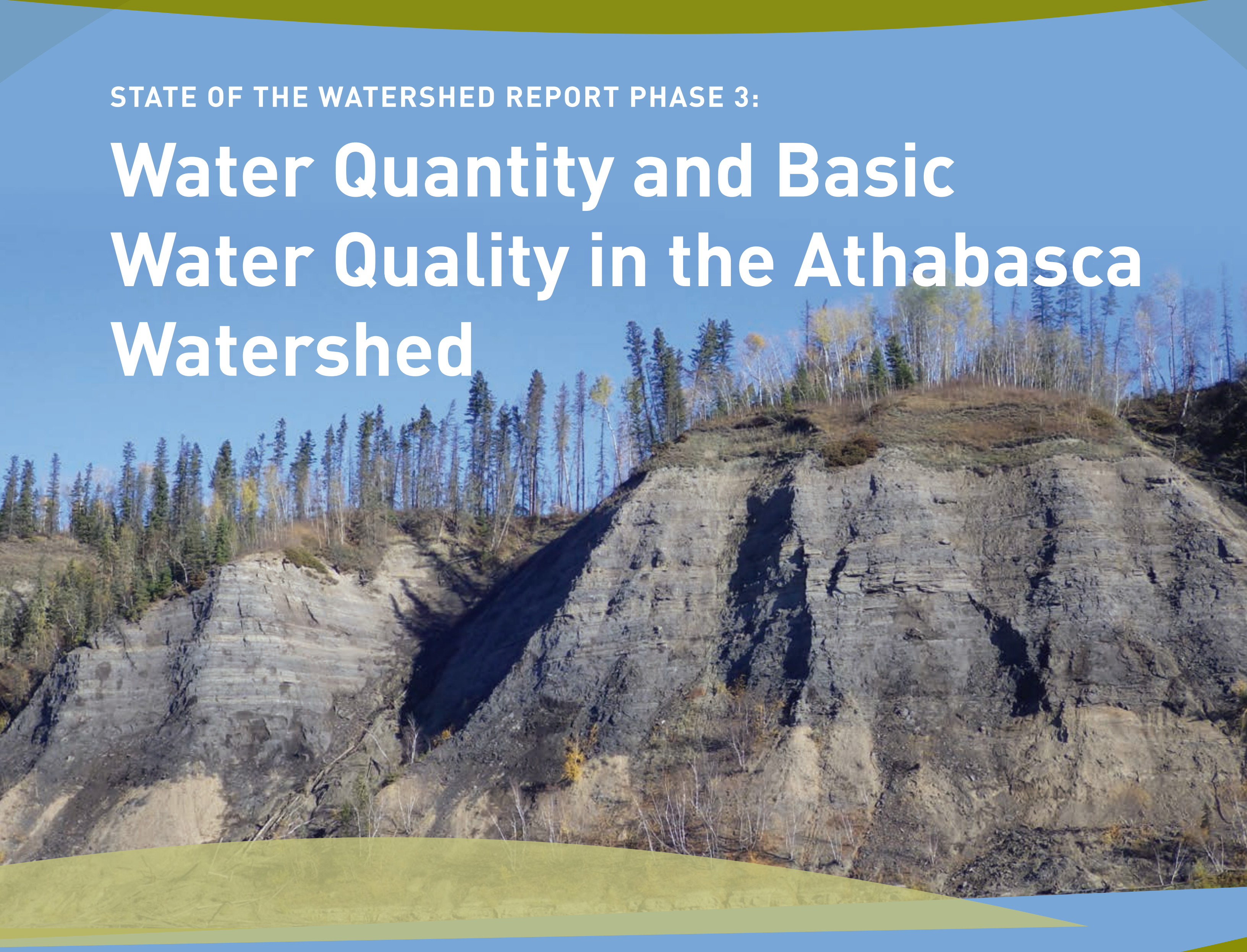

STATE OF THE WATERSHED REPORT PHASE 3:

Water Quantity and Basic Water Quality in the Athabasca Watershed

PREPARED FOR
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Note to Reader

This report does not necessarily reflect the opinions of all stakeholders or sections within the AWC-WPAC.

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Executive Summary

As a designated Watershed Planning and Advisory Council under Alberta's Water For Life Strategy, the Athabasca Watershed Council (AWC-WPAC) has been mandated by the provincial government to complete a State of the Watershed (SoW) assessment for the Athabasca Watershed. The objective of a state of the watershed assessment is to provide an overall description of the current condition of the watershed, which will serve as the basis against which future environmental change may be compared (Alberta Environment 2008). In addition, the intent of the SoW report is to provide managers with information regarding the existing knowledge or data gaps that are barriers to a more complete understanding of the current state of the watershed. The SoW report is intended to help identify ecological concerns or issues within the watershed, and will be used by the Athabasca Watershed Council Watershed Planning and Advisory Council (AWC-WPAC) as a foundation for developing future recommendations that will be included in an integrated watershed management plan.

To this end, the Athabasca Watershed Council initiated the SoW Phase 3 in August of 2012, with a focus on better understanding issues of water quality and quantity in the Athabasca Watershed. Specifically, the objectives of the SoW Phase 3 assessment were as follows:

1. To evaluate water quantity throughout the Athabasca Watershed within the historical and future hydrological and climatic contexts. In order to assess water quantity, we examined five key metrics of the surface water budget of each tertiary watershed.

2. To evaluate water quality in the Athabasca River and major tributaries between 2007 and 2012 using available, accessible data. In order to evaluate water quality, we examined over 40 water chemistry parameters that were limited to physico-chemical properties and inorganic constituents (including trace metals). In addition, we examined community composition and abundance of benthic invertebrates in the Athabasca River, and a limited number of major tributaries in the upper and lower regions of the watershed.

The focus of this work was to gather all of the data that were both available and accessible over the period of the study. This information was then used to conduct a critical evaluation of water quality and quantity in the watershed. The focus of this project was not on providing a comprehensive literature review of previous work or research that has been conducted in the Athabasca Watershed. Rather, this work focused on collecting and critically evaluating water quality and quantity data that were collected in the watershed between 2007 and 2011, and included only the data that were accessible within the timeframe of this project.

Water Quantity

In order to assess the quantity of water involved in the hydrological-ecological functioning of the Athabasca Watershed, we compiled and analyzed each component of the water budget (precipitation, evapotranspiration, discharge, and change in surface water storage) for the 31 tertiary watersheds as delineated by the Water Survey of Canada. We defined the current state of the watershed in terms of its water quantity by computing the most recent 30-year climate normal (1981 to 2010). In order to make better sense of the current state of the system, we placed the 1981-2010 climate normal into a longer historical context, in addition to considering its future trajectory using global climate model scenario analyses. Given the available datasets, our entire temporal window of consideration spanned 200 years, from 1901 to 2100.

The analysis of annual hydro-climatic trends in the Athabasca Watershed over the last 110 years suggests a combination of natural variability and directional climate change signals. Increasing temperature (2°C warming since 1901) has been driving increases in evapotranspiration; however, there is also an apparent 80 to 100-year natural periodicity for precipitation (and to some degree temperature), which is most likely driven by sea surface temperature changes in the Pacific Ocean. Although total annual precipitation has been decreasing over the past 40 years, the extrapolation of the apparent natural variation would suggest an increase in precipitation over the next 30-40 years. Climate models also indicate an increase in precipitation over the course of the 21st century; however, an increase in precipitation may not translate into higher water availability if more of that water is lost by evapotranspiration. In fact, an increase in potential evapotranspiration over the last 110 years is what has been observed. The hydrologic response of the landscape has been a gradual decrease in discharge for much of the Athabasca Watershed and also a decrease in storage for the northern half of the watershed. Future hydro-climatic monitoring of the Athabasca Watershed should consider the changes to evapotranspiration due to a warming climate, as well changes to ice and snow cover in the mountains.

Water Quality – Water Chemistry

A total of 47 physico-chemical and inorganic variables at 22 locations in the watershed were examined over a 5-year period between 2007 and 2011. Water quality data came from six provincial Long-term River Network (LTRN) stations, four Medium-term River Network (MTRN) stations, and 12 Regional Aquatics Monitoring Program (RAMP) stations. Reported water quality values were plotted for all variables examined, and concentrations over the 5-year period were compared against federal and provincial water quality guidelines, where available.

Water quality characteristics in the Athabasca River are highly influenced by the seasons: spring-summer (May-September) and fall-winter (October-April). Indications of potential risks to the health of the Athabasca River arose from a number of water quality parameters examined. For example, dissolved oxygen is an important indicator of healthy aquatic ecosystems, and we found concentrations that were below the federal water quality guideline value of 9.5 mg/L (for protection of early life stages of cold-water fish species) at many of the sites examined during the summer months. In addition, we found elevated nutrient concentrations throughout the length of the river. Both of these results support findings from previous work that has been done in the Athabasca Watershed.

Other factors that may require additional study include seasonal pH depression, the occurrence of saline seepage, and episodic increases in trace metal concentrations to values exceeding CCME guidelines. We suggest that the next crucial step in understanding trace metals and their potential effects on water quality in the Athabasca River is to characterize their predominant physical and chemical forms. Existing trace metals data for Cd, Cr, Cu, Hg, Pb, and Se suggest detailed studies of chemical speciation are warranted.

Water Quality – Benthic Invertebrates

The purpose of the benthic invertebrate assessment was to expand on the general water quality assessment by providing both an additional corroborative proxy for water quality, and a glimpse into potential ecological issues associated with water quality in the Athabasca River. This benthic invertebrate assessment included an evaluation of three different metrics, including: 1) Abundance & Community Composition of Indicator Taxa; 2) Taxon Richness & Abundance, and 3) Modified Index of Invertebrate Pollution Sensitivity.

Three aquatic invertebrate datasets were assessed: Environment Canada's Canadian Aquatic Biomonitoring Network (CABIN) dataset; Alberta Environment and Sustainable Resource Development's (AESRD) Long-Term River Network Healthy Aquatic Ecosystems (LTRN-HAE) dataset; and the Regional Aquatics Monitoring Program (RAMP) dataset. These were the three major sampling programs active in Alberta during the 2007 to 2011 period, to which our analysis was limited.

Discernible patterns in benthic invertebrate communities are evident from this assessment of CABIN, LTRN, and RAMP data, including longitudinal trends in invertebrate communities that reflect natural changes in geomorphologic and hydrologic factors that occur along the length of a river. Such patterns were evident in the tributaries in the upper and lower regions of the watershed, and in the mainstem of the Athabasca River, at least to the degree that it was sampled. Anthropogenic disturbance in the form of municipal wastewater, industrial point-source inputs, diffuse agricultural inputs, and disruptions in flow regimes were not evident based on the invertebrate communities represented in the CABIN, LTRN and RAMP datasets that were examined here.

One of the main findings of this work, which is supported by previous studies in the watershed, is that while there are a variety of distinct and on-going monitoring programs occurring in different regions of the Athabasca Watershed, these programs are not integrated either in their pursuit or in the management and interpretation of data. As a result, there is no broad-scale, integrated, and routine monitoring program for benthic invertebrates in the Athabasca Watershed that follows standardized methods for site selection, sampling, analysis, and interpretation. Specifically, there is relatively little broad scale monitoring and assessment of benthic communities occurring between Jasper National Park and the Lower Athabasca region, on either the mainstem of the Athabasca or in tributary rivers and streams. While there is routine sampling conducted as part of the federal Environmental Effects Monitoring program, this program is regulatory in nature, and is intended to identify major effluent point-source impacts, rather than provide an understanding of changes occurring throughout the watershed.

Infrequent and patchy sampling was found to be an issue with the LTRN program, but was also a concern with the CABIN and RAMP monitoring programs. Without combining benthic invertebrate sampling with mechanistic experimental studies designed specifically to test the effects of nutrient enrichment or contaminant deposition, or other physico-chemical changes on benthic invertebrate community structure and function, it is difficult to discern whether observed differences, either longitudinally along the river or over time, are the result of anthropogenic activities, or are the product of natural processes and variation. In order to address these concerns, the invertebrate monitoring programs must be integrated in design and implementation, and intensity of long-term invertebrate sampling efforts must be increased substantially, both in sampling frequency and in the number of sites sampled.

Data Availability, Quality, and Gaps

One of the major tasks and challenges associated with this project was the acquisition of existing water quality and quantity data. In a watershed as large and diverse as the Athabasca, assembling and acquiring data is an enormous task. While we contacted a large number of organizations to acquire data, in many cases we were unsuccessful. Our inability to acquire data was the result of several factors, including: 1) the data do not exist in a usable format (e.g., existed only as hardcopy or PDF reports); 2) owners of the data were unable or unwilling to share the information; and/or 3) data were delivered after the specified deadline and could not be included, or 4) we did not become aware of existing or available data in time to acquire and include it in this evaluation. The most notable data sets that were absent from this assessment included the Environmental Effects Monitoring (EEM) program and those representing municipal wastewater data. Additionally, the industrial wastewater dataset that was received from the provincial government was limited to only seven industrial facilities.

Of the water quality data that were included in this assessment, we examined the sensitivity, precision, and accuracy of the provincial LTRN and MTRN data. Several issues and concerns were commonly identified, including: multiple and changing detection limits over time, unacceptably low analytical precision, and a complete lack of data with which to calculate the accuracy of the measured values. All of these issues raise concern over the reliability of the provincial water quality data that were included in this report, as well as the reliability of any interpretation of those findings. In regard to trace elements, there is generally very little usable data, as the accuracy of the measurements are unknown, and the lower limits of detection are inadequate for many elements, including Cd, Cr, Ni, Pb, and Se.

Statistical precision was also assessed for the LTRN and RAMP invertebrate community datasets. Precision in the LTRN dataset is reasonably high for total abundance, numbers of unique taxa, family and genera richness, diversity, and MBI, but is insufficient when assessed at higher levels of taxonomic resolution. It also is lower at the Fort McMurray site than at the two LTRN sites upstream. Total invertebrate numbers and precision are too low at the Old Fort site for inclusion in any analysis, suggesting monitoring efforts at this site must be expanded. Because the ecologically relevant changes in invertebrate functional groups and dominant taxa that are of most interest, from a management perspective, the current LTRN monitoring program design is likely sufficient. However, annual sampling is needed if a goal is to be able to detect functional changes in invertebrate communities in a handful of years, versus in at least 15 to 20 years.

As has been reported elsewhere, variance in benthic invertebrate community samples in the RAMP dataset is generally high, resulting in generally low precision. The high variance and low precision are undoubtedly contributed to in great part by sampling along the length of a reach, as opposed to clustering repeated sampling and returning to individual sites, as is done in the LTRN and EEM programs. Sites also must be selected for their value as references or because of a sensitivity to or likelihood of observable change. Because of the high variance and low precision in RAMP's benthic invertebrate data, there is little or no chance of identifying benthic invertebrate community changes over time, or attributing any change that might be detected to a specific cause. Consequently, the RAMP benthic invertebrate monitoring program is of little use to managers when it comes to basing land use decisions on an ability to detect environmental change. Significant spatiotemporal expansion of monitoring efforts and adoption of common site selection, sampling, and data generation and analysis protocols for all monitoring the Athabasca Watershed are necessary, if managers desire sufficient information to inform land use decisions in a timely manner.

Recommendations and Conclusions

In order for surface water quality monitoring and assessment to be useful to decision-makers at all levels of government, greater attention should be given to maintaining, improving, and/or expanding existing monitoring and assessment programs. Water quality monitoring and assessment must be integrated among different levels of government (i.e., provincial and federal), monitoring techniques and QA/QC protocols should be standardized, and every effort should be made to merge data reporting and management practices for all programs into an on-line "one-stop" program or service that allows for electronic submission of, and free public access to, data. Amongst the many recommendations made in this report, we suggest that the Provincial government strengthen their role in environmental monitoring in the Athabasca Watershed to ensure the following:

1. A watershed-wide water monitoring program that is comprehensive, coordinated, and effective, with representative sampling in space and time that acknowledges the natural variations in the landscape from the headwaters to the Peace-Athabasca delta.
2. Quality assurance and quality control should be a focus of the program to ensure that the data collected are consistent and reliable. Standard Measurement Quality Objectives should be established and regularly evaluated, and QA/QC data should be made readily available in electronic format, and should automatically accompany other publically available water quality data that are accessed or distributed.
3. Data collected as part of a watershed-wide monitoring program should be regularly assessed and interpreted, and information should be made available for use by water and land managers, as well as the broader scientific community.
4. Expert assessments of the program and the data should be conducted at arm's-length from government, industry, and special interest groups to ensure transparency and prevent bias in reporting.

Table of Contents

List of Appendices

List of Figures

List of Tables

List of Abbreviations

AWC: Athabasca Watershed Council

AWC-WPAC: Athabasca Watershed Council Watershed Planning and Advisory Council

CCME: Canadian Council of Ministers of the Environment

CEA: Cumulative Effects Assessment

EEM: Environmental Effects Monitoring Program

LTRN: Long-term River Network

MTRN: Medium-term River Network

MDL: Method detection limit -

JOSM - Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring

RAMP: Regional Aquatic Monitoring Program

SDL: Sample detection limit

SoW: State of the Watershed

QA/QC: Quality assurance/quality control

WQL: Water Quality Limits

Chapter 1: The Athabasca Watershed

1. Introduction

1.1. State of the Watershed Reporting

As a designated Watershed Planning and Advisory Council under Alberta's *Water For Life Strategy*, the Athabasca Watershed Council (AWC) has been mandated by the provincial government to complete a State of the Watershed (SoW) assessment for the Athabasca Watershed. The objective of a state of the watershed assessment is to provide an overall description of the current condition of the watershed, which will serve as the basis against which future environmental change may be compared (Alberta Environment 2008). In addition, the intent of the SoW report is to provide managers with information regarding the existing knowledge or data gaps that are barriers to a more complete understanding of the current state of the watershed. The SoW report is intended to help identify ecological concerns or issues within the watershed, and will be used by the Athabasca Watershed Council Watershed Planning and Advisory Council (AWC-WPAC) as a foundation for developing future recommendations that will be included in an integrated watershed management plan.

In 2012, the Athabasca State of the Watershed Phase 2 Report was completed, with a focus on providing a large-scale overview of the various factors that may be impacting the ecological condition of the watershed (Fiera Biological 2012). Specifically, this assessment focused on quantifying and evaluating a variety of pressure indicators that have the potential to impact the health or condition of the Athabasca Watershed. While the SoW Phase 2 assessment addressed issues of water quality and quantity, the scope of the work did not allow for an in-depth examination of the current state of water quality or quantity. As a result, the Athabasca Watershed Council initiated the SoW Phase 3 in August of 2012, with a focus on better understanding issues of water quality and quantity in the Athabasca Watershed.

A comprehensive picture of the hydrologic condition of any watershed is dependent upon understanding how atmospheric, surface, and ground water interact with the physical, chemical and biological components of the landscape. For example, highly soluble elements, whether they are natural or anthropogenic, can be carried long distances through surface and groundwater hydrologic pathways (Wrona et al. 2000). In contrast, elements with low-solubility typically adsorb to sediment or soil particles, making their distribution in the watershed highly dependent upon sediment transport driven by erosion and runoff. Thus, understanding water quality requires consideration of the physical and chemical properties of various natural and man-made elements that may cause concerns for human or ecological health, as well as a comprehensive understanding of how these elements are influenced by geology, climate, and hydrology (Wrona et al. 2000).

Given the limitations associated with time, budget, and data availability, a comprehensive understanding of hydrologic conditions in the watershed was beyond the scope of this work. Rather, the SoW Phase 3 assessment focused on understanding basic water chemistry and water quantity in the Athabasca River and its major tributaries. Specifically, the objectives of the SoW Phase 3 assessment were as follows:

1. To evaluate water quantity throughout the Athabasca Watershed within the historical and future hydrological and climatic contexts. In order to assess water

quantity, we examined five key metrics of the surface water budget of each tertiary watershed.

2. To evaluate water quality in the Athabasca River and major tributaries between 2007 and 2012 using available, accessible data. In order to evaluate water quality, we examined over 40 water chemistry parameters that were limited to physico-chemical properties and inorganic constituents (including trace metals). In addition, we examined community composition and abundance of benthic invertebrates in the Athabasca River and a limited number of major tributaries in the upper and lower regions of the watershed.

It is important to note that the focus of this work was on gathering available and accessible data. All available data were then used to conduct a critical evaluation of water quality and quantity in the watershed. The focus of this project was not on providing a comprehensive literature review of previous work or research that has been conducted in the Athabasca Watershed, or other northern river basins in Alberta. Rather, this work focused on assembling and evaluating water quality and quantity data that were collected in the watershed between 2007 and 2011, and included only the data that were accessible to us within the timeframe of this project.

1.2. Defining the Scope of Phase 3

Water Quality

Water quality is generally described as an overall understanding of the chemical, physical, and biological components of water, which together represent a state or condition that can be measured, monitored, and evaluated (Chapman 1996; Wrona et al. 2000; Meybeck 2005). The list of variables that constitute "water quality" is diverse and continually changing as our understanding of aquatic ecosystems evolves, and our technical ability to detect and measure variables in water improves (Figure 1-1). Thus, it is important to understand what is, and is not, being measured when one refers to water quality.

Box 1: What is Water Quality?

Water quality is made up of various physical, chemical, and biological components that together represent a state or condition that can be measured and evaluated. Water quality is made up of a wide range of different variables, some of the most common of which are listed below:

Physical Variables:
Temperature, conductivity, odor, colour, taste, turbidity, conductivity, suspended solids

Inorganic Chemical Variables:
Major ions, metals, nutrients

Organic Chemical Variables:
Pesticides, nutrients, hydrocarbons, phenols, surfactants, endocrine disruptors

Biological Variables:
Fish, invertebrates, microbes, bacteria, plants, zooplankton

Water quality is not an all-encompassing term (see Box 1), and the metrics that are selected to measure water quality can be largely constrained by the design of a given water quality monitoring program, as well as the spatial and temporal sampling frequency of the program. Establishing water quality parameters is also a management decision that can be driven by efforts to balance the socio-economic activities responsible for water quality impacts, against those activities that are impacted by water quality degradation (Meybeck 2005). Regardless of the parameters that are selected to make up a given water quality assessment, and the rationale behind their selection, it is important that the selected parameters are relevant to the question or issues of concern, as well as to the range of stakeholders. As the question and interests of stakeholders change, so too should the list of water parameters that are being assessed.

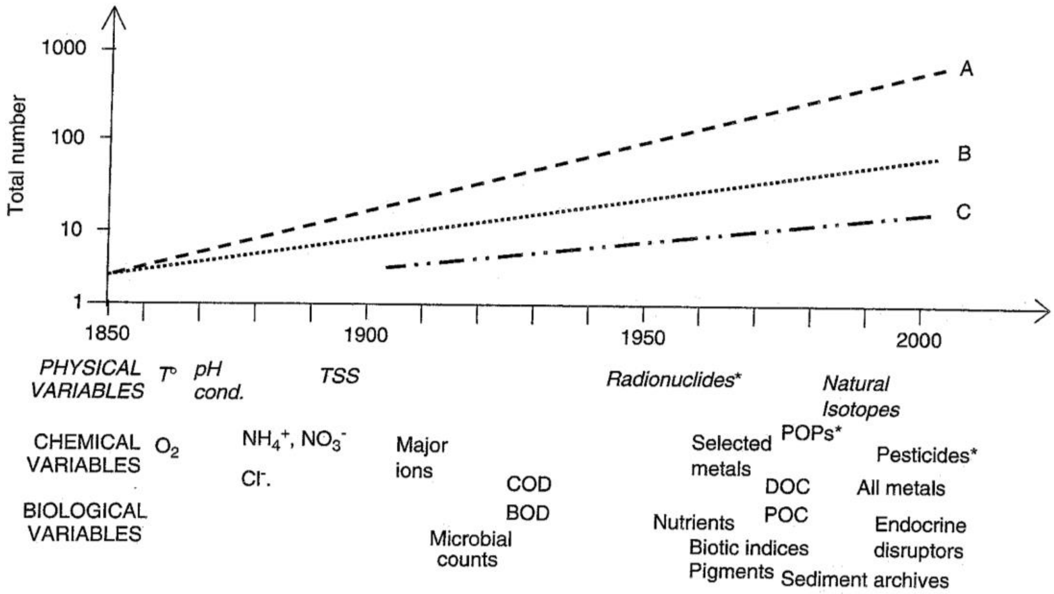


Figure 1-1. The growth of physical, chemical, and biological water quality parameters and occurrence of their first analysis in regular surveys. Trajectory A shows the maximum number of variables that should be considered if all regulations (in the US) are implemented. Trajectory B shows the number of variables that are routinely monitored. Trajectory C shows the capabilities of least developed monitoring programs or regions (taken from Meybeck 2005). Variables with an asterisk have no natural source.

In this report, water quality has been strictly limited to an examination of a select number of physical, inorganic chemical, and biological variables. The water chemistry variables incorporated into this evaluation include the most commonly assessed physical and inorganic water quality variables, in addition to an extensive list of trace metals. In response to requests from members of the Athabasca Watershed Council Technical and Scientific Advisory Teams, the list of water quality parameters examined in this report expanded considerably from the original list of 19, to include a total of 47 physical and inorganic variables (Table 1-1). In addition to water chemistry parameters, we also examined three biological metrics of water quality that were focused exclusively on benthic invertebrates, including:

1. Abundance & Community Composition of Indicator Taxa
2. Taxon Richness & Abundance
3. Modified Index of Invertebrate Pollution Sensitivity

It is important to note that the parameter names listed in Table 1-1 came directly out of the datasets that we obtained from the provincial government and from the Regional Aquatic Monitoring Program (RAMP). Parameters have not been renamed or combined in any way as part of this assessment. In many instances, there were multiple variable names for a single parameter in the data (e.g., ammonia, ammonia dissolved, ammonia total), and it is our understanding that this reflects changes in methods with respect to how certain parameters have been collected or measured over time. Rather than combining variables erroneously, we chose to treat each variable separately, and have presented each one individually in this report. Where possible, we included the same parameters from the various data sources, such that parameters could be compared between the different datasets.

Table 1-1. List of water quality variables that were examined as part of the Athabasca State of the Watershed Phase 3 Report at select Long-term River Network (LTRN), Medium-term River Network (MTRN), and Regional Aquatic Monitoring Program (RAMP) stations. Variable names are taken directly from data obtained from the provincial government (for LTRN and MTRN data) and from RAMP.

LTRN & MTRN	RAMP
Alkalinity Total	Alkalinity Total
Aluminum Dissolved	Aluminum Dissolved
Ammonia	Ammonia-N
Ammonia Dissolved	Arsenic Dissolved
Ammonia Total	Bicarbonate
Arsenic Dissolved	Cadmium Dissolved
Bicarbonate (Calculated)	Calcium
Cadmium Dissolved	Carbon Dissolved Organic
Calcium Dissolved	Carbonate
Calcium Dissolved Filtered	Chloride
Carbon Dissolved Organic	Chromium Dissolved
Carbonate (Calculated)	Colour True
Chloride Dissolved	Conductivity
Chromium Dissolved	Copper Dissolved
Colour (Visual) At Site	Dissolved Oxygen
Colour True	Hardness (as CaCO3)
Conductivity - FIELD	Iron Dissolved
Conductivity - LAB	Lead Dissolved
Copper Dissolved	Magnesium
Dissolved Oxygen - FIELD	Mercury Dissolved
Dissolved Oxygen - WINKLER	Nickel Dissolved
Fluoride Dissolved	Nitrate
Hardness Total ($CaCo_3$)	Nitrite
Iron Dissolved	pH
Lead Dissolved	Phosphorus Dissolved
Manganese Dissolved	Phosphorus Total
Mercury Total	Selenium Dissolved
Nickel Dissolved	Sodium
Nitrogen Dissolved Nitrate	Sulphate
Nitrogen Dissolved Nitrite	Temperature
Nitrogen, Nitrate	Total Dissolved Solids
Nitrogen, Nitrite	Nitrogen Total Kjeldahl (TKN)
Nitrogen Total Kjeldahl (TKN)	Total Dissolved Solids
pH (FIELD)	Total Suspended Solids
pH (LAB)	Uranium Dissolved
Phosphorus Dissolved	Vanadium Dissolved
Phosphorus Total	Zinc Dissolved
Residue Nonfilterable (Total Suspended Solids - TSS)	
Selenium Dissolved	
Sodium Dissolved/Filtered	
Sulphate Dissolved	
Temperature	
Total Dissolved Solids (Calculated)	
Turbidity	
Uranium Dissolved	
Vanadium Dissolved	
Zinc Dissolved	

Organic contaminants, such as polycyclic aromatic hydrocarbons (PAHs) or naphthenic acids (NAs), were not included in this phase of the watershed assessment for a variety of reasons, most relevant of which were concerns over the persistent technical problems with the quantification of certain organic elements, a lack of understanding of their environmental effects and specific toxicities, and a lack of either federal or provincial water quality limits or regulatory standards for some of these elements. For example, naphthenic acids are an important and yet very broad class of compounds that are found in petroleum and defined operationally as toxic acid-extractable organic compounds in oil sands process water. NAs are a growing concern in the Lower Athabasca River because of their highly toxic nature and their prevalence in bitumen and oil sands tailings ponds; however, as a class, they have a very complex chemistry that poses major challenges in identification, quantification, and characterization of toxicity (Bowman et al. 2005a; Clemente and Fedorak 2005; Allen 2008; Timoney and Lee 2009; Headley et al. 2010). In addition, until the Fall of 2009, the analytical detection limit for NA concentrations in the oil sands region was 1 mg/L (see Table A8.1, RAMP 2005 Technical Report, Appendix 8), despite the fact that ambient concentrations in northern Alberta rivers are typically less than 1 mg/L (Headley and McMartin 2004). For this reason, reported values of “non-detectable” NAs prior to 2009 may be both inaccurate and misleading if used in an assessment of water quality, especially as changes in analytical techniques have only recently been implemented to enable the detection of NAs at relevant environmental concentrations (RAMP 2009 Technical Report).

While biological indicators of ecological change are preferred over indicators that simply characterize water chemistry, a number of important biological metrics were excluded from this report because of data quality concerns, or because we felt that the state of the science or data availability limited our ability to accurately evaluate how these various taxa may be impacted by water quality in the watershed. After examining the data that were available to us, we determined that there was insufficient sample coverage at a watershed-scale to confidently evaluate biological indicators such as benthic algae and the associated indices that reflect community structure changes caused by such things as high nitrogen or phosphorus concentration (trophic index) or high suspended sediments and siltation (siltation index). The difficulty of obtaining data for such an analysis speaks to a broader issue of data availability, and the difficulties associated with obtaining data from diverse and distinct monitoring programs (e.g., Environmental Effects Monitoring performed by various municipalities and companies throughout the watershed) for use in an integrated assessment of the state of water quality at a broad scale under restrictive and demanding project timelines (see Chapter 5 for a more detailed discussion of data availability).

In addition to benthos and algae, fish communities serve as important biological indicators of water quality, and past studies have raised concerns over apparent indicators of stress, as well as the presence of organic contaminants (e.g., PCBs) in fish tissue in certain locations in the watershed (Cash et al. 2000; Northern Rivers Ecosystem Initiative 2004; McMaster et al. 2006). While these studies have raised concerns regarding the effects of water quality on fish, comprehensive toxicological studies on fish populations in the Athabasca Watershed are limited in geographic scope and are rare, making it difficult to use fish as an indicator of current condition in the watershed. Thus, we have restricted our assessment of biological variables to include measures of benthic invertebrate community abundance and composition, taxon diversity, and a modified index of pollution sensitivity, as there is relatively good data coverage for this group of biological indicators in the Athabasca River.

This SoW Phase 3 assessment has also been limited to examining surface water quality in the Athabasca River and a select number of major tributaries. While we recognize that this presents an incomplete picture of water quality, understanding the dynamics of surface water, ground water, and sediment quality is an enormously challenging undertaking that was well beyond the scope of this assessment given both time and budgetary constraints.

1.3. Assessing the "Current State" of the Watershed

Determining the reference (or benchmark) condition against which the "current state" will be compared and evaluated is a critically important and exceptionally challenging component of any watershed or water quality assessment. Benchmarks serve as a measure of the deviation of the current condition from a desired, expected, or previous condition, and can be established through either quantitative or qualitative methods (Hawkins et al. 2010). While both qualitative and quantitative approaches can be used to establish benchmarks or reference conditions, it is generally agreed that quantitative methods are preferred because they provide a more rigorous standard against which change over time and space can be tracked and compared. Common approaches to establishing benchmarks for watershed assessments include Cumulative Effects Assessments (Dubé et al. 2006; Squires et al. 2007; Dubé et al. 2013), a reference condition approach (Bailey et al. 1998; Hawkins et al. 2010), establishment of condition gradients (Davies & Jackson 2006; Nielsen et al. 2007), or indices of biologic integrity (Karr 1991; Wilson & Bayley 2012). Qualitative approaches that have been used to establish benchmarks for condition assessments include expert opinion (Lomnicky et al. 2002) or the adoption of targets that represent a "desired" condition, such as existing standards or guidelines.

In general, two approaches are taken to assessing water quality: upstream-downstream comparisons, to attempt to quantify effects of point source inputs of municipal or industrial effluent on ecological function, or physiological responses of various target organisms (e.g., Environmental Effects Monitoring program); and pre-disturbance/post-disturbance comparisons that attempt track the changes at a particular site that are the result of anthropogenic activity. Ultimately, the methods and indicators employed will depend on the nature of disturbance, the nature of anticipated effects, the relevant spatial scale (i.e., local to regional or basin-wide), and the relevant temporal scale (e.g., diel, seasonal, inter-annual, or long-term). It also will depend on the goal of the monitoring or assessments, which could conceivably range from simply descriptive understanding of existing conditions, to the provision of as-yet-unknown information that is needed to inform management decisions or actions. Further, if the goal is to establish ecological thresholds that are lacking, then site-specific studies specifically designed to provide information that is required to establish particular thresholds should be combined with temporal and spatial comparisons (Adams 2003).

Regardless of the approach used to establish benchmarks, there is general agreement that benchmarks should represent properties that are generally associated with naturalness or the degree of deviation from a pre-disturbance condition (Hawkins et al. 2010). Indicators of condition typically reflect changes to ecological integrity and are chosen based on their sensitivity to change. As Meybeck (2005) has articulated, *"establishing reference water quality is not trivial"* (p. 33, italics original), and the questions of how to establish reference or benchmark conditions, and at what temporal or spatial scale benchmarks should be established and applied (i.e., reach versus river) are contentious and difficult to answer definitively. For example, natural background water quality conditions are often masked by ambient contamination and measures of water quality rely on spatially and temporally discrete information (Meybeck 2005). Thus, the density and distribution of sampling stations, as well as the frequency of sampling can profoundly influence the quantitative value of a benchmark, as well as "current state" conditions. Understanding that the quantification of benchmark and current state conditions is dependent upon the quality of the design of the monitoring program, the indicators selected to measure change, and the quality and reliability of the data, is important context for any watershed assessment.

Ideally, monitoring programs are designed with these considerations in mind; however, that has not generally been the case in Alberta. Consequently, opportunities for analyzing water quality in the Athabasca River Basin have been constrained by data availability and quality. A number of attempts have been made to apply a reference condition approach in assessments of water quality in the Athabasca River Basin (e.g., Squires et al. 2010, Squires and Dubé in press). However, despite the existence of various substantial federal, provincial, and industrial aquatic monitoring programs, the lack of consistency within and among programs and uncertain data reliability have undermined any attempts to do basin-wide, integrated water quality assessments. In the words of Squires et al (2010), "[c]onsidering the increasing emphasis of regional assessments and watershed management, ...data simply do not exist to optimally assess change at this scale." Similarly, while advocating a shift toward a reference condition approach in integrated, holistic assessments of water quality on a watershed-basis, Squires & Dubé (in press) reported that they were limited solely to using water quality and quantity data as the main indicators of change, because of incomplete biological and landscape data for the Athabasca River Basin.

In this evaluation of water quality in the Athabasca Watershed, we used a qualitative approach to define water quality benchmarks. These benchmarks included federal water quality standards for the protection of aquatic life (Canadian Council of Ministers of the Environment 2007) and provincial surface water quality guidelines (Alberta Environment 1999; Tables 1-2a and 1-2b). We acknowledge that adopting existing water quality guidelines as the benchmark against which current state is measured has drawbacks and limitations. For example, water quality guidelines do not exist for a wide range of parameters we examined, and most water quality guidelines do not consider or account for site-specific conditions where concentrations of particular parameters may be naturally high (de Rosemond et al. 2008). Further, water quality guidelines, such as CCME, are derived from controlled laboratory toxicology studies that use a single species that is exposed to a single compound, and such toxicology-based guideline values typically reflect what is needed to protect individuals of the most sensitive of species from individual contaminants, and these species may or may not be present in the aquatic system being assessed (Kilgor et al. 2006). In addition, the sensitivities normally assessed in determinations of water quality guidelines do not generally include more subtle physiological, behavioural, or community-level impacts (Azizishirazi et al. 2013). Finally, a toxicological approach to establishing guidelines does not reflect or consider the innumerable variety of processes or interactions that occur in natural aquatic ecosystems, such as chemical speciation, which can have a profound effect on the biosensitivity to, as well as bioaccessibility and bioavailability of, trace metals. For example, aluminum is profoundly affected by pH, with low pH values promoting mineral dissolution and increasing the concentration of aquo Al^{3+}, which is toxic to aquatic organisms.

Notwithstanding the limitations associated with using established water quality guidelines as benchmarks for water quality assessments, this approach is useful in the absence of having quantitative ecological benchmarks established using a reference condition or CEA approach.

Guidelines such as those established by CCME provide context for understanding the maximum acceptable level or threshold value above which aquatic life may be compromised or adverse ecological and biological effects may occur (Wiersma 2005). As such, existing water quality guidelines are frequently used as water quality limits (WQL) against which current conditions are compared. For example, the recently released report entitled "*Surface Water Quality Management Framework for the Lower Athabasca Region"* uses "provincially-accepted water quality guidelines" as water quality limits within their management framework to identify areas where the "risk of adverse effects is heightened" (Government of Alberta 2012, p. 18). Other examples of using established guideline values against which current condition is compared can be found in scholarly work that has been conducted in Alberta (see for example, Lumb et al. 2006 and Squires et al. 2010). Thus, it is clear that established guidelines have some value in the context of evaluating water quality, however limited the application of these guidelines may be.

In light of the drawbacks that have been outlined above with respect to using existing water quality guidelines to define benchmarks in the Athabasca Watershed, adopting a quantitative approach to measuring condition is preferred to assessing change or defining triggers for management action. Thus, the goal of future SoW assessments for the Athabasca Watershed should be to adopt a quantitative approach to assessing water quality, which would allow for direct measures of both spatial and temporal change. Much work has been done over the past 10 years in Alberta advancing watershed assessment science (e.g. Squires et al. 2007; Squires and Dubé in press; Dubé et al. 2013), and the AWC-WPAC should consider working collaboratively with experts in the field to select appropriate water quality indicators, methods for establishing ecosystem condition, and benchmarks against which condition can be compared.

Table 1-2a. Benchmarks for evaluating the current state of water quality in the Athabasca River, as taken from the federal water quality standards for the protection of aquatic life (CCME 2010) and provincial surface water quality guidelines (Alberta Environment 1999).

Parameter	Provincial Acute Guidelines*	Provincial Chronic Guidelines**	CCME Guidelines
Aluminum	-	-	5-100 µg/L[a]
Ammonia Total	-	-	1.04-32.4 mg/L[b]
Arsenic	-	-	5 µg/L
Cadmium	-	-	0.021-0.082 µg/L[c]
Chromium	-	-	1.0 µg/L[d]
Colour	-	Narrative[e]	-
Copper	Table 1-2c	7 µg/L[f]	2-4 µg/L[g]
Dissolved Oxygen	5.0 mg/L (1-day minimum)	6.5 mg/L[h] (7-day mean)	5.5-9.5 mg/L[i]
Fluoride	-	-	120 µg/L
Iron	-	-	300 µg/L
Lead	-	-	1-7 µg/L[j]
Mercury	13 ng/L	5 ng/L	26 ng/L
Nickel	-	-	25-150 µg/L[k]
Nitrate	-	-	13,000 µg/L[l]
Nitrite	-	-	60 µg/L[m]
pH	Narrative[n]		6.5-9
Phosphorus (total)	-	0.05 mg/L	-
Selenium	-	-	1.0 µg/L
Suspended Solids	Narrative[o]		Narrative[p]
Temperature	Narrative[q]		Narrative[r]
Turbidity	-	-	Narrative[s]
Zinc	-	-	30 µg/L

Narrative and Comments

*Acute guidelines are equal to one-half the Final Acute Value. The Final Acute Value is an estimate of the concentration of the toxicant corresponding to a cumulative probability of 0.05 of the acute values of all genera for which acceptable acute tests have been conducted. Acute guidelines require an averaging period.

**Chronic guidelines are equal to the lowest of the Final Chronic Value or the Final Plant Value, unless other data show that a lower value should be used. The Final Plant Value is an appropriate measure of acute toxicity tests to plants. The final plant value is obtained by selecting the lowest result from a test in which the concentrations of test material were measured and the endpoint was biologically important.

[a] 5 µg/L at pH <6.5; 100 µg/L at pH ≥6.5.

[b] 1.04 mg/L NH_3 at pH 8.0 and 10°C; 32.4 mg/L NH_3 at pH 6.5 and 10°C. See also Table 1.2b.

[c] $10^{\{0.86[\log(\text{hardness})]-3.2\}}$. Guideline values calculated at hardness (as $CaCO_3$) of 59.5 and 288 mg/L, which is the range of hardness found in the available data for the Athabasca River and main tributaries between 2007 and 2012. See also Table 1.2c.

[d] Chromium III: 8.9; Chromium VI: 1.0.

[e] Not to be increased more than 30 colour units above natural value.

[f] Chronic toxicity of copper in soft water inconclusive; guideline should only be applied at water hardness ≥50 mg/L $CaCO_3$. Guideline applies to acid-extractable copper concentrations.

[g] 2 µg/L at hardness of 0–120 mg/L (soft to medium) as $CaCO_3$; 3 µg/L at harness of 120–180 mg/L (hard) as $CaCO_3$; 4 µg/L at harness >180 mg· mg/L (very hard) as $CaCO_3$.

[h] Increase to 8.3 from mid May to end of June to protect mayfly emergence. Increase to 9.5 mg/L for areas and times where embryonic and larval stages (from spawning to 30 days after hatching) develop within gravel beds to account for the depletion of dissolved oxygen. Where natural conditions create dissolved oxygen concentrations <110% of the applicable criteria means or minima or both, the minimum acceptable concentration is 90% of the natural concentrations.

[i] Warm water biota: early life stages = 6.0 mg/L; other life stages = 5.5 mg/L. Cold-water biota: early life stages = 9.5 mg/L; other life stages = 6.5 mg/L.

[j] 1 µg/L at a harness of 0–60 mg/L (soft) as $CaCO_3$; 2 µg/L at a harness of 60–120 mg/L (medium) as $CaCO_3$. 4 µg/L at a harness of 120–180 mg/L (hard) as $CaCO_3$; 7 µg/L at a harness >180 mg/L (very hard) as $CaCO_3$.

[k] 25 µg/L at a harness of 0–60 mg/L (soft) as $CaCO_3$; 65 µg/L at a harness of 60–120 mg/L (medium) as $CaCO_3$; 110 µg/L at a harness of 120–180 mg/L (hard) as $CaCO_3$; 150 µg/L at a harness >180 mg/L (very hard) as $CaCO_3$.

[l] Expressed in µg nitrate/L. Value equivalent to 2900 µg nitrate-nitrogen/L.

[m] Expressed as µg nitrite-nitrogen/L. Value equivalent to 197 µg nitrite/L.

[n] In the range of 6.5 to 8.5 but not altered >0.5 pH units from background values.

[o] Not to be increased >10 mg/L over background value.

[p] Clear flow: Maximum increase of 5 mg/L from background levels for any long-term exposure (e.g., inputs lasting between 24 hrs & 30 days). High flow: Maximum increase of 25 mg/L from background at any time when background is 25-250 mg/L. Should not increase >10% of background when background is >250 mg/L.

[q] Not to increase >3°C above ambient water temperature.

[r] Thermal additions should not alter thermal stratification or turnover dates, exceed maximum weekly average temperatures, nor exceed maximum short-term temperatures.

[s] Clear flow: Maximum increase of 8 NTU from background for short-term exposure (e.g., 24 hr period). Maximum increase of 2 NTU from background for long-term exposure (e.g. inputs lasting between 24 hrs & 30-days). High flow or turbid waters: Maximum increase of 8 NTU from background at any one time when background is 8-80 NTU. Should not increase >10% of background when background is >80 NTU.

Table 1-2b. CCME water quality guidelines for total ammonia for the protection of aquatic life (mg/L NH_3).

Temperature (°C)	**pH**							
	6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**10.0**
0	**231**	**73.0**	**23.1**	**7.32**	**2.33**	**0.749**	**0.25**	**0.042**
5	**153**	**48.3**	**15.3**	**4.84**	**1.54**	**0.502**	**0.172**	**0.034**
10	**102**	**32.4**	**10.3**	**3.26**	**1.04**	**0.343**	**0.121**	**0.029**
15	**69.7**	**22.0**	**6.98**	**2.22**	**0.715**	**0.239**	**0.089**	**0.026**
20	**48.0**	**15.2**	**4.82**	**1.54**	**0.499**	**0.171**	**0.067**	**0.024**
25	**33.5**	**10.6**	**3.37**	**1.08**	**0.354**	**0.125**	**0.053**	**0.022**
30	**23.7**	**7.50**	**2.39**	**0.767**	**0.256**	**0.094**	**0.043**	**0.021**

Note: Measurements of total ammonia in the aquatic environment are often expressed as mg/L total ammonia-N. The present guideline values (mg/L NH_3) can be converted to mg/L total ammonia-N by multiplying the corresponding guideline value by 0.8224.

Table 1-2c. Provincial and federal water quality guidelines for metals (cadmium and copper) that are hardness dependent (Alberta Environment 1999).

Hardness (mg/L as $CaCO_3$)	**CCME Cadmium** (µg/L)[1]	**Draft Alberta Acute Guidelines for Copper** (µg/L)
10	0.005	1.7
50	0.018	8.1
100	0.033	16
125	0.040	20
150	0.047	24
175	0.054	28
200	0.060	32
225	0.067	35
250	0.073	39
275	0.079	43
300	0.085	47
325	0.091	51
350	0.097	55

[1] Cadmium guideline = $10^{\{0.86[\log(\text{hardness})]-3.2\}}$

1.4. The Athabasca River: Background and Context

1.4.1. The Athabasca River – Reach by Reach

For the purposes of describing and characterizing the Athabasca River, we have divided the River into five reaches, which generally represent ecologically and hydrologically similar units, and reach boundaries largely follow previous reach delineations outlined by Squires et al. (2010). As the river flows downstream towards the northeast, the reaches are defined as follows:

1. Headwaters Reach: Athabasca Glacier to upstream of Hinton
2. Hinton Reach: Upstream of Hinton to upstream of Whitecourt
3. Whitecourt Reach: Upstream of Whitecourt to Town of Athabasca
4. Athabasca: Town of Athabasca to Town of Fort McMurray
5. Mouth Reach: Fort McMurray to mouth of Athabasca River

The Athabasca River originates at the glaciers of the Columbia Ice Field, located along the Continental Divide in Jasper National Park (Figure 1-3 A-C). In this Headwaters reach, the water is cold, hard, and alkaline, with low organic content, and flows through alpine, sub-alpine and montane zones (Holland & Coen 1983; MacLock et al. 1997; Ricketts et al. 1999). Anthropogenic land use is limited to less than 1% of the reach by area, with the dominant land cover being characterized as mountain and forest (Figure 1-2). The most conspicuous anthropogenic land use in this reach is the town of Jasper, which discharges municipal effluent into the Athabasca River. In 2003, wastewater treatment was upgraded in the town to secondary treatment with UV disinfection, exfiltration, and biological removal via a constructed wetland, prior to discharge into the Athabasca River. Mean annual air temperatures in the montane regions range from 0 to 3˚C, with monthly average minima ranging from -10 to -15 ˚C in January, and maxima from 13 to 15˚C in July. Average annual precipitation ranges from 465 to 665 mm, with approximately twice as much during the winter as summer (Bowman et al. 2005a).

From the town of Jasper, the river travels north, out of the National Park and into the rolling foothills that are characteristic of the Hinton Reach (Figure 1-4 A-C). Forestry is the dominant industrial land use in this reach, with coal mining, conventional oilfield development, and agriculture constituting other major anthropogenic land uses (Figure 1-2). This reach contains the oldest pulp mill in the watershed, located in the town of Hinton, as well as the Alberta Newsprint Company pulp mill, located upstream of the town of Whitecourt. In addition to industrial pulp mill effluent, this reach receives municipal effluent from the towns of Hinton and Edson. Upstream of Edson, the McLeod River, which contributes approximately 7% of the final volume of the Athabasca River, drains lands where the main industrial activities include forestry, oilfield development, and coal mining (MacLock et al. 1997).

The confluence of the McLeod and Athabasca Rivers is located in the town of Whitecourt, and here effluent from both the municipality and Millar Western pulp mill discharges into the river (Figure 1-5 A-C). Anthropogenic land use in the Whitecourt reach is dominated by agriculture, which constitutes approximately 14% of the reach by area, and is concentrated in the southern portion of the reach, as well as around the town of High Prairie, in the northwest corner of the reach (Figure 1-2). The Swan Hills Treatment Facility, which is located in the central part of the reach near the town of Swan Hills, was opened in 1987 to handle and process hazardous waste. This facility is designed to handle up to 45,000 tonnes of waste per year through processes that include incineration and physical/chemical treatment (Swan Hills Treatment Centre 2009). The Pembina River, a major tributary, flows into the Athabasca River downstream of the town of Whitecourt, and primarily drains agricultural lands in the southern portion of the reach. Further downstream, the Lesser Slave River flows into the Athabasca River, contributing approximately 6% of the river's final volume (MacLock et al. 1997). A fourth pulp mill, Slave Lake Pulp, is located along the banks of the Lesser Slave River, with the town of Slave Lake located upstream of the mill. Both the pulp mill and the town, which uses an aerated lagoon treatment system, discharge effluent to the Lesser Slave River, which carries the effluent downstream to the Athabasca River. Downstream of the Lesser Slave Lake confluence, the Athabasca River swings southward towards the town of Athabasca.

Land cover in the middle portion of the watershed near the town of Athabasca is dominated by forest and wetlands, with forestry and agriculture being the major anthropogenic land use (Figure 1-2 and 1-6 A-C). This reach contains the largest Forest Management Area in Alberta, which is managed by Alberta Pacific (Al-Pac) for both softwood and hardwood. The town of Lac La Biche is located on the southern portion of the reach, and agricultural lands surround both the town and the lake for which the town was named. Lac La Biche is an important commercial fishery, and has experienced water quality issues related to anthropogenic nutrient enrichment (Schindler et al. 2008). The lake drains north to the Athabasca River via the La Biche River, which contributes approximately 7% of the final volume of the Athabasca River (MacLock et al. 1997). Further downstream, the Athabasca River flows through the boreal mixedwood towards the city of Fort McMurray, where the Clearwater River flows into the Athabasca River. The Clearwater is the largest tributary to the Athabasca River, contributing approximately 18% of the final volume of the river (MacLock et al. 1997). Here at Fort McMurray, the Athabasca River also receives municipal effluent from the city. In 2010, the city of Fort McMurray carried out a major upgrade on their wastewater treatment system, moving from an aerated lagoon wastewater treatment system to a tertiary treatment system with biological removal.

Downstream of Fort McMurray, the Athabasca River enters the Mouth Reach, which is characterized by rich deposits of bituminous sand that are the focus of industrial oil and gas operations in the region. Land cover is dominated by wetlands and forest, with oil sands mining making up the largest anthropogenic land use in the reach (Figure 1-2 and 1-7 A-C). The Athabasca River receives both industrial and municipal effluent as it flows towards Lake Athabasca, with industrial effluent flowing in from the oil sands mines in the region, as well as municipal effluent from the towns of Fort McKay and Fort Chipewyan. Approximately 1,200 km from the headwaters, the Athabasca River discharges into Lake Athabasca, having fallen approximately 1,200 m at an average slope of 0.86 m/km (MacLock et al. 1997).

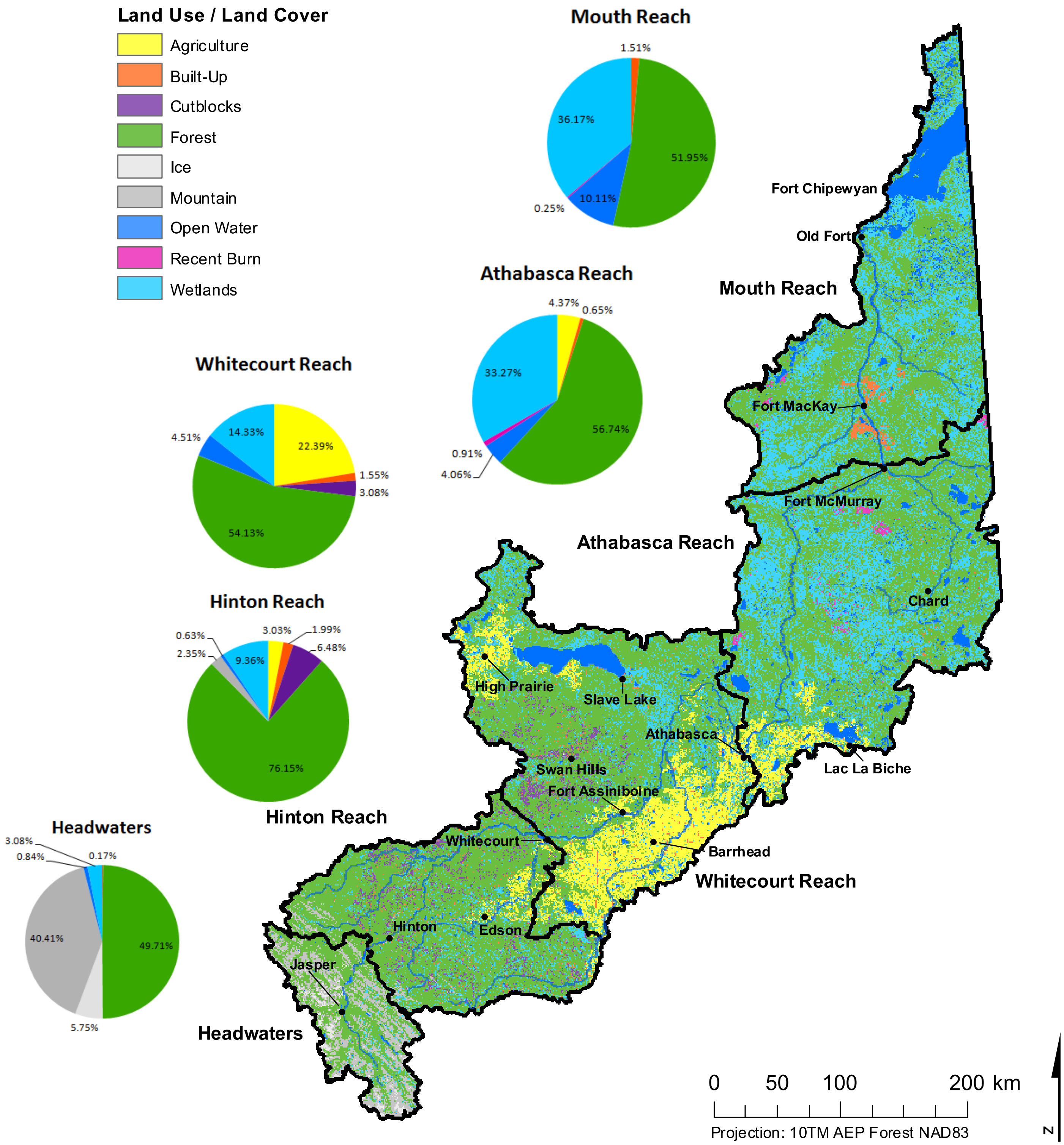
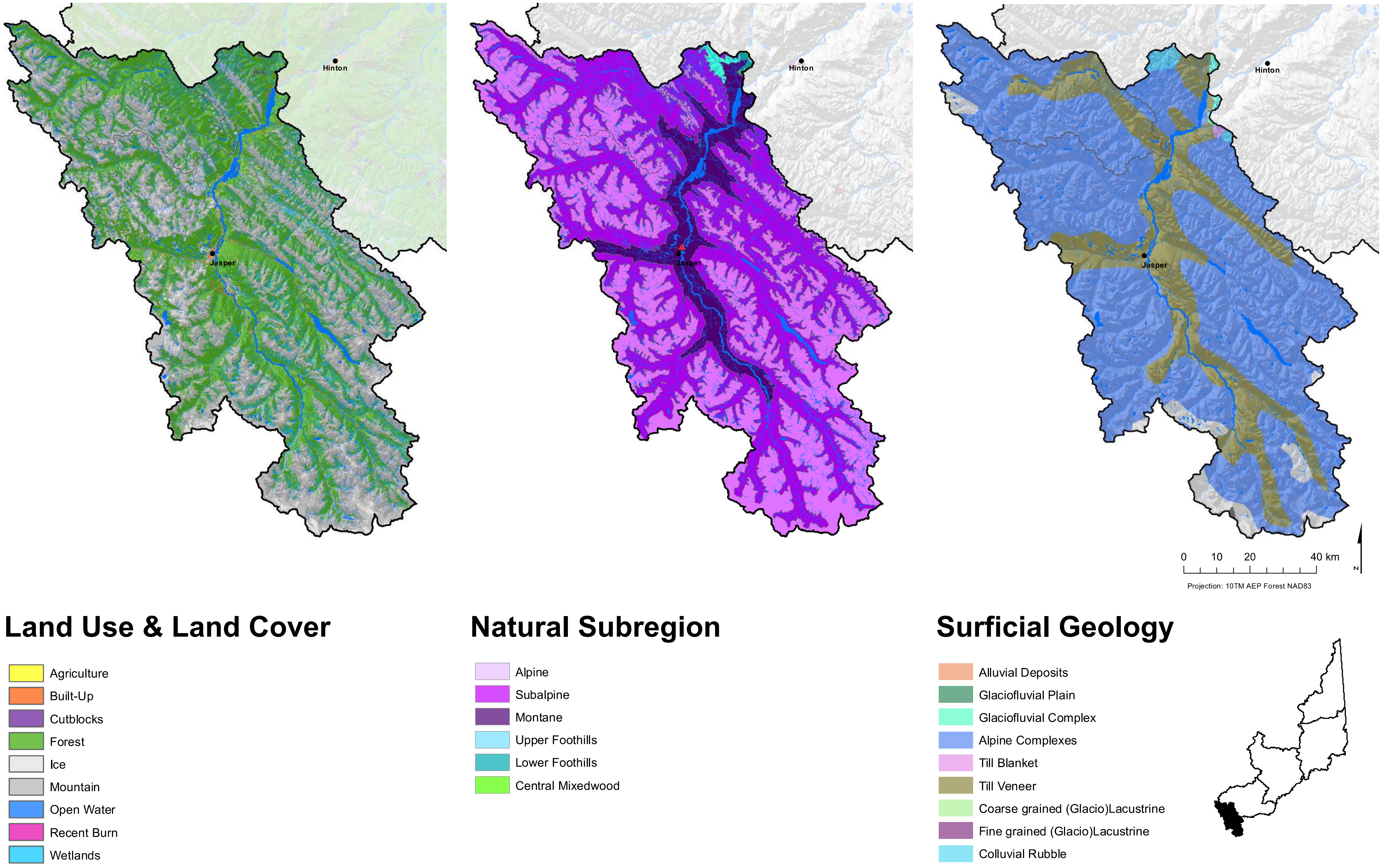


Figure 1-2. The Athabasca River divided into hydrological reaches, with corresponding land use/land cover information by reach. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biologoical 2012).



Land Use & Land Cover

Natural Subregion

Surficial Geology

Figure 1-3. Land use and land cover, Natural Subregions, and Surficial Geology in the Headwaters reach of the Athabasca River. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biological 2012).

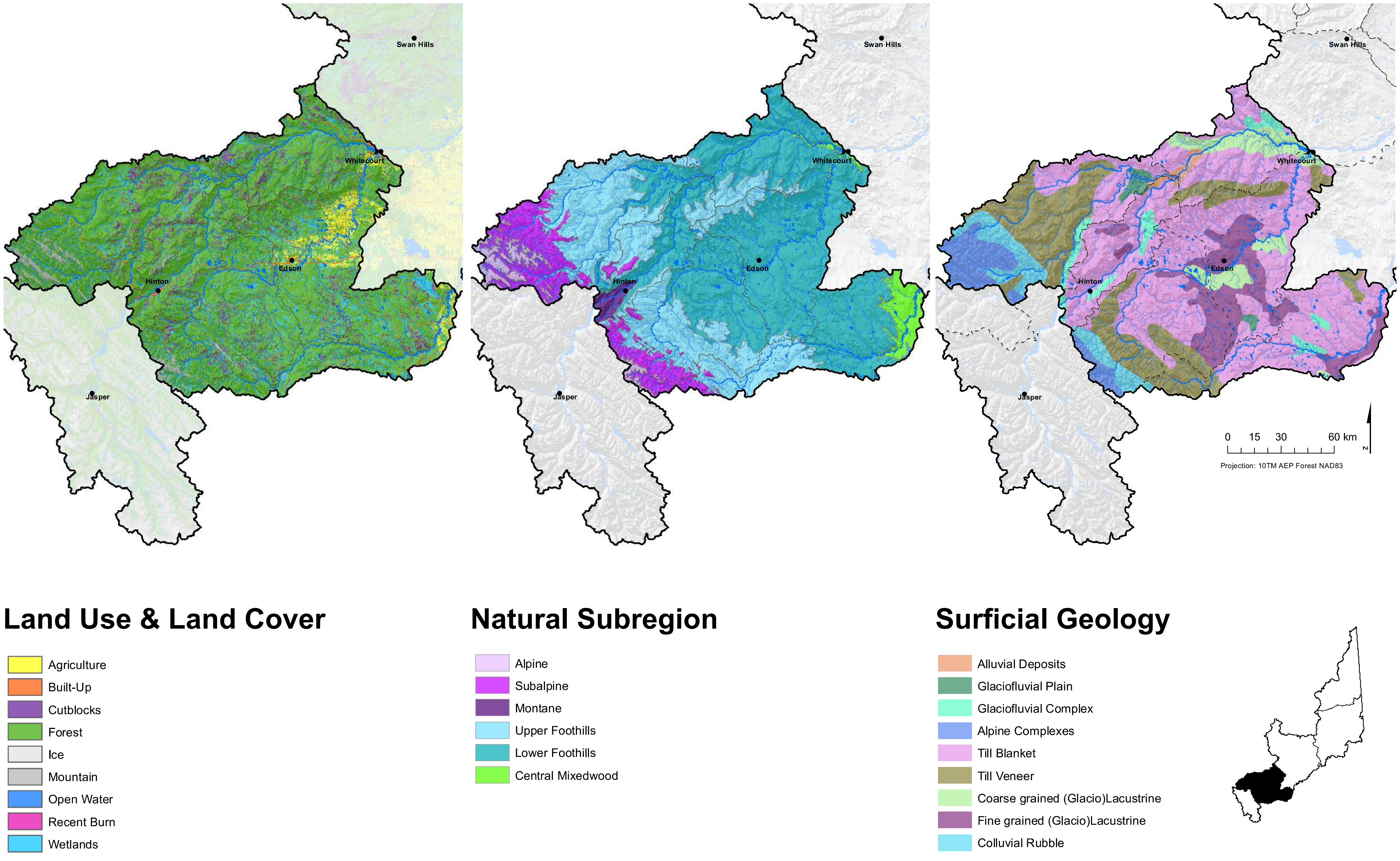
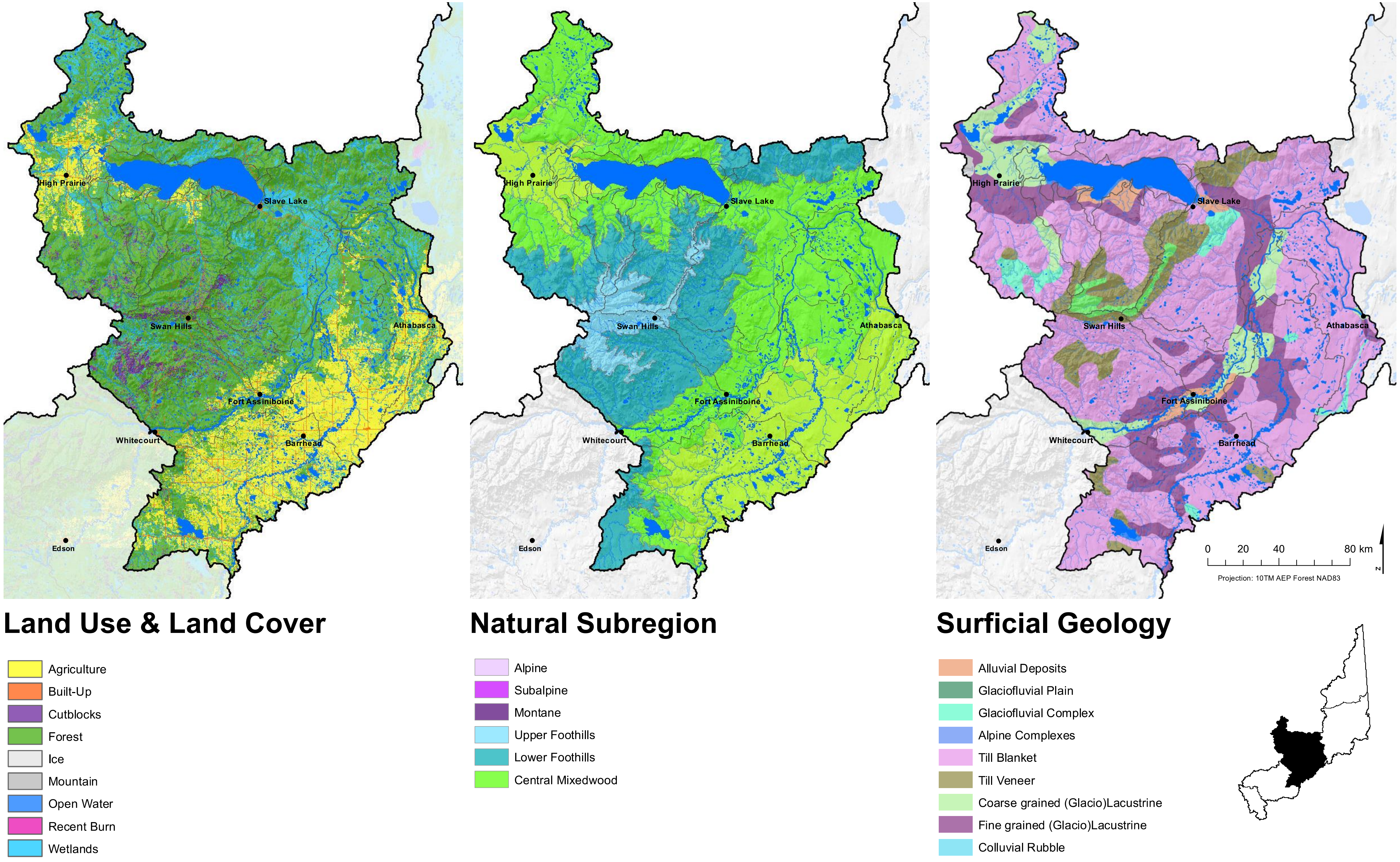


Figure 1-4. Land use and land cover, Natural Subregions, and Surficial Geology in the Hinton reach of the Athabasca River. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biological 2012).

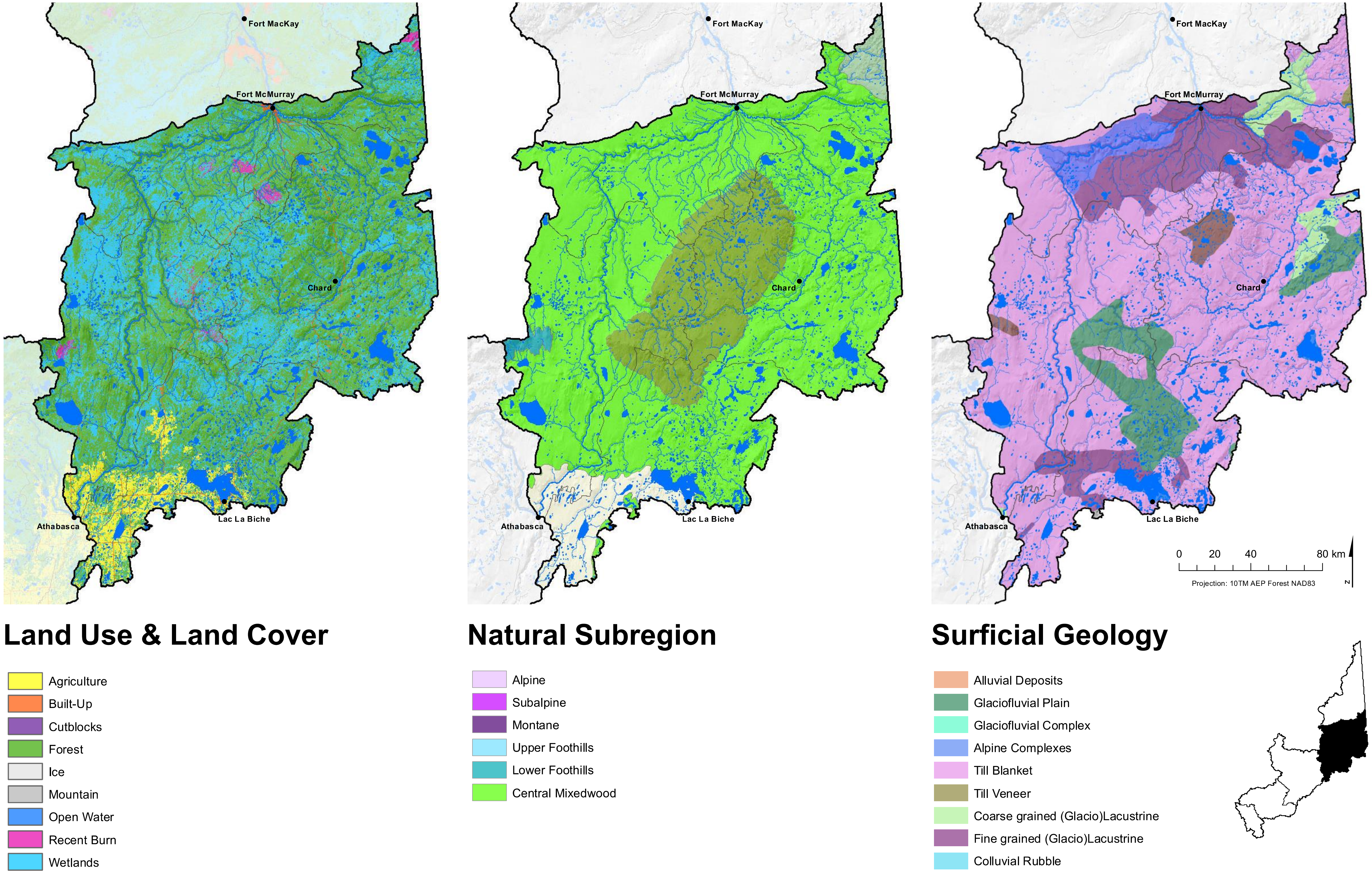


Land Use & Land Cover

Natural Subregion

Surficial Geology

Figure 1-5. Land use and land cover, Natural Subregions, and Surficial Geology in the Whitecourt reach of the Athabasca River. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biological 2012).


Land Use & Land Cover

Natural Subregion

Surficial Geology

Figure 1-6. Land use and land cover, Natural Subregions, and Surficial Geology in the Athabasca reach of the Athabasca River. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biological 2012).

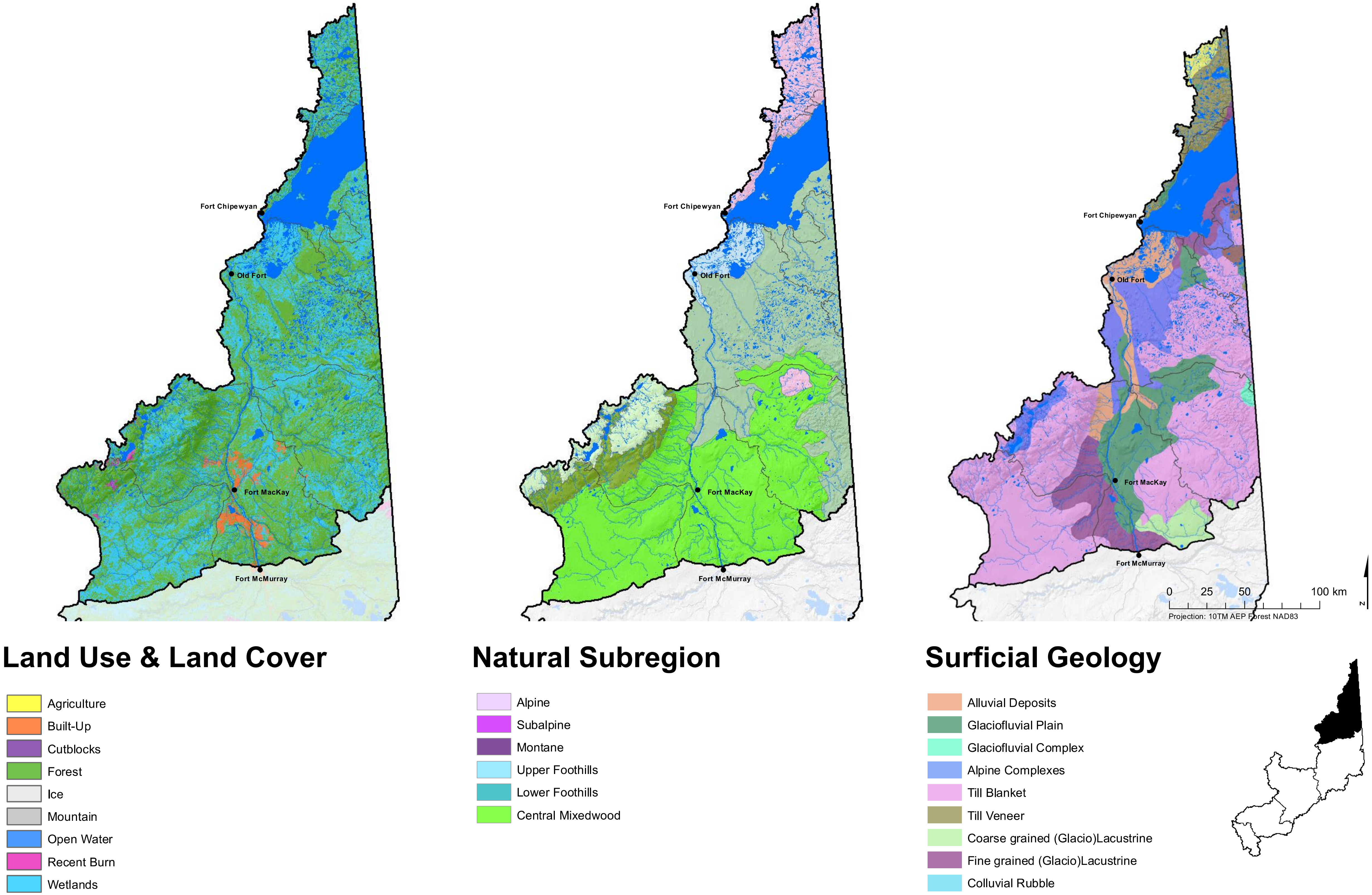


Figure 1-7. Land use and land cover, Natural Subregions, and Surficial Geology in the Mouth reach of the Athabasca River. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biological 2012).

1.4.2. Municipal and Industrial Wastewater Point Sources

In total, there are 136 municipal or industrial wastewater point sources regulated by Alberta Environment and Sustainable Resource Development in the Athabasca Watershed (data source: Municipal Approvals Group, Northern Region, Alberta Environment and Sustainable Resource Development. Date of acquisition: April 12, 2013). Of these facilities, the vast majority (40%) are lagoon stabilization ponds, with less than 6% of treatment systems being reported as Mechanical Activated Sludge, Mechanical Aerated Lagoon, or other treatment system types (Table 1-3). For an additional 40% of facilities, no treatment system type was reported in the data we received from the government. The majority of facilities (38%) are located in the Athabasca Reach, with 15% of the facilities located in tertiary watershed 07CE, 12% in tertiary watershed 07CC, and 8% in tertiary watershed 07CA (Figure 1-8). The Whitecourt Reach has the second highest number of reported facilities (34%), followed by the Mouth Reach (18%).

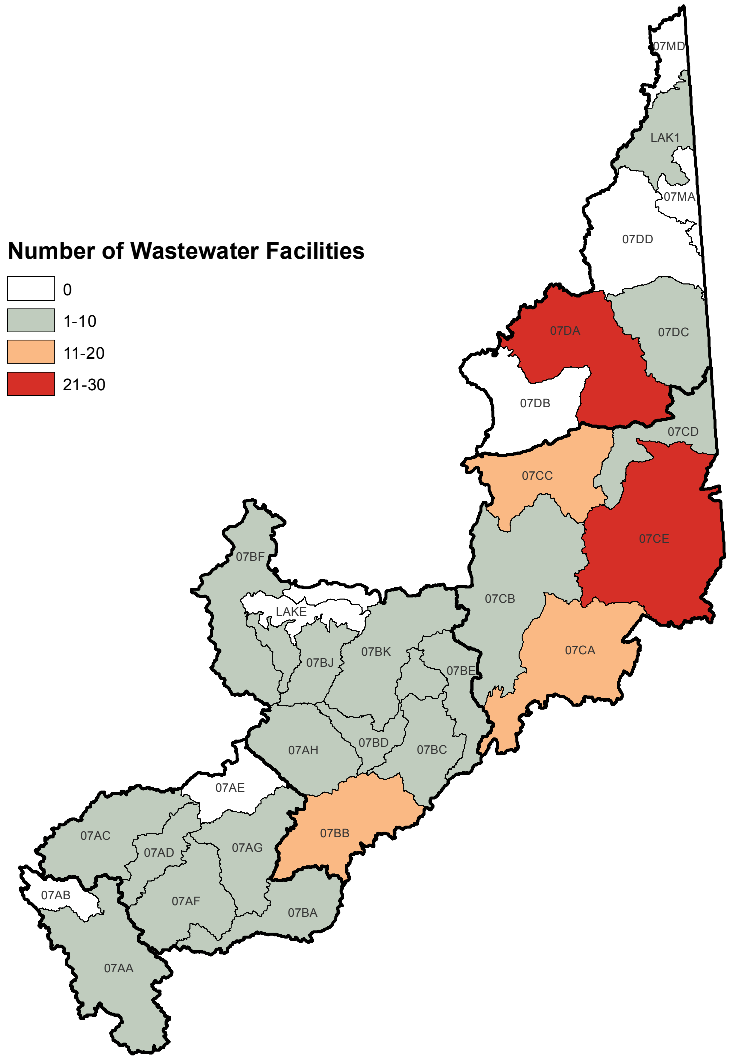


Figure 1-8. Number and location of municipal and industrial wastewater facilities in the Athabasca Watershed (source: Municipal Approvals Group, Northern Region, Alberta Environment and Sustainable Resource Development. Date of acquisition: April 12, 2013)

Table 1-3. Municipal and industrial wastewater facilities in the Athabasca Watershed. Source: Municipal Approvals Group, Northern Region, Alberta Environment and Sustainable Resource Development. Date of acquisition: April 12, 2013.

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
AMADOU LAKE WORK CAMP WASTEWATER SYSTEM, HUSKY OIL	07CB	-	-	-	-
ANZAC SCHOOL WASTEWATER SYSTEM	07CE	Lagoon Stabilization Pond	Final clarification, storage cell	1/yr	Direct to Christina River
ARC RESOURCES FIELD STATION WASTEWATER SYSTEM	07BA	-	-	-	-
ATHABASCA OILSANDS BIRCH CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
ATHABASCA WASTEWATER SYSTEM	07BE	Mechanical Aerated Lagoon	Complete mix cell, partial mix cell, storage cell	Continuous	Direct to Athabasca River
BAPTISTE/ISLAND LAKE REGIONAL WASTEWATER SYSTEM	07BF	Lagoon Stabilization Pond	Storage cell (evaporation)		
BARRHEAD WASTEWATER SYSTEM	07BB	Mechanical Aerated Lagoon	Complete mix cell, 2x partial mix cell, polishing cell, 2x storage cell	Continuous	Paddle River then Pembina River
BLACK PEARL WORK CAMP WASTEWATER SYSTEM	07CA	-	-	-	-
BLUE RIDGE SAWMILL AND MDF MANUFACTURING PLANT	07AH	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, storage cell	1/yr	Direct into wetland
BLUE RIDGE WASTEWATER SYSTEM	07AH	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Bull Creek then Athabasca River
BOYLE REGIONAL LAGOON WASTEWATER SYSTEM	07CA	Lagoon Stabilization Pond	Anaerobic cell, final clarification, storage cell		
BOYLE WASTEWATER SYSTEM	07CA	Lagoon Stabilization Pond	Anaerobic cell, final clarification, storage cell	1/yr	Via unnamed creek into Flat Lake
BP TERRE DE GRACE TEMPORARY WORK CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
BRANCH CORNER MHP WASTEWATER SYSTEM	07AG	Lagoon Stabilization Pond	Storage cell (evaporation)	-	-
CADOMIN WASTEWATER SYSTEM	07AF	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Direct to MacLeod River
CALLING LAKE WASTEWATER SYSTEM	07CB	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Calling Lake, to Calling River, to Athabasca River
CARSON-PEGASUS PROVINCIAL PARK WASTEWATER SYSTEM	07AH	Lagoon Stabilization Pond	Final clarification	1/yr	Carson Creek to Athabasca River
CGGVERITAS TEMPORARY WORK CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
CHERHILL WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	Final clarification	1/yr	Pembina River
CHEVIOT COAL MINE	07AF	Mechanical Biofilm	2x Primary settling tank, fine screen, membrane filtration, emergency storage tank	Continuous	Cheviot Creek Pond then McLeod River

Continued…

Table 1-3. Continued

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
CHIMO CAMPSITE WASTEWATER SYSTEM	07CE	-	-	-	-
CHIMO TEMPORARY WORK CAMP WASTEWATER SYSTEM	07CE	-	-	-	-
CHIMO WORK CAMP WASTEWATER SYSTEM	07CE	-	-	-	-
CHRISTINA LAKE ELK'S POINT LODGE AND MARTIN'S POINT CAMPS WASTEWATER SYSTEM	07CE	-	-	-	-
CHRISTINA LAKE/O&G/MEG ENERGY	07CE	-	-	-	-
CNRL (JEAN LAKE) CONSTRUCTION CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
CNRL JANVIER CAMP WASTEWATER SYSTEM	07CE	Mechanical Biofilm	2x (Solids separation tank, aeration tank with fine screen, ultrafiltration)	Continuous	Continuous to land
COLINTON WASTEWATER SYSTEM	07BE	Lagoon Stabilization Pond	Storage cell	1/yr	Direct to Tawatinaw River
CONKLIN WASTEWATER SYSTEM	07CE	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Via marsh to Jackfish River
CONKLIN WORKCAMP WASTEWATER SYSTEM	07CE	Mechanical Activated Sludge	Aerated equalization tank, activated sludge tank, 2x secondary clarifier, rotary drum microstrainers, ultraviolet irradiation or chlorination	Continuous	
CONKLIN/O&G/DEVON NEC CORPORATION	07CE	Lagoon + Biofilm	Storage cell, ultraviolet irradiation	Continuous	
CONOCOPHILLIPS (SURMONT SAG-D) WORK CAMP WASTEWATER SYSTEM	07CE	-	-	-	-
CPC SURMONT PHASE II WORK CAMP WASTEWATER TREATMENT PLANT	07CE	-	-	-	-
CYNTHIA WASTEWATER SYSTEM	07BA	Mechanical Activated Sludge	Solar Aquatics System w/ gravity clarifier, surge tank, blending tanks, blending tanks, gravity clarifier, sand filters, storage cell	2 per year	Unnamed Creek to Pembina River
DAPP WASTEWATER SYSTEM	07BC	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Ditch to Dapp Creek, then Pembina River
DEVON PIKE TEMPORARY WORK CAMP WASTEWATER SYSTEM	07CE	-	-	-	-
EAST BANK (STEEP BANK) PLANT SITE WASTEWATER SYSTEM	07CC	-	-	-	-

Continued…

Table 1-3. Continued

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
EAST PRAIRIE METIS STLMT WASTEWATER SYSTEM	07BF	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, storage cell	1/yr	Devil's Creek to East Prairie River, then South Heart River
EDSON WASTEWATER SYSTEM	07AG	Mechanical Aerated Lagoon	4x anaerobic cell, 2x partial mix cell, polishing cell	Continuous	Direct to McLeod River
ENILDA WASTEWATER SYSTEM	07BF	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Acadia Creek to Lesser Slave Lake
ENTWISTLE WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, 2x storage cell	1/yr	Drainage ditch to Pembina River
EVANSBURG WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	4x anaerobic cell, final clarification, storage cell, overflow pond	1/yr	Lobstick River to Pembina River
FAUST WASTEWATER SYSTEM	07BJ	Lagoon Stabilization Pond	4x anaerobic cell, final clarification, 2x storage cell	1/yr	Unnamed Creek to Lesser Slave Lake
FAWCETT WASTEWATER SYSTEM	07BC	Lagoon Stabilization Pond	Final clarification	1/yr	Drainage ditch to Pembina River
FIREBAG STAGE 3 CENTRAL PLANT WASTEWATER SYSTEM	07CC	-	-	-	-
FLATBUSH WASTEWATER SYSTEM	07BC	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Drainage to Flatbush Creek, then Pembina River
FOLDING MOUNTAIN VILLAGE CONDOMINIUM WASTEWATER SYSTEM	07AA	Septic Tank and Tile Field	Septic tank, effluent tank, 4 component tile field system.	Continuous	Septic tile field system
FORT ASSINIBOINE WASTEWATER SYSTEM	07BD	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Direct to Athabasca River
FORT CHIPEWYAN	LAKE	Lagoon Stabilization Pond	complete mix cell, 2x partial mix cell, polishing cell	Continuous	Riviere Des Rochers to Lake Athabasca
FORT HILLS OIL SANDS WASTEWATER SYSTEM	07CC	-	-	-	-
FORT MACKAY WORK CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
FORT MACKAY/O&G/SUNCOR	07DC	-	-	-	-
FORT MCKAY WASTEWATER SYSTEM	07DA	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, storage cell	1/yr	Direct to Athabasca River
FORT MCKAY/O&G/SHELL CANADA	07DA	Mechanical Biofilm	Rotating drum screens, , anoxic tank, , supplemental aeration tanks, membrane filtration, ultraviolet irradiation	Continuous	Jackpine Creek to Muskeg River
FORT MCKAY/O&G/SHELL CANADA	07CC	-	-	-	-
FORT MCMURRAY INDIAN BAND/GREGOIRE LAKE WASTEWATER SYSTEM	07CD	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Unnamed creek to Hanging Stone Creek, then Athabasca River

Continued…

Table 1-3. Continued

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
FORT MCMURRAY WASTEWATER SYSTEM	07CC	Aerated Lagoon + Activated Sludge	4x complete mix cell, 2x partial mix cell, + (primary clarifier, biological nutrient removal, secondary clarifier, ultraviolet irradition, dissolved air flotation)	Continuous	Direct to Athabasca River
FORT MCMURRAY/O&G/CANADIAN NATURAL RESOURCES	07CA	Mechanical Biofilm	fine screen, bioreactor tank, membrane filtration, storage cell (emergency)	Continuous	Tar River to Athabasca River
FORT MCMURRAY/O&G/CONNACHER OIL AND GAS	07CC	-	-	-	-
FORT MCMURRAY/O&G/CONNACHER OIL AND GAS	07CC	-	-	-	-
FORT MCMURRAY/O&G/HUSKY OIL OPERATIONS	07CC	-	-	-	-
FORT MCMURRAY/O&G/IMPERIAL OIL RESOURCES VENTURES	07DC	-	-	-	-
FORT MCMURRAY/O&G/SHELL CANADA	07DA	-	-	-	-
GLENEVIS WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	anaerobic cell, final clarification (evaporation)	-	-
GRASSLAND WASTEWATER SYSTEM	07CA	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Unnamed Creek to Pine Creek
GREAT DIVIDE MARIANNA LAKES CAMP WASTEWATER SYSTEM	07CC	Mechanical Biofilm	Solids separation tank, aerated equalization tank , activated sludge tank	Continuous	Continuous to land
GREENCOURT WASTEWATER SYSTEM	07BB	-	-	-	-
GREGG LAKE CAMPGROUND (WILLIAM A. SWITZER PARK) PROVINCIAL PARK WASTEWATER SYSTEM	07AC	-	-	-	-
GROUARD WASTEWATER SYSTEM	07BF	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, storage cell	1/yr	Ditch/wetland to Lesser Slave Lake
HIGH PRAIRIE WASTEWATER SYSTEM	07BF	Lagoon Stabilization Pond	6x anaerobic cell, final clarification, 2x storage cell	2 per year	West Prairie River to South Heart River, then Little Slave Lake
HIGHWAY 43 NORTH WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Wetland, then Sturgeon River
HINTON WASTEWATER SYSTEM	07AD	Collection System	-	-	-
HORIZON NORTH LOGISTICS - BLACK STANDS LODGE WASTEWATER SYSTEM	07DA	-	-	-	-
JACKFISH 1 WORK CAMP WASTEWATER SYSTEM	07CE	-	-	-	-
JACKFISH 2 WORK CAMP WASTEWATER SYSTEM	07CE	-	-	-	-

Continued…

Table 1-3. Continued

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
JACKFISH DISTRICT CAMP WASTEWATER SYSTEM	07CE	-	-	-	-
JANVIER WASTEWATER SYSTEM	07CE	Lagoon Stabilization Pond	2x anaerobic cell, storage cell	1/yr	Christina River
JARVIE WASTEWATER SYSTEM	07BC	Lagoon Stabilization Pond	Final clarification	1/yr	Direct to Pembina River
JASPER WASTEWATER SYSTEM	07AA	Mechanical Activated Sludge	Communitor, 2x complete mix cell, 2x partial mix cell/mechanical screening, storage cell, primary clarifier, chemical process control, 2x secondary clarifier, ultraviolet irradiation, biofilters for odour control.	-	Direct to Athabasca River
JOSLYN CREEK LODGE (TEMPORARY WORK CAMP) WASTEWATER SYSTEM	07DA	-	-	-	-
JOUSSARD WASTEWATER SYSTEM	07BH	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, storage cell	1/yr	Mission Creek to Lesser Slave Lake
KEARL LODGE (TEMPORARY WORK CAMP) WASTEWATER SYSTEM	07DA	-	-	-	-
KIRBY CAMP WASTEWATER SYSTEM	07CA	-	-	-	-
LAC LA BICHE WASTEWATER SYSTEM	07CA	Mechanical Aerated Lagoon	2x Partial mix cell	Continuous	Field Lake to Red Deer Creek
LAC LA NONNE AREA WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	Storage cell (evaporation)		
LAC ST ANNE COUNTY NORTHEAST WASTEWATER SYSTEM	07BB	-	-	-	-
LAKELAND COUNTY (EAST OF LAC LA BICHE) WASTEWATER SYSTEM	07CA	Collection System	-	-	-
LARICINA GERMAIN BASE CAMP WASTEWATER SYSTEM	07CC	-	-	-	-
LEISMER LODGE (CAMPSITE) WASTEWATER SYSTEM	07CE	-	-	-	-
LODGEPOLE WASTEWATER SYSTEM	07BA	Lagoon Stabilization Pond	Final clarification, storage cell, 2x modified wetlands/ infiltration cells	1/yr	Unnamed Creek to Pembina River
LONG LAKE WASTEWATER SYSTEM	07CA	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Direct to Flat Creek
LONG LAKE/O&G/NEXEN INC.	07CE	Mechanical-Extended Aeration	2x (aerated basin, secondary clarifier, ultraviolet irradiation	Continuous	Wetland, lime sludge pond
MANOLA WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	Final clarification	1/yr	Unnamed Creek to Pembina River
MARATHON WORK CAMP WASTEWATER SYSTEM	07CC	-	-	-	-

Continued…

Table 1-3. Continued

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
MAYERTHORPE WASTEWATER SYSTEM	07BB	-	-	-	-
MEADOWVIEW SCHOOL WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	Final clarification	1/yr	Unnamed Creek to Pembina River
MILDRED LAKE/O&G/SYNCRUDE	07DA	Lagoon Stabilization Pond	Anaerobic cell		Horseshoe Lake to Athabasca River
NEERLANDIA WASTEWATER SYSTEM	07BC	Lagoon Stabilization Pond	Final clarification	1/yr	Shoal Creek to Pembina River
NEXEN CAMP WASTEWATER SYSTEM	07CE	-	-	-	-
NITON JUNCTION WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	Final clarification	1/yr	Lobstick River to Pembina River
OILSANDS LODGE TEMPORARY WORK CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
OVERLANDER LODGE CONDOMINIUM WASTEWATER SYSTEM	07AD	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Direct/via swale and slough to Athabasca River
PEERS WASTEWATER SYSTEM	07AG	Lagoon Stabilization Pond	Final clarification	1/yr	January Creek to Beaver River, then McLeod River
PIBROCH WASTEWATER SYSTEM	07BC	Lagoon Stabilization Pond	Storage cell	1/yr	Drainage ditch to Bath Creek, then Pembina River
PINEDALE WASTEWATER SYSTEM	07AG	Lagoon Stabilization Pond	Storage cell	1/yr	Unnamed Creek to McLeod River
PLAMONDON WASTEWATER SYSTEM	07CA	Lagoon Stabilization Pond	4x anaerobic cell, final clarification, 2x storage cell	1/yr	Plamondon Creek to Lac La Biche
POPLAR CREEK CAMP WASTEWATER SYSTEM	07CC	-	-	-	-
PTI GROUP BEAVER RIVER PROPERTIES FORT MCMURRAY WASTEWATER SYSTEM	07CC	-	-	-	-
PTI LODGE WASTEWATER SYSTEM	07DA	Mechanical Activated Sludge	Flow equalization, extended aeration, rotary drum microstrainers	Continuous	Forested area
ROBB WASTEWATER SYSTEM	07AF	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, 2x storage cell	1/yr	Wagner Creek to Embarras River
ROCHESTER WASTEWATER SYSTEM	07BE	Lagoon Stabilization Pond	2x anaerobic cell with synthetic liners, infiltration storage cell		
ROCHFORT BRIDGE WASTEWATER SYSTEM	07BB	-	-	-	-
SANDY BEACH/SUNRISE BEACH WASTEWATER SYSTEM	07BB	-	-	-	-

Continued…

Table 1-3. Continued

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
SANGUDO WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, 2x storage cell	2 per year	Direct to Pembina River
SLAVE LAKE WASTEWATER SYSTEM	07BK	Mechanical Aerated Lagoon	Complete mix cell/ partial mix cell, partial mix cell, partial mix cell/ storage cell	Continuous	Sawridge Creek to Lesser Slave River
SMITH WASTEWATER SYSTEM	07BD	Lagoon Stabilization Pond	2x anaerobic cell, final clarification, storage cell	2 per year	Direct to Athabasca River
SOUTH SHORE REGIONAL (RE-USE) WASTEWATER SYSTEM	07BJ	-	-	-	-
SUNCOR DOVER WORK CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
SUNCOR FIREBAG WASTEWATER SYSTEM	07DA	-	-	-	-
SUNCOR INDUSTRIAL CAMPSITE WASTEWATER SYSTEM	07CC	Mechanical Biofilm	2x (primary clarifier, aerated equalization tank ,submerged fix film, ultrafiltration)	Continuous	Continuous to land
SUNCOR MACKAY RIVER CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
SUNCOR MILLENNIUM PROJECT WASTEWATER SYSTEM	07DA	Mechanical Activated Sludge	Activated sludge tank, membrane filtration, ultraviolet irradiation	Continuous	Athabasca River
SUNCOR MILLENNIUM PROJECT WASTEWATER SYSTEM	07DA	Mechanical Activated Sludge	Sequencing batch reactor, ultrviolet irradiation	Continuous	Athabasca River
SUNCOR VOYAGEUR TEMPORARY CAMP WASTEWATER SYSTEM	07DA	-	-	-	-
SWAN HILLS WASTEWATER SYSTEM	07AH	Lagoon Stabilization Pond	4x anaerobic cell, final clarification, 2x storage cell	1/yr	Morse River to Freeman River, then Athabasca River
THUNDER LAKE RECR. SUBD. WASTEWATER SYSTEM	07BB	Lagoon Stabilization Pond	storage cell (evaporation)		
TRAVERS FOOD SERVICES WORKCAMP WASTEWATER SYSTEM	07CC	Mechanical Activated Sludge	Solids separation tank, aerated equalization tank, aerated basin, secondary clarifier, filtration, ultraviolet irradiation,	Continuous	Adjacent treed area
TRAVERS FOOD SERVICES WORKCAMP WASTEWATER SYSTEM	07CE	-	-	-	-
VOYAGEUR (SUNCOR UPGRADER) WASTEWATER SYSTEM	07CC	-	-	-	-
WANDERING RIVER WASTEWATER SYSTEM	07CA	Lagoon Stabilization Pond	Final clarification, Storage cell	1/yr	Drainage ditch to Wandering River

Continued…

Table 1-3. Continued

Facility Name	Tertiary Watershed	Treatment System	Treatment Processes	Frequency of Discharge	Discharges To
WESTLOCK WASTEWATER SYSTEM	07BC	Lagoon Stabilization Pond	4x anaerobic cell, 2x final clarification, 3x storage cell,	1/yr	Direct to Wabash Creek
WESTWIND MOBILE HOME PARK WASTEWATER SYSTEM	07BE	Lagoon Stabilization Pond	Final clarification	1/yr	Muskeg Creek to Athabasca River
WHITECOURT WASTEWATER SYSTEM	07AH	Mechanical Activated Sludge	Communitor, clarifier	Continuous	Direct to Athabasca River
WHITECOURT/O&G/SEMCAMS	07AH	-	-	-	-
WOODLANDS COUNTY (INCL WHITECOURT AIRPORT) WASTEWATER SYSTEM	07AH	-	-	-	-

1.5. The Athabasca River – Previous Water Quality and Quantity Studies

Water quality and quantity in the Athabasca Watershed have been the focus of a number of scientific studies over the last 30 years. Among the issues of concern, the most commonly identified water quality parameters of interest include chloride, dissolved nitrogen, total phosphorus, polycyclic aromatic hydrocarbons, total organic carbon, turbidity, conductivity, dissolved sodium, trace metals and dissolved sulphate (e.g., Northern Rivers Basin Study 1999, Seitz et al. 2011, Squires et al. 2010). Long-term declines in river flow, increases in basin aridity associated with climate change, and substantial growth in water-dependent industrial development also have been highlighted as significant issues in the Athabasca River Basin, particularly in the lower reaches (Schindler and Donahue 2006, Schindler et al 2007).

The Northern Rivers Basin Study (NRBS), which was a 5-year study initiated in 1991 in response to concerns over pulp mill expansion in the basin, made several key findings and recommendations for management of the Athabasca River. Most notable was the finding that important fish species contained toxic dioxins, furans, and mercury at levels that prompted the NRBS to recommend a review of fish consumption guidelines for the northern river basins (Alberta Environment 1996). This study also raised concerns over high nutrients and low dissolved oxygen (DO) levels in northern rivers. As a result, more stringent DO water quality guidelines (from 5.0 to 6.5 mg/L) were adopted for the protection of aquatic life, and recommendations were made for further study of these water quality concerns (Chambers et al. 2000a). In response to other specific recommendations that came from the NRBS, the Northern Rivers Ecosystem Initiative (NREI) was initiated in 1997. This eight year study focused its efforts on better understanding ecological impacts of changing river flow, ecological responses to pollution and cumulative effects, and vulnerability of drinking water quality (Gummer et al. 2006).

Results from the NREI and other studies conducted since the early 2000s, have consistently raised concerns over the occurrence of organic contaminants throughout the Athabasca Watershed, and in particular, those organic contaminants typically associated with pulp and papers mills, such as organochlorines, chlorinated dioxins and furans, chloro-phenolics, terpenes, organic acids, and polycyclic aromatic hydrocarbons (PAHs) (McCubbin & Folke 1993; Wrona et al. 2000; Carey et al. 2001; McMaster et al. 2006). In response to many of these concerns, changes were made to industrial effluent treatment in the 1990s, and these changes have reduced organic contaminant loading in the Athabasca River (Chambers et al. 2006). However, Gummer et al. (2006, p. 78) have noted that results from the Environmental Effects Monitoring (EEM) program “indicate low level exposure effects to some of the pulp mill effluents” and that “there may be masking of toxicological effects caused by nutrient enrichment”. This has resulted in calls for continued and ongoing monitoring and reporting of results (Gummer et al. 2006). Further, municipal wastewater treatment facilities have been cited as a point source for organic contaminants in the Athabasca Watershed, including volatile organic compounds and major families of chlorinated compounds (Gummer et al. 2006).

Forestry and agriculture have also been identified as important land uses that result in point and non-points sources of organic contaminants such as pesticides, such as herbicides, insecticides, and fungicides (Wrona et al. 2000; Carey et al. 2001). Sub-surficial oil sands formations in the Lower Athabasca region have been identified as natural non-point sources of hydrocarbons, and the large-scale oil sands mining and upgrader developments that operate in the same region have been shown to be point sources of hydrocarbons, naphthenic acids, PAHs, heavy metals, and acidifying compounds (Headley and McMartin 2004; Hazewinkel et al. 2008; Scott et al. 2009; Timoney and Lee 2009; Curtis et al. 2010a; Giesy et al. 2010; Headley et al. 2010; Jeffries et al. 2010; Timoney and Lee 2011; Jordaan 2012).

Most government-based and industry-based environmental monitoring has failed to detect significant accumulation or impacts of contaminant emissions in the oil sands region; however, these monitoring programs have been questioned by some parties in regards to technical design, sampling, analysis, and interpretation (Ayles et al. 2004; Burn et al. 2011). Significant attention was brought to this issue after it was demonstrated that oil sands mining and upgrading activities are contributing to substantial increases in deposition of PAHs and heavy metals within approximately 50 km of these operations (Kelly et al. 2009; Kelly et al. 2010). Since then, other studies have demonstrated significant increases in contaminant deposition and accumulation both downstream and downwind of oil sands operations in the sediments in the Athabasca River, in regional lakes, and upon the surrounding landscapes (Hazewinkel et al. 2008; Timoney and Lee 2009; Timoney and Lee 2011; Kurek et al. 2013).

It was recently reported that there is no evidence of increases in downstream delivery of heavy metals or atmospheric delivery of PAHs northward to the Peace-Athabasca Delta (Hall et al. 2012; Wiklund et al. 2012); however, these studies demonstrate a number of technical problems or oversights. For example, neither study included an assessment of annual deposition rates and only considered long-term changes in concentrations of contaminants in lake sediments, without accounting for long-term changes in the rates of deposition of sediments. Without accounting for differences in the rate of sediment deposition, either from year to year or between sites, there is no way to tell whether the annual amount of contaminants delivered to the lake sediments from flooding or atmospheric deposition have increased over time, stayed the same, or declined. There are also discrepancies in the data presented in the Hall et al. (2012) paper, suggesting that either not all data were considered in drawing conclusions, or that mistakes in calculations and/or data presentation and interpretation were committed. Notwithstanding the apparent technical problems with the Hall et al. (2012) paper, there is little reason to think that atmospheric contaminant deposition from minable oil sands operations in the Lower Athabasca would be a significant problem in the Peace-Athabasca Delta, at least at this time. This is because the wind in northeastern Alberta rarely comes from the south (2.7% of the time, and in total 8.1% of the time from the SSW to SSE). Simply put, atmospheric deposition of contaminants is expected to occur in the direction of the prevailing wind. It is for this reason that there is a significant sampling program being done by Environment Canada and Environment Saskatchewan in northwestern Saskatchewan, and why increases in effects of nitrogen and sulphur compounds in lakes located in the Canadian Shield Natural region to the east and south-east of oil sands mine development in both Alberta and Saskatchewan are being observed for changes in nutrient enrichment and acidification (Hazewinkel et al. 2008; Curtis et al. 2010b). It also explains why the extent and degree of organic contaminant accumulation in regional lakes that are downwind of the minable oil sands region is greater than previously estimated (Kurek et al. 2013).

Concerns have also been raised over the addition of nutrients from a variety of sources to the Athabasca River. The addition of nutrient-rich organic effluents from secondarily-treated municipal and industrial effluents to the naturally nutrient poor waters in the Headwaters and Hinton reaches has resulted in an increase in the abundance of benthic algae, as well as changes in the abundance and composition of benthic invertebrates (Scrimgeour and Chambers

1997 and 2000; Chambers et al. 2006). Algal communities in these reaches are typically phosphorus (P) limited, and relatively low increases in effluent-based total phosphorus (TP; 0.1-5.6 µg/L) have resulted in 4- to 30-fold increases in abundances of benthic algae and macroinvertebrates (Bowman et al. 2007). However, total phosphorus concentrations are not typically a good predictor of attached algae abundance in the Headwater reaches of the Athabasca River, because relatively high concentrations of natural P are bound to glacial flour[1] and not readily bioavailable. Nutrients in municipal and industrial effluent are readily bioavailable to algae in the upper reaches of the Athabasca River, which explains the high sensitivity of benthic communities to cultural eutrophication point-sources (Bowman et al. 2005b).

In addition to downstream biological nutrient-enrichment effects, municipal and industrial effluents in the upper Athabasca contribute to declines in dissolved oxygen (DO) levels, particularly during low-discharge periods in the fall and winter (Chambers et al. 1997 and 2006). Water column concentrations of DO have rarely been demonstrated to fall below guideline concentrations of 6.5 mg/L in the Athabasca River; however, studies performed in the Peace River Basin have demonstrated frequent failures of porewater DO concentrations (i.e., water in the surface layers of river sediments) to meet DO guidelines, and porewater DO concentrations cannot be predicted from water column DO concentrations (Chambers et al. 2000a). While a similar study has not been performed in the Athabasca River Basin, it is likely that similar low porewater DO concentration are present downstream of municipal and effluent point-sources on the Athabasca River.

In a recent investigation of longitudinal and temporal trends in a number of water quality and biological parameters, the effects of four pulp mill point sources along the length of the mainstem Athabasca River were examined and described (Dubé et al 2006). This study drew on water quality data that were collected at three federal government monitoring stations (data from 1969-2003), five provincial government monitoring stations (data from 1985-2001), and 11 Environmental Effects Monitoring program stations, all located along the mainstem of the Athabasca River (Dubé et al 2006). Due to inconsistencies between monitoring programs and scarcity of reliable long-term data, only dissolved oxygen (DO), biological oxygen demand (BOD), dissolved organic carbon (DOC), total phosphorus (TP), dissolved nitrogen (nitrate+nitrite), and total ammonia data were considered, in addition to a select number of biological indicators from the EEM program that were related to fish and benthic invertebrate communities (Dubé et al 2006).

In general, results from this study revealed that water chemistry and biological changes in the Athabasca River reflected major point sources, internal recovery mechanisms, and non-point source and tributary inputs (Dubé et al 2006). As previously documented by Chambers et al. (2000b), DO decreased along the length of the river, coincident with increases in riverine BOD. In addition, DOC increased 12-fold along the length of river (0.8 to 9.2 mg/L), with various peaks between major municipal and industrial point sources. Longitudinal DOC increases were attributed to a combination of point sources, non-point sources, and tributary inputs. TP

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[1] Glacial flour is the fine-grained sediment carried by glacial rivers that results from the abrasion of rock at the glacier bed. Its presence turns lake water aqua blue or brown, depending on its parent rock type. Rivers originating beneath glaciers are choked with glacial flour, the silty fine-grained sediment produced by the abrasion of rocks at the glacier bed (source: http://vulcan.wr.usgs.gov/Glossary/Glaciers/glacier_terminology.html, accessed April 9, 2013).

increased 4-fold along length of river (0.02 to 0.074 mg/L), with a variety of peaks downstream of major industrial and municipal point sources, followed by longitudinal declines in concentrations to levels similar to headwater reaches. The major longitudinal increase was observed downstream of the Fort McMurray municipal sewage effluent inputs, and this pattern was also reflected in DOC and dissolved $NO_2 + NO_3$ data. Dissolved NO_2+NO_3 also decreased between the headwaters (0.093 mg/L) and Hinton (0.043 mg/L), with subsequent major peaks mainly downstream of municipal effluent inputs.

In terms of biological changes downstream of the four pulp mills on the Athabasca River, of the 96 identified responses identified in the Cycle 2 Environmental Effects Monitoring (EEM) data, the majority of changes occurred in fish communities (69%), with fewer changes documented in benthic invertebrate communities (4%) (Dubé et al 2006). Downstream of the pulp mill located in the town of Hinton, significant nutrient enrichment responses were demonstrated in longnose sucker (*Catostomus catostomus*) and spoonhead sculpin (*Cottus ricei*), in the form of increased condition and gonad and liver size. This conclusion was supported by significant upstream-downstream increases in TP and benthic algal biomass. This enrichment effect is consistent with fact that the pulp mill in the town of Hinton, at that time, contributed the highest daily loadings of BOD, TSS, and ammonia of the four pulp mills included in the study, although only the third highest TP. There was no change in abundance or number of taxa, which differed from an earlier finding from 1992 that documented increases in both (Culp et al 2000).

Downstream of the Alberta Newsprint Company (ANC) pulp mill near Whitecourt, faster growth, better condition, and reduced gonad size were observed in longnose sucker, with no change in benthic invertebrate community metrics (Dubé et al 2006). The Millar Western pulp mill near Whitecourt also decreased condition and liver size in fish, and longnose sucker and female trout perch grew more slowly, but gonad sizes increased. There was also an increase in number of benthic invertebrate taxa (nearfield) and community dissimilarity downstream of the Millar Western mill. The effects of the Alberta-Pacific pulp mill downstream of Athabasca included decreased liver size in fish, with decreased gonad size and condition, and faster growth in trout perch, but no changes in benthic invertebrate communities. Data collected in Cycle 3 of the EEM program demonstrated enrichment responses in fish downstream of the pulp mill in the town of Hinton, and smaller liver sizes downstream of the Alberta Pacific mill (there was no fish monitoring by ANC and Millar Western in Cycle 3). Significant effects of pulp mill point source inputs on benthic invertebrates were not evident in Cycle 3 of the EEM program. The overall conclusion of Dubé et al (2006) was that the combined municipal-industrial point source at Hinton remains a significant stressor in the Athabasca River, and that general patterns in a limited number of water quality parameters and biological indicators reflect the combination of municipal and pulp mill effluent point sources, non-point sources, and tributary inputs.

Results from past studies of the Athabasca River suggest that both point and non-point sources contribute a variety of ecologically significant inorganic and organic contaminants to the Athabasca River, and a more comprehensive examination of organic constituents throughout the watershed is needed to determine whether these contaminants are having an effect on the condition of the watershed, including in major tributaries and lakes. In addition to concerns over water quality in the watershed, concerns have been raised over water quantity. For example, past studies have suggested that climate change has the potential to significantly change the timing and volume of water flow in the Athabasca River (Schindler and Donahue 2006; Schindler et al. 2007), as well as lake levels in the Peace Athabasca Delta (Prowse et al. 2006).

Such changes are expected to have significant effects on the hydrology, ecosystems, and natural resources in the basin (Gummer et al. 2006).

1.6. References

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Chapter 2: Water Quantity in the Athabasca Watershed

2. Introduction

In order to assess the quantity of water participating in the hydro-ecological functioning of a watershed it is important to quantify the different components of the water budget, including water inputs, storage, and outputs. Maintaining sufficient water quantity flowing through the hydrological system is important because it makes water available for geomorphologic, hydrologic, and ecological processes, as well as for societal use. However, the way water availability is defined depends greatly on which components of the hydrological system are of most interest to managers. For example, precipitation is a good first approximation of water availability when plants are considered, whereas river discharge, which integrates terrestrial uses of water including evapotranspiration and storage in wetlands and aquifers, is more appropriate for aquatic organisms in streams and rivers.

Given the changing definition of water availability depending on the position within the water cycle, the intent of characterizing the state of watershed with respect to water quantity was to compile and analyze all of the separate components of the water budget (as metrics of water availability) for the 31 tertiary watersheds of the Athabasca Watershed. We define the water budget as:

$$P - ET = Q + \Delta S;$$

where: P = precipitation, ET = evapotranspiration, Q = discharge, and ΔS = change in storage (in lakes and large wetlands with open water) (Figure 2-1).

We did not consider groundwater flows and human withdrawals, due mainly to a shortage of data available for the entire watershed, but also because at larger spatial scales (e.g., tertiary watersheds) and over longer time periods (e.g., one year), fluxes of P, ET, and Q dominate the water budget.

2.1. Assessing the “Current State” of Water Quantity

We defined the current state of the watershed in terms of its water quantity by computing the most recent 30-year climate normal (1981 to 2010). A climate normal is a climatological concept that aims to encapsulate the arithmetic average of a climate element such as precipitation over a 30-year interval (WMO 1989). This time period is sufficiently long to average out inter-annual variation in climate, although perhaps not decadal variability, and provide us with good first approximation of the expected climate condition. It is important to note, however, that climate is influenced by natural cycles that are longer than 30-year time steps, and more importantly, by directional change as is currently occurring due to human driven climate change. Thus, in order to make better sense of the current state of the system, we placed the 1981-2010 climate normal into a longer historical context, in addition to considering its future trajectory using global climate model (GCM) scenario analyses. Given the available datasets, our entire temporal window of consideration spanned 200 years, from 1901 to 2100. Ideally, even longer time-horizons should be considered to better understand the natural range of variability, as opposed to changes introduced by human activity.

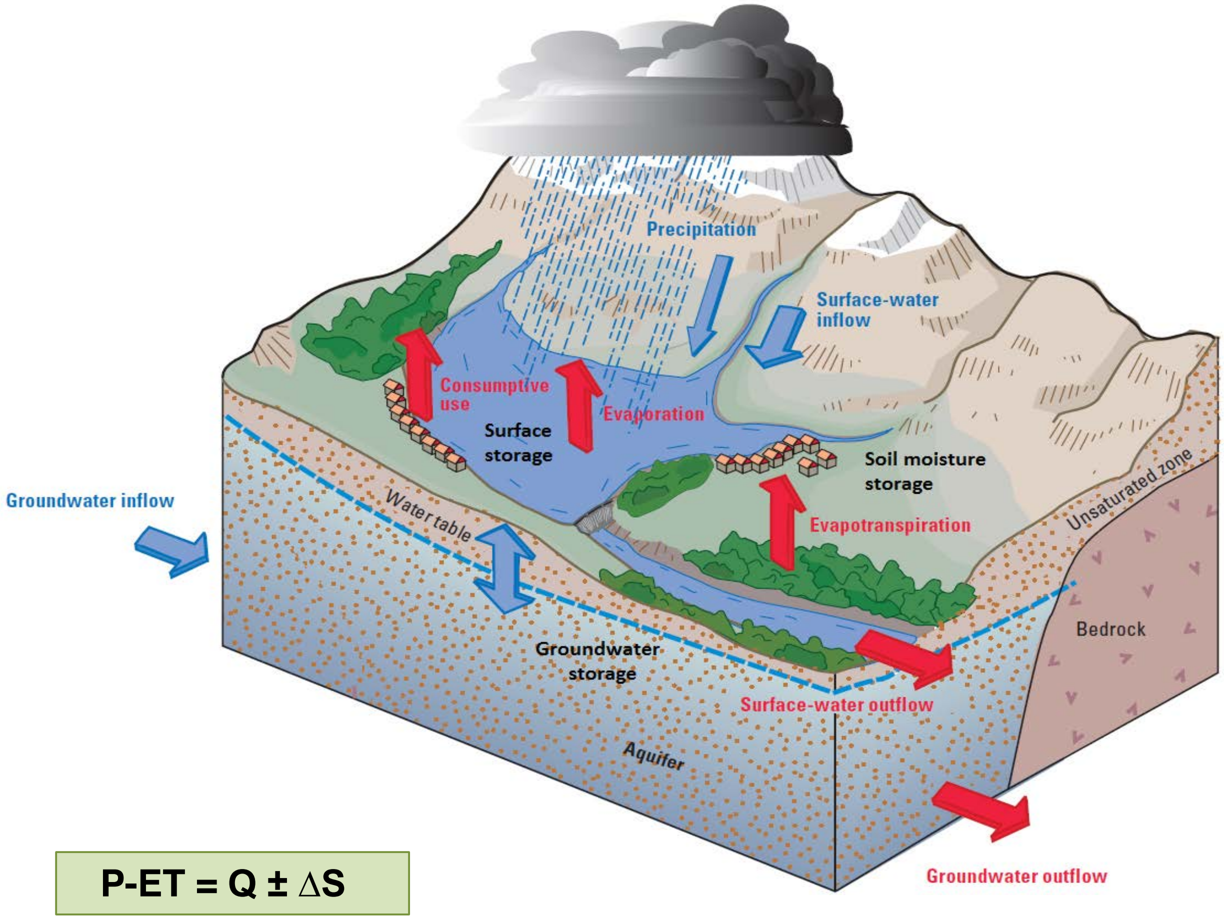

Figure 2-1. Pictorial water budget for a hypothetical watershed including natural fluxes of precipitation, evapotranspiration, discharge (surface water flow), and groundwater flow [red and bold], as well as water storage in lakes, wetlands, soils and aquifers [black and bold]. In addition, humans directly modify this budget, by taking water from surface and groundwater sources, as well as by modifying ET rates through land cover change (modified from Maupin and Weakland 2009).

Previous work has shown that the prairies of Western Canada and the adjacent boreal ecozone to the north are most likely to enter a significantly drier phase, mostly driven by a substantial increase in evapotranspiration and melting of snow and/or ice in the mountains and lowland regions as a result of a warming global climate (Schindler and Donahue 2006, Schindler et al. 2007). Likewise, Yip et al. (2012) showed decreases in water storage, precipitation and increases in temperature and evapotranspiration across the Athabasca Watershed from 1961 to 2002**. This state of watershed report for water quantity will assess with a temporally comprehensive database of climatic and hydrologic variables the current state embedded in a long-term hydro-climatic context**.

2.2. Methods

2.2.1. Unit of Analysis

The smallest unit of reporting for the water quantity indicators will be based on the tertiary watersheds as defined by the Water Survey of Canada (WSC) (Figure 2-2). There are 31 tertiary watersheds, 10 located along the trunk of the Athabasca River (most of these are composed of many smaller watersheds that separately flow into the river), and the remaining tertiary watersheds belonging to major tributaries such as the Clearwater, Lesser Slave, McLeod, and Pembina. The 31 tertiary watersheds are grouped into 10 subwatersheds, most of them comprising the major tributaries (for example, the McLeod subwatershed is made up of two tertiary watersheds 07AF and 07AG). A general physiographic description of the Athabasca Watershed is provided in Section 1.4. For illustrating the long-term temporal variation in the metrics of water availability, we will use the entire Athabasca Watershed as the spatial unit to which all data will be aggregated.

2.2.2. Methodology to Compile and Analyze Hydro-climate Data Series

In order to estimate the current state and 200-year trajectory of the water budget, we assembled five key metrics of the budget at the monthly time-step (where data availability allowed). We compiled three climatic variables: precipitation (P), potential evapotranspiration (PET), and P-PET, and two hydrological variables: discharge (Q) and storage (S).

2.2.3. Climate Data Based Metrics

The climatic metrics of the water budget were assembled using spatially interpolated grids of P and T. Climate data were acquired from Natural Resources Canada's Canadian Forest Service (CFS), where a team of scientists have compiled a continent wide climate database from 1901 to 2010 (McKenney et al. 2011). The climate grids were interpolated from monthly values of P and T collected at Environment Canada's meteorological station network using thin-plate smoothing splines, as implemented in the ANUSPLIN climate modeling software (e.g., Hutchinson 2011). The spatial resolution of the climate grids was 10 km^2. The accuracy of these products was assessed (for the entire continent) by leaving out 50 representative stations and assessing the mean absolute error (accuracy) and mean error (bias). The accuracy of temperature grids was approximately ±1.0°C and ±30% for precipitation, but with essentially no bias (McKenney et al. 2011). Given the difficulty of interpolation of precipitation in mountainous areas, the greatest uncertainty is highest there and decreases as relief decreases.

For each tertiary watershed, we computed a mean value for each month of the 110-year series. T_{min} and T_{max} were then averaged to produce T_{mean}, which was used to compute PET based on Thornthwaite (1948) (also see methods of Schindler and Donahue [2006] for quick overview of equations). PET is not the same as actual ET (AET), which is what we are interested in. PET was initially developed to estimate the maximum transpiration rate from a canopy of crops with water in the soil at field capacity (i.e., water is not limiting ET). It is a radiation-based computation of potential ET where energy is estimated from air temperature and corrected by latitude. Watershed based AET is usually lower than PET, because ET only proceeds at the potential rate when water is not limiting. In data-sparse northern regions, it does give a reasonable approximation of ET, especially at the annual time-step. Based on P and PET, we computed effective precipitation (P-PET), which has been used as a useful indicator of water availability in the Athabasca Watershed and adjacent watersheds (Schindler and Donahue 2006; Sass and Creed 2008). The units of measurement for P, PET, and P-PET are millimeters (mm), which can be understood as the depth of water that would blanket the entire watershed if it were flat and impermeable. We also converted Q to units of millimeters so that it could be compared directly to the climate metrics. Converting the areal coverage of open water (metric for storage) to depth of water was not possible due to the lack of spatially comprehensive lake depth data.

McKenney et al. (2011) also used the runs of five Global Circulation Models (GCMs) to provide different downscaled scenarios for P and T (both T_{min} and T_{max}). Downscaling involves taking the GCM outputs at approximately 400 km * 400 km grid resolution and using the spatial pattern of P and T based on historical data to estimate future P and T at 10 km * 10 km grid resolution. We used the four available downscaled GCM outputs provided as monthly normals for three time periods 2011 to 2040, 2041 to 2070, and 2071 to 2100. We calculated a grand average based on the three emission scenarios (A2, A1B, B1) from each of Canadian Centre for Climate Modeling and Analysis Coupled GCM (CGCM) version 3.1, Commonwealth Scientific and Industrial Organization (CSIRO) version 3.5, National Center for Atmospheric Research (NCAR) version CCSM3.0, and Center for Climate System Research Model for Interdisciplinary Research on Climate (MIROC) version 3.2 modeled surfaces (McKenney et al. (2011).

Once the basic variables of P, PET, and P-PET were assembled for each tertiary watershed at a monthly time step, they were aggregated to the annual time step by summing up the monthly totals. In order to characterize the current state of the system, 30-year averages (1981-2010) of annual P, PET, and P-PET were computed. For analyzing historical trends (1901-2010), we ran Mann-Kendall test which is a non-parametric test ideal for analyzing time-series data (Helsel and Hirsch 1992). Mann-Kendall's tau (τ) uses a rank-based procedure to determine the correlation between two variables. A significance level of $p<0.05$ was used to identify highly significant correlations, meaning that there was a 5% probability that the observed results occurred by chance only. We also identified correlations of 'moderate' significance ($p<0.10$). The sign and the strength of the correlations were mapped by creating different categories for either negative or positive trends.

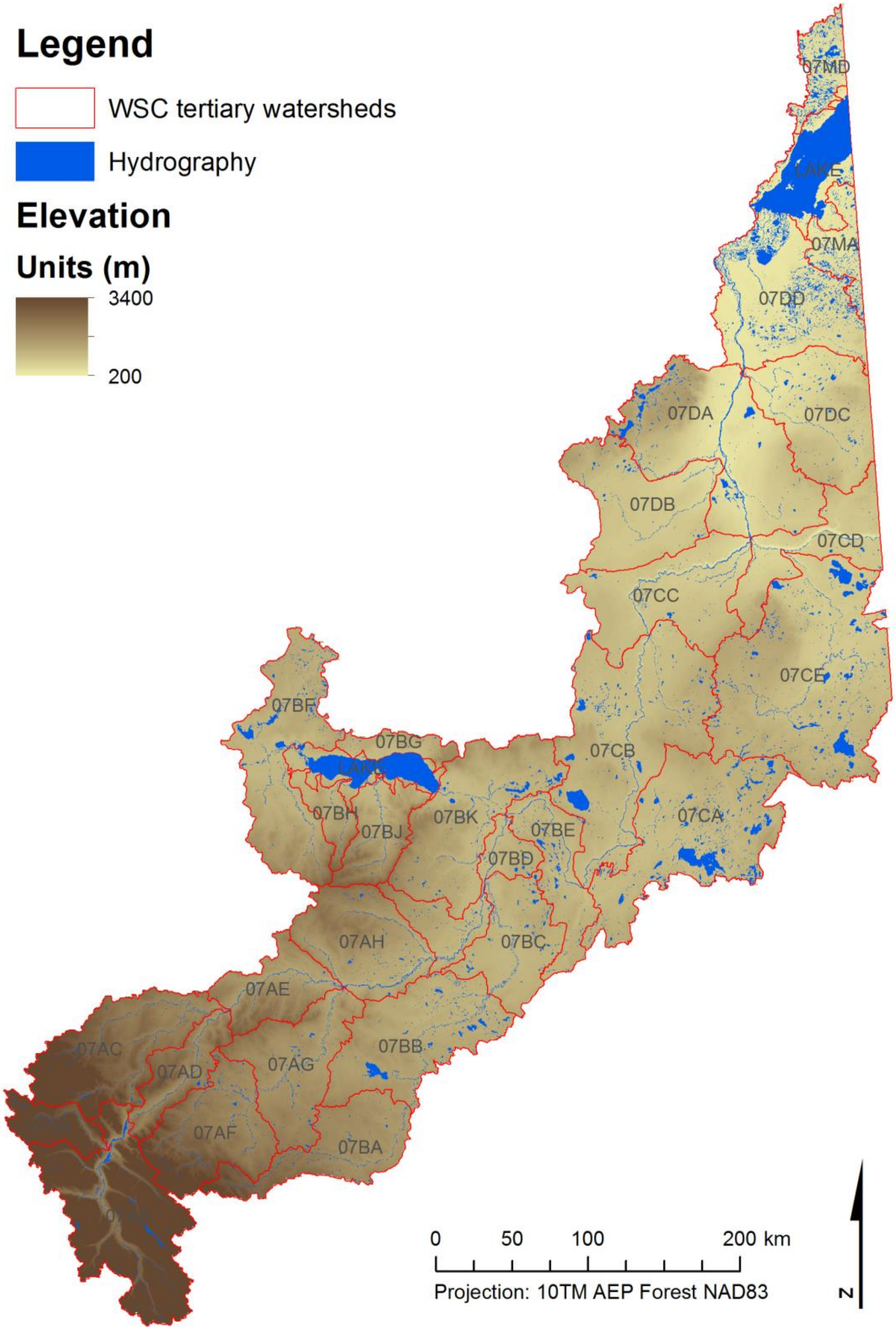

Figure 2-2. The unit of analysis for assessing the state of water quantity for Athabasca Watershed is the Water Survey of Canada tertiary watershed unit.

2.2.4. Hydrologic Metrics

For each tertiary watershed, one long-term (>30 year), continuous and all-season Water Survey of Canada station was identified. In an ideal world, there would be a discharge station at the outlet (or mouth) of each tertiary watershed so that the flows being measured reflected all of the processes occurring in that tertiary watershed. This was the case for only a few of the stations, the rest measured flow as close to the mouth as possible, and with as much data as available. The WSC data were downloaded at the monthly time step. All flow measuring station data were converted to water depth based on watershed area so that they could be compared to other components of the water budget. Monthly discharge totals were aggregated to the annual time-step by summing up the monthly totals. Some tertiary watersheds only had water level data, which cannot be easily converted into flow values; however, we did use the water level values to assess long-term trends in water level. For stations with only water level data, maximum summer levels were extracted and analyzed for long-term trends. Long-term trends for both flow and level data were analyzed using Mann-Kendall tests.

To estimate water storage in each tertiary watershed, we analyzed the change in the areal extent of open water derived from remotely sensed imagery. Changes in open water extent provide a good proxy for changes in water level, especially where lakes and wetlands are shallow. Changes in water level, in turn, provide a good indicator of water availability by revealing fluctuations in water storage. We assumed that most water bodies had similar shapes and thus responded similarly to inputs of water, which was reflected in areal changes of open water extent. This is probably not unreasonable given the numerous shallow lakes dotting the Boreal Plain portion of the Athabasca Watershed. Applying this technique for lakes that are deeper and have steeper littoral zones introduces error because volumetric changes are not reflected by areal changes. While the mountainous tertiary watersheds were probably most sensitive to this kind of error, we assumed that the areal extent of open water for most of the Athabasca Watershed is a useful measure of water storage as demonstrated by Sass and Creed (2008) for the Utikuma Uplands.

To delineate open water areas, we used the middle-infrared band (Band 5: 1.55 to 1.75 μm) of the Landsat Thematic Mapper sensor, as it is excellent at classifying open water areas (Lunetta and Balogh 1999; Frazier and Page 2000) (Figure 2-3a). Water pixels have very low reflection in the middle-infrared part of the electro-magnetic spectrum. This can be seen readily in a histogram derived using band 5, which contains two distinct populations of pixels: one containing water pixels and another containing non-water pixels (Figure 2-3A). Thus, water areas can be separated from non-water areas by applying a single threshold value. To correct for any radiometric differences between the images, histogram matching was performed, although most images had a very standard histogram resembling Figure 2-3B.

For the open water mapping, we used three time-periods, 1985, 1996, and 2010 to assemble watershed wide maps of open water at 30m spatial resolution. August was the target month but some of the images were from outside this range (July or September) because of cloud cover apparent in some of the imagery for the month of August. Although cloud-free images were chosen, there were stray clouds and areas of haze that were later removed from the analysis. As a result, our final analysis does not include the entire area of each tertiary watershed. Images were mosaicked (i.e., multiple images had to be pieced together to cover each tertiary watershed) and the area of open water was delineated by applying a threshold value that corresponded with the minimum value in the histogram. The same threshold was used for all images. Given that shadows cast by mountains have similarly low reflectance, areas with a slope of ≥5% were masked out in the headwaters region of the Athabasca Watershed. Open water extent was converted to 'percent cover' for each tertiary watershed. The three temporal data points did not allow for a statistical test of significance of linear trends. In order to determine long-term changes we calculated the percent change in open water extent between 1985 and 2010 and mapped the spatial pattern of changes.

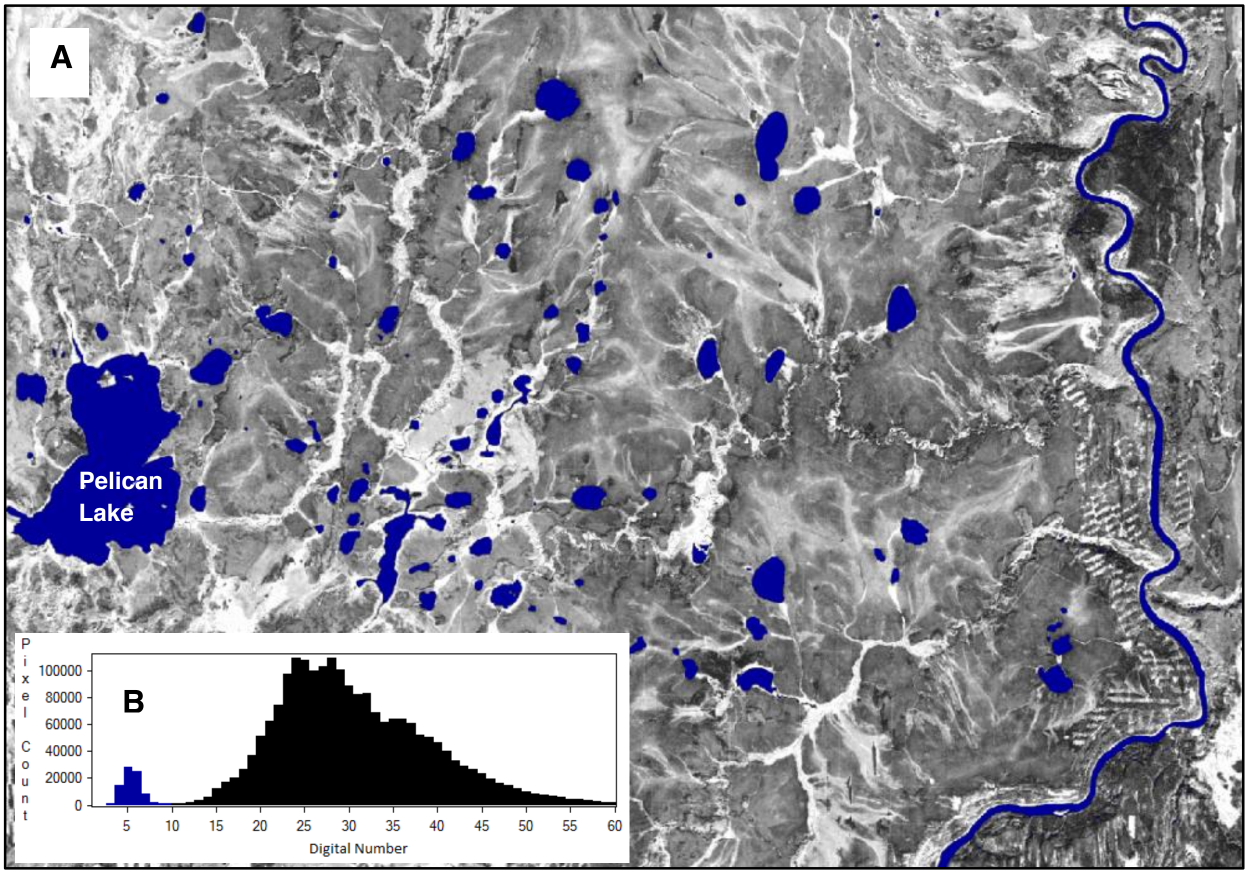

Figure 2-3. Landsat Band 5 (Near-infra-red image) showing open water areas classified as blue (A) and accompanying histogram of image pixel values (B) for this scene along the Athabasca River near Pelican Lake.

2.3. Results and Discussion

We have organized the results and related discussion into two parts: (1) analysis of metrics of climate (P, PET, and P-PET), which are the forcing variables of the rest of the water budget components, and (2) analysis of metrics of hydrology (Q and S), which reflect the response of the watershed to the climate forcing variables. For the climatic variables, data were available to analyze the current state, as defined by the 1981-2010 climate normal, and then compare it to historical (1910-2010) and future (2011-2100) trajectories. With respect to the hydrologic variables, the current state was analyzed in the context of a limited historical dataset and a future outlook based on inference from climate trends.

2.3.1. Climate Forcing of Water Budget

Climate is the master control variable affecting ecosystem hydrologic processes at all spatial and temporal scales. It determines the input of water and through its control of the surface radiation balance and vapour pressure deficit (i.e., the difference of water vapour pressure between inside of leaf and bulk air above the vegetation) has a great impact on how much water is drawn back up by the atmosphere in the form of evapotranspiration.

a) Current state of Climate (1981-2010)

Athabasca Watershed stretches across diverse climatic zones, from the sub-humid and cold north to the humid and cold south. Based on the current climate normal (1981-2010), precipitation ranges from less than 370 mm around Lake Athabasca to over 670 mm in the mountains (Figure 2-4). This is expected as mountain air has lower condensation points and plenty of sources of moisture (snow and ice fields and precipitation coming in from the west). Whereas the rest of the watershed lies in the general rain shadow of the Rockies, with only summer convective activity dominating water input (>70%). The trend of PET is opposite to that of P, where higher summer temperatures in the summer drive the higher PET (≈500 mm) across most of the watershed, with the exception of the mountains where it is less than 400 mm (Figure 2-4). We compared the long-term average of PET to that measured in lakes from across the region, as assembled by McKenney et al. (2011), and found very good agreement between the two data sources (490 mm PET versus 505 mm LakeET). The spatial trends in P-PET reflect more the pattern of P, as P has much higher spatial variability (Figure 2-4). Outside of the headwater tertiary watersheds, the Athabasca Watershed experiences a deficit as estimated by P-PET. Clearly, this is not an actual water deficit as there would be no runoff in these systems. This means that ET does not occur at the potential PET rate, but at a lower rate. This assessment also does not consider or account for local and regional surface water-groundwater interactions, including groundwater discharge and recharge

b) Historical Climatic Context (1901-2010)

We evaluated the longer-term context of the 1981-2010 normal by looking at the 110-year historical evolution of the three climate metrics. While the graphs in Figure 2-5 show the aggregate response of the entire watershed, we also analyzed the spatial distribution of linear trends for each tertiary watershed (Figure 2-7).

Over the 110-year historical period and aggregated to the entire Athabasca Watershed, there were significant increasing trends in P, PET, and the drivers of PET, including average annual minimum and maximum temperatures (T_{min} and T_{max}) (Figure 2-5). P-PET showed no significant change over the same time period (Figure 2-5). The most significant increases occurred in PET, which was driven by increases in air temperature, and in particular, minimum temperature. This indicates that the climate stations of the Athabasca Watershed are clearly measuring the signal of a warming climate. As greenhouse gases increase in the atmosphere, they trap more radiation and re-radiate it back towards the surface. This effect is most pronounced at night, as the only source of incoming radiation at night is the emission of long wave radiation absorbed by the atmosphere (Easterling et al. 1997). In the summer, there is also more cloud and haze cover, which leads to even more heat being trapped. This is why the warming effect is highest in T_{min} during the hydro-ecologically active season (May to September). T_{min} has increased by about 2°C since the early 1900s from about -7°C to -5°C (Figure 2.5). Given that PET is computed from T, it has also increased from about 470 mm to 500 mm (Figure 2-5).

While PET has shown an almost constant increasing trend, the time-series of P has shown a slightly increasing trend super-imposed on a cyclical pattern with approximately 80 to 100-year wavelength. When considering the entire 110-year time-period, P has not changed substantially; however, when considering only the past 40 years there has been a significant decline in P, as also reported by Yip et al. (2012). What is causing these long-term cycles? It is most likely driven by sea surface temperature change in the Pacific Ocean. Short-term changes in the sea surface temperatures produce the El Nino cycle, which is a short 4 to 7 year cycle (Trenberth 1997); however, there are also longer cycles of sea surface temperature patterns. The Pacific Decadal Oscillation has been shown to have a strong impact on the climate of North America (Mantua et al. 1997) and there is an apparent correlation with some lag between the PDO and P observed for the Athabasca Watershed (Figure 2-6). For example, the warm and dry PDO phase of 1920-1945 was reflected by drier than average conditions in the Athabasca Watershed between 1910-1950, and the subsequent cold and wet PDO phase of 1946-1977 was matched to some degree by wetter than average conditions from 1950-1980. This periodicity is also reflected to some degree in the average annual maximum temperatures (Figure 2.5e). If this long-term variation in P (and T) is a reoccurring phenomenon then, by extrapolation, we can expect the current dry phase to reverse and be followed by a wetter phase. On top of this natural cycle, there does seem to be an increasing linear trend of P. This is perhaps not surprising given the higher ET rates experienced in a warmer climate. For most of the Athabasca Watershed precipitation is driven by summer convection where much of the water comes from the landscape itself (wetlands, lakes, and soil moisture) (Hogg et al. 2000). An increase in ET can certainly contribute to a higher P.

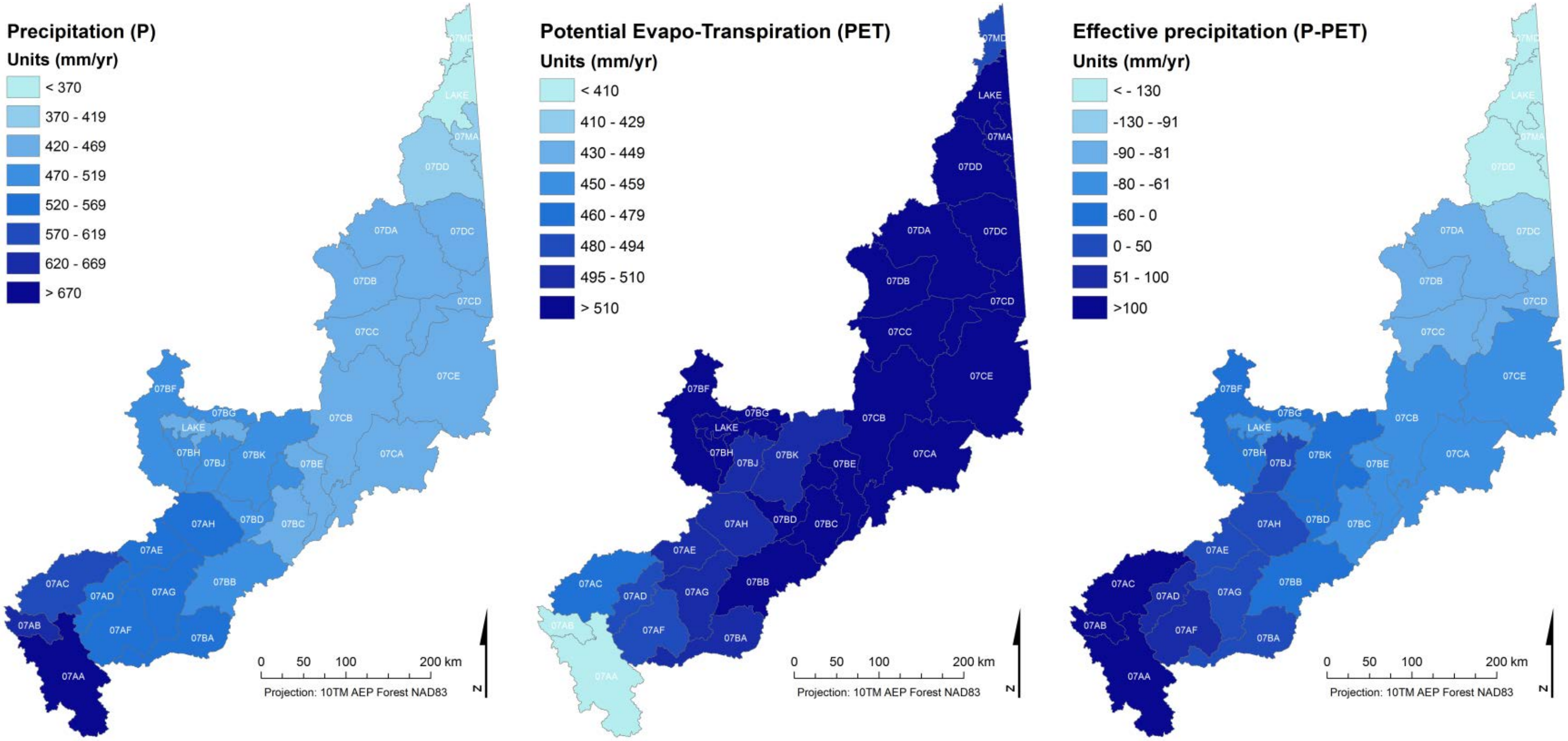

Figure 2-4. Current state of Athabasca Watershed based on climate normals (1981-2010) for precipitation (P), potential evapotranspiration (PET) and *effective* precipitation (P-PET).

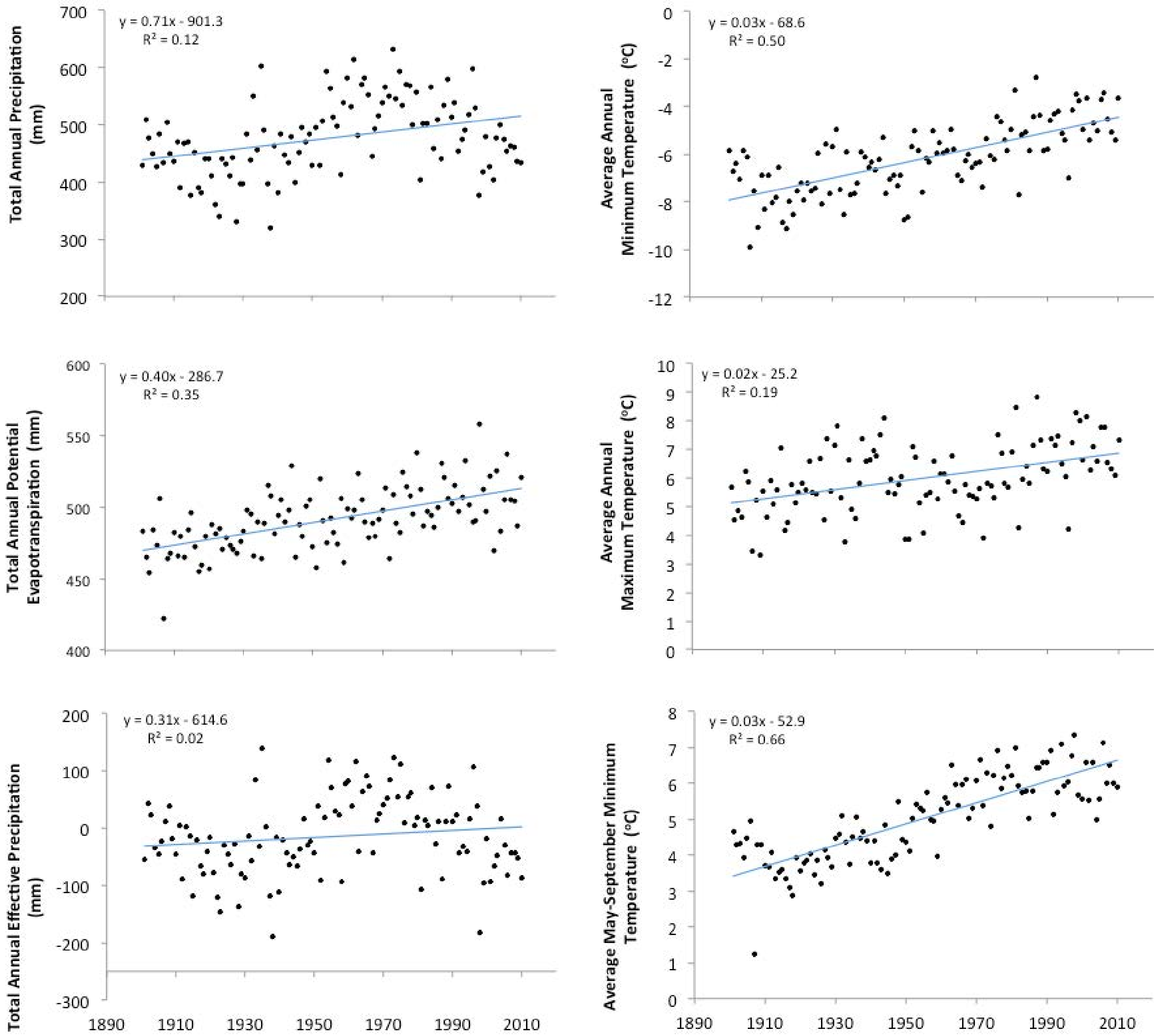

Figure 2-5. Historical trends in P, PET, P-PET, and average annual minimum and maximum temperatures (T_{min} and T_{max}) which were used in calculating PET. T_{min} for hydro-ecologically active season (May to September) exhibited the strongest increase in temperature. The time-series in these figures are compiled at the scale of the entire Athabasca Watershed.

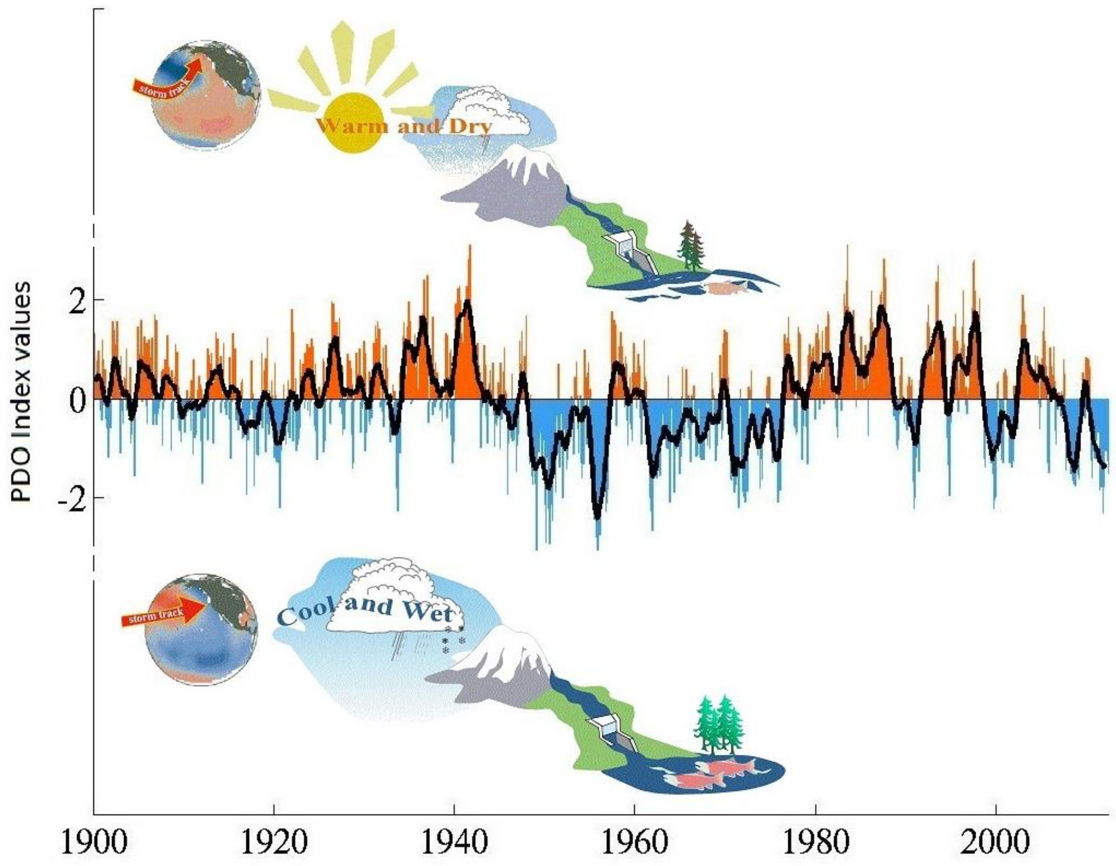

Figure 2-6. Variability of the north Pacific sea surface temperatures as measured by the Pacific Decadal Oscillation index (Mantua et al. 1997). Graphics are depicting the two phases (warm and cold) of the PDO and their hydro-climatic effects on western part of North America (from ftp://ftp.atmos.washington.edu/mantua/).

Given strong indication for directional changes in climate variables (especially PET), we ran statistical tests (Mann-Kendall) to identify the direction and strength of these linear changes. For the climate metrics showing strong periodicity (P and P-PET), these statistics can be biased based on the starting point, and therefore the evolution of the P and P-PET needs to be monitored for detecting stronger directional changes. For P, the central and northern part of the watershed shows significant changes over the last 110 years, with little change in the southern mountainous region of the watershed (Figure 2-7). All tertiary watersheds showed significant increases in PET, with the strongest increases occurring in the north in areas that correspond with the greatest increase in temperature. When looking at long-term trends in P-PET, there were only a few tertiary watersheds exhibiting significant changes, and these tertiary watersheds were primarily located along the boundary of the Athabasca and Mouth reaches of the Athabasca River. Clearly, the future of the climatically determined part of the hydrological cycle will depend on the balance of P and ET, and if ET increases at a much higher rate than corresponding P increases, the overall balance can be tipped towards more water deficit, as measured by P-PET. ET can also be controlled by landscape processes, especially the change in water storage and change in land cover.

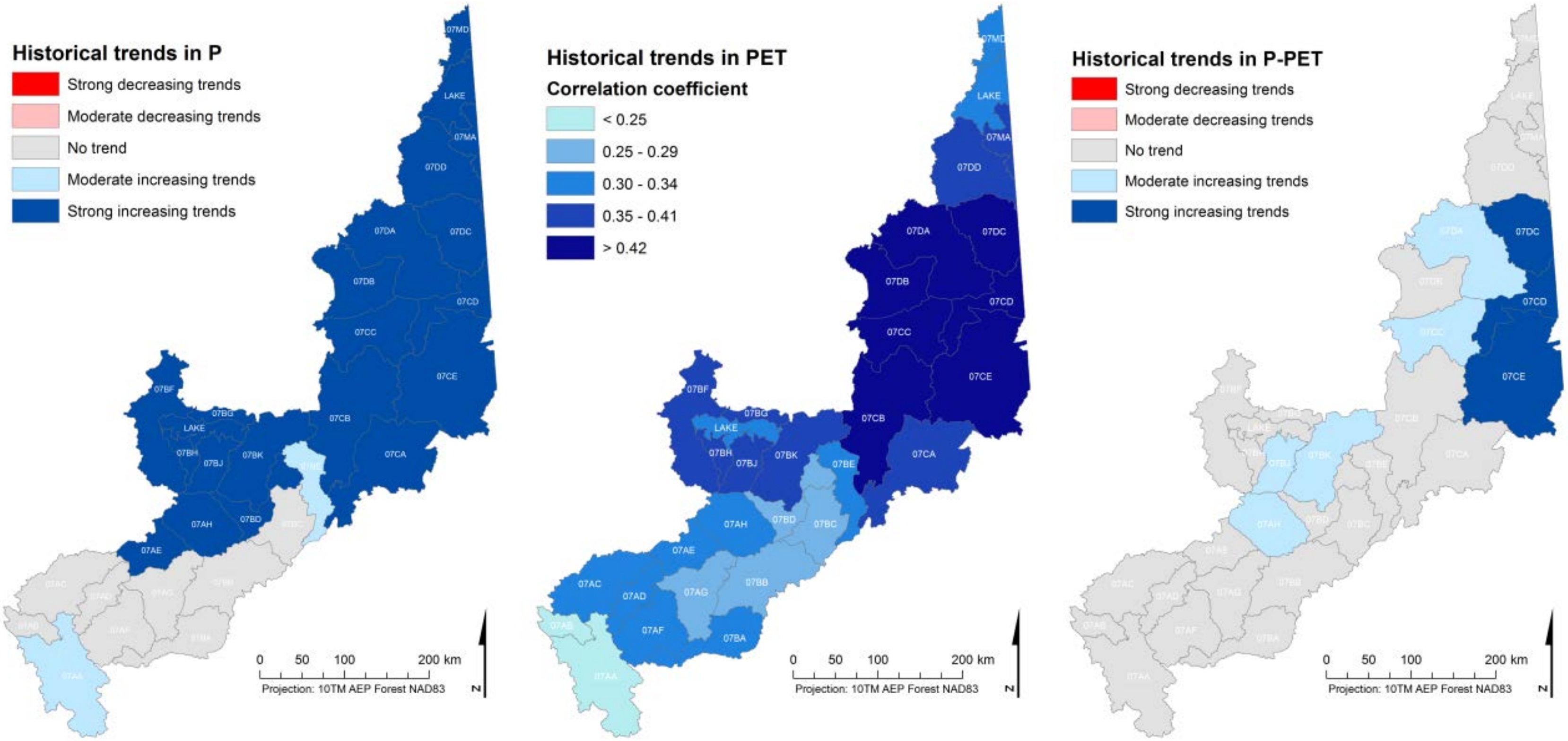

Figure 2-7. Spatial variation in the strength and direction of linear trends in P, PET, P-PET from 1901 to 2010 as measured by Mann-Kendall tests. All tertiary watersheds experienced a significant increase in PET; therefore, the different blue hues signify strength of increasing trend, with dark hues representing the strongest trends. Note: strong trends correspond to significance value of $p<0.05$, whereas moderate trends correspond to significance value of $p<0.10$.

c) Future Climate Scenarios (2011-2100)

The critical question for the Athabasca Watershed, as for many other parts of the world, is how increases in ET will compare to changes in P? Climate scenario averages suggest that both P and PET are forecast to rise, with PET increasing at a much higher rate (Figure 2-8). PET is forecast to rise above 550 mm in most of the Athabasca Watershed with the highest (not shown on map) being close to 600 mm within the Mouth reach. The combined effect of these predicted changes is hard to determine, as the three future data points are within the variability of the 20th century signal. It should be noted that GCM uncertainly increases as forecasts are extended into the future, especially for precipitation, so the evolution of climate change needs to be closely monitored in the Athabasca Watershed. This is why it is essential to maintain or establish climate stations, especially in data-sparse and topographically heterogeneous environments, so that climate trends can be evaluated in their historical and future contexts.

2.3.2. Hydrologic Response Reflected in Water Budget

a) Current State of Hydrology (1981-2010)

Where Q data are available, results indicate that approximately 100 mm of water flows out of the lowland tertiary watersheds on an annual basis, with Q increasing substantially (to ≈600 mm) in the mountainous region of the watershed (Figure 2-9). As a percentage of water input (P), the percent water running off is up to 90% in the Rockies, declining to between 20 to 30% in the lowland tertiary watersheds. The actual runoff percentage in the mountains is probably lower given that climate stations are located at lower elevations, which do not capture the higher P rates at higher elevations.

Water storage (S) in the 31 watersheds follows a somewhat different pattern than Q (Figure 2-9). The Boreal Shield tertiary watersheds near the mouth of the river have the most water stored (≈20%), which is primarily held in the numerous lakes and deltaic marshes in the region. There is also a considerable amount of water stored in the lowland tertiary watersheds (e.g. Clearwater and Lac La Biche), which have a high percentage (approximately 5 to 10%) of lakes and open water wetlands, reflecting more stagnant water on flat topography. Water storage is minimal in the foothills and the hills near Lesser Slave Lake (Swan Hills, Marten Mountain) (<1%), but increases in the Rockies where there is more water stored in lakes, particularly in terminal lakes at the mouth of glaciers. In conclusion, the steeper landscape of the southern watersheds (e.g. Rockies, Swan Hills) means that most of the water runs off, whereas more of the water is retained by the flatter landscape of the northern watersheds, despite a decrease in P-PET as one goes north. These northerly watersheds also have much higher percentage of organic materials, which further impedes the movement of water

b) Historical Hydrological Context (1971-2010)

In order to make a balanced spatial comparison (i.e., equal length of record), we fitted trend lines to all available Q time-series that ranged from 1971 to 2010. All of the significant trends over this time-interval were negative, meaning that flows have been decreasing across the Athabasca Watershed (Figure 2-10). This is not surprising given that the input of water (P) has been decreasing, while PET has been increasing over the same time-period. Schindler and Donahue (2006), Schindler et al (2007), and Yip et al. (2012) have also reported decreases in Q in the Athabasca Watershed.

At some of the WSC stations, datasets reach back further in time and their analysis suggests, as do the long-term P time-series, that there is substantial natural variation in Q (Figure 2-11 A-

F). In the headwaters, near the foot of the Athabasca glacier, discharge (Q) has increased over the last 30 years reflecting increased glacial and snow melt due to warming (Figure 2-11 A). Interestingly, there has been a substantial decline in Q in the past 5 years which could be an indication of a tipping point beyond which melt is still occurring but at a slower and slower rate (Moore and Demuth 2001; Comeau et al. 2009), although this trend needs to confirmed with additional analysis of data from the most recent years. Lower down in the watershed at the town of Athabasca, Q has decreased over the last 80 years, but not at the rate suggested by the last 40 years of data (Figure 2-11 E). When trend lines are fit to the 1971-2010 time-period over which Q data exist for all of the stations along the Athabasca River, the strength of the decrease in Q intensifies as one moves downstream, most likely reflecting the drier conditions in the tertiary watersheds closer to the mouth. Similar trends in Q have also been mapped by Kienzle (2010).

Water storage has also changed in the Athabasca Watershed between 1985 and 2010. The changes have reflected the aridity gradient from the headwaters to the mouth, where in the upper tertiary watersheds (upstream of the town of Athabasca) storage has increased. In contrast, storage in the lowland tertiary watersheds has decreased by as much as 20% when comparing 2010 to 1985. The only exception to this is tertiary watershed 07DA, which saw an increase in storage that appears to be driven by the large increases of open water due to the expansion of oil sands tailing ponds (Figure 2-10).

c) Future Hydrological Scenarios

How will discharge and storage change in the future? Storage and Q are dependent on how much water falls as precipitation *versus* how much of that water is lost to evapotranspiration. Increasing ET will result in less water being stored on the landscape. Less storage translates into a decrease in discharge (Q), as more of the water that is available is directed towards refilling water stores. In tertiary watersheds with substantial permafrost, this pattern could be different as melting permafrost could increase wetland and lake areas.

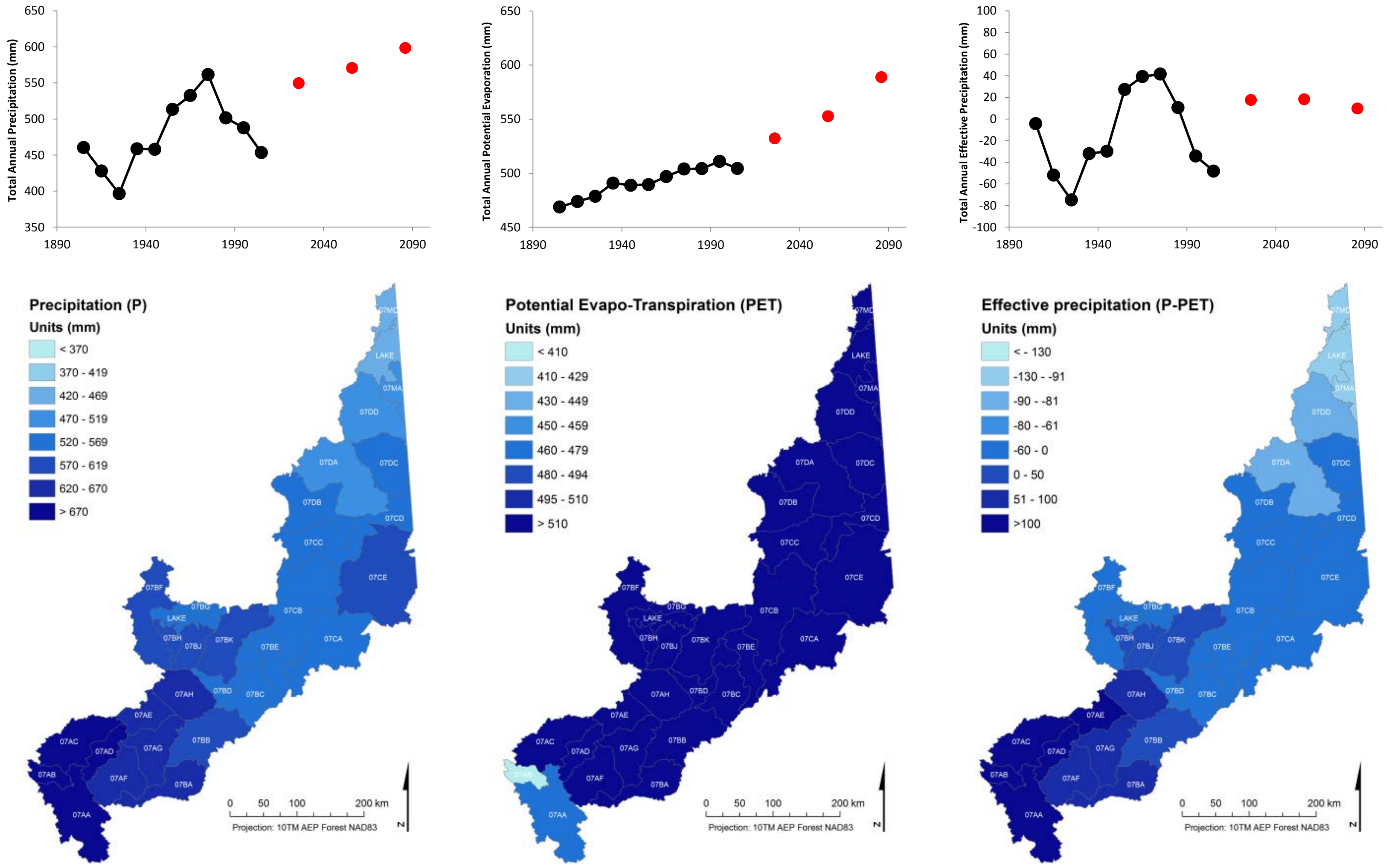

Figure 2-8. Average of future scenarios of P, PET, and P-PET for the 2071- 2100 time-period shown for each tertiary watershed in the maps and for the future normals (red dots) of 2011-2040, 2041-2070, 2071-2100 aggregated to the entire Athabasca Watershed shown in the time-series. The black dots represent historical decadal averages of P, PET, and P-PET.

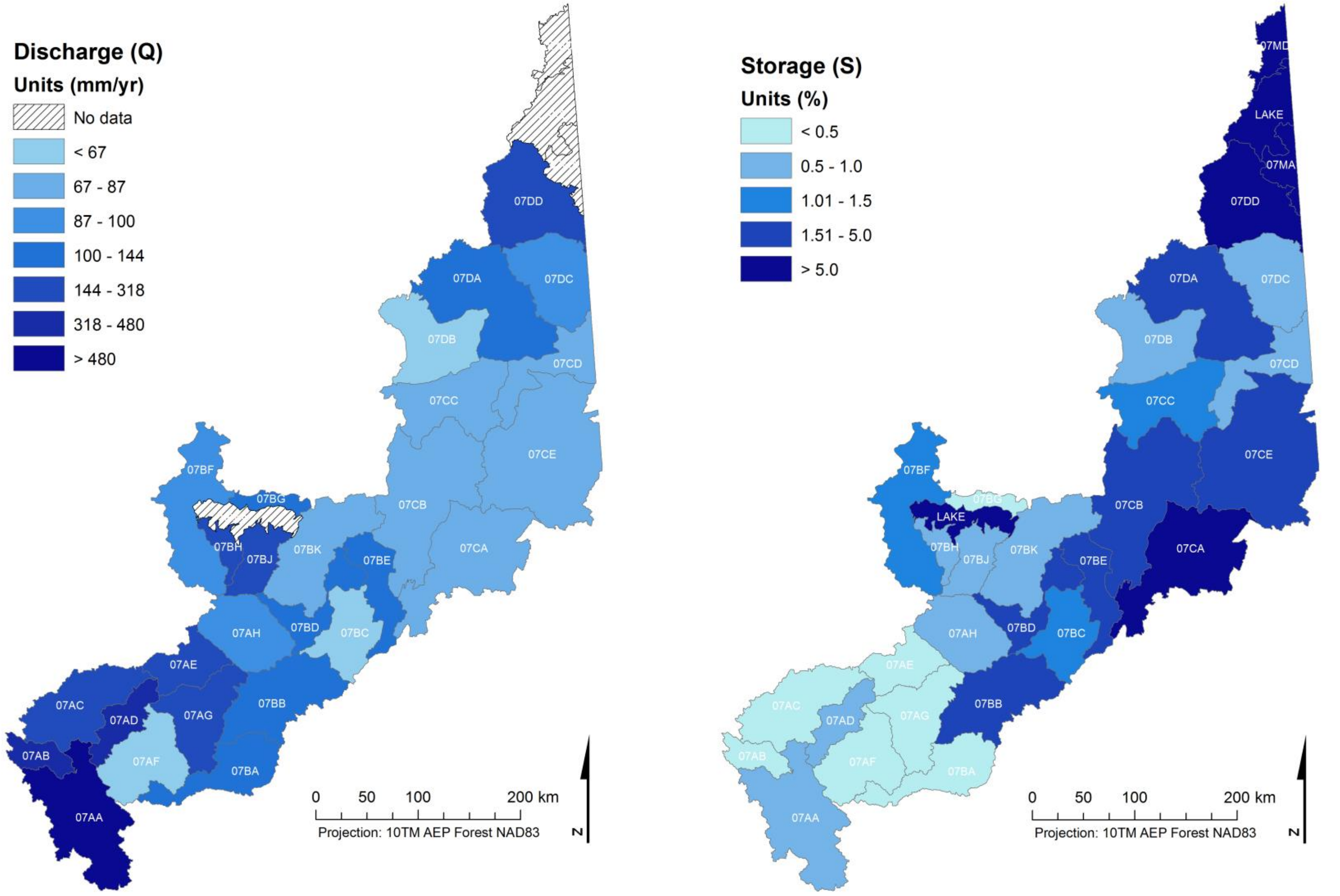

Figure 2-9. Current state of Athabasca Watershed based on hydrological variables for discharge (Q) and storage (S) for the most recent climate normal (1981-2010).

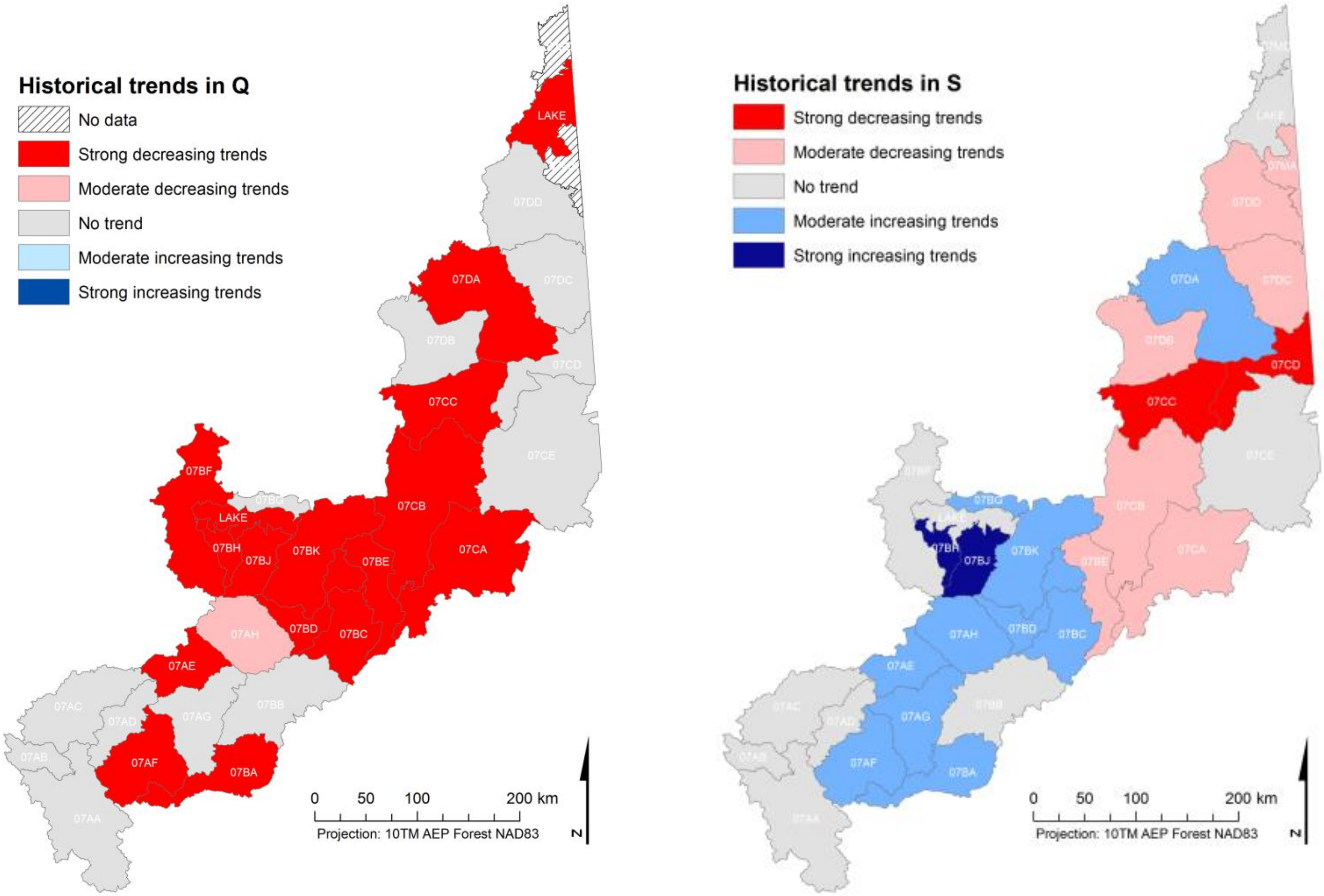

Figure 2-10. Spatial variation in the strength and direction of linear trends in discharge (Q) (1971-2010) and change in storage in lakes and open water wetlands (S) as measured by satellite in 1985 and 2010.

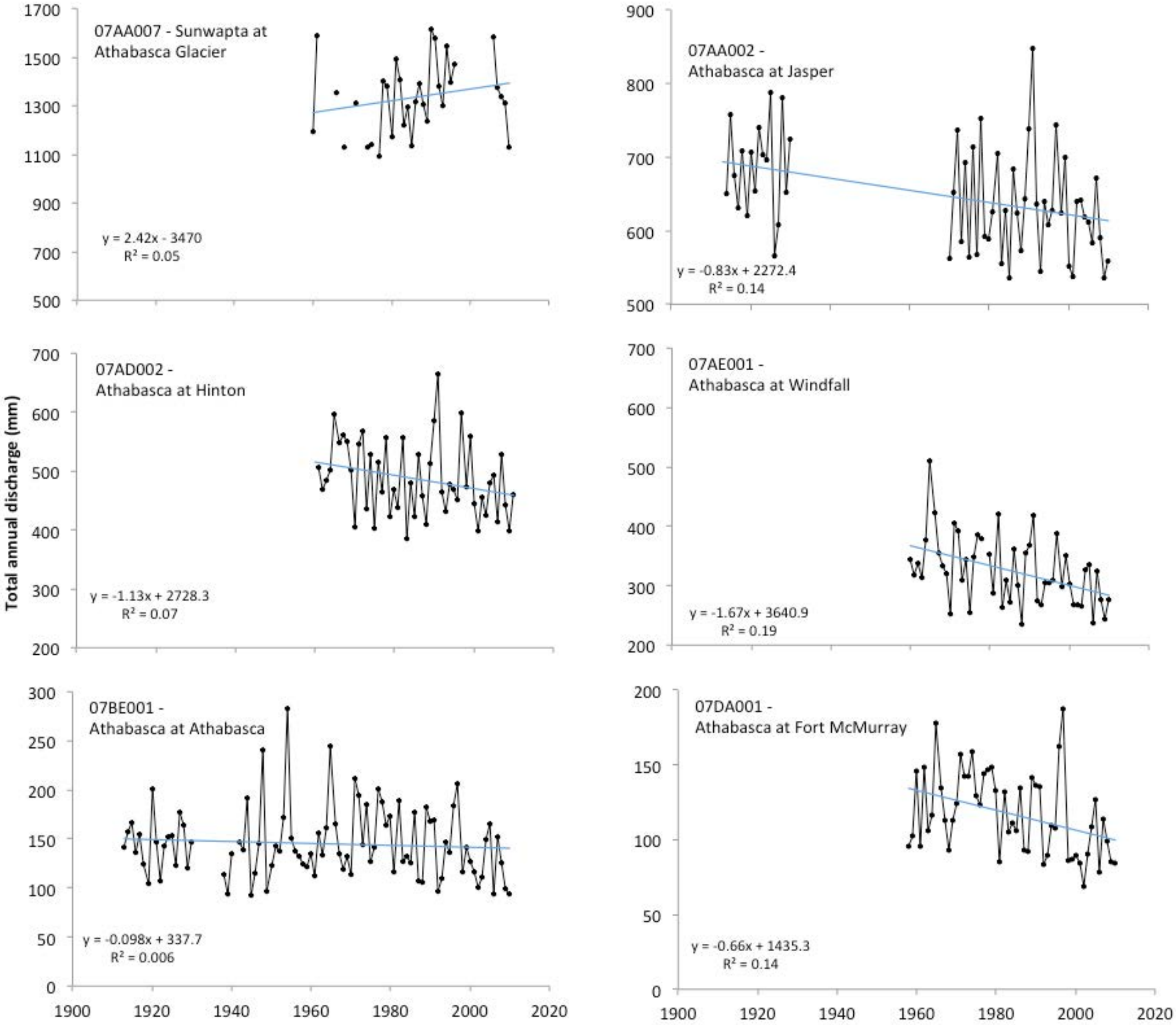

Figure 2-11. Trends in discharge along the Athabasca River from the Athabasca glacier to Fort McMurray.

2.4. Conclusions

The analysis of hydro-climatic trends in the Athabasca Watershed over the last 110 years suggests a combination of natural variability and directional climate change signals. Increasing temperature (2°C warming since 1901) has been driving increases in evapotranspiration; however, there is also an apparent 80-100-year natural periodicity for precipitation (and to some degree temperature), which is most likely driven by sea surface temperature changes in the Pacific Ocean. If the periodic behavior of climate is a stable and long-term phenomenon, we can expect the current dry phase to end in the near future and be followed by an increase in precipitation. Climate models also indicate an increase in P; however, an increase in P may not translate into higher water availability if more of that water is evapotranspired. In fact, an increase in potential evapotranspiration is what has been observed. The hydrologic response of the landscape has been a gradual decrease in Q for much of the Athabasca Watershed and also a decrease in storage for the northern half of the watershed. Future hydro-climate monitoring of the Athabasca Watershed should consider the changes to evapo-transpiration due to a warming climate, as well changes to ice and snow cover in the mountains.

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Chapter 3: Water Quality – Water Chemistry

3. Introduction

In this State of the Watershed report, water quality has been strictly limited to an examination of physico-chemical and inorganic chemical variables. The full list water quality variables that were selected in consultation with the AWC-WPAC Technical Committee for evaluation in this report can be found in Table 1-1.

3.1. Assessing the “Current State” of Water Quality

Current state in this evaluation of water quality was considered to be the most recent 5-year period for which water quality data were available. In our case, the most recent and complete 5-year period was 2007 to 2011. The decision to select this 5-year period for evaluating water quality in the Athabasca Watershed was also informed by our understanding of the analytical approach used by the provincial government for water quality samples collected as part of the Long-term River Network (LTRN) and Medium-Term River Network (MTRN) monitoring programs. Prior to 2005, the water quality samples taken as part of these programs were submitted to a number of different accredited laboratories across the province for processing. In 2005, all water sample analysis was consolidated into a single laboratory (D. LeClair, Surface Water Data Specialist, Environment and Sustainable Resource Development, personal communication, November 26, 2012). Thus, in order to eliminate a potentially confounding parameter associated with analytical methods, and because the provincial water quality data comprises a substantial subset of the data included in this evaluation, our examination of the current state was limited to the years in which LTRN/MTRN water samples were analyzed by a single facility.

3.2. Data Included in the Phase 3 Assessment

While there is no shortage of water quality data that have been collected in the Athabasca Watershed, there is a paucity of *usable* and *accessible* data (see Section 5.1 for a more detailed discussion about data availability). Thus, our analysis was limited to provincial water quality data that has been collected as part of the provincial Long-term and Medium-term River Network monitoring programs, as well as water quality data collected as part of the Regional Aquatics Monitoring Program (RAMP) (Figure 3-1).

Water quality data from six provincial LTRN stations were obtained from Alberta Environment and Sustainable Resource Development (AESRD). These stations are situated on the mainstem of the Athabasca River in the following locations (Table 3-1):

1) Upstream of the town of Hinton
2) At the town of Athabasca
3) Upstream of the city of Fort McMurray
4) Above the Firebag River
5) At the town of Old Fort
6) Downstream of the Devils Elbow, near Fort Chipewyan

Data from MTRN stations were also included in this evaluation, and included station situated on major tributaries in the following locations (Table 3-1):

1) On the McLeod River at the confluence with the Athabasca River, in the town of Whitecourt

2) On the Lesser Slave River 9.5 km upstream of the confluence with the Athabasca River
3) At the mouth of the Lesser Slave River, upstream of the town of Smith
4) On the Muskeg River at the Water Survey of Canada gauge and downstream of the Kearl Lake Road

Data from 12 RAMP stations were also included in this water quality evaluation. RAMP data are publically available and were downloaded from the RAMP website (http://www.ramp-alberta.org/RAMP.aspx). The majority of the data came from 10 stations located on the mainstem of the Athabasca River, with the remaining two stations located at the mouth of the Muskeg and Firebag Rivers (Table 3-1).

Table 3-1. Code, description, and location of water quality stations that were included in this evaluation of water quality in the Athabasca Watershed.

Source	Station Code	Station Description	Latitude	Longitude
LTRN	AB07AD0100	Athabasca River at old entrance town site - left bank	53.3675	-117.7225
LTRN	AB07BE0010	Athabasca River at town of Athabasca	54.7222	-113.2861
LTRN	AB07CC0030	Athabasca River upstream of Fort McMurray, 100 m above the confluence with Horse River - left bank	56.7203	-111.4056
LTRN	AB07DA0980	Athabasca River - transect above the Firebag River	57.7236	-111.3792
LTRN	AB07DD0010	Athabasca River at Old Fort - right bank	58.3828	-111.5178
LTRN	AB07DD0105	Athabasca River downstream of Devils Elbow at winter road crossing	58.4472	-111.1858
MTRN	AB07AG0390	Mcleod River at Whitecourt - Highway #43 bridge right bank	54.1361	-115.6958
MTRN	AB07BK0125	Lesser Slave River - 9.5 km upstream of Athabasca River confluence	55.2067	-114.1225
MTRN	AB07BK0130	Lesser Slave River at confluence with Athabasca River above the town of Smith Mouth: km 794.0	55.1658	-114.0619
MTRN	AB07DA0610	Muskeg River at WSC gauge downstream of Kearl Lake Road	57.1917	-111.5681
RAMP	ATR-DC-CC	Athabasca River at Donald Creek - cross-channel	56.8266	-111.4093
RAMP	ATR-DC-E	Athabasca River at Donald Creek - east bank	56.8266	-111.4077
RAMP	ATR-DC-W	Athabasca River at Donald Creek - west bank	56.8265	-111.4080
RAMP	ATR-DD-E	Athabasca River downstream of development- east bank	57.4528	-111.6023
RAMP	ATR-DD-W	Athabasca River downstream of development- west bank	57.4553	-111.6098
RAMP	ATR-FR-CC	Athabasca River upstream of the Firebag River - cross-channel	57.7407	-111.3684
RAMP	ATR-MR-E	Athabasca River upstream of the Muskeg River- east bank	57.1319	-111.6029
RAMP	ATR-MR-W	Athabasca River upstream of the Muskeg River- west bank	57.1302	-111.6079
RAMP	ATR-SR-E	Athabasca River upstream of the Steepbank River- east bank	57.0192	-111.4787
RAMP	ATR-SR-W	Athabasca River upstream of the Steepbank River- west bank	57.0154	-111.4811
RAMP	FIR-1	Mouth of the Firebag River	57.7436	-111.3508
RAMP	MUR-1	Mouth of the Muskeg River	57.1335	-111.6035

This evaluation of water quality also included industrial "Class B" effluent data that were publically available from AESRD. Industrial "Class B" effluent data are collected by industry and are reported monthly or annually to the provincial government as part of industrial *Water Act* approval conditions. Currently, there is no electronic data transfer process in place for these data, and as a consequence, government personnel manually enter the data from hardcopy reports (D. LeClair, Surface Water Data Specialist, Environment and Sustainable Resource Development, personal communication, December 28, 2012).

Given that these data are manually entered by Government, the process of manually entering data is incomplete, and therefore, industrial Class B data are only available in electronic format for a limited number of industrial facilities that operate in the Athabasca Watershed (Table 3-2). **Thus, the industrial effluent data included in this evaluation are not complete, as not all industrial facilities that discharge effluent into the Athabasca River were included in the data provided by the provincial government.** In particular, there are a number of oil sands operations that were not included in the data that we received directly from the government; therefore, these data, despite their existence, could not be considered as part of this report because they were not accessible to us in electronic format.

Table 3-2. Station number, description, and location of industrial Class B facilities included in the publically available data provided by Alberta Environment and Sustainable Resource Development.

Station Number	**Station Description**	**Latitude**	**Longitude**
AB07AD0610	Hinton Wood Products - West Fraser Mills Ltd.	53.4022	-117.6055
AB07AE0460	Alberta Newsprint Company	54.1763	-115.8013
AB07AF0471	Cardinal River Operations - Teck Coal Ltd.	53.0661	-117.3758
AB07AH0530	Millar Western Forest Products	54.1486	-115.6888
AB07BK0330	Slave Lake Pulp - West Fraser Mills Ltd.	55.2527	-114.5402
AB07CB0840	Alberta-Pacific Forest Industries Inc.	54.9316	-112.8633
AB07DA2431	Suncor Energy	57.0062	-111.4611

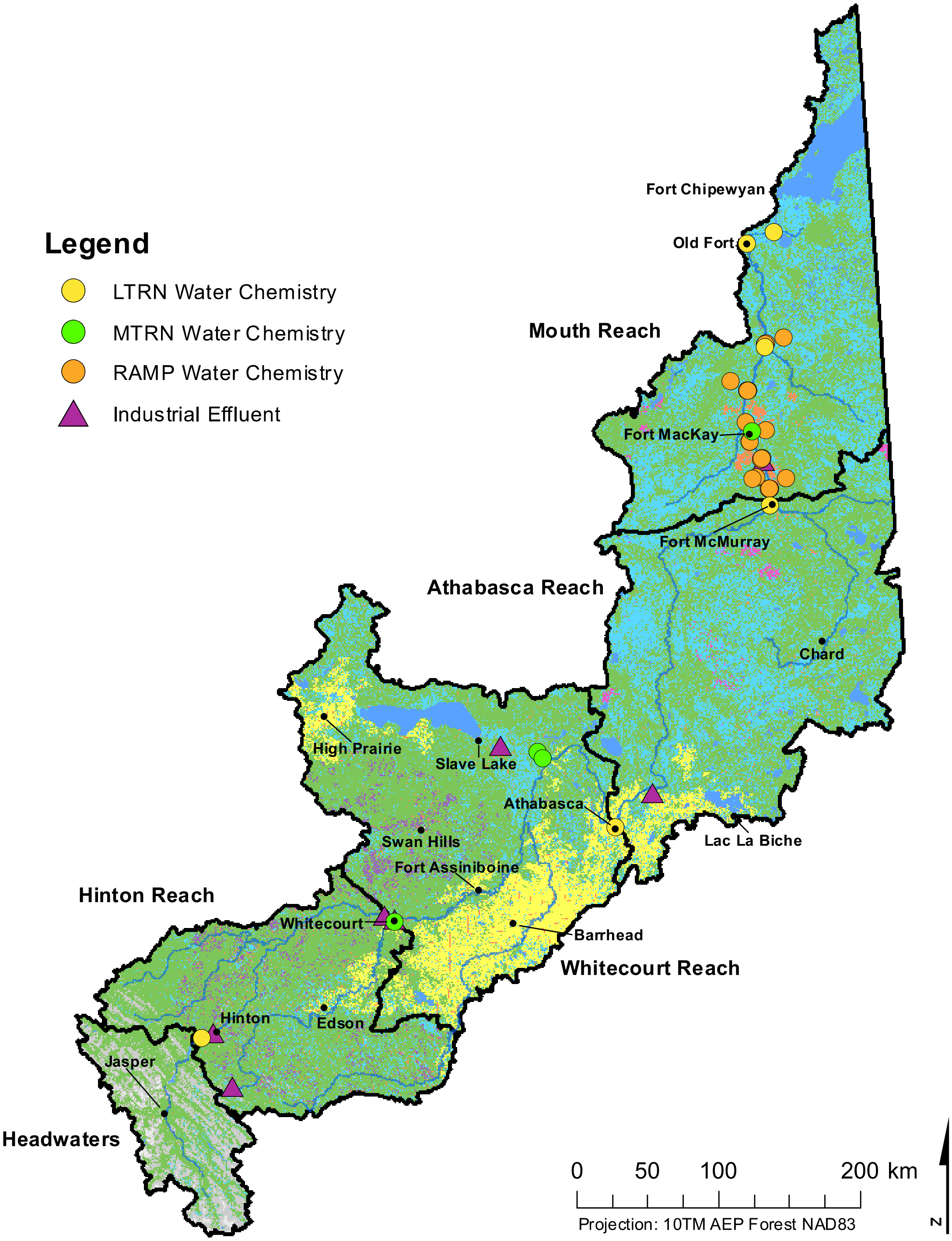

Figure 3-1. Location of LTRN, MTRN, and RAMP stations, as well as Industrial Class B facilities that were included in the evaluation of water quality in the Athabasca Watershed between 2007 and 2012. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biological 2012).

3.3. Methods

3.3.1. Data Assembly and Parameter Visualization

Water quality data obtained from all sources were combined in a Microsoft Access database. Data for the period between 2007 and 2011 were extracted for RAMP, LTRN, MTRN, and Class B Industrial Effluent data (note that provincial data included several records for the early part of 2012, which were also included in this analysis). In total, over 52,000 records were incorporated in this assessment, including 11,708 records from the provincial LTRN/MTRN monitoring programs, 3,448 records from RAMP, and 36,999 records from Class B Industrial facilities.

Data from all sources were standardized to include common variable names and measurement units. For example, water quality data collected by RAMP is reported as mg/L, while many parameters measured by LTRN/MTRN are reported in µg/L; thus, a common unit of measurement for each parameter was selected, and reported values for each data set were converted to the common unit, if required. Where necessary, provincial and federal water quality benchmark values were converted to correspond with the common sampling unit, allowing for comparison across data sources. All LTRN/MTRN records associated with true split samples, as flagged in the provincial water quality data by a “Y” in the “QC_SAMPLE_FLAG” column, were stripped from the data, such that only a single sample associated with a triplicate split was evaluated.

Detection limits for parameters of interest were extracted from available sources. In the case of the provincial water quality datasets, detection limits were included in the electronic data received from AESRD, and for any given parameter, a method detection limit[2] (MDL) and/or a sample detection limit (SDL) was reported. The method detection limit is “based on data from samples containing the constituent of interest, which are processed through the complete analytical method. The MDL is determined by adding a constituent to reagent water or matrix of interest to make a concentration from one to five times the estimated MDL. Seven to ten portions of this are analyzed and the standard deviation determined. A standard *t* distribution at 99% is used to calculate the MDL. MDLs are matrix, method, and laboratory specific” (Mitchell 2006, p. 41). The sample detection limit is the actual detection limit that is submitted by the laboratory along with the parameter measurement, and the SDL may or may not match the MDL for a given parameter (D. LeClair, Surface Water Data Specialist, Environment and Sustainable Resource Development, personal communication, December 4, 2012).

Over the time period used in this evaluation, detection limits for a given parameter may have changed; thus, where applicable, we determined the upper and lower MDL and SDL for each parameter of interest, and these detection limit values were plotted along with reported water quality measurements. In the case of RAMP data, detection limits were not included with the electronic dataset; therefore, detection limits were extracted from the 2011

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[2] Based on data from samples containing the constituent of interest, which are processed through the complete analytical method. The MDL is determined by adding a constituent to reagent water or matrix of interest to make a concentration from one to five times the estimated MDL. Seven to ten portions of this are analyzed and the standard deviation determined. A standard *t* distribution at 99% is used to calculate the MDL. MDLs are matrix, method, and laboratory specific (Mitchell 2006)

annual report that was available in hardcopy from the RAMP website (RAMP 2011 Implementation Team 2012), Detection limits did not accompany the Industrial Class B data that were received from the provincial government; thus, we do not know the detection limits for these data.

Values for all parameters of interest were plotted over time by station location (in the case of LTRN/MTRN and RAMP data) or discharge location (in the case of the industrial Class B data). All measured values were included in this assessment, including those values that fell below the reported detection limits. In instances where the measured value was reported as a "less than" detection limit value, these records were assigned the detection limit value, and were plotted along with all other reported data. This approach was taken such that the frequency of sampling for each could be visualized on each figure. Given that statistical trends were not calculated for any of the parameters included in this report, assigning the detection limit to "less than" values does not influence our understanding of water quality trends over time or across space.

In the case of LTRN/MTRN and RAMP data, provincial and/or CCME concentration limits (see Table 1-2 A &B) were plotted on the figure, along with the MDL and/or SDL values. In cases where provincial or CCME benchmark concentrations varied by water hardness or pH (e.g., aluminum), the reported values for those parameters were plotted on a double-axis graph to allow for easier interpretation of the benchmark guidelines. All figures were generated using the statistical software R (R Development Core Team 2008).

3.4. Results

Based on a survey of all of the data available that was available as of December 2012, it was noted that the data for LTRN site AB07BE0010 (Athabasca River at the town of Athabasca) could be used to describe and discuss general phenomena that were observed at most of the other water quality sites that were included in this evaluation. Thus, the data from the town of Athabasca LTRN site were used to illustrate results typical of other sites, and to and explain the possible significance of these results. However, there are numerous exceptions to the general observations made at the town of Athabasca LTRN site, and these exceptions are described later in the chapter (see Sections 3.4.5, 3.4.6, and 3.4.7).

3.4.1. Physico-chemical Properties at LTRN Site AB07BE0010 (town of Athabasca)

Temperature

Water temperature (Figure 3-2 A) serves as a guide to indicate the effects of season on the physical properties of the water in the river, and is used to understand the variation in other physical and chemical properties. A recent study of dissolved oxygen dynamics in the Athabasca River conducted by Martin et al. (2013) documented annual variation in flows and temperatures between 2000 and 2006, with the peak flows found in summer. The timing of the peak flows of the Athabasca River, therefore, correspond to the maximum temperature values seen in Figure 3-2 A.

Total Dissolved Solids (TDS)

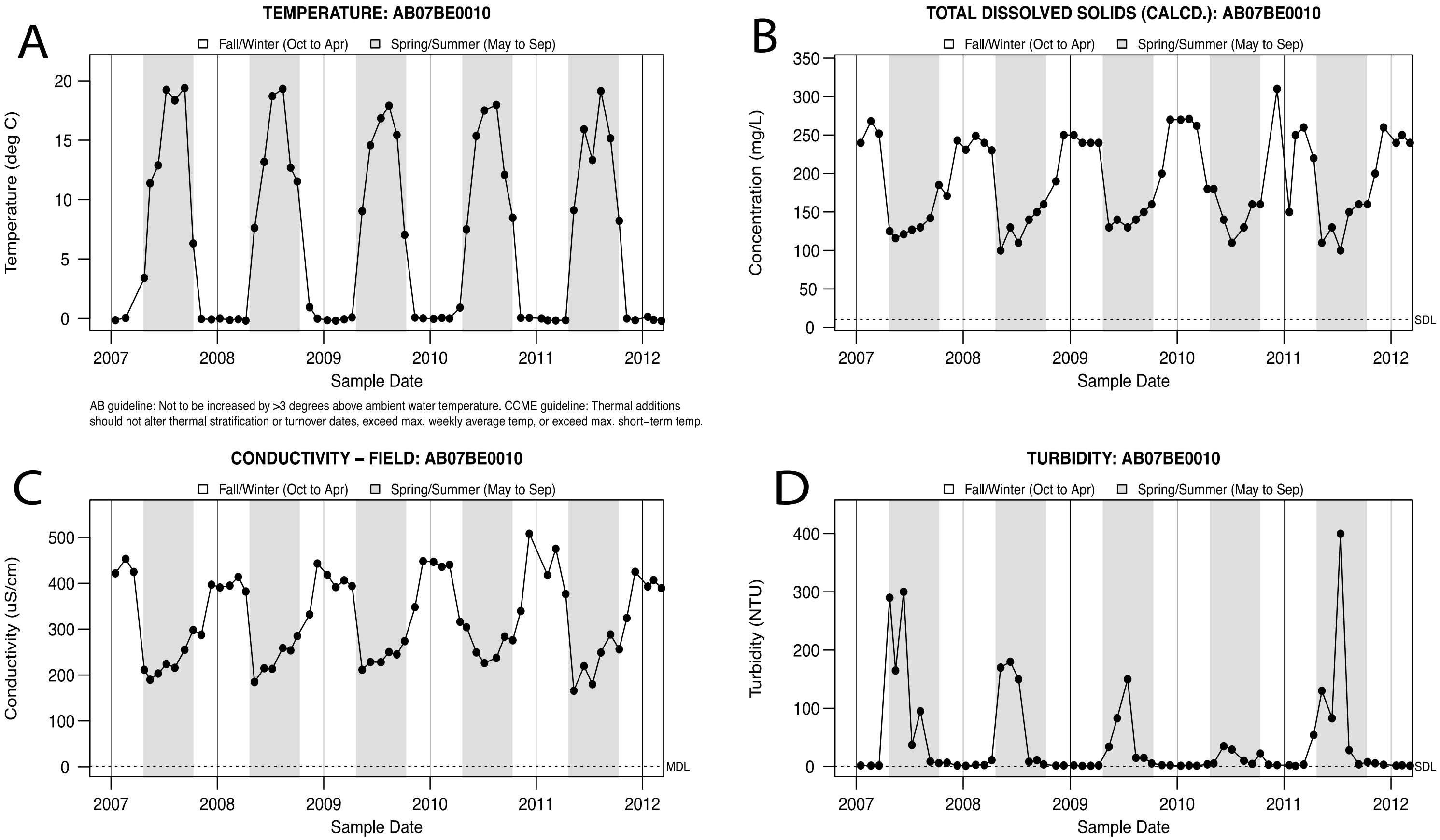
The seasonal variation in total dissolved solids (TDS) is approximately a factor of two from *circa* (ca.) 120 mg/L in summer to ca. 250 mg/L in winter (Figure 3-2 B). The seasonal difference in TDS is driven by dilution caused by spring snowmelt followed by summer rains. The variation in TDS provides a rough guide to the variation, which could be expected in respect to conservative chemical species.

Conductivity

As expected based on TDS above, seasonal variation in electrical conductivity (EC) is approximately a factor of two from ca. 200 µS/cm in summer to ca. 400 µS/cm in winter (Figure 3-2 C). Again, the seasonal differences are being driven by dilution caused by spring snowmelt followed by summer rains. To put these values into perspective, rainwater might have a conductivity of ca. 10 µS/cm and groundwater in a carbonate terrain, ca. 300 µS/cm. The EC of the water reflects the abundance of dissolved ionic species and in an unpolluted natural water is a guide to the extent of chemical weathering of minerals which has taken place in the watershed.

Turbidity

The winter values for turbidity approach zero, but summer values are far greater, from ca. 150 nephelometric turbidity units (NTU) in 2009 to 400 during 2011 (Figure 1d). Turbidity is a guide to the amount of particulate and colloidal material which has been added to the water e.g. from erosion. The extreme values seen in summer presumably reflect flooding.



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure 3-2. Temperature (A), total dissolved solids (TDS; B), electrical conductivity (EC; C) and turbidity (D) measured at the town of Athabasca. Grey areas represent the summer period (May-September), while the white areas represent the winter period (October-April) as defined by Seneka (2006). Source: Provincial Long-term River Network database.

Total Carbonate Alkalinity

The Athabasca River contains a considerable amount of carbonate alkalinity, which is a guide to the amount of chemical weathering that has taken place in the watershed. Because calcium carbonate (calcite) that makes up limestone is chemically quite reactive, rivers in watersheds with abundant limestones contain high levels of carbonate alkalinity. Groundwater in a carbonate terrain, for example, typically contains on the order of 150 mg/L of carbonate alkalinity. As expected based on TDS above, seasonal variation in alkalinity in the Athabasca River is approximately a factor of two from ca. 90 mg/L in summer to ca. 180 mg/L in winter (Figure 3-3 A).

pH

The pH of the water at this site ranges from 6.8 to 8.5 (Figure 3-3 A), with depressed pH values seen during spring snowmelt. It is important to remember that the pH scale is a logarithmic scale (-log [H+]) meaning that the range in pH values (from 6.8 to 8.5) represents a variation in hydrogen ion concentration of 50 times. Notice that the variation in hydrogen ion concentration (50 x) is disproportionate to that of TDS. In other words, the shifts in pH values are independent of the total amount of solids dissolved in the water.

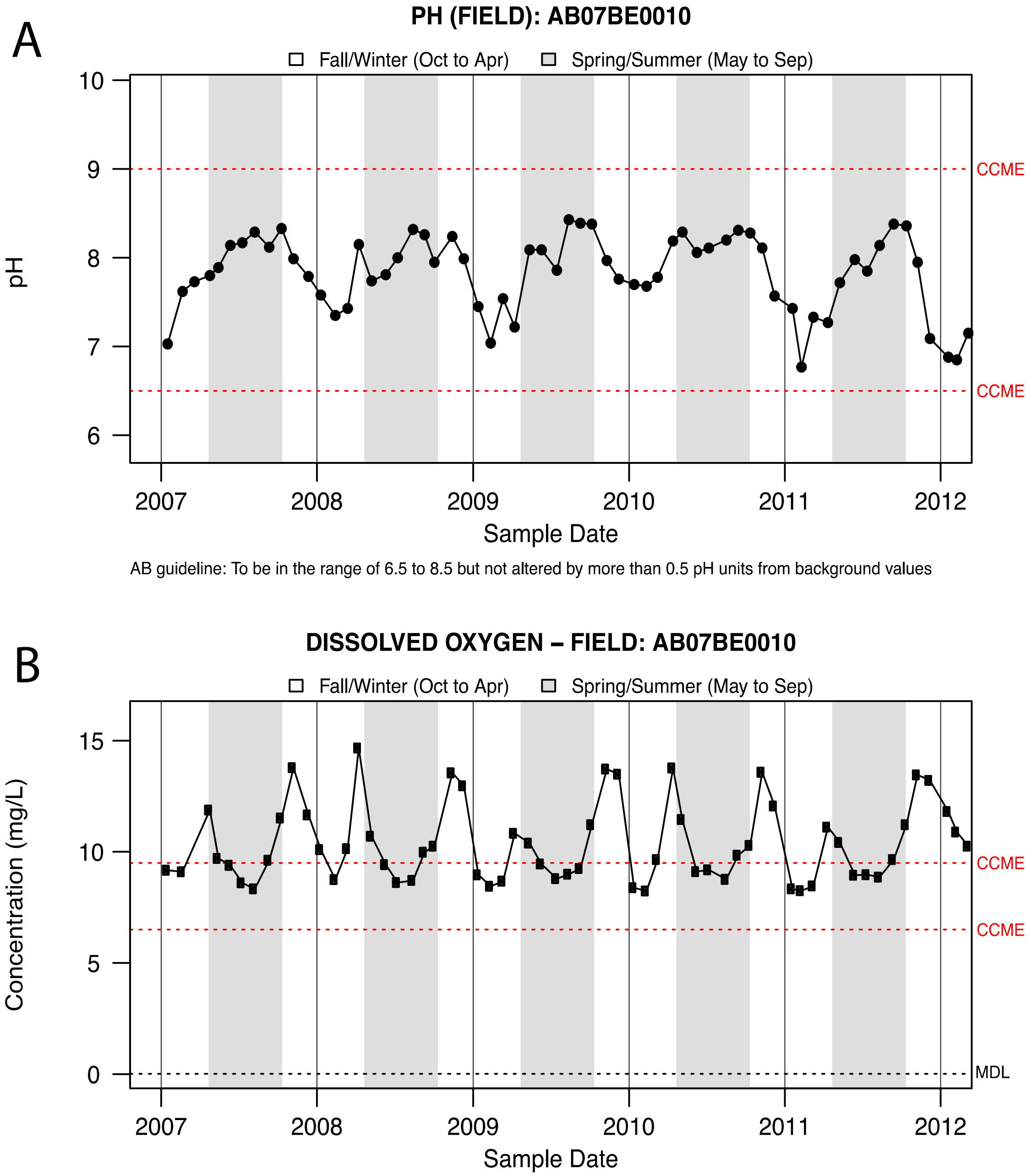
The pH of the water in and of itself is less important than the consequences which pH has for the abundance, speciation, availability and potential toxicity of many other dissolved constituents.

Dissolved Oxygen (DO)

The concentrations of dissolved oxygen (DO) range from ca. 9 to 15 mg/L (Figure 3-3 B) with lower values typically found during summer months when water temperature is the highest (and oxygen solubility is the lowest) and biological activity is greatest. The CCME guidelines for DO differ for warm-water and cold-water biota: for warm-water biota, 6 mg/L are required for early life stages and 5.5 mg/L for other life stages; in the case of cold-water biota, early life stages require 9.5 mg/L and other life stages 6.5 mg/L. As the Athabasca River is considered a cold-water fishery (Dr. M. Poesch, Department of Renewable Resources, University of Alberta, personal communication, February 28, 2013), the latter set of guideline values apply. Clearly, during the early part of the year and during the summer months, DO concentrations in this section of the river fall below the CCME guideline values developed for early life stages of cold-water biota, which are characteristic of the Athabasca River.

Bicarbonate (calculated)

Bicarbonate is the dominant form of dissolved carbon dioxide between pH 6.3 and 10.3 (corresponding to the first and second dissociation constant of carbonic acid), so most of the carbonate alkalinity (Figure 3-4 A) is in the form of bicarbonate because the pH of water at this site falls between these two values (Figure 3-4 B). As expected based on TDS, seasonal variation in bicarbonate is approximately a factor of two from ca. 100 mg/L in summer to ca. 200 mg/L in winter. Bicarbonate is the dominant anion in freshwaters, is ultimately derived from atmospheric carbon dioxide and reflects the amount of chemical weathering by carbonic acid. The bicarbonate ion is an important pH buffer. The values seen here are typical for surface waters in geological terrains containing calcium carbonate in the form of limestones and in contact with atmospheric carbon dioxide.



AB guideline: To be in the range of 6.5 to 8.5 but not altered by more than 0.5 pH units from background values

Cold water biota: early life stages = 9.5 mg/L; other life stages = 6.5 mg/L

Figure 3-3. pH (A) and dissolved oxygen (B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

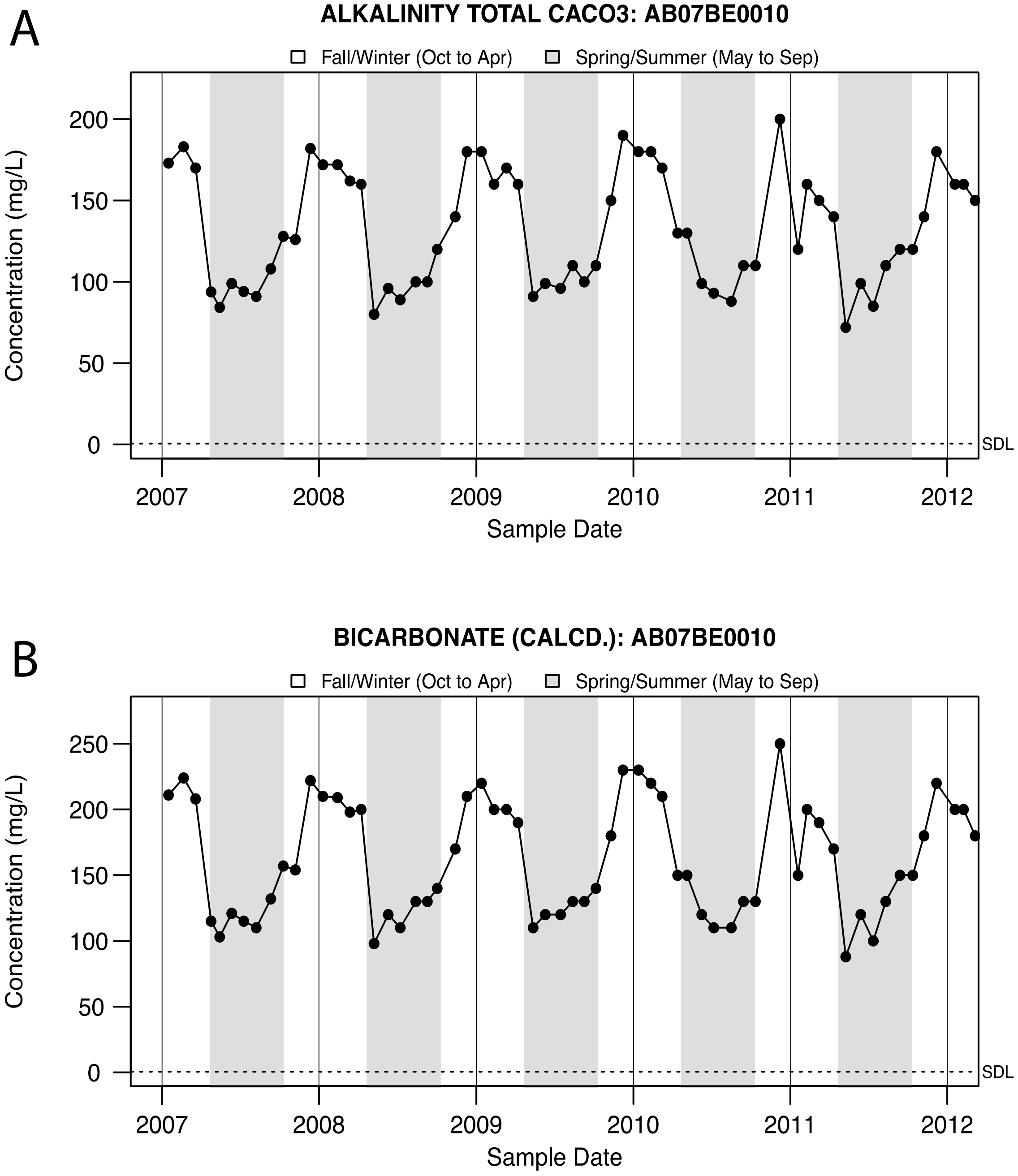


Figure 3-4. Total carbonate alkalinity (A) and bicarbonate (calculated; B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

Colour

The colour of the water is typically on the order of 10 true colour units (TCU) but can be up to 50 in early summer (Figure 3-5 A). The values seen during the summer of 2011 (up to nearly 150) are exceptional, and may reflect the extreme flooding which was apparently experienced in that section of the river during that year. The colour of the water is partly a reflection of turbidity (see Fig. 3-2 D) and the amount of dissolved organic carbon (see below), but also affected by the amount of iron in the water and its interactions with natural organic matter.

Dissolved Organic Carbon (DOC)

Dissolved organic carbon (DOC) is a general measure of the total carbon concentration represented by the mixture of all organic compounds present in water. Concentrations of DOC at this site are typically around 5 mg/L (Figure 3-5 B). For comparison, groundwaters typically contain ca. 1 mg/L, and the surface water in bogs and fens ca. 50 mg/L. The higher DOC concentrations in the Athabasca River, relative to groundwater values, are likely a function of abundant wetlands, peatlands, and organic-rich soils in the watershed, although municipal and industrial wastewaters also are commonly rich in DOC. Because DOC is a mixture of organic compounds, its presence does not indicate either its source or the organic compounds it may contain. The greatest values for DOC (10 - 20 mg/L) are seen in early summer and may reflect inputs from wetlands and peatlands, when the water tables in these ecosystems are at their maximum levels. An examination of the abundance of wetlands in the watershed in relation to the concentrations of DOC in the river would provide a first indication of the relative importance of natural inputs of organic matter to the water. Similarly, the DOC values should be examined in relation to wastewater inputs from municipal and industrial sources.

3.4.2. Major Constituents at AB07BE0010 (Town of Athabasca)

Calcium (Ca)

The seasonal variation in Ca is slightly more than a factor of two from ca. 20 mg/L in summer to ca. 50 mg/L in winter (Figure 3-6 A) with the difference being driven by dilution due to spring snowmelt and summer rains. As expected, seasonal variations in Ca are more or less in line with the seasonal variation in TDS (Figure 3-2 B). The range of Ca concentrations seen here are typical for surface waters and groundwaters in geological terrains containing calcium carbonate in the form of limestones and in contact with atmospheric carbon dioxide. Calcium is the dominant cation in freshwaters and reflects the amount of chemical weathering in the watershed. For comparison, the global average Ca concentration in freshwater is ca. 13 mg/L (Livingstone 1963).

Sodium (Na)

The seasonal variation in Na is approximately a factor of four from ca. 5 mg/L in summer to ca. 20 mg/L in winter (Figure 3-6 B), with the difference being driven by dilution caused by spring snowmelt followed by summer rains. The minimum Na values are comparable to global average freshwater values (Livingstone, 1963). Notice however that the variation in Na (4 times) exceeds that of Ca (2 times), either because of the greater solubility of Na-bearing minerals and the greater mobility of Na^+ compared to Ca^{2+}, or possibly reflecting additional sources of Na to the water at this site.

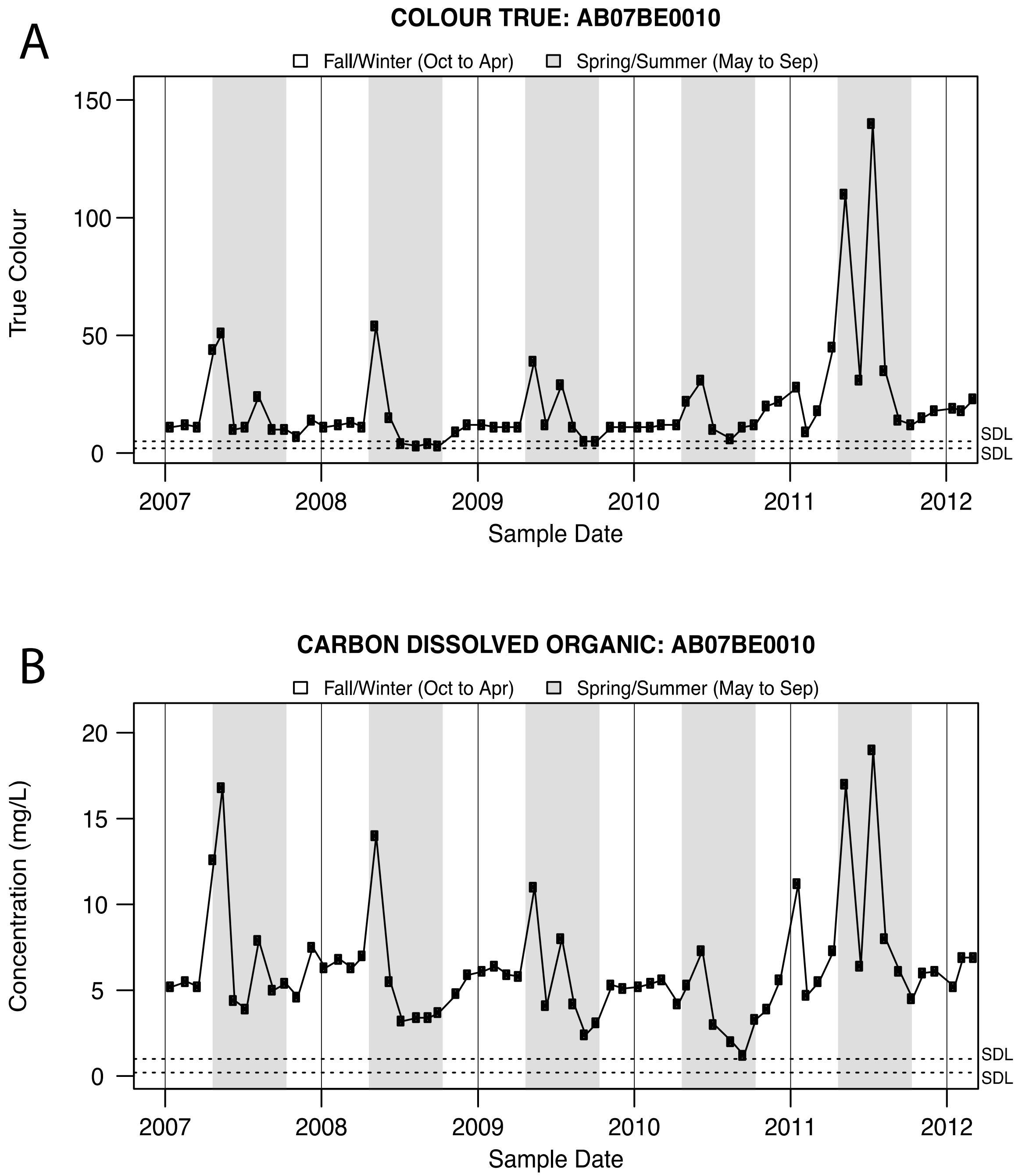


Figure 3-5. True colour (A) and dissolved organic carbon (DOC; B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

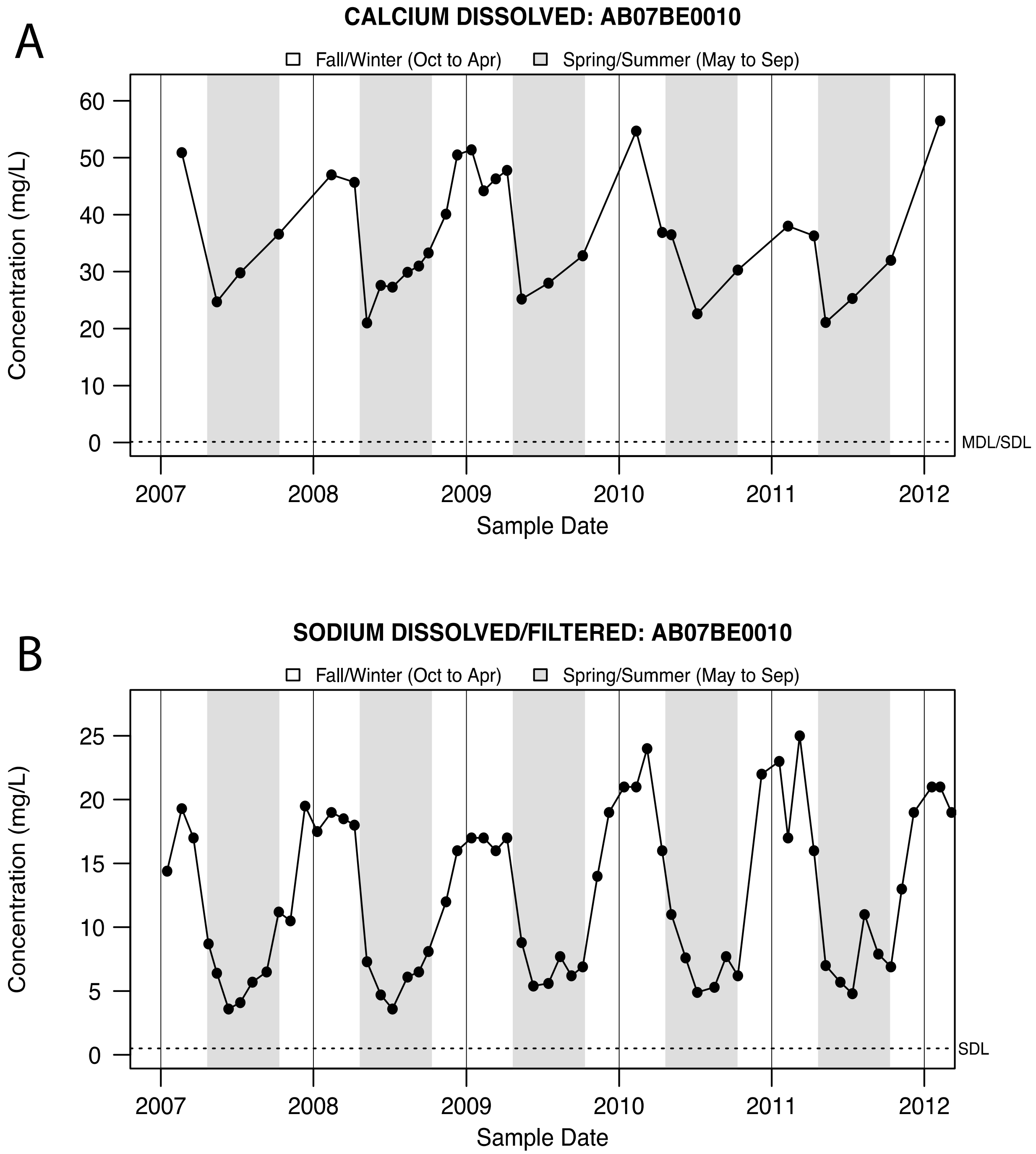


Figure 3-6. Calcium (Ca; A) and sodium (Na; B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

Chloride (Cl^-)

The seasonal variation in Cl^- is approximately a factor of four from ca. 1 mg/L in summer to ca. 4 mg/L in winter (Figure 3-7 A). Again, these pronounced variations are mainly driven by the dilution created during spring snowmelt followed by summer rains. Notice that the variation in Cl^- (4 times) resembles that Na (Figure 3-6 B) and that both of these exceed that of Ca (2 times), suggesting that there may be additional sources of Na and Cl^- to the water at this site. While the use of road salt in this area could be a contributing factor, natural sources of NaCl may also be important. To put these data into perspective, a typical concentration of Cl^- in continental rainwater is 0.5 mg/L and the global river water average is 5 mg/L (Livingstone 1963).

Sulphate (SO_4^{2-})

The seasonal variation in SO_4^{2-} is approximately a factor of two from ca. 20 mg/L in summer to ca. 50 mg/L in winter (Figure 3-7 B), with the difference being driven by spring dilution. The seasonal variation in SO_4^{2-} matches that of Ca (Figure 3-6 A) and both of these resemble the variation in TDS (Fig. 3-2 B). For comparison, the global average concentration of SO_4^{2-} in freshwater is ca 3.5 mg/L (Livingstone 1963), but in sedimentary terrains (such as the Athabasca River watershed), typical concentrations are roughly ten times the global average value.

Iron (Fe) and Manganese (Mn)

Iron and manganese, along with aluminum, are the most abundant “trace” metals in freshwaters. The concentrations of both Fe and Mn in natural waters are generally very variable as they are strongly dependent on redox potential, with the reduced forms, Fe (II) and Mn (II) being much more soluble than compounds of Fe (III) and Mn (IV). Given the lack of environmental concern about Fe and Mn, the values are presented (Figure 3-8 A and B, respectively) but not considered further.

Aluminum (Al)

The greatest Al concentrations are seen in late winter/early spring, with up to 80 µg/L during 2008 (Figure 3-9). Notice that the variations in Al concentrations exceed those of TDS (Figure 3-2 B) by a wide margin. Unlike Fe and Mn, the concentration, and more importantly the chemical speciation of this element, is of considerable ecological significance: the aquo aluminum ion, Al^{3+}, is potentially toxic to aquatic organisms. There are two CCME guideline values for total dissolved Al, depending on pH. At pH 8 (i.e., in the case of the Athabasca River at this site), the CCME value is 100 µg/L, which exceeds the maximum Al concentrations present at this site. While the dissolved Al concentrations are below the guideline value at this station, concentrations at the guideline value are present at other stations (see Discussion in Section 3.5).

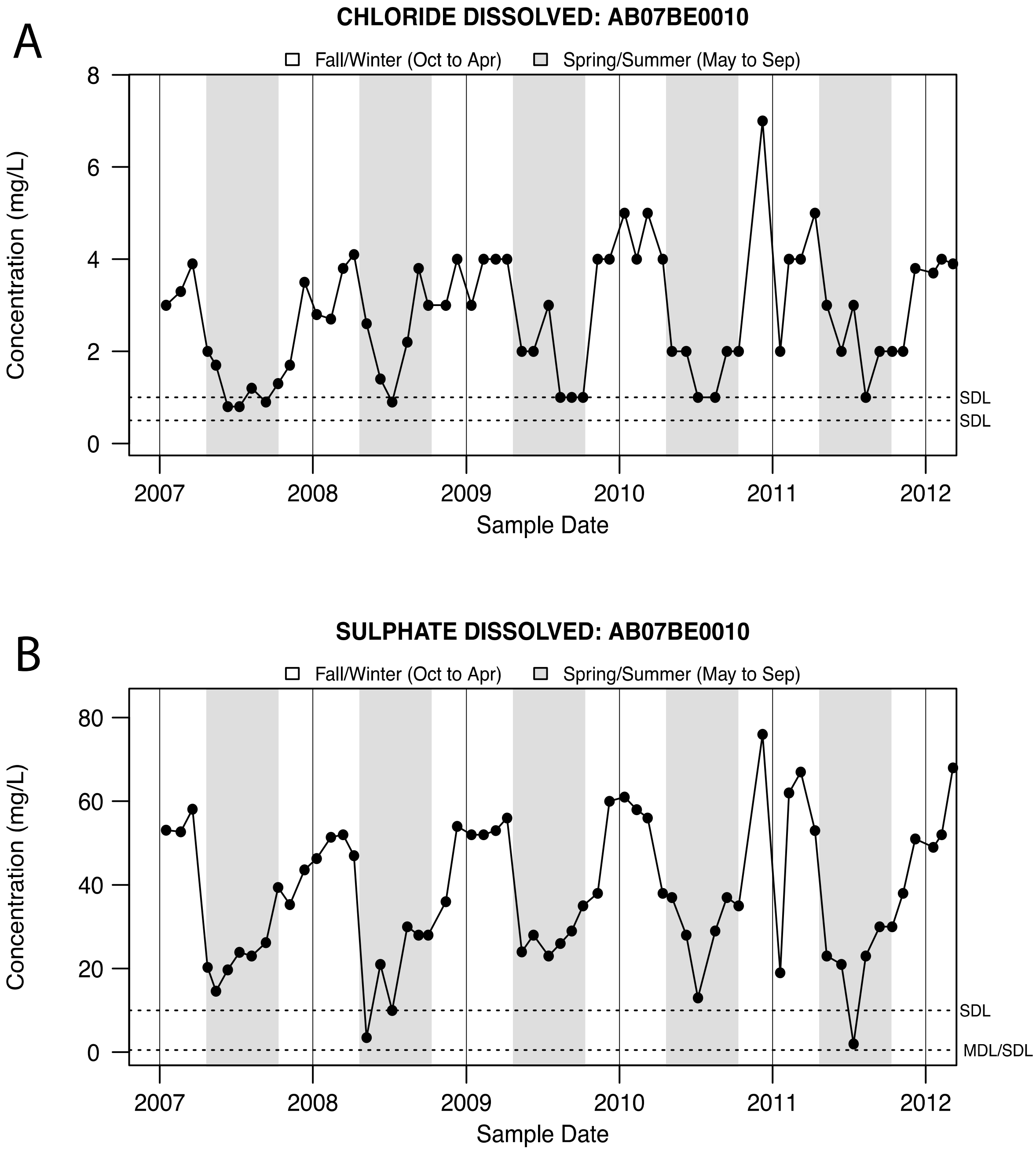


Figure 3-7. Chloride (Cl^-; A) and sulphate (SO_4^{2-}; B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

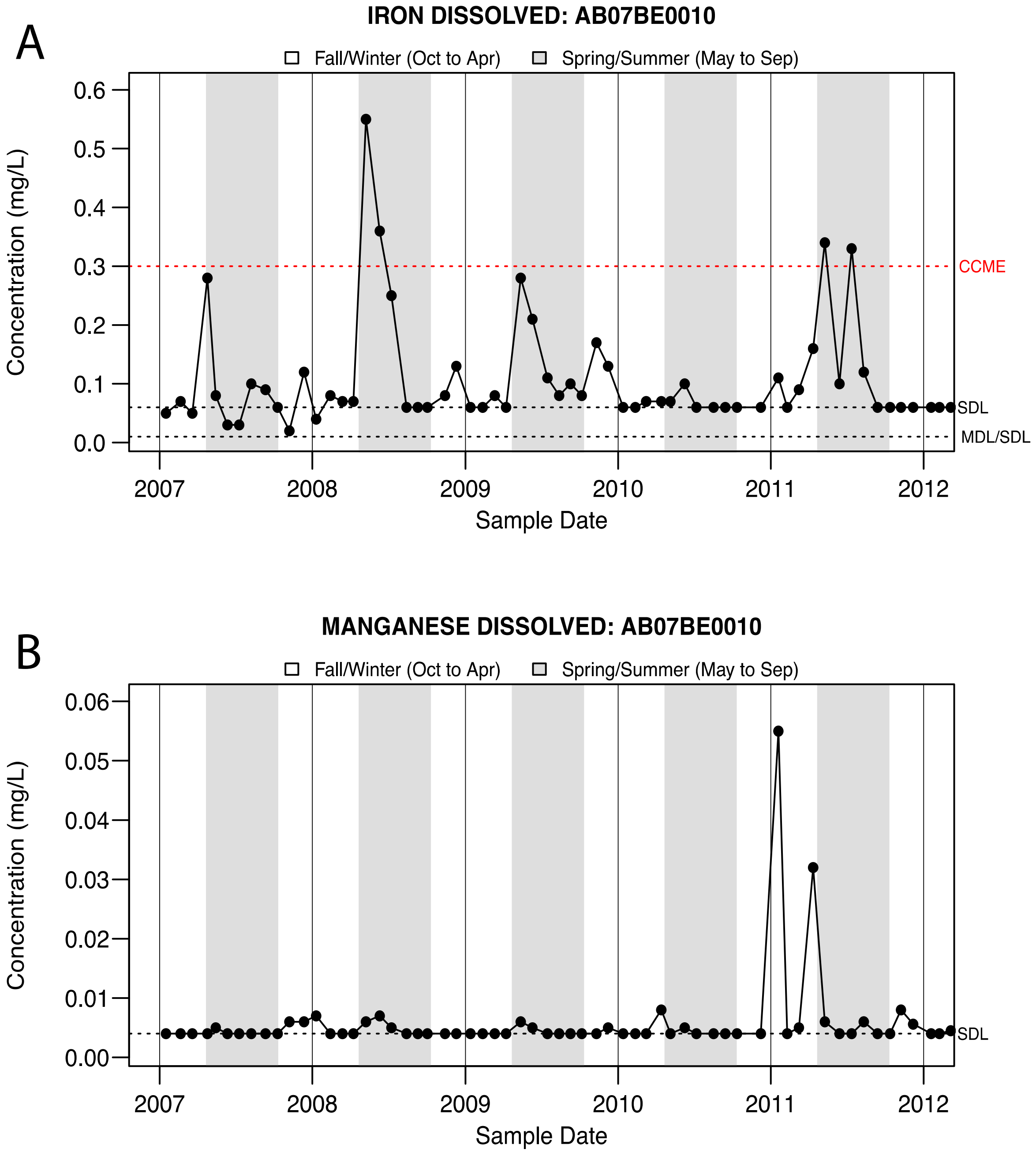
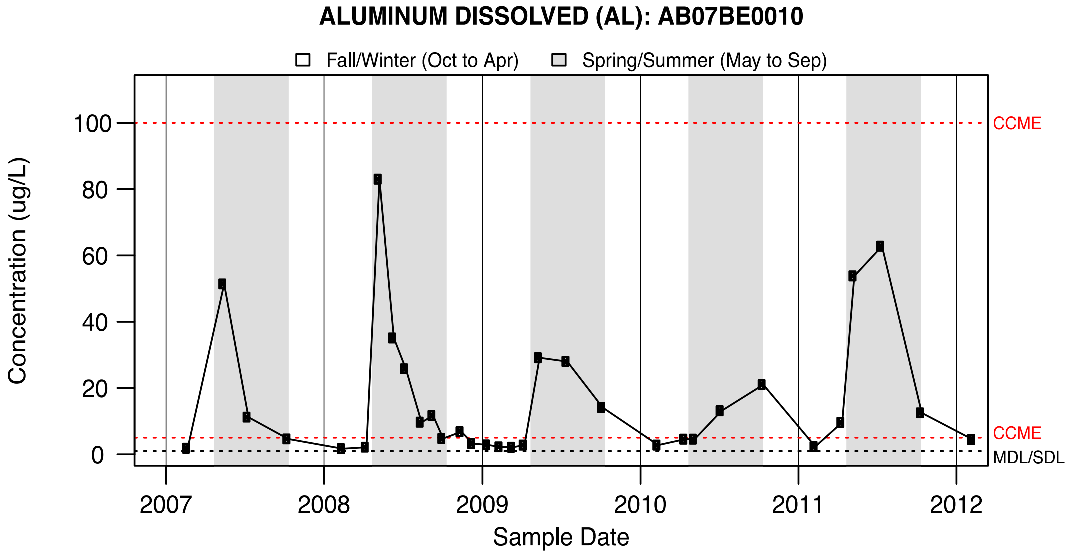


Figure 3-8. Iron (Fe; A) and manganese (Mn; B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure 3-9. Aluminum (Al) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

3.4.3. Nutrients at LTRN Site AB07BE0010 (town of Athabasca)

Nitrate (NO_3^-)

Nitrate concentrations in water usually reflect anthropogenic inputs simply because most of the N in soils is in the form of organic N compounds in humus, and with considerable biological demand, particularly during the plant growing season, typically very little nitrate is released to groundwaters and surface waters. Agriculture is the greatest single source of anthropogenic nitrate inputs to surface waters and groundwaters, from the use of nitrogenous fertilizers as well as animal manures. In the Athabasca River, low concentrations are seen in summer when biological activity is at its greatest extent (Figure 3-10 A). Maximum concentrations (0.35 mg/L in 2011) are seen during the first months of the year and these are far below the CCME guideline value of 13 mg/L.

Total Kjeldahl Nitrogen (TKN)

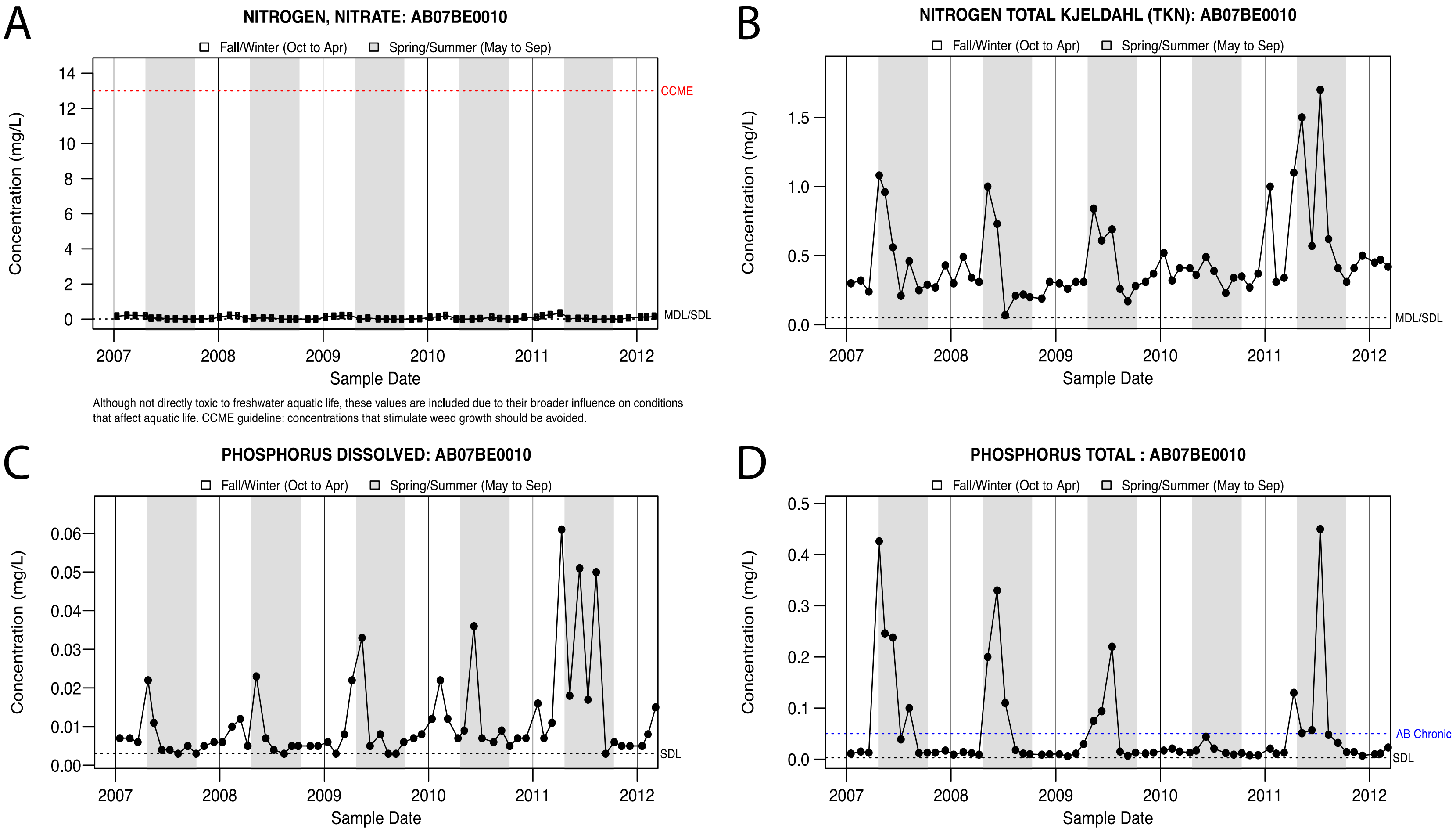
Total Kjeldahl Nitrogen is the sum of ammonia, ammonium and organic N-containing compounds. The greatest values of TKN are seen during late spring and early summer (Figure 3-10 B). The greatest concentrations were seen during 2011 when apparently there was extensive flooding. The strong resemblance between TKN and DOC (Fig. 4b) is logical because a large part of the TKN is in the form of organic N-containing compounds.

Dissolved P

The greatest dissolved P concentrations are seen in early summer and typically peak in the range 20 to 30 µg/L (Figure 3-10 C) except for 2011 when values were found exceeding 50 µg/L. Notice that the seasonal variations in nitrate and dissolved P are independent of one another, with the greatest nitrate values present in late winter (Figure 3-10 A), whereas dissolved P peaks in early summer (Figure 3-10 C). The mean value for dissolved P from LTRN stations between 2007 and spring 2012 (n=309) is 13.6 µg/L.

Total Phosphorus (TP)

Total phosphorus values are generally low (Figure 3-10 D), but elevated values are seen in late spring-early summer. Maximum concentrations between 0.4 and 0.5 mg/L were seen both in 2007 and 2011. The median value for TP from LTRN stations between 2007 and spring 2012 (n=307) is 50.7 µg/L. For comparison, and according to CCME guidelines, oligotrophic waters contain < 10 µg/L total P whereas eutrophic water contains > 35 µg/L. However, it should be noted that these general classifications of freshwater trophic status based on TP concentrations, rather than ecological or functional responses by algal communities, were developed using surface waters with relatively high TP concentrations. As described above in Section 1.4.2, relatively low increases in effluent-based TP (0.1-5.6 µg/L) have resulted in 4- to 30-fold increases in abundances of benthic algae and macroinvertebrates in the Upper Athabasca River (Bowman et al. 2007).



NITROGEN, NITRATE: AB07BE0010

NITROGEN TOTAL KJELDAHL (TKN): AB07BE0010

Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

PHOSPHORUS DISSOLVED: AB07BE0010

PHOSPHORUS TOTAL : AB07BE0010

Figure 3-10. Nitrate (NO_3^-) (A), Total Kjeldahl Nitrogen (TKN: NH_3 + NH_4^+ + Organic Nitrogen) (B), dissolved phosphorus (C), and total phosphorus (D) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

3.4.4. Trace Constituents at LTRN Site AB07BE0010 (town of Athabasca)

Fluoride (F^-)

The variation in F^-, ranging from 0.09 mg/L in summer to 0.18 mg/L in winter (Figure 3-11) is largely in line with the variation in TDS (Figure 3-2 B). Of itself, F^- is perhaps uninteresting, but as it may have a pronounced effect on the chemical speciation of Al (see below), it was included in this report.

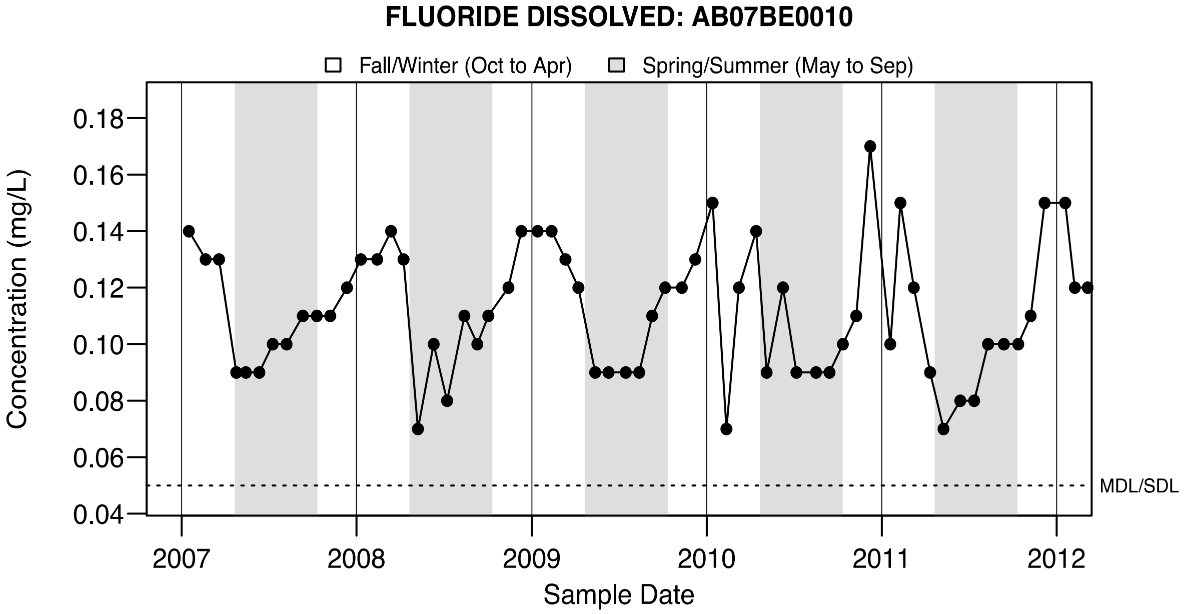


Figure 3-11. Fluoride (F^-) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

Cadmium (Cd)

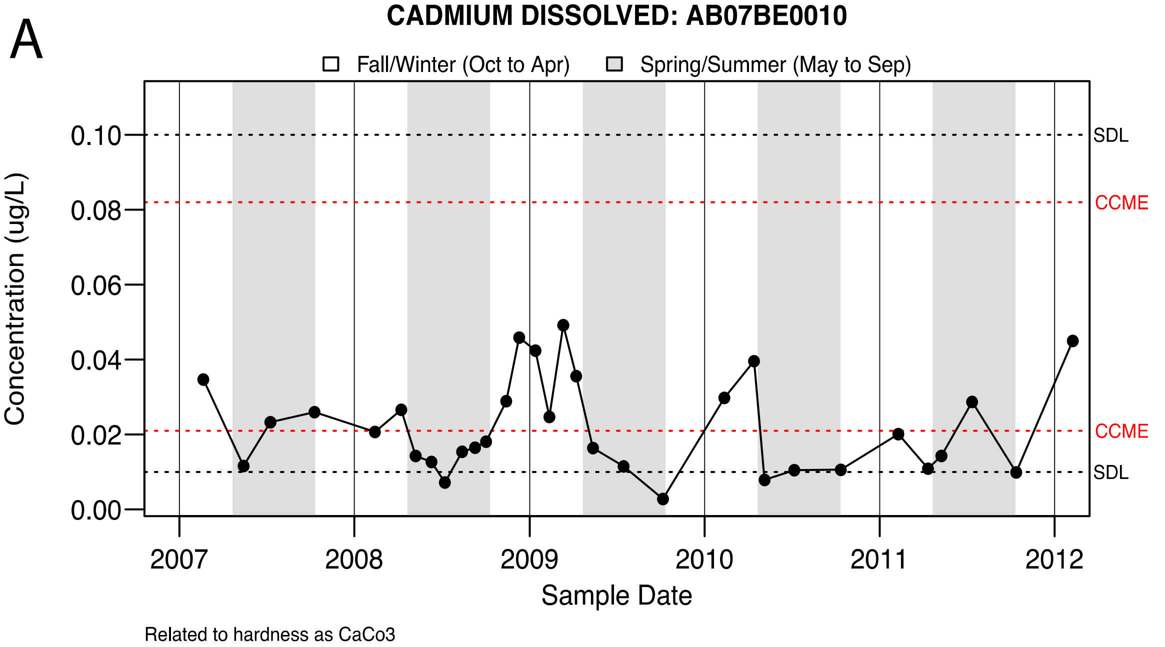
The concentrations of Cd are generally very low at this site (Figure 3-12 A), with all of the values below the maximum Sample Detection Limit (SDL) reported for the LTRN data (0.1 µg/L), and many values at or below the lowest reported SDL (0.01 µg/L). Given the proximity of the Cd concentrations to the lower limit of the SDL, and the distance between the concentrations and the upper limit of the SDL, it becomes clear that even the lowest SDL is inadequate to reliably measure Cd in the waters of the Athabasca River. To help put the abundance of Cd into perspective, the measured concentration of Cd in surface waters of Kawagama Lake in southern Ontario (Shotyk and Krachler, 2009), is 7.5 ± 0.25 ng/L (parts per trillion). The limit of detection reported in that paper for Cd in surface water was 0.01 ng/L) which is *one thousand times lower* than the lowest SDL reported for the LTRN data. In other words, the concentrations of Cd that may be encountered in surface waters could easily be far below the lower limit of the SDL reported for the LTRN data.

Further, as noted in Section 5.2.2, there is no information about the accuracy of the Cd values reported here. While many Cd values shown in Figure 3-12 exceed the lowest reported SDL, the accuracy of these measurements remains unknown because no certified standard reference materials were included in the analytical campaign. The lack of any information about the accuracy of the Cd measurements is a severe limitation to providing any quantitative assessment of the data. Taken together, the Cd concentration values shown in Figure 3-12 must be viewed with extreme caution, as their validity is difficult to assess.

Although the Cd concentrations seen in the river are generally low, so too is the CCME guideline value for the protection of aquatic life: an interim value of 0.017 µg/L is given, but in fact, the guideline value increases with water “hardness”. Given the range in hardness reported in the data set examined for this watershed (60 to 288 mg/L), the guideline value for Cd in these waters obtained using the CCME calculator (see: http://st-ts.ccme.ca/?lang=en&factsheet=20) ranges from 0.021 to 0.082 µg/L. The elevated Cd values (on the order of 0.04 µg/L) during the winters of 2009, 2010, and 2012 are within this range of guideline values. However, a more detailed examination of Cd in relation to seasonal variations in water hardness is not justified, given the uncertainty in the Cd data at these concentrations.

Mercury (Hg)

As expected, the Hg concentrations typically are very low, with most on the order of 1 ng/L (part per trillion; Figure 3-12 B). However, elevated values (15 to 20 ng/L) are seen during the summers of 2008, 2009, and 2011 and these reported values clearly exceed the Alberta guideline values for acute toxicity. However, based on the close correspondence between Hg concentrations (Fig. 3-12 B) and DOC (Figure 3-5 B), caution should be applied in interpreting the Hg concentration data. It may be that much of the Hg is bound to organic matter, and therefore, may be unavailable or much less available to aquatic organisms. Given that Hg concentrations exceed guideline values, a more in-depth study of Hg is warranted.



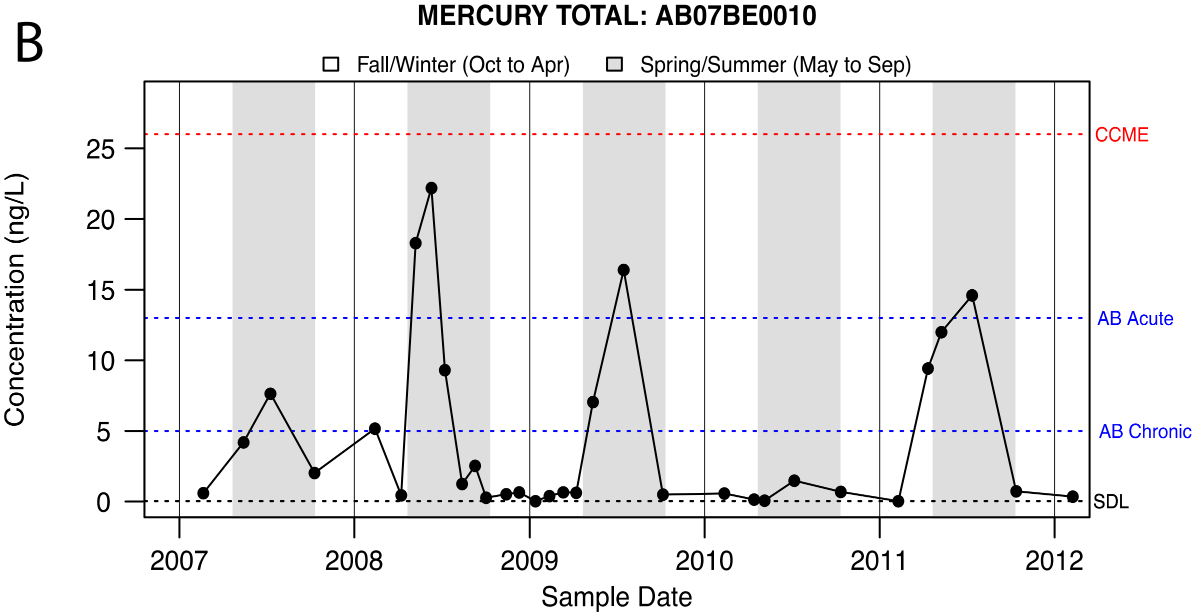


Figure 3-12. Cadmium (Cd) (A) and mercury (Hg) (B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

Uranium (U)

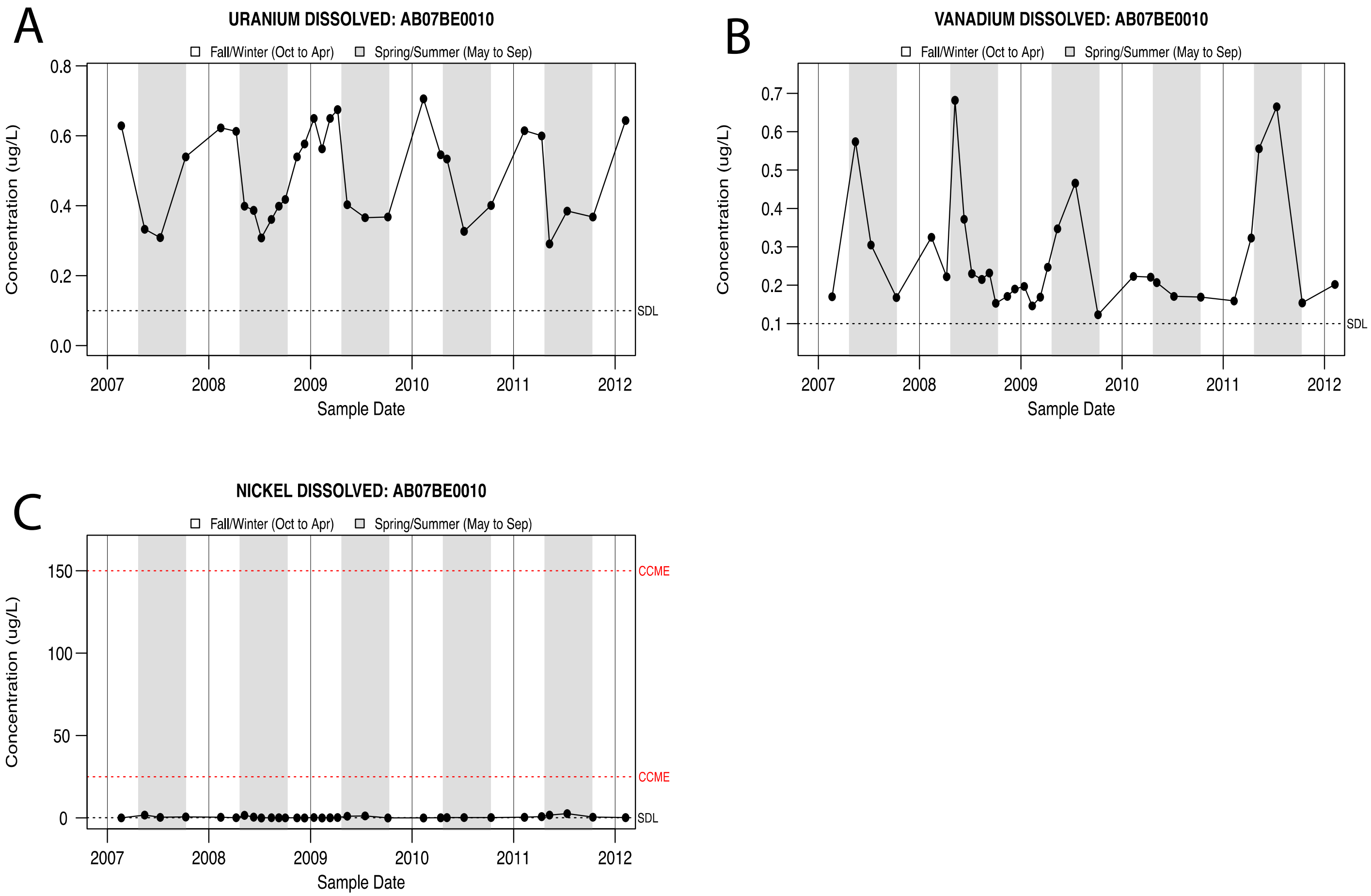
The seasonal variation in U concentrations, from ca. 0.25 µg/L during the summers to 0.6 µg/L during the winters (Figure 3-13 A), are largely in line with the seasonal variations in TDS (Fig. 3-2 B). Uranium is included in the list of trace metals being evaluated because it serves as an example of a predominantly anionic (i.e., negatively-charged) trace metal. Notice that U concentrations are low (Figure 3-13 A) when DOC is high (Figure 3-5 B), suggesting that metal-organic interactions for this element are relatively unimportant, in contrast to vanadium (see below).

Vanadium (V)

The seasonal variation in V concentrations, from ca. 0.15 µg/L during the summers to 0.7 µg/L during the winters (Figure 3-13 B), contrasts with those of U, an element with which V is often compared. However, the variations in V are largely in line with the seasonal variations in DOC (Figure 3-5 B). Based on our understanding of the aquatic chemistry of V, it should be present in the river predominantly in anionic form, with little affinity for dissolved organic compounds. However, the results shown in Figure 3-13 B suggest that this is not the case, and that much of the V may be associated with organic complexes.

Nickel (Ni)

The concentrations of Ni are generally at or below the reported sample detection limit (SDL) of 0.1 µg/L (Figure 3-13 C). For the purpose of this report, this means that there is little Ni data. However, despite unacceptably low accuracy and precision and the general lack of data, the CCME guideline values for this trace metal increase with water hardness and are fairly high, ranging from 25 to 150 µg/L. The lower CCME guideline value (25 µg/L), for example, is 250 times greater than the SDL. So, although Ni is largely undetectable, if the Ni concentrations were high enough to be relevant, then they would have been detected as part of the water quality monitoring at this station.



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure 3-13. Uranium (U) (A), vanadium (V) (B), and nickel (Ni) (C) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

Chromium (Cr)
Like nickel (Ni), the concentrations of Cr are generally at or below the reported sample detection limit (Figure 3-14 A), meaning that there are little, if any, Cr data. Assuming that most of the Cr is in the form of Cr (VI), which is a reasonable assumption for oxygenated surface water, the CCME guideline of 1 µg/L for Cr (VI) would apply (Table 1-2a). Unfortunately, the calculated precision value for chromium exceeds the stated measurement quality objective (see Table 5-2), and the absence of any data to determine the accuracy for Cr render the existing data unacceptable to study the ecological significance of this element in the Athabasca River.

Zinc (Zn)
Although some Zn values approach the reported sample detection limit (Figure 3-14 B), most values are far enough above the SDL that it is clear the reported values are well below the CCME guideline levels.

Copper (Cu)
The copper (Cu) concentrations are consistently elevated during summer months (Figure 3-14 C), possibly related to the elevated DOC during those periods (Figure 3-5 B). Copper forms extremely stable complexes with natural organic matter in freshwaters and therefore, similarities between Cu and DOC are not surprising. However, given that the maximum Cu values approach the CCME guideline values (2 to 4 µg/L, depending on water hardness), the Cu data are considered in more detail later.

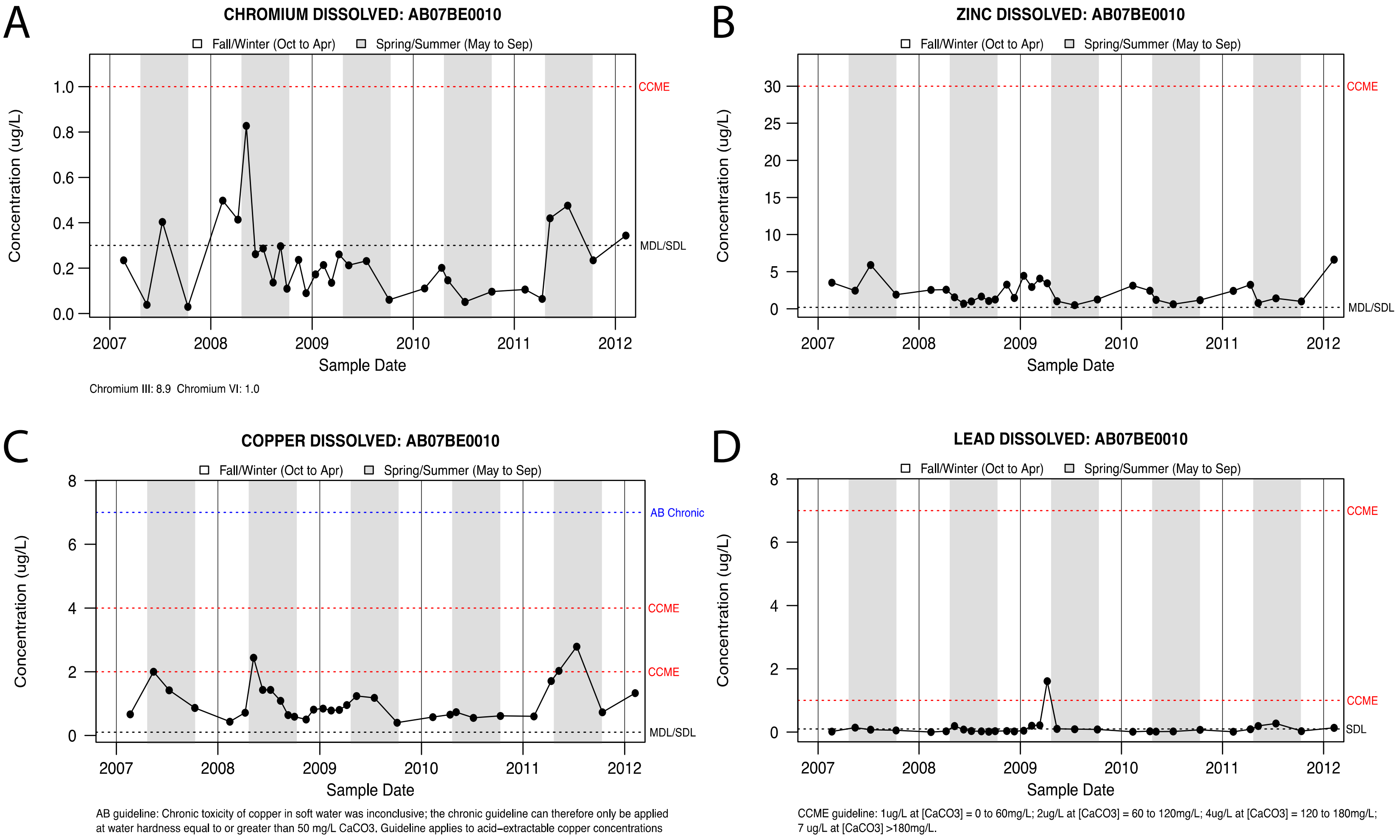
Lead (Pb)
With the exception of a single sample during 2009, the concentrations of Pb (Figure 3-14 D) are generally at or below the reported sample detection limit of 0.1 µg/L. As explained above, this means that there are few, if any, reliable Pb concentration data. The extremely low natural concentrations of Pb in freshwaters indicate that the limit of detection employed here is not adequate. Referring once again to the surface waters of Kawagama Lake in southern Ontario, simply to have a basis for comparison, Pb concentrations are as low as 10 ng/L in that lake (Shotyk and Krachler, 2010), which is an order of magnitude less than the SDL reported here.

As is true of Cd, the CCME guideline value for Pb increases with water “hardness”. Given the range in hardness in the Athabasca River (59 to 288 mg/l), the guideline value for Pb in these waters ranges from 1 to 7 µg/L. Given the anomalous Pb concentration reported in 2009 at this station (Figure 3-14 B), combined with the anomalous concentration reported in the same year at LTRN station AB07DD0105 (Figure 3-20 B), it appears that a more thorough examination of Pb in the Athabasca Watershed is warranted.

Arsenic (As)
The reported As concentrations at this station are near the stated sample detection limit (Figure 3-15 A). Although the SDL (0.1 µg/L) is inadequate for accurate and precise As concentration measurements, the values that have been obtained for As are below the concentrations (5 µg/L) generally considered to be of concern.

Selenium (Se)
The reported Se concentrations (Figure 3-15 B) are at or below the stated sample detection limit of 0.3 µg/L. The calculated mean value of the triplicate splits (Table 5-2), which is used here to estimate precision, is also 0.3 µg/L, meaning that there is no data to evaluate the precision of the measurements. Given these two circumstances, combined with the fact that

there is no information about the accuracy of the Se determinations, there is effectively no usable Se concentration data. Given that the CCME guideline for Se is 1 µg/L, and that this is only a factor of three times greater than the SDL, more sensitive analytical methods should be used in future to evaluate the potential ecological significance of this element in the Athabasca Watershed.

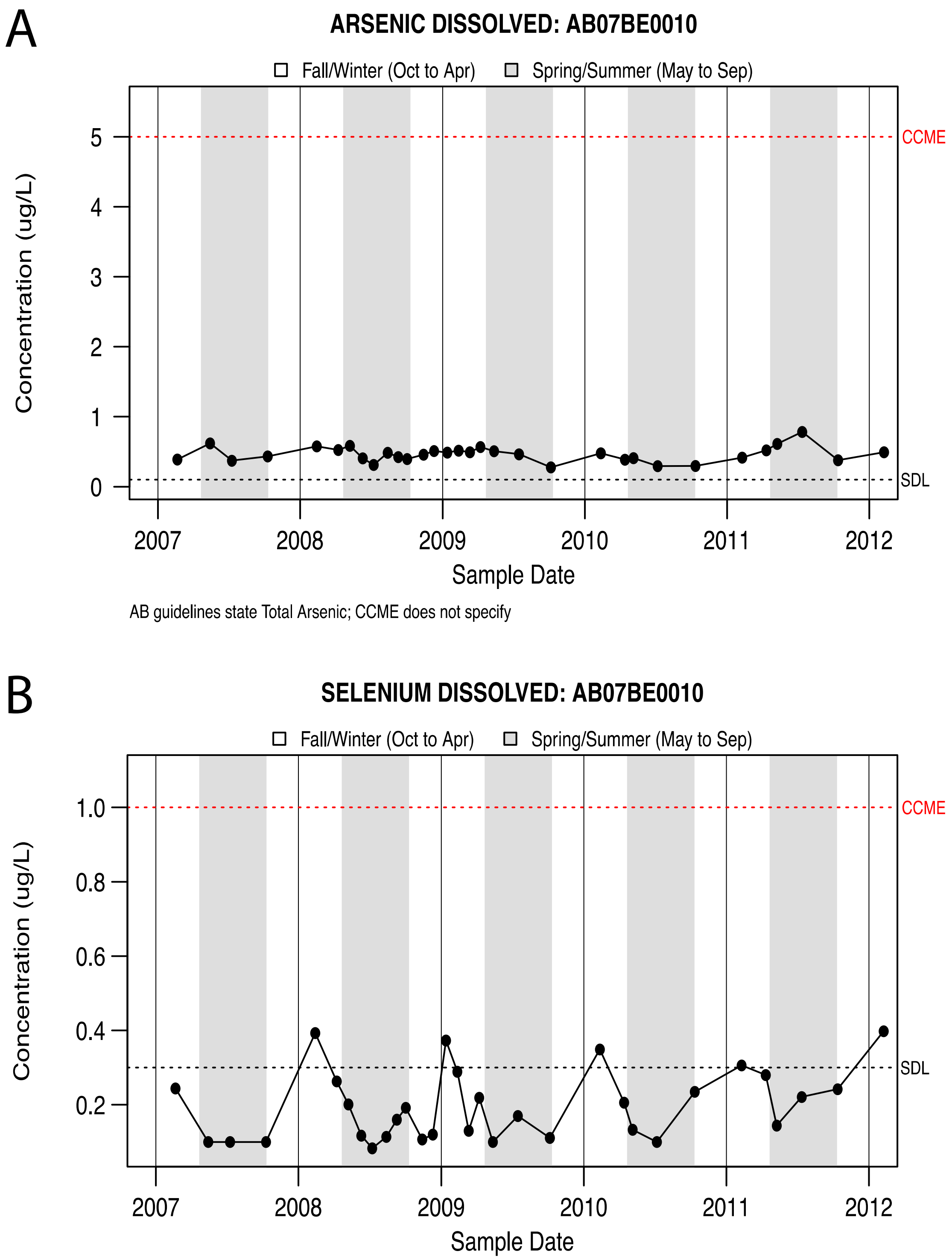


Chromium III: 8.9 Chromium VI: 1.0

AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure 3-14. Chromium (Cr) (A), zinc (Zn) (B), copper (Cu) (B) and lead (Pb) (D) measured at the town of Athabasca. Source: Provincial Long-term River Network database.



AB guidelines state Total Arsenic; CCME does not specify

Figure 3-15. Arsenic (As) (A) and selenium (Se) (B) measured at the town of Athabasca. Source: Provincial Long-term River Network database.

3.4.5. Water Chemistry at Other LTRN Sites

The use of the data from the Town of Athabasca was intended to illustrate typical values seen at stations throughout the Athabasca Watershed for the water quality parameters selected for assessment in this report, including their seasonal variation. In addition, this data set was used to describe some of the natural processes affecting water quality in the Athabasca River. However, the data obtained from other sites on the Athabasca River show clear differences, and these are presented and discussed below. A complete set of figures for all water quality parameters assessed at all LTRN sites can be found in Appendix 1.

Old Fort (LTRN Station AB07DD0010)

The pH depression at Old Fort (Figure 3-16) is notable because the pH drops below the CCME guideline of 6.5. Again, the pH scale is logarithmic meaning that water at pH 6.5 is 100 times more acidic than water at pH 8.5. When the pH drops below 6.5, the CCME guideline for Al, for example, declines from 100 µg/L to 5 µg/L. Therefore, it is important to evaluate the possible importance of the pH drop for other chemical parameters, and this is done below.

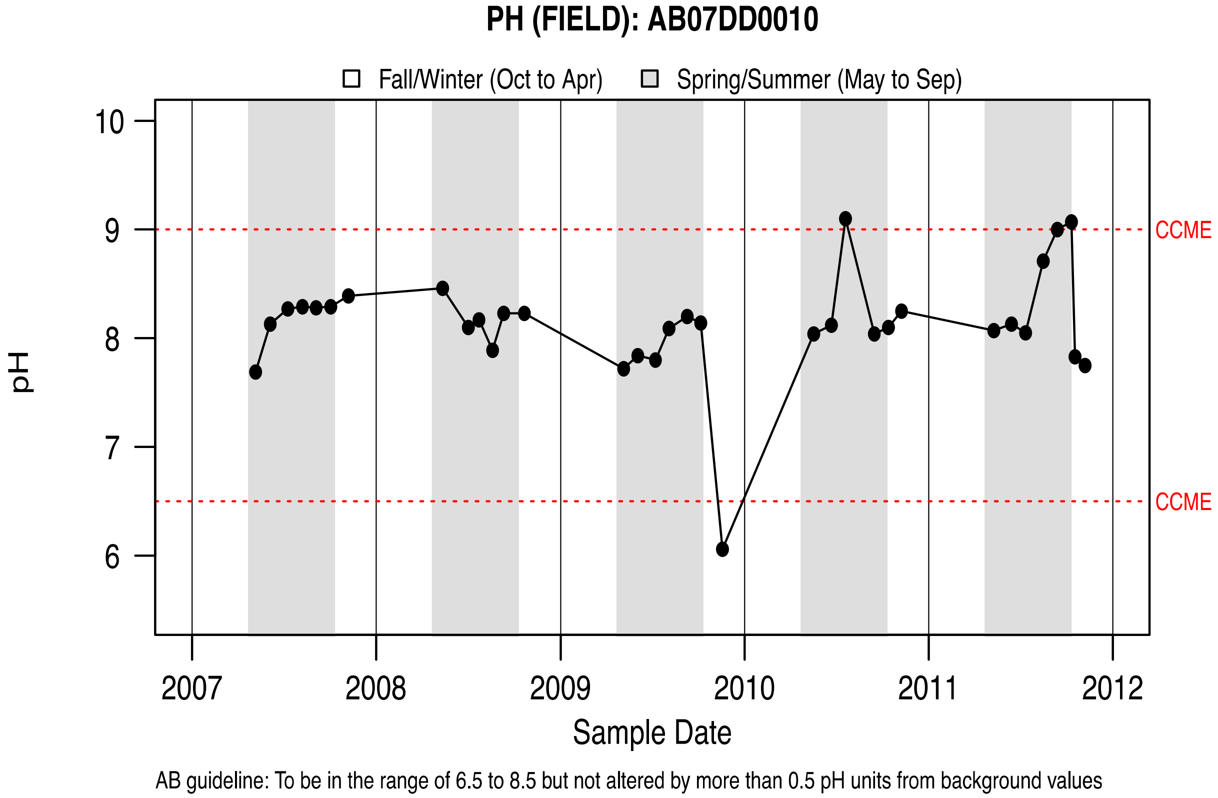


Figure 3-16. pH measured at Old Fort. Source: Provincial Long-term River Network database.

Above the Firebag River (LTRN Station AB07DA0980)
At this site, chloride concentrations are elevated (Figure 3-17a). Compared to the typical concentration range seen for Cl^-, e.g., ca. 5 mg/L (summer) and 10 mg/L (winter) at the Town of Athabasca, this site is clearly exceptional with Cl^- elevated up to 50 mg/L. Chloride is easily and reliably measured, so there is no question about the validity of the data. In fact, Cl^- is generally considered the most reliable, conservative tracer of ion inputs to natural waters (Livingstone, 1963). The elevated Cl^- concentrations at this site indicate an additional source of dissolved salts to the river. This interpretation is confirmed by the elevated concentrations of Na (Figure 3-17 C). Given the location of this site and the known occurrence of natural, saline seepages extending for many km along the banks of the river (Gibson et al. 2011), natural inputs are likely.

Downstream of Devil's Elbow (LTRN Station AB07DD0105)
Elevated Cl^- is also seen downstream of Devil's Elbow at the winter road crossing (AB07DD0105; Figure 3-17 B), which is also in the lower reaches of the river, so the phenomenon is certainly seen at more than one location. In this case, however, much less seasonal variation is evident than above the Firebag River, although natural inputs may again be the principal cause.

Old Entrance (LTRN Station AB07AD0100)
Elevated concentrations of sulphate are seen at Old Entrance during winter (Figure 3-18), with values (ca. 100 mg/L) much greater than the winter values seen at the town of Athabasca (50 mg/L). The higher values seen at Old Entrance are not of concern, but rather they are included here to illustrate the variability in water quality. The elevated values may be a natural feature and simply reflect the geology of the area such as an abundance of gypsum in the soils and rocks, for example. However, these sorts of variations need to be understood: the impacts of human activities on this watershed will be difficult to quantify until the extent of natural, inherent variation in the water quality is known.

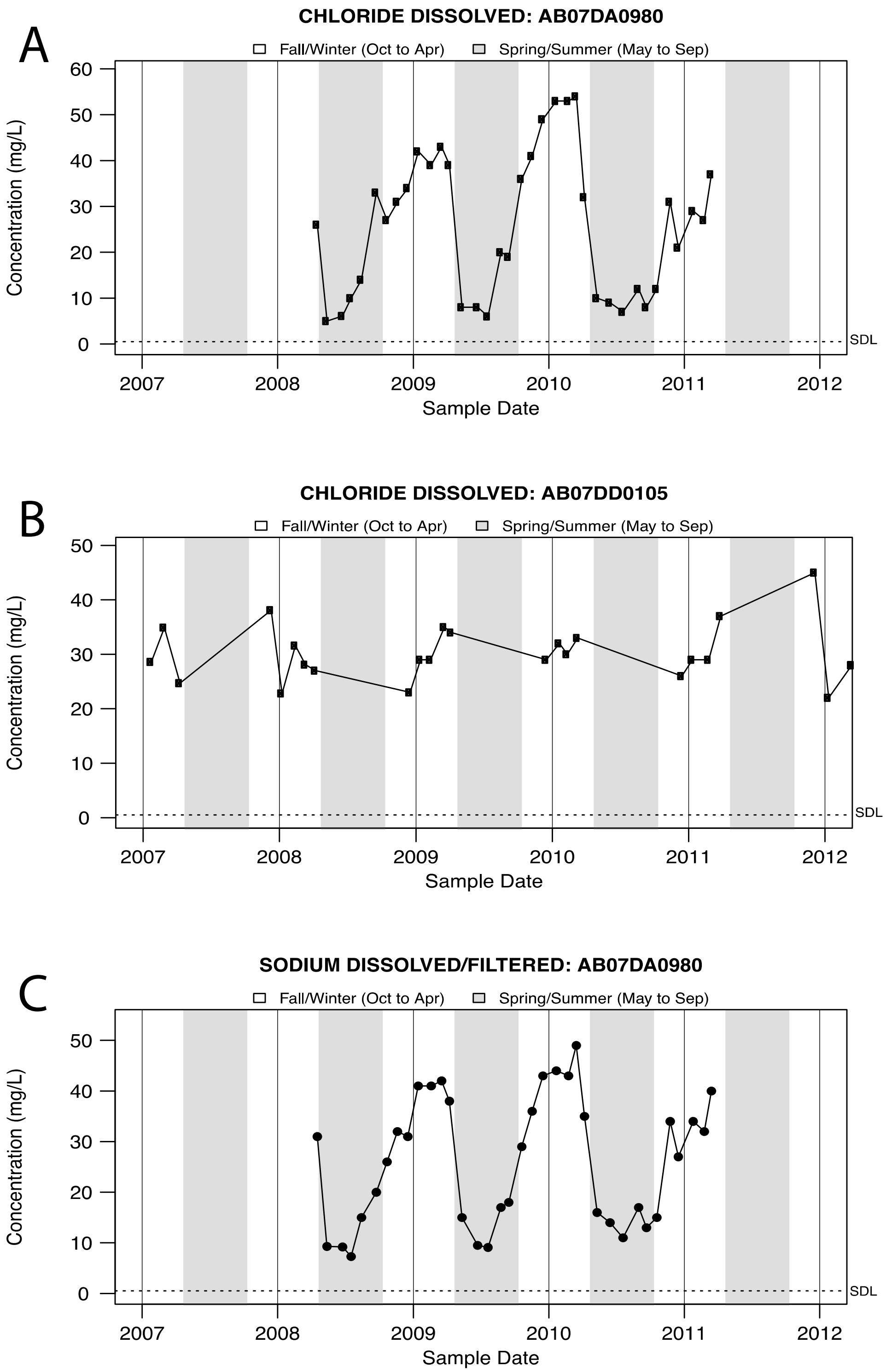


Figure 3-17. Chloride (A & B) and sodium (C) measured in the Lower Athabasca region, upstream of the Firebag River and downstream of the Devils Elbow. Source: Provincial Long-term River Network database.

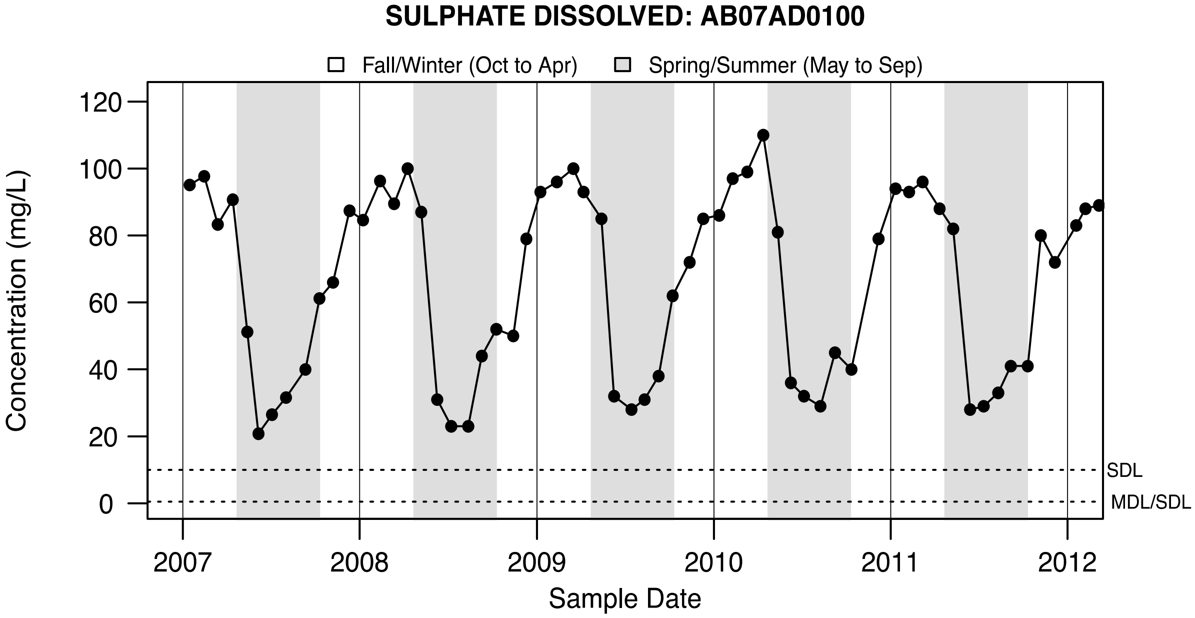


Figure 3-18. Sulphate measured at Old Entrance, upstream of the town of Hinton. Source: Provincial Long-term River Network database.

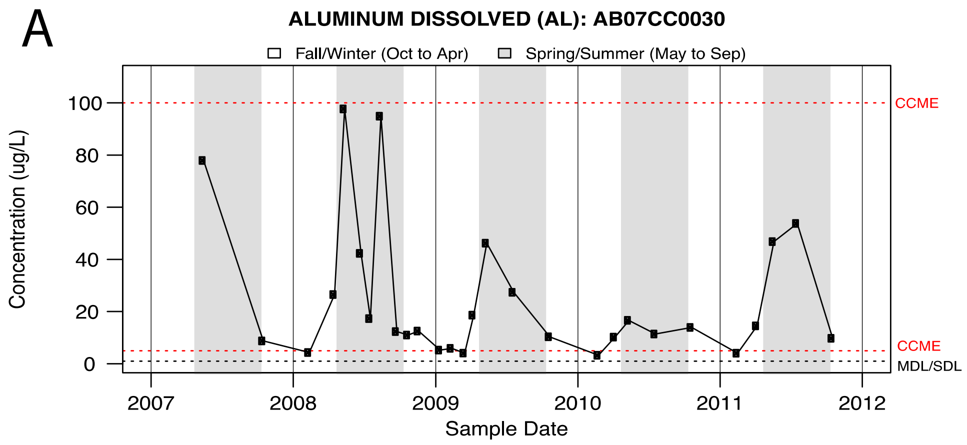
Major Constituents and Trace Constituents of Note at LTRN Stations

Concentrations of aluminum are clearly elevated at three sites in the Lower Athabasca region, including the station at the confluence with the Horse River, the transect above the Firebag River, and at Old Fort (Figure 3-19). The maximum concentrations meet, but do not exceed, the CCME guideline value of 100 µg/L on the three occasions seen here. As noted earlier, however, the CCME guidelines for Al vary, depending on the pH of water, and this is considered below.

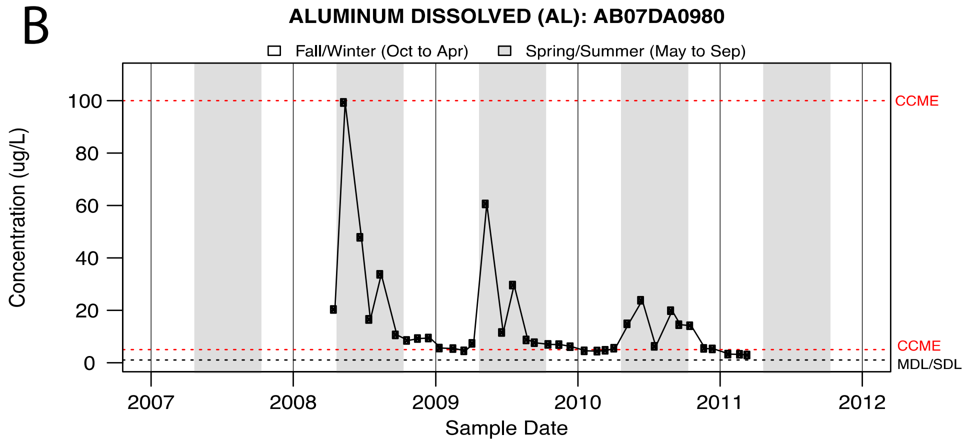
The concentrations of cadmium measured in 2008 at Old Fort are up to 1 µg/L on two occasions (Figure 3-20 A). A single outstanding value for Cd might be considered an outlier, but the instance of two elevated values makes this less likely. These Cd values exceed the interim guideline value of 0.017 µg/L by a considerable margin and exceed the detection limit by a factor of ten.

There is an unusual lead concentration reported at the station downstream of Devil's Elbow of ca. 18 µg/L (Figure 3-20 B), which exceeds the guideline value of 7 µg/L (for hard water). The reported value is unlikely to have been an analytical error as the concentration is so high. As noted earlier, and to help put this value into perspective, the Pb concentrations in the surface waters of Kawagama Lake in southern Ontario (Shotyk and Krachler, 2010), are typically 1,000 times lower. In fact, this anomalous value for Pb in the Athabasca River is comparable to those reported for rainwater in northeastern North America during the early 1970's when leaded gasoline was still being used (see the discussion in Shotyk et al., 2010). In other words, the value is truly outstanding and there is no apparent, simple explanation.

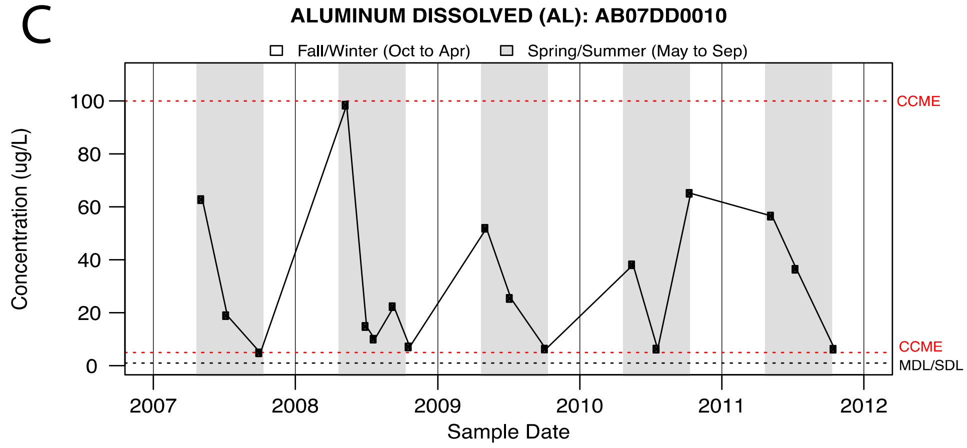
Concentrations of mercury exceeding Alberta surface water quality guideline values (5 ng/L for chronic effects and 13 ng/L for acute effects) are common at Old Entrance (Figure 3-21), and at three sites in the lower Athabasca region, including stations located at the Horse River confluence, above the Firebag River, and at Old Fort. In many cases, however, the elevated Hg concentrations are seen during periods when DOC is also elevated, and this point will be discussed later in Section 3.5.



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

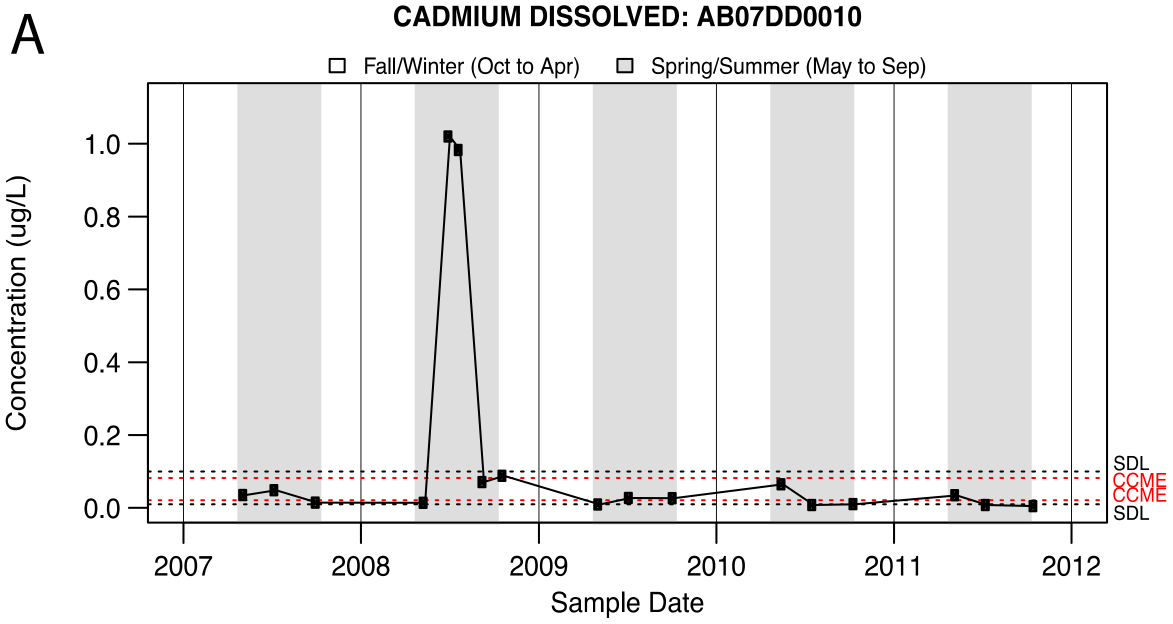


CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

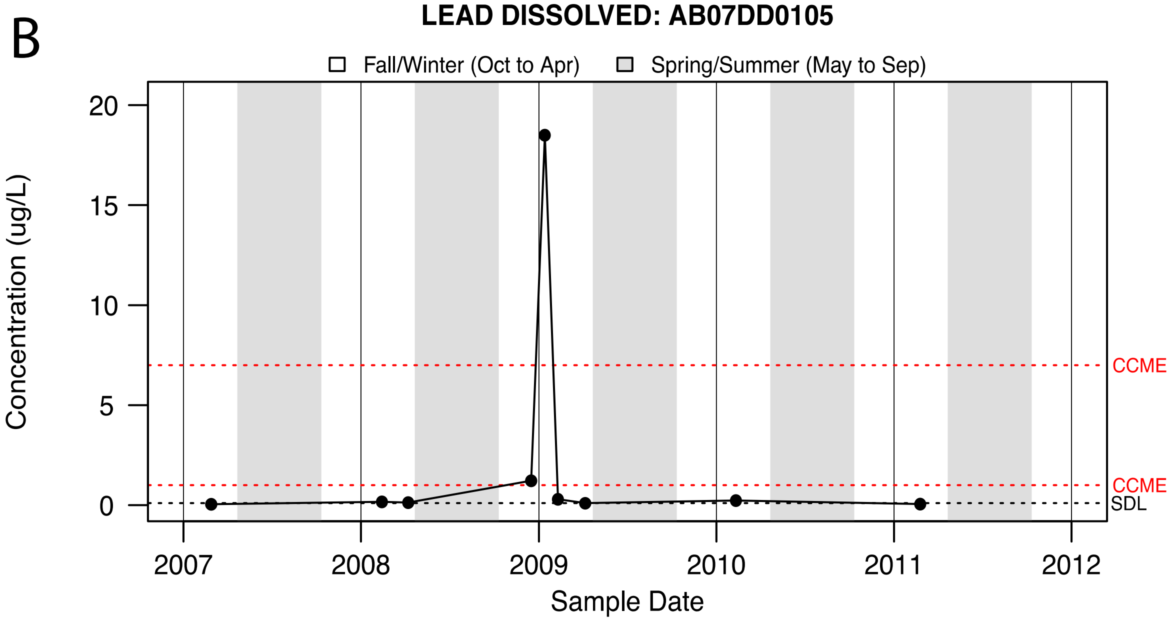


CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure 3-19. Aluminum in the Lower Athabasca region, as measured upstream of Fort McMurray (A), above the Firebag River (B), and at Old Fort (C). Source: Provincial Long-term River Network database.



Related to hardness as CaCo3



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure 3-20. Cadmium (Cd) (A) and lead (Pb) (B) measured downstream of Fort McMurray at Old Fort and downstream of Devils Elbow at the winter road crossing. Source: Provincial Long-term River Network database.

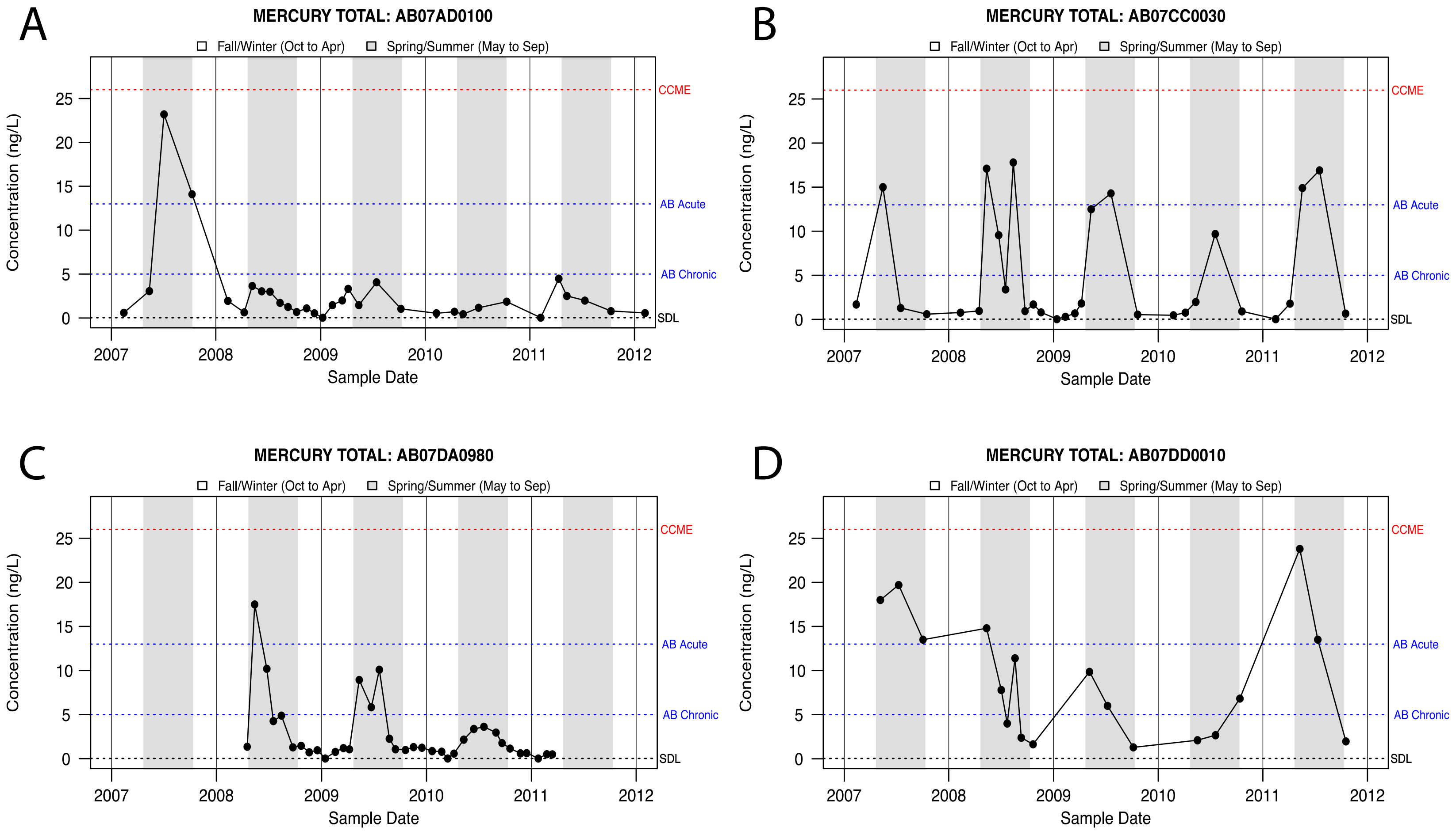


Figure 3-21. Mercury measured at Old Entrance (A), upstream of Fort McMurray at the Horse River (B), upstream of the Firebag River (C), and at Old Fort (D). Source: Provincial Long-term River Network database.

3.4.6. Water Chemistry at MTRN Sites

Exceptional values were reported for both sodium and sulphate at the McLeod River station, located at the confluence of the Athabasca River in the town of Whitecourt (AB07AG0390; Figure 3-22). However, unlike the elevated concentrations of sulphate seen at Old Entrance (AB07AD0100), which is reproducible over a period of five years (Figure 3-18), the elevated sodium and sulphate at AB07AG0390 is a single episode and the concentrations were very high, namely 250 mg/L (Figure 3-22). Although these water quality parameters themselves are not critical, the cause for these changes needs to be understood in case there are other, related issues. Unfortunately, there does not appear to be trace metals data for this site, so possible impacts of this “event” on the chemistry of trace metals cannot be evaluated.

Dissolved oxygen is below CCME guidelines at the Kearl Lake Road station (AB07DA0610; Figure 3-23), which is clearly of concern for aquatic health. At this site, DOC is significantly elevated (15 to 25 mg/L), compared to the values seen at the Town of Athabasca which are ca. 5 to 15 mg/L. Given that DOC values in peatland surface waters are commonly on the order of 50 mg/L, the elevated DOC could be a natural feature in this section of the river, especially given that peatland waters are generally anoxic. At this same site, although there appears to be a decline in pH values, there is neither dissolved oxygen data nor pH data since early 2009. Taken together, the dissolved oxygen concentrations, DOC values, and pH values suggest that attention should be paid to this site (Kearl Lake Road). Regular sampling at this site is warranted and should be a priority.

A complete set of figures for all water quality parameters assessed at selected MTRN stations can be found in Appendix 2.

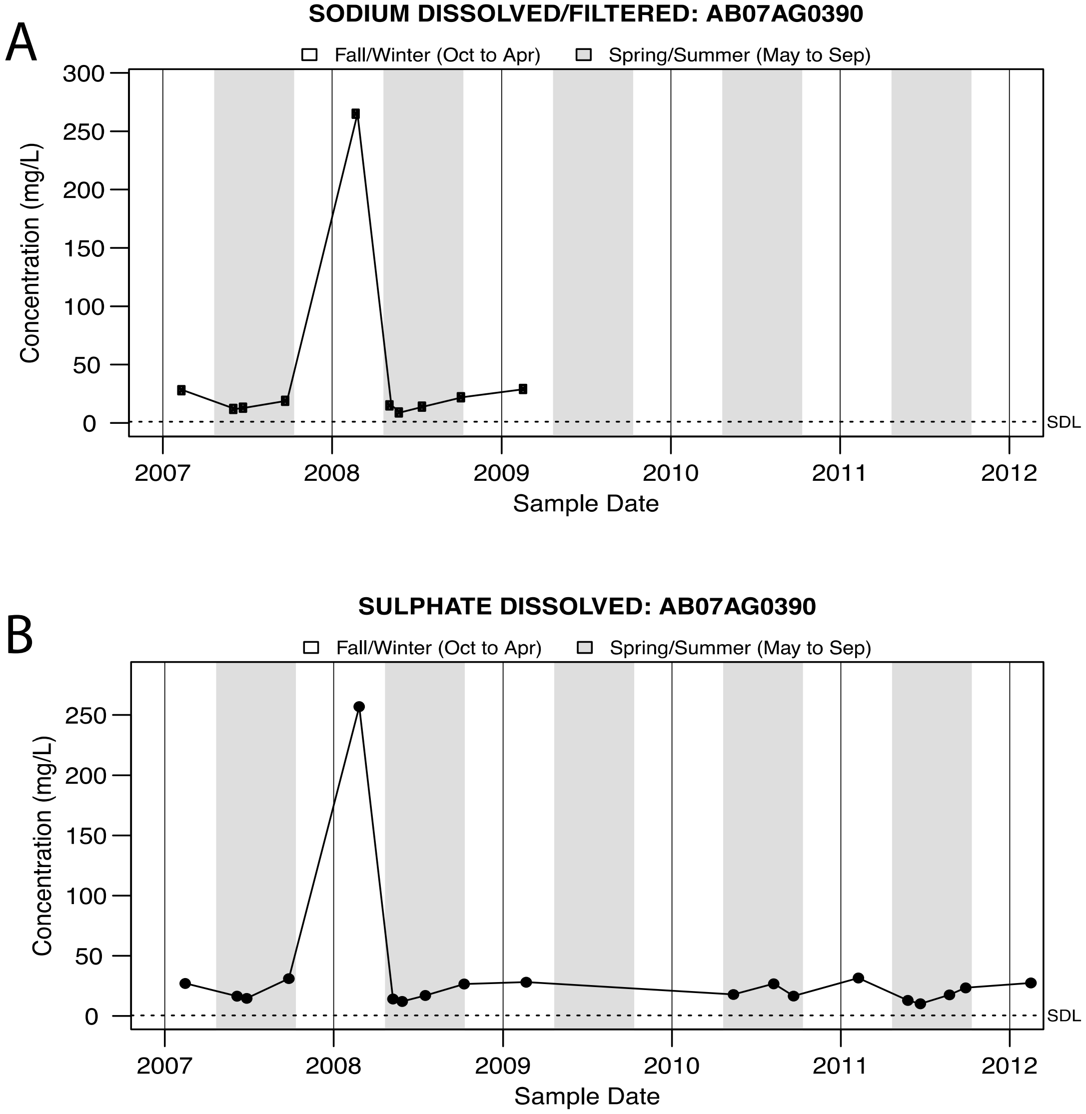
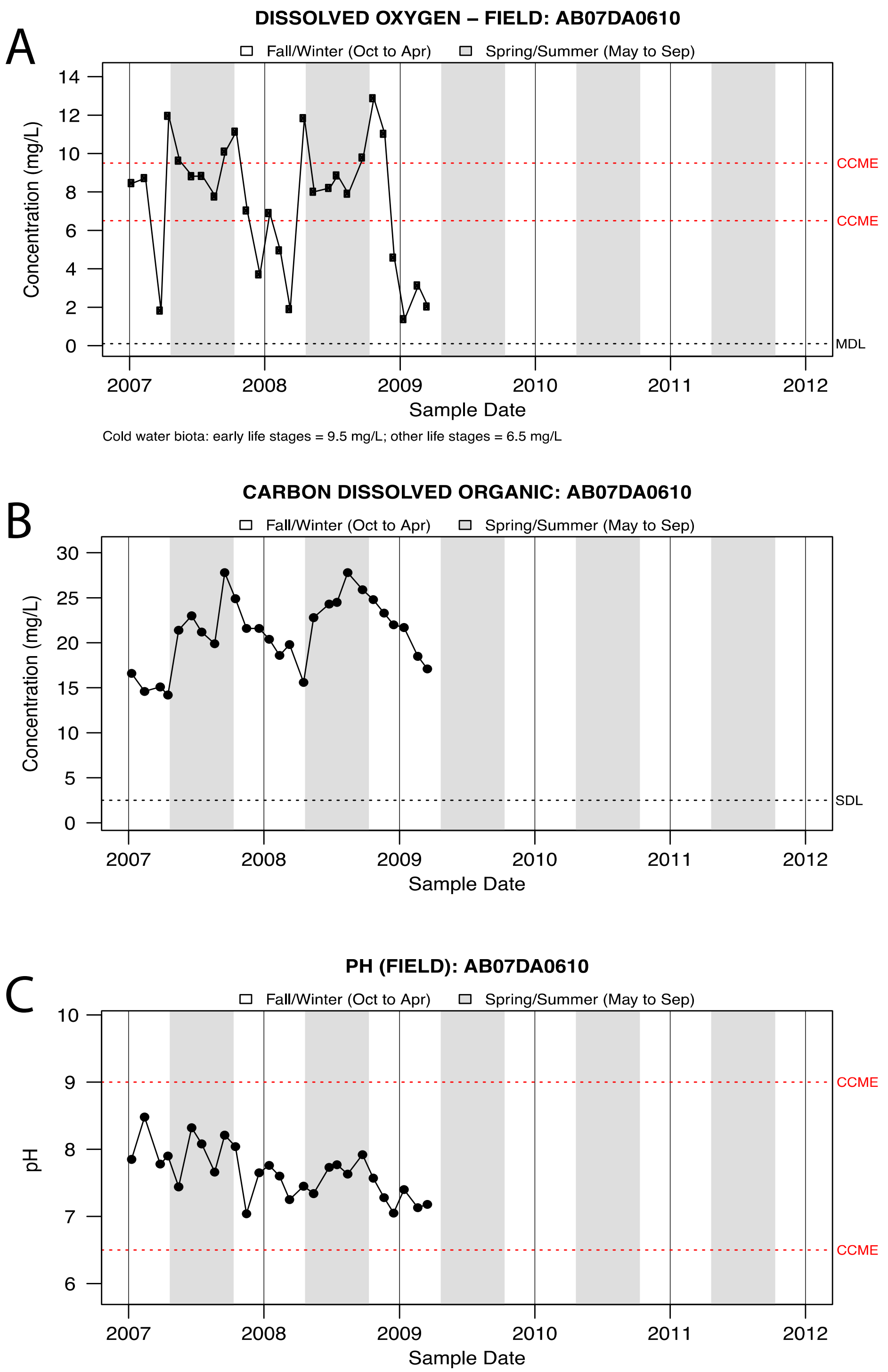


Figure 3-22. Figure 21. Sodium (A) and sulphate (B) measured in the Town of Whitecourt at the confluence of the McLeod and Athabasca Rivers. Source: Provincial Medium-term River Network database.



Cold water biota: early life stages = 9.5 mg/L; other life stages = 6.5 mg/L

AB guideline: To be in the range of 6.5 to 8.5 but not altered by more than 0.5 pH units from background values

Figure 3-23. Dissolved oxygen (A), dissolved organic carbon (B), and pH measured in the Lower Athabasca region downstream of the Kearl Lake Road. Source: Provincial Medium-term River Network database.

3.4.7. Water Chemistry at RAMP Sites

Exceptional values for sodium and chloride were measured at several sites in the Lower Athabasca region (Figure 3-24 A, B & C). As mentioned previously, elevated chloride was also reported for some of the LTRN sites (Figure 3-17 A & B), which supports the reproducibility of the feature. Once again, Na and Cl^- in and of itself at these concentrations is not a concern, but serve as indicators of saline seepage into the Athabasca River. Regardless of whether it is natural or anthropogenic, this type of seepage may be a significant source of other relevant chemical species.

The RAMP data reveals copper (Cu) concentrations exceeding the CCME guideline value (4 µg/L) at several sites (Figures 3-25 A, 3-26 A, and 3-27 A). These results were plotted together with DOC, TKN, and total dissolved P to illustrate the correspondence between Cu and organic matter in the waters. Dissolved organic matter can dominate the chemical speciation of Cu in freshwater, especially at the pH values (ca. 8) of the Athabasca River. Complexation of the Cu by organic matter, in turn, may have a profound effect on the bioaccessibility and bioavailability of this metal and this is discussed further below.

Selenium concentrations exceed the CCME guideline value (1 µg/L) at two of the RAMP sites (Figure 3-28).

A complete set of figures for all water quality parameters assessed at selected RAMP stations can be found in Appendix 3.

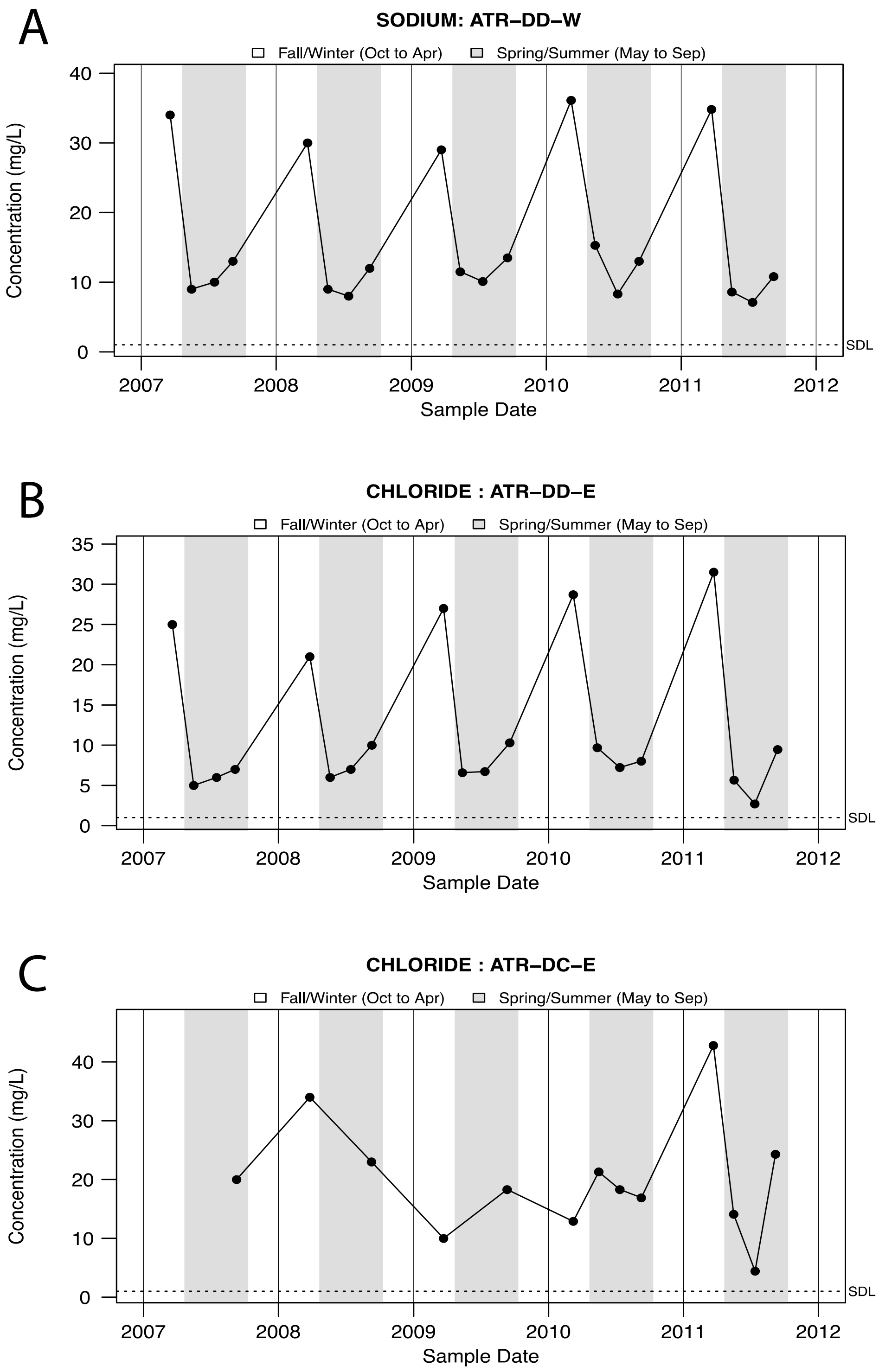
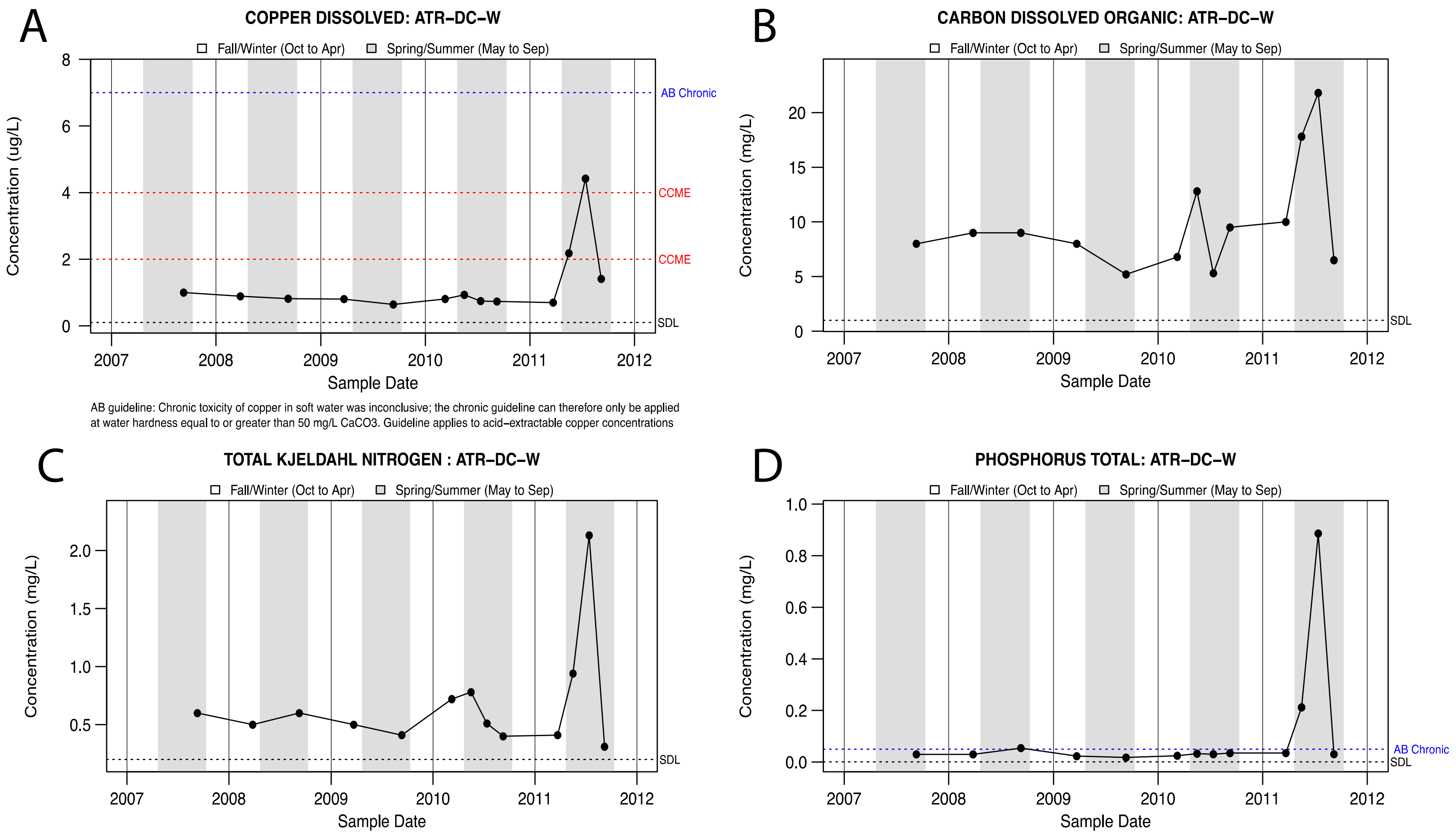
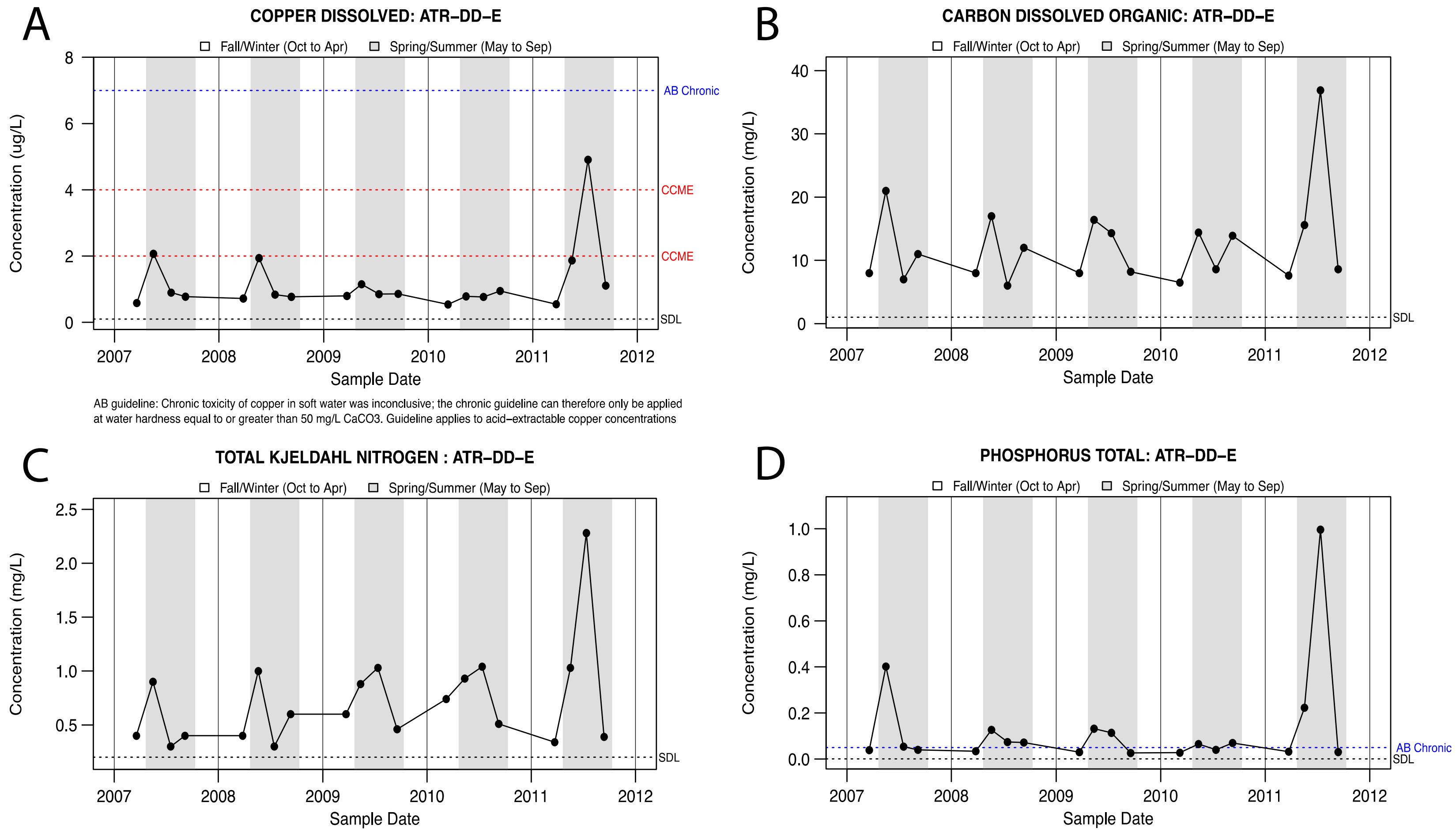


Figure 3-24. Sodium (A) and Chloride (B & C) measured in the Lower Athabasca Region at three RAMP stations on the mainstem of the Athabasca River. Source: Regional Aquatics Monitoring Program database.



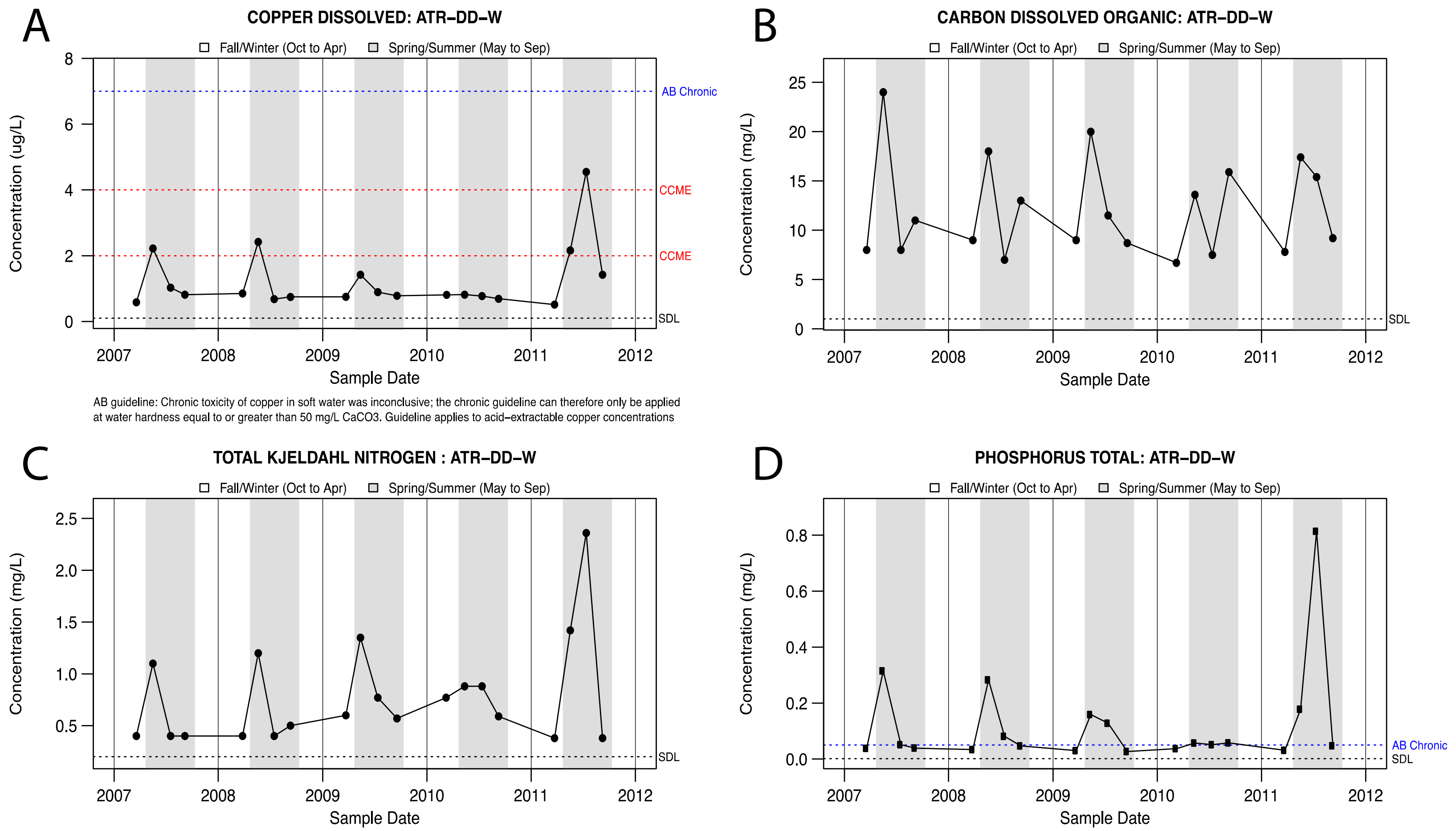
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure 3-25. Copper (A), DOC (B), TKN (C), and total P (D) measured at RAMP station ATR-DC-W on the mainstem of the Athabasca River in the Lower Athabasca Region. Source: Regional Aquatics Monitoring Program database.



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure 3-26. Copper (A), DOC (B), TKN (C), and total P (D) measured at RAMP station ATR-DD-E on the mainstem of the Athabasca River in the Lower Athabasca Region. Source: Regional Aquatics Monitoring Program database.



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure 3-27. Copper (A), DOC (B), TKN (C), and total P (D) measured at RAMP station ATR-DD-W on the mainstem of the Athabasca River in the Lower Athabasca Region. Source: Regional Aquatics Monitoring Program database.

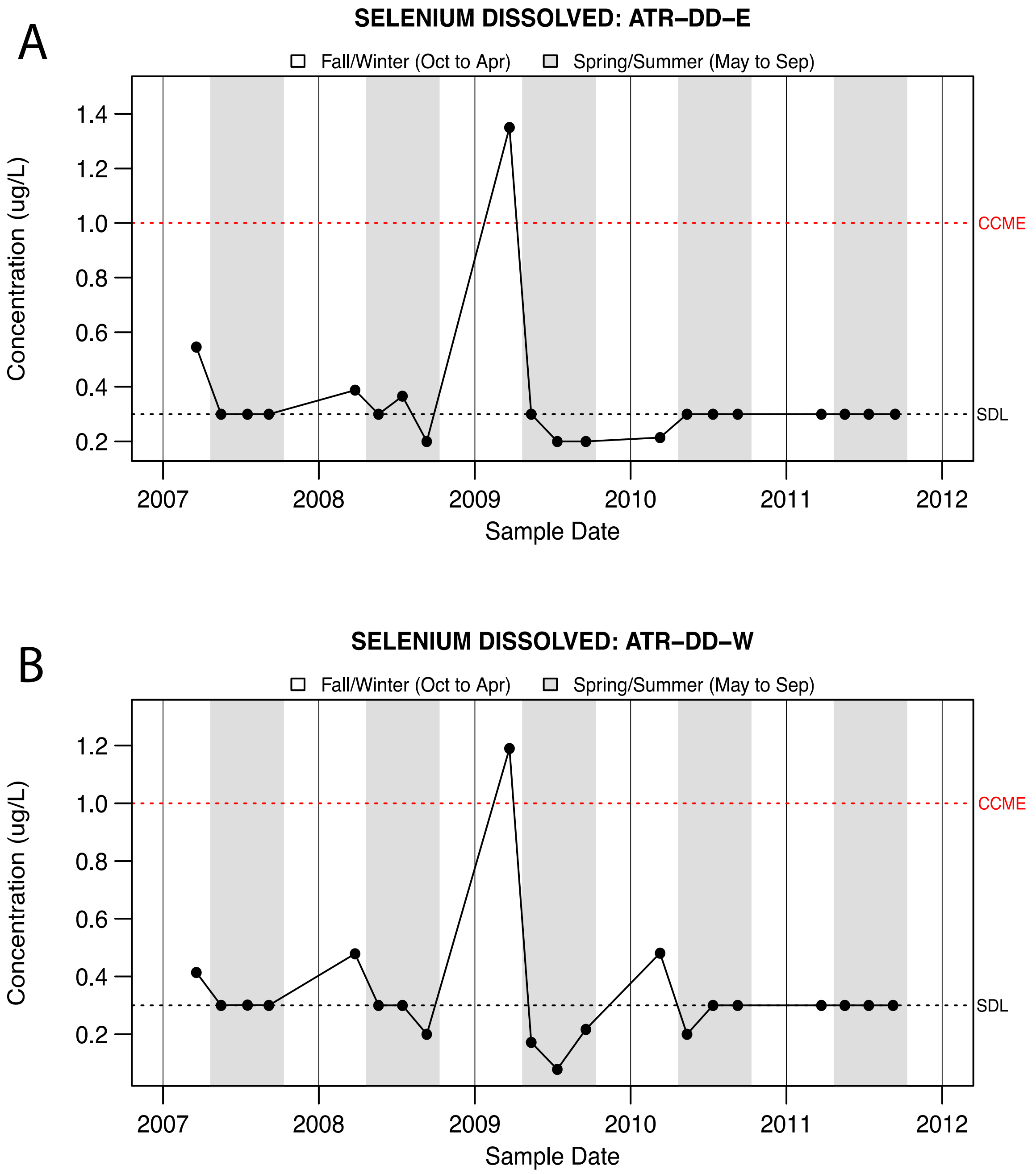


Figure 3-28. Selenium measured at RAMP stations ATR-DD-E and ATR-DD-W on the mainstem of the Athabasca River in the Lower Athabasca Region. Source: Regional Aquatics Monitoring Program database.

3.5. Discussion

3.5.1. Physico-chemical Properties

Parameters such as temperature, TDS, conductivity and turbidity provide a sense of the physical and chemical composition of the water, and its natural variation. In summer, TDS and conductivity are low because of dilution (Figure 3-2), so too is alkalinity (Figure 3-3), but turbidity is high because of rain, erosion, and flooding. The pH and DO values also vary (Figure 3-4), as does DOC (Figure 3-5). These pronounced seasonal variations influence a number of water quality parameters, and clearly impact major ions such as calcium and sodium (Figure 3-6), sulphate and chloride (Figure 3-7) and even aluminum (Figure 3-9). Nutrients are also strongly affected by seasonality, with nitrate much lower in summer, but TKN, dissolved P, and total P much higher (Figure 3-10). Several of these parameters, in particular the pH, DOC, and alkalinity may have tremendous influence on the concentrations and speciation of many trace metals, a phenomenon that is examined in more detail below.

pH

The pH of surface water in chemical in equilibrium with atmospheric PCO_2 (partial pressure of carbon dioxide) and in the presence of calcium carbonate would be expected to be approximately 8. The pH of the water in the Athabasca River is generally in the expected pH range, except during spring snowmelt. Within the typical pH range seen in the river, the pH of the water is buffered against changes in pH by the abundance of dissolved bicarbonate; this species (HCO_3^-)is converted to carbonic acid (H_2CO_3) as hydrogen ions (H^+) are added to the river (e.g. by strong mineral acids such as HNO_3 and H_2SO_4 in rain and snow), thereby preventing a pH change to the water. The drop in pH during spring snowmelt seen at several sites indicates that acidic compounds are being released to the watershed in sufficient quantities to be significantly impacting the pH. These acidic compounds could be accumulated acidic aerosols in the snow pack (e.g. sulphuric acid from coal combustion or gas flaring, nitric acid from vehicle exhausts), but there may be other sources. The possible ecological significance of the pH drop is discussed further below.

Note that although acidic compounds in DOC such as humic acids can affect pH, there is no correlation between pH depression and the DOC values in the river. Also, although changes in dissolved carbon dioxide due to biological processes such as photosynthesis and respiration can also affect pH, the pH depression occurs prior to the seasonal increase in biological activity. It is important to understand the cause of the pH depression of the waters, and also to determine whether its intensity is changing over time.

Dissolved Oxygen

As noted earlier, at the Town of Athabasca site, for example, the concentrations of dissolved oxygen (DO) range from ca. 9 to 15 mg/L (Figure 3-4 B), with lower values typically found during summer months when biological activity is greatest. These dissolved oxygen concentrations approximate the solubility of oxygen in pure water at temperatures of 20 and 0 degrees C, respectively. In the case of cold-water biota, the CCME guidelines for DO are 9.5 mg/L for early life stages and 6.5 mg/L for other life stages. Clearly, during the early part of the year and during the summer months, DO concentrations in this section of the river fall below the concentrations needed for early life stages of cold-water biota; this issue, and the natural as well as anthropogenic causes to which it may be due, have been previously reviewed by Chambers et al., (2000, 2006). At Kearl Lake Road (Figure 3-23), the problem appears to be much more severe, although several years of recent data are not available, making it very difficult to understand more recent trends in DO at this station.

Major Constituents

The elevated concentrations of dissolved salts in the Lower Athabasca (Figure 3-17) is consistent with recent reports of natural, saline seepages extending for many kilometers along the banks of the river (Gibson et al. 2011). Although these seeps are now recognized, their general significance for the quality of water in the river, in particular for trace inorganic and organic compounds, is not known.

Nutrients

Nitrate values are generally low, relative to the CCME guideline values; however, elevated concentrations of total P are seen at many sites (e.g. Figures 3-25 to 3-27), with values far above the CCME value (100 µg/L) considered hypo-eutrophic. Given that the mean value calculated for LTRN sites between 2007 and 2012 (50 µg/L) is considered eutrophic, phosphorus inputs to the river appear to be a general, widespread concern. Nutrient inputs, and the consequences of elevated nutrient concentrations for biotic activity and dissolved oxygen concentration in the Athabasca River, have been previously reviewed by Chambers et al. (2000, 2006).

Trace Elements

Measuring trace metals in natural freshwaters

Trace metals of comparative abundance such as aluminum (Al), iron (Fe), and manganese (Mn) are typically found in surface waters in the part per billion concentration range and are readily measurable. With the advent of more sensitive methods of chemical analyses, and with growing concerns during the past decades about environmental contamination by “heavy metals”, elements such as chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn), were added to the list of trace metals routinely measured in water. With still more recent developments in analytical chemistry and orders of magnitude improvements in sensitivity (parts per trillion and below), trace metals normally found at extremely low concentrations such as cadmium (Cd), lead (Pb), silver (Ag), antimony (Sb), and thallium (Tl) can now be routinely monitored.

As our ability to measure ever-smaller analyte concentrations has improved, our awareness of the risks posed by contamination during sampling, handling, and analysis has also grown. It is now broadly recognized that reliable measurements of metals at ultratrace (part per trillion and below) concentrations are less restricted by the analytical sensitivity of available instrumentation, and more by contamination. A recent editorial, “Determination of trace element concentrations in natural freshwaters: How low is ‘‘low’’, and how low do we need to go?” (Shotyk and Krachler, 2009) addressed some of these issues and includes concentration data for snow, surface water, and groundwater in southern Ontario, to illustrate the severity of the challenges. Some of the trace metals listed above may be found in surface waters in the concentration range typical of ancient (i.e., pre-industrial) polar snow and ice. Thus, reliable measurements of many trace metals in surface waters requires the same extreme “clean lab” methods, protocols, and lab facilities as those used in studies of trace metals in polar snow and ice. Given the extent of the problems associated with trace element analyses of natural freshwaters, even today, any reported data must be viewed critically, and any critical evaluation must begin with the QA/QC data, which is an integral part of any measurement campaign

Effect of Organic Complexation on Metal Speciation

It is very well known that many trace metals form stable complexes with natural organic matter dissolved in freshwaters. It is difficult not to notice that the periods of elevated concentrations of V and Hg (two metals with profoundly different chemical characteristics and behaviours) correspond with periods of elevated DOC (Figure 3-29). It may well be that much of the V and Hg, and possibly many other trace metals, are associated with the natural organic compounds in the water, either via complexation or adsorption, or as part of the original biomolecules from which the DOC is derived. The physical and chemical speciation (i.e., forms) of these metals dissolved in the water govern the bioaccessibility and bioavailability. While the concentration of a metal in water is certainly a first step in understanding its possible ecological relevance, in fact the chemical speciation of the element is far more important. Given the toxicological significance of Hg and the fact that it exceeds guideline values at many sites on many occasions, Hg in the river warrants a more detailed evaluation.

Effect of pH Depression on Al Concentrations

A comparison was made of the seasonal increases in aluminum (Al) concentrations and the periods of pH depression for all sites where data were available (Figure 3-30 and Appendix 4). The CCME guideline value for Al at pH 8 is 100 µg/L, but this drops to 5 µg/L below a pH 6.5 because of the enhanced solubility of aluminum hydroxide below this pH value. In general, however, the episodes of pH depression (blue arrows in Figure 3-30) are characterized by low Al concentrations. Only in one case (downstream of Devil's Elbow) did the pH value drop below the CCME guideline value of 6.5, *while at the same time*, Al concentrations clearly exceed the guideline value of 5 µg/L at this pH (red arrow in Figure 3-30). In other words, when the greatest Al concentrations are found, the pH is approximately 8 and the CCME guideline value at this pH is 100 µg/L. Having said this, given that Al concentrations at three sites with pH ca. 8 are at the CCME guideline value (Figure 3-19), it is probably safe to say that a closer look at the chemistry of Al in the Athabasca River is needed.

The RAMP data for Al and pH were also compared (Figure 3-31), but there were no Al exceedences at the pH values for these sites.

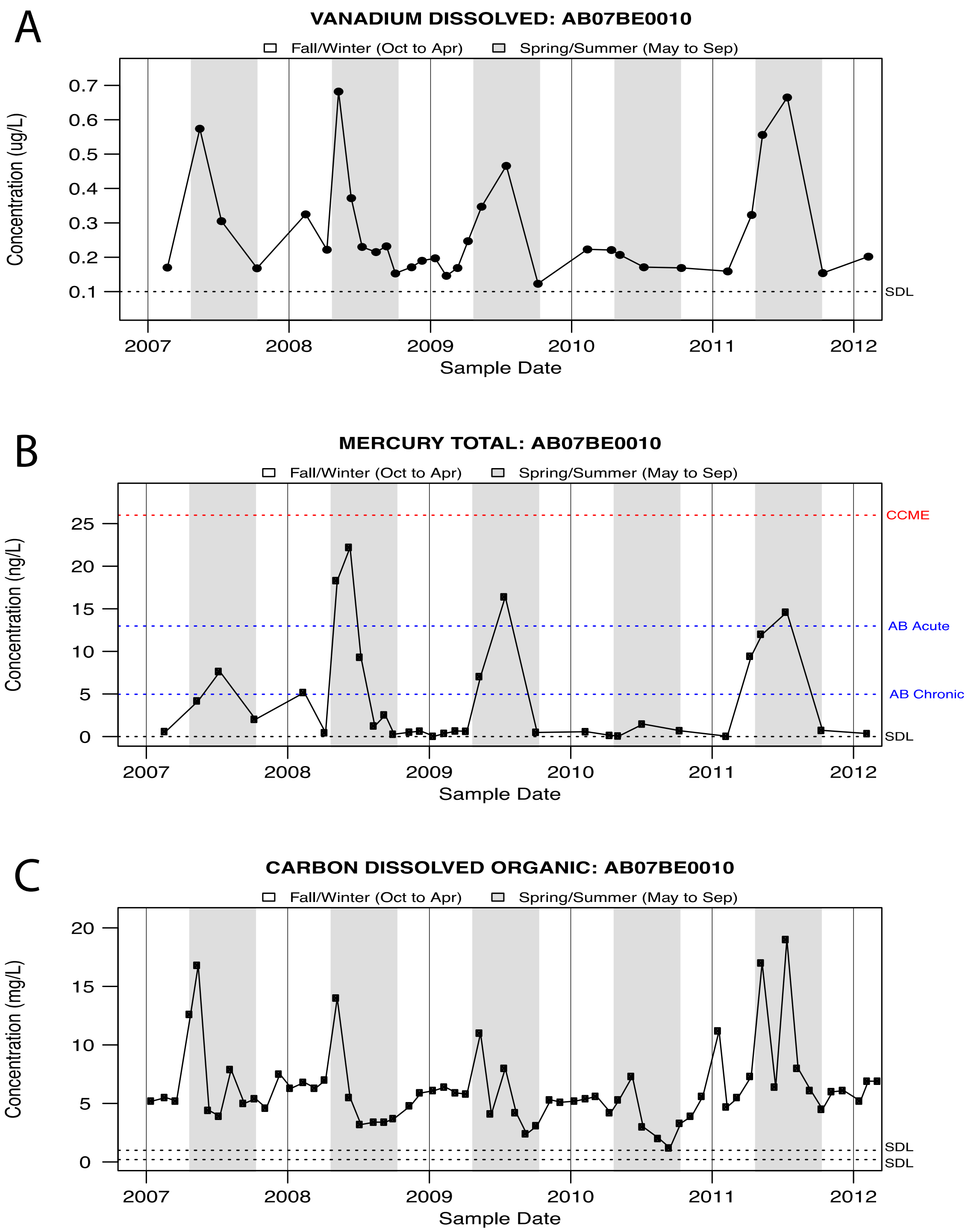
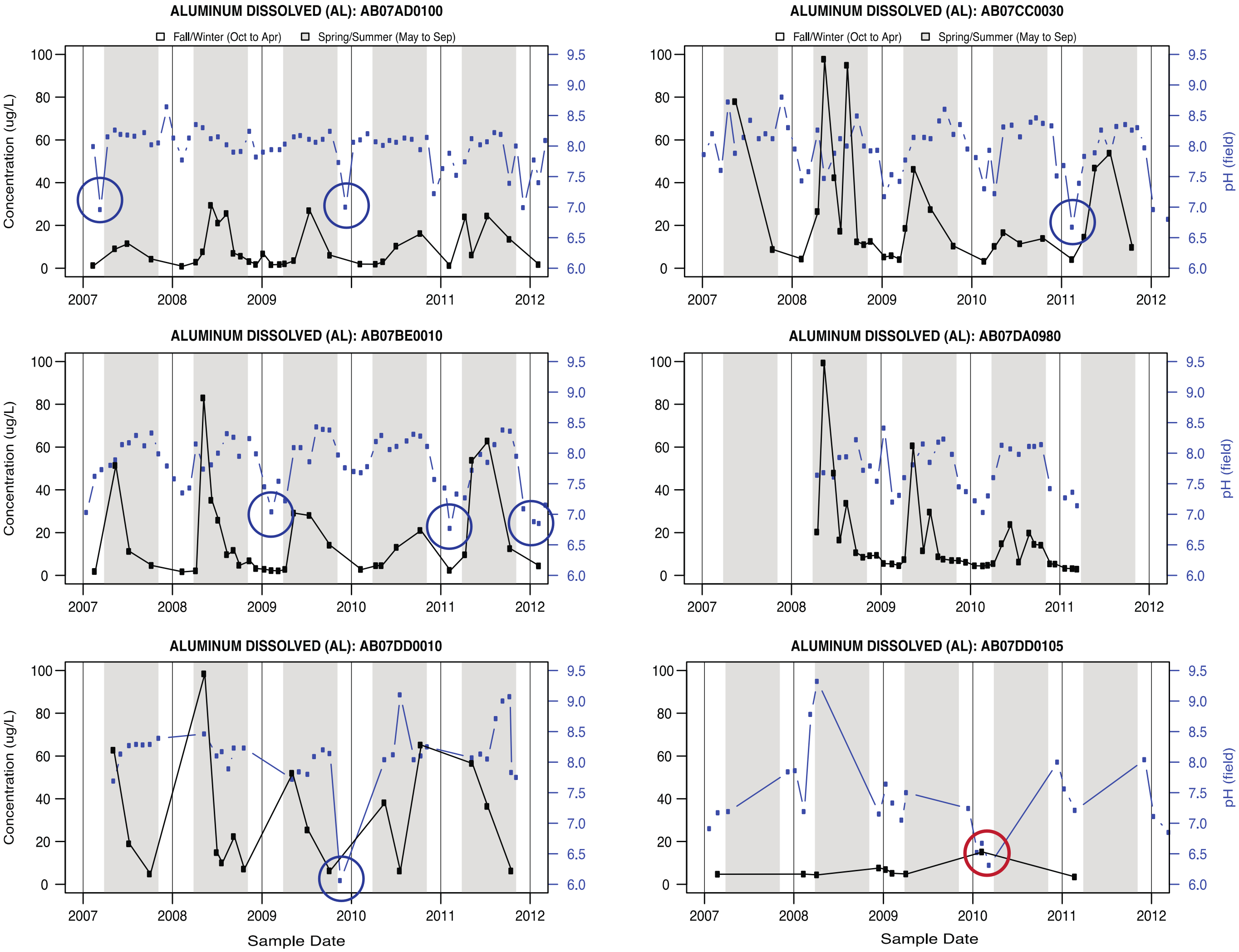


Figure 3-29. Vanadium (A), mercury (B) and dissolved organic carbon (C) concentrations in the Athabasca River at the Town of Athabasca. Source: Provincial Long-term River Network database.



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ALUMINUM DISSOLVED (AL): AB07BE0010

ALUMINUM DISSOLVED (AL): AB07DA0980

ALUMINUM DISSOLVED (AL): AB07DD0010

ALUMINUM DISSOLVED (AL): AB07DD0105

Figure 3-30. LTRN data for aluminum and pH. Blue circles indicate depressed pH values where Al concentrations remain low. The red circle indicates an exceptional case where depressed pH values correspond with elevated Al values. Source: Provincial Long-term River Network database.

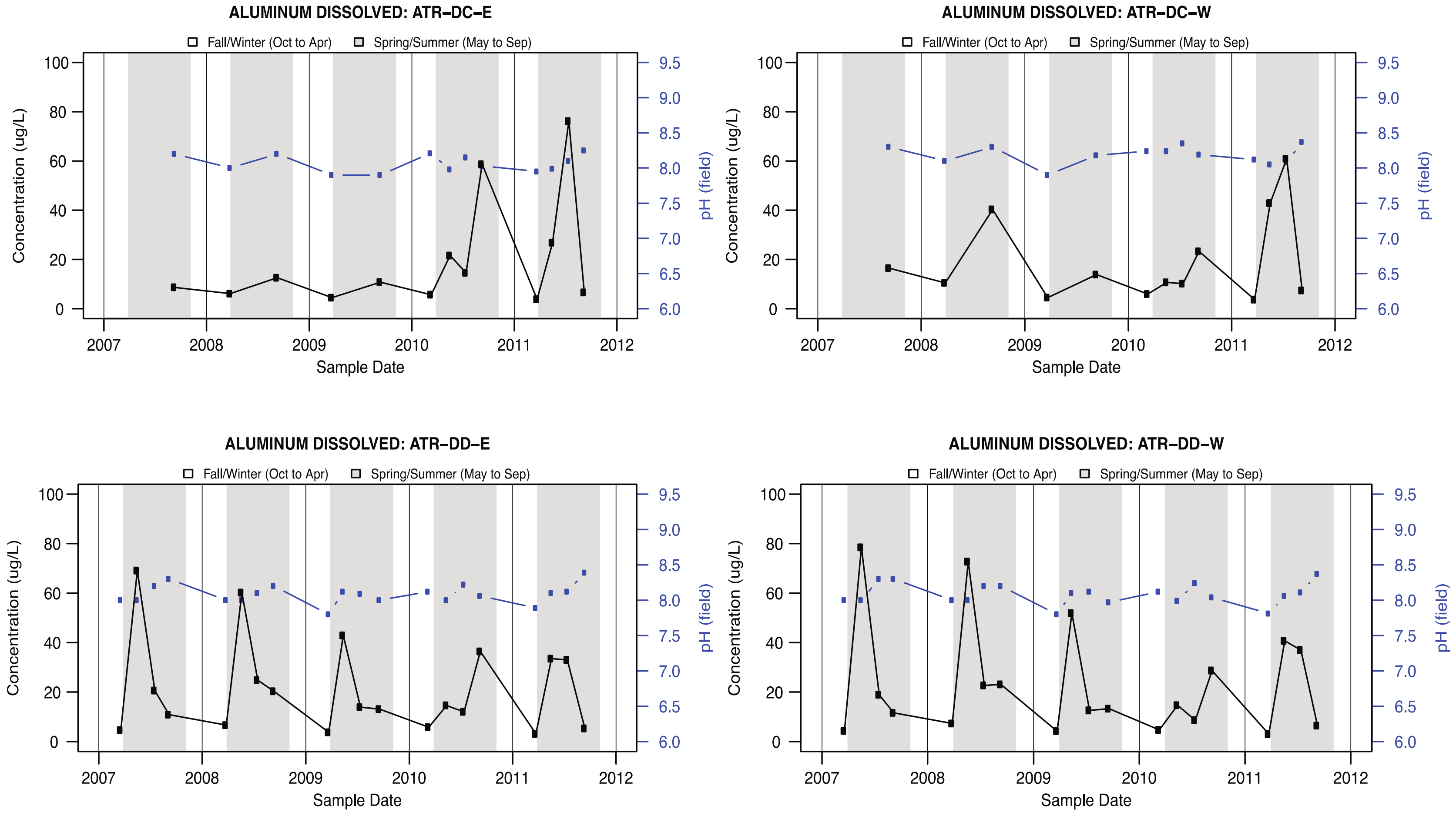

Figure 3-31. Aluminum and pH measured at RAMP stations located on the Athabasca River. Source: Regional Aquatics Monitoring Program database.

Comparing Copper Concentrations and Water Hardness

In contrast to aluminum, whose CCME guideline value varies with pH, the CCME guideline value for copper (Cu) varies with water hardness. The CCME guideline value for Cu is 4 µg/L when hardness exceeds 180 mg/L, but the Cu guideline drops to 2 µg/L in soft to medium waters (below 120 mg/l hardness). Comparing Cu concentrations with hardness at three LTRN sites shows many values exceeding the CCME guideline for Cu of 2 µg/L (Figure 3-32, see also Appendix 4); this phenomenon is also seen in the RAMP data (Figure 3-33). Clearly, the variation in water hardness (Figure 3-3 A) may have important consequences for the ecological significance of Cu in the Athabasca River. Like V and Hg, however, the periods of elevated Cu concentrations are often also rich in DOC. For example, for the Town of Athabasca, compare Cu (Figure 3-14 C) with DOC (Figure 3-5 B). Copper forms extremely stable complexes with natural organic ligands such that, even when Cu concentrations in the water are comparatively high, most of the Cu may be organically bound. Given that Cu exceeds guideline values at many sites on many occasions, this metal too, like Hg, warrants a more detailed examination.

Other Trace Metals

The available data evaluated here for LTRN, MTRN, and RAMP sites, shows one exceedence of Pb, two of Se, several of Cd, and many of Cu. These exceedences take place at different locations and different times, and presumably have different causes. Given their ecological significance, each of these elements, in addition to Hg, warrant further study.

The Need for Chemical Speciation

As noted earlier, the chemical speciation of trace metals has a profound effect on their bioaccessibility and bioavailability. The speciation of aluminum (Al), for example, is profoundly affected by pH with low pH values promoting mineral dissolution and increasing the concentration of aquo Al^{3+}, which is toxic to aquatic organisms. But fluoride also complexes Al^{3+} as do natural organic ligands (as represented by DOC). Good data are available from the LTRN and MTRN databases for all of these parameters. Although it was beyond the scope of the present report, it would be worthwhile to do some computer modeling speciation calculations based on the thermodynamic stability of the Al complexes (e.g. using PHREEQE C), to obtain a first estimate of Al^{3+} concentrations (as well as other, potentially toxic inorganic species) in the Athabasca River. In general, there is a considerable volume of data that could be used as a first step in estimating the chemical speciation of several trace metals.

The speciation of a given metal in any natural water system is dependent upon many factors: the concentration of other metal ions in solution which may compete for available complex-forming ligands, the abundance of organic and inorganic ligands and their thermodynamic binding constants, various solubility equilibria, oxidation-reduction reactions, adsorption onto organic and inorganic solid phases (humic substances, clay minerals, Fe and Al oxyhydroxides), pH, and redox potential. All of these parameters are variable and most are interdependent so that the entire system must be considered in order that the form of a given metal ion can be predicted under certain conditions. In fact, the individual calculations involved in determining the equilibrium distribution of metals in natural waters are often rather trivial. However, because so many different calculations have to be performed simultaneously, computer programs such as PHREEQE C (available from the U.S. Geological Survey) are commonly employed. The quality of the speciation calculations, however, is only as good as the quality of the analytical data upon which those calculations are based.

Calculations of metal speciation are at best a guide; however, as with the saying, “Theory guides, experiments decide”, these calculations should be followed by physical and chemical speciation measurements. Water quality monitoring is about much more than just making measurements; it is about asking relevant scientific questions, and developing a procedure to answer them. An important question at this stage, as guided by the results of this assessment, might be “what is the chemical speciation of Cd, Cr, Cu, Hg, Ni, Pb, Se and V in the Athabasca River, and how do these species vary with changes in pH, DOC, water hardness, and carbonate alkalinity?”.

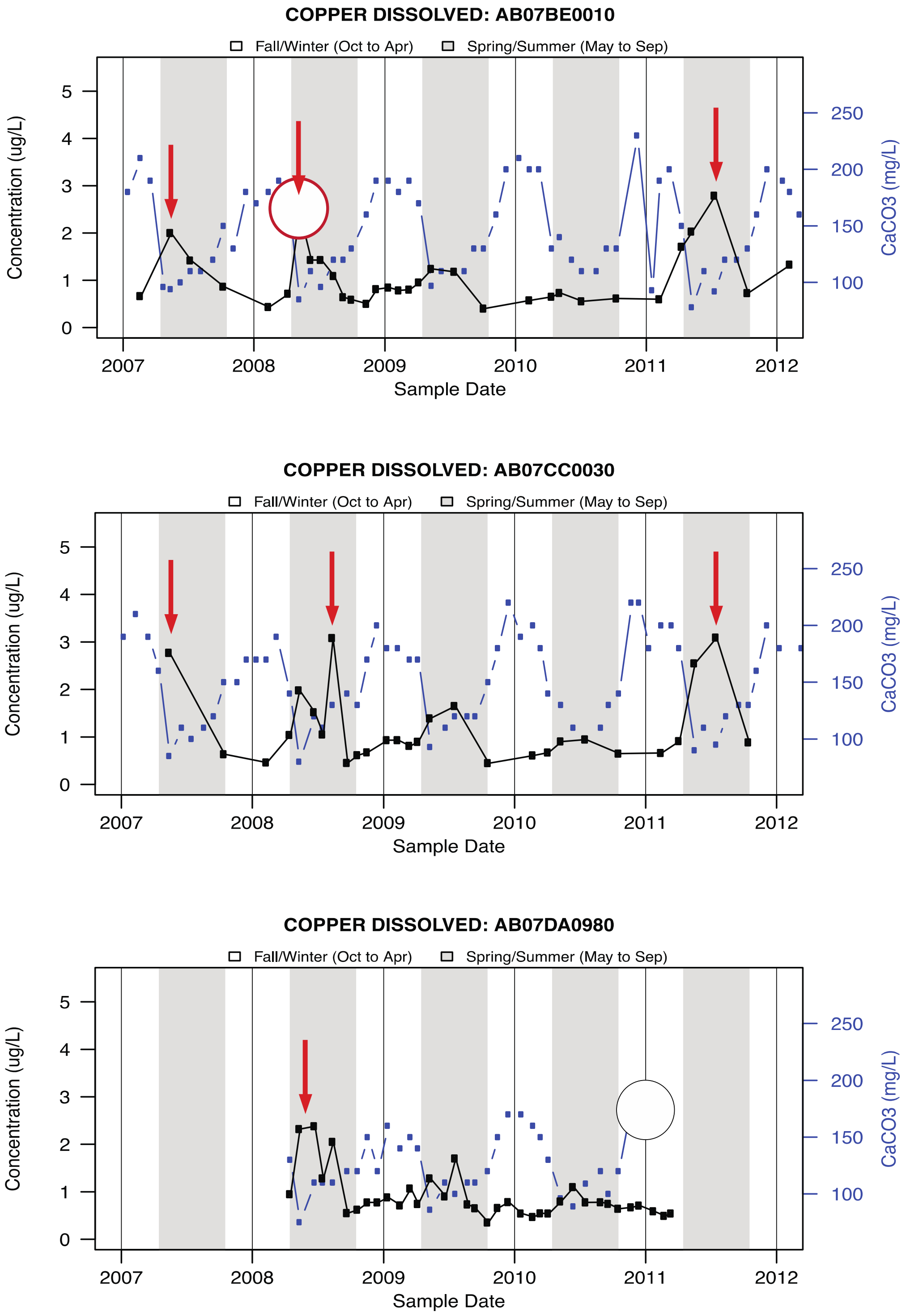

Figure 3-32. LTRN data for copper and water hardness (as $CaCO_3$). Red arrows indicate depressed hardness values combined with elevated copper concentrations; under these conditions, copper concentrations exceed the CCME guideline value of 2 µg/L in soft to medium waters (below 120 mg/l hardness). Source: Provincial Long-term and Medium-term River Network database.

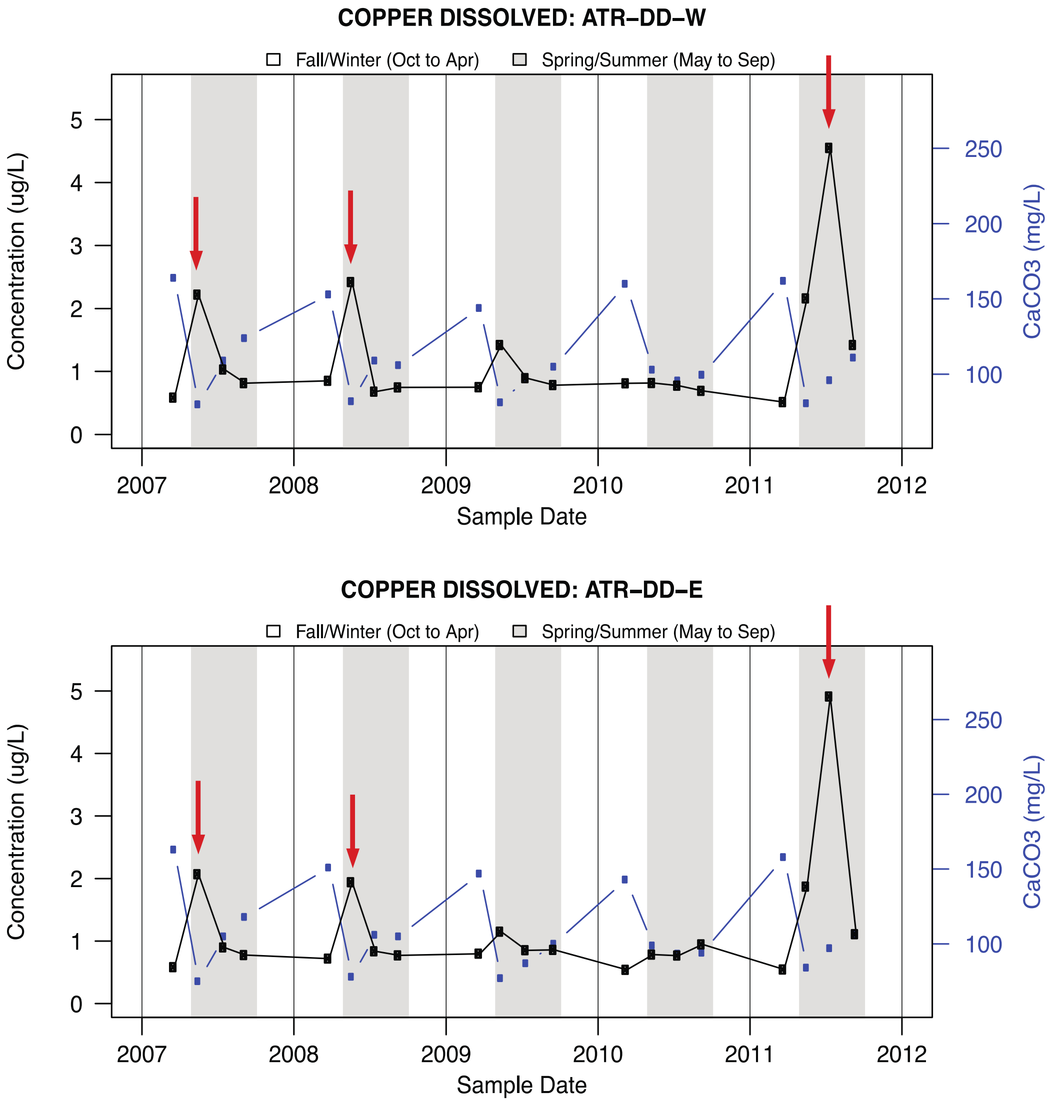
COPPER DISSOLVED: ATR–DD–W

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Figure 3-33. RAMP data for copper and water hardness (as $CaCO_3$). Red arrows indicate depressed hardness values combined with elevated copper concentrations; under these conditions, copper concentrations exceed the exceed the CCME guideline value of 2 µg/L in soft to medium waters (below 120 mg/l hardness). Source: Regional Aquatics Monitoring Program database.

The Need for Improved Analytical Sensitivity and Quality Control

Trace metals are so named because they are present in the Earth's Crust in trace amounts, and because they tend not to be very soluble, trace metals are present in ultratrace concentrations in most natural waters. Measuring trace metals at these ultralow concentrations presents two great challenges: the need for tremendous analytical sensitivity, and the risks of sample contamination (Shotyk and Krachler 2009). Of the trace elements studied here, the reported limits of detection were inadequate for Cd, Cr, Ni, Pb, and Se.

Sensitive analytical methods and "clean" lab procedures to prevent contamination, however, by themselves are not sufficient: accuracy and precision are paramount. Measurements of unknown accuracy are not usable: in future, certified standard reference materials for trace metals in water must be used extensively and rigorously to evaluate the accuracy of the analytical data. For a more detailed discussion of Quality Control and water quality monitoring, see Chapter 5.

Wastewater

The data that were obtained for selected wastewaters revealed elevated concentrations of DOC, TKN, and dissolved P (Figure 3-34), as well as Cr and Cd (Figure 3-35). Data for vanadium (V) and nickel (Ni) in wastewater from oil sands mining operations is limited to data from Suncor (Figure 3-36 A & C), and although it is difficult to compare against such a limited data set, the V concentrations in the effluent from the Slave Lake pulp mill are far greater (Figure 3-36 B) than the limited values available from the Suncor mine. Given that V is the most highly enriched trace metal in the Athabasca bituminous sands, V is a potential tracer of leaching from oil sands tailing ponds. The very high V concentrations in the wastewater from the Slave Lake pulp mill, however, indicates that other possible anthropogenic sources of V to the watershed must also be considered. A complete set of figures for Class B effluent measured at all facilities reported by Alberta Environment and Sustainable Resource Development between 2007 and spring 2012 can be found in Appendix 3. Note that this is not a complete dataset, and does not include all industrial facilities that operate in the Athabasca Watershed.

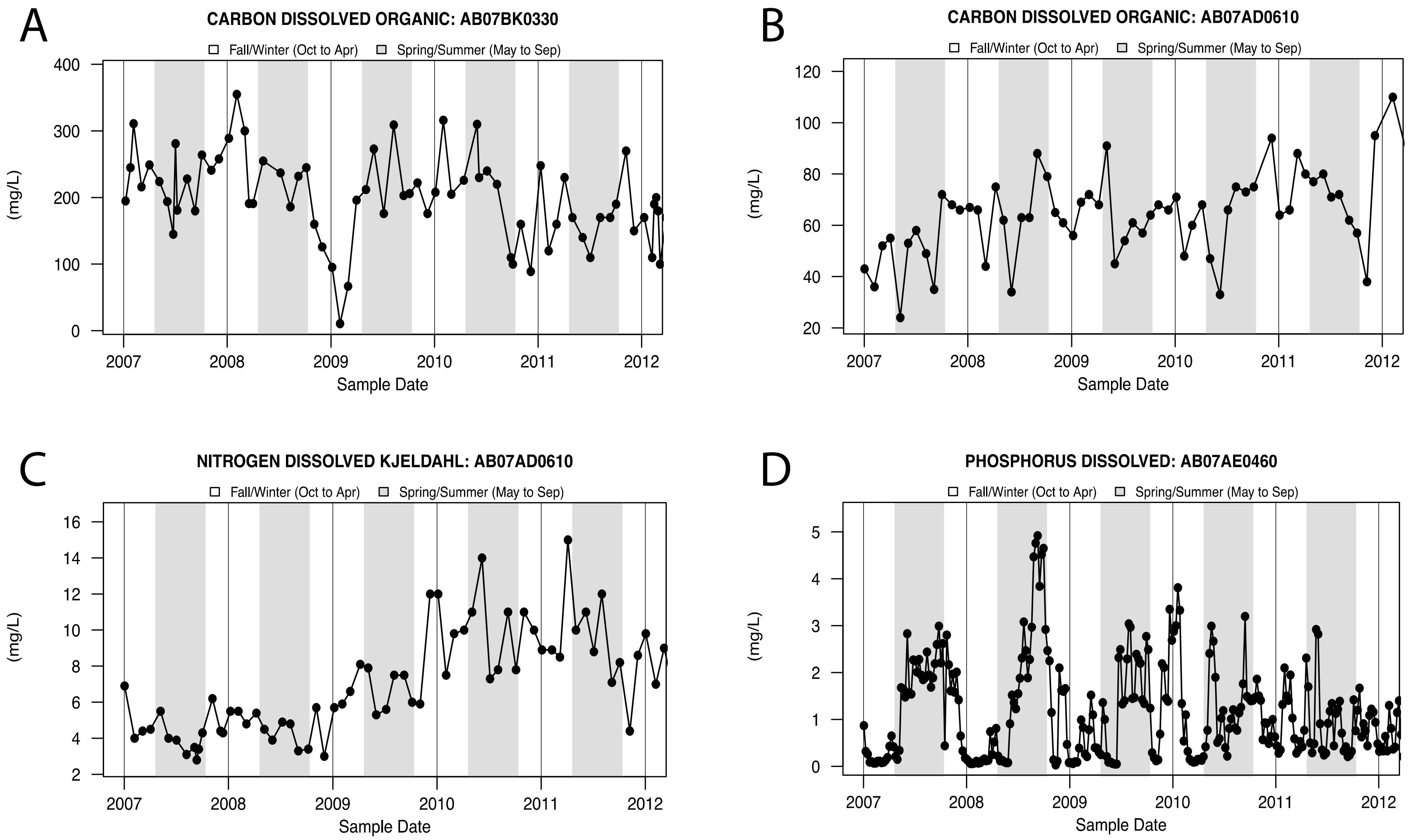

Figure 3-34. Dissolved organic carbon (A & B), TKN (C), and total dissolved P (D) measured in industrial (pulp mill) effluent being discharged into the Lesser Slave (A) and Athabasca Rivers (B, C, & D). Source: Provincial Class B Industrial Effluent database.

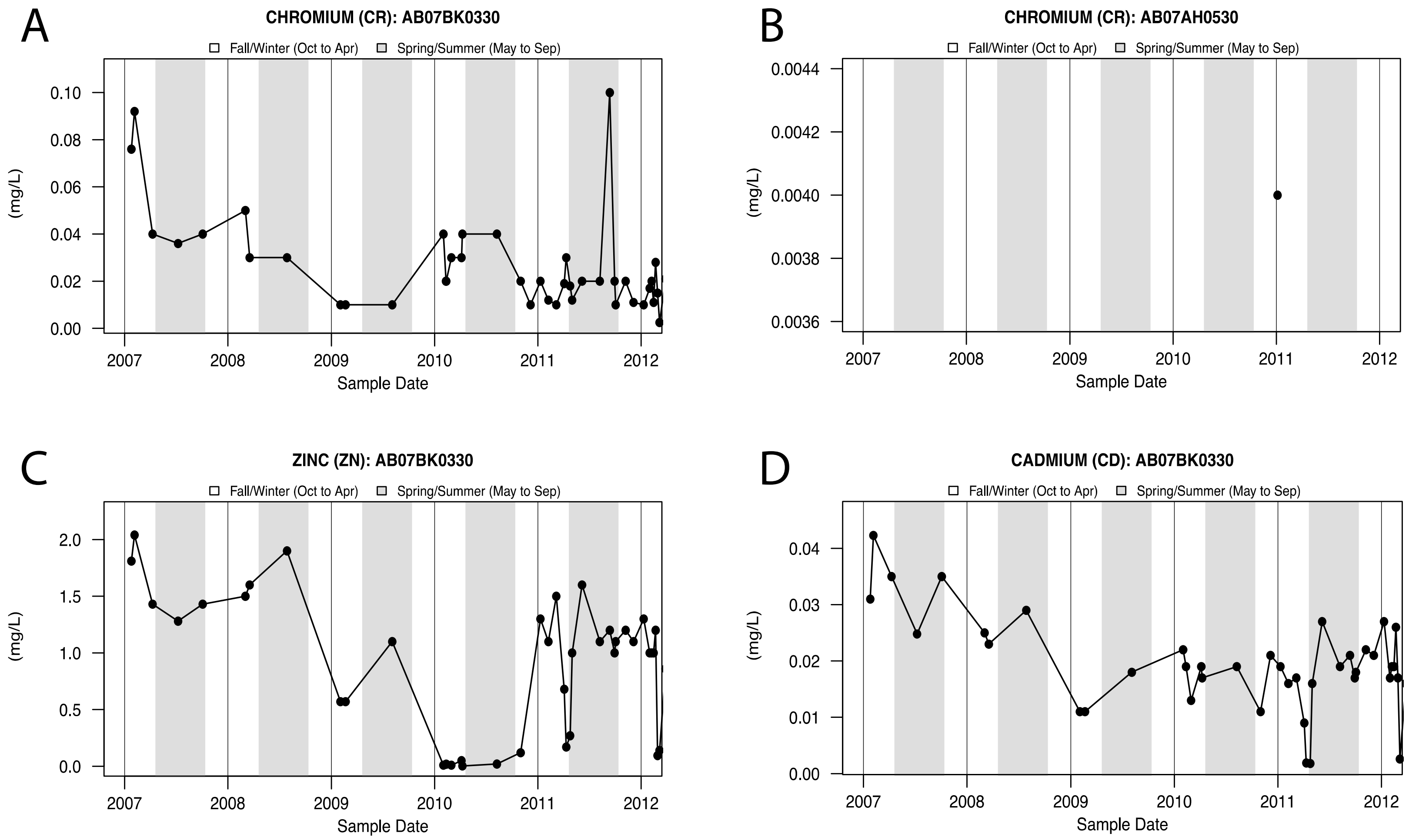

Figure 3-35. Chromium (A & B), zinc (C), and cadmium (D) measured in industrial (pulp mill) effluent being discharged into the Lesser Slave (A) and Athabasca Rivers (B, C, & D). Source: Provincial Class B Industrial Effluent database.

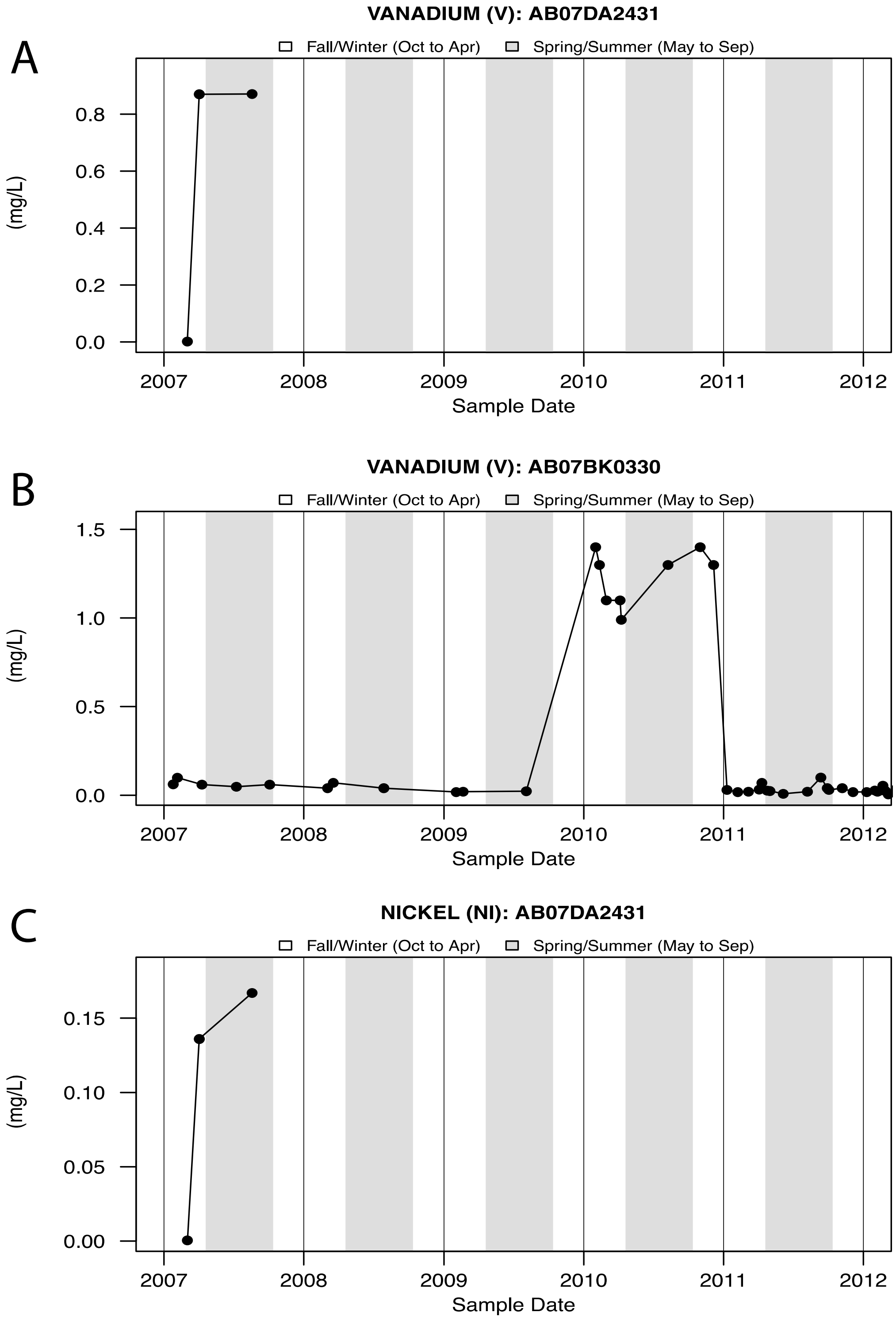

Figure 3-36. Vanadium (A & B) and nickel (C) measured in industrial (pulp mill and oil sands) effluent being discharged into the Lesser Slave (B) and Athabasca Rivers (A & C). Source: Provincial Class B Industrial Effluent database.

3.6. Conclusions

We examined hundreds of graphs for a broad range of chemical parameters measured at LTRN (Appendix 1), MTRN (Appendix 2), and RAMP (Appendix 3) between 2007 and 2011. Concerns for the health of the Athabasca River arose from a number of water quality parameters examined, beginning with dissolved oxygen. Dissolved oxygen is an important indicator of healthy aquatic ecosystems, and we found concentrations that were below the CCME guideline value of 9.5 mg/L (for protection of early life stages of cold-water fish species) at many of the sites we examined. In addition, we found evidence of elevated nutrient concentrates throughout the watershed. Both of these results support findings from previous work that have discussed these issues at length (e.g., Chambers et al. 2006, see Section 1.4.2 for overview).

Other factors that appear to have received less attention, or may have gone largely unnoticed thus far include seasonal pH depression, the occurrence of saline seepage, and episodic increases in trace metal concentrations. While we have noted potential concerns over elevated trace metal concentrations in some areas of the watershed, reliable measurements of trace metal concentrations represent only the first step in understanding their ecological significance. The next crucial step in understanding trace metals and their potential effects on water quality is in characterizing their predominant physical and chemical forms. Existing trace metals data for Cd, Cr, Cu, Hg, Pb, and Se, despite the limitations noted in this chapter, suggest detailed studies of chemical speciation are warranted.

3.7. References

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Chapter 4: Water Quality – Benthic Invertebrates

4. Introduction

Monitoring, evaluation and reporting of aquatic ecosystem health is part of Alberta's commitment to preservation of "healthy aquatic ecosystems" ("HAE"), as identified as a guiding management principles within its Water for Life: Alberta's Strategy for Sustainability (i.e., Water for Life Strategy) and Water for Life: A Renewal (Environment 2003, 2008). A HAE can be defined as one that is "sustainable and resilient to stress, maintaining its ecological structure and function over time similar to the natural (undisturbed) ecosystems of the region, with the ability to recover from disturbance, while continuing to meet social needs and expectations" (Stantec Consulting Ltd. 2005). A critical component of any assessment of aquatic ecosystem health is the assessment of invertebrate community structure, as both a proxy for, and an indicator of, water quality.

Benthic invertebrate communities in rivers are those that inhabit river bottoms, and fill a variety of ecological niches. Macroinvertebrates are generally quite responsive to the sorts of physical predictors or variables normally associated with longitudinal river patterns, and many species and families demonstrate differential sensitivity to organic pollution, in addition to other chemical and physical variables to which they are exposed. Benthic invertebrates are suitable and reliable as general indicators of change because of their relatively long life cycles (seasonal or annual times scales). Benthic invertebrate communities are recognized as a valuable indicator of short- and long-term changes in water quality and ecosystem health because of the breadth of their niches and different sensitivities to chemical, physical, and biological changes, whether natural or anthropogenic (Vannote et al. 1980; Anderson 1991; Bothwell, Sherbot, and Pollock 1994; Hilsenhoff 1998, 1987, 1988; Donahue et al. 2003; Hodkinson 2005; Saffran and Anderson 2009; Anderson et al. 2009). Often, invertebrate community changes are associated with changes in water quality variables, although geochemistry, current velocity, flow disturbance and local reach-specific or even microhabitat factors such as canopy cover or shading can be also important in influencing invertebrate community structure (Kelly, Bothwell, and Schindler 2003; Sweeney et al. 2004). The complexity of interactions among these and other variables complicates interpretation of primary causes of change, and for this reason analyses and descriptions of invertebrate community responses to human activities are generally qualitative and involve comparison to undisturbed or reference conditions, where available.

Although invertebrate species exhibit drift behaviours in a river - resulting in downstream movement - the invertebrate community at a particular site generally reflects the most common physical and chemical state at that site. Therefore, major environmental differences between sites are usually reflected in the structural and functional characteristics of benthic invertebrate communities at those sites (Vannote et al. 1980). These differences can be the result of natural differences in watershed characteristics, such as prevalence of forests and wetlands, geology, elevation, and rate and variability in water flow (See Figure 4-1).

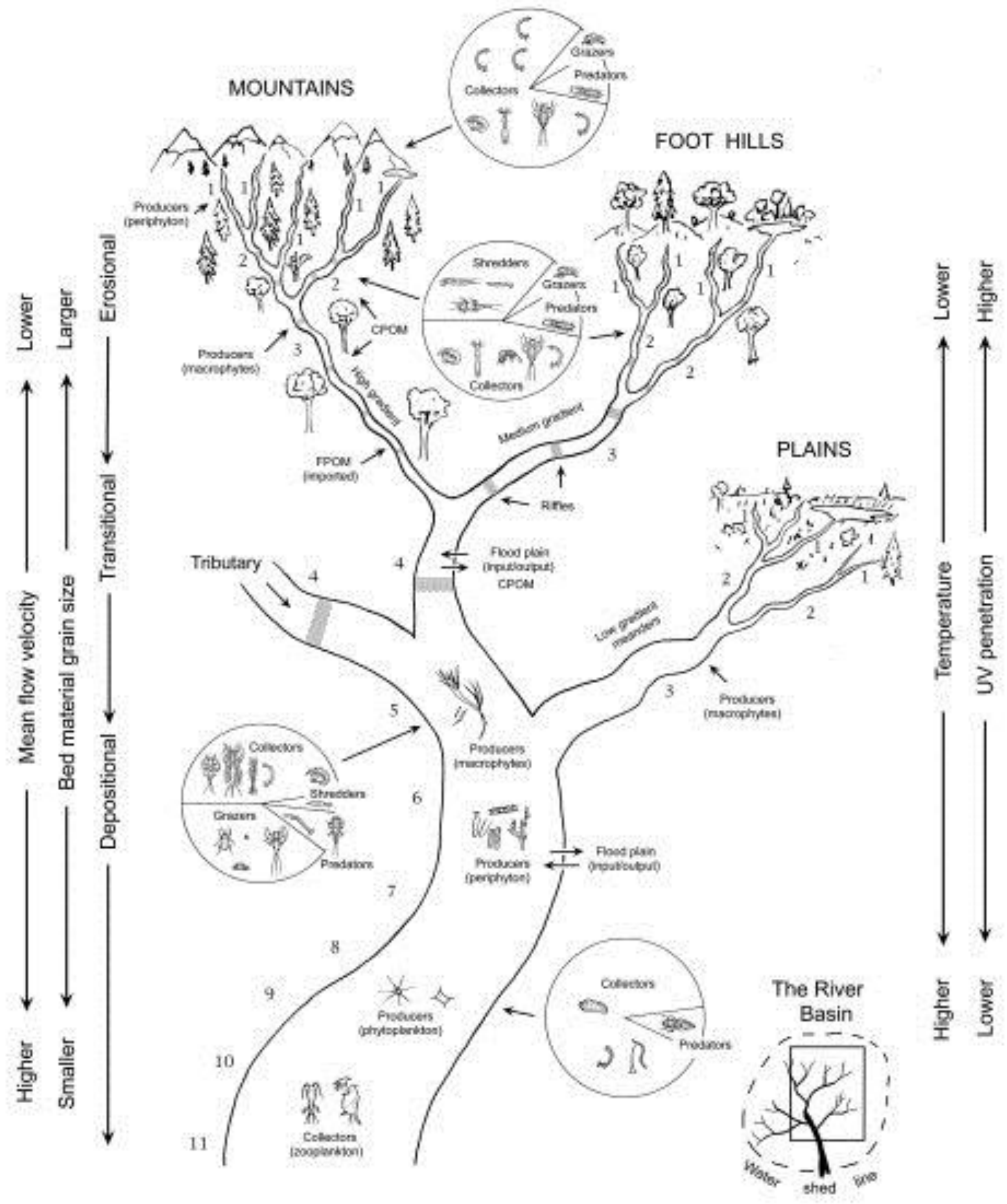

Figure 4-1. Diagram of River Continuum Concept (image by Doug Craig, Bob Newbury & Joseph Culp. (Taken from: http://www.btwatershed.org/About%20Files/Newsletters/Archives/2002Newsletter/Fall2002/River%20Continuum.htm).

For any river, there is a natural gradient in the physical conditions from the headwaters to the lowlands or river mouth, and this physical gradient is typically reflected in changes in plant and animal communities that are established along the length of the river. In general, headwaters are strongly influenced by riparian vegetation, which contributes large amounts of detritus and course organic materials to streams and effectively reduces in-stream photosynthesis via shading. Substrates in these low-order streams also tend to be more course because of the relative lack of fine organic matter and highly variable flow rates that can scour sediments. As stream size increases, there is a shift towards greater relative importance of in-stream primary production and transport of organic materials from upstream, rather than adjacent terrestrial sources. Organic materials, in the form of detrital and woody debris, tend to decrease in size as stream size increases, because of decomposition, consumption, and physical destruction processes that continue to act upon organic matter from headwaters to lowlands.

The invertebrate communities throughout a basin reflect the shifts in physical and chemical conditions, and the types and location of food resources that are associated with increasing stream size. In headwater regions, waters tend to be cooler, more turbulent, and have low nutrient and high oxygen levels. Headwater communities are typically dominated by shredders (e.g., stoneflies) that feed upon coarse particular organic matter, like leaf litter and woody debris, collectors (e.g., caddisflies, black flies, and chironomids) that feed upon fine particulate organic matter and microbial food sources from sediments or filtered from water, and predators (e.g., dragonflies, damselflies, some beetles) (Vannote et al. 1980). As stream size increases, scrapers/grazers (e.g., some beetle and chironimid taxa, snails) that shear off attached algae from surfaces, and collectors increase in dominance, with relative declines in shredders. Furthest downstream, in large rivers, invertebrate communities tend to be dominated by collectors and predators that feed upon them. This "River Continuum Concept" provides a framework for assessing community structure in rivers, and the degree to which invertebrate communities at different sites are typical of those that are expected to occur, or instead perhaps reflect human influences on aquatic ecosystem function (Vannote et al. 1980).

The purpose of this benthic invertebrate assessment is to expand on the general water quality assessment by providing both an additional corroborative proxy for water quality, and a glimpse of potential ecological issues associated with water quality changes in the Athabasca River. Our intention is to also assess the suitability of current invertebrate monitoring practices, and make recommendations for improvements where necessary to facilitate a better understanding of the effects of water quality changes on aquatic ecosystem health in the watershed

4.1. Agencies Contacted for Invertebrate Data

In a provincial overview on water quality, sediment quality, and non-fish biota, North South Consulting et al. (2007a) recognized that water quality of large provincial river systems was reasonably well documented, but the lack of recent invertebrate community monitoring and assessment was one of the major limitations to more comprehensive reporting on the status of aquatic ecosystems in Alberta, including in the Athabasca Watershed (North-South Consulting et. al. 2007). In the past, there was substantial monitoring and assessment of invertebrate communities as part of the Northern River Basins Study and the Northern River Ecosystems Initiative, but we do not consider those data relevant to a current assessment of water quality in the Athabasca Watershed.

4.2. Data Included in the Phase 3 Analysis

Three aquatic invertebrate datasets are assessed here: Environment Canada's Canadian Aquatic Biomonitoring Network (CABIN) dataset; Alberta Environment and Sustainable Resource Development's (AESRD) Long-Term River Network Healthy Aquatic Ecosystems (LTRN-HAE) dataset; and the Regional Aquatics Monitoring Program (RAMP) dataset (Figure 4-2). These were the three major sampling programs active in Alberta during the 2007 to 2011 period, to which our analysis of water quality in the Athabasca River is limited.

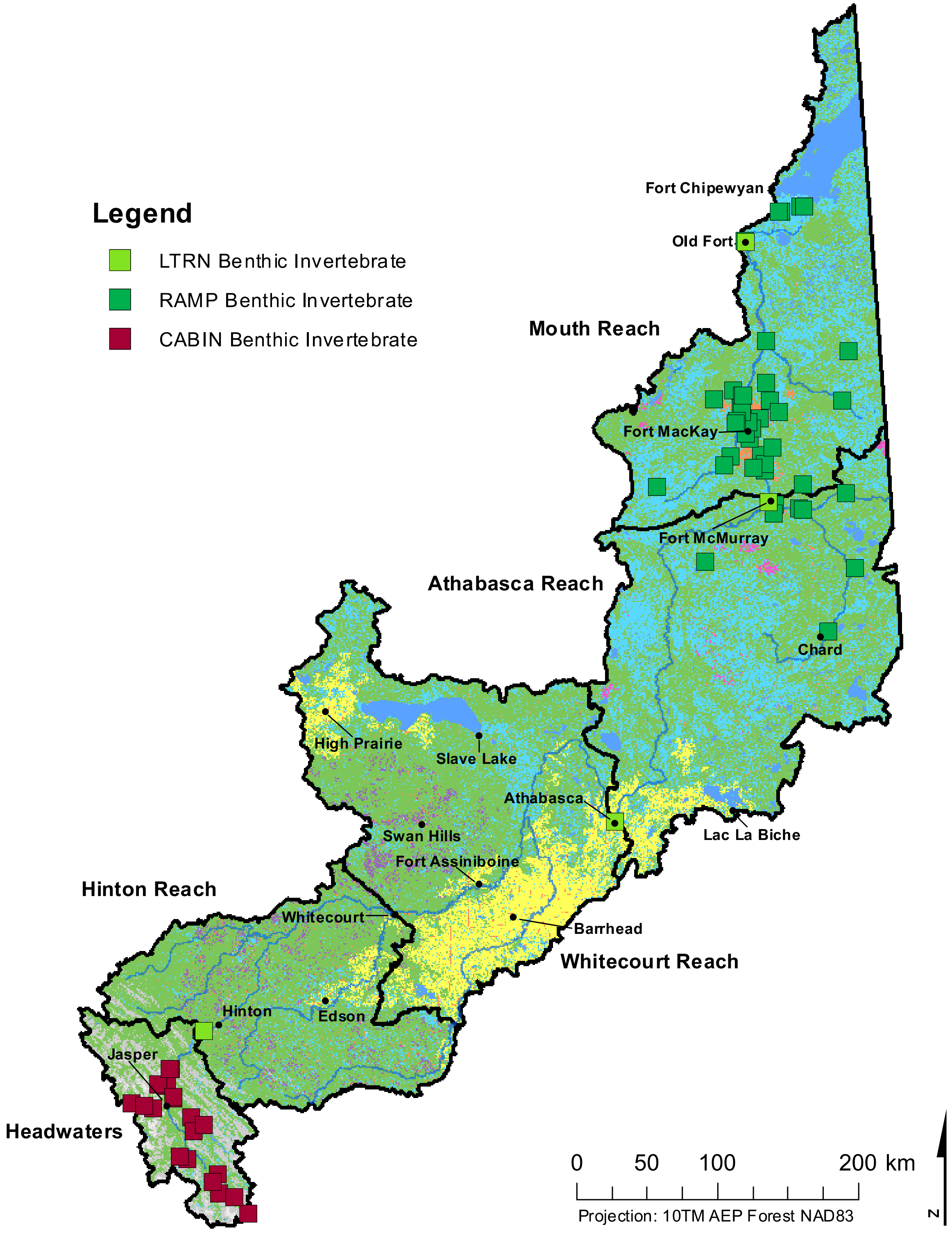

Figure 4-2. Location of CABIN, LTRN-HAE, and RAMP benthic invertebrate sampling locations. Land use/land cover was derived using Landsat imagery from 2009 (Fiera Biological 2012).

4.3. Methods

4.3.1. Sampling Programs

The LTRN-HAE sampling program was initiated and pursued between 2006 and 2008 on major rivers in Alberta. In 2008, autumn benthic invertebrate samples were collected from erosional and depositional zones at four sites on the Athabasca River mainstem (Table 4-1).

RAMP was initiated in 1997, as part of efforts to "determine, evaluate, and communicate the state of the aquatic environment and any changes that may result from cumulative resource development within the Regional Municipality of Wood Buffalo"[3]. More specifically, RAMP was created to assess cumulative effects of oil sands development in the Lower Athabasca region, and to characterize natural variability in regional aquatic ecosystems.

The CABIN monitoring program is an inter-agency, partner-based, collaborative data-sharing effort in which consistent sampling, analysis, and reporting methods are employed for assessing comparable freshwater quality and aquatic ecosystem conditions in Canada. The database is maintained by Environment Canada, and because it is a collaborative, partner-based program, data are available only for those rivers or regions in which a partner has pursued sampling activities. In the Athabasca Watershed, CABIN data have been generated in two regions: in the headwaters (in Jasper National Park); and at two locations in the Lower Athabasca (several sites in the Christina River headwaters, southwest of the Stony Mountain Wildland, and at a number of sites northwest of the mineable oil sands developments in the headwaters of the Ells and Tar Rivers). Currently, reference condition models for assessing the degree to which a site may be potentially impaired relative to and unimpacted reference sites have only been created for the Jasper National Park dataset. Efforts are underway to create methods and models for the oil sands region that would address difficulties associated with an absence of unimpacted regional reference sites. In this assessment, we consider only the subset of CABIN data from Jasper National Park.

4.3.2. Invertebrate Sampling

Invertebrate samples were collected for identification and enumeration from riffle (erosional) and depositional zones throughout the watershed using Neill/Hess samplers and/or standard kick sampling methods. Invertebrate community information from kicknet sampling is generally considered semi-quantitative because the area of substrate disturbed is not standardized or isolated from the surrounding substrate, as it is with the Neill-Hess method. However, kicknet sampling is still useful for comparing relative proportions of invertebrate taxa and community composition. The CABIN dataset is comprised solely of data generated via kicknet sampling, whereas the LTRN dataset incorporated both Neill and kicknet sampling (Anderson 1990; Environment 2006; Saffran and Anderson 2009). The RAMP sampling included a mix of kicknet sampling, along with quantitative areal sampling performed with either Neill-Hess or Ekman samplers (Table 4-1).

For sites identified as "erosional" (i.e., higher flow velocities and turbulence tends to maintain fine sediments in suspension, resulting in course sandy or rocky river substrates) by Alberta Environment's LTRN program, quantitative, areal samples were taken with the

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[3] RAMP Mandate and Objectives (source: http://www.ramp-alberta.org/ramp/terms+of+reference/mandate+and+objectives.aspx, accessed 10 February 2013)

Neill cylinder (0.1 m^2), permitting estimates of invertebrate population density. The cylinder is pushed into the substrate, isolating that portion of the substrate from the surrounding substrate. Rocks enclosed by the cylinder are cleaned by hand and the substrate within the cylinder is agitated with a shovel, and all debris and invertebrates wash into a collecting net (210 µm mesh aperture) and attached sample collection bottle. This is done until the water flowing into the collecting net is clear. In accordance with AENV protocols, five replicate samples were taken at all sites. Kick-net sampling methods were used to sample "depositional" (i.e., fine, suspended sediments tend to drop out of the water column because of relatively low flow velocities and turbulence, resulting in fine-textured, muddy substrates) zones at the LTRN sites. This method is typically used for “rapid assessment”, wherein single site-specific samples are taken after 3 minutes spent agitating the sediment upstream of the net (Saffran and Anderson 2009).

For the RAMP invertebrate sampling, an Ekman dredge (0.023 m^2) was used to sample invertebrates at sites identified as "depositional" (with 6 sites also sampled in 2010 using the kicknet method), and a Neill-Hess sampler (0.093 m^2) was used at sites identified as "erosional" (instead of a Neill sampler). Typically, there were either 5 or 10 replicates of Ekman and Hess samples taken at each site, along with a single kicknet sample that was taken after 3 minutes of upstream substrate disturbance. For more detailed descriptions of site locations, field sampling techniques, and identification and enumeration techniques employed by RAMP, see s. 3.1.3 and Appendix E.1, Regional Aquatics Monitoring Program Final 2011 Technical Report (April 2012).

Table 4-1. Monitoring sites sampled for invertebrate taxa (LTRN and CABIN).

Location	Site Code	Sample Type	Year
LTRN			
Old Entrance	AB07AD0100	Erosional / Depositional	2008
Town of Athabasca	AB07BE0010	Erosional / Depositional	2008
U/s Ft McMurray*	AB07CC0030	Erosional / Depositional	2008
Old Fort	AB07DD0010	Erosional / Depositional	2008
CABIN			
Unknown	JNP142	Depositional	2007
Beaver Creek	JNP151	Depositional	2007, 2009, 2011
Sunwapta	JNP152	Depositional	2007
	JNP153	Depositional	2007
Unnamed Creek	JNP172	Depositional	2007, 2009
Unnamed Creek	JNP173	Depositional	2007
Evelyne Creek	JNP178	Depositional	2007, 2008
Maligne River	JNP179	Depositional	2007, 2008, 2011
Pobokton	JNP180	Depositional	2007
Miette River	JNP183	Depositional	2007, 2008, 2011
	JNP186	Depositional	2007, 2009. 2011
Clairvaux Creek	JNP201	Depositional	2008
Snaring River	JNP184	Depositional	2007, 2009
Rocky River	JNP182	Depositional	2007
Athabasca River	JNP189	Depositional	2007, 2008
	JNP192	Depositional	2007, 2008
Test	JNP616	Depositional	2009
Test	JNP640	Depositional	2009
Test	JNP-Range	Depositional	2009

Continued…

Table 4-1. *continued…*

Location	**Site Code**	**Sample Type**	**Year**
RAMP – Athabasca Delta			
Athabasca Delta	ARD-D1	Depositional	2002
Big Point Channel		Delta	2007-2011
Embarras River	EMR-1	Delta	2011
Embarras River	EMR-2	Delta	2010
Fletcher Channel	FLC	Delta	2007-2011
Goose Isl Channel	GIC	Delta	2007-2011
RAMP – Upstream Fort McMurray			
Christina R - upper	CHR-D2	Depositional	2009
Christina R - middle	CHR-E2A	Erosional	2007
Christina R - mouth	CHR-D1	Depositional	2007
Clearwater R - u/s Christina R	CLR-D2	Depositional	2008, 2011
Clearwater R - u/s Ft. McMurray	CLR-D1	Depositional	2008, 2011
Hangingstone R	HAR-E1	Erosional	2007, 2008
High Hils R	HHR-E1	Erosional	2011
Horse R - upper	HOR-E1	Erosional	2009
RAMP – Central Mineable Oil sands Region			
Beaver R	BER-D2	Depositional	2008-2011
Dunkirk R	DUR-E1	Erosional	2009
Jackpine Ck - upper	JAC-D2	Depositional	2007-2011
Jackpine Ck - mouth	JAC-D1	Depositional	2007-2011
MacKay R - upper	MAR-E3	Erosional	2010, 2011
MacKay R - middle	MAR_E2	Erosional	2007-2011
MacKay R - mouth	MAR-E1	Erosional	2007-2011
Muskeg R - upper	MUR-D3	Depositional	2007-2011
Muskeg R - middle	MUR-D2	Depositional	2007-2011
Muskeg R - mouth	MUR-E1	Erosional	2007-2011
Poplar Ck - mouth	POC-D1	Depositional	2008-2011
Steepbank R - middle	STR-E2	Erosional	2007-2011
Steepbank R - mouth	STR-E1	Erosional	2007-2011
Kearl Lk – Muskeg River	KEL-1	Lake (D)	2007-2011
Shipyard Lk – east side	SHL-1	Lake (D)	2007-2011
RAMP – Lower Mineable Oil sands Region			
Calumet R - upper	CAR-D2	Depositional	2009
Calumet R - mouth	CAR-D1	Depositional	2009
Ells R - upper	ELR-E2A	Erosional	2010, 2011
Ells R - mouth	ELR-E2	Depositional	2010, 2011
Firebag R - upper	FIR-E2	Erosional	2010
Firebag R - mouth	FIR-D1	Depositional	2010
Fort Creek - mouth	FOC-D1	Depositional	2010, 2011
Tar R - upper	TAR-E2	Erosional	2009-2011
Tar R - mouth	TAR-D1	Depositional	2009-2011
Isadore's Lk	ISL-1	Lake (D)	2007-2011
Johnson Lk	JOL-1	Lake (D)	2011
McClelland Lk – Firebag River	MCL-1	Lake (D)	2007-2011

**Replicate invertebrate kick-net samples gathered for QA/QC comparisons*

4.3.3. Invertebrate Sample Treatment and Taxonomy

Benthic invertebrate samples were sorted through sieves with mesh apertures of 2, 1, and 0.2 mm (or 0.25 mm for RAMP samples), and counts were performed under a dissecting microscope (6-50X magnification), with some fine fractions containing large numbers of organisms sub-sampled for enumeration, according to Wrona et al. (1982). For LTRN samples, specimens were identified to genus or species where possible, and for RAMP samples, specimens were typically identified to genus, with the exception of oligochaetes, which were identified to family.[4] Invertebrate counts were performed by a number of individuals, and because of their varying specialties some of them identified individuals in different families to different taxonomic levels (i.e., to subfamily, genus or species). This was especially the case for the families Corixidae and Chironomidae, although detail of identification was generally inconsistent so that analyses and interpretations presented here are restricted to family-level taxa. CABIN sample handling and enumeration techniques are standardized according to standard CABIN methods (McDermott et al. 2012).

4.3.4. Patterns in Invertebrate Communities and Biotic and Abiotic Variables

a) Parametric Statistical Analyses

Given that our objective is to describe the current state of water quality in the Athabasca River, we have considered available invertebrate data from the recent sampling efforts (dating back to 2007), as secondary indicators of the general state of water quality in the river. We did not perform temporal trend analyses of invertebrate community indices for this report. This is because significant inter-annual variation in flow levels, temperature, and other physical and chemical conditions of streams and rivers may contribute to statistically significant temporal trends in invertebrate community metrics that may be merely coincidental, but not ecologically meaningful, largely because of the inability to attribute community change to any particular environmental state or condition in the watershed, or to separate natural and human causes for such changes. However, a qualitative assessment of inter-site differences in invertebrate community structure, including the longitudinal changes in the Athabasca River, is possible and has been performed here.

For the LTRN sites, comparisons among sites for summary community indices are presented graphically, e.g., total invertebrate abundance, relative abundance, number of unique taxa, and richness (i.e., number of families or genera) for major taxa (Chironomidae, Ephemeroptera, Plecoptera, Tricoptera, Oligochaeta, Cladocera, etc.). These summary variables are presented in order to identify ecologically significant trends in community differences between the sites, rather than community-based metrics and proportions (which are assessed via Principal Components Analysis [PCA]).

b) Community Metrics

A number of invertebrate community metrics were calculated, to simplify comparisons between sites and rivers. Included among these metrics are taxonomic diversity indices (Shannon-Wiener and Simpson's; Smith 1986; Simpson 1949), species richness (*i.e.*,

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[4] *E.g.*, Brooks and Kelton 1967, Teskey 1969, Edmunds et al. 1976, Oliver and Roussel 1983, Wiederholm 1983, McCafferty and Randolph 1998, Stewart and Stark 1988, Brinkhurst 1989, Pennak 1989, Clifford 1991, Merritt and Cummins 1996, Westfall and May 1996, Wiggins 1996, Zloty and Pritchard 1997, Epler 2001; see s. E.1.1.4, Appendix E, Regional Aquatics Monitoring Program *Final 2011 Technical Report* (April 2012).

number of species), and absolute and proportional (percent) abundance (Barbour *et al.* 1999). Some families were grouped together, such as members of the orders Ephemeroptera, Plecoptera, and Tricoptera (“*EPT taxa*”), or Ephemeroptera, Tricoptera, and Odonata (“*ETO taxa*”). These orders of invertebrates are generally considered to be sensitive to pollution. They prefer oxygen-rich waters, and should demonstrate higher richness and proportional abundance with high water quality conditions, decreasing in relative abundance with increasing ecosystem perturbation (Barbour *et al.* 1999, Saffran and Anderson, 2009). Abundance and proportional abundance of chironomids and oligochaetes is generally expected to be high at sites that are more impacted, or where fine, organic sediments dominate. The ratio of EPT to chironomids is an indication of community balance, and the ratio should be lower under conditions of environmental stress or with increasing ecosystem disturbance (Saffran and Anderson 2009).

The diversity indices were calculated as follows:

<u>Shannon-Wiener Index:</u>

$$H = -\sum_{i=1}^{s} (\rho_i)(\log_2 \rho_i)$$

where H = diversity of species; s = number of species; and ρ_i = proportion of individuals belonging to the i^{th} species.

<u>Simpson's Index:</u>

$$Diversity = 1 - \sum \frac{n_i(n_i - 1)}{N(N - 1)}$$

where N = total number of individuals (all species), and n_i = total no. individuals of i^{th} species

Both indices account for the number and relative abundance of species. A higher index value indicates a higher number of species and more even relative abundance among them. Conversely, a low index number indicates a low number of species and a dominance of the community by relatively few species (Simpson 1949; Smith 1986). However, the Simpson’s Index emphasizes common taxa and their evenness and puts less weight on rare taxa. Conversely, the Shannon-Wiener Index places more emphasis on rare taxa (Beals et al. 2000, Mandaville 2002).

c) Pollution Sensitivity (Modified Biotic Index and Family Biotic Index)

According to Hilsenhoff (1998), the EPT index is highly variable and exhibits seasonal variation in many streams. To account for this, an index of invertebrate pollution sensitivity was developed, wherein different families, genera, or species are assigned different pollution sensitivity scores based on observed relative pollution sensitivities, ranging from 1 (least sensitive) to 10 (most sensitive) (Mandaville 2002; modified from Hilsenhoff 1987, 1988). The Modified Biotic Index (10-Max BI, or "MBI") was derived to minimize effects of seasonal changes in invertebrate communities on the inferred pollution sensitivity

(Hilsenhoff 1998), and is used here to minimize the effect of sampling only once per year. The MBI is calculated according to the following formula:

$$10\text{-Max BI} = \Sigma(n_i * t_i) / (N);$$

where n_i = total no. individuals of i^{th} taxon, to a maximum of 10; t_i = tolerance score of the i^{th} taxon; N = total number of individuals (all species)

The MBI scores are correlated to the following qualitative degrees of organic pollution (Hilsenhoff, 1988):

Biotic Index	**Water Quality**	**Degree of Organic Pollution**
0.00 – 3.50	Excellent	No apparent organic pollution
3.51 – 4.50	Very Good	Possible slight organic pollution
4.51 – 5.50	Good	Some organic pollution
5.51 – 6.50	Fair	Fairly significant organic pollution
6.51 – 6.70	Fairly Poor	Significant organic pollution
7.51 – 8.50	Poor	Very significant organic pollution
8.51 – 10.00	Very Poor	Severe organic pollution

It is important to keep in mind that these qualitative classes were derived for streams in the Eastern USA and Canada, and no such correlation or calibration has been attempted in western streams. Therefore, it is probably best to consider MBI scores as measures of relative sensitivity to organic pollution, rather than indicative of particular degrees of organic pollution. Unlike the original Biotic Index (BI; 1987) or the subsequent Family-level Biotic Index (FBI; 1988), the MBI caps the total number of individuals of a particular taxon at 10, in order to reduce the potential dominance of the index by taxa that have very high numbers. As a result, index scores are less influenced by the presence of insensitive taxa in clean streams, a small number of insensitive taxa in somewhat polluted streams, the inability to identify larvae of some genera to species, and seasonal variability in community structure and life stages or maturity of the various taxa (Hilsenhoff 1998). Although Hilsenhoff (1987) has stated that BI estimates should be restricted to riffle zones, values for depositional zones are presented here, with the caveat that their interpretation may be limited.

d) Invertebrate Community Structure

Invertebrate communities in the Athabasca River were compared qualitatively to each other using principal components analysis (PCA) (ter Braak 1988). PCA is typically used to analyze and identify patterns in large, complex datasets. In a PCA bi-plot (e.g., Figure 4-3), the relative similarity of communities at different sites is represented by the distance between two points on the graph; points that are close together have invertebrate communities that are more similar to each other than points that are further apart in space. At either end of each axis, we have listed the most important community metrics that reflect the differences between sites. For example, the community at a site in the upper right quadrant of a PCA plot will possess higher values of the metrics listed at the right end of the x-axis and the top of the y-axis, than sites in the lower left quadrant (which itself will have higher values of the metrics listed at the left end of the x-axis and the bottom of the y-axis).

PCAs were performed using a broad suite of community indices (Table 4-2), rather than raw invertebrate community data, to determine general patterns of change in invertebrate community structure among all sites and rivers. Values and standard deviation of data for each variable were scaled or normalized for all samples, to mean variable values equal to zero and standard deviations equal to one, to ensure all variables have equal potential to contribute to all principal components. In addition, only taxa for which there were at least 5 occurrences among replicate samples from each sampling location were included, since this analysis is intended to illustrate which taxa account the most for the observed groupings of sites in canonical space.

Table 4-2. Invertebrate community variables and indices assessed using PCA.

Invertebrate Community Variable/Index			
Abundance (m^2)	**No. Unique Taxa**	**Family Richness**	**Others**
Total	Total	Total	EPT: Chironomidae (abundance)
EPT	EPT	EPT	Genera Richness (Chironomidae; EPT)
Coleoptera	Coleoptera	Coleoptera	Diversity (Shannon-Wiener; Simpson's)
Diptera	Diptera	Diptera	Pollution Sensitivity (FBI; Modified BI)
Hemiptera	Chironomidae	Hemiptera	
Odonata	Hemiptera	Odonata	
Crustacea	Odonata	Crustacea	
Oligochaeta	Crustacea	Oligochaeta	
Mollusca	Oligochaeta	Mollusca	
Chironomidae	Mollusca		

It should be noted that the CABIN cumulative environmental effects assessment program is based on what is referred to as the "Reference Condition Approach", or RCA (Bowman and Somers 2005). Typically, this involves using a PCA-based analysis of benthic communities at a selection of undisturbed reference sites and potentially impacts "test" sites, to create a model that identifies statistical differences between undisturbed and disturbed sites, based on differences in the invertebrate communities and known differences in environmental condition. These models are typically developed for regions, and such a model has been developed using the Jasper National Park CABIN dataset. However, because there has been less standardized CABIN assessment of benthic invertebrate communities in the rest of the Athabasca River, models have not been developed elsewhere (pers. comm., S. Humphries, Parks Canada, December 2012). A further confounding factor in developing such a model and assessment method for the oil sands region is the difficulty in identifying undisturbed reference sites. For this reason, researchers are still in the process of developing techniques for an RCA-based approach to assessing cumulative effects of oil sands development on benthic invertebrates in the Lower Athabasca region.

e) Statistical Methods

All statistical assessments of invertebrate data were performed using PASWStatistics 18.0 for Macintosh. Where comparisons of major quantitative indices (e.g., total abundance, number of taxa, etc.) for the five replicate samples from the four LTRN sites are made, sample precision - as represented by the standard error - is presented in order to assess its influence on trend detection (Elliott 1977).

