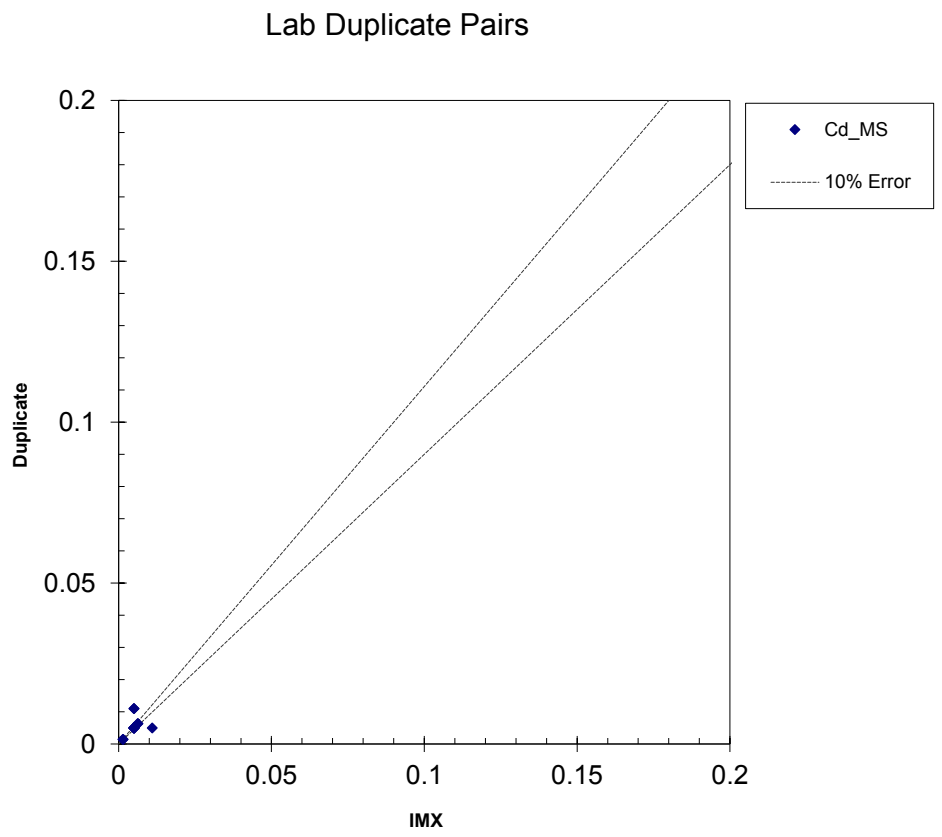
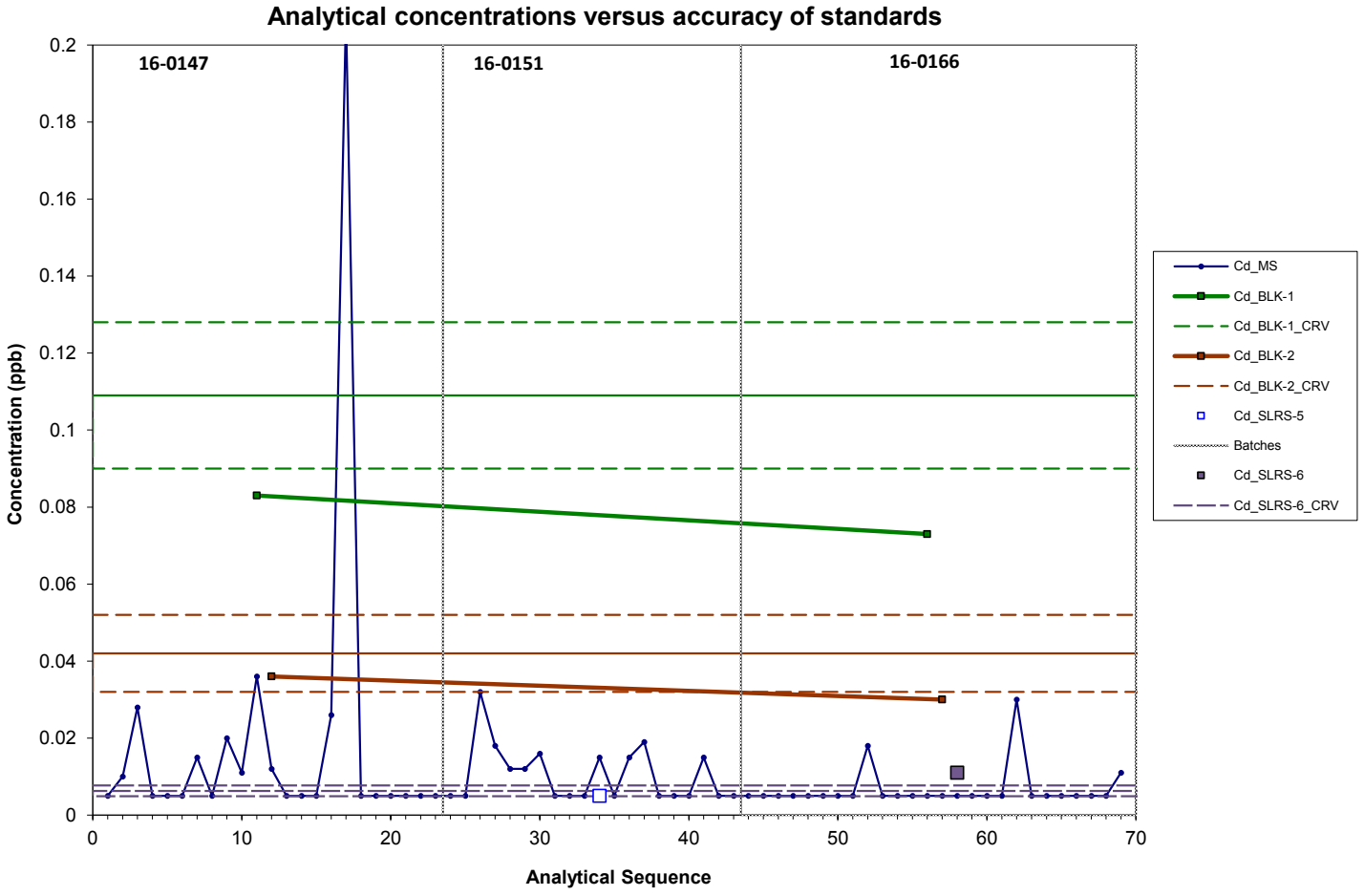
Quality-control plots: Cadmium (Cd) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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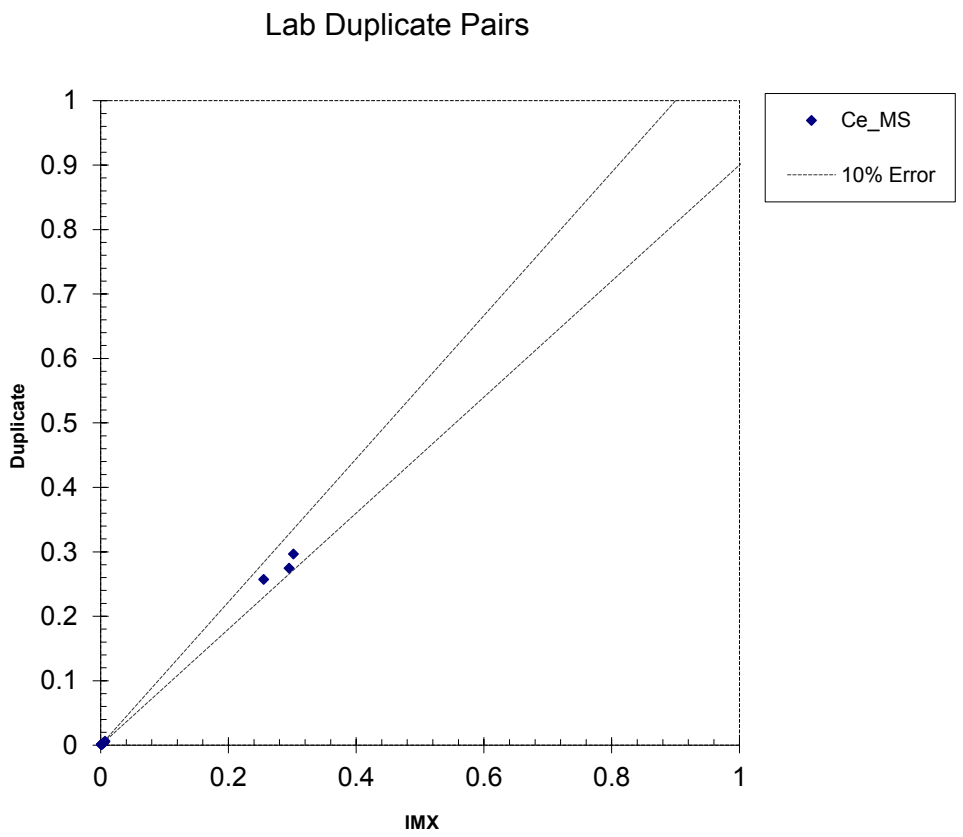
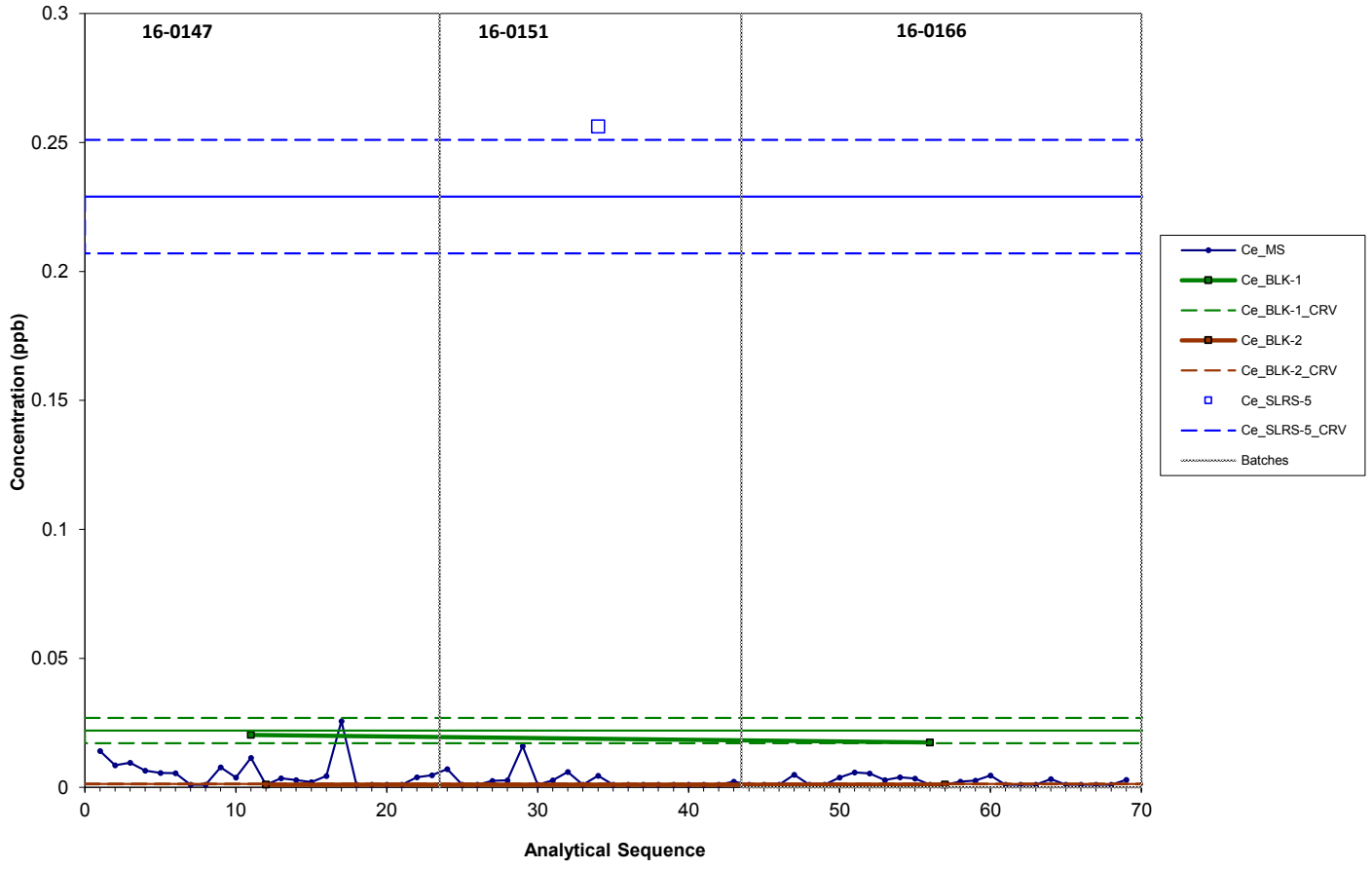
Quality-control plots: Cerium (Ce) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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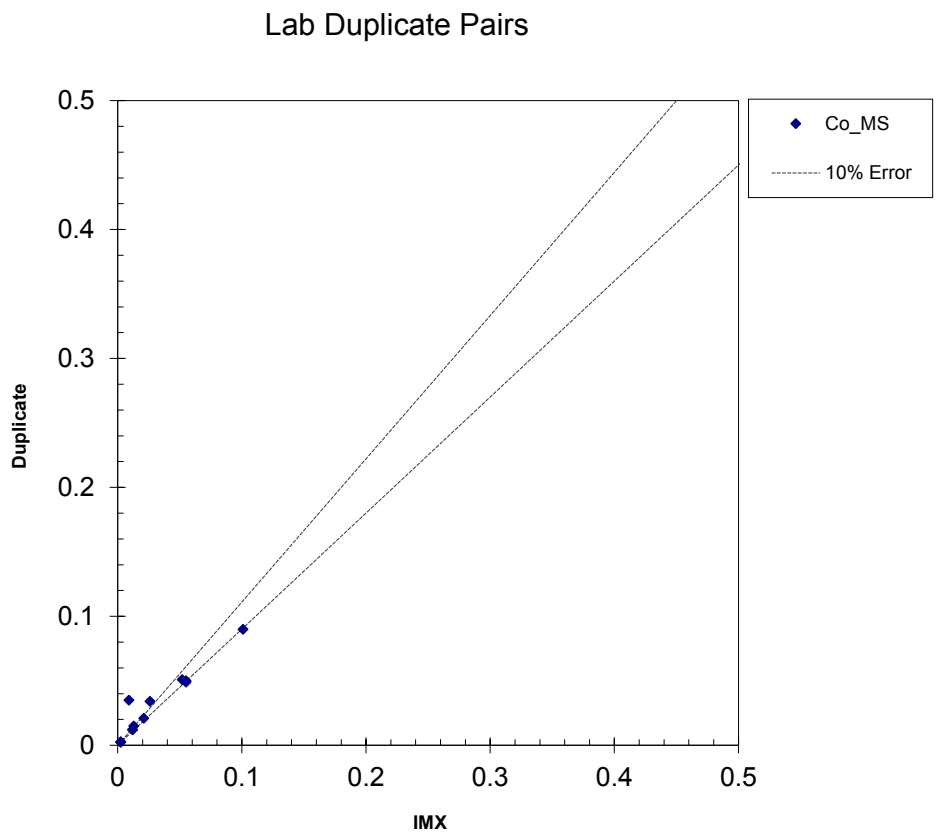
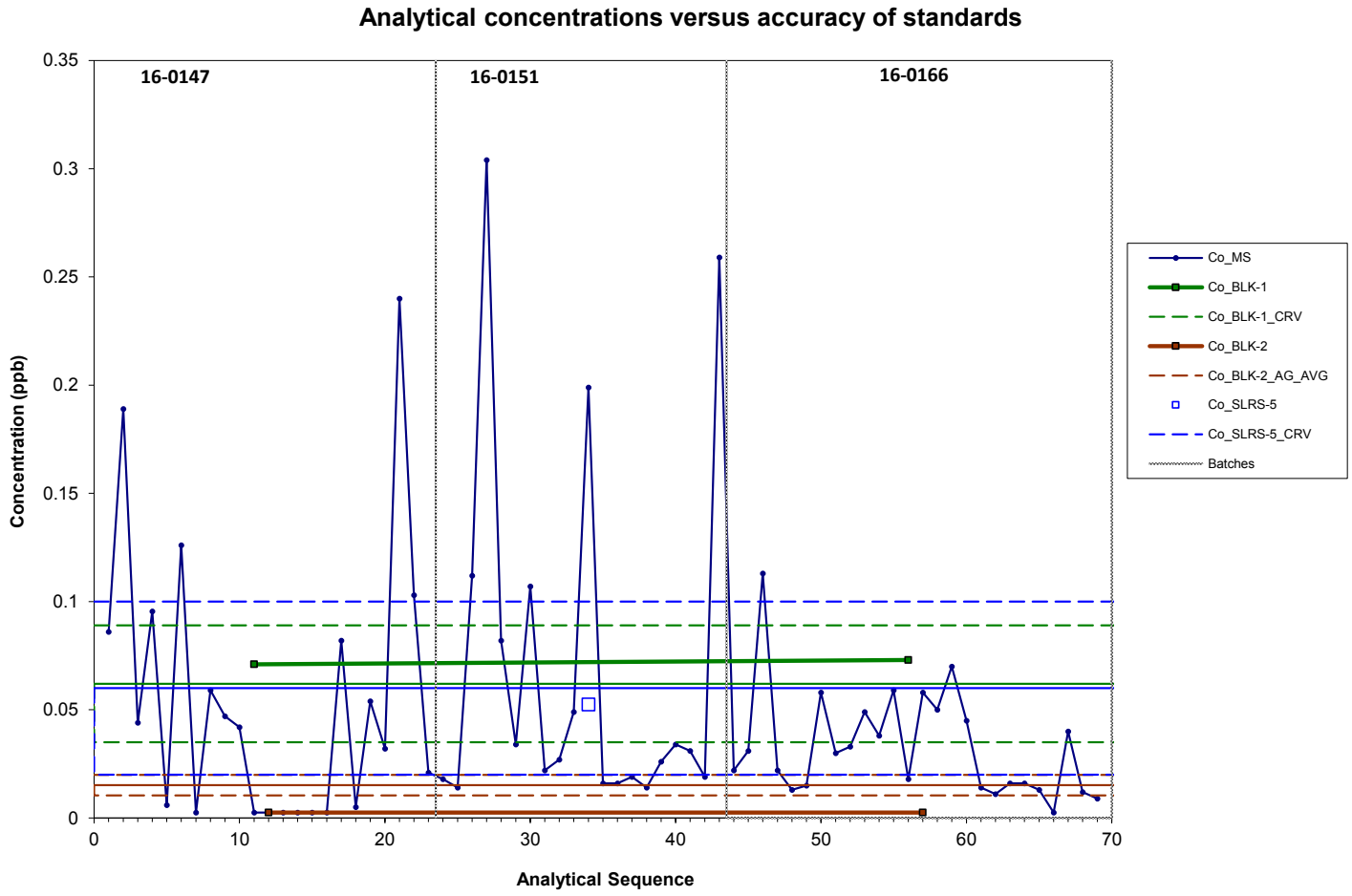
Quality-control plots: Cobalt (Co) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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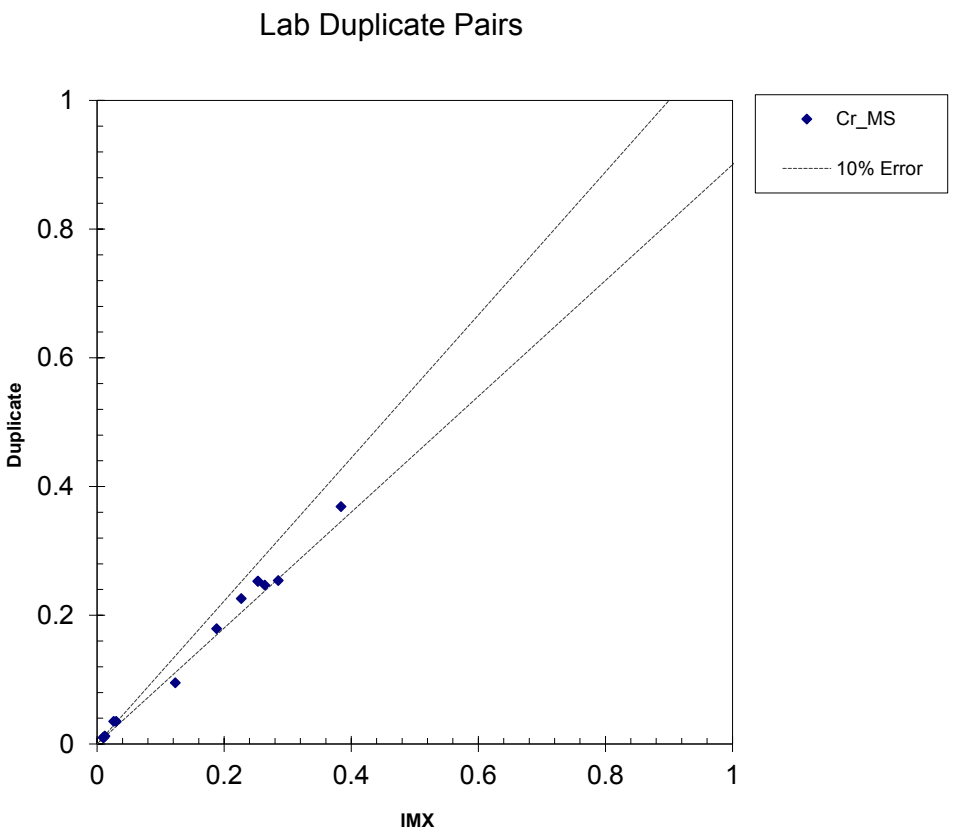
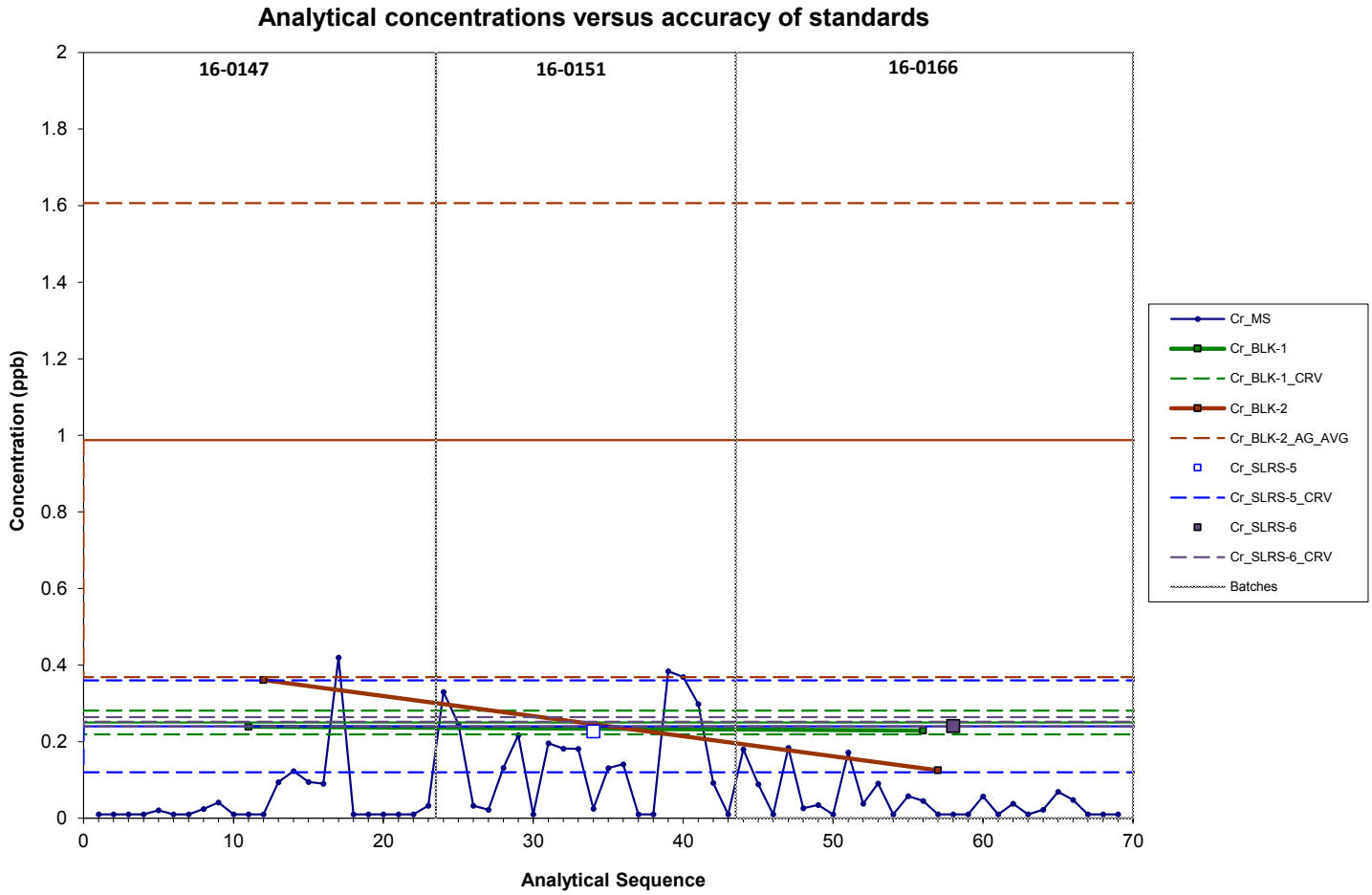
Quality-control plots: Chromium (Cr) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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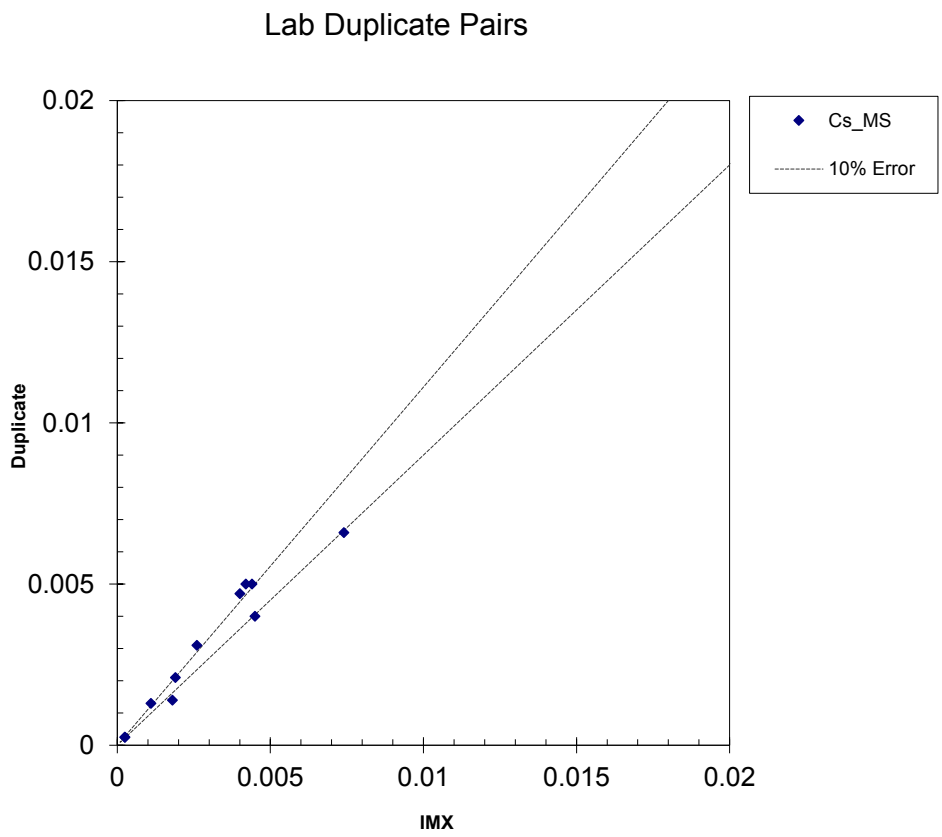
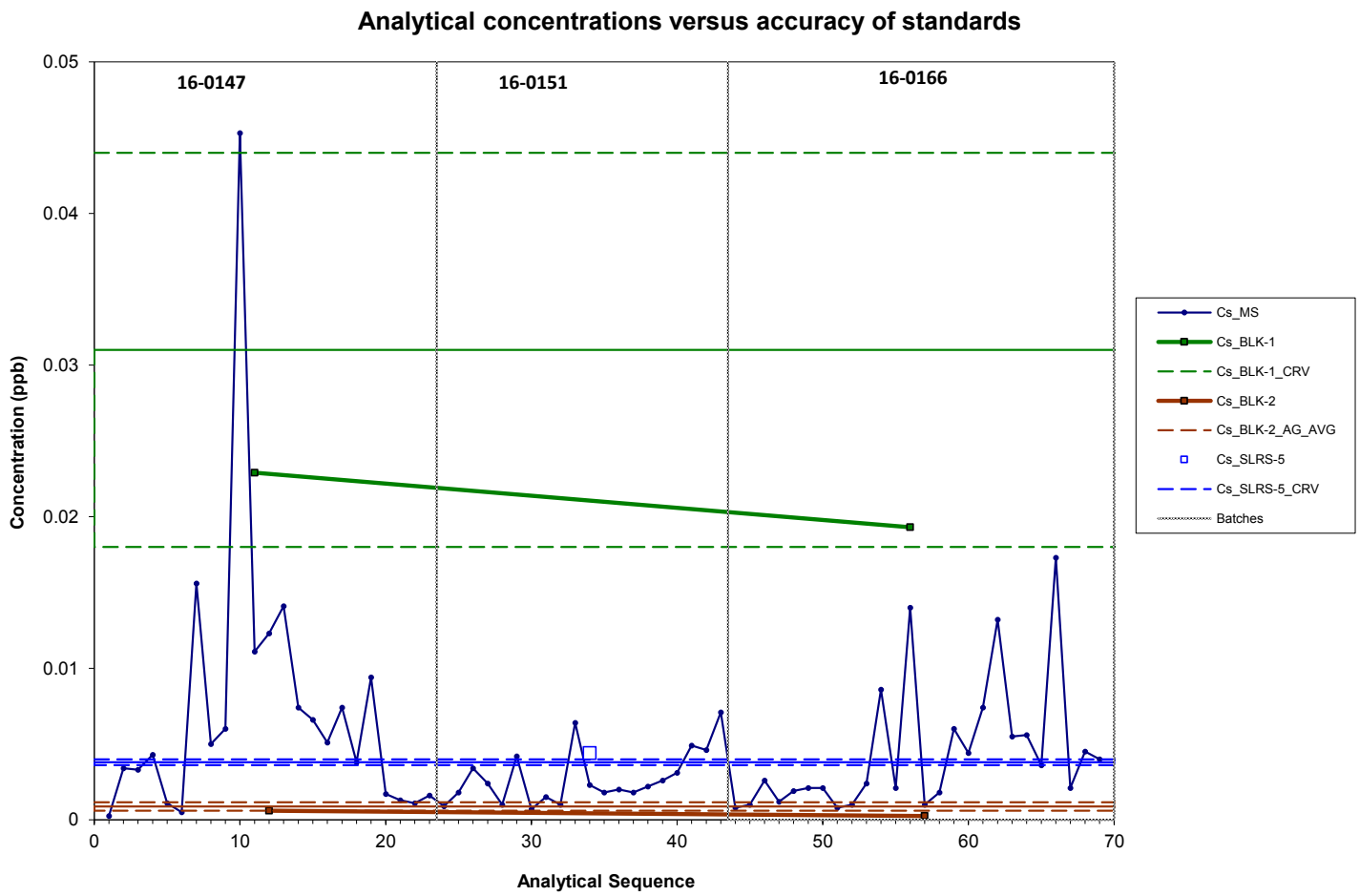
Quality-control plots: Cesium (Cs) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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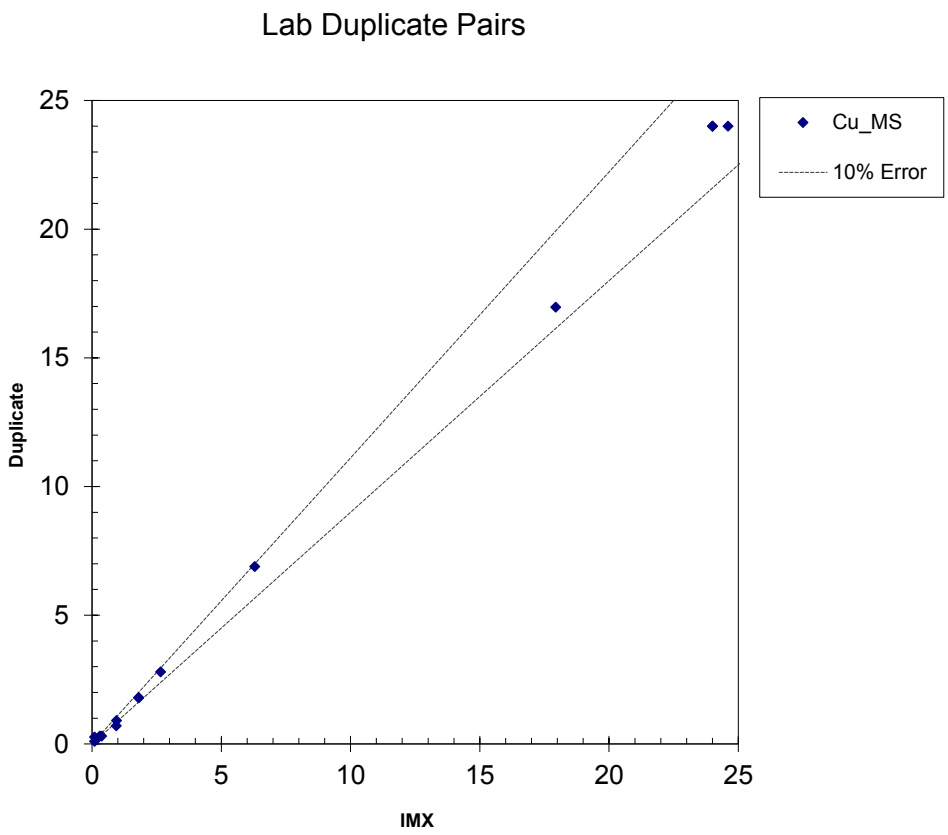
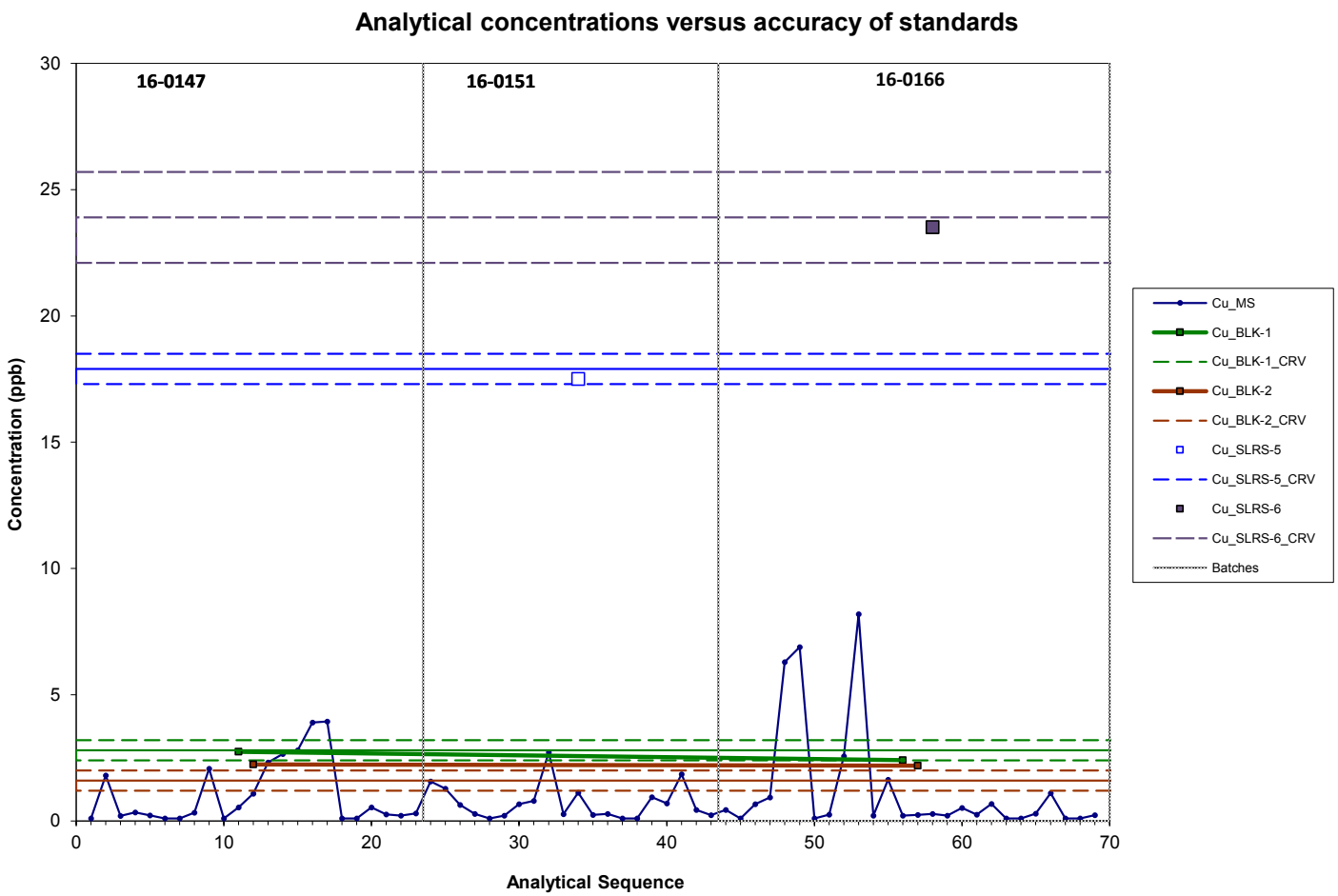
Quality-control plots: Copper (Cu) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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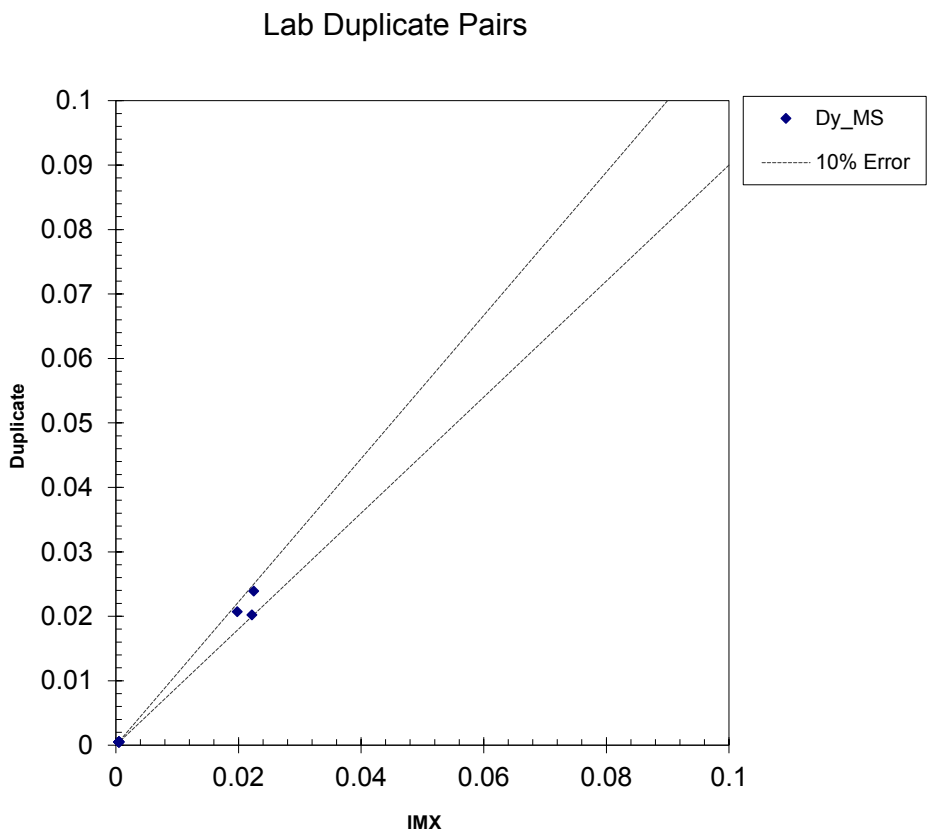
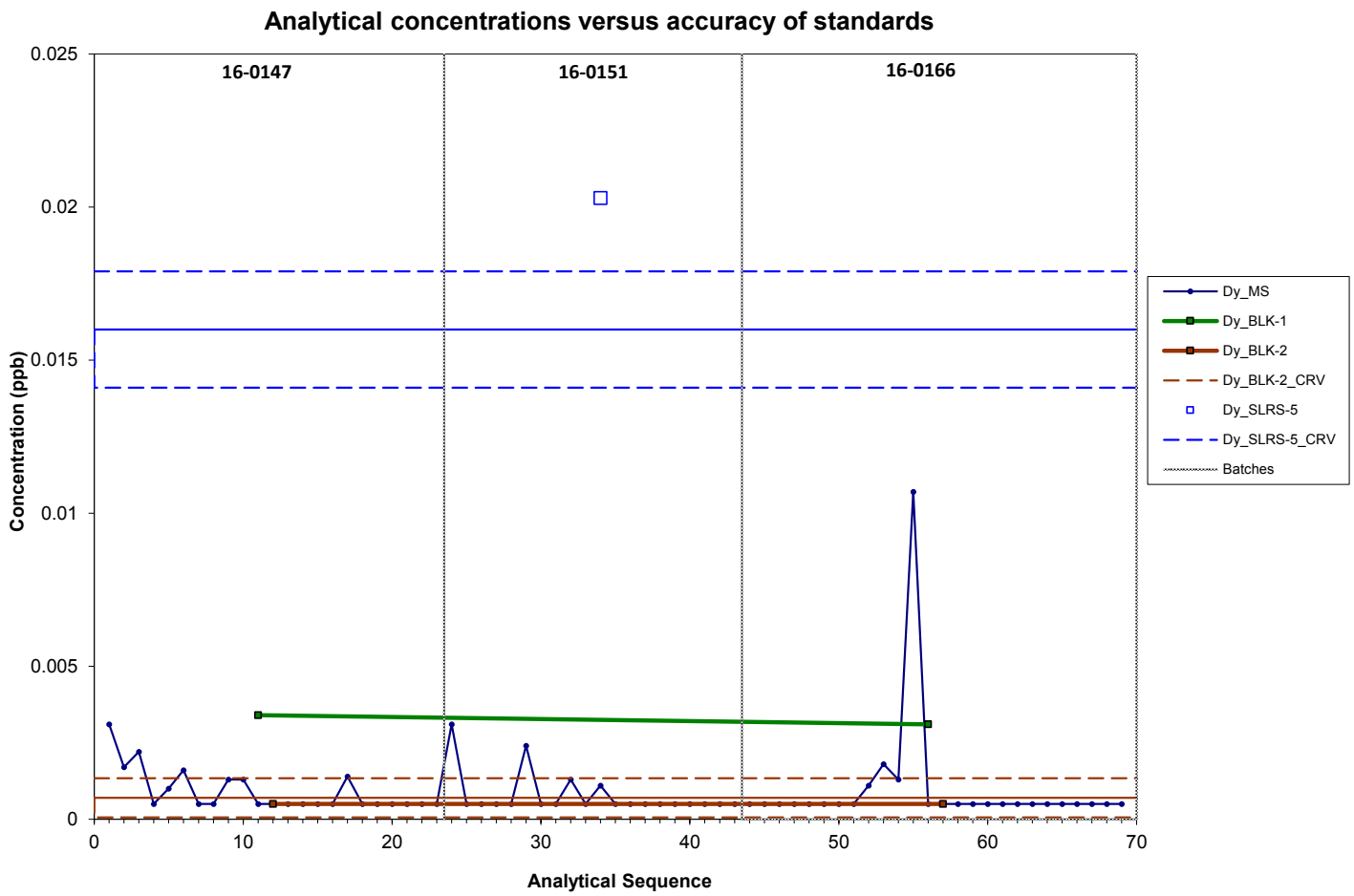
Quality-control plots: Dysprosium (Dy) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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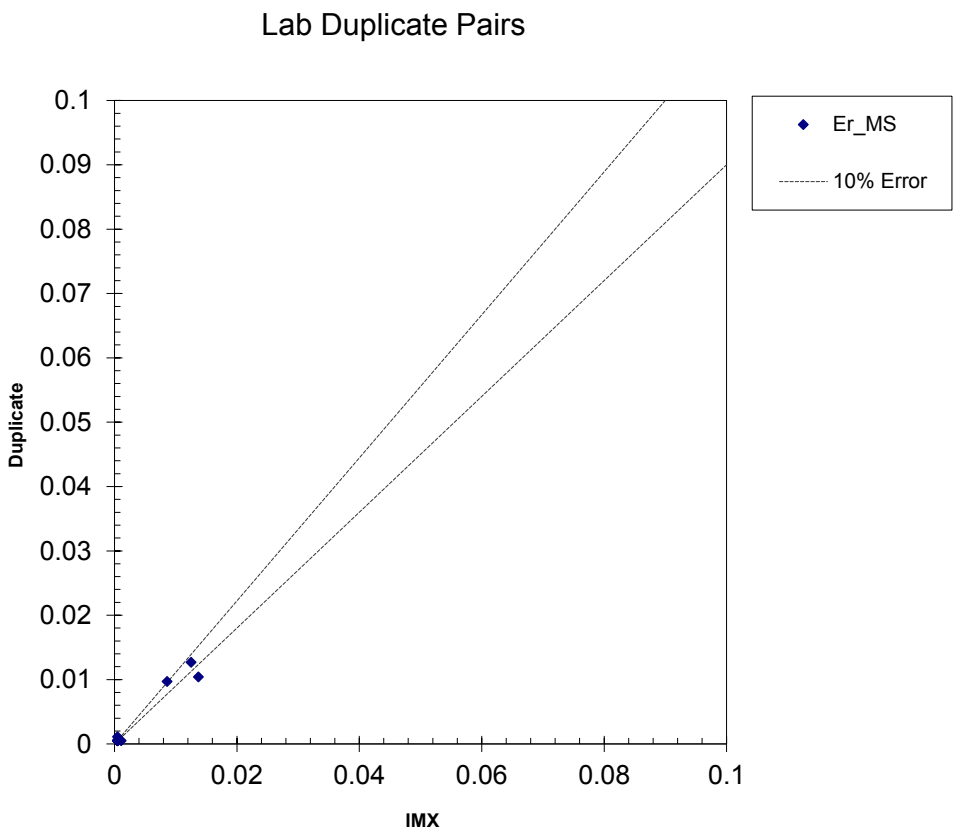
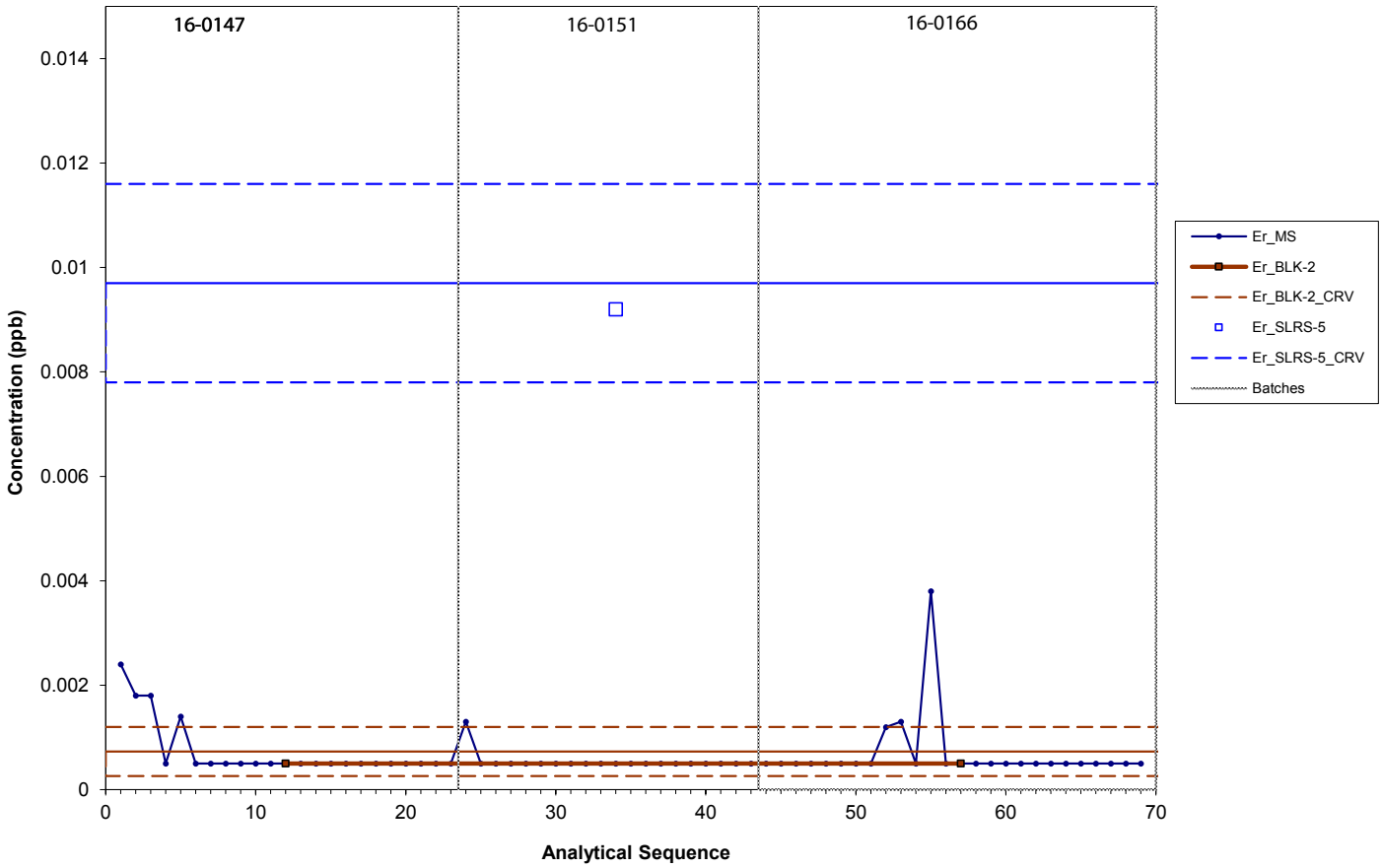
Quality-control plots: Erbium (Er) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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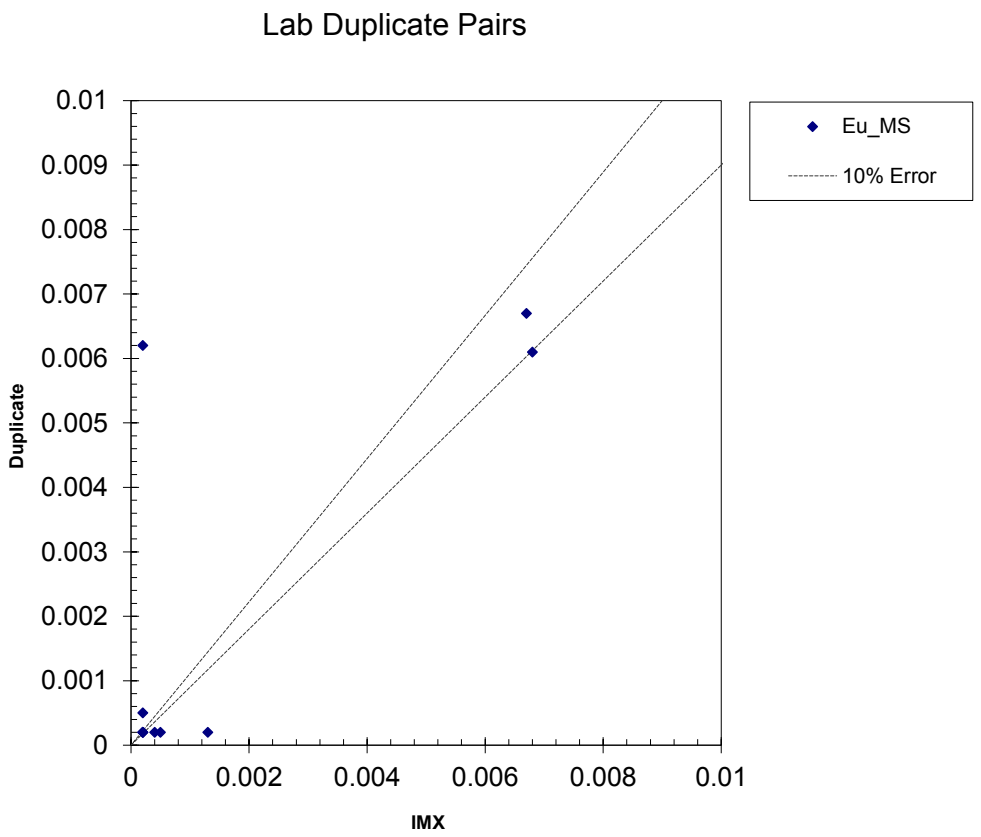
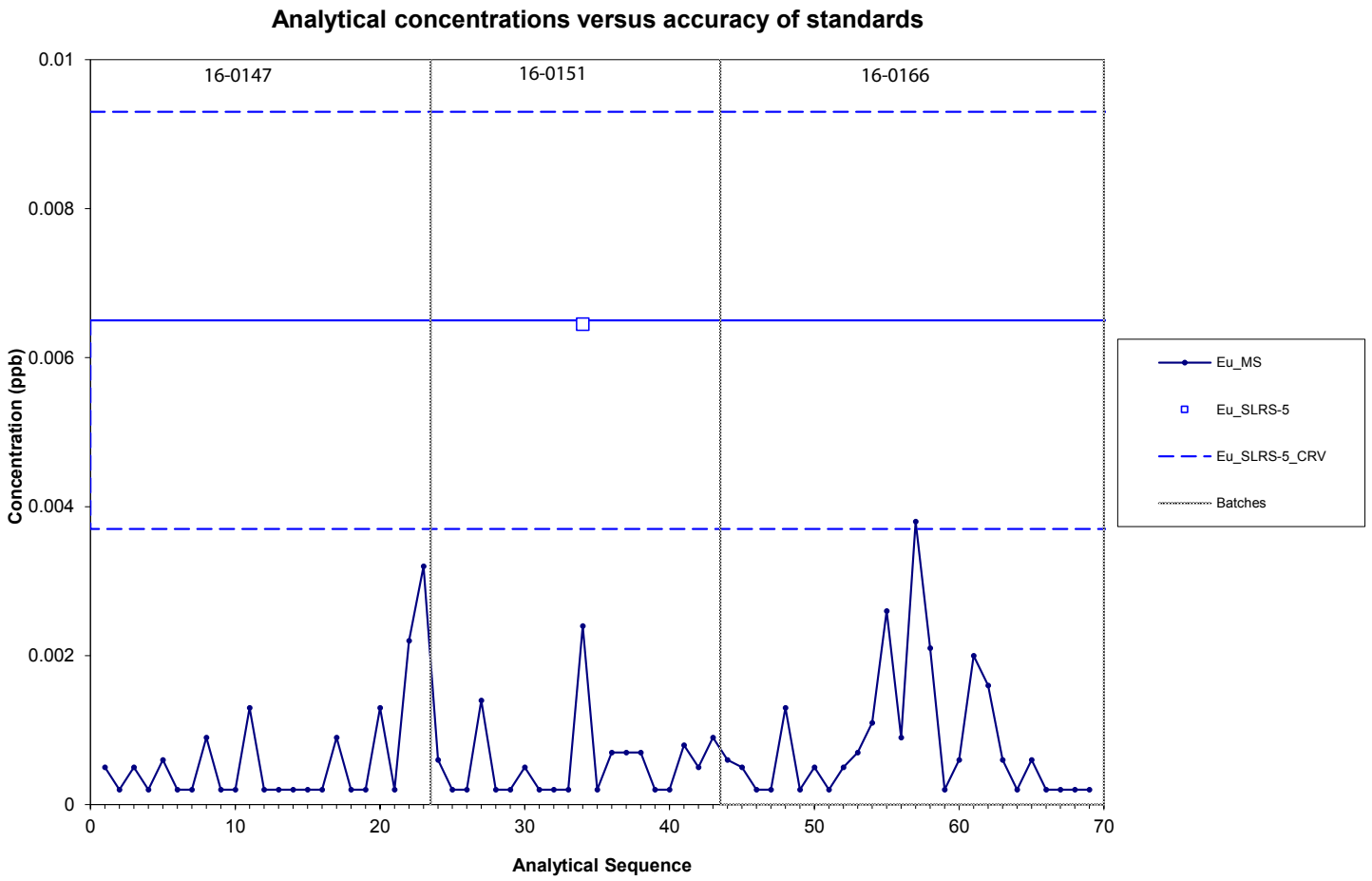
Quality-control plots: Europium (Eu) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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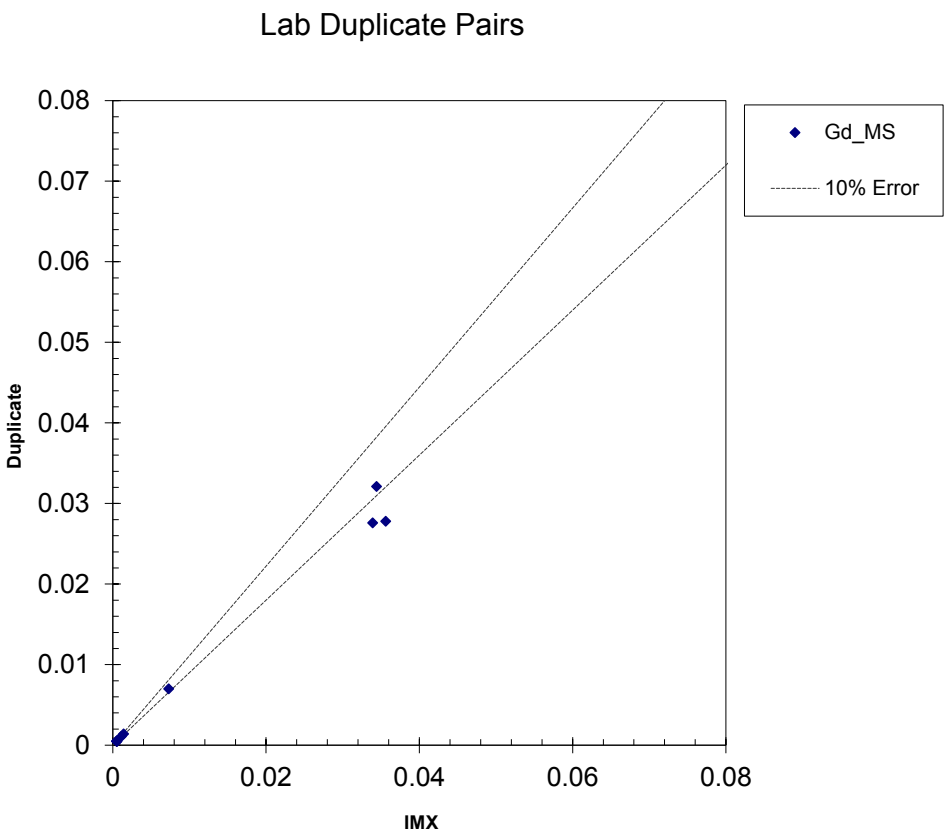
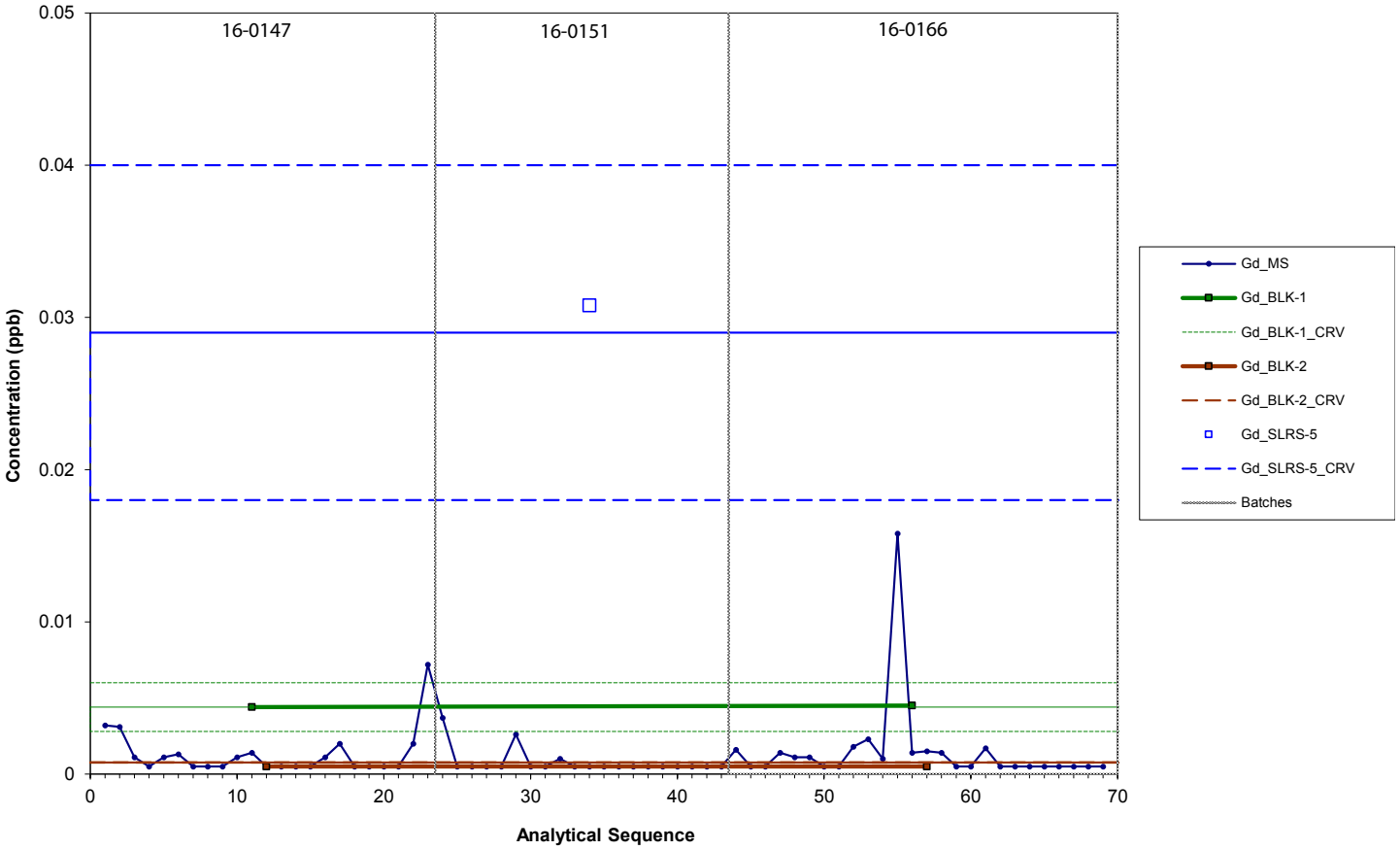
Quality-control plots: Gadolinium (Gd) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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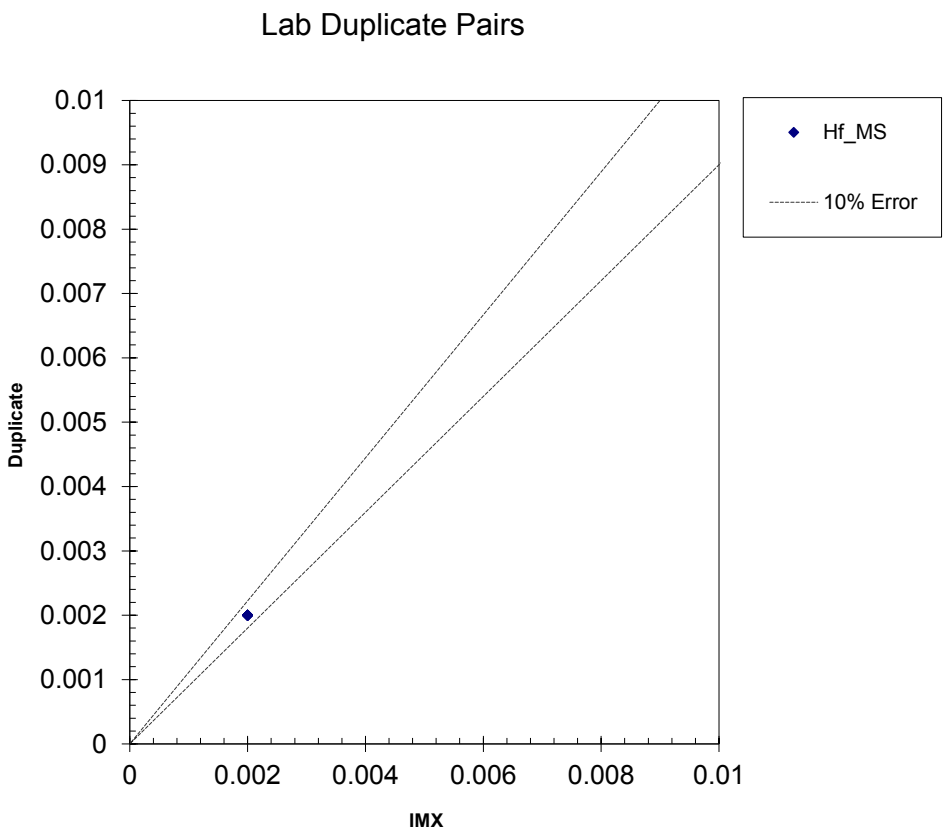