4.4. Results and Discussion

General patterns in invertebrate communities are normally apparent as one travels from mountainous headwaters to the flat-land terminus of a river, as these changes reflect the physical and chemical differences in catchment inputs, nutrient supply and availability, and shading from either changes in bank-side vegetation or turbidity. Typically, headwater systems are metabolically reliant on catchment organic inputs. As stream size increases, so too does the relative importance of in-river primary productivity, coincident with an upstream-to-downstream shift to algal and vascular rooted plant production. Invertebrate communities reflect these shifts in type and location of food resources with stream size, exhibiting changes in the relative dominance of different functional groups – shredders, collectors, scraper/grazers, and predators (Vannote et al. 1980). Invertebrate community structure can change dramatically between sites and at the same location on a seasonal basis, because of differences in the site- and time-specific nature of their physical and chemical environment, as well as available food resources. For this reason, caution should be taken when interpreting the results from single samples at a particular site, and any apparent patterns among samples from different sites on a river or between and among rivers.

General patterns in benthic invertebrate communities at sites in the Athabasca River, based on quantified areal sampling (i.e., Neill/Hess and Ekman samples; LTRN and RAMP), can be seen in the PCA bi-plot shown in Figures 4-3 to 4-6. Patterns of abundance and number of unique taxa in areal LTRN samples are shown in Figure 4-75, and community richness, diversity and pollution sensitivity from these sites are shown in Figure 4-8. General patterns in benthic invertebrate communities from kicknet samples can be seen in the PCA bi-plot shown in Figure 4-9, and relative abundance of major taxa, diversity, and pollution sensitivity of communities at the LTRN sites are shown in Figure 4-10.

4.4.1. Community Patterns

The first two factors (or principal components) of the PCA explained approximately 50% of variance in the invertebrate community metrics in the areal samples from the LTRN and RAMP sites (Figure 4-3). In general, as one moves along the mainstem of the Athabasca River from Old Entrance, downstream of Jasper National Park, to Old Fort, downstream of Fort McMurray, there is a decline in the abundance of EPT taxa, EPT:Chironomids, and EPT community richness, and an increase in MBI (Factor 2 metrics). This coincides with an increase in the diversity and richness of the community, as one moves downstream to the site upstream of Fort McMurray (Factor 1 metrics). This is likely because of a shift toward more rich and diverse dipteran (especially chironomid) and oligochaete communities (Figure 4-3).

The samples from the LTRN site at Old Fort were generally very low in abundance, which accounts for the low apparent diversity at that site. Communities from the RAMP sites in the Athabasca Delta and its channels mimic the upstream-downstream patterns evident among the mainstem Athabasca LTRN sites, with further declines in the abundance of EPT taxa, EPT:Chironomids, and EPT community richness. While these sites do have higher values of MBI than upstream, it should be kept in mind that all of these sites are depositional.

Therefore, this is likely a reflection of the increase in sediment organic matter and increased turbidity, rather than the result of increased exposure to organic pollution.

Relative to the mainstem LTRN sites downstream, the invertebrate community at Old Entrance had high numbers of *Baetis*, *Ephemerellid*, *Rhithrogena* spp. (*Heptageniidae*) mayflies, and *Capniid* stoneflies, which typify swift waters of relatively high quality and low nutrient concentrations (Bowman et al. 2005a). Downstream, the communities from Athabasca to Old Fort demonstrated longitudinal declines in *Heptagenia* spp. mayflies and *Brachycentrus*, *Glossosoma*, *Cheumatopsyche* and *Lepidostoma* spp. caddisflies, among other taxa. These genera of caddisflies tend to prefer running waters with heterogeneous substrate in riffle regions (Clifford 1991). Based on their lower P-content, heptageniid mayflies also may have evolved to thrive in low-P environment. However, abundances of mayflies downstream of wastewater inputs in the Upper Athabasca appear to be the result of higher algal food quality, rather than increased food availability, and do not correlate well with either algal biomass of benthic chlorophyll a concentrations (Bowman et al. 2005a). The communities at Old Entrance also included most of these taxa that were prevalent at the Athabasca site. These upstream-downstream community shifts are consistent with changes in river geomorphology and the water and sediment quality that are expected as one travels downstream from the headwaters to the terminus of a major river.

The RAMP sites in the Lower Athabasca region upstream of Fort McMurray have communities that are generally similar to the communities in the lower mainstem Athabasca and Delta region, in terms of EPT abundance and richness, and EPT:Chironomids (Figure 4-4). However, they also have generally higher diversity, and total, *Chironomid*, and *Oligochaete* richness (Factor 1, Figure 4-4). As may be expected, the erosional site in the middle reaches of Christina River had slightly higher values of the Factor 2 metrics than at the two depositional sites upstream and downstream of it, and substantially higher values of the Factor 1 metrics. Similar community patterns were also present at the Hangingstone, High Hills, and Horse River sites, which also are erosional. As in the mainstem Athabasca itself, these community patterns are generally consistent with what would be expected in lowland tributaries of a major river like the Athabasca. The increase in community diversity and richness (Factor 1 metrics), EPT taxa, EPT:Chironomids, EPT community richness, and MBI (Factor 2 metrics) at erosional RAMP sites is consistent with what would be expected with increased water velocities and reduced organic sediment deposition that are present at these sorts of sites

The RAMP tributaries and lakes in the central part of the mineable oil sands region (Table 4-1) demonstrate patterns that are not as clear as those upstream of Fort McMurray (Figure 4-5). Kearl and Shipyard Lakes had invertebrate communities very similar to those at the channel sites in the Athabasca Delta. This is not unexpected, given the tendency toward lower water velocities, smaller sediment particle size, and higher sediment organic content in delta regions, relative to upstream erosional sites (i.e., attributes likely shared with lake sites in the Boreal Lowlands). The communities at the tributary sites in this region were generally quite variable, in terms of both Factor 1 and Factor 2 metrics, demonstrating substantial inter-annual variation. However, as with tributaries upstream of Fort McMurray, erosional sites (Dunkirk, MacKay, Muskeg, and Steepbank Rivers) had higher values of both Factor 1 and Factor 2 metrics (i.e., higher EPT abundance and richness, EPT:Chironomids, diversity, and total, Chironomid, and Oligochaete richness) than the depositional sites in this part of the watershed. Of the depositional sites, despite that there was great inter-annual variation in the communities in Jackpine Creek, the upstream site consistently had higher EPT:Chironomids, and EPT abundance, richness and diversity, than at the downstream site.

The invertebrate communities in tributaries and lakes in the lower part of the mineable oil sands region (Table 4-1) reflect patterns that are similar to those of the other tributaries in the Lower Athabasca region, described above (Figure 4-4). All the sites demonstrated communities that were relatively low in EPT abundance and richness and EPT:Chironomids (at or below levels seen in the mainstem Athabasca upstream of Fort McMurray). However, the erosional sites in the upper reaches of the Ells, Firebag, and Tar Rivers, had higher values of these metrics than the depositional sites both downstream in the same rivers, and in the other tributaries (Figure 4-6). The erosional sites also had higher diversity and numbers of taxa (total, Chironomid, and Oligochaete) than the depositional sites.

Consistent with the patterns described above for the mainstem Athabasca River, strong upstream-downstream patterns are evident in total invertebrate abundance and relative abundance of major taxa in erosional zones in the Athabasca River (Figure 4-7 A-D). As mentioned above, invertebrate abundances were very low in the Old Fort Abundance samples (mean of 76 individuals m^2; Table 4-3), so apparent patterns in the invertebrate community at this site must be considered uncertain. EPT comprised 73% of the total abundance at Old Entrance, declining to 63% at Athabasca and 52% upstream of Fort McMurray (Table 4-3). At Old Entrance, mayflies and stoneflies were dominant, whereas at Athabasca, there was shift in dominance to caddisflies and mayflies. Chironomid abundance was proportionately the same at Old Entrance (16%) and Athabasca (22%) and significantly higher upstream of Fort McMurray (30%). Therefore, longitudinal declines in EPT : Chironomids were observed, from 4.7 at Old Entrance to 1.7 upstream of Fort McMurray (Table 4-3). All of these patterns are consistent with those described above, based on the PCA bi-plots shown in Figures 4-3 to 4-6.

Of the more than 40 different taxa found at the three upstream LTRN sites on the mainstem of the Athabasca River (versus 5 at Old Fort), more than 50% of the sample was comprised of EPT (Figures 4-7 and 4-8; Table 4-3). Among the replicate samples taken, those from the town of Athabasca (LTRN site #2) on average contained more unique taxa with less variation in the number of taxa, suggesting greater precision among these samples than the samples taken at Old Entrance (LTRN site #1) and upstream of Fort McMurray (LTRN site #3). Patterns in species richness, including richness of EPT taxa, were similar to those for total numbers of unique taxa at LTRN sites (Table 4-3, Figure 4-8 A-B). Invertebrate community diversity in the Athabasca River was relatively high in 2008, compared to LTRN invertebrate sites being monitored on other rivers in the province during the same year (Donahue 2010).

Diversity index values at Old Entrance (LTRN site #1) were comparable to values from Hwy 40, Watino, and upstream of Smoky River on the Peace River, and increased sequentially from Old Entrance to upstream of Fort McMurray (Table 4-3, Figure 4-8 C). Pollution sensitivity values at the three upstream sites (LTRN sites 1-3) were relatively low (4.16 to 4.62), and indicative of very good (Old Entrance and Athabasca) and good (upstream of Fort McMurray) water quality (Table 4-3).

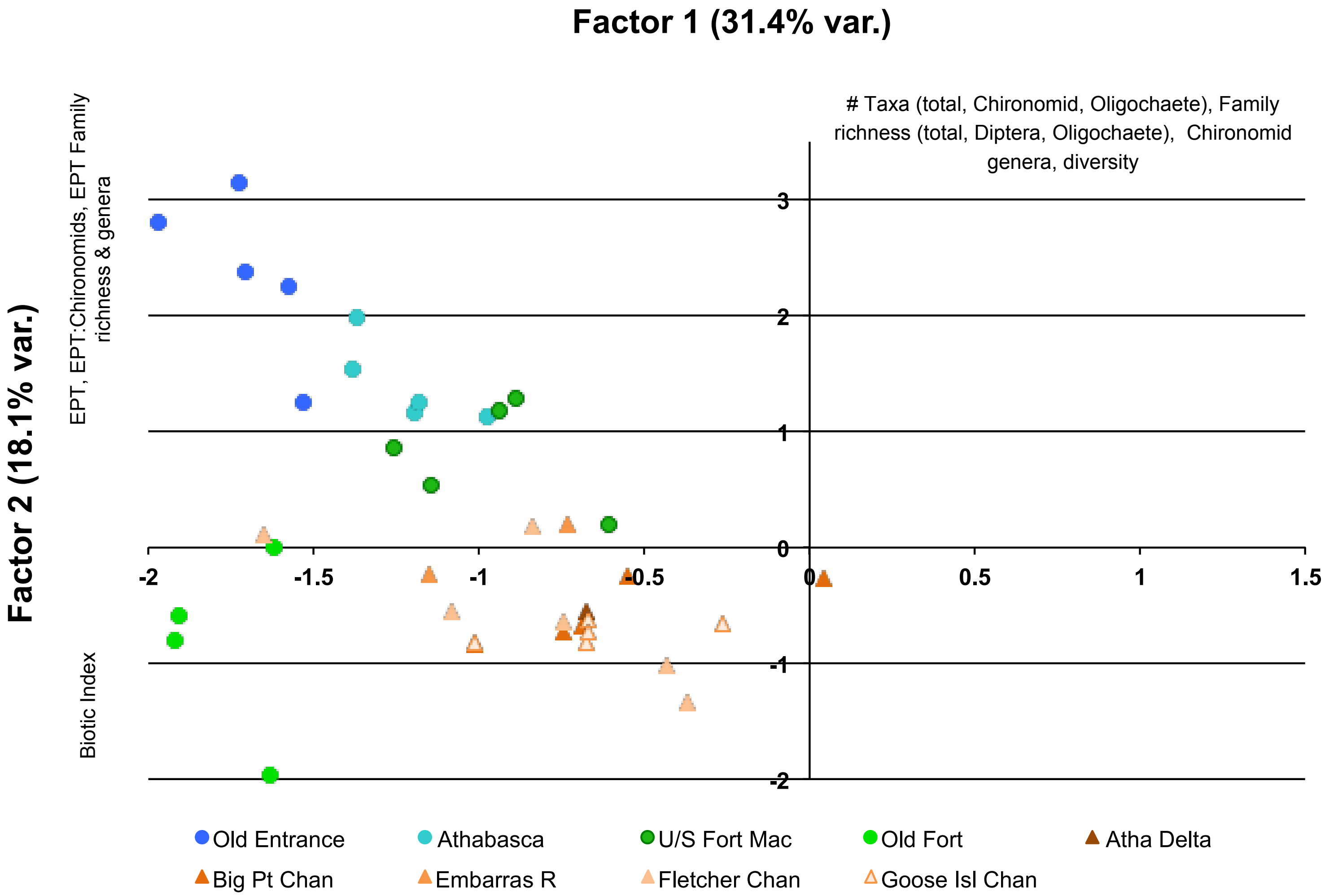


Figure 4-3. PCA of benthic invertebrates in the mainstem Athabasca River and delta region (LTRN, RAMP; Neill/Hess samples).

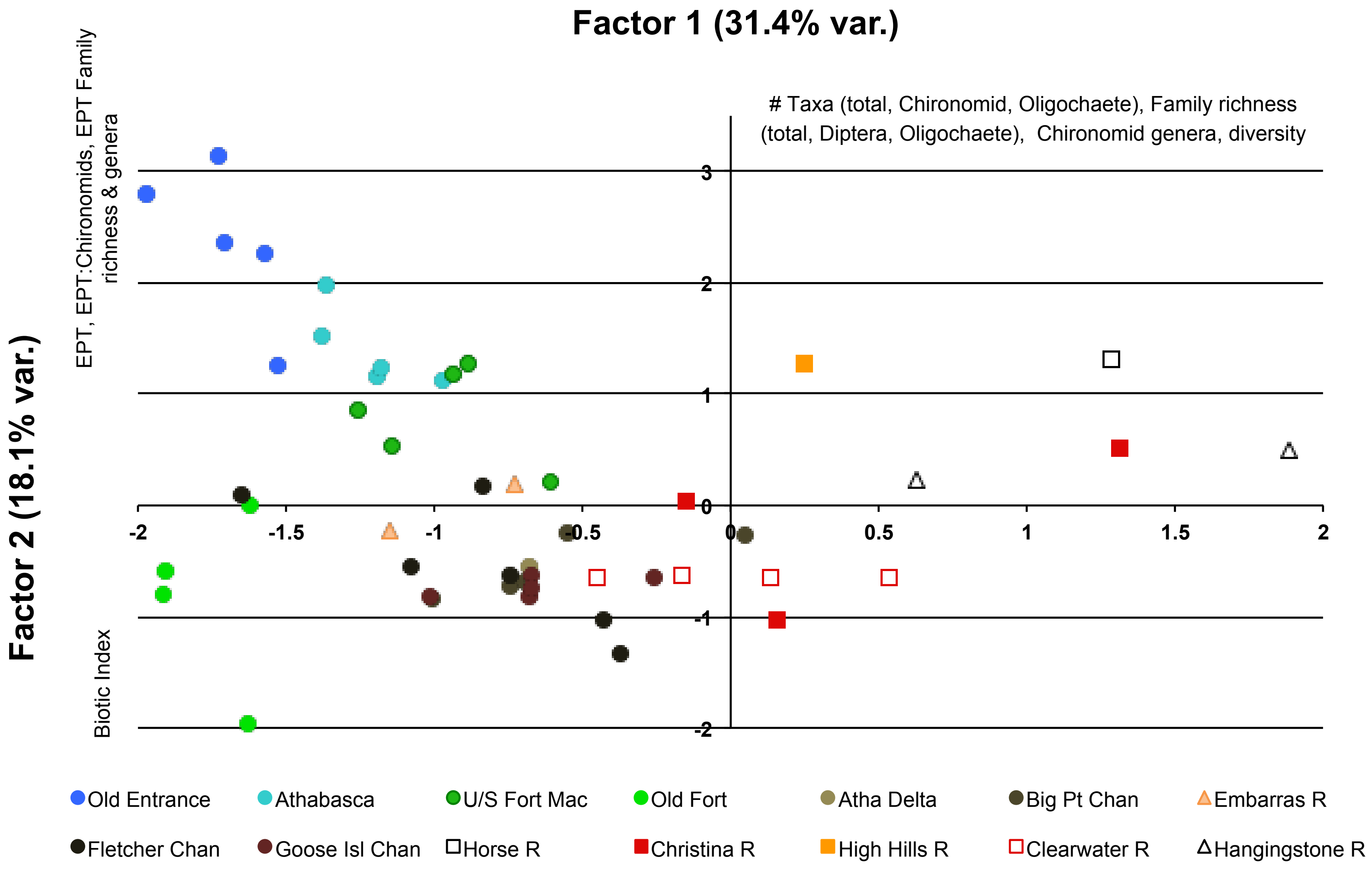


Figure 4-4. PCA of benthic invertebrates in the mainstem Athabasca River and tributaries upstream of Fort McMurray (LTRN, RAMP; Neill/Hess samples).

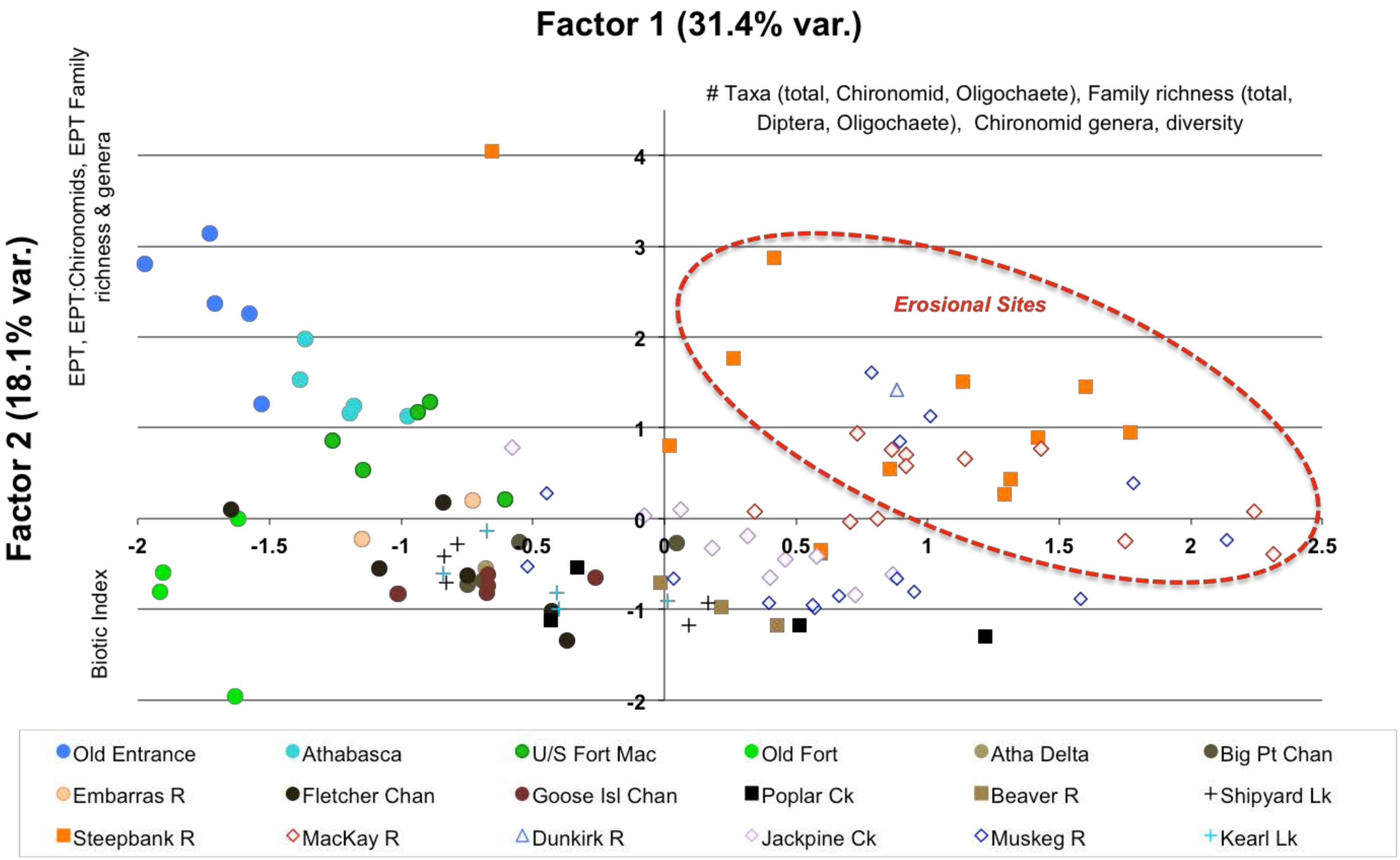


Figure 4-5. PCA of benthic invertebrates in the mainstem Athabasca River and central Mineable Oil sands Region tributaries (LTRN, RAMP; Neill/Hess samples).

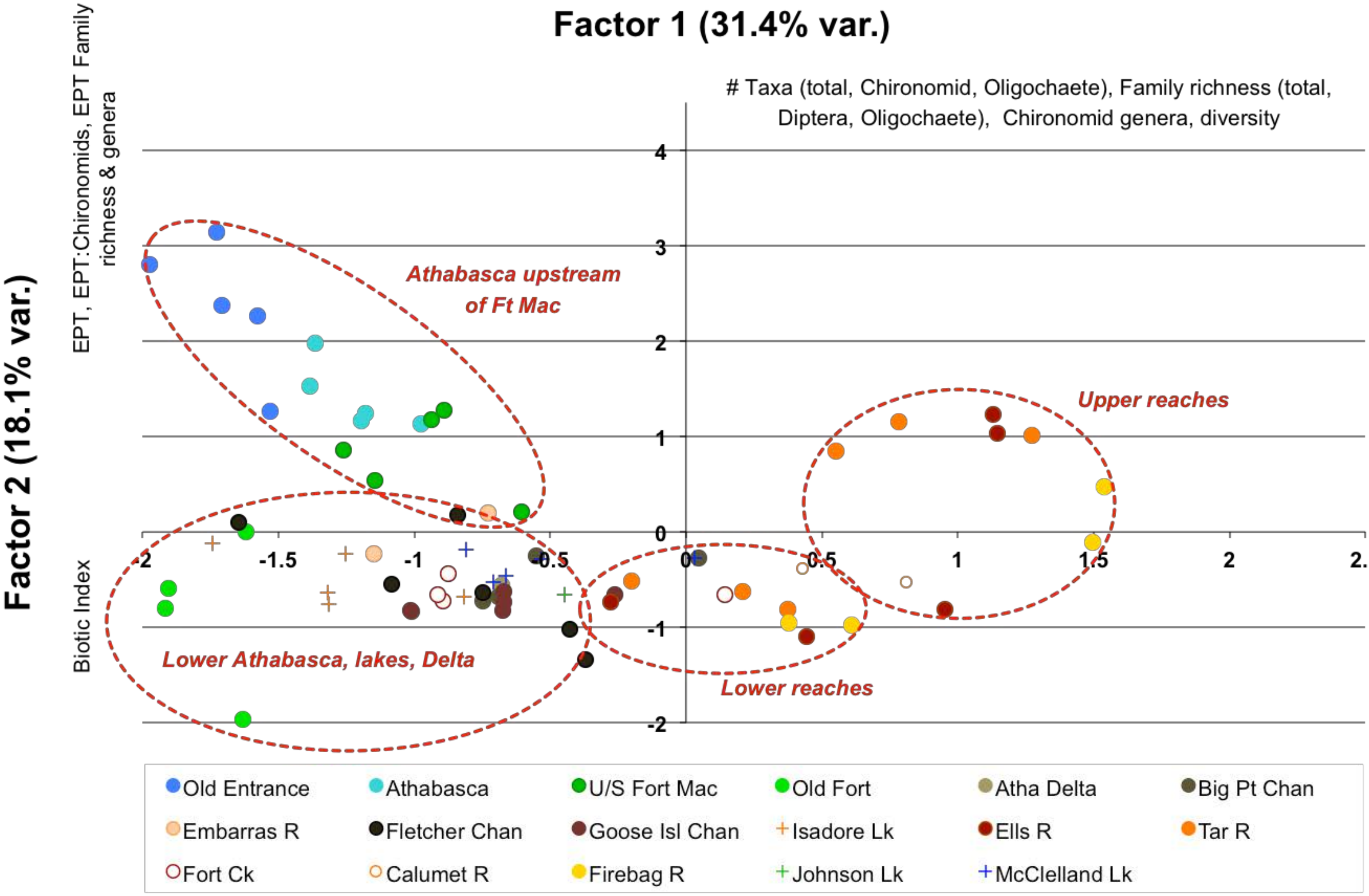


Figure 4-6. PCA of benthic invertebrates in the mainstem Athabasca River and lower Mineable Oil sands Region tributaries (LTRN, RAMP; Neill/Hess samples)

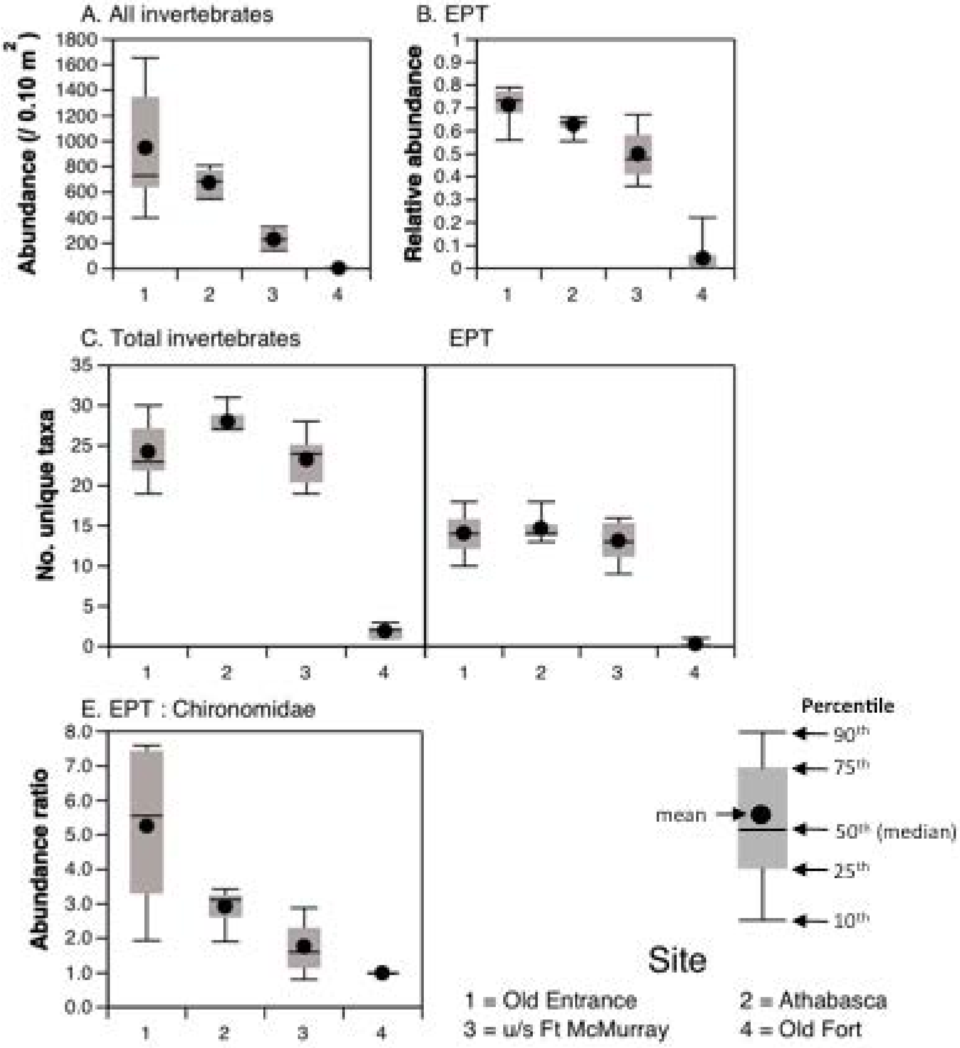


Figure 4-7. Invertebrate community abundance and number of unique taxa in the Athabasca River (LTRN sites; Neill cylinder samples). As illustrated in the lower right, six different statistical metrics are displayed in these box plots: The top, bottom, and line through the middle of the box correspond to the 75th (top quartile), 25th (bottom quartile), and 50th percentile (median), respectively. The whiskers at the bottom and top extend from the 10th to the 90th percentile, respectively.

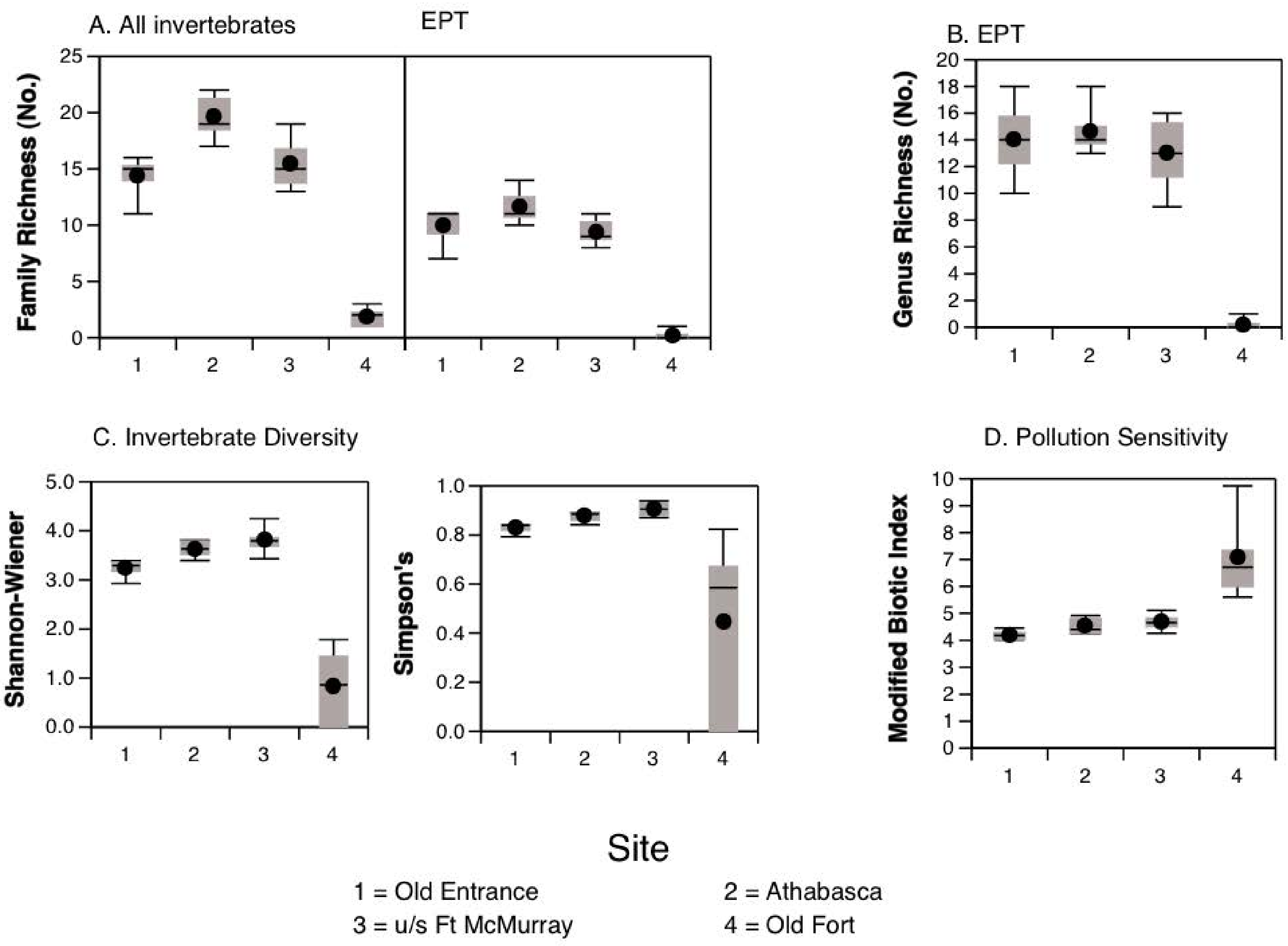


Figure 4-8. Invertebrate community richness, diversity, and pollution sensitivity in the Athabasca River (LTRN; Neill cylinder samples).

Table 4-3. Abundance, number of unique taxa, and richness of benthic invertebrate communities in the Athabasca (n = 5; LTRN 2008).

		Mean values				Standard deviation			
		Old Entrance	Athabasca	u/s Ft McMurray	Old Fort	Old Entrance	Athabasca	u/s Ft McMurray	Old Fort
Abundance	Total	950.3	672.8	231.8	3.8	495.1	113.6	77.1	3.1
(# / 0.10 m^2)	EPT	697.9	423.4	121.4	0.4	388.0	88.4	66.8	0.9
	Coleoptera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Diptera	152.0	164.8	86.6	2.6	95.5	24.1	19.1	2.7
	Ephemeroptera	362.5	98.6	52.0	0.0	269.8	27.7	29.3	0.0
	Plecoptera	294.6	9.2	46.4	0.0	112.2	6.1	36.9	0.0
	Tricoptera	40.8	315.6	23.0	0.4	48.2	84.1	10.5	0.9
	Hemiptera	0.4	1.0	0.8	0.0	0.9	0.7	0.8	0.0
	Odonata	0.0	3.0	1.2	0.0	0.0	2.2	1.6	0.0
	Crustacea	0.0	0.2	0.0	0.0	0.0	0.4	0.0	0.0
	Oligochaeta	38.0	61.6	21.0	0.8	10.6	21.4	14.6	0.8
	Mollusca	0.0	7.4	0.2	0.0	0.0	3.1	0.4	0.0
	Chironomidae	147.0	148.0	69.4	0.4	97.6	22.0	14.8	0.9
	Other	62.0	11.4	0.6	0.0	29.1	7.9	0.9	0.0
Relative Abundance	EPT	73.4%	62.9%	52.4%	10.5%	9.0%	4.0%	11.9%	9.9%
	Coleoptera	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Diptera	16.0%	24.5%	37.4%	68.4%	7.8%	4.4%	8.7%	40.0%
	Ephemeroptera	38.1%	14.7%	22.4%	0.0%	9.3%	4.3%	6.7%	0.0%
	Plecoptera	31.0%	1.4%	20.0%	0.0%	6.1%	1.0%	9.6%	0.0%
	Tricoptera	4.3%	46.9%	9.9%	10.5%	4.3%	5.3%	2.9%	9.9%
	Hemiptera	0.0%	0.1%	0.3%	0.0%	0.1%	0.1%	0.6%	0.0%
	Odonata	0.0%	0.4%	0.5%	0.0%	0.0%	0.3%	0.7%	0.0%
	Crustacea	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
	Oligochaeta	4.0%	9.2%	9.1%	21.1%	2.4%	1.7%	6.4%	43.9%
	Mollusca	0.0%	1.1%	0.1%	0.0%	0.0%	0.5%	0.3%	0.0%
	Chironomidae	15.5%	22.0%	29.9%	10.5%	7.9%	4.1%	8.1%	9.9%
	Other	6.5%	1.7%	0.3%	0.0%	1.8%	1.4%	0.3%	0.0%
Ratio	EPT : Chironomids	4.75	2.86	1.75	1.00	2.40	0.59	0.79	N/A
Unique Taxa*	Total	42.0	45.0	41.0	5.0	4.1	1.7	3.4	0.8
	EPT	25.0	22.0	21.0	1.0	2.9	1.9	2.7	0.4
	ETO	17.0	19.0	16.0	1.0	2.2	1.8	2.7	0.4
	Coleoptera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Diptera	10.0	12.0	14.0	2.0	1.8	1.0	0.4	0.7
	Ephemeroptera	12.0	10.0	7.0	0.0	1.3	1.1	1.5	0.0
	Chironomidae	6.0	11.0	9.0	1.0	1.1	1.0	0.7	0.4
	Plecoptera	8.0	5.0	6.0	0.0	1.0	1.1	0.8	0.0
	Tricoptera	5.0	7.0	8.0	1.0	1.3	0.4	1.5	0.4
	Hemiptera	1.0	2.0	1.0	0.0	0.4	0.4	0.5	0.0
	Odonata	0.0	2.0	1.0	0.0	0.0	0.8	0.5	0.0
	Crustacea	0.0	1.0	0.0	0.0	0.0	0.4	0.0	0.0
	Oligochaeta	1.0	1.0	2.0	2.0	0.0	0.0	0.5	0.5
	Mollusca	0.0	3.0	1.0	0.0	0.0	0.8	0.4	0.0
	Other	5.0	2.0	1.0	0.0	0.4	0.9	0.5	0.0
Family Richness	Total	20.0	26.0	24.0	5.0	1.9	1.9	2.3	0.8
	EPT	14.0	15.0	13.0	1.0	1.7	1.5	1.1	0.4
	ETO	10.0	12.0	9.0	1.0	1.2	1.2	0.8	0.4
	Coleoptera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Diptera	3.0	2.0	5.0	2.0	0.4	0.0	0.5	0.7
	Ephemeroptera	6.0	5.0	3.0	0.0	0.5	0.9	0.0	0.0
	Plecoptera	4.0	4.0	5.0	0.0	0.7	0.9	0.8	0.0
	Tricoptera	4.0	6.0	5.0	1.0	1.1	0.4	0.8	0.4
	Hemiptera	1.0	1.0	1.0	0.0	0.4	0.4	0.5	0.0
	Odonata	0.0	1.0	1.0	0.0	0.0	0.4	0.5	0.0
	Crustacea	0.0	1.0	0.0	0.0	0.0	0.4	0.0	0.0
	Oligochaeta	1.0	1.0	2.0	2.0	0.0	0.0	0.5	0.5
	Mollusca	0.0	3.0	1.0	0.0	0.0	0.8	0.4	0.0
	Other	1.0	2.0	1.0	0.0	0.0	0.9	0.5	0.0
Genera Richness	Chironomid genera	6.0	11.0	9.0	1.0	1.1	1.0	0.7	0.4
	EPT genera	25.0	22.0	21.0	1.0	2.9	1.9	2.7	0.4
Diversity Indices	Shannon-Wiener	3.39	3.81	4.29	2.00				
	Simpson's	0.84	0.89	0.94	0.83				
Pollution Sensitivity	FBI	4.42	5.25	5.30	6.40				
	Modified BI (10-Max BI)	4.15	4.42	4.62	5.79				

For the kick-net samples, the first two factors explained approximately 60% of the variance in the invertebrate community data from the CABIN, LTRN, and RAMP sites (Figure 4-9). In general, the RAMP sites had higher values of Odonate (dragonfly larvae) abundance, number of taxa (total, Odonata, Mollusca), family richness (total, Diptera, Odonata, Mollusca), and the number of EPT genera, than observed at the CABIN and LTRN sites. This is likely because of smaller sediment sizes and warmer waters with higher nutrient concentrations, relative to CABIN sites, and more diverse microhabitats relative to LTRN sites. The LTRN sites had higher abundances of Diptera, Chironomid & Crustaceans, higher numbers of Crustacea taxa, higher Hempitera & Crustacea richness, and higher MBI values than at the CABIN and RAMP sites, and lower EPT richness. As described above, this may be the result of the difference in the size of the rivers (i.e., the Athabasca River versus its tributaries), the diversity of microhabitats, and general water quality.

The invertebrate communities at all sites were dominated by chironomids and crustaceans (82-94%), and demonstrated longitudinal declines the relative proportion of EPT from Old Entrance (2.2%) to upstream of Fort McMurray (0.2%; Figure 4-10A). Prevalent taxa included: chydorids, water mites, cyclopoid copepods, ostracods and nematodes at Old Entrance; *Ilyocryptus*, cyclopoids, and ostracods at Athabasca; *Ilyocryptus*, ostracods and nematodes upstream of Fort McMurray; and ostracods and nematodes at Old Fort (10% of relative abundance was comprised of “other” taxa). In terms of contributions of the different families to richness, communities at all sites included individuals from most of the major taxonomic groups (Figure 4-10B). Molluscans and coleopterans were present at the three upstream sites, but not at Old Fort. Diversity index values reflected the exceptional dominance of communities at Athabasca and Fort McMurray by crustaceans and chironomids, and were lower than at Old Entrance and Old Fort (Figure 4-10C).

Pollution sensitivity index values were similar to those determined from areal sampling and described above, demonstrating a longitudinal increase from Old Entrance to Fort McMurray, although Old Fort had a similar score to Fort McMurray (Figure 4-10D). In general, mainstem Athabasca River invertebrate communities, as collected by kick samples, seem to shift more towards those indicative of nutrient enrichment, based on community shifts from EPT-dominated, to chironomid-dominated downstream of Athabasca. Prevalence of *Ilyocryptus* at Athabasca and upstream of Fort McMurray suggests higher effects of siltation at these sites. This could be the natural consequence of being lower in the watershed, or alternatively, to decreased scouring of riverbeds in recent years from declining water inputs from snowmelt and summer runoff in the middle reaches (Schindler and Donahue 2006; Schindler, Donahue and Thompson 2007).

The Athabasca River receives Continuous discharge from five pulp mills and five municipal wastewater treatment plants, in addition to municipal discharge inputs from its tributaries (Chambers et al. 2000). Substantial oil sands development is also prevalent in the reaches of the Athabasca River downstream of Fort McMurray. Water quality in the Athabasca River has consistently been rated as “good” to “excellent”, with increases in concentrations of nutrients and metals in an upstream-to-downstream direction that have contributed to declines in Alberta Water Quality Index values, from excellent in the upper reaches, to good in the lower reaches (North/South Consulting Ltd 2007; AENV data). Sediment quality index scores for the three upper LTRN sites were also high (98-100), with total sediment extractable priority pollutant (EPP) concentrations being very similar at Old Entrance (24.7 µg/kg) and upstream of Fort McMurray (21.9 µg/kg), and higher than at Athabasca (9.1 µg/kg). On the other hand, concentrations of nutrients and total metals were lower at Old Entrance than at downstream sites.

Unfortunately, invertebrate numbers were so low in the Old Fort LTRN samples as to be unsuitable for interpretation, likely because of shifting sand substrates. For this reason, this sample was not included in the analysis performed and is not discussed here. More sampling effort is required at this site to determine the nature of the benthic invertebrate community or how they compare to upstream sites. Among the three upstream LTRN sites there is longitudinal pattern consistent with increasing nutrient enrichment effects, which corresponds to longitudinal increases in total nitrogen water concentrations. Total phosphorus concentrations in September were lowest at Old Entrance, highest at the Athabasca site, and moderate upstream of Fort McMurray. The increased nutrient concentrations at the town of Athabasca and below the town, are likely the result of a combination of the inflow of the Lesser Slave River and natural nutrient sources in the Boreal mixedwood ecoregion, with lower autumn flows and declines in water inputs by approximately 50% in these middle reaches over the last 40 years (Chambers et. al. 2000; Schindler, Donahue, and Thompson 2007).

The relatively high numbers of chironomids at the Old Entrance site may be the result of substrate being comprised of 62% silt and clay, whereas these constituents formed 49% of the substrate at Athabasca and 66% upstream of Fort McMurray (Alberta Environment sediment data). It is uncertain whether this substrate composition is typical of erosional reaches at Old Entrance. In general, invertebrate communities in the Athabasca River appear to reflect what could be thought of as “normal” changes associated with changes in geomorphology, hydrology, and substrate quality, and increases along its length in natural and anthropogenic nutrient sources from industrial and municipal effluent inputs. A previous report by Anderson (1991) supports this conclusion, based on similar patterns in invertebrate communities in the Athabasca River. However, as described further below, it is likely that the lack of monitoring in large portions of the watershed, inappropriate sampling frequency, and/or inappropriate site selection and replicate sampling contribute to a general inability to detect change that can be attributed to a specific cause.

Despite the lack of evidence of cumulative negative effects of human impacts on benthic invertebrate communities, it has been demonstrated that benthic algal accumulation in the upper reaches of the Athabasca River are more closely related to variation in flow, temperature, and dissolved inorganic nitrogen concentrations than phosphorus concentrations (Bowman et al 2007). Past studies have shown that industrial and municipal effluent increases benthic algae biomass by 2 to 50 times for an average of 21 km downstream of the point source (Scrimgeour and Chambers 2000). Specifically, algal biomass increased significantly for at least 20 km downstream of Jasper's sewage treatment plant (STP) and Hinton's bleached kraft pulp mill (BKPM), 23 km downstream of Whitecourt's chemithermomechanical pulp mill (CTMPM), 13 km downstream of the confluence with the Lesser Slave River, 1 km downstream of the town of Athabasca's STP and 4 km downstream of its BKPM, and 60 km downstream of Fort McMurray's STP (Scrimgeour and Chambers 2000).

These point sources along the Athabasca River also caused metabolic changes in algal nutrient dynamics, with the community typically switching from P-limited upstream of point sources, to ether non-limited or N-limited downstream, for an average of 71 km. Eventually, algal communities shifted back to P-limited downstream of Jasper and Whitecourt, after 4 and 94 km, respectively. The change in nutrient condition or status persisted for at least 120 km downstream of Hinton, for at least 111 km downstream of the confluence with the Lesser Slave River, and at least 60 km downstream of Fort McMurray (Scrimgeour and Chambers 2000). This shift to N-limitation was attributed to effluent point-sources along the length of the river, rather than natural geological sources (Scrimgeour and Chambers 2000). These persistent downstream changes in the nutrient status of algal communities likely explain, at least in part, the general shift we observed from nutrient-limited communities in the upper reaches of the Athabasca River, to communities more representative of nutrient enrichment in the lower reaches of the river.

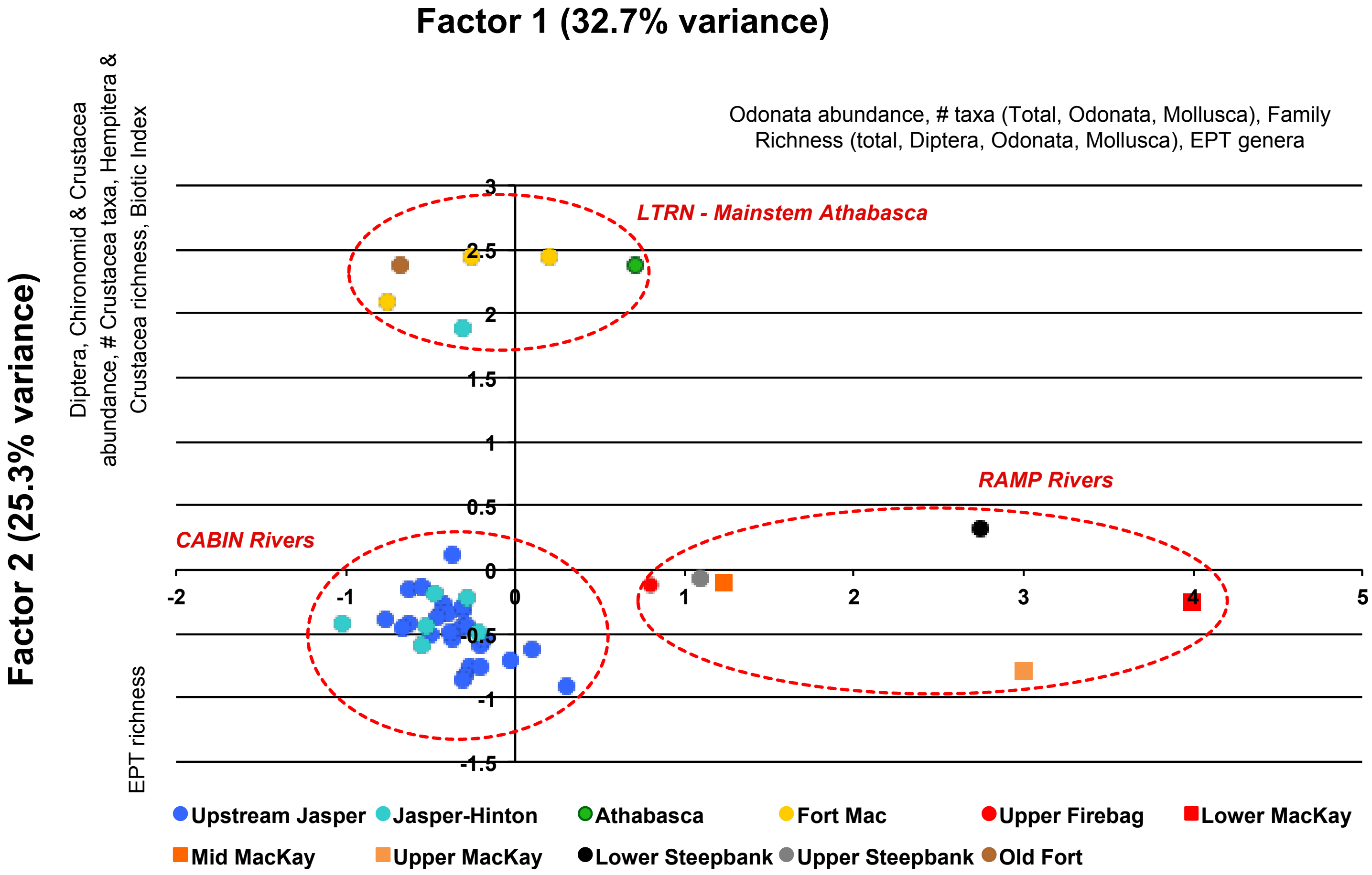
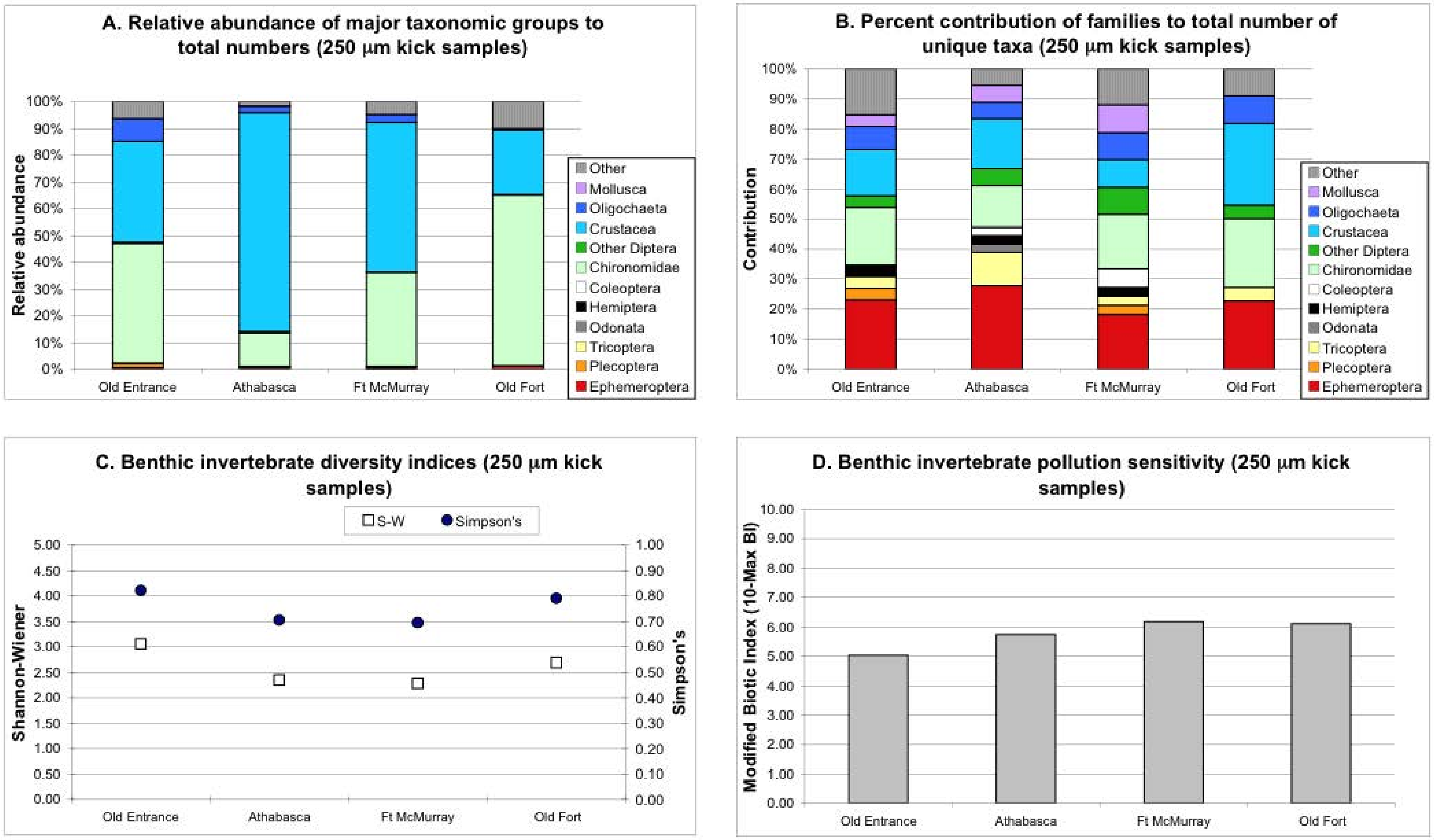


Figure 4-9. PCA of benthic invertebrates in the Athabasca River (CABIN, LTRN, RAMP; kicknet samples).



A. Relative abundance of major taxonomic groups to total numbers (250 µm kick samples)

B. Percent contribution of families to total number of unique taxa (250 µm kick samples)

C. Benthic invertebrate diversity indices (250 µm kick samples)

D. Benthic invertebrate pollution sensitivity (250 µm kick samples)

Figure 4-10. Invertebrate relative abundance and diversity in the Athabasca River (LTRN; Kick samples).

4.5. Conclusions

Discernible patterns in benthic invertebrate communities are evident from this assessment of CABIN, LTRN, and RAMP data, including longitudinal trends in invertebrate communities that reflect natural changes in geomorphologic and hydrologic factors that occur along the length of a river. Such patterns were evident in the tributaries in the upper and lower regions of the watershed, and in the mainstem of the Athabasca River, at least to the degree that it was sampled. Anthropogenic disturbance in the form of municipal wastewater, industrial point-source inputs, diffuse agricultural inputs, and disruptions in flow regimes were not evident based on the invertebrate communities represented in the CABIN, LTRN and RAMP datasets that we examined here.

In many instances where both kick samples and areal samples were coincidentally collected, patterns of change and effects on communities inferred from kick samples in depositional zones are contrary to those inferred from erosional zone data. Because of the highly qualitative nature of data that are derived from kick samples, their value are much lower than those derived from quantitative areal sampling (e.g., Neill, Hess, or Ekman dredge). While the CABIN program employs kick-sampling methods, this method is appropriate because the program (including site selection, data analysis, and interpretation techniques) was designed with the goal of identifying sites that may be impacted by human activities. However, it is uncertain how much additional value kick data provide for assessing ecosystem change in the context of the LTRN and RAMP programs, because these programs lack reference sites that preclude a reference-condition comparison approach (as used in CABIN). In addition, the infrequency of sampling in the LTRN program, and the variability in sampling sites in the RAMP program, make the kick sample data collected as part of these programs less useful for evaluating change over time.

Long-term monitoring in Alberta, and elsewhere, has demonstrated the value of using benthic invertebrates as indicators of water quality, ecosystem change, and ecosystem health because of their consistent and predictable response to physical and chemical changes that are of interest to ecosystem managers. While there are a variety of distinct and on-going monitoring programs occurring in different regions of the Athabasca Watershed, or at discrete and specific locations, these programs are not integrated either in their pursuit or in the management and interpretation of data. As a result, there is no broad-scale, integrated, and routine monitoring program for benthic invertebrates in the Athabasca Watershed. Specifically, there is relatively little broad scale monitoring and assessment of benthic communities occurring between Jasper National Park and the Lower Athabasca region, on either the mainstem of the Athabasca or in tributary rivers and streams. While there is routine sampling conducted as part of the Environmental Effects Monitoring program, this program is regulatory in nature and are intended to identify major effluent point-source impacts, rather than provide an understanding of changes occurring throughout the watershed. Of the programs that involve monitoring at a variety of sites, e.g., CABIN, LTRN, and RAMP, the sampling is performed in a matter of days and is typically limited to the autumn. Consequently, it is possible that variations in communities that are the result of either natural or anthropogenic variations in physical or chemical conditions at particular sites could be attributed to other factors, or missed entirely.

The infrequent sampling in the LTRN program (thus far, only once, but conceivably every five years going forward), and the lack of sampling on the mainstem and on tributaries in the central part of the watershed, means that any real disturbance effect on invertebrates and ecosystem health would likely not be detectible for decades, in the context of this monitoring program. Even where sampling is occurring, it must be acknowledged that sampling sites every five years will reduce the ability of managers to detect change for at least 15 years, given the need for a minimum of three points in time to statistically identify trends.

While infrequent and patchy sampling is particularly problematic with the LTRN program, it is also a concern with the CABIN and RAMP monitoring programs. Without combining benthic invertebrate sampling with mechanistic experimental studies designed specifically to test the effects of nutrient enrichment or contaminant deposition on benthic invertebrate community structure and function, it will be difficult to discern whether observed differences, either longitudinally along the river or over time, are the result of anthropogenic activities, or are associated with natural variation in environmental variables or invertebrate communities and populations. In order to address these concerns, the intensity of long-term invertebrate sampling efforts must be increased substantially, both in sampling frequency and in the number of sites sampled. This increase in monitoring effort should occur both on the mainstem of the Athabasca River, as well as in tributaries and lakes throughout the watershed. Particular focus should be directed towards the large portion of the river between Jasper National Park and the oil sands region where there is currently no sampling that is part of a larger, integrated monitoring program.

The major impediment to any large-scale assessment of benthic communities and what they indicate about distinct and cumulative effects of natural and human disturbance in the Athabasca Watershed is the lack of monitoring and assessment programs designed specifically to provide that information. Secondary to this problem is that data from most historical monitoring and the monitoring programs beyond CABIN, LTRN, and RAMP are not readily available, either because they are not in electronic form or because they are considered proprietary. So long as these two problems exist, it will be difficult to effectively undertake and execute an assessment of change in benthic communities at a watershed scale.

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Chapter 5: Data Availability, Quality, and Gaps

5. Introduction

While we assembled a variety of data for this assessment, it is important to note that not all data are available for use, and further, not all available data are usable data, particularly when dealing with data from multiple sources that have been collected using non-standardized methodologies for detecting, monitoring, and reporting contaminant levels for water and biota (Wrona et al. 2000). In this chapter, we discuss some of the issues and challenges related to data availability and data quality, as well as gaps in knowledge or understanding of water quality and quantity issues in the Athabasca Watershed.

5.1. Data Availability

A large number of organizations and individuals collect water quality data in the Athabasca Watershed, and one of the objectives of this project was to assemble the most comprehensive water quality database that was possible within the given time and budgetary constraints. While we contacted a large number of organizations to acquire data, in many cases we were unsuccessful. Our inability to acquire data was the result of several factors, including: 1) the data do not exist in a usable format (e.g., existed only as hardcopy or PDF reports); 2) owners of the data were unable or unwilling to share the information; and/or 3) data were delivered after the specified deadline and could not be included, or we did not become aware of exiting or available data in time to acquire and include it in this evaluation.

Of particular note was the inability to obtain Environmental Effects Monitoring (EEM) data from Environment Canada. Environmental Effects Monitoring is required by the federal government to ensure that effluent discharged by industries regulated under the Pulp and Paper Effluent Regulations and the Metal Mining Effluent Regulations does not have deleterious impacts on fish and fish habitat. The EEM program includes water quality studies, effluent characterization studies, sub-lethal toxicity testing, and biological monitoring studies. When Environment Canada was contacted to request the EEM water quality and biological data for the Athabasca Watershed, we were told that a Freedom of Information request would have to be filed before the data could be released, a process that can take more than 6 months. Given the restrictive timeline associated with this project, we instead appealed to the industry representatives on the AWC-WPAC committee to request that they help facilitate access to the data; however, these data were not received in time to be included in this assessment. The lack of EEM data is important to note, as these data would have allowed for a more detailed examination of the effects of industrial point sources on water quality and biological communities. Inclusion of EEM data in this assessment would have permitted a more detailed and careful consideration of whether industrial effluent is having any detectable effects in the Athabasca River downstream of major point-source facilities in the watershed.

Requests for municipal wastewater data were also made to the major municipalities in the Athabasca Watershed, and we received data from Jasper, Hinton, Whitecourt, Edson, Athabasca, and the Municipal District of Wood Buffalo (Fort McMurray and Fort Chipewyan). While we felt these were important data to include in this State of the Watershed assessment, we had to exclude them because of challenges associated with working with the data. The data received by each municipality varied substantially with respect to the reported parameters, the time period covered by the data, the nature of the reported values (e.g., daily values versus monthly averages), and the inclusion or availability of associated QA/QC information. These inconsistencies proved very difficult to contend with, and did not allow for any systematic or comprehensive examination of municipal wastewater in the watershed. In addition, as we noted earlier in section 3.2, the industrial effluent data that we evaluated as part of this report were not complete, as not all industrial facilities that discharge effluent into the Athabasca River were included in the industrial Class B data that was provided to us by the provincial government. In particular, there are a number of oil sands operations that were not included in the data that we received directly from the government; therefore, these data, despite their existence, could not be considered as part of this report because they were not accessible to us in electronic format. The inability to critically evaluate a complete wastewater dataset as part of the scope of this work is important to note, given that previous studies have demonstrated both water quality and biological impacts associated with wastewater effluent discharge into the river (for example, Chambers et al. 1997; Scrimgeour and Chambers 2000; Chambers et al. 2006; Dubé et al 2006).

5.2. Data Quality

5.2.1. Water Quantity

The data available for characterizing metrics of water quality and quantity are perhaps the most comprehensive for climate related metrics of water quantity. While the climate grids created by Canadian Forest Service in an ongoing fashion permit continuous and spatially extensive monitoring, the grids are only as good as the climate station data that go into making them. Hence, continued support for the monitoring programs that keep climate stations functioning is vital, as is directing resources towards filling data gaps, particularly in mountainous watersheds.

In this study, there was no systematic assessment of climate grid accuracy performed specifically for the Athabasca Watershed (although there was for the entire continental grid, see section 2.2.3). This would be a worthwhile exercise to complete in order to identify any areas of higher-than-average uncertainty in the interpolated climate grids. In addition, establishing a network of stations that measures ecosystem level evapotranspiration on an ongoing basis using eddy-covariance flux towers contribute substantially to better estimating this key component of surface water budgeting and modeling, as it holds the key to understanding impacts of future climate on surface water supplies in Alberta. While this would be a very costly exercise if borne by a single stakeholder, it is recommended that an integrated monitoring network be pursued with other provinces, the federal government and other existing measurement networks (e.g.FluxNET). Finally, the evolution of future climate in the context of climate change needs to be monitored very closely. There are large uncertainties with respect to the local effects of climate change on surface water supplies. Local and regional stakeholders need to be vigilant in regularly re-evaluating how changes in climate may impact water availability, so that the most-up-to-date scientific understanding of the impacts of regional climate change forms part of on-going decision-making and planning. One way to get a better handle on future climate impacts is to perform simulations of hydrological dynamics that take the output of GCMs and make them more regionally relevant by using finer scale dataset of physiography, hydrography, and human modifications of land cover (e.g. Kerkhoven and Gan 2013).

5.2.2. Water Quality: Water Chemistry

Water quality data have been collected by a variety of organizations, both private and public, throughout the Athabasca Watershed since the 1950s. While there is a large volume of data available, an important consideration is whether the data being collected by various organizations are comparable and of sufficient data quality to draw reliable conclusions.

Quality Assurance (QA) programs include a system of activities that pertain to the overall management of the sampling program. These activities are directed by standards and guidelines associated with planning, documentation, training, data collection and handling, analysis, data validation, and reporting (Mitchell 2006). A Quality Control (QC) program includes the technical activities that are used to reduce errors in the sampling program, as well as measurement quality objectives (MQO) to ensure the data meet a certain standards after this has been sampled in the field (Mitchell 2006). While the majority of water quality monitoring programs in the Athabasca Watershed employ accepted sampling methods and use accredited laboratories for sample analysis, these factors alone do not ensure that the data are of high quality (Mitchell 2006). All water quality monitoring programs should also include a Quality Assurance and Quality Control (QA/QC) program that permits evaluation of whether the water sampling and processing are being done correctly, and whether the results obtained from those samples are reliable and accurate.

In this assessment, we made every effort possible to consider data QA/QC procedures, such that we could put the results of this assessment into context. This proved to be a difficult endeavor because of difficulty in obtaining QA/QC data itself (where they exist – much of these data are only in hardcopy reports). The only Quality Control data that we were able to obtain electronically came from the provincial government and were associated with the LTRN and MTRN monitoring programs. Consequently, ***the following analysis of data quality is limited to the provincial LTRN and MTRN data only***.

1. Sensitivity (Detection Limit):

Sensitivity is defined as “the capability of a method or instrument to discriminate between measurement responses for different levels of the variable of interest” (Mitchell 2006, p. 7), and includes the limit or range of detection of any given laboratory instrument. Detection limits are defined as the “smallest amount of a substance that can be detected above the noise in a procedure and within a stated level of confidence” (Mitchell 2006, p. 50). There are a number of different ways to determine detection limits, and these methods may vary between laboratories and studies (Mitchell 2006). Further, detection limits change over time as laboratory methods and instruments improve; therefore, it is important to know lab-specific detection limits in order to reliably interpret reported concentrations for any given parameter.

Understanding the limit of detection for any given parameter is an important aspect of analytical chemistry and because of this, we went to great lengths to obtain detection limits for those parameters considered in this report. For the provincial LTRN and MTRN data, detection limits are provided along with all reported parameter concentrations, and may include a method detection limit (MDL), a sample detection limit (SDL), or both. In cases where an MDL and SDL are reported for a single parameter, these values may be different, and each value may change over time. While we made every effort to track and include the range of detection limits in this analysis, this task alone proved challenging. Further, the presence of more than one limit of detection that may or may not change over time also contributes to uncertainty with respect to interpreting the data. Because the accuracy and precision of concentration measurements decline as the limit of detection is approached, uncertainty around which limit of detection to use decreases the reliability of the data, and makes interpretation of results much more difficult.

While information on detection limits accompanies the provincial water quality data, this is not the case for much of the other data that we obtained for this assessment, including the RAMP data. Detection limits for RAMP are not routinely included in requests for water quality data from RAMP, and thus, must be requested separately, or must be extracted from hard copy or digital (PDF) reports.

b) Accuracy

Accuracy is a “measure of the agreement of a value of a variable in a sample with a known or ‘true’ value” (Mitchell 2006, p. 6). Accuracy is measured with standard or certified reference materials, for which element concentrations are known, and are either measured directly or are inserted into samples as known concentration "spikes". Measures of accuracy can alert one to systematic measurement errors that may occur in the laboratory as the result of such things as improper sample handling or analytical practices. The accuracy for the LTRN or MTRN sites could not be calculated because there were no standard reference materials used in the LTRN monitoring program, although we have been told that the province is moving towards adopting this approach (D. LeClair, Surface Water Data Specialist, Environment and Sustainable Resource Development, personal communication, November 26, 2012). Thus, **the accuracy of the LTRN data evaluated in this report is unknown**, and we have thus limited our assessment of data quality to measures of precision and sample contamination only.

c) Blanks

Blank samples are composed of water that is free of any analyte being measured, and blanks are used to identify contamination that may result from improper cleaning procedures, leaching from containers or filters, contributions from acids used to acidify samples (for trace metal determinations), or sampling techniques that may result in biased results (Mitchell 2006), and to establish the "zero" value in instrument determinations. The LTRN/MTRN monitoring programs include both field and trip blanks. Field blanks include reagent water that is put through the entire sampling procedure, wherein the water is opened in the field and filtered or processed in the same manner as a routine water sample taken in the field. Such field blanks provide information regarding contamination that may occur in any phase of the field sampling program. Trip blanks are carried in the field in bottles that are provided by the laboratory, and is returned to the lab for analysis unopened and unexposed to the sampling procedure. These trip blanks provide information regarding contamination that may occur from bottles, caps, or preservatives.

Currently, there are no established Measurement Quality Objectives (MQO) for blanks in Alberta. However, Cavanagh et al. (1997) has suggested that no more than 5% of blanks should exceed the MDL for water quality programs in British Columbia, and Mitchell (2006) has suggested a MQO of no more than twice (2x) the reported detection limit for phosphorus blanks collected as part of Alberta monitoring program. For this analysis, we calculated the percentage of blank samples that exceed the detection limit, and adopted the

5% standard recommended by Cavanagh et al. (1997) and our MQO for blank samples. Given that there are multiple detection limits specified for various parameters in the provincial dataset, we used the most sensitive sample detection limit (SDL) reported in the data. In instances where there was no SDL reported for a given parameter, we used the most sensitive method detection limit (MDL) value reported in the data as the Detection Limit against which reported blank values were compared.

In total, 17 of the LTRN/MTRN water quality parameters exceeded the MQO of 5%, and an additional 11 parameters did not have any blank data available for evaluation (Table 5-1 and Appendix A6). In the case of true colour and total mercury, blanks exceeded the specified detection limits in 100% of samples, while over 50% of blanks for total ammonia, dissolved organic carbon, chloride, iron, and sulphate exceeded the specified detection limits. These results raise concerns about possible sources of contamination and potential bias of the LTRN/MTRN water quality data.

Table 5-1. Number and percentage of trip and field blank samples from the LTRN/MTRN water quality monitoring program that exceeded specified detection limits. Trip and field blank samples were combined for each parameter, and the % over the detection limit represents the total number of exceedances between 2007 and spring of 2012. Parameters highlighted in bold are those that exceeded the Measurement Quality Objective of 5%. Data for each blank sample are presented in Appendix 6.

Parameter	Detection Limit (DL)	Total # of Blank Samples	# Samples Over DL	% Over DL
ALKALINITY TOTAL (mg/L)	0.5	**28**	**10**	**36%**
ALUMINUM DISSOLVED (µg/L)	1	54	0	0%
AMMONIA (mg/L)	0.01	-	-	NO BLANKS
AMMONIA DISSOLVED (mg/L)	0.01	-	-	NO BLANKS
AMMONIA TOTAL (mg/L)	0.01	**28**	**25**	**89%**
ARSENIC DISSOLVED (µg/L)	0.1	54	0	0%
BICARBONATE (CALCD.) (mg/L)	0.5	-	-	N/A
CADMIUM DISSOLVED (µg/L)	0.01	54	0	0%
CALCIUM DISSOLVED (mg/L)	0.1	54	0	0%
CALCIUM DISSOLVED FILTERED (mg/L)	0.3	28	0	0%
CARBON DISSOLVED ORGANIC (mg/L)	0.2	**28**	**20**	**71%**
CARBONATE (CALCD.) (mg/L)	0.5	28	0	0%
CHLORIDE DISSOLVED (mg/L)	0.5	**28**	**17**	**61%**
CHROMIUM DISSOLVED (µg/L)	0.3	54	1	2%
COLOUR (VISUAL) AT SITE	0.5	-	-	NO BLANKS
COLOUR TRUE	0.5	**28**	**28**	**100%**
CONDUCTIVITY - FIELD (µs/cm)	1	-	-	NO BLANKS
CONDUCTIVITY – LAB (µs/cm)	1	**28**	**3**	**11%**
COPPER DISSOLVED (µg/L)	0.1	**54**	**3**	**6%**
DISSOLVED OXYGEN - FIELD (mg/L)	0.01	-	-	NO BLANKS
DISSOLVED OXYGEN - WINKLER (mg/L)	0.01	-	-	NO BLANKS
FLUORIDE DISSOLVED (mg/L)	0.05	28	0	0%
HARDNESS TOTAL (CALCD.) CACO3 (mg/L)	0.5	-	-	NO BLANKS
IRON DISSOLVED (mg/L)	**0.01**	**28**	**0**	**0%**
LEAD DISSOLVED (µg/L)	0.1	54	0	0%
MANGANESE DISSOLVED (mg/L)	0.004	28	0	0%
MERCURY TOTAL (ng/L)	0.03	**54**	**54**	**100%**
NICKEL DISSOLVED (µg/L)	0.1	54	0	0%
NITROGEN DISSOLVED NITRATE (mg/L)	0.003	-	-	NO BLANKS
NITROGEN DISSOLVED NITRITE (mg/L)	0.003	-	-	NO BLANKS
NITROGEN TOTAL KJELDAHL (TKN)	0.05	**28**	**13**	**46%**
NITROGEN, NITRATE (mg/L)	0.003	**28**	**9**	**32%**
NITROGEN, NITRITE (mg/L)	0.003	28	1	4%
PH (FIELD)	**-**	-	-	NO BLANKS
PH (LAB)	-	-	-	NO BLANKS
PHOSPHORUS DISSOLVED (mg/L)	0.003	**35**	**9**	**26%**
PHOSPHORUS TOTAL (mg/L)	0.003	**34**	**8**	**24%**
RESIDUE NONFILTERABLE (TSS)	1	**27**	**7**	**26%**
SELENIUM DISSOLVED (µg/L)	0.3	54	0	0%
SODIUM DISSOLVED/FILTERED (mg/L)	0.5	28	0	0%
SULPHATE DISSOLVED (mg/L)	0.5	**28**	**20**	**71%**
TOTAL DISSOLVED SOLIDS (CALCD.) (mg/L)	10	28	0	0%
TURBIDITY (NTU)	0.1	**28**	**3**	**11%**
URANIUM DISSOLVED (µg/L)	0.1	54	0	0%
VANADIUM DISSOLVED (µg/L)	0.1	54	1	2%
ZINC DISSOLVED (µg/L)	**0.2**	**54**	**16**	**30%**

c) Triplicate Splits: Sample Precision

Precision is measured as the degree of similarity between two or more measurements taken as a subsample of a single sample (splits), or from two or more repeat water samples taken from the same location at the same point in time (Mitchell 2006). From these samples, one can estimate the precision of the sample, which is measured as the relative standard deviation of the split or replicate.

If samples are split in the laboratory, a measure of laboratory precision is derived, and if split in the field, these samples yield a measure of both field and laboratory precision (Mitchell 2006). As part of the LTRN and MTRN programs, the government collects triplicate splits in the field. These triplicates are sampled by collecting water in a large intermediate container that is kept well shaken, and the sample is poured into three separate bottles, one-third at a time, to ensure a homogenous sample (D. LeClair, Surface Water Data Specialist, Environment and Sustainable Resource Development, personal communication, December 4, 2012). These samples are then submitted blind to the laboratory for analysis.

We calculated precision for those parameters in the LTRN/MTRN dataset that had sufficient data. Precision was calculated as the relative standard deviation (RSD) of the triplicate split samples, with precision decreasing as the RSD increases (Mitchell 2006). RSD was calculated as follows:

$$s \div mean * 100;$$

where: s = standard deviation of the mean.

Any parameter values that were reported as less than the detection limit were excluded from the calculation of RSD. In addition, precision for mercury was not calculated using triplicate splits, as this methodological approach is not recommended (Mitchell 2006). While the Government of Alberta is in the process of developing provisional Measurement Quality Objectives (MQOs) for surface water quality programs in Alberta (T. Hebben, Limnologist and Water Quality Specialist, Environment and Sustainable Resource Development, personal communication, February 26, 2013), these MQOs have not yet been finalized. As such, we have adopted a measurement quality objective of ≤18% (Mitchell 2006), against which precision of water quality sampled collected as part of the LTRN and MTRN were compared (Mitchell 2006).

The mean, standard deviation, and relative standard deviation for all triplicates with sufficient data (n=408) were calculated (Appendix 7). In addition, the 5-year average for each parameter was calculated and is summarized in Table 5-2. Those samples for which precision could not be calculated, or for which the RSD was above the MQO are flagged. In total, five parameters in the LTRN/MTRN dataset had unacceptably low precision, including: total ammonia, dissolved chromium, nitrite, turbidity, and zinc. These results suggest that interpretation of the data associated with these parameters should be done with caution, and raise concerns over field and/or laboratory methods. Precision results calculated for all triplicate splits in the LTRN/MTRN dataset collected between 2007 and spring of 2012 can be found in Appendix 7.

Table 5-2. Mean, standard deviation, and relative standard deviation (RSD) for triplicate splits sampled between 2007 and spring 2012 as part of the LTRN/MTRN monitoring programs. Parameters in bold exceed the measurement quality objective of <18% RSD. Data for each triplicate sample are presented in Appendix 7.

Parameter	Number of Triplicates	Mean	Standard Deviation	Relative Standard Deviation (%)
ALKALINITY TOTAL (mg/L)	13	131	1.1	0.8
ALUMINUM DISSOLVED (µg/L)	13	15.8	0.89	5.6
AMMONIA (mg/L)	-	-	-	-
AMMONIA DISSOLVED (mg/L)	-	-	-	-
AMMONIA TOTAL (mg/L)	**5**	**0.07**	**0.02**	**22.3**
ARSENIC DISSOLVED (µg/L)	13	0.33	0.02	4.5
BICARBONATE (CALCD.) (mg/L)	14	-	-	DNA*
CADMIUM DISSOLVED (µg/L)	12	0.01	0.00	12.6
CALCIUM DISSOLVED (mg/L)	13	41.3	0.67	1.6
CALCIUM DISSOLVED FILTERED (mg/L)	14	45.4	0.74	1.6
CARBON DISSOLVED ORGANIC (mg/L)	11	7.6	0.21	2.8
CARBONATE (CALCD.) (mg/L)	-	-	-	-
CHLORIDE DISSOLVED (mg/L)	10	8.7	0.19	2.2
CHROMIUM DISSOLVED (µg/L)	**12**	**0.28**	**0.05**	**18.9**
COLOUR (VISUAL) AT SITE	-	-	-	-
COLOUR TRUE	9	32.0	1.4	4.3
CONDUCTIVITY - FIELD (µs/cm)	-	-	-	-
CONDUCTIVITY - LAB (µs/cm)	14	364	3.0	0.8
COPPER DISSOLVED (µg/L)	13	0.88	0.09	10.5
DISSOLVED OXYGEN - FIELD (mg/L)	-	-	-	-
DISSOLVED OXYGEN – WINKLER (mg/L)	-	-	-	-
FLUORIDE DISSOLVED (mg/L)	14	0.12	0.00	3.5
HARDNESS TOTAL (CALCD.) CACO3 (mg/L)	14	167	2.7	1.6
IRON DISSOLVED (mg/L)	7	0.19	0.01	5.4
LEAD DISSOLVED (µg/L)	12	0.06	0.01	9.3
MANGANESE DISSOLVED (mg/L)	3	0.02	0.00	12.9
NICKEL DISSOLVED (µg/L)	8	0.88	0.07	7.5
NITROGEN DISSOLVED NITRATE (mg/L)	-	-	-	-
NITROGEN DISSOLVED NITRITE (mg/L)	-	-	-	-
NITROGEN TOTAL KJELDAHL (TKN) (mg/L)	11	0.51	0.04	7.0
NITROGEN, NITRATE (mg/L)	12	0.13	0.01	5.5
NITROGEN, NITRITE (mg/L)	**2**	**0.01**	**0.00**	**47.2**
PH (FIELD)	-	-	-	-
PH (LAB)	14	8.1	0.03	0.4
PHOSPHORUS DISSOLVED (mg/L)	12	0.01	0.00	13.3
PHOSPHORUS TOTAL (mg/L)	14	0.06	0.00	3.6
RESIDUE NONFILTERABLE (TSS)	12	71.3	6.5	9.1
SELENIUM DISSOLVED (µg/L)	11	0.30	0.04	14.4
SODIUM DISSOLVED/FILTERED (mg/L)	14	12.4	0.33	2.6
SULPHATE DISSOLVED (mg/L)	14	54.3	0.68	1.3
TOTAL DISSOLVED SOLIDS (CALCD.) (mg/L)	14	217	2.5	1.2
TURBIDITY (NTU)	**15**	**34.8**	**6.4**	**18.4**
URANIUM DISSOLVED (µg/L)	13	0.51	0.01	2.1
VANADIUM DISSOLVED (µg/L)	12	0.26	0.02	7.1
ZINC DISSOLVED (µg/L)	**13**	**1.8**	**0.51**	**29.3**

**DNA: Does not apply.*

5.2.3. Water Quality: Benthic Invertebrates

Sample Precision

As reported in Anderson (1991), statistical precision of 20-40% (i.e., “D”; standard error as a percentage of the sample mean) has been considered acceptable in benthic invertebrate studies and monitoring programs (Elliott 1977, Morin 1985, Canton and Chadwick 1988). Precision for mean values for the invertebrate samples and replicates from LTRN sites is variable among sites [Table 5-1]. The average statistical precision for the various invertebrate community metrics assessed here, for replicate samples taken at LTRN sites, is reasonably high, with 70% of metrics having D less than 20%, and 88% with D less than 40% [Table 5-1(a)]. While precision is lower at the Fort McMurray site than at the two LTRN sites upstream, 80% of metrics at this lower site still had D less than 40%. Total invertebrate abundance at LTRN sites on the Athabasca River did not satisfy Elliott’s requirement that D be no more than 20%; however, if a lower level of precision is accepted (e.g., 40%), then the samples from the Athabasca River satisfies the precision requirement for total invertebrate abundance.

Sample precision among LTRN sample replicates was generally high (i.e., D ≤ 20%) at the level of most major taxonomic groups, including numbers of unique taxa, family and genera richness, diversity, and MBI, but was insufficient when assessed at higher levels of taxonomic precision (see Table 5-1a in section 5.2.3, and full tables in Appendix 8). While values of precision for estimates of relative abundance and the ratio of EPT to chironomids are generally lower than for other variables, these variables are all functions of two other variables, and therefore would be expected to display much greater variability and therefore less apparent precision simply because the variation inherent to mean values should be up to the square of the variation of the means themselves. While the precision of the mean estimates of abundance is generally not high, the estimates of variables that indicate invertebrate community diversity (i.e., number of taxa, richness) exhibit high levels of precision. Overall, precision is lower for variables associated with higher taxonomic resolution (e.g., at individual family levels; see tables for individual sites in Appendix 8).

This suggests that a larger number of replicate samples may be required to achieve optimal precision when it comes to making estimates of population structure of invertebrate taxa, based on abundance. However, this is a common shortfall of routine monitoring programs, and in the interests of balancing precision with affordability AENV has in the past chosen to limit their sampling to five replicates (Anderson 1991). This decision was supported by reference to previous conclusions that five replicate samples are sufficient for biomonitoring programs and detection of changes in the most abundant invertebrate taxa. Further, in the context of a long-term monitoring program that has continued for at least five years, as few as two samples may provide sufficient precision and clarity to enable detection of significant changes in dominant taxa (Hamer and Soulsby 1980; Houston, Lowthion, and Soulsby 1983). From an ecological and management perspective, it is arguably the ecologically relevant changes in invertebrate functional groups and dominant taxa that are of most interest, rather than changes in less common taxa. Given limits on financial resources, and considering that functional ecological patterns and changes in time and space are of more use to managers than attempting to discern trends and patterns from individual genus and species data, five replicate samples are likely sufficient for continued sampling at LTRN sites.

As has been reported elsewhere (Burn et al 2011, Appendix E), variance in benthic invertebrate community samples in the RAMP dataset is generally high, resulting in generally low precision. This high variance may be the result of inconsistent sampling techniques, or because of monitoring program design and site selection. Unlike for LTRN sampling, where replicates are taken from the same site (or in close proximity to each other), RAMP invertebrate samples are taken from specific reaches that are 2 to 4 kilometers long, with sampling "replicates" distributed along a kilometer within that reach (Burn et al 2011, Appendix E). The result is that there are no real replicates, but rather independent samples taken within one kilometer of each other, along the selected reach of stream or river. The high variance among what are referred to in the RAMP dataset as replicates is undoubtedly contributed to in great part by collecting samples along the length of a reach - where high spatial heterogeneity in invertebrate habitat at scales of several kilometers in streams and rivers can increase sample variance - as opposed to clustering replicates at individual sites as is done in the LTRN program. Because of the design of the benthic invertebrate monitoring sub-program in RAMP, and the very high sample variance that results from it, there is little or no chance of identifying benthic invertebrate community changes over time, or attributing any change that might be detected to a specific cause. Consequently, the RAMP benthic invertebrate monitoring program is of little use to managers when it comes to basing land use decisions on an ability to detect environmental change.

Table 5-1(a). Average statistical precision (D) of LTRN benthic invertebrate data in the Athabasca River. Precision of 20-40% (i.e., "D"; standard error as a percentage of the sample mean) has been considered acceptable in benthic invertebrate studies and monitoring programs (Elliott 1977; Morin 1985; Canton and Chadwick 1988; Anderson 1991).

Location	Site Code	D ≤ 0.20	0.20 < D ≤ 0.40	D > 0.40
Old Entrance	AB07AD0100	73%	17%	10%
Town of Athabasca	AB07BE0010	71%	22%	7%
U/s Ft McMurray*	AB07CC0030	66%	14%	20%
LTRN Average		70%	18%	12%

Table 5-1(b). Average statistical precision (D) of RAMP benthic invertebrate data in the Athabasca River.

Location	Site Code	D ≤ 0.20	0.20 < D ≤ 0.40	D > 0.40
Athabasca Delta				
Big Point Channel	BPC	45%	17%	39%
Embarras River	EMR-1	65%	6%	29%
Embarras River	EMR-2	67%	22%	11%
Fletcher Channel	FLC	53%	10%	36%
Fletcher Channel	FLC-A	54%	5%	41%
Goose Isl Channel	GIC	55%	14%	31%
Upstream Fort McMurray				
Christina R - upper	CHR-D2	24%	22%	54%
Christina R - middle	CHR-E2A	60%	33%	6%
Christina R - mouth	CHR-D1	40%	32%	29%
Clearwater R - u/s Christina R	CLR-D2	34%	25%	40%
Clearwater R - u/s Ft. McMurray	CLR-D1	38%	26%	36%
Hangingstone R	HAR-E1	62%	21%	17%
High Hills R	HHR-E1	67%	14%	19%
Horse R - upper	HOR-E1	59%	19%	22%
Central Mineable Oil Sands Region				
Beaver R	BER-D2	36%	28%	37%
Dunkirk R	DUR-E1	62%	27%	11%
Jackpine Ck - upper	JAC-D2	39%	26%	36%
Jackpine Ck - mouth	JAC-D1	39%	30%	30%
MacKay R - upper	MAR-E3	54%	25%	21%
MacKay R - upper	MAR-E3 (kicknet)	59%	21%	21%
MacKay R - middle	MAR_E2	60%	22%	18%
MacKay R - middle	MAR-E2 (kicknet)	70%	17%	13%
MacKay R - mouth	MAR-E1	54%	28%	19%
MacKay R - mouth	MAR-E1 (kicknet)	43%	21%	37%
Muskeg R - upper	MUR-D3	42%	25%	34%
Muskeg R - middle	MUR-D2	44%	33%	23%
Muskeg R - mouth	MUR-E1	62%	31%	7%
Poplar Ck - mouth	POC-D1	44%	26%	30%
Steepbank R - middle	STR-E2	59%	21%	20%
Steepbank R - middle	STR-E2 (kicknet)	60%	13%	27%
Steepbank R - mouth	STR-E1	55%	24%	21%
Steepbank R - mouth	STR-E1 (kicknet)	57%	8%	35%
Kearl Lk – Muskeg River	KEL-1	46%	20%	34%
Shipyard Lk – east side	SHL-1	53%	25%	22%
Calumet R - upper	CAR-D2	38%	27%	35%
Calumet R - mouth	CAR-D1	35%	24%	41%
Ells R - upper	ELR-E2A	68%	18%	13%
Ells R - mouth	ELR-D1	38%	22%	40%
Firebag R - upper	FIR-E2	60%	29%	11%
Firebag R - upper	FIR-E2 (Kicknet)	73%	14%	13%
Firebag R - mouth	FIR-D1	41%	17%	41%
Fort Creek - mouth	FOC-D1	46%	15%	38%
Tar R - upper	TAR-E2	75%	19%	6%
Tar R - mouth	TAR-D1	34%	16%	50%
Isadore's Lk	ISL-1	54%	14%	32%
Johnson Lk	JOL-1	56%	37%	8%
McClelland Lk – Firebag River	MCL-1	54%	26%	21%

Continued…

Table 5-1(b). *continued…*

Location	Site Code	D ≤ 0.20	0.20 < D ≤ 0.40	D > 0.40
Lower Mineable Oil Sands Region				
Calumet R - upper	**CAR-D2**	**38%**	**27%**	**35%**
Calumet R - mouth	**CAR-D1**	**35%**	**24%**	**41%**
Ells R - upper	**ELR-E2A**	**68%**	**18%**	**13%**
Ells R - mouth	**ELR-D1**	**38%**	**22%**	**40%**
Firebag R - upper	**FIR-E2**	**60%**	**29%**	**11%**
Firebag R - upper	**FIR-E2 (Kicknet)**	**73%**	**14%**	**13%**
Firebag R - mouth	**FIR-D1**	**41%**	**17%**	**41%**
Fort Creek - mouth	**FOC-D1**	**46%**	**15%**	**38%**
Tar R - upper	**TAR-E2**	**75%**	**19%**	**6%**
Tar R - mouth	**TAR-D1**	**34%**	**16%**	**50%**
Isadore's Lk	**ISL-1**	**54%**	**14%**	**32%**
Johnson Lk	**JOL-1**	**56%**	**37%**	**8%**
McClelland Lk – Firebag River	**MCL-1**	**54%**	**26%**	**21%**
RAMP Average		**52%**	**22%**	**27%**

*Replicate invertebrate kick-net samples gathered for QA/QC comparisons

5.3. Data Gaps

5.3.1. Water Quantity

In terms of hydrological metrics of water quantity, there is a greater paucity of data than for climate metrics of water quantity. For example, few of the Water Survey of Canada (WSC) stations have long-term records of flow that adequately characterize the much drier 1930s and 40s. As shown by the datasets of precipitation and discharge at a few of the WSC stations, hydro-climate in the Athabasca Watershed has a wide range or natural variation. Therefore, any effort that aims to characterize the natural variability of river flow must take into account the lack of long-term data. While some of this data gap could be bridged by recreating historical discharge data (by applying hydrological models), in the minimum it needs to be ensured that current monitoring programs are maintained, so that the long-term picture emerges more clearly at all locations along the watershed. Unfortunately, for a variety of reasons, few of the WSC stations with long-term data are located at the outlet of the tertiary watersheds, which would be ideal for better understanding the integrated response of the watershed when using the tertiary watersheds as unit of analysis and management. Certainly, watersheds can be delineated from any point on a river network and therefore WSC data at any point on the river network offers great value in uncovering the response of watersheds to climate and land cover changes. Although this study did not investigate the effect of land cover change (natural or anthropogenic) on runoff, more discharge stations should be located at the lowest scales (i.e. headwaters) where the various signals in hydrologic response can be separated more easily.

In addition to better understanding impacts of land cover, attention also needs to be given to consumptive use of water throughout the watershed. At present, northern Alberta is not facing the same acute water shortages faced by river systems in the south; however, the Athabasca River and its major tributaries need to be assessed to determine whether river flows meet various geomorphological and ecological requirements. While a statistical assessment of flow changes has been completed for the lower Athabasca and Muskeg rivers, Instream Flow Needs (IFN) assessments should be systematically completed for the Athabasca River and its major tributaries.

Finally, while there are existing datasets for soil moisture (Alberta Environment) and groundwater (Alberta Water Well Information Database) that cover portions of the Athabasca Watershed, more of this information needs to been used to create spatially contiguous maps of relevant metrics such as groundwater head and groundwater recharge and discharge zones. For example, remote sensing could be used to estimate the surface components of the water budget, water storage in lakes, wetlands as well as soil moisture content and even groundwater recharge and discharge areas (e.g. Barron and Van Niel 2009). Integrated surface water and groundwater models could then be used to fill some of the blanks left by ground-based and remote-based monitoring.

5.3.2. Water Quality

One of the most serious concerns associated with water quality data available for the Athabasca Watershed is the central part of the basin is virtually devoid of any water quality stations. This is despite the fact that this portion of the watershed is subject to intensive industrial land use (e.g., agriculture and forestry) and municipal and industrial point sources that contribute contaminants and nutrients to the Athabasca River. This issue was previously identified in the NRBS and NREI studies, yet to-date, nothing has been done to address this critical void in monitoring of both water quality and benthic invertebrates (McMaster et al. 2006).

In addition to a lack on monitoring in the central part of the watershed, monitoring on the major tributaries at MTRN stations is either spotty, or non-existent (Appendix 2). For example, many parameters are only sampled a handful of times within a given year, or their sampling appears to have been discontinued entirely, as with the case of calcium (Figure A2.3) and sodium (Figure A2.17) at station AB07AG0390 (McLeod River). Further, stations AB07BK0125 (Lesser Slave River) and AB07DA0610 (downstream of Kearl Lake Road on the Muskeg River) appears to have been dropped from routine sampling program all together, as station AB07BK0125 has not been sampled since early 2007, while sampling at station AB07DA0610 has not occurred since early 2009. There also appears to be issues with respect to the frequency of monitoring of RAMP sites, with sampling frequency limited to four times per year at most stations, with other stations being sampled even less frequently (Appendix 3). Sampling of lakes in the Athabasca Watershed is even spottier than for rivers, with monitoring occurring regularly in only a small number of lakes, and new monitoring activity only pursued in response to public complaints, usually related to algal blooms, fish kills, or other water quality problems. As has been highlighted by other studies and critiques, such infrequent sampling makes it unlikely that changes in water quality will be detected, and attributing that change to any particular source (either natural or anthropogenic) is difficult (e.g., Ayles et al. 2004, Schindler 2010, Donahue 2011). It also means that we are tied to very reactive, and often expensive, management approaches that are geared towards responding to degraded freshwater systems. These management responses often have a greater likelihood of failure, rather than anticipatory approaches that aim to prevent major problems from developing.

In regards to trace elements, there is generally very little usable data: the accuracy of the measurements are unknown, and the lower limits of detection are inadequate for many elements, including Cd, Cr, Ni, Pb, and Se. While there appears to be issues with some trace metals in the watershed (e.g. Cd, Hg, Pb, Se), the available data make it difficult to reliably evaluate the source or severity of the problems.

5.4. References

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6. Recommendations and Conclusions

The Athabasca Watershed today has a global audience and a world-class environmental monitoring program has been promised by the provincial and federal governments. It is important to note that monitoring is not simply about collecting data; rather, environmental monitoring is about asking important scientific questions, and developing methods and procedures that can answer those questions. For the Province of Alberta, the Athabasca Watershed is a unique opportunity, and the solutions to the challenges of water quality and quantity are likely to find applications in other parts of the Province. As such, we have provided a list of recommendations, considerations, and research questions that can help improve existing monitoring programs, as well as increase the overall understanding of water quality and quantity monitoring in the Athabasca Watershed.

6.1. Water Quantity

Climate change is forecasted to have major impacts on northern ecosystems. The climate of the Athabasca Watershed is already changing, and this change is reflected in steadily increasing temperatures. The actual changes in hydrology and its effect on water availability will be determined by an interaction between natural cycles (most likely driven by decadal changes in Pacific Ocean surface temperatures) and the combined effect of higher temperatures on precipitation, evapotranspiration, and ice and snow melt in the mountains. Due to an assumed future shift in Pacific Decadal Oscillation from a dry to a wet phase, the Athabasca Watershed can expect higher rates of precipitation. However, the amount of water that will be available for ecosystem processes and human use will also depend on evapotranspiration, which has been gradually increasing over the course of the 20th century. Therefore, the regional impacts of climate change need to be considered as a high priority and factored into all areas of ecosystem management in the watershed. As such, we provide the following recommendations:

1. Existing networks of climate and flow stations should be maintained and sufficient resources should be provided to ensure that these stations continue to provide critical climatic and hydrologic information.
2. Additional resources should be directed towards establishing new climate and hydrological stations in order to fill existing information gaps. Specifically, these new stations should be established in the mountainous and data sparse northern areas of the watershed, at the outlet of all tertiary watersheds, and in areas dominated by different land uses and land cover.
3. In order to better understand the water budget in the watershed, additional effort should be directed towards estimating evapotranspiration fluxes, soil moisture storage and groundwater storage, and fluxes. This can be done using a combination of ground based, remotely sensed, and modeling techniques.
4. Continue current efforts that are directed towards compiling and completing In-stream Flow Needs Assessments for the Athabasca River and its tributaries, to ensure maintenance of ecological services provided by aquatic systems in the watershed.

6.2. Water Quality – Water Chemistry

1. Dissolved oxygen is one of the single most important parameters, if not the most important, for the maintenance of aquatic life and therefore ecosystem health. There are clearly profound spatial and temporal variations in dissolved oxygen concentrations seen in the watershed, but there are also considerable differences in the susceptibility (sensitivity) to low oxygen levels by various species of aquatic organisms. A thorough investigation of spatial and temporal variations in dissolved oxygen, in relation to individual aquatic organisms, would be worthwhile.
2. Total phosphorus (P) is commonly elevated throughout the watershed, and the relative importance of natural versus anthropogenic inputs should be determined. Given that the Athabasca River watershed lies in a sedimentary basin with abundant natural sources of P, distinguishing these from anthropogenic inputs is not trivial but may prove to be helpful in the long-term for managing inputs to the watershed.
3. The origin of the seasonal pH depression seen at many of the sites needs to be identified, and its consequences for trace metal abundance, chemical speciation, and bioavailability needs to be understood.
4. Concentrations of dissolved organic carbon (DOC) are elevated at many stations, possibly because of natural inputs (e.g. from wetlands and humus-rich forest soils), anthropogenic sources (e.g. industrial and municipal wastewater), or both. More important than the concentration of DOC is its composition: the chemistry of organic compounds in the river was beyond the scope of this assessment, but in future, available data (e.g., LTRN, MTRN, RAMP) for organic compounds should be examined and evaluated.
5. Detailed studies of the chemical speciation of Al are warranted, in particular the effects of pH, fluoride, and DOC on the concentration of the potentially toxic aquo aluminum ion, Al^{3+}, especially during periods of pH depression.
6. There is evidence from the Cl^- concentrations that saline seeps are important in the Lower Athabasca River, but their quantitative significance for inputs of trace inorganic and organic compounds is not known.
7. The available data for trace elements, despite concerns about quality control (inadequate limits of detection for Cd, Cr, Ni, Pb, and Se, for example) and the lack of any information regarding accuracy, suggests that the following elements warrant study: Cd, Cr, Cu, Hg, Pb, and Se. In particular, it is important to understand the effects of pH, alkalinity, and DOC on the abundance and speciation of these elements. Vanadium (V) might become a valuable tracer of environmental impacts of oil sands development, simply because this element is highly enriched in the bituminous sands, but the natural inputs to the river must first be quantified, and the data presented here show that there are other industrial sources of V that should also be considered.
8. The available analytical data for physico-chemical properties, major constituents, and nutrients is valuable and helpful; however, the data for trace elements does not meet the criteria for accuracy needed for any scientific study. This observation should be considered when planning any future monitoring programs.

9. Although the data examined here represents a start regarding interpretation of measurements made to date, much more could be done, and should be done, to summarize, synthesize, and interpret data from provincial sources.
10. In respect to the potentially toxic 'heavy metals', it is very important to understand the distribution of their predominant chemical species. Although chemical speciation can be predicted by calculation using appropriate models, the quality of most of the trace element data evaluated here rendered them largely inadequate for this purpose.

6.3. Water Quality – Benthic Invertebrates

1. As highlighted in the most recent external science review of RAMP, a major philosophical shift in sampling design, analysis, and interpretation is necessary if the desired outcome is to be able to detect invertebrate community changes (Burn et al 2011). Currently, the focus is on determining whether invertebrate community metrics at a given site fall within what is determined to be the regional range of "natural variation". This focus must be changed to one of being able to identify local changes in invertebrate community and function, and the causes for such change.
2. The goal of any monitoring program should be to be able to detect invertebrate community changes at a particular site, and identify the cause of such change. Therefore, sites should be selected where they are expected to be most sensitive to ecosystem change, at both impacted sites and unimpacted sites. Environmental condition also must be assessed coincidentally with invertebrate community sampling. Especially for the RAMP benthic invertebrate sub-program, true replicate samples should be taken from the same site on a stream or river - or in close proximity to each other - each year, rather than from a randomly selected 1-km stretch of a reach that is two to four kilometers long. Until changes in benthic invertebrate site selection and replicate sampling practices are adopted, it is unlikely that variance in invertebrate community metrics will be reduced sufficiently to enable identification of invertebrate community changes and reasons for such change in the oil sands region.
3. There is little or no invertebrate community monitoring throughout large portions of the Athabasca Watershed. While there is Environmental Effects Monitoring done to assess the impacts of pulp and paper and municipal effluent on some reaches of particular rivers in the watershed, there is little or no understanding of the health of those rivers or the watershed as a whole. This is largely because of a lack of capacity at all levels of government to perform the sort of integrated, large-scale assessment needed. Regular, routine, standardized monitoring of benthic invertebrate communities must be expanded to more sites on the Athabasca River itself, and extended into all of the major tributaries. It also should include a subset of small streams and lakes throughout the watershed, selected so that each ecoregion and land use impact is sufficiently represented to provide critical information for assessing impacts that can inform management decisions.
4. Alberta's LTRN and MTRN monitoring programs should be integrated, standardized, and expanded to provide sufficient spatial and temporal coverage that managers have an continuing understanding of the state of water quality and impacts on indicator biological communities, so that decisions are fact-based and reflect actual

> and anticipated impacts on rivers, lakes, and streams in the watershed. A preliminary part of integrating and establishing such a program is the performance of power analysis, to determine the necessary frequency of sampling. If sampling is irregular, or restricted to every 5 years (as at LTRN sites), then the ability to detect environmental change will be sufficiently limited as to prevent a legitimate reactive or adaptive management approach to land use and watershed planning.

6.4. Data Availability and Integration

While an integrated assessment of the state of water quality and quantity in the Athabasca Watershed is a major objective of a state of the watershed assessment, achieving this goal is largely constrained by a lack of data, or limited availability to existing data. As discussed previously, we faced exceptional challenges with respect to accessing existing data, and in many cases, data were in different forms, techniques were not standardized, and sampling programs varied in quality and scientific rigour.

The difficulties that we encountered assembling existing data, and using this data to conduct an integrated assessment of watershed condition, is certainly not unique to this project. Other researchers have also experienced challenges with respect to accessing data for use in assessments of the Athabasca Watershed, as articulated by Squires et al. (2010):

> "Despite there being both federal and provincially managed water quality monitoring programs, t***here was a limited amount of consistent and reliable data available for use in this study***. Our objectives were to measure change in water quality and water quantity at a watershed scale. Considering the increasing emphasis of regional assessments and watershed management, ***our study shows that data simply do not exist to optimally assess change at this scale***. Thus, it is critical to improve our monitoring programs so that data are collected in a continuous and consistent way to facilitate continued broad scale assessments to protect one of our most important natural resources" (emphasis added, p.132).

The challenges associated with assessing watershed condition in the Athabasca Watershed have been further highlighted in a recent publication by Squires and Dubé (2013), in which they discuss the development of an effects-based approach to assessing cumulative effects that the watershed scale. In this paper, the authors conclude:

> "The major limitation of this conceptual model is that it requires significant amounts of data, spanning over a large time period (historical to current) (Squires et al. 2010). For this reason, when applying the framework to the Athabasca River basin, ***we were limited to using water quality and quantity data as the main indicators due to limitations in the availability of complete biological (fish and benthos) and landscape data***. This problem will affect most river basins where long-term monitoring stations are not well maintained, sampled frequently enough, or do not exist at all. ***It is important for regulatory bodies to improve our monitoring programs*** in Canada, especially in basins (such as the Athabasca) that are experiencing a significant amount of industrial and urban growth." (emphasis added, p. 389)

Thus, in order to accomplish an integrated assessment of water quality and quantity at the watershed scale, more focus needs to be placed on establishing and/or maintaining a network of water quality stations that sample a suite of variables at temporal and spatial scales that are relevant for addressing and answering questions related to the state or condition of the watershed. To this end, we offer the following recommendations:

1. All levels of government should commit to adopting standardized invertebrate sampling and counting protocols, specifically those used and promoted by CABIN. These protocols should be extended to include monitoring and reporting that is part of regulatory monitoring conducted by industry and municipalities.
2. Invertebrate community monitoring programs should be combined with experimental testing of impacts upstream and downstream of major effluent point sources, and should be designed to identify mechanisms and causes of any observed changes (e.g., for nutrients, the sort of experiments performed under the NRBS program and other similar studies that have highlighted the high sensitivity of low-nutrient systems in headwaters to effluent-based nutrients, and the lower importance of TP as a general measure).
3. A single digital, searchable, online freshwater database should be established that is managed in a coordinated fashion by provincial and federal governments. Data should be accessible to any user without the need to make individual requests or access data through government personnel. Environment Canada's National Climate Data and Information Archive or Water Survey of Canada's HYDAT database could be used as models for such a freshwater database.
4. All regulatory data reporting to provincial and federal governments should be submitted in digital, rather than hard-copy form via an on-line portal that inserts data into the common public database, subject to quality assurance confirmation by government staff.
5. All data - whether government or regulatory compliance data – should include relevant, standardized QA/QC data that are directly relatable to the relevant data, and this should be delivered to requesting parties as part of any data request, whether through government staff or via an on-line database described above.

6.5. Conclusions

If the objective of management in the Athabasca Watershed is to effectively respond to land use changes (either natural or human-induced) that impact watershed condition, then greater attention should be given to maintaining, improving, and/or expanding existing monitoring and assessment programs. Freshwater monitoring and assessment must be integrated among different levels of government (i.e., provincial and federal), monitoring techniques and QA/QC protocols must be standardized, and every effort should be made to merge data reporting and management practices for all programs into a "one-stop" program or service that allows for free public access to data.

Given the limitations that we encountered related to data availability and quality, it is our opinion that both the provincial and federal governments need to take on a larger role in the monitoring and assessment of freshwater ecosystems in Alberta. This should include an expanded role not only in overseeing and executing monitoring programs, but also in increasing internal government capacity to interpret and incorporate monitoring and regulatory reporting data into a more complete understanding of watershed condition.

Specifically, we recommend that the Provincial government strengthen their role in water management in the Athabasca Watershed to ensure the following:

1. A basin-wide water monitoring program that is comprehensive, coordinated, and effective, with representative sampling in space and time that acknowledges the profound natural variations in the landscape from the headwaters to the Peace-Athabasca delta.
2. Quality assurance and quality control should be a focus of the program to ensure that the data collected are consistent and reliable. Standard Measurement Quality Objectives should be established and regularly evaluated, and QA/QC data should be made readily available in electronic format, and should accompany other publically available water quality data.
3. Data collected as part of a basin-wide monitoring program should be regularly assessed and interpreted, and information should be made available for use by water and land managers as well as the broader scientific community.
4. Expert assessments of the program and the data should be conducted at arm's-length from government, industry, and special interest groups to ensure transparency and prevent bias in reporting.

It should be noted that the provincial government has recently established an arm's-length environmental monitoring agency, and has committed to the creation of a "world class environmental monitoring, evaluation and reporting system for Alberta" (Alberta Environmental Monitoring Working Group 2012). As part of this program, both the provincial and federal governments have initiation the Joint (Canada-Alberta) Oil Sands Monitoring Program (JOSM), which is currently in its first year of monitoring water and benthos in the Lower Athabasca region. Full implementation of this program is not expected until at least 2015, and efforts are currently underway to address some of the technical challenges that exist with respect to aligning existing monitoring programs with the new JOSM program. As part of this monitoring program, work is on-going to develop and establish standardized procedures, as well as to identify data for public release. In short, the JOSM is not yet a fully operational environmental assessment program, and while the creation of such a monitoring program has great potential to address some of the data gaps we have outlined in this report, full implementation of such a program is still many years from being realized, and is limited in scope to the Lower Athabasca Region. Further, the establishment and implementation of such a program will require substantial and sustained commitment of both financial and human resources.

6.6. References

Alberta Environmental Monitoring Working Group. 2012. Implementing a World Class Environmental Monitoring, Evaluation and Reporting System for Alberta. Northern Rivers Basin Study. Government of Alberta, Edmonton, AB, Canada.

Squires, A. J., and M. G. Dubé. 2013. Development of an effects-based approach for watershed scale aquatic cumulative effects assessment. Integrated Environmental Assessment and Management 9(3): 380-391.

Squires, A. J., C. J. Westbrook, and M. G. Dubé. 2010. An Approach for Assessing Cumulative Effects in a Model River, the Athabasca River Basin. Integrated Environmental Assessment and Management 6(1):119–134.

Appendix 1:

Overview of select water quality parameters measured at
Long-term River Network (LTRN) sites between 2007 and spring of 2012

List of Abbreviations

AB Acute: Alberta provincial surface water quality acute guideline value

AB Chronic: Alberta provincial surface water quality chronic guideline value

CCME: Canadian Council of Ministers of the Environment Guideline Value for the Protection of Aquatic Life

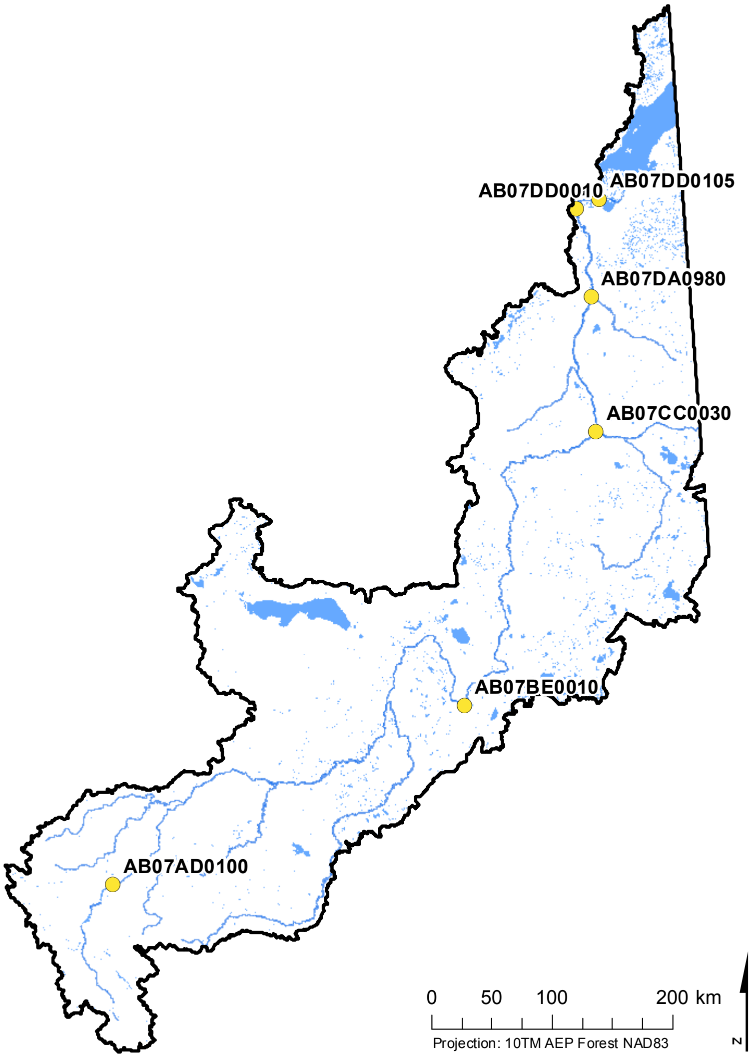
LTRN: Long-term River Network

MDL: Method detection limit

SDL: Sample detection limit

Table A1-1. Station number, description, and location of Long-term River Network stations evaluated as part of the Phase 3 State of the Watershed Assessment.

Station Code	Station Description	Latitude	Longitude
AB07AD0100	Athabasca River at Old Entrance town site - left bank	53.3675	-117.7225
AB07BE0010	Athabasca River at town of Athabasca	54.7222	-113.2861
AB07CC0030	Athabasca River upstream of Fort McMurray, 100 m above the confluence with Horse River - left bank	56.7203	-111.4056
AB07DA0980	Athabasca River - transect above the Firebag River	57.7236	-111.3792
AB07DD0010	Athabasca River at Old Fort - right bank	58.3828	-111.5178
AB07DD0105	Athabasca River downstream of Devils Elbow at winter road crossing	58.4472	-111.1858



List of Figures

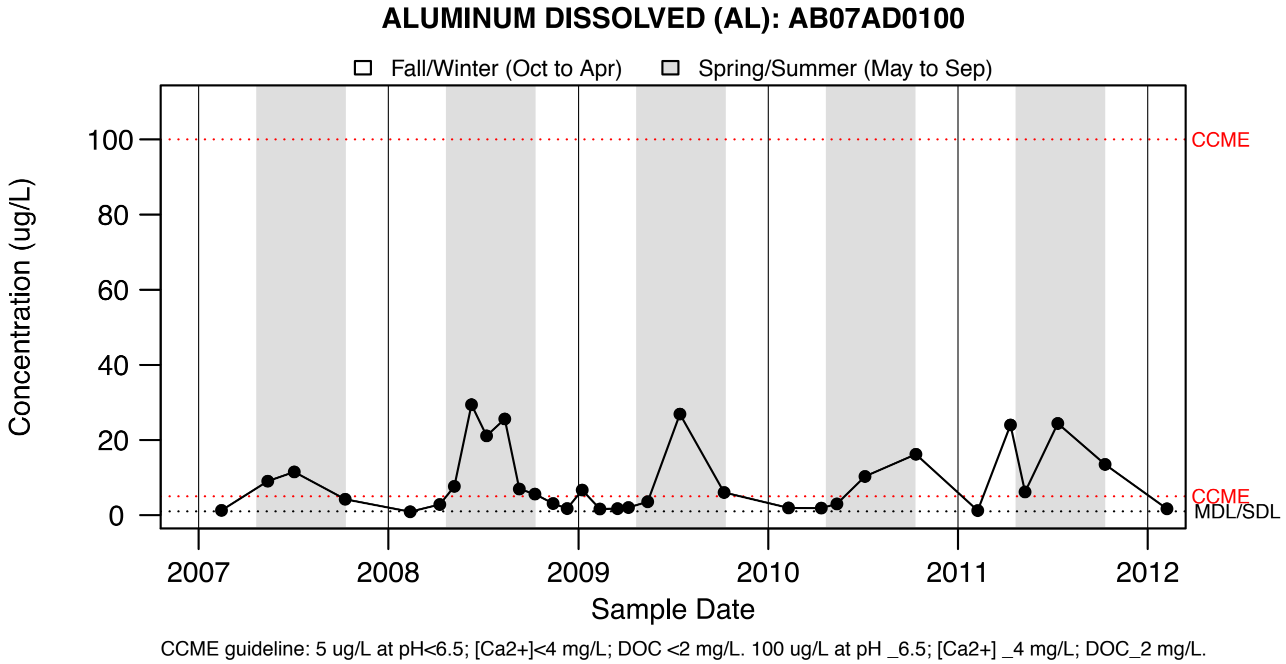


Figure A1.1: ALUMINUM DISSOLVED (AL): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

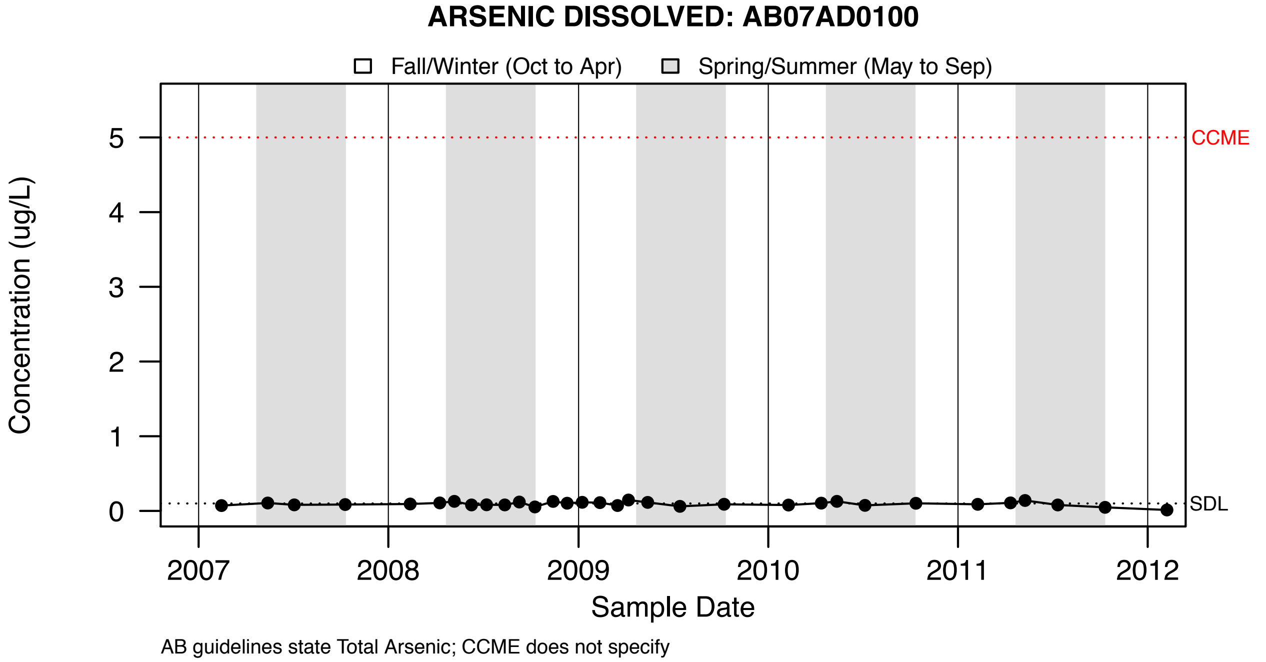


Figure A1.2: ARSENIC DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

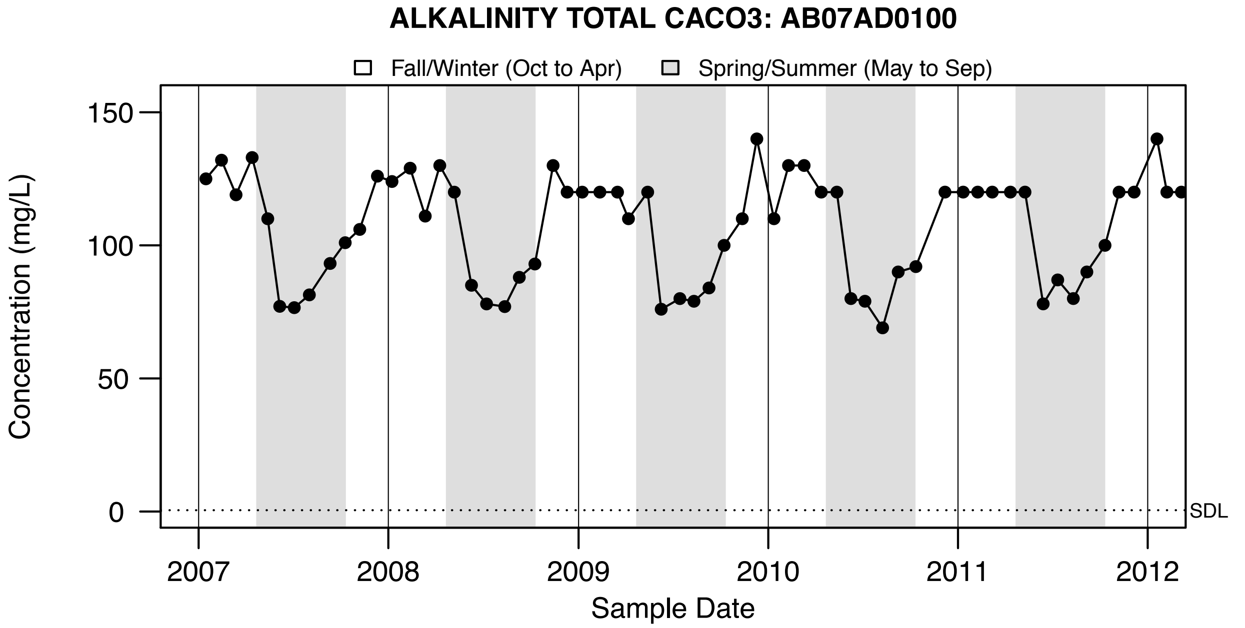


Figure A1.3: ALKALINITY TOTAL CACO3: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

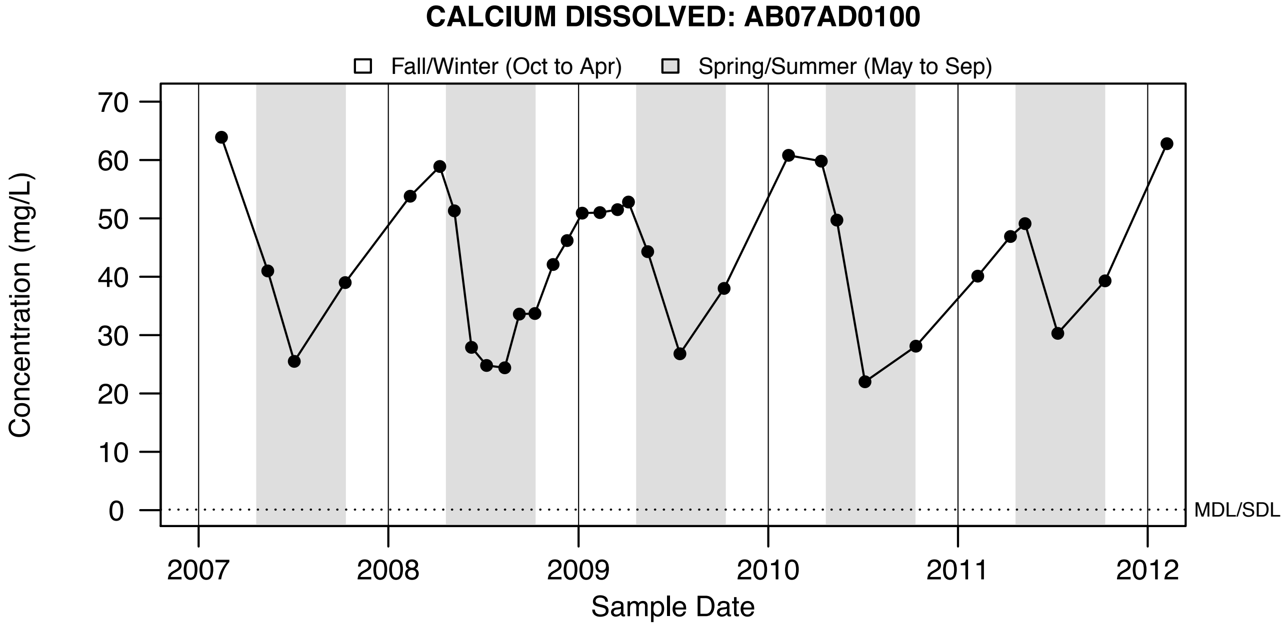


Figure A1.4: CALCIUM DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

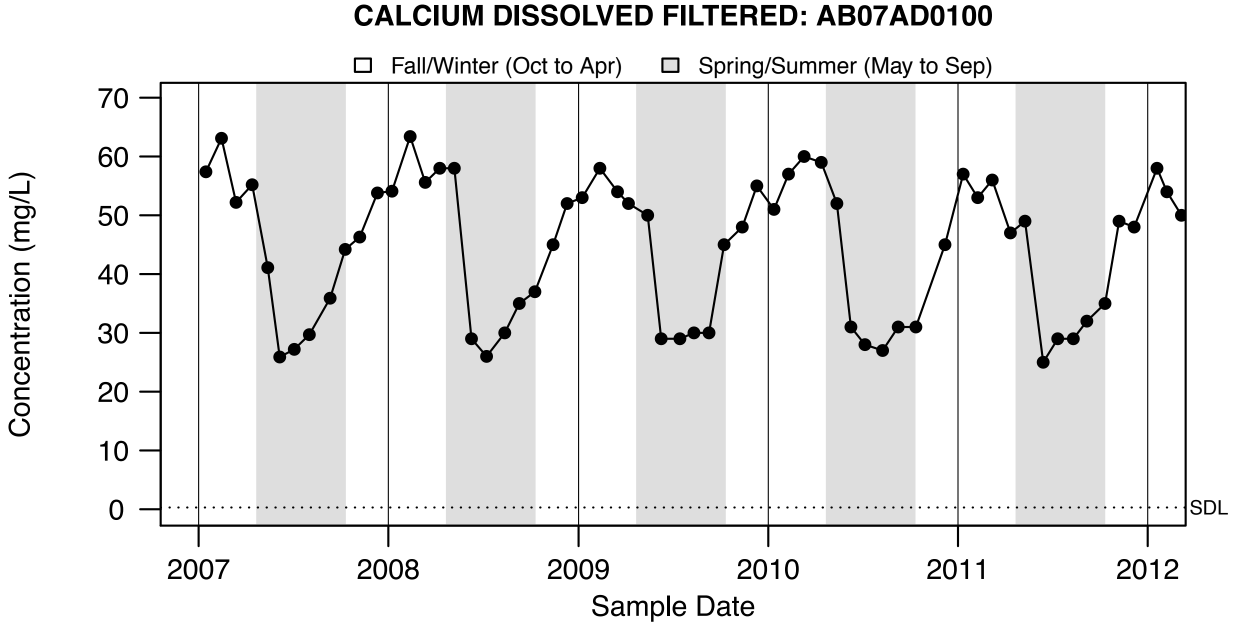


Figure A1.5: CALCIUM DISSOLVED FILTERED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

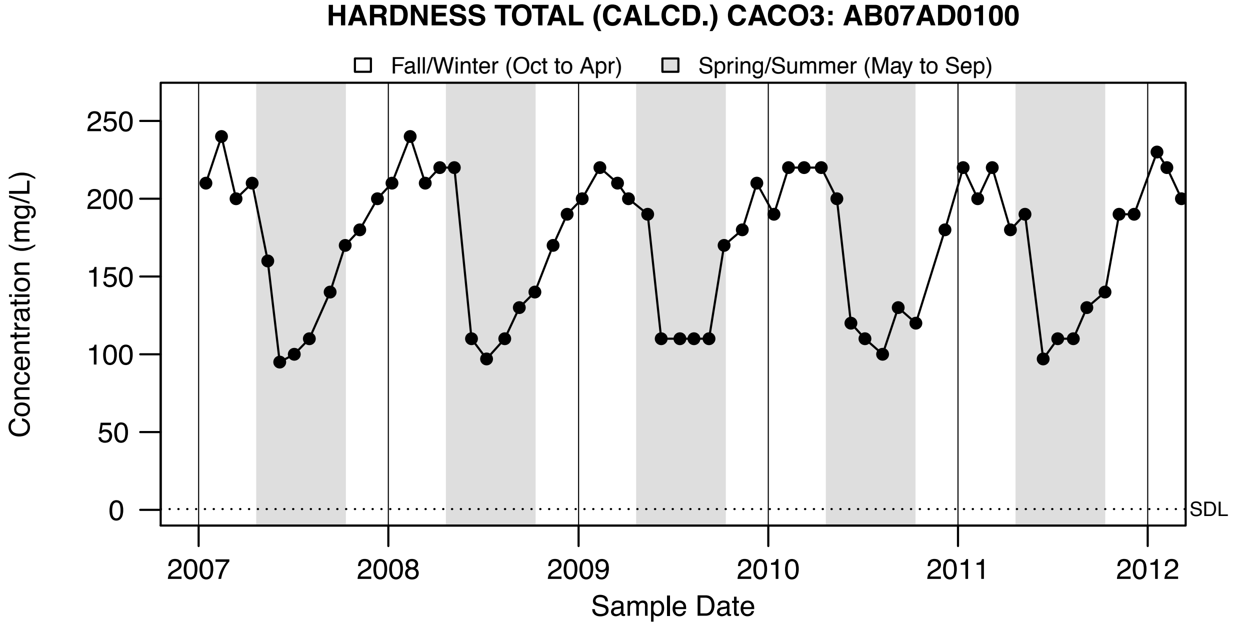


Figure A1.6: HARDNESS TOTAL (CALCD.) CACO3: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

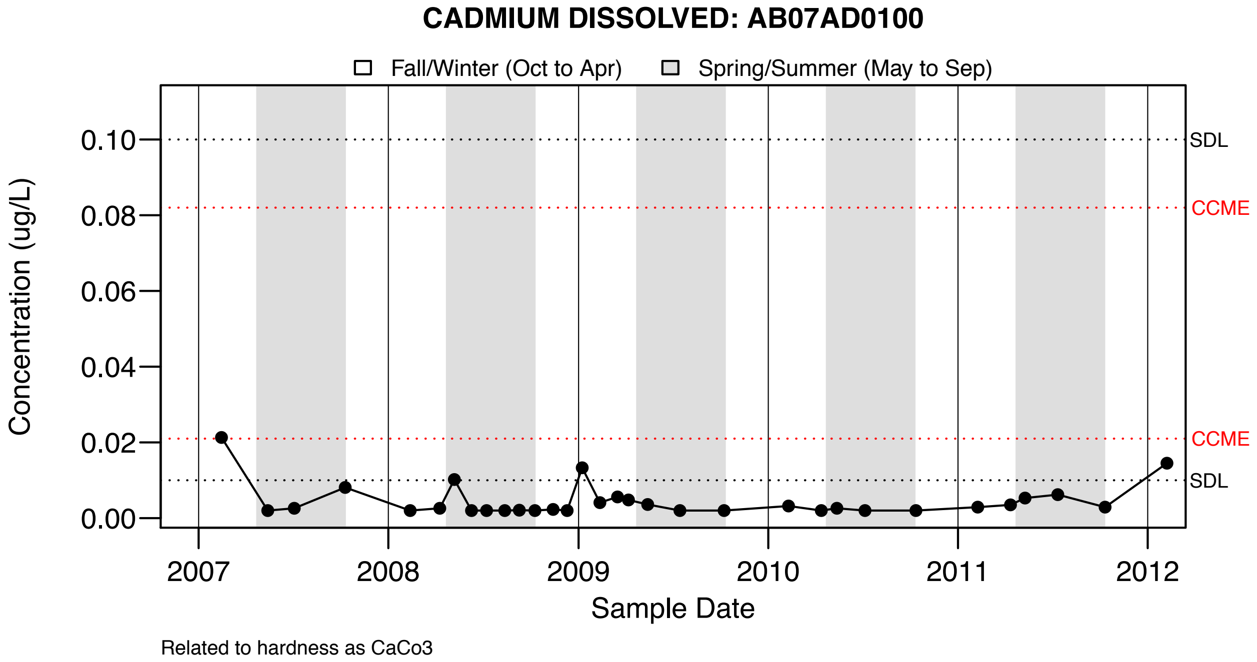


Figure A1.7: CADMIUM DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

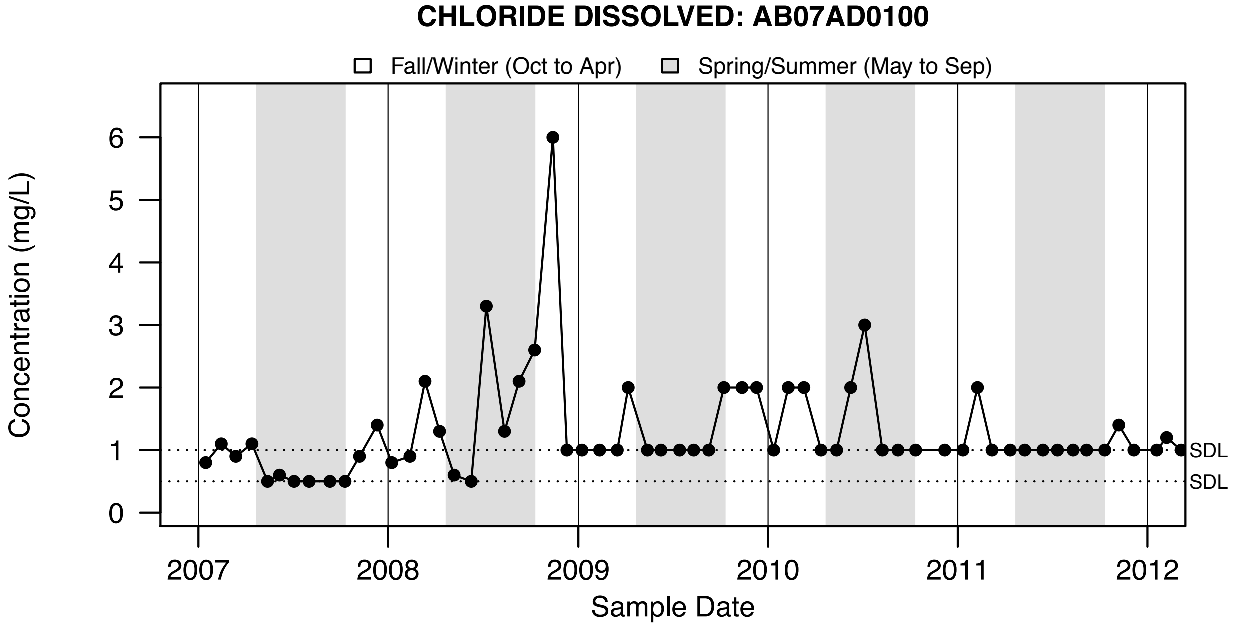


Figure A1.8: CHLORIDE DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

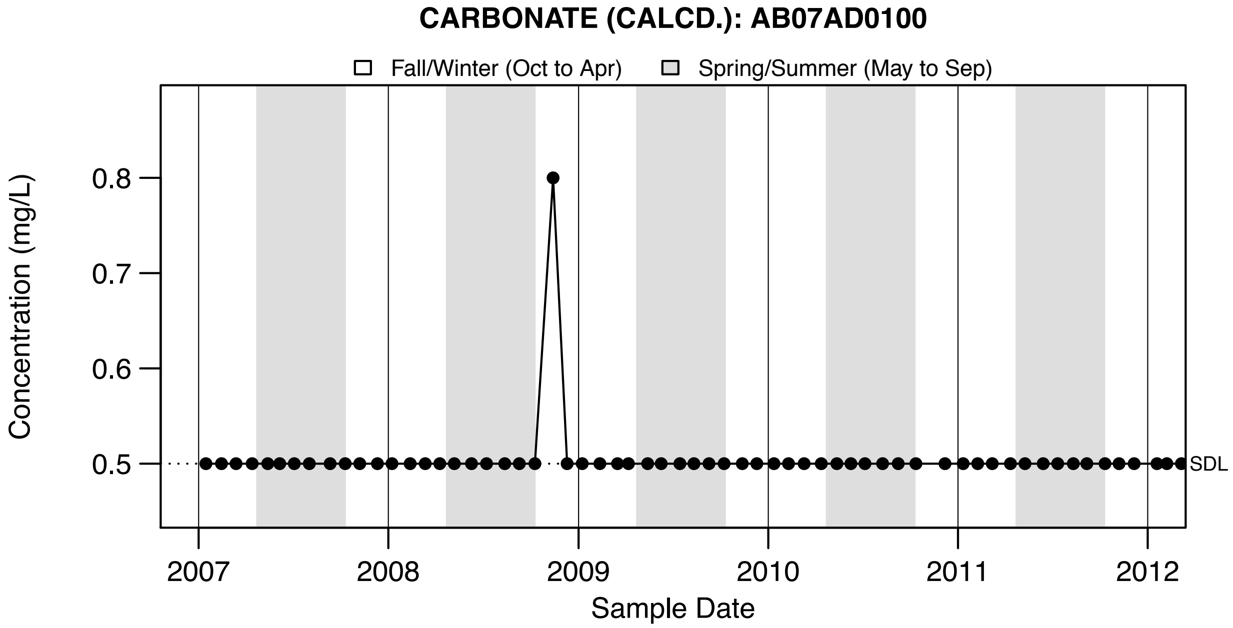


Figure A1.9: CARBONATE (CALCD.): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

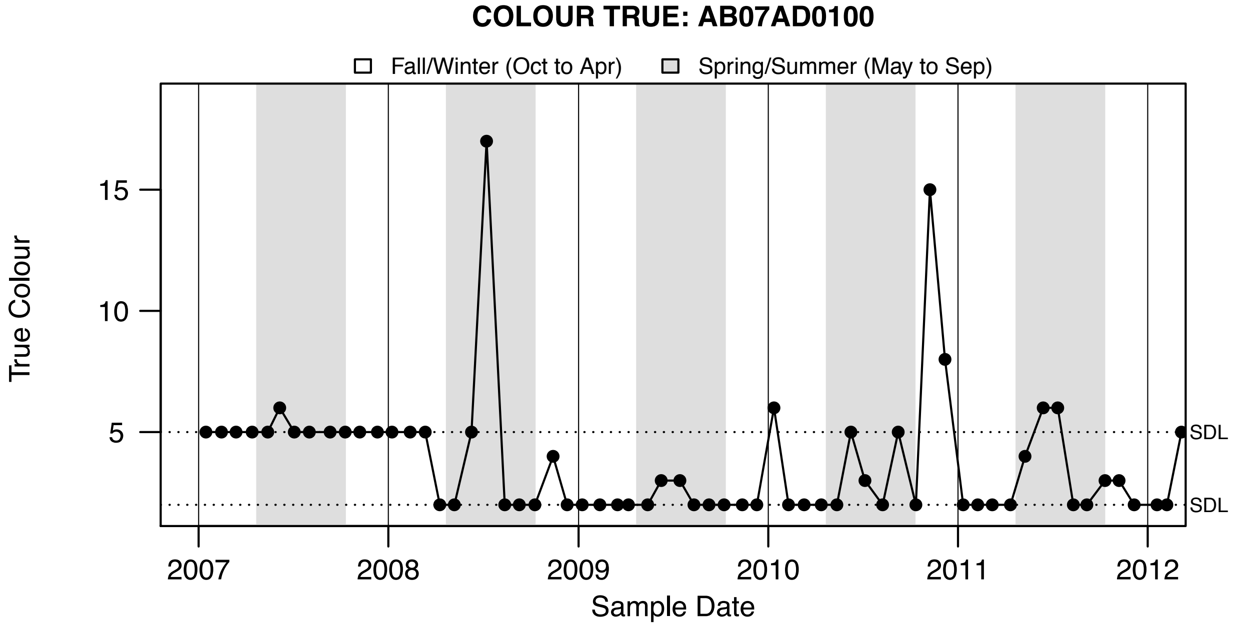


Figure A1.10: COLOUR TRUE: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

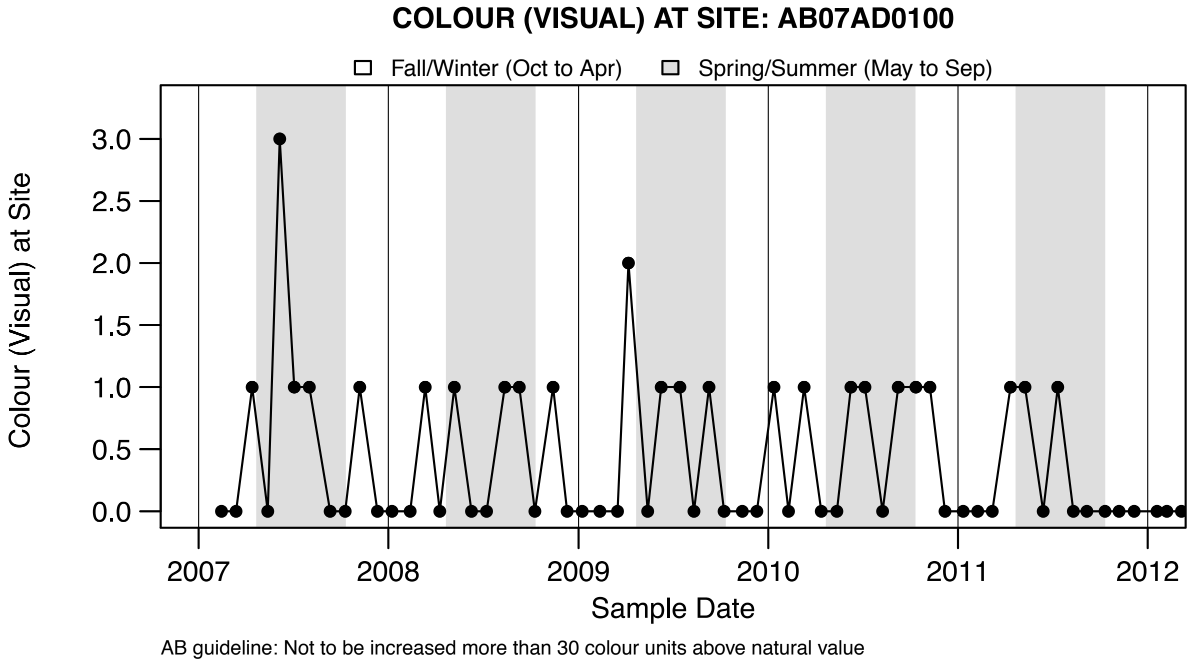


Figure A1.11: COLOUR (VISUAL) AT SITE: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

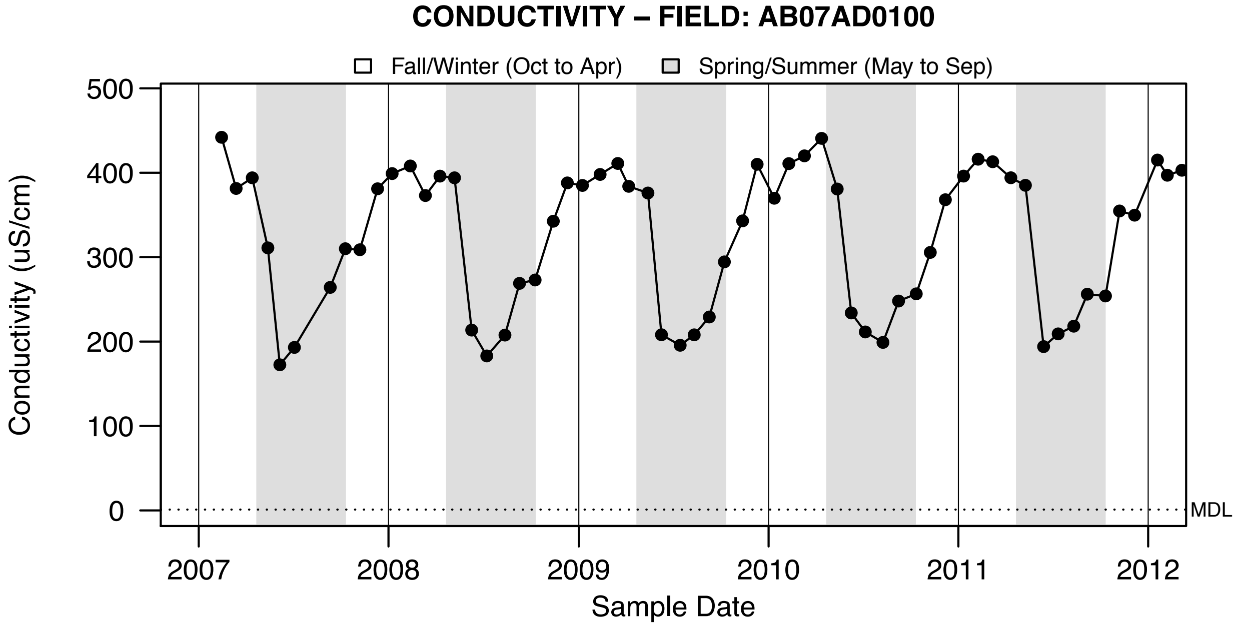


Figure A1.12: CONDUCTIVITY - FIELD: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

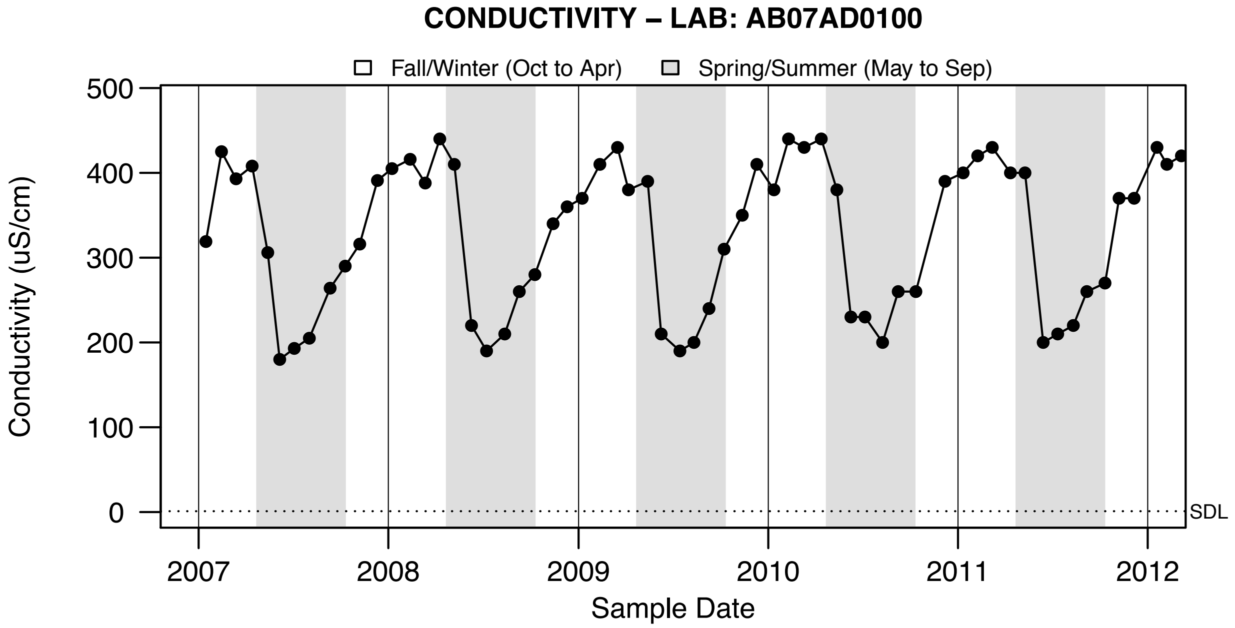
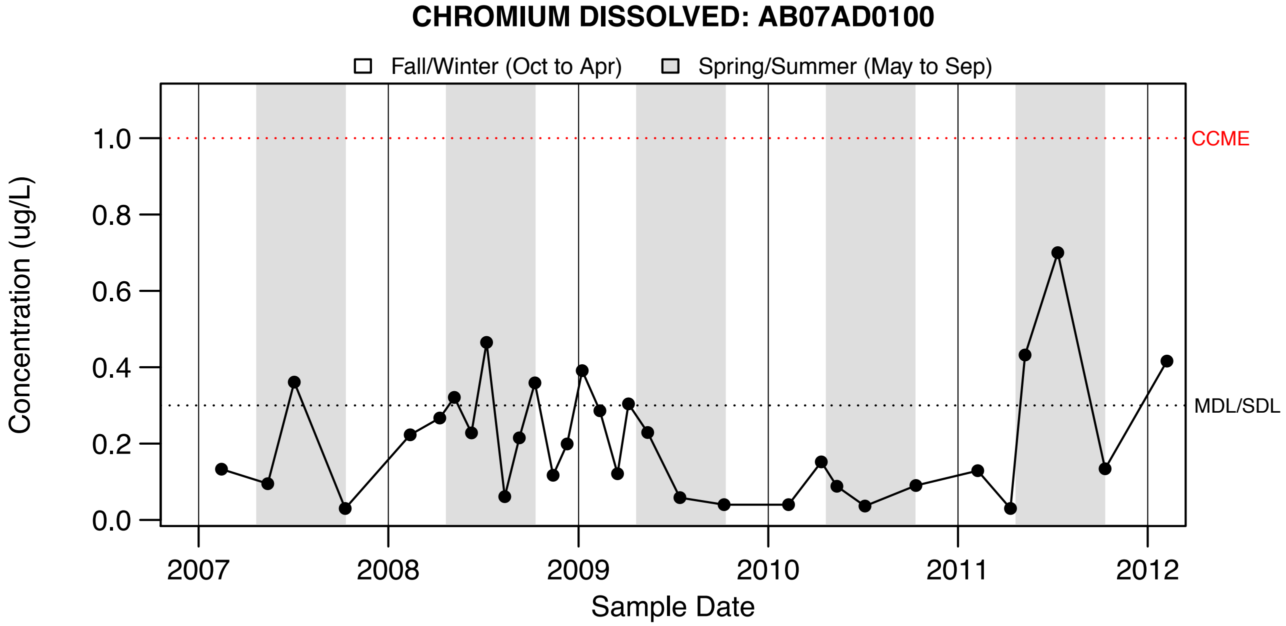


Figure A1.13: CONDUCTIVITY - LAB: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



Chromium III: 8.9 Chromium VI: 1.0

Figure A1.14: CHROMIUM DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

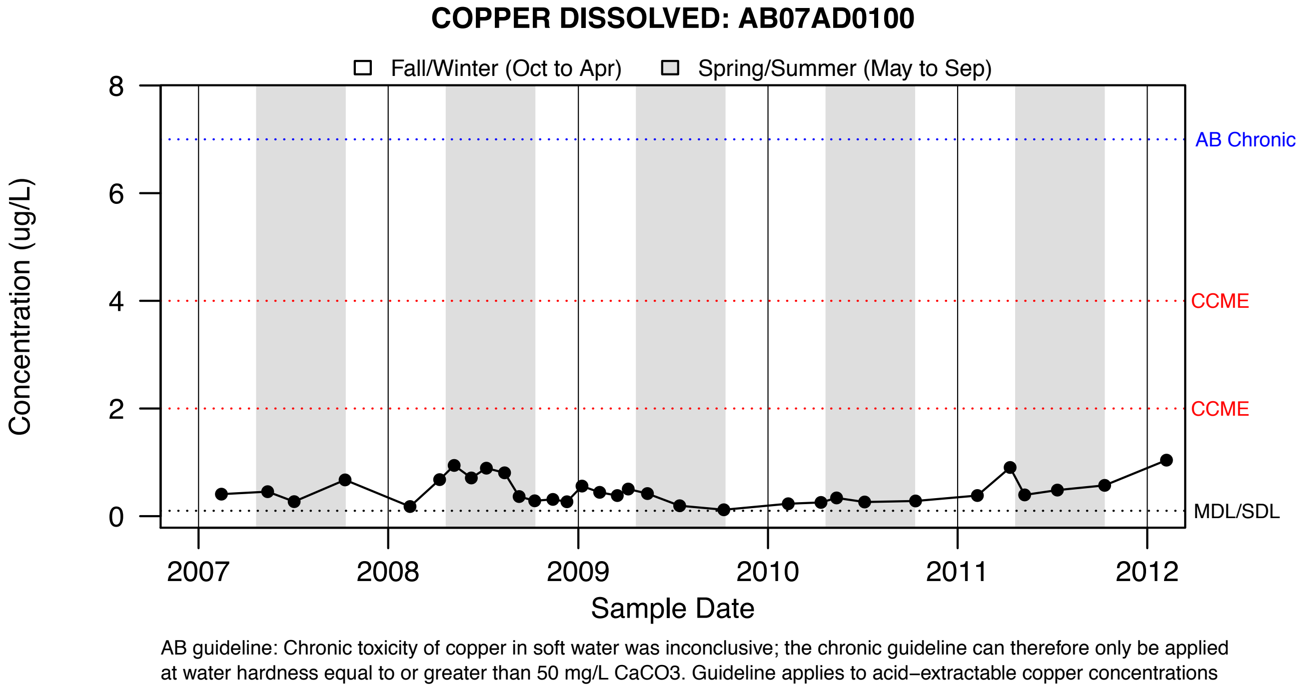


Figure A1.15: COPPER DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

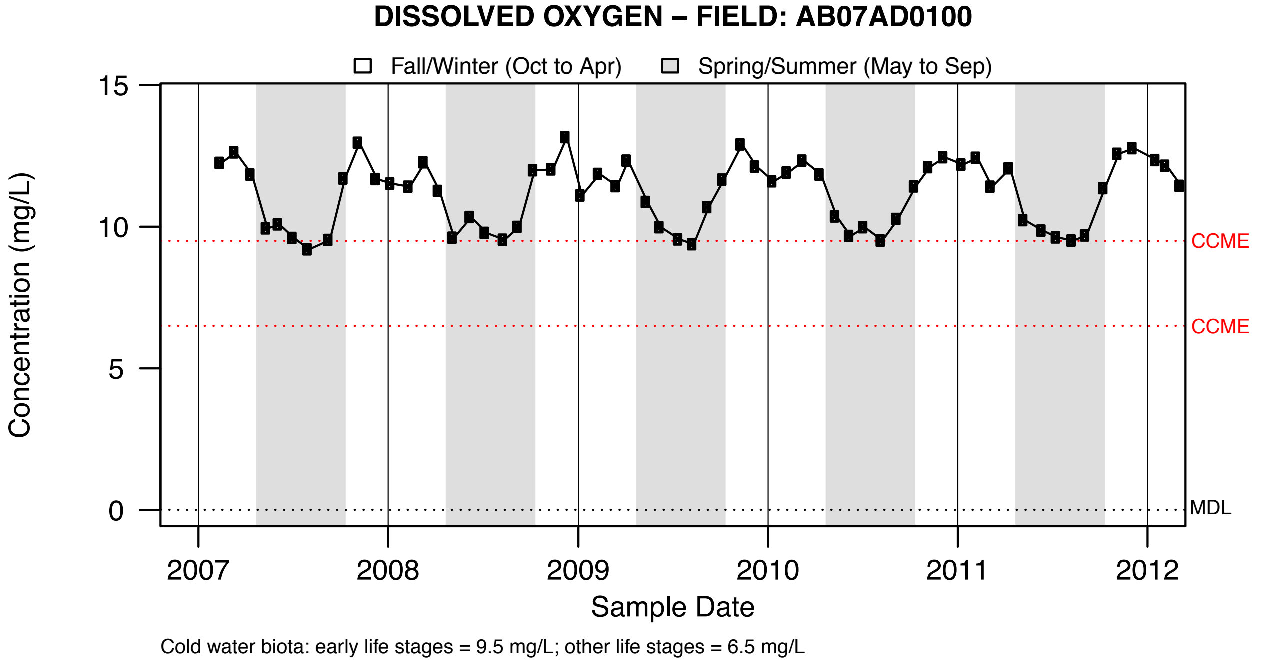


Figure A1.16: DISSOLVED OXYGEN - FIELD: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

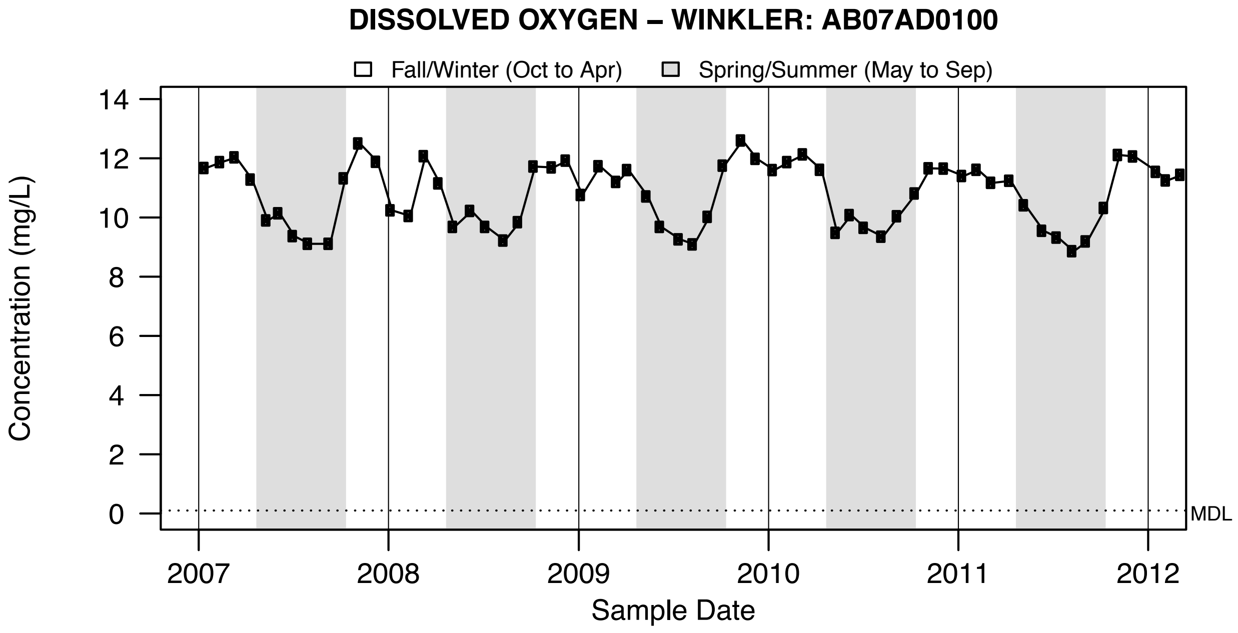


Figure A1.17: DISSOLVED OXYGEN - WINKLER: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

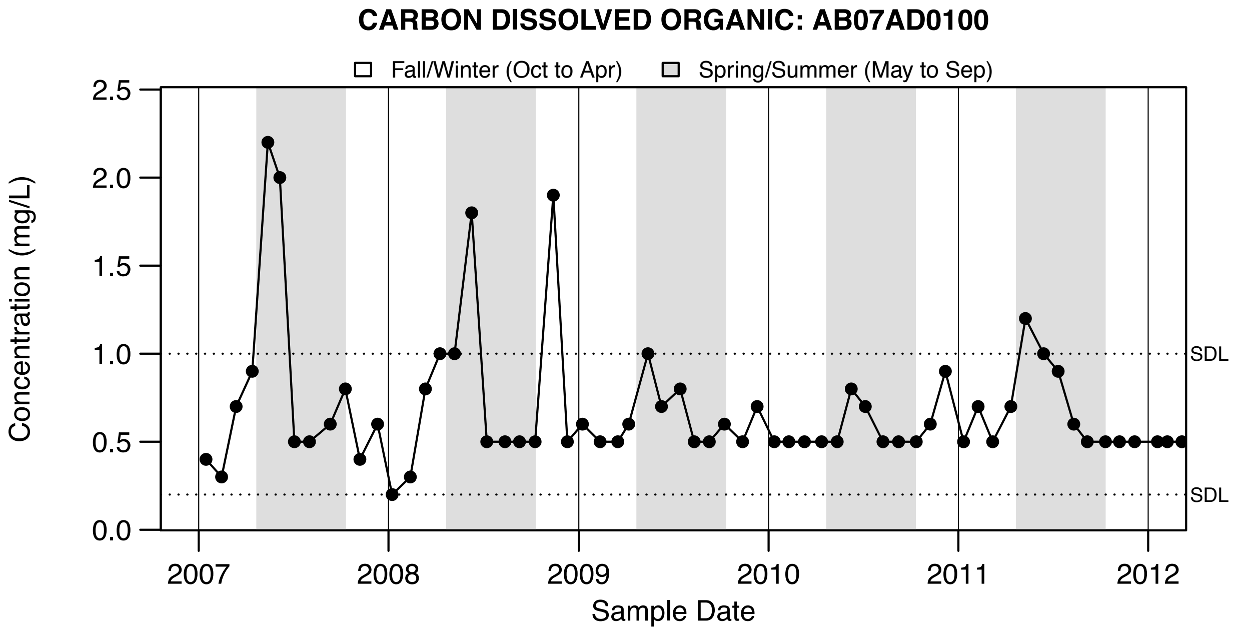


Figure A1.18: CARBON DISSOLVED ORGANIC: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

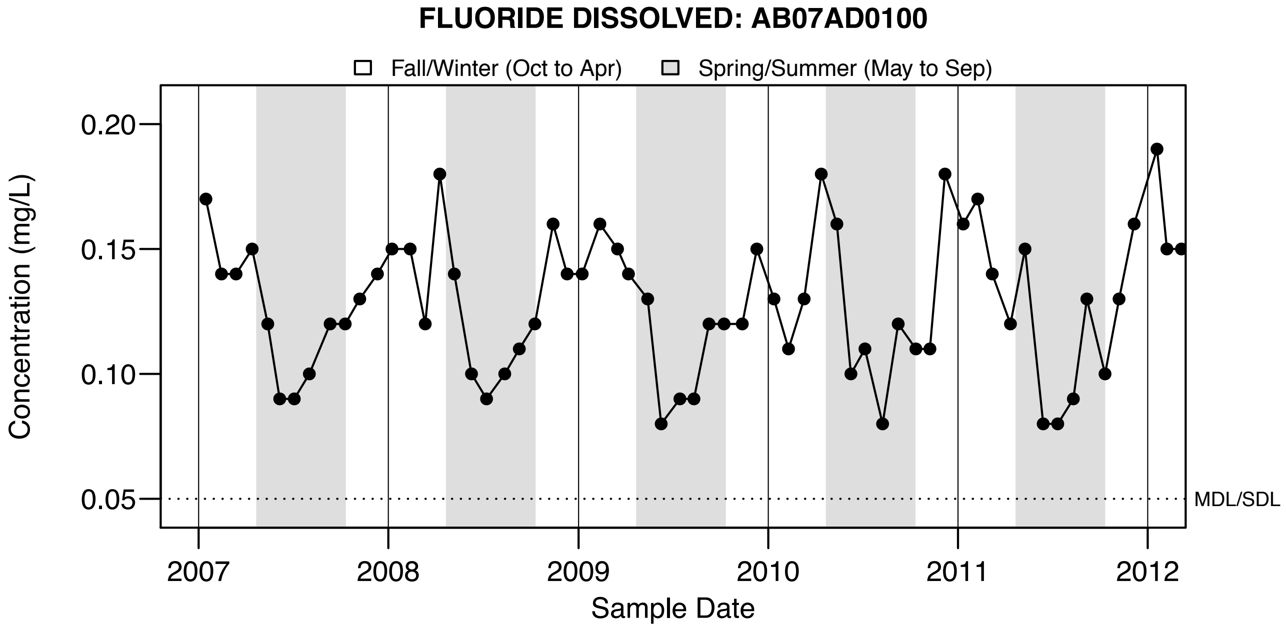


Figure A1.19: FLUORIDE DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

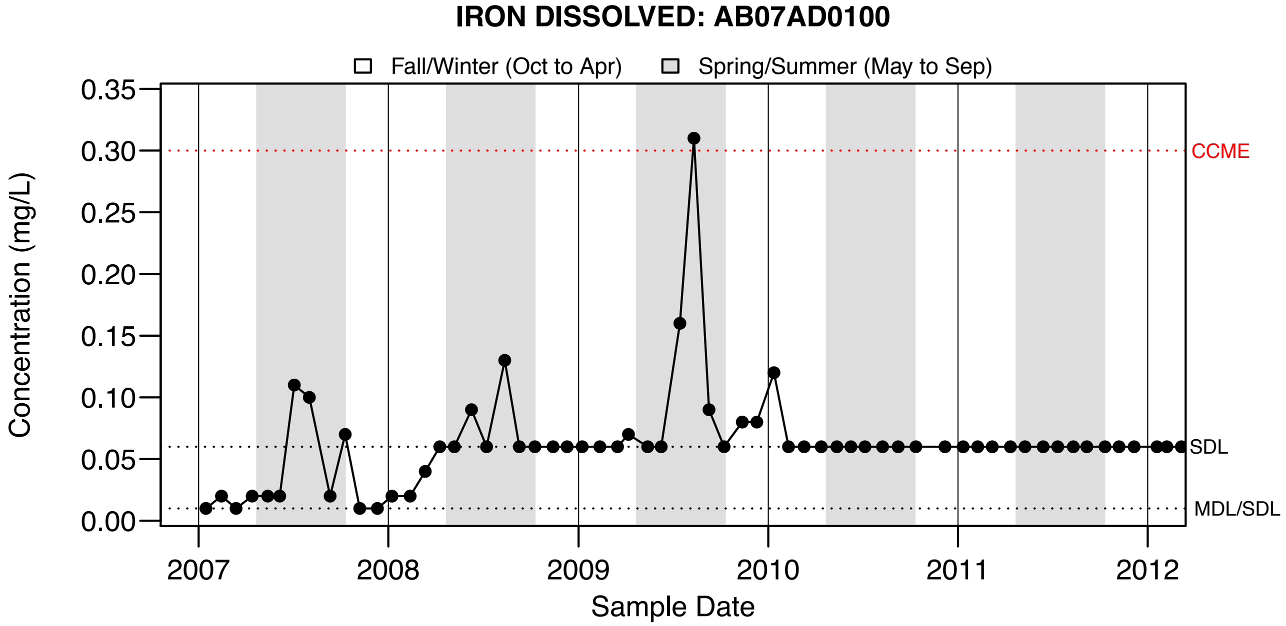


Figure A1.20: IRON DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

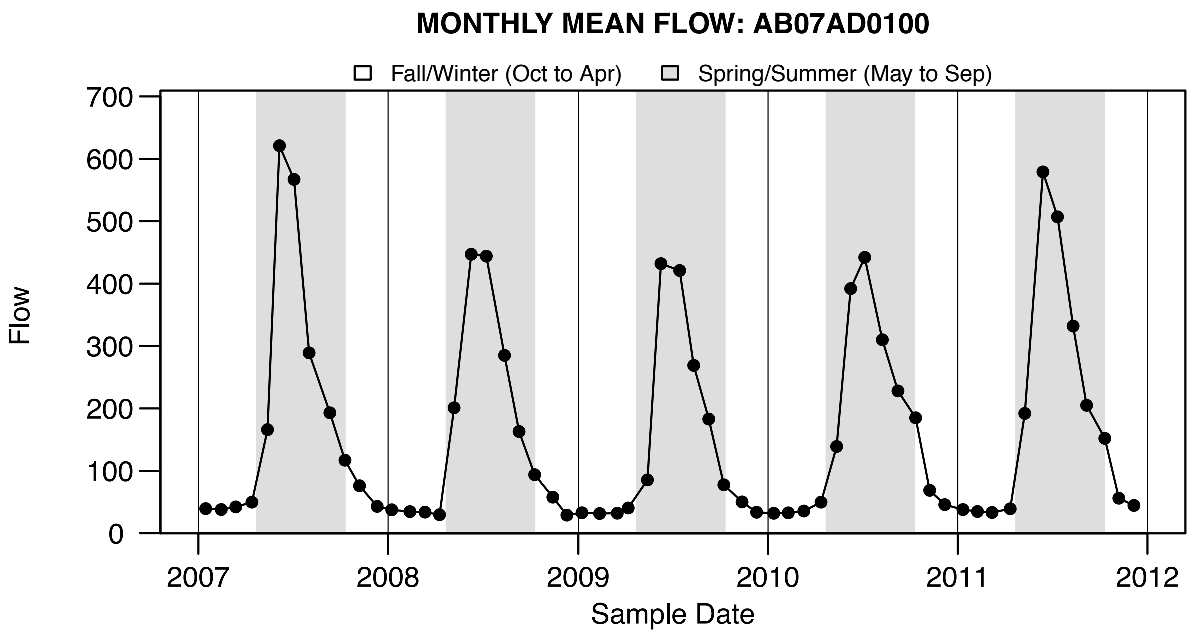


Figure A1.21: MONTHLY MEAN FLOW: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

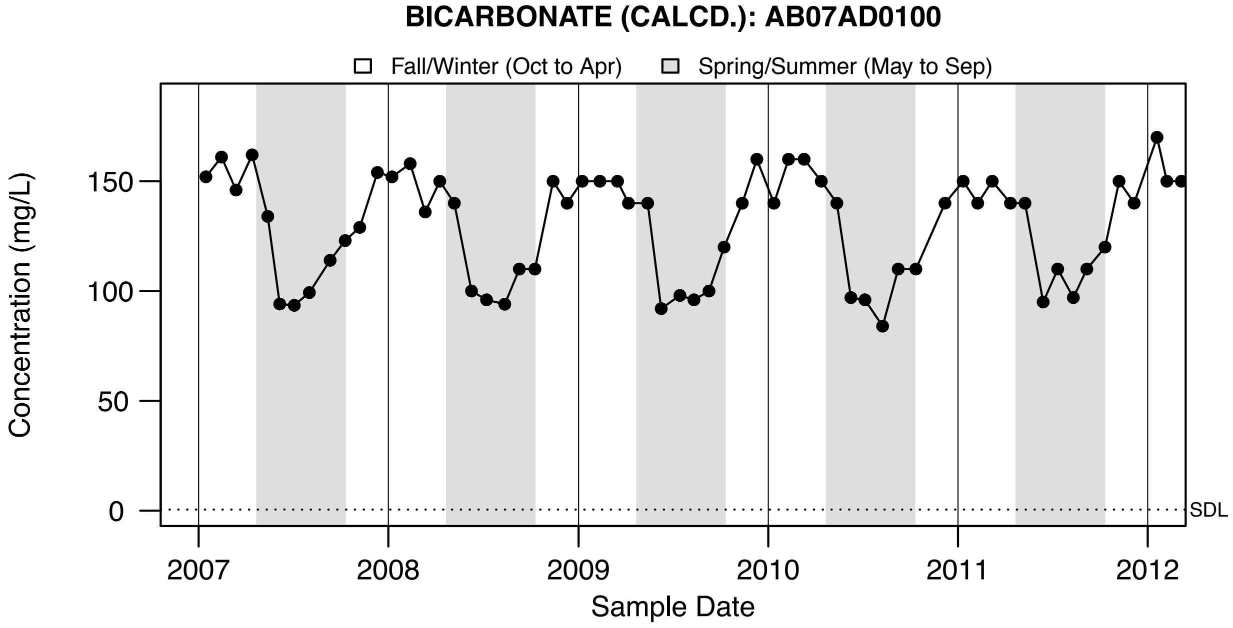


Figure A1.22: BICARBONATE (CALCD.): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

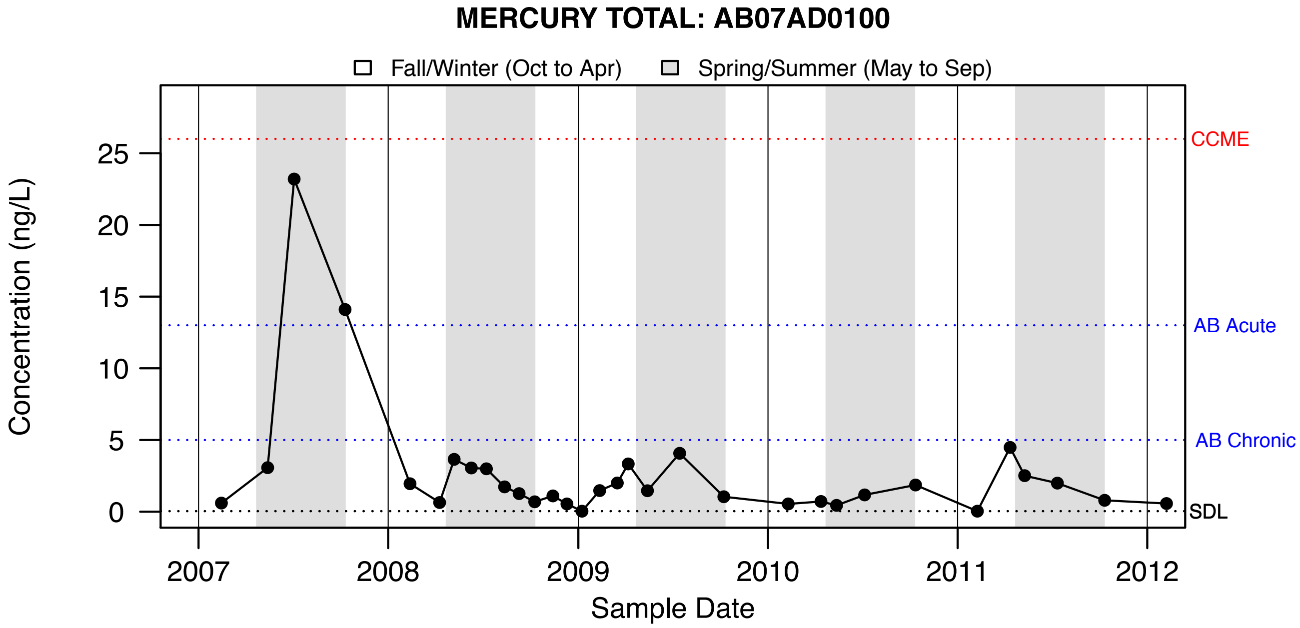


Figure A1.23: MERCURY TOTAL: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

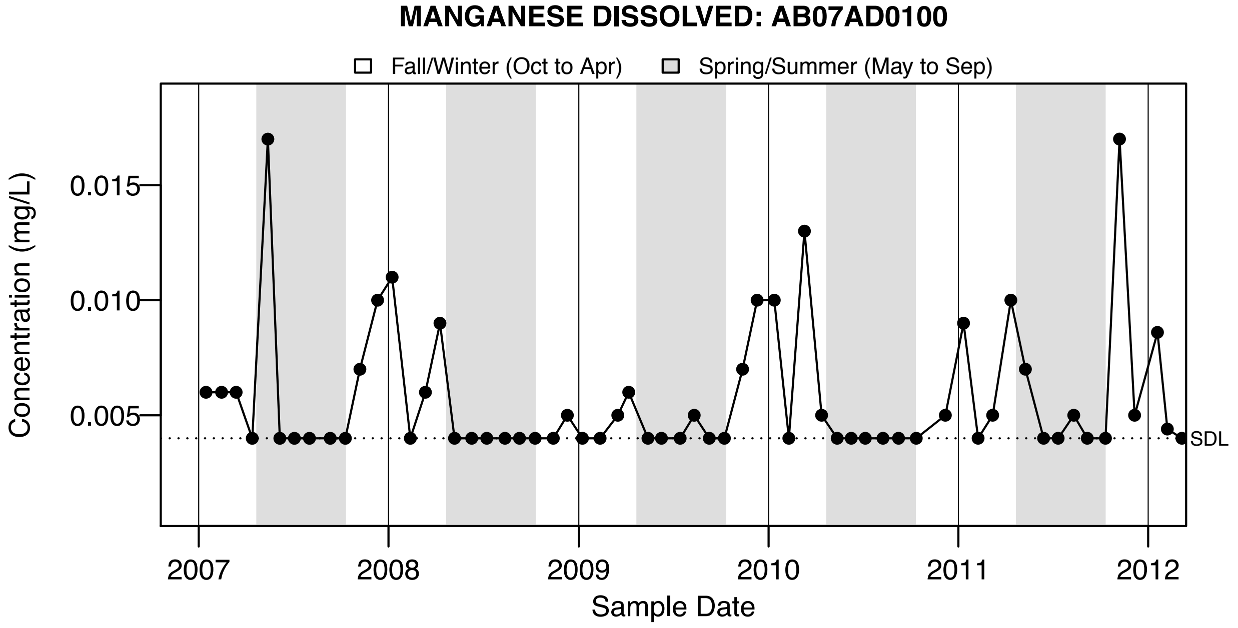


Figure A1.24: MANGANESE DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

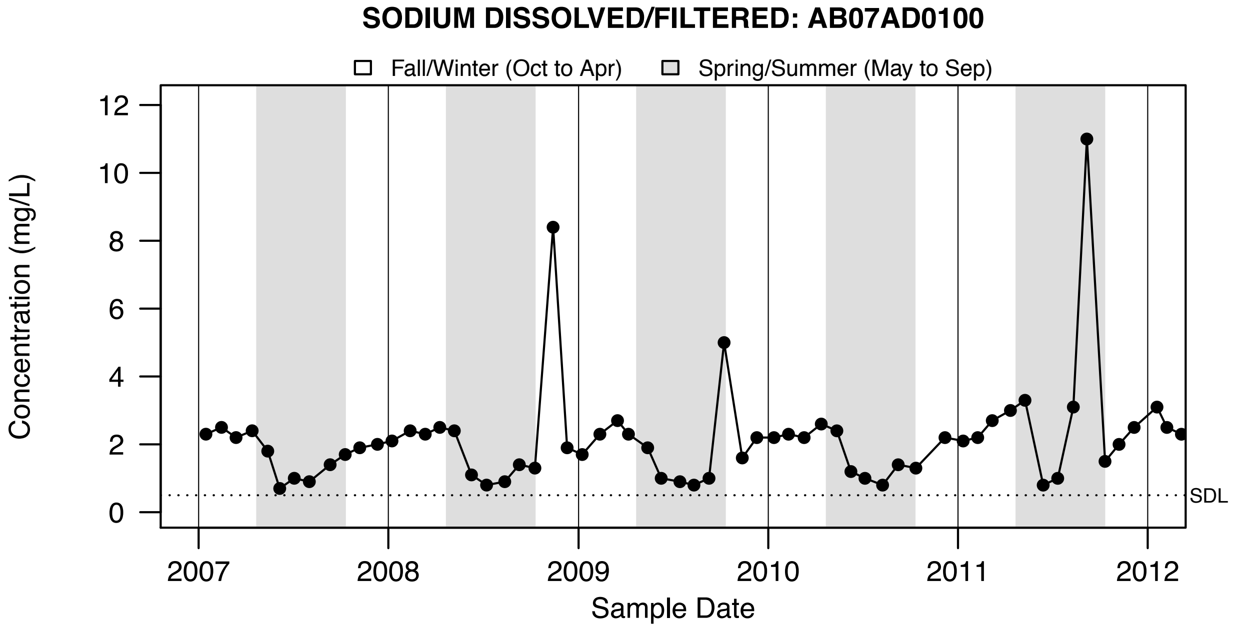


Figure A1.25: SODIUM DISSOLVED/FILTERED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

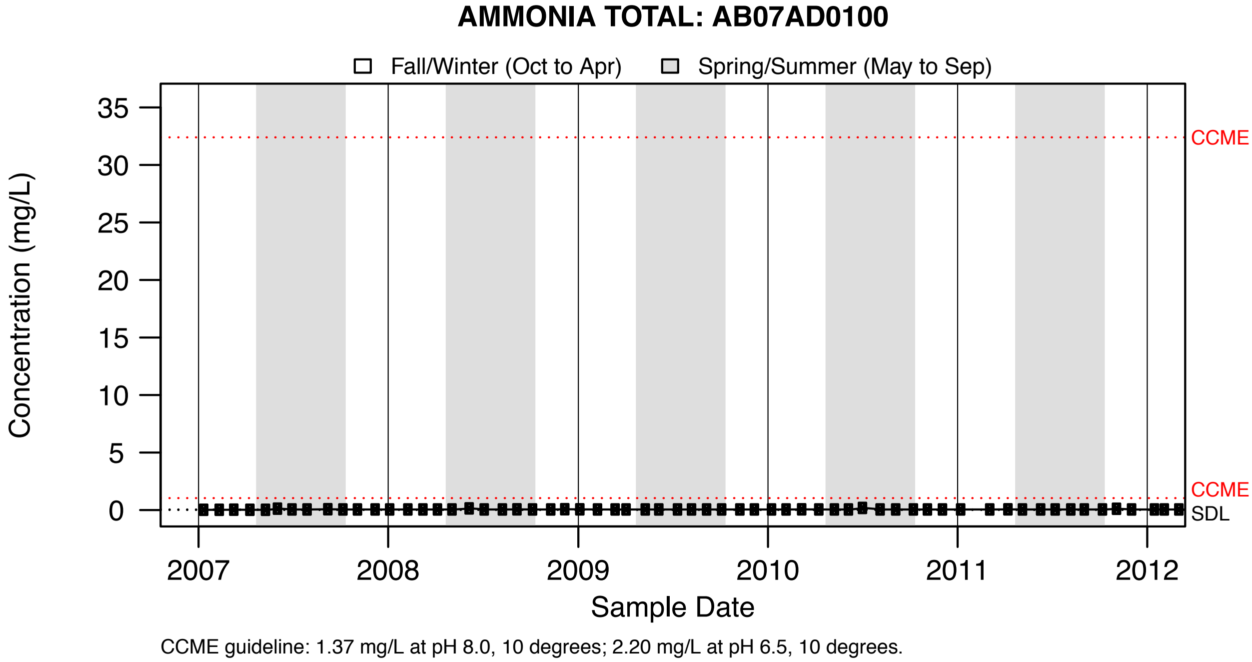
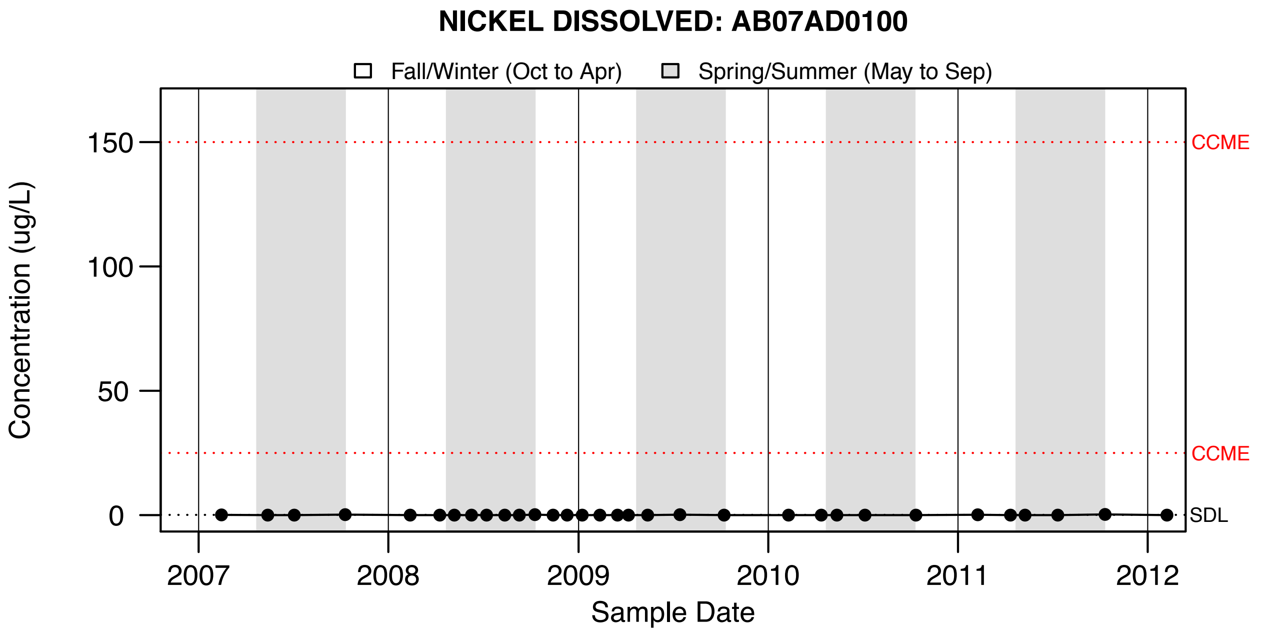


Figure A1.26: AMMONIA TOTAL: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A1.27: NICKEL DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

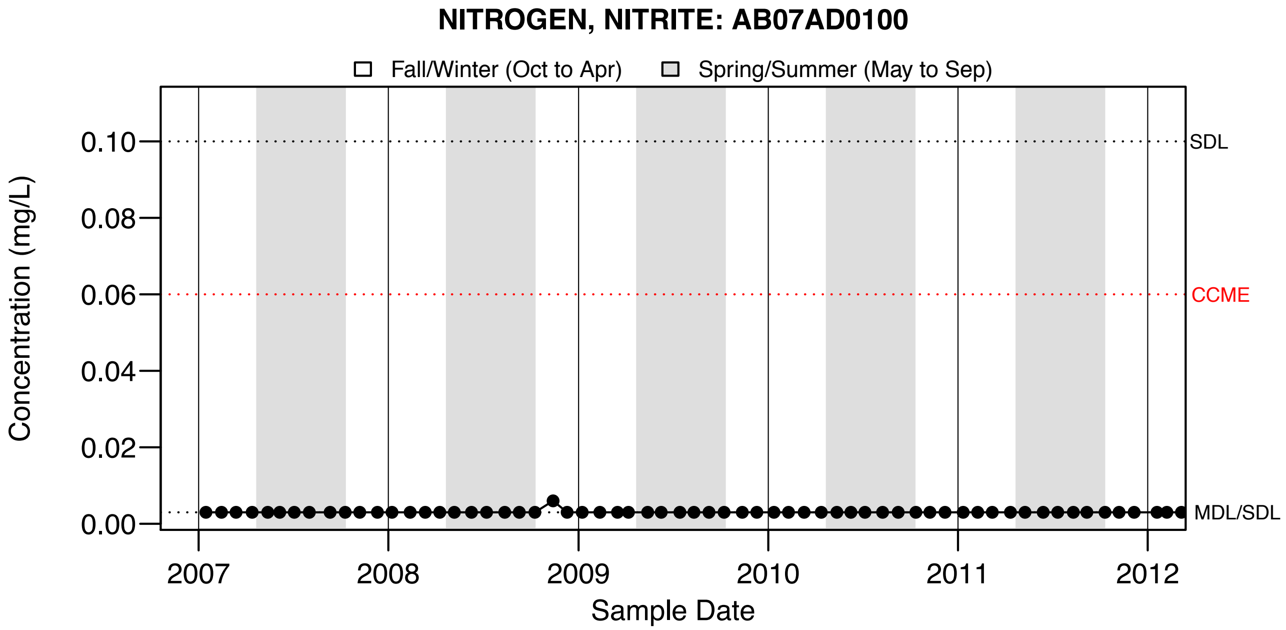
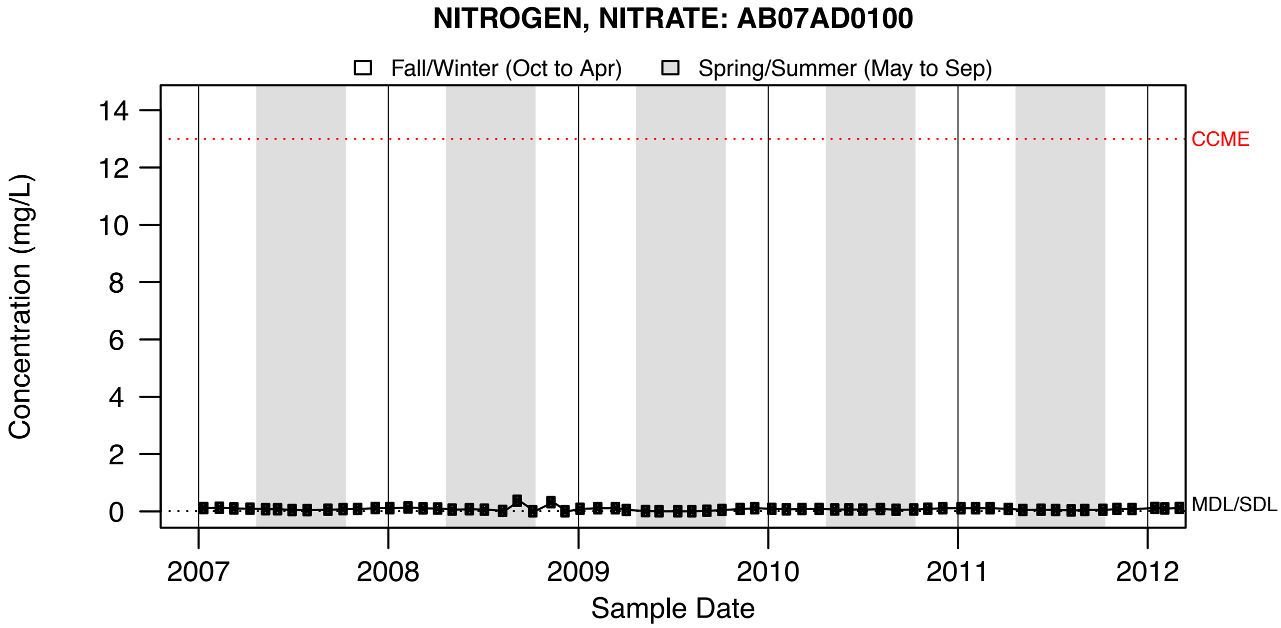


Figure A1.28: NITROGEN, NITRITE: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A1.29: NITROGEN, NITRATE: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

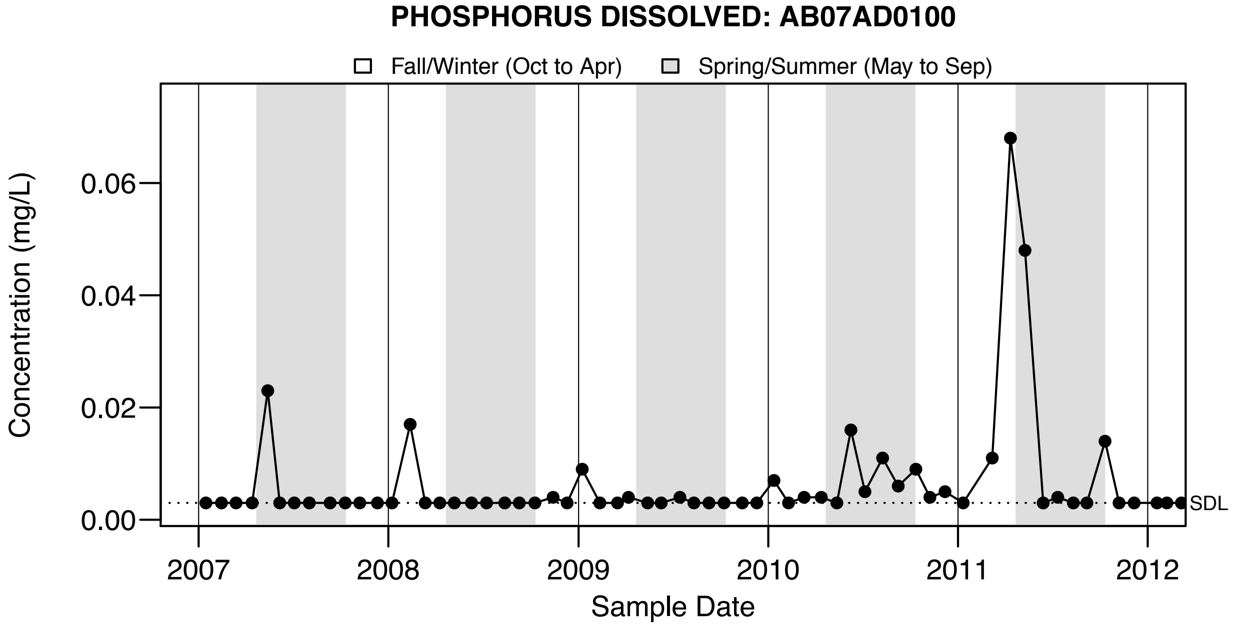


Figure A1.30: PHOSPHORUS DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

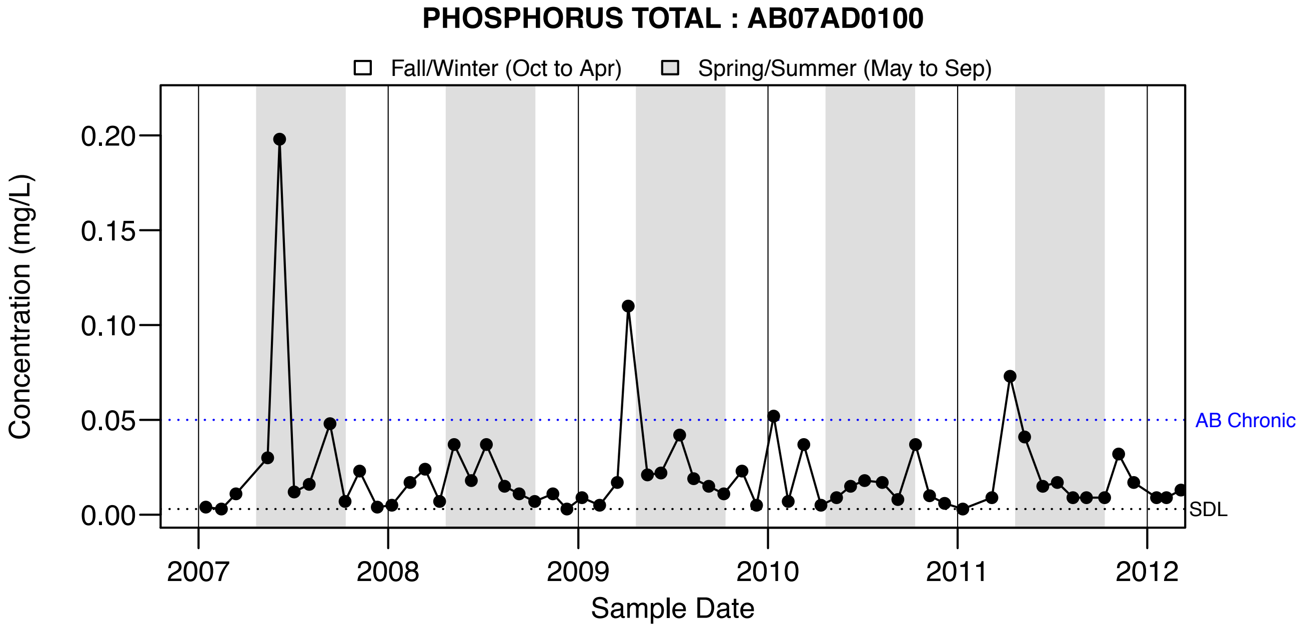
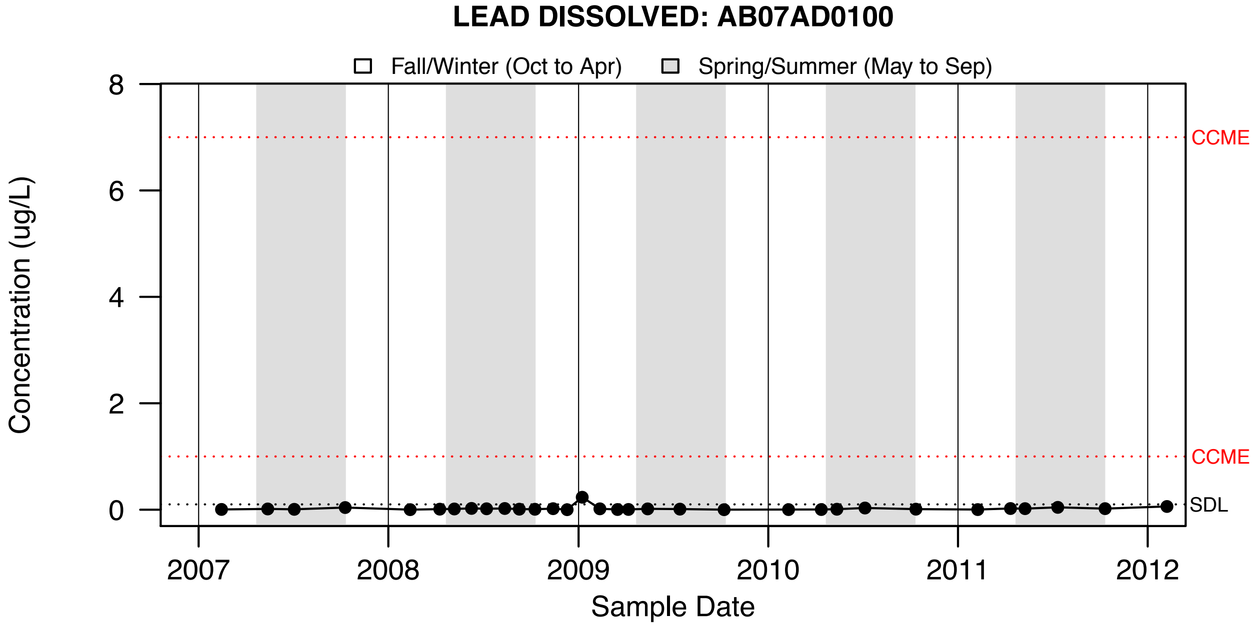


Figure A1.31: PHOSPHORUS TOTAL : AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A1.32: LEAD DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

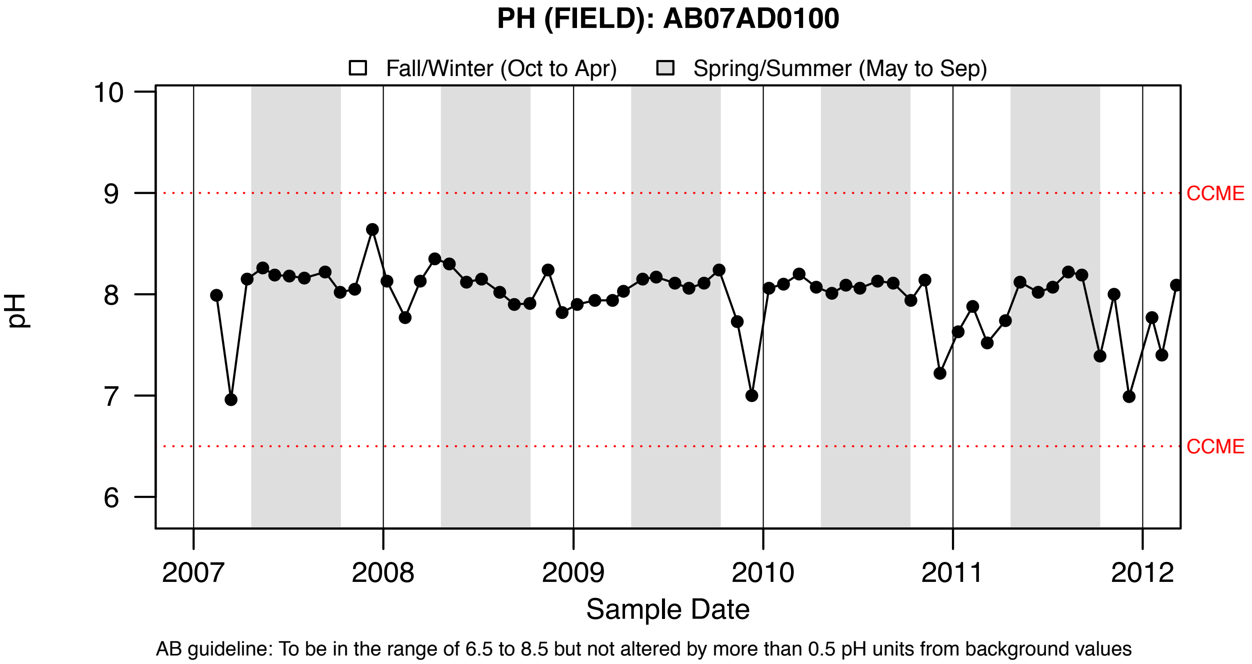


Figure A1.33: PH (FIELD): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

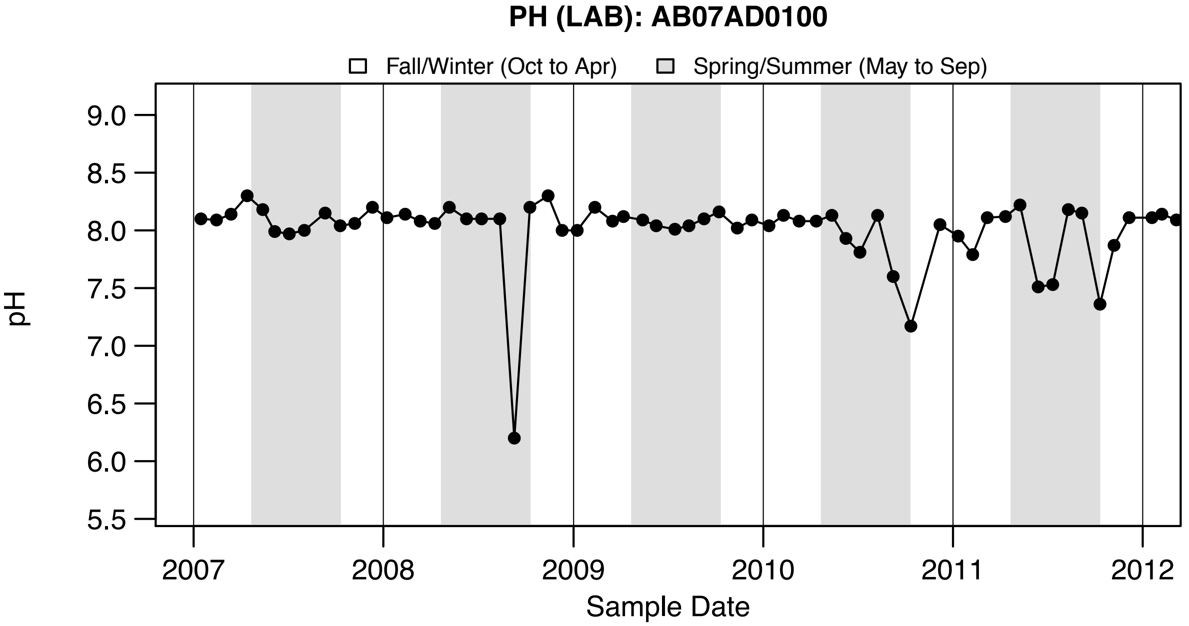


Figure A1.34: PH (LAB): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

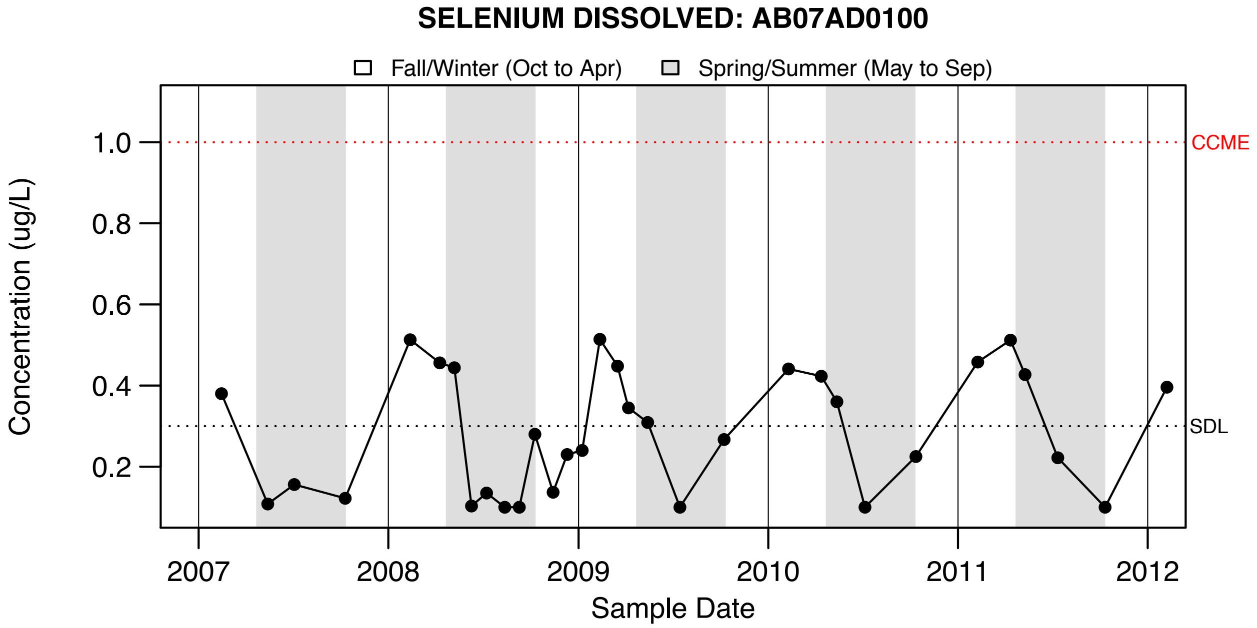


Figure A1.35: SELENIUM DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

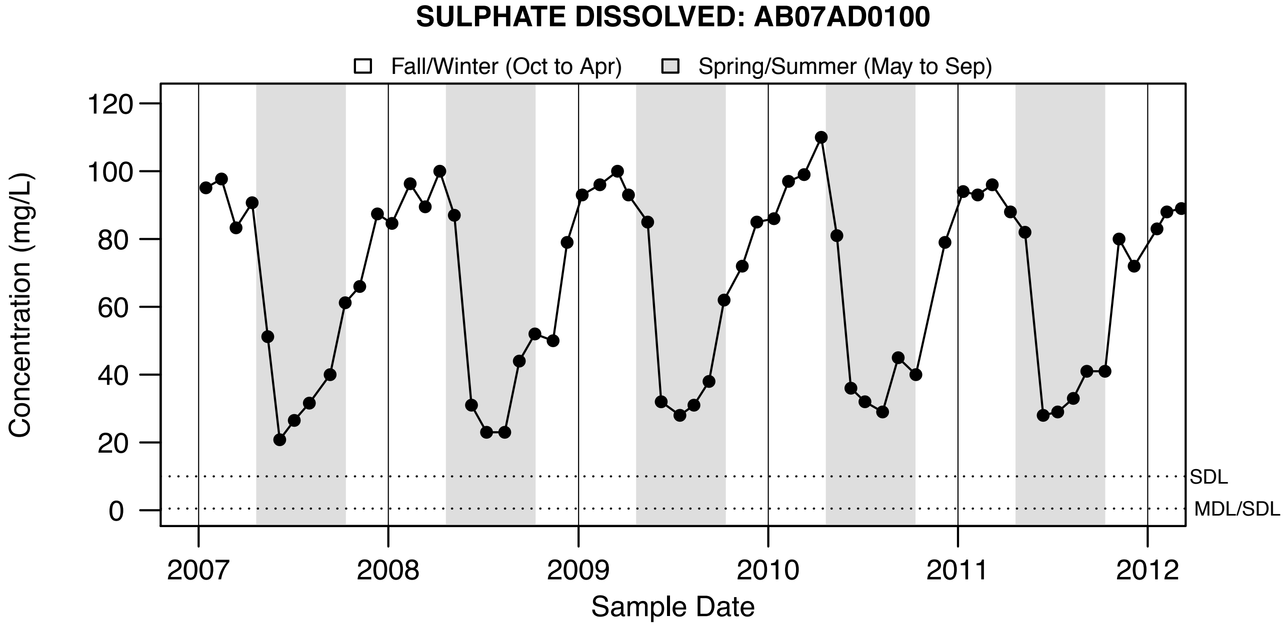


Figure A1.36: SULPHATE DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

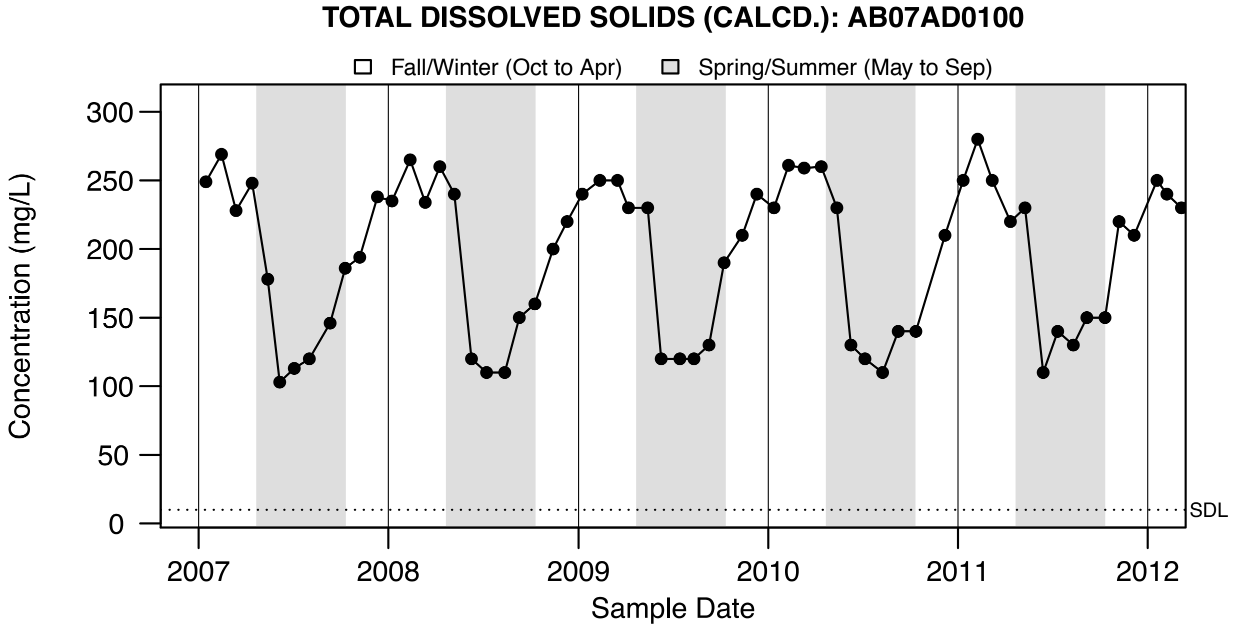
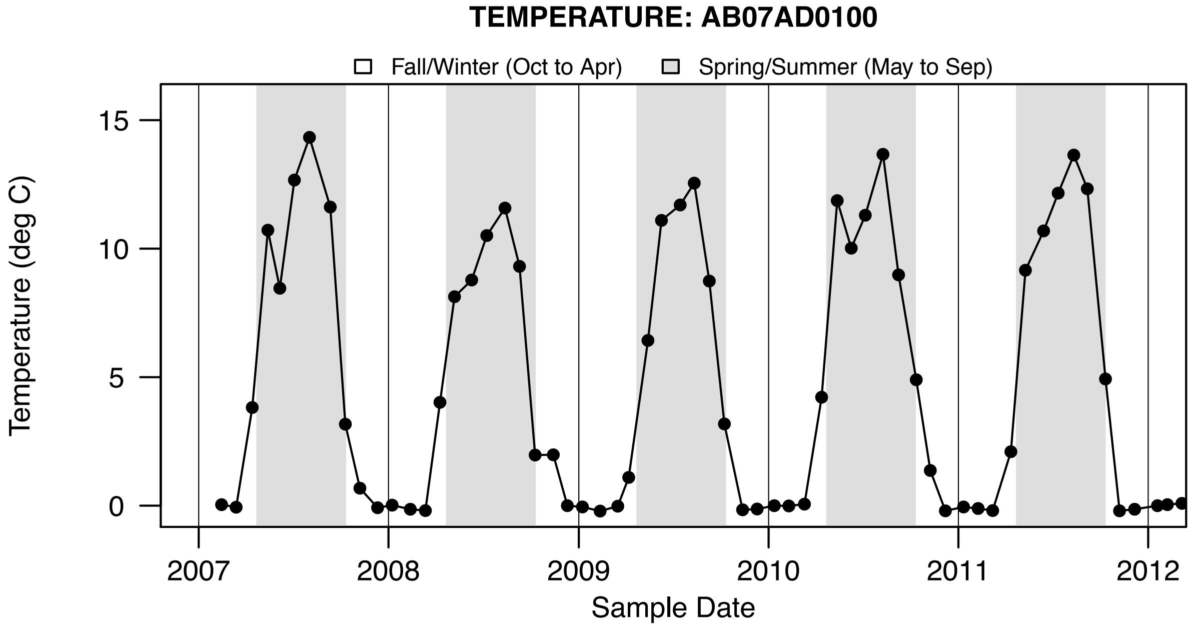


Figure A1.37: TOTAL DISSOLVED SOLIDS (CALCD.): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A1.38: TEMPERATURE: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

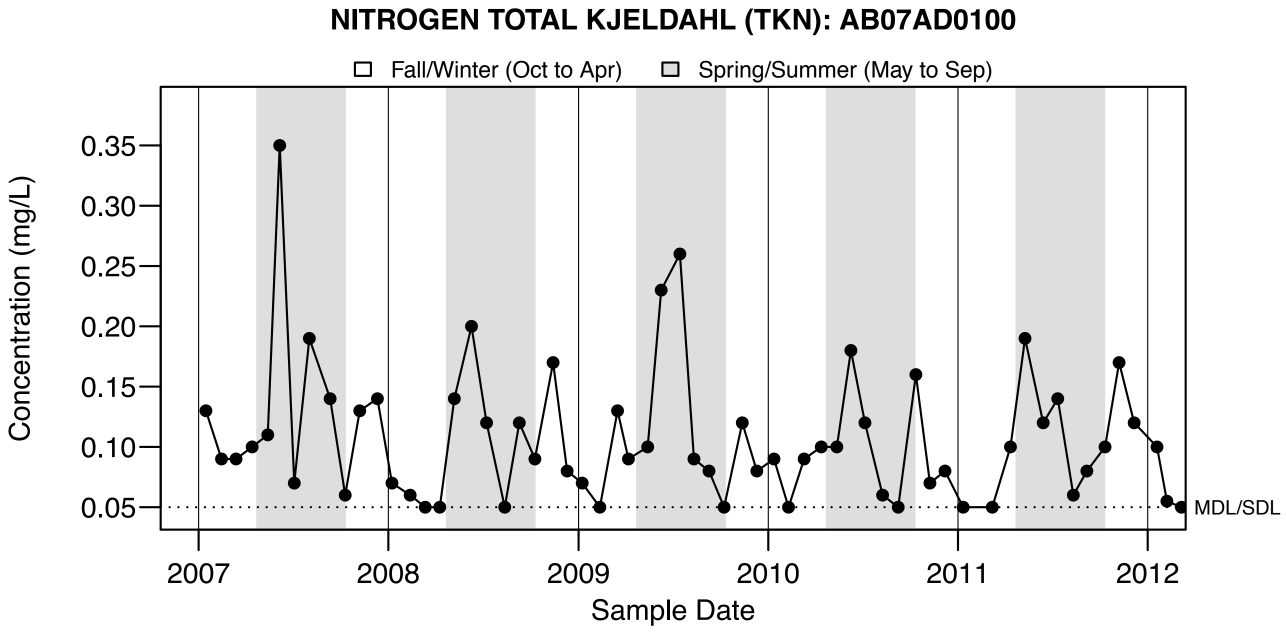
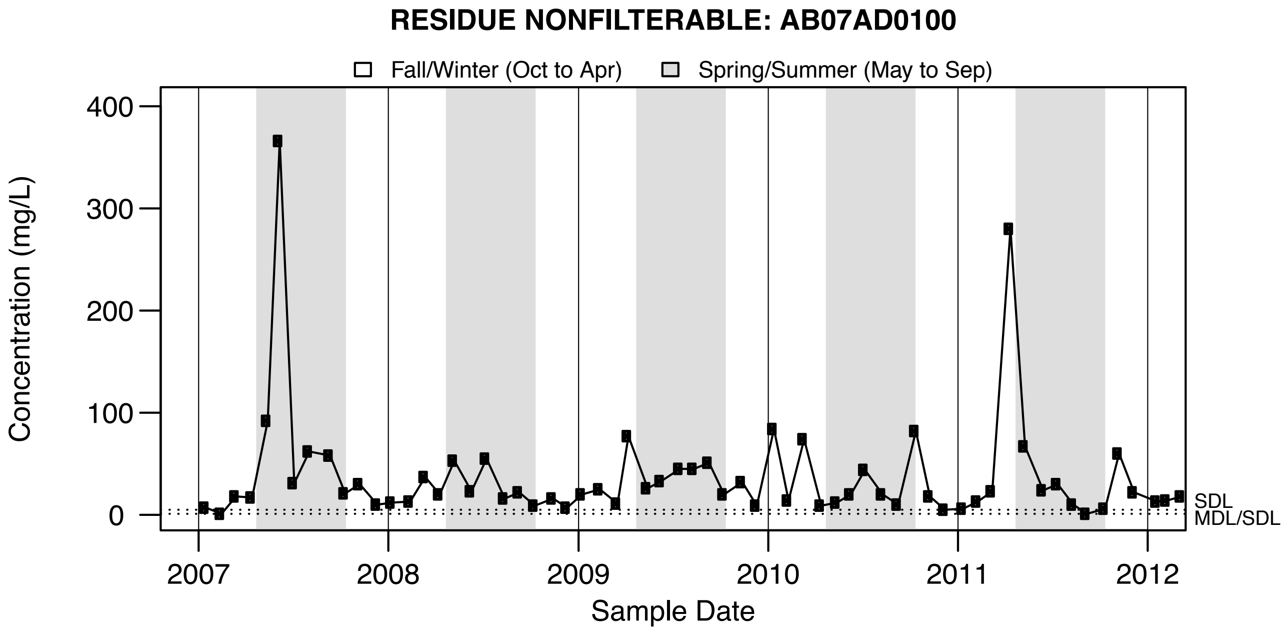


Figure A1.39: NITROGEN TOTAL KJELDAHL (TKN): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A1.40: RESIDUE NONFILTERABLE: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

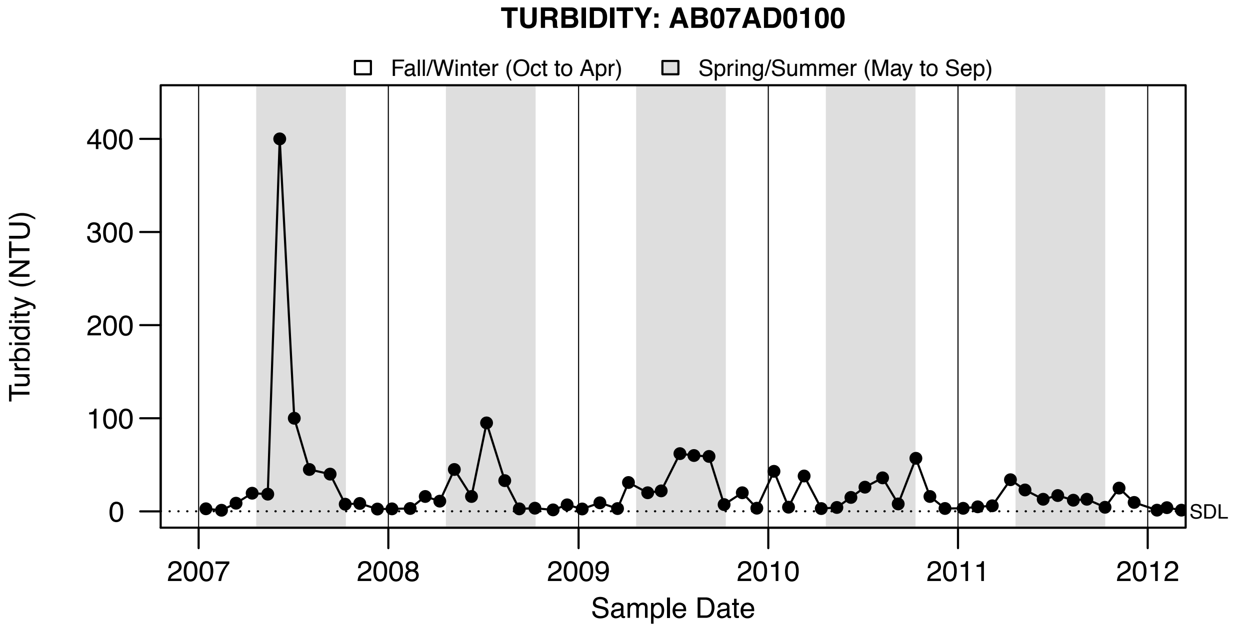


Figure A1.41: TURBIDITY: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

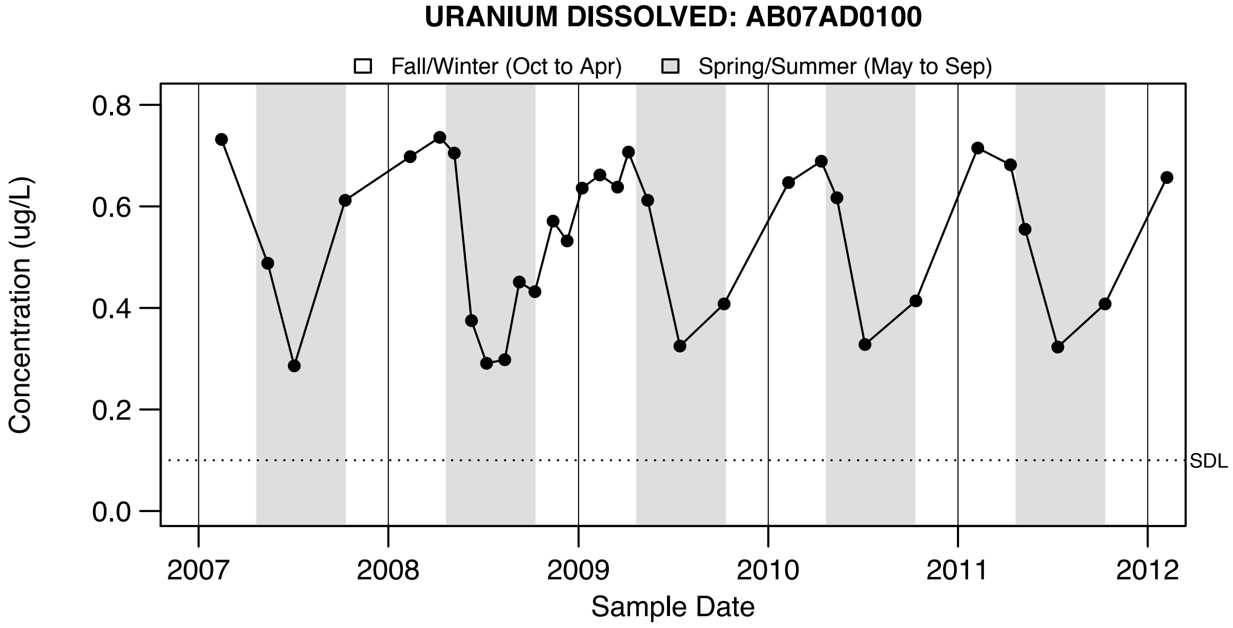


Figure A1.42: URANIUM DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

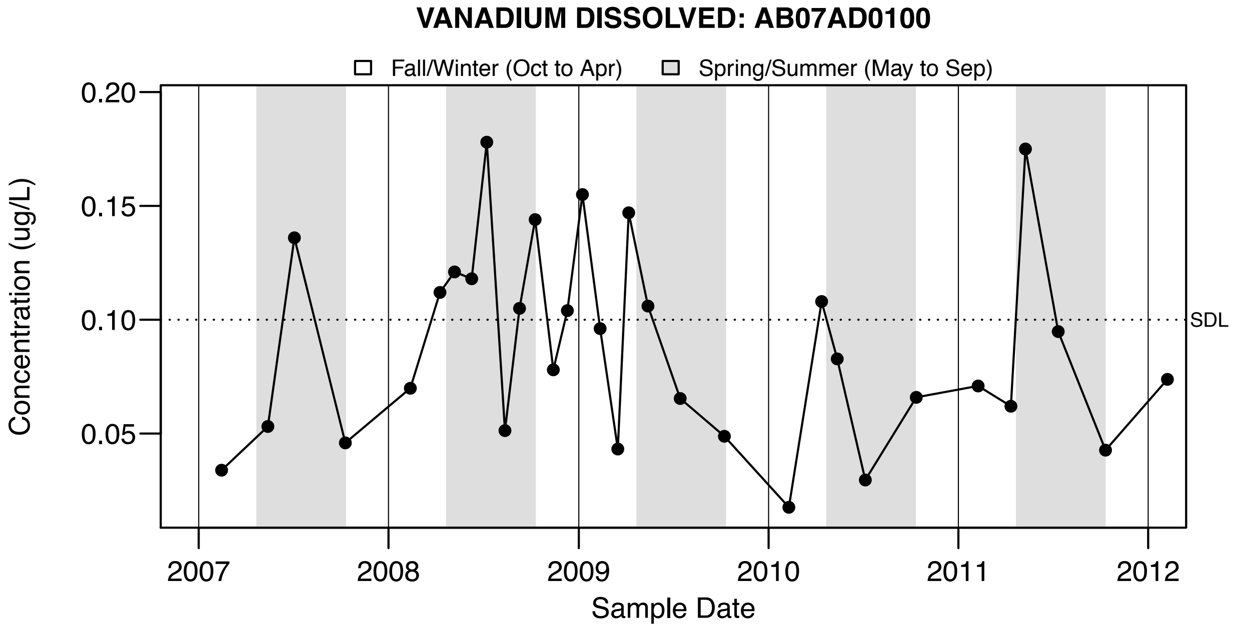


Figure A1.43: VANADIUM DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

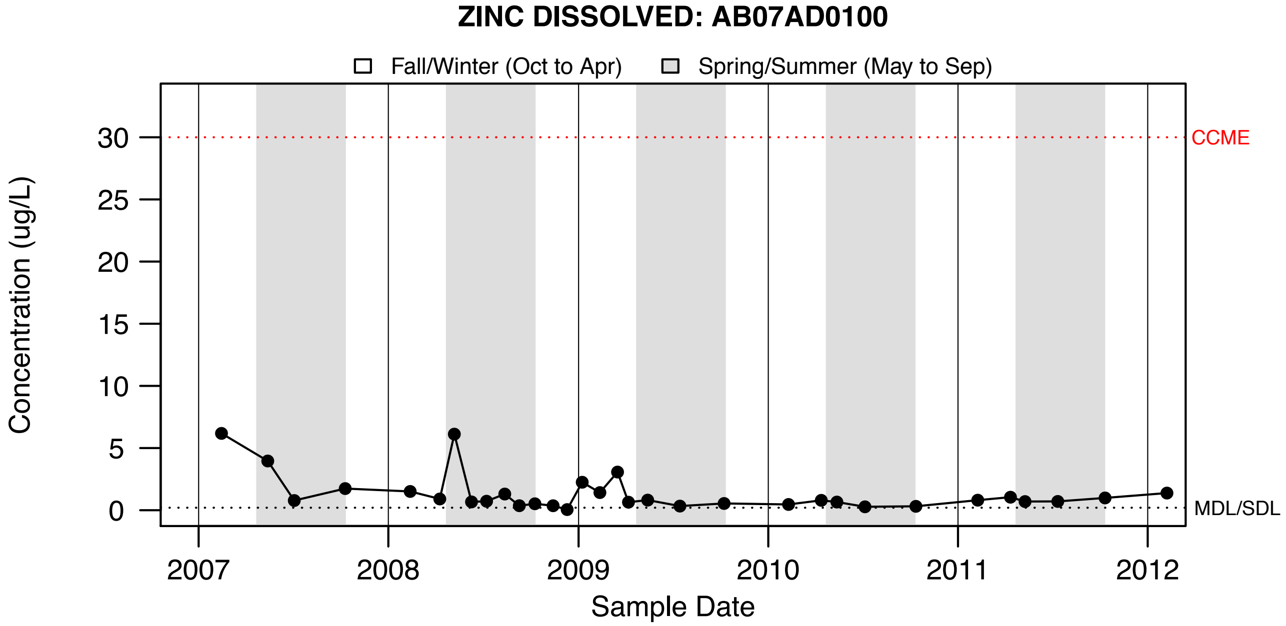
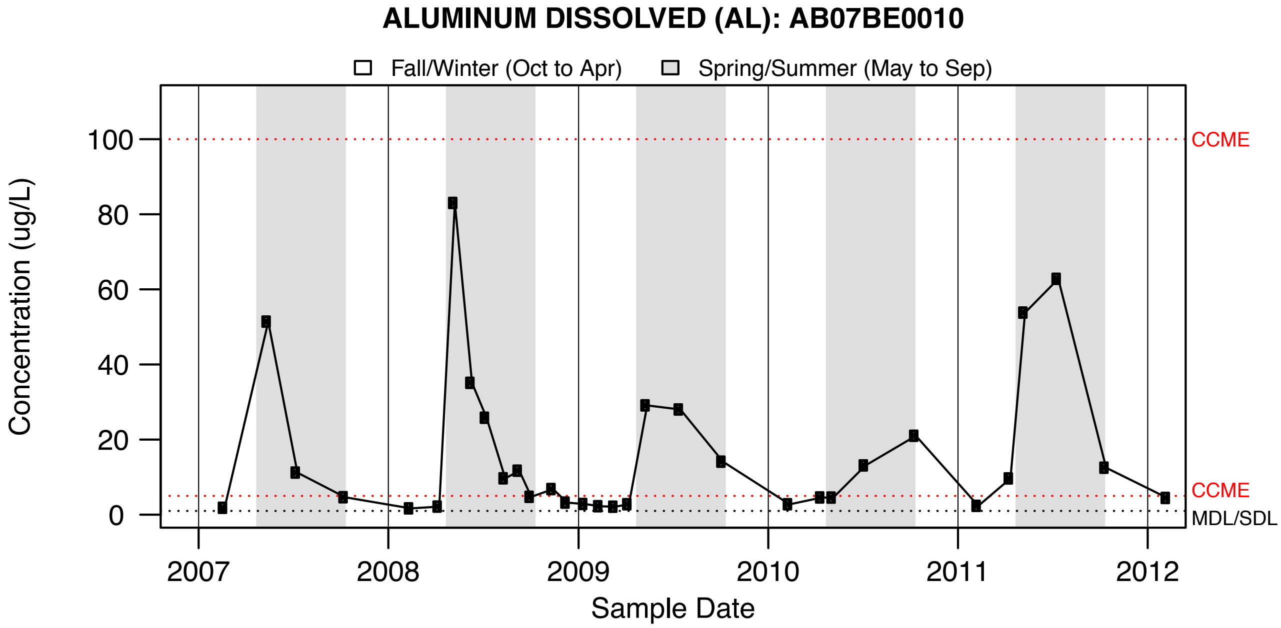
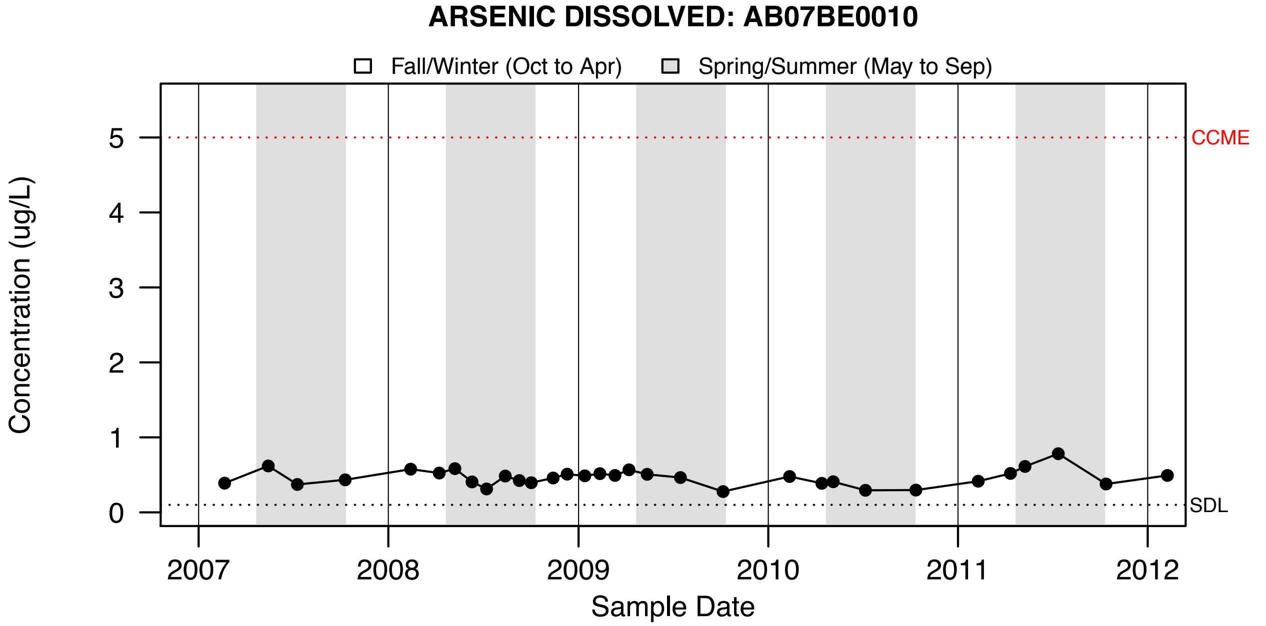


Figure A1.44: ZINC DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A1.45: ALUMINUM DISSOLVED (AL): AB07BE0010 - AT TOWN OF ATHABASCA



AB guidelines state Total Arsenic; CCME does not specify

Figure A1.46: ARSENIC DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

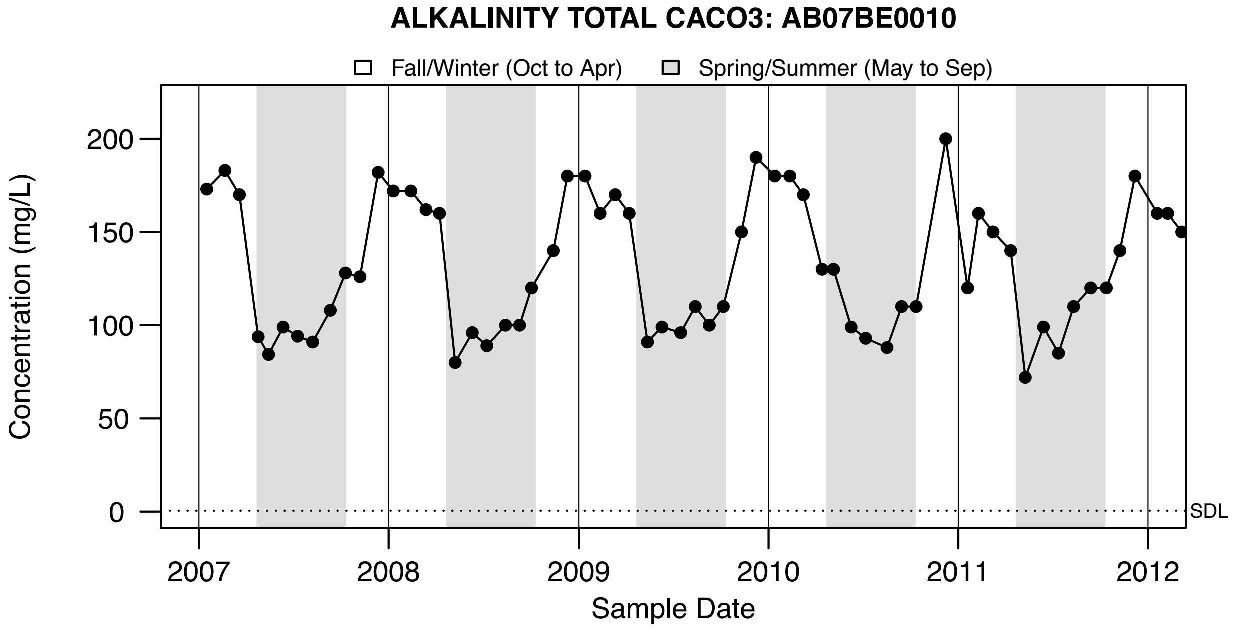


Figure A1.47: ALKALINITY TOTAL CACO3: AB07BE0010 - AT TOWN OF ATHABASCA

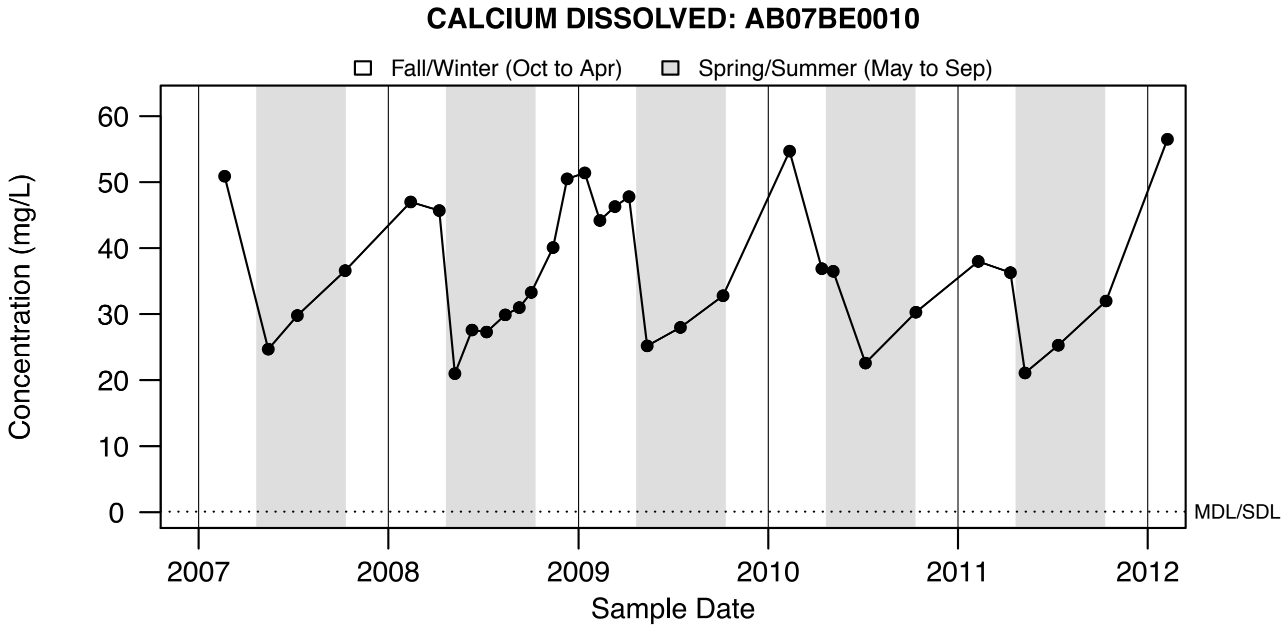


Figure A1.48: CALCIUM DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

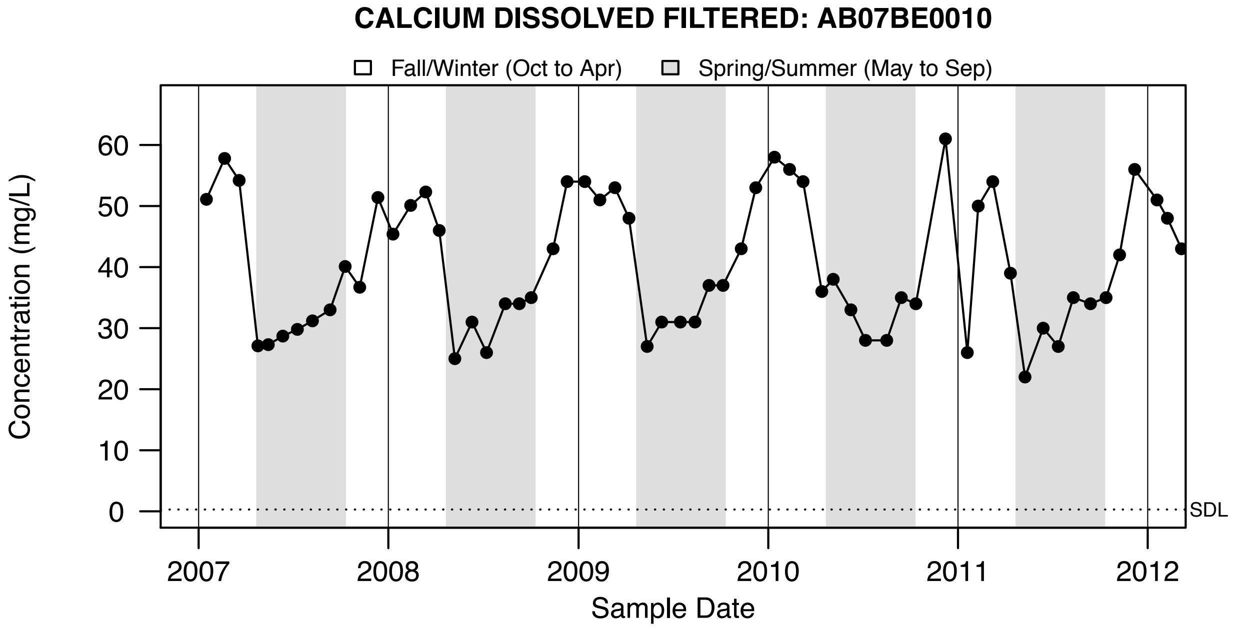


Figure A1.49: CALCIUM DISSOLVED FILTERED: AB07BE0010 - AT TOWN OF ATHABASCA

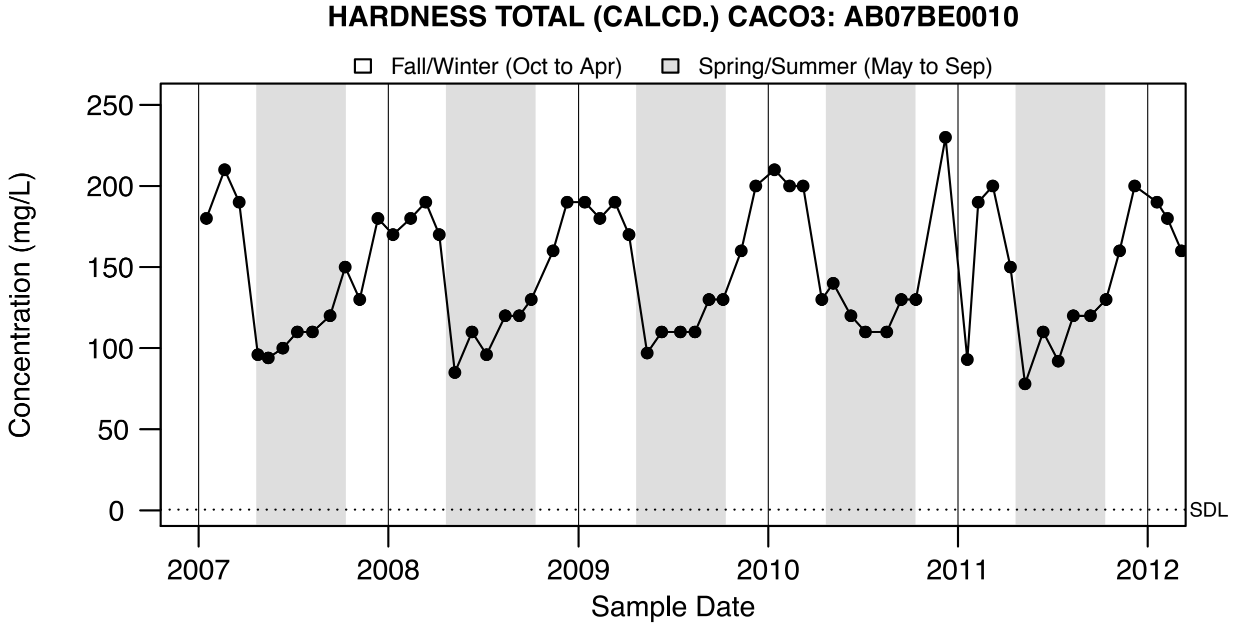


Figure A1.50: HARDNESS TOTAL (CALCD.) CACO3: AB07BE0010 - AT TOWN OF ATHABASCA

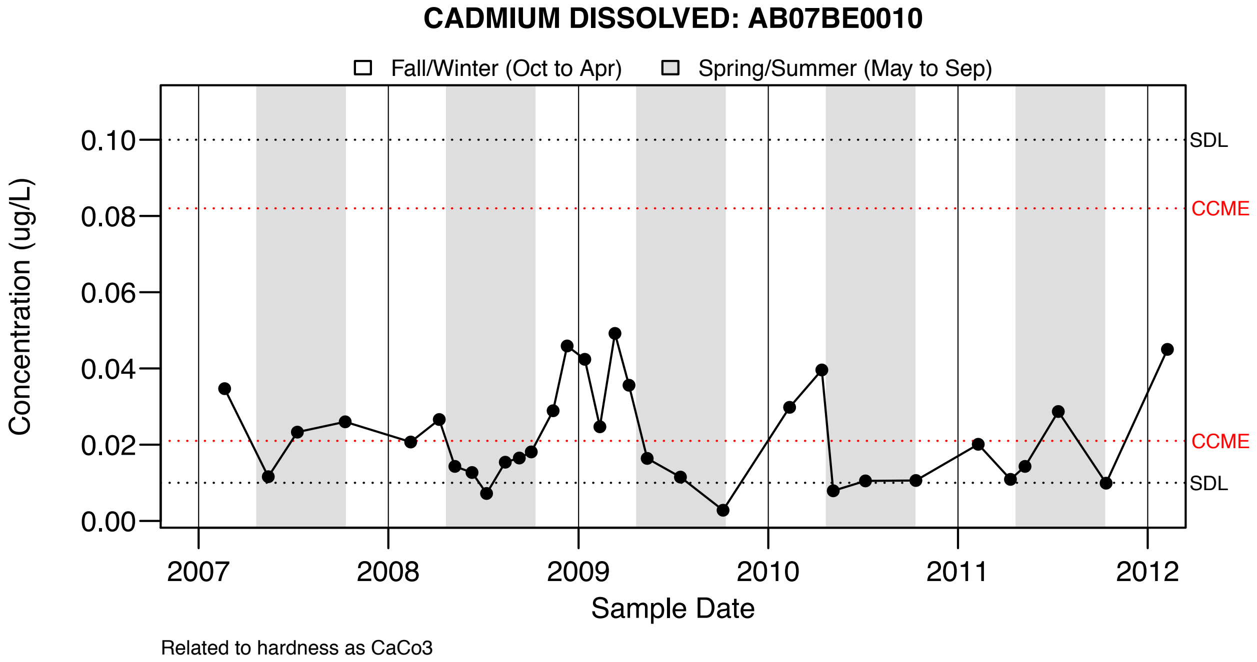


Figure A1.51: CADMIUM DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

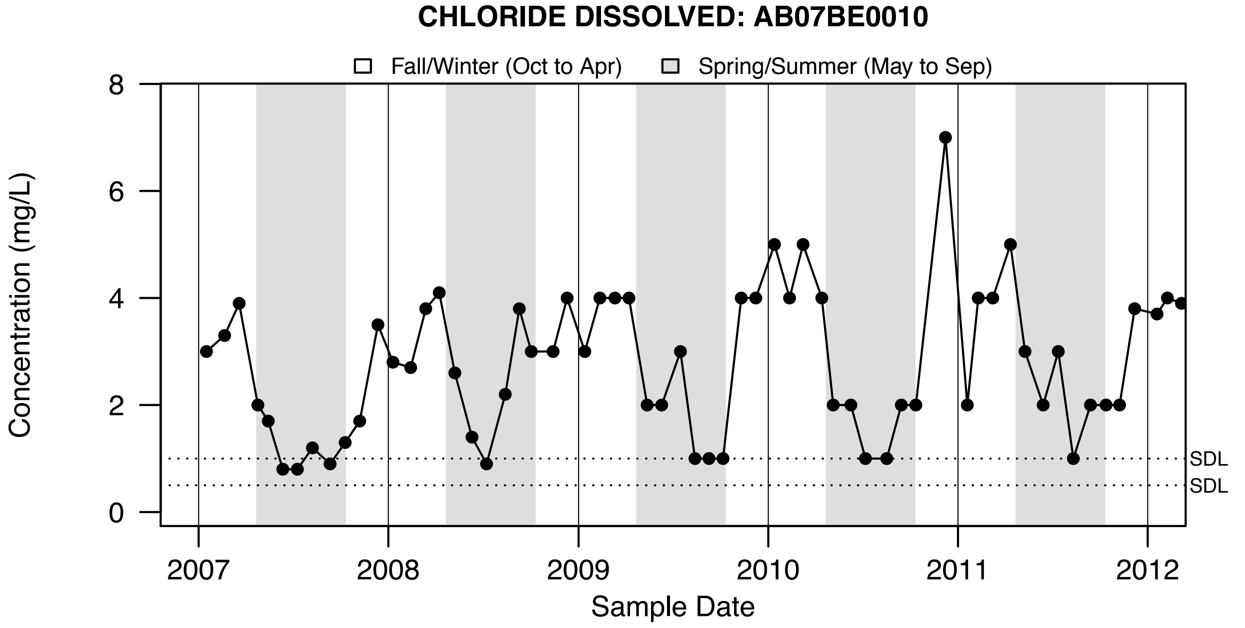


Figure A1.52: CHLORIDE DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

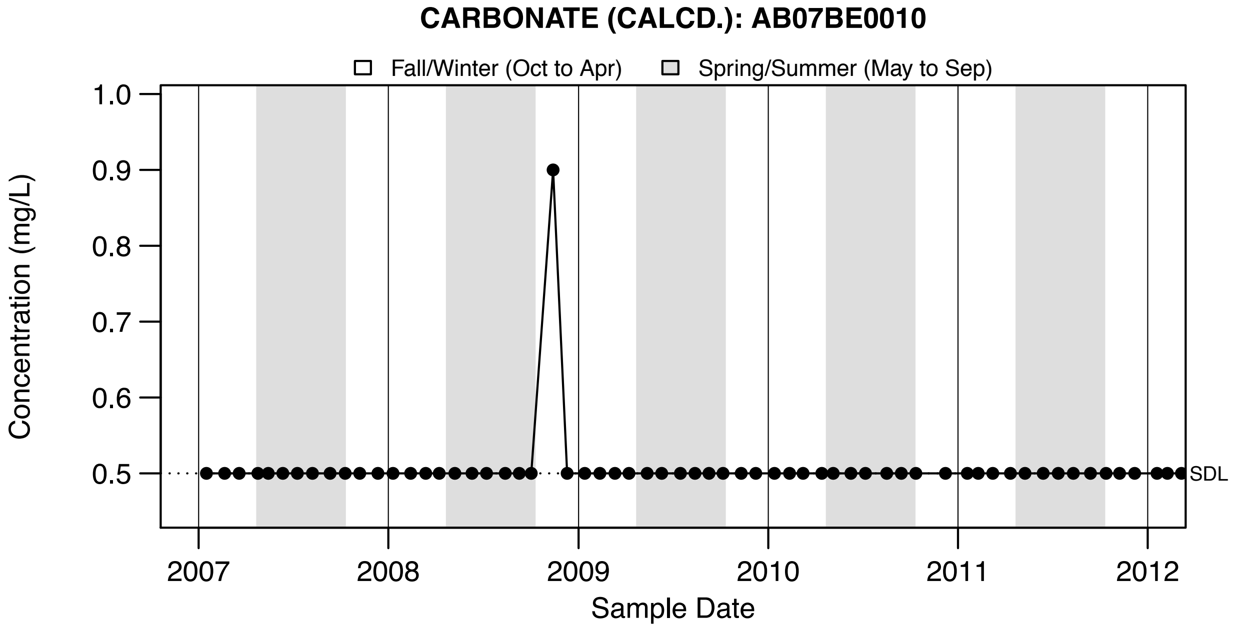


Figure A1.53: CARBONATE (CALCD.): AB07BE0010 - AT TOWN OF ATHABASCA

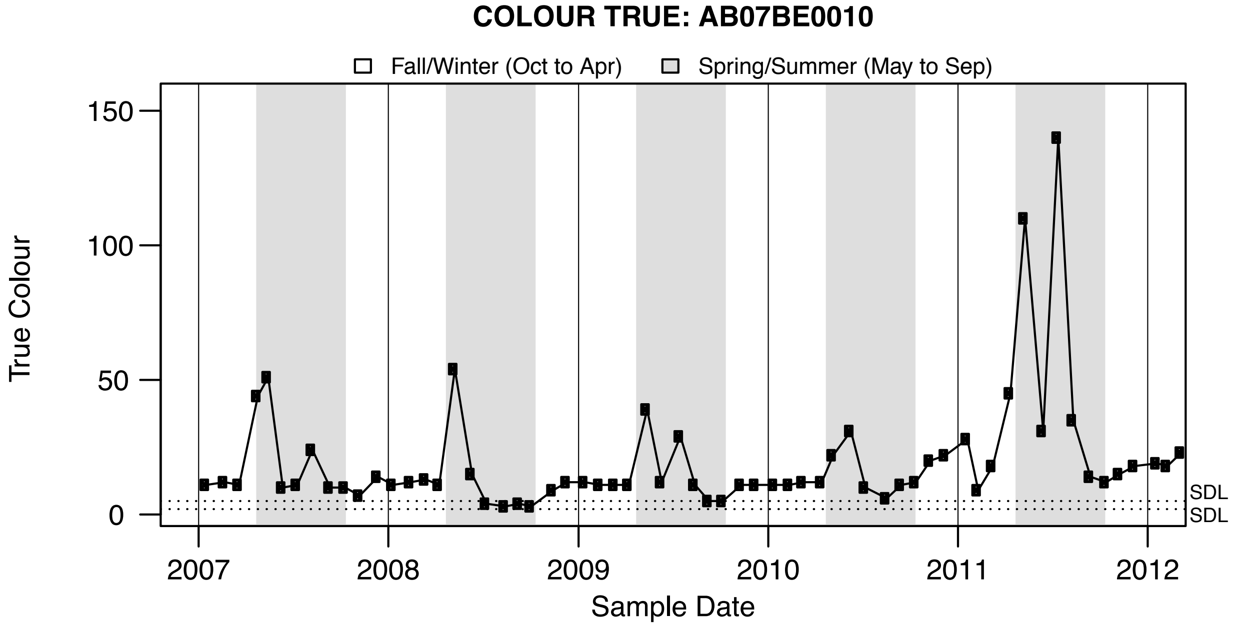


Figure A1.54: COLOUR TRUE: AB07BE0010 - AT TOWN OF ATHABASCA

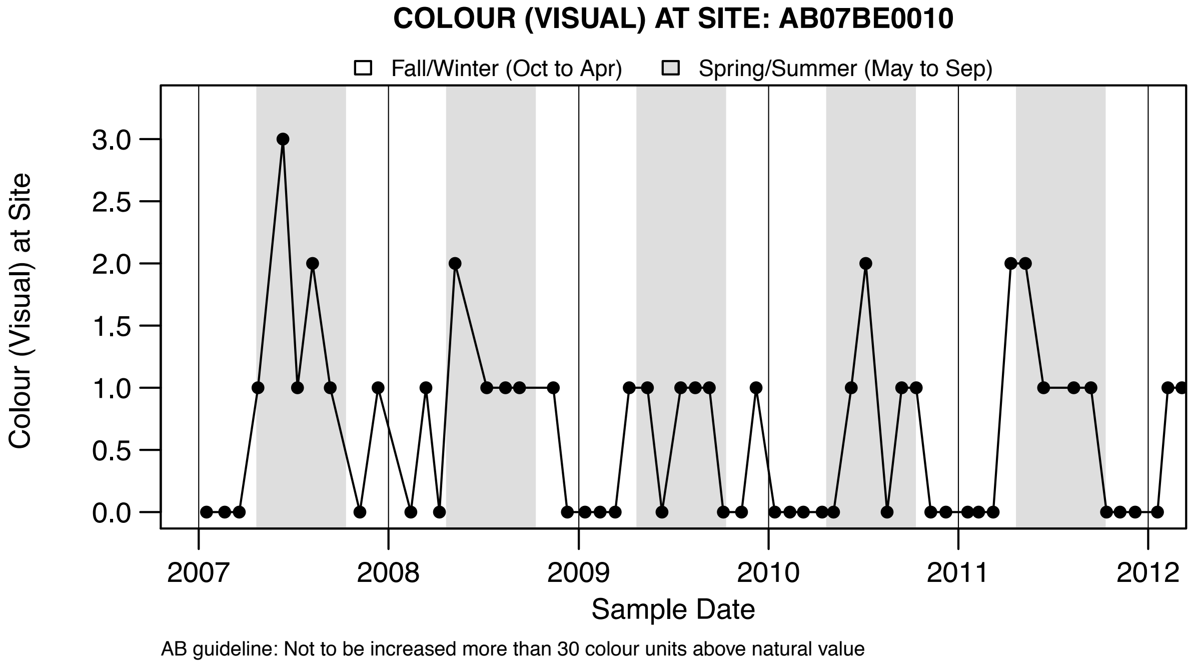


Figure A1.55: COLOUR (VISUAL) AT SITE: AB07BE0010 - AT TOWN OF ATHABASCA

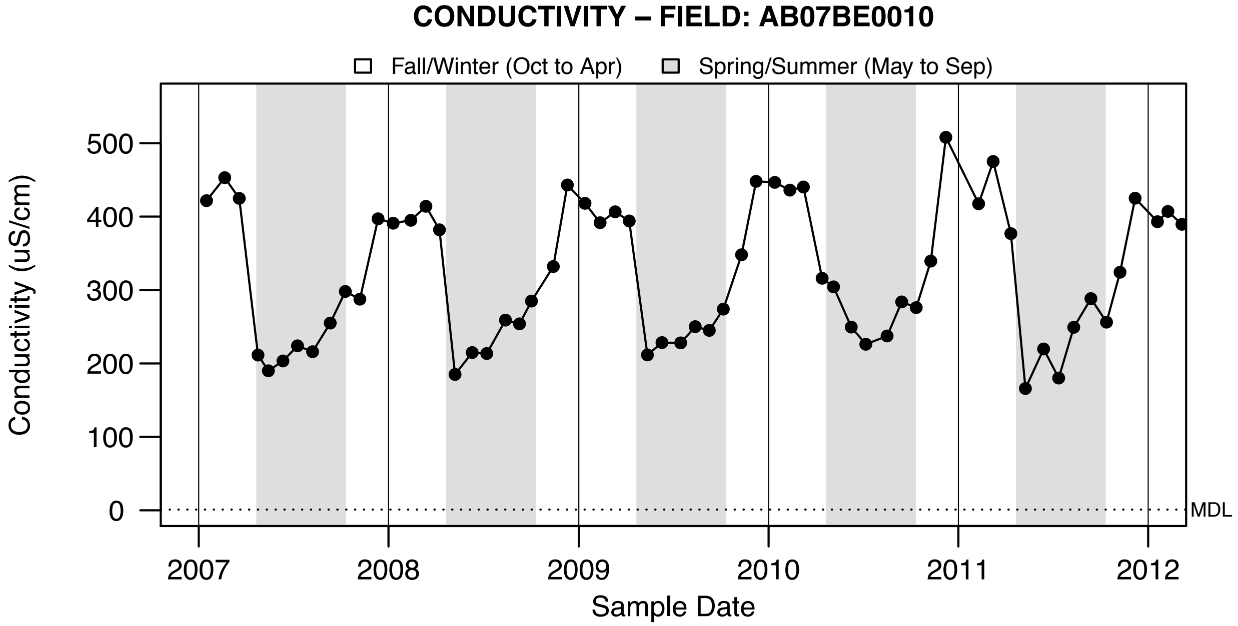


Figure A1.56: CONDUCTIVITY - FIELD: AB07BE0010 - AT TOWN OF ATHABASCA

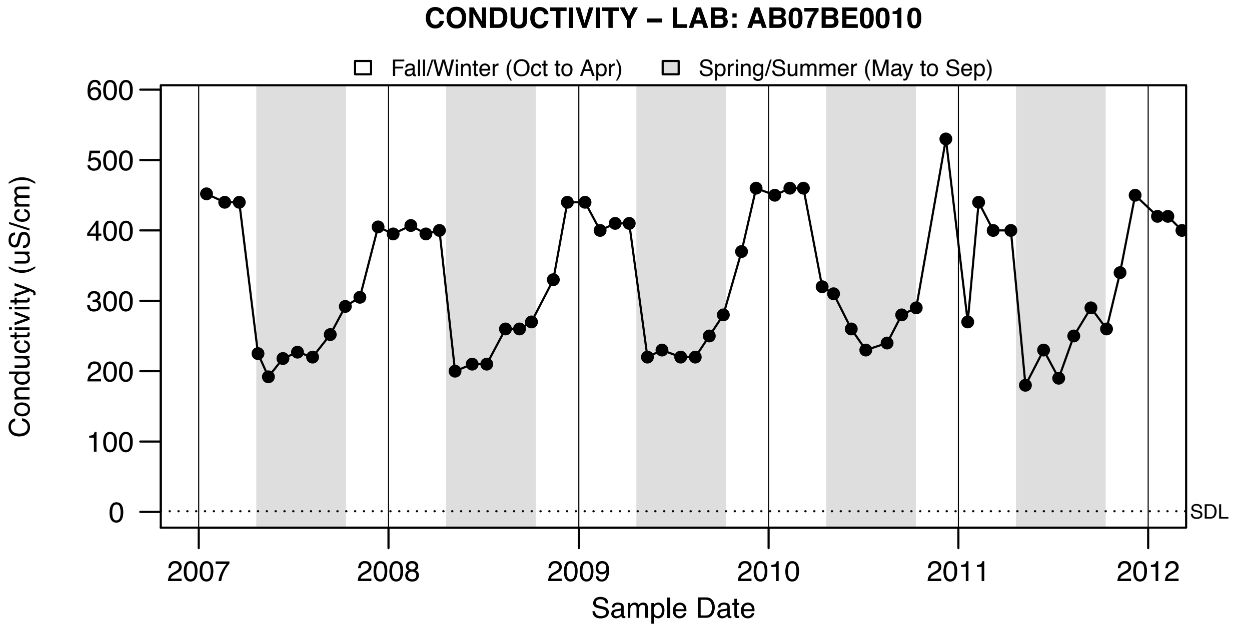
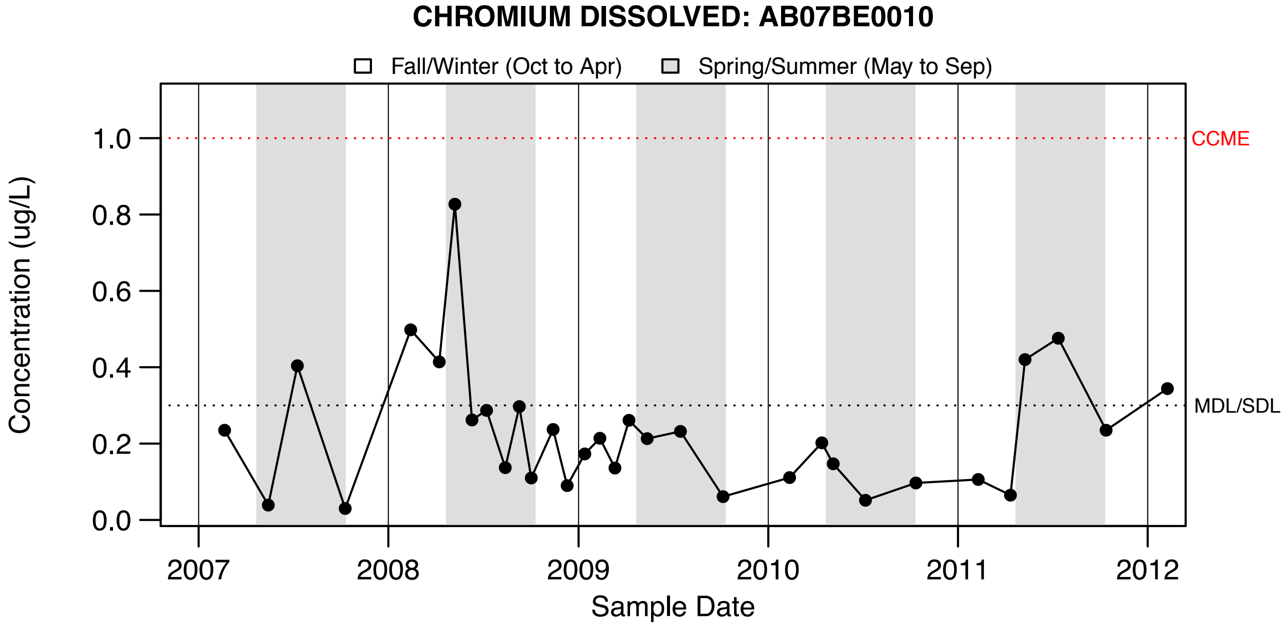
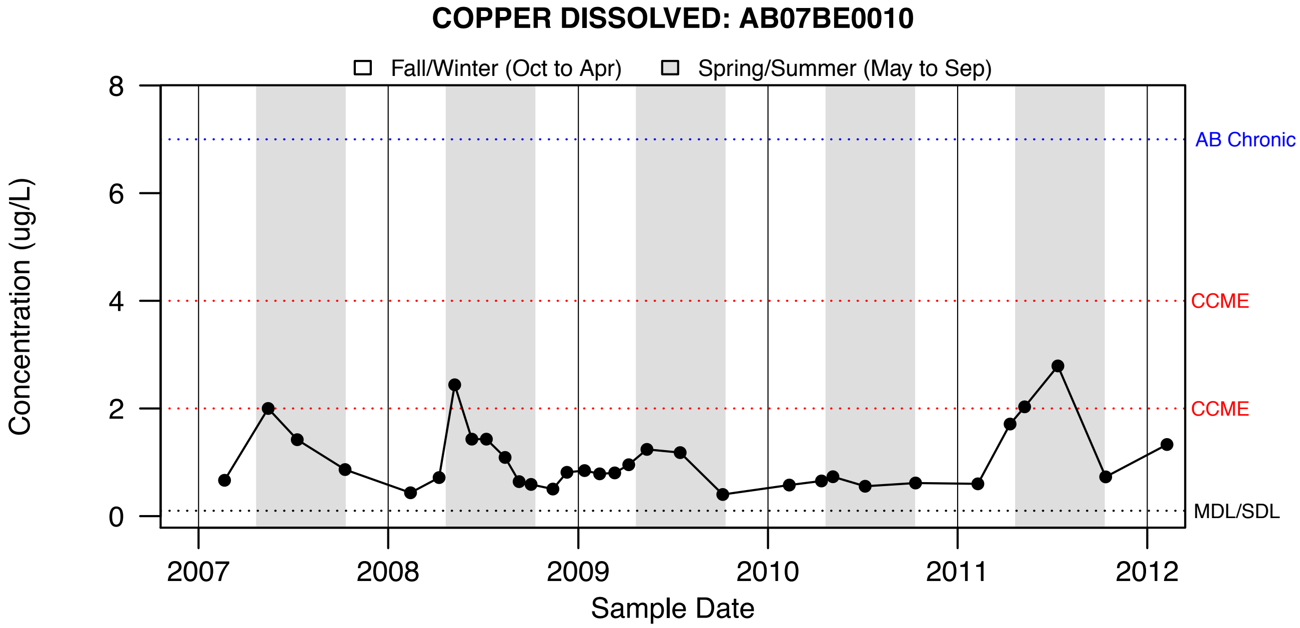


Figure A1.57: CONDUCTIVITY - LAB: AB07BE0010 - AT TOWN OF ATHABASCA



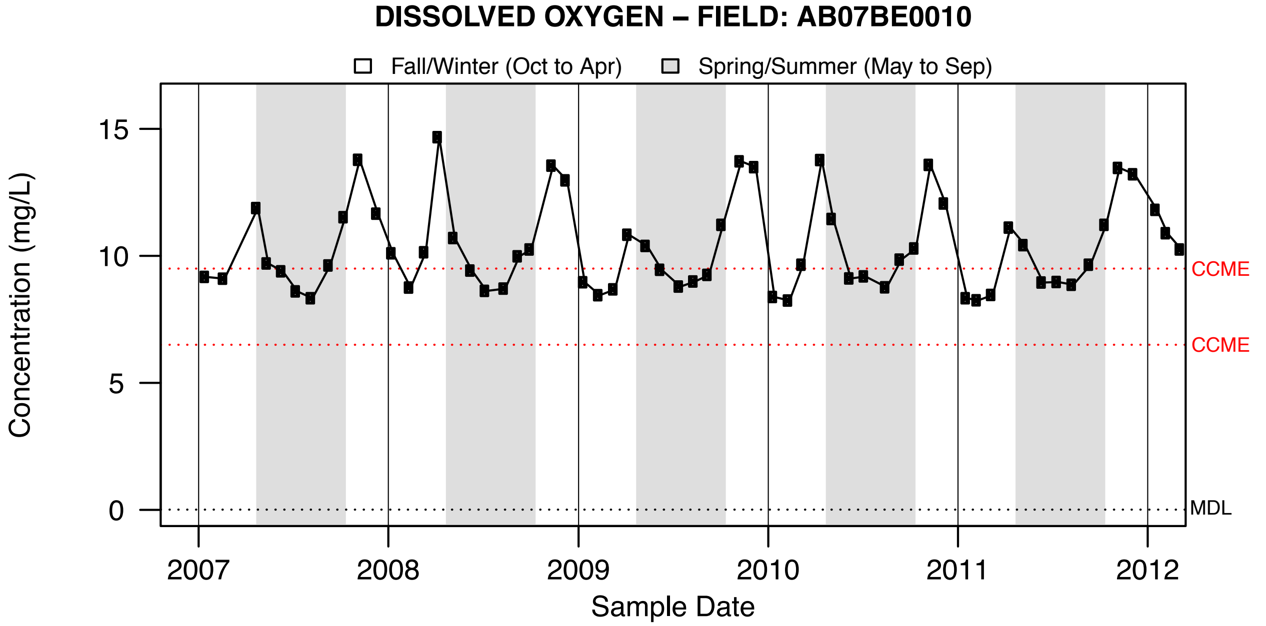
Chromium III: 8.9 Chromium VI: 1.0

Figure A1.58: CHROMIUM DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A1.59: COPPER DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA



Cold water biota: early life stages = 9.5 mg/L; other life stages = 6.5 mg/L

Figure A1.60: DISSOLVED OXYGEN - FIELD: AB07BE0010 - AT TOWN OF ATHABASCA

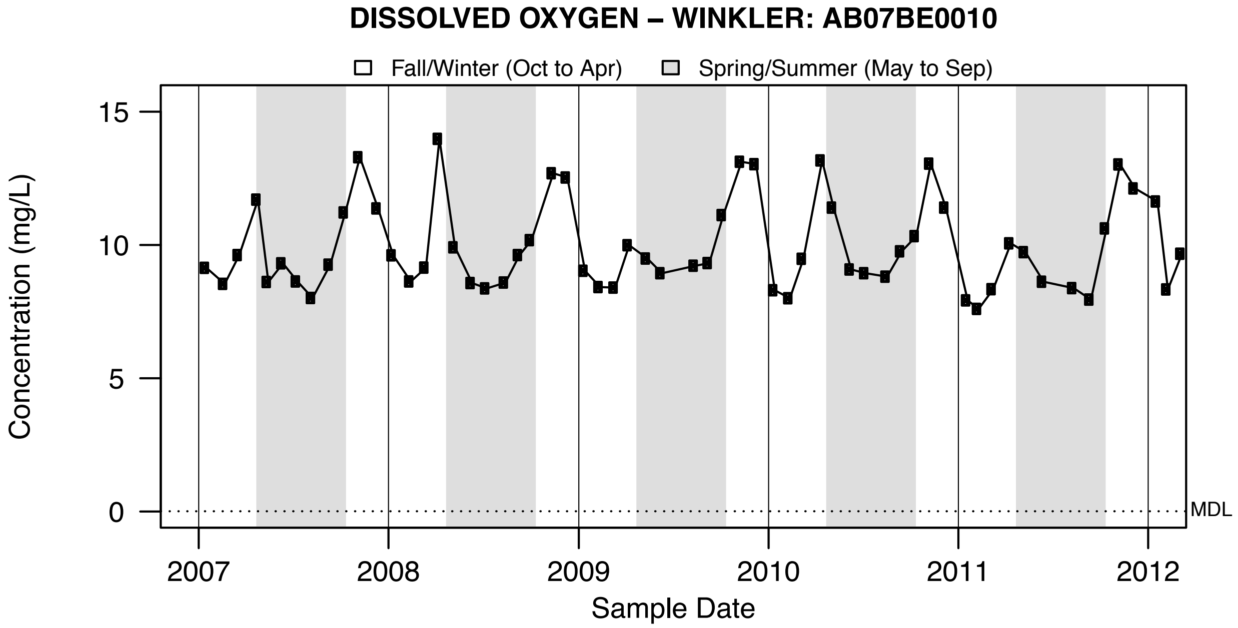


Figure A1.61: DISSOLVED OXYGEN - WINKLER: AB07BE0010 - AT TOWN OF ATHABASCA

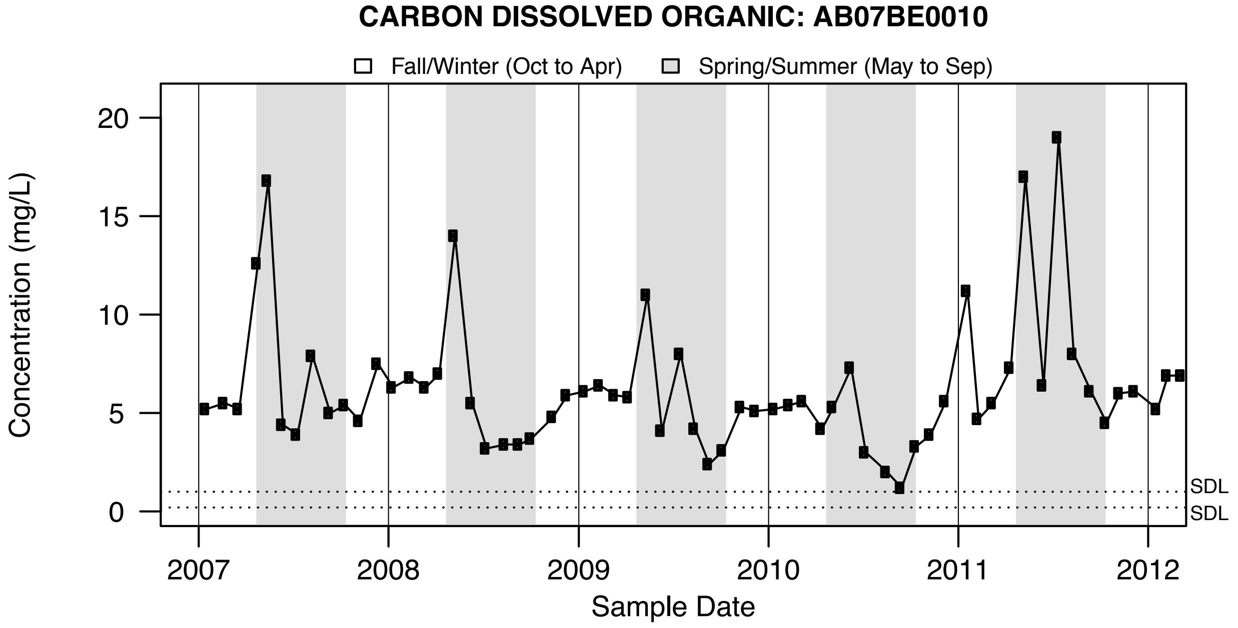


Figure A1.62: CARBON DISSOLVED ORGANIC: AB07BE0010 - AT TOWN OF ATHABASCA

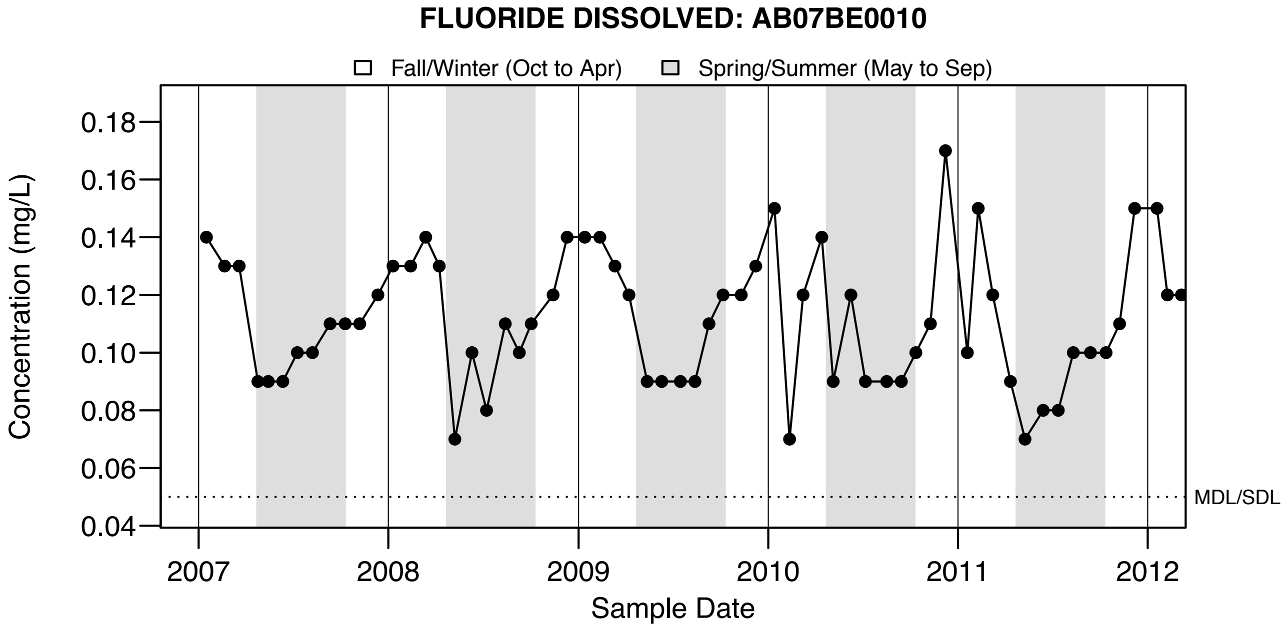


Figure A1.63: FLUORIDE DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

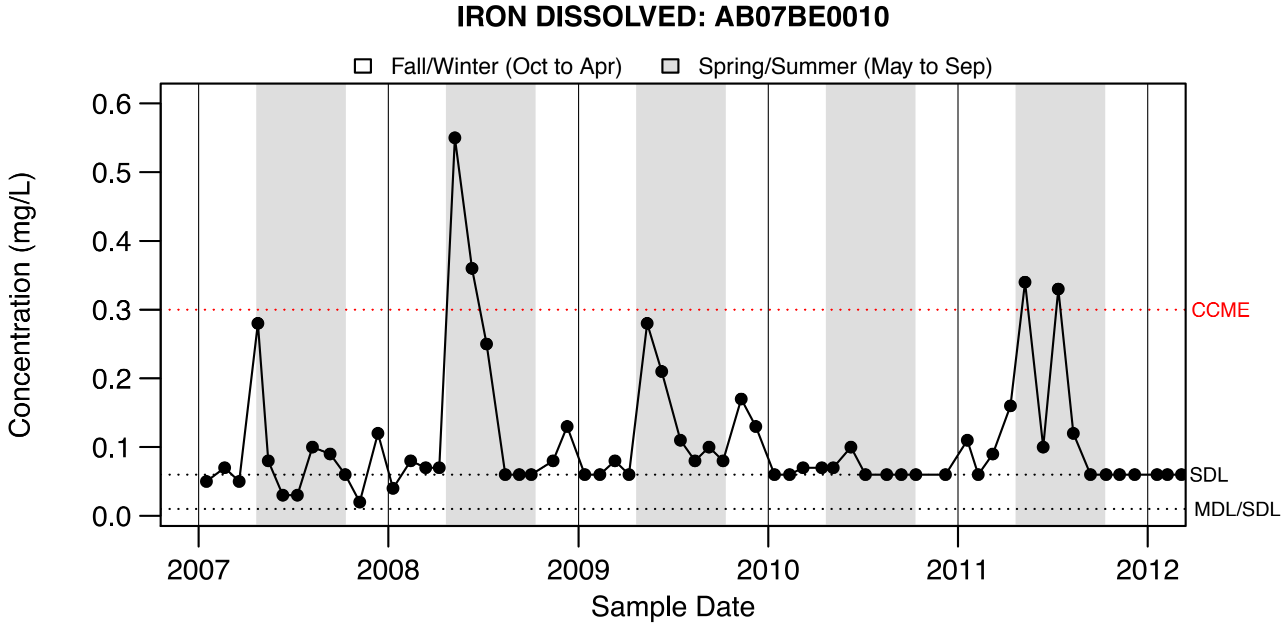


Figure A1.64: IRON DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

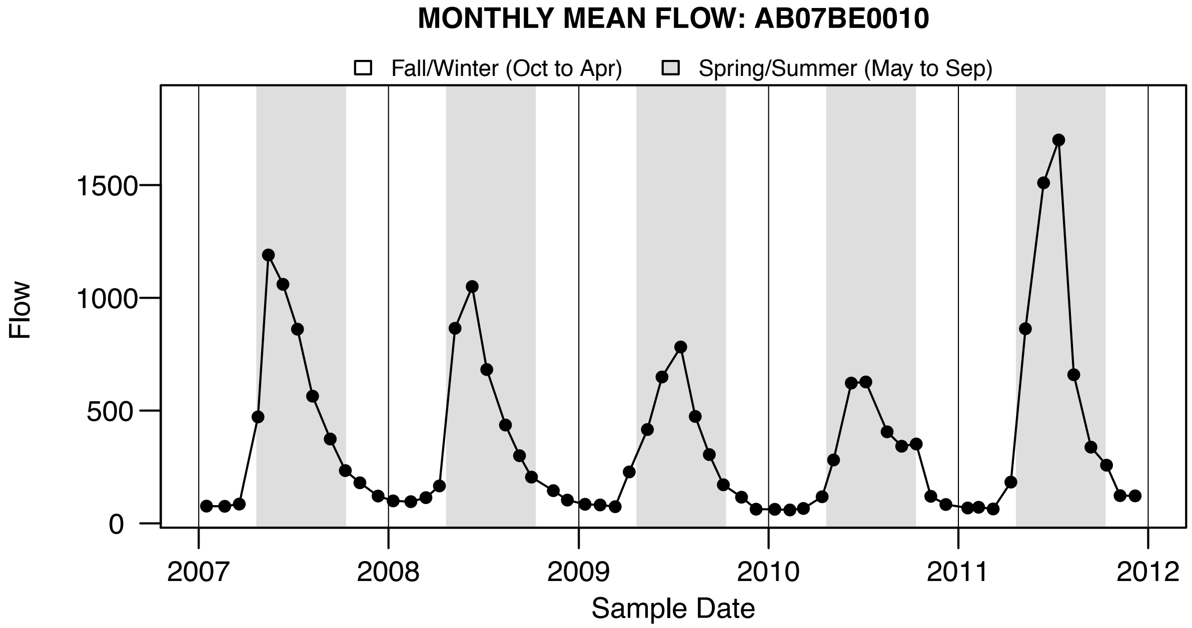


Figure A1.65: MONTHLY MEAN FLOW: AB07BE0010 - AT TOWN OF ATHABASCA

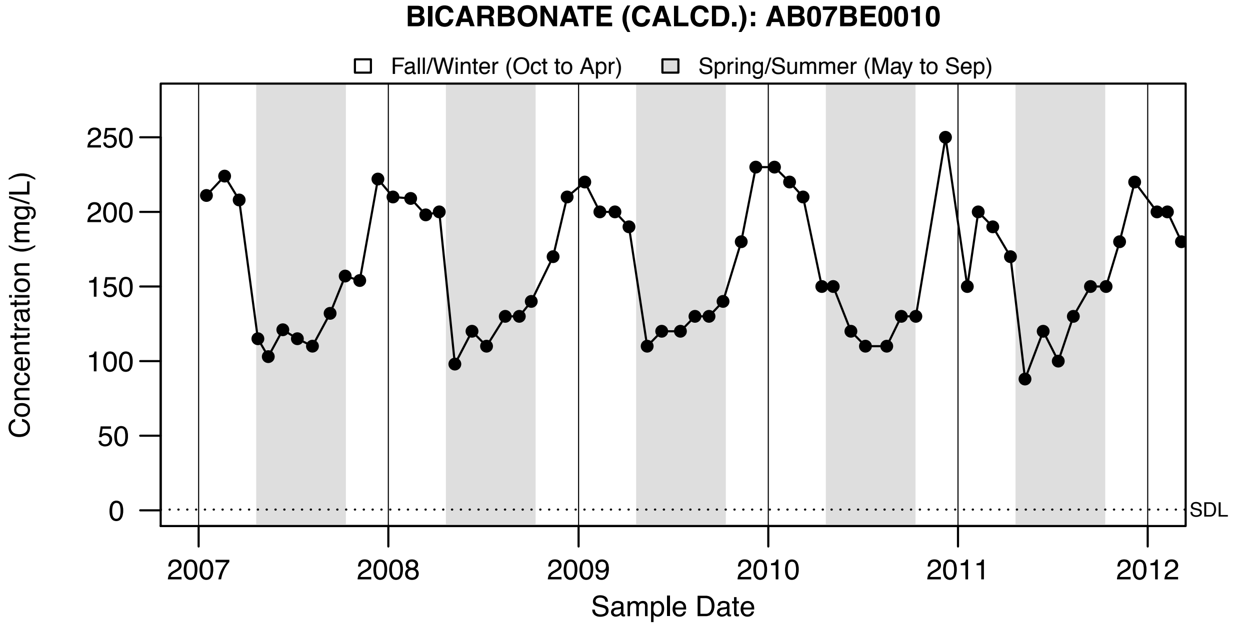


Figure A1.66: BICARBONATE (CALCD.): AB07BE0010 - AT TOWN OF ATHABASCA

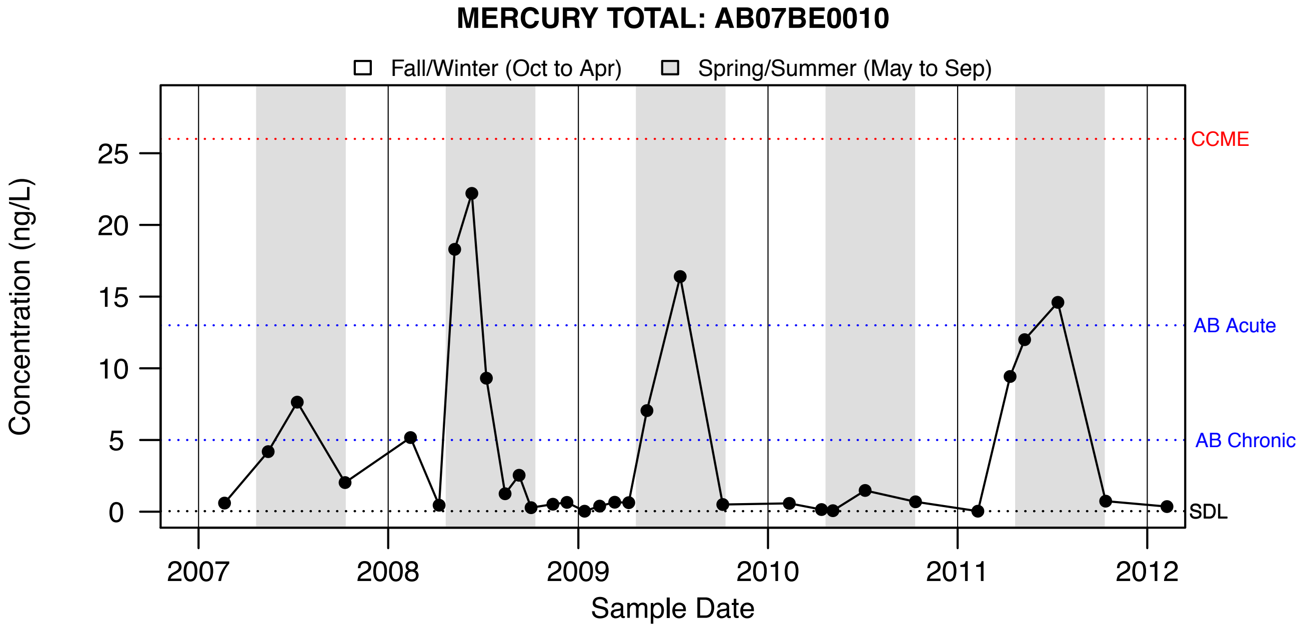


Figure A1.67: MERCURY TOTAL: AB07BE0010 - AT TOWN OF ATHABASCA

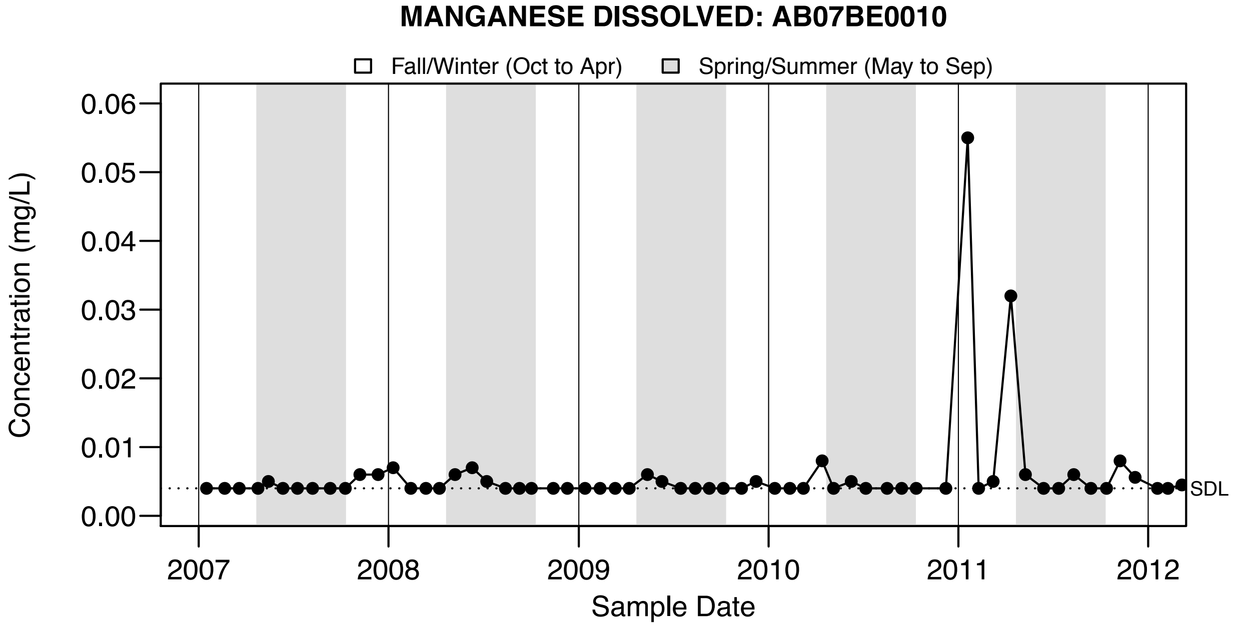


Figure A1.68: MANGANESE DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

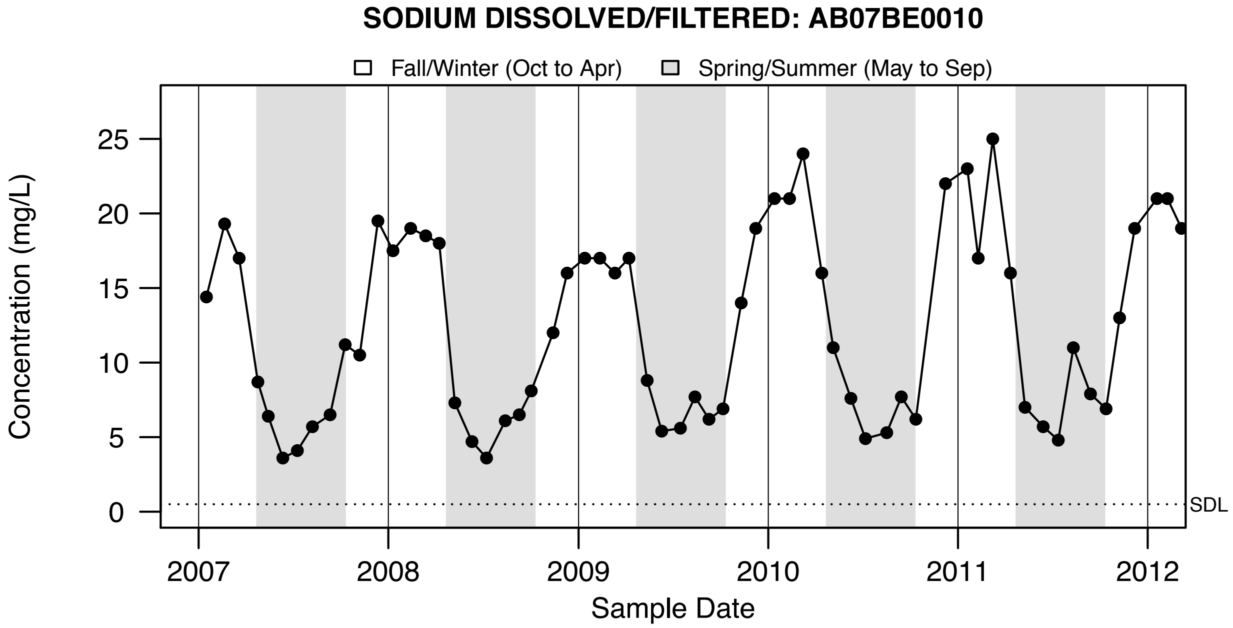
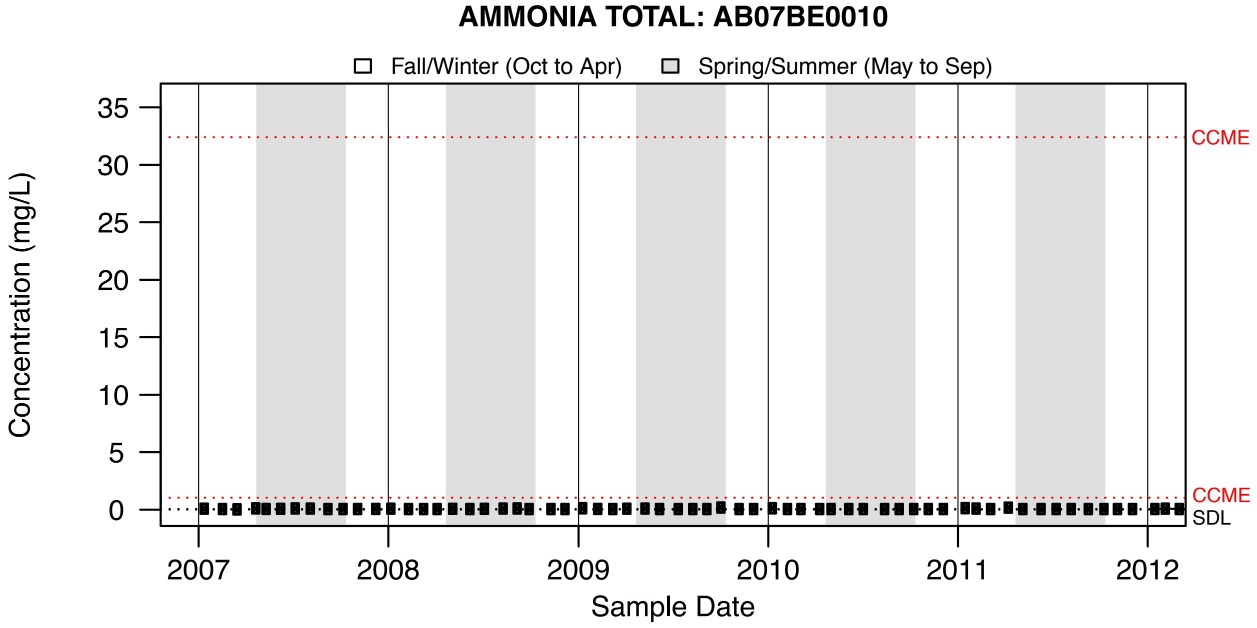
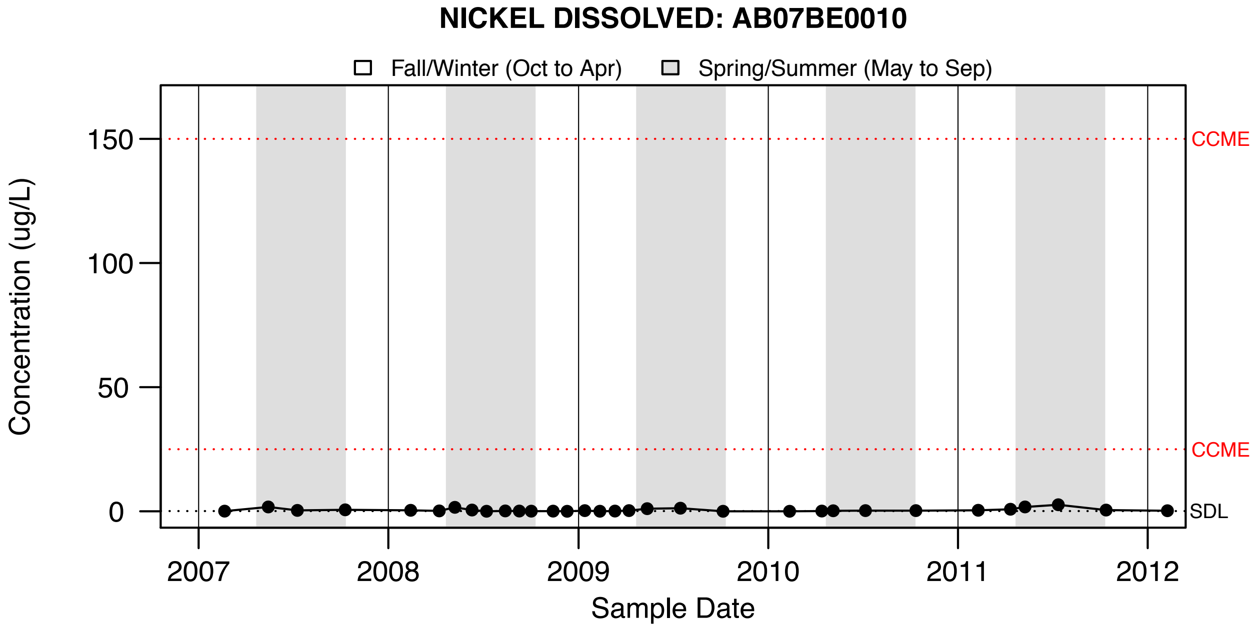


Figure A1.69: SODIUM DISSOLVED/FILTERED: AB07BE0010 - AT TOWN OF ATHABASCA



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A1.70: AMMONIA TOTAL: AB07BE0010 - AT TOWN OF ATHABASCA



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A1.71: NICKEL DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

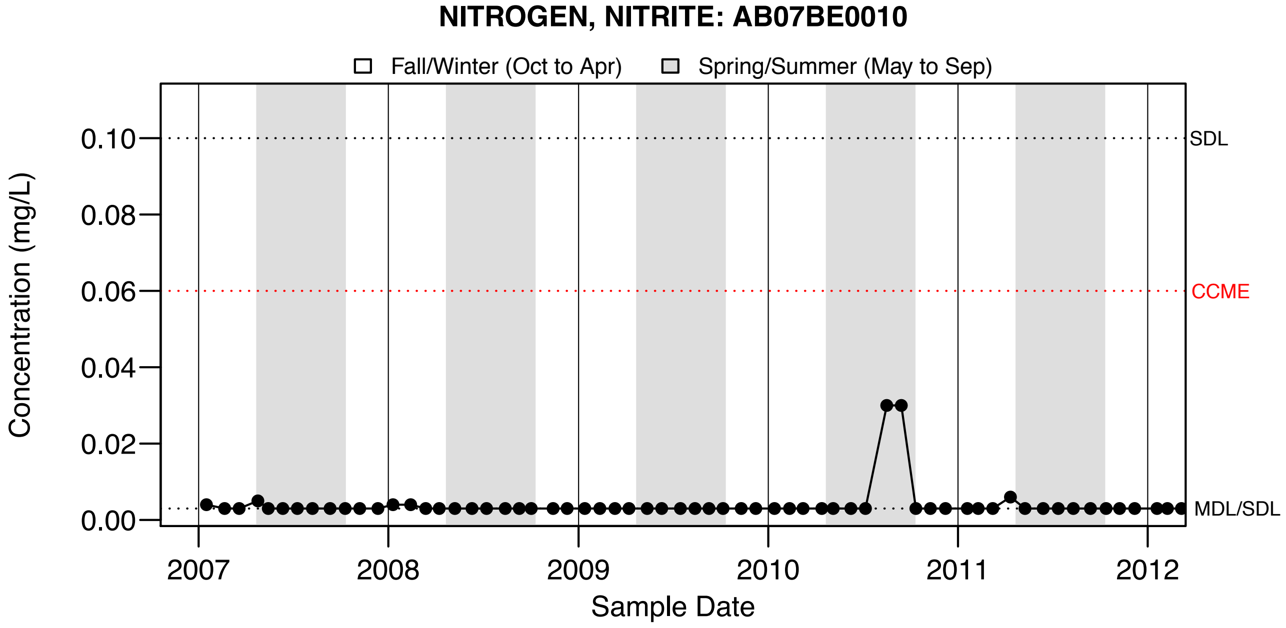
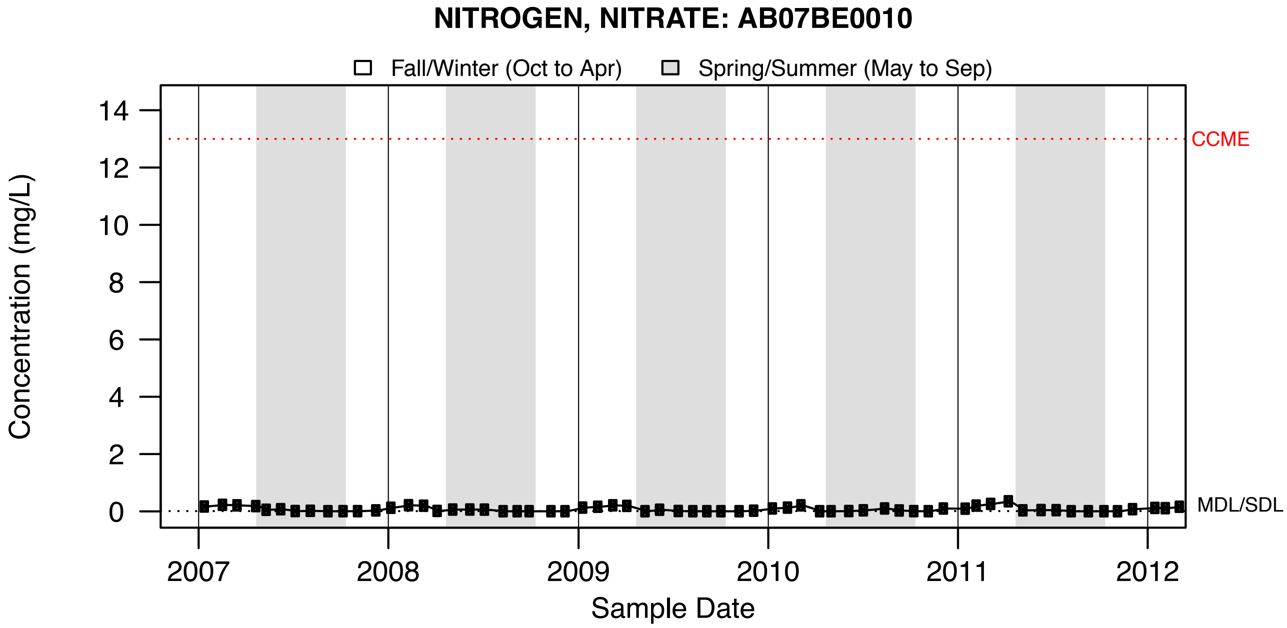


Figure A1.72: NITROGEN, NITRITE: AB07BE0010 - AT TOWN OF ATHABASCA



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A1.73: NITROGEN, NITRATE: AB07BE0010 - AT TOWN OF ATHABASCA

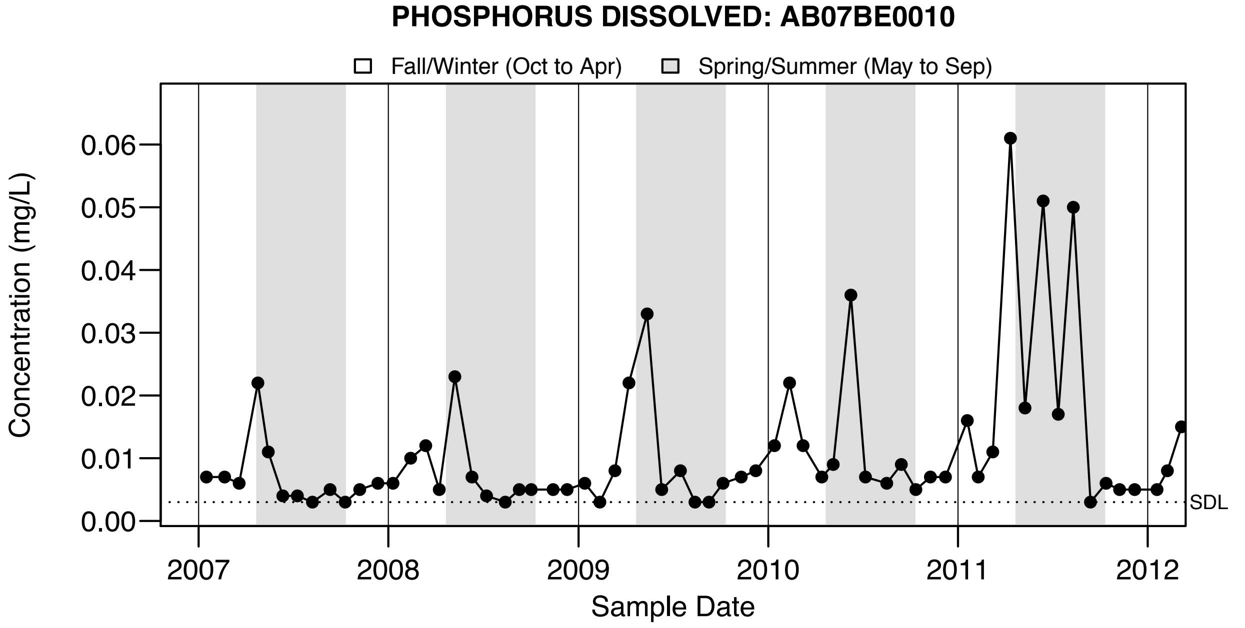


Figure A1.74: PHOSPHORUS DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

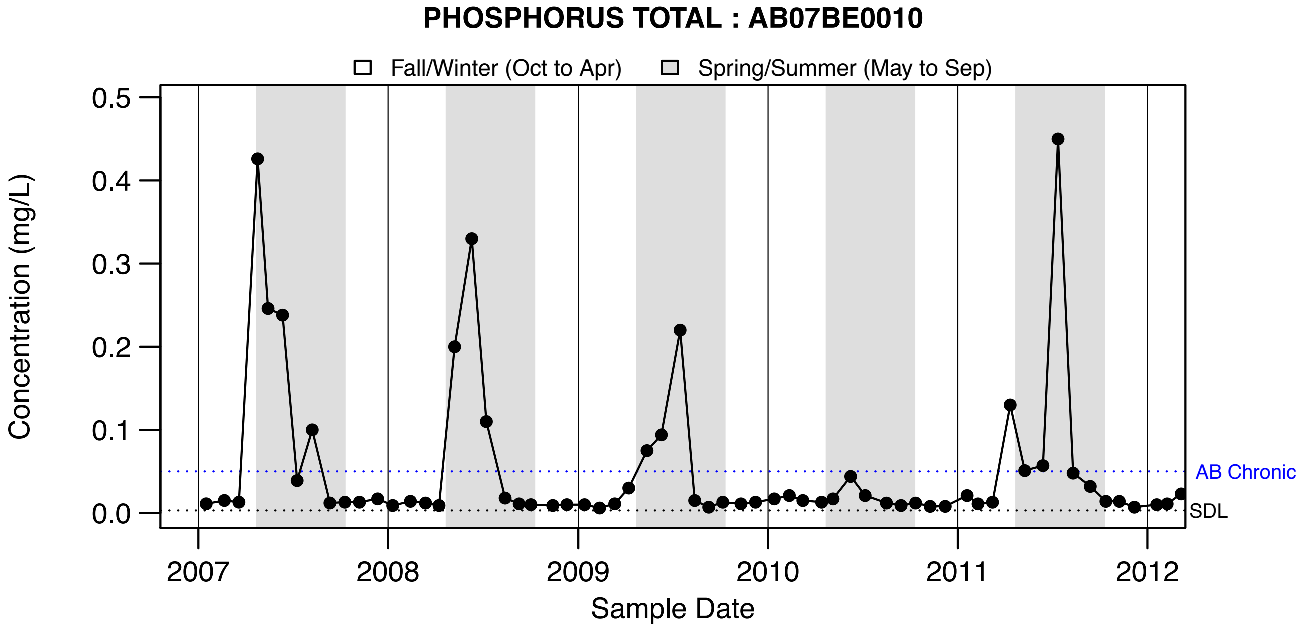
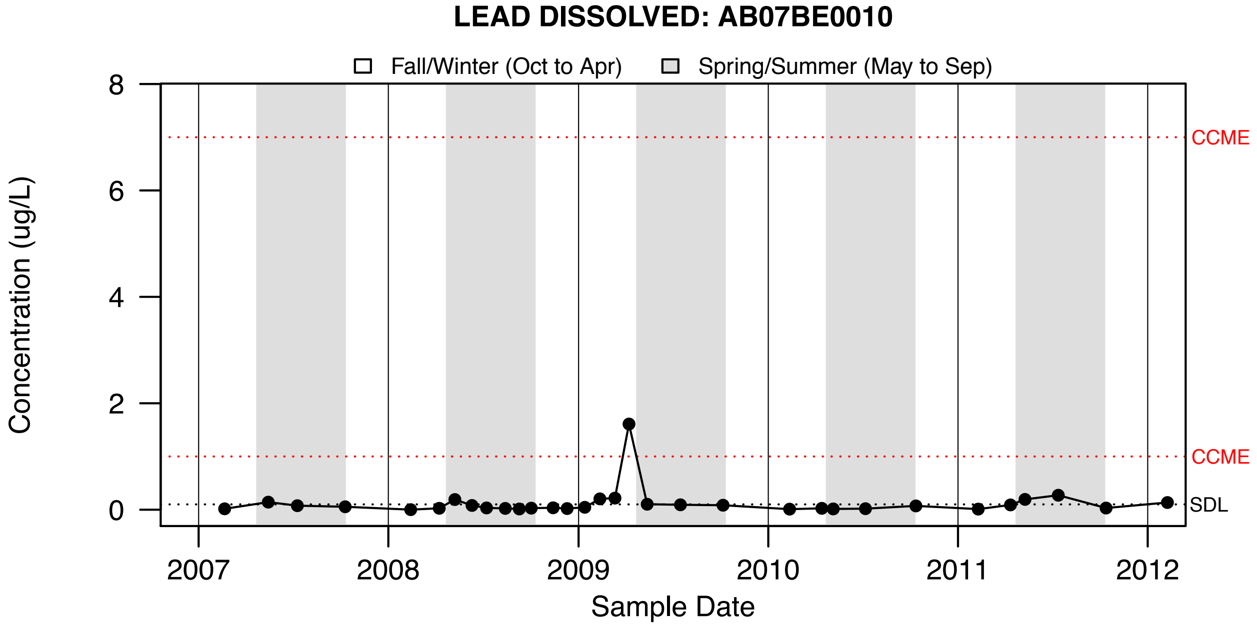


Figure A1.75: PHOSPHORUS TOTAL : AB07BE0010 - AT TOWN OF ATHABASCA



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A1.76: LEAD DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

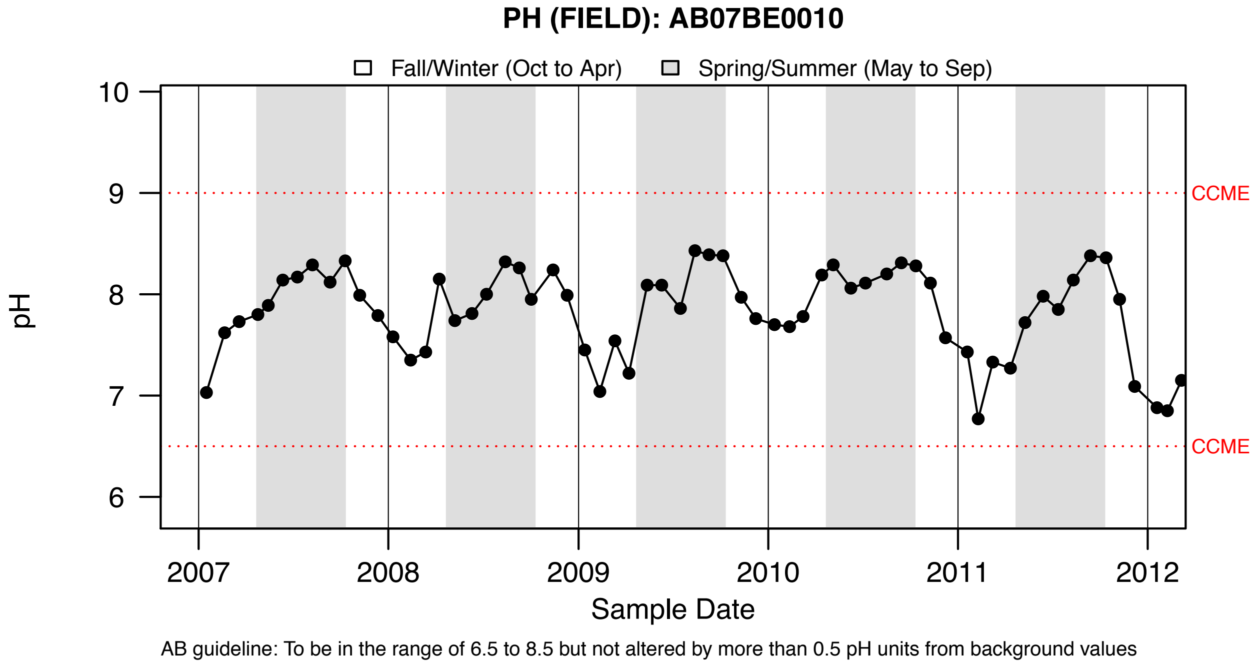


Figure A1.77: PH (FIELD): AB07BE0010 - AT TOWN OF ATHABASCA

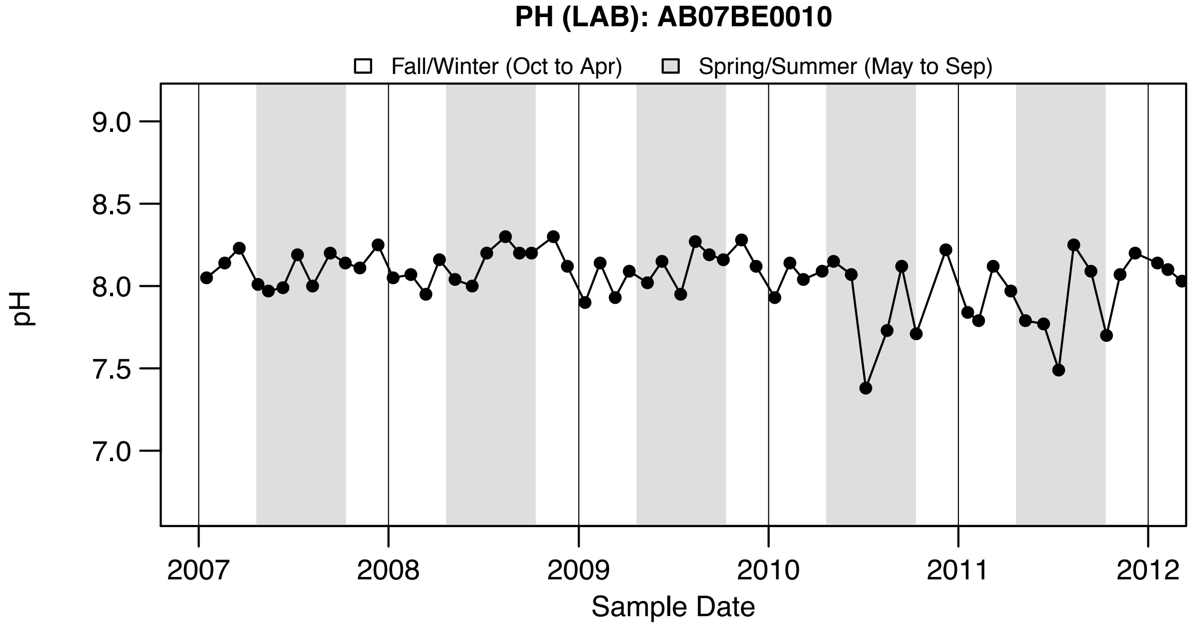


Figure A1.78: PH (LAB): AB07BE0010 - AT TOWN OF ATHABASCA

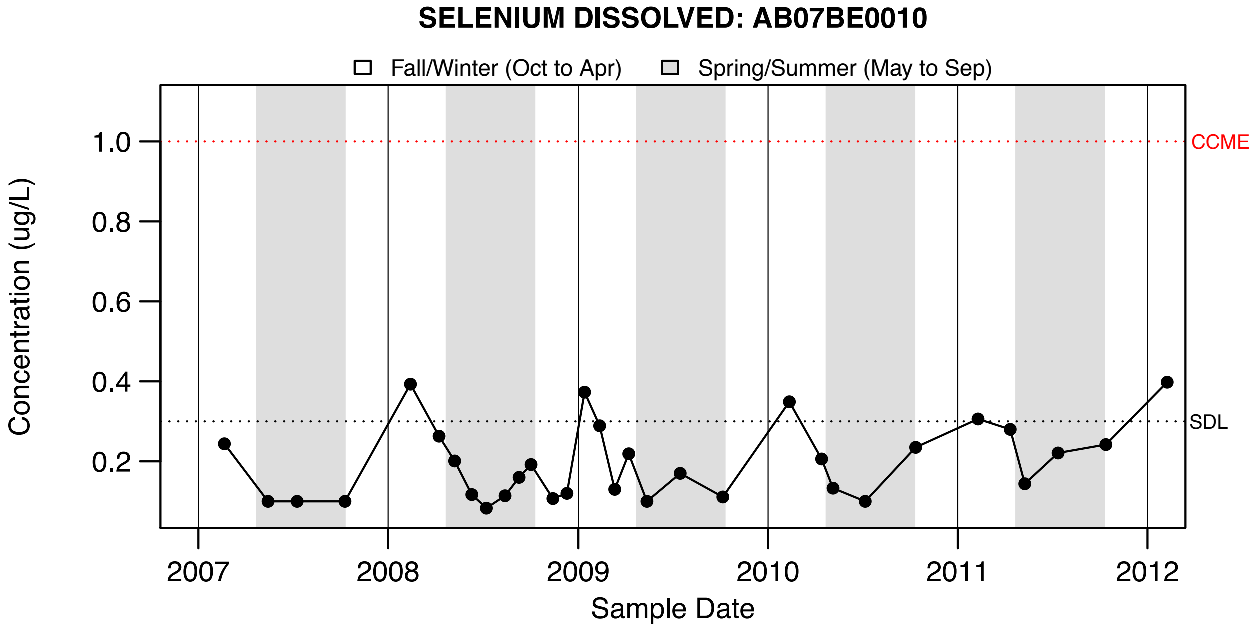


Figure A1.79: SELENIUM DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

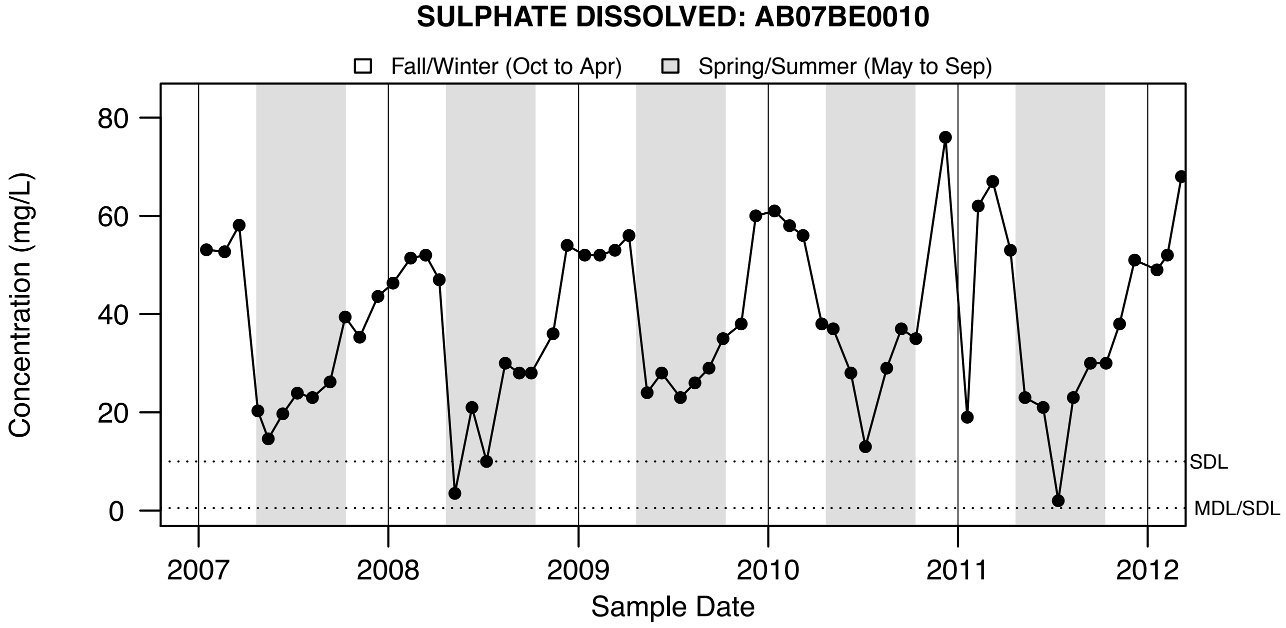


Figure A1.80: SULPHATE DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

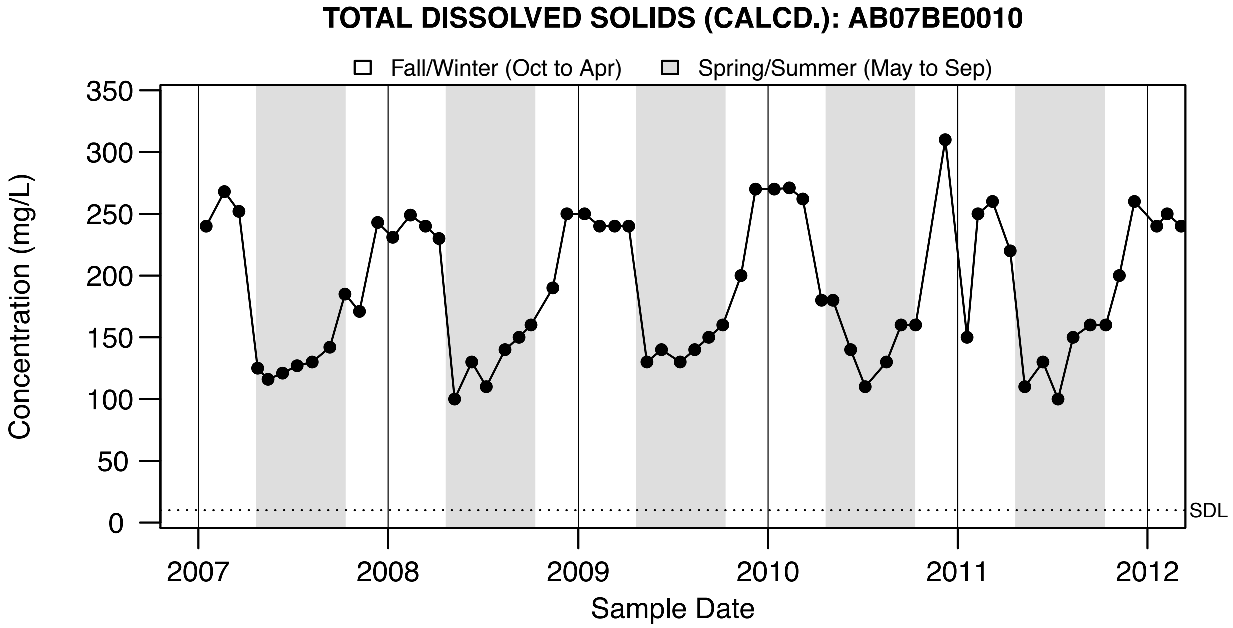
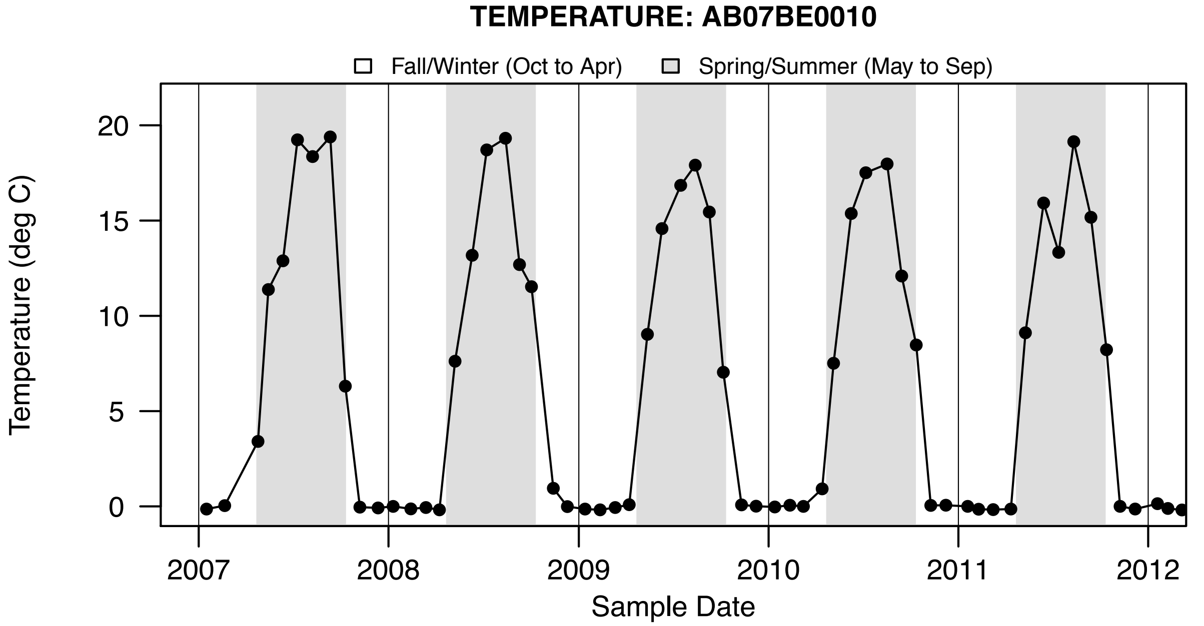


Figure A1.81: TOTAL DISSOLVED SOLIDS (CALCD.): AB07BE0010 - AT TOWN OF ATHABASCA



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A1.82: TEMPERATURE: AB07BE0010 - AT TOWN OF ATHABASCA

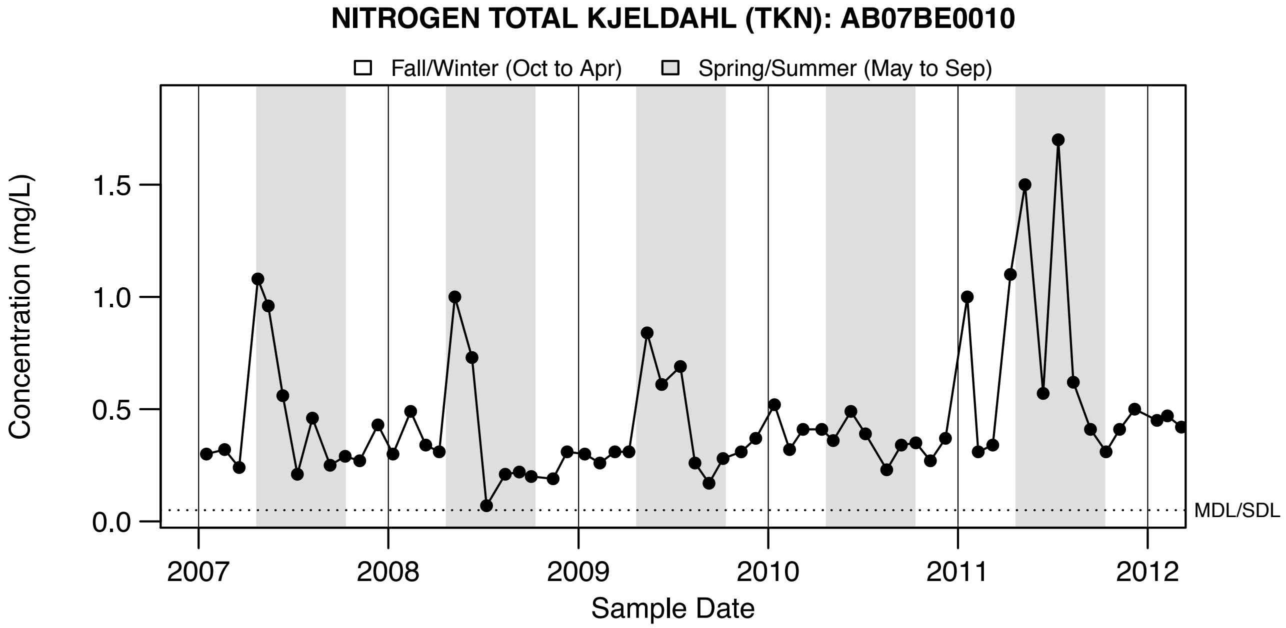
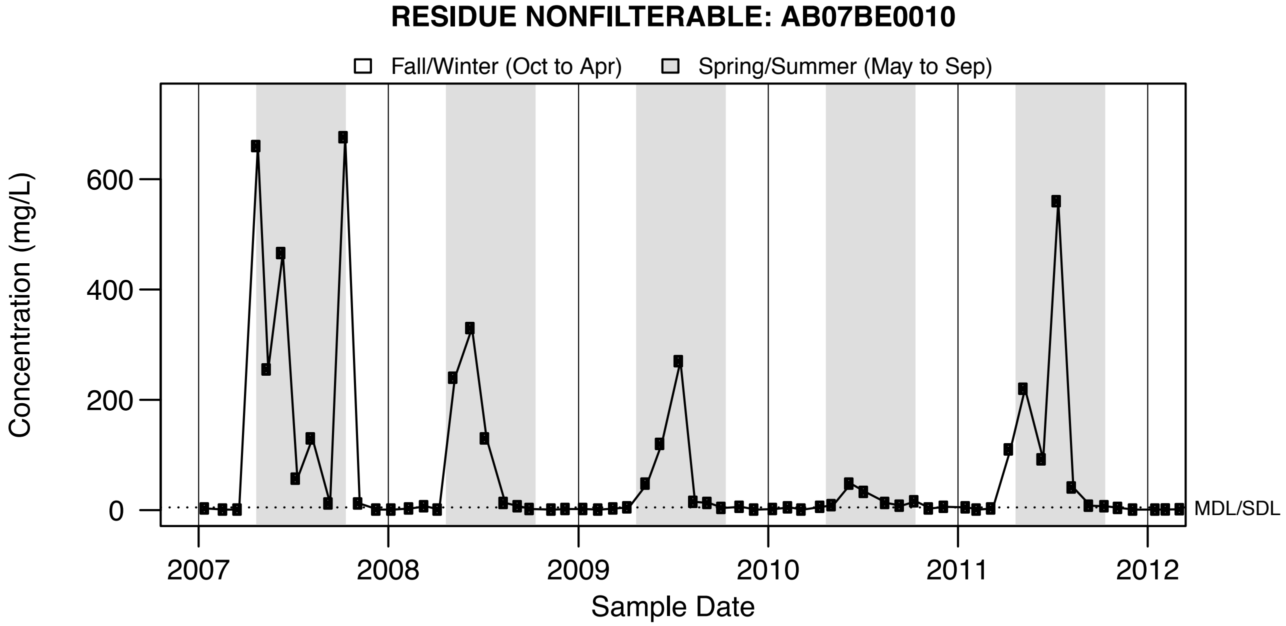


Figure A1.83: NITROGEN TOTAL KJELDAHL (TKN): AB07BE0010 - AT TOWN OF ATHABASCA



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term).
Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background
when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A1.84: RESIDUE NONFILTERABLE: AB07BE0010 - AT TOWN OF ATHABASCA

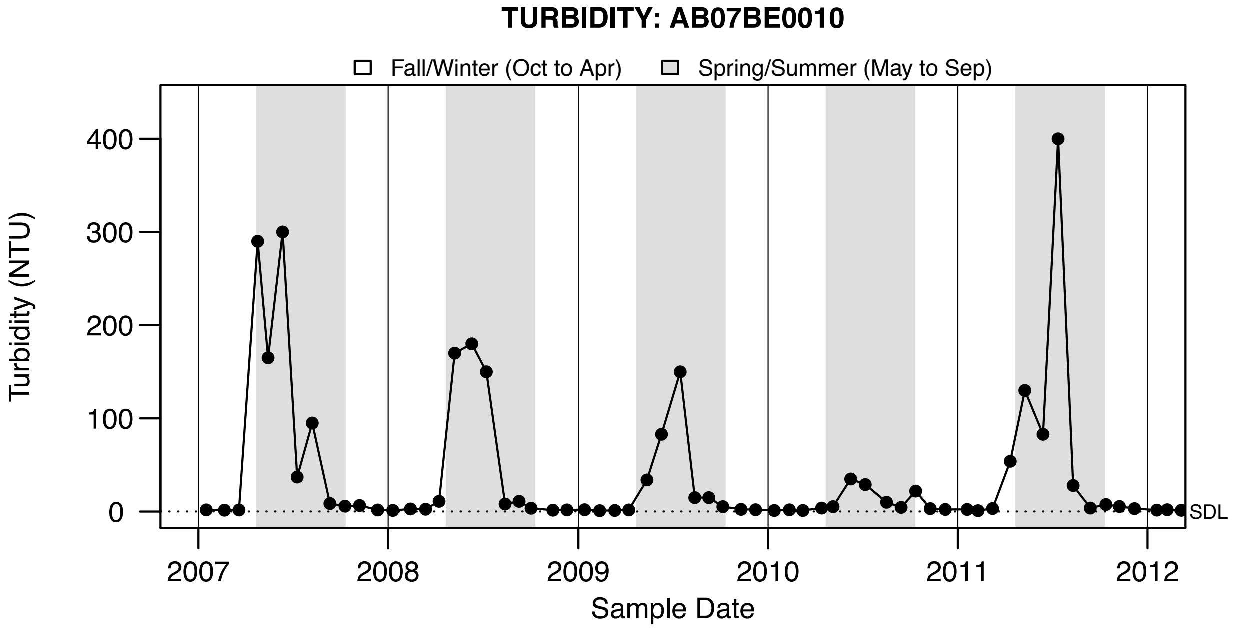


Figure A1.85: TURBIDITY: AB07BE0010 - AT TOWN OF ATHABASCA

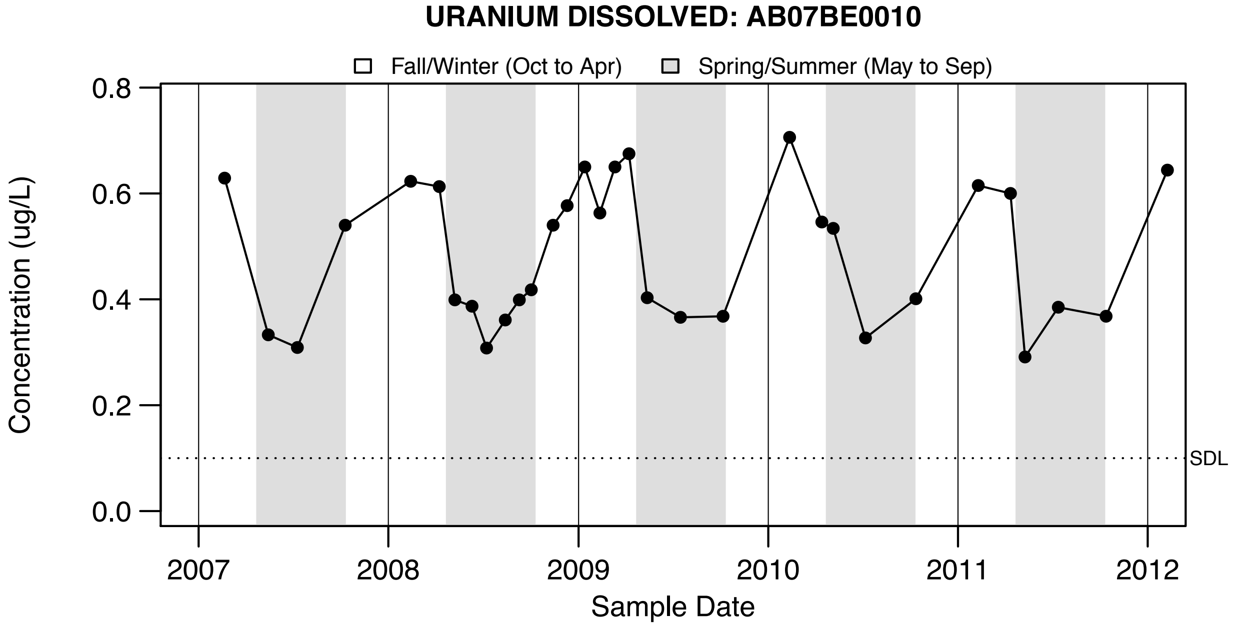


Figure A1.86: URANIUM DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

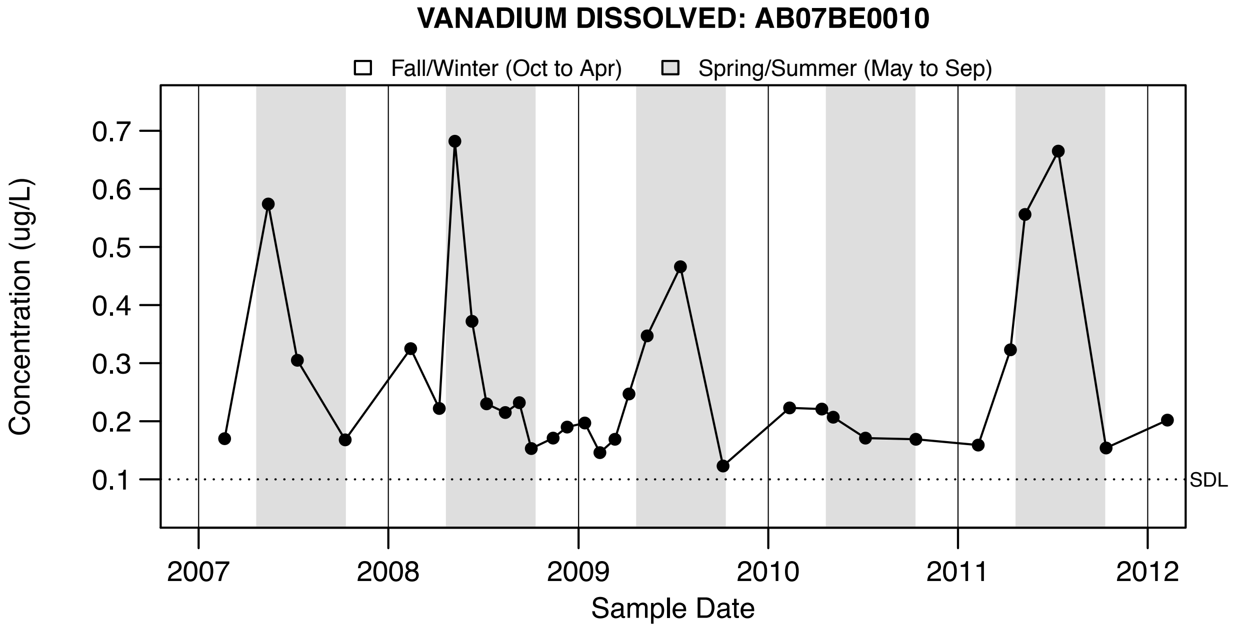


Figure A1.87: VANADIUM DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA

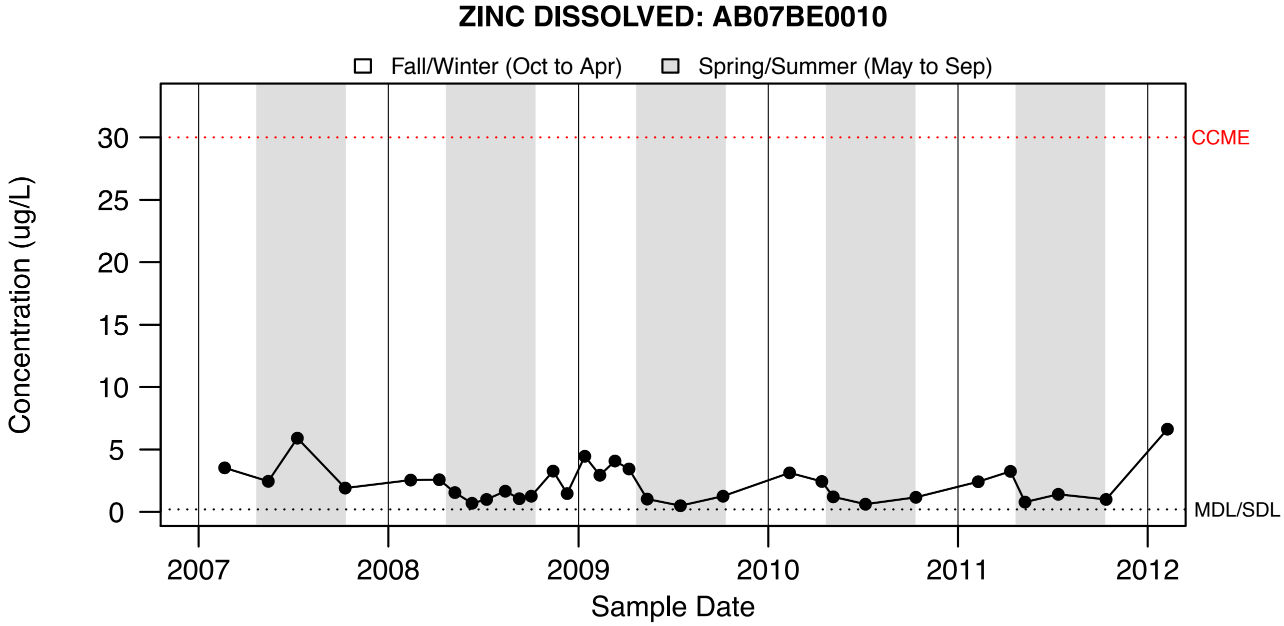
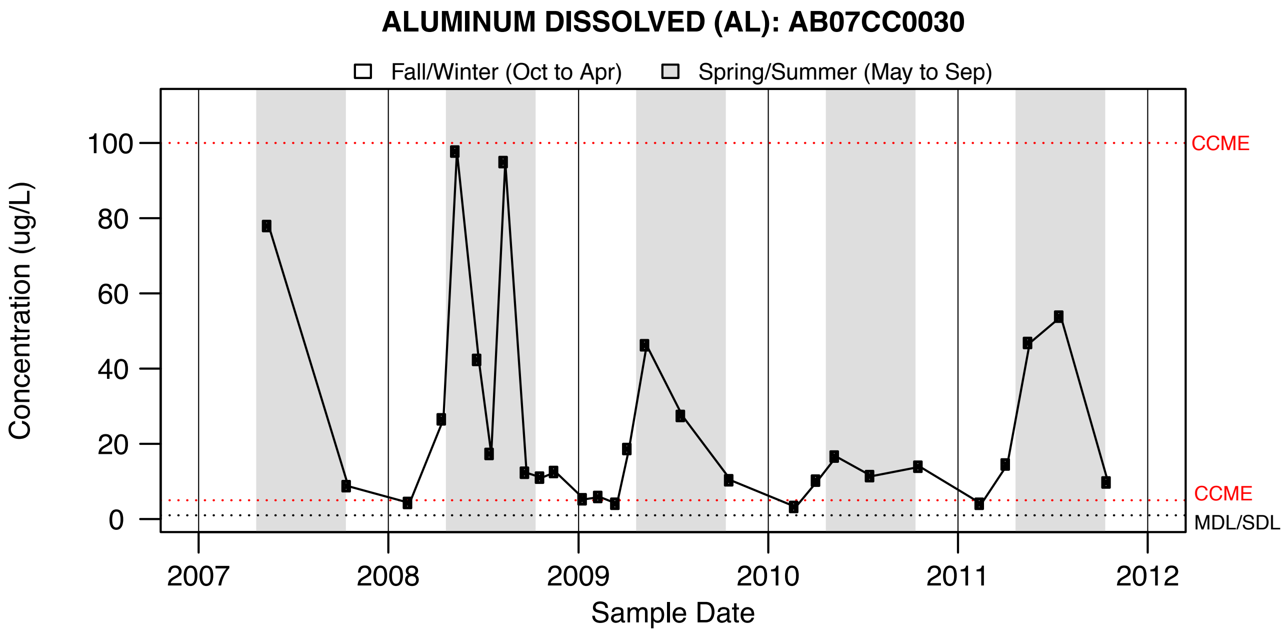
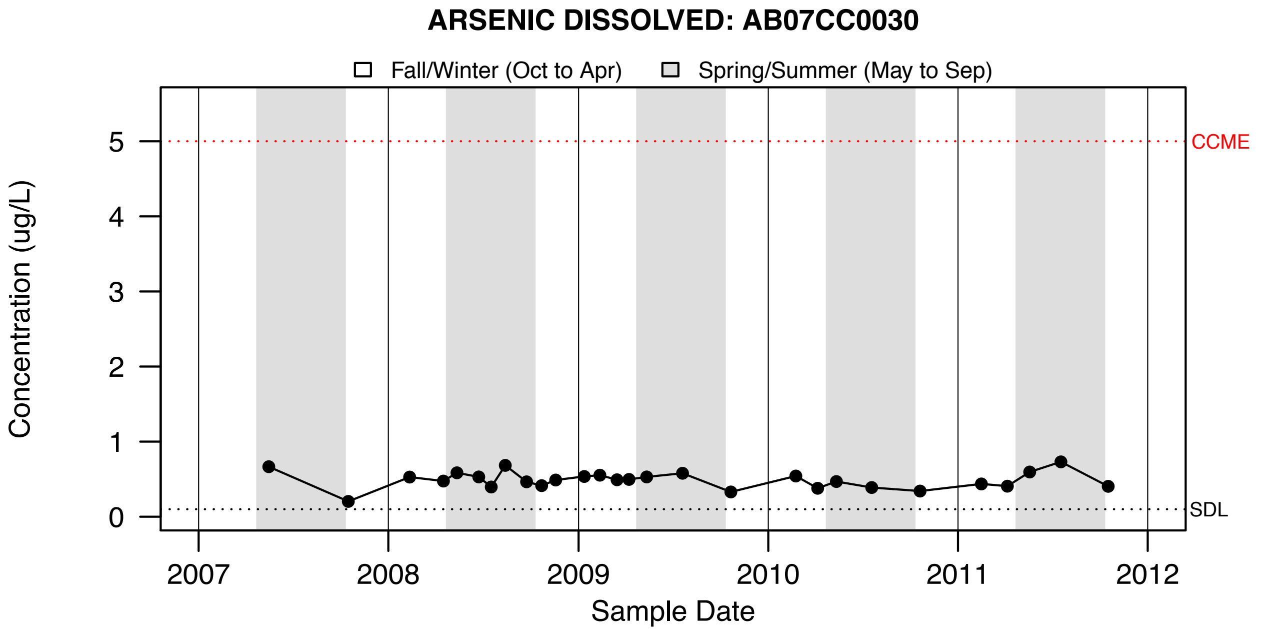


Figure A1.88: ZINC DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A1.89: ALUMINUM DISSOLVED (AL): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



AB guidelines state Total Arsenic; CCME does not specify

Figure A1.90: ARSENIC DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

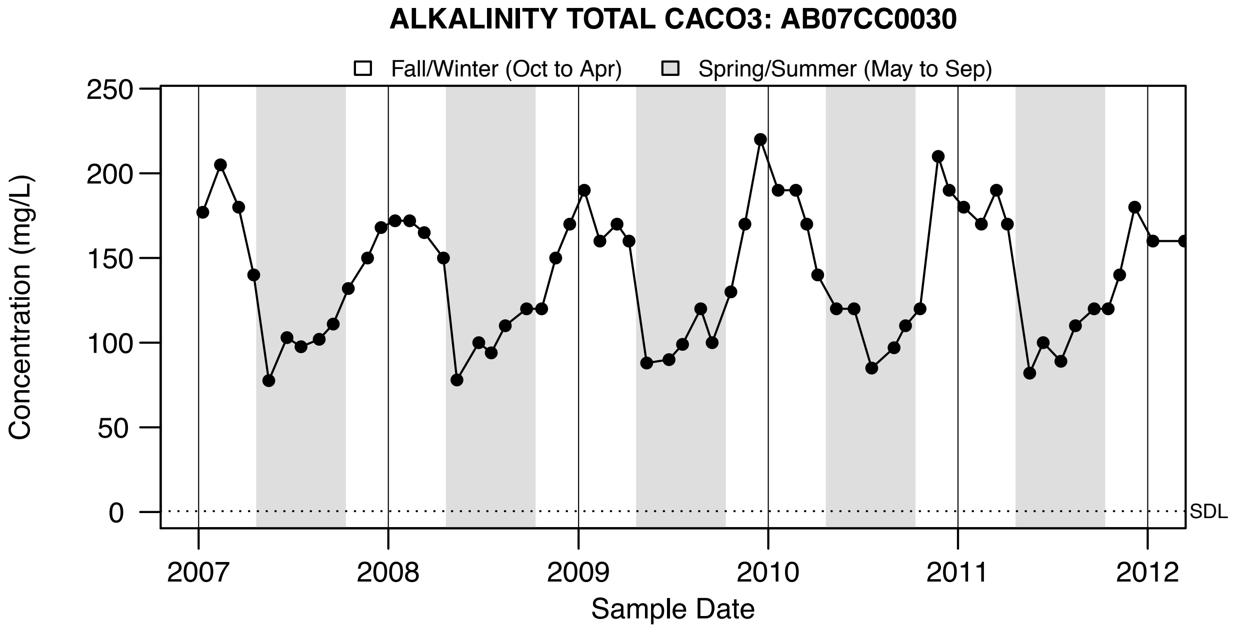


Figure A1.91: ALKALINITY TOTAL CACO3: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

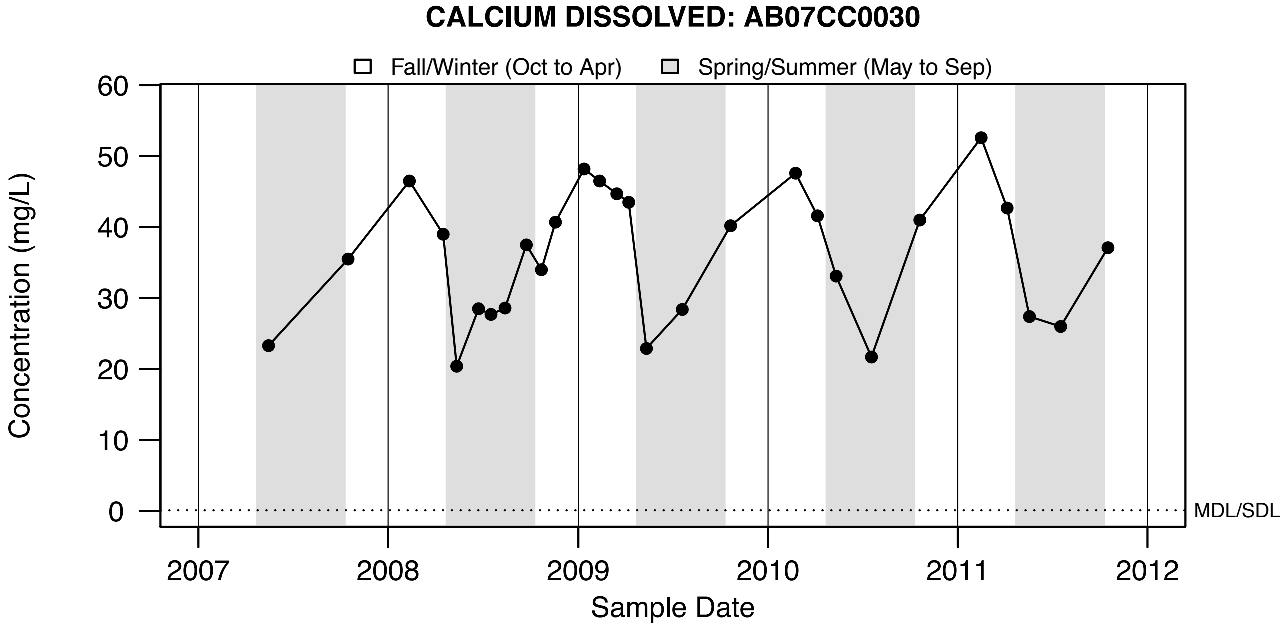


Figure A1.92: CALCIUM DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

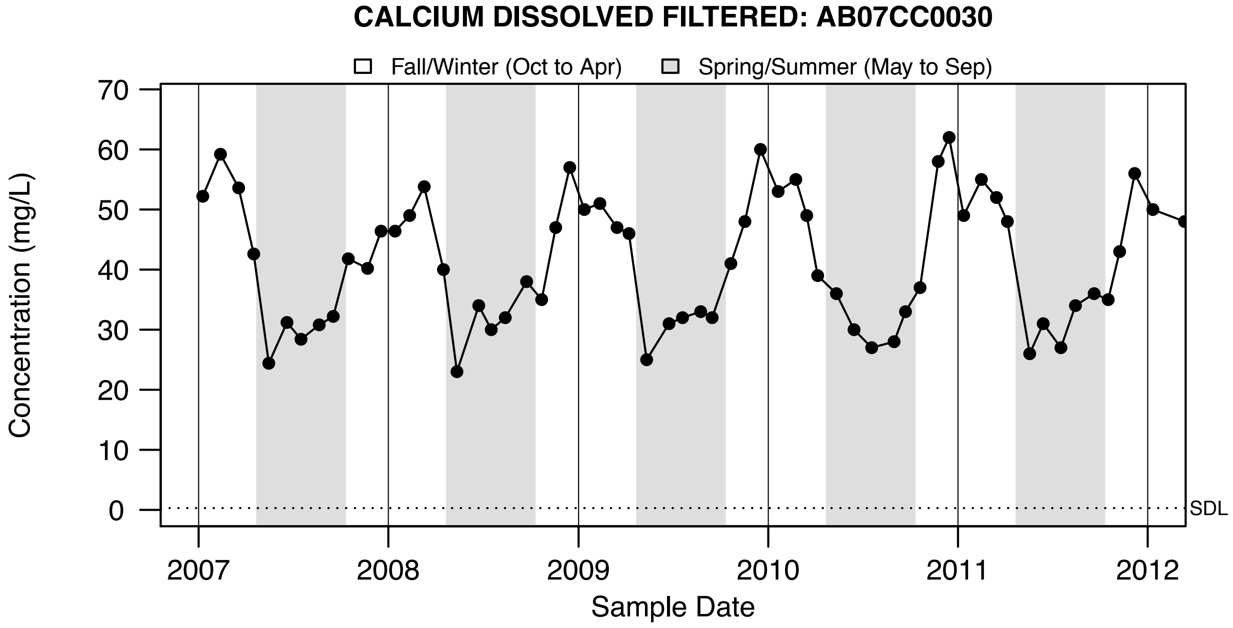


Figure A1.93: CALCIUM DISSOLVED FILTERED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

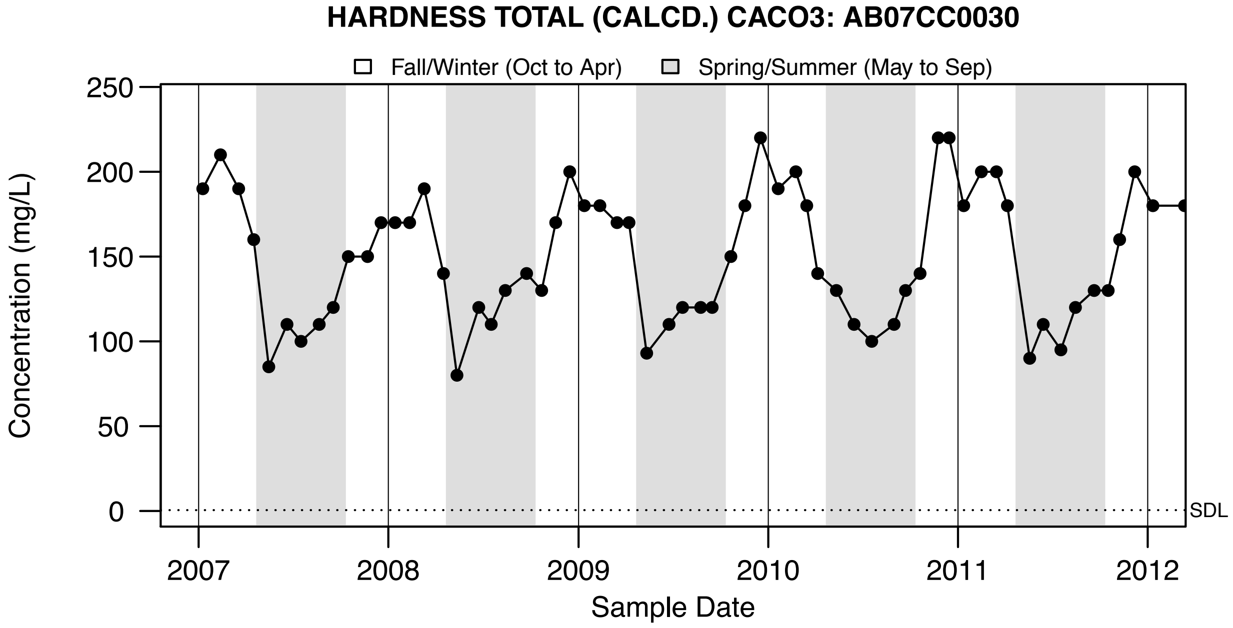


Figure A1.94: HARDNESS TOTAL (CALCD.) CACO3: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

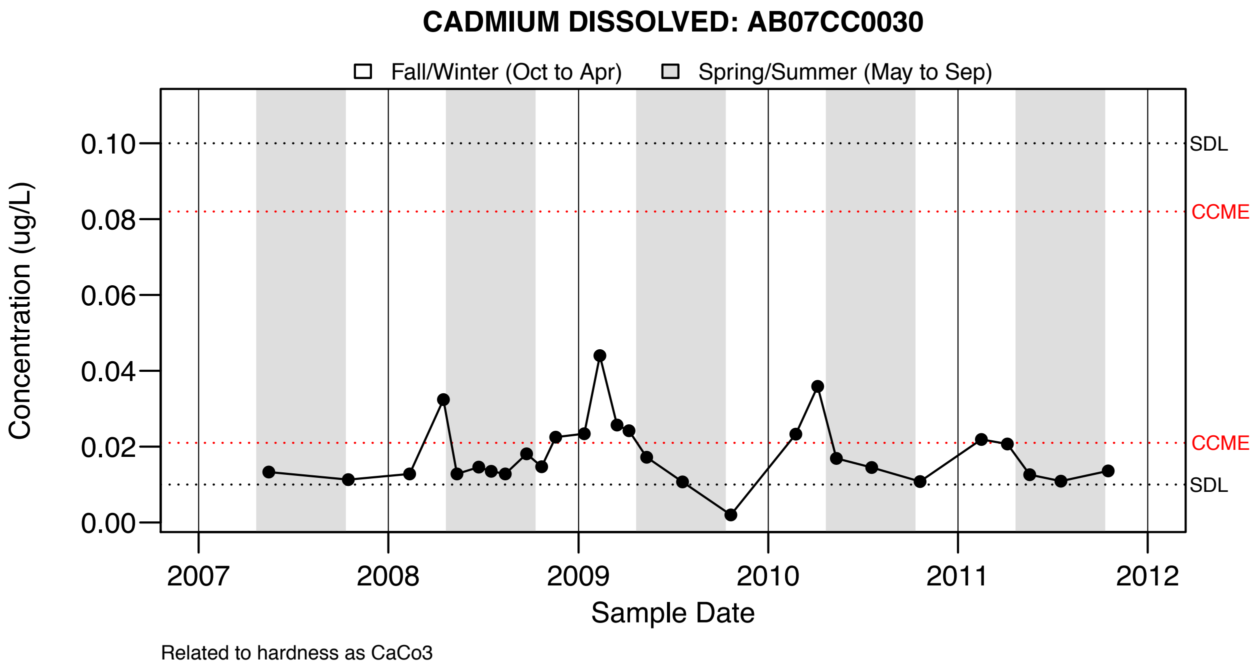


Figure A1.95: CADMIUM DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

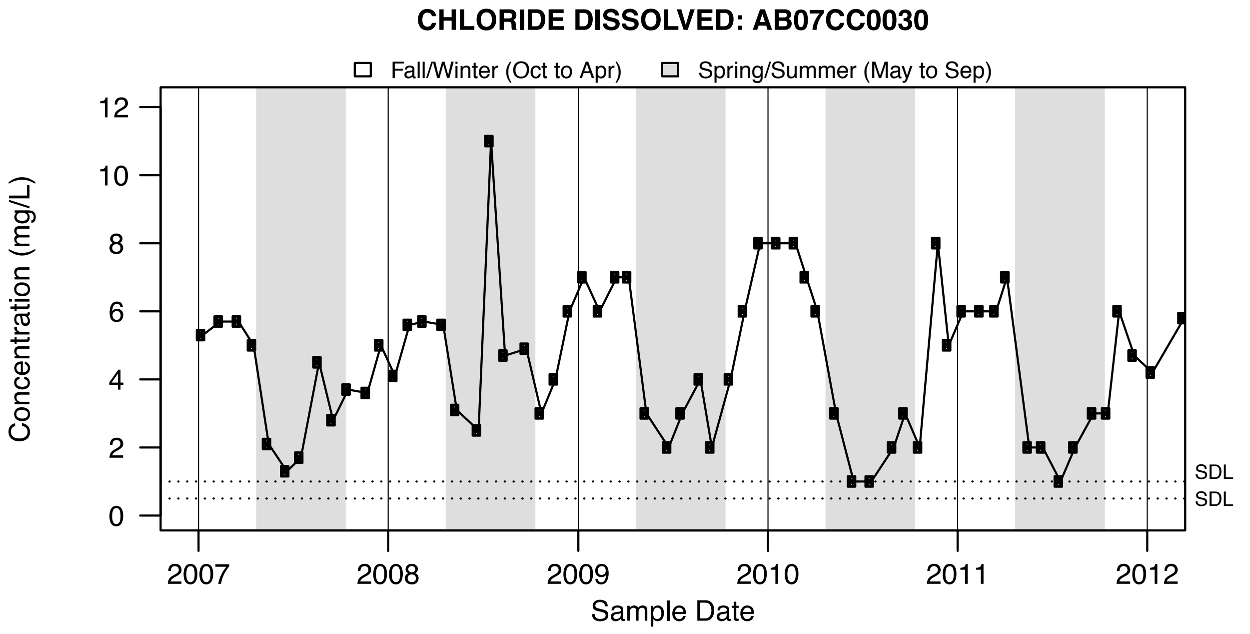


Figure A1.96: CHLORIDE DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

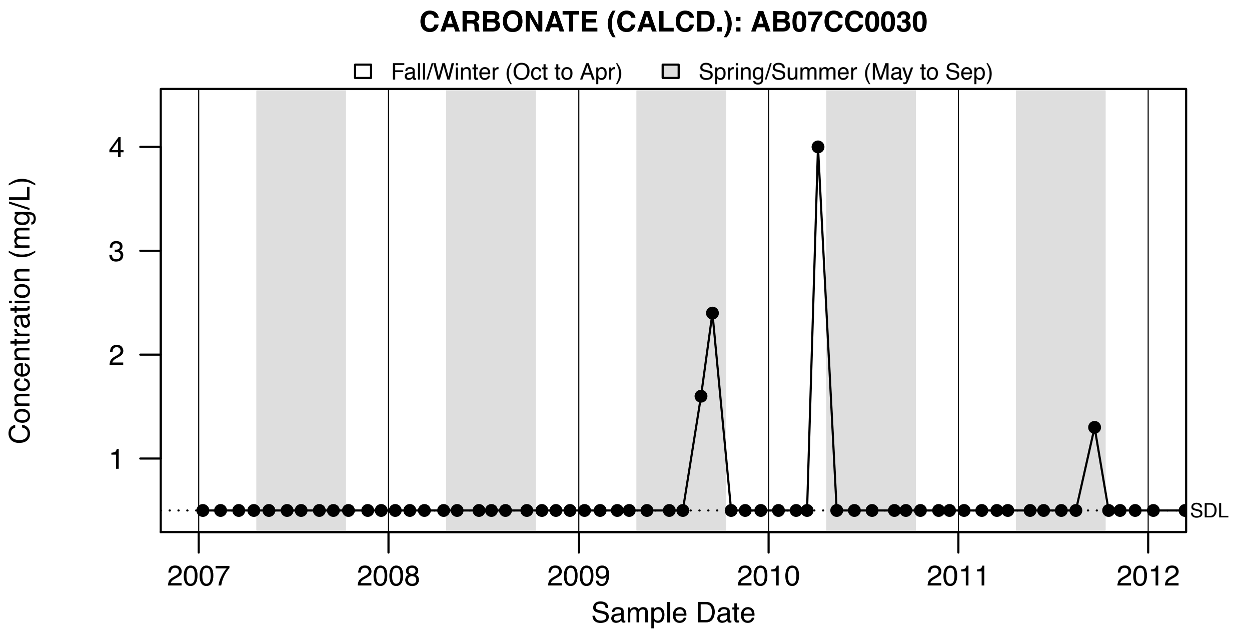


Figure A1.97: CARBONATE (CALCD.): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

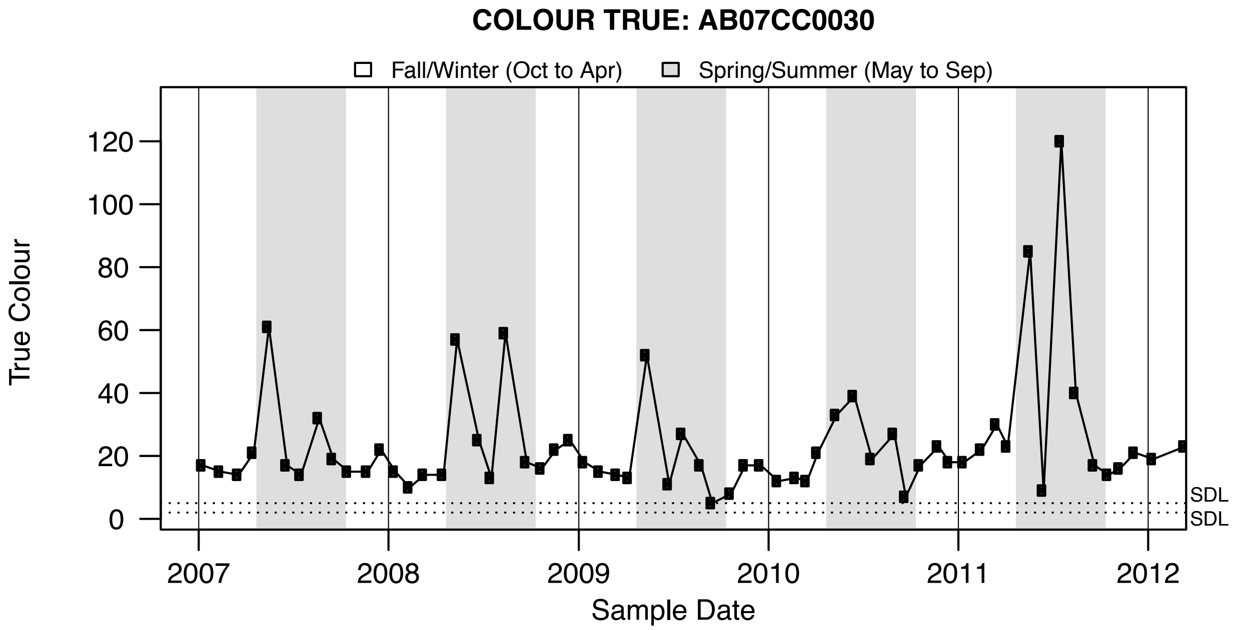


Figure A1.98: COLOUR TRUE: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

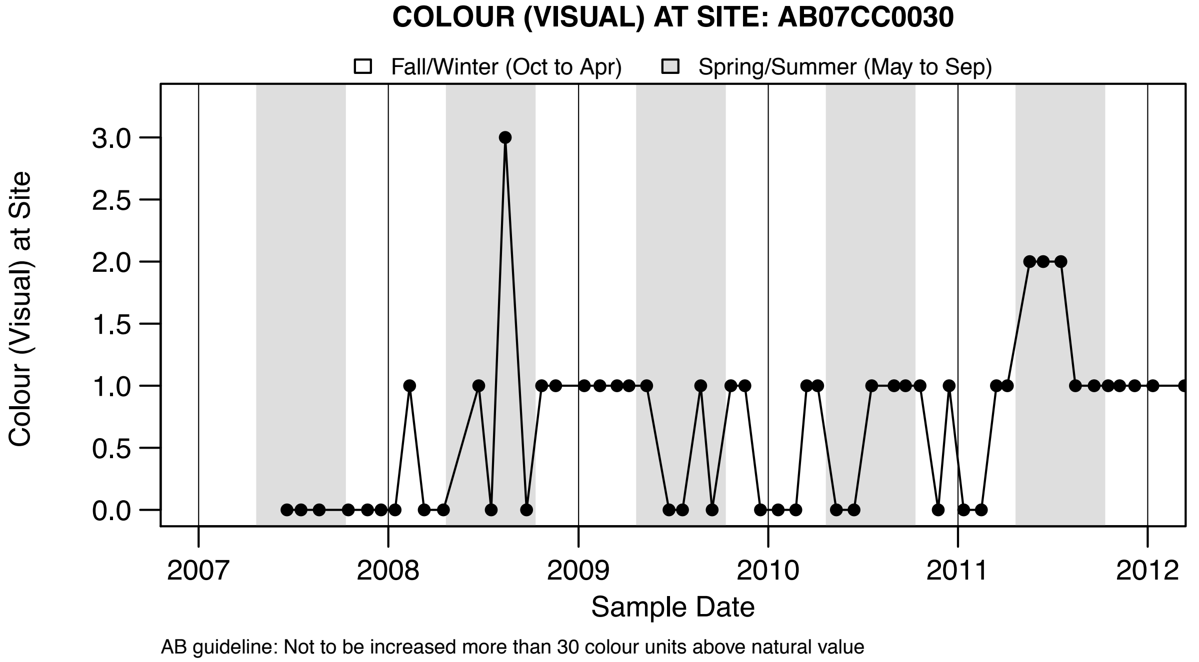


Figure A1.99: COLOUR (VISUAL) AT SITE: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

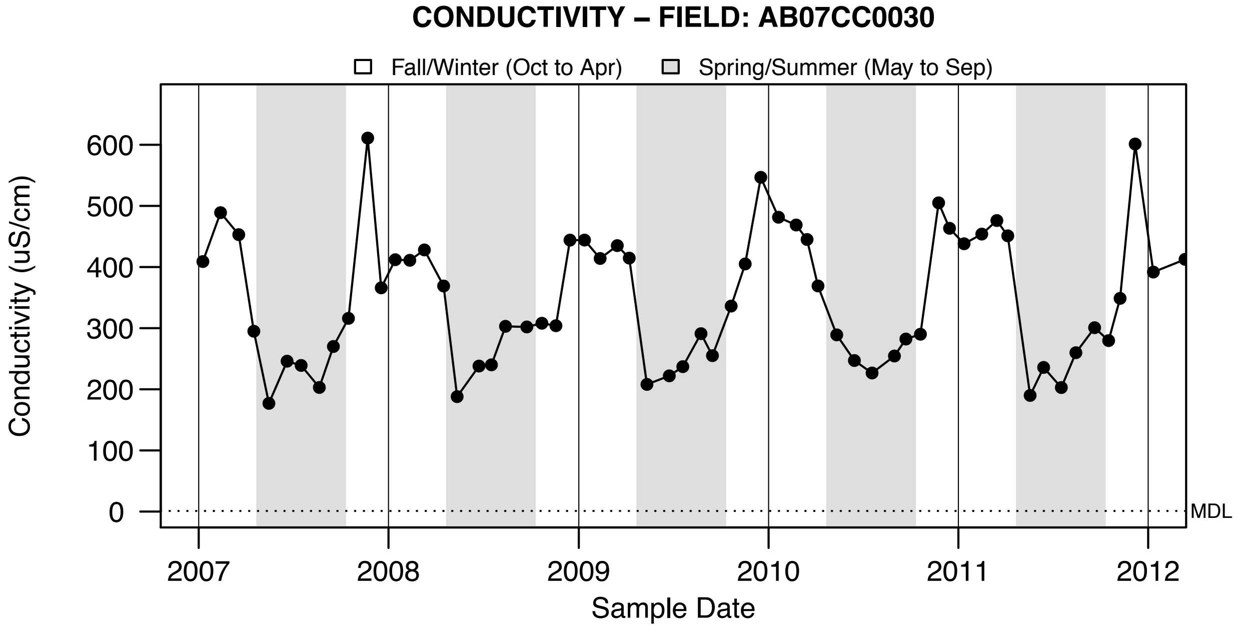


Figure A1.100: CONDUCTIVITY - FIELD: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

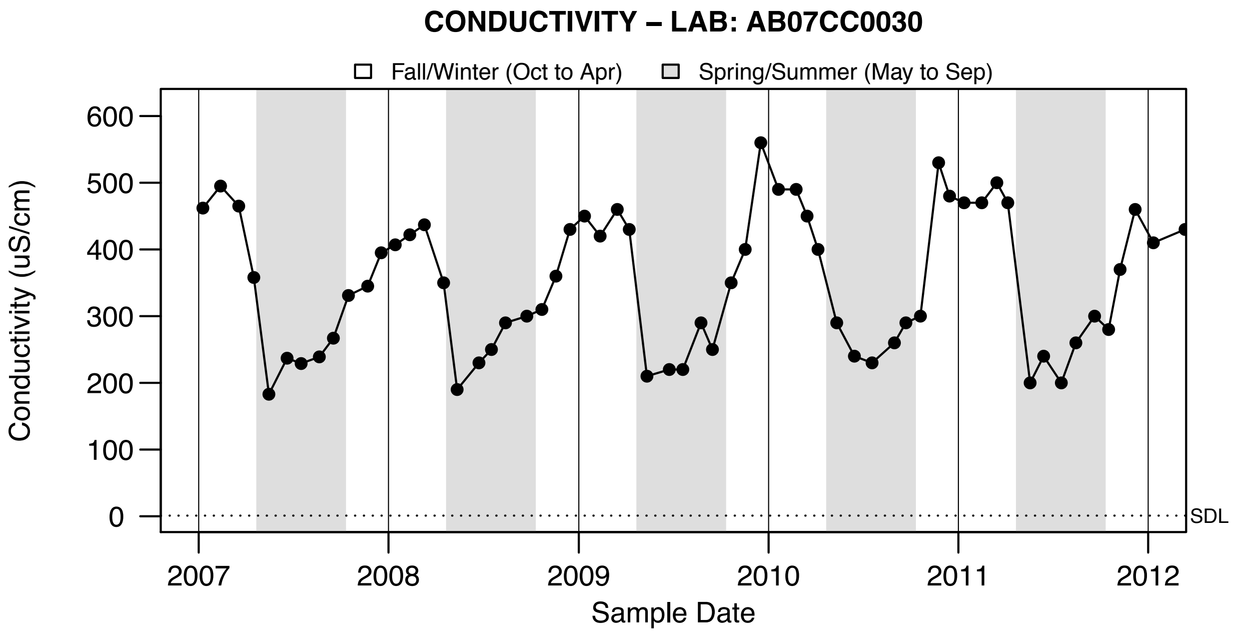
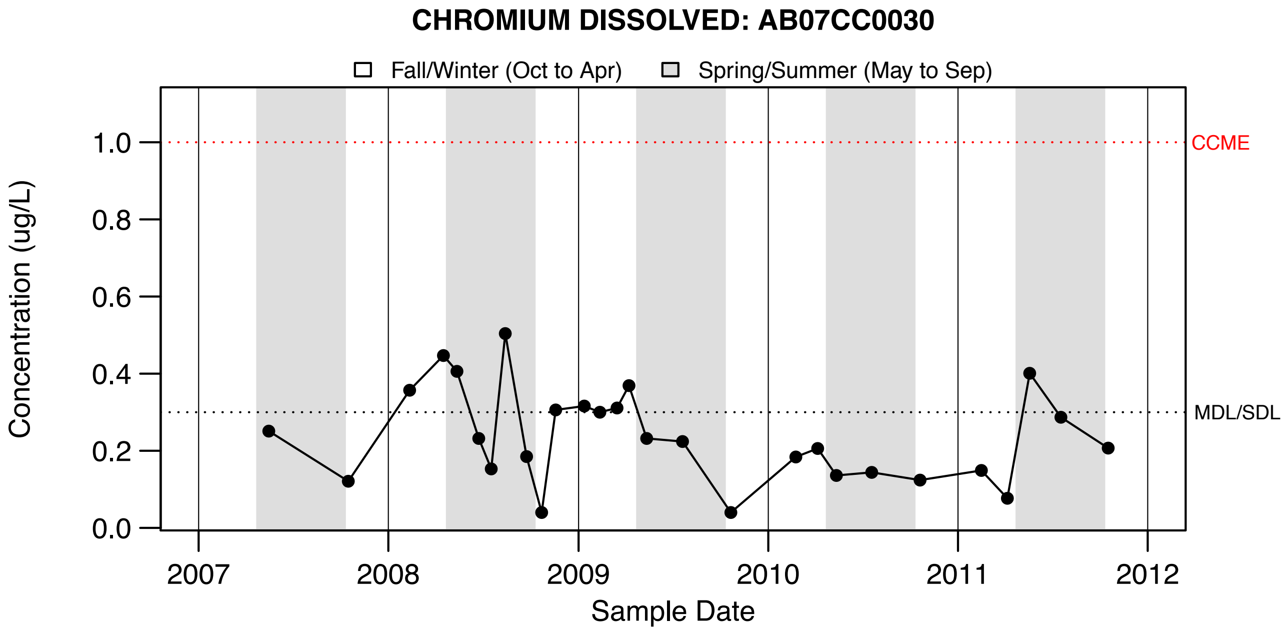


Figure A1.101: CONDUCTIVITY - LAB: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



Chromium III: 8.9 Chromium VI: 1.0

Figure A1.102: CHROMIUM DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

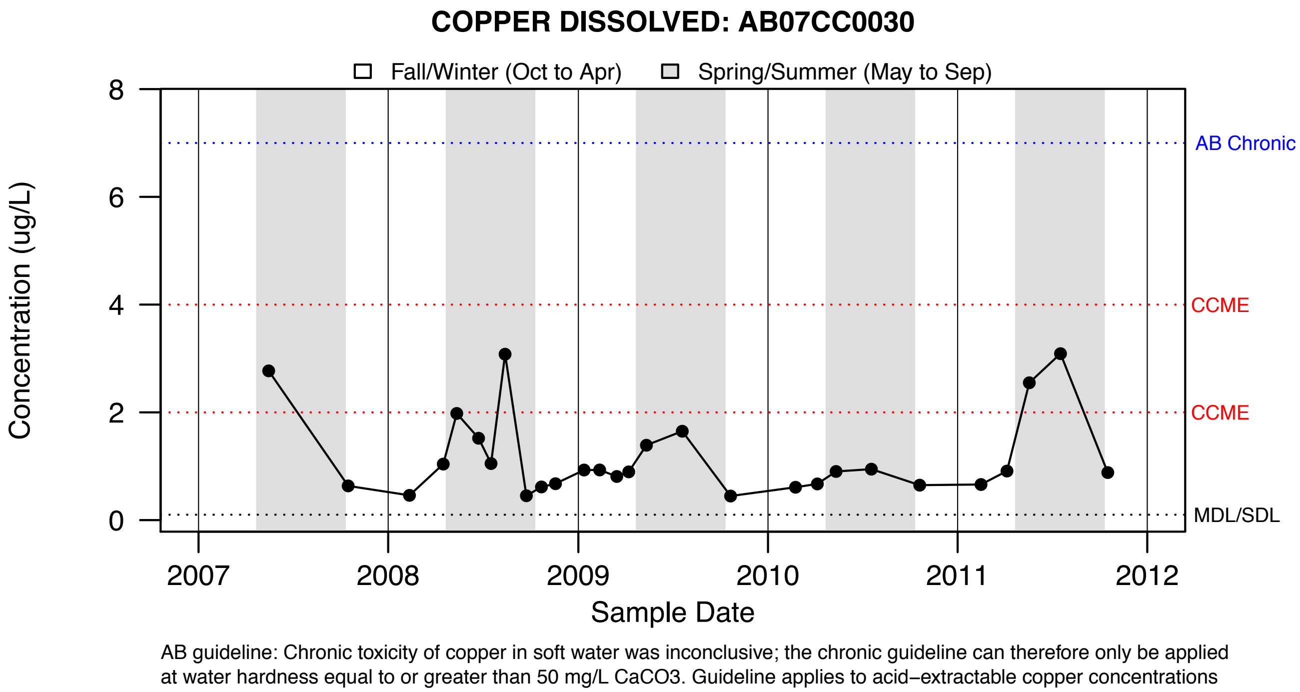


Figure A1.103: COPPER DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

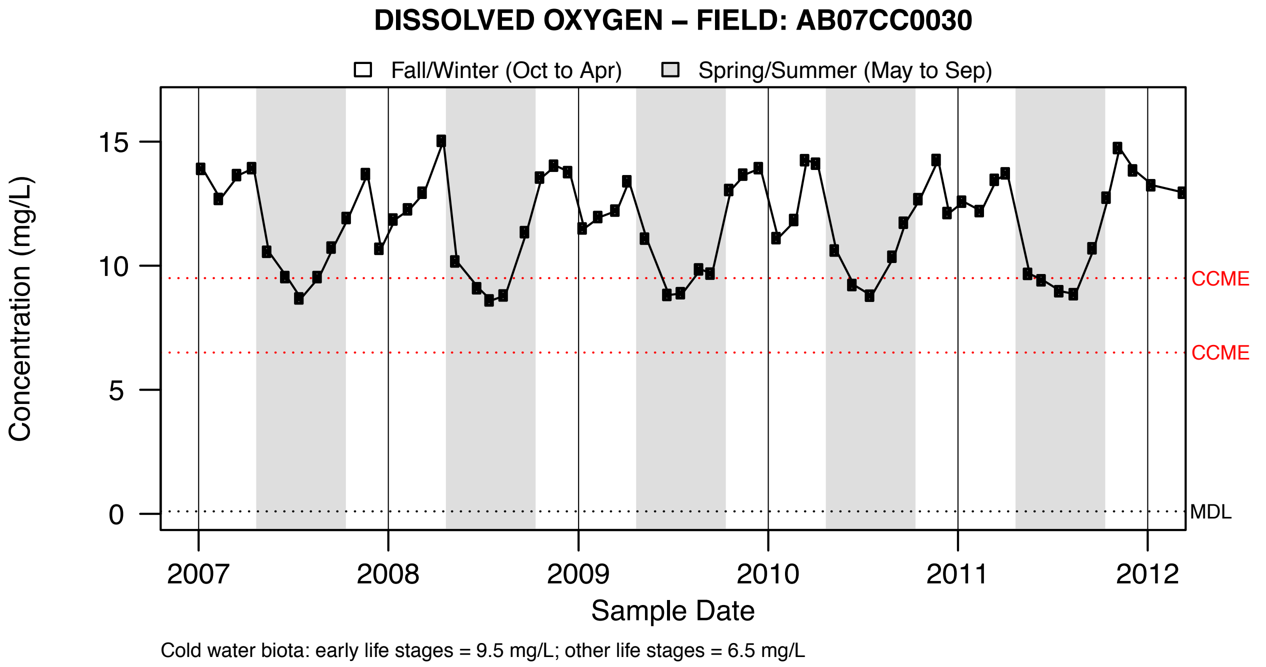


Figure A1.104: DISSOLVED OXYGEN - FIELD: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

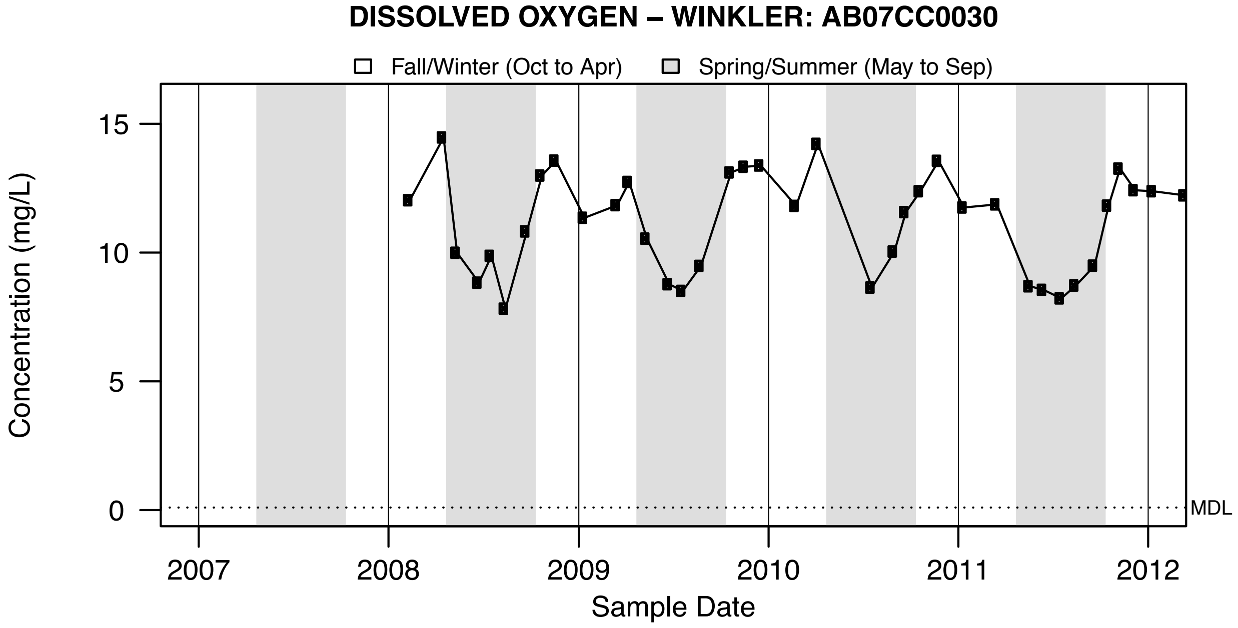


Figure A1.105: DISSOLVED OXYGEN - WINKLER: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

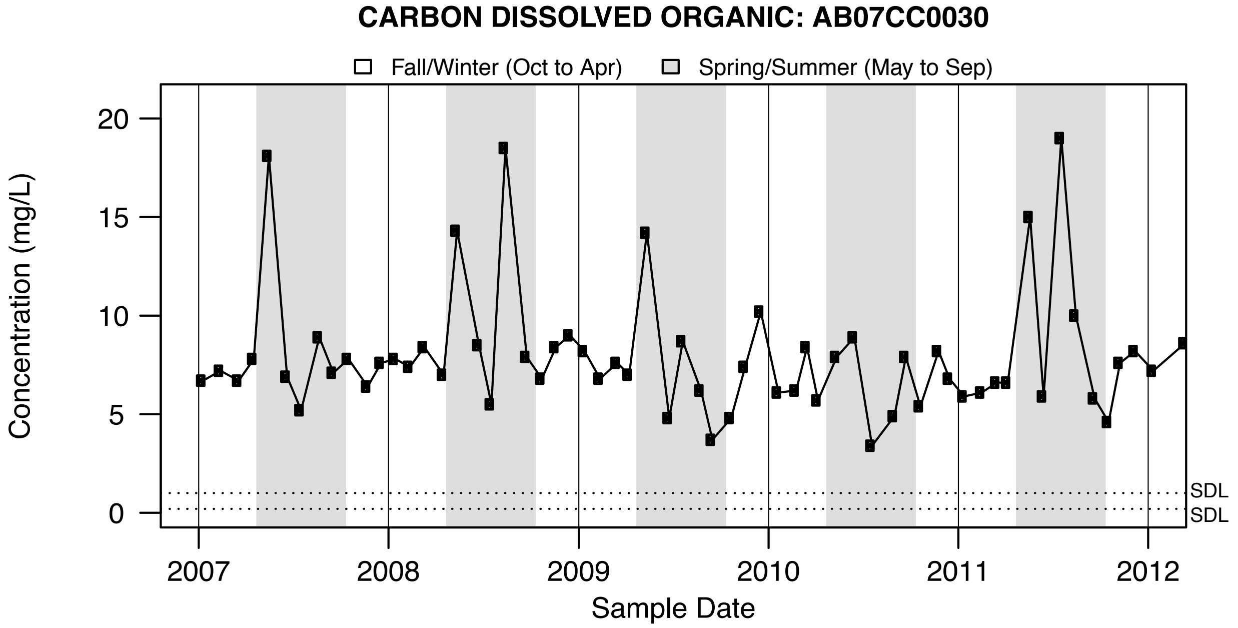


Figure A1.106: CARBON DISSOLVED ORGANIC: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

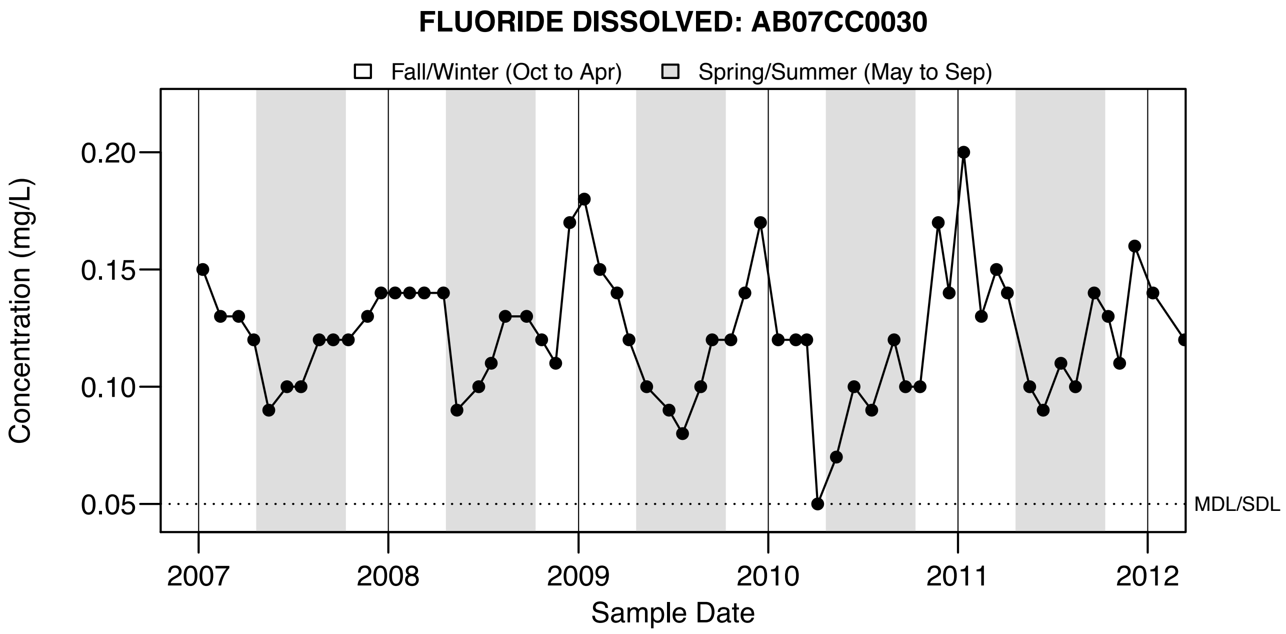


Figure A1.107: FLUORIDE DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

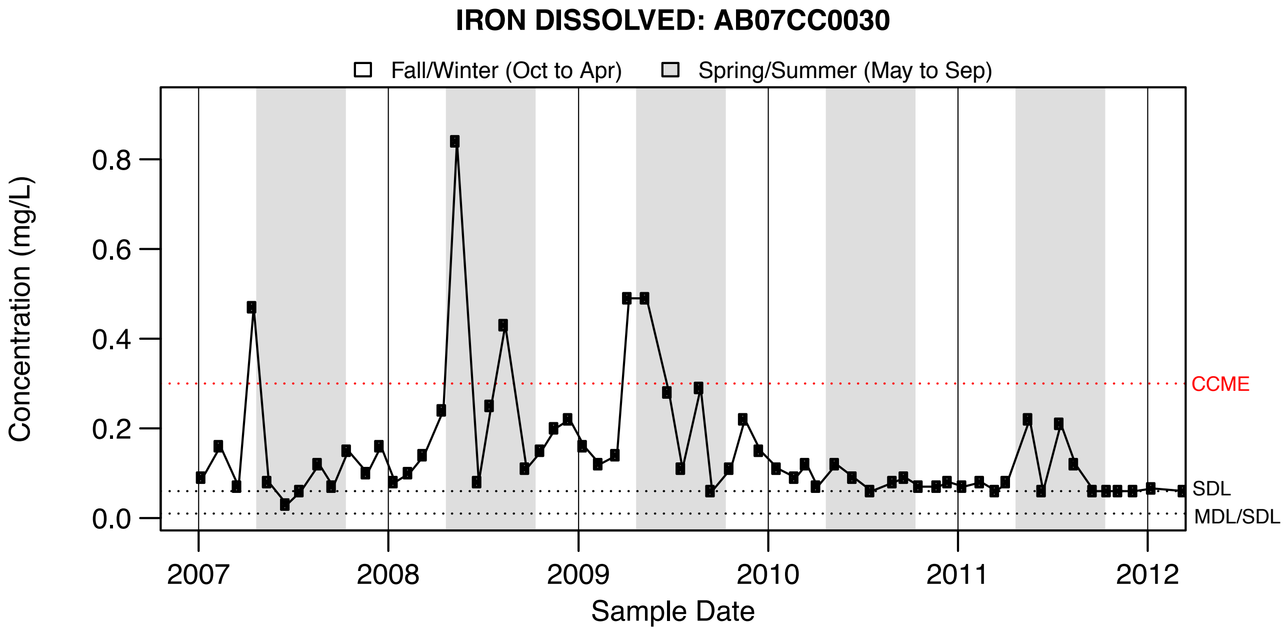


Figure A1.108: IRON DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

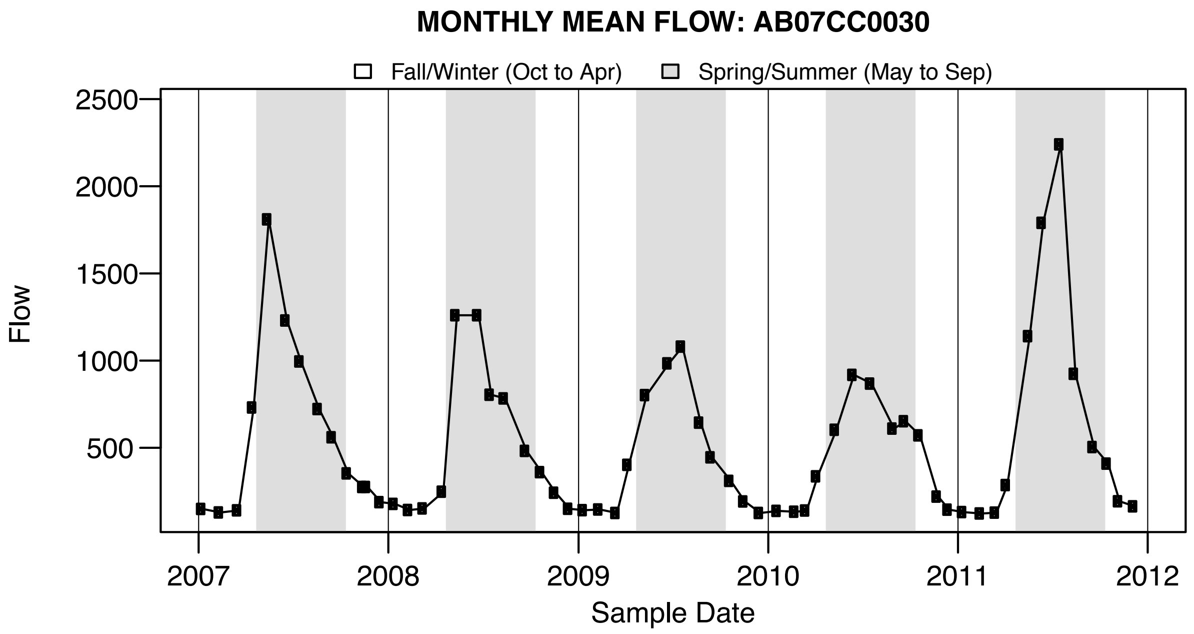


Figure A1.109: MONTHLY MEAN FLOW: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

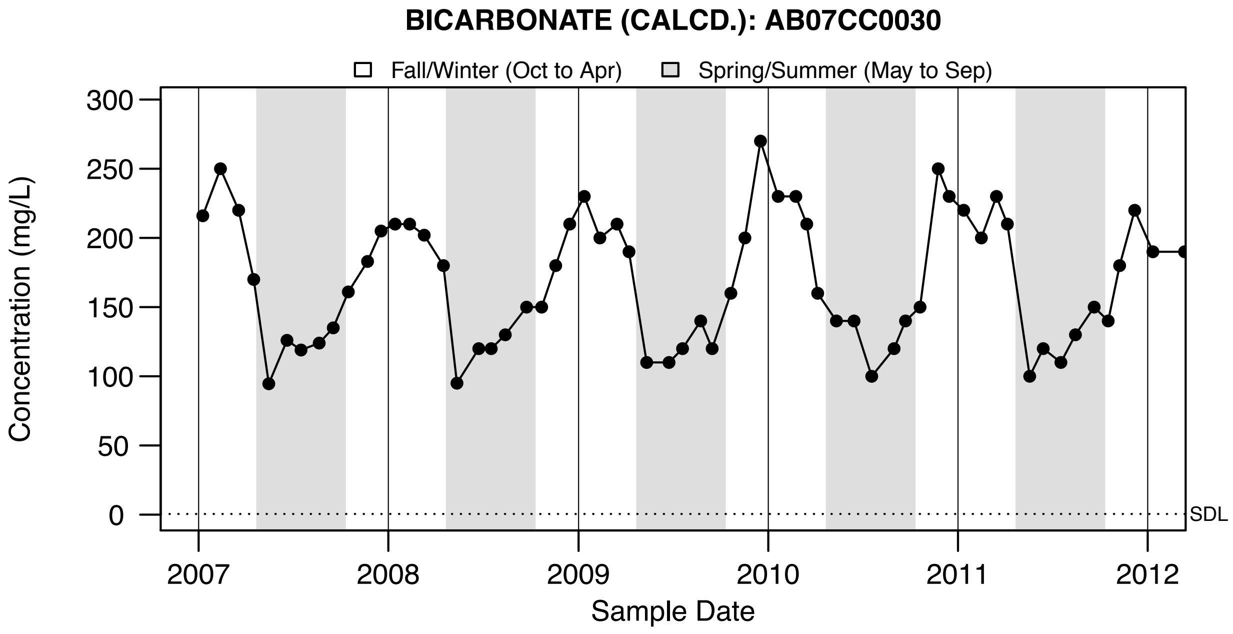


Figure A1.110: BICARBONATE (CALCD.): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

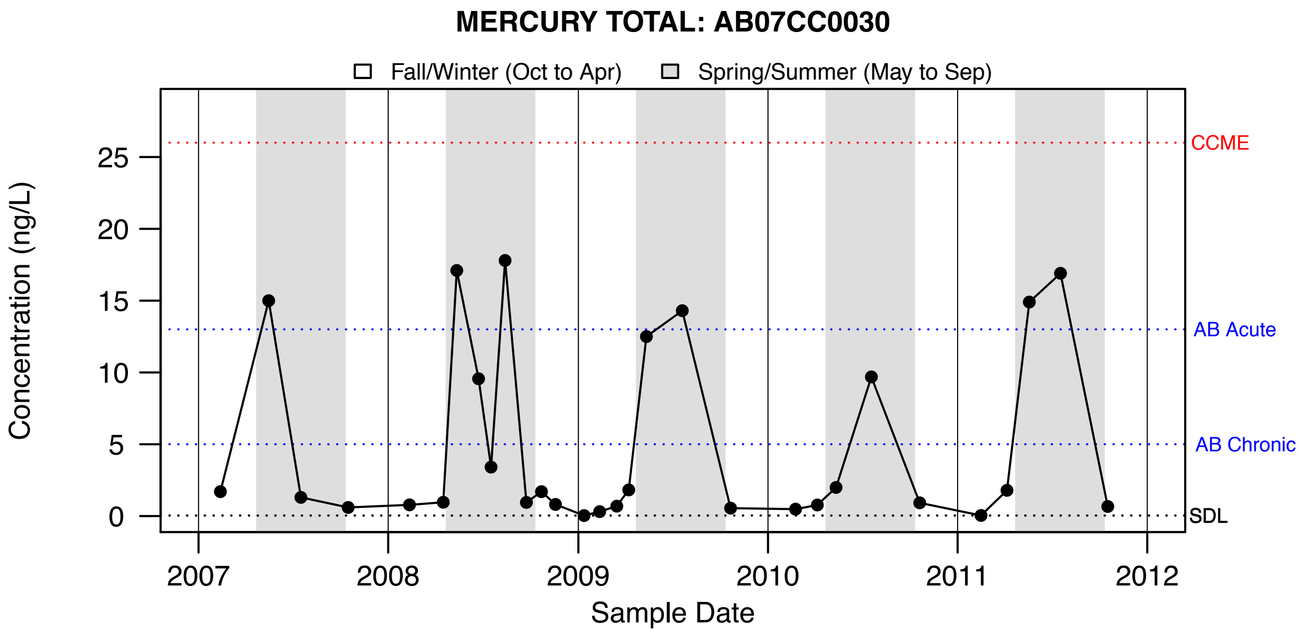


Figure A1.111: MERCURY TOTAL: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

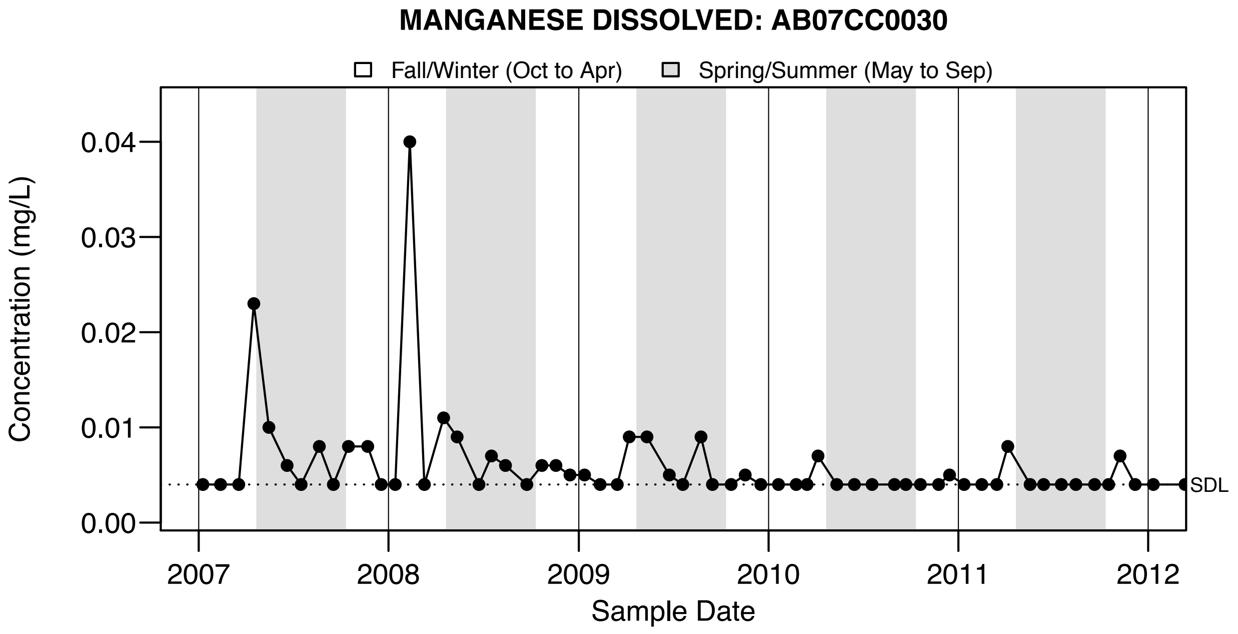


Figure A1.112: MANGANESE DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

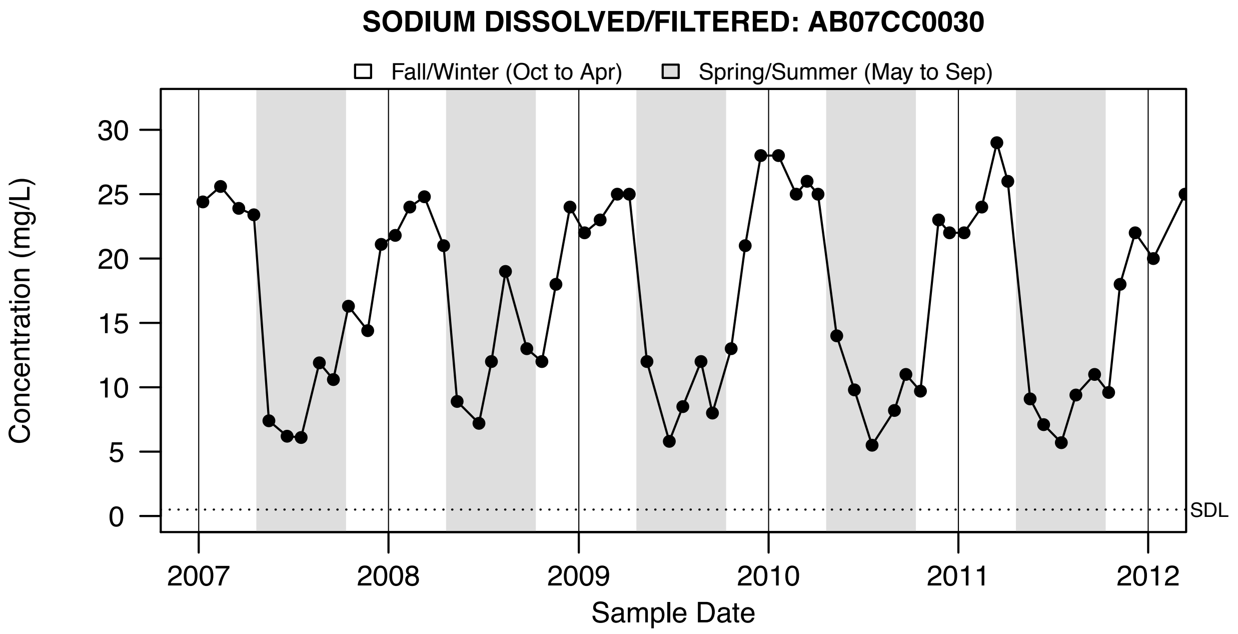
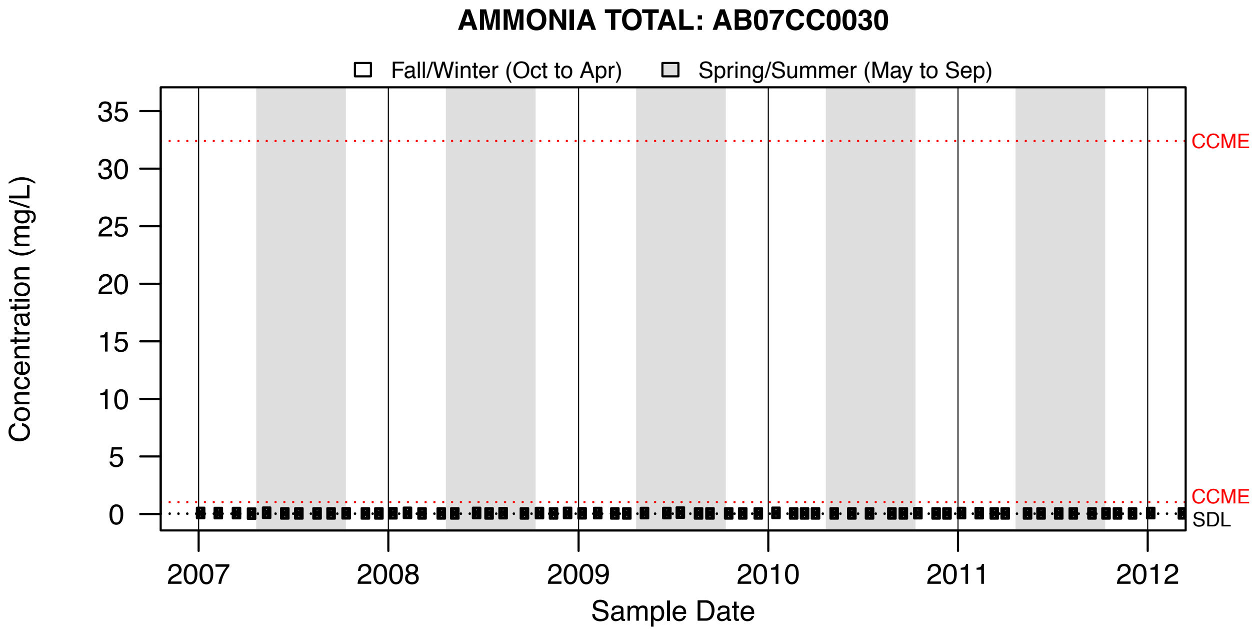
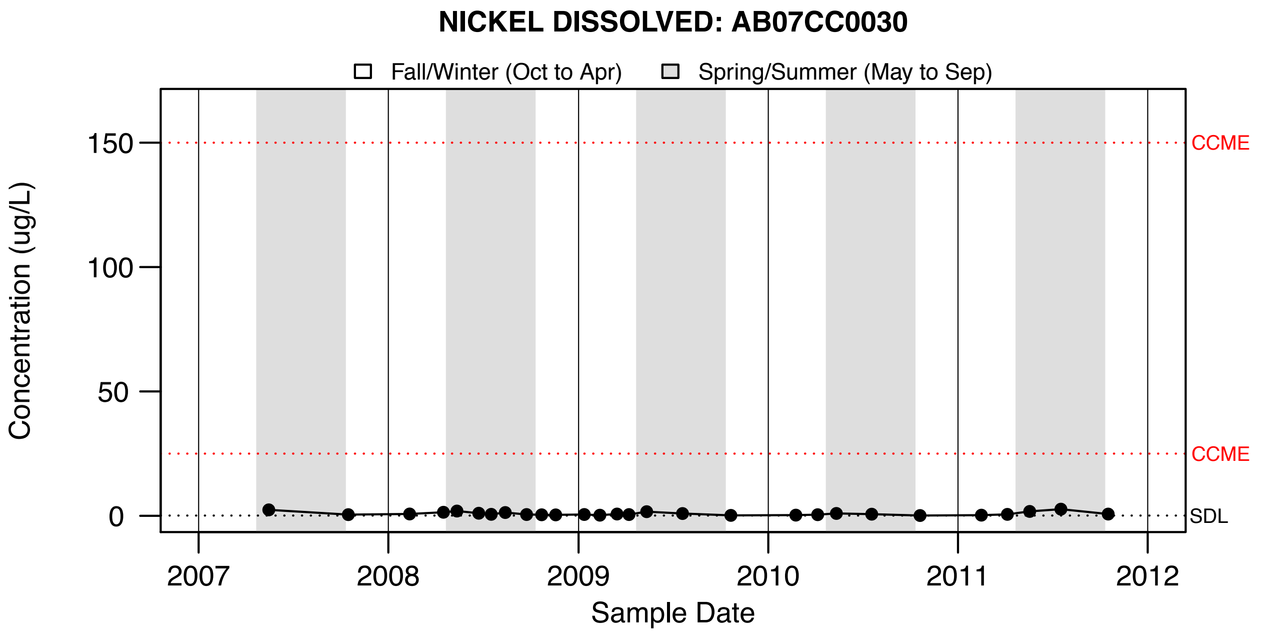


Figure A1.113: SODIUM DISSOLVED/FILTERED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A1.114: AMMONIA TOTAL: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A1.115: NICKEL DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

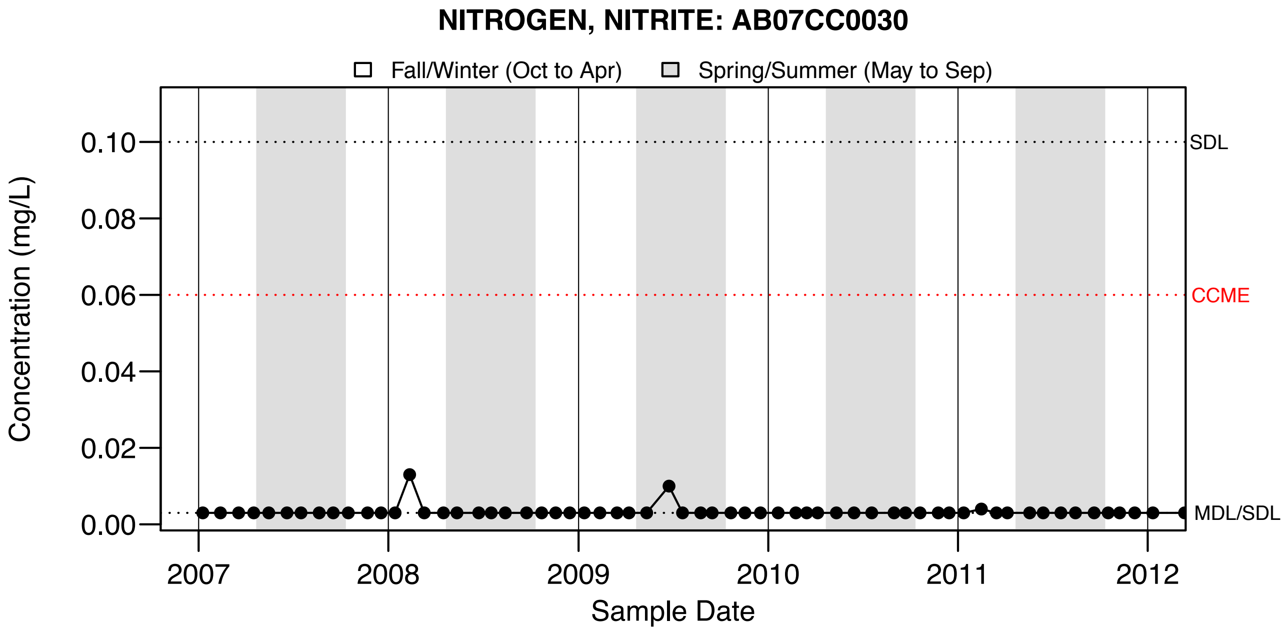
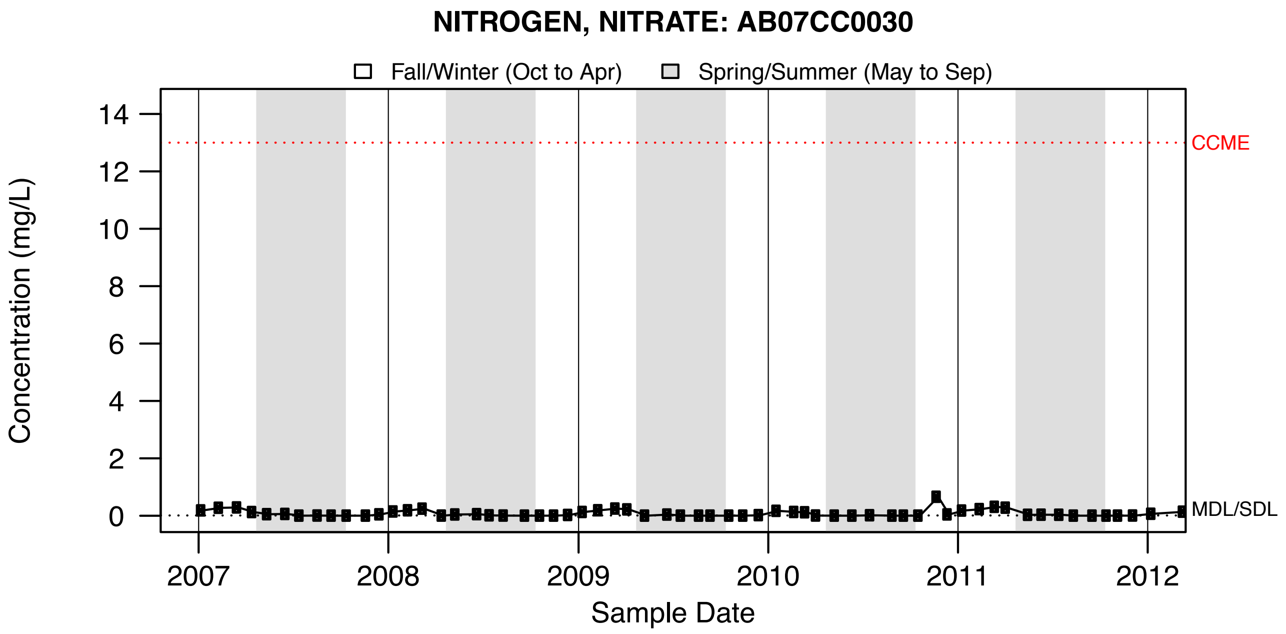


Figure A1.116: NITROGEN, NITRITE: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A1.117: NITROGEN, NITRATE: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

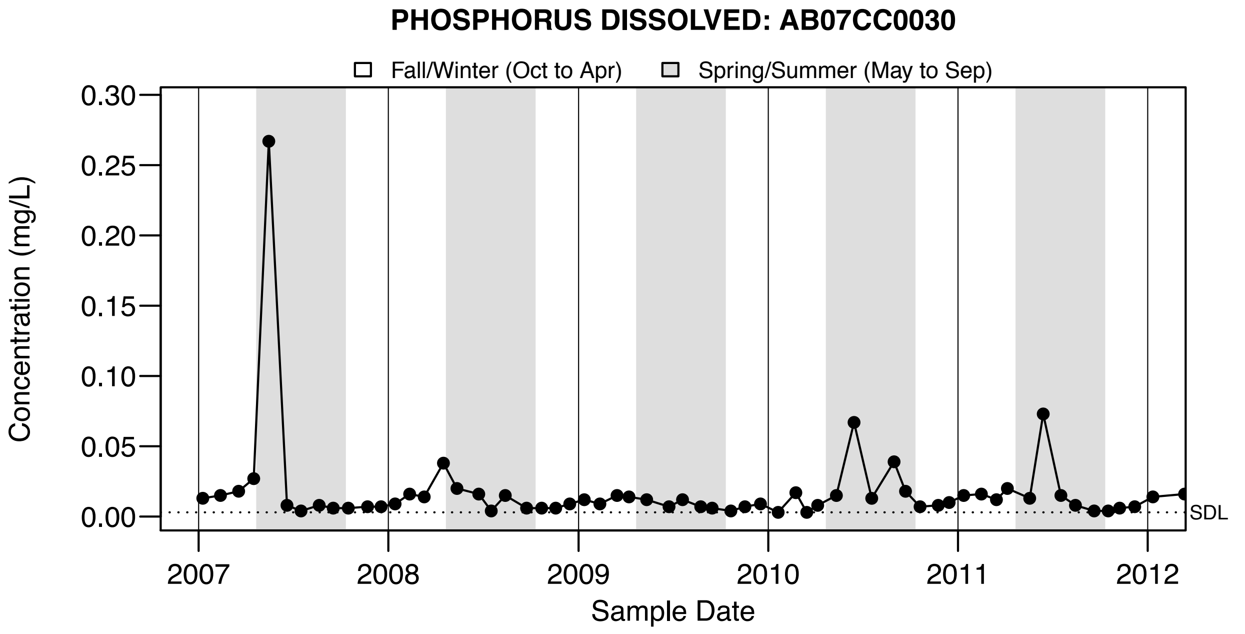


Figure A1.118: PHOSPHORUS DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

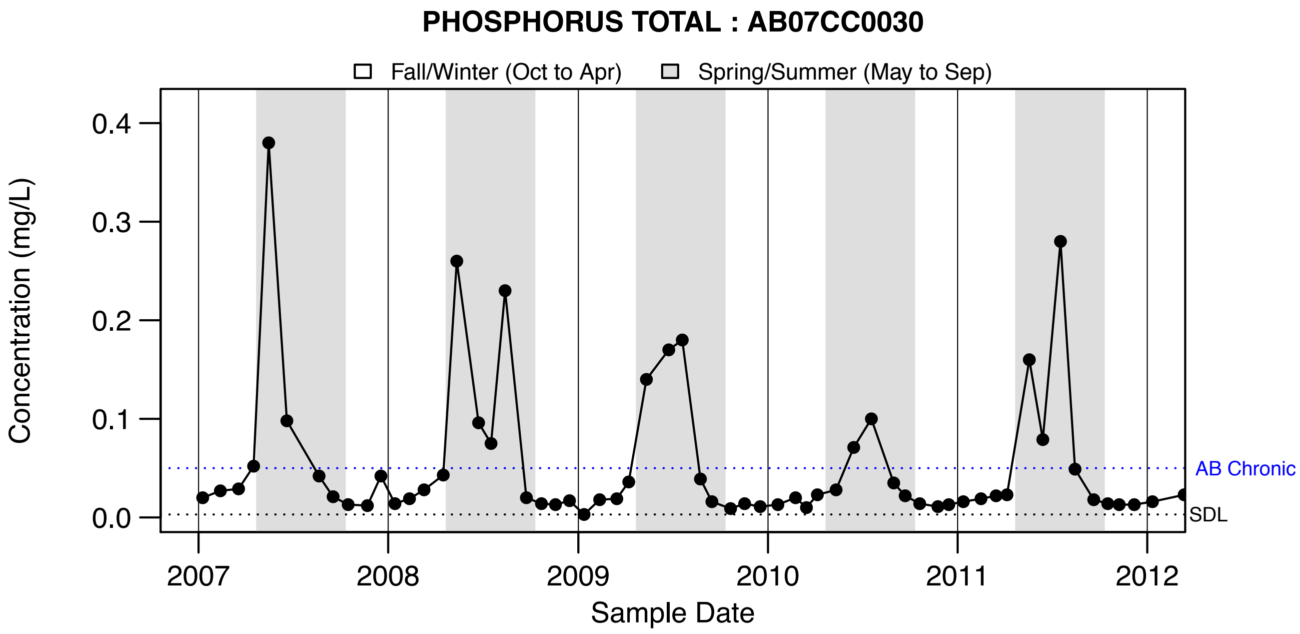
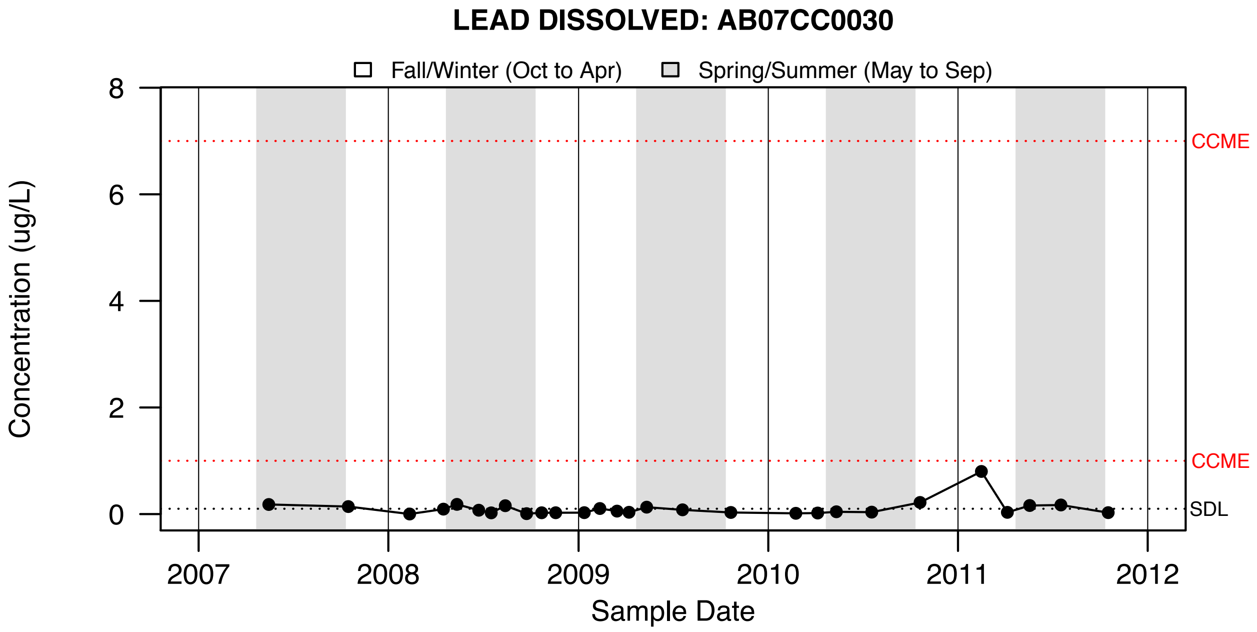


Figure A1.119: PHOSPHORUS TOTAL : AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A1.120: LEAD DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

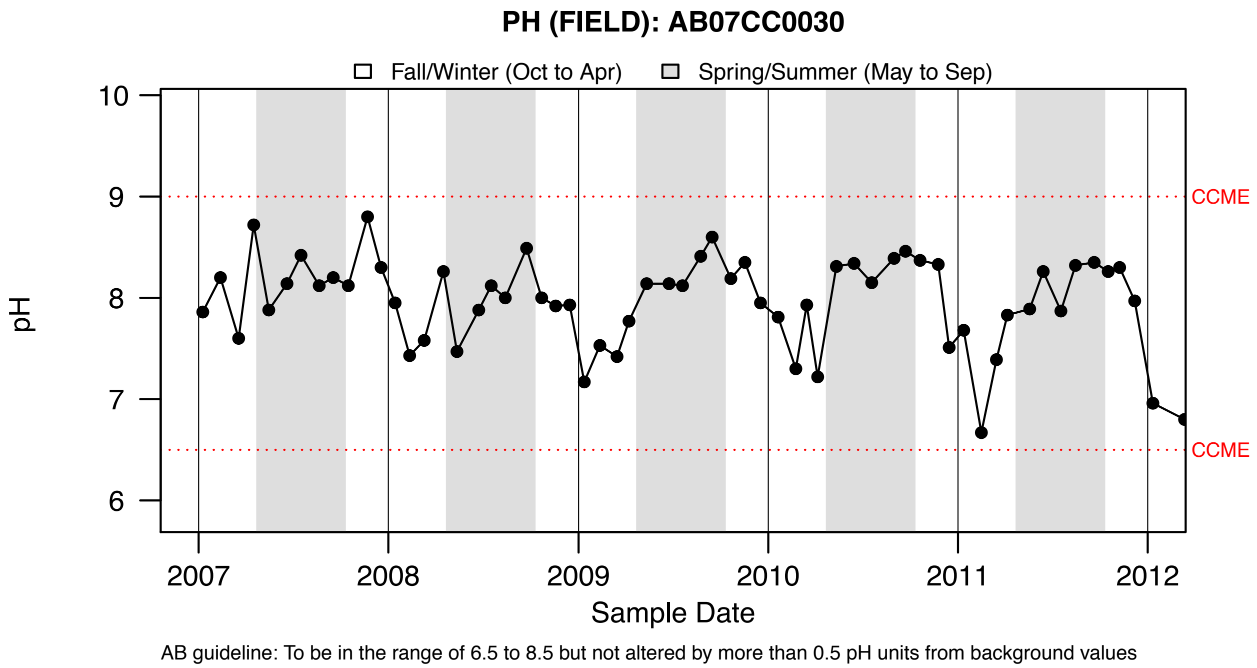


Figure A1.121: PH (FIELD): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

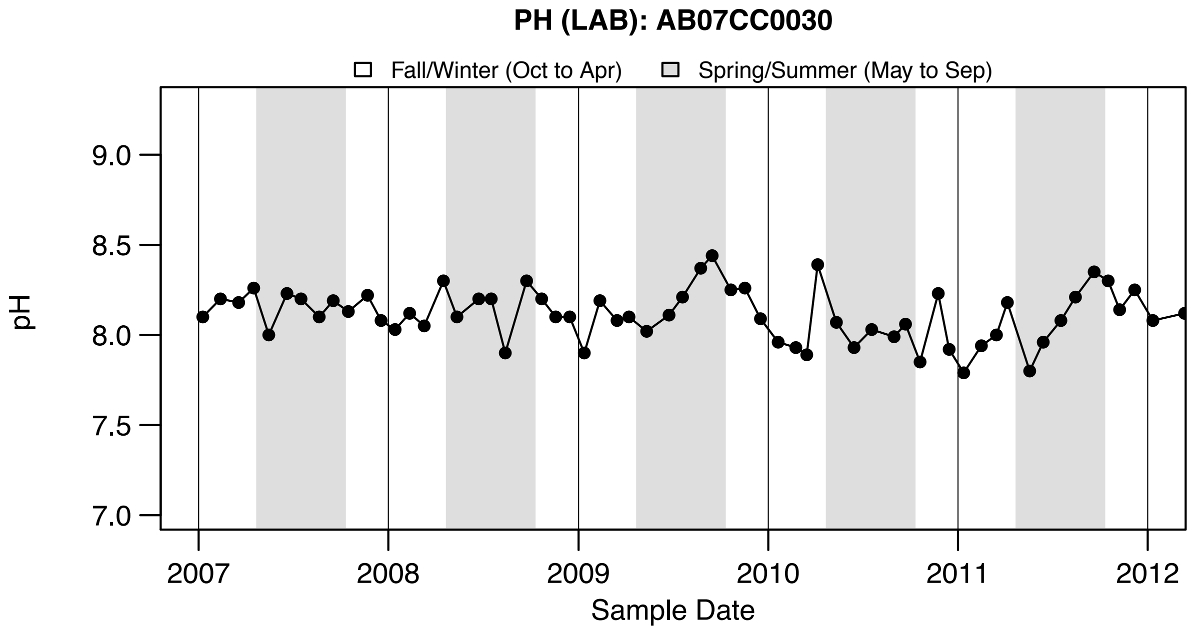


Figure A1.122: PH (LAB): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

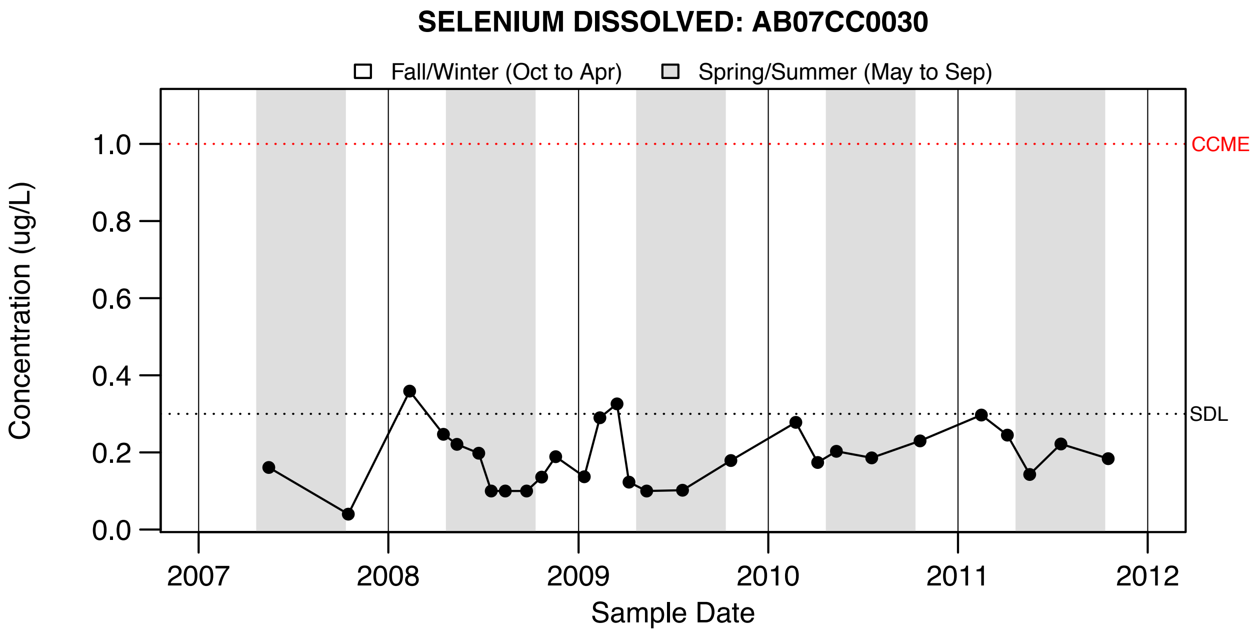


Figure A1.123: SELENIUM DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

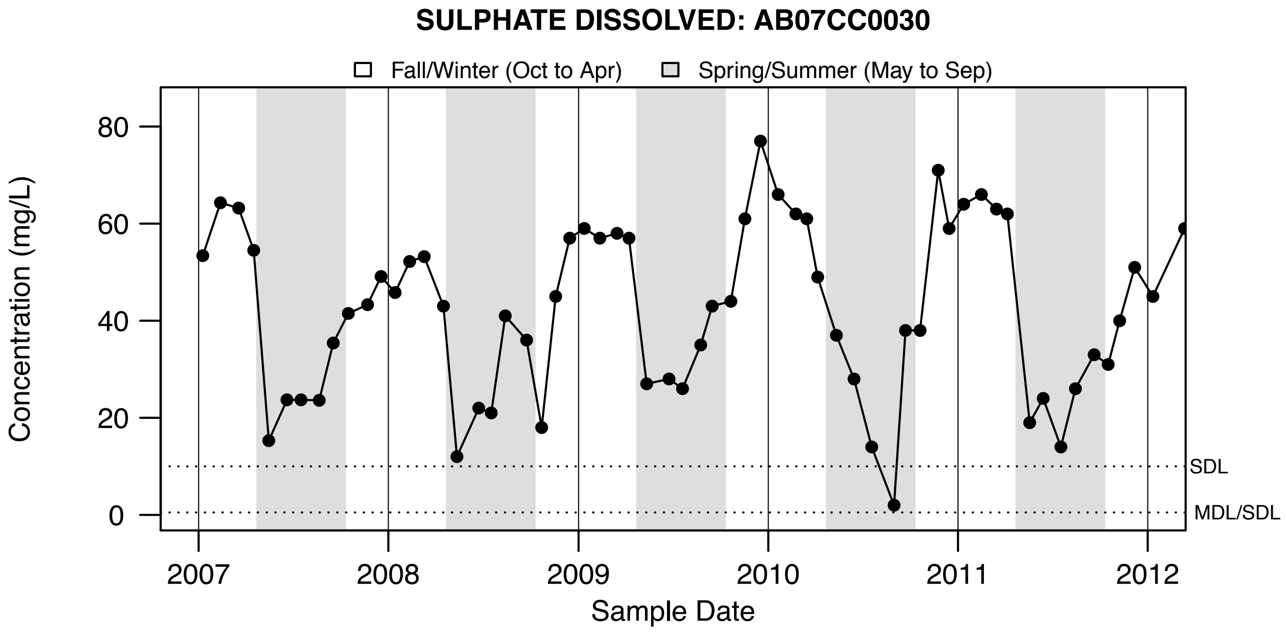


Figure A1.124: SULPHATE DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

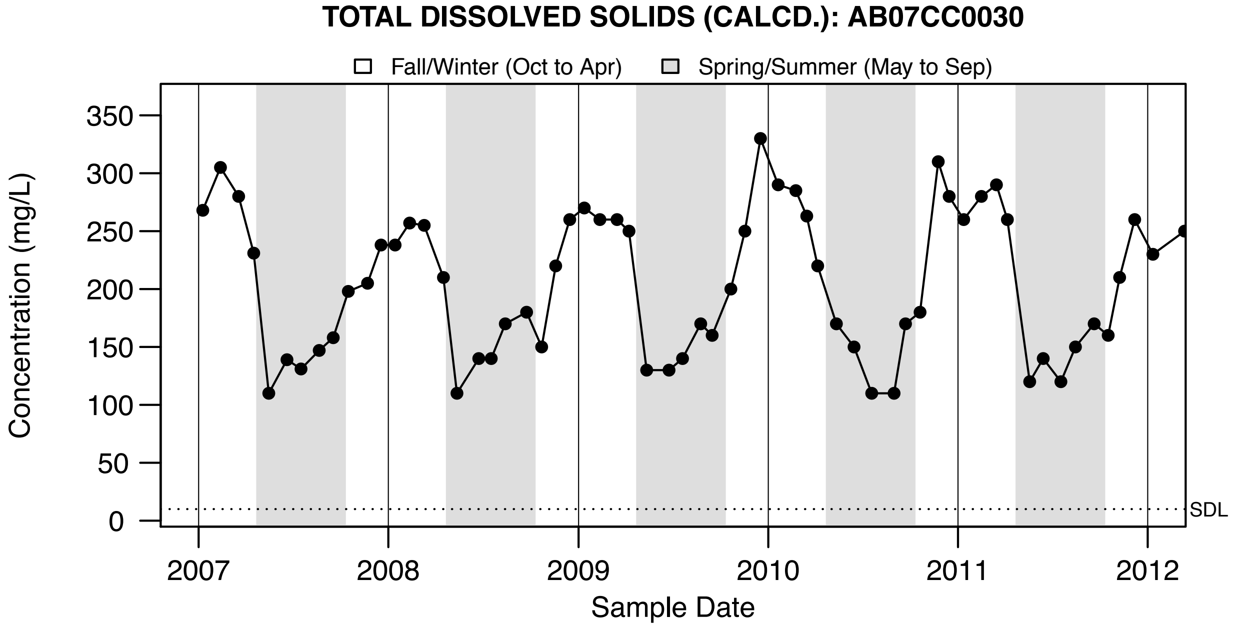
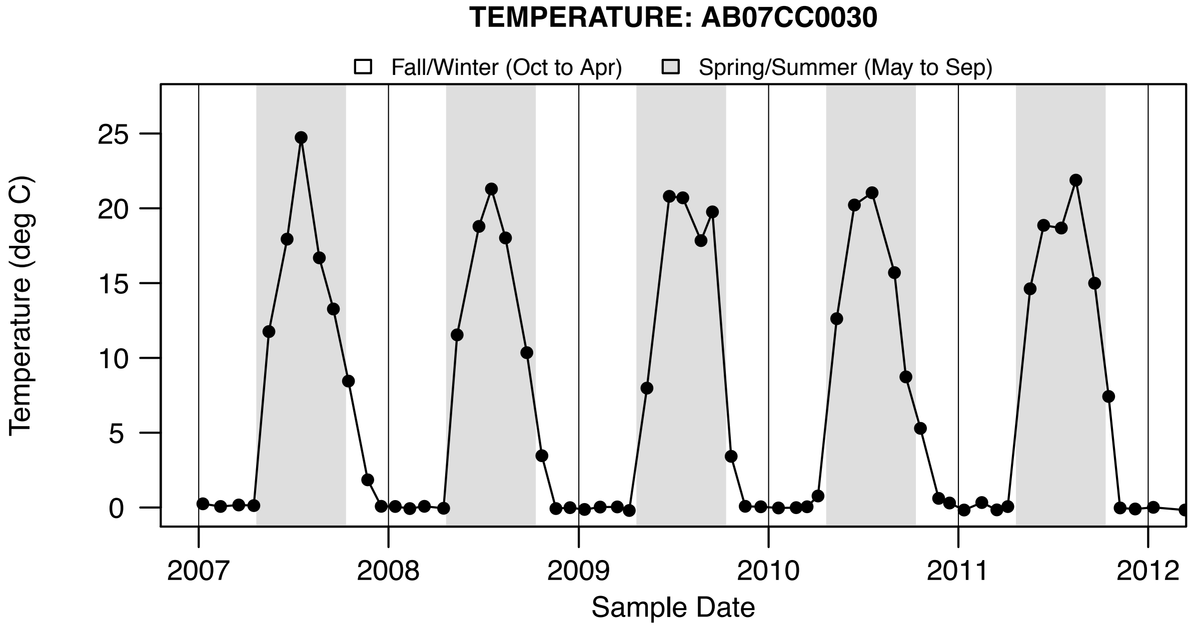


Figure A1.125: TOTAL DISSOLVED SOLIDS (CALCD.): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A1.126: TEMPERATURE: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

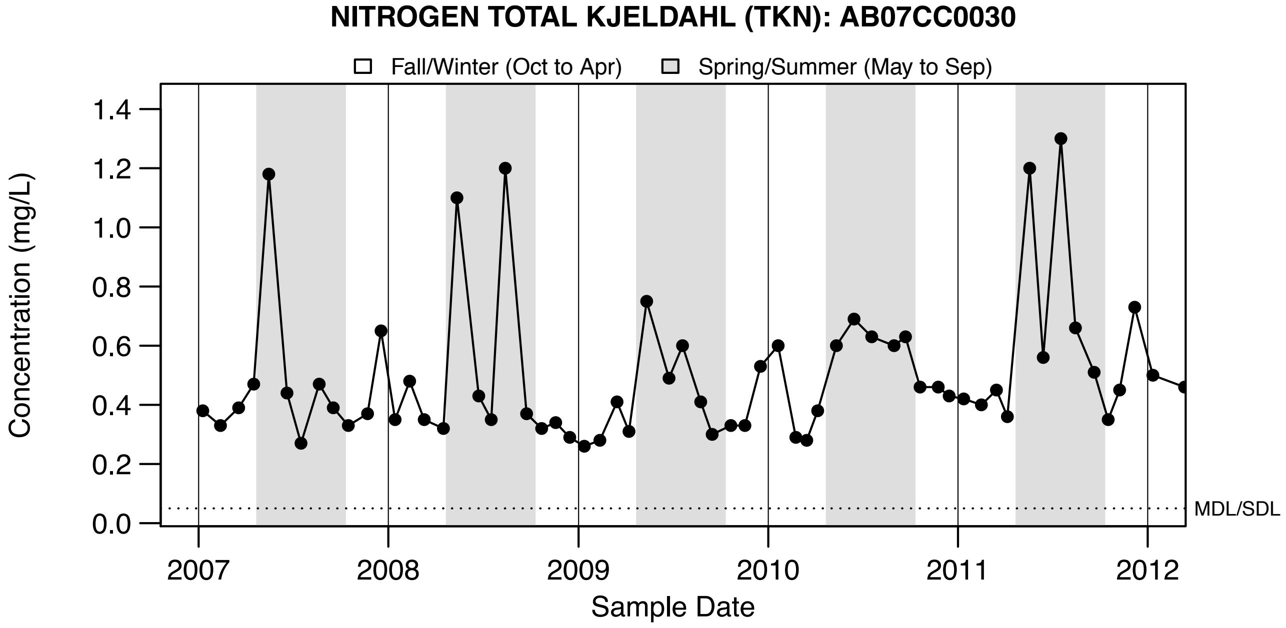
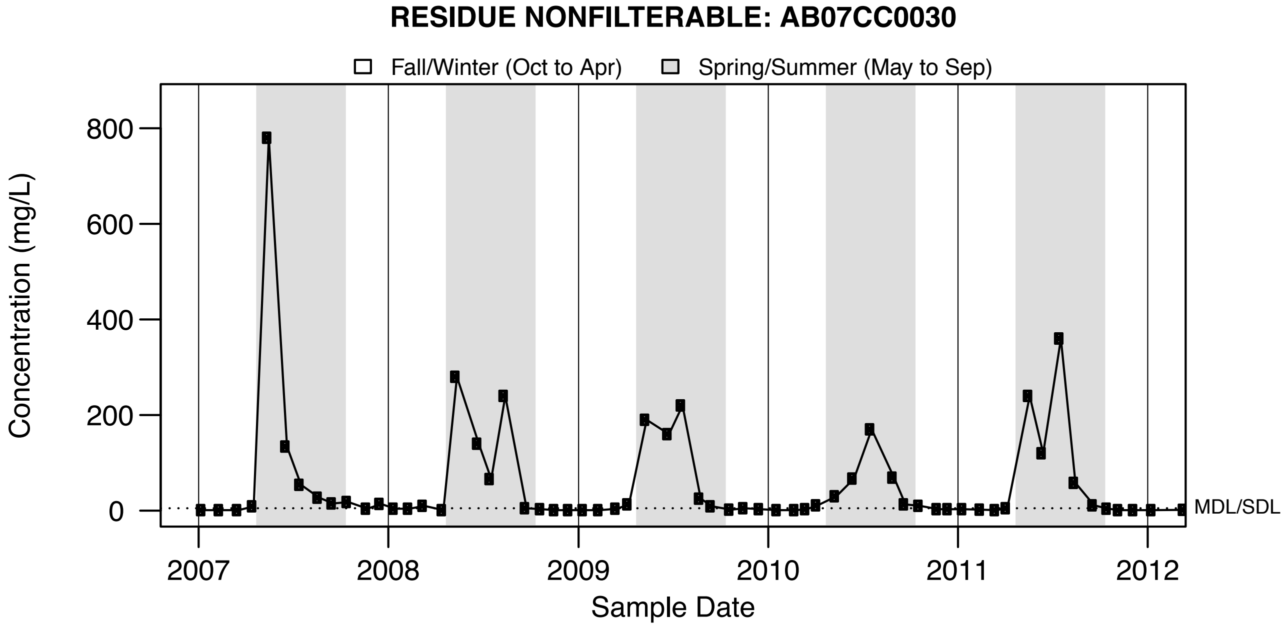


Figure A1.127: NITROGEN TOTAL KJELDAHL (TKN): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A1.128: RESIDUE NONFILTERABLE: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

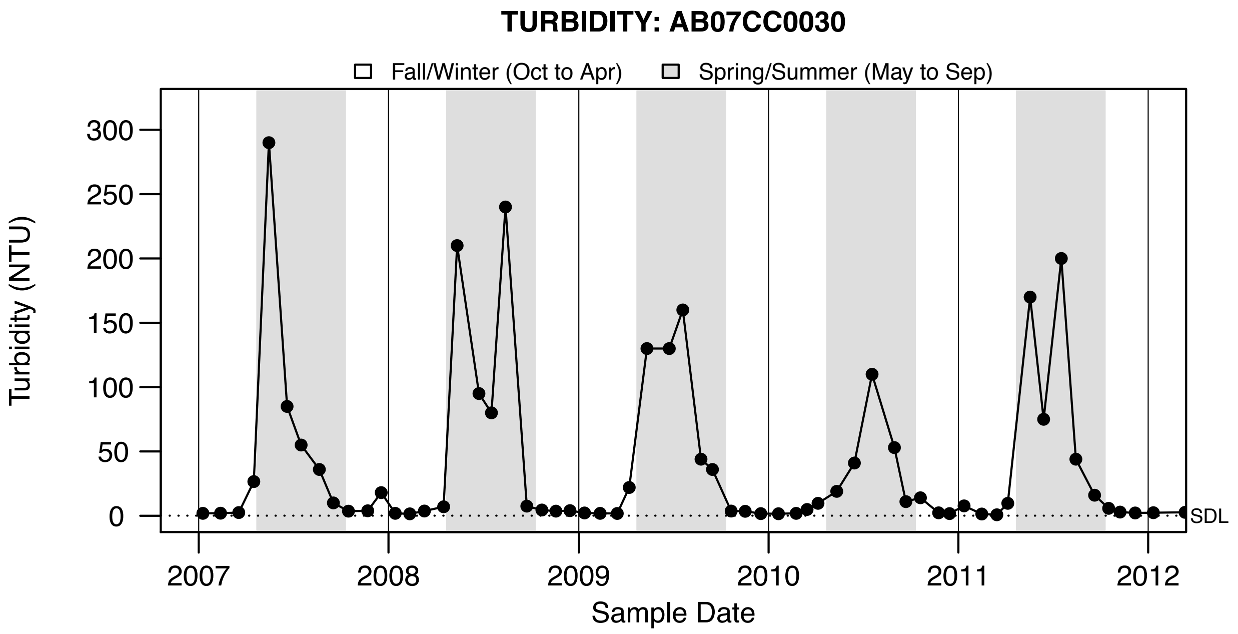


Figure A1.129: TURBIDITY: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

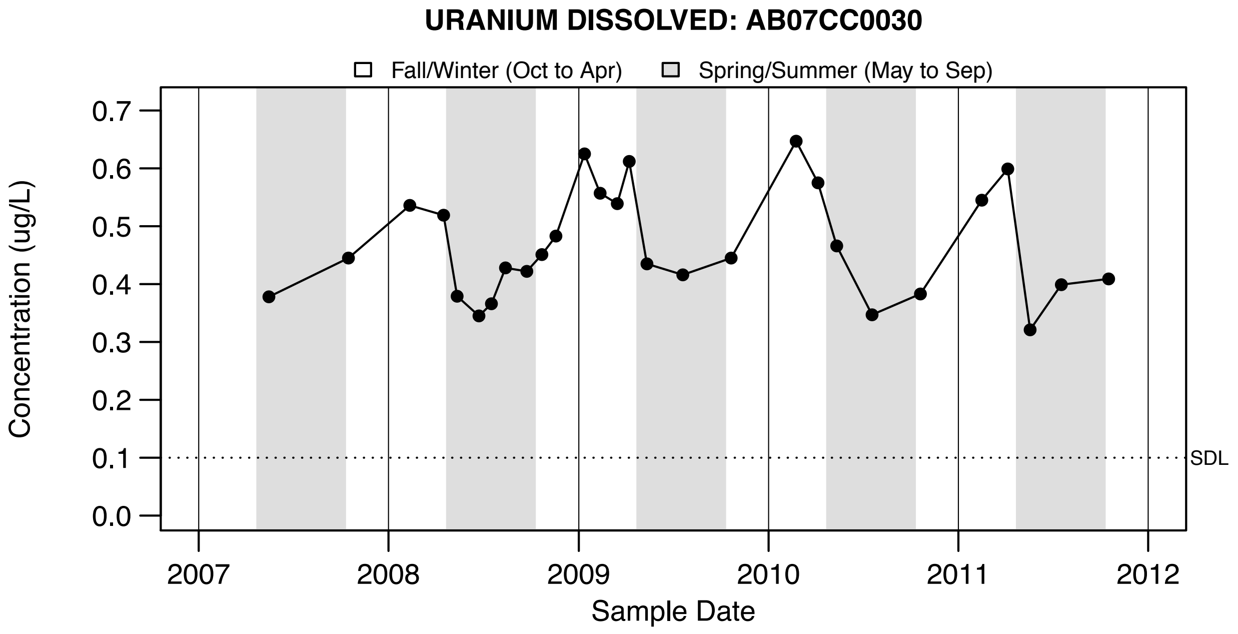


Figure A1.130: URANIUM DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

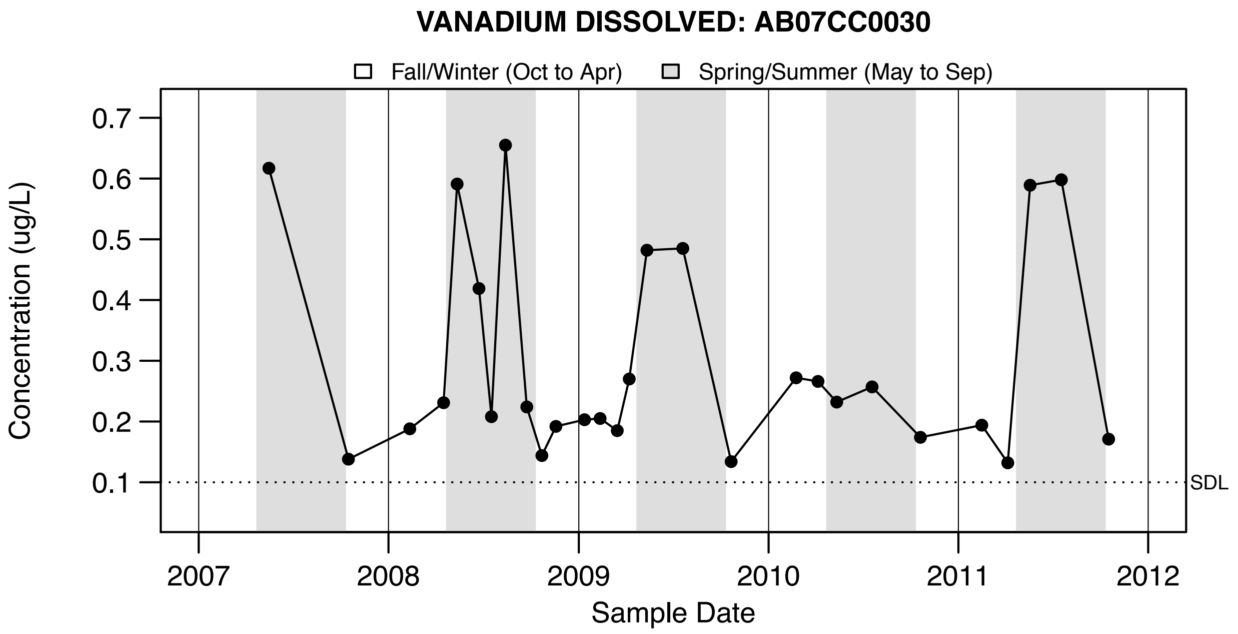


Figure A1.131: VANADIUM DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

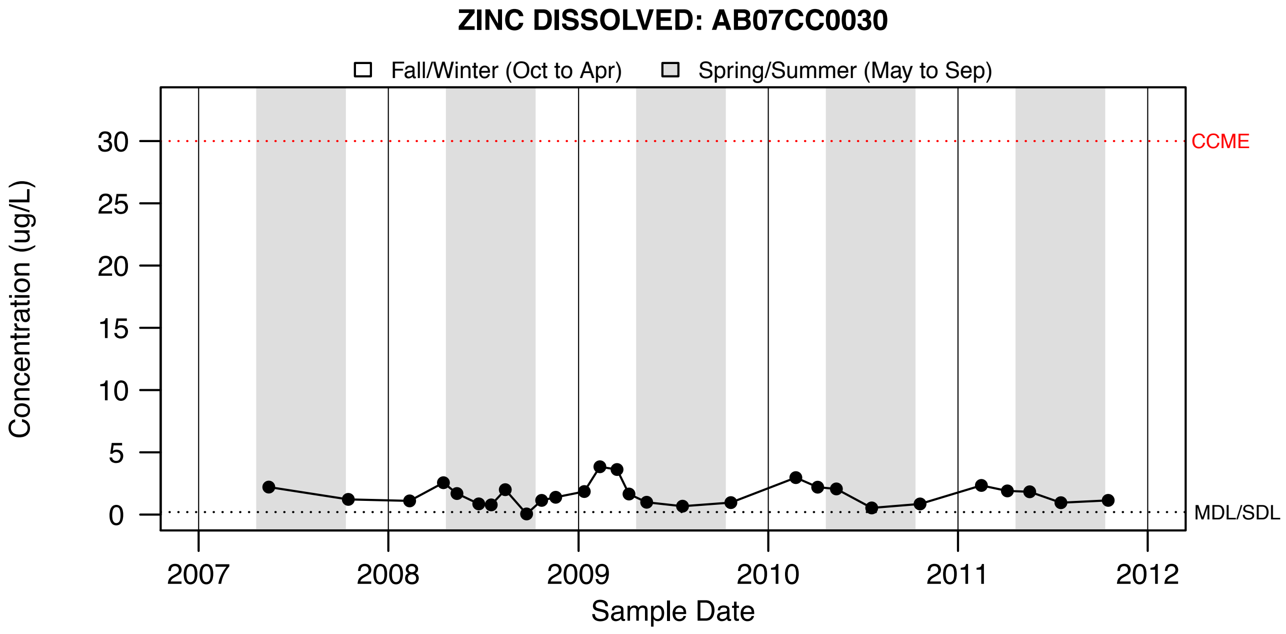


Figure A1.132: ZINC DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK

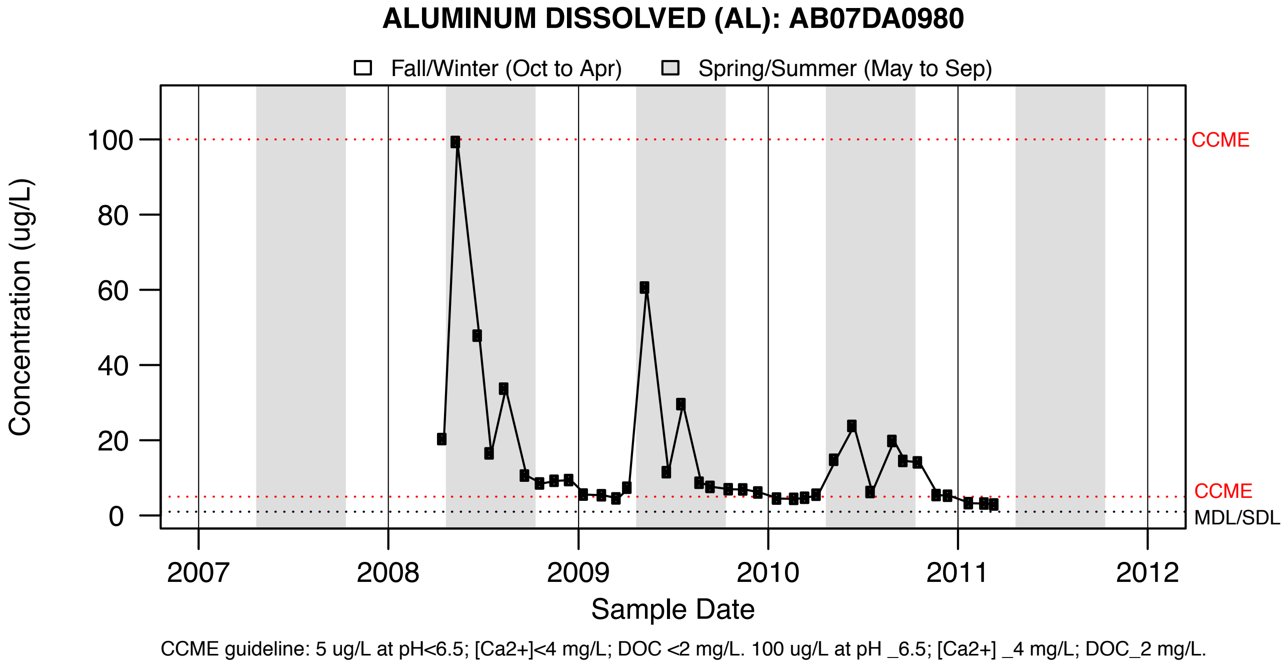


Figure A1.133: ALUMINUM DISSOLVED (AL): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

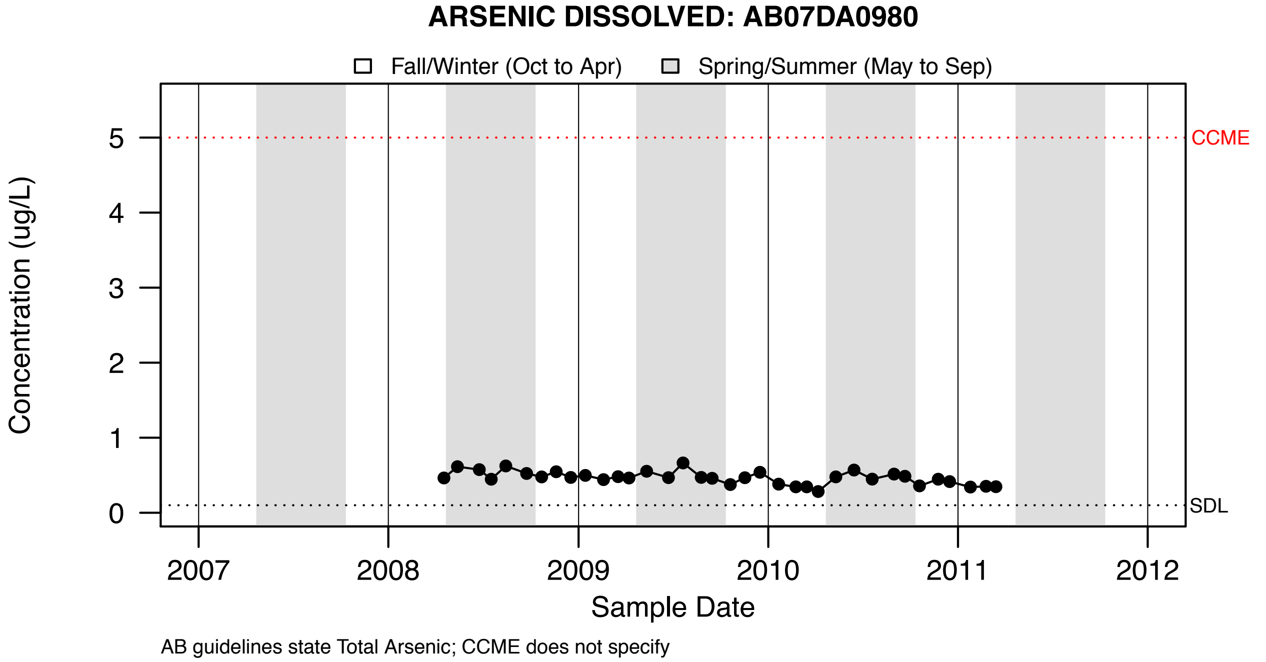


Figure A1.134: ARSENIC DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

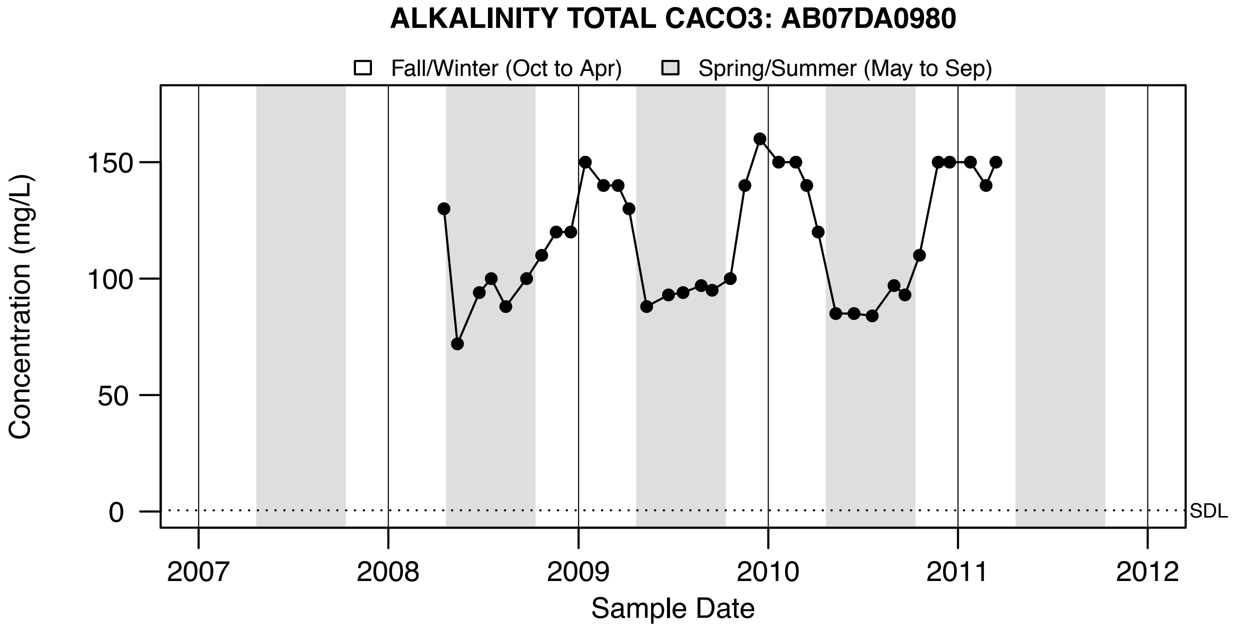


Figure A1.135: ALKALINITY TOTAL CACO3: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

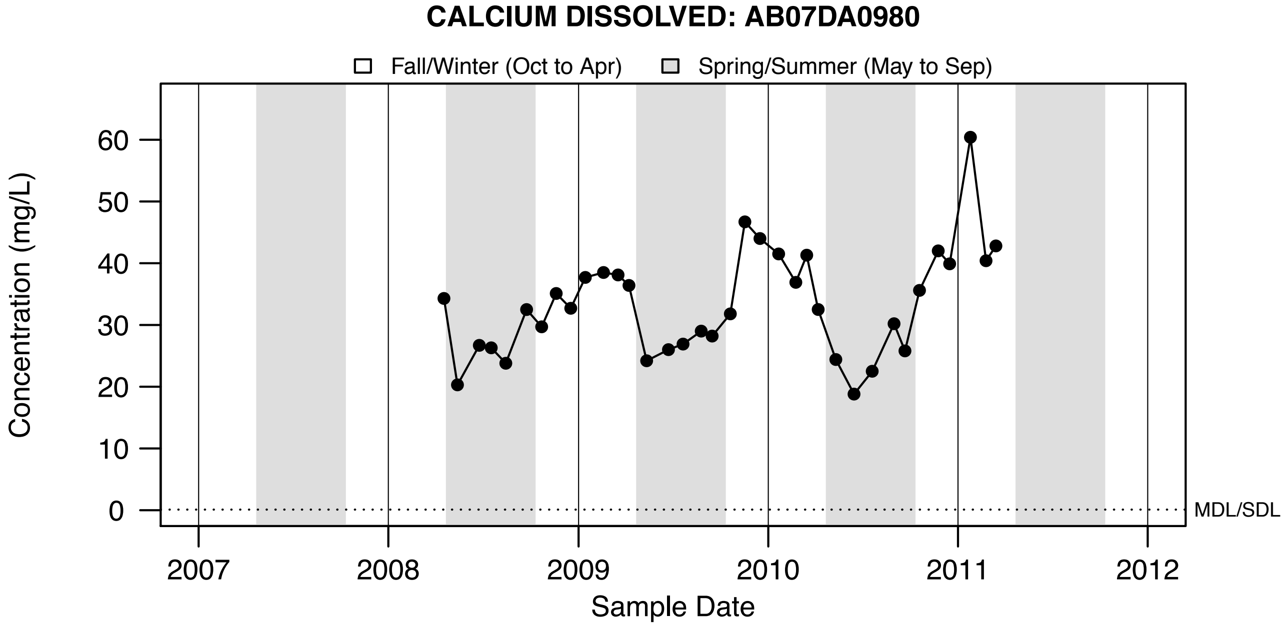


Figure A1.136: CALCIUM DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

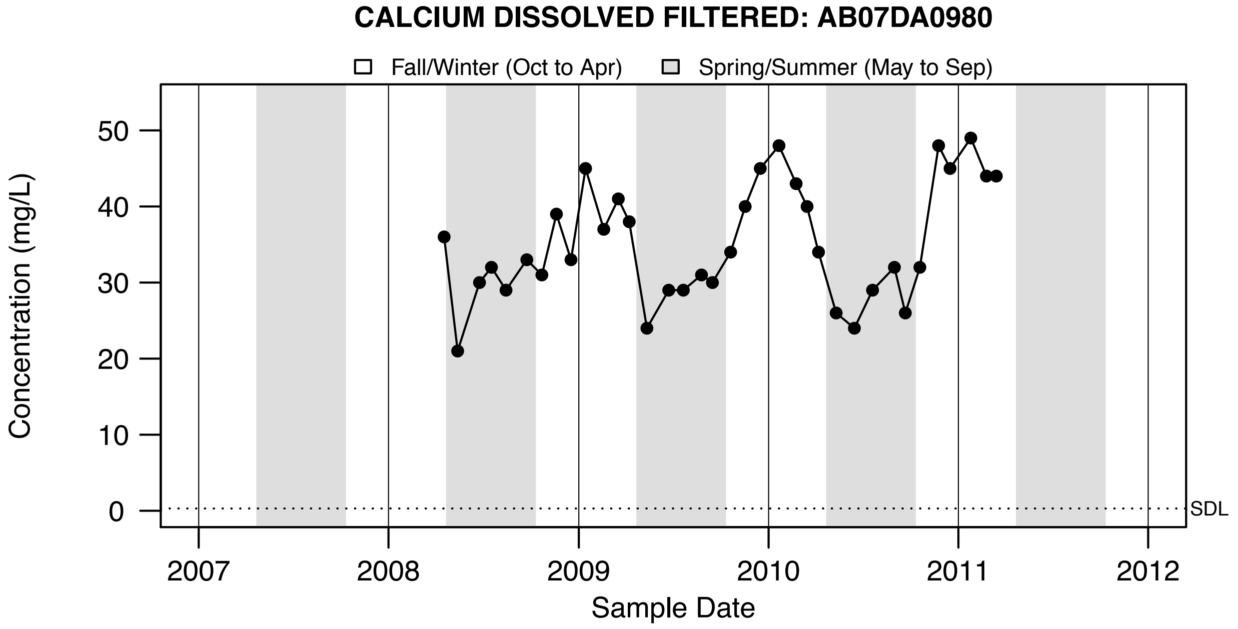


Figure A1.137: CALCIUM DISSOLVED FILTERED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

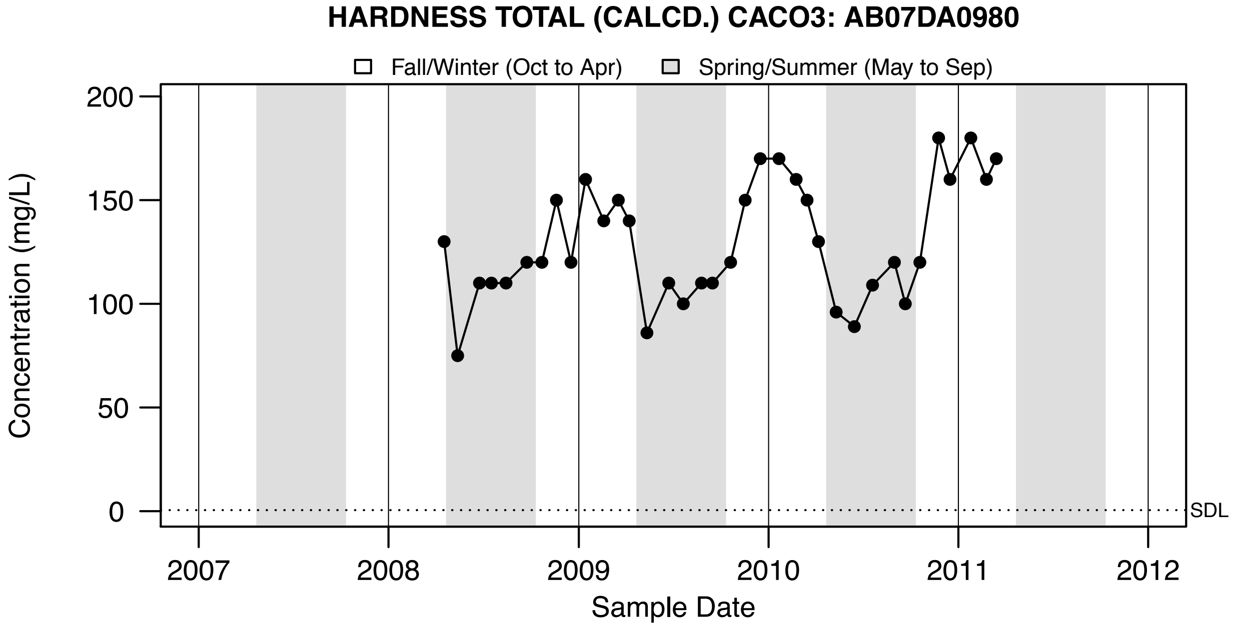


Figure A1.138: HARDNESS TOTAL (CALCD.) CACO3: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

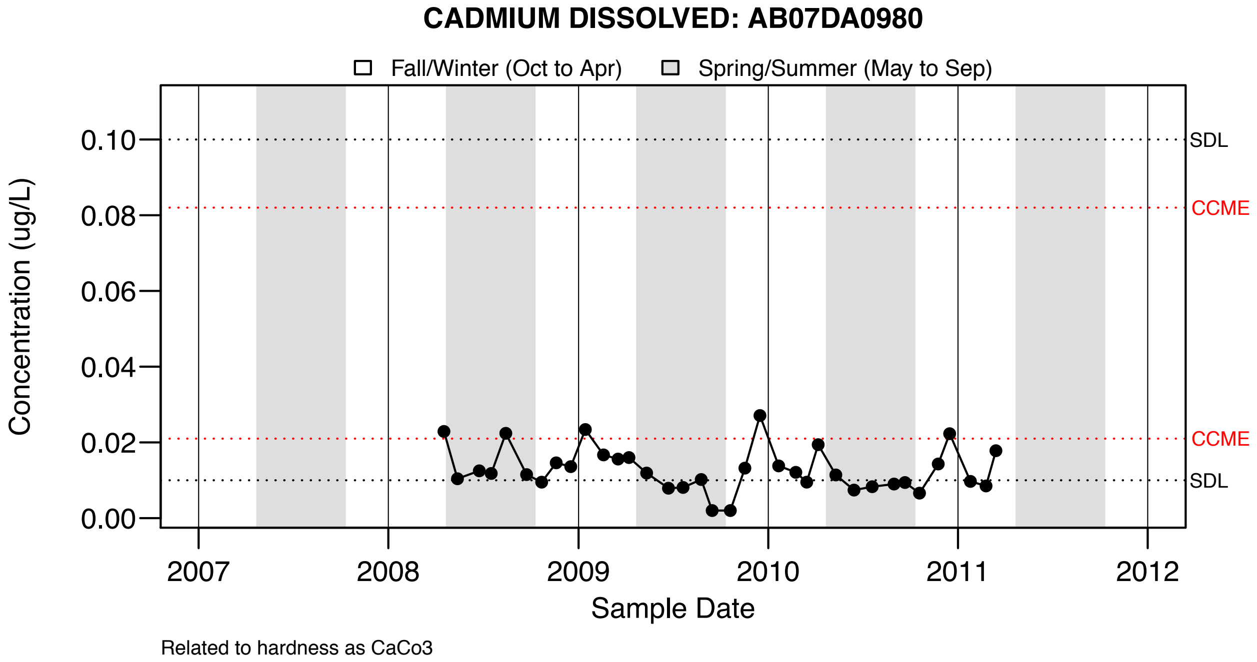


Figure A1.139: CADMIUM DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

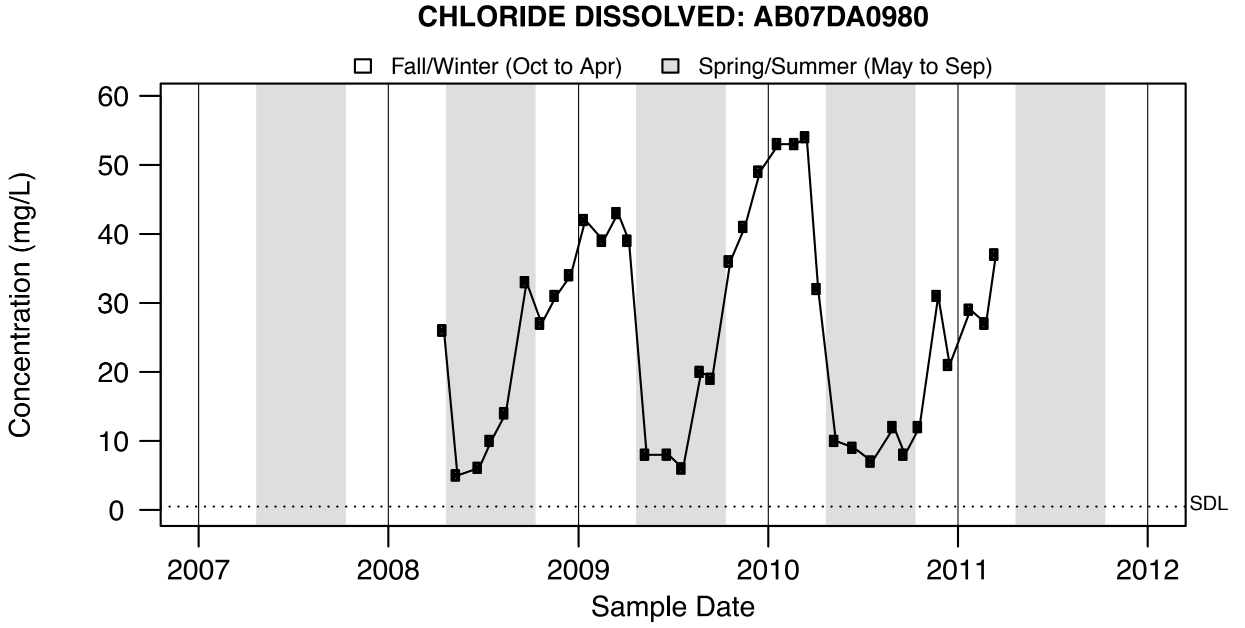


Figure A1.140: CHLORIDE DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

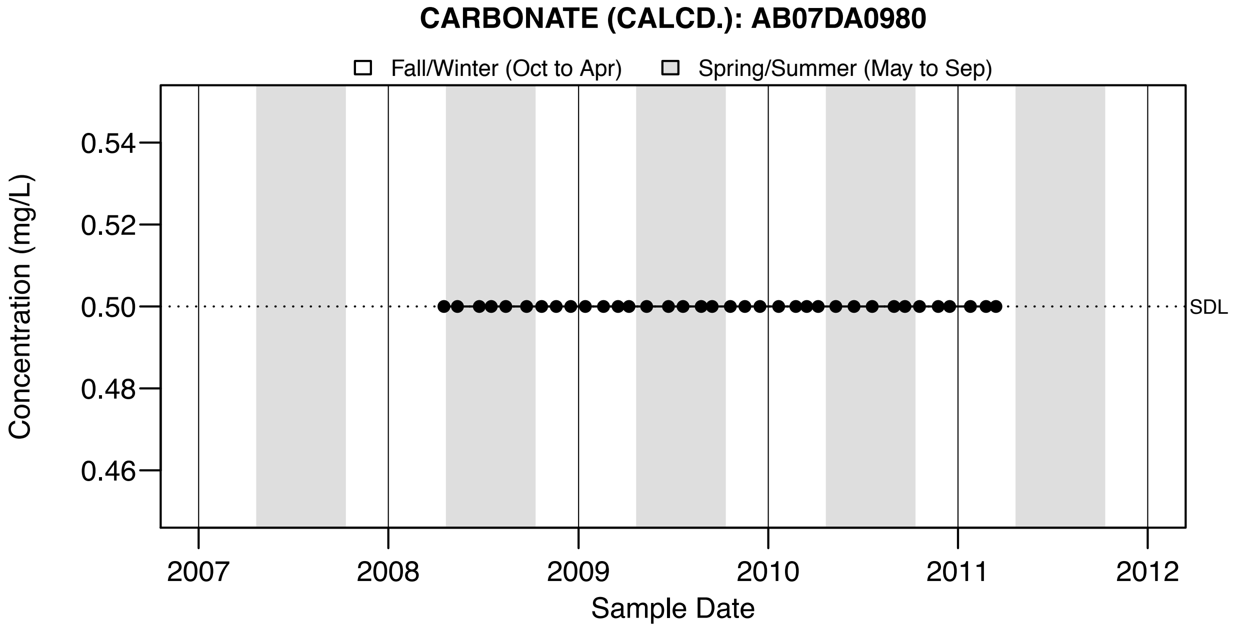


Figure A1.141: CARBONATE (CALCD.): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

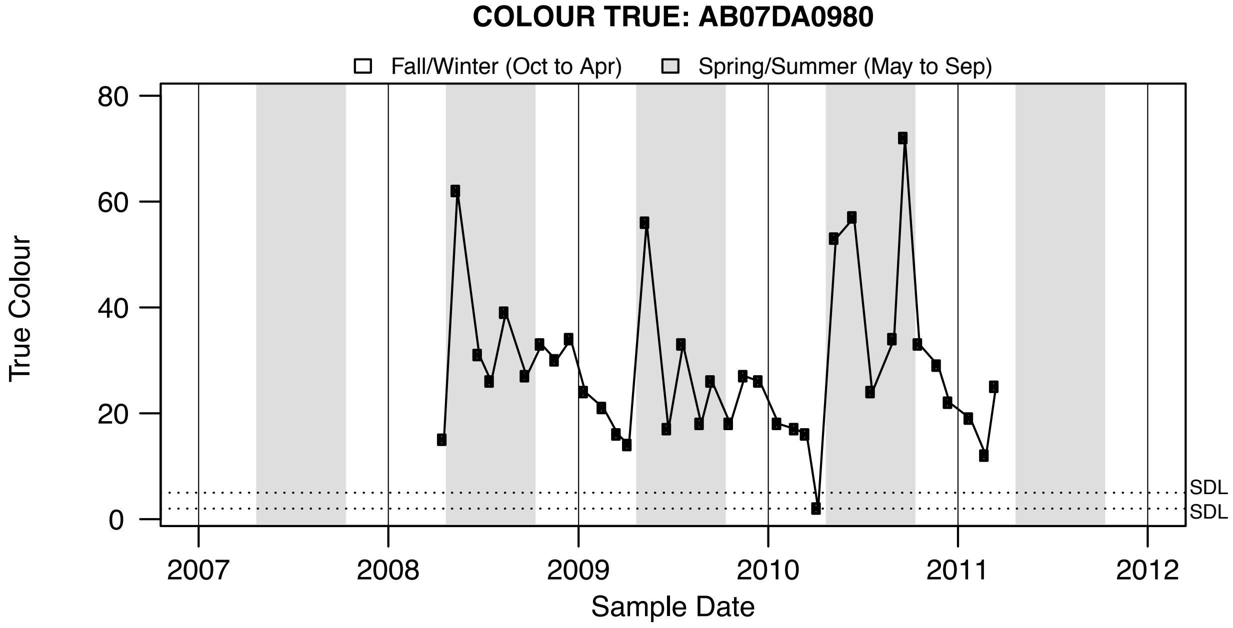


Figure A1.142: COLOUR TRUE: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

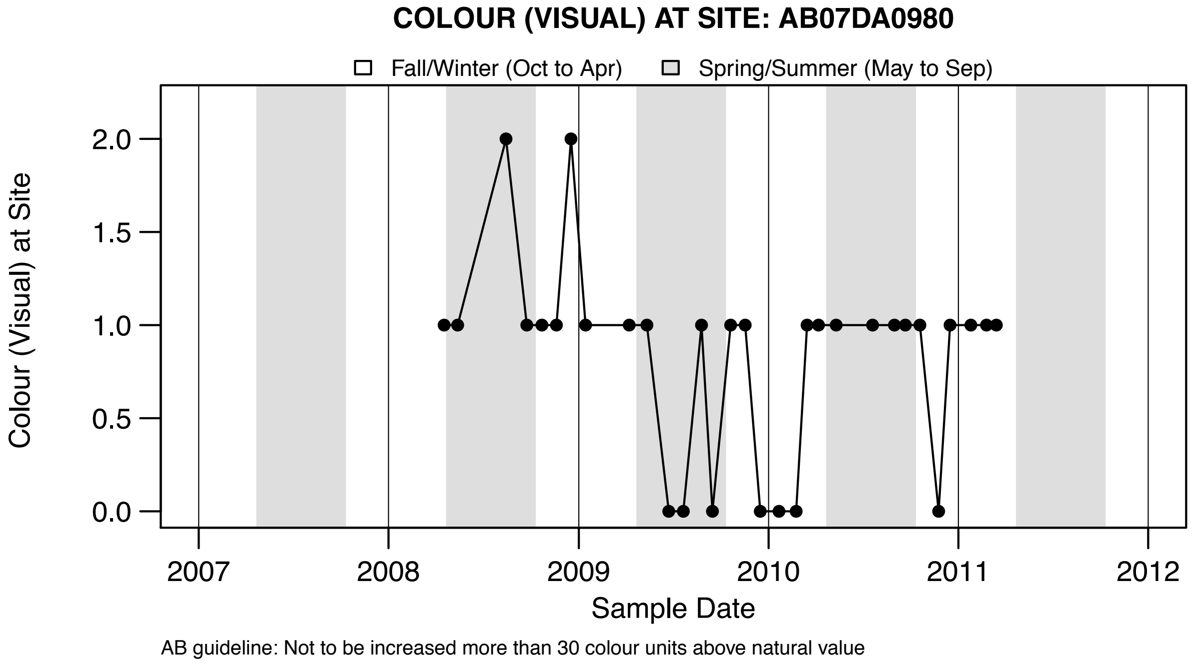


Figure A1.143: COLOUR (VISUAL) AT SITE: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

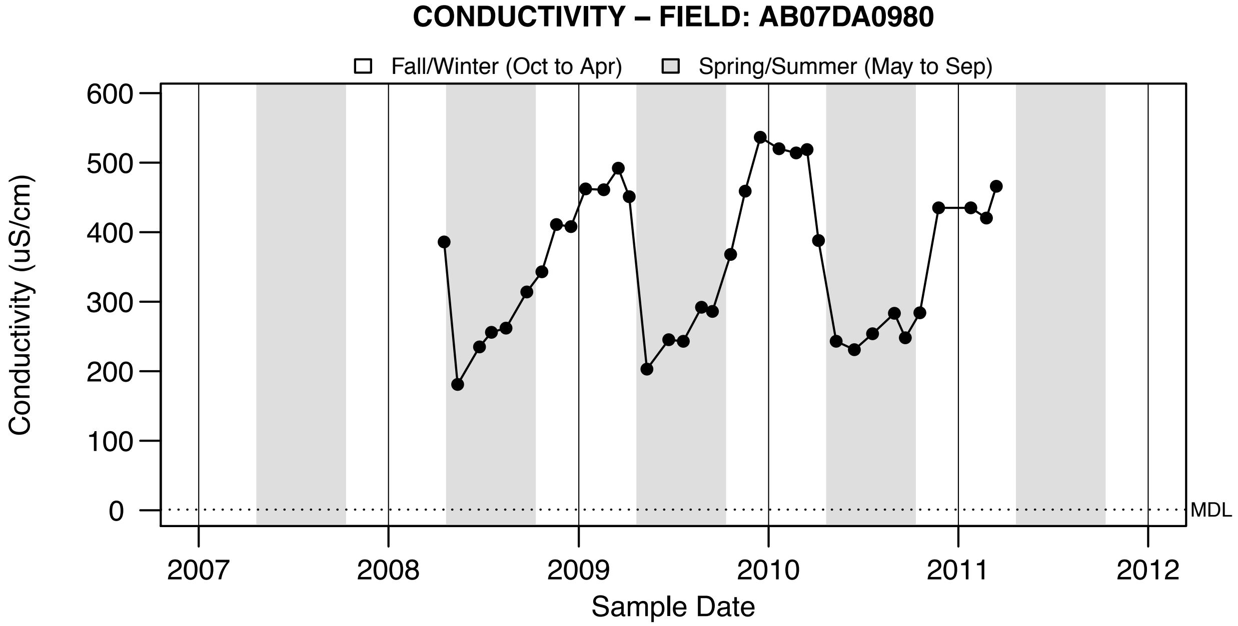


Figure A1.144: CONDUCTIVITY - FIELD: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

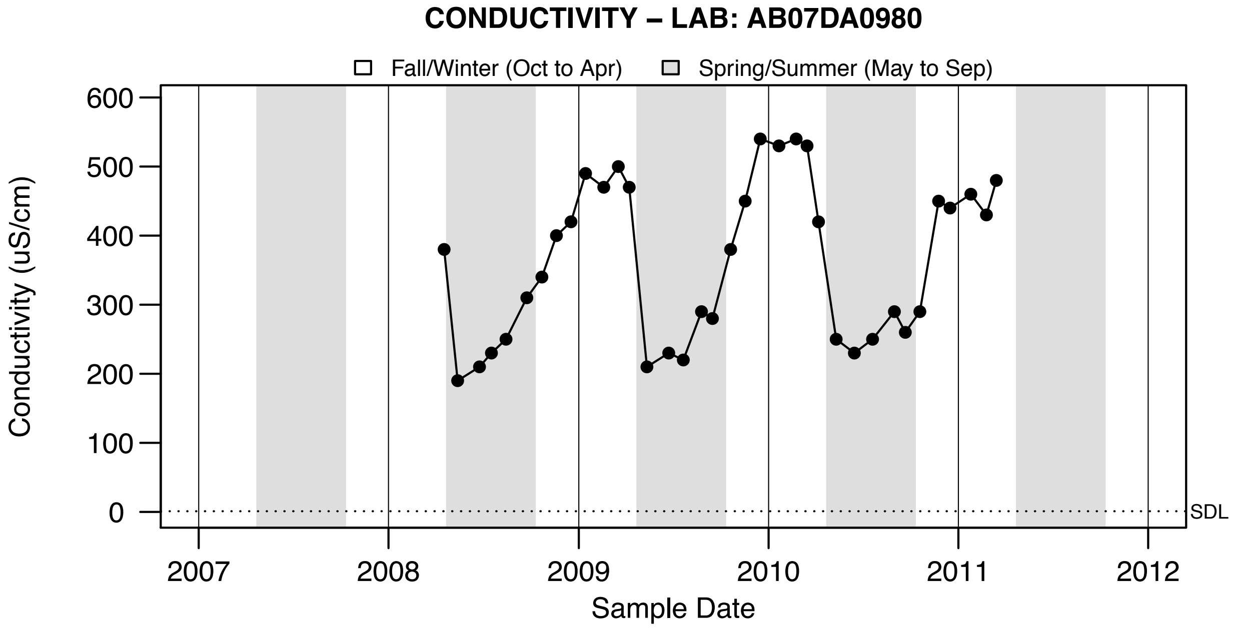


Figure A1.145: CONDUCTIVITY - LAB: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

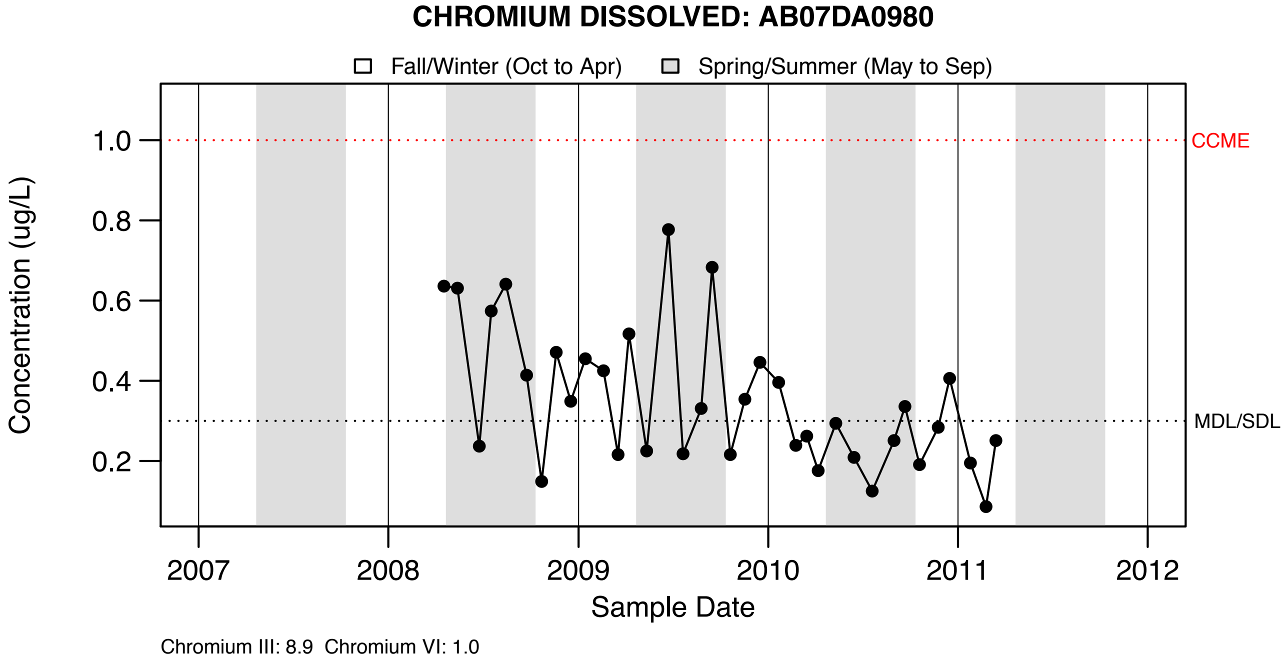
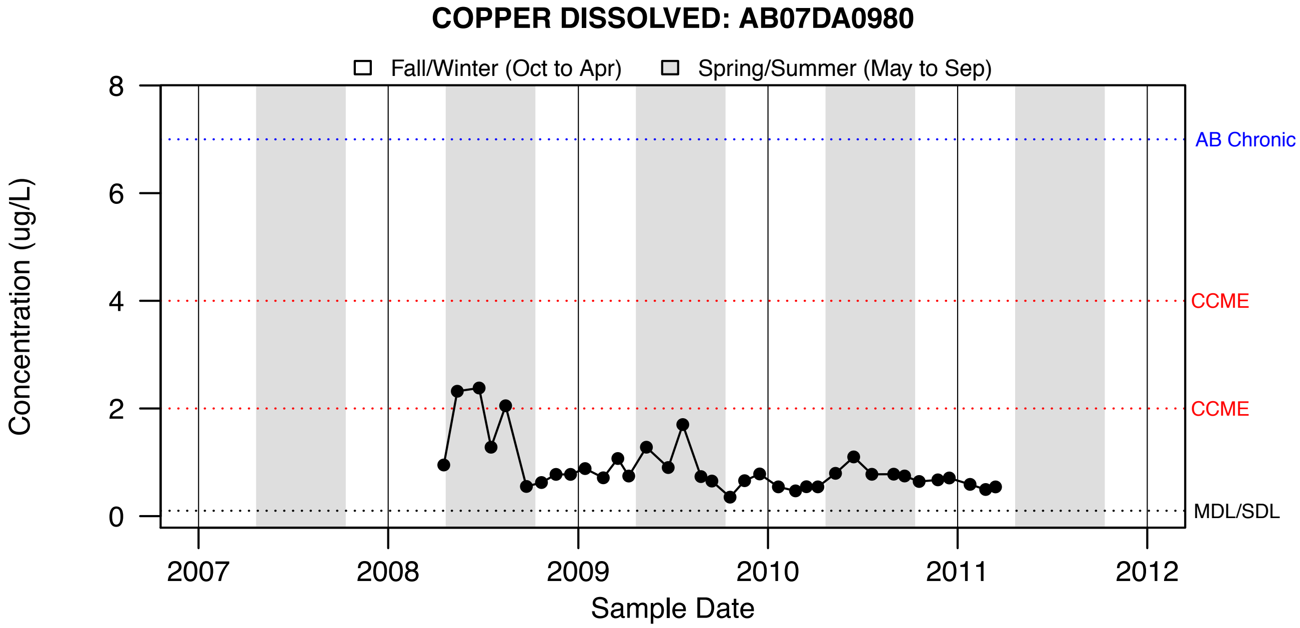
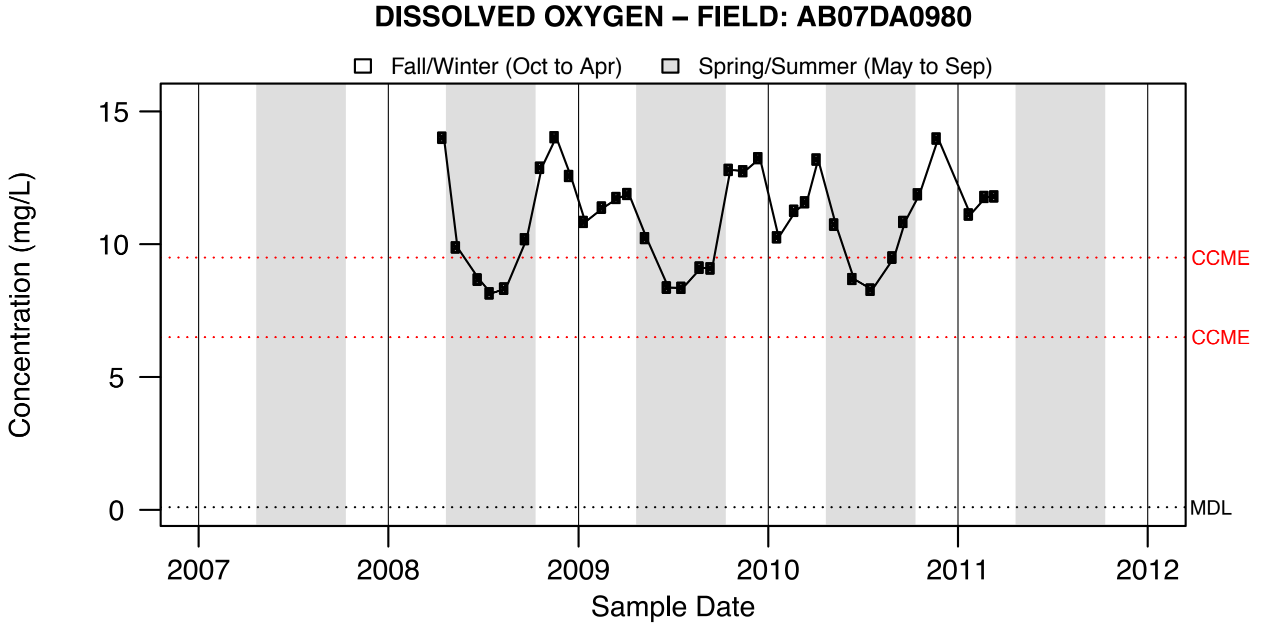


Figure A1.146: CHROMIUM DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A1.147: COPPER DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



Cold water biota: early life stages = 9.5 mg/L; other life stages = 6.5 mg/L

Figure A1.148: DISSOLVED OXYGEN - FIELD: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

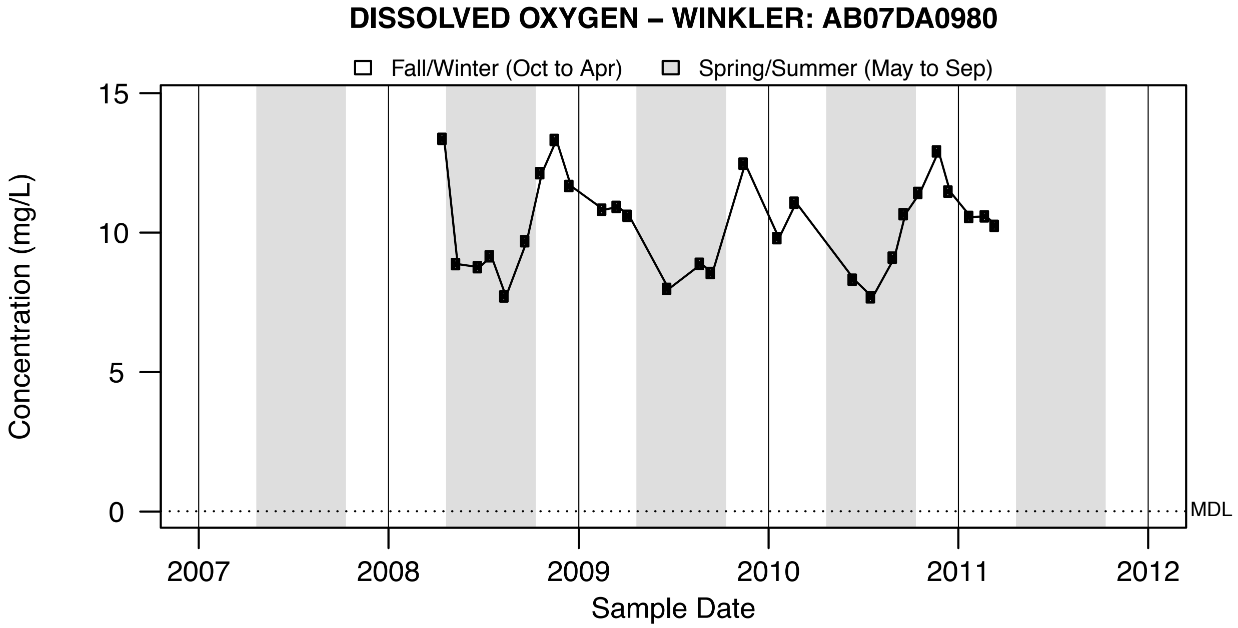


Figure A1.149: DISSOLVED OXYGEN - WINKLER: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

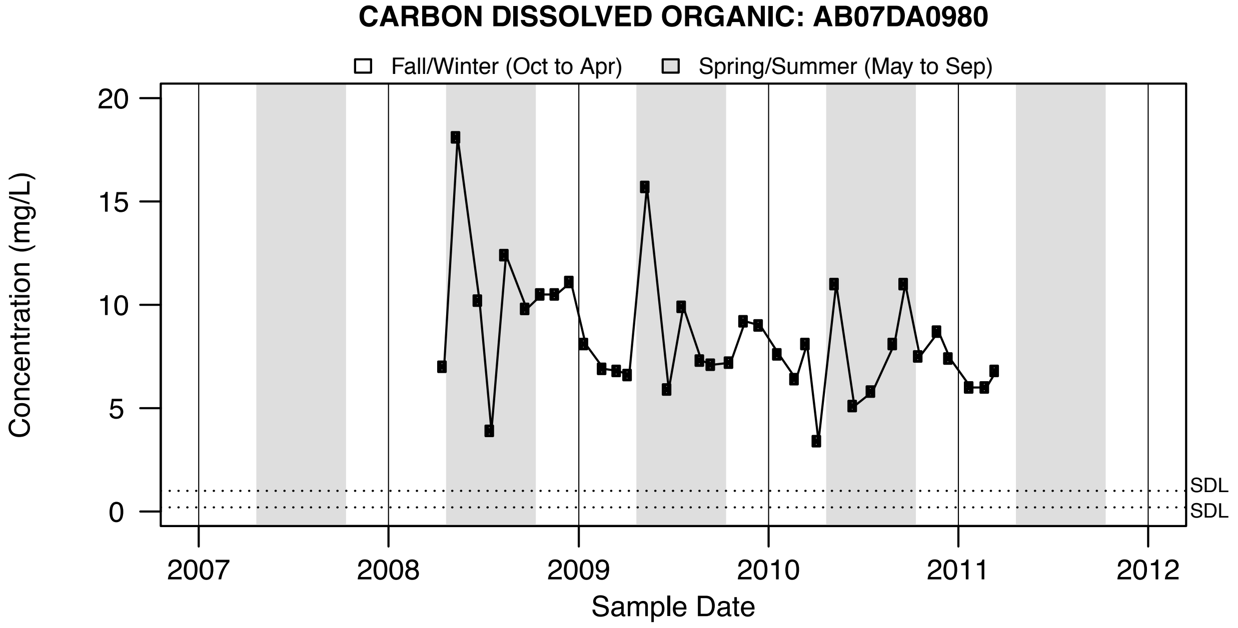


Figure A1.150: CARBON DISSOLVED ORGANIC: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

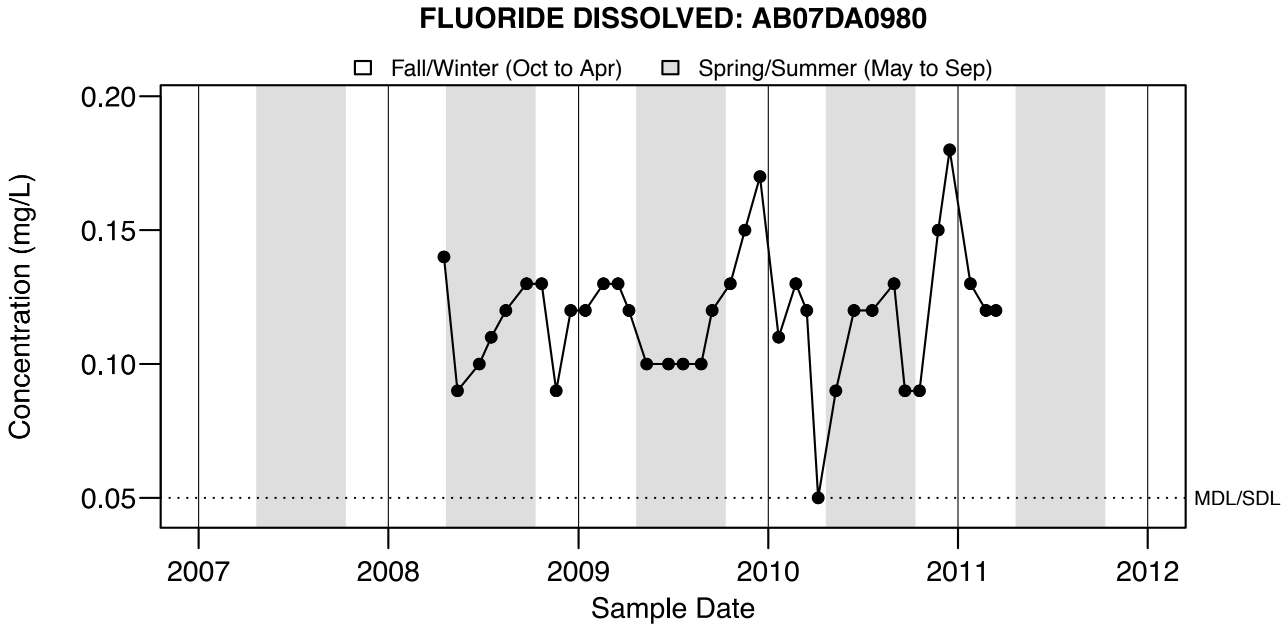


Figure A1.151: FLUORIDE DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

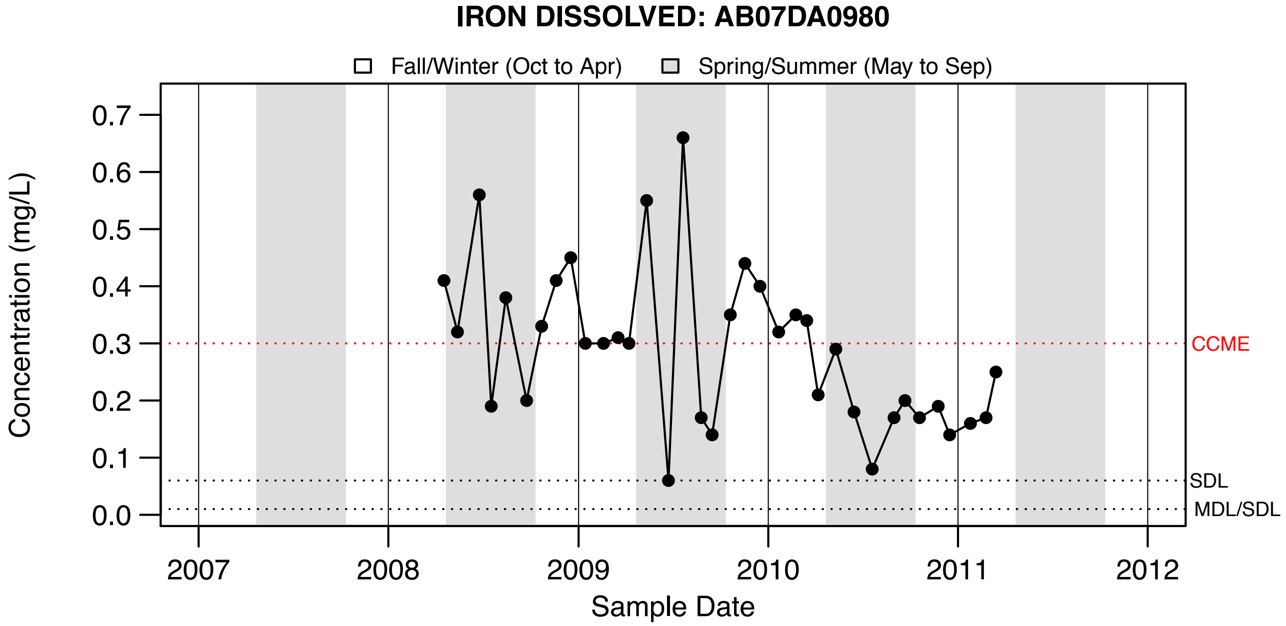


Figure A1.152: IRON DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

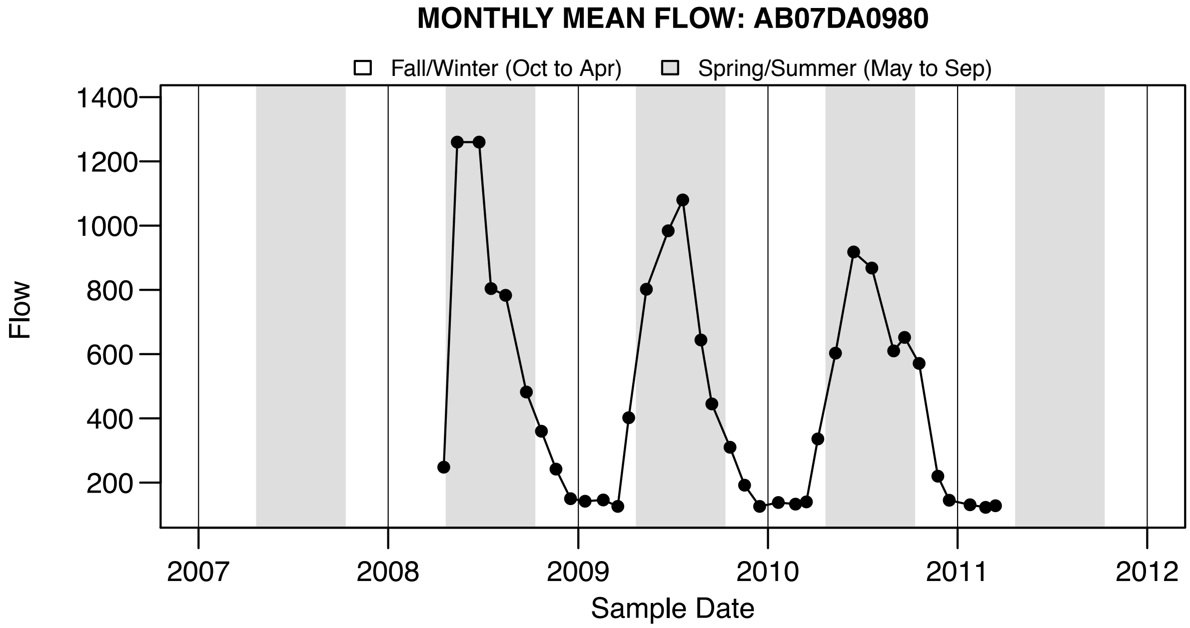


Figure A1.153: MONTHLY MEAN FLOW: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

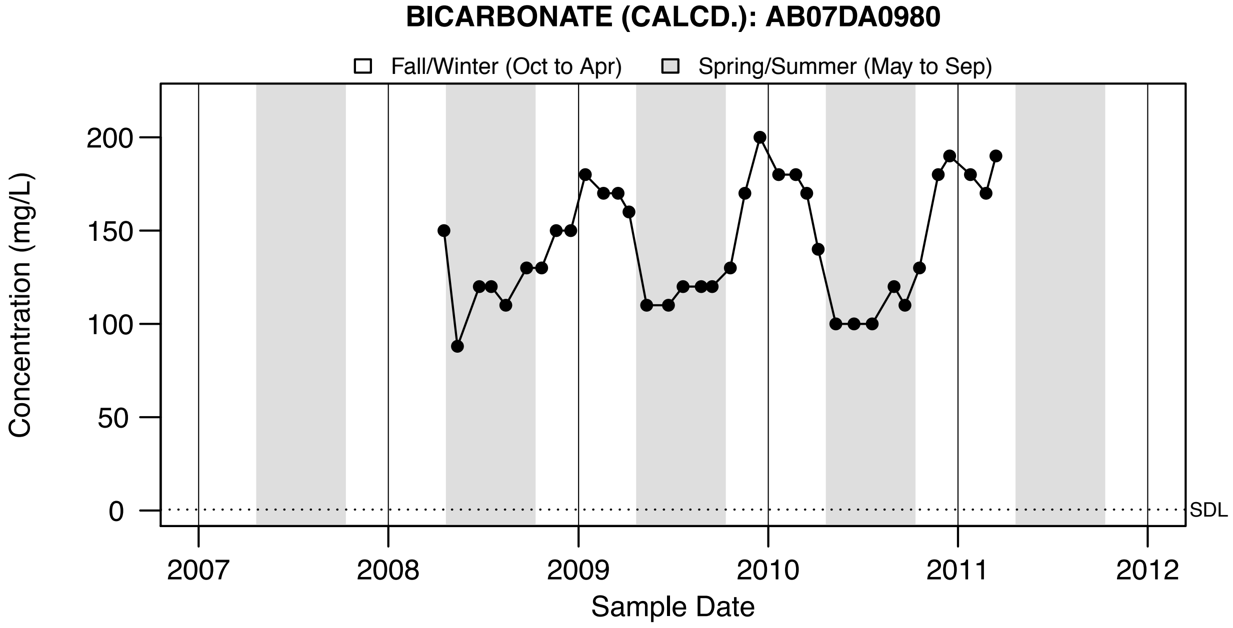


Figure A1.154: BICARBONATE (CALCD.): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

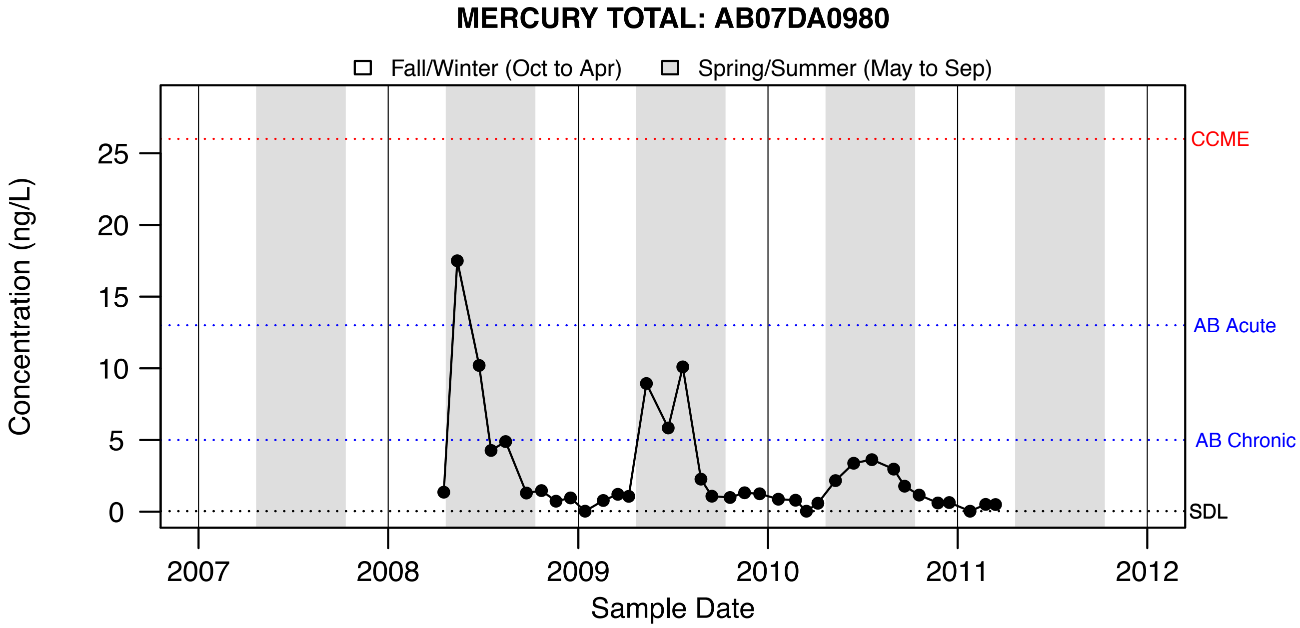


Figure A1.155: MERCURY TOTAL: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

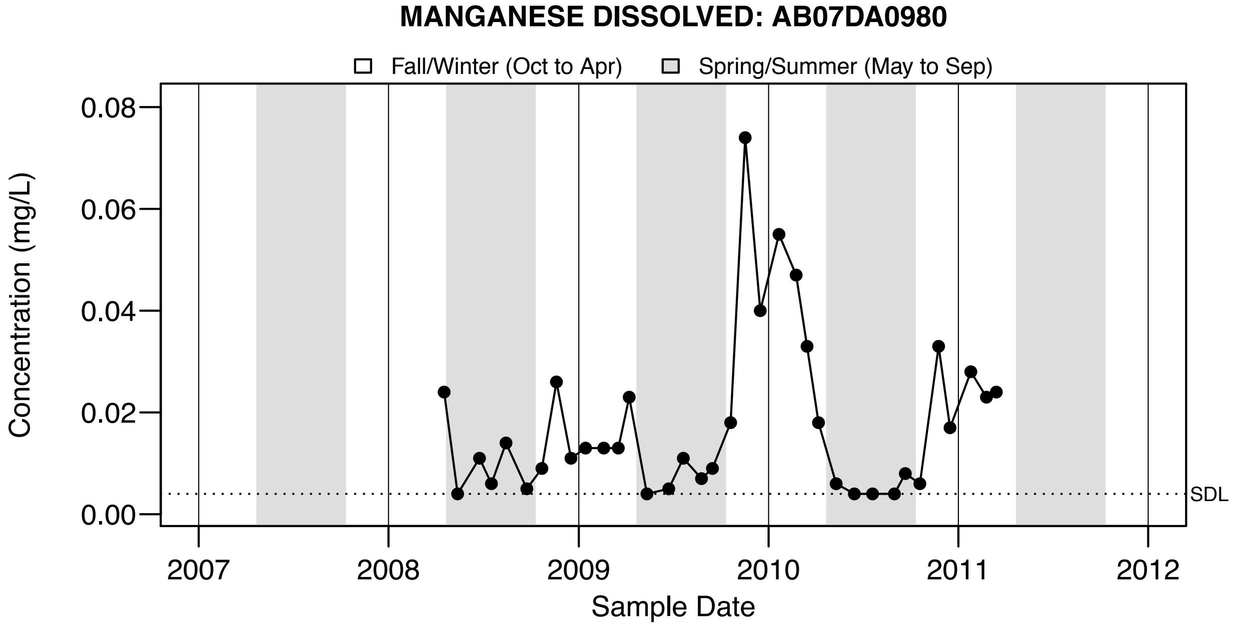


Figure A1.156: MANGANESE DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

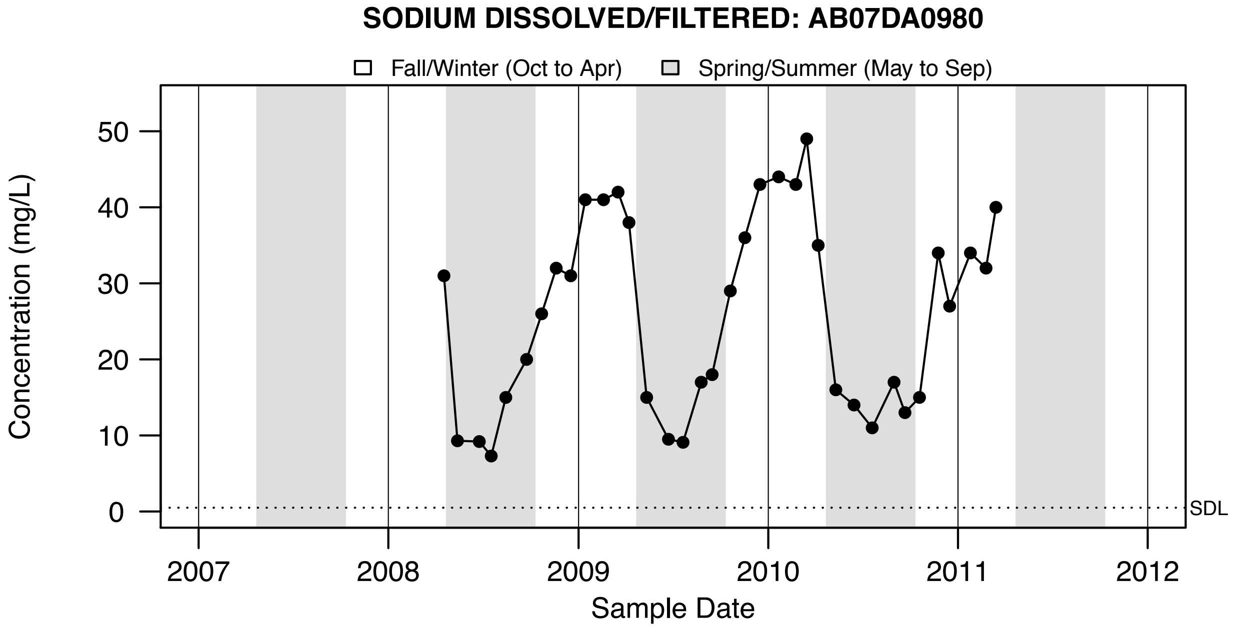
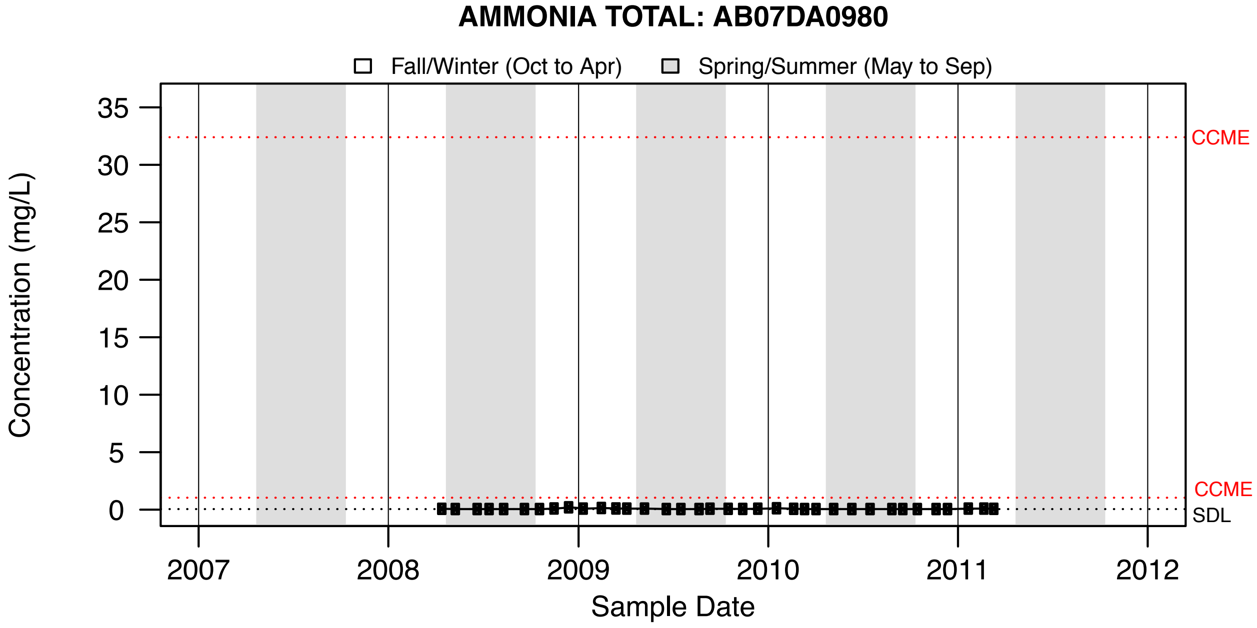
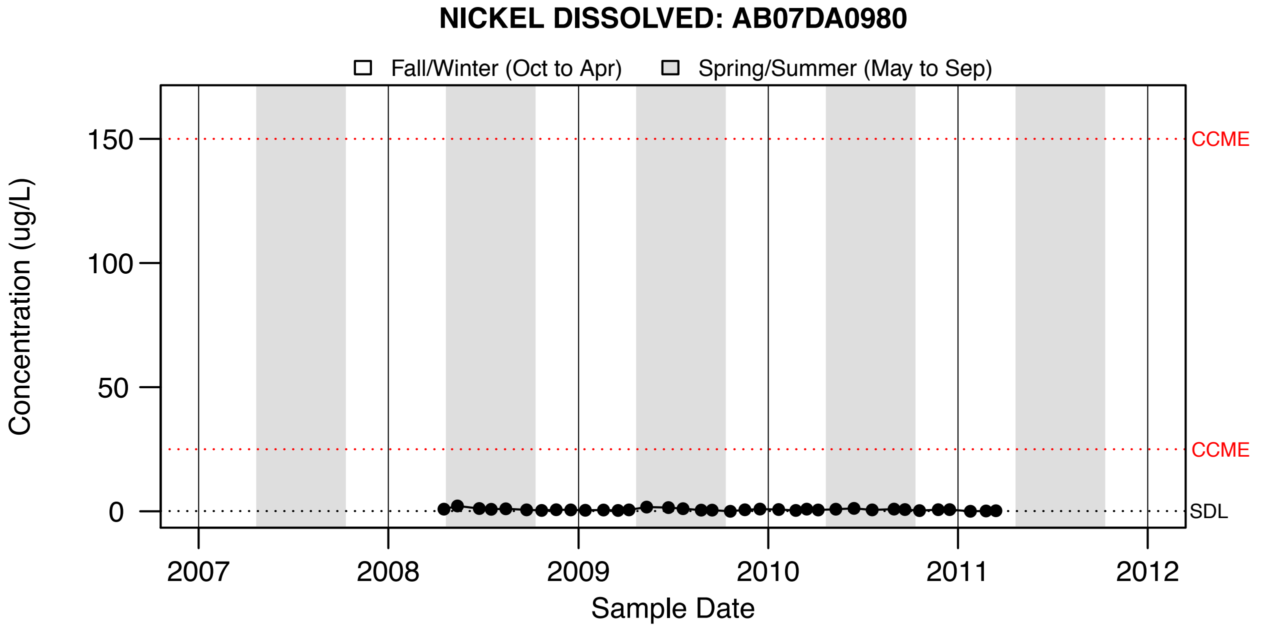


Figure A1.157: SODIUM DISSOLVED/FILTERED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A1.158: AMMONIA TOTAL: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A1.159: NICKEL DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

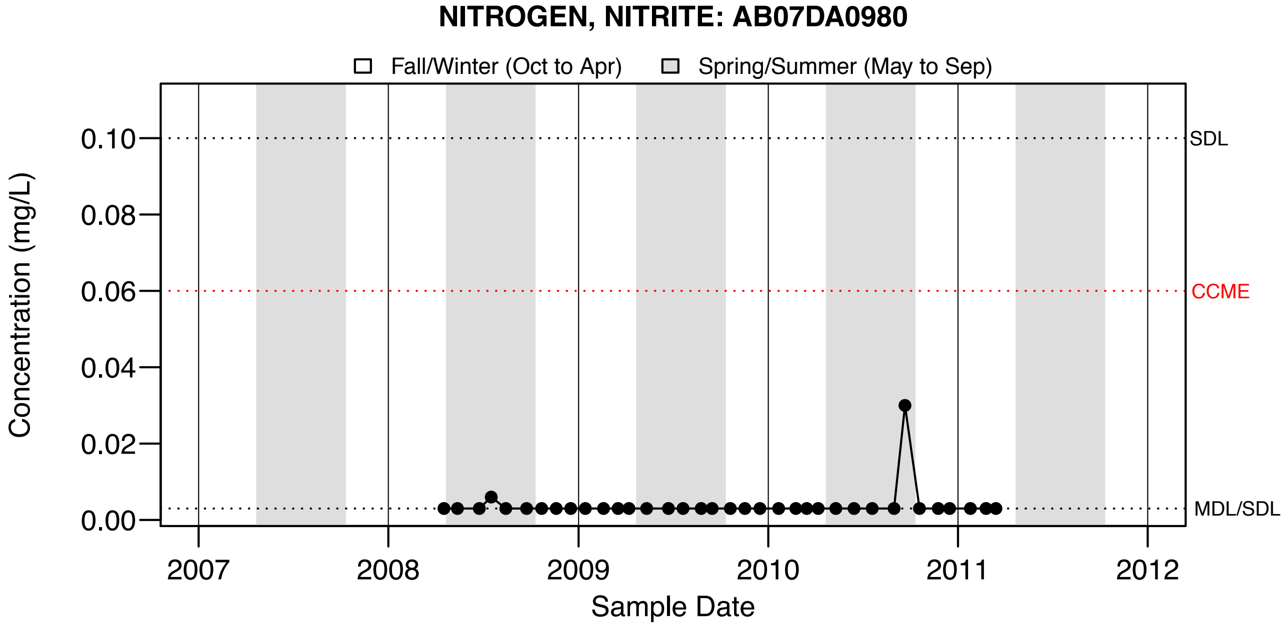
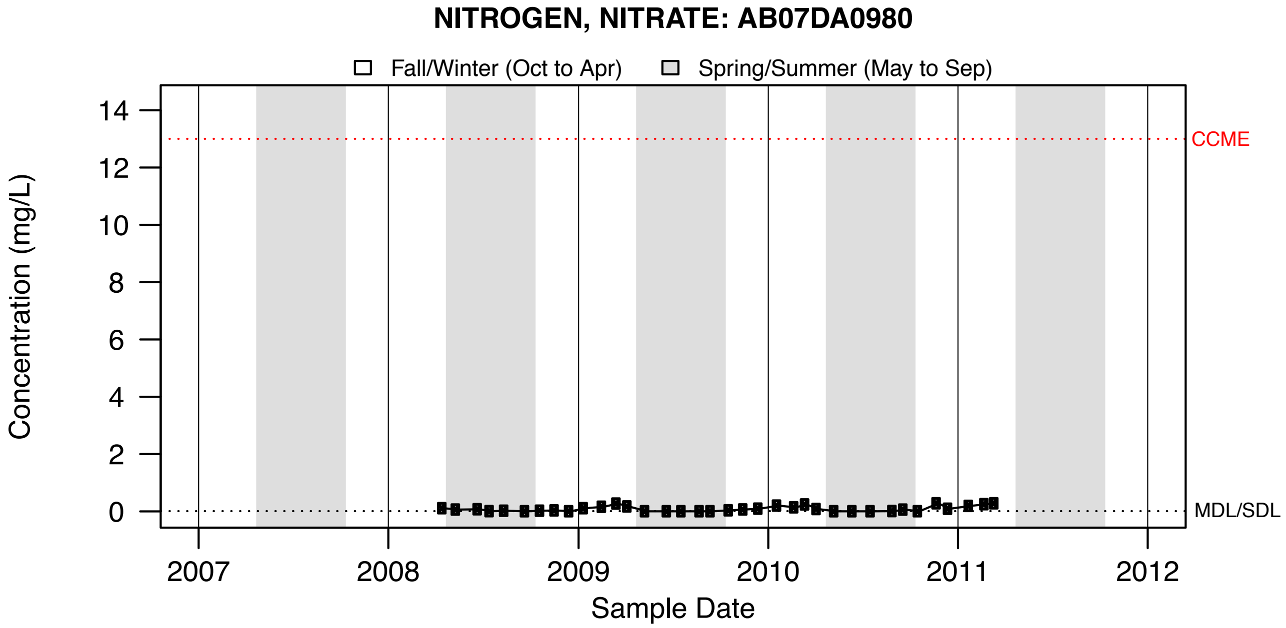


Figure A1.160: NITROGEN, NITRITE: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A1.161: NITROGEN, NITRATE: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

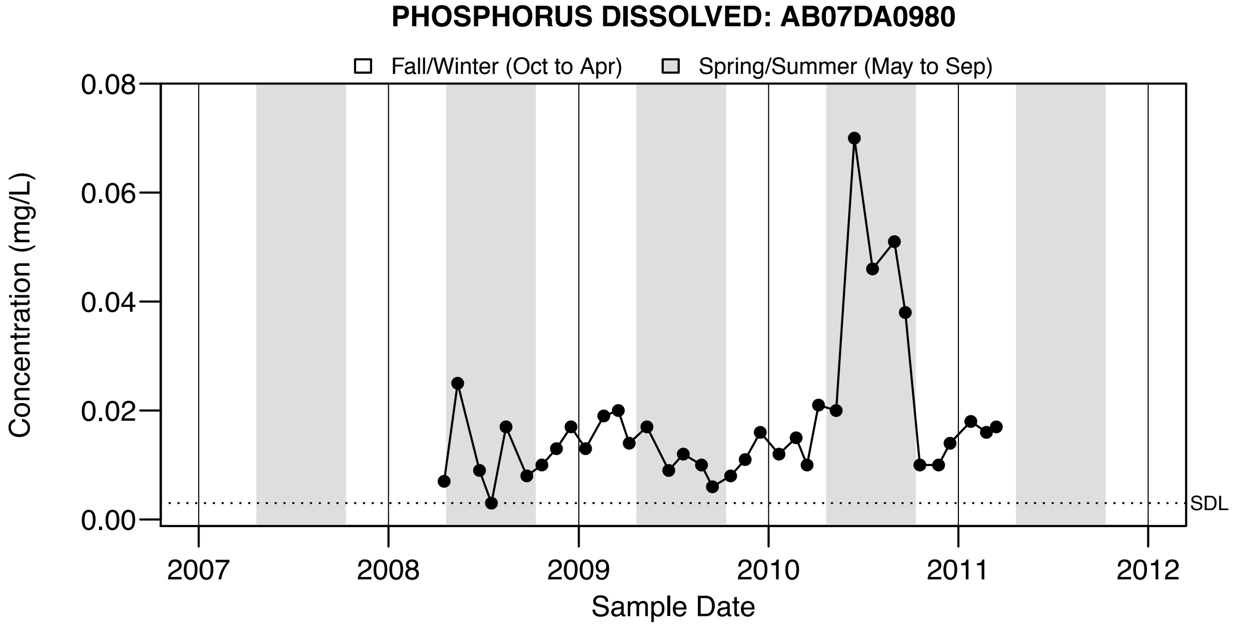


Figure A1.162: PHOSPHORUS DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

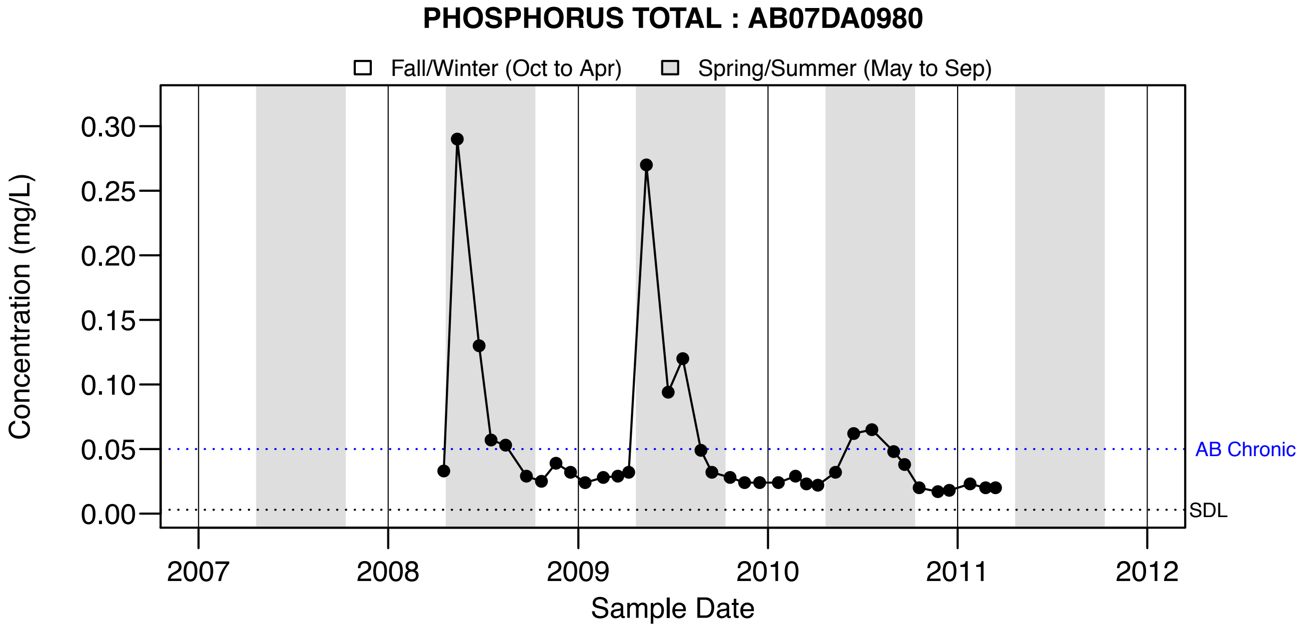
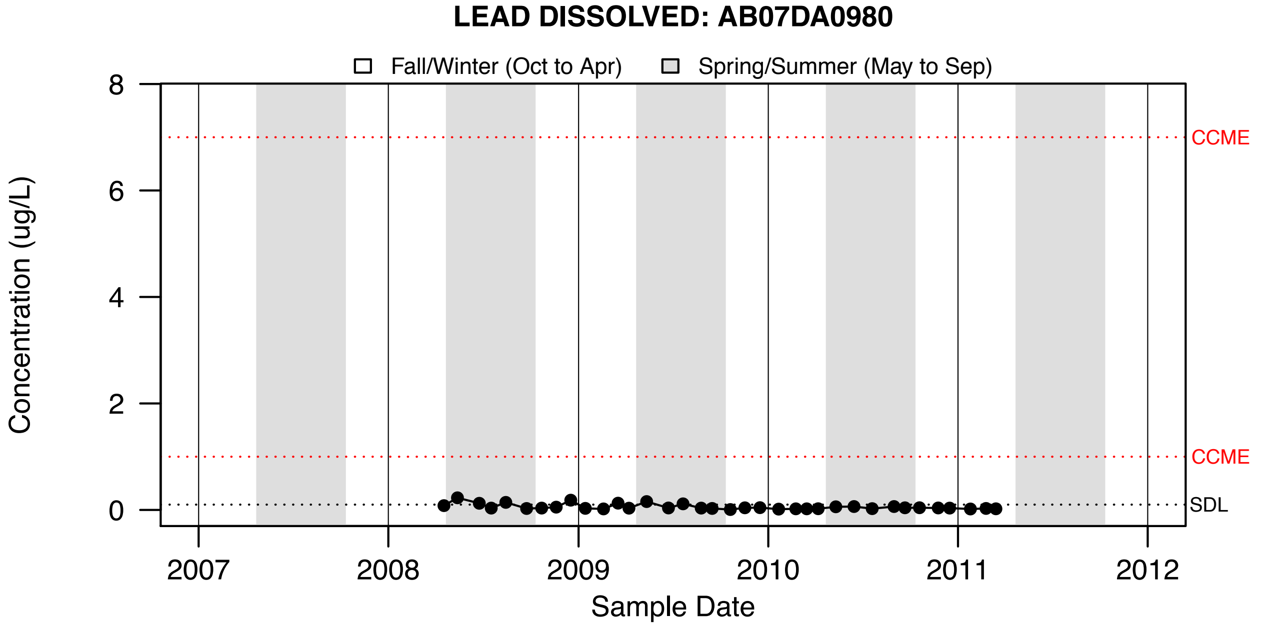


Figure A1.163: PHOSPHORUS TOTAL : AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A1.164: LEAD DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

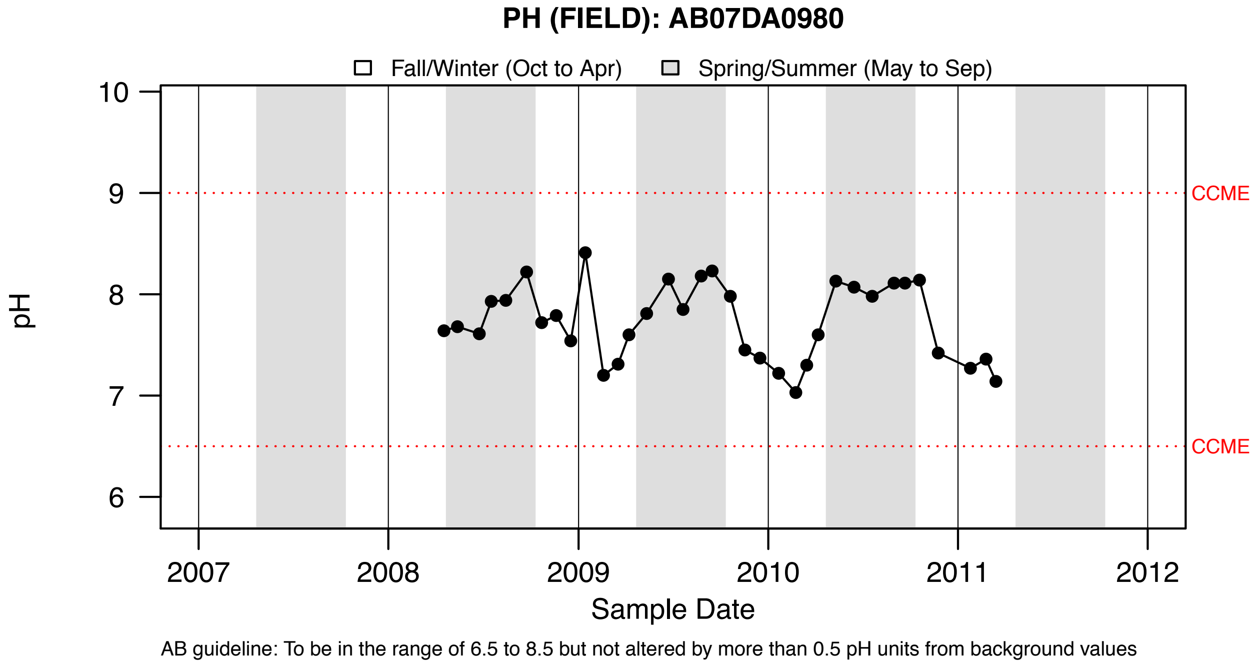


Figure A1.165: PH (FIELD): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

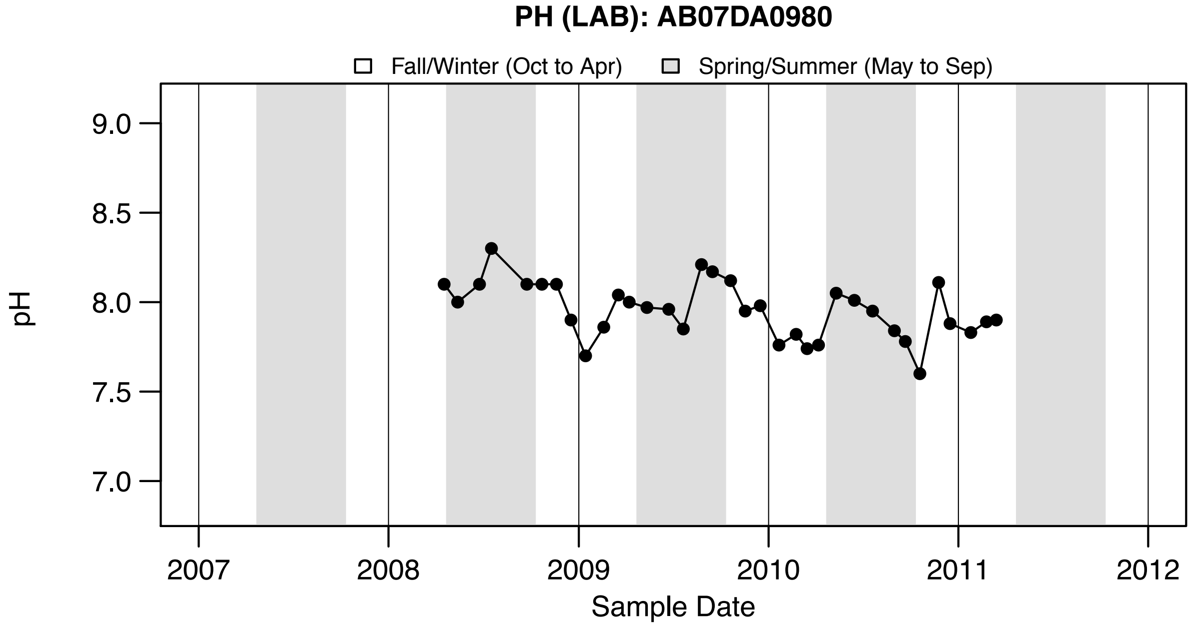


Figure A1.166: PH (LAB): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

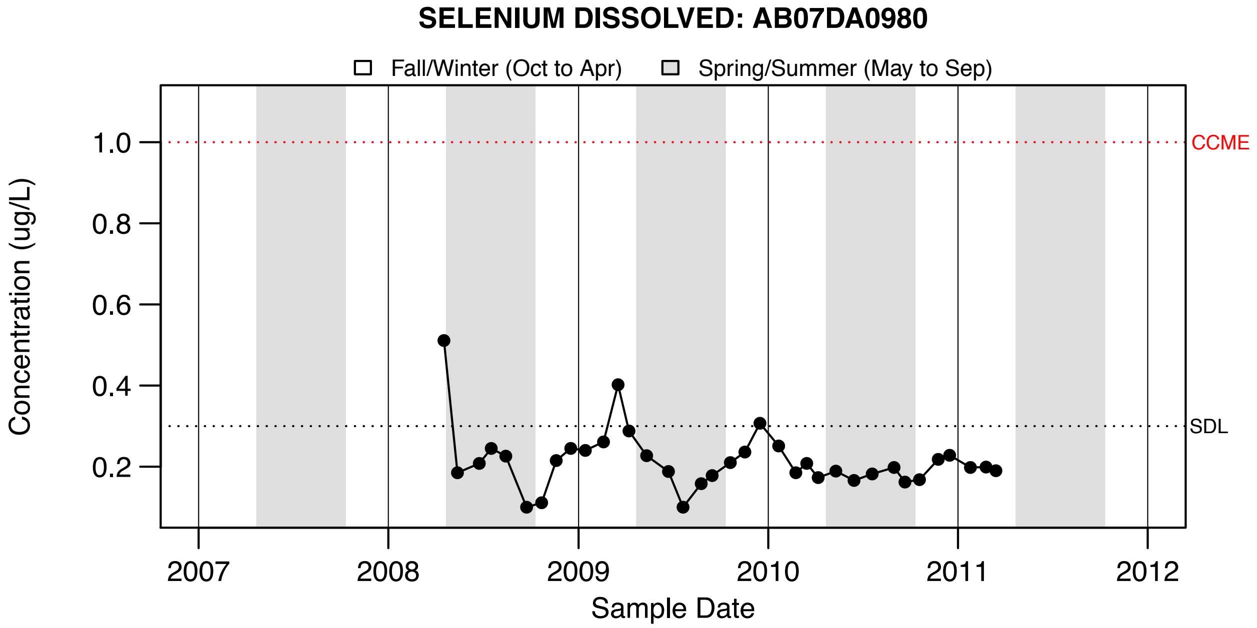


Figure A1.167: SELENIUM DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

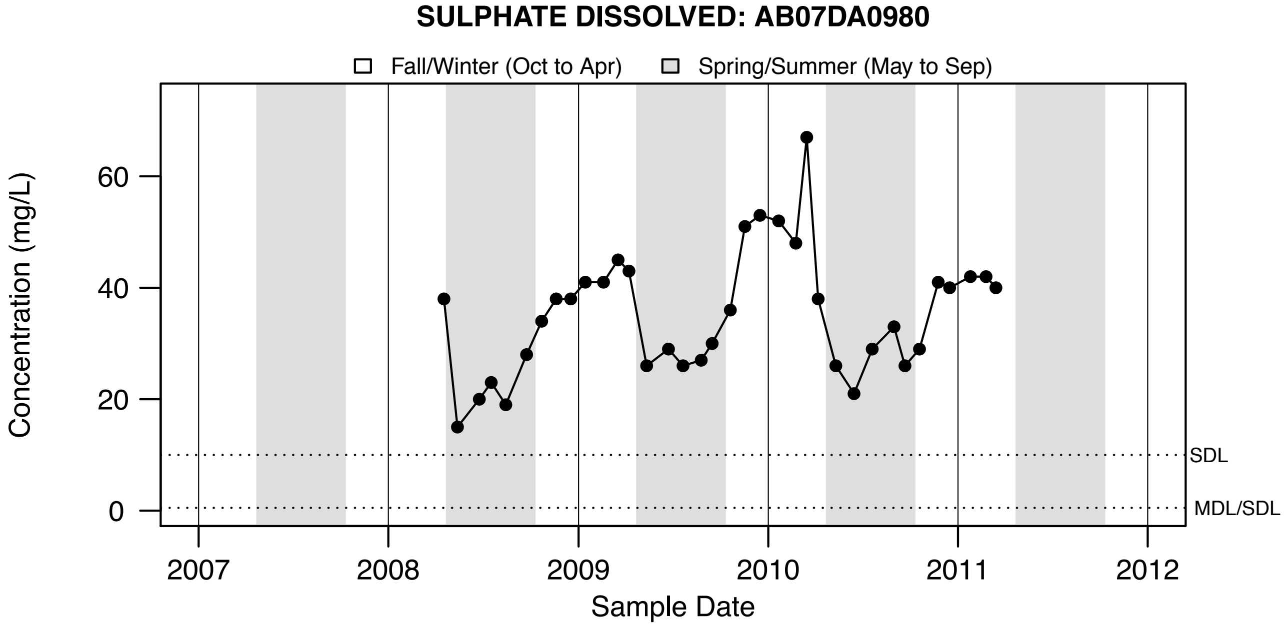


Figure A1.168: SULPHATE DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

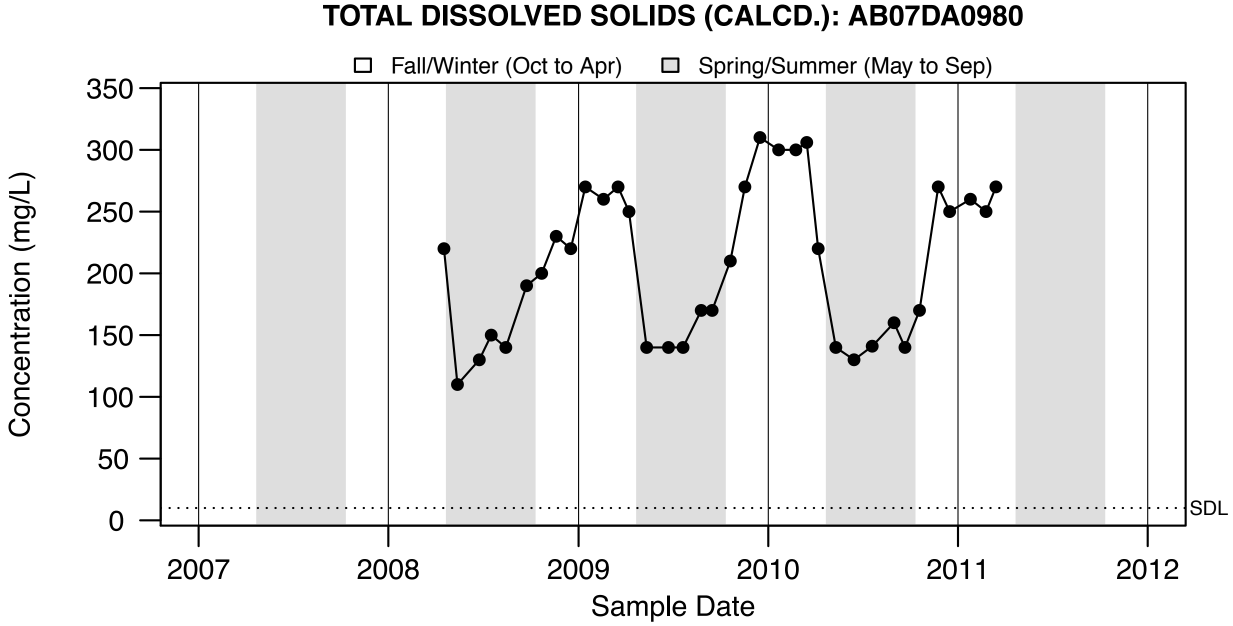
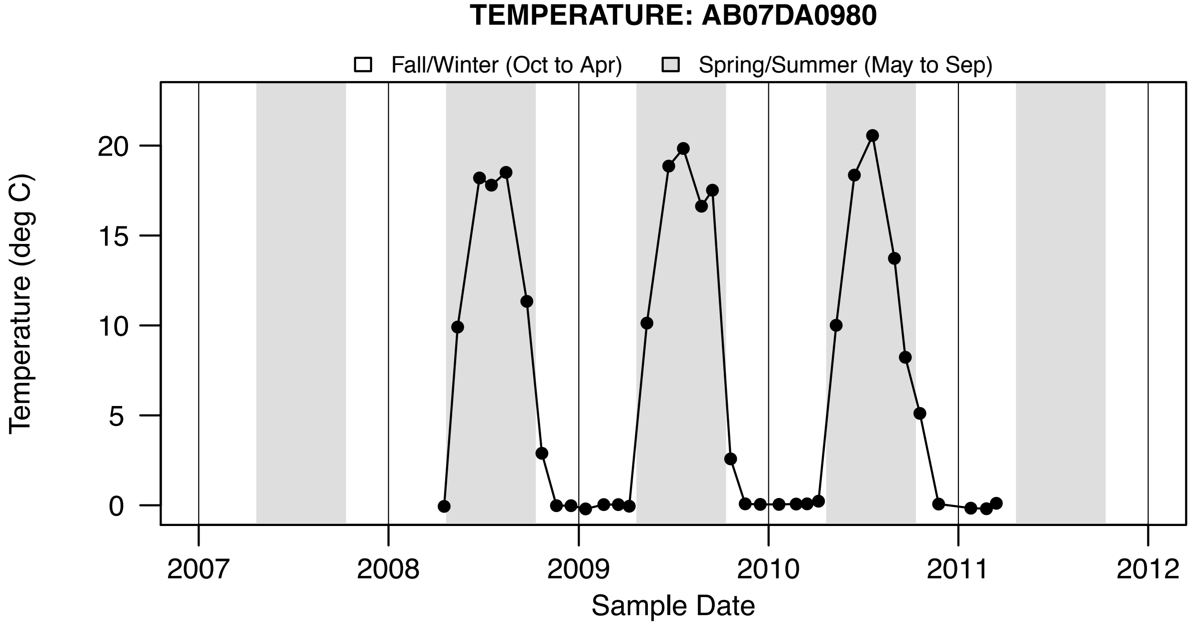


Figure A1.169: TOTAL DISSOLVED SOLIDS (CALCD.): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A1.170: TEMPERATURE: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

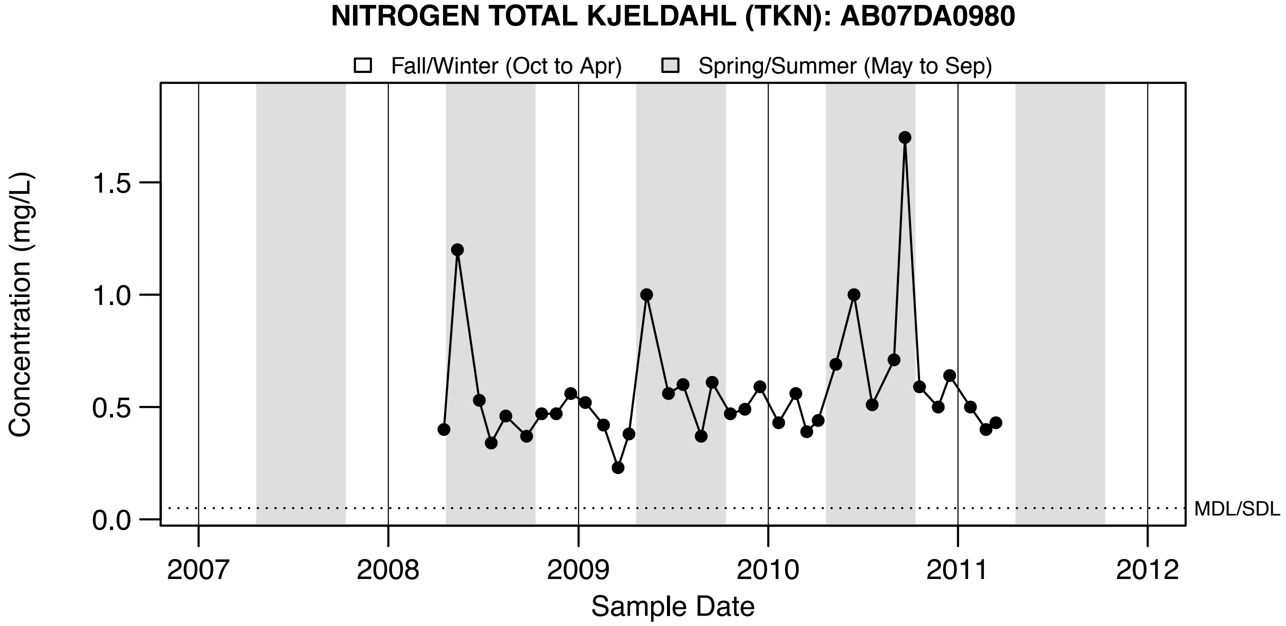
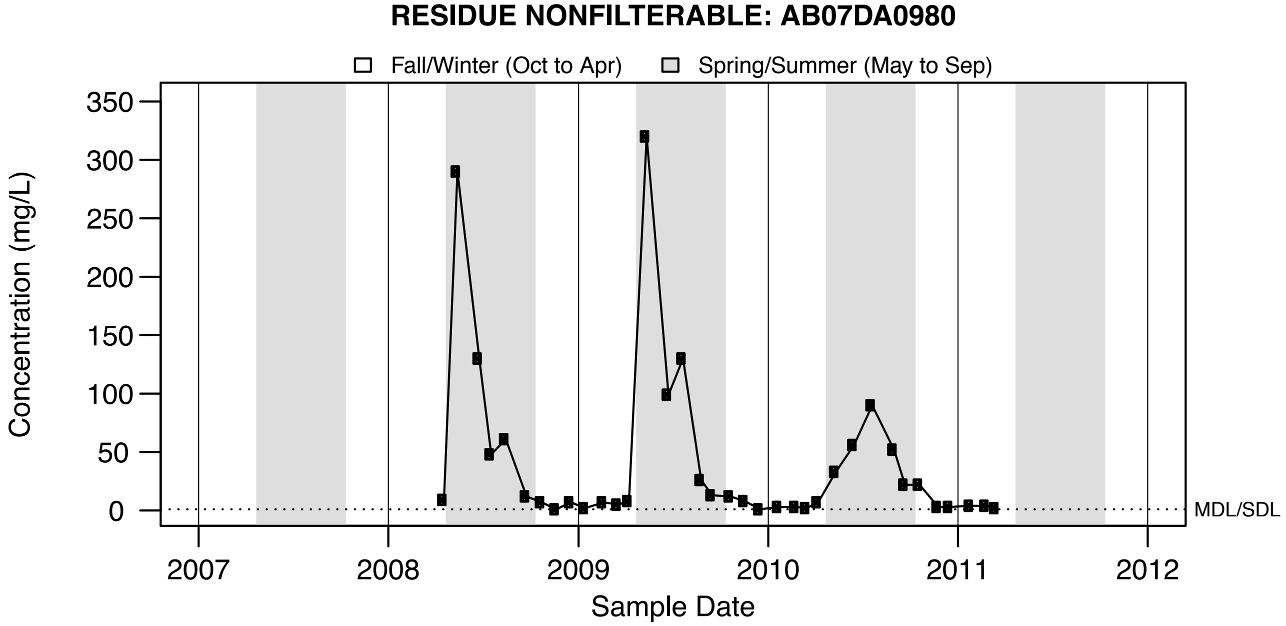


Figure A1.171: NITROGEN TOTAL KJELDAHL (TKN): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term).
Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background
when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A1.172: RESIDUE NONFILTERABLE: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

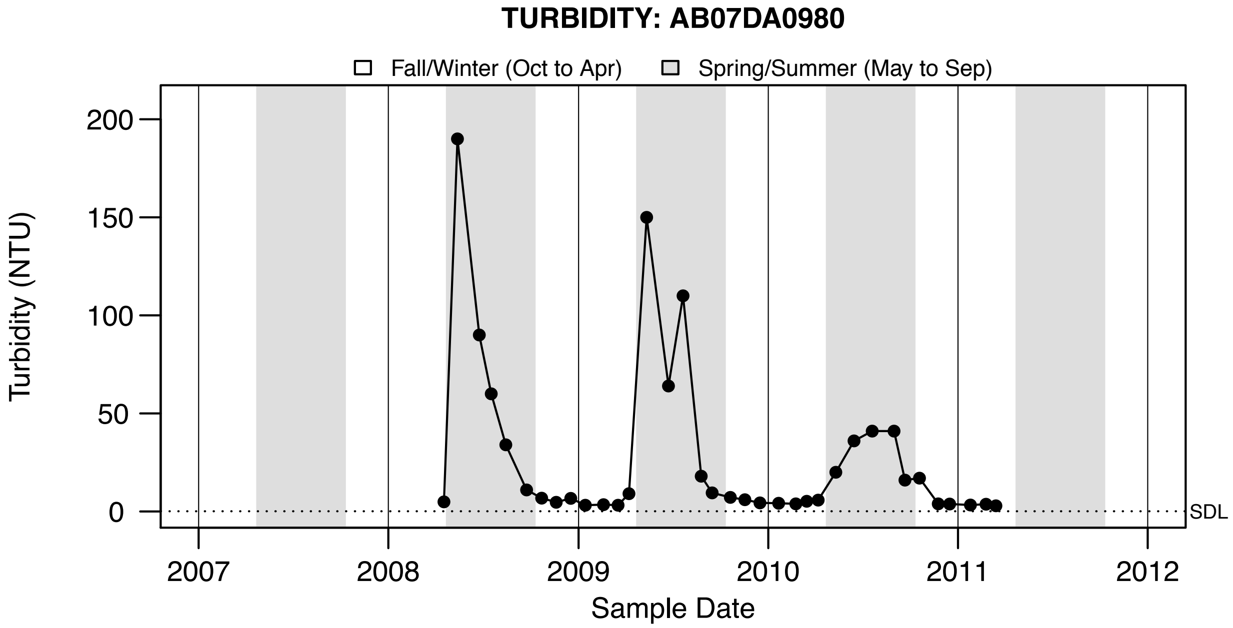


Figure A1.173: TURBIDITY: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

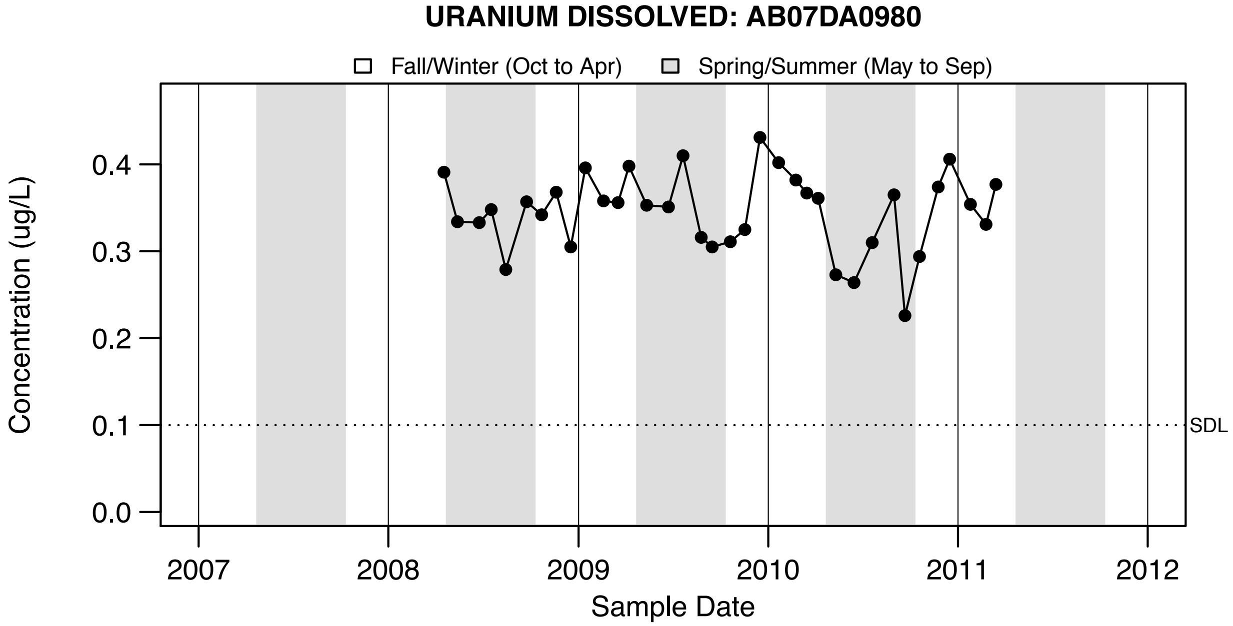


Figure A1.174: URANIUM DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

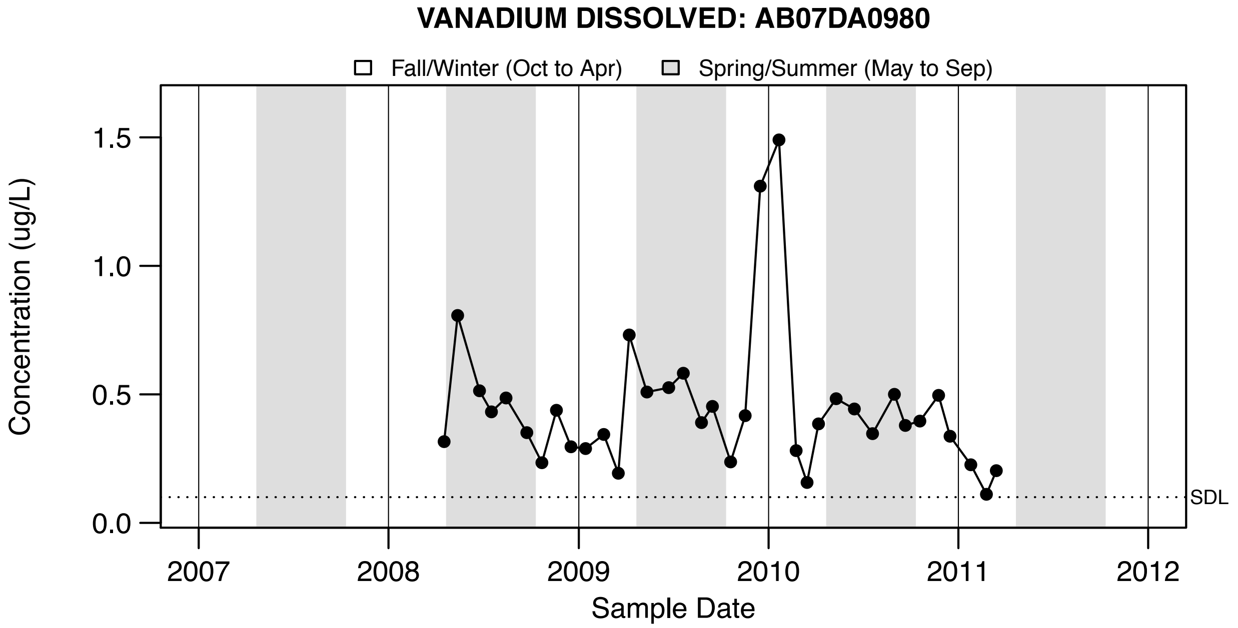


Figure A1.175: VANADIUM DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

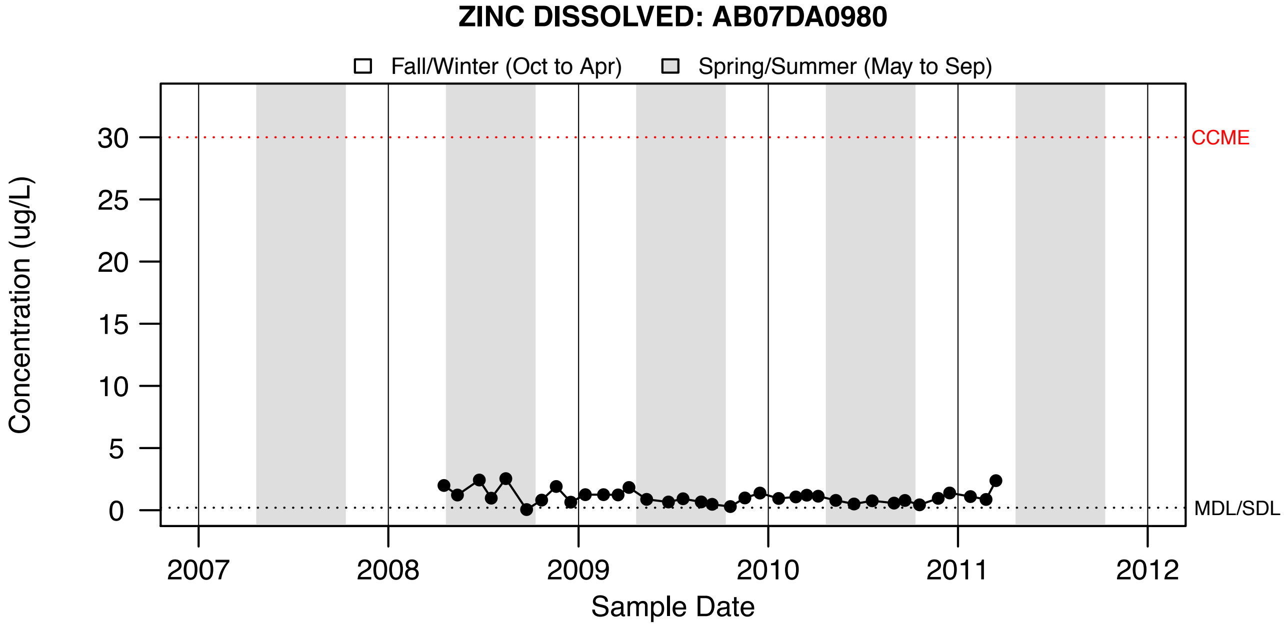
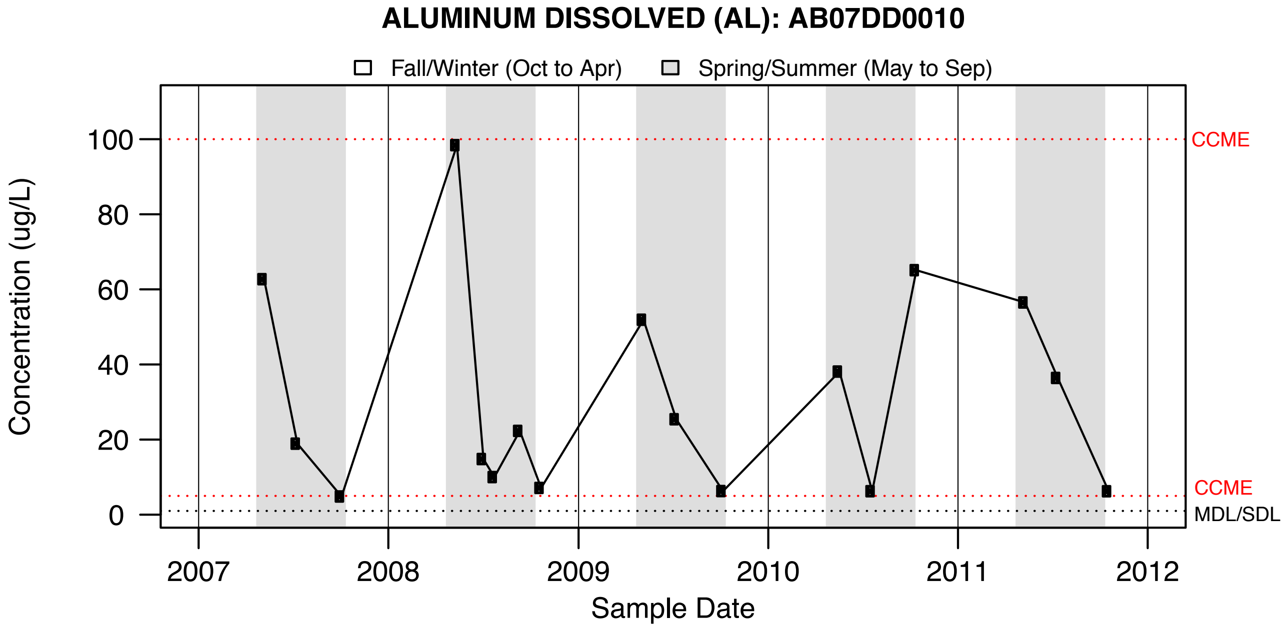
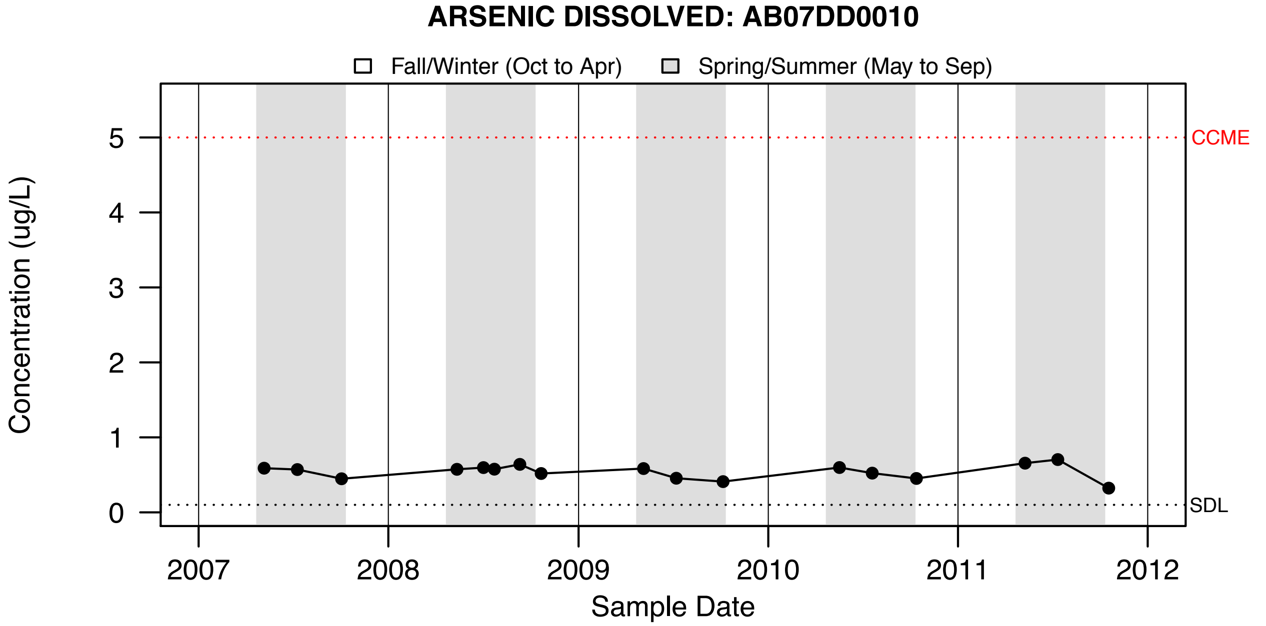


Figure A1.176: ZINC DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A1.177: ALUMINUM DISSOLVED (AL): AB07DD0010 - AT OLD FORT - RIGHT BANK



AB guidelines state Total Arsenic; CCME does not specify

Figure A1.178: ARSENIC DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

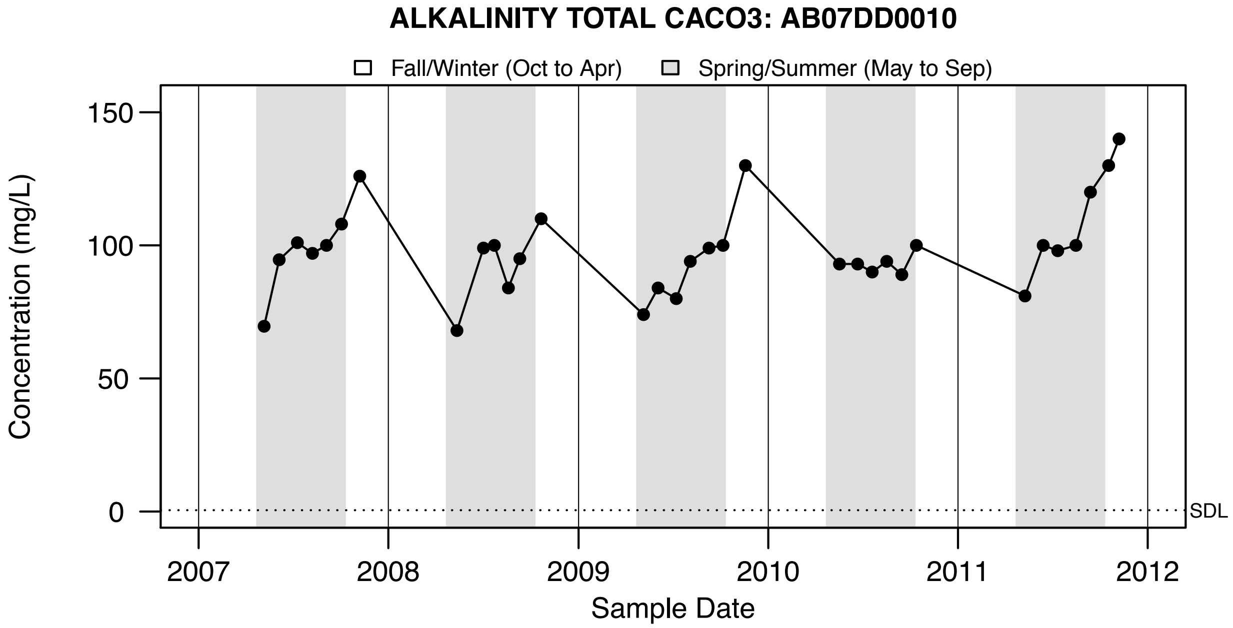


Figure A1.179: ALKALINITY TOTAL CACO3: AB07DD0010 - AT OLD FORT - RIGHT BANK

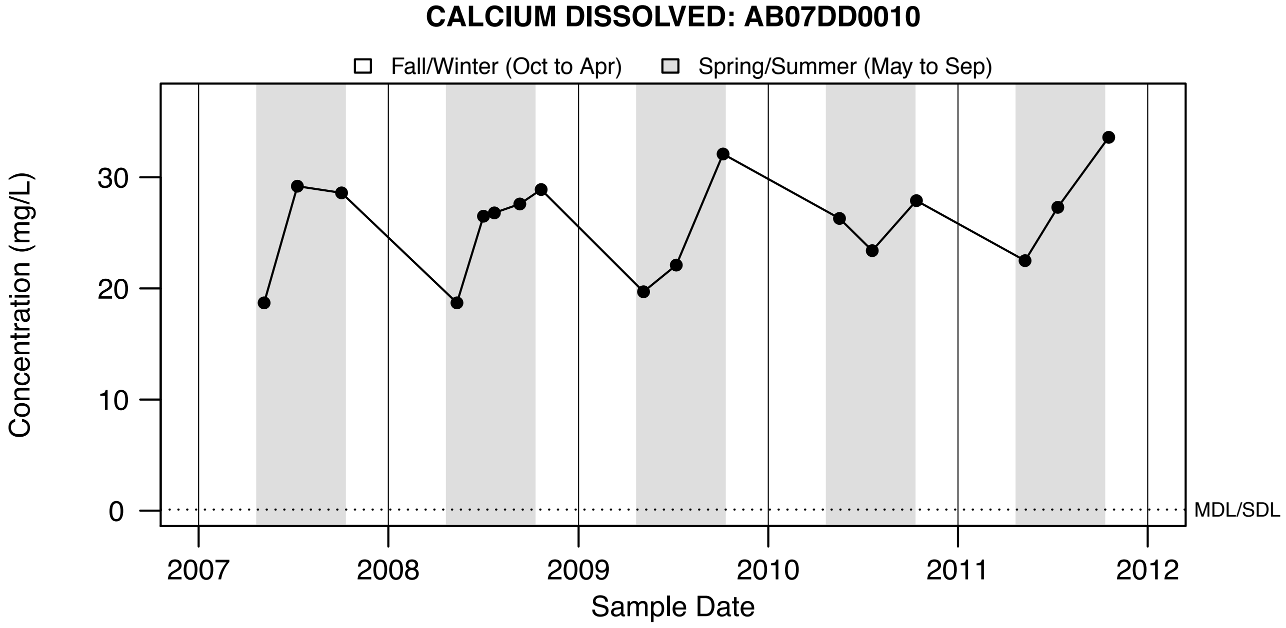


Figure A1.180: CALCIUM DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

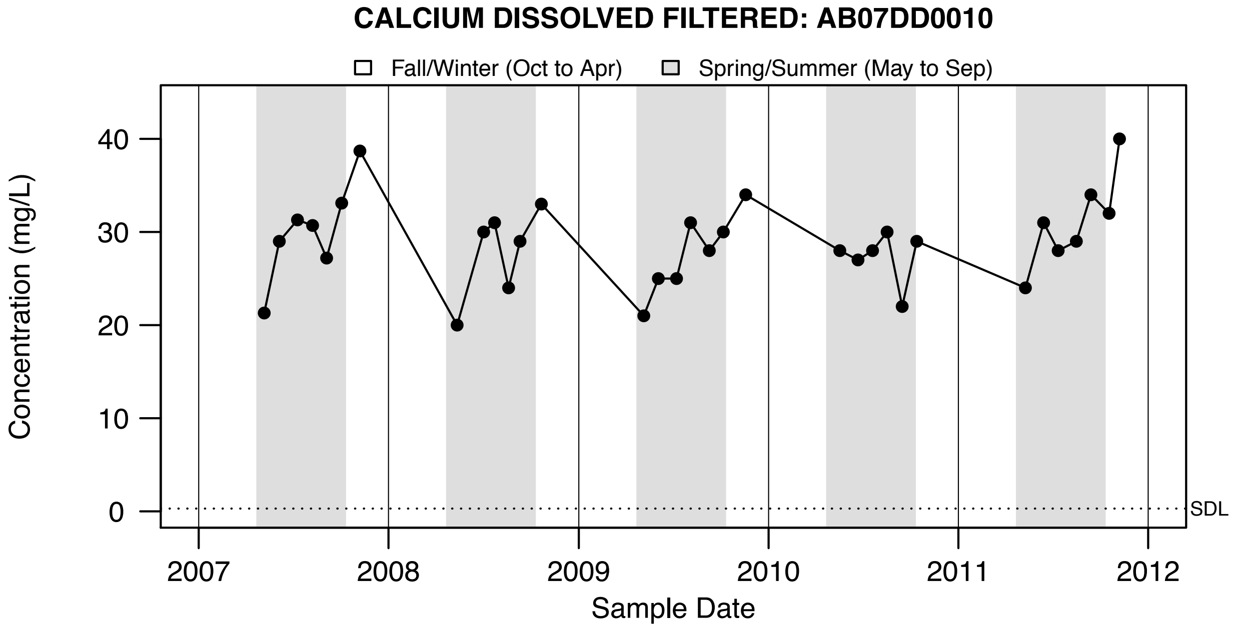


Figure A1.181: CALCIUM DISSOLVED FILTERED: AB07DD0010 - AT OLD FORT - RIGHT BANK

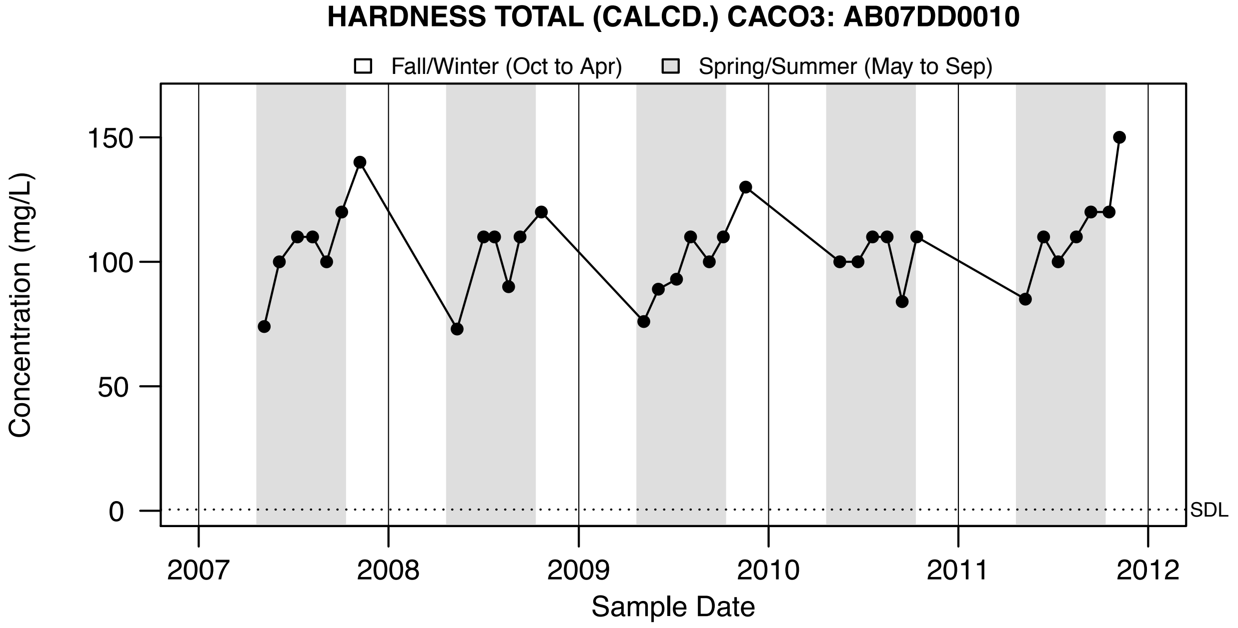


Figure A1.182: HARDNESS TOTAL (CALCD.) CACO3: AB07DD0010 - AT OLD FORT - RIGHT BANK

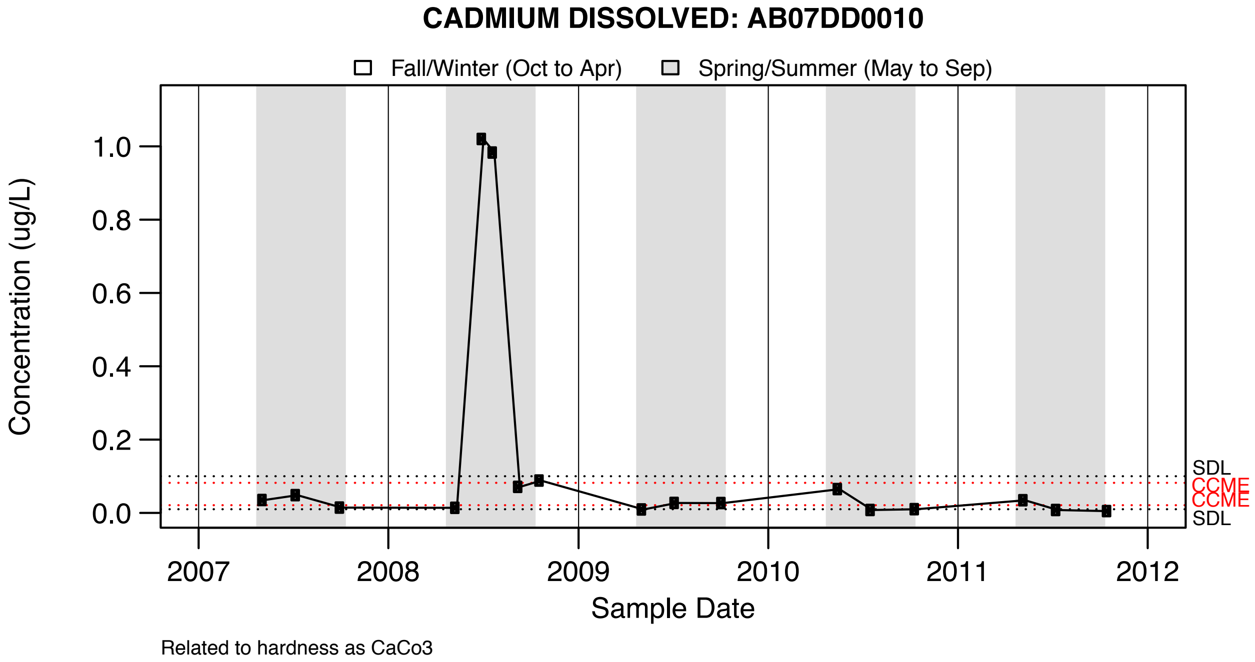


Figure A1.183: CADMIUM DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

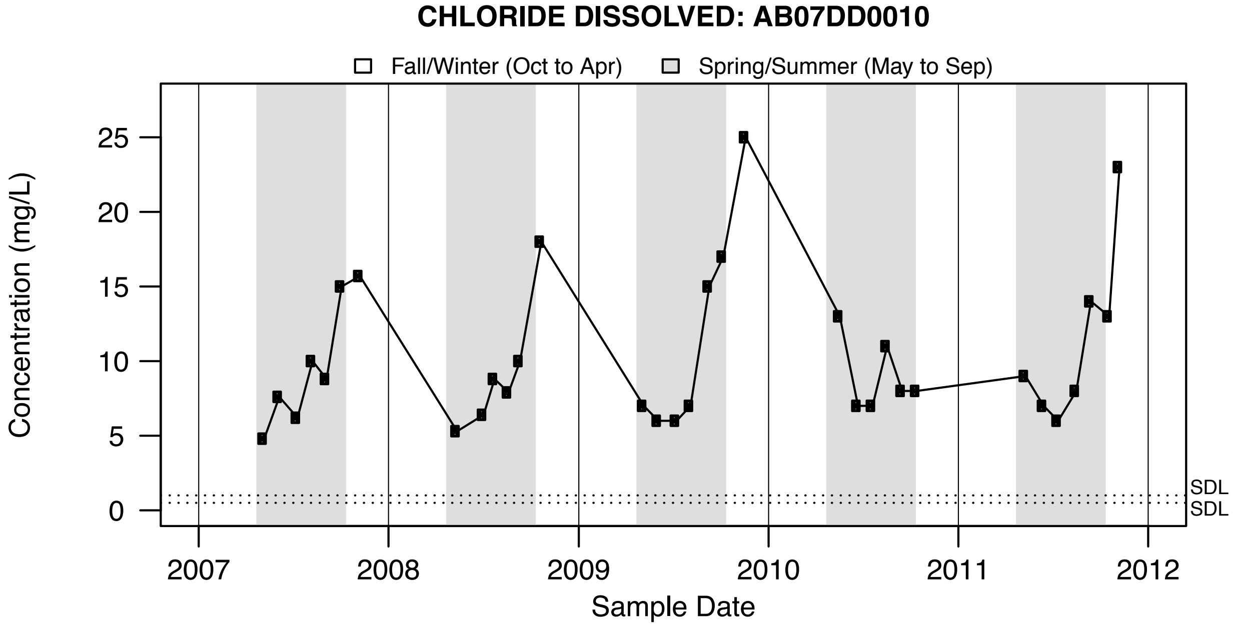


Figure A1.184: CHLORIDE DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

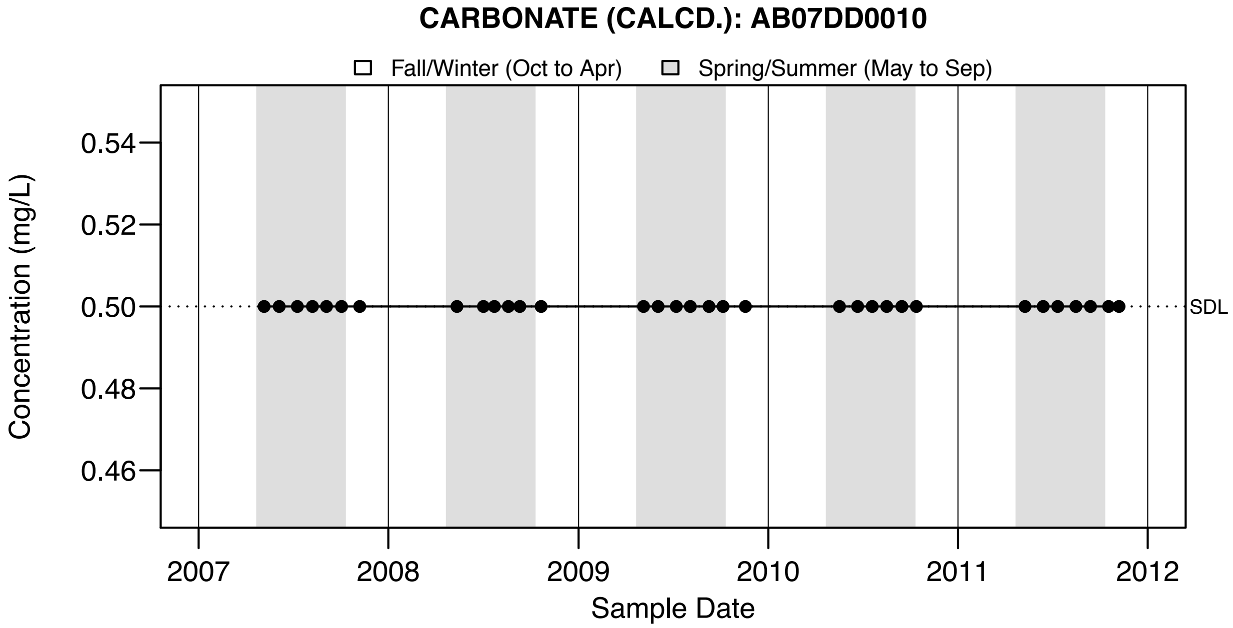


Figure A1.185: CARBONATE (CALCD.): AB07DD0010 - AT OLD FORT - RIGHT BANK

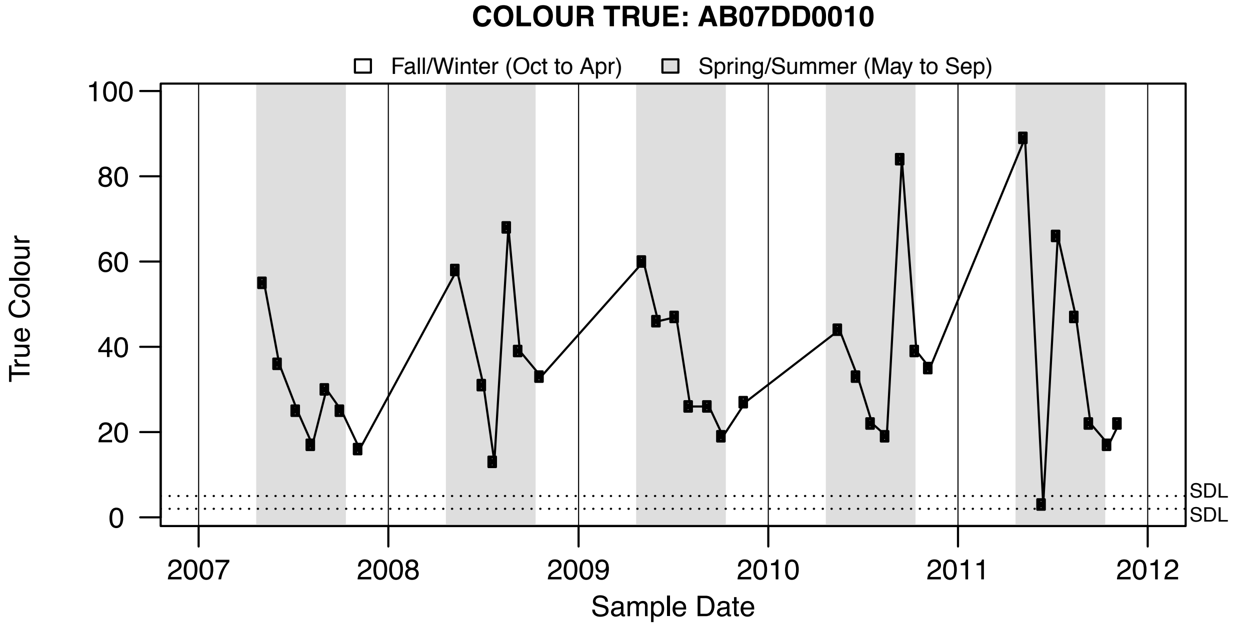


Figure A1.186: COLOUR TRUE: AB07DD0010 - AT OLD FORT - RIGHT BANK

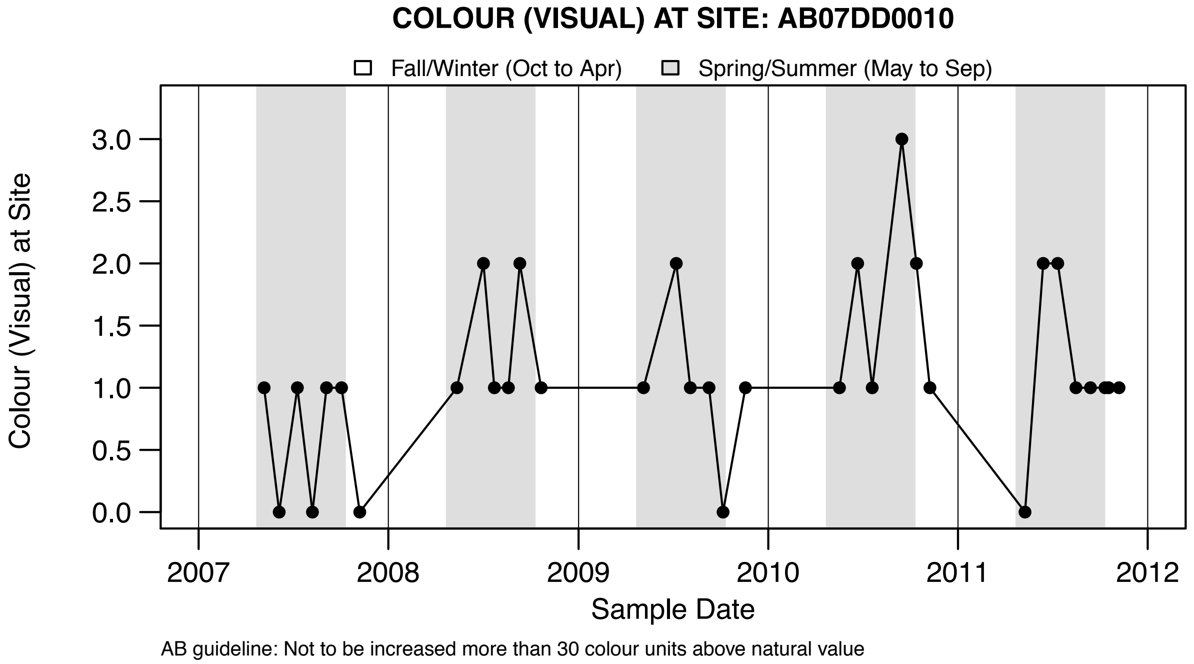


Figure A1.187: COLOUR (VISUAL) AT SITE: AB07DD0010 - AT OLD FORT - RIGHT BANK

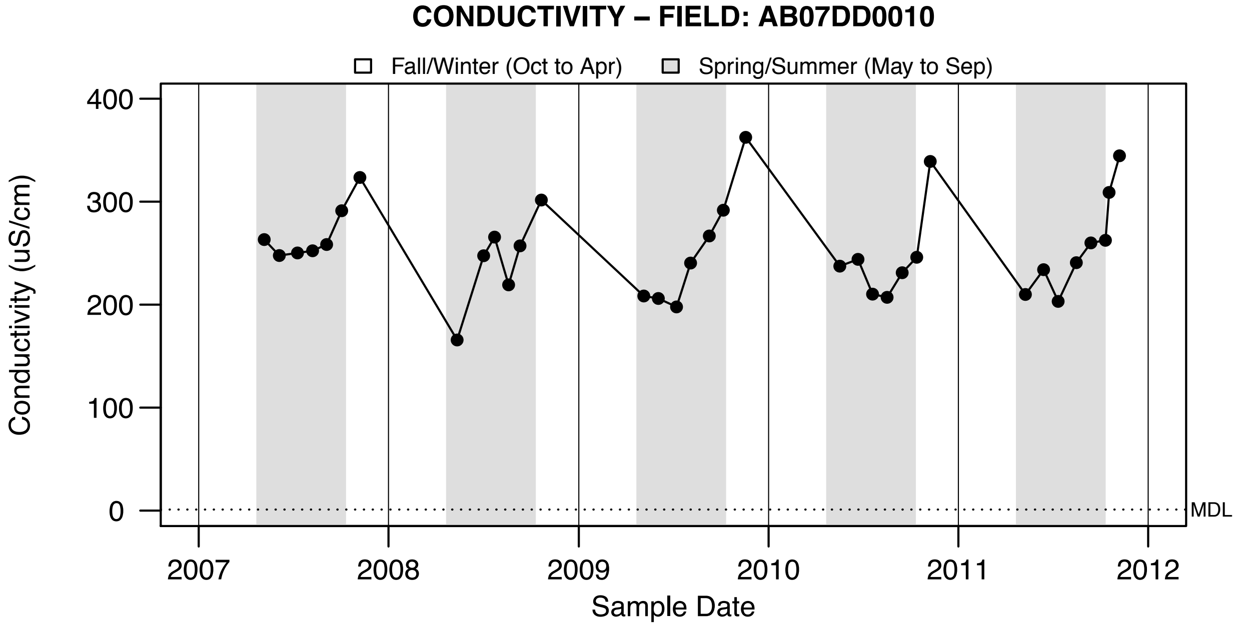


Figure A1.188: CONDUCTIVITY - FIELD: AB07DD0010 - AT OLD FORT - RIGHT BANK

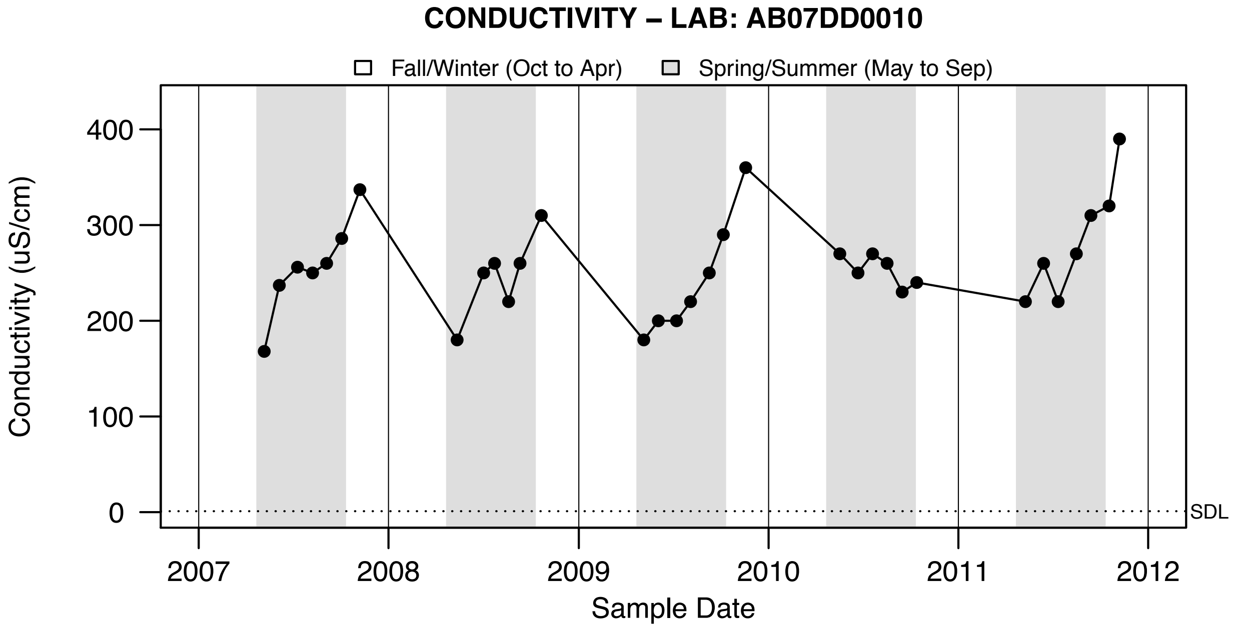
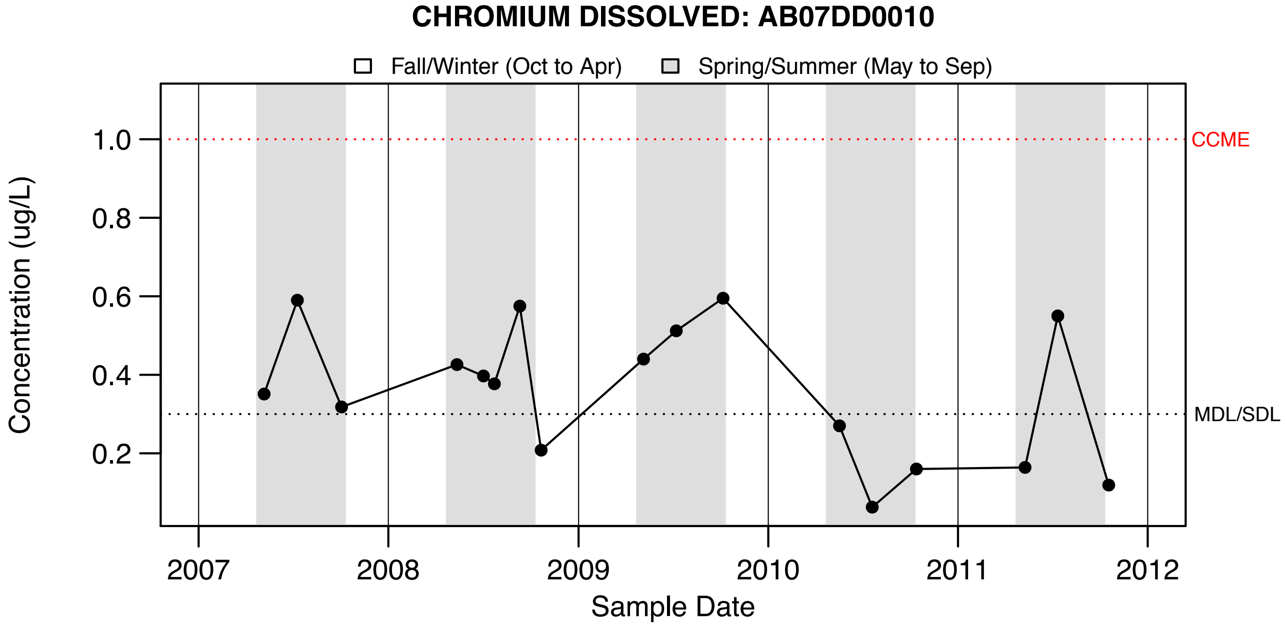
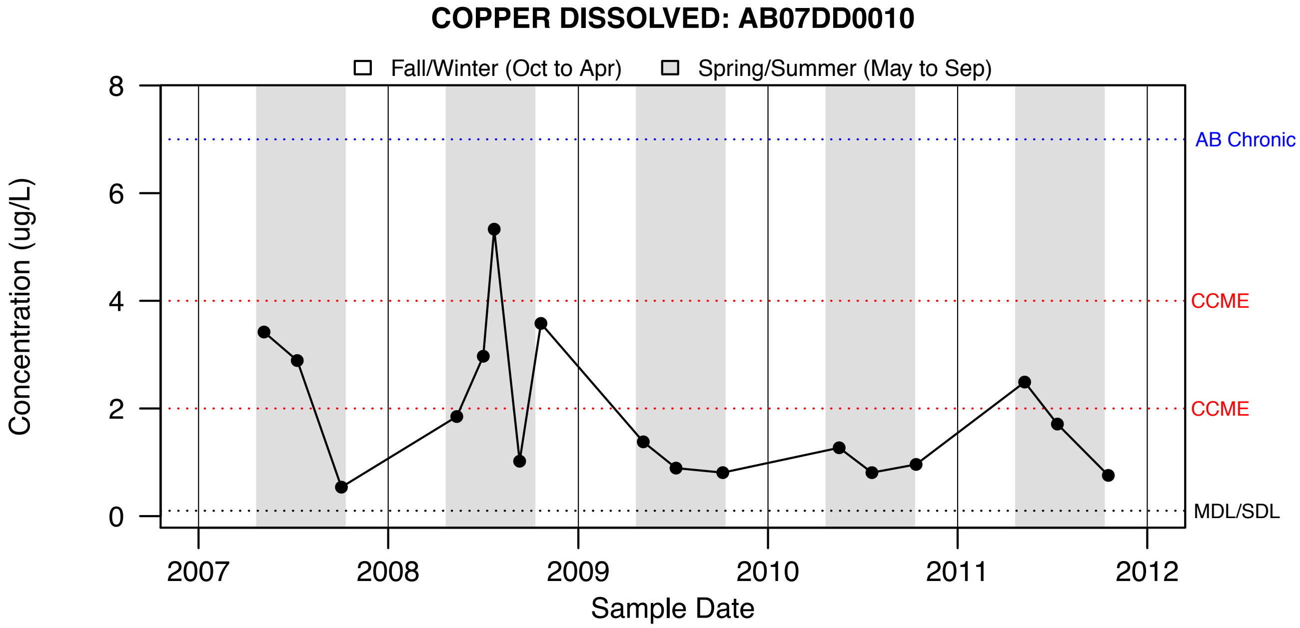


Figure A1.189: CONDUCTIVITY - LAB: AB07DD0010 - AT OLD FORT - RIGHT BANK



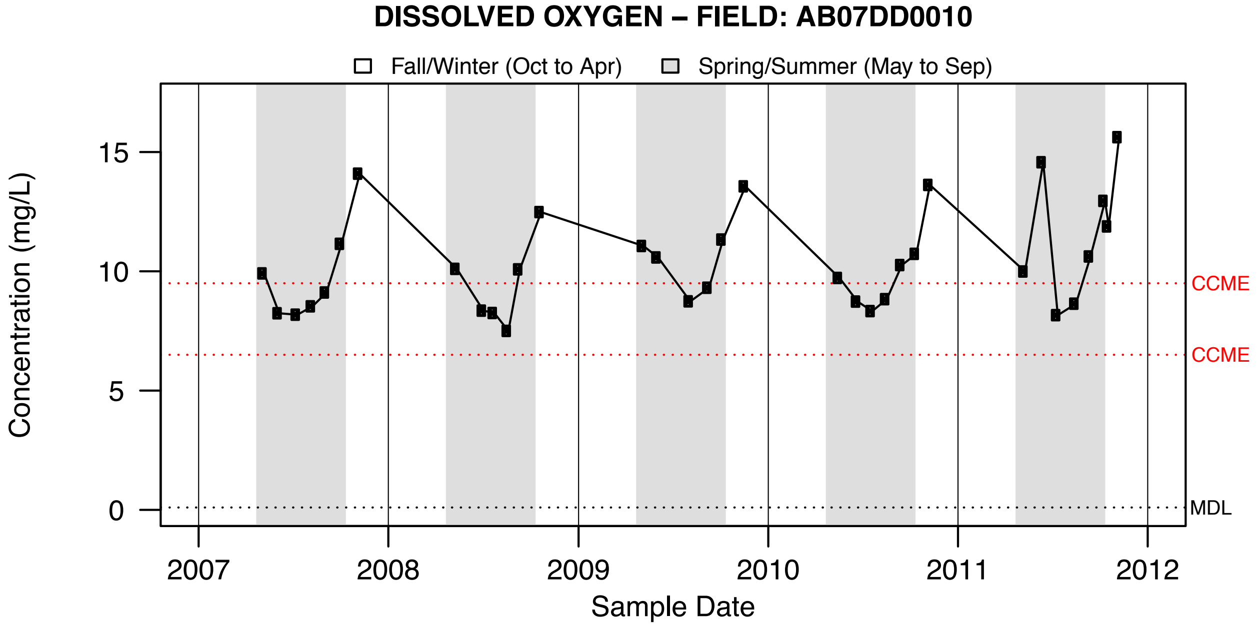
Chromium III: 8.9 Chromium VI: 1.0

Figure A1.190: CHROMIUM DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A1.191: COPPER DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK



Cold water biota: early life stages = 9.5 mg/L; other life stages = 6.5 mg/L

Figure A1.192: DISSOLVED OXYGEN - FIELD: AB07DD0010 - AT OLD FORT - RIGHT BANK

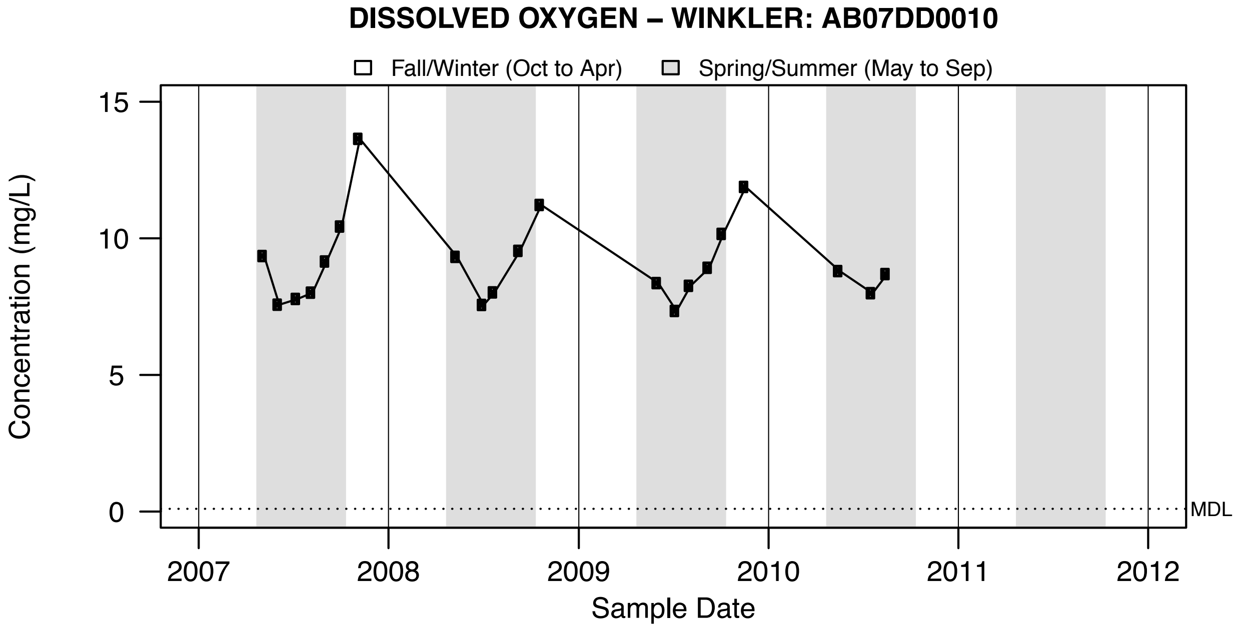


Figure A1.193: DISSOLVED OXYGEN - WINKLER: AB07DD0010 - AT OLD FORT - RIGHT BANK

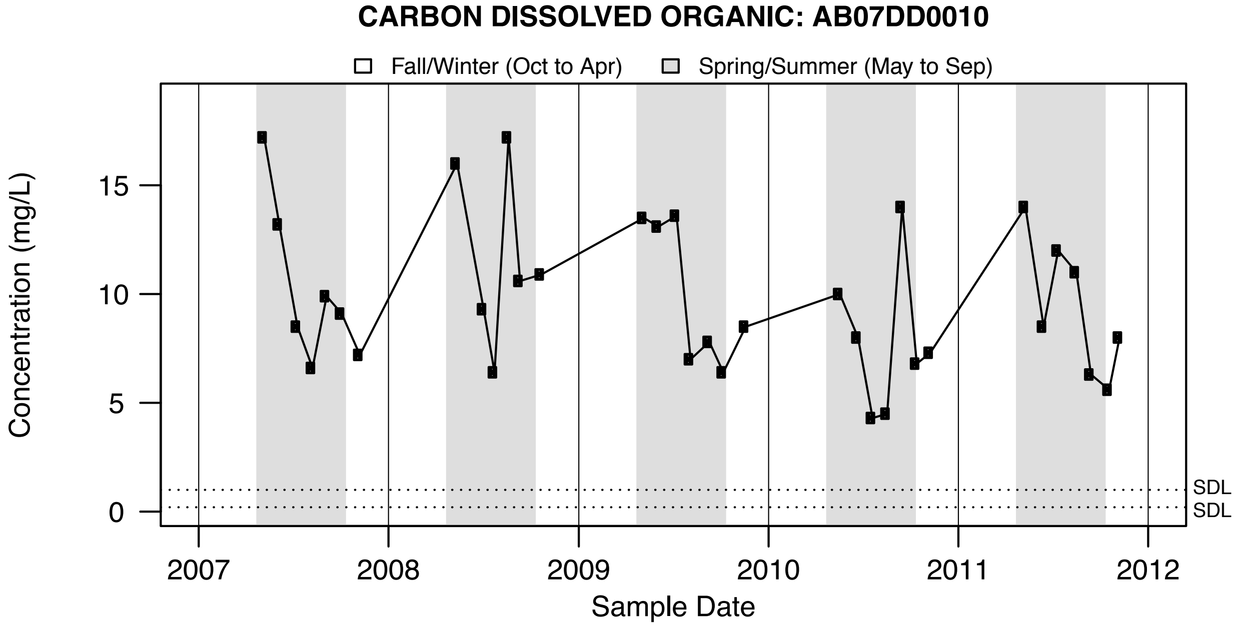


Figure A1.194: CARBON DISSOLVED ORGANIC: AB07DD0010 - AT OLD FORT - RIGHT BANK

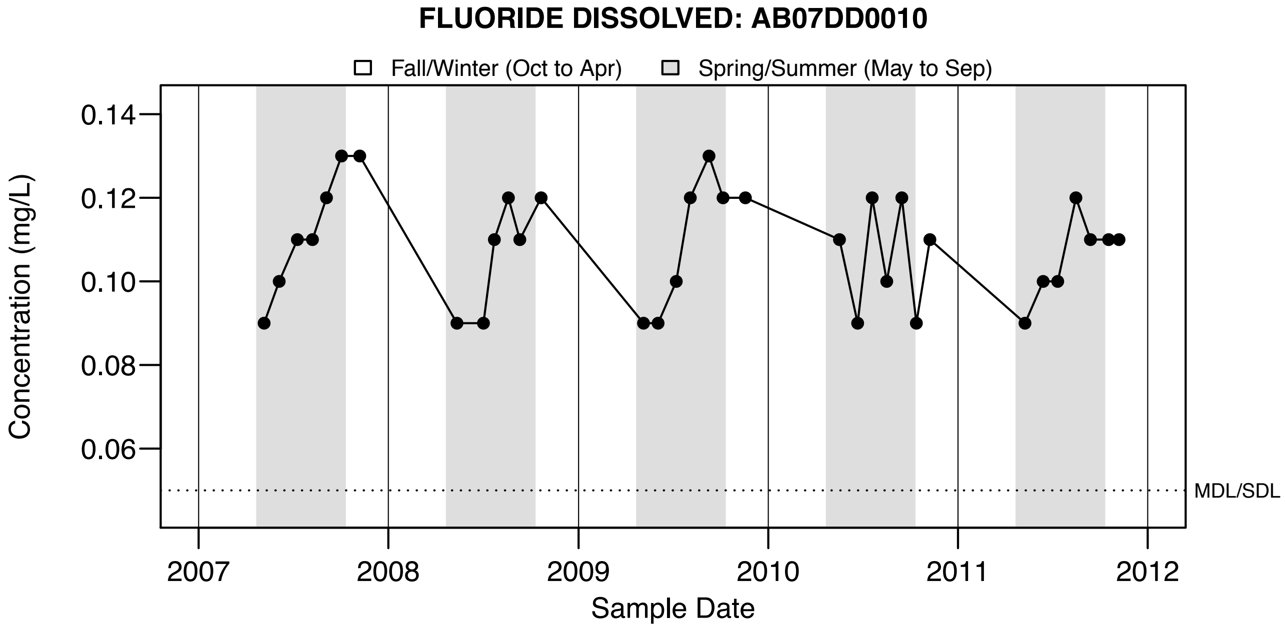


Figure A1.195: FLUORIDE DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

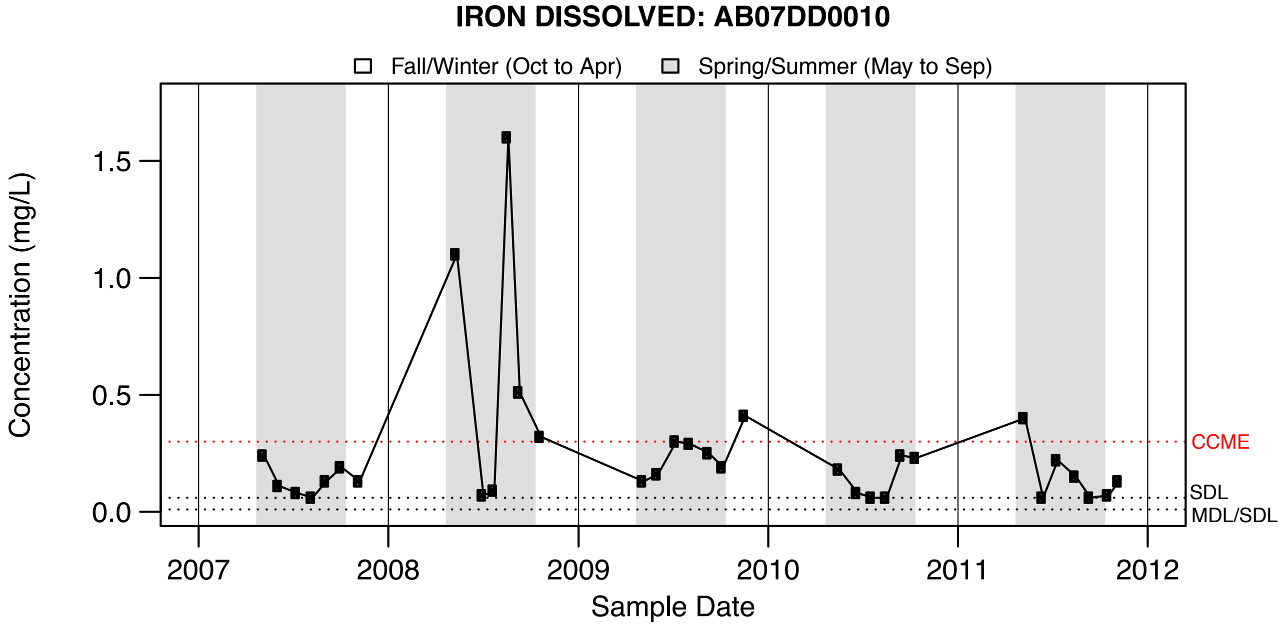


Figure A1.196: IRON DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

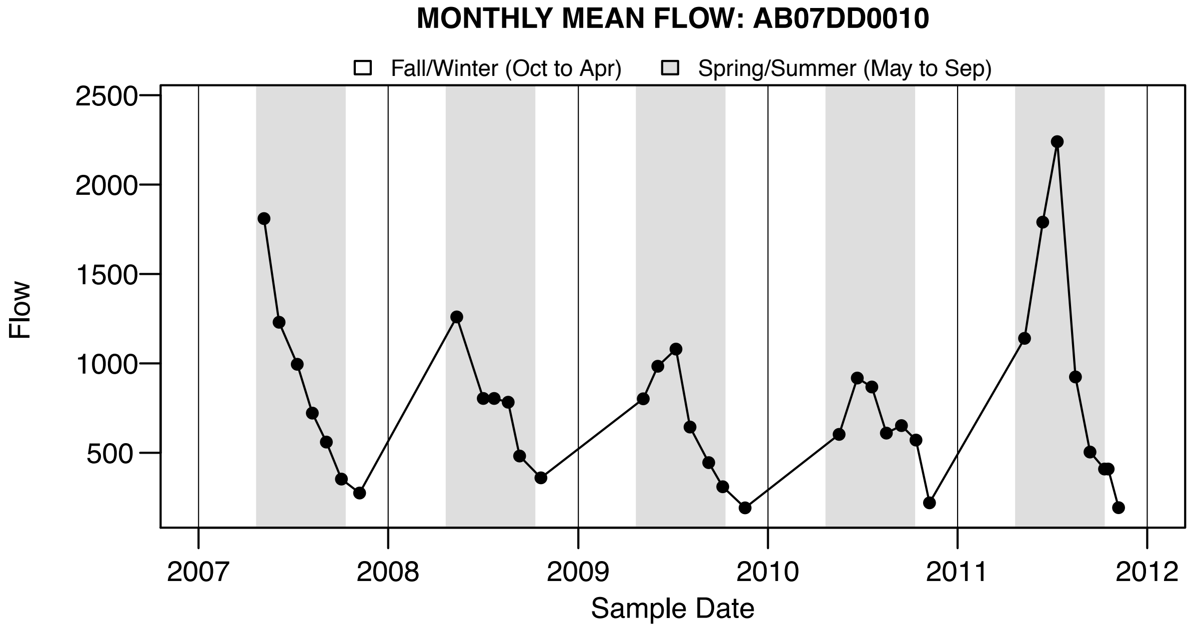


Figure A1.197: MONTHLY MEAN FLOW: AB07DD0010 - AT OLD FORT - RIGHT BANK

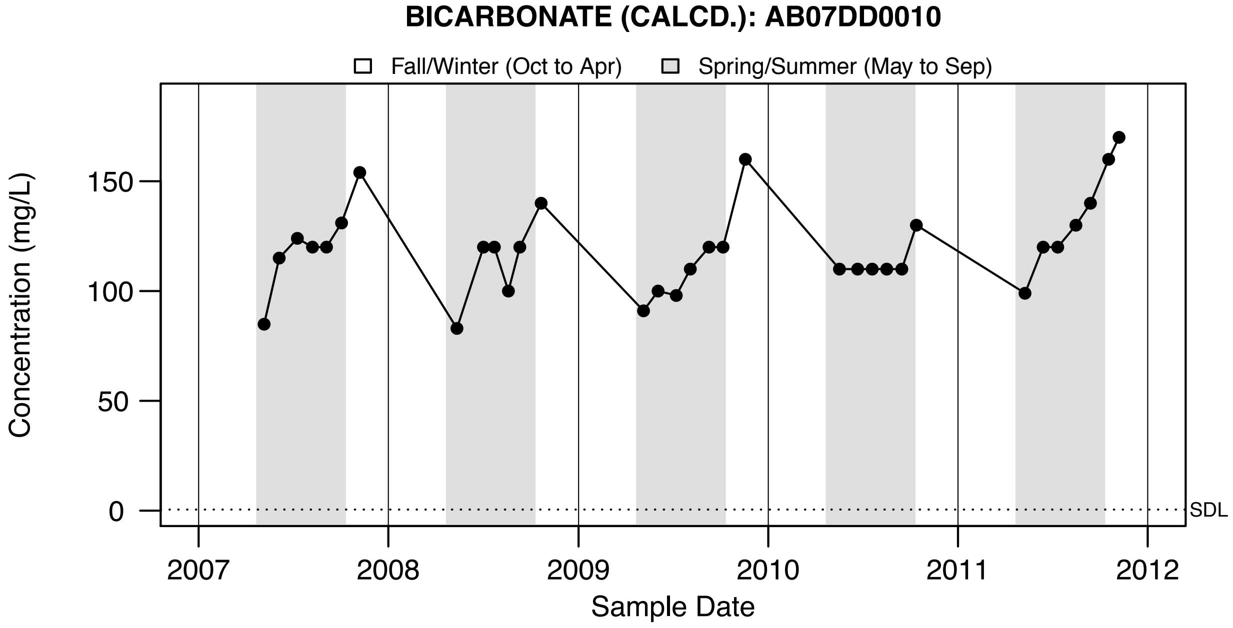


Figure A1.198: BICARBONATE (CALCD.): AB07DD0010 - AT OLD FORT - RIGHT BANK

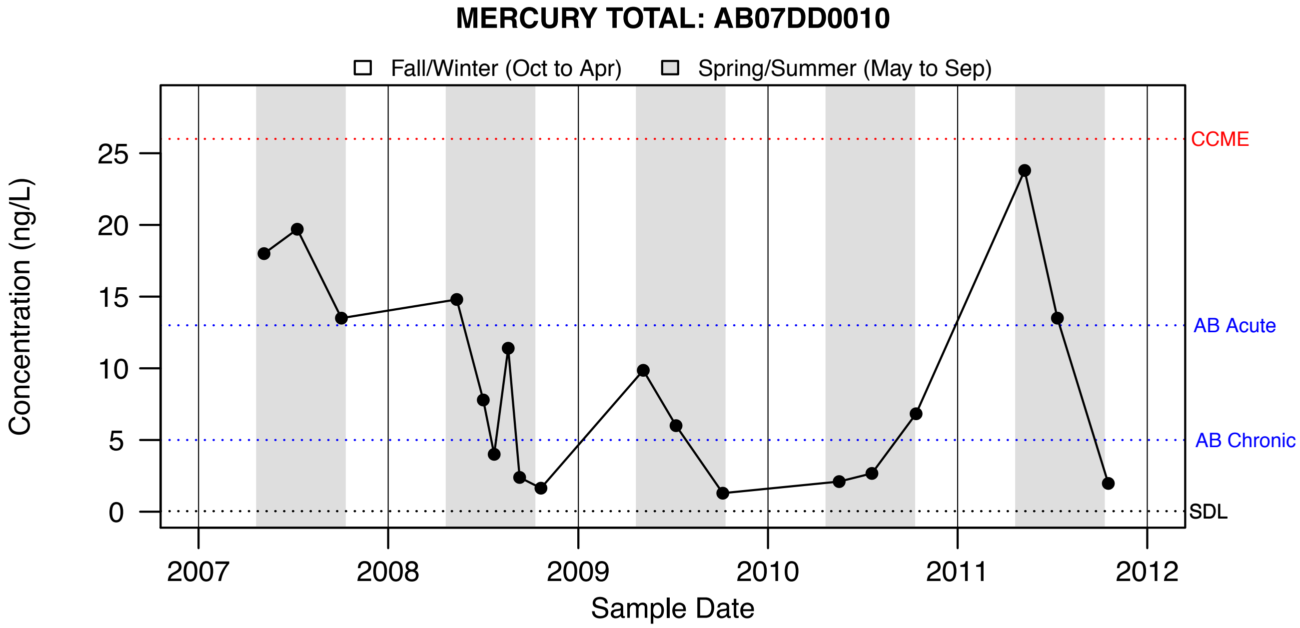


Figure A1.199: MERCURY TOTAL: AB07DD0010 - AT OLD FORT - RIGHT BANK

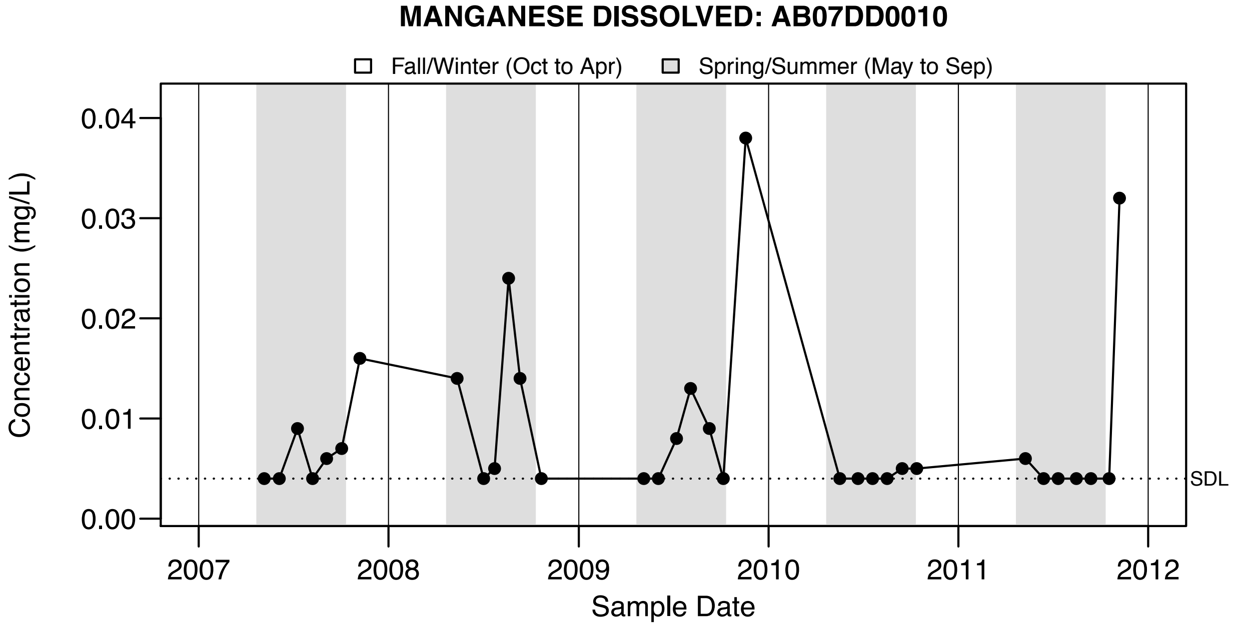


Figure A1.200: MANGANESE DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

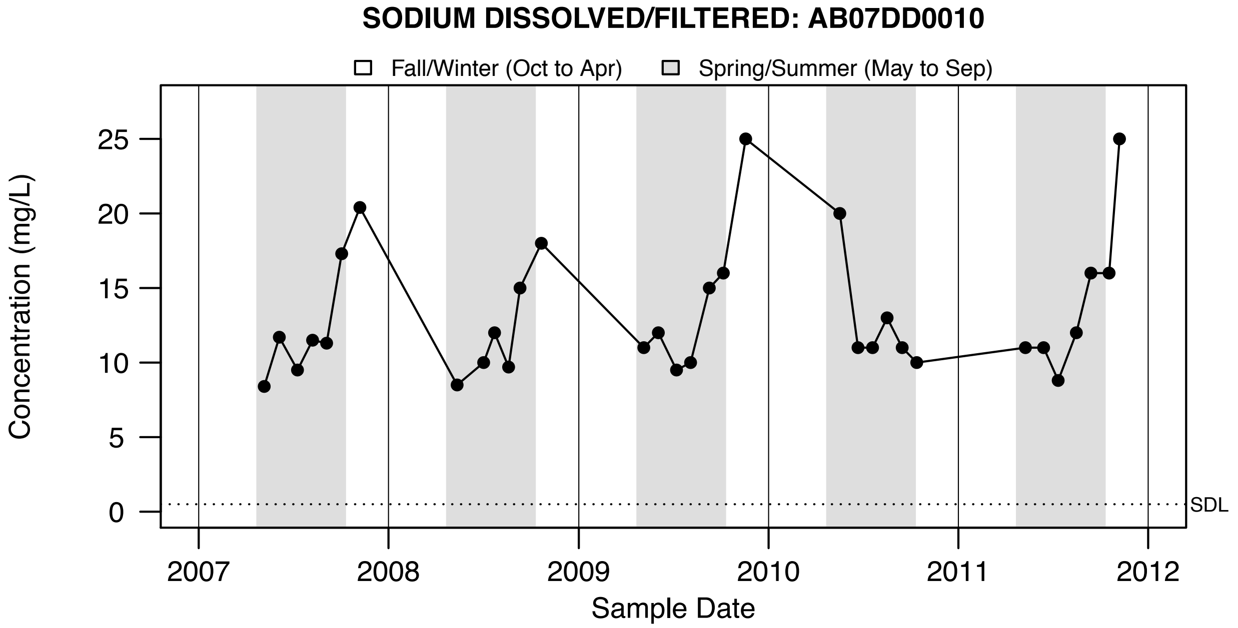
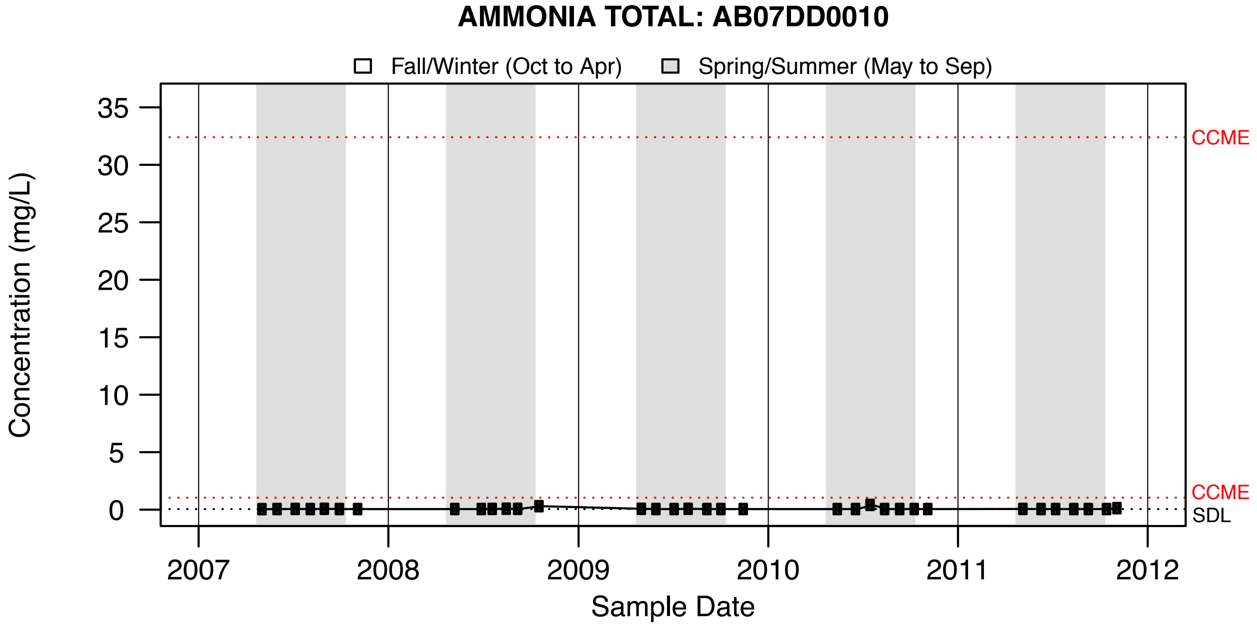
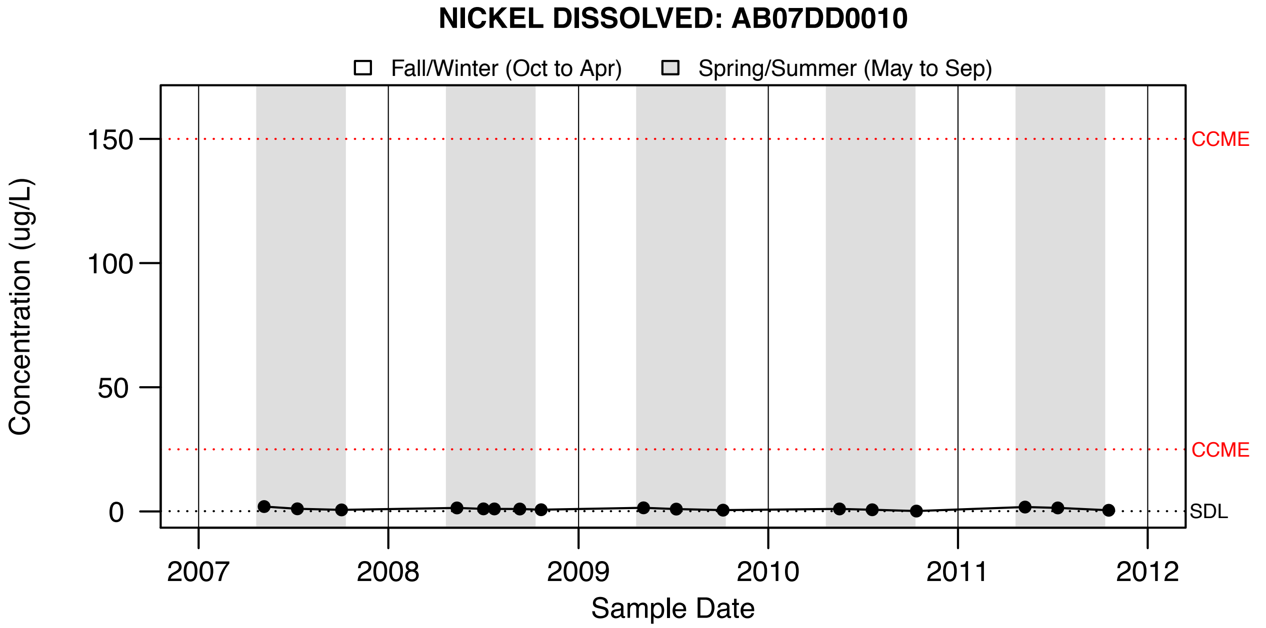


Figure A1.201: SODIUM DISSOLVED/FILTERED: AB07DD0010 - AT OLD FORT - RIGHT BANK



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A1.202: AMMONIA TOTAL: AB07DD0010 - AT OLD FORT - RIGHT BANK



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A1.203: NICKEL DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

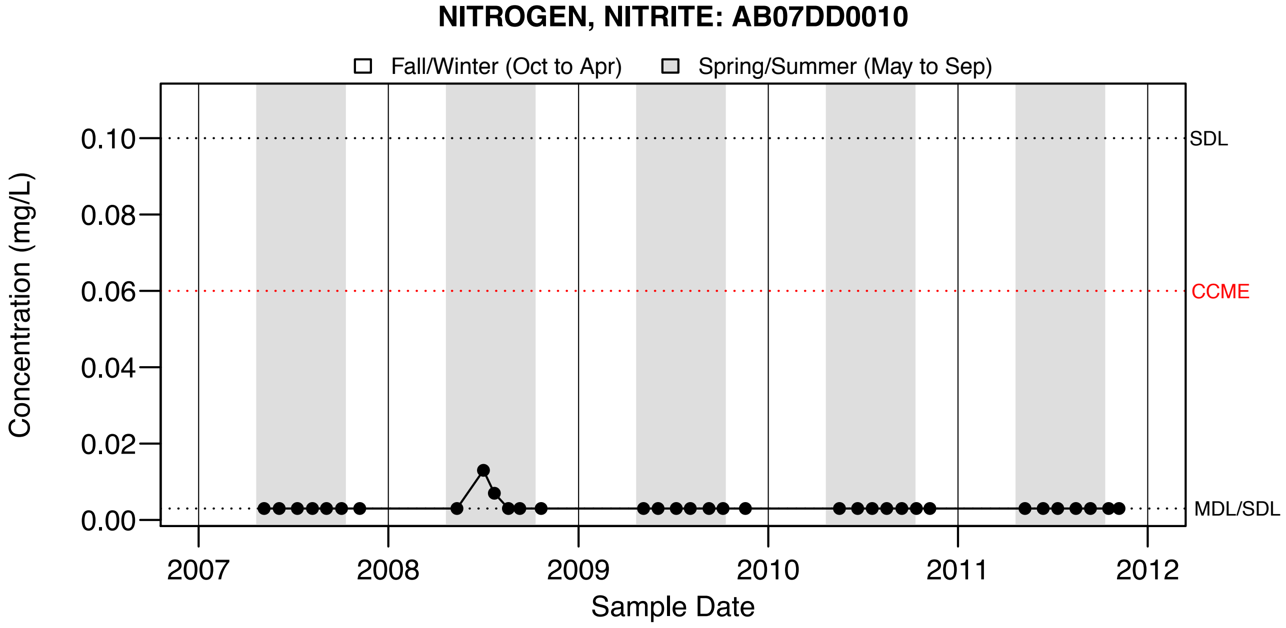
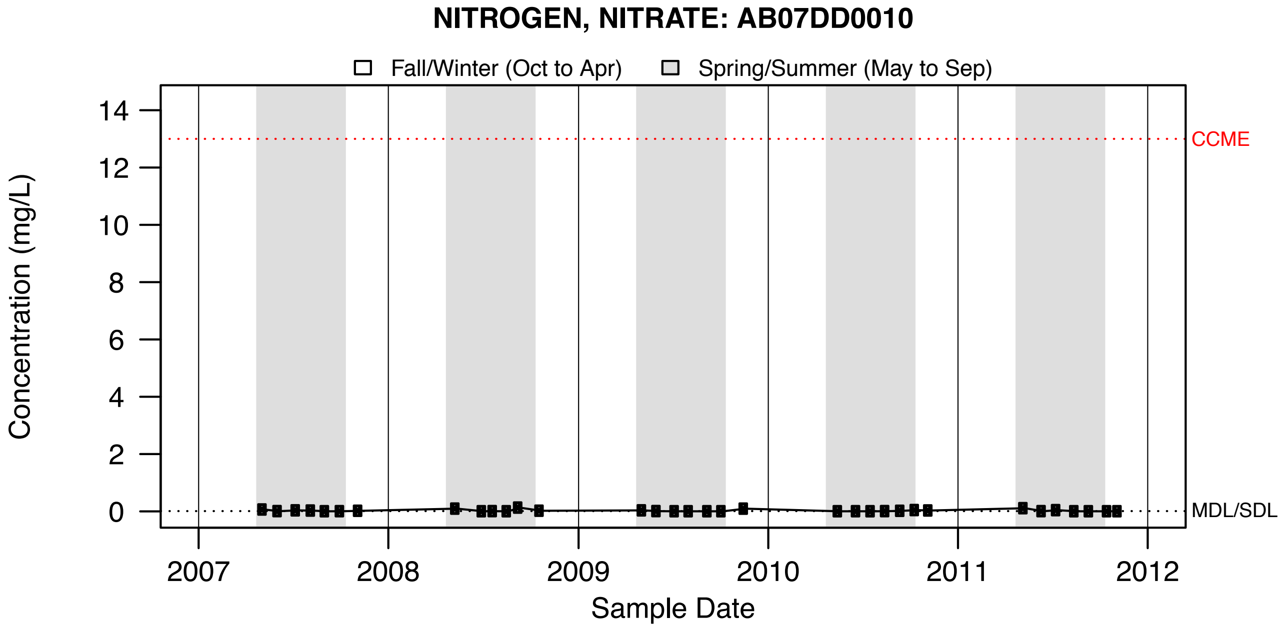


Figure A1.204: NITROGEN, NITRITE: AB07DD0010 - AT OLD FORT - RIGHT BANK



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A1.205: NITROGEN, NITRATE: AB07DD0010 - AT OLD FORT - RIGHT BANK

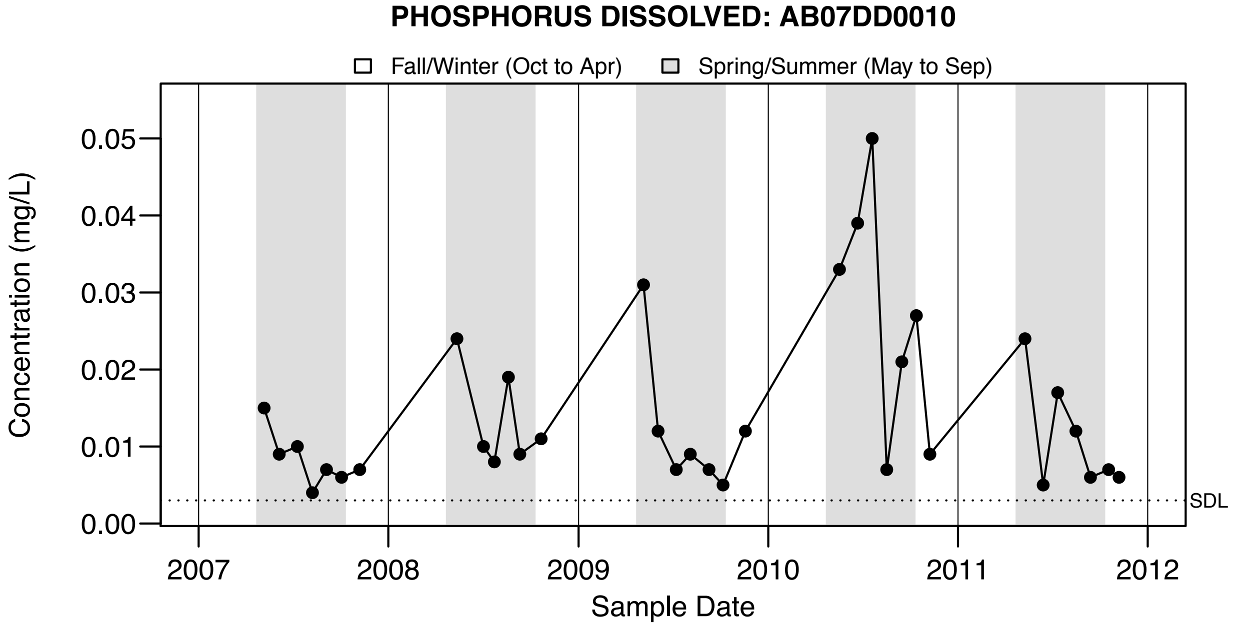


Figure A1.206: PHOSPHORUS DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

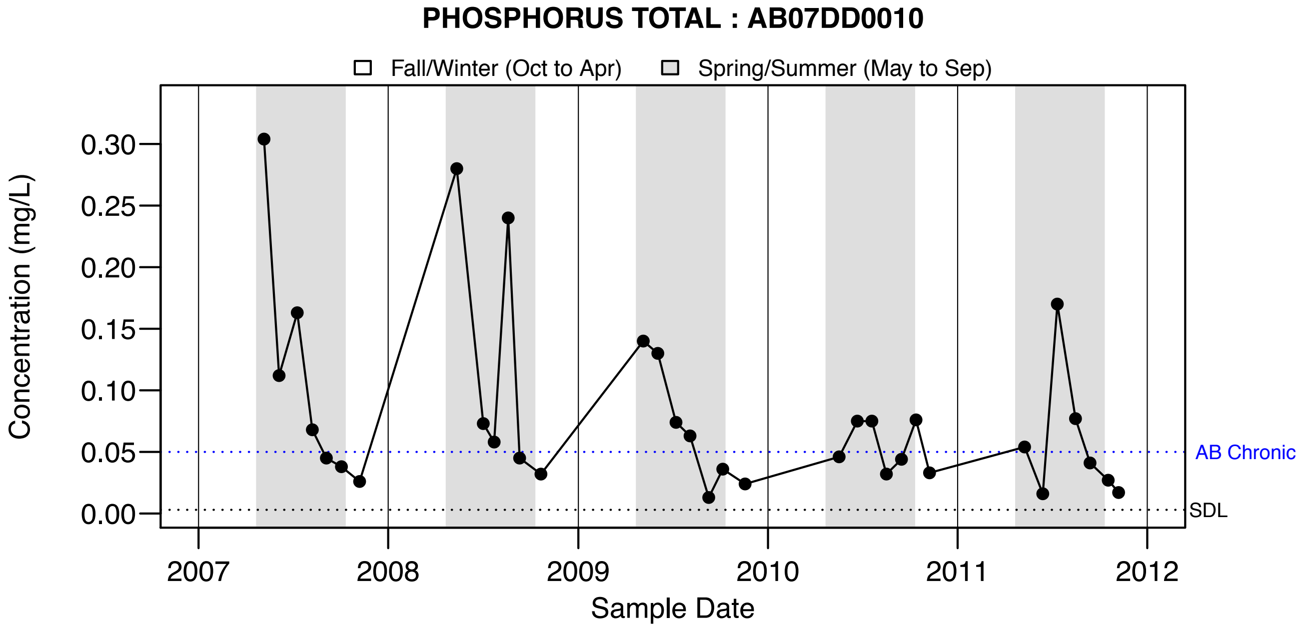
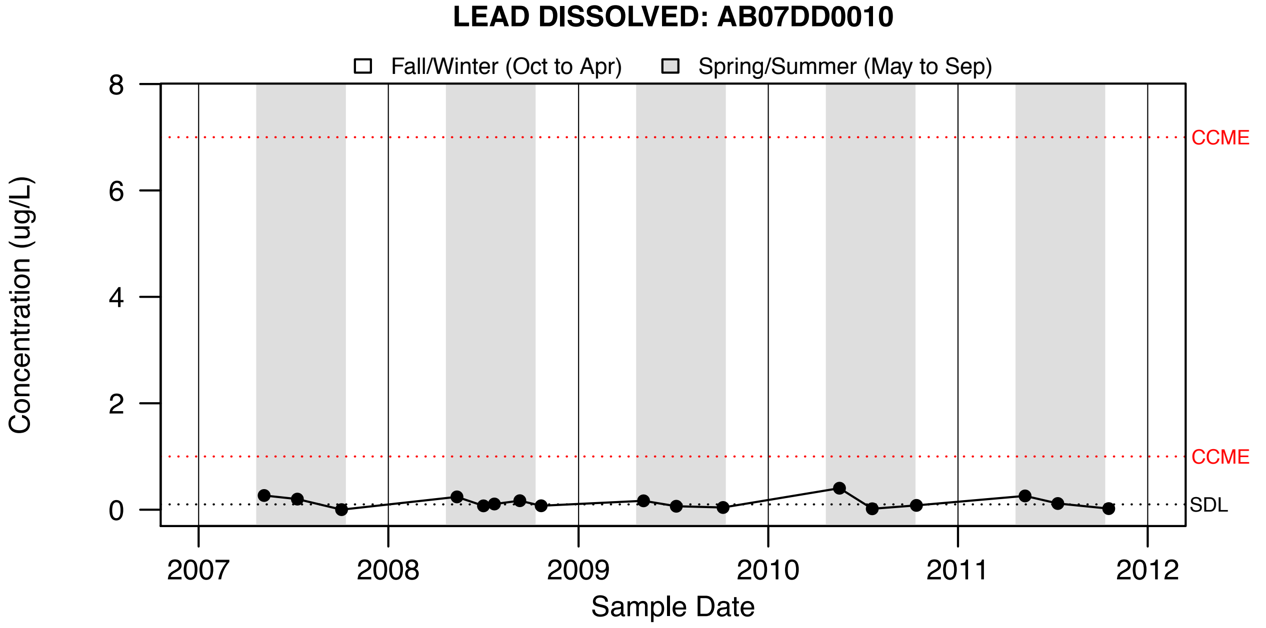


Figure A1.207: PHOSPHORUS TOTAL : AB07DD0010 - AT OLD FORT - RIGHT BANK



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A1.208: LEAD DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

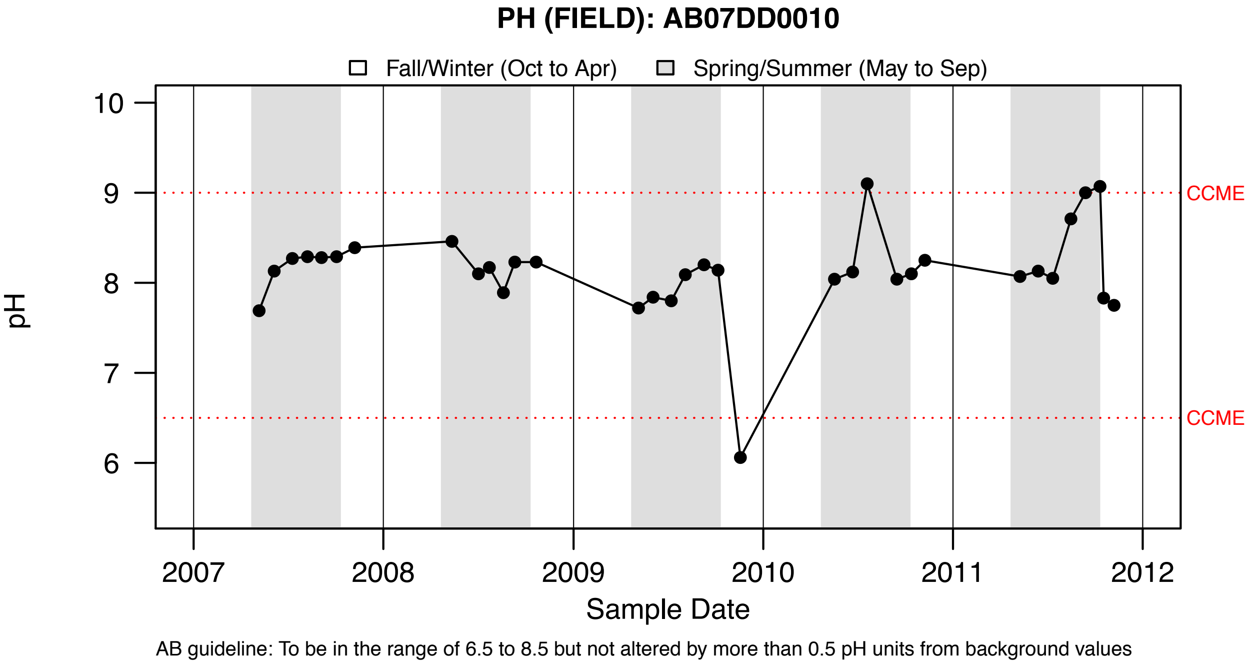


Figure A1.209: PH (FIELD): AB07DD0010 - AT OLD FORT - RIGHT BANK

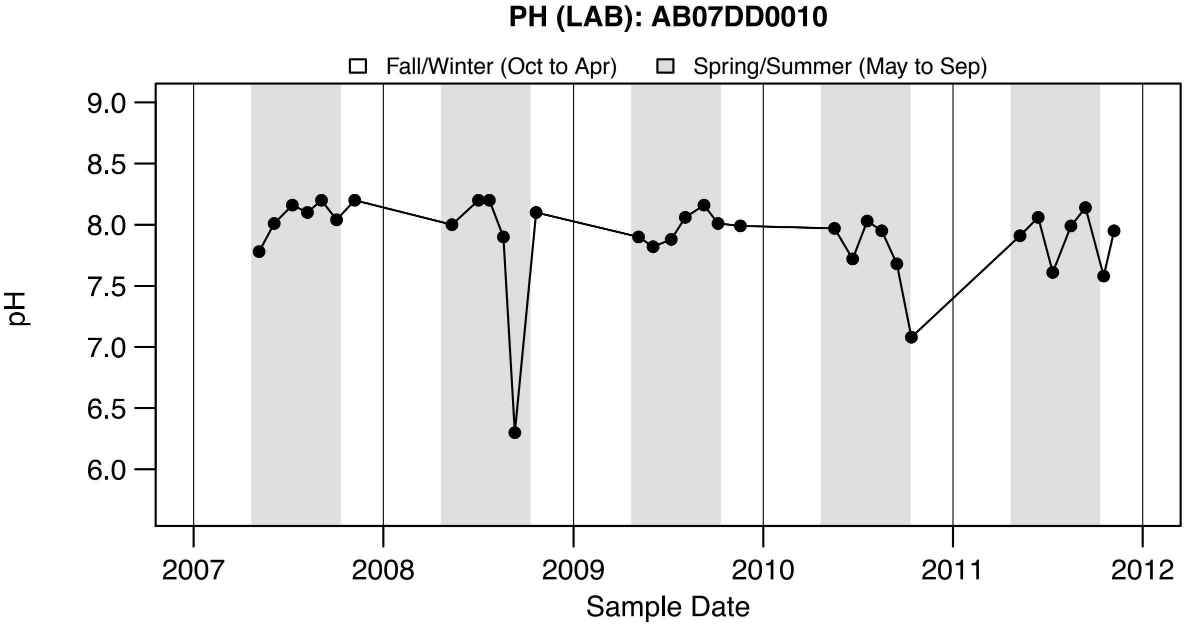


Figure A1.210: PH (LAB): AB07DD0010 - AT OLD FORT - RIGHT BANK

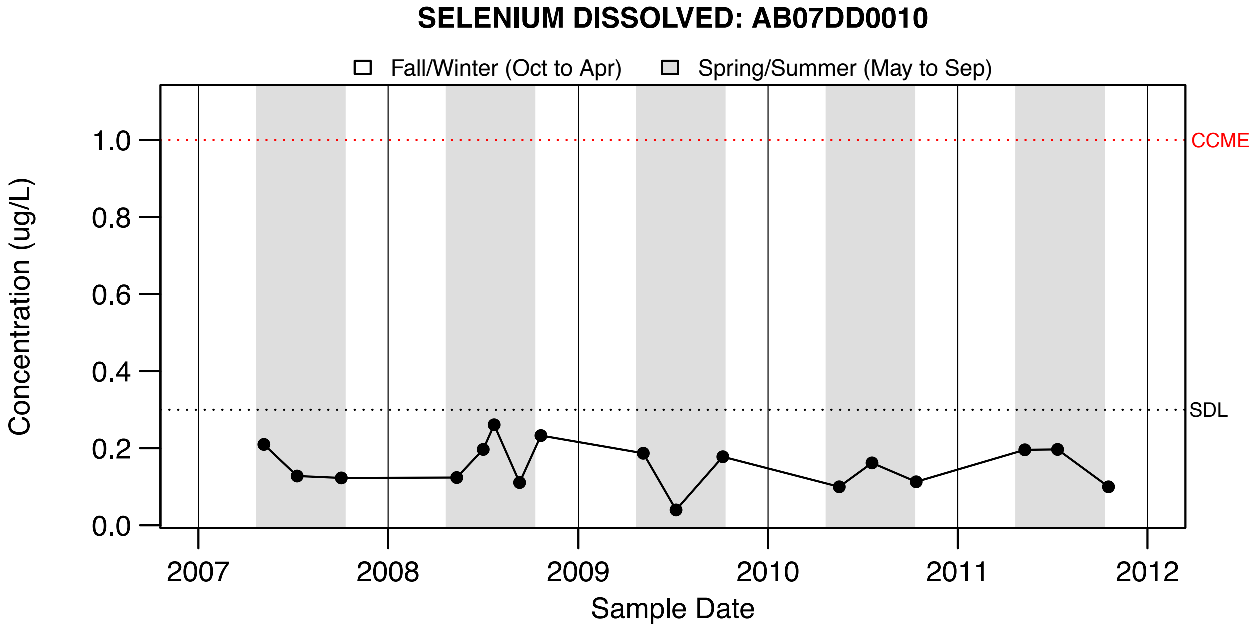


Figure A1.211: SELENIUM DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

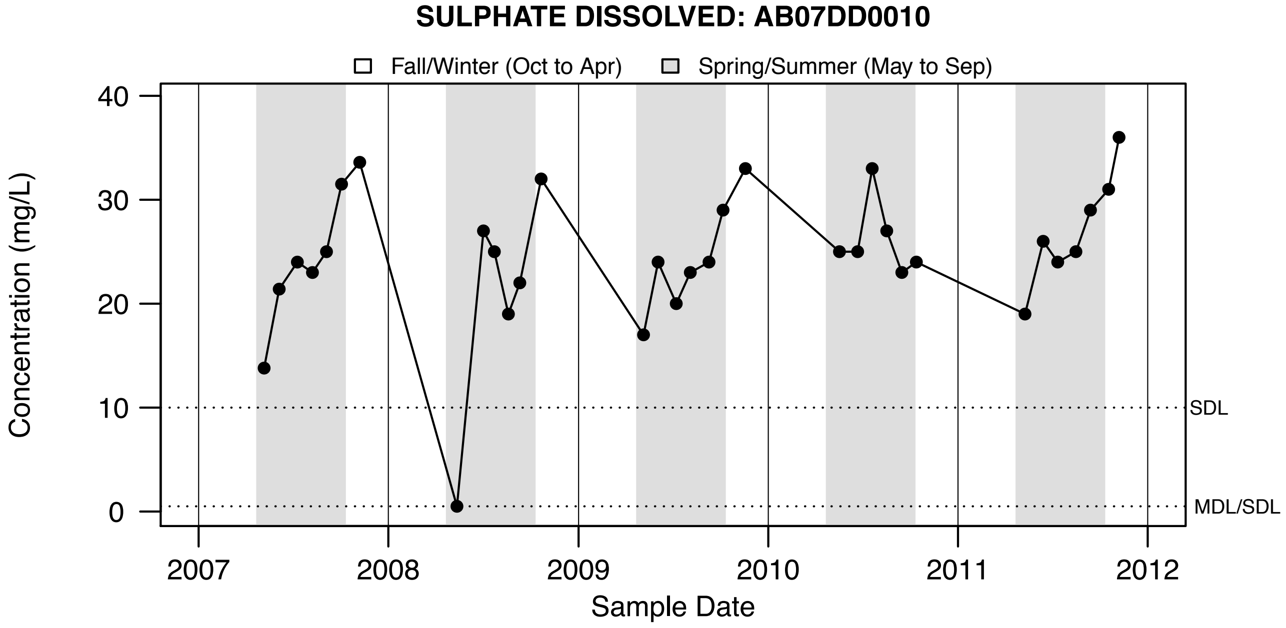


Figure A1.212: SULPHATE DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

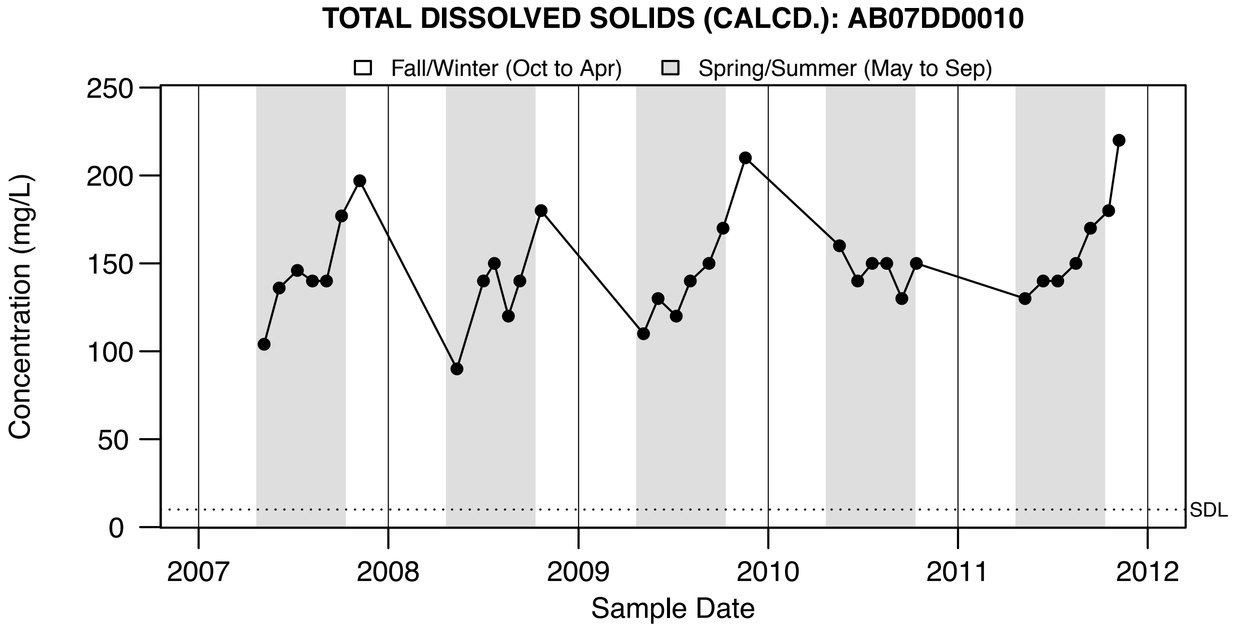
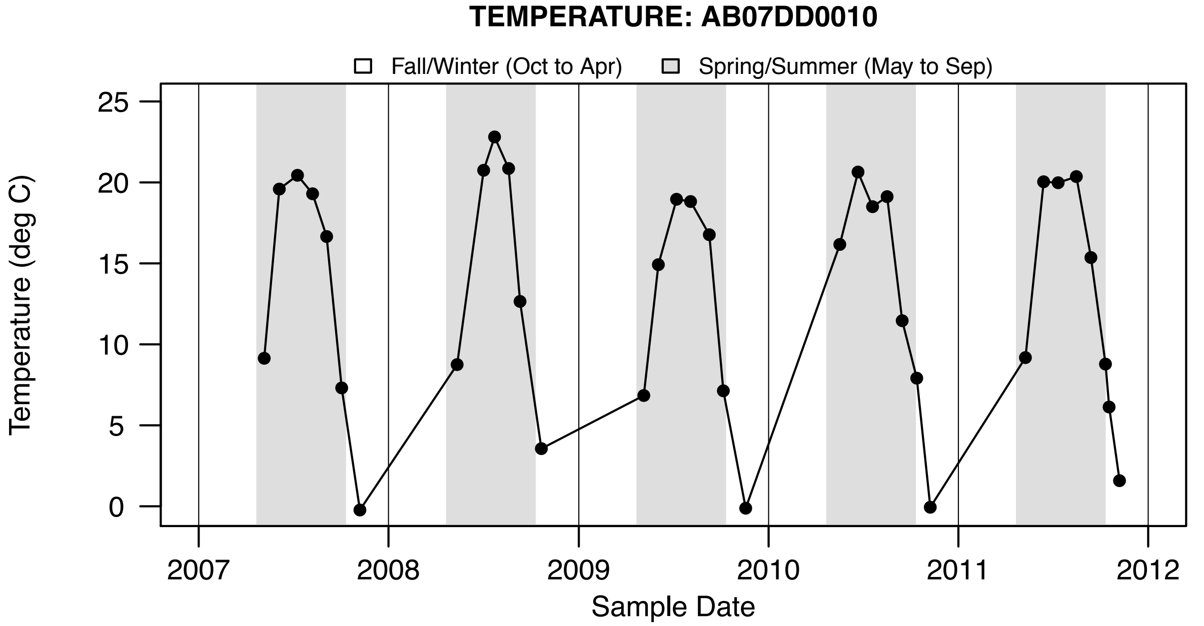


Figure A1.213: TOTAL DISSOLVED SOLIDS (CALCD.): AB07DD0010 - AT OLD FORT - RIGHT BANK



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A1.214: TEMPERATURE: AB07DD0010 - AT OLD FORT - RIGHT BANK

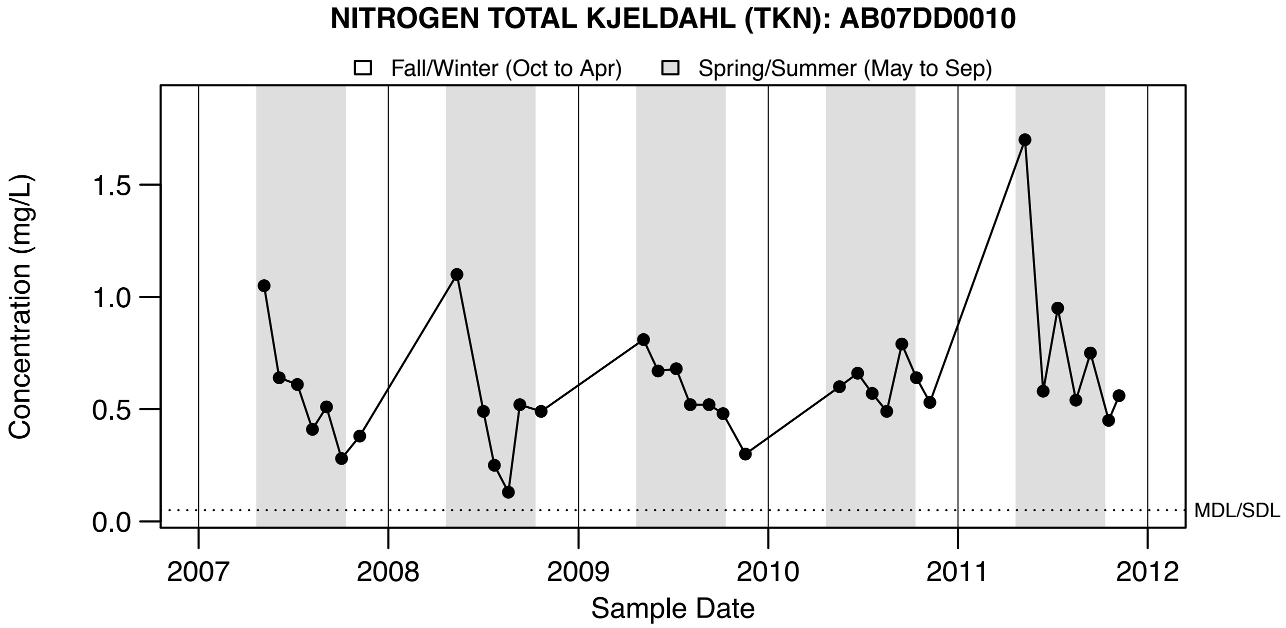
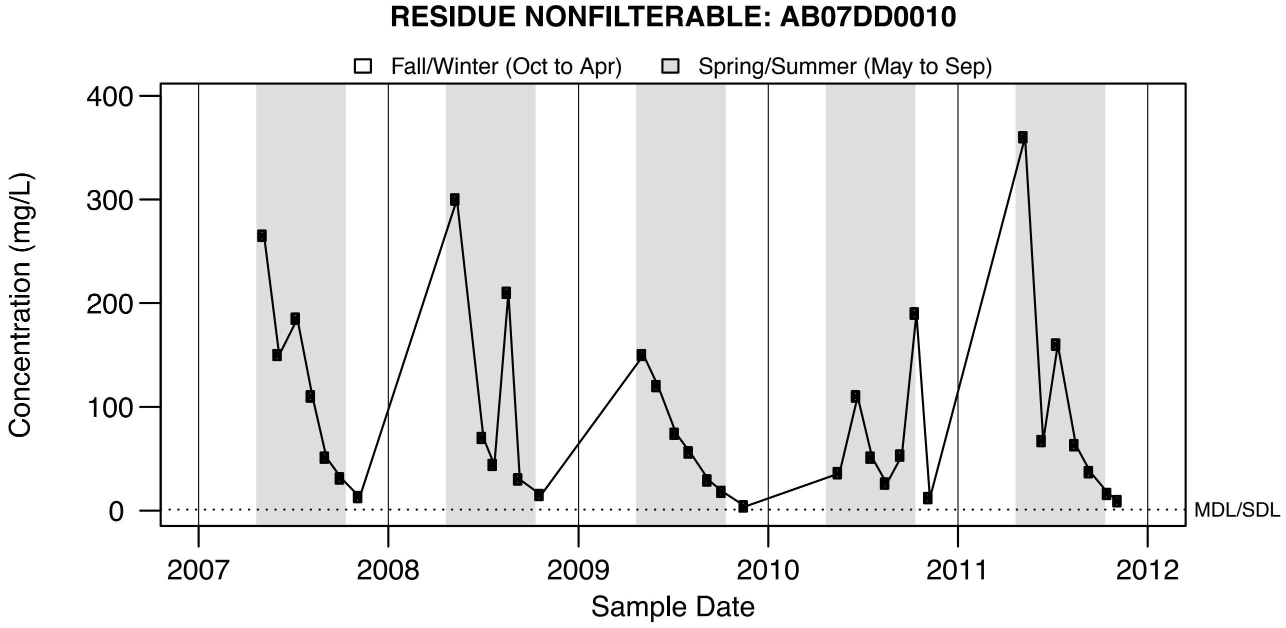


Figure A1.215: NITROGEN TOTAL KJELDAHL (TKN): AB07DD0010 - AT OLD FORT - RIGHT BANK



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A1.216: RESIDUE NONFILTERABLE: AB07DD0010 - AT OLD FORT - RIGHT BANK

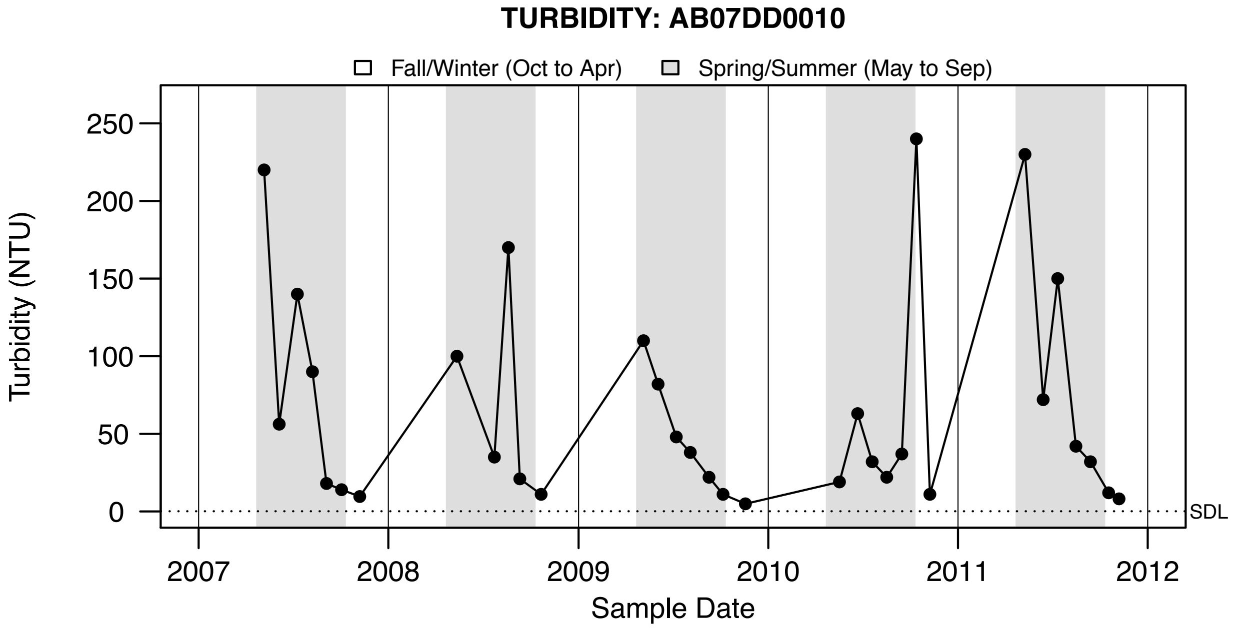


Figure A1.217: TURBIDITY: AB07DD0010 - AT OLD FORT - RIGHT BANK

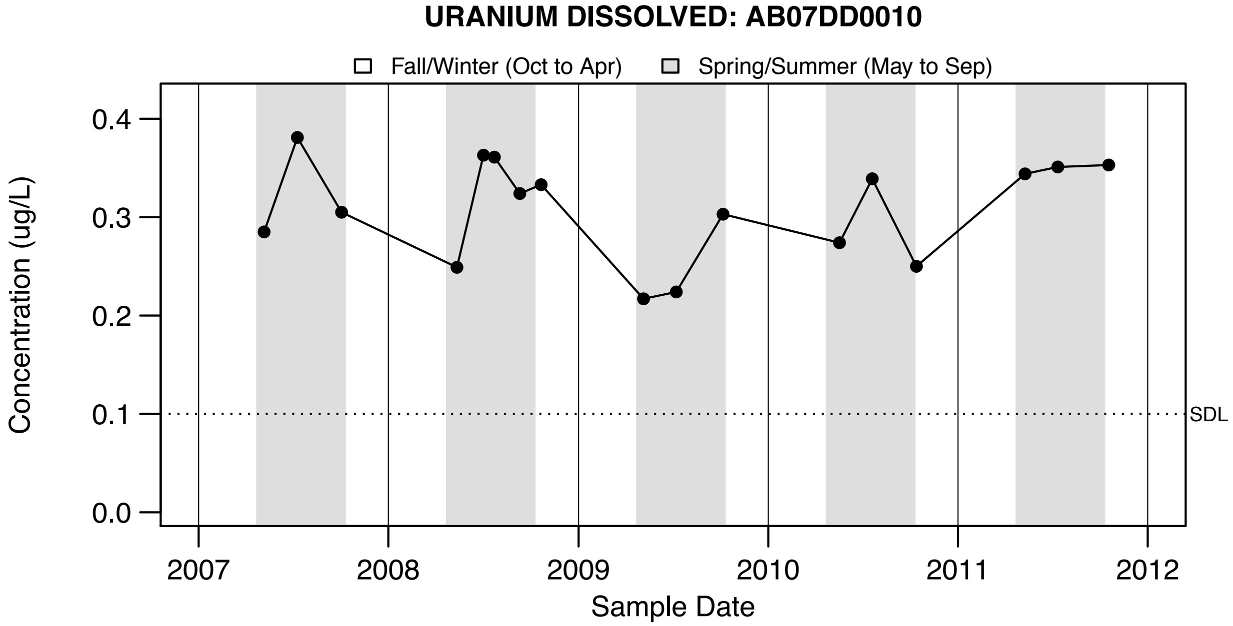


Figure A1.218: URANIUM DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

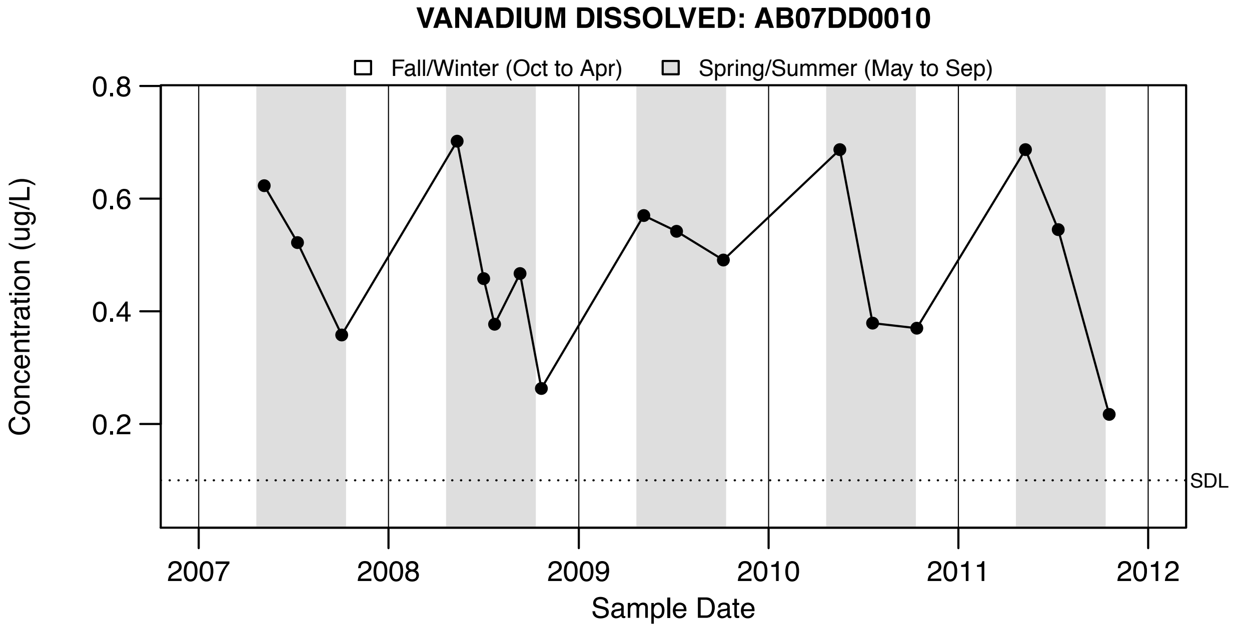


Figure A1.219: VANADIUM DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK

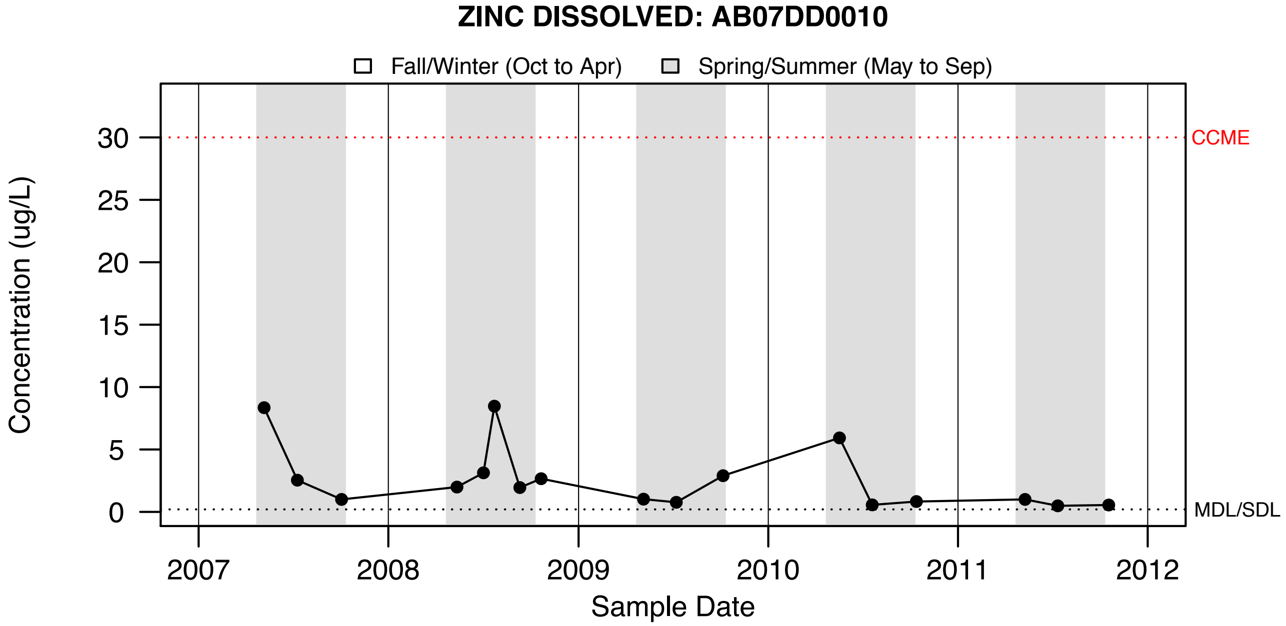
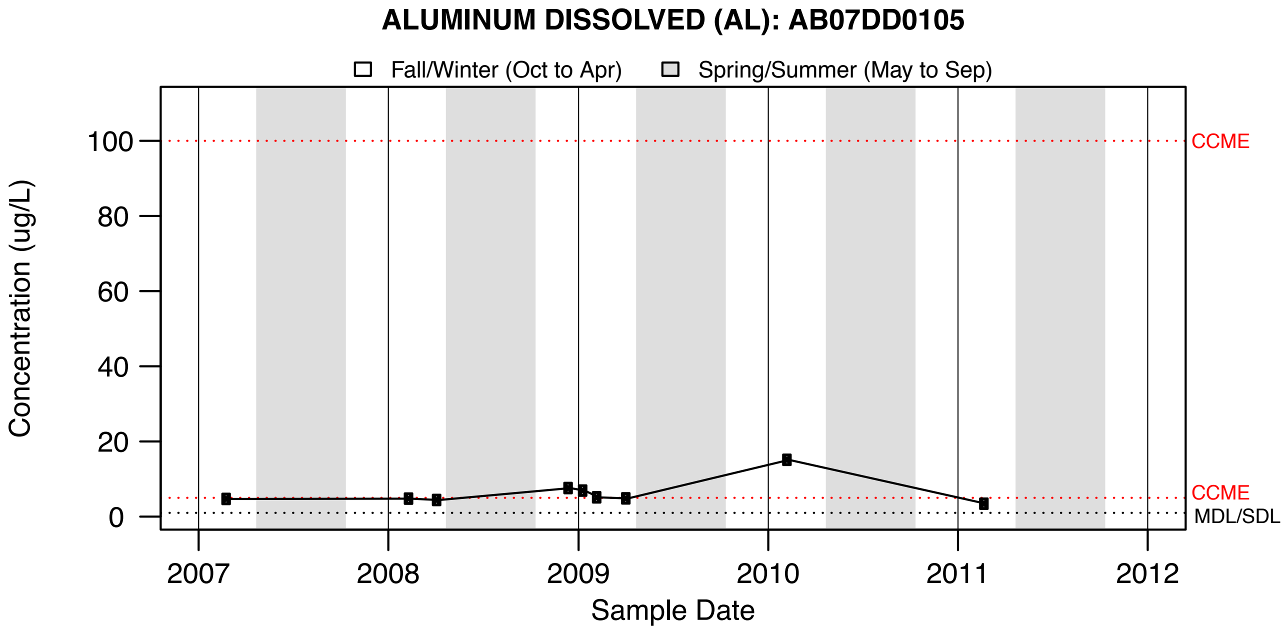
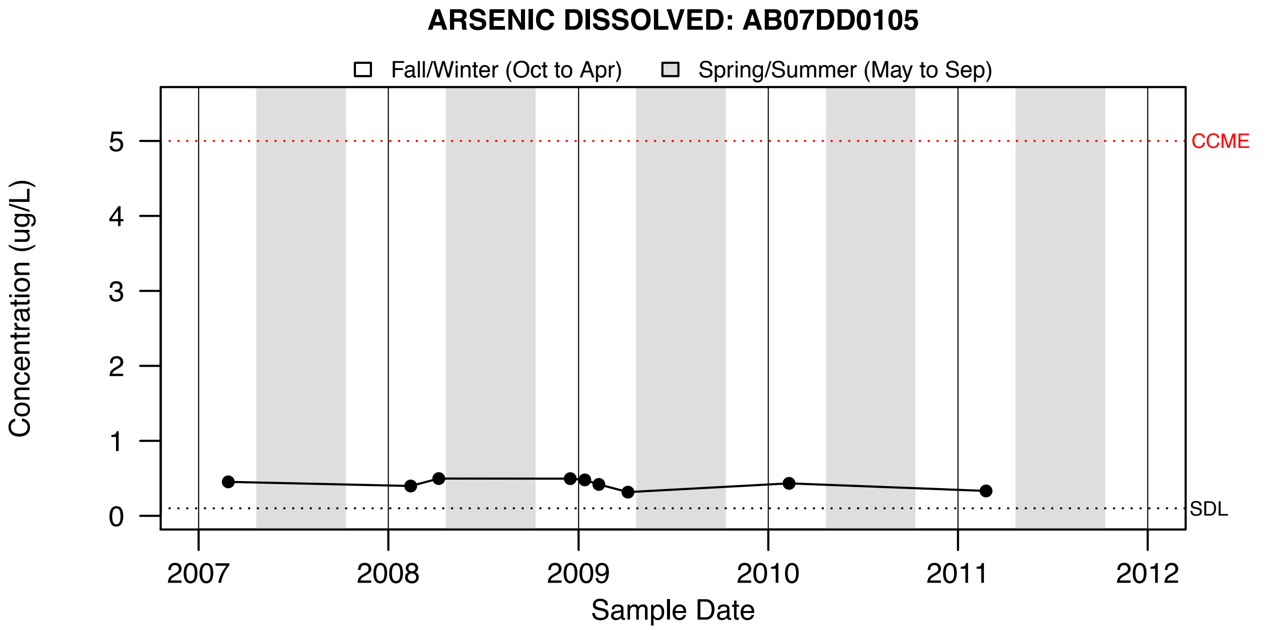


Figure A1.220: ZINC DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A1.221: ALUMINUM DISSOLVED (AL): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



AB guidelines state Total Arsenic; CCME does not specify

Figure A1.222: ARSENIC DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

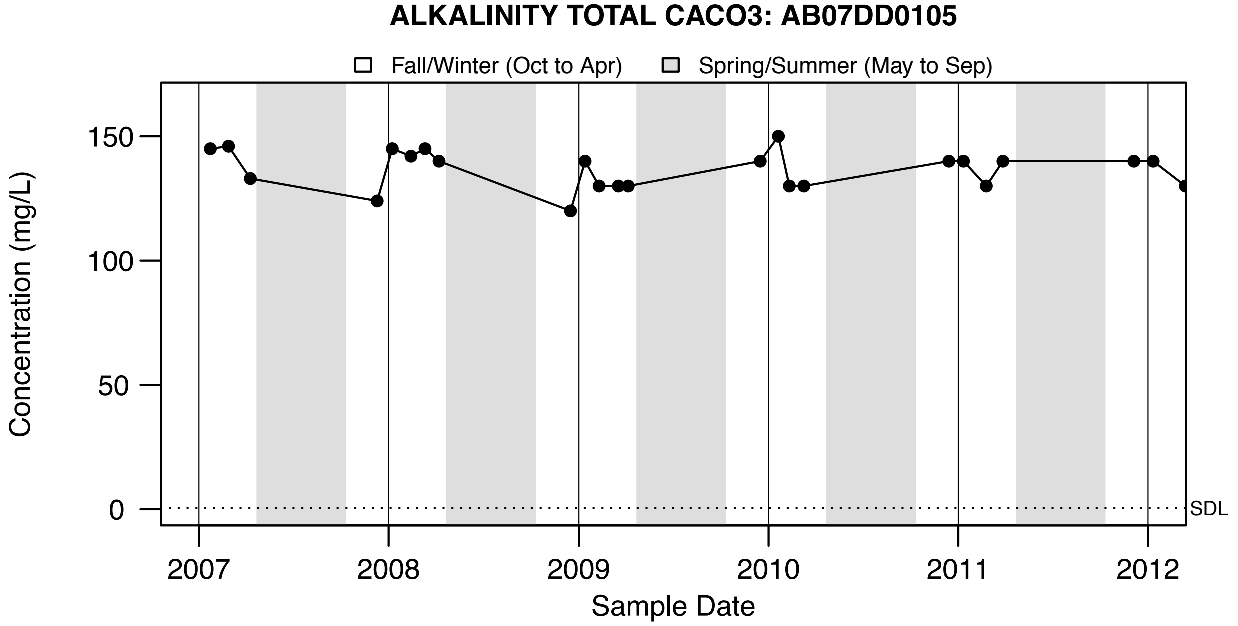


Figure A1.223: ALKALINITY TOTAL CACO3: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

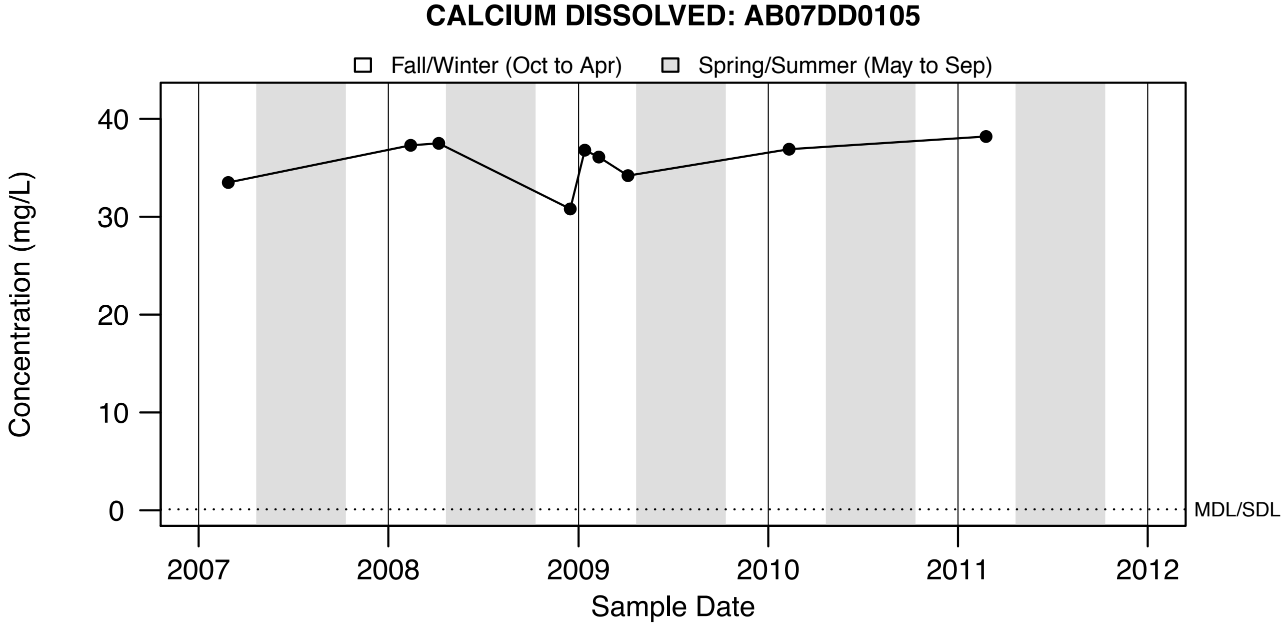


Figure A1.224: CALCIUM DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

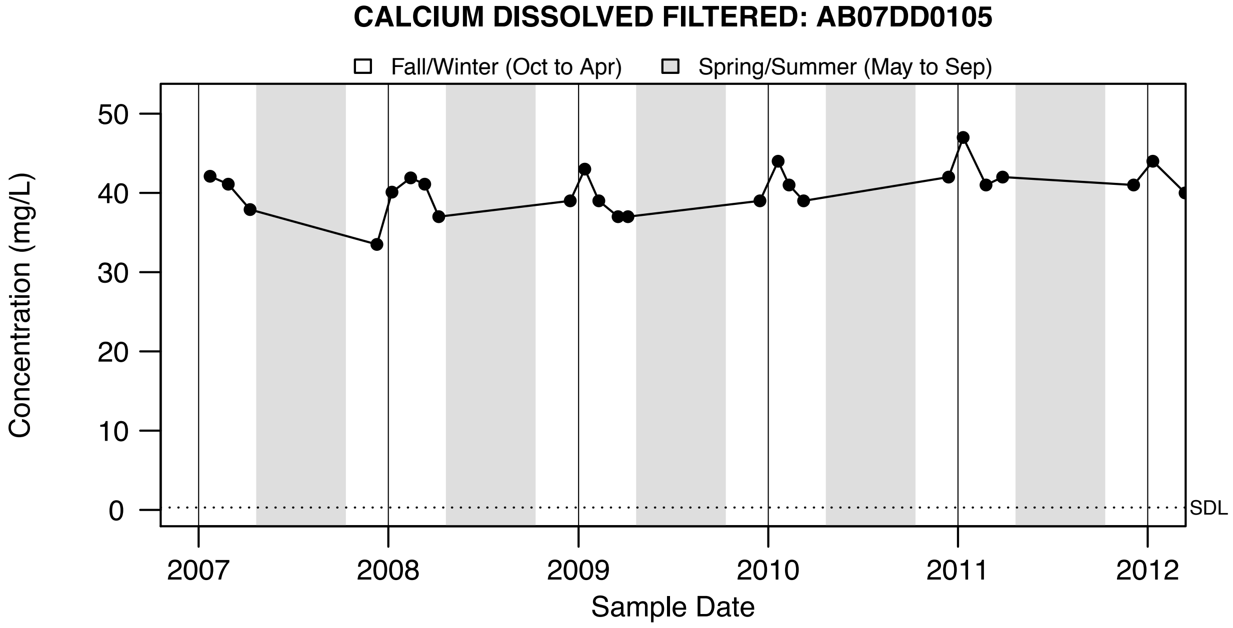


Figure A1.225: CALCIUM DISSOLVED FILTERED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

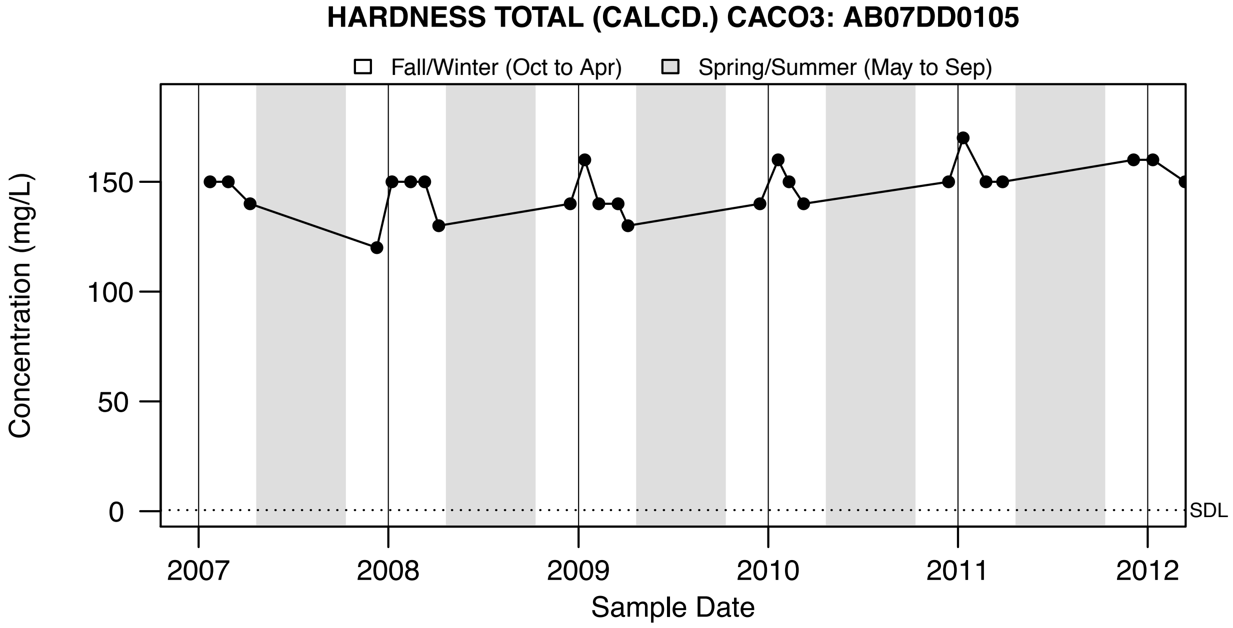


Figure A1.226: HARDNESS TOTAL (CALCD.) CACO3: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

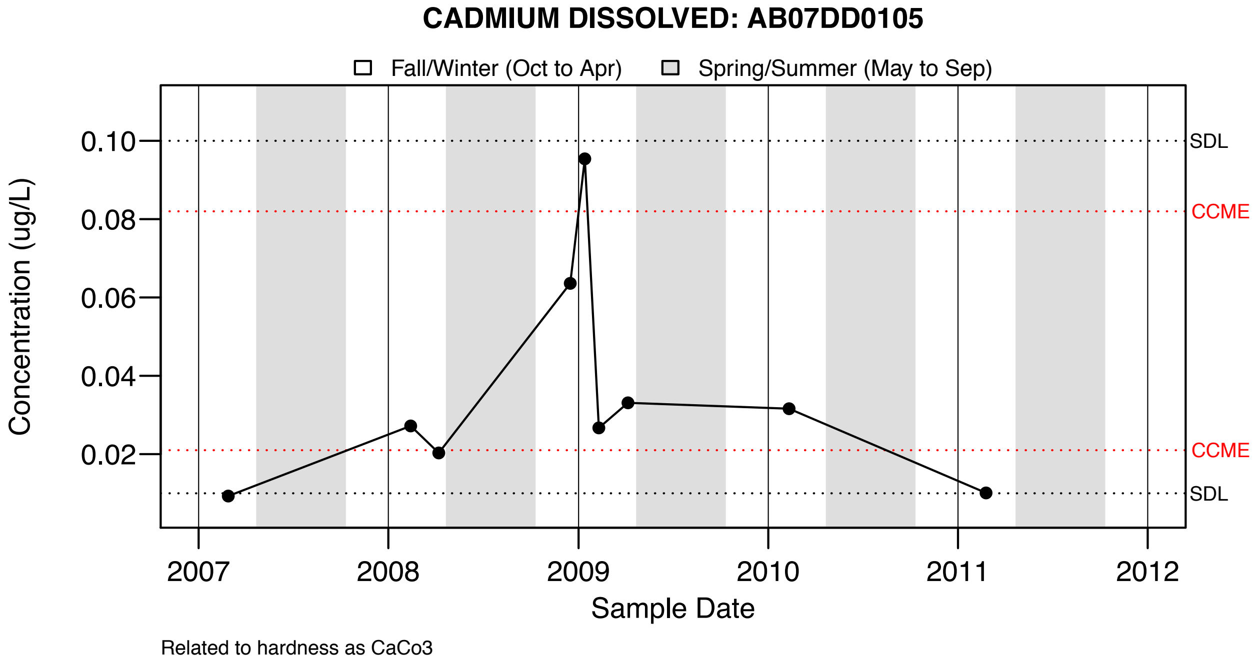


Figure A1.227: CADMIUM DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

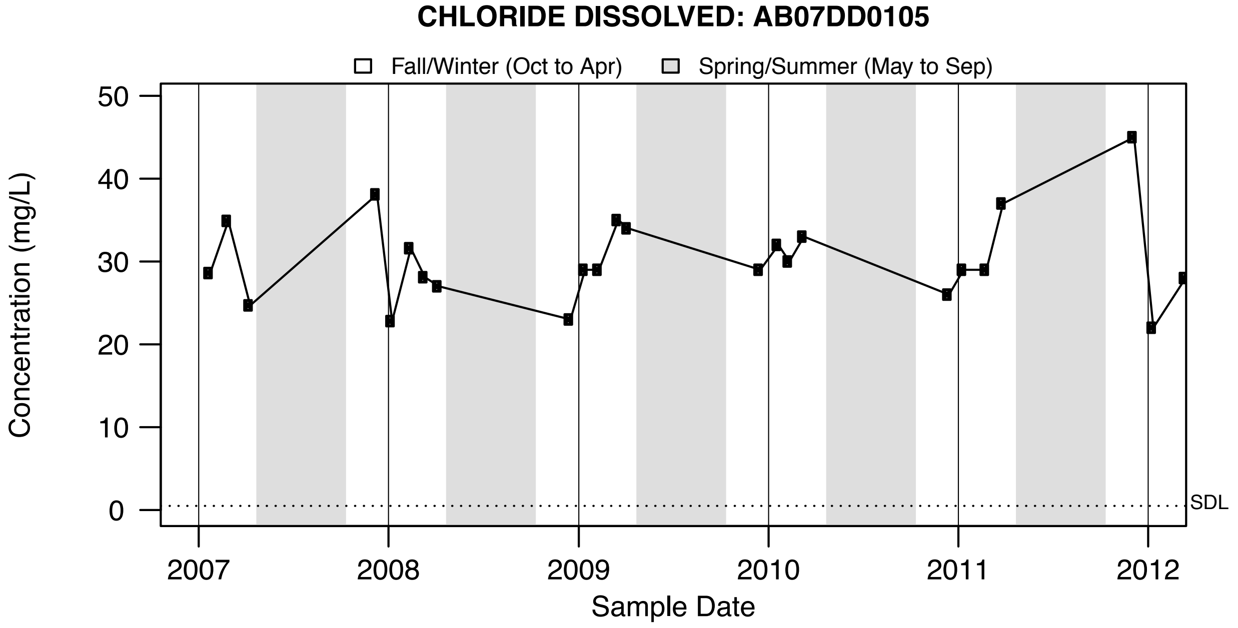


Figure A1.228: CHLORIDE DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

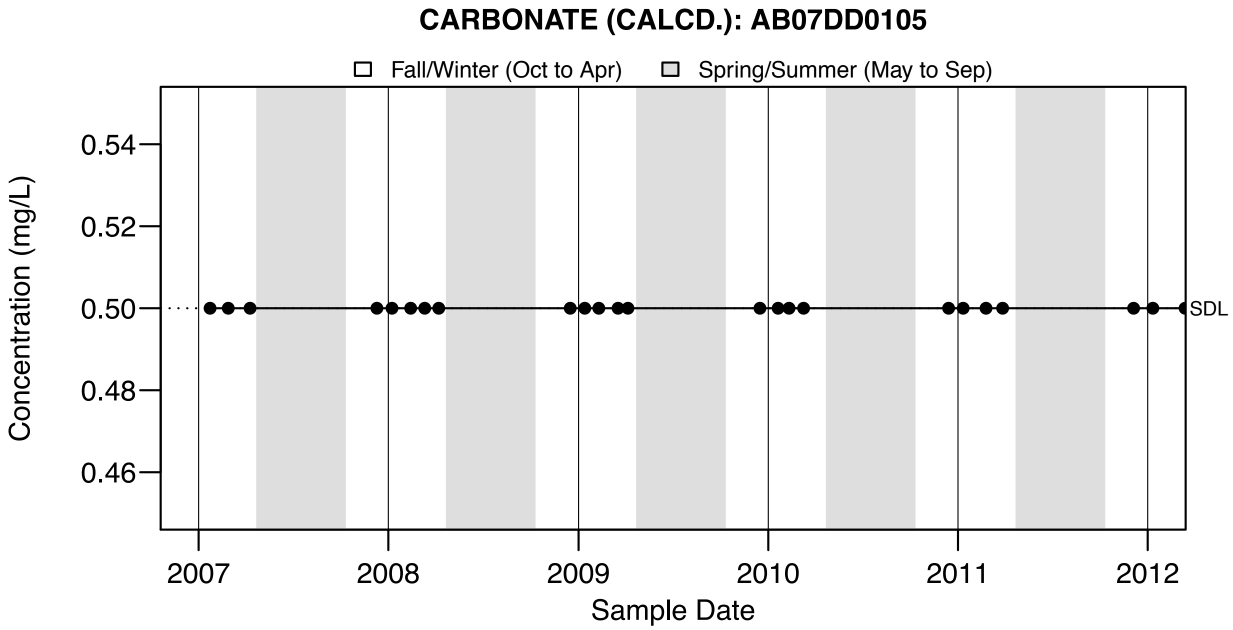


Figure A1.229: CARBONATE (CALCD.): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

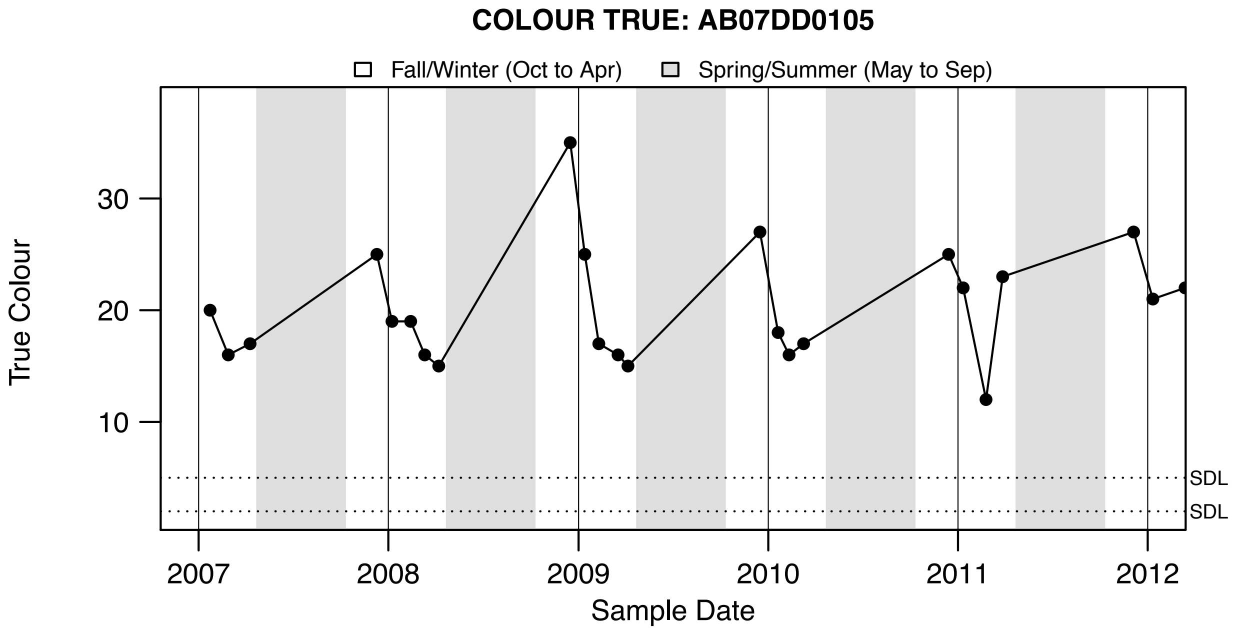


Figure A1.230: COLOUR TRUE: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

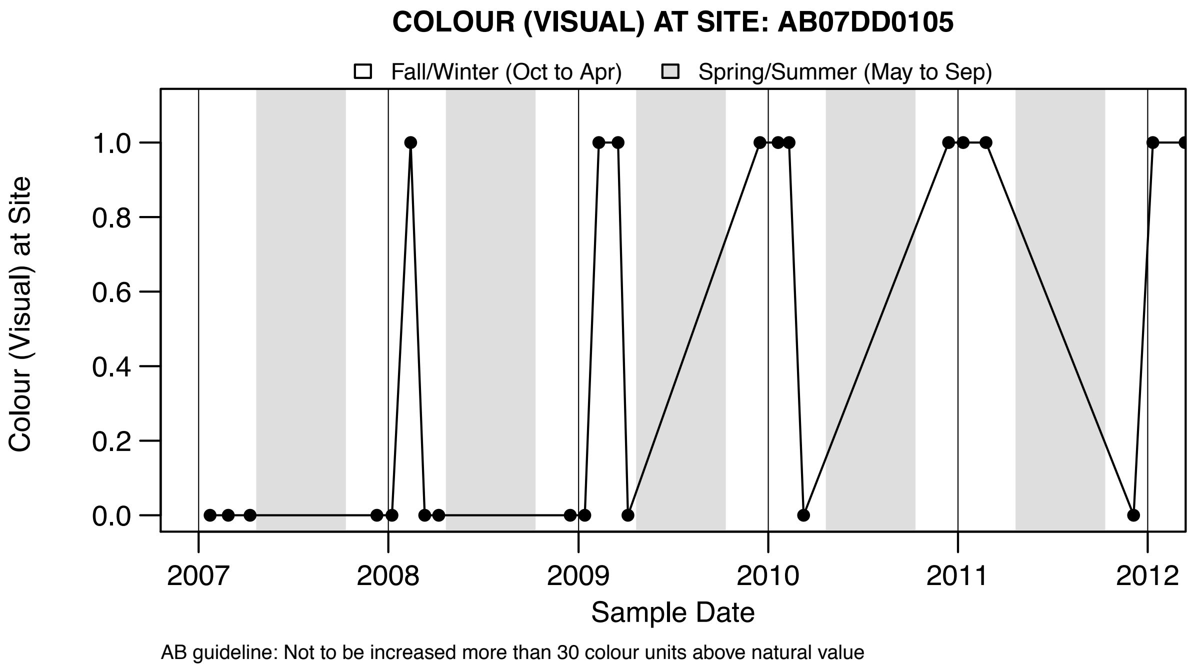


Figure A1.231: COLOUR (VISUAL) AT SITE: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

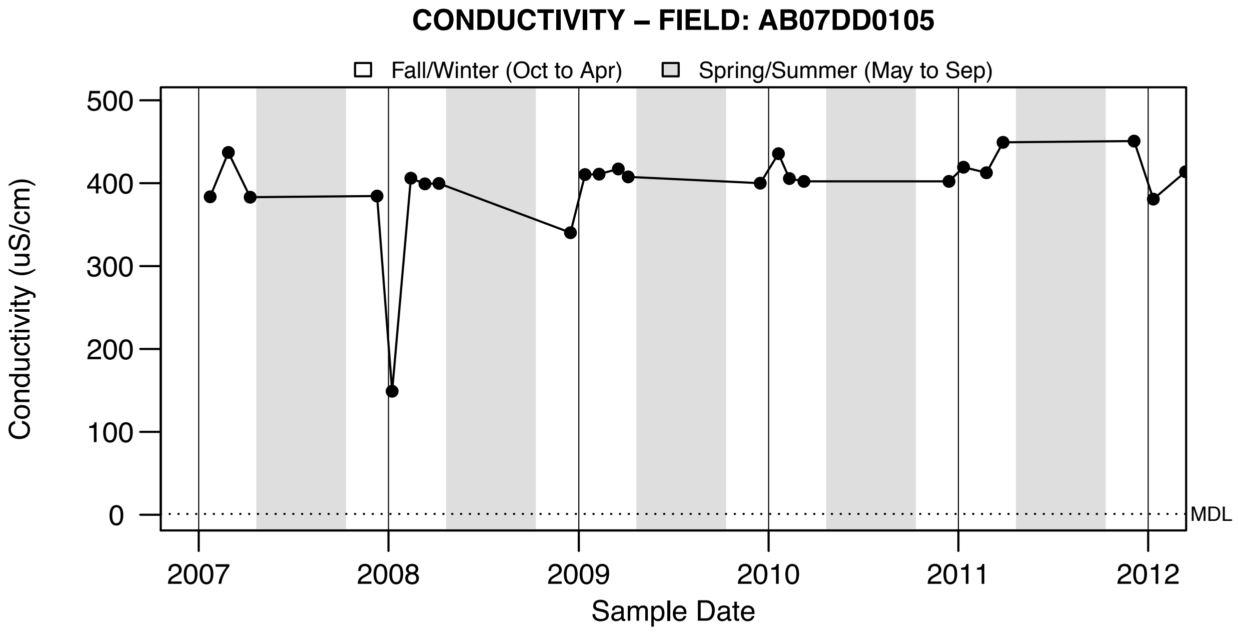


Figure A1.232: CONDUCTIVITY - FIELD: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

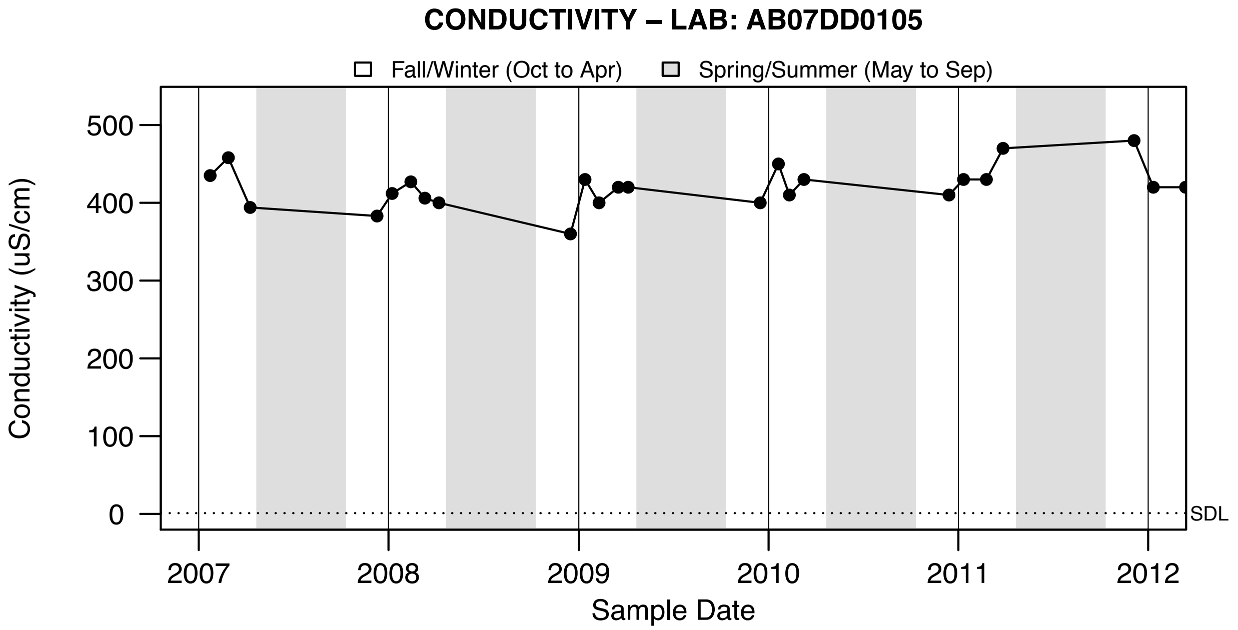
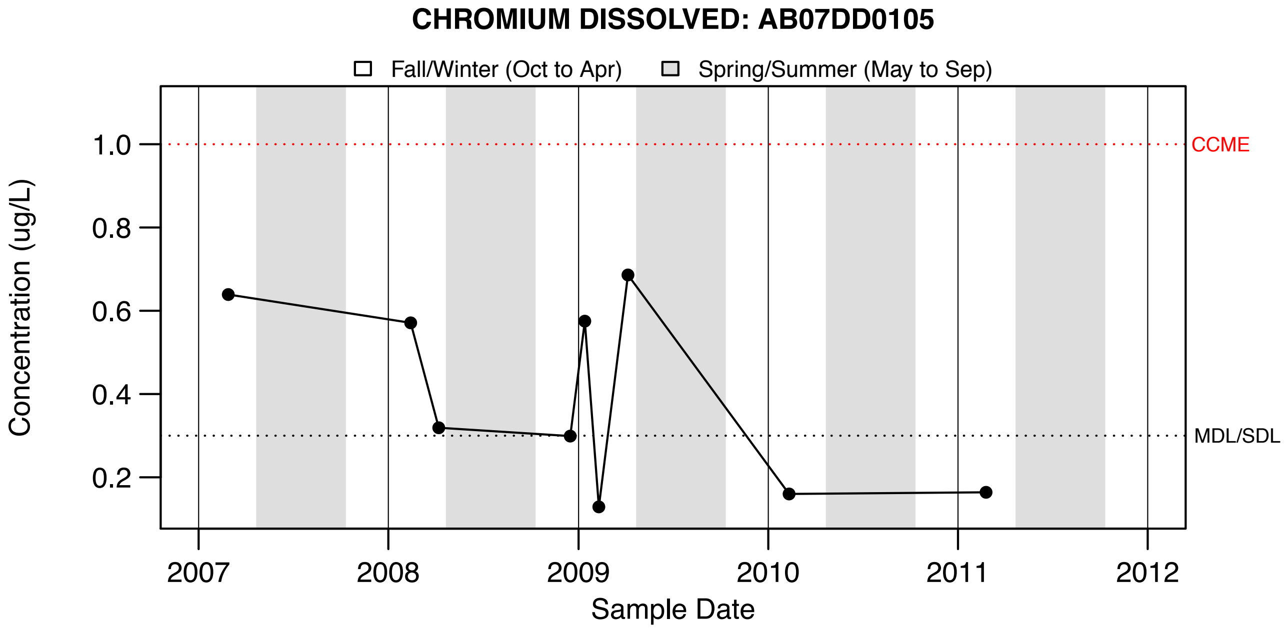


Figure A1.233: CONDUCTIVITY - LAB: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



Chromium III: 8.9 Chromium VI: 1.0

Figure A1.234: CHROMIUM DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

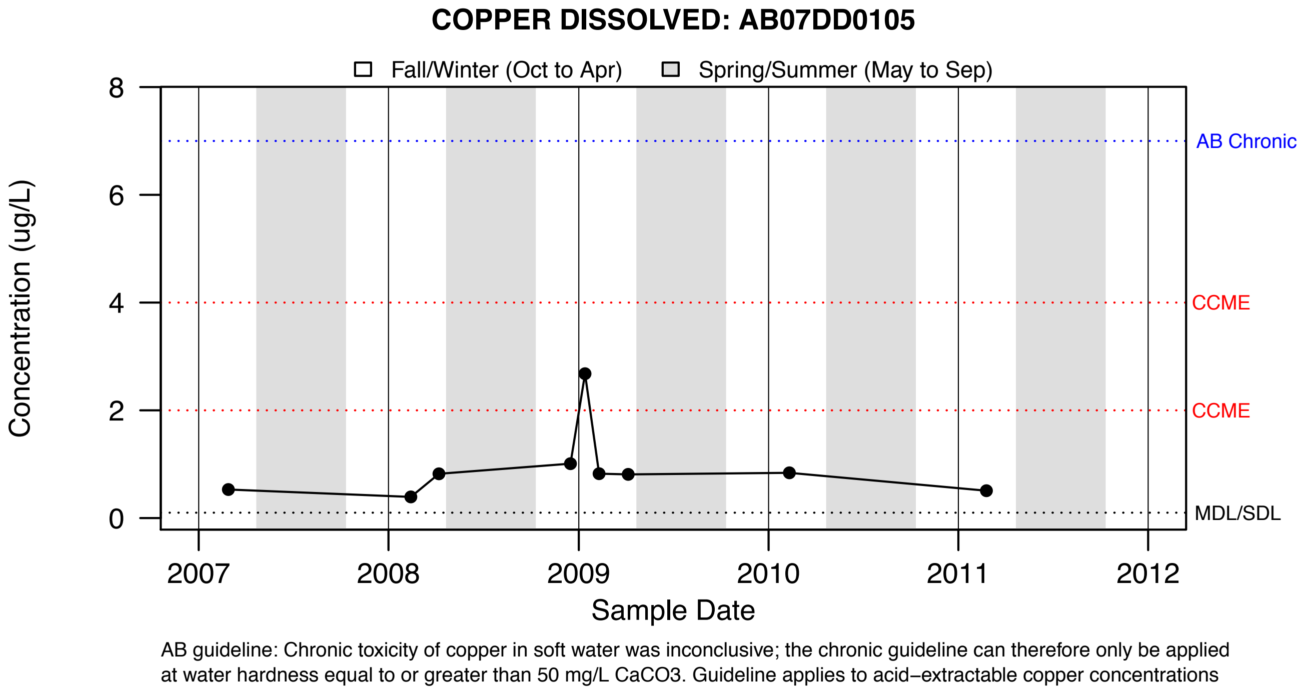


Figure A1.235: COPPER DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

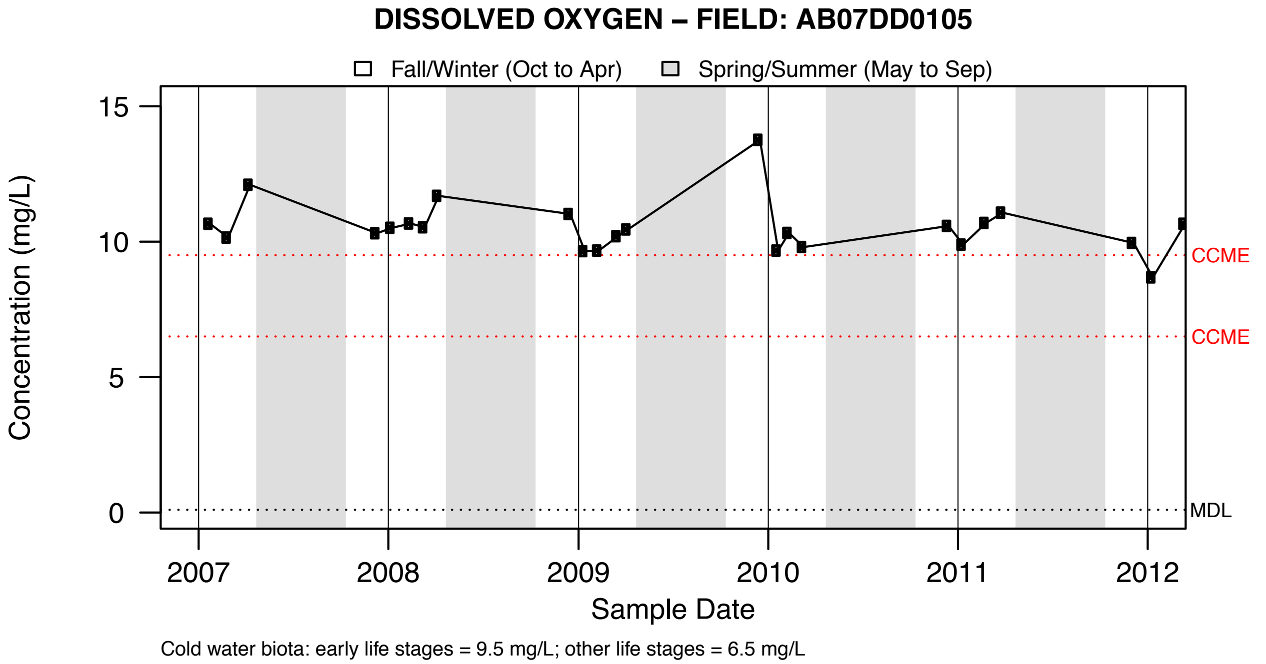


Figure A1.236: DISSOLVED OXYGEN - FIELD: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

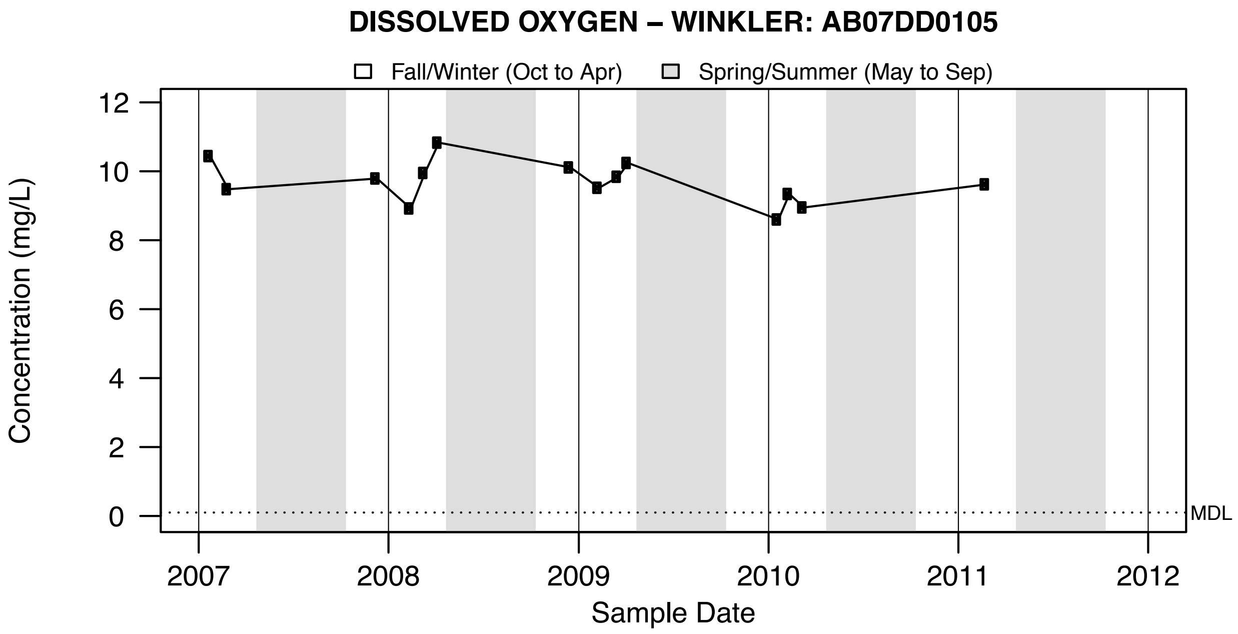


Figure A1.237: DISSOLVED OXYGEN - WINKLER: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

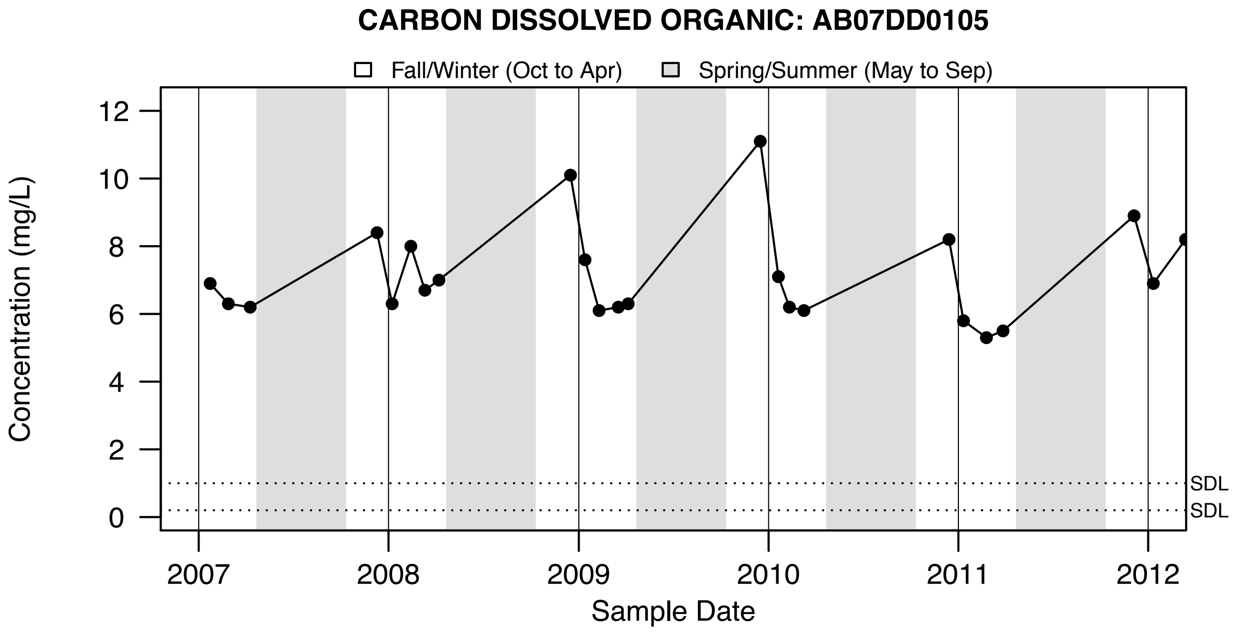


Figure A1.238: CARBON DISSOLVED ORGANIC: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

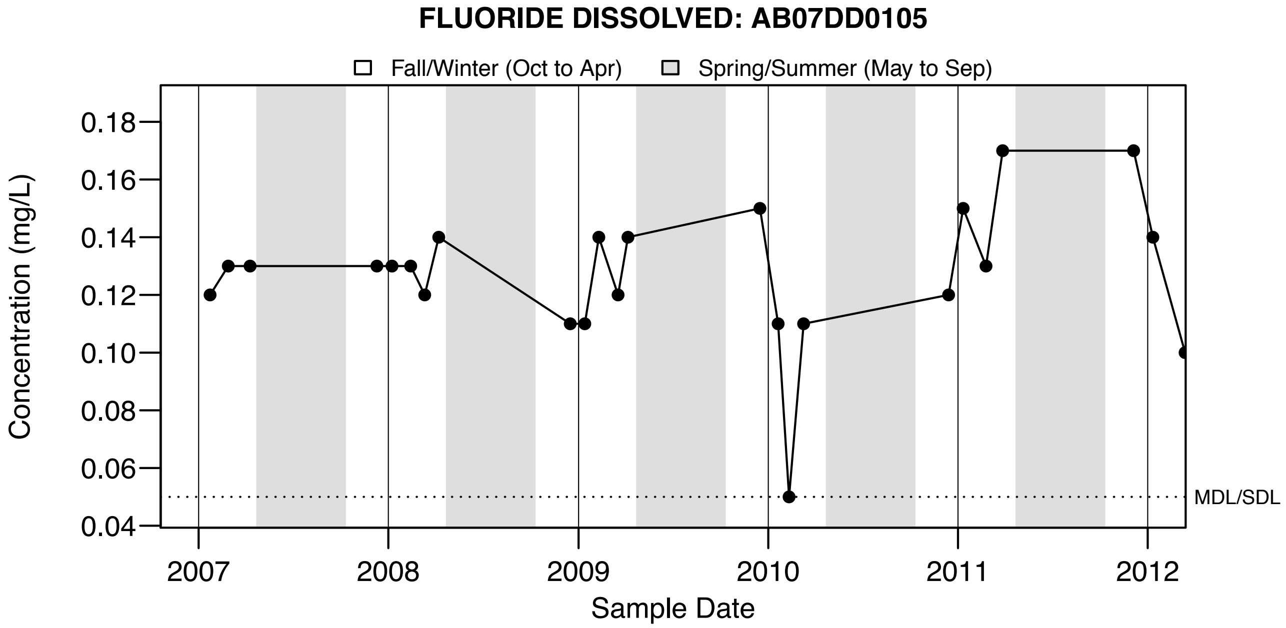


Figure A1.239: FLUORIDE DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

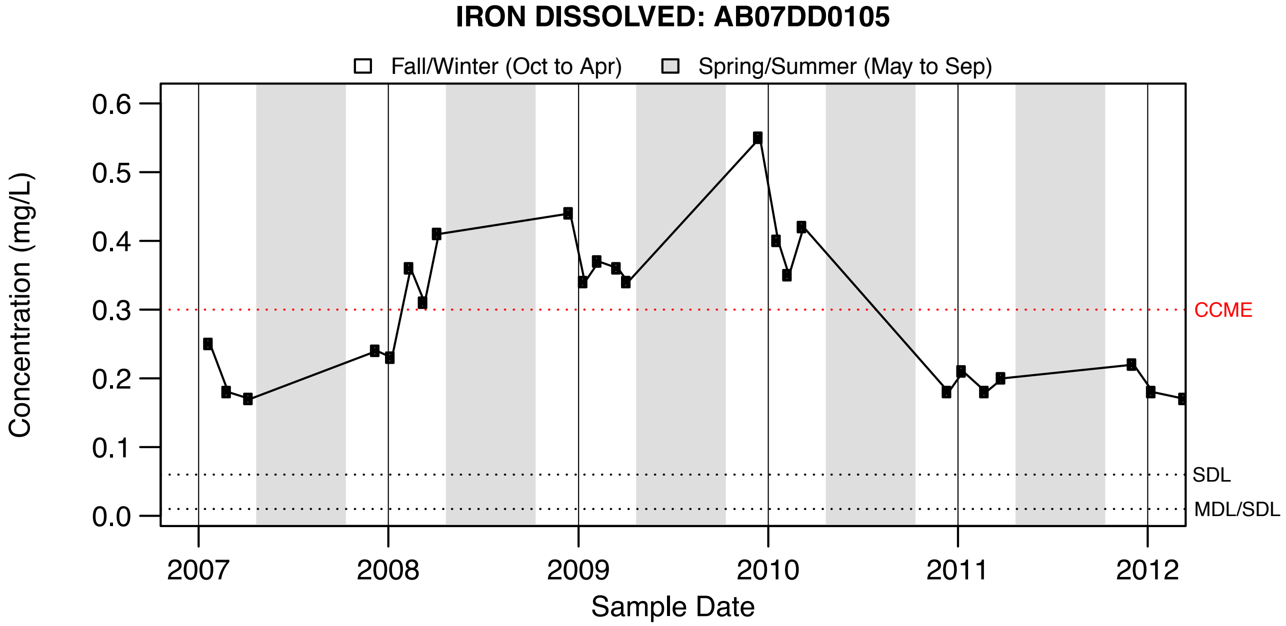


Figure A1.240: IRON DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

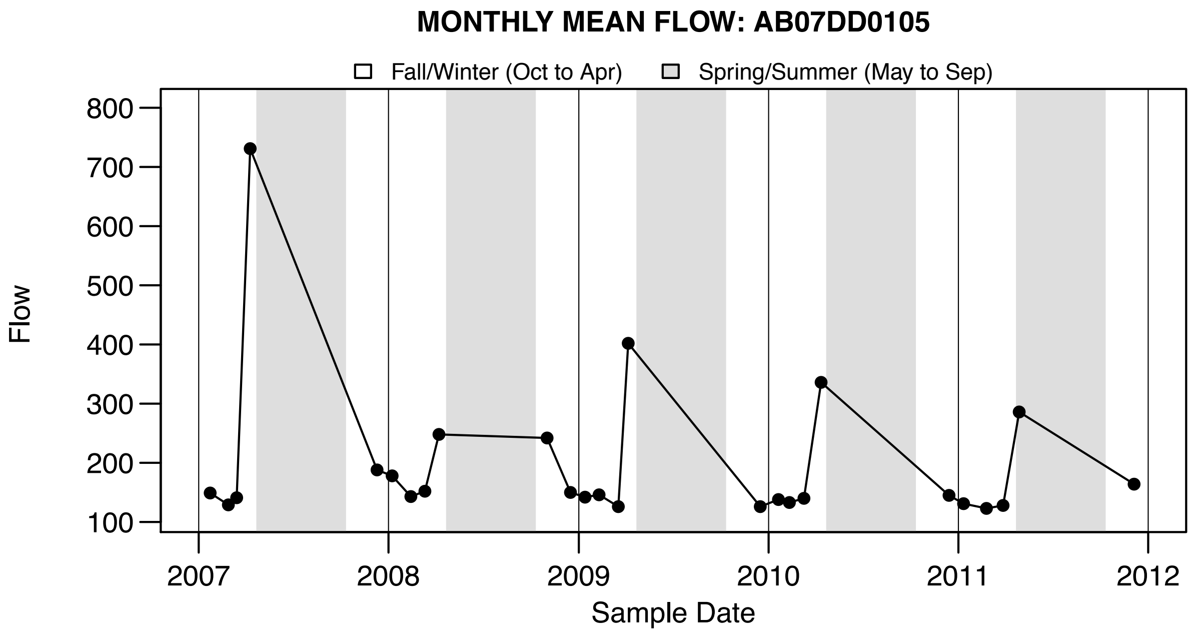


Figure A1.241: MONTHLY MEAN FLOW: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

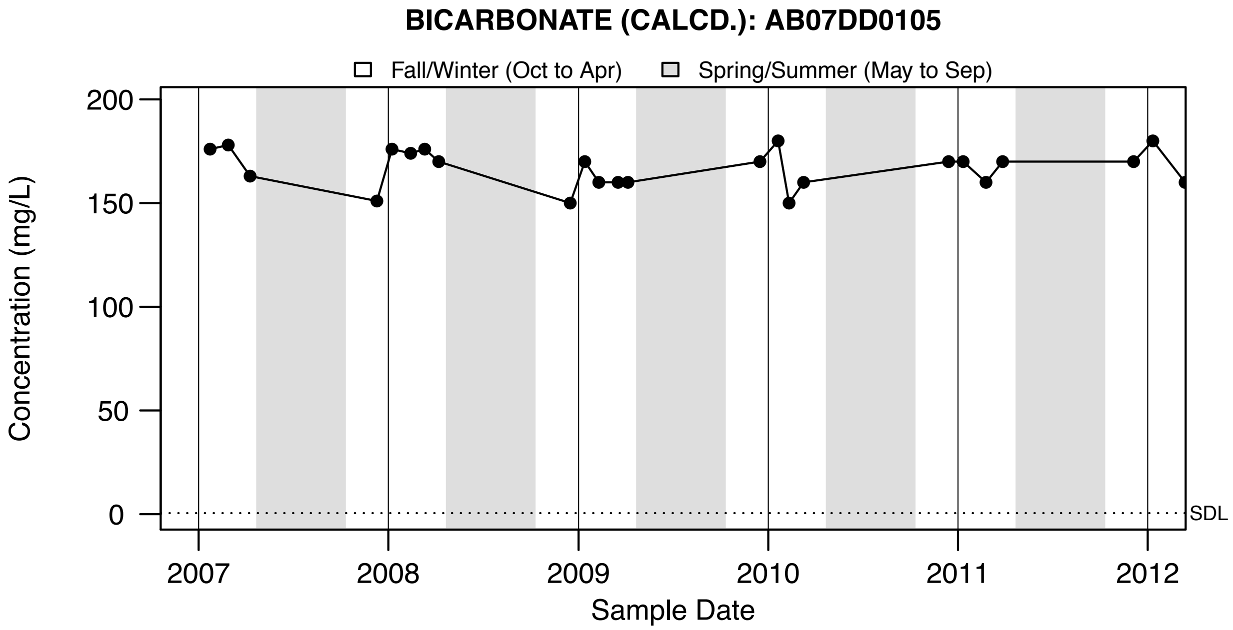


Figure A1.242: BICARBONATE (CALCD.): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

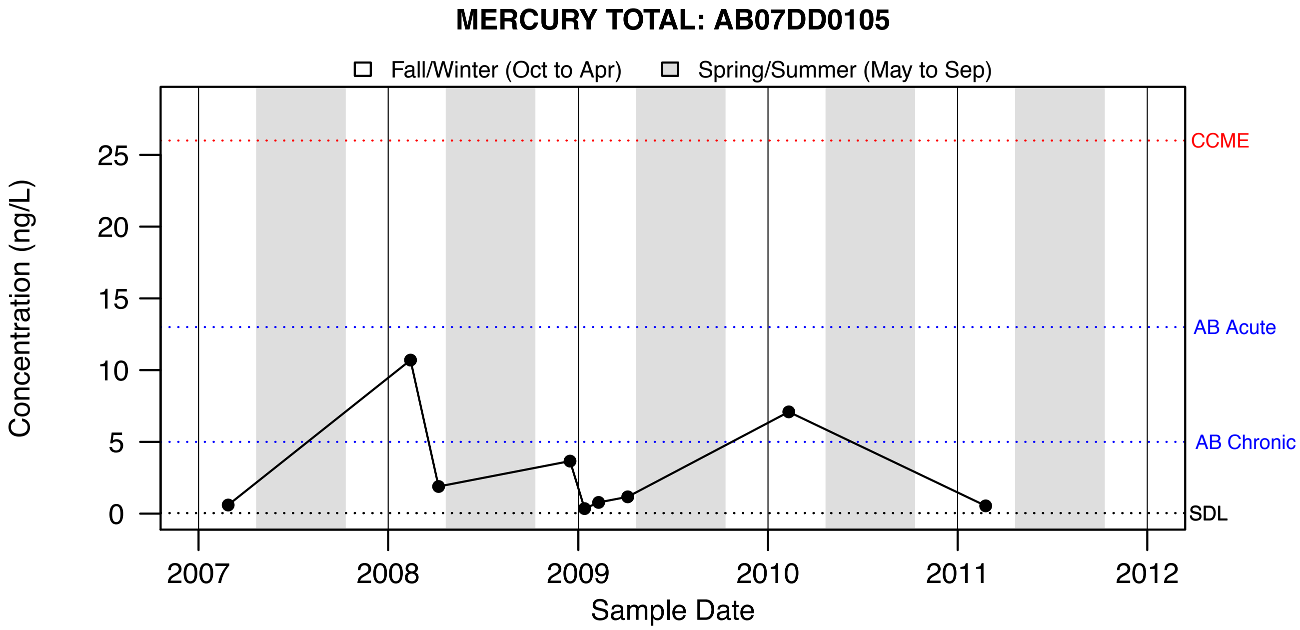


Figure A1.243: MERCURY TOTAL: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

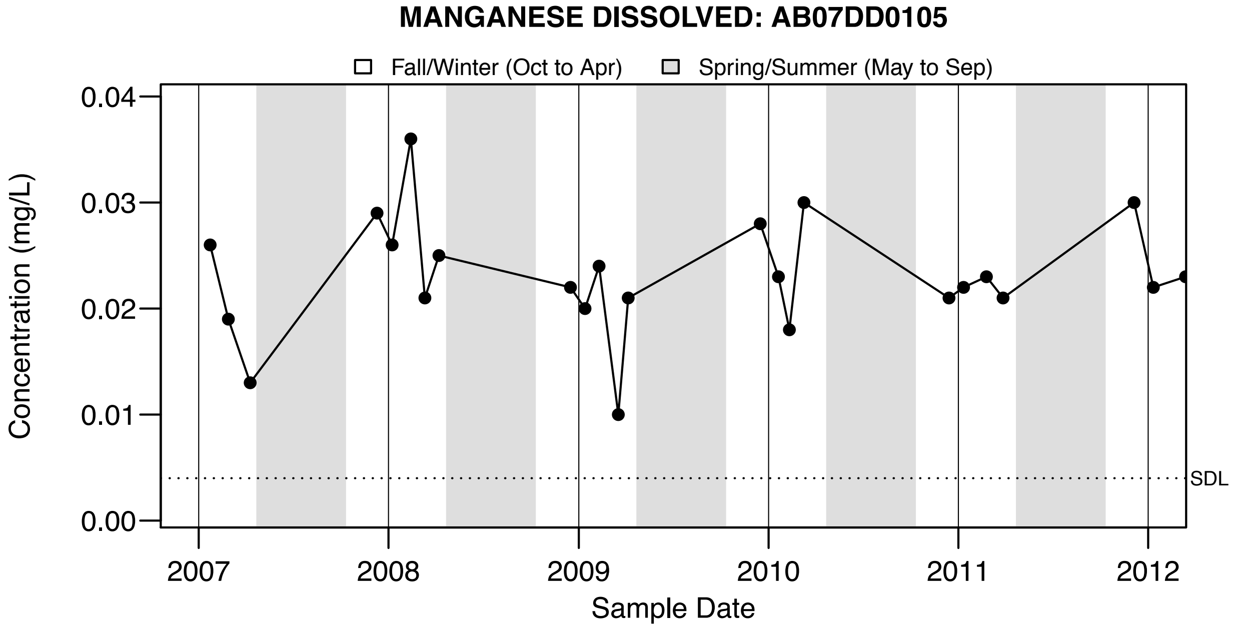


Figure A1.244: MANGANESE DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

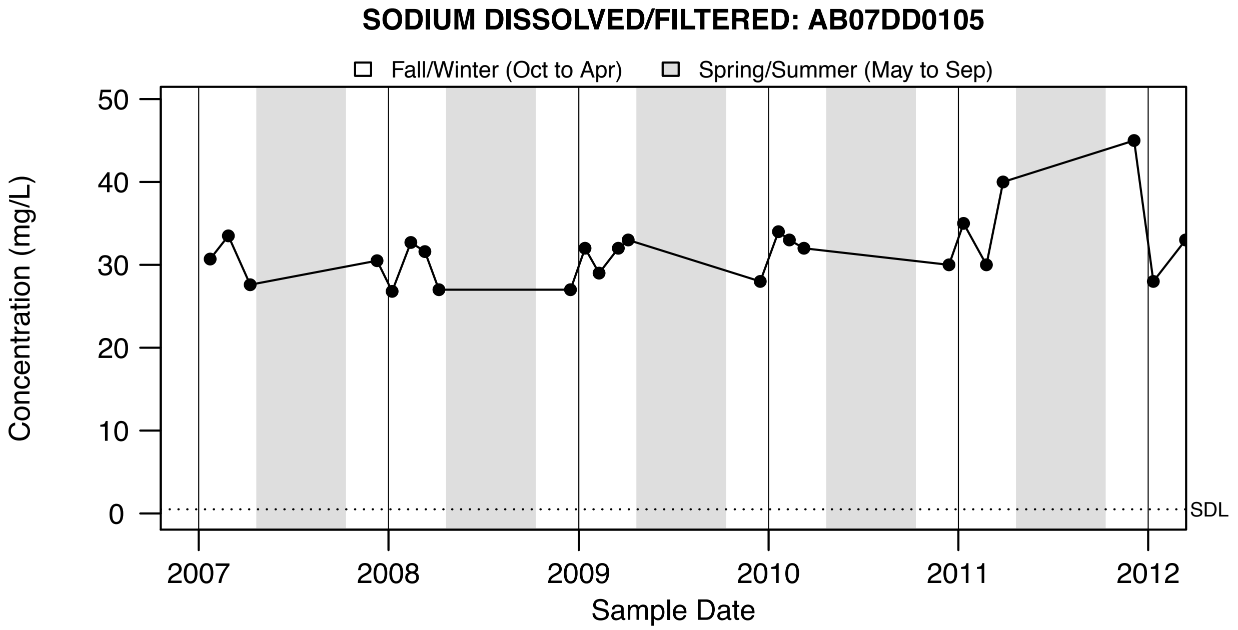
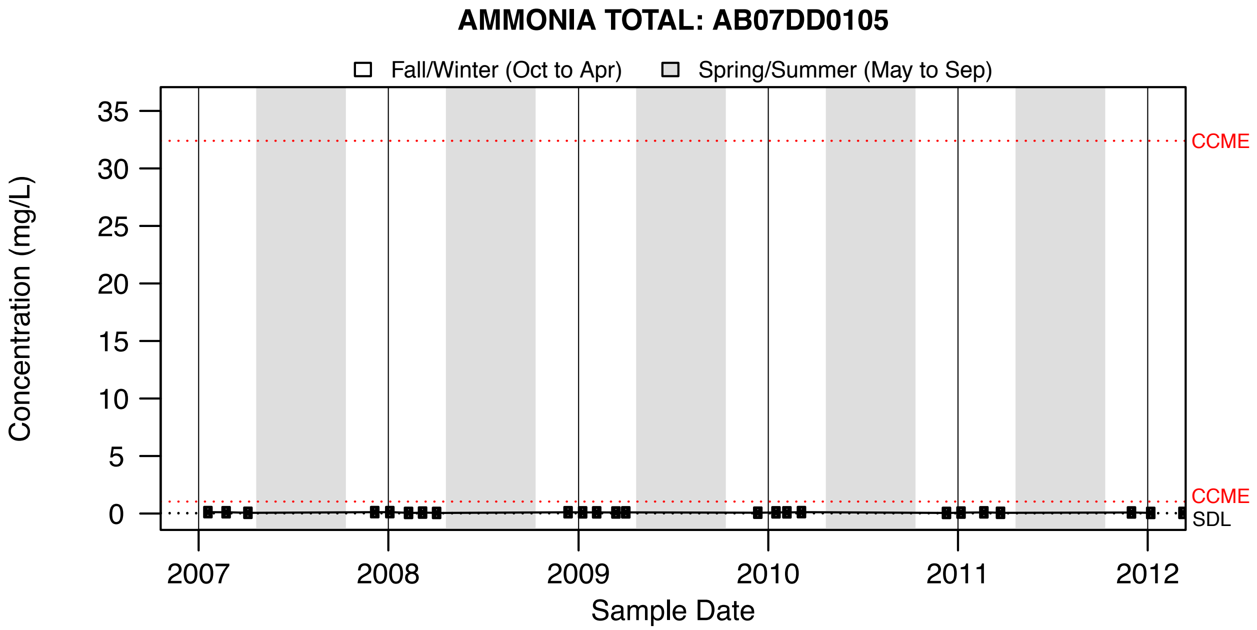
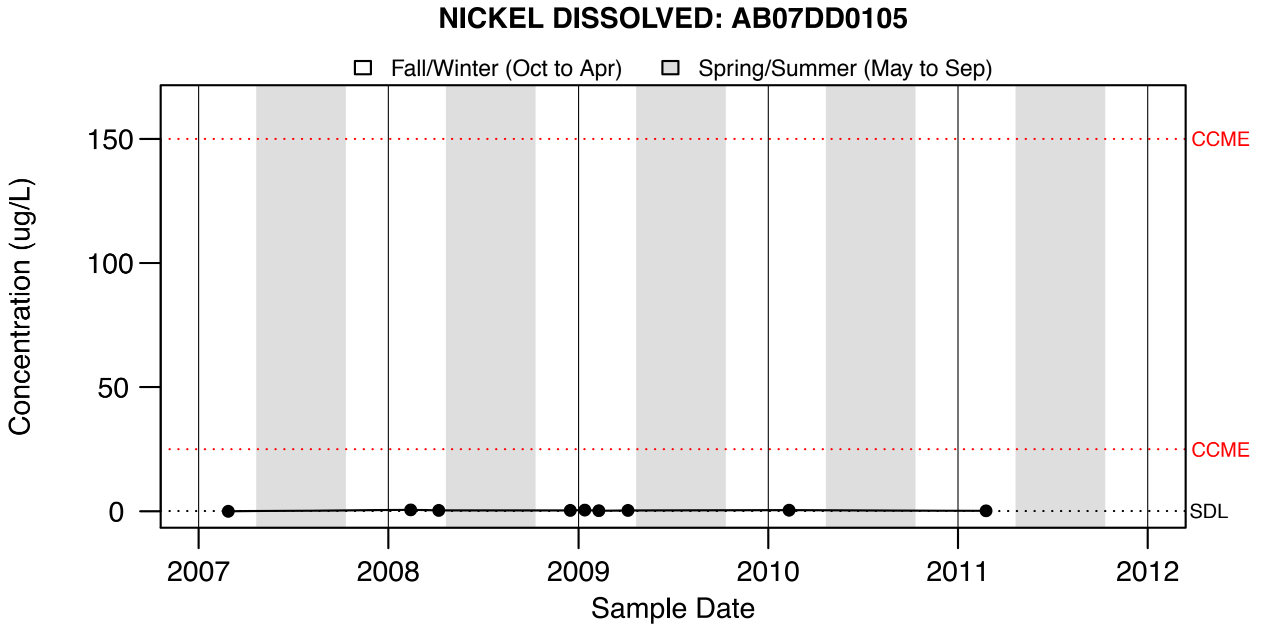


Figure A1.245: SODIUM DISSOLVED/FILTERED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A1.246: AMMONIA TOTAL: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A1.247: NICKEL DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

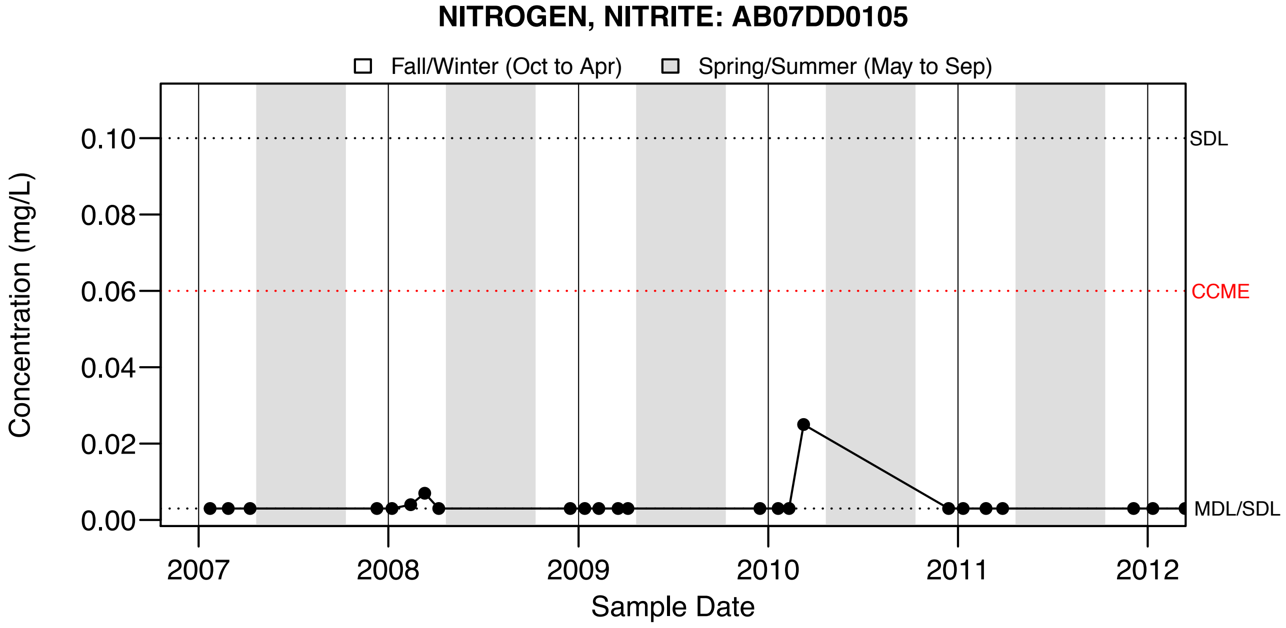
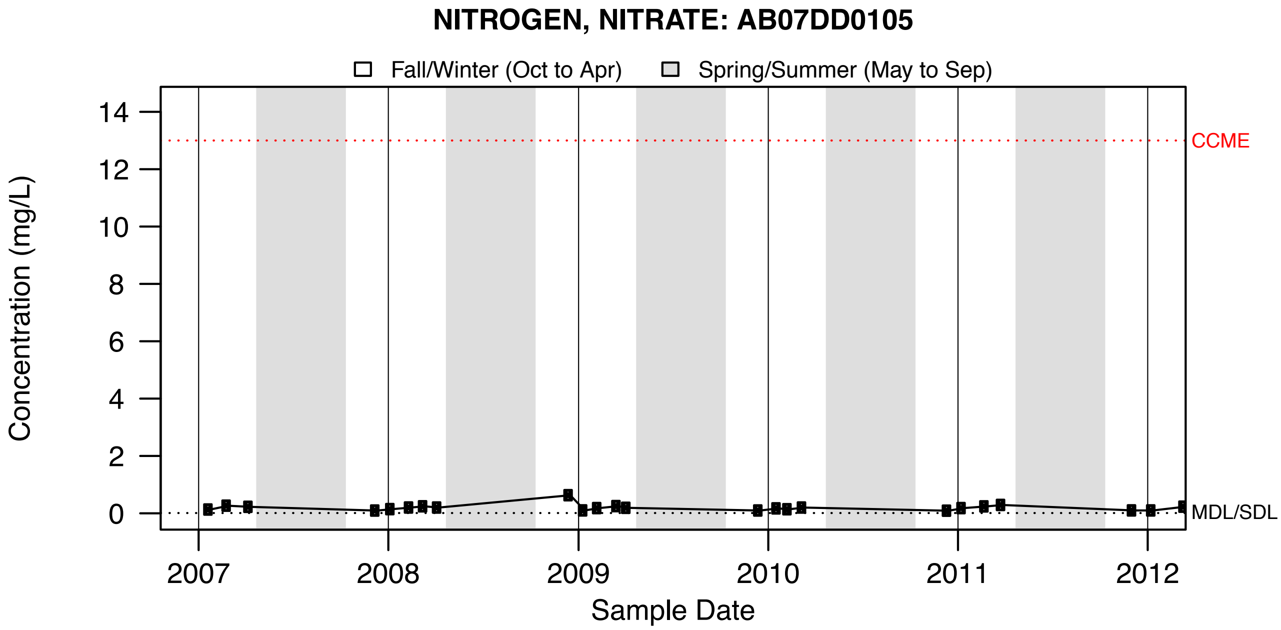


Figure A1.248: NITROGEN, NITRITE: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A1.249: NITROGEN, NITRATE: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

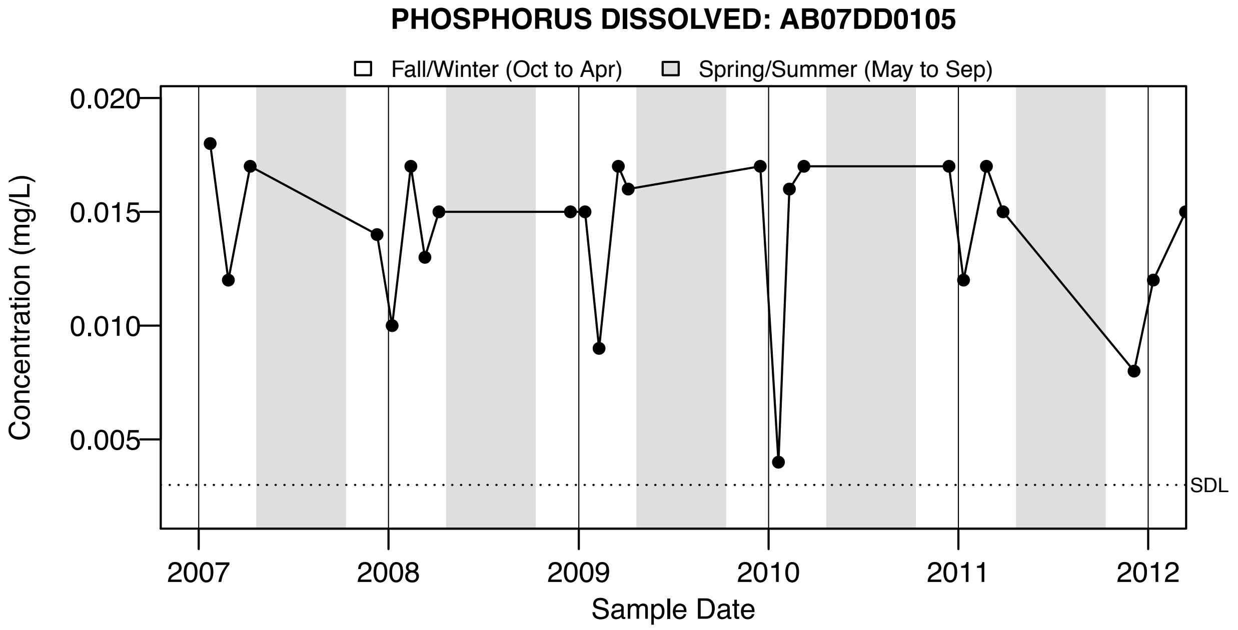


Figure A1.250: PHOSPHORUS DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

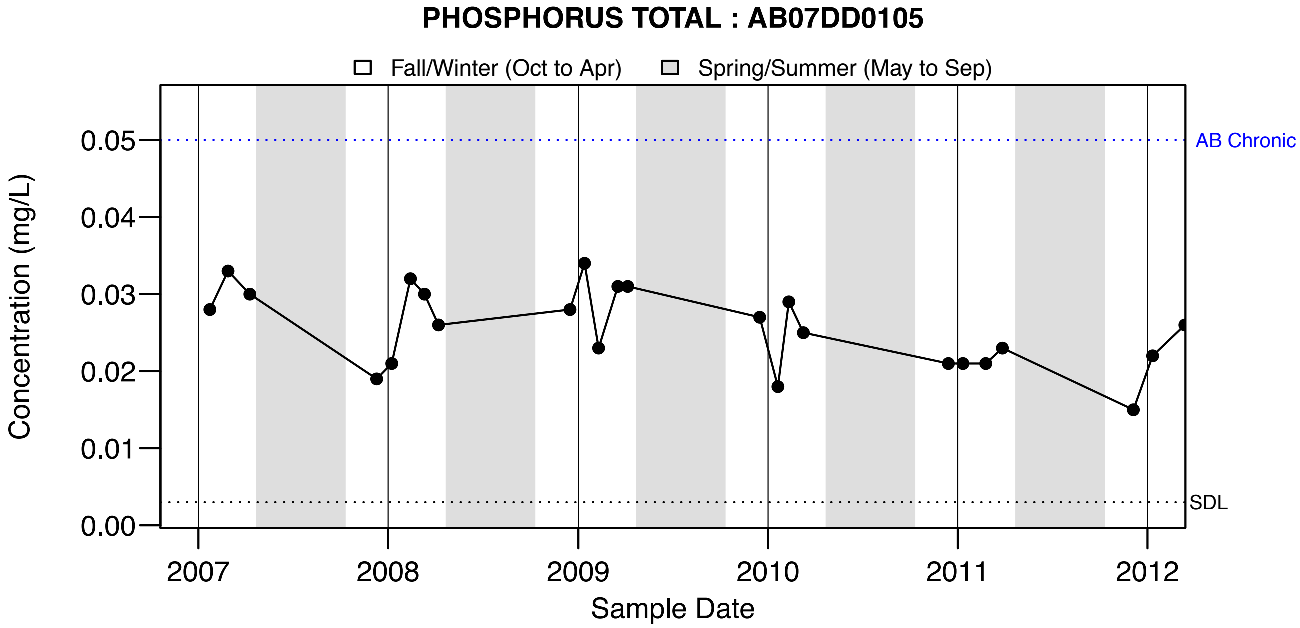
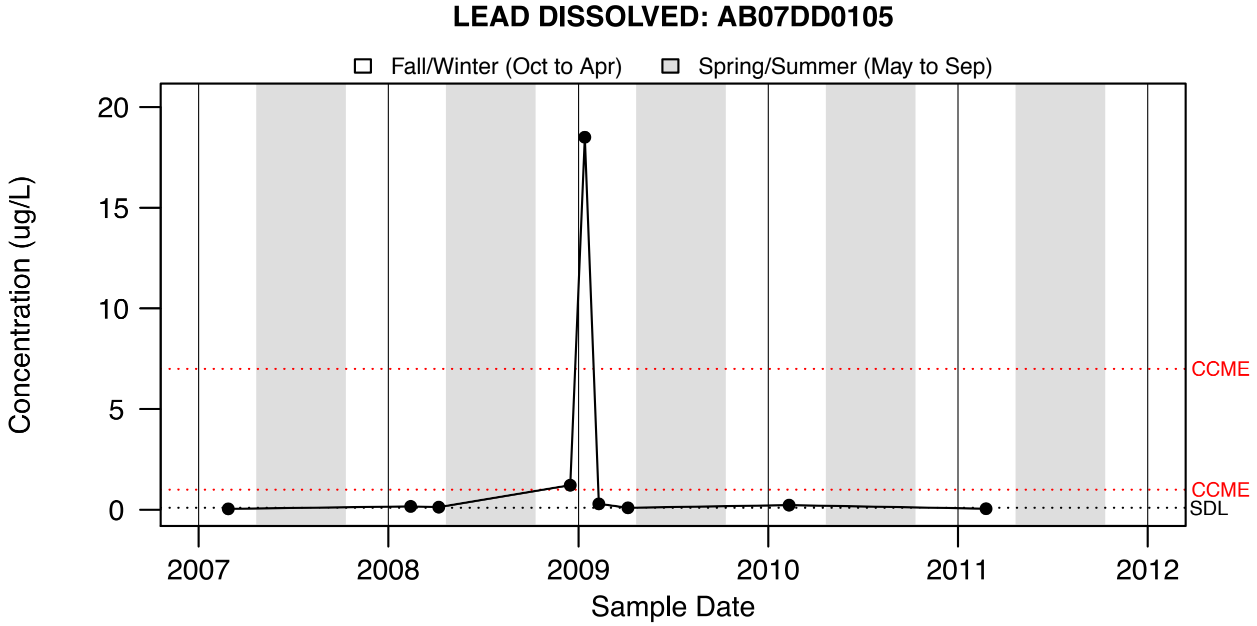


Figure A1.251: PHOSPHORUS TOTAL : AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A1.252: LEAD DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

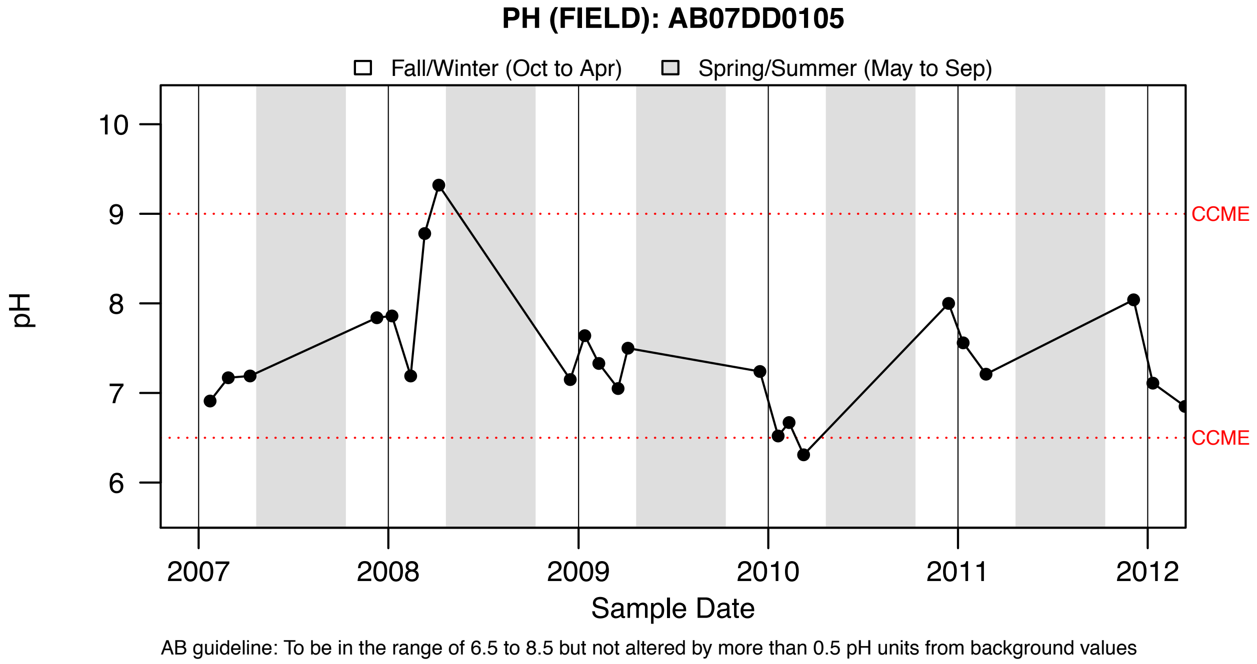


Figure A1.253: PH (FIELD): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

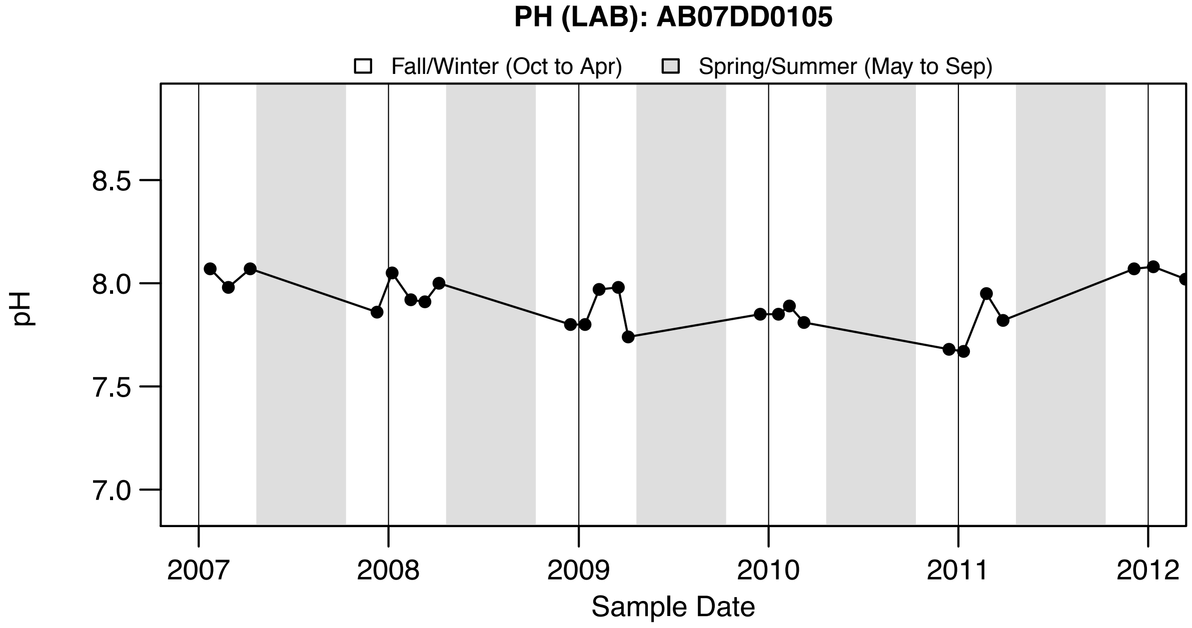


Figure A1.254: PH (LAB): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

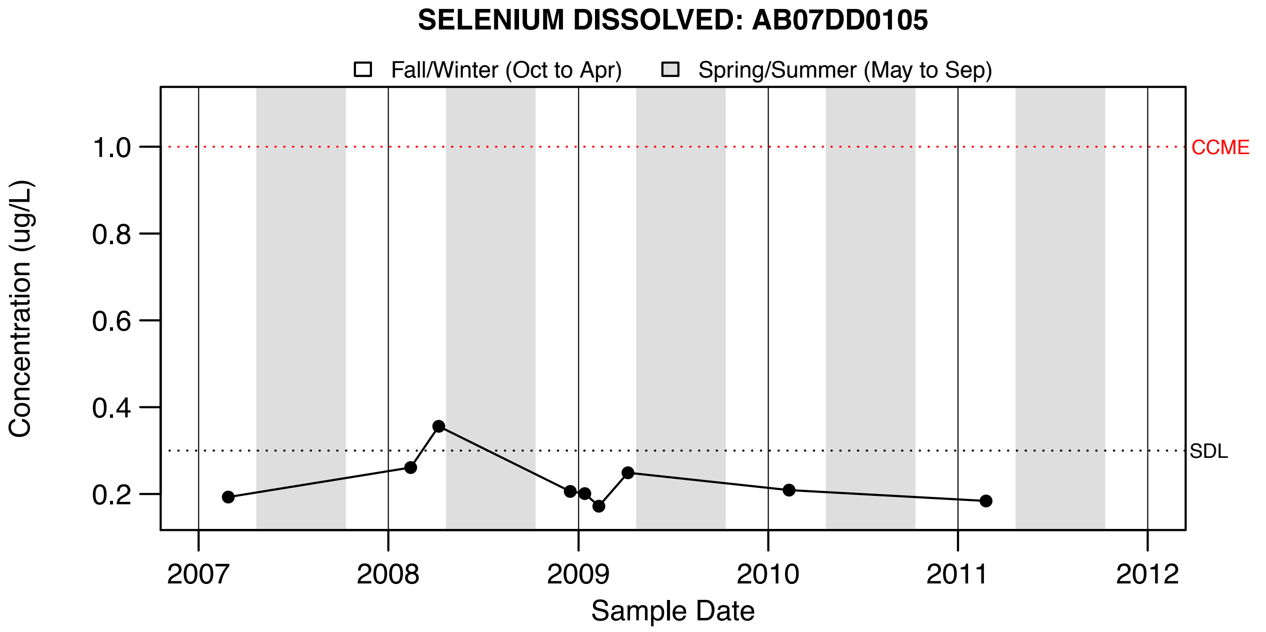


Figure A1.255: SELENIUM DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

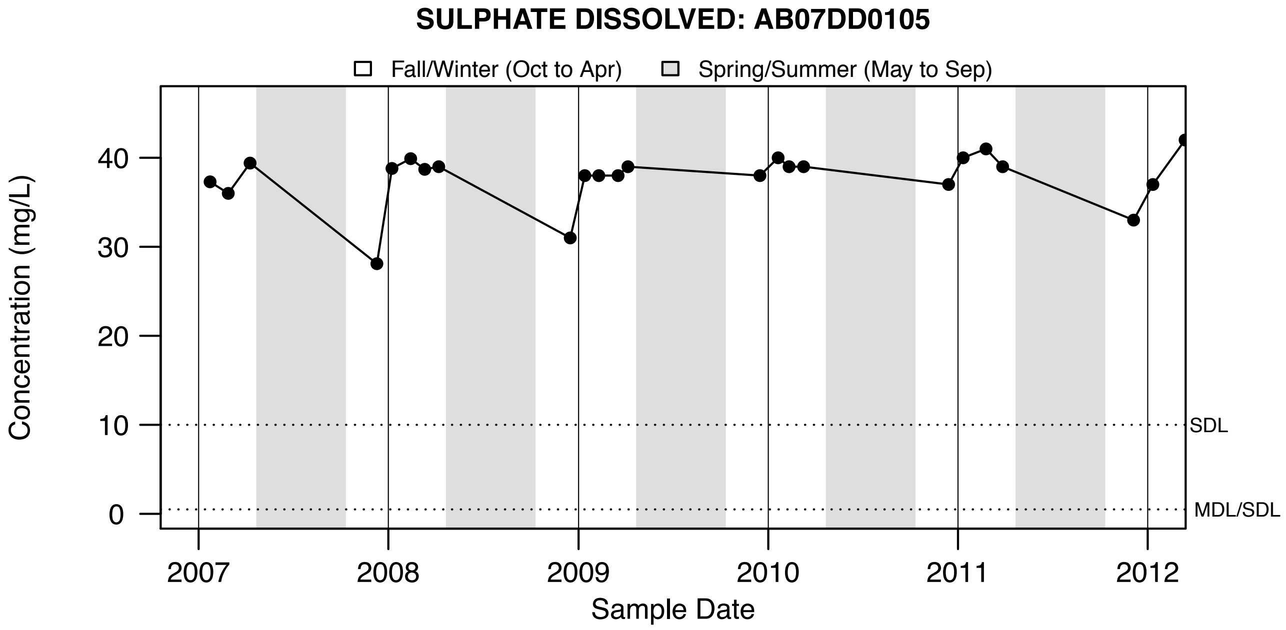


Figure A1.256: SULPHATE DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

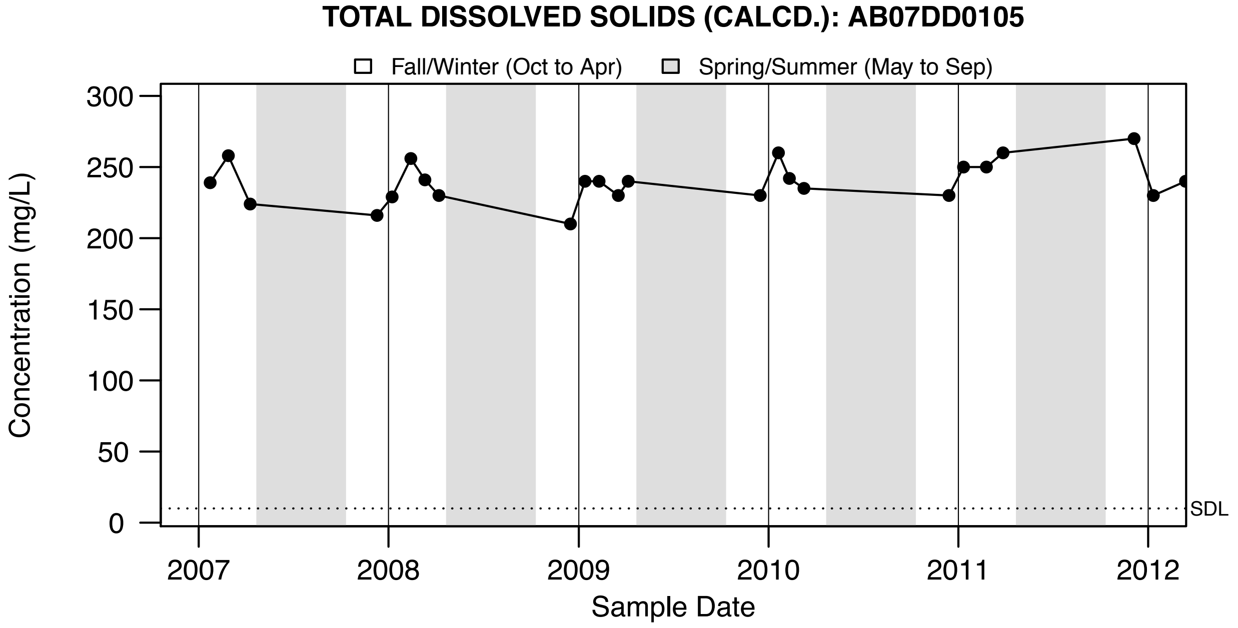


Figure A1.257: TOTAL DISSOLVED SOLIDS (CALCD.): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

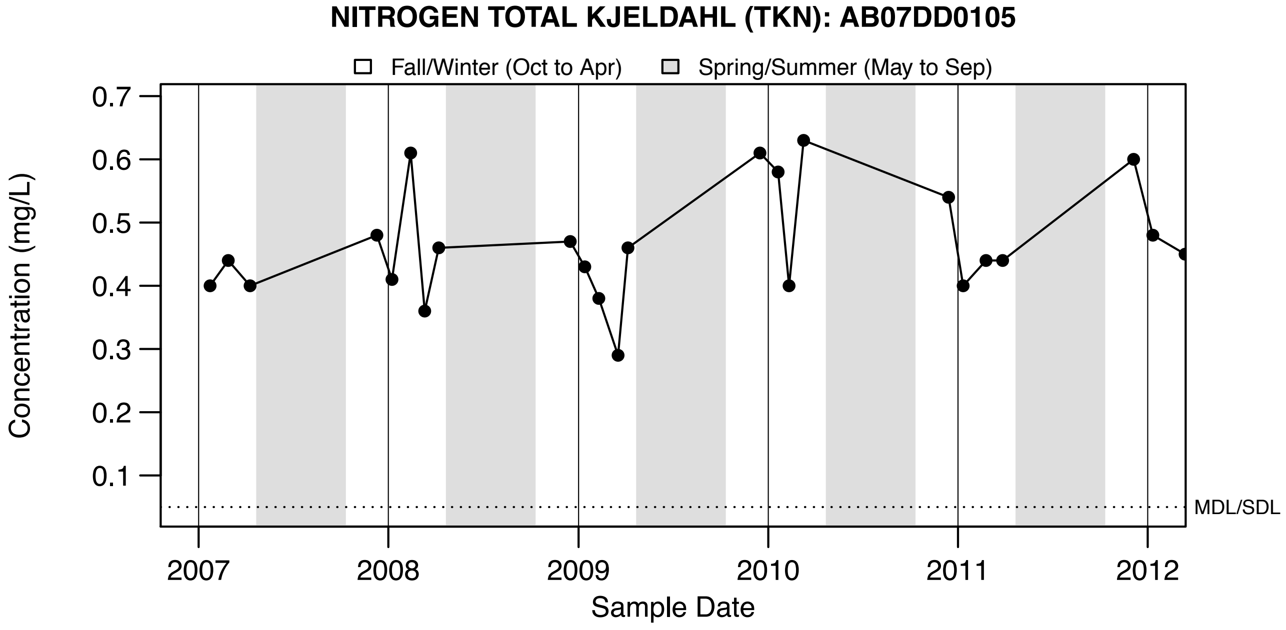
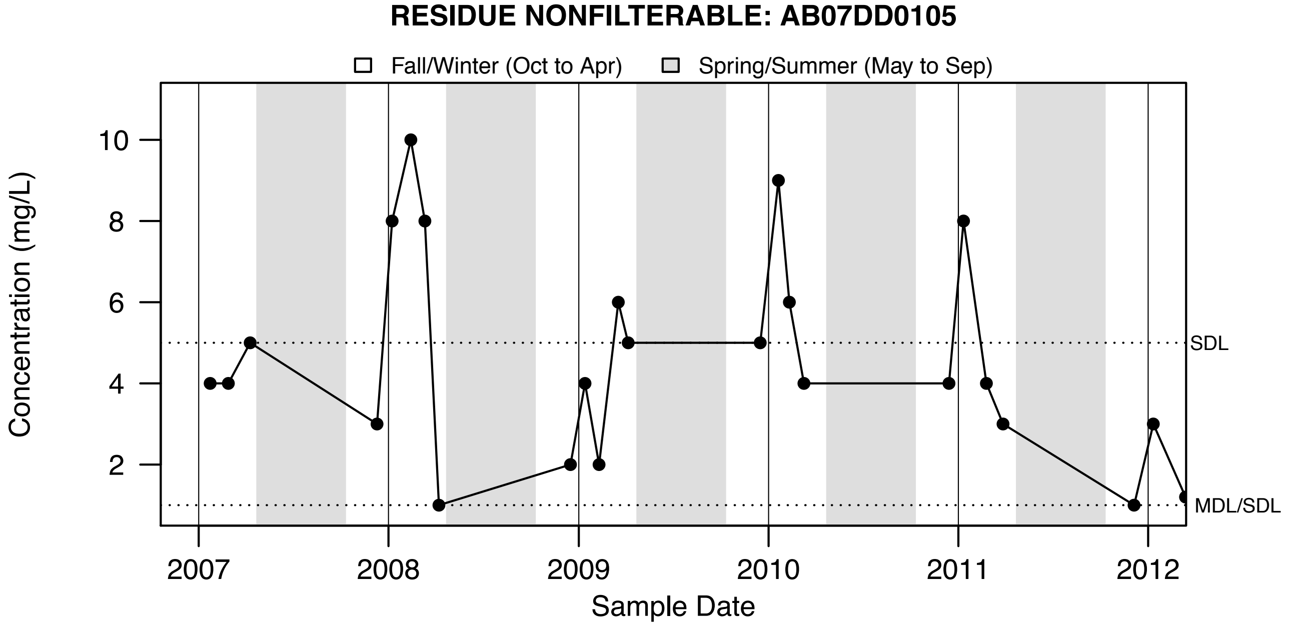


Figure A1.258: NITROGEN TOTAL KJELDAHL (TKN): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A1.259: RESIDUE NONFILTERABLE: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

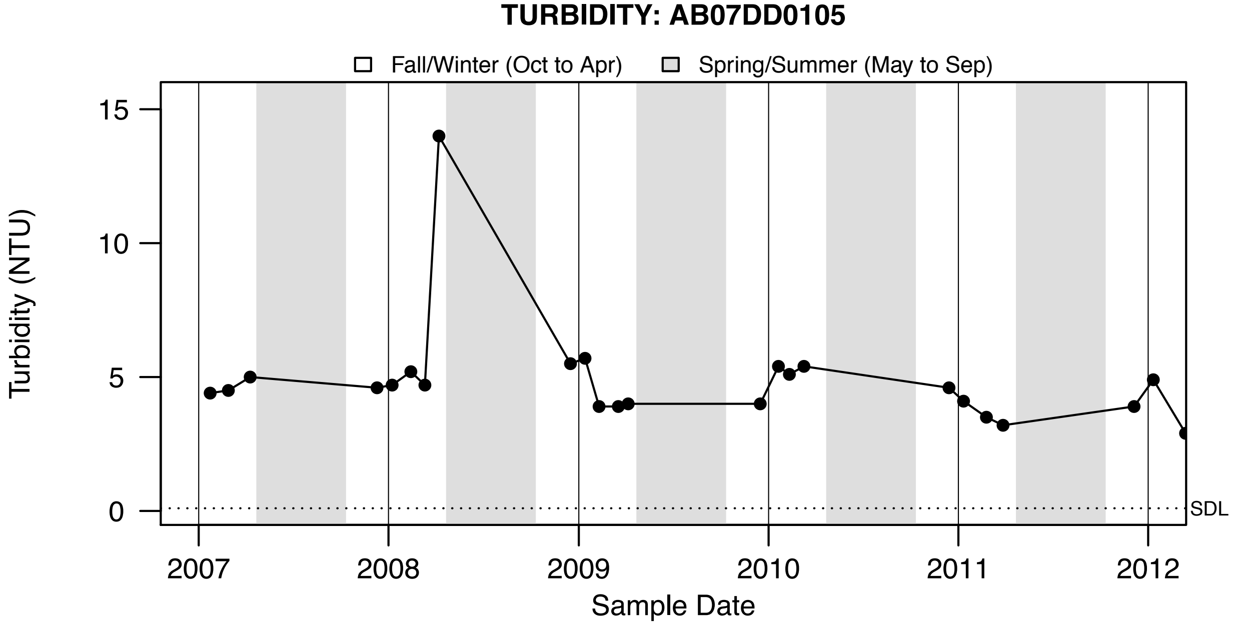


Figure A1.260: TURBIDITY: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

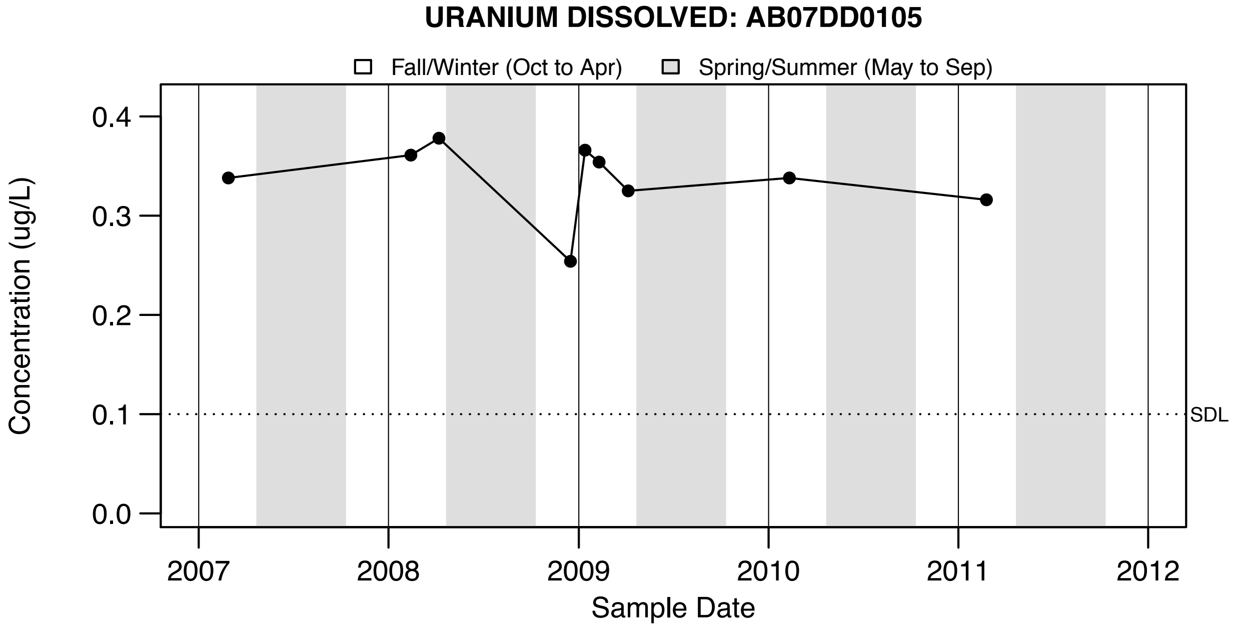


Figure A1.261: URANIUM DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

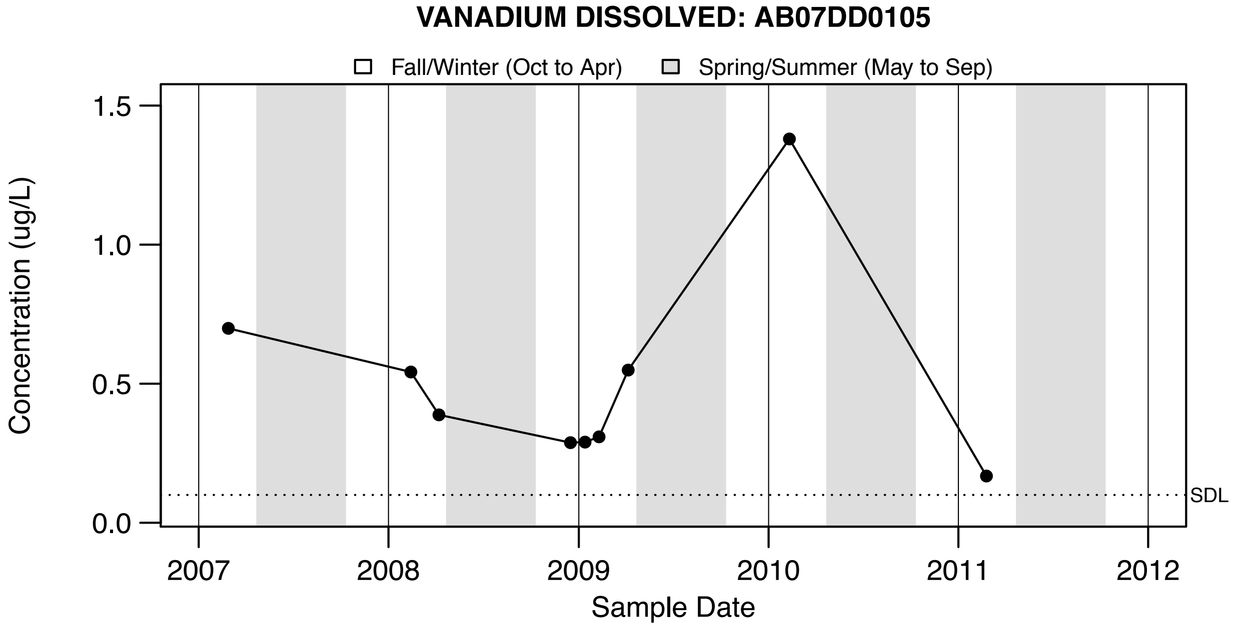


Figure A1.262: VANADIUM DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

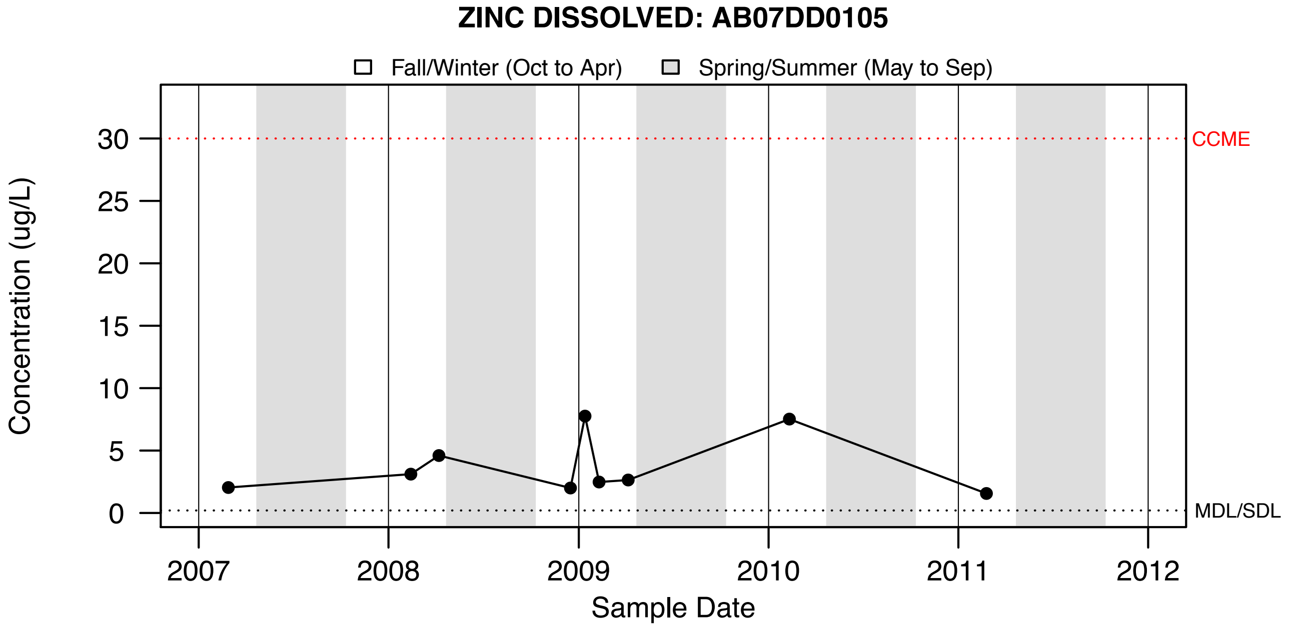


Figure A1.263: ZINC DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING

Appendix 2:

Overview of select water quality parameters measured at
Medium-term River Network (MTRN) sites between 2007 and spring of 2012

List of Abbreviations

AB Acute: Alberta provincial surface water quality acute guideline value

AB Chronic: Alberta provincial surface water quality chronic guideline value

CCME: Canadian Council of Ministers of the Environment Guideline Value for the Protection of Aquatic Life

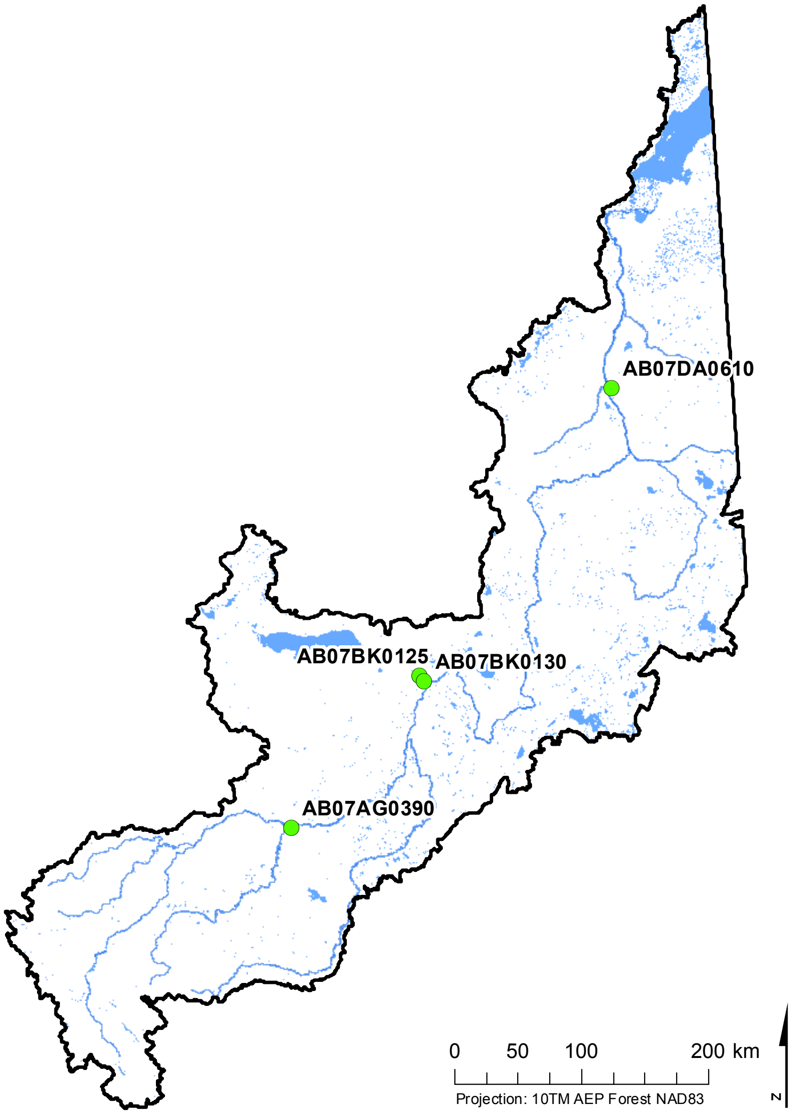
MDL: Method detection limit

MTRN: Medium-term River Network

SDL: Sample detection limit

Table A2-1. Station number, description, and location of Medium-term River Network (MTRN) stations evaluated as part of the Phase 3 State of the Watershed Assessment.