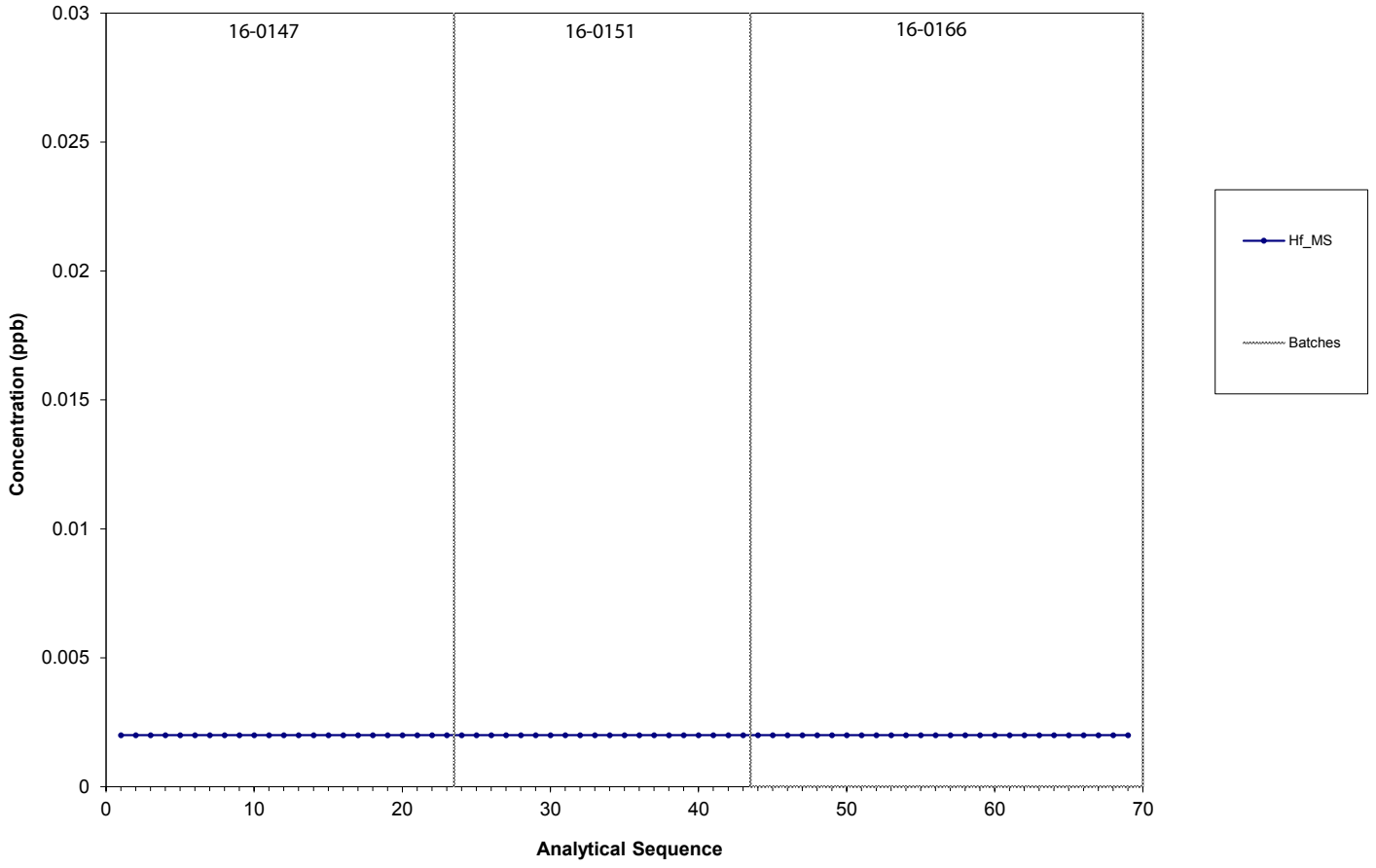
Quality-control plots: Hafnium (Hf) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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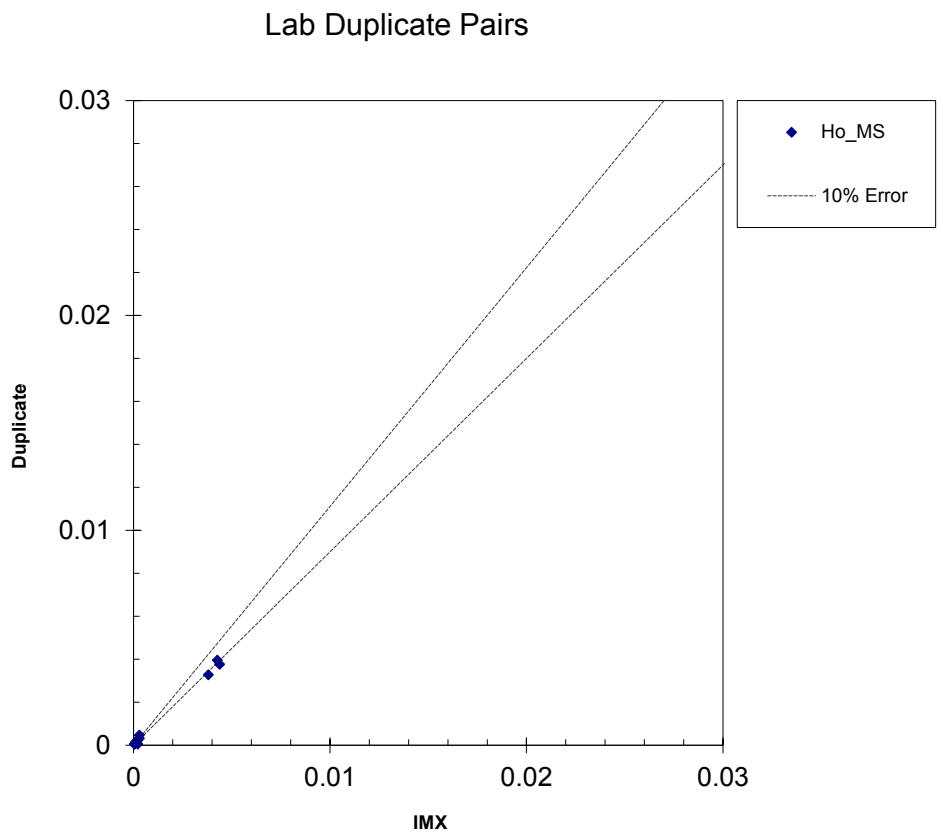
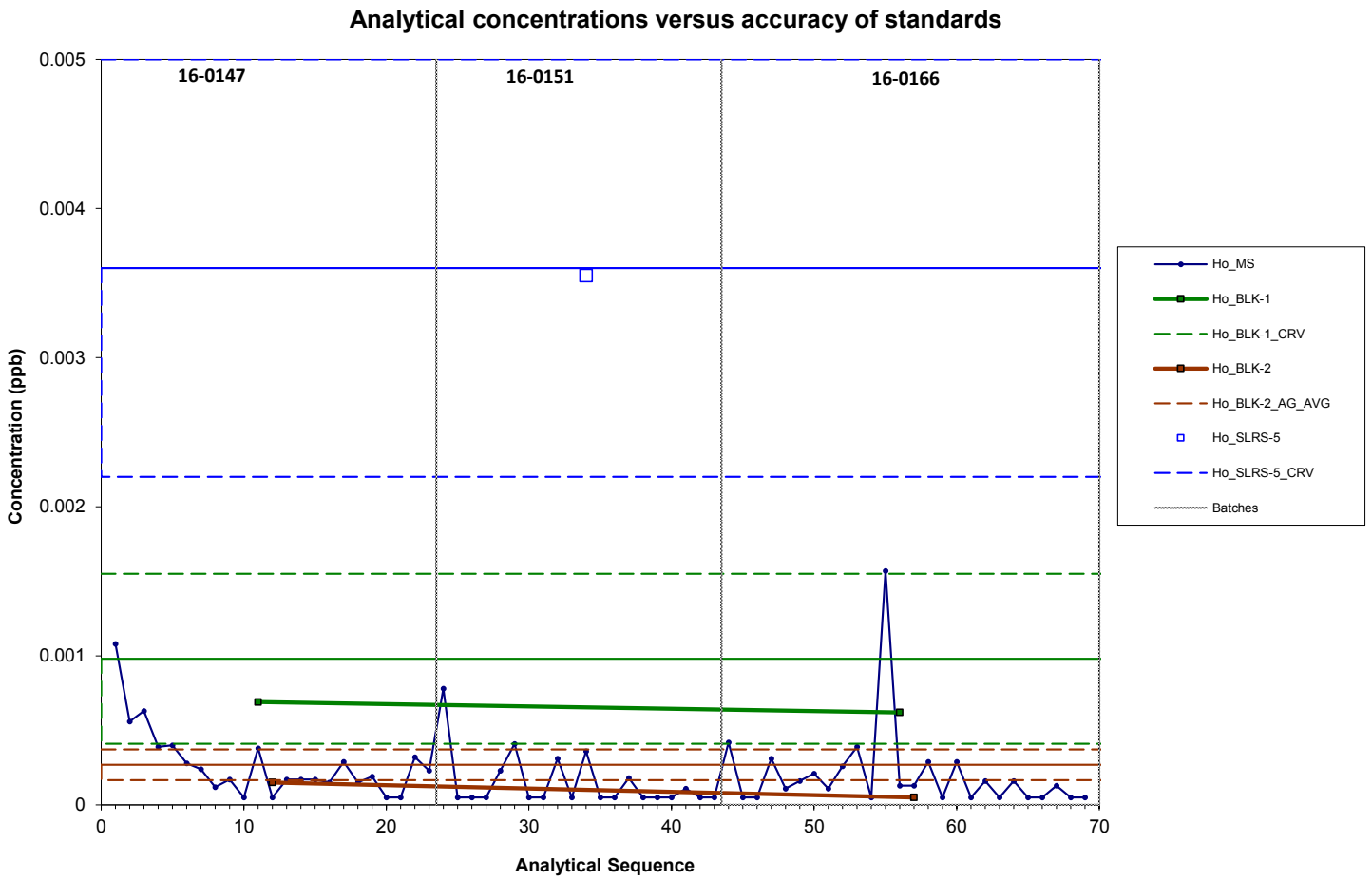
Quality-control plots: Holmium (Ho) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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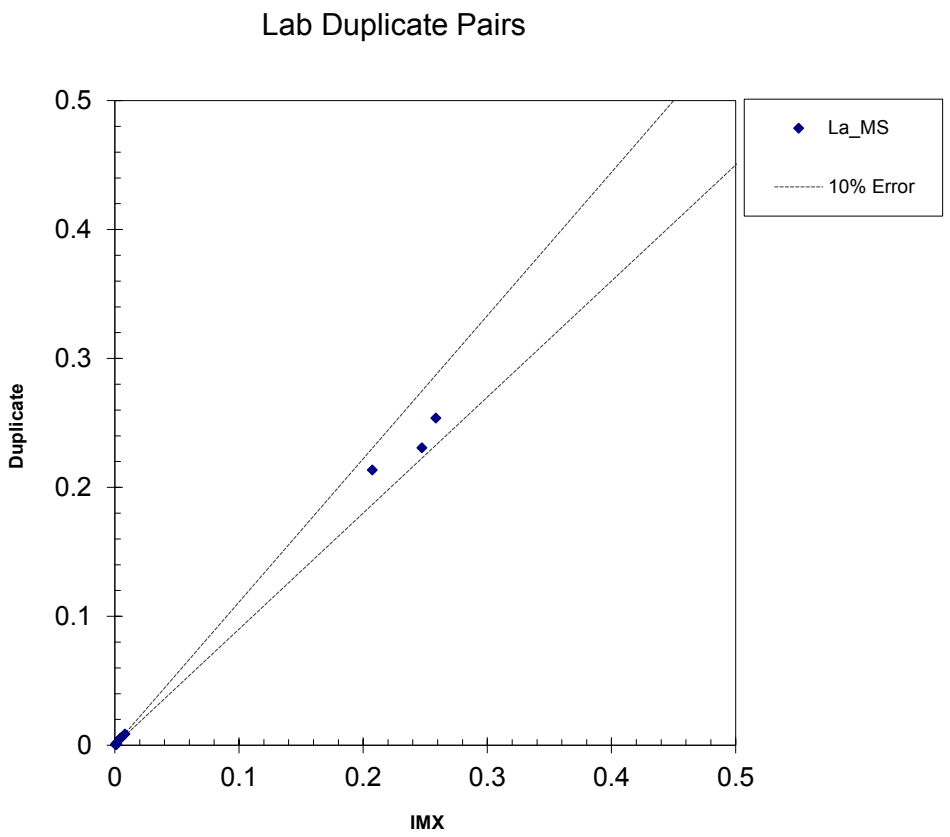
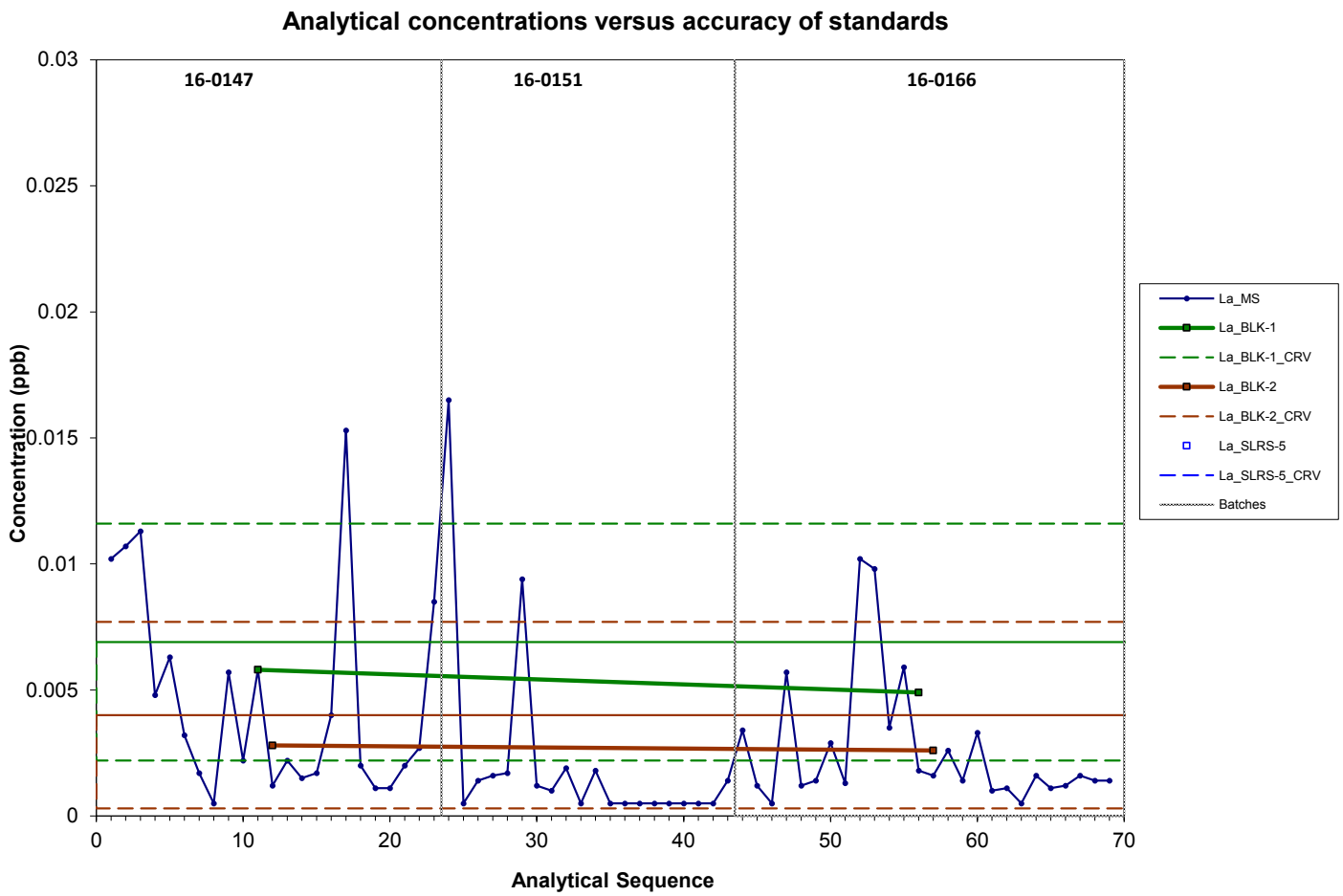
Quality-control plots: Lanthanum (La) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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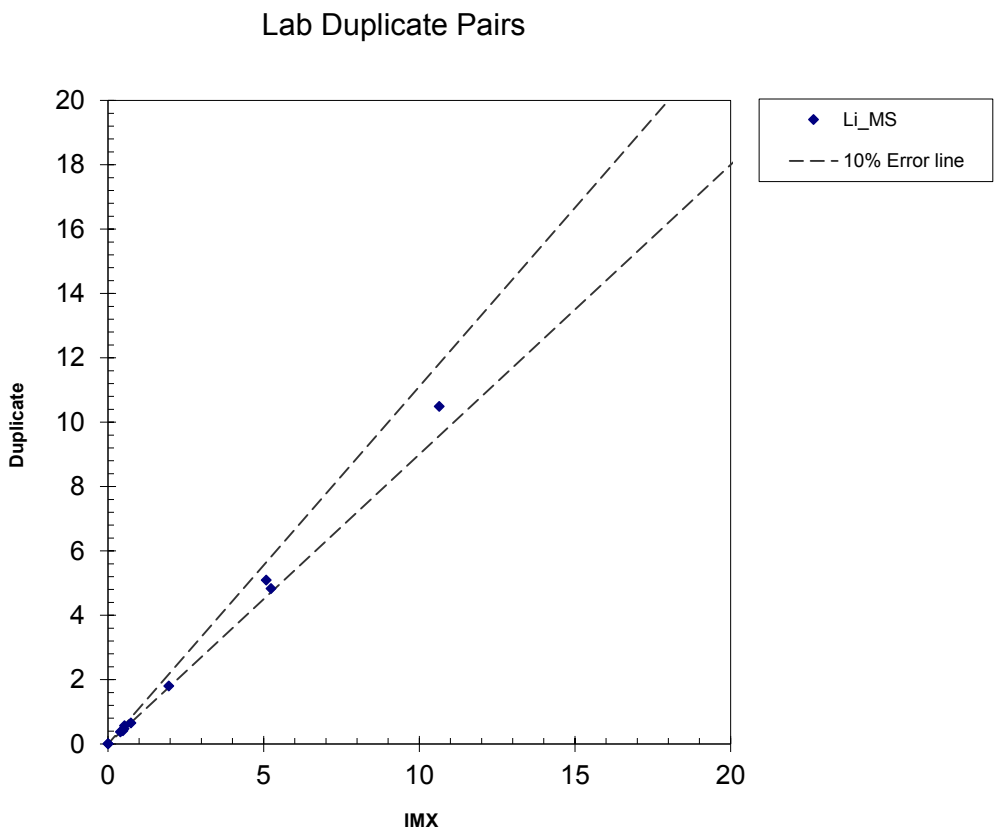
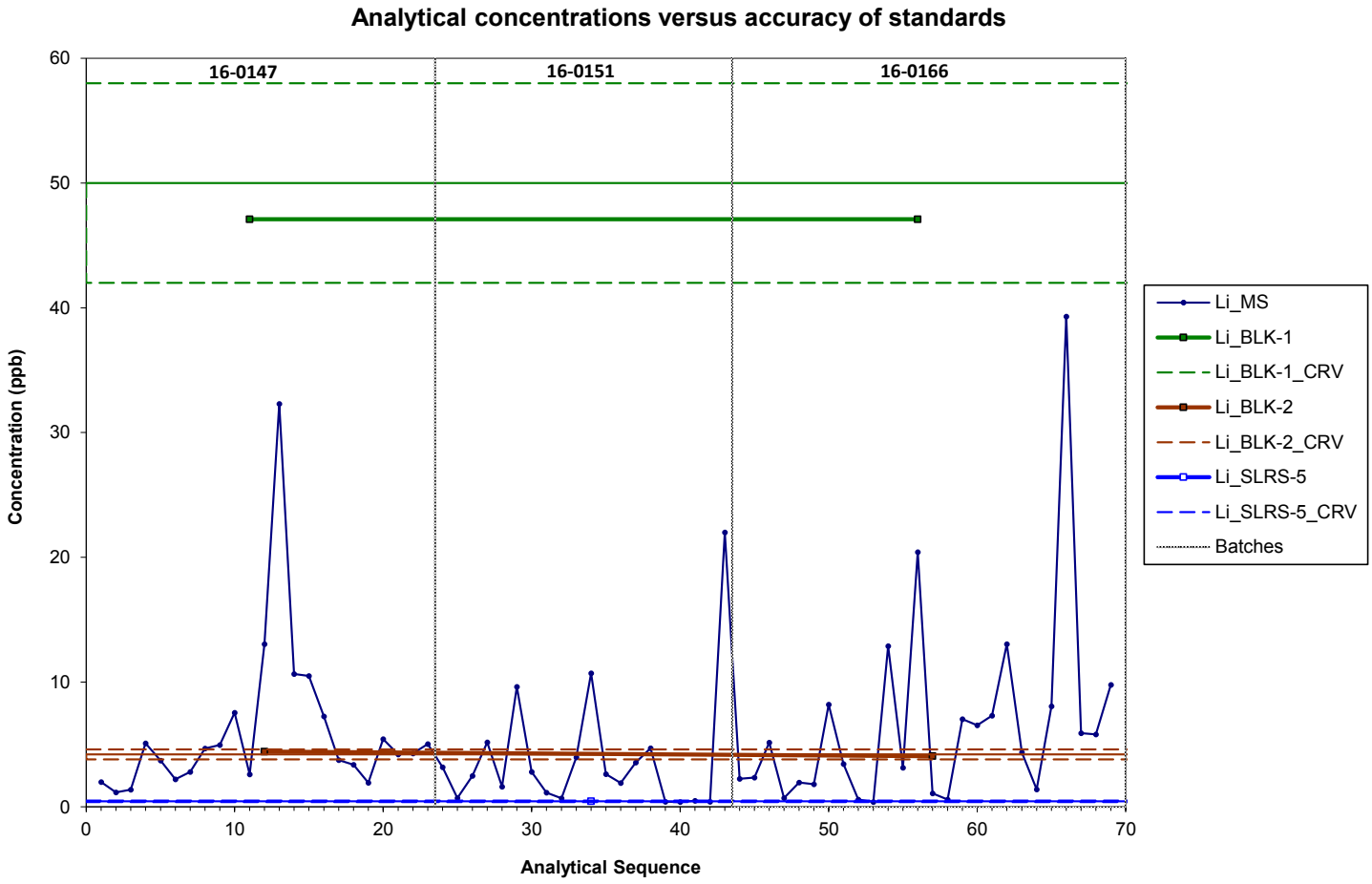
Quality-control plots: Lithium (Li) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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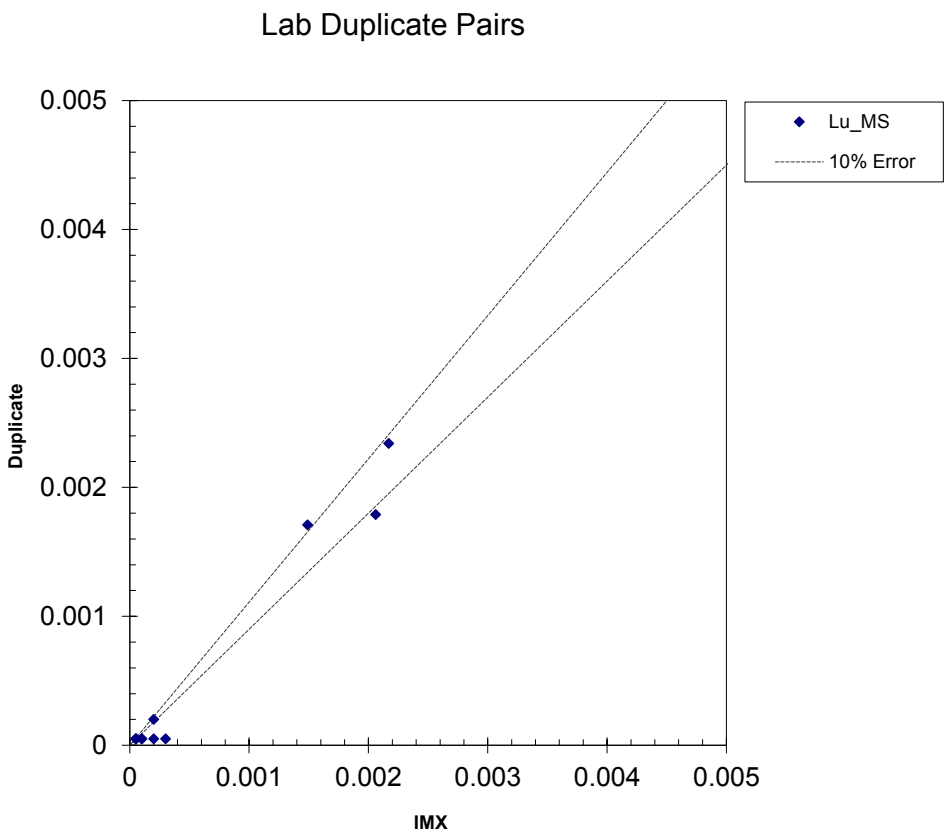
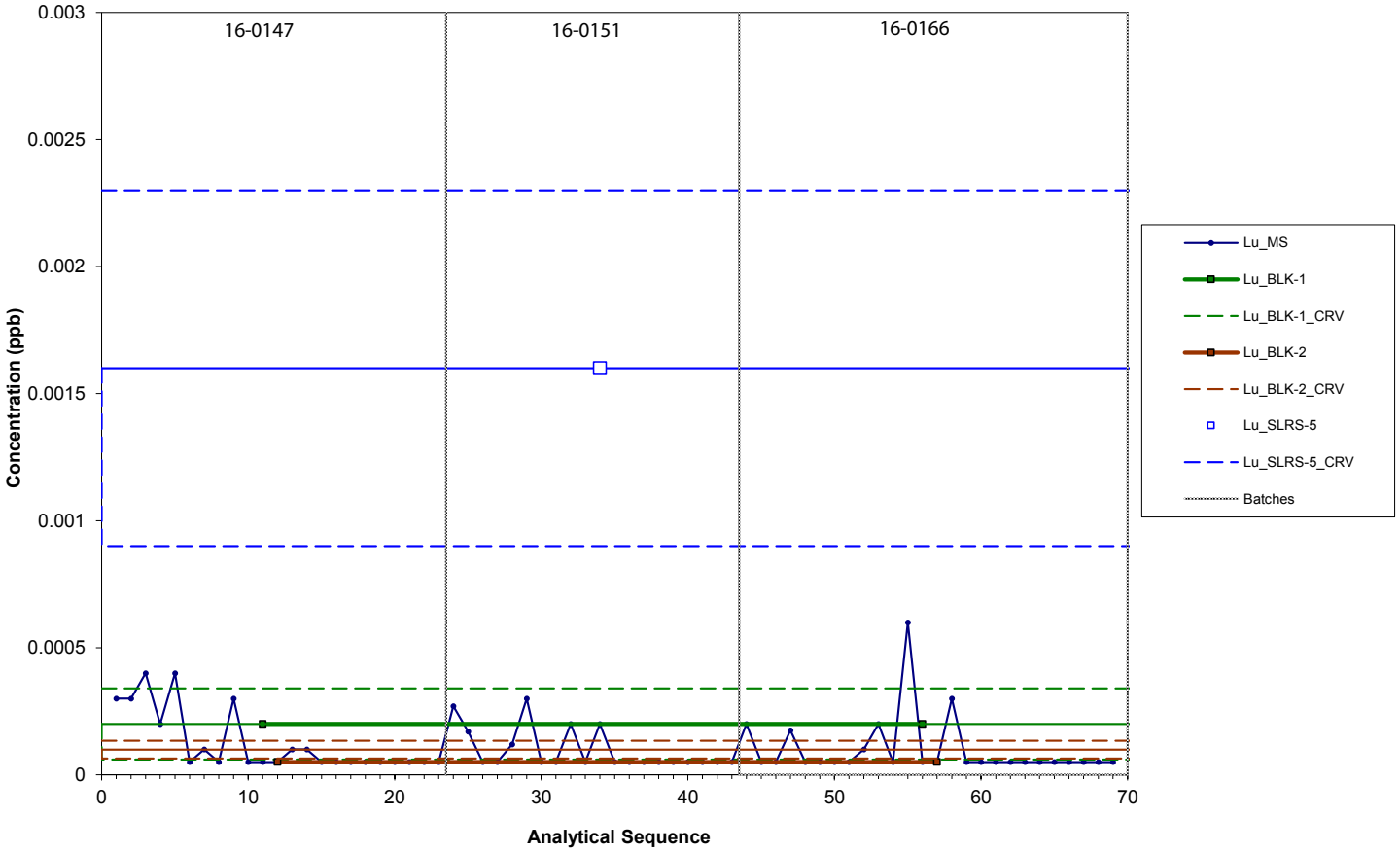
Quality-control plots: Lutetium (Lu) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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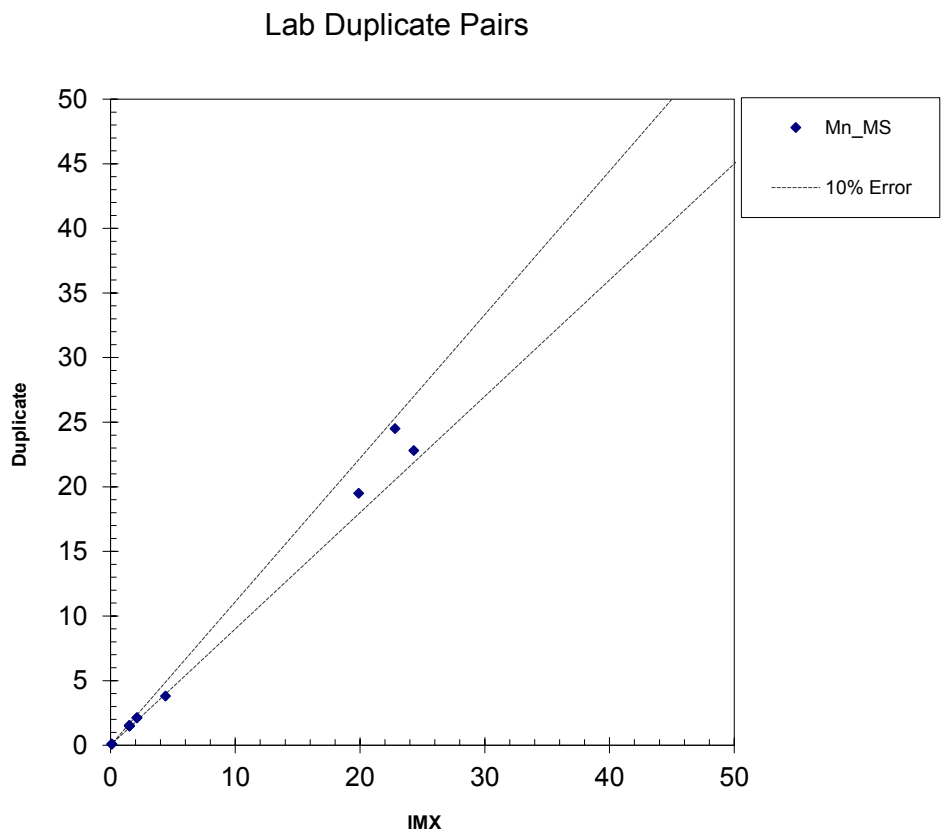