Station Code	Station Description	Latitude	Longitude
AB07AG0390	Mcleod River at Whitecourt - Highway #43 bridge right bank	54.1361	-115.6958
AB07BK0125	Lesser Slave River - 9.5 km upstream of Athabasca River confluence	55.2067	-114.1225
AB07BK0130	Lesser Slave River at confluence with Athabasca River above the town of Smith Mouth: km 794.0	55.1658	-114.0619
AB07DA0610	Muskeg River at WSC gauge downstream of Kearl Lake Road	57.1917	-111.5681



List of Figures

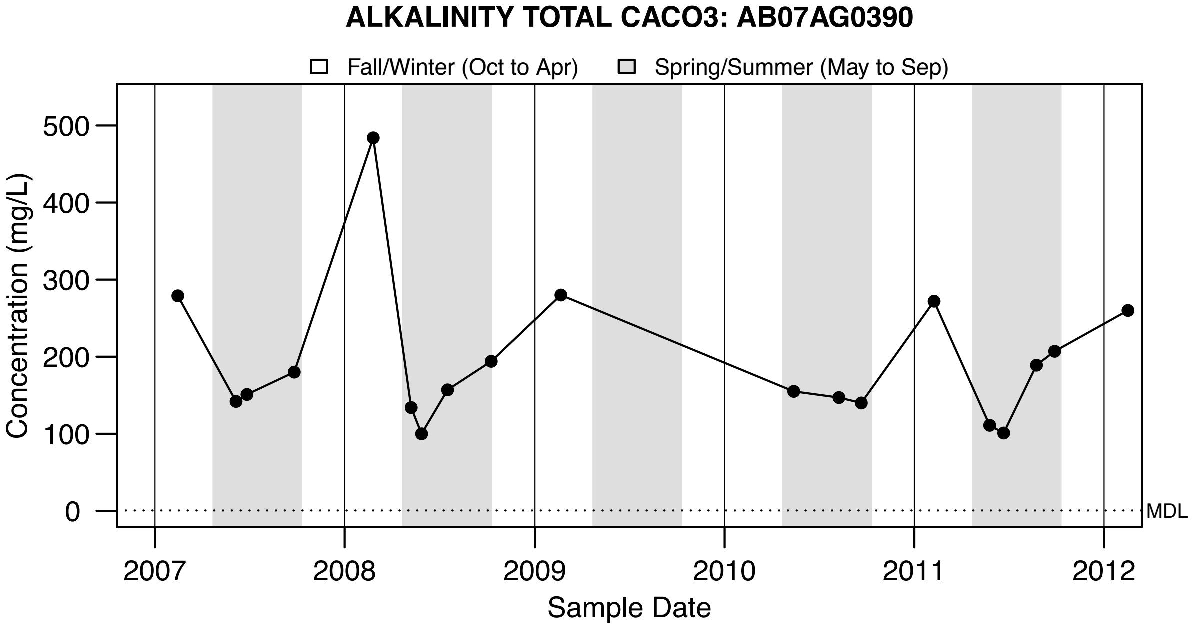


Figure A2.1: ALKALINITY TOTAL CACO3: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

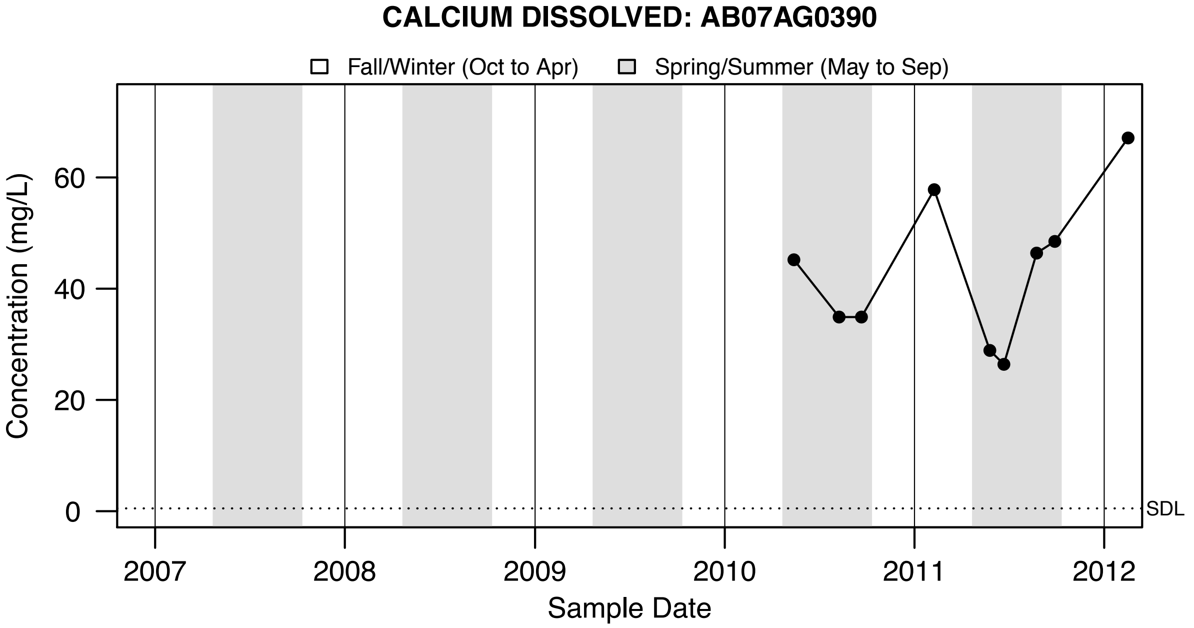


Figure A2.2: CALCIUM DISSOLVED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

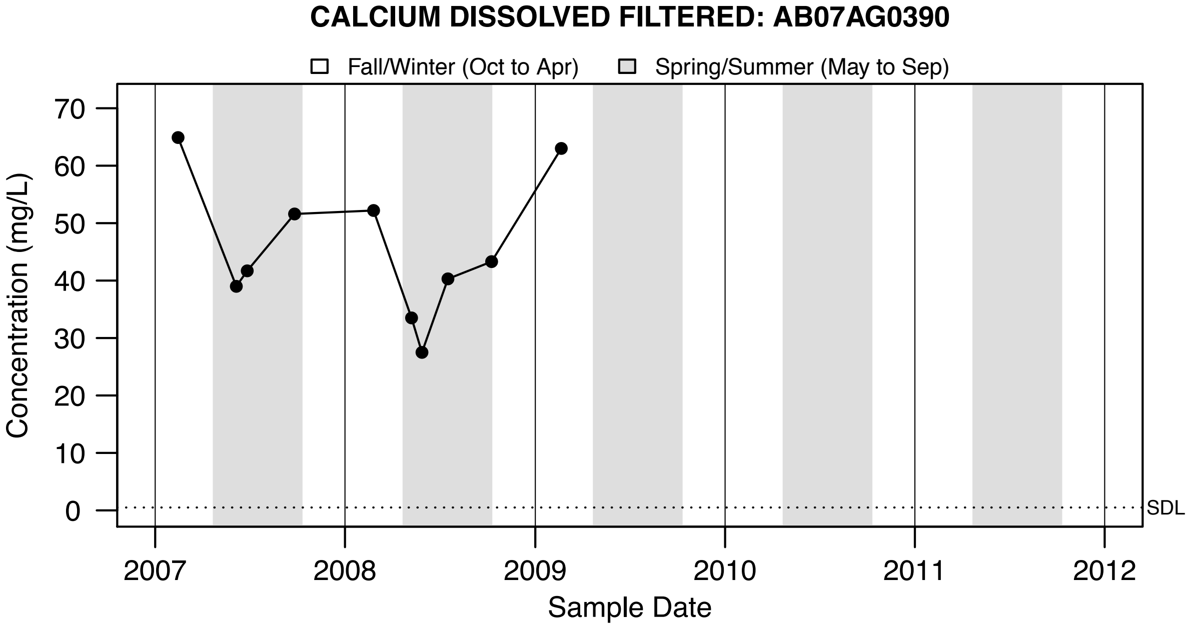


Figure A2.3: CALCIUM DISSOLVED FILTERED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

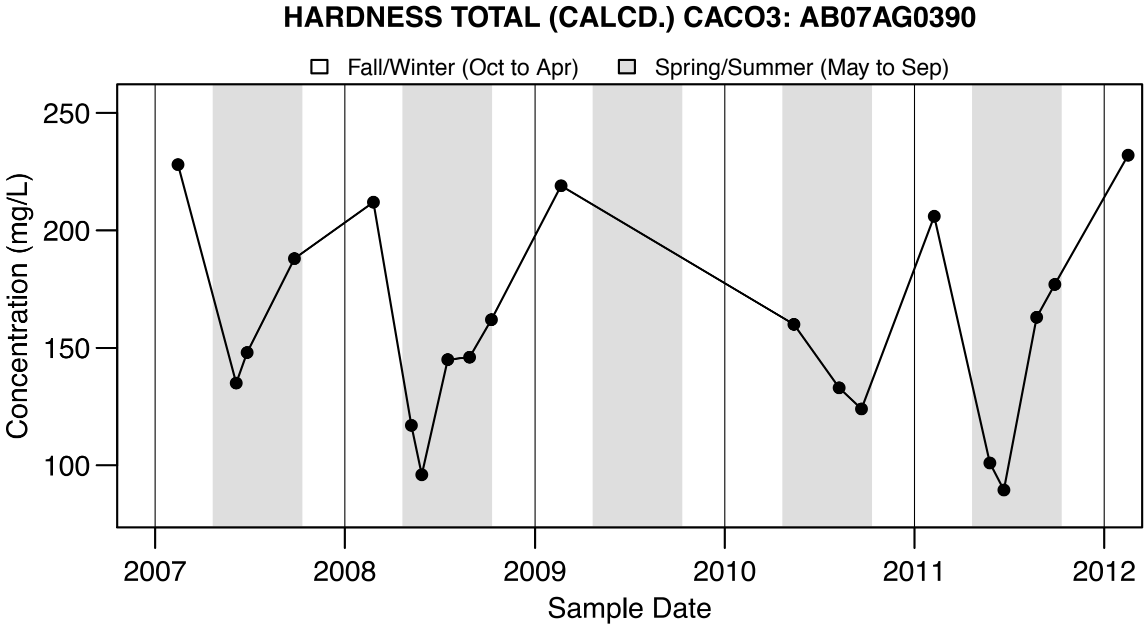


Figure A2.4: HARDNESS TOTAL (CALCD.) CACO3: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

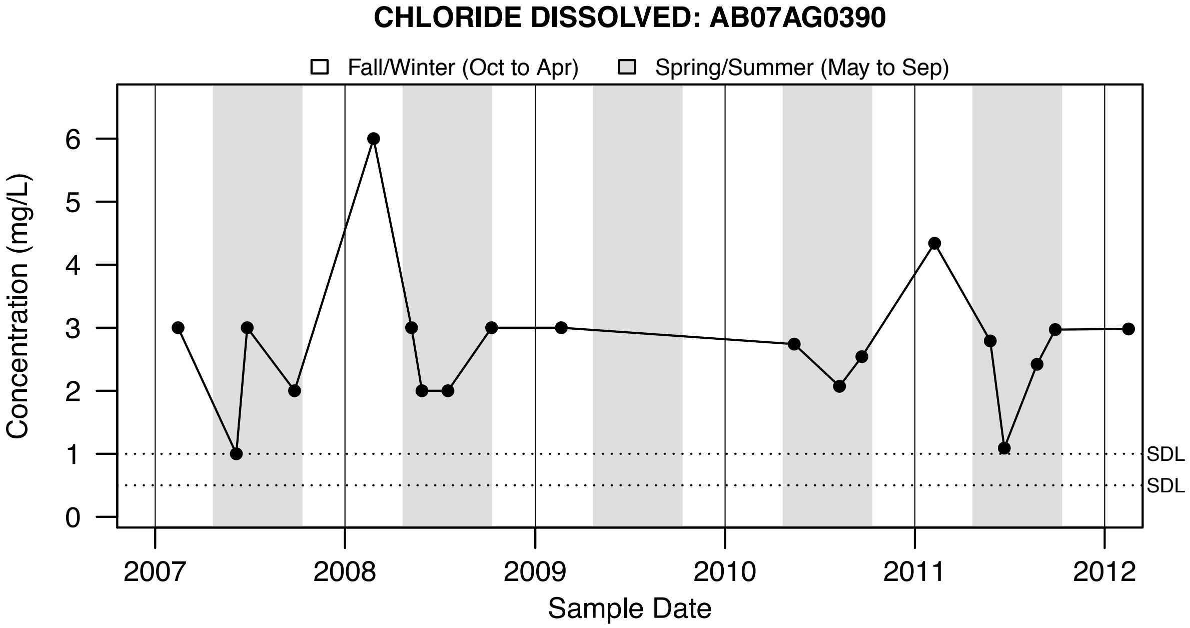


Figure A2.5: CHLORIDE DISSOLVED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

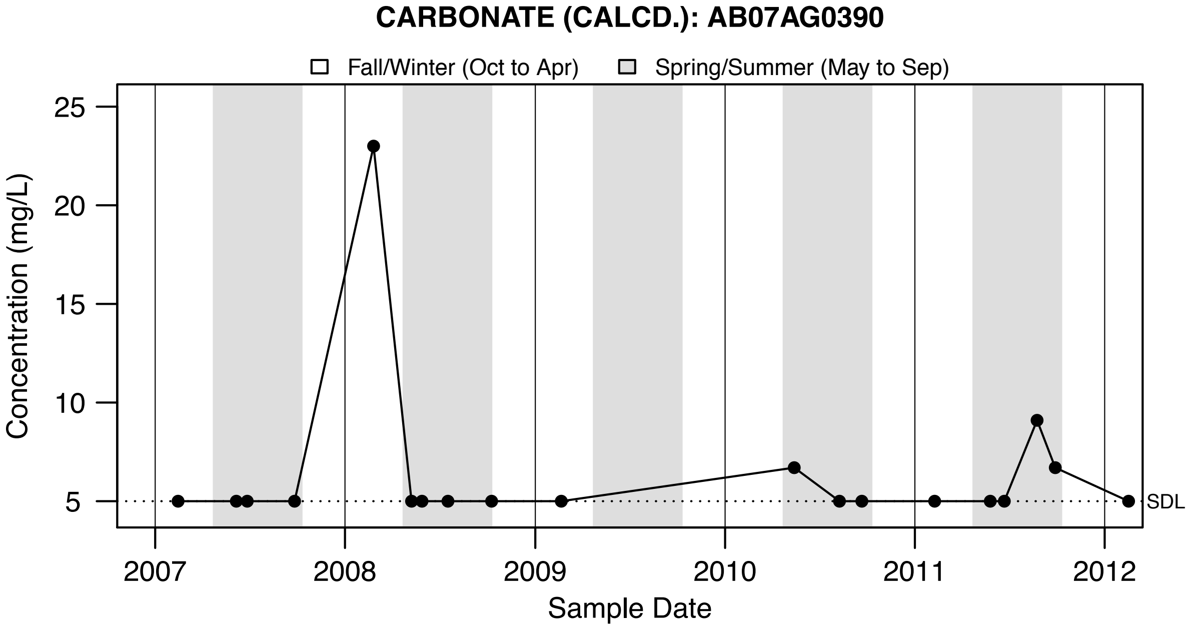


Figure A2.6: CARBONATE (CALCD.): AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

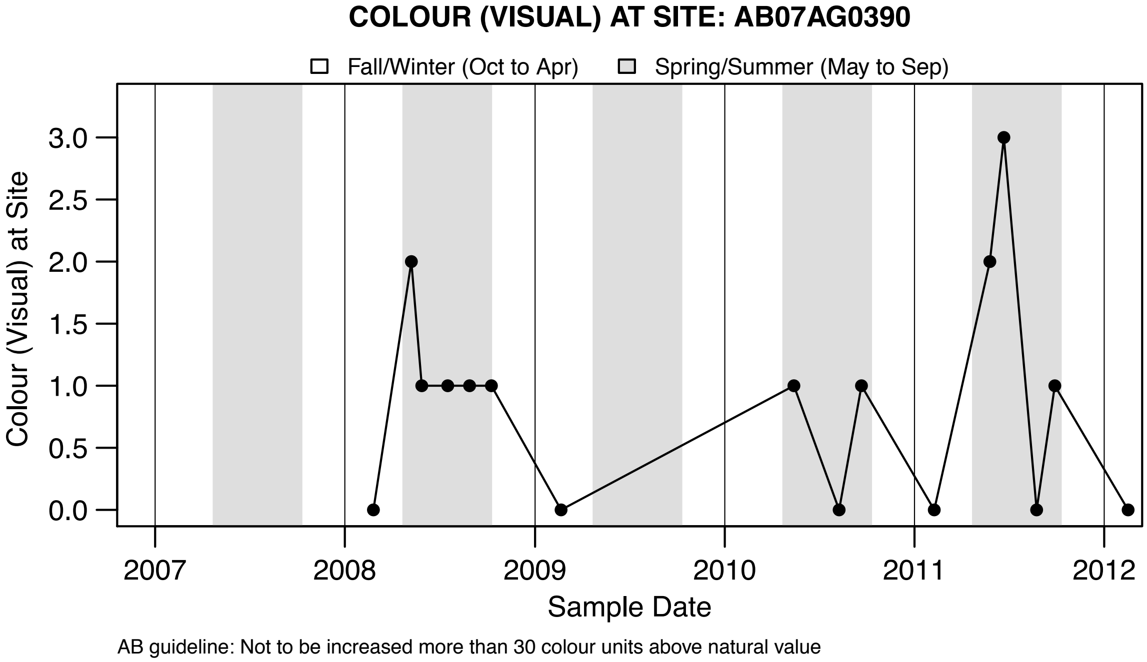


Figure A2.7: COLOUR (VISUAL) AT SITE: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

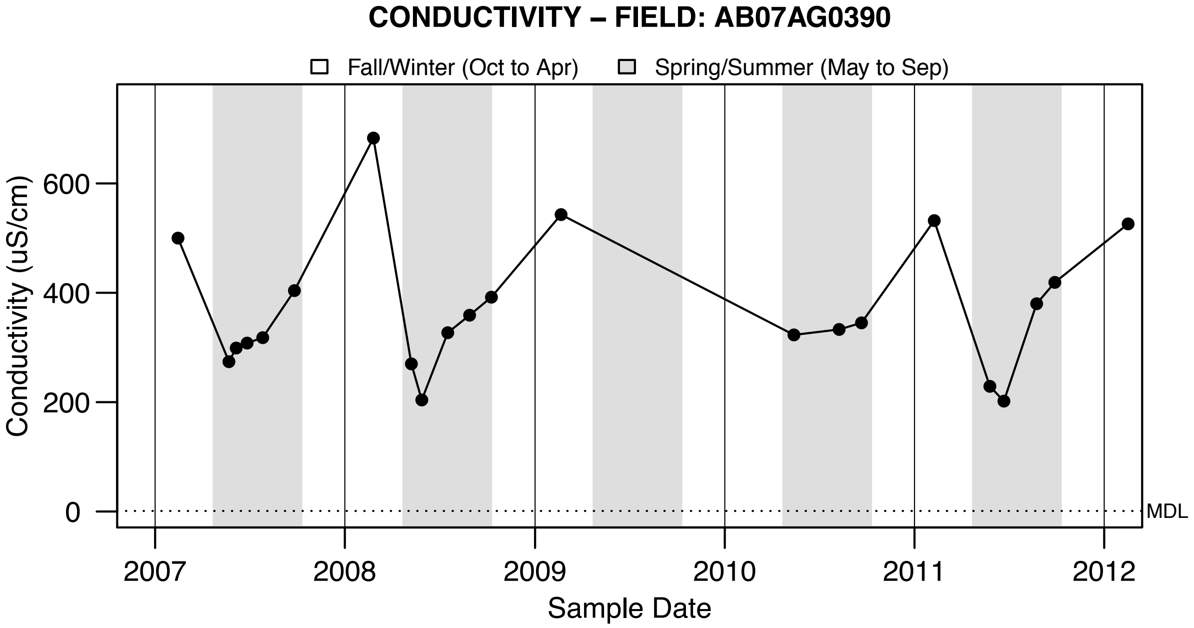


Figure A2.8: CONDUCTIVITY - FIELD: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

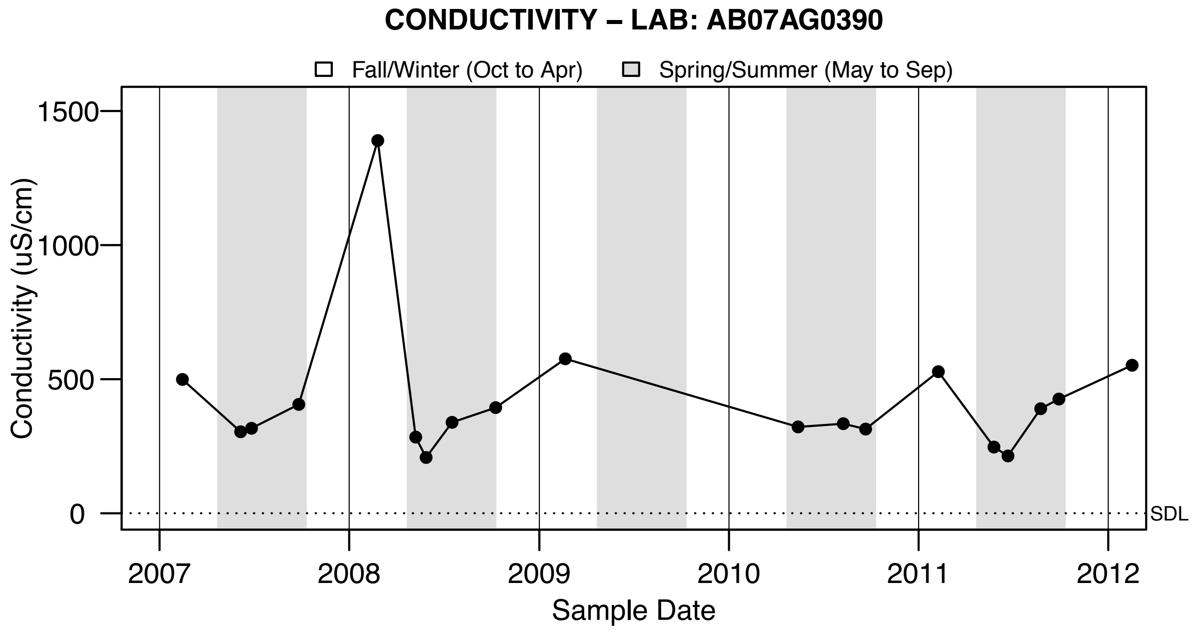


Figure A2.9: CONDUCTIVITY - LAB: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

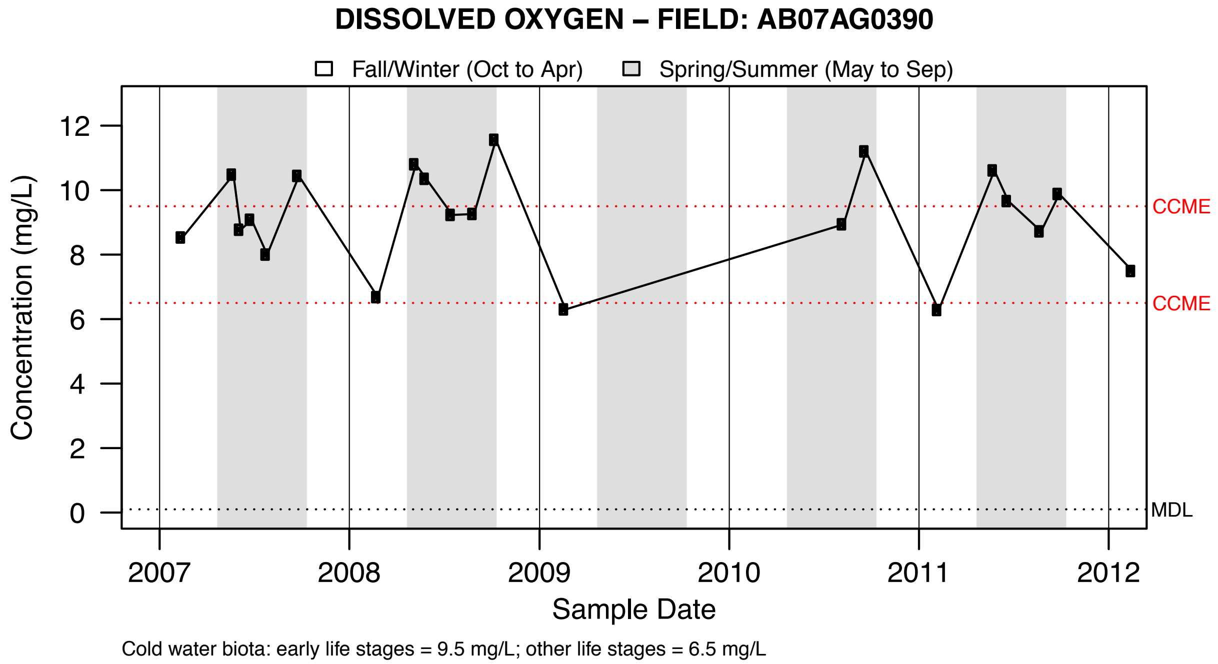


Figure A2.10: DISSOLVED OXYGEN - FIELD: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

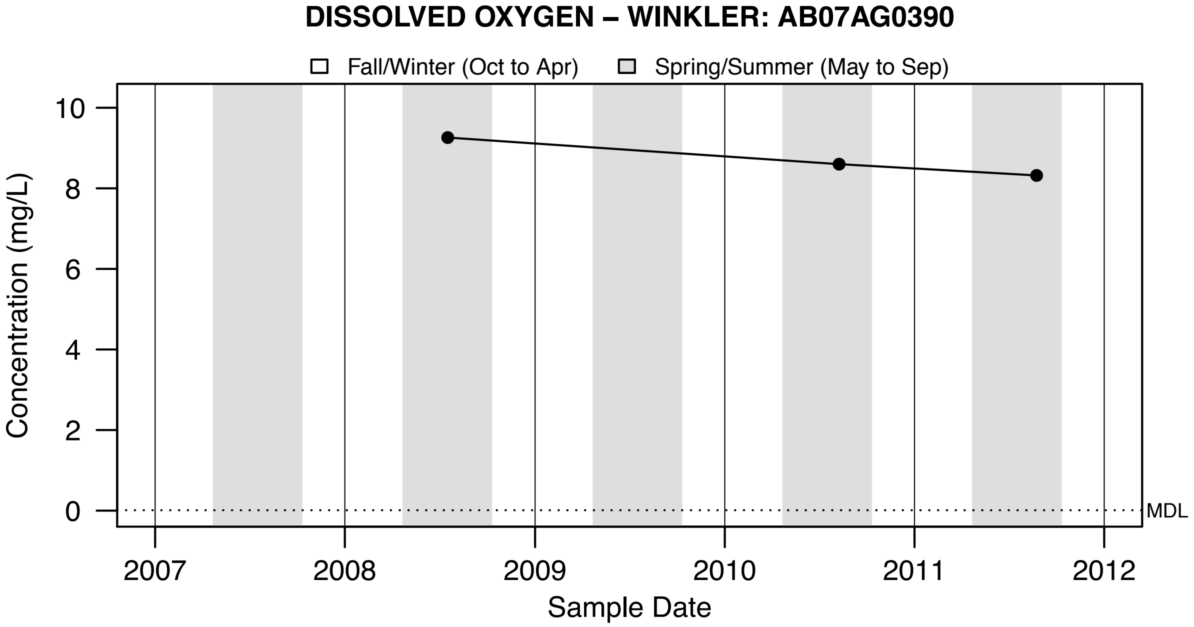


Figure A2.11: DISSOLVED OXYGEN - WINKLER: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

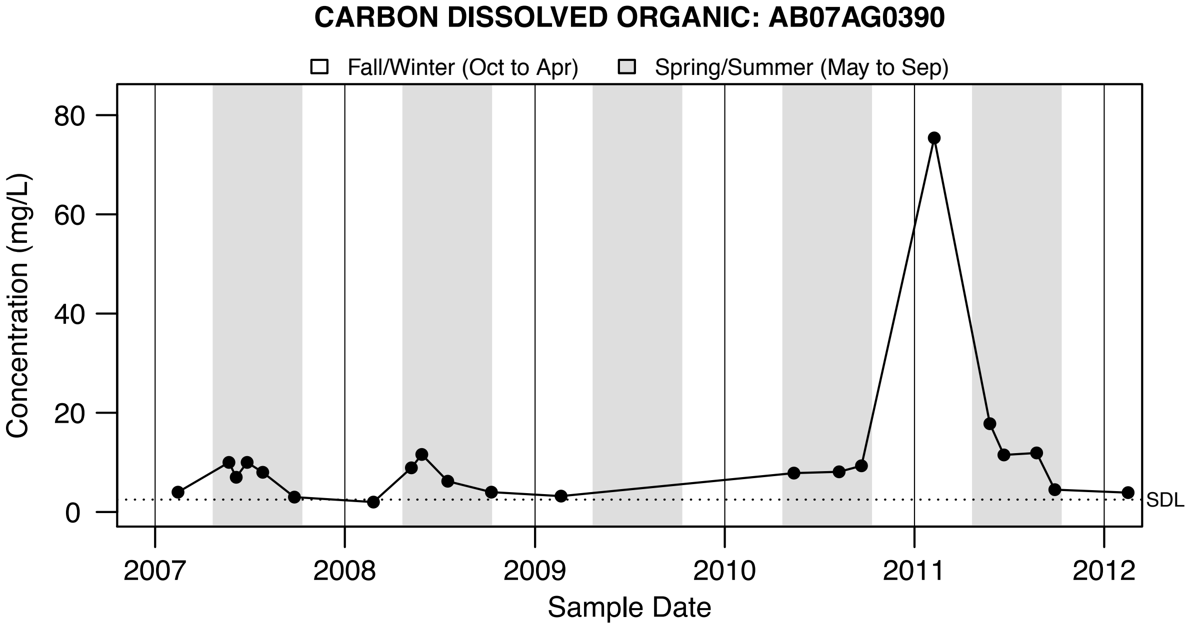


Figure A2.12: CARBON DISSOLVED ORGANIC: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

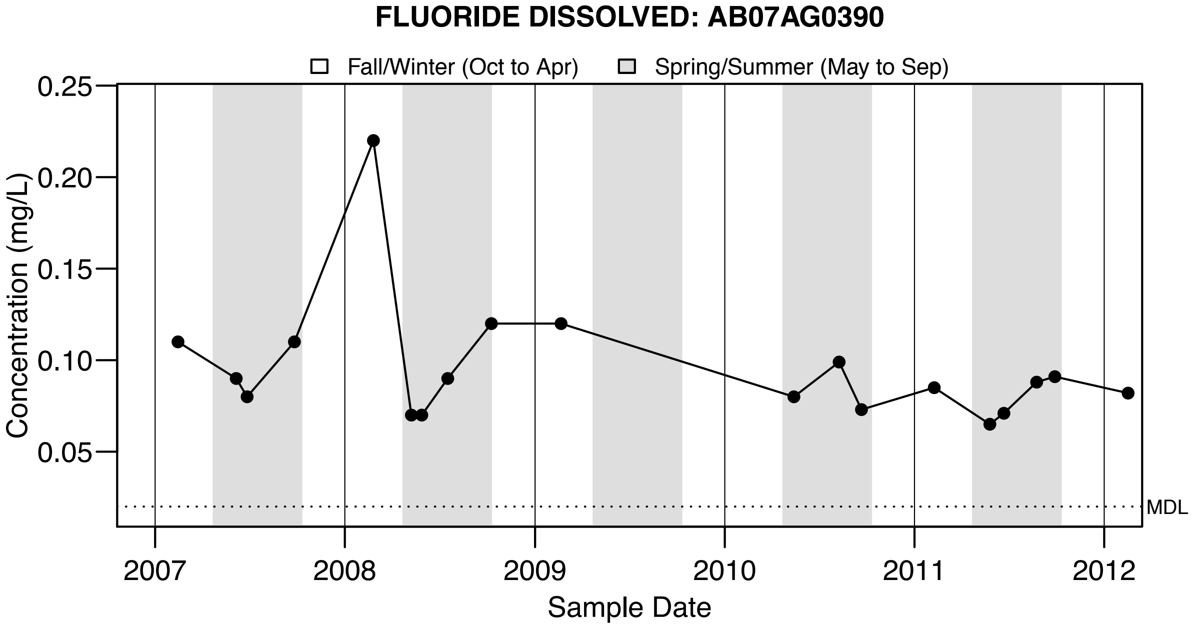


Figure A2.13: FLUORIDE DISSOLVED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

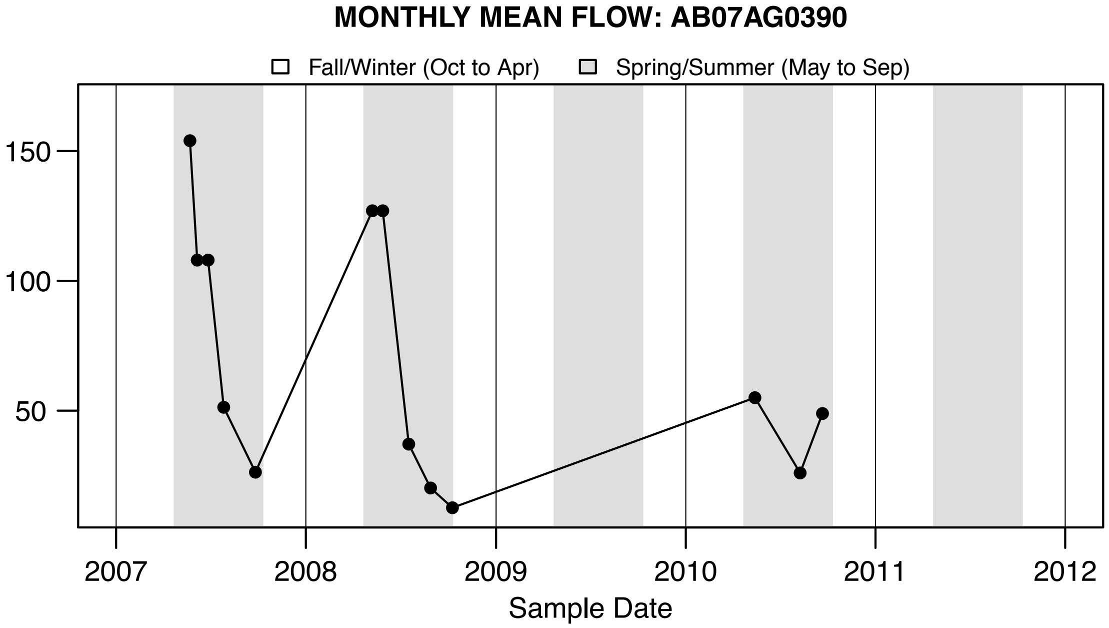


Figure A2.14: MONTHLY MEAN FLOW: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

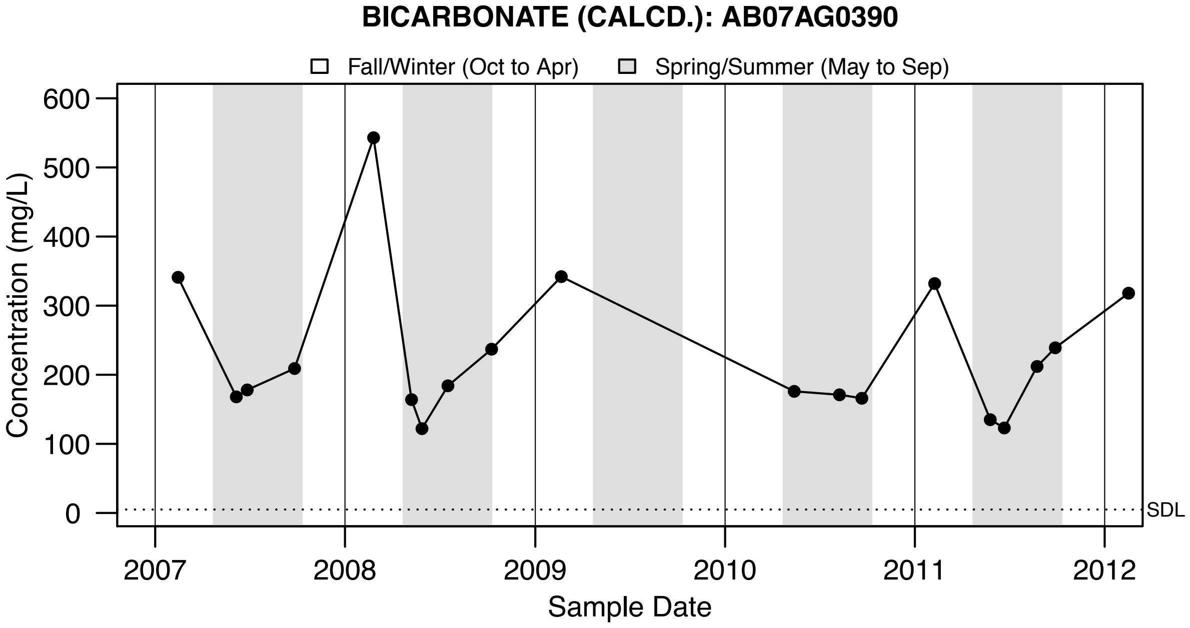


Figure A2.15: BICARBONATE (CALCD.): AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

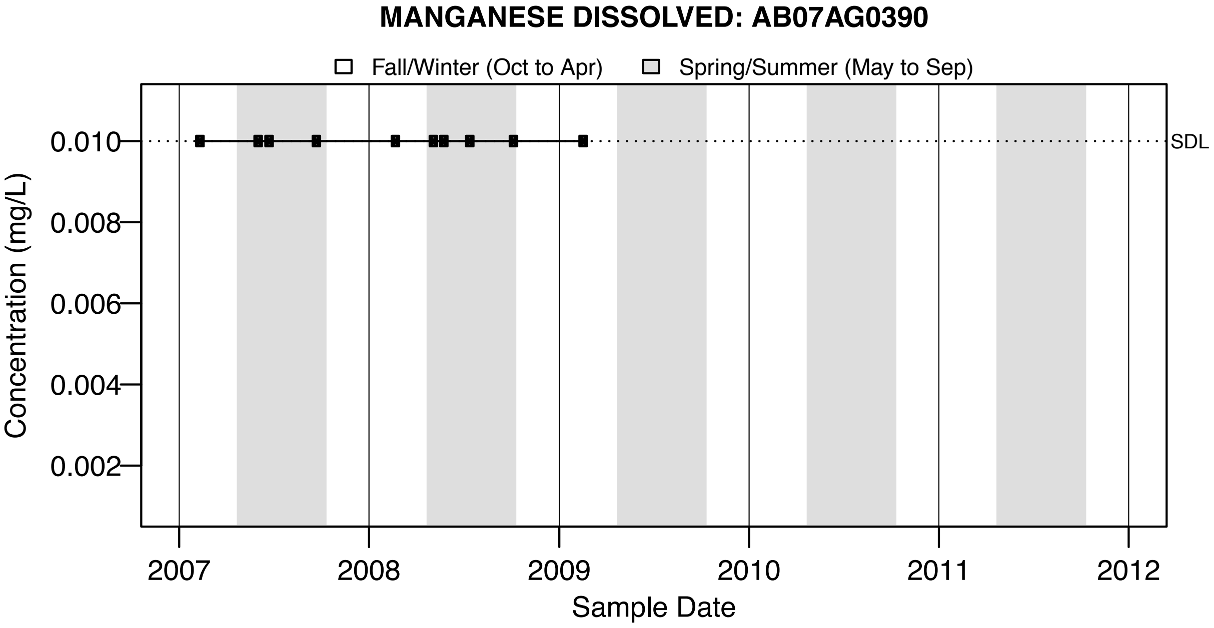


Figure A2.16: MANGANESE DISSOLVED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

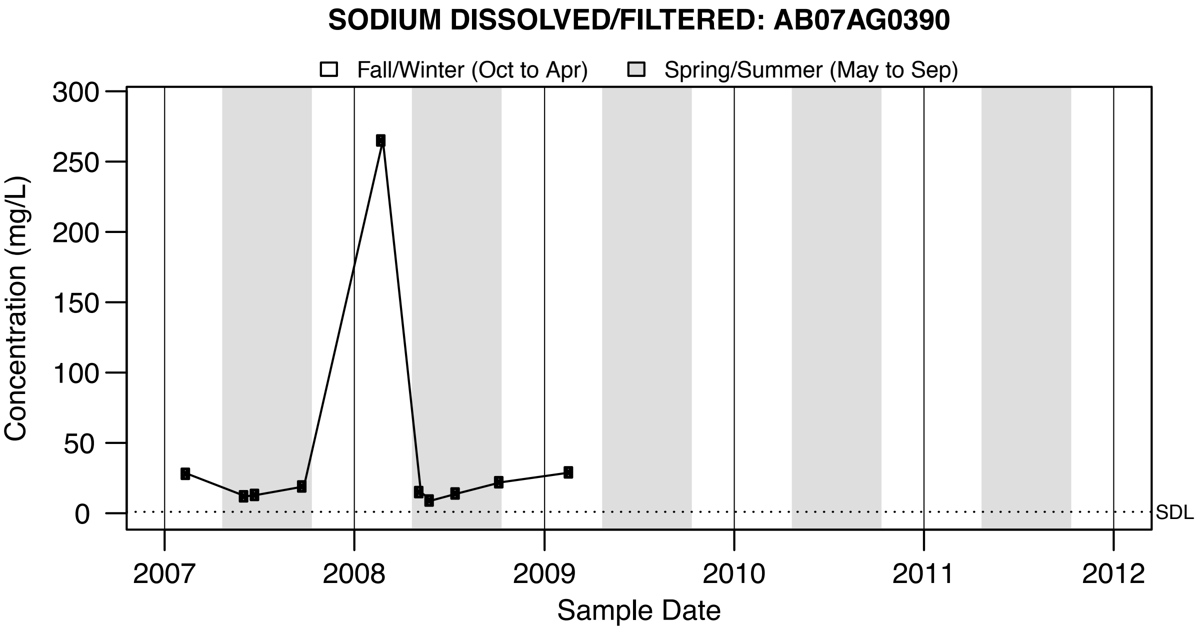


Figure A2.17: SODIUM DISSOLVED/FILTERED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

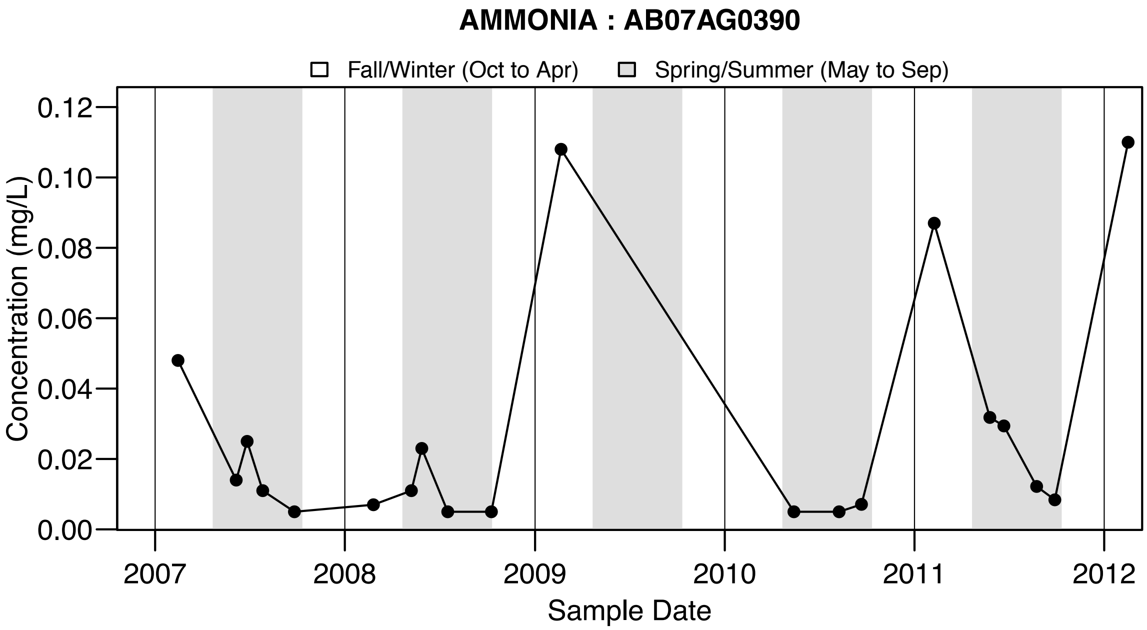


Figure A2.18: AMMONIA : AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

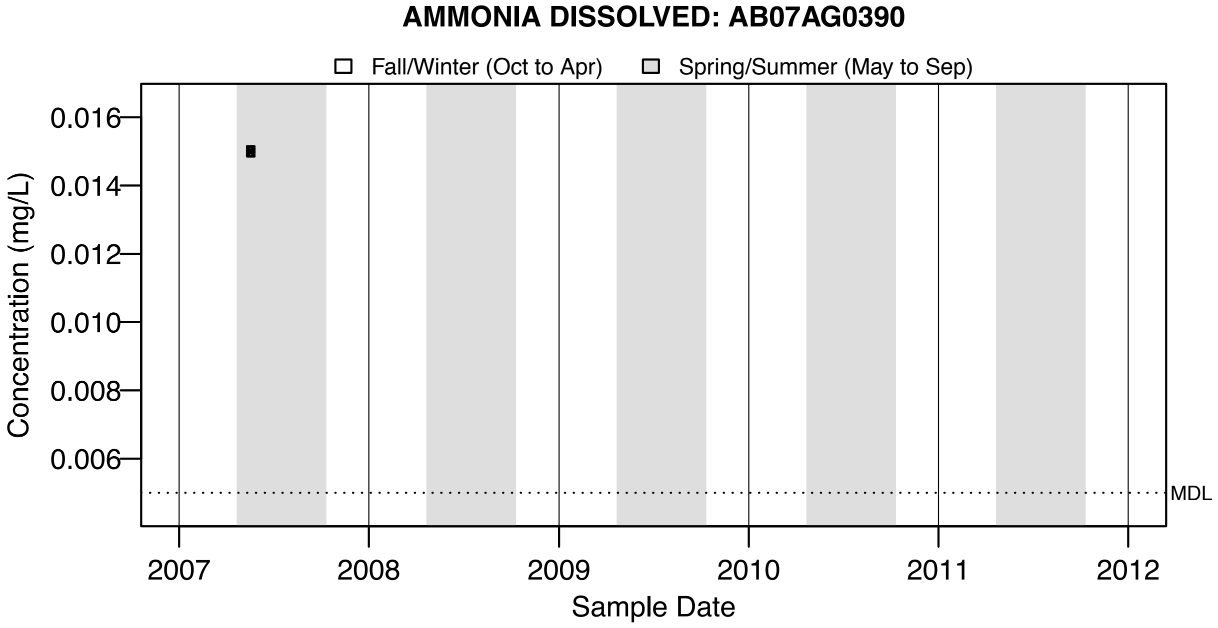


Figure A2.19: AMMONIA DISSOLVED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

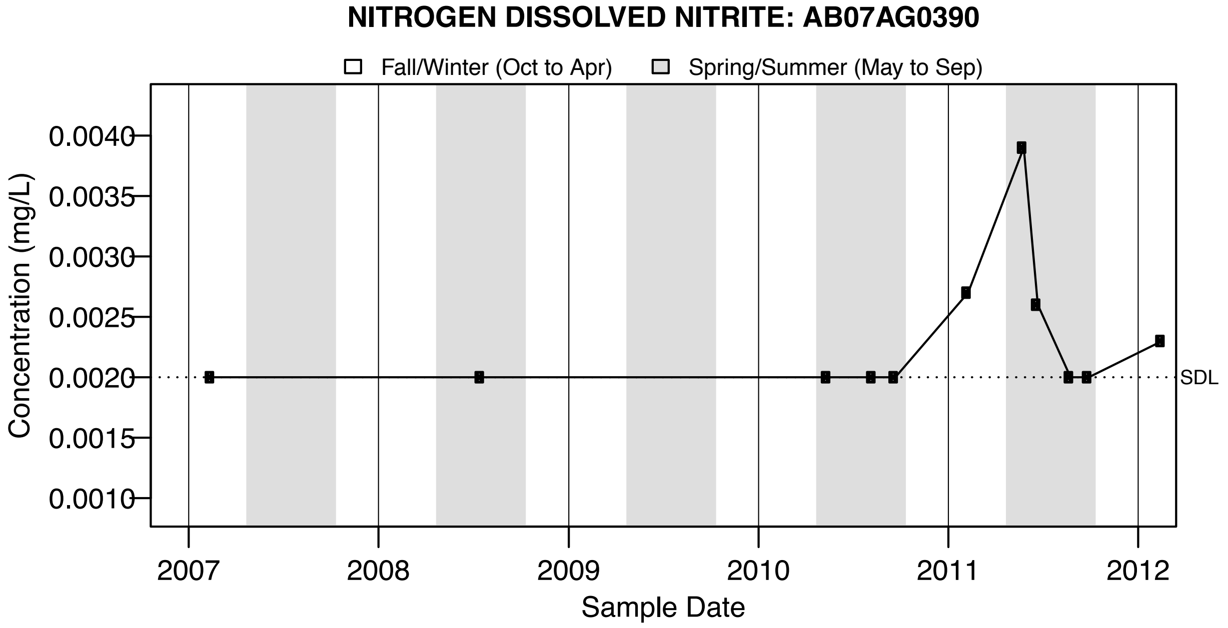


Figure A2.20: NITROGEN DISSOLVED NITRITE: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

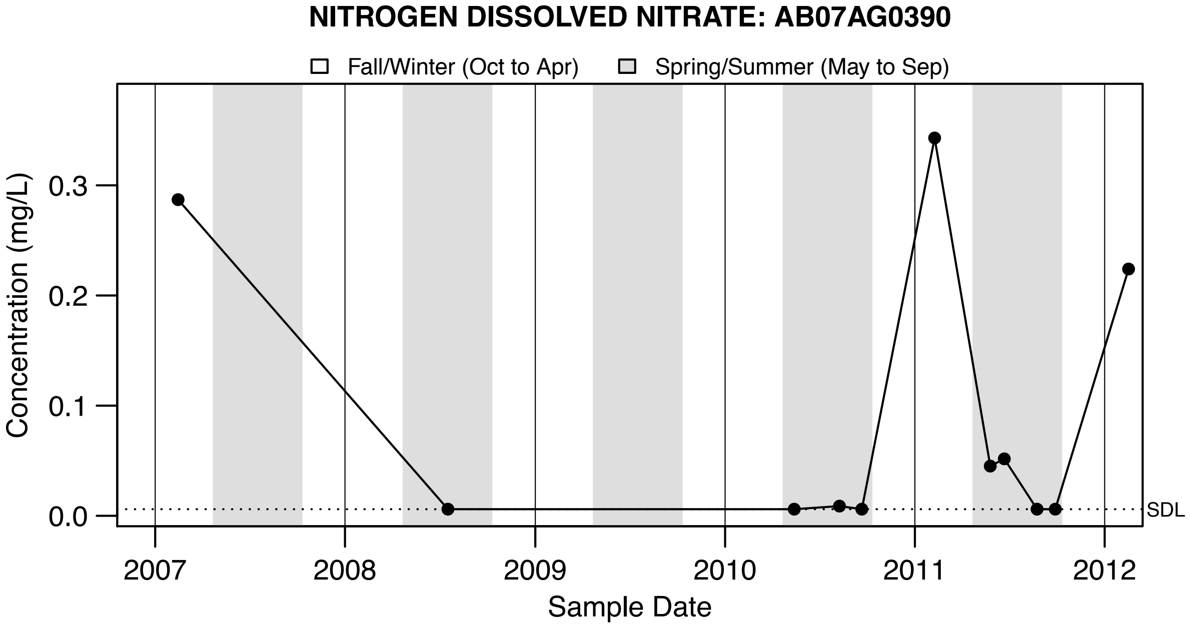


Figure A2.21: NITROGEN DISSOLVED NITRATE: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

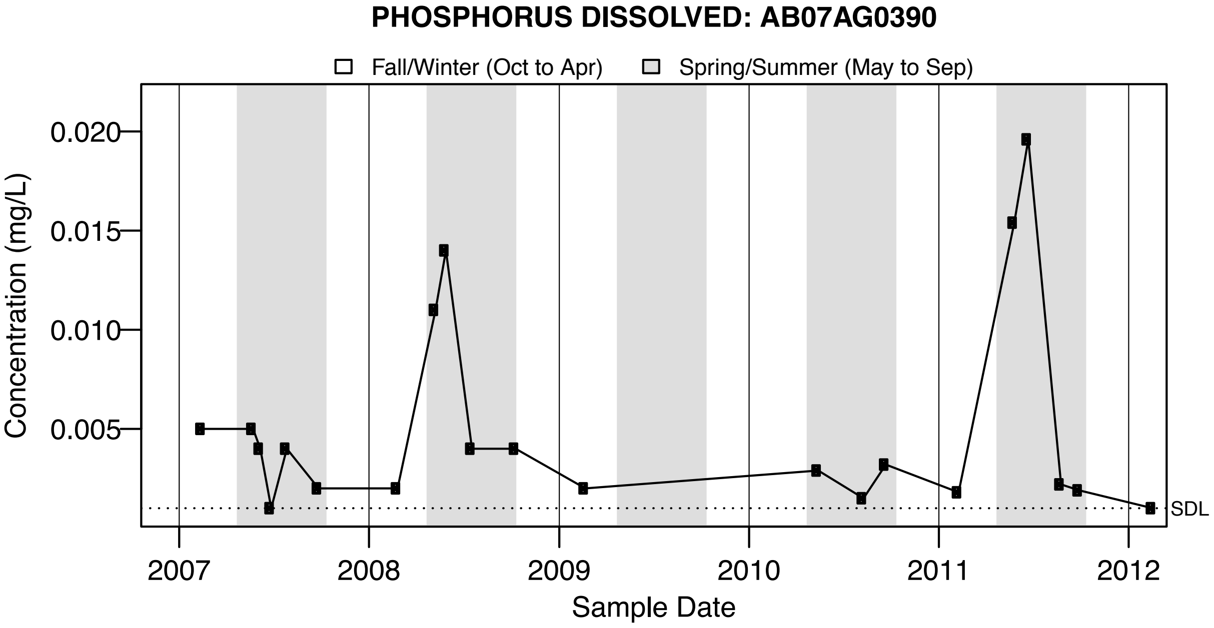


Figure A2.22: PHOSPHORUS DISSOLVED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

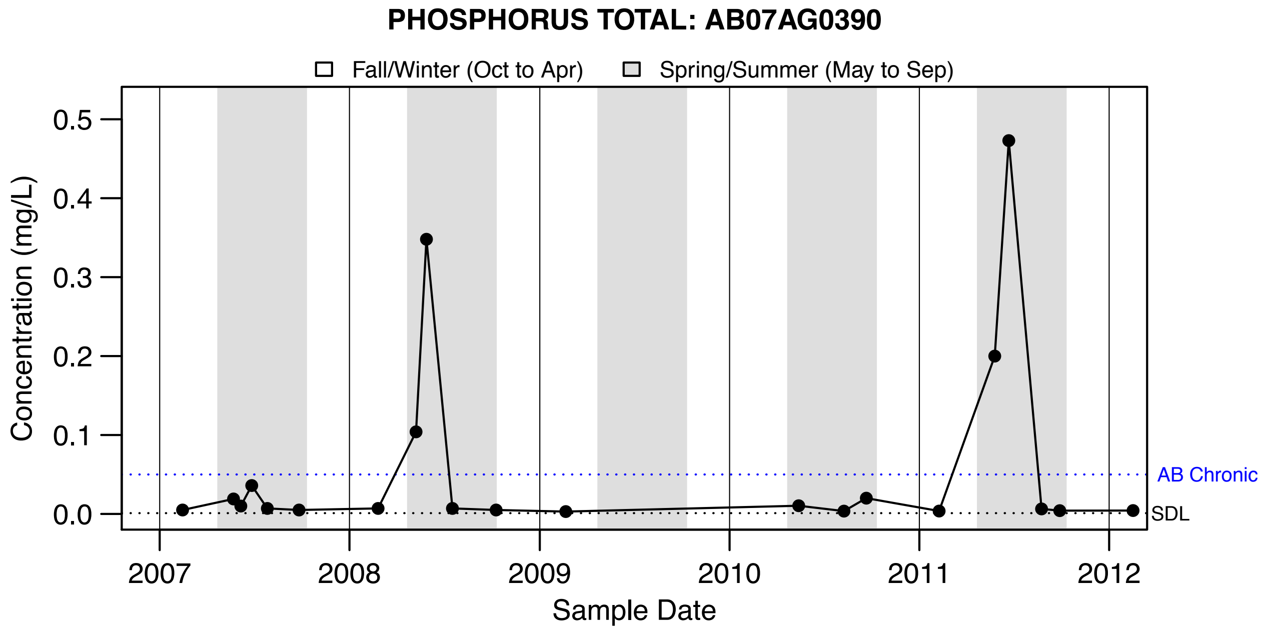


Figure A2.23: PHOSPHORUS TOTAL: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

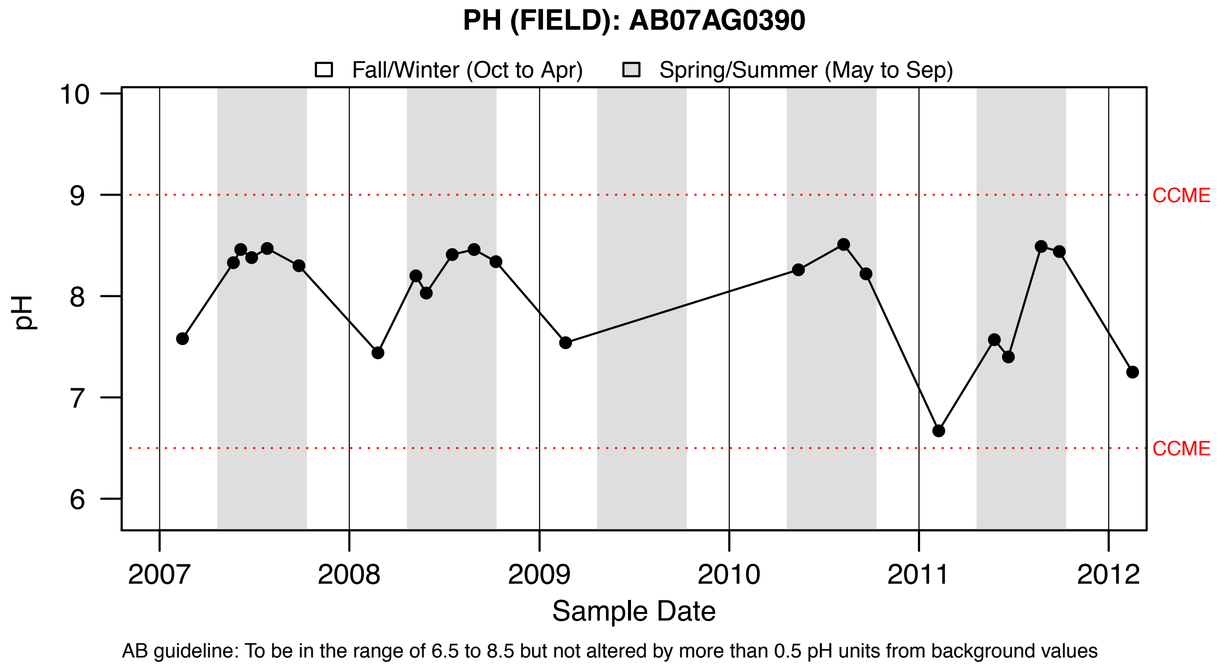


Figure A2.24: PH (FIELD): AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

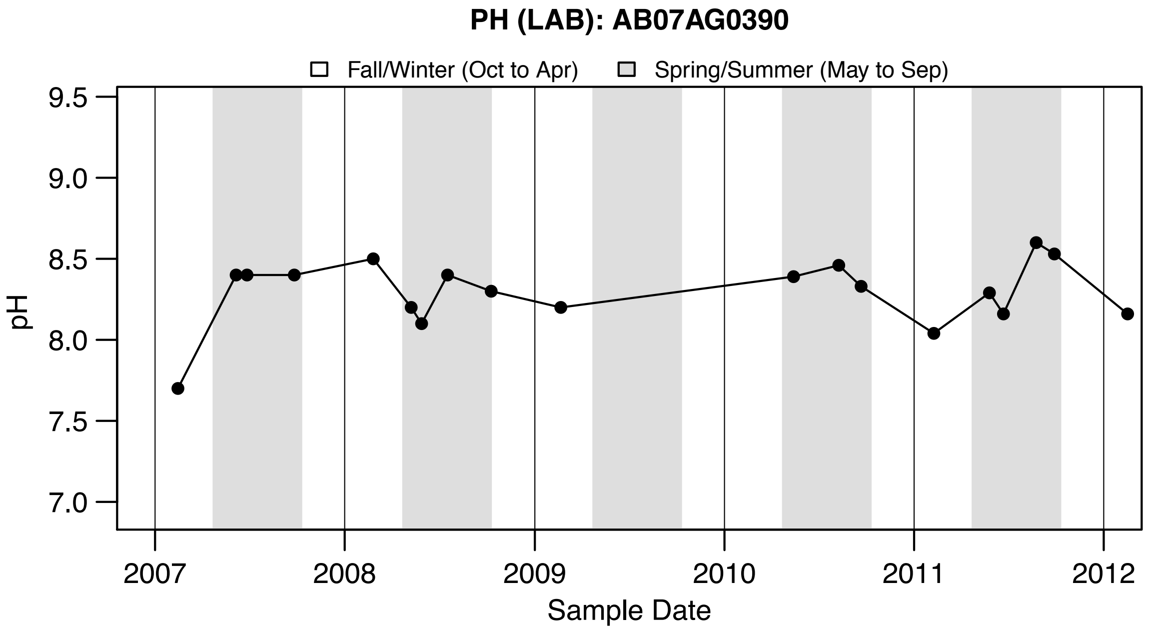


Figure A2.25: PH (LAB): AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

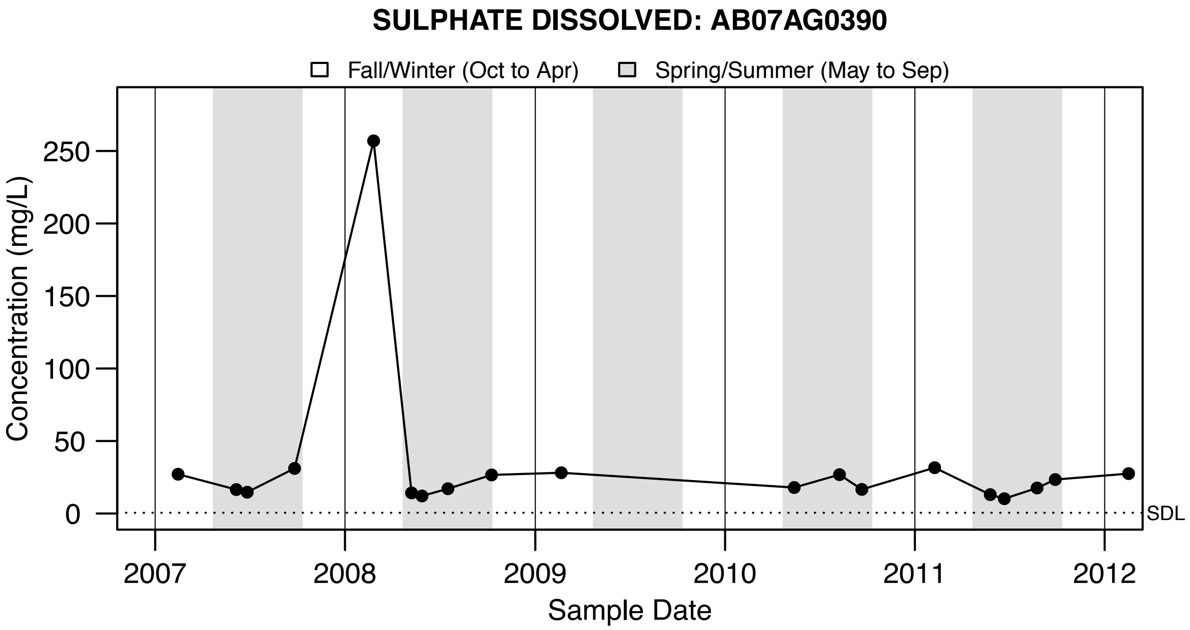


Figure A2.26: SULPHATE DISSOLVED: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

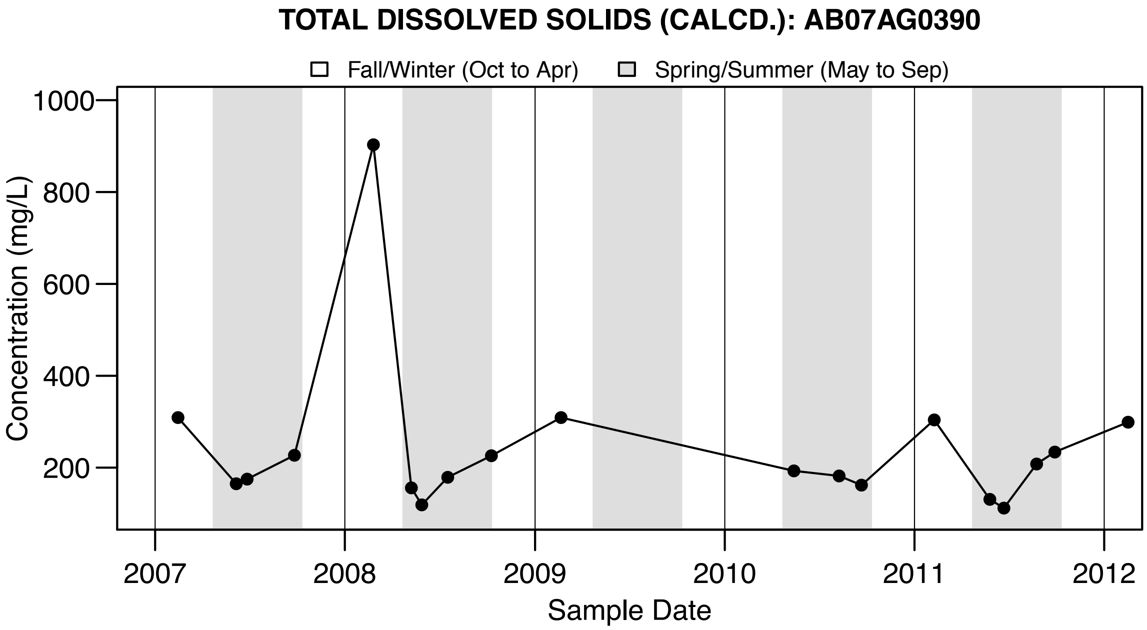
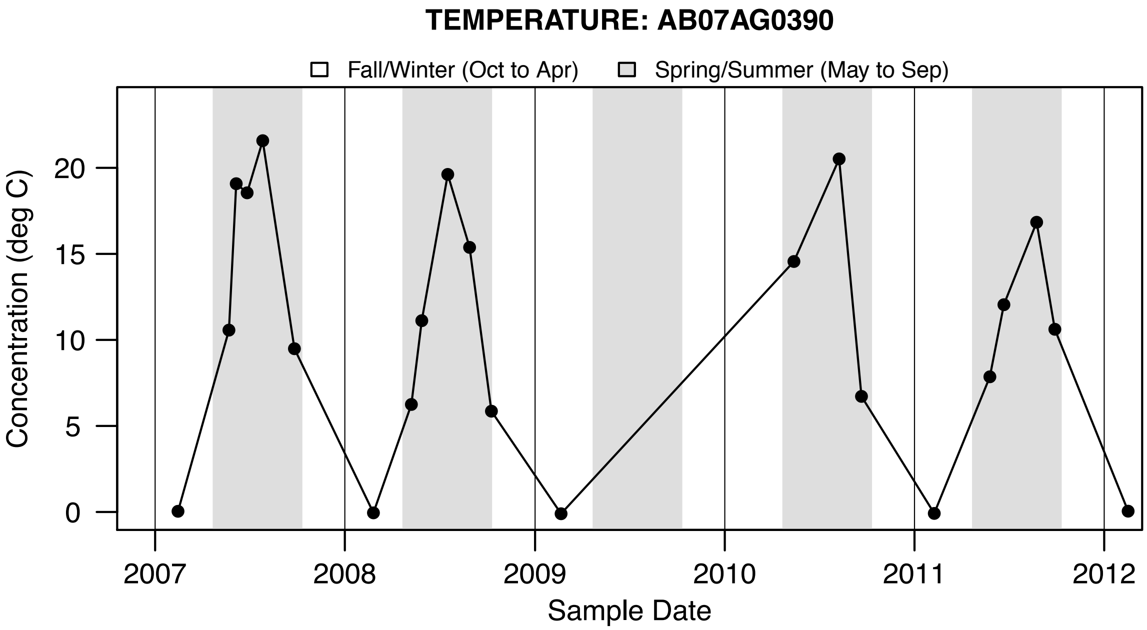


Figure A2.27: TOTAL DISSOLVED SOLIDS (CALCD.): AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A2.28: TEMPERATURE: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

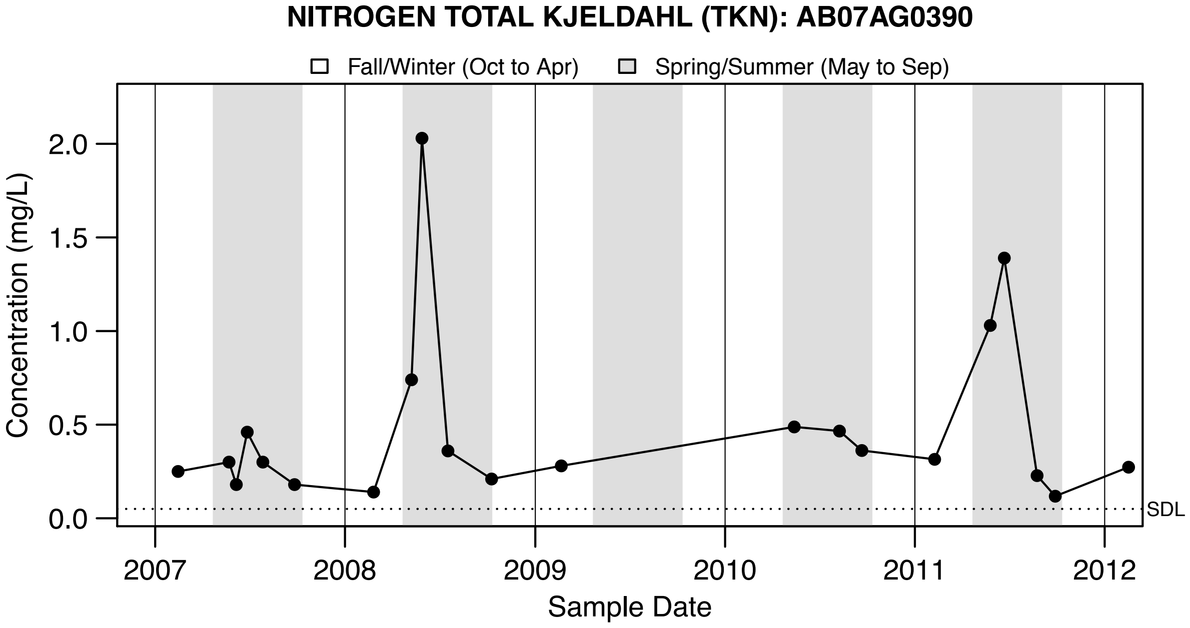
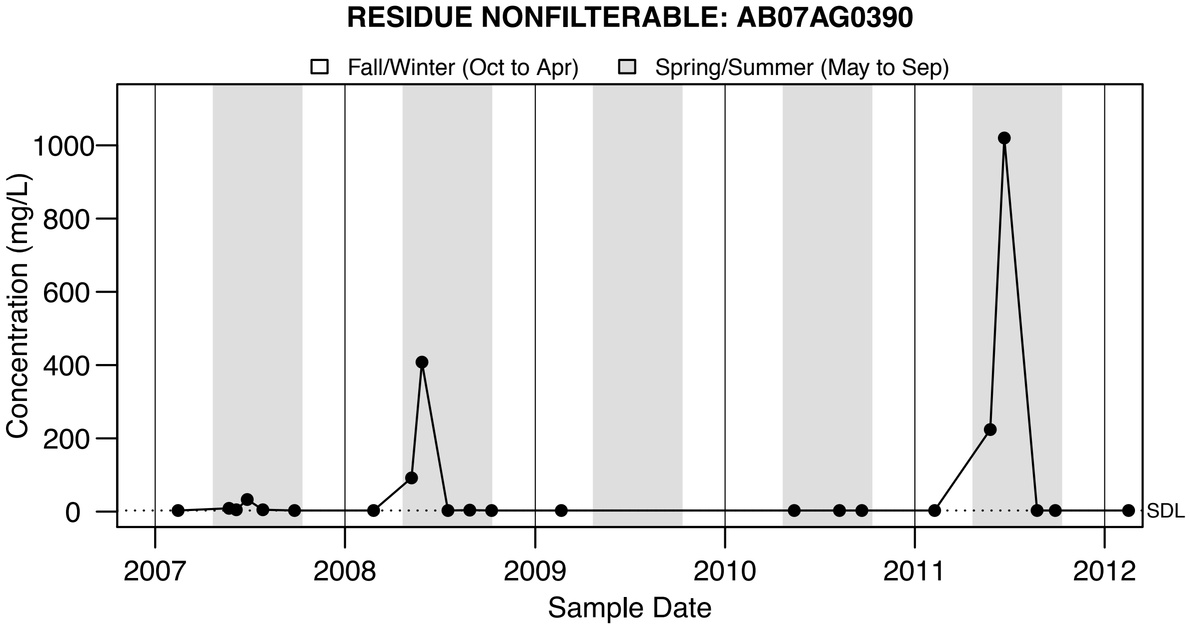


Figure A2.29: NITROGEN TOTAL KJELDAHL (TKN): AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A2.30: RESIDUE NONFILTERABLE: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK

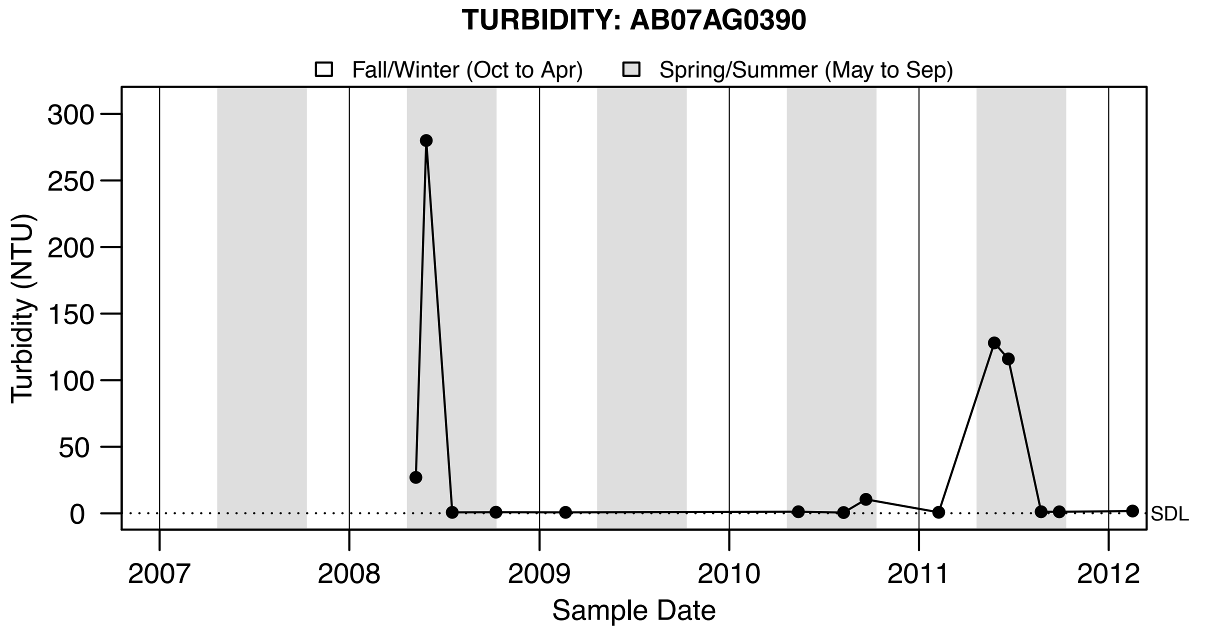
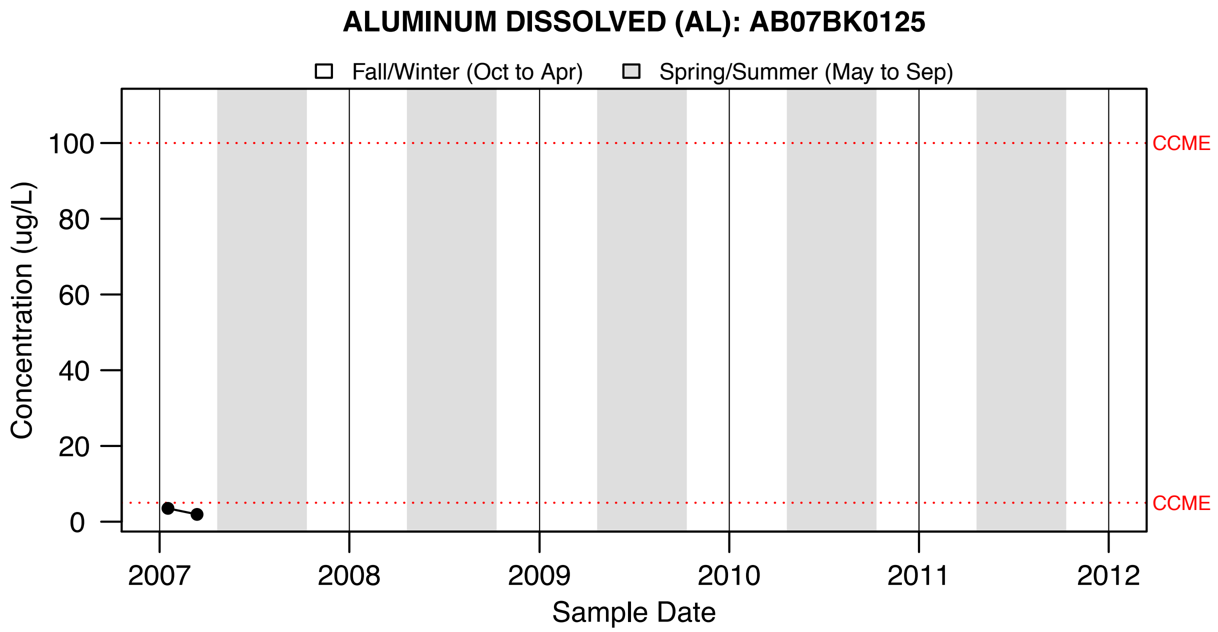
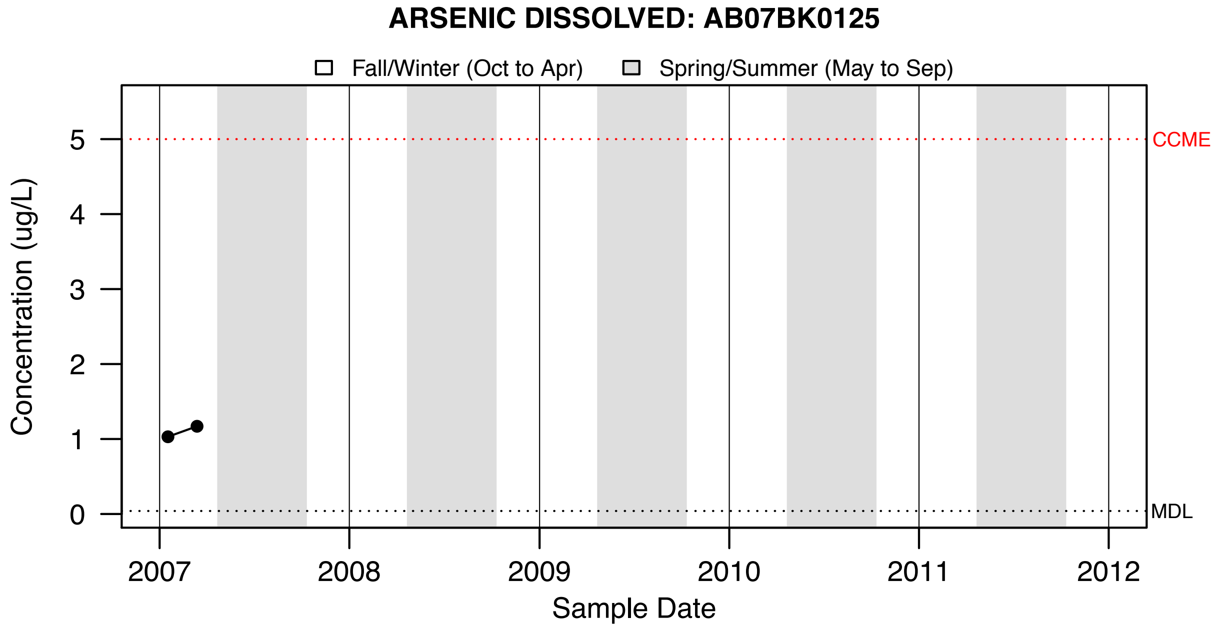


Figure A2.31: TURBIDITY: AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A2.32: ALUMINUM DISSOLVED (AL): AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



AB guidelines state Total Arsenic; CCME does not specify

Figure A2.33: ARSENIC DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

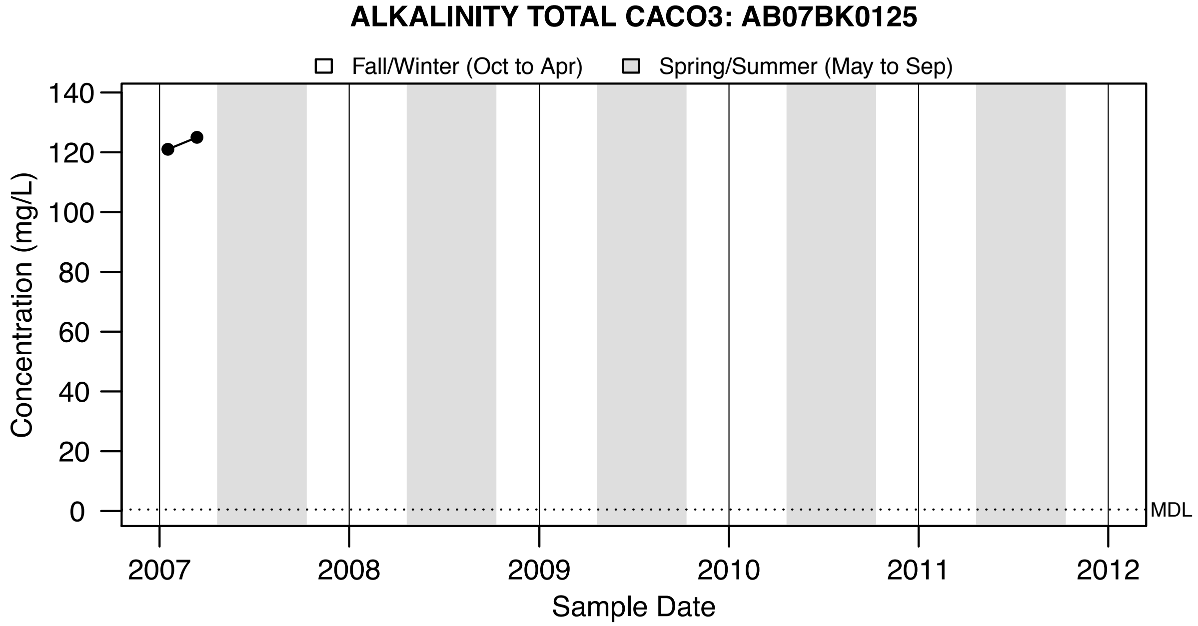


Figure A2.34: ALKALINITY TOTAL CACO3: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

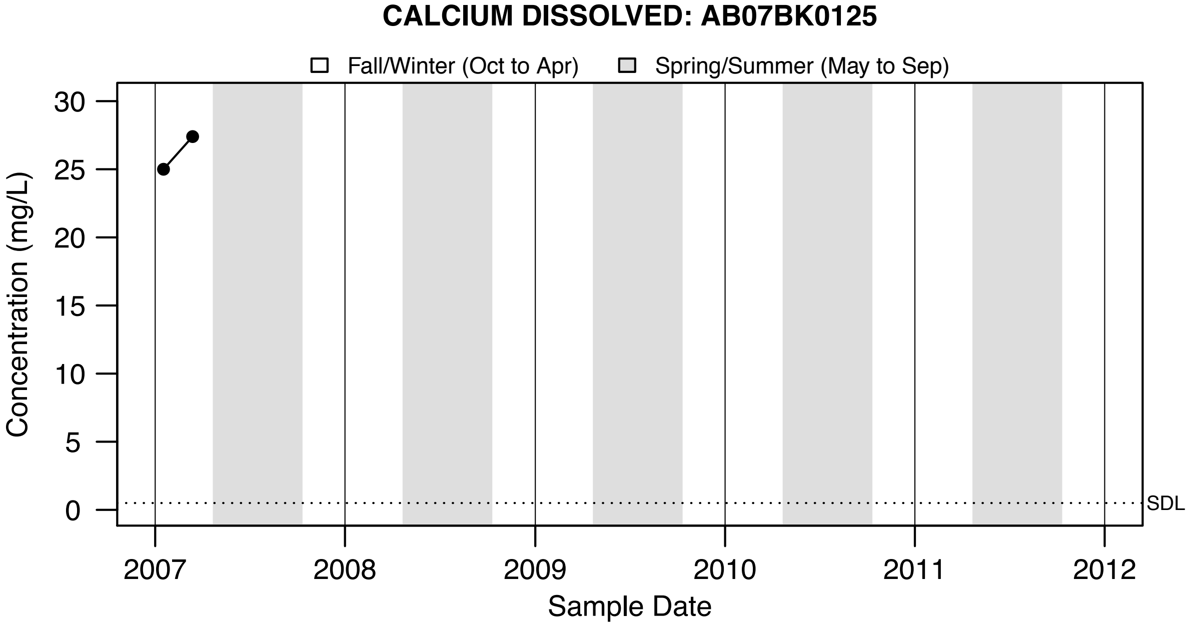


Figure A2.35: CALCIUM DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

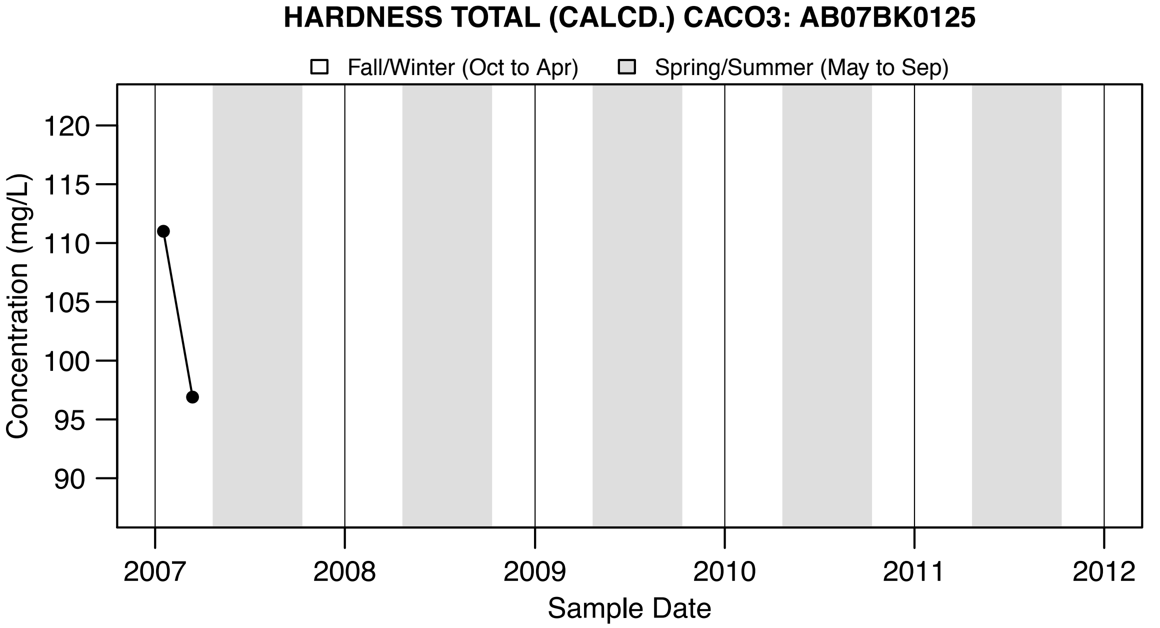


Figure A2.36: HARDNESS TOTAL (CALCD.) CACO3: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

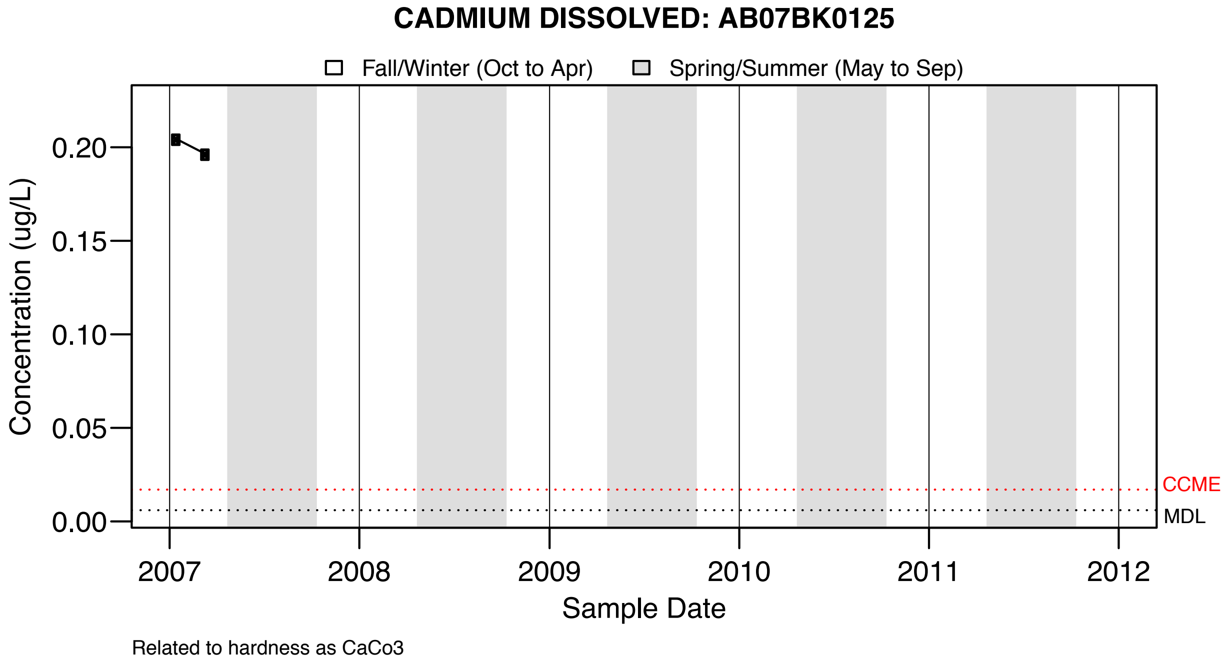


Figure A2.37: CADMIUM DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

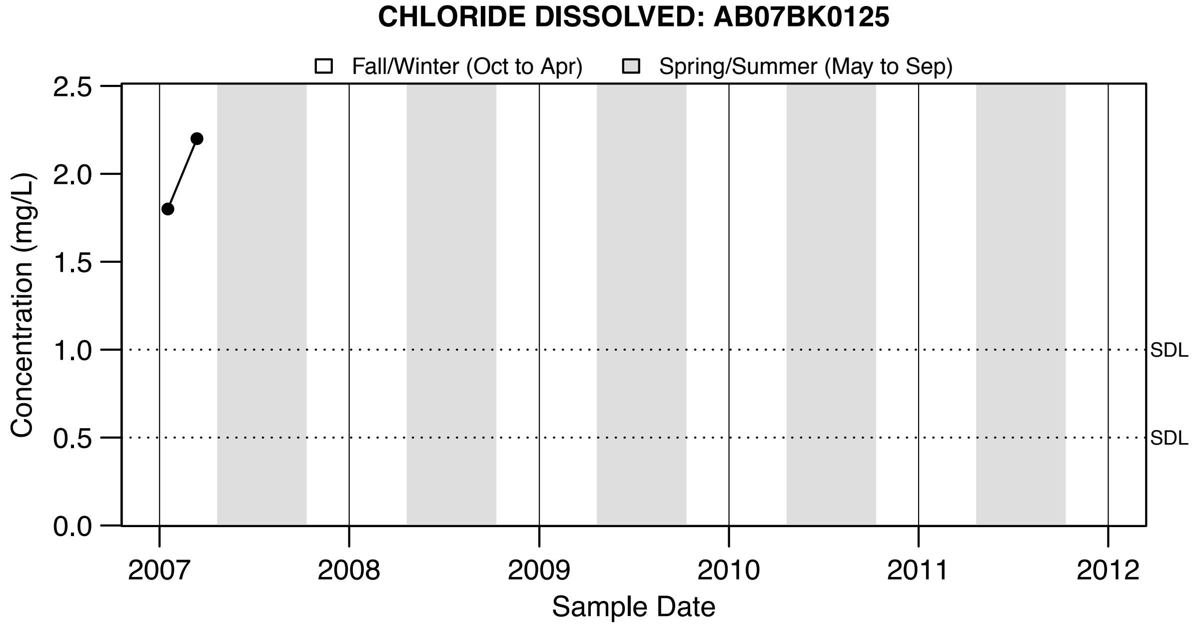


Figure A2.38: CHLORIDE DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

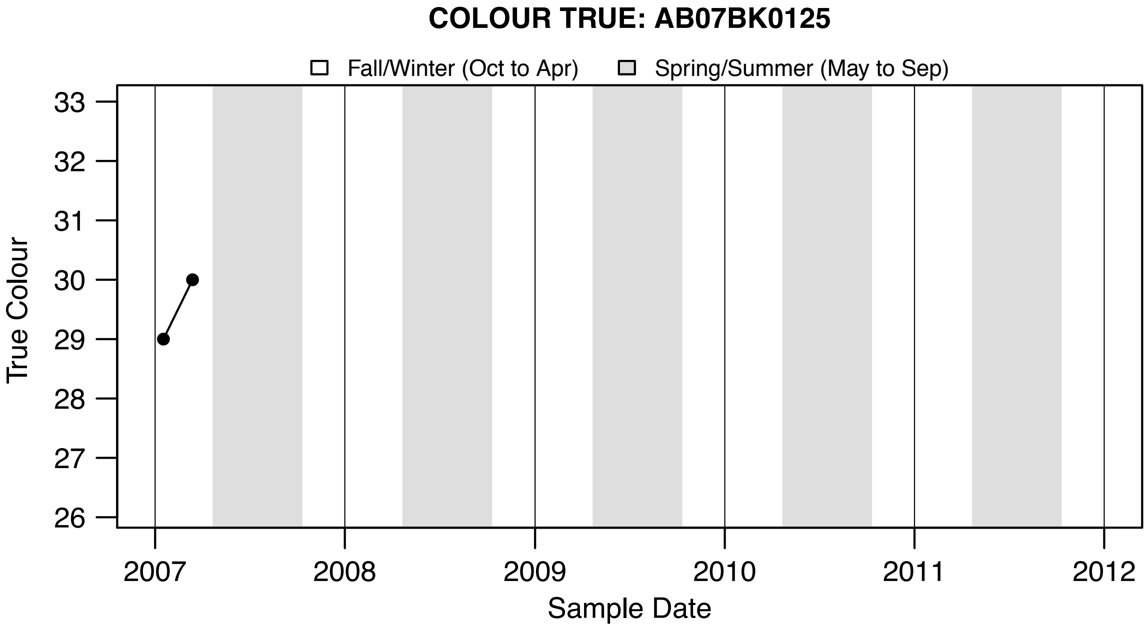
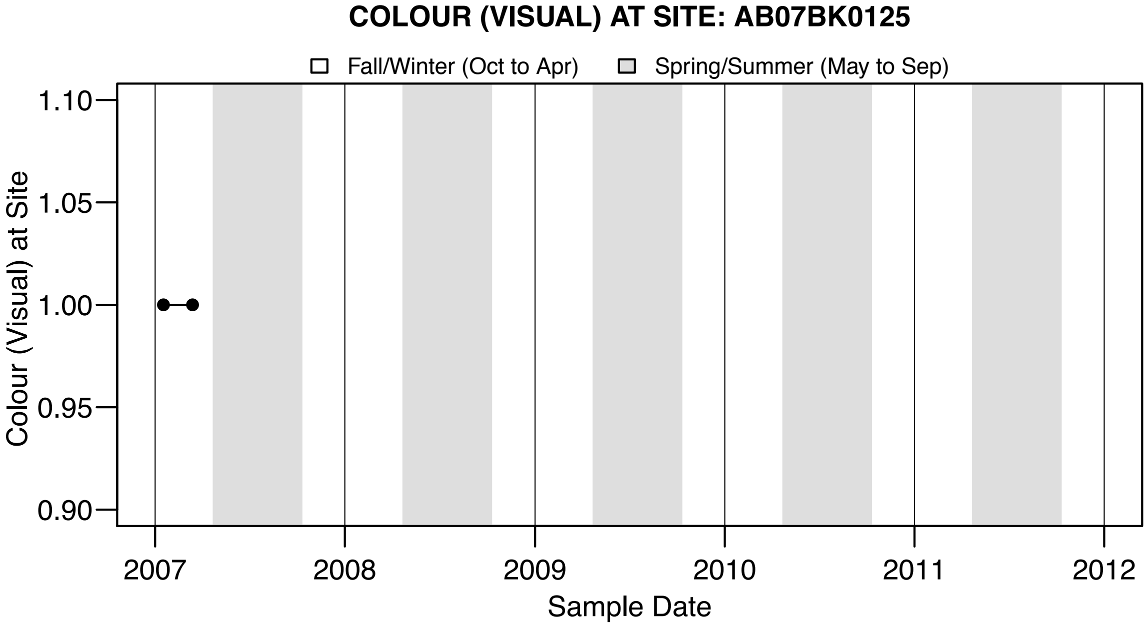


Figure A2.39: COLOUR TRUE: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



AB guideline: Not to be increased more than 30 colour units above natural value

Figure A2.40: COLOUR (VISUAL) AT SITE: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

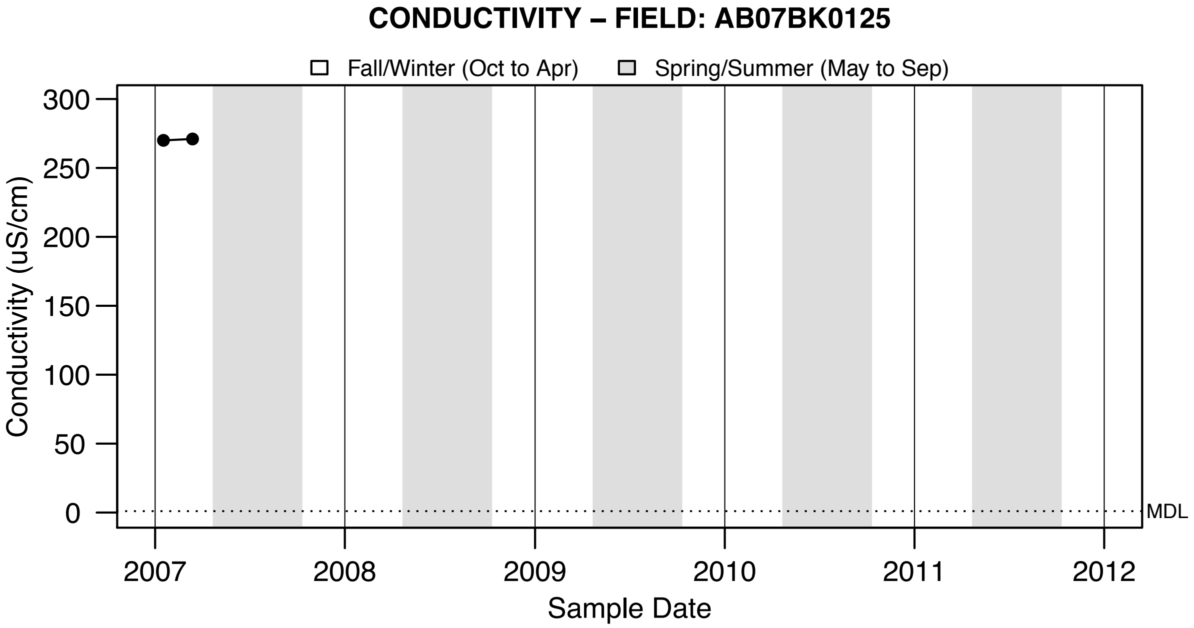


Figure A2.41: CONDUCTIVITY - FIELD: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

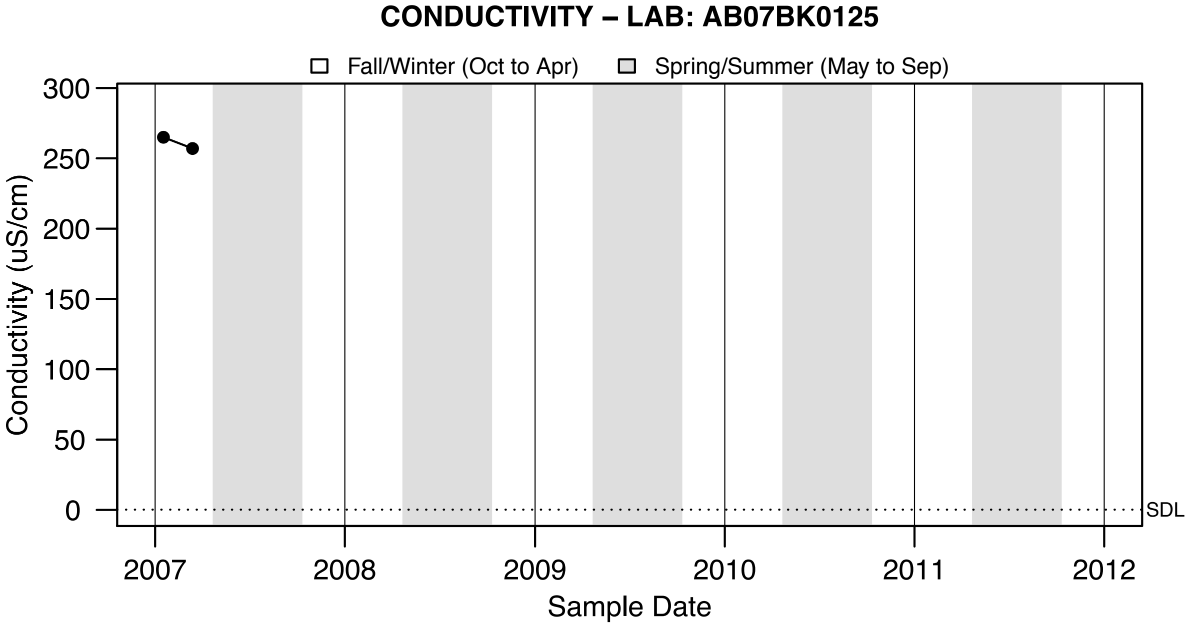
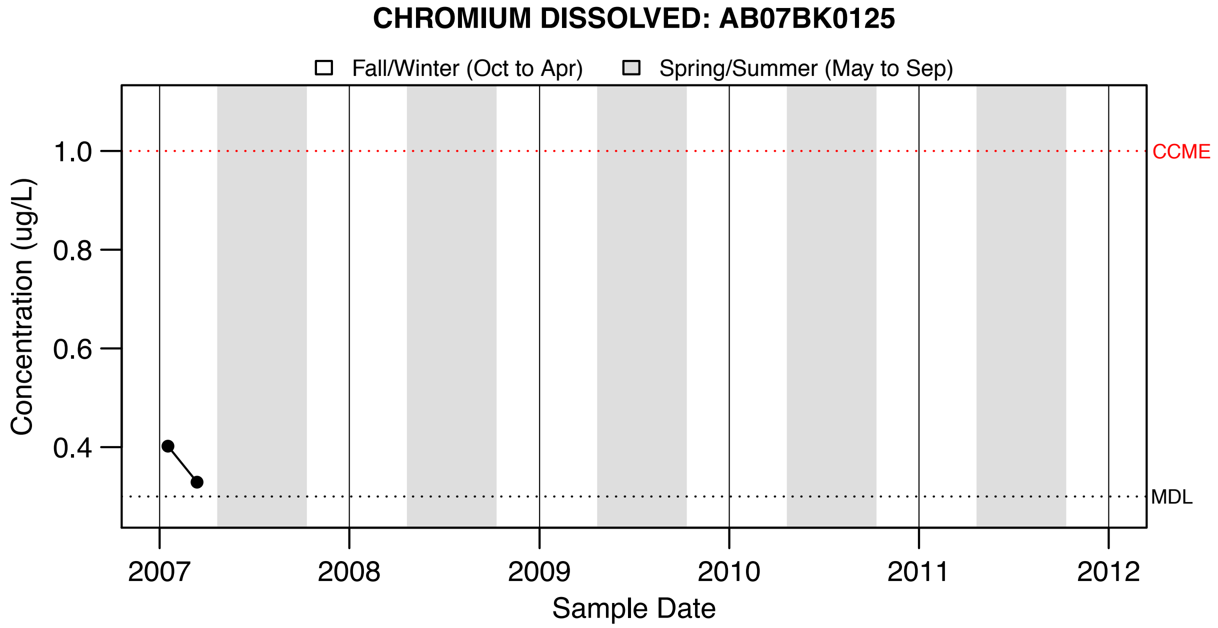
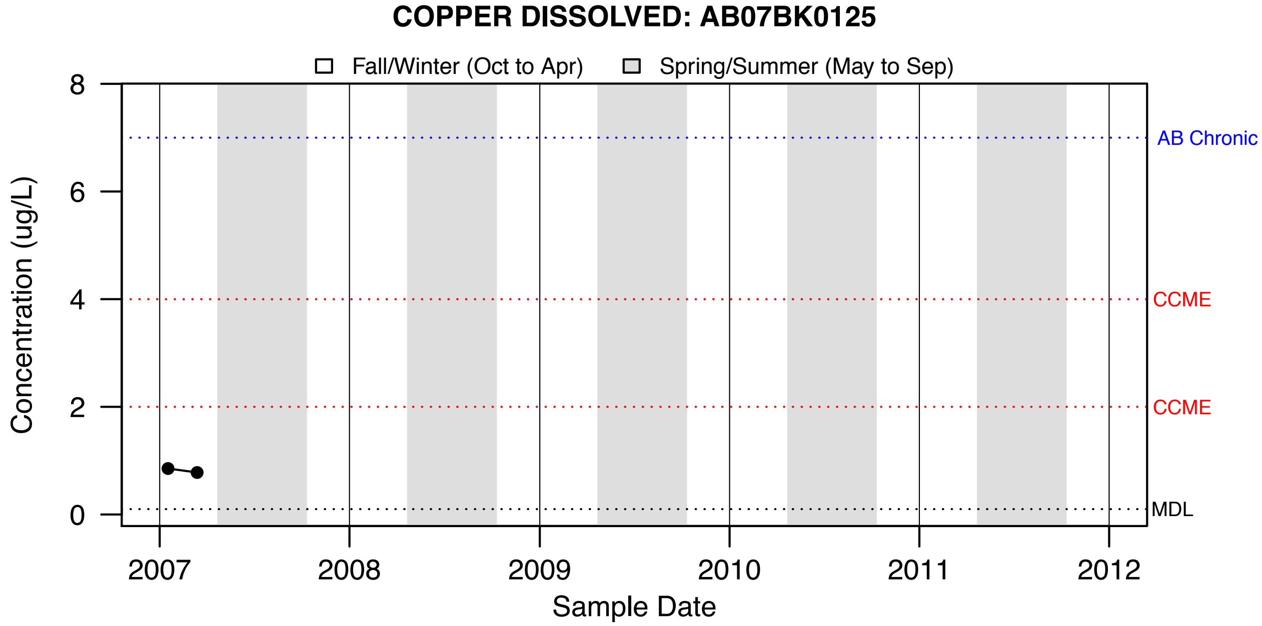


Figure A2.42: CONDUCTIVITY - LAB: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



Chromium III: 8.9 Chromium VI: 1.0

Figure A2.43: CHROMIUM DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A2.44: COPPER DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

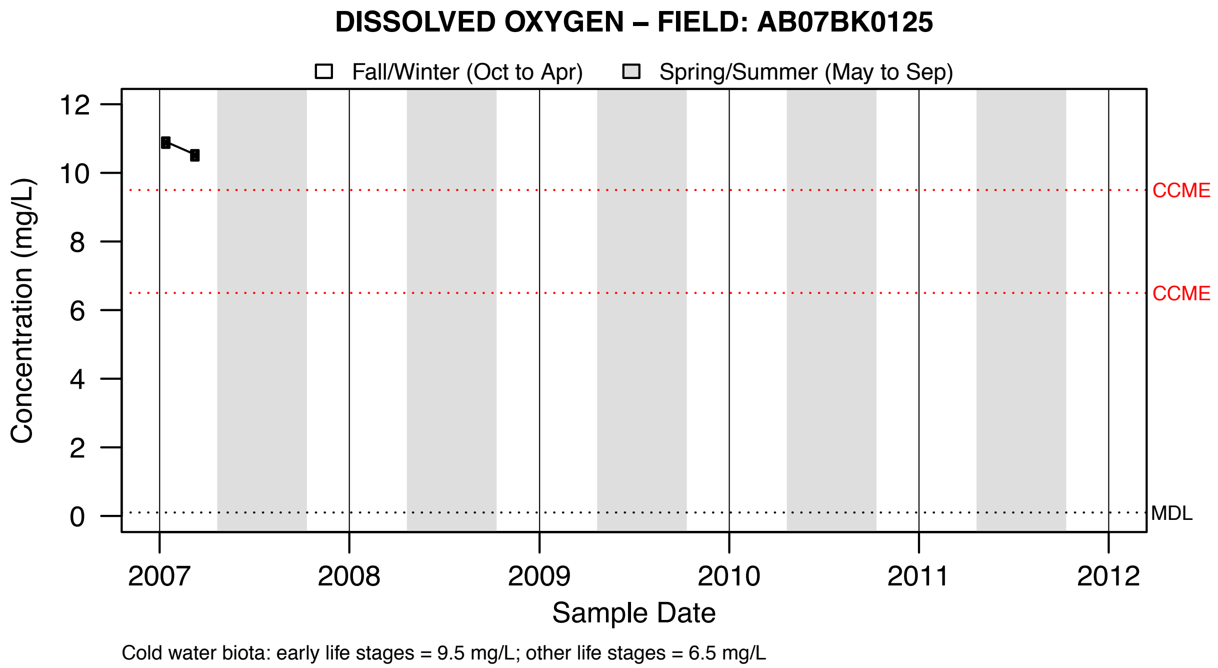


Figure A2.45: DISSOLVED OXYGEN - FIELD: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

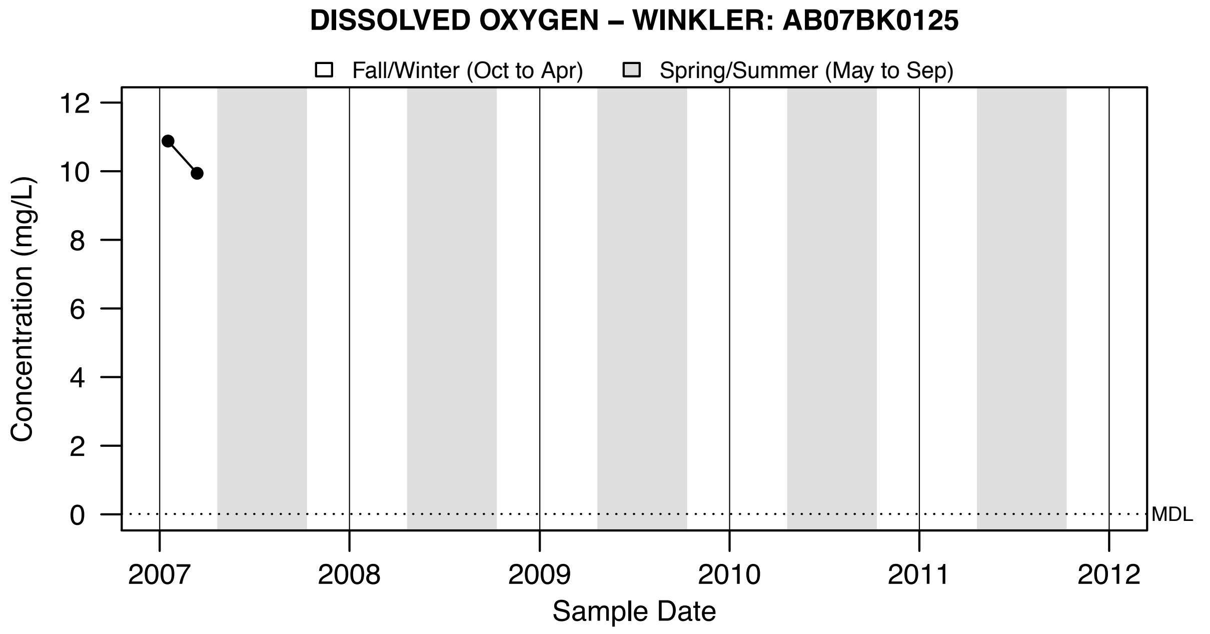


Figure A2.46: DISSOLVED OXYGEN - WINKLER: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

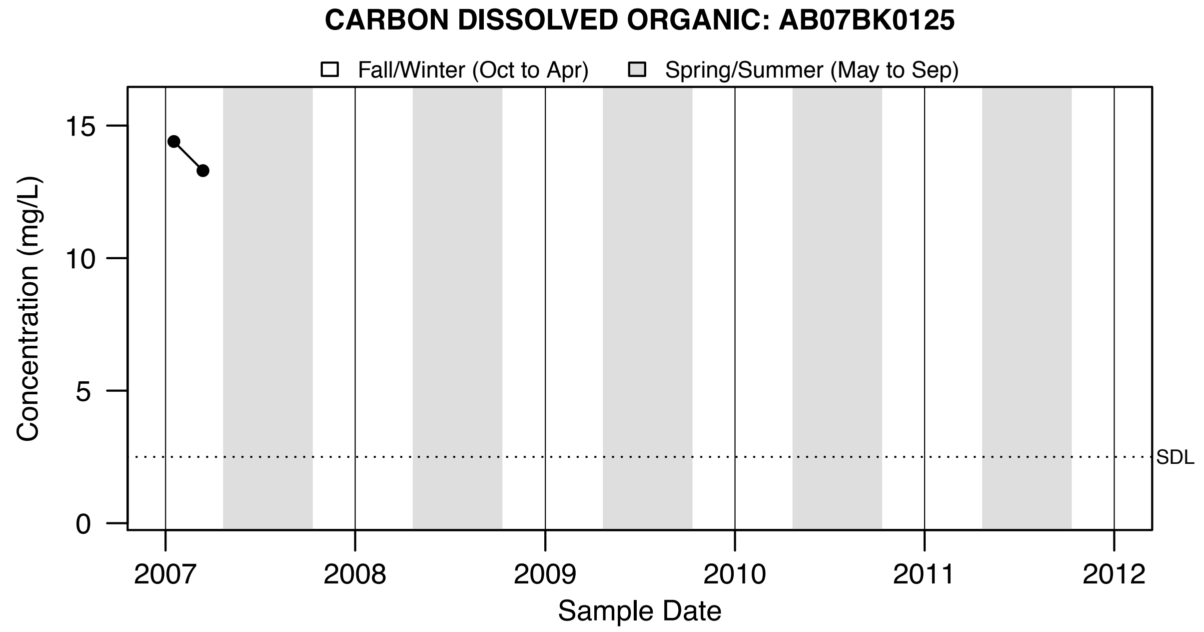


Figure A2.47: CARBON DISSOLVED ORGANIC: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

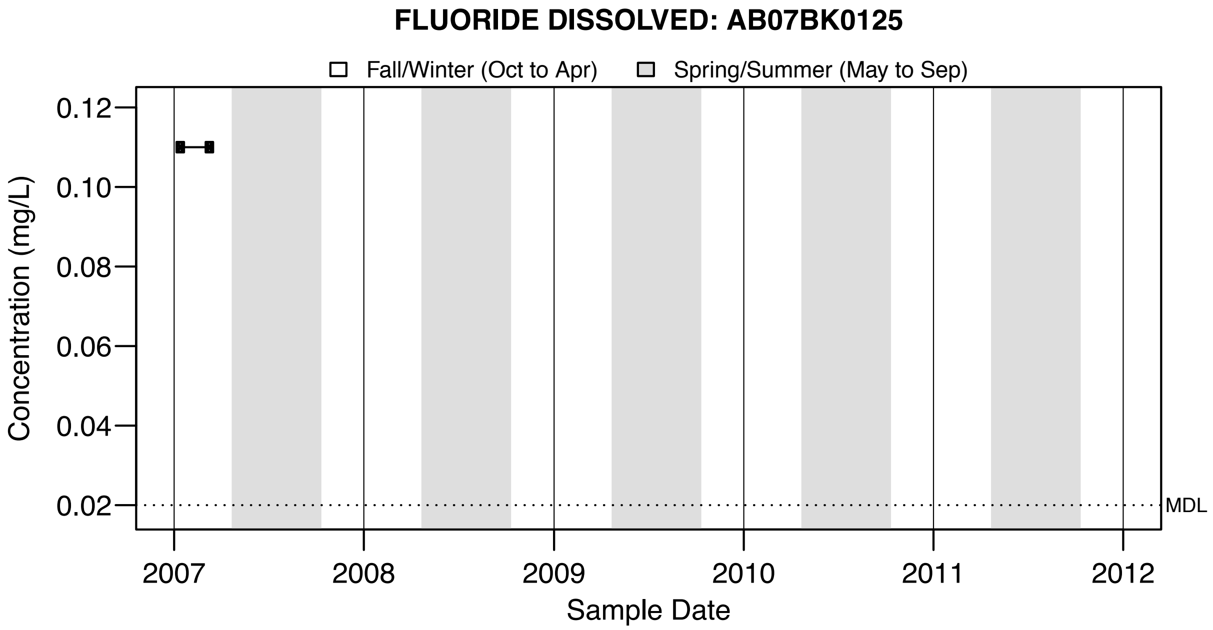


Figure A2.48: FLUORIDE DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

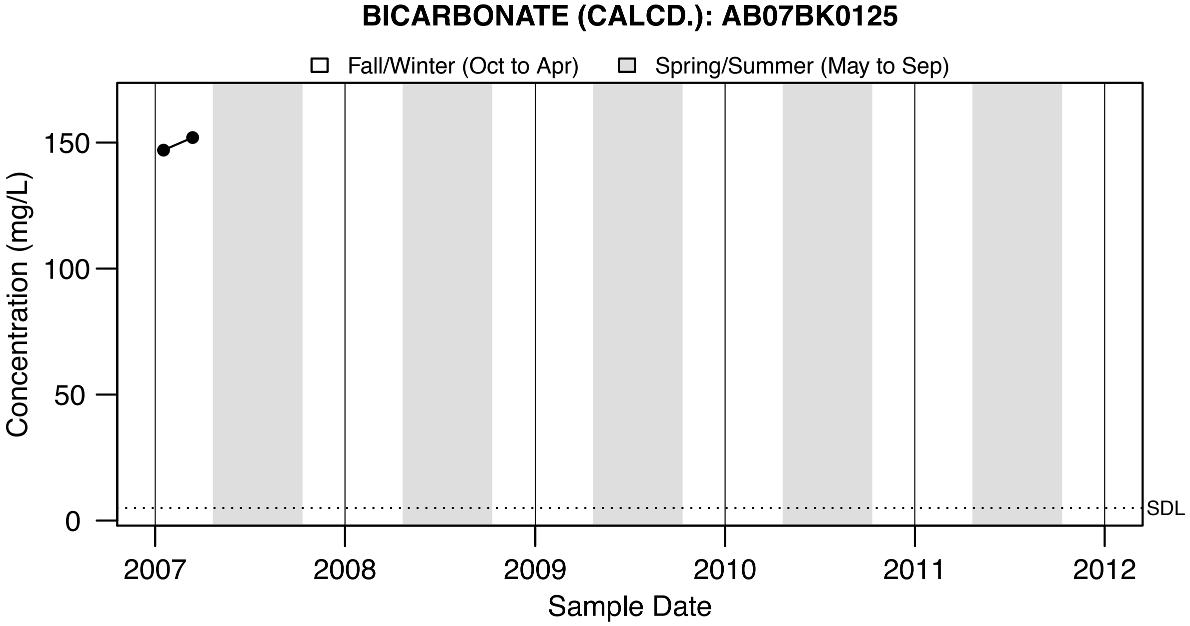


Figure A2.49: BICARBONATE (CALCD.): AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

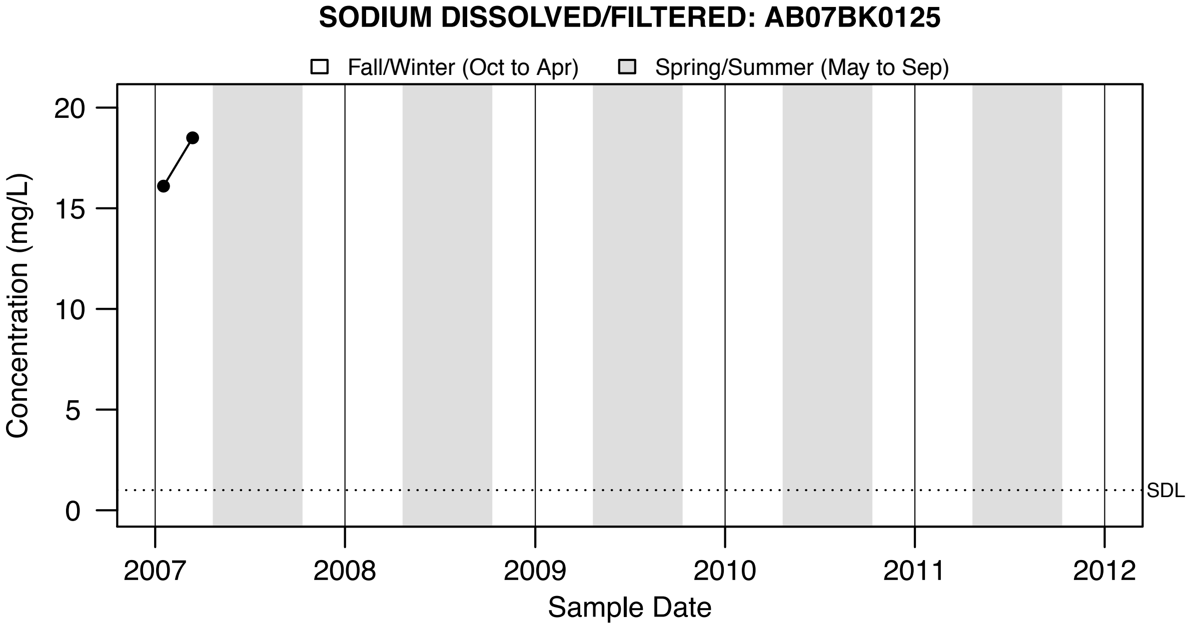


Figure A2.50: SODIUM DISSOLVED/FILTERED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

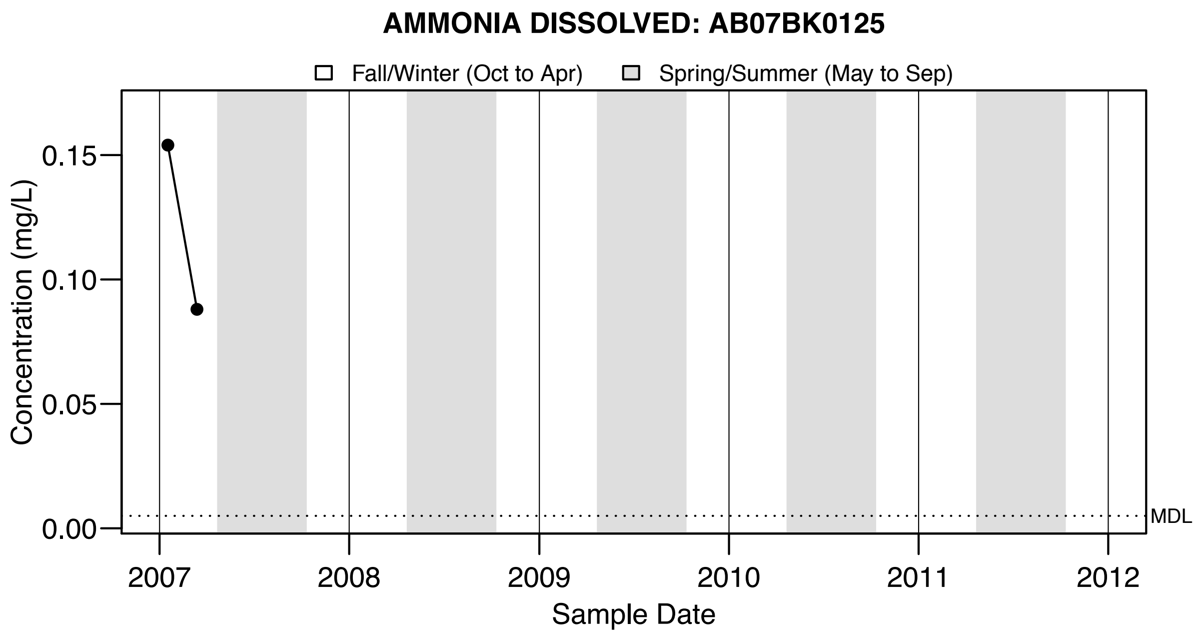
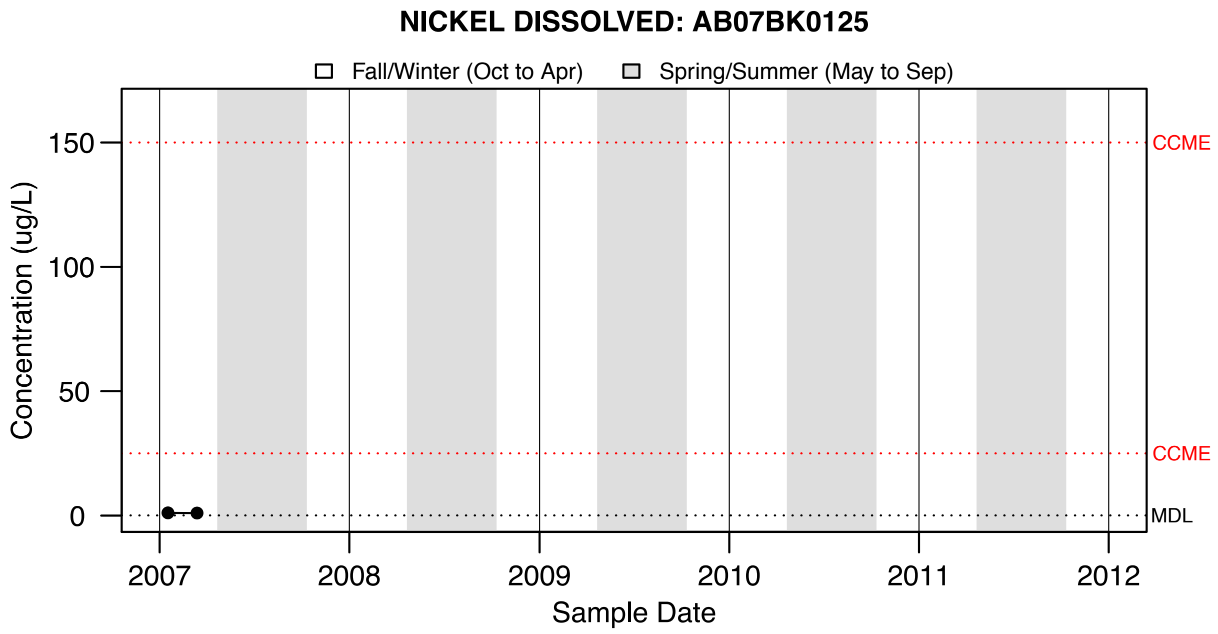


Figure A2.51: AMMONIA DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A2.52: NICKEL DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

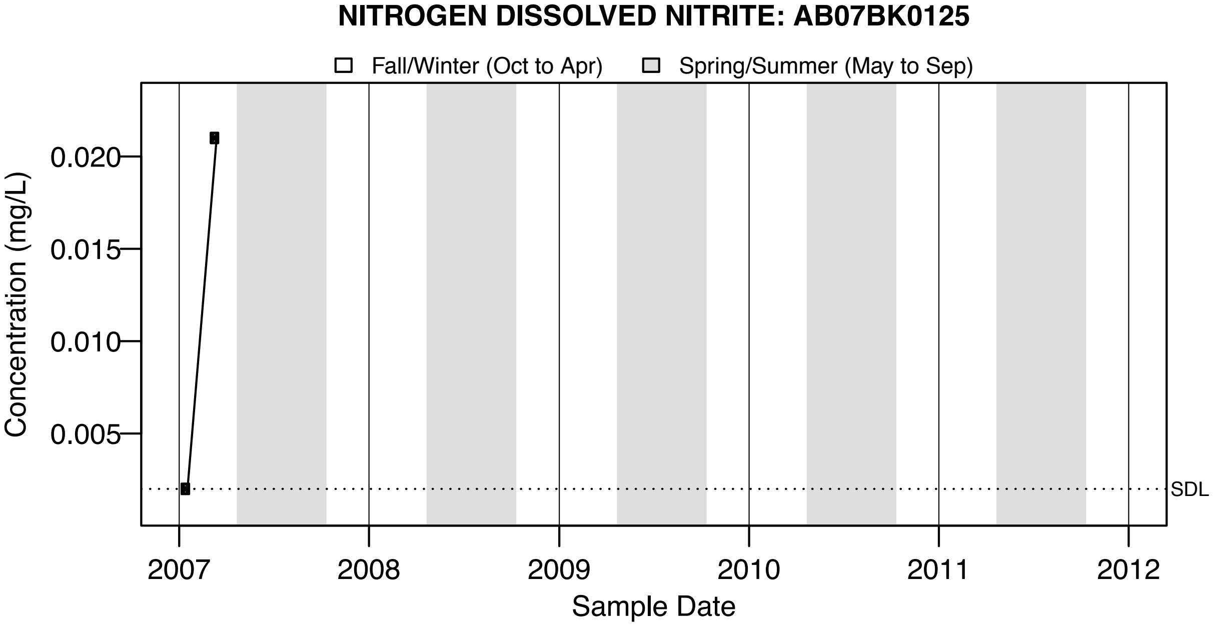


Figure A2.53: NITROGEN DISSOLVED NITRITE: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

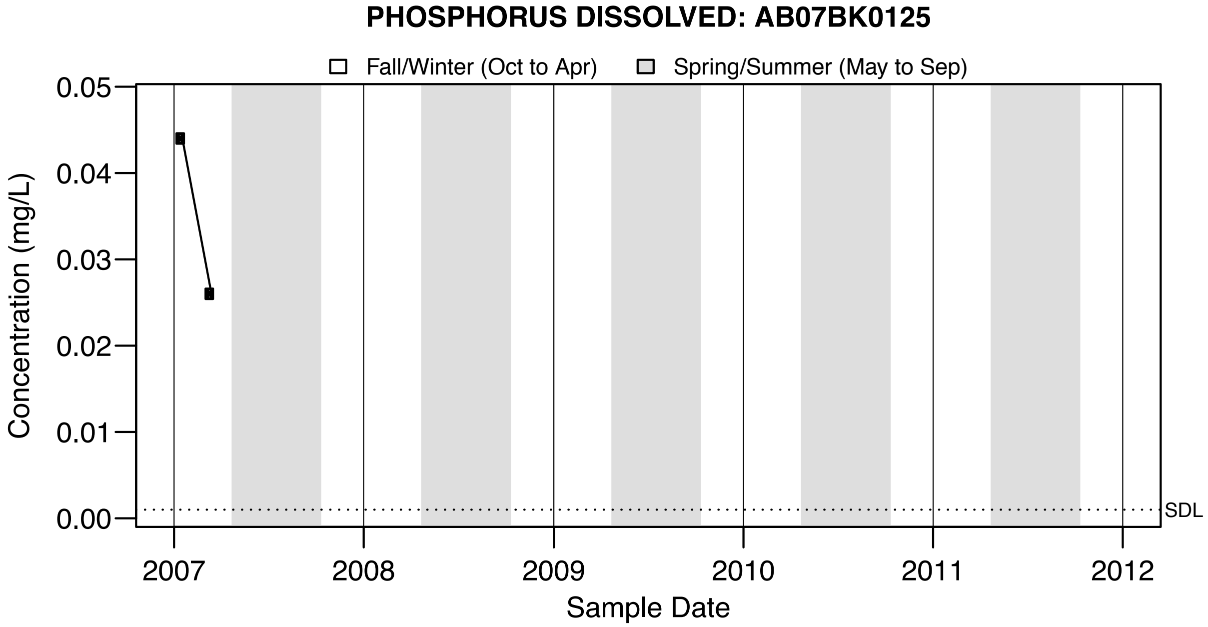


Figure A2.54: PHOSPHORUS DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

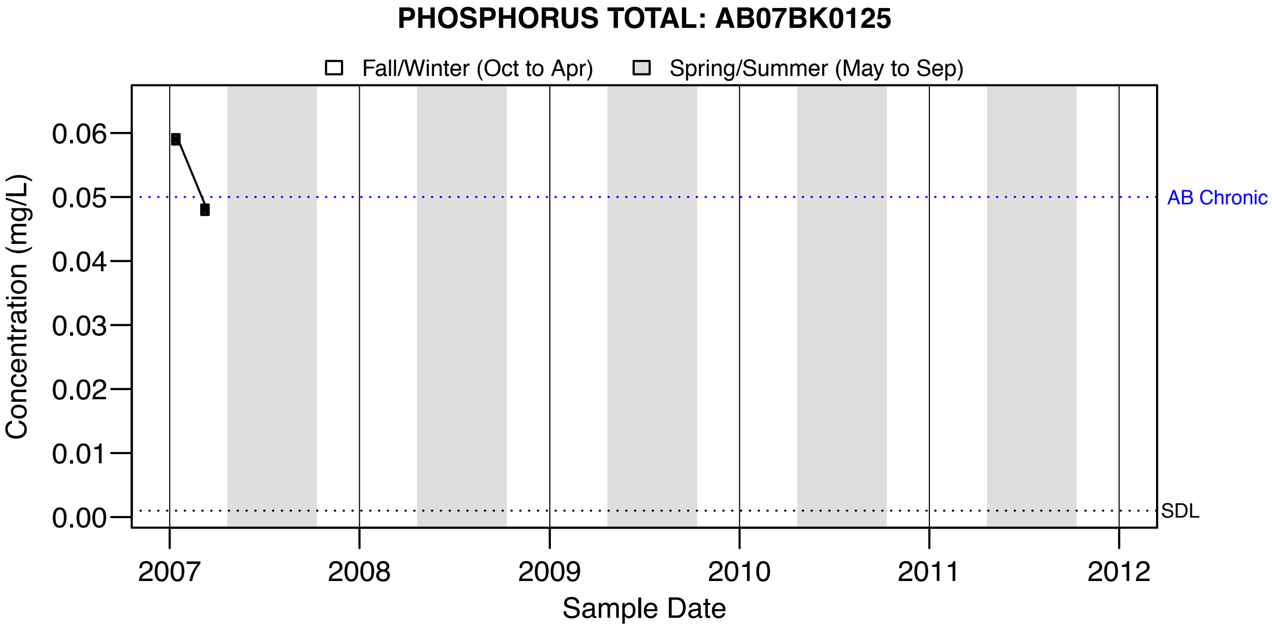
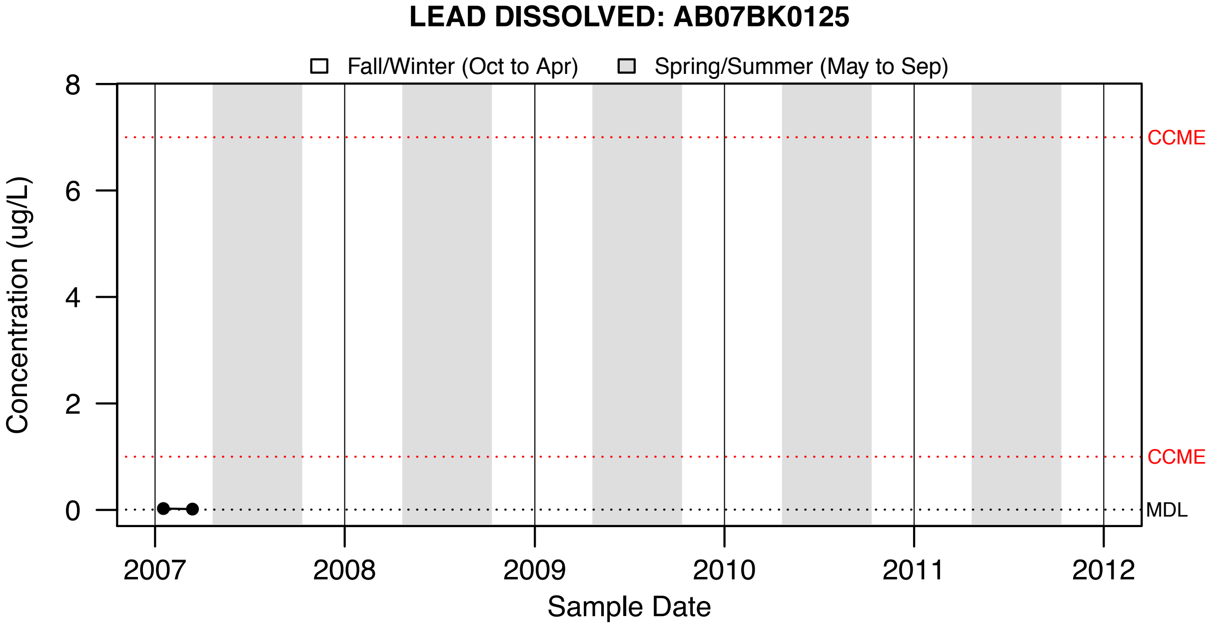


Figure A2.55: PHOSPHORUS TOTAL: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A2.56: LEAD DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

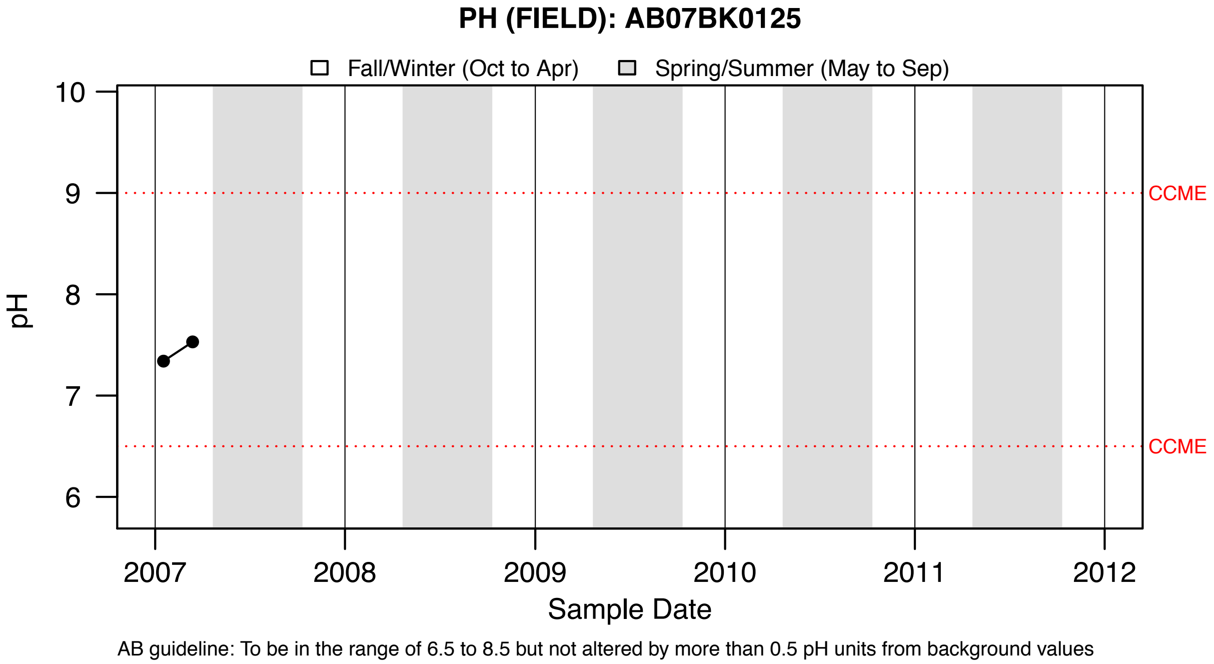


Figure A2.57: PH (FIELD): AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

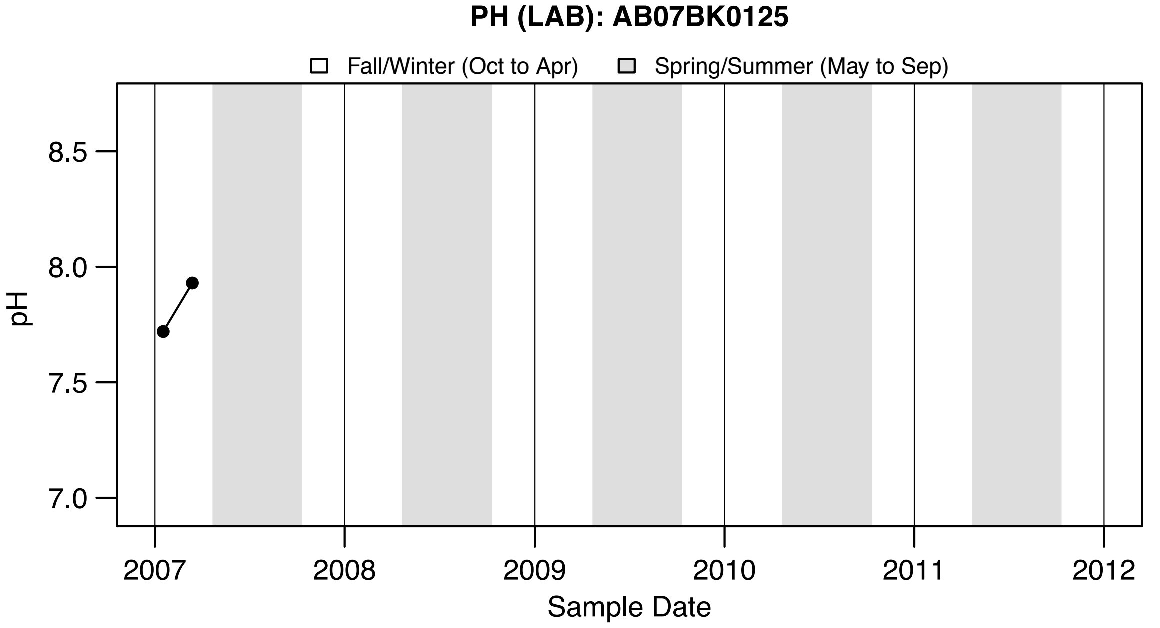


Figure A2.58: PH (LAB): AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

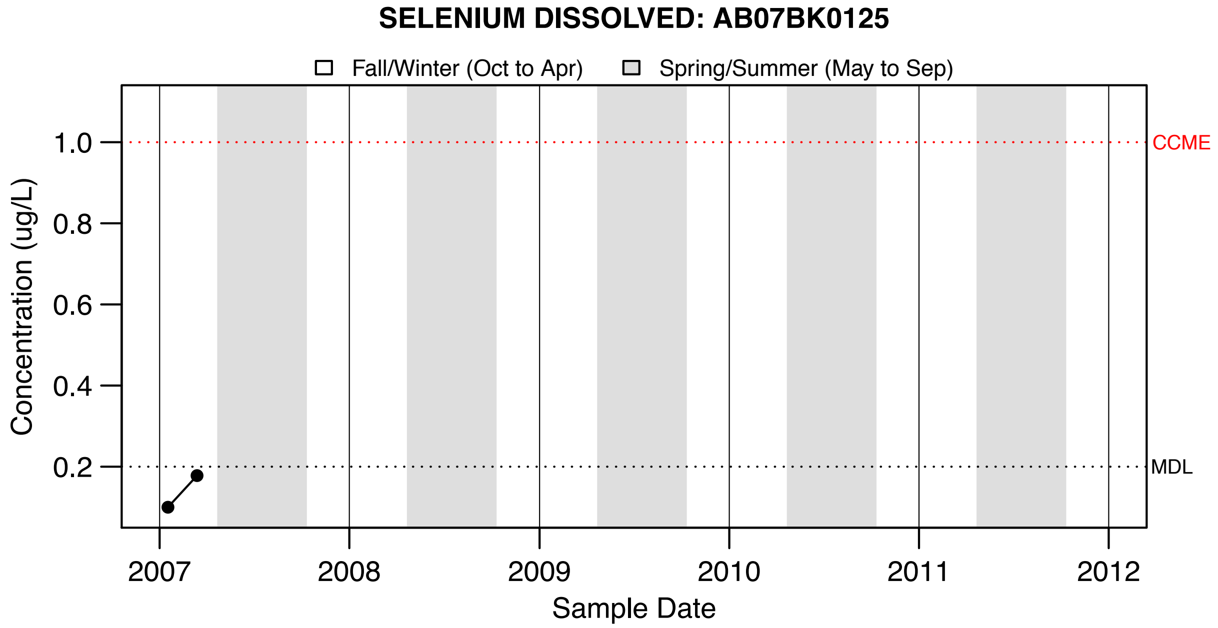


Figure A2.59: SELENIUM DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

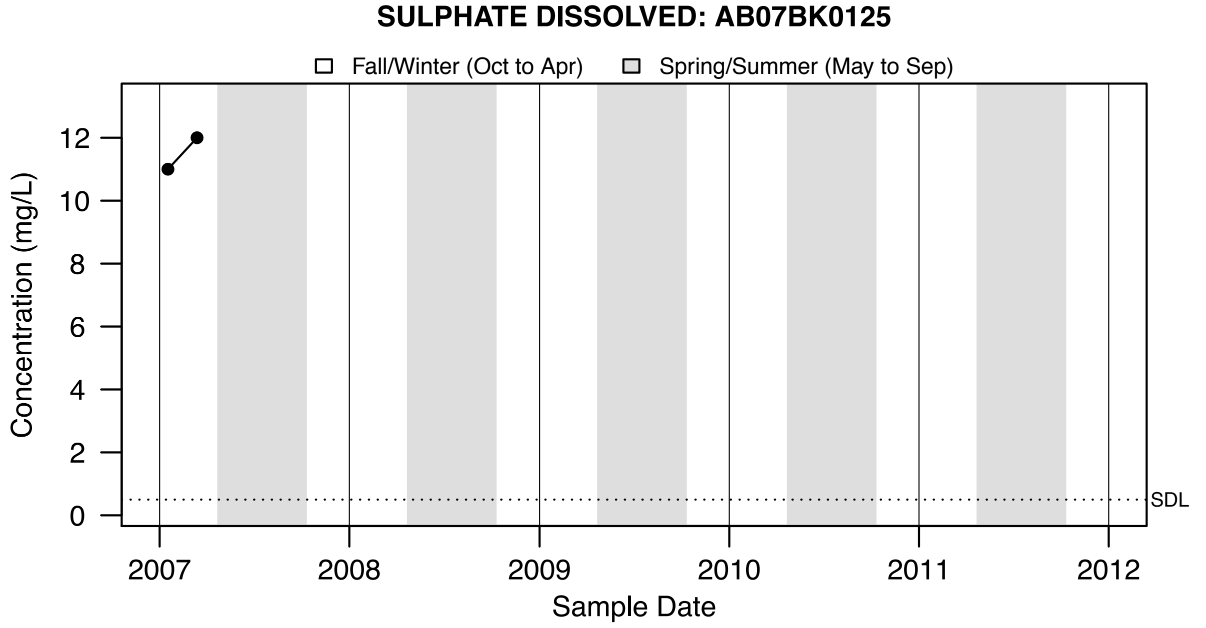


Figure A2.60: SULPHATE DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

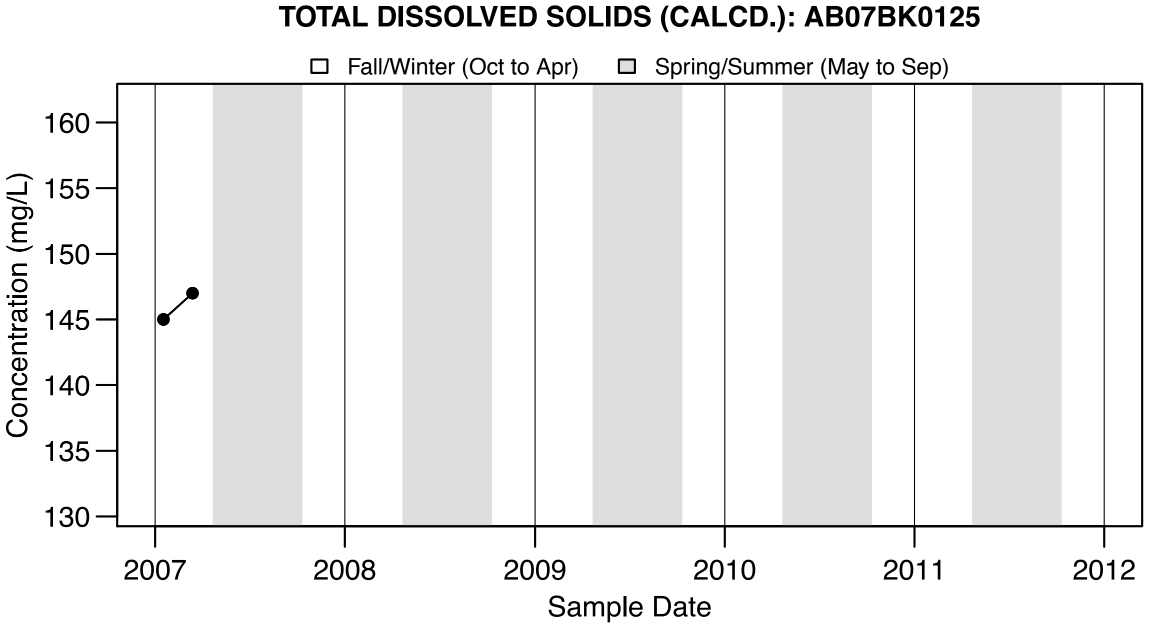


Figure A2.61: TOTAL DISSOLVED SOLIDS (CALCD.): AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

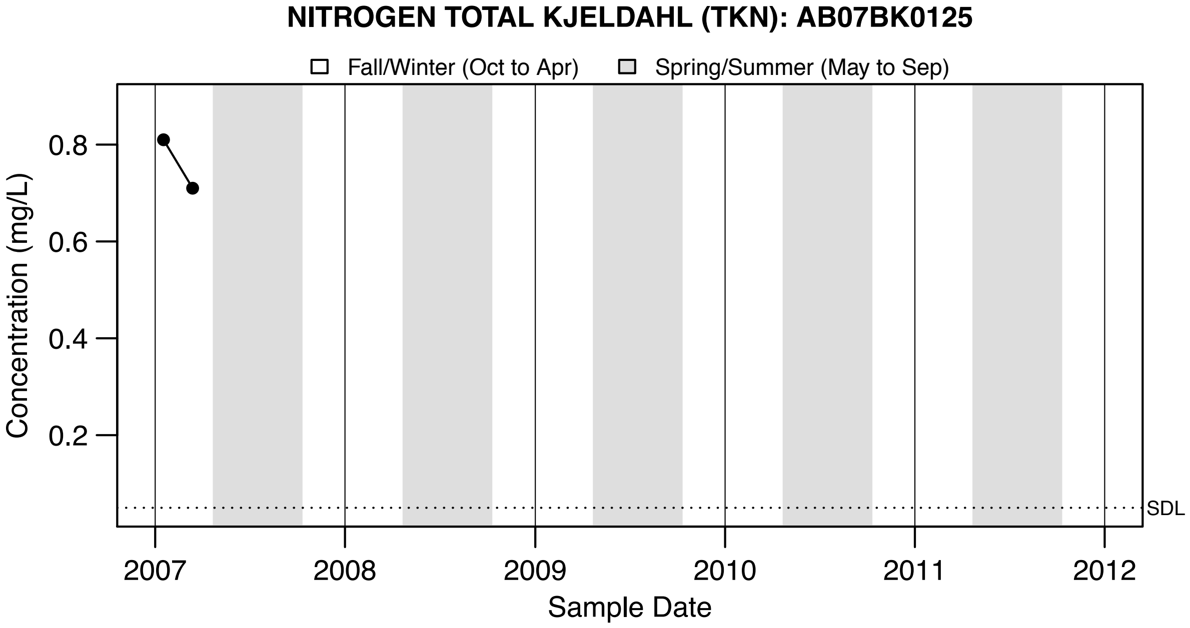


Figure A2.62: NITROGEN TOTAL KJELDAHL (TKN): AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

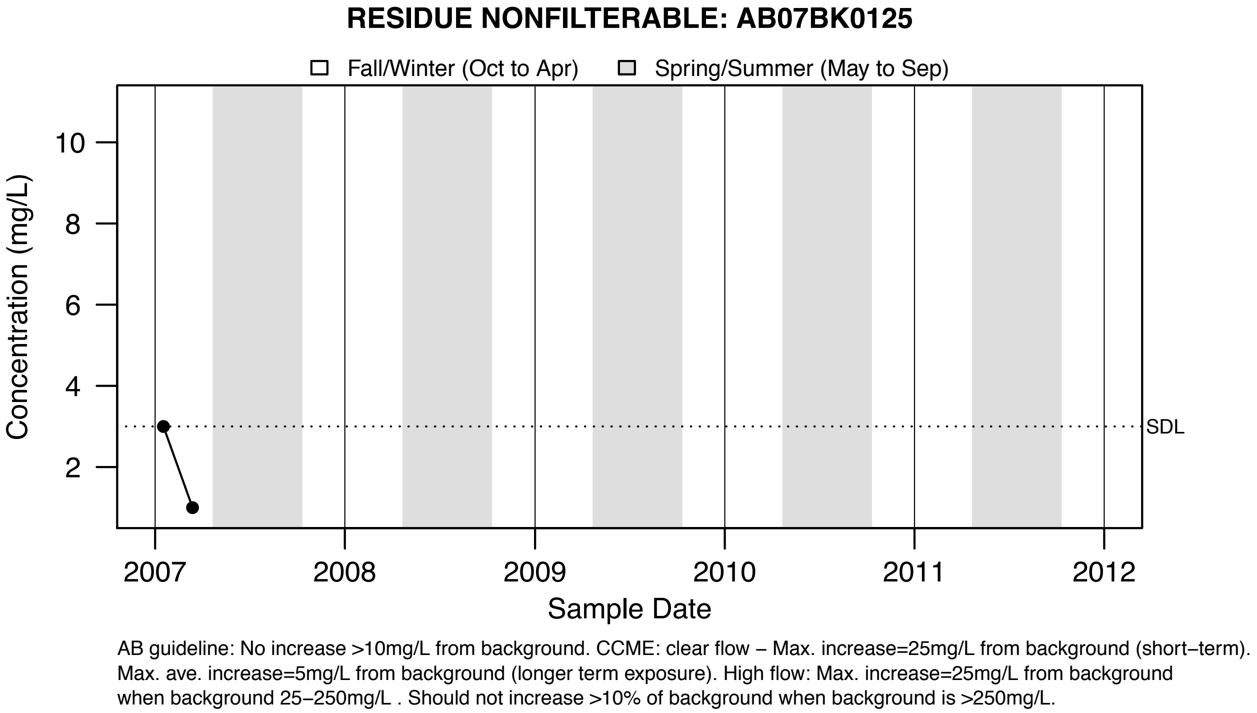


Figure A2.63: RESIDUE NONFILTERABLE: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

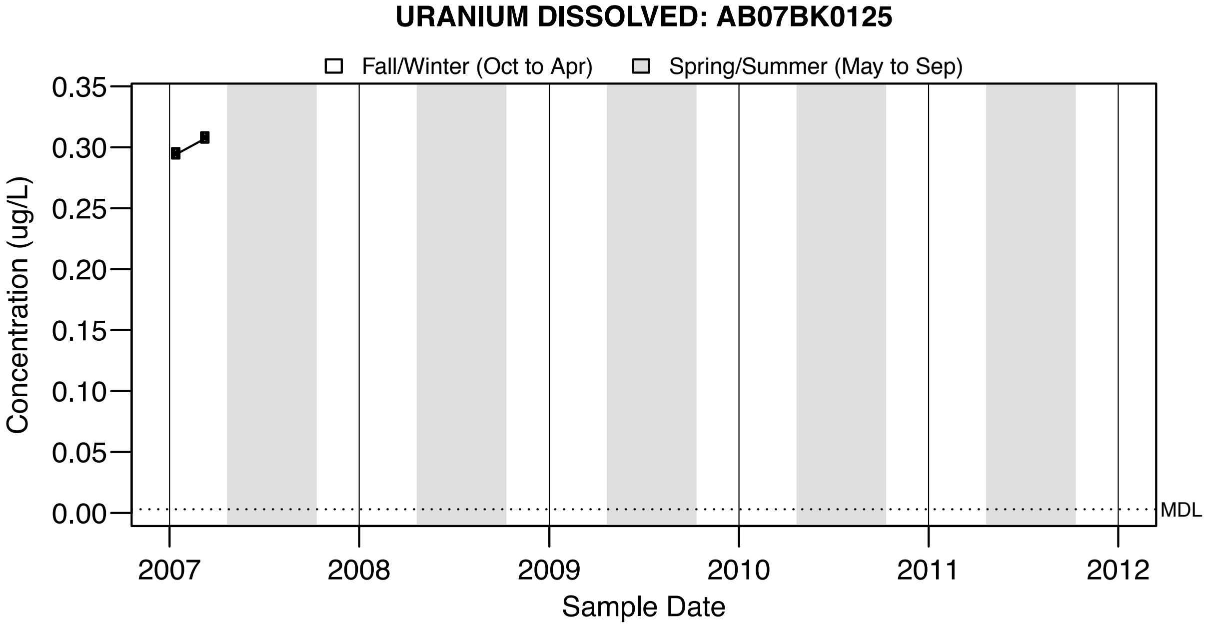


Figure A2.64: URANIUM DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

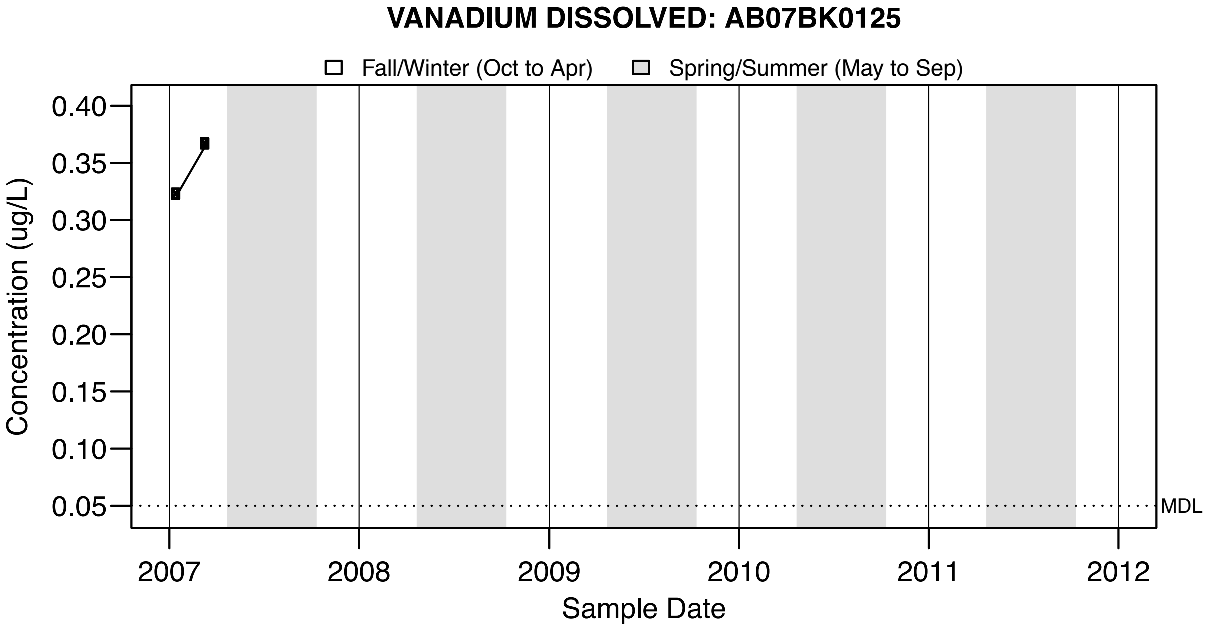


Figure A2.65: VANADIUM DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

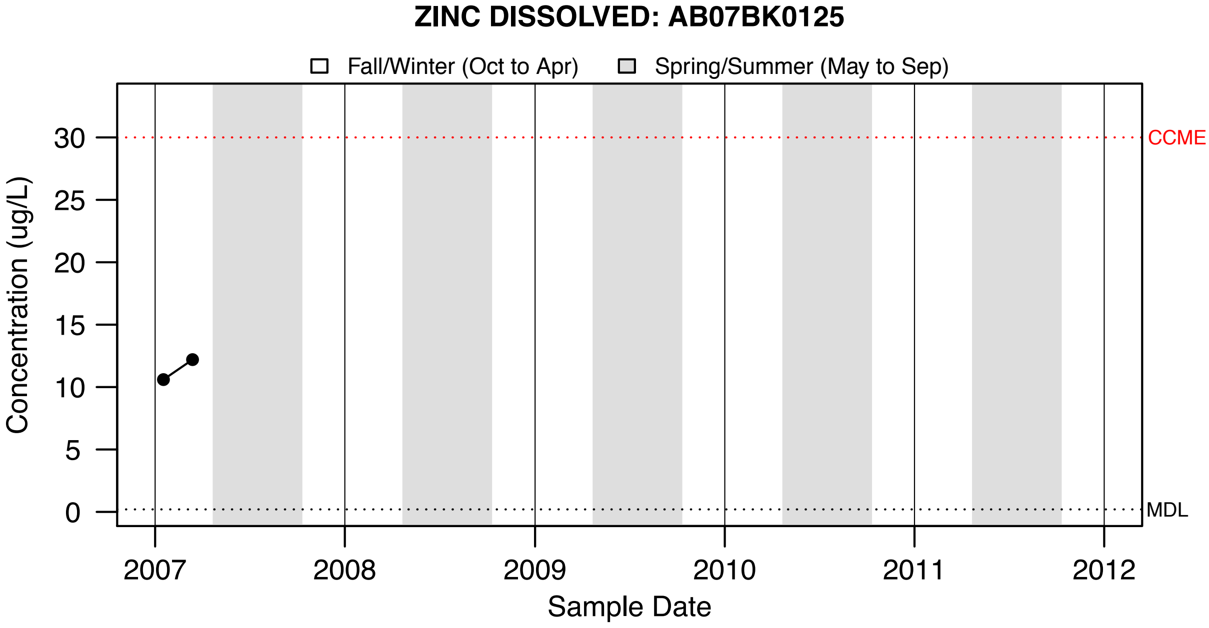
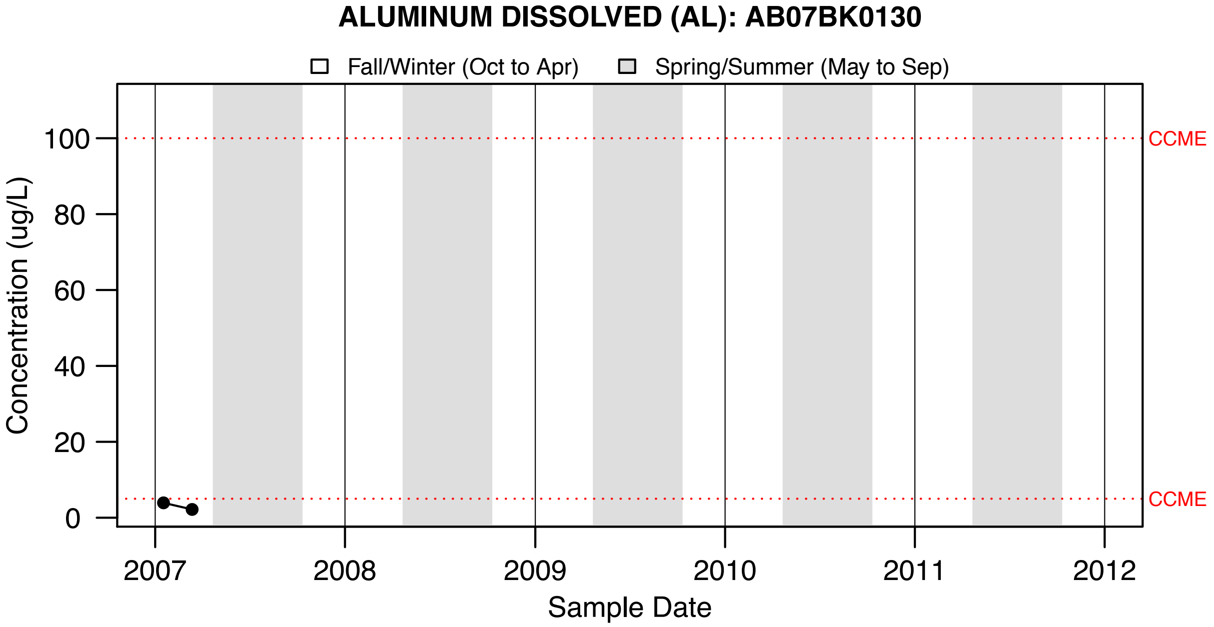
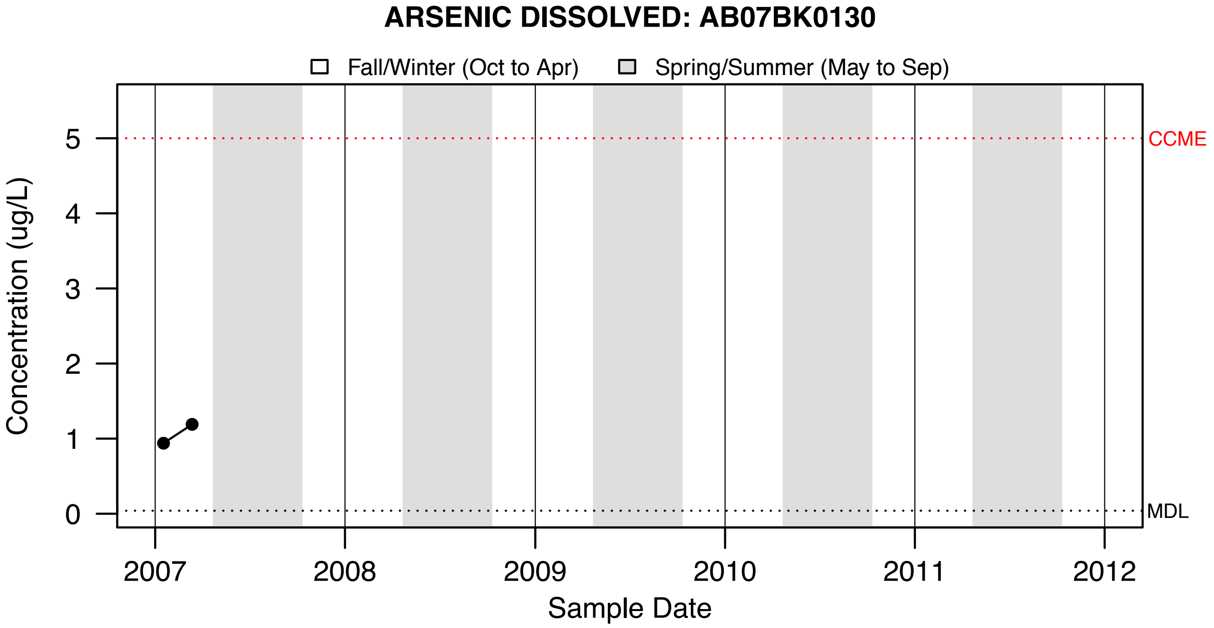


Figure A2.66: ZINC DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A2.67: ALUMINUM DISSOLVED (AL): AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



AB guidelines state Total Arsenic; CCME does not specify

Figure A2.68: ARSENIC DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

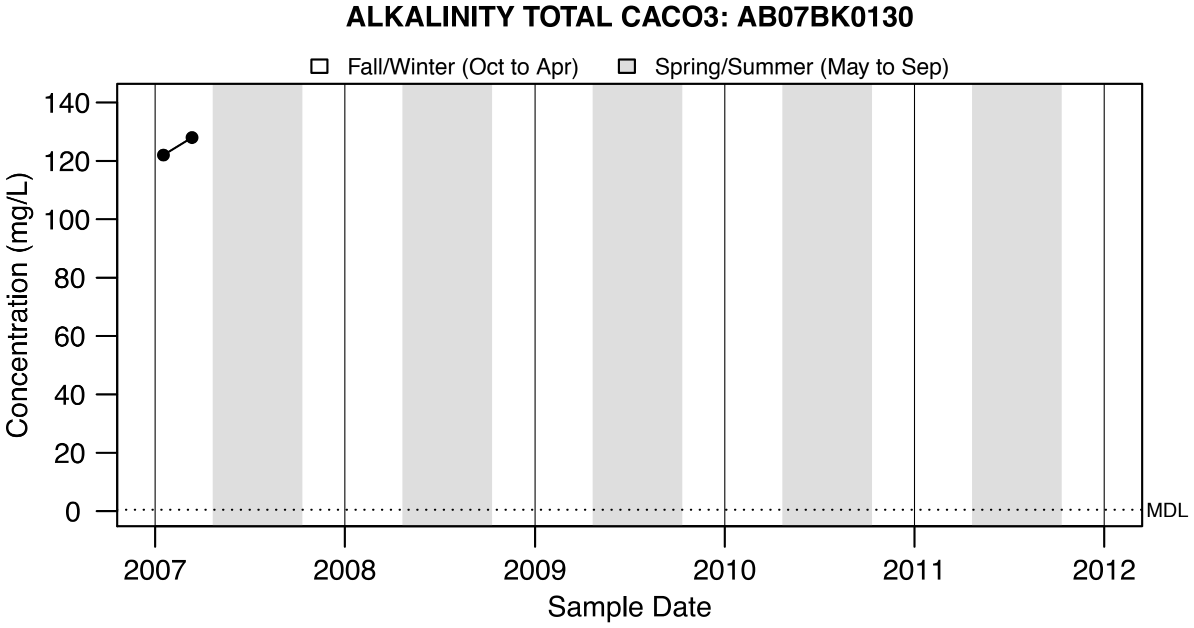


Figure A2.69: ALKALINITY TOTAL CACO3: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

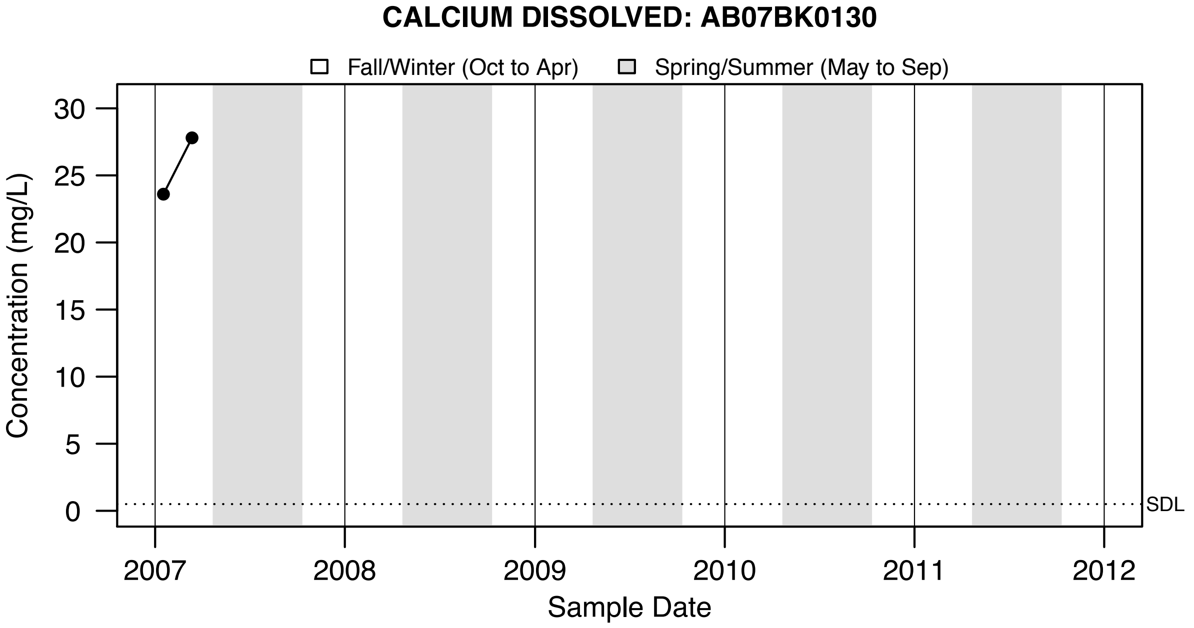


Figure A2.70: CALCIUM DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

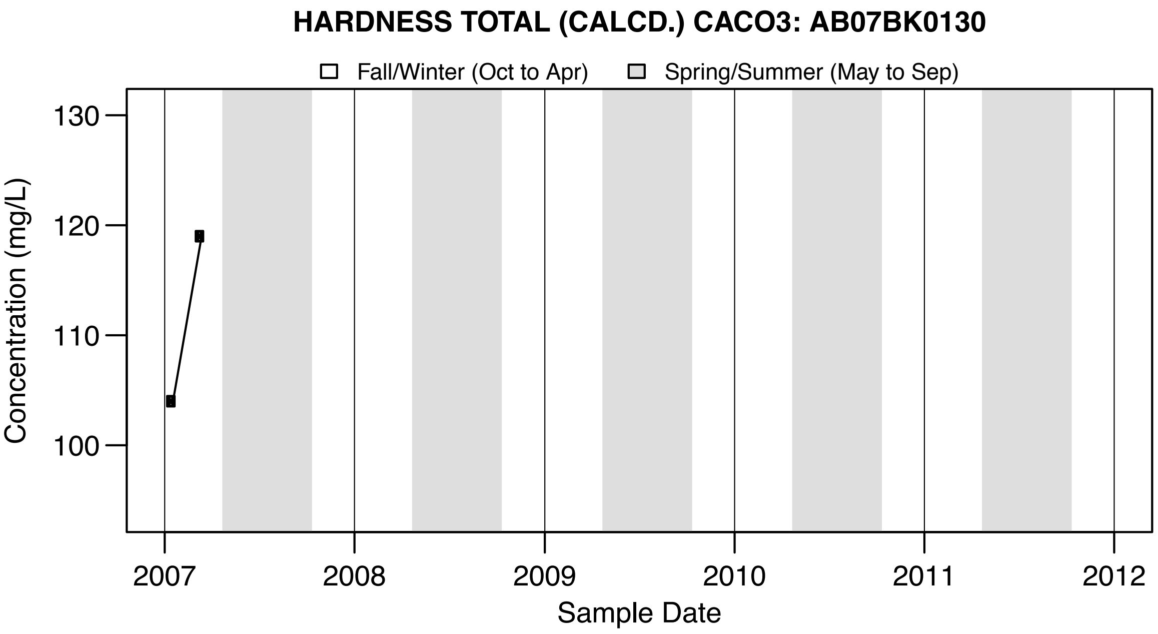


Figure A2.71: HARDNESS TOTAL (CALCD.) CACO3: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

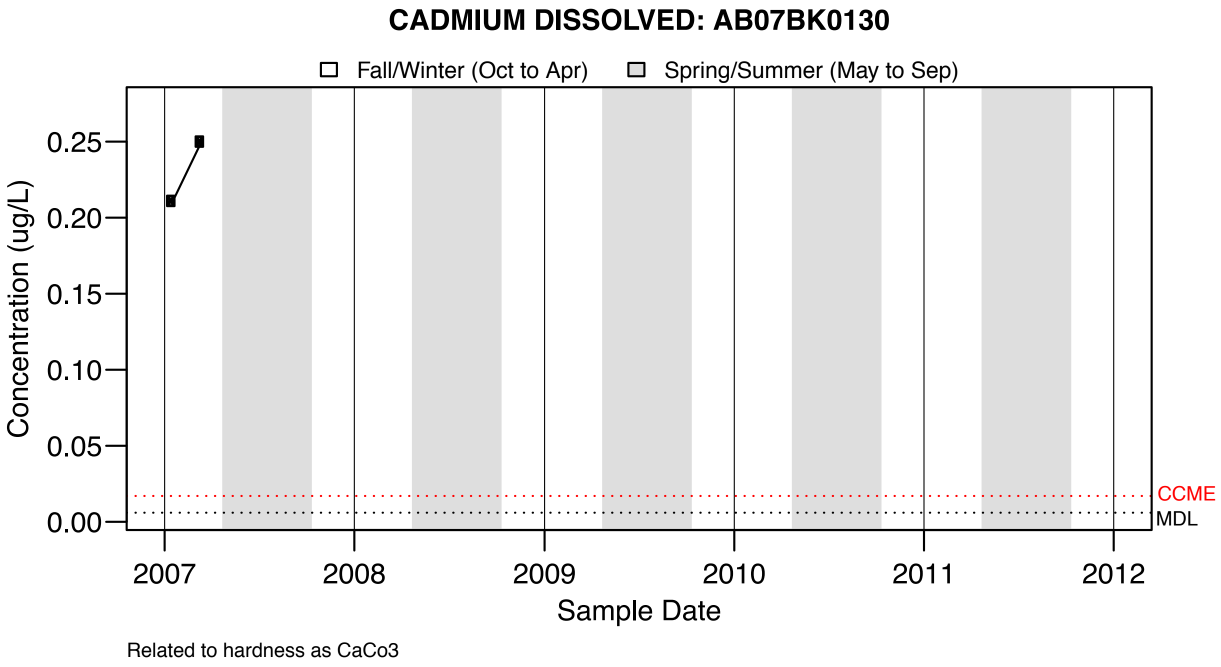


Figure A2.72: CADMIUM DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

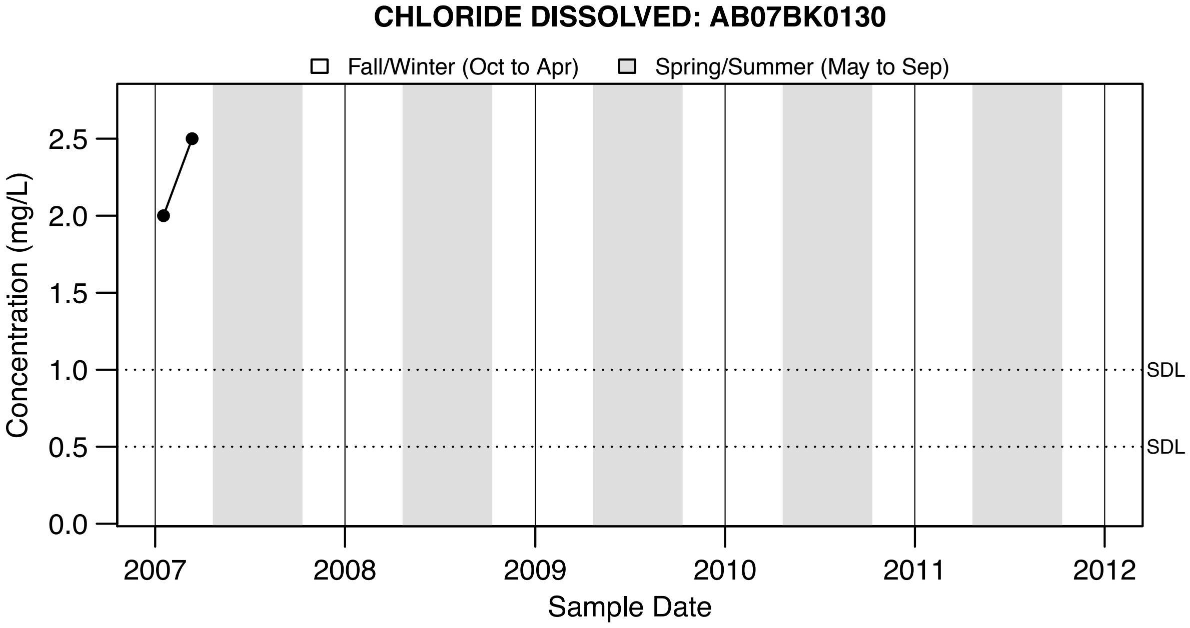


Figure A2.73: CHLORIDE DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

Figure A2.74: COLOUR TRUE: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

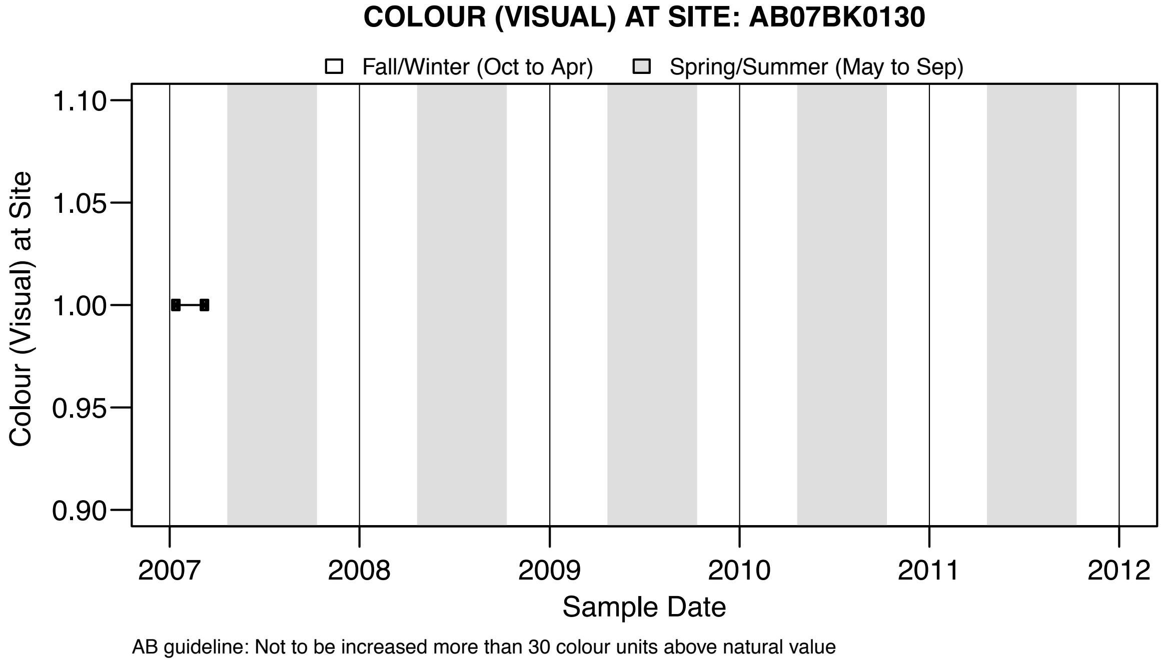


Figure A2.75: COLOUR (VISUAL) AT SITE: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

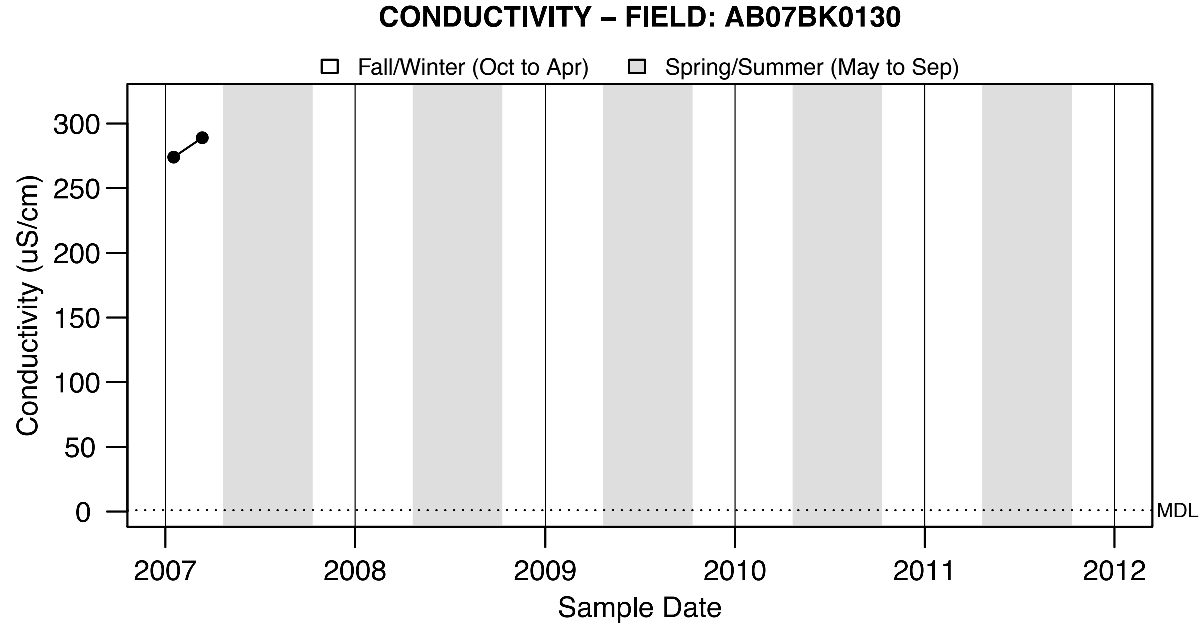


Figure A2.76: CONDUCTIVITY - FIELD: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

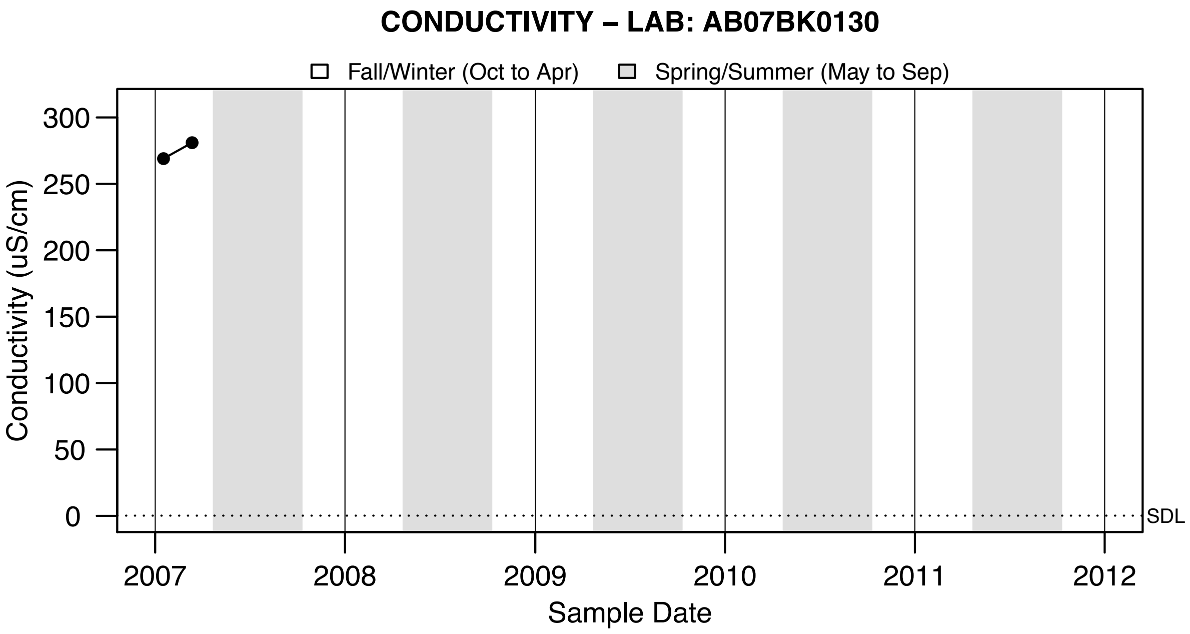


Figure A2.77: CONDUCTIVITY - LAB: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

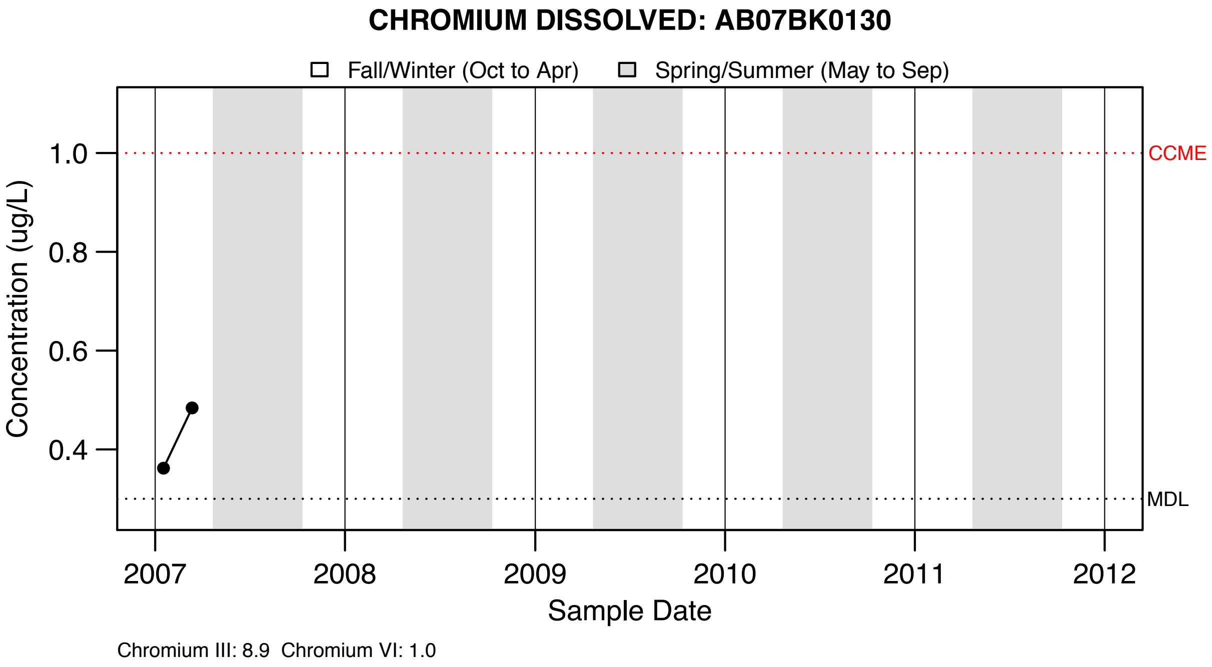
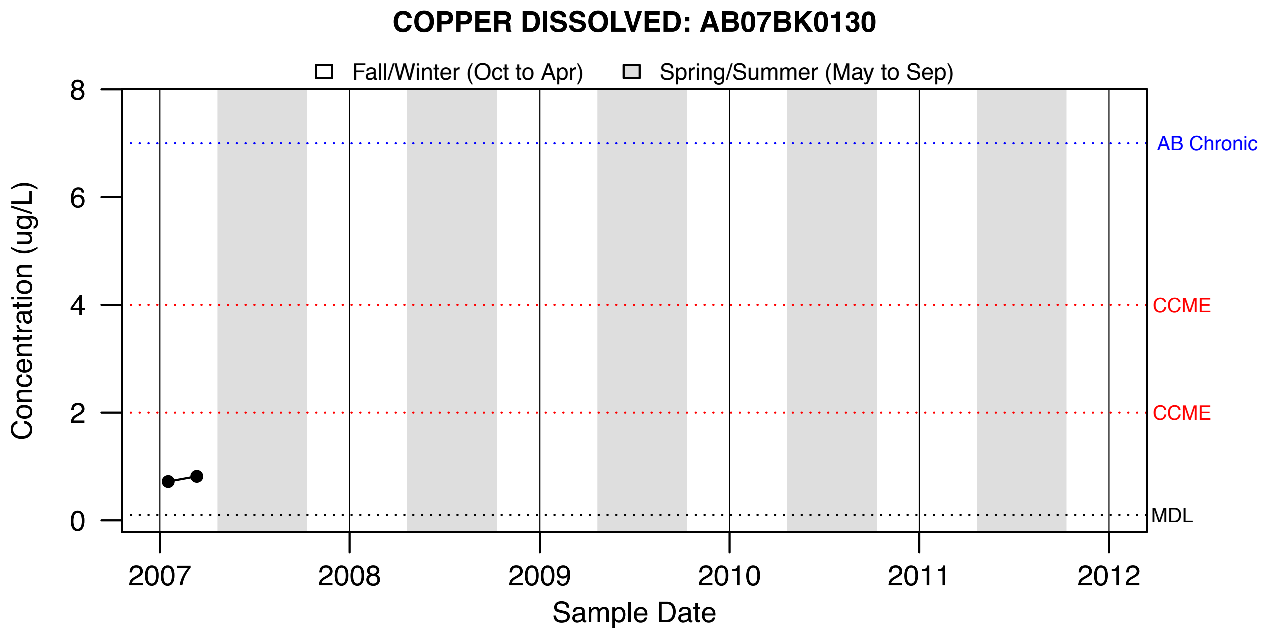
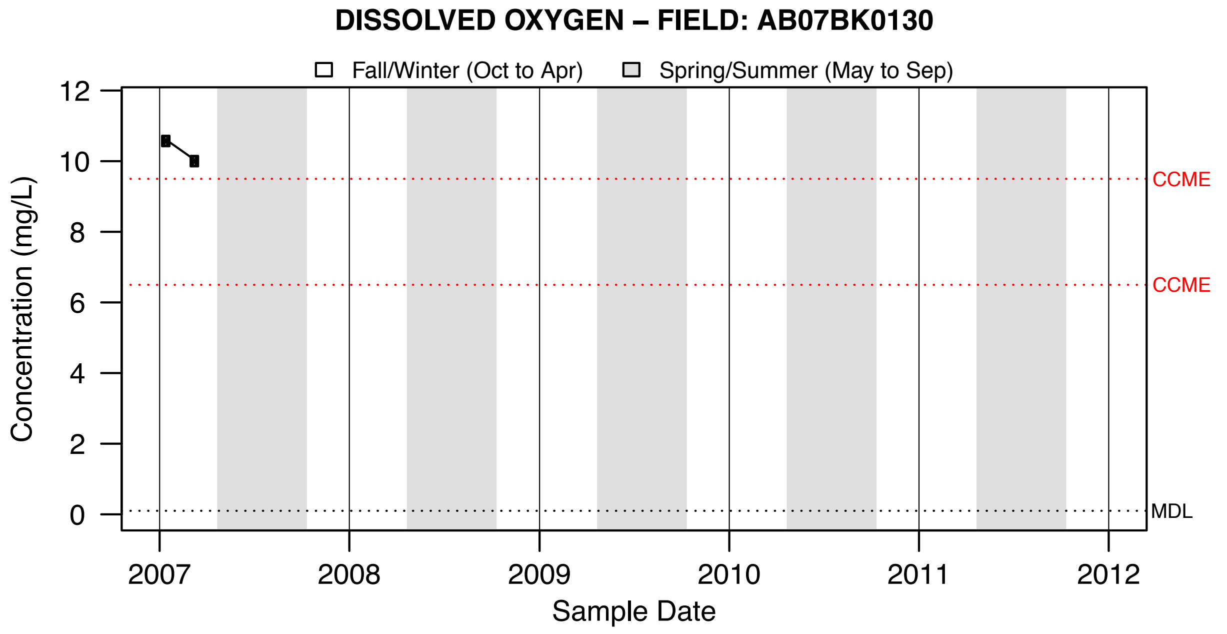


Figure A2.78: CHROMIUM DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A2.79: COPPER DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



Cold water biota: early life stages = 9.5 mg/L; other life stages = 6.5 mg/L

Figure A2.80: DISSOLVED OXYGEN - FIELD: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

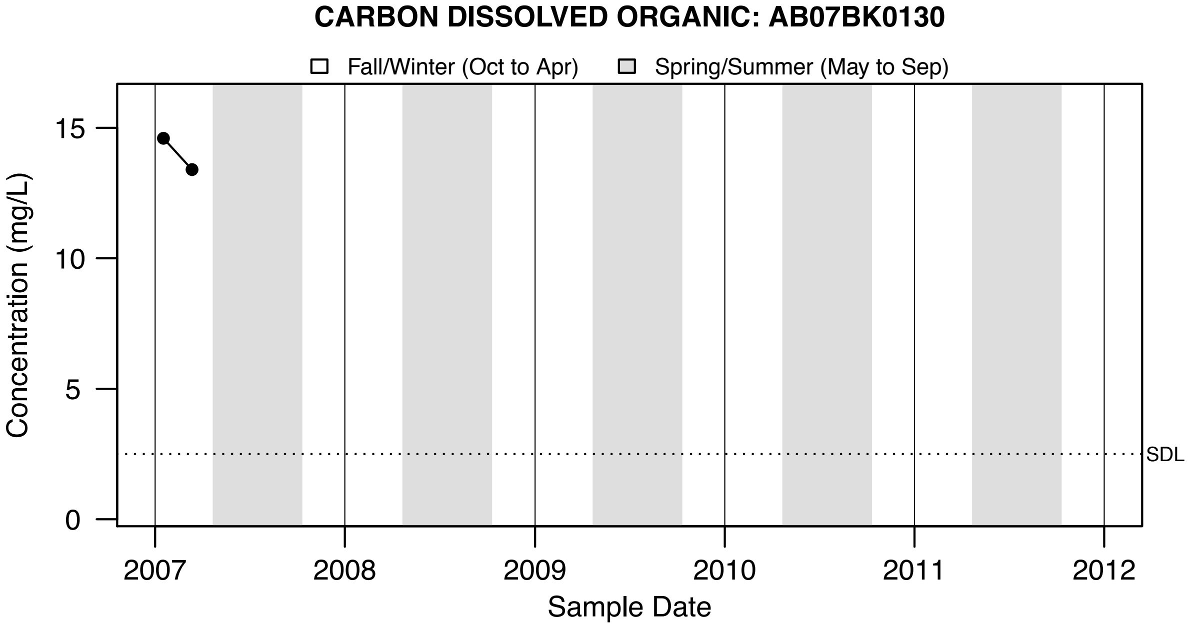


Figure A2.81: CARBON DISSOLVED ORGANIC: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

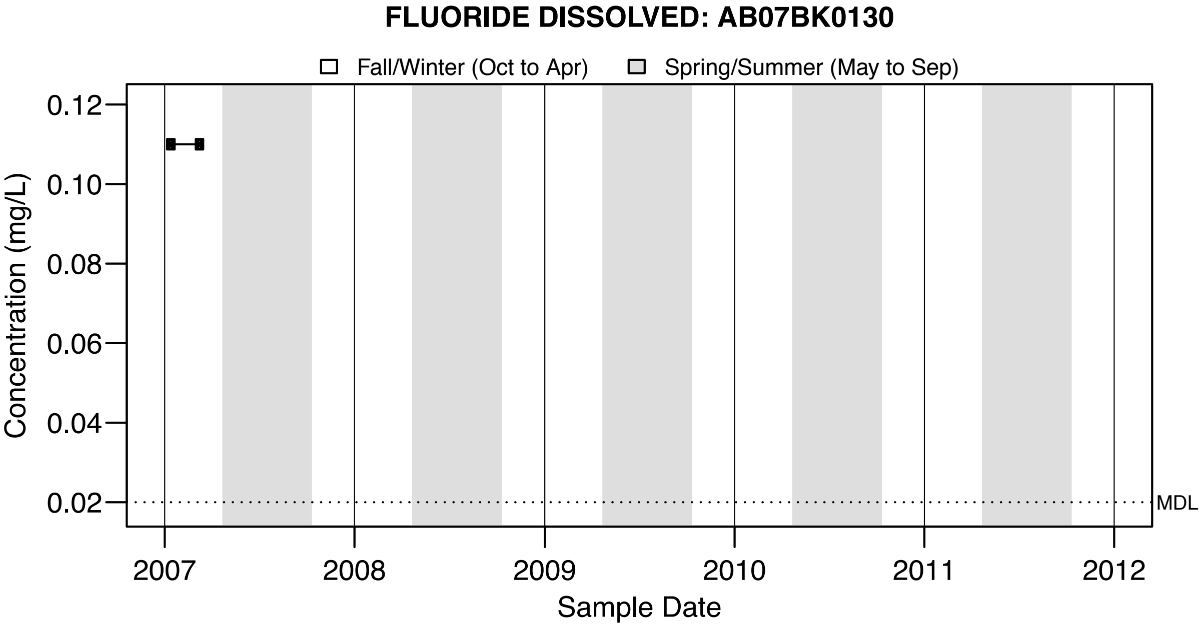


Figure A2.82: FLUORIDE DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

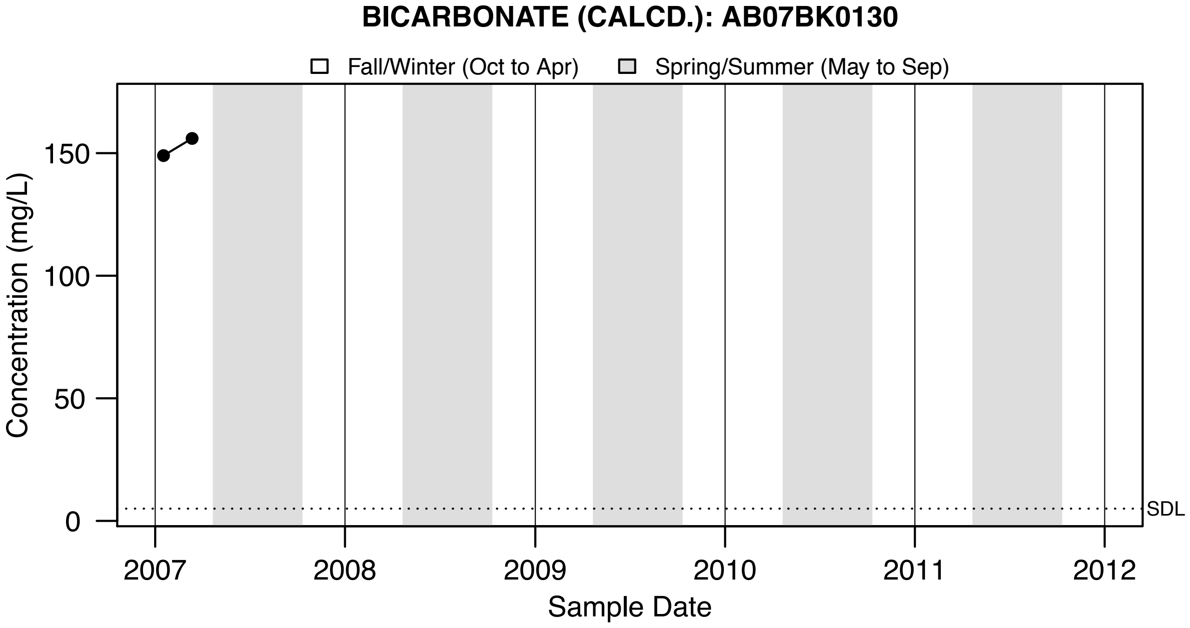


Figure A2.83: BICARBONATE (CALCD.): AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

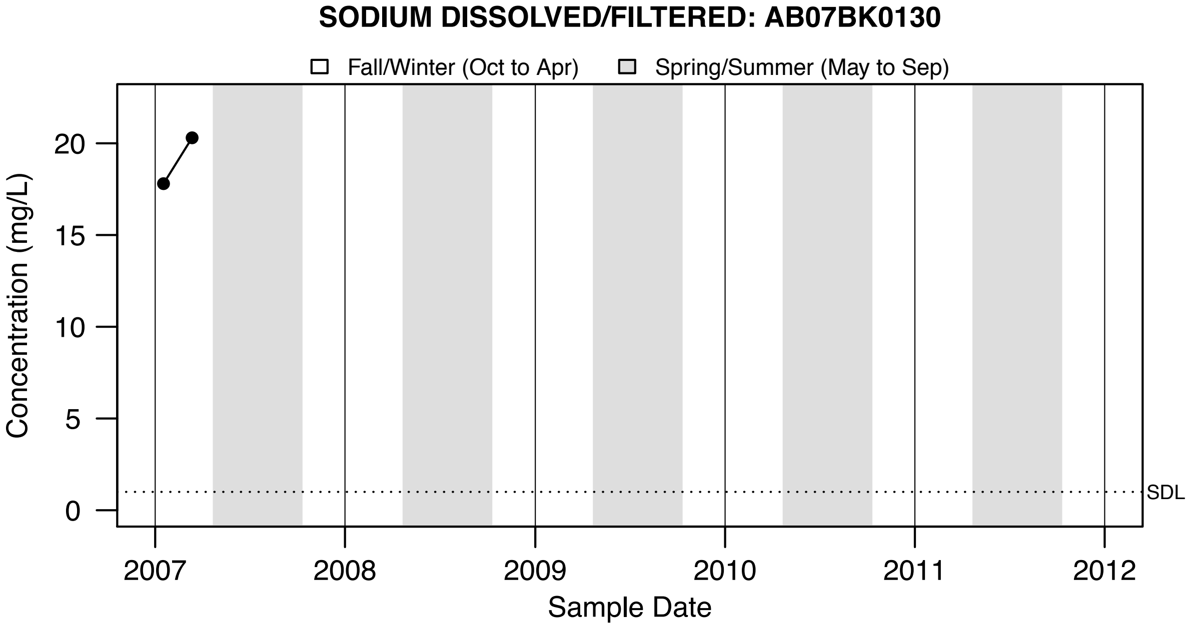


Figure A2.84: SODIUM DISSOLVED/FILTERED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

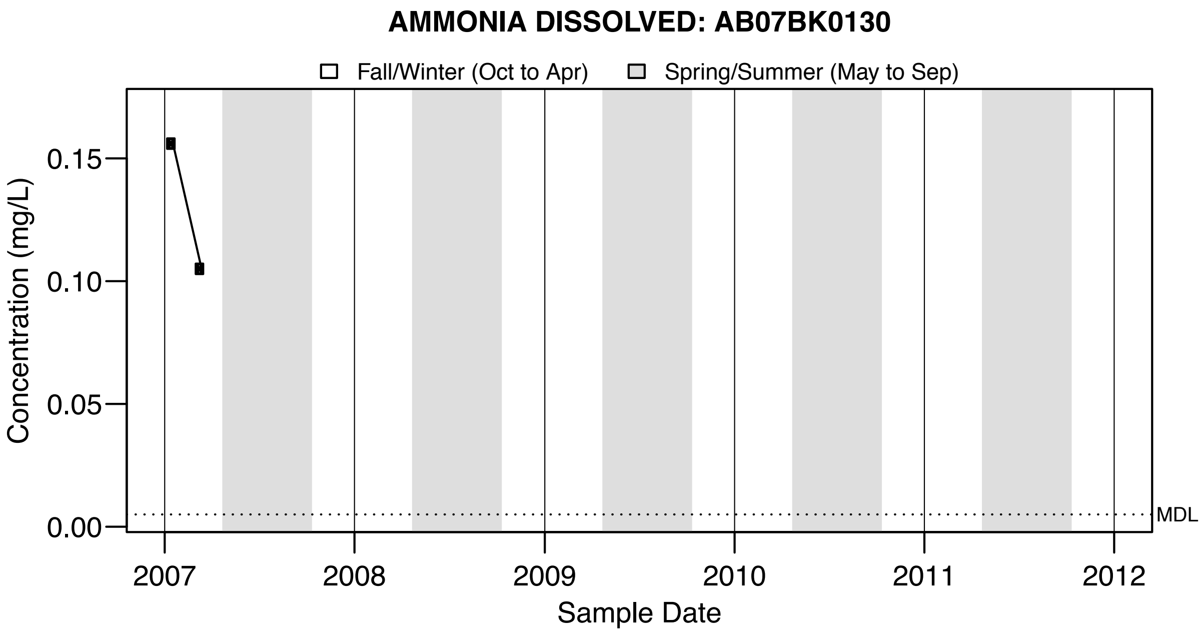
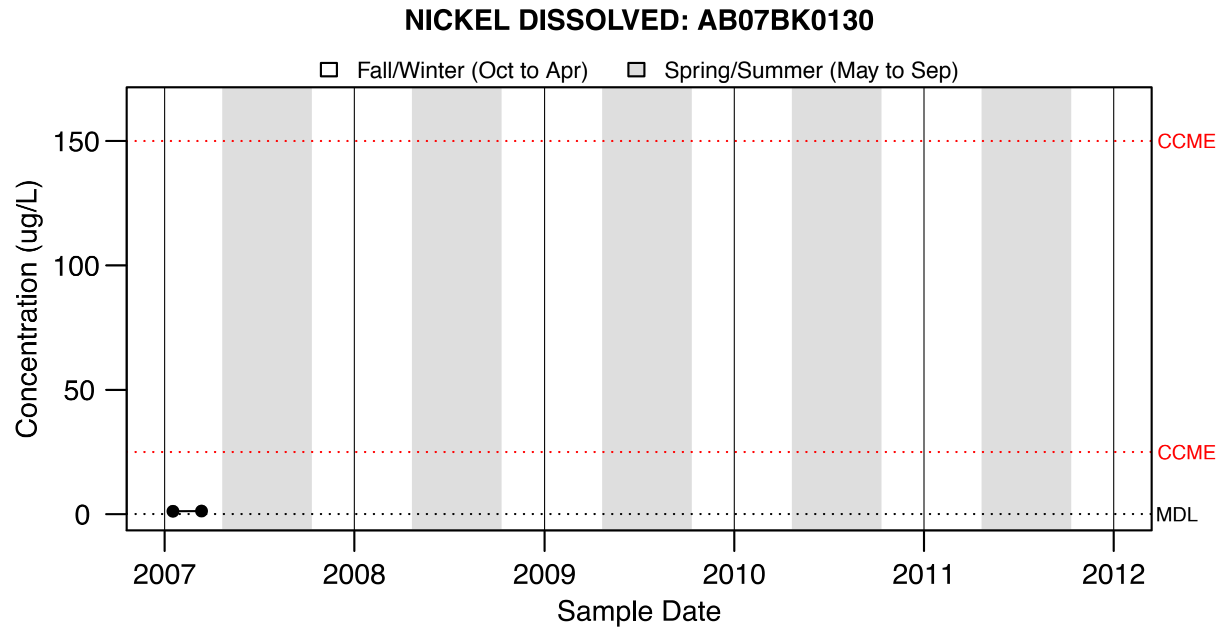


Figure A2.85: AMMONIA DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A2.86: NICKEL DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

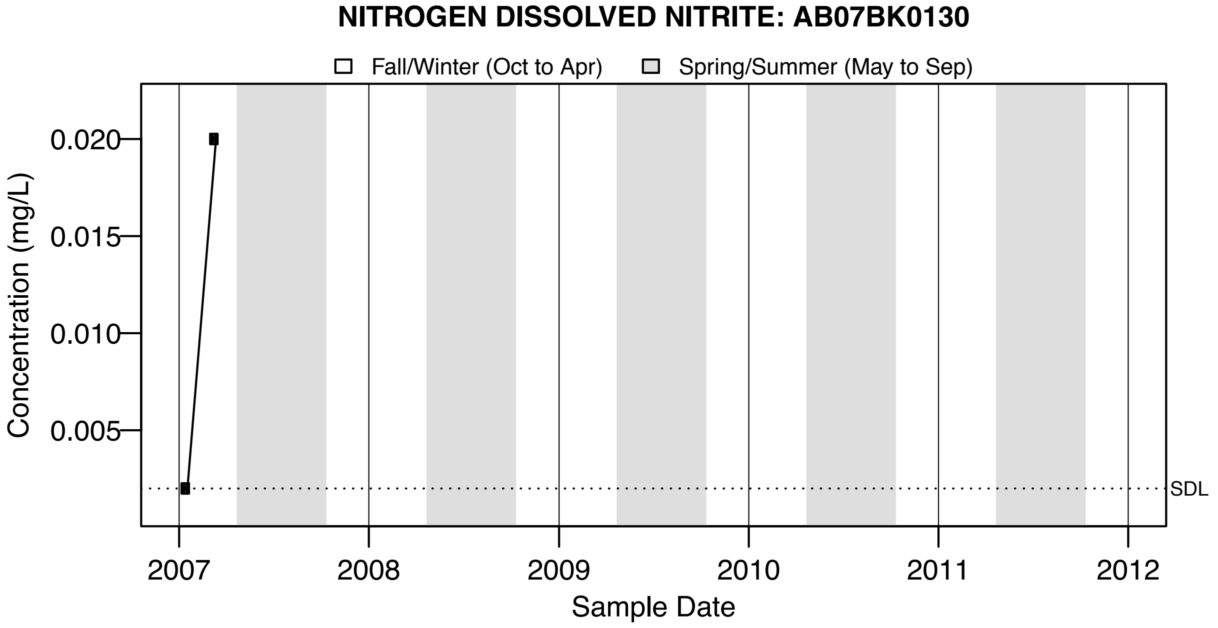


Figure A2.87: NITROGEN DISSOLVED NITRITE: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

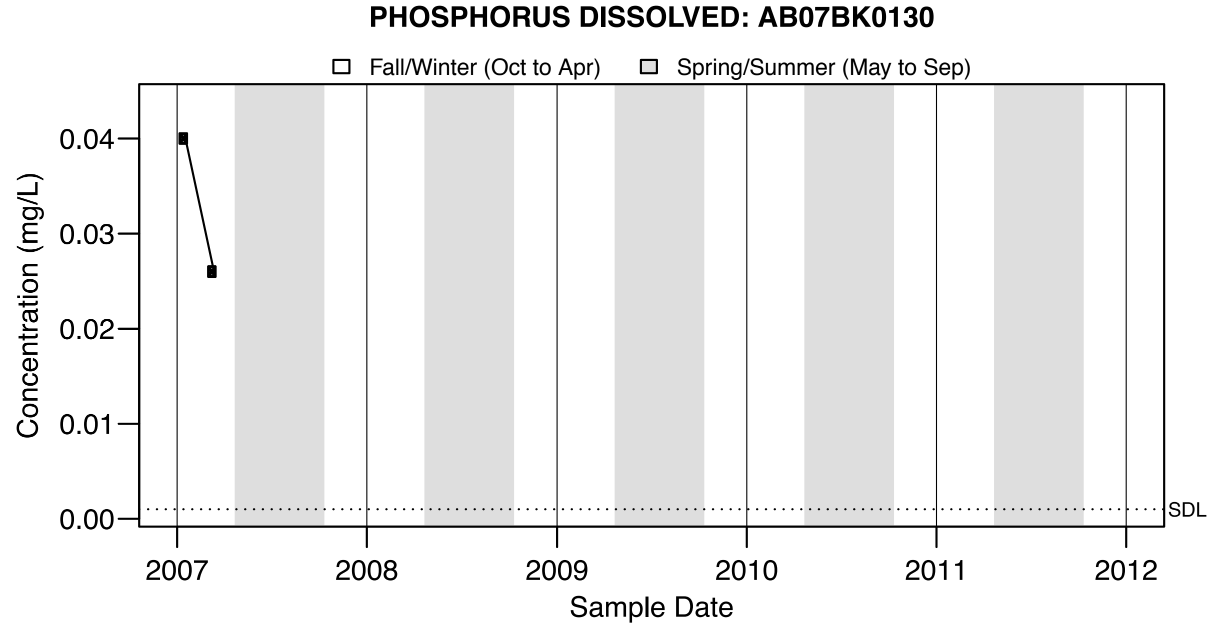


Figure A2.88: PHOSPHORUS DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

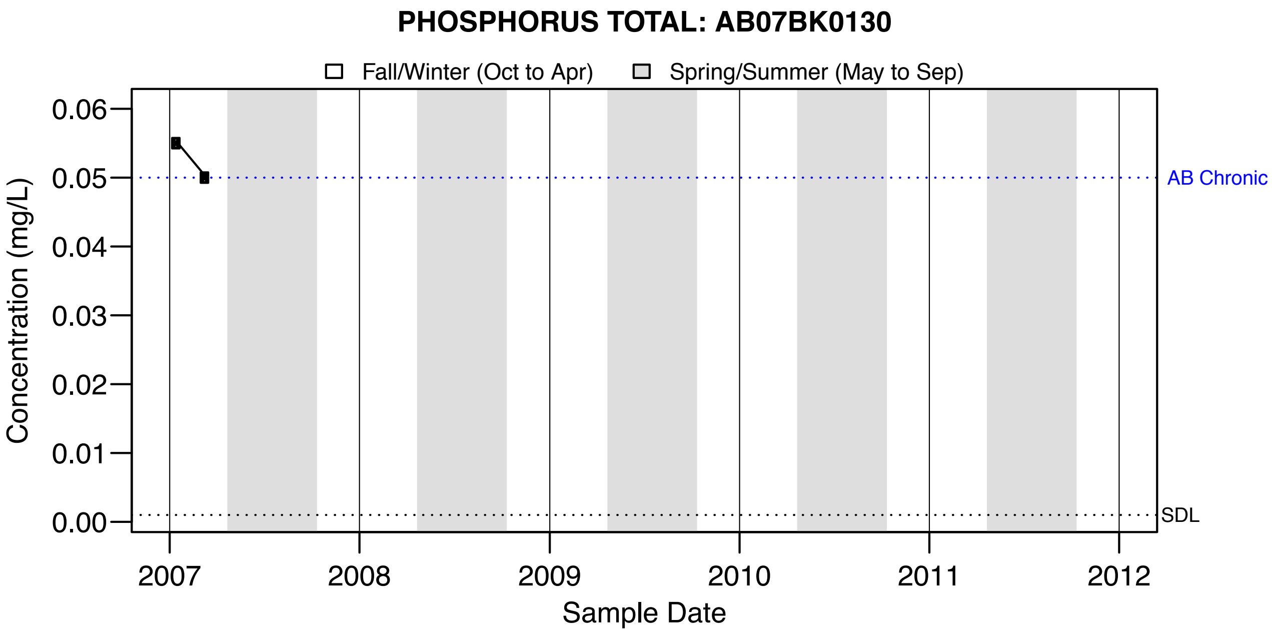
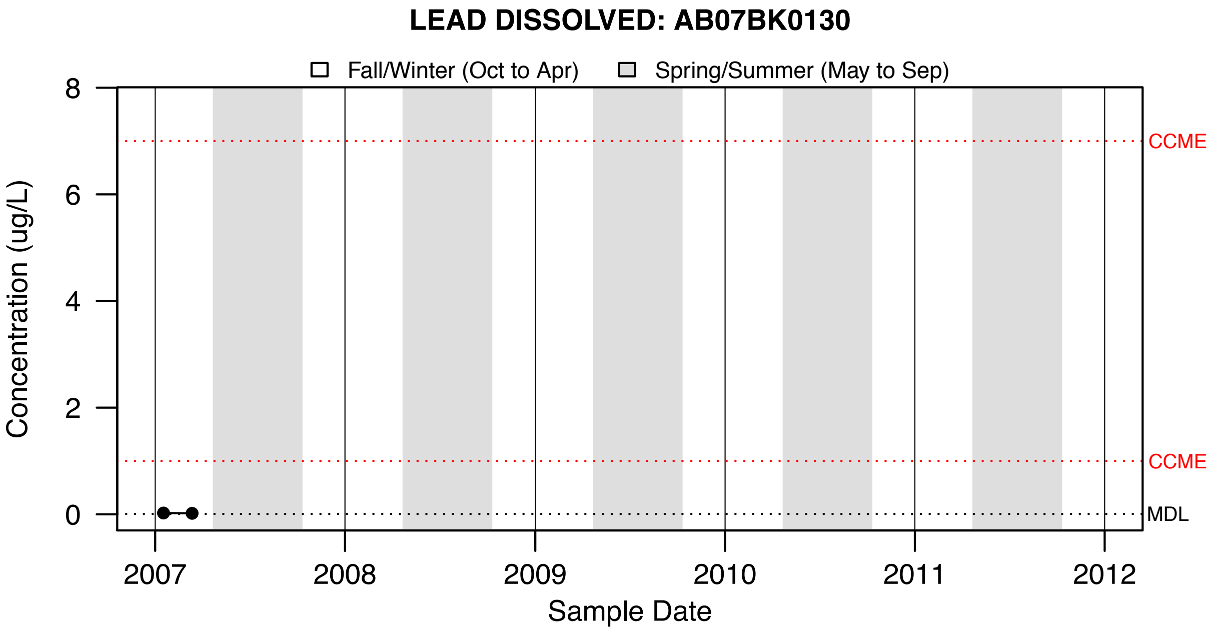


Figure A2.89: PHOSPHORUS TOTAL: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A2.90: LEAD DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

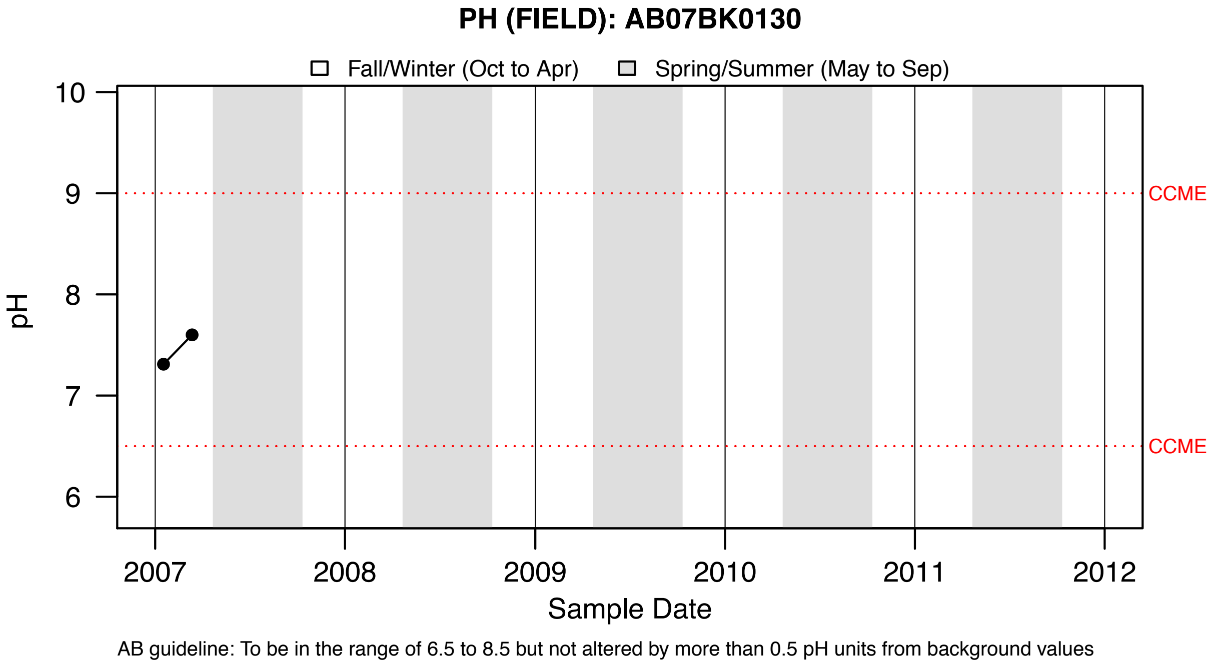


Figure A2.91: PH (FIELD): AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

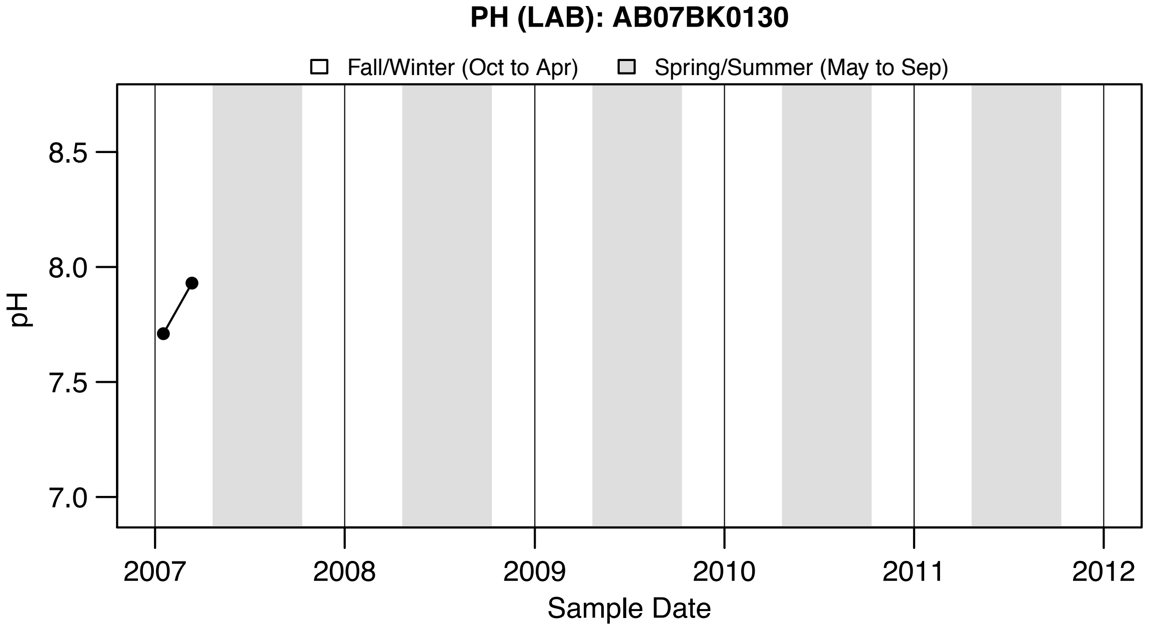


Figure A2.92: PH (LAB): AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

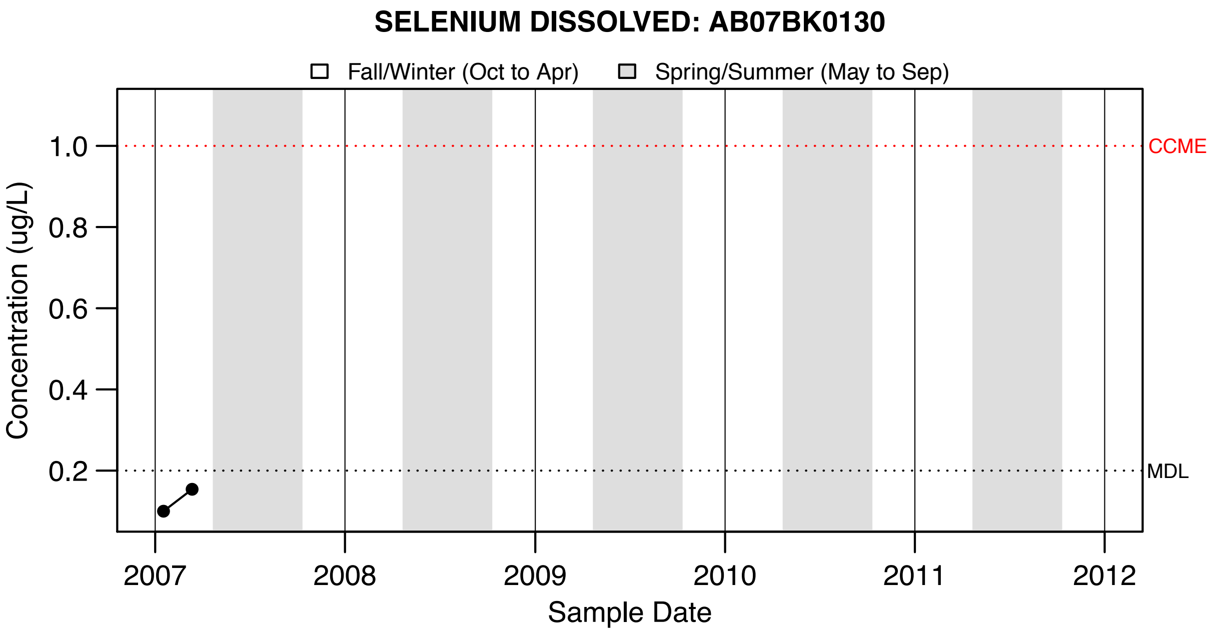


Figure A2.93: SELENIUM DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

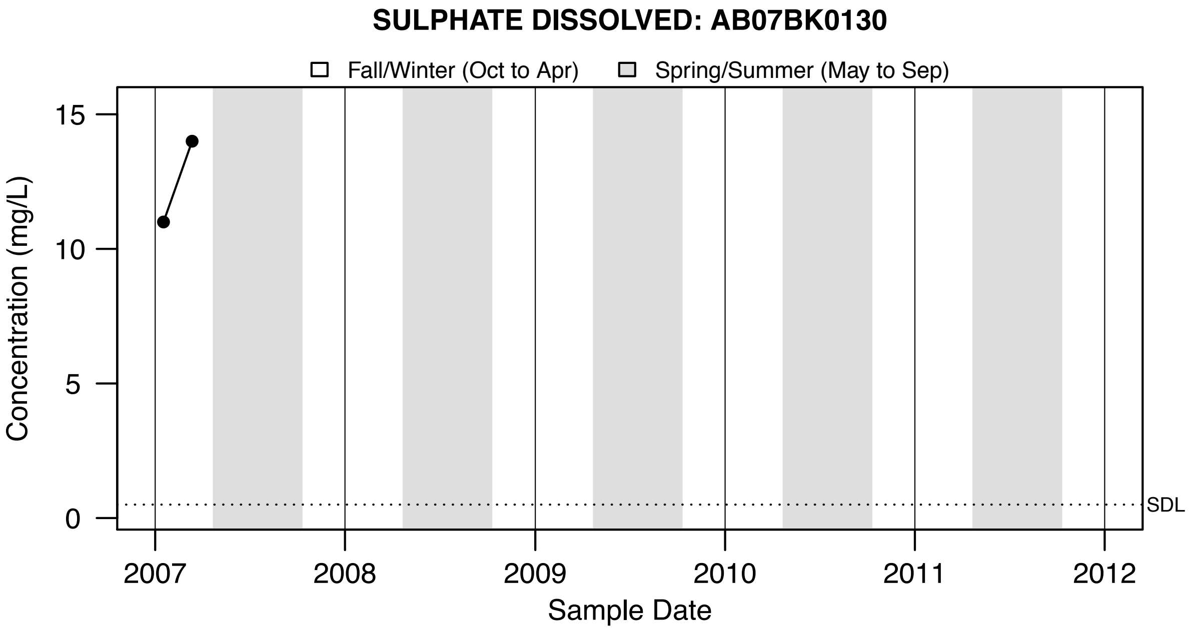


Figure A2.94: SULPHATE DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

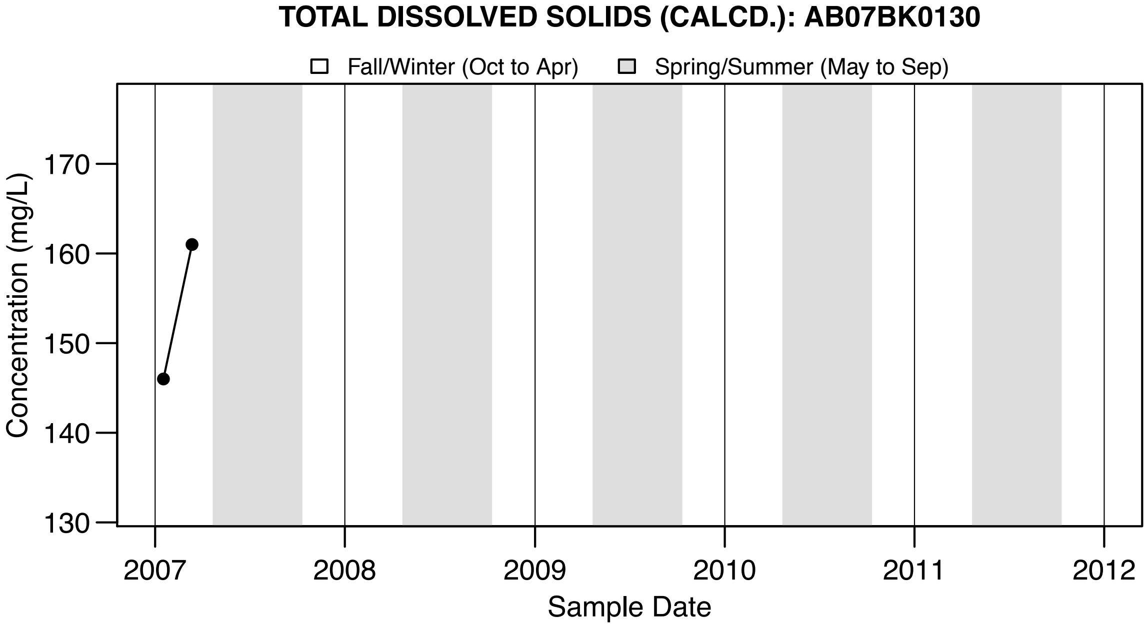


Figure A2.95: TOTAL DISSOLVED SOLIDS (CALCD.): AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

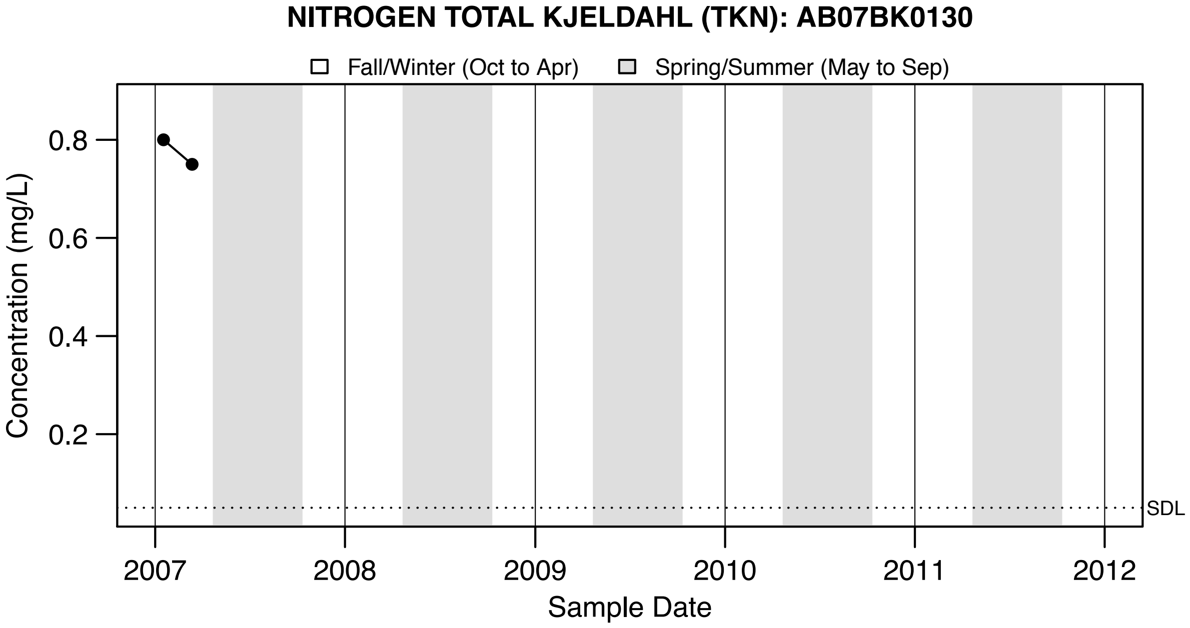
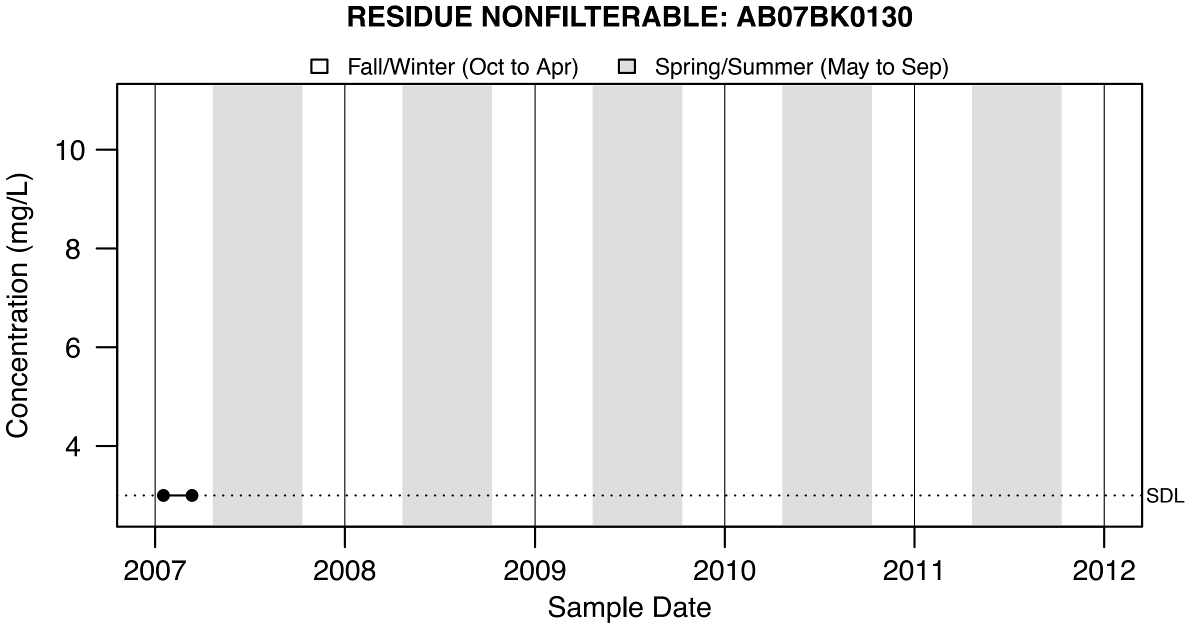


Figure A2.96: NITROGEN TOTAL KJELDAHL (TKN): AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A2.97: RESIDUE NONFILTERABLE: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

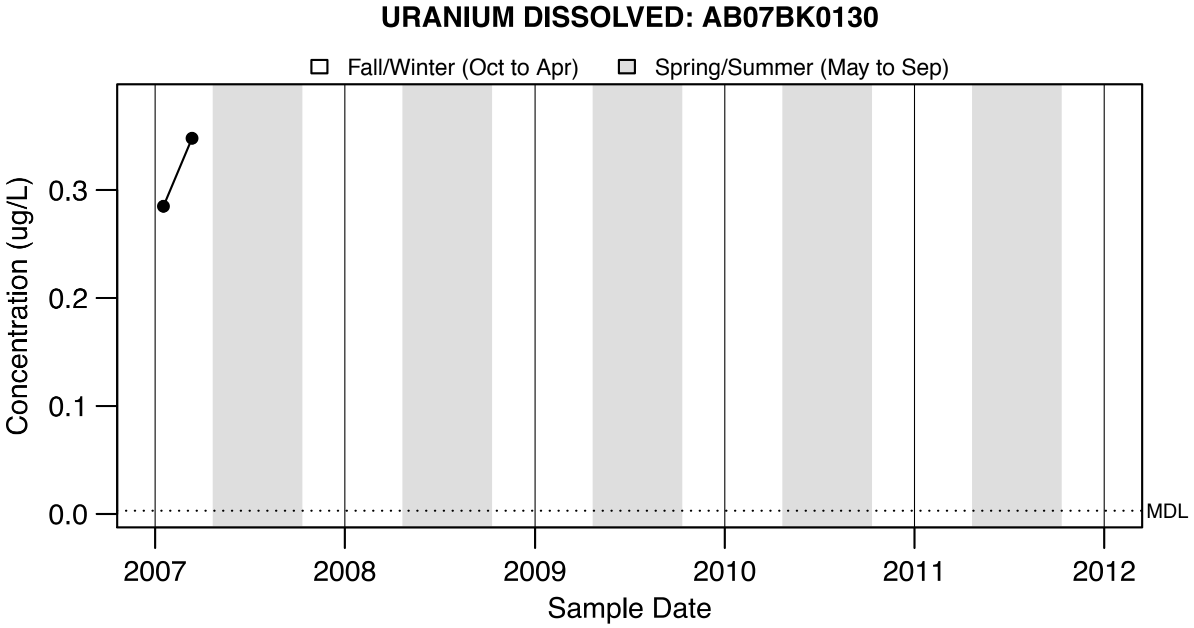


Figure A2.98: URANIUM DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

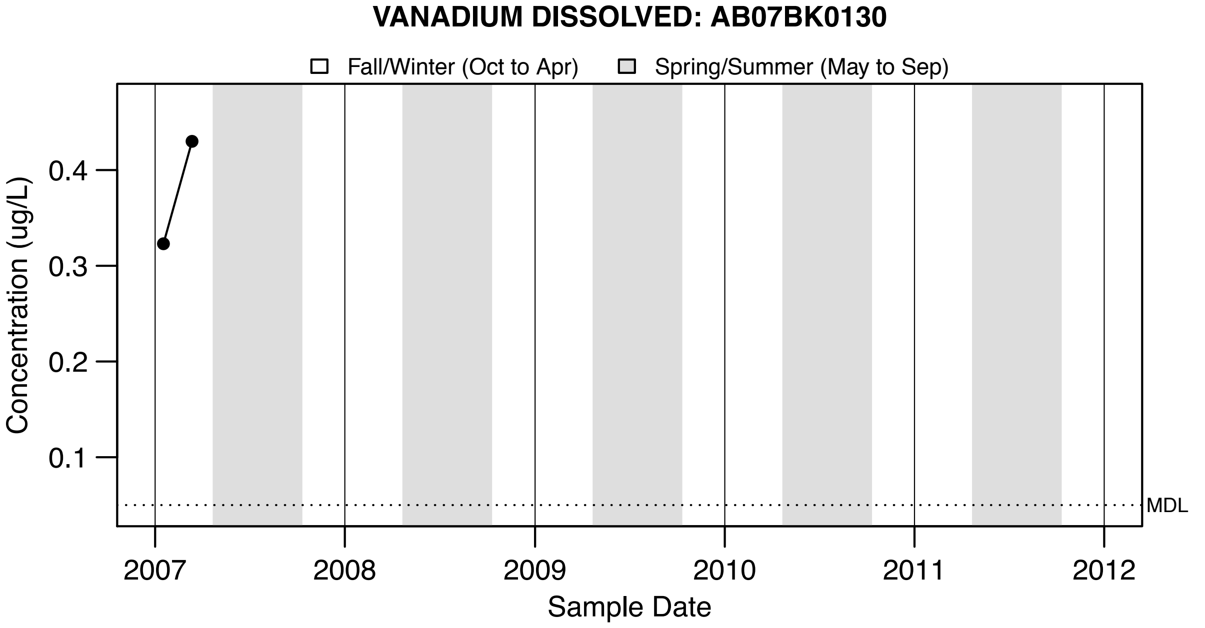


Figure A2.99: VANADIUM DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

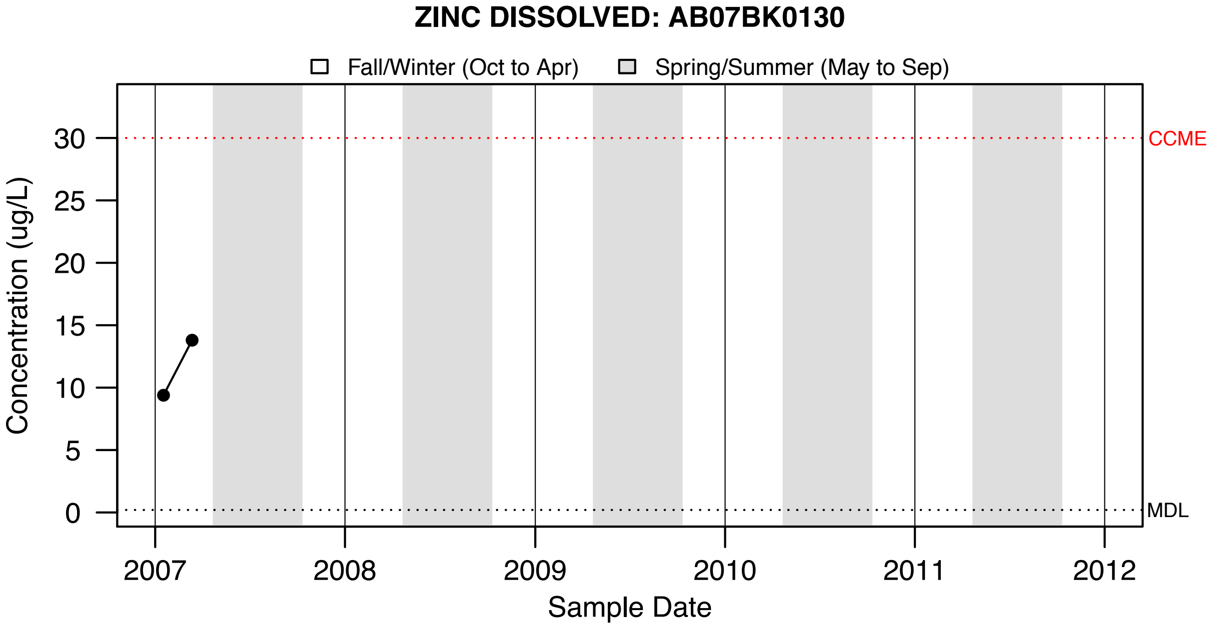
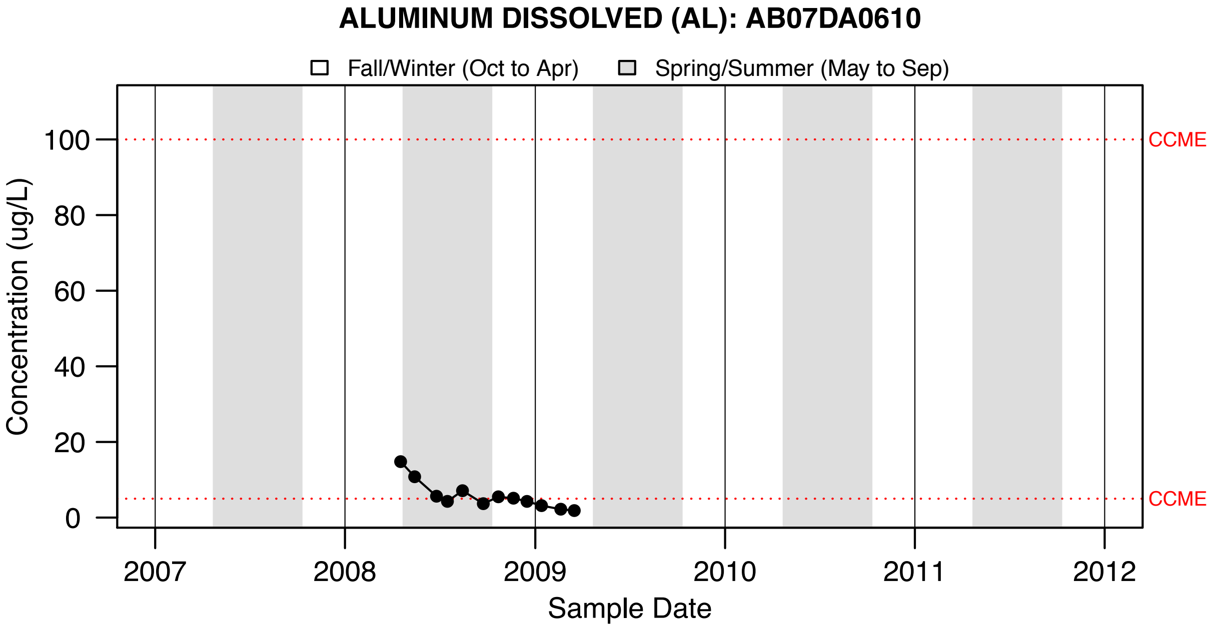


Figure A2.100: ZINC DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0

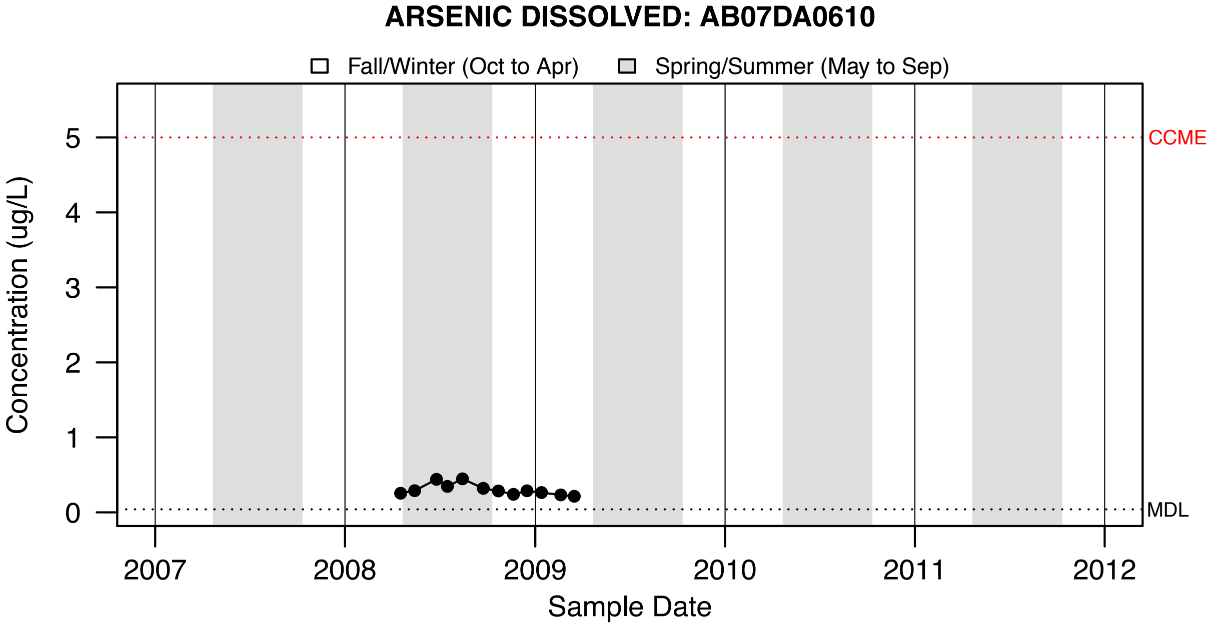
ALUMINUM DISSOLVED (AL): AB07DA0610



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A2.101: ALUMINUM DISSOLVED (AL): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

ARSENIC DISSOLVED: AB07DA0610



AB guidelines state Total Arsenic; CCME does not specify

Figure A2.102: ARSENIC DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

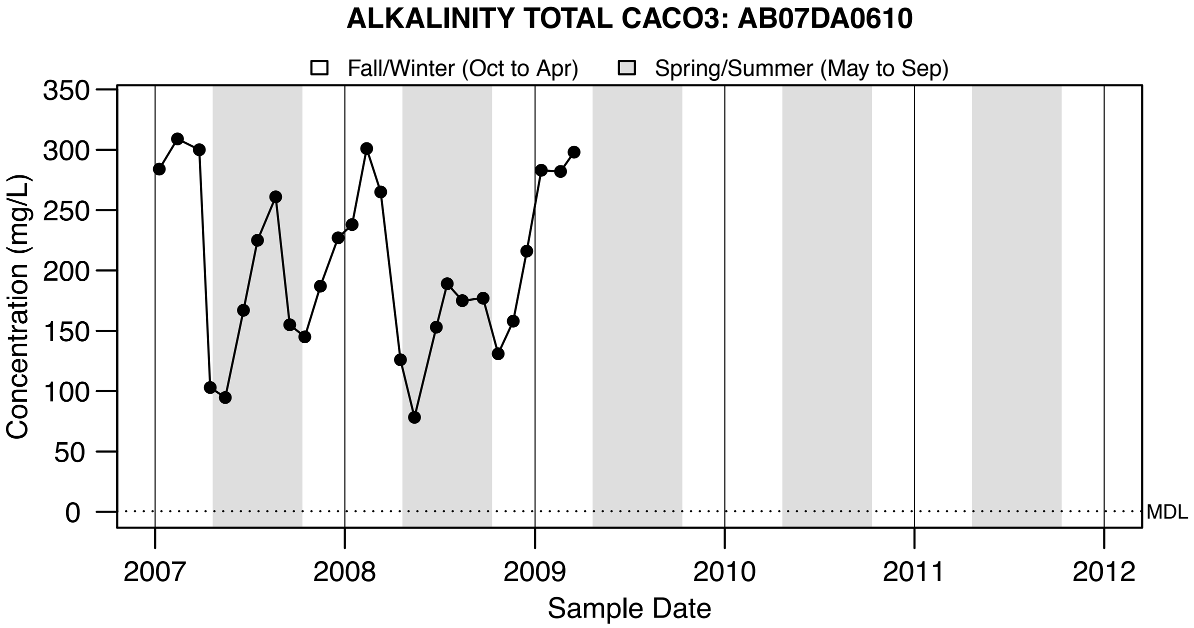


Figure A2.103: ALKALINITY TOTAL CACO3: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

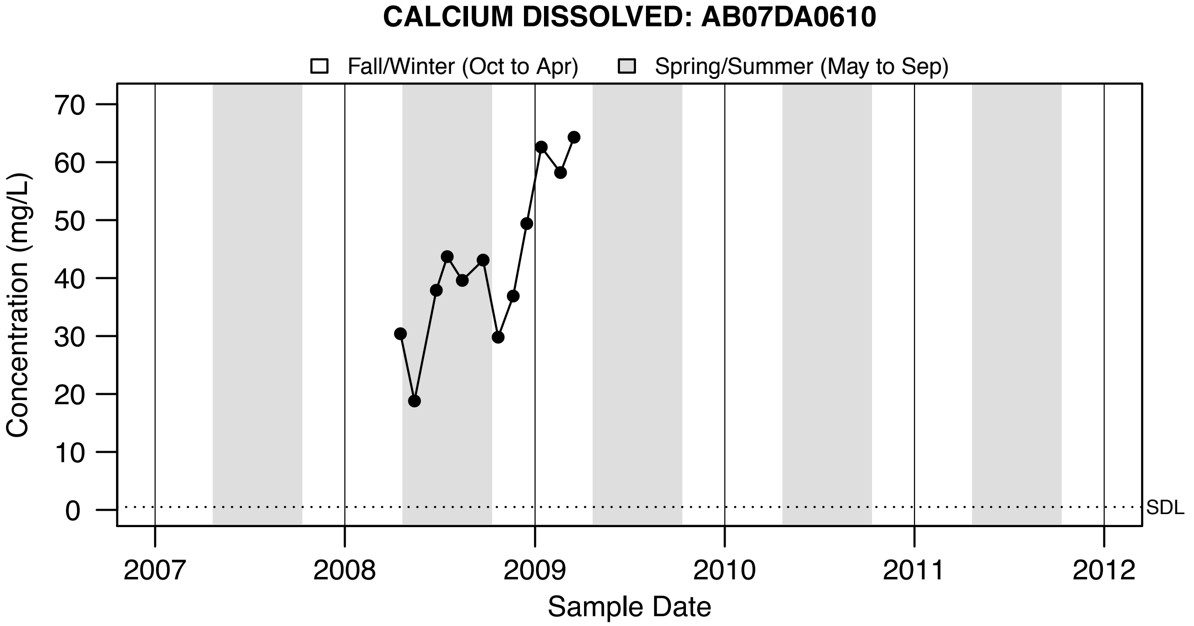


Figure A2.104: CALCIUM DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

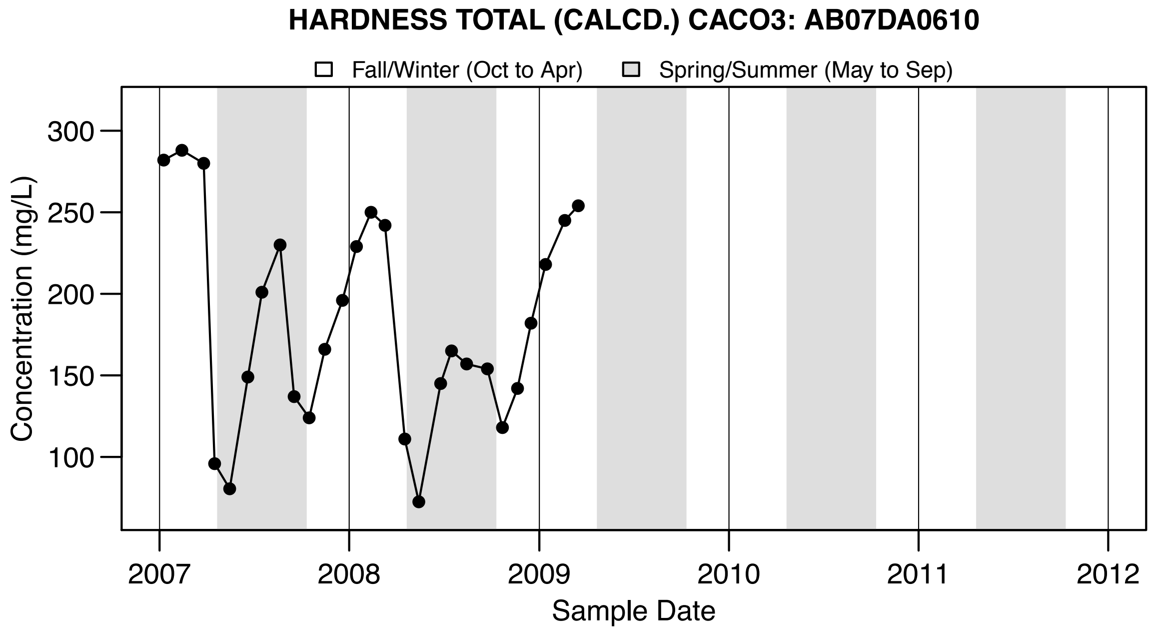


Figure A2.105: HARDNESS TOTAL (CALCD.) CACO3: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

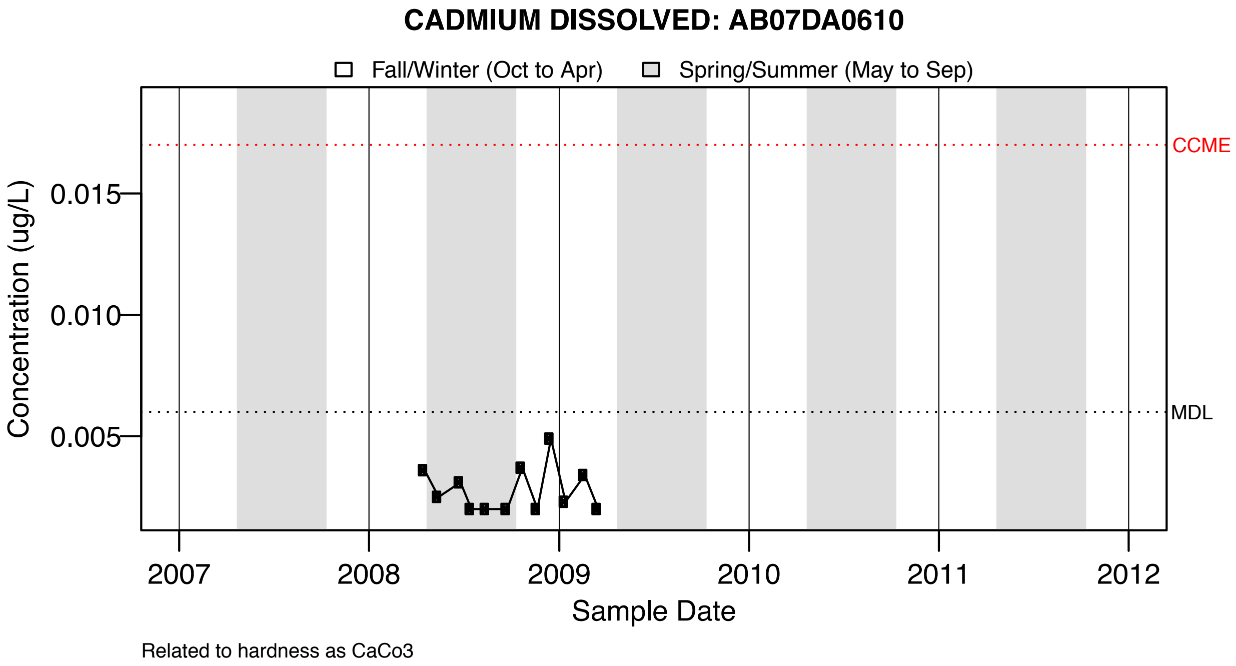


Figure A2.106: CADMIUM DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

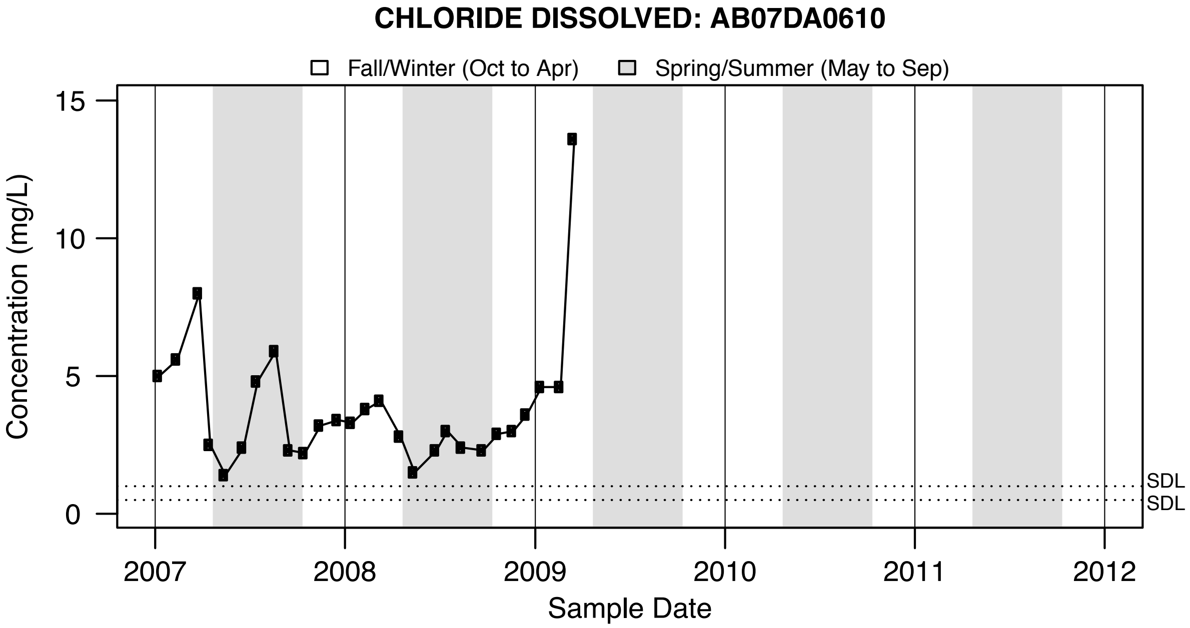


Figure A2.107: CHLORIDE DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

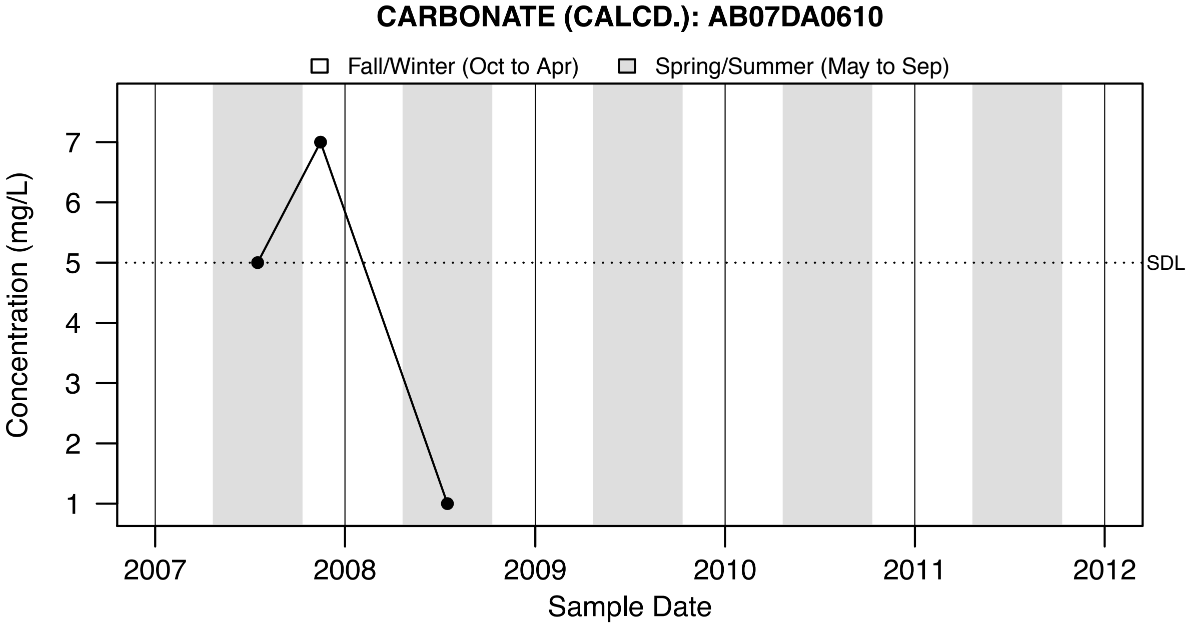


Figure A2.108: CARBONATE (CALCD.): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

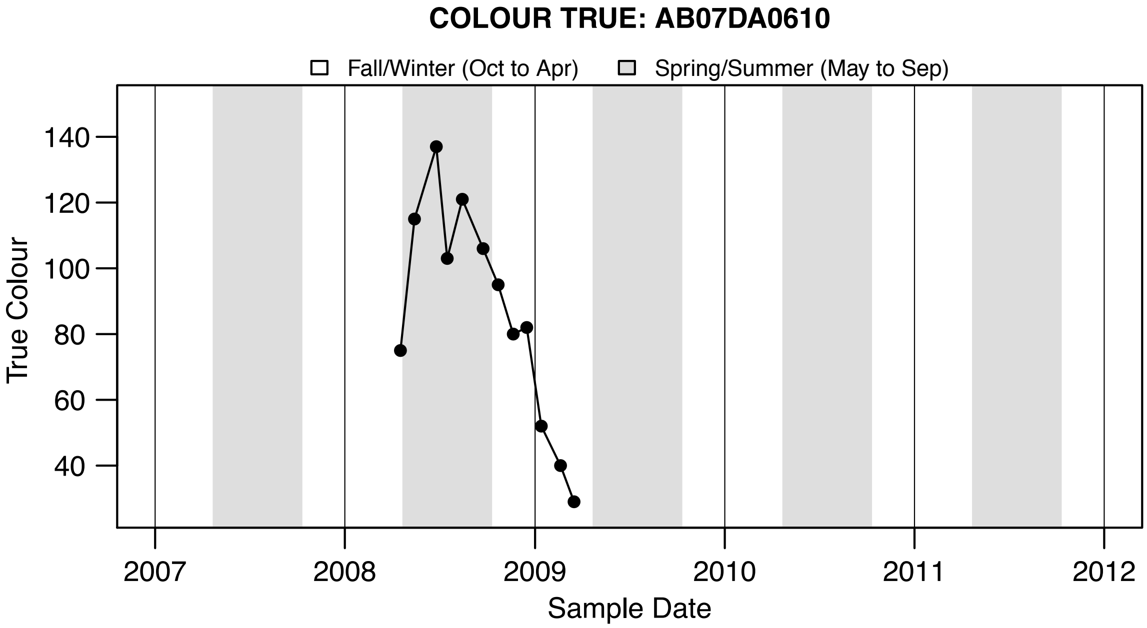
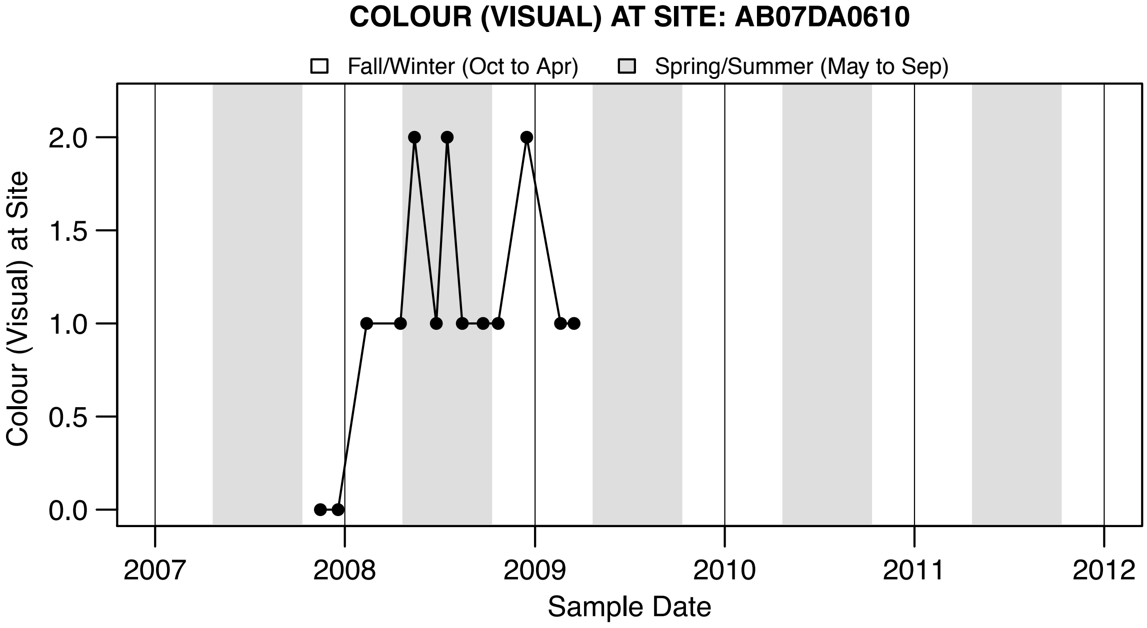


Figure A2.109: COLOUR TRUE: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



AB guideline: Not to be increased more than 30 colour units above natural value

Figure A2.110: COLOUR (VISUAL) AT SITE: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

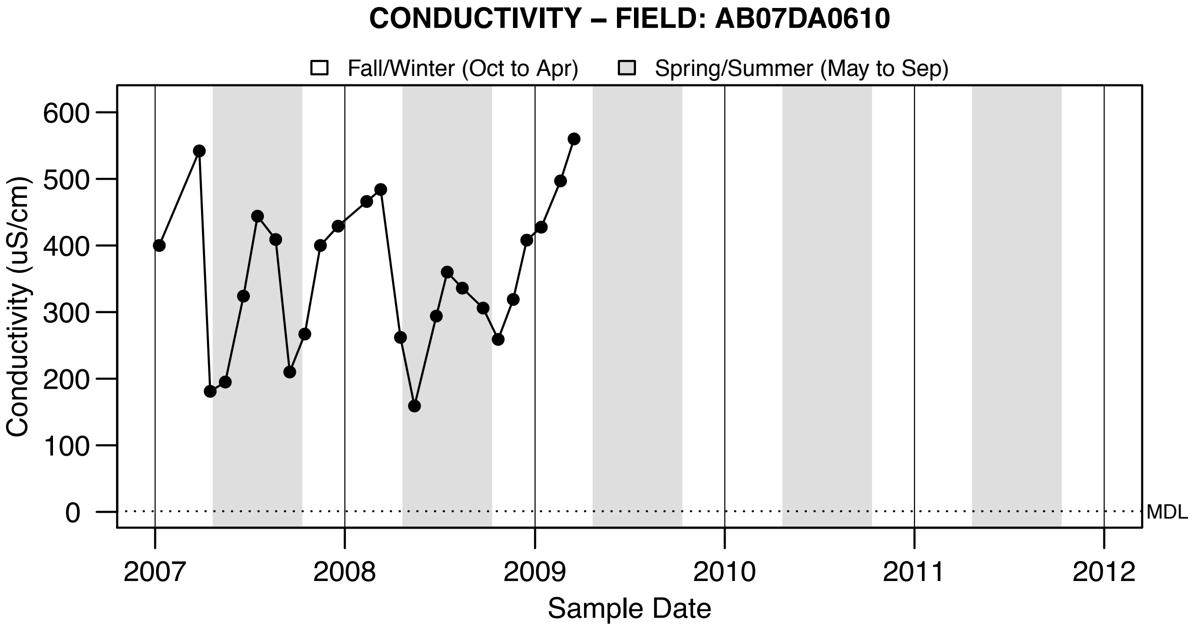


Figure A2.111: CONDUCTIVITY - FIELD: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

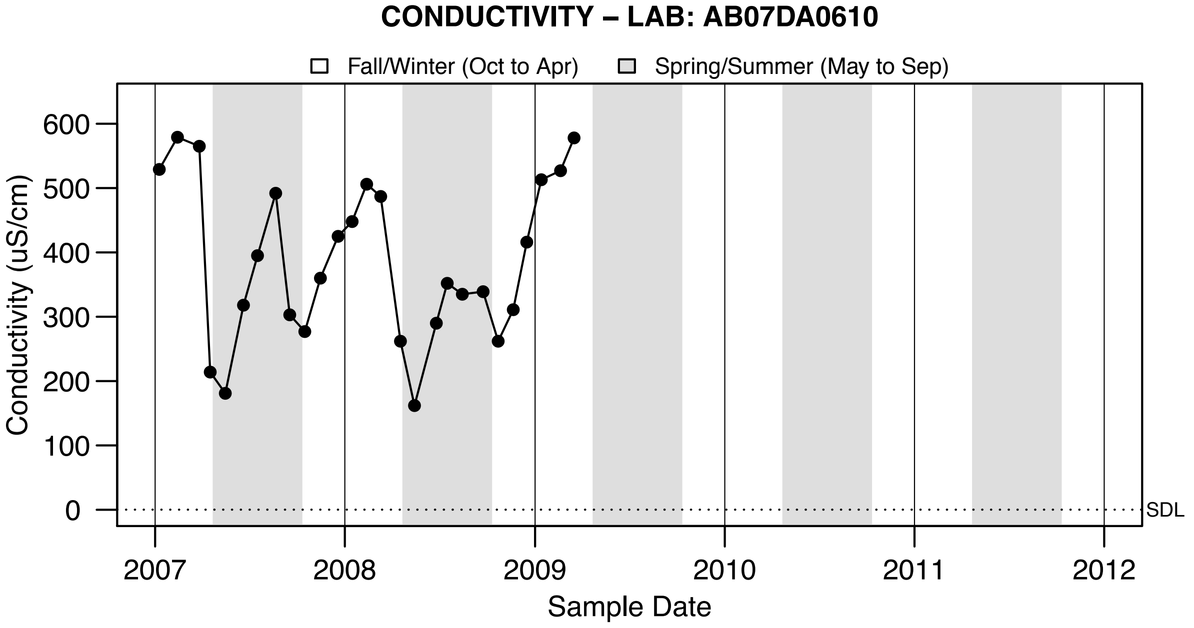
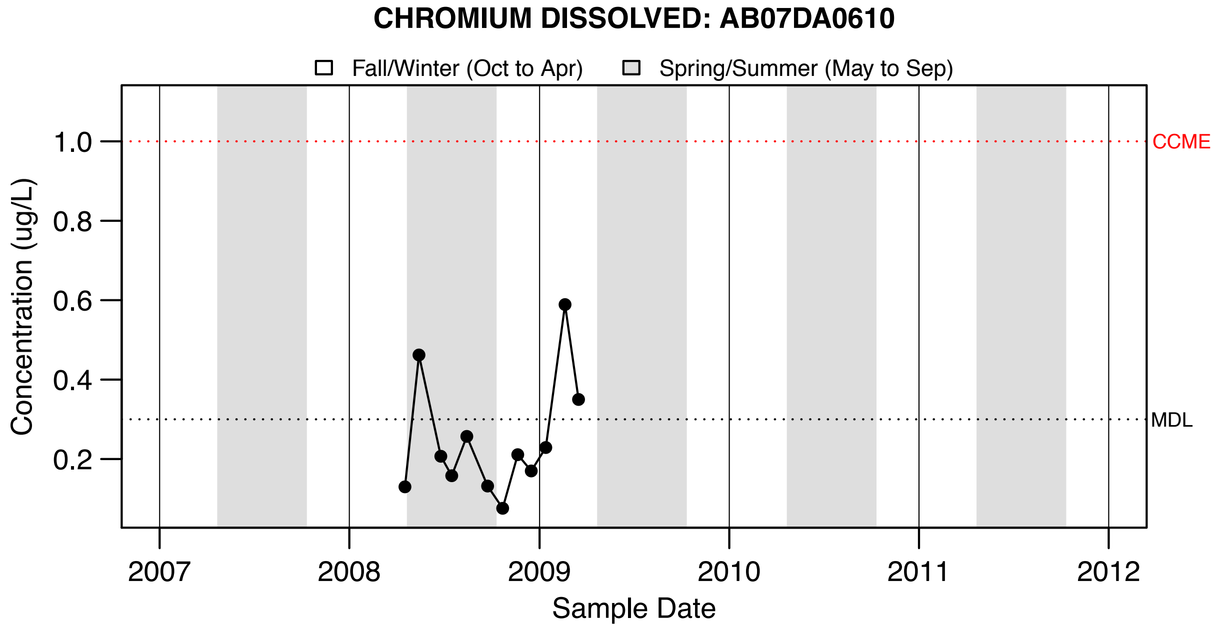
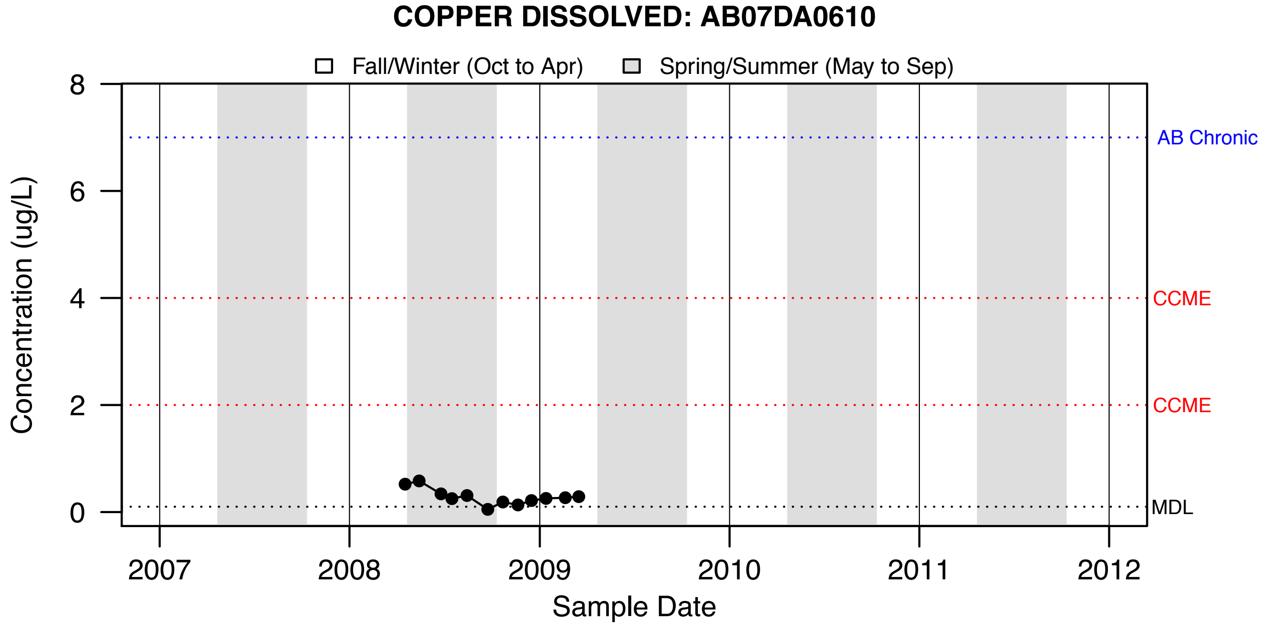


Figure A2.112: CONDUCTIVITY - LAB: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



Chromium III: 8.9 Chromium VI: 1.0

Figure A2.113: CHROMIUM DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid−extractable copper concentrations

Figure A2.114: COPPER DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

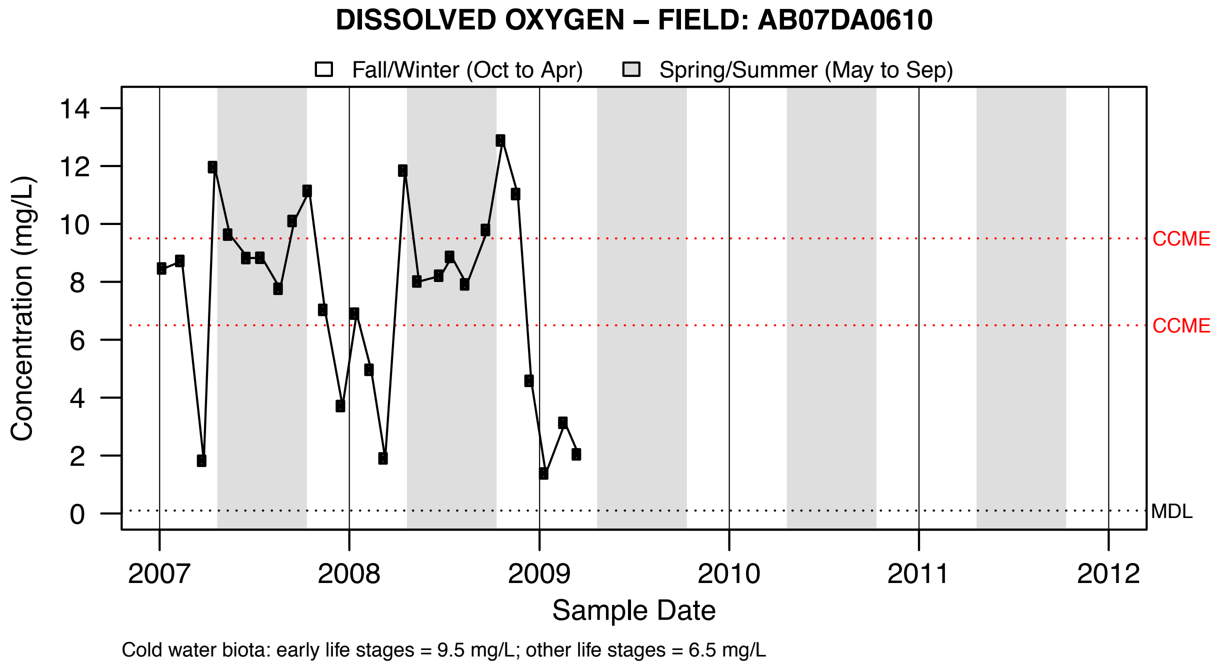


Figure A2.115: DISSOLVED OXYGEN - FIELD: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

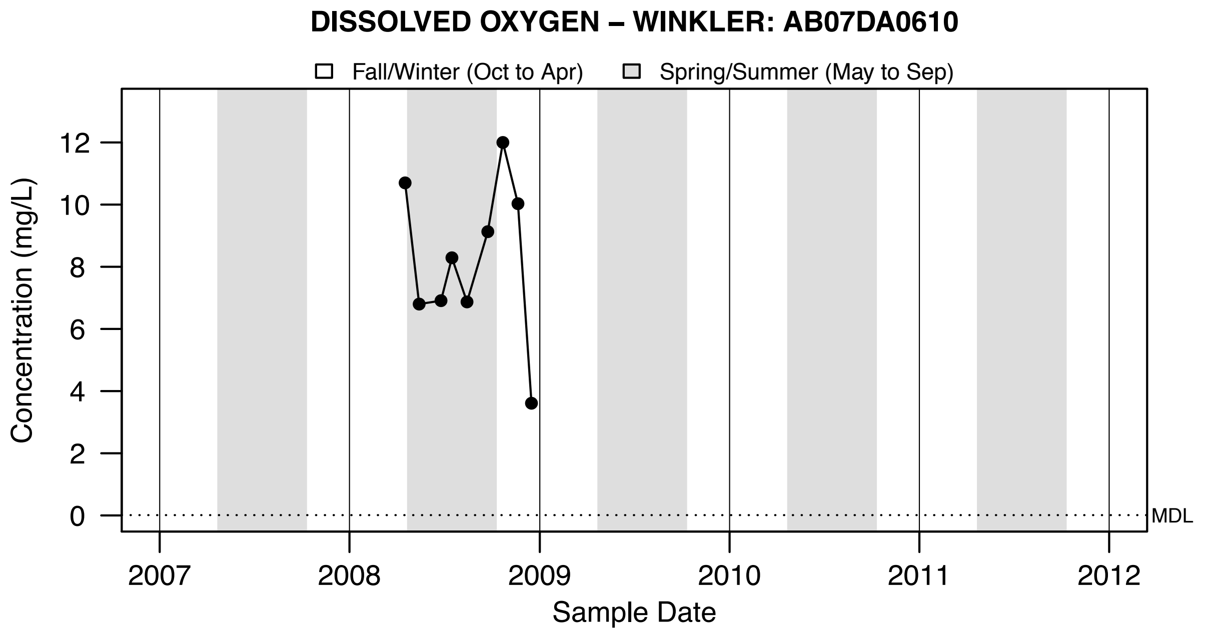


Figure A2.116: DISSOLVED OXYGEN - WINKLER: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

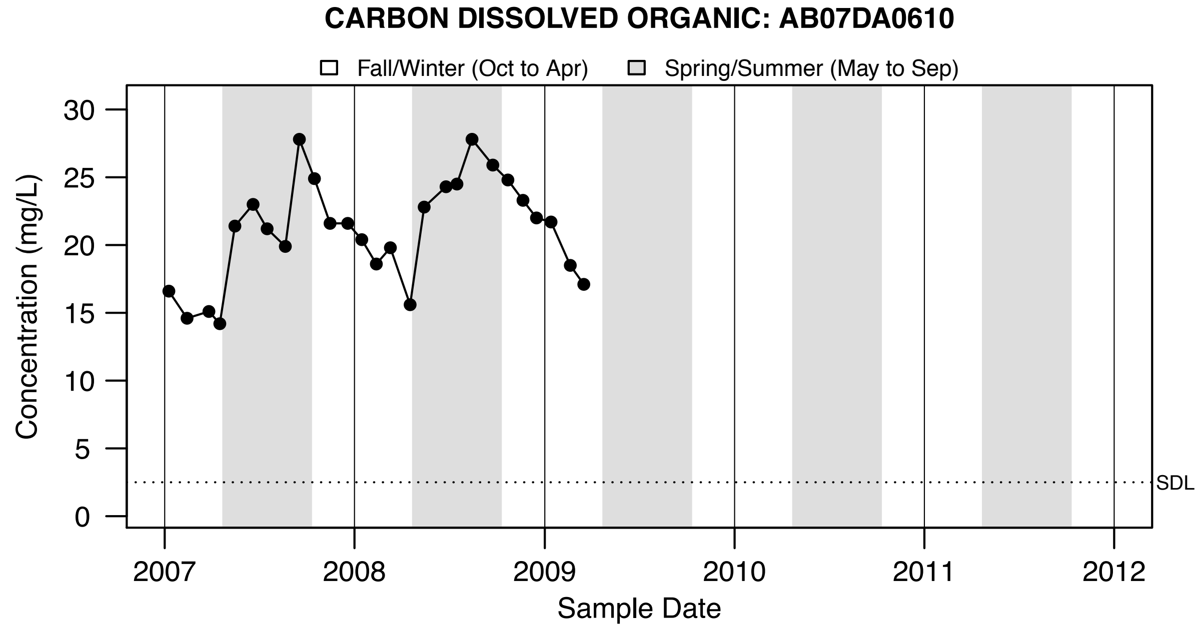


Figure A2.117: CARBON DISSOLVED ORGANIC: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

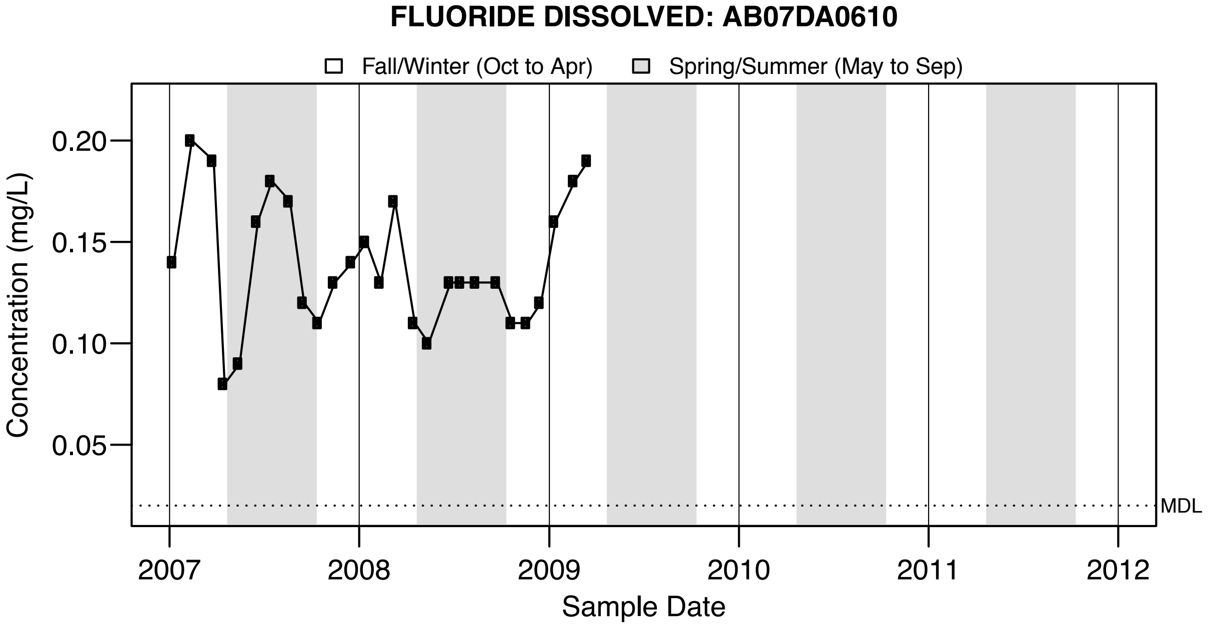


Figure A2.118: FLUORIDE DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

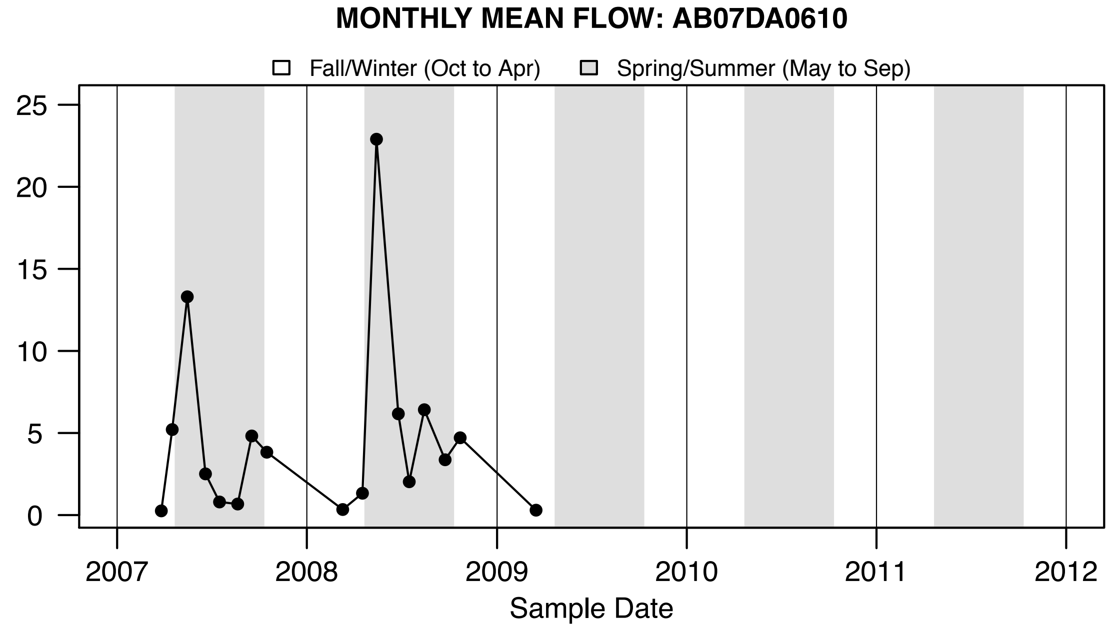


Figure A2.119: MONTHLY MEAN FLOW: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

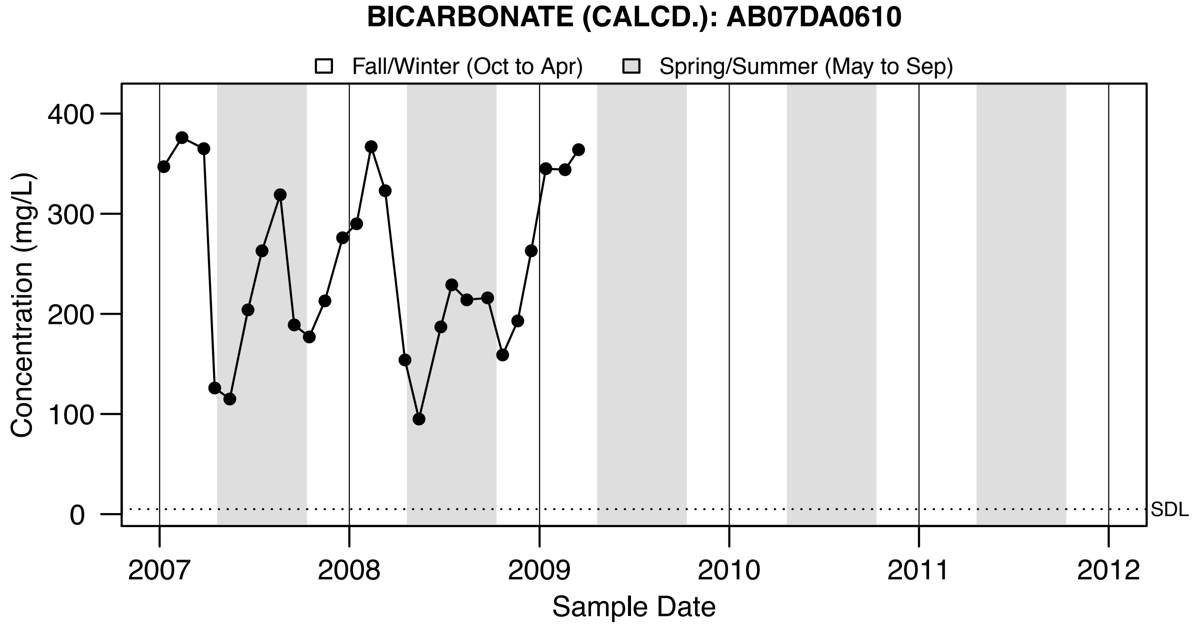


Figure A2.120: BICARBONATE (CALCD.): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

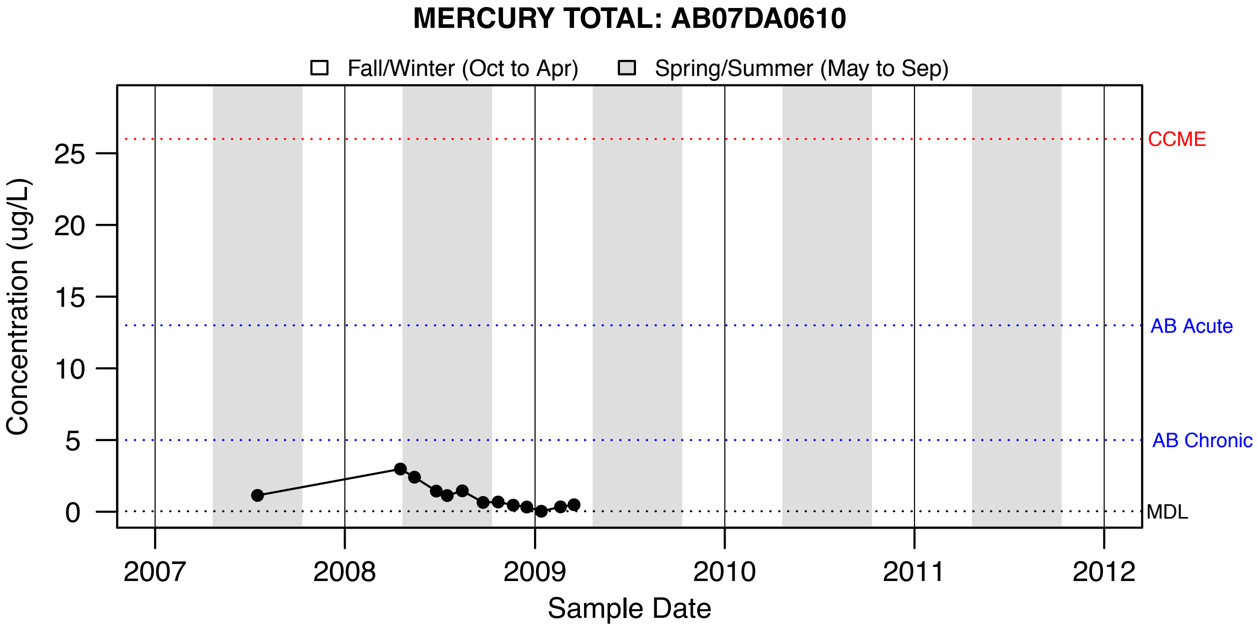


Figure A2.121: MERCURY TOTAL: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

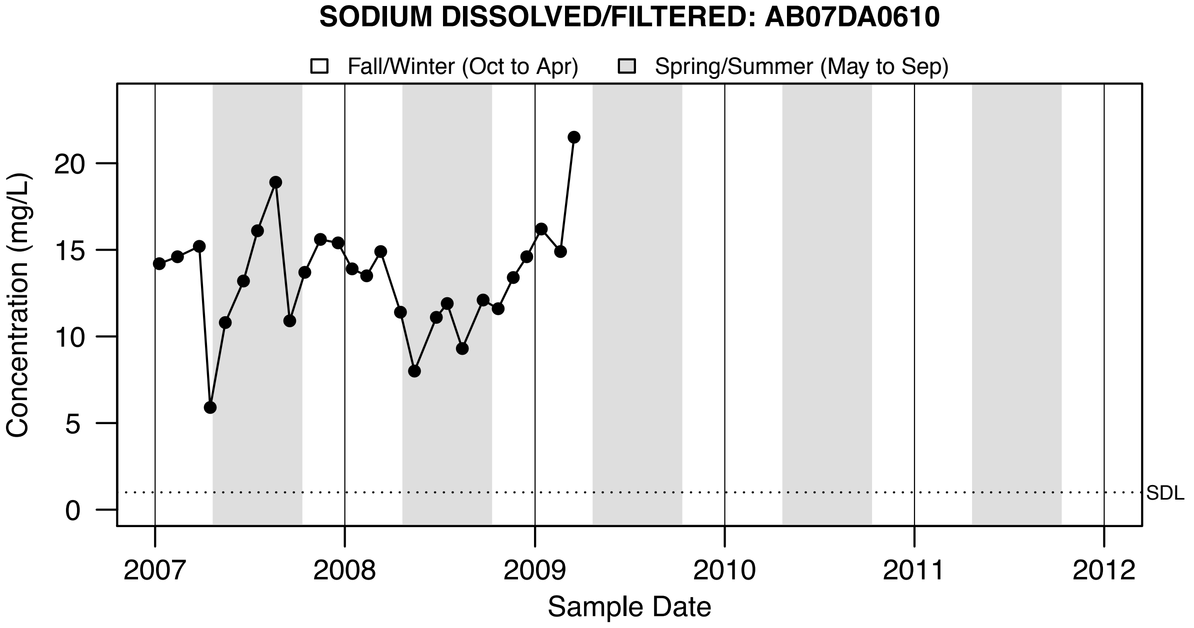


Figure A2.122: SODIUM DISSOLVED/FILTERED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

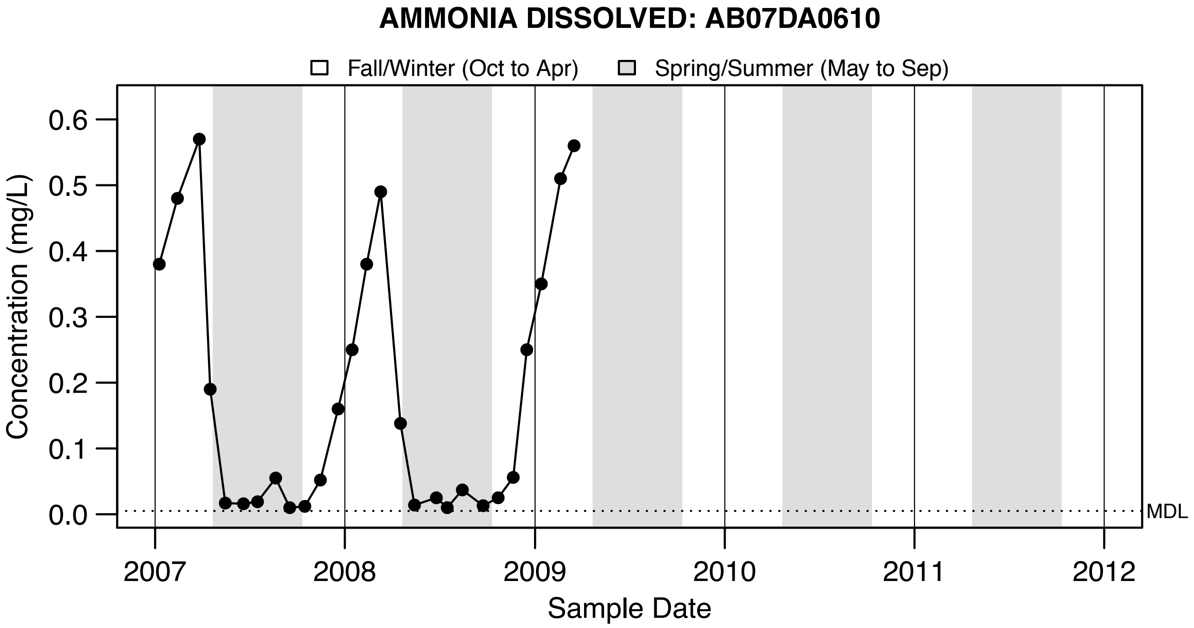
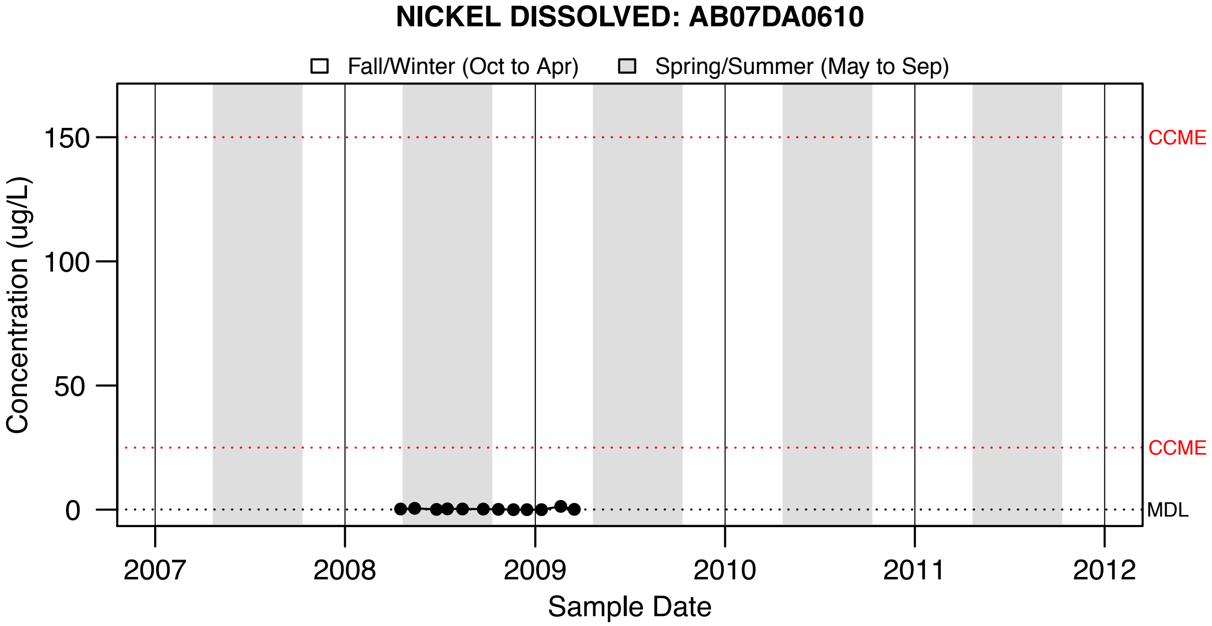


Figure A2.123: AMMONIA DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A2.124: NICKEL DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

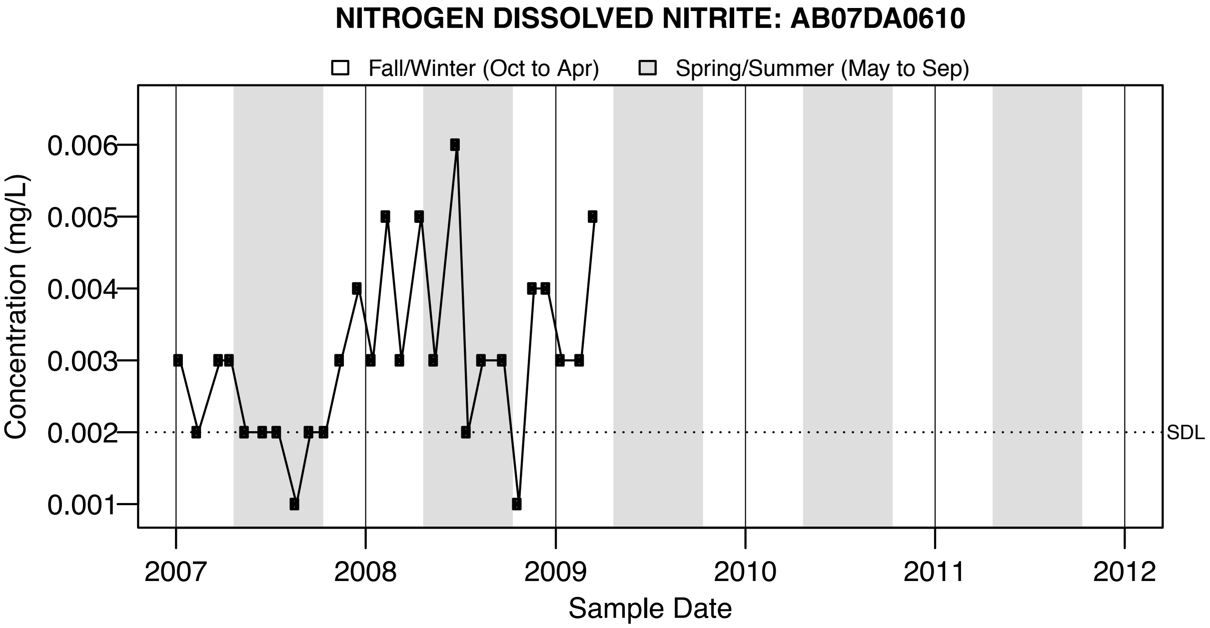


Figure A2.125: NITROGEN DISSOLVED NITRITE: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

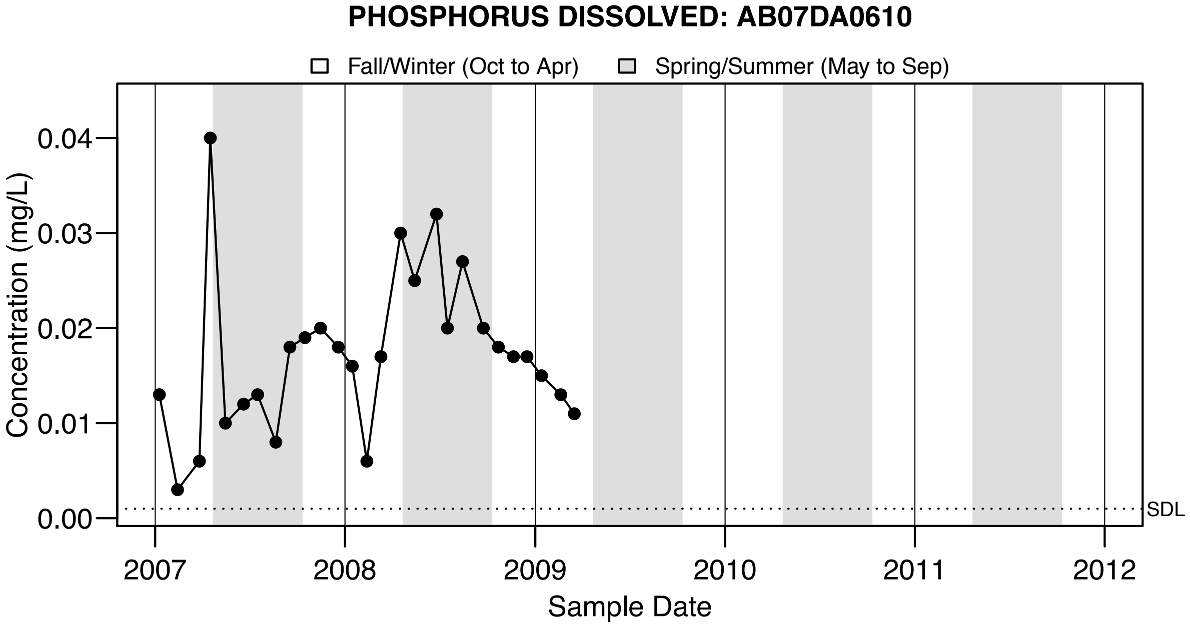


Figure A2.126: PHOSPHORUS DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

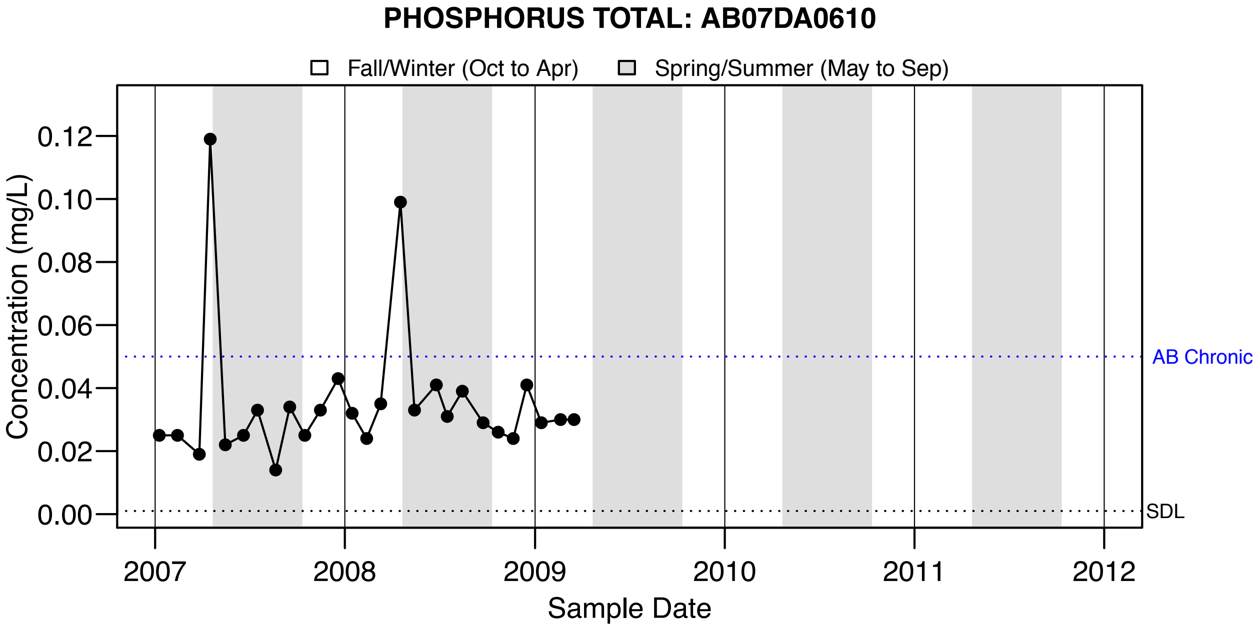
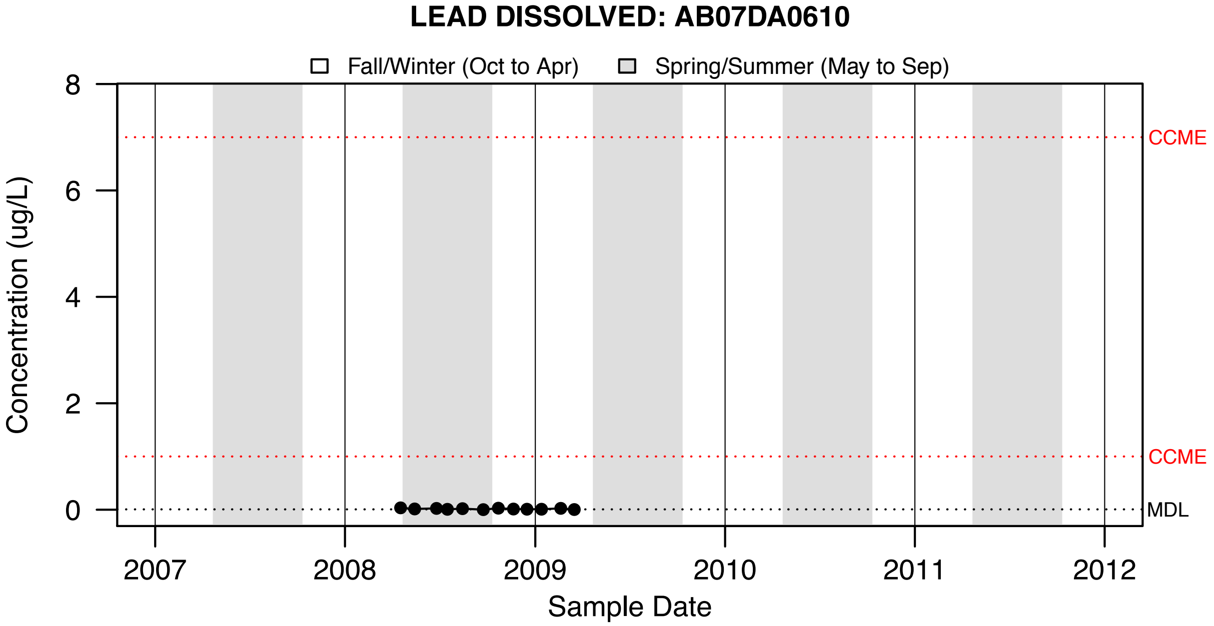


Figure A2.127: PHOSPHORUS TOTAL: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A2.128: LEAD DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

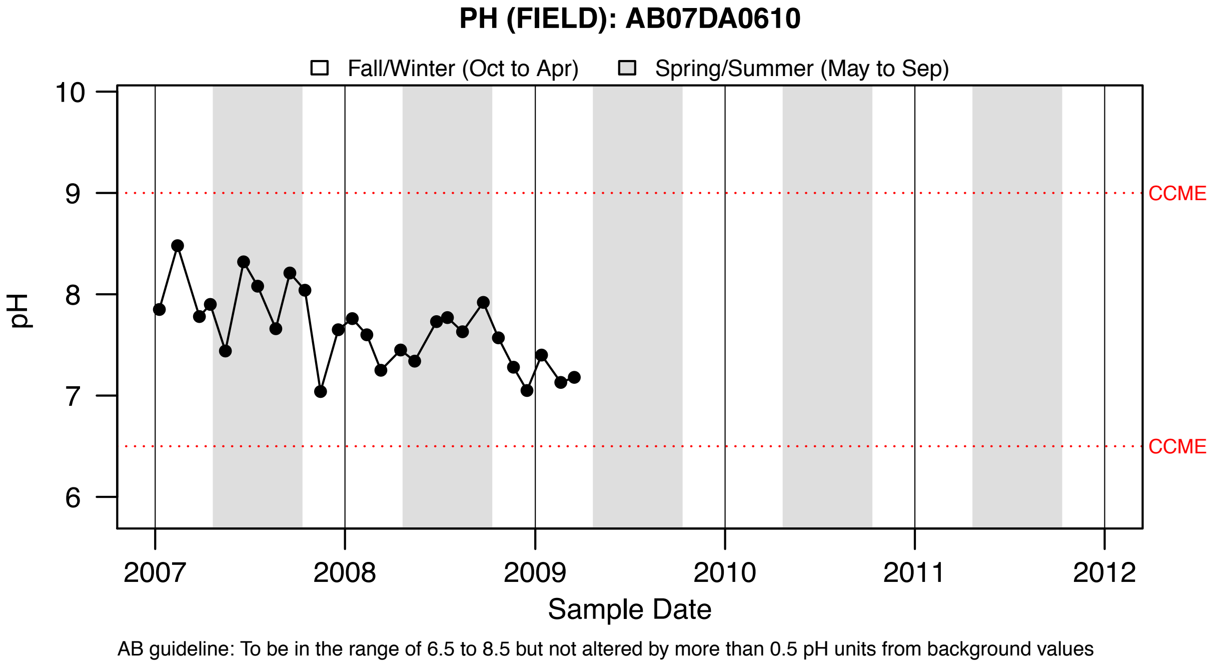


Figure A2.129: PH (FIELD): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

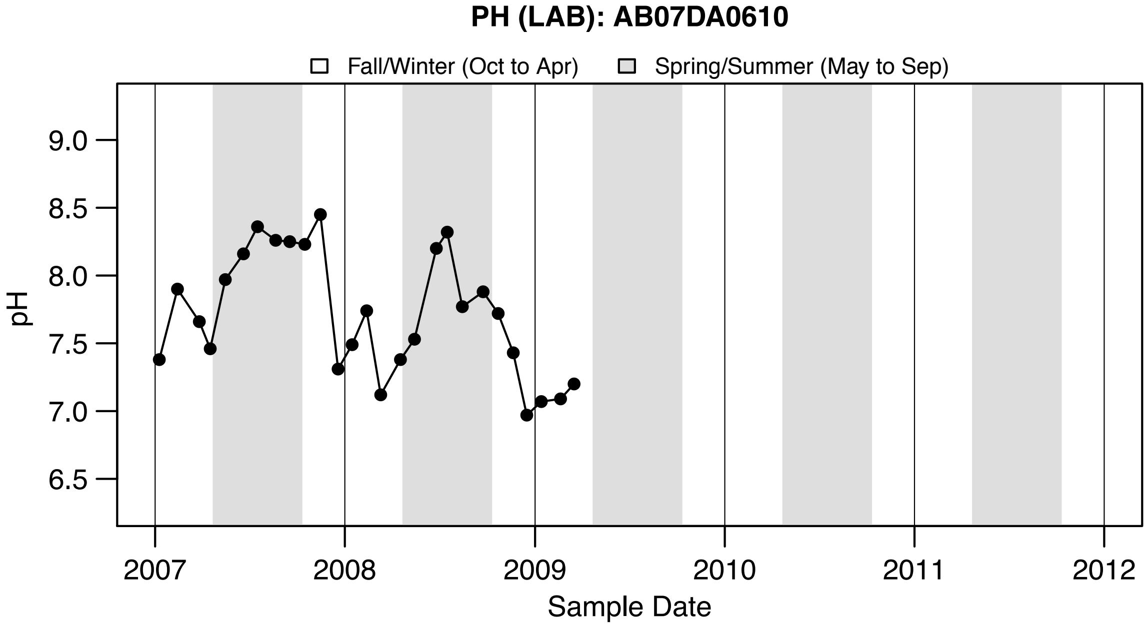


Figure A2.130: PH (LAB): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

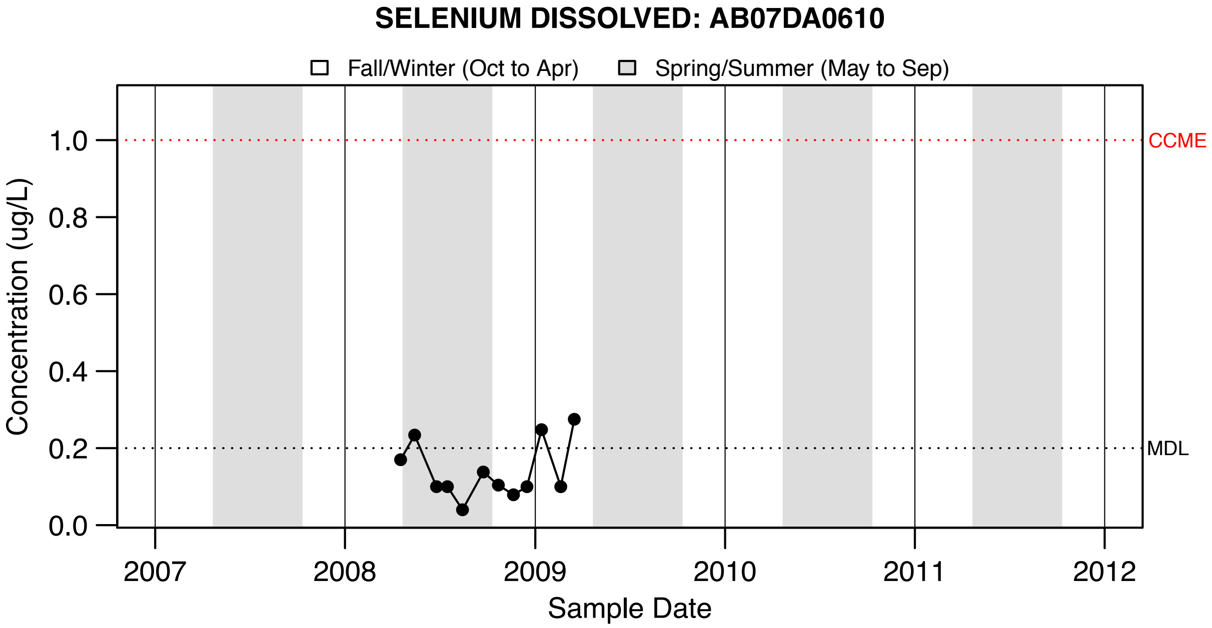


Figure A2.131: SELENIUM DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

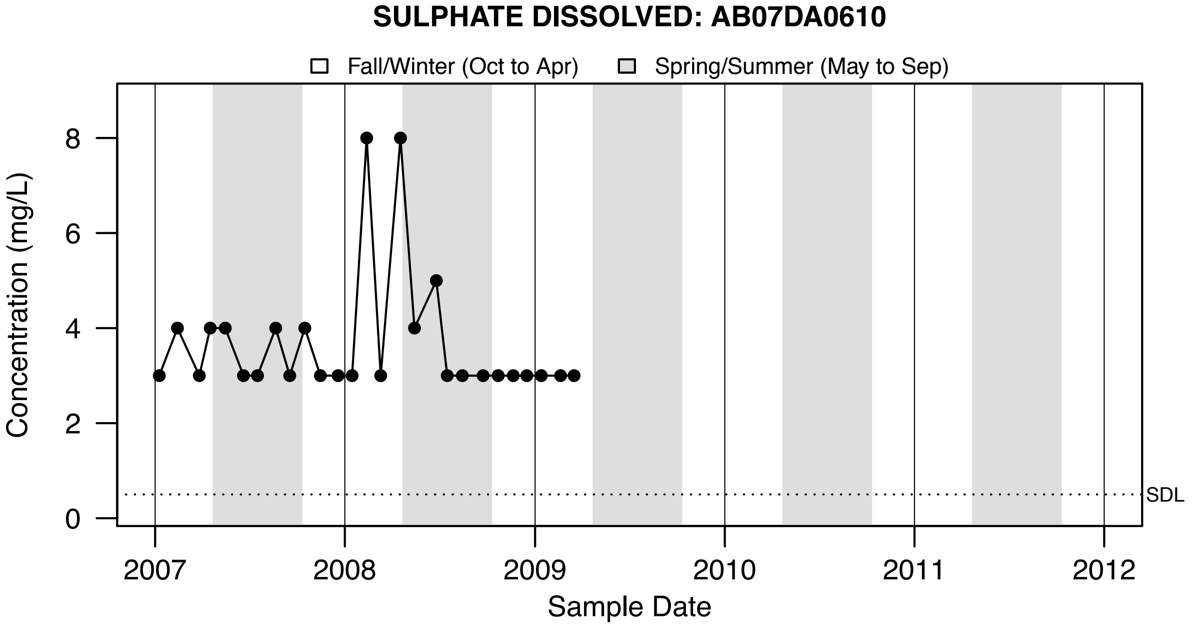


Figure A2.132: SULPHATE DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

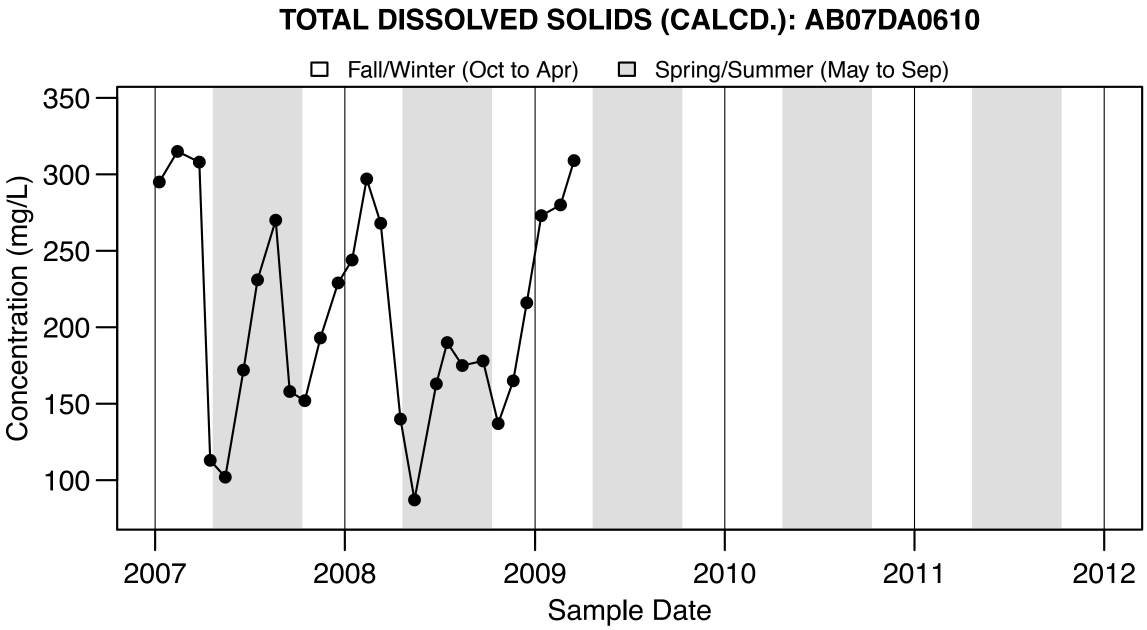
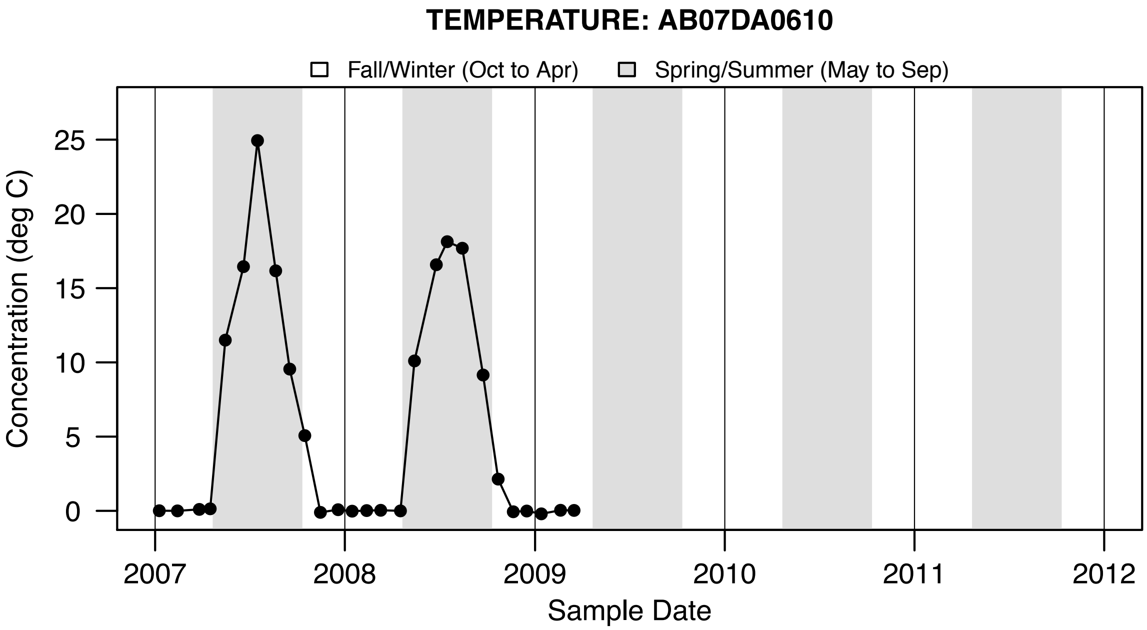


Figure A2.133: TOTAL DISSOLVED SOLIDS (CALCD.): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A2.134: TEMPERATURE: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

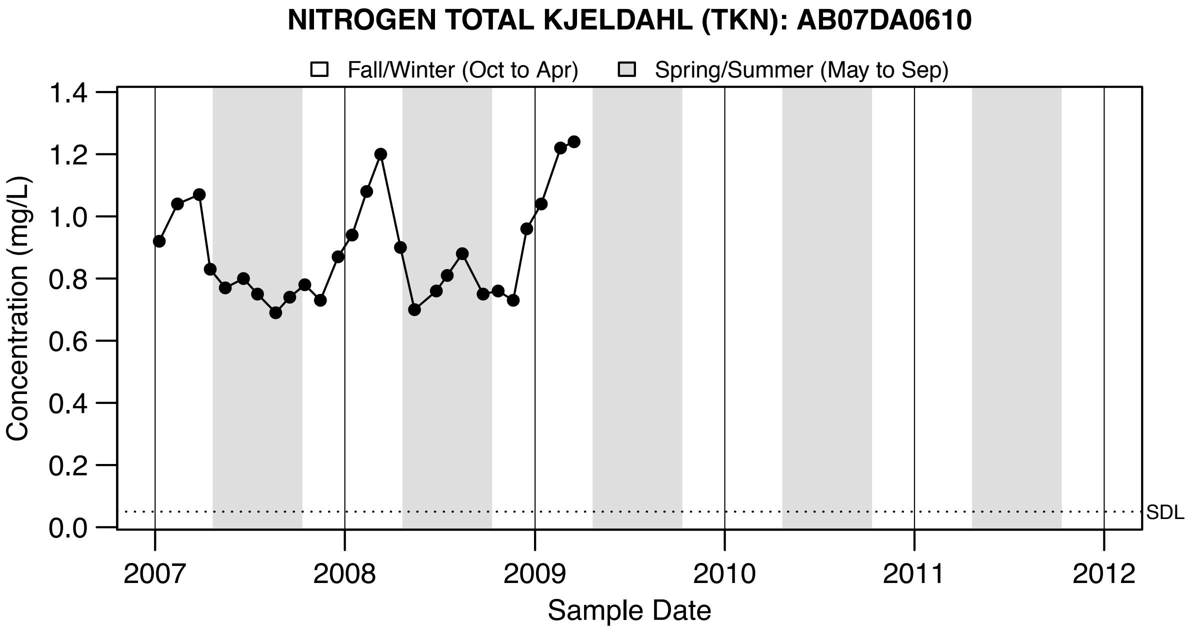
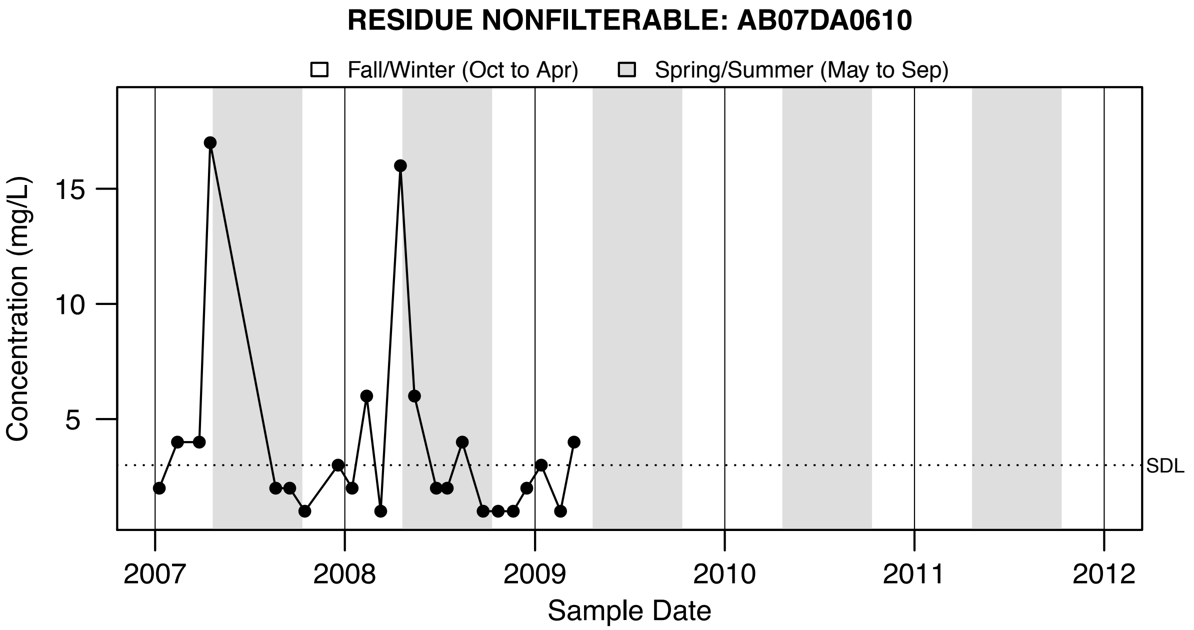


Figure A2.135: NITROGEN TOTAL KJELDAHL (TKN): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A2.136: RESIDUE NONFILTERABLE: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

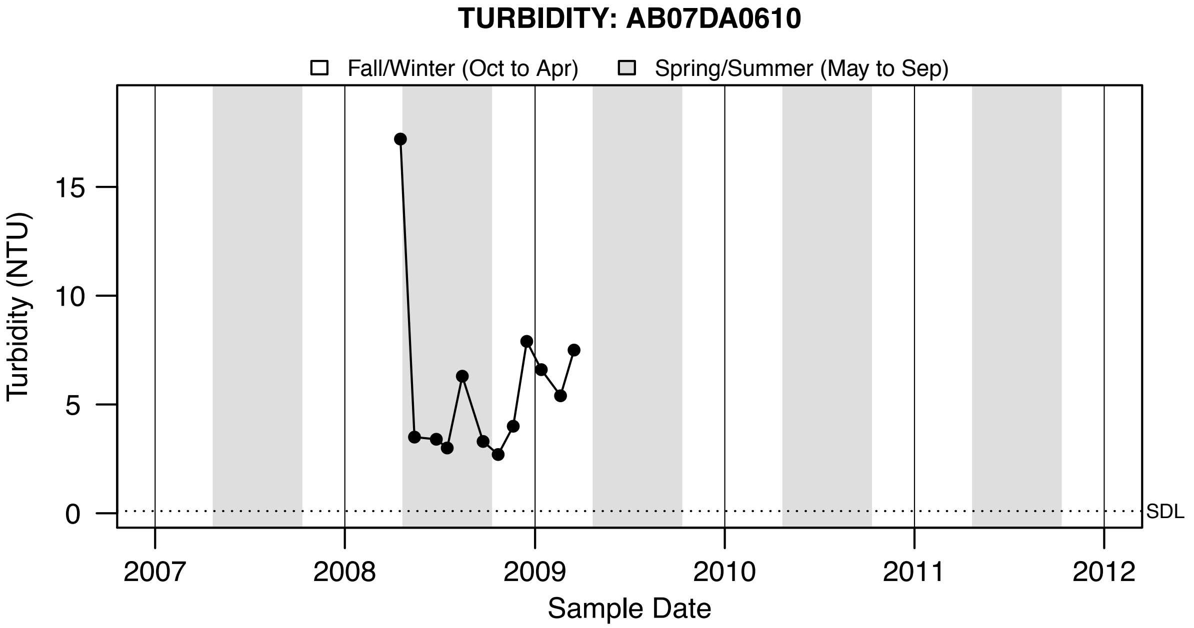


Figure A2.137: TURBIDITY: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

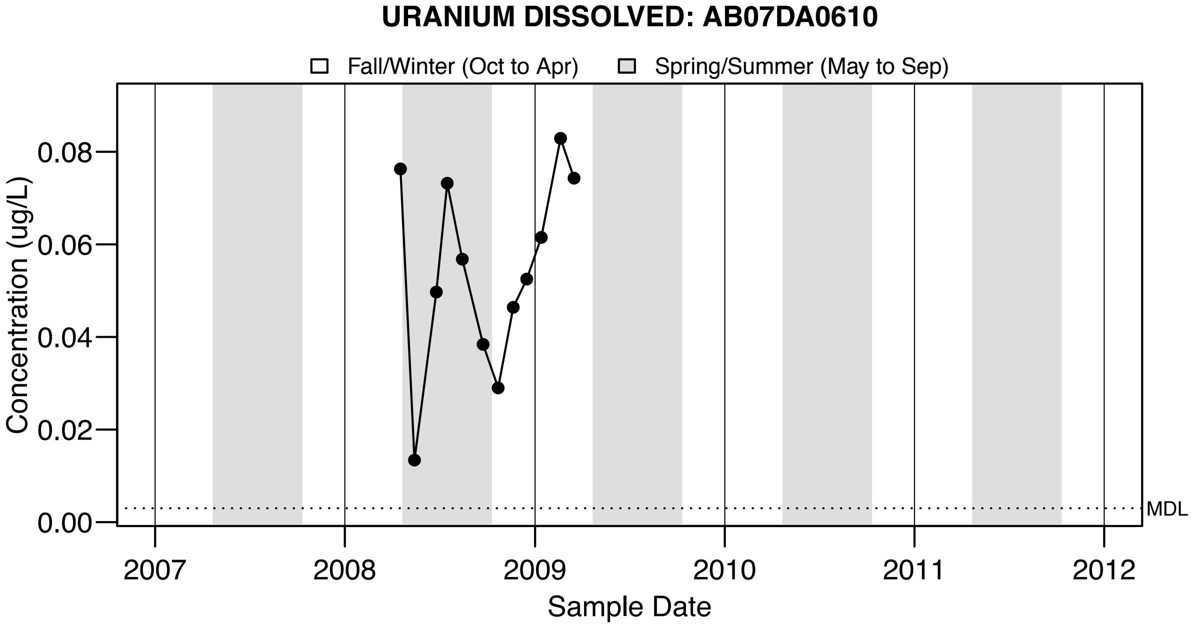


Figure A2.138: URANIUM DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

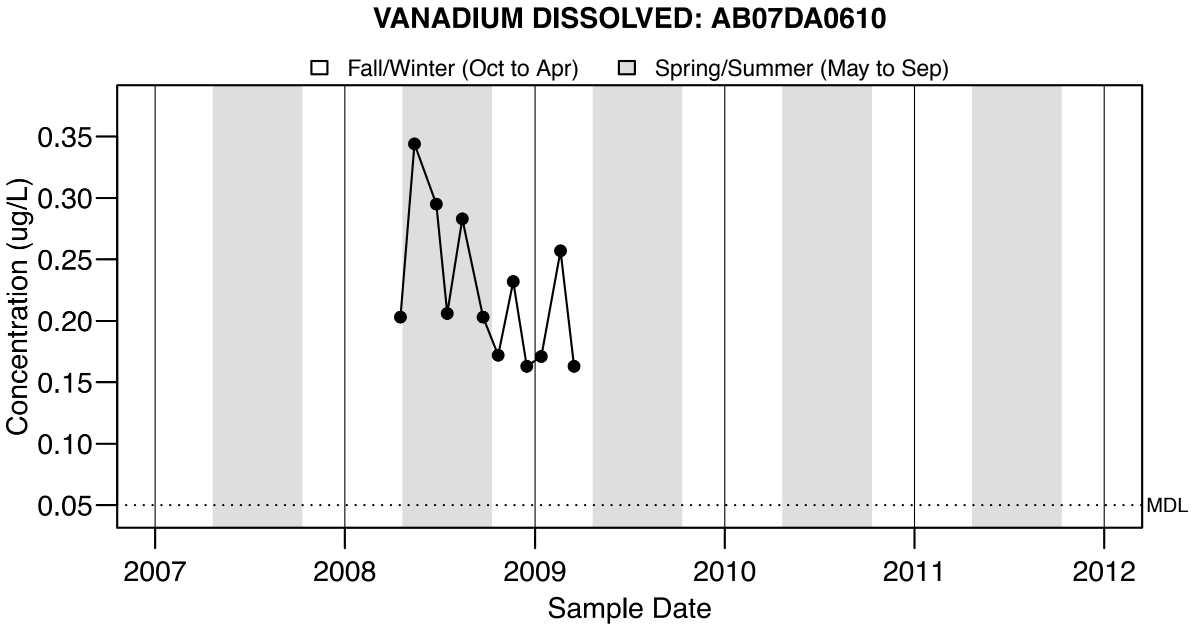


Figure A2.139: VANADIUM DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

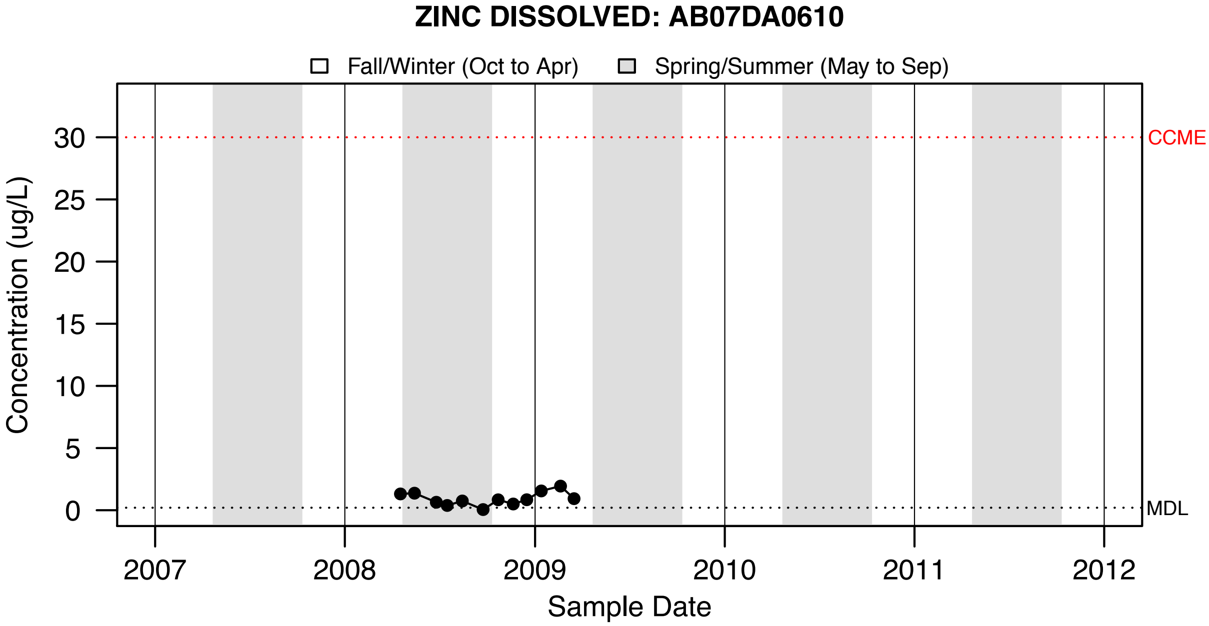


Figure A2.140: ZINC DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD

Appendix 3:

Overview of select water quality parameters measured at
Regional Aquatic Monitoring Program (RAMP) sites between 2007 and 2011

List of Abbreviations

AB Acute: Alberta provincial surface water quality acute guideline value

AB Chronic: Alberta provincial surface water quality chronic guideline value

CCME: Canadian Council of Ministers of the Environment Guideline Value for the Protection of Aquatic Life

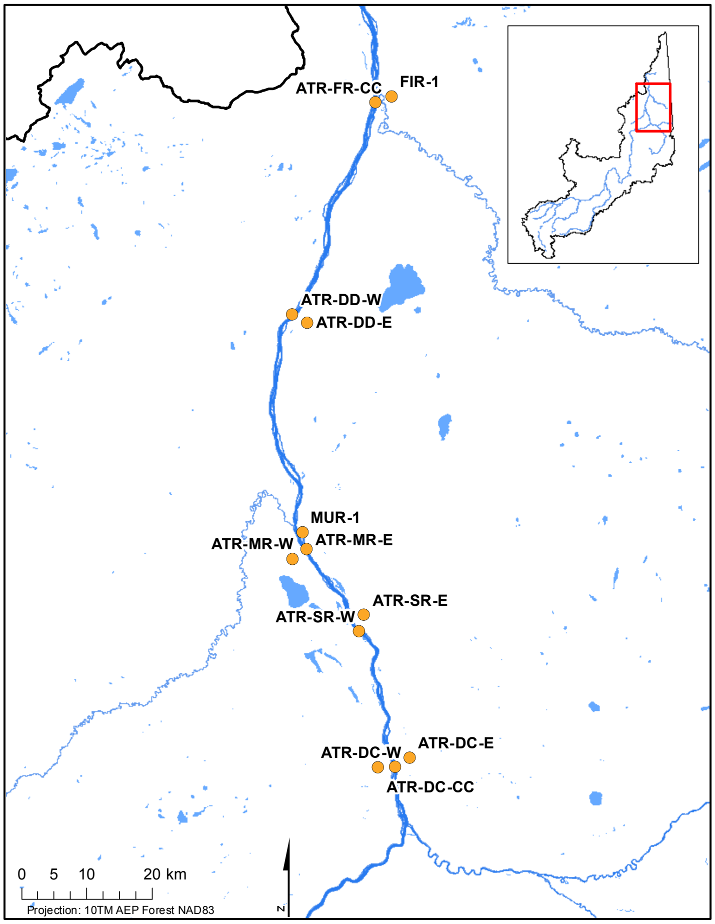
MDL: Method detection limit

RAMP: Regional Aquatics Monitoring Program

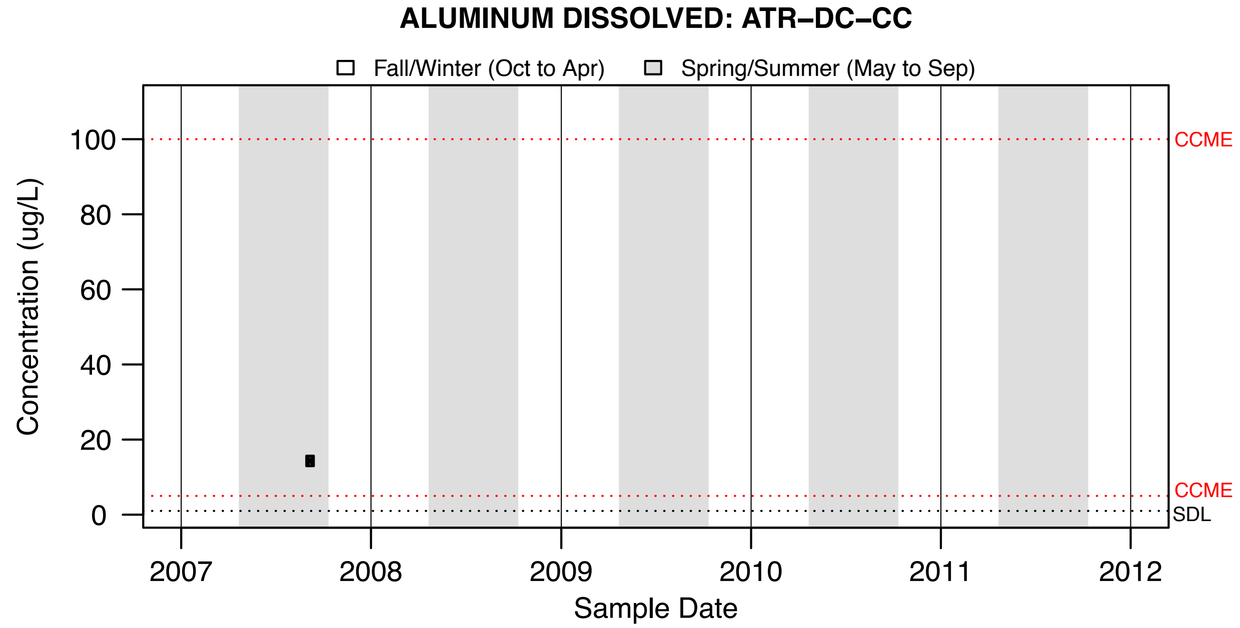
SDL: Sample detection limit

Table A3-1. Station number, description, and location of Regional Aquatics Monitoring Program (RAMP) stations evaluated as part of the Phase 3 State of the Watershed Assessment.

Station Code	Station Description	Latitude	Longitude
ATR-DC-CC	Athabasca River at Donald Creek - cross-channel	56.8266	-111.4093
ATR-DC-E	Athabasca River at Donald Creek - east bank	56.8266	-111.4077
ATR-DC-W	Athabasca River at Donald Creek - west bank	56.8265	-111.4080
ATR-DD-E	Athabasca River downstream of development- east bank	57.4528	-111.6023
ATR-DD-W	Athabasca River downstream of development- west bank	57.4553	-111.6098
ATR-FR-CC	Athabasca River upstream of the Firebag River - cross-channel	57.7407	-111.3684
ATR-MR-E	Athabasca River upstream of the Muskeg River- east bank	57.1319	-111.6029
ATR-MR-W	Athabasca River upstream of the Muskeg River- west bank	57.1302	-111.6079
ATR-SR-E	Athabasca River upstream of the Steepbank River- east bank	57.0192	-111.4787
ATR-SR-W	Athabasca River upstream of the Steepbank River- west bank	57.0154	-111.4811
FIR-1	Mouth of the Firebag River	57.7436	-111.3508
MUR-1	Mouth of the Muskeg River	57.1335	-111.6035

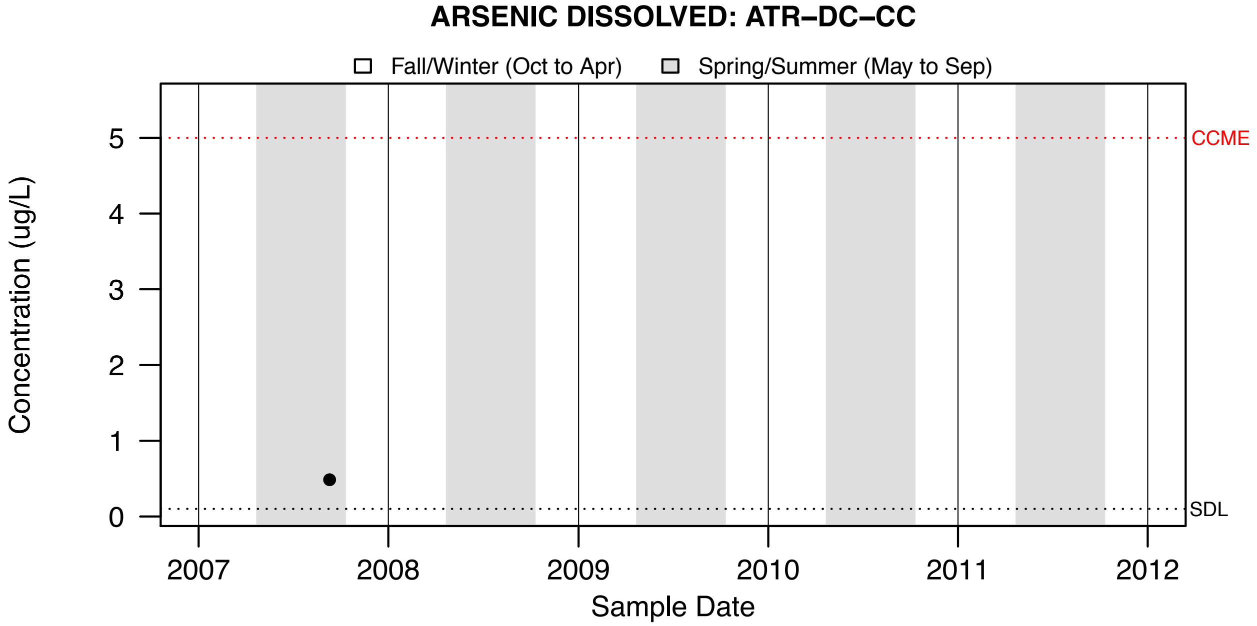


List of Figures



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.1: ALUMINUM DISSOLVED: ATR-DC-CC -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.2: ARSENIC DISSOLVED: ATR-DC-CC -

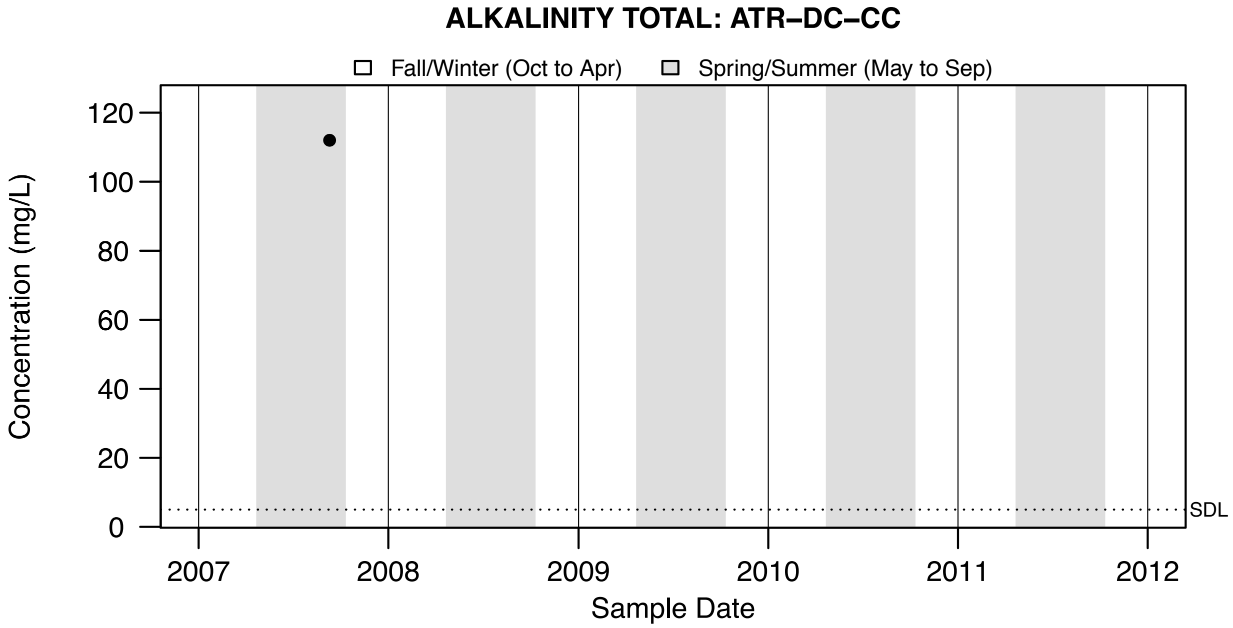


Figure A3.3: ALKALINITY TOTAL: ATR-DC-CC -

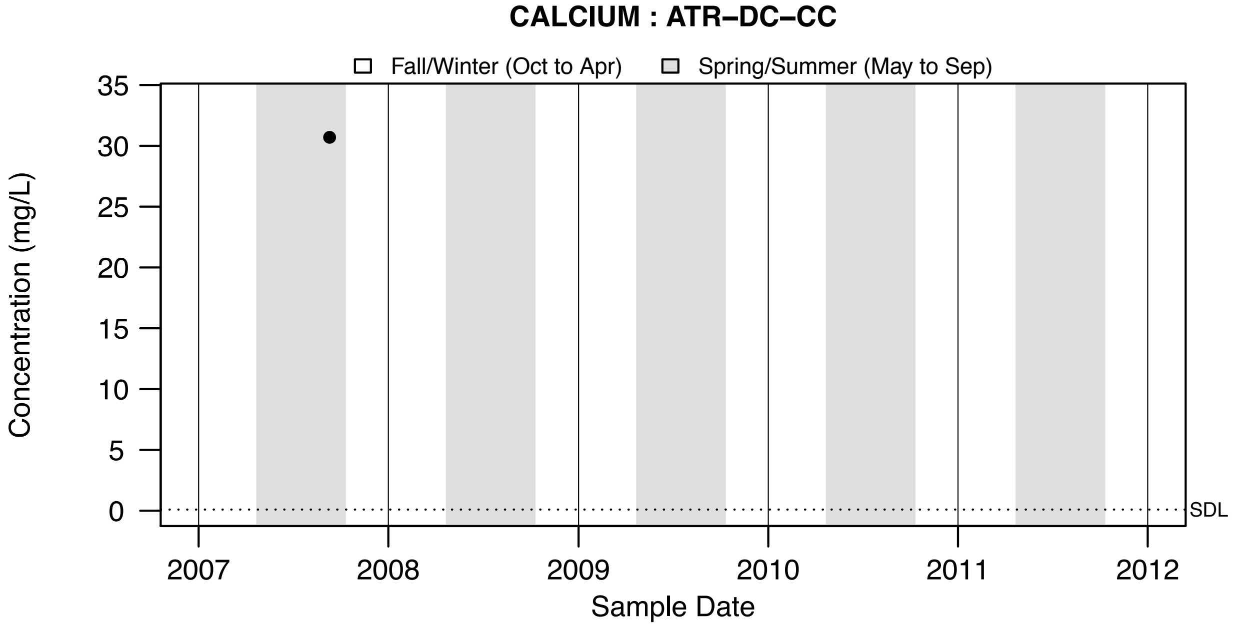


Figure A3.4: CALCIUM : ATR-DC-CC -

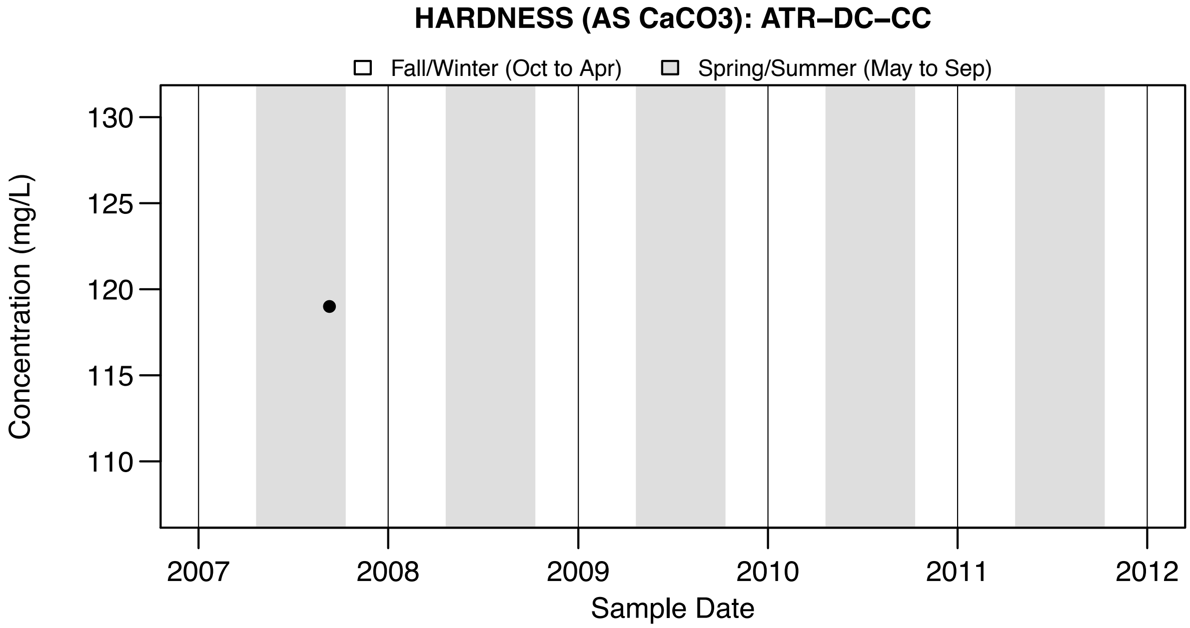
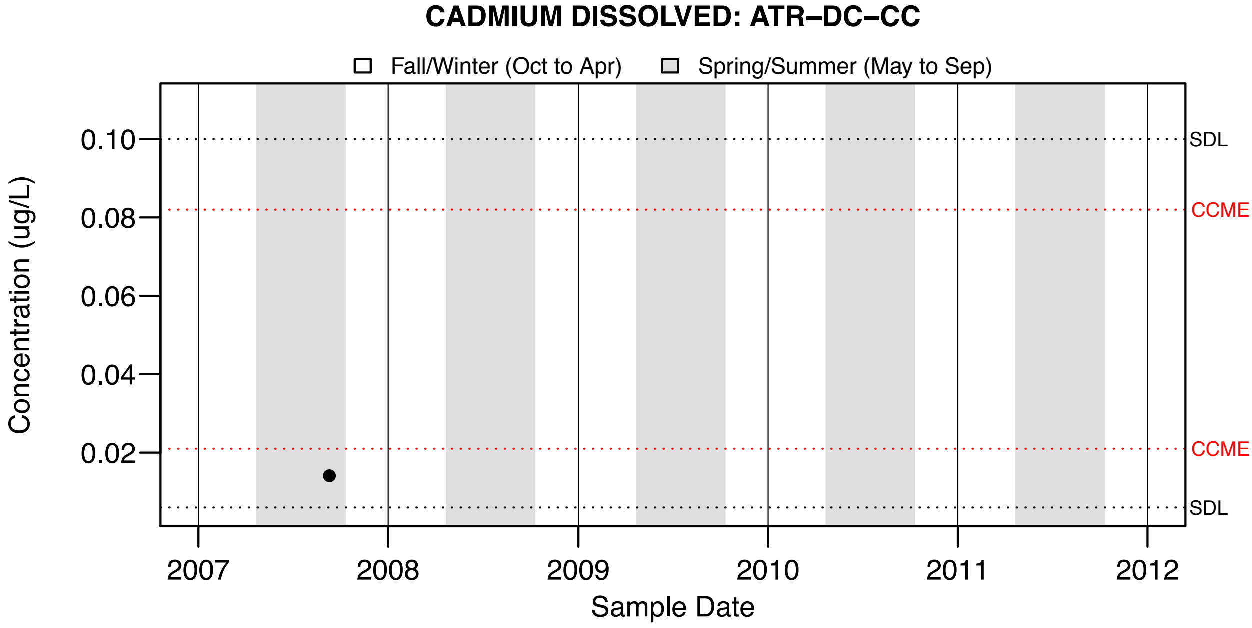


Figure A3.5: HARDNESS (AS CaCO3): ATR-DC-CC -



Related to hardness as CaCo3

Figure A3.6: CADMIUM DISSOLVED: ATR-DC-CC -

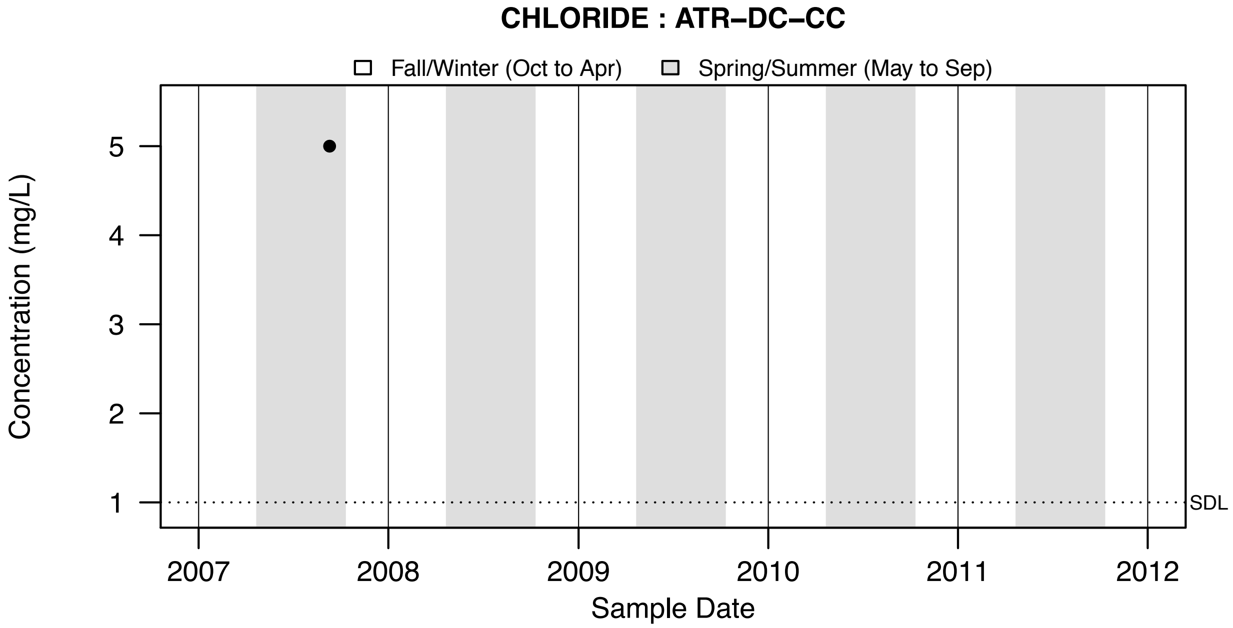


Figure A3.7: CHLORIDE : ATR-DC-CC -

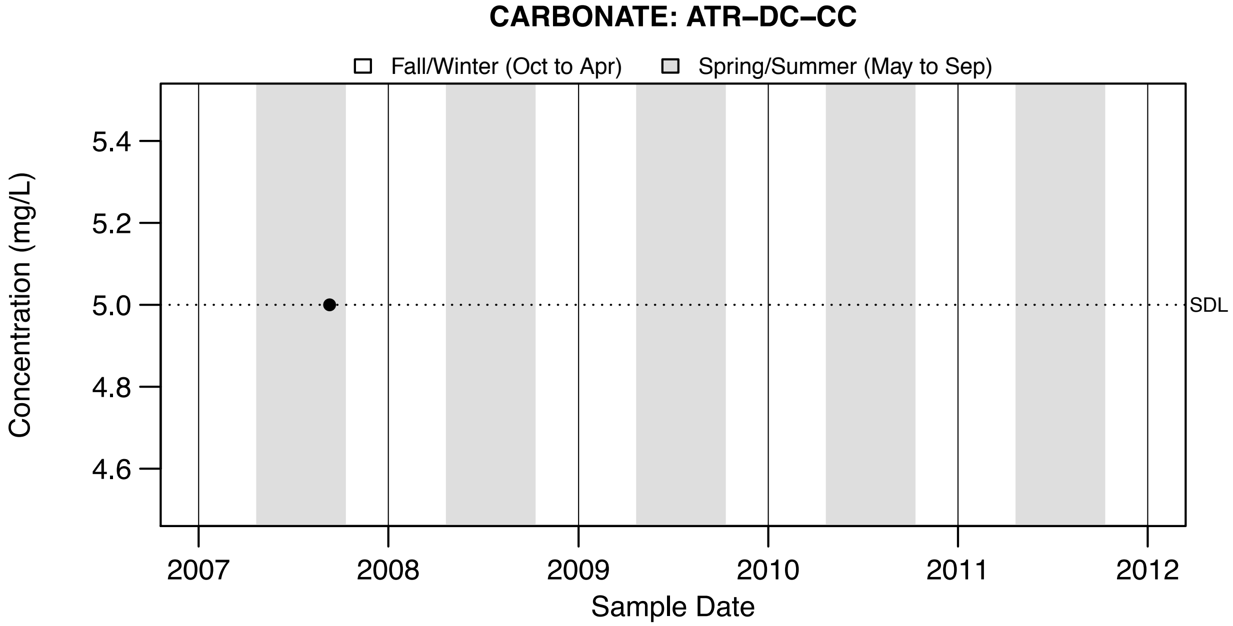


Figure A3.8: CARBONATE: ATR-DC-CC -

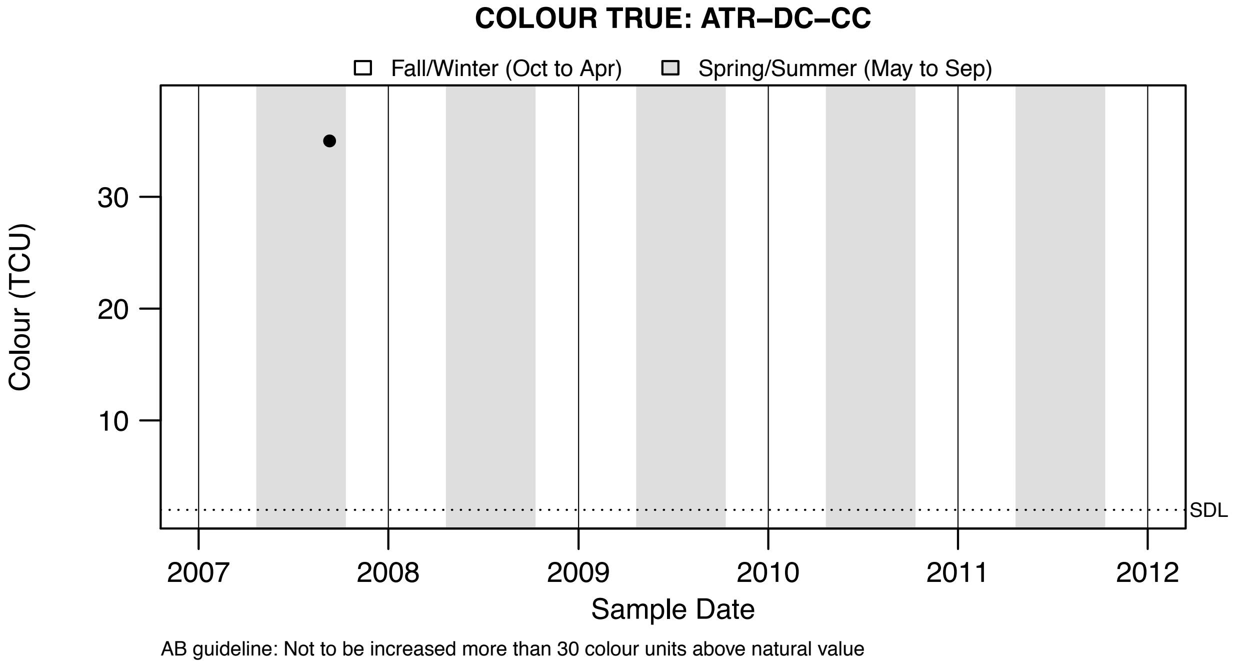


Figure A3.9: COLOUR TRUE: ATR-DC-CC -

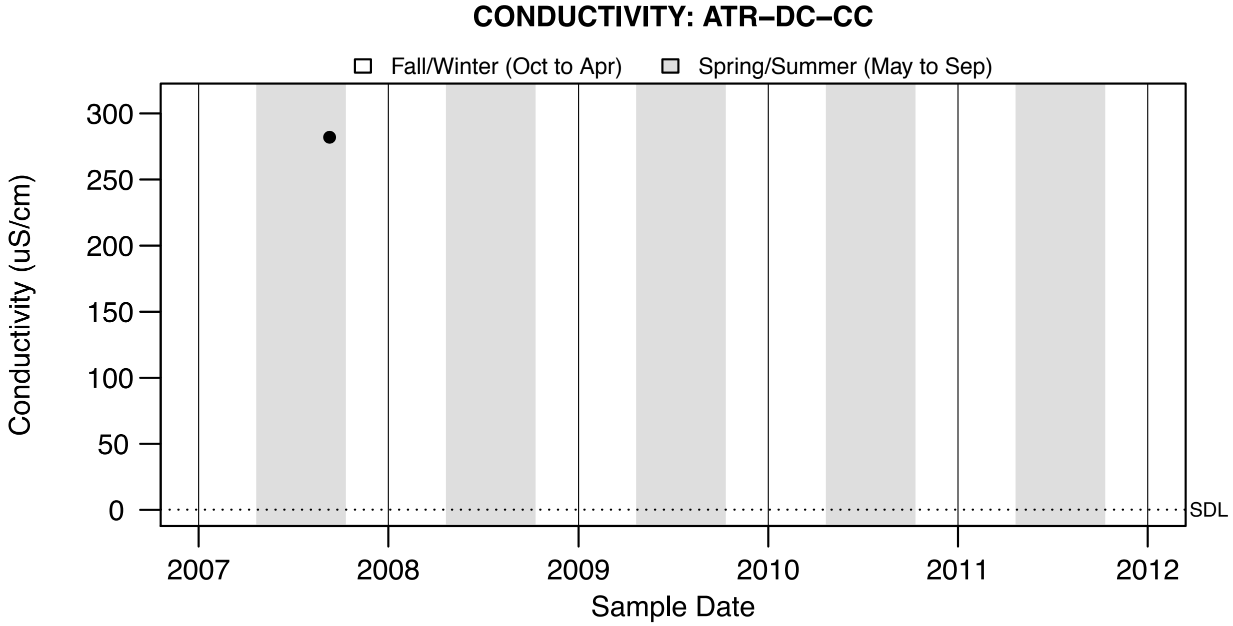
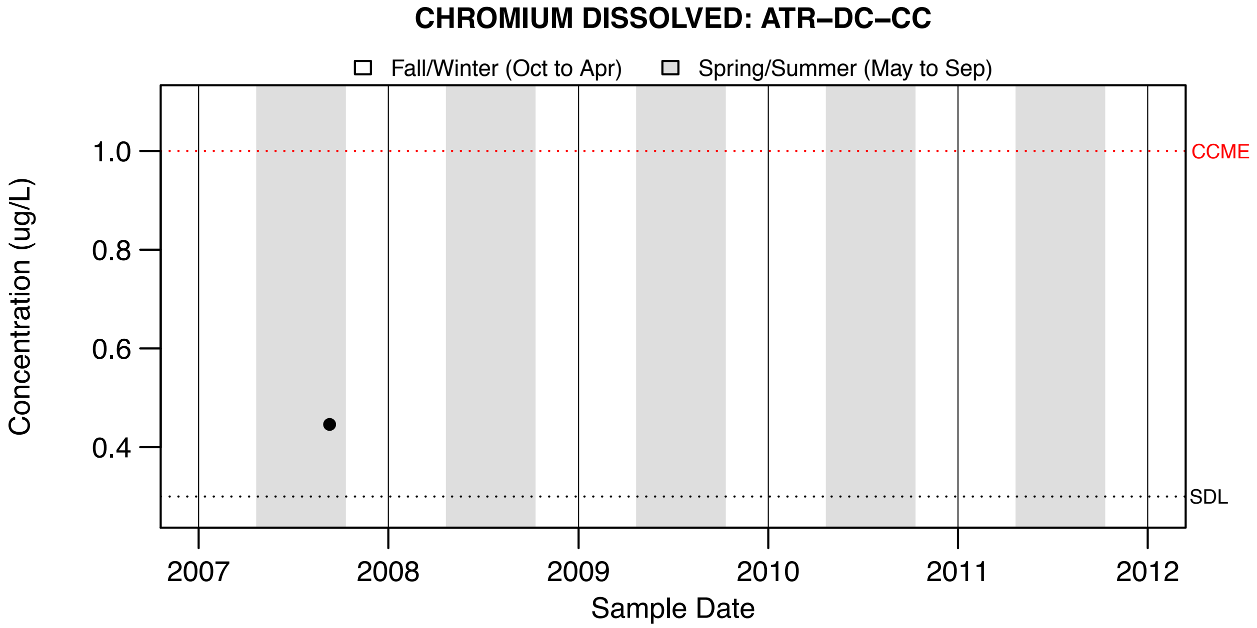
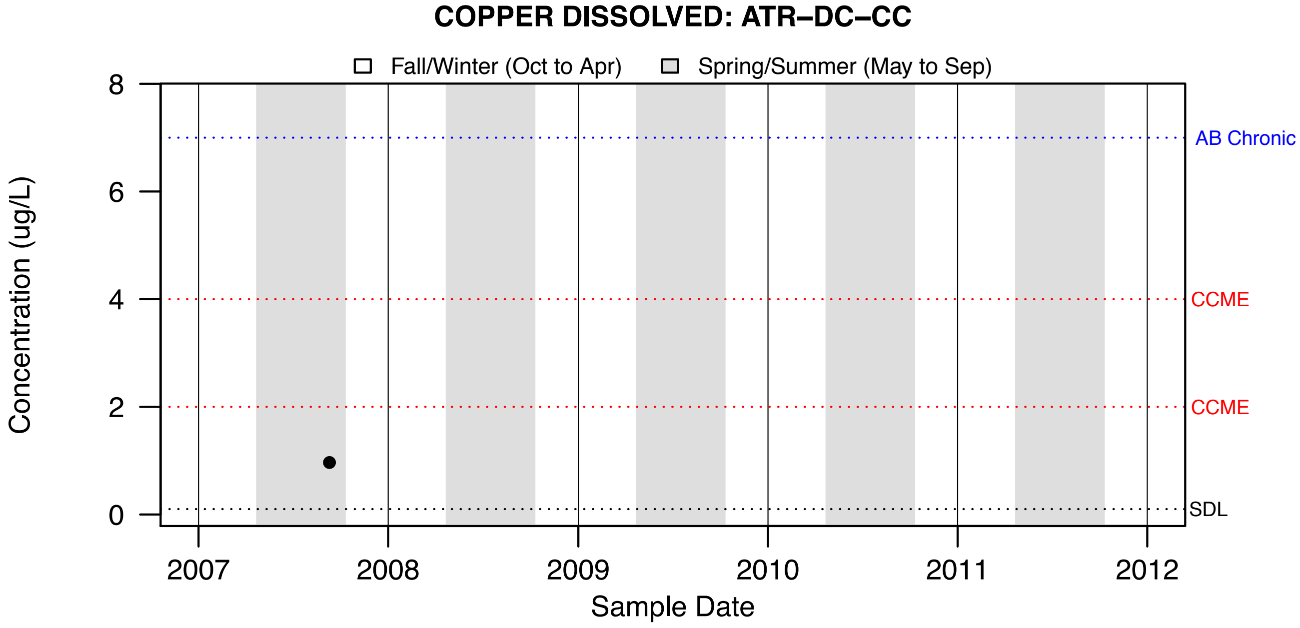


Figure A3.10: CONDUCTIVITY: ATR-DC-CC -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.11: CHROMIUM DISSOLVED: ATR-DC-CC -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.12: COPPER DISSOLVED: ATR-DC-CC -

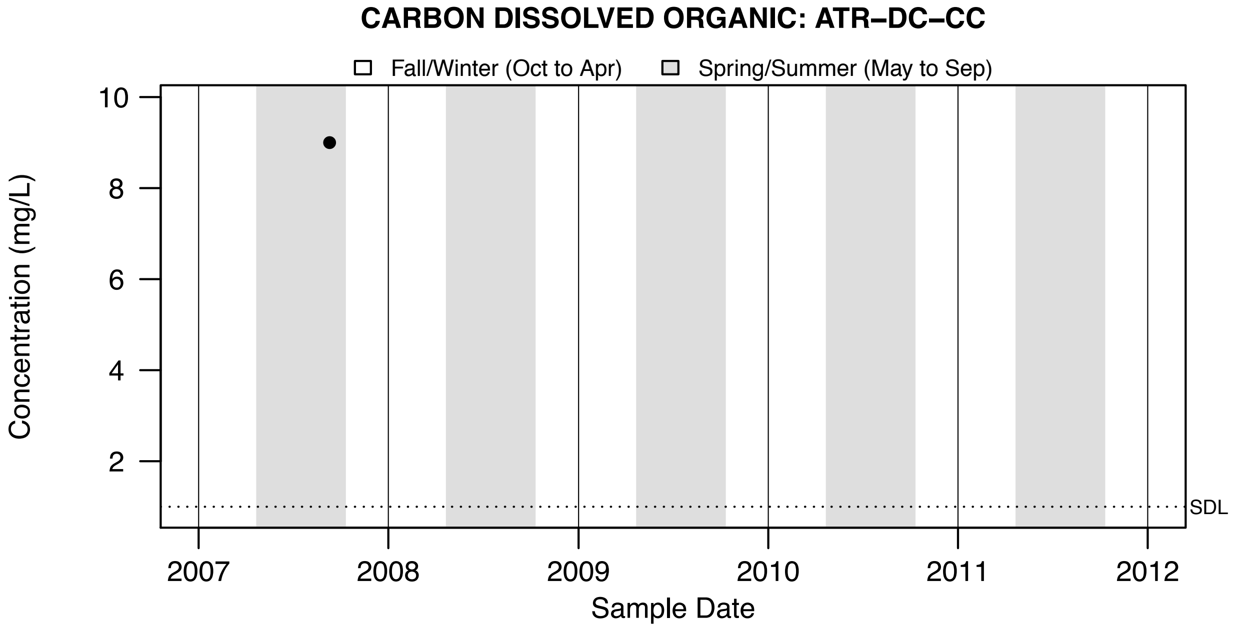


Figure A3.13: CARBON DISSOLVED ORGANIC: ATR-DC-CC -

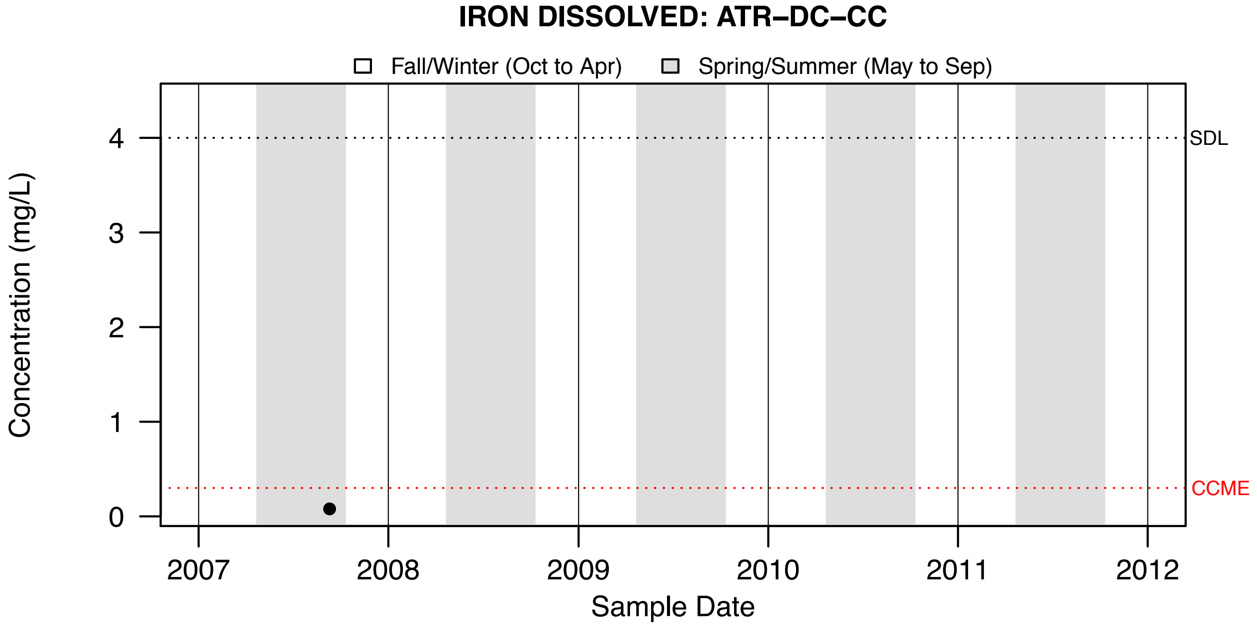


Figure A3.14: IRON DISSOLVED: ATR-DC-CC -

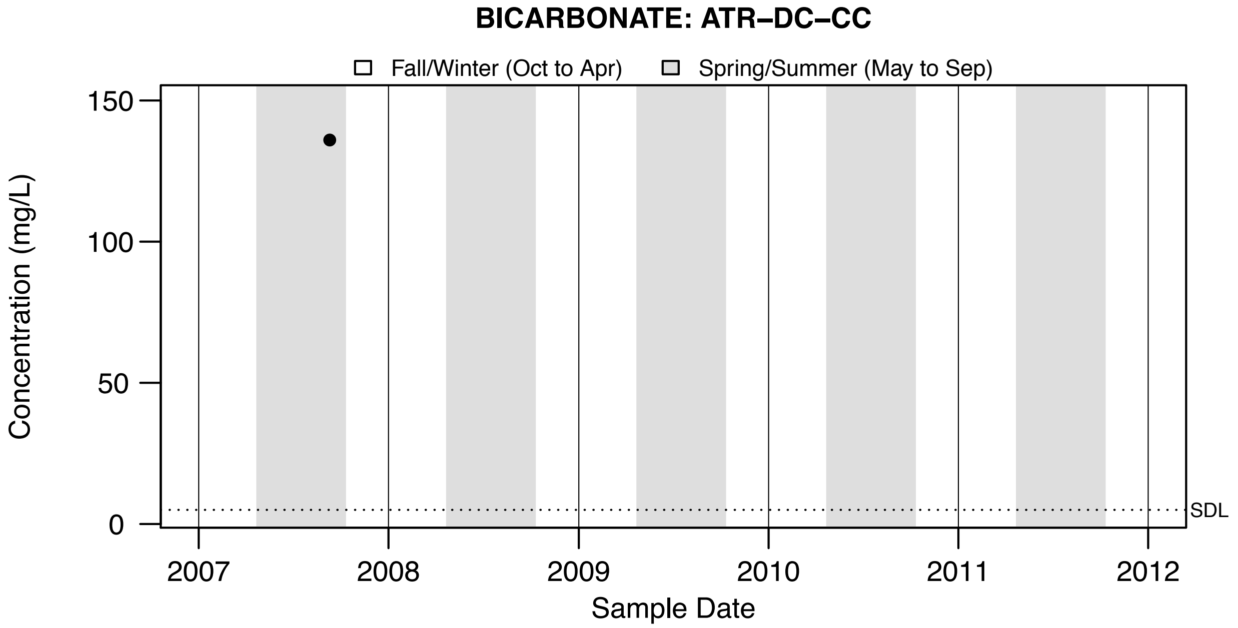


Figure A3.15: BICARBONATE: ATR-DC-CC -

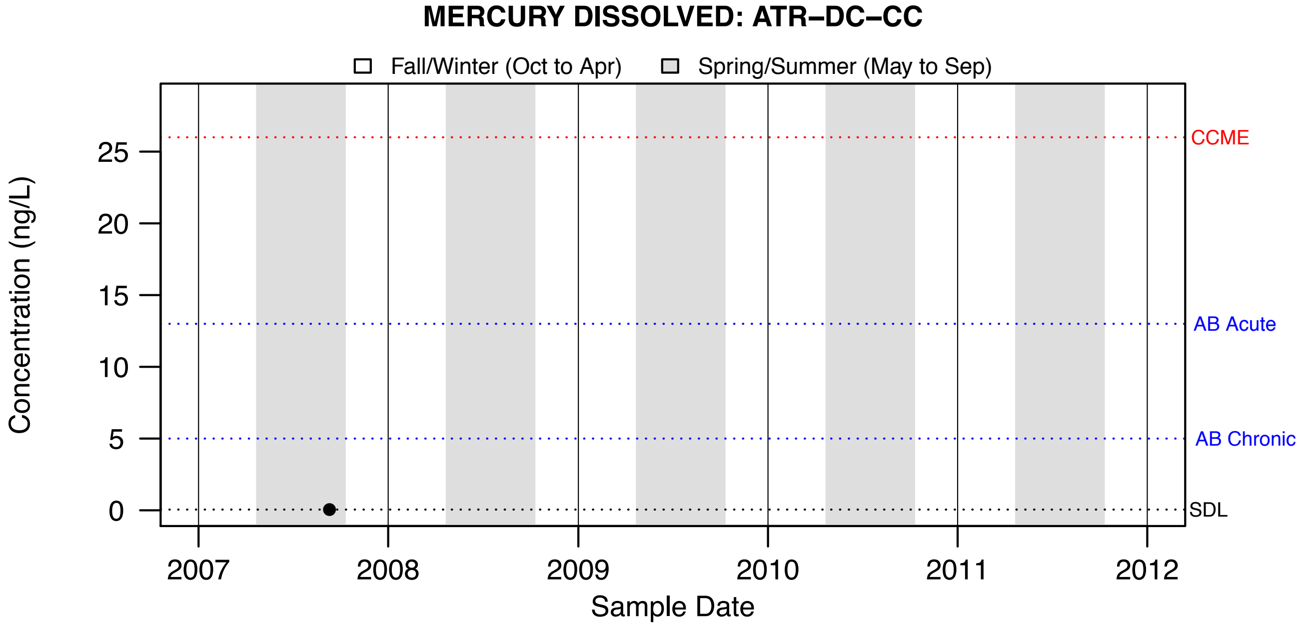


Figure A3.16: MERCURY DISSOLVED: ATR-DC-CC -

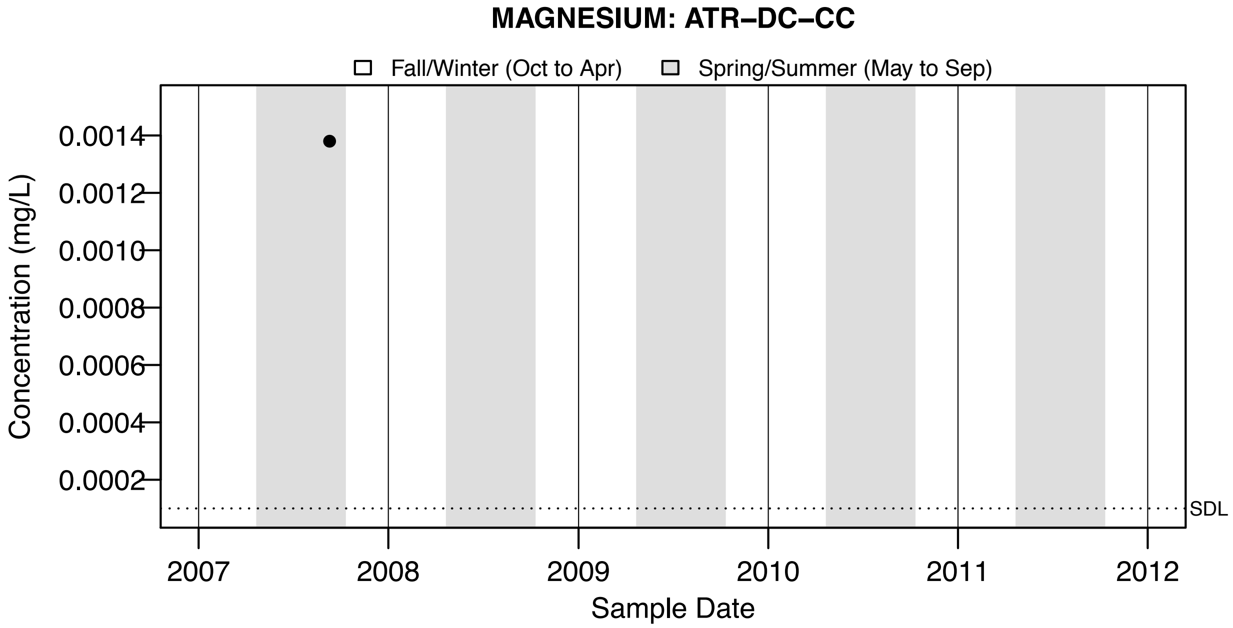


Figure A3.17: MAGNESIUM: ATR-DC-CC -

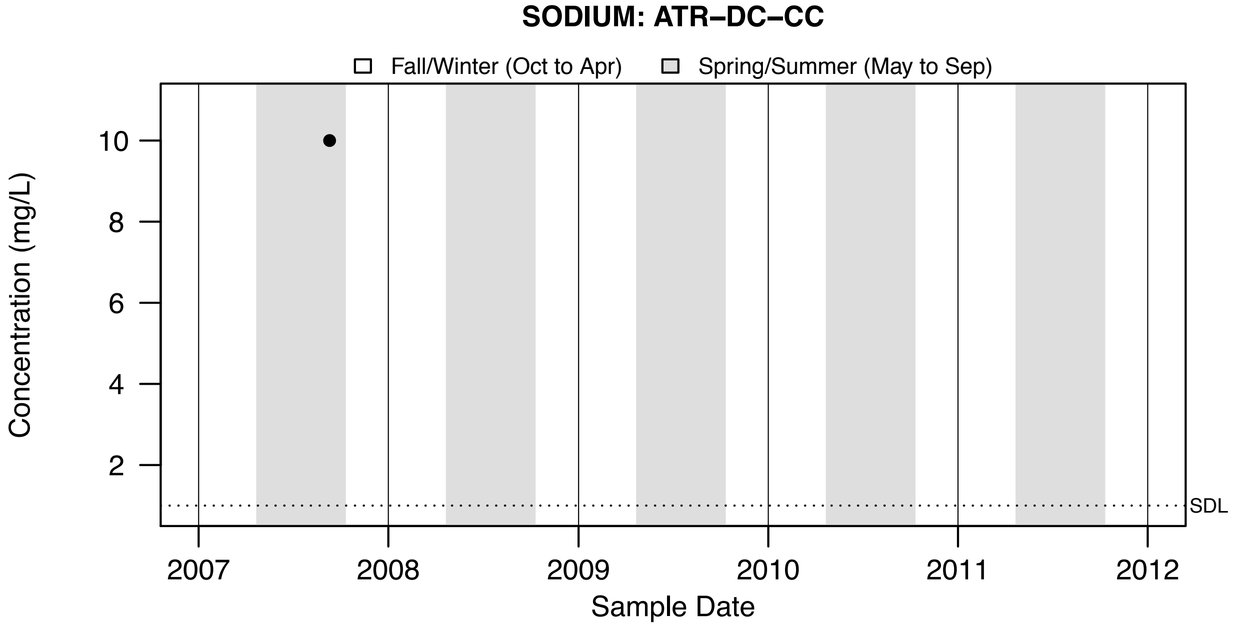
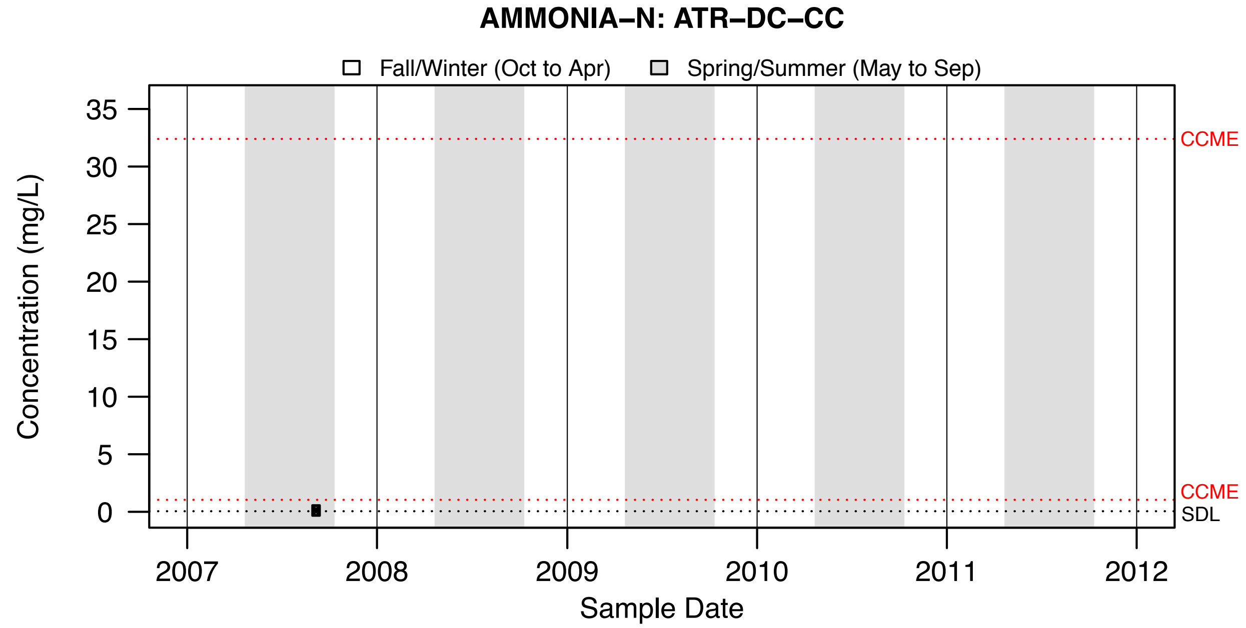
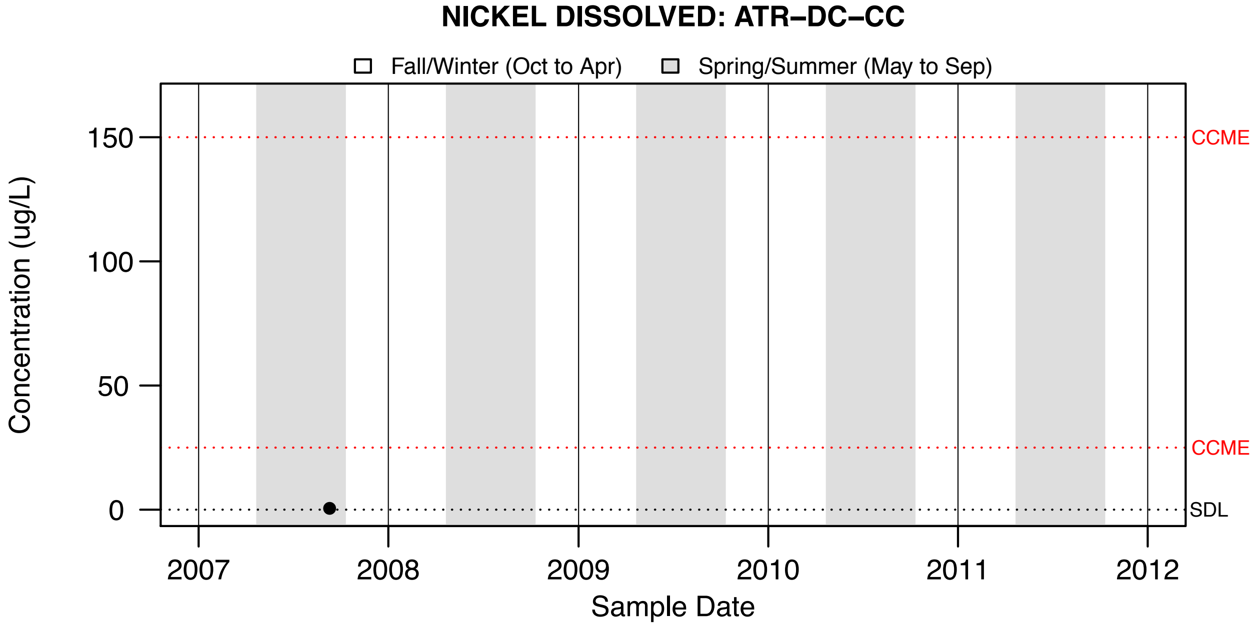


Figure A3.18: SODIUM: ATR-DC-CC -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.19: AMMONIA-N: ATR-DC-CC -



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A3.20: NICKEL DISSOLVED: ATR-DC-CC -

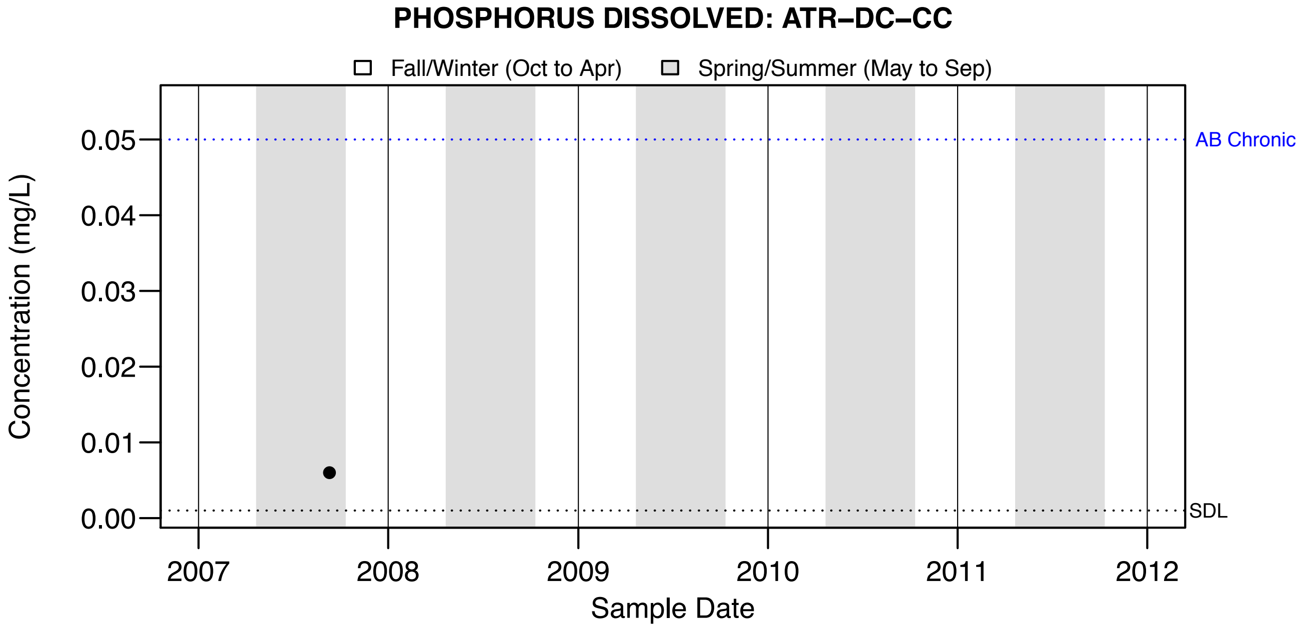


Figure A3.21: PHOSPHORUS DISSOLVED: ATR-DC-CC -

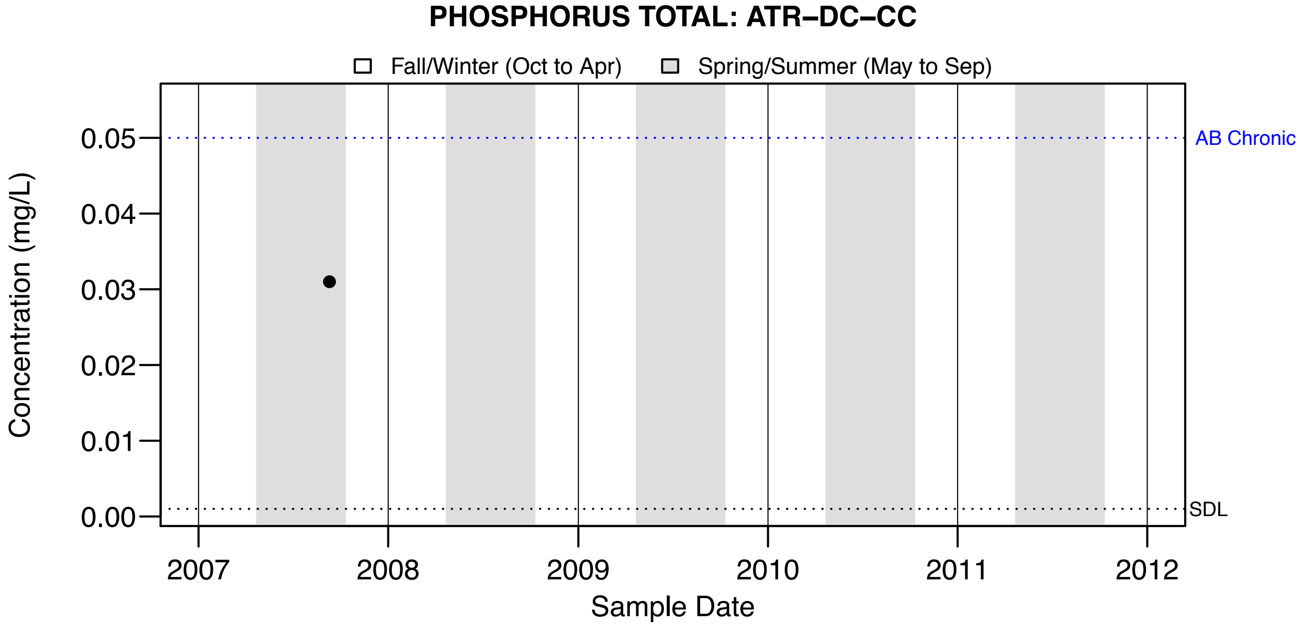
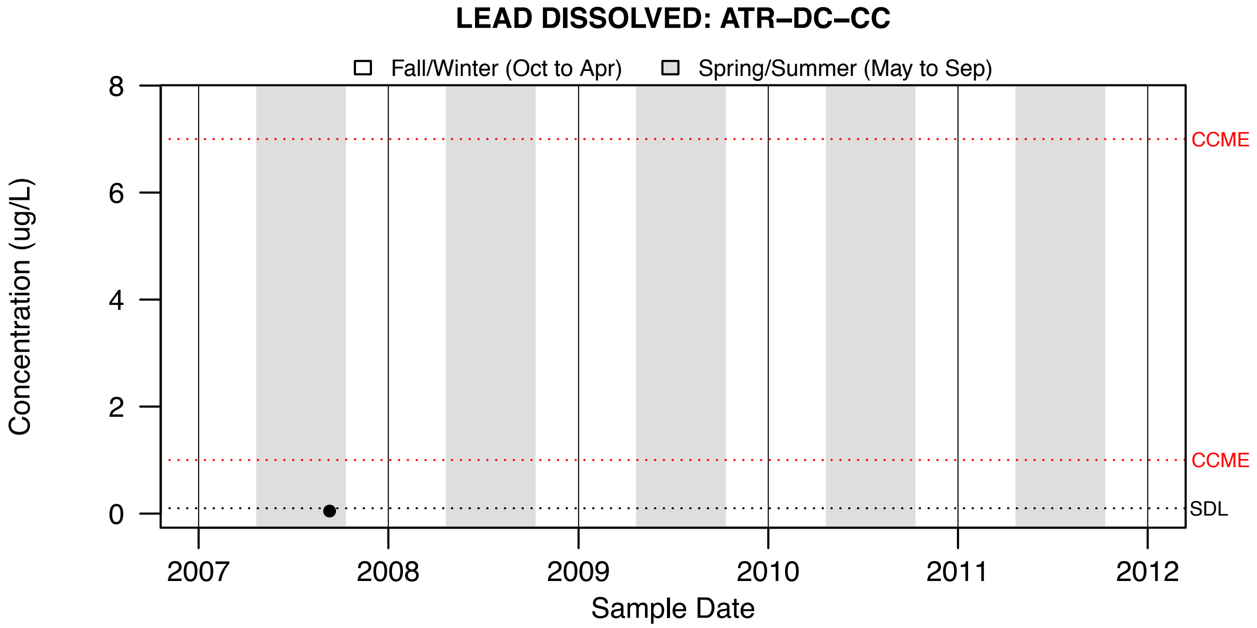
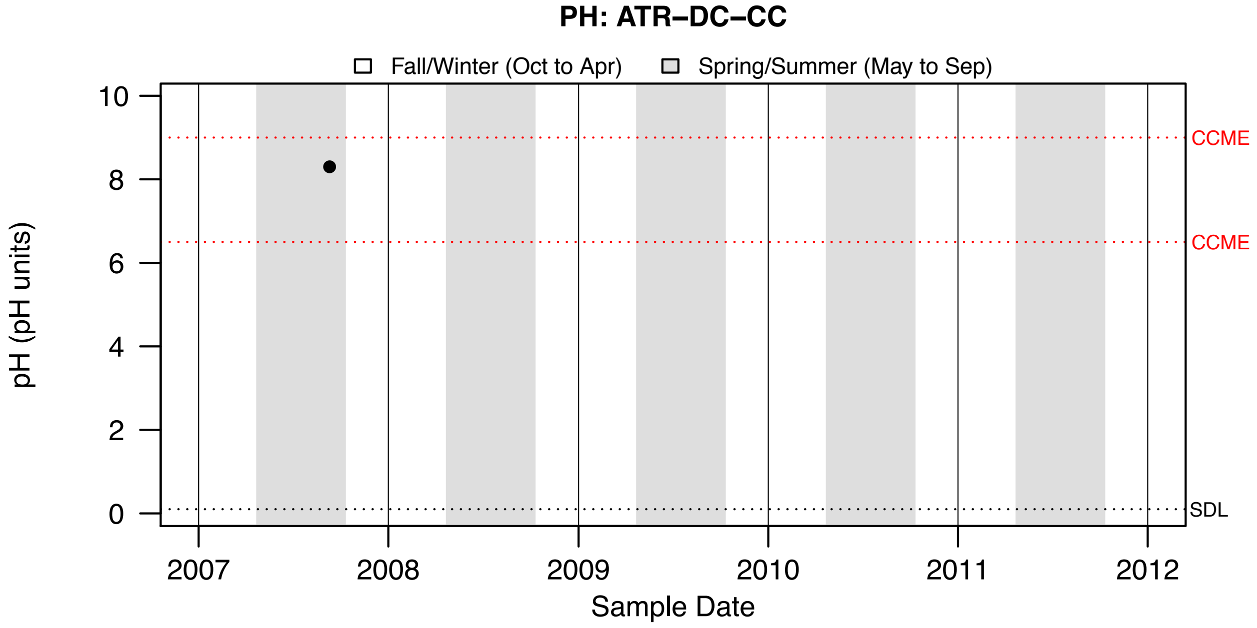


Figure A3.22: PHOSPHORUS TOTAL: ATR-DC-CC -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.23: LEAD DISSOLVED: ATR-DC-CC -



AB guideline: To be in the range of 6.5 to 8.5 but not altered by more than 0.5 pH units from background values

Figure A3.24: PH: ATR-DC-CC -

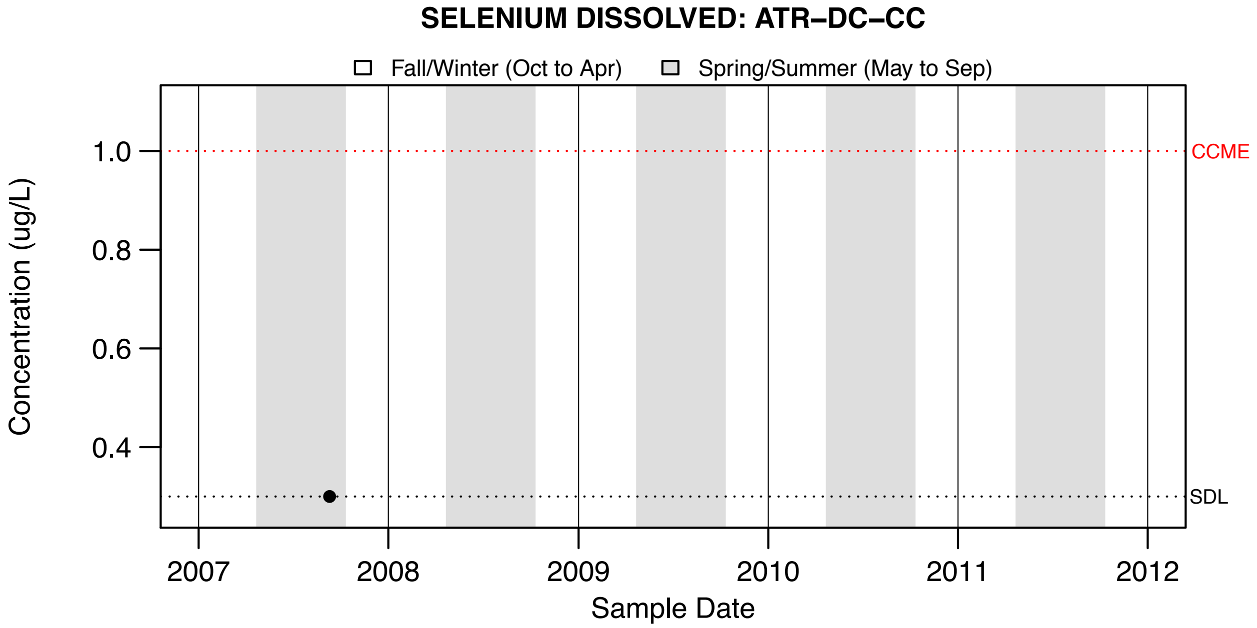


Figure A3.25: SELENIUM DISSOLVED: ATR-DC-CC -

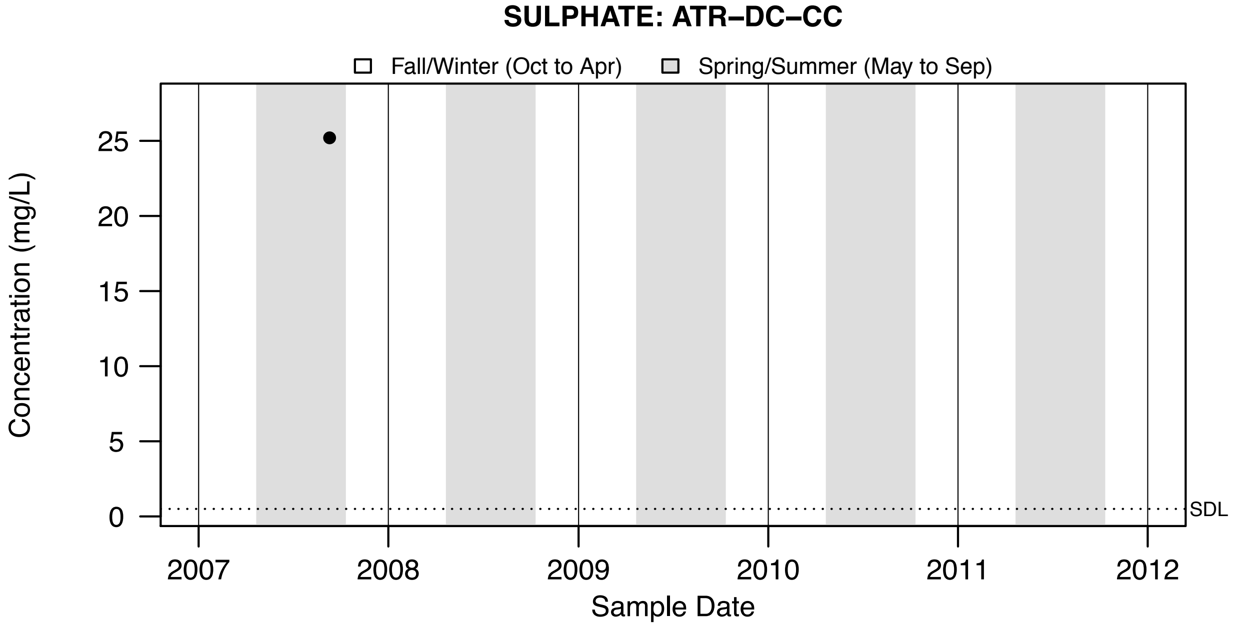


Figure A3.26: SULPHATE: ATR-DC-CC -

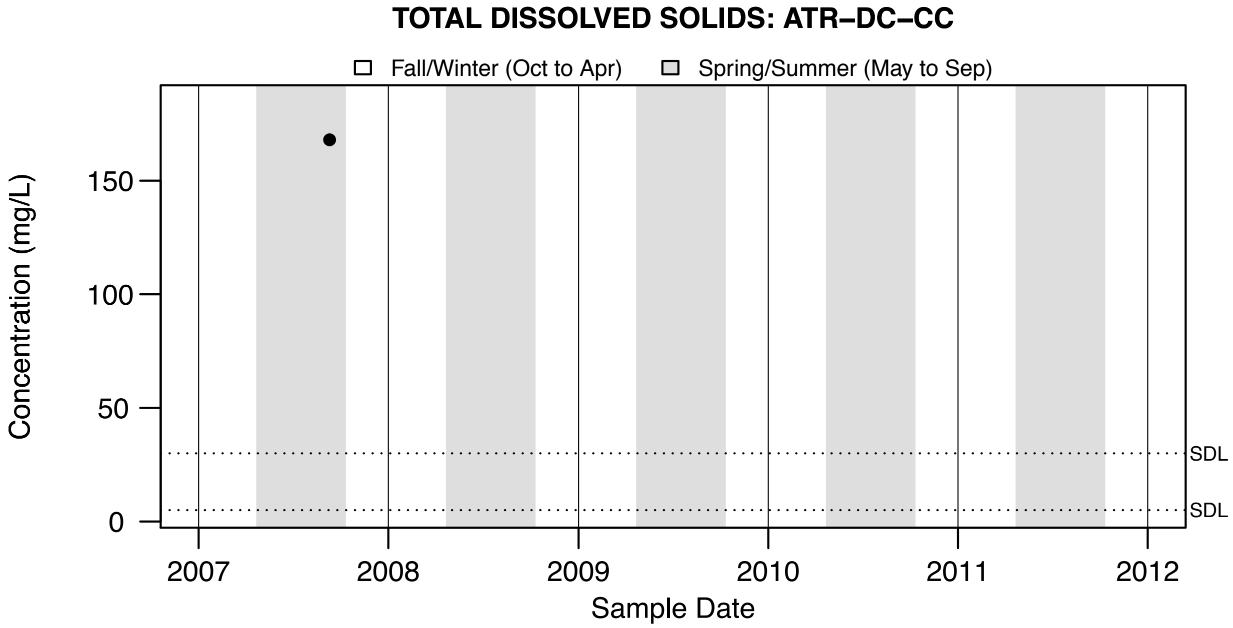


Figure A3.27: TOTAL DISSOLVED SOLIDS: ATR-DC-CC -

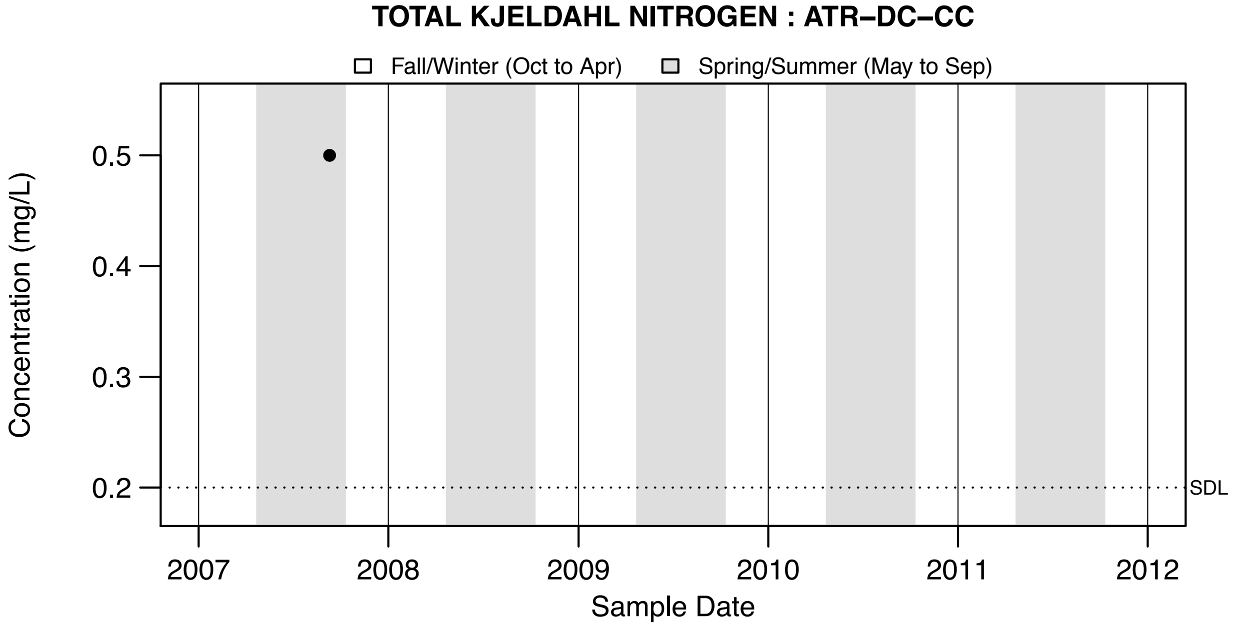
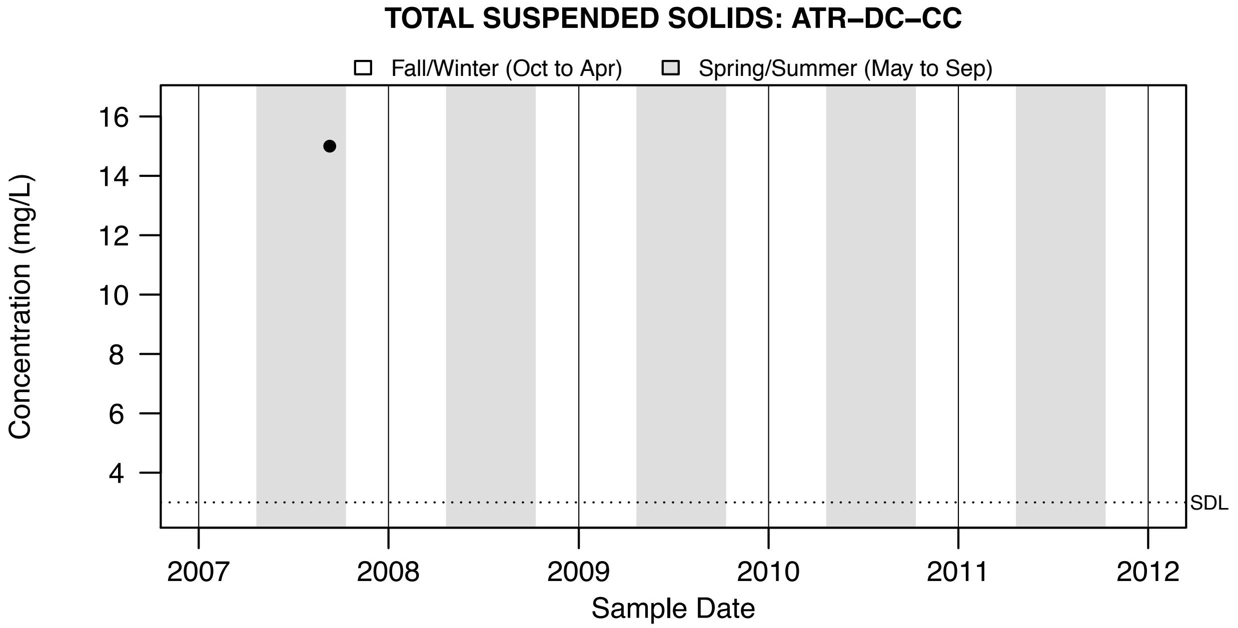


Figure A3.28: TOTAL KJELDAHL NITROGEN : ATR-DC-CC -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.29: TOTAL SUSPENDED SOLIDS: ATR-DC-CC -

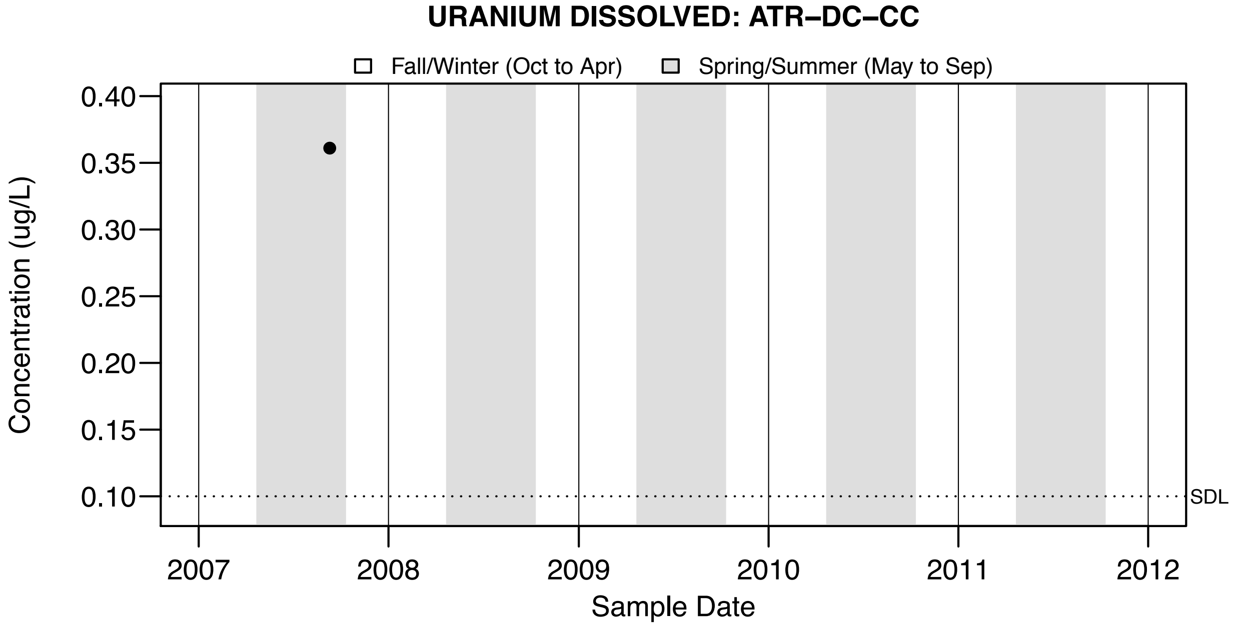


Figure A3.30: URANIUM DISSOLVED: ATR-DC-CC -

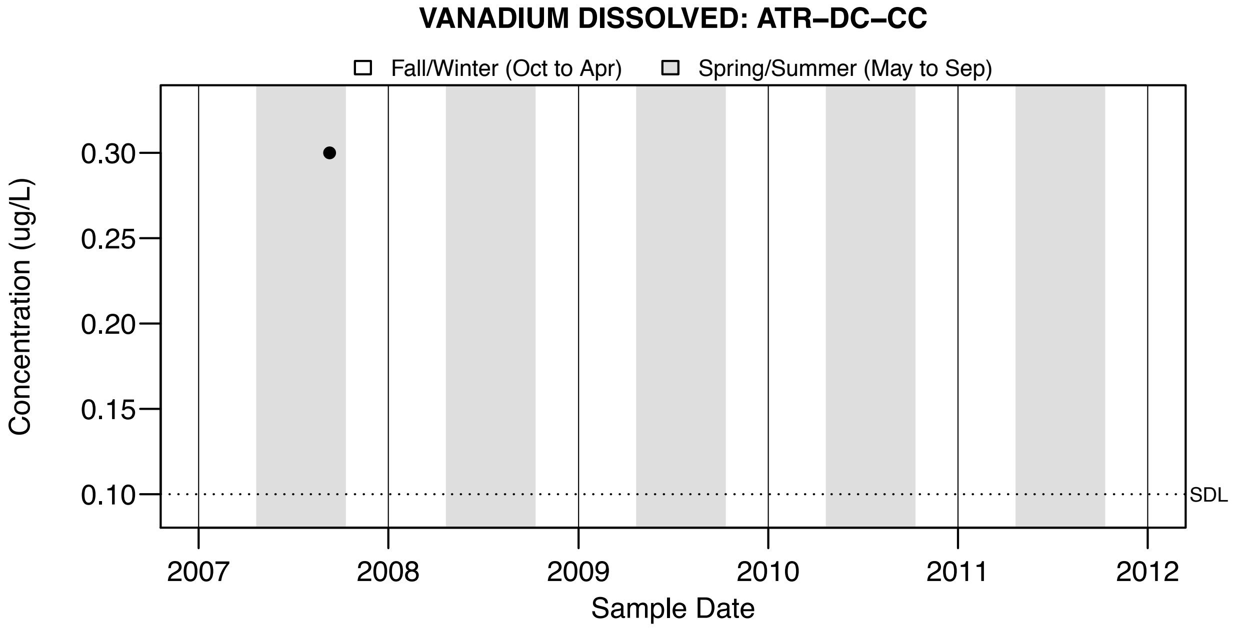


Figure A3.31: VANADIUM DISSOLVED: ATR-DC-CC -

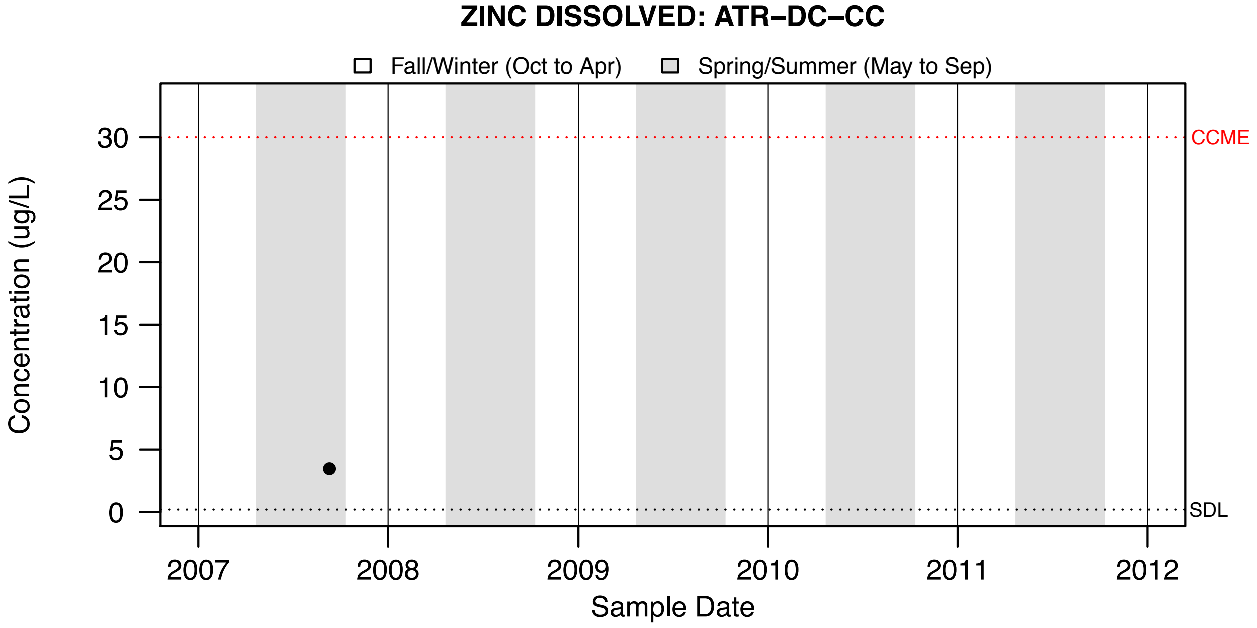
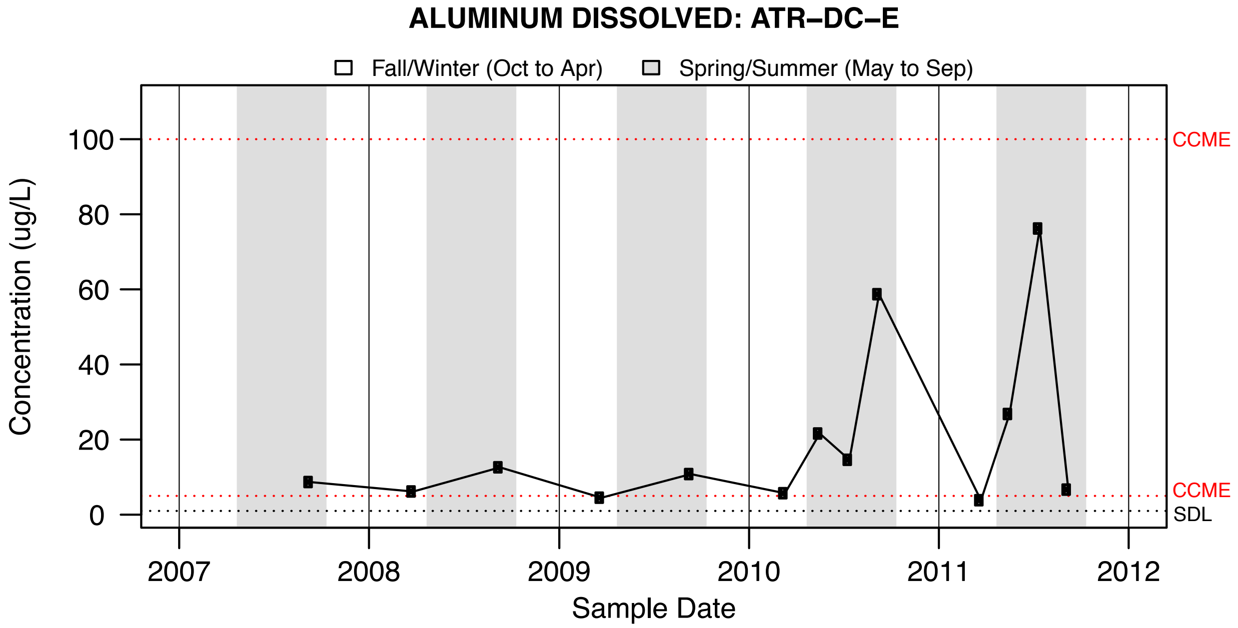
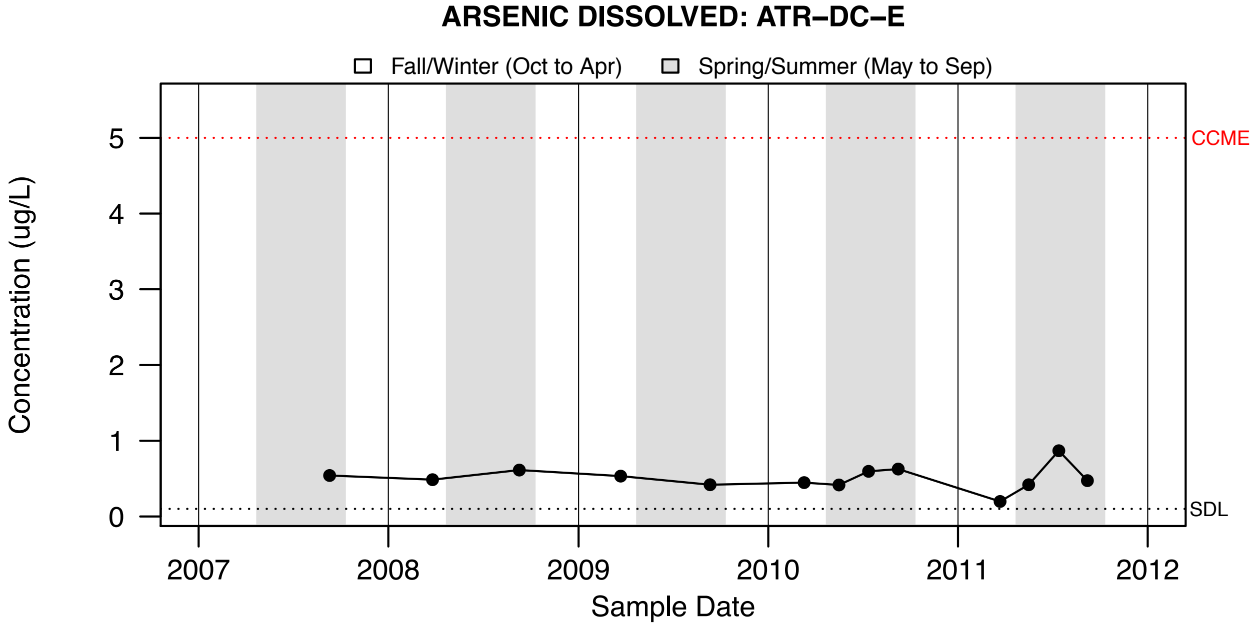


Figure A3.32: ZINC DISSOLVED: ATR-DC-CC -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.33: ALUMINUM DISSOLVED: ATR-DC-E -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.34: ARSENIC DISSOLVED: ATR-DC-E -

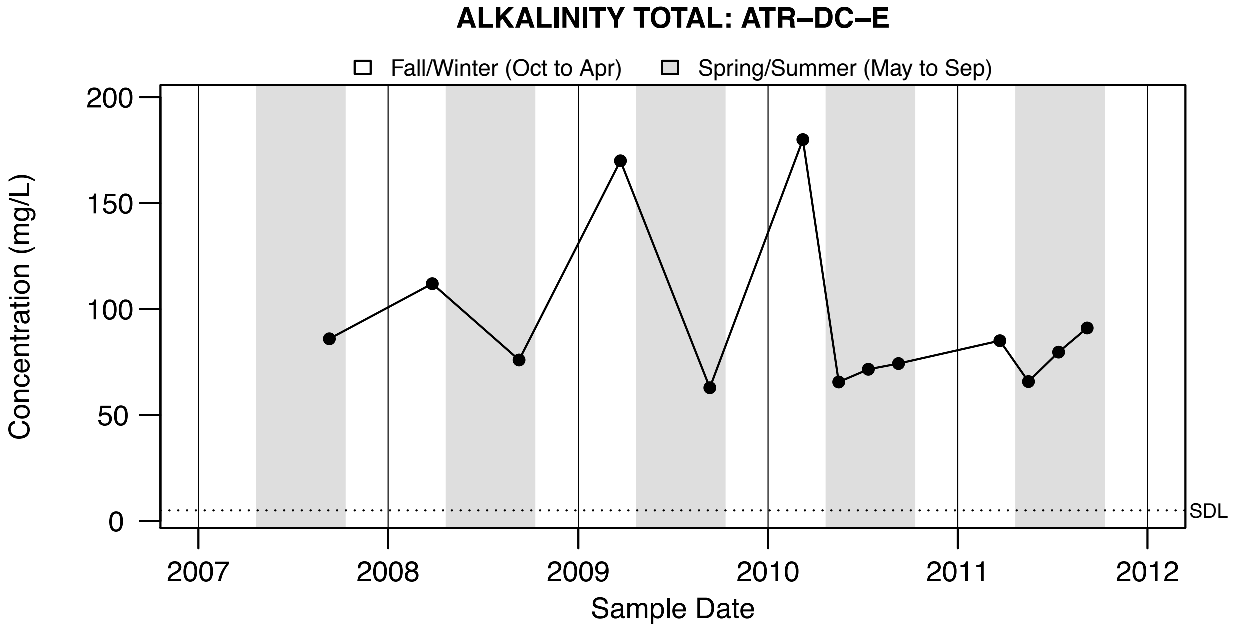


Figure A3.35: ALKALINITY TOTAL: ATR-DC-E -

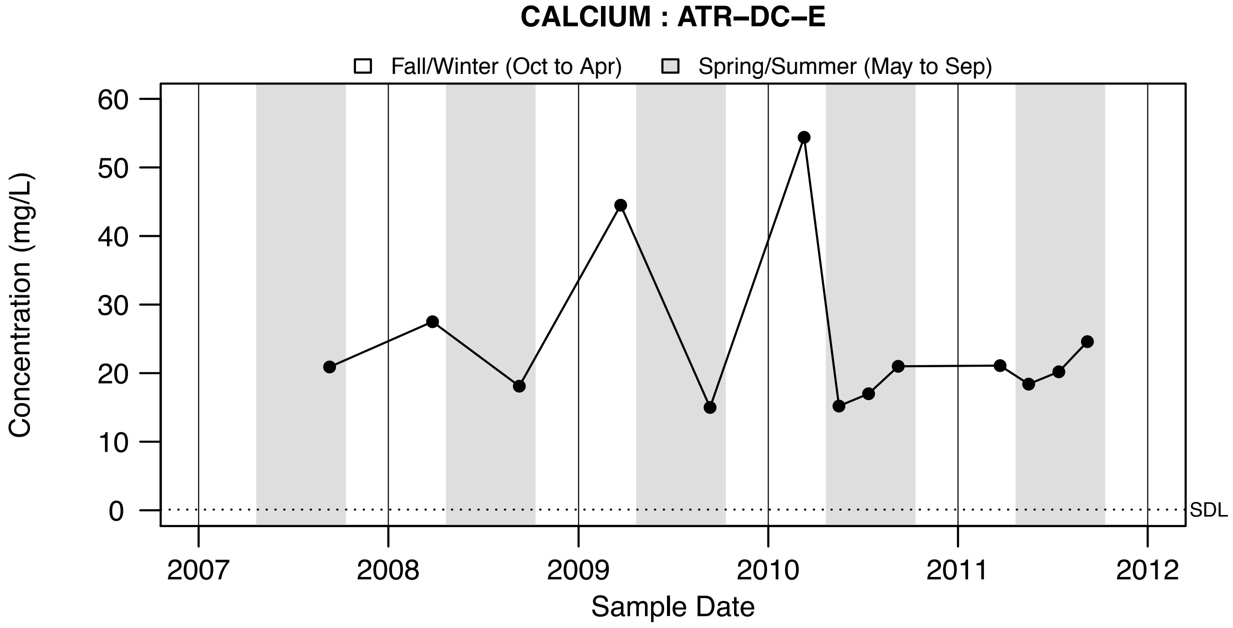


Figure A3.36: CALCIUM : ATR-DC-E -

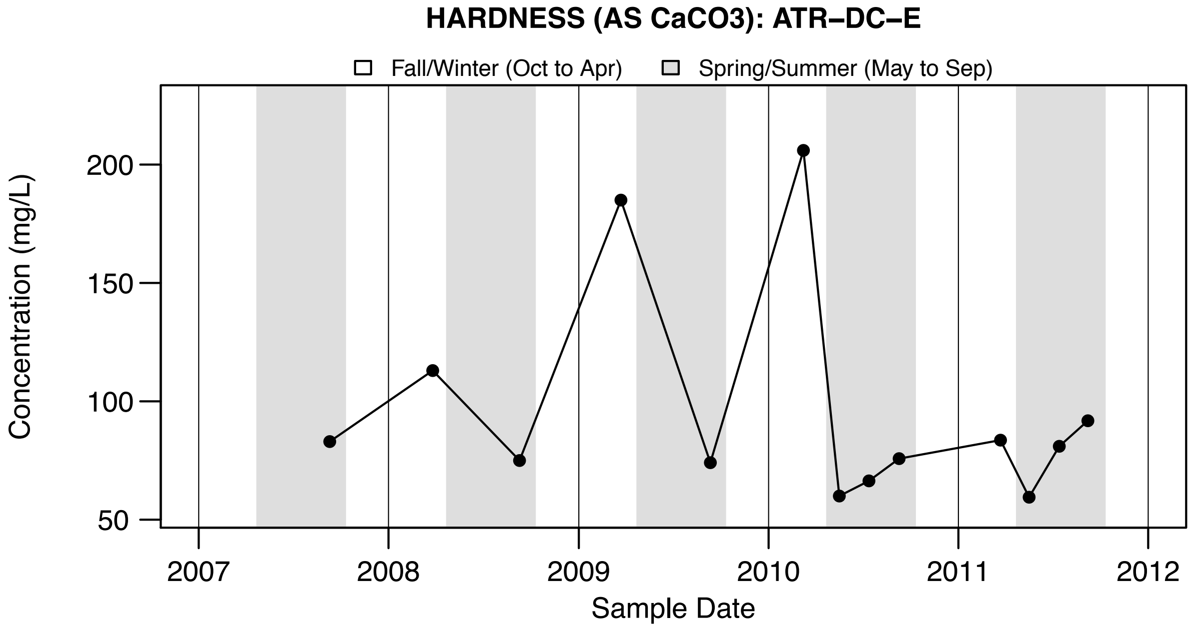


Figure A3.37: HARDNESS (AS CaCO3): ATR-DC-E -

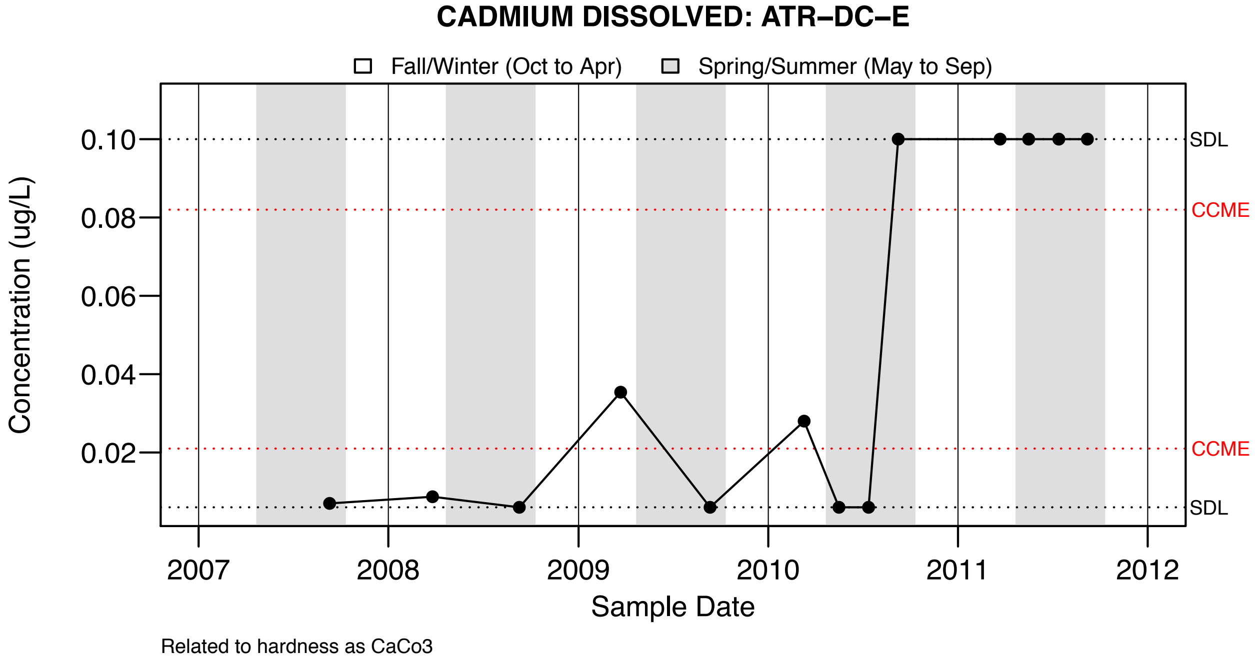


Figure A3.38: CADMIUM DISSOLVED: ATR-DC-E -

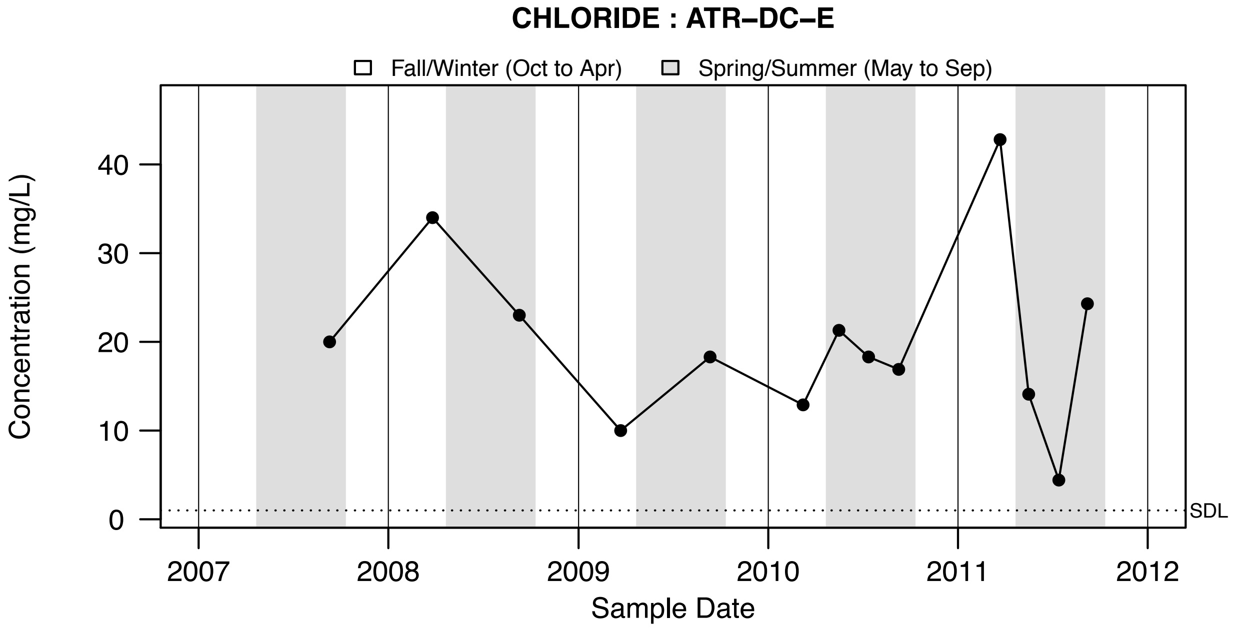


Figure A3.39: CHLORIDE : ATR-DC-E -

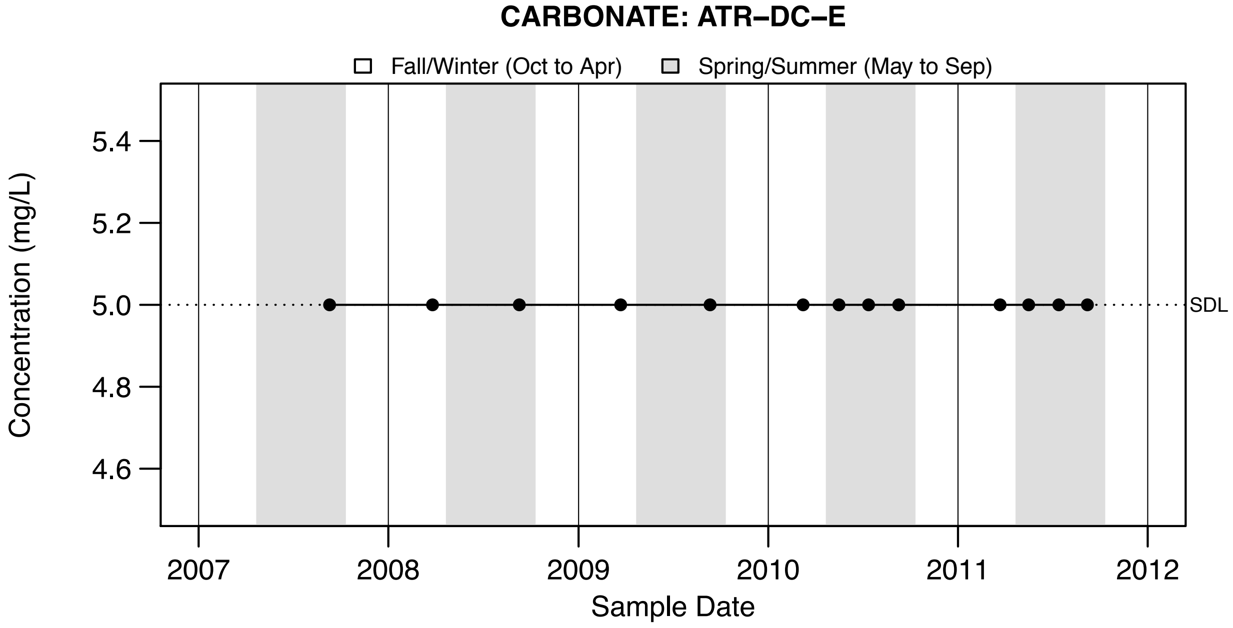


Figure A3.40: CARBONATE: ATR-DC-E -

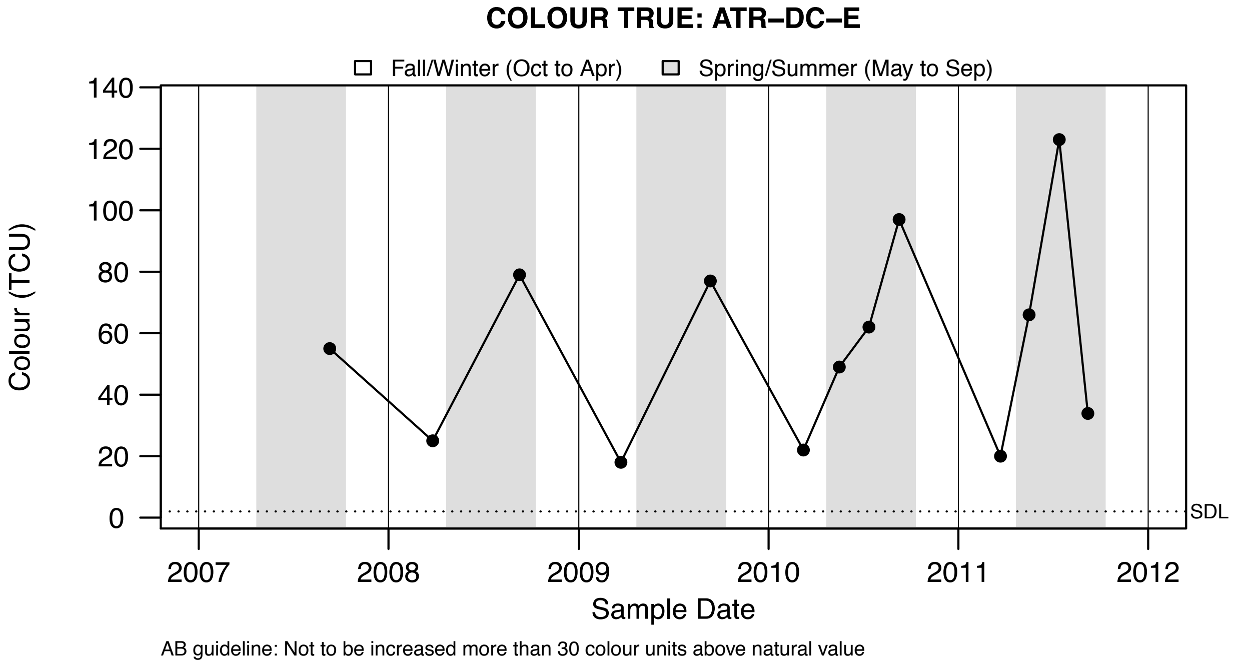


Figure A3.41: COLOUR TRUE: ATR-DC-E -

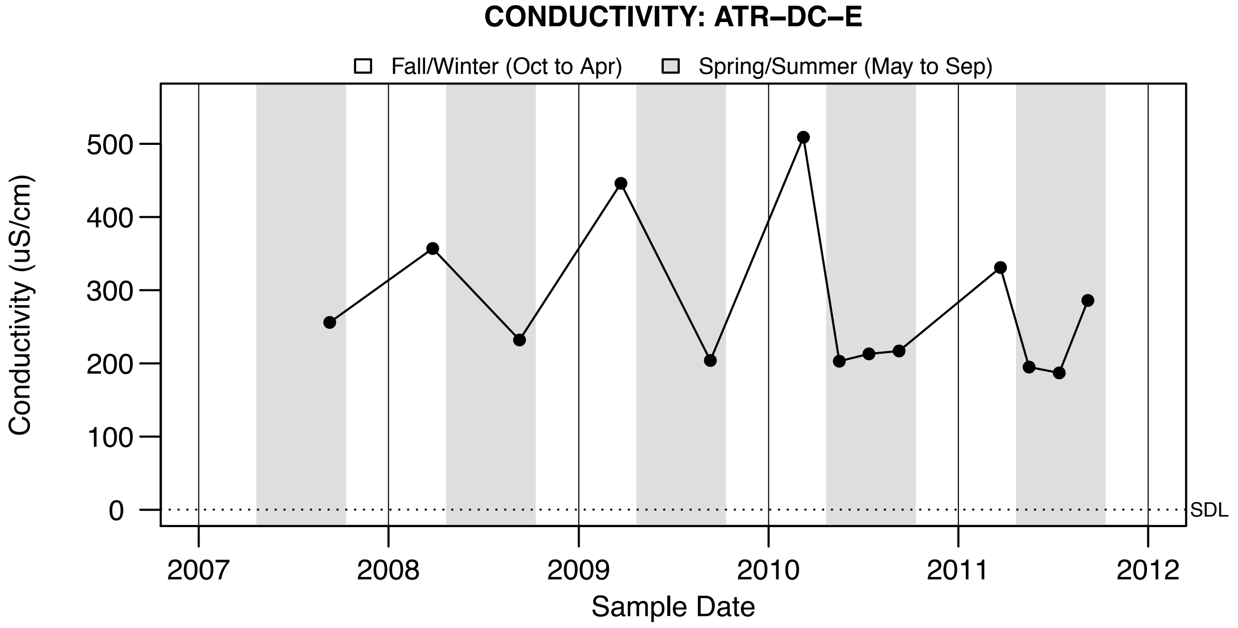
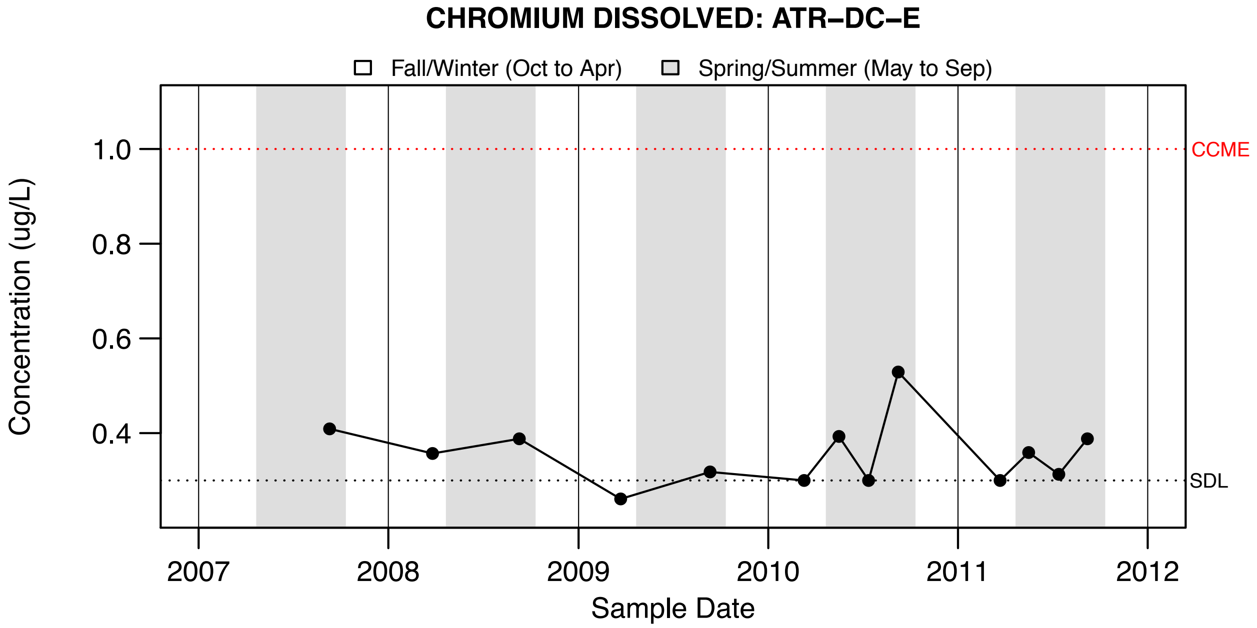
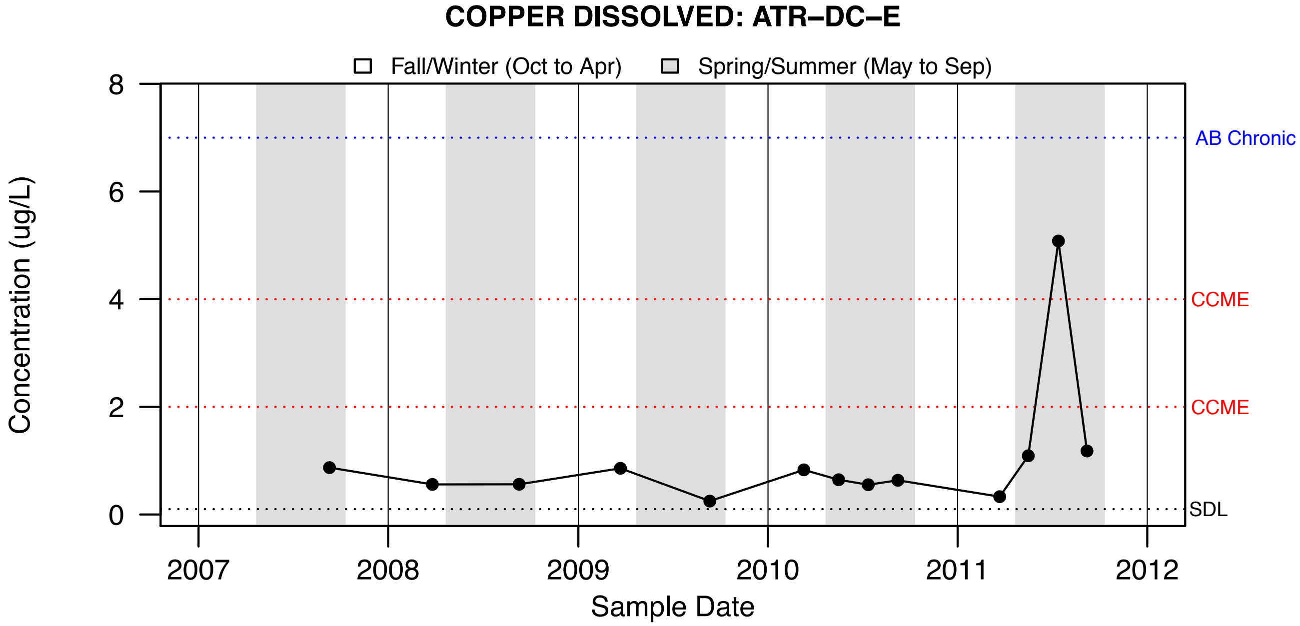


Figure A3.42: CONDUCTIVITY: ATR-DC-E -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.43: CHROMIUM DISSOLVED: ATR-DC-E -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.44: COPPER DISSOLVED: ATR-DC-E -

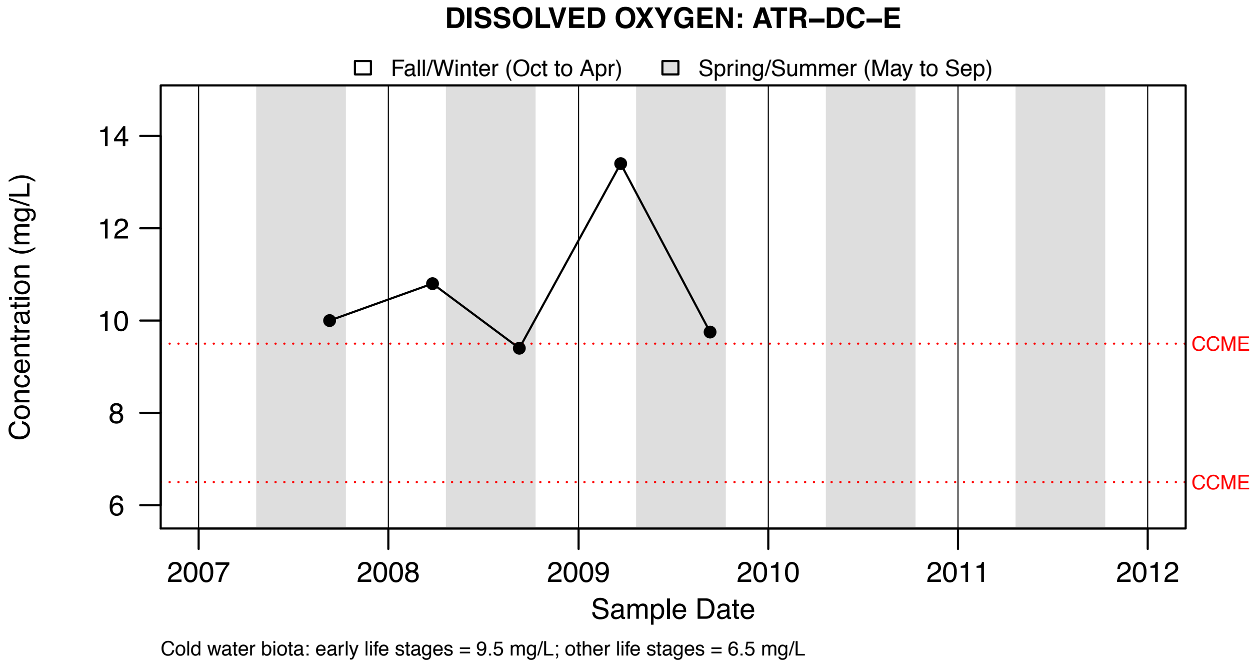


Figure A3.45: DISSOLVED OXYGEN: ATR-DC-E -

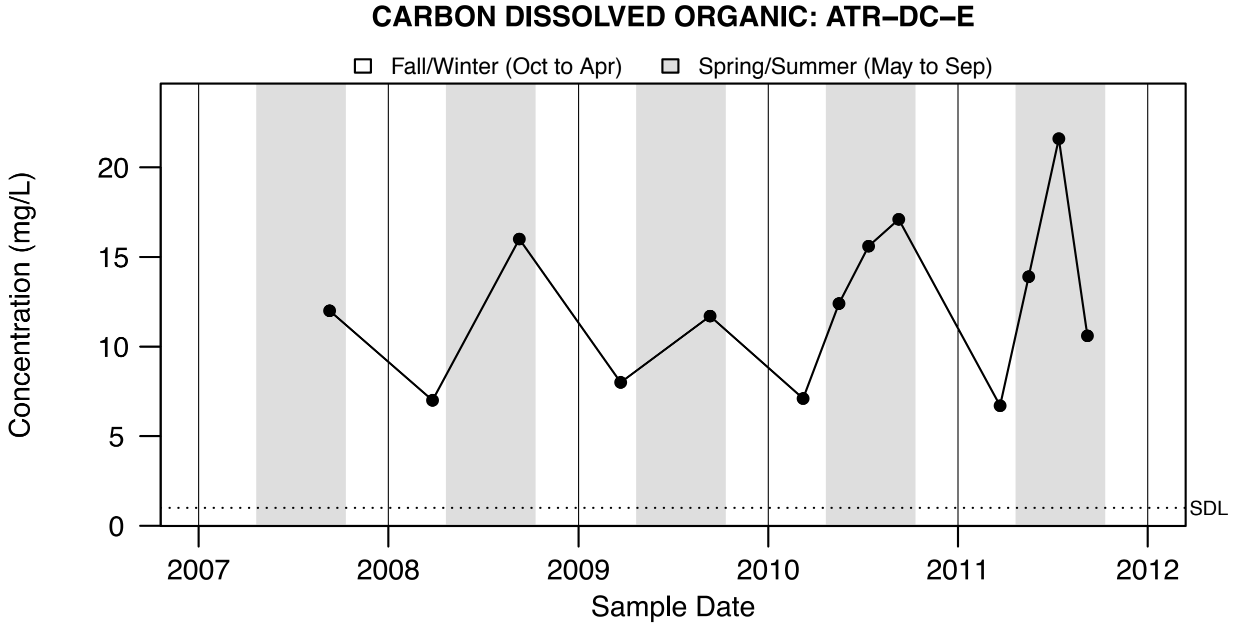


Figure A3.46: CARBON DISSOLVED ORGANIC: ATR-DC-E -

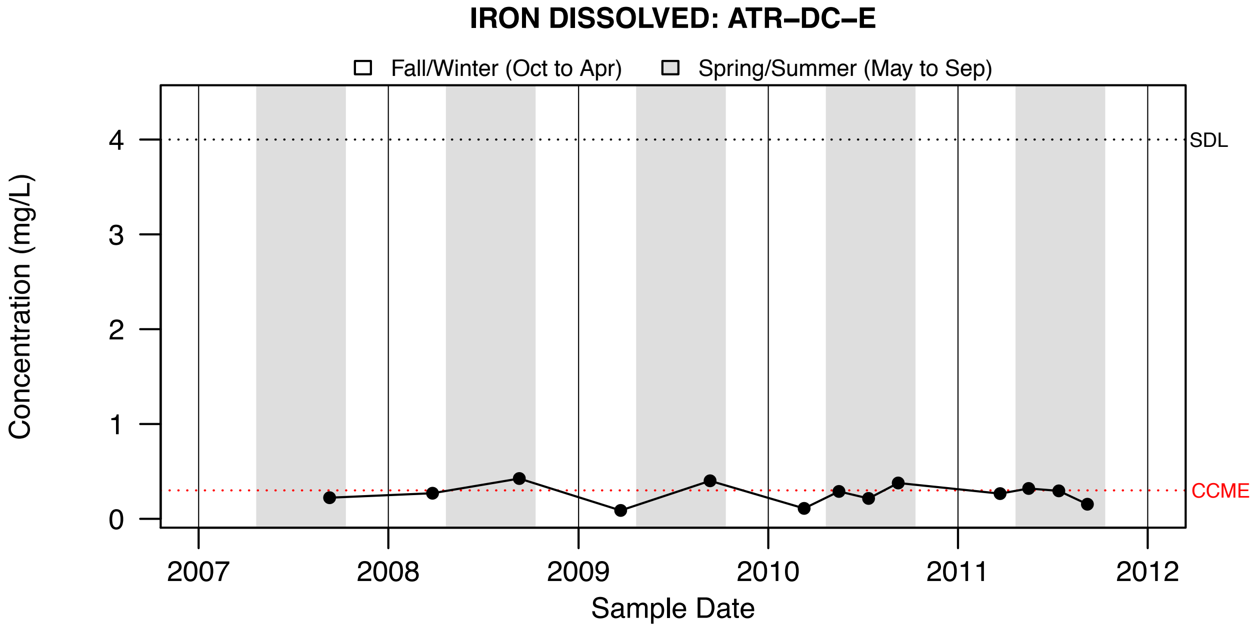


Figure A3.47: IRON DISSOLVED: ATR-DC-E -

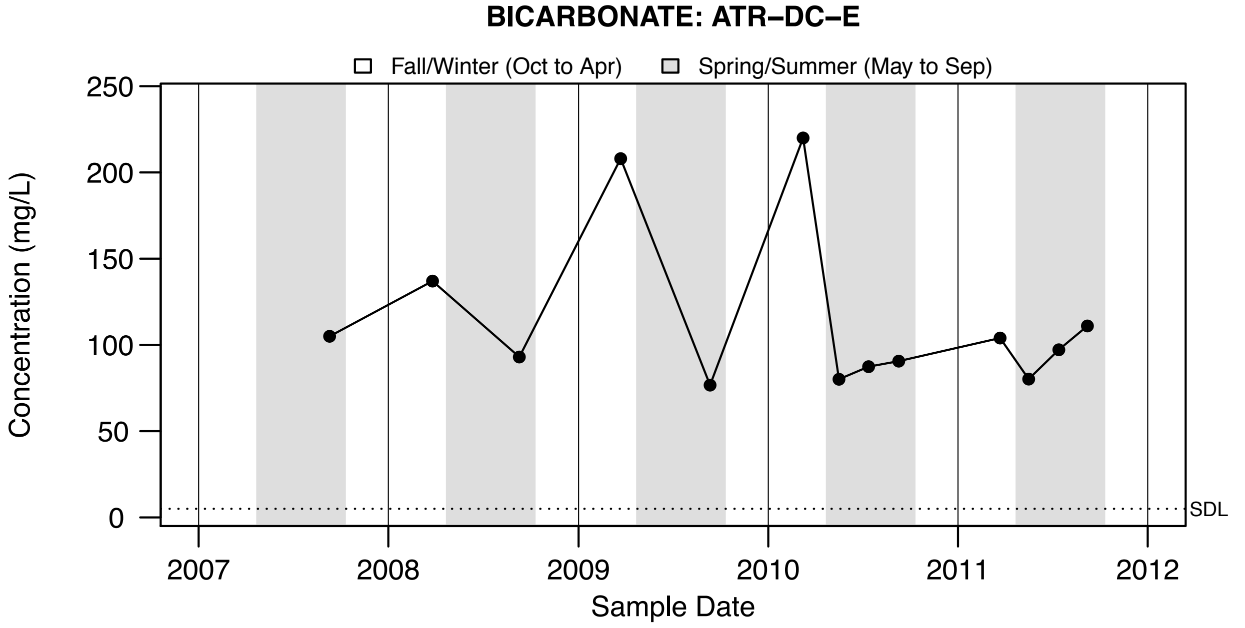


Figure A3.48: BICARBONATE: ATR-DC-E -

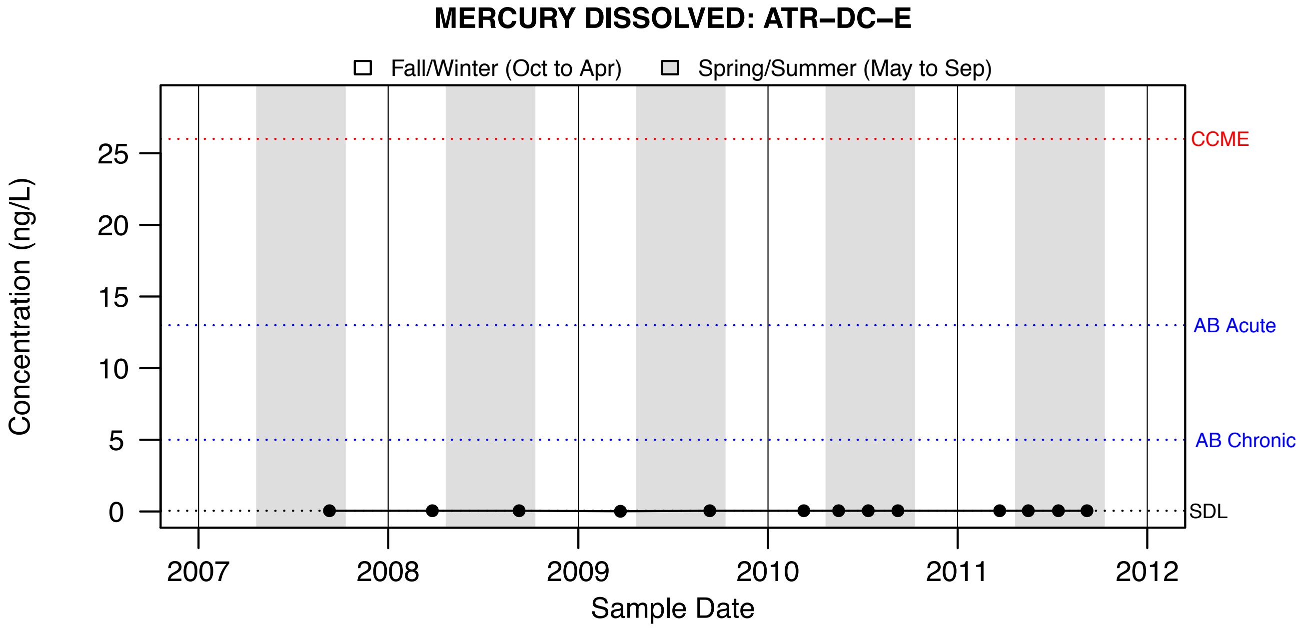


Figure A3.49: MERCURY DISSOLVED: ATR-DC-E -

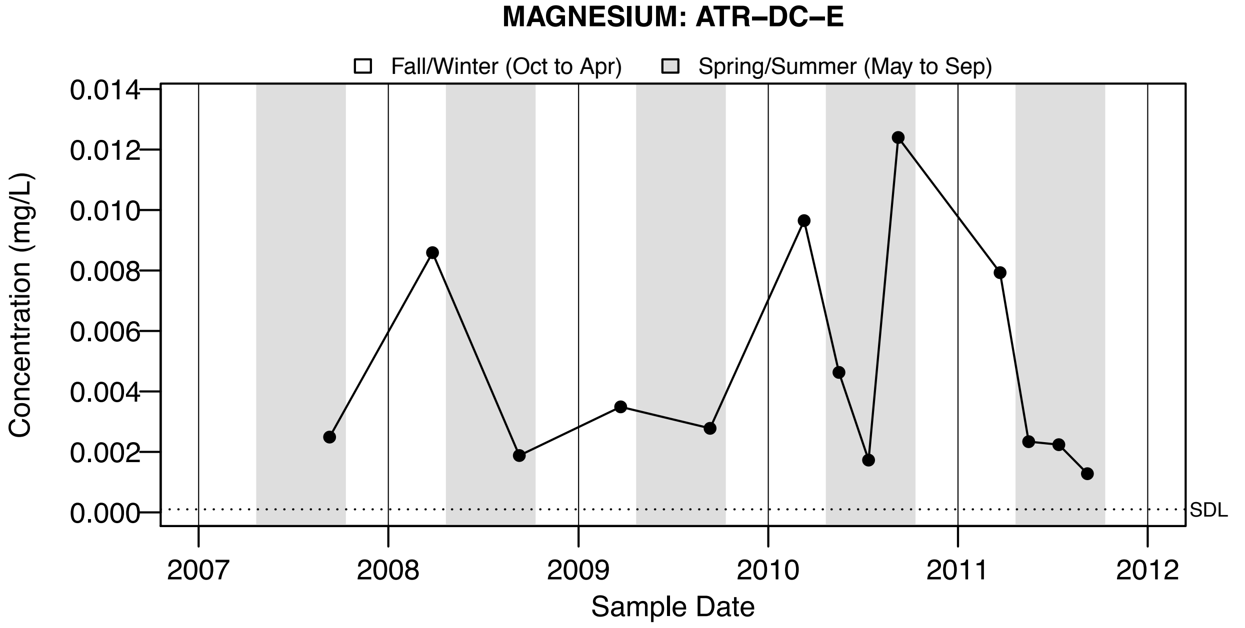


Figure A3.50: MAGNESIUM: ATR-DC-E -

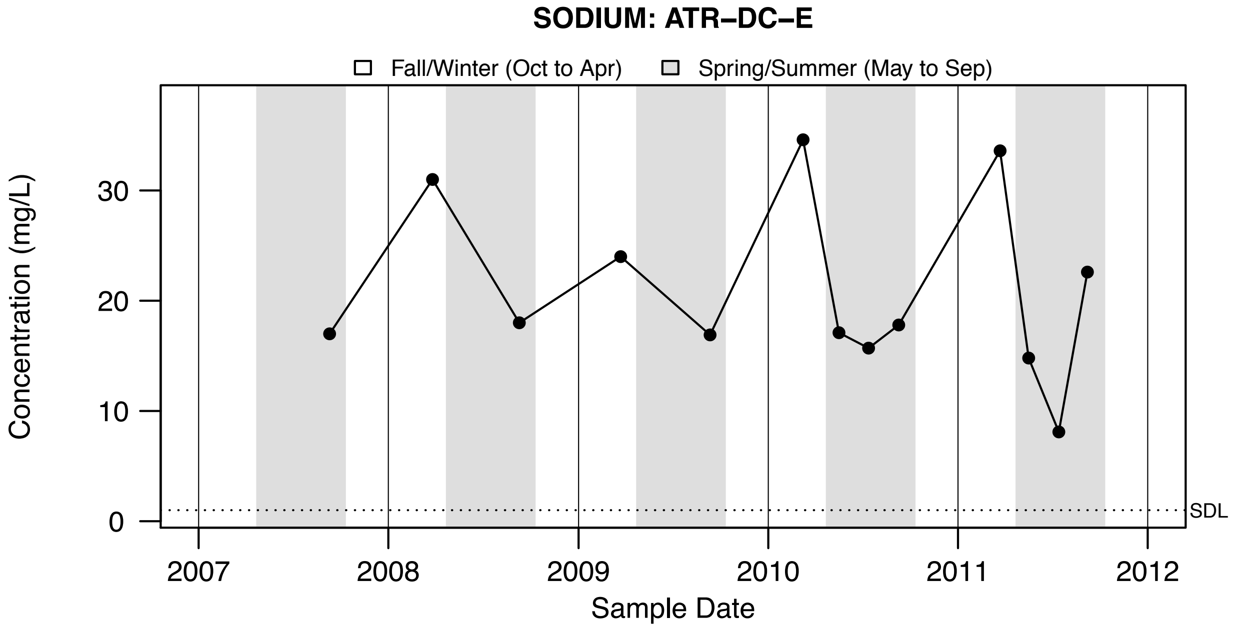
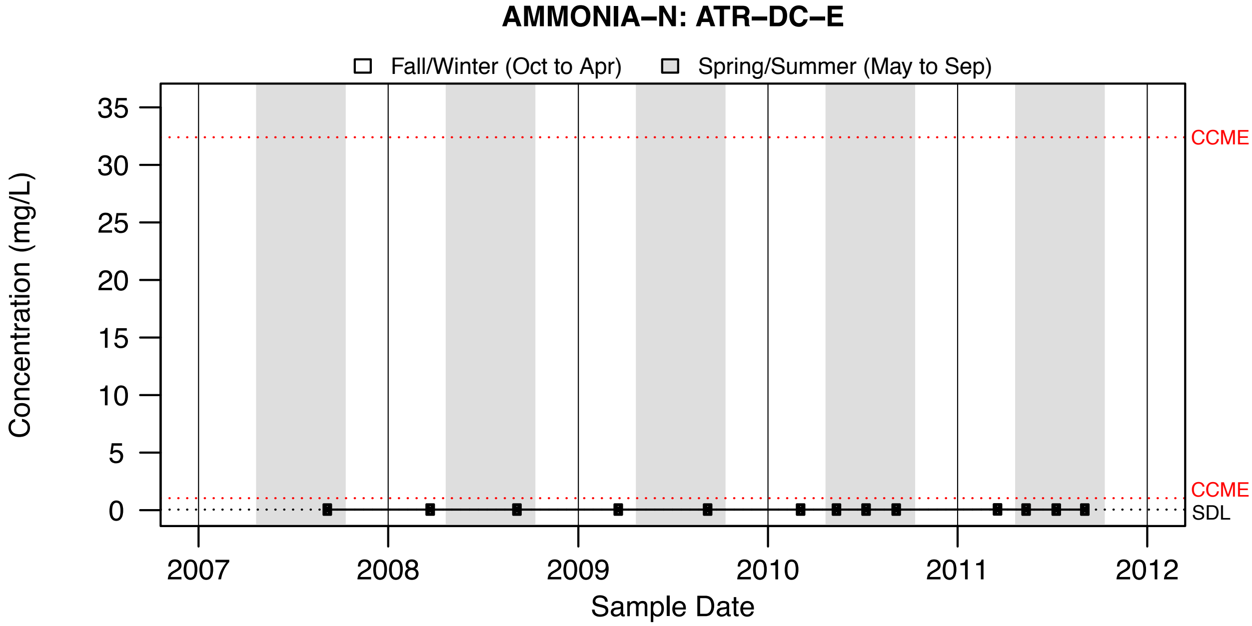


Figure A3.51: SODIUM: ATR-DC-E -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.52: AMMONIA-N: ATR-DC-E -

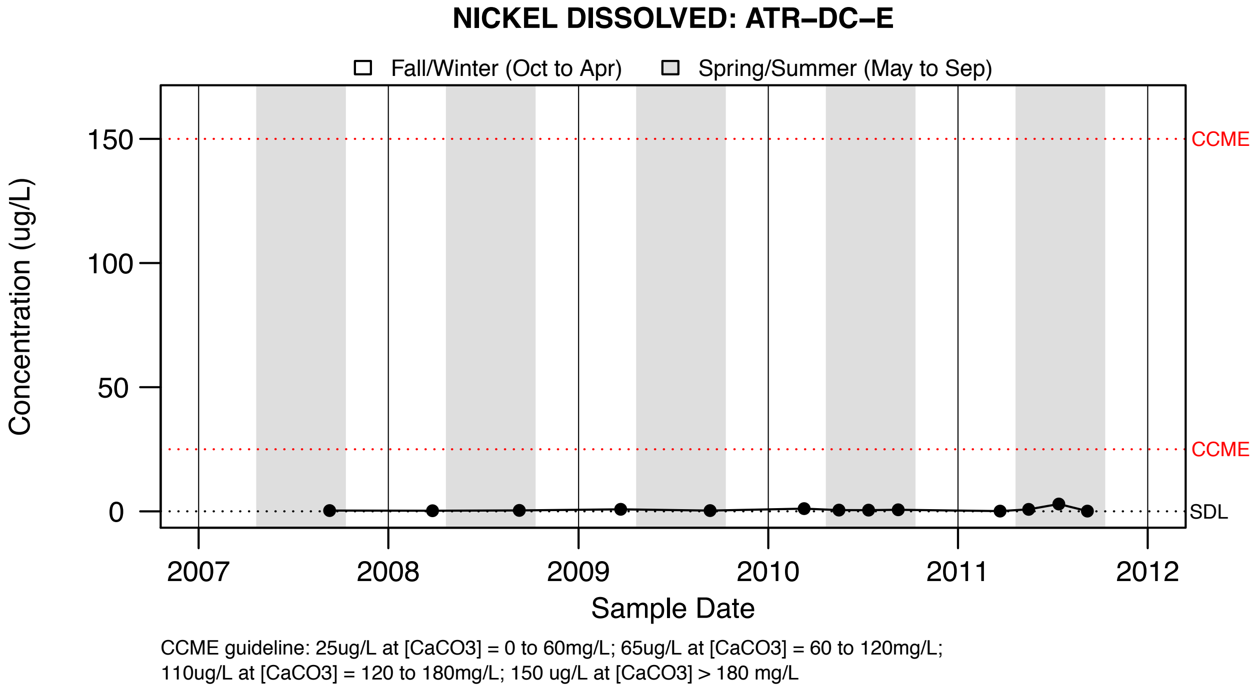


Figure A3.53: NICKEL DISSOLVED: ATR-DC-E -

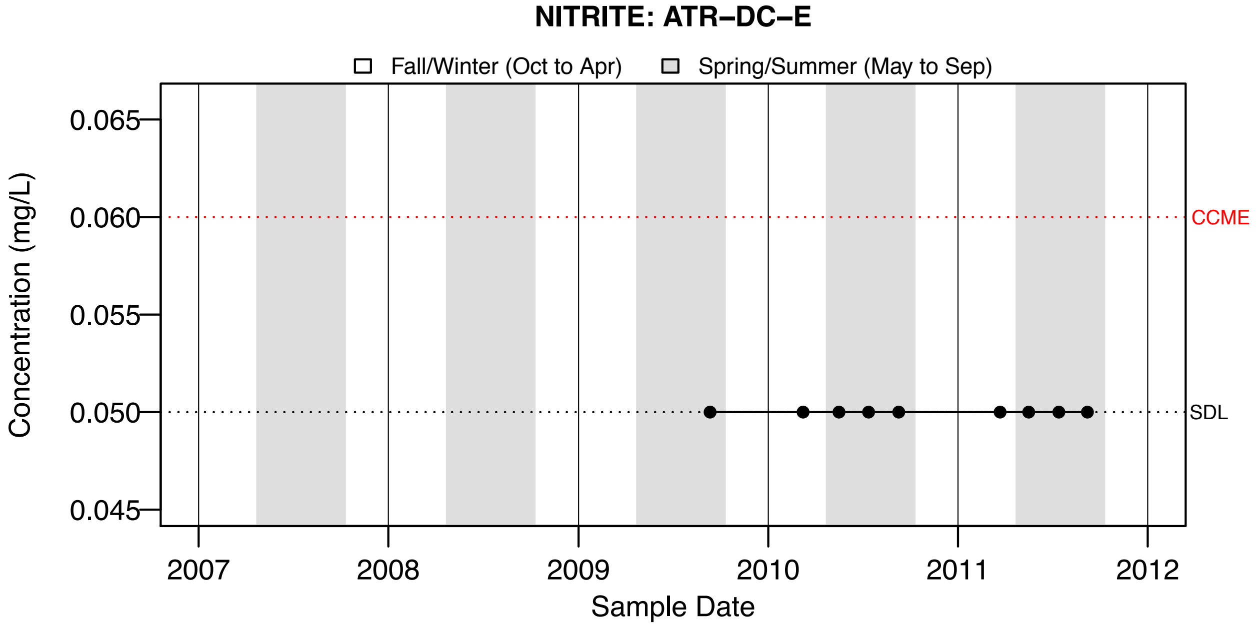
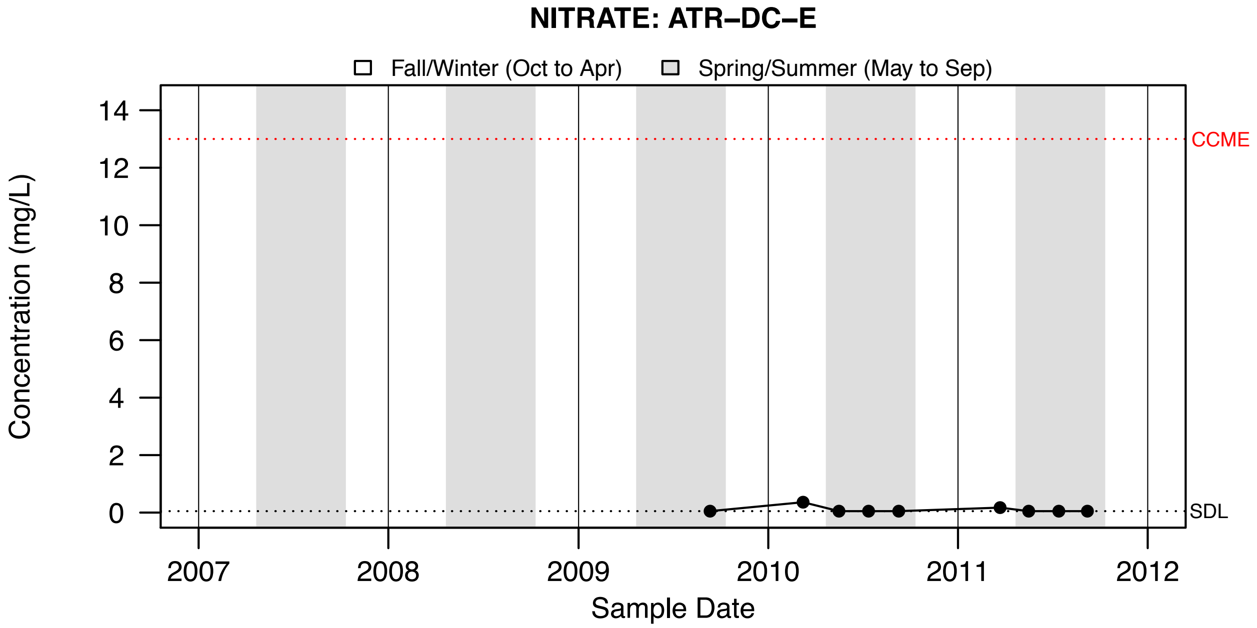


Figure A3.54: NITRITE: ATR-DC-E -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.55: NITRATE: ATR-DC-E -

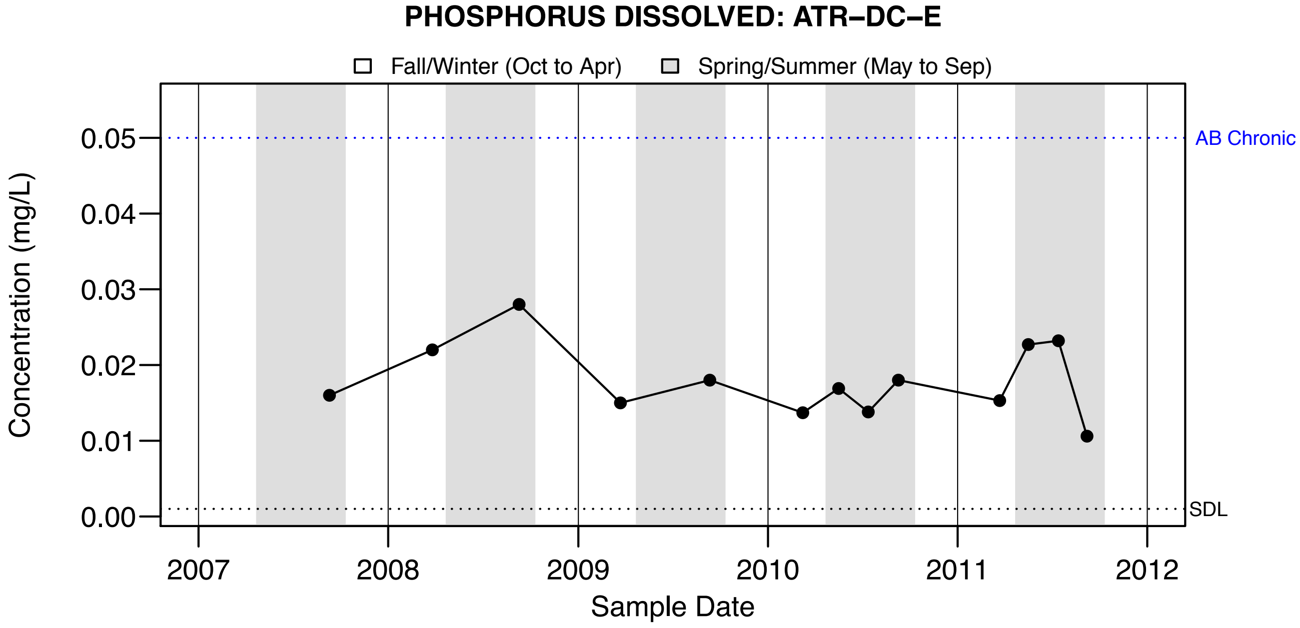


Figure A3.56: PHOSPHORUS DISSOLVED: ATR-DC-E -

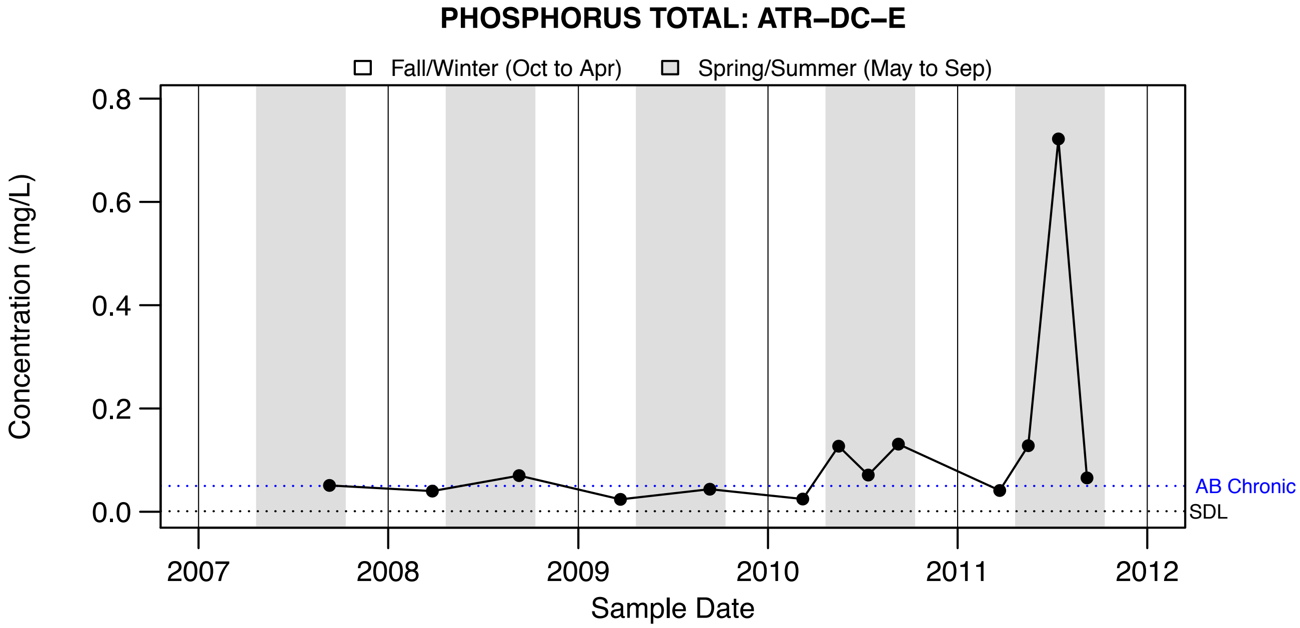
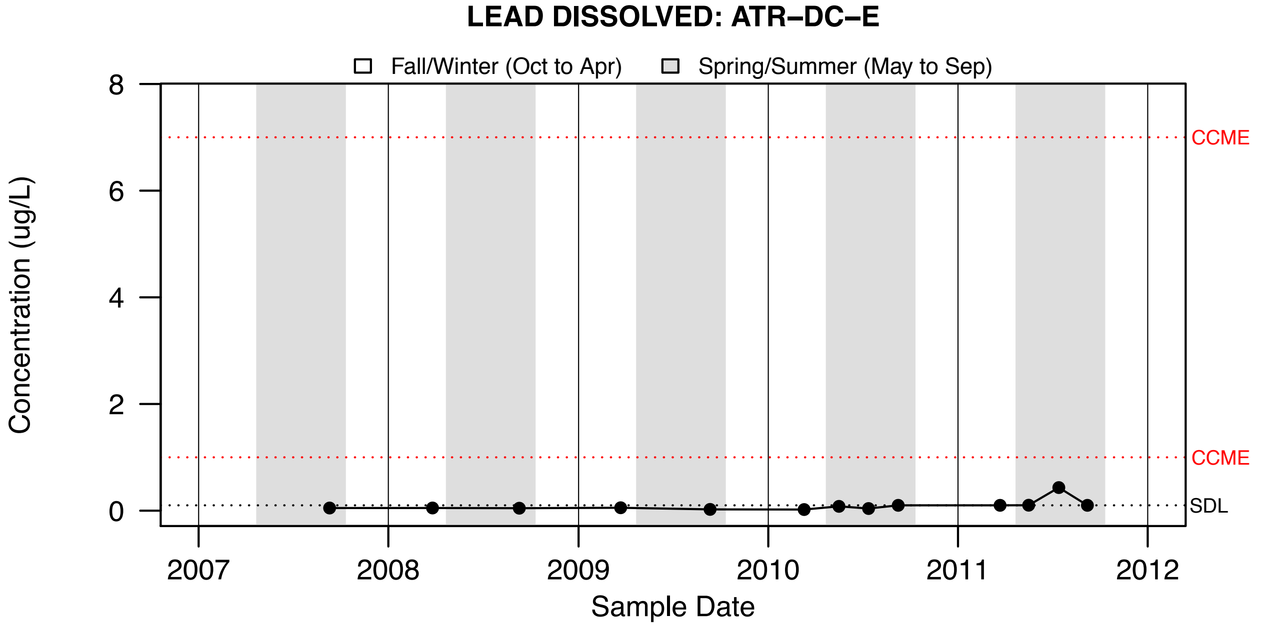


Figure A3.57: PHOSPHORUS TOTAL: ATR-DC-E -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.58: LEAD DISSOLVED: ATR-DC-E -

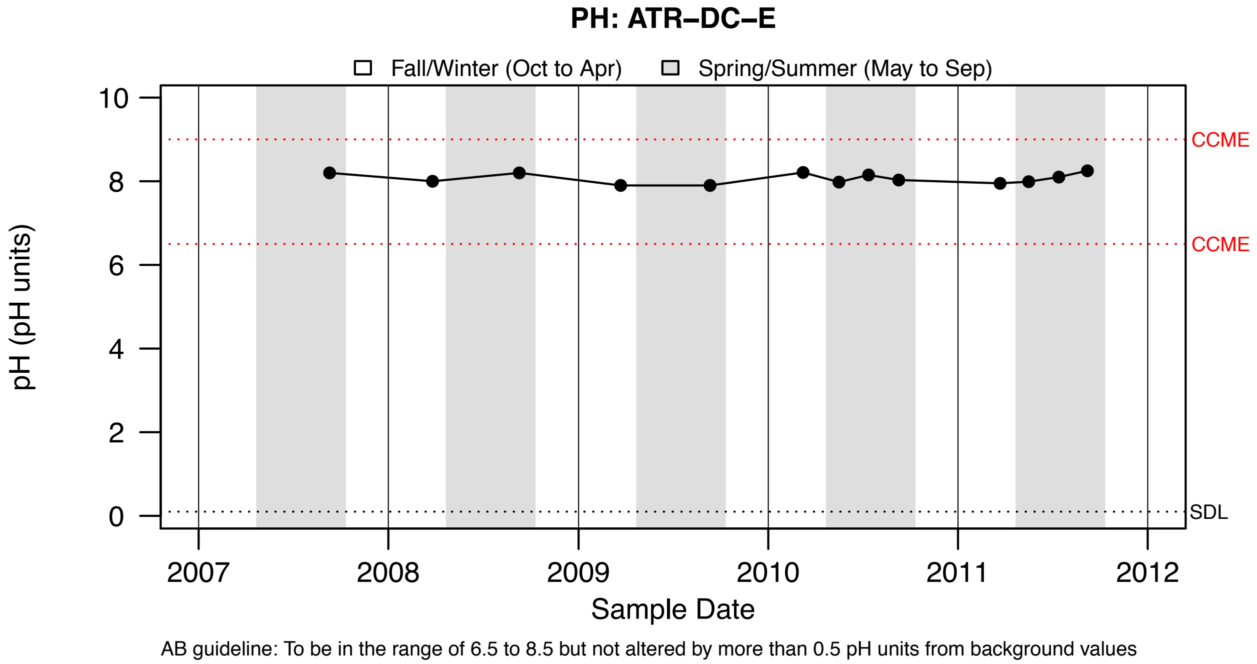


Figure A3.59: PH: ATR-DC-E -

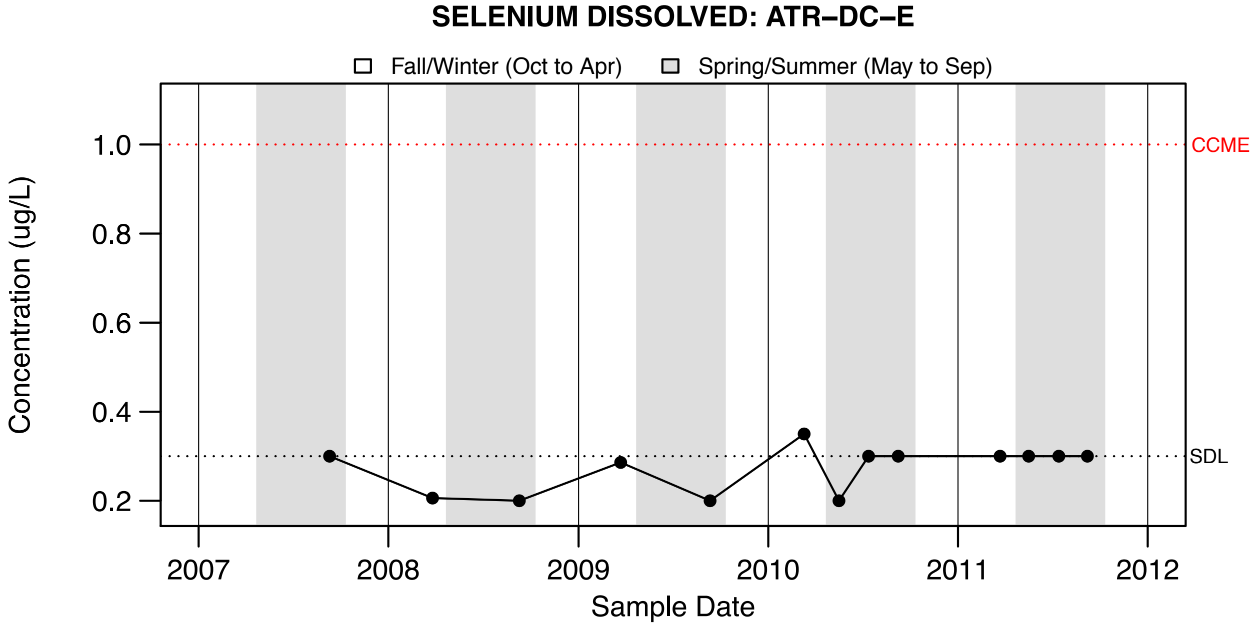


Figure A3.60: SELENIUM DISSOLVED: ATR-DC-E -

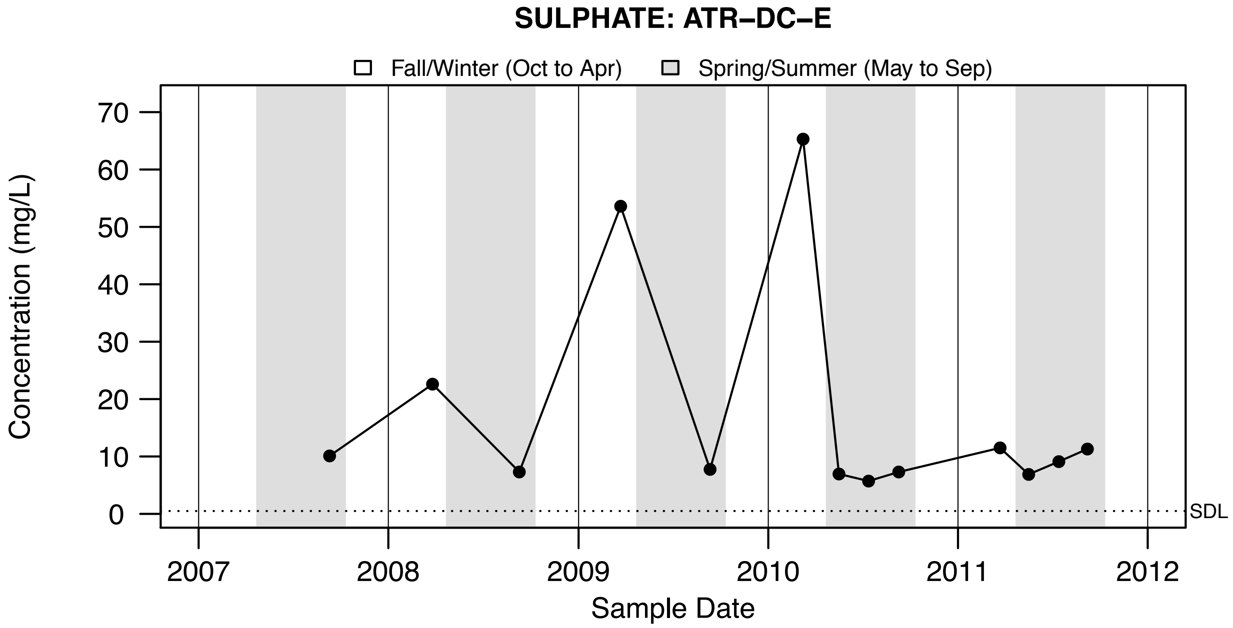


Figure A3.61: SULPHATE: ATR-DC-E -

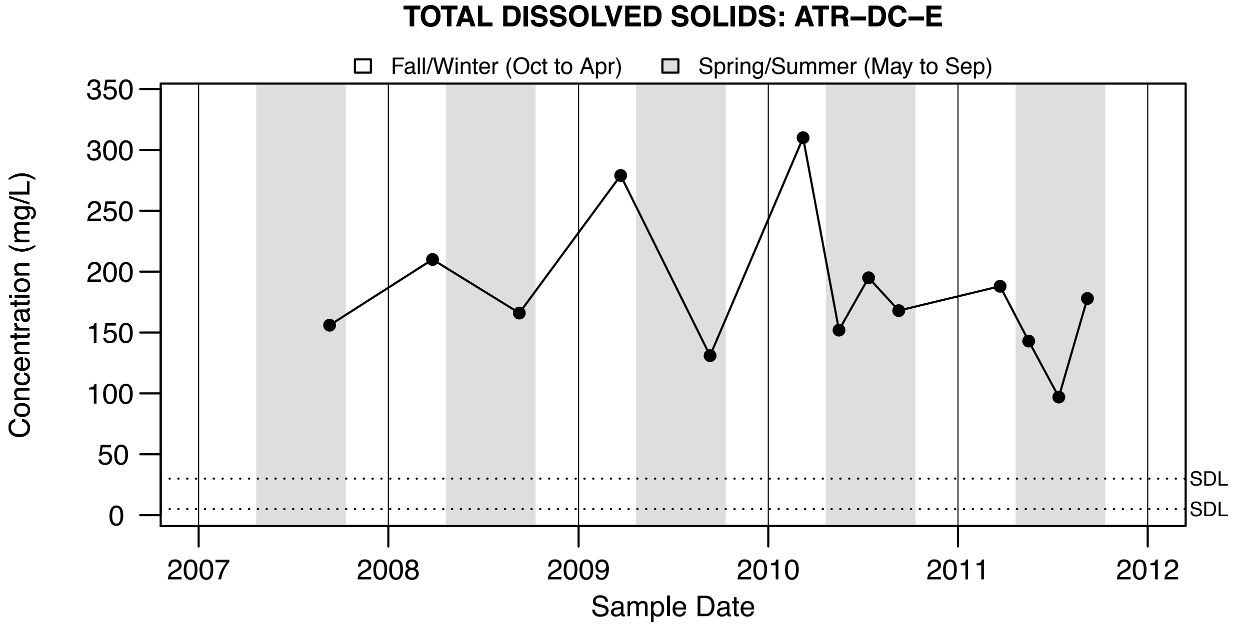
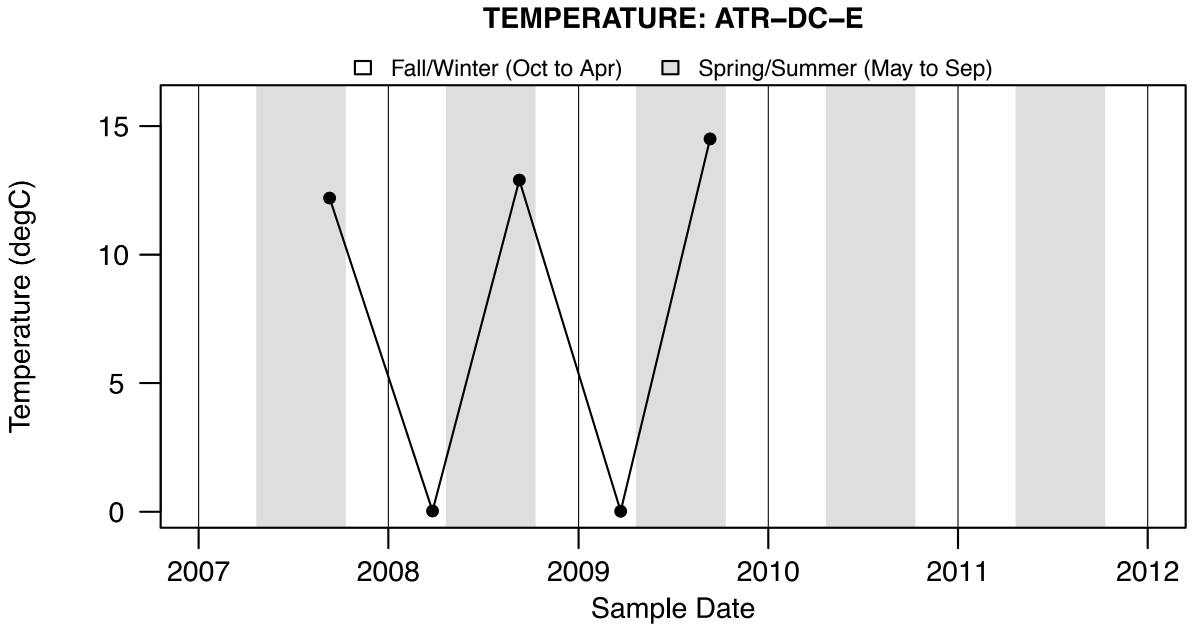


Figure A3.62: TOTAL DISSOLVED SOLIDS: ATR-DC-E -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.63: TEMPERATURE: ATR-DC-E -

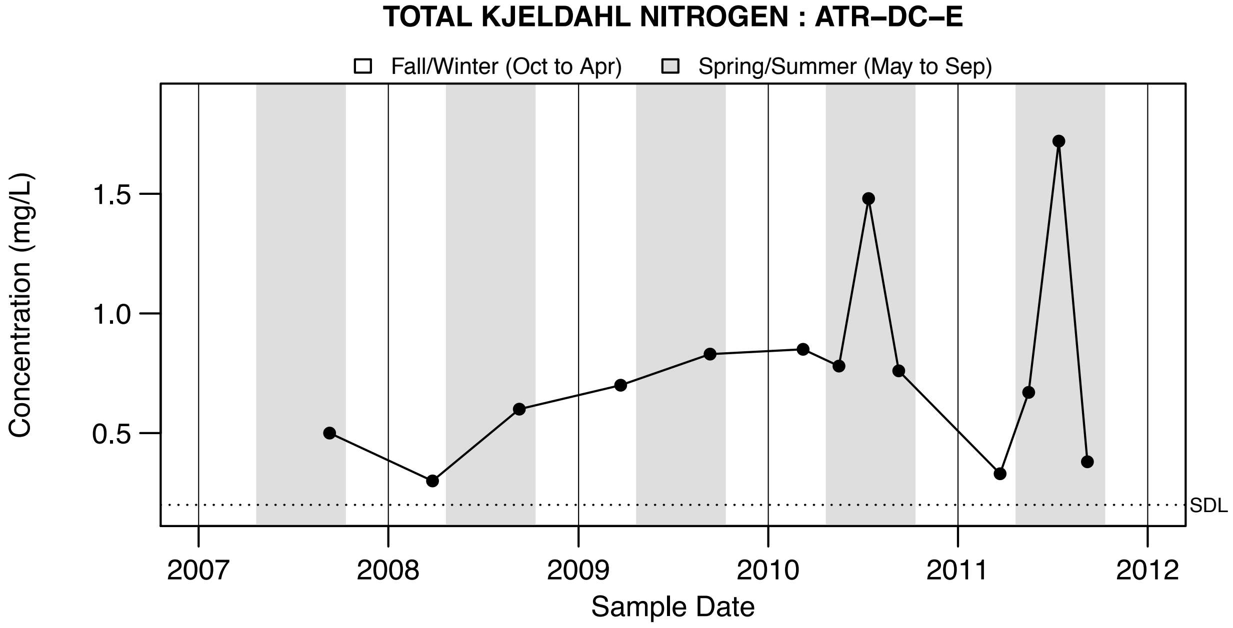
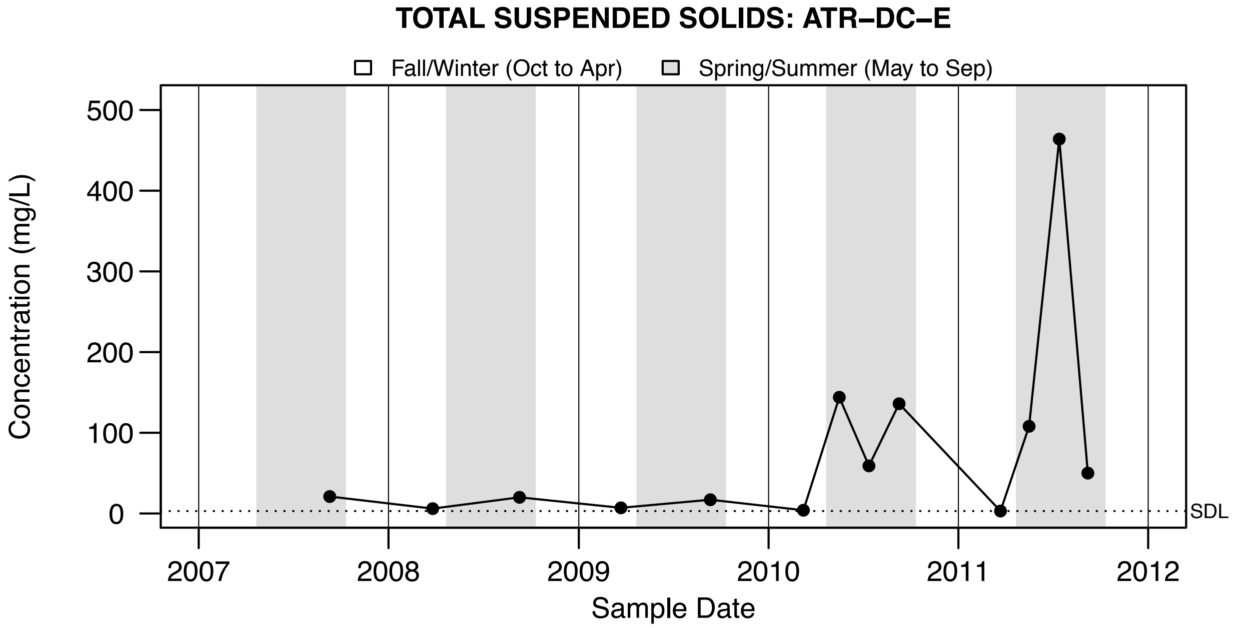


Figure A3.64: TOTAL KJELDAHL NITROGEN : ATR-DC-E -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.65: TOTAL SUSPENDED SOLIDS: ATR-DC-E -

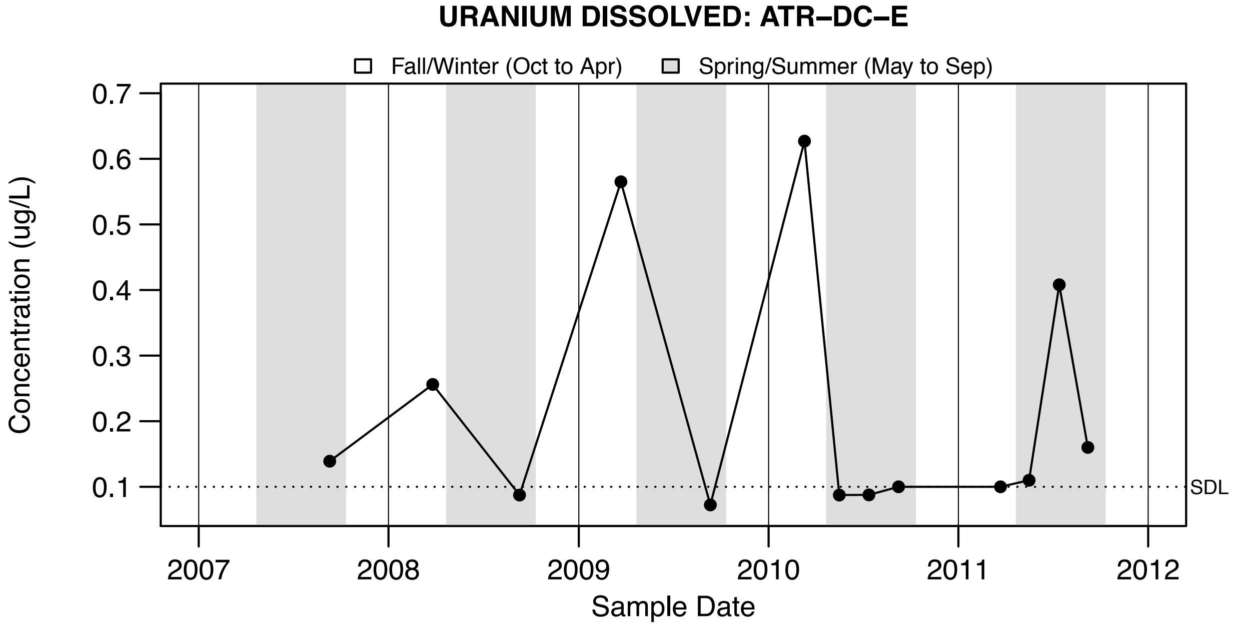


Figure A3.66: URANIUM DISSOLVED: ATR-DC-E -

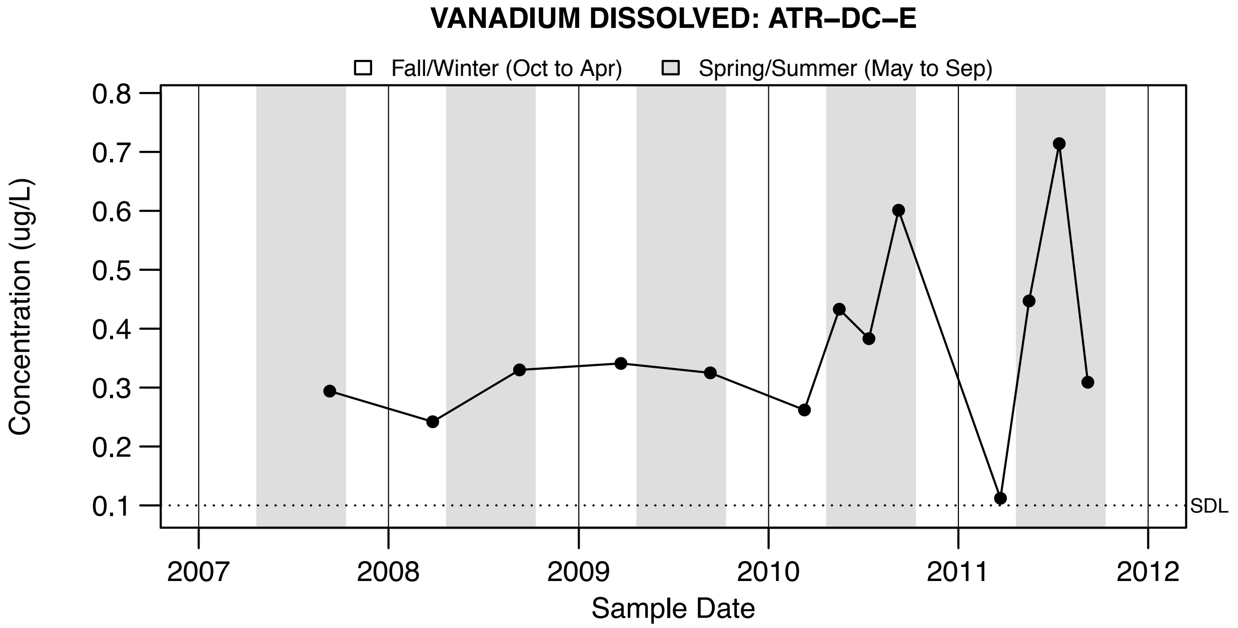


Figure A3.67: VANADIUM DISSOLVED: ATR-DC-E -

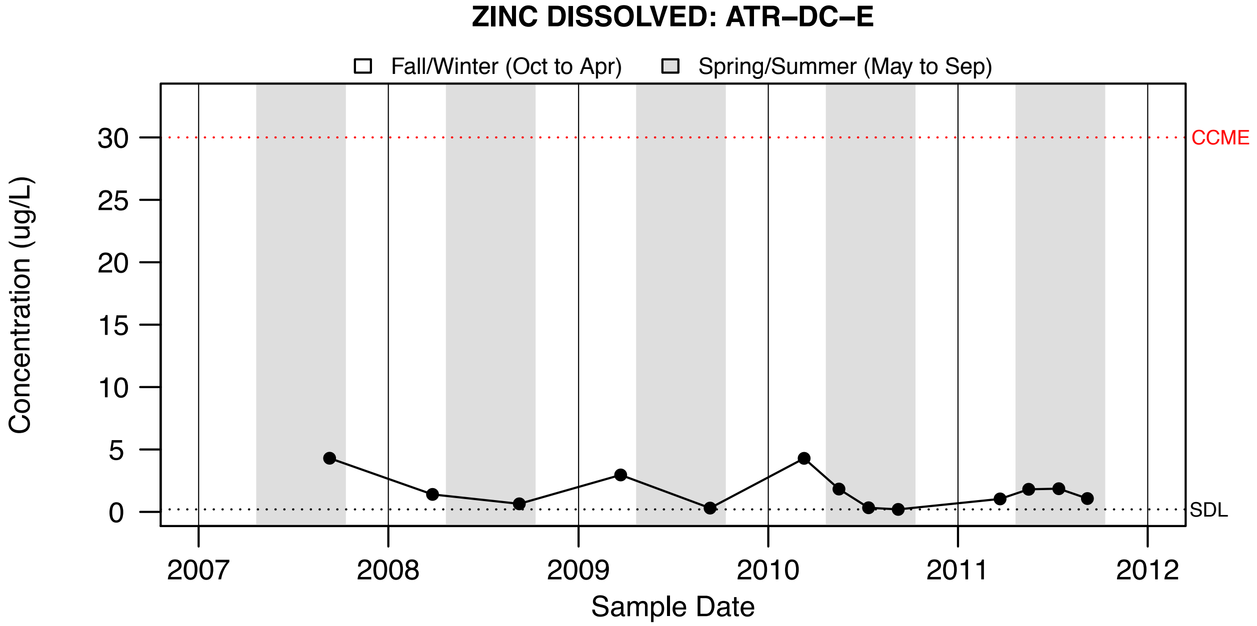
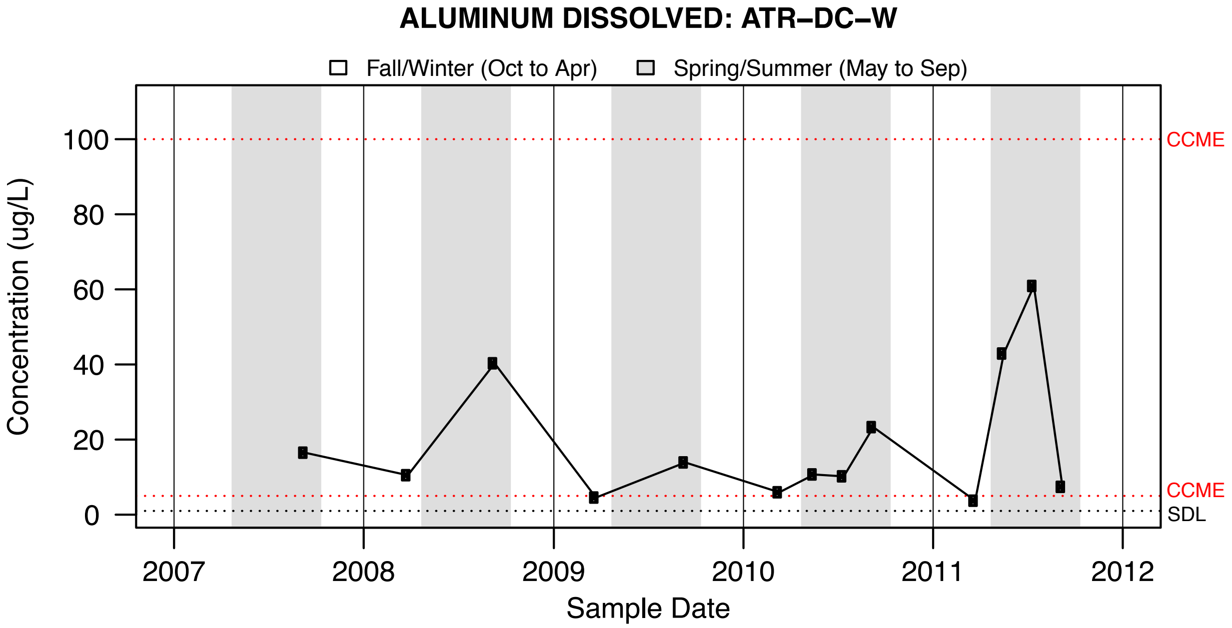
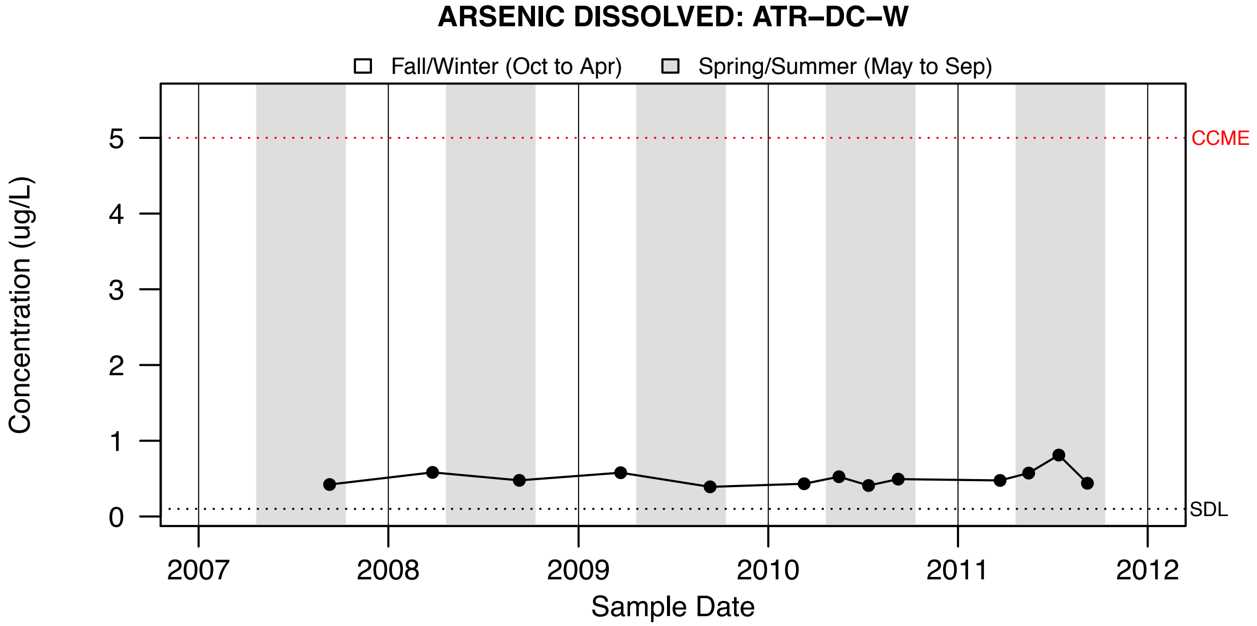


Figure A3.68: ZINC DISSOLVED: ATR-DC-E -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.69: ALUMINUM DISSOLVED: ATR-DC-W -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.70: ARSENIC DISSOLVED: ATR-DC-W -

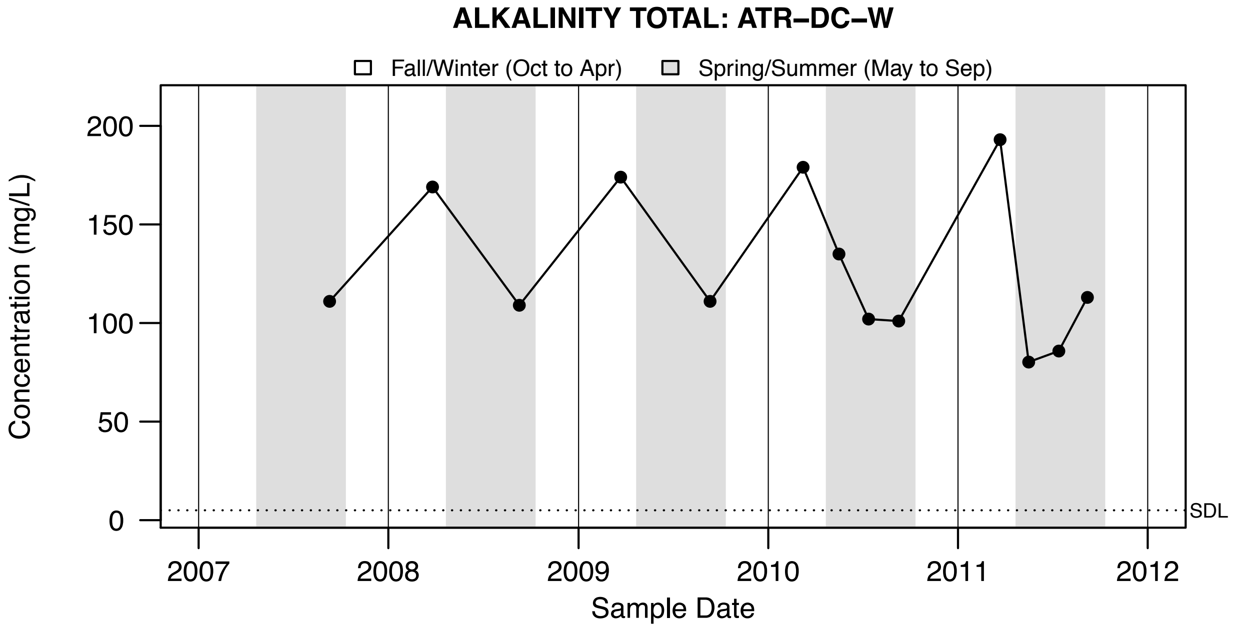


Figure A3.71: ALKALINITY TOTAL: ATR-DC-W -

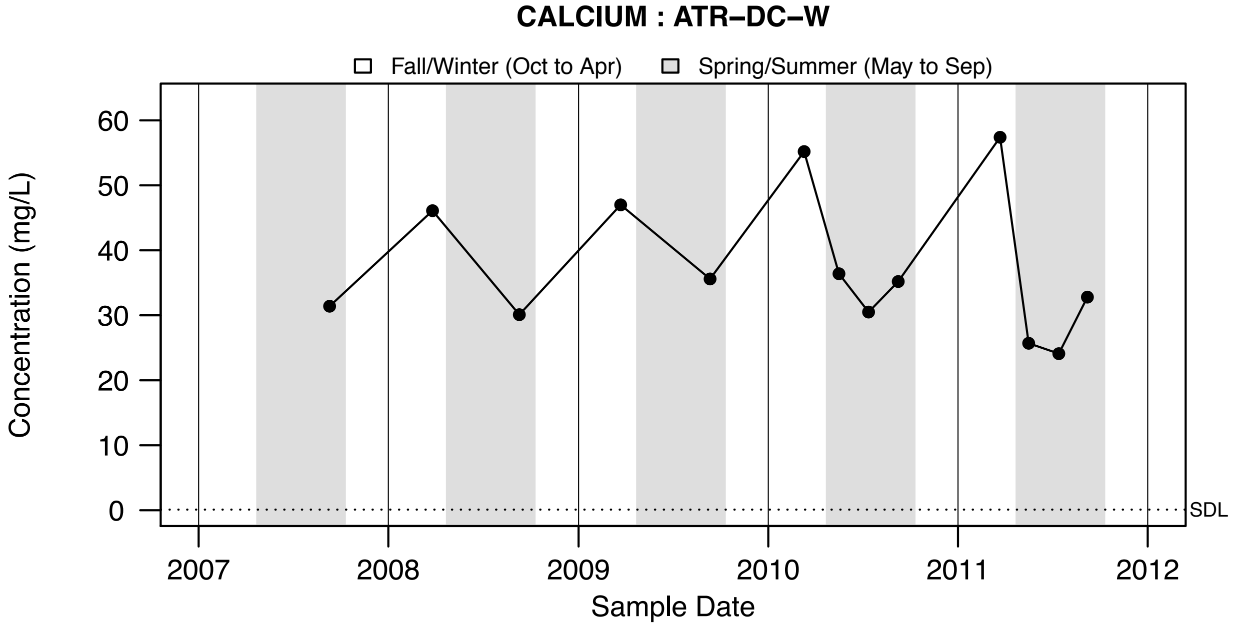


Figure A3.72: CALCIUM : ATR-DC-W -

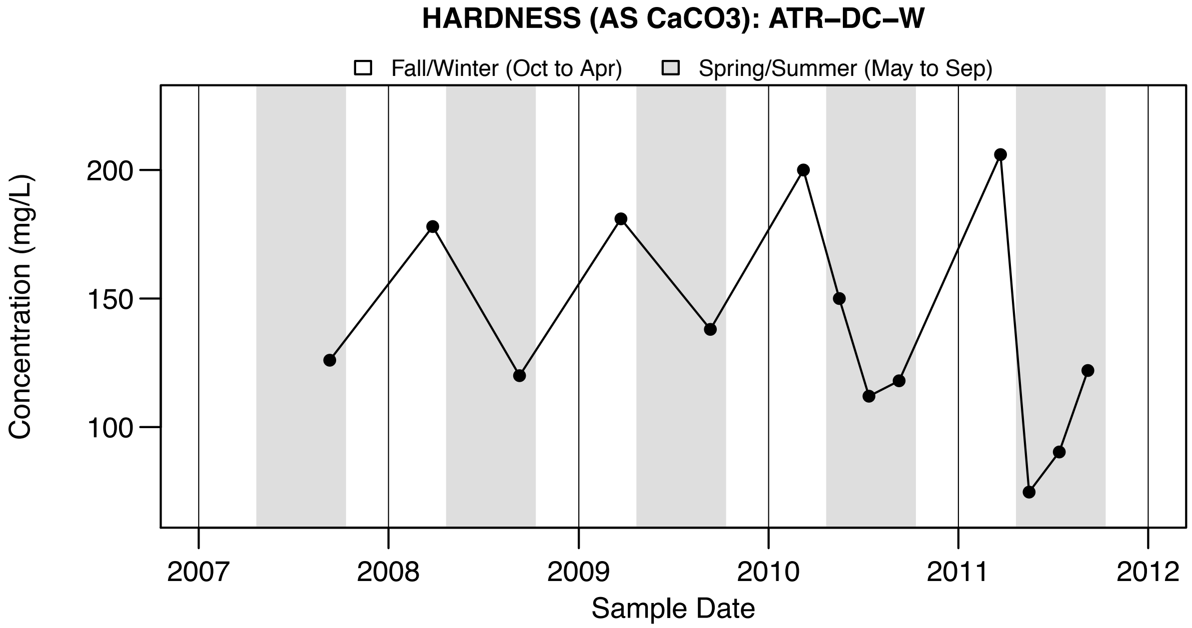


Figure A3.73: HARDNESS (AS CaCO3): ATR-DC-W -

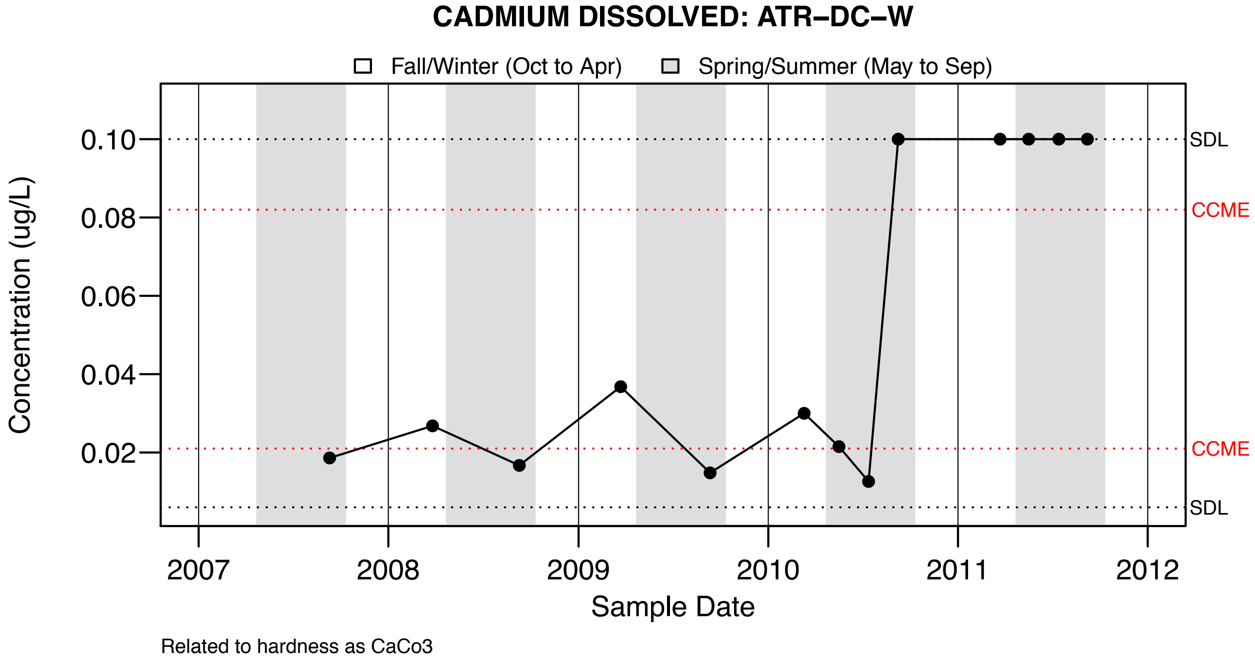


Figure A3.74: CADMIUM DISSOLVED: ATR-DC-W -

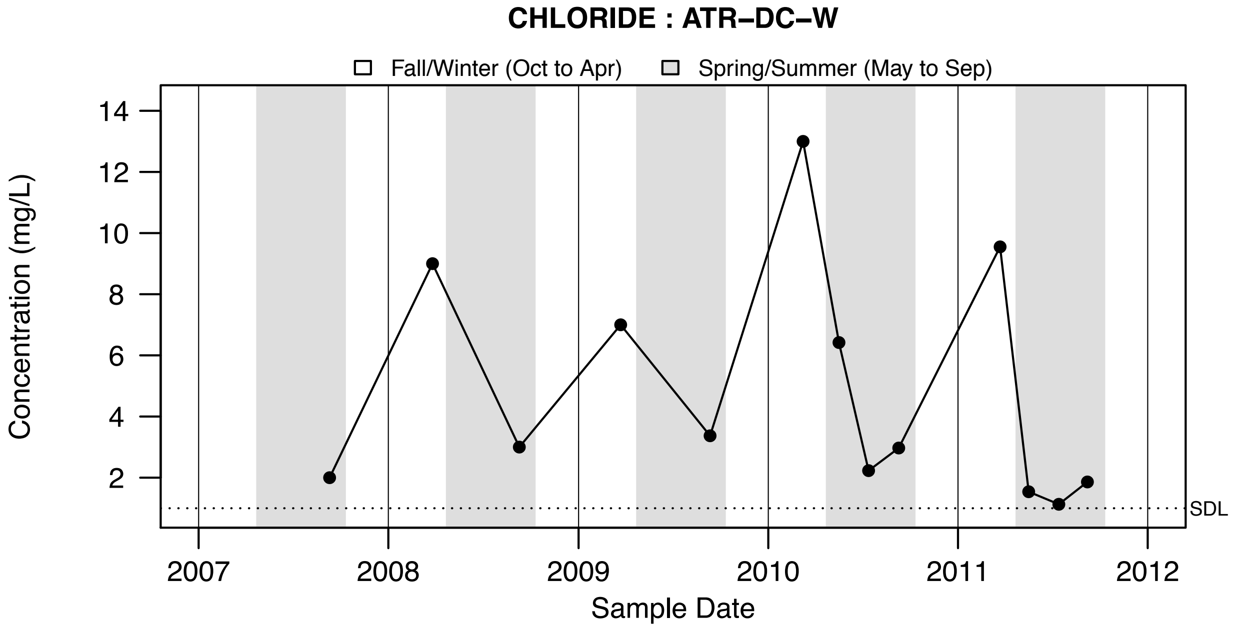


Figure A3.75: CHLORIDE : ATR-DC-W -

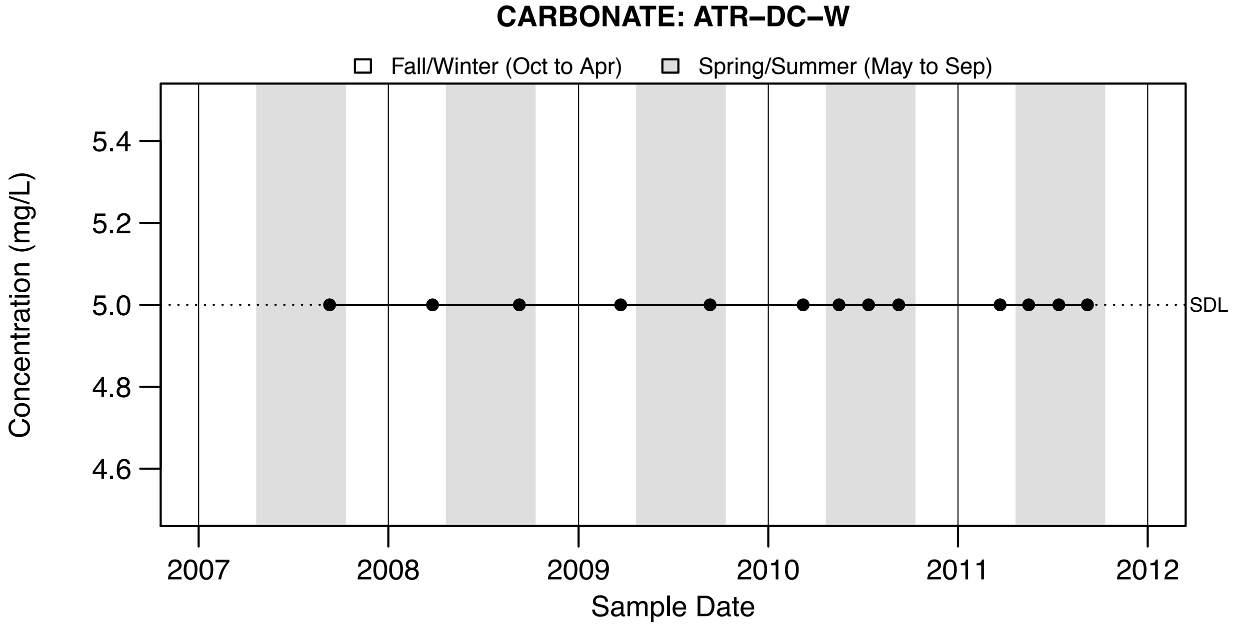


Figure A3.76: CARBONATE: ATR-DC-W -

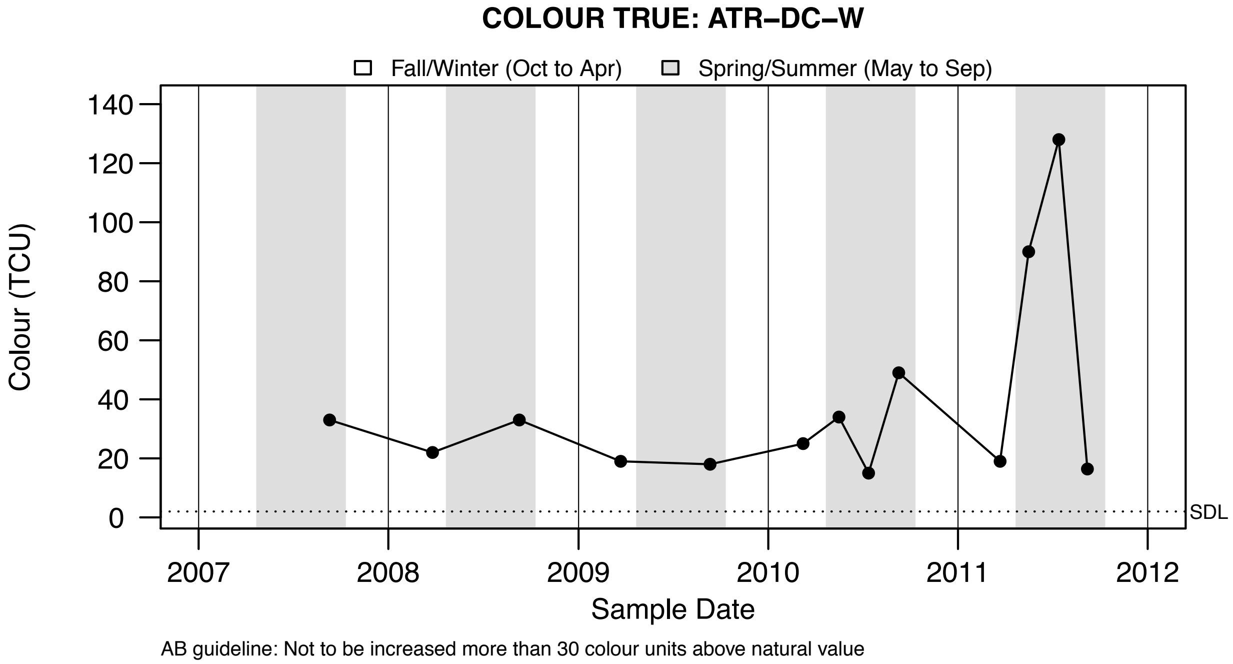


Figure A3.77: COLOUR TRUE: ATR-DC-W -

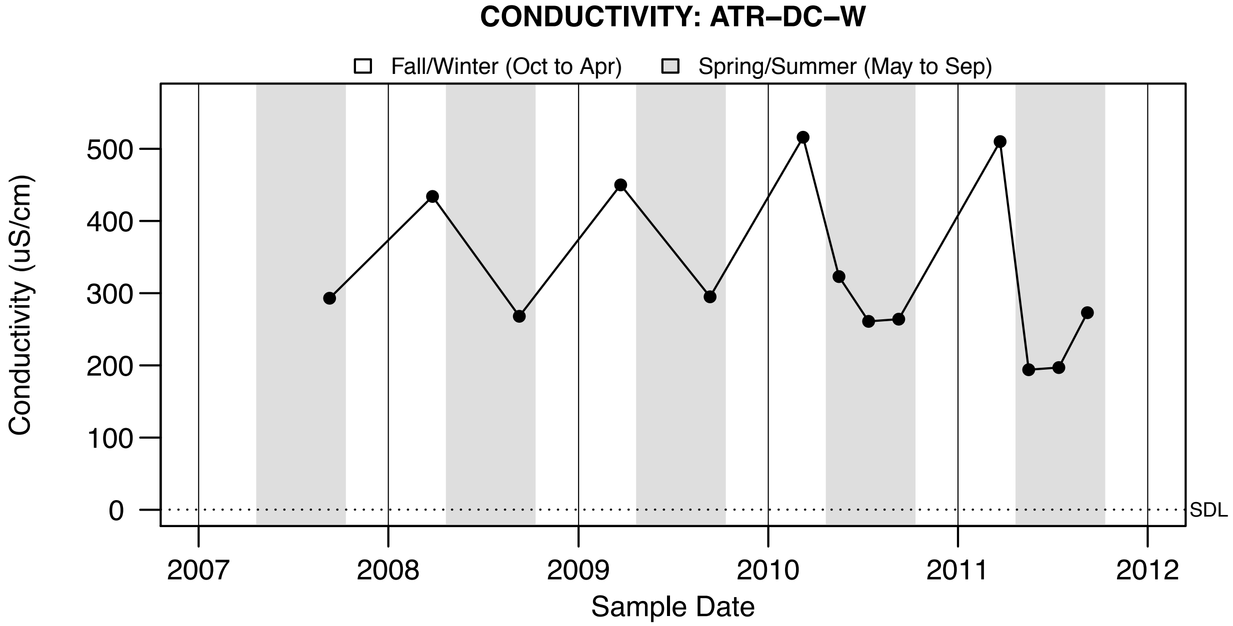
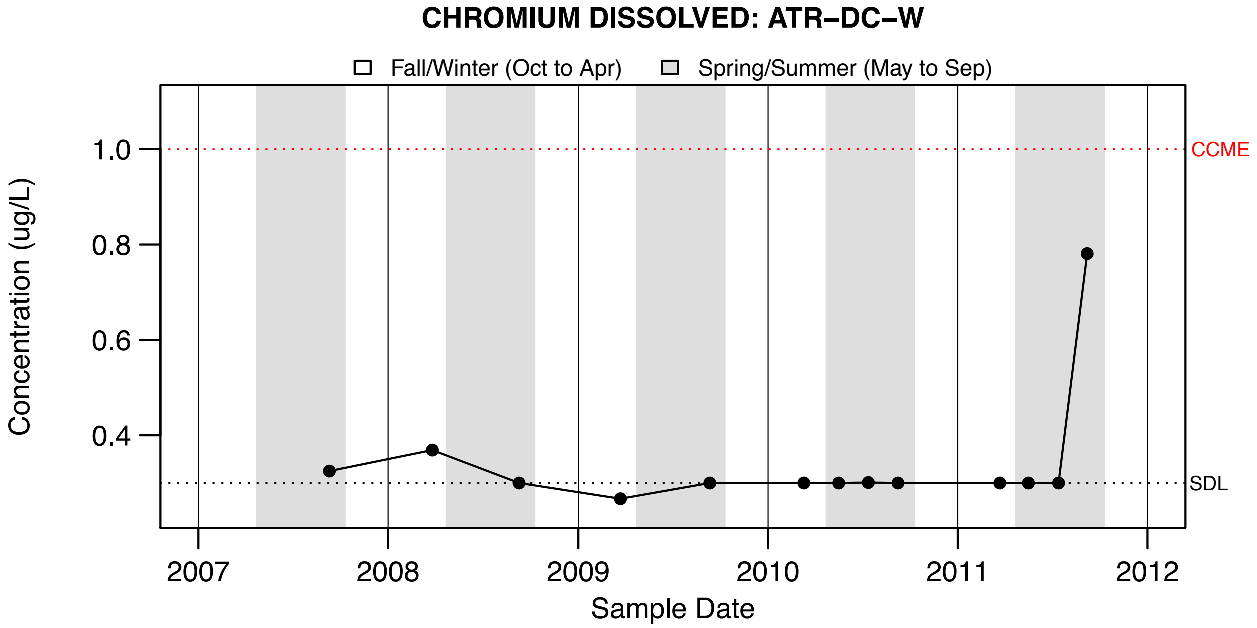
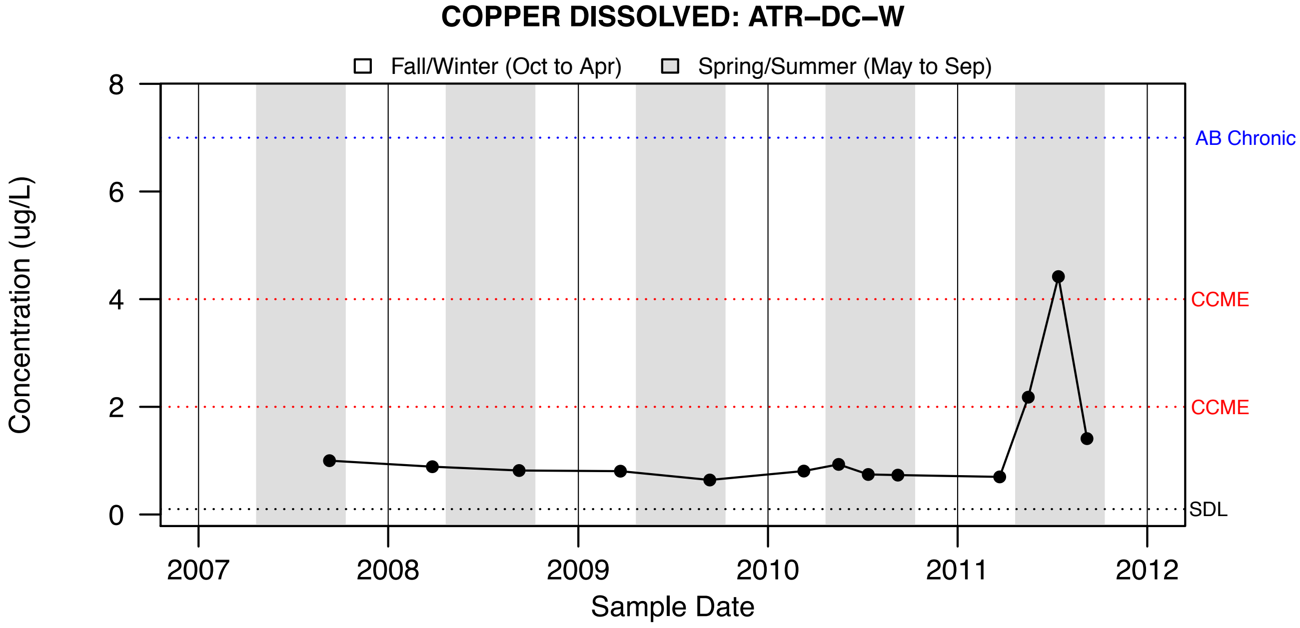


Figure A3.78: CONDUCTIVITY: ATR-DC-W -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.79: CHROMIUM DISSOLVED: ATR-DC-W -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.80: COPPER DISSOLVED: ATR-DC-W -

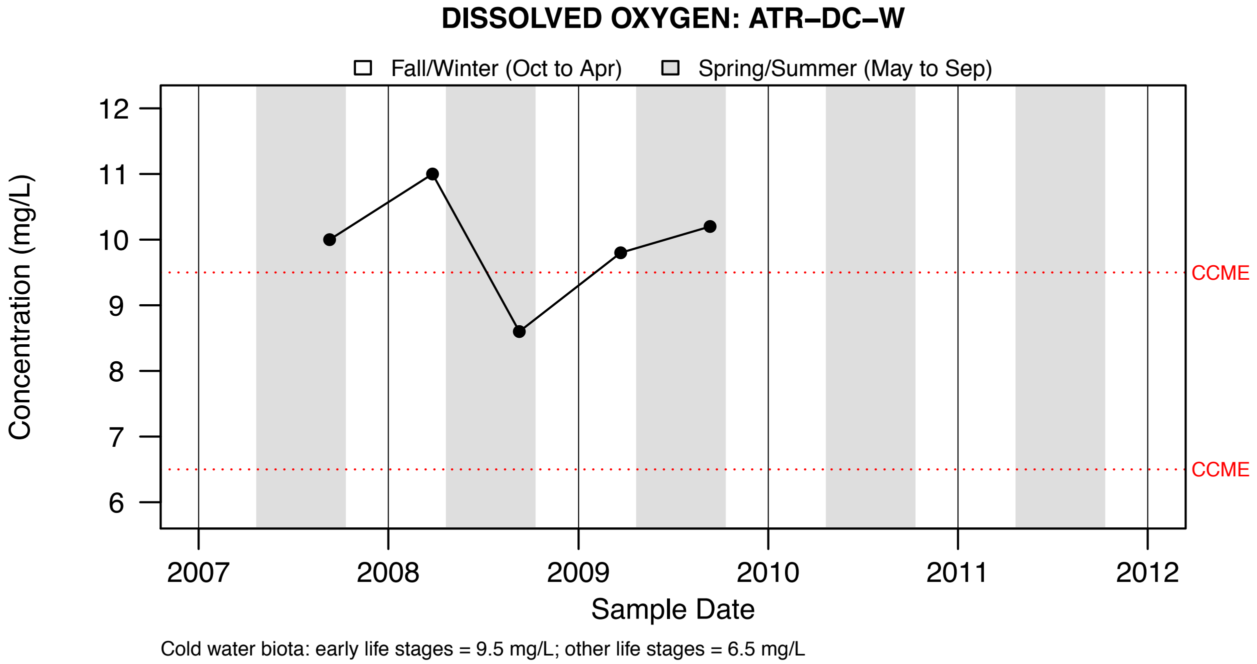


Figure A3.81: DISSOLVED OXYGEN: ATR-DC-W -

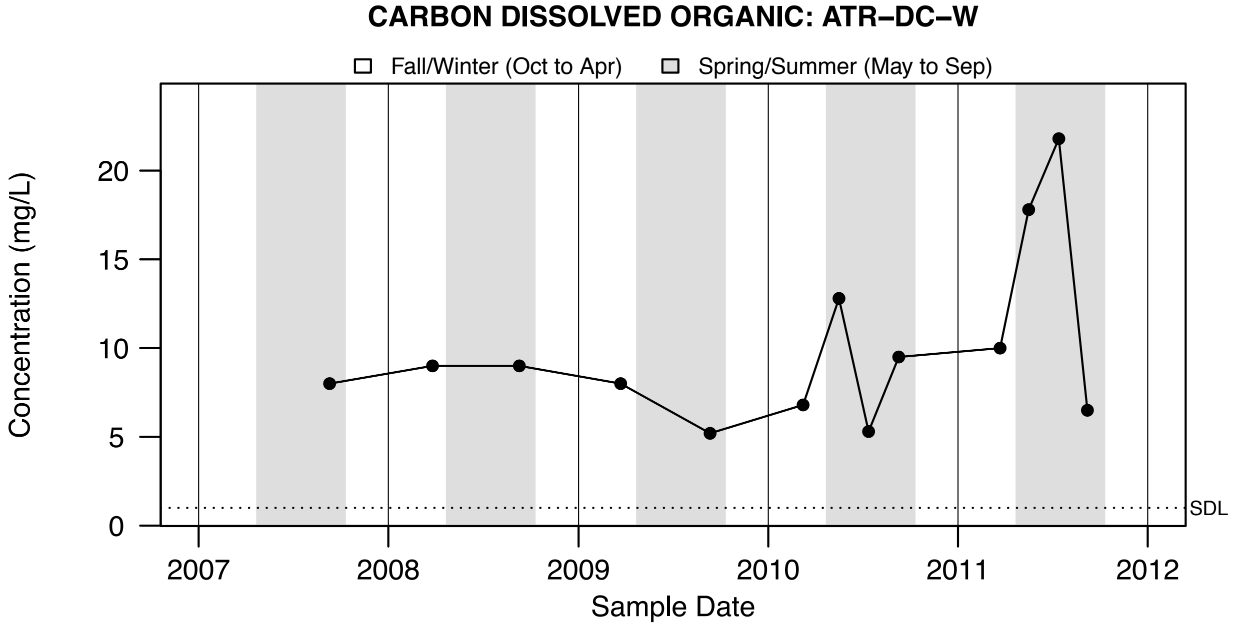


Figure A3.82: CARBON DISSOLVED ORGANIC: ATR-DC-W -

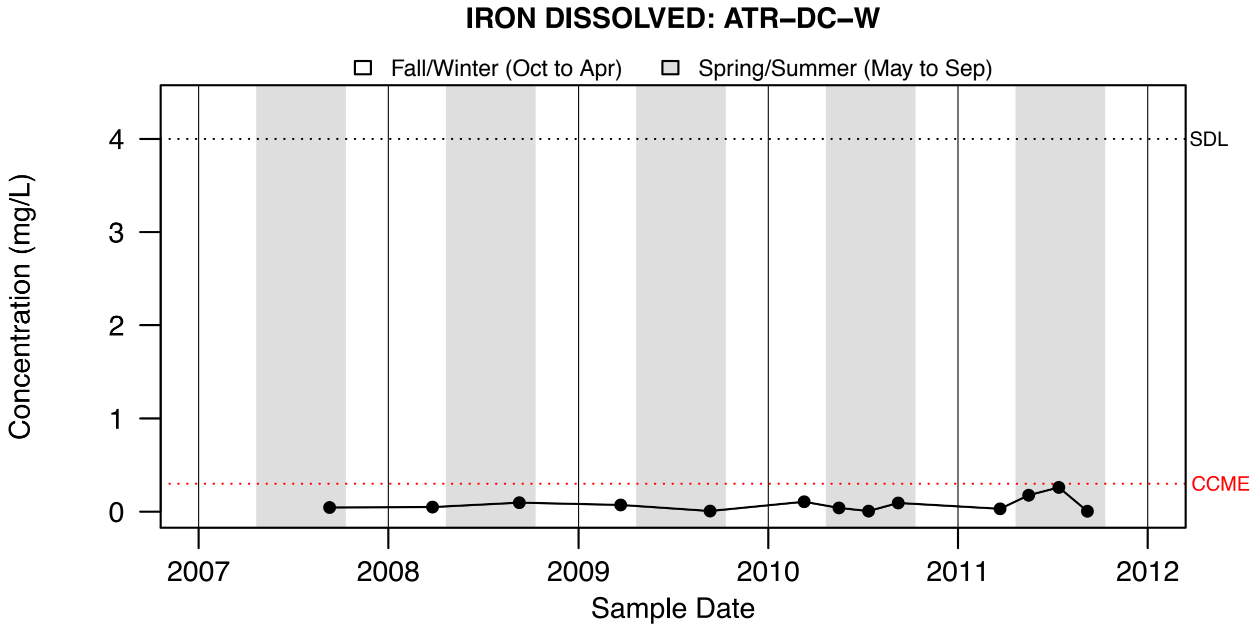


Figure A3.83: IRON DISSOLVED: ATR-DC-W -

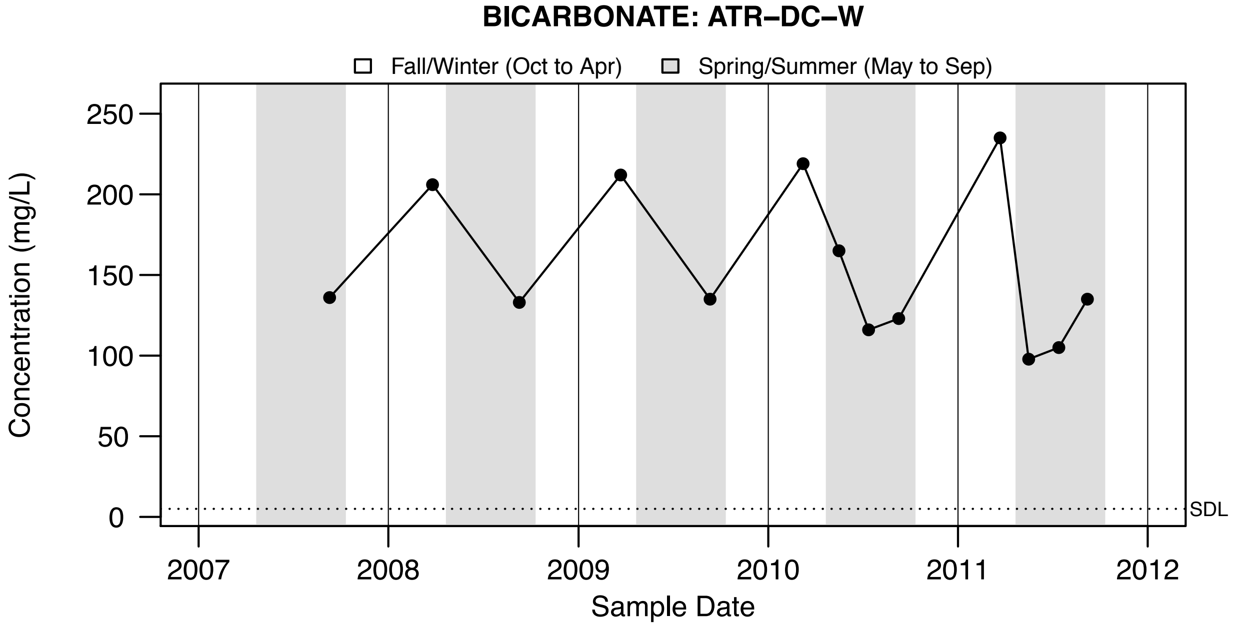


Figure A3.84: BICARBONATE: ATR-DC-W -

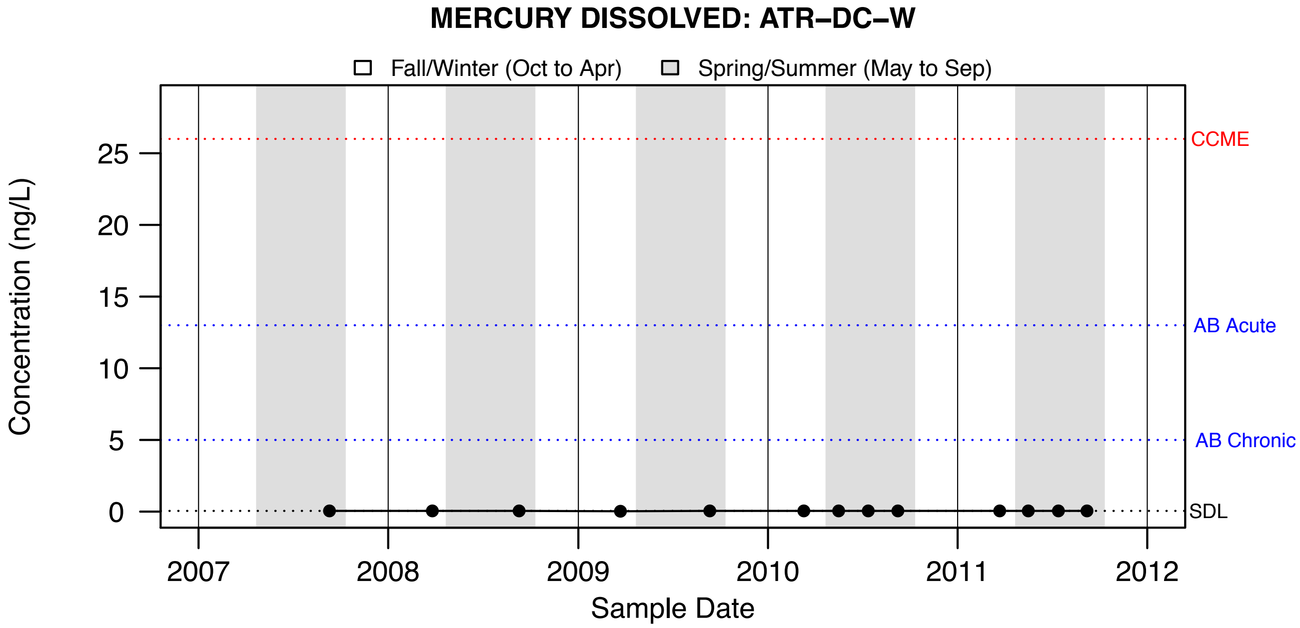


Figure A3.85: MERCURY DISSOLVED: ATR-DC-W -

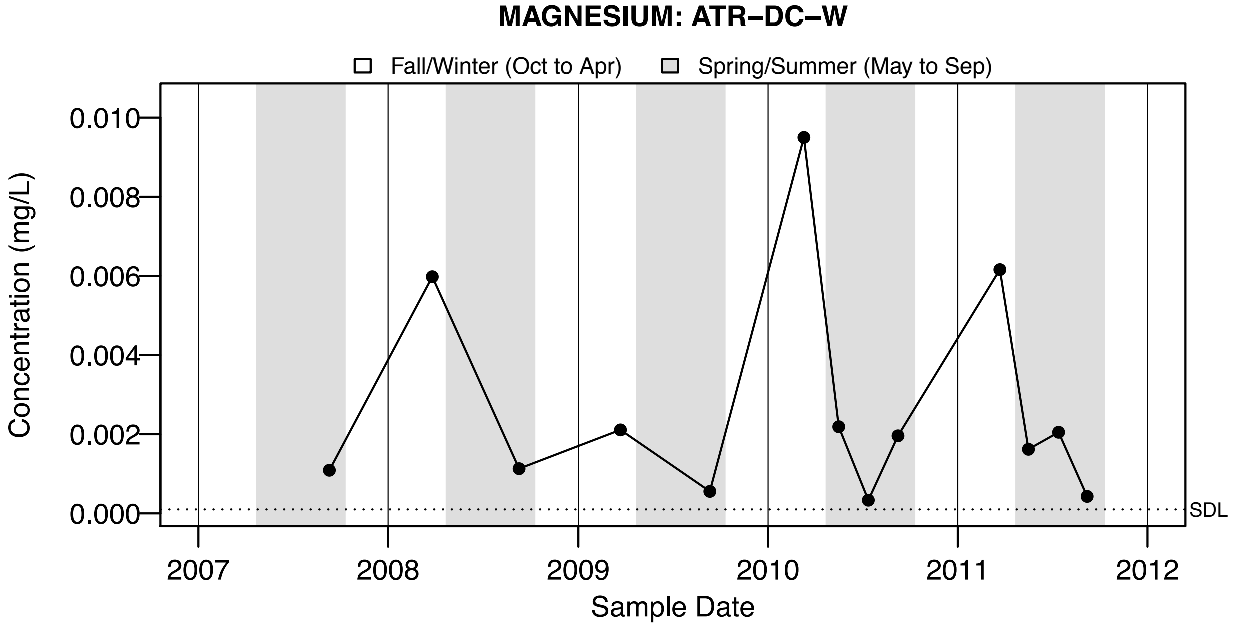


Figure A3.86: MAGNESIUM: ATR-DC-W -

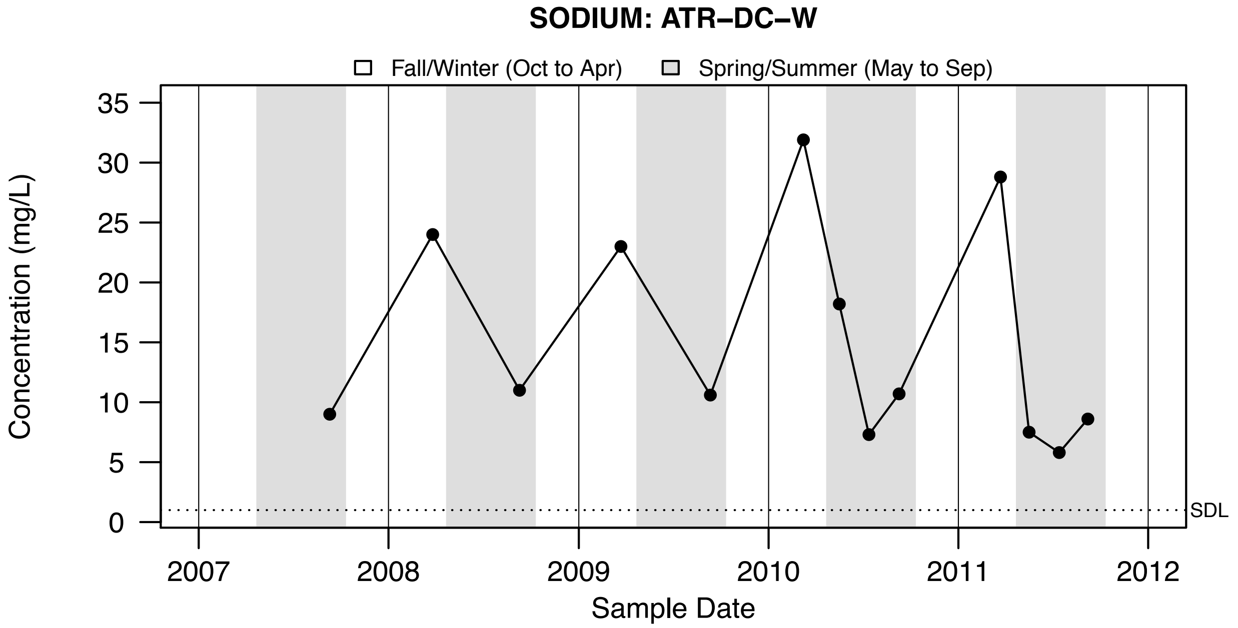
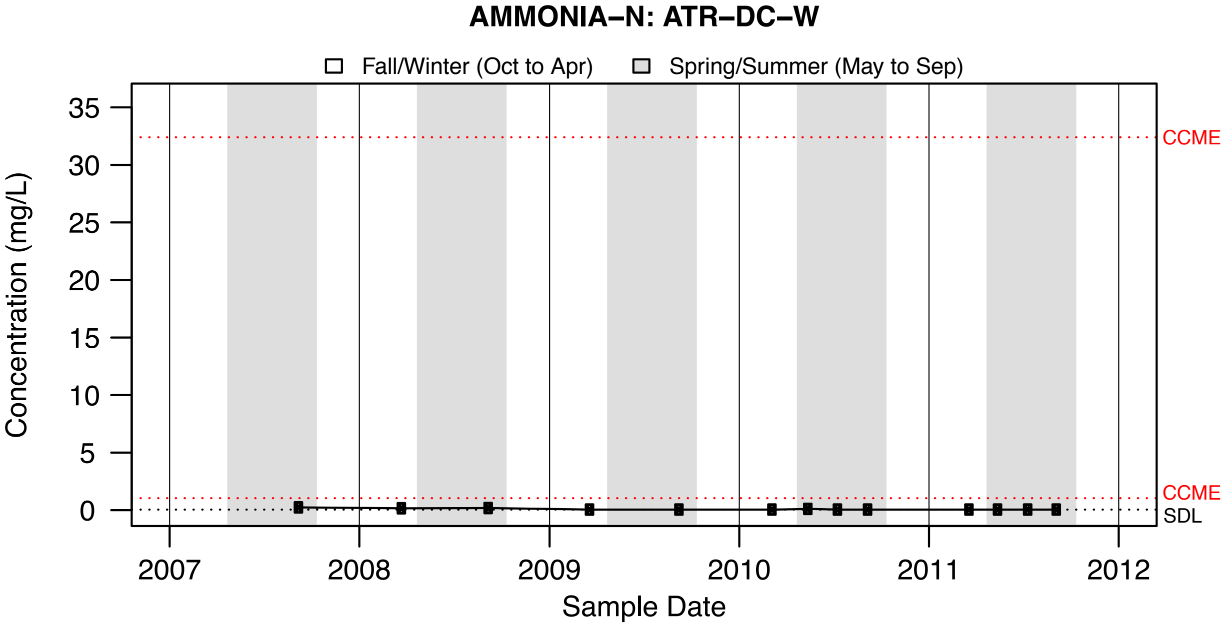


Figure A3.87: SODIUM: ATR-DC-W -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.88: AMMONIA-N: ATR-DC-W -

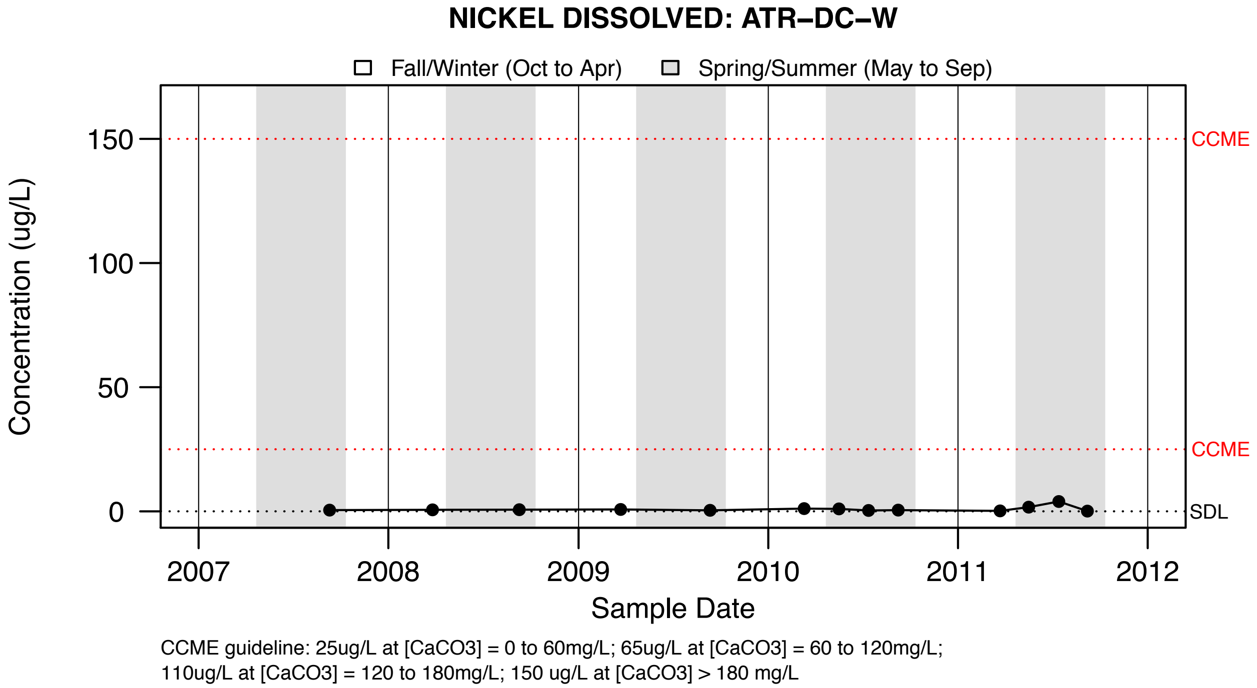


Figure A3.89: NICKEL DISSOLVED: ATR-DC-W -

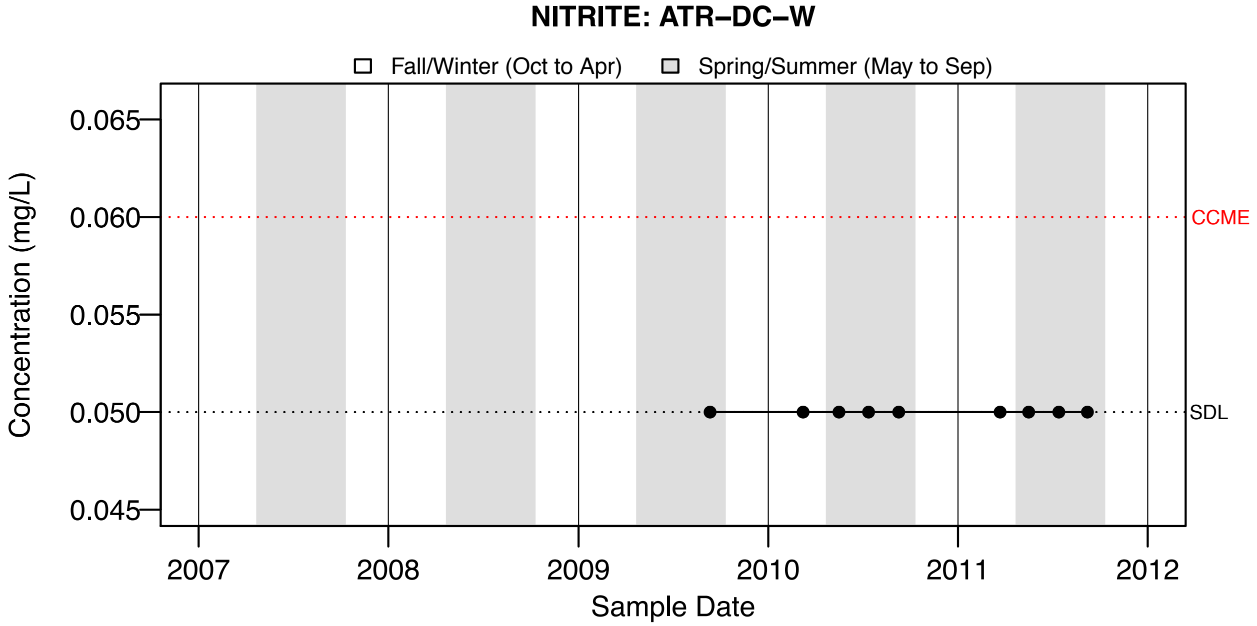
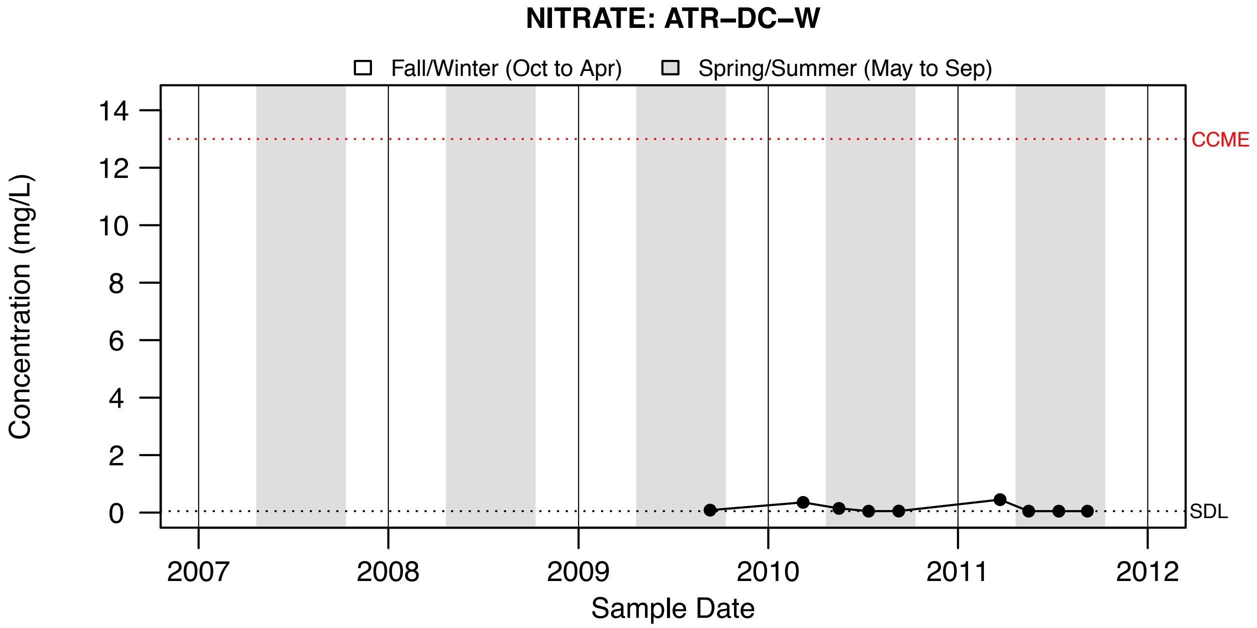


Figure A3.90: NITRITE: ATR-DC-W -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.91: NITRATE: ATR-DC-W -

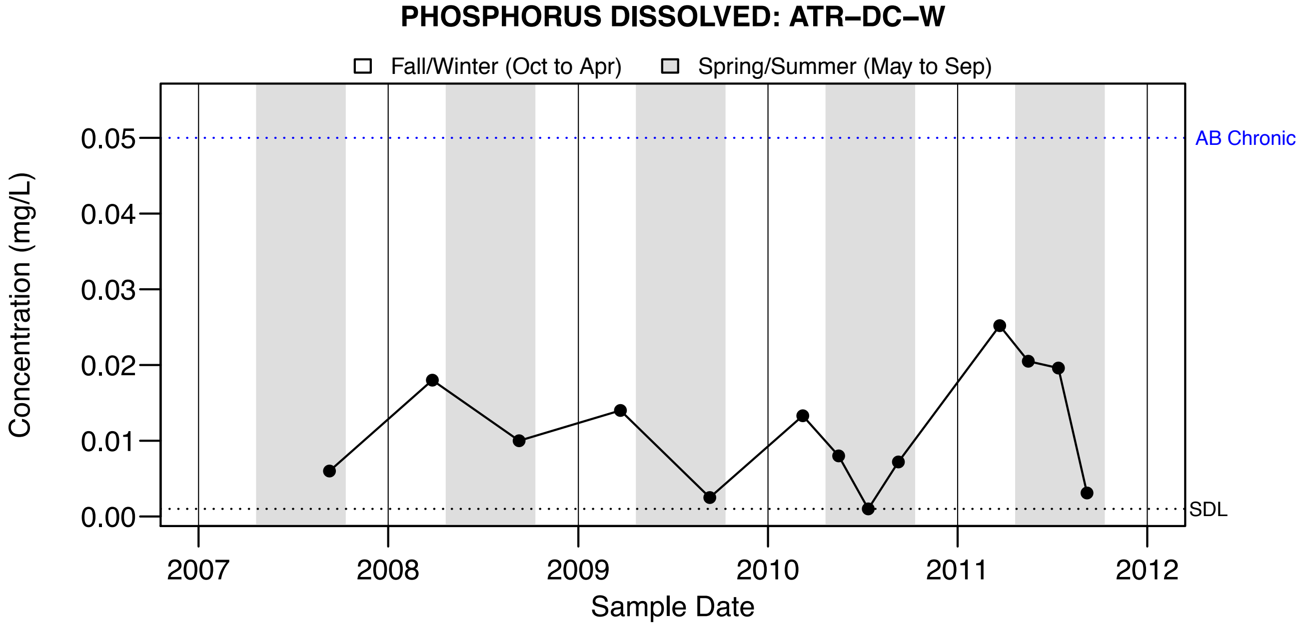


Figure A3.92: PHOSPHORUS DISSOLVED: ATR-DC-W -

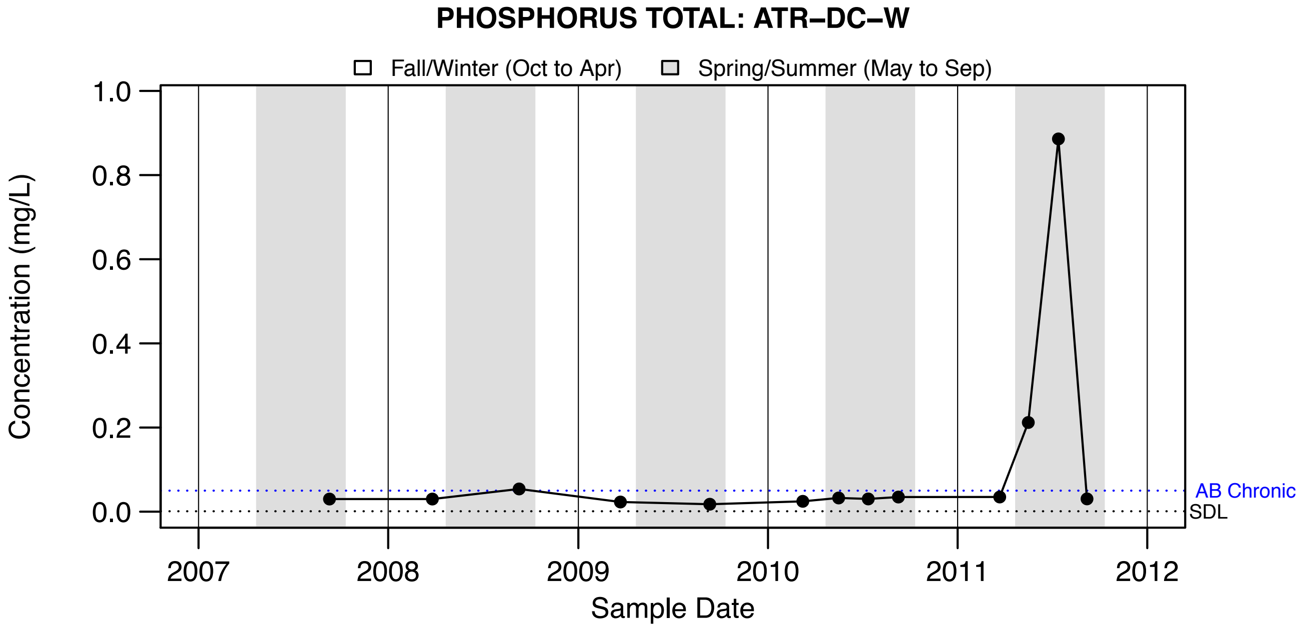
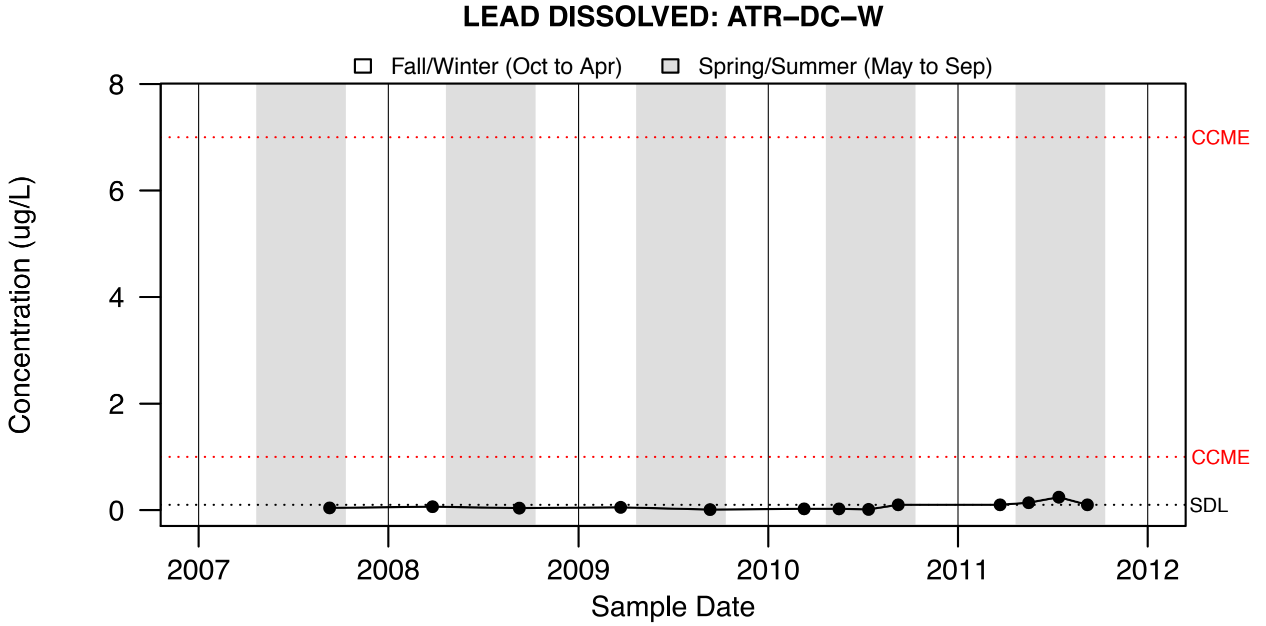
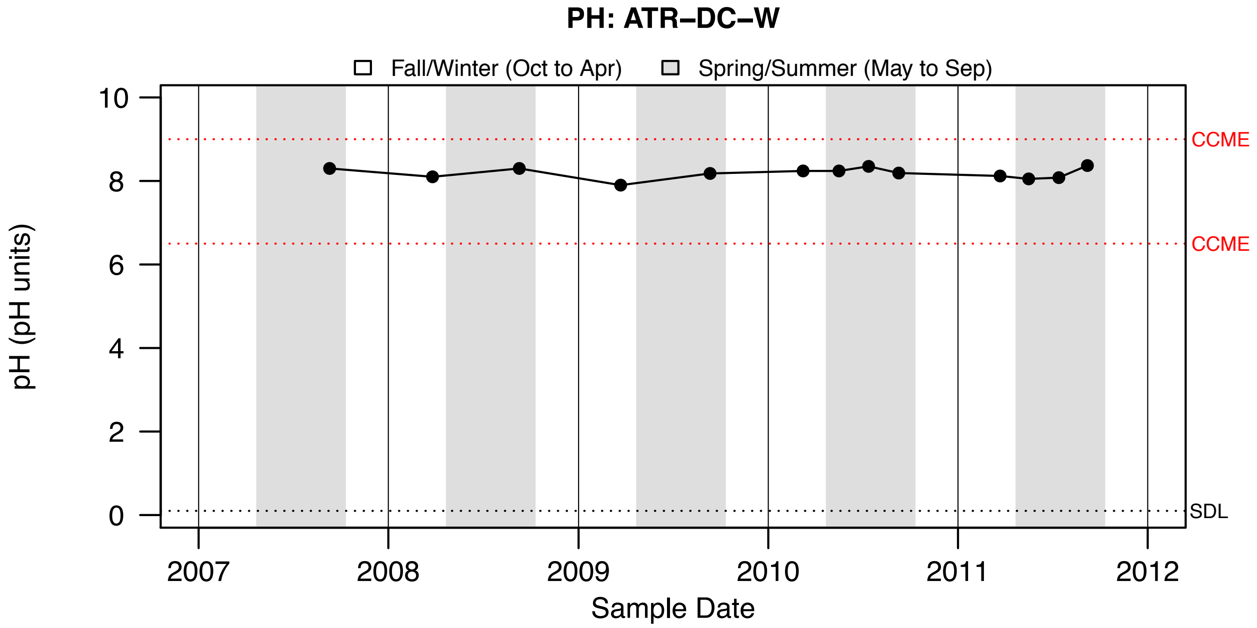


Figure A3.93: PHOSPHORUS TOTAL: ATR-DC-W -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.94: LEAD DISSOLVED: ATR-DC-W -



AB guideline: To be in the range of 6.5 to 8.5 but not altered by more than 0.5 pH units from background values

Figure A3.95: PH: ATR-DC-W -

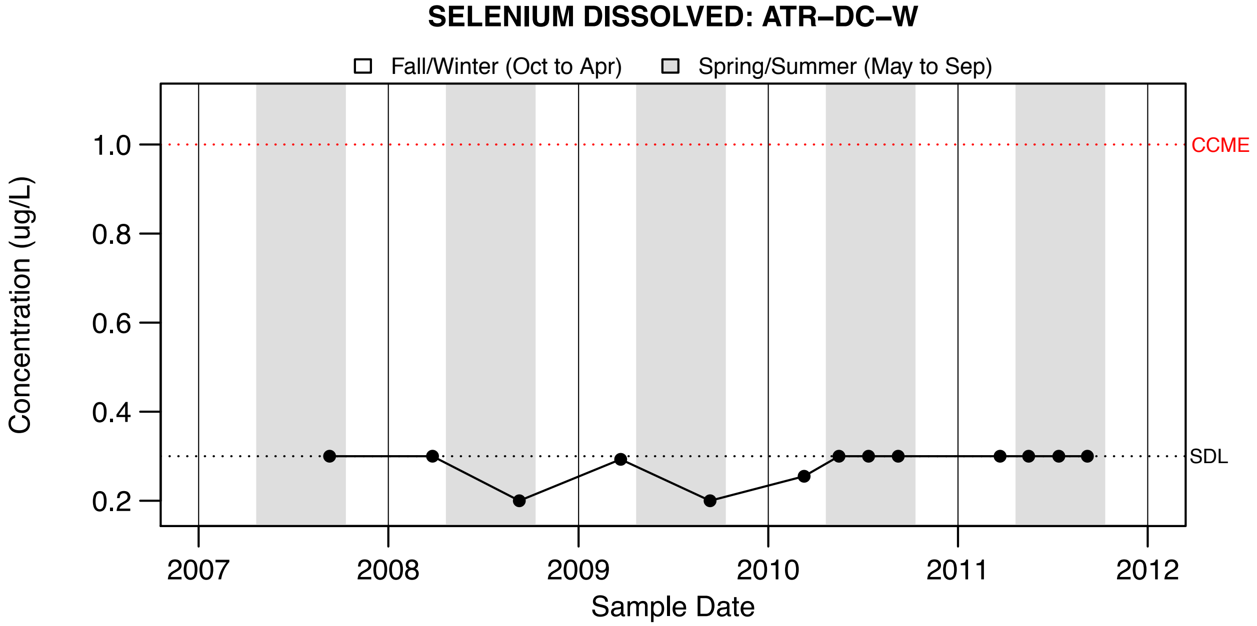


Figure A3.96: SELENIUM DISSOLVED: ATR-DC-W -

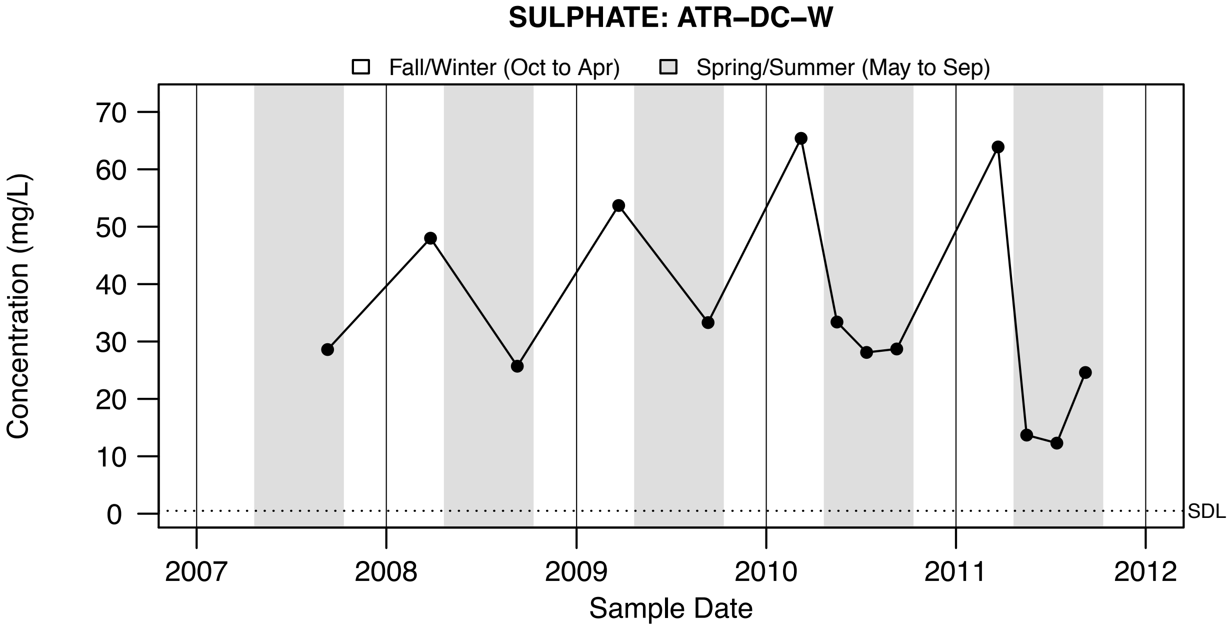


Figure A3.97: SULPHATE: ATR-DC-W -

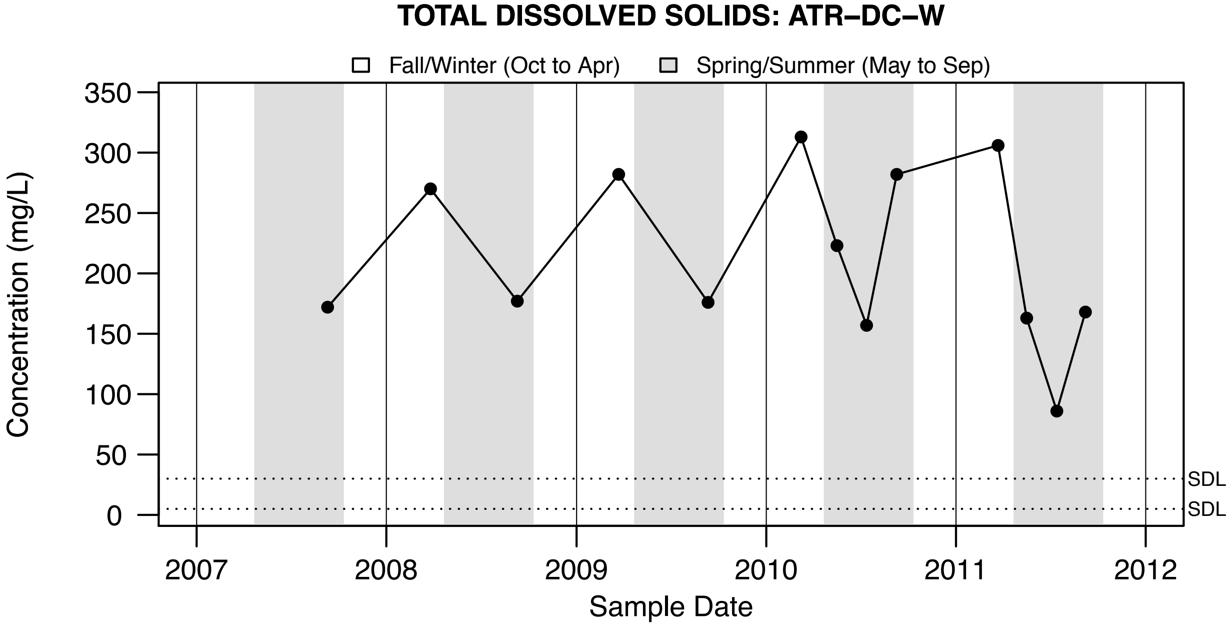


Figure A3.98: TOTAL DISSOLVED SOLIDS: ATR-DC-W -

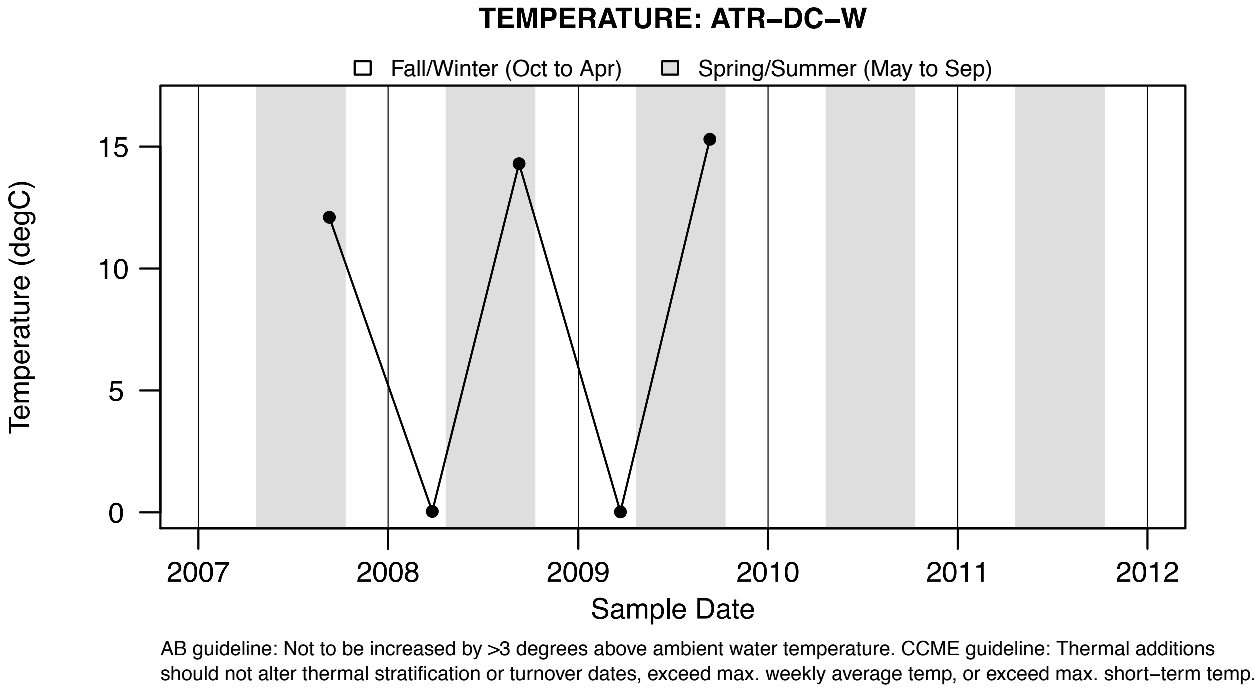


Figure A3.99: TEMPERATURE: ATR-DC-W -

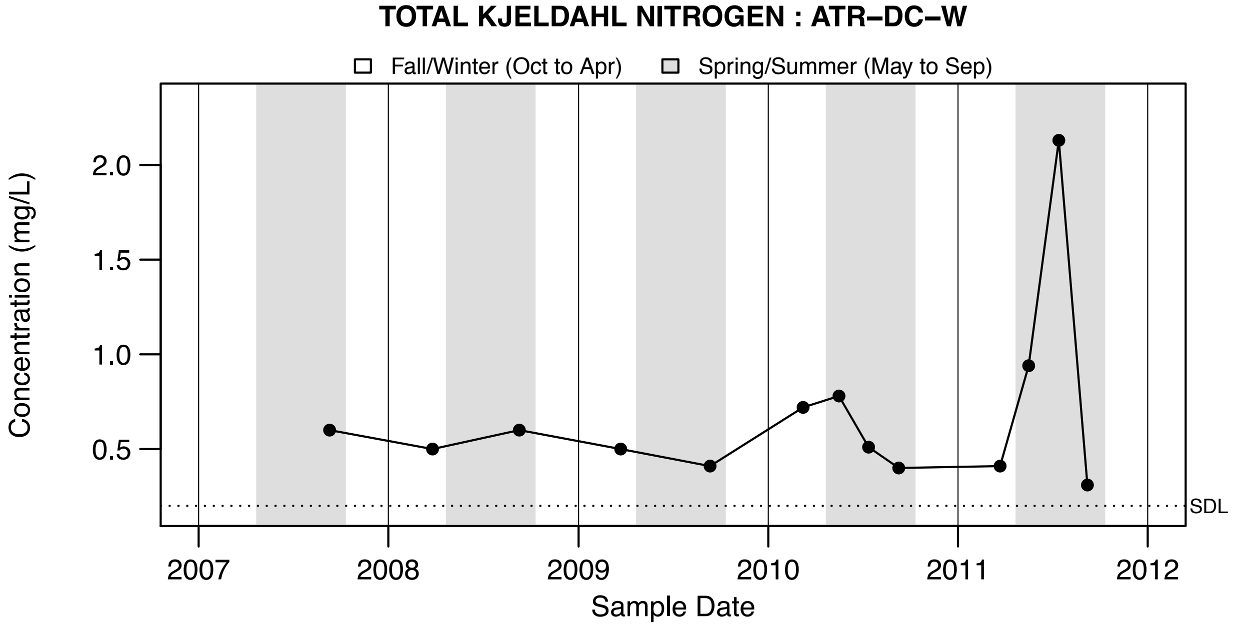
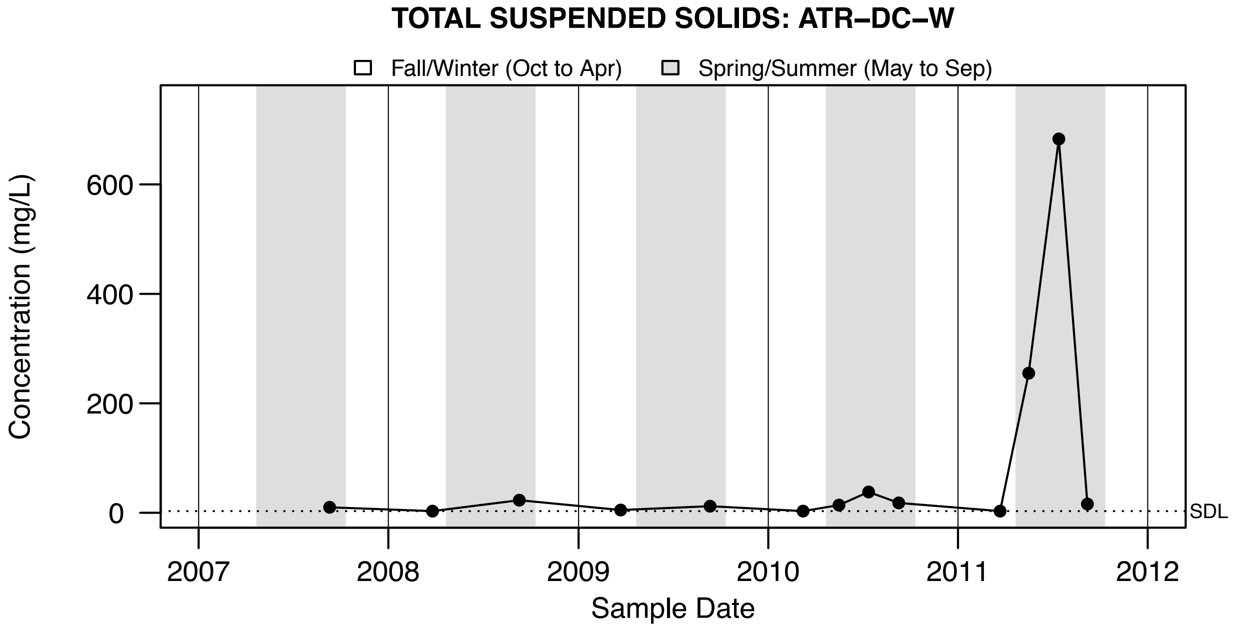


Figure A3.100: TOTAL KJELDAHL NITROGEN : ATR-DC-W -



AB guideline: No increase >10mg/L from background. CCME: clear flow − Max. increase=25mg/L from background (short−term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25−250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.101: TOTAL SUSPENDED SOLIDS: ATR-DC-W -

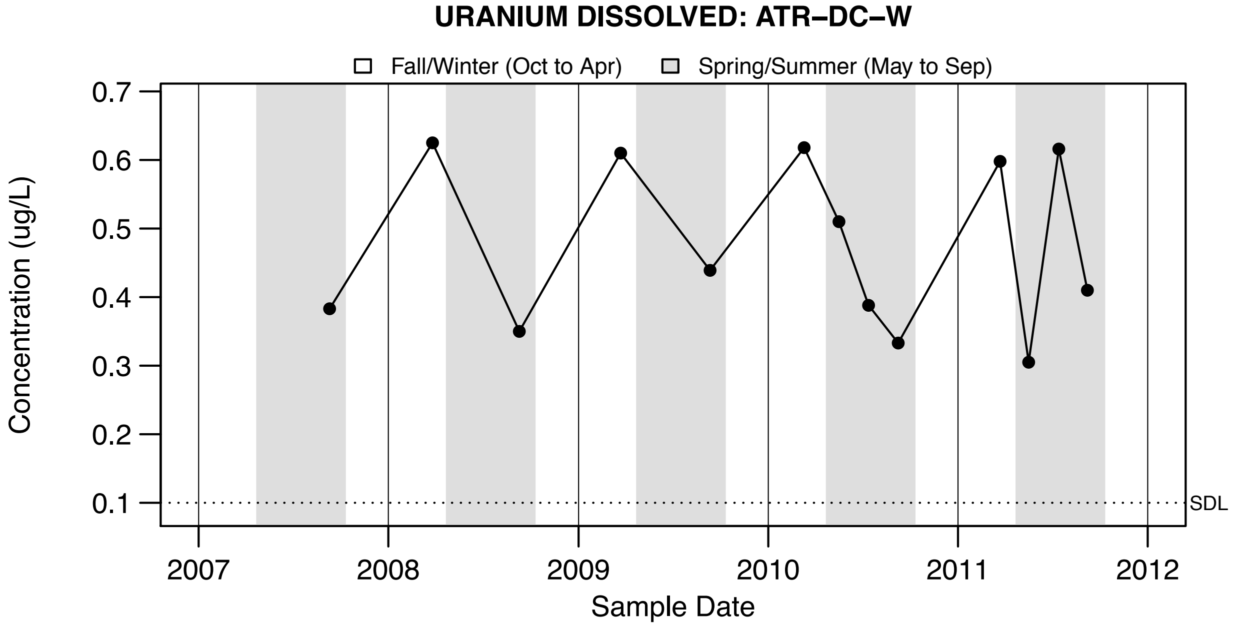


Figure A3.102: URANIUM DISSOLVED: ATR-DC-W -

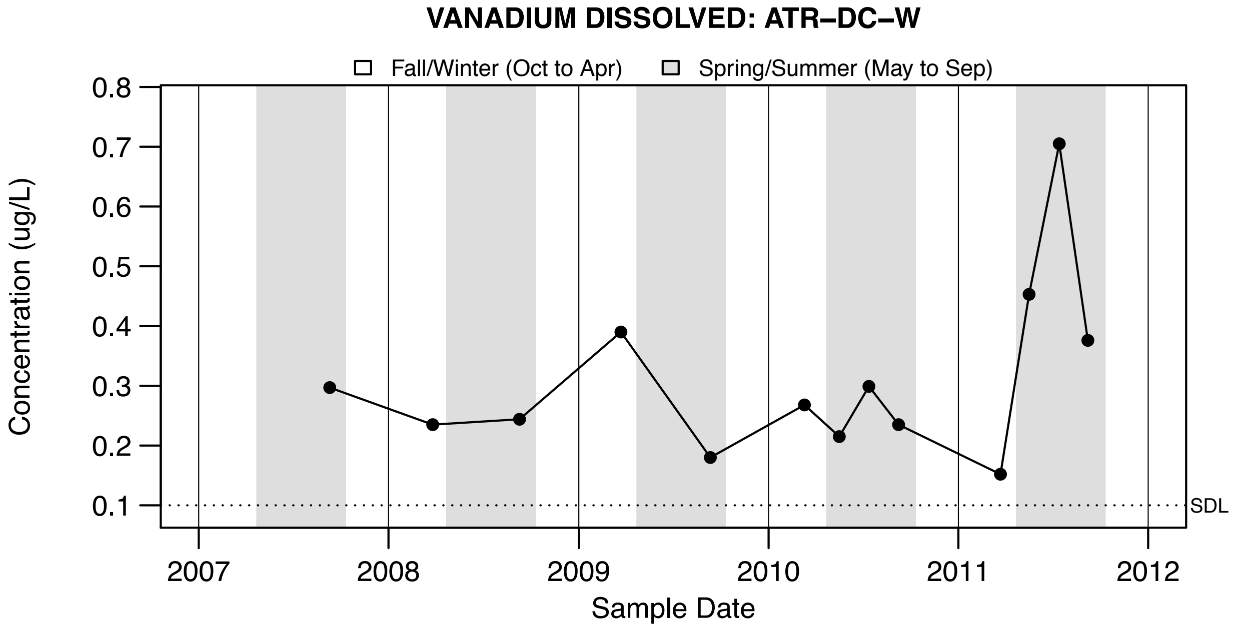


Figure A3.103: VANADIUM DISSOLVED: ATR-DC-W -

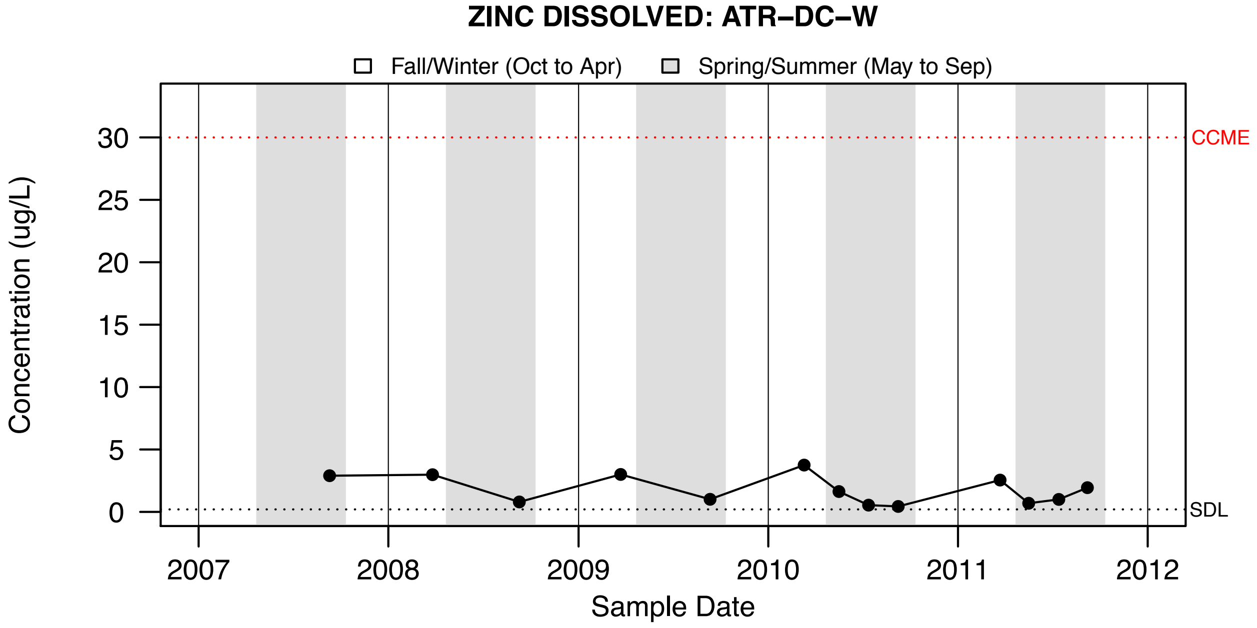
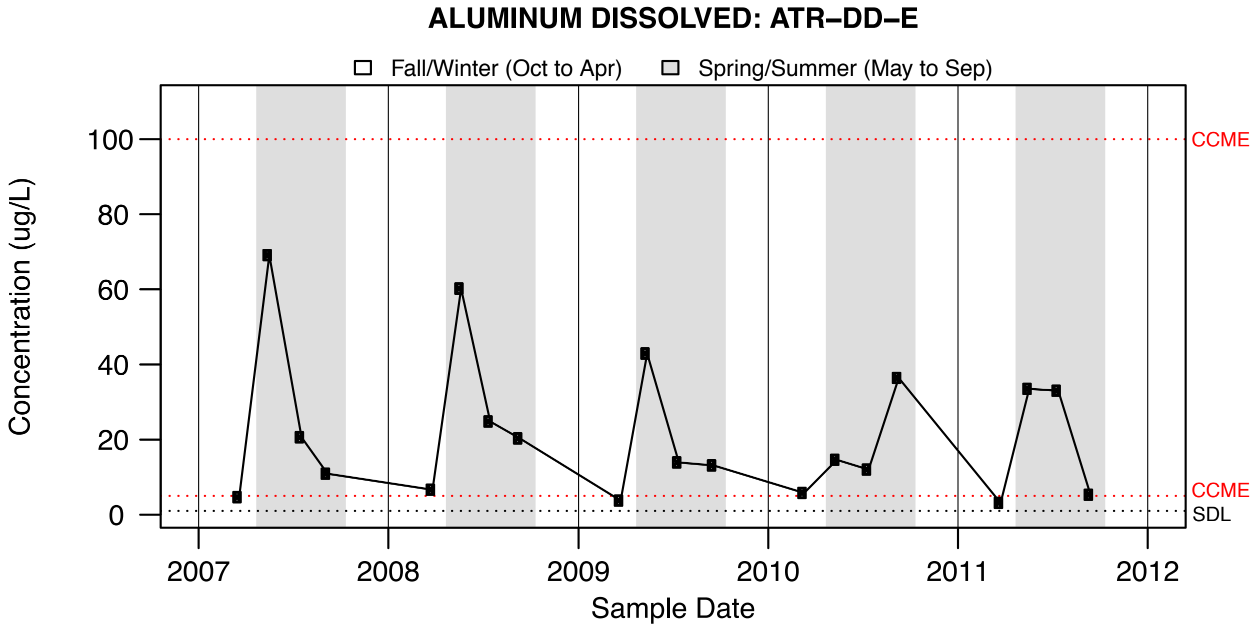
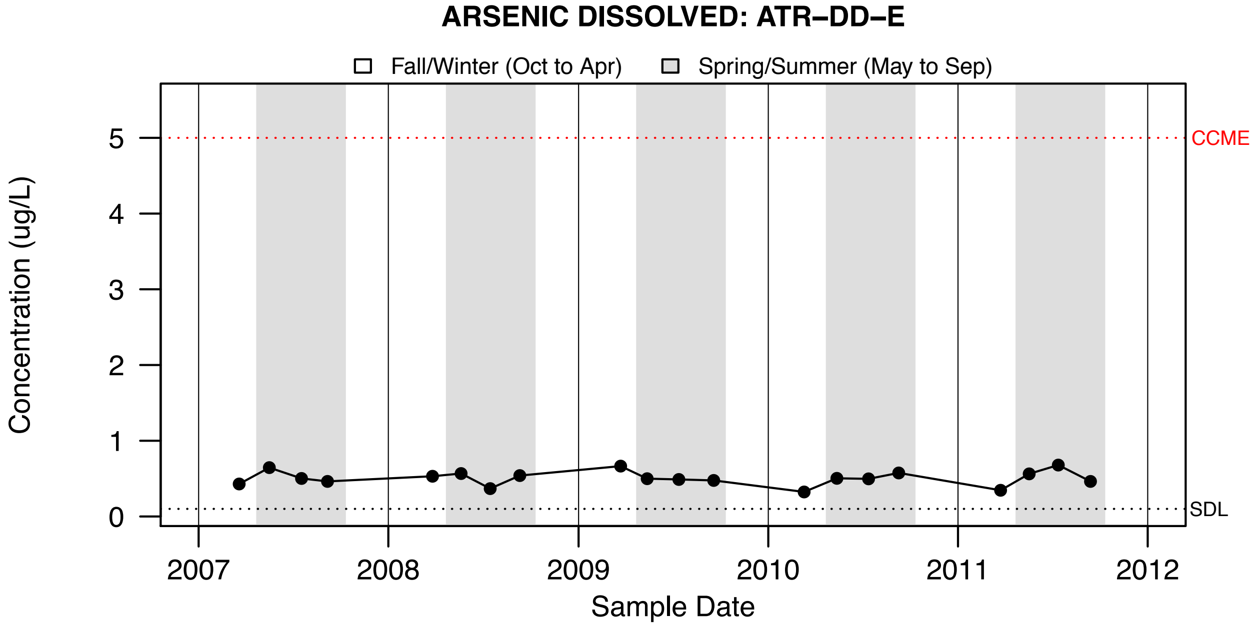


Figure A3.104: ZINC DISSOLVED: ATR-DC-W -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.105: ALUMINUM DISSOLVED: ATR-DD-E -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.106: ARSENIC DISSOLVED: ATR-DD-E -

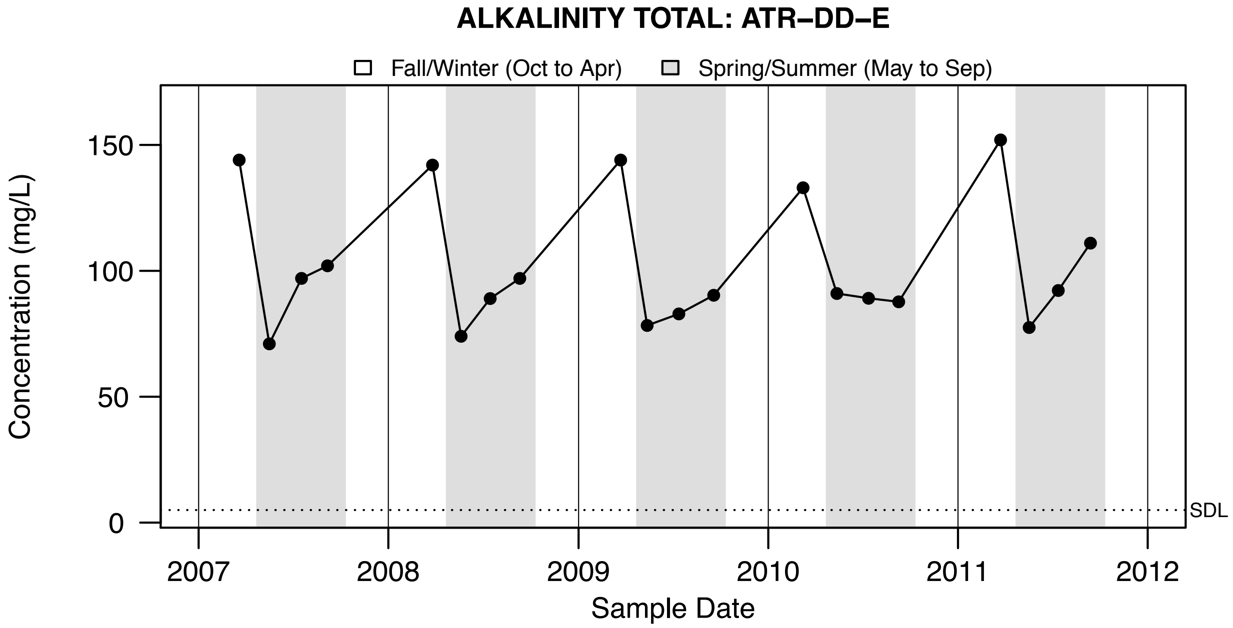


Figure A3.107: ALKALINITY TOTAL: ATR-DD-E -

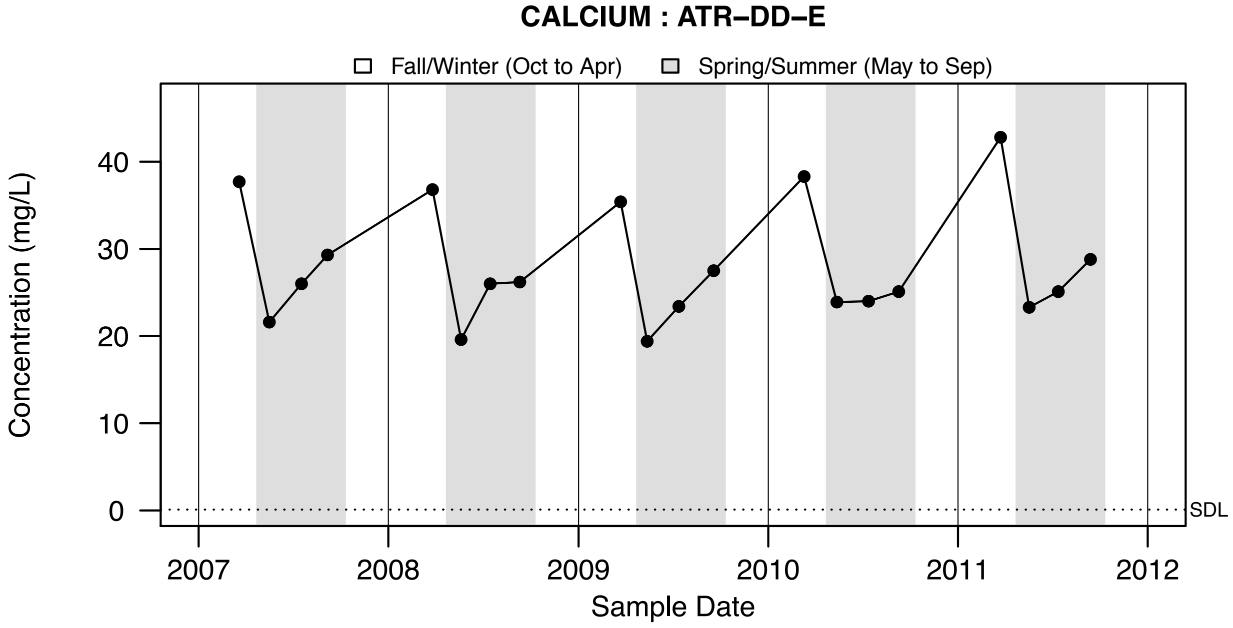


Figure A3.108: CALCIUM : ATR-DD-E -

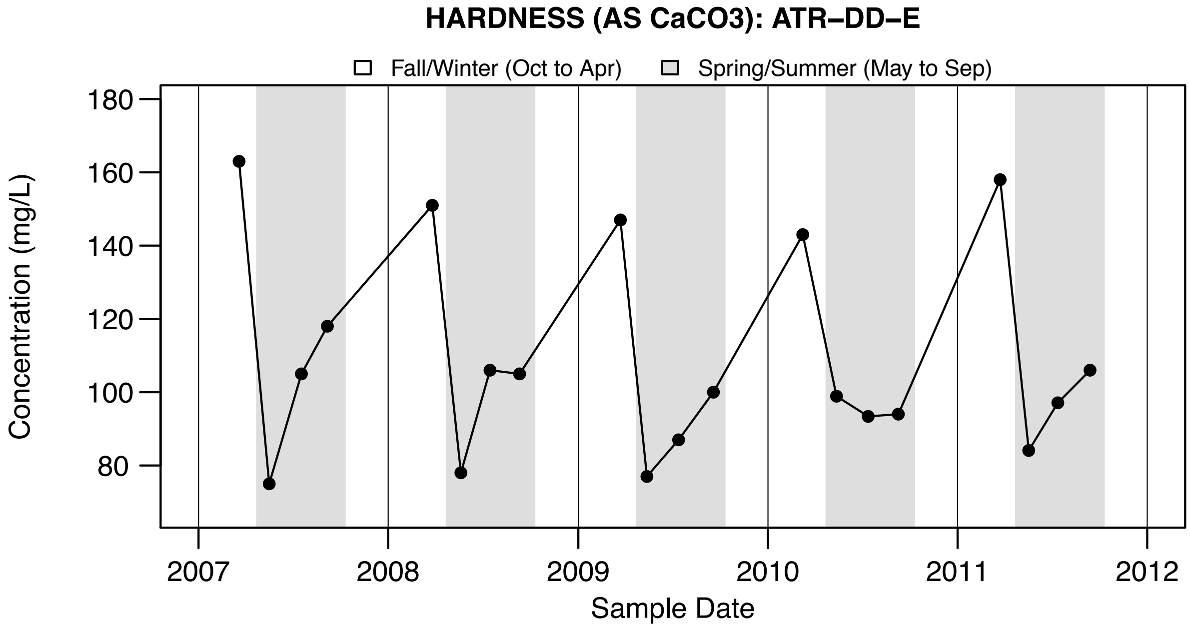
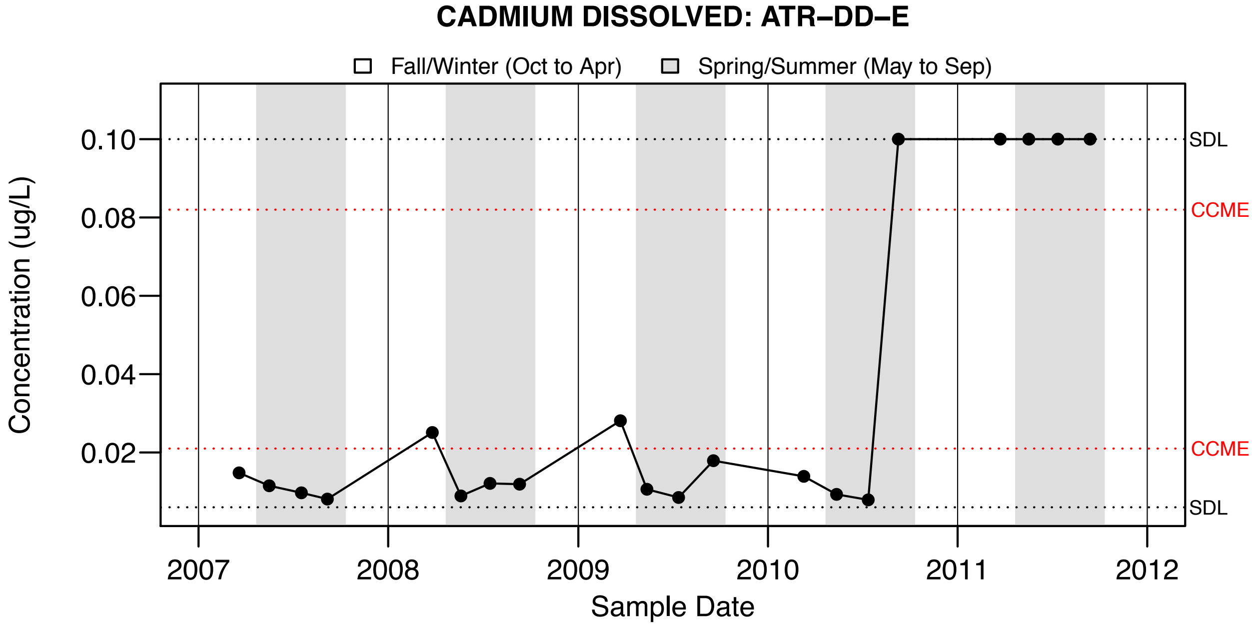


Figure A3.109: HARDNESS (AS CaCO3): ATR-DD-E -



Related to hardness as CaCo3

Figure A3.110: CADMIUM DISSOLVED: ATR-DD-E -

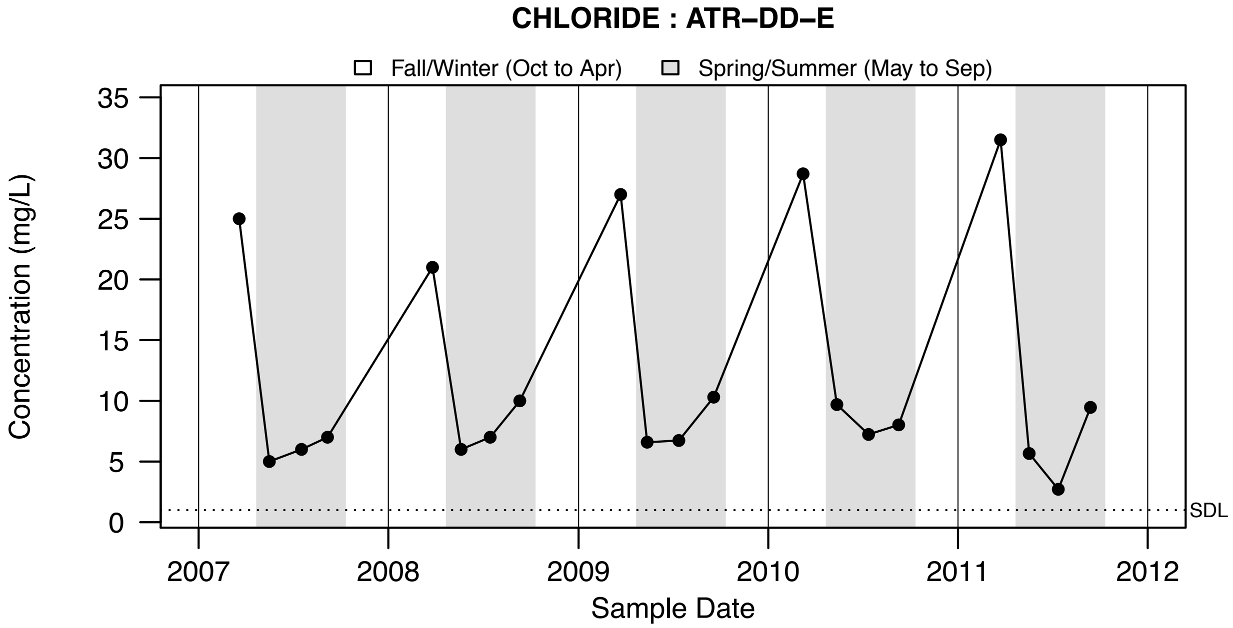


Figure A3.111: CHLORIDE : ATR-DD-E -

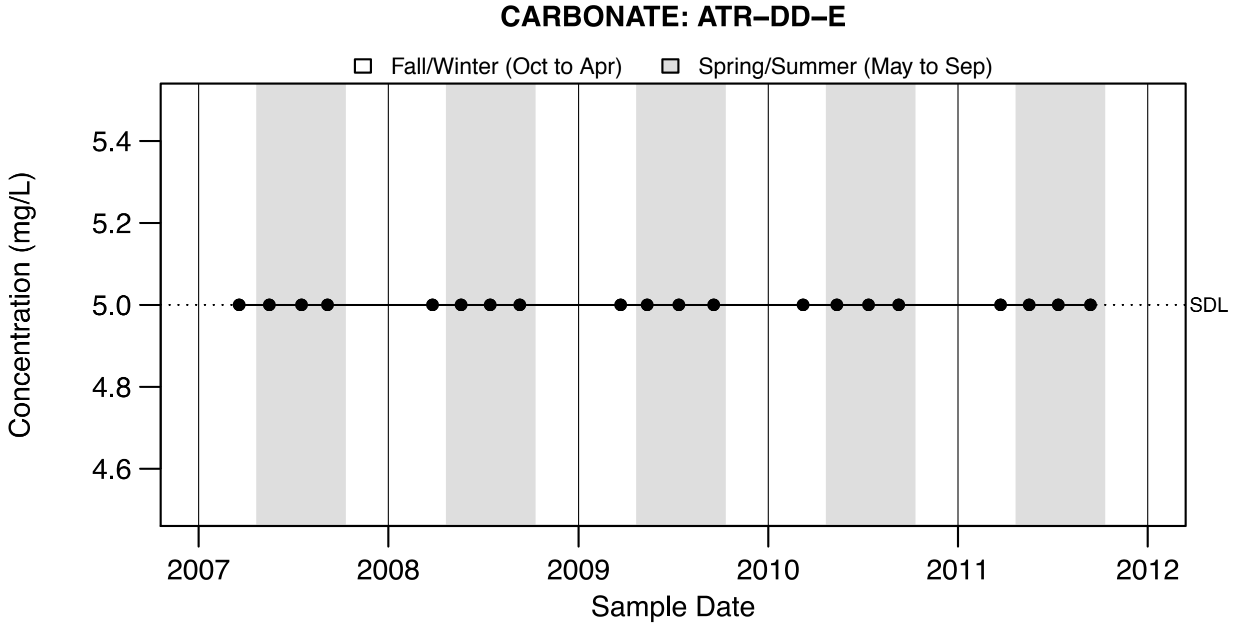


Figure A3.112: CARBONATE: ATR-DD-E -

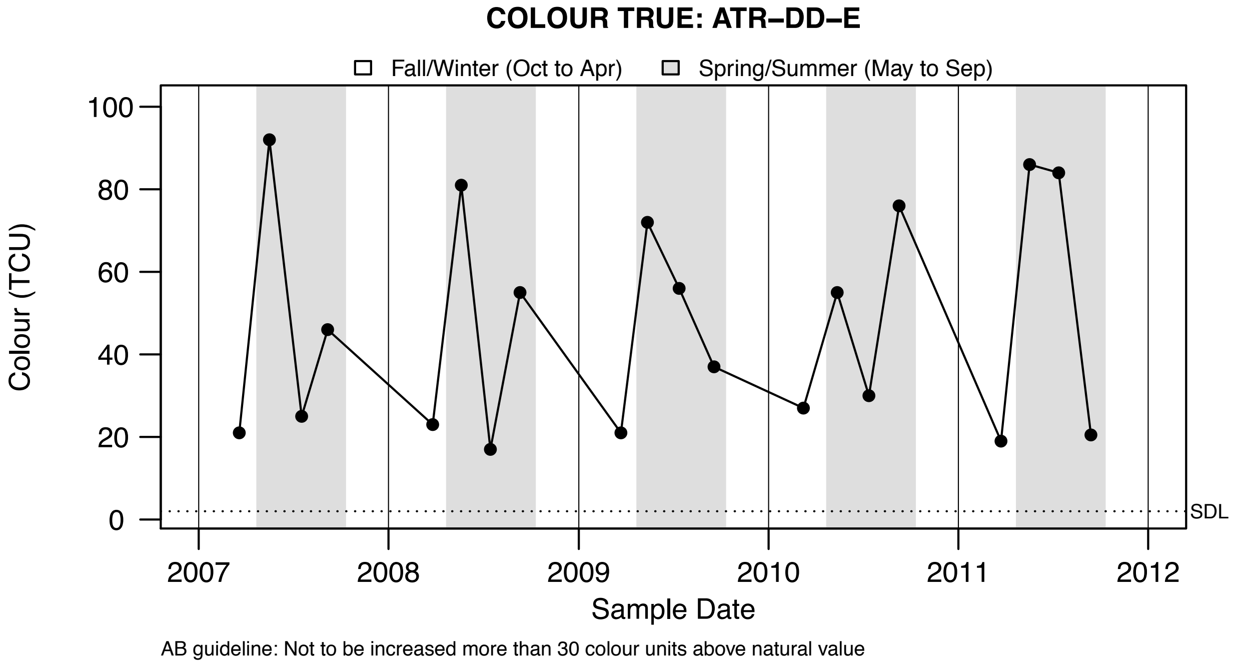


Figure A3.113: COLOUR TRUE: ATR-DD-E -

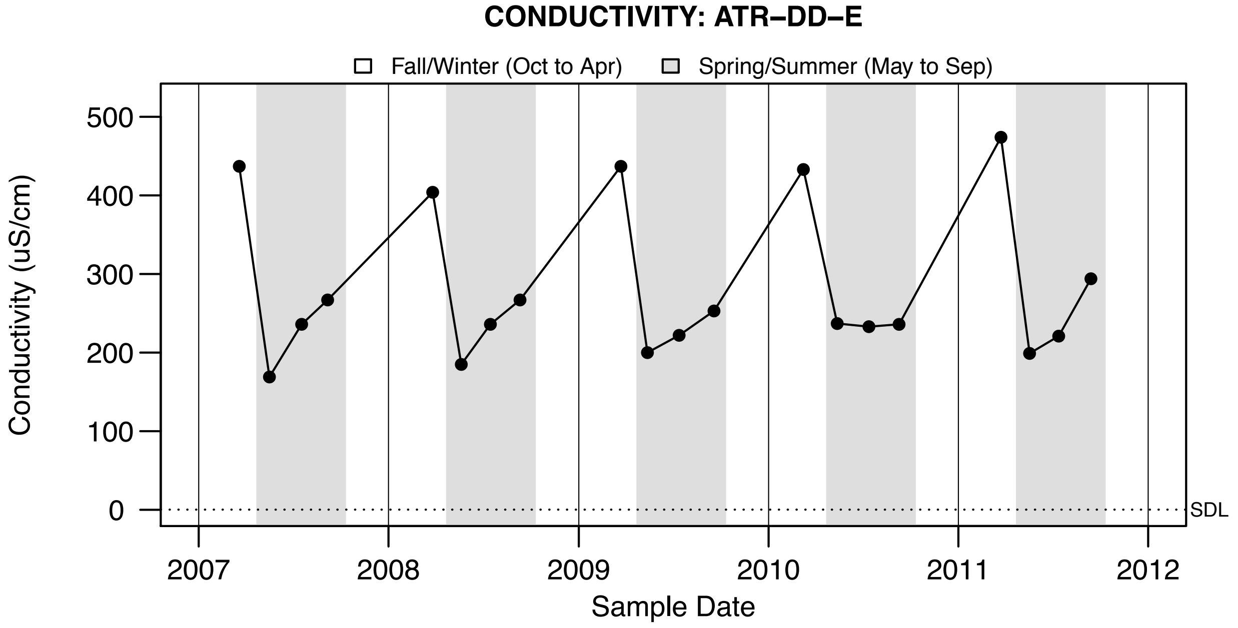
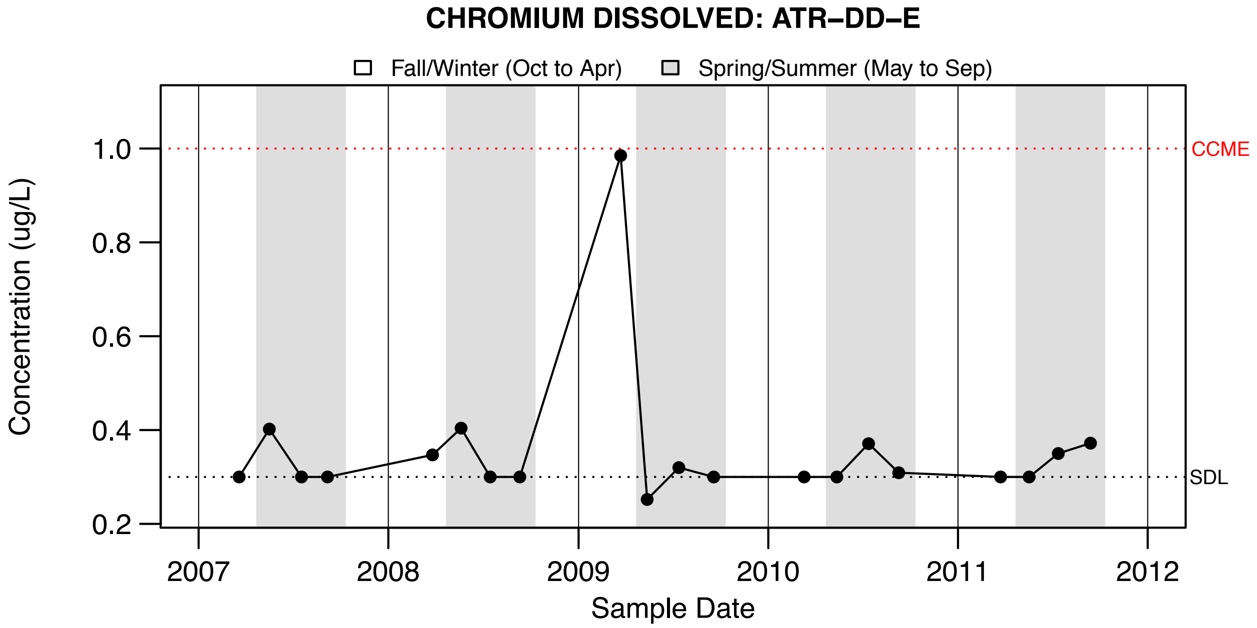
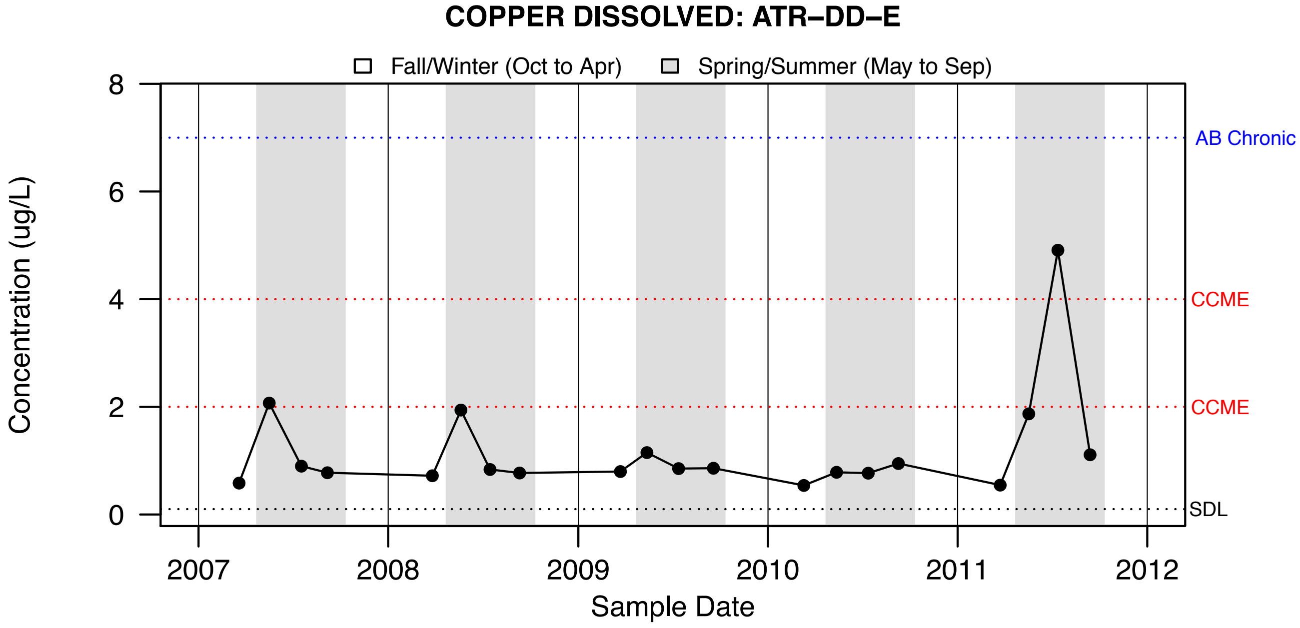


Figure A3.114: CONDUCTIVITY: ATR-DD-E -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.115: CHROMIUM DISSOLVED: ATR-DD-E -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.116: COPPER DISSOLVED: ATR-DD-E -

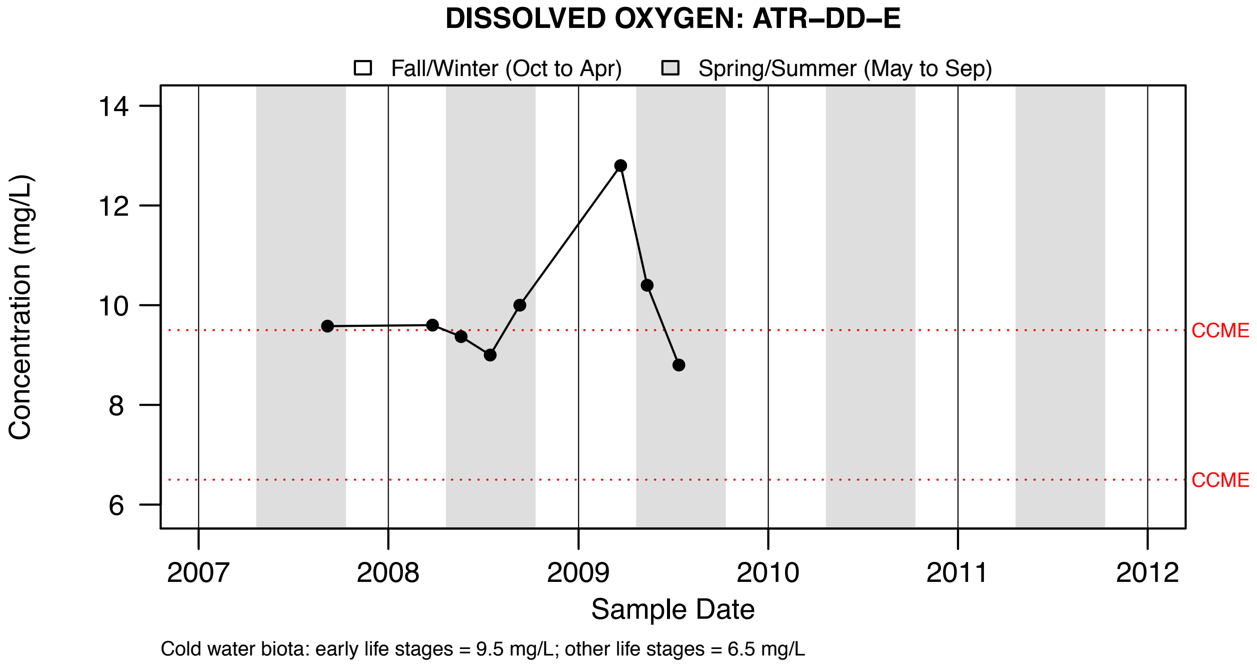


Figure A3.117: DISSOLVED OXYGEN: ATR-DD-E -

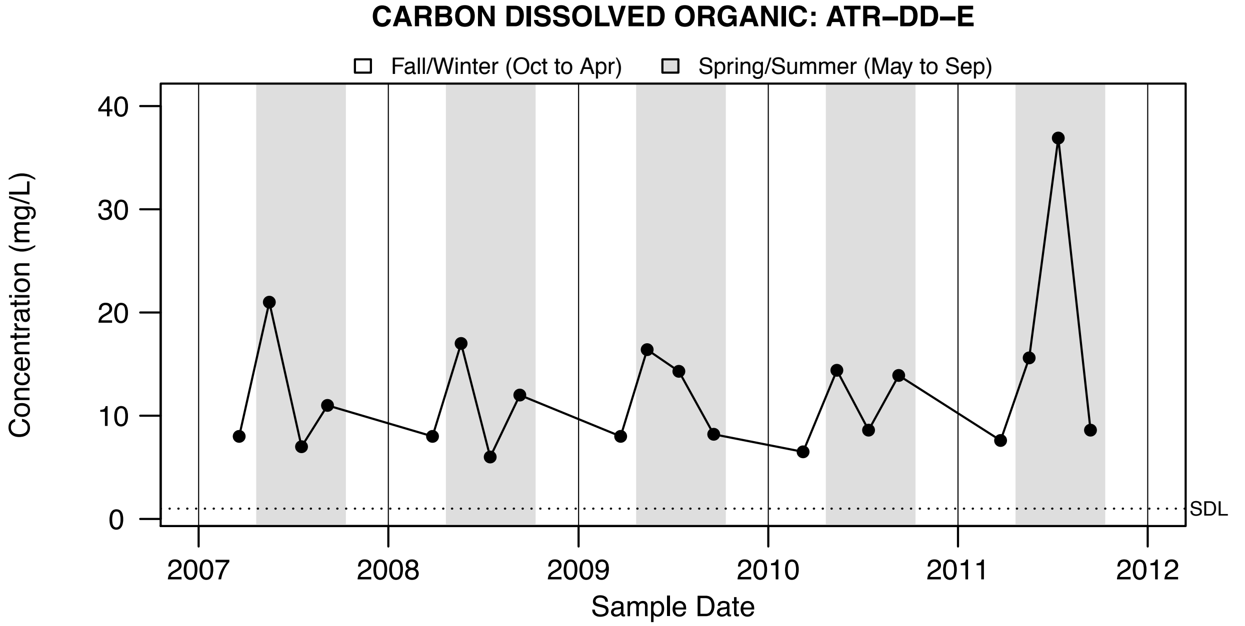


Figure A3.118: CARBON DISSOLVED ORGANIC: ATR-DD-E -

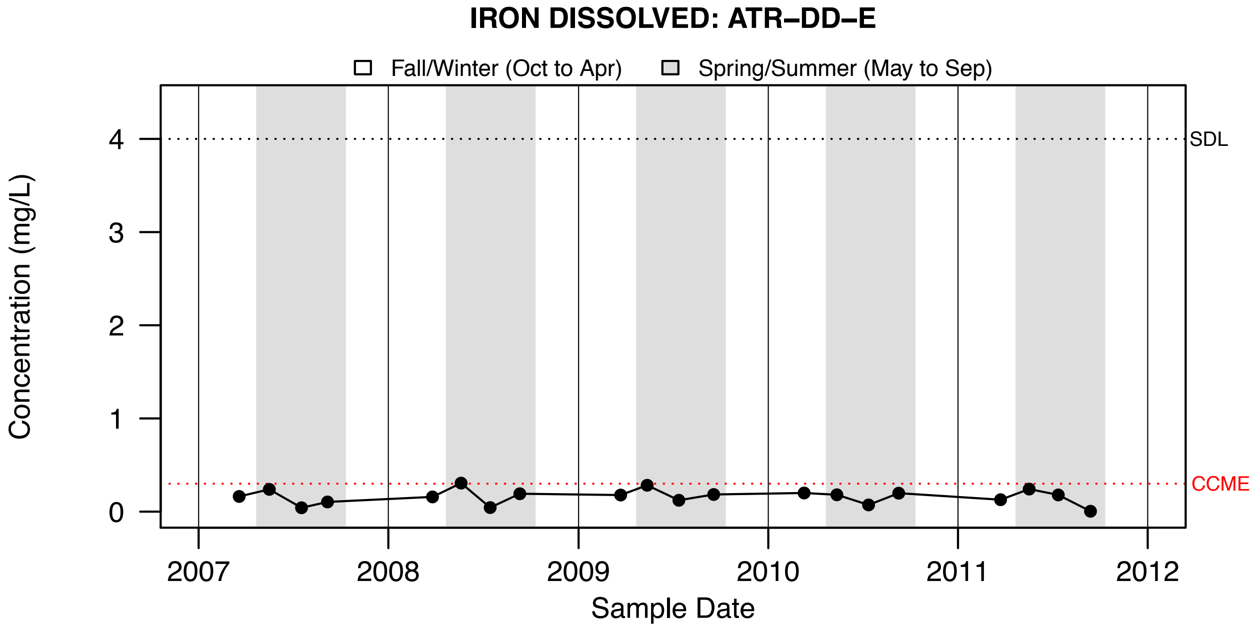


Figure A3.119: IRON DISSOLVED: ATR-DD-E -

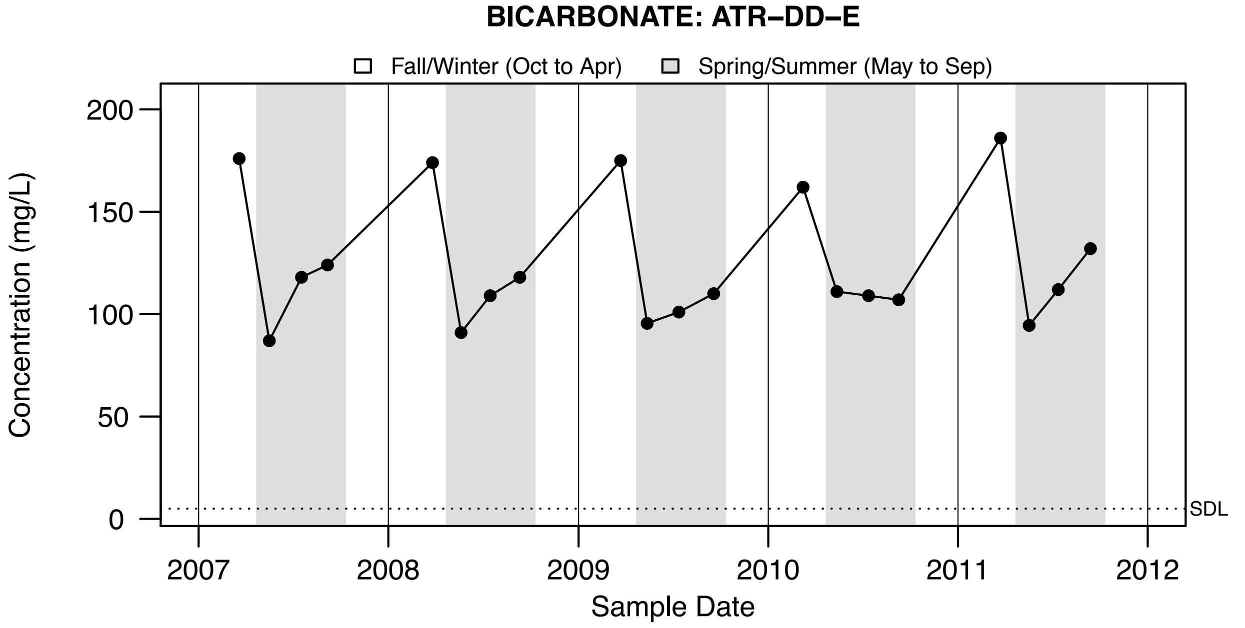


Figure A3.120: BICARBONATE: ATR-DD-E -

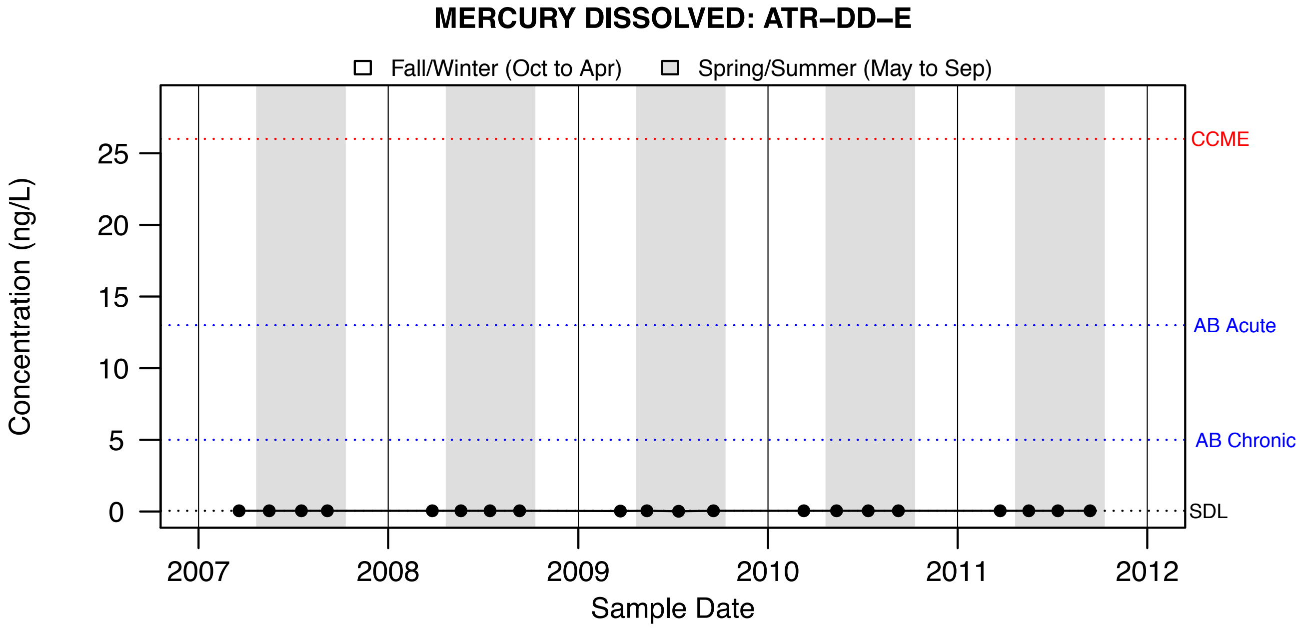


Figure A3.121: MERCURY DISSOLVED: ATR-DD-E -

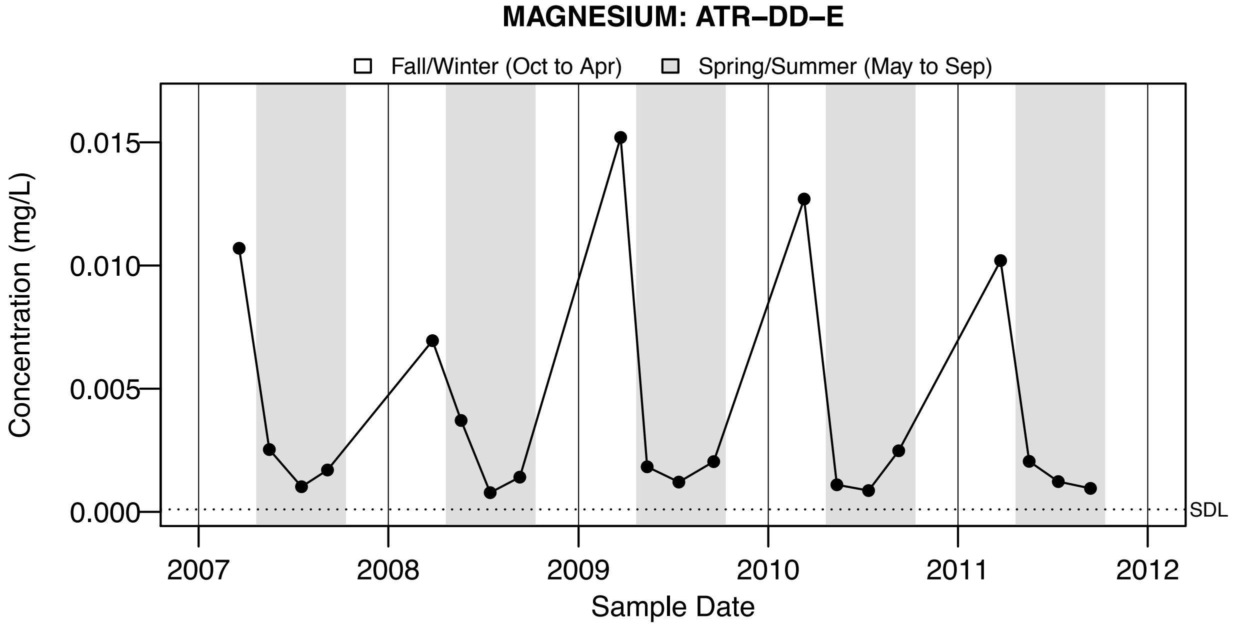


Figure A3.122: MAGNESIUM: ATR-DD-E -

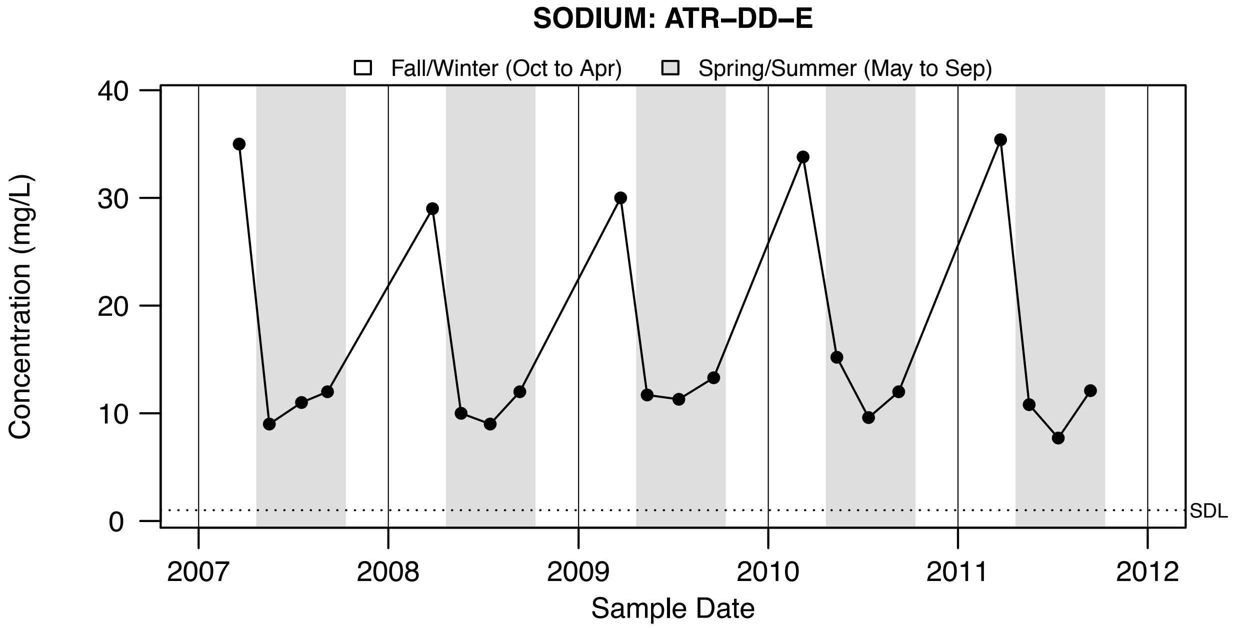
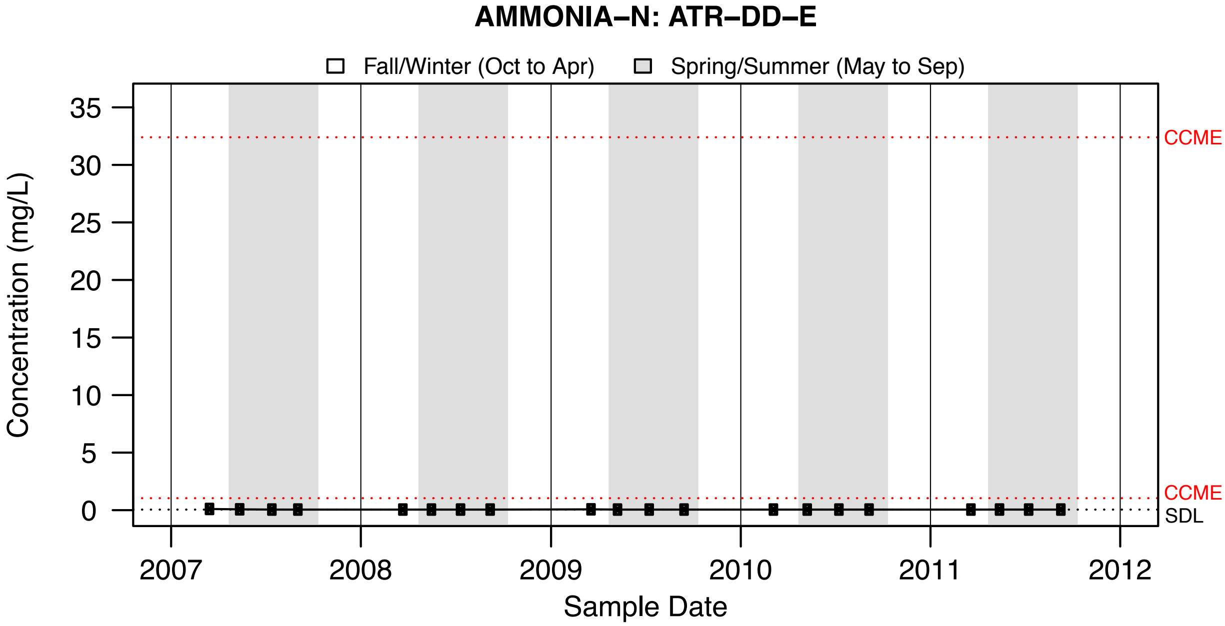


Figure A3.123: SODIUM: ATR-DD-E -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.124: AMMONIA-N: ATR-DD-E -

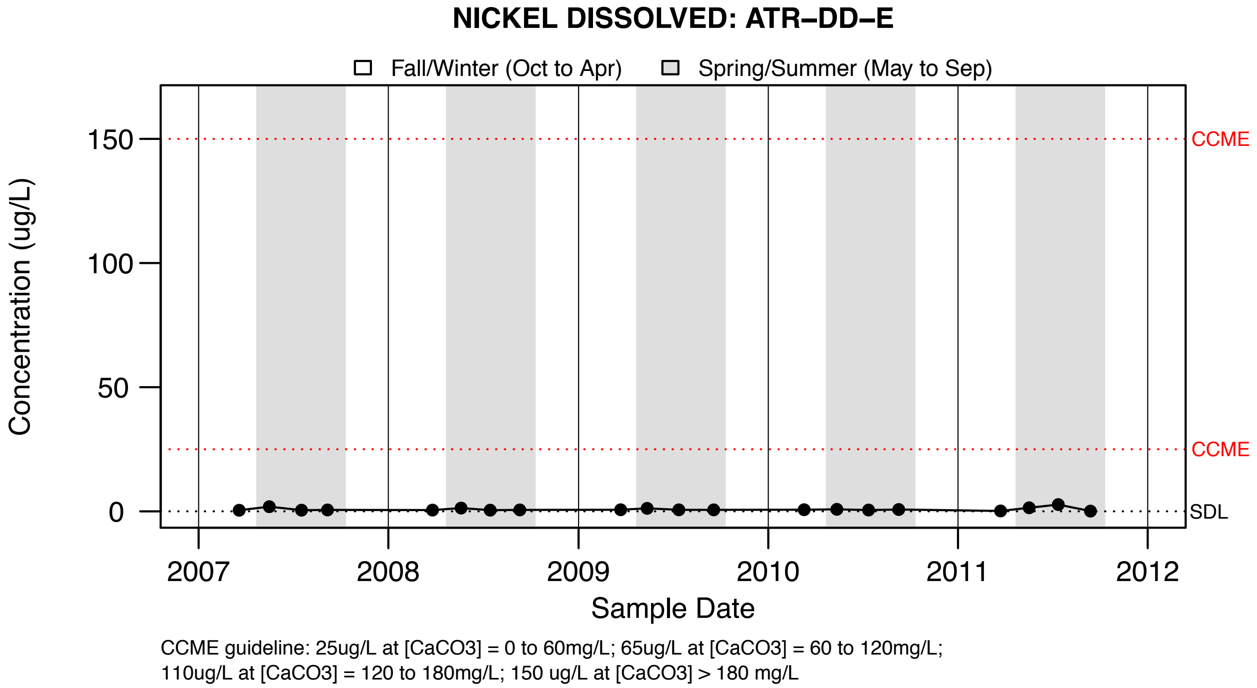


Figure A3.125: NICKEL DISSOLVED: ATR-DD-E -

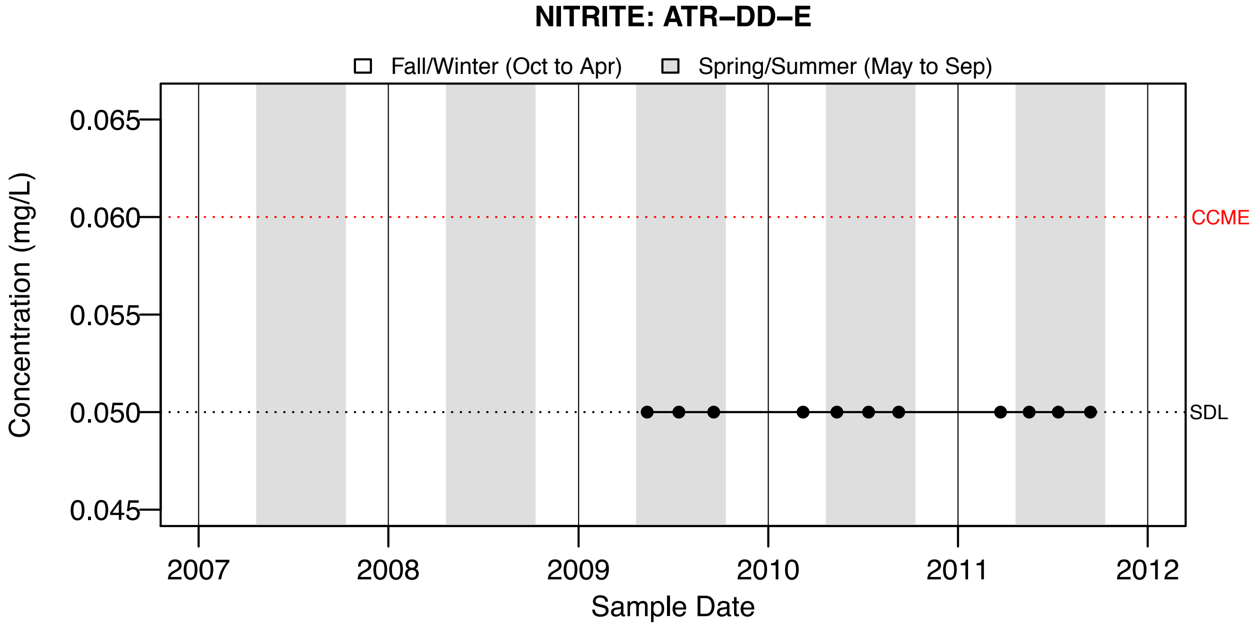
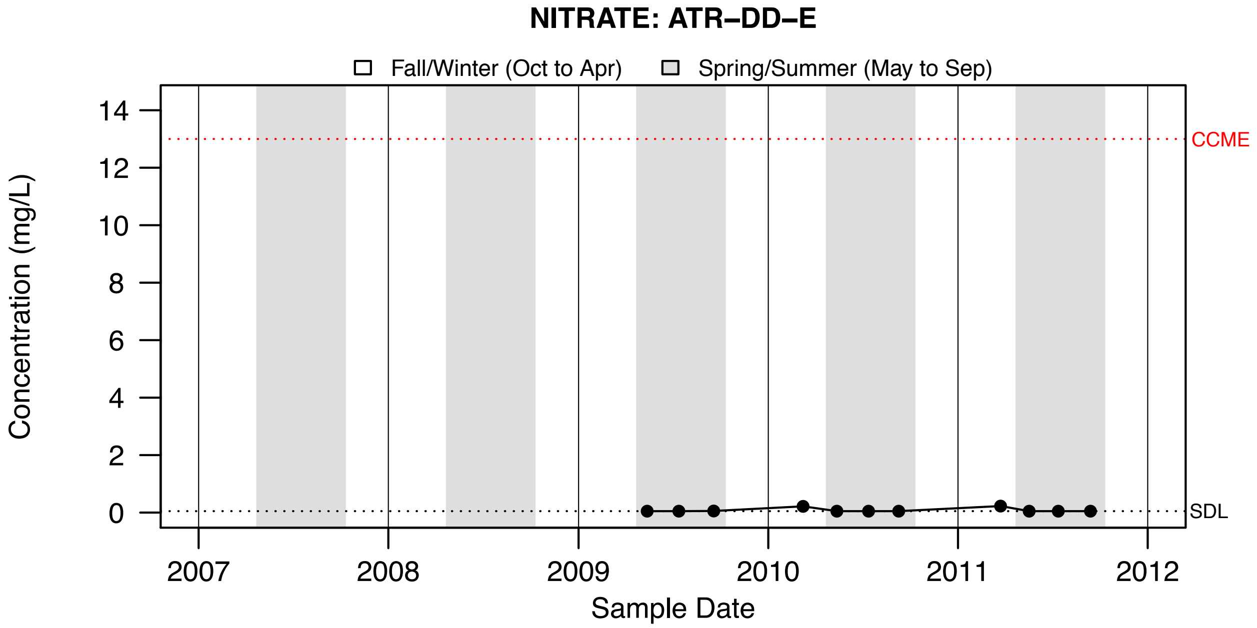


Figure A3.126: NITRITE: ATR-DD-E -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.127: NITRATE: ATR-DD-E -

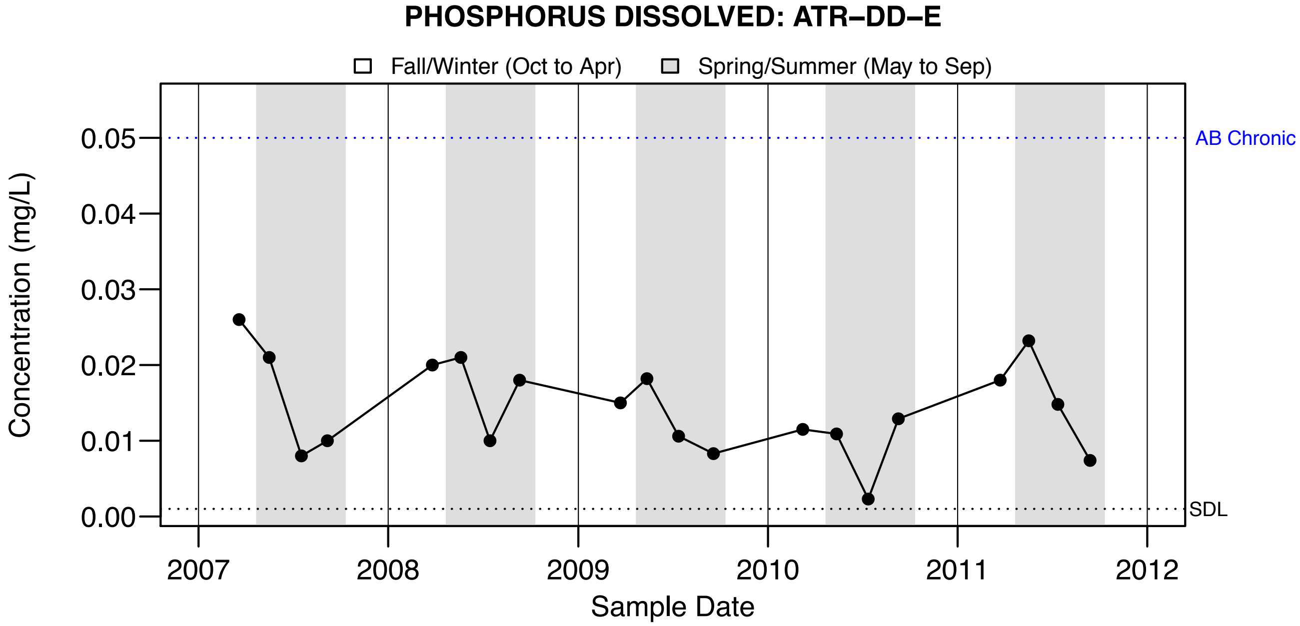


Figure A3.128: PHOSPHORUS DISSOLVED: ATR-DD-E -

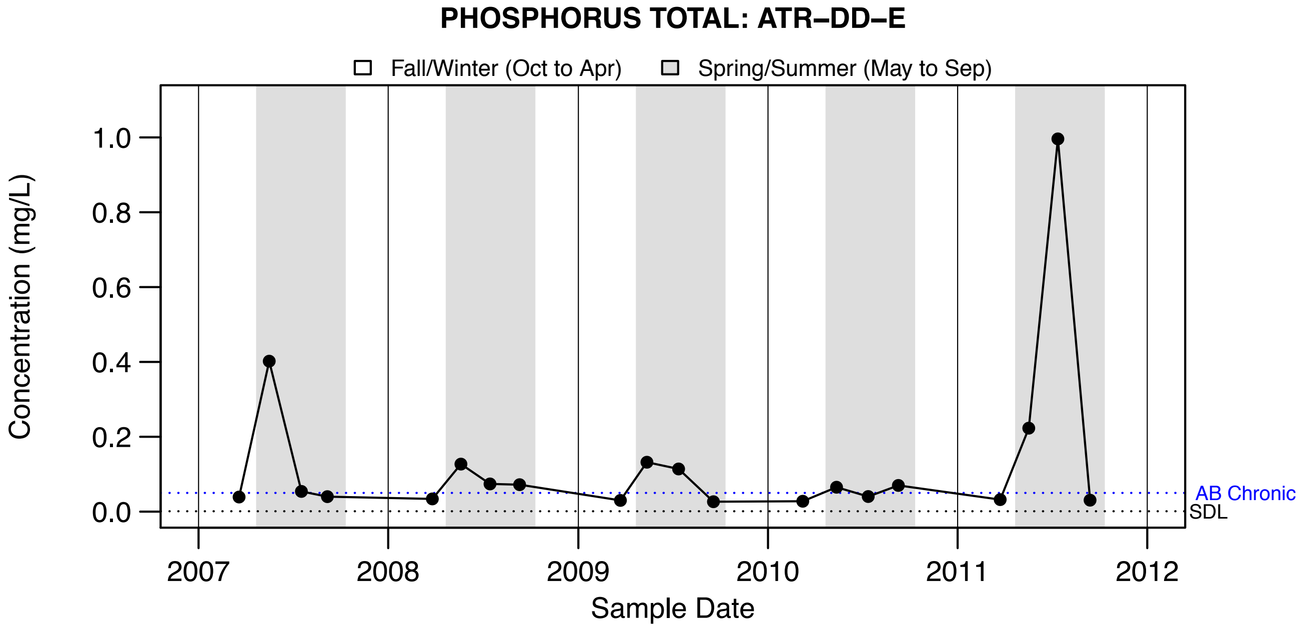
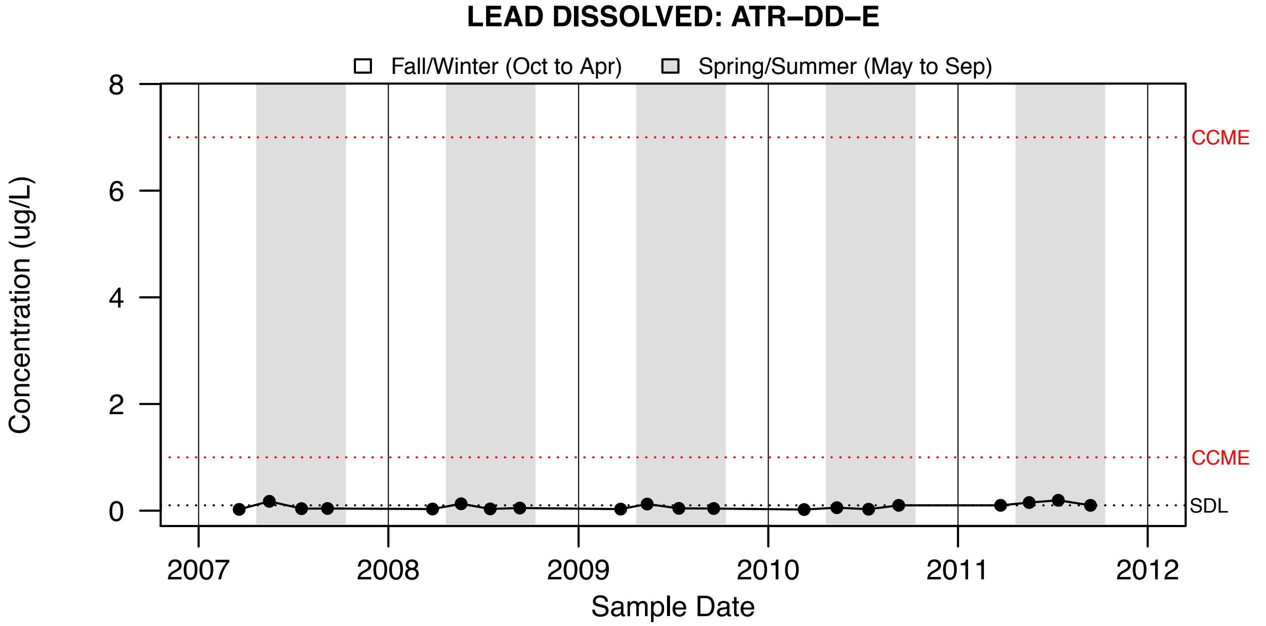
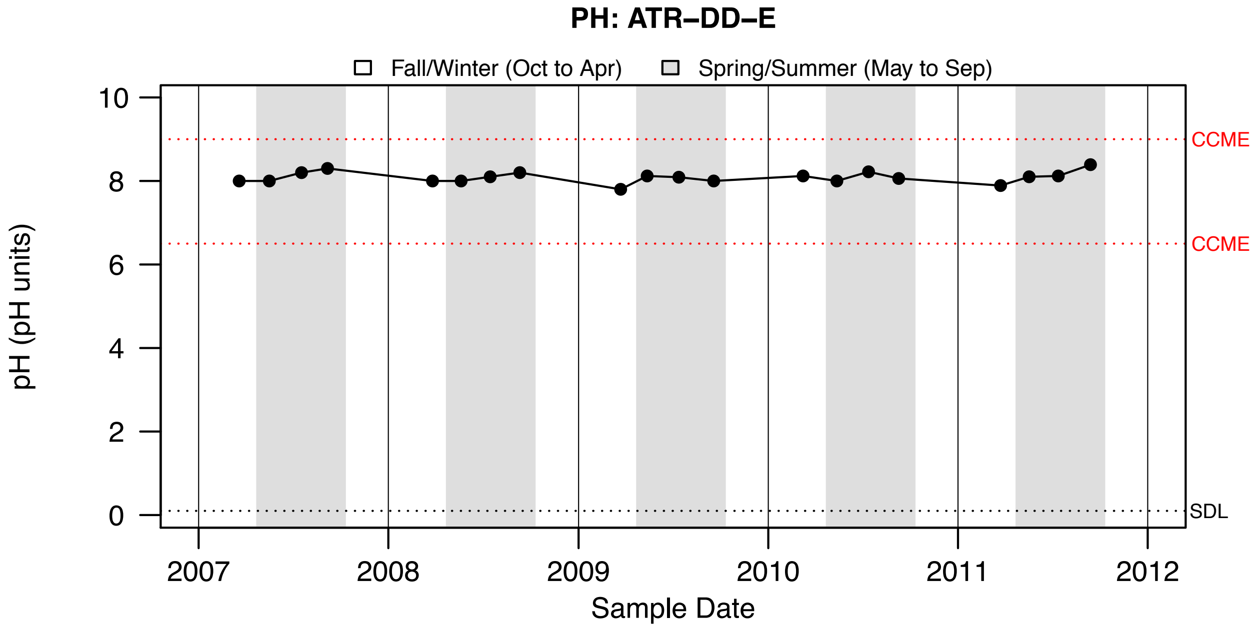


Figure A3.129: PHOSPHORUS TOTAL: ATR-DD-E -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.130: LEAD DISSOLVED: ATR-DD-E -



AB guideline: To be in the range of 6.5 to 8.5 but not altered by more than 0.5 pH units from background values

Figure A3.131: PH: ATR-DD-E -

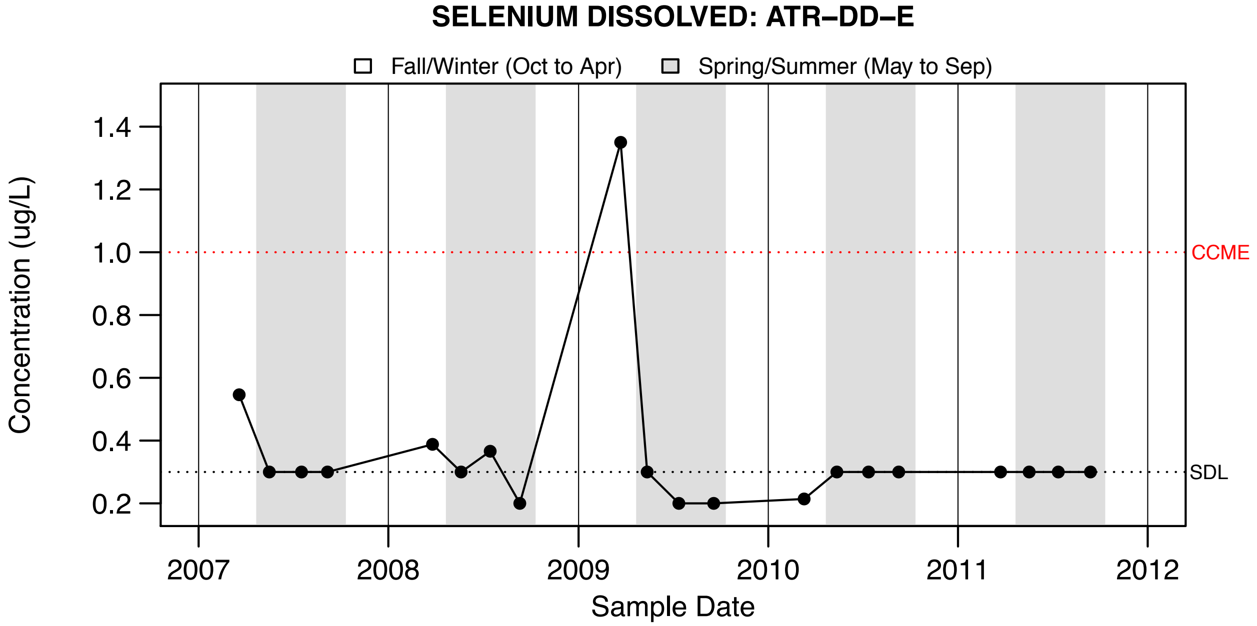


Figure A3.132: SELENIUM DISSOLVED: ATR-DD-E -

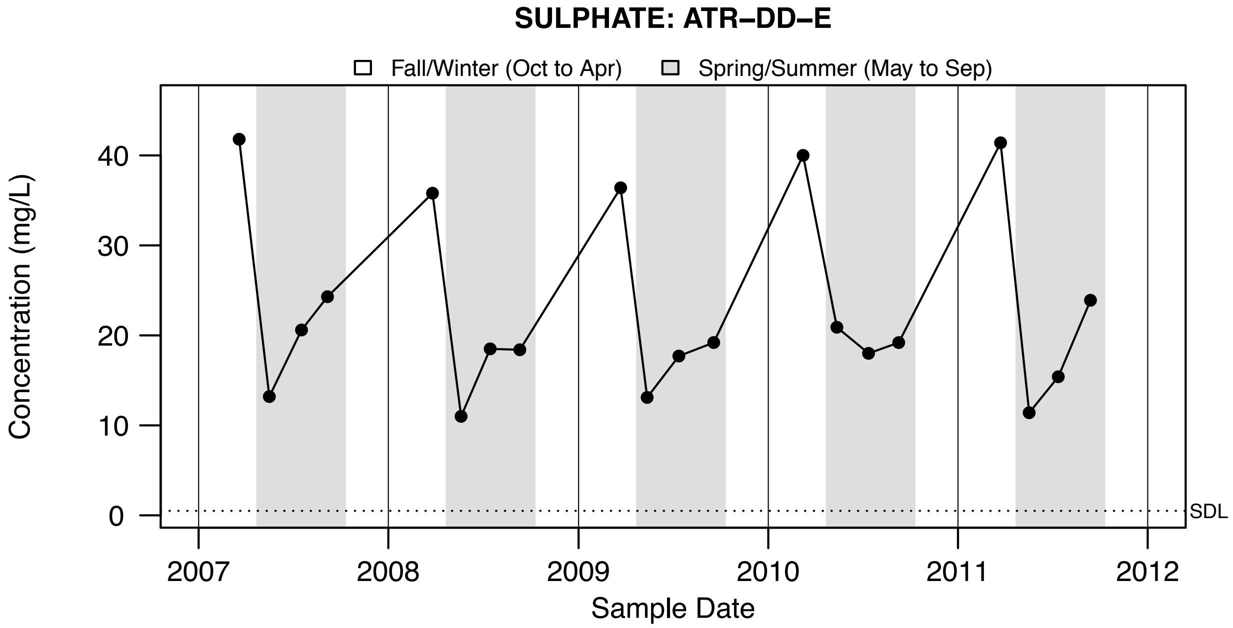


Figure A3.133: SULPHATE: ATR-DD-E -

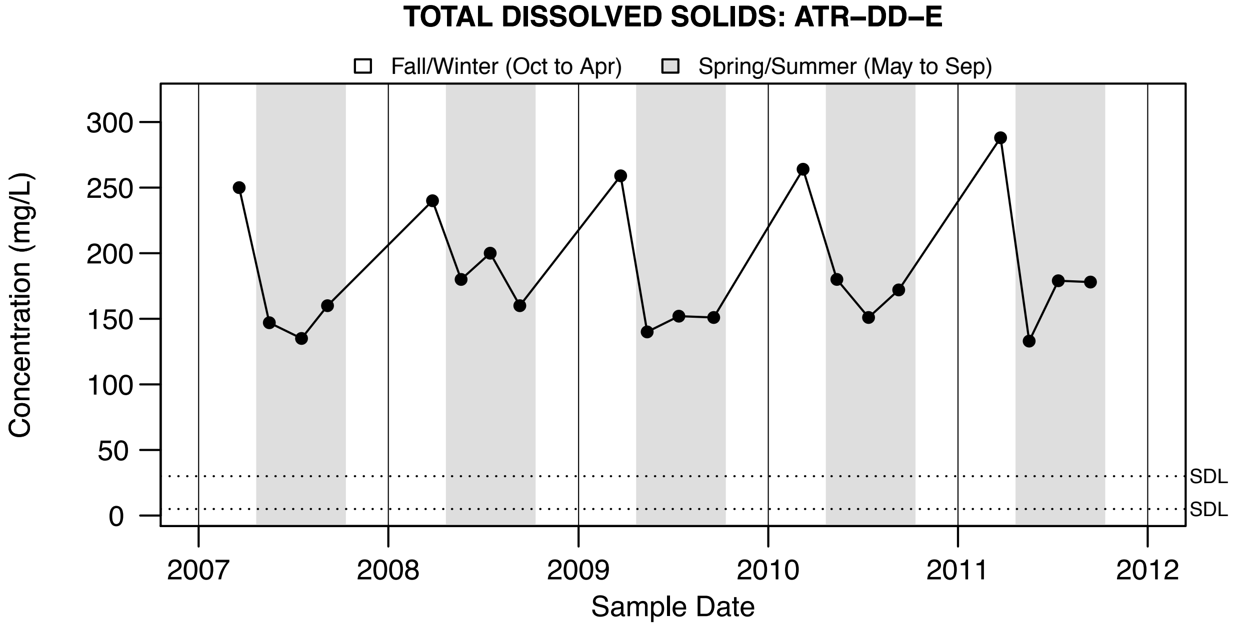
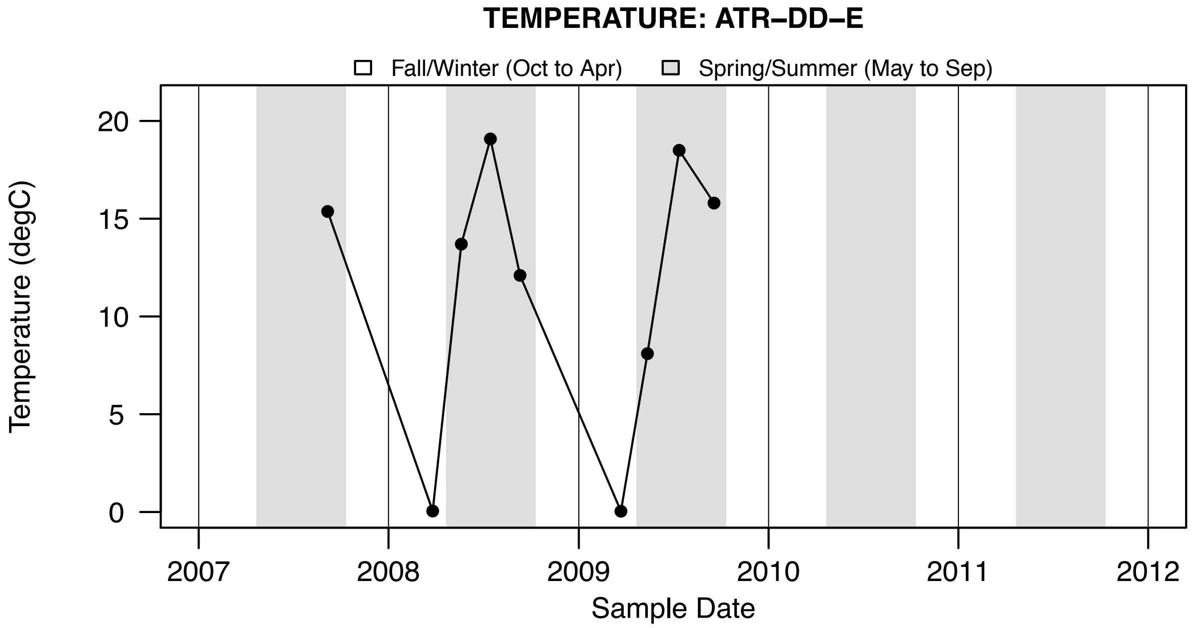


Figure A3.134: TOTAL DISSOLVED SOLIDS: ATR-DD-E -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.135: TEMPERATURE: ATR-DD-E -

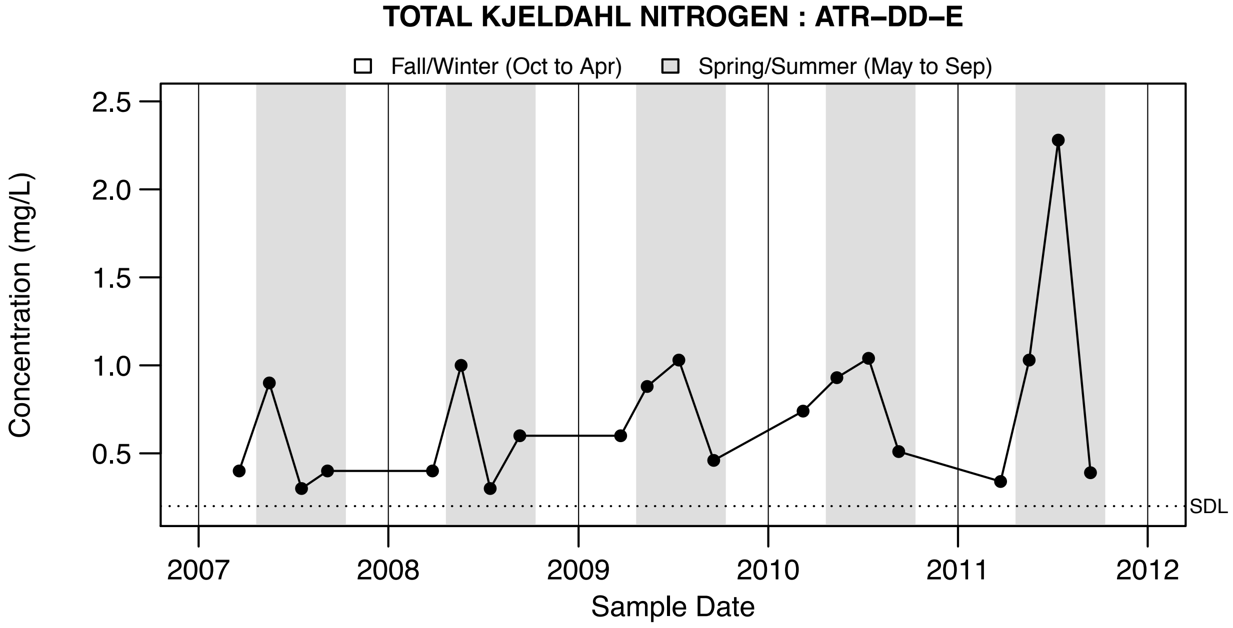
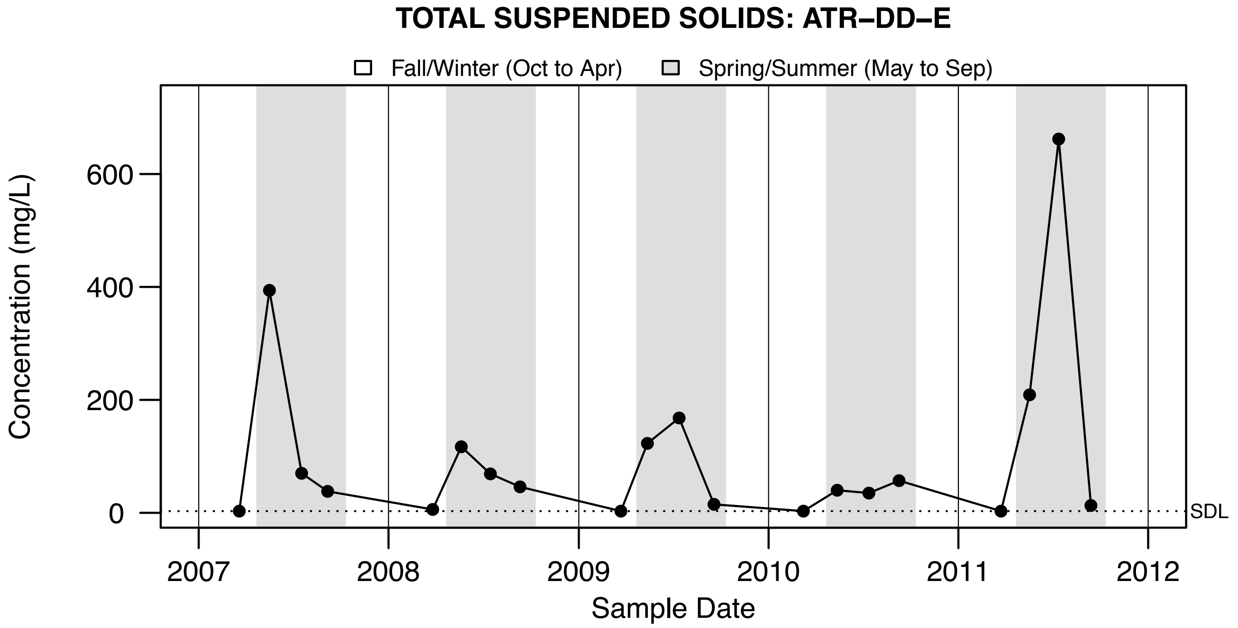


Figure A3.136: TOTAL KJELDAHL NITROGEN : ATR-DD-E -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.137: TOTAL SUSPENDED SOLIDS: ATR-DD-E -

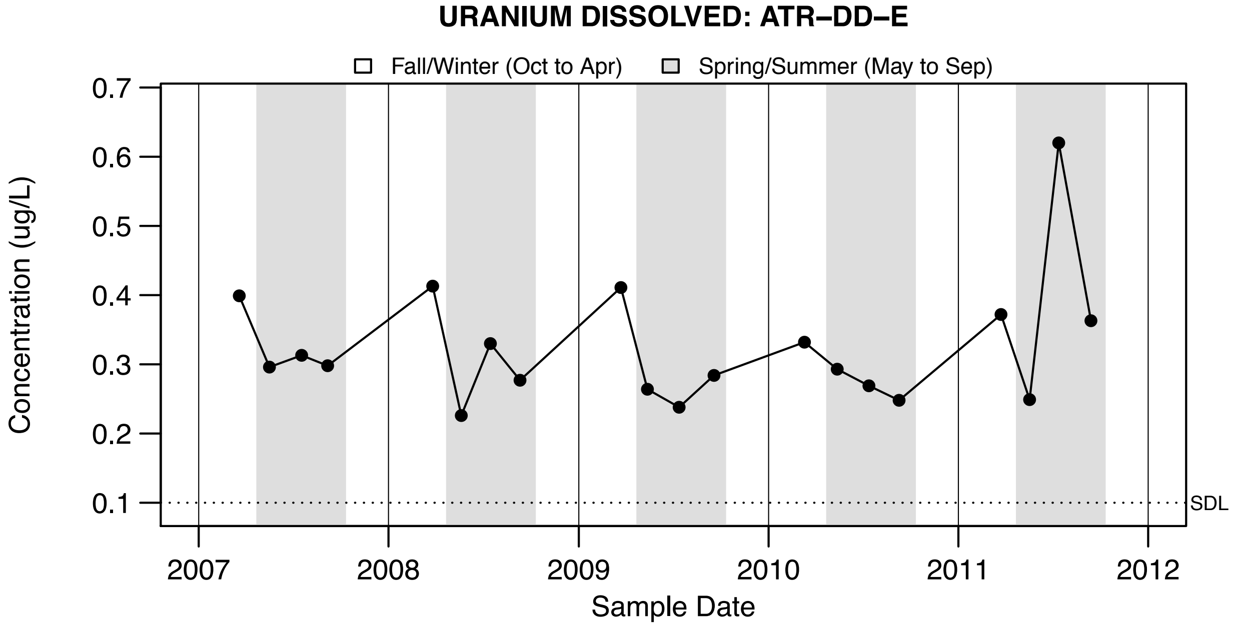


Figure A3.138: URANIUM DISSOLVED: ATR-DD-E -

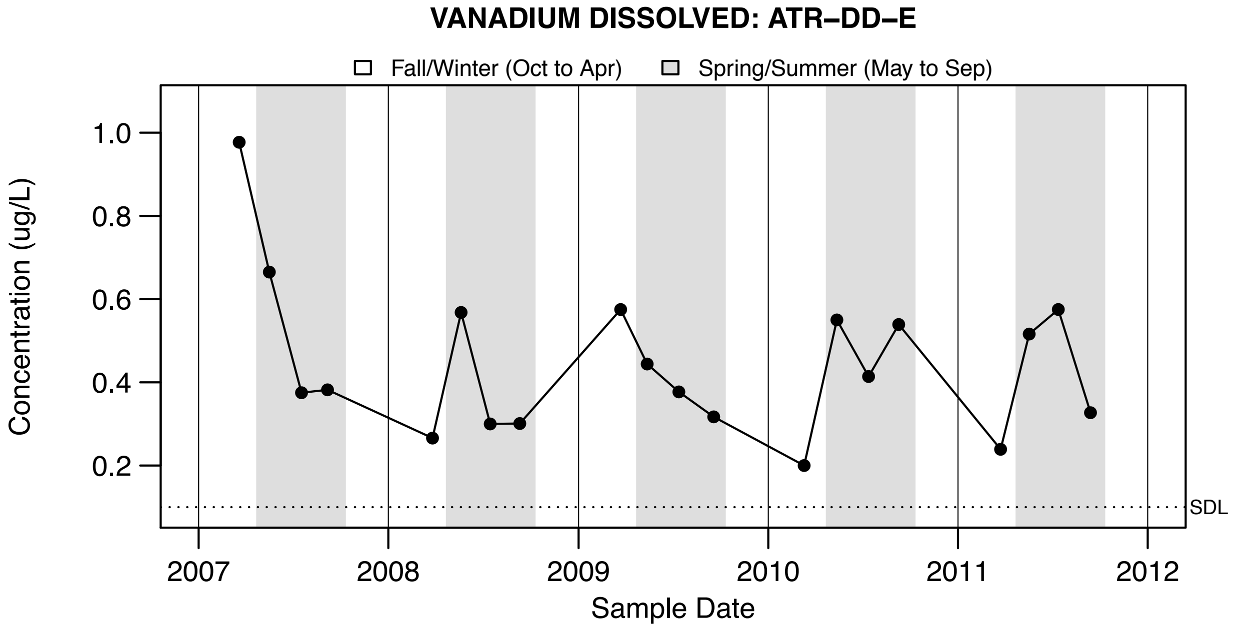


Figure A3.139: VANADIUM DISSOLVED: ATR-DD-E -

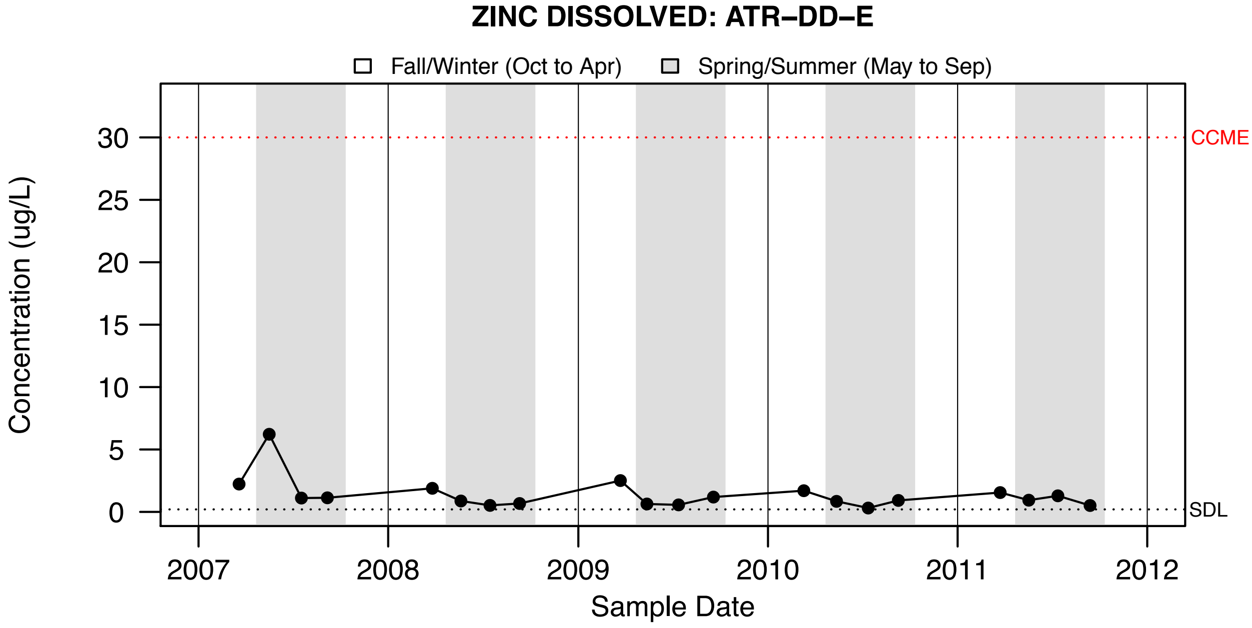
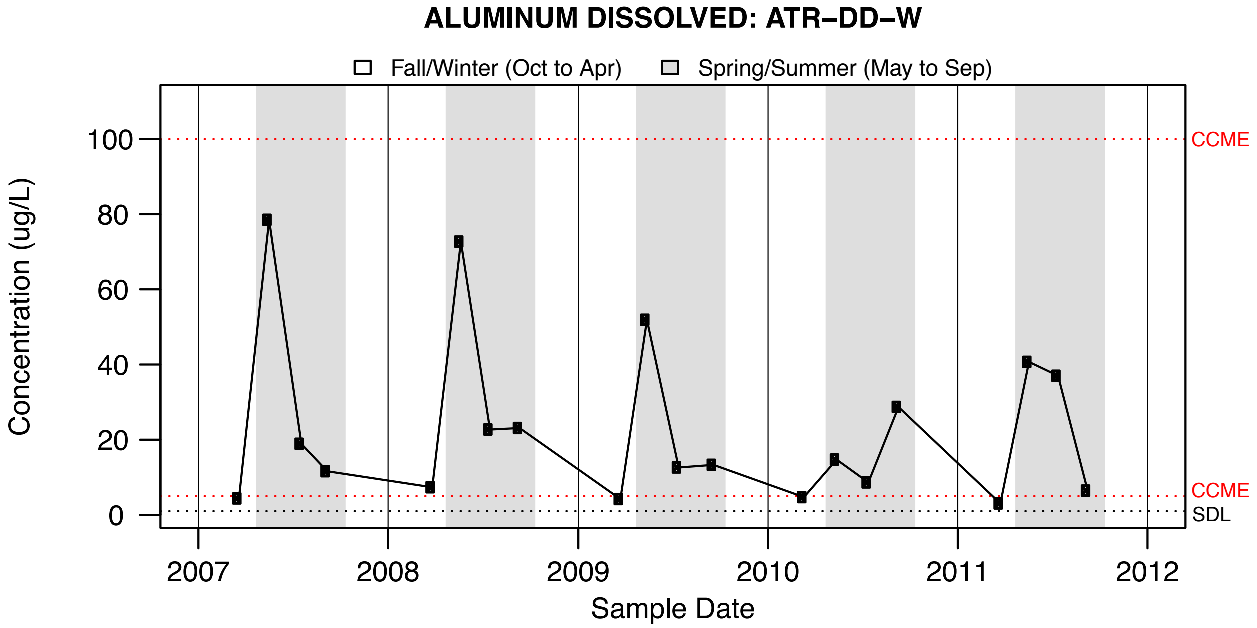
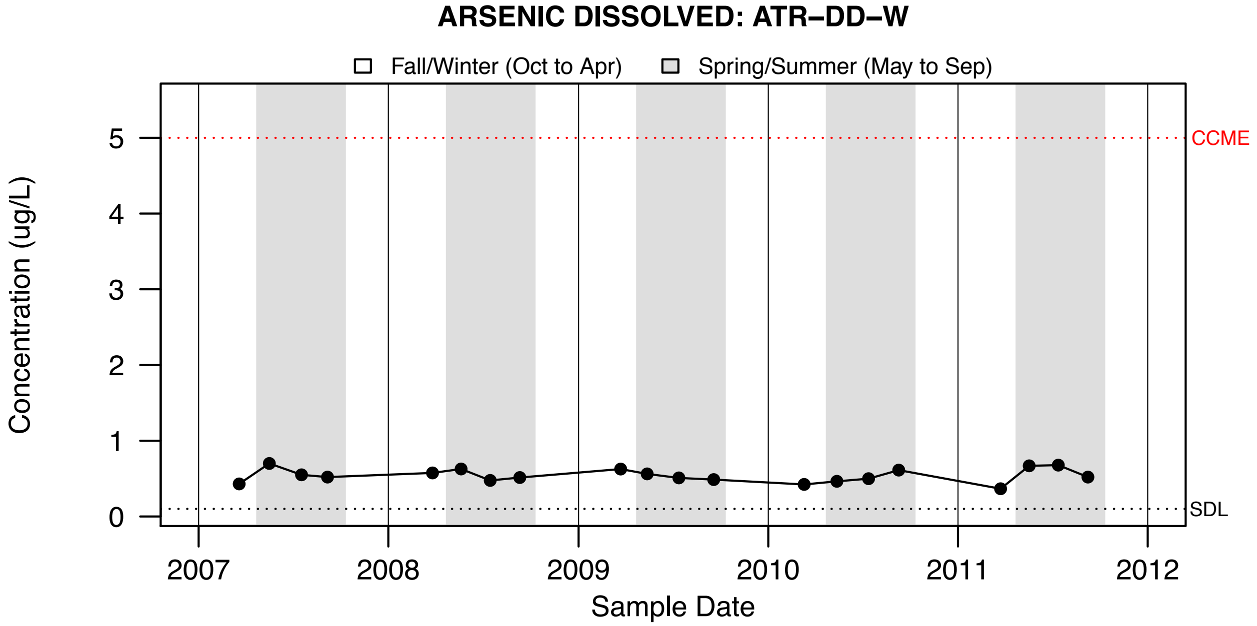


Figure A3.140: ZINC DISSOLVED: ATR-DD-E -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.141: ALUMINUM DISSOLVED: ATR-DD-W -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.142: ARSENIC DISSOLVED: ATR-DD-W -

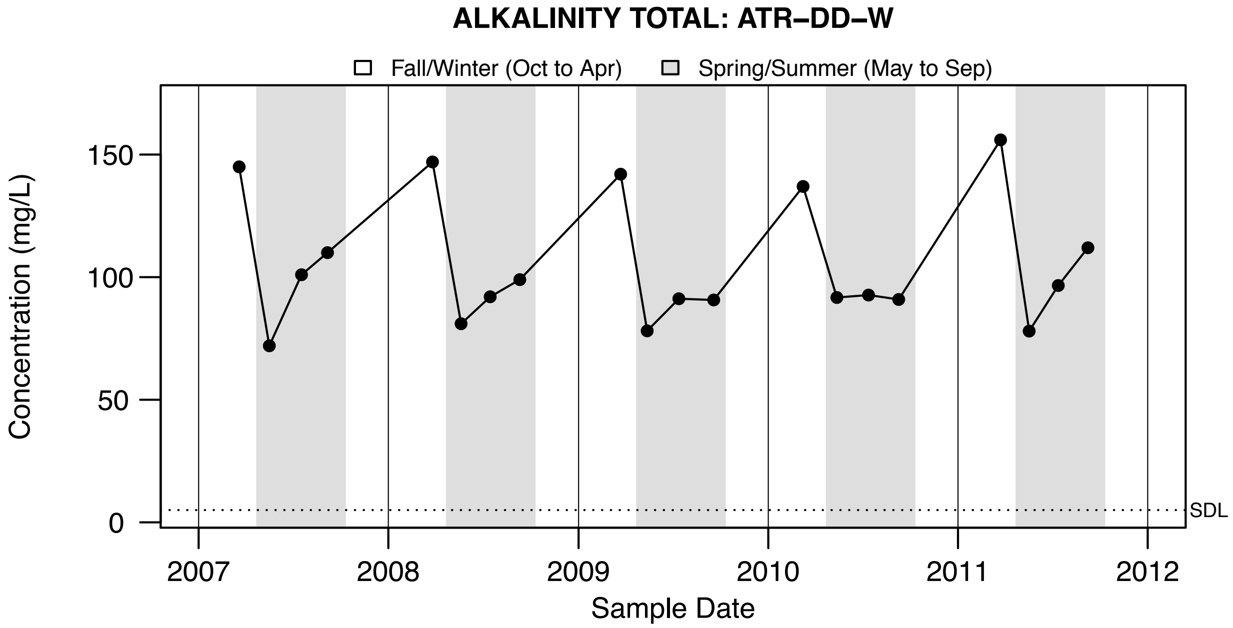


Figure A3.143: ALKALINITY TOTAL: ATR-DD-W -

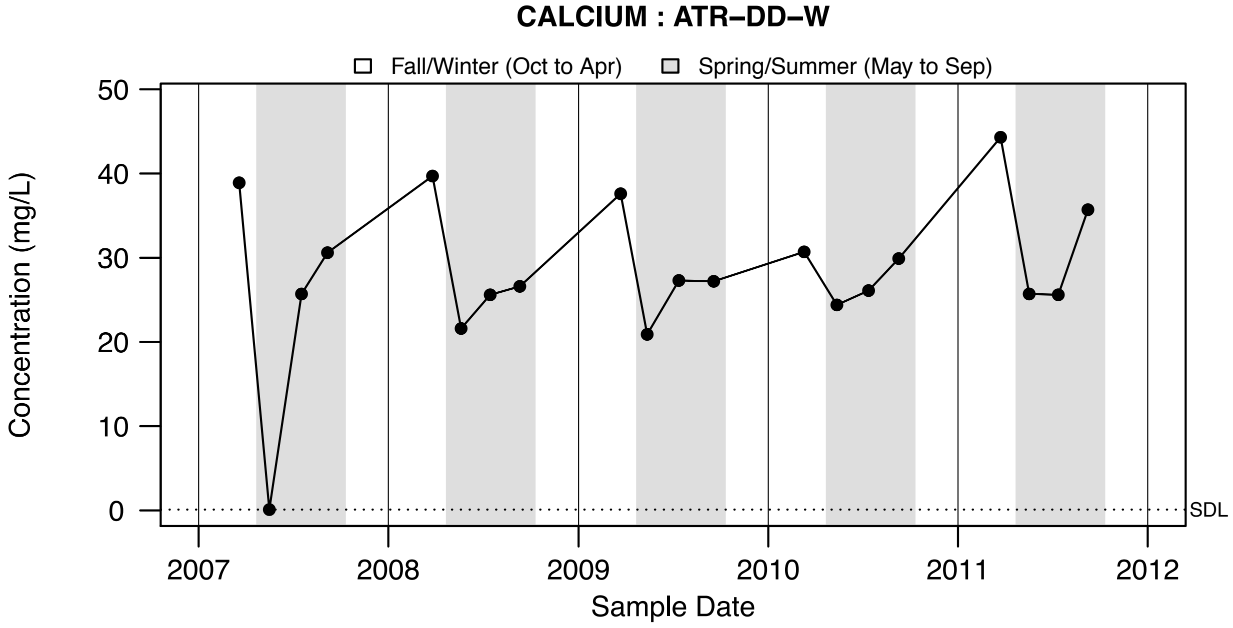


Figure A3.144: CALCIUM : ATR-DD-W -

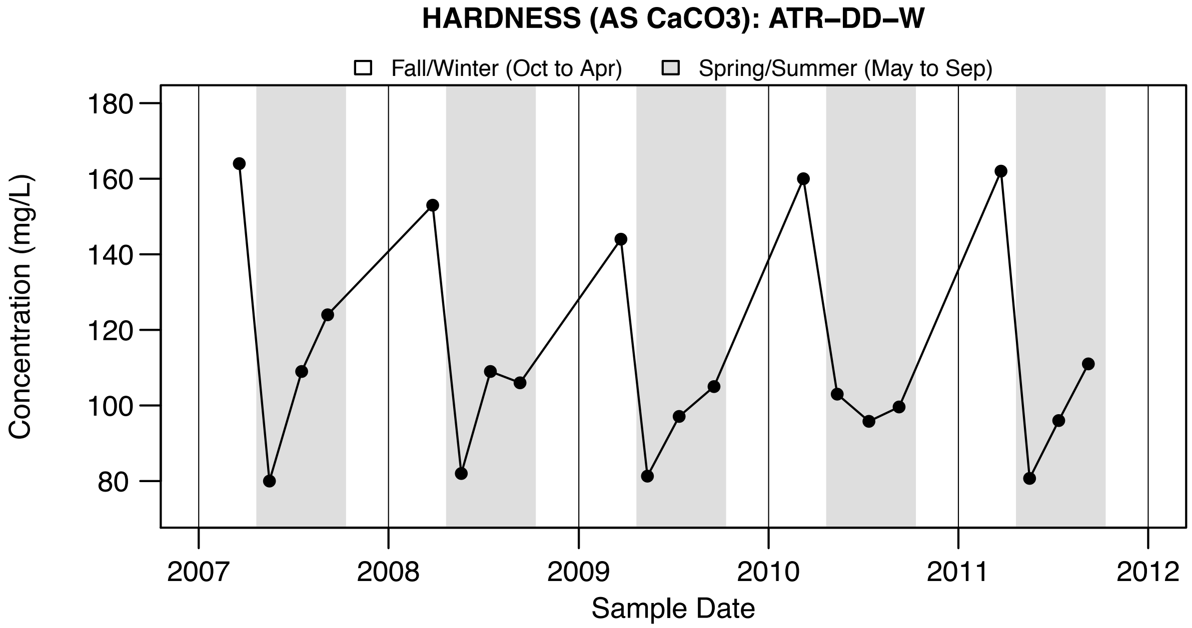
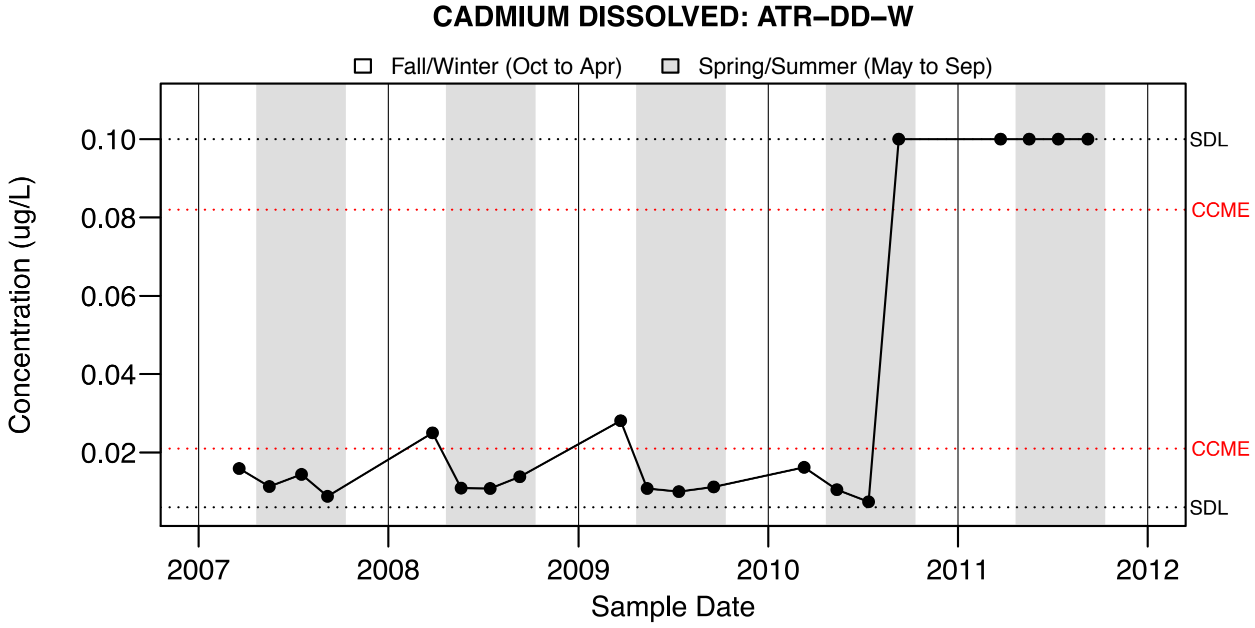


Figure A3.145: HARDNESS (AS CaCO3): ATR-DD-W -



Related to hardness as CaCo3

Figure A3.146: CADMIUM DISSOLVED: ATR-DD-W -

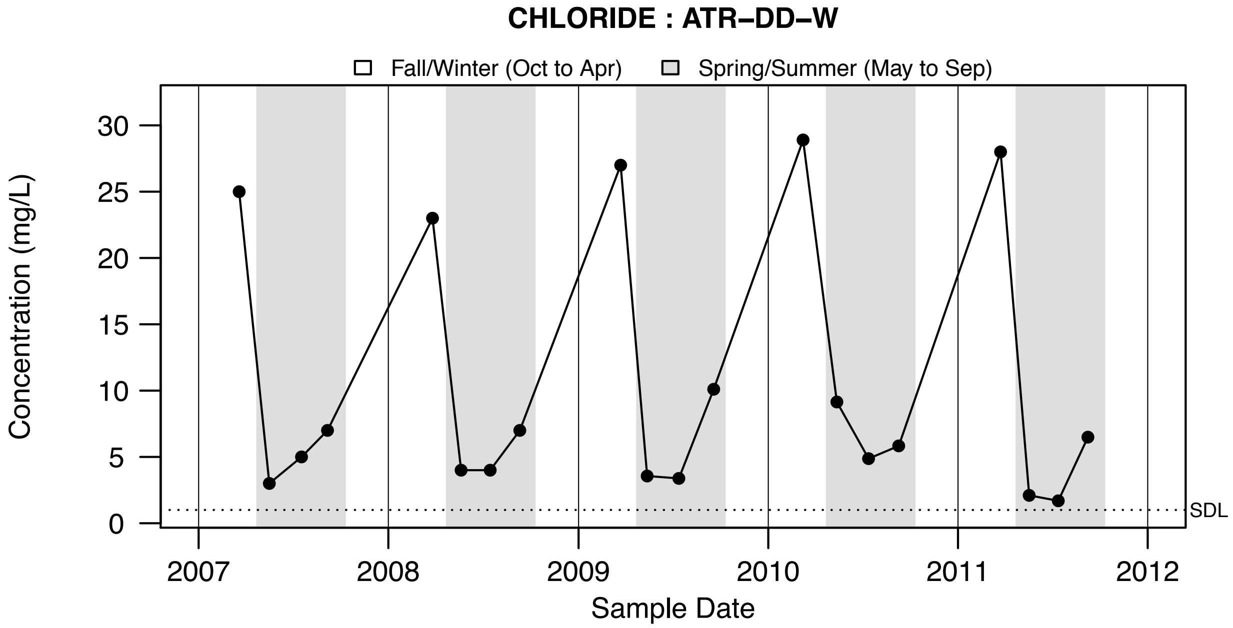


Figure A3.147: CHLORIDE : ATR-DD-W -

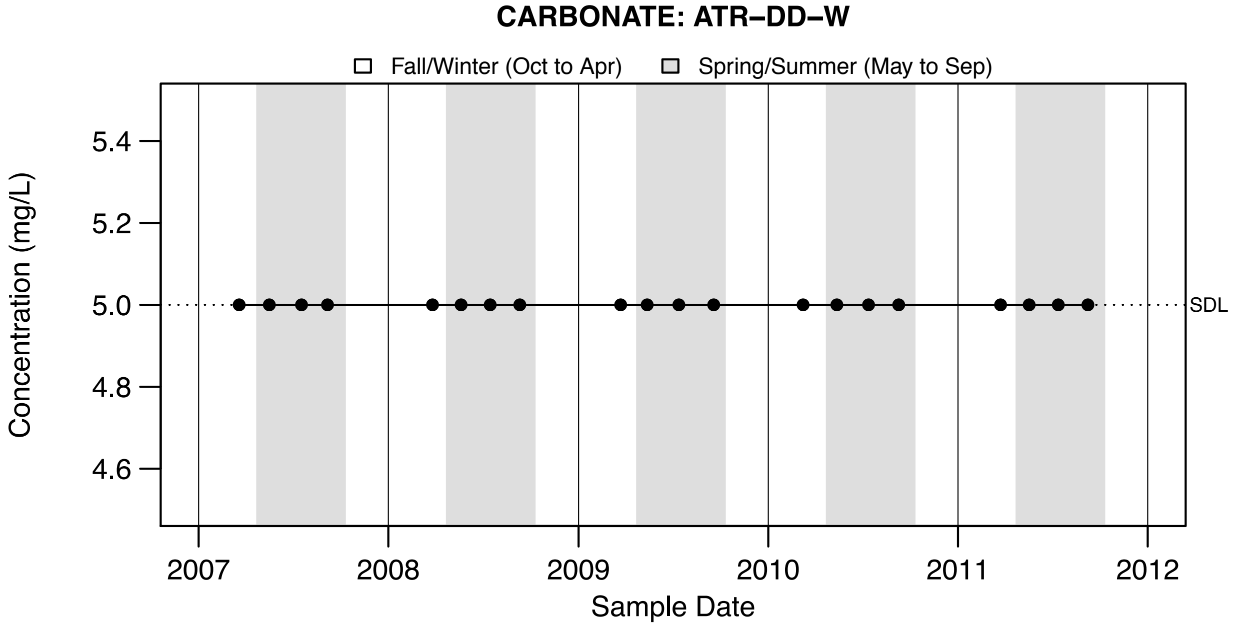
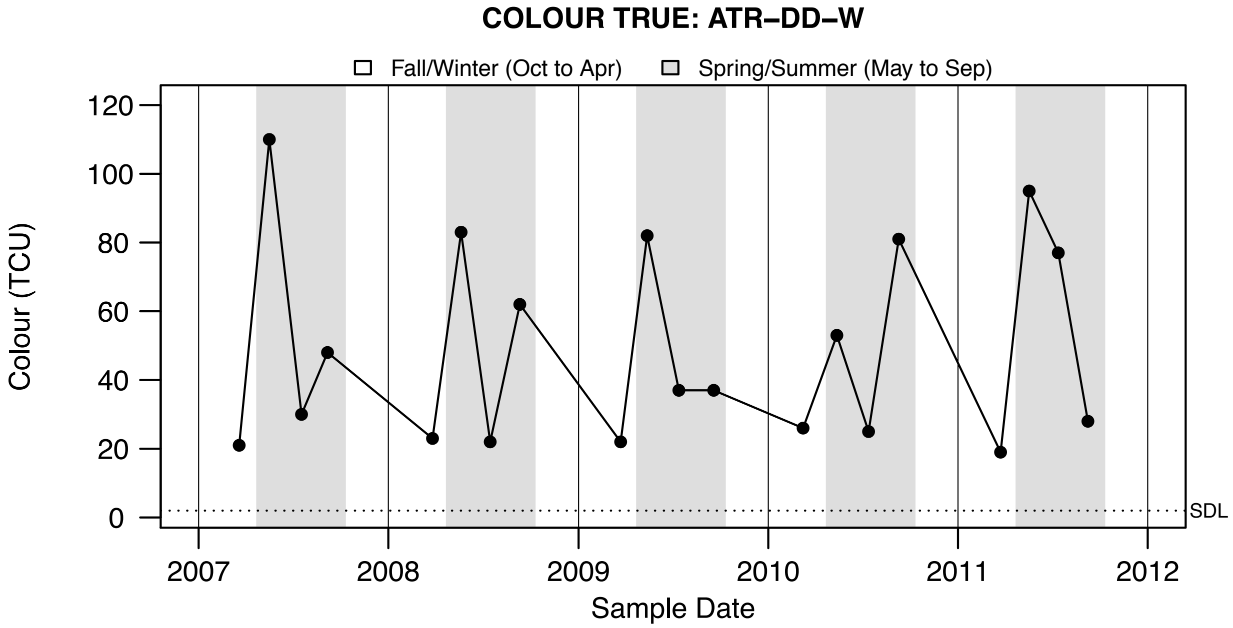


Figure A3.148: CARBONATE: ATR-DD-W -



AB guideline: Not to be increased more than 30 colour units above natural value

Figure A3.149: COLOUR TRUE: ATR-DD-W -

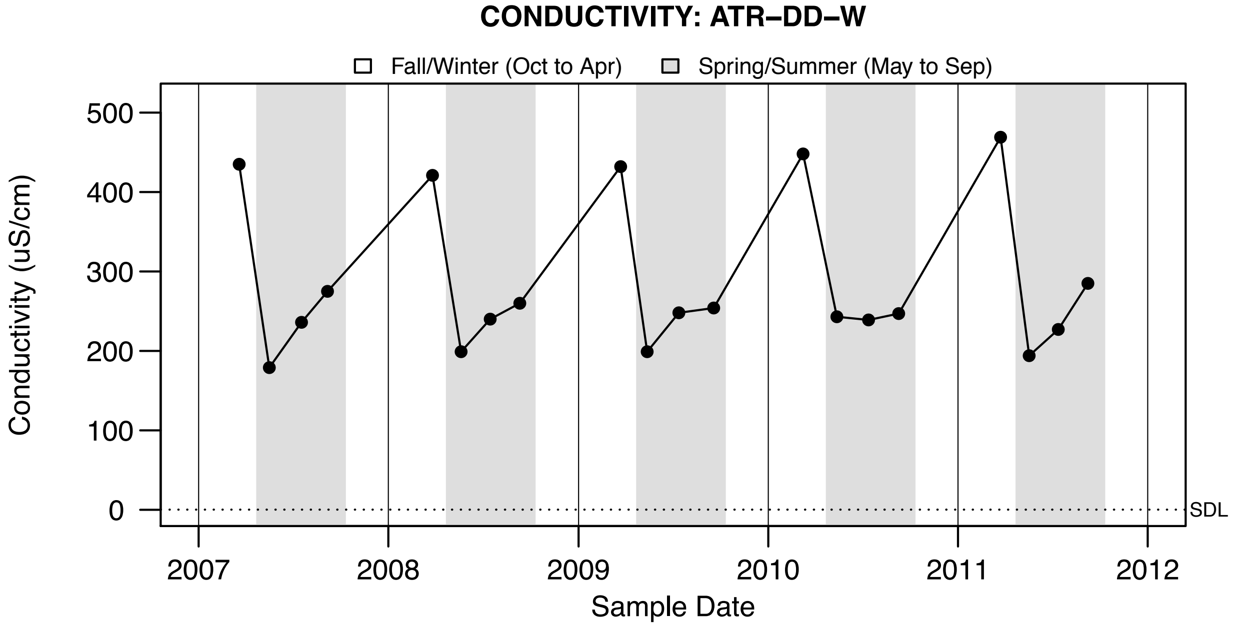
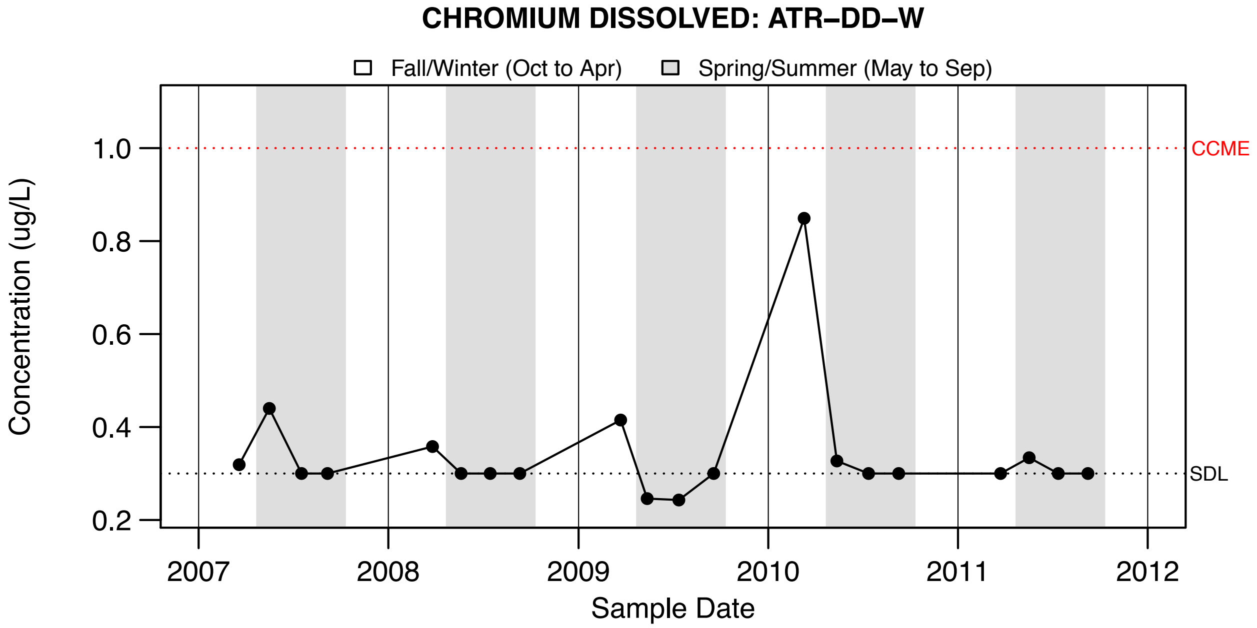
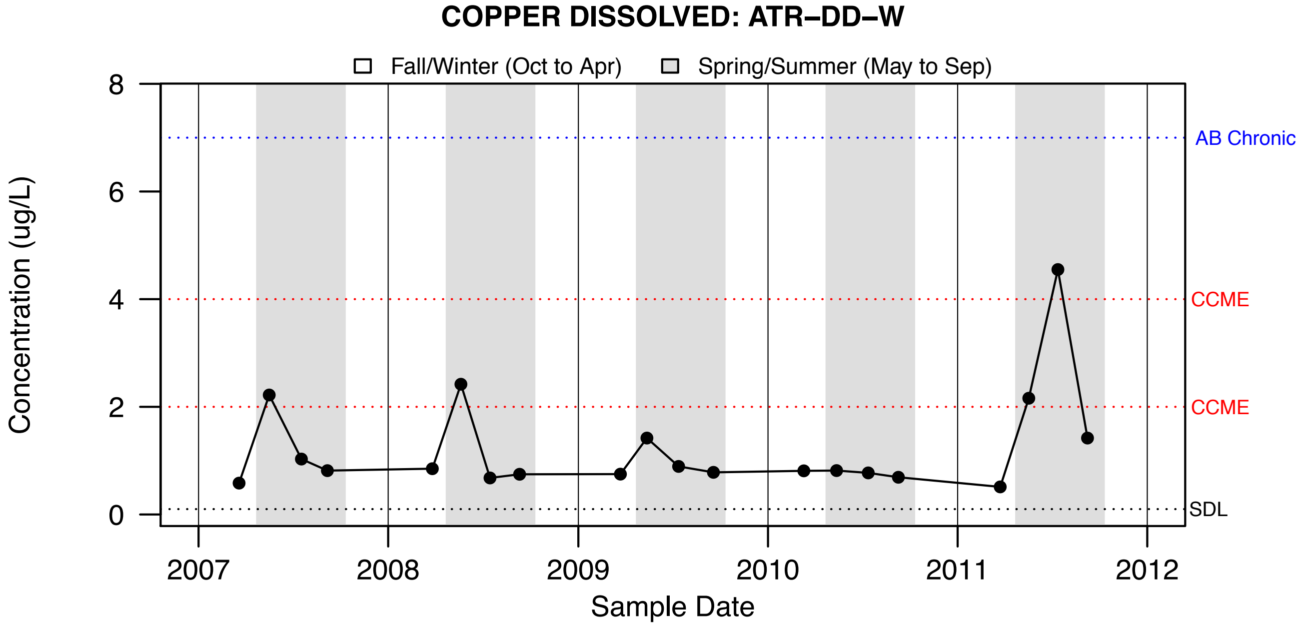


Figure A3.150: CONDUCTIVITY: ATR-DD-W -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.151: CHROMIUM DISSOLVED: ATR-DD-W -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.152: COPPER DISSOLVED: ATR-DD-W -

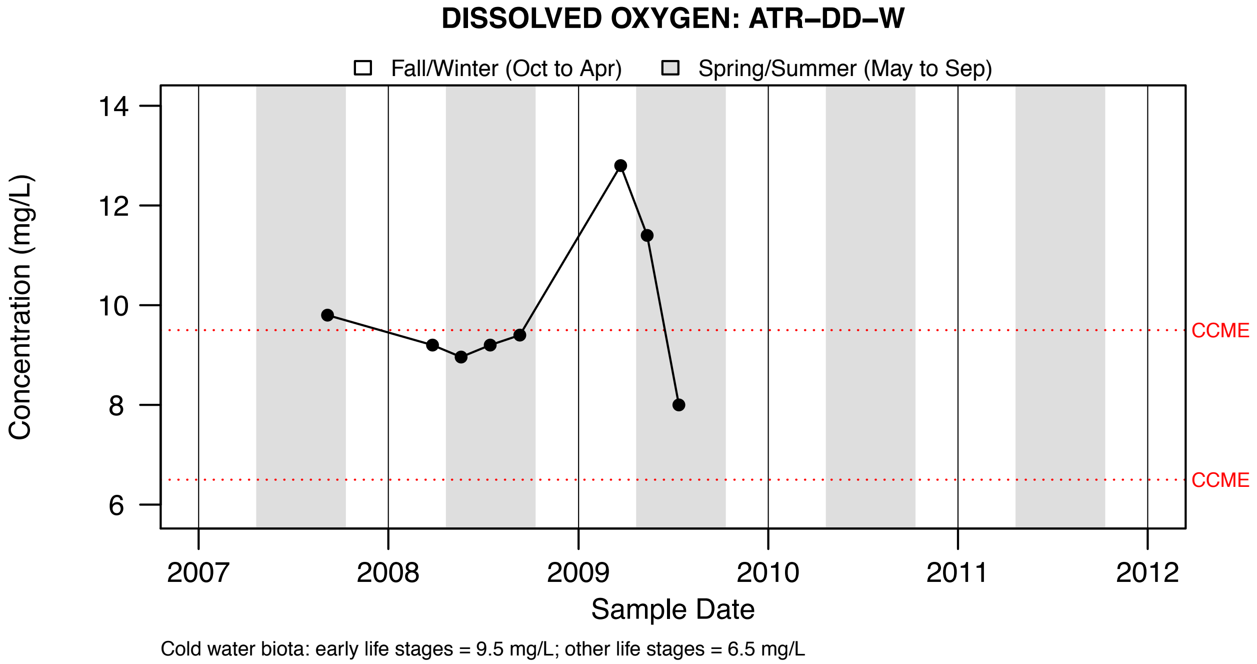


Figure A3.153: DISSOLVED OXYGEN: ATR-DD-W -

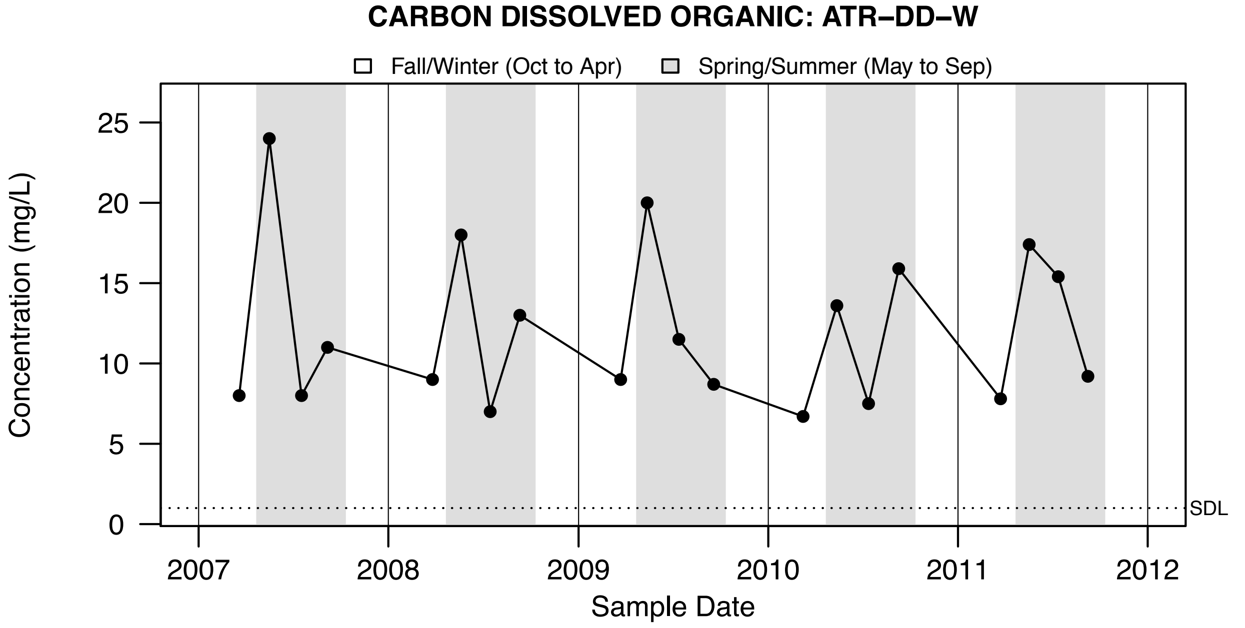


Figure A3.154: CARBON DISSOLVED ORGANIC: ATR-DD-W -

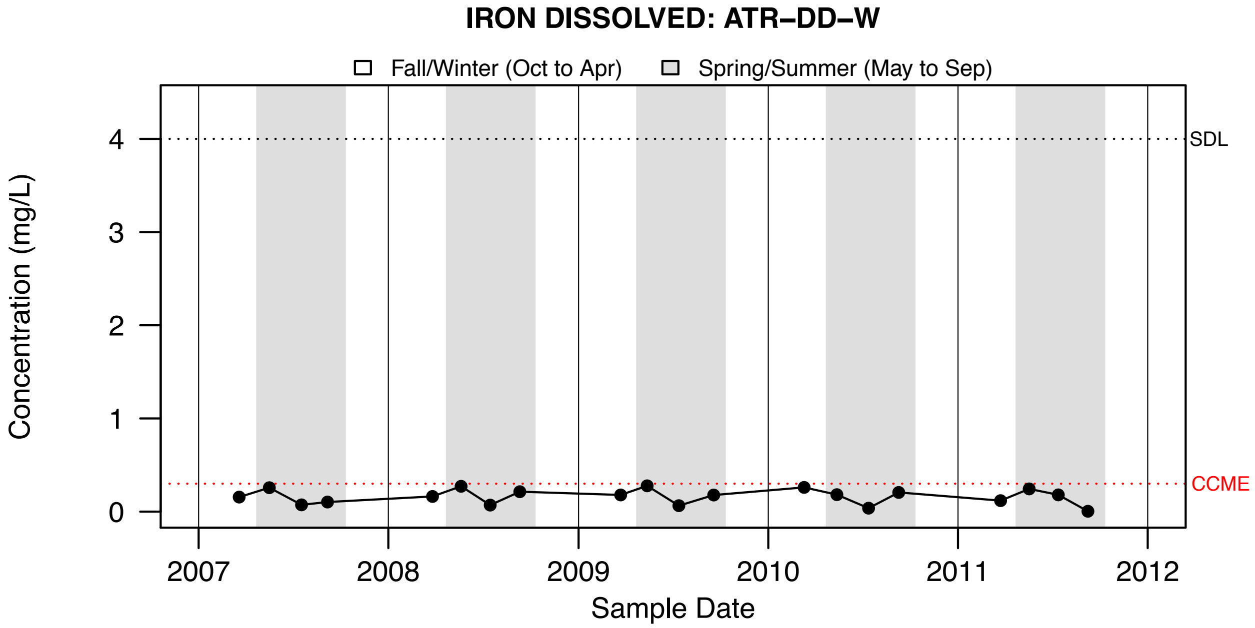


Figure A3.155: IRON DISSOLVED: ATR-DD-W -

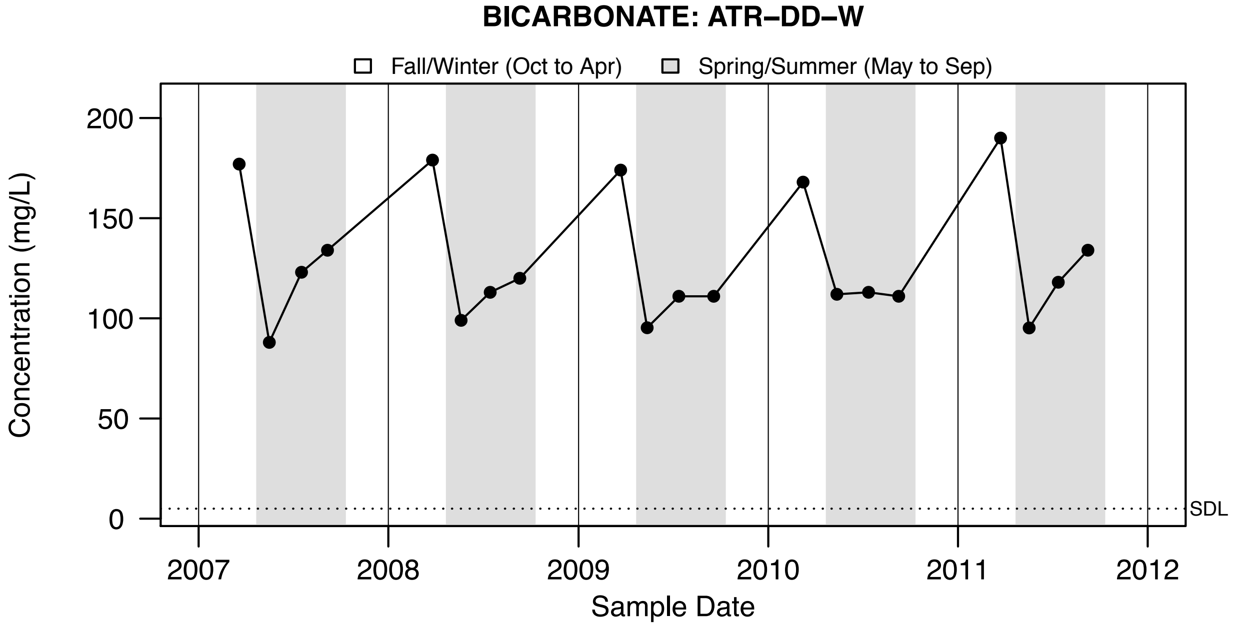


Figure A3.156: BICARBONATE: ATR-DD-W -

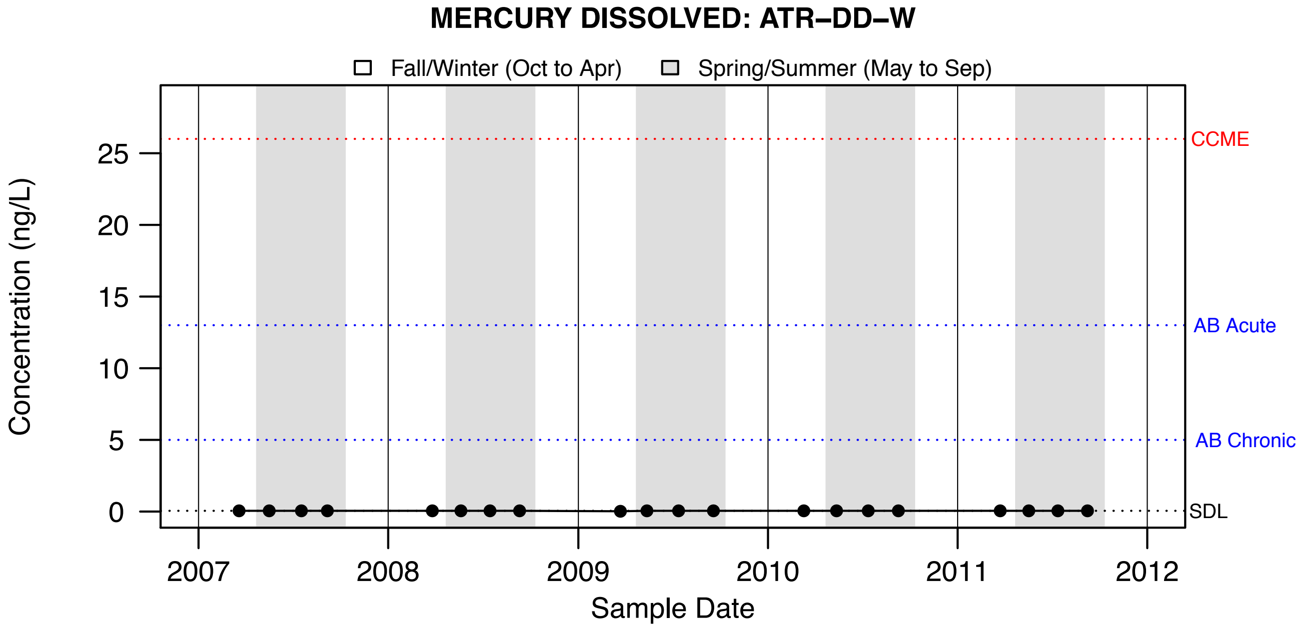


Figure A3.157: MERCURY DISSOLVED: ATR-DD-W -

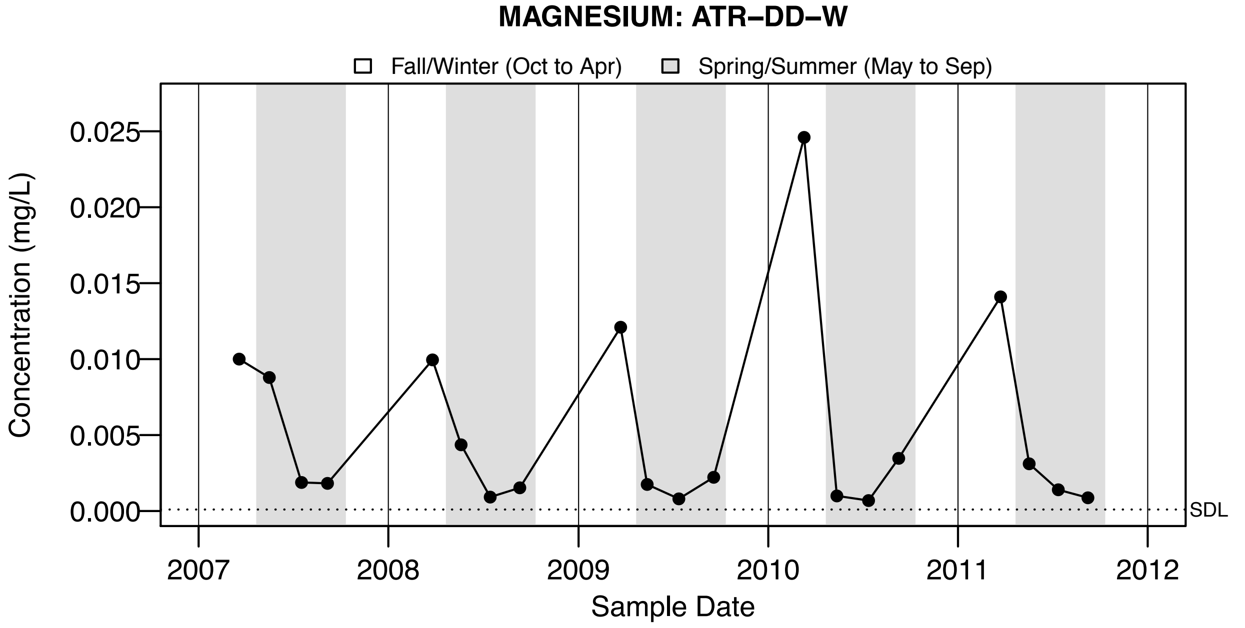


Figure A3.158: MAGNESIUM: ATR-DD-W -

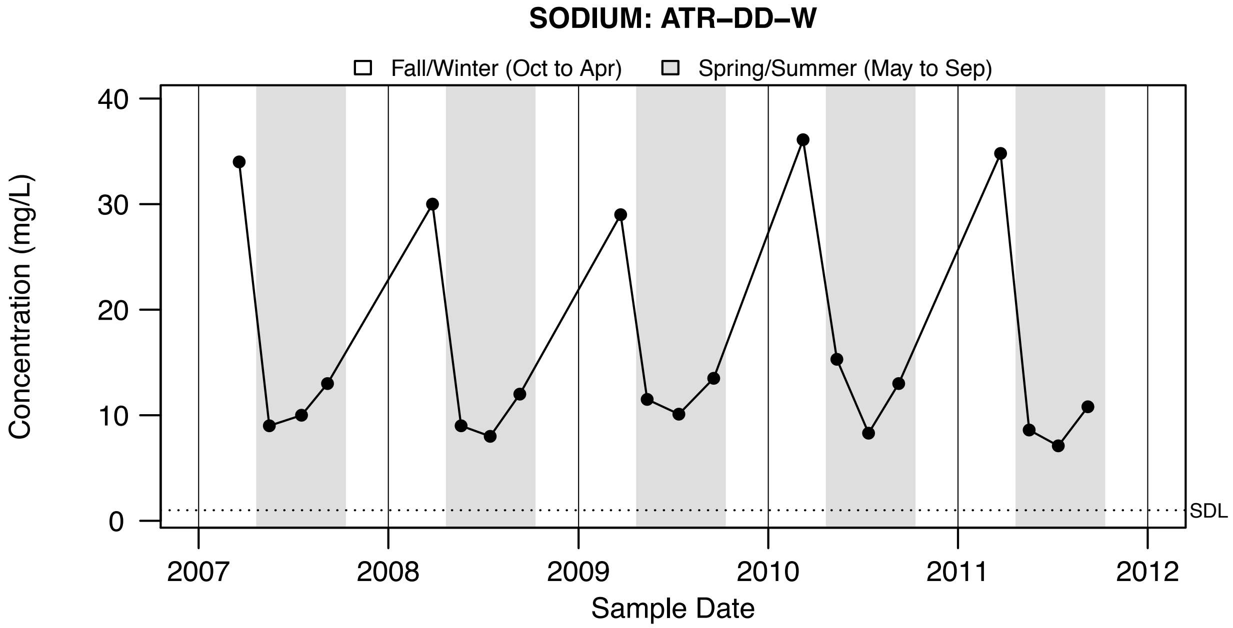
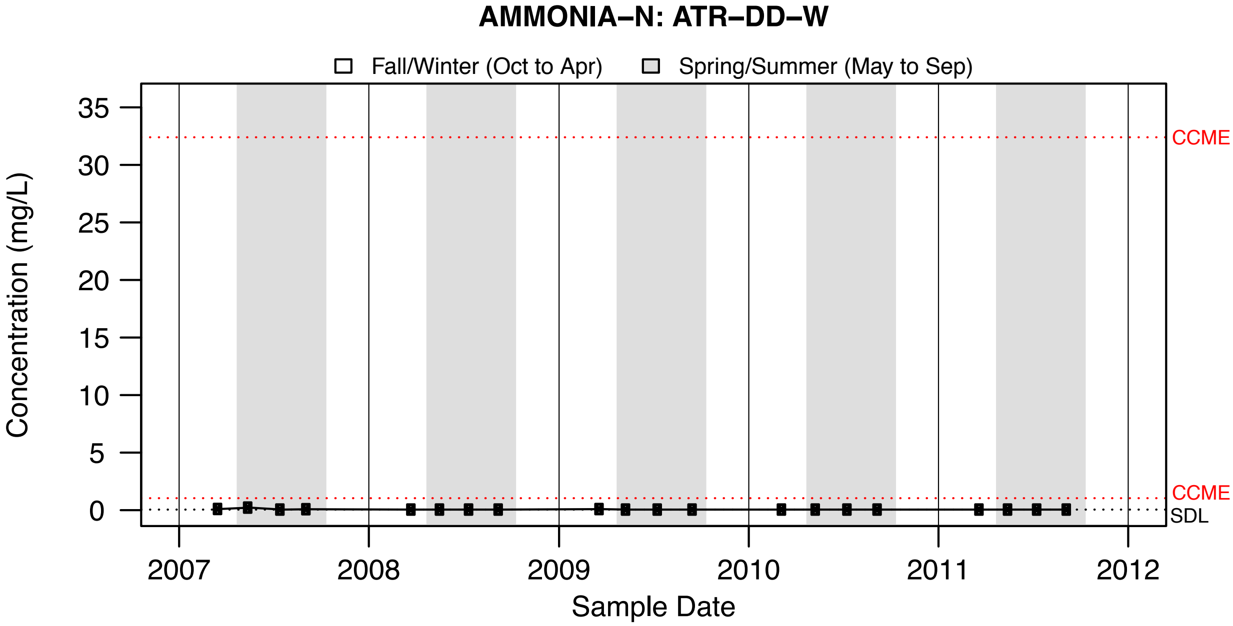
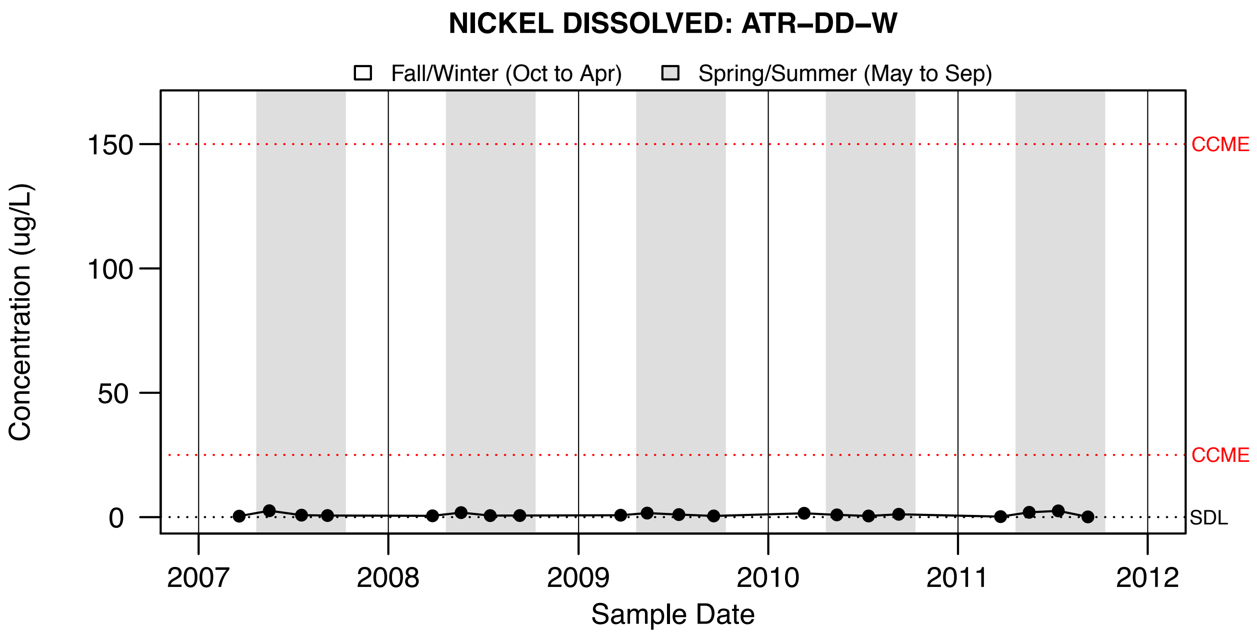


Figure A3.159: SODIUM: ATR-DD-W -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.160: AMMONIA-N: ATR-DD-W -



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A3.161: NICKEL DISSOLVED: ATR-DD-W -

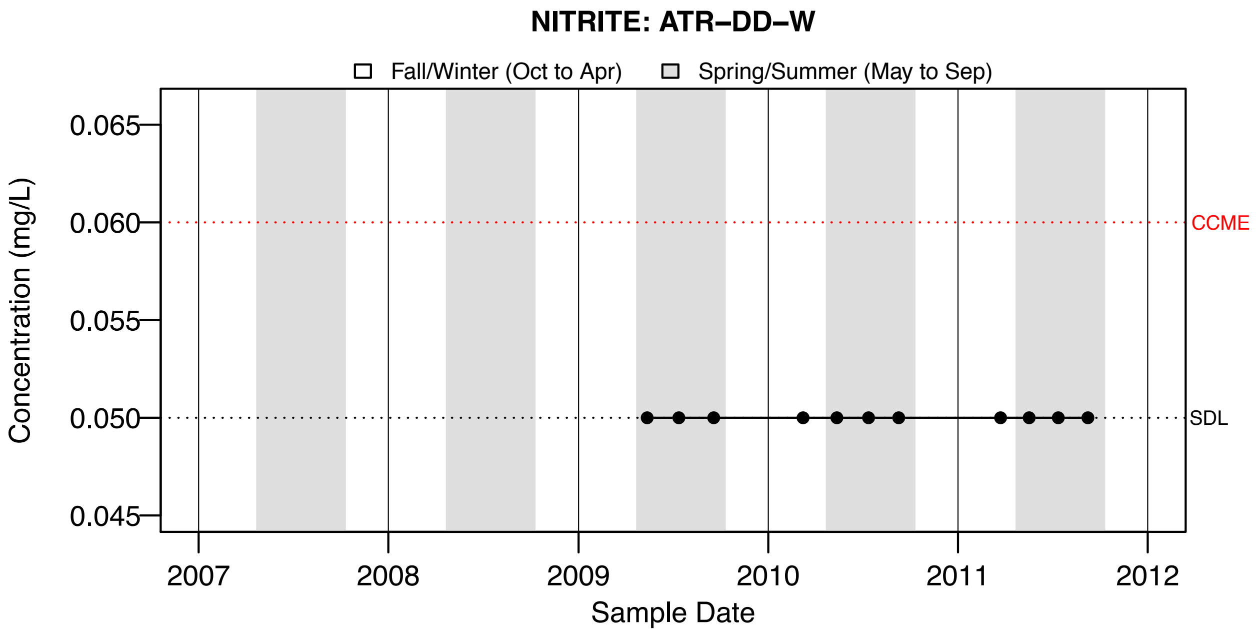
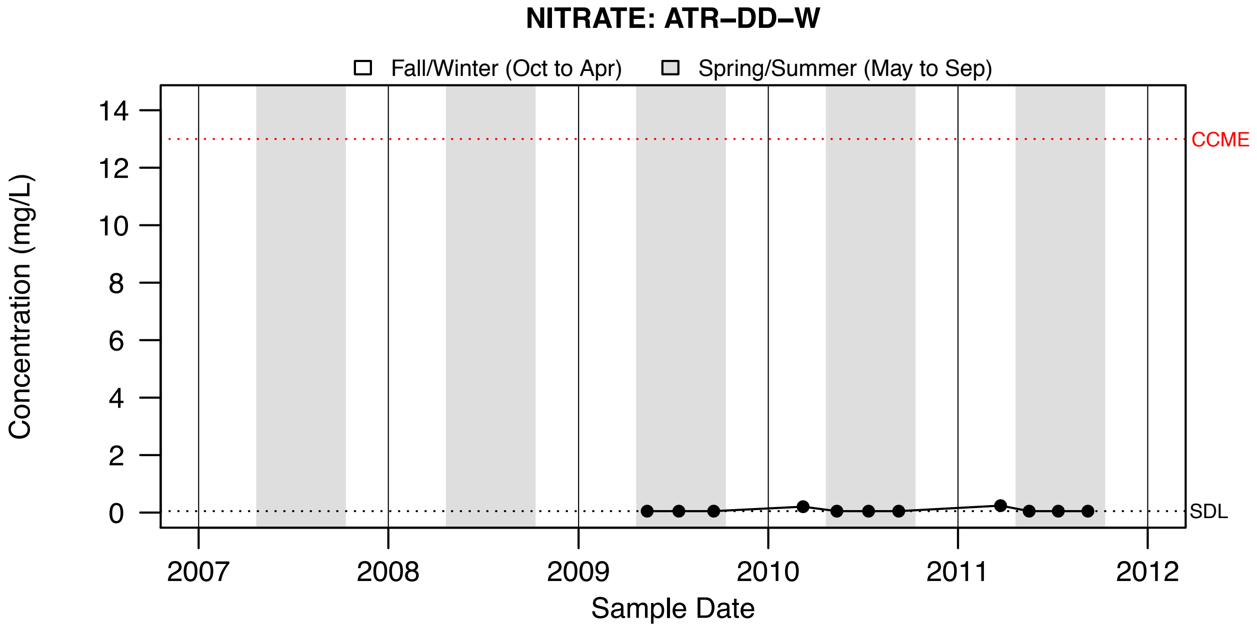


Figure A3.162: NITRITE: ATR-DD-W -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.163: NITRATE: ATR-DD-W -

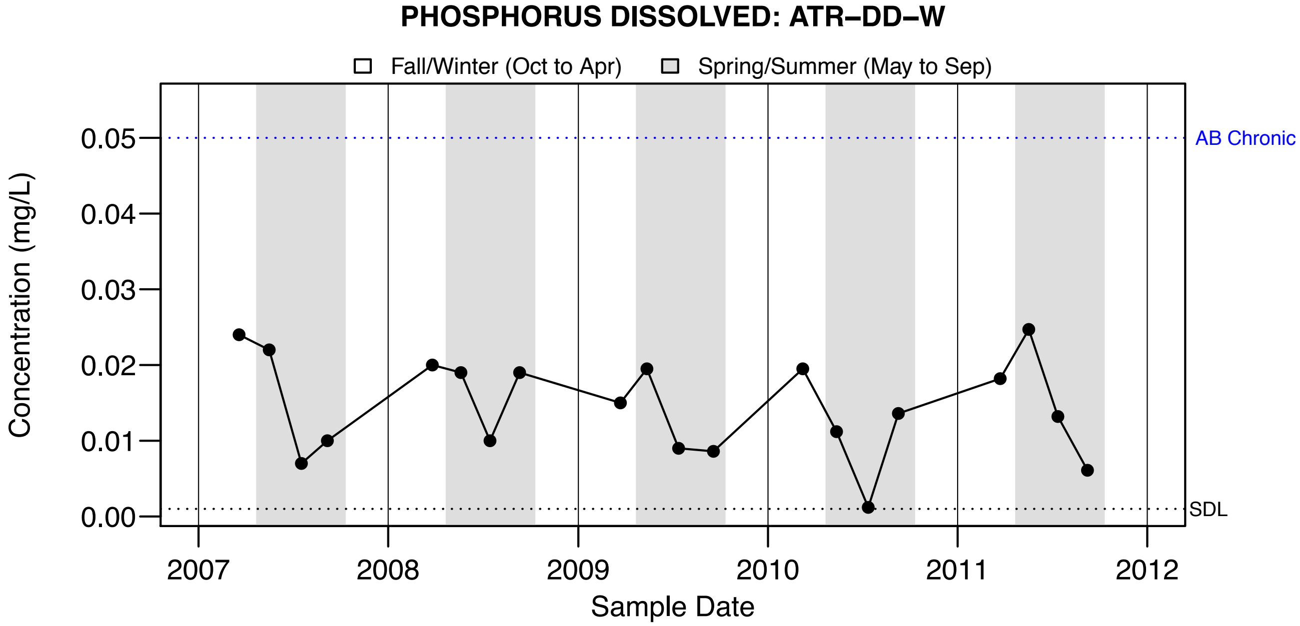


Figure A3.164: PHOSPHORUS DISSOLVED: ATR-DD-W -

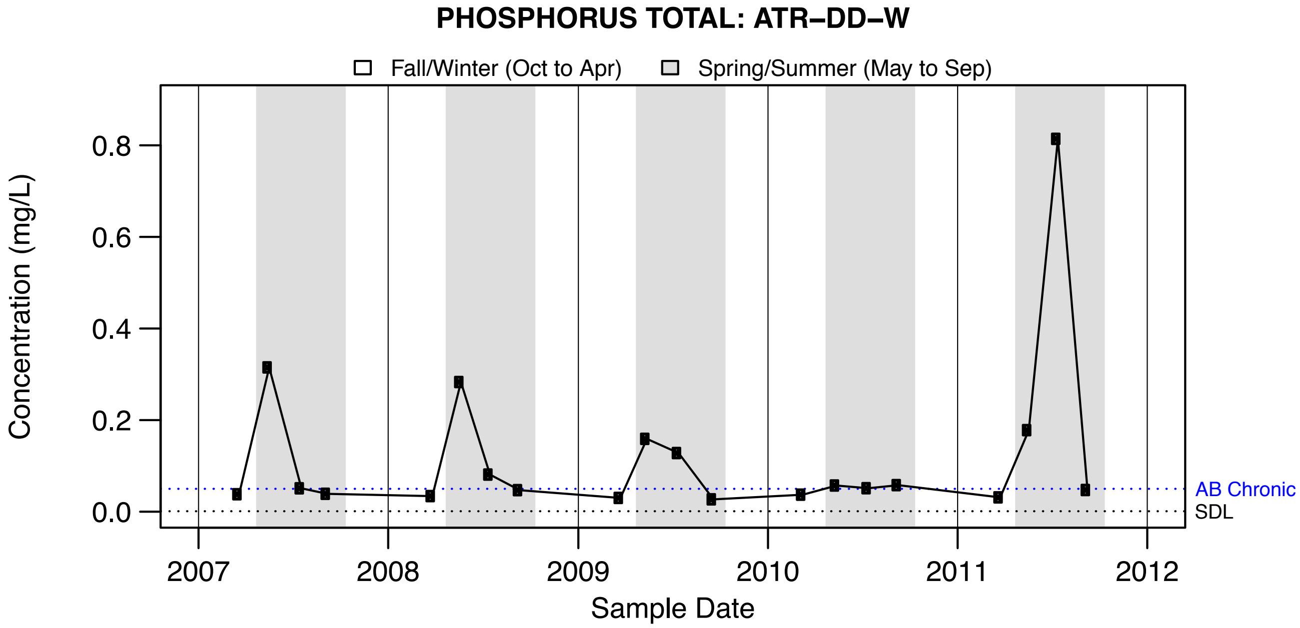
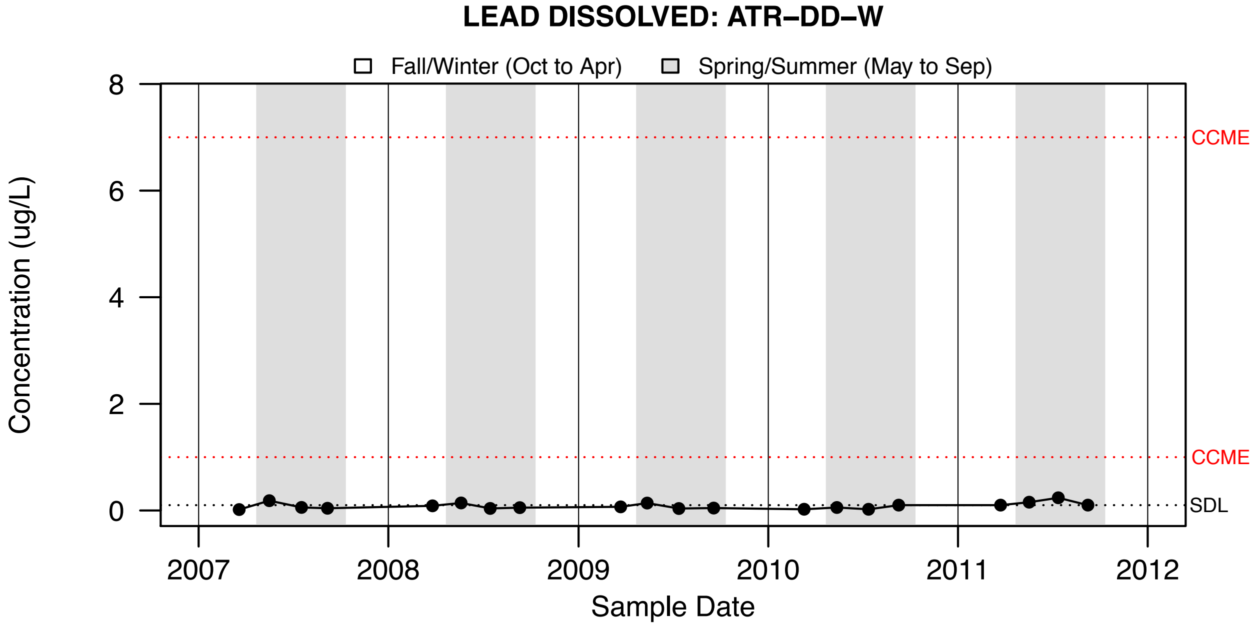


Figure A3.165: PHOSPHORUS TOTAL: ATR-DD-W -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.166: LEAD DISSOLVED: ATR-DD-W -

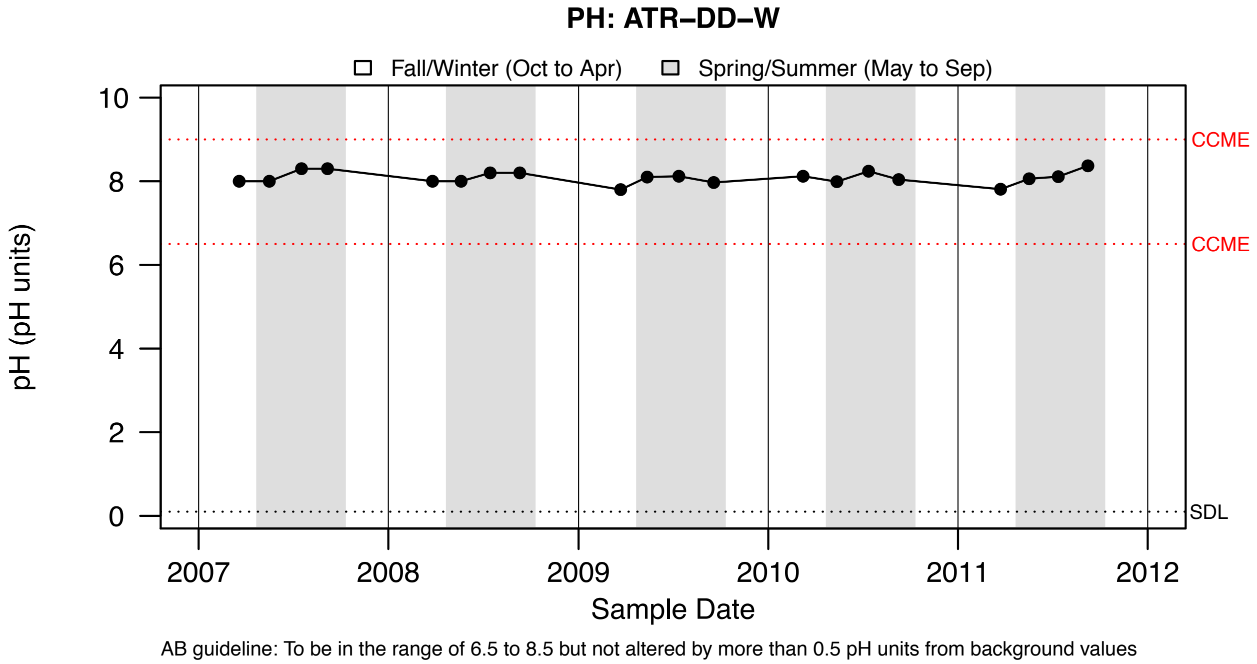


Figure A3.167: PH: ATR-DD-W -

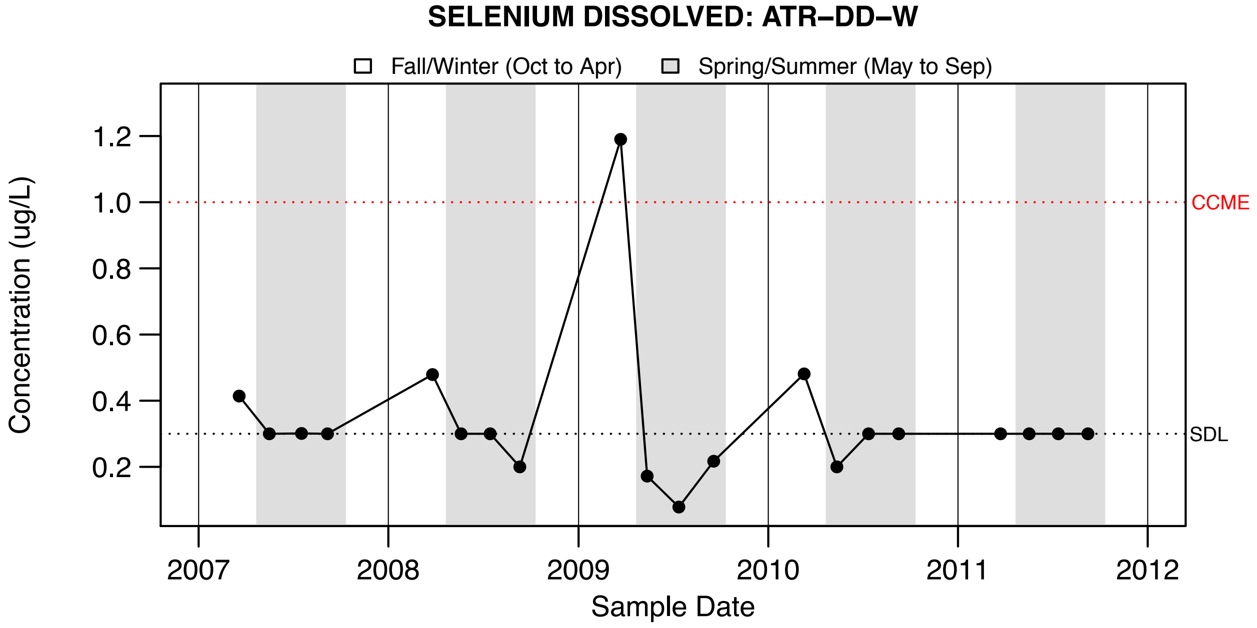


Figure A3.168: SELENIUM DISSOLVED: ATR-DD-W -

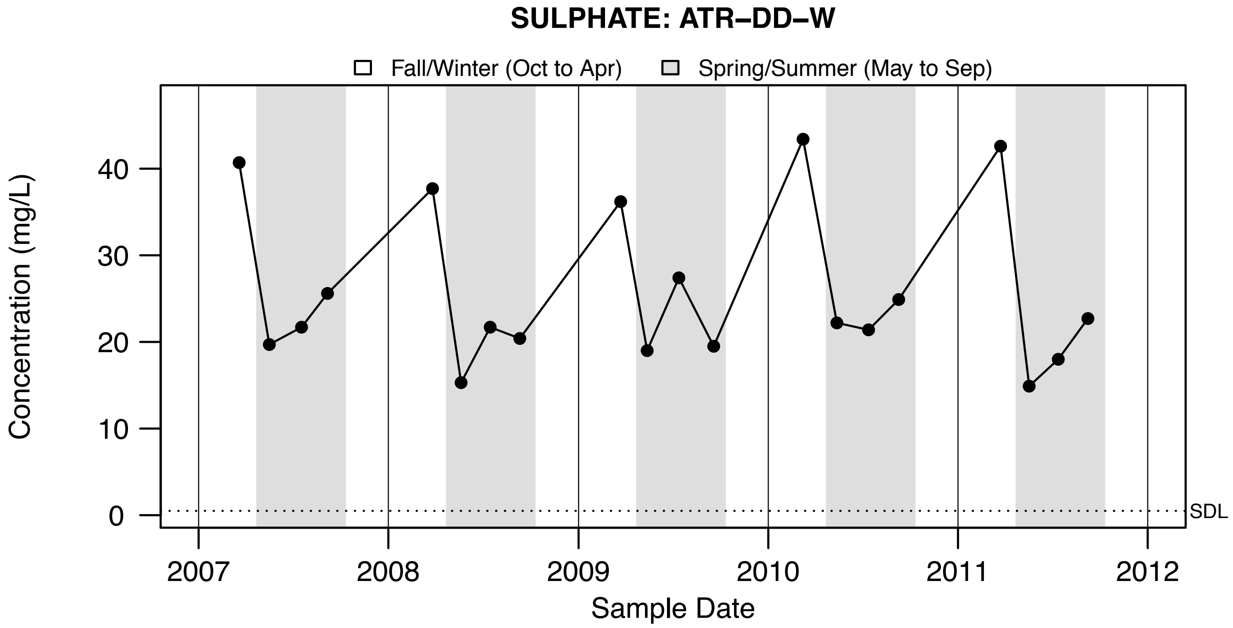


Figure A3.169: SULPHATE: ATR-DD-W -

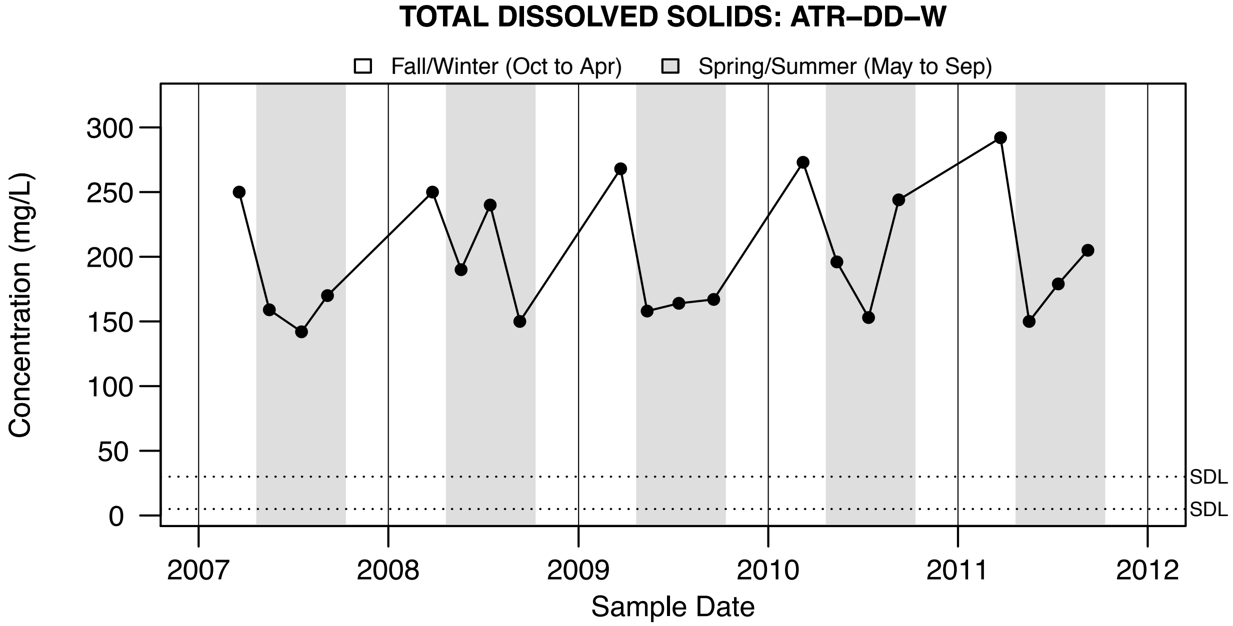
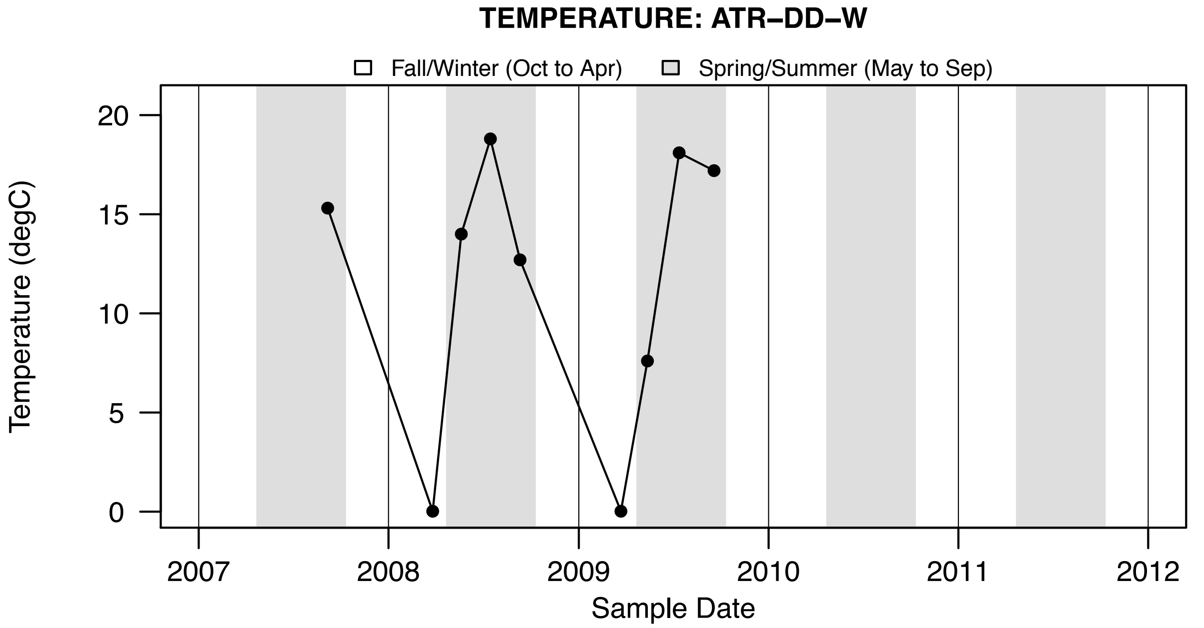


Figure A3.170: TOTAL DISSOLVED SOLIDS: ATR-DD-W -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.171: TEMPERATURE: ATR-DD-W -

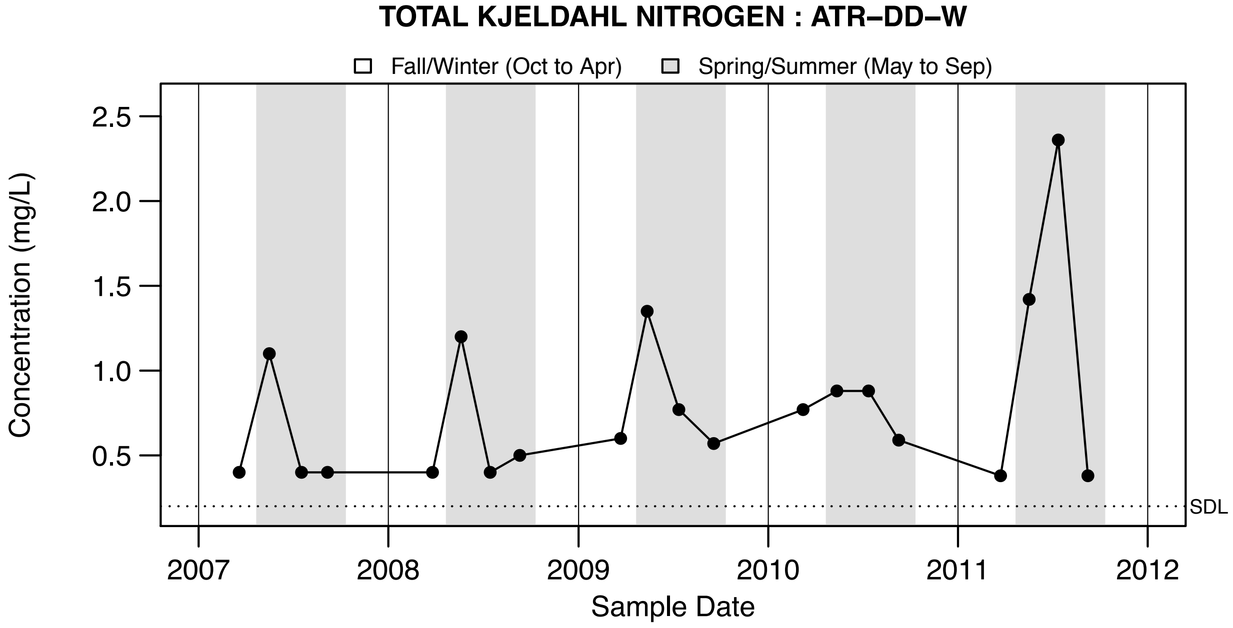
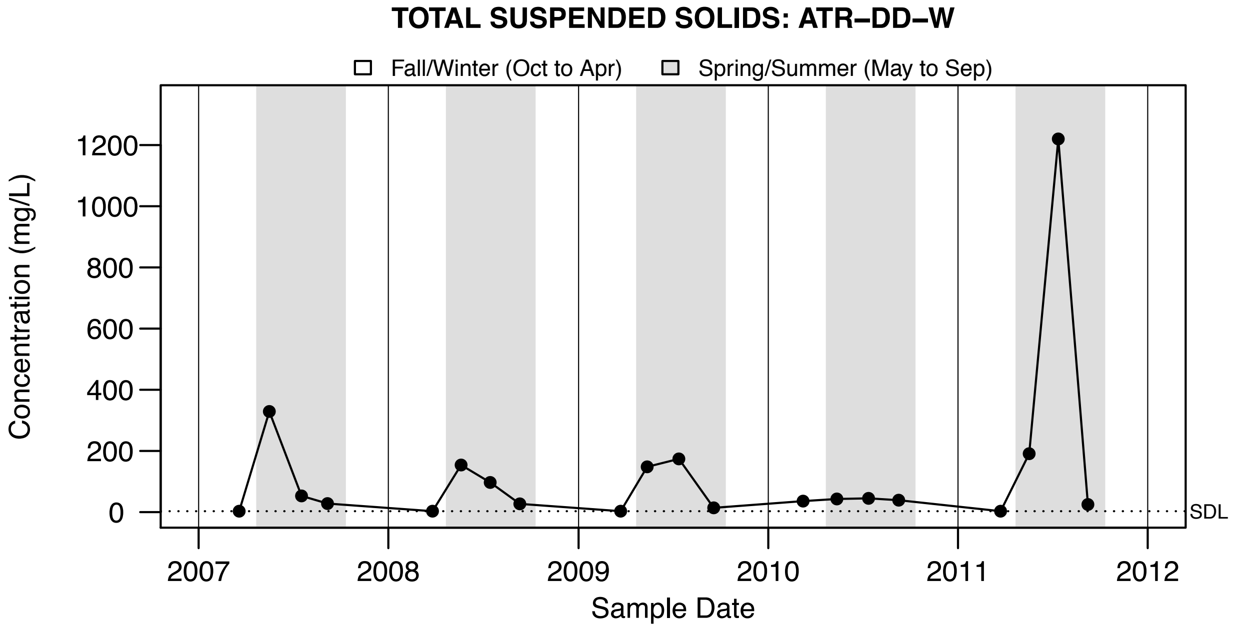


Figure A3.172: TOTAL KJELDAHL NITROGEN : ATR-DD-W -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.173: TOTAL SUSPENDED SOLIDS: ATR-DD-W -

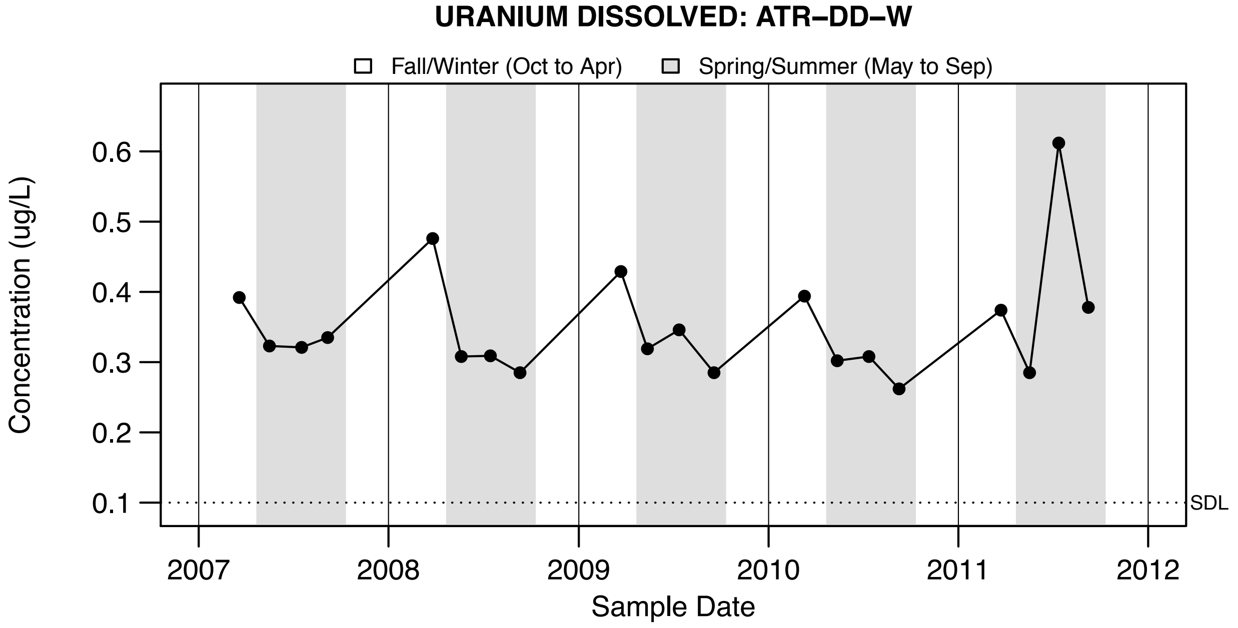


Figure A3.174: URANIUM DISSOLVED: ATR-DD-W -

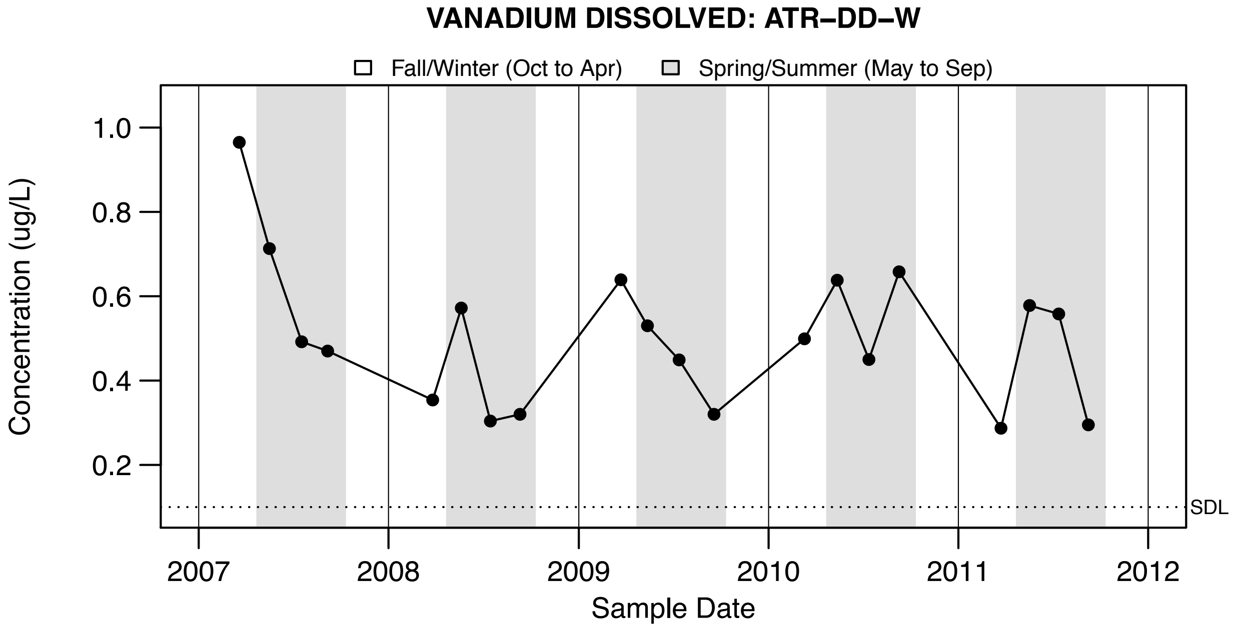


Figure A3.175: VANADIUM DISSOLVED: ATR-DD-W -

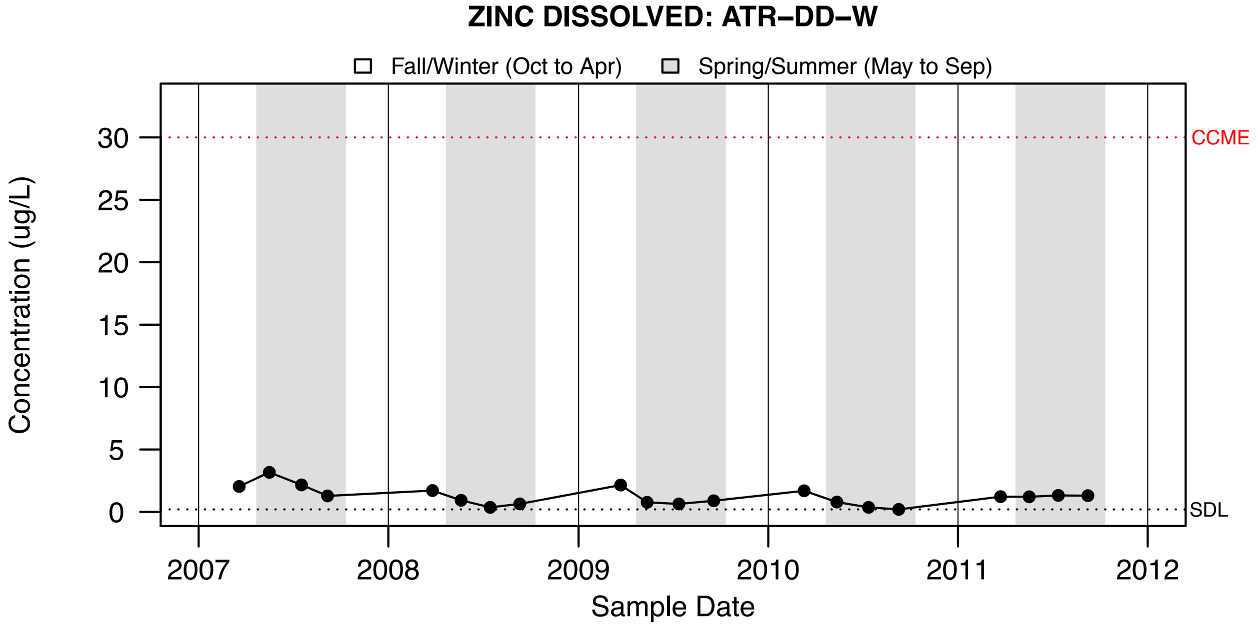
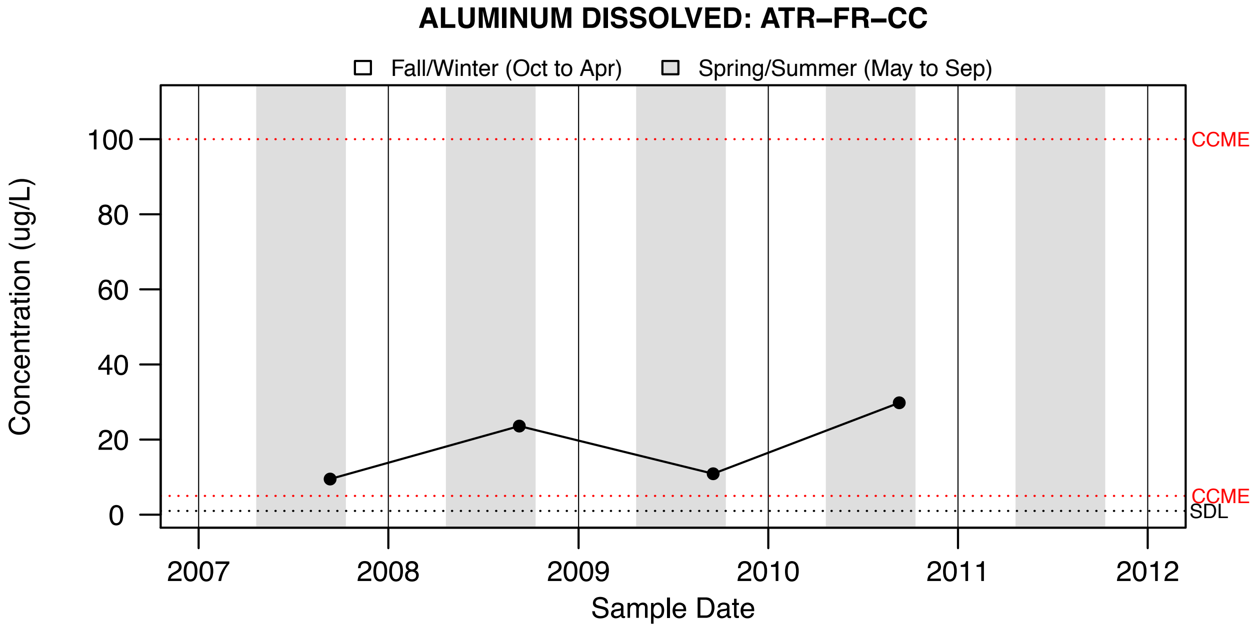
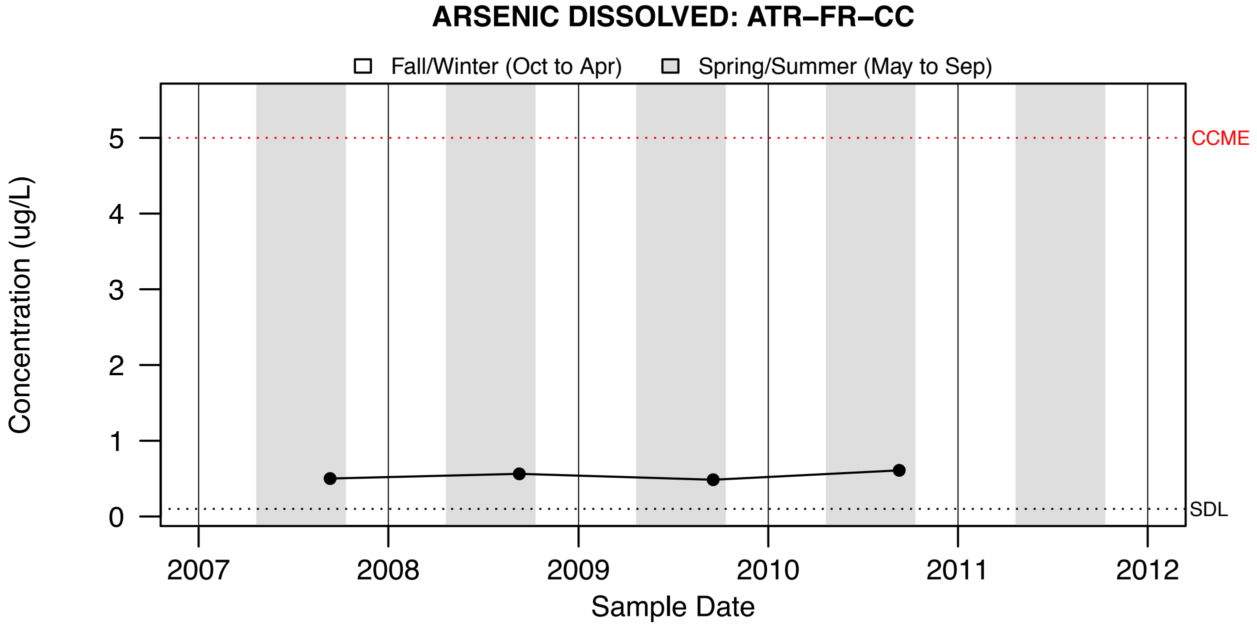


Figure A3.176: ZINC DISSOLVED: ATR-DD-W -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.177: ALUMINUM DISSOLVED: ATR-FR-CC -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.178: ARSENIC DISSOLVED: ATR-FR-CC -