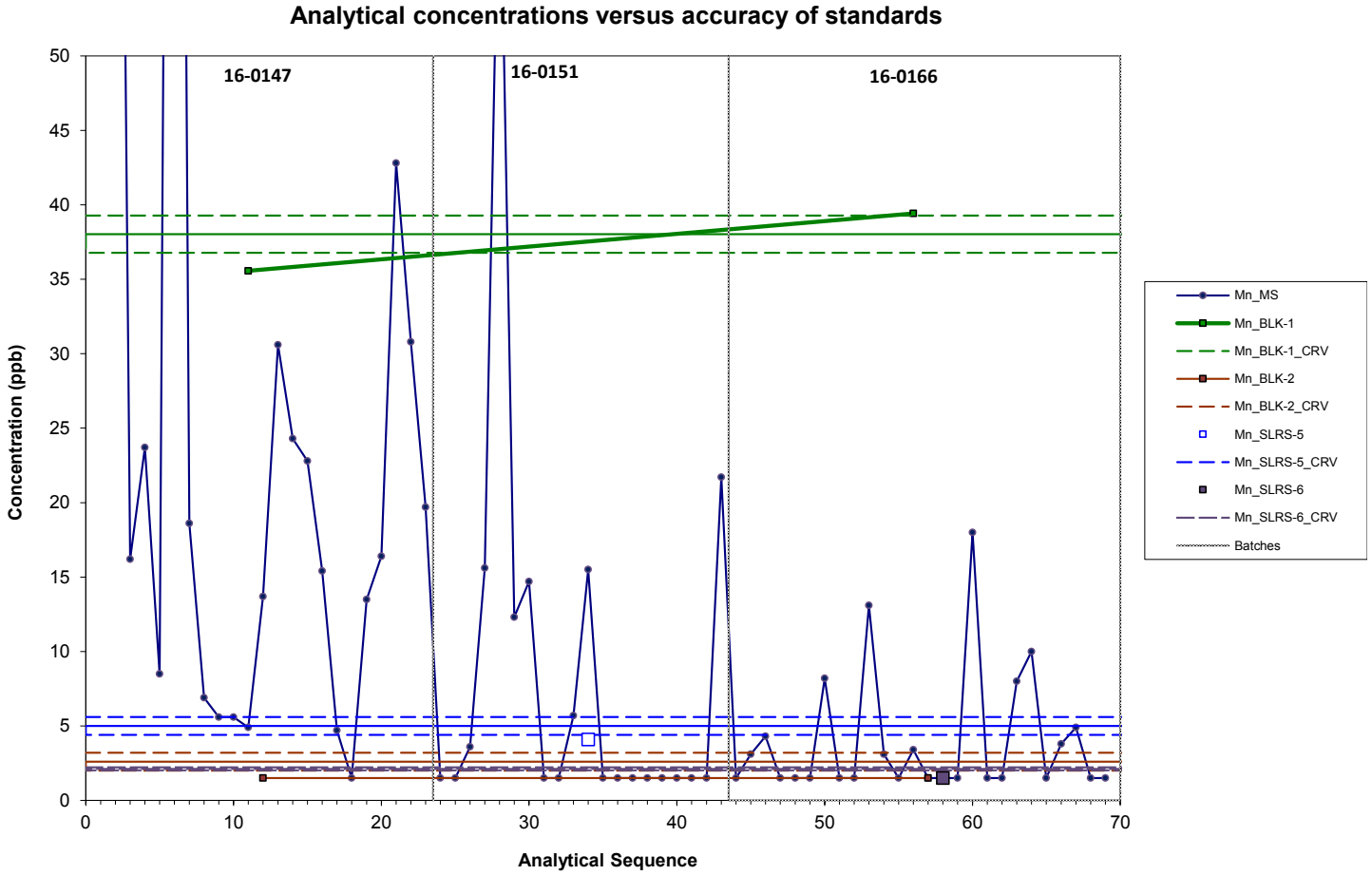
Quality-control plots: Manganese (Mn) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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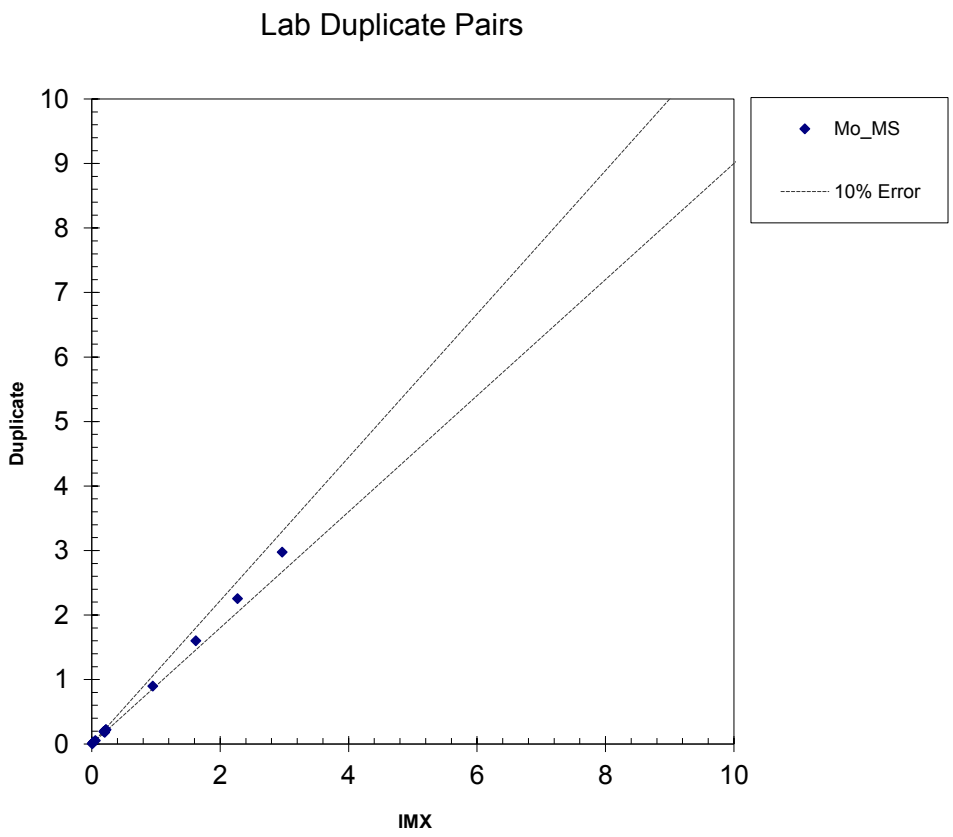
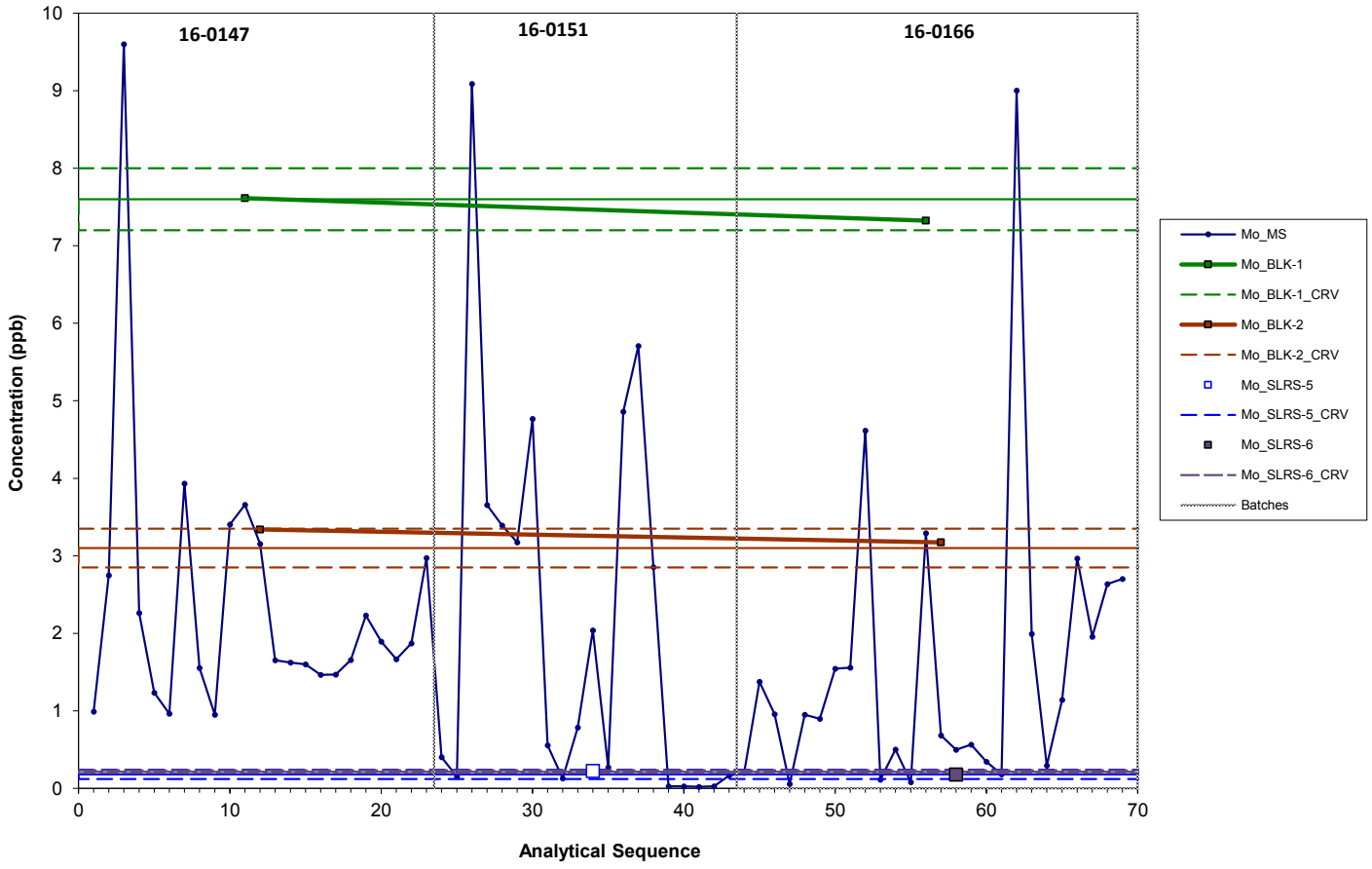
Quality-control plots: Molybdenum (Mo) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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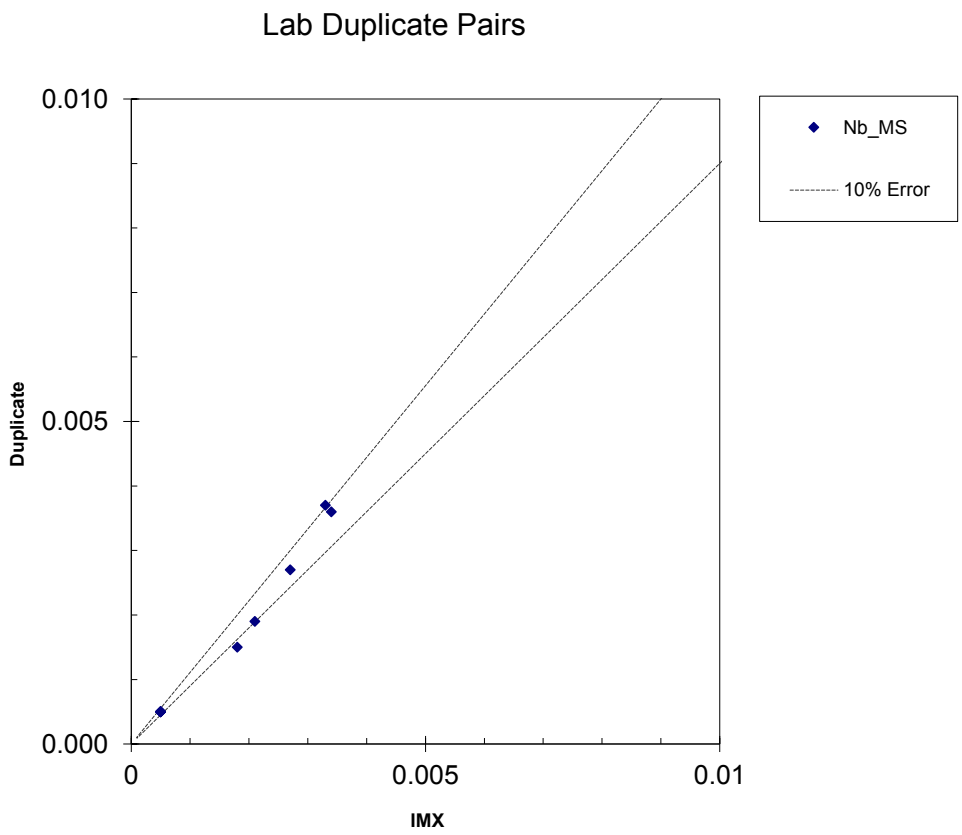
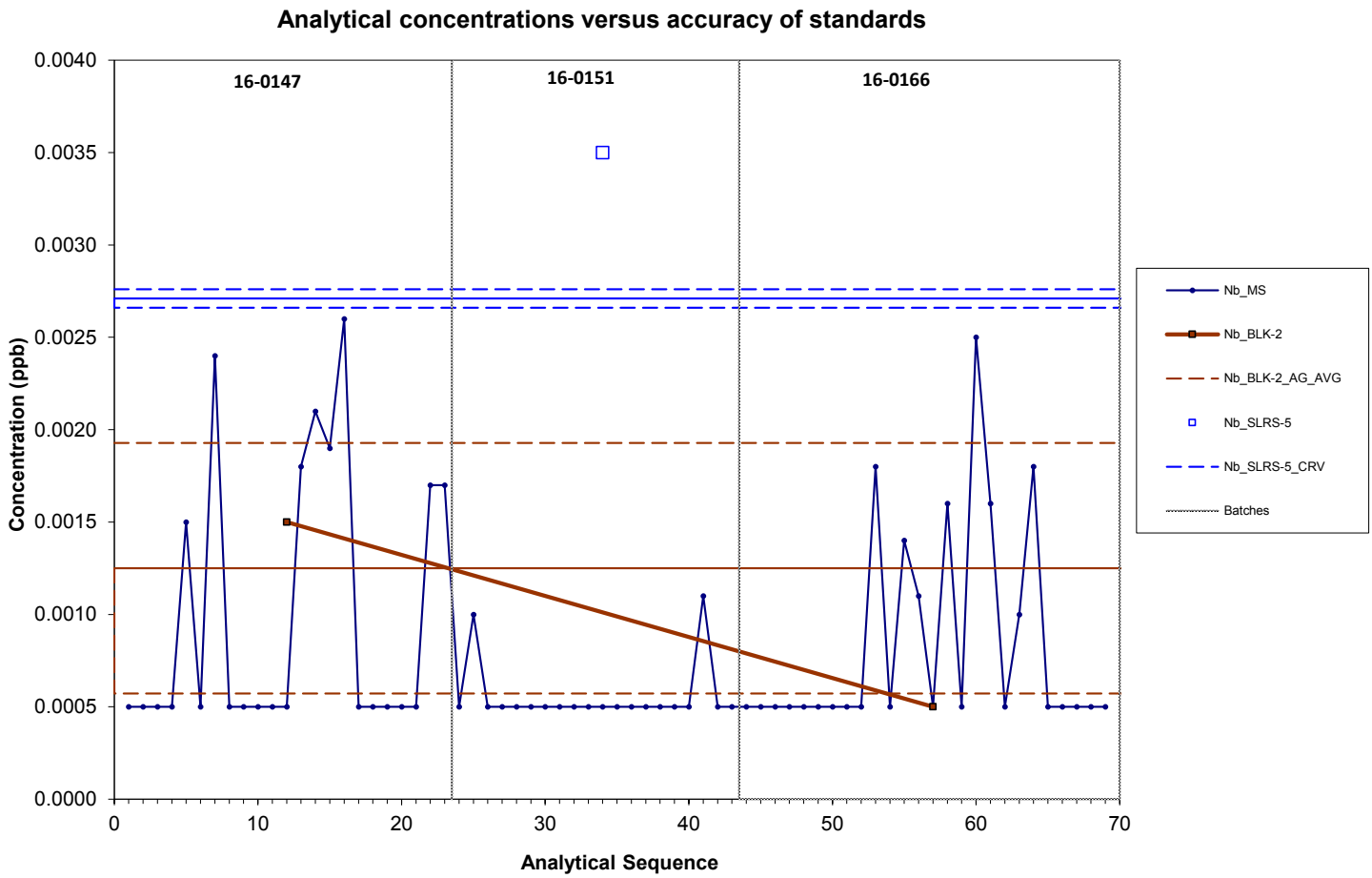
Quality-control plots: Niobium (Nb) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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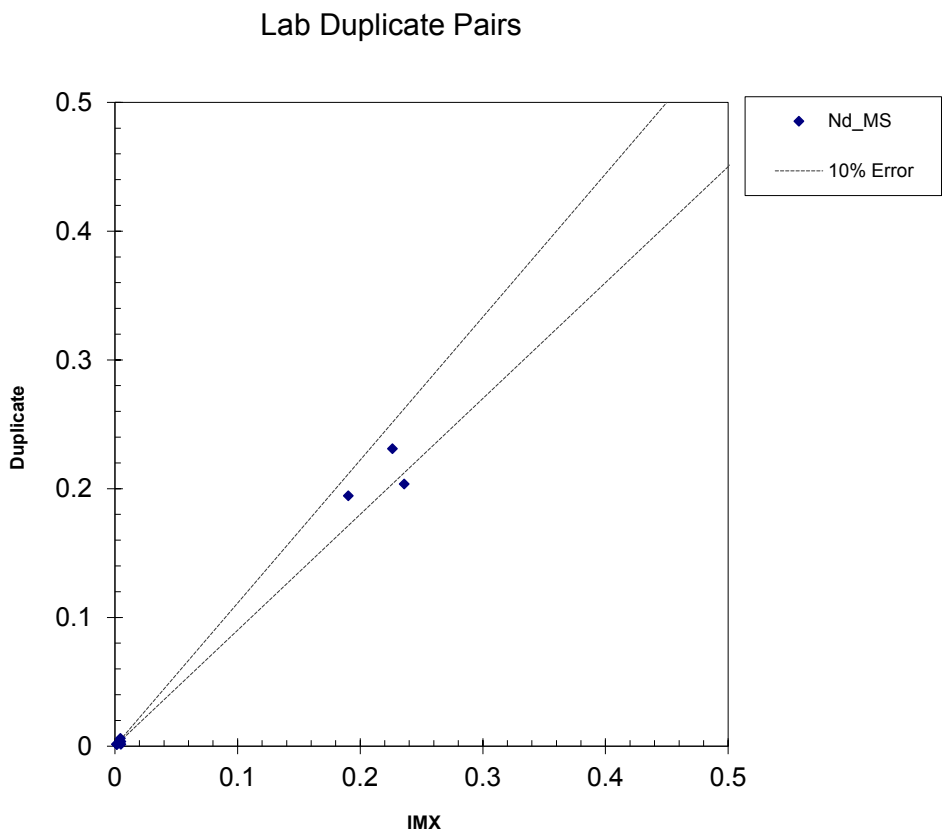
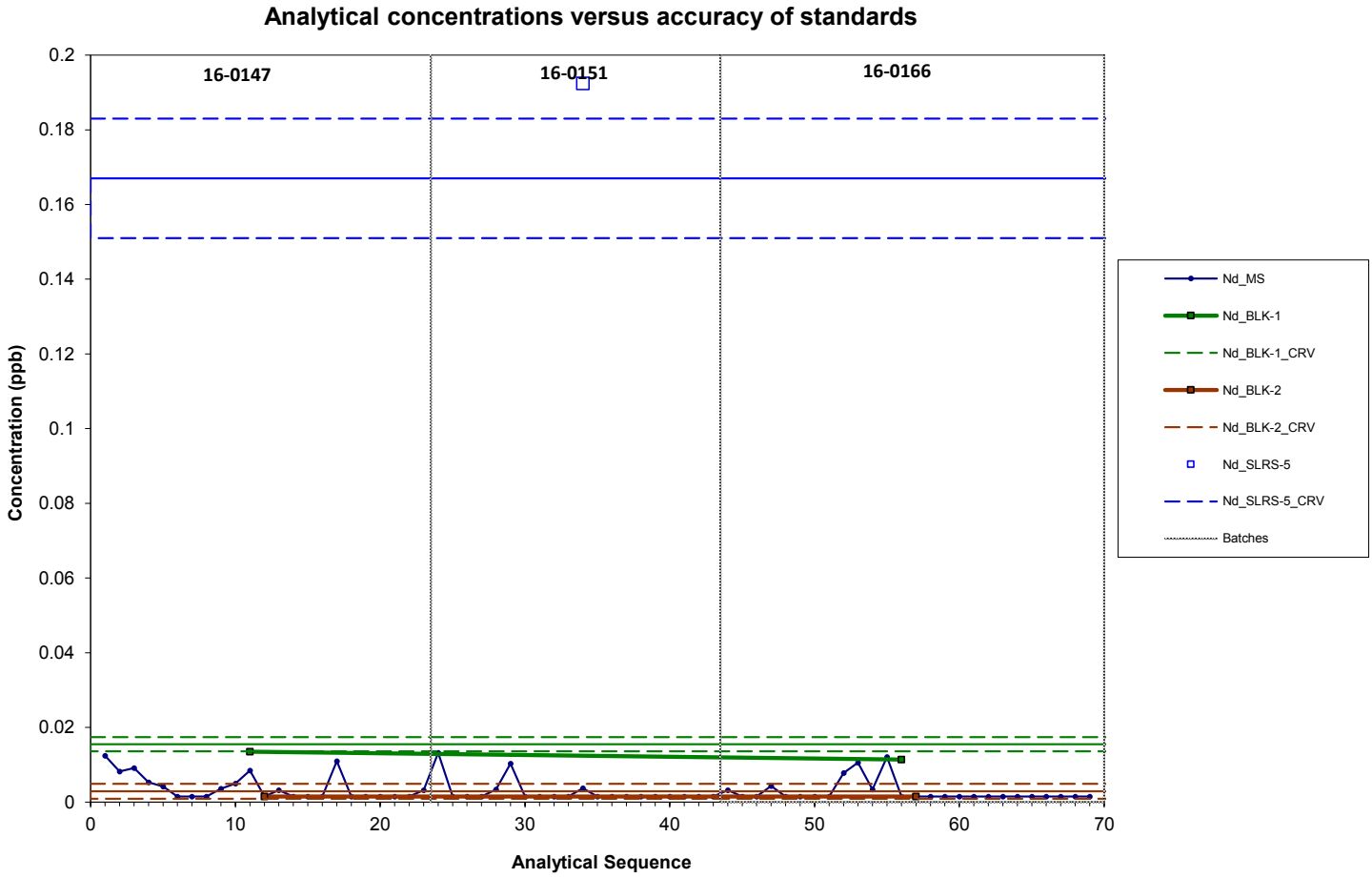
Quality-control plots: Neodymium (Nd) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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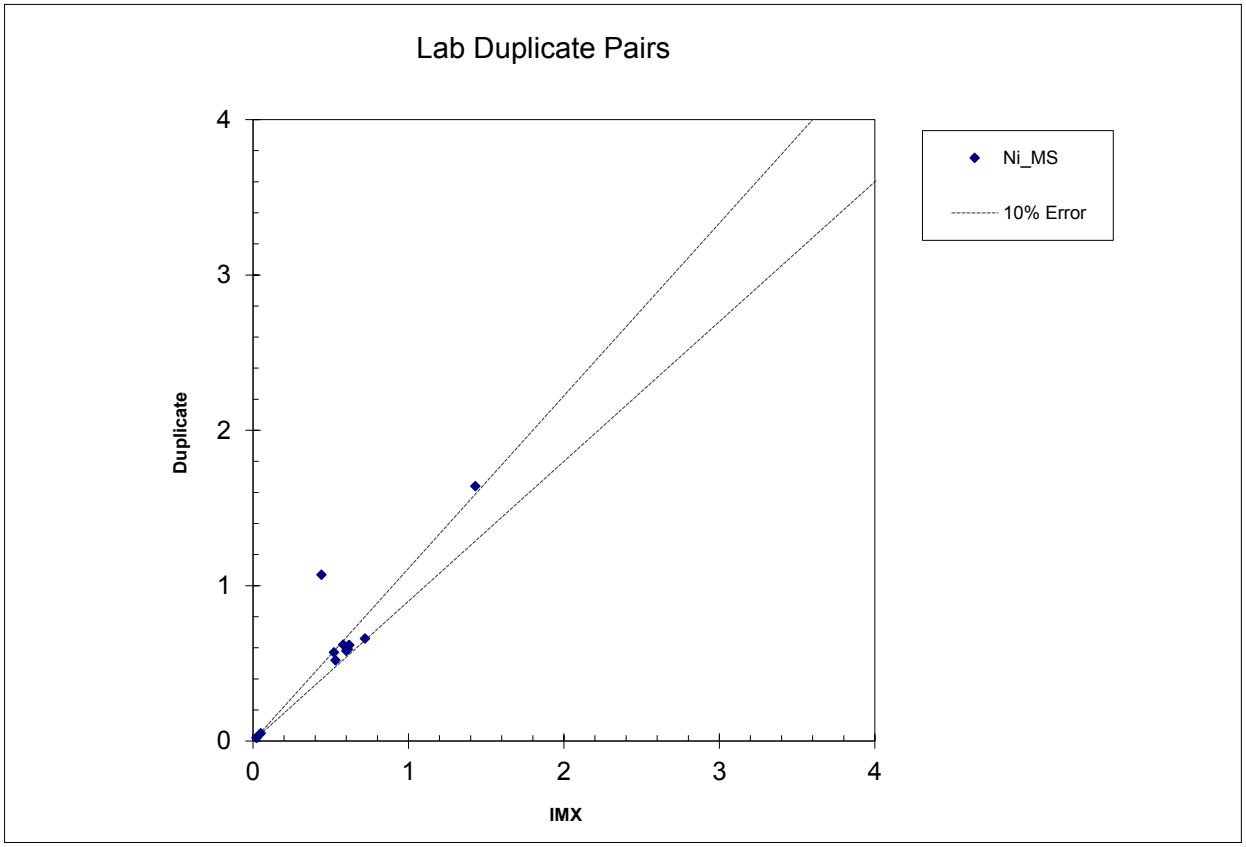
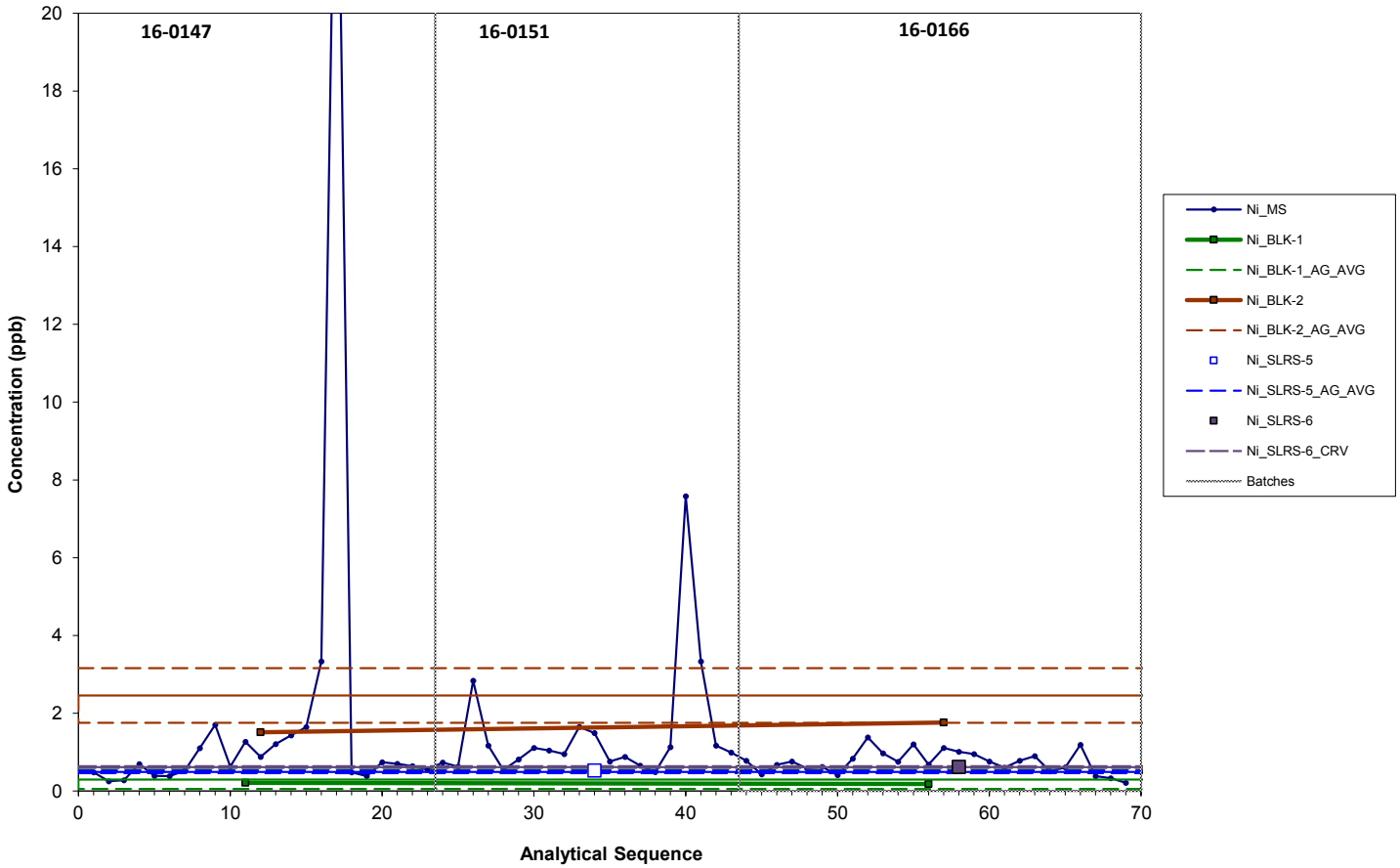
Quality-control plots: Nickel (Ni) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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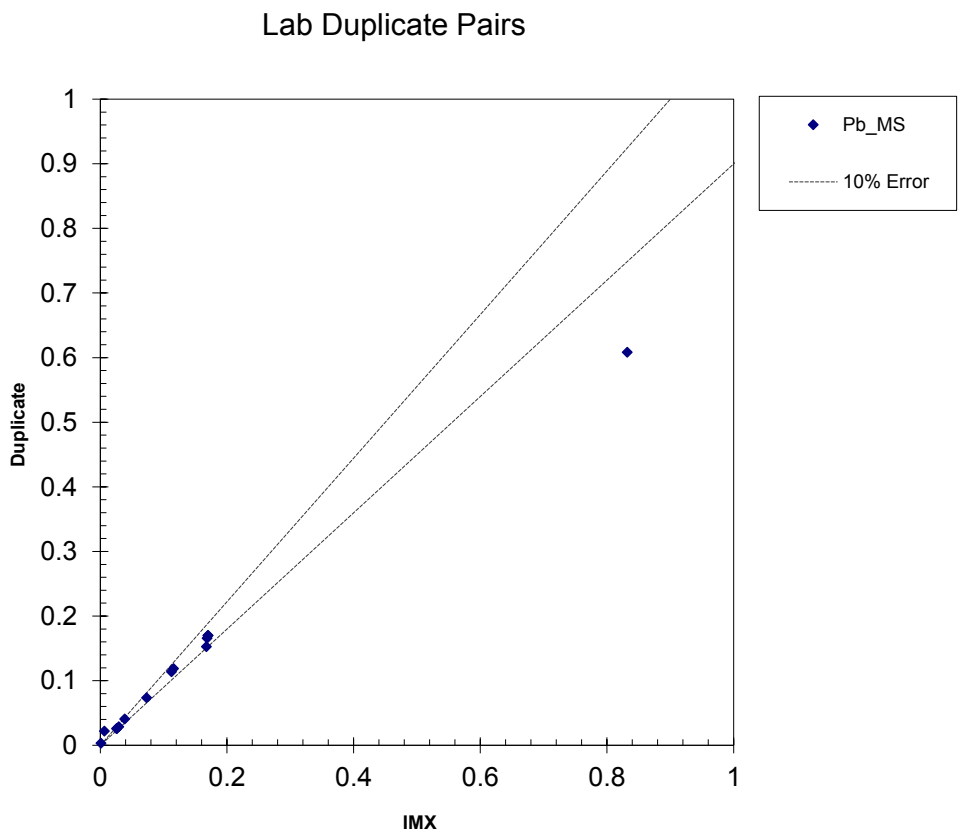
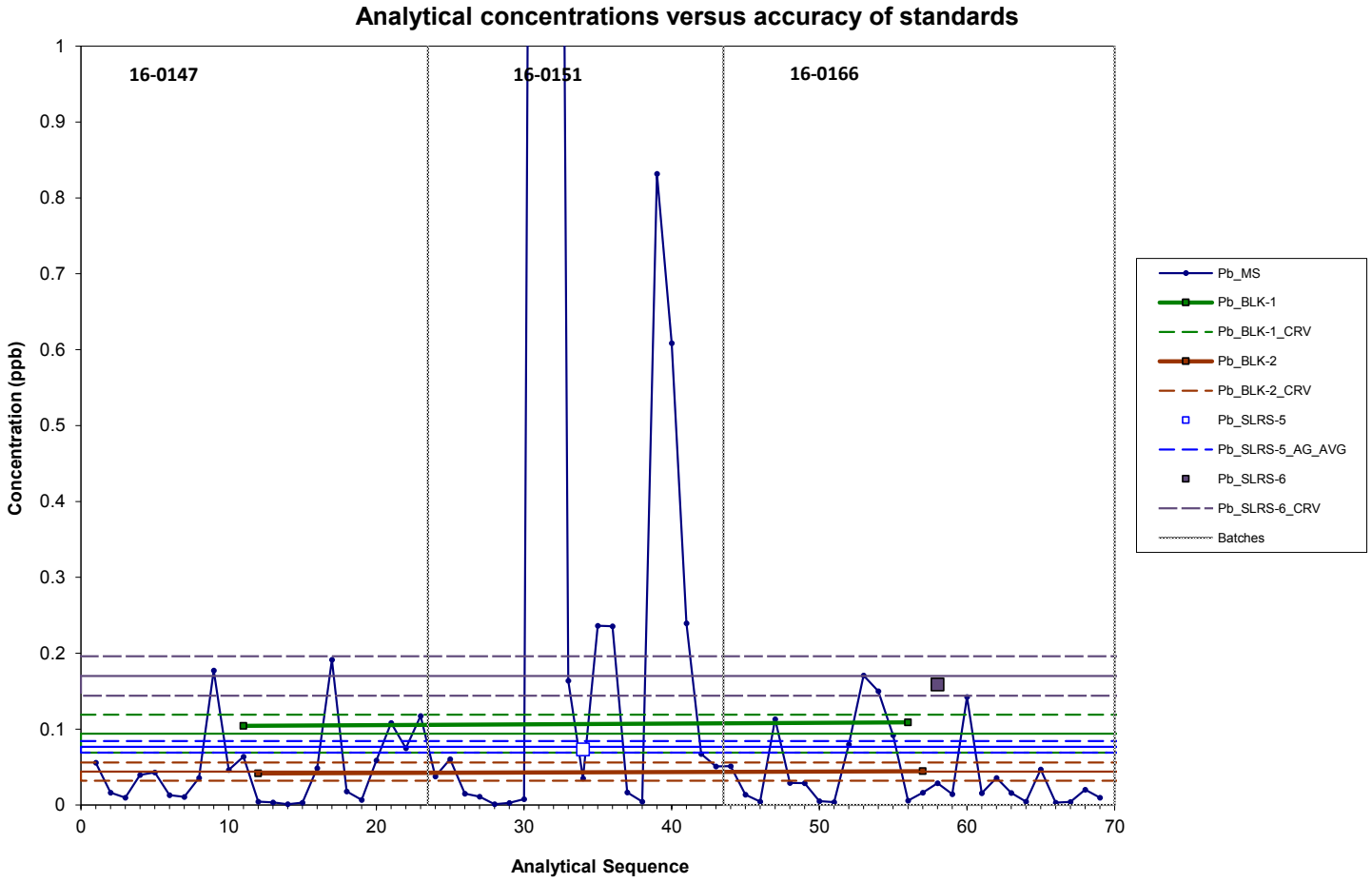
Quality-control plots: Lead (Pb) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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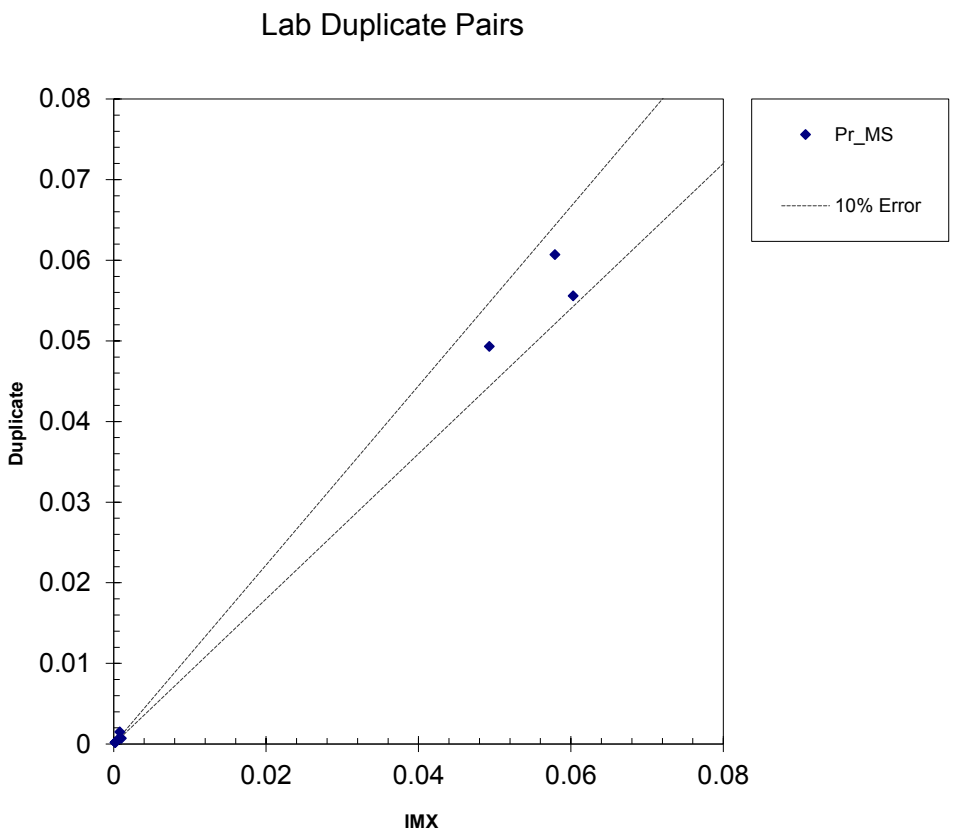
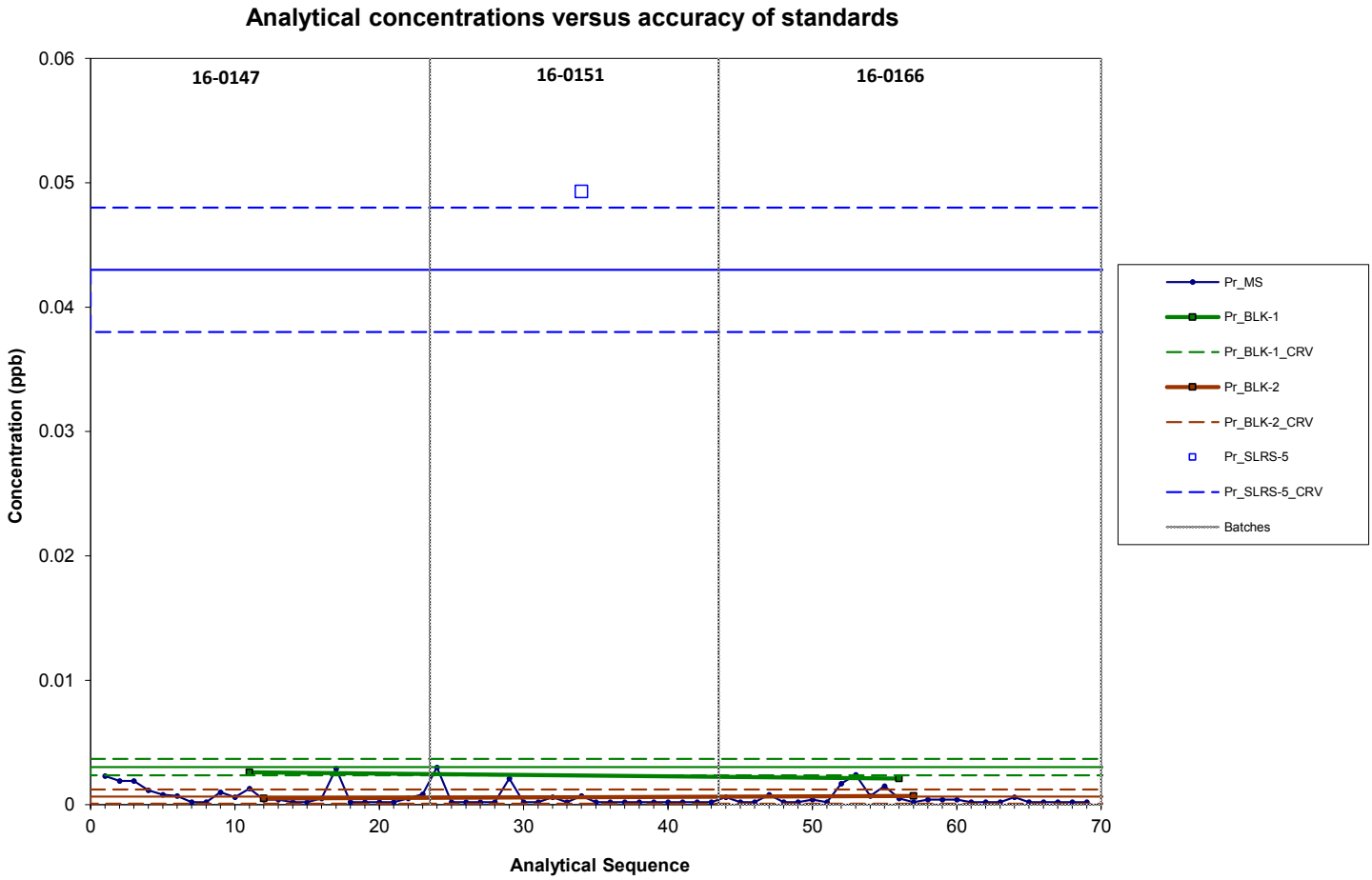
Quality-control plots: Praseodymium (Pr) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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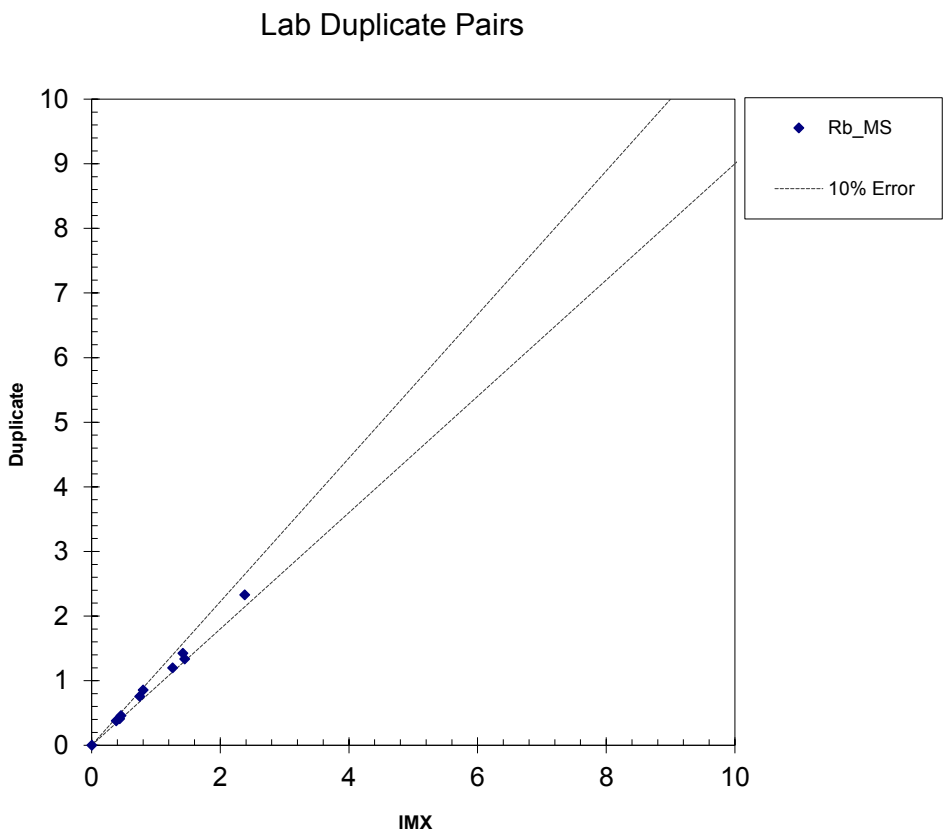
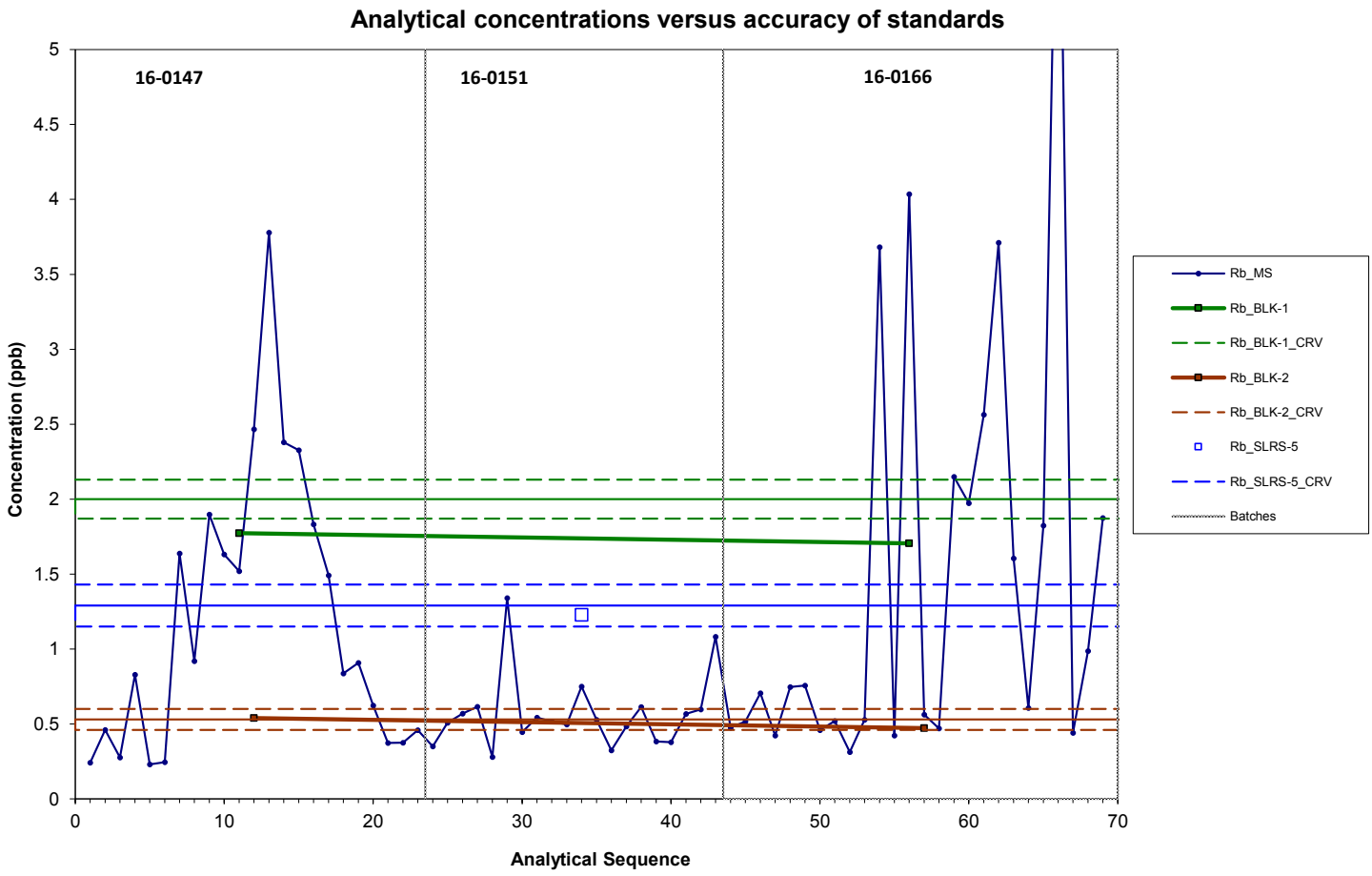
Quality-control plots: Rubidium (Rb) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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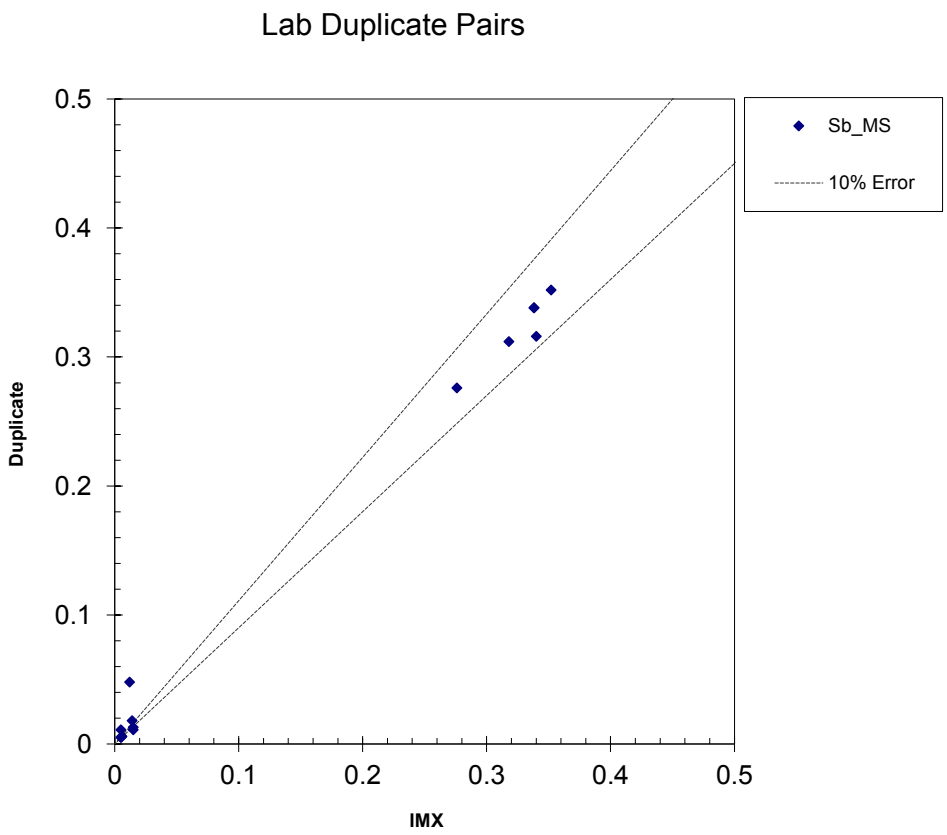
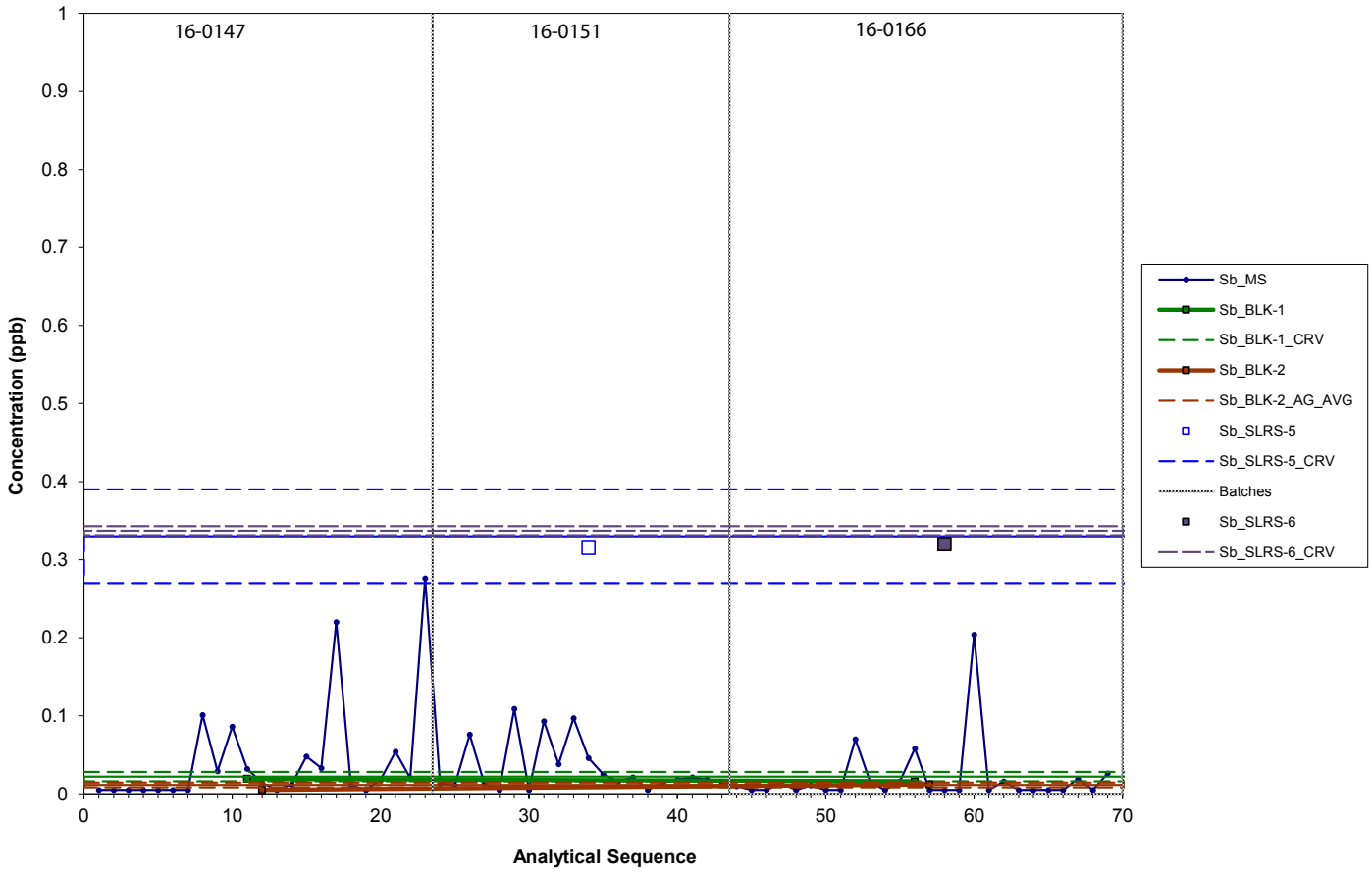
Quality-control plots: Antimony (Sb) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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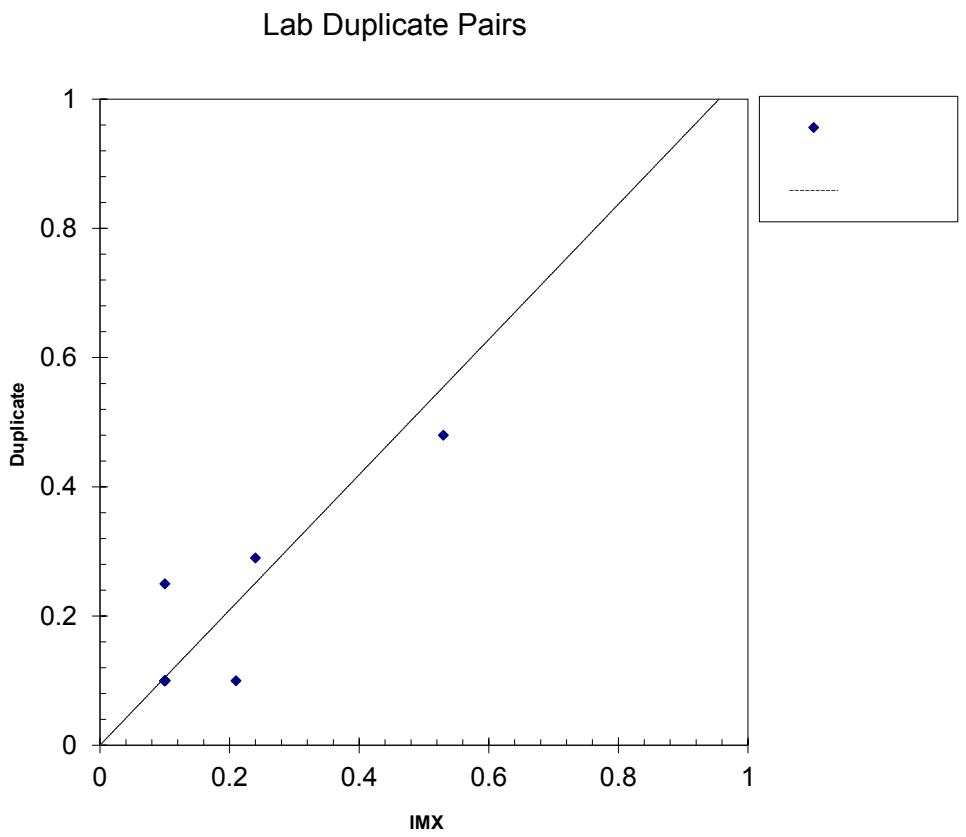
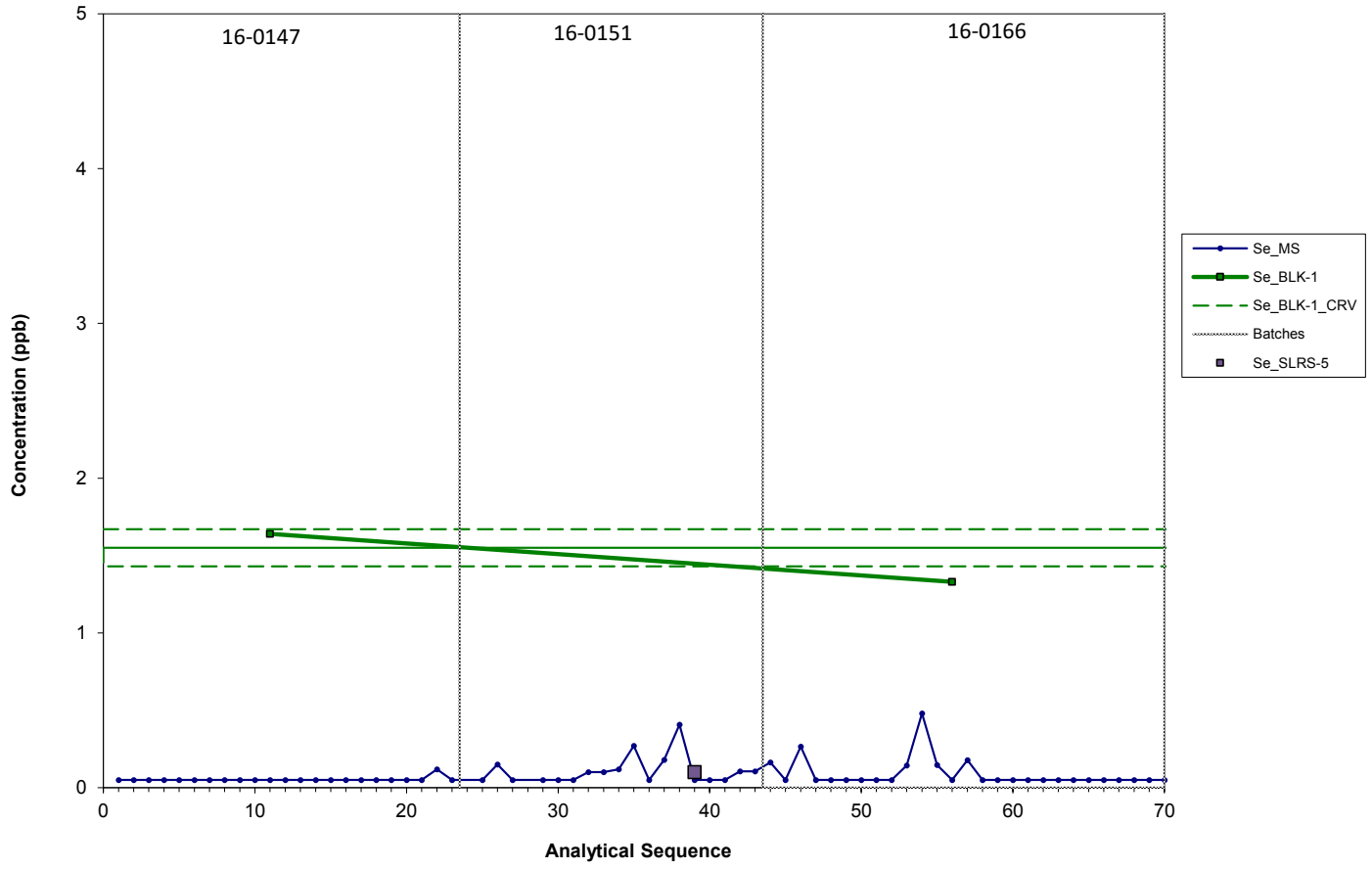
Quality-control plots: Selenium (Se) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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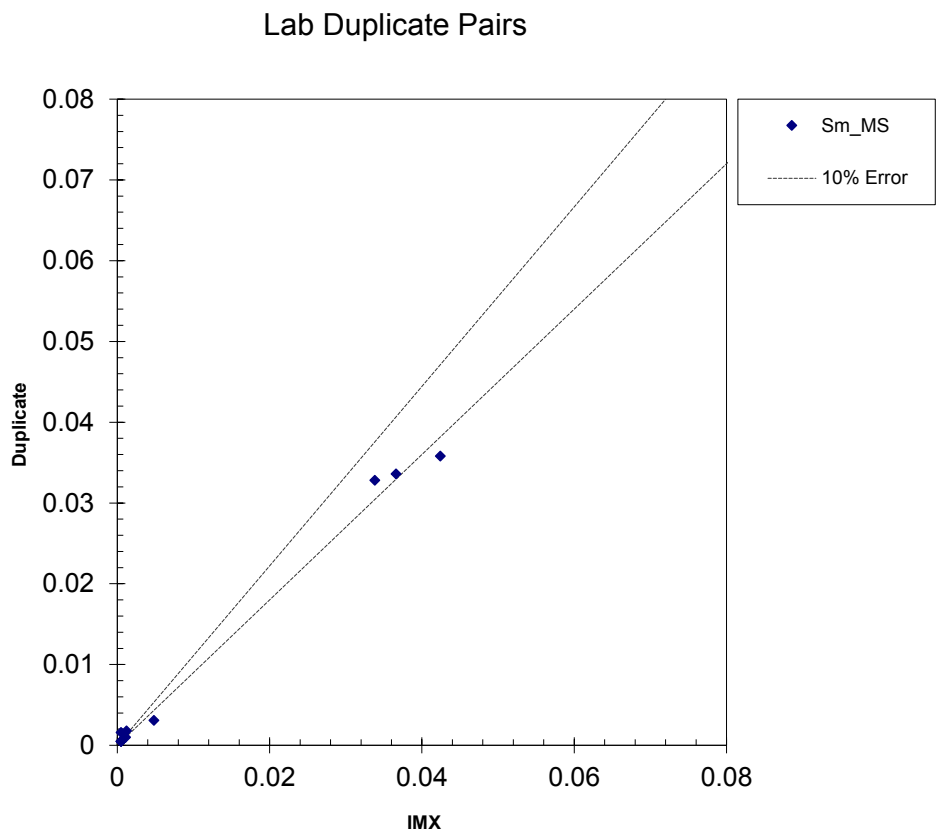
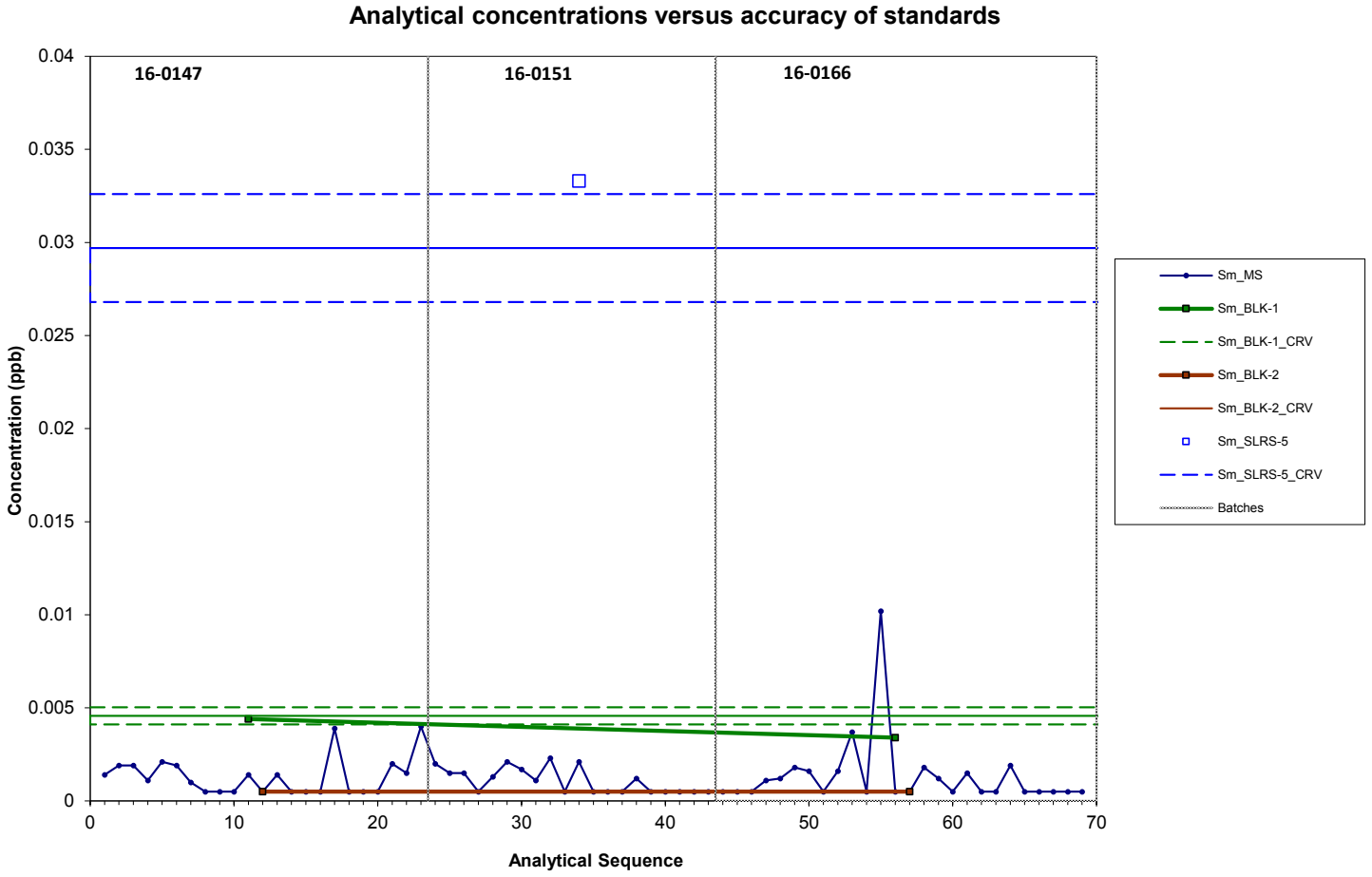