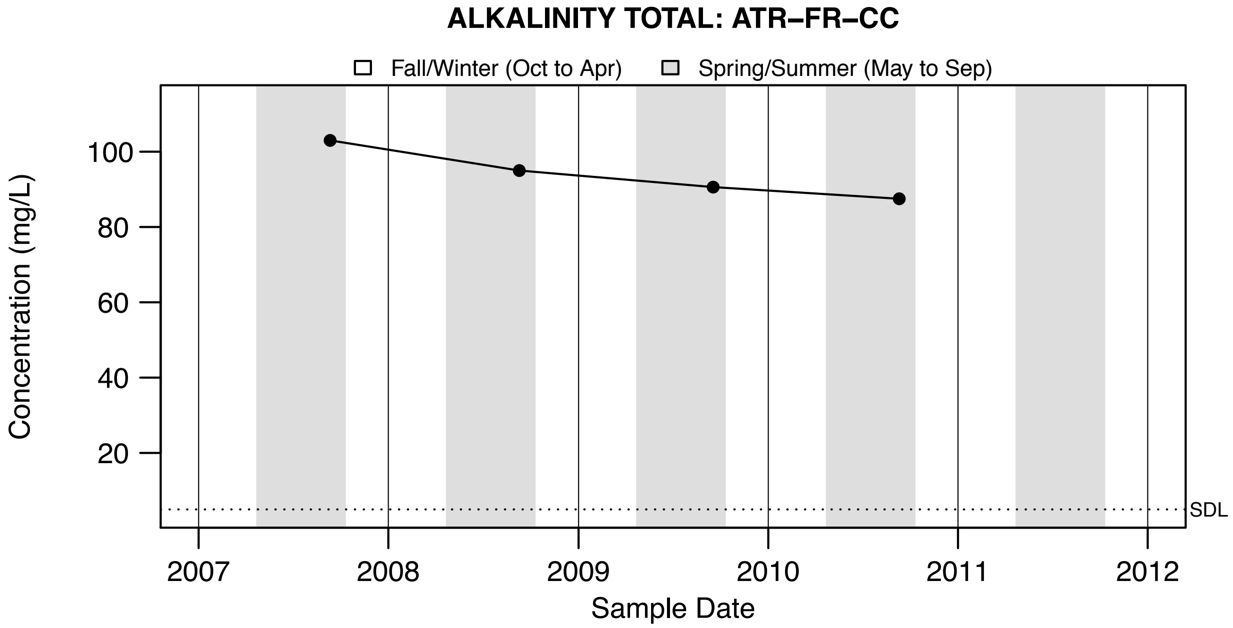


Figure A3.179: ALKALINITY TOTAL: ATR-FR-CC -

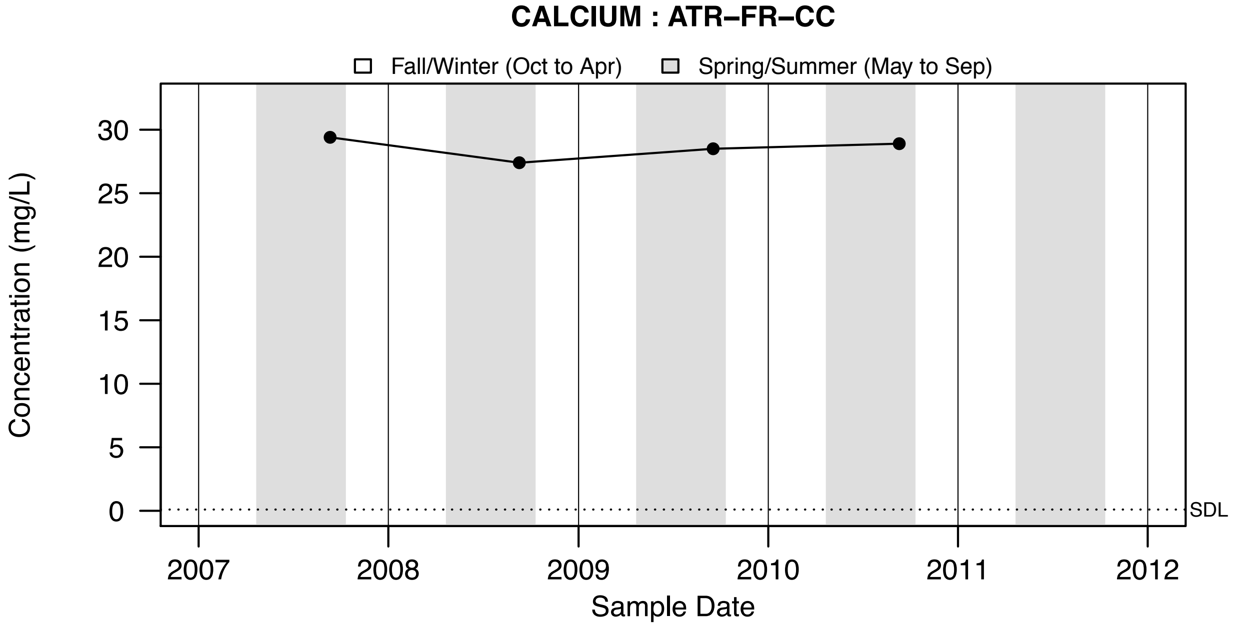


Figure A3.180: CALCIUM : ATR-FR-CC -

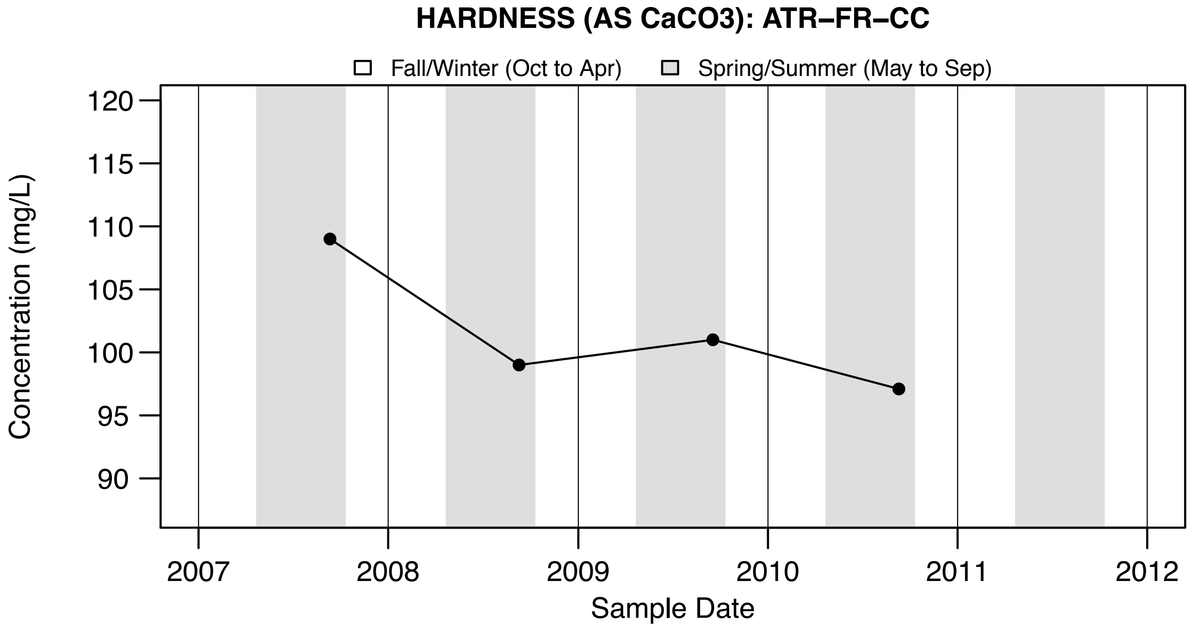
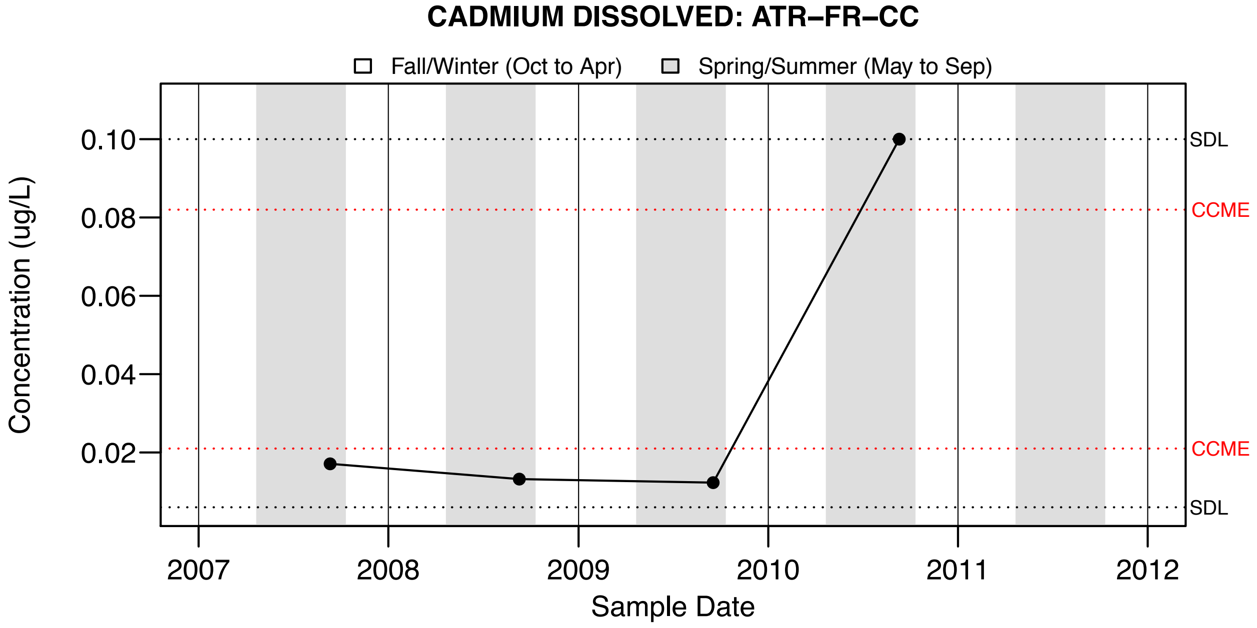


Figure A3.181: HARDNESS (AS CaCO3): ATR-FR-CC -



Related to hardness as CaCo3

Figure A3.182: CADMIUM DISSOLVED: ATR-FR-CC -

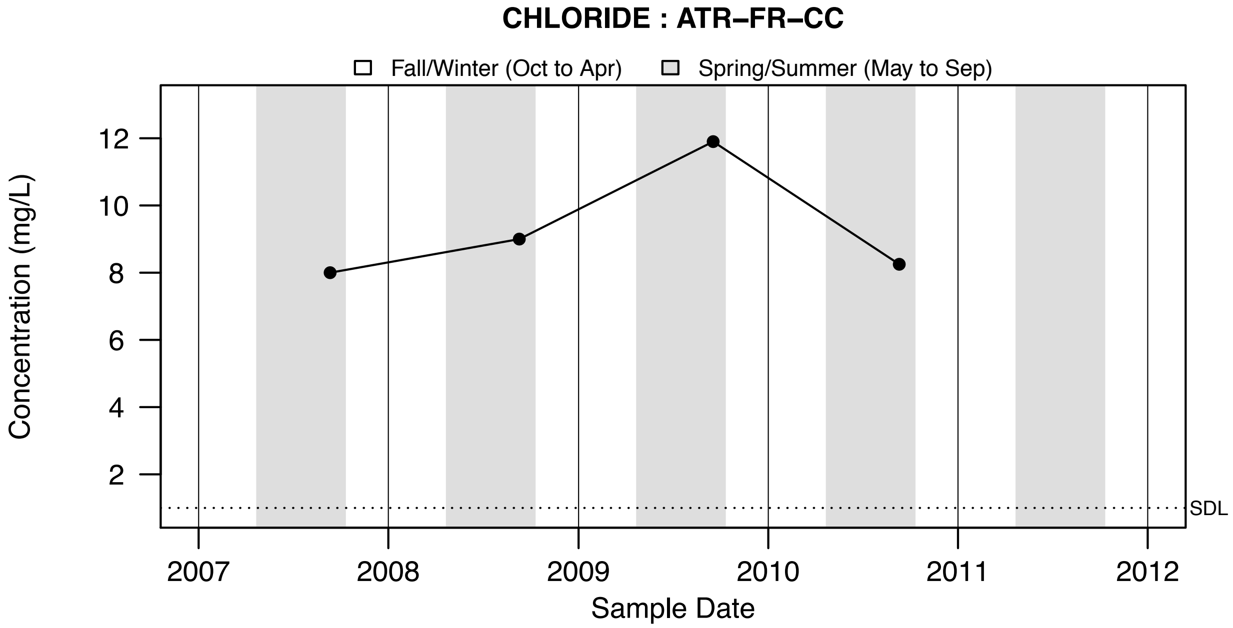


Figure A3.183: CHLORIDE : ATR-FR-CC -

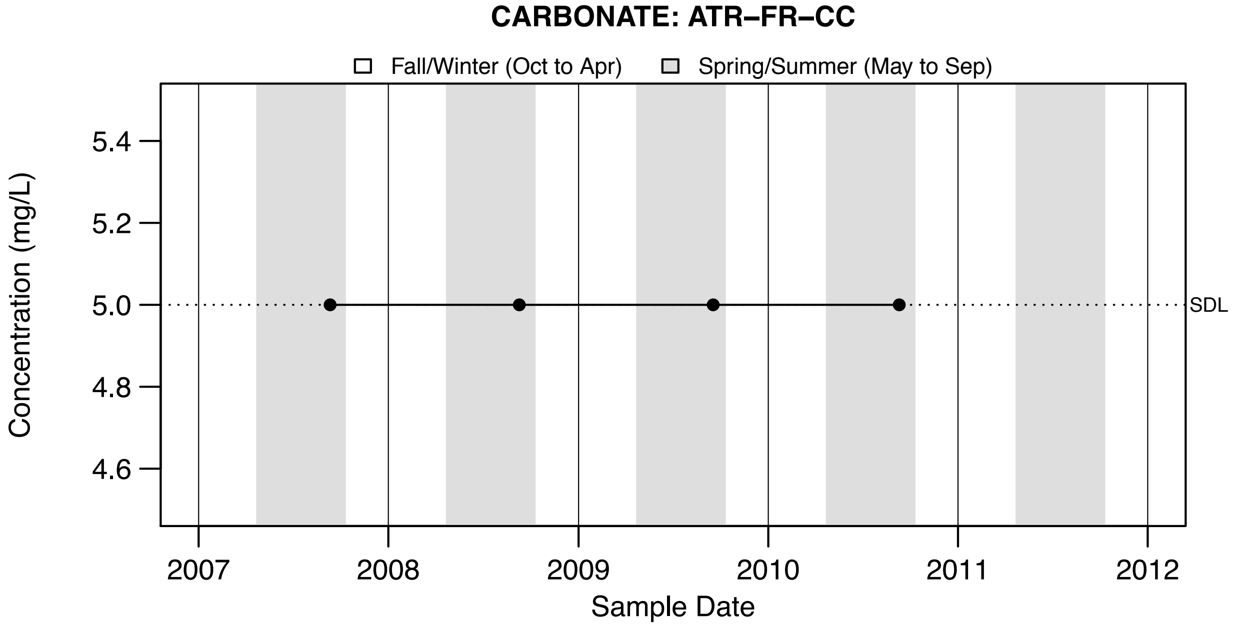


Figure A3.184: CARBONATE: ATR-FR-CC -

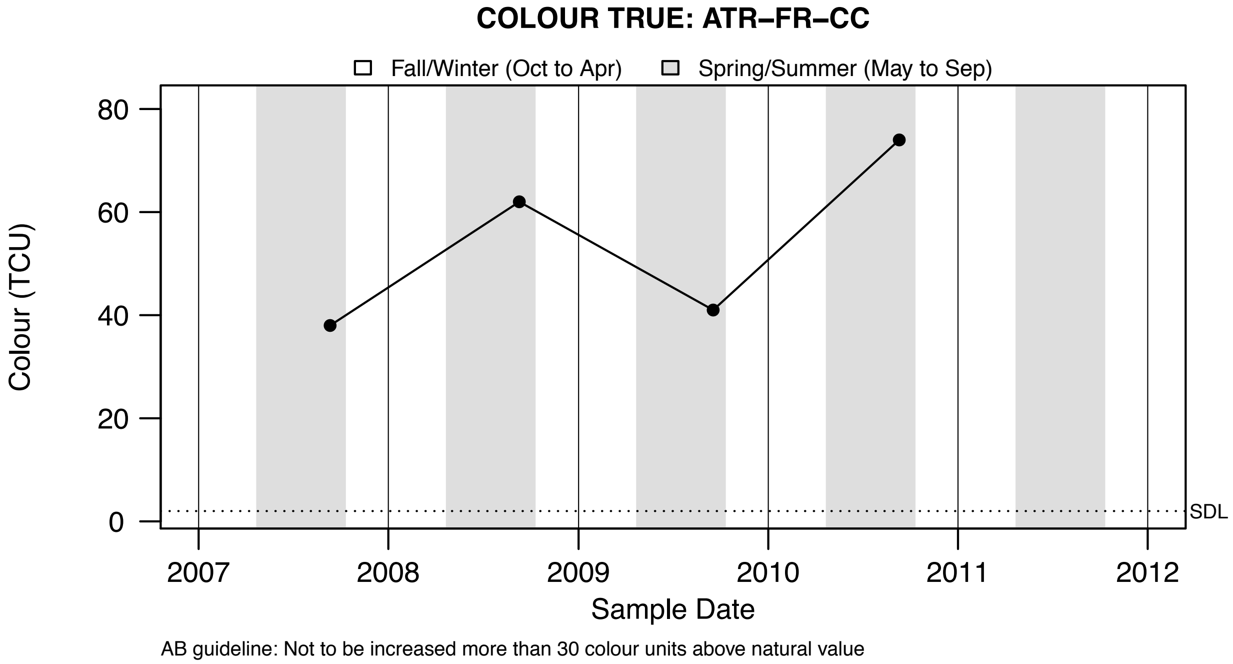


Figure A3.185: COLOUR TRUE: ATR-FR-CC -

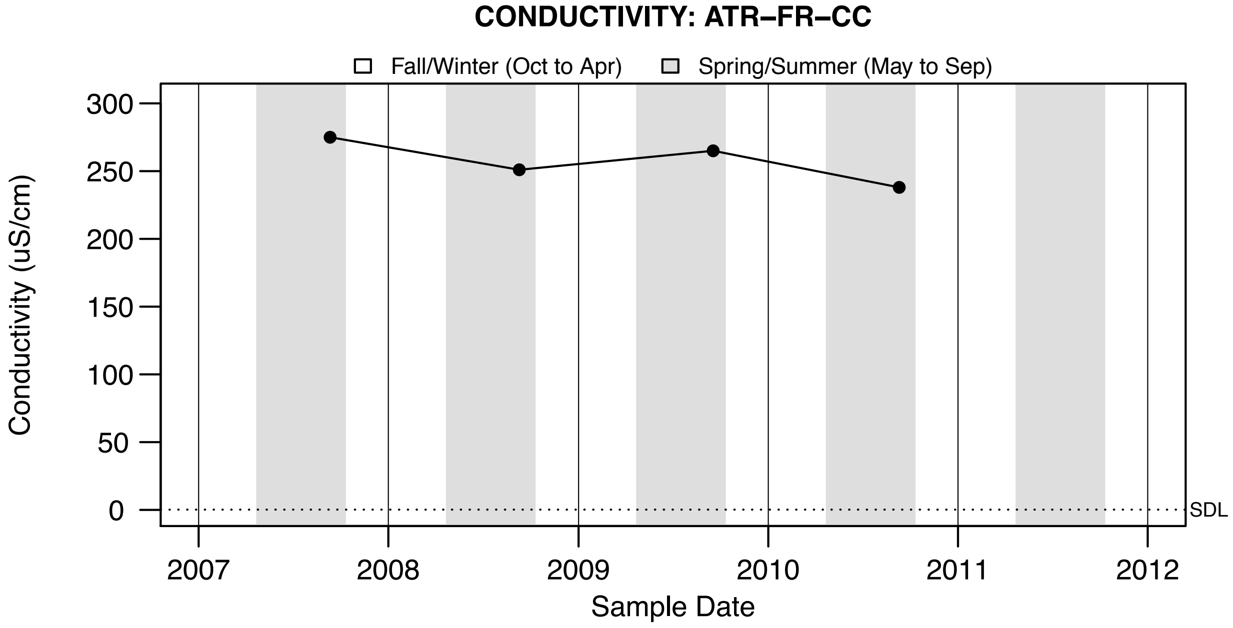
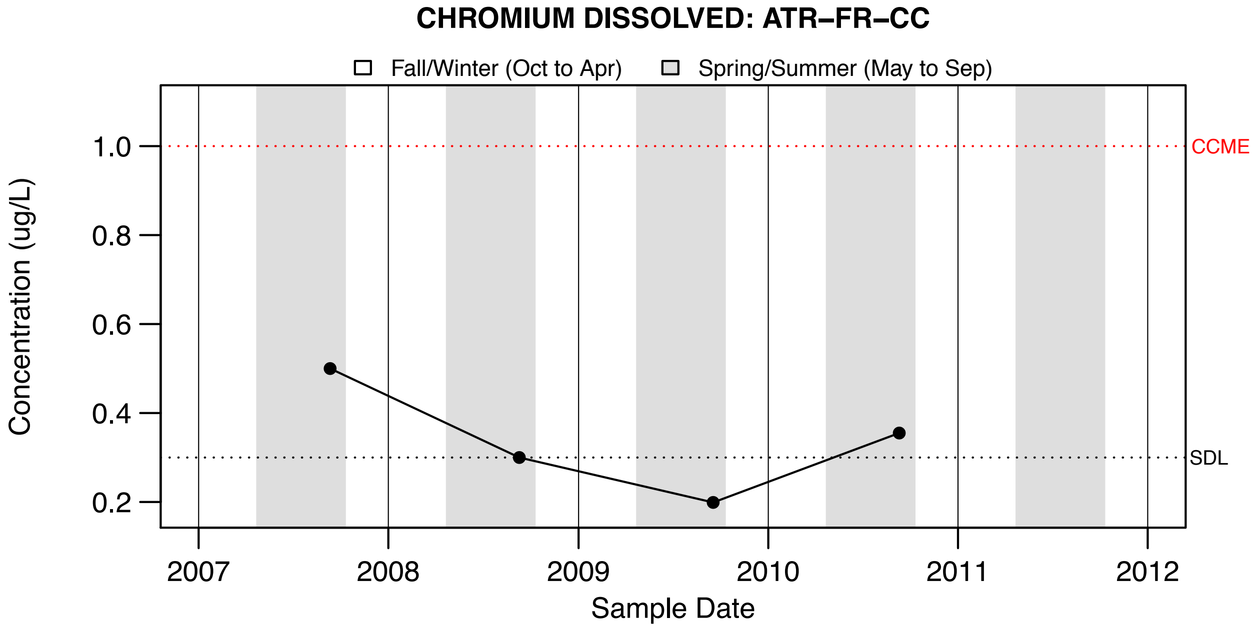
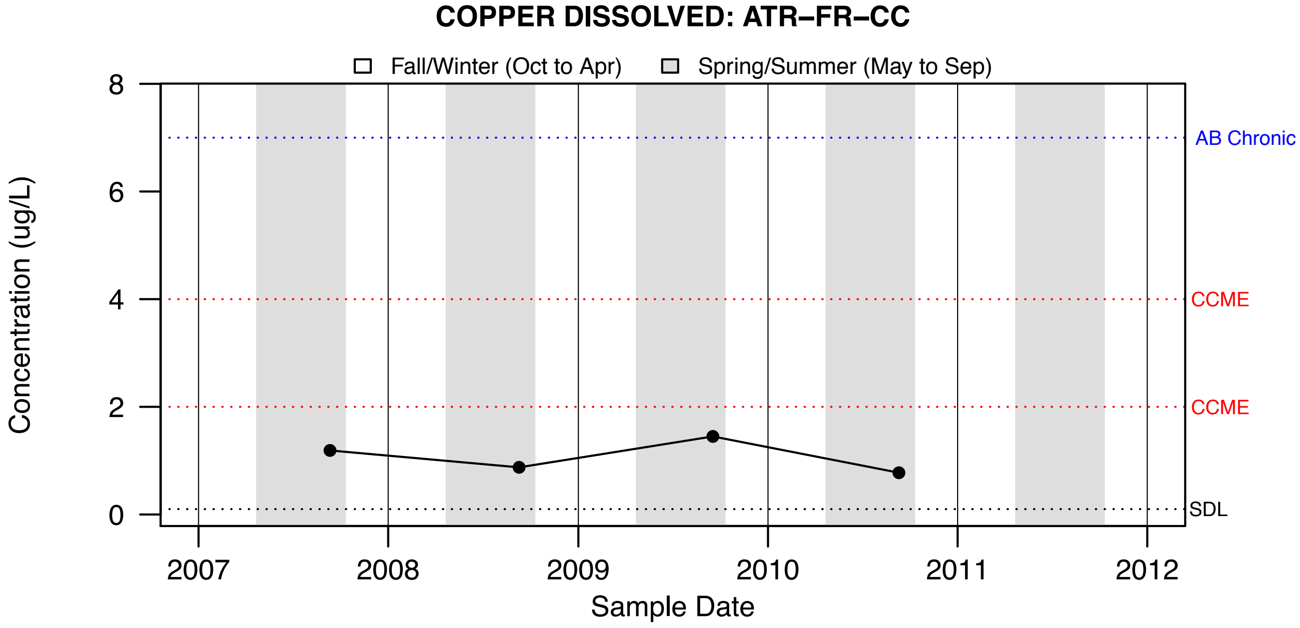


Figure A3.186: CONDUCTIVITY: ATR-FR-CC -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.187: CHROMIUM DISSOLVED: ATR-FR-CC -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.188: COPPER DISSOLVED: ATR-FR-CC -

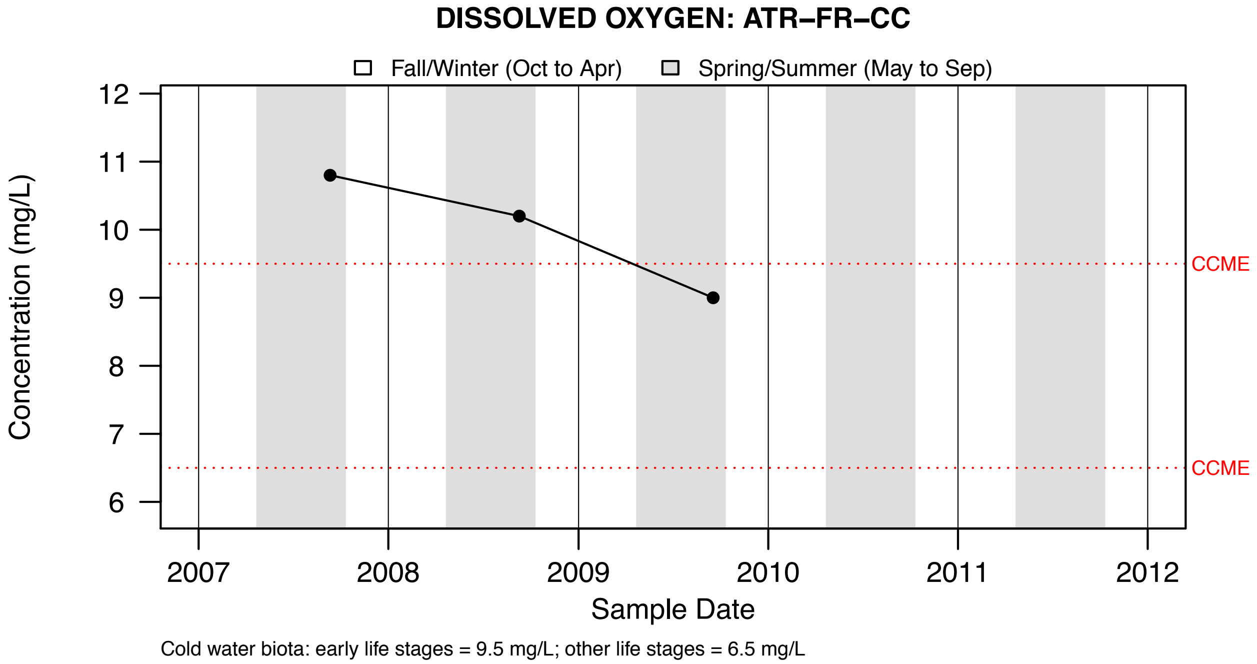


Figure A3.189: DISSOLVED OXYGEN: ATR-FR-CC -

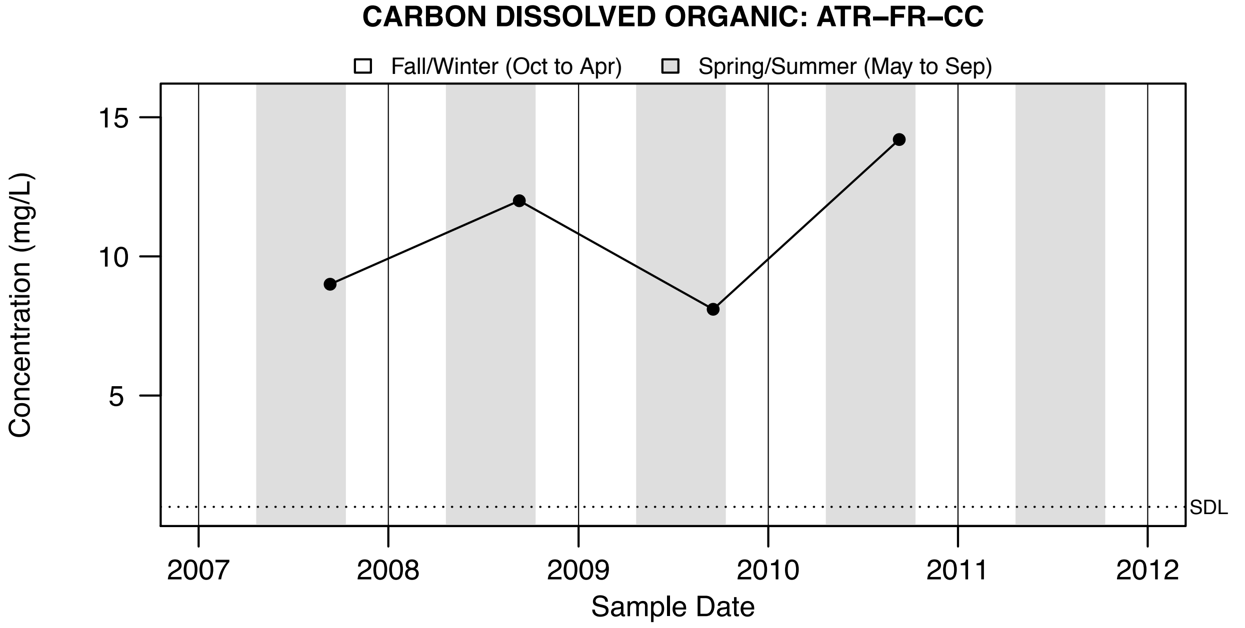


Figure A3.190: CARBON DISSOLVED ORGANIC: ATR-FR-CC -

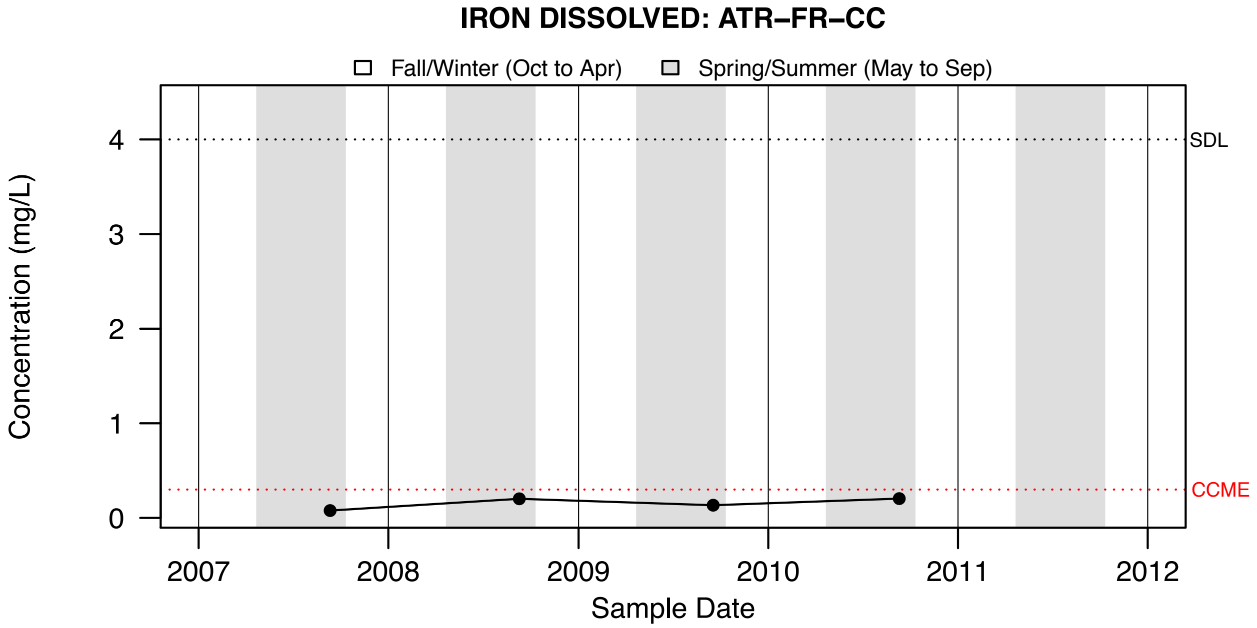


Figure A3.191: IRON DISSOLVED: ATR-FR-CC -

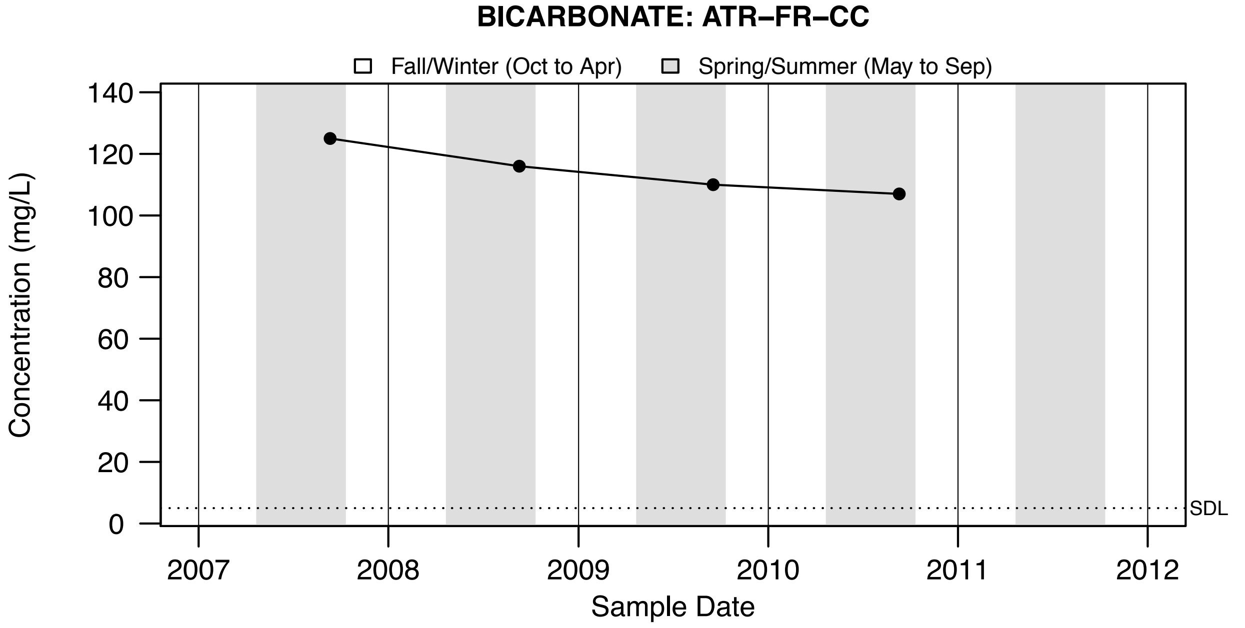


Figure A3.192: BICARBONATE: ATR-FR-CC -

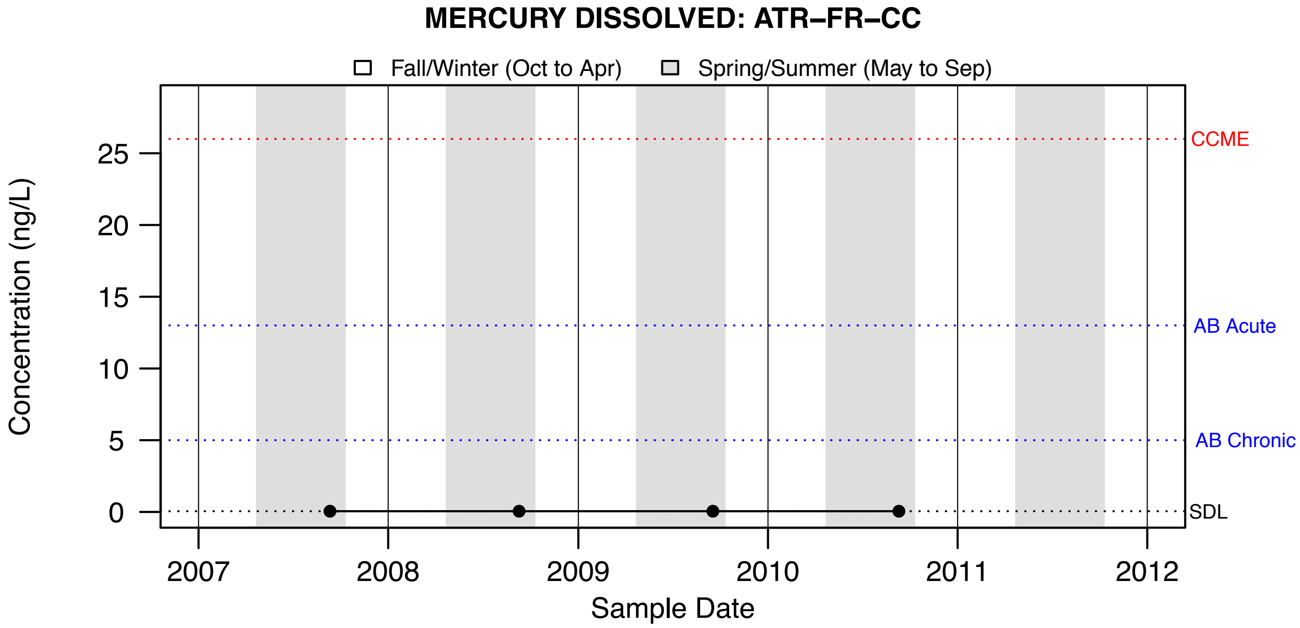


Figure A3.193: MERCURY DISSOLVED: ATR-FR-CC -

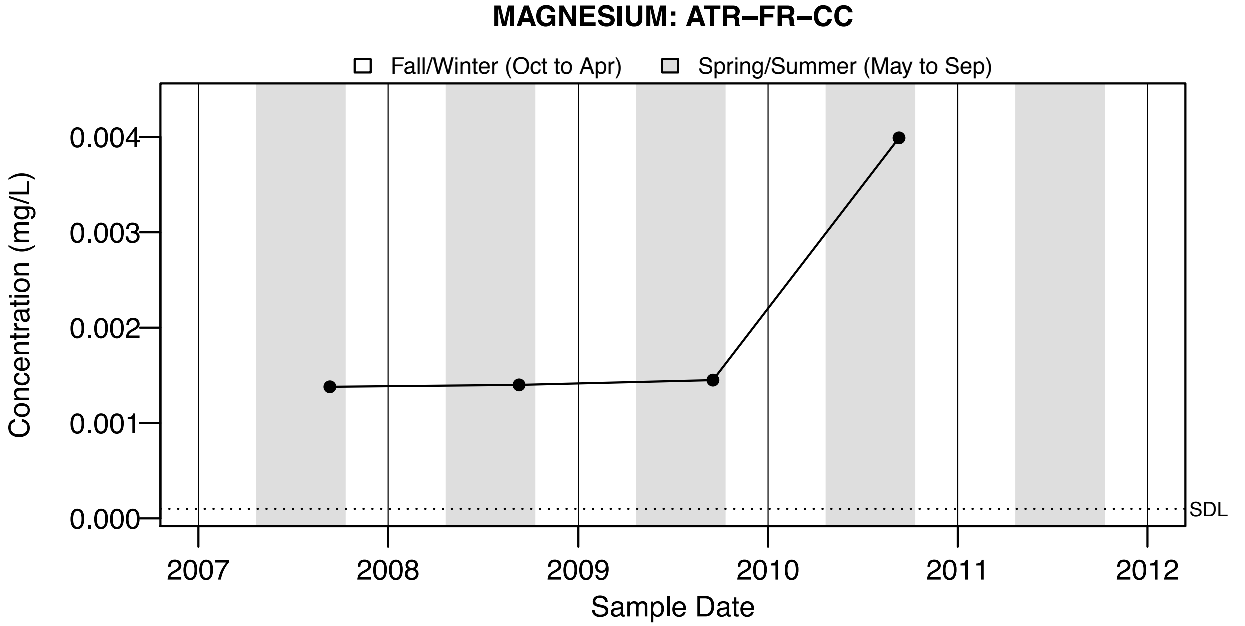


Figure A3.194: MAGNESIUM: ATR-FR-CC -

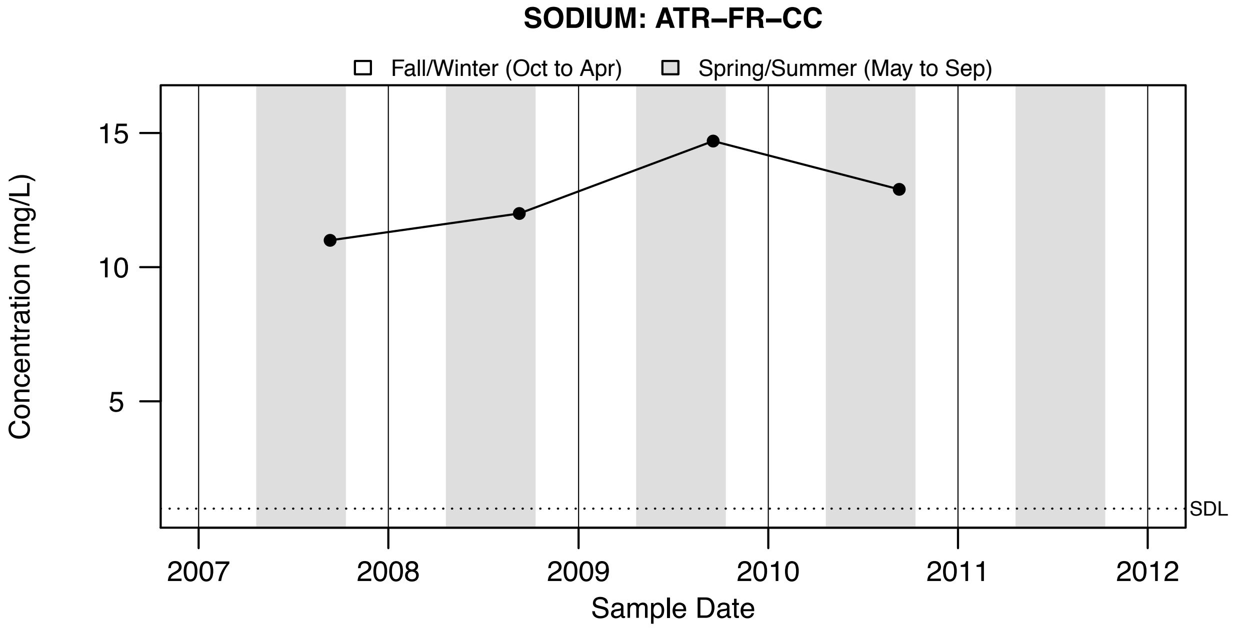


Figure A3.195: SODIUM: ATR-FR-CC -

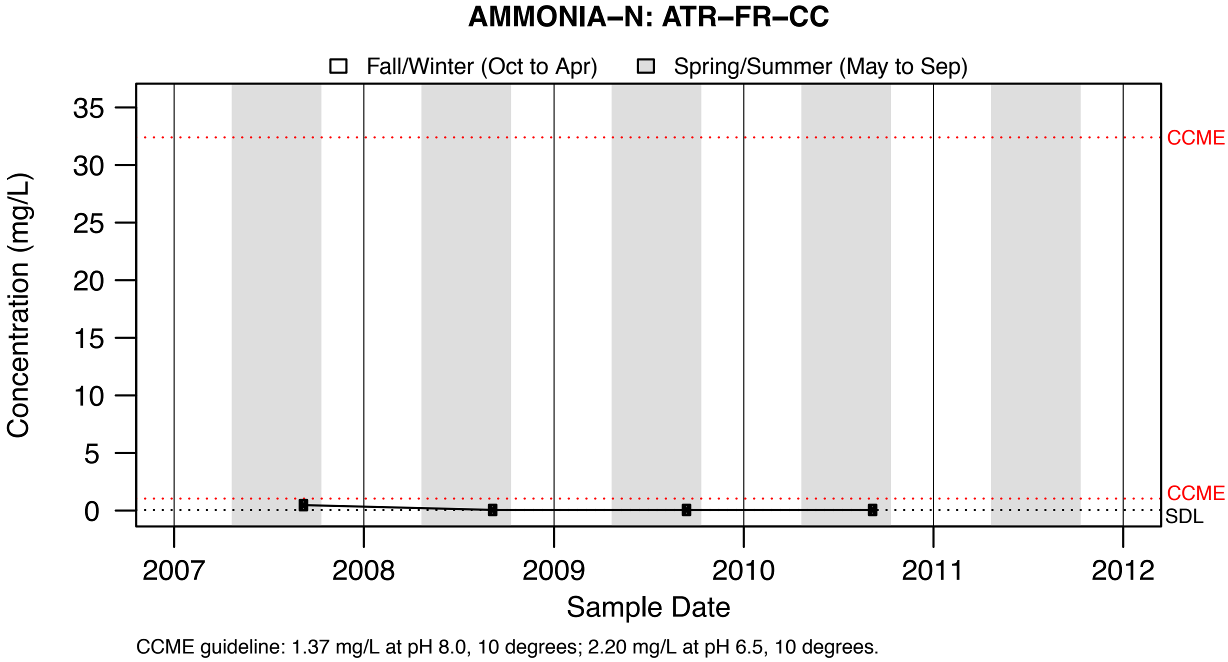
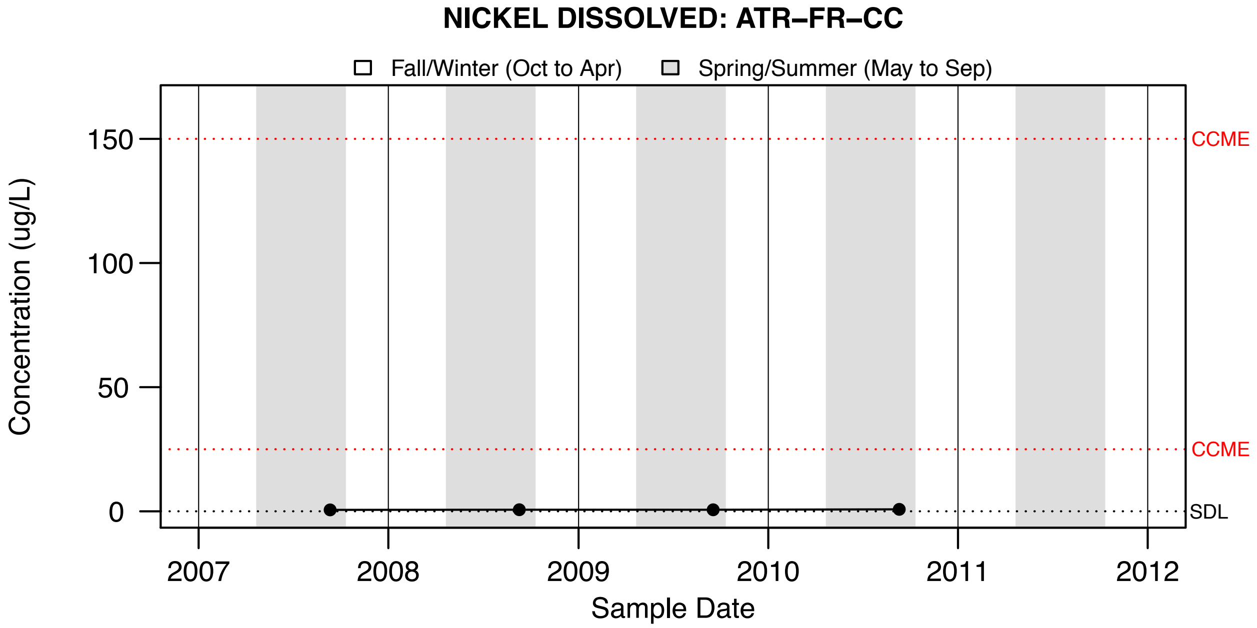


Figure A3.196: AMMONIA-N: ATR-FR-CC -



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A3.197: NICKEL DISSOLVED: ATR-FR-CC -

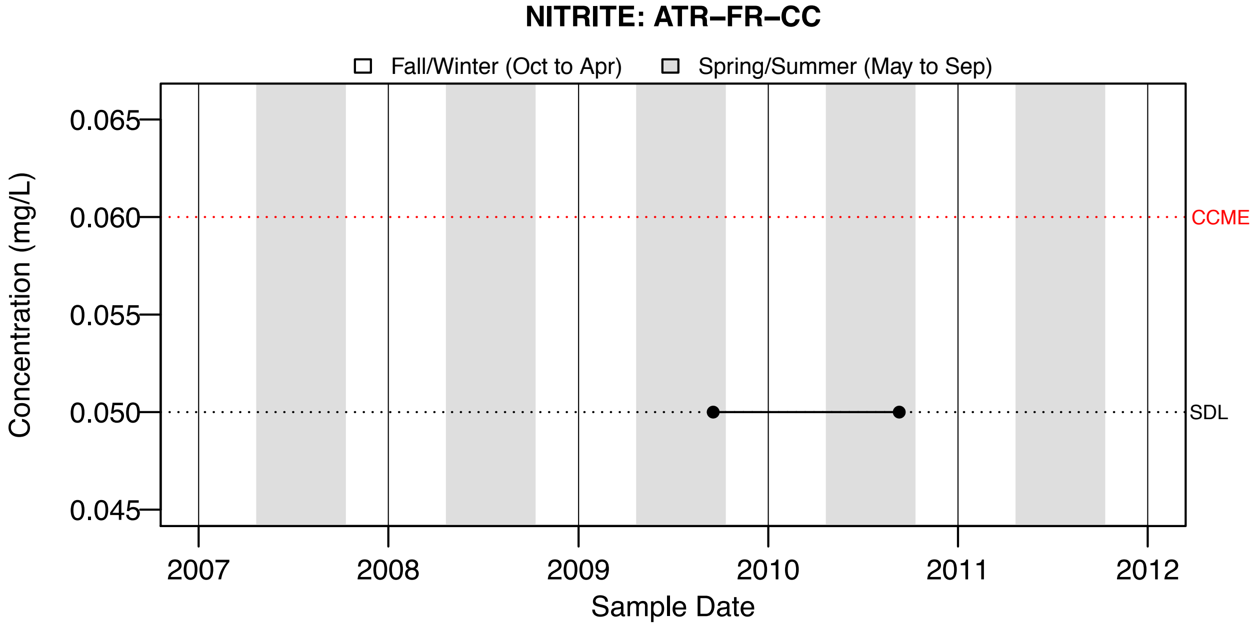
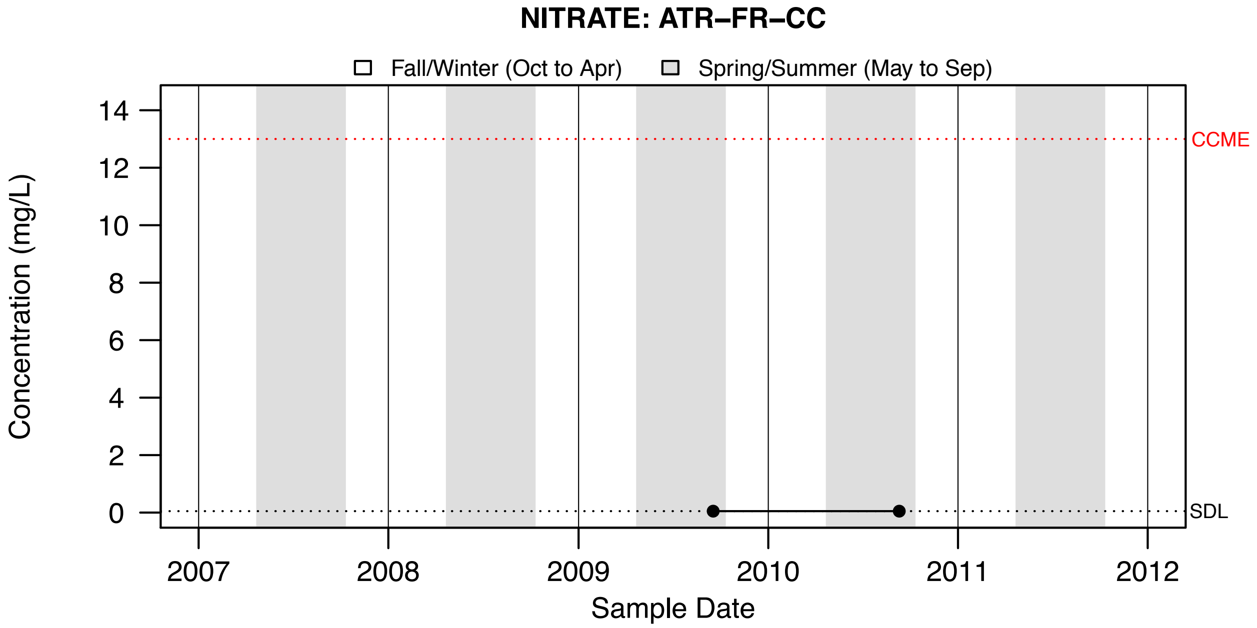


Figure A3.198: NITRITE: ATR-FR-CC -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.199: NITRATE: ATR-FR-CC -

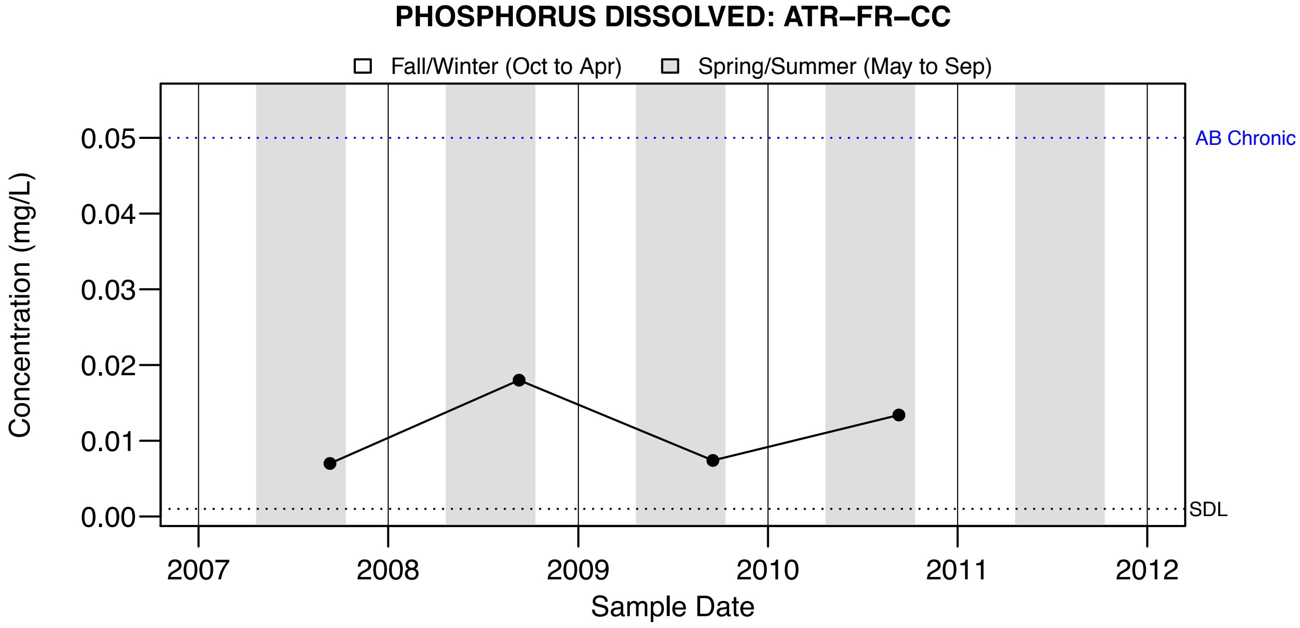


Figure A3.200: PHOSPHORUS DISSOLVED: ATR-FR-CC -

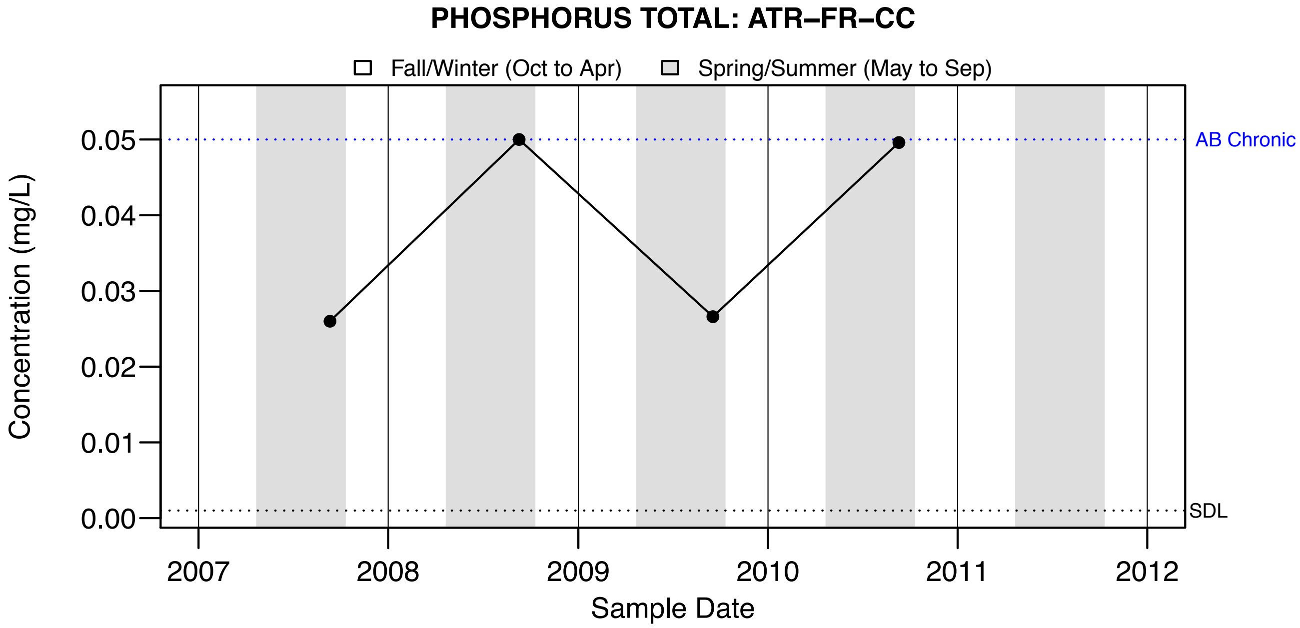
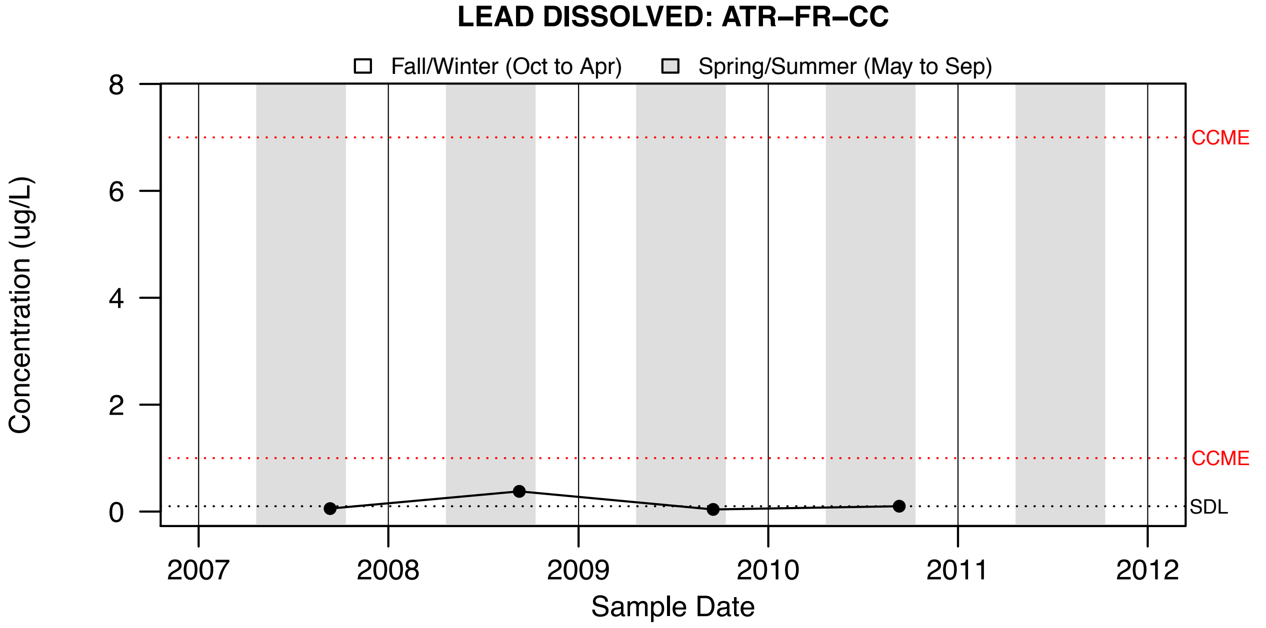


Figure A3.201: PHOSPHORUS TOTAL: ATR-FR-CC -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.202: LEAD DISSOLVED: ATR-FR-CC -

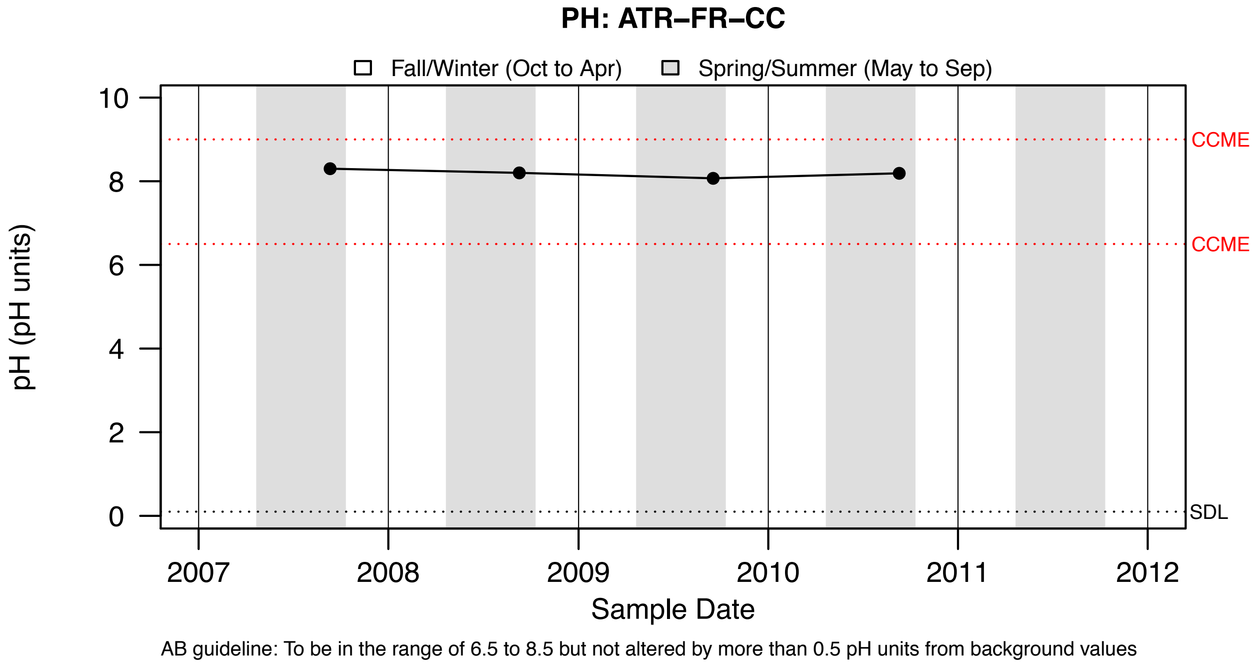


Figure A3.203: PH: ATR-FR-CC -

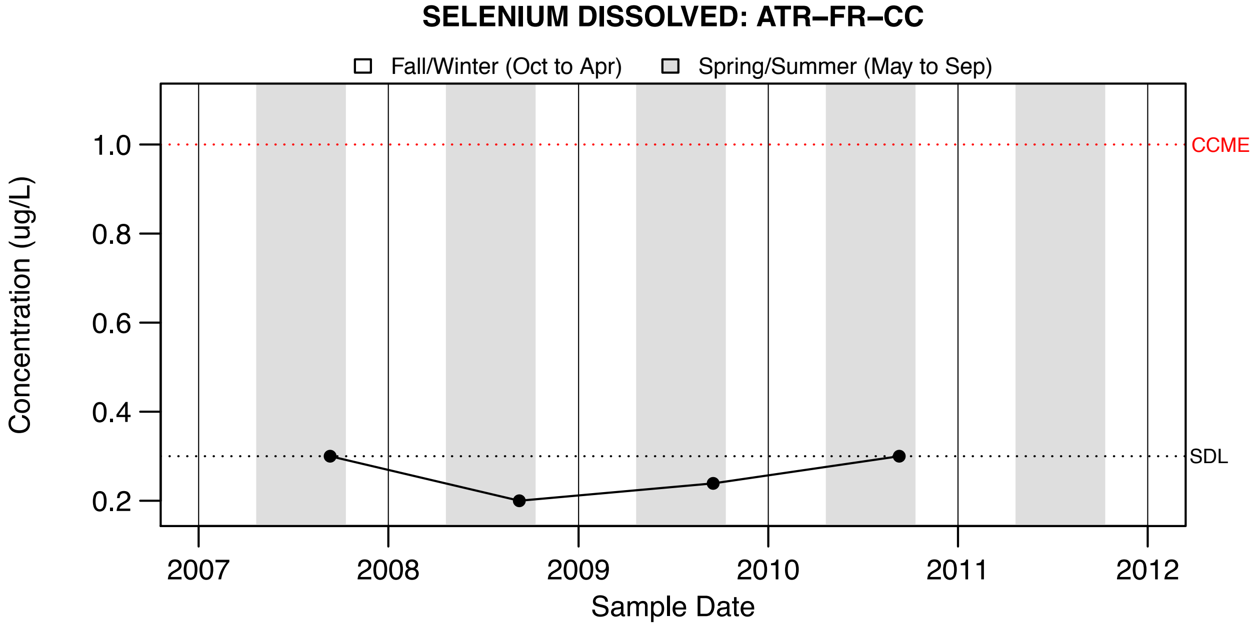


Figure A3.204: SELENIUM DISSOLVED: ATR-FR-CC -

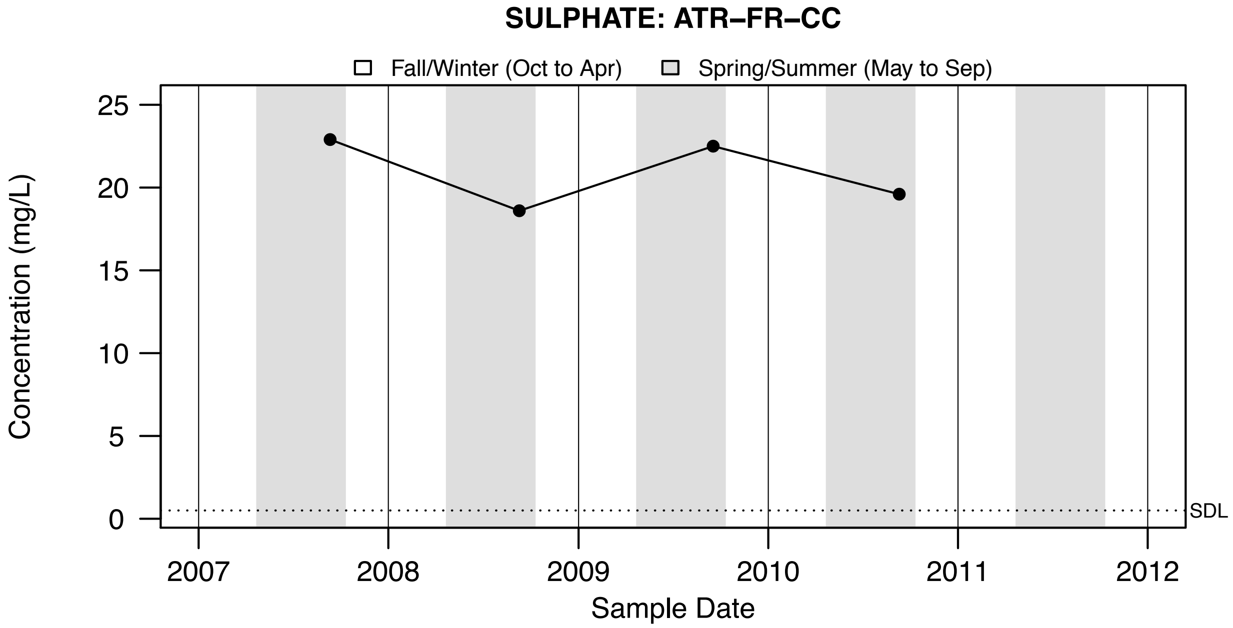


Figure A3.205: SULPHATE: ATR-FR-CC -

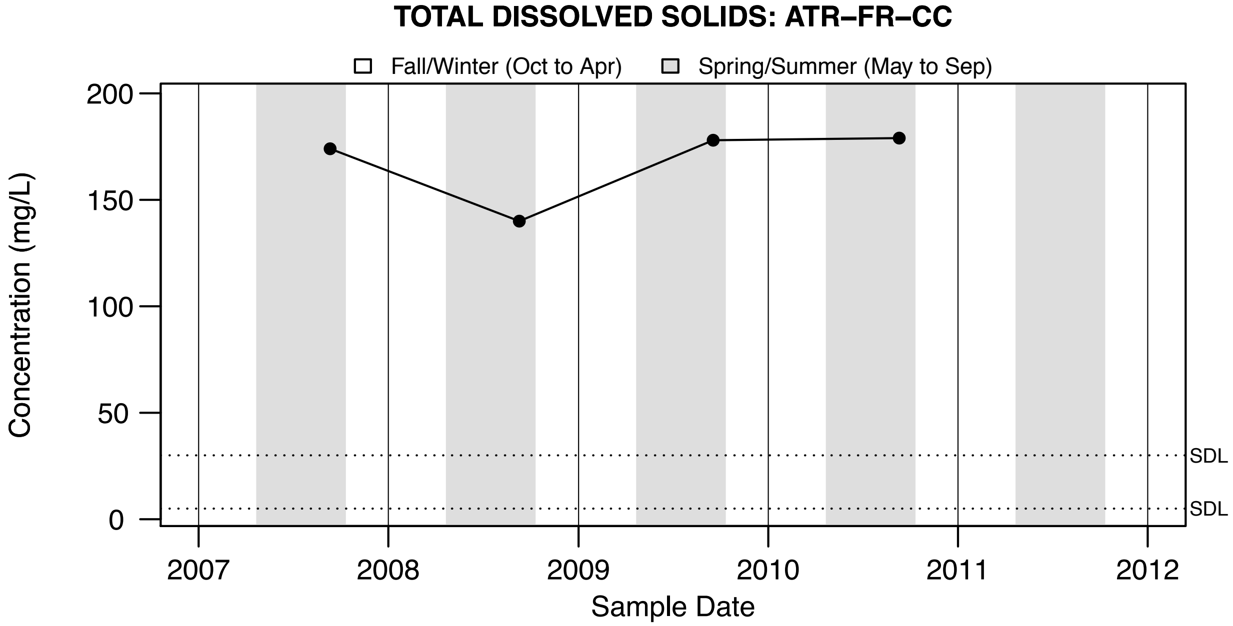
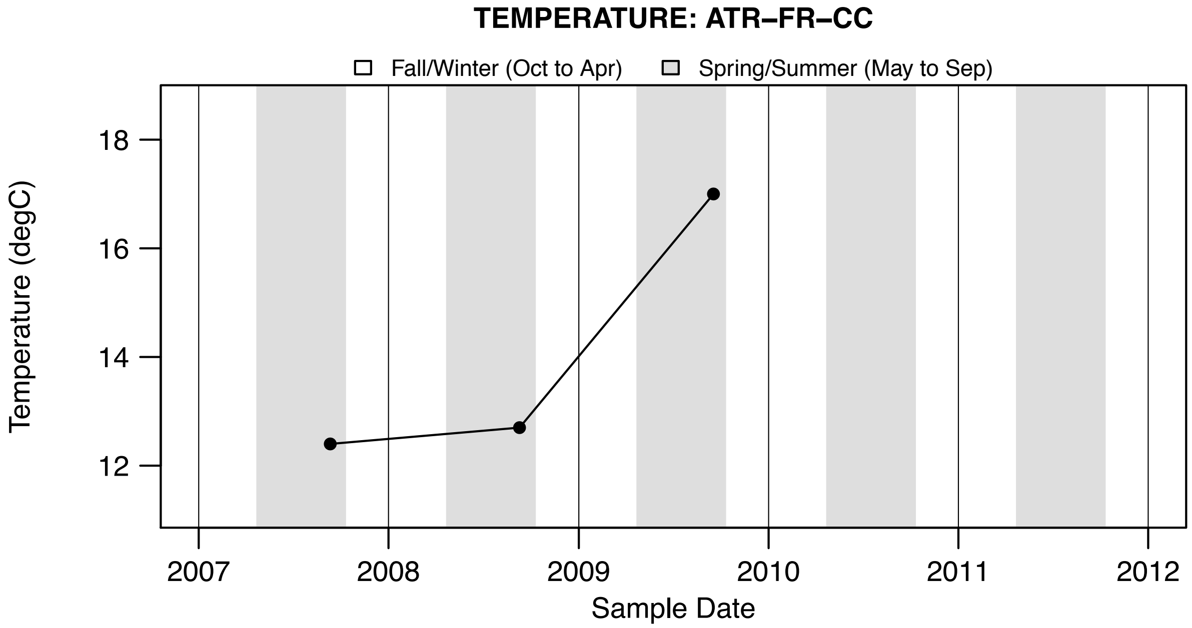


Figure A3.206: TOTAL DISSOLVED SOLIDS: ATR-FR-CC -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.207: TEMPERATURE: ATR-FR-CC -

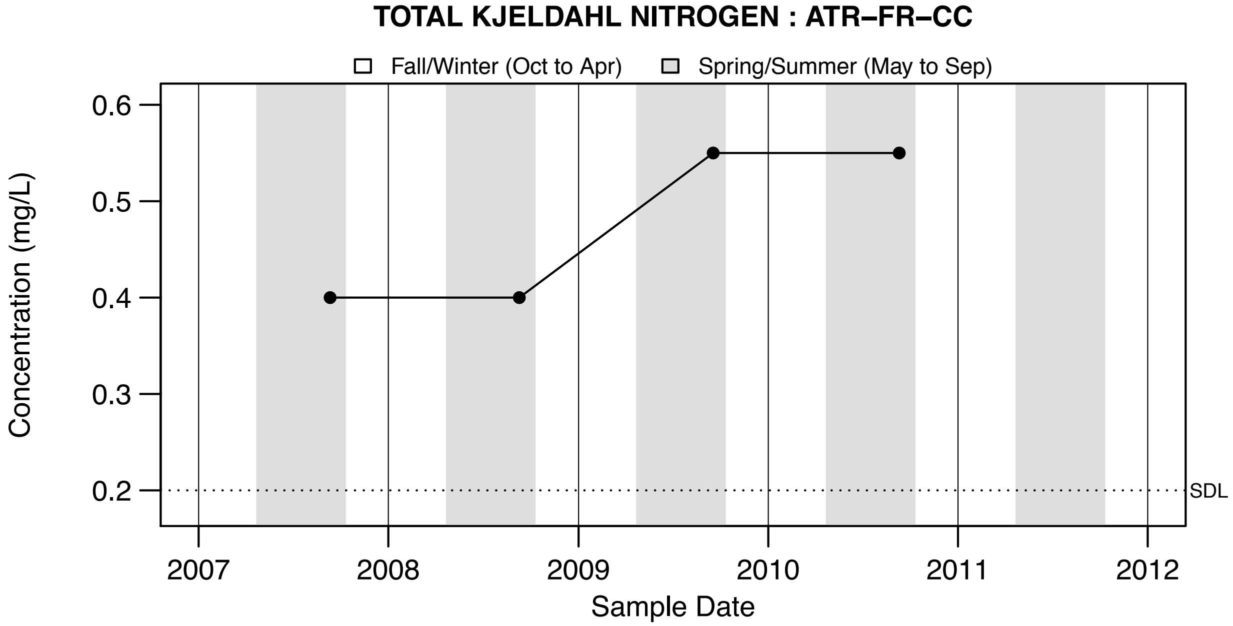
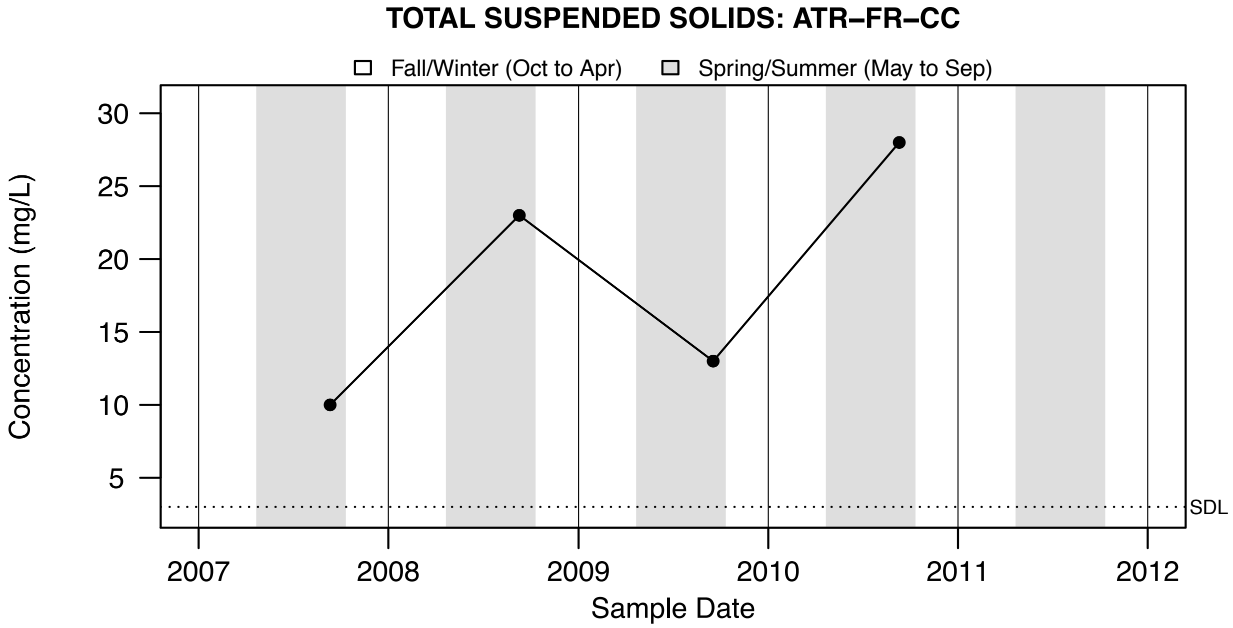


Figure A3.208: TOTAL KJELDAHL NITROGEN : ATR-FR-CC -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.209: TOTAL SUSPENDED SOLIDS: ATR-FR-CC -

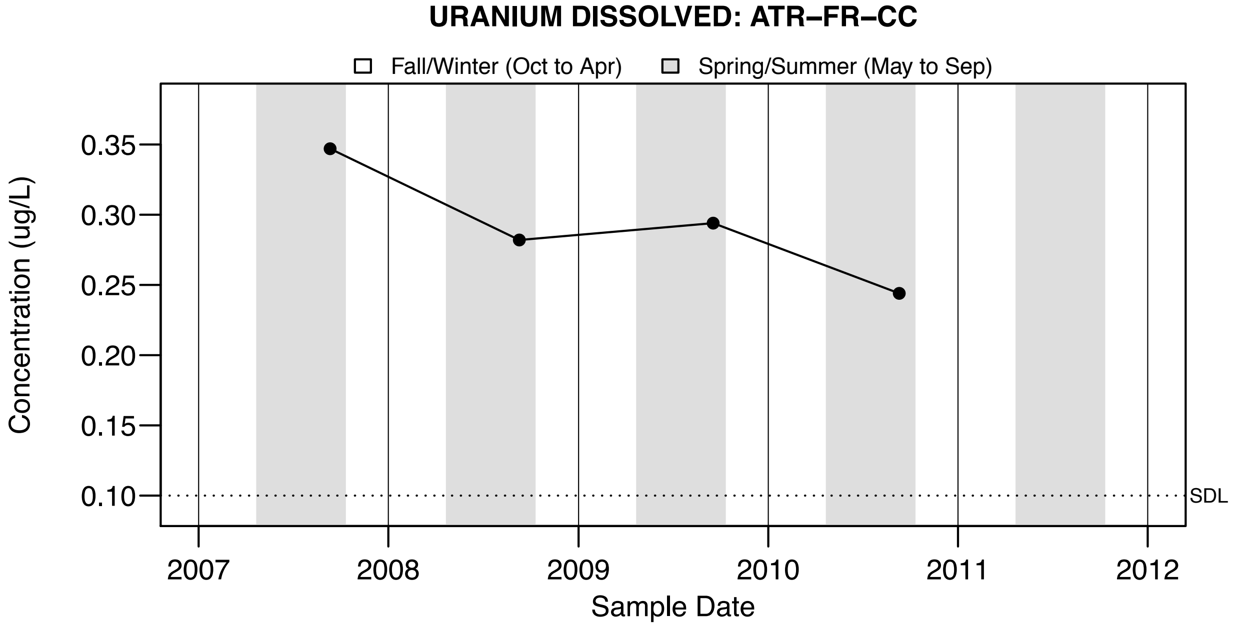


Figure A3.210: URANIUM DISSOLVED: ATR-FR-CC -

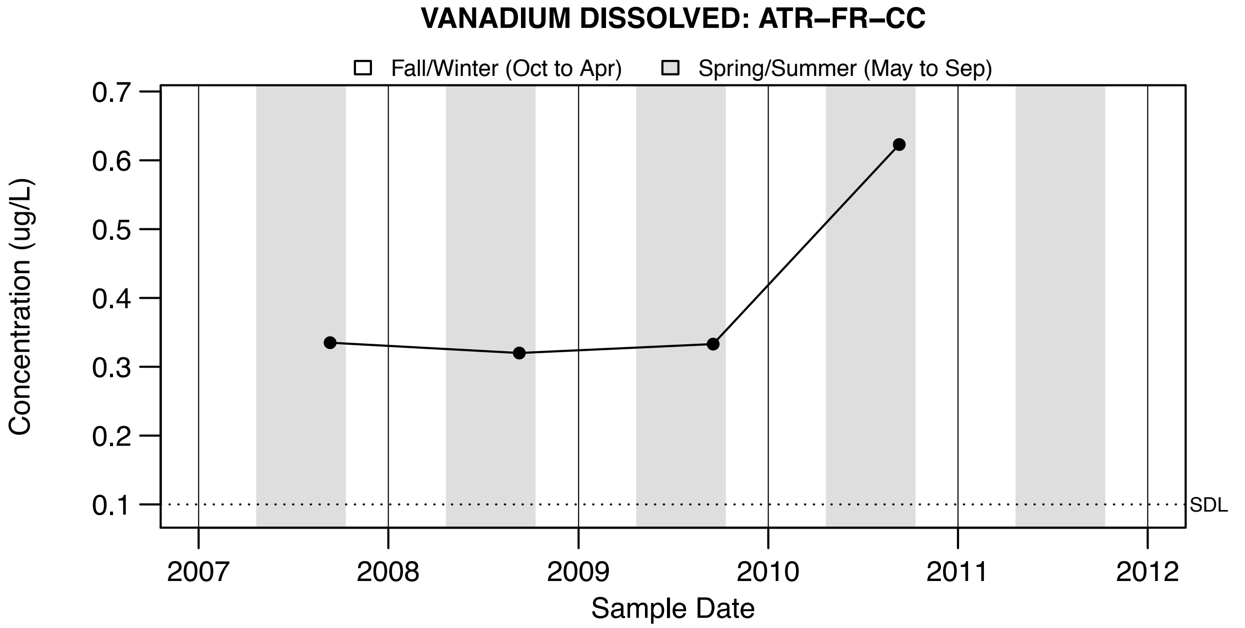


Figure A3.211: VANADIUM DISSOLVED: ATR-FR-CC -

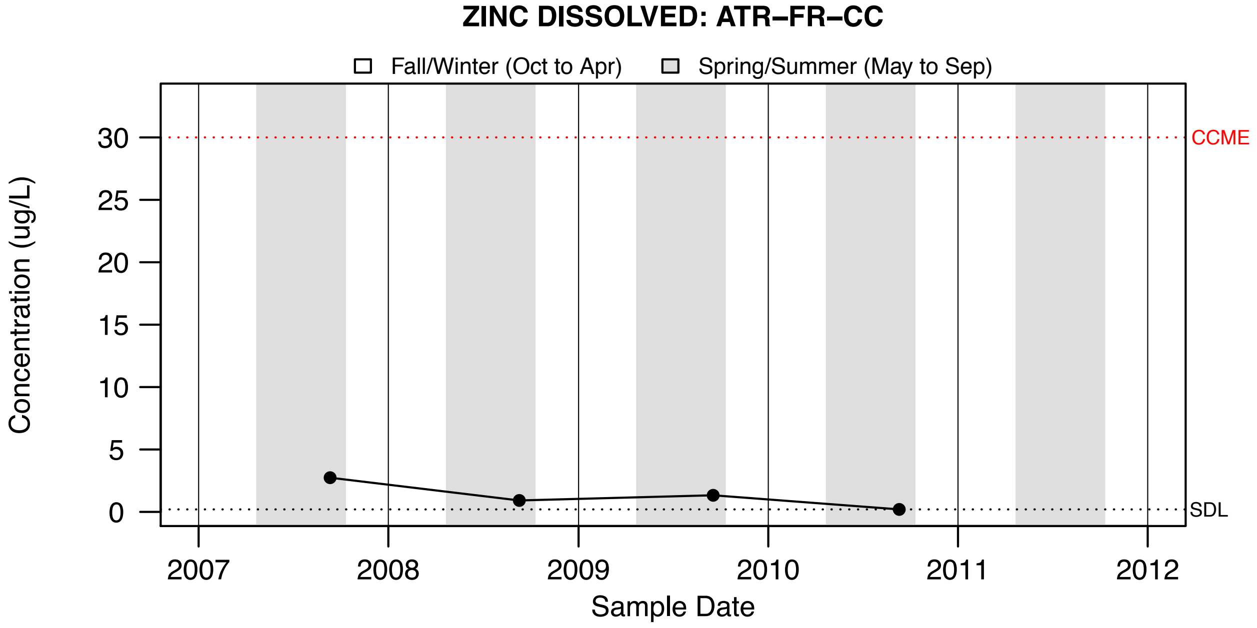
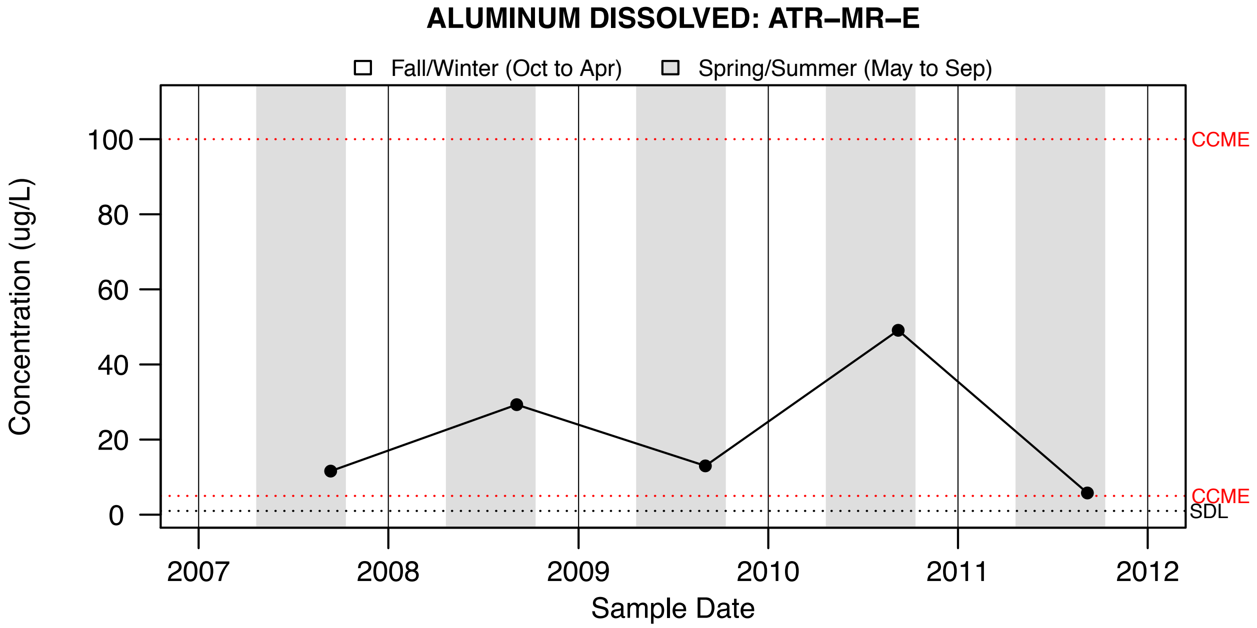
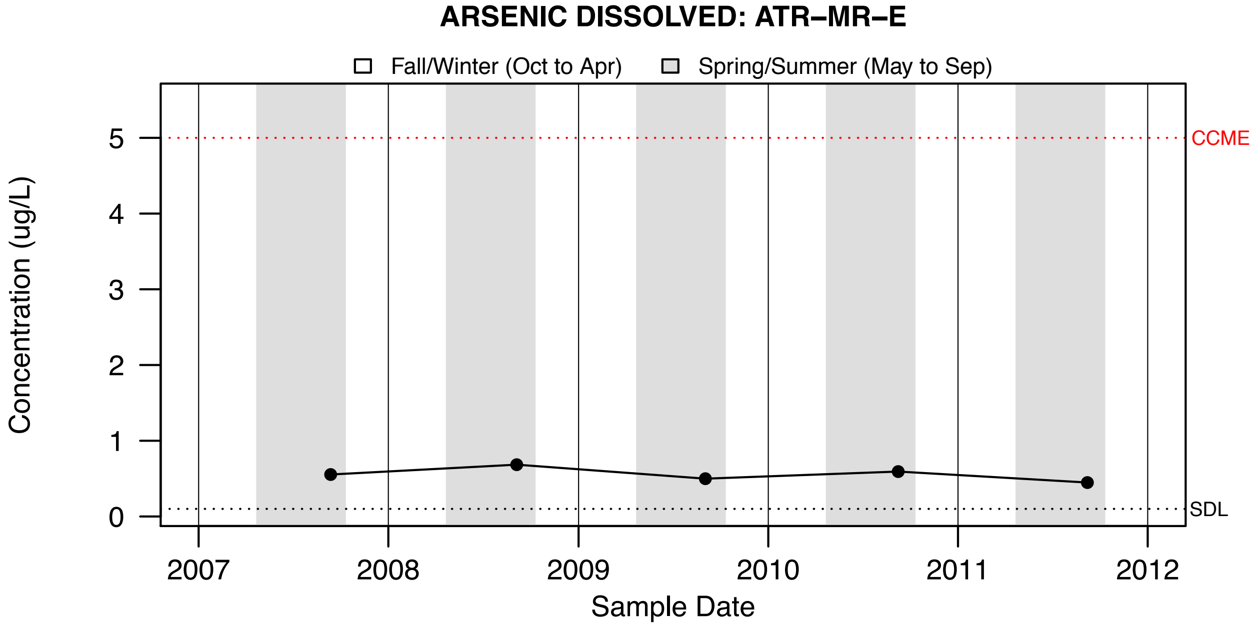


Figure A3.212: ZINC DISSOLVED: ATR-FR-CC -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.213: ALUMINUM DISSOLVED: ATR-MR-E -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.214: ARSENIC DISSOLVED: ATR-MR-E -

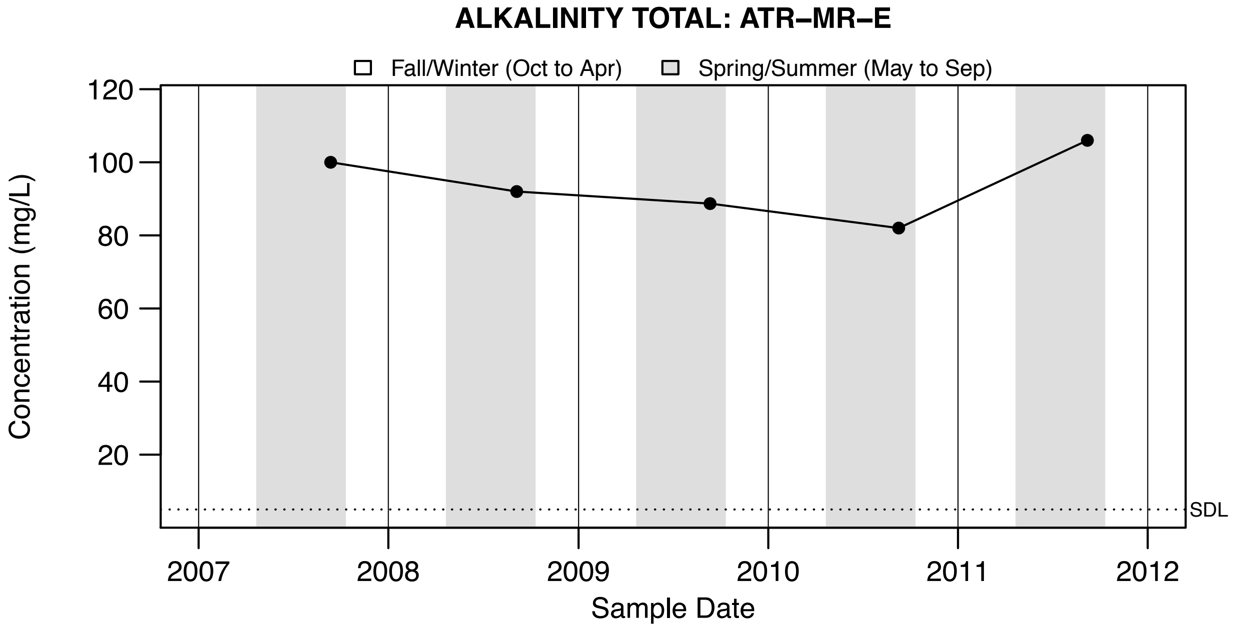


Figure A3.215: ALKALINITY TOTAL: ATR-MR-E -

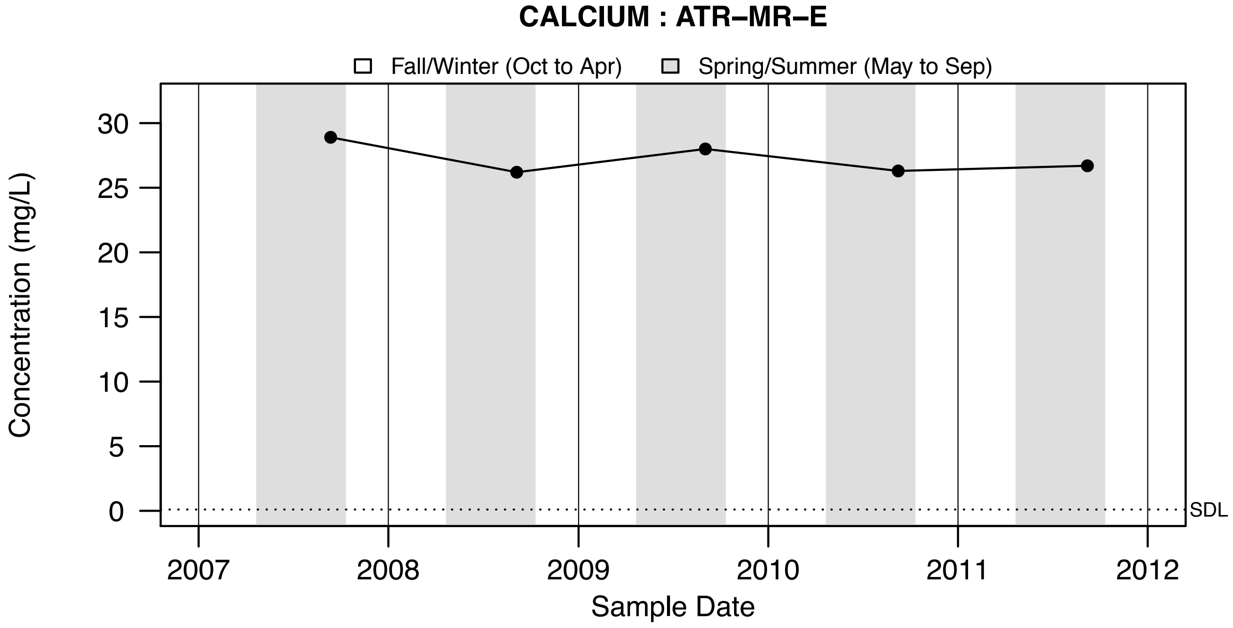


Figure A3.216: CALCIUM : ATR-MR-E -

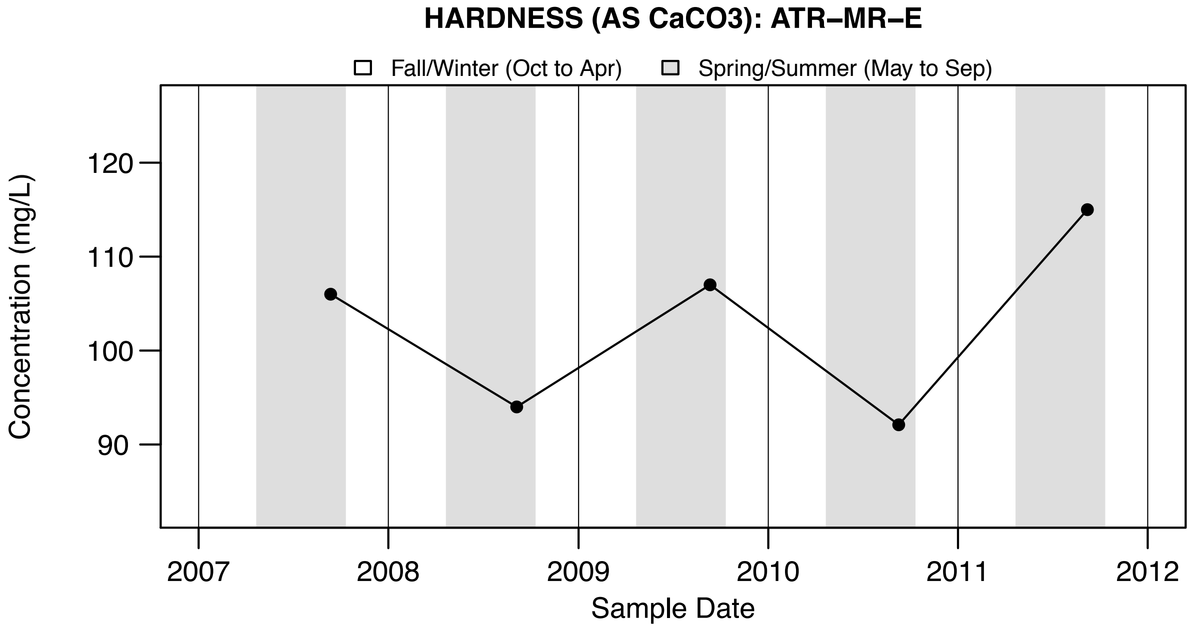
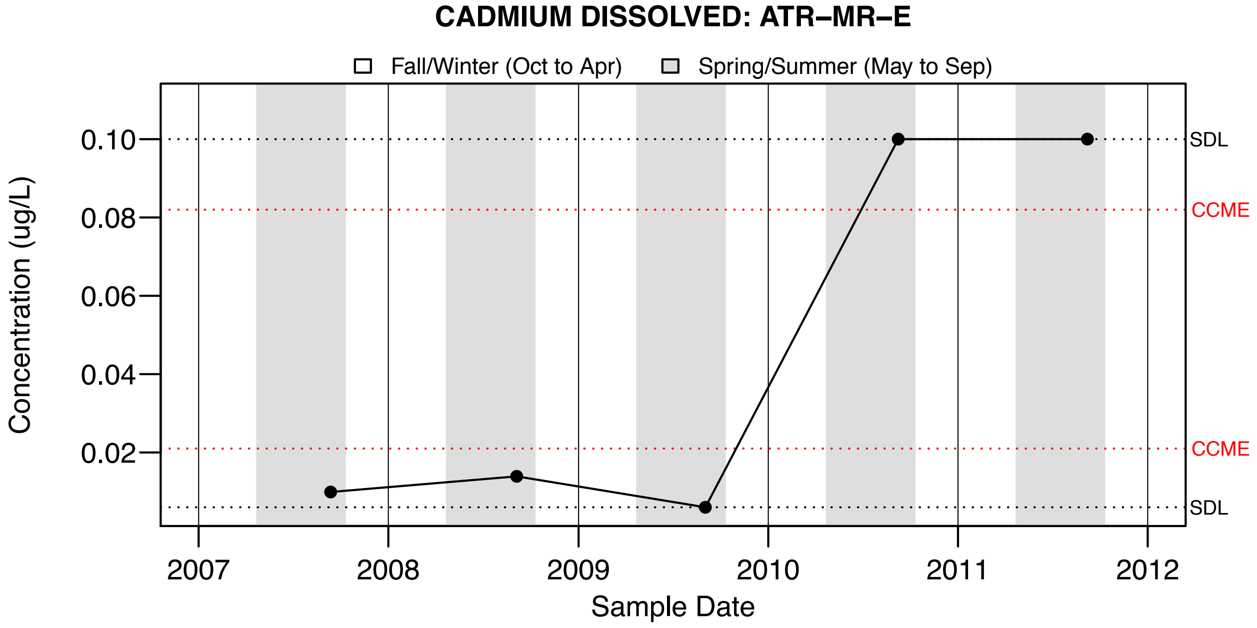


Figure A3.217: HARDNESS (AS CaCO3): ATR-MR-E -



Related to hardness as CaCo3

Figure A3.218: CADMIUM DISSOLVED: ATR-MR-E -

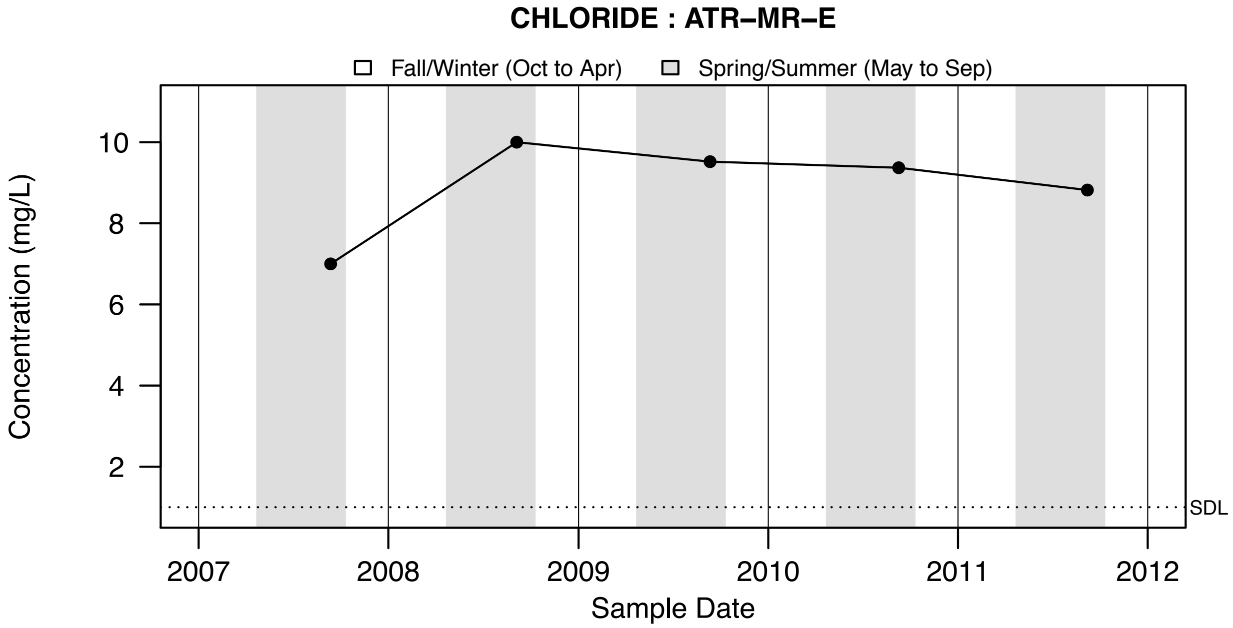


Figure A3.219: CHLORIDE : ATR-MR-E -

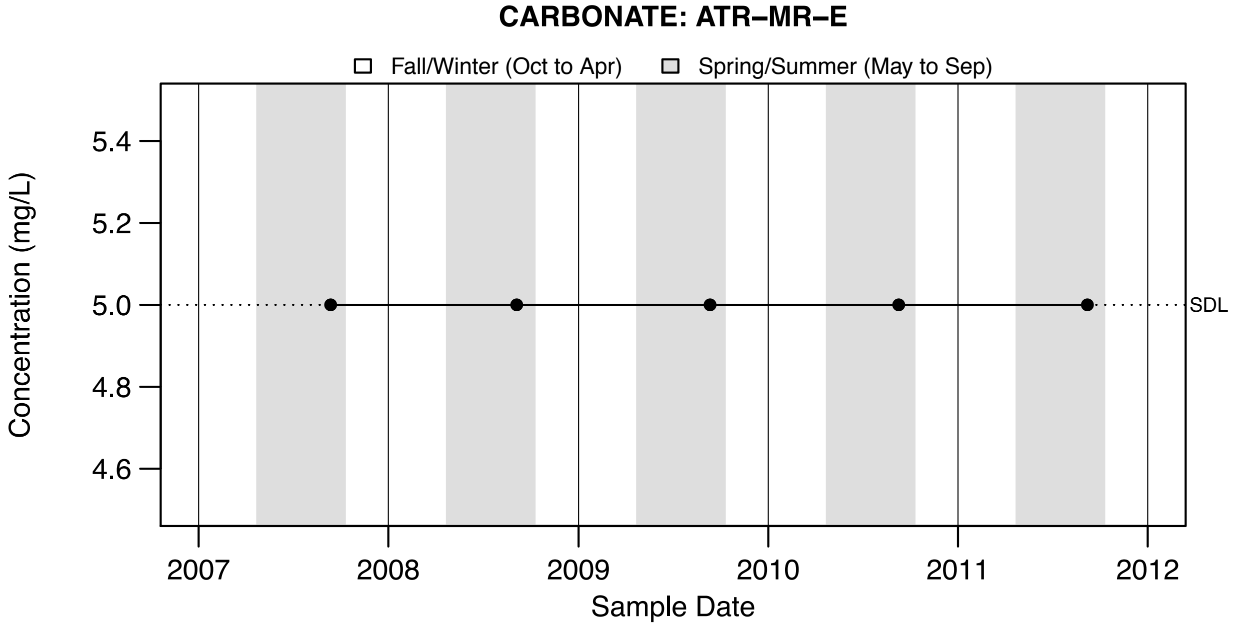


Figure A3.220: CARBONATE: ATR-MR-E -

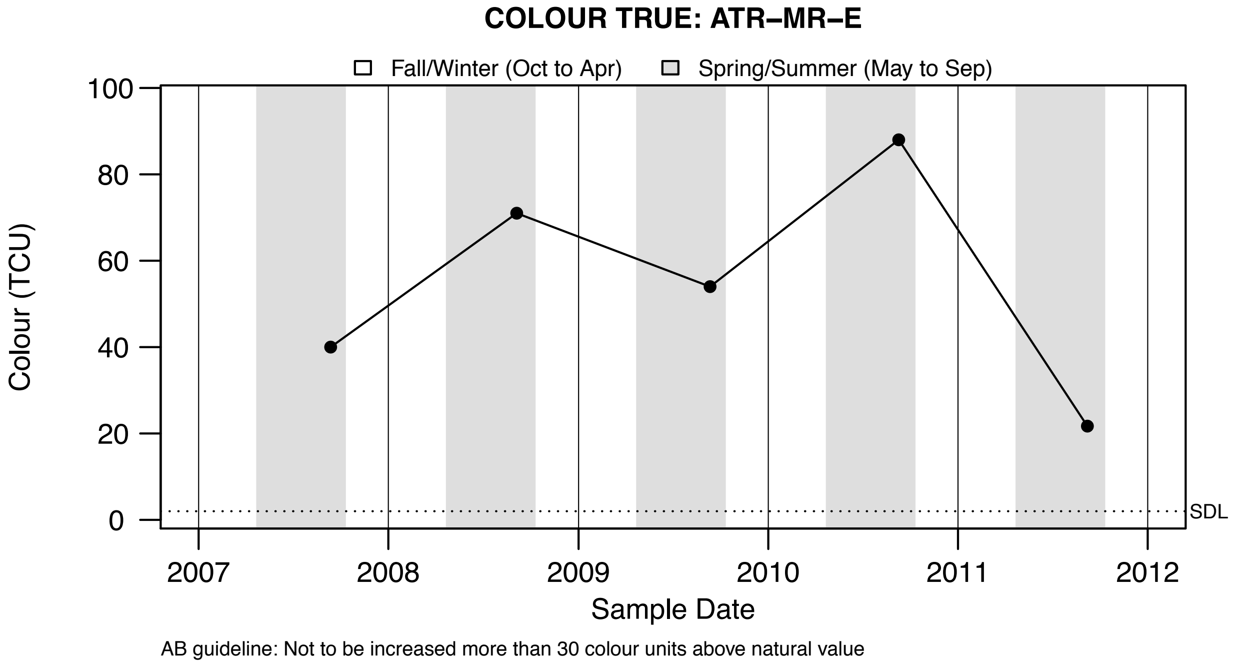


Figure A3.221: COLOUR TRUE: ATR-MR-E -

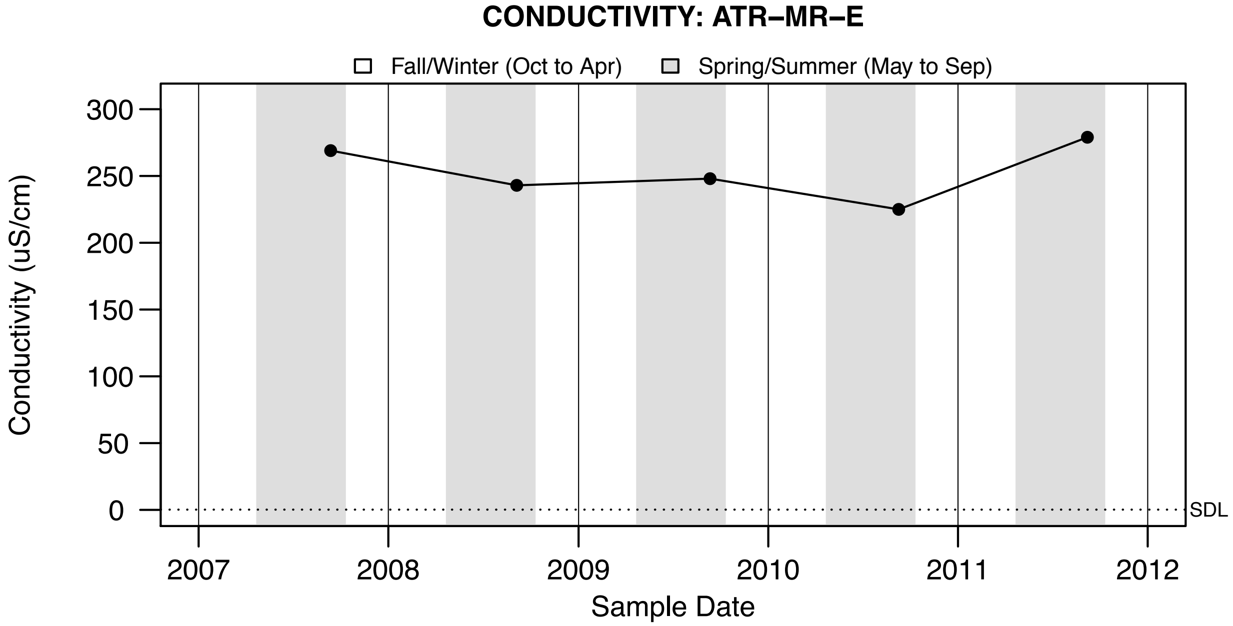
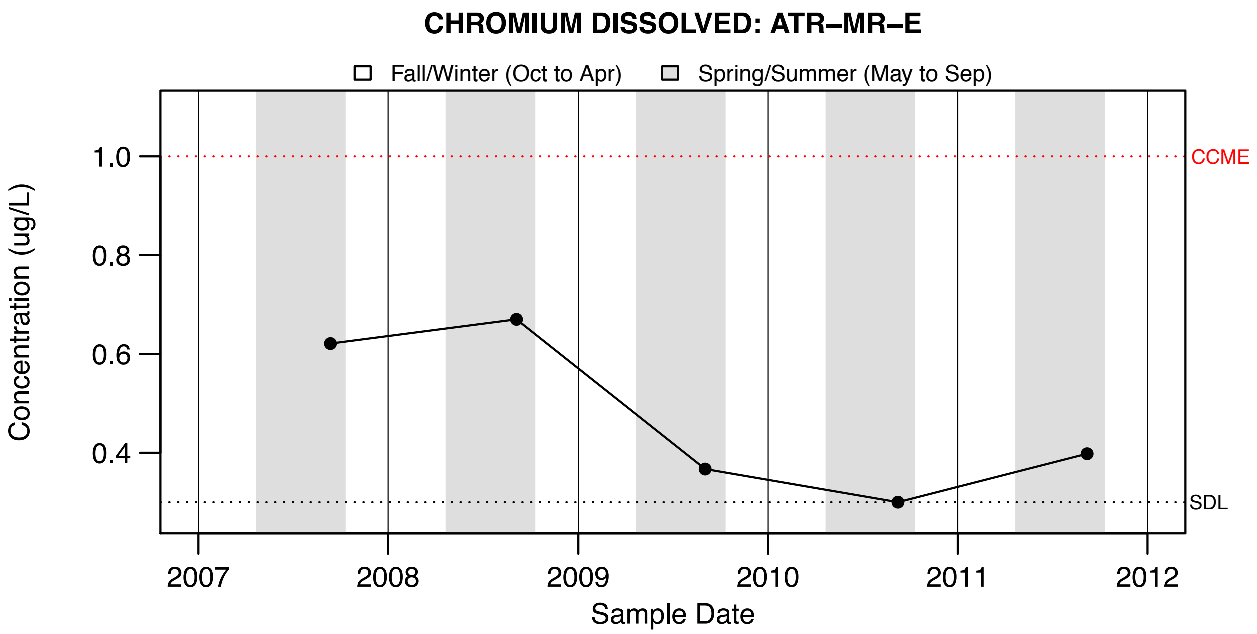
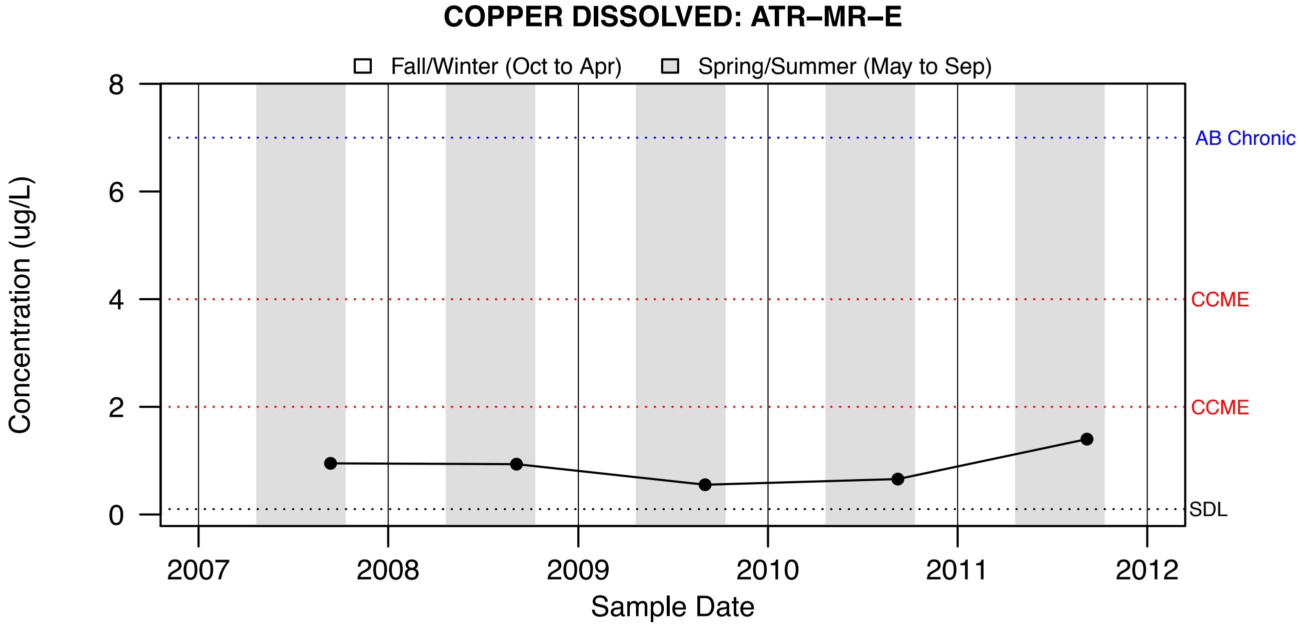


Figure A3.222: CONDUCTIVITY: ATR-MR-E -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.223: CHROMIUM DISSOLVED: ATR-MR-E -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.224: COPPER DISSOLVED: ATR-MR-E -

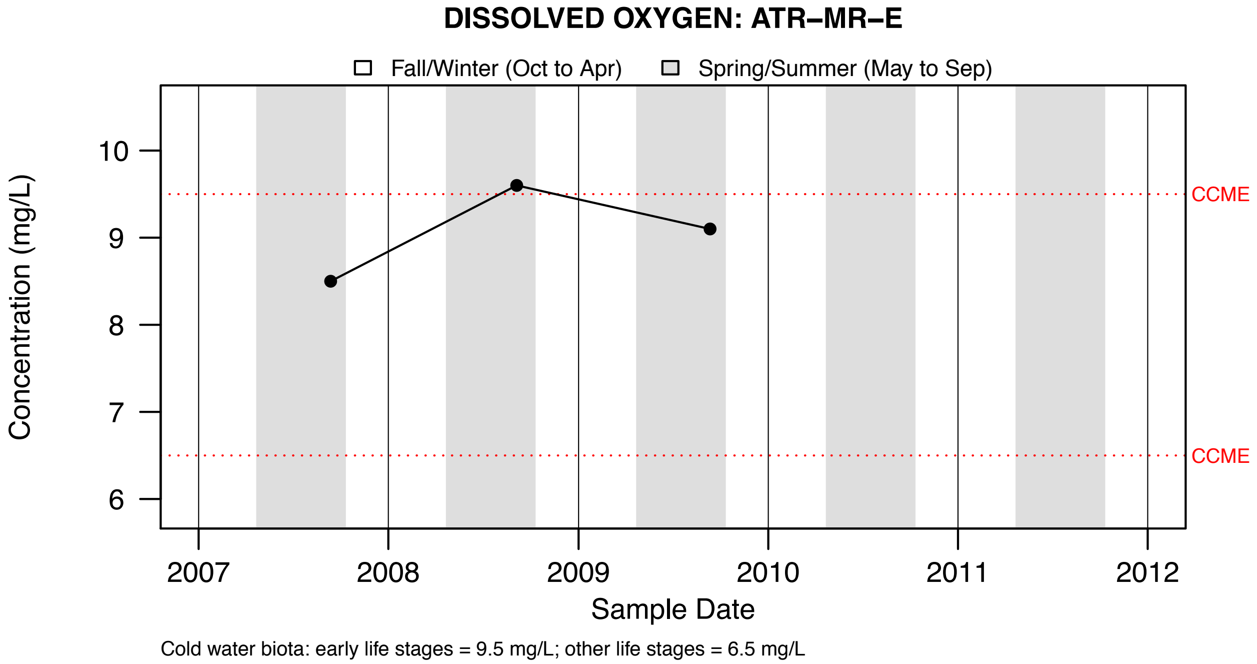


Figure A3.225: DISSOLVED OXYGEN: ATR-MR-E -

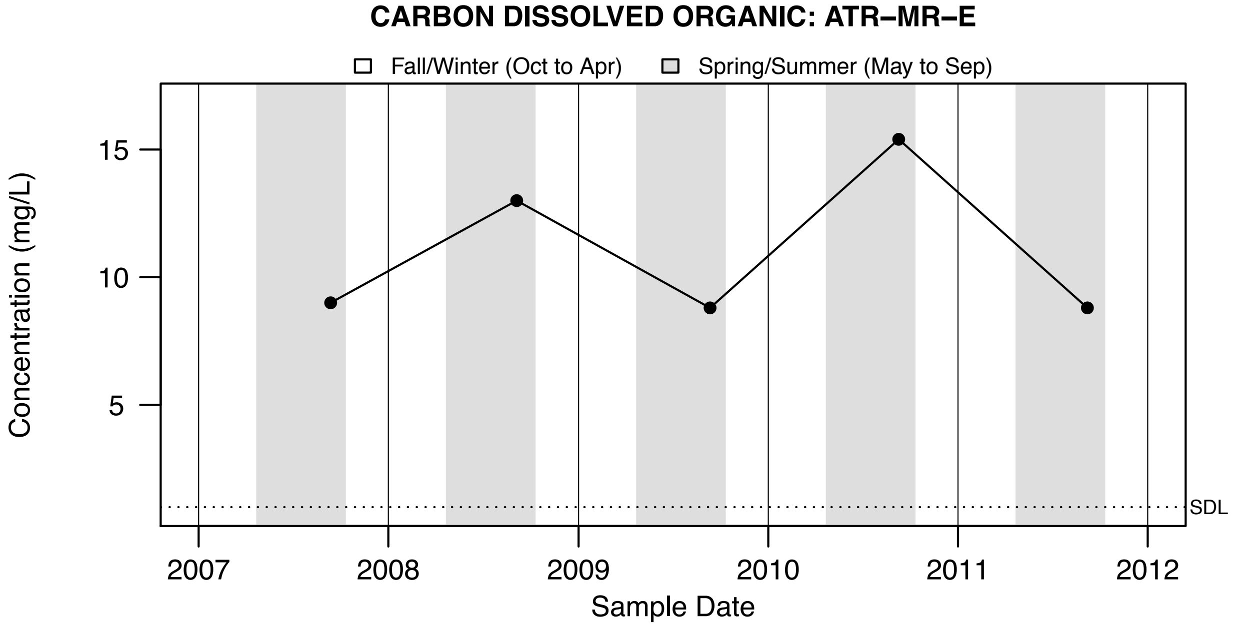


Figure A3.226: CARBON DISSOLVED ORGANIC: ATR-MR-E -

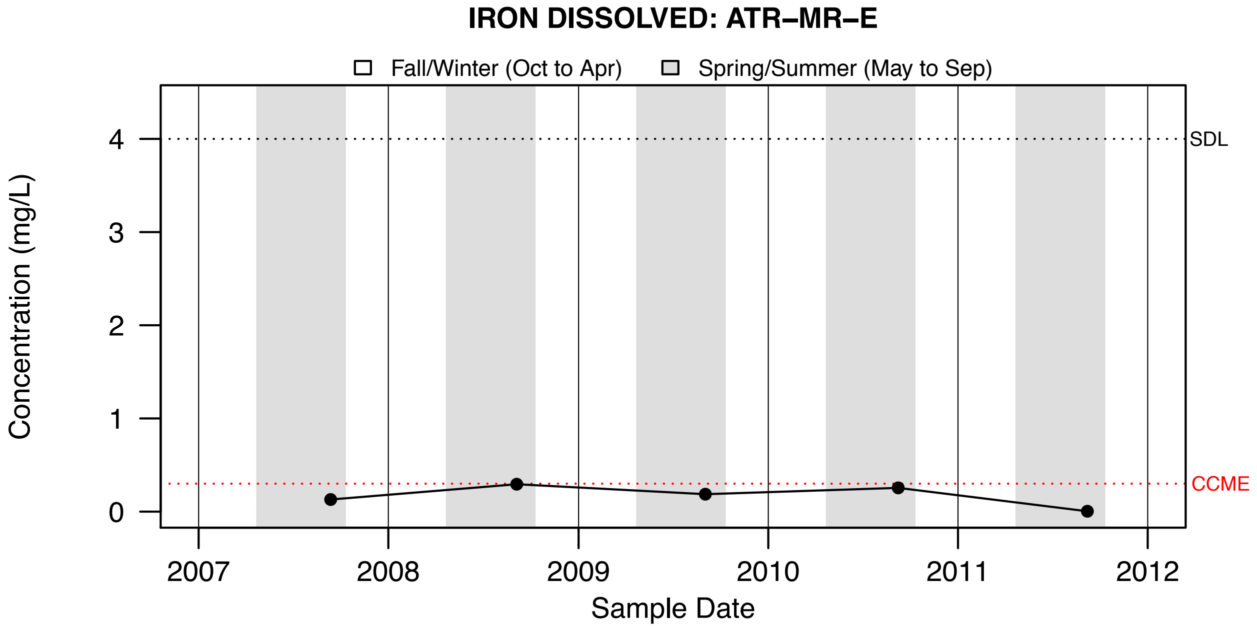


Figure A3.227: IRON DISSOLVED: ATR-MR-E -

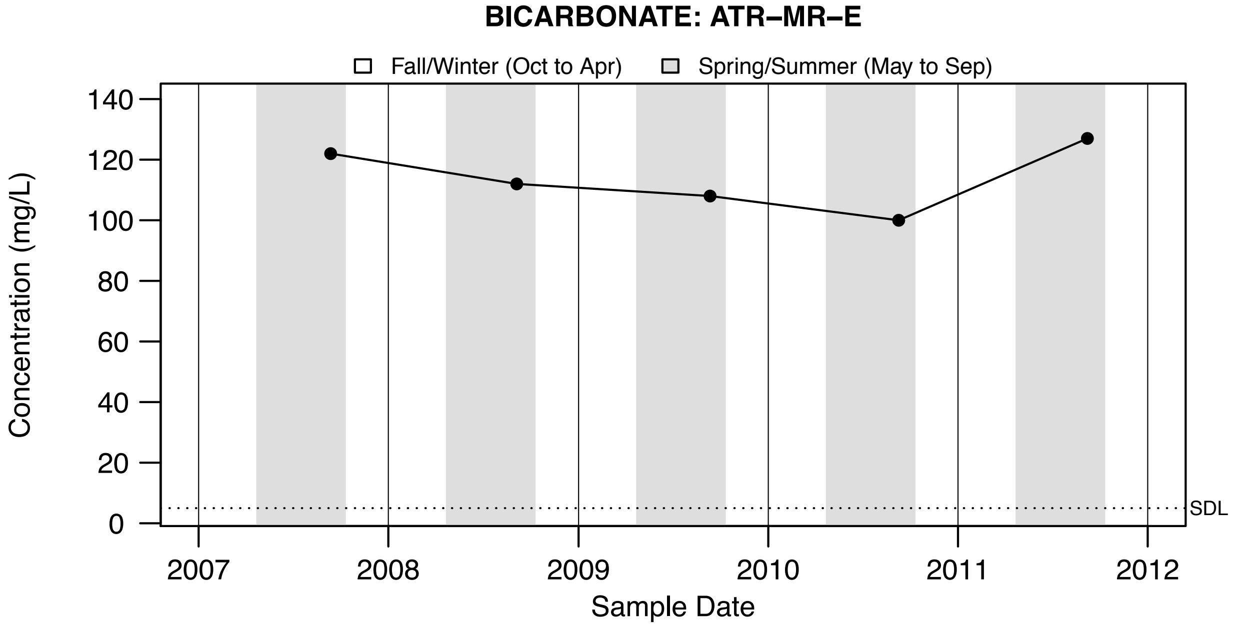


Figure A3.228: BICARBONATE: ATR-MR-E -

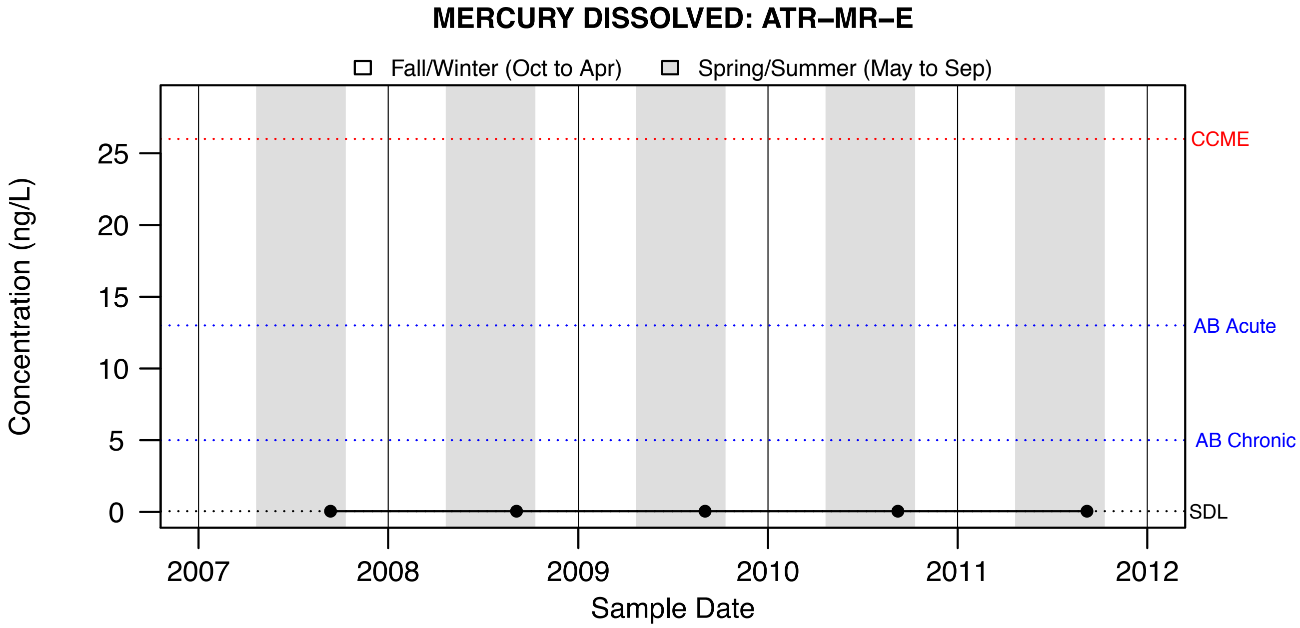


Figure A3.229: MERCURY DISSOLVED: ATR-MR-E -

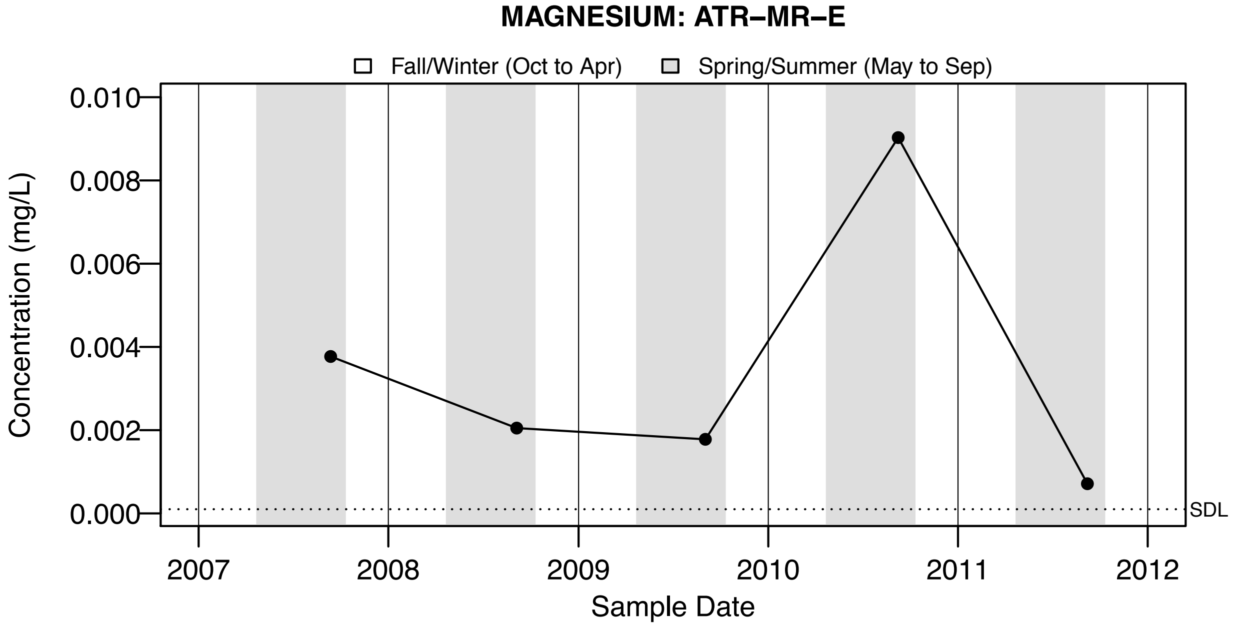


Figure A3.230: MAGNESIUM: ATR-MR-E -

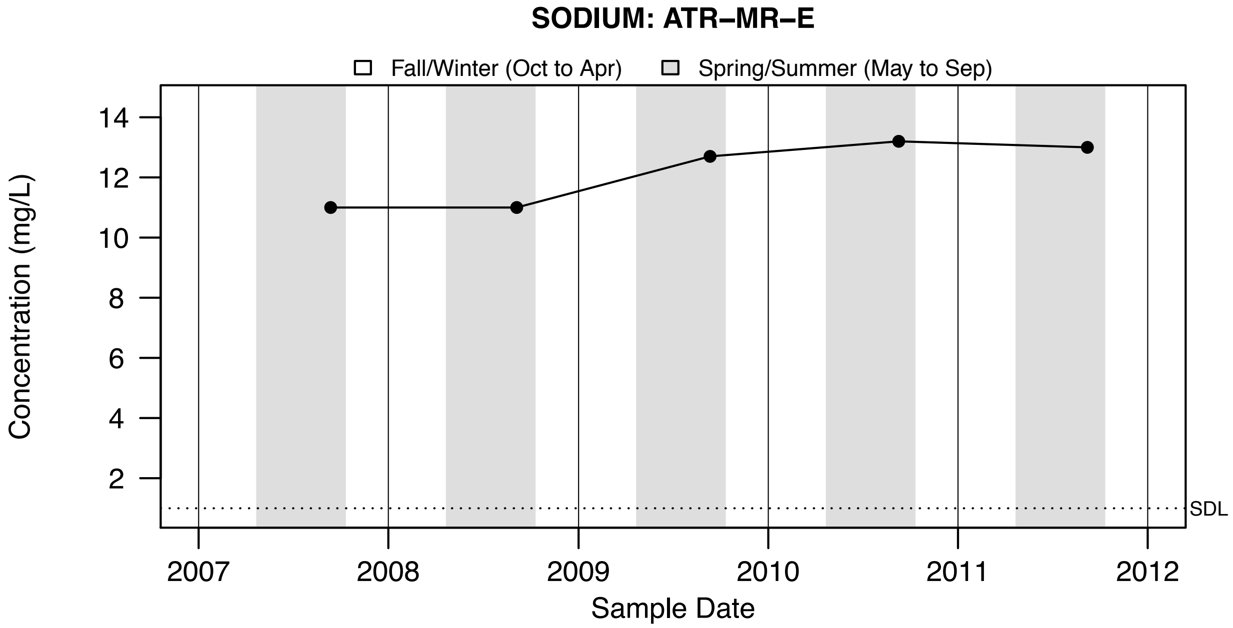
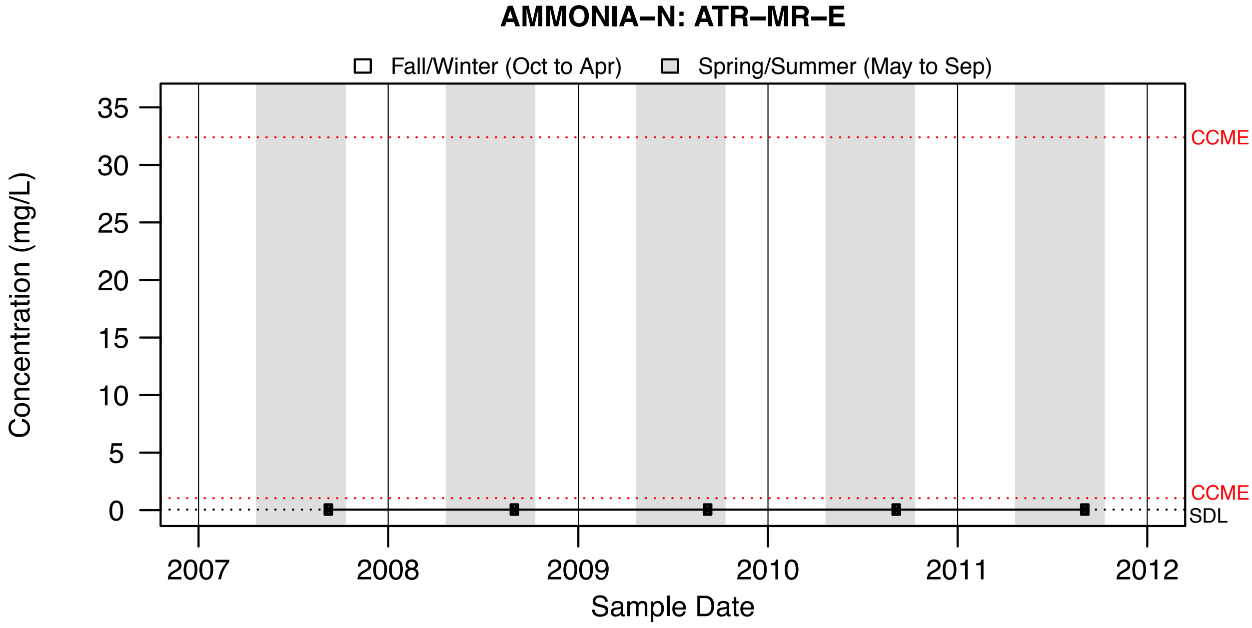
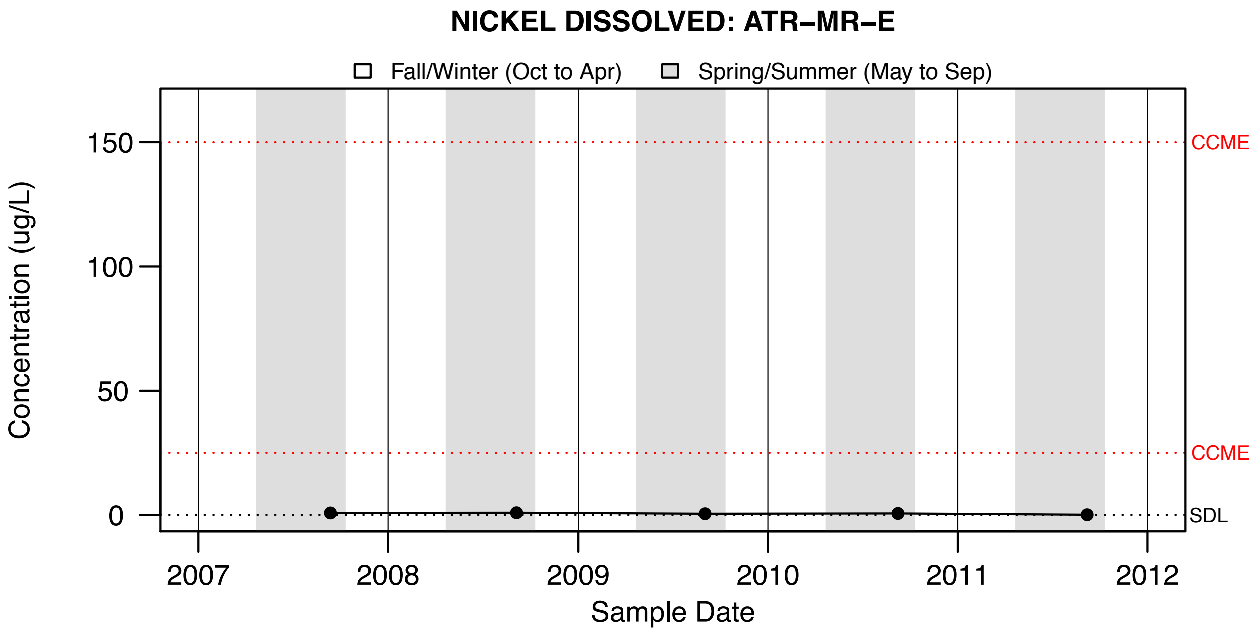


Figure A3.231: SODIUM: ATR-MR-E -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.232: AMMONIA-N: ATR-MR-E -



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A3.233: NICKEL DISSOLVED: ATR-MR-E -

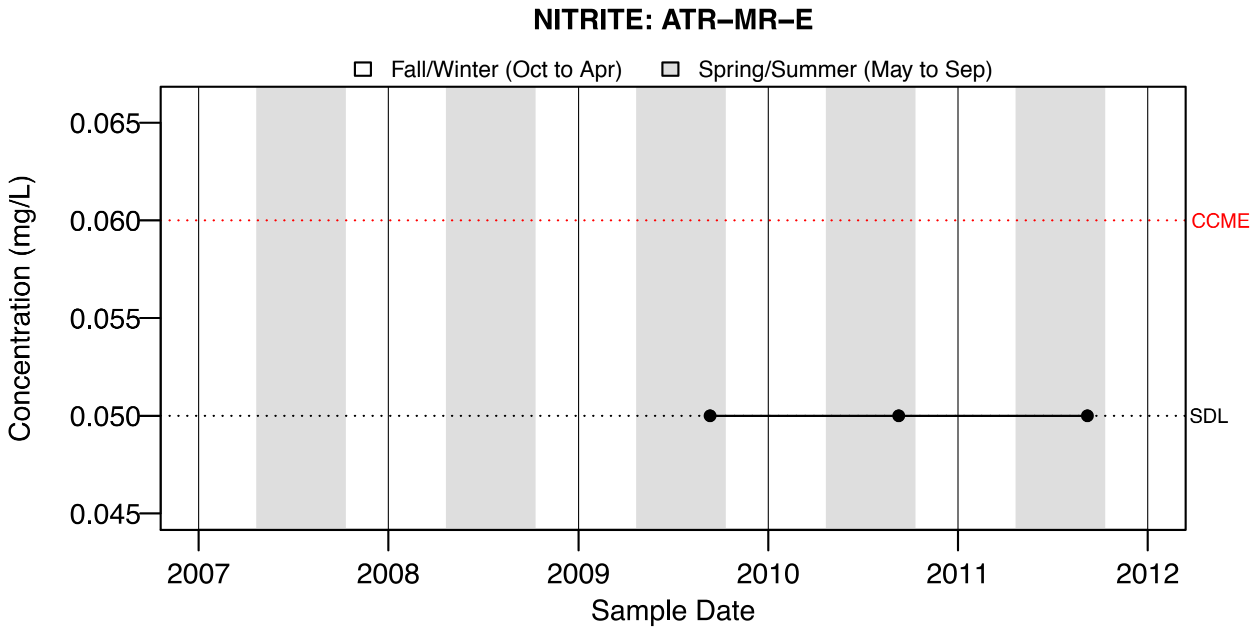
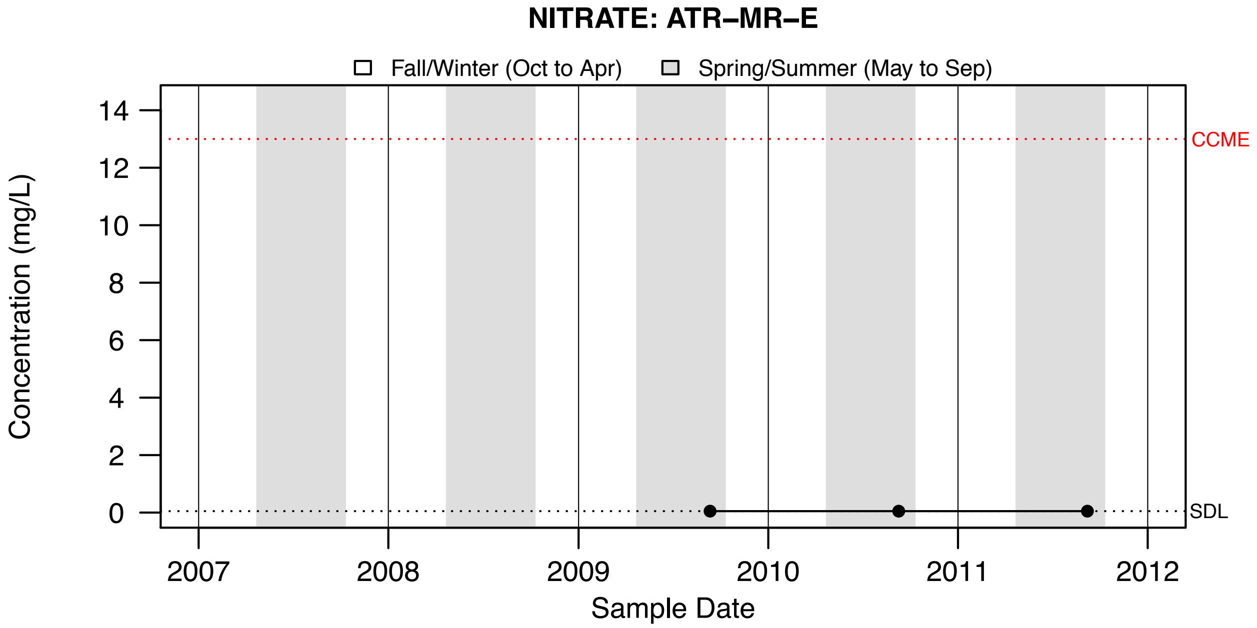


Figure A3.234: NITRITE: ATR-MR-E -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.235: NITRATE: ATR-MR-E -

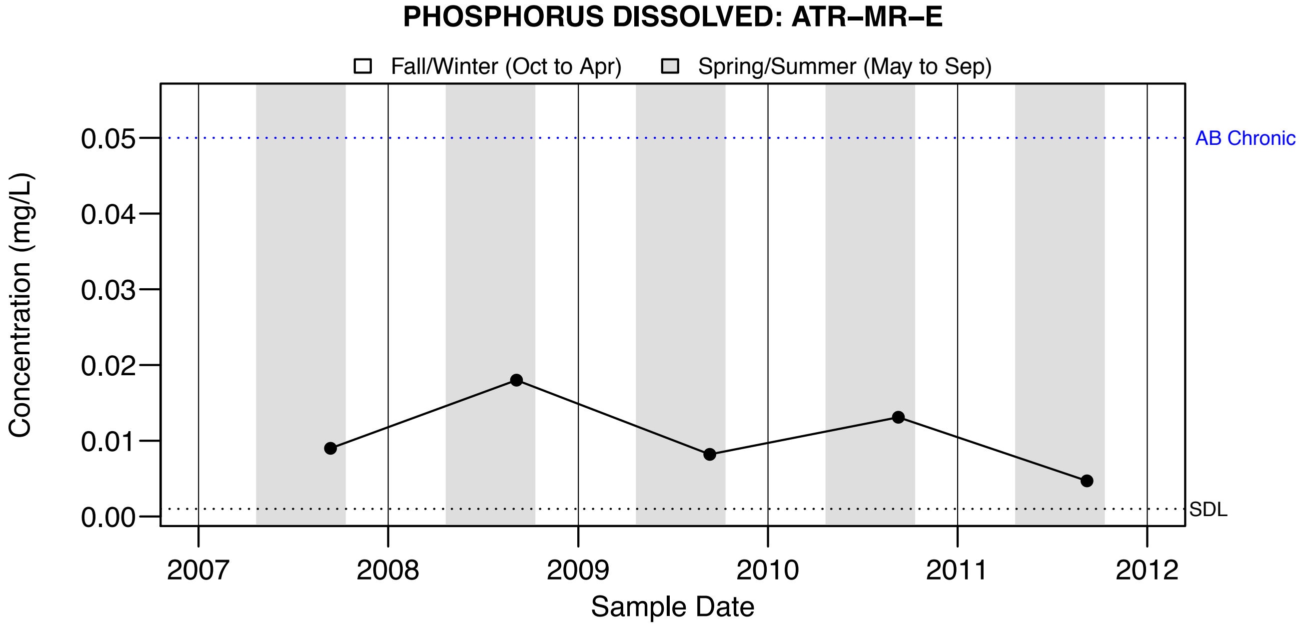


Figure A3.236: PHOSPHORUS DISSOLVED: ATR-MR-E -

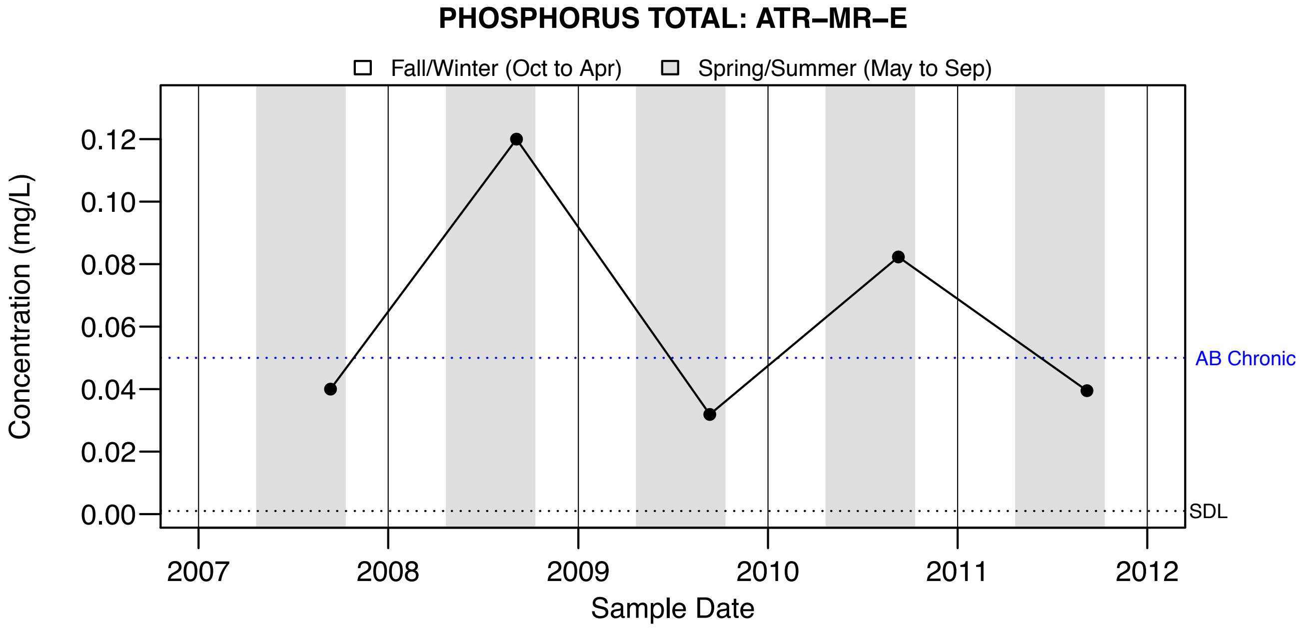
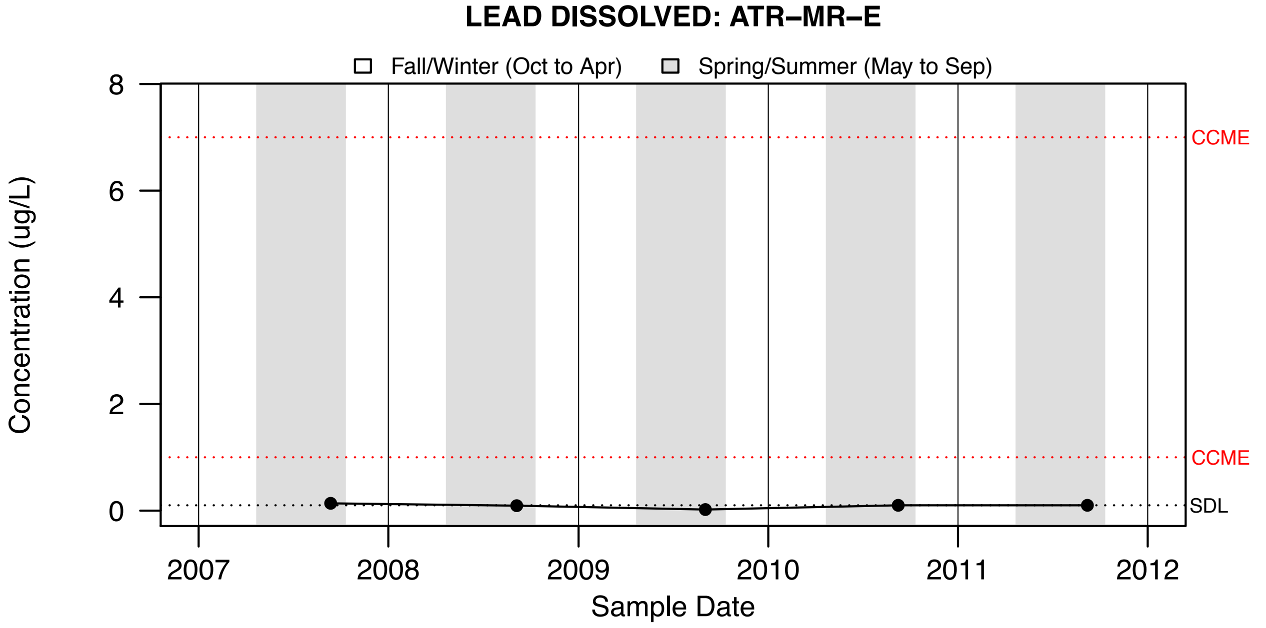


Figure A3.237: PHOSPHORUS TOTAL: ATR-MR-E -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.238: LEAD DISSOLVED: ATR-MR-E -

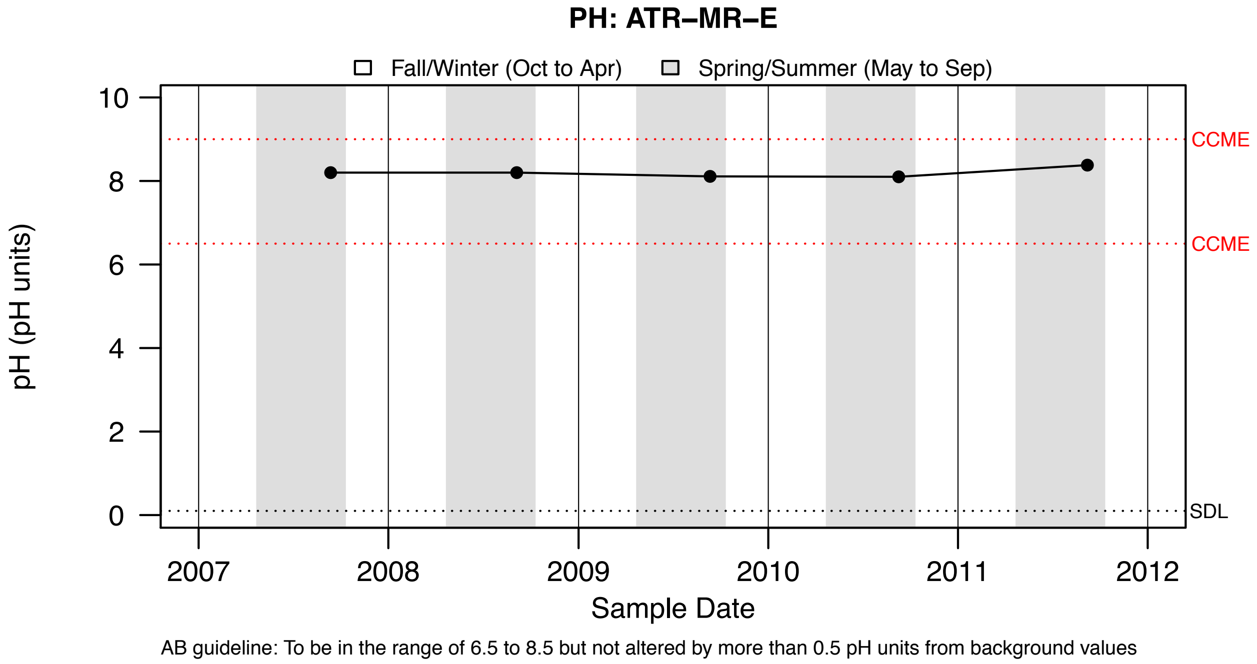


Figure A3.239: PH: ATR-MR-E -

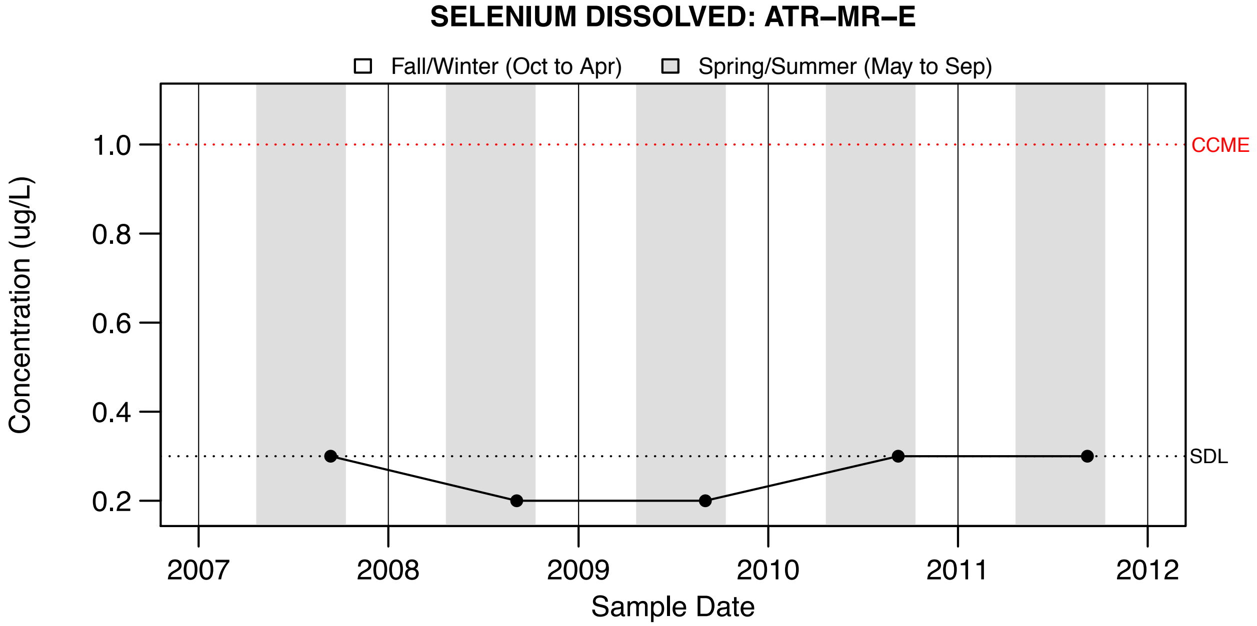


Figure A3.240: SELENIUM DISSOLVED: ATR-MR-E -

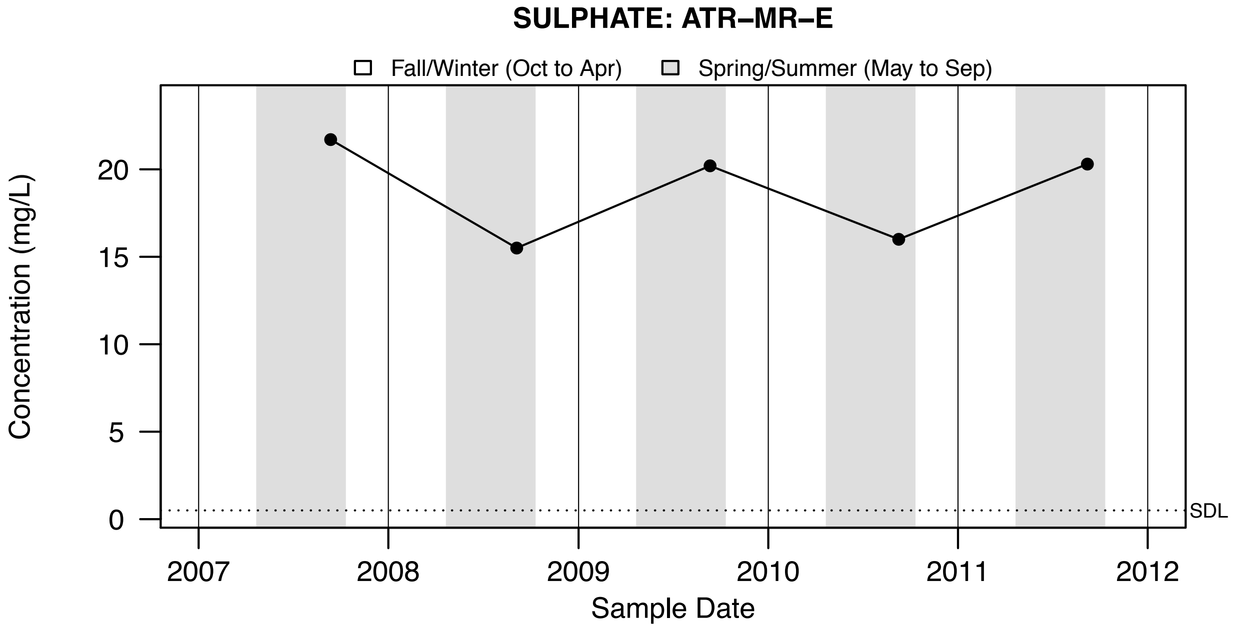


Figure A3.241: SULPHATE: ATR-MR-E -

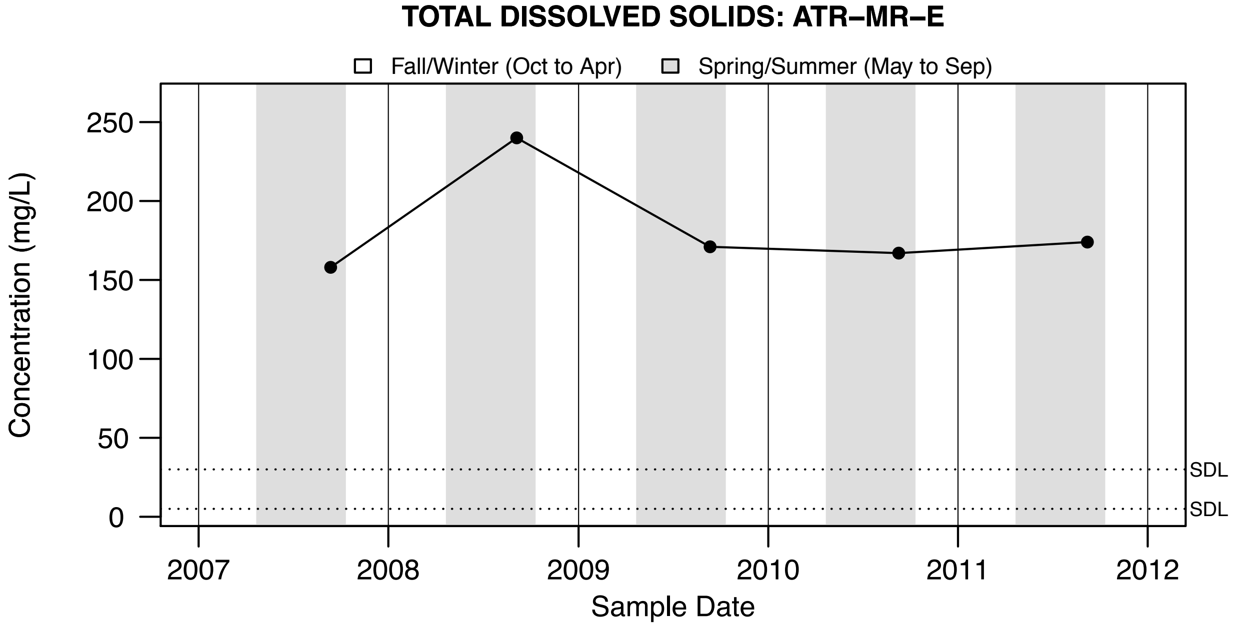
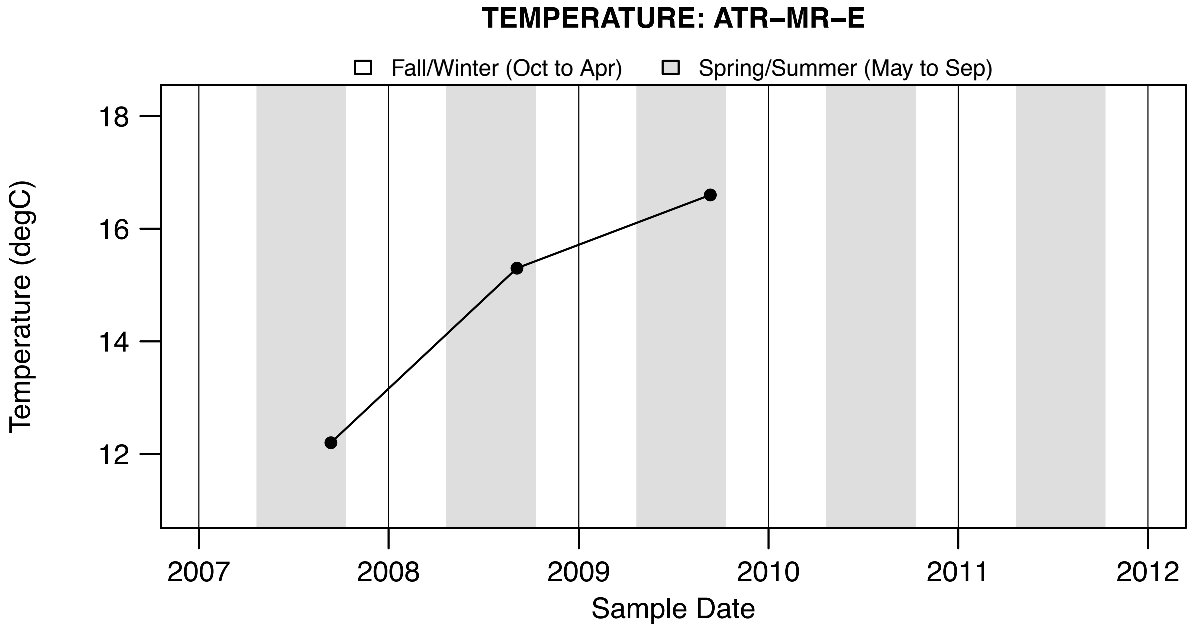


Figure A3.242: TOTAL DISSOLVED SOLIDS: ATR-MR-E -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.243: TEMPERATURE: ATR-MR-E -

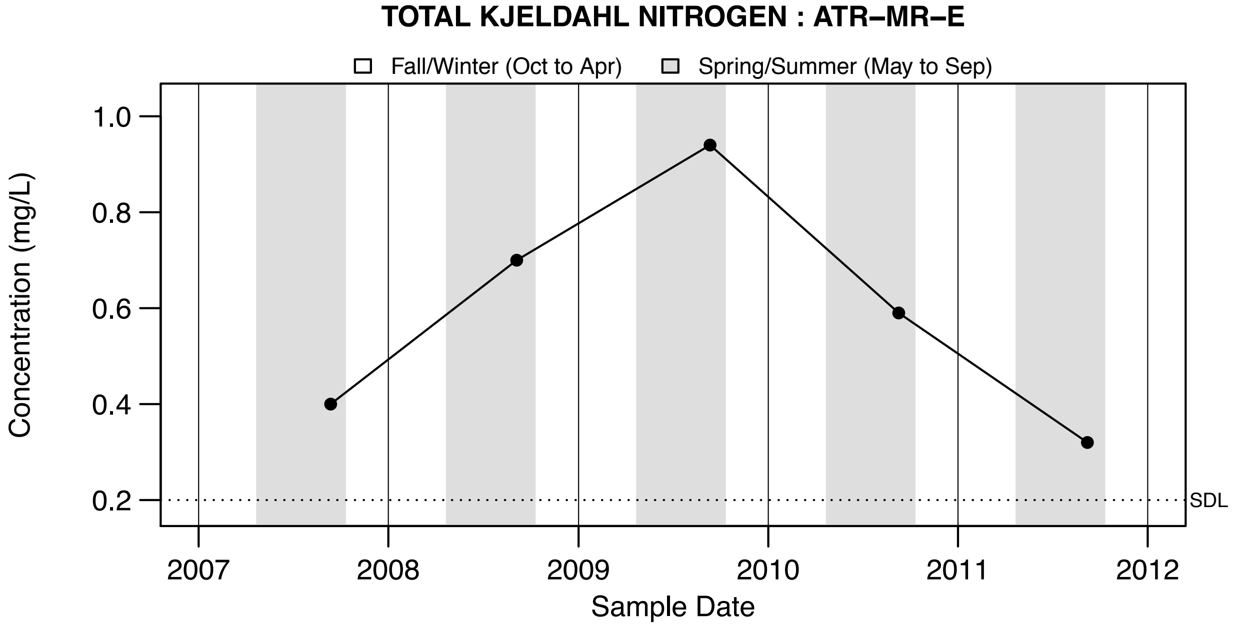
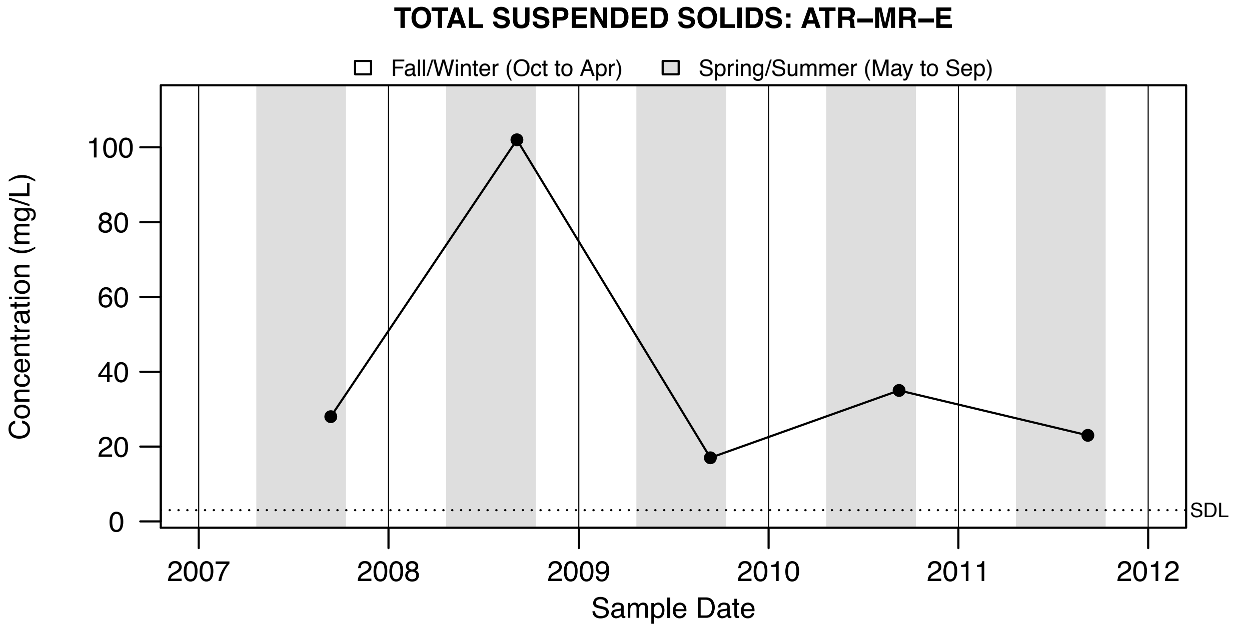


Figure A3.244: TOTAL KJELDAHL NITROGEN : ATR-MR-E -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.245: TOTAL SUSPENDED SOLIDS: ATR-MR-E -

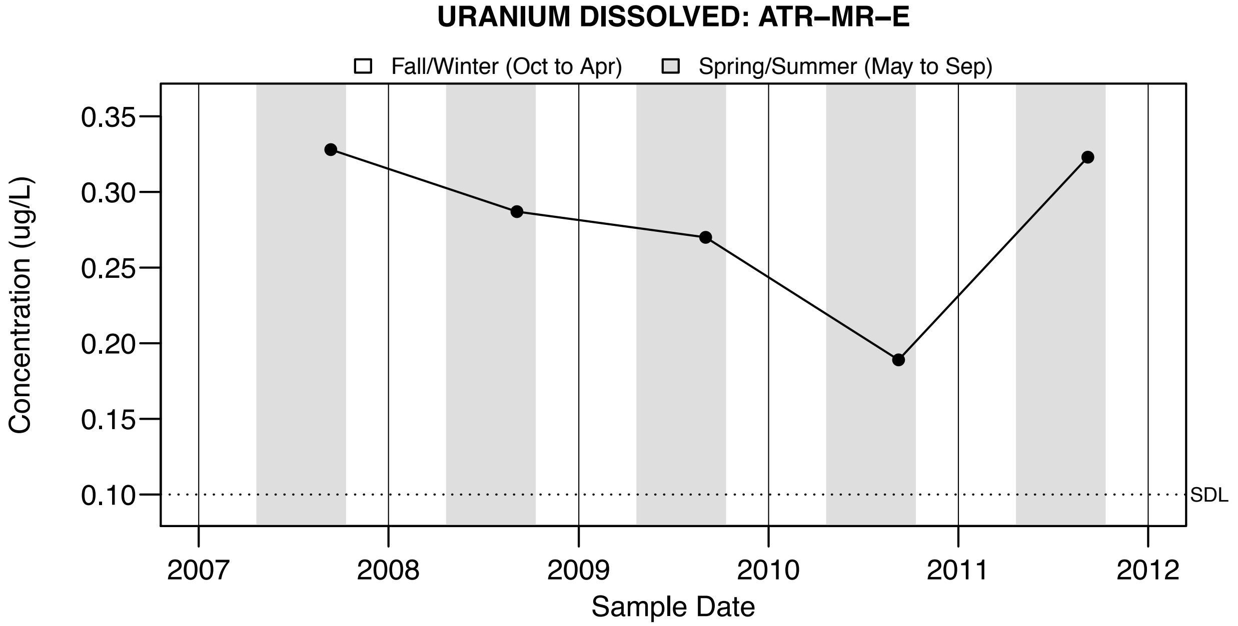


Figure A3.246: URANIUM DISSOLVED: ATR-MR-E -

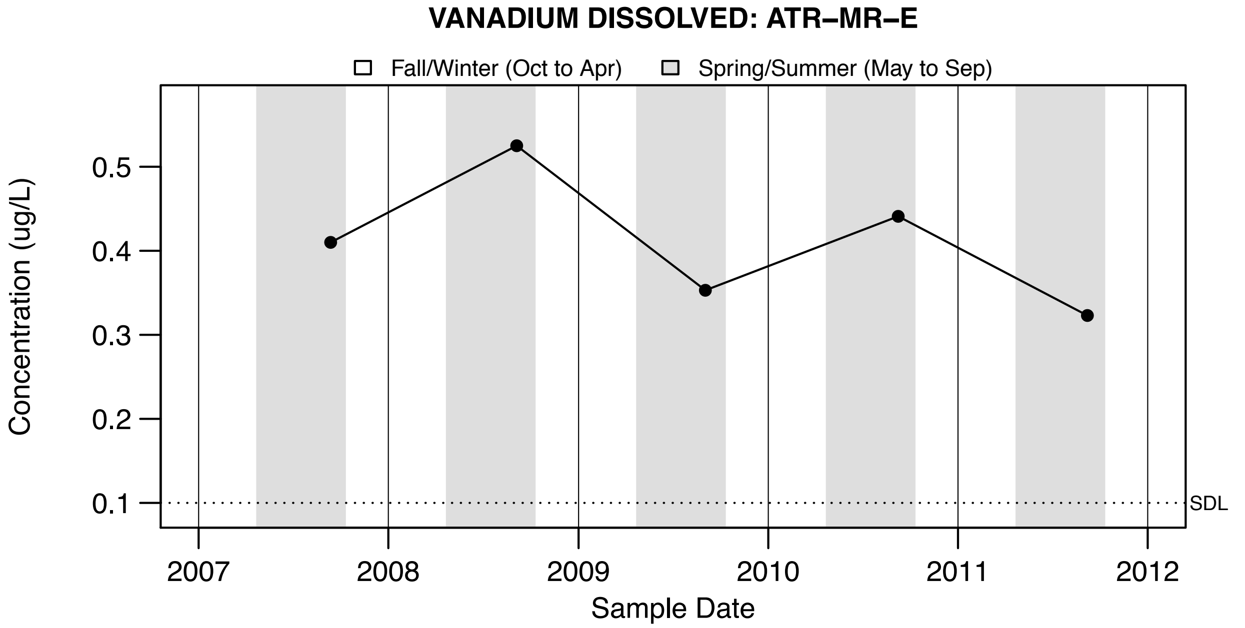


Figure A3.247: VANADIUM DISSOLVED: ATR-MR-E -

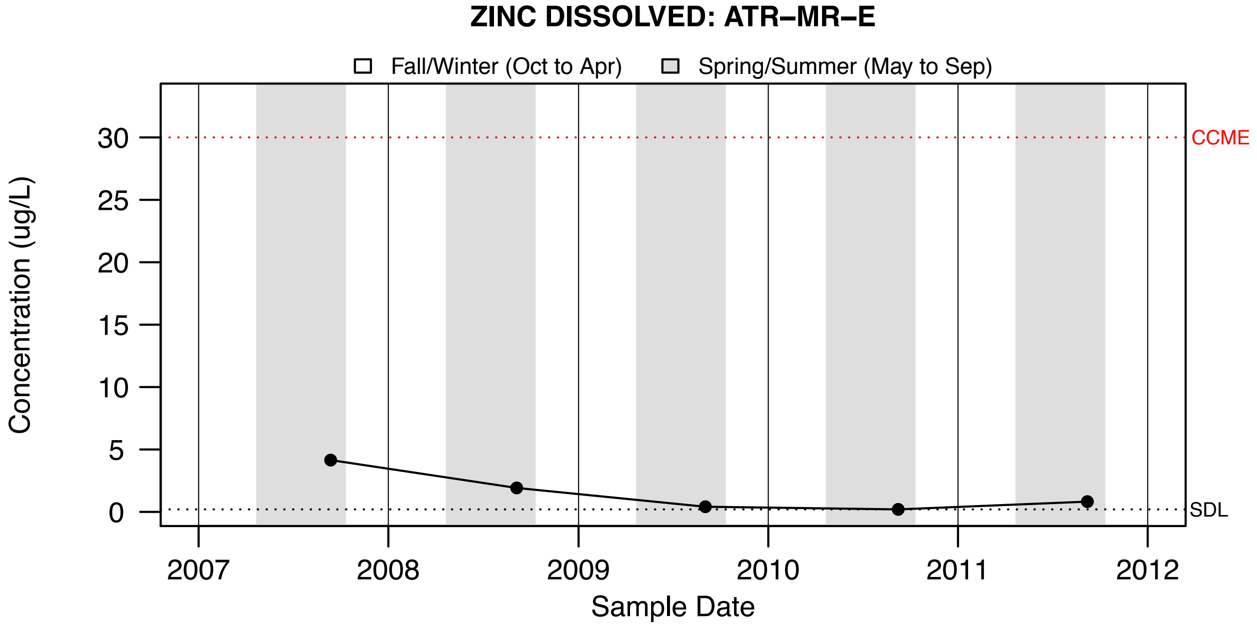


Figure A3.248: ZINC DISSOLVED: ATR-MR-E -

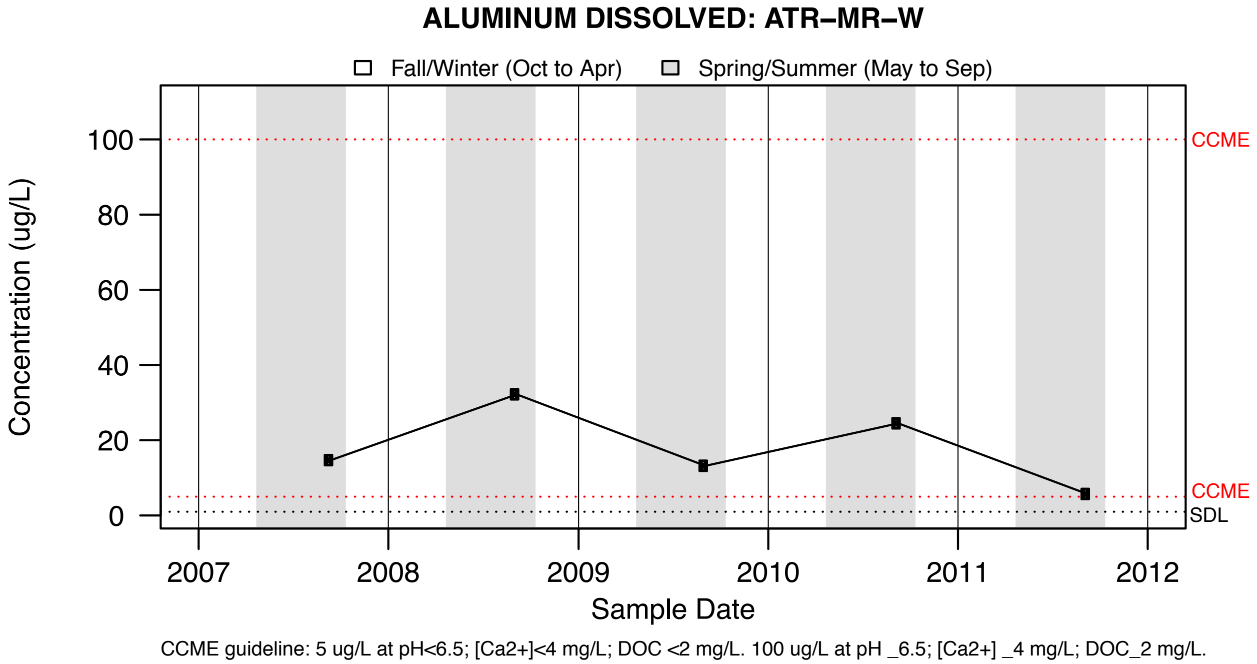


Figure A3.249: ALUMINUM DISSOLVED: ATR-MR-W -

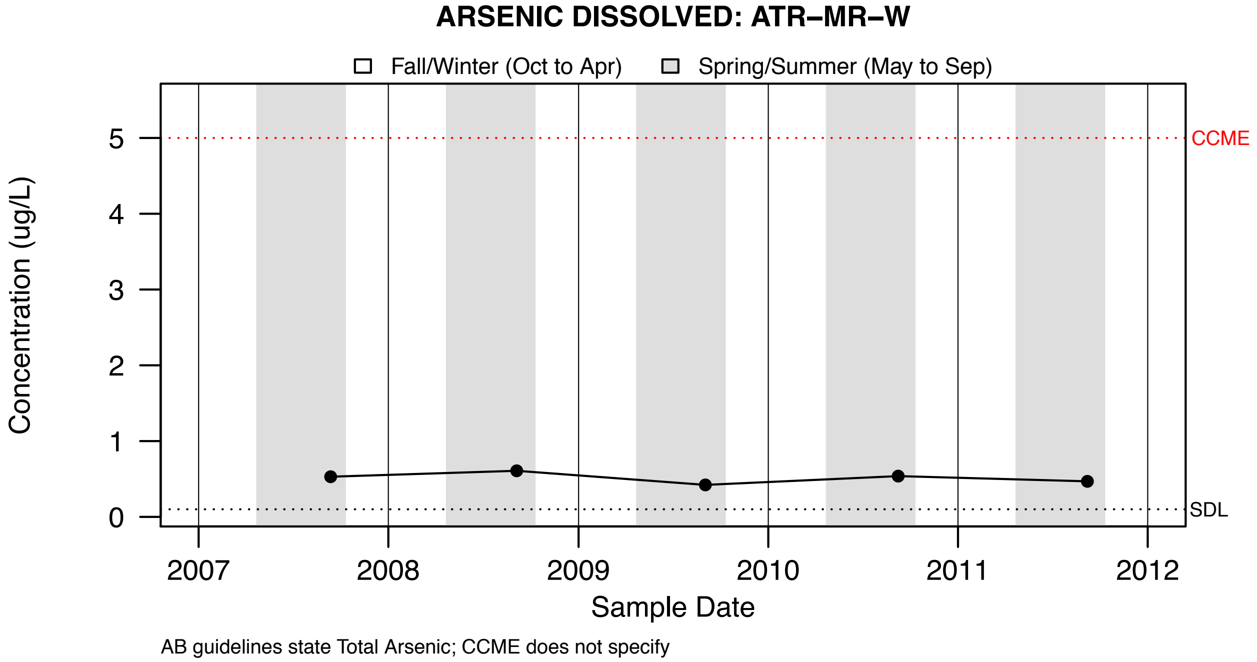


Figure A3.250: ARSENIC DISSOLVED: ATR-MR-W -

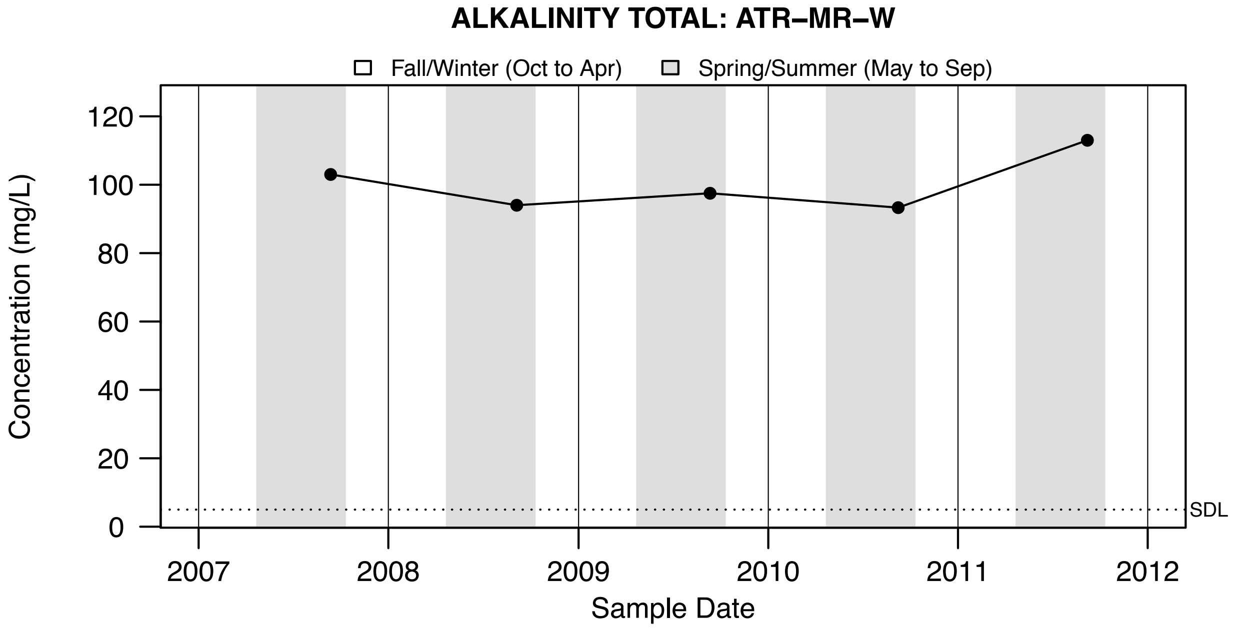


Figure A3.251: ALKALINITY TOTAL: ATR-MR-W -

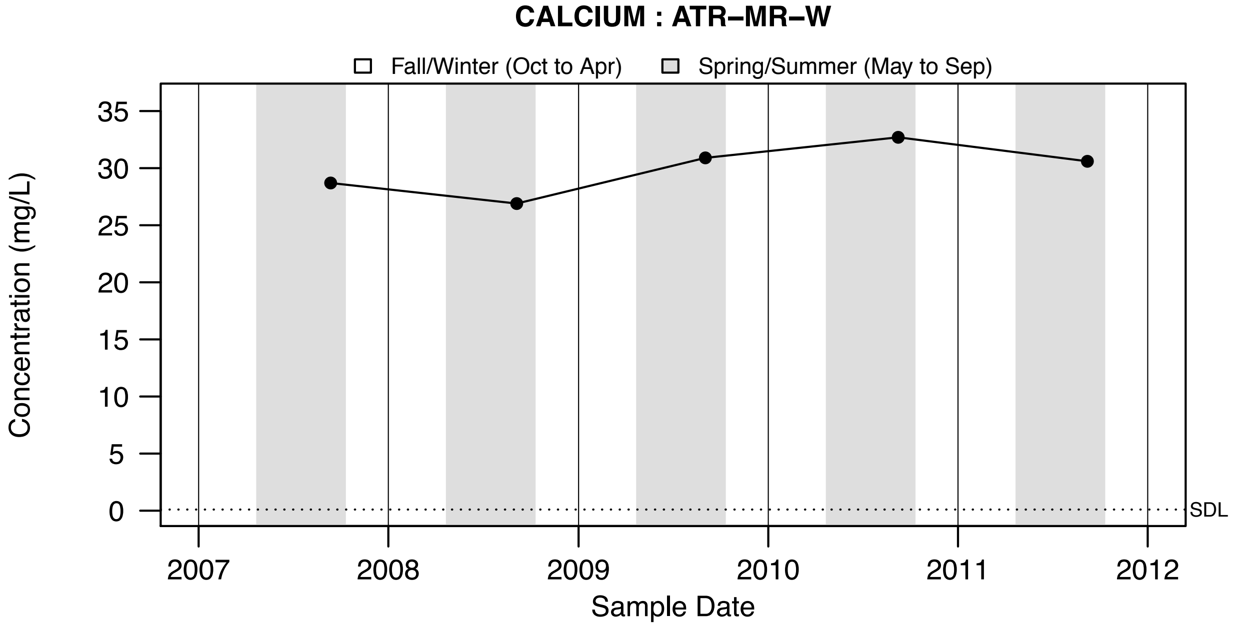


Figure A3.252: CALCIUM : ATR-MR-W -

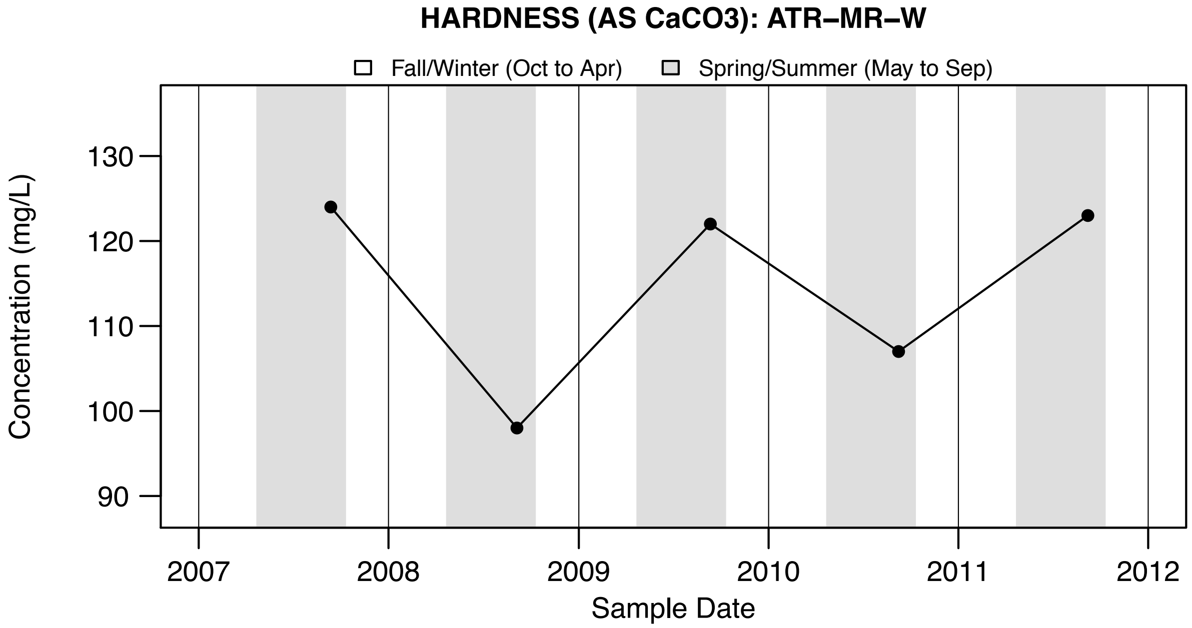
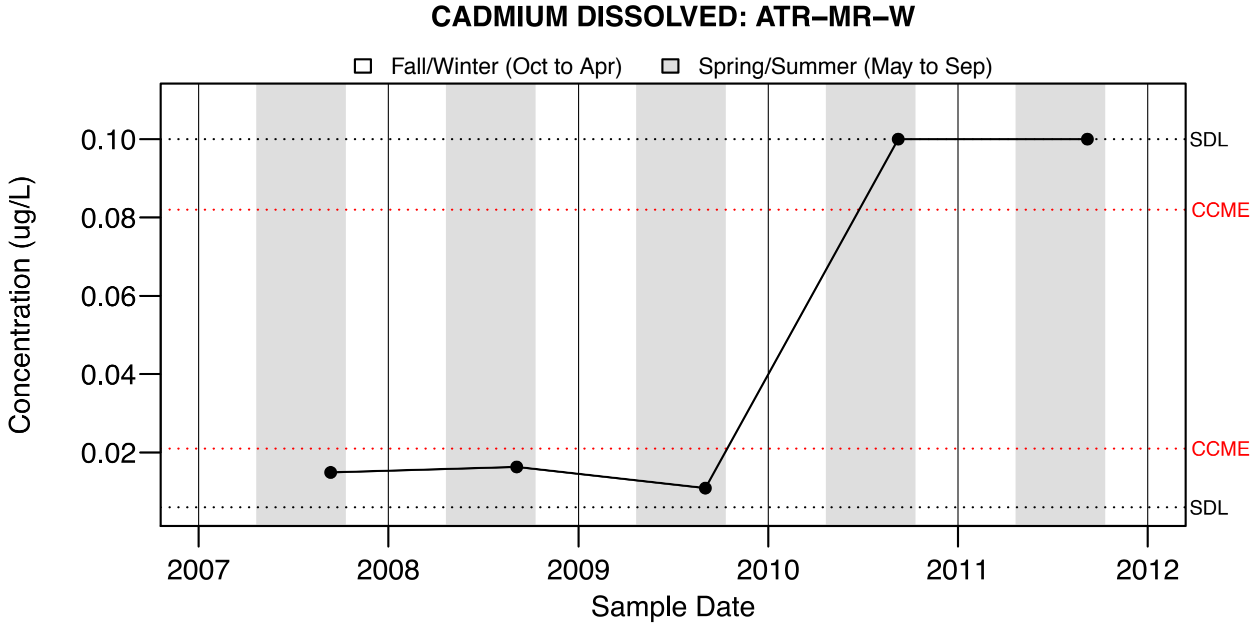


Figure A3.253: HARDNESS (AS CaCO3): ATR-MR-W -



Related to hardness as CaCo3

Figure A3.254: CADMIUM DISSOLVED: ATR-MR-W -

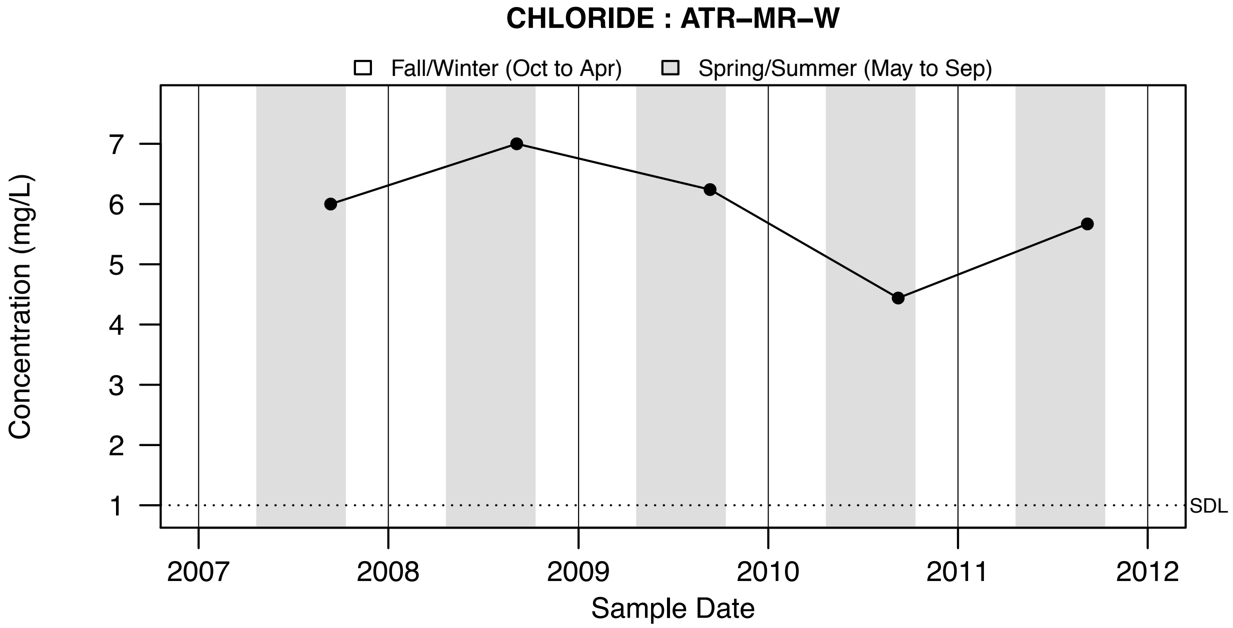


Figure A3.255: CHLORIDE : ATR-MR-W -

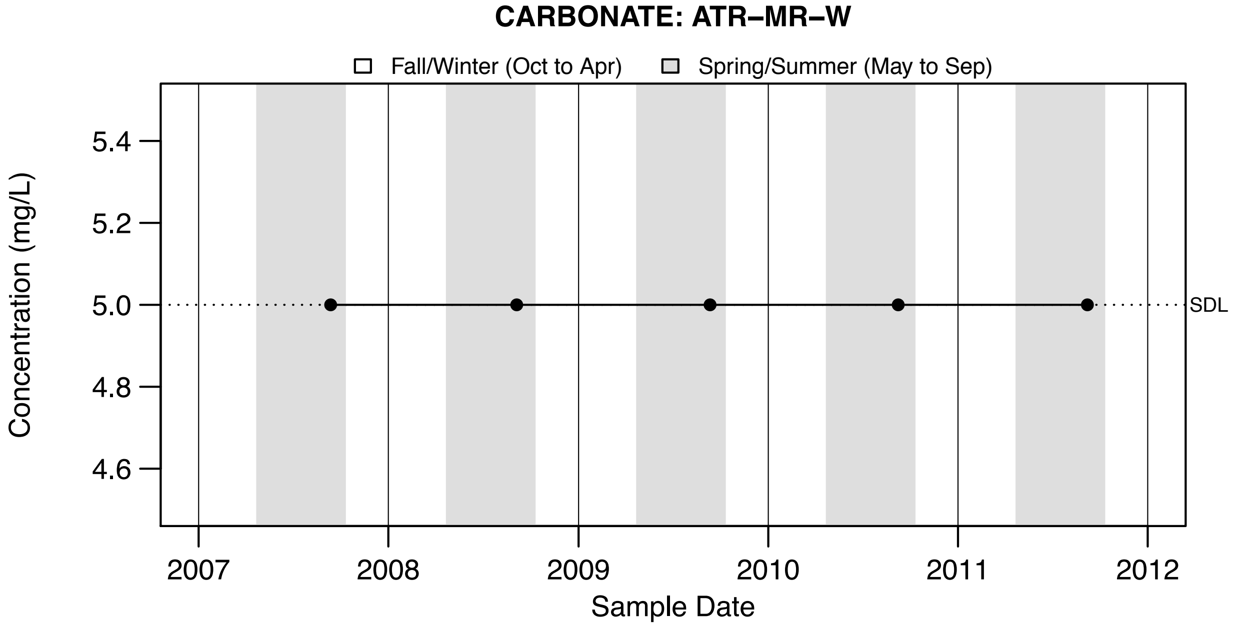


Figure A3.256: CARBONATE: ATR-MR-W -

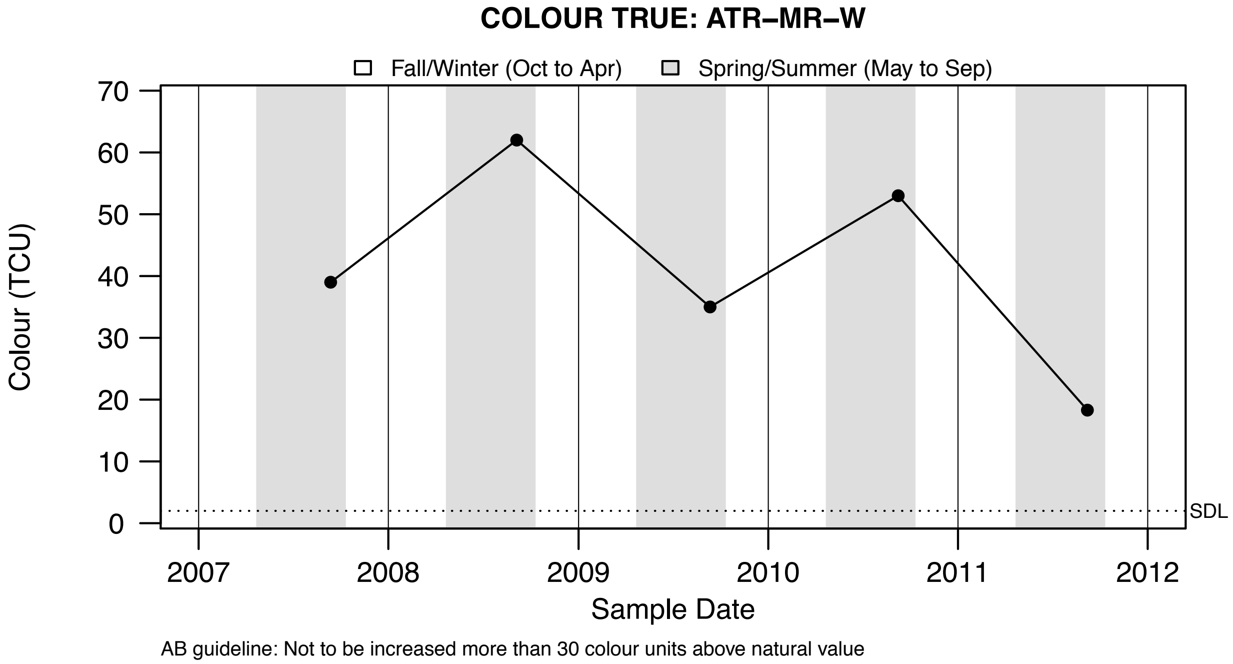


Figure A3.257: COLOUR TRUE: ATR-MR-W -

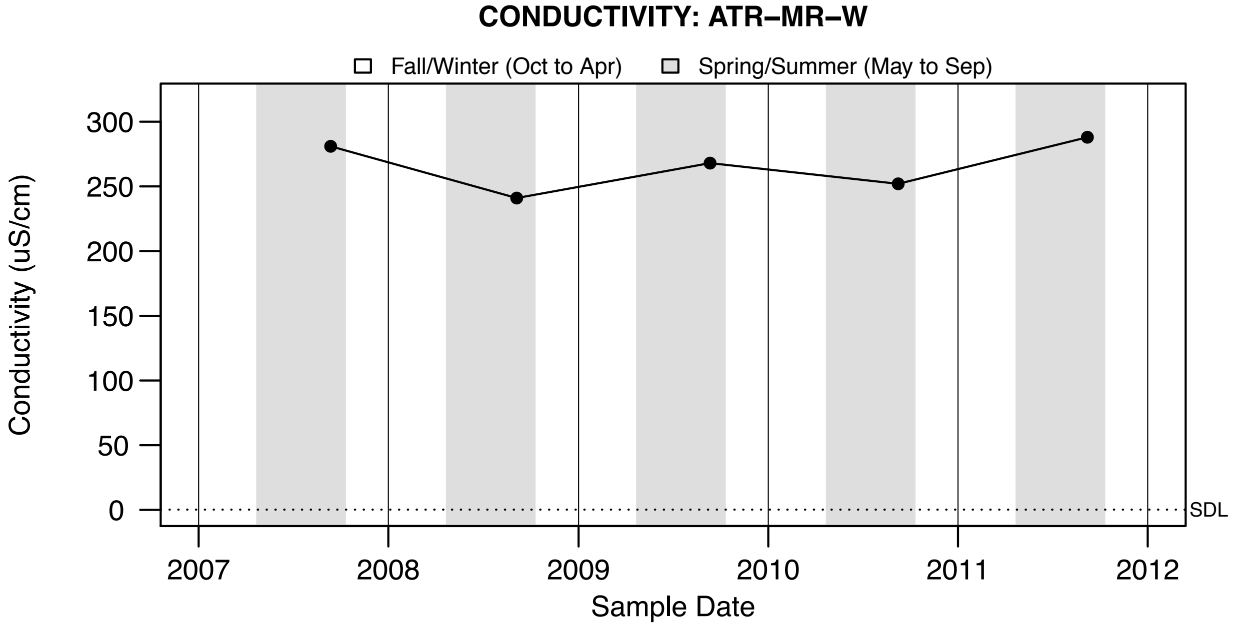
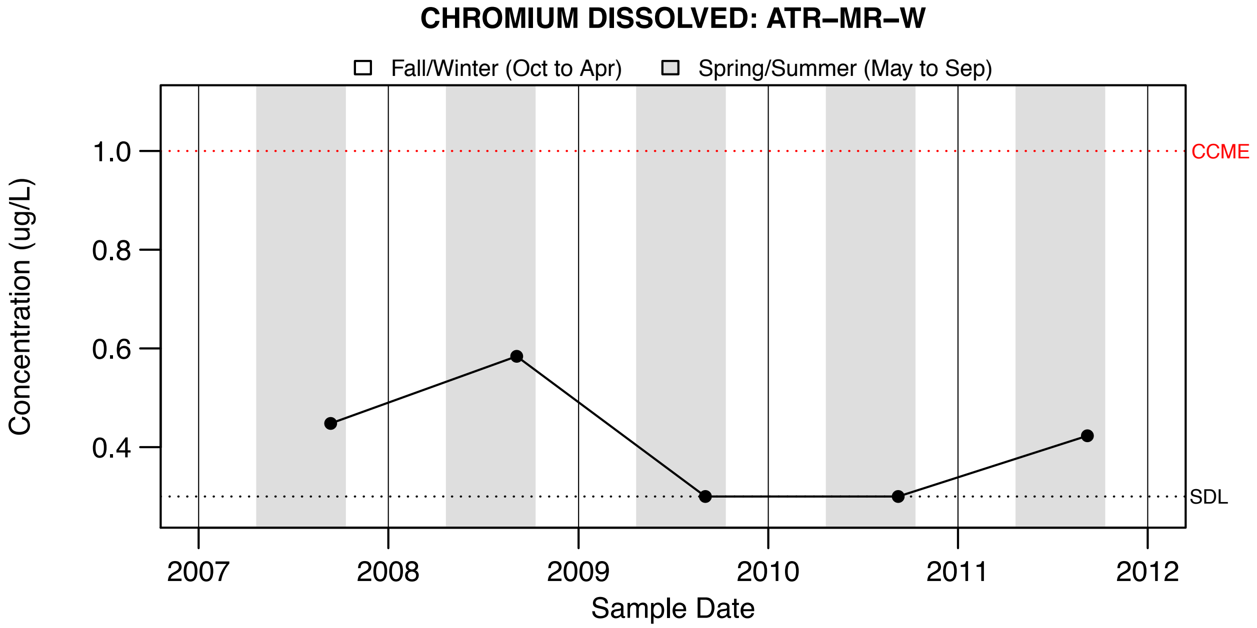
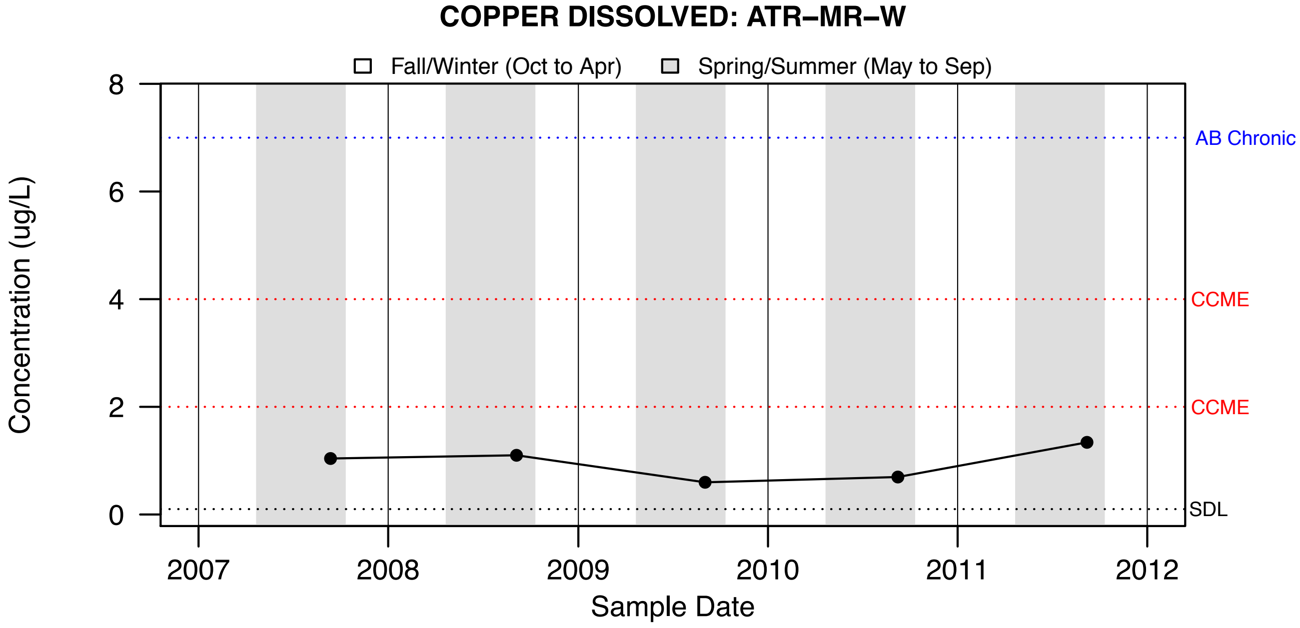


Figure A3.258: CONDUCTIVITY: ATR-MR-W -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.259: CHROMIUM DISSOLVED: ATR-MR-W -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.260: COPPER DISSOLVED: ATR-MR-W -

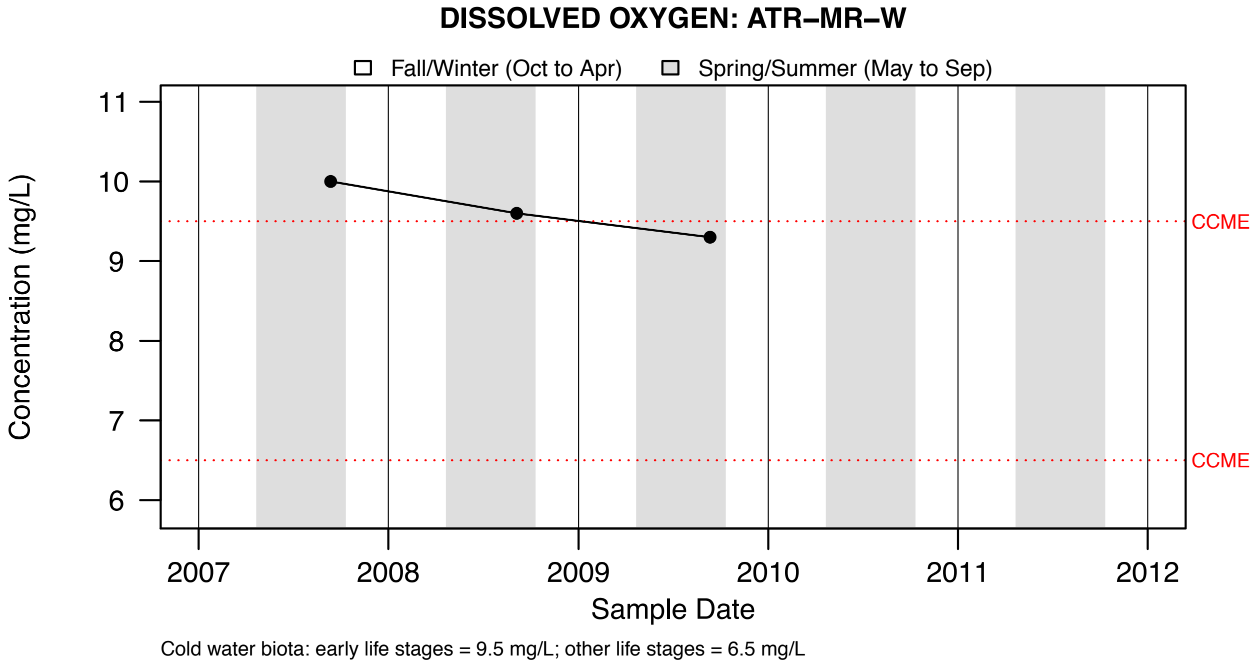


Figure A3.261: DISSOLVED OXYGEN: ATR-MR-W -

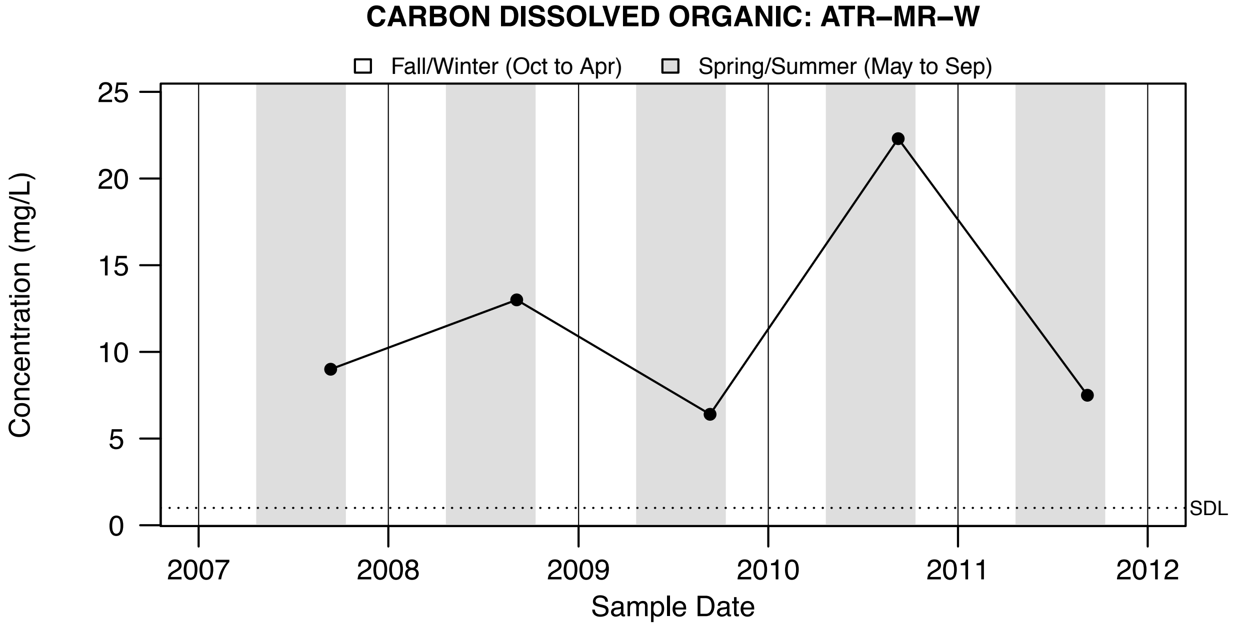


Figure A3.262: CARBON DISSOLVED ORGANIC: ATR-MR-W -

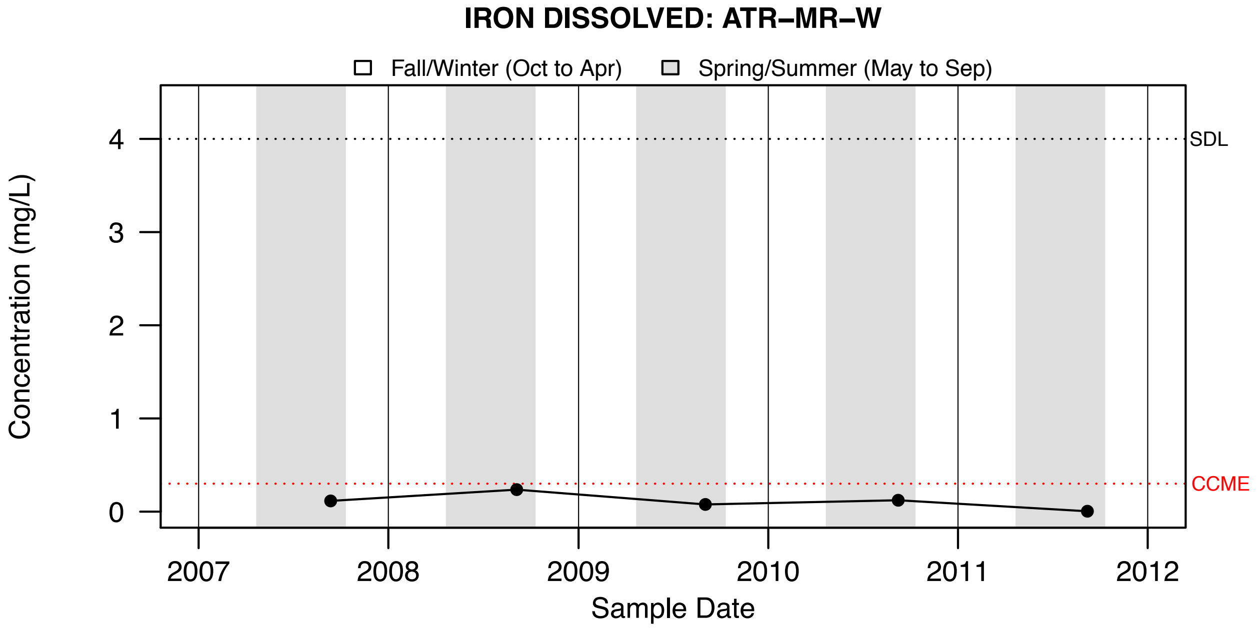


Figure A3.263: IRON DISSOLVED: ATR-MR-W -

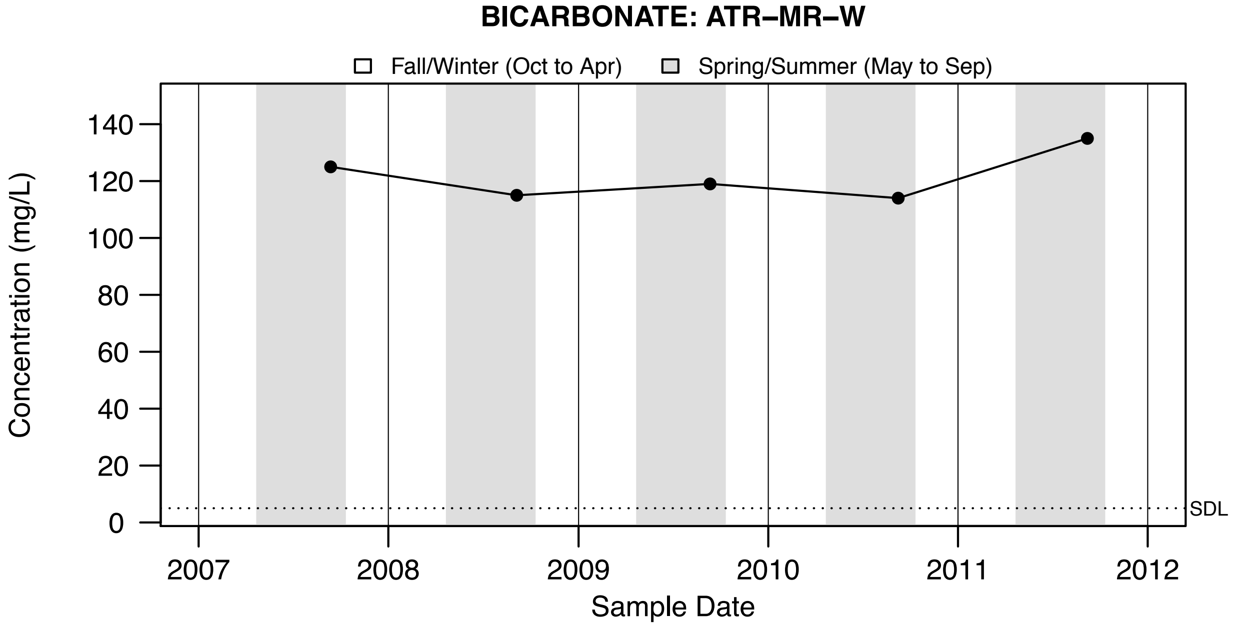


Figure A3.264: BICARBONATE: ATR-MR-W -

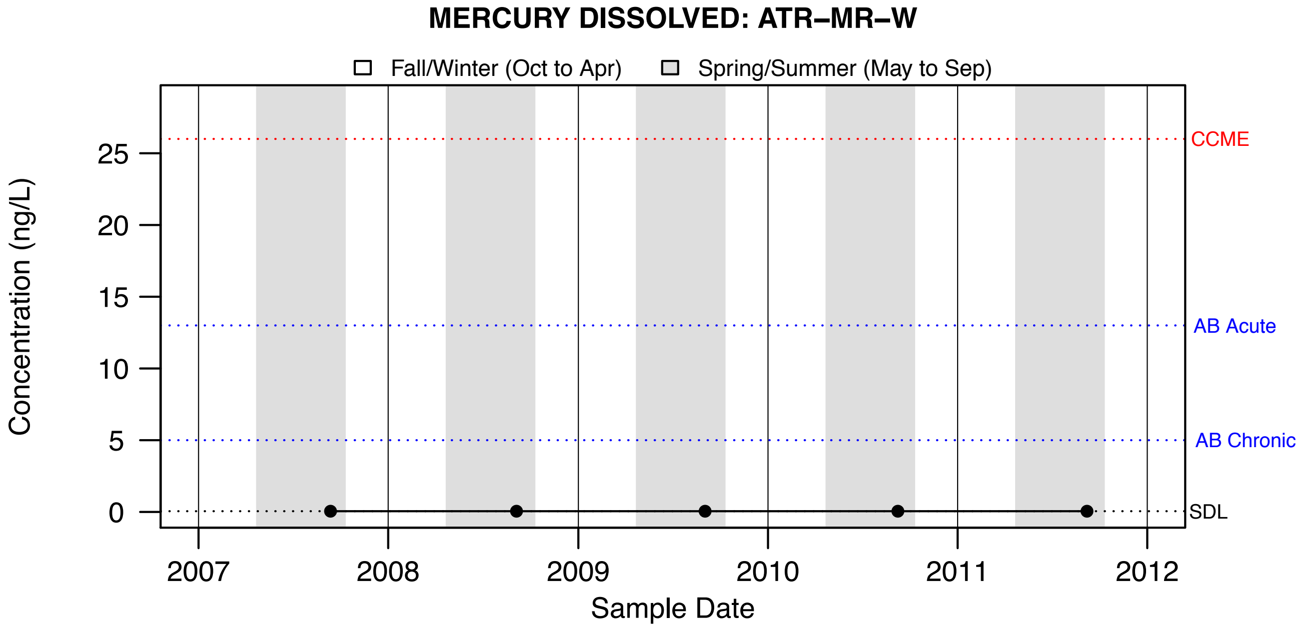


Figure A3.265: MERCURY DISSOLVED: ATR-MR-W -

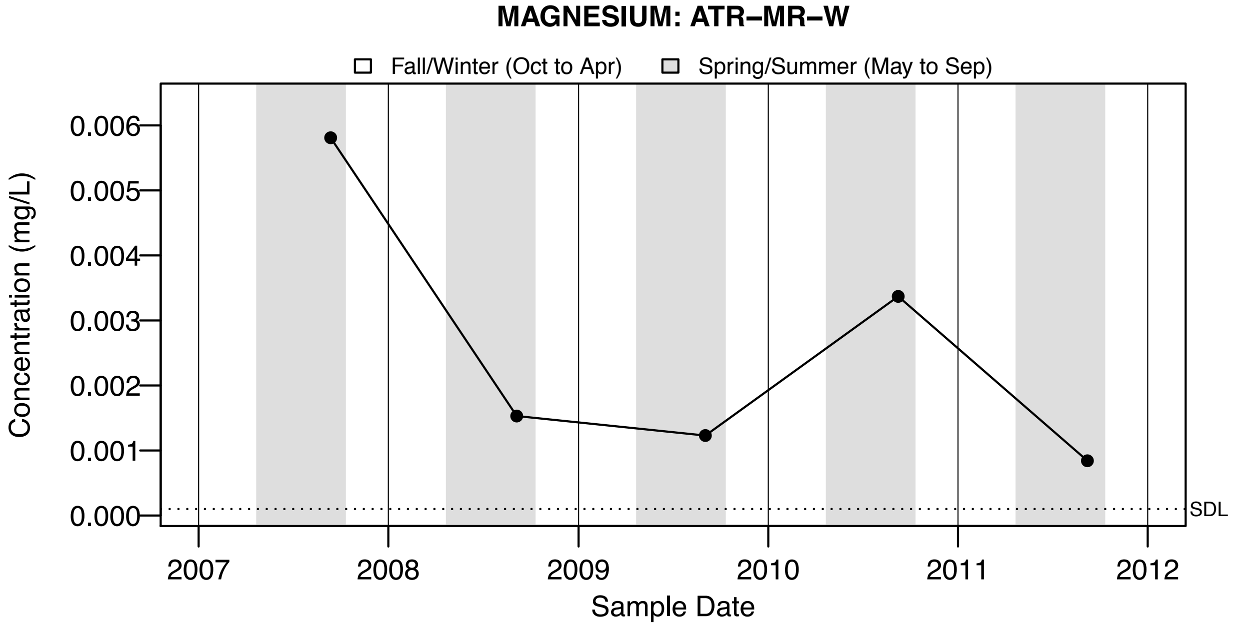


Figure A3.266: MAGNESIUM: ATR-MR-W -

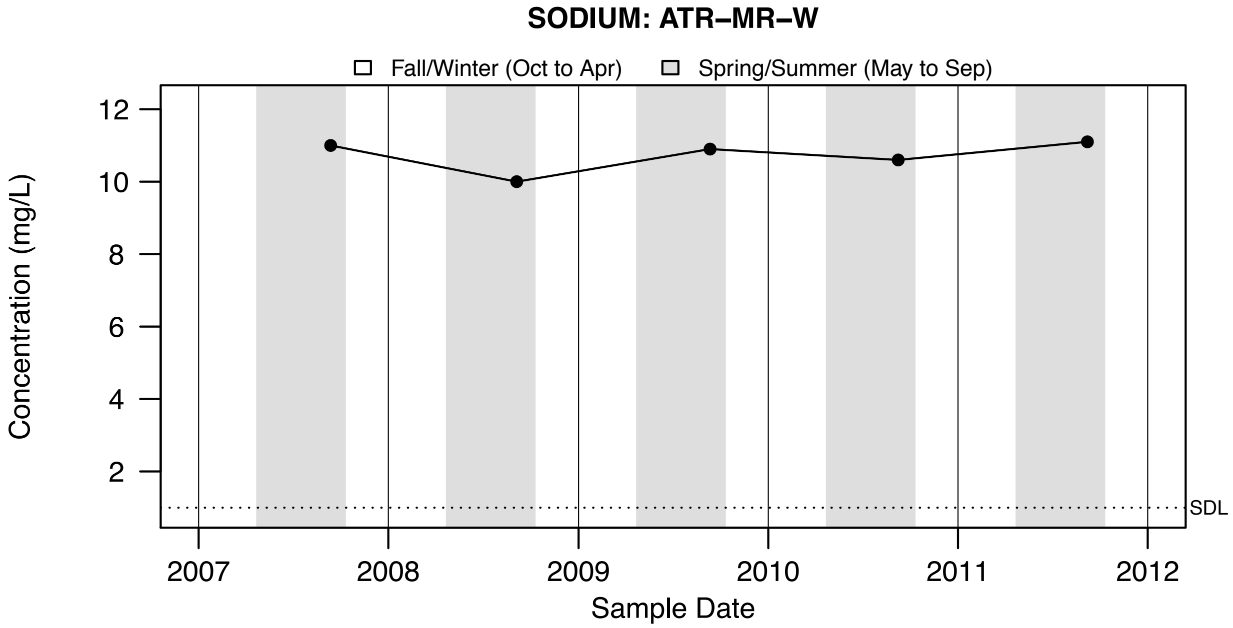
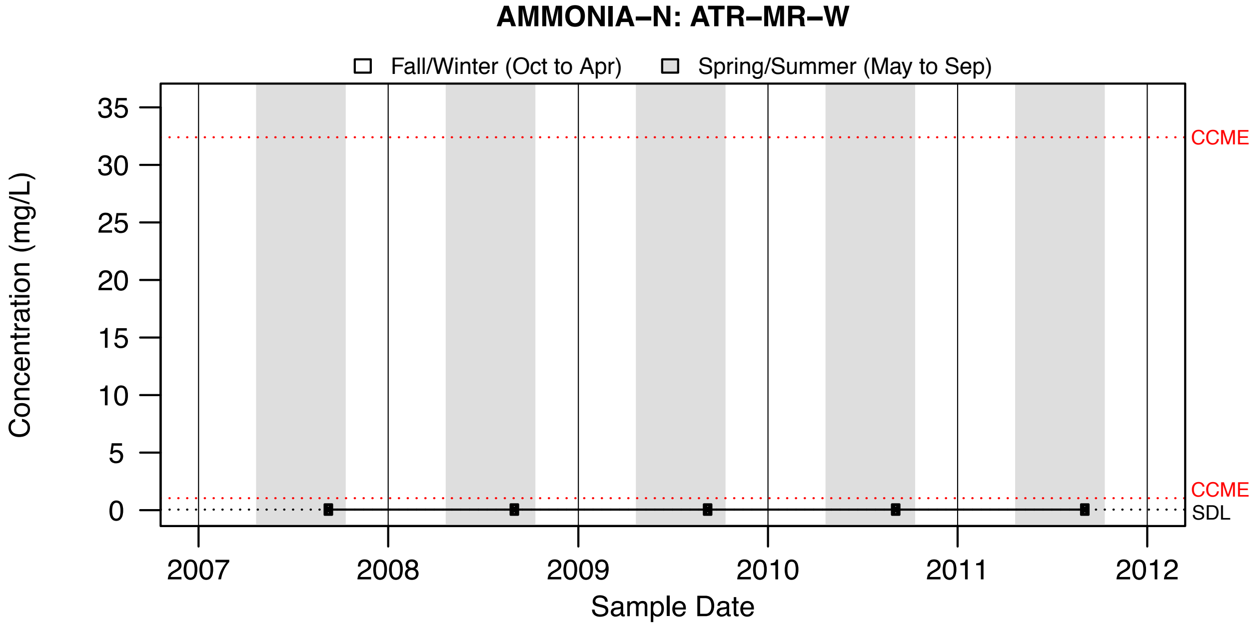
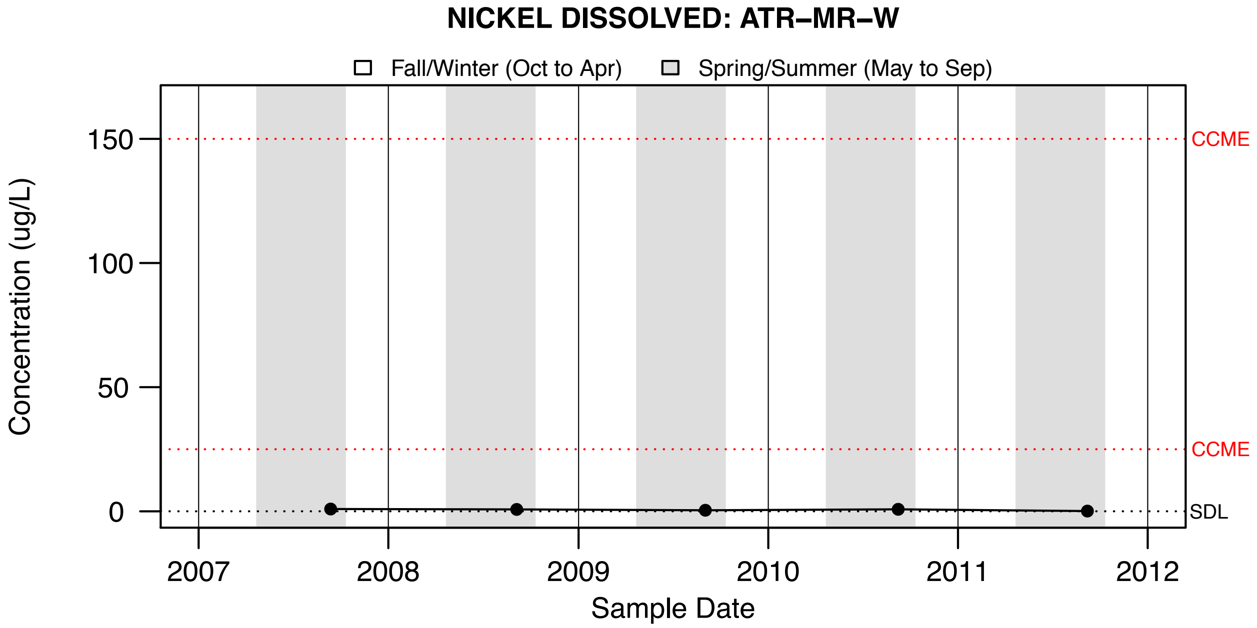


Figure A3.267: SODIUM: ATR-MR-W -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.268: AMMONIA-N: ATR-MR-W -



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A3.269: NICKEL DISSOLVED: ATR-MR-W -

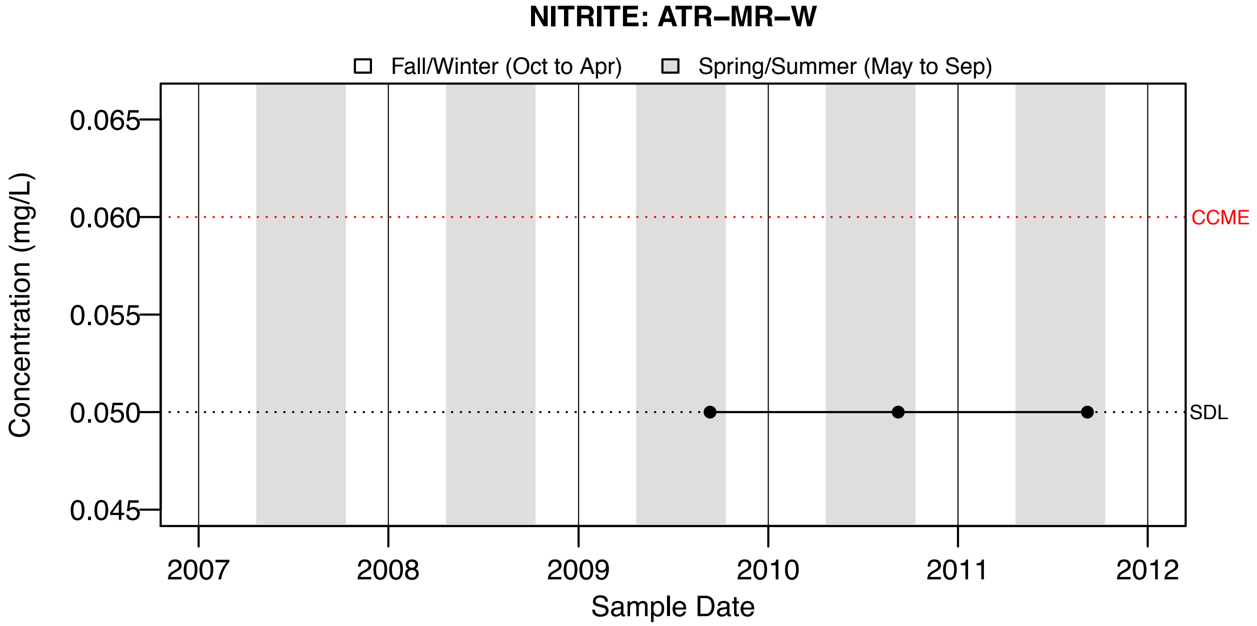
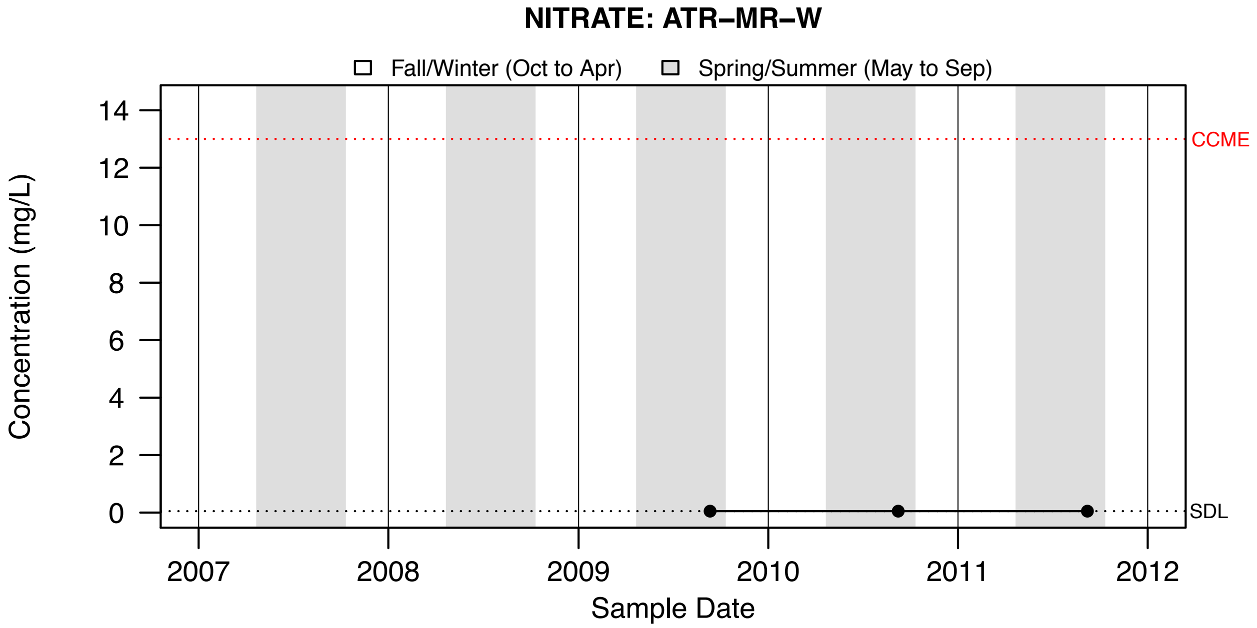


Figure A3.270: NITRITE: ATR-MR-W -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.271: NITRATE: ATR-MR-W -

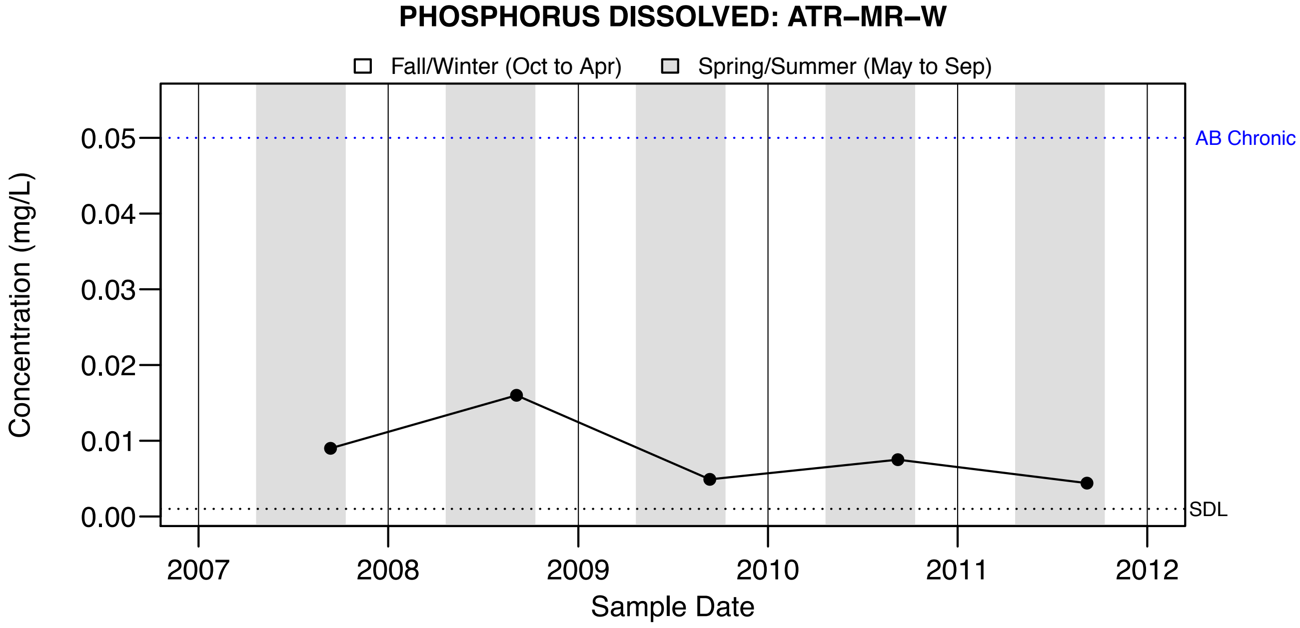


Figure A3.272: PHOSPHORUS DISSOLVED: ATR-MR-W -

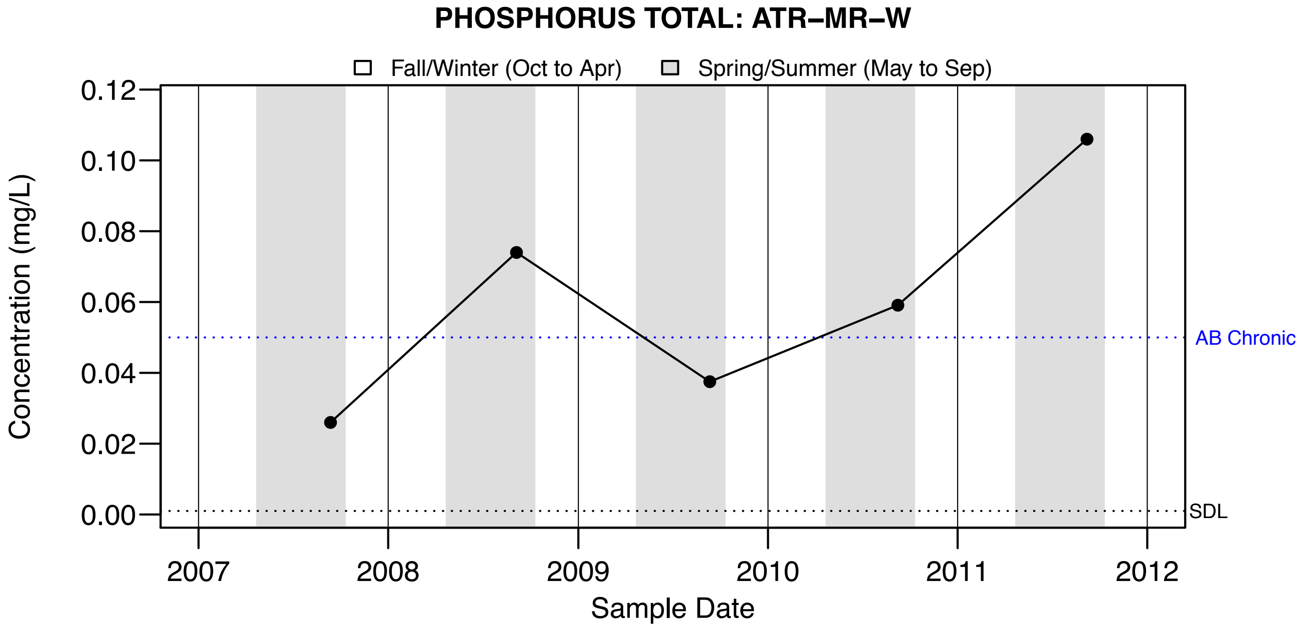
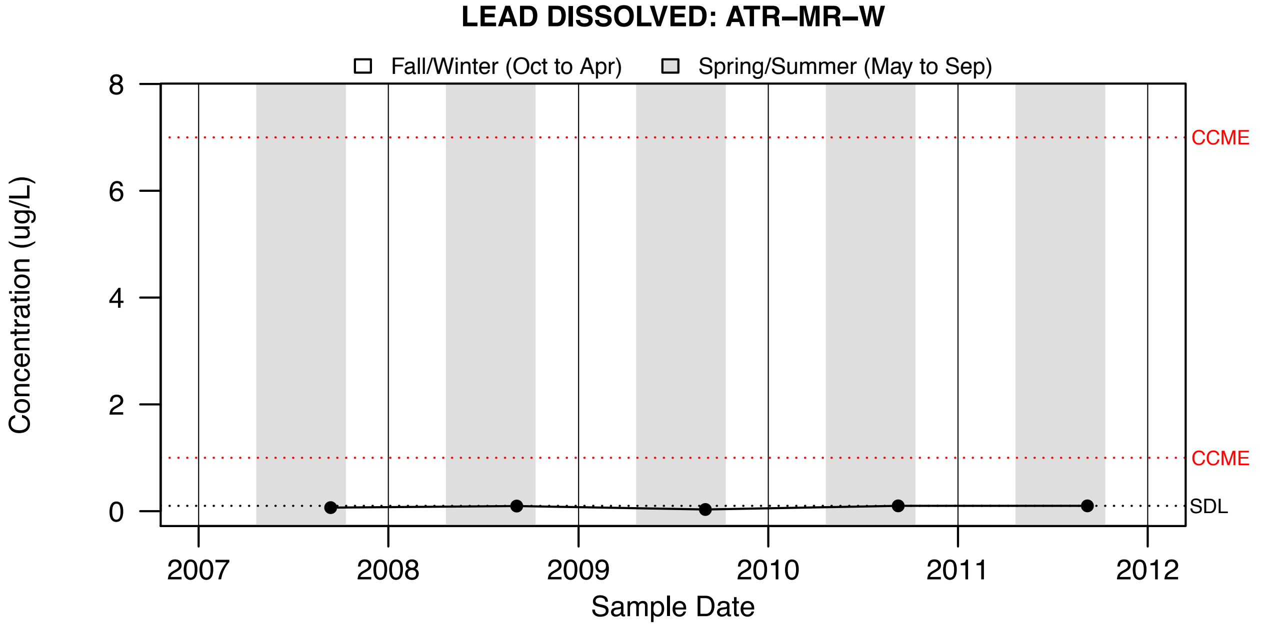


Figure A3.273: PHOSPHORUS TOTAL: ATR-MR-W -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.274: LEAD DISSOLVED: ATR-MR-W -

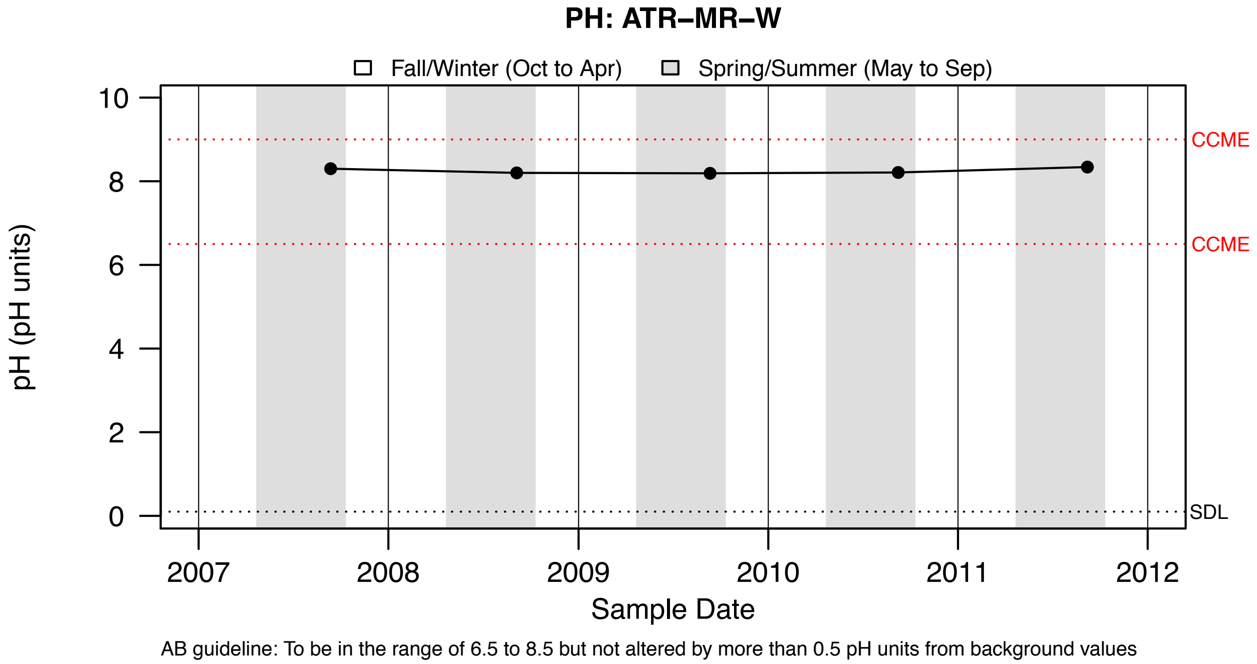


Figure A3.275: PH: ATR-MR-W -

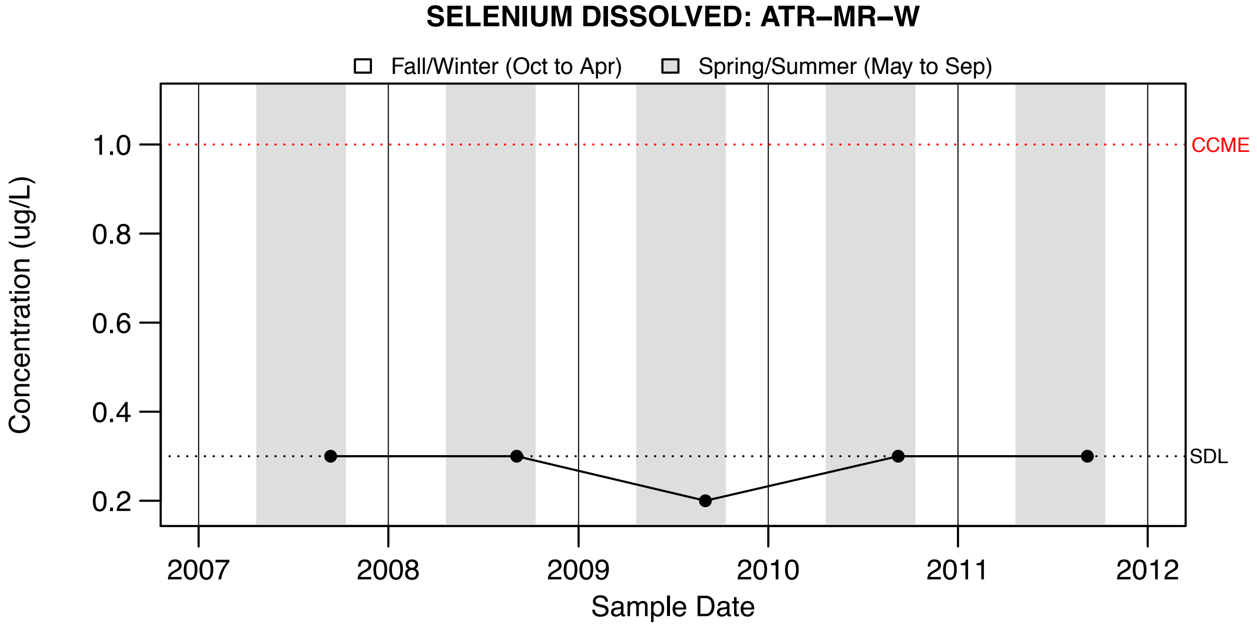


Figure A3.276: SELENIUM DISSOLVED: ATR-MR-W -

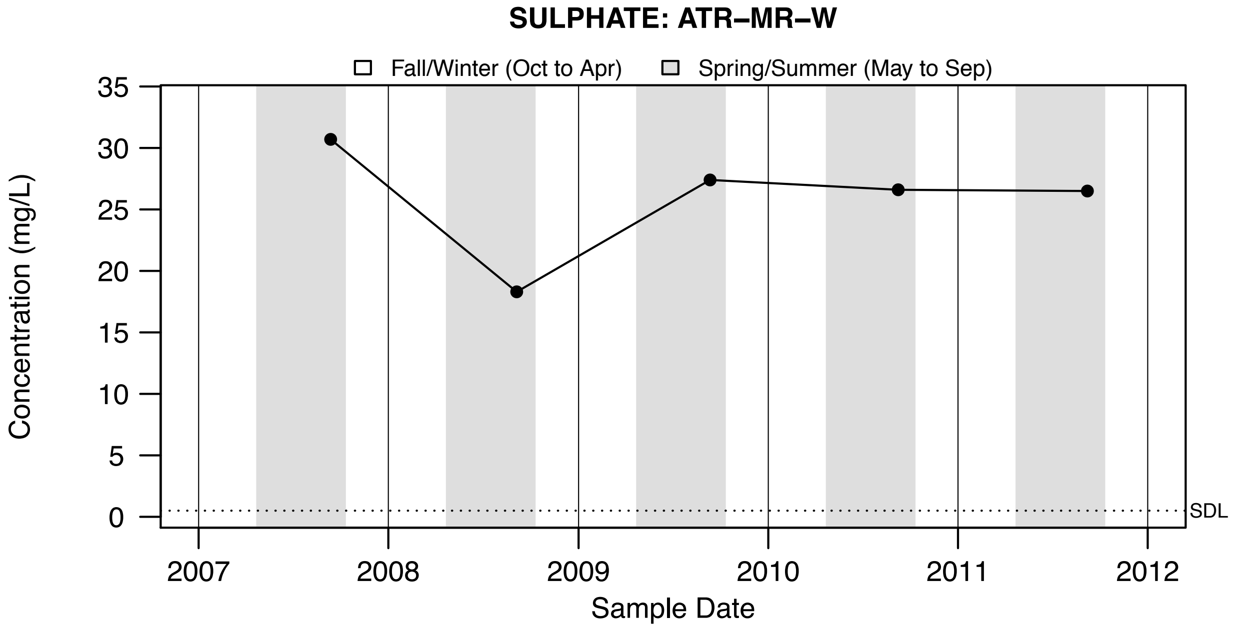


Figure A3.277: SULPHATE: ATR-MR-W -

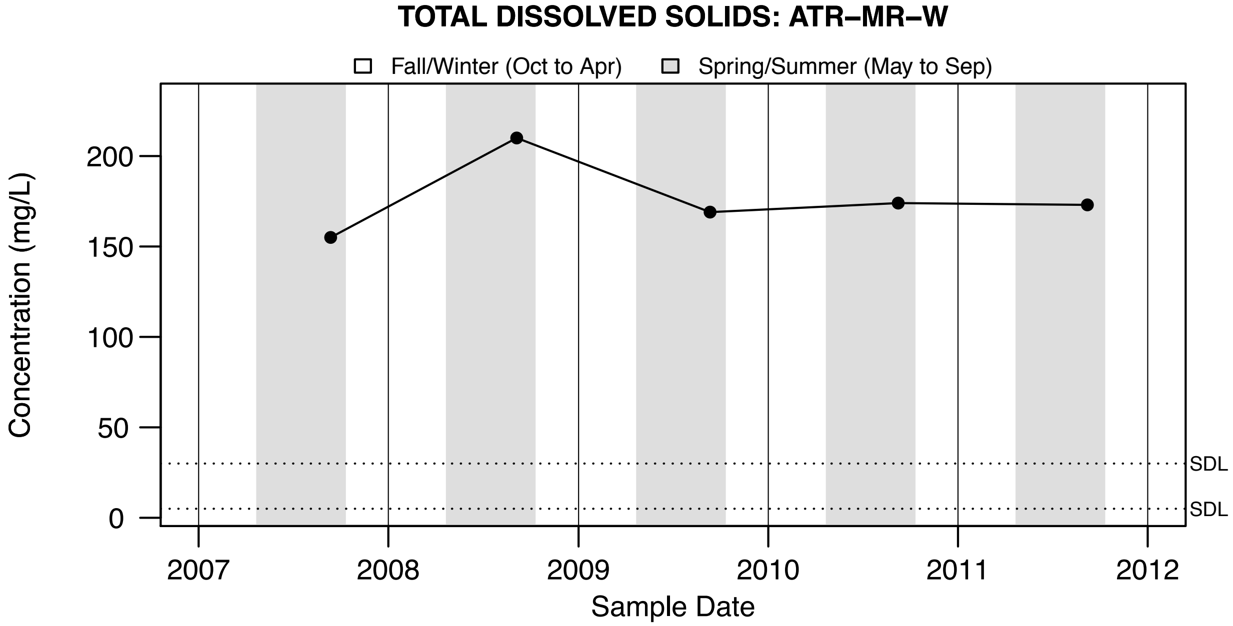
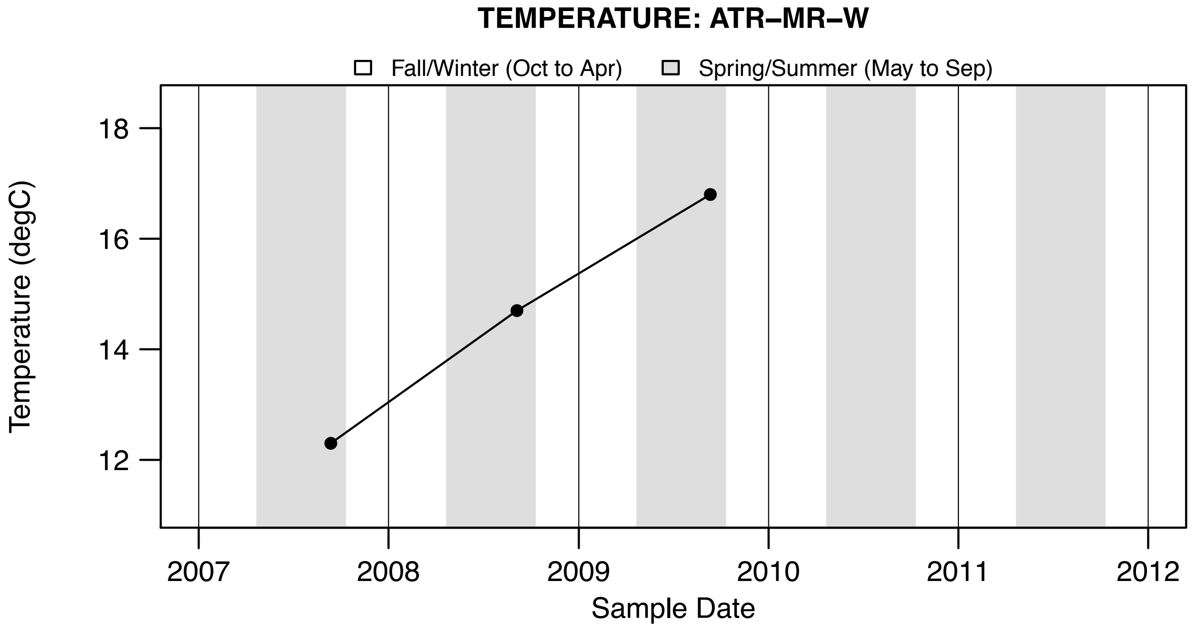


Figure A3.278: TOTAL DISSOLVED SOLIDS: ATR-MR-W -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.279: TEMPERATURE: ATR-MR-W -

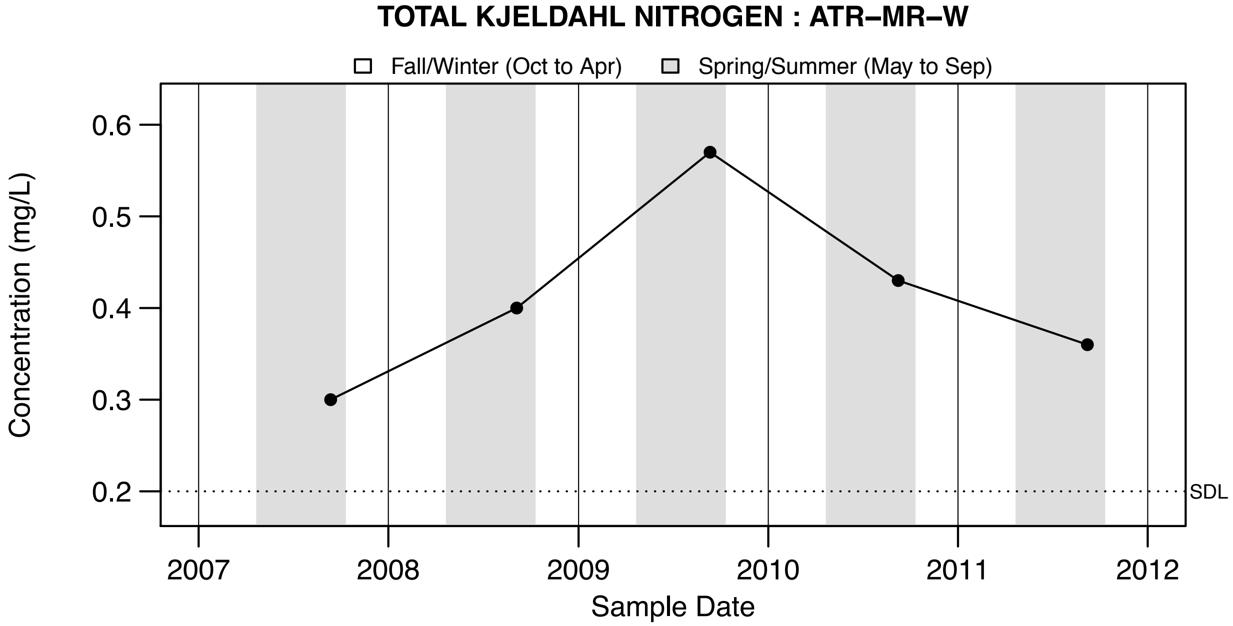
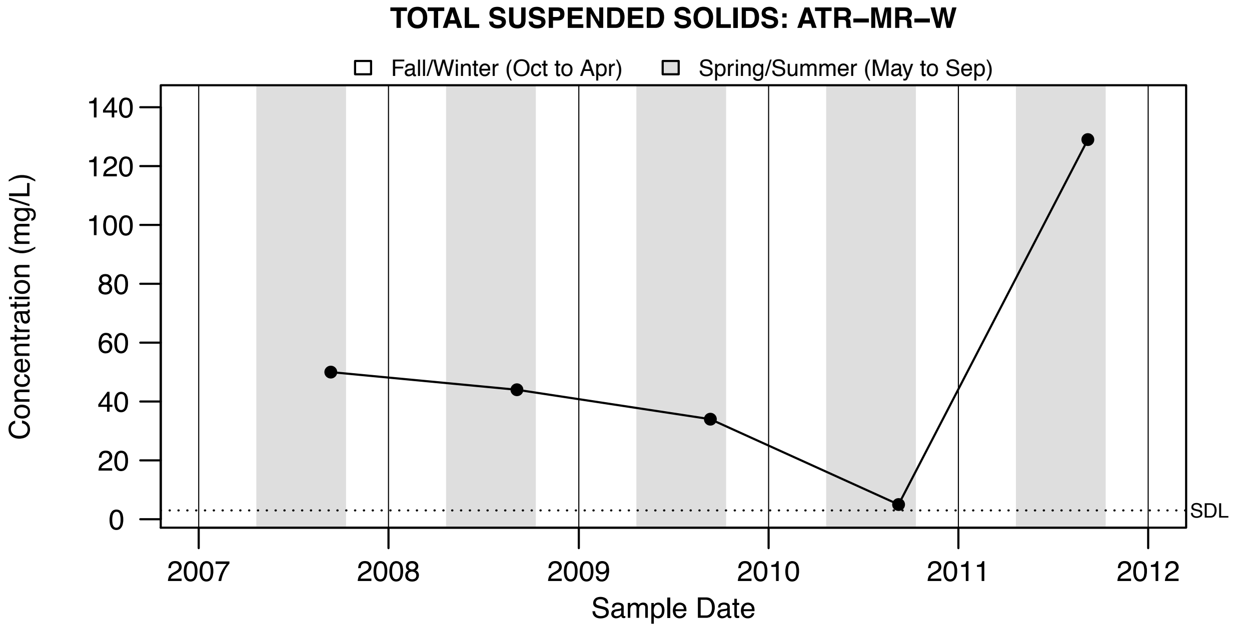


Figure A3.280: TOTAL KJELDAHL NITROGEN : ATR-MR-W -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.281: TOTAL SUSPENDED SOLIDS: ATR-MR-W -

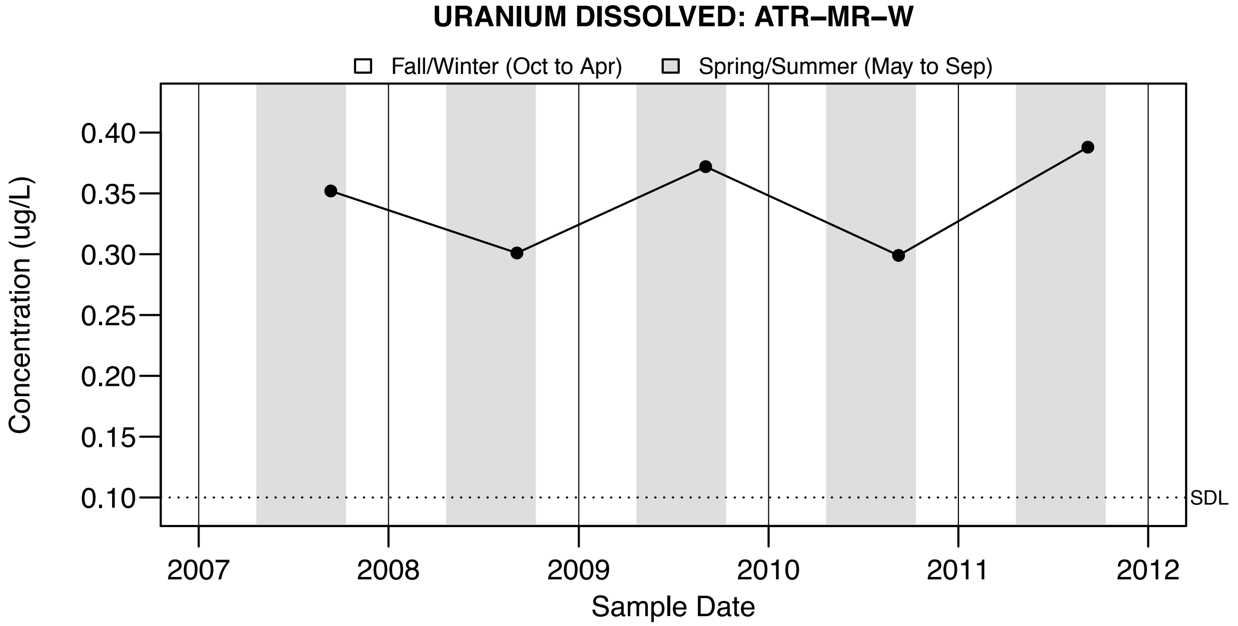


Figure A3.282: URANIUM DISSOLVED: ATR-MR-W -

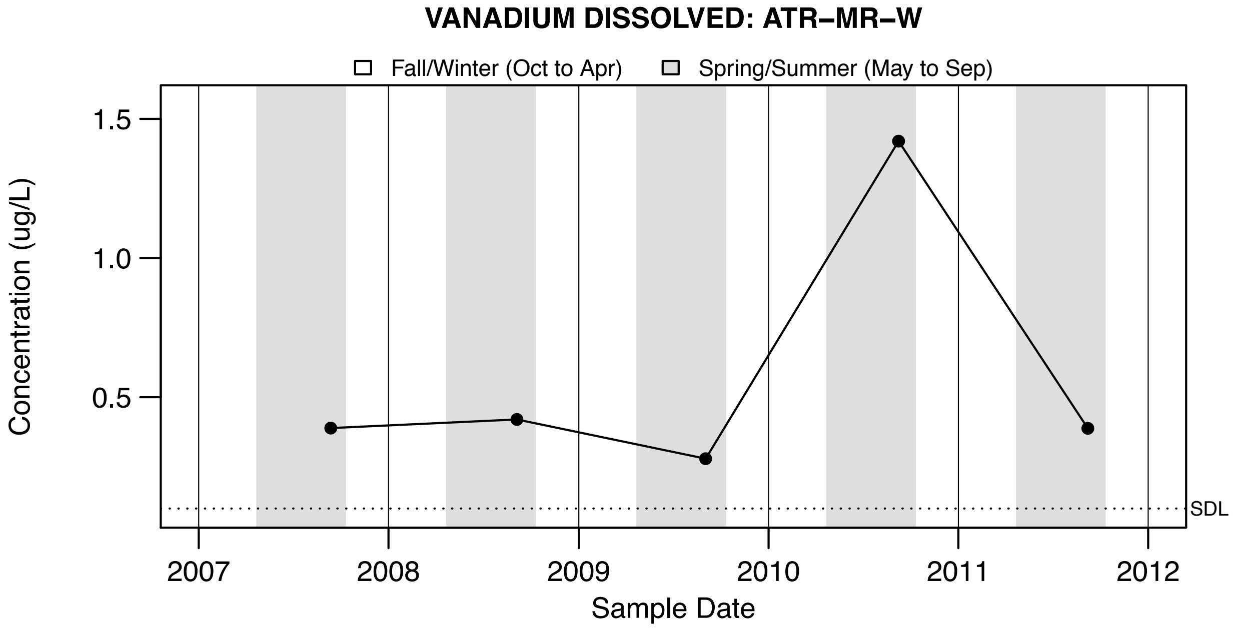


Figure A3.283: VANADIUM DISSOLVED: ATR-MR-W -

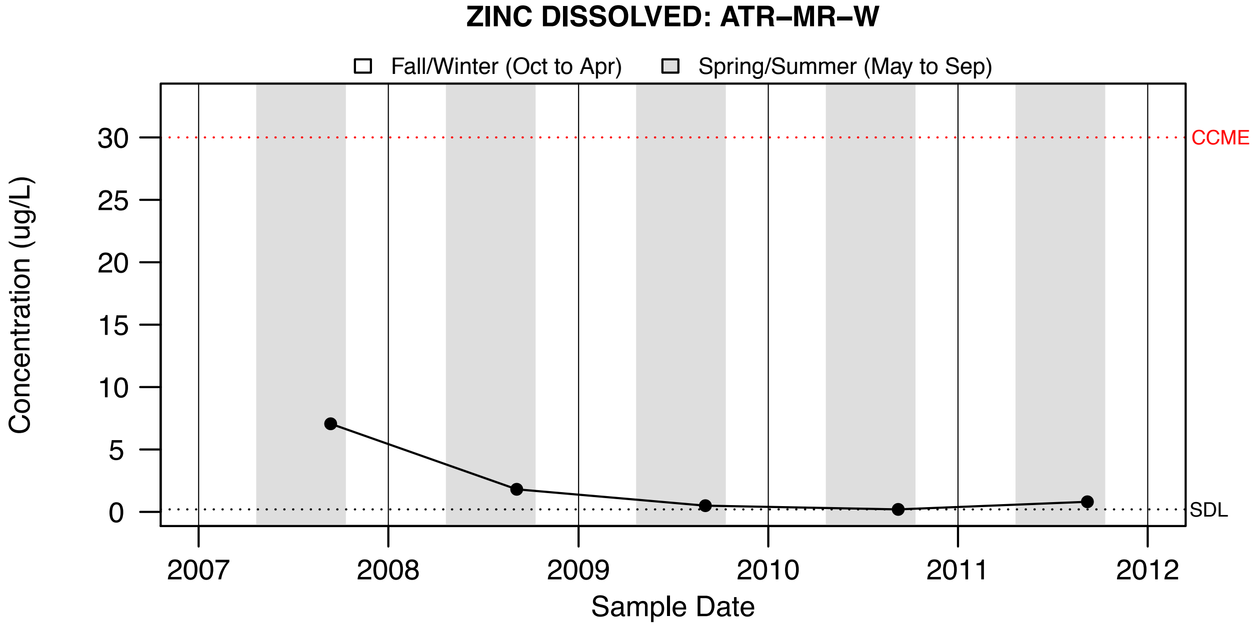
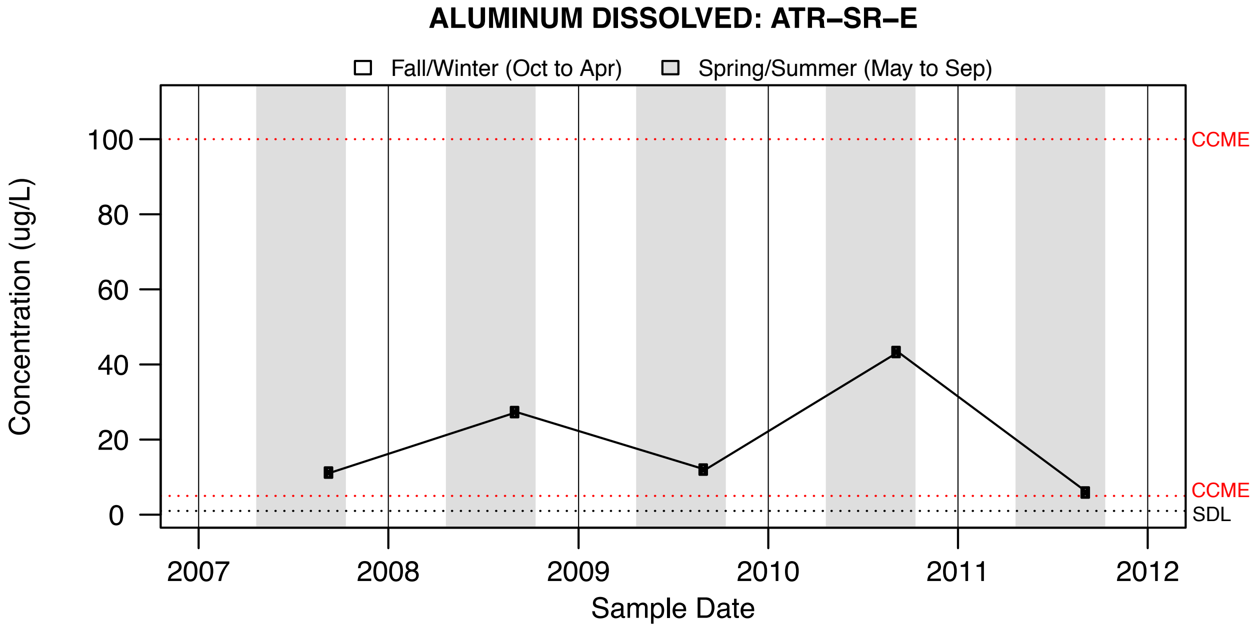
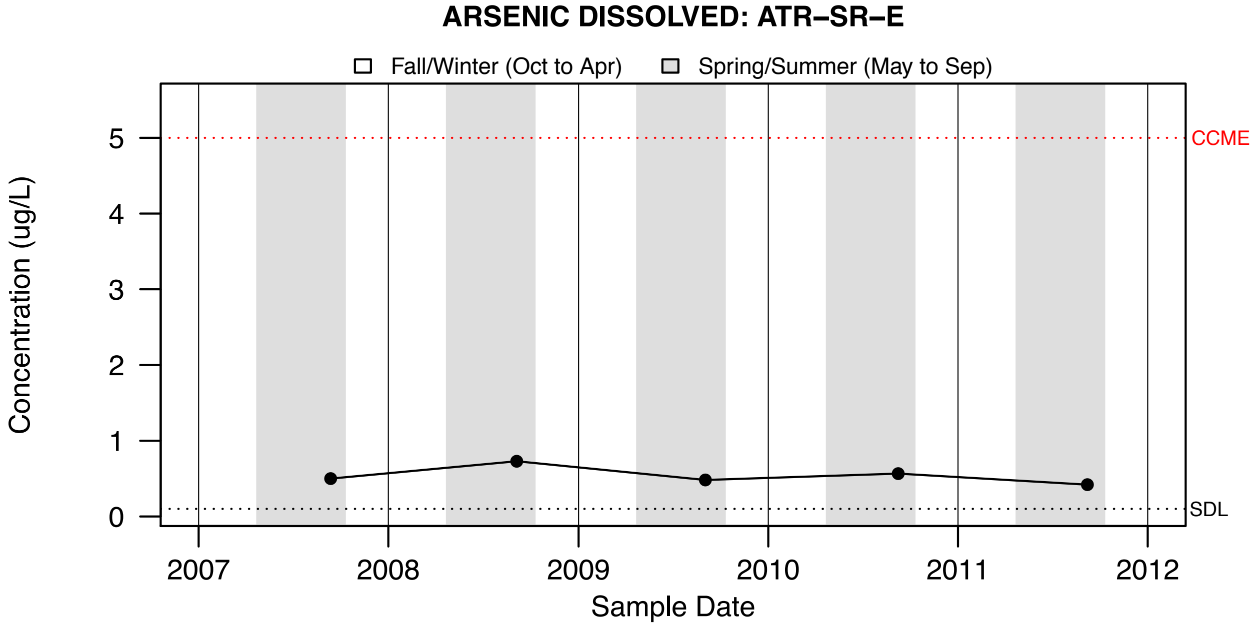


Figure A3.284: ZINC DISSOLVED: ATR-MR-W -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.285: ALUMINUM DISSOLVED: ATR-SR-E -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.286: ARSENIC DISSOLVED: ATR-SR-E -

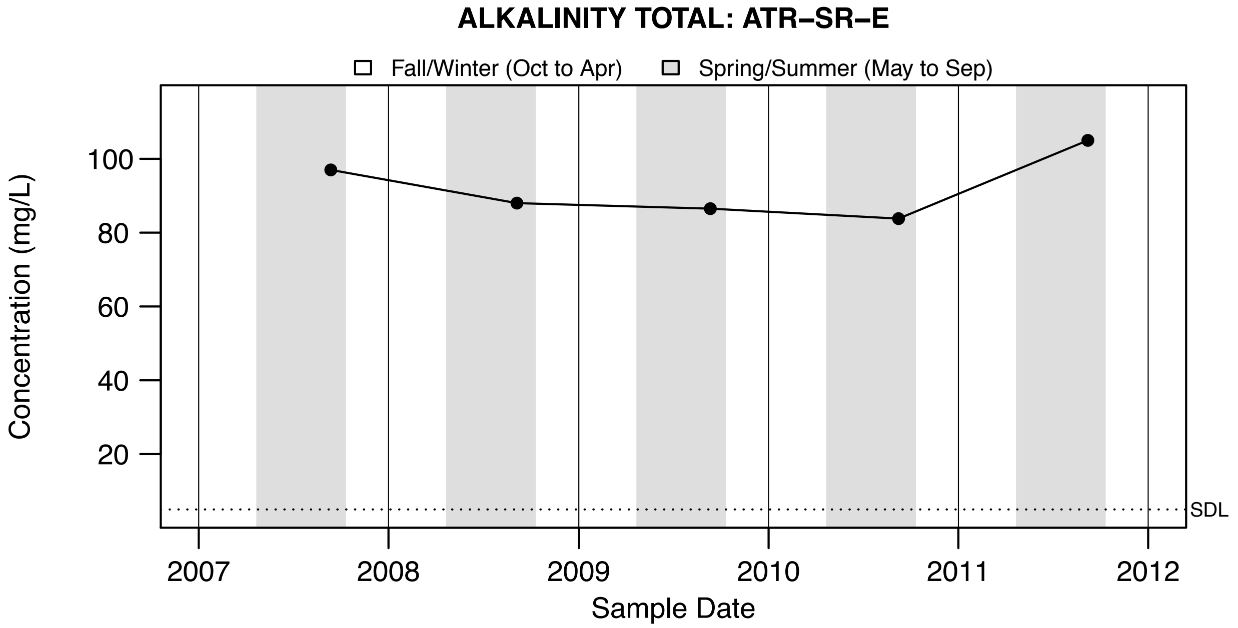


Figure A3.287: ALKALINITY TOTAL: ATR-SR-E -

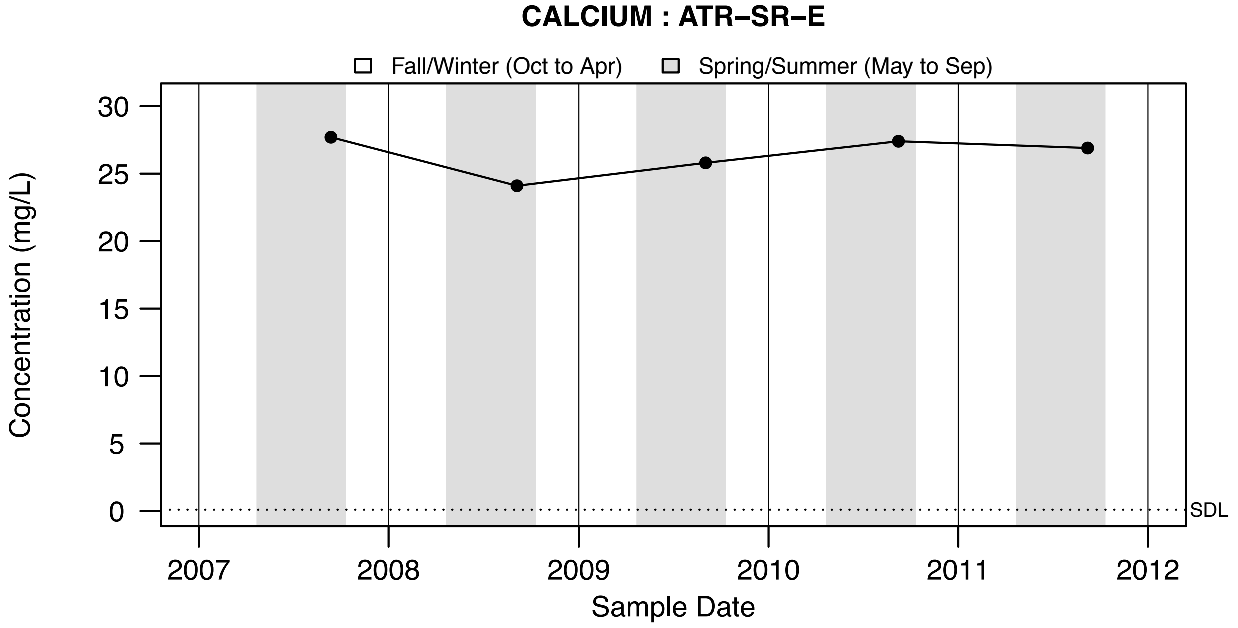


Figure A3.288: CALCIUM : ATR-SR-E -

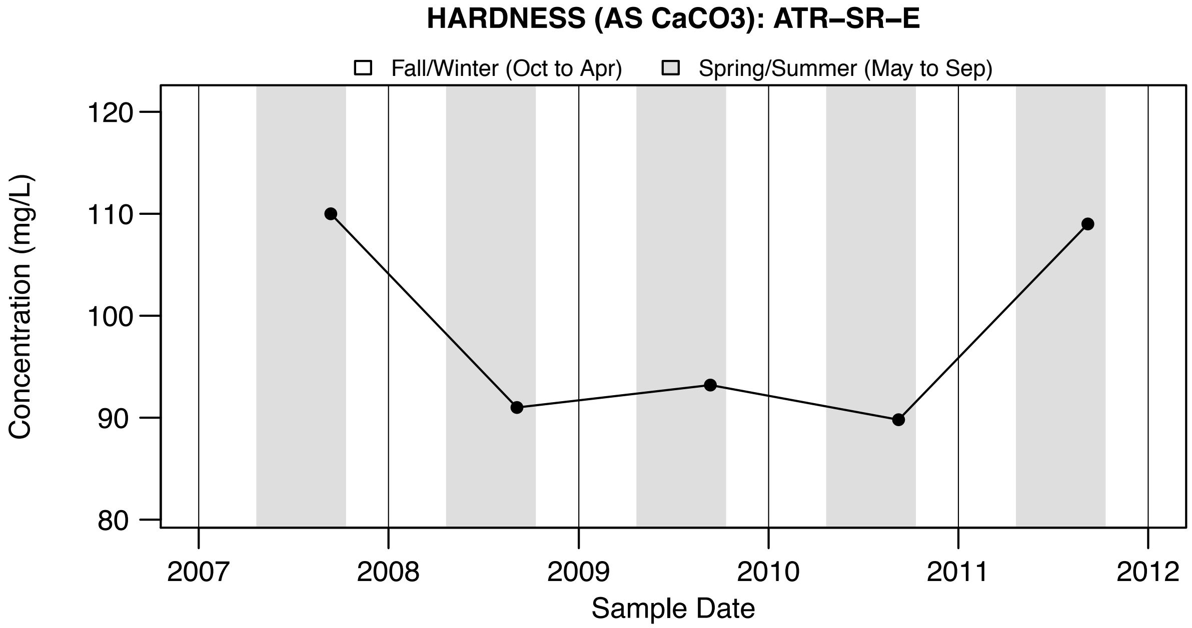


Figure A3.289: HARDNESS (AS CaCO3): ATR-SR-E -

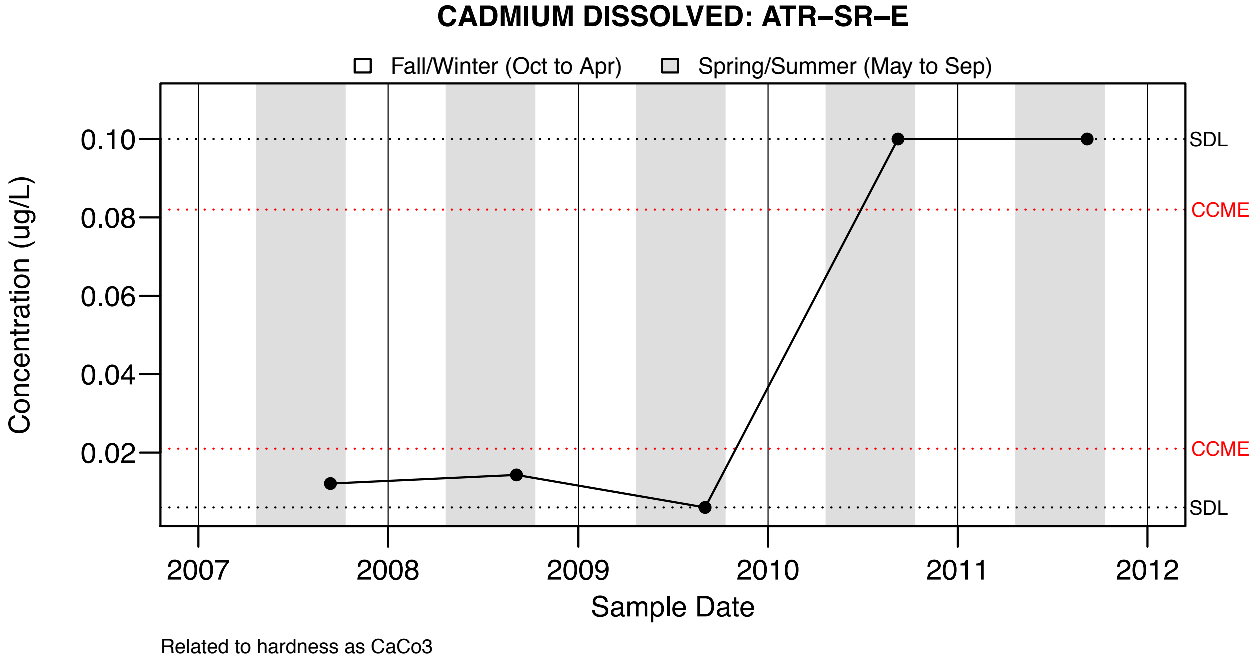


Figure A3.290: CADMIUM DISSOLVED: ATR-SR-E -

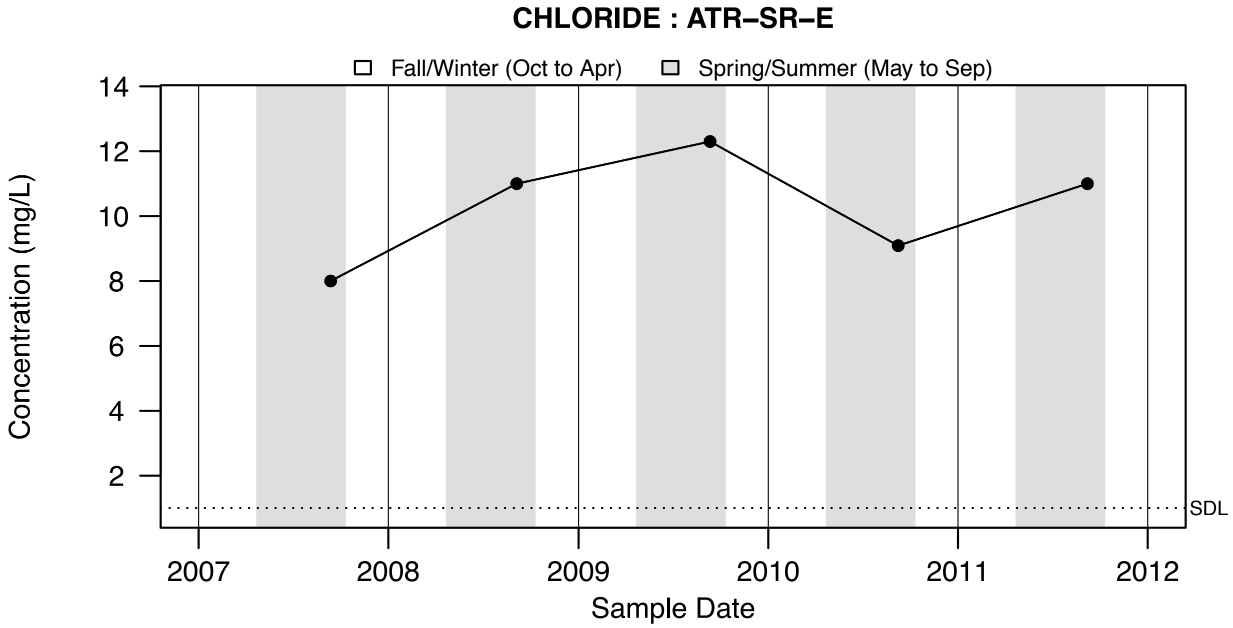


Figure A3.291: CHLORIDE : ATR-SR-E -

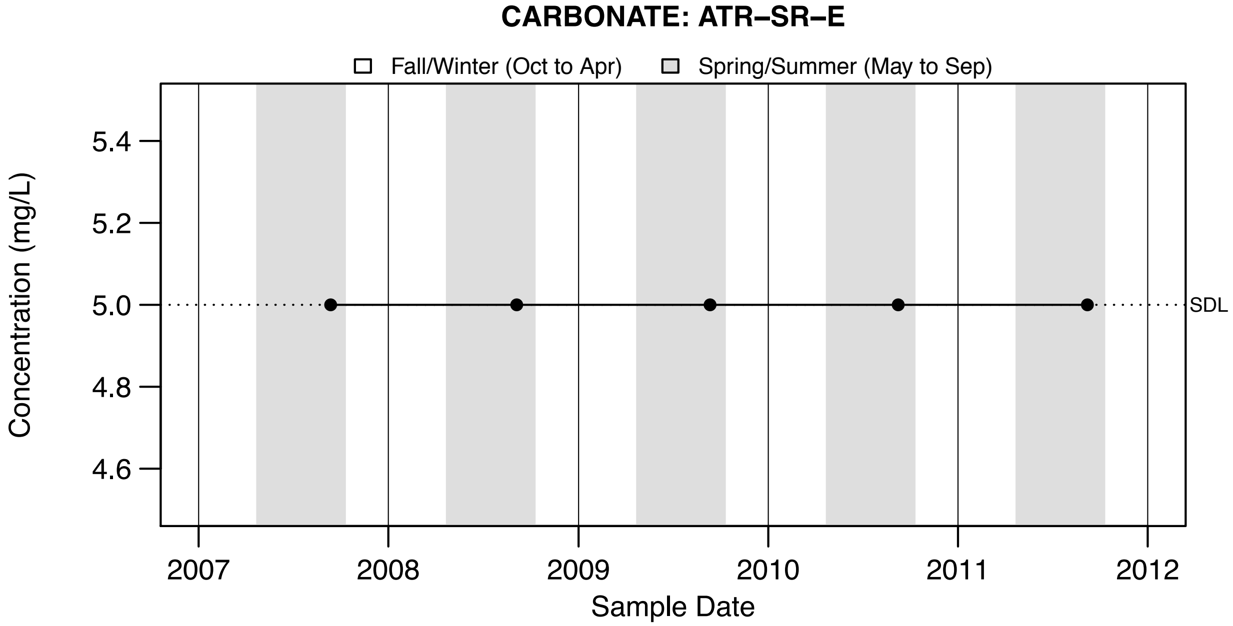


Figure A3.292: CARBONATE: ATR-SR-E -

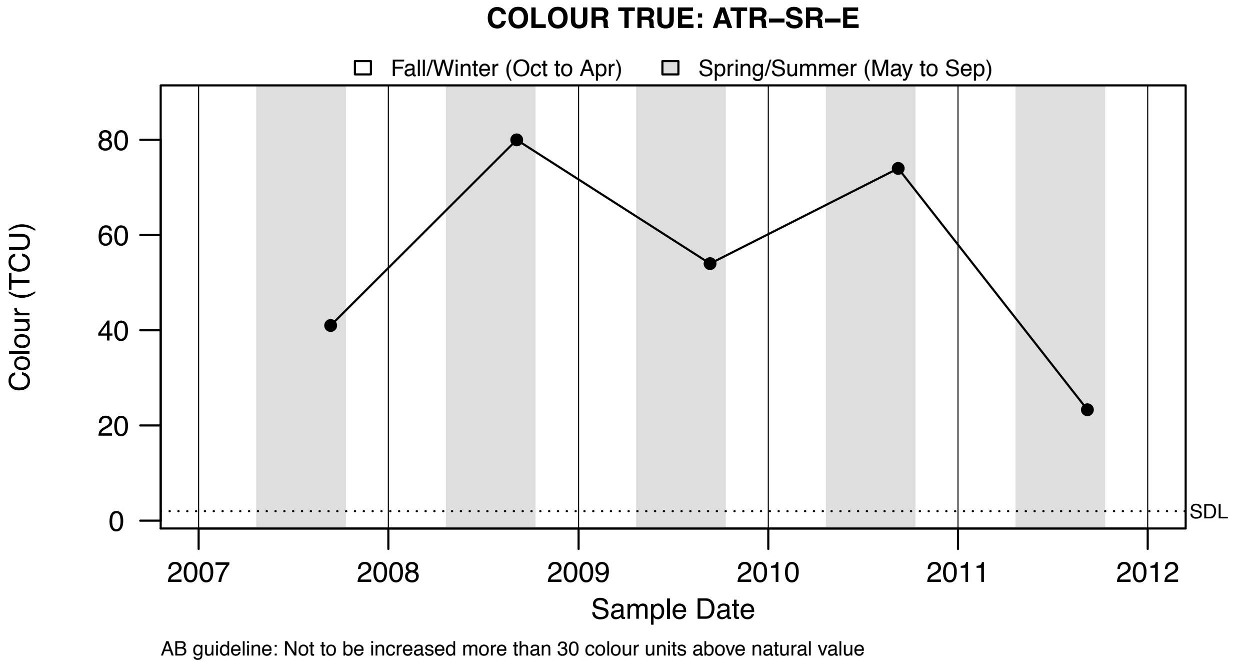


Figure A3.293: COLOUR TRUE: ATR-SR-E -

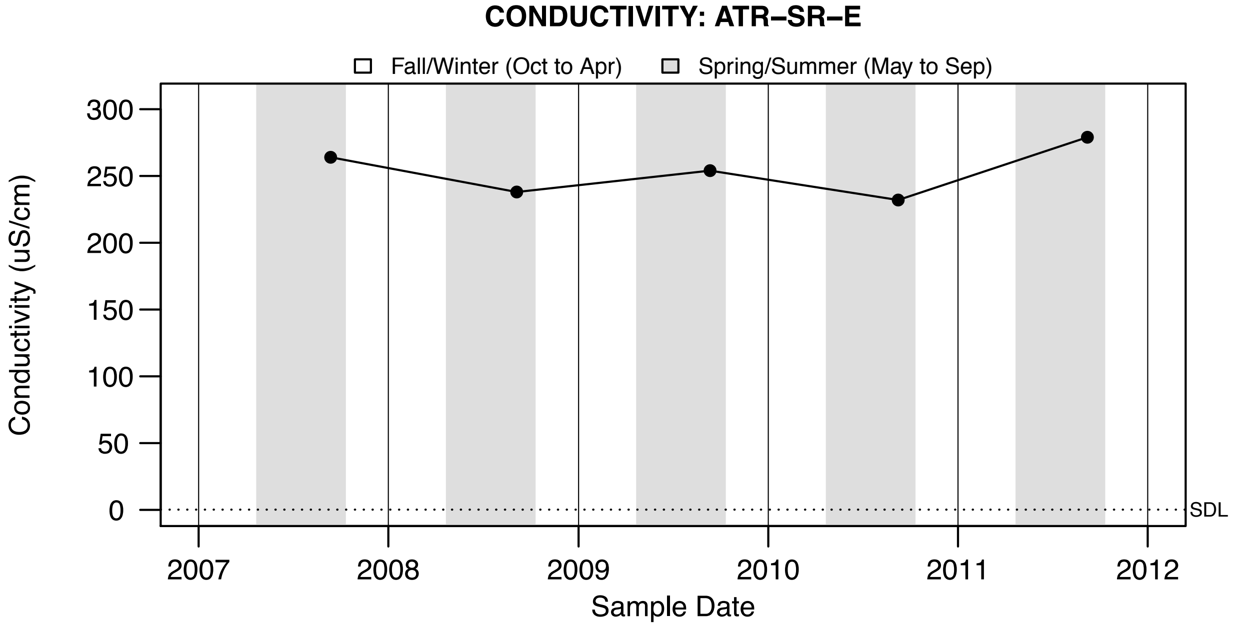
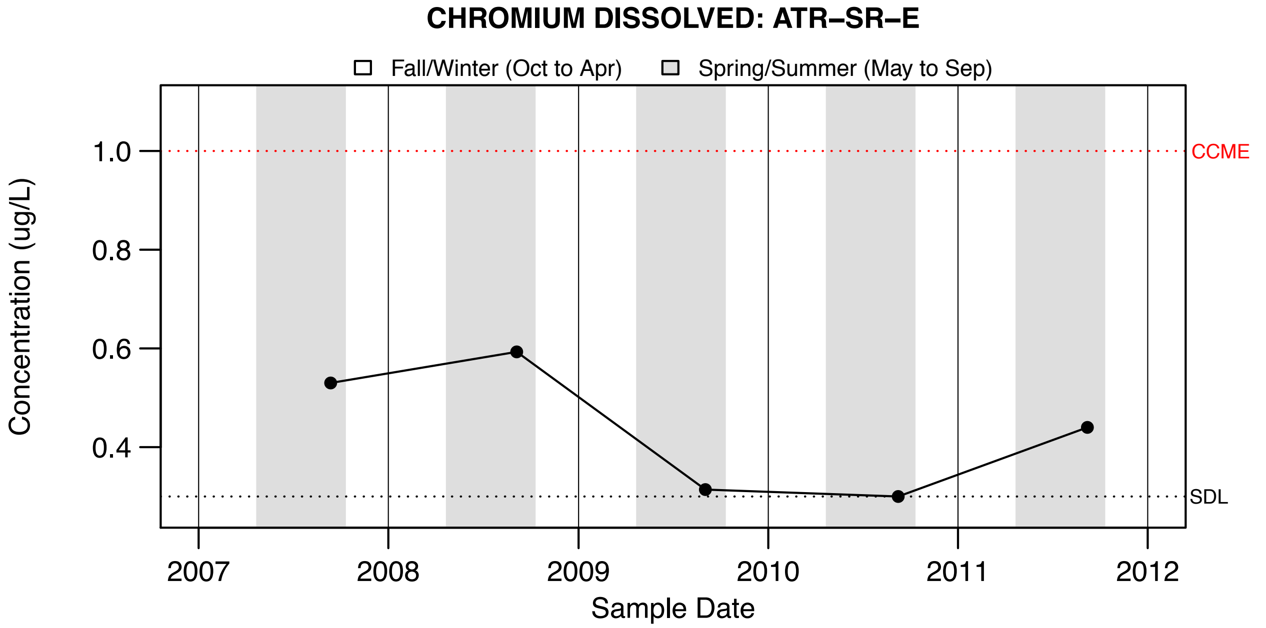
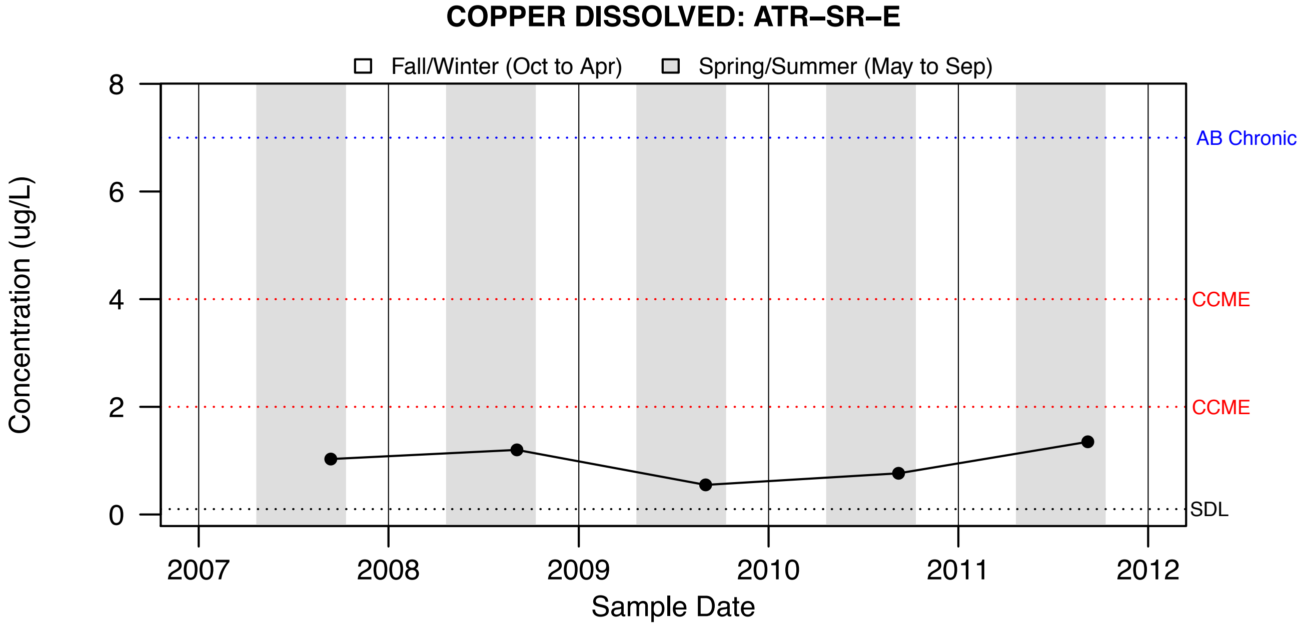


Figure A3.294: CONDUCTIVITY: ATR-SR-E -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.295: CHROMIUM DISSOLVED: ATR-SR-E -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.296: COPPER DISSOLVED: ATR-SR-E -

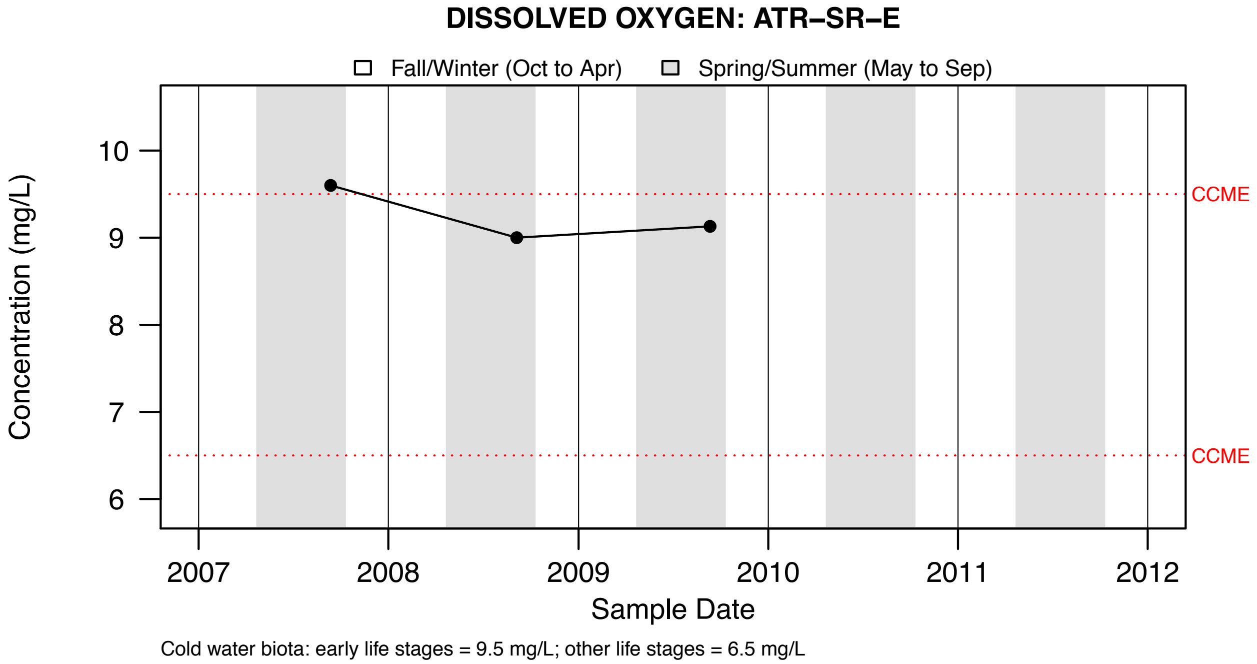


Figure A3.297: DISSOLVED OXYGEN: ATR-SR-E -

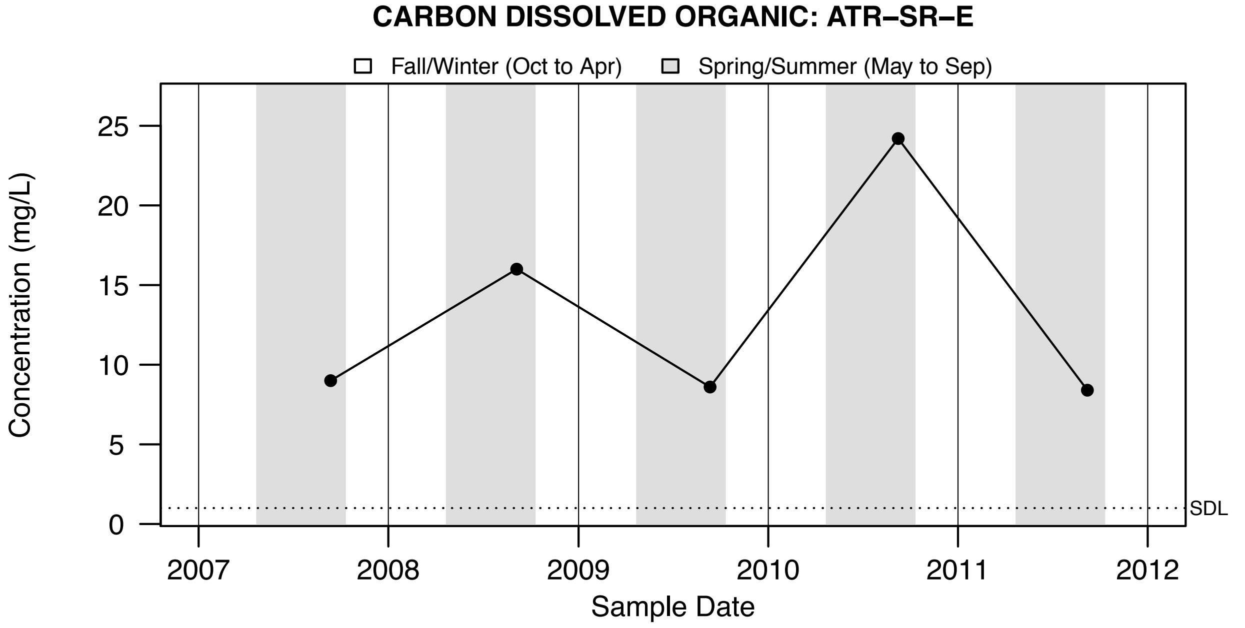


Figure A3.298: CARBON DISSOLVED ORGANIC: ATR-SR-E -

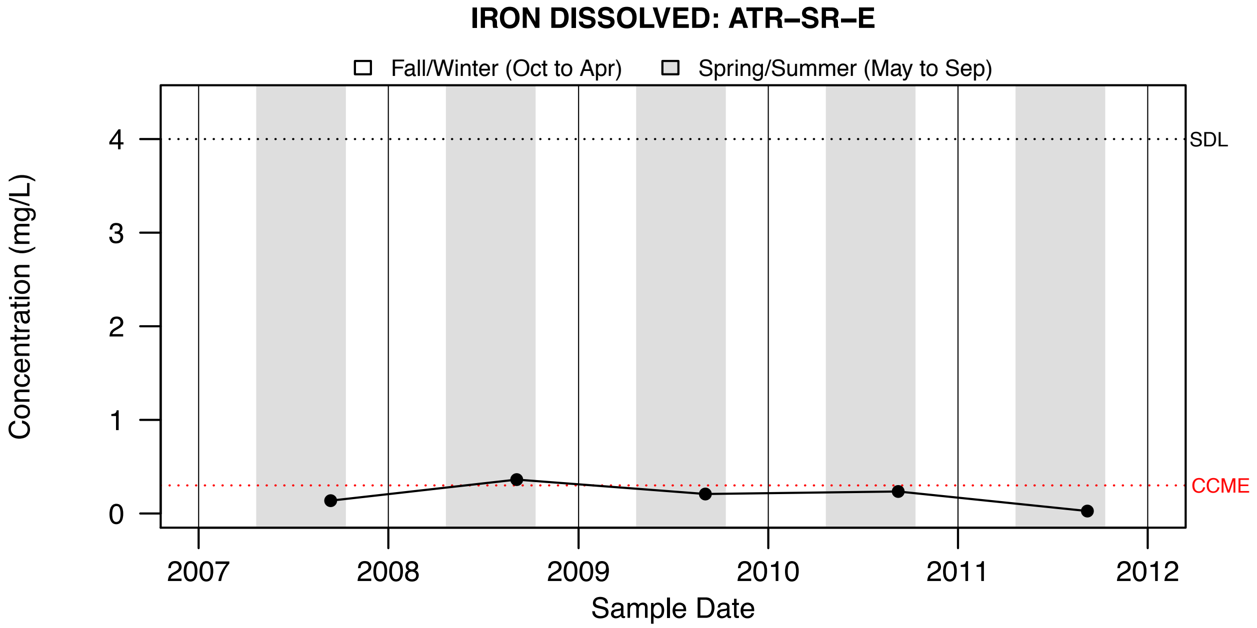


Figure A3.299: IRON DISSOLVED: ATR-SR-E -

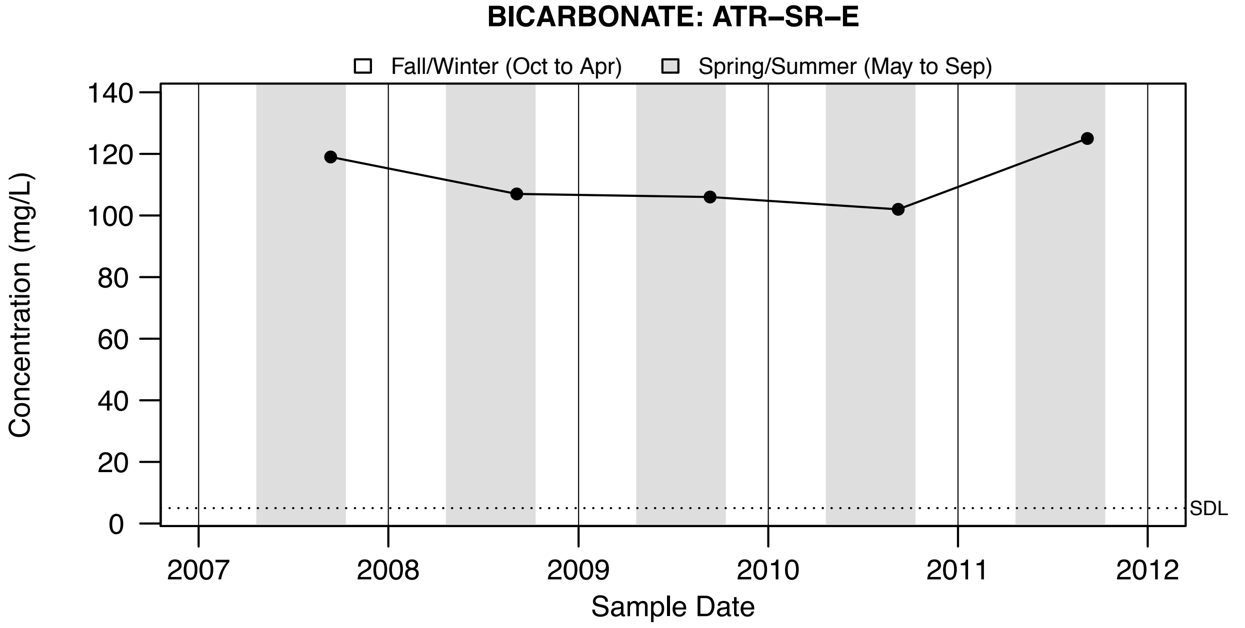


Figure A3.300: BICARBONATE: ATR-SR-E -

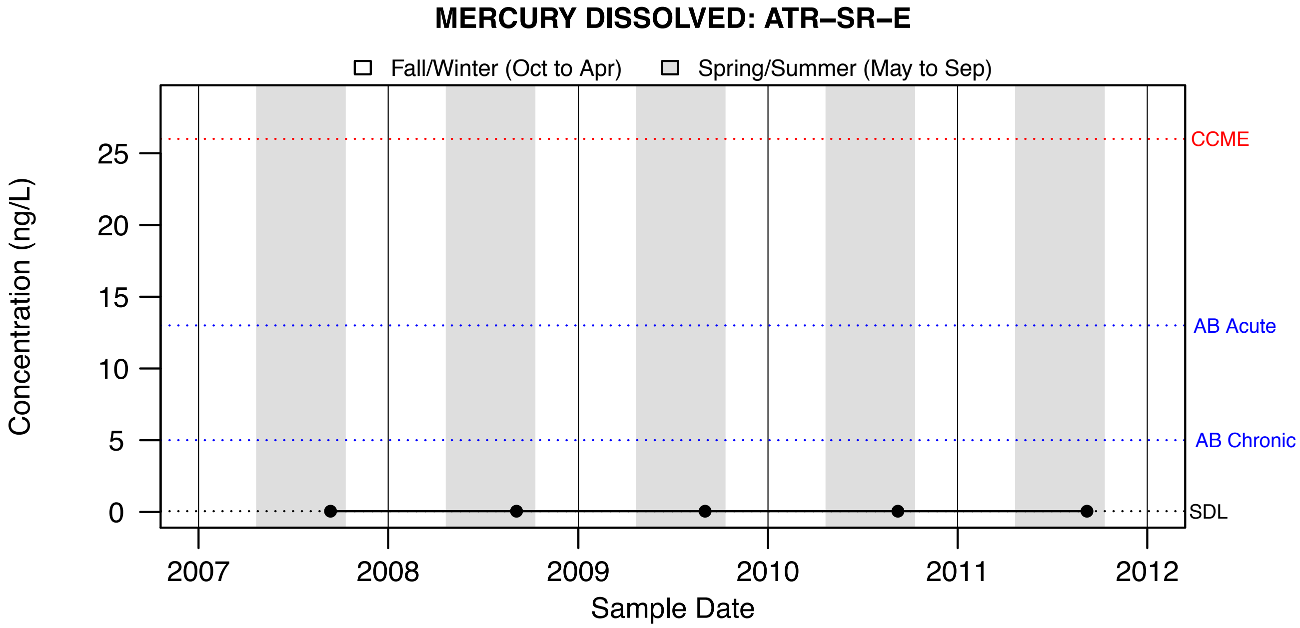


Figure A3.301: MERCURY DISSOLVED: ATR-SR-E -

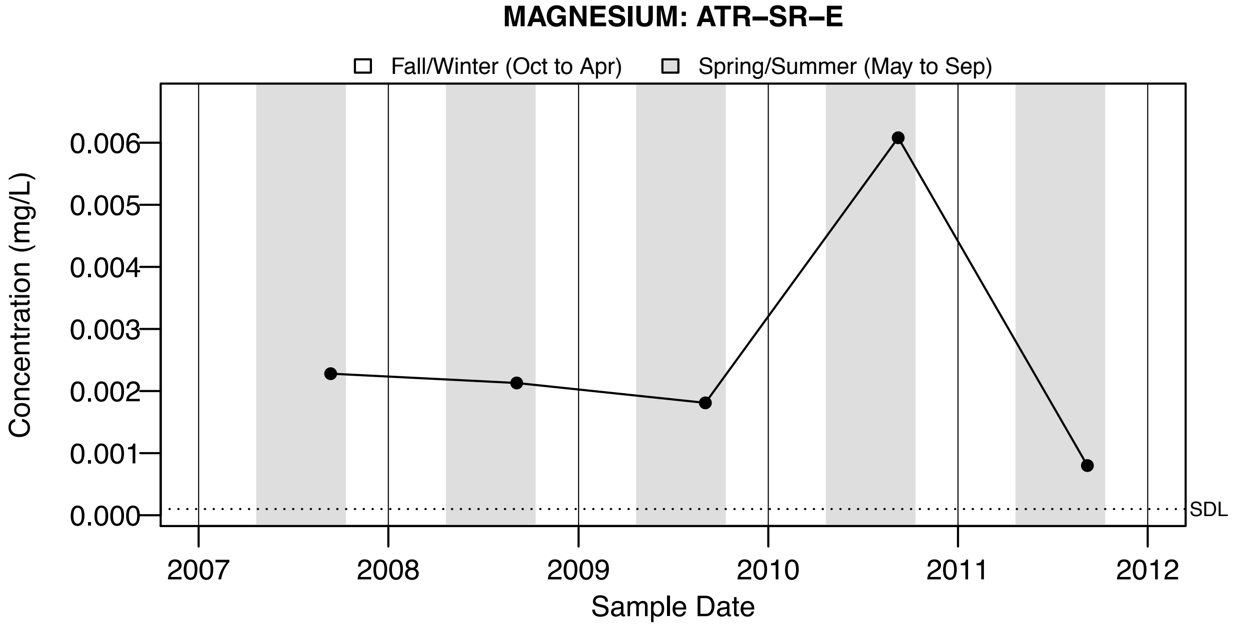


Figure A3.302: MAGNESIUM: ATR-SR-E -

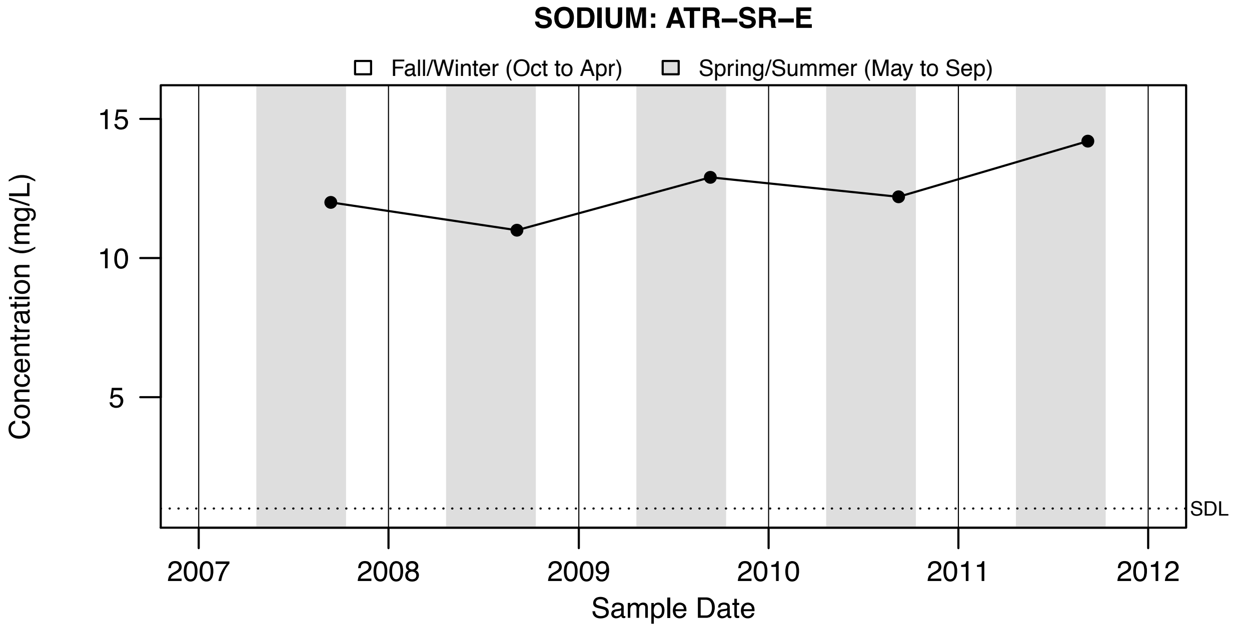
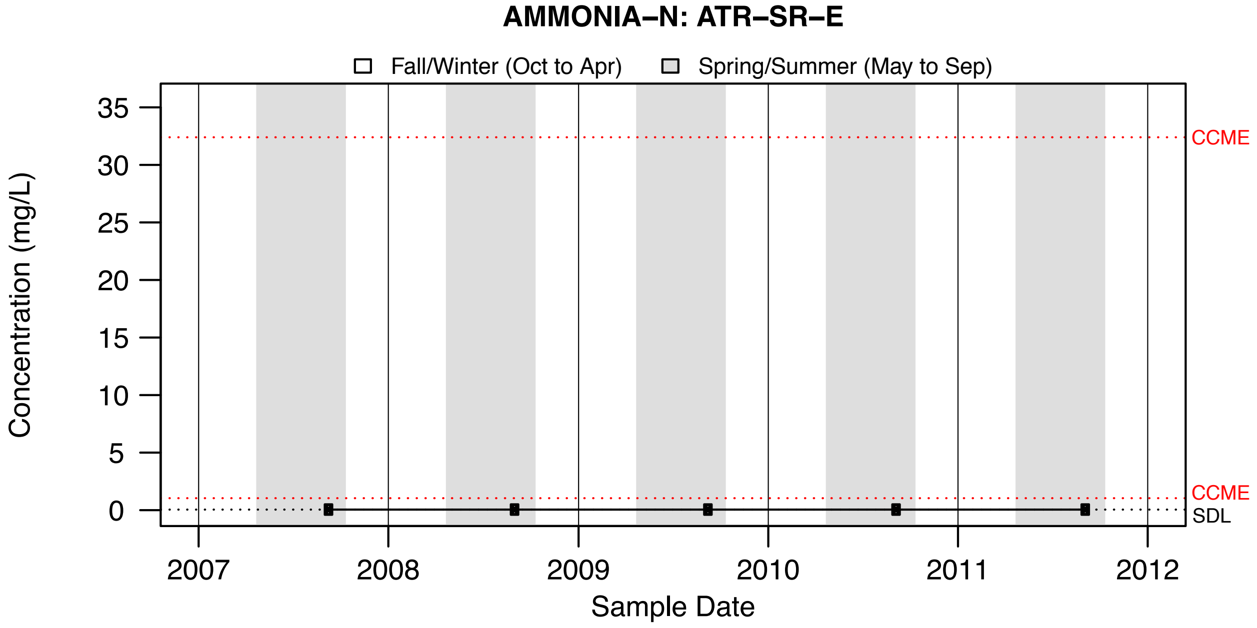
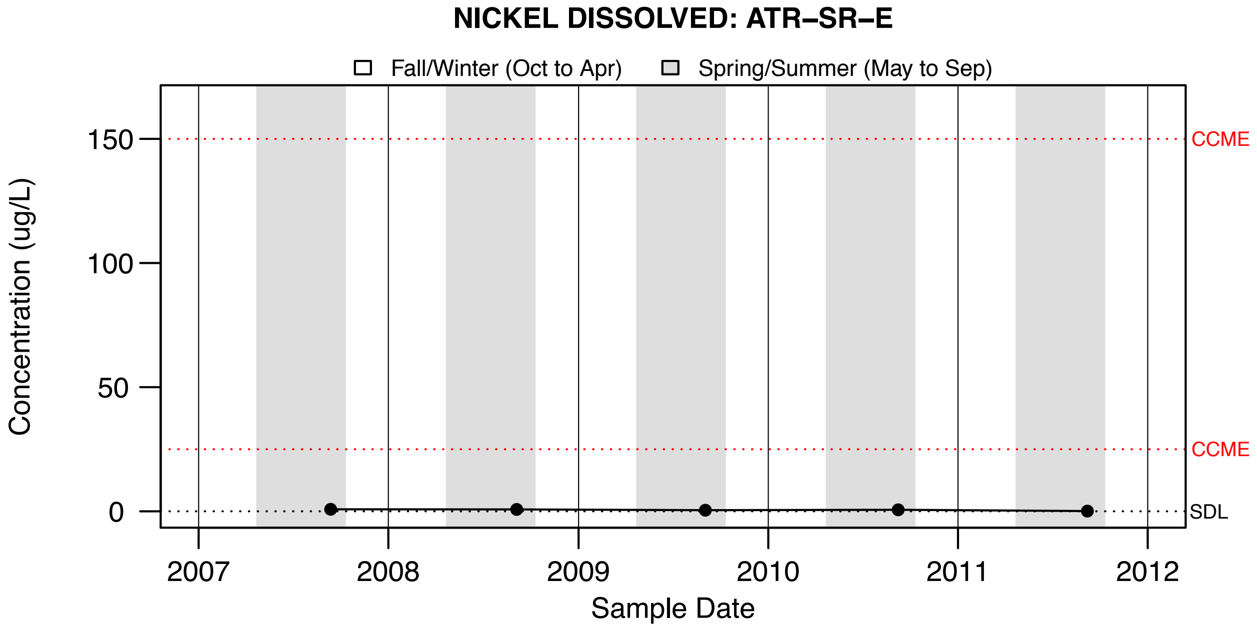


Figure A3.303: SODIUM: ATR-SR-E -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.304: AMMONIA-N: ATR-SR-E -



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A3.305: NICKEL DISSOLVED: ATR-SR-E -

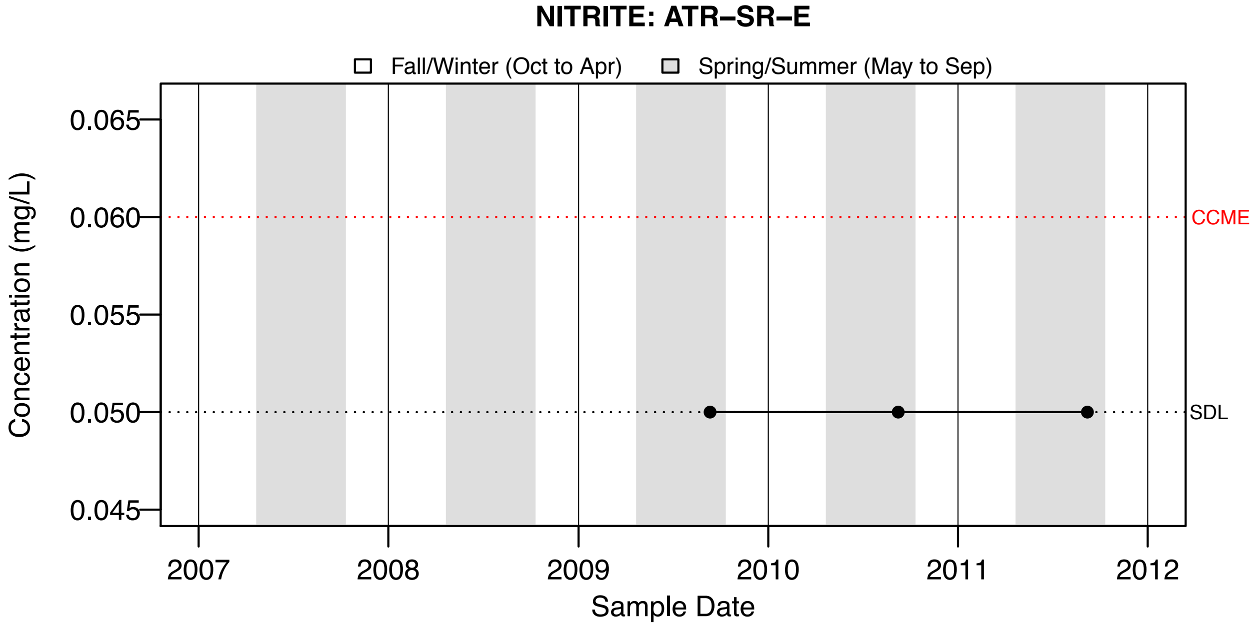
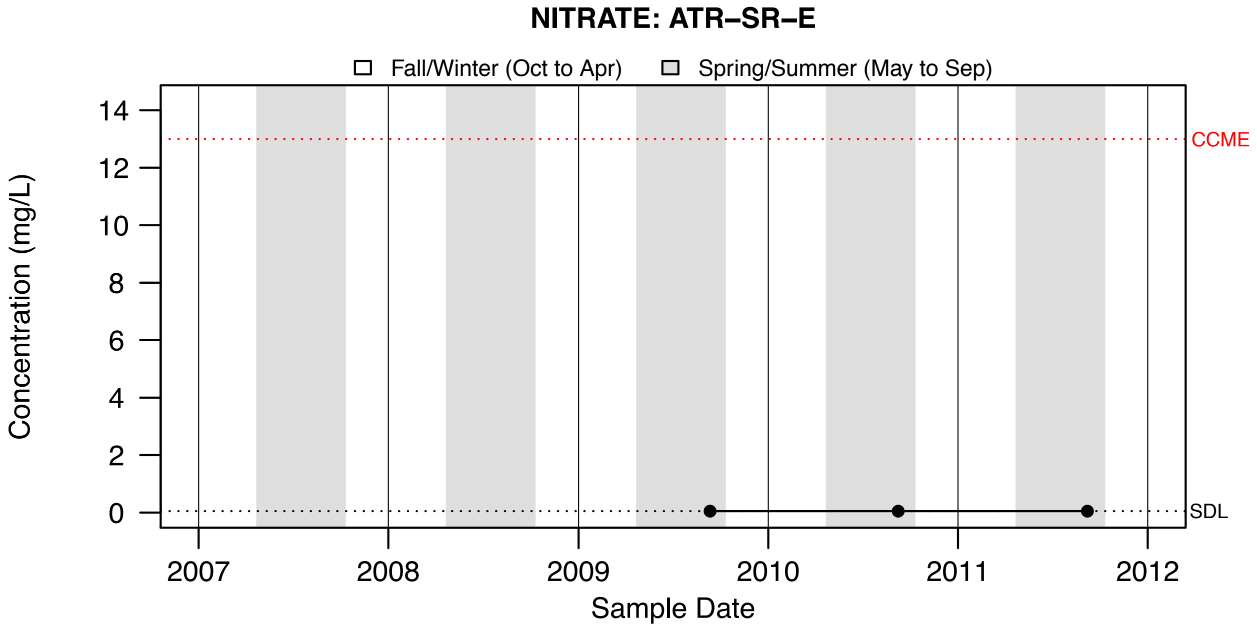


Figure A3.306: NITRITE: ATR-SR-E -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.307: NITRATE: ATR-SR-E -

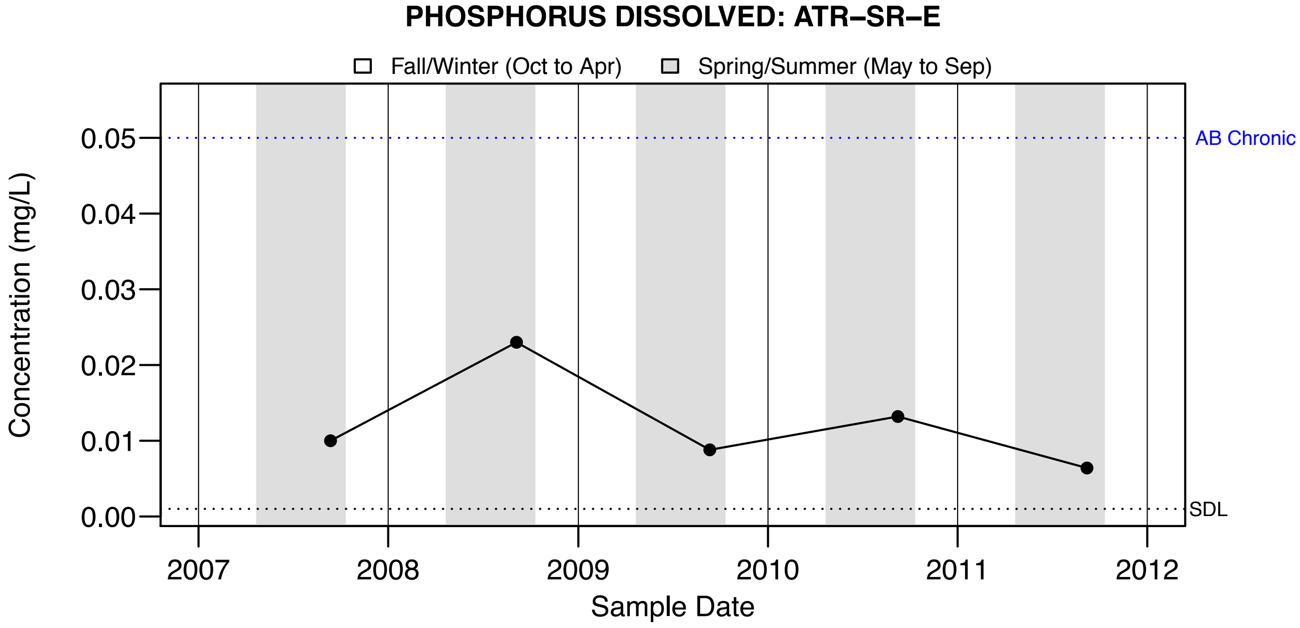


Figure A3.308: PHOSPHORUS DISSOLVED: ATR-SR-E -

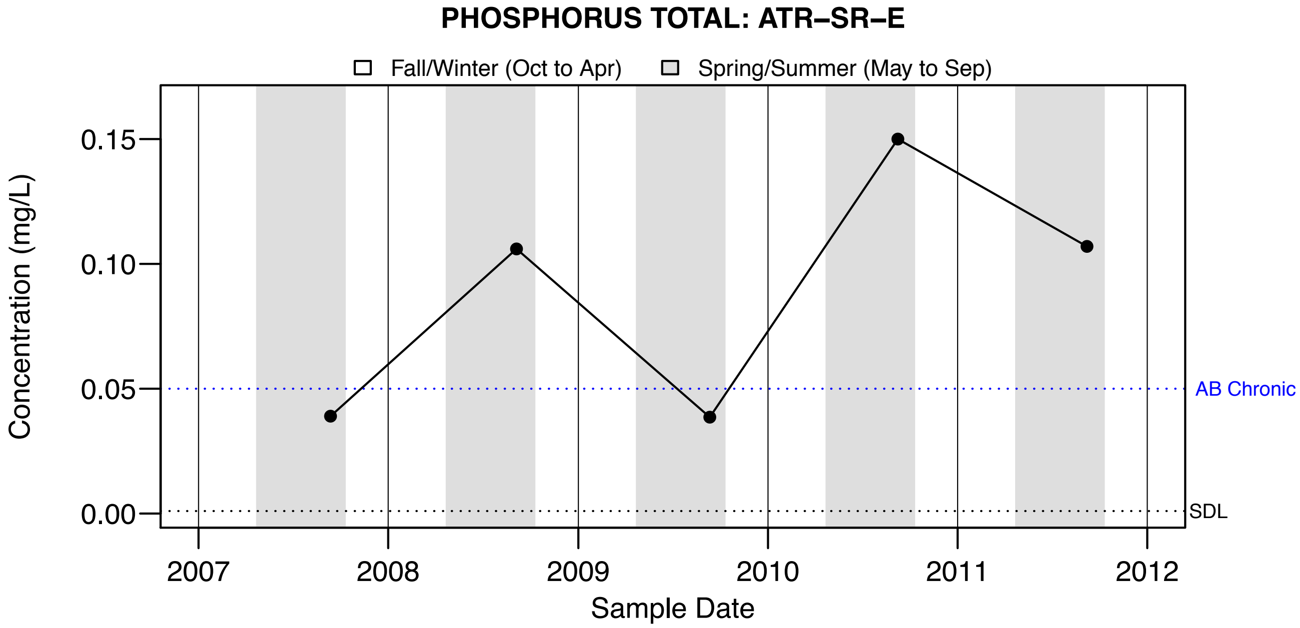
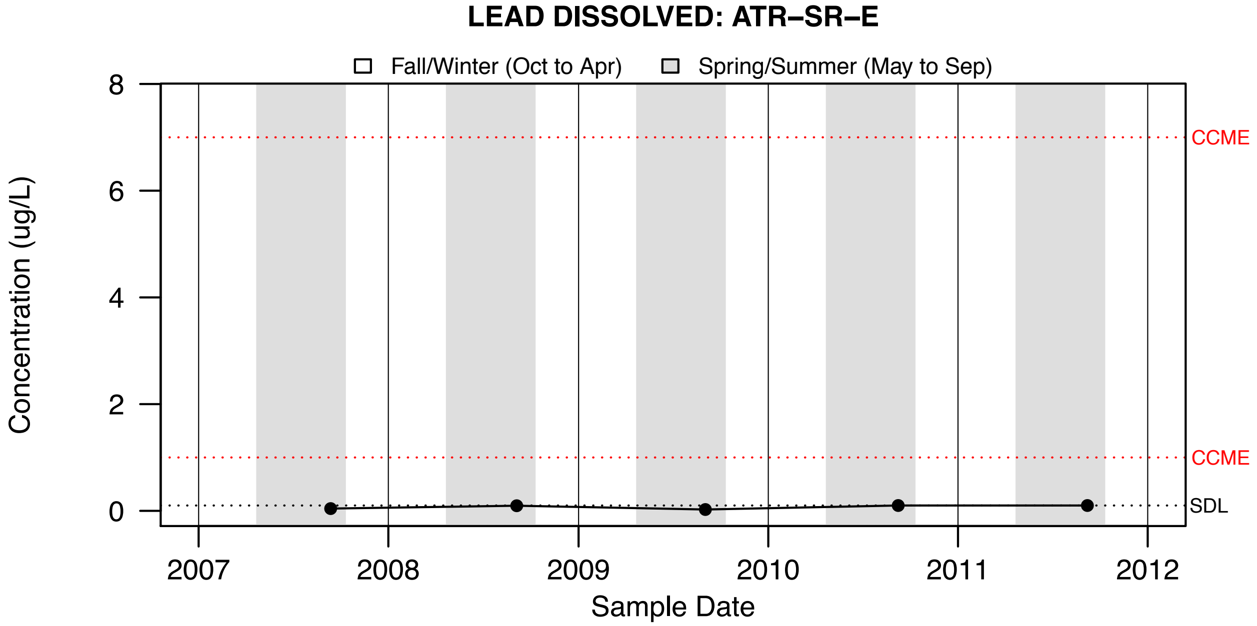


Figure A3.309: PHOSPHORUS TOTAL: ATR-SR-E -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.310: LEAD DISSOLVED: ATR-SR-E -

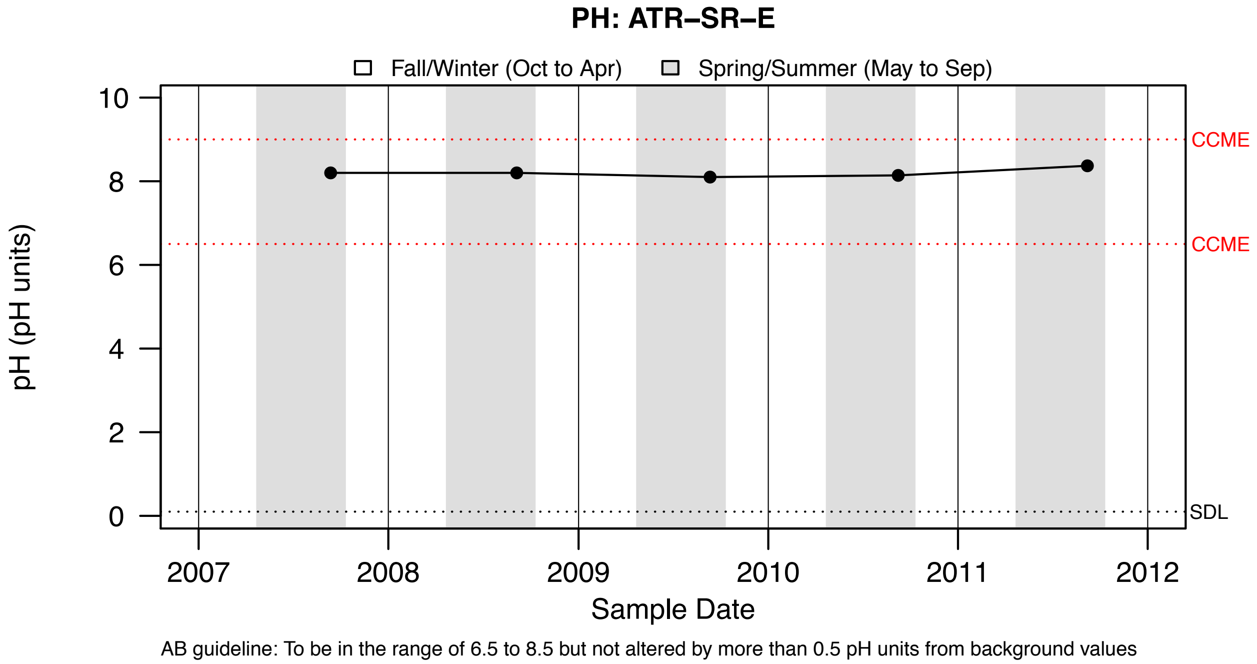


Figure A3.311: PH: ATR-SR-E -

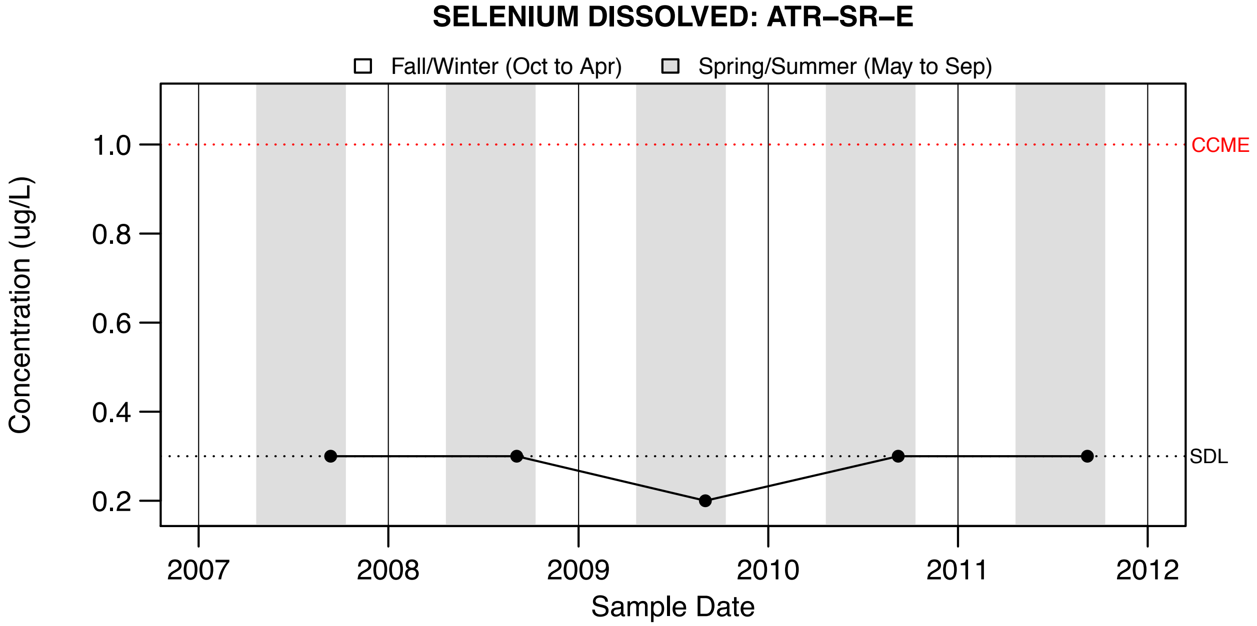


Figure A3.312: SELENIUM DISSOLVED: ATR-SR-E -

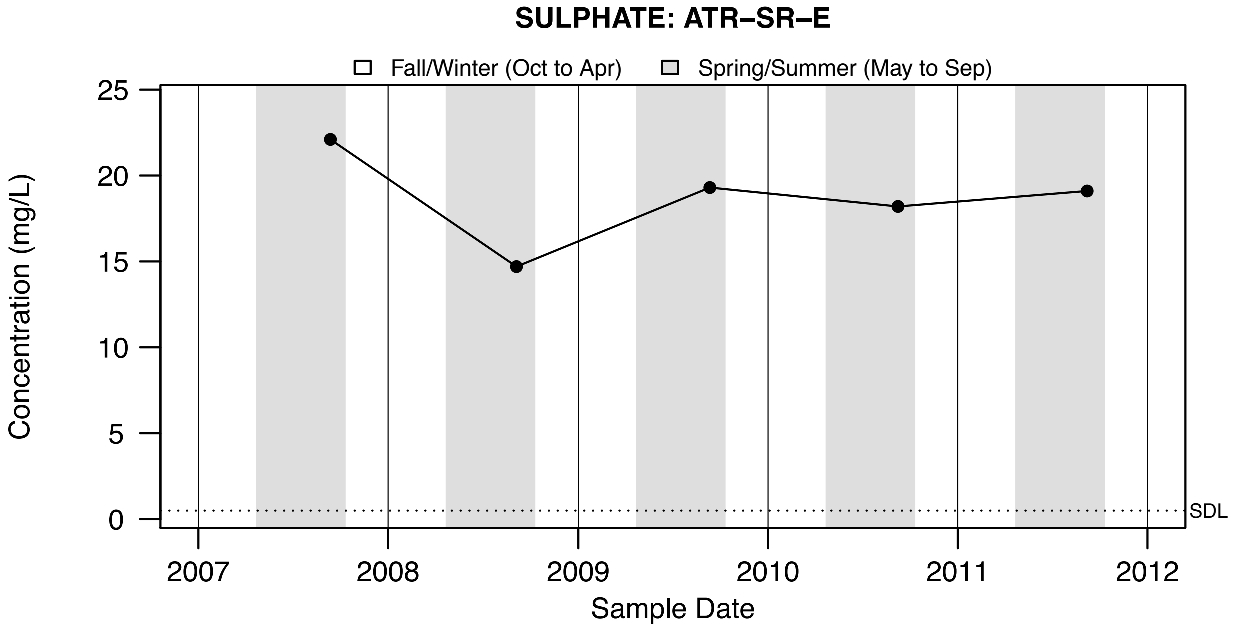


Figure A3.313: SULPHATE: ATR-SR-E -

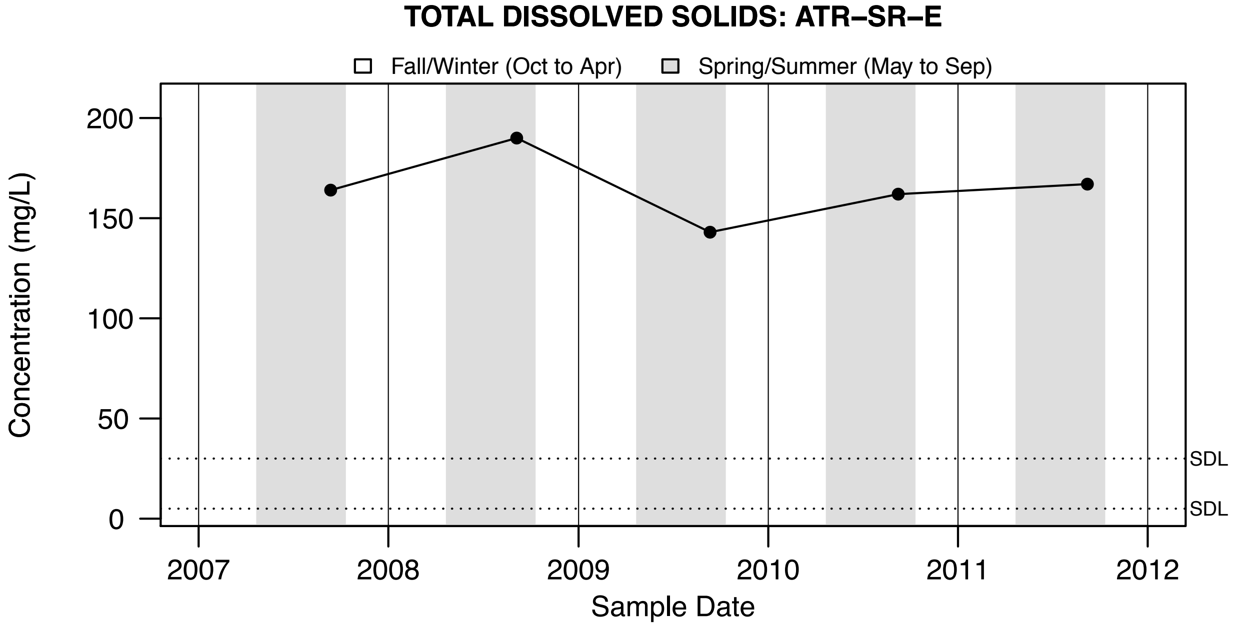
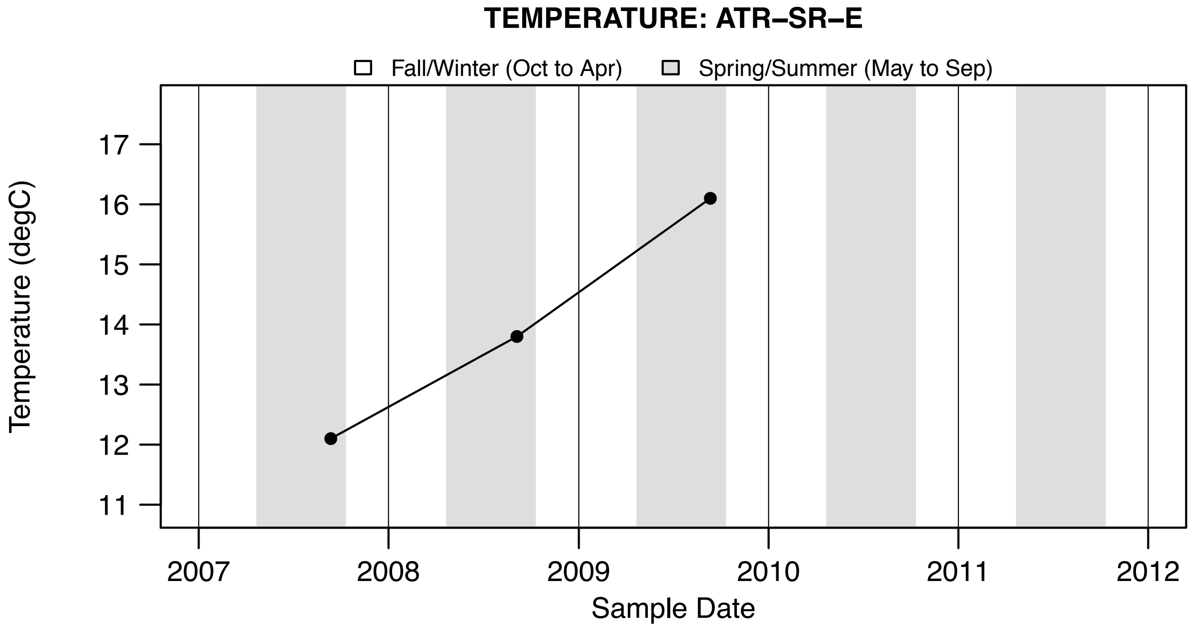


Figure A3.314: TOTAL DISSOLVED SOLIDS: ATR-SR-E -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.315: TEMPERATURE: ATR-SR-E -

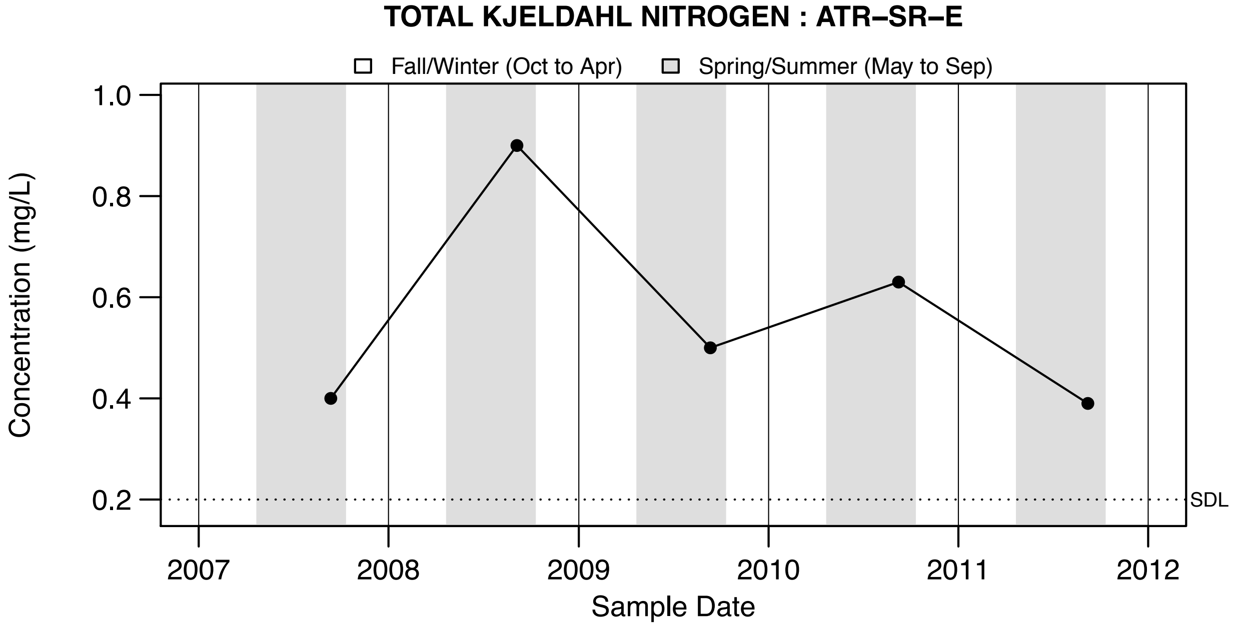
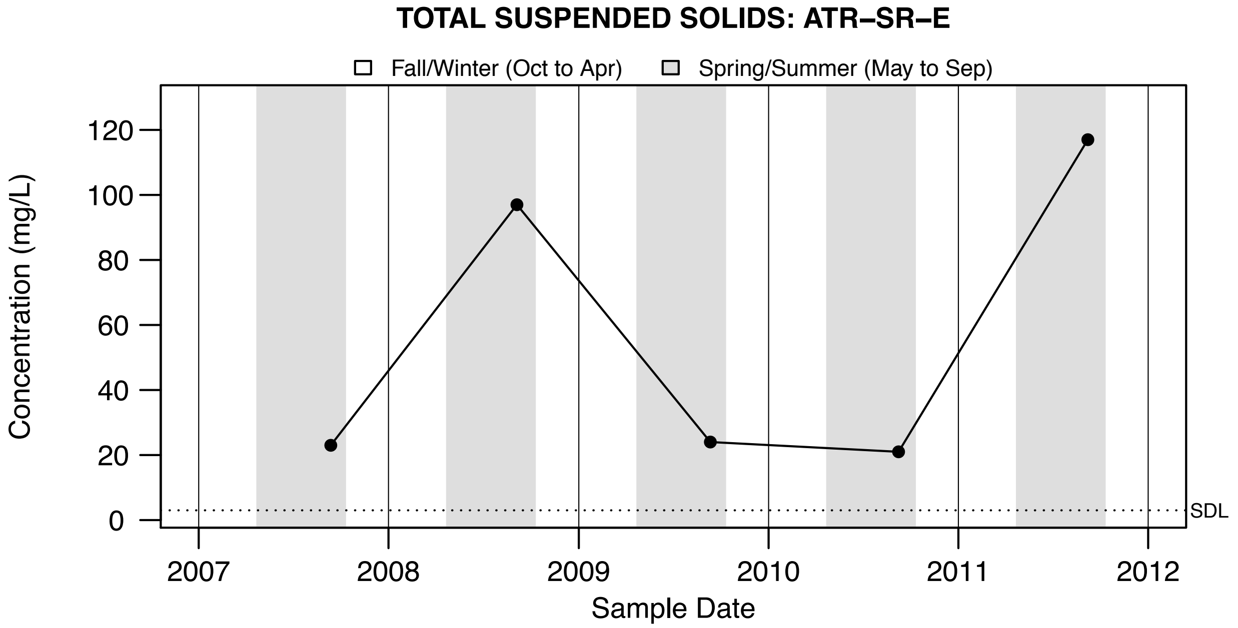


Figure A3.316: TOTAL KJELDAHL NITROGEN : ATR-SR-E -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.317: TOTAL SUSPENDED SOLIDS: ATR-SR-E -

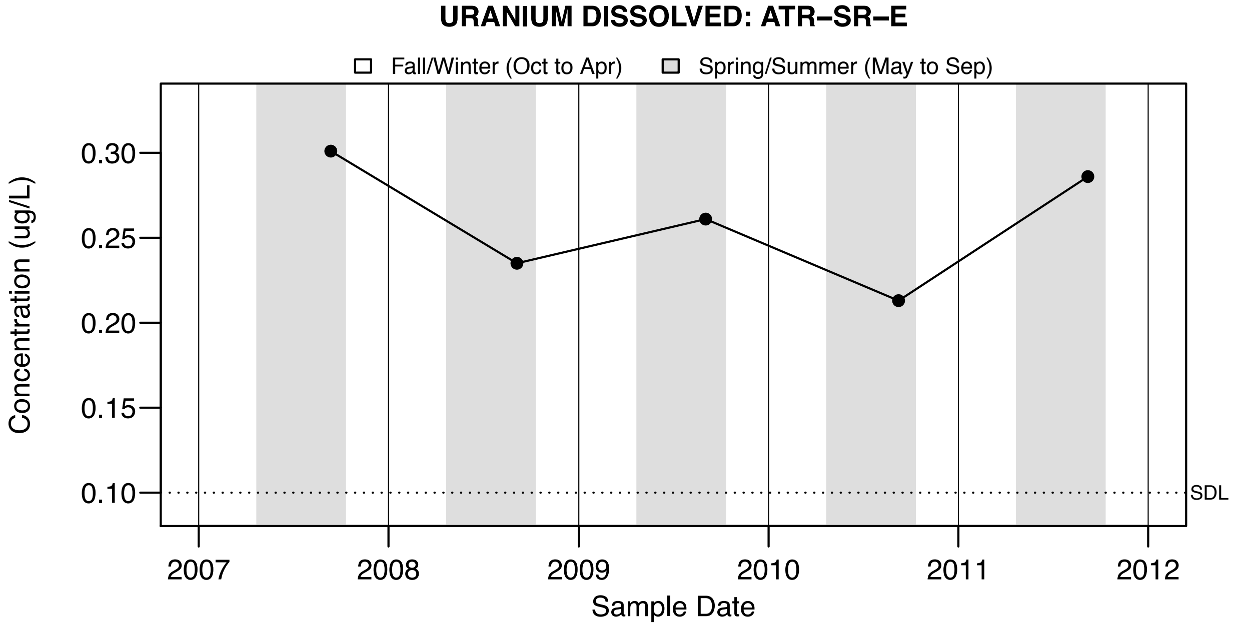


Figure A3.318: URANIUM DISSOLVED: ATR-SR-E -

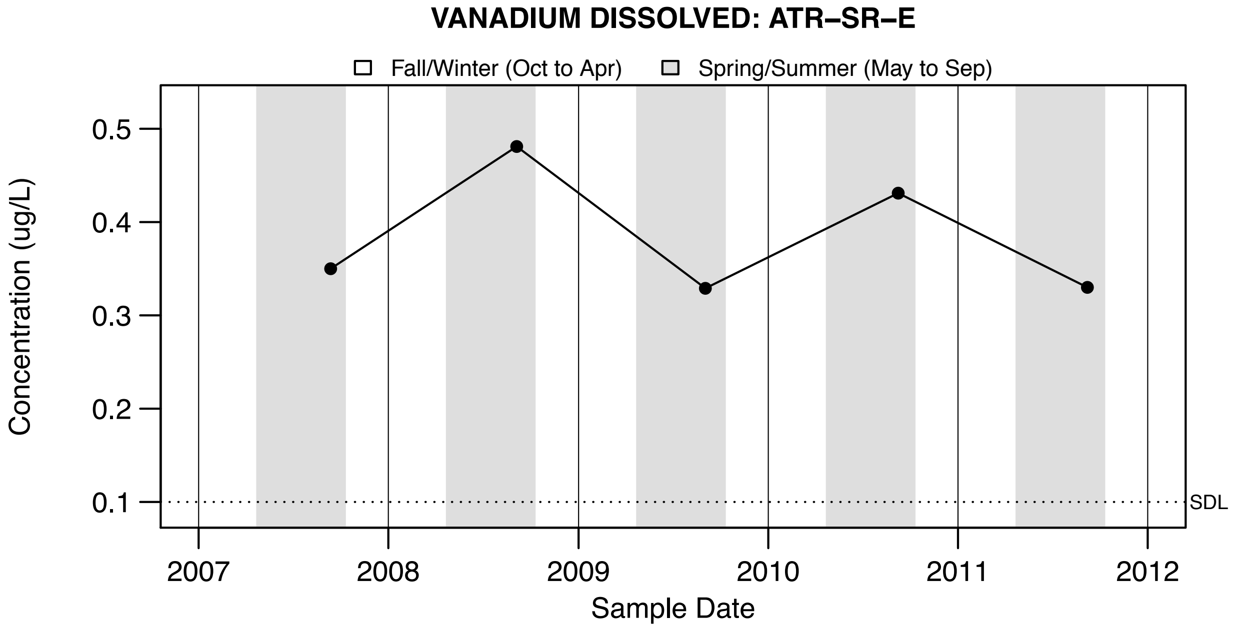


Figure A3.319: VANADIUM DISSOLVED: ATR-SR-E -

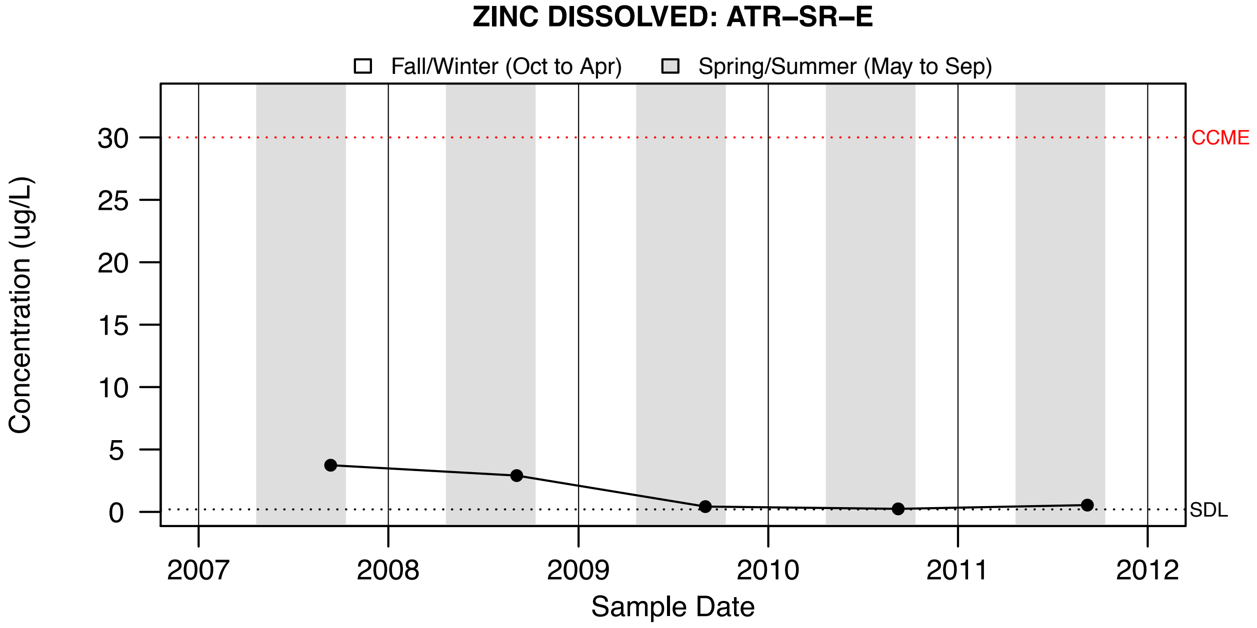
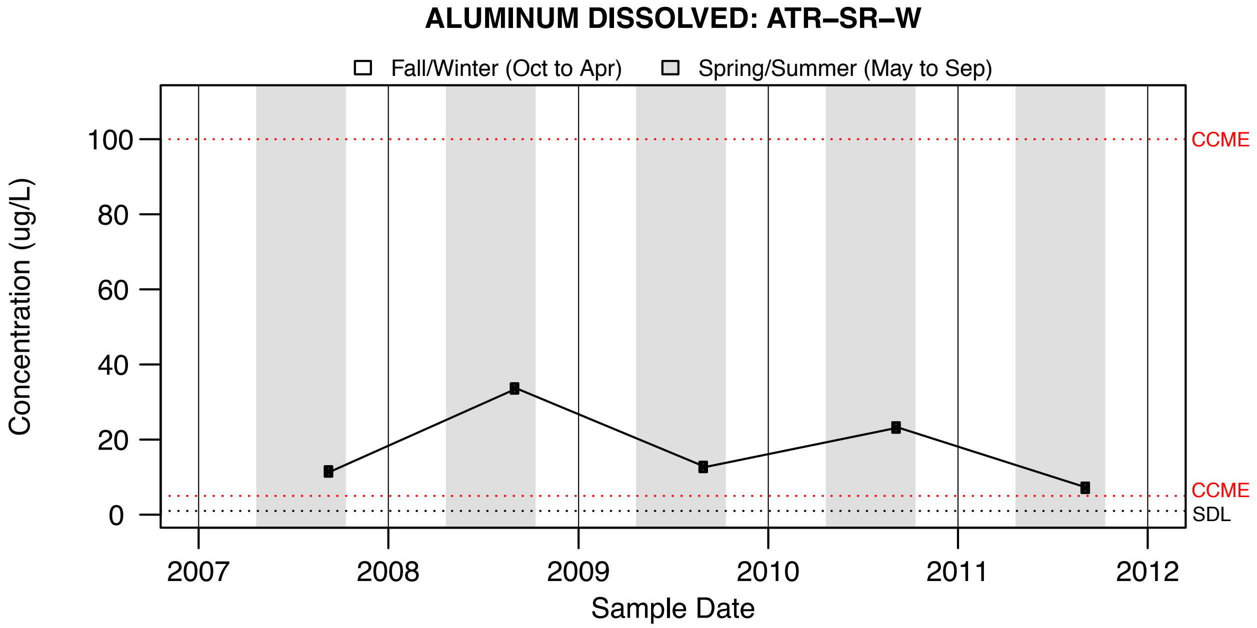
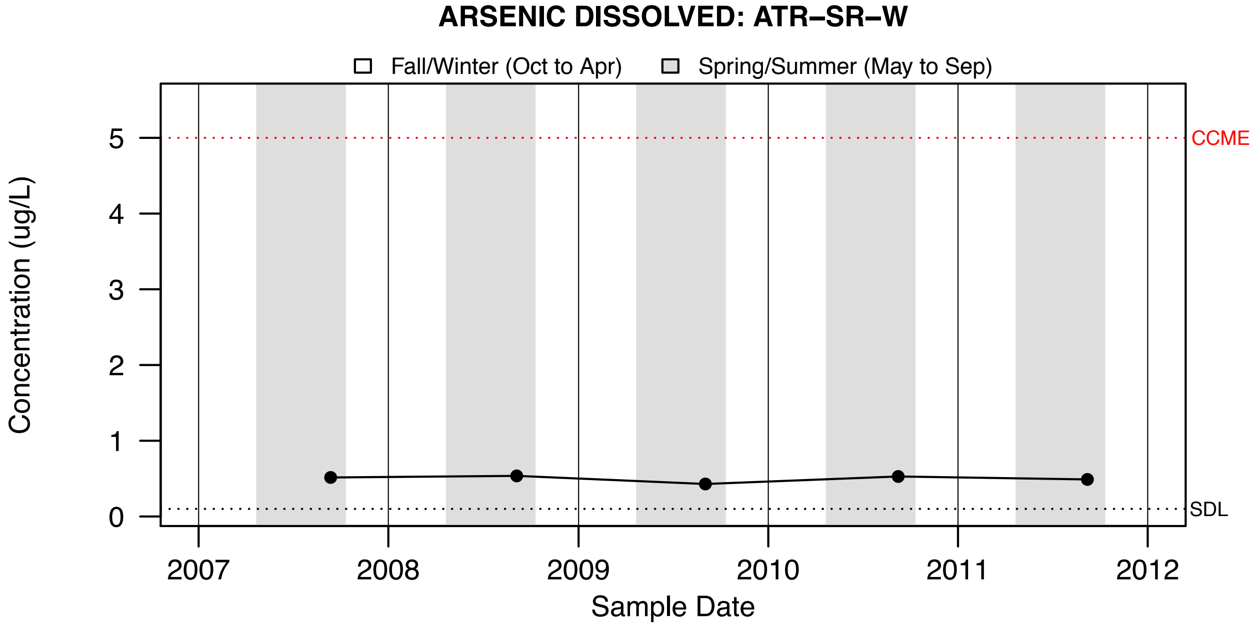


Figure A3.320: ZINC DISSOLVED: ATR-SR-E -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.321: ALUMINUM DISSOLVED: ATR-SR-W -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.322: ARSENIC DISSOLVED: ATR-SR-W -

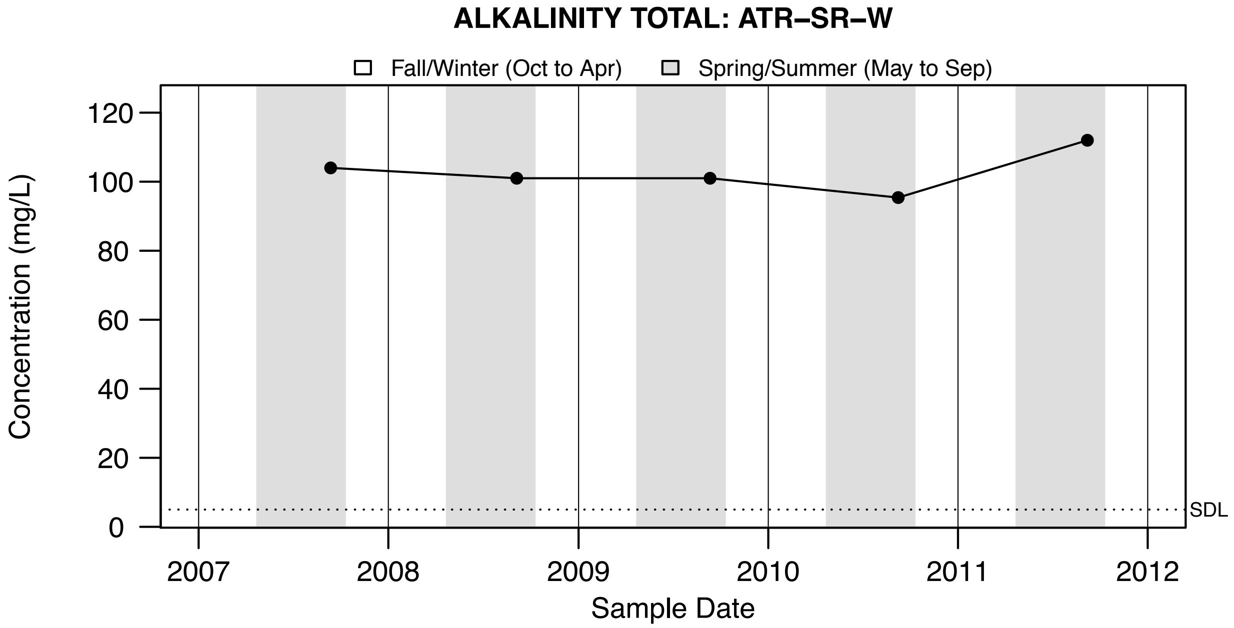


Figure A3.323: ALKALINITY TOTAL: ATR-SR-W -

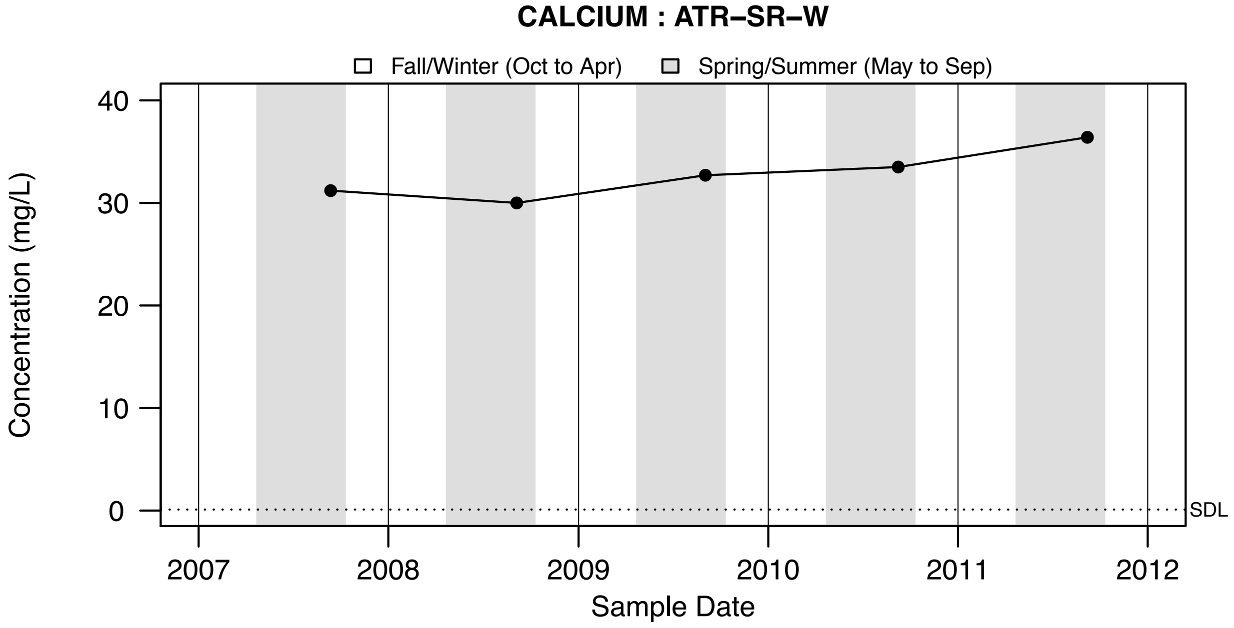


Figure A3.324: CALCIUM : ATR-SR-W -

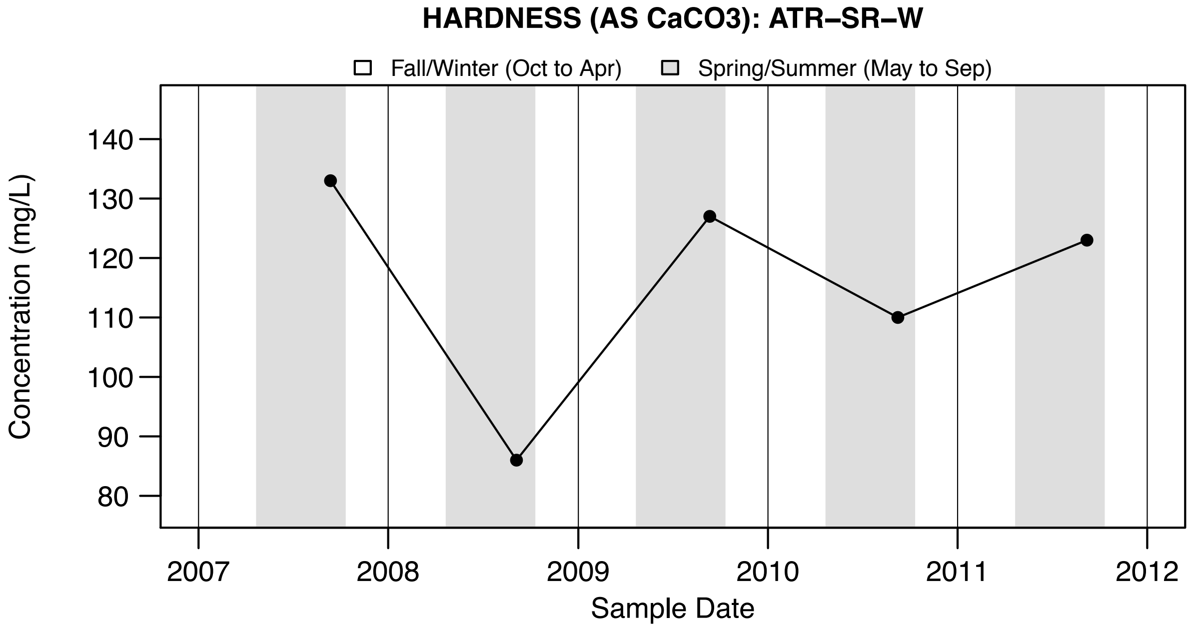
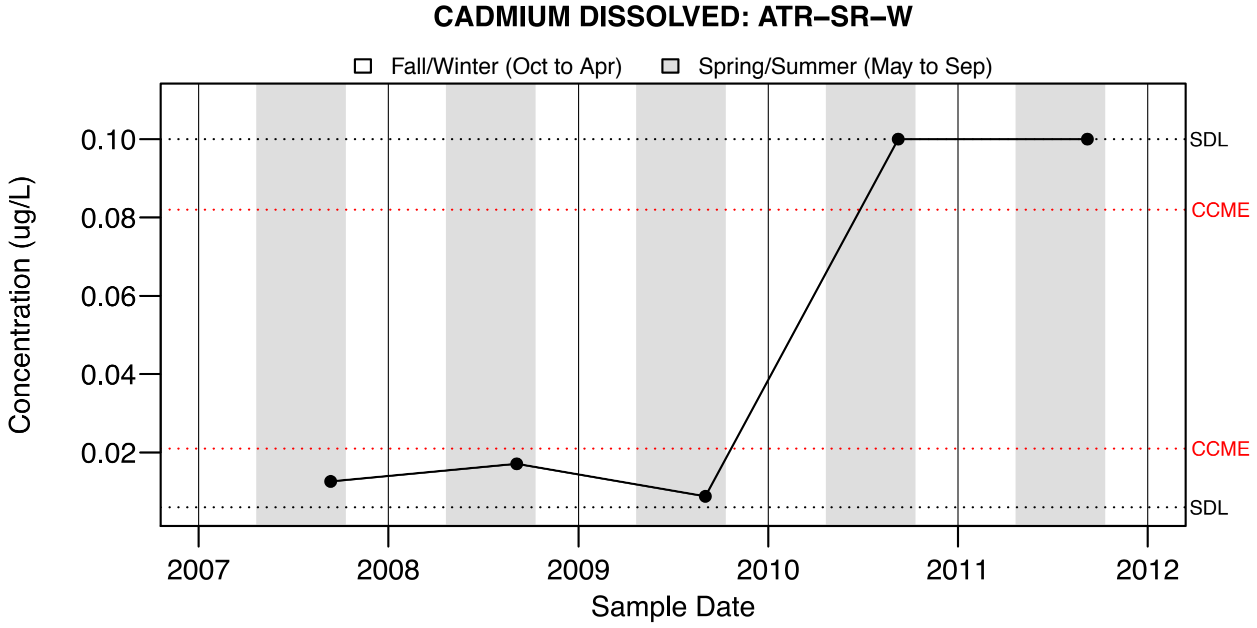


Figure A3.325: HARDNESS (AS CaCO3): ATR-SR-W -



Related to hardness as CaCo3

Figure A3.326: CADMIUM DISSOLVED: ATR-SR-W -

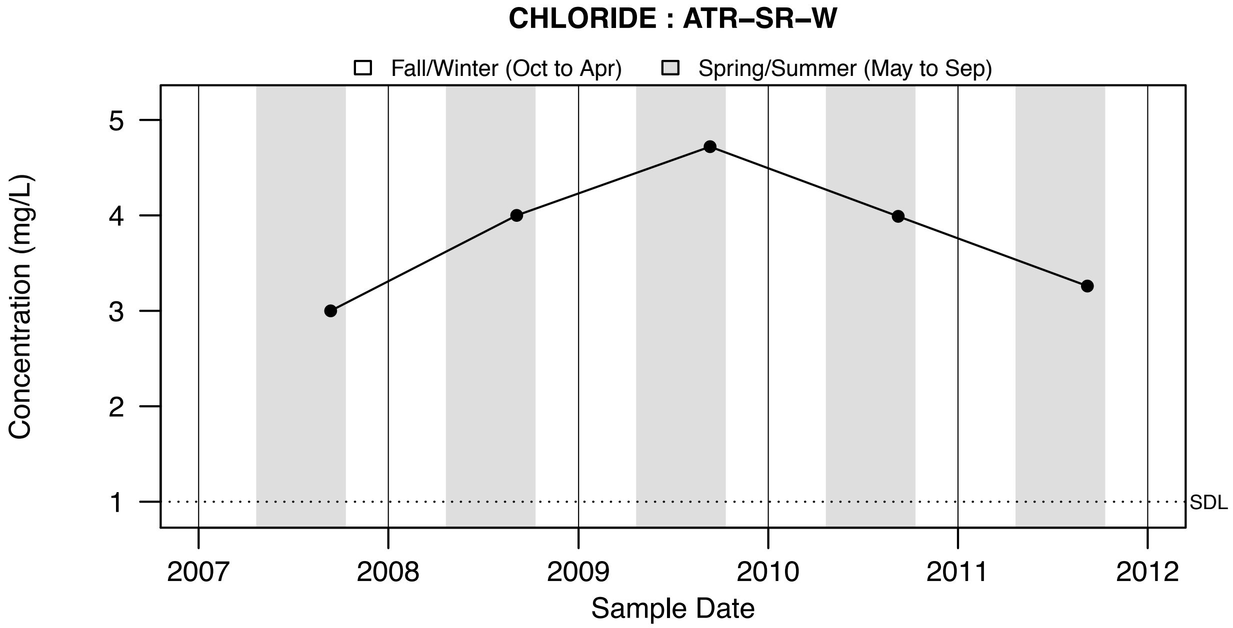


Figure A3.327: CHLORIDE : ATR-SR-W -

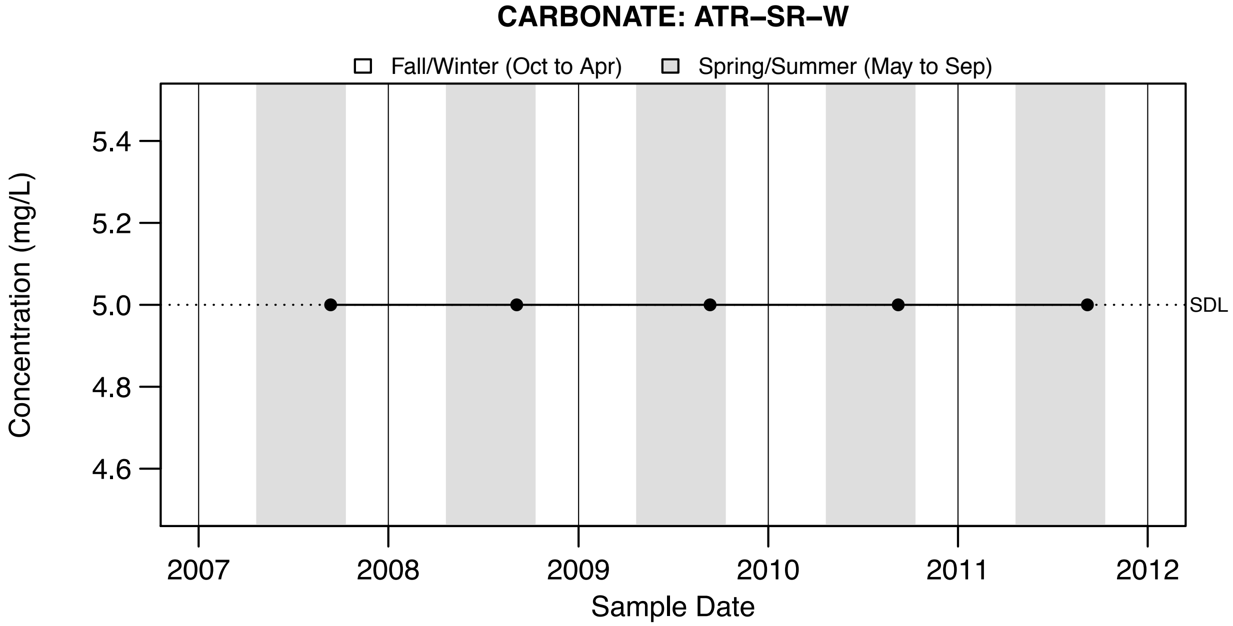


Figure A3.328: CARBONATE: ATR-SR-W -

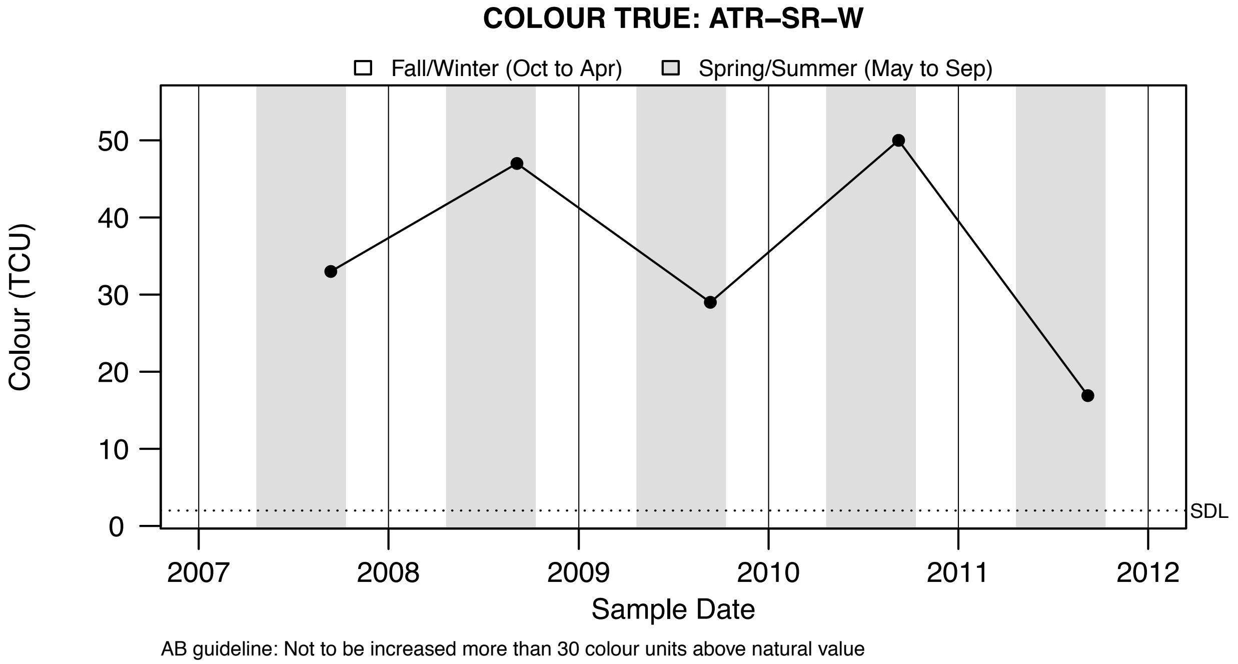


Figure A3.329: COLOUR TRUE: ATR-SR-W -

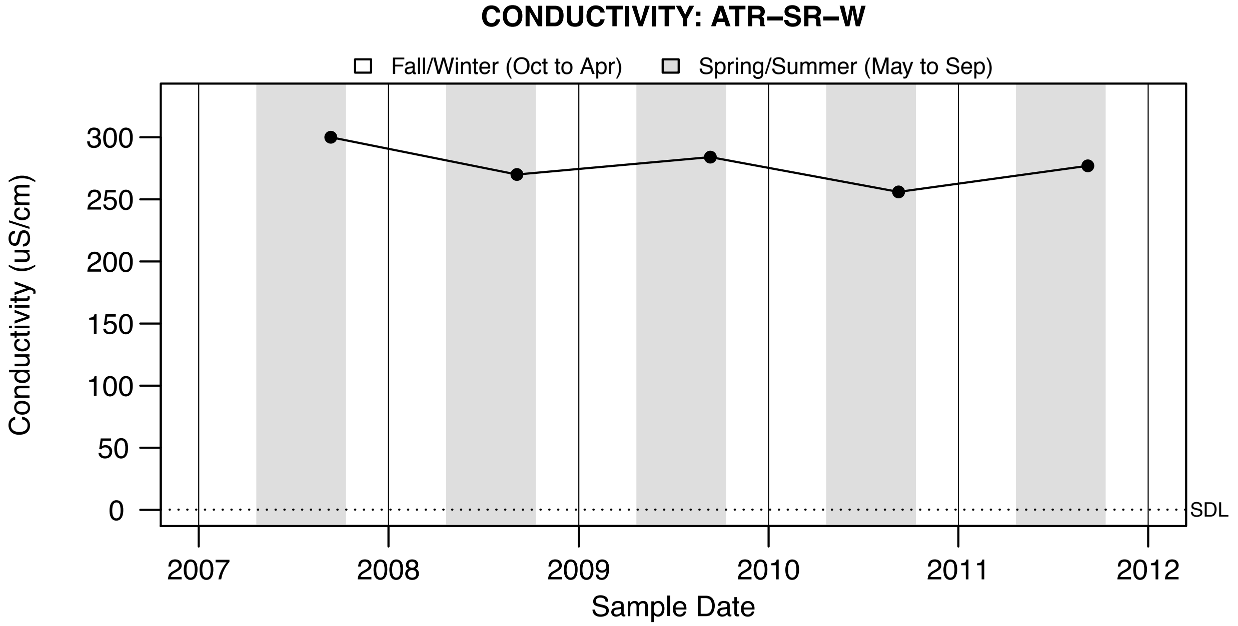
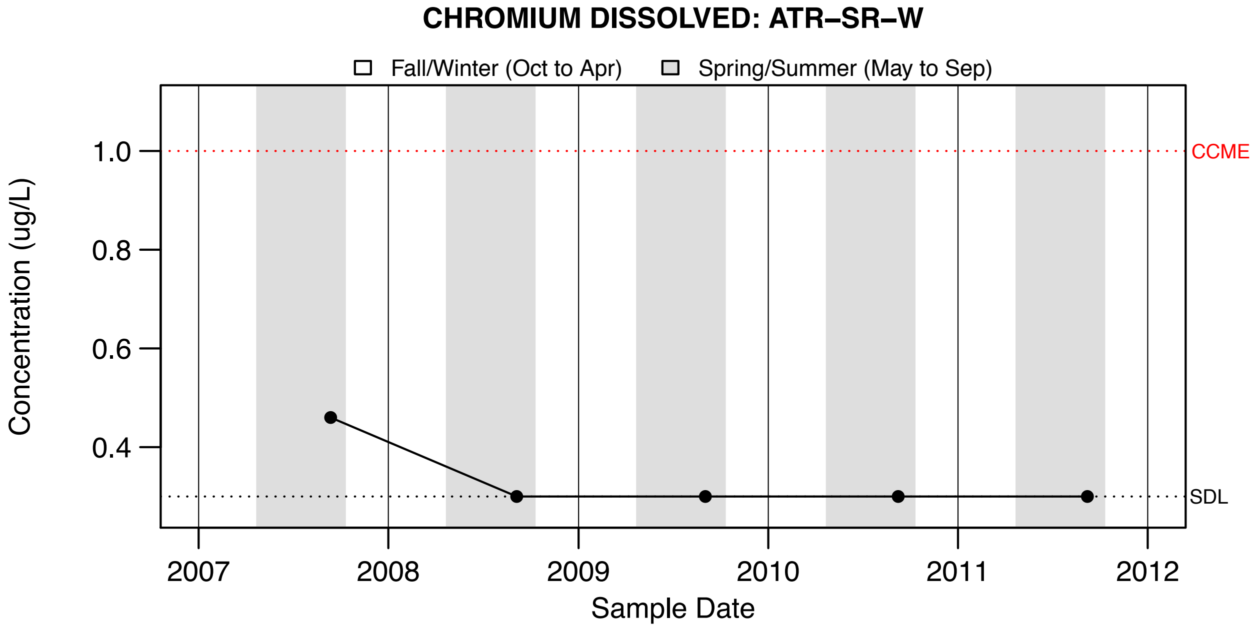
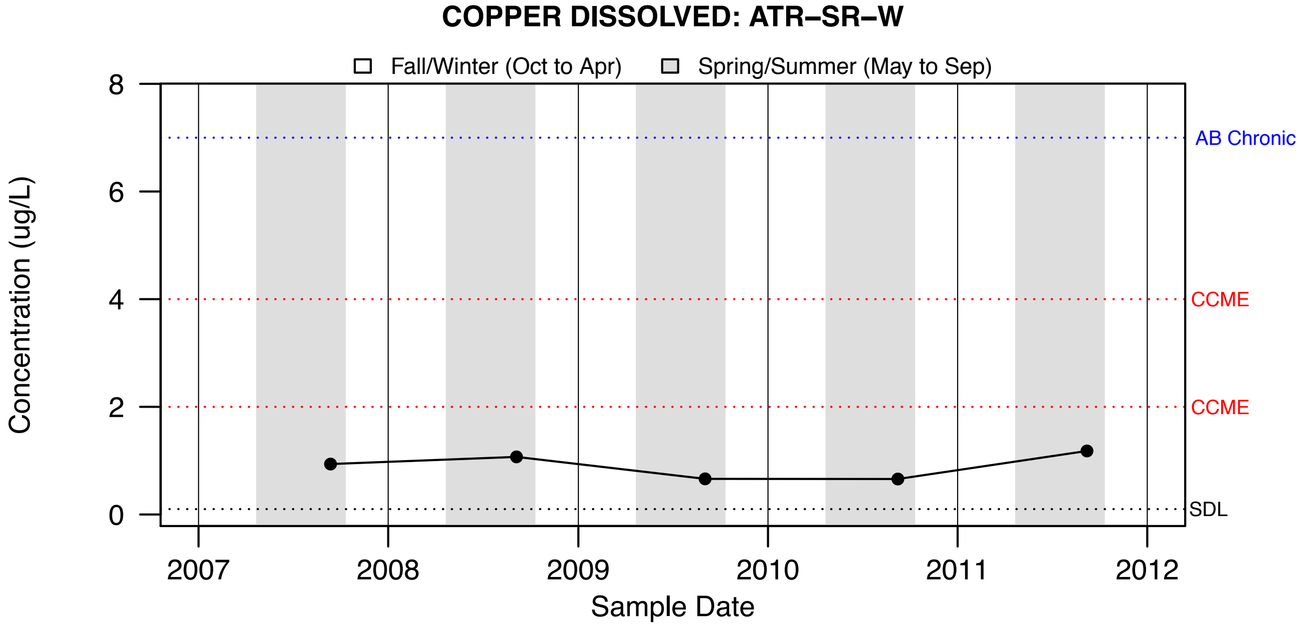


Figure A3.330: CONDUCTIVITY: ATR-SR-W -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.331: CHROMIUM DISSOLVED: ATR-SR-W -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.332: COPPER DISSOLVED: ATR-SR-W -