Quality-control plots: Samarium (Sm) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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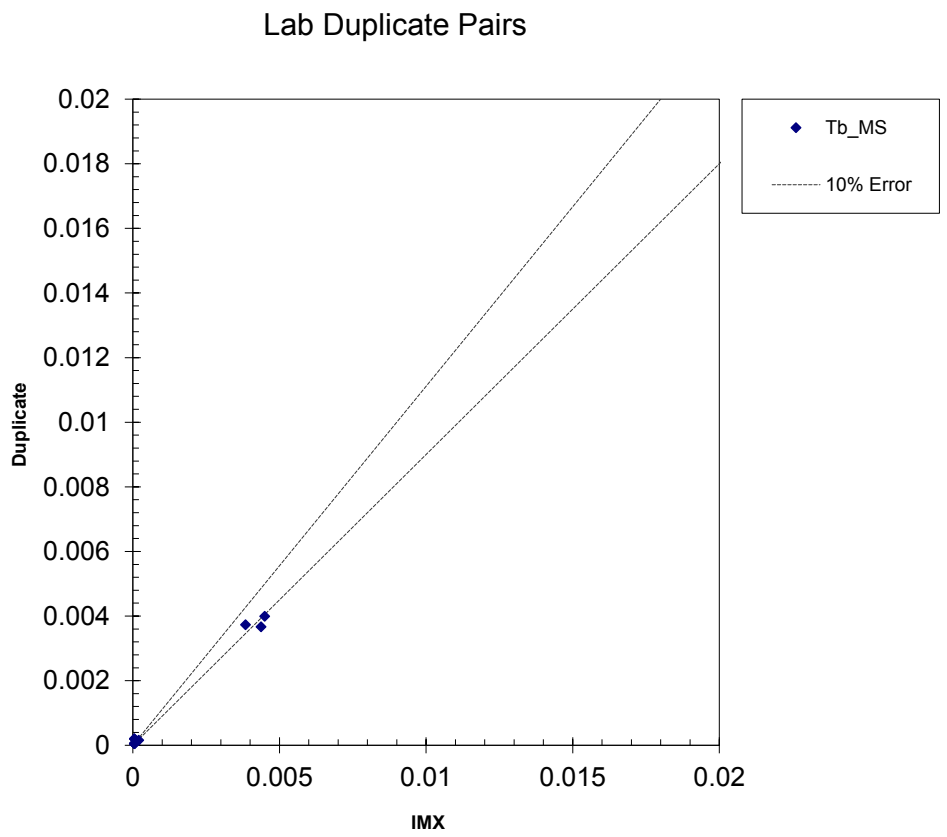
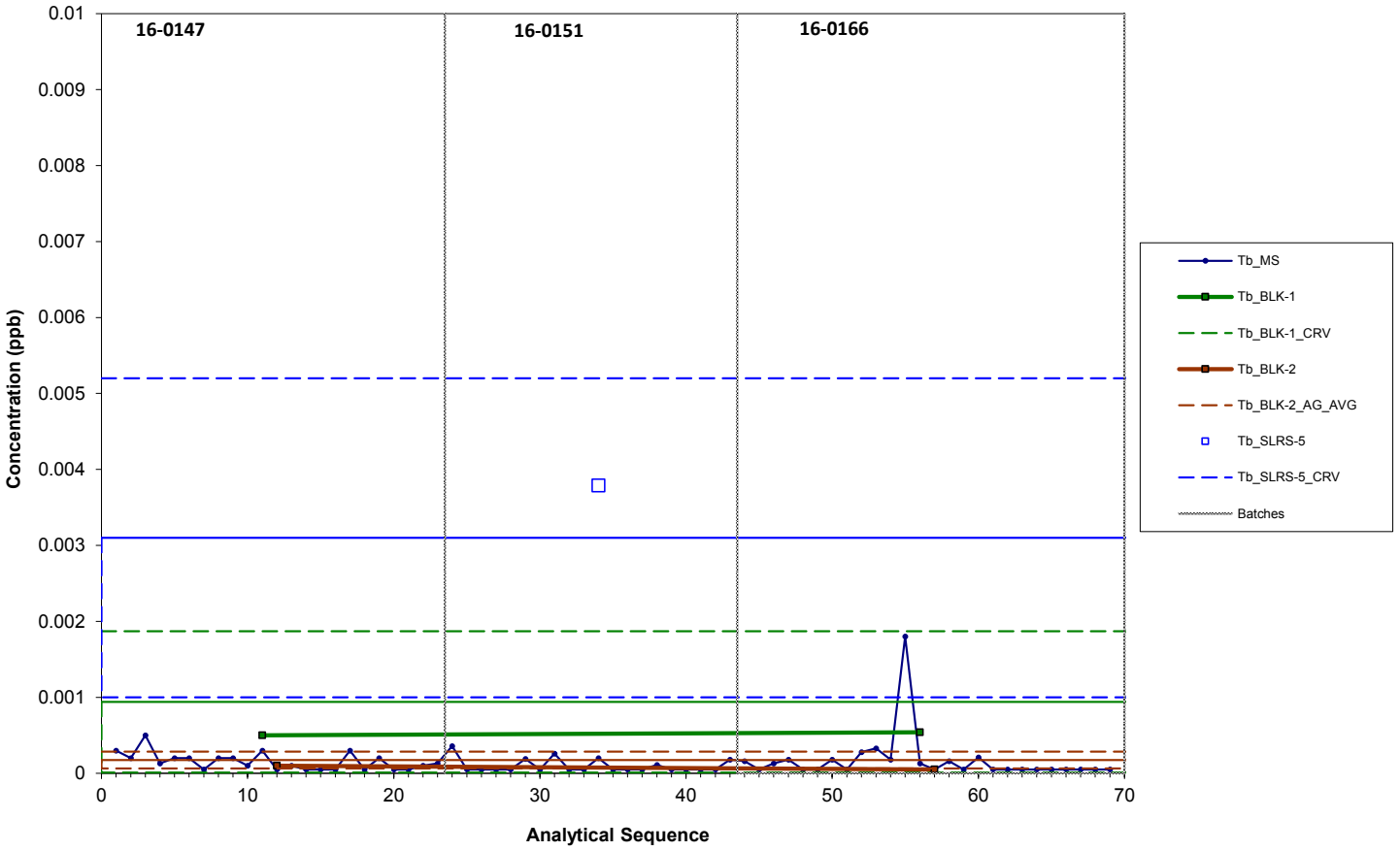
Quality-control plots: Terbium (Tb) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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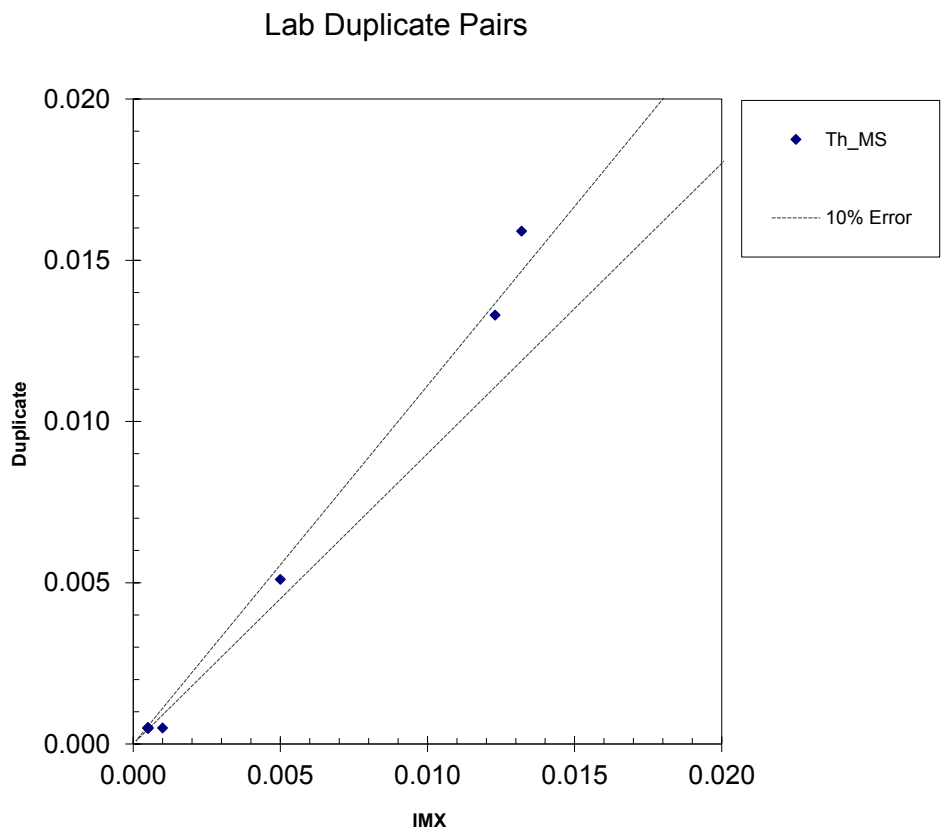
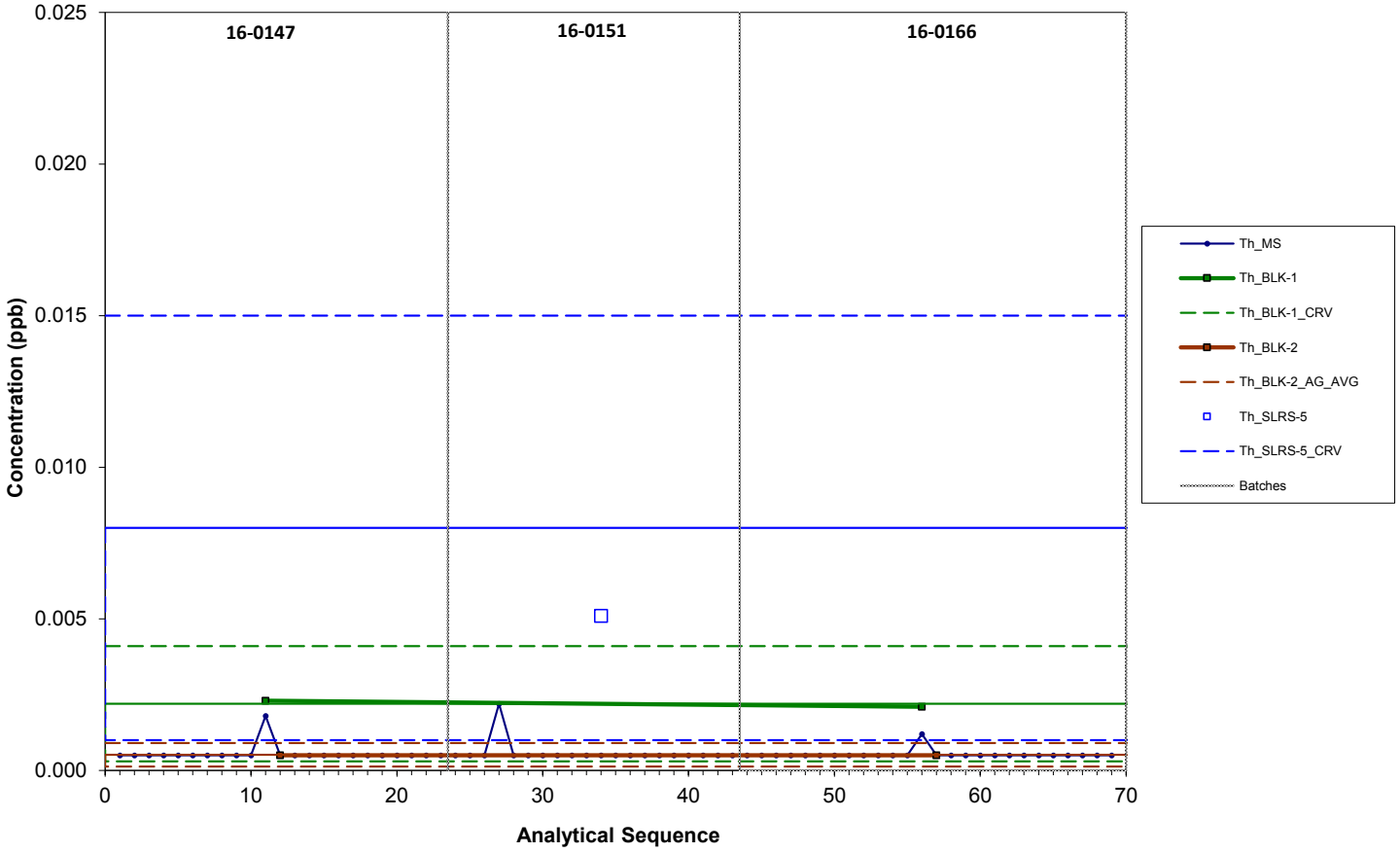
Quality-control plots: Thorium (Th) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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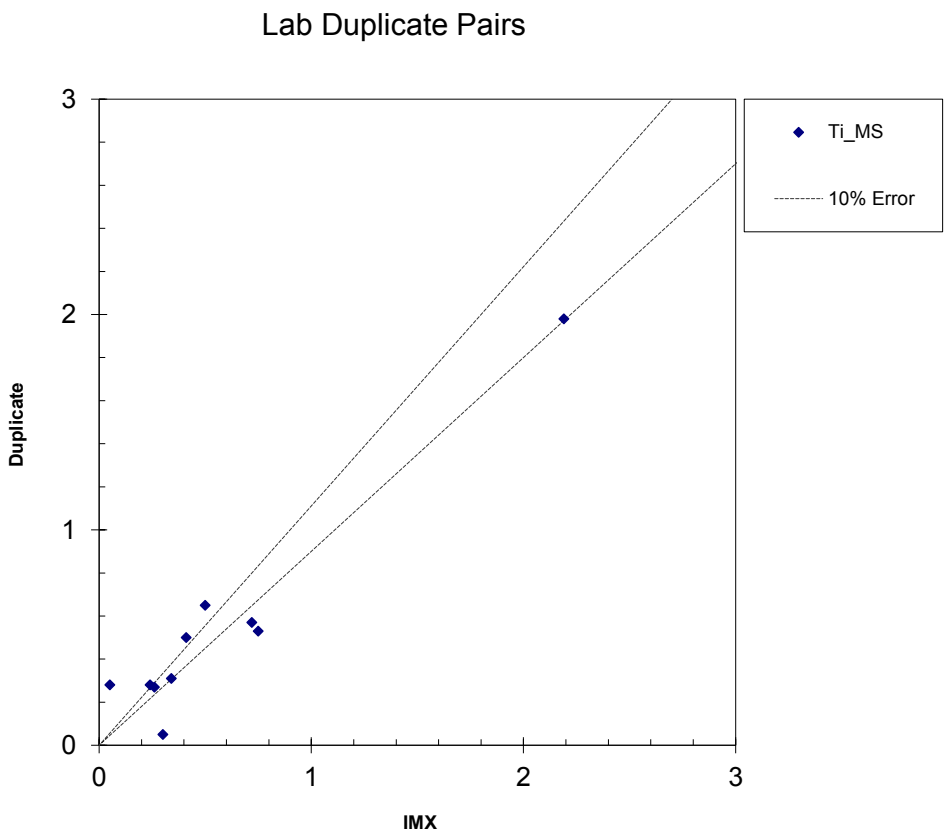
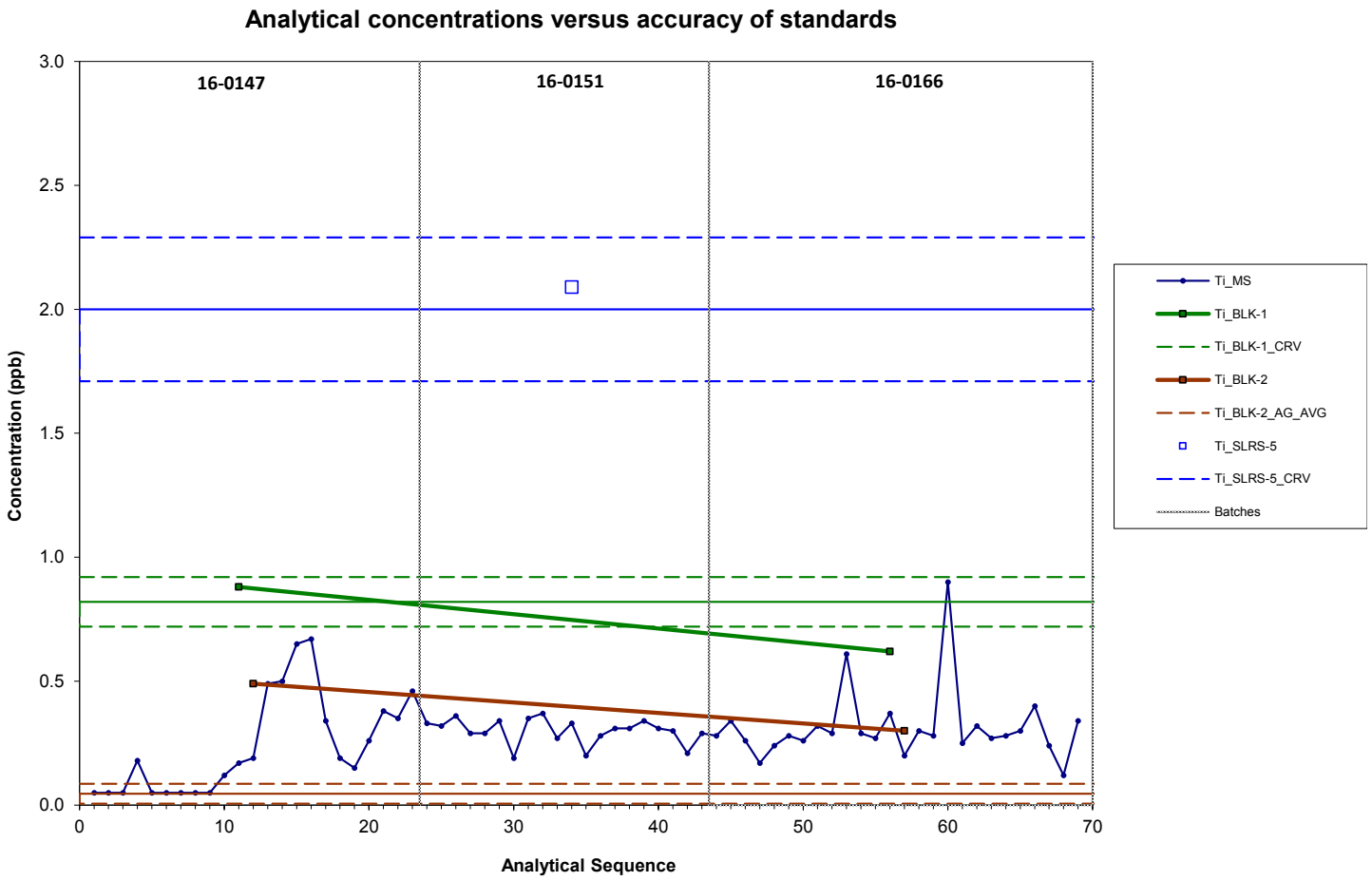
Quality-control plots: Titanium (Ti) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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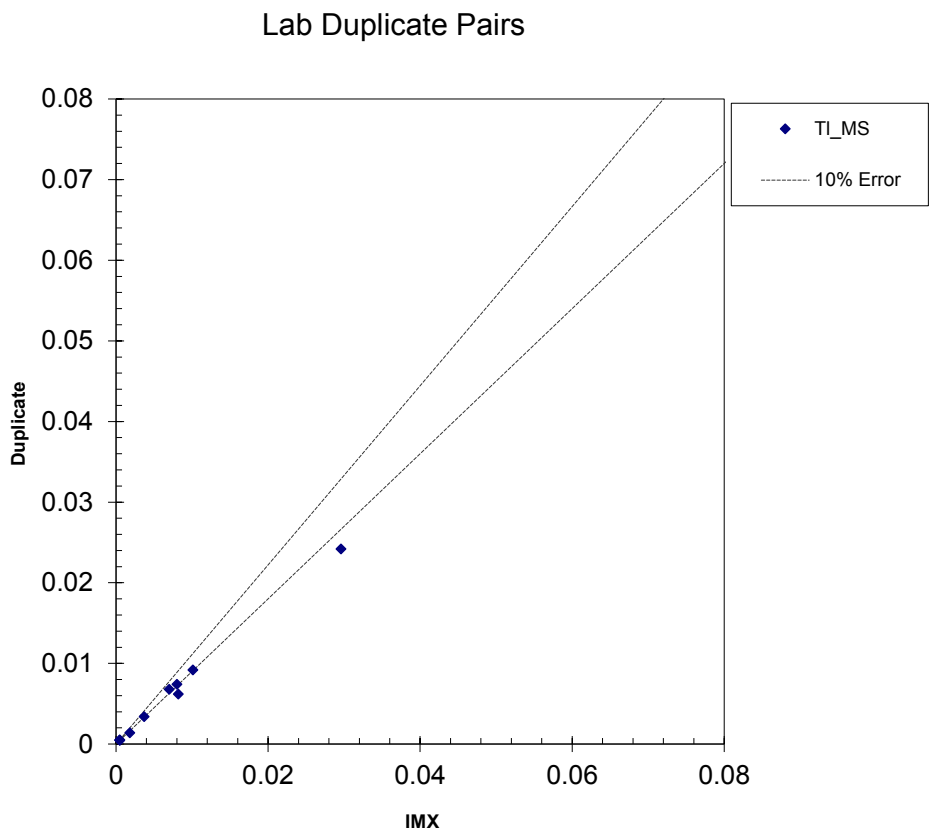
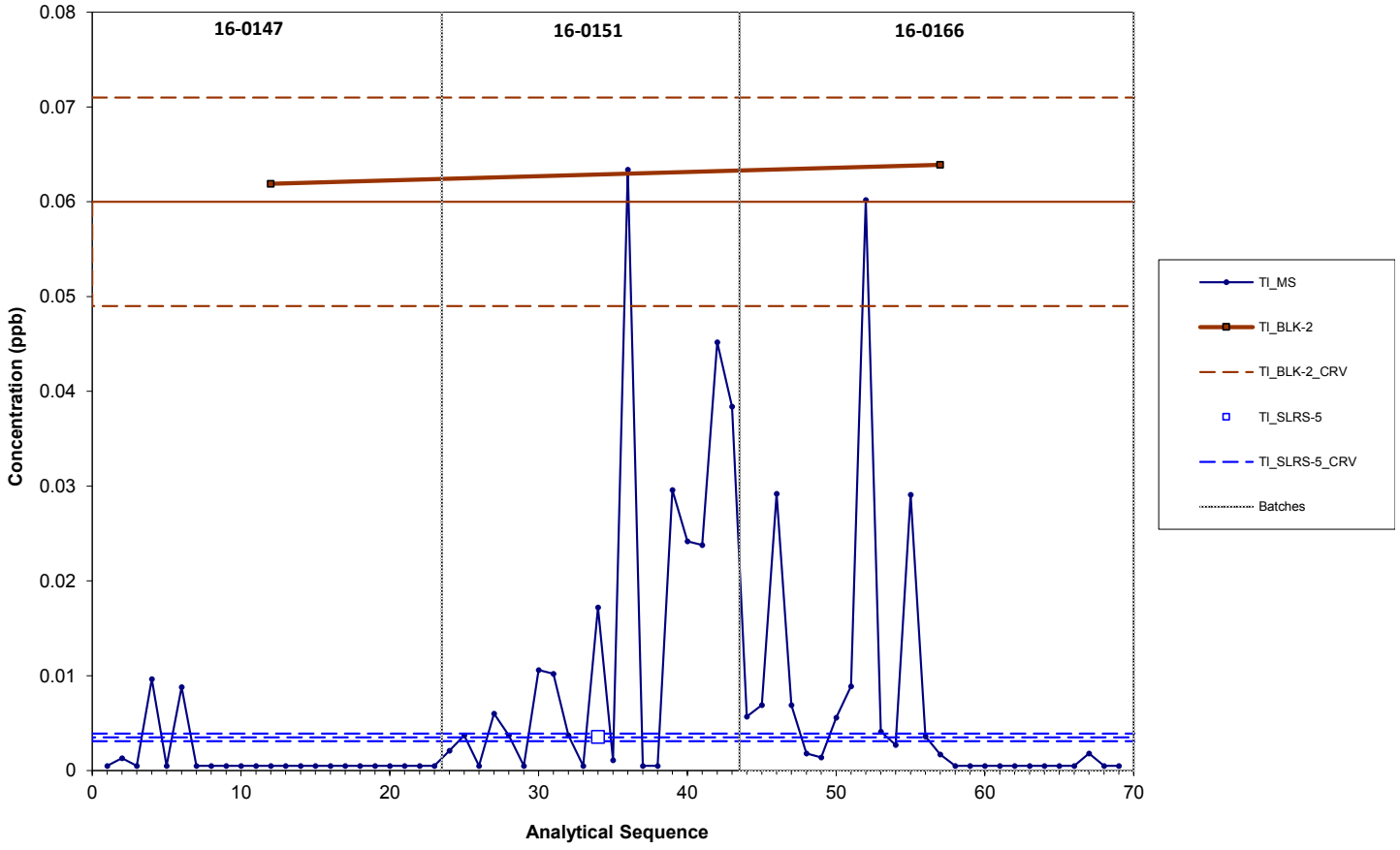
Quality-control plots: Thallium (Tl) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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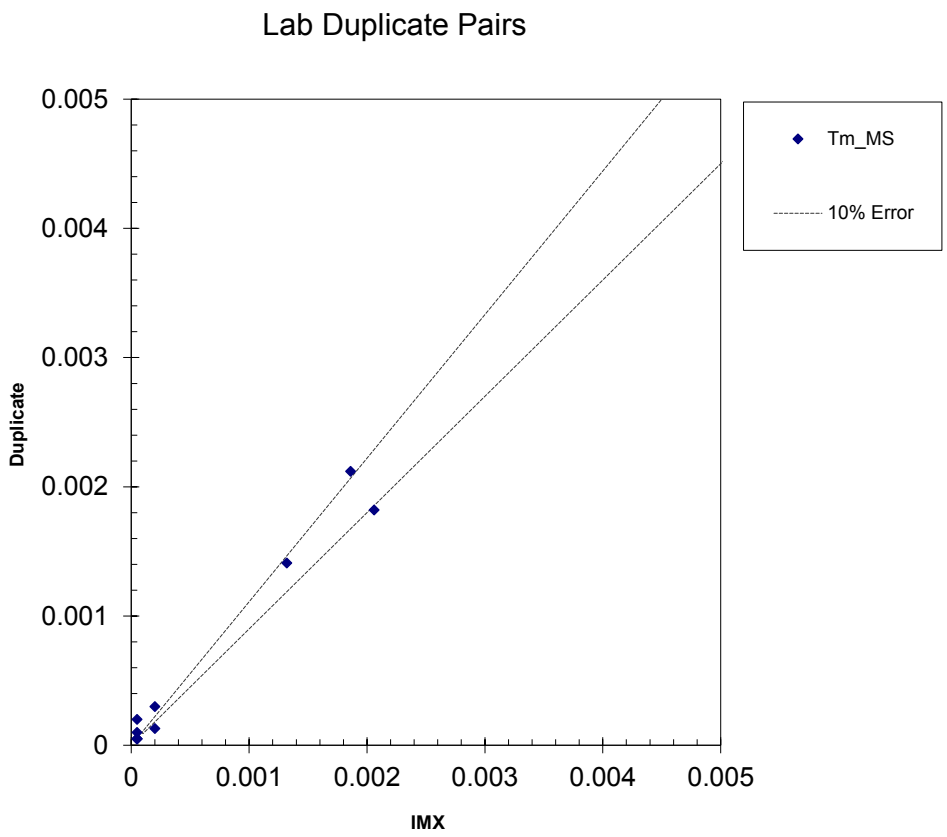
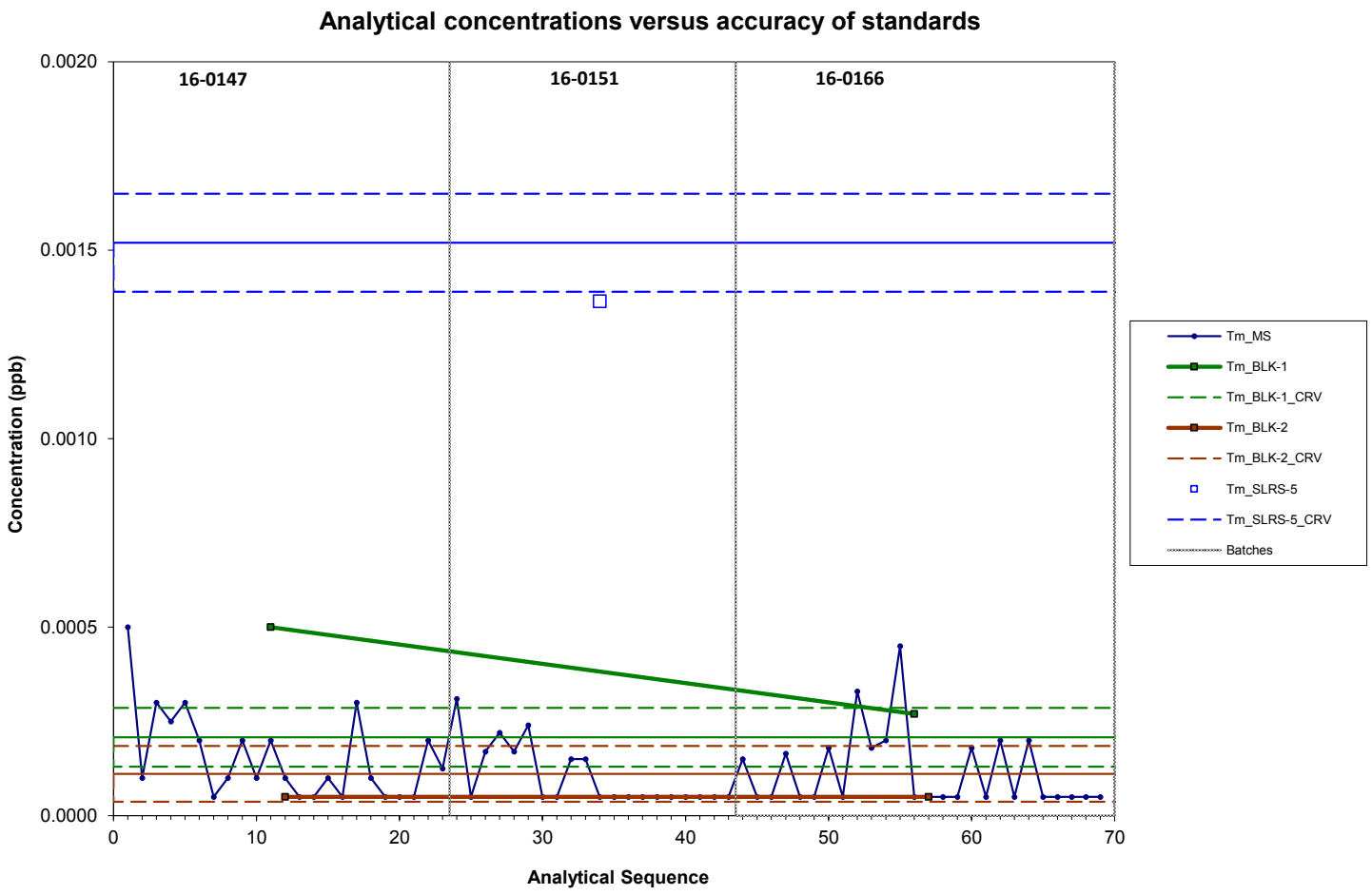
Quality-control plots: Thulium (Tm) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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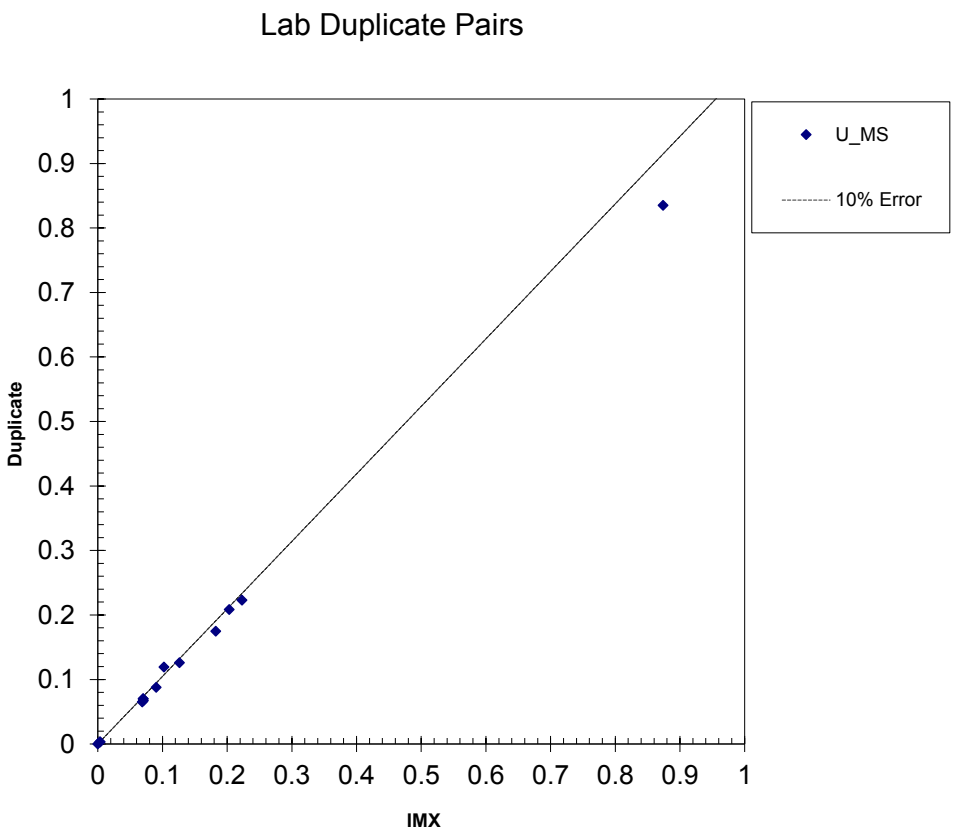
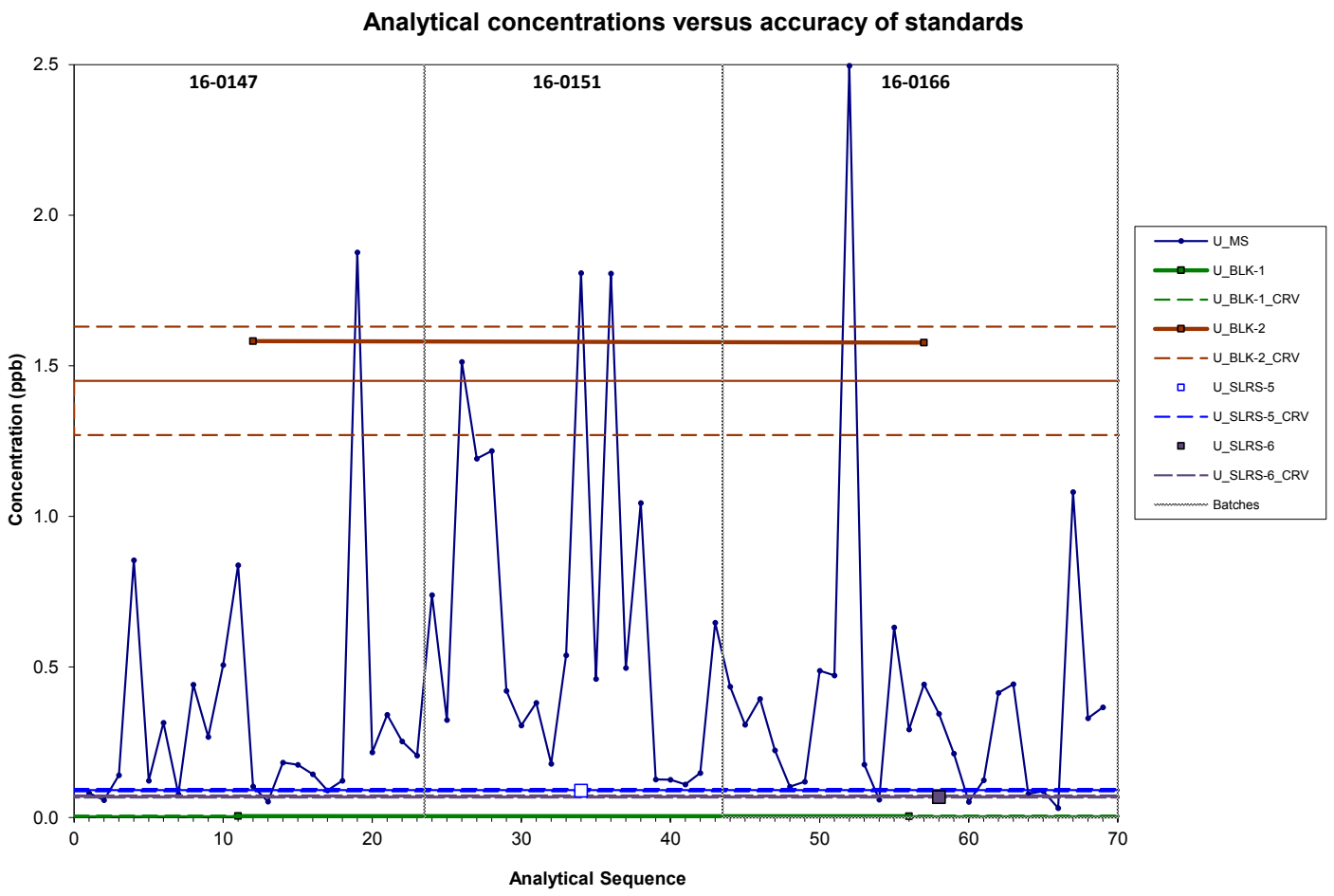
Quality-control plots: Uranium (U) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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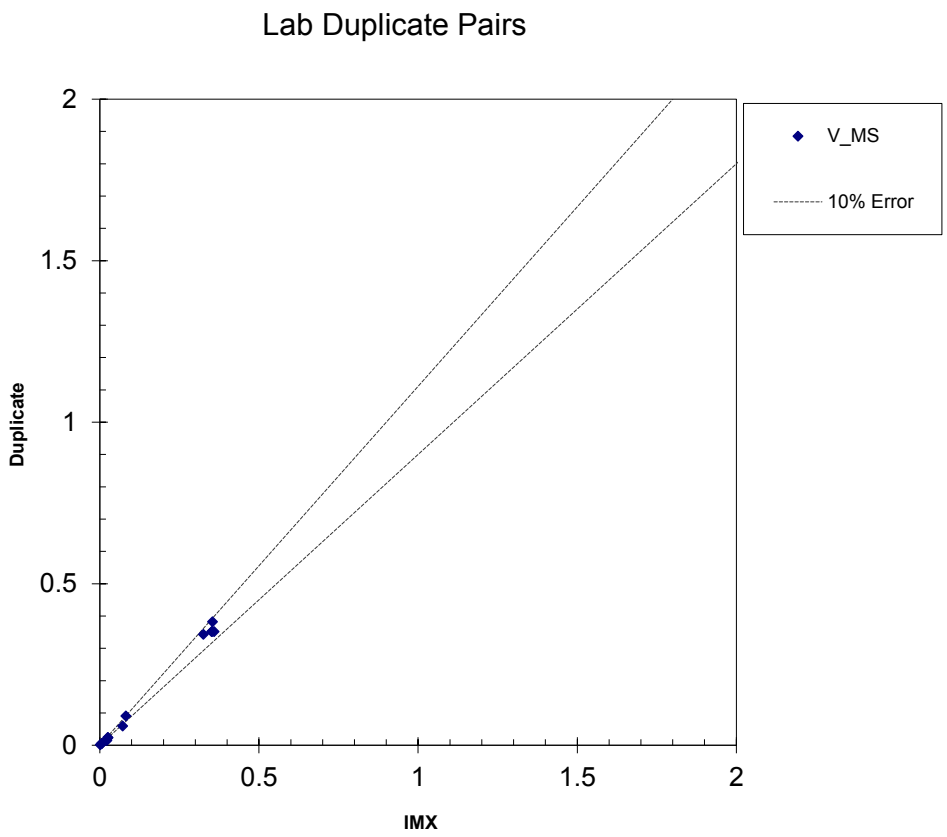
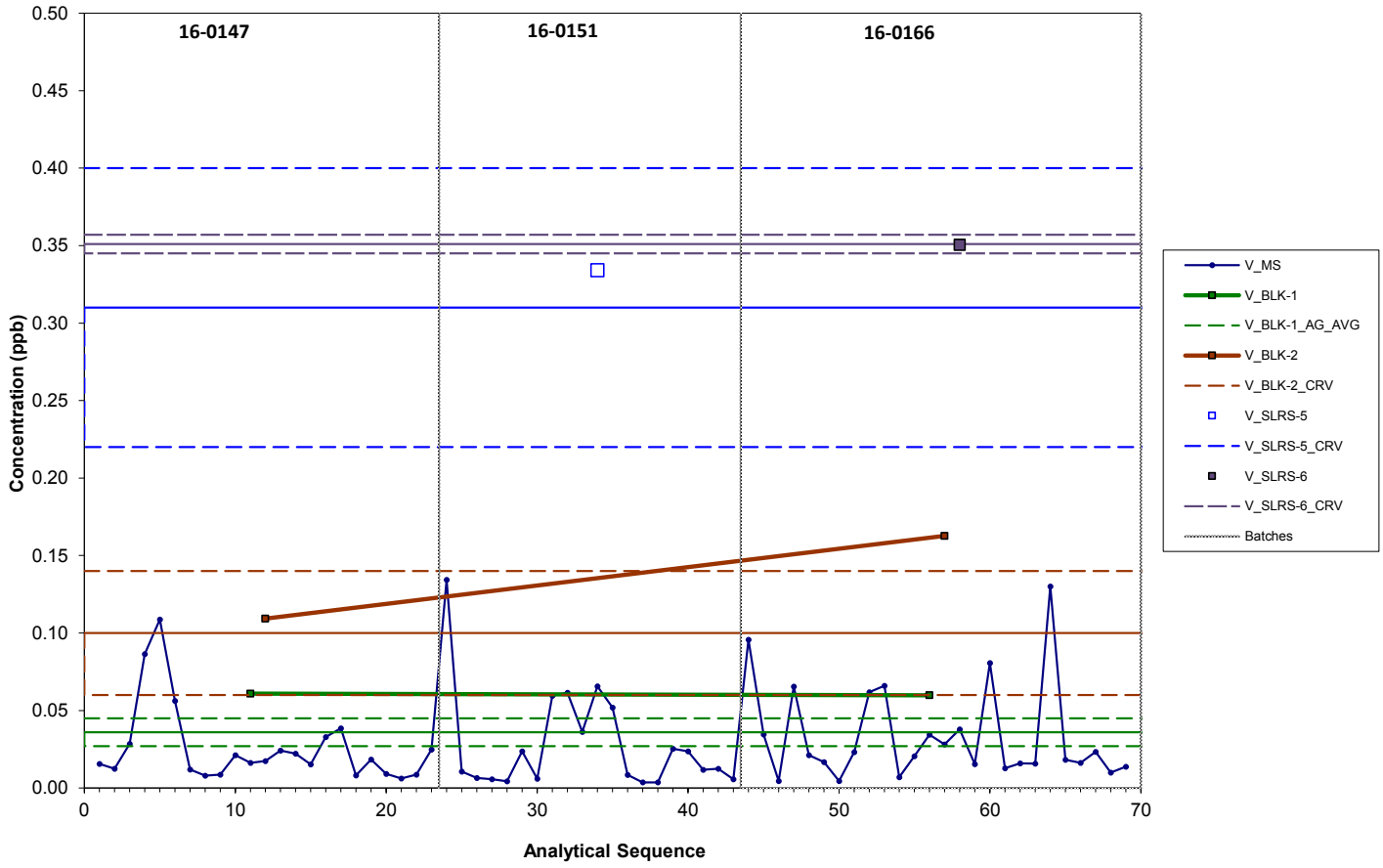
Quality-control plots: Vanadium (V) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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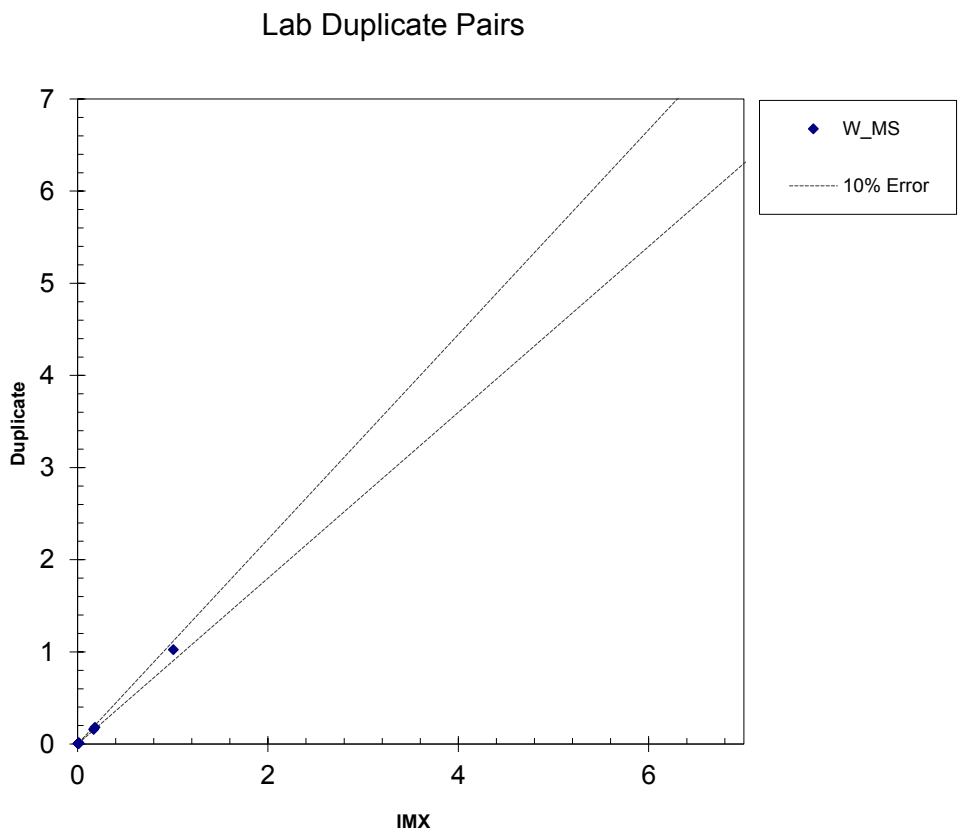
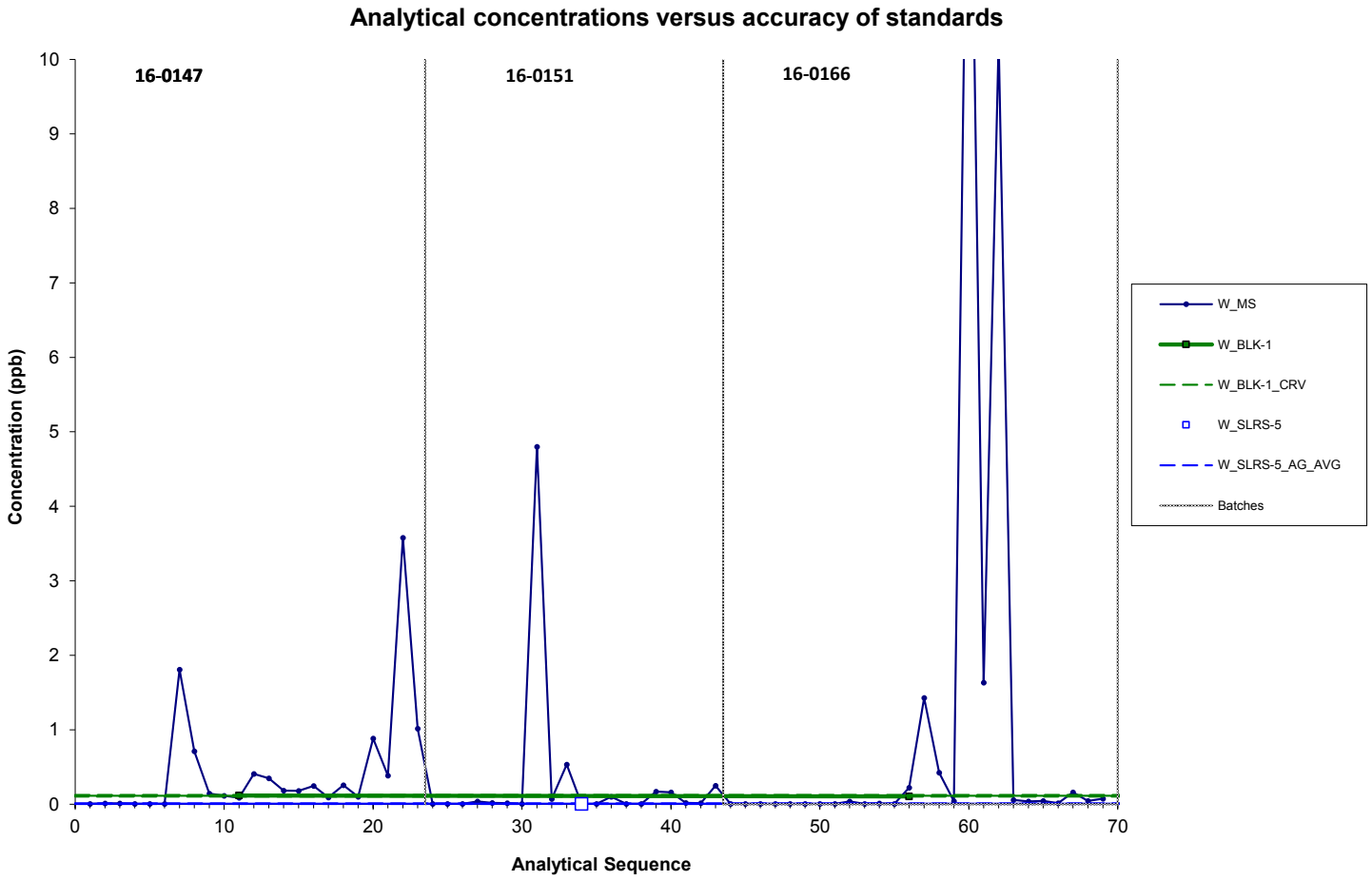
Quality-control plots: Tungsten (W) analyses using inductively coupled plasma mass spectrometry (ICP-MS)





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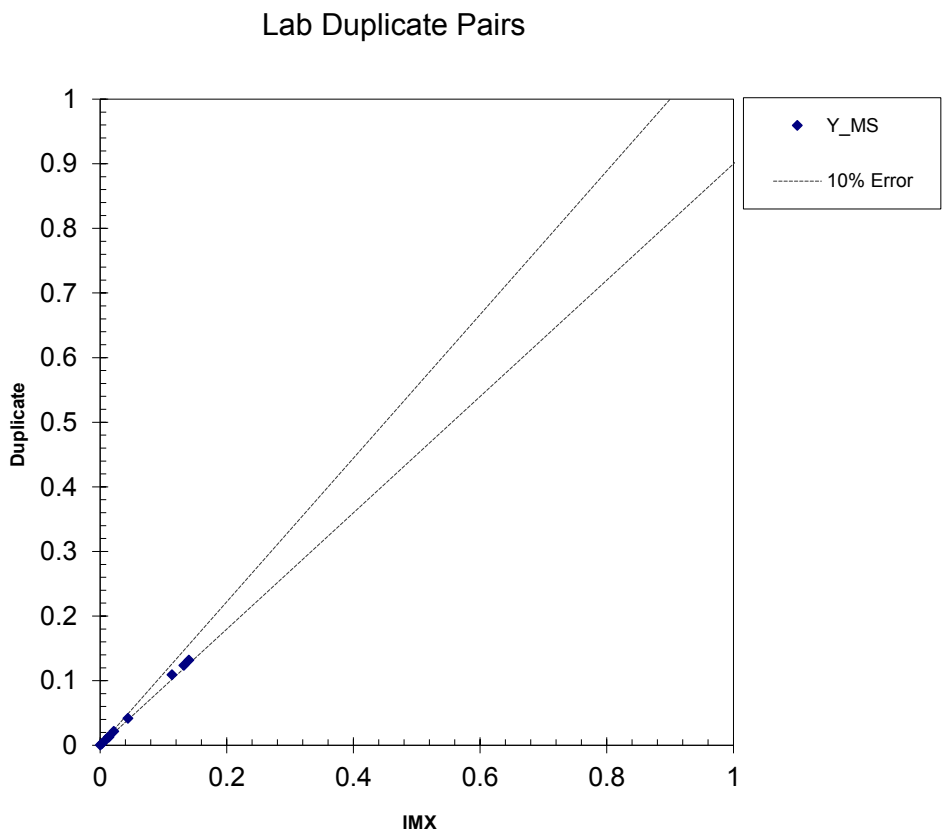
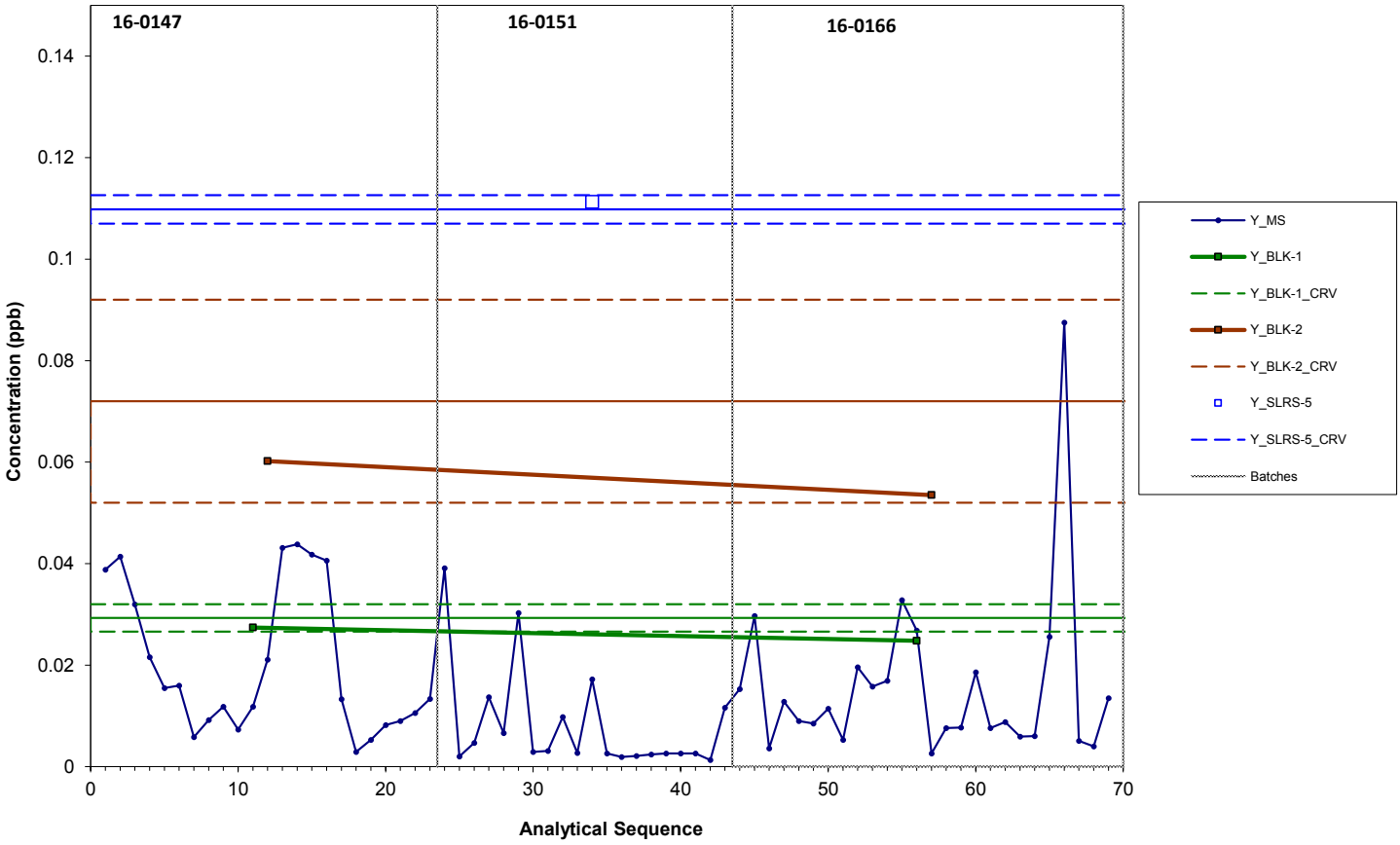
Quality-control plots: Yttrium (Y) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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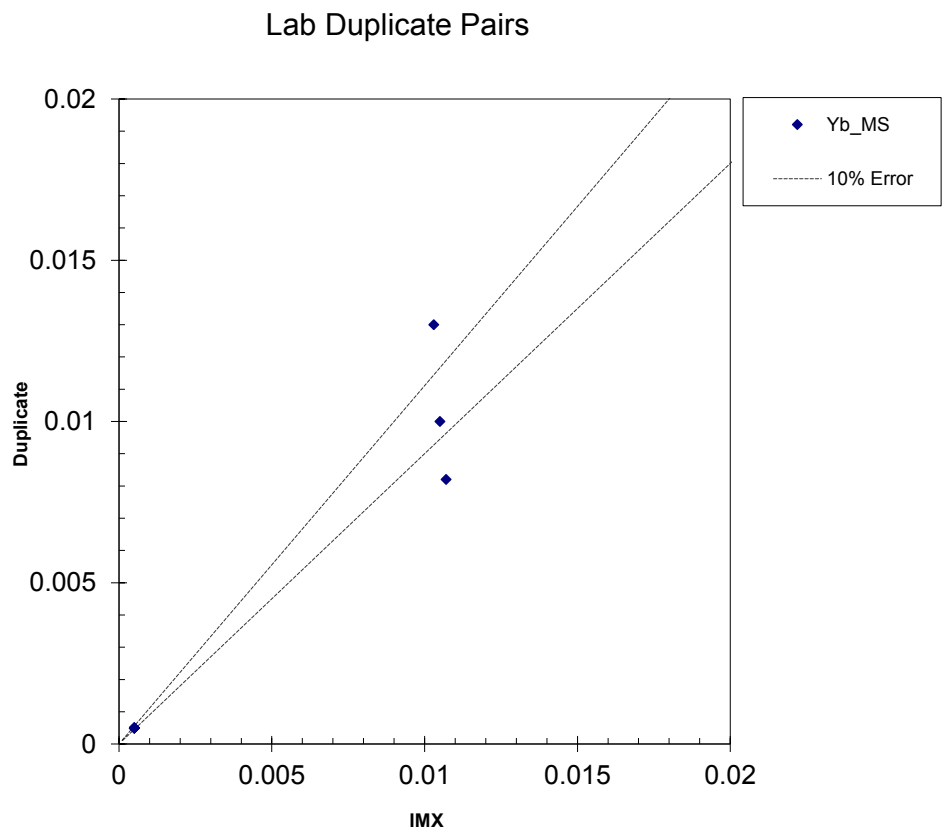
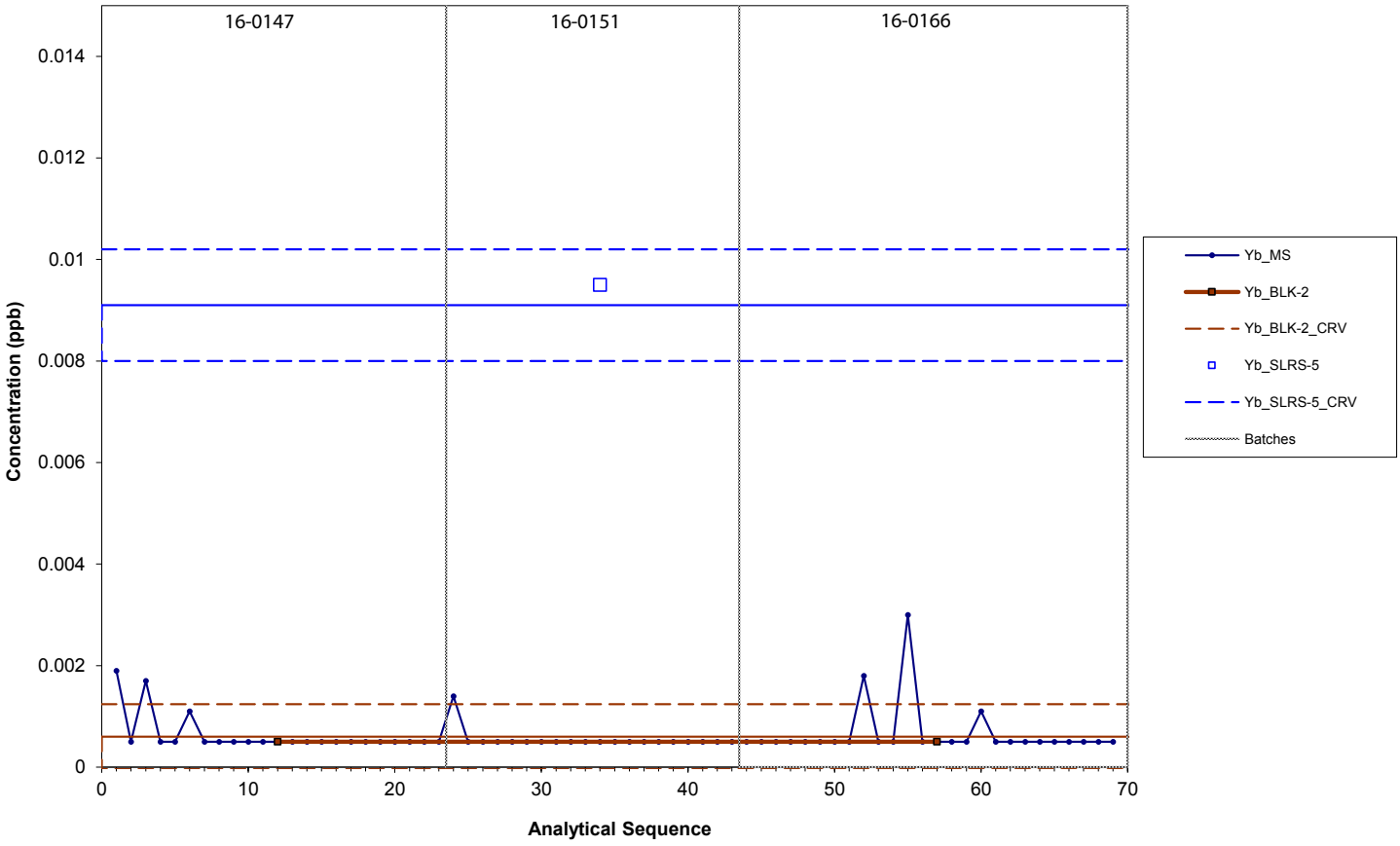