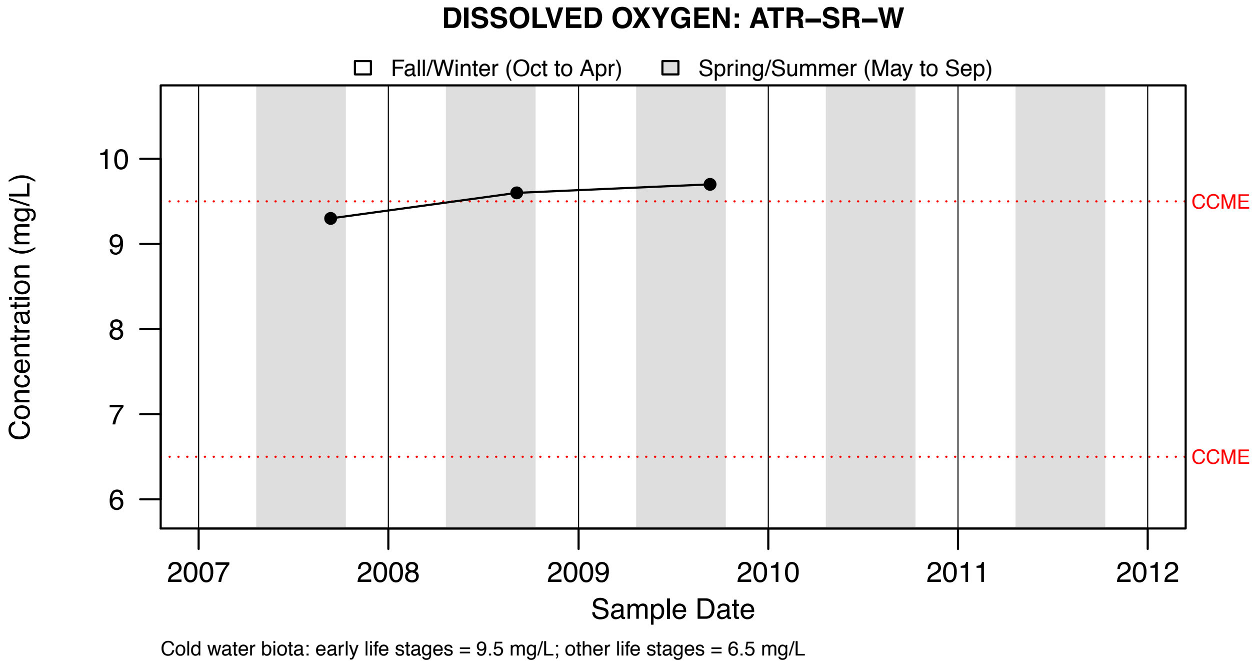


Figure A3.333: DISSOLVED OXYGEN: ATR-SR-W -

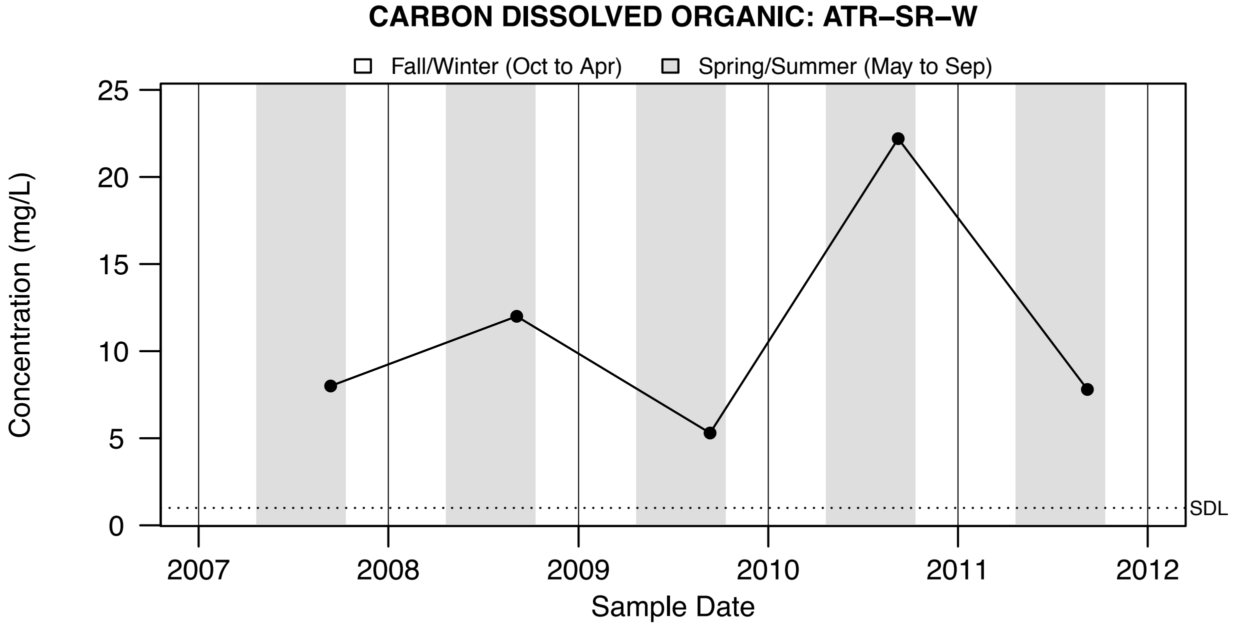


Figure A3.334: CARBON DISSOLVED ORGANIC: ATR-SR-W -

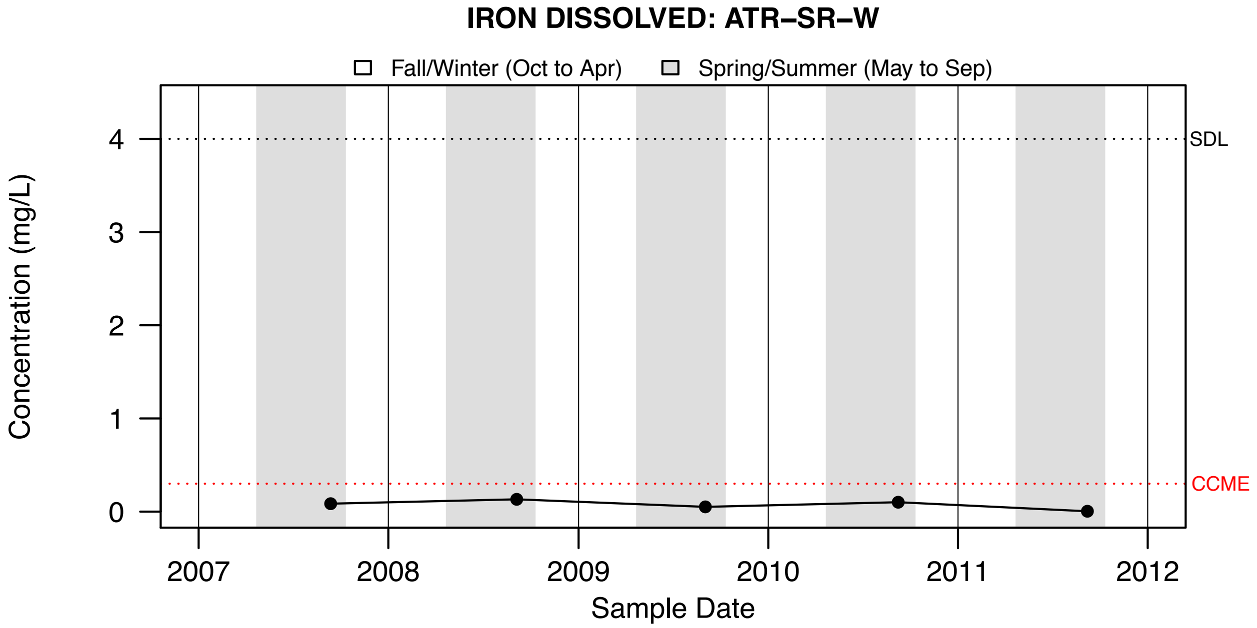


Figure A3.335: IRON DISSOLVED: ATR-SR-W -

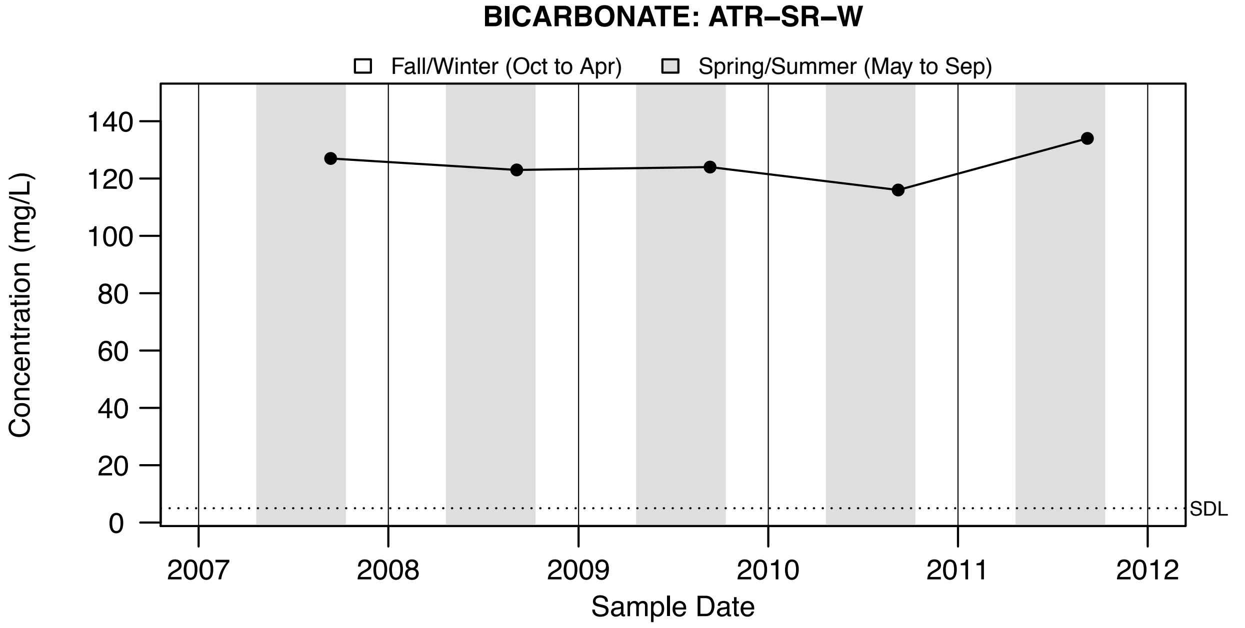


Figure A3.336: BICARBONATE: ATR-SR-W -

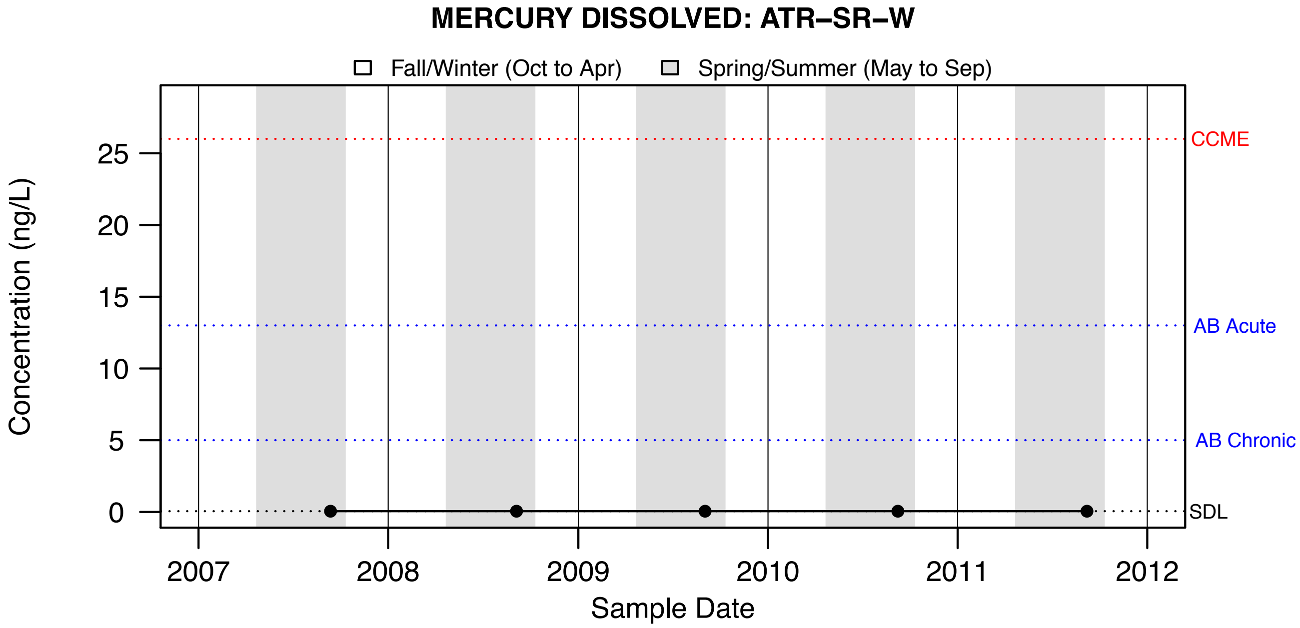


Figure A3.337: MERCURY DISSOLVED: ATR-SR-W -

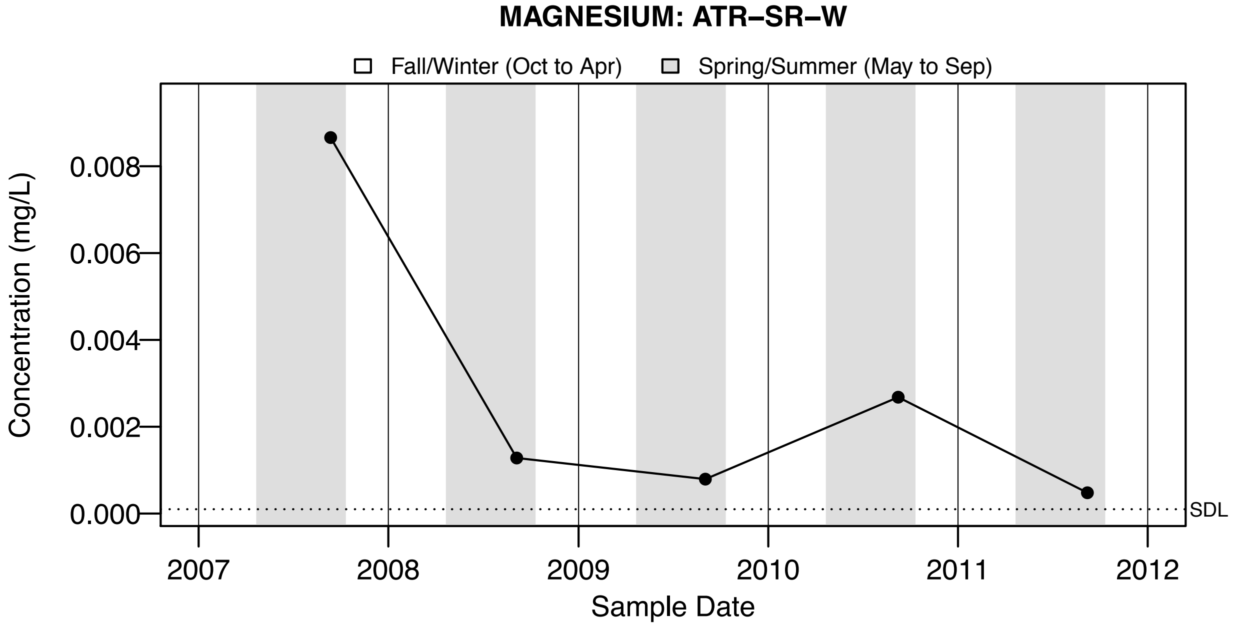


Figure A3.338: MAGNESIUM: ATR-SR-W -

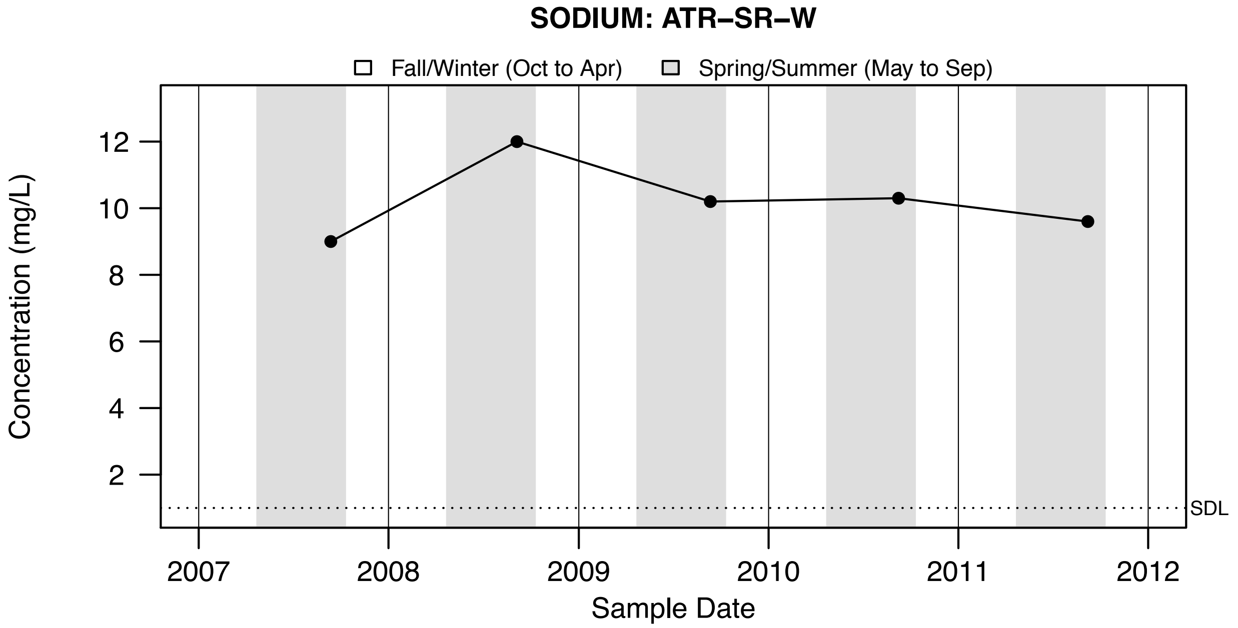
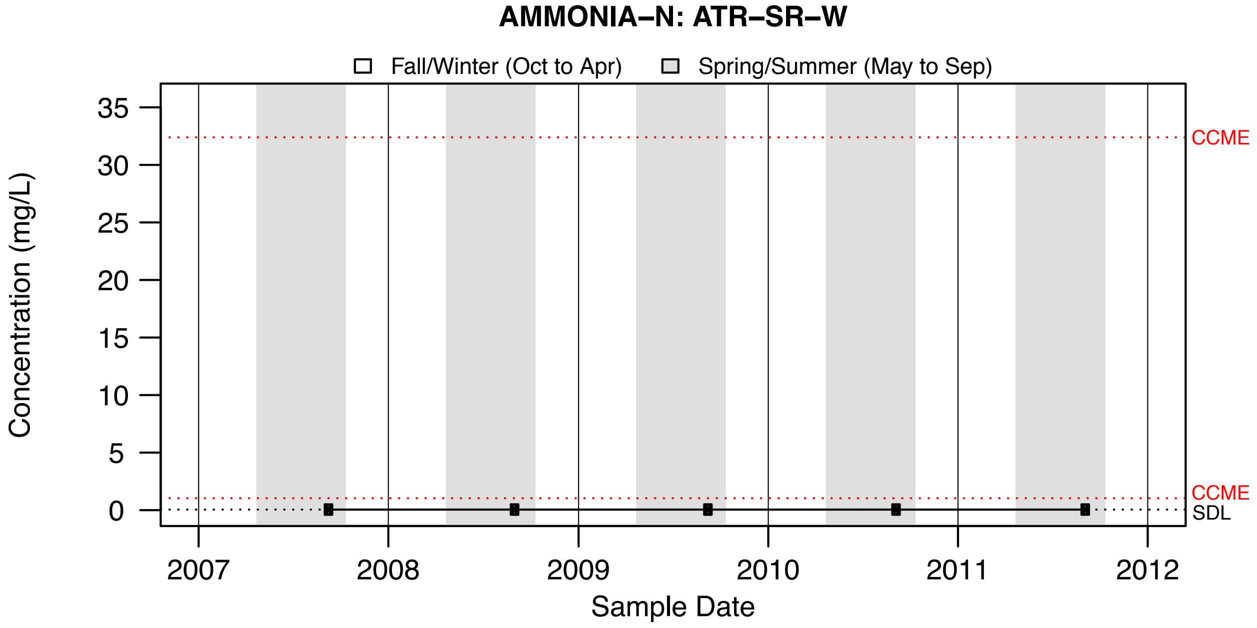


Figure A3.339: SODIUM: ATR-SR-W -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.340: AMMONIA-N: ATR-SR-W -

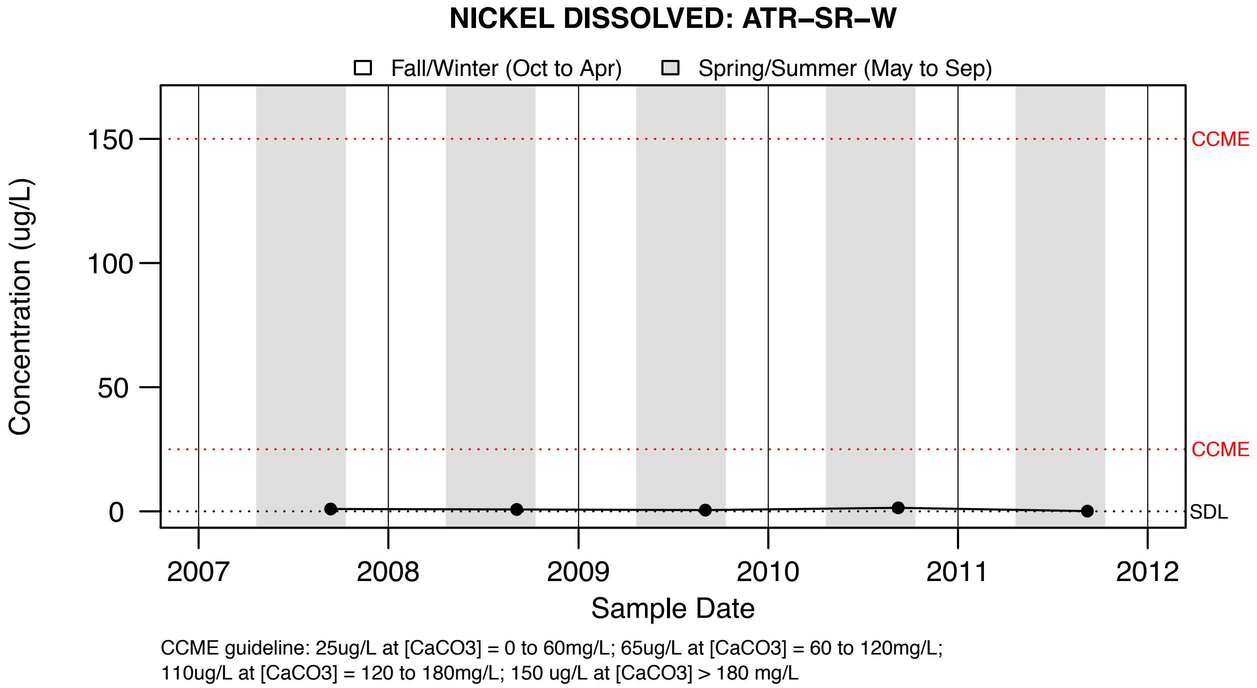


Figure A3.341: NICKEL DISSOLVED: ATR-SR-W -

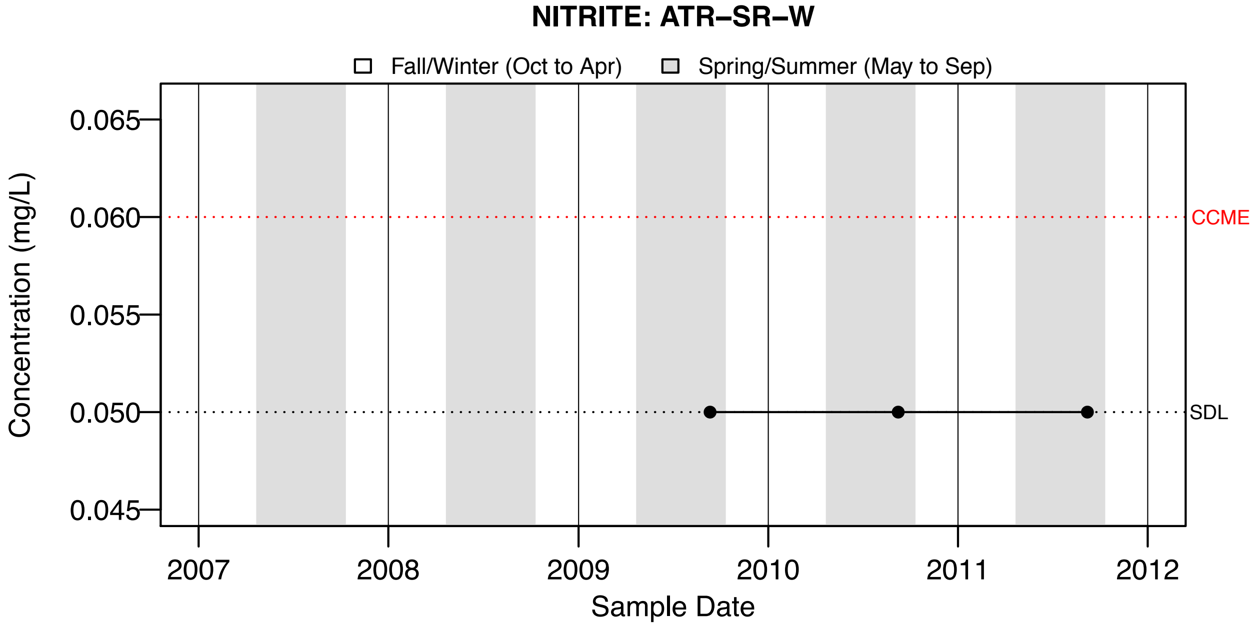
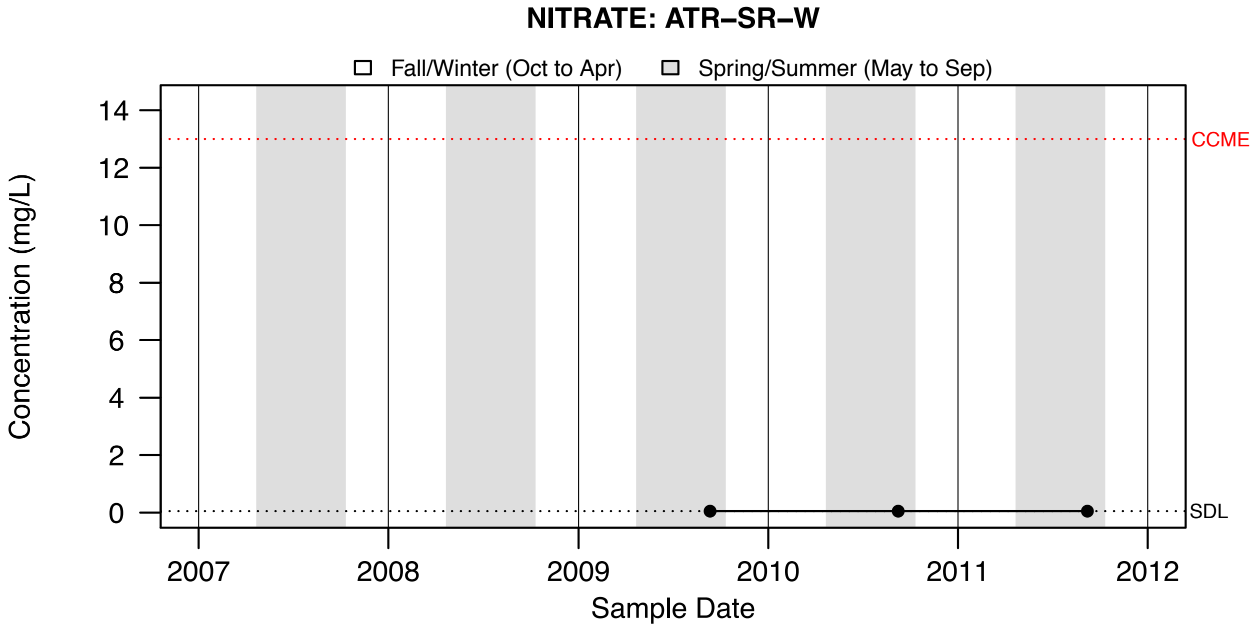


Figure A3.342: NITRITE: ATR-SR-W -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.343: NITRATE: ATR-SR-W -

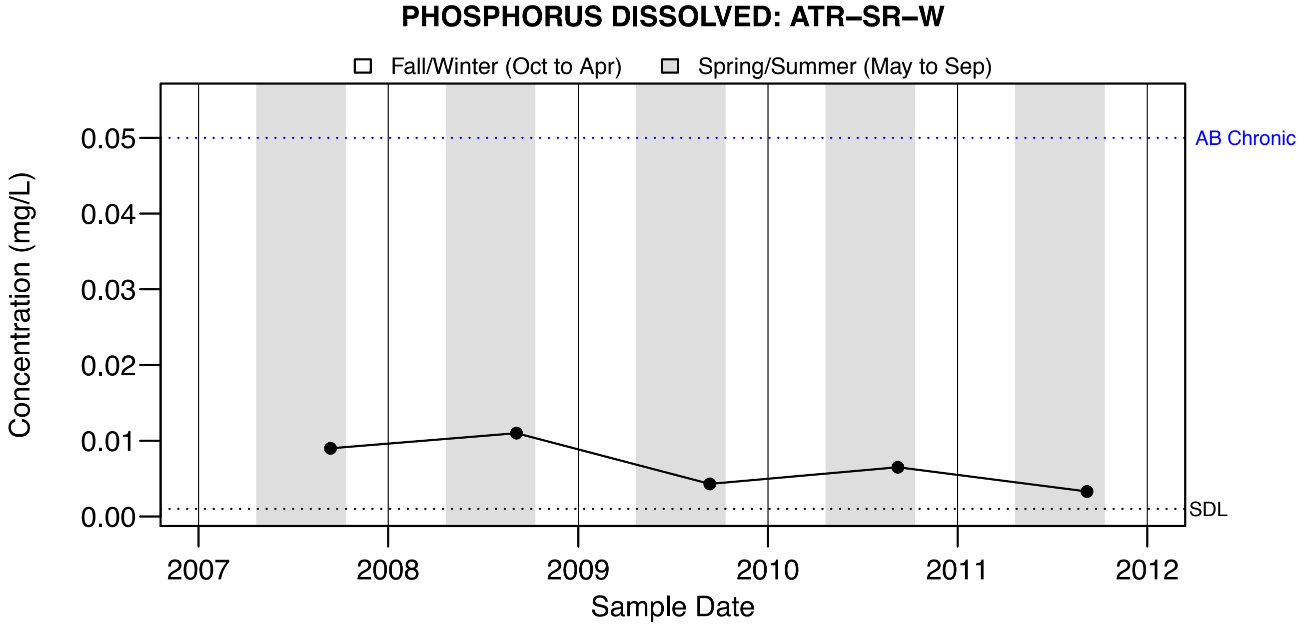


Figure A3.344: PHOSPHORUS DISSOLVED: ATR-SR-W -

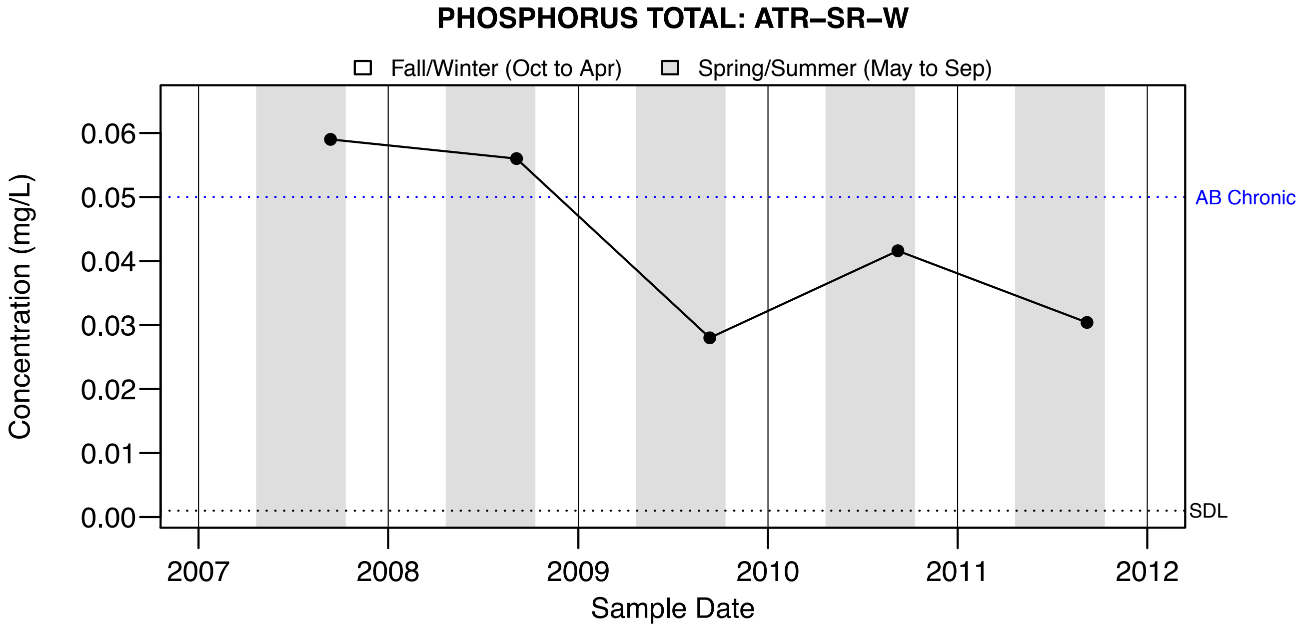
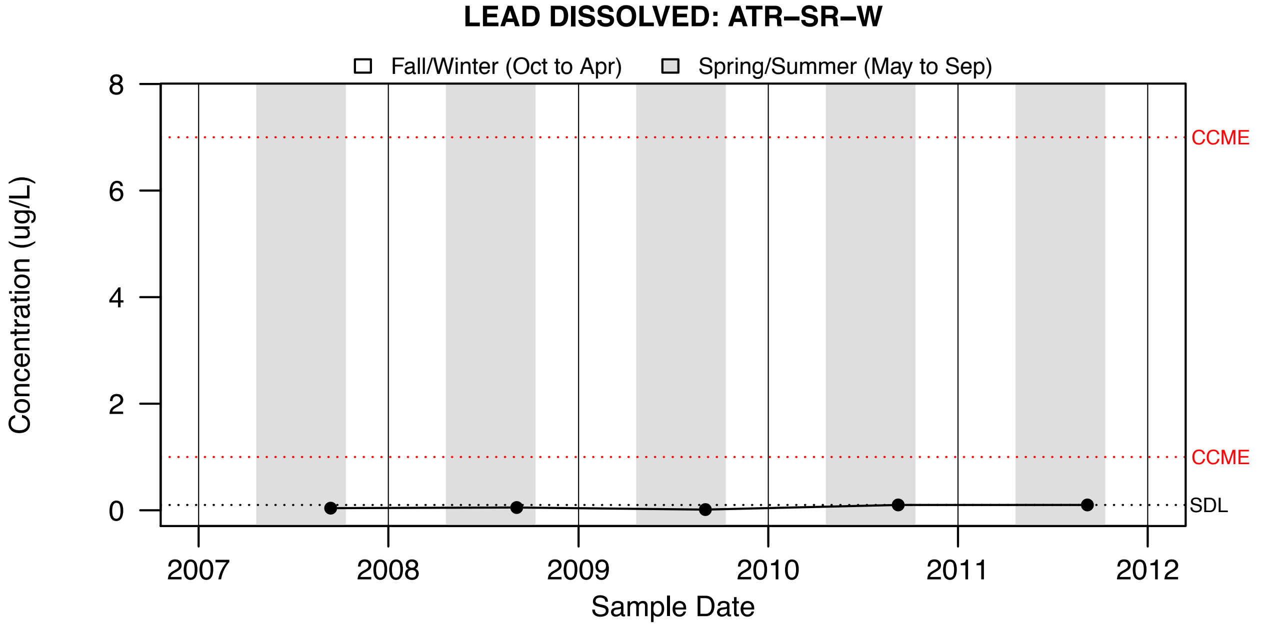


Figure A3.345: PHOSPHORUS TOTAL: ATR-SR-W -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.346: LEAD DISSOLVED: ATR-SR-W -

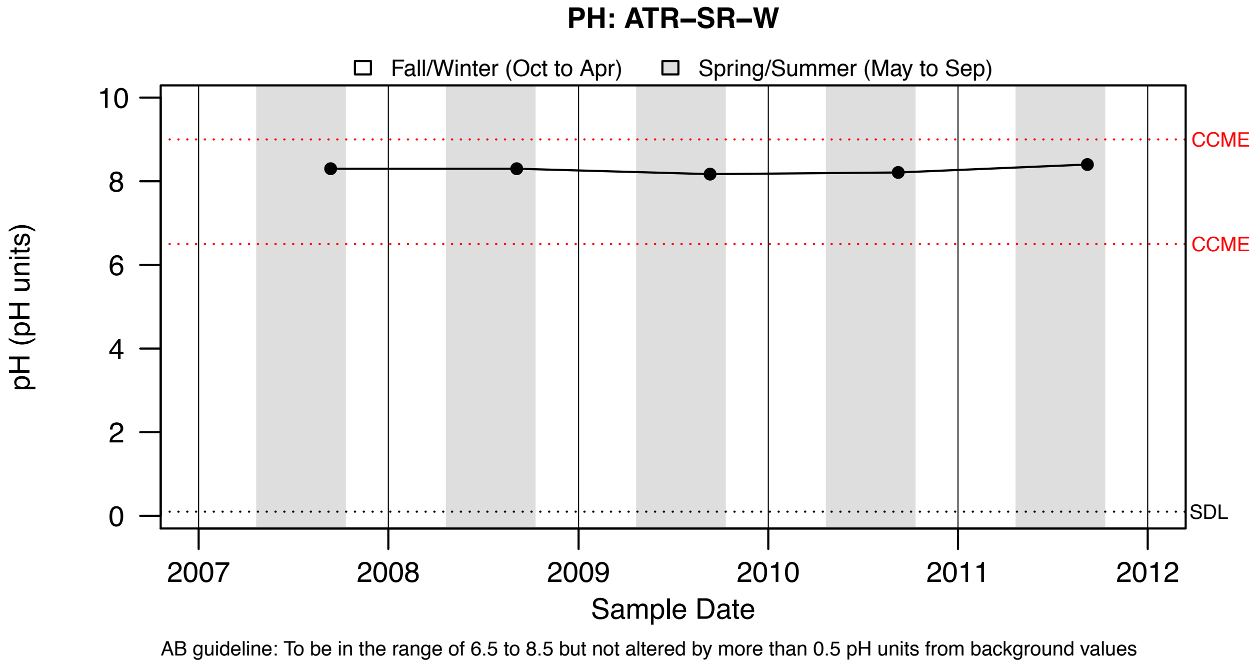


Figure A3.347: PH: ATR-SR-W -

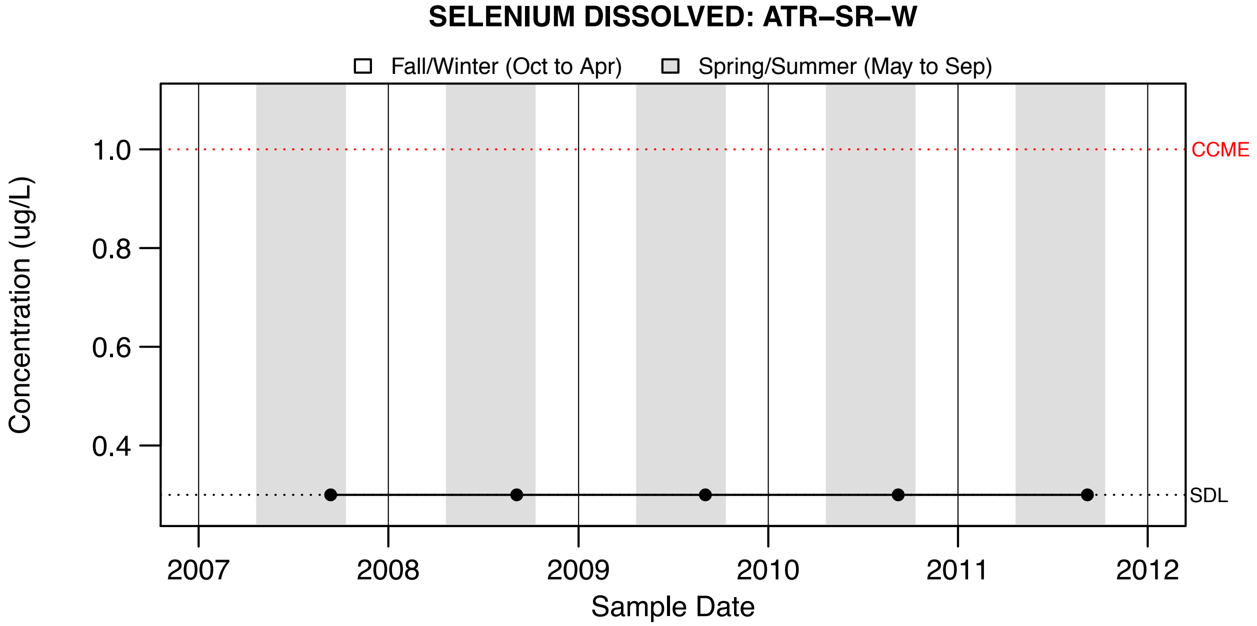


Figure A3.348: SELENIUM DISSOLVED: ATR-SR-W -

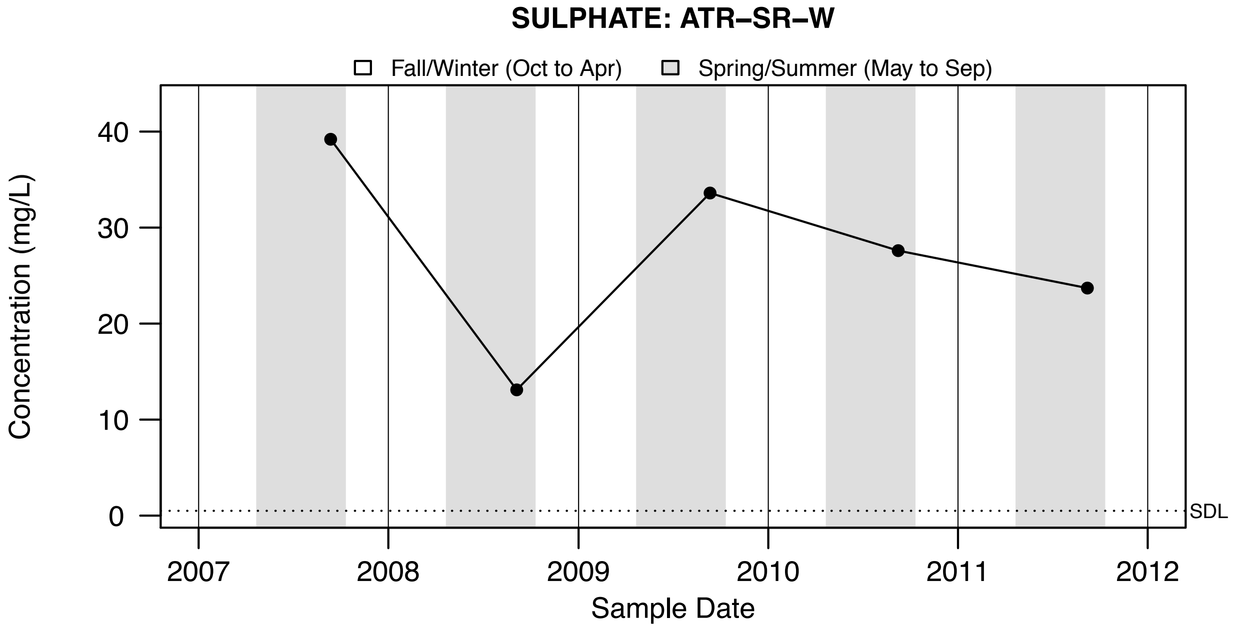


Figure A3.349: SULPHATE: ATR-SR-W -

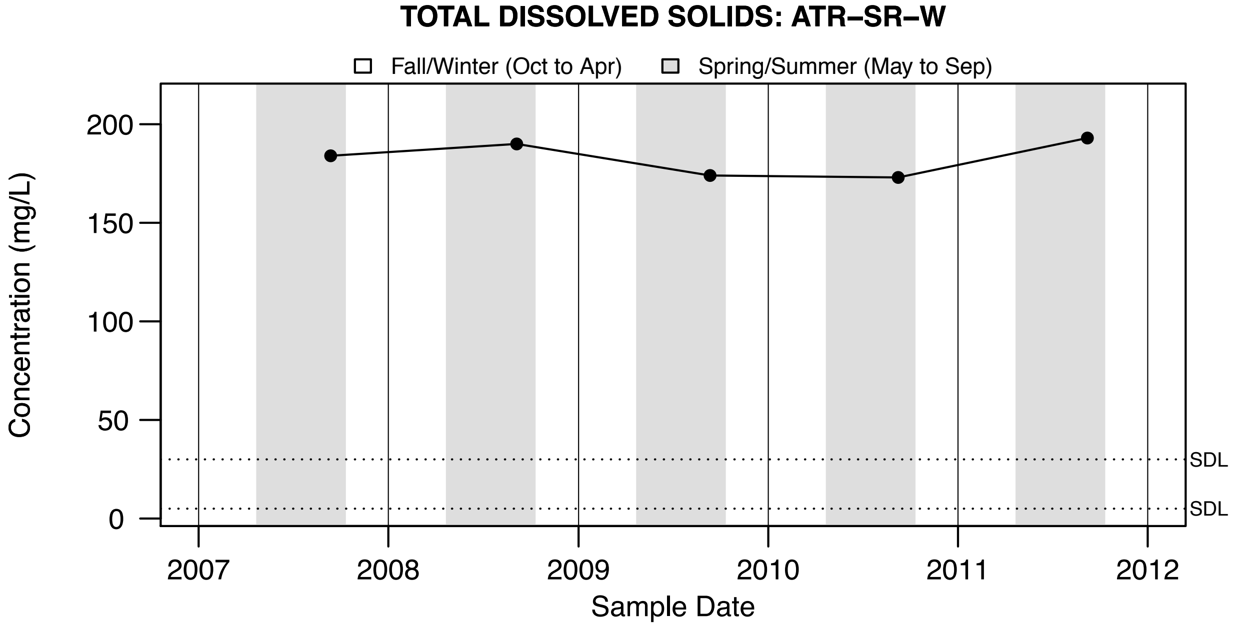


Figure A3.350: TOTAL DISSOLVED SOLIDS: ATR-SR-W -

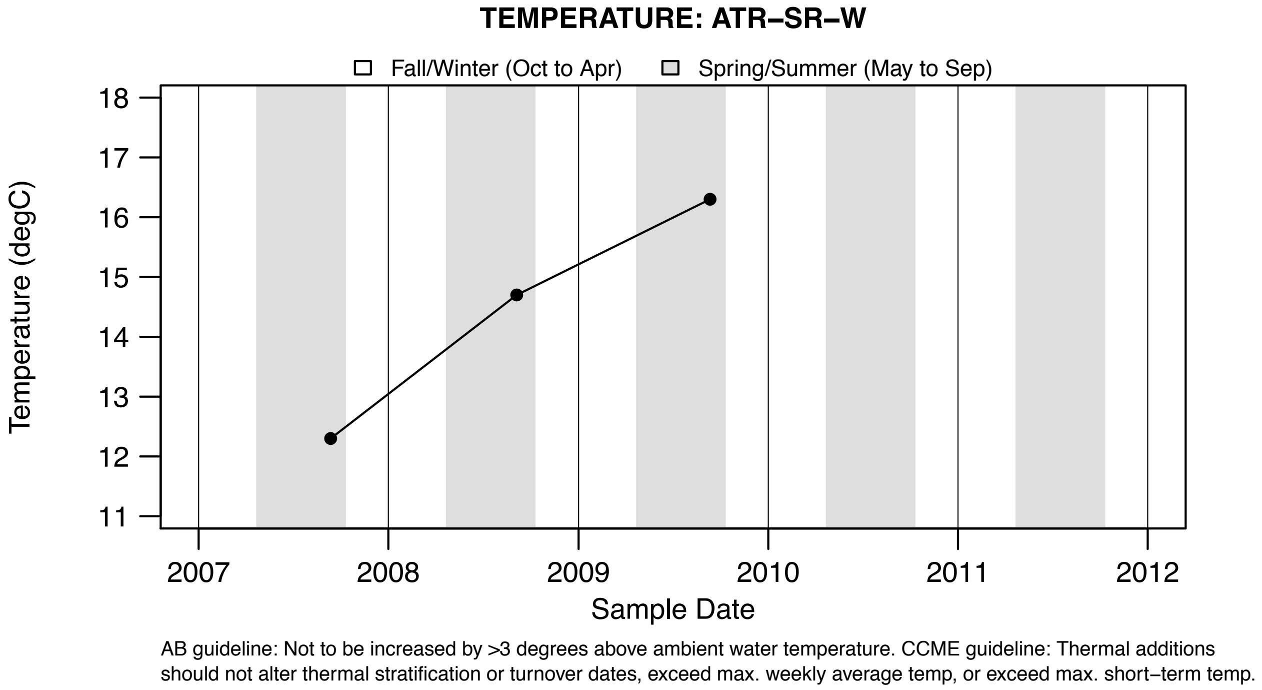


Figure A3.351: TEMPERATURE: ATR-SR-W -

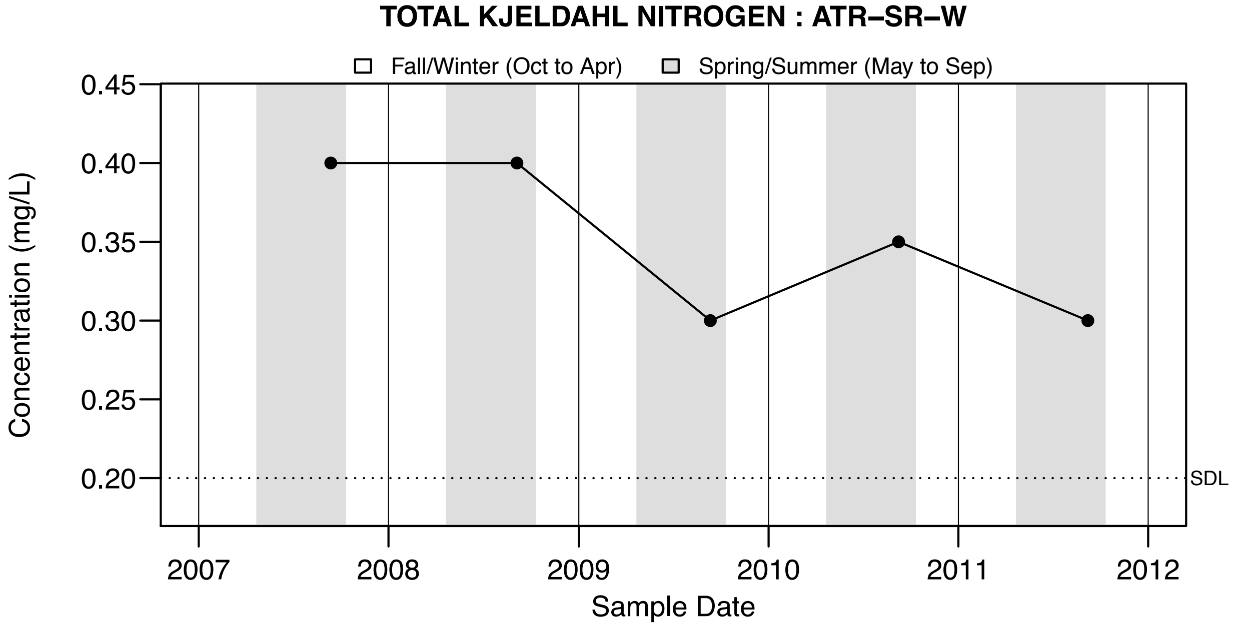
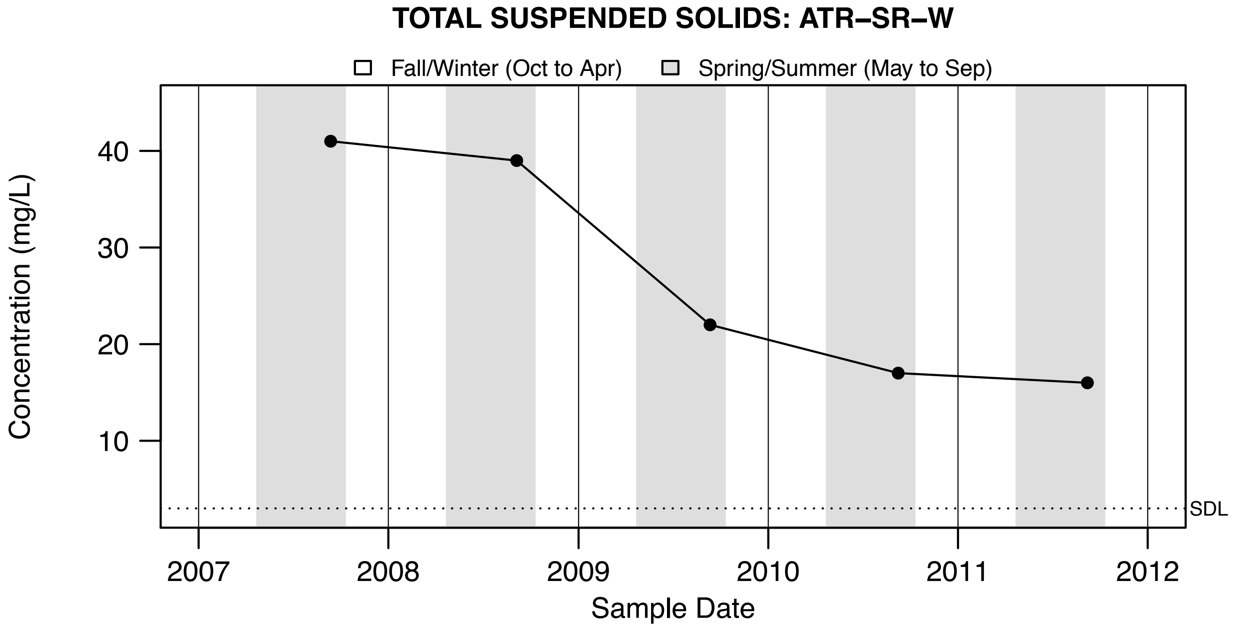


Figure A3.352: TOTAL KJELDAHL NITROGEN : ATR-SR-W -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.353: TOTAL SUSPENDED SOLIDS: ATR-SR-W -

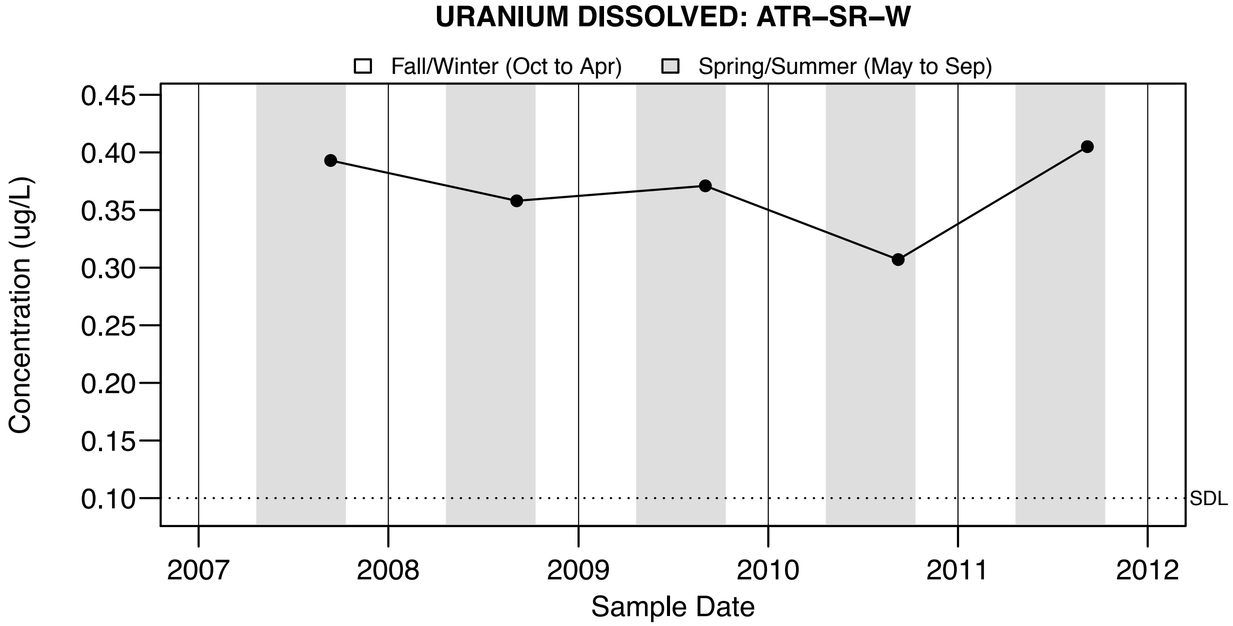


Figure A3.354: URANIUM DISSOLVED: ATR-SR-W -

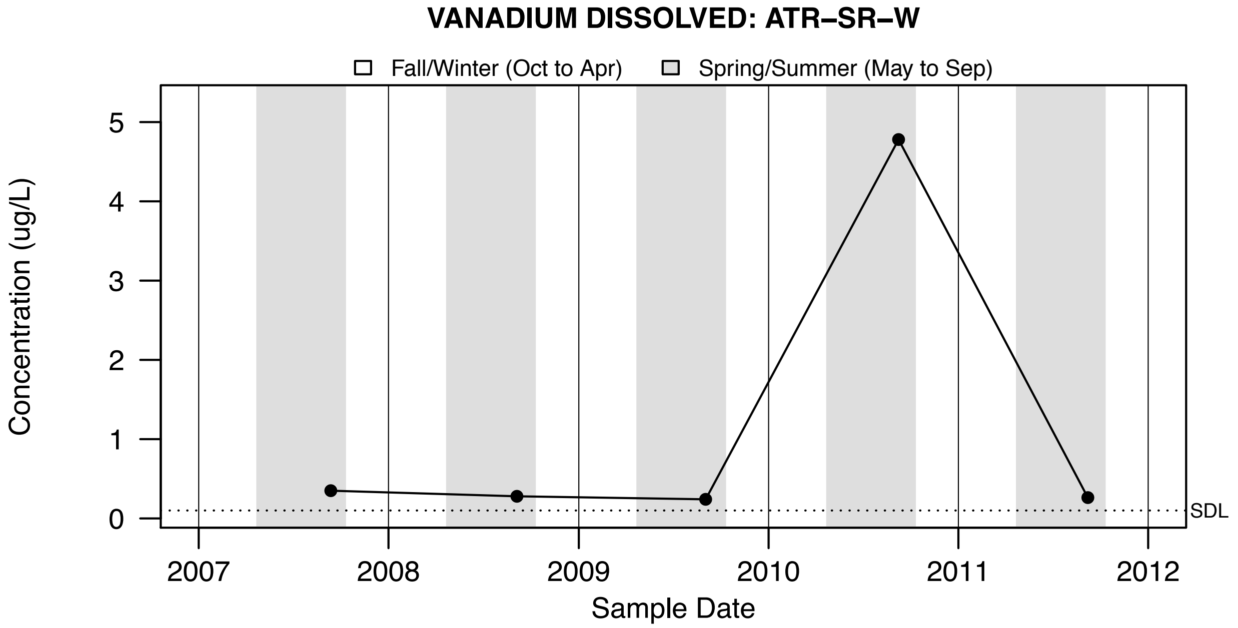


Figure A3.355: VANADIUM DISSOLVED: ATR-SR-W -

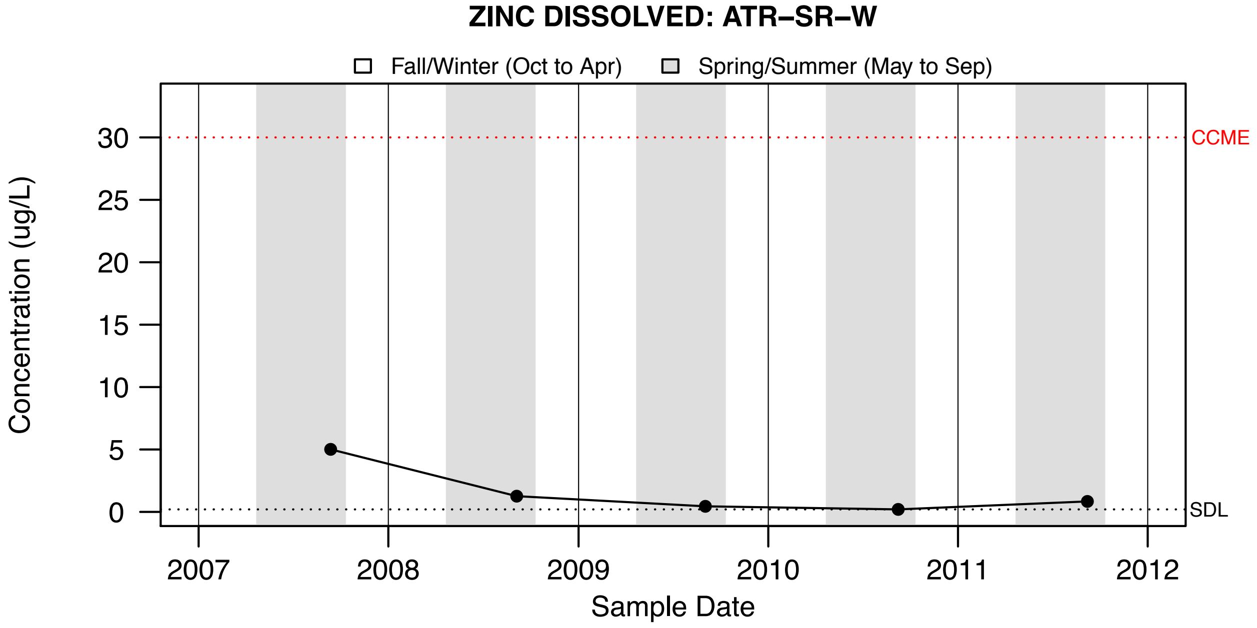
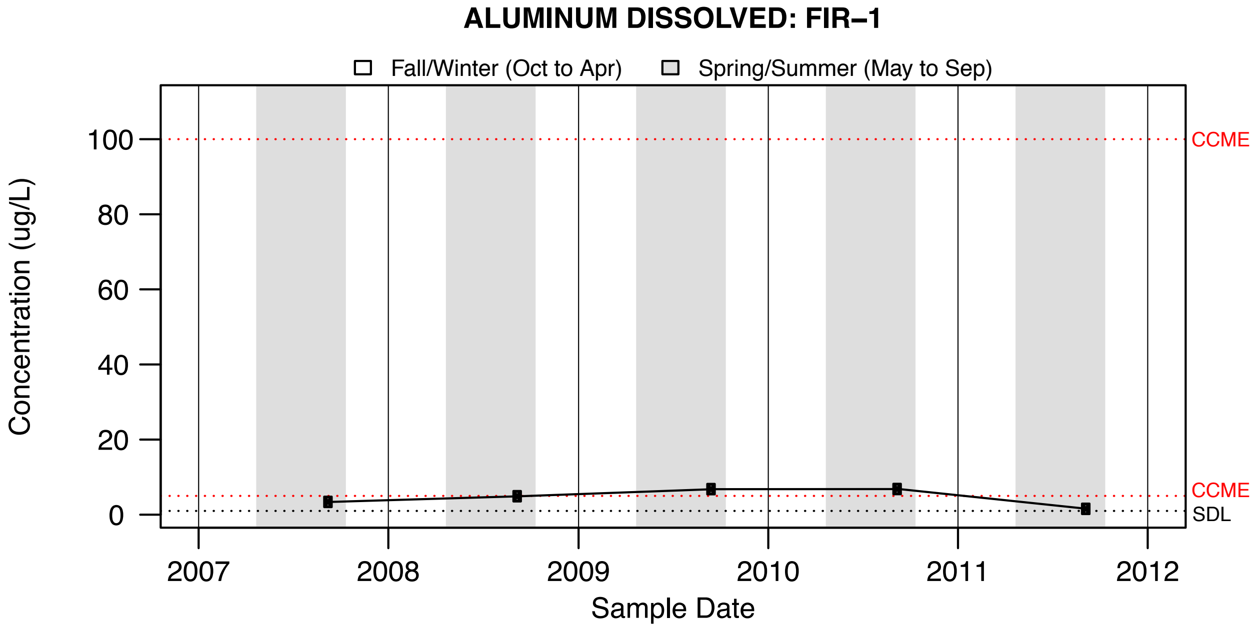
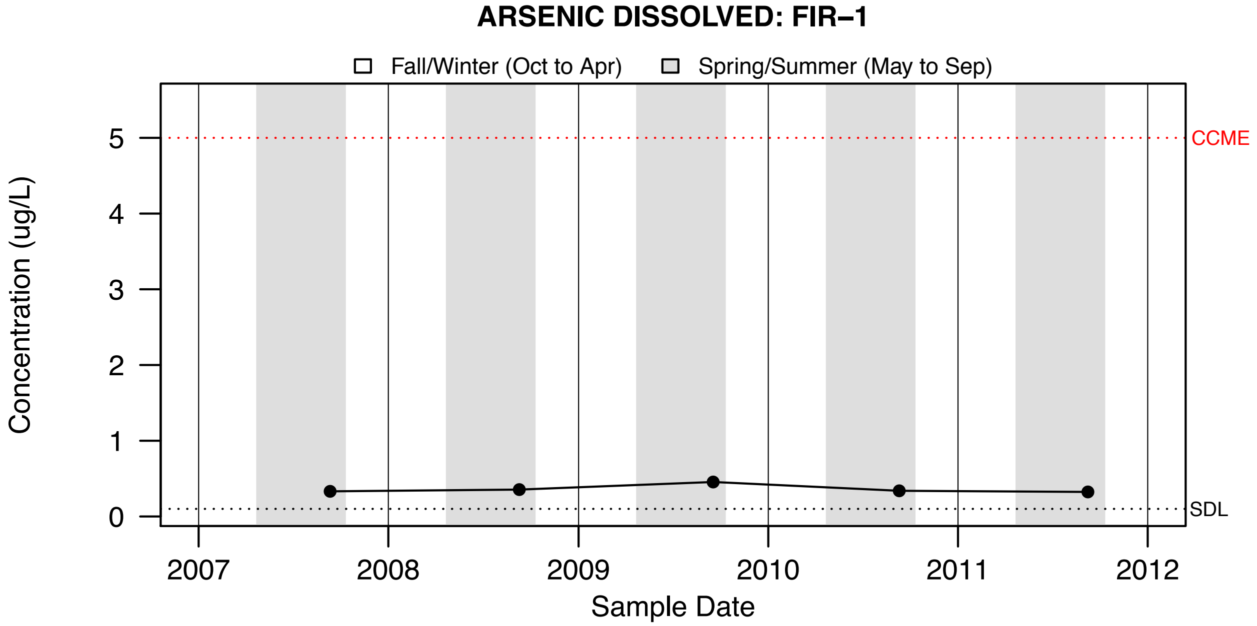


Figure A3.356: ZINC DISSOLVED: ATR-SR-W -



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A3.357: ALUMINUM DISSOLVED: FIR-1 -



AB guidelines state Total Arsenic; CCME does not specify

Figure A3.358: ARSENIC DISSOLVED: FIR-1 -

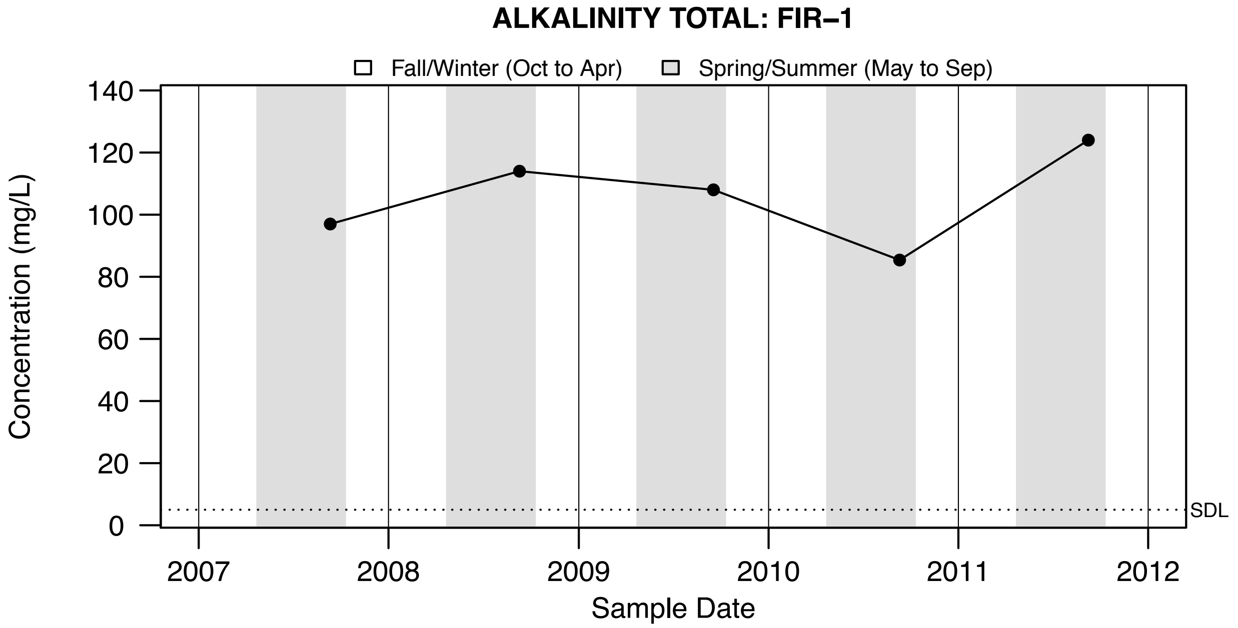


Figure A3.359: ALKALINITY TOTAL: FIR-1 -

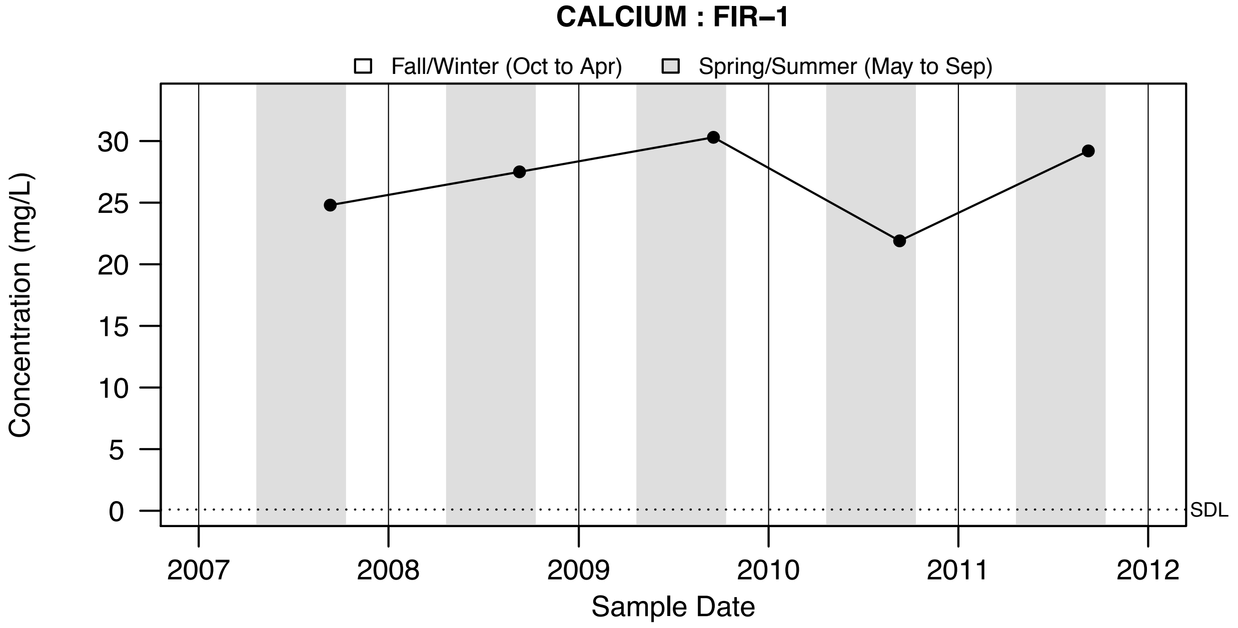


Figure A3.360: CALCIUM : FIR-1 -

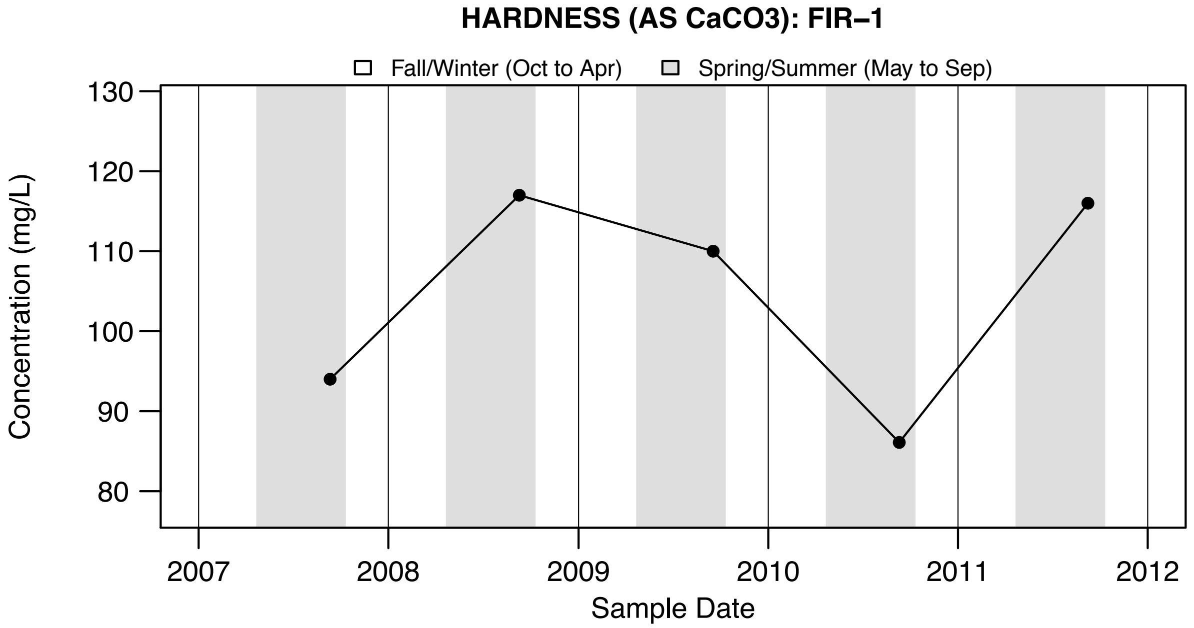


Figure A3.361: HARDNESS (AS CaCO3): FIR-1 -

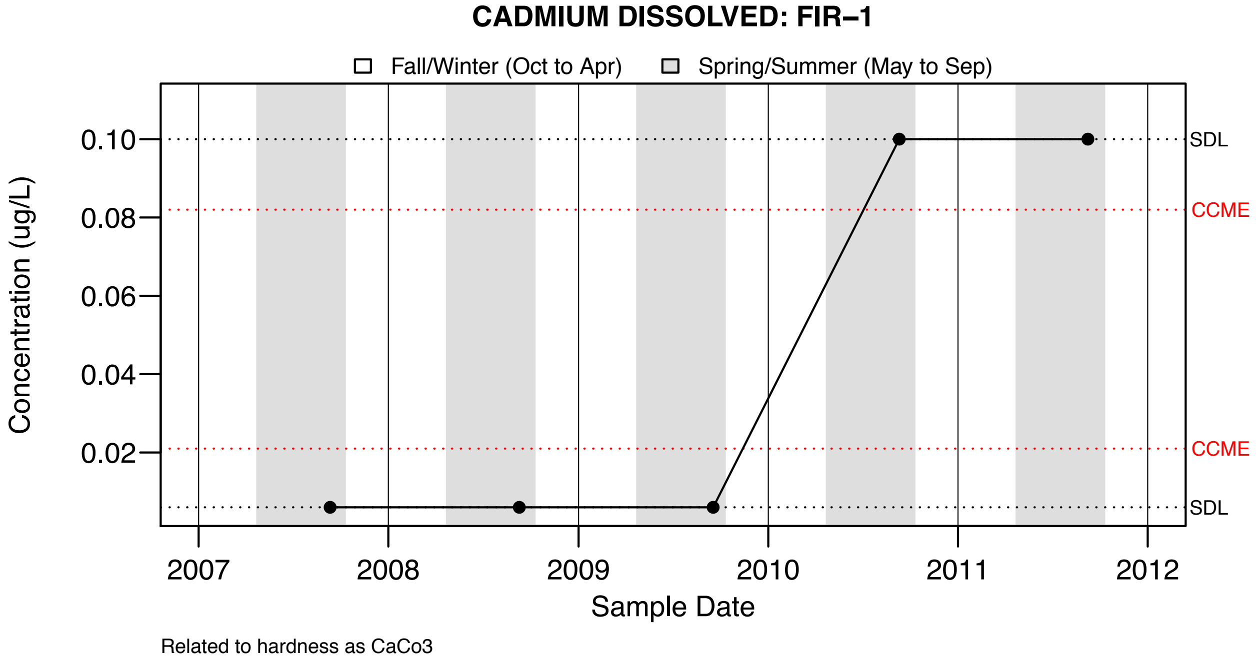


Figure A3.362: CADMIUM DISSOLVED: FIR-1 -

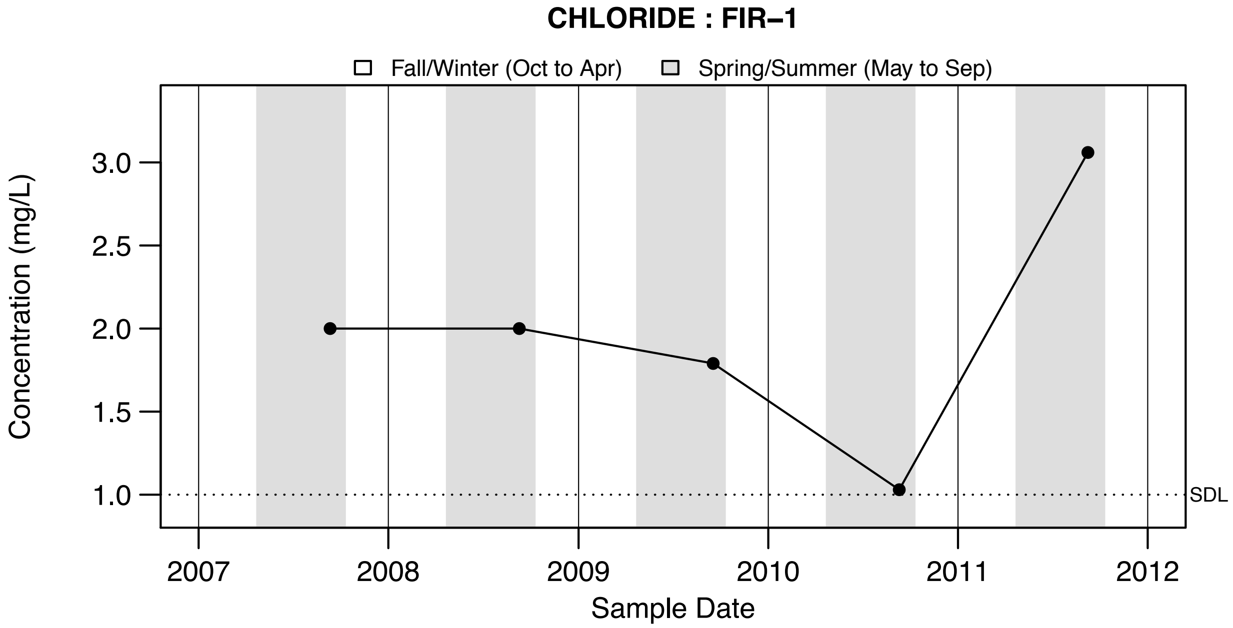


Figure A3.363: CHLORIDE : FIR-1 -

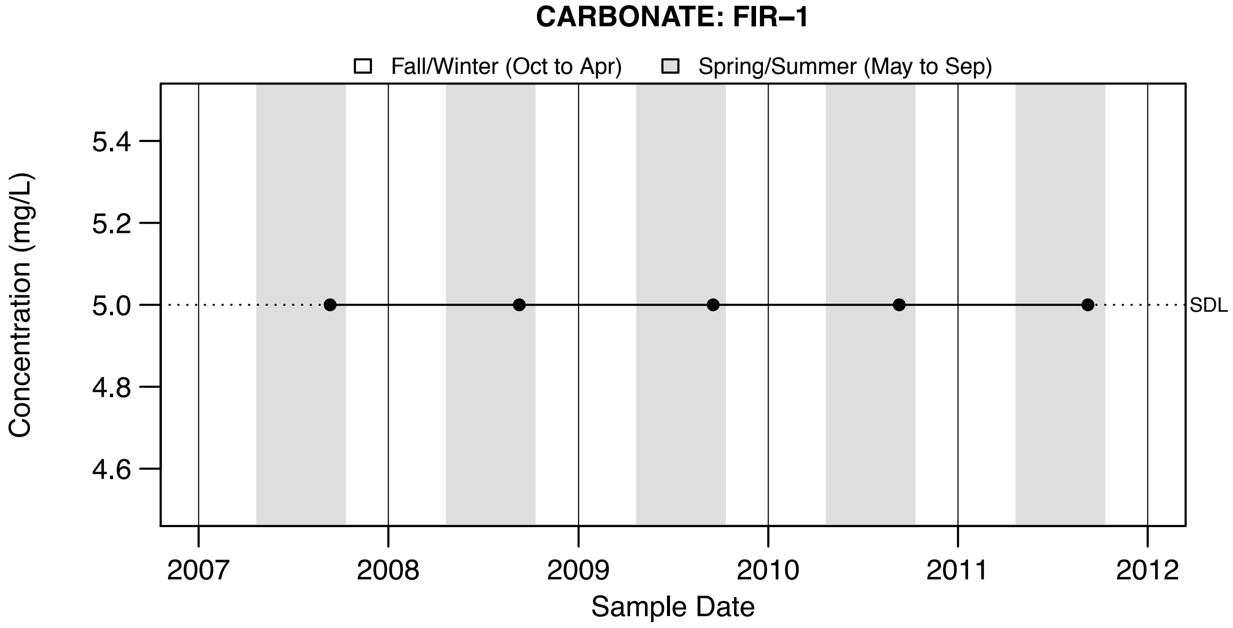


Figure A3.364: CARBONATE: FIR-1 -

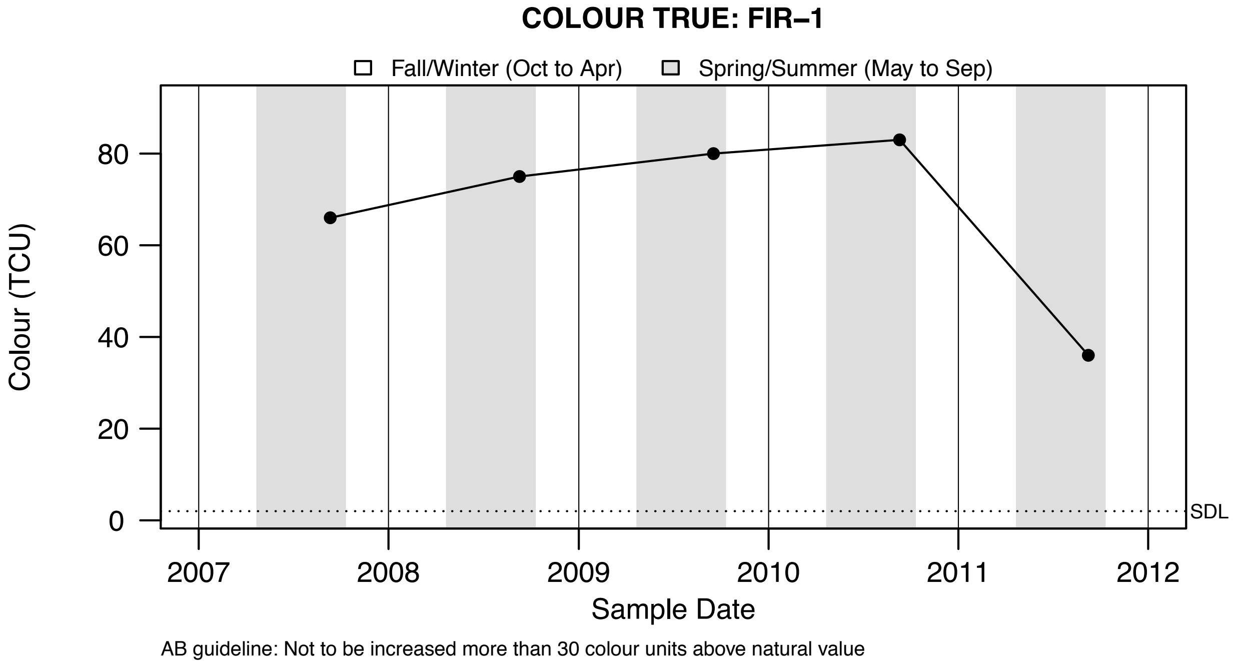


Figure A3.365: COLOUR TRUE: FIR-1 -

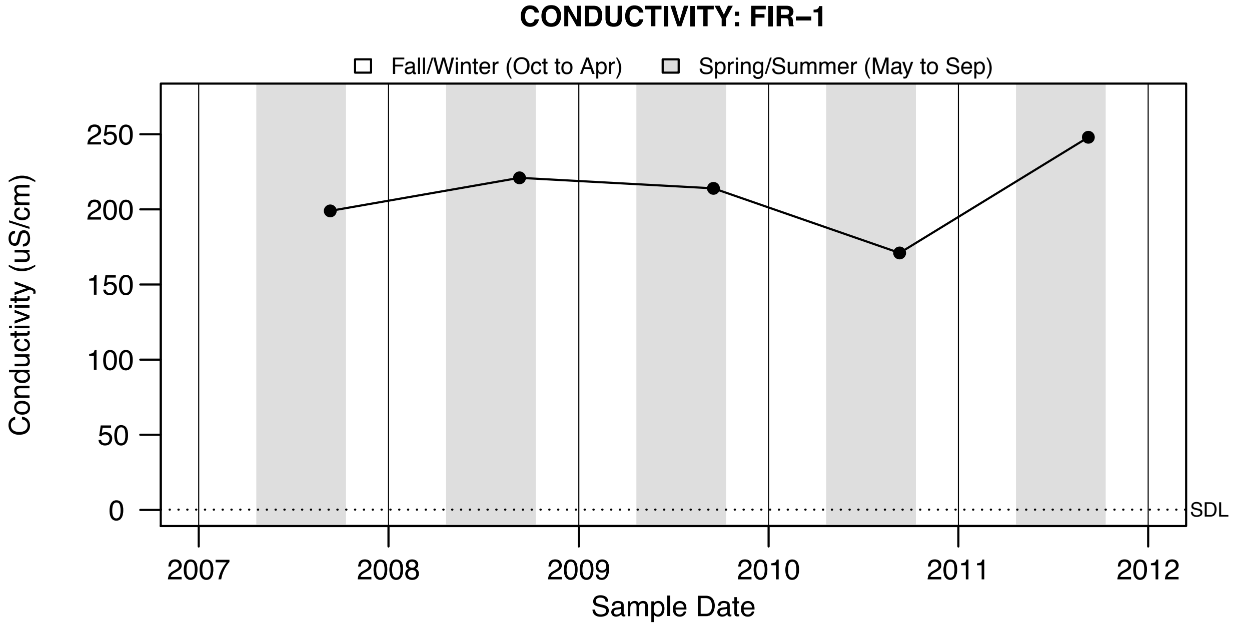
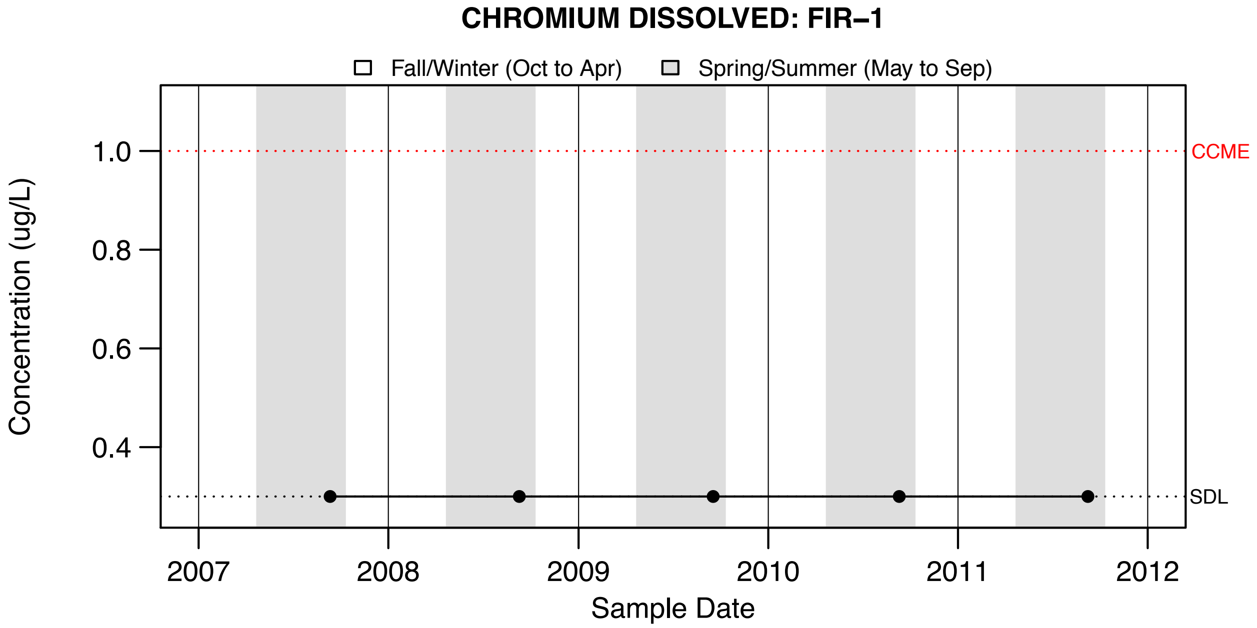
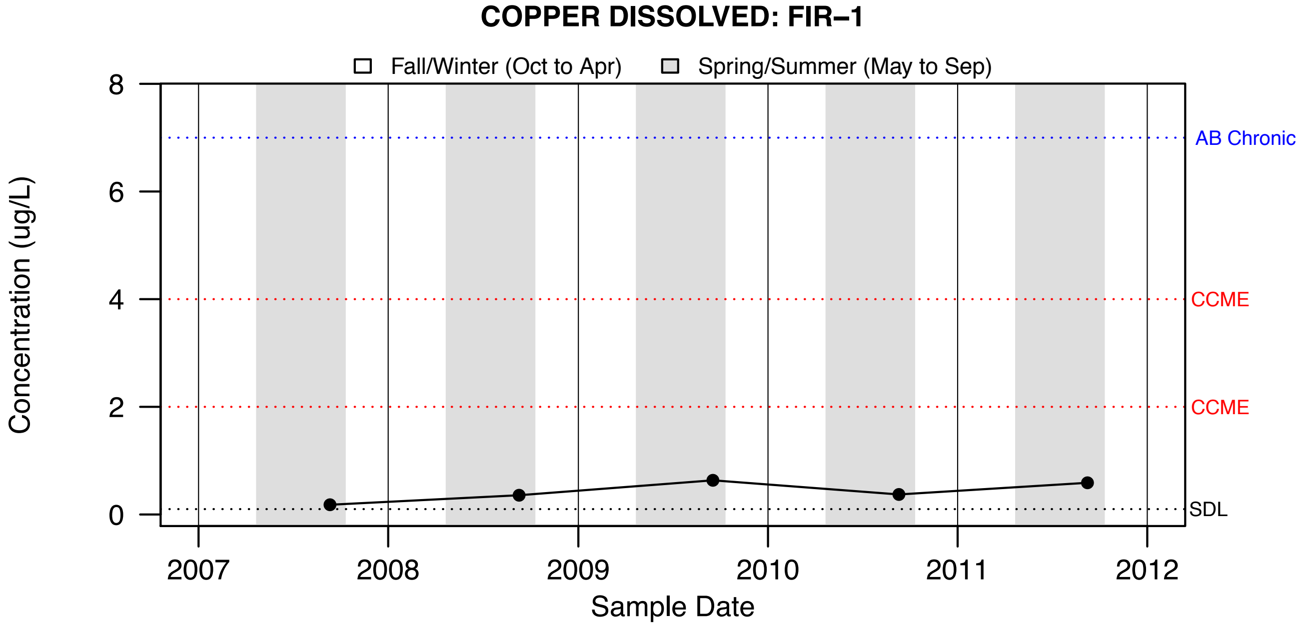


Figure A3.366: CONDUCTIVITY: FIR-1 -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.367: CHROMIUM DISSOLVED: FIR-1 -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.368: COPPER DISSOLVED: FIR-1 -

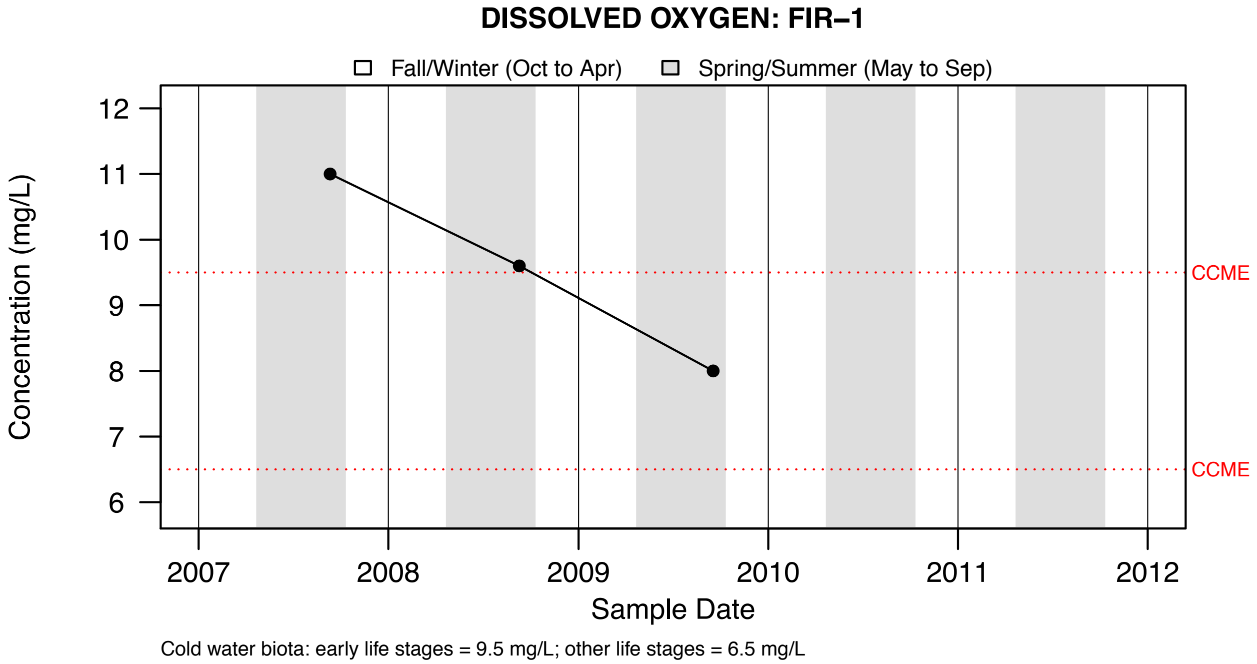


Figure A3.369: DISSOLVED OXYGEN: FIR-1 -

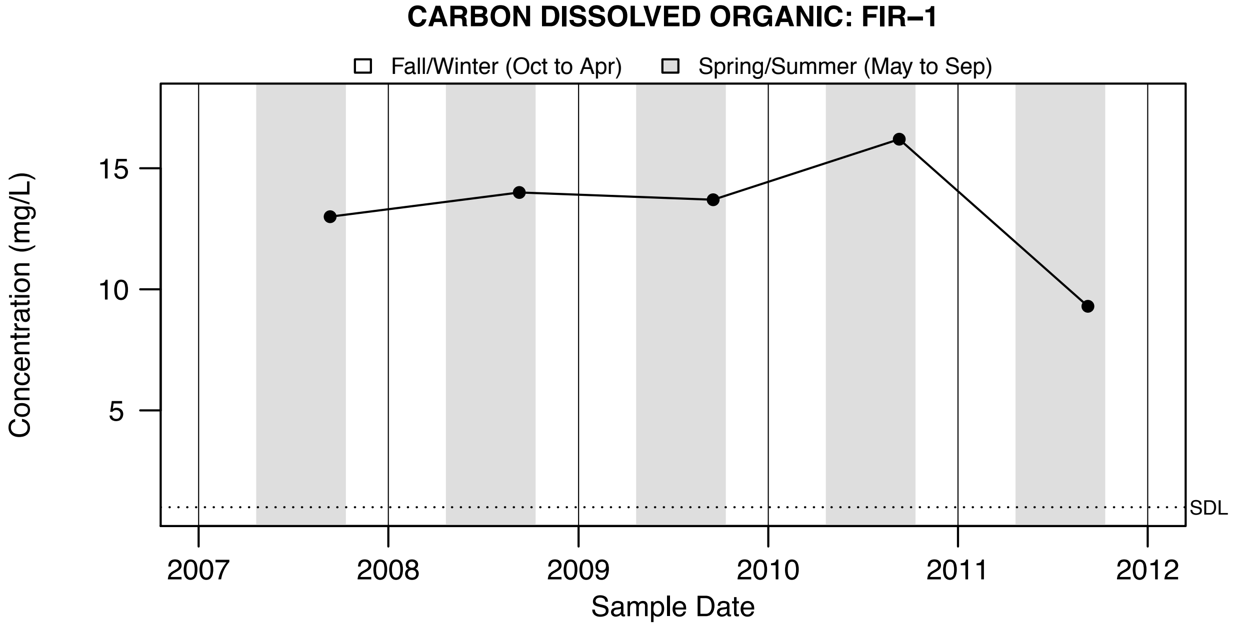


Figure A3.370: CARBON DISSOLVED ORGANIC: FIR-1 -

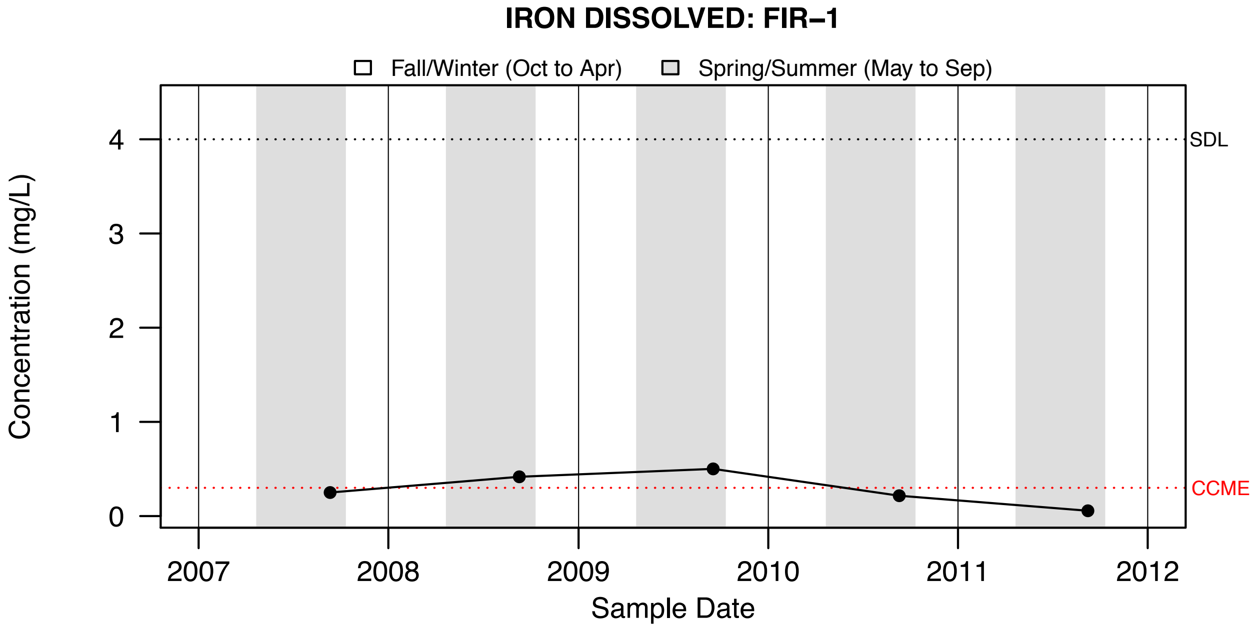


Figure A3.371: IRON DISSOLVED: FIR-1 -

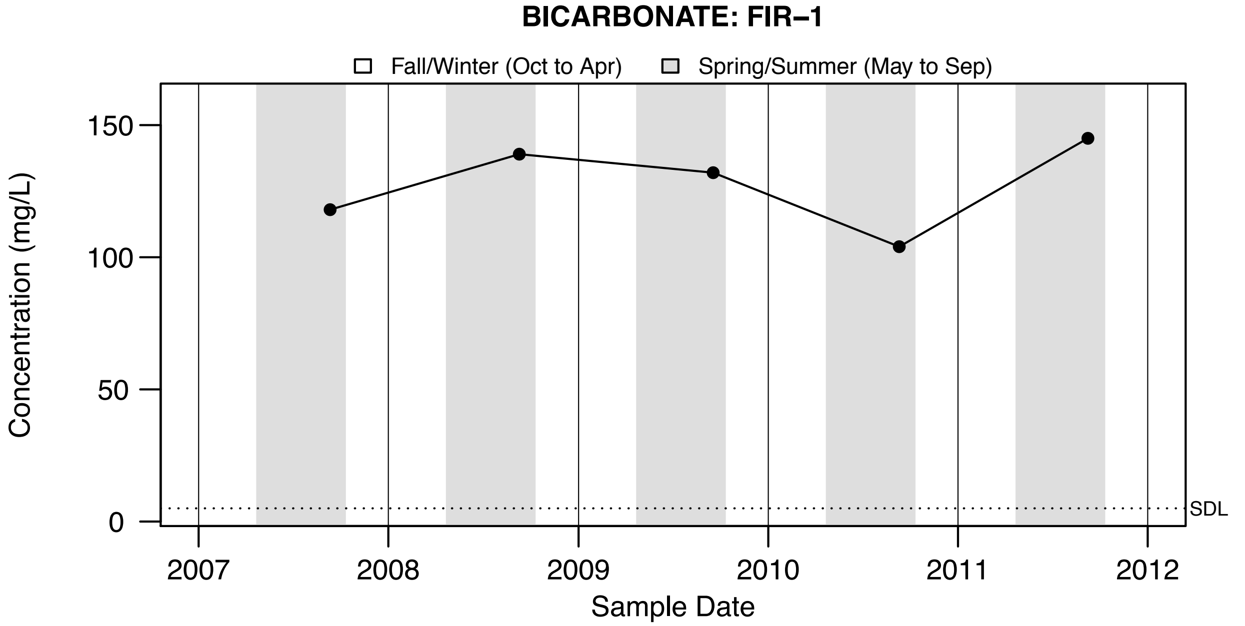


Figure A3.372: BICARBONATE: FIR-1 -

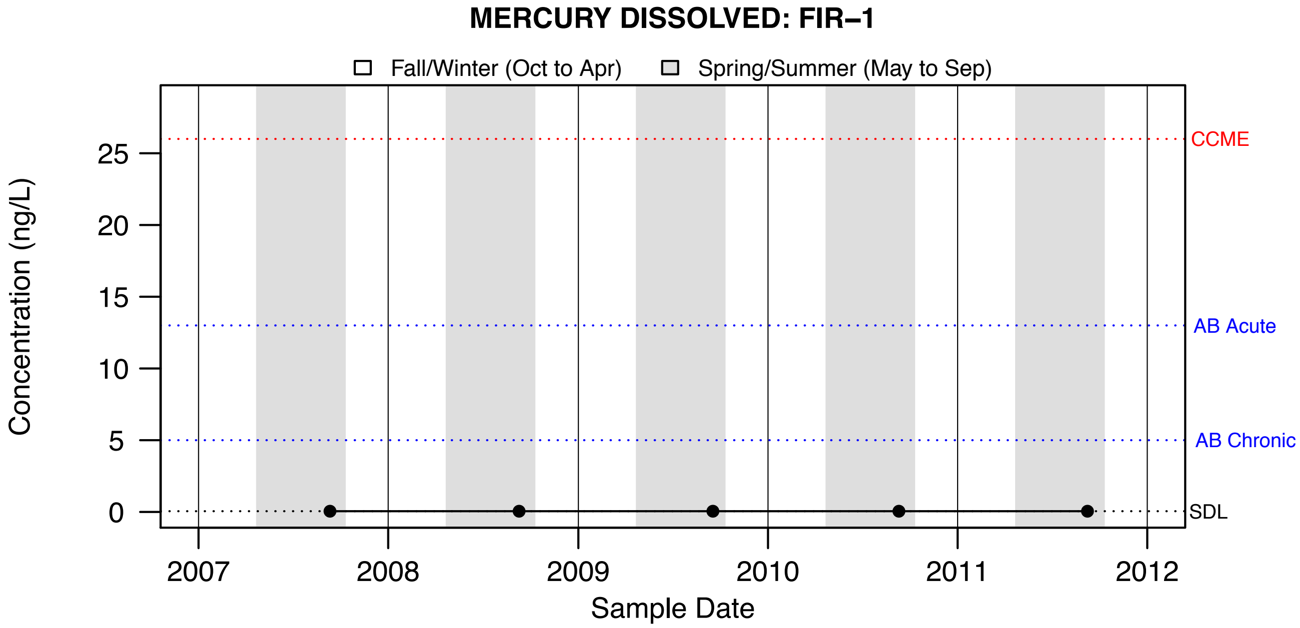


Figure A3.373: MERCURY DISSOLVED: FIR-1 -

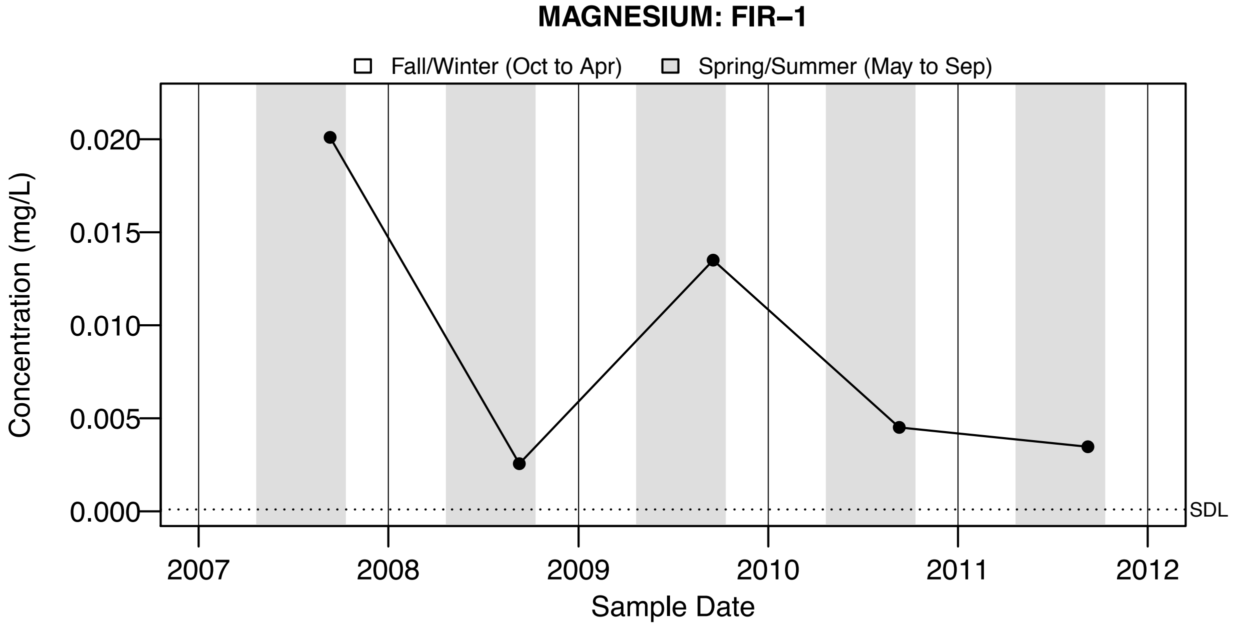


Figure A3.374: MAGNESIUM: FIR-1 -

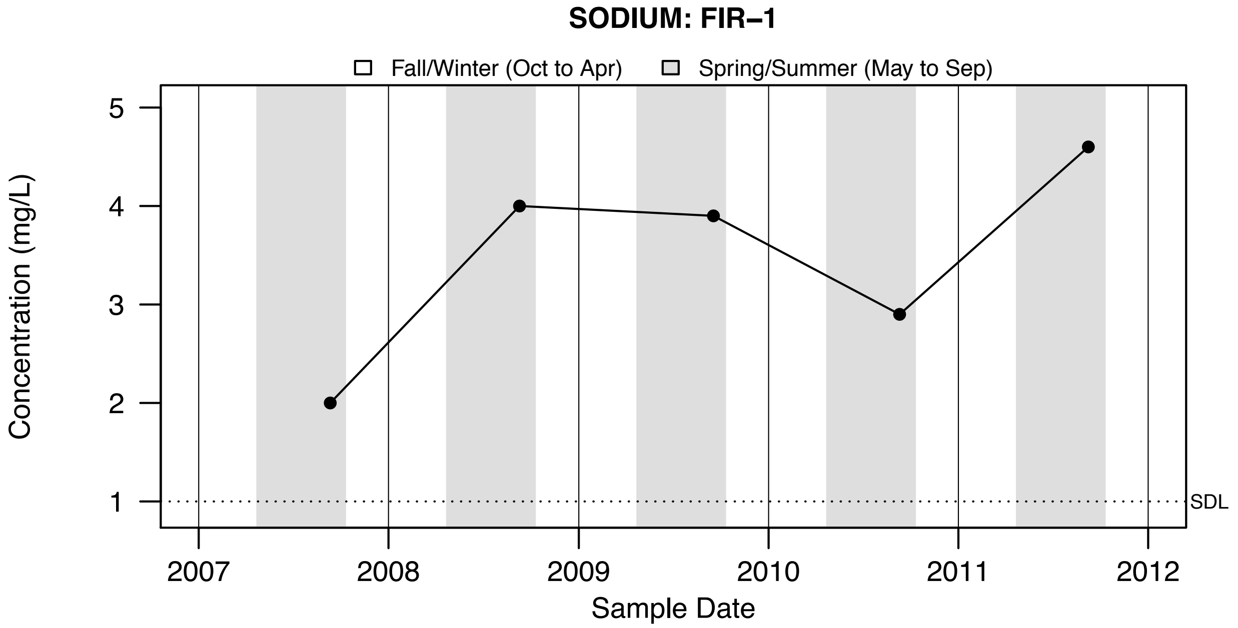
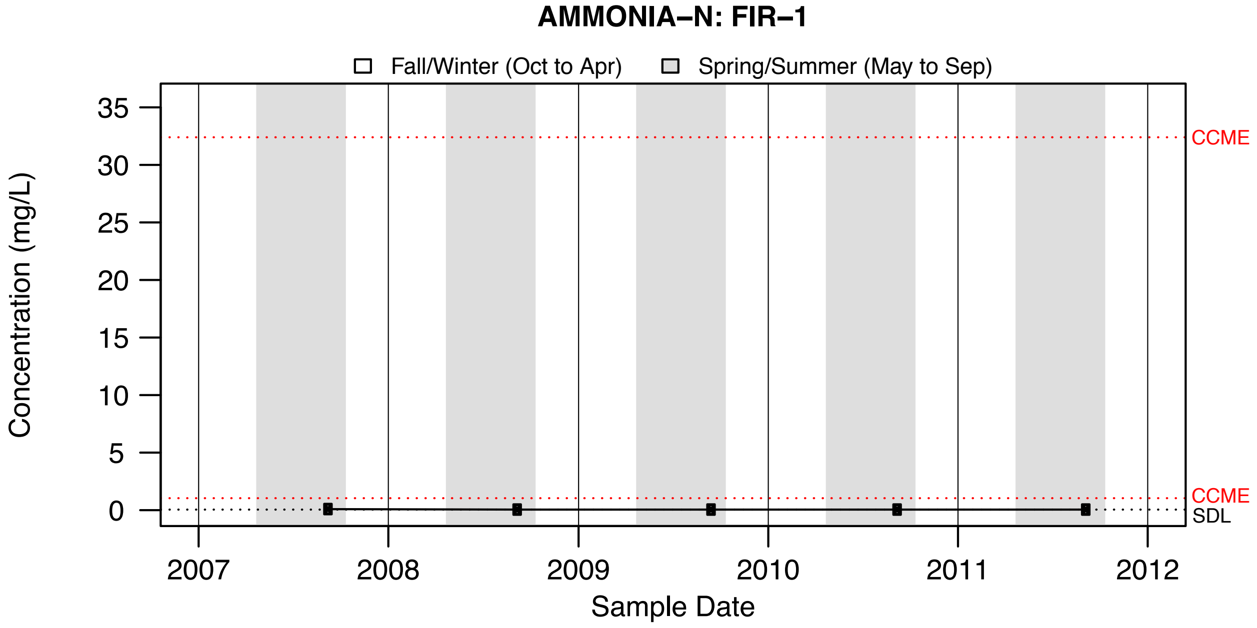


Figure A3.375: SODIUM: FIR-1 -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.376: AMMONIA-N: FIR-1 -

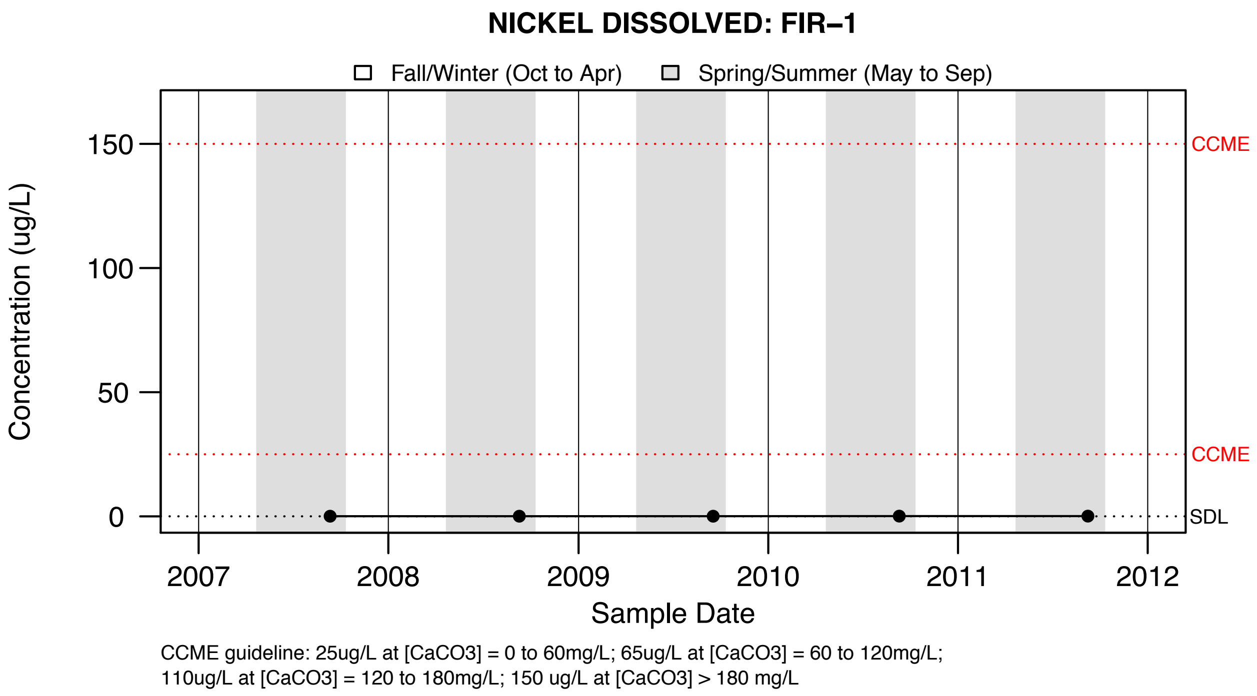


Figure A3.377: NICKEL DISSOLVED: FIR-1 -

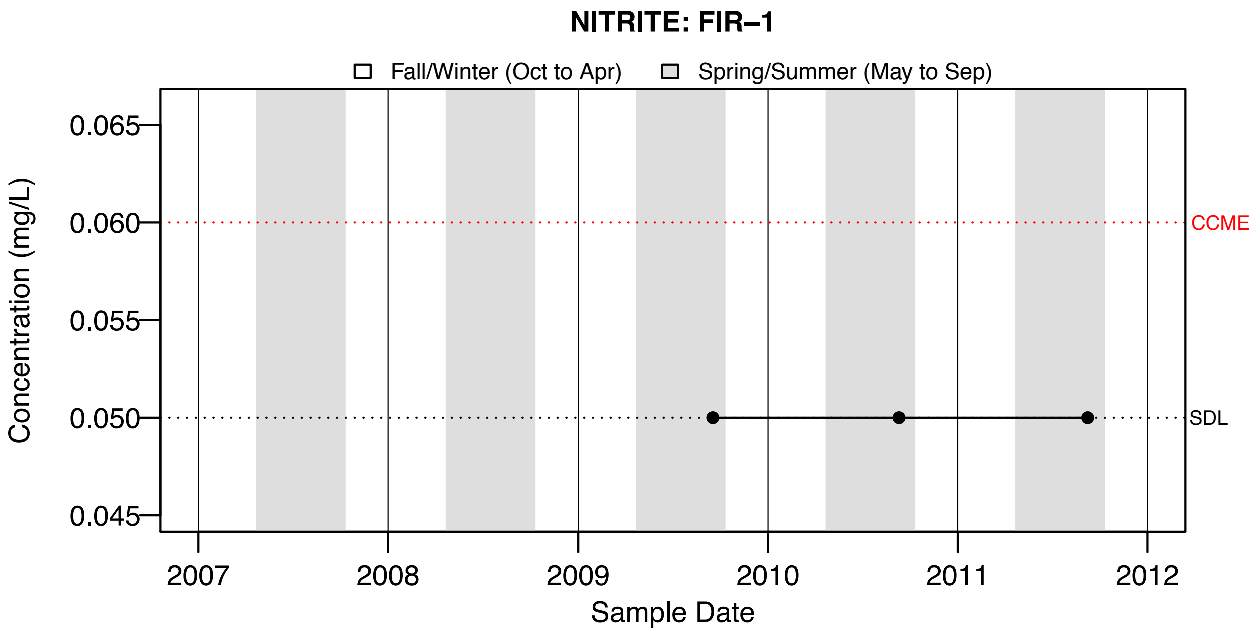
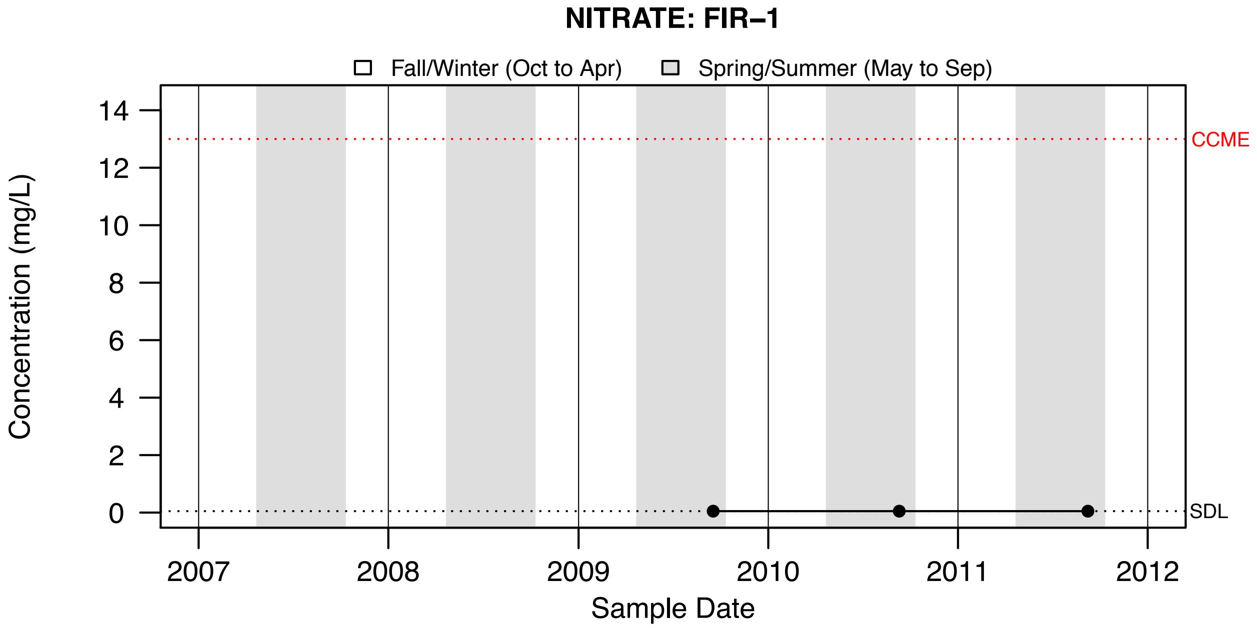


Figure A3.378: NITRITE: FIR-1 -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.379: NITRATE: FIR-1 -

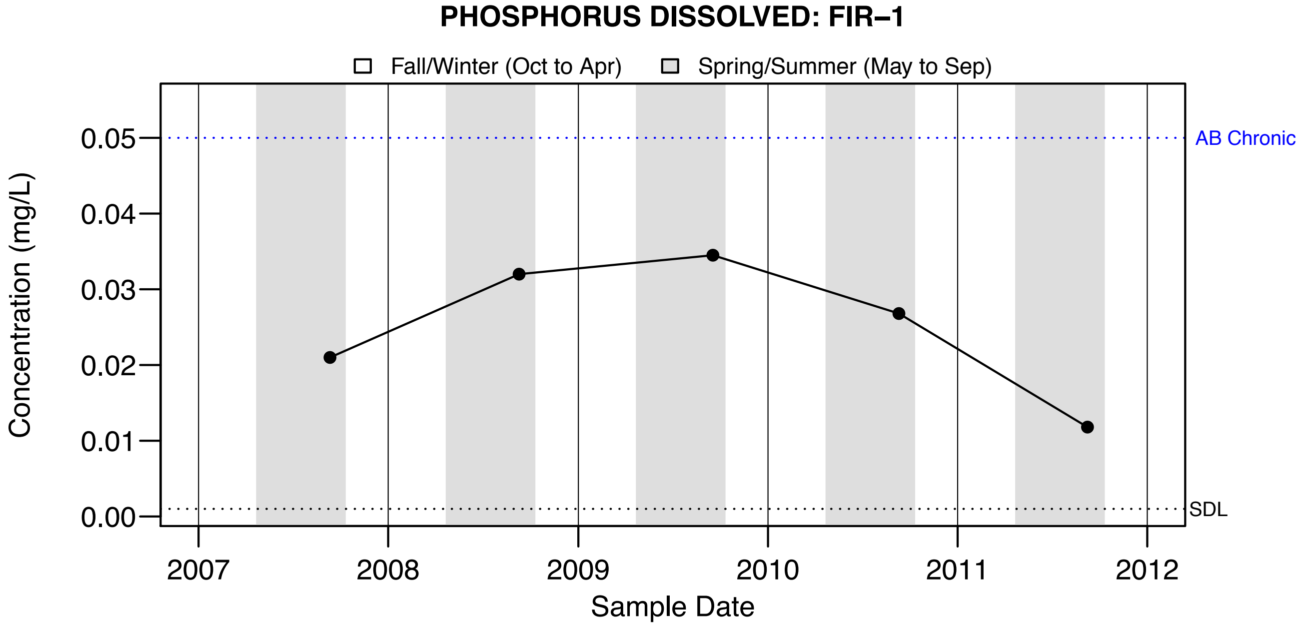


Figure A3.380: PHOSPHORUS DISSOLVED: FIR-1 -

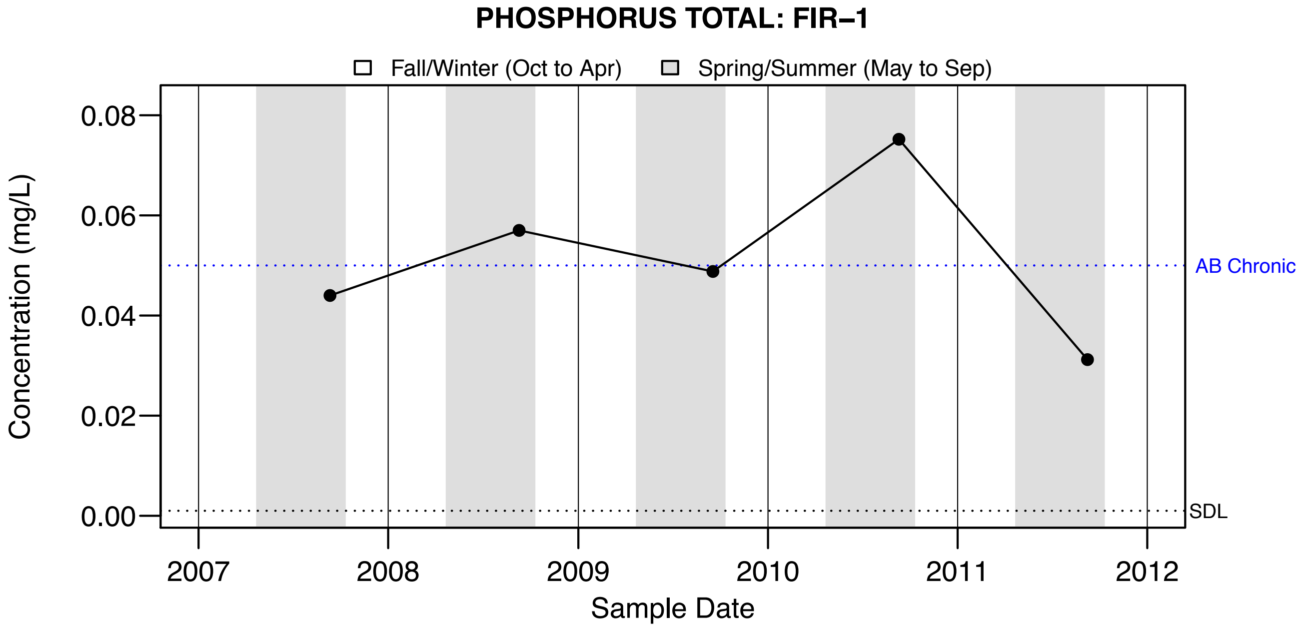
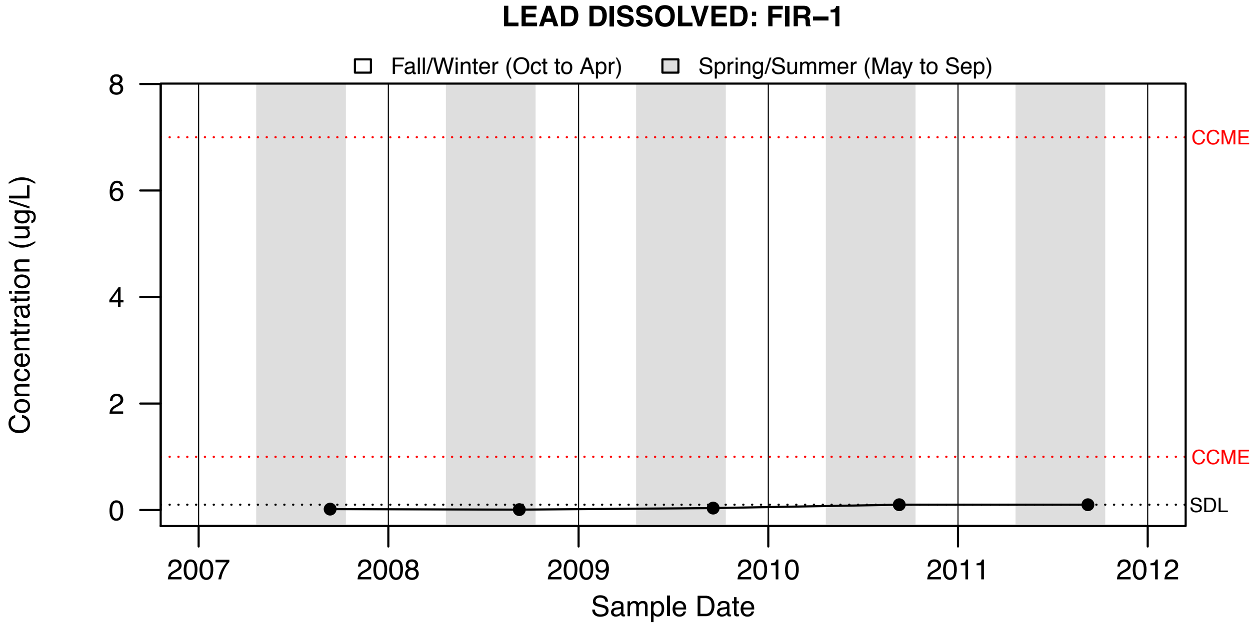


Figure A3.381: PHOSPHORUS TOTAL: FIR-1 -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.382: LEAD DISSOLVED: FIR-1 -

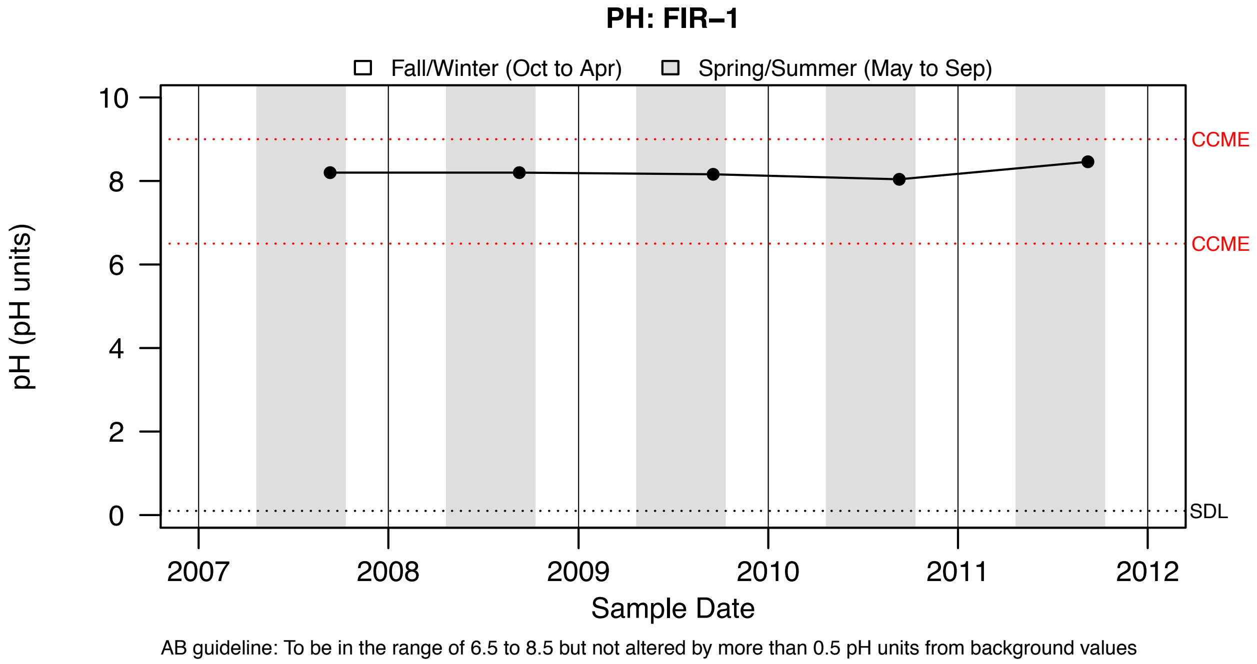


Figure A3.383: PH: FIR-1 -

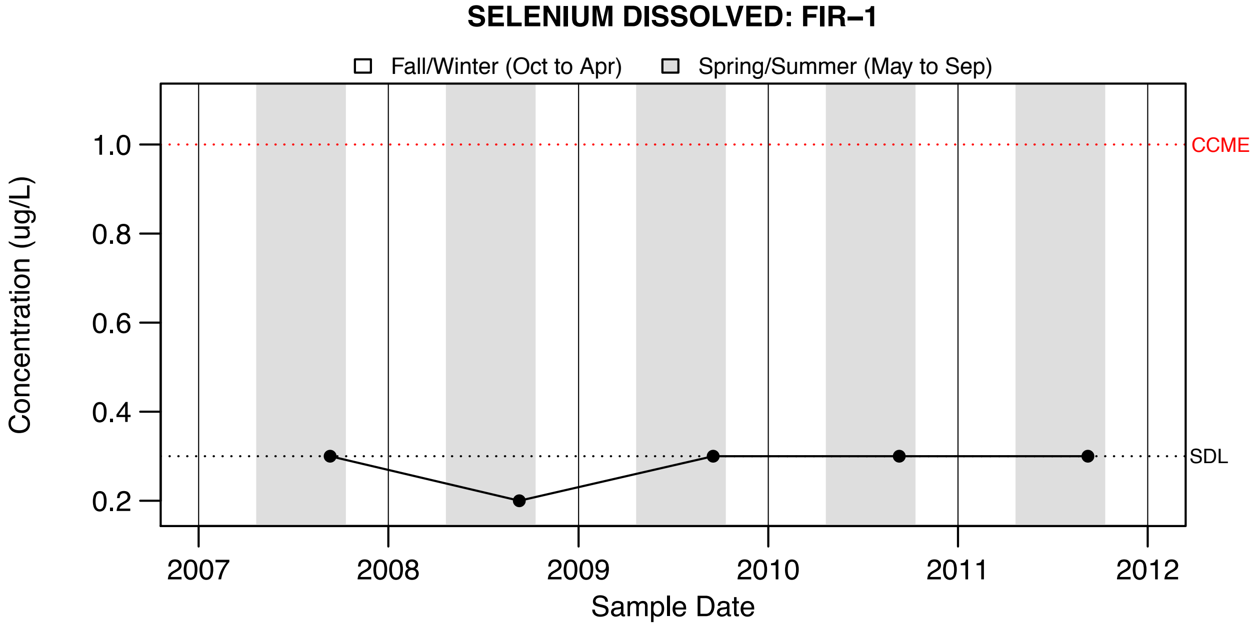


Figure A3.384: SELENIUM DISSOLVED: FIR-1 -

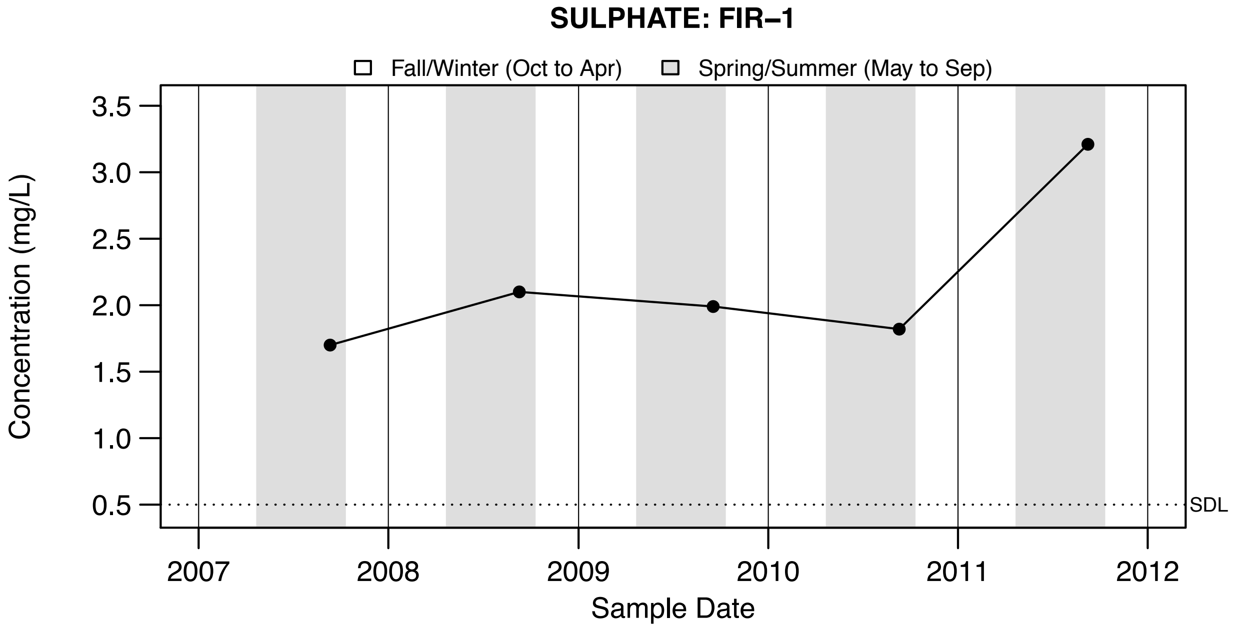


Figure A3.385: SULPHATE: FIR-1 -

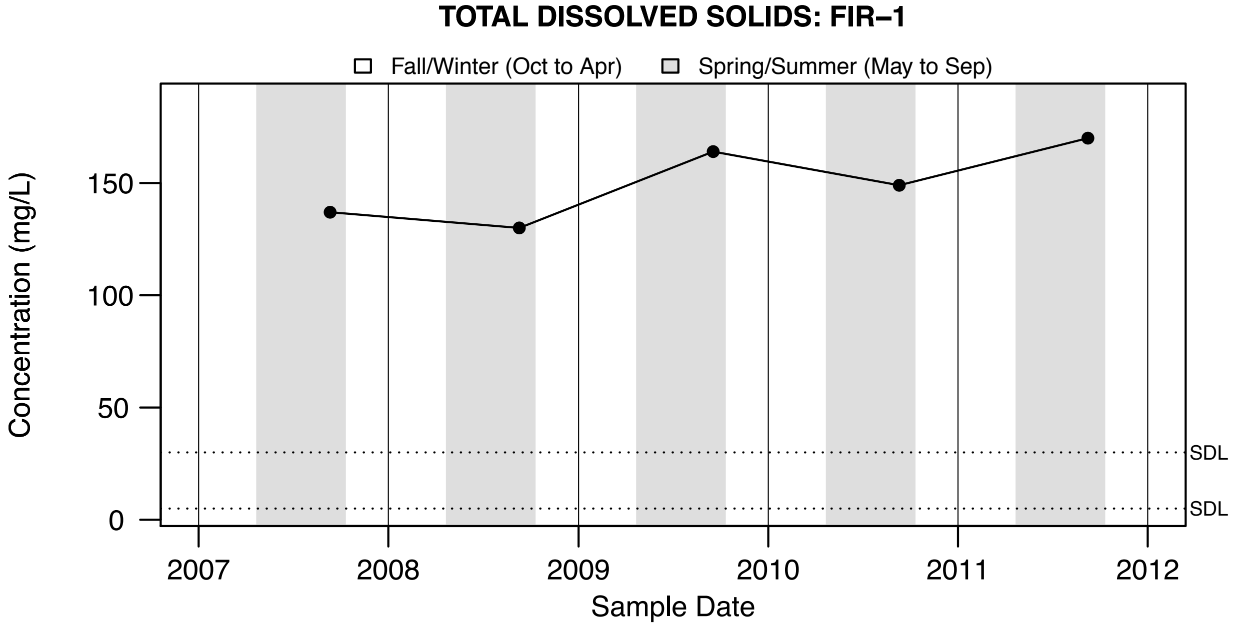
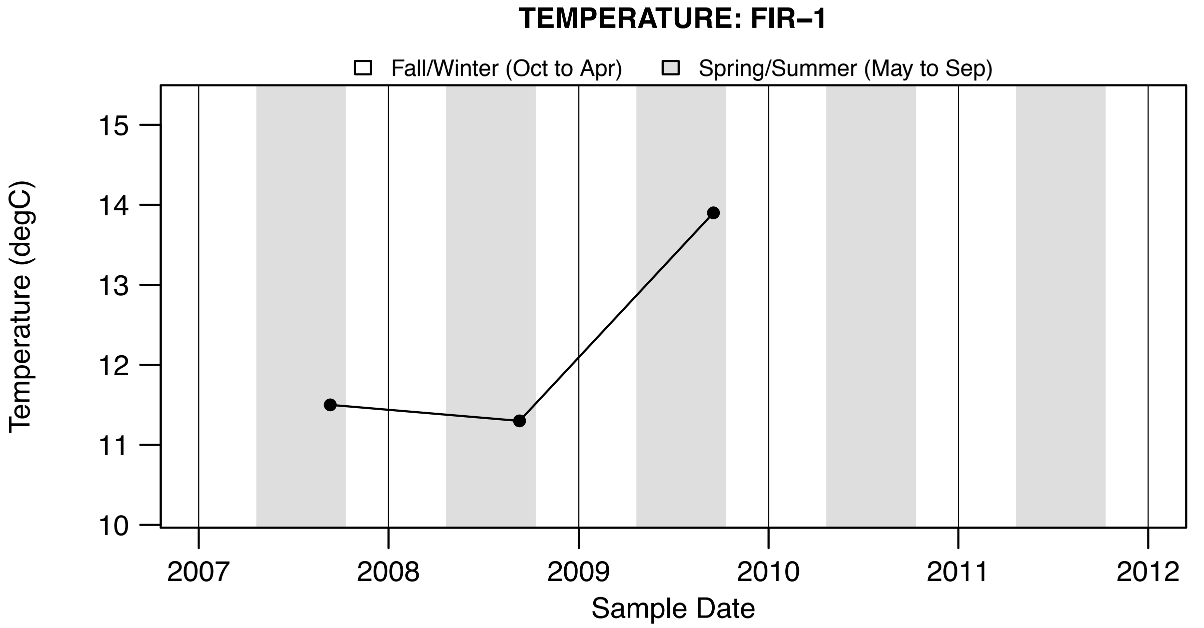


Figure A3.386: TOTAL DISSOLVED SOLIDS: FIR-1 -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.387: TEMPERATURE: FIR-1 -

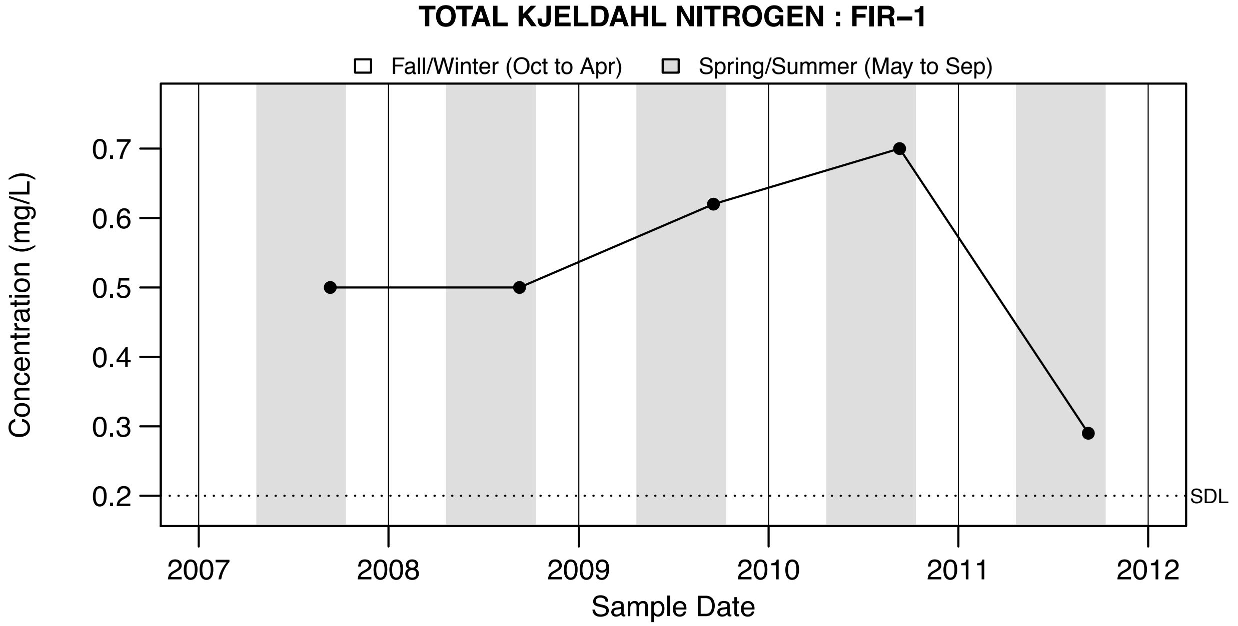
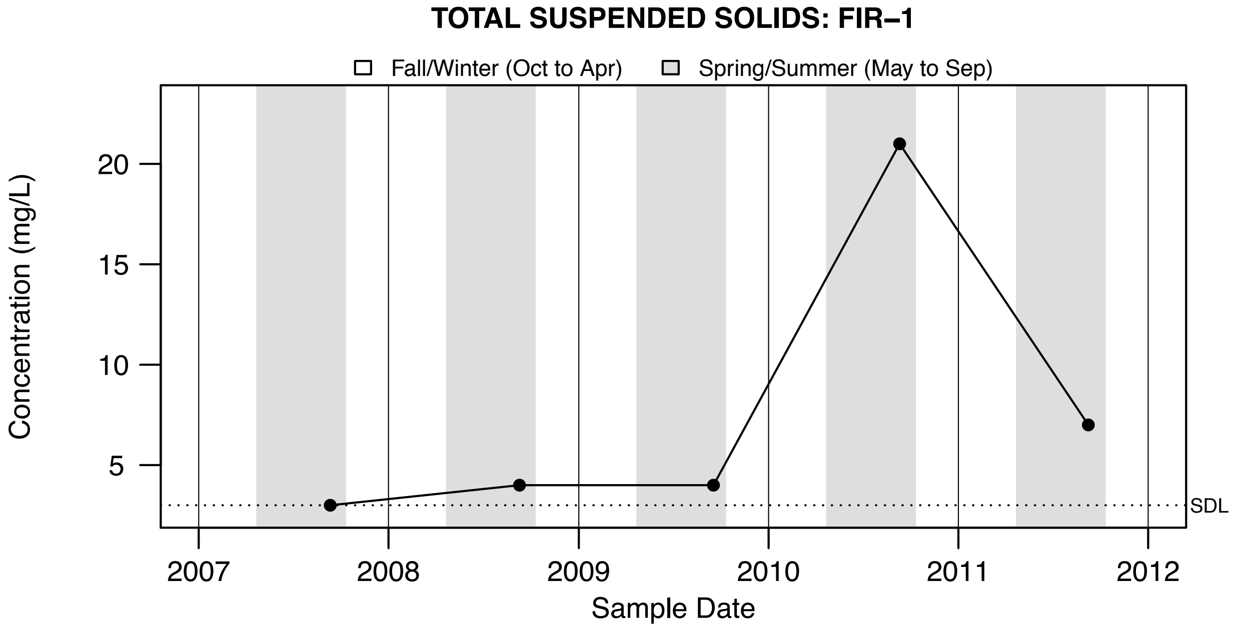


Figure A3.388: TOTAL KJELDAHL NITROGEN : FIR-1 -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.389: TOTAL SUSPENDED SOLIDS: FIR-1 -

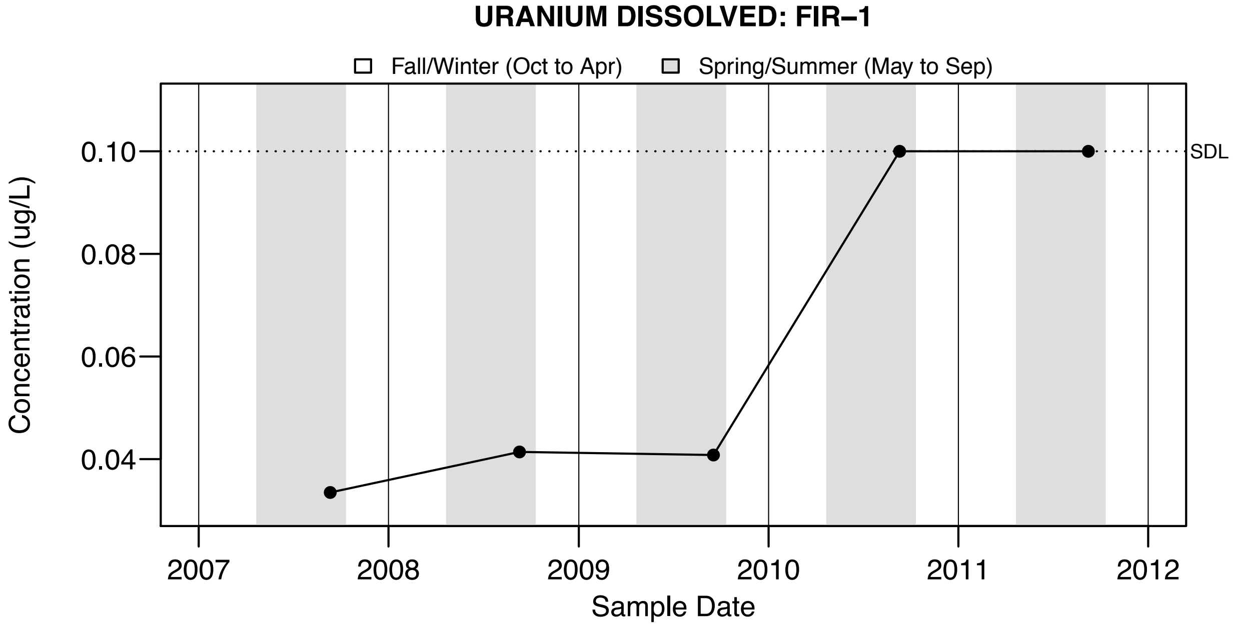


Figure A3.390: URANIUM DISSOLVED: FIR-1 -

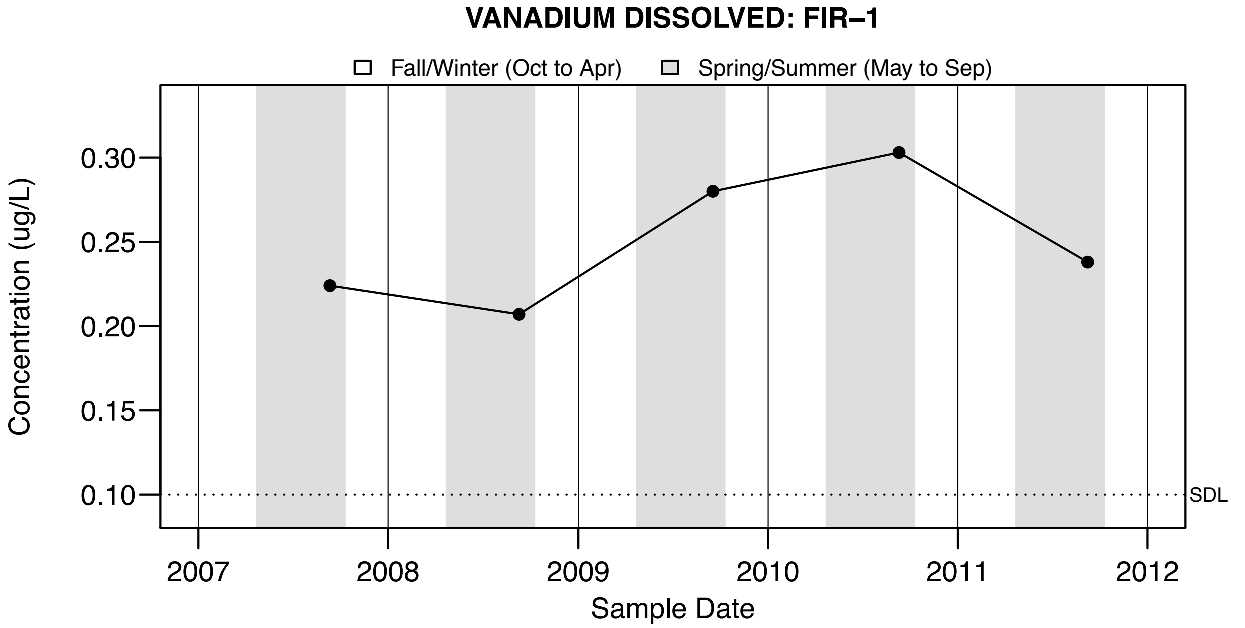


Figure A3.391: VANADIUM DISSOLVED: FIR-1 -

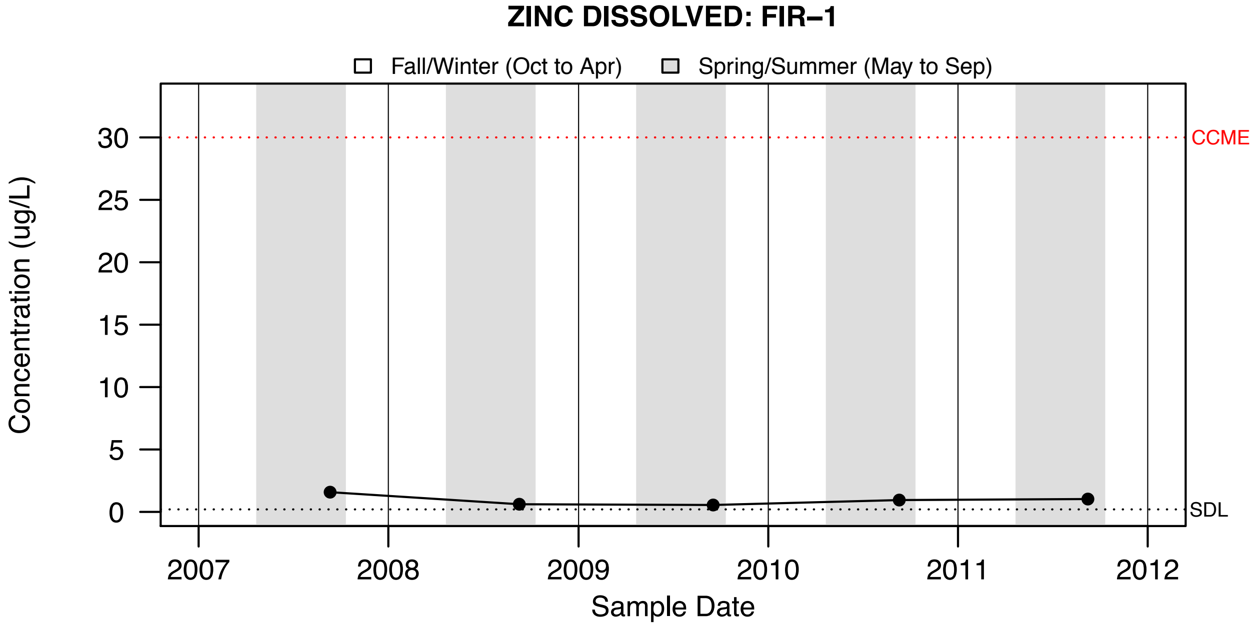


Figure A3.392: ZINC DISSOLVED: FIR-1 -

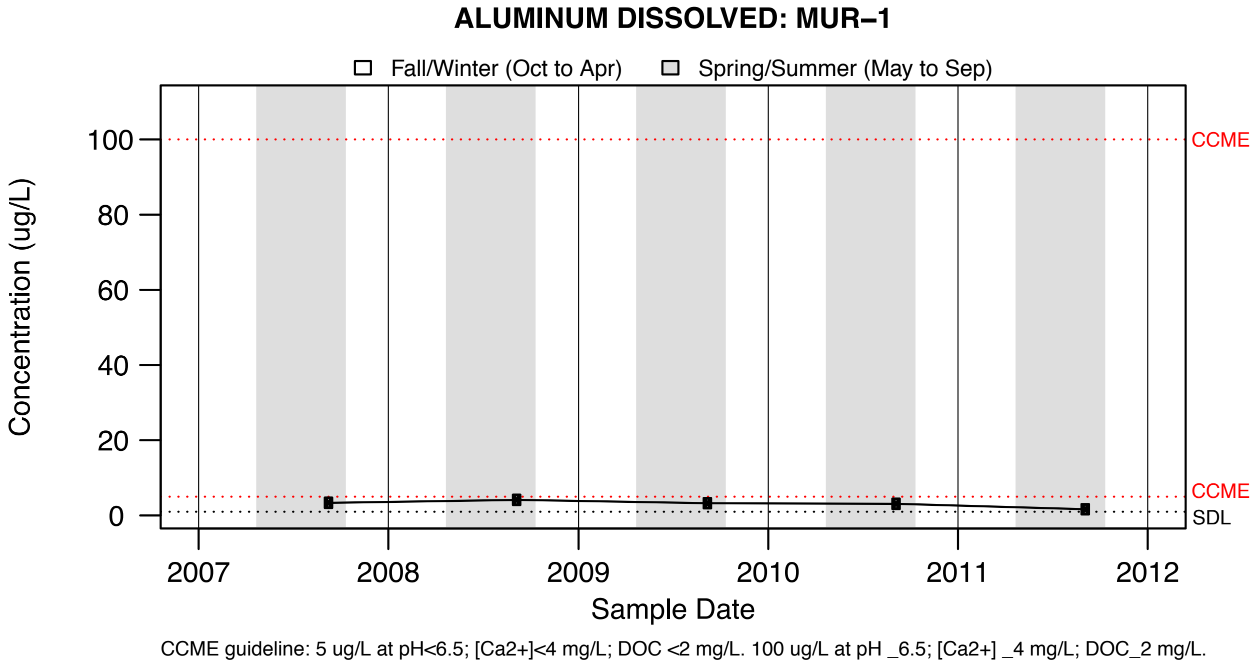


Figure A3.393: ALUMINUM DISSOLVED: MUR-1 -

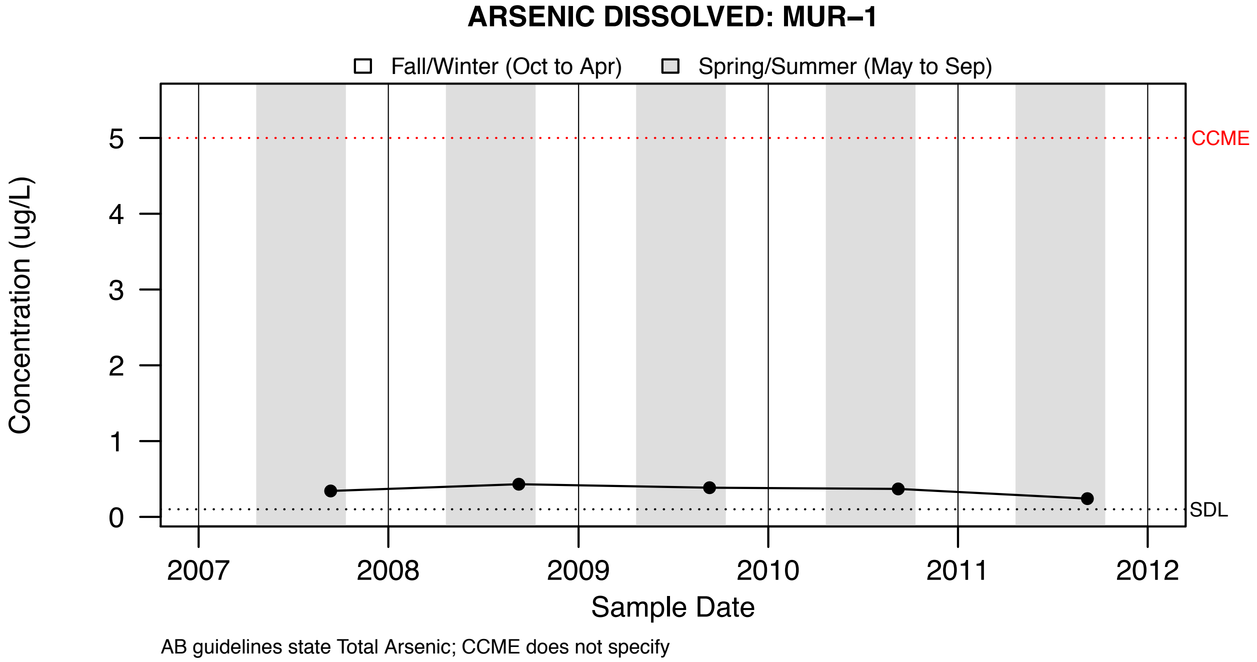


Figure A3.394: ARSENIC DISSOLVED: MUR-1 -

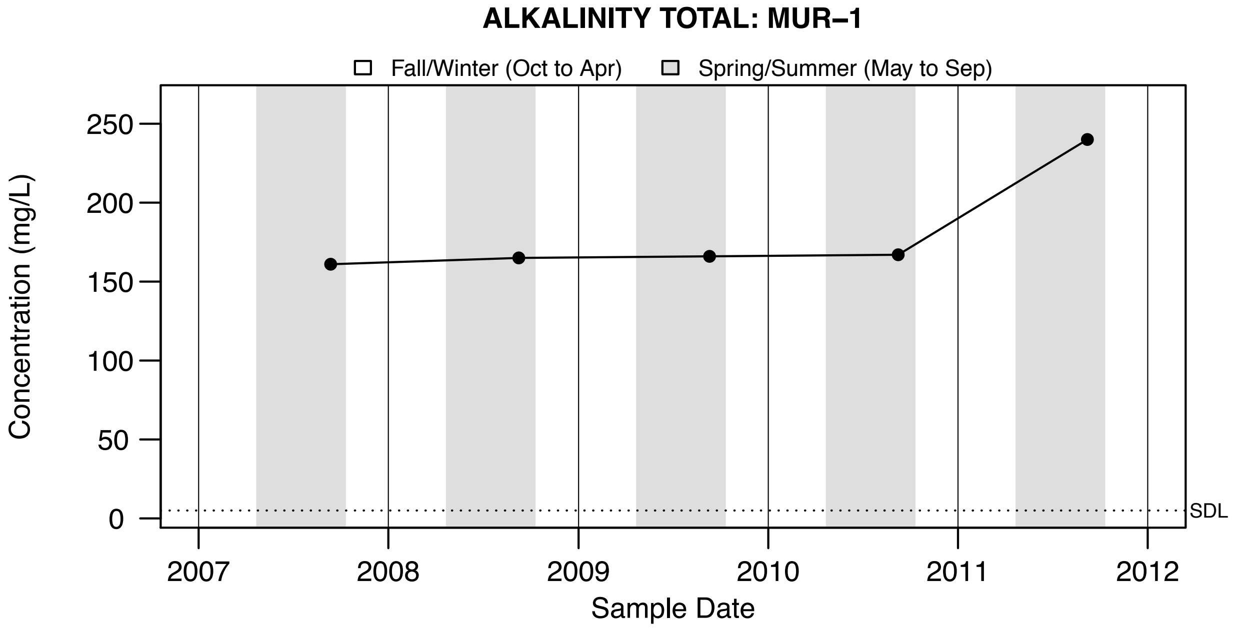


Figure A3.395: ALKALINITY TOTAL: MUR-1 -

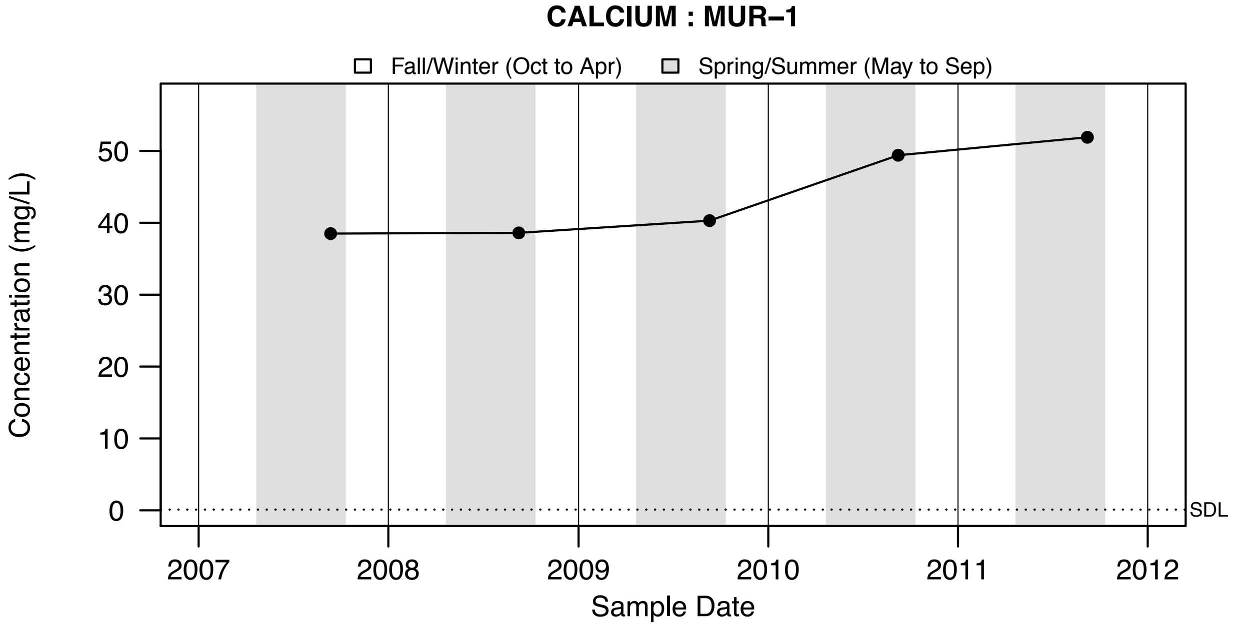


Figure A3.396: CALCIUM : MUR-1 -

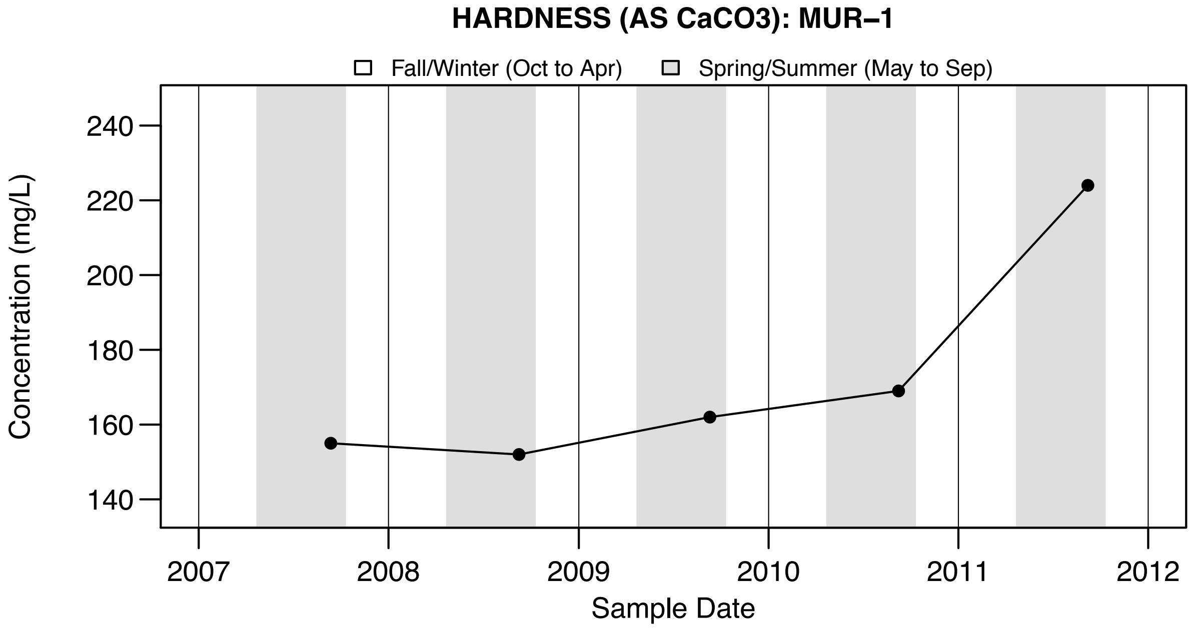
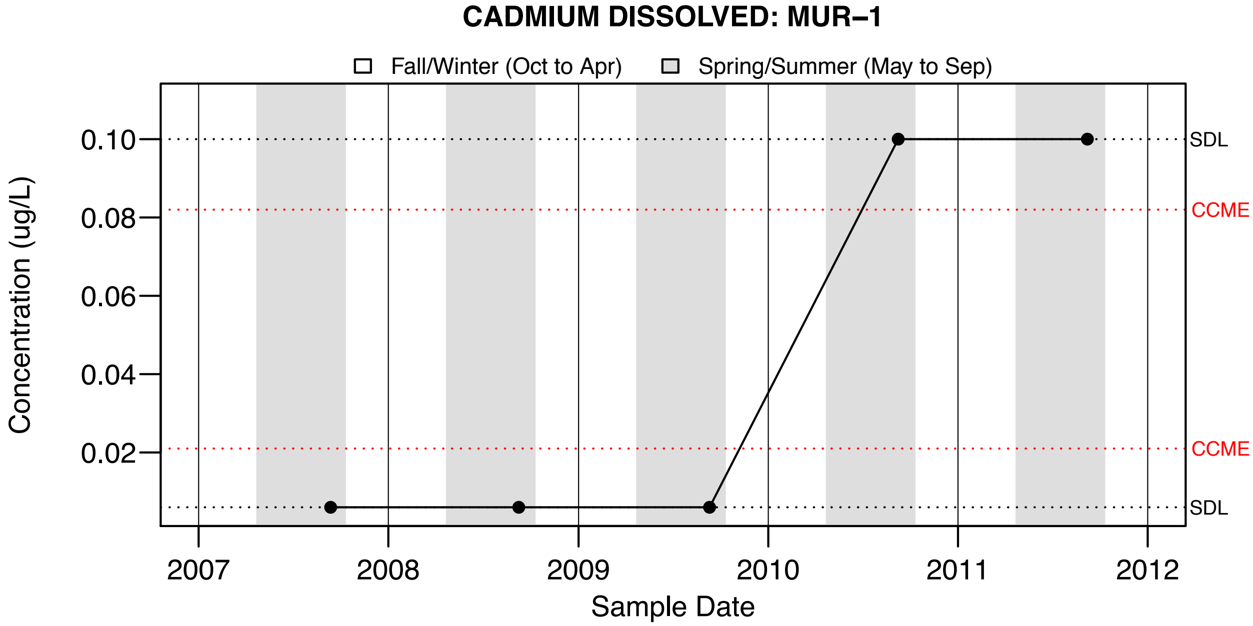


Figure A3.397: HARDNESS (AS CaCO3): MUR-1 -



Related to hardness as CaCo3

Figure A3.398: CADMIUM DISSOLVED: MUR-1 -

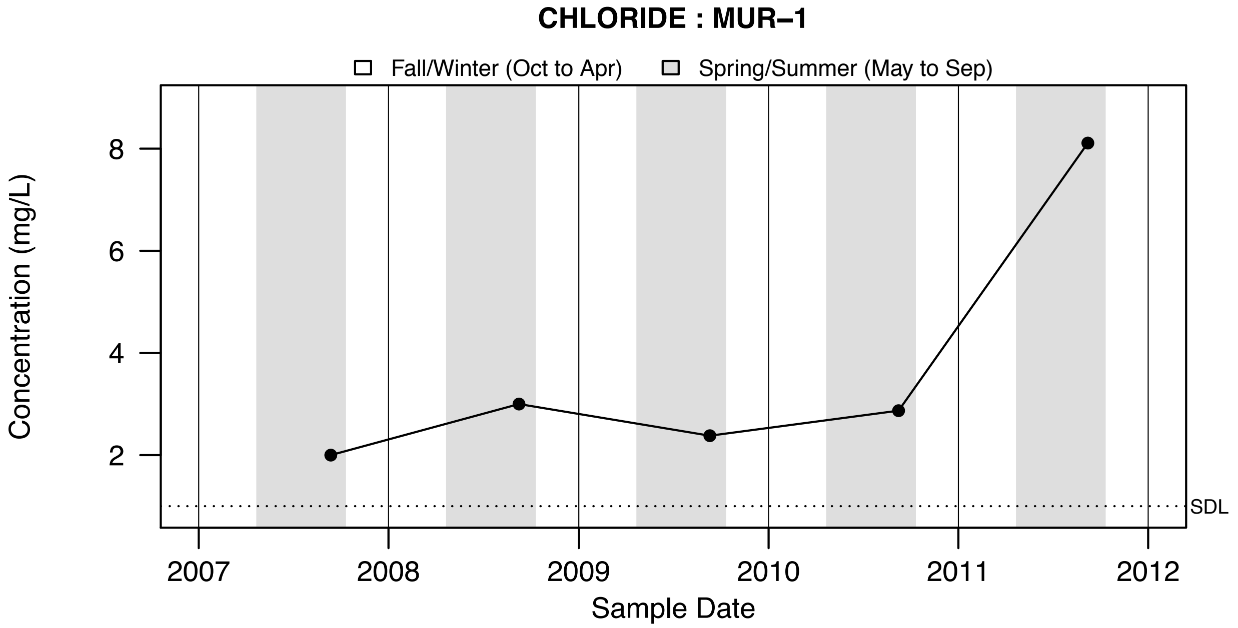


Figure A3.399: CHLORIDE : MUR-1 -

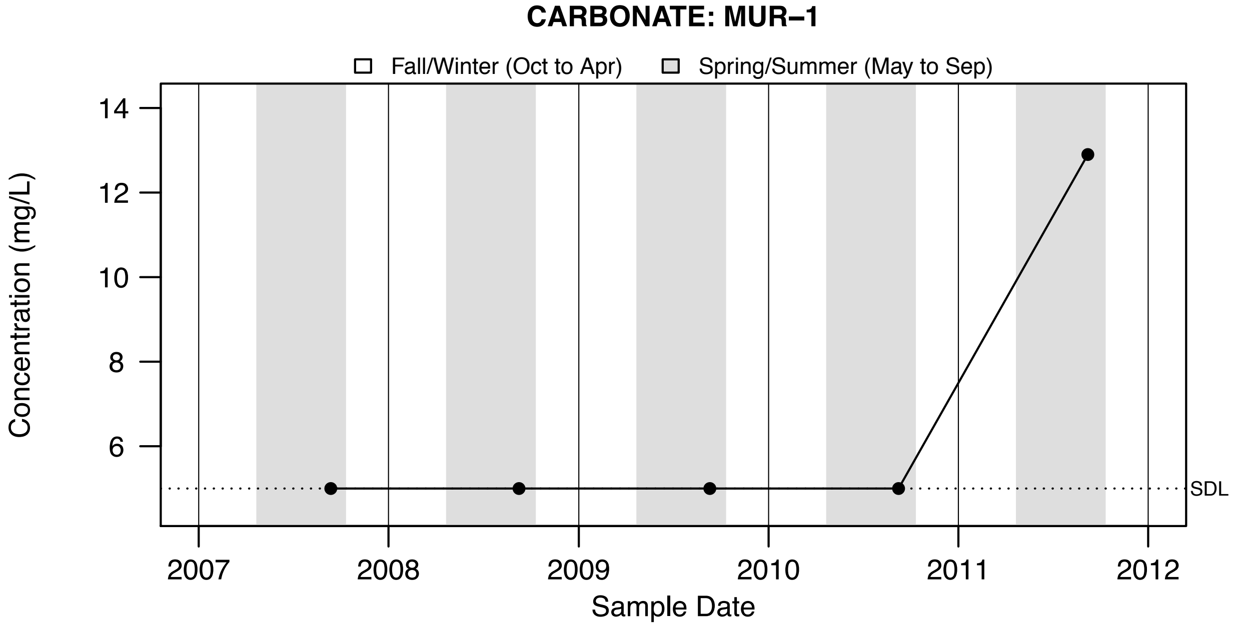


Figure A3.400: CARBONATE: MUR-1 -

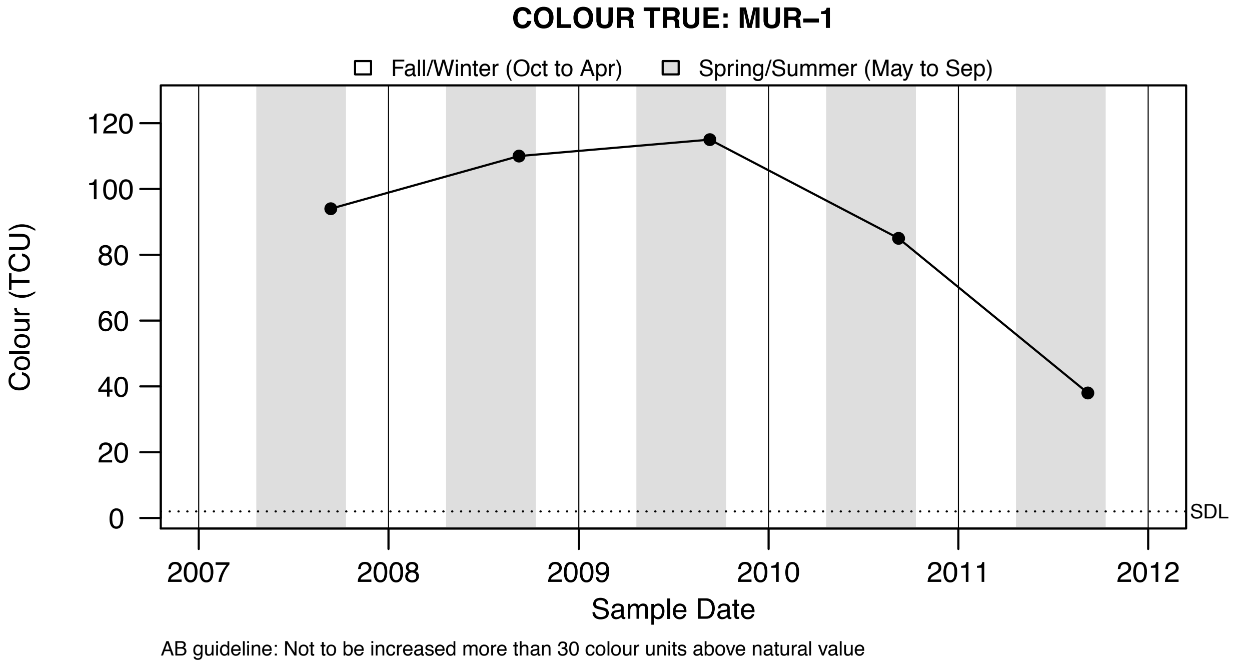


Figure A3.401: COLOUR TRUE: MUR-1 -

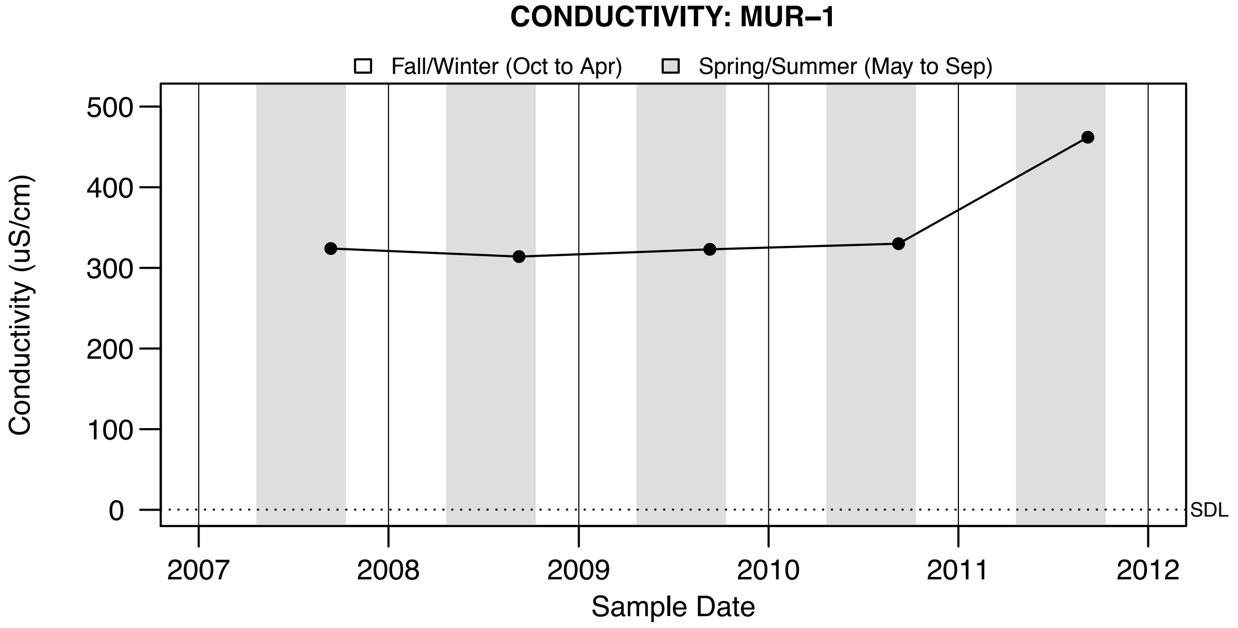
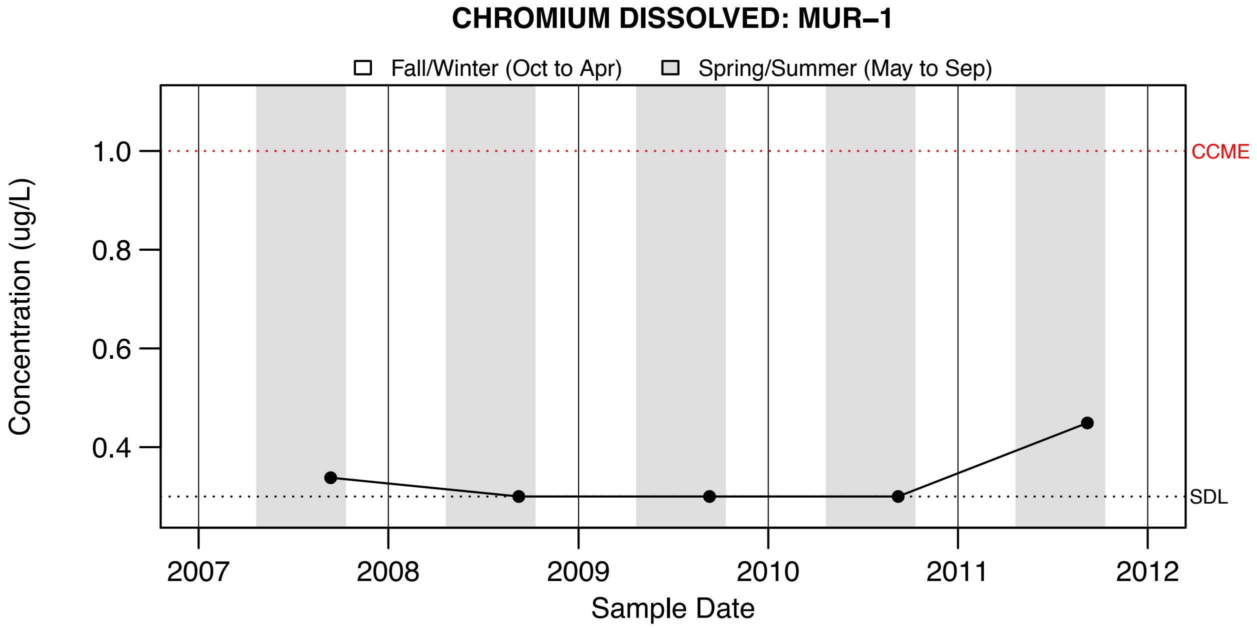
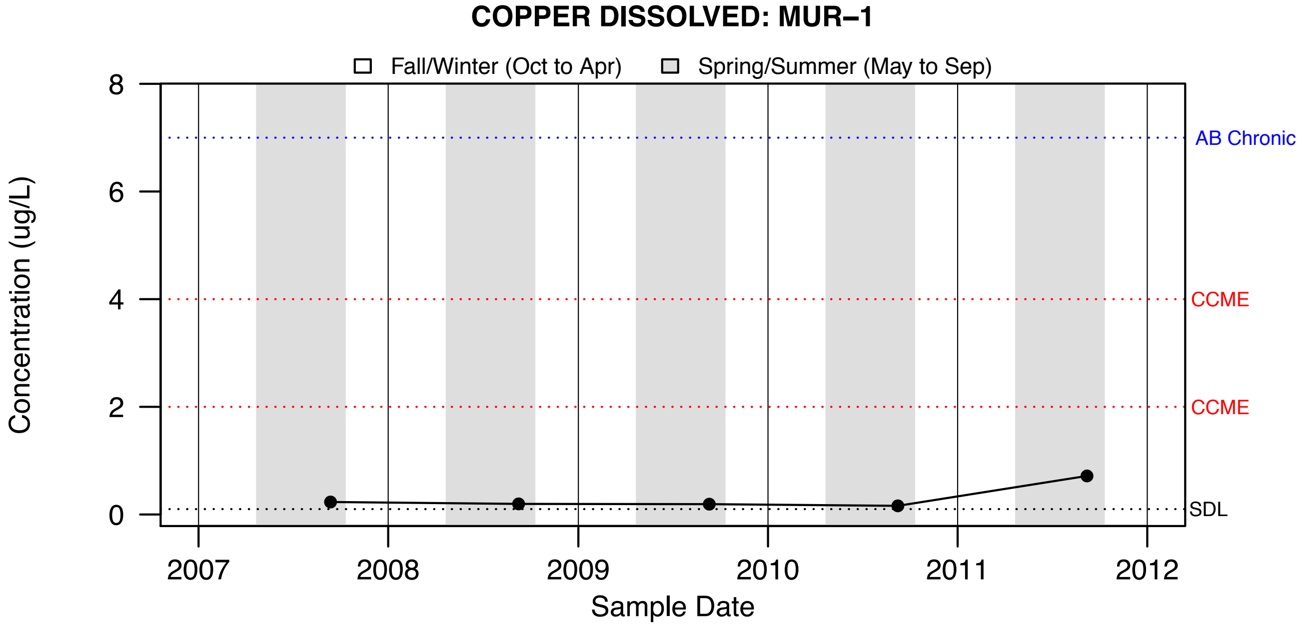


Figure A3.402: CONDUCTIVITY: MUR-1 -



Chromium III: 8.9 Chromium VI: 1.0

Figure A3.403: CHROMIUM DISSOLVED: MUR-1 -



AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A3.404: COPPER DISSOLVED: MUR-1 -

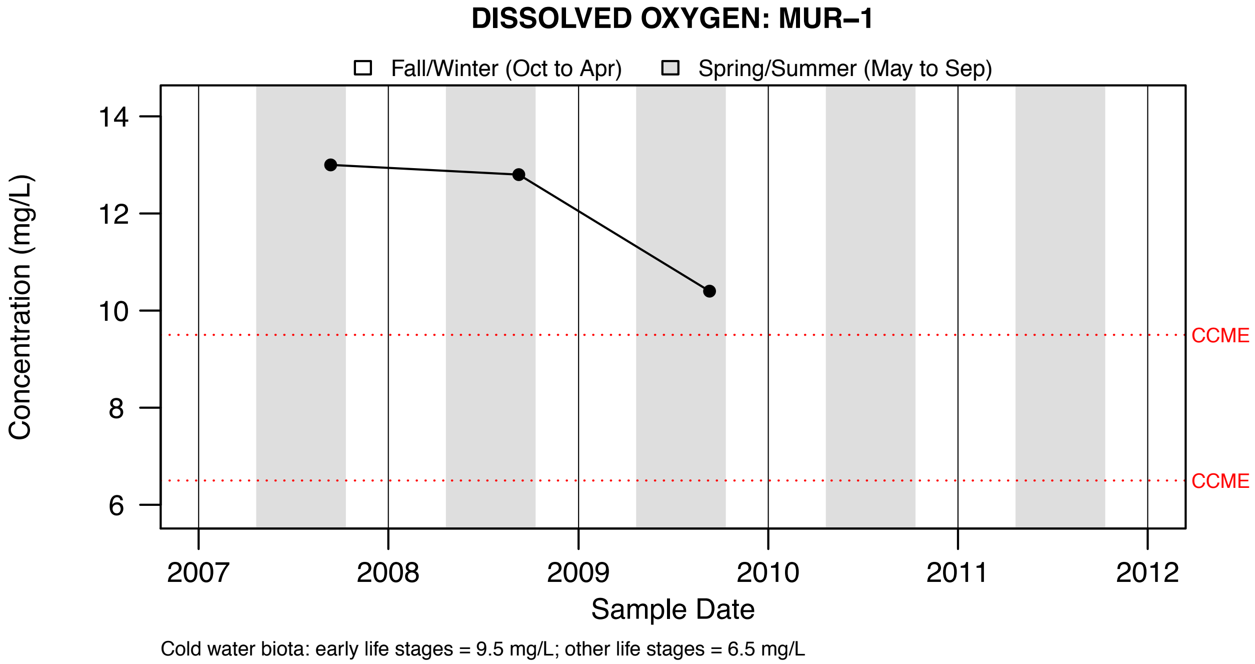


Figure A3.405: DISSOLVED OXYGEN: MUR-1 -

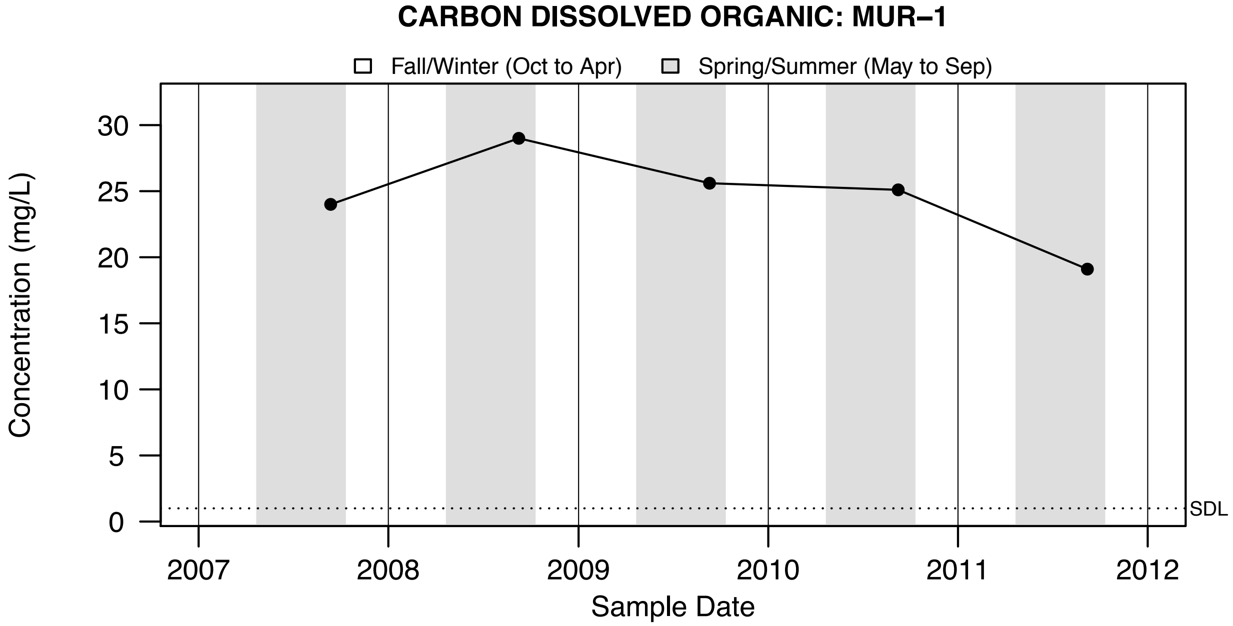


Figure A3.406: CARBON DISSOLVED ORGANIC: MUR-1 -

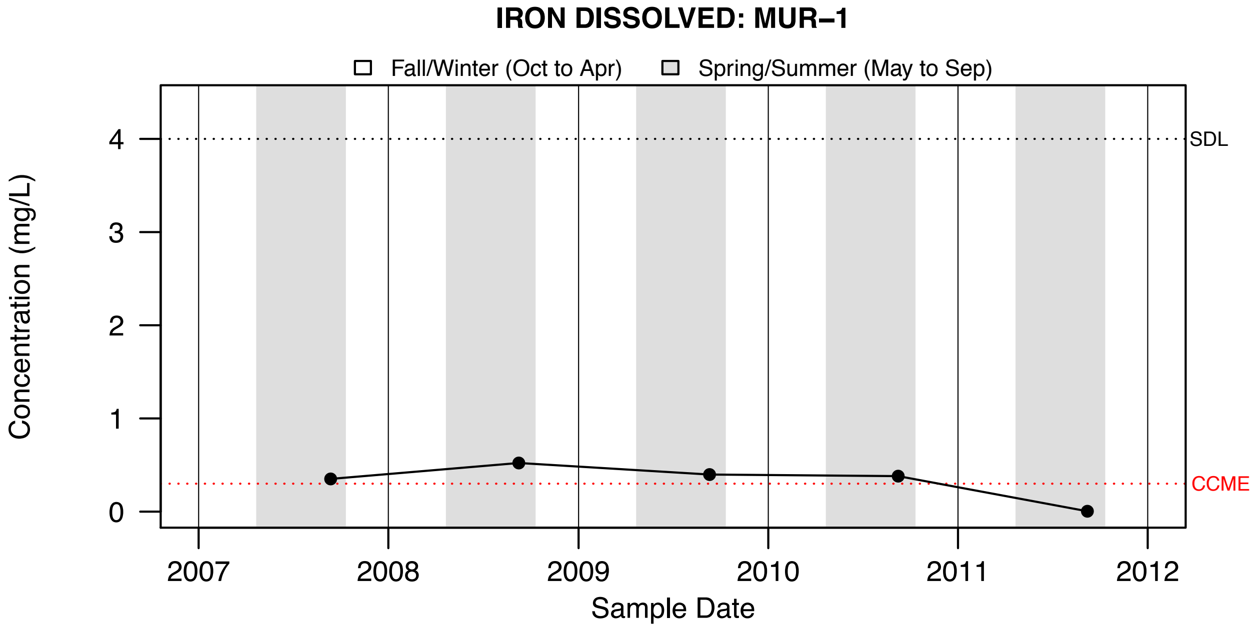


Figure A3.407: IRON DISSOLVED: MUR-1 -

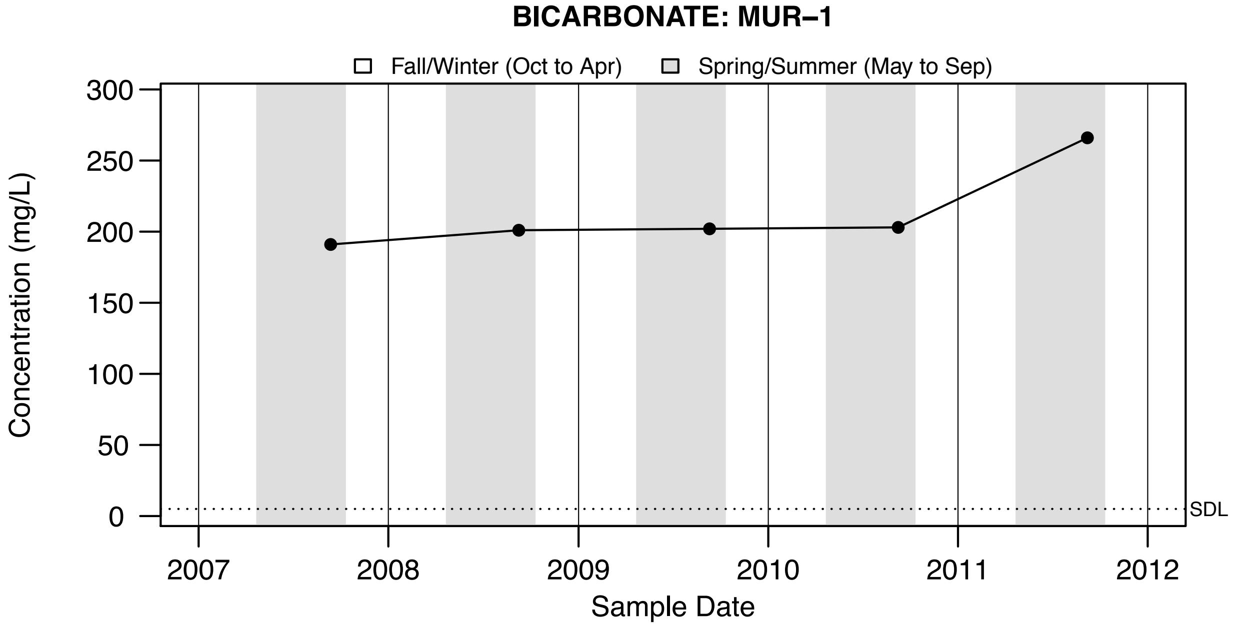


Figure A3.408: BICARBONATE: MUR-1 -

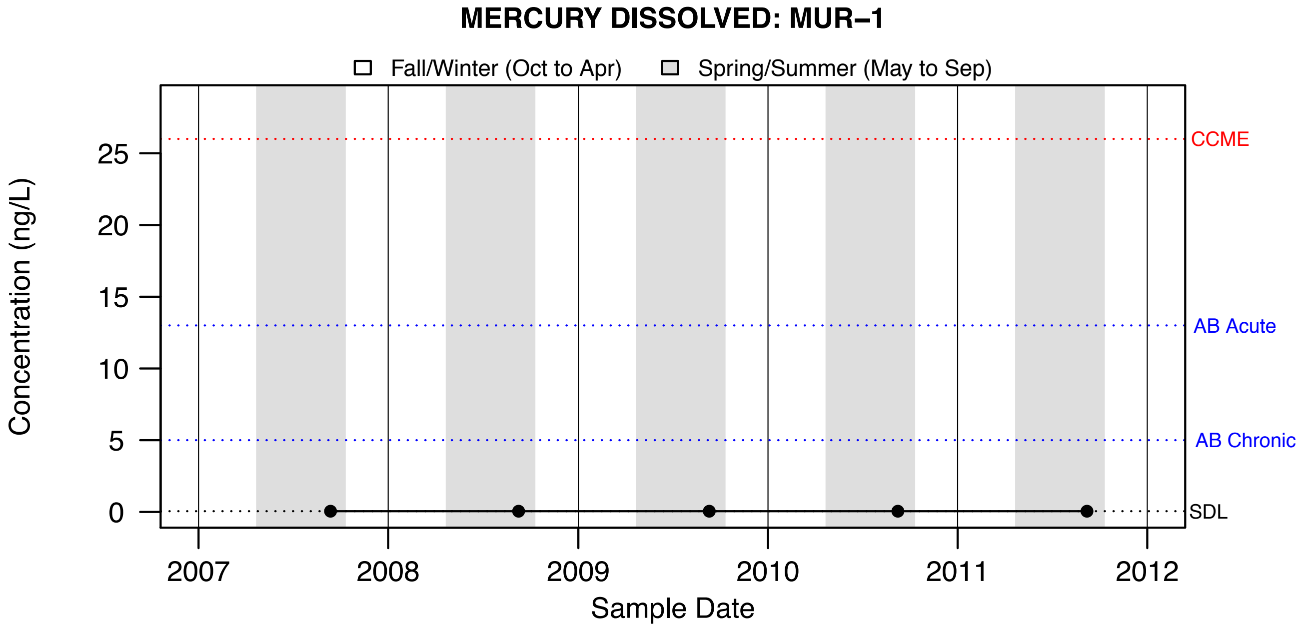


Figure A3.409: MERCURY DISSOLVED: MUR-1 -

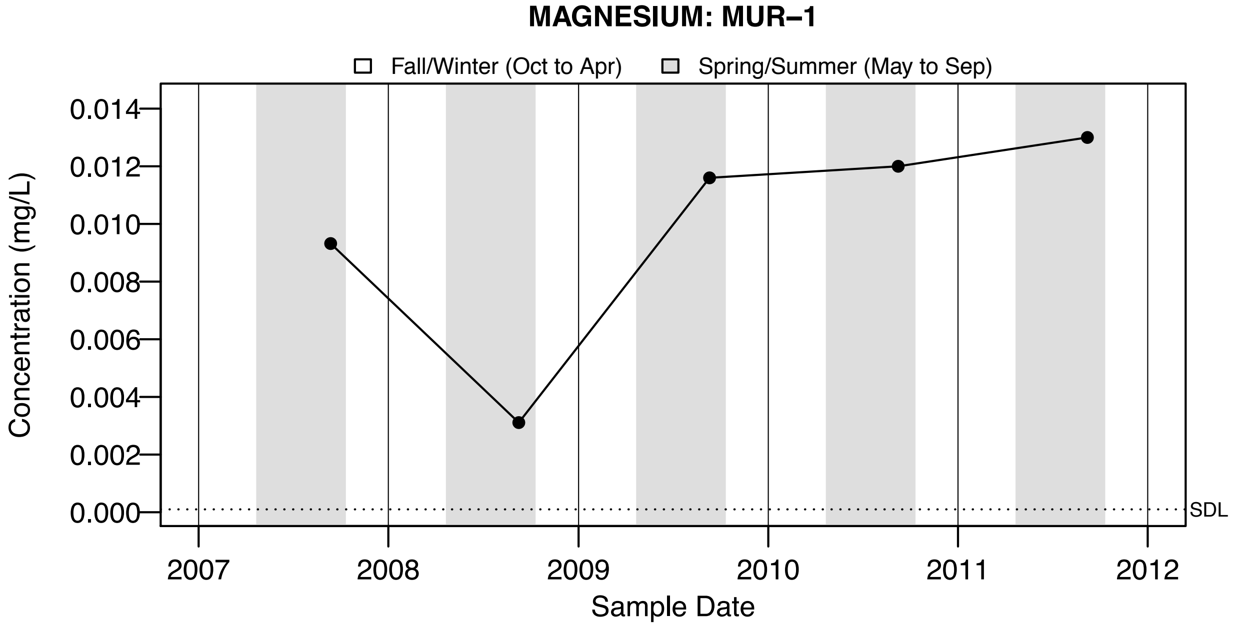


Figure A3.410: MAGNESIUM: MUR-1 -

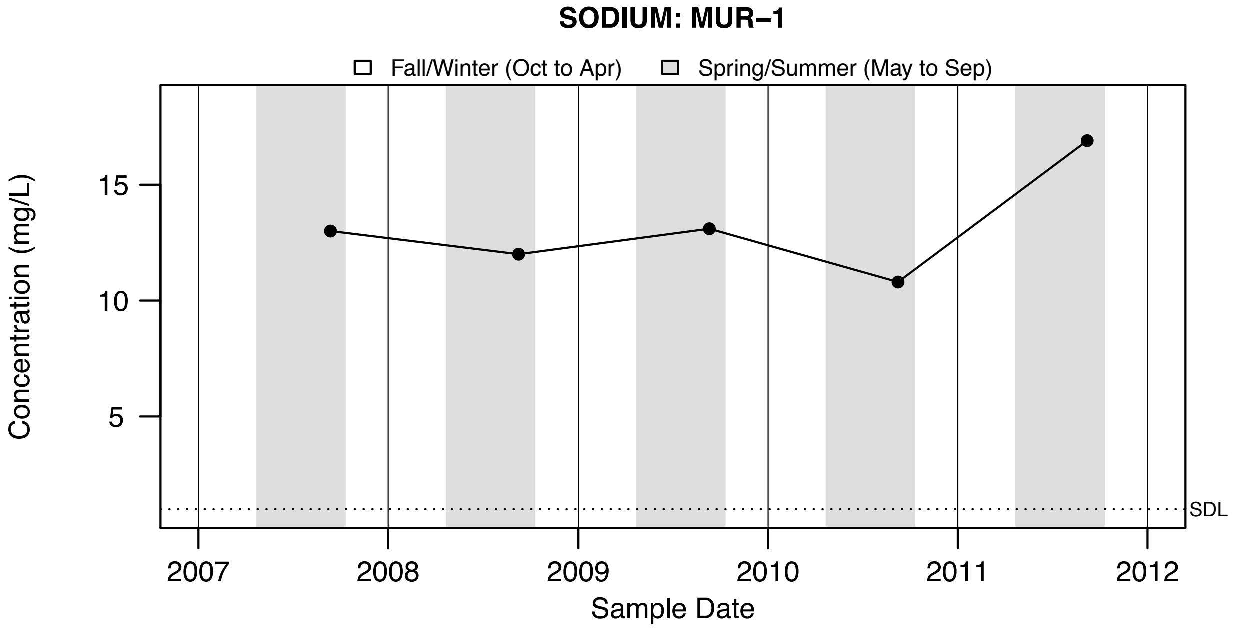
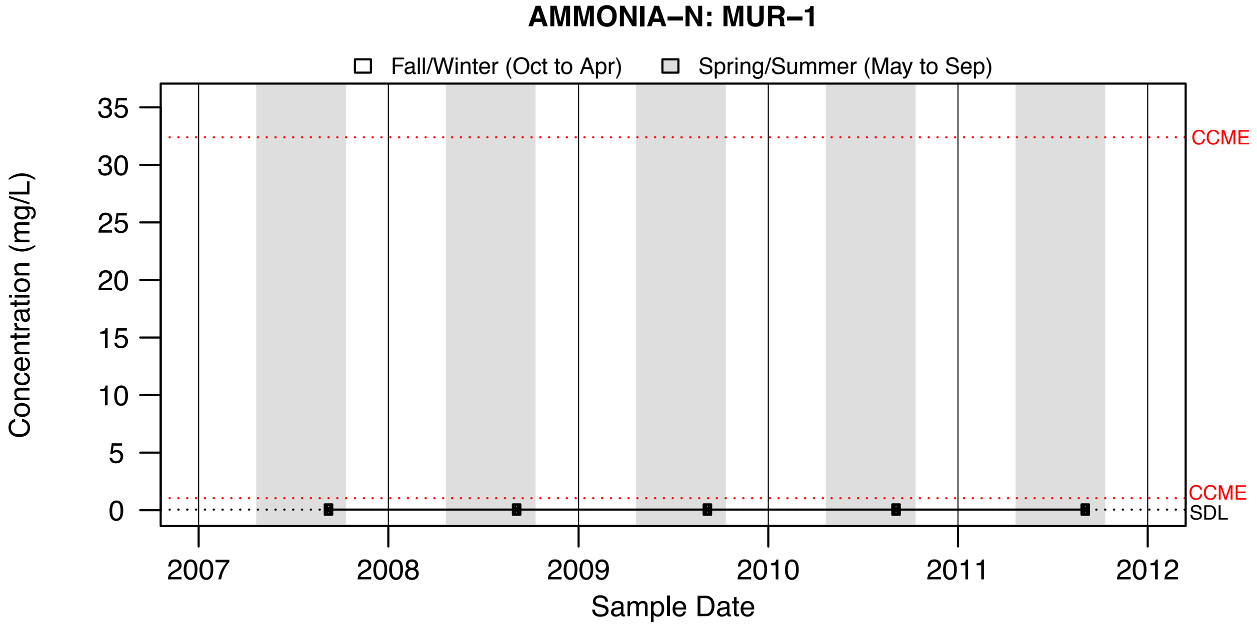
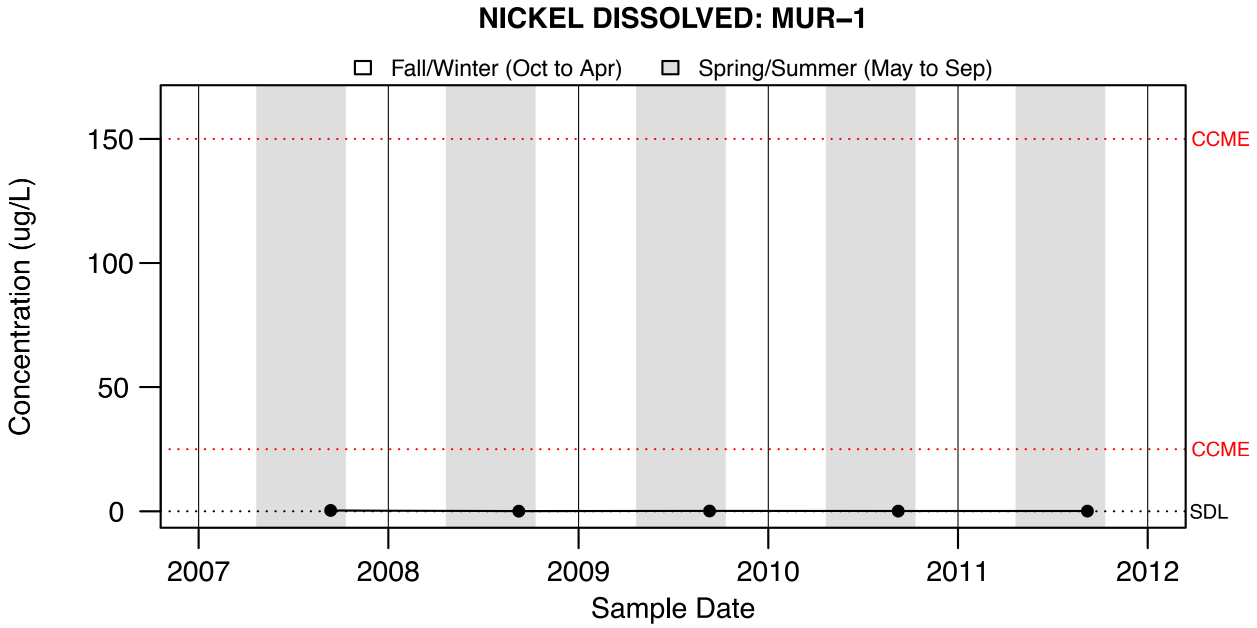


Figure A3.411: SODIUM: MUR-1 -



CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A3.412: AMMONIA-N: MUR-1 -



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A3.413: NICKEL DISSOLVED: MUR-1 -

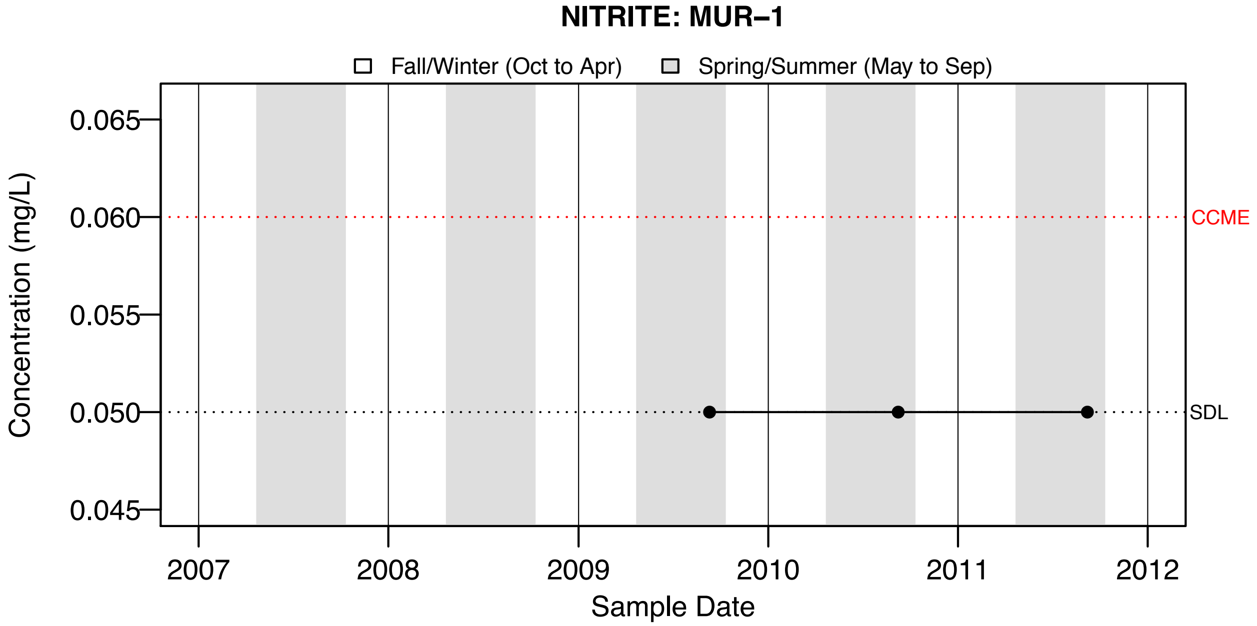
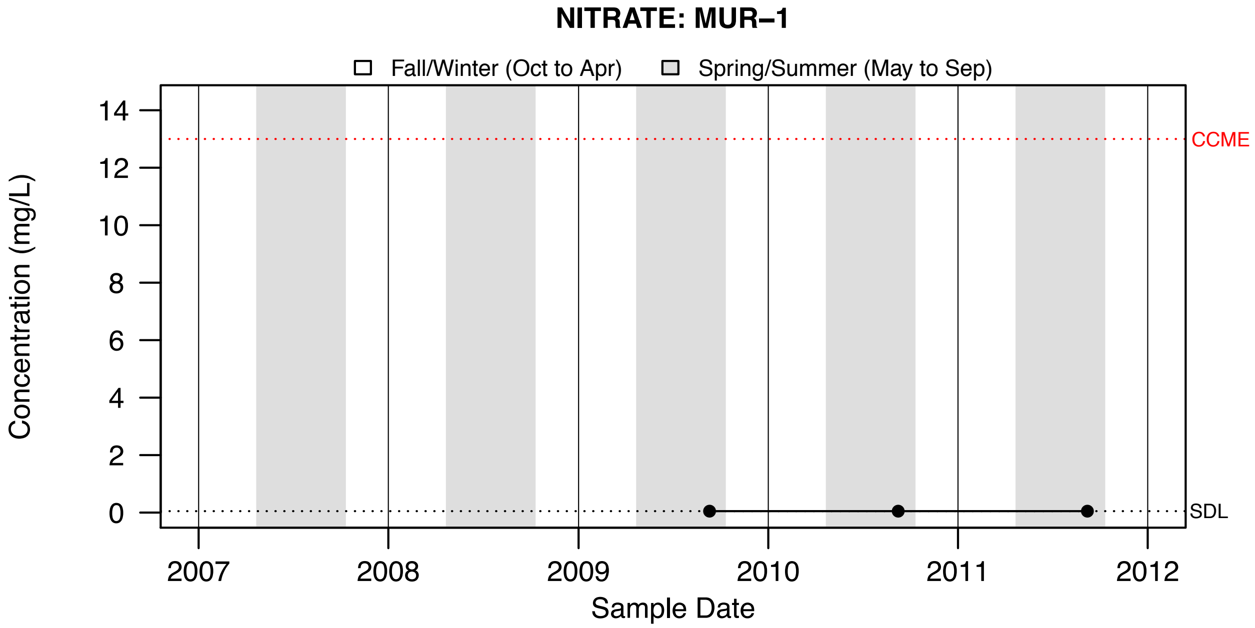


Figure A3.414: NITRITE: MUR-1 -



Although not directly toxic to freshwater aquatic life, these values are included due to their broader influence on conditions that affect aquatic life. CCME guideline: concentrations that stimulate weed growth should be avoided.

Figure A3.415: NITRATE: MUR-1 -

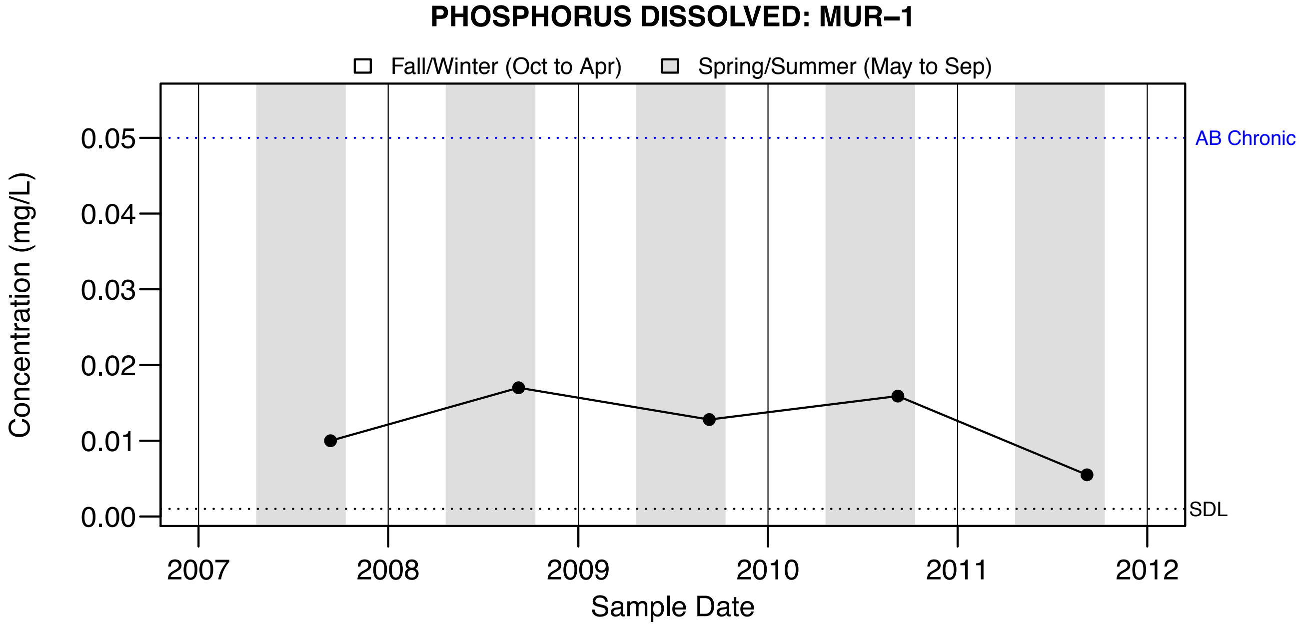


Figure A3.416: PHOSPHORUS DISSOLVED: MUR-1 -

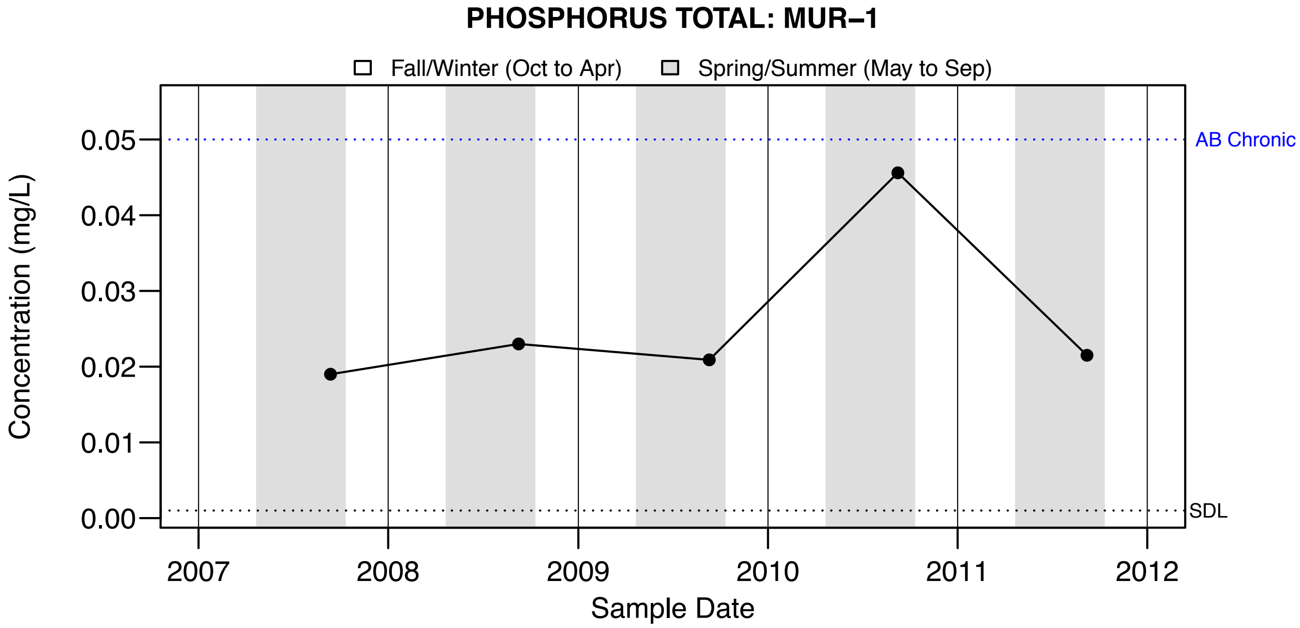
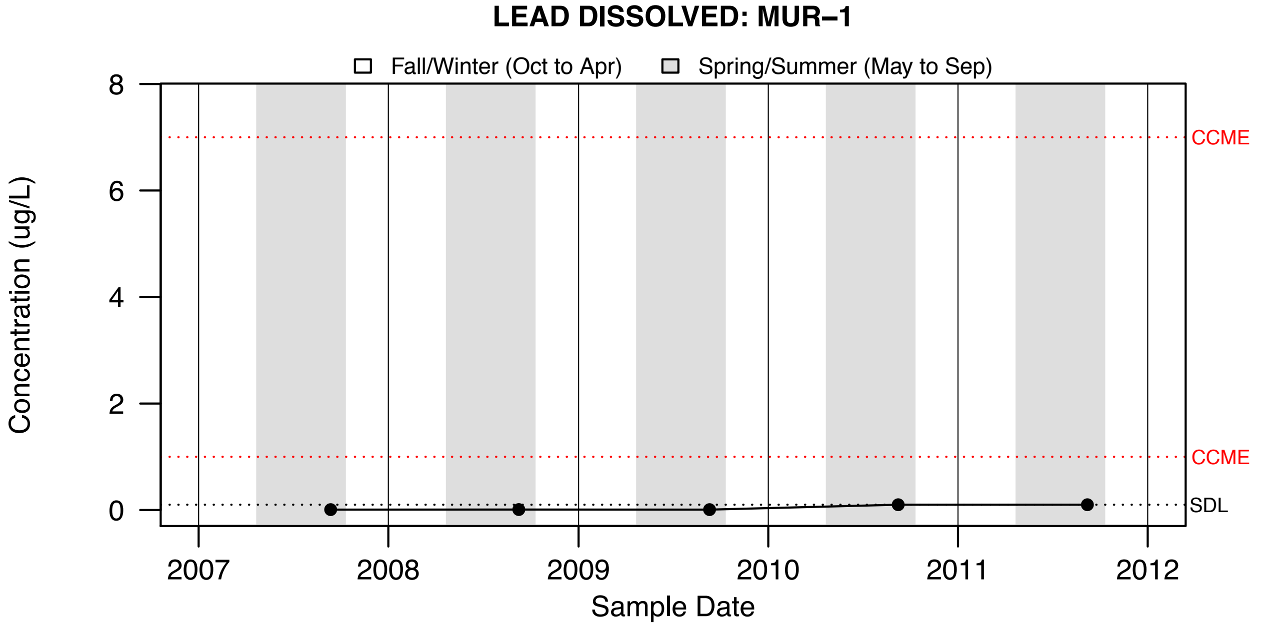


Figure A3.417: PHOSPHORUS TOTAL: MUR-1 -



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A3.418: LEAD DISSOLVED: MUR-1 -

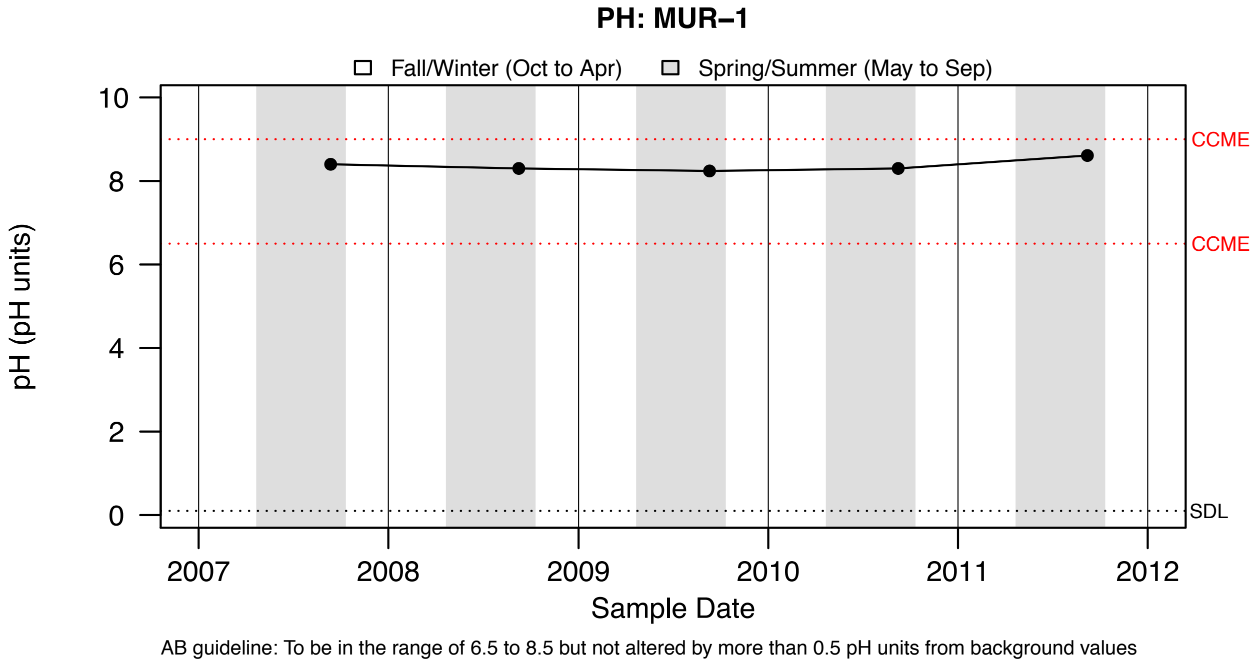


Figure A3.419: PH: MUR-1 -

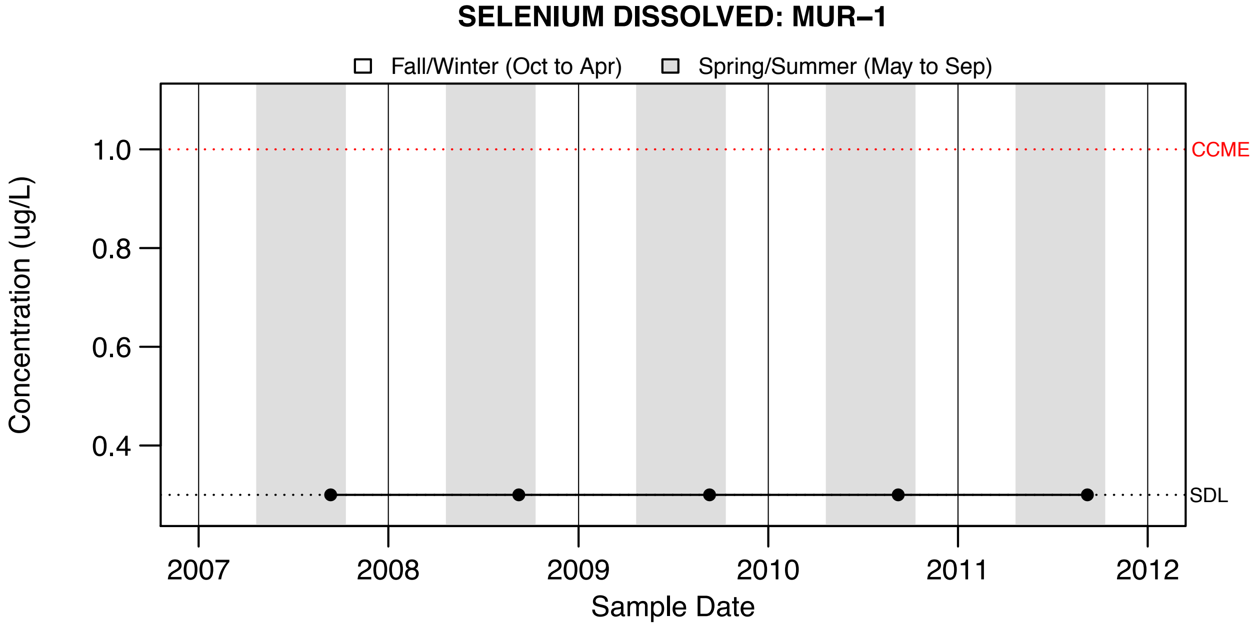


Figure A3.420: SELENIUM DISSOLVED: MUR-1 -

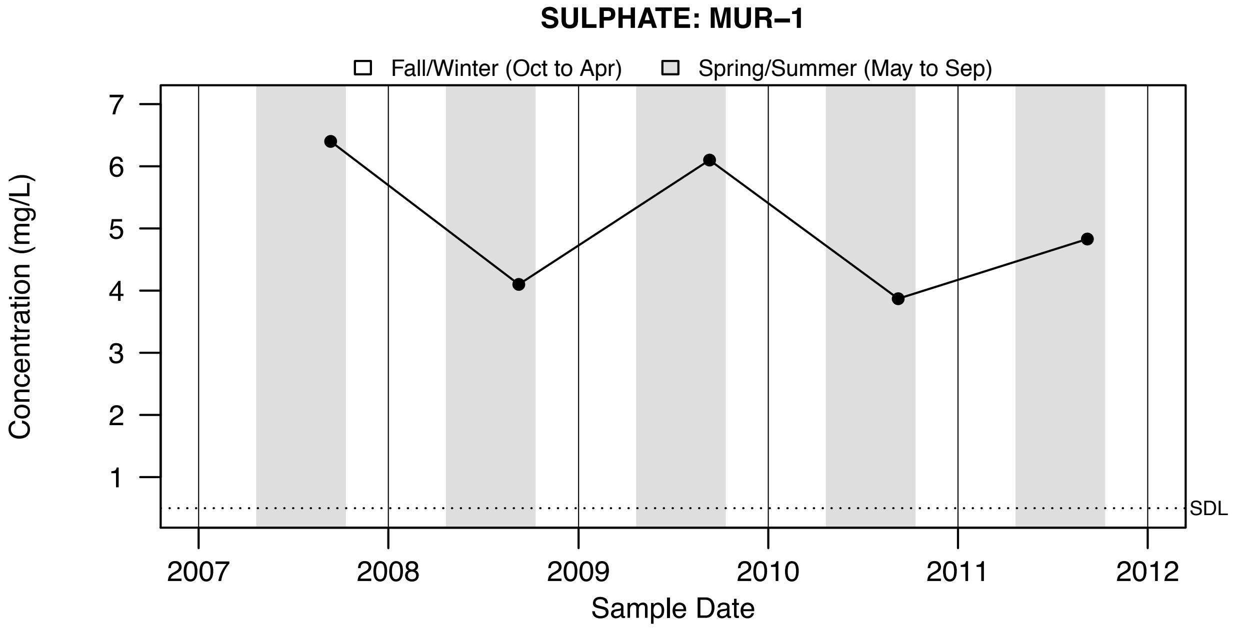


Figure A3.421: SULPHATE: MUR-1 -

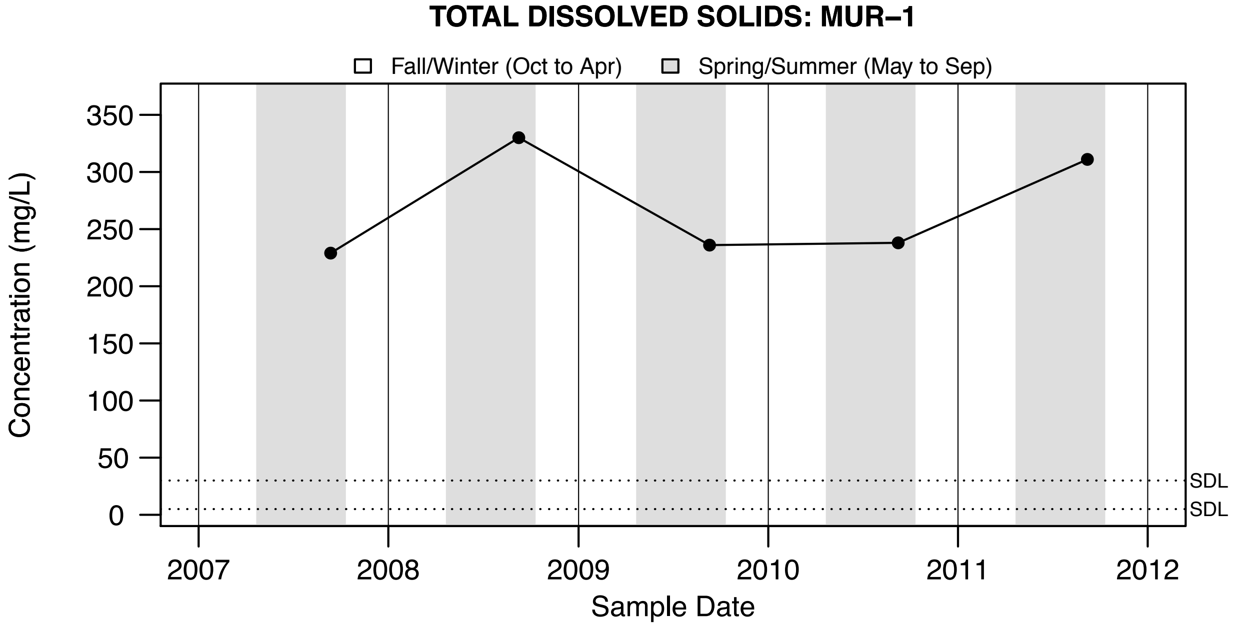
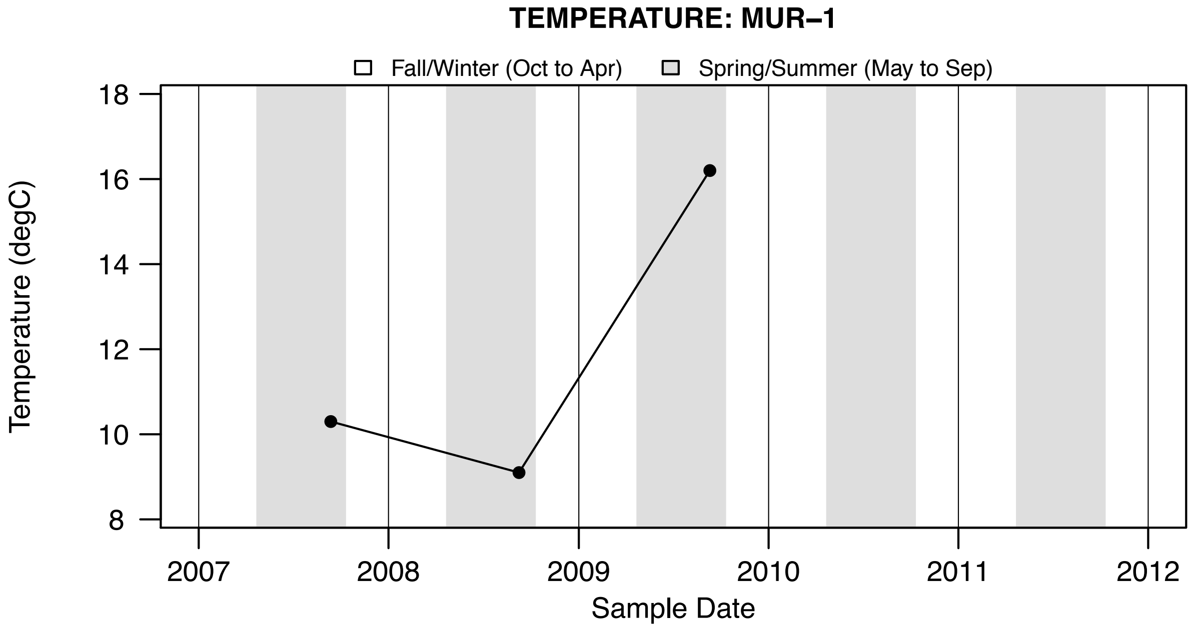


Figure A3.422: TOTAL DISSOLVED SOLIDS: MUR-1 -



AB guideline: Not to be increased by >3 degrees above ambient water temperature. CCME guideline: Thermal additions should not alter thermal stratification or turnover dates, exceed max. weekly average temp, or exceed max. short–term temp.

Figure A3.423: TEMPERATURE: MUR-1 -

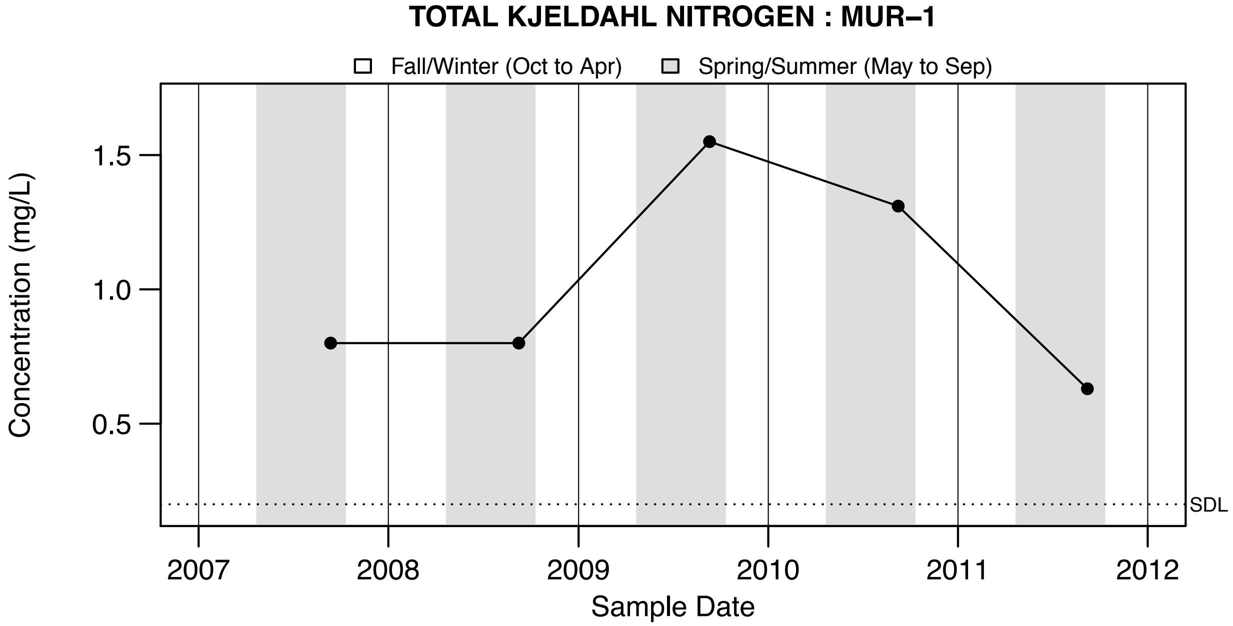
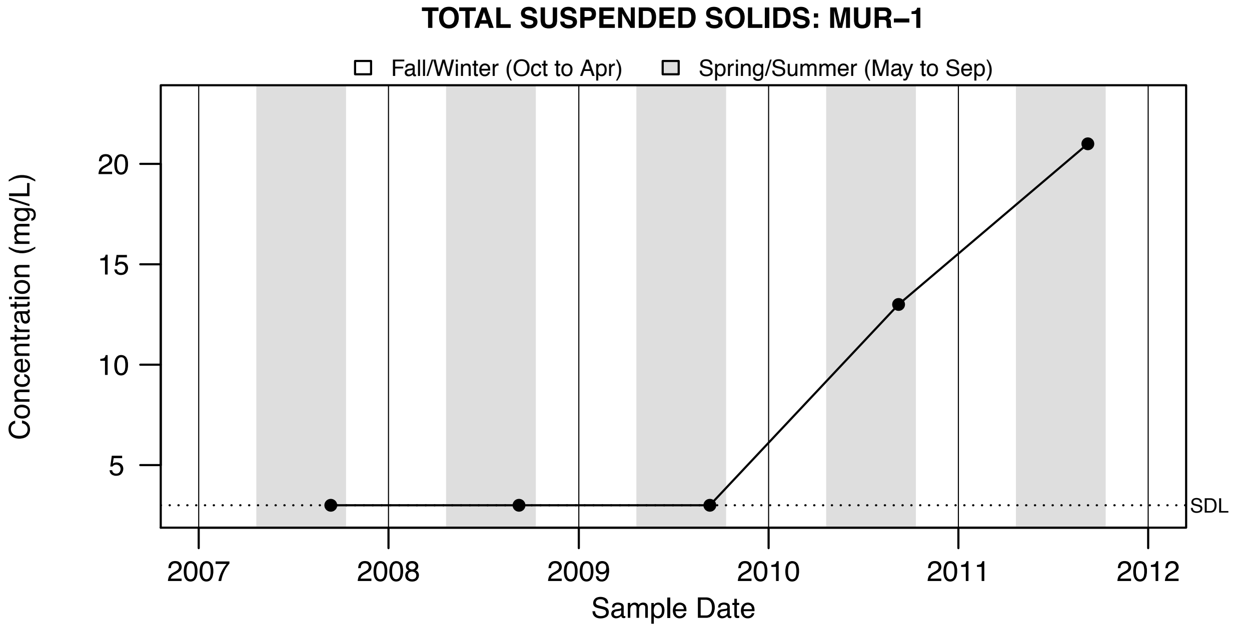


Figure A3.424: TOTAL KJELDAHL NITROGEN : MUR-1 -



AB guideline: No increase >10mg/L from background. CCME: clear flow – Max. increase=25mg/L from background (short–term). Max. ave. increase=5mg/L from background (longer term exposure). High flow: Max. increase=25mg/L from background when background 25–250mg/L . Should not increase >10% of background when background is >250mg/L.

Figure A3.425: TOTAL SUSPENDED SOLIDS: MUR-1 -

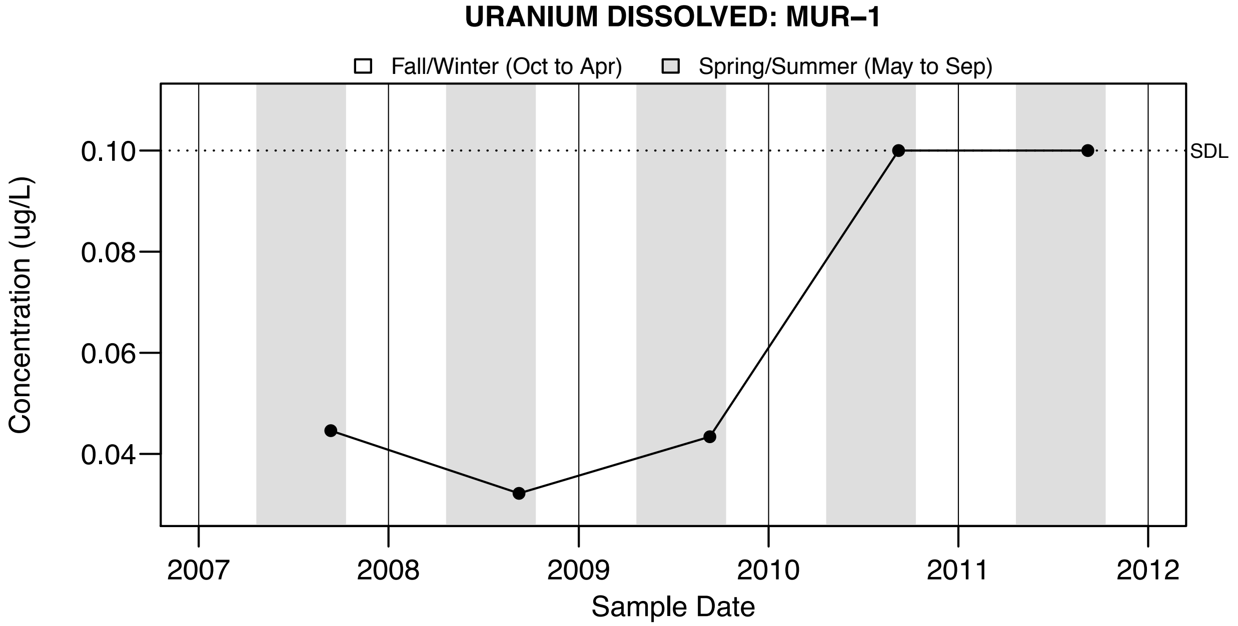


Figure A3.426: URANIUM DISSOLVED: MUR-1 -

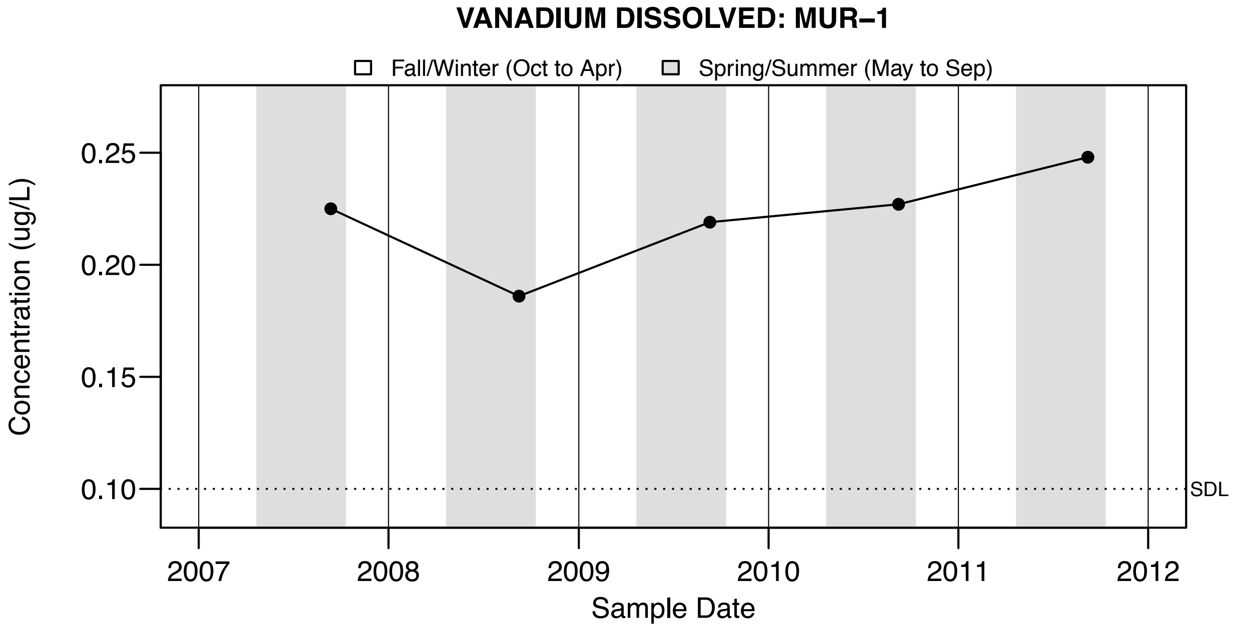


Figure A3.427: VANADIUM DISSOLVED: MUR-1 -

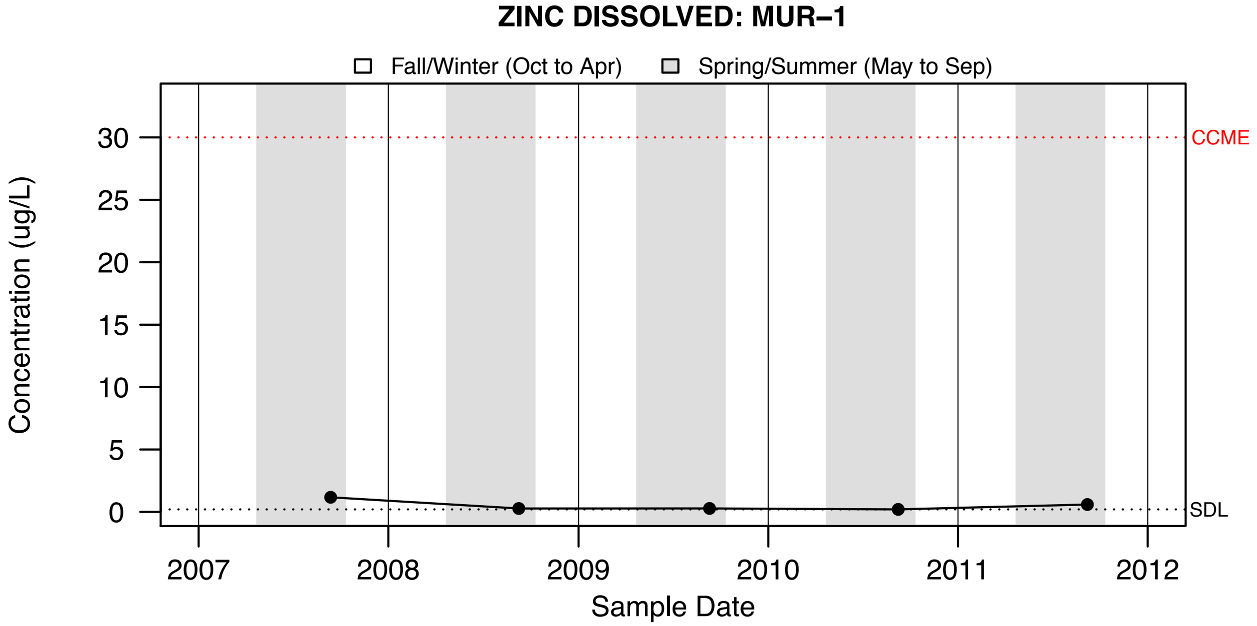


Figure A3.428: ZINC DISSOLVED: MUR-1 -

Appendix 4:

Overview of select water quality parameters influenced by pH or water hardness as measured at Long-term River Network, Medium-term River Network, and Regional Aquatics Monitoring Program sites between 2007 and spring 2012

List of Abbreviations

AB Acute: Alberta provincial surface water quality acute guideline value

AB Chronic: Alberta provincial surface water quality chronic guideline value

CCME: Canadian Council of Ministers of the Environment Guideline Value for the Protection of Aquatic Life

LTRN: Long-term River Network

MDL: Method detection limit

MTRN: Medium-term River Network

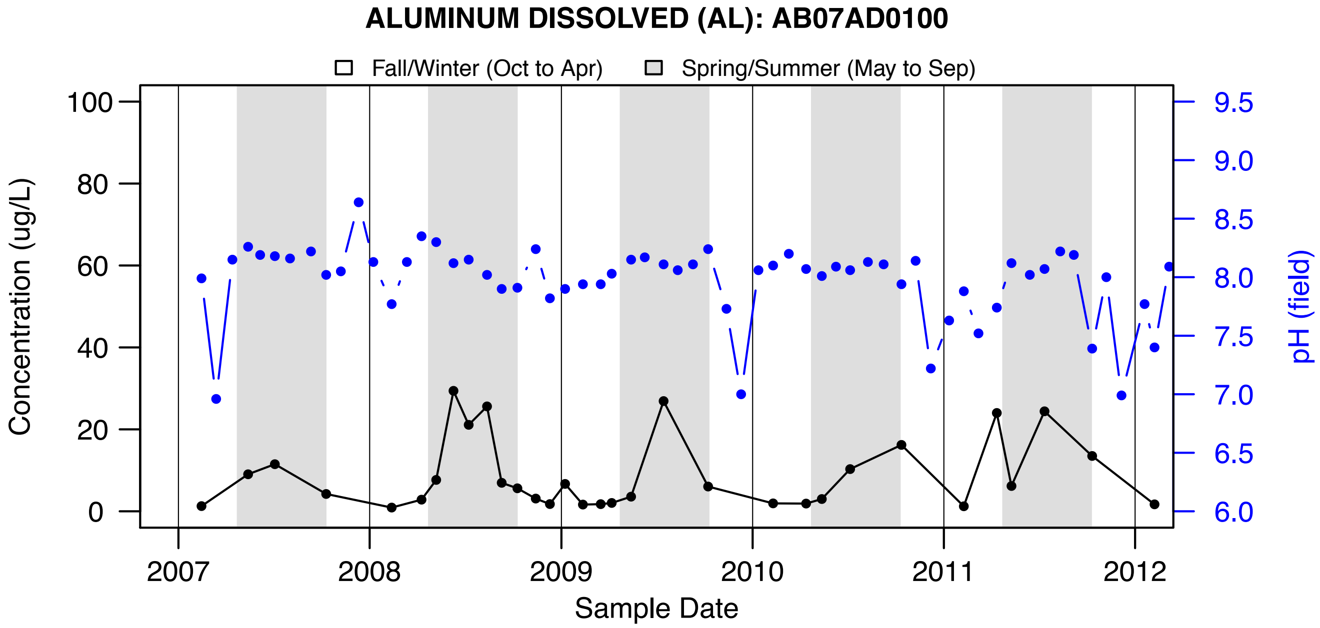
RAMP: Regional Aquatics Monitoring Program

SDL: Sample detection limit

Table A4-1. Station number, description, and location of LTRN, MTRN, and RAMP stations evaluated as part of the Phase 3 State of the Watershed Assessment.

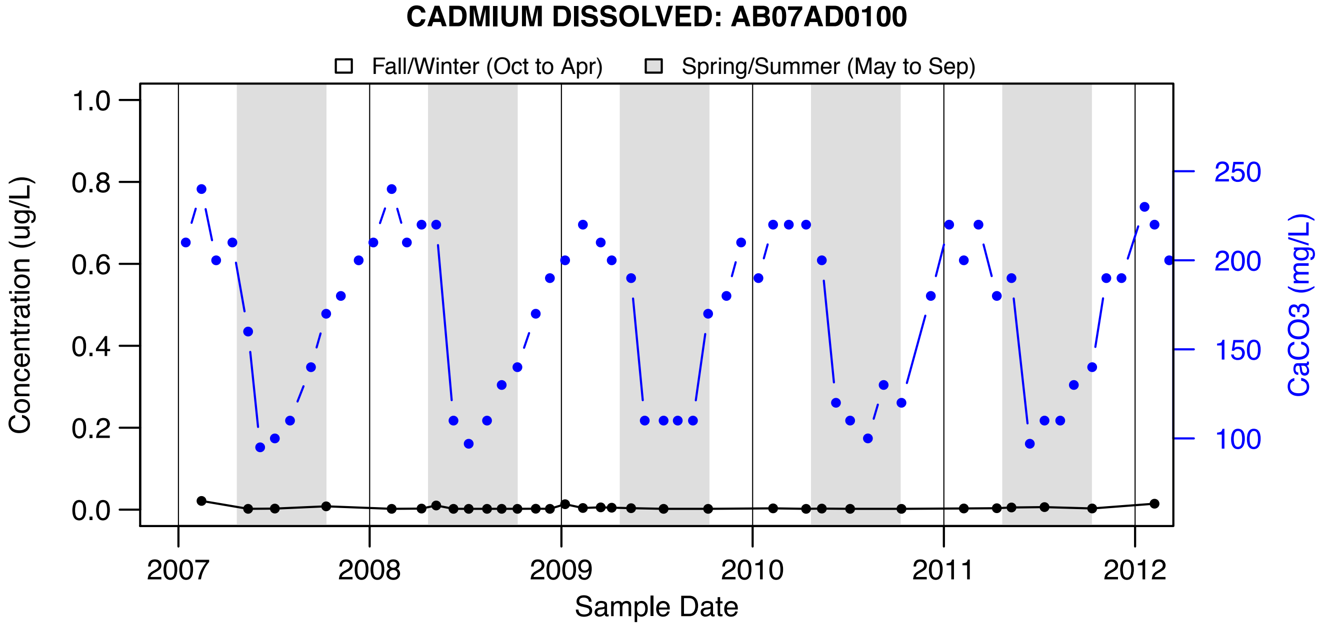
Source	Station Code	Station Description	Latitude	Longitude
LTRN	AB07AD0100	Athabasca River at old entrance town site - left bank	53.3675	-117.7225
LTRN	AB07BE0010	Athabasca River at town of Athabasca	54.7222	-113.2861
LTRN	AB07CC0030	Athabasca River upstream of Fort McMurray, 100 m above the confluence with Horse River - left bank	56.7203	-111.4056
LTRN	AB07DA0980	Athabasca River - transect above the Firebag River	57.7236	-111.3792
LTRN	AB07DD0010	Athabasca River at Old Fort - right bank	58.3828	-111.5178
LTRN	AB07DD0105	Athabasca River downstream of Devils Elbow at winter road crossing	58.4472	-111.1858
MTRN	AB07AG0390	Mcleod River at Whitecourt - Highway #43 bridge right bank	54.1361	-115.6958
MTRN	AB07BK0125	Lesser Slave River - 9.5 km upstream of Athabasca River confluence	55.2067	-114.1225
MTRN	AB07BK0130	Lesser Slave River at confluence with Athabasca River above the town of Smith Mouth: km 794.0	55.1658	-114.0619
MTRN	AB07DA0610	Muskeg River at WSC gauge downstream of Kearl Lake Road	57.1917	-111.5681
RAMP	ATR-DC-CC	Athabasca River at Donald Creek - cross-channel	56.8266	-111.4093
RAMP	ATR-DC-E	Athabasca River at Donald Creek - east bank	56.8266	-111.4077
RAMP	ATR-DC-W	Athabasca River at Donald Creek - west bank	56.8265	-111.4080
RAMP	ATR-DD-E	Athabasca River downstream of development- east bank	57.4528	-111.6023
RAMP	ATR-DD-W	Athabasca River downstream of development- west bank	57.4553	-111.6098
RAMP	ATR-FR-CC	Athabasca River upstream of the Firebag River - cross-channel	57.7407	-111.3684
RAMP	ATR-MR-E	Athabasca River upstream of the Muskeg River- east bank	57.1319	-111.6029
RAMP	ATR-MR-W	Athabasca River upstream of the Muskeg River- west bank	57.1302	-111.6079
RAMP	ATR-SR-E	Athabasca River upstream of the Steepbank River- east bank	57.0192	-111.4787
RAMP	ATR-SR-W	Athabasca River upstream of the Steepbank River- west bank	57.0154	-111.4811
RAMP	FIR-1	Mouth of the Firebag River	57.7436	-111.3508
RAMP	MUR-1	Mouth of the Muskeg River	57.1335	-111.6035

List of Figures



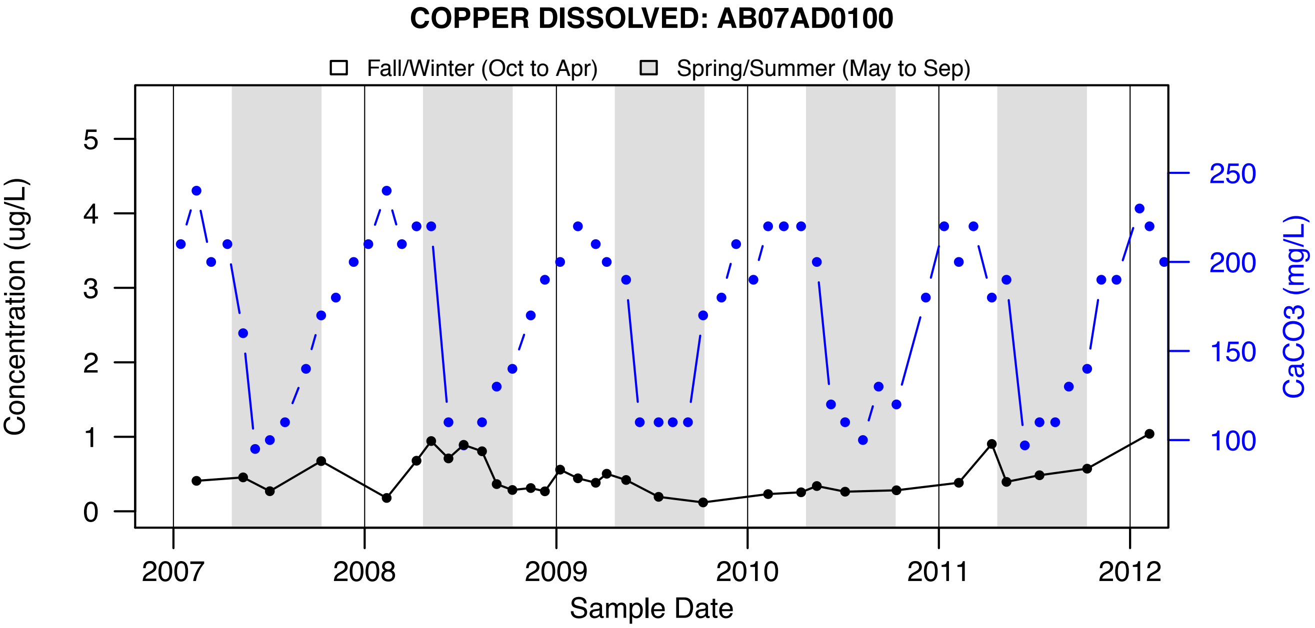
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.1: ALUMINUM DISSOLVED (AL): AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



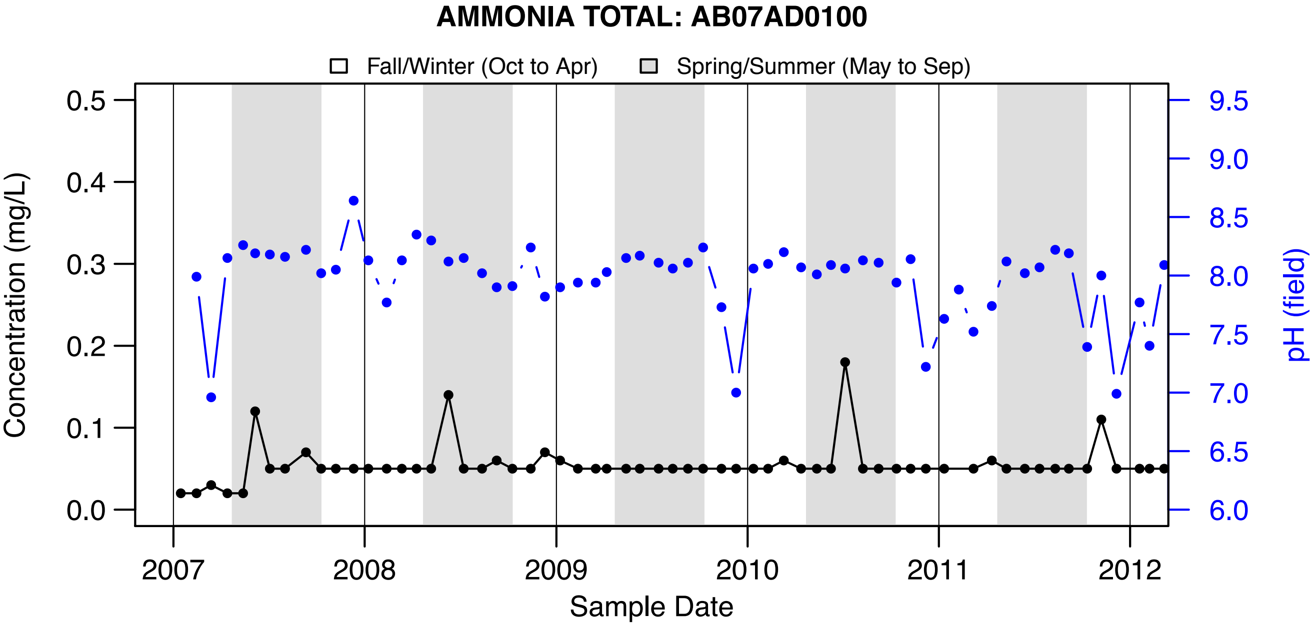
Related to hardness as CaCo3

Figure A4.2: CADMIUM DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



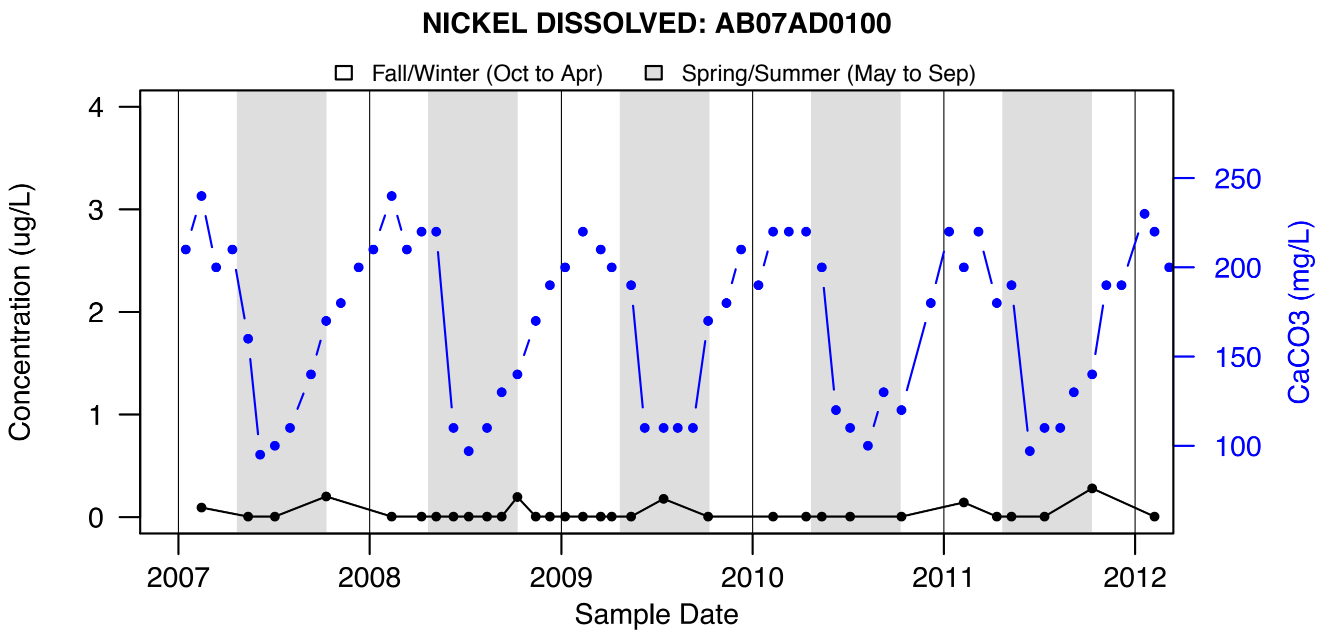
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.3: COPPER DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



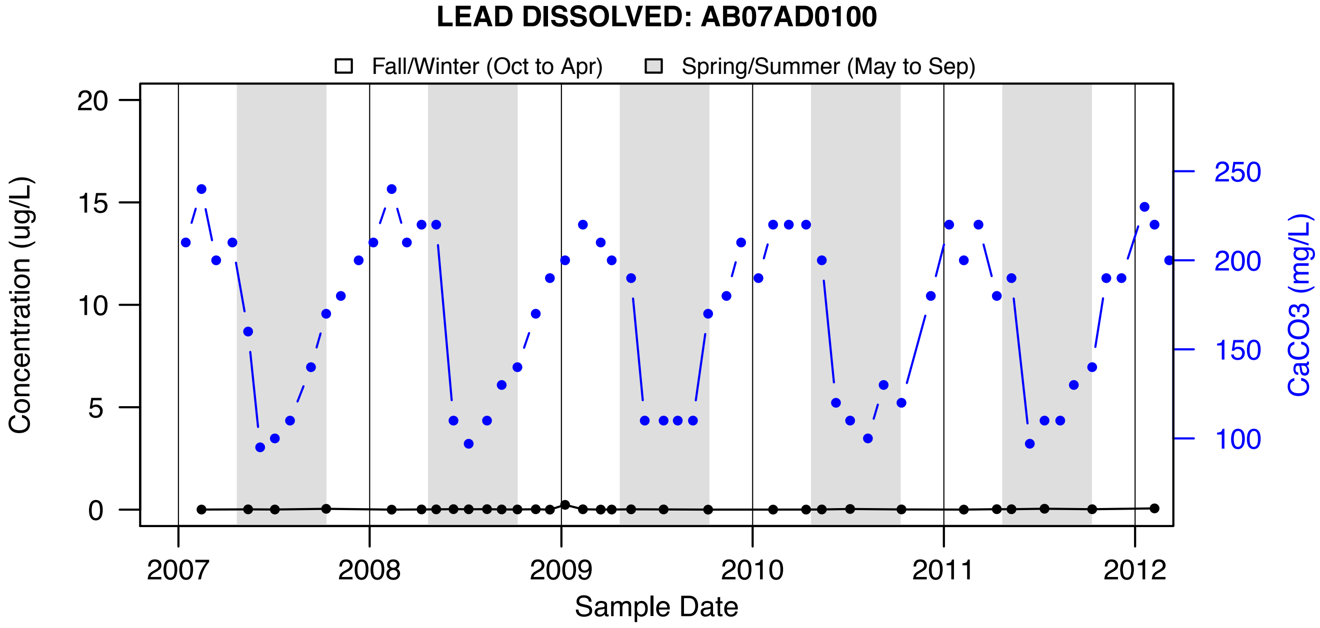
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.4: AMMONIA TOTAL: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.5: NICKEL DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.6: LEAD DISSOLVED: AB07AD0100 - AT OLD ENTRANCE TOWN SITE - LEFT BANK

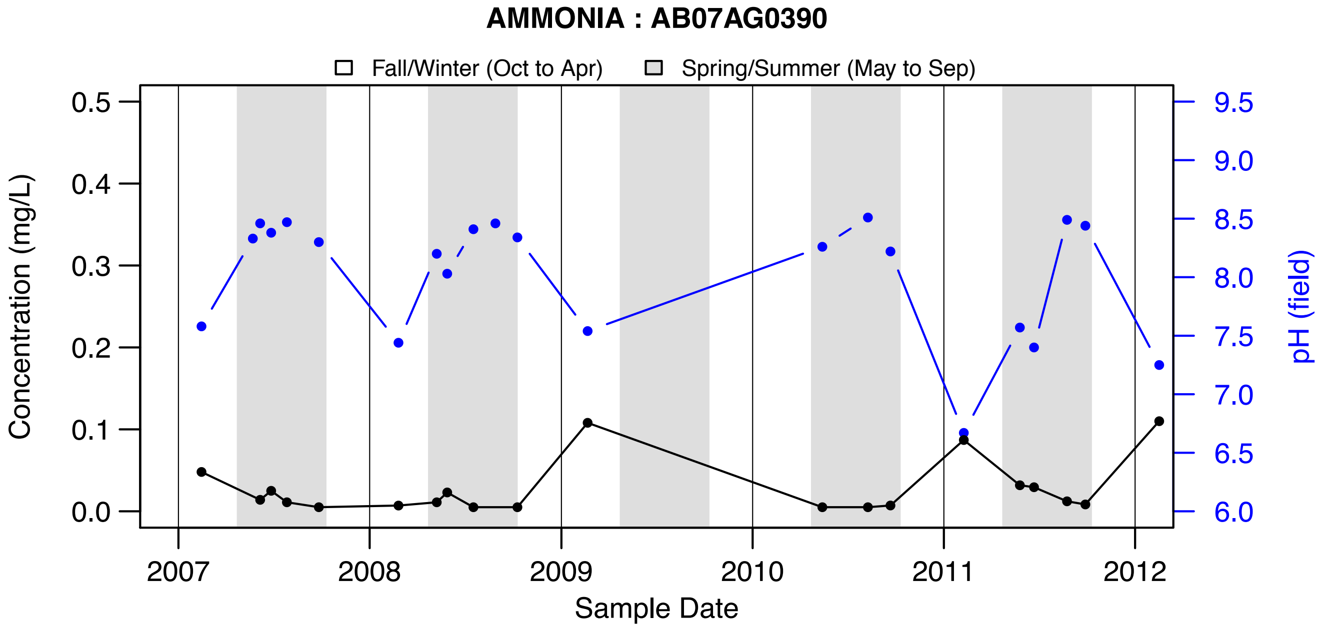
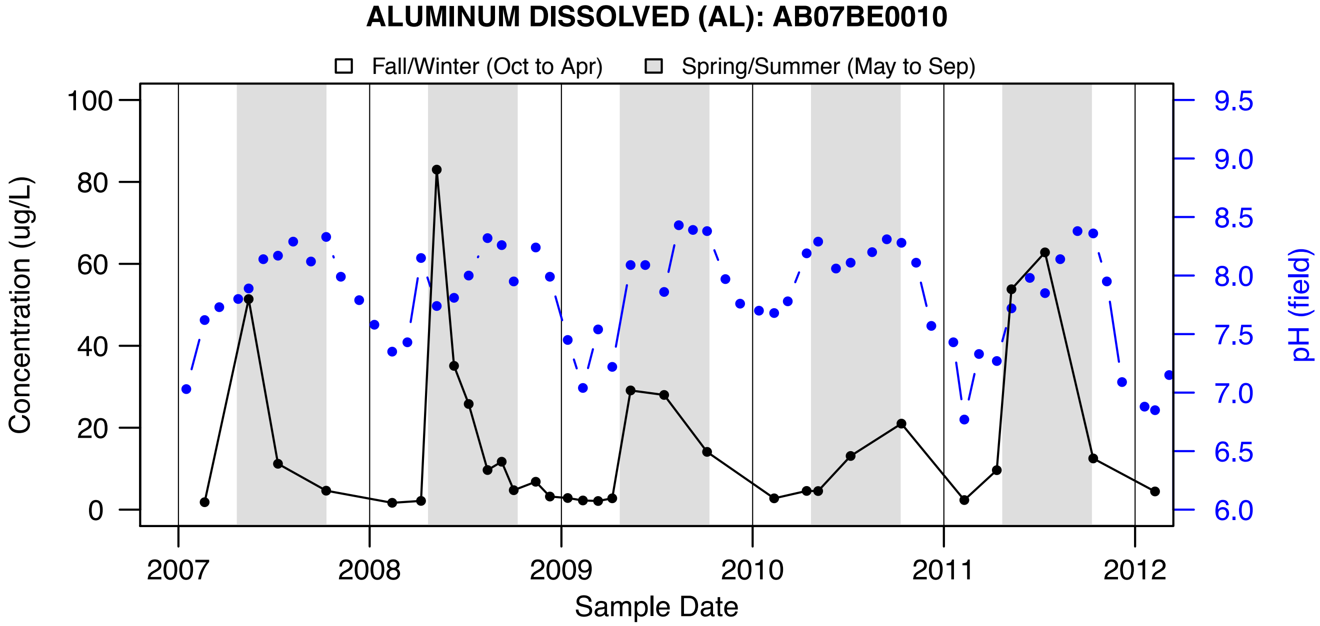
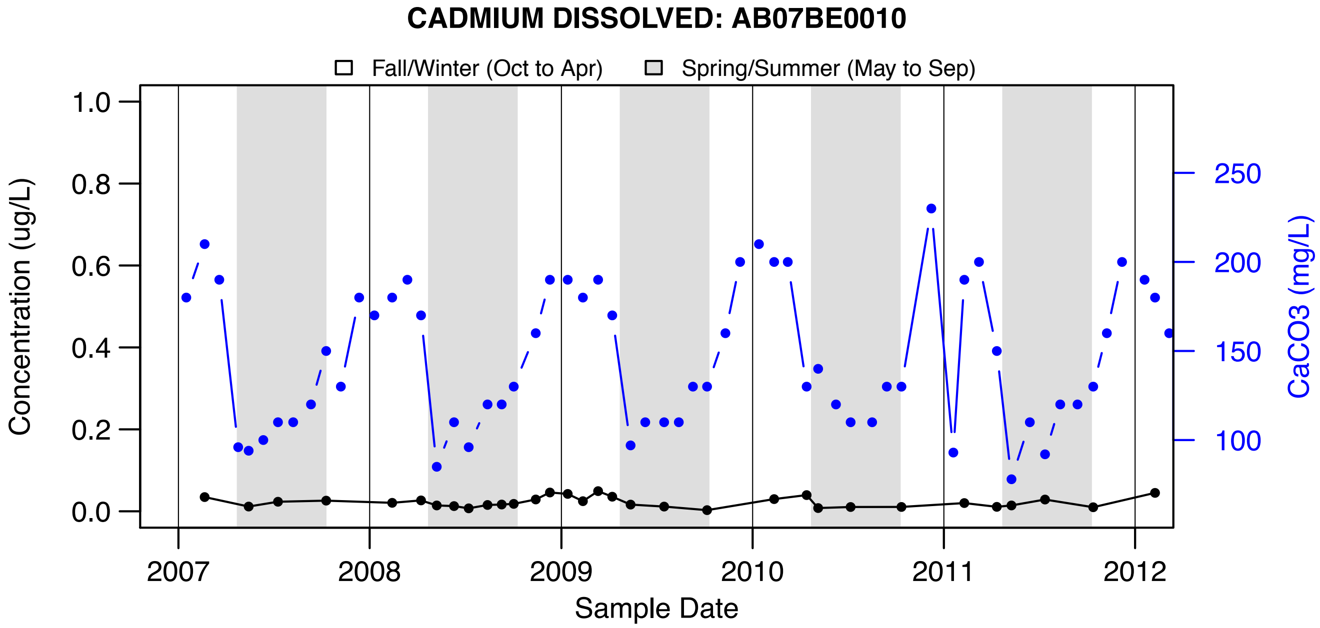


Figure A4.7: AMMONIA : AB07AG0390 - AT WHITECOURT - HIGHWAY #43 BRIDGE RIGHT BANK



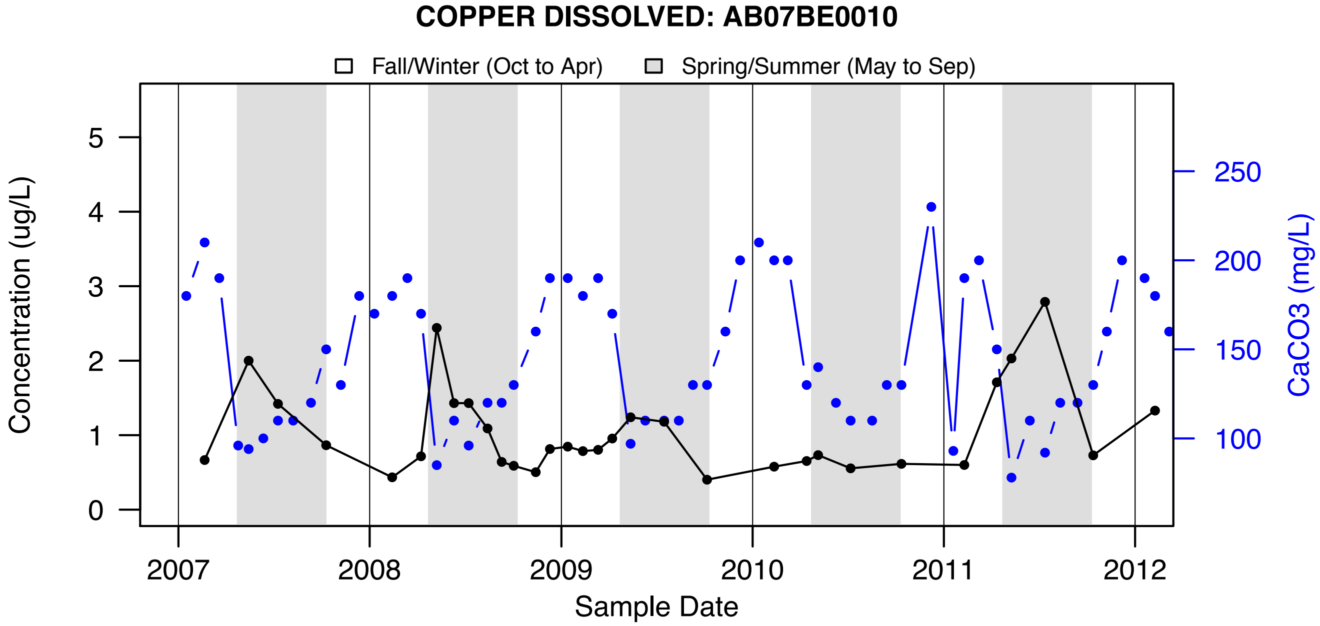
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.8: ALUMINUM DISSOLVED (AL): AB07BE0010 - AT TOWN OF ATHABASCA



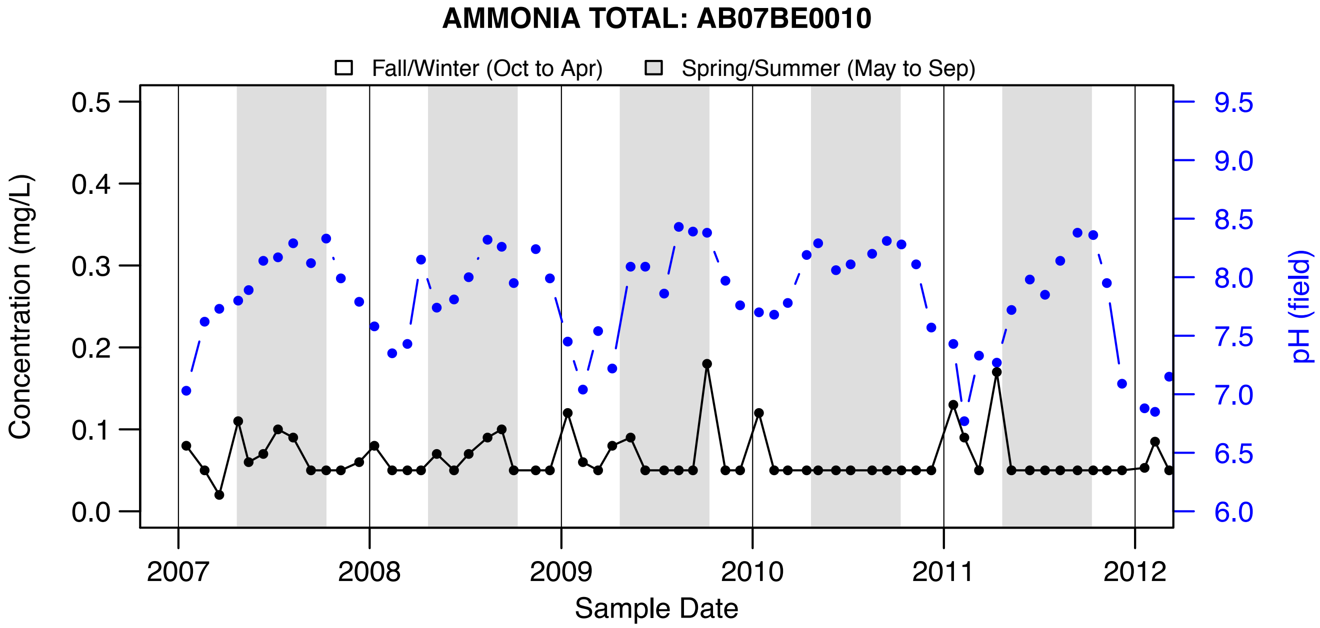
Related to hardness as CaCo3

Figure A4.9: CADMIUM DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA



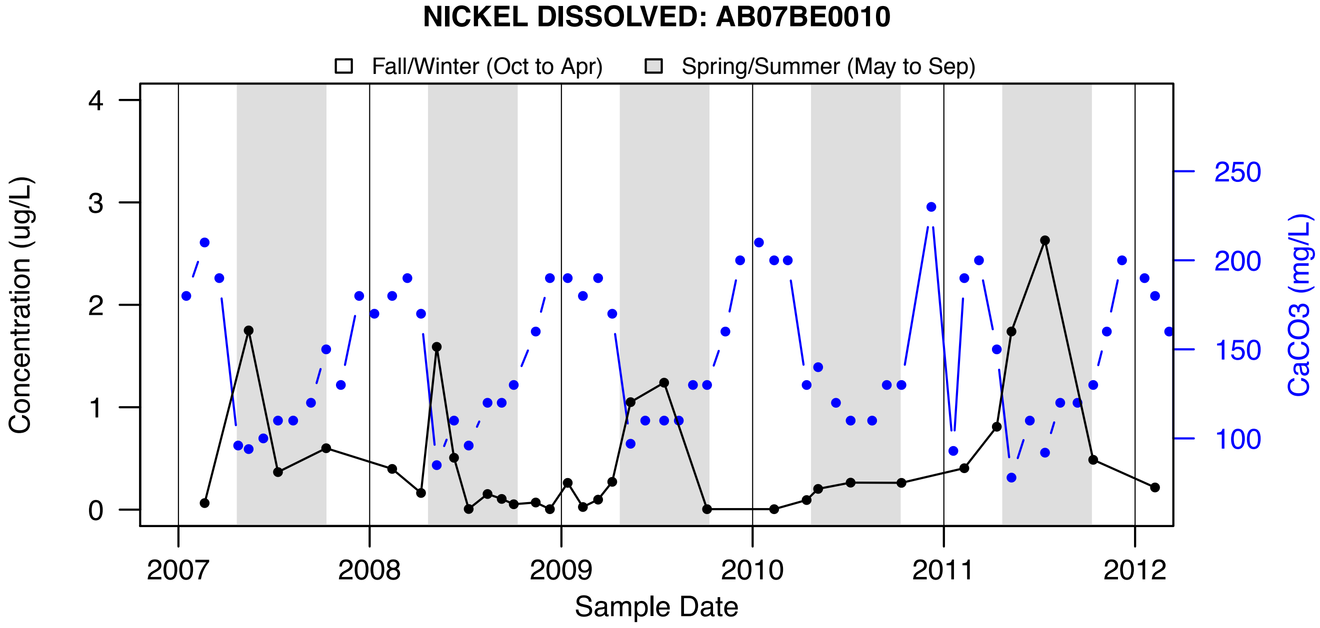
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid−extractable copper concentrations

Figure A4.10: COPPER DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA



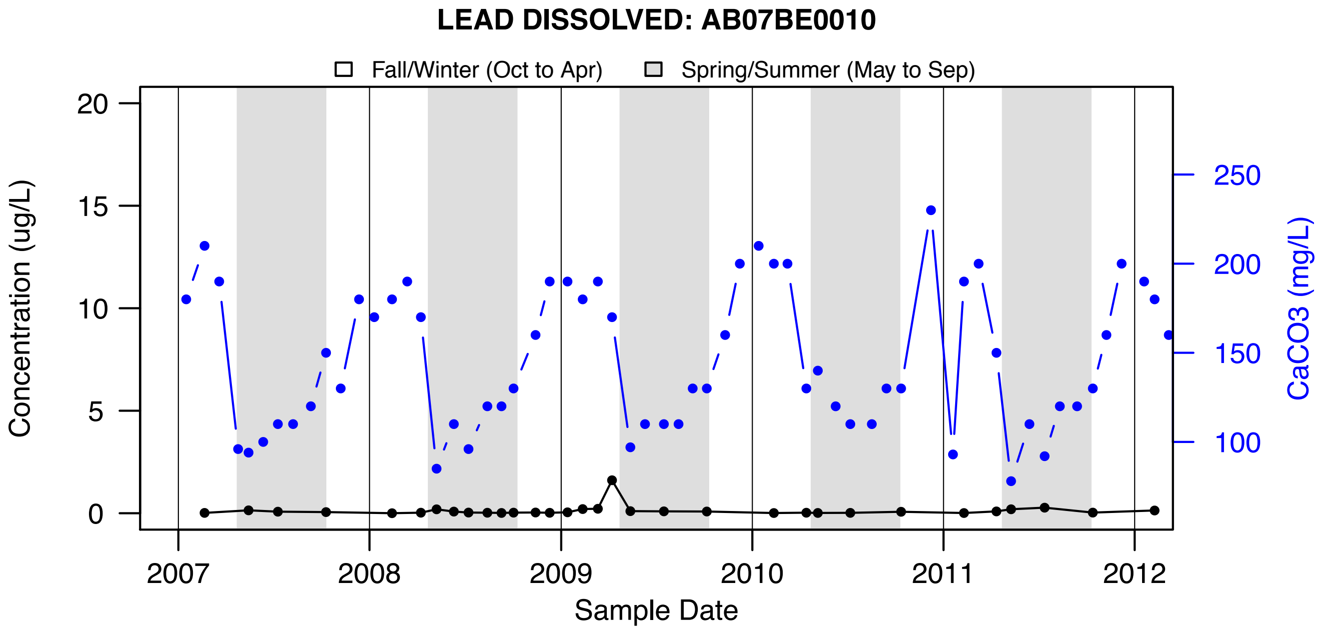
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.11: AMMONIA TOTAL: AB07BE0010 - AT TOWN OF ATHABASCA



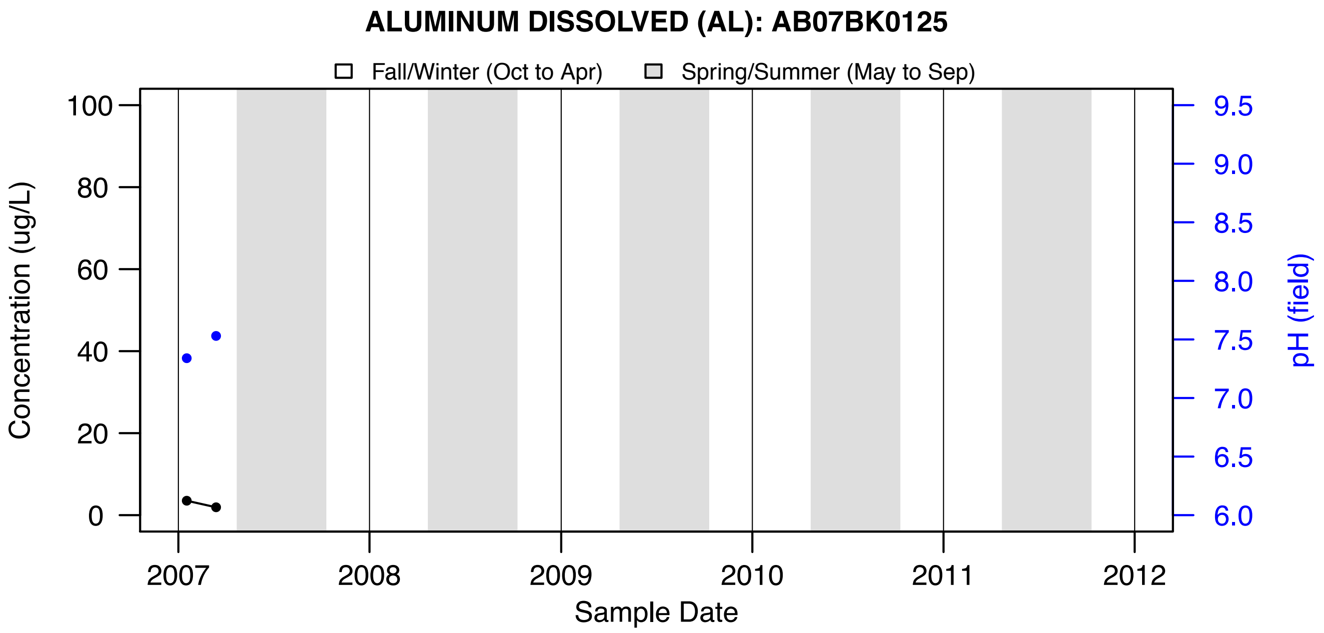
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L; 110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.12: NICKEL DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A4.13: LEAD DISSOLVED: AB07BE0010 - AT TOWN OF ATHABASCA



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.14: ALUMINUM DISSOLVED (AL): AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

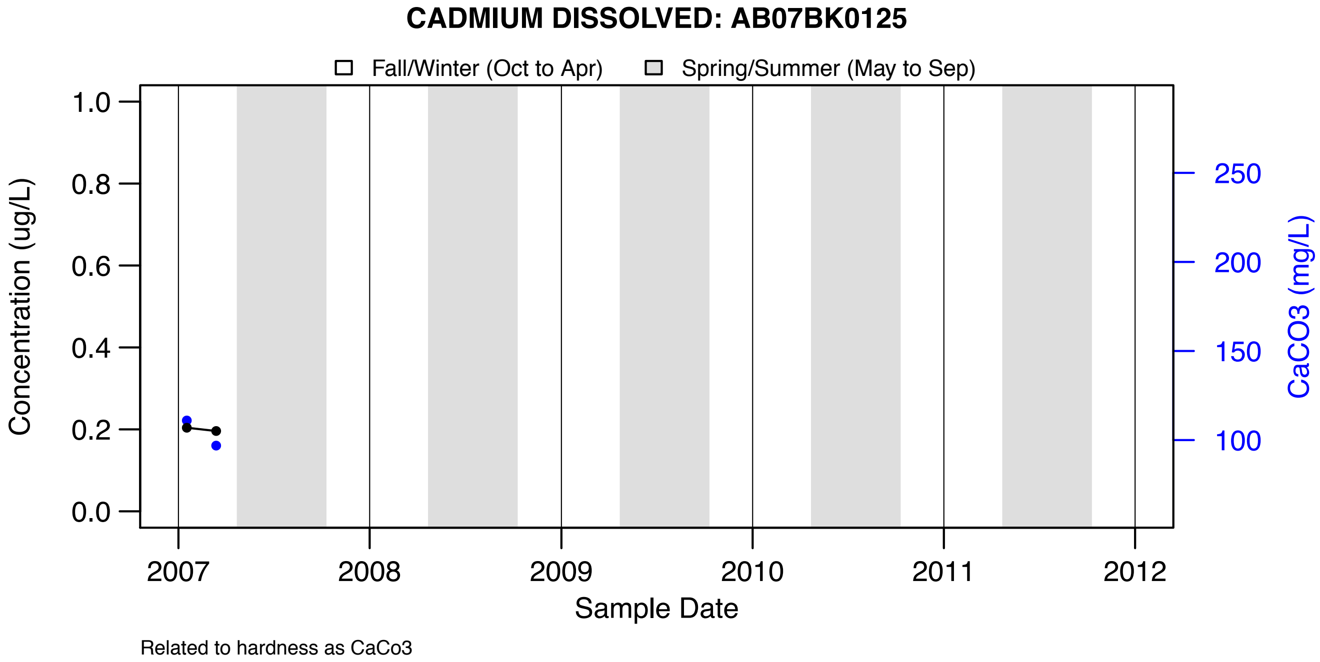


Figure A4.15: CADMIUM DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE

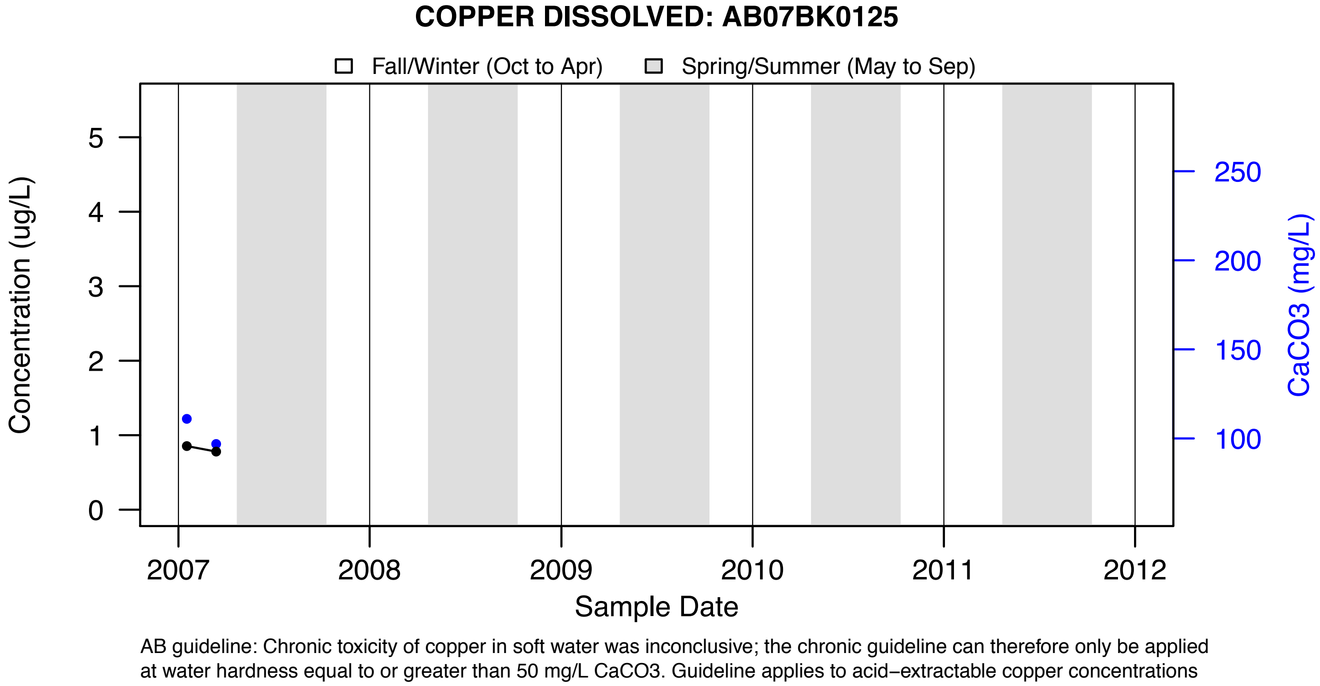
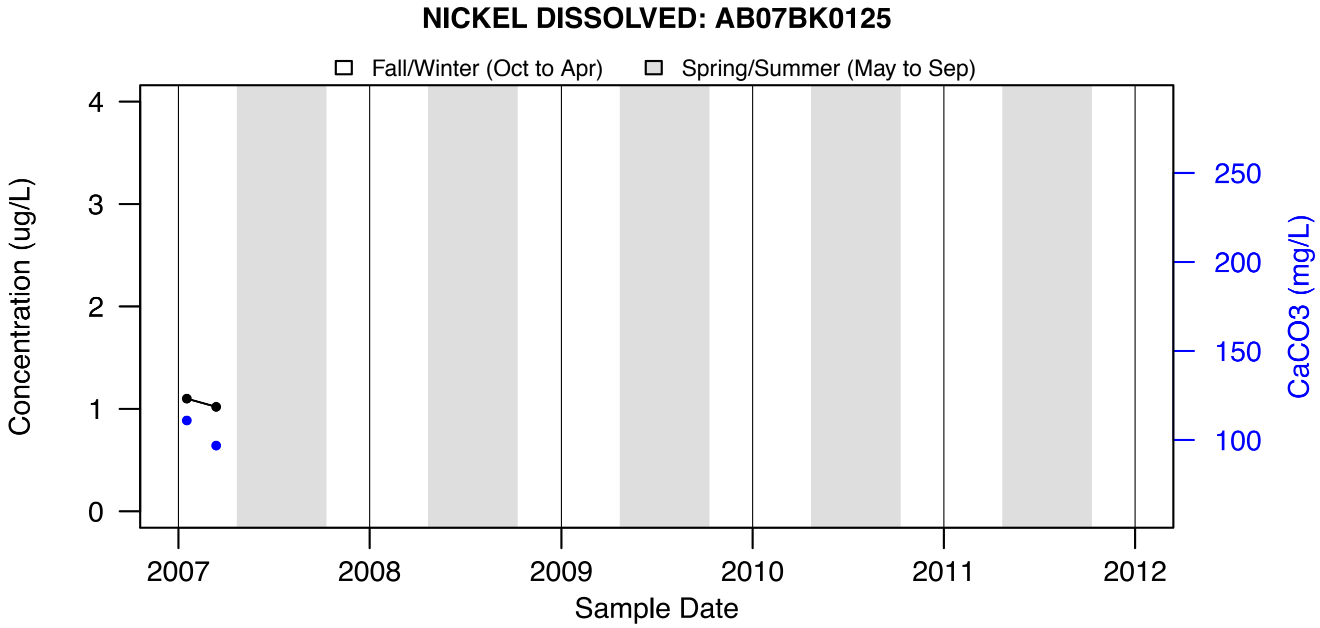
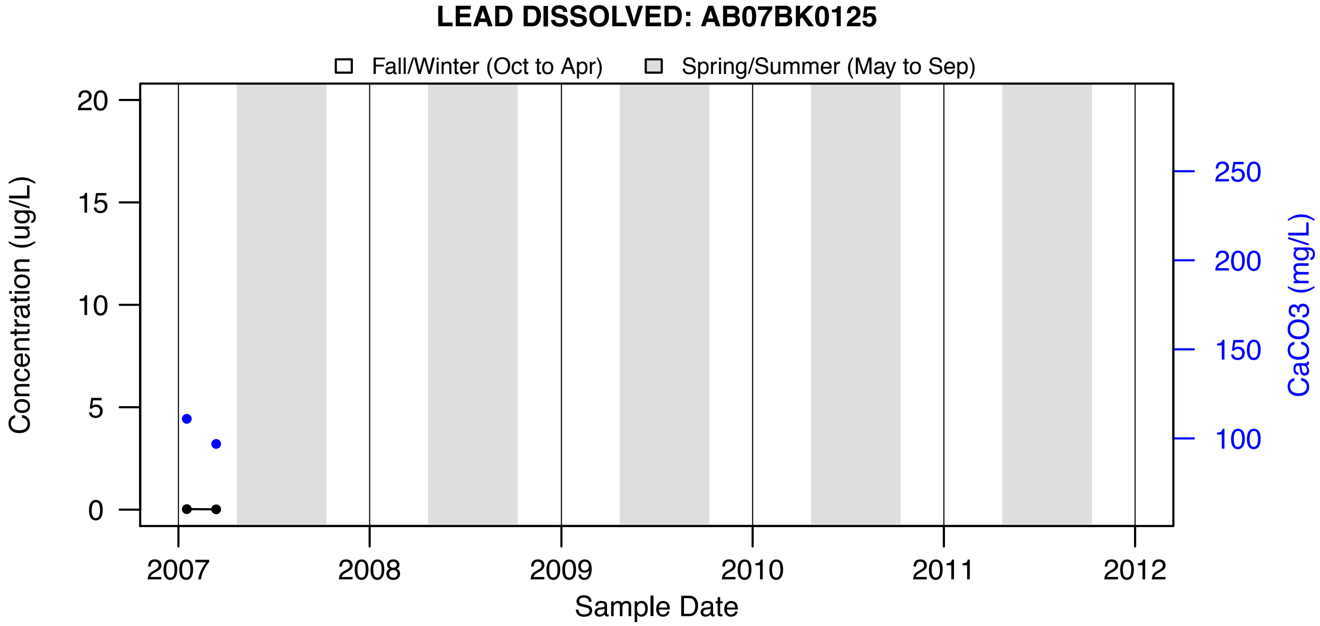


Figure A4.16: COPPER DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



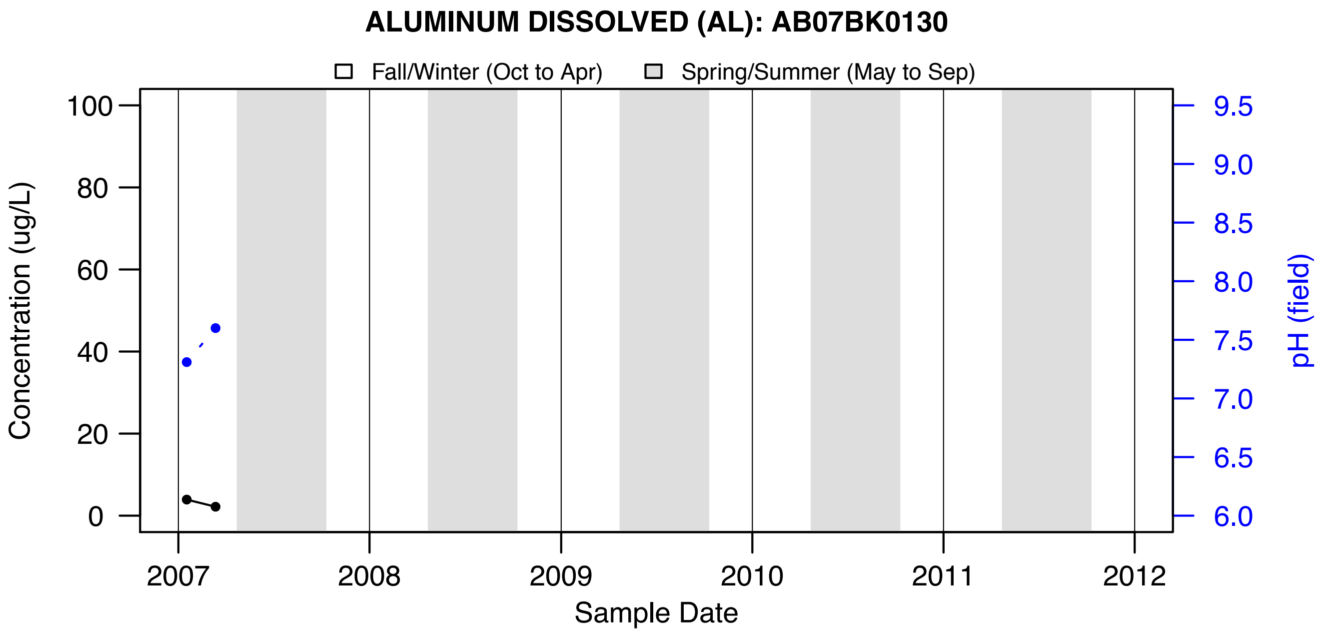
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.17: NICKEL DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



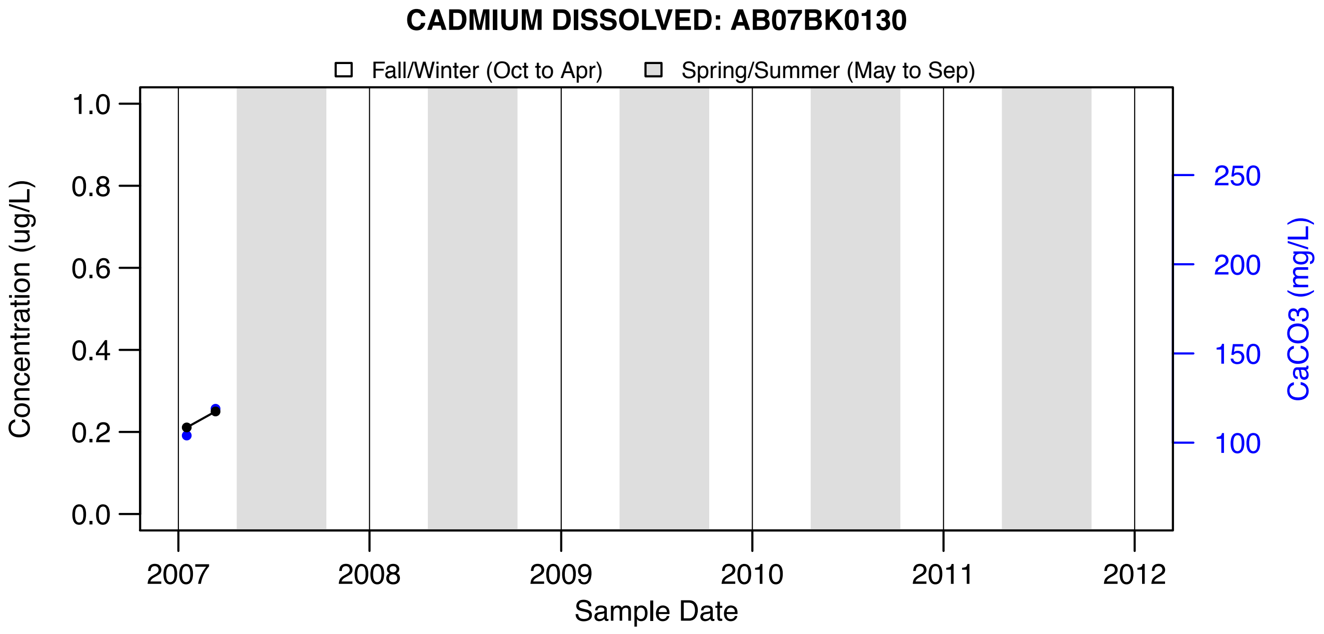
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.18: LEAD DISSOLVED: AB07BK0125 - 9.5 KM U/S OF ATHABASCA RIVER CONFLUENCE



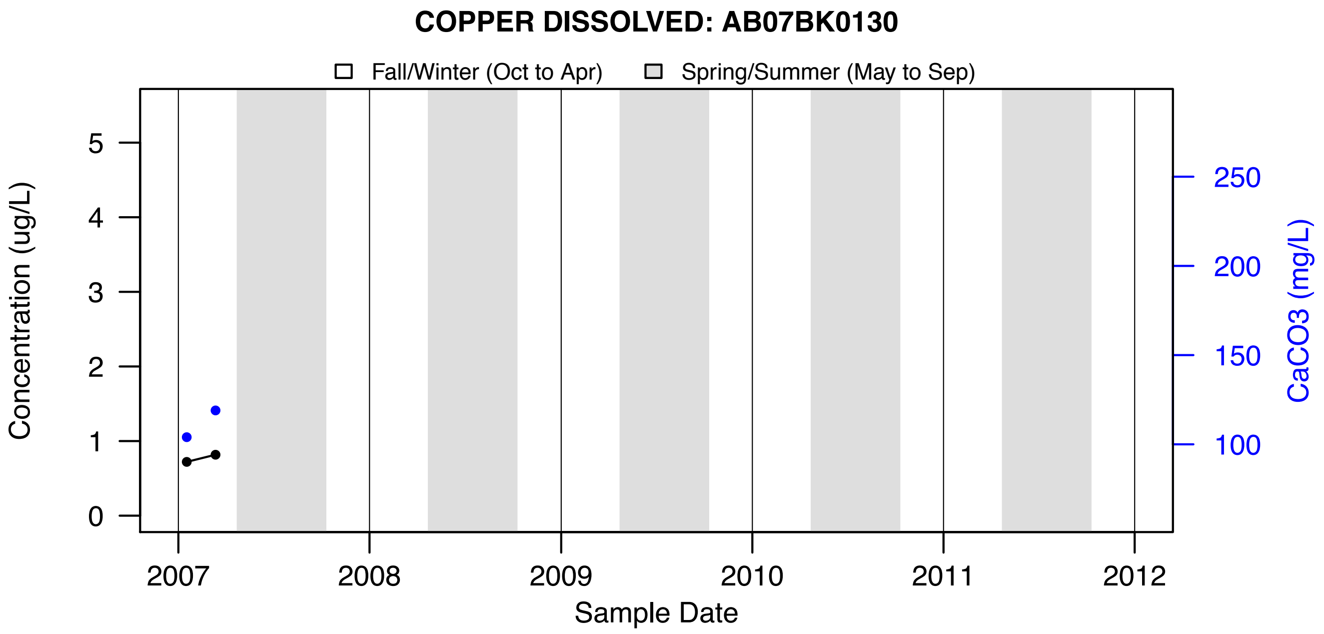
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.19: ALUMINUM DISSOLVED (AL): AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



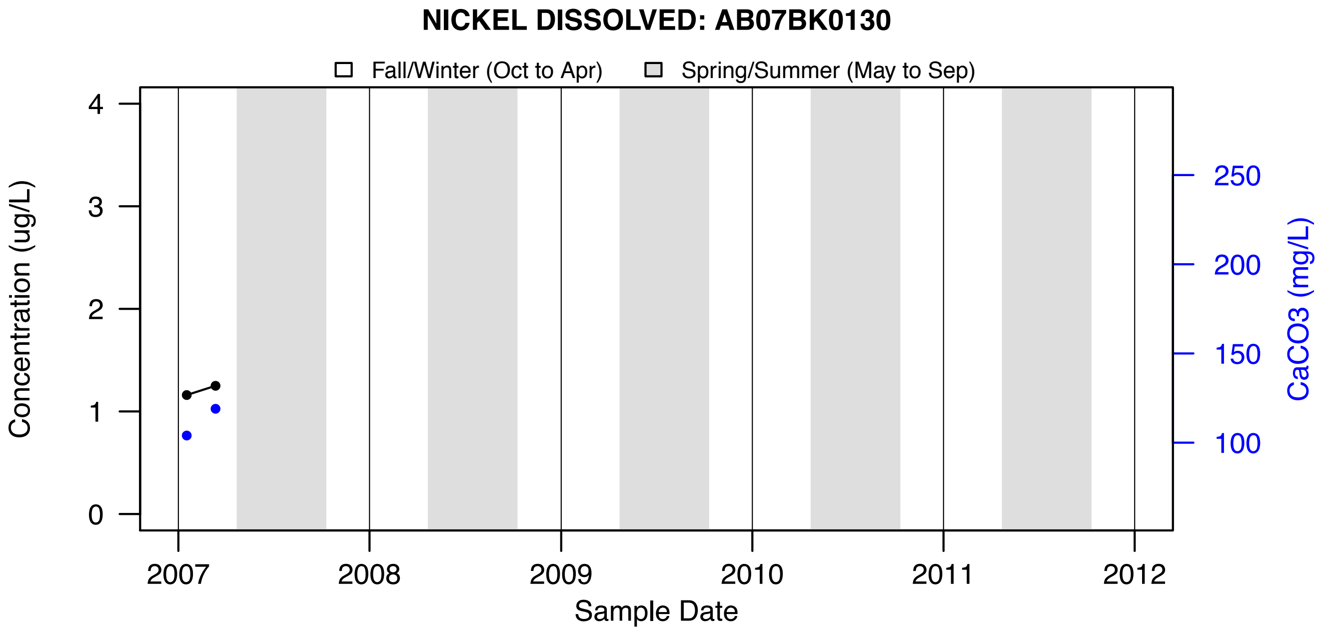
Related to hardness as CaCo3

Figure A4.20: CADMIUM DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



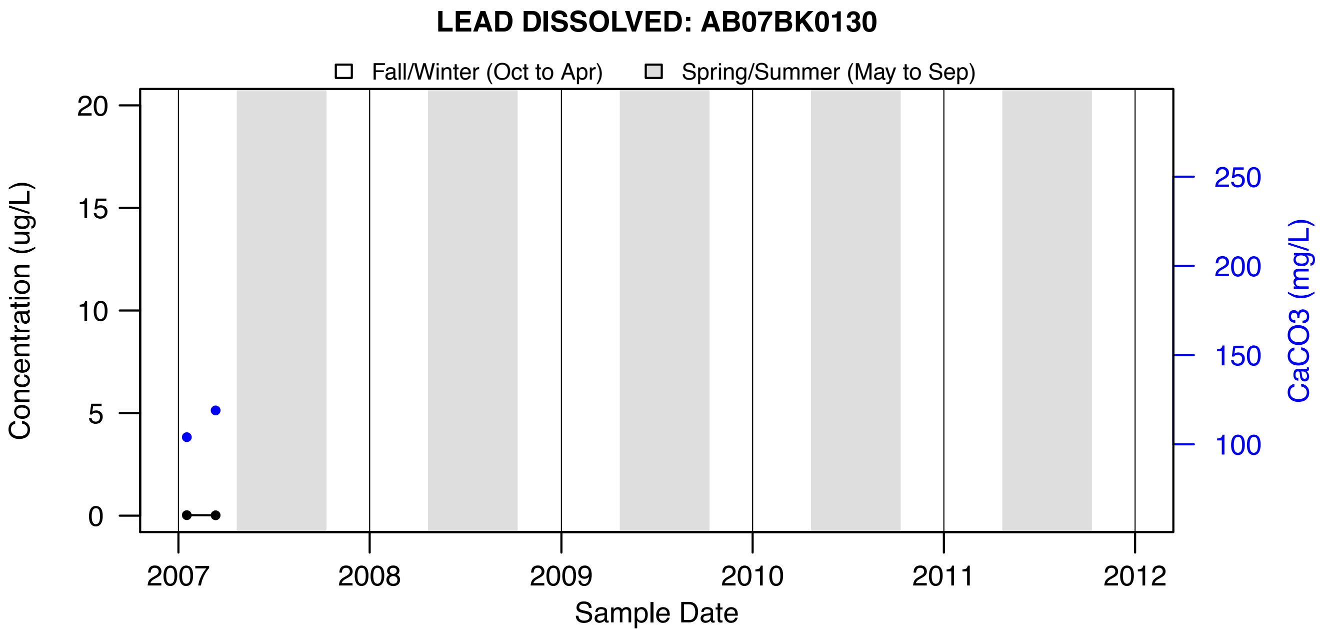
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid−extractable copper concentrations

Figure A4.21: COPPER DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



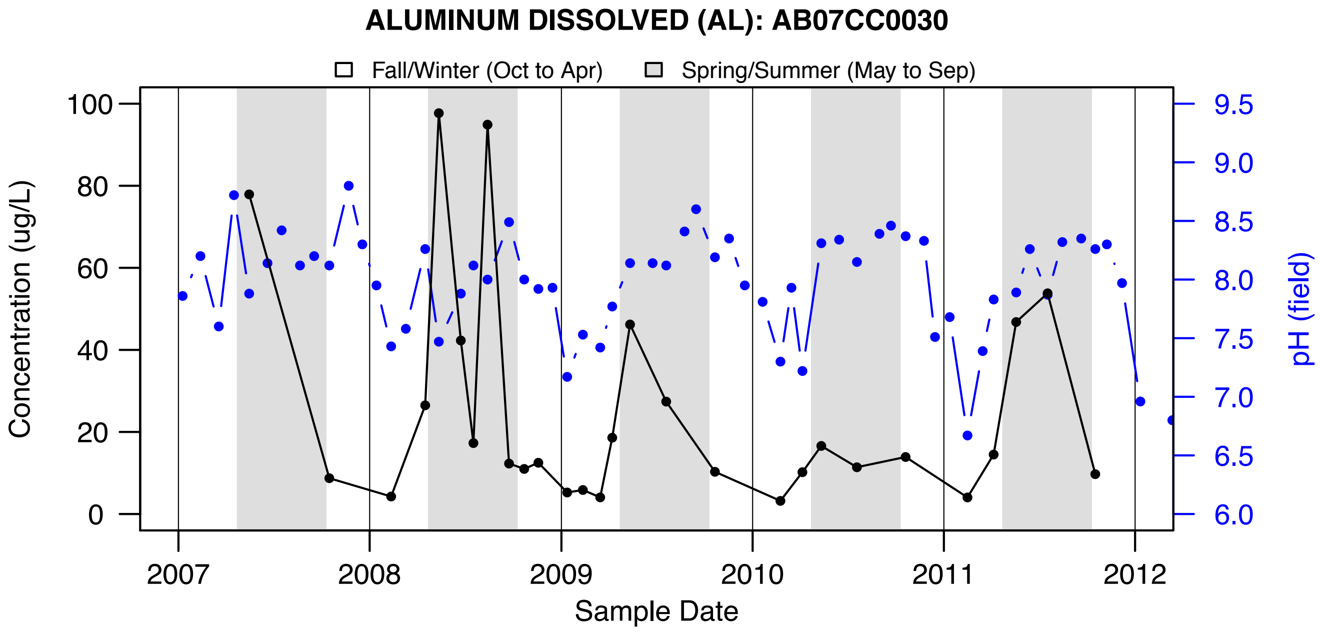
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L; 110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.22: NICKEL DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



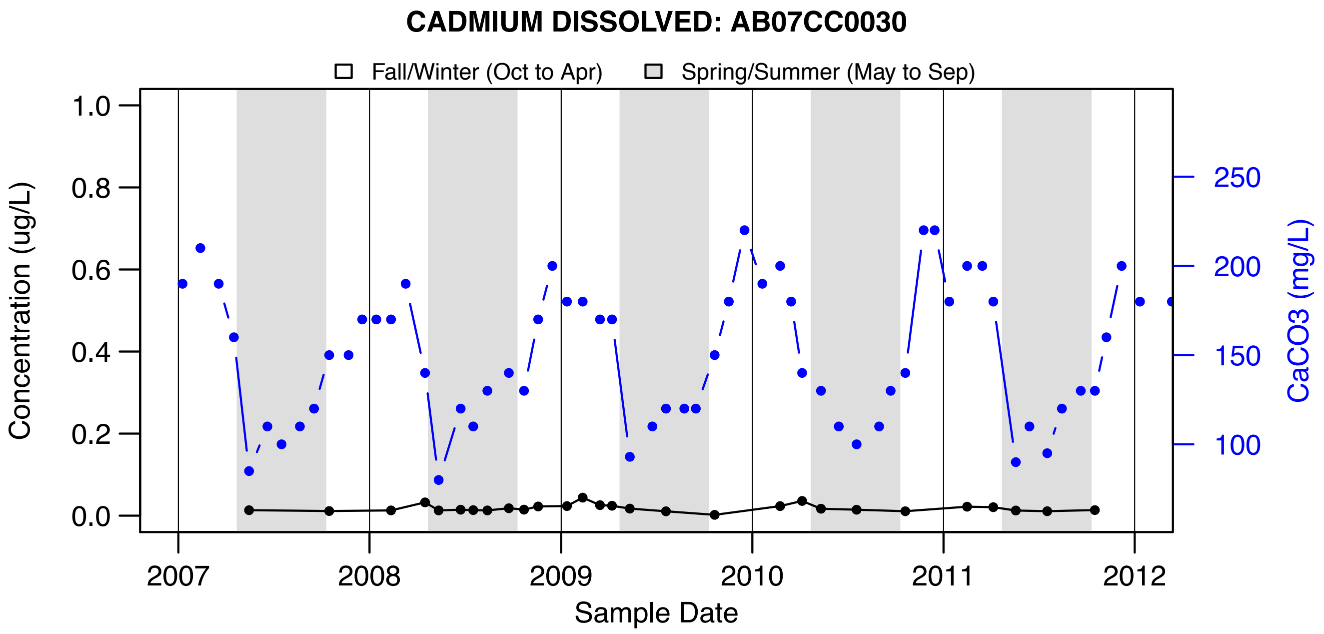
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A4.23: LEAD DISSOLVED: AB07BK0130 - AT CONFLUENCE WITH ATHABASCA RIVER ABOVE THE TOWN OF SMITH MOUTH: KM 794.0



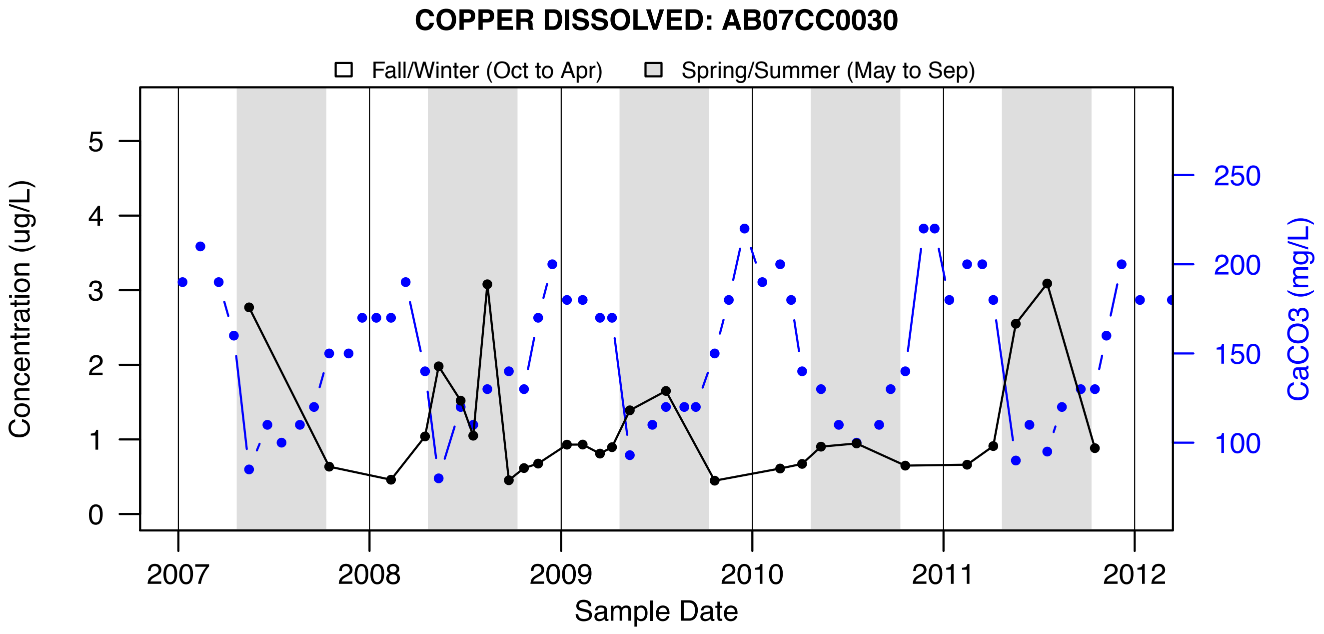
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.24: ALUMINUM DISSOLVED (AL): AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



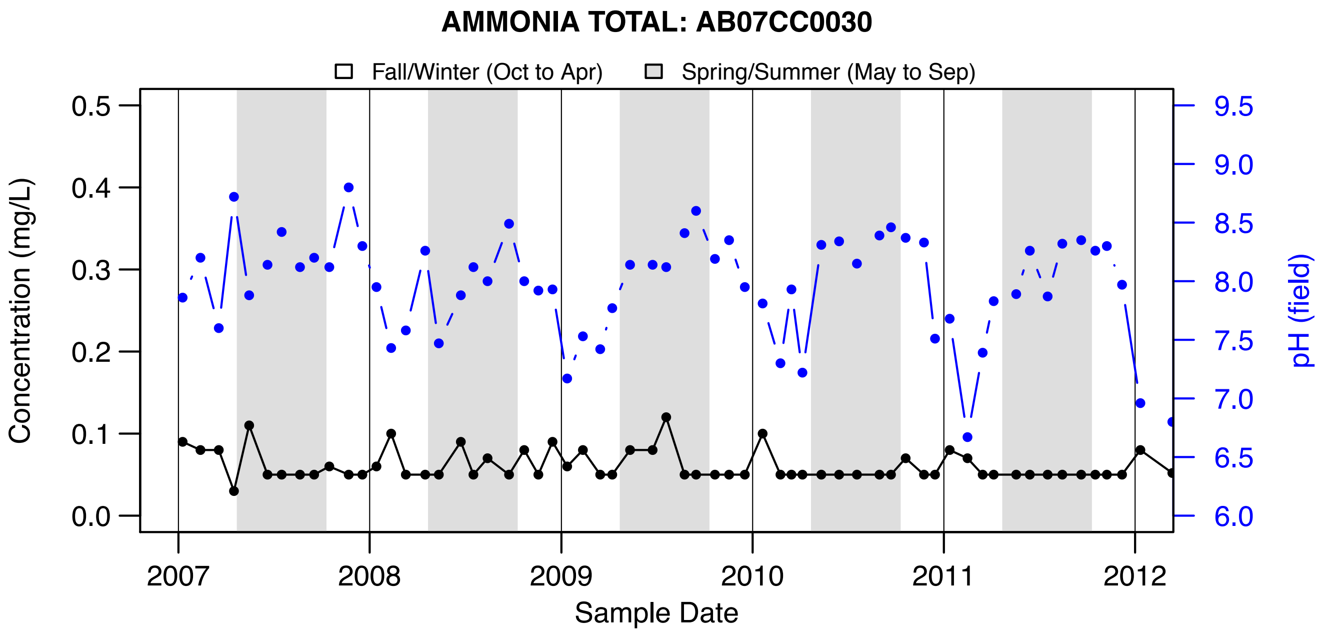
Related to hardness as CaCo3

Figure A4.25: CADMIUM DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



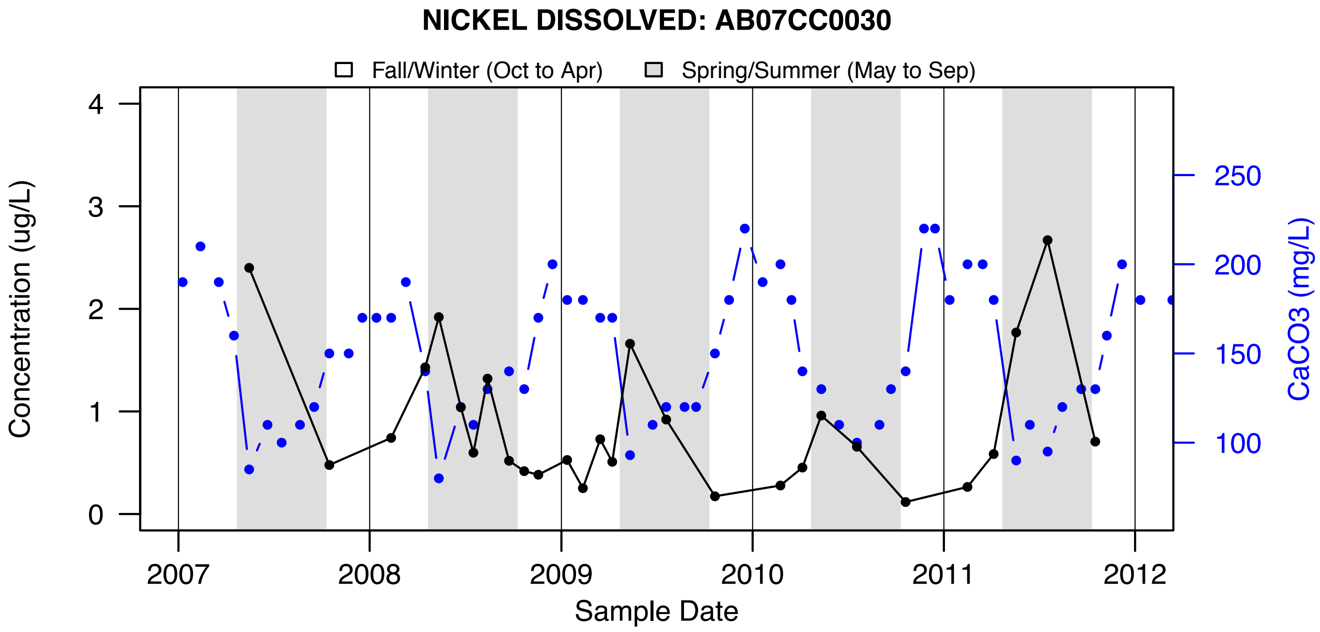
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.26: COPPER DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



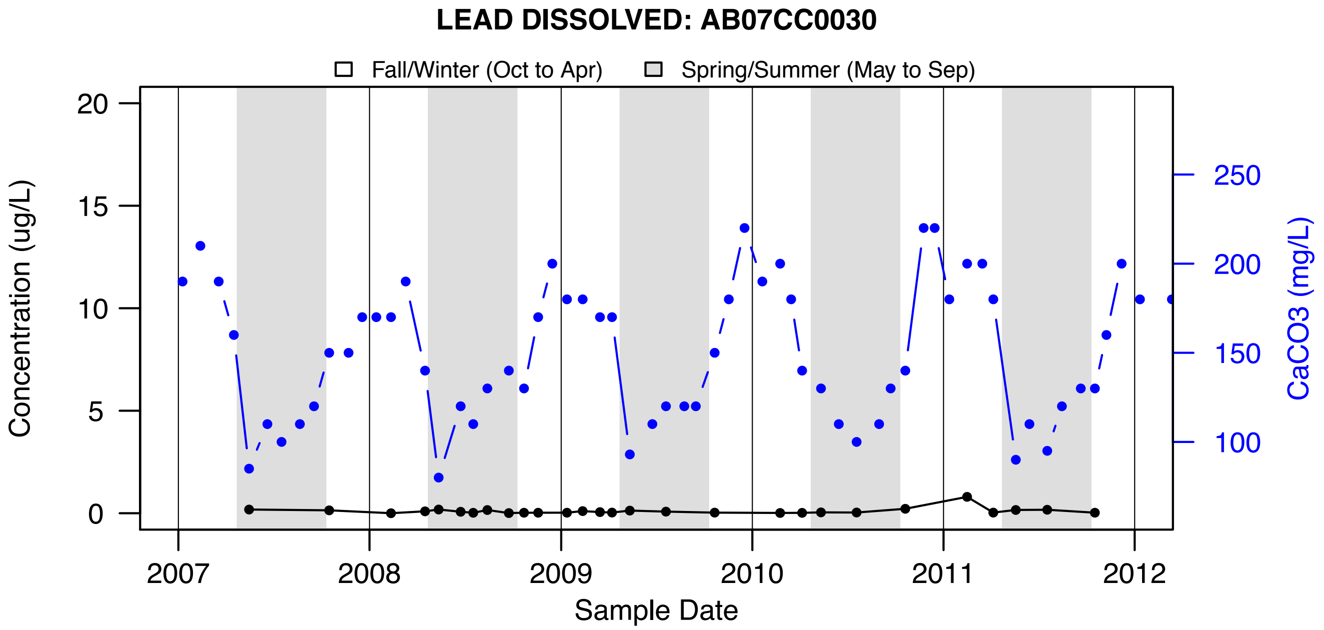
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.27: AMMONIA TOTAL: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



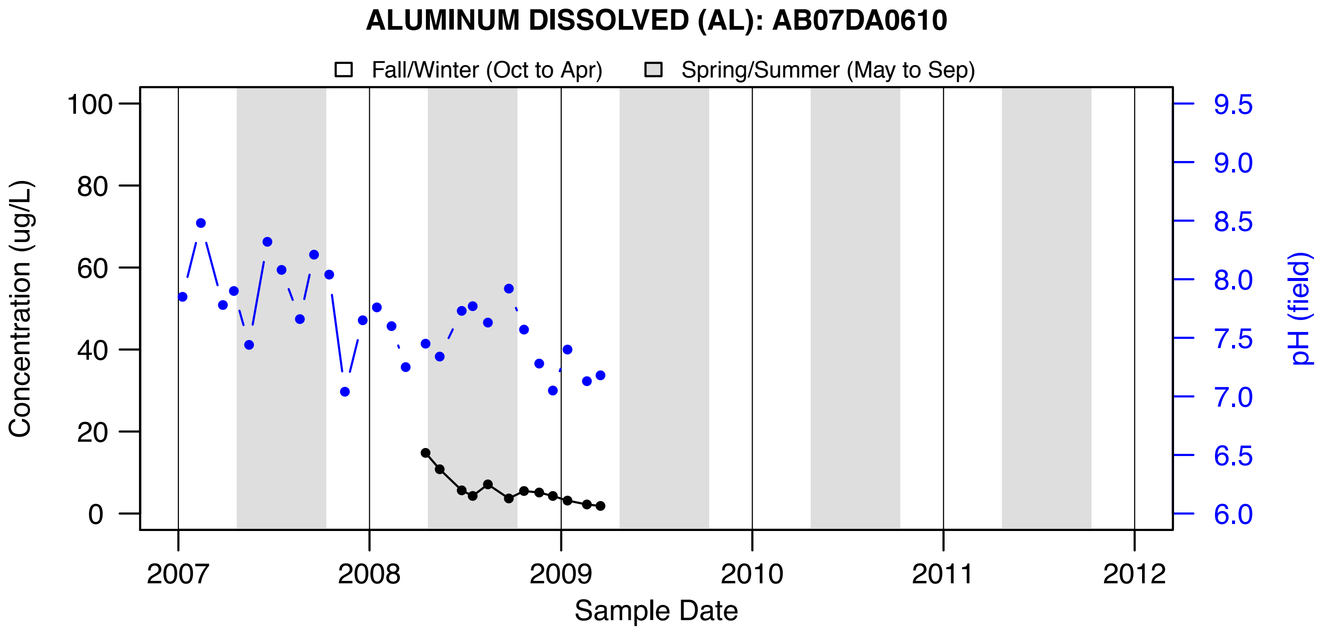
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.28: NICKEL DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



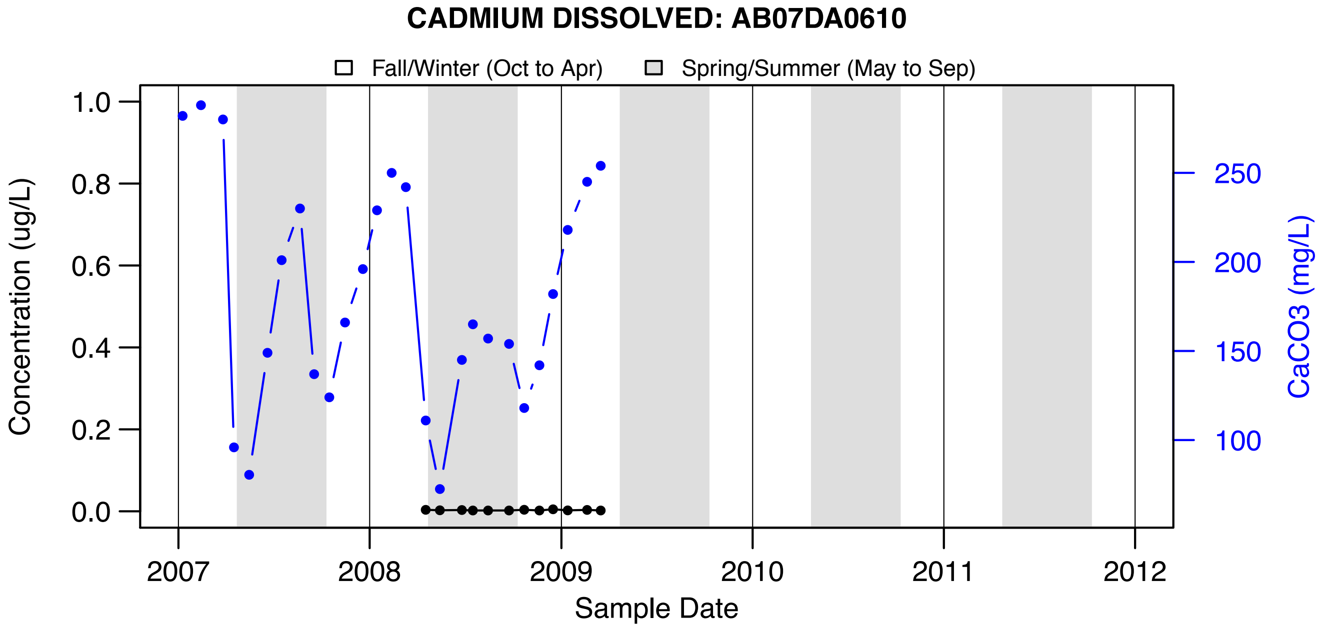
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L; 7 ug/L at [CaCO3] >180mg/L.

Figure A4.29: LEAD DISSOLVED: AB07CC0030 - U/S FORT MCMURRAY, 100 M ABOVE THE CONFLUENCE WITH HORSE RIVER - LEFT BANK



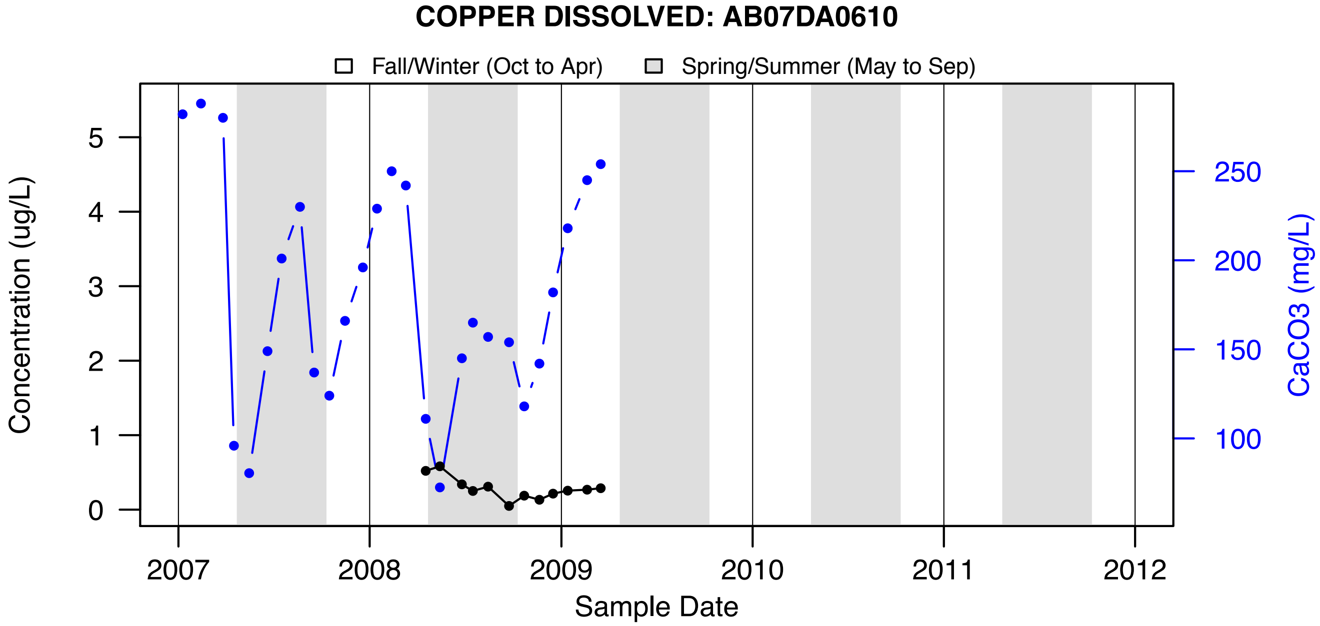
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.30: ALUMINUM DISSOLVED (AL): AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



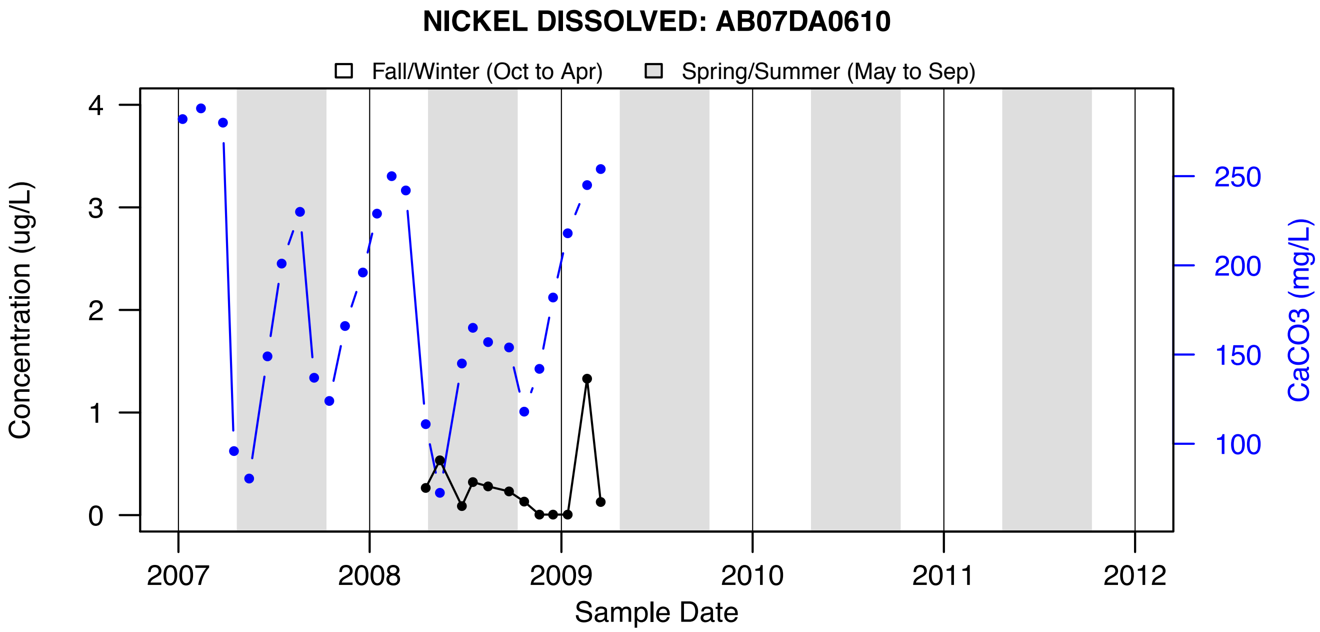
Related to hardness as CaCo3

Figure A4.31: CADMIUM DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



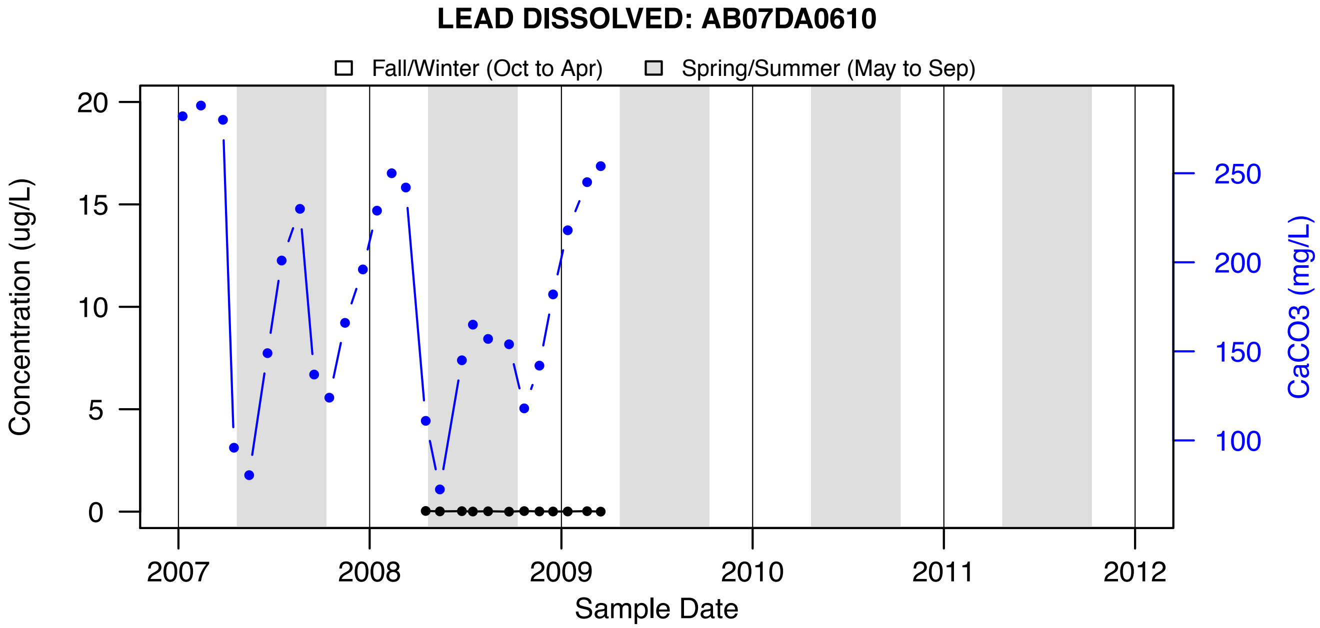
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid−extractable copper concentrations

Figure A4.32: COPPER DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



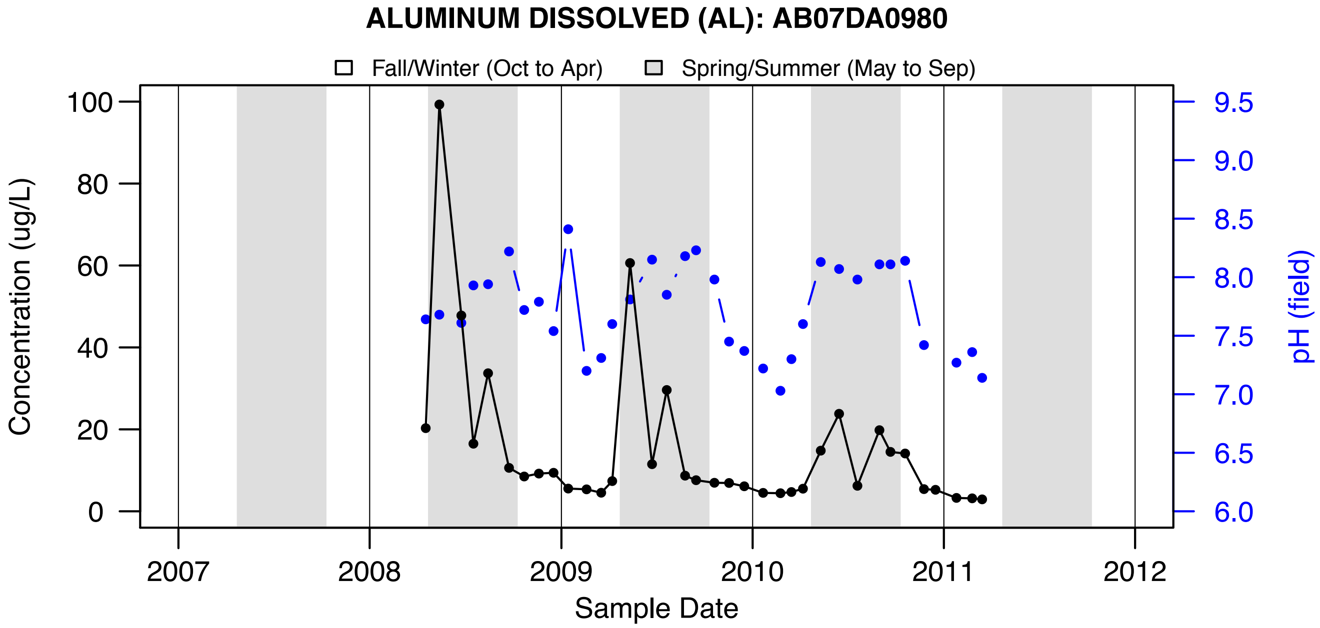
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.33: NICKEL DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



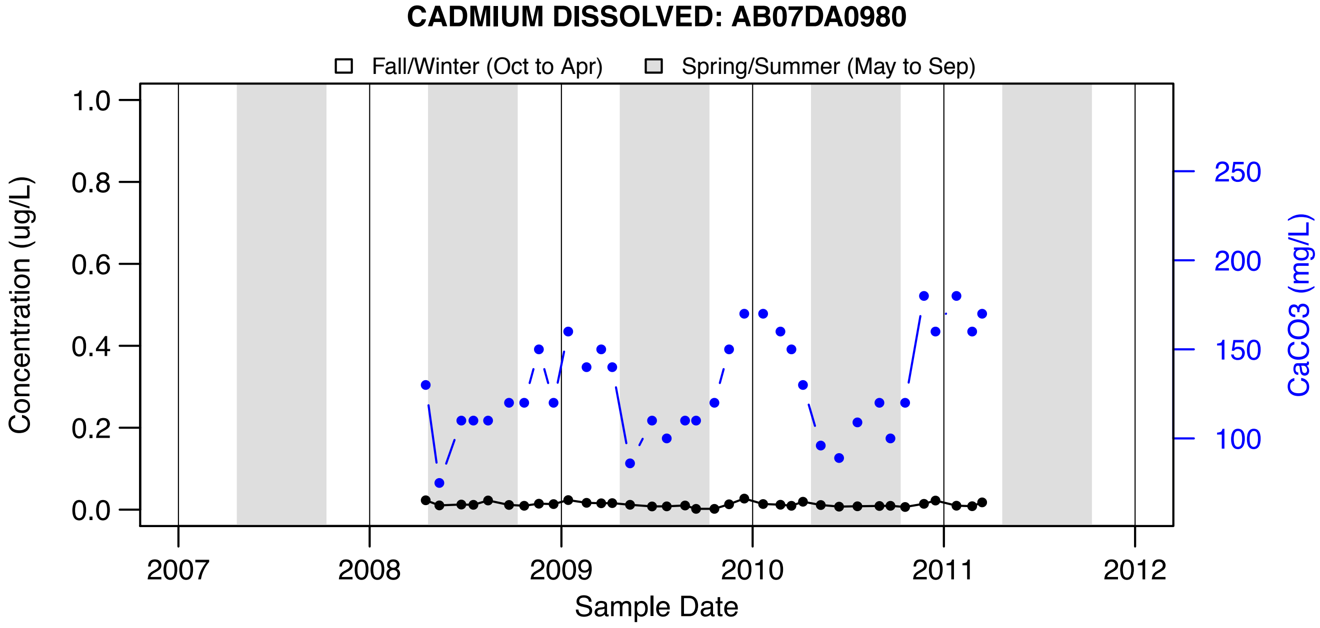
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.34: LEAD DISSOLVED: AB07DA0610 - AT WSC GAUGE D/S OF KEARL LAKE ROAD



CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.35: ALUMINUM DISSOLVED (AL): AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



Related to hardness as CaCo3

Figure A4.36: CADMIUM DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

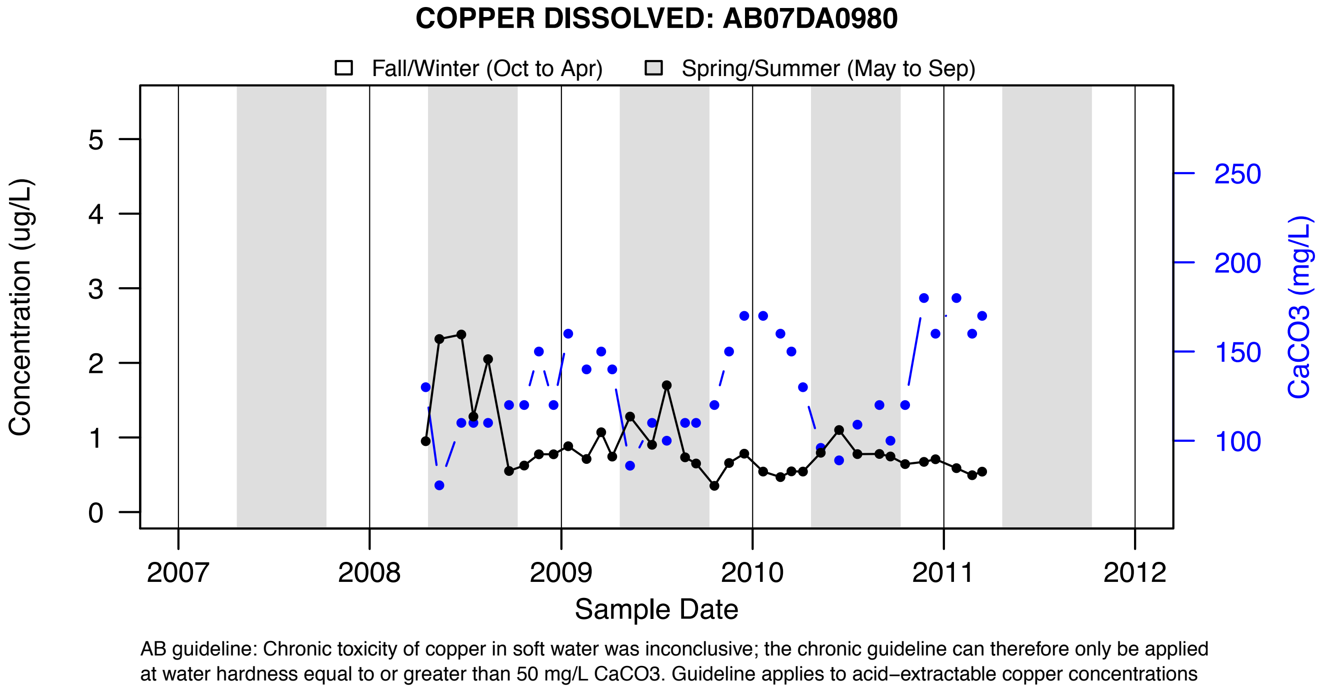


Figure A4.37: COPPER DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER

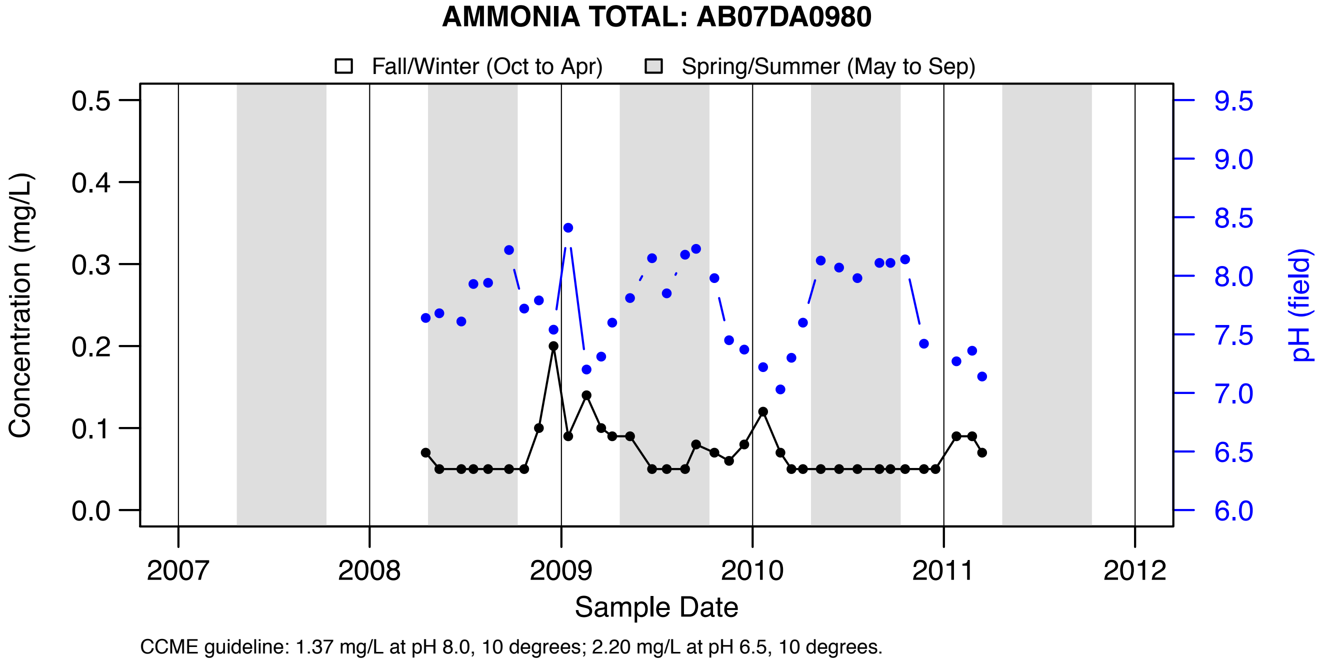
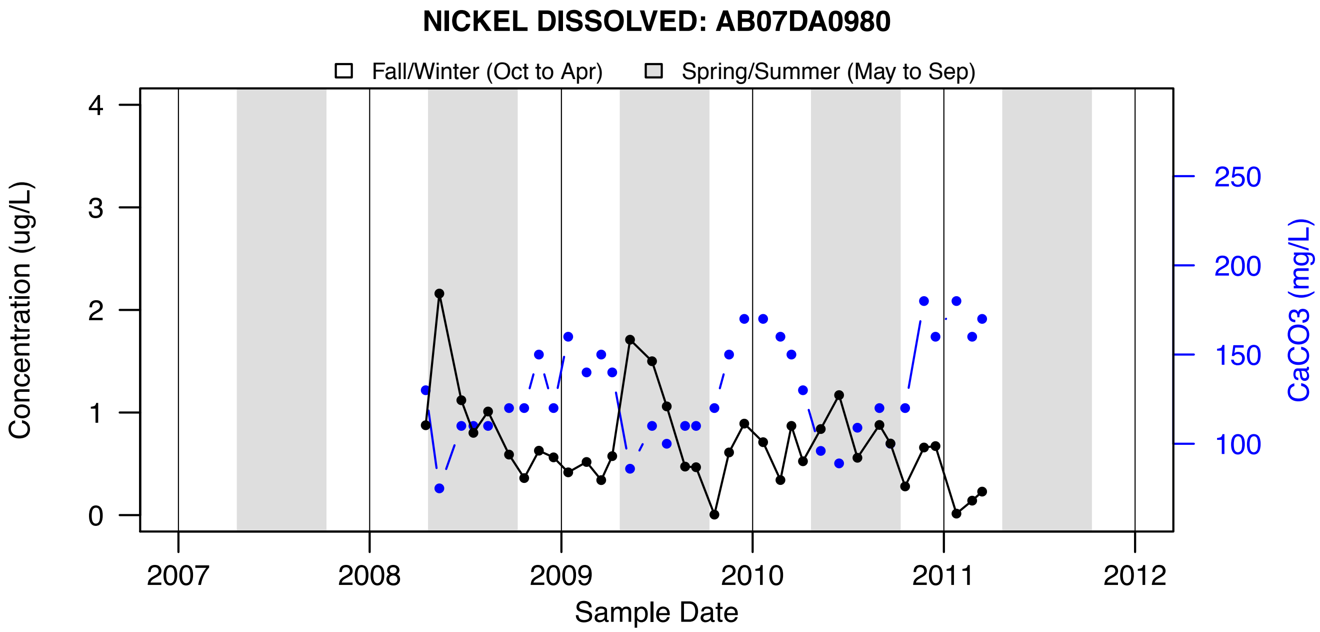
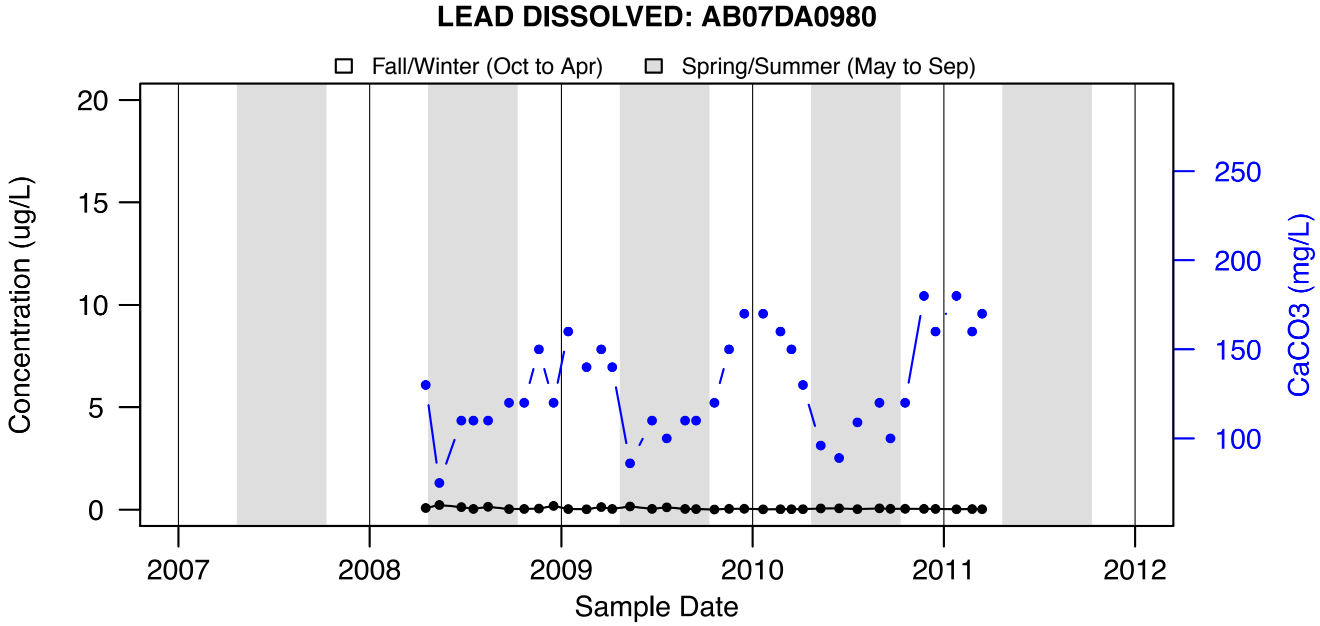


Figure A4.38: AMMONIA TOTAL: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



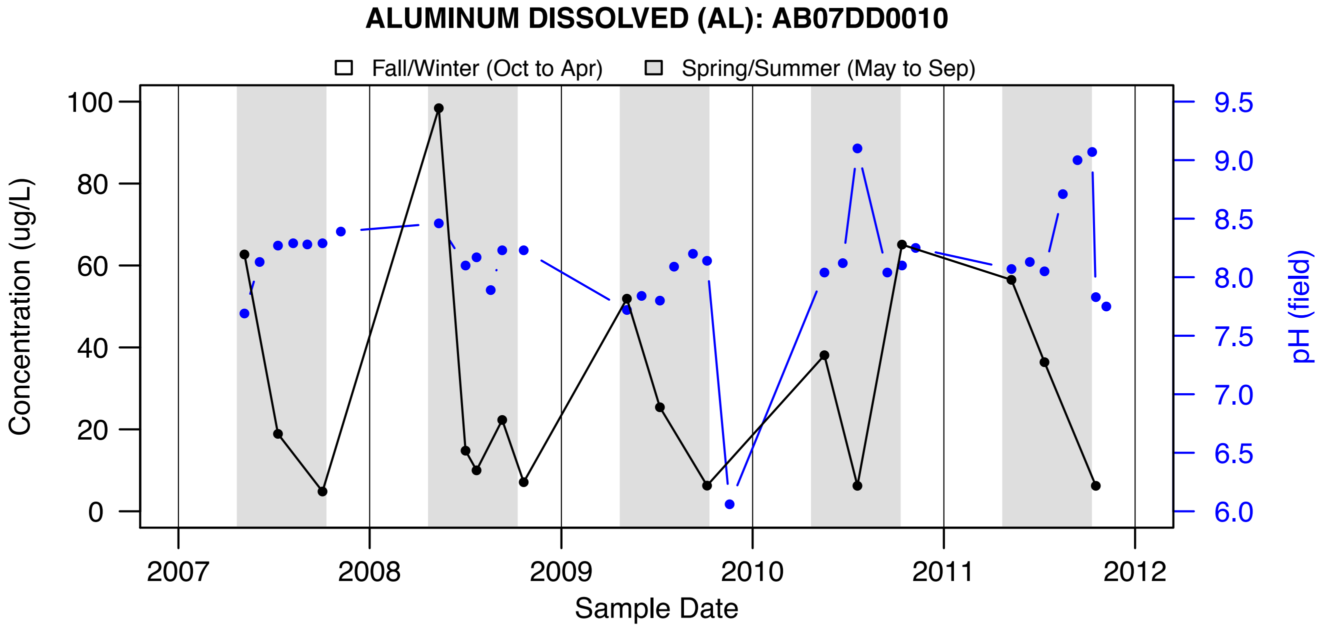
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.39: NICKEL DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



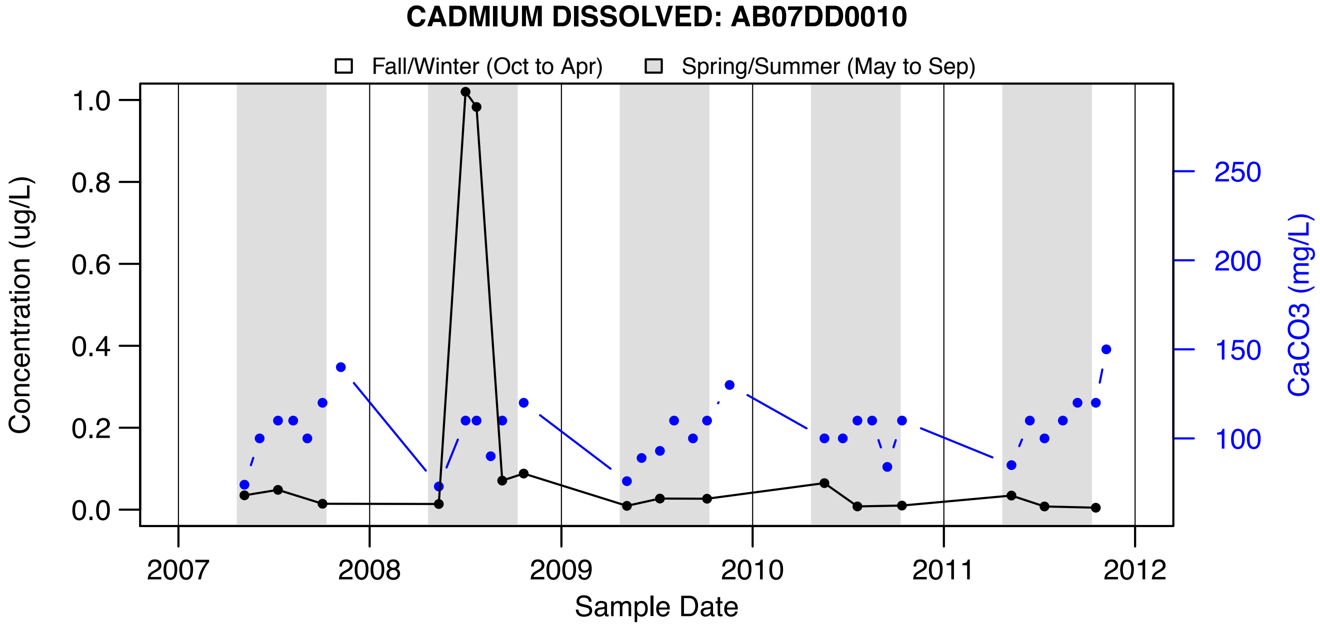
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.40: LEAD DISSOLVED: AB07DA0980 - TRANSECT ABOVE THE FIREBAG RIVER



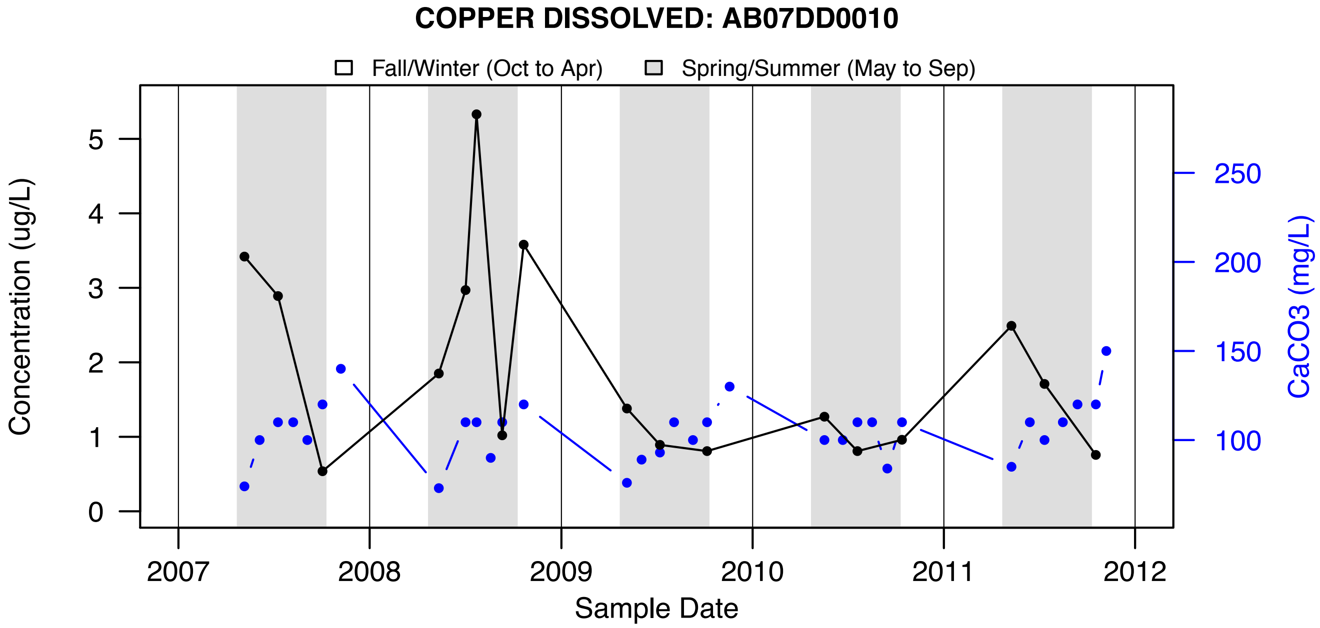
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.41: ALUMINUM DISSOLVED (AL): AB07DD0010 - AT OLD FORT - RIGHT BANK



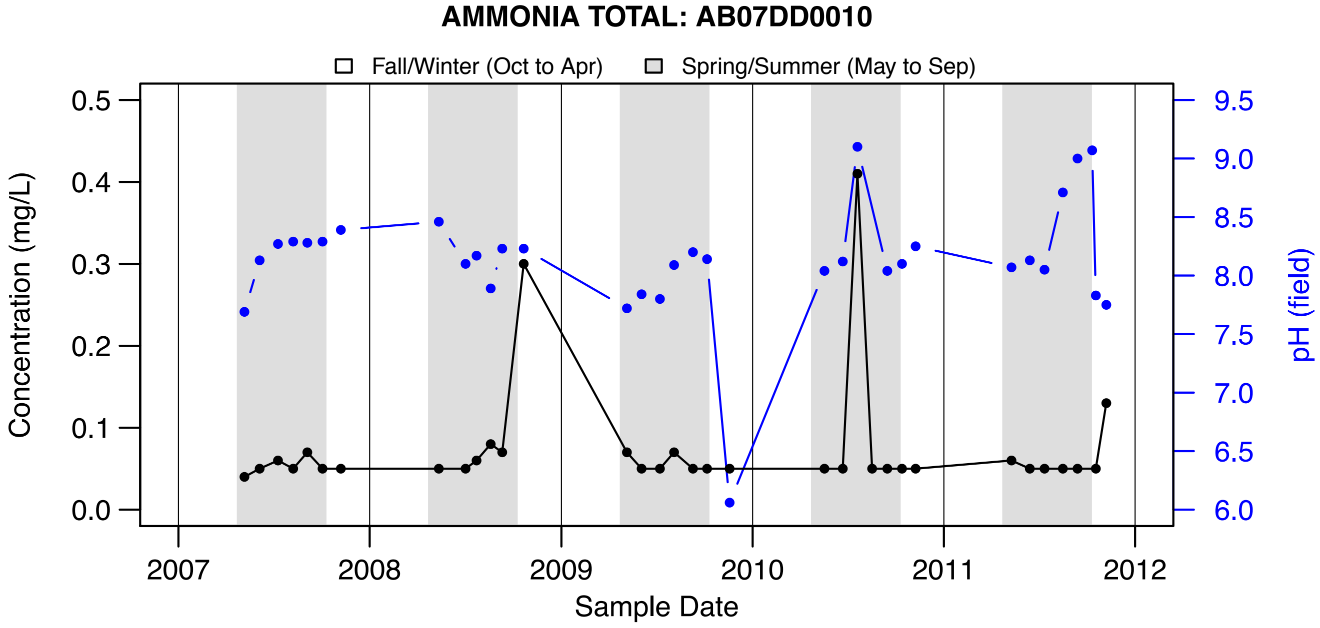
Related to hardness as CaCo3

Figure A4.42: CADMIUM DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK



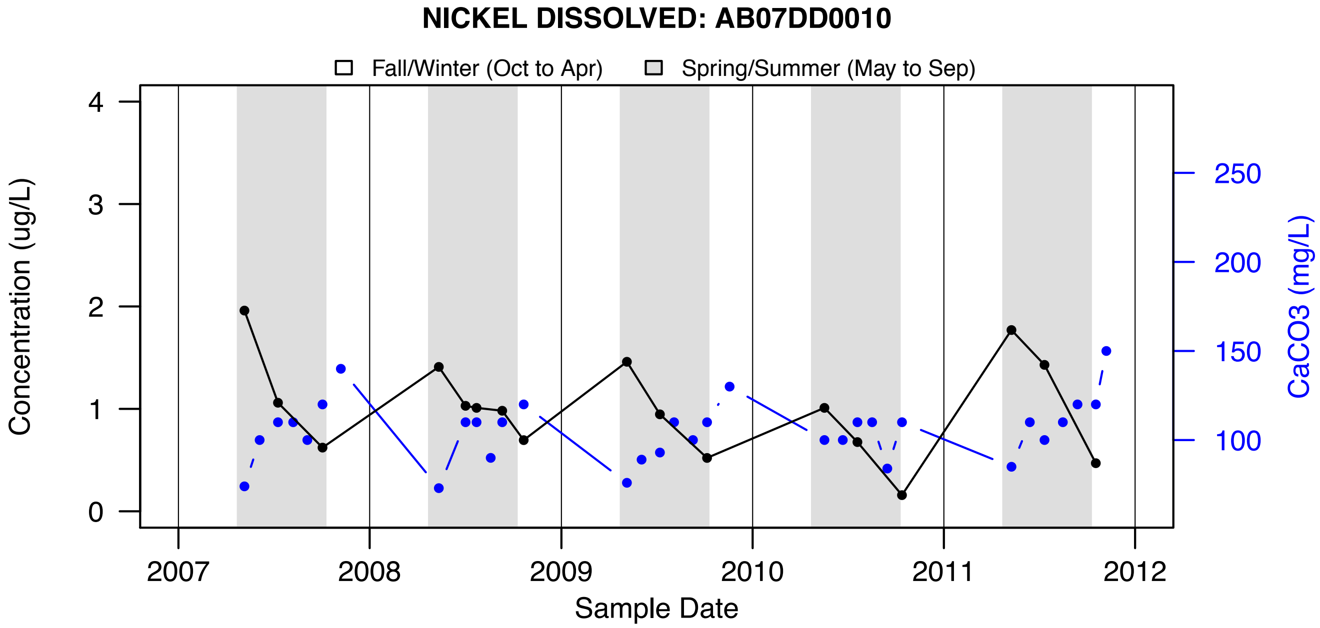
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid−extractable copper concentrations

Figure A4.43: COPPER DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK



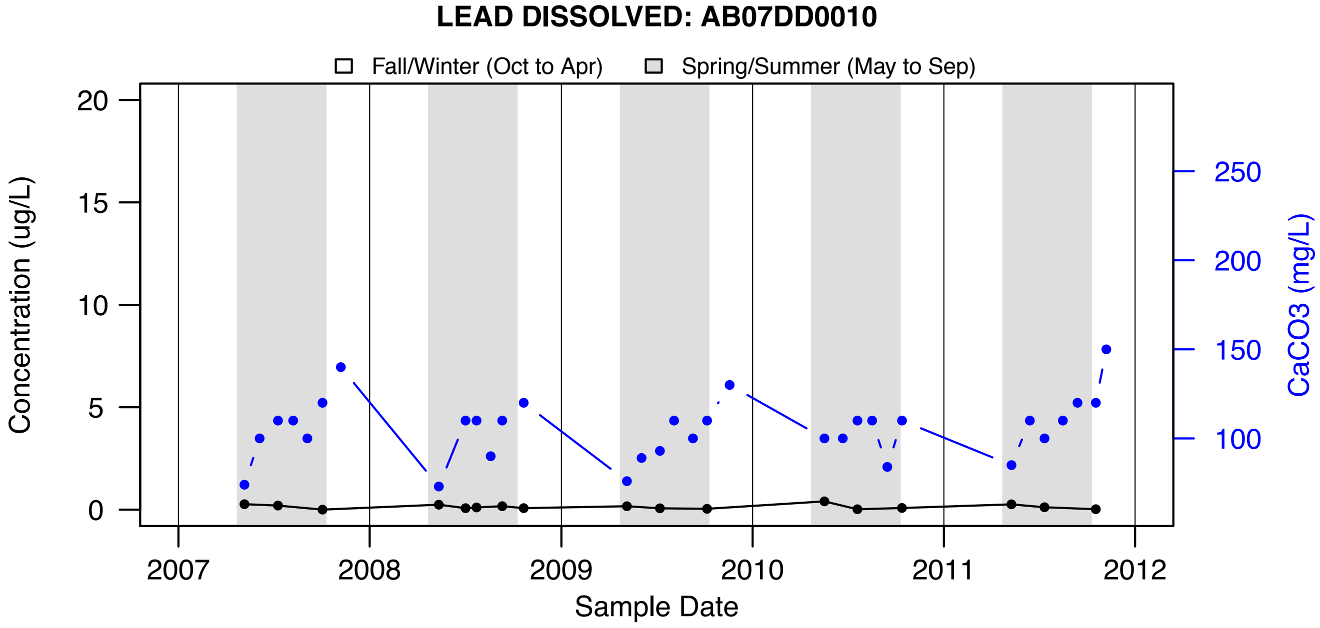
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.44: AMMONIA TOTAL: AB07DD0010 - AT OLD FORT - RIGHT BANK



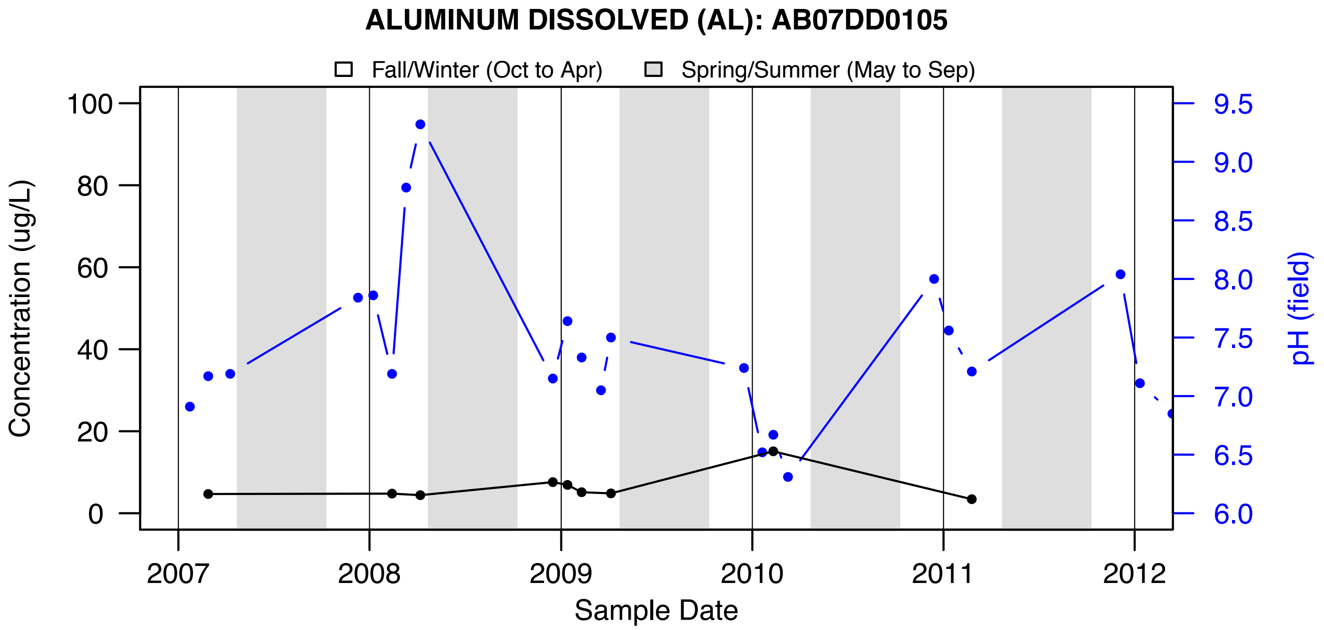
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.45: NICKEL DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK



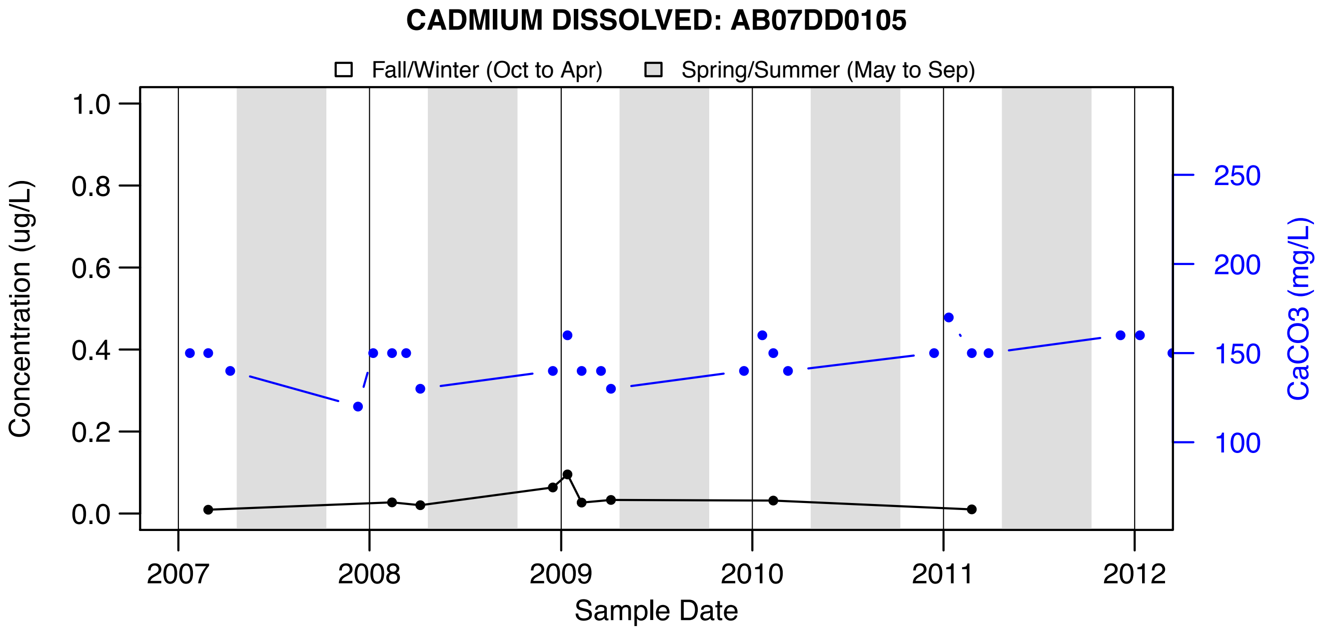
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.46: LEAD DISSOLVED: AB07DD0010 - AT OLD FORT - RIGHT BANK



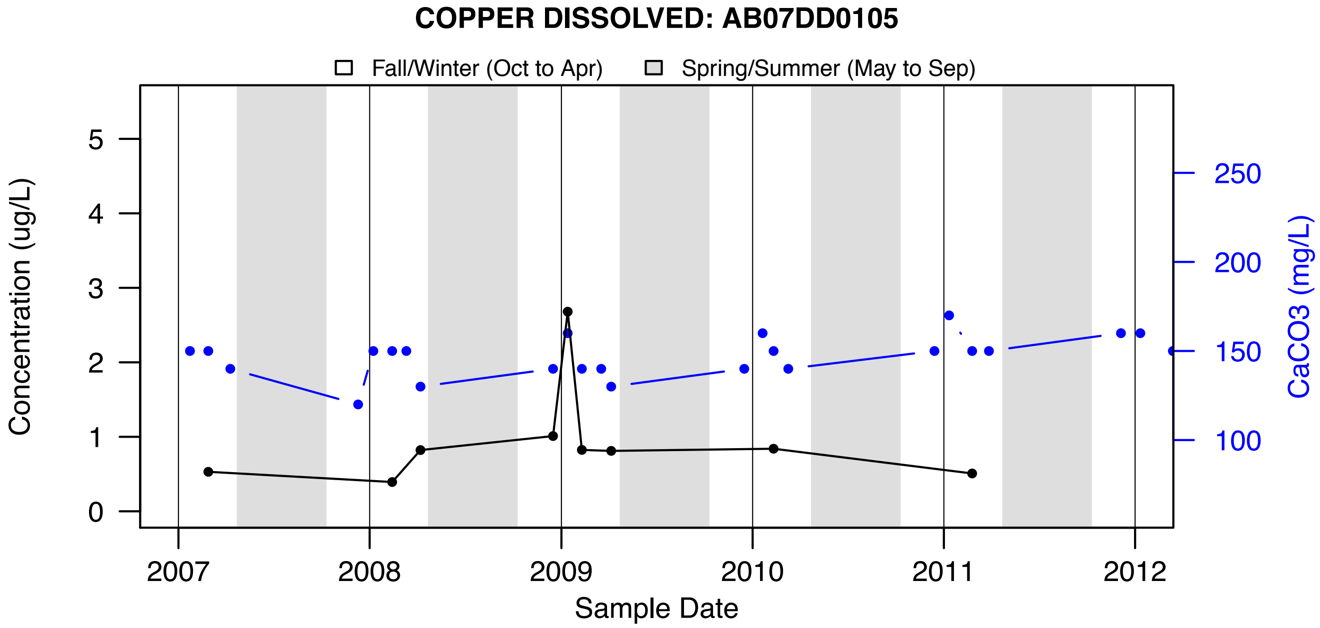
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.47: ALUMINUM DISSOLVED (AL): AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



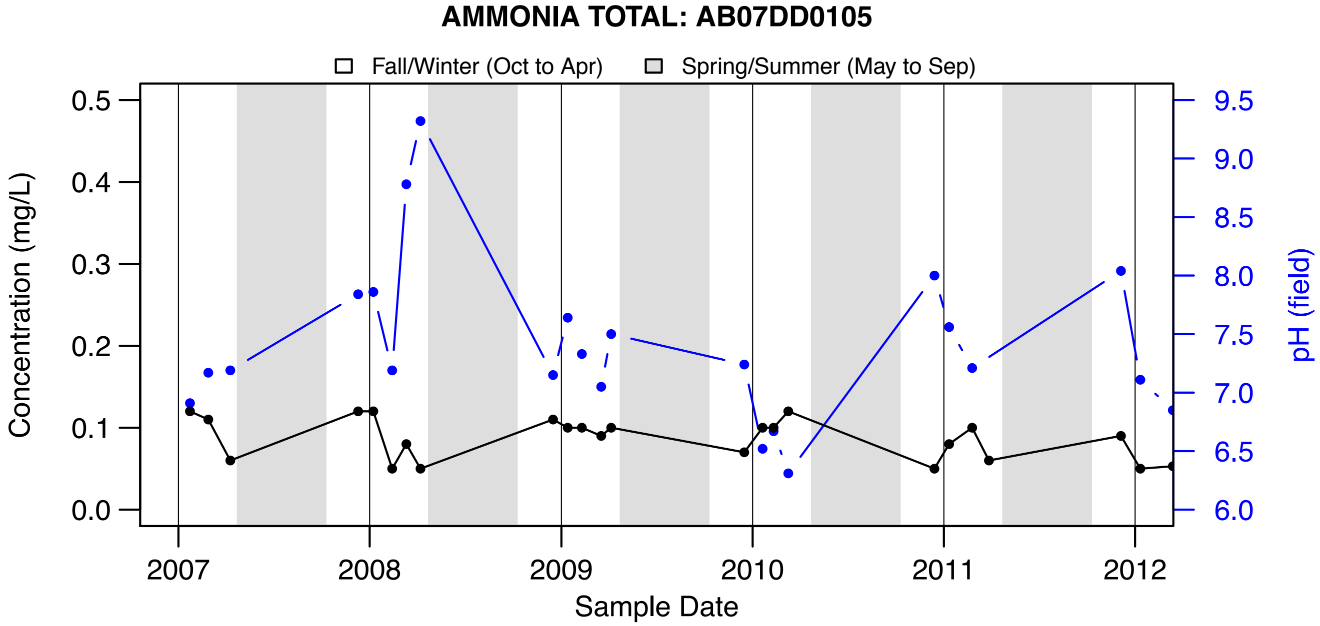
Related to hardness as CaCo3

Figure A4.48: CADMIUM DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



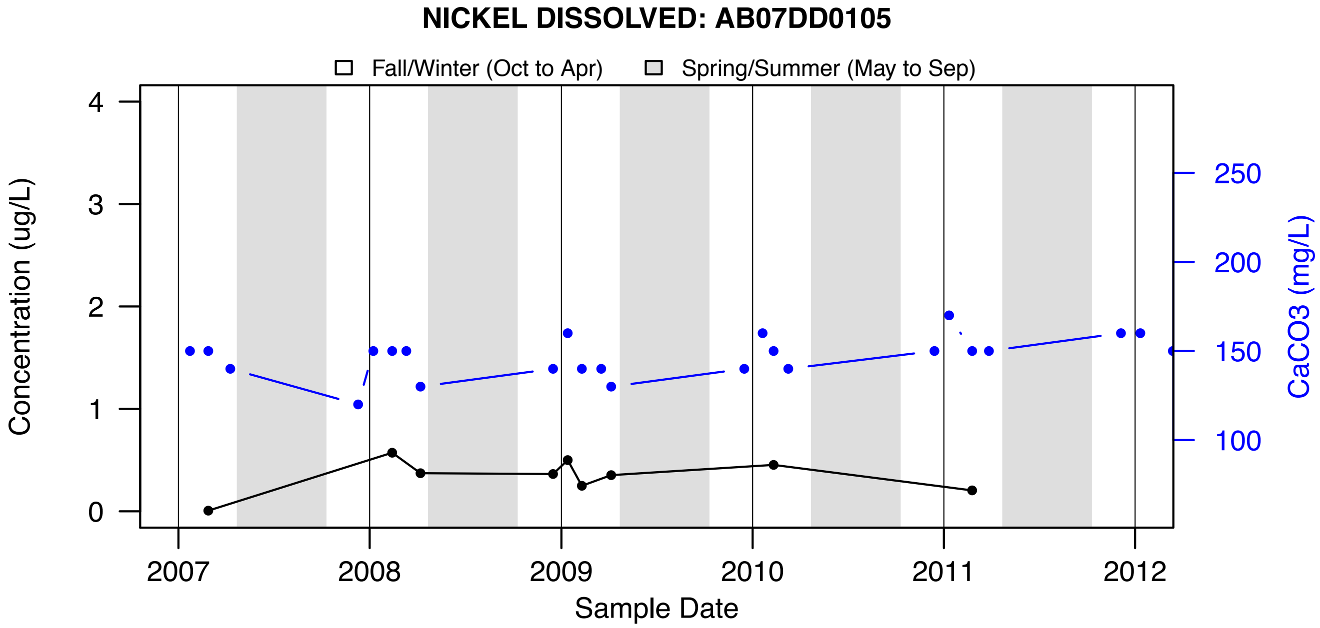
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid−extractable copper concentrations

Figure A4.49: COPPER DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



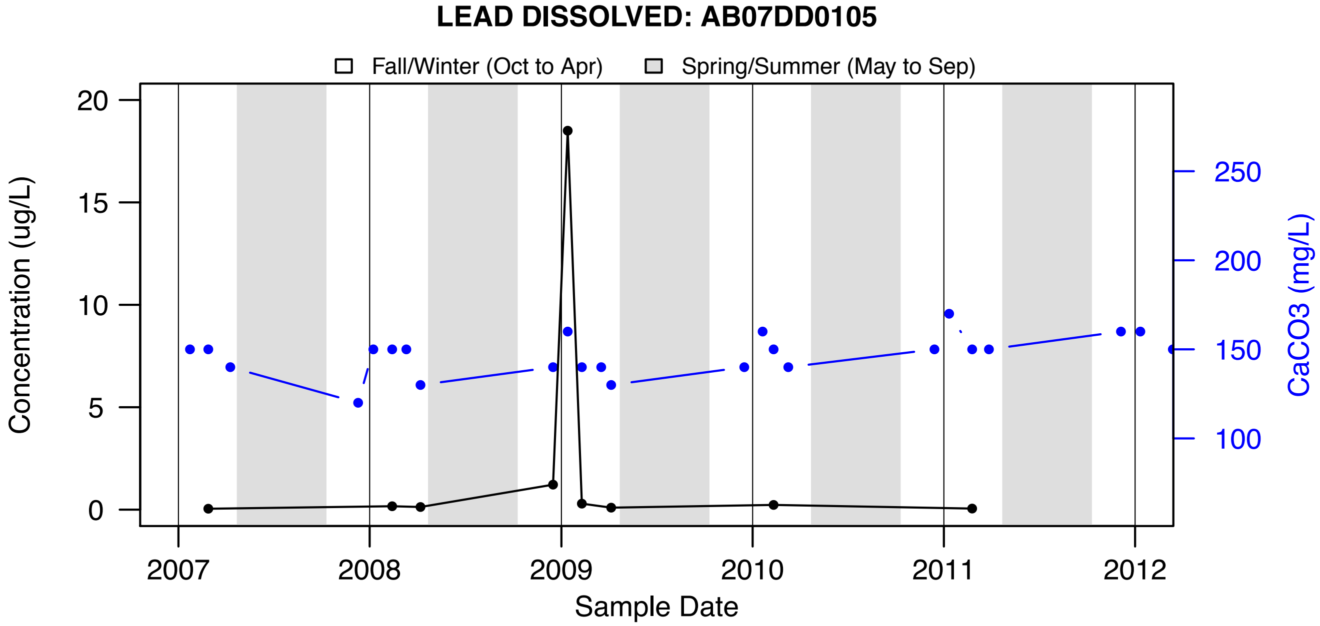
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.50: AMMONIA TOTAL: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



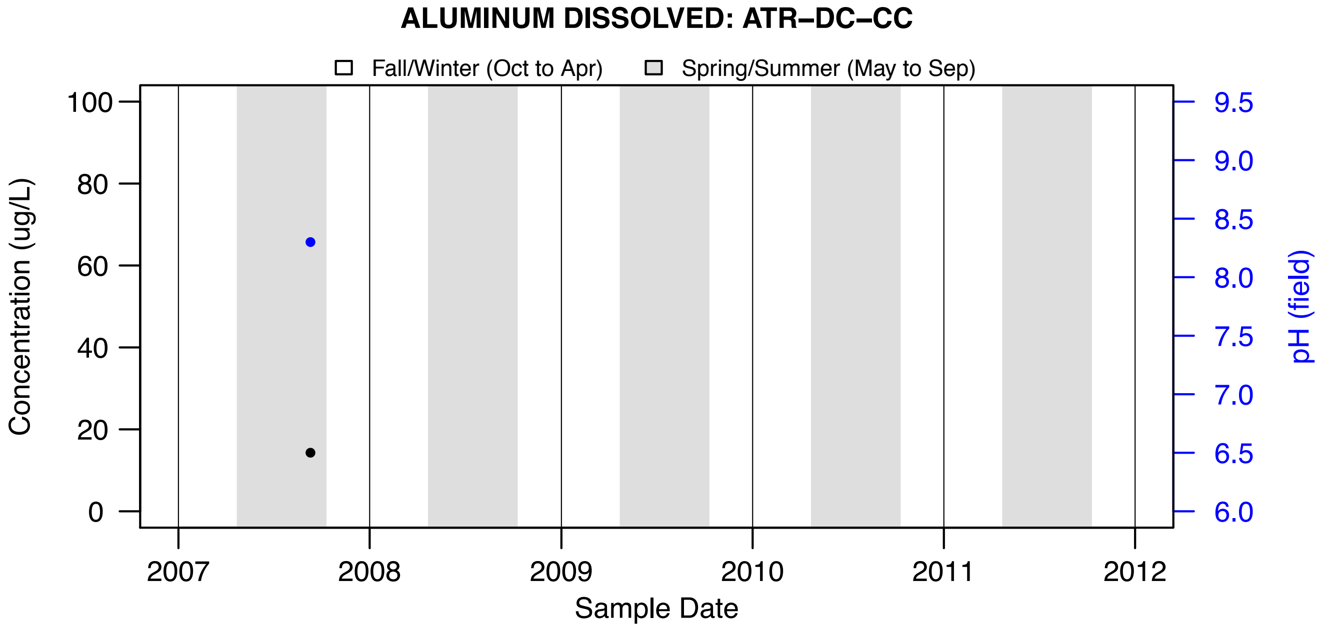
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.51: NICKEL DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



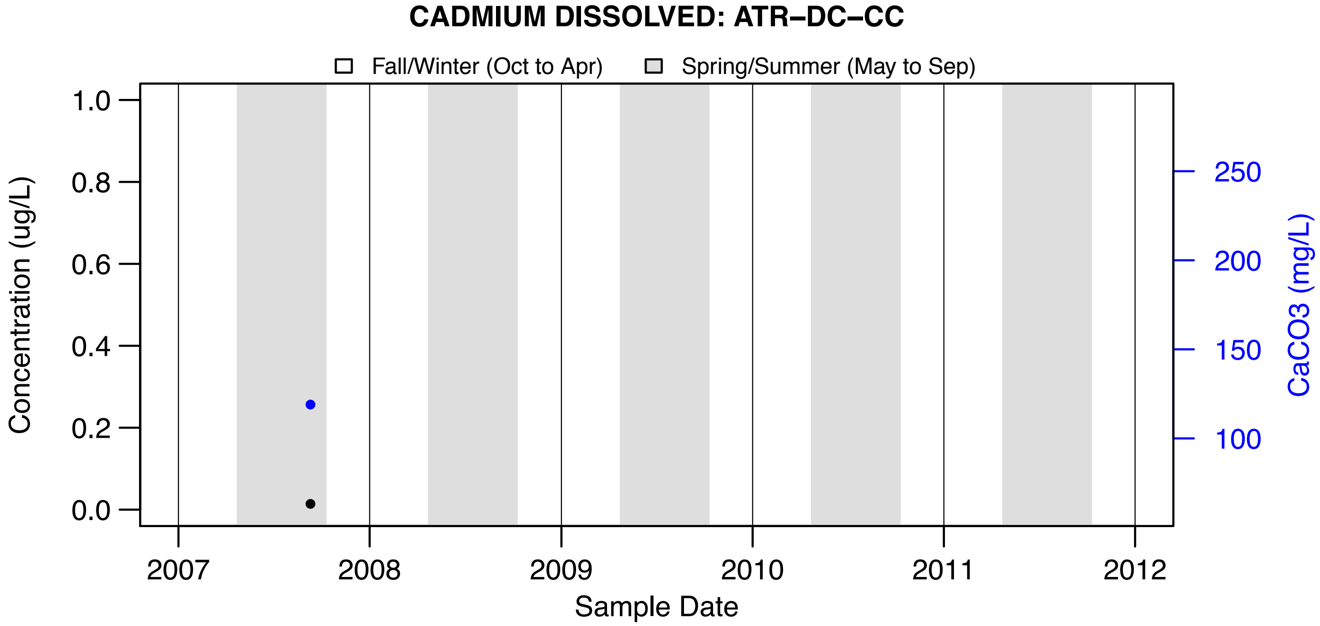
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.52: LEAD DISSOLVED: AB07DD0105 - D/S OF DEVILS ELBOW AT WINTER ROAD CROSSING



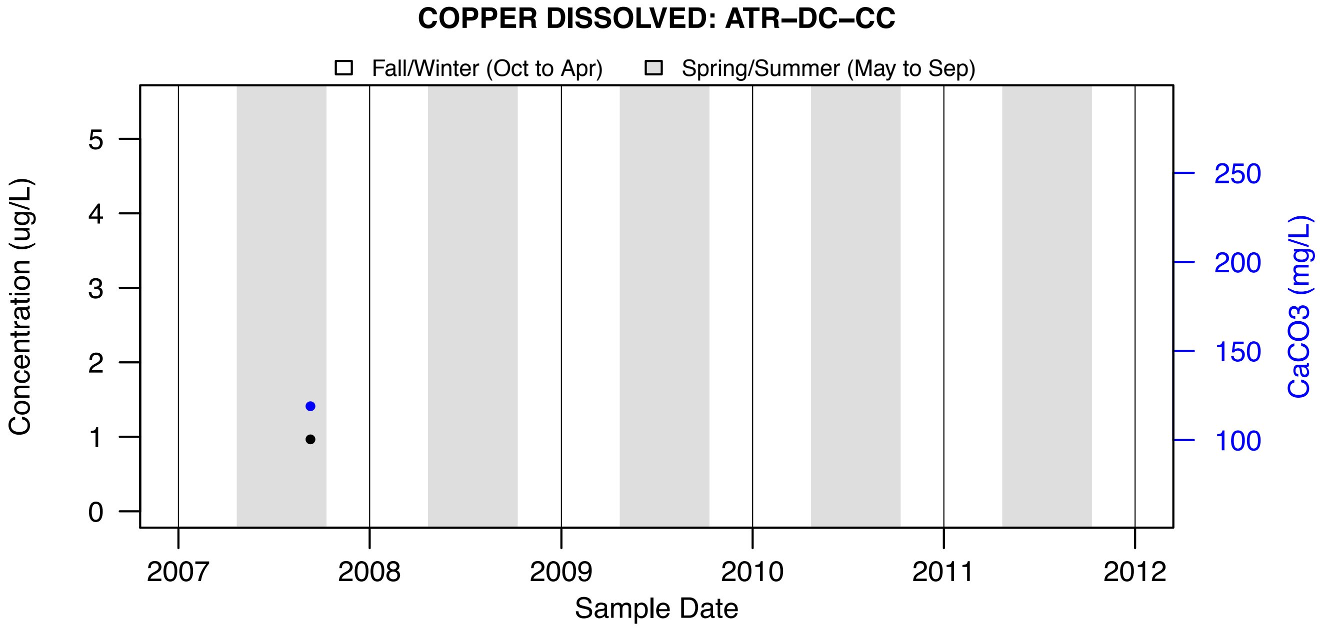
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.53: ALUMINUM DISSOLVED: ATR-DC-CC - NA



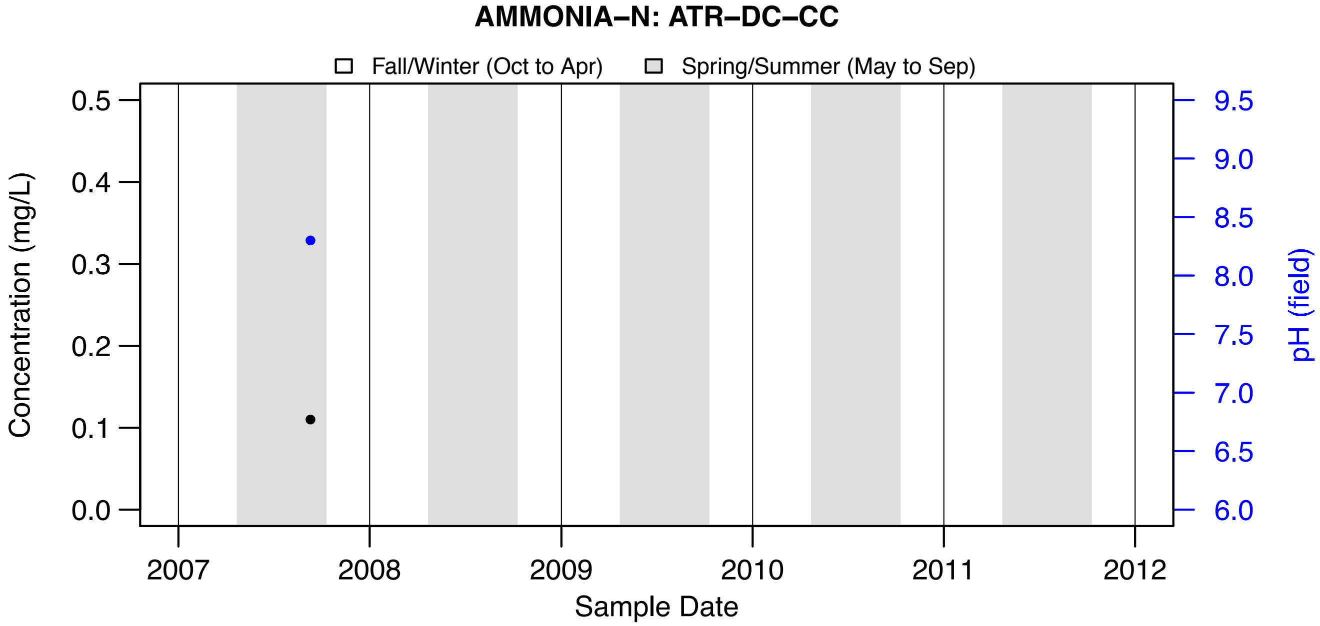
Related to hardness as CaCo3

Figure A4.54: CADMIUM DISSOLVED: ATR-DC-CC - NA



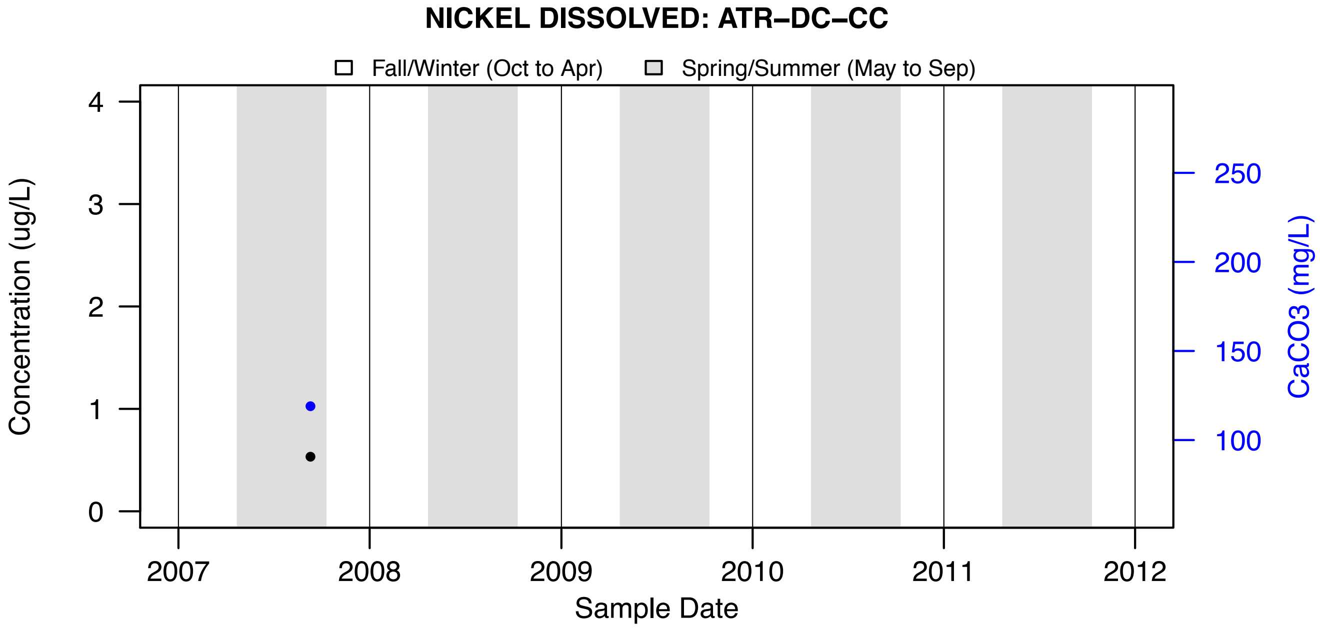
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.55: COPPER DISSOLVED: ATR-DC-CC - NA