Quality-control plots: Ytterbium (Yb) analyses using inductively coupled plasma mass spectrometry (ICP-MS)



Analytical concentrations versus accuracy of standards



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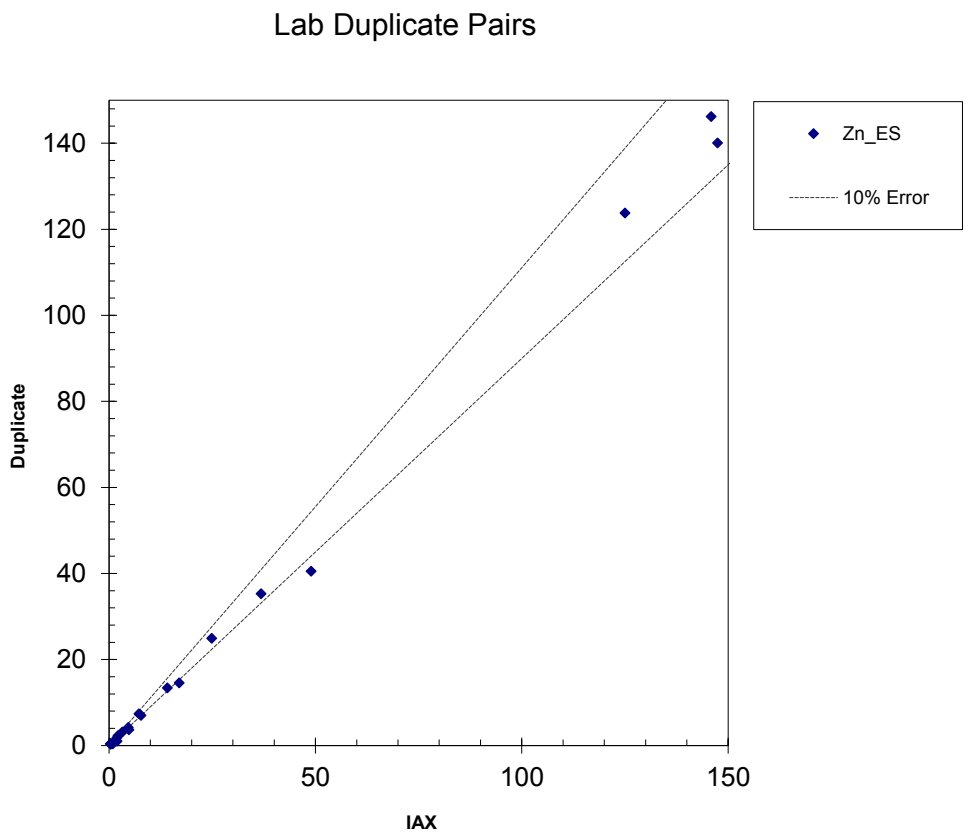
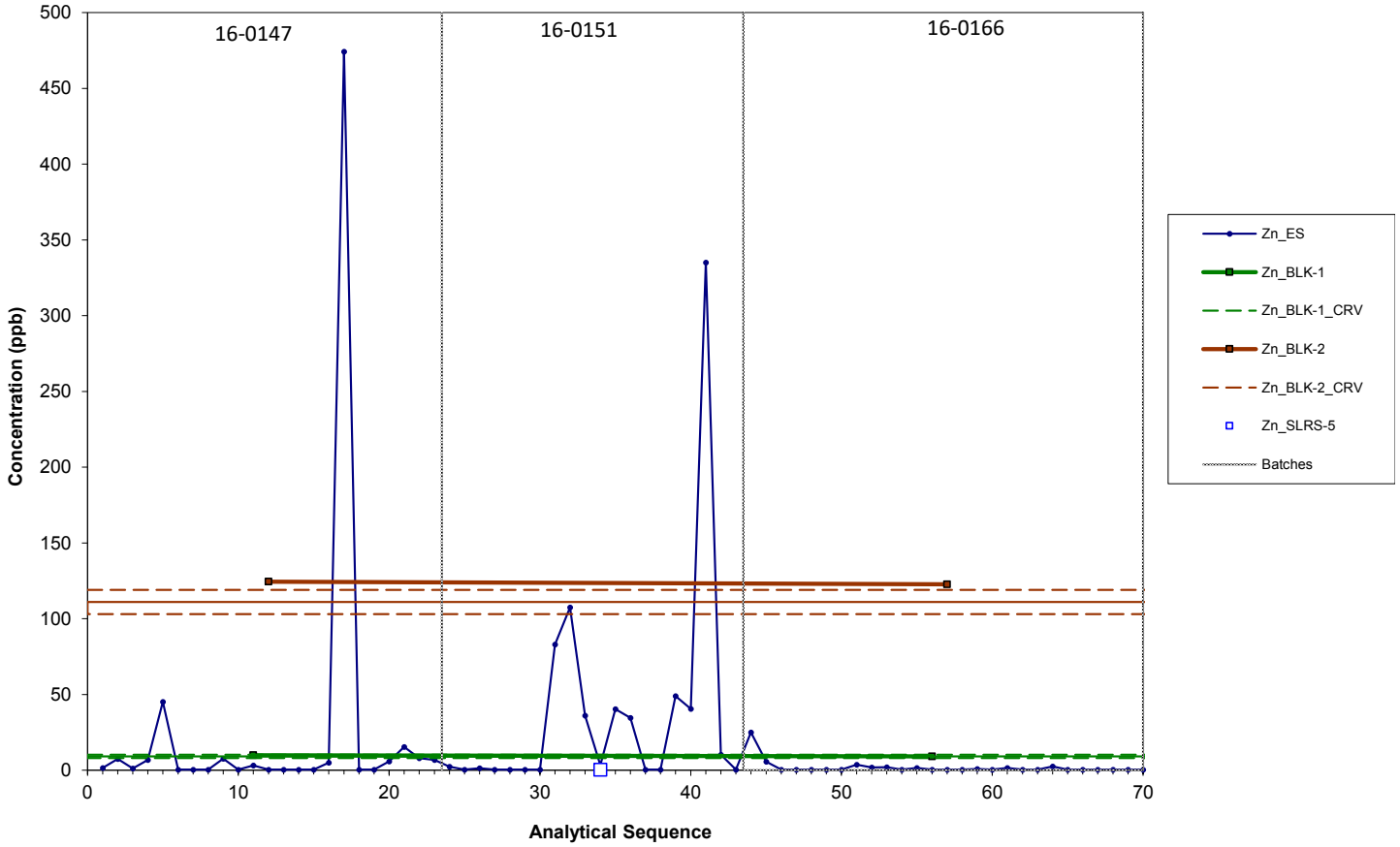
Quality-control plots: Zinc (Zn) analyses using inductively coupled plasma emission spectrometry (ICP-ES)



Analytical concentrations versus accuracy of standards



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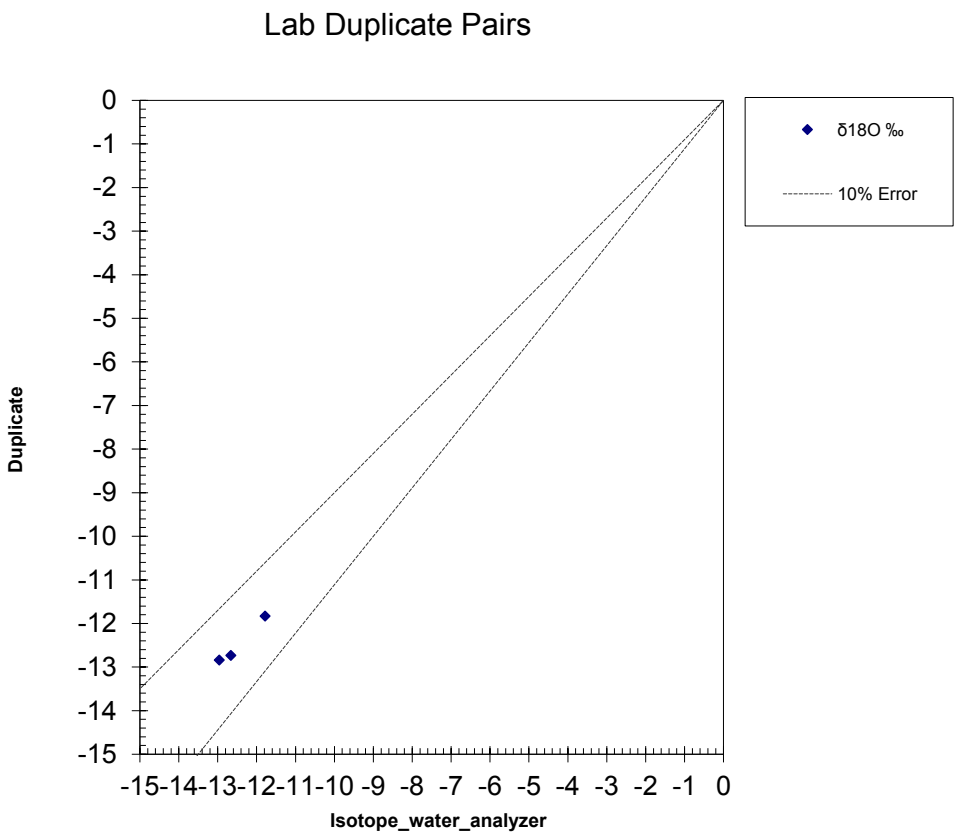
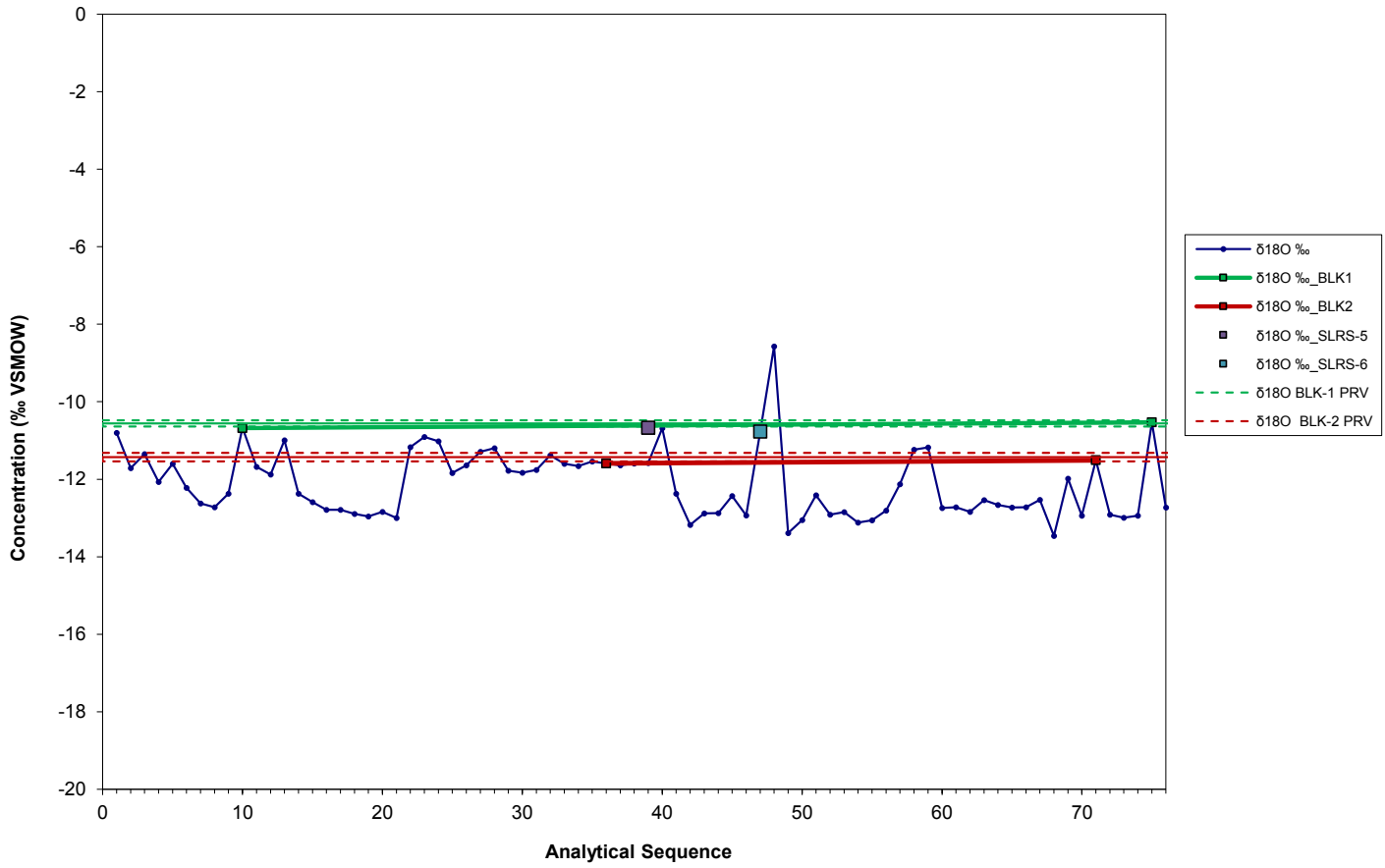
Quality-control plots: δ18O



Analytical concentrations versus accuracy of standards



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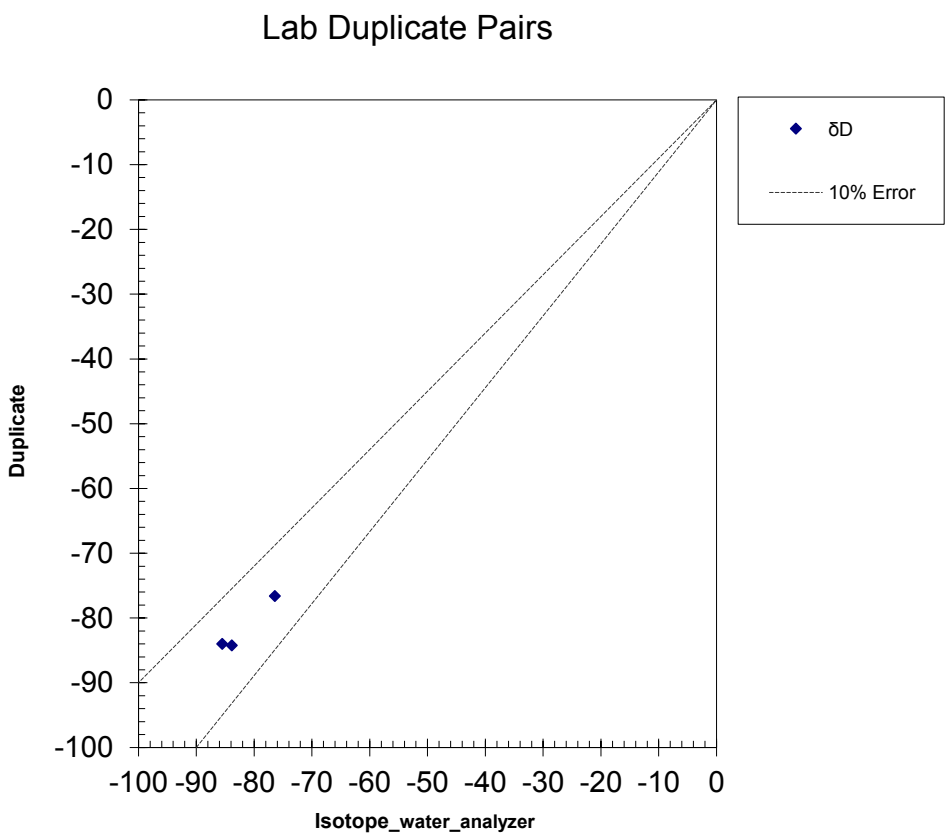
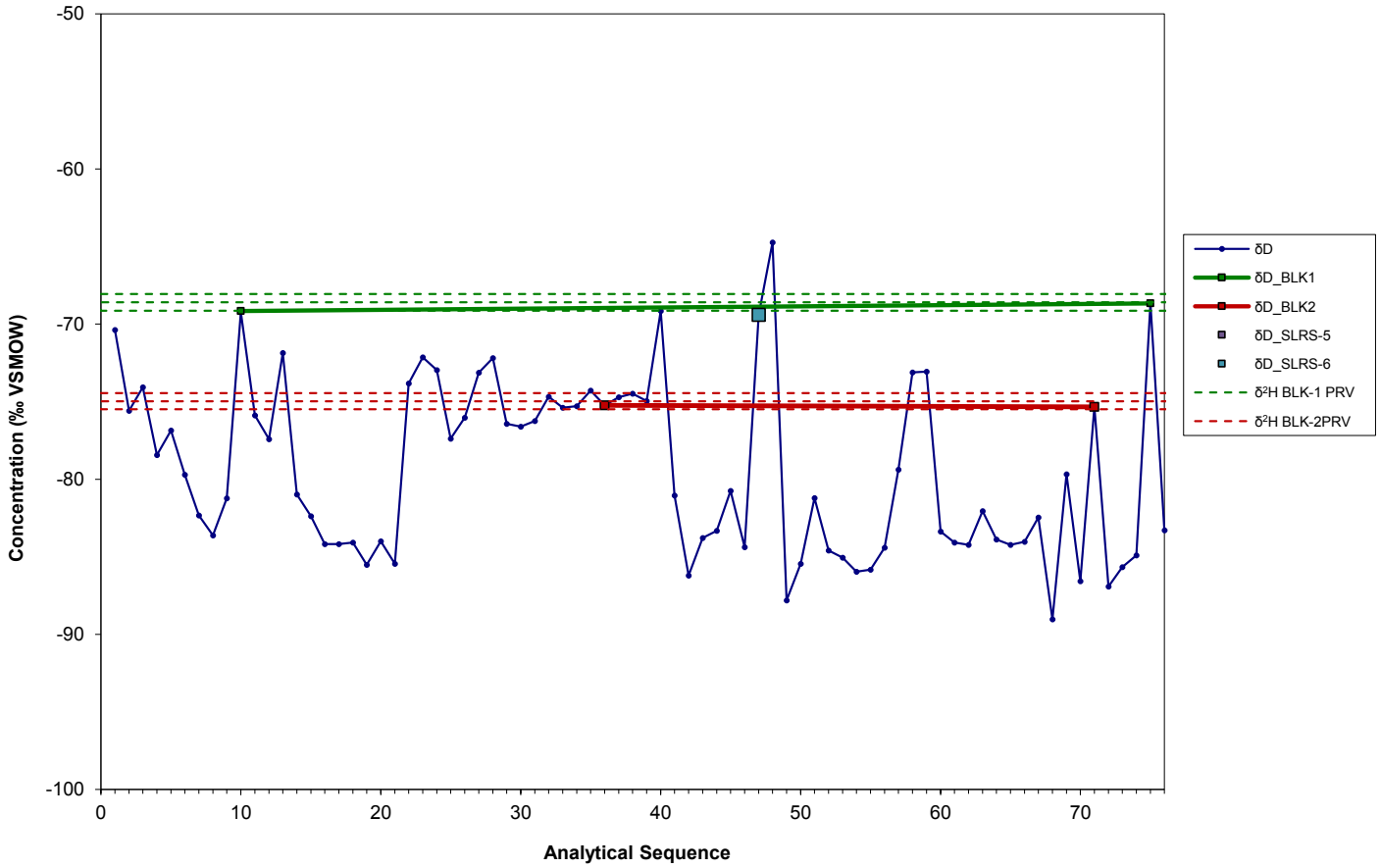
Quality-control plots: δ ^{2}H



Analytical concentrations versus accuracy of standards



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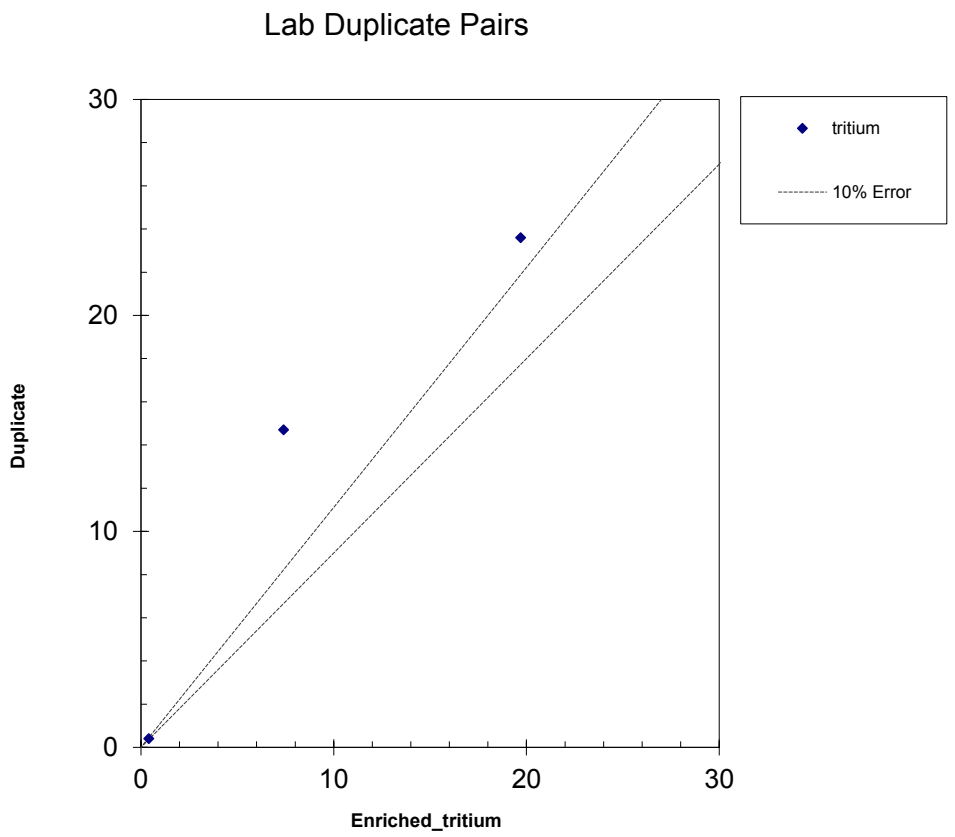
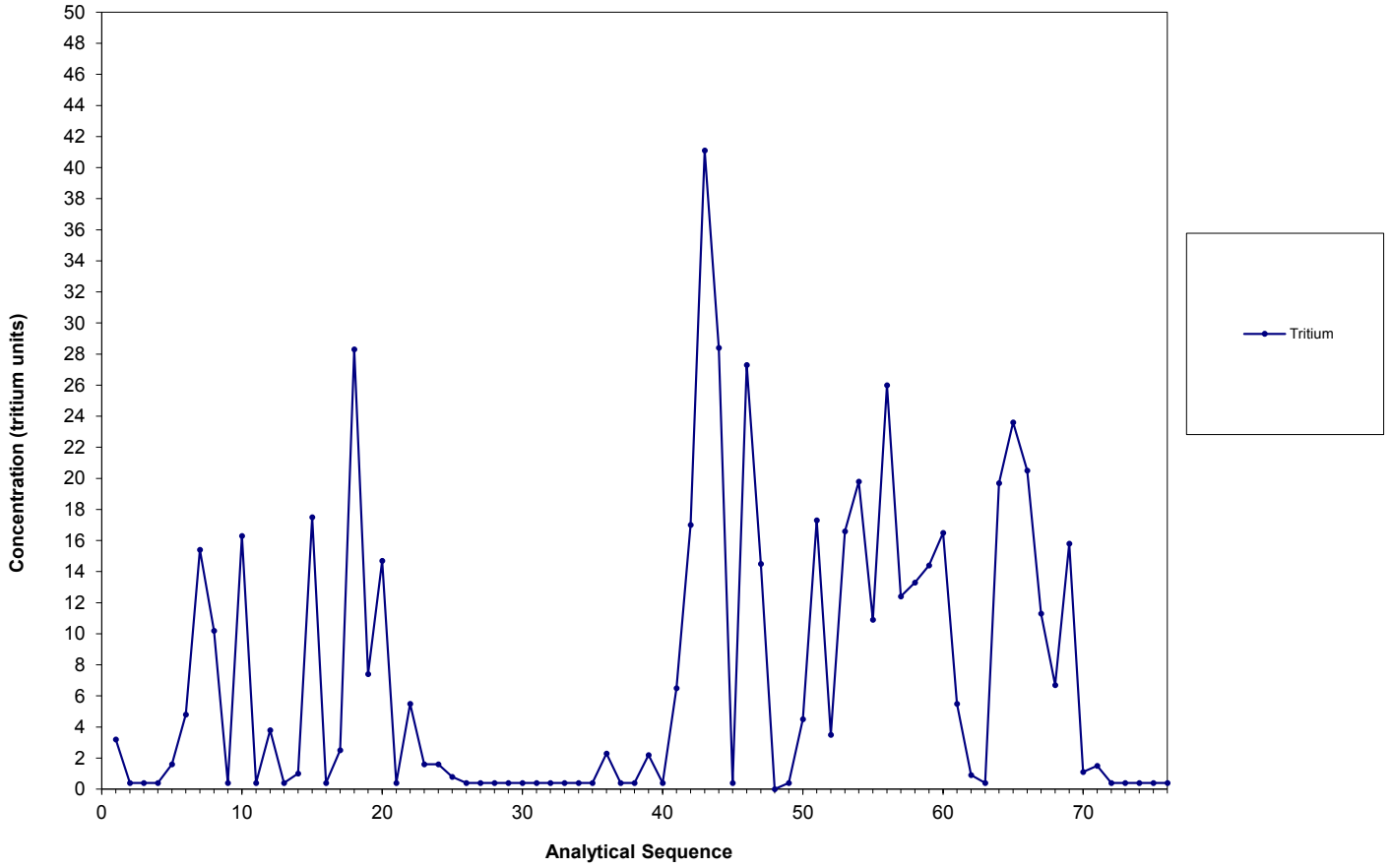
Quality-control plots: Tritium



Analytical concentrations versus accuracy of standards