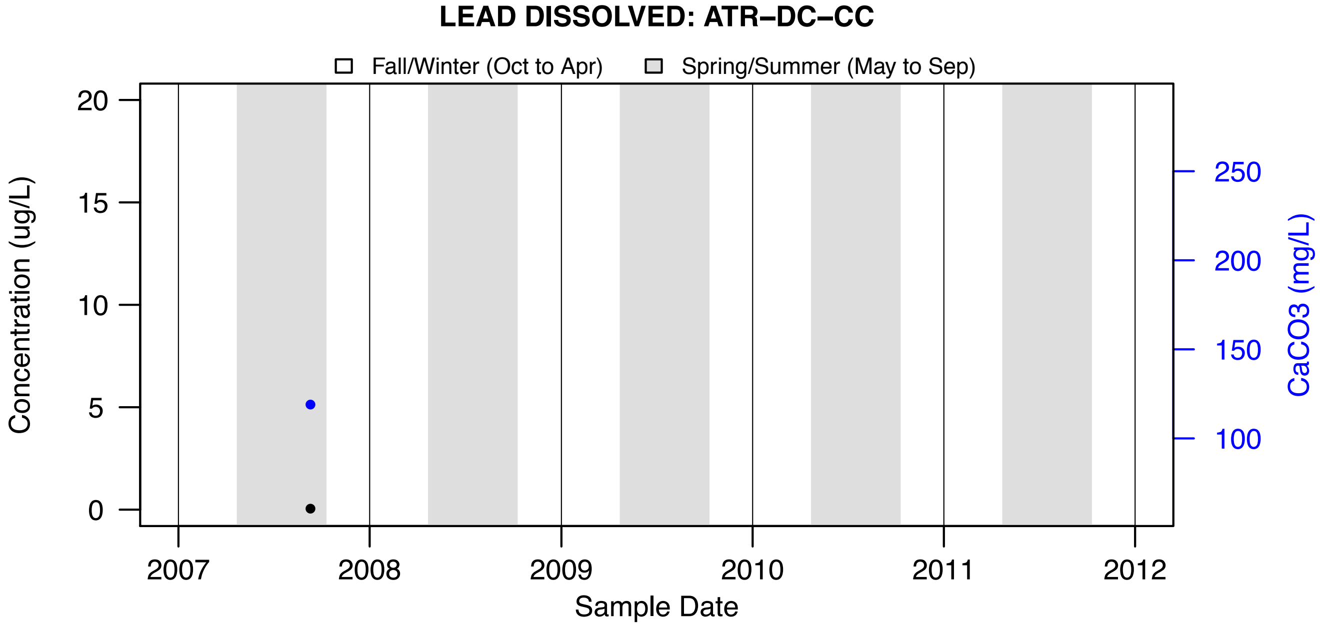
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.56: AMMONIA-N: ATR-DC-CC - NA



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.57: NICKEL DISSOLVED: ATR-DC-CC - NA



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.58: LEAD DISSOLVED: ATR-DC-CC - NA

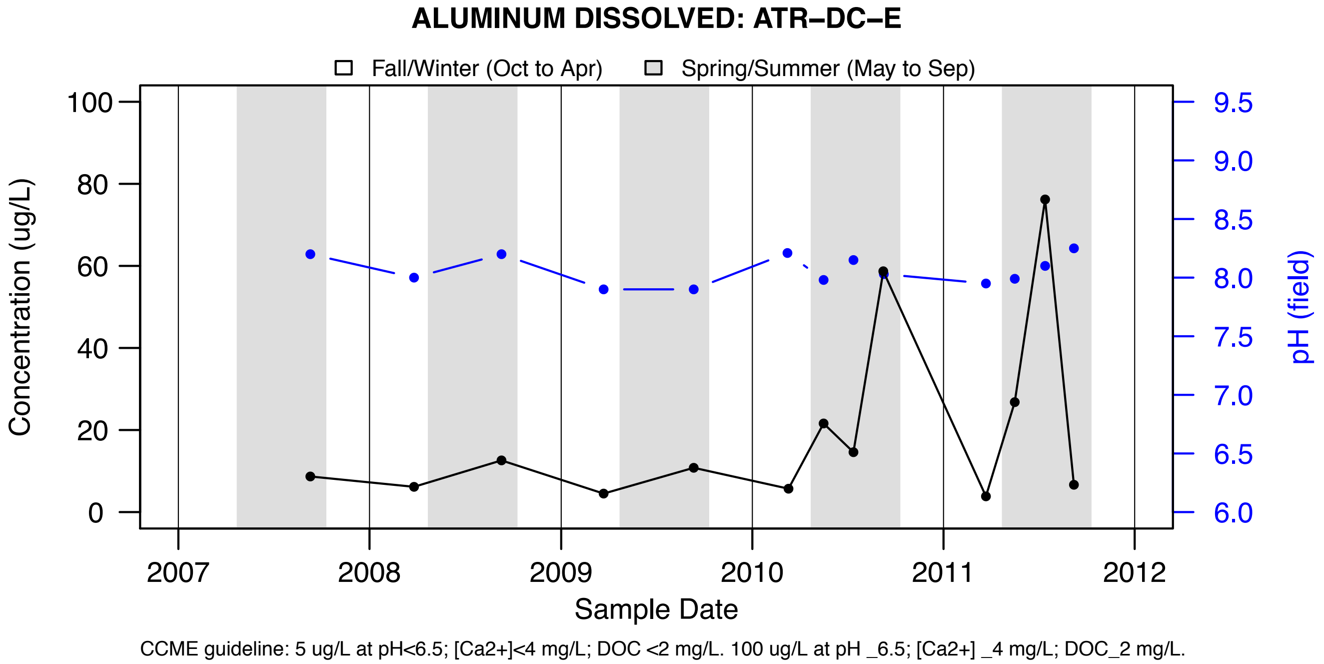


Figure A4.59: ALUMINUM DISSOLVED: ATR-DC-E - NA

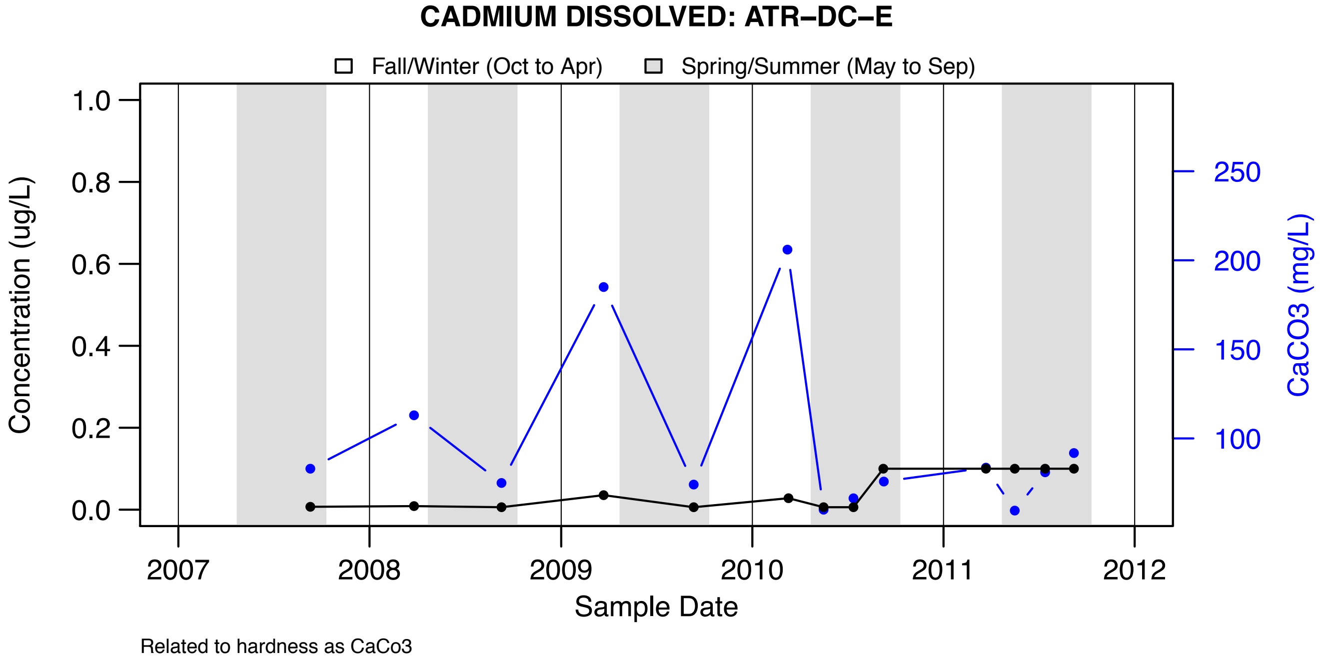
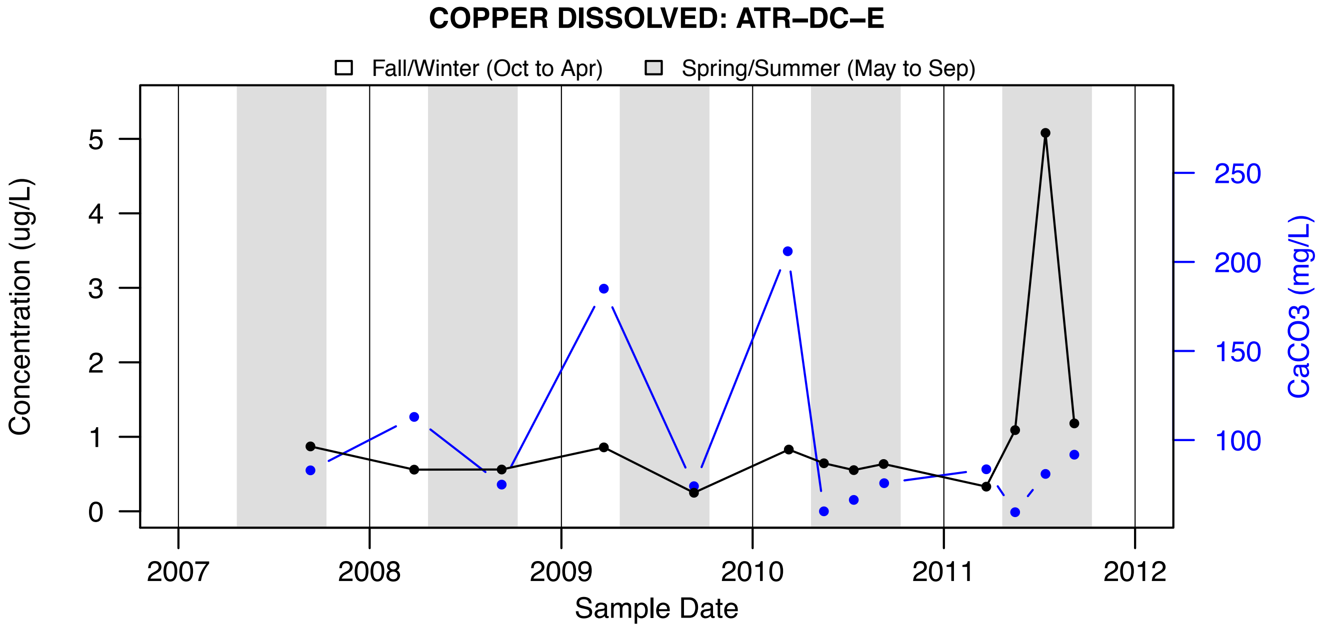
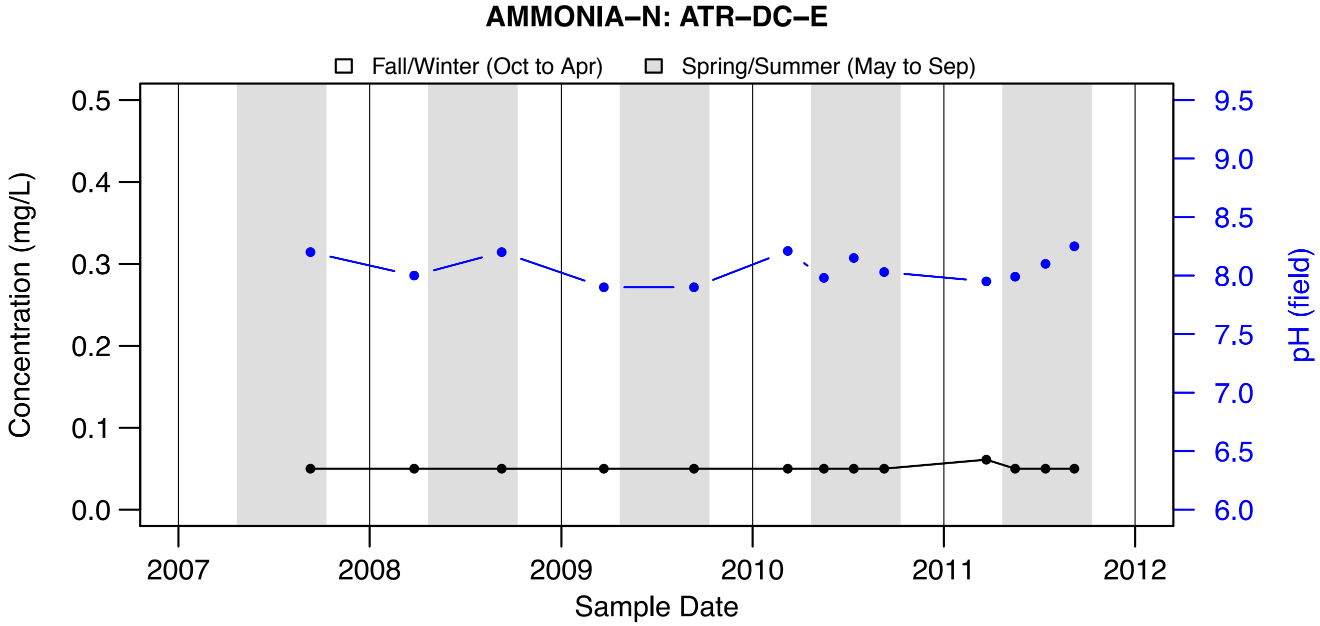


Figure A4.60: CADMIUM DISSOLVED: ATR-DC-E - NA



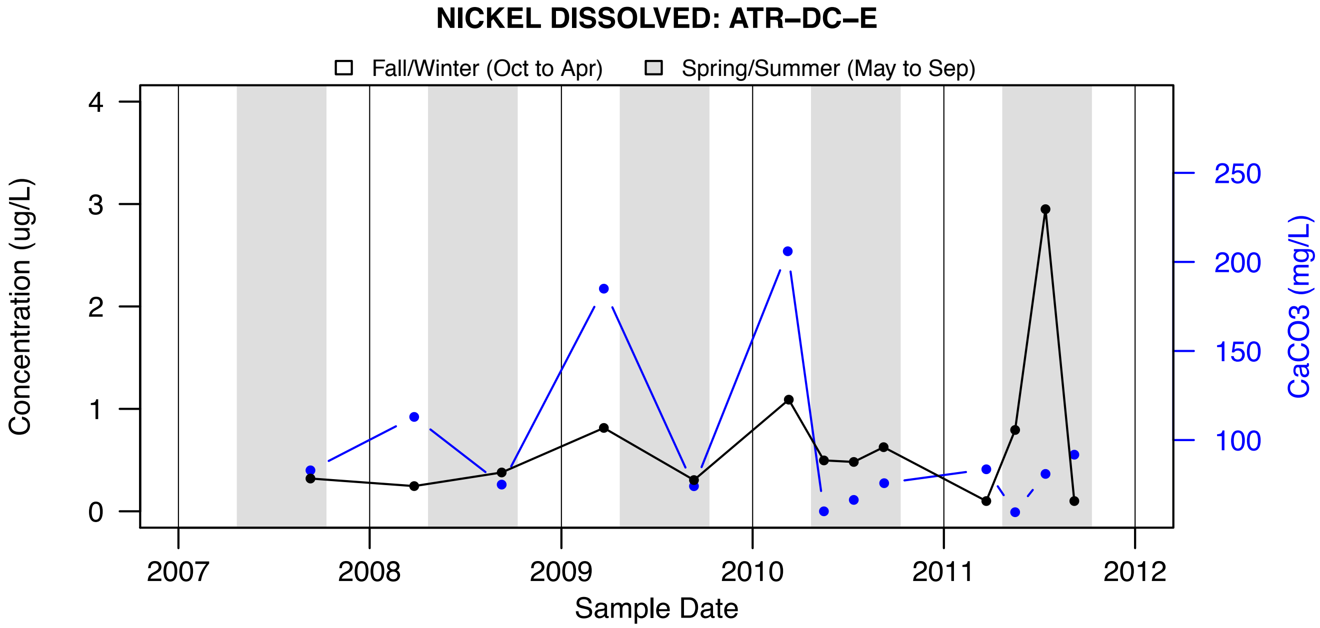
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.61: COPPER DISSOLVED: ATR-DC-E - NA



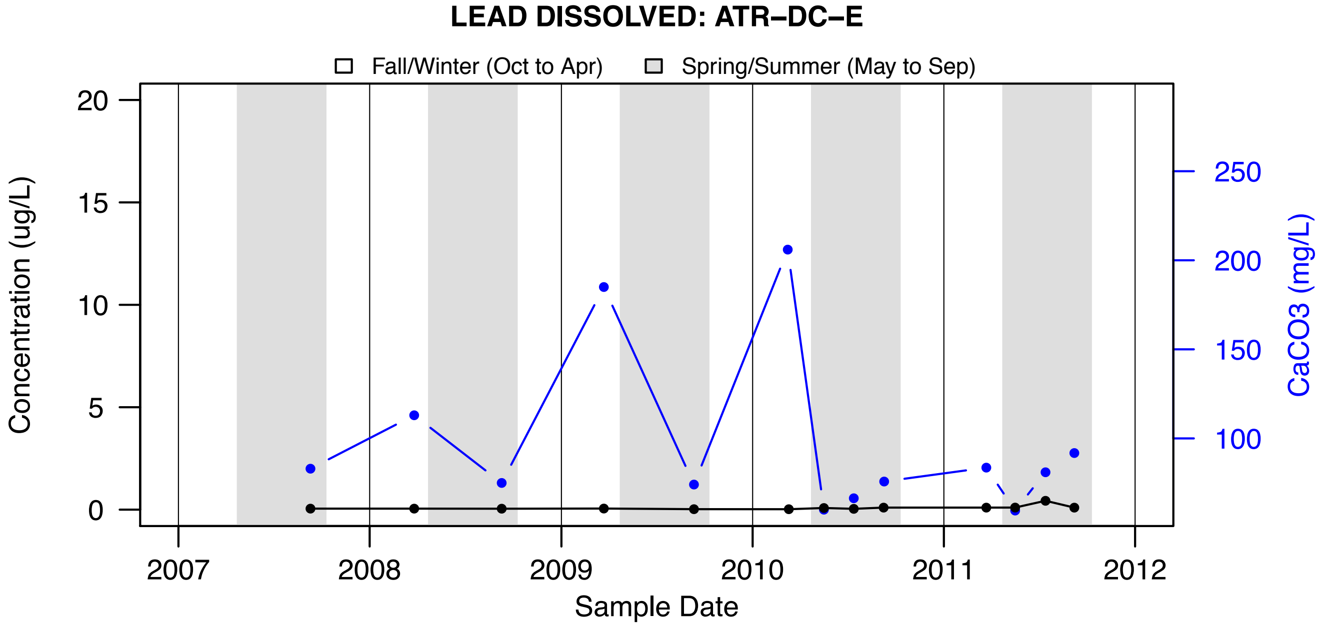
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.62: AMMONIA-N: ATR-DC-E - NA



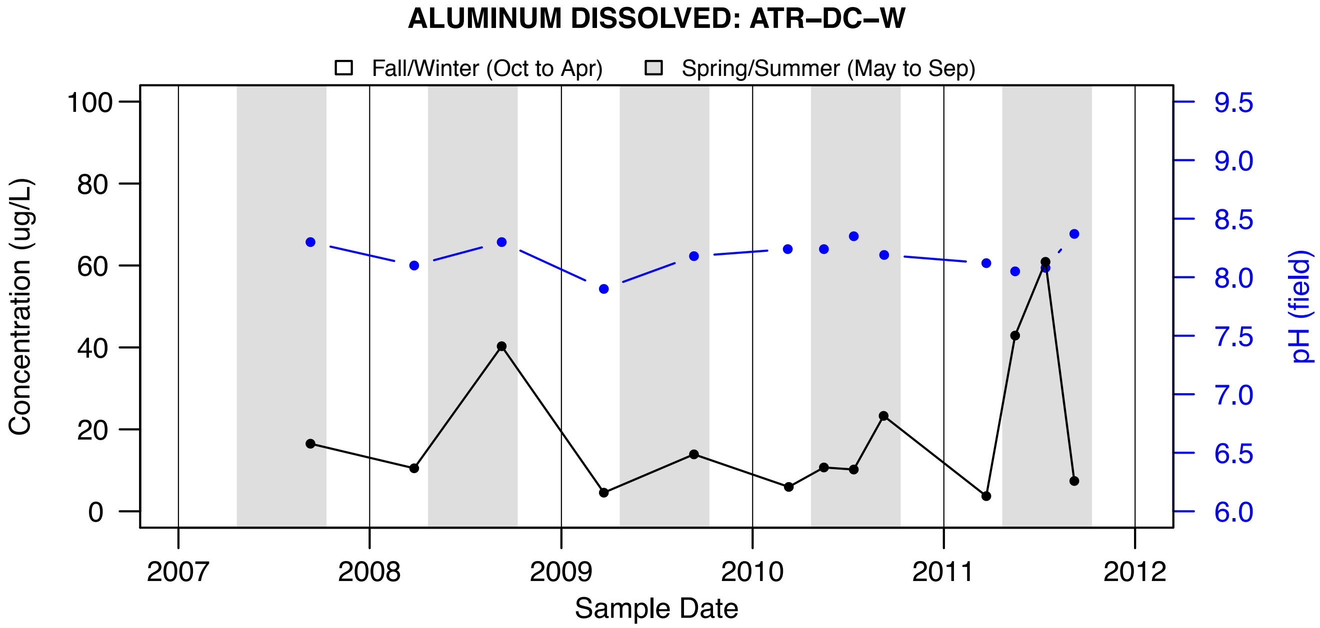
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.63: NICKEL DISSOLVED: ATR-DC-E - NA



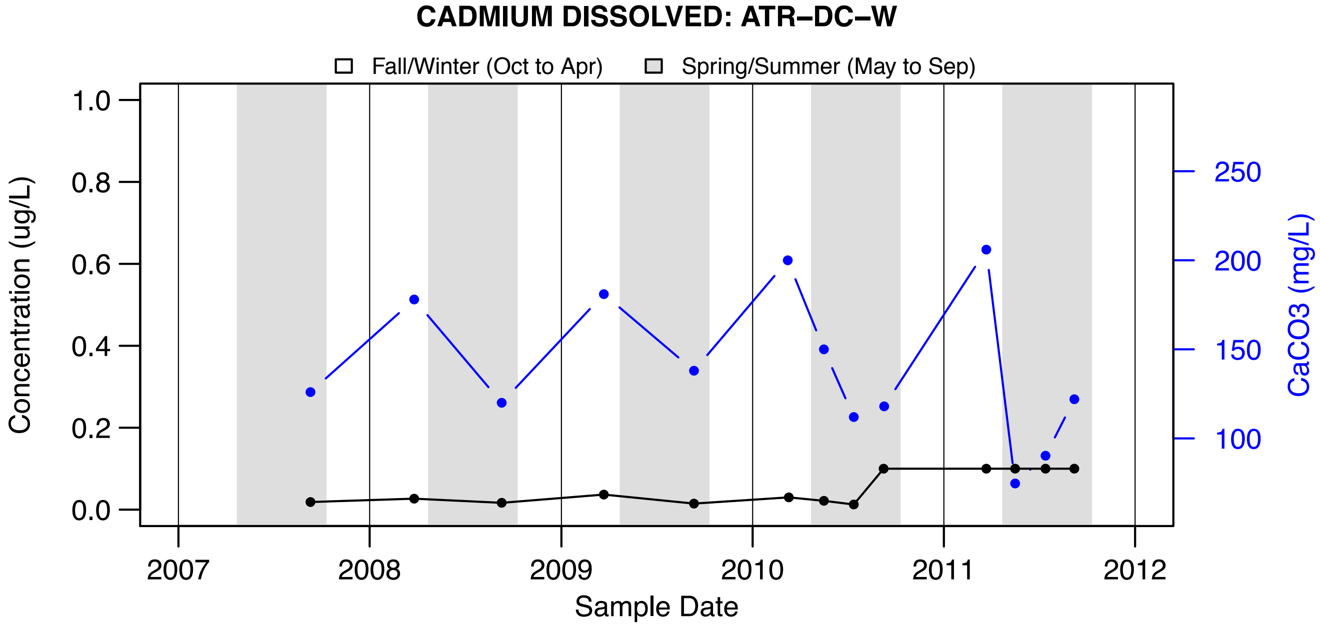
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.64: LEAD DISSOLVED: ATR-DC-E - NA



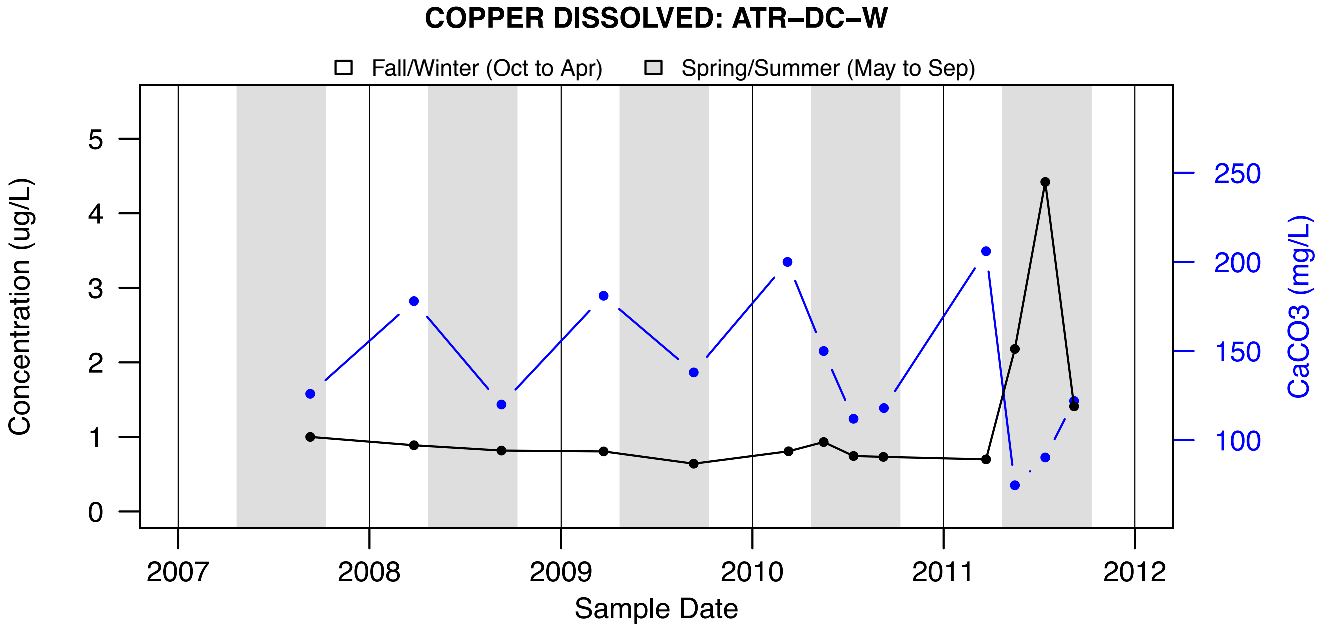
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.65: ALUMINUM DISSOLVED: ATR-DC-W - NA



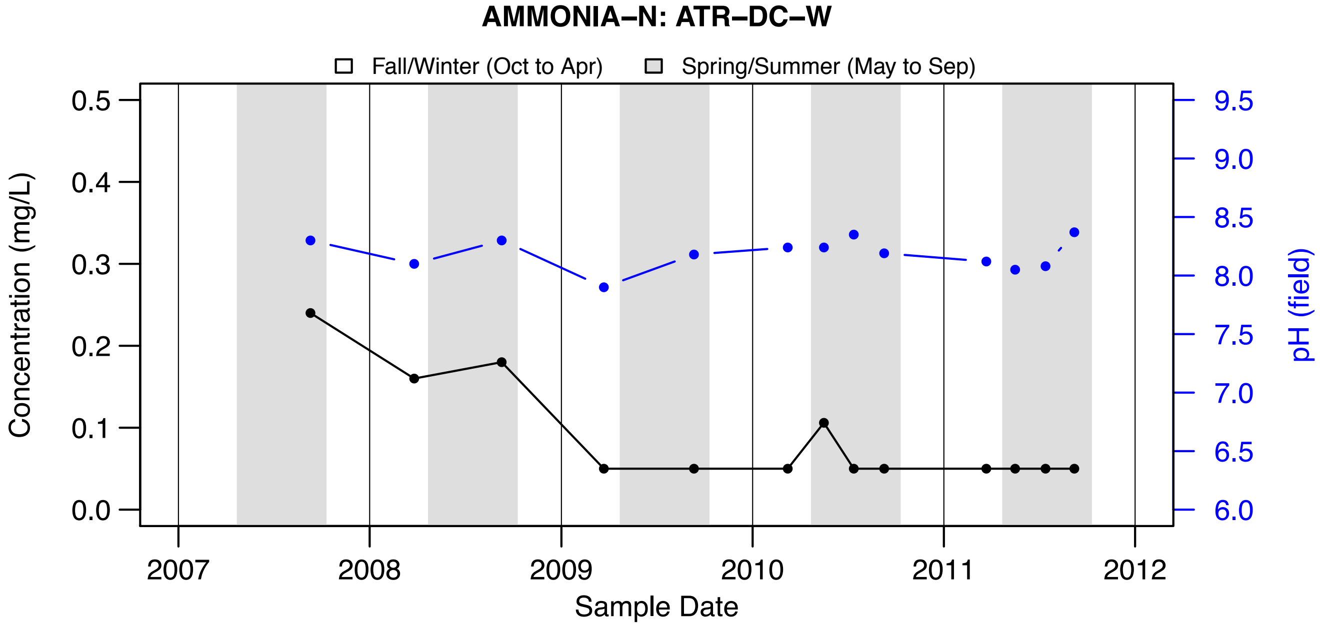
Related to hardness as CaCo3

Figure A4.66: CADMIUM DISSOLVED: ATR-DC-W - NA



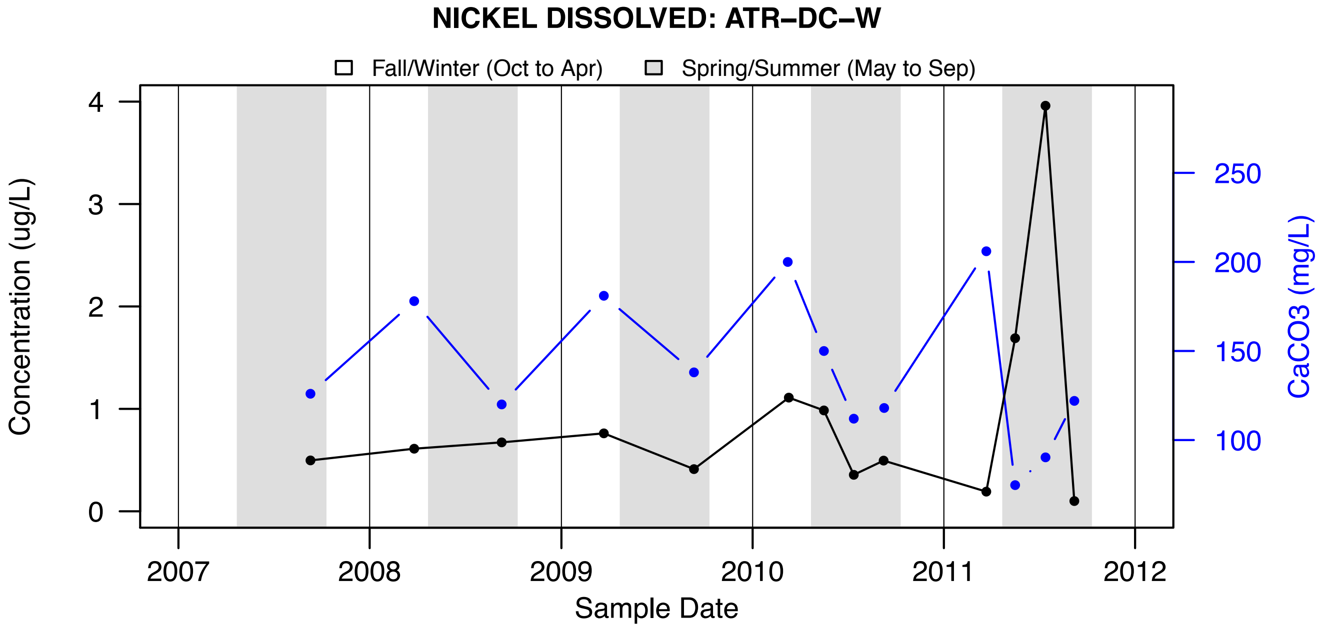
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.67: COPPER DISSOLVED: ATR-DC-W - NA



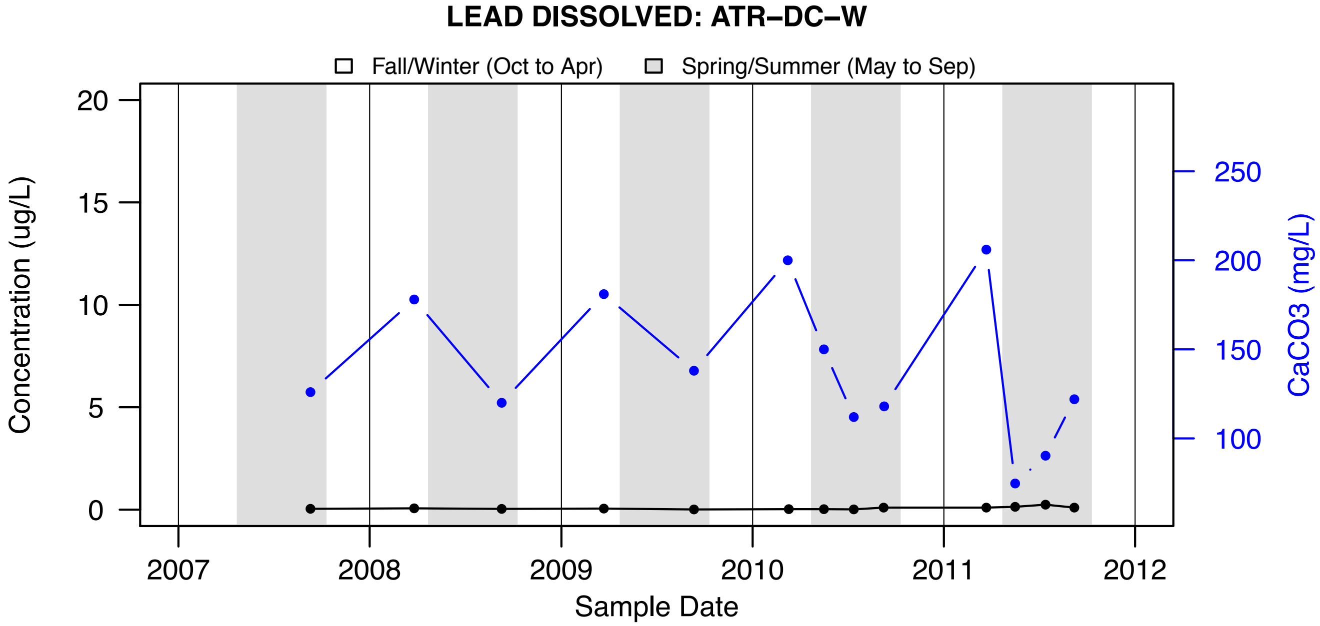
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.68: AMMONIA-N: ATR-DC-W - NA



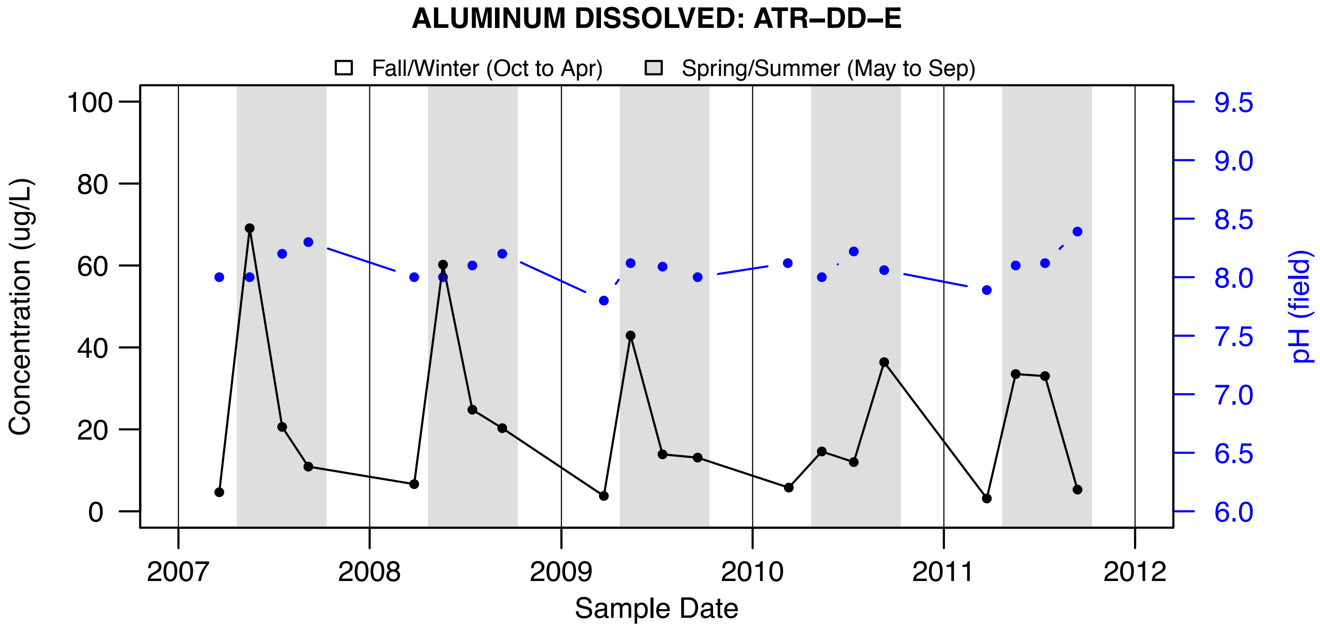
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.69: NICKEL DISSOLVED: ATR-DC-W - NA



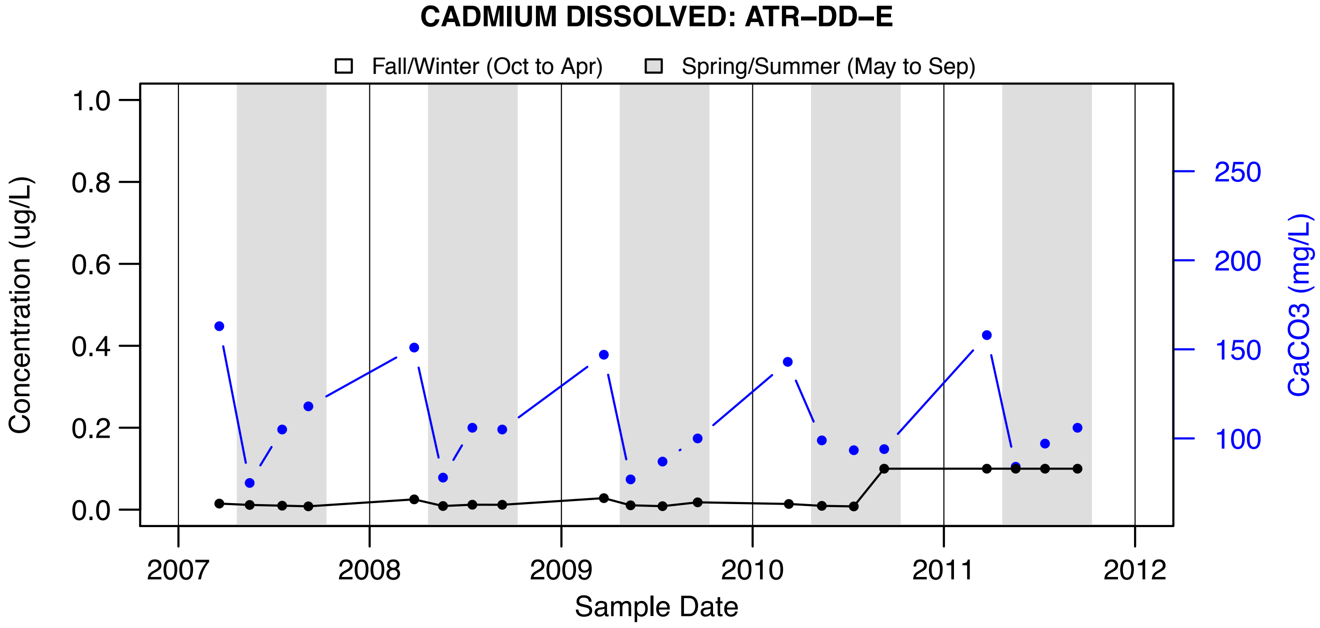
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.70: LEAD DISSOLVED: ATR-DC-W - NA


ALUMINUM DISSOLVED: ATR–DD–E

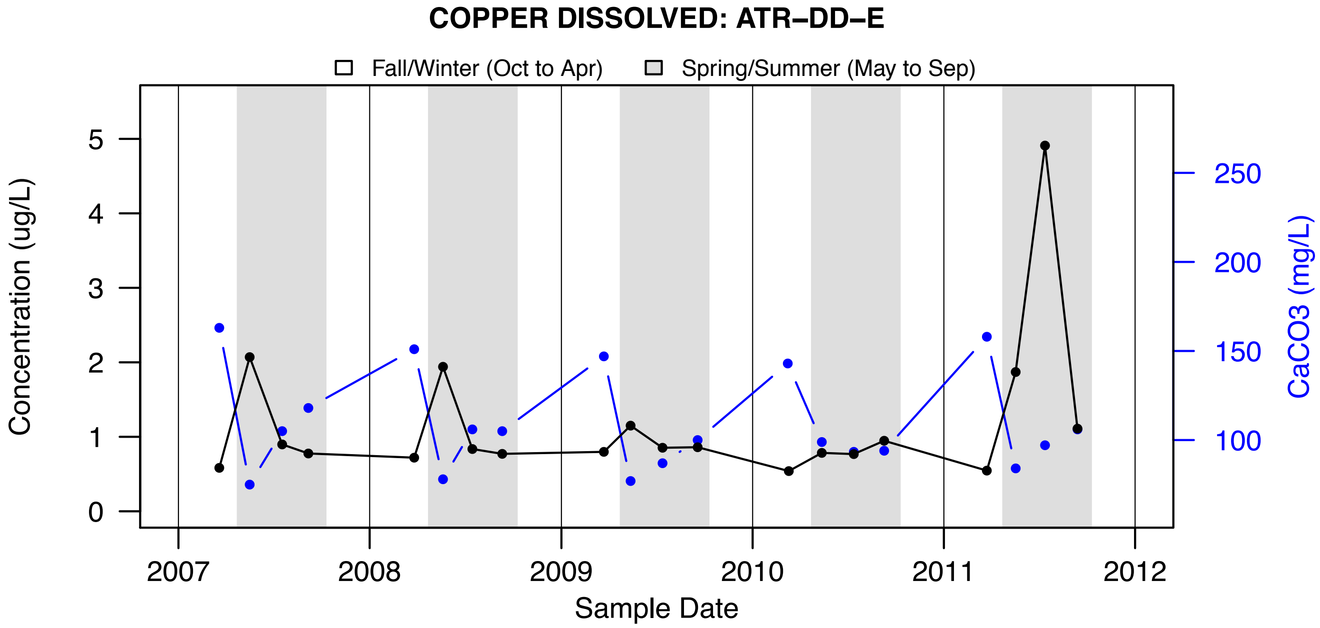
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.71: ALUMINUM DISSOLVED: ATR-DD-E - NA


CADMIUM DISSOLVED: ATR–DD–E

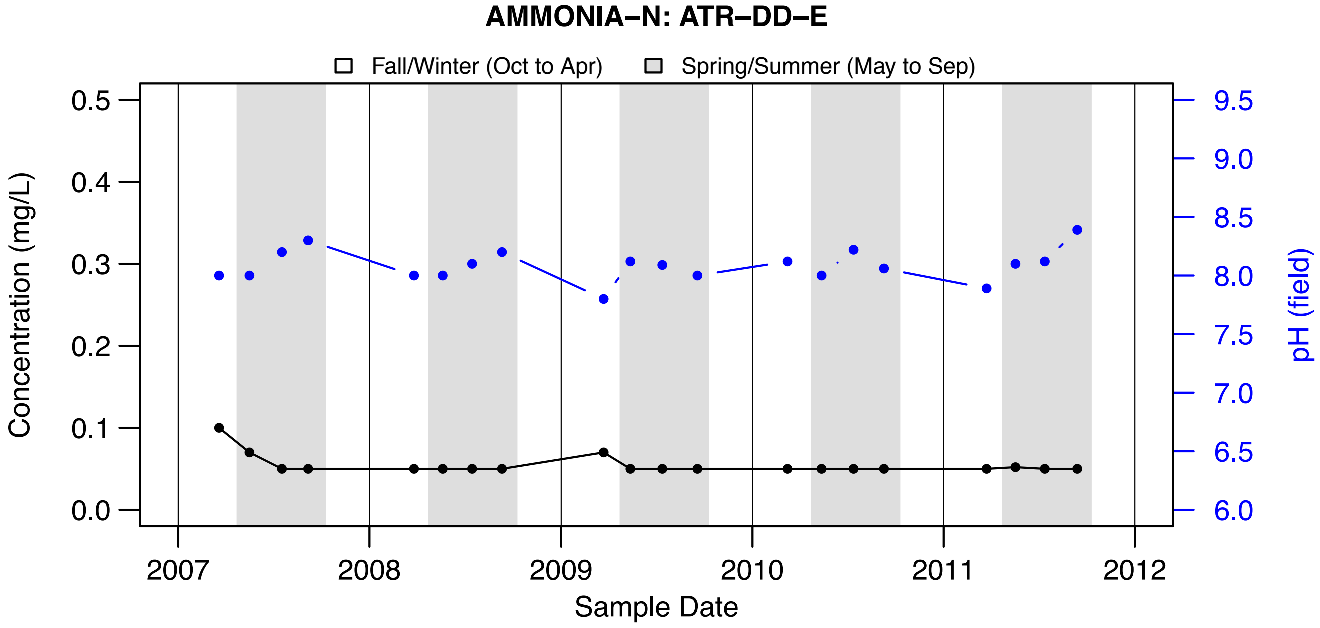
Related to hardness as CaCo3

Figure A4.72: CADMIUM DISSOLVED: ATR-DD-E - NA



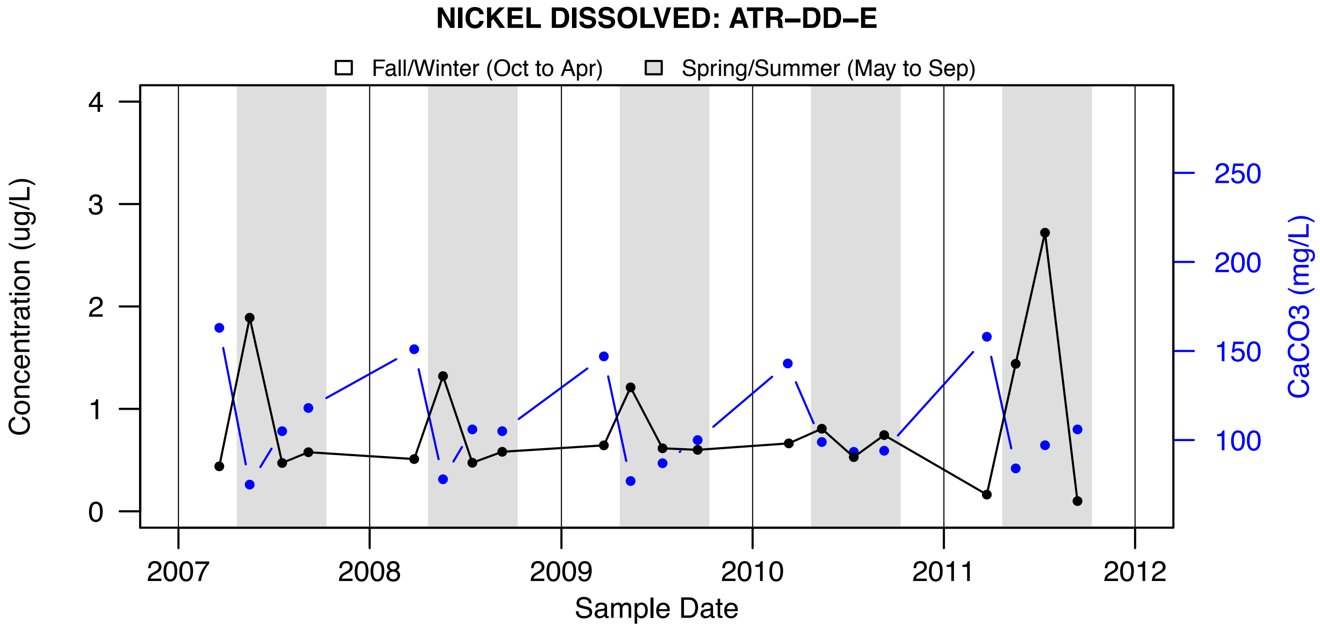
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.73: COPPER DISSOLVED: ATR-DD-E - NA



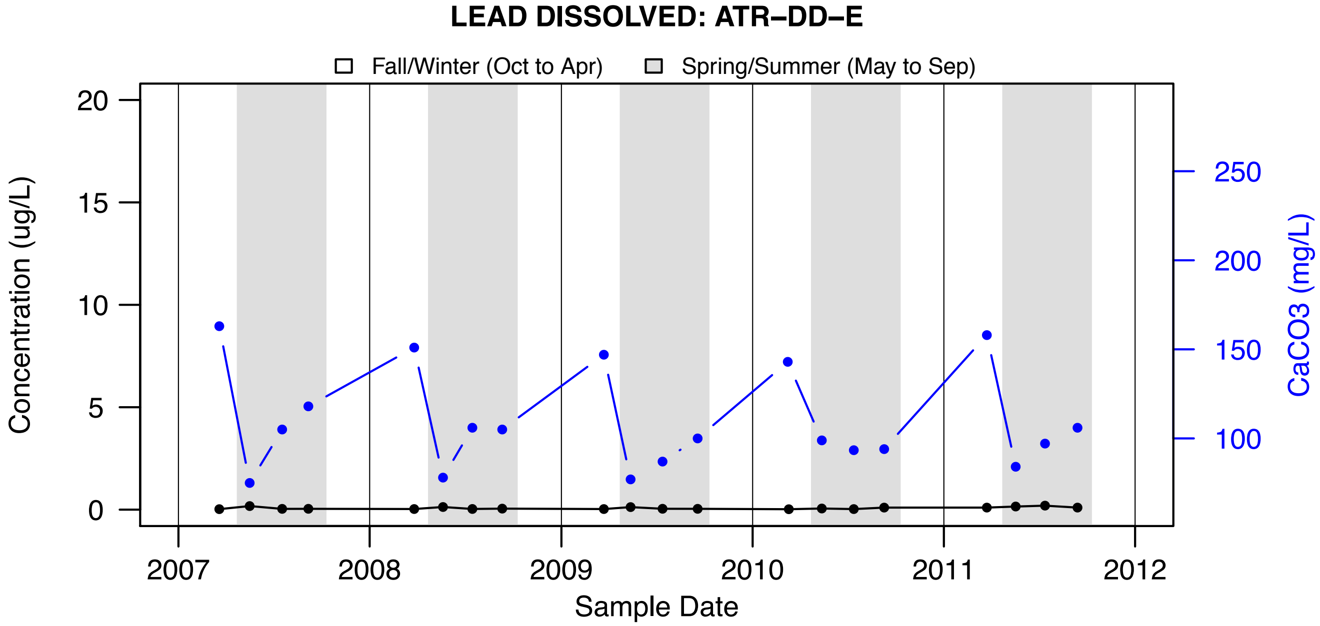
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.74: AMMONIA-N: ATR-DD-E - NA



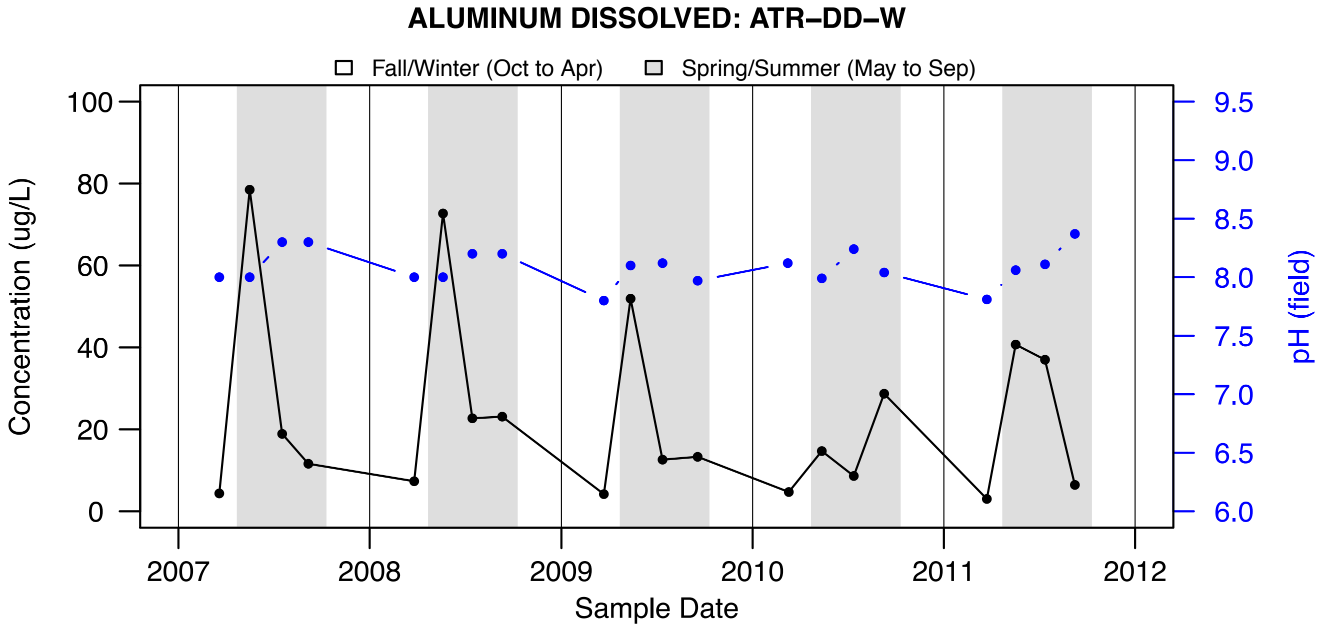
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.75: NICKEL DISSOLVED: ATR-DD-E - NA



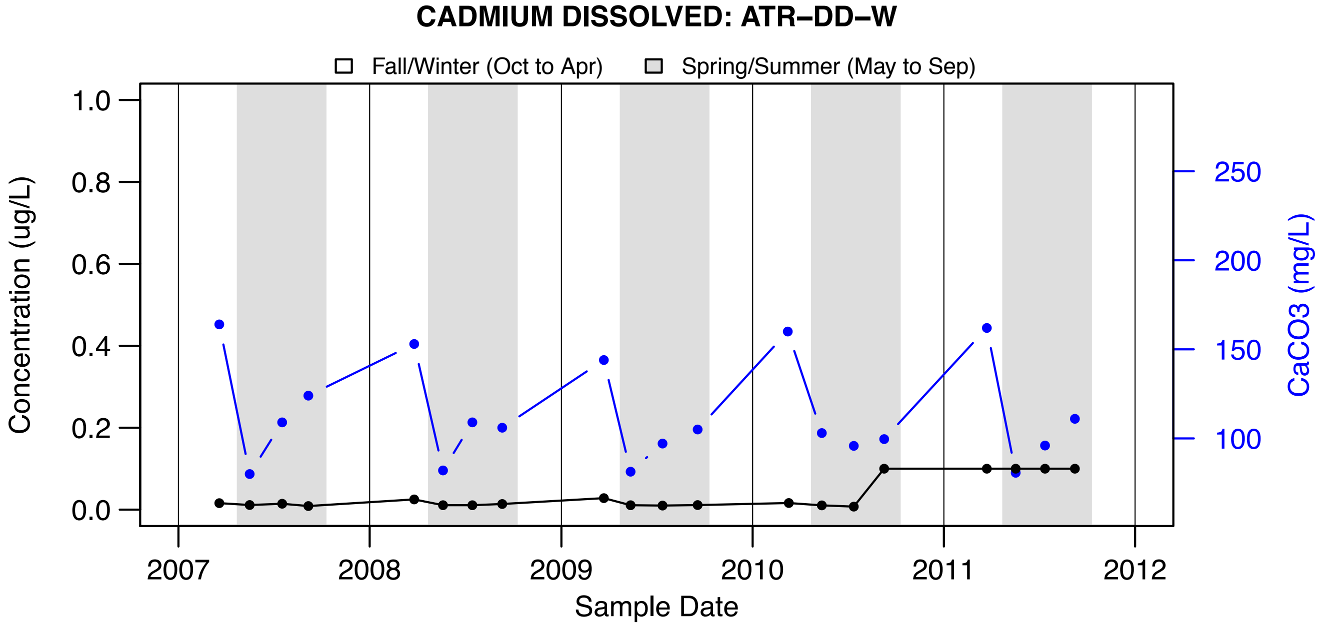
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.76: LEAD DISSOLVED: ATR-DD-E - NA



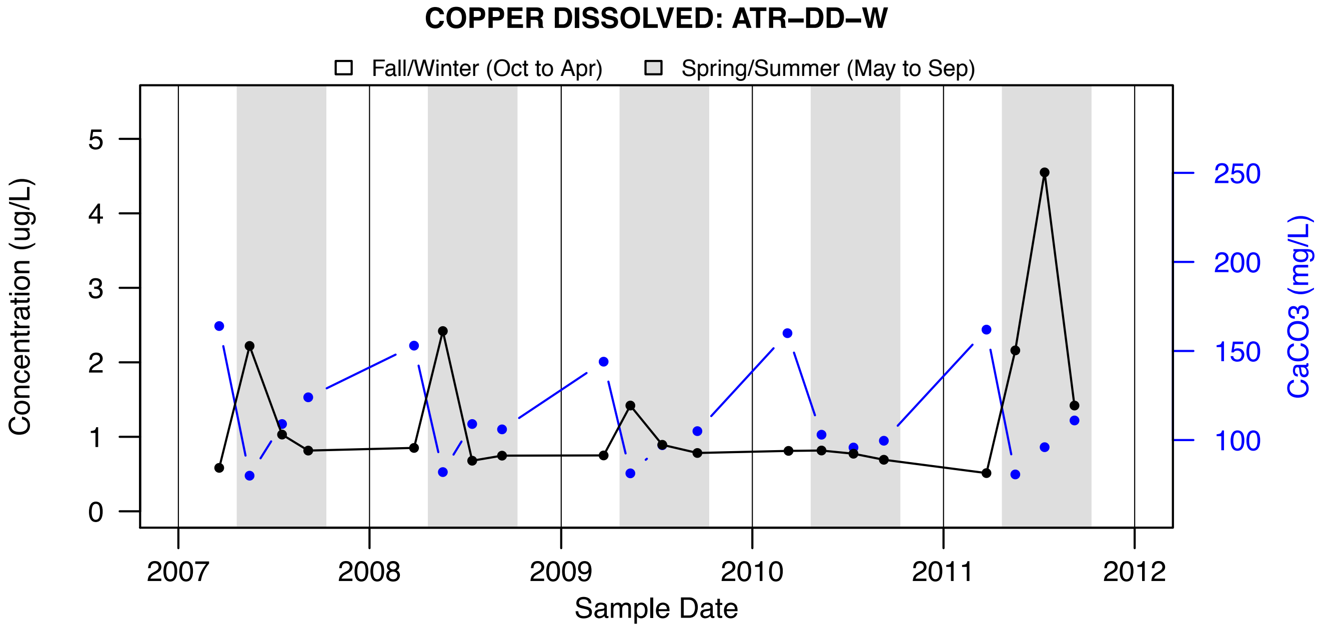
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.77: ALUMINUM DISSOLVED: ATR-DD-W - NA



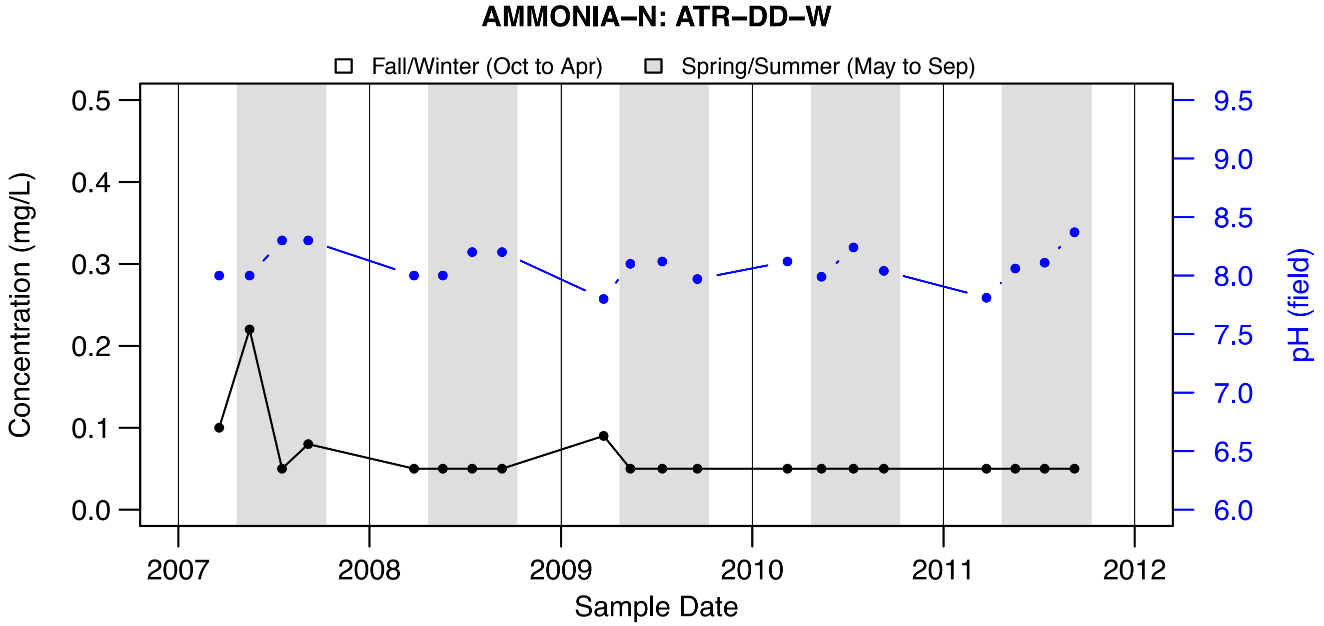
Related to hardness as CaCo3

Figure A4.78: CADMIUM DISSOLVED: ATR-DD-W - NA



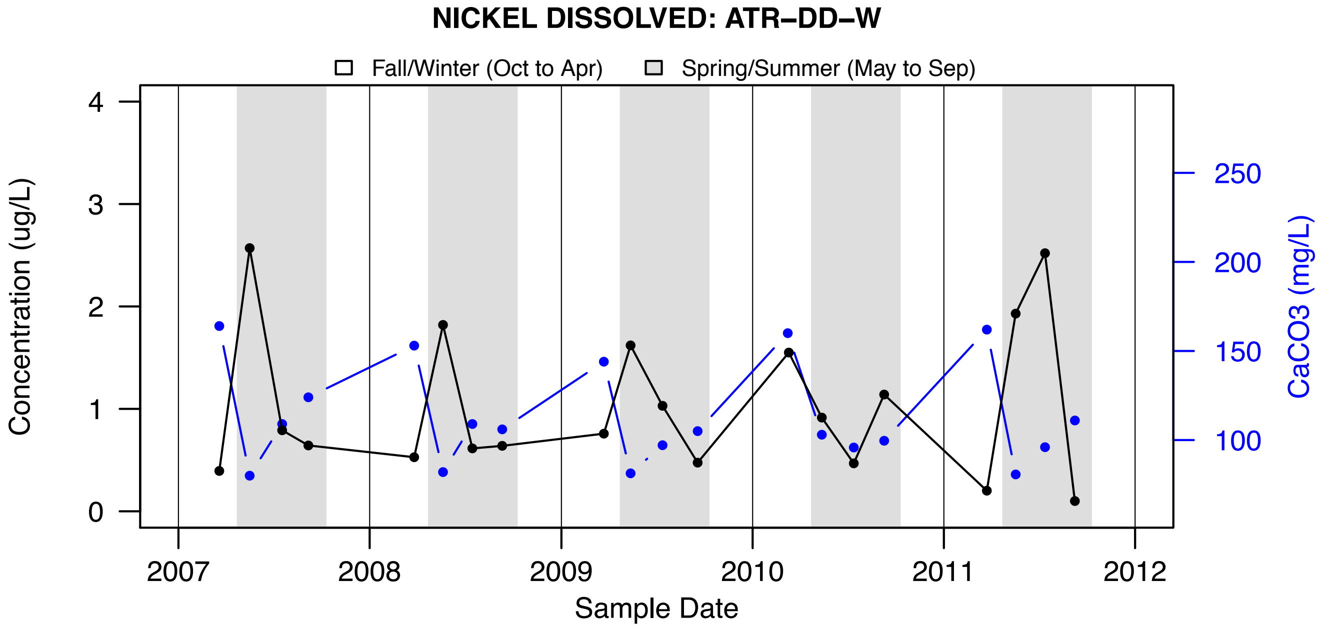
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.79: COPPER DISSOLVED: ATR-DD-W - NA



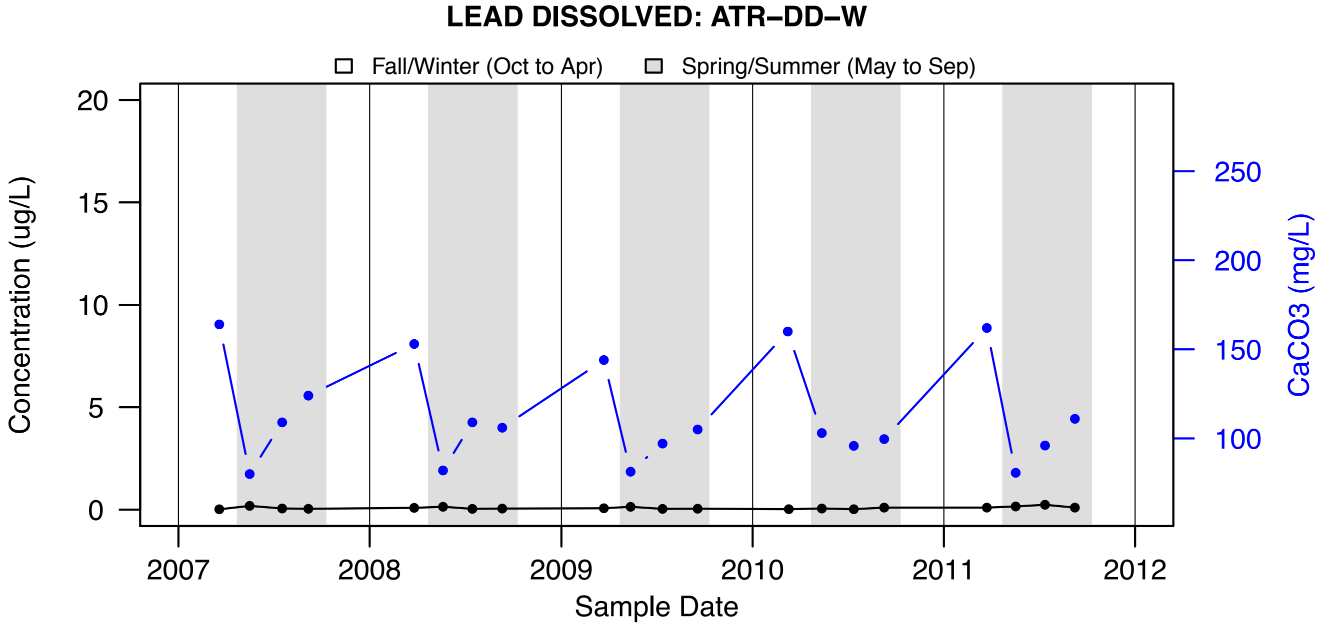
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.80: AMMONIA-N: ATR-DD-W - NA



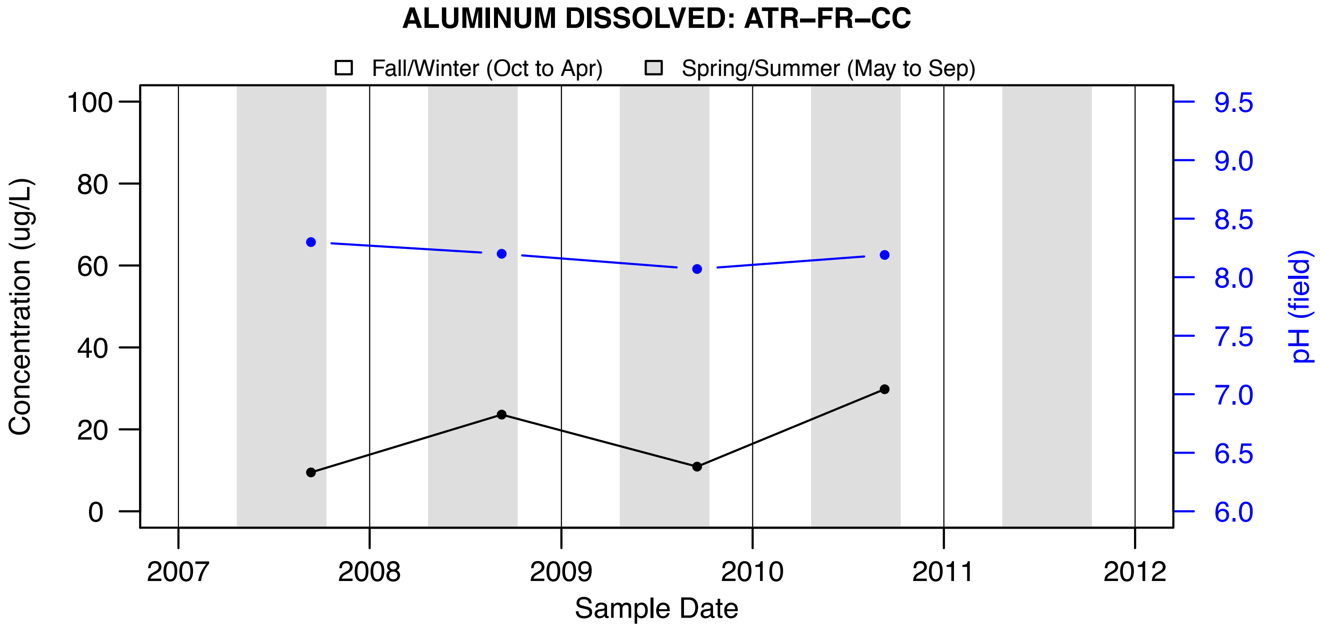
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.81: NICKEL DISSOLVED: ATR-DD-W - NA



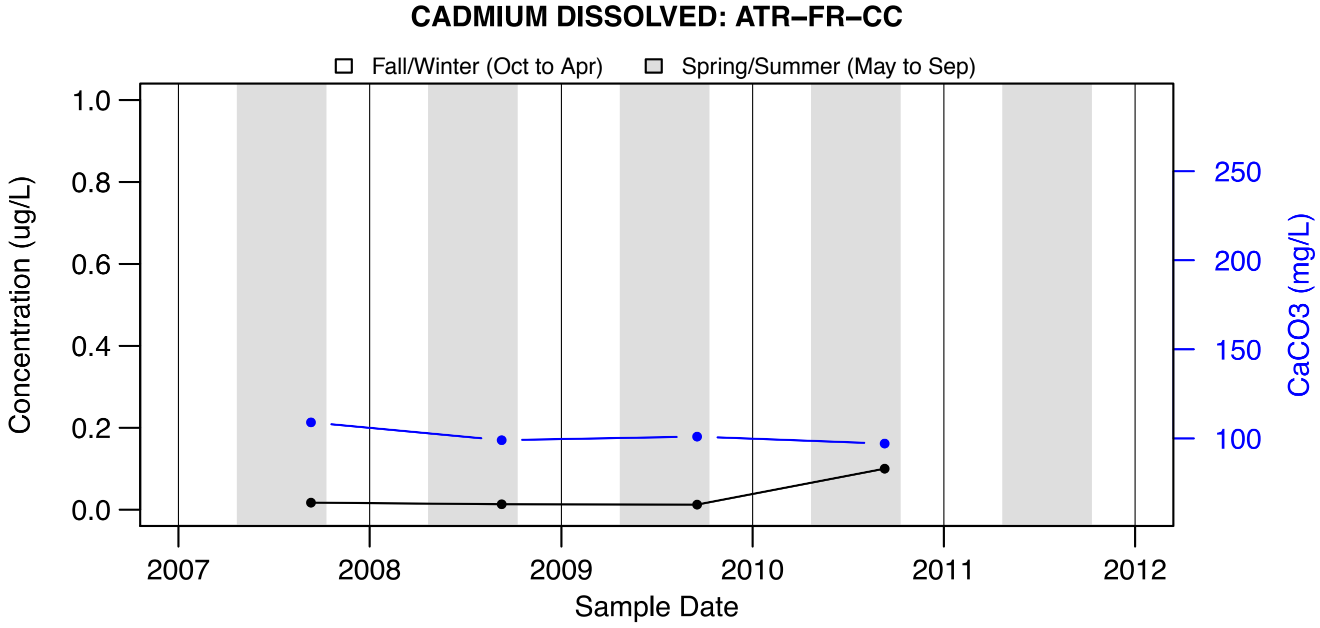
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.82: LEAD DISSOLVED: ATR-DD-W - NA



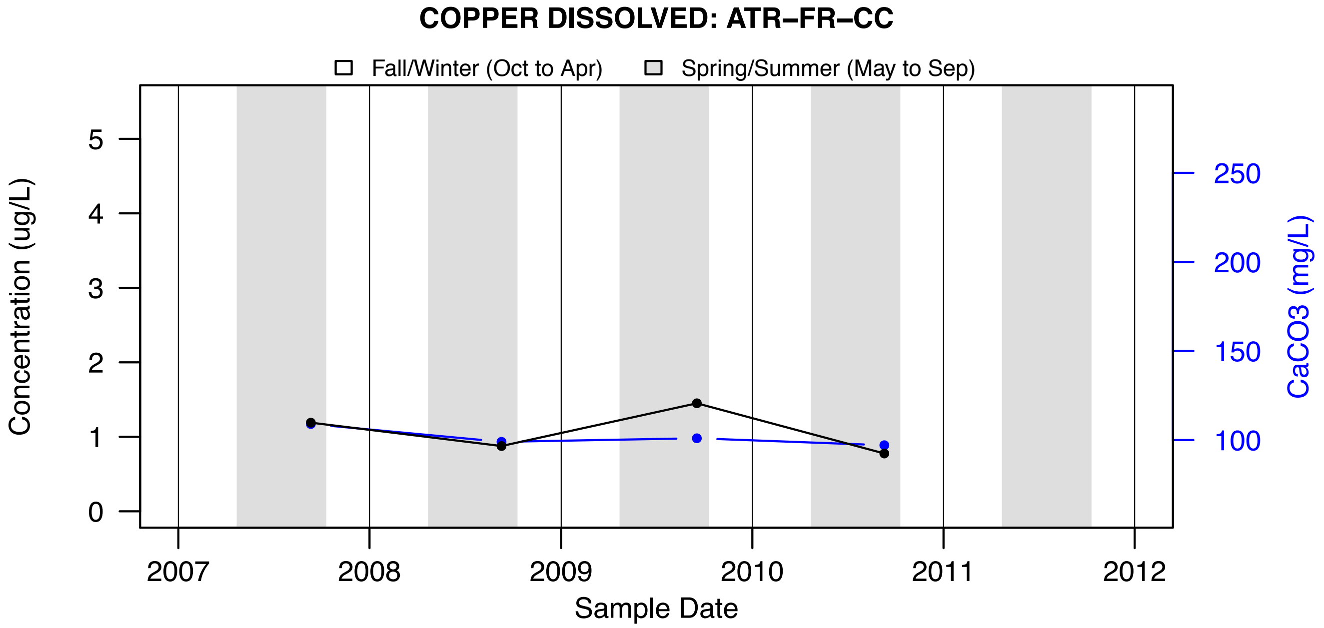
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.83: ALUMINUM DISSOLVED: ATR-FR-CC - NA



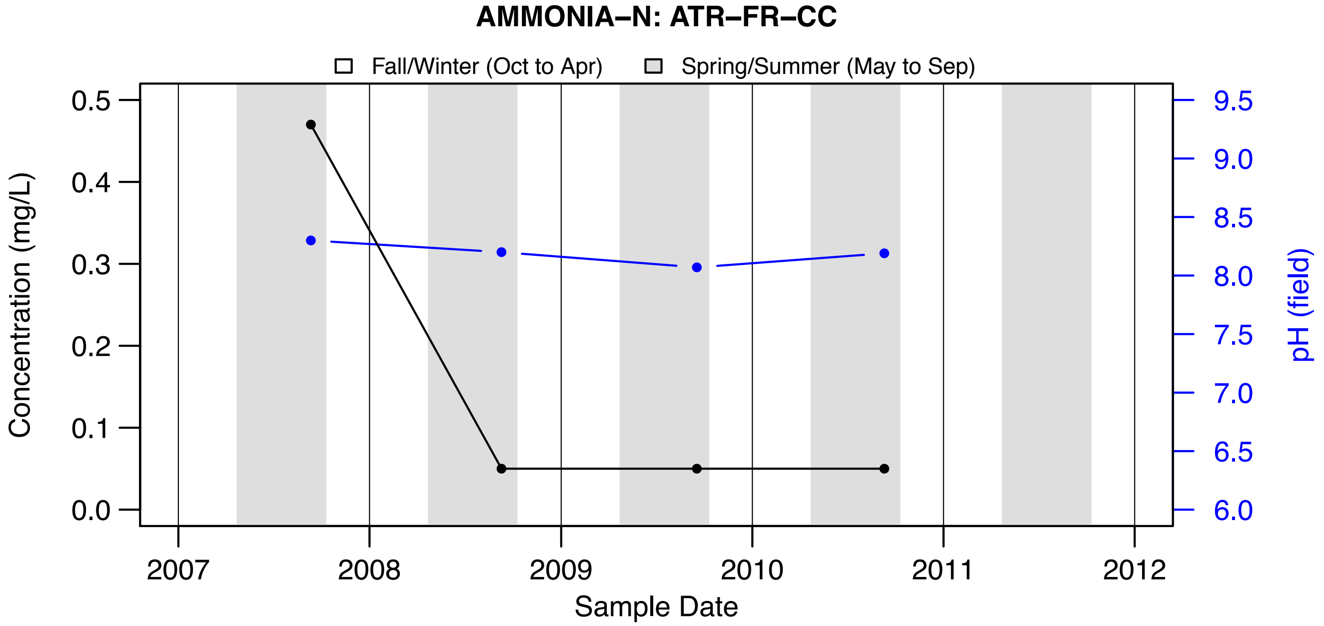
Related to hardness as CaCo3

Figure A4.84: CADMIUM DISSOLVED: ATR-FR-CC - NA



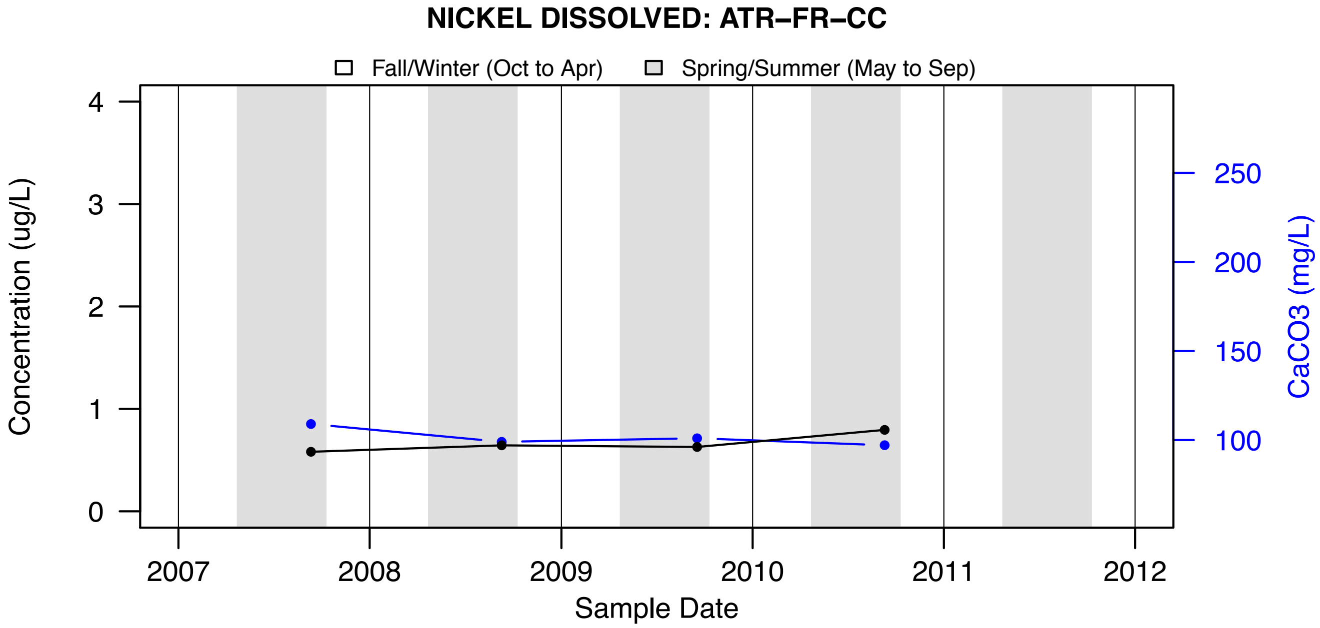
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.85: COPPER DISSOLVED: ATR-FR-CC - NA



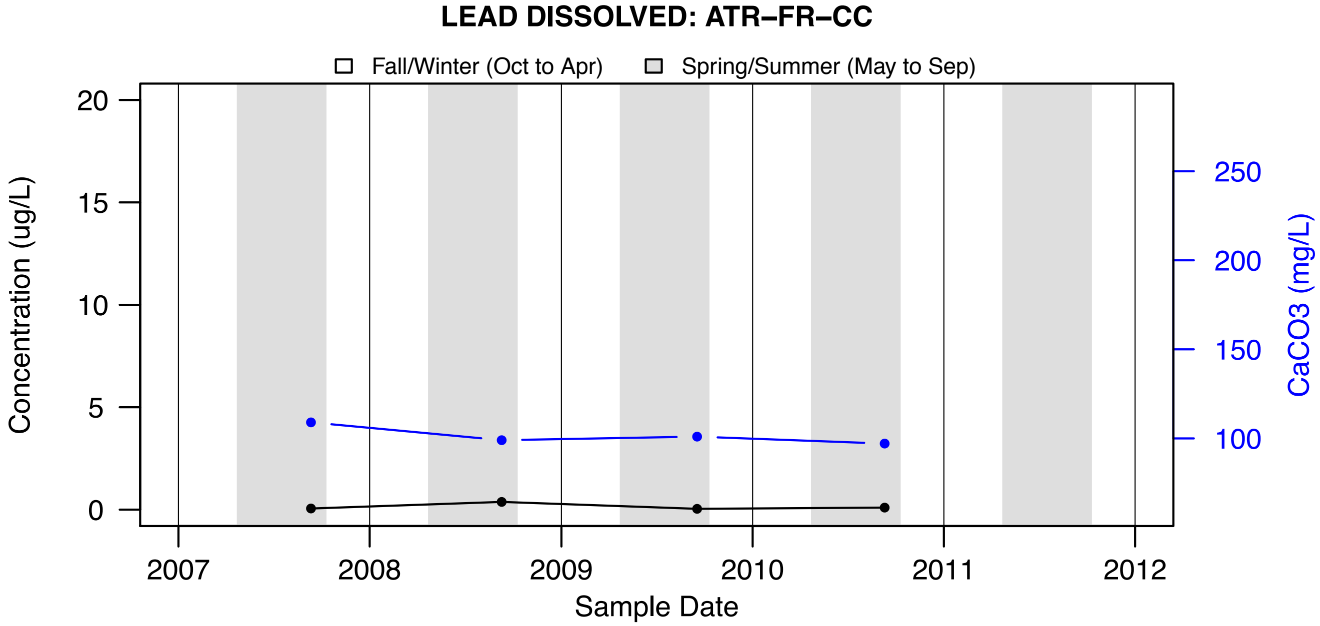
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.86: AMMONIA-N: ATR-FR-CC - NA



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.87: NICKEL DISSOLVED: ATR-FR-CC - NA



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.88: LEAD DISSOLVED: ATR-FR-CC - NA

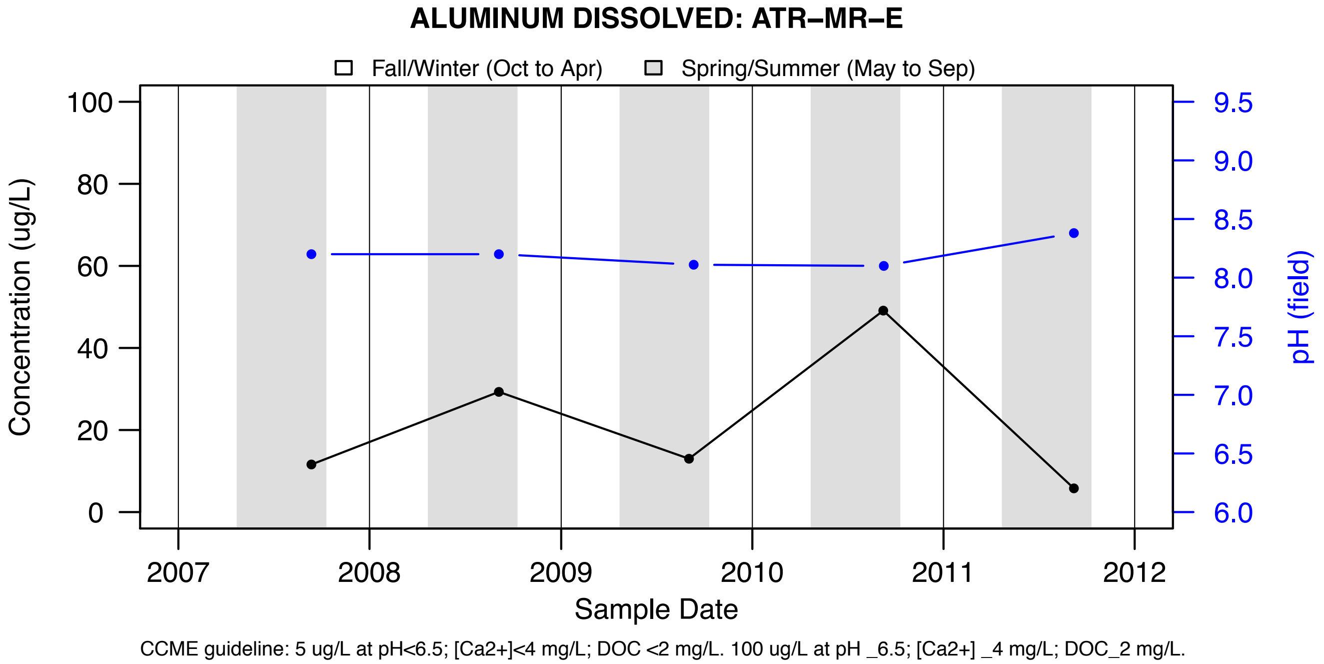


Figure A4.89: ALUMINUM DISSOLVED: ATR-MR-E - NA

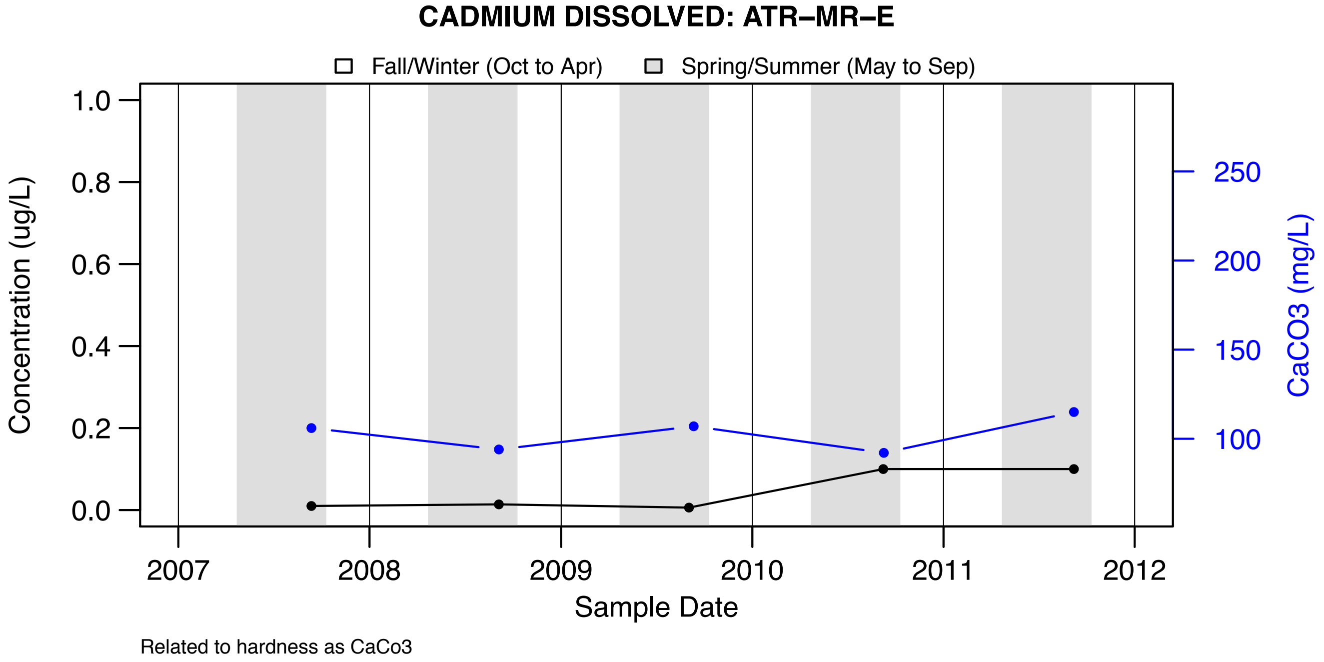
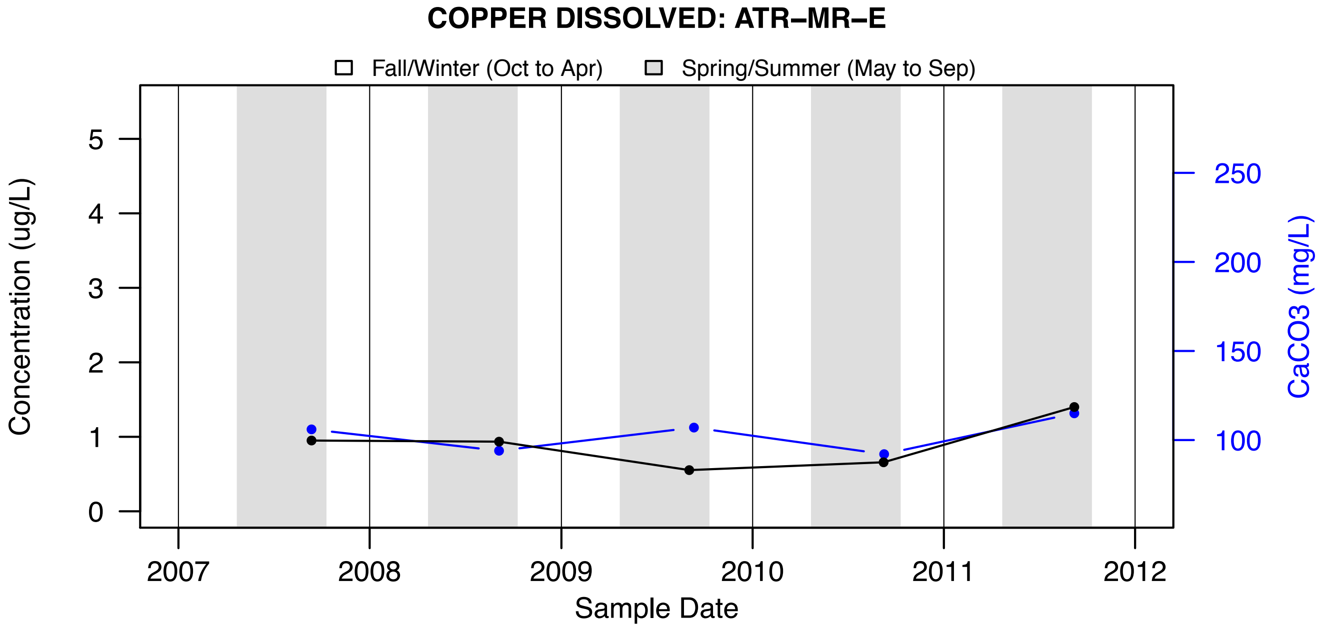
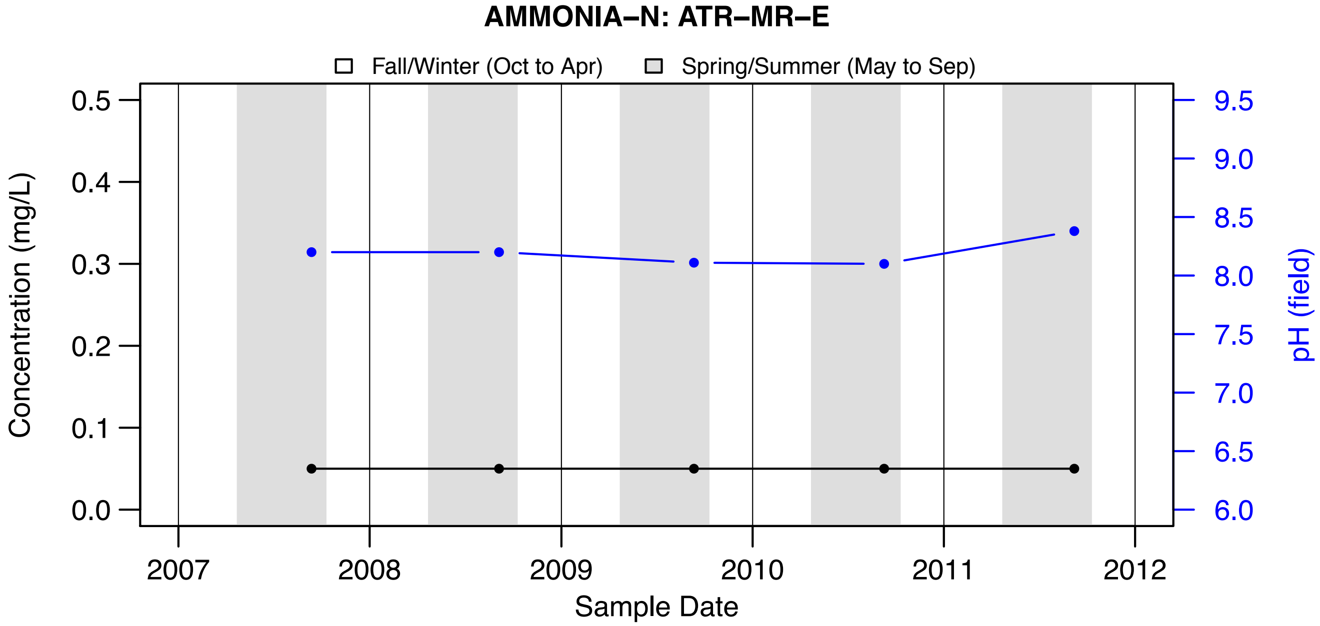


Figure A4.90: CADMIUM DISSOLVED: ATR-MR-E - NA



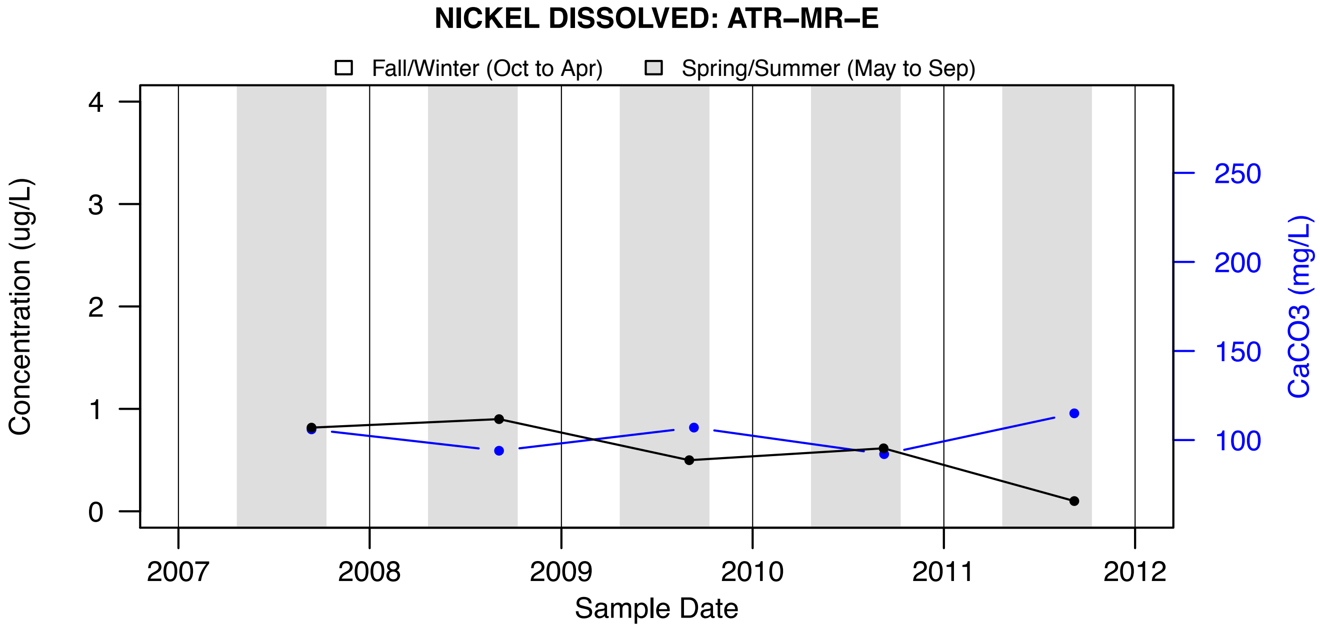
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.91: COPPER DISSOLVED: ATR-MR-E - NA



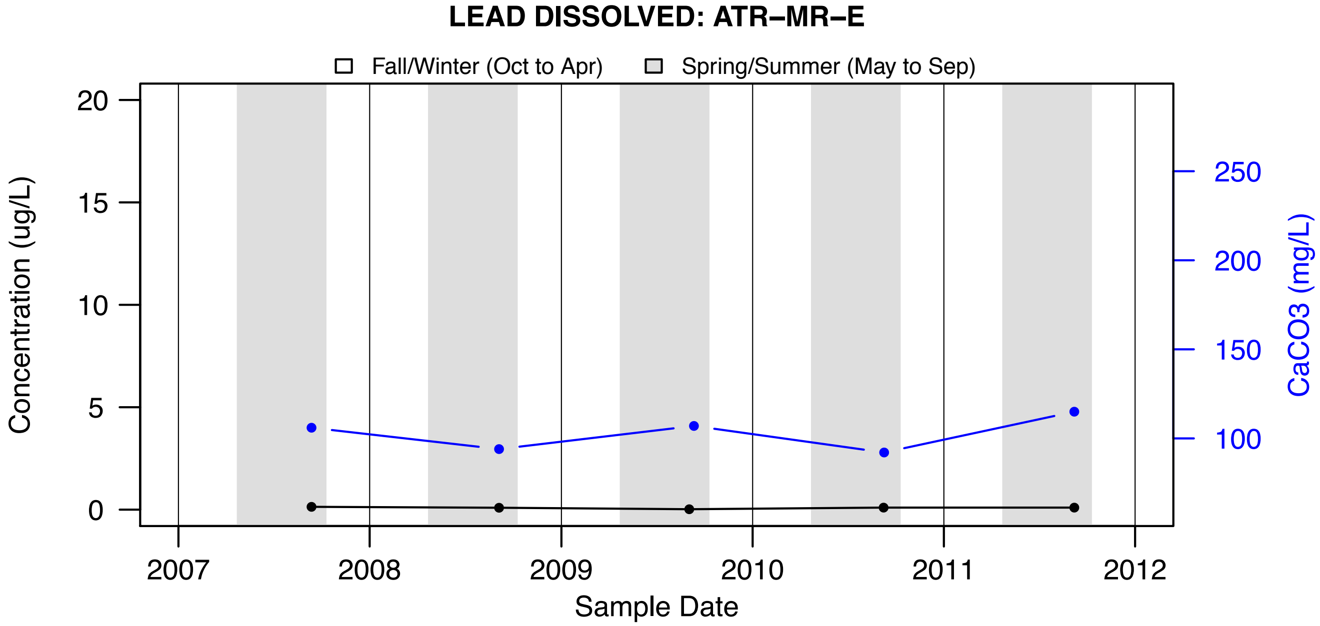
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.92: AMMONIA-N: ATR-MR-E - NA



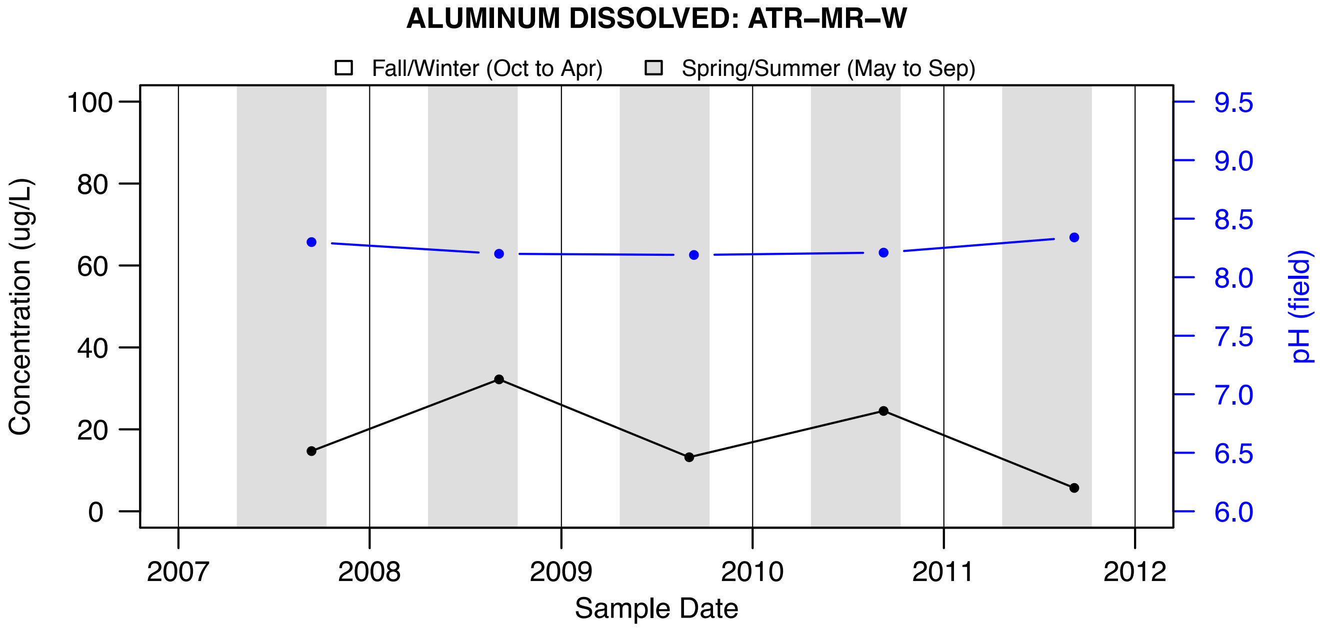
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.93: NICKEL DISSOLVED: ATR-MR-E - NA



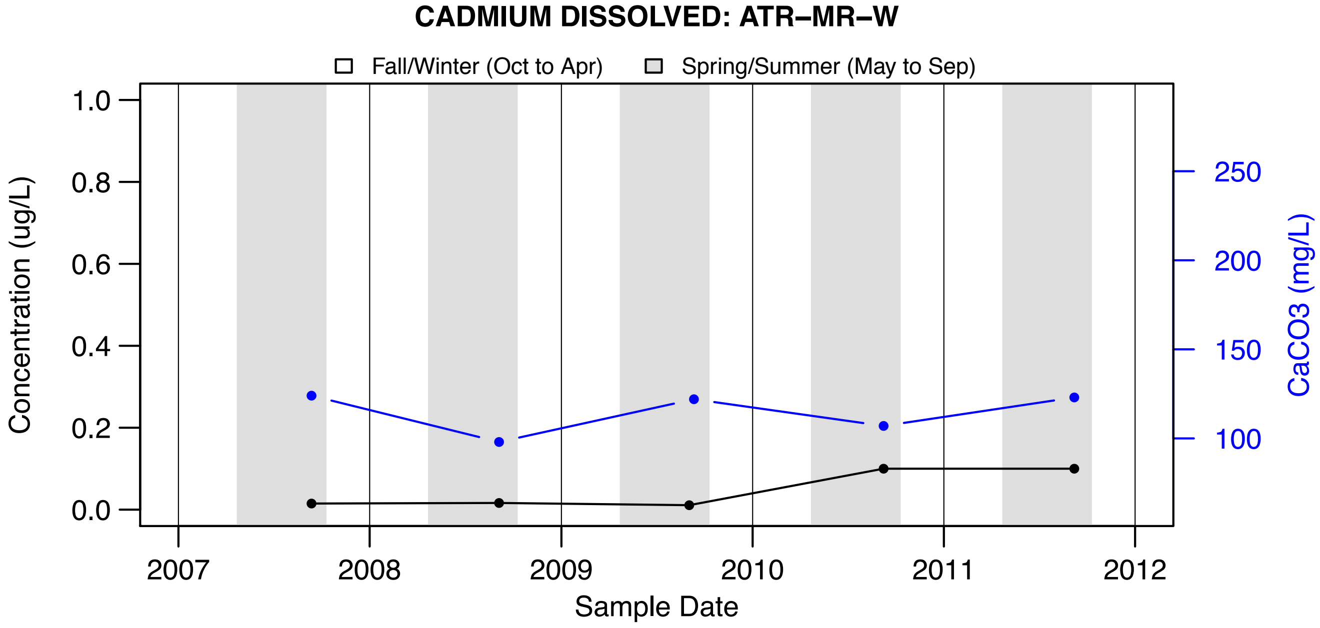
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.94: LEAD DISSOLVED: ATR-MR-E - NA



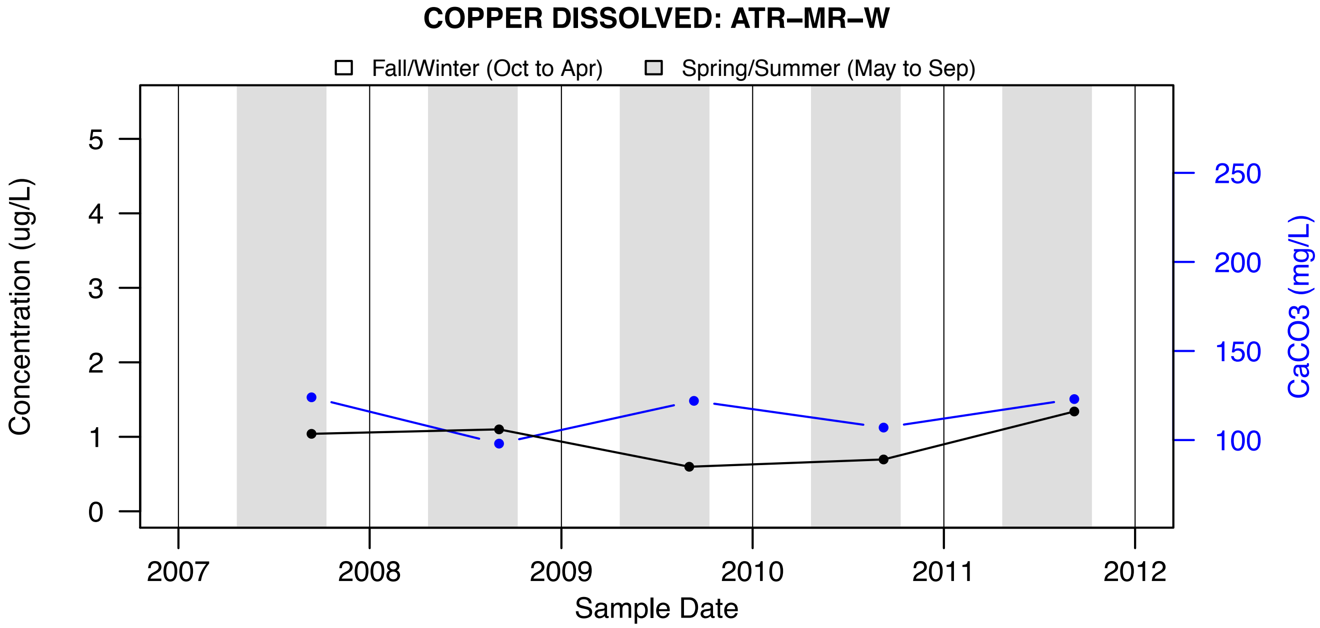
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.95: ALUMINUM DISSOLVED: ATR-MR-W - NA



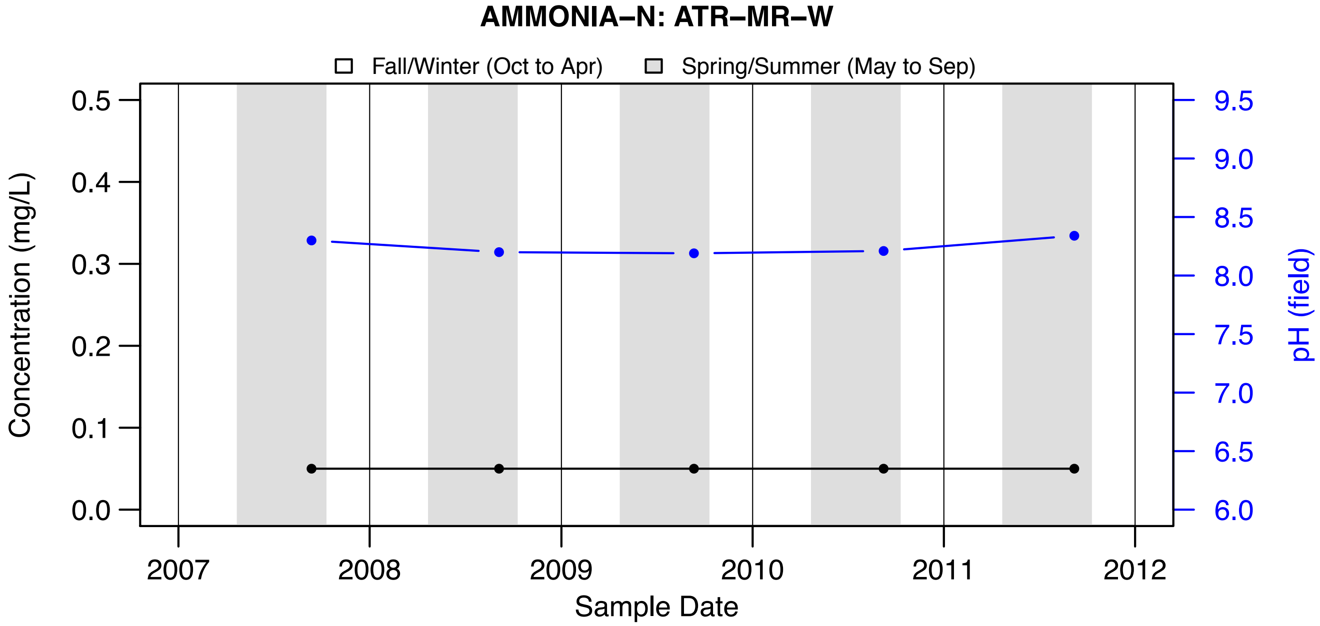
Related to hardness as CaCo3

Figure A4.96: CADMIUM DISSOLVED: ATR-MR-W - NA



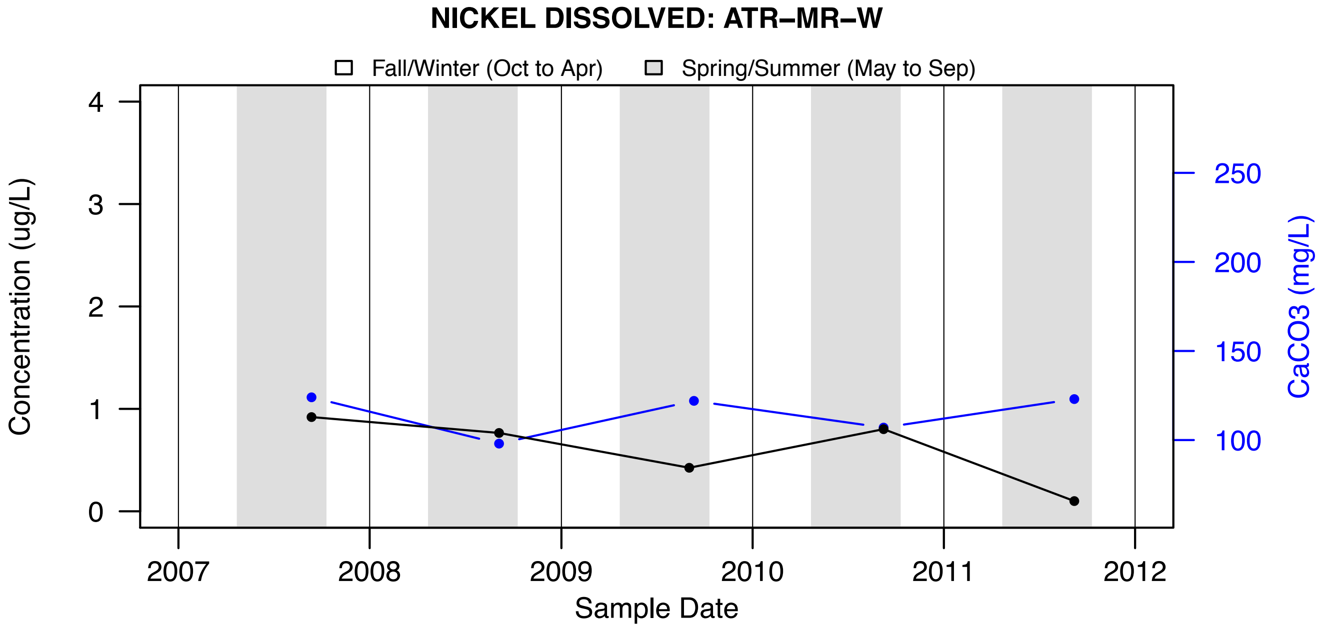
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.97: COPPER DISSOLVED: ATR-MR-W - NA



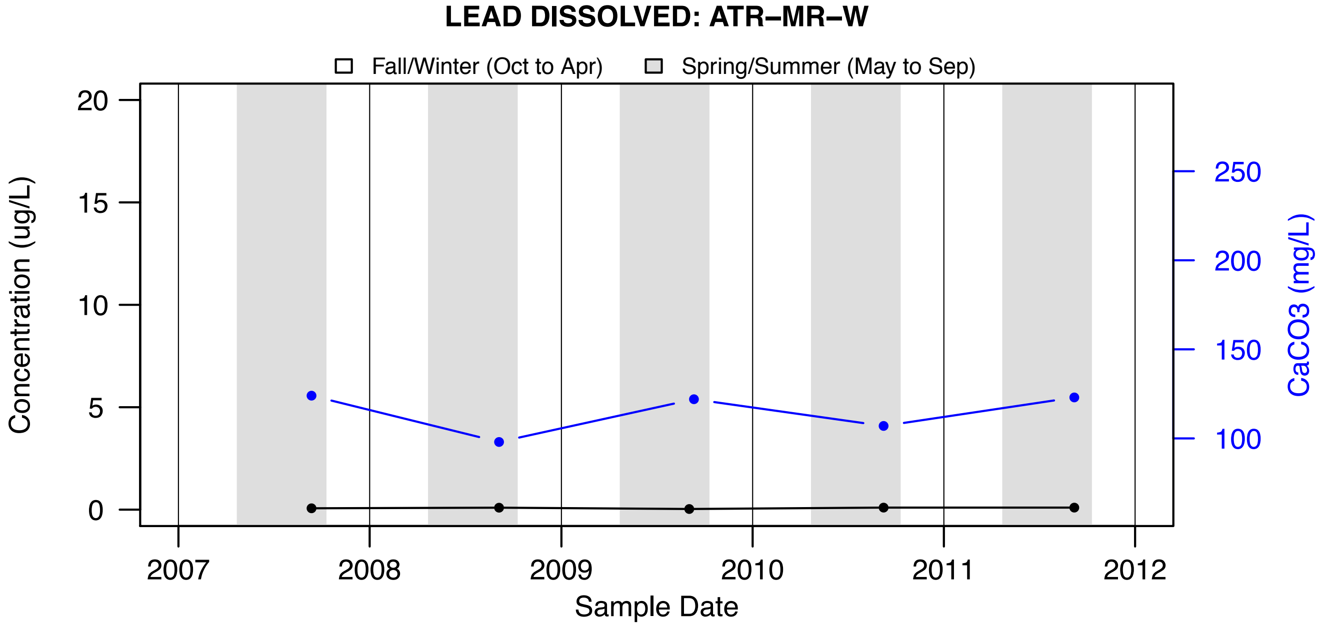
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.98: AMMONIA-N: ATR-MR-W - NA



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.99: NICKEL DISSOLVED: ATR-MR-W - NA



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.100: LEAD DISSOLVED: ATR-MR-W - NA

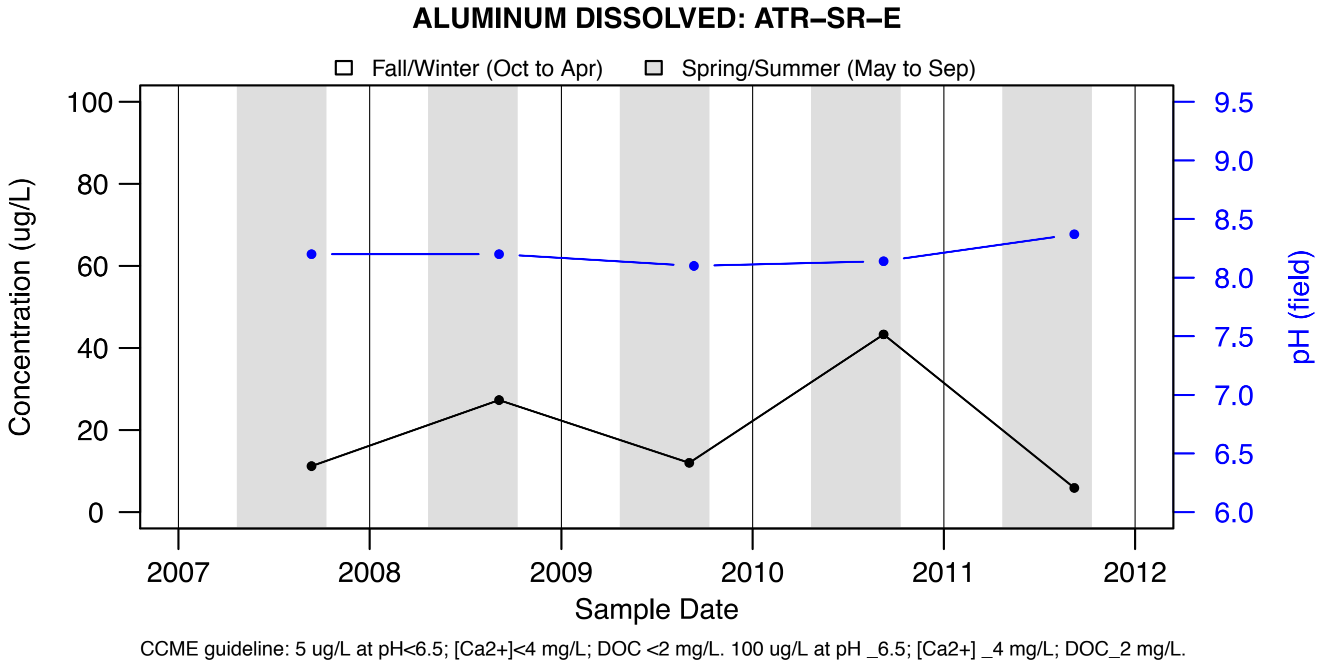


Figure A4.101: ALUMINUM DISSOLVED: ATR-SR-E - NA

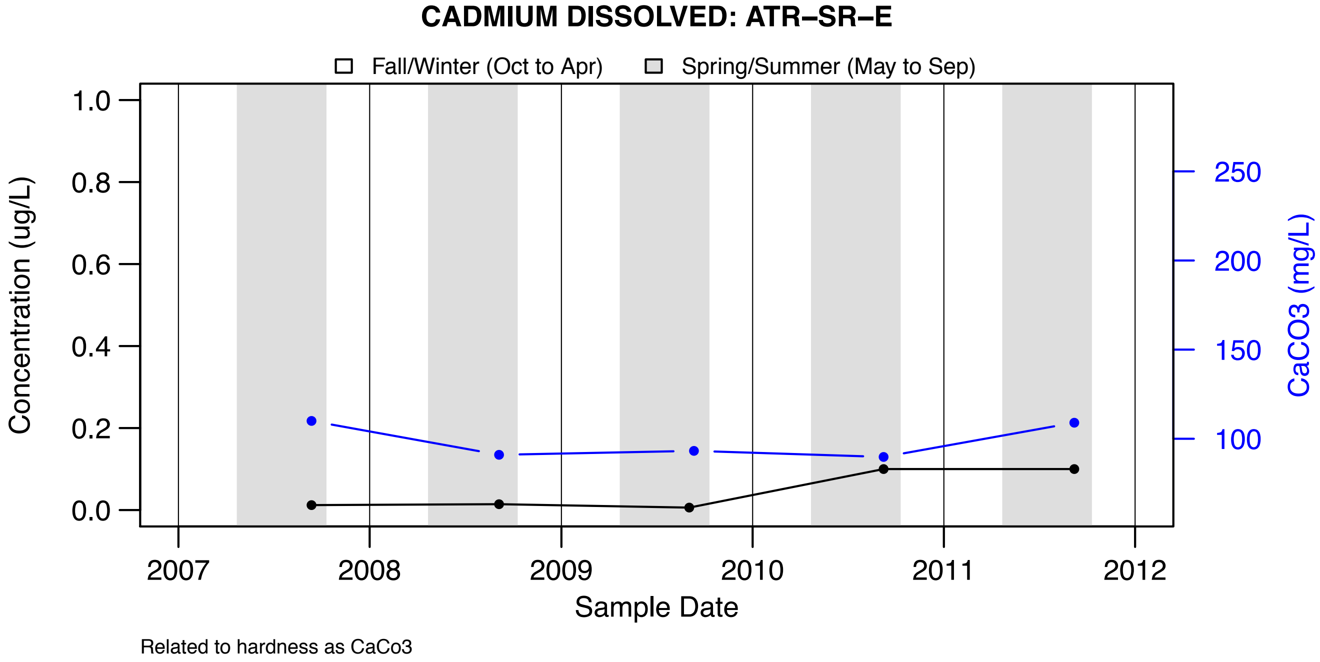
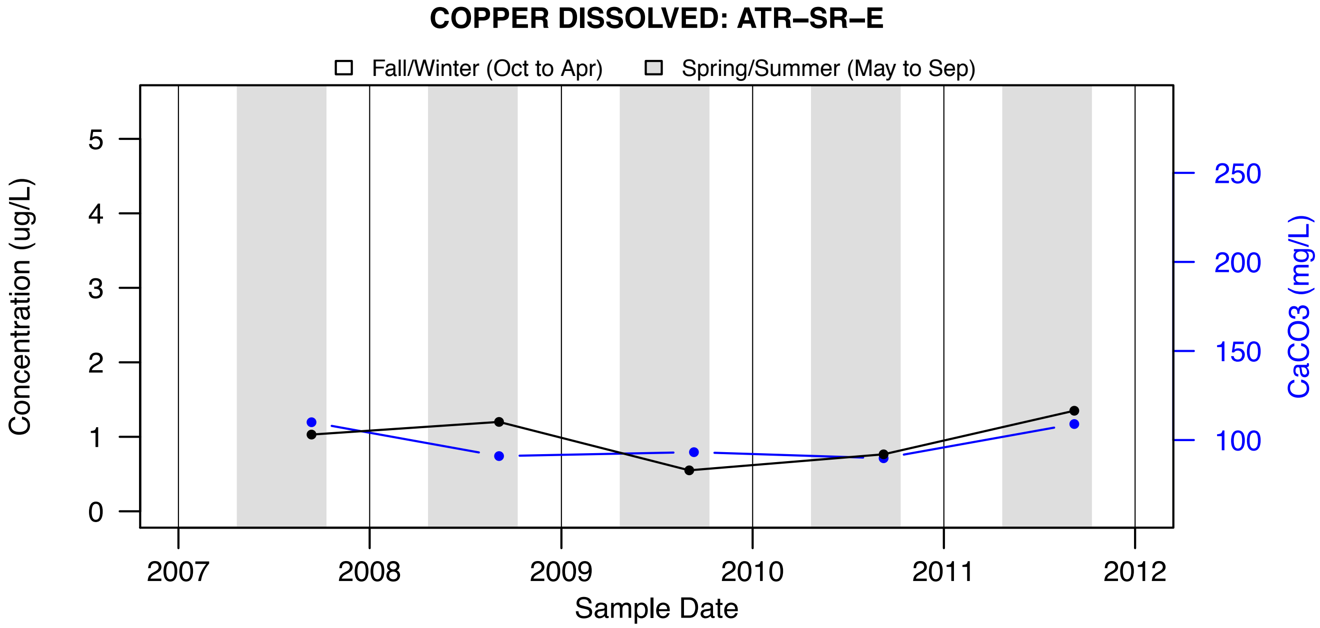
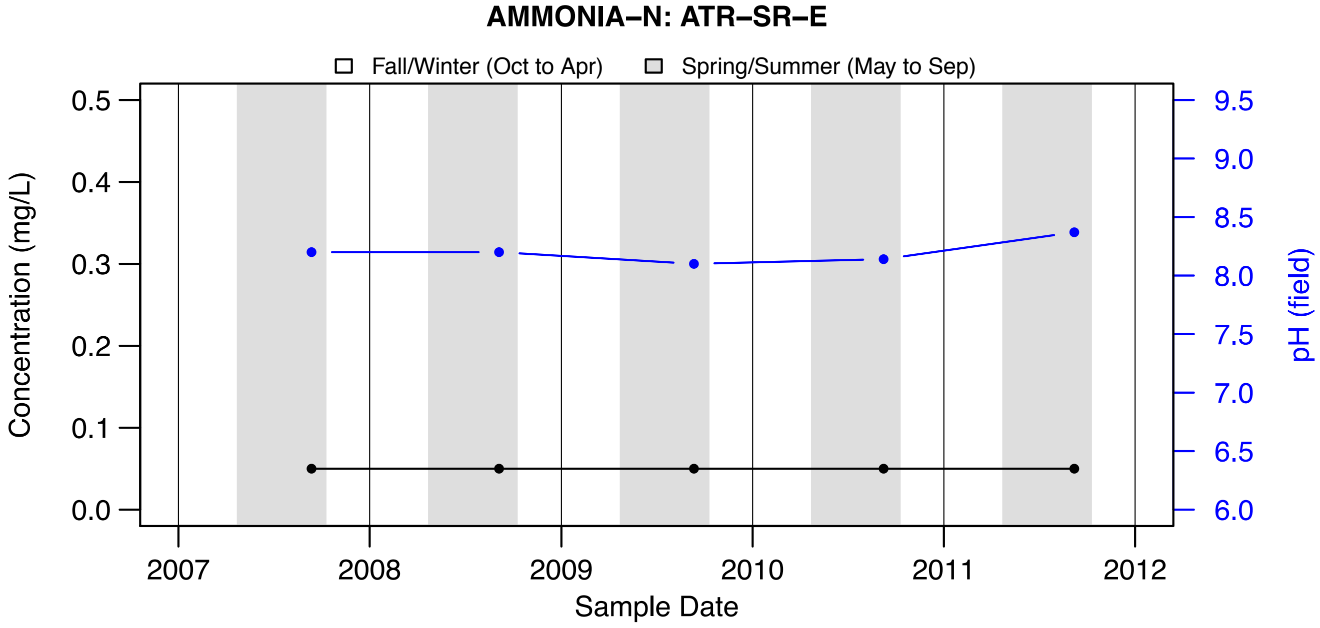


Figure A4.102: CADMIUM DISSOLVED: ATR-SR-E - NA



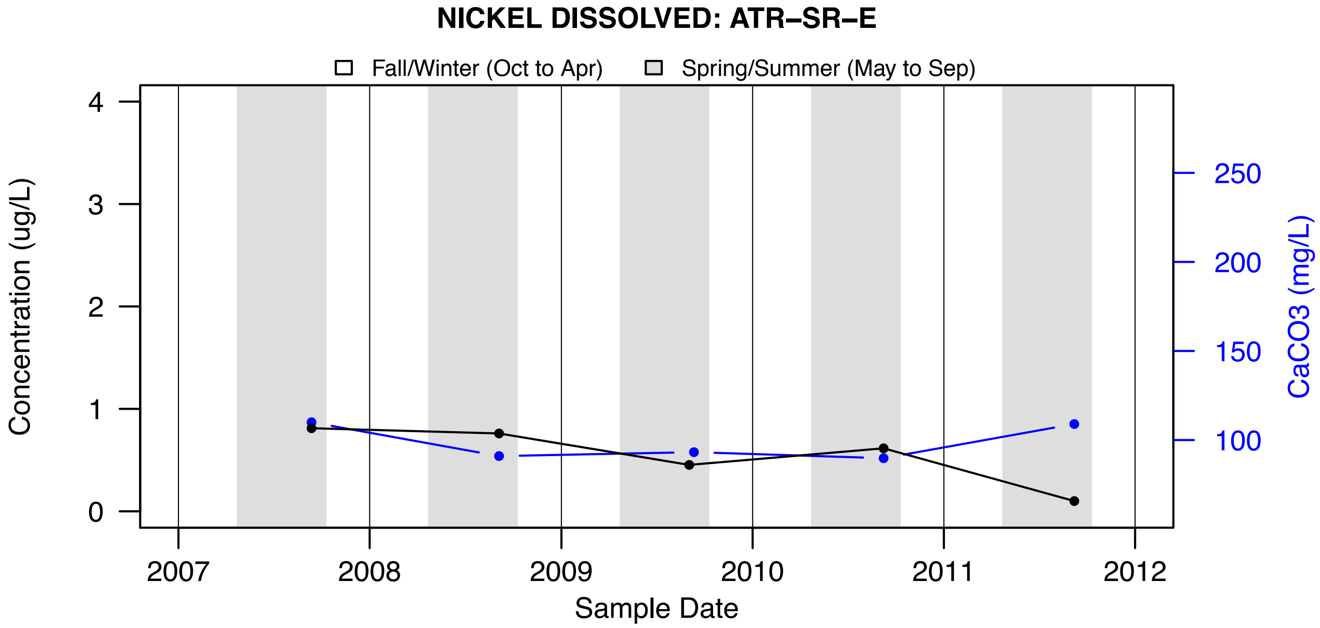
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.103: COPPER DISSOLVED: ATR-SR-E - NA



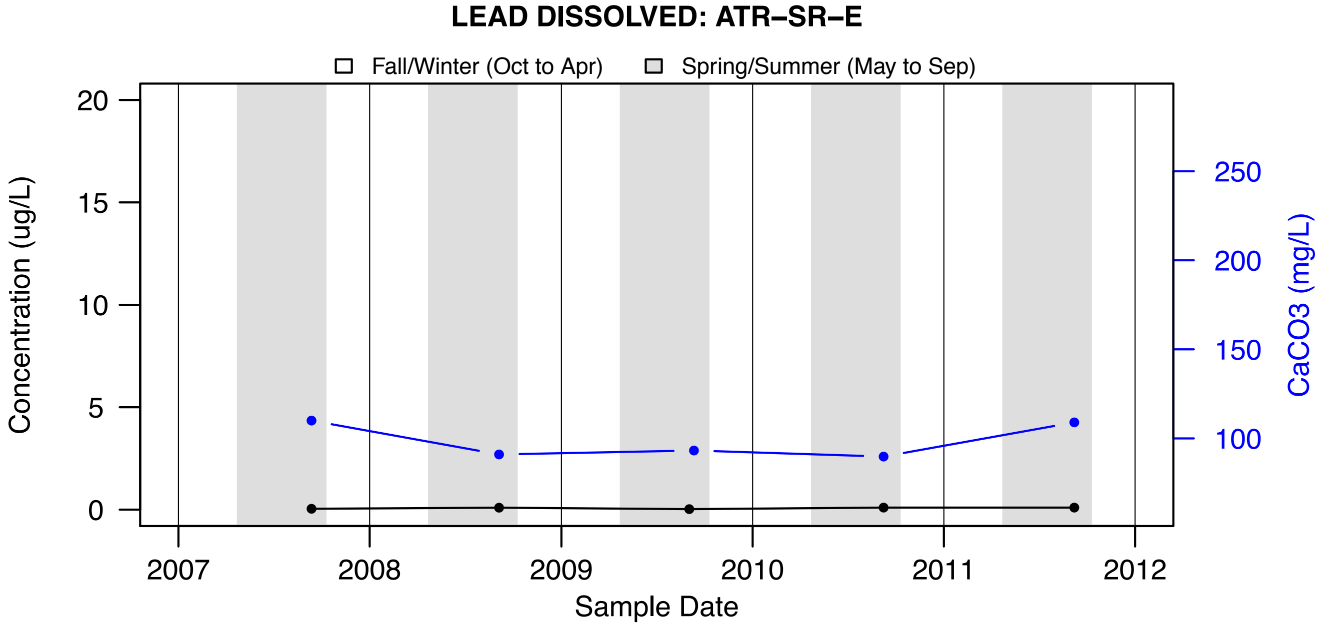
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.104: AMMONIA-N: ATR-SR-E - NA



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.105: NICKEL DISSOLVED: ATR-SR-E - NA



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.106: LEAD DISSOLVED: ATR-SR-E - NA

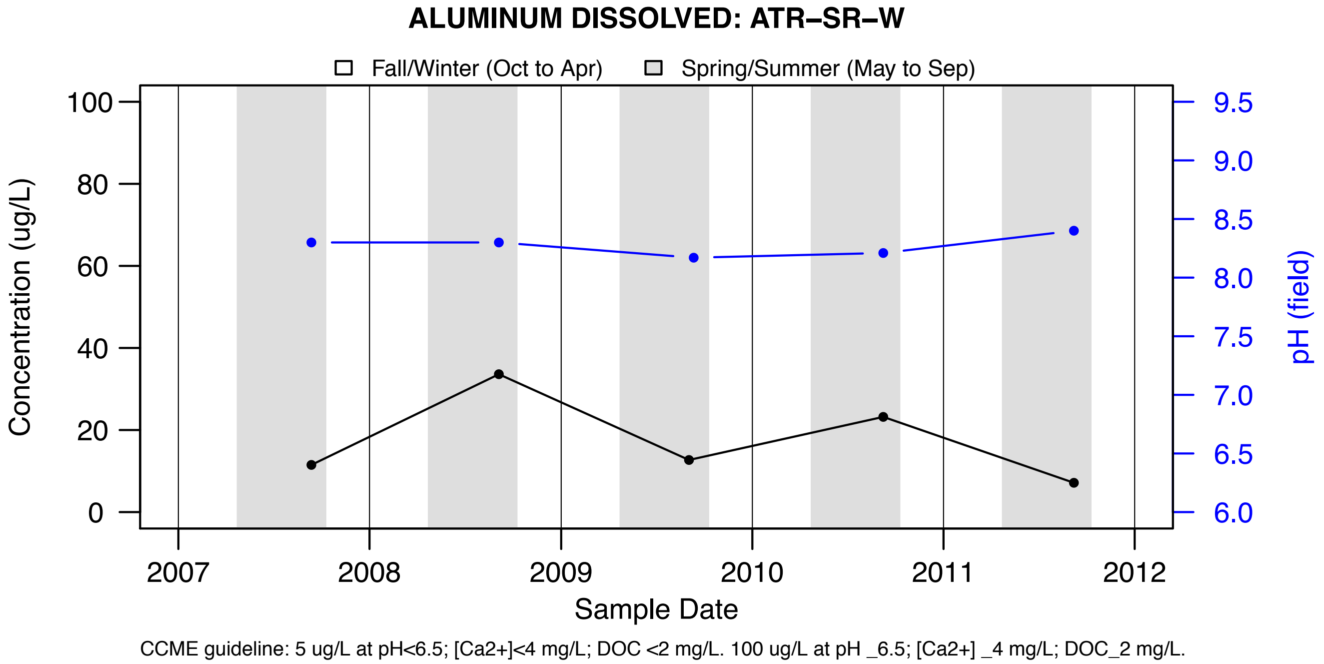


Figure A4.107: ALUMINUM DISSOLVED: ATR-SR-W - NA

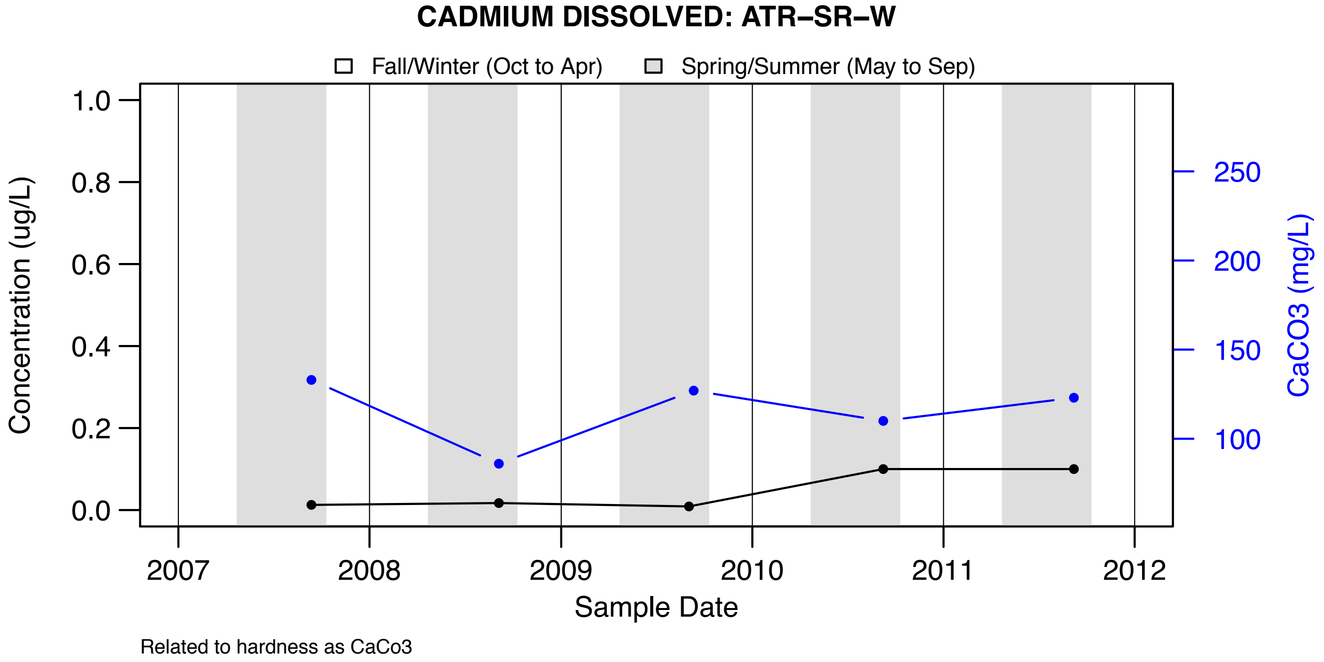
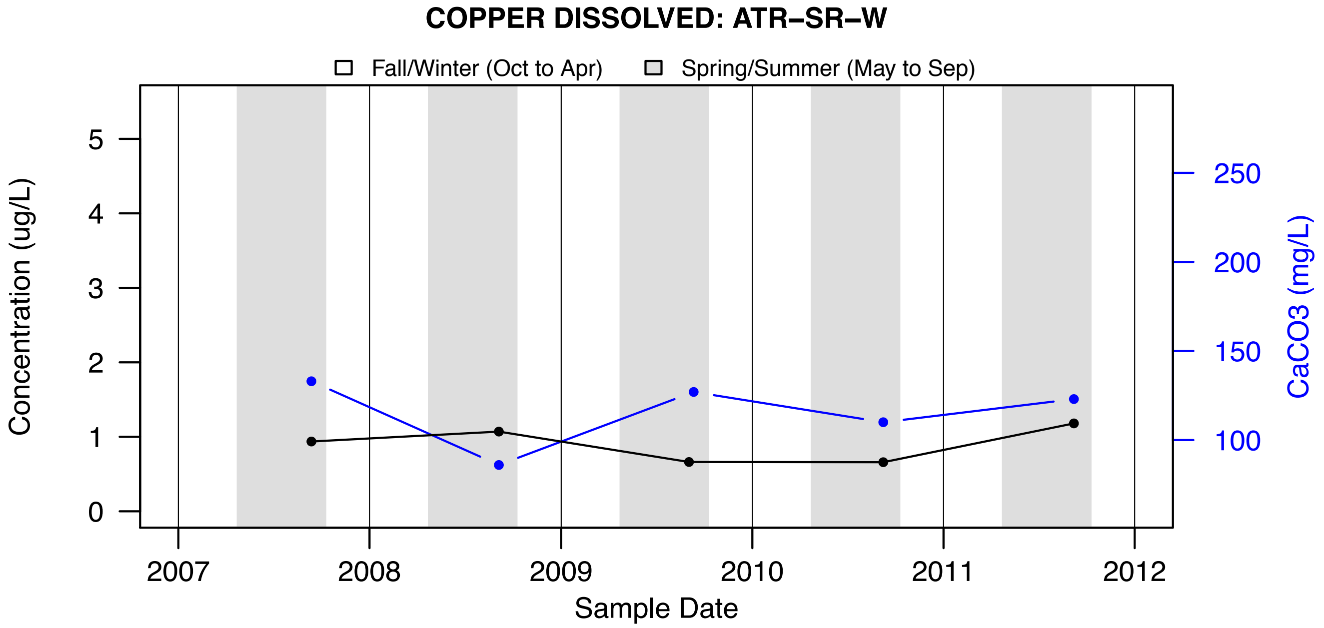
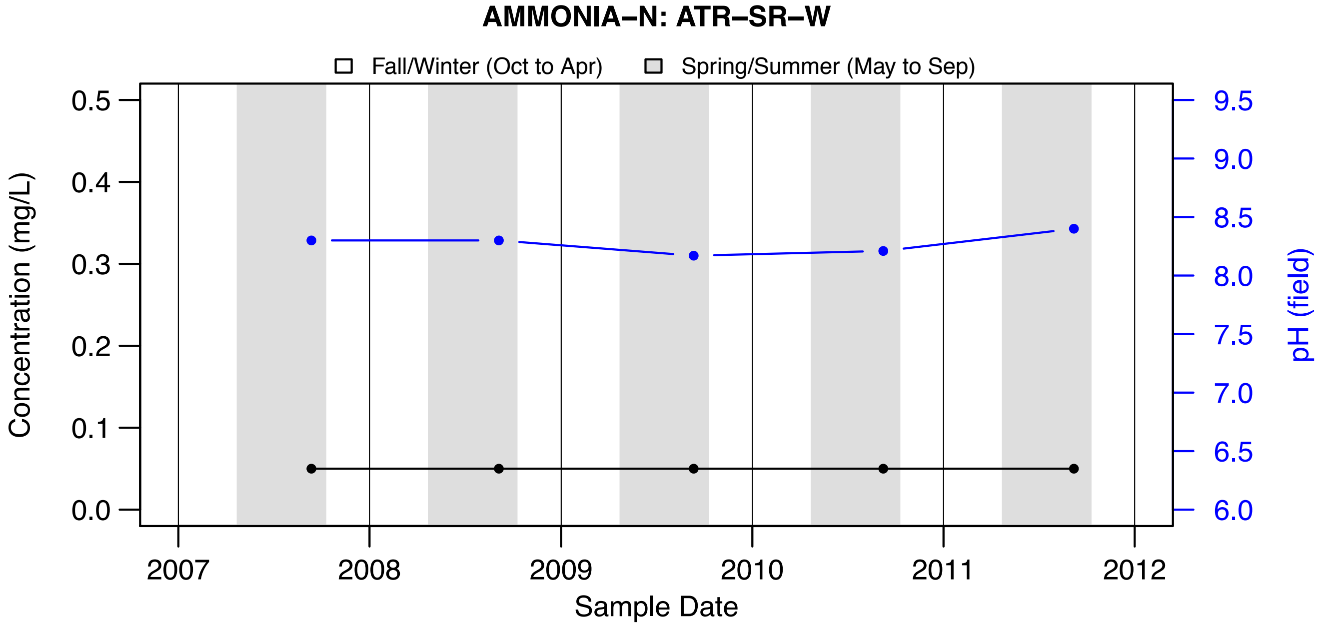


Figure A4.108: CADMIUM DISSOLVED: ATR-SR-W - NA



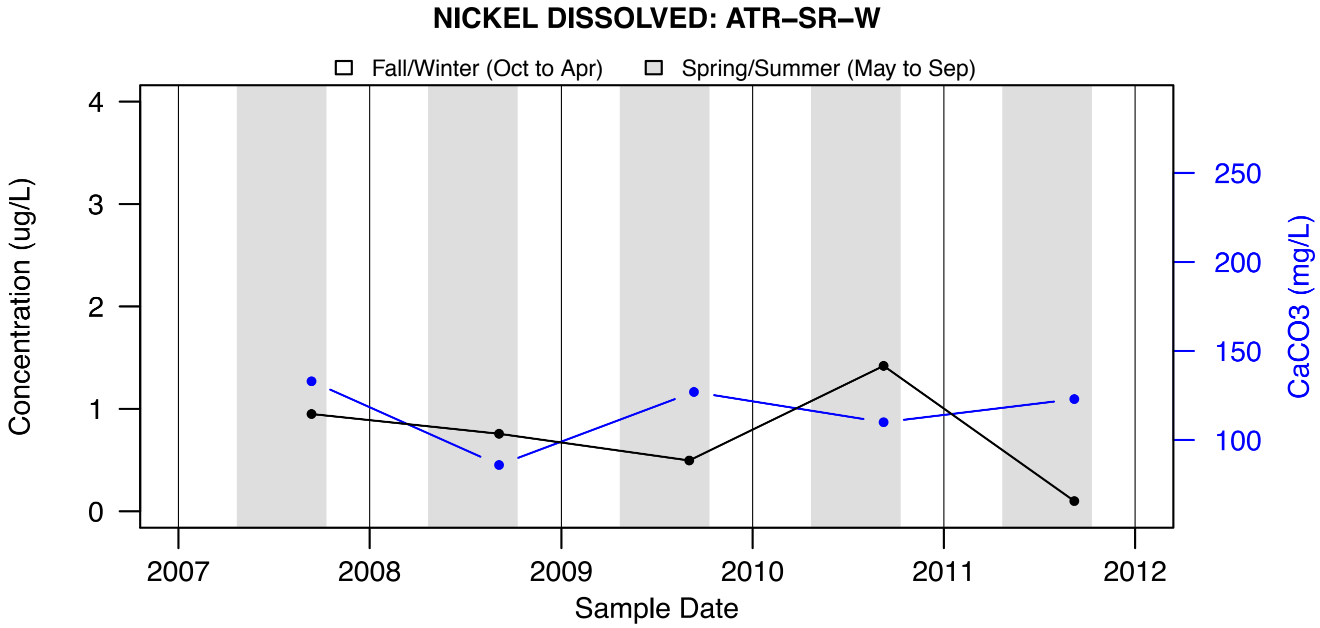
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.109: COPPER DISSOLVED: ATR-SR-W - NA



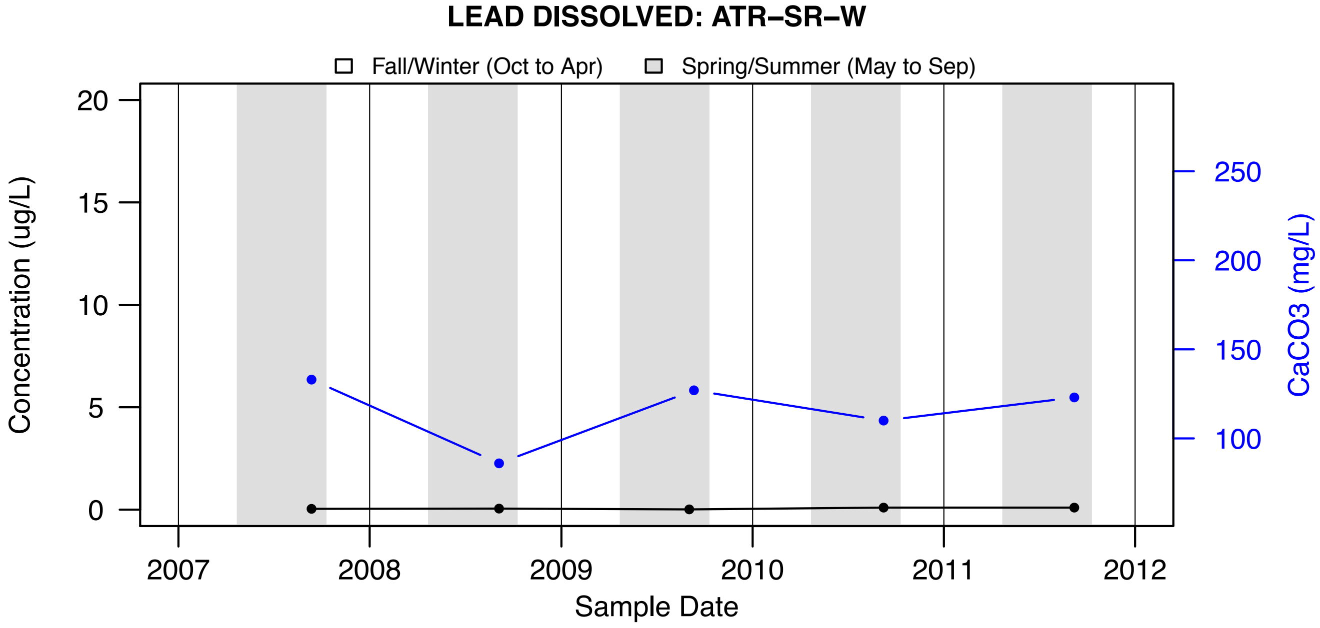
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.110: AMMONIA-N: ATR-SR-W - NA



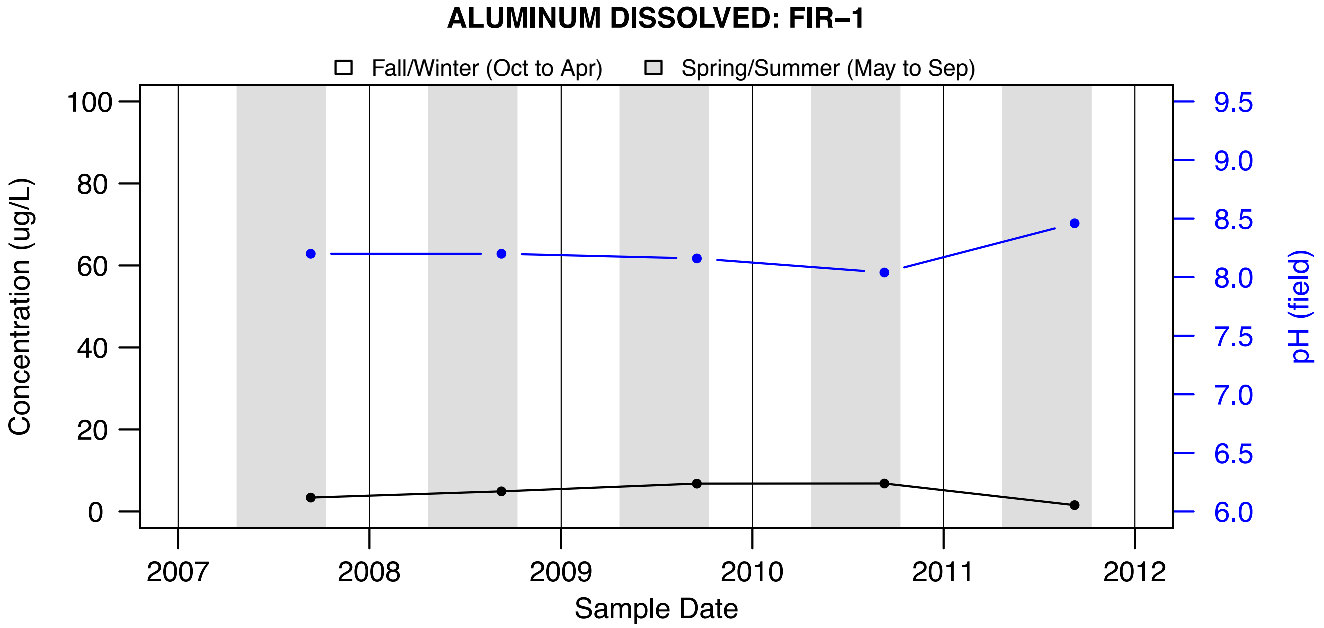
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.111: NICKEL DISSOLVED: ATR-SR-W - NA



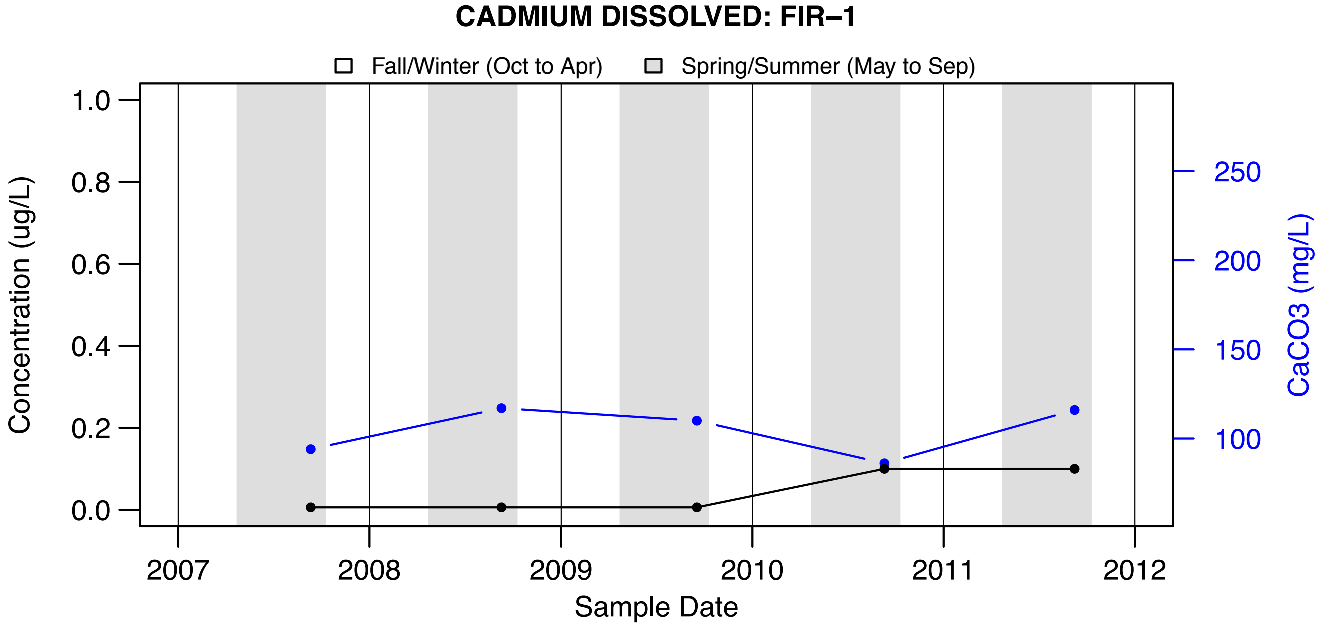
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.112: LEAD DISSOLVED: ATR-SR-W - NA



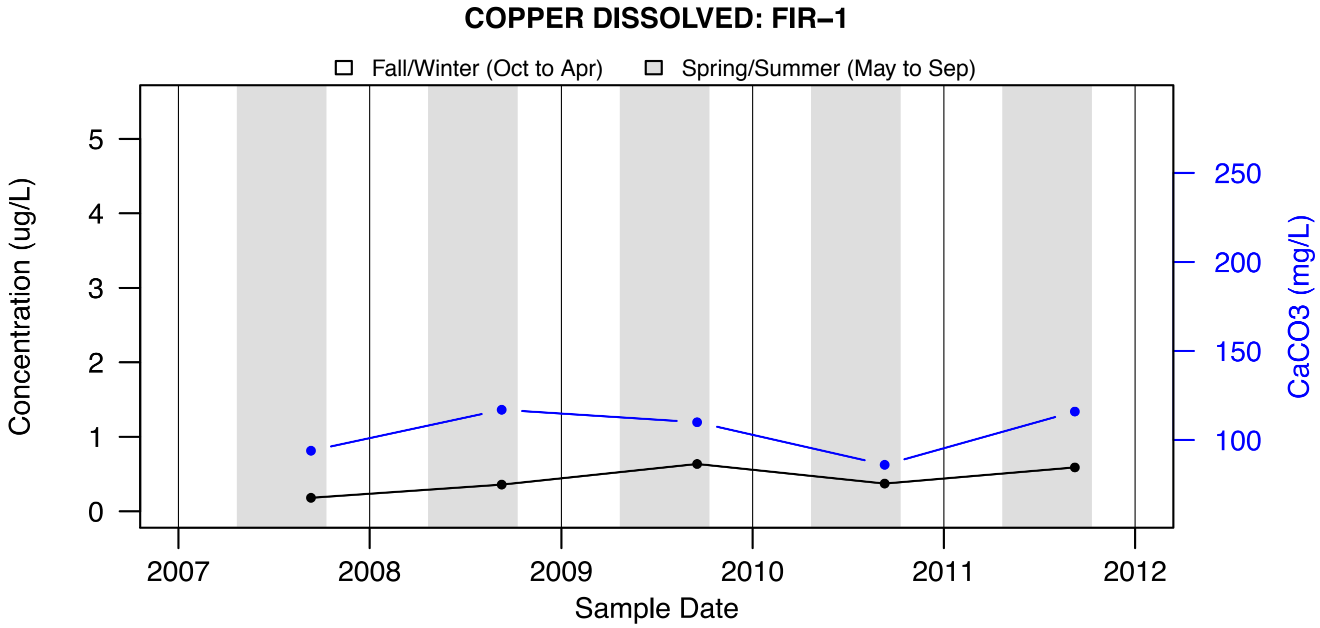
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.113: ALUMINUM DISSOLVED: FIR-1 - NA



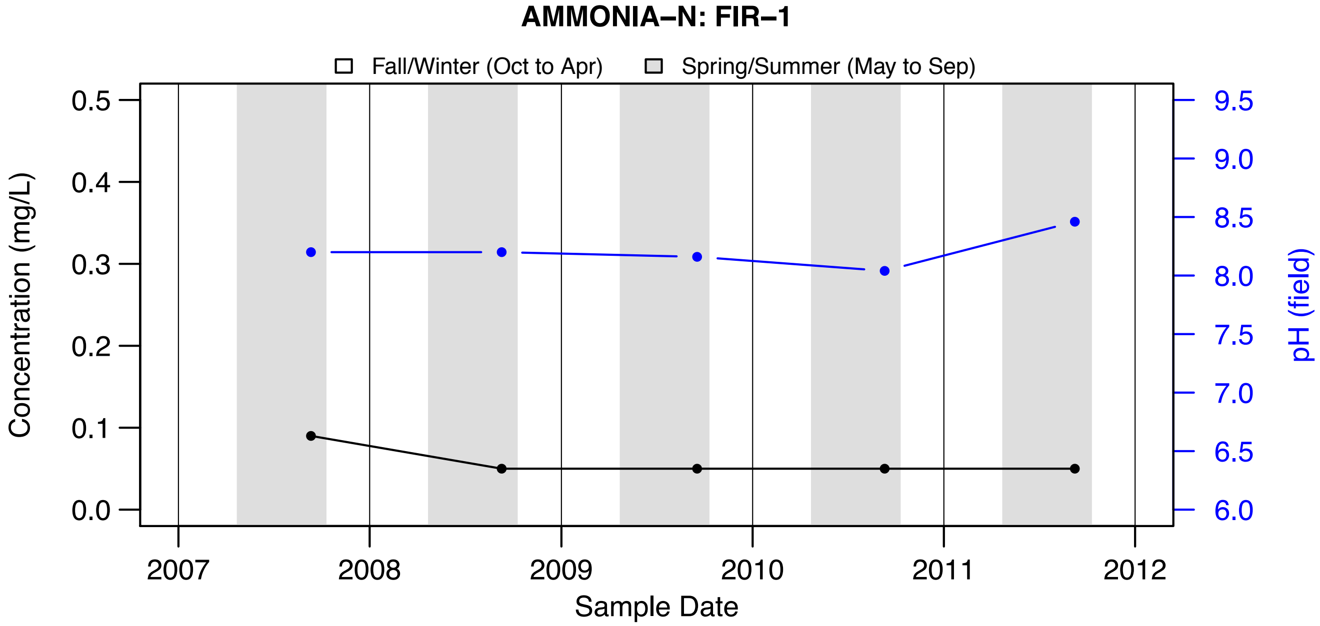
Related to hardness as CaCo3

Figure A4.114: CADMIUM DISSOLVED: FIR-1 - NA



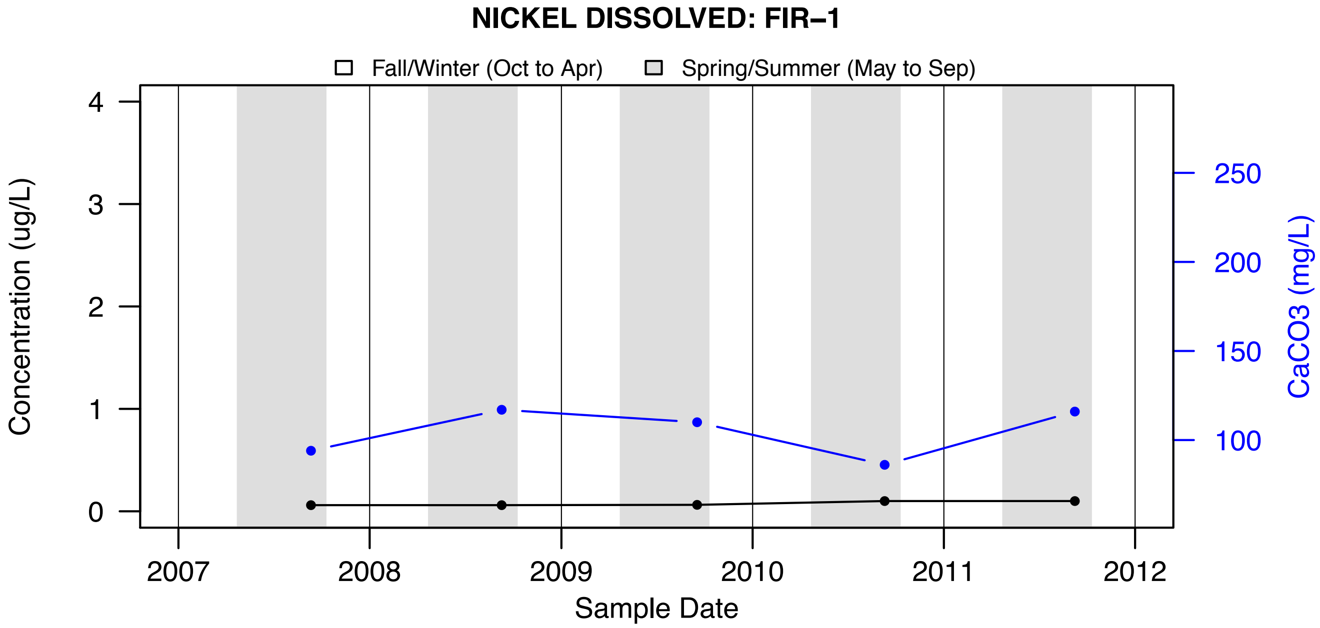
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid−extractable copper concentrations

Figure A4.115: COPPER DISSOLVED: FIR-1 - NA



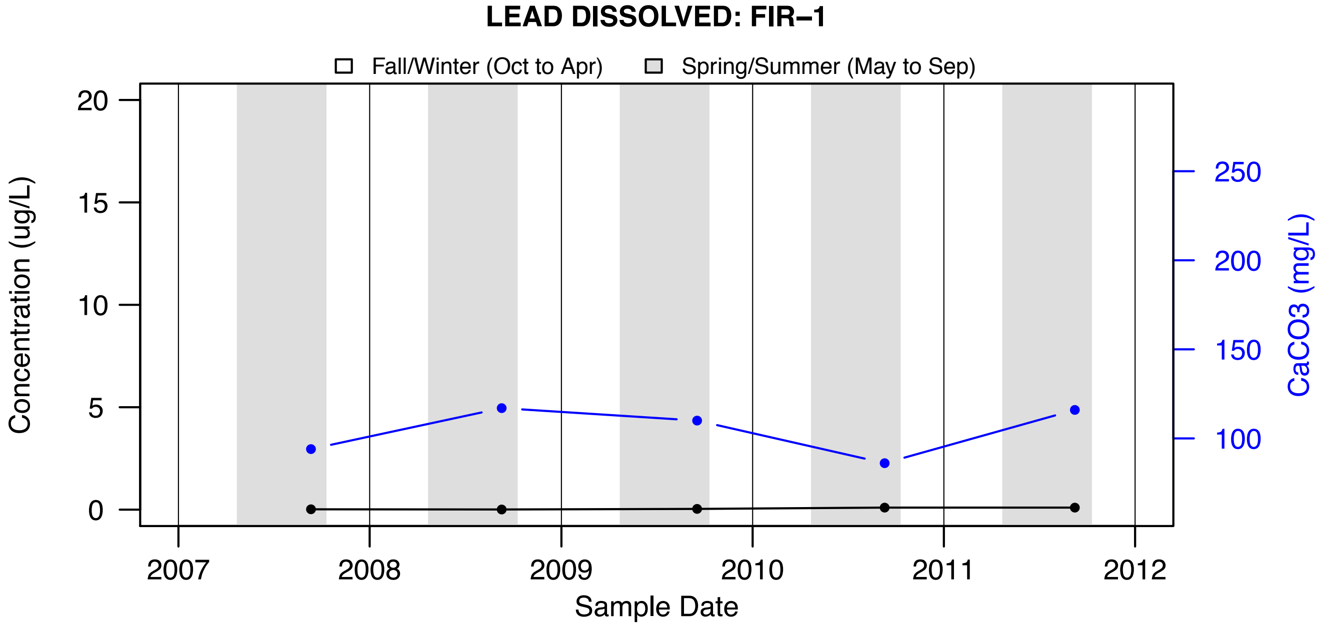
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.116: AMMONIA-N: FIR-1 - NA



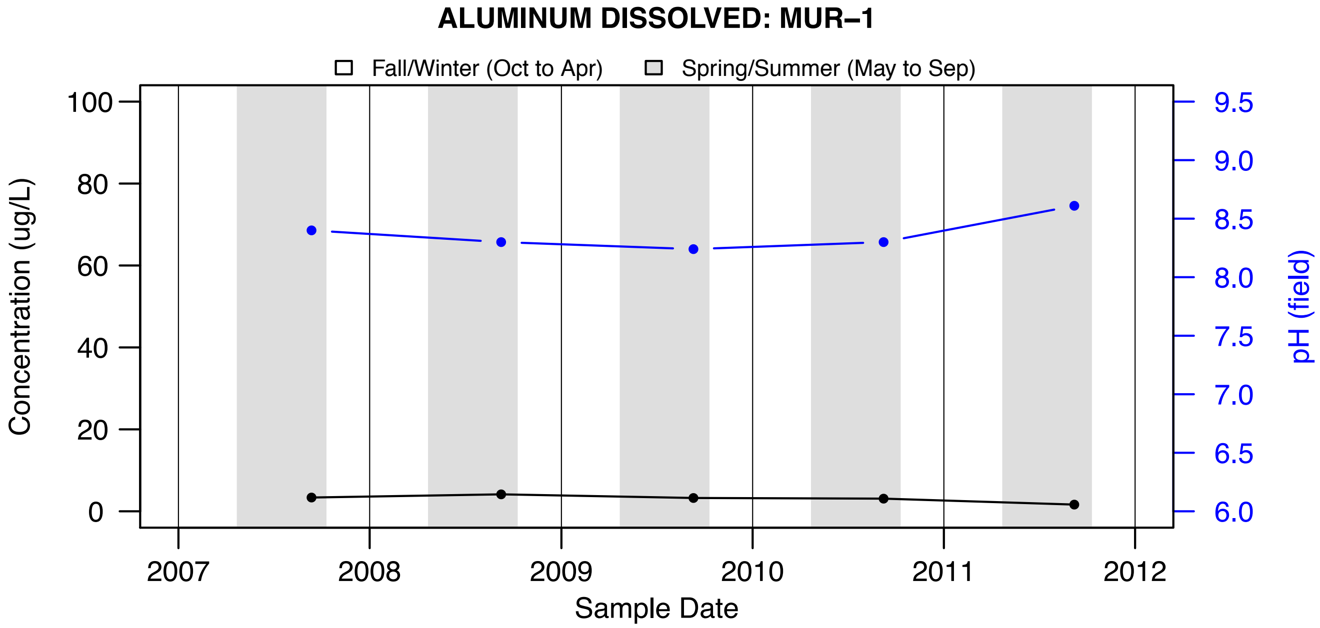
CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.117: NICKEL DISSOLVED: FIR-1 - NA



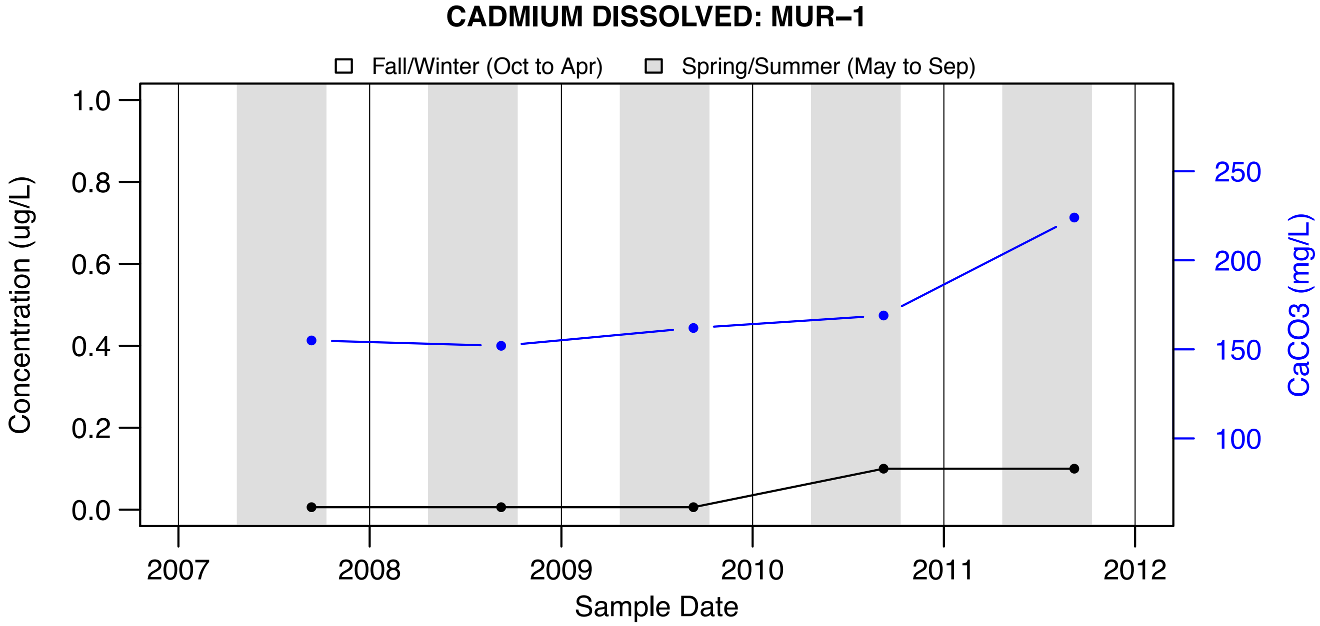
CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

Figure A4.118: LEAD DISSOLVED: FIR-1 - NA



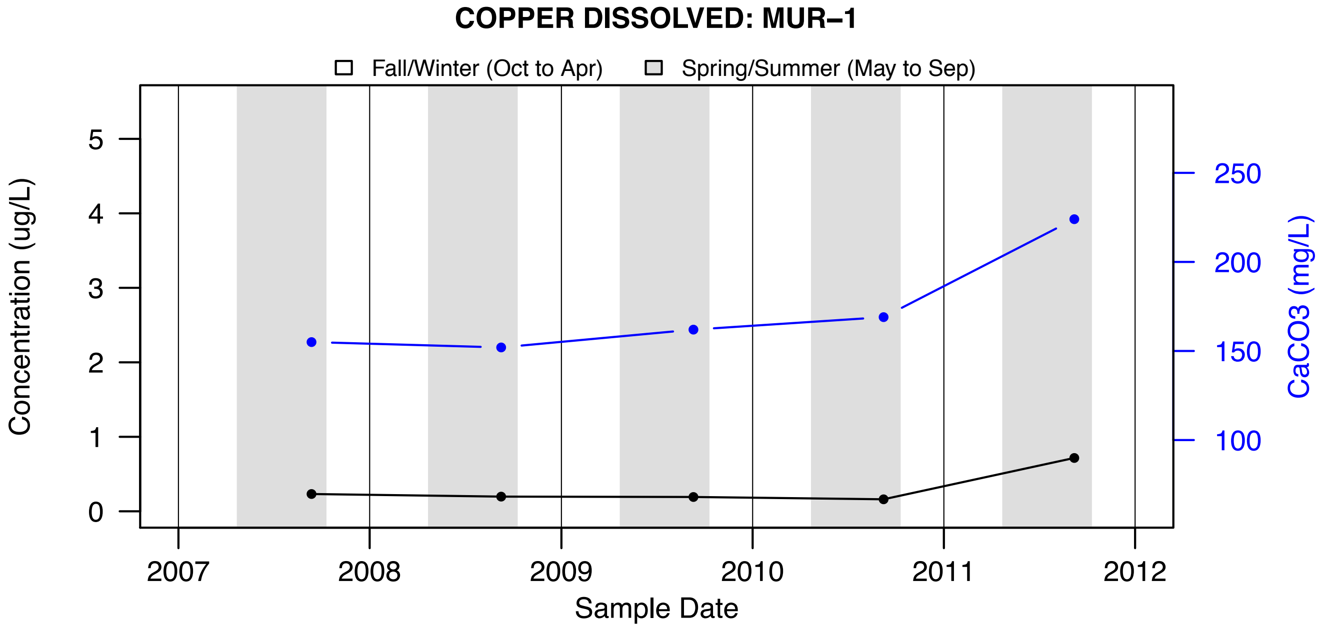
CCME guideline: 5 ug/L at pH<6.5; [Ca2+]<4 mg/L; DOC <2 mg/L. 100 ug/L at pH _6.5; [Ca2+] _4 mg/L; DOC_2 mg/L.

Figure A4.119: ALUMINUM DISSOLVED: MUR-1 - NA



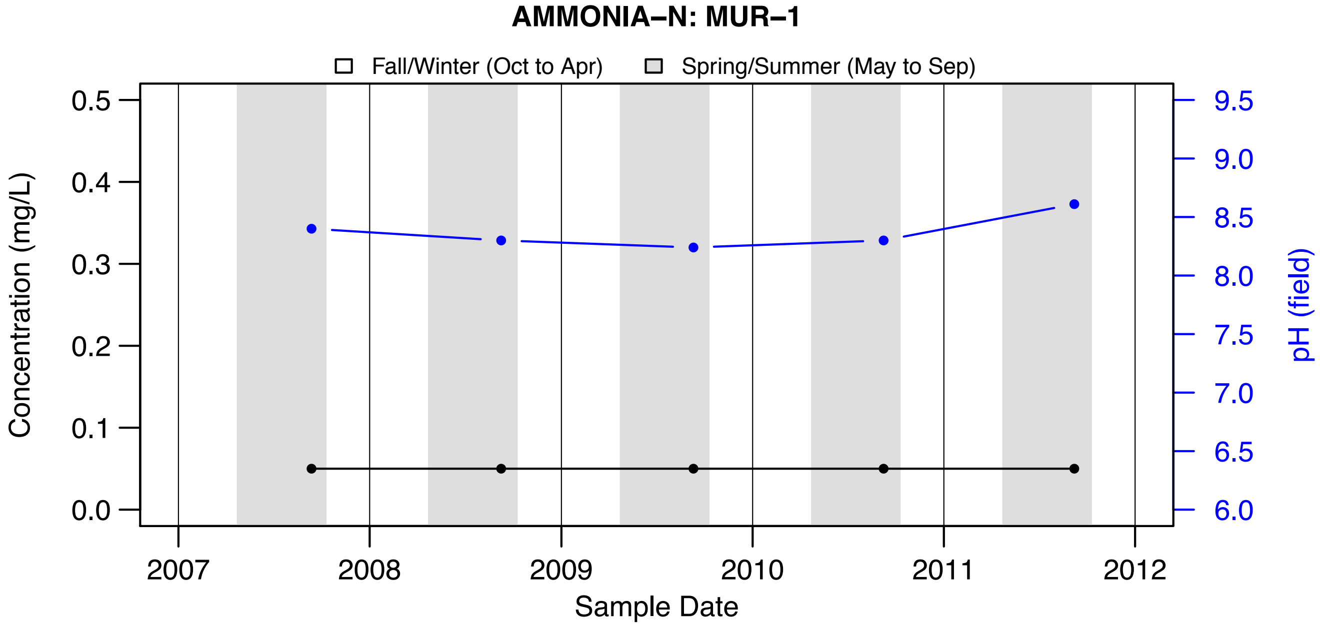
Related to hardness as CaCo3

Figure A4.120: CADMIUM DISSOLVED: MUR-1 - NA



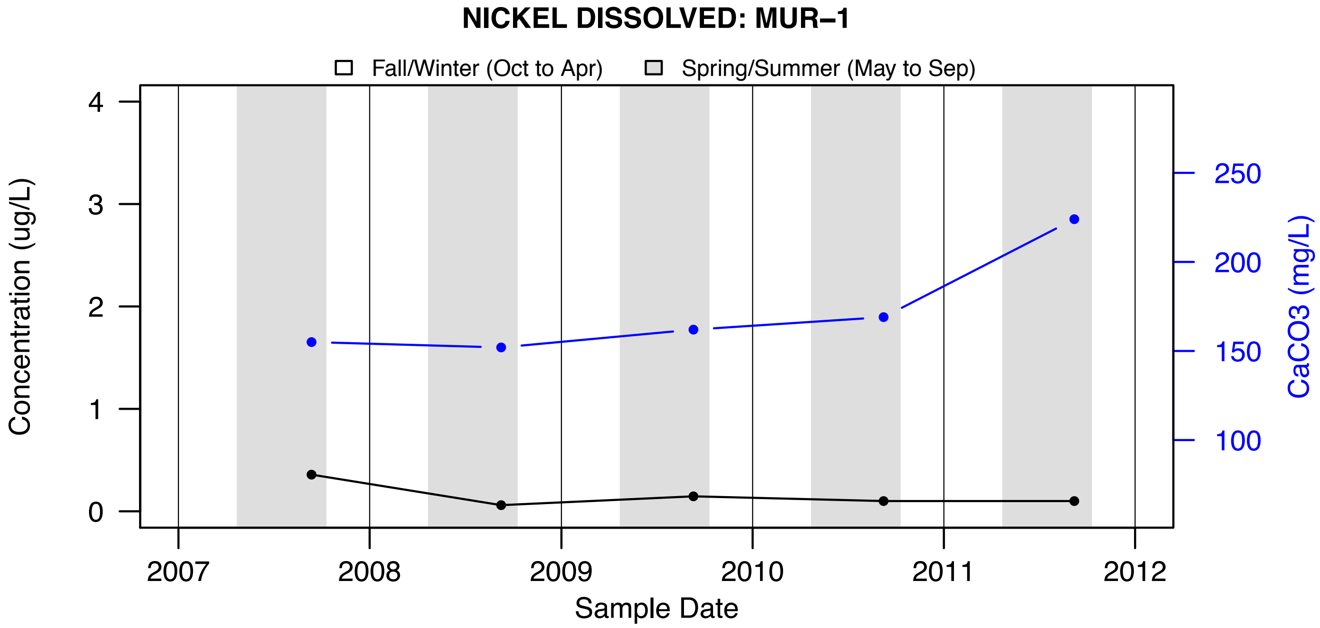
AB guideline: Chronic toxicity of copper in soft water was inconclusive; the chronic guideline can therefore only be applied at water hardness equal to or greater than 50 mg/L CaCO3. Guideline applies to acid–extractable copper concentrations

Figure A4.121: COPPER DISSOLVED: MUR-1 - NA



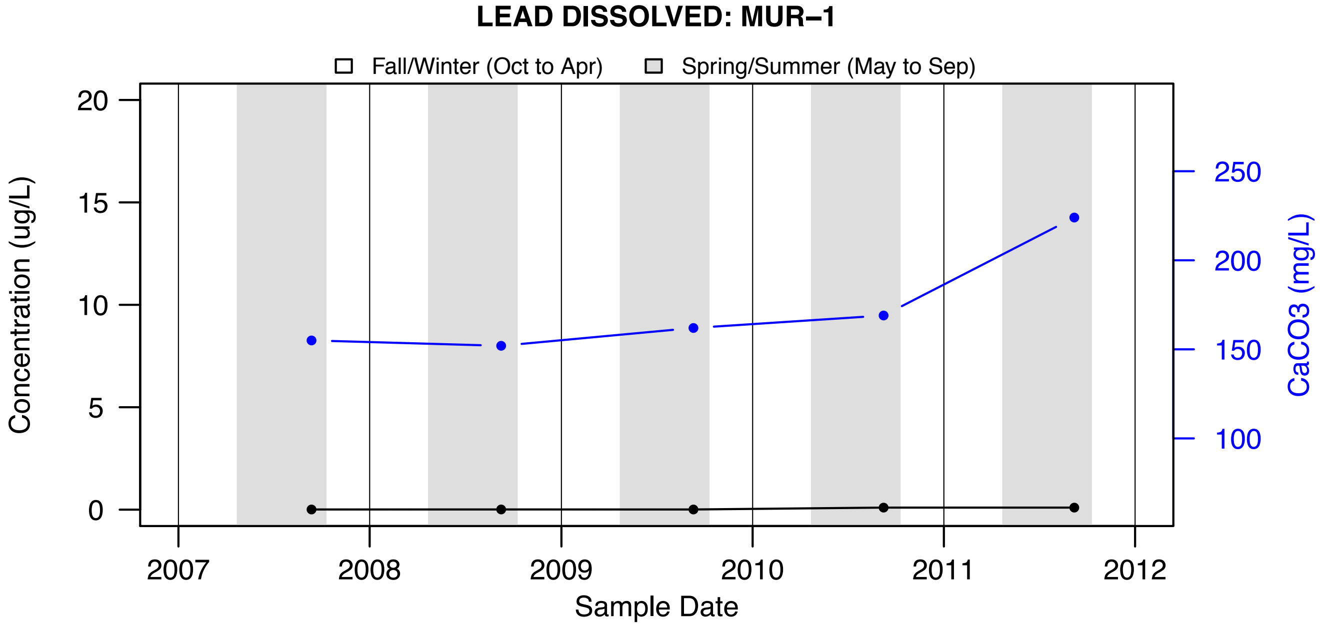
CCME guideline: 1.37 mg/L at pH 8.0, 10 degrees; 2.20 mg/L at pH 6.5, 10 degrees.

Figure A4.122: AMMONIA-N: MUR-1 - NA



CCME guideline: 25ug/L at [CaCO3] = 0 to 60mg/L; 65ug/L at [CaCO3] = 60 to 120mg/L;
110ug/L at [CaCO3] = 120 to 180mg/L; 150 ug/L at [CaCO3] > 180 mg/L

Figure A4.123: NICKEL DISSOLVED: MUR-1 - NA



CCME guideline: 1ug/L at [CaCO3] = 0 to 60mg/L; 2ug/L at [CaCO3] = 60 to 120mg/L; 4ug/L at [CaCO3] = 120 to 180mg/L;
7 ug/L at [CaCO3] >180mg/L.

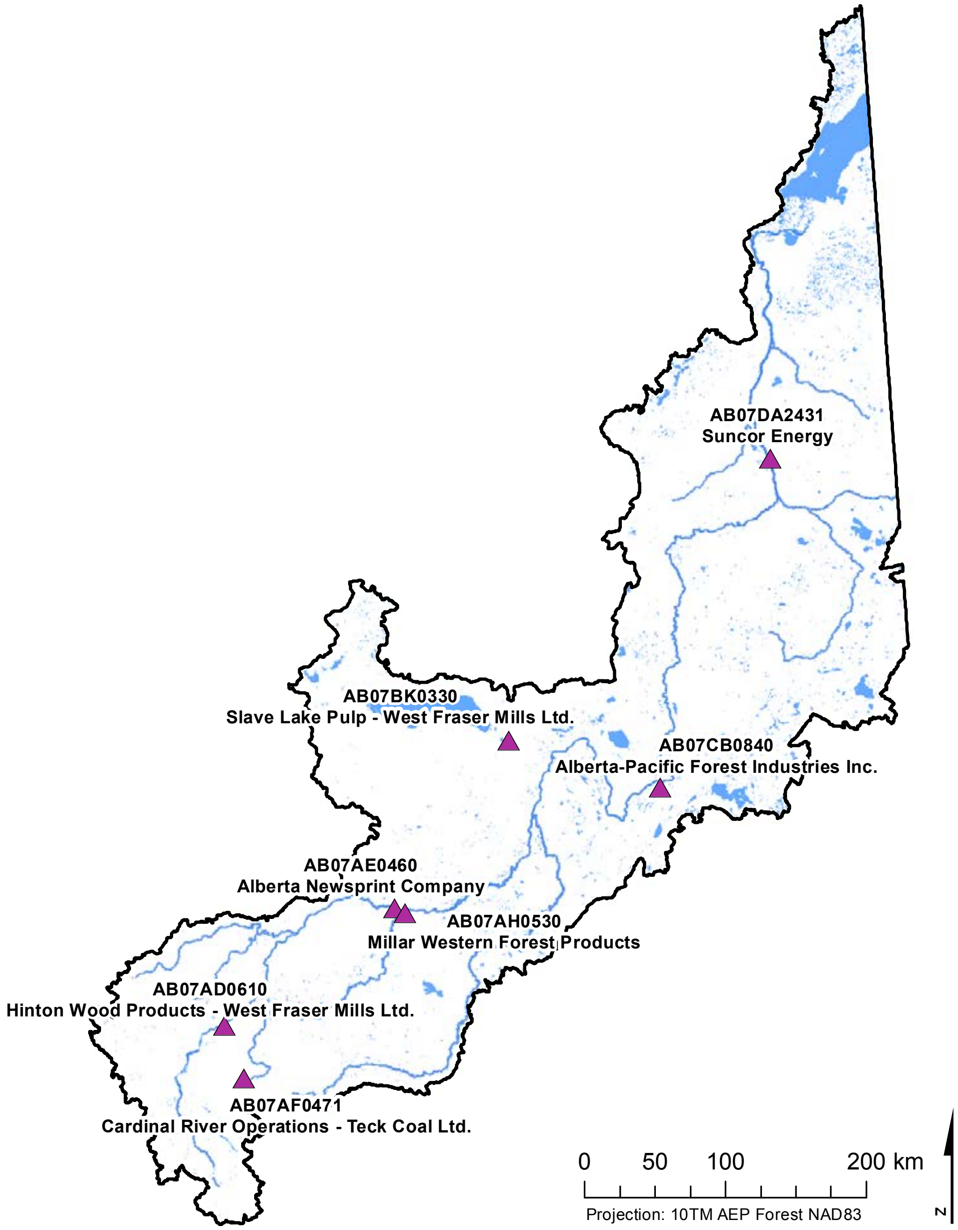
Figure A4.124: LEAD DISSOLVED: MUR-1 - NA

Appendix 5:

Overview of select water quality parameters measured at Industrial Class B facilities between 2007 and spring 2012

Table A5-1. Station number, description, and location of industrial Class B facilities included in the publically available data provided by Alberta Environment and Sustainable Resource Development.

Station Number	Station Description	Latitude	Longitude
AB07AD0610	Hinton Wood Products - West Fraser Mills Ltd.	53.4022	-117.6055
AB07AE0460	Alberta Newsprint Company	54.1763	-115.8013
AB07AF0471	Cardinal River Operations - Teck Coal Ltd.	53.0661	-117.3758
AB07AH0530	Millar Western Forest Products	54.1486	-115.6888
AB07BK0330	Slave Lake Pulp - West Fraser Mills Ltd.	55.2527	-114.5402
AB07CB0840	Alberta-Pacific Forest Industries Inc.	54.9316	-112.8633
AB07DA2431	Suncor Energy	57.0062	-111.4611



List of Figures

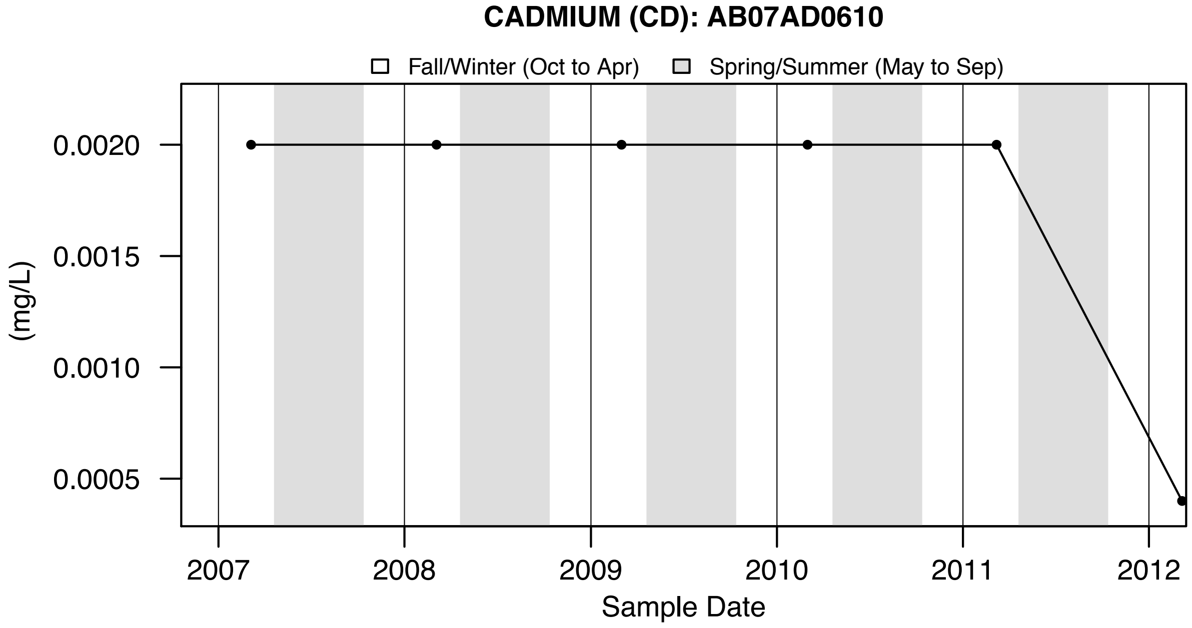


Figure A5.1: CADMIUM (CD): AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

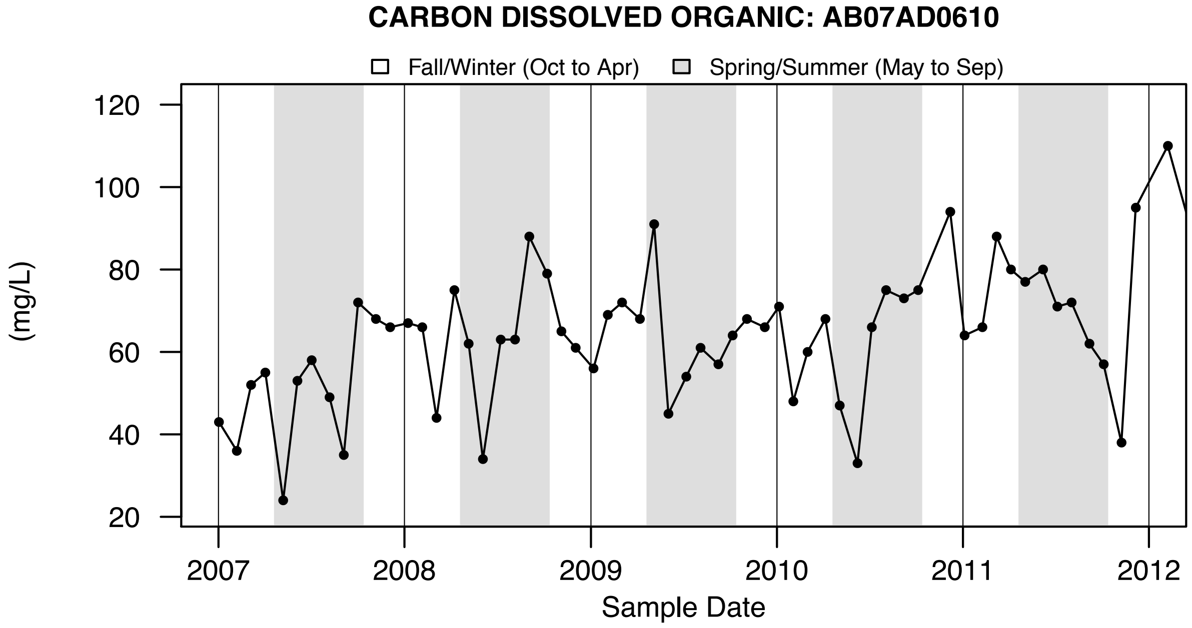


Figure A5.2: CARBON DISSOLVED ORGANIC: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

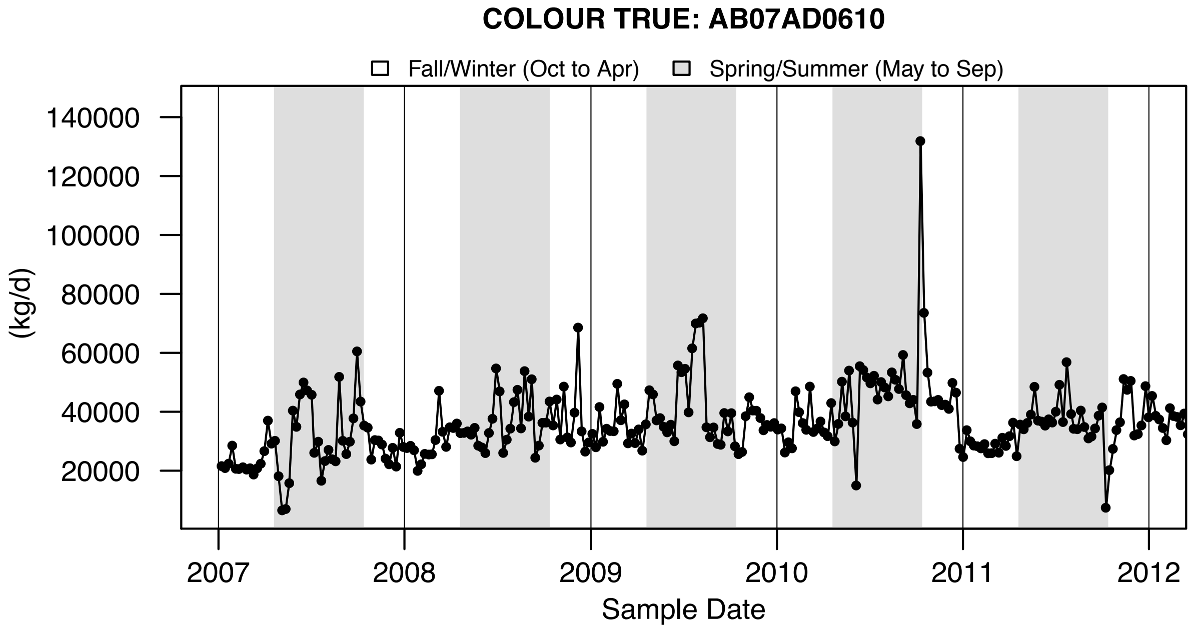


Figure A5.3: COLOUR TRUE: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

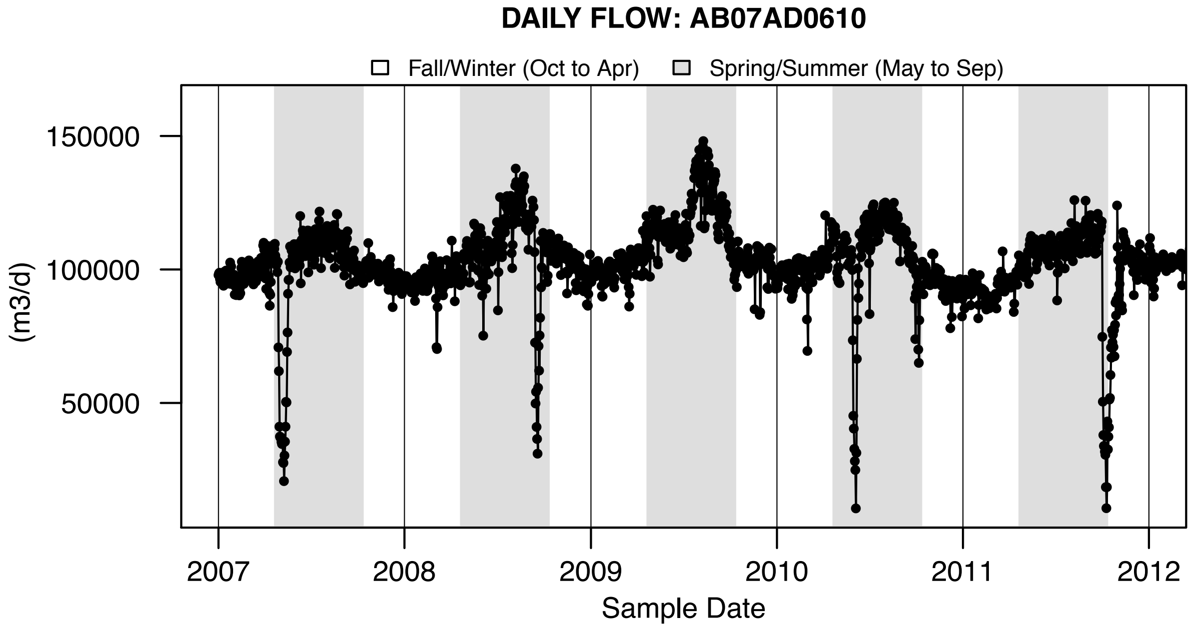


Figure A5.4: DAILY FLOW: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

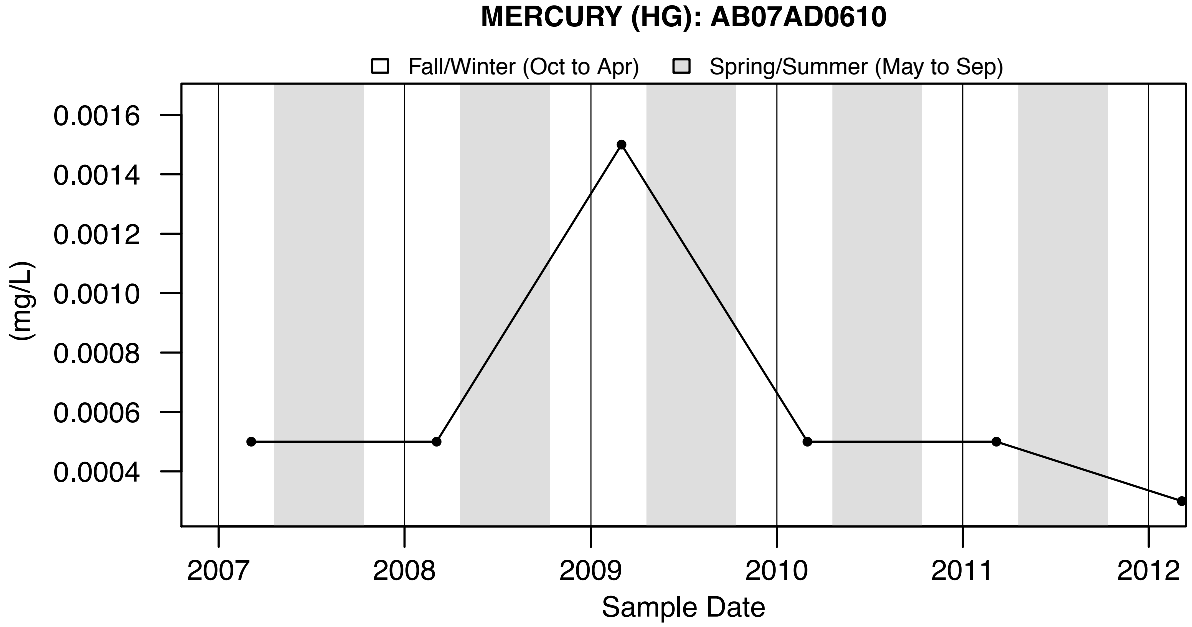


Figure A5.5: MERCURY (HG): AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

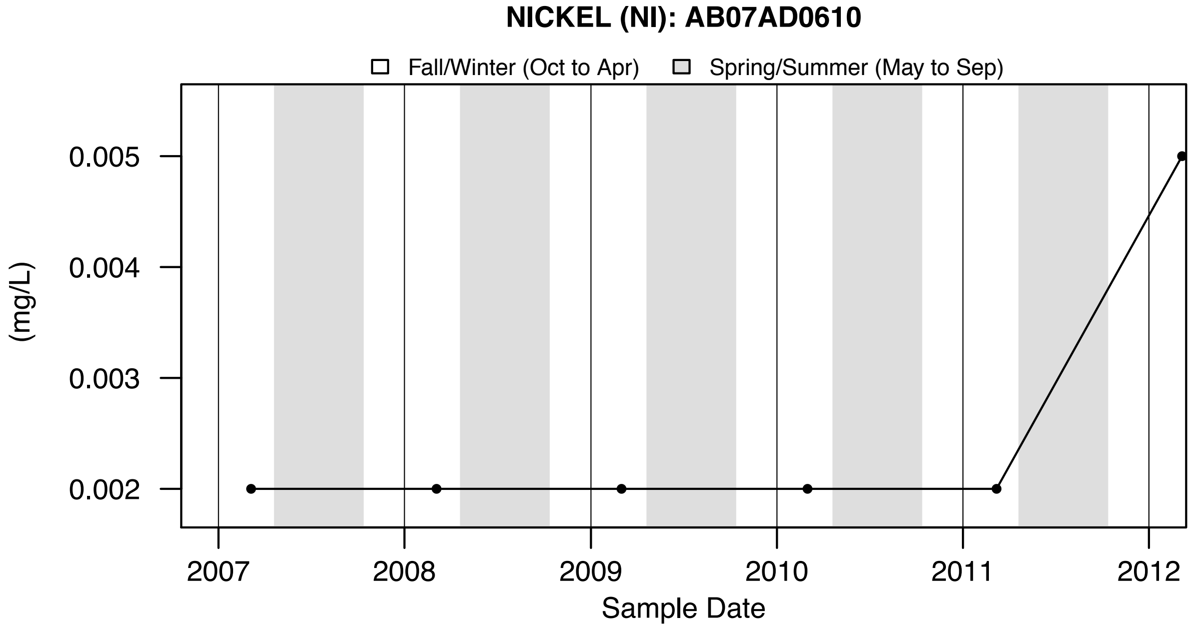


Figure A5.6: NICKEL (NI): AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

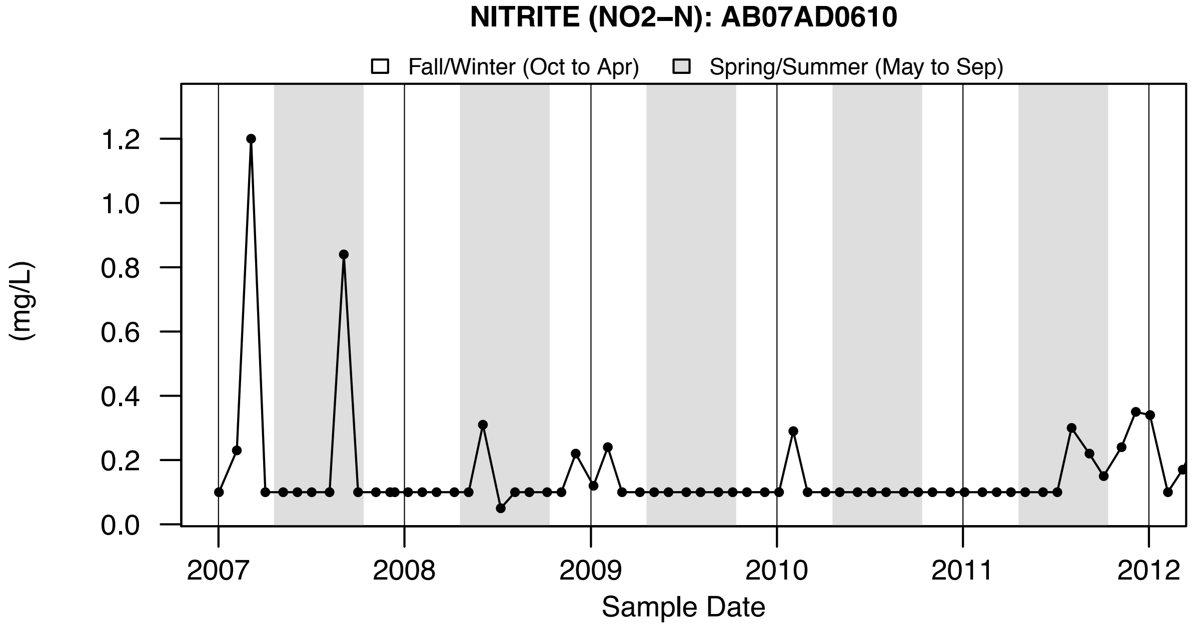


Figure A5.7: NITRITE (NO2-N): AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

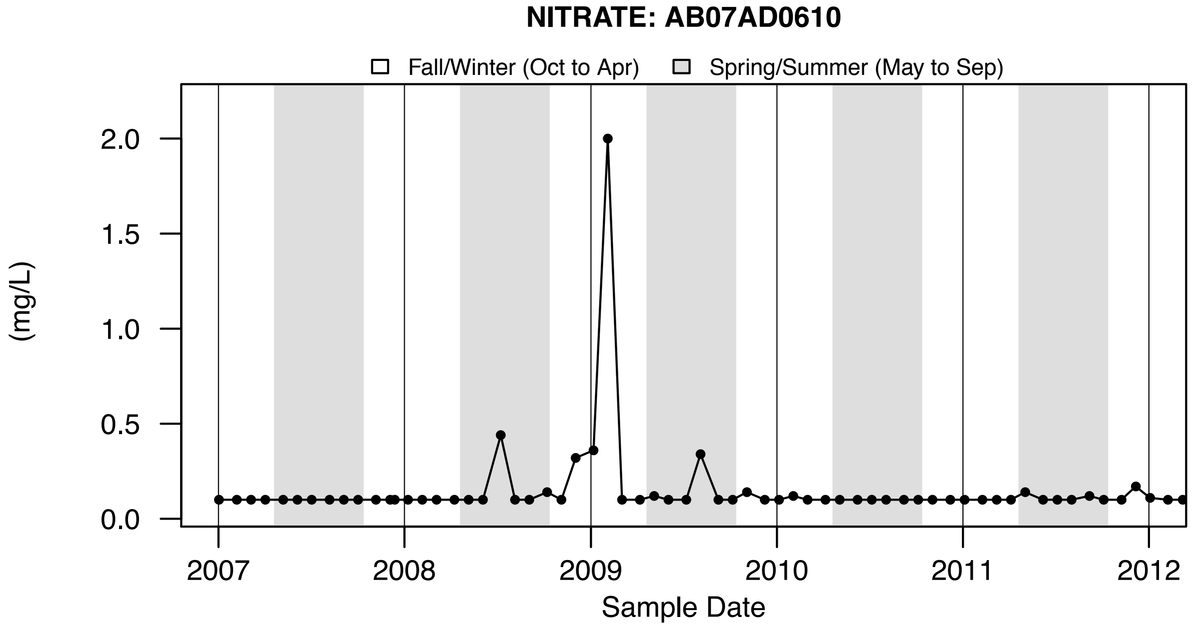


Figure A5.8: NITRATE: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

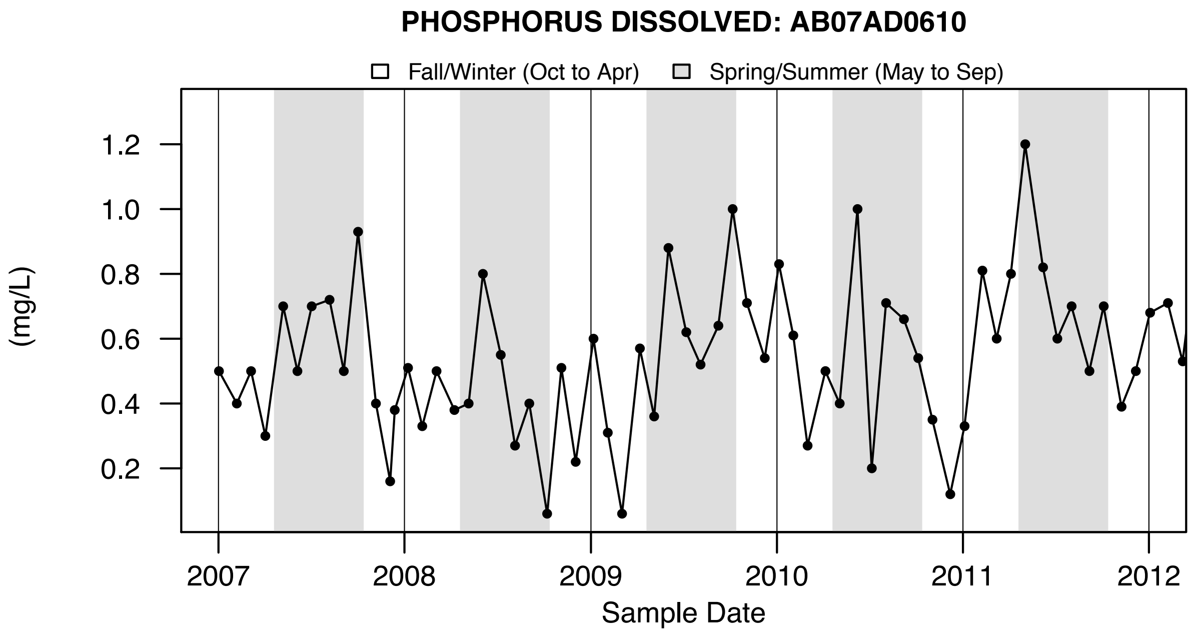


Figure A5.9: PHOSPHORUS DISSOLVED: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

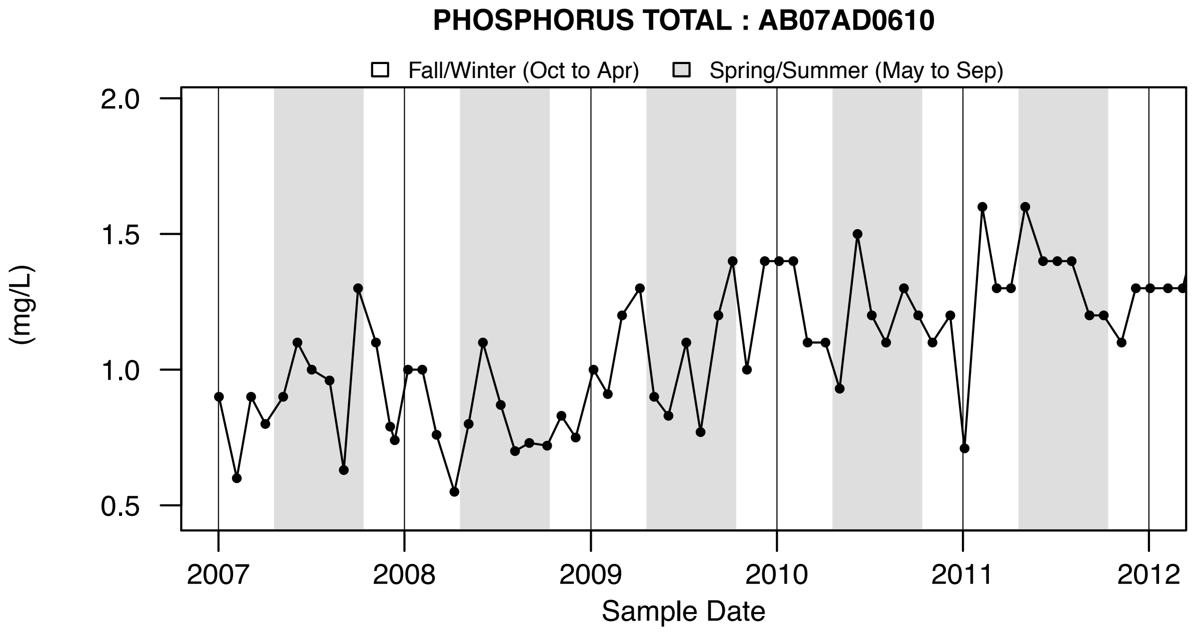


Figure A5.10: PHOSPHORUS TOTAL : AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

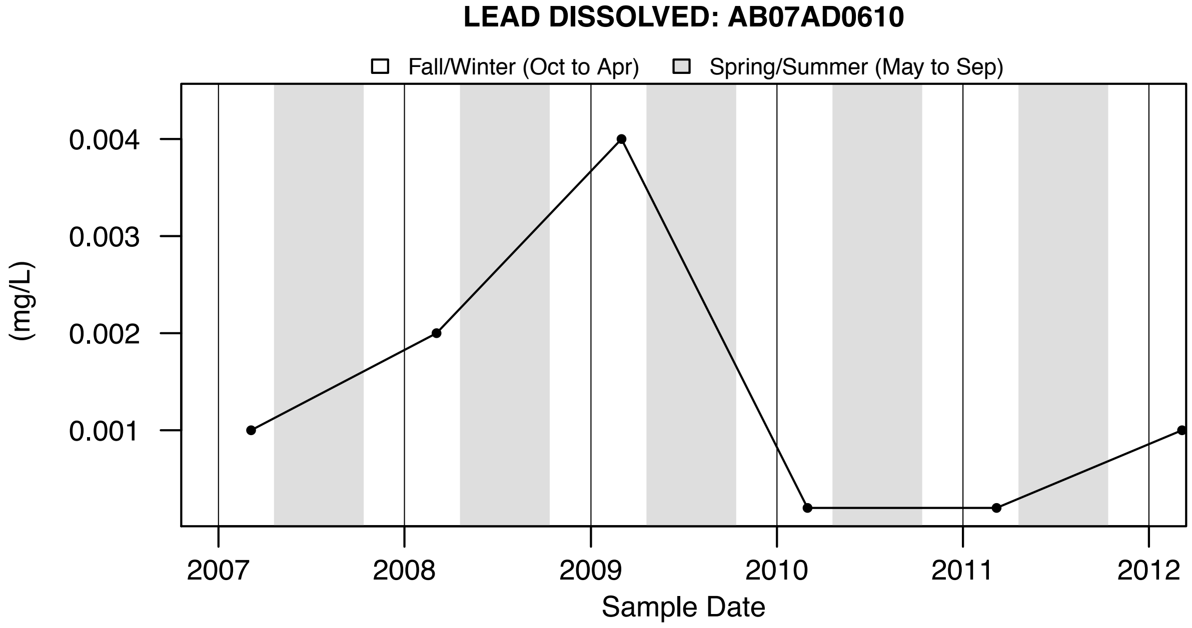


Figure A5.11: LEAD DISSOLVED: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

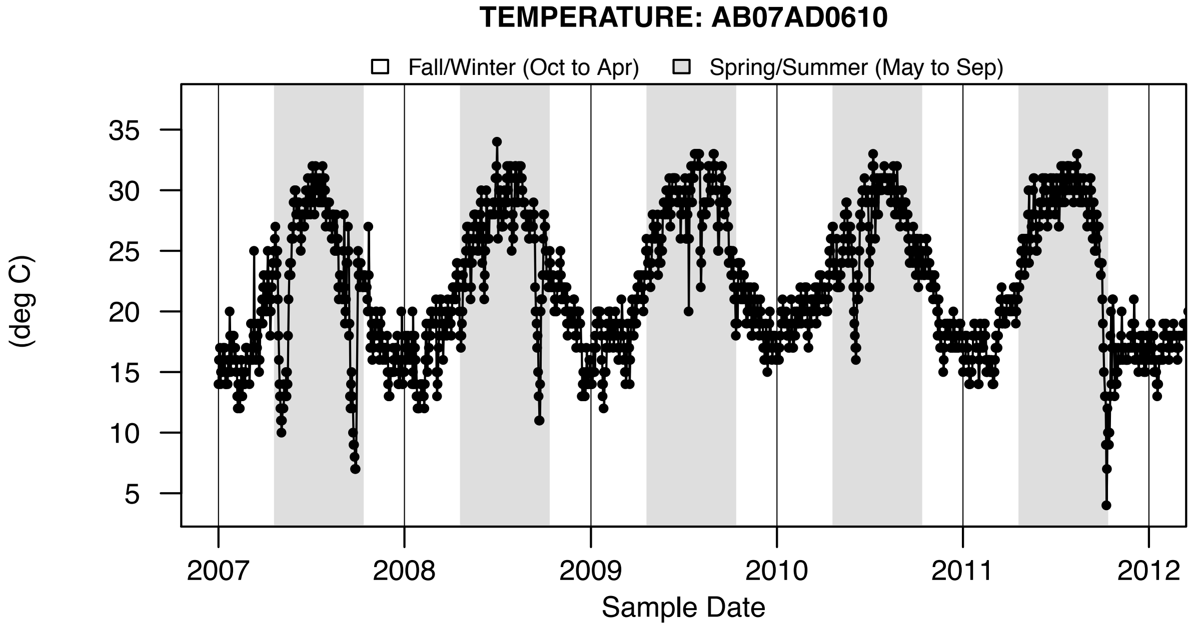


Figure A5.12: TEMPERATURE: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

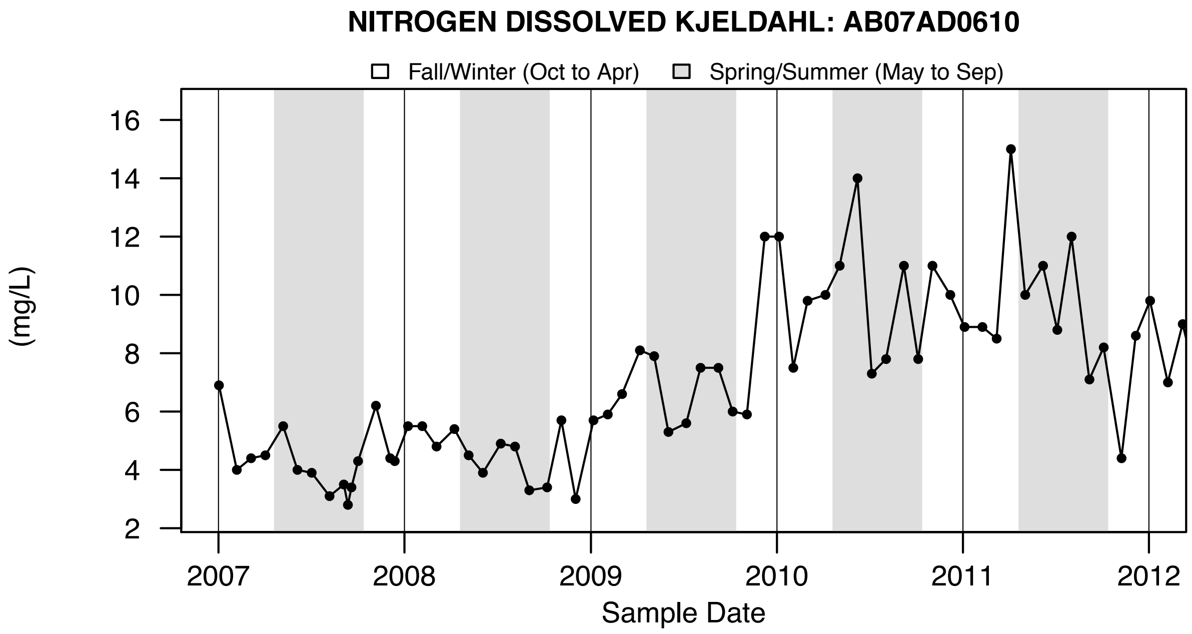


Figure A5.13: NITROGEN DISSOLVED KJELDAHL: AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

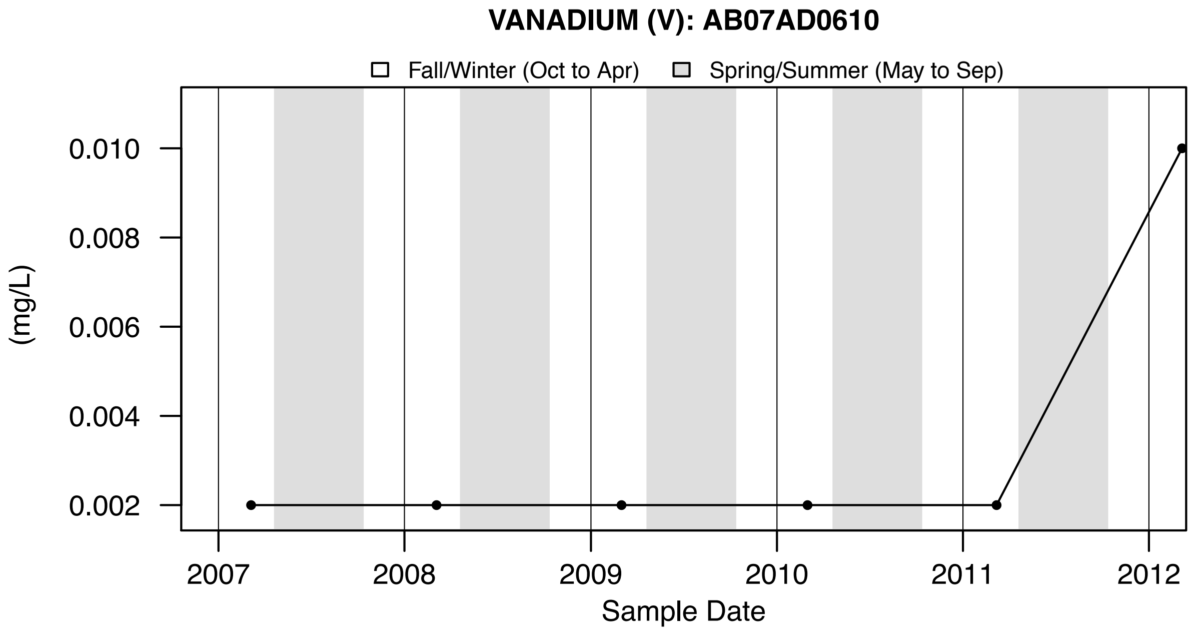


Figure A5.14: VANADIUM (V): AB07AD0610 - HINTON WOOD PRODUCTS - WEST FRASER MILLS LTD (FINAL EFFLUENT)

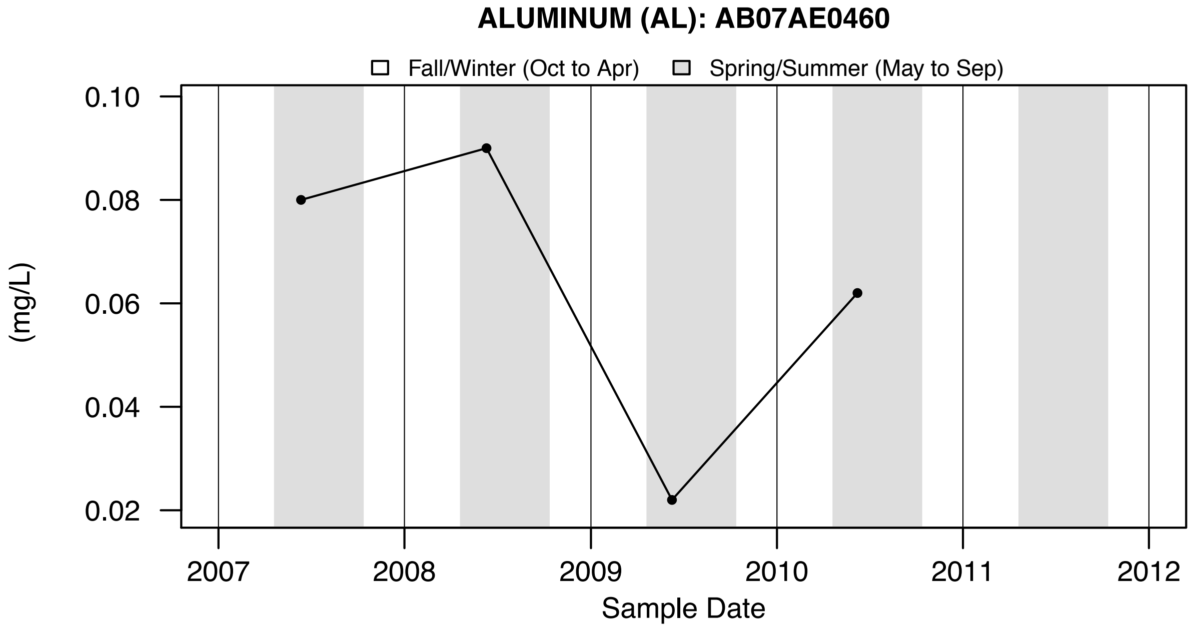


Figure A5.15: ALUMINUM (AL): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

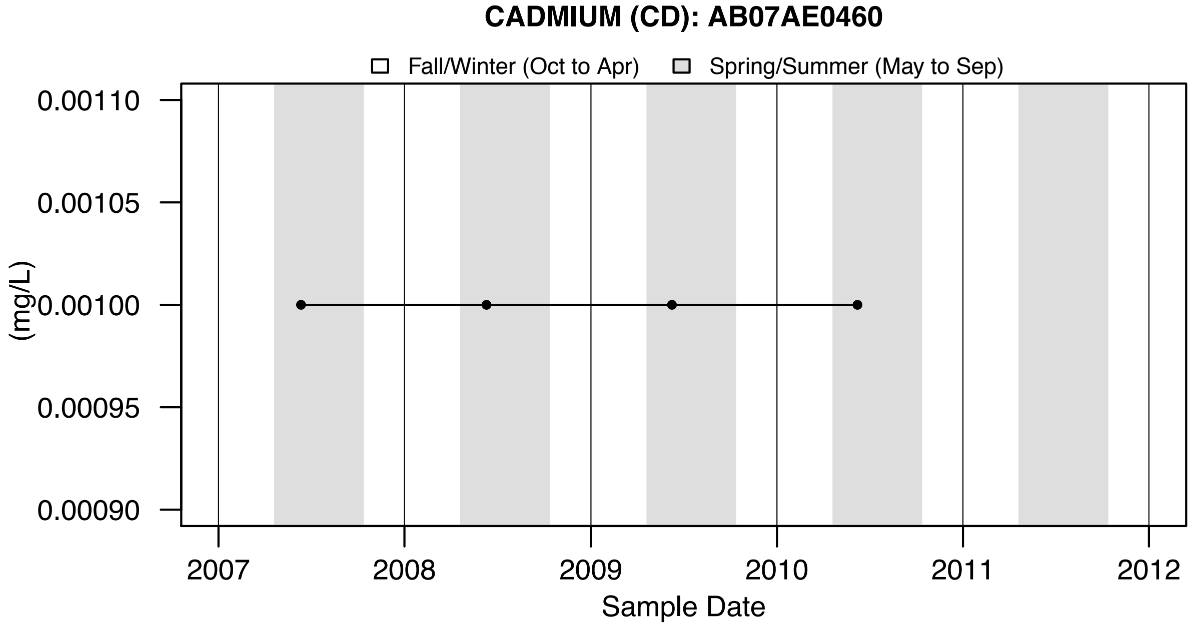


Figure A5.16: CADMIUM (CD): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

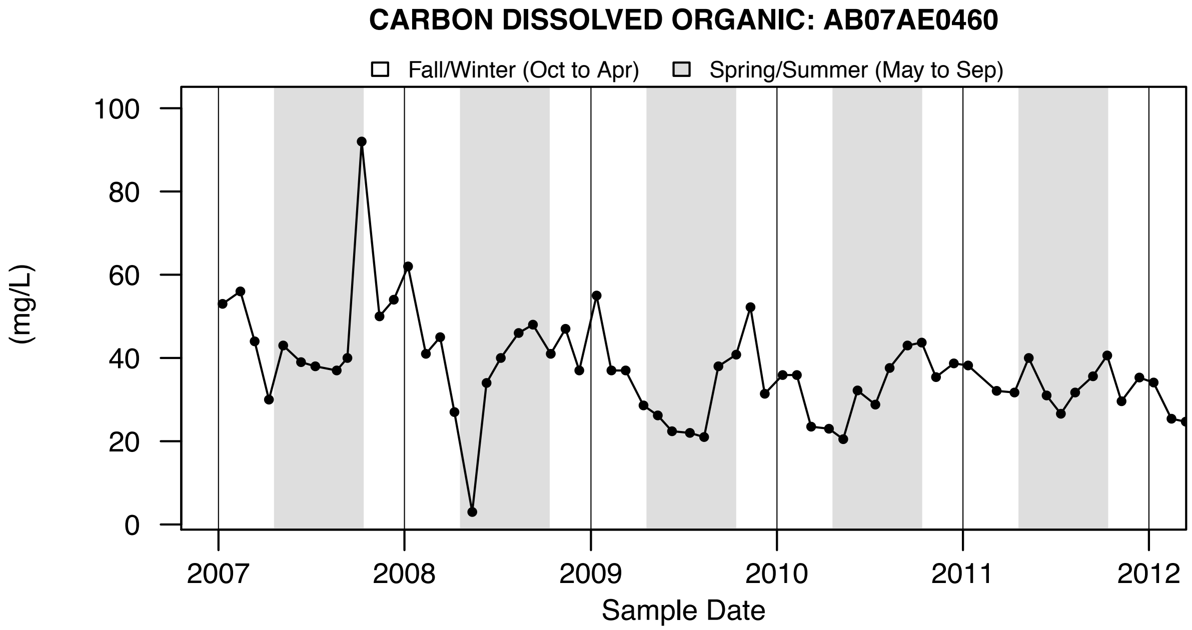


Figure A5.17: CARBON DISSOLVED ORGANIC: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

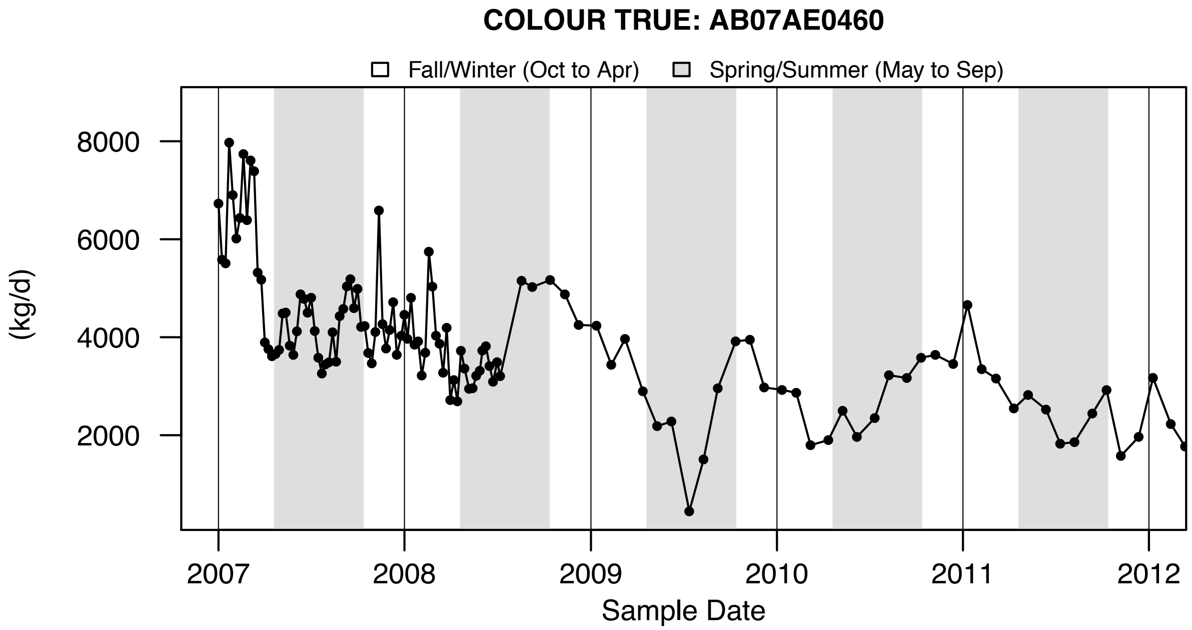


Figure A5.18: COLOUR TRUE: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

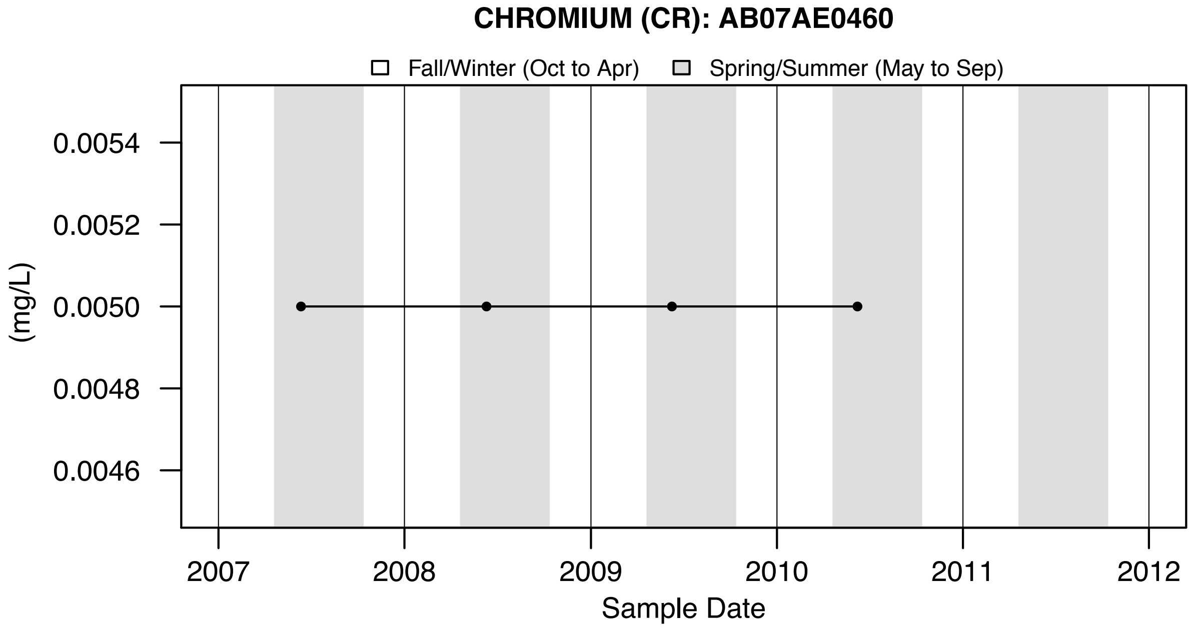


Figure A5.19: CHROMIUM (CR): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

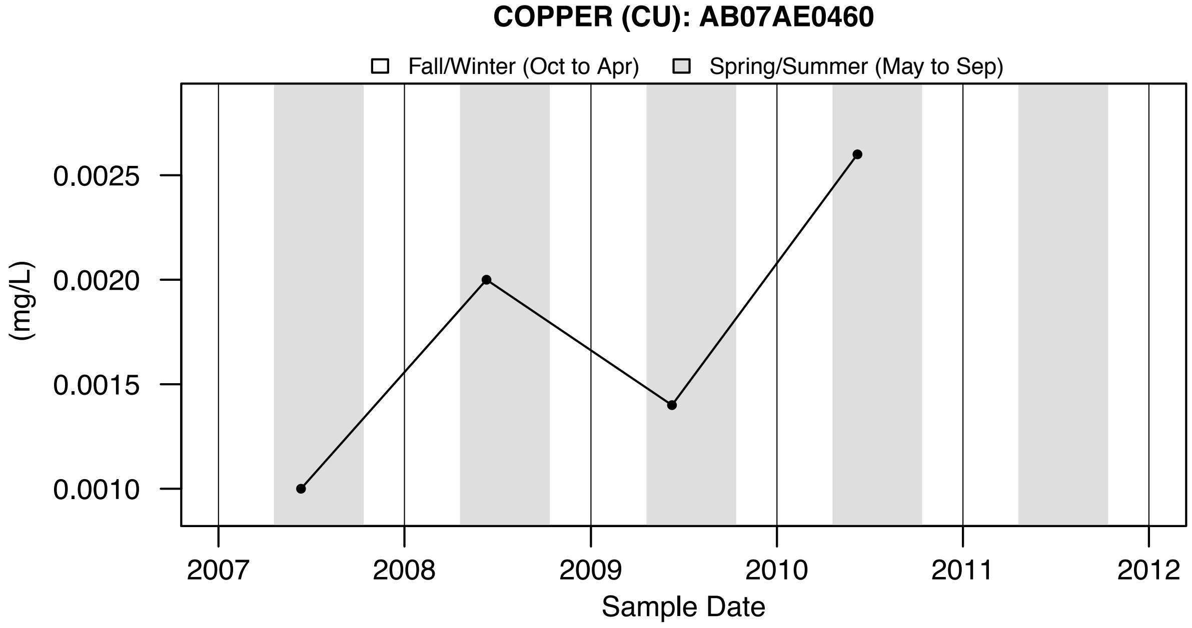


Figure A5.20: COPPER (CU): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

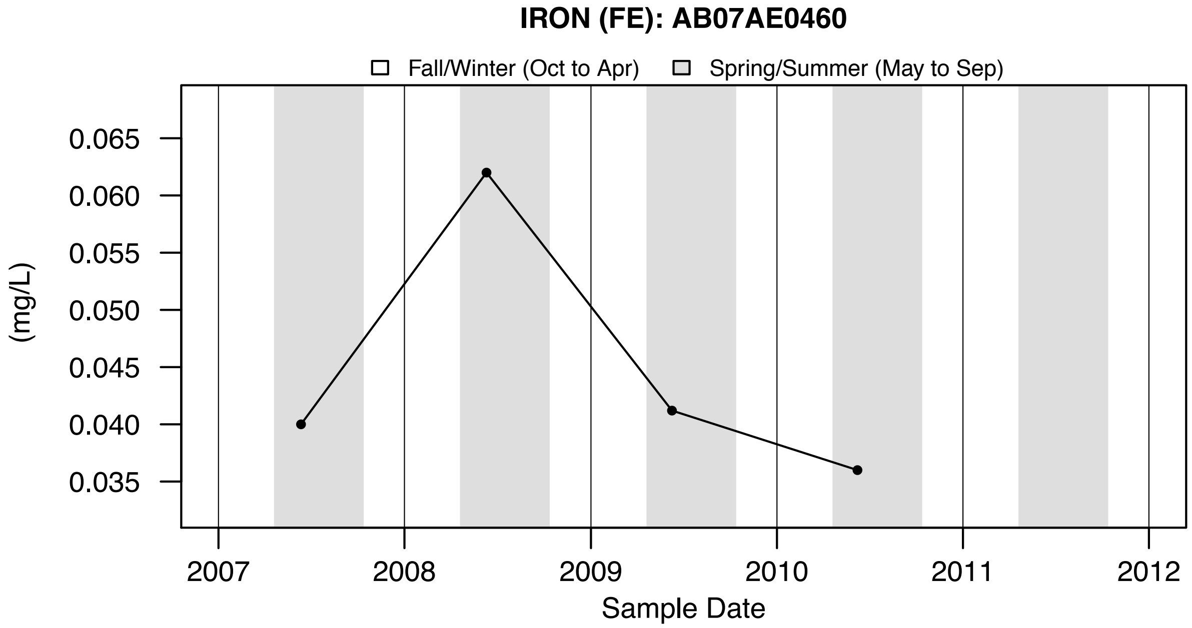


Figure A5.21: IRON (FE): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

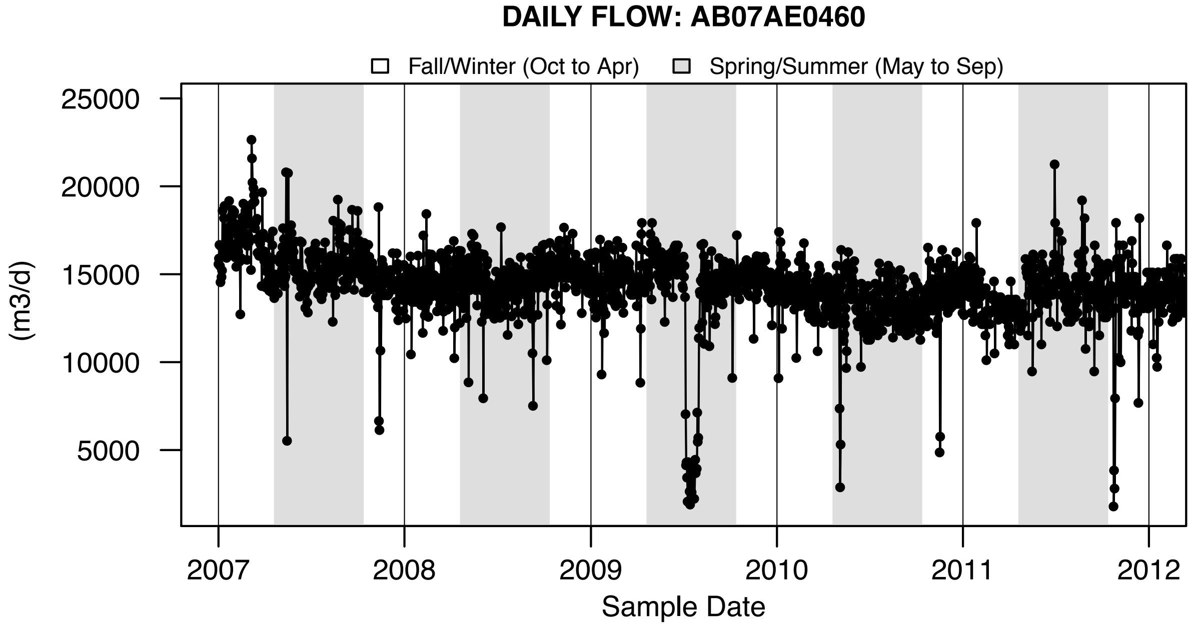


Figure A5.22: DAILY FLOW: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

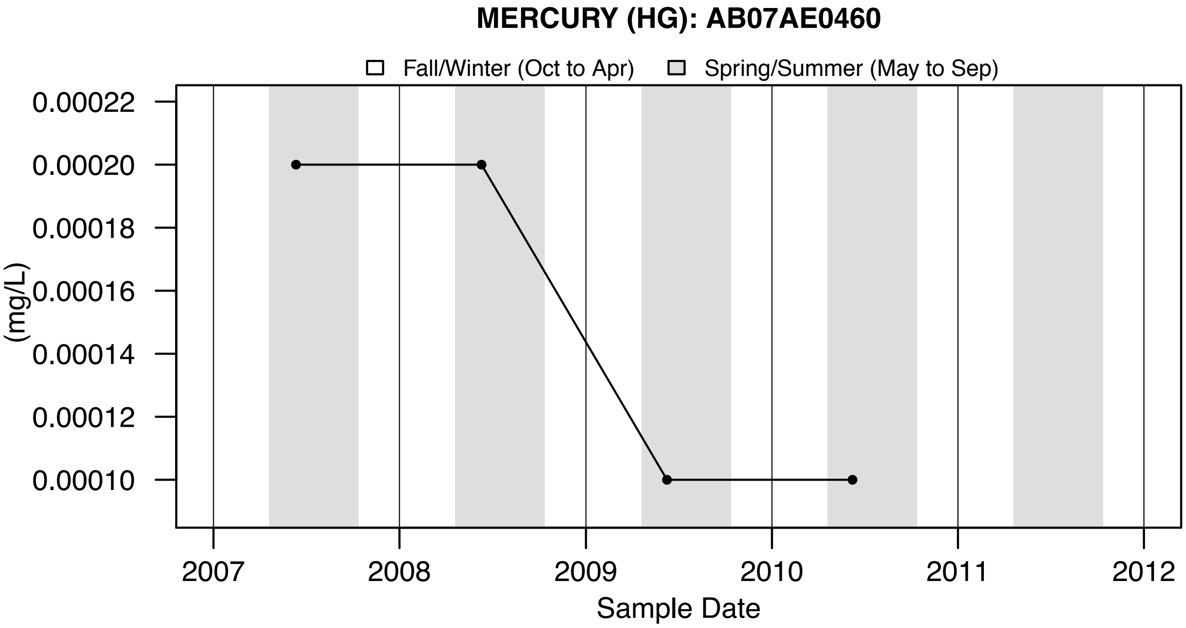


Figure A5.23: MERCURY (HG): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

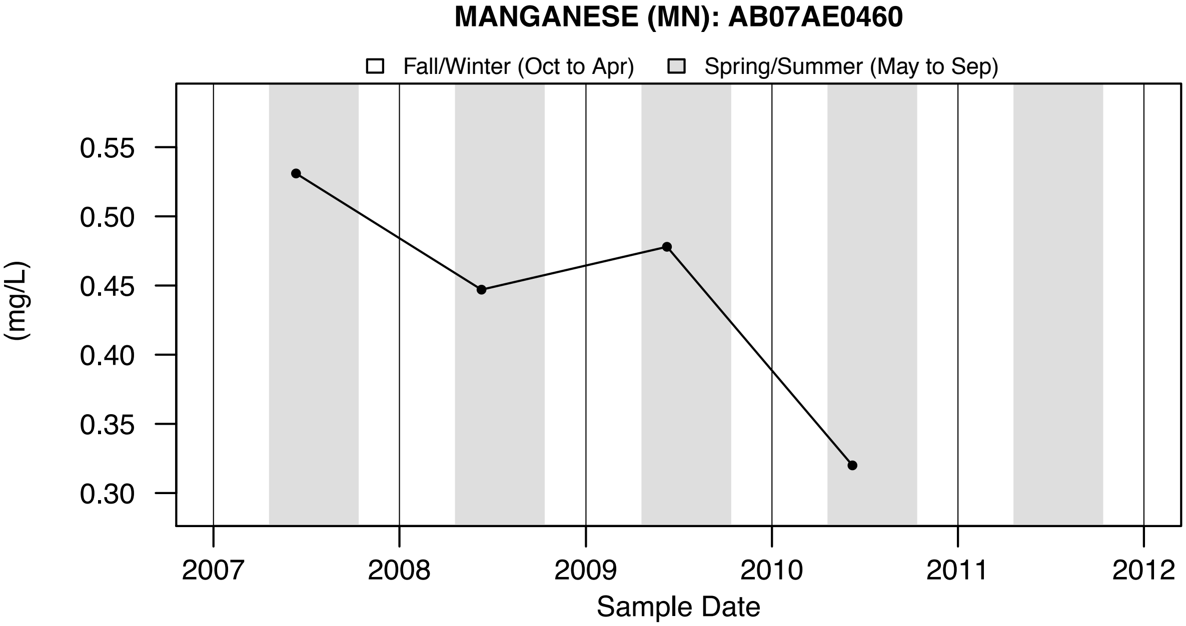


Figure A5.24: MANGANESE (MN): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

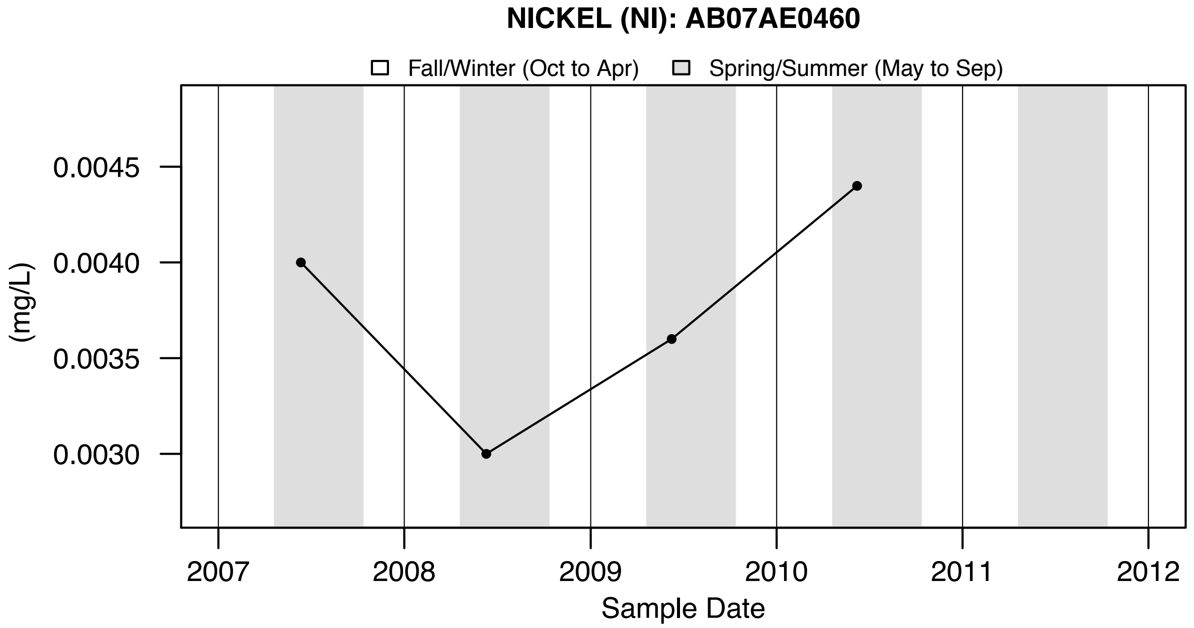


Figure A5.25: NICKEL (NI): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

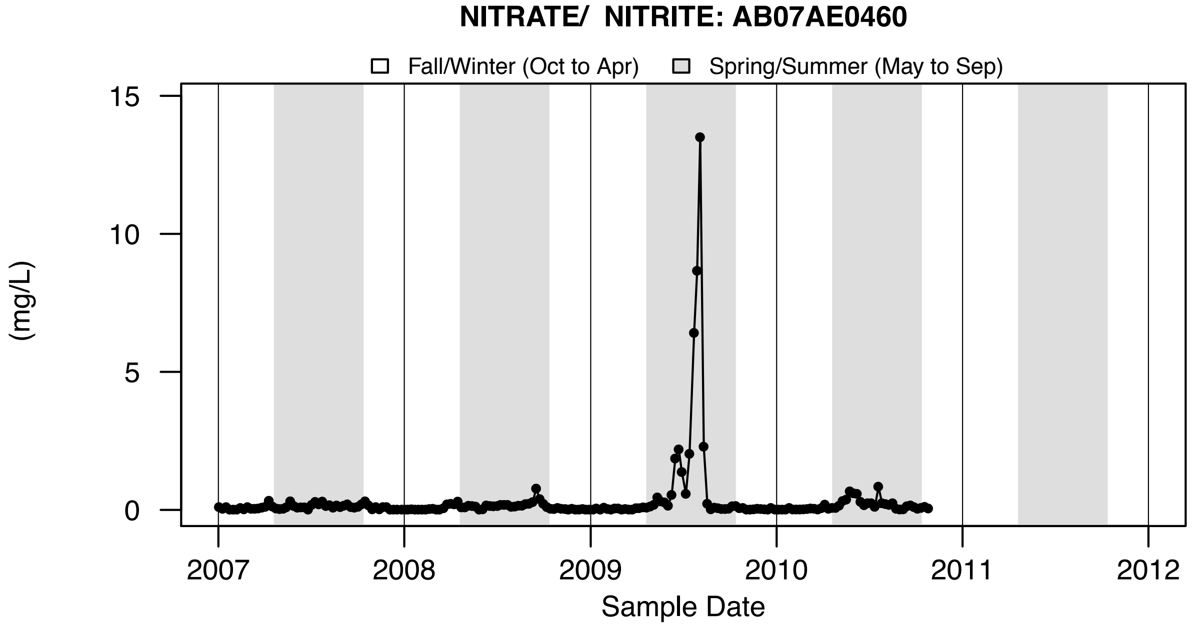


Figure A5.26: NITRATE/ NITRITE: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

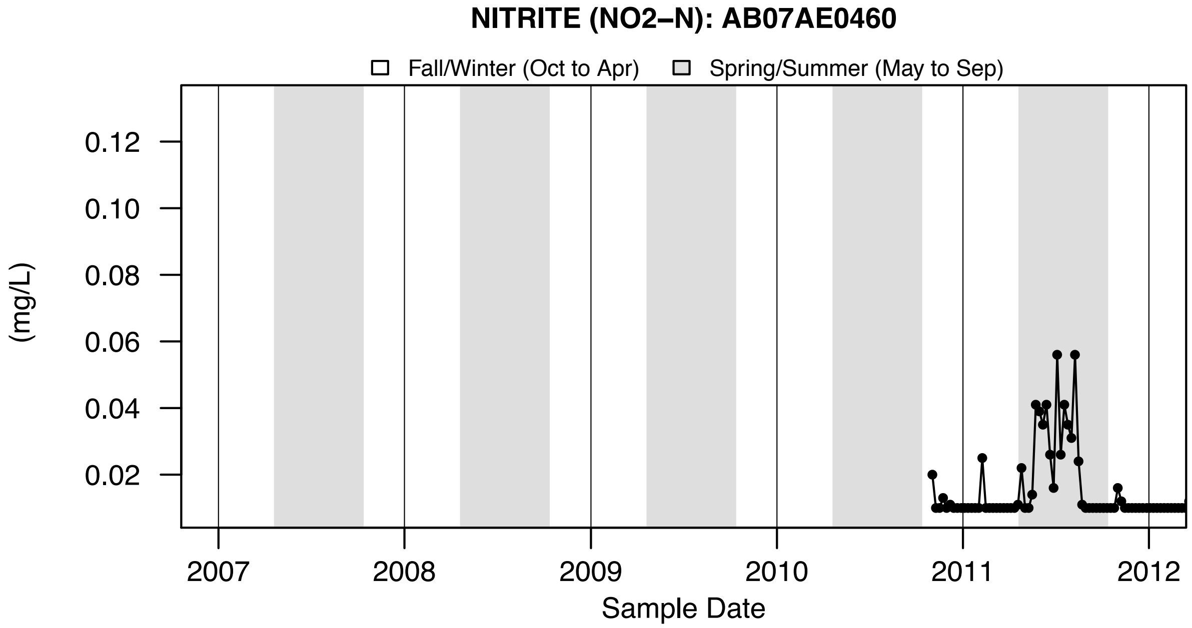


Figure A5.27: NITRITE (NO2-N): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

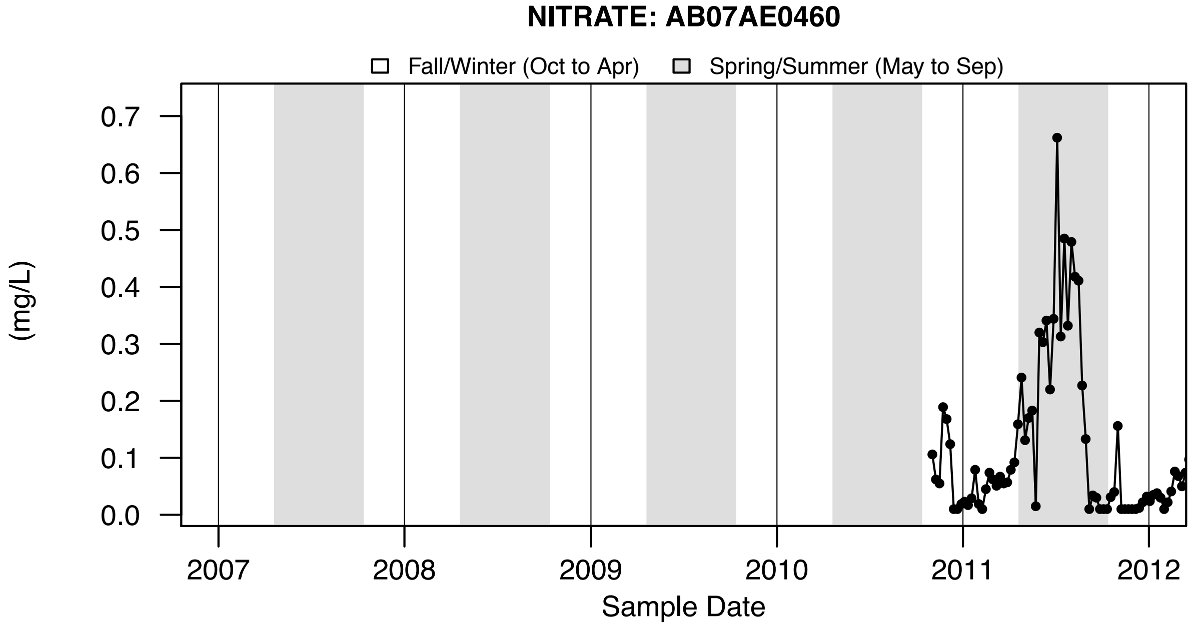


Figure A5.28: NITRATE: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

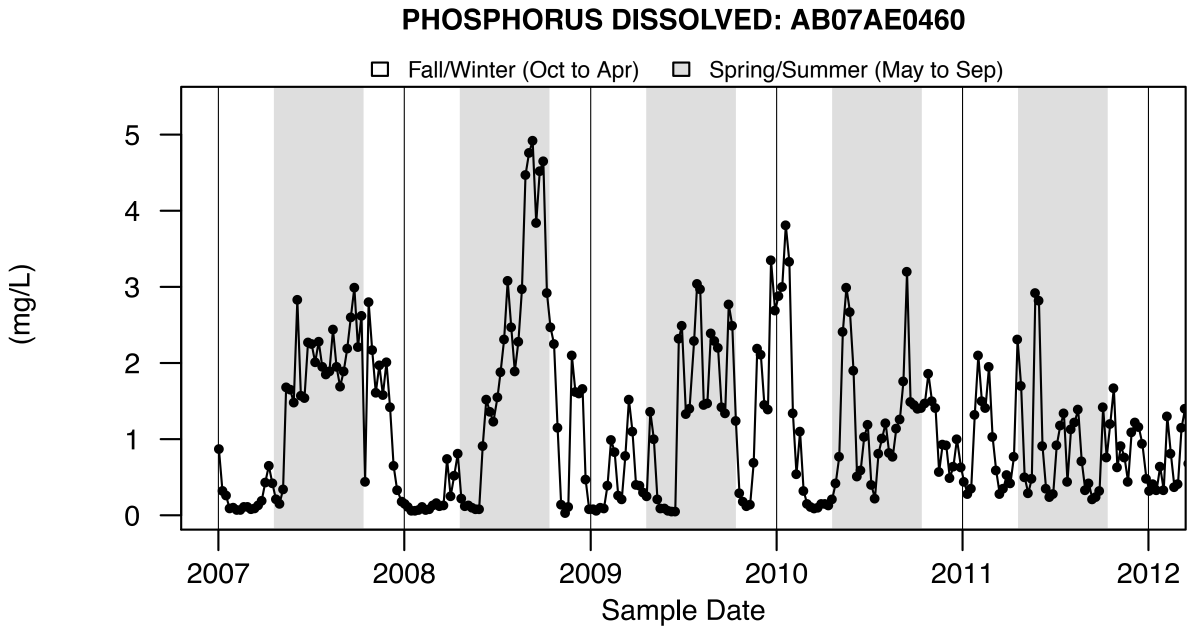


Figure A5.29: PHOSPHORUS DISSOLVED: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

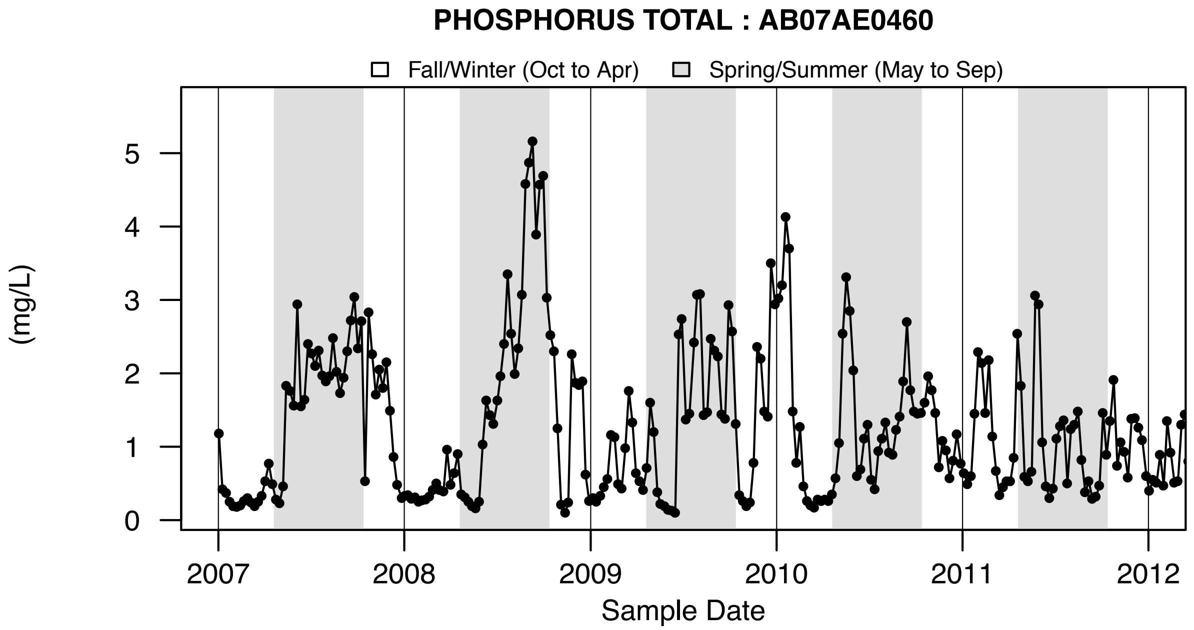


Figure A5.30: PHOSPHORUS TOTAL : AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

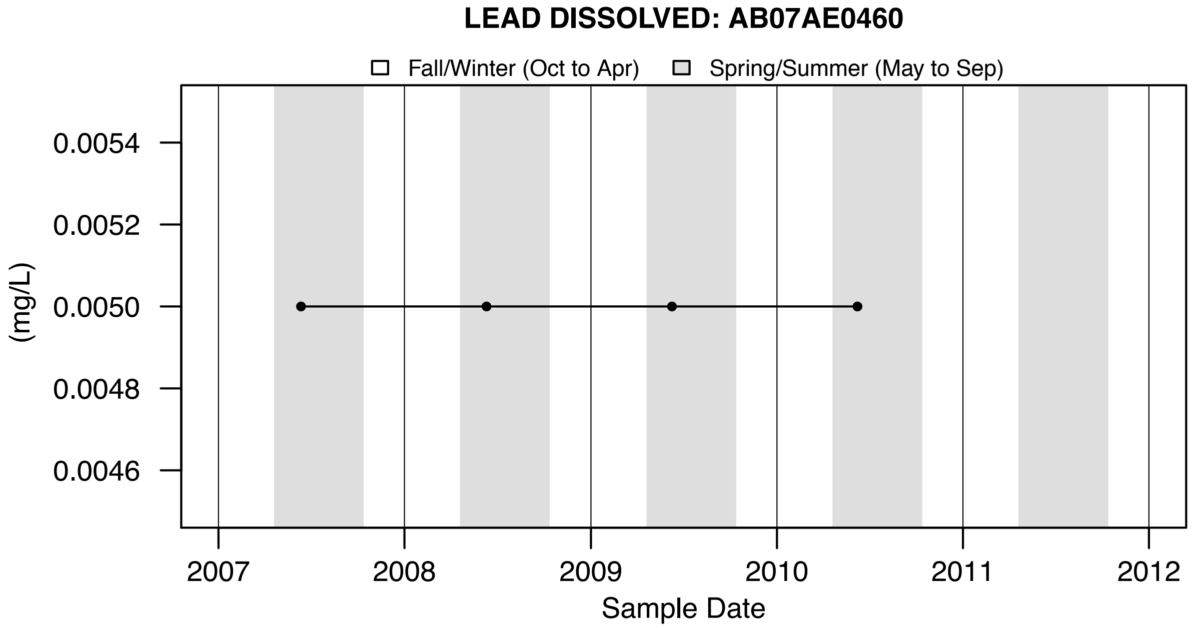


Figure A5.31: LEAD DISSOLVED: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

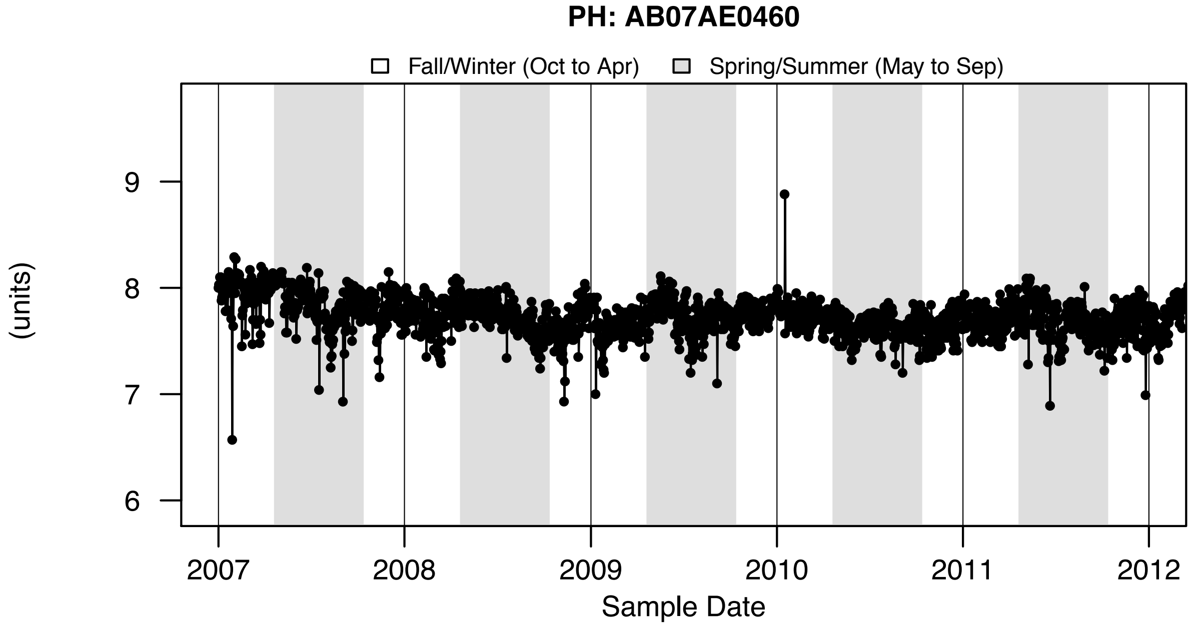


Figure A5.32: PH: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

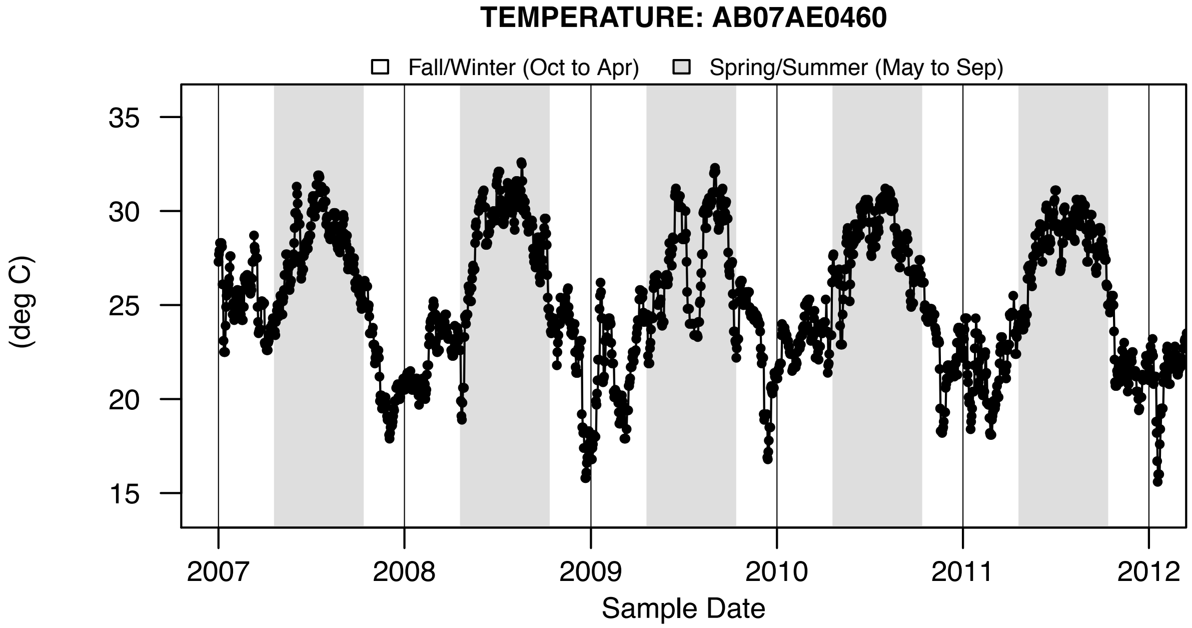


Figure A5.33: TEMPERATURE: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

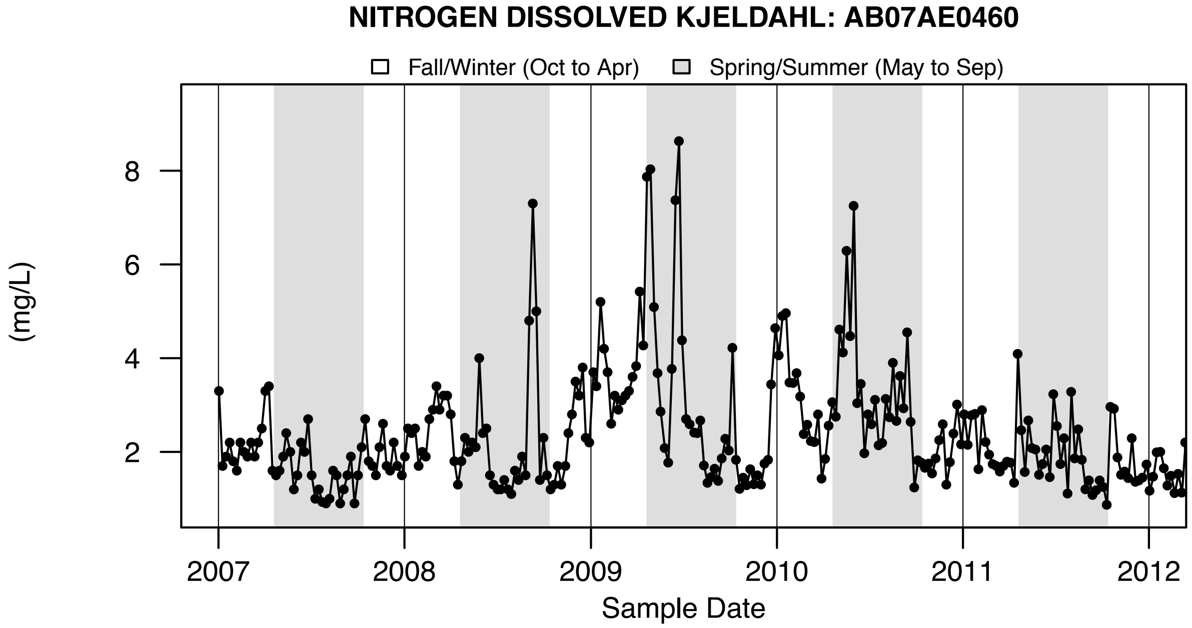


Figure A5.34: NITROGEN DISSOLVED KJELDAHL: AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

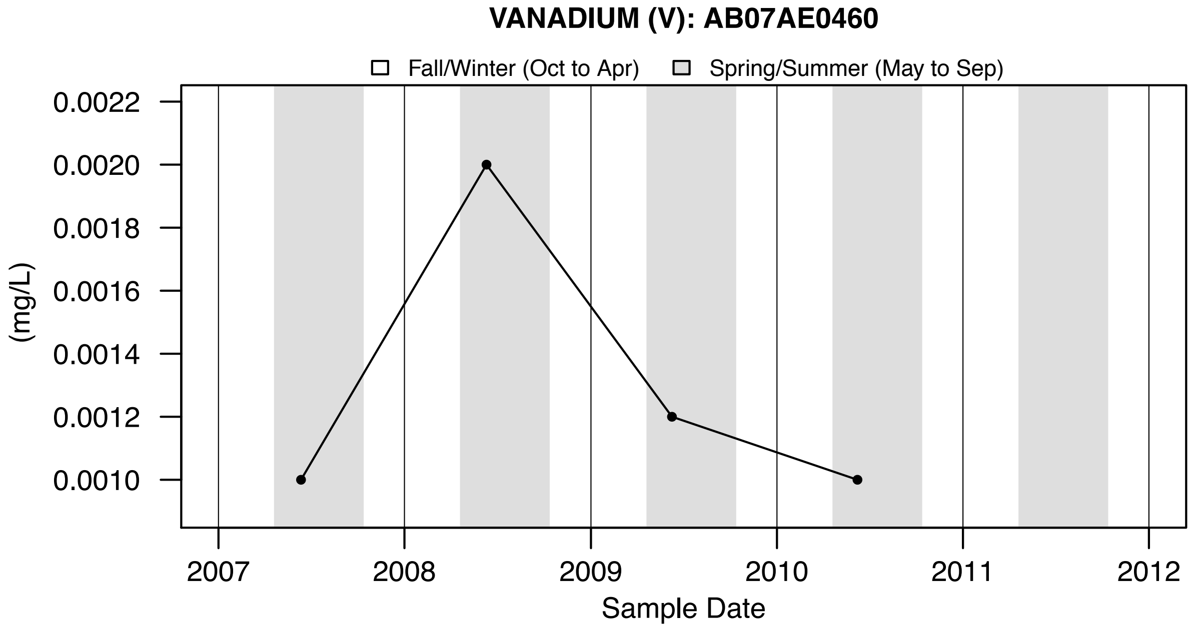


Figure A5.35: VANADIUM (V): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

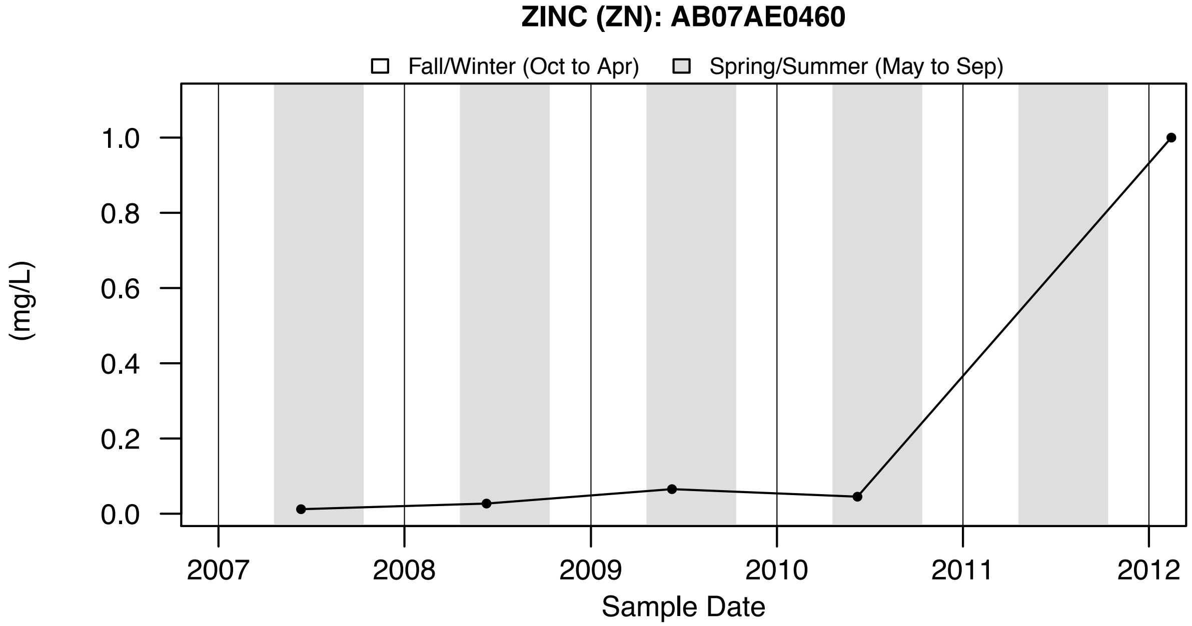


Figure A5.36: ZINC (ZN): AB07AE0460 - ALBERTA NEWSPRINT COMPANY (FINAL EFFLUENT)

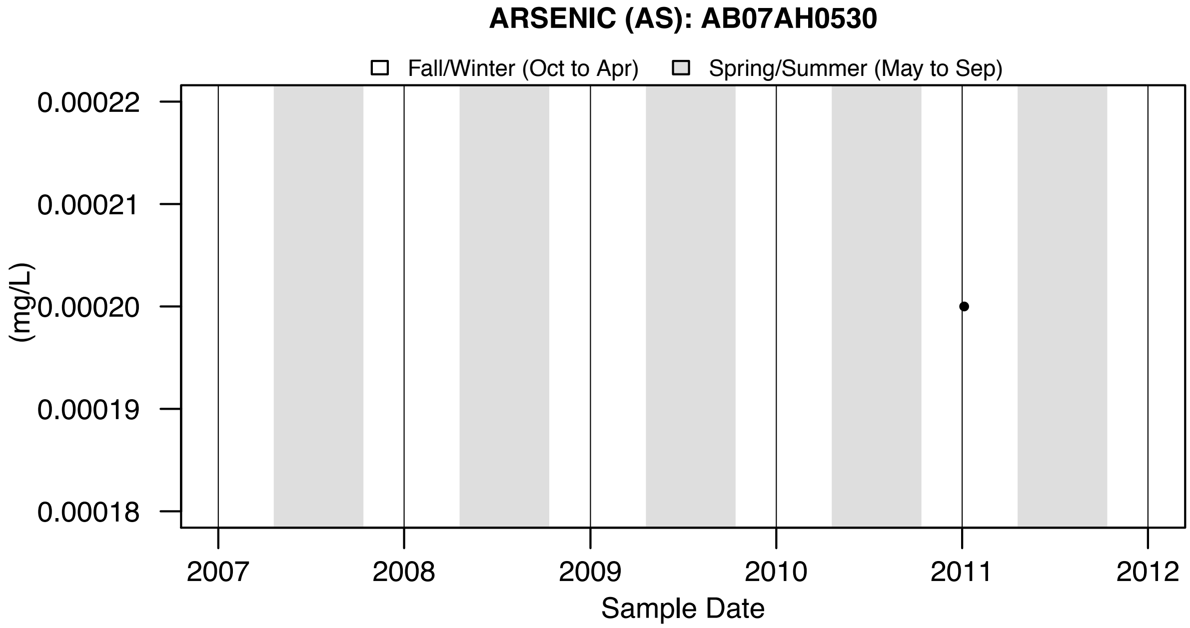


Figure A5.37: ARSENIC (AS): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

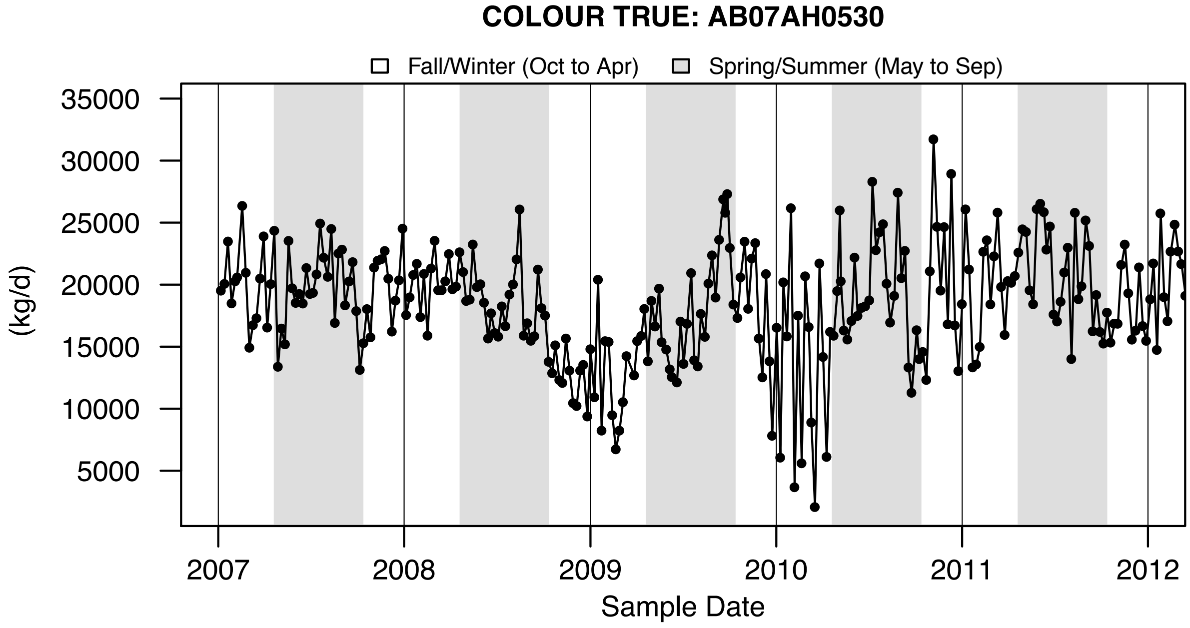


Figure A5.38: COLOUR TRUE: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

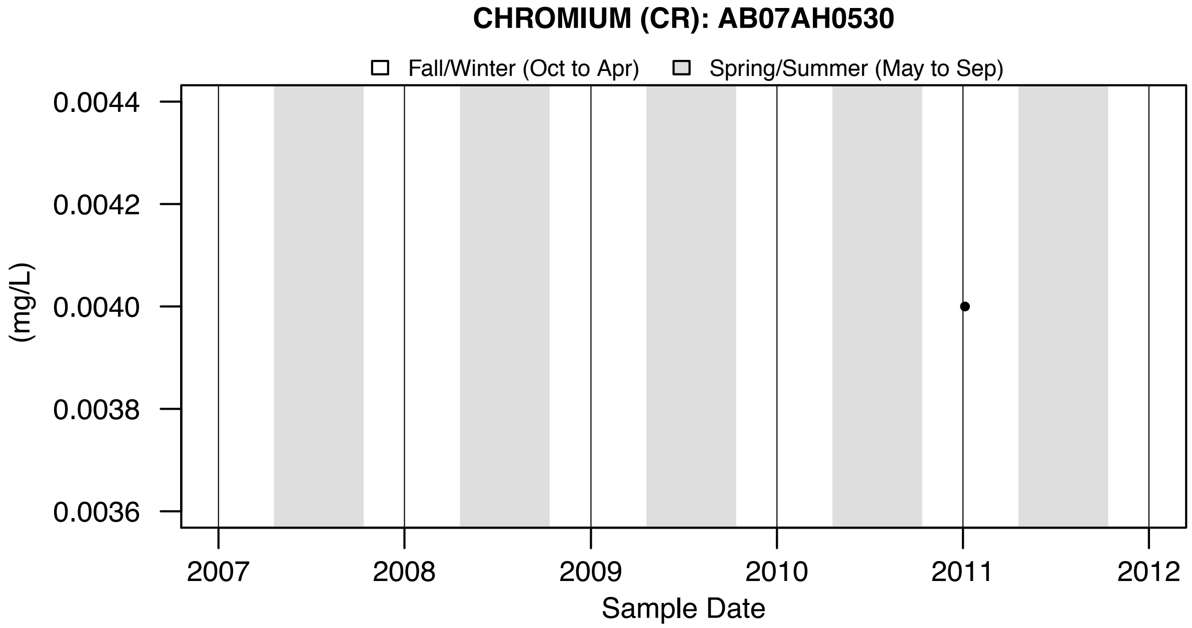


Figure A5.39: CHROMIUM (CR): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

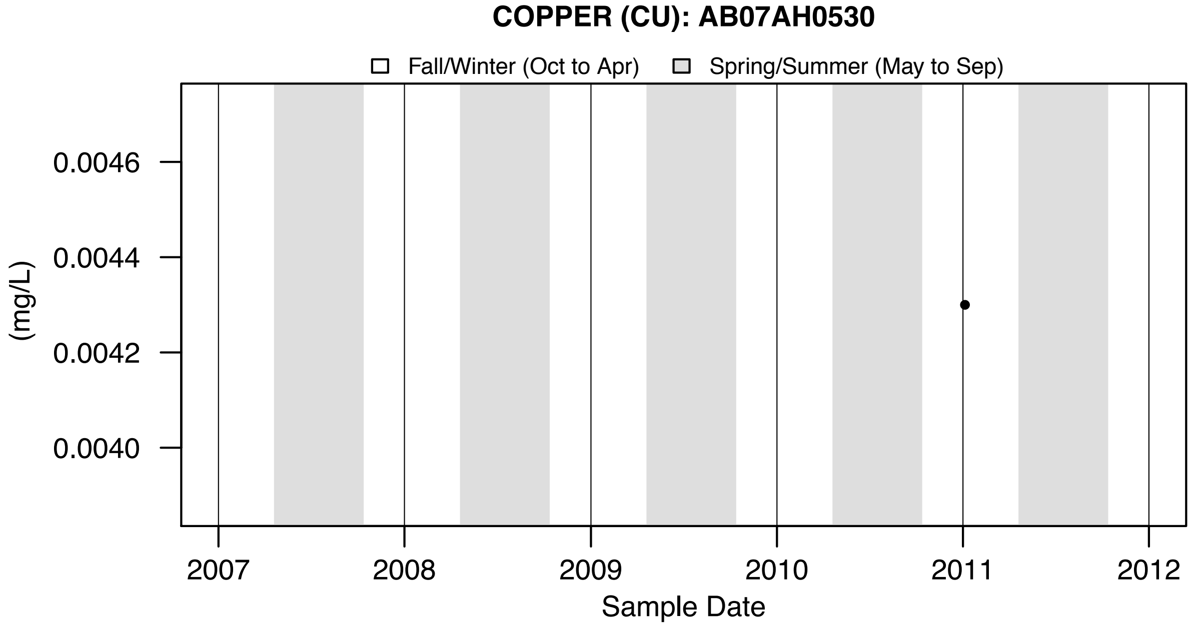


Figure A5.40: COPPER (CU): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

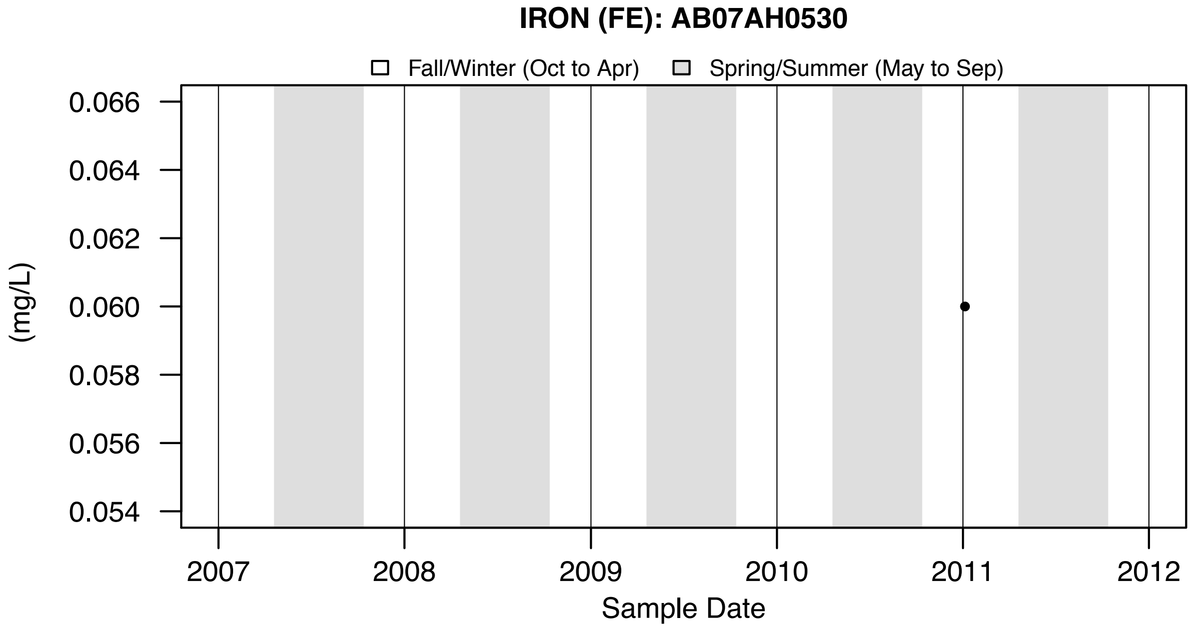


Figure A5.41: IRON (FE): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

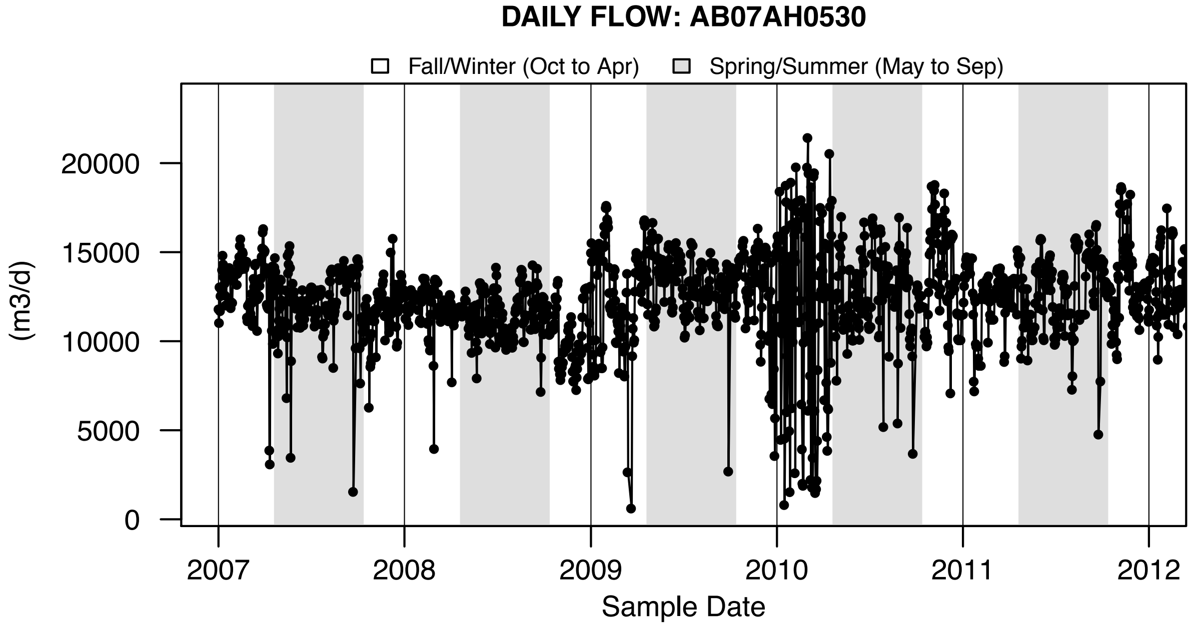


Figure A5.42: DAILY FLOW: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

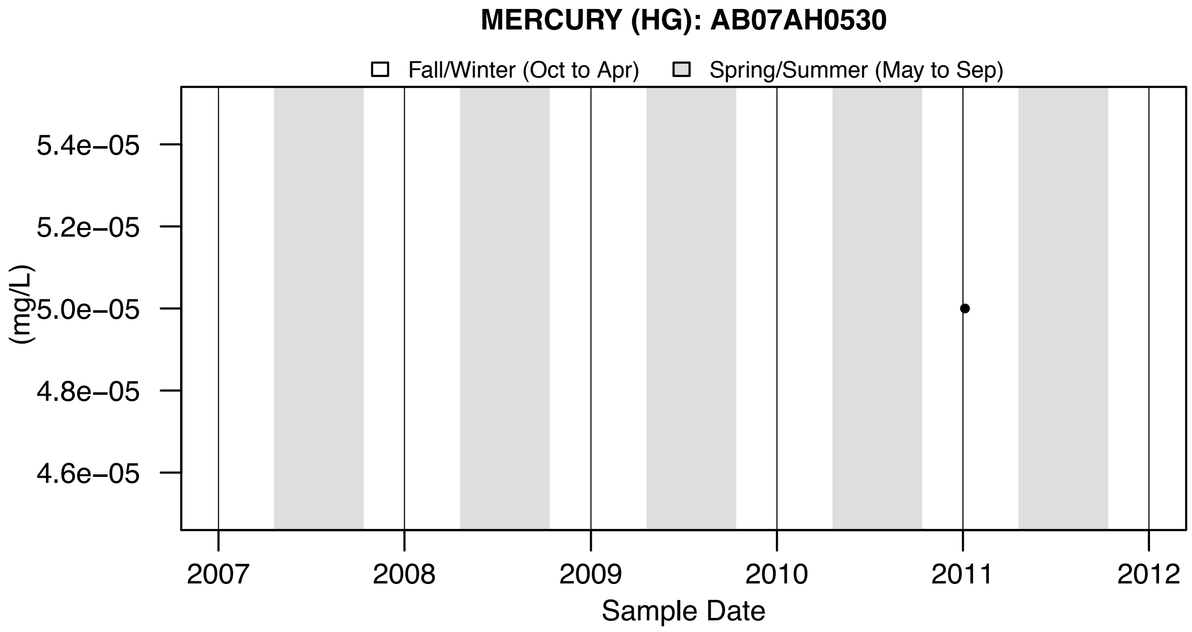


Figure A5.43: MERCURY (HG): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

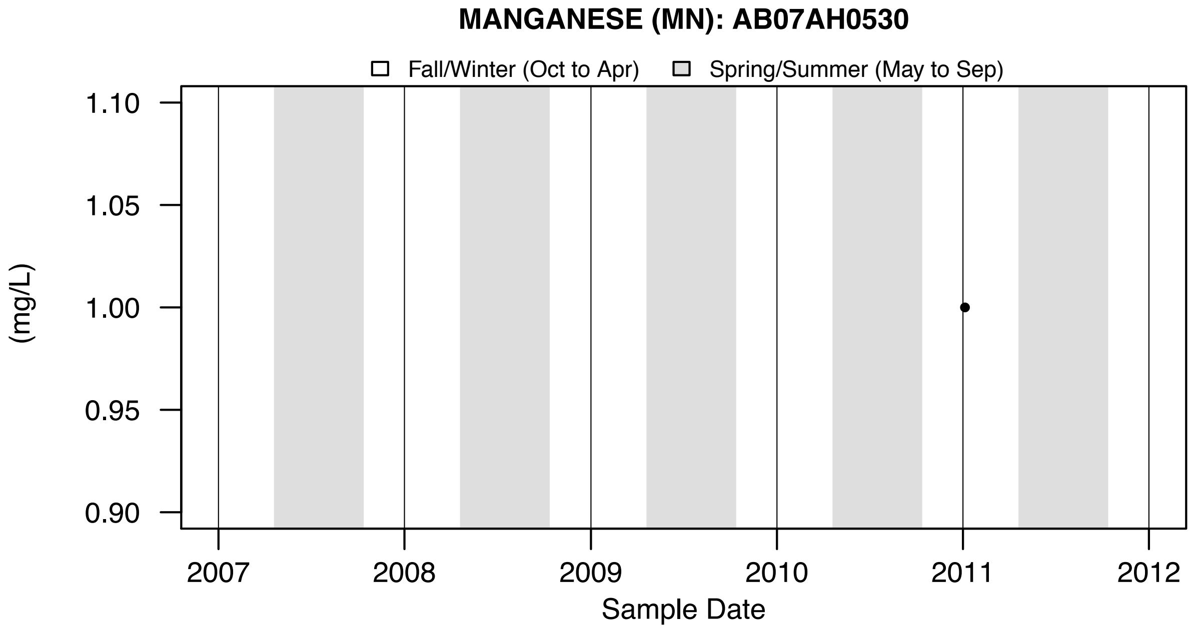


Figure A5.44: MANGANESE (MN): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

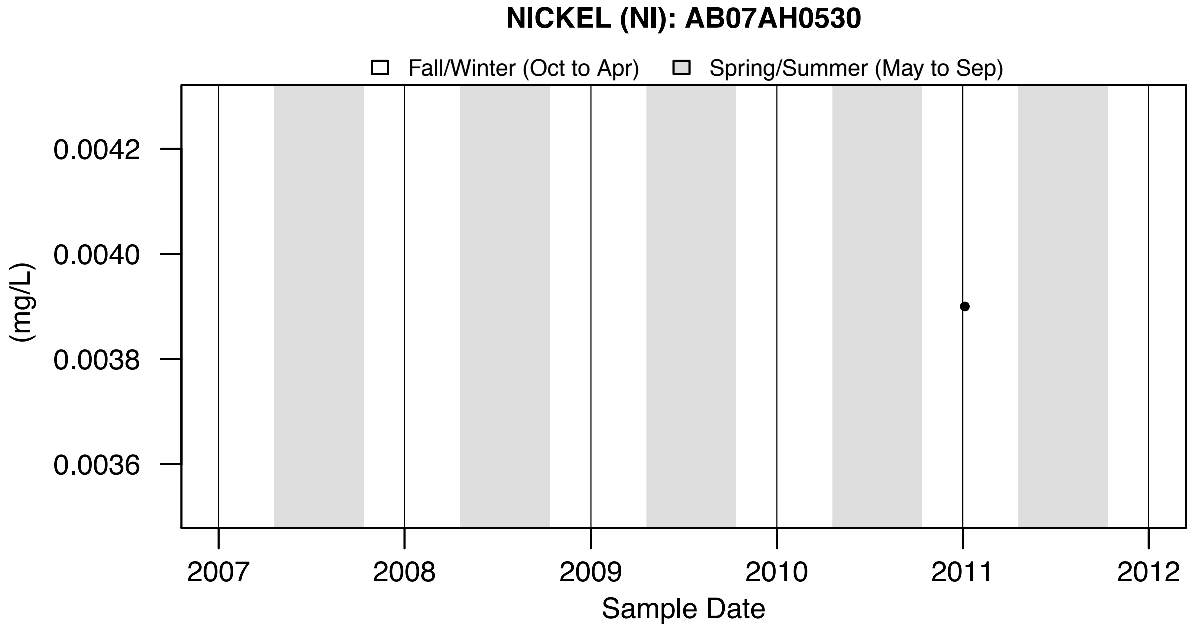


Figure A5.45: NICKEL (NI): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

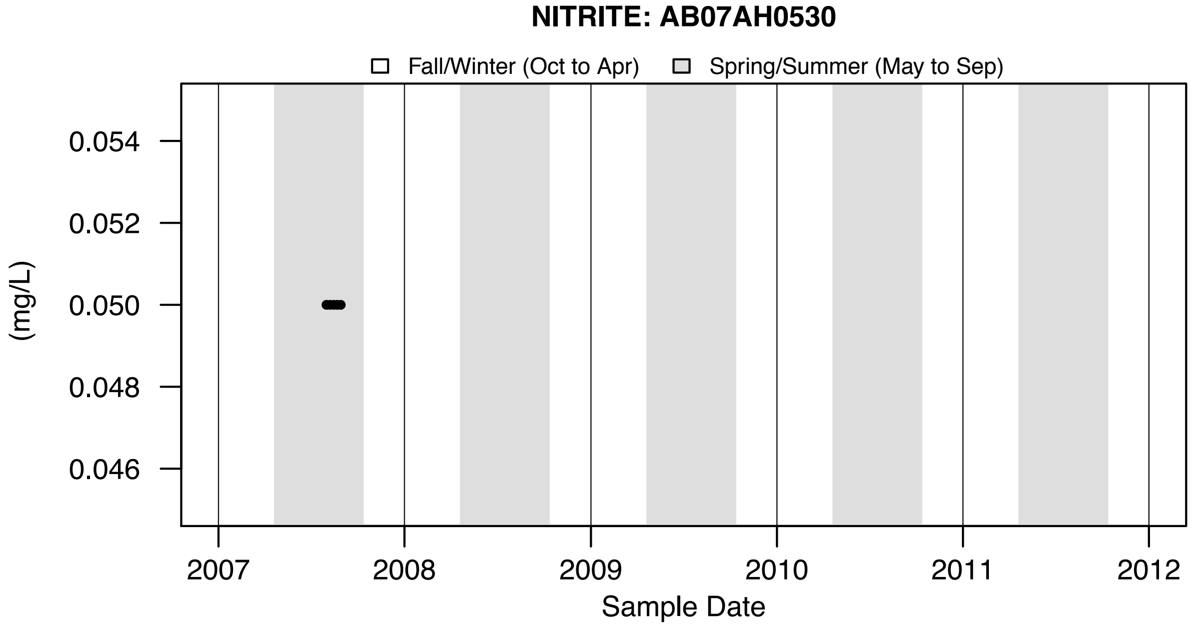


Figure A5.46: NITRITE: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

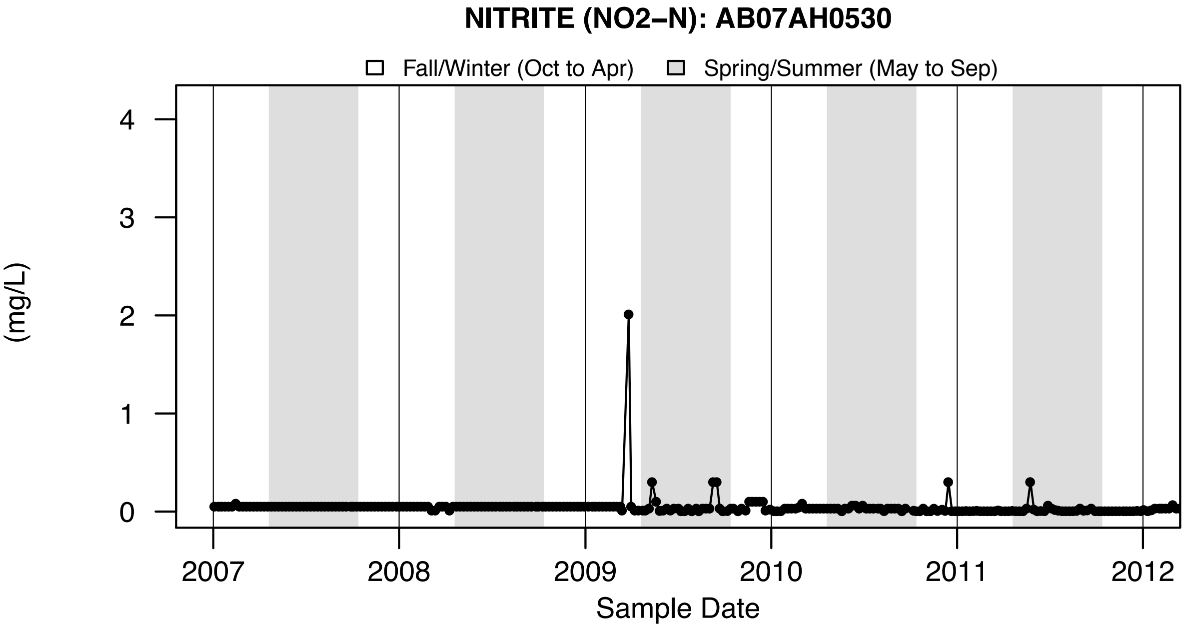


Figure A5.47: NITRITE (NO2-N): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

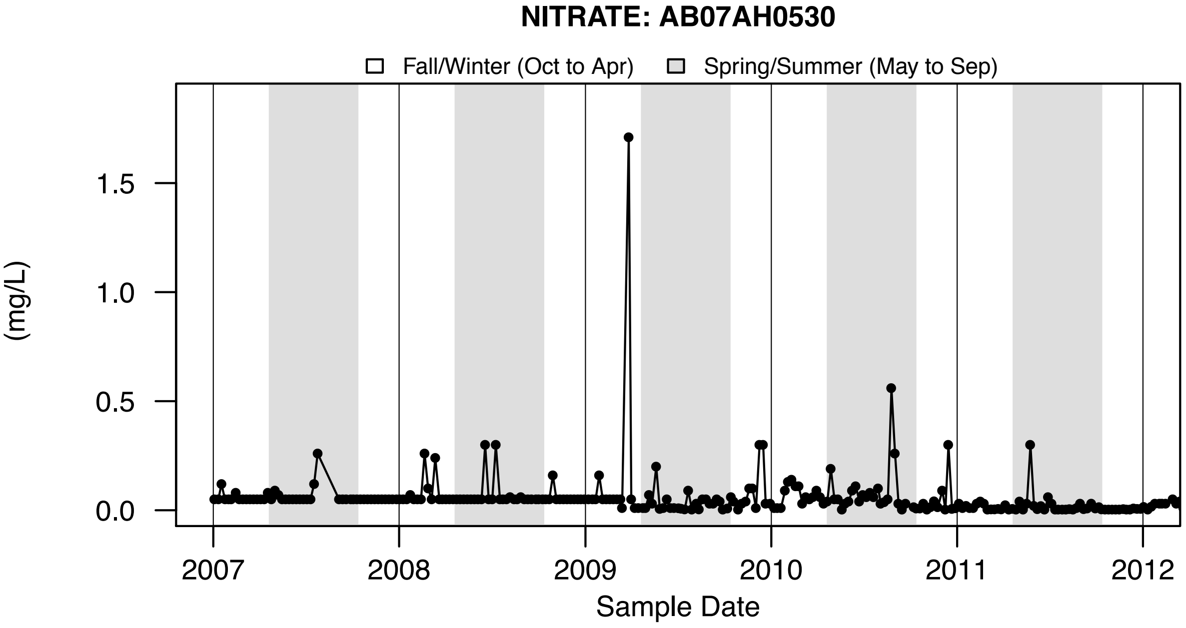


Figure A5.48: NITRATE: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

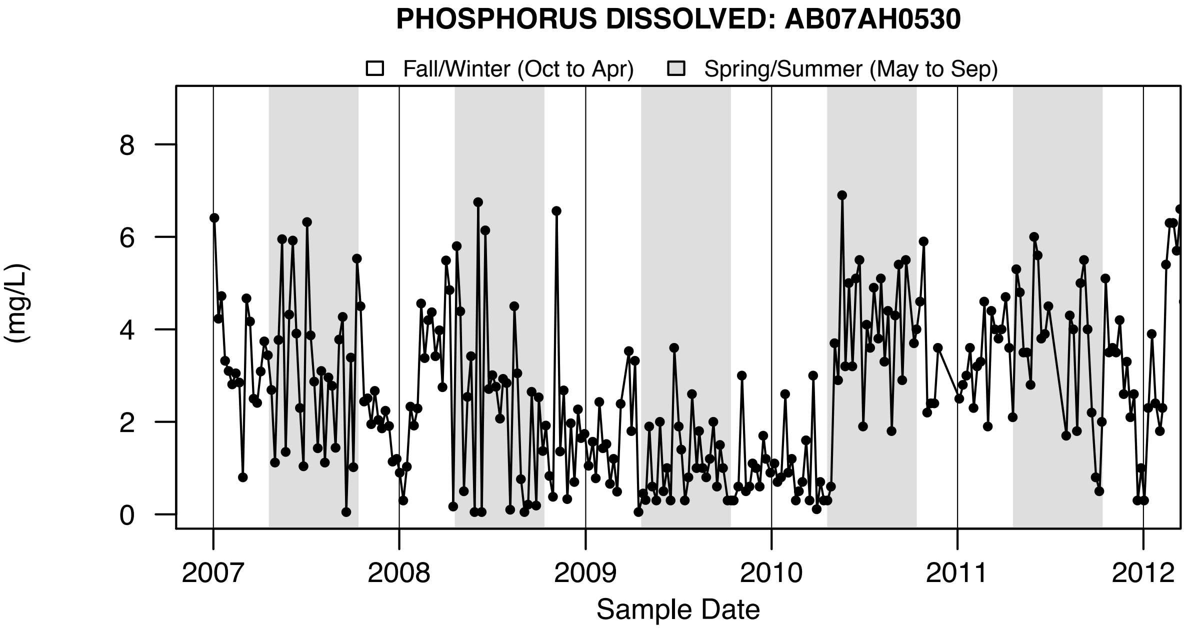


Figure A5.49: PHOSPHORUS DISSOLVED: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

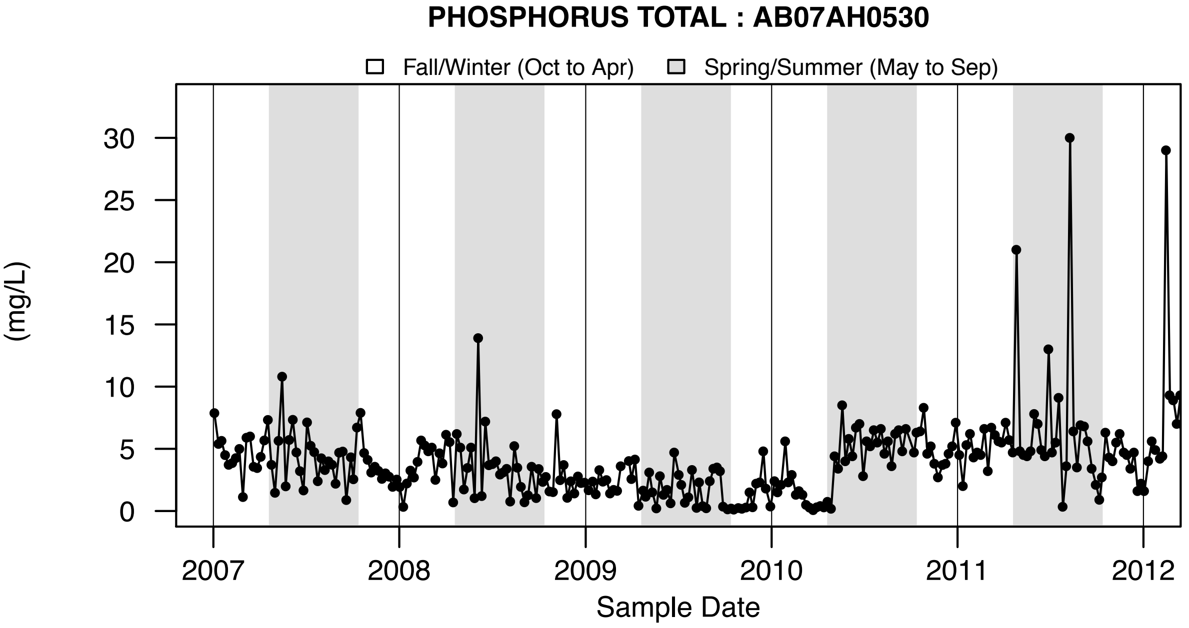


Figure A5.50: PHOSPHORUS TOTAL : AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

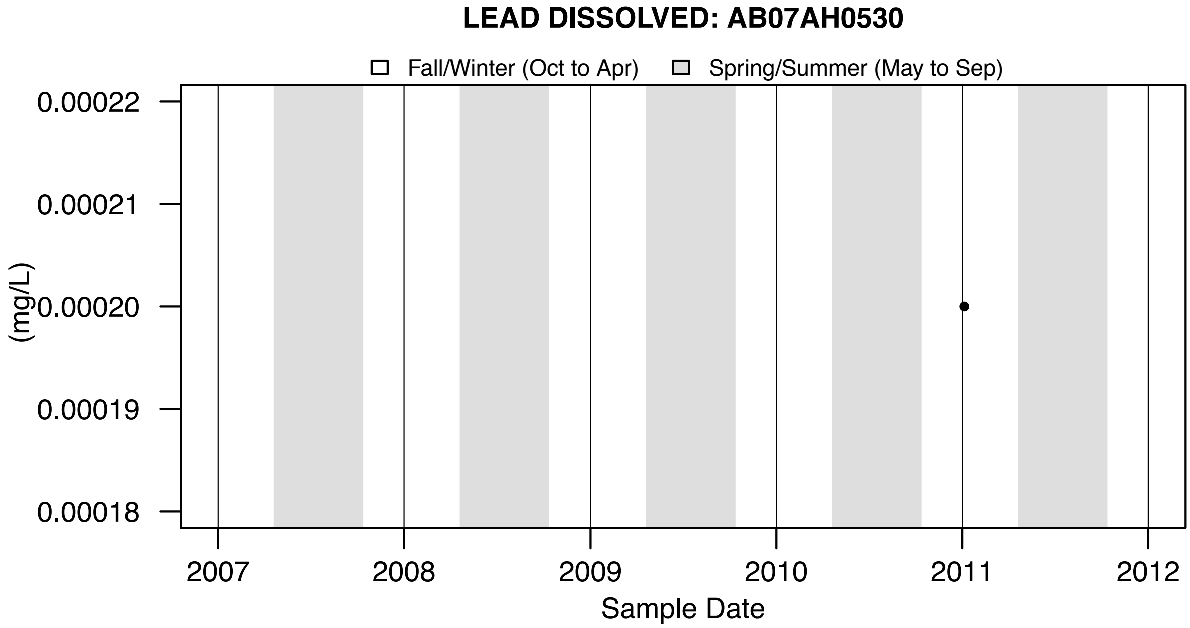


Figure A5.51: LEAD DISSOLVED: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

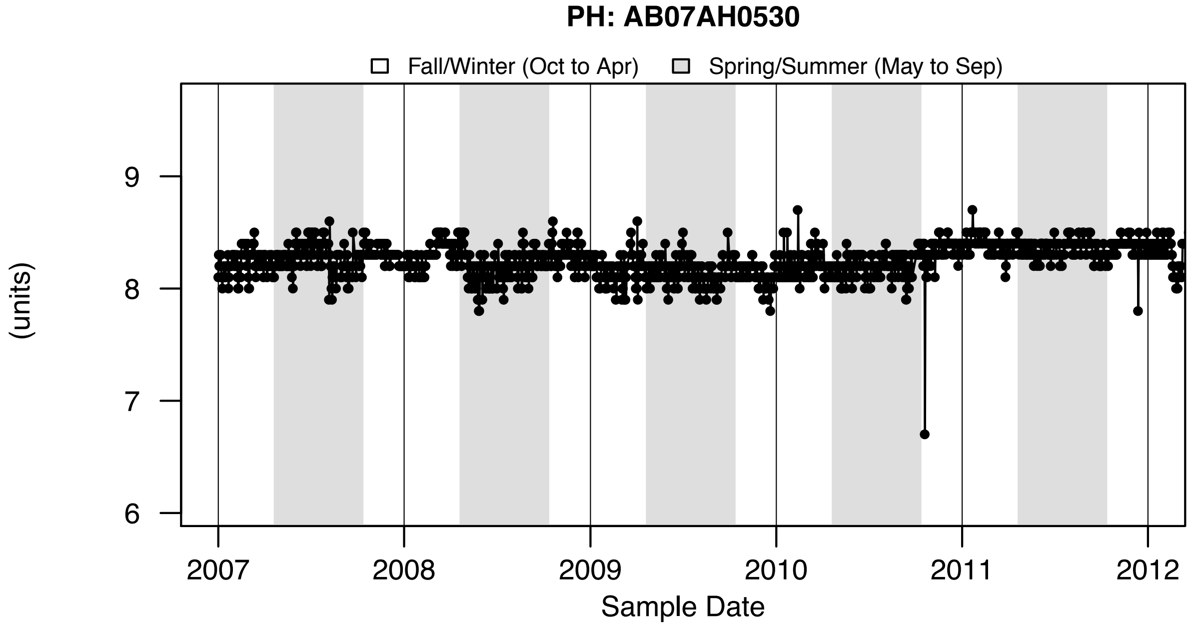


Figure A5.52: PH: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

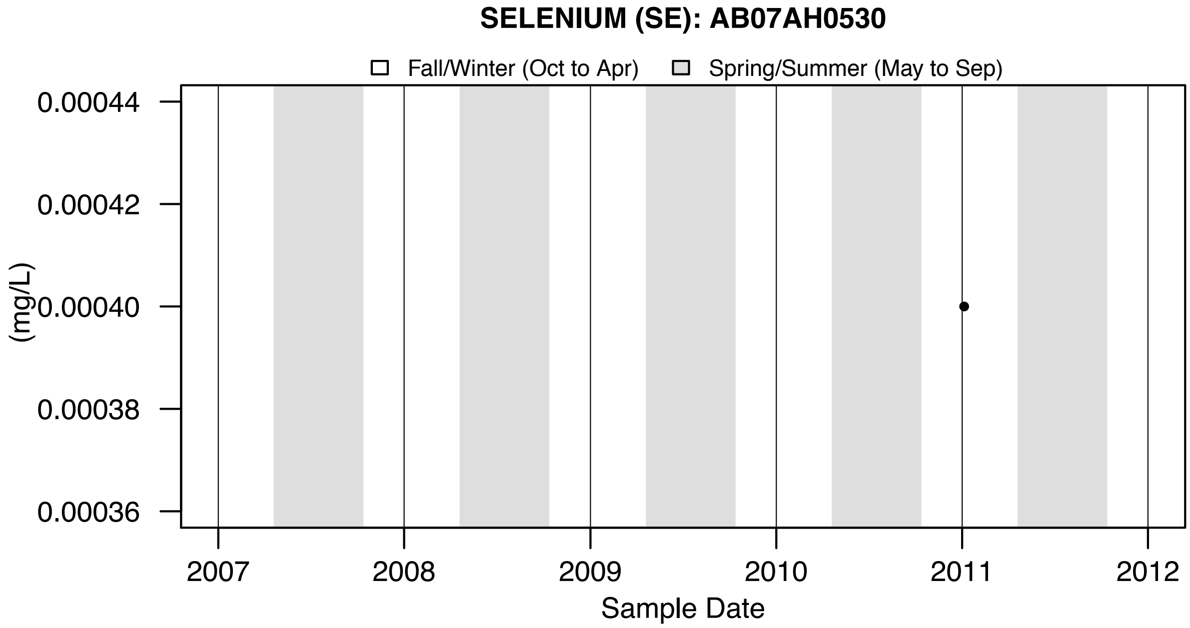


Figure A5.53: SELENIUM (SE): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

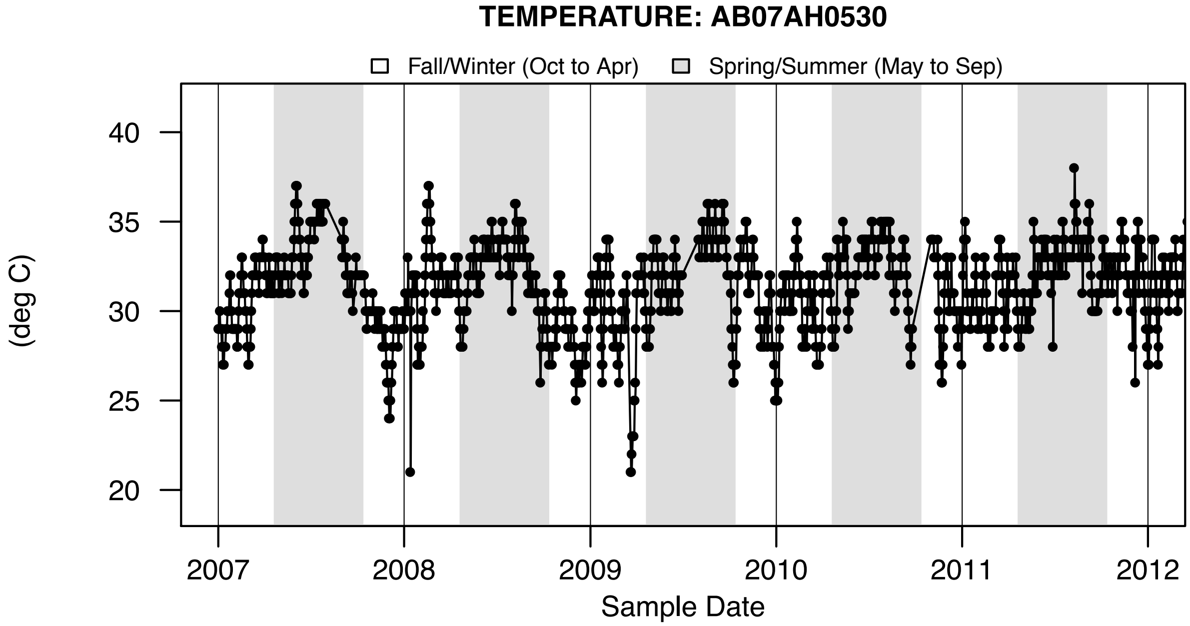


Figure A5.54: TEMPERATURE: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

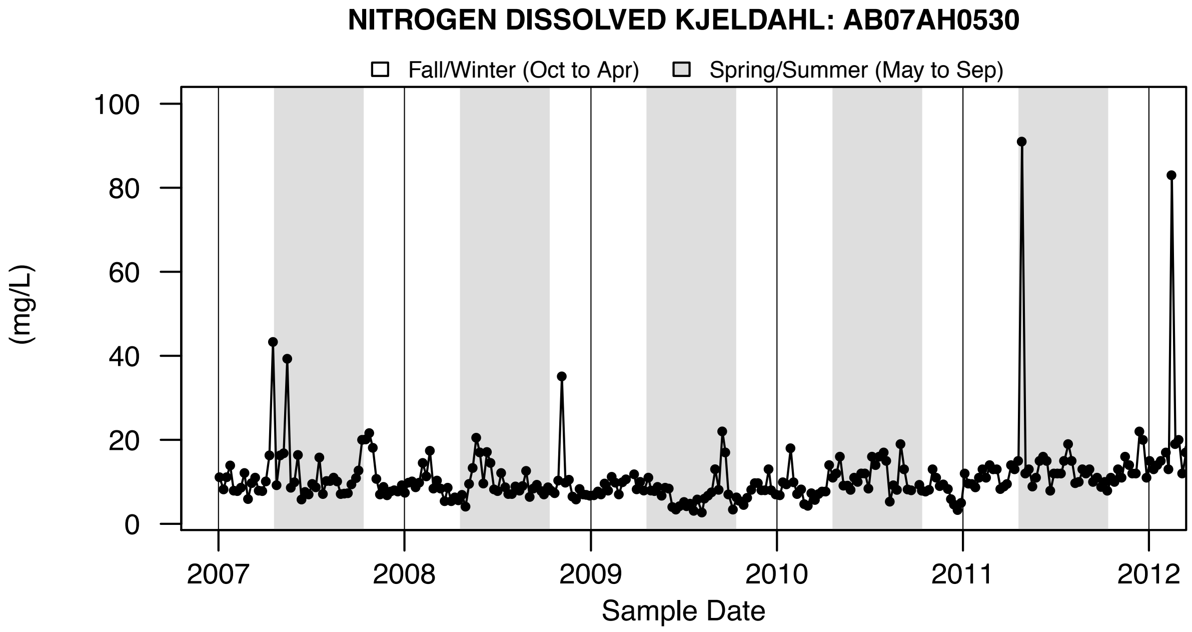


Figure A5.55: NITROGEN DISSOLVED KJELDAHL: AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

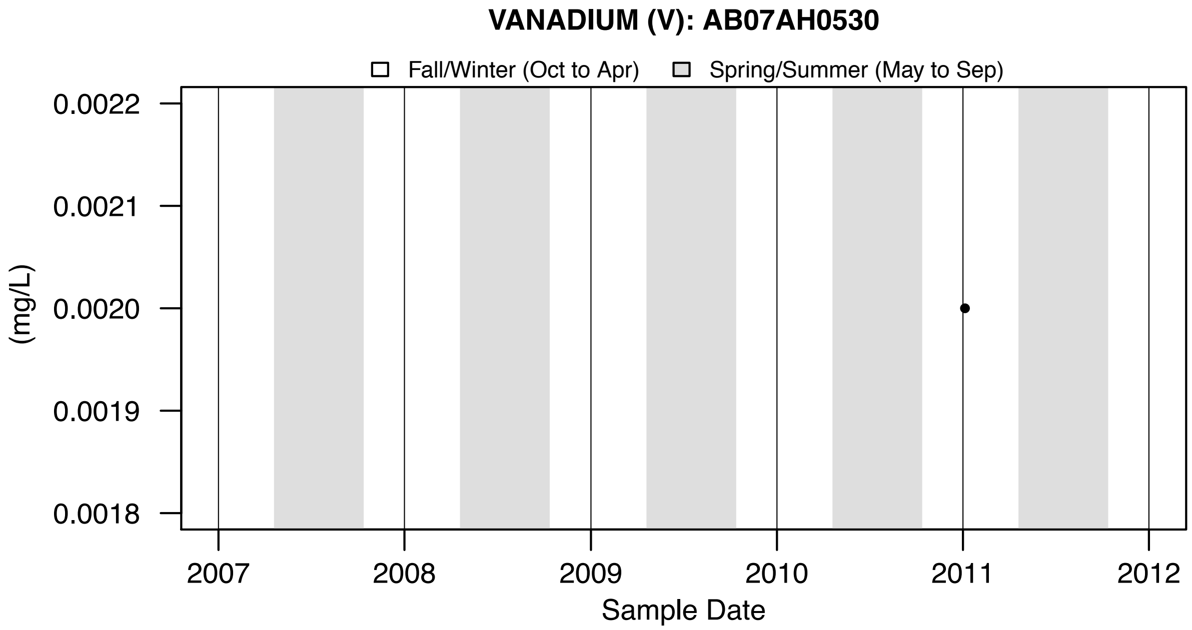


Figure A5.56: VANADIUM (V): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

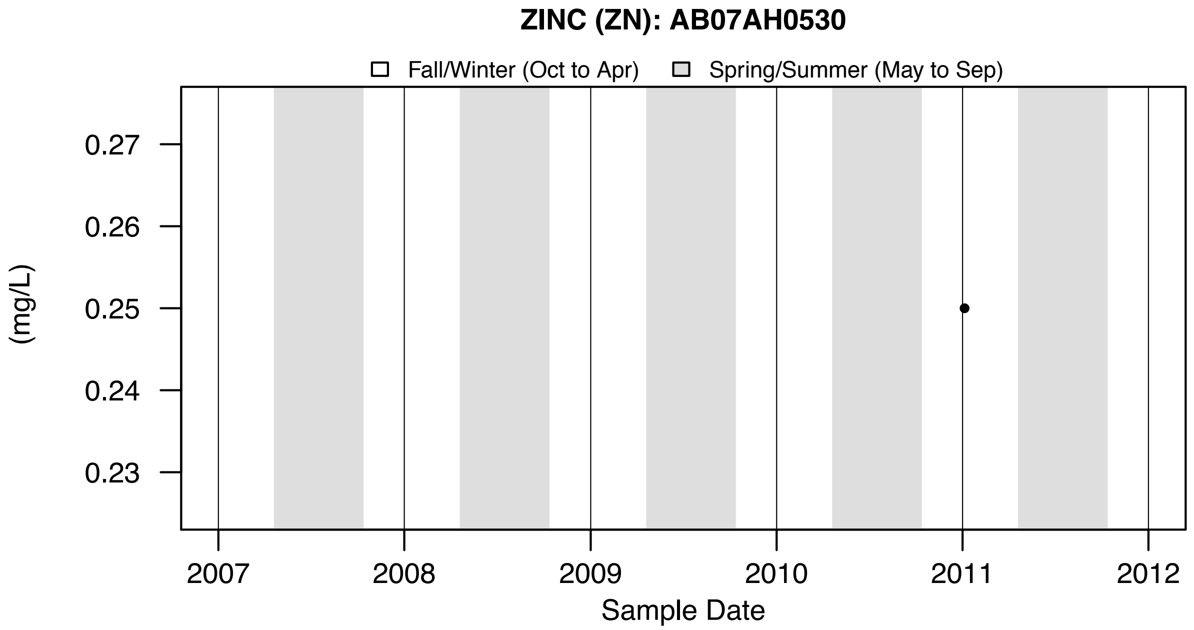


Figure A5.57: ZINC (ZN): AB07AH0530 - MILLAR WESTERN FOREST PRODUCTS (FINAL EFFLUENT)

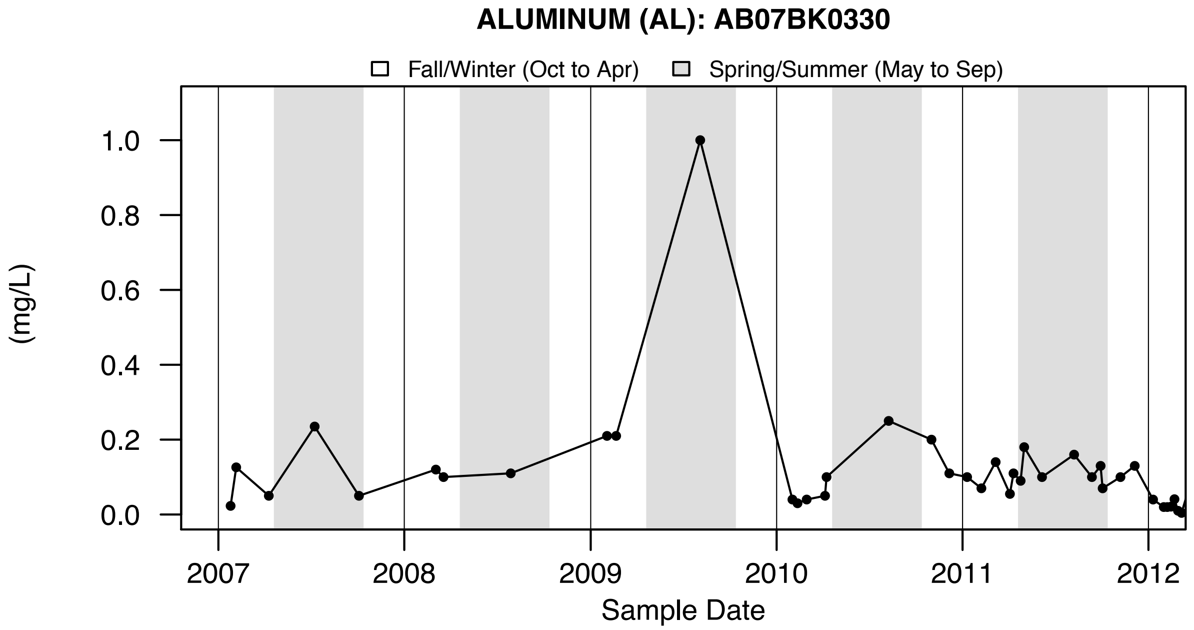


Figure A5.58: ALUMINUM (AL): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

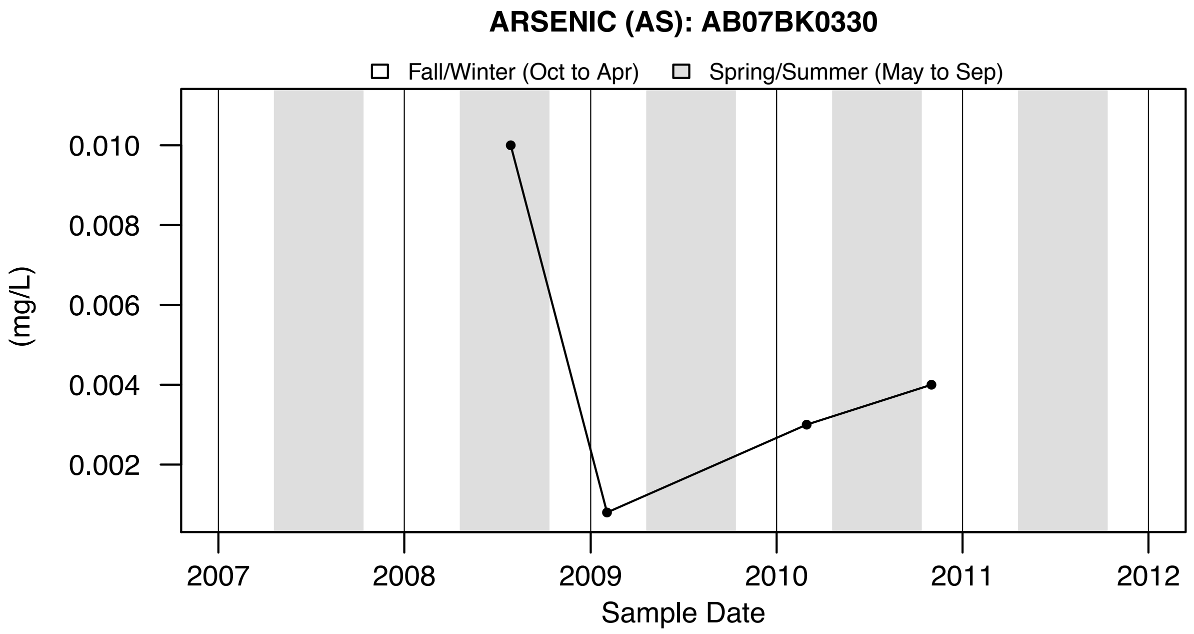


Figure A5.59: ARSENIC (AS): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

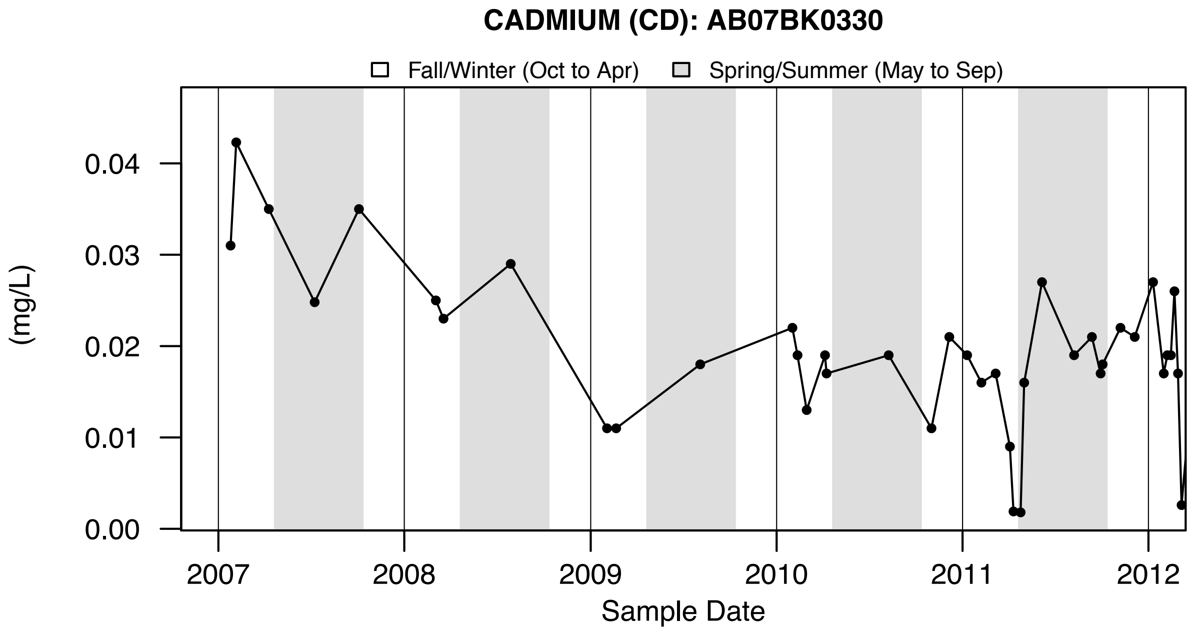


Figure A5.60: CADMIUM (CD): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

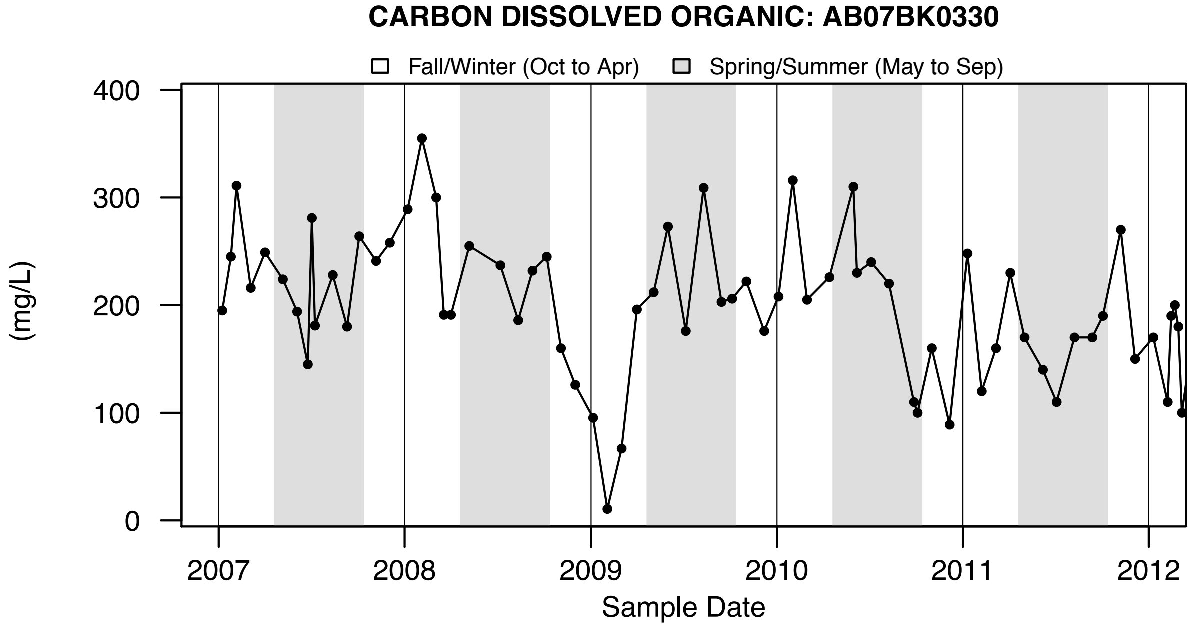


Figure A5.61: CARBON DISSOLVED ORGANIC: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

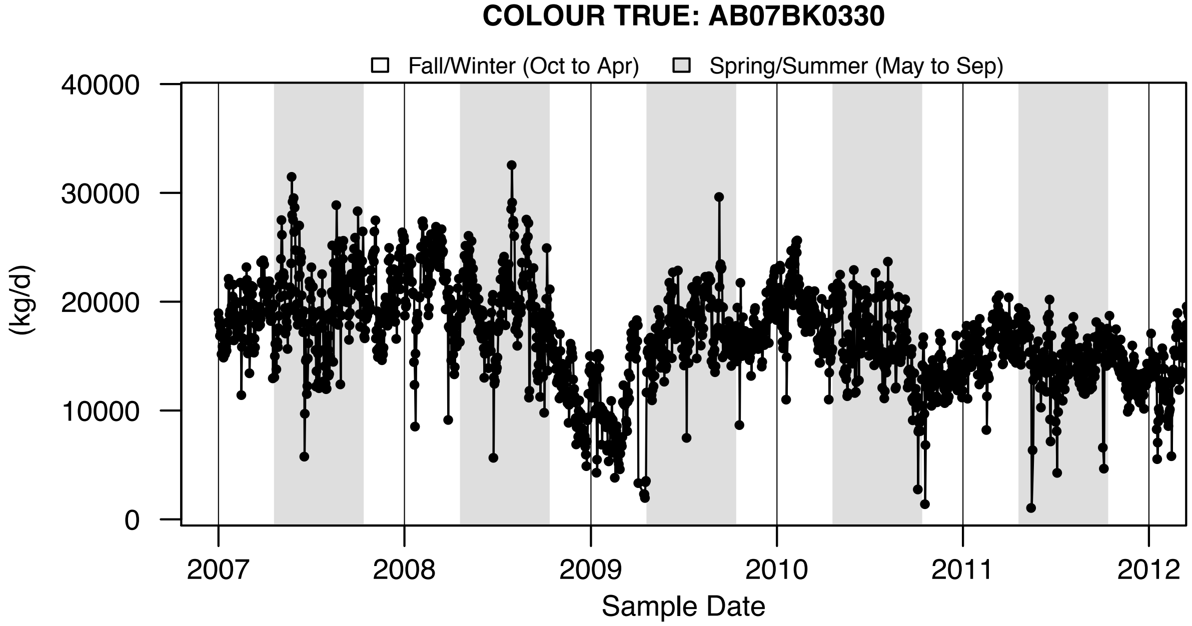


Figure A5.62: COLOUR TRUE: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

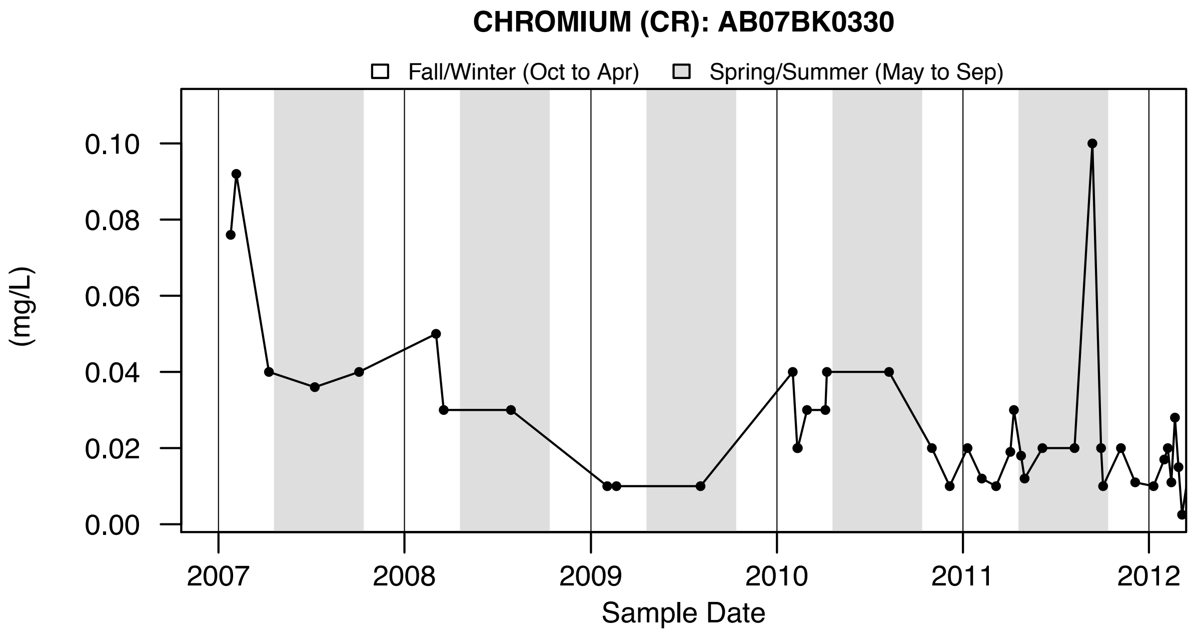


Figure A5.63: CHROMIUM (CR): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

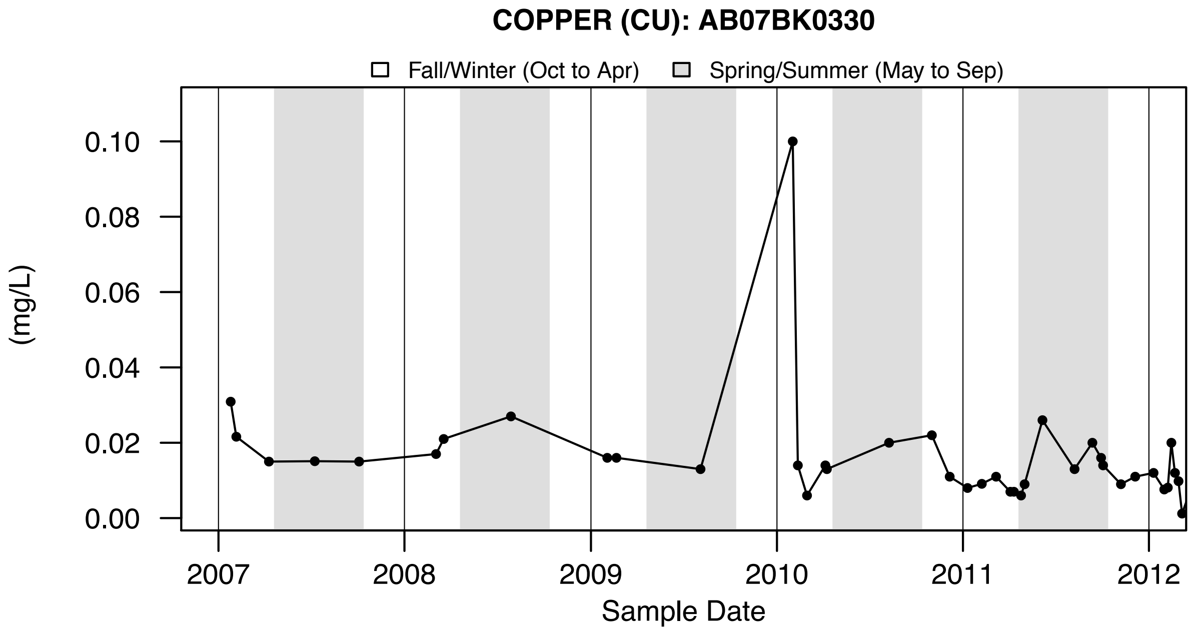


Figure A5.64: COPPER (CU): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

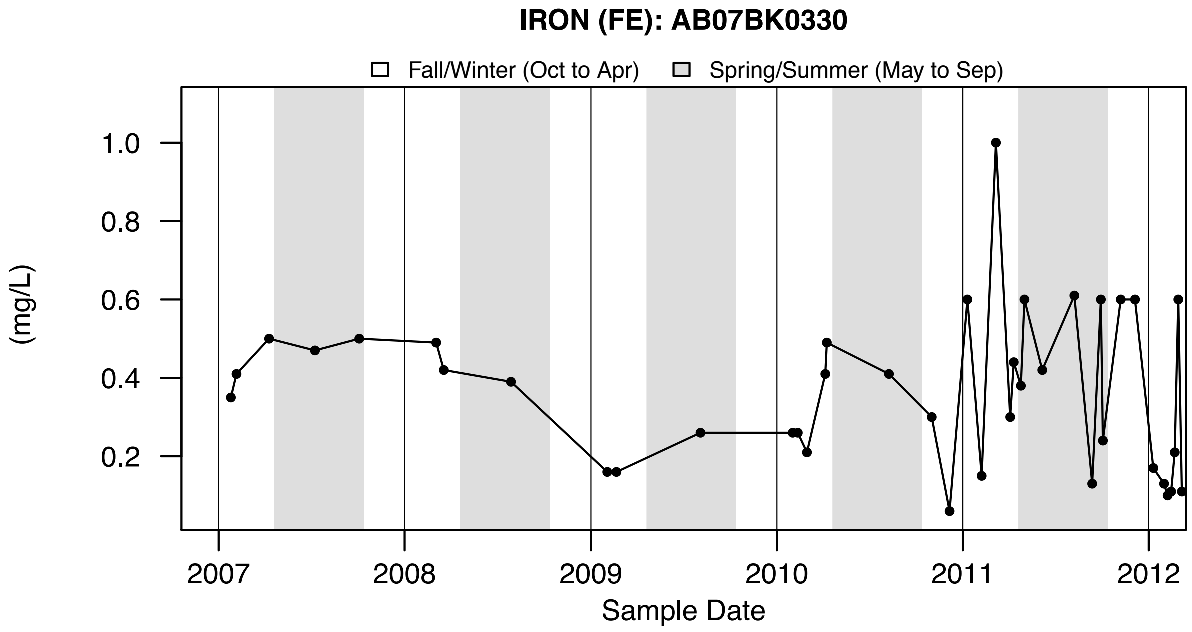


Figure A5.65: IRON (FE): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

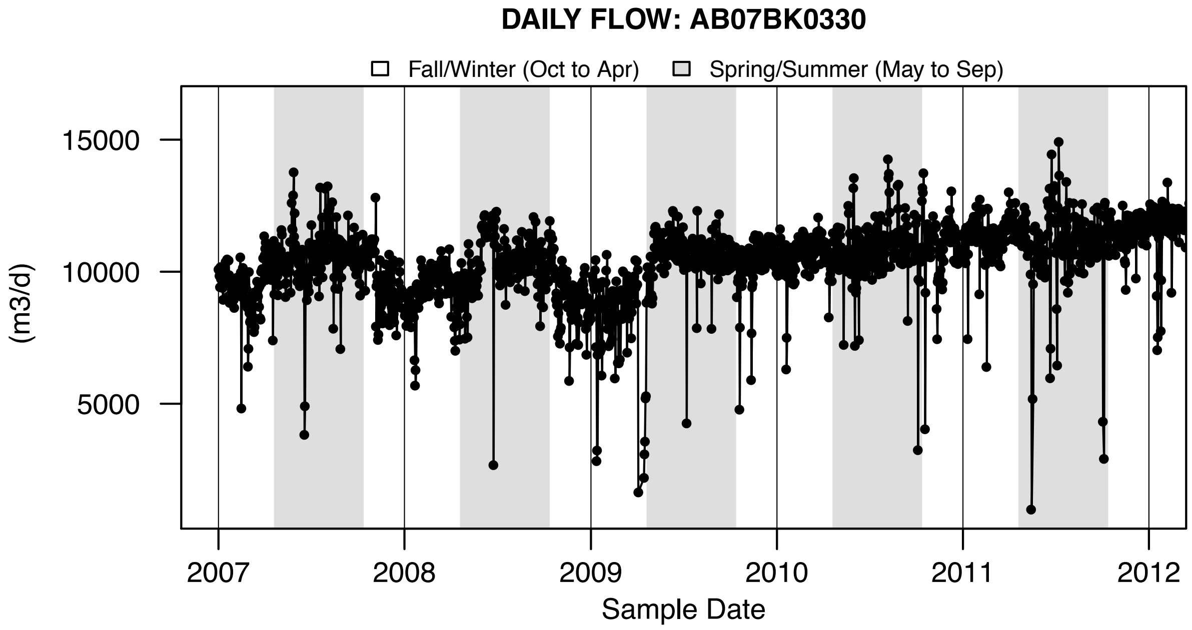


Figure A5.66: DAILY FLOW: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

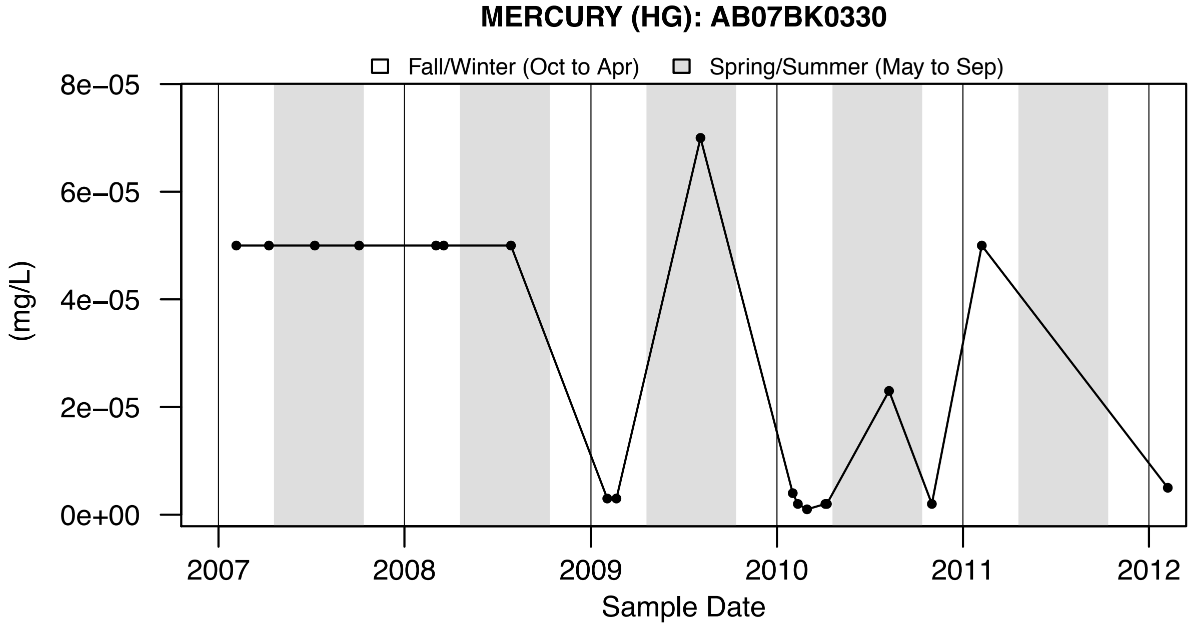


Figure A5.67: MERCURY (HG): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

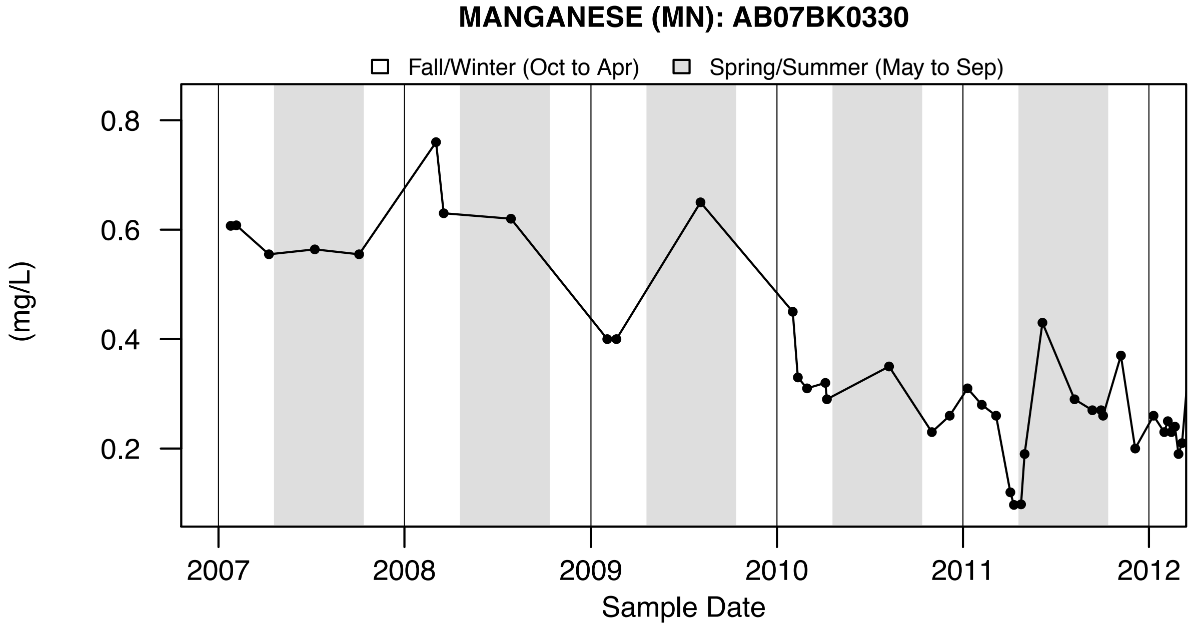


Figure A5.68: MANGANESE (MN): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

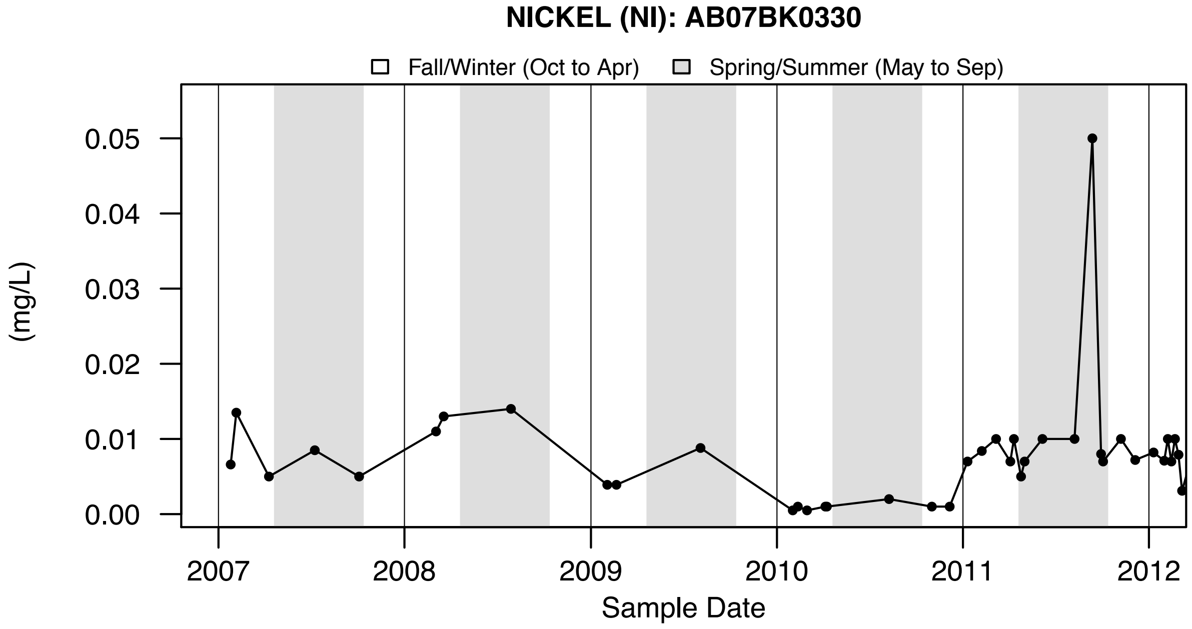


Figure A5.69: NICKEL (NI): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

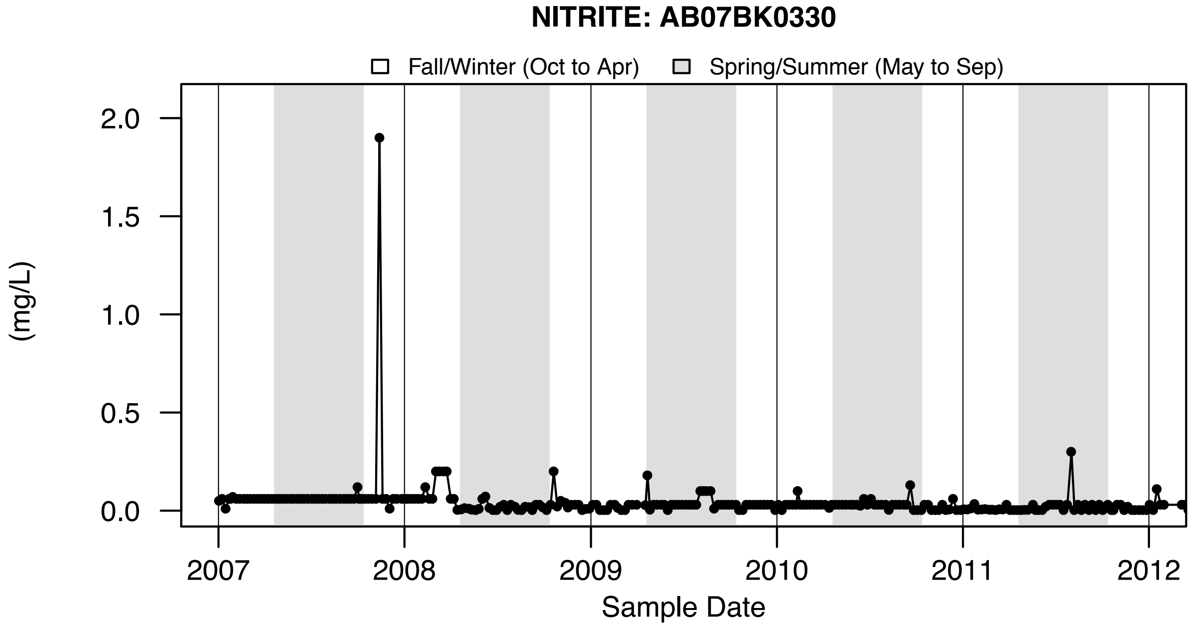


Figure A5.70: NITRITE: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

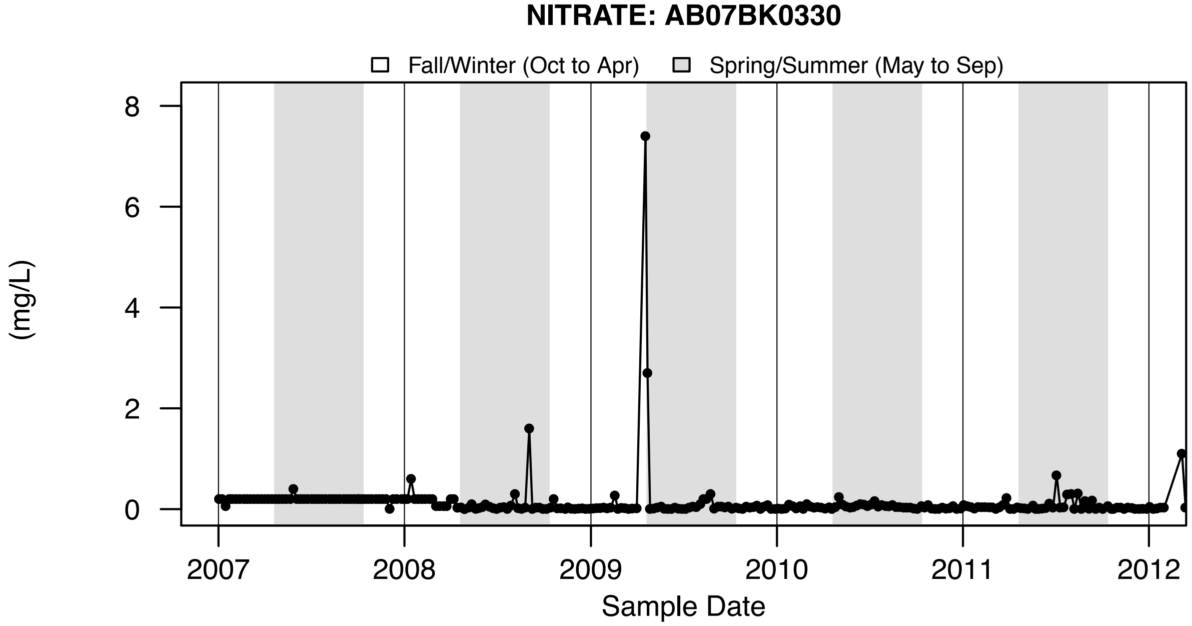


Figure A5.71: NITRATE: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

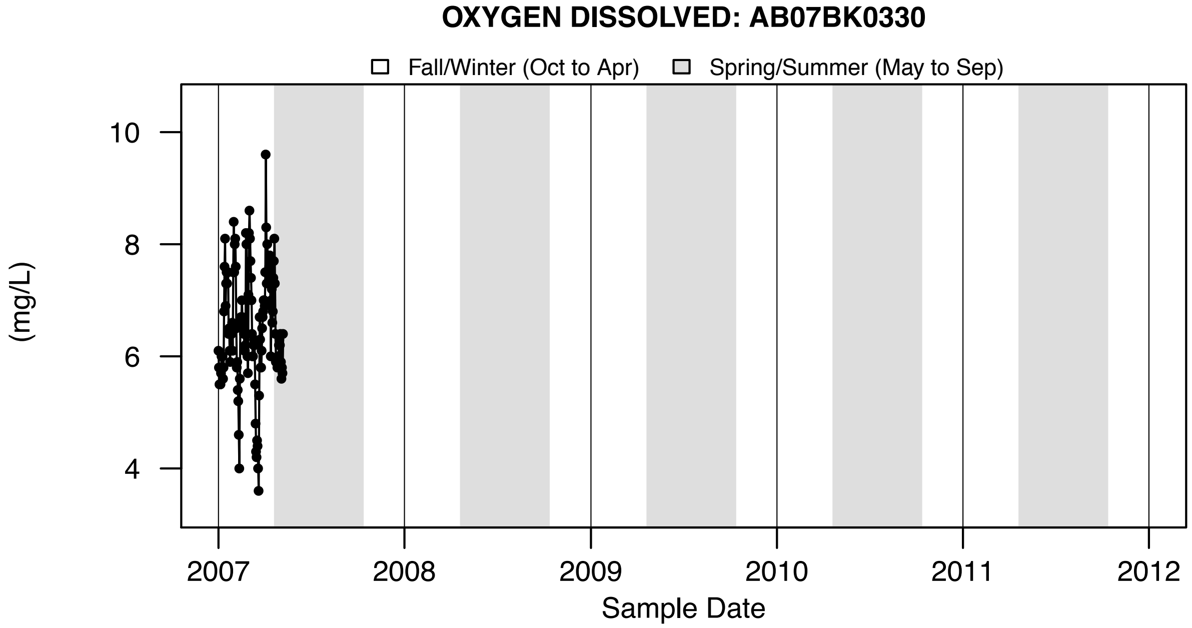


Figure A5.72: OXYGEN DISSOLVED: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

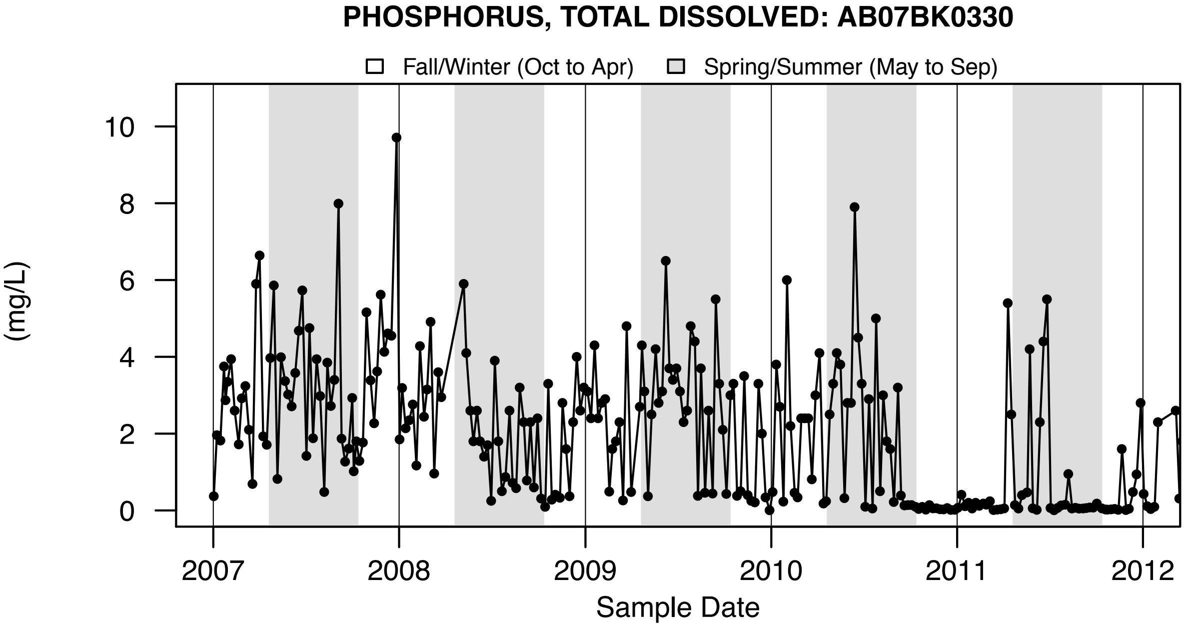


Figure A5.73: PHOSPHORUS, TOTAL DISSOLVED: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

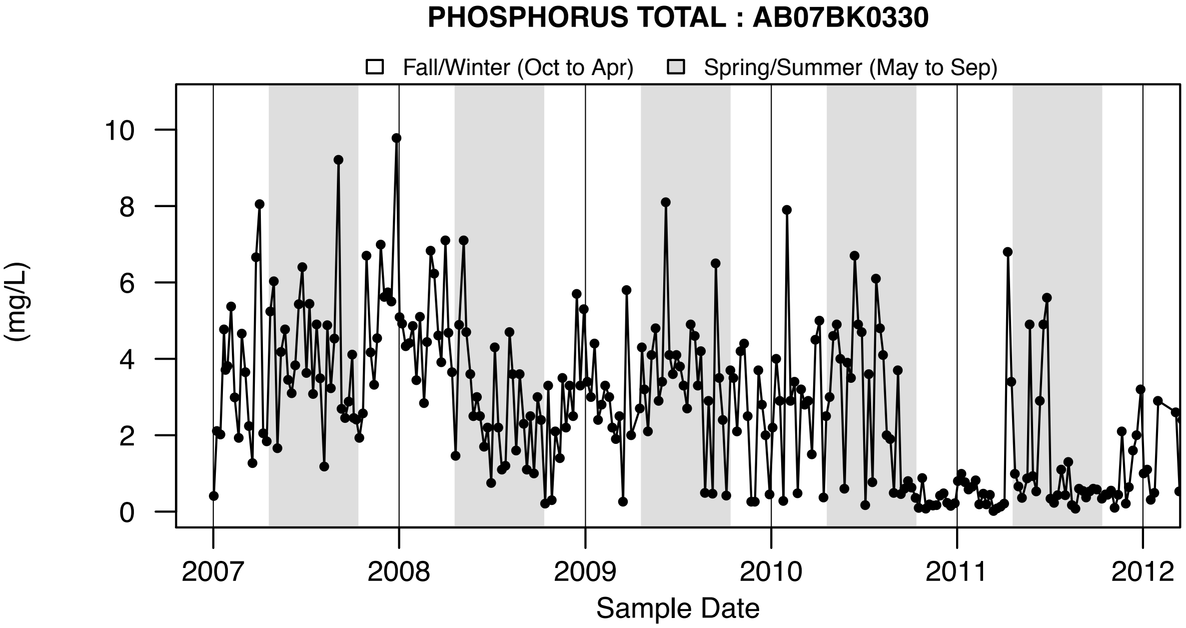


Figure A5.74: PHOSPHORUS TOTAL : AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

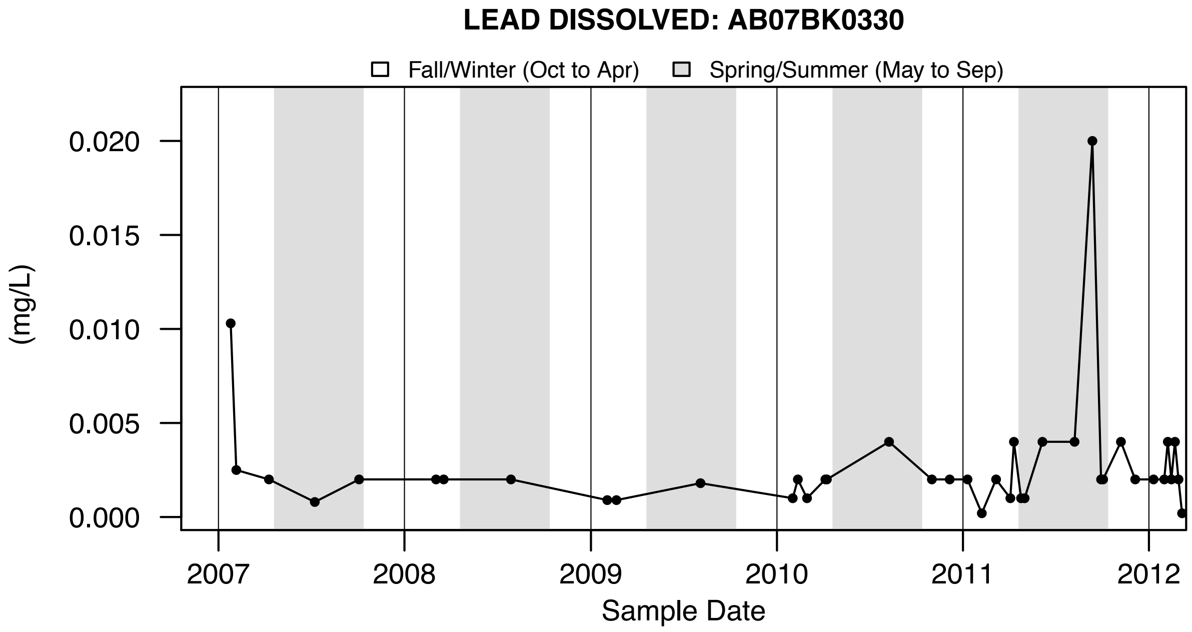


Figure A5.75: LEAD DISSOLVED: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

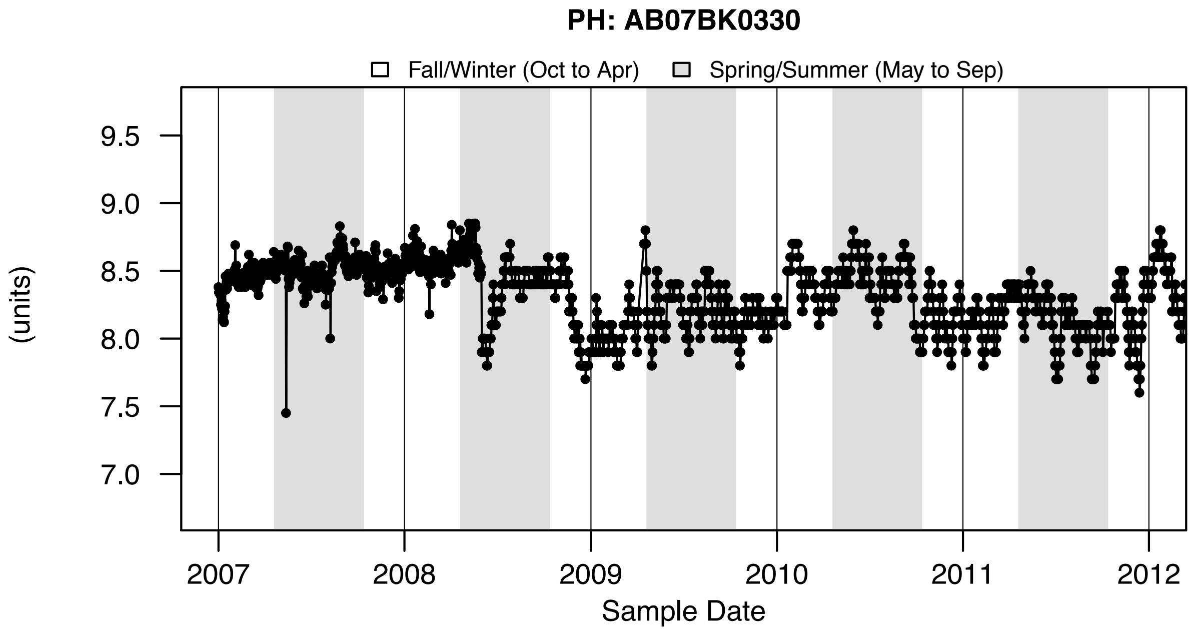


Figure A5.76: PH: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

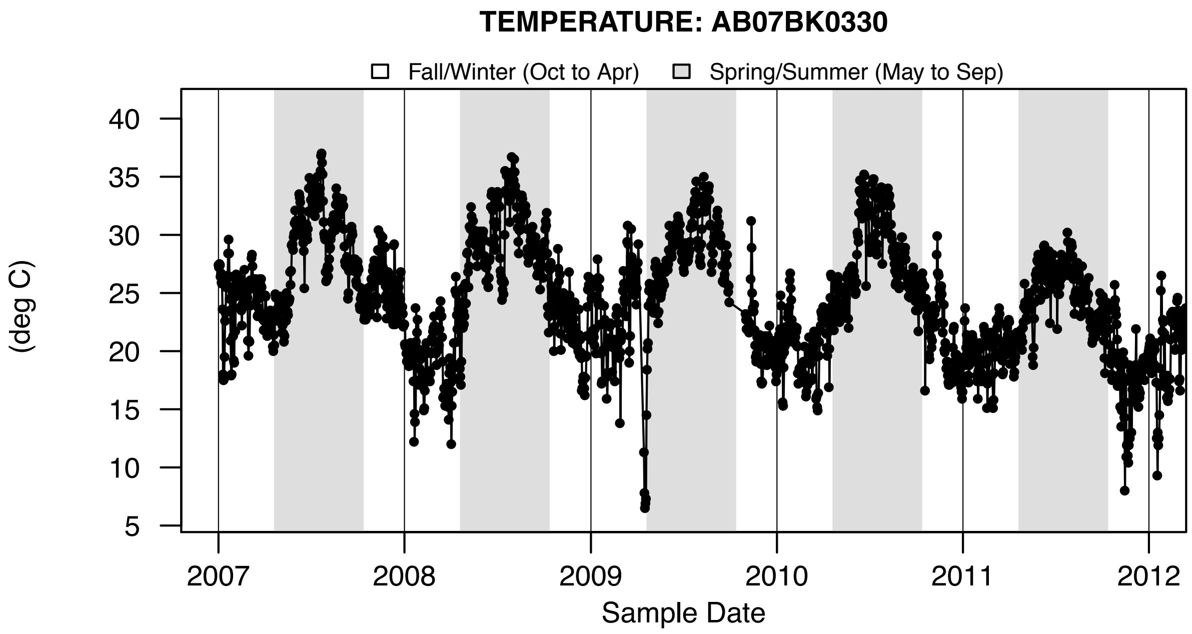


Figure A5.77: TEMPERATURE: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

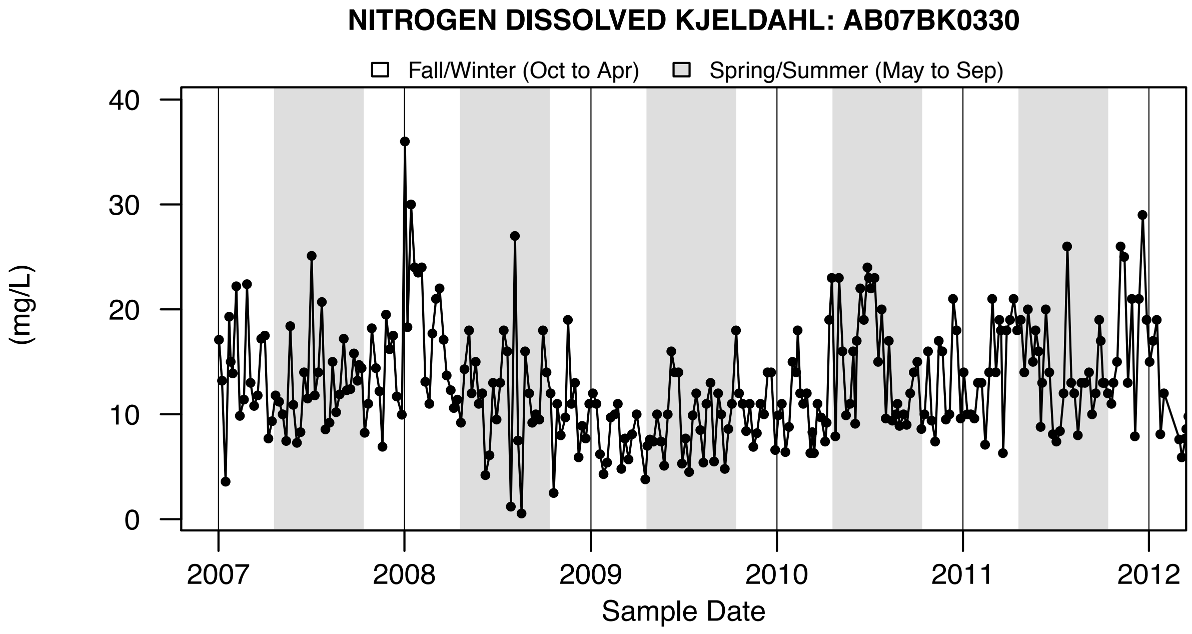


Figure A5.78: NITROGEN DISSOLVED KJELDAHL: AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

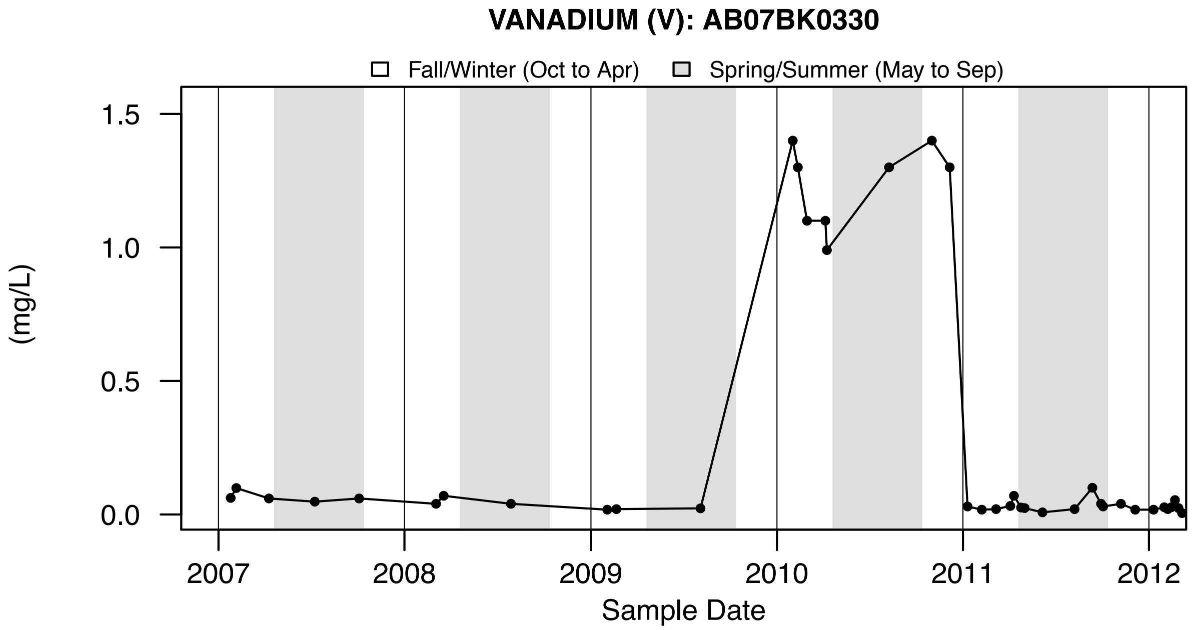


Figure A5.79: VANADIUM (V): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

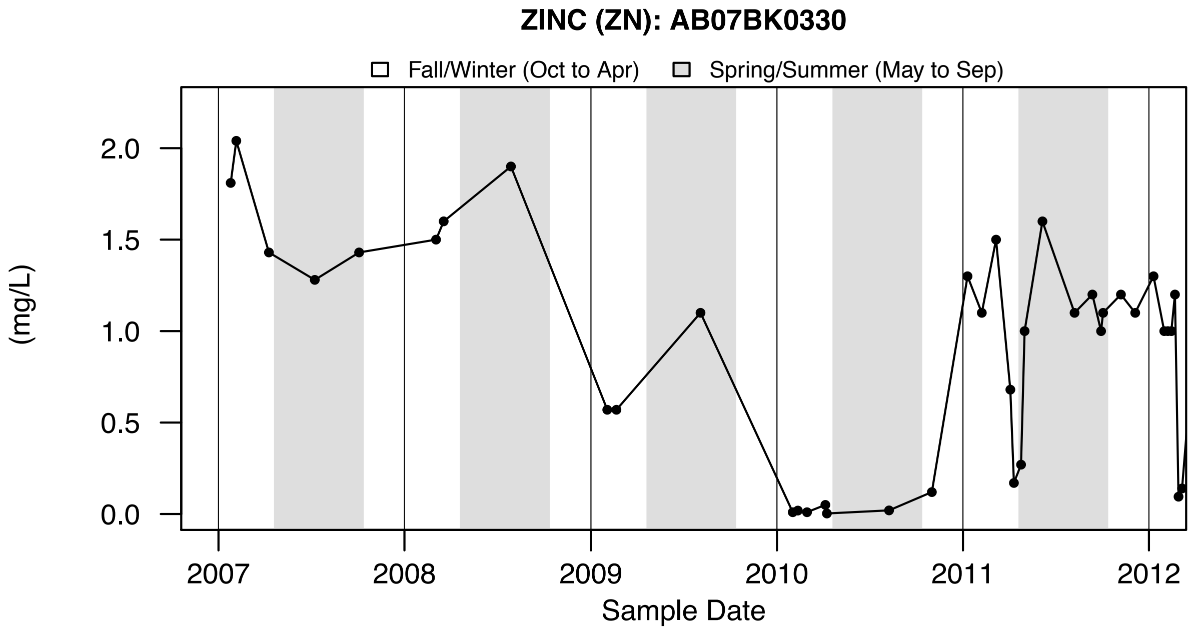


Figure A5.80: ZINC (ZN): AB07BK0330 - SLAVE LAKE PULP - WEST FRASER MILLS LTD (FINAL EFFLUENT)

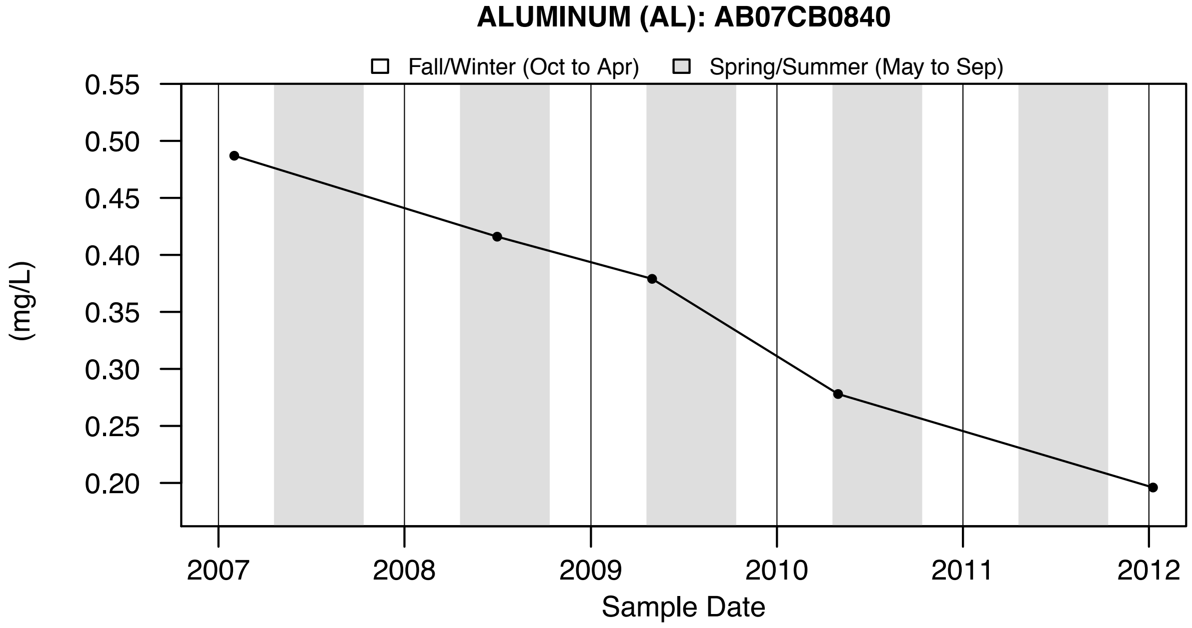


Figure A5.81: ALUMINUM (AL): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

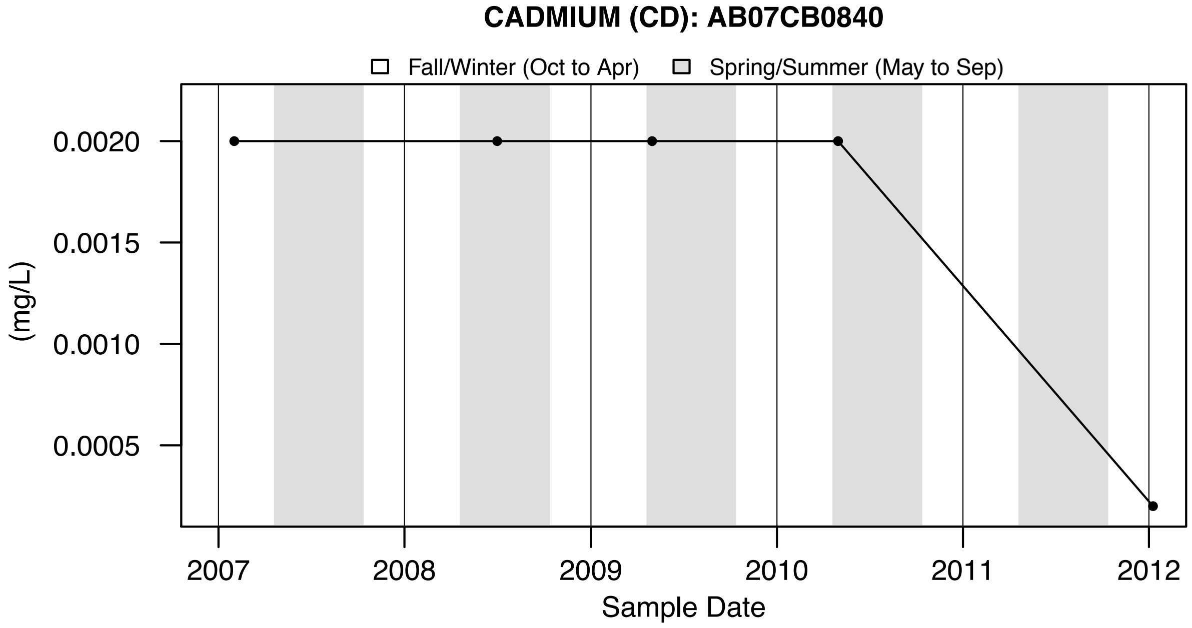


Figure A5.82: CADMIUM (CD): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

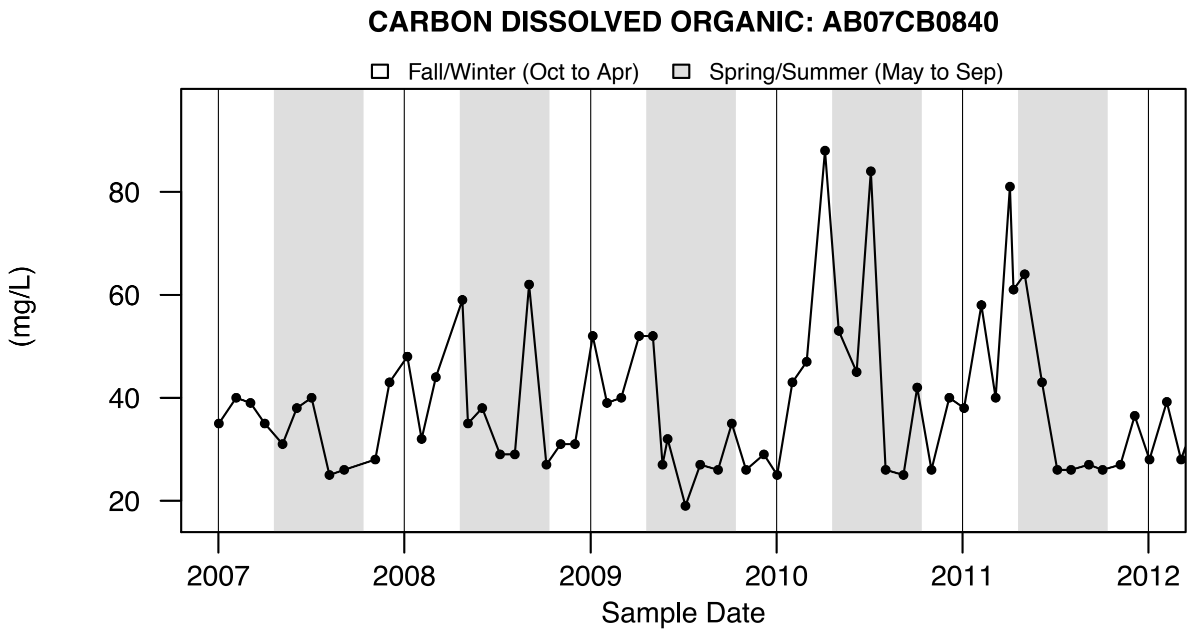


Figure A5.83: CARBON DISSOLVED ORGANIC: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

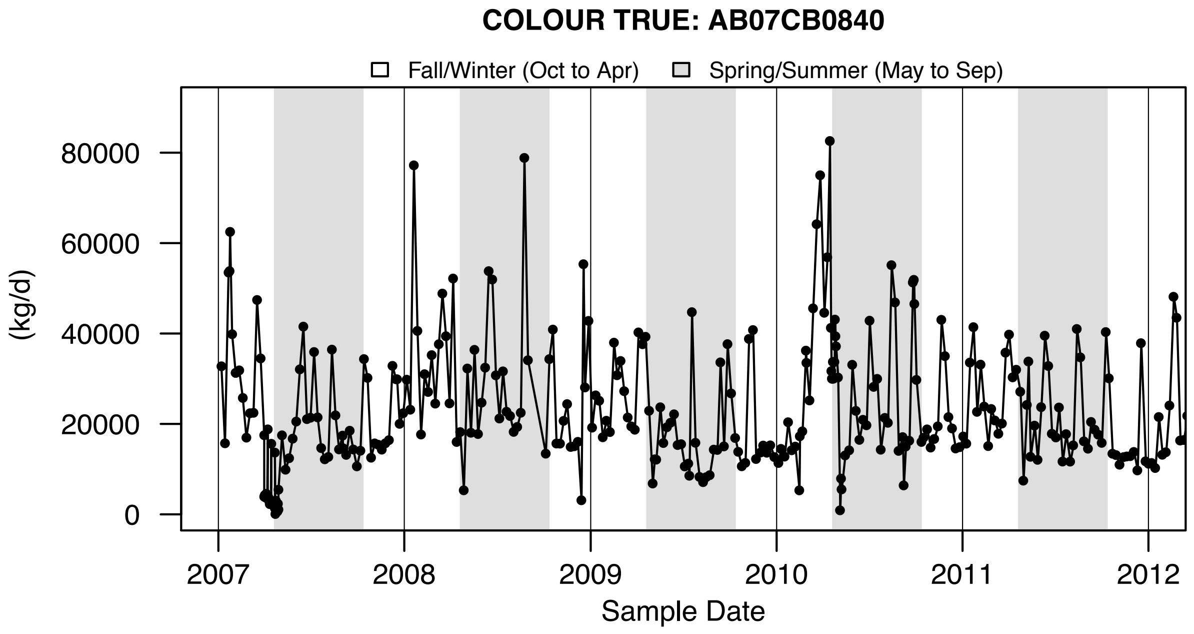


Figure A5.84: COLOUR TRUE: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

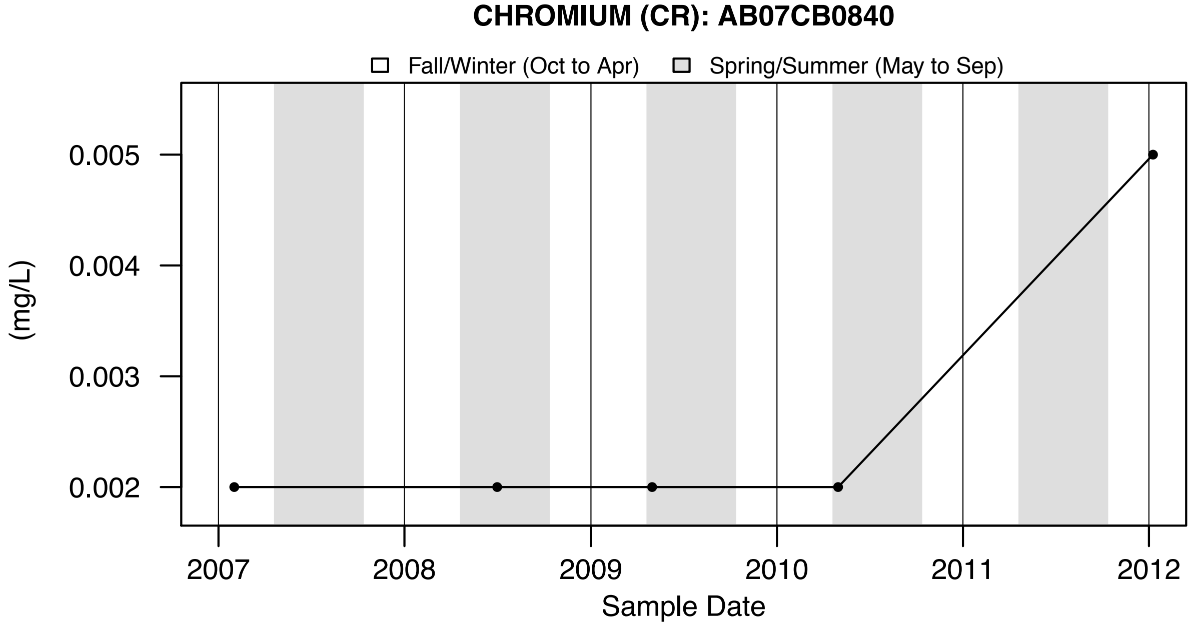


Figure A5.85: CHROMIUM (CR): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

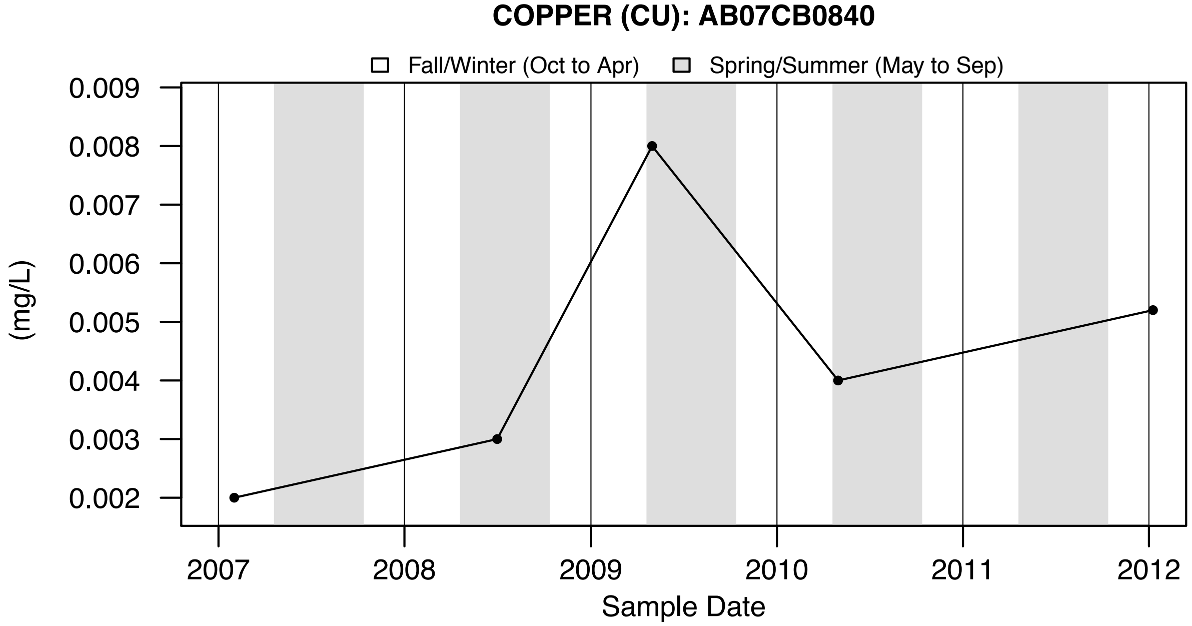


Figure A5.86: COPPER (CU): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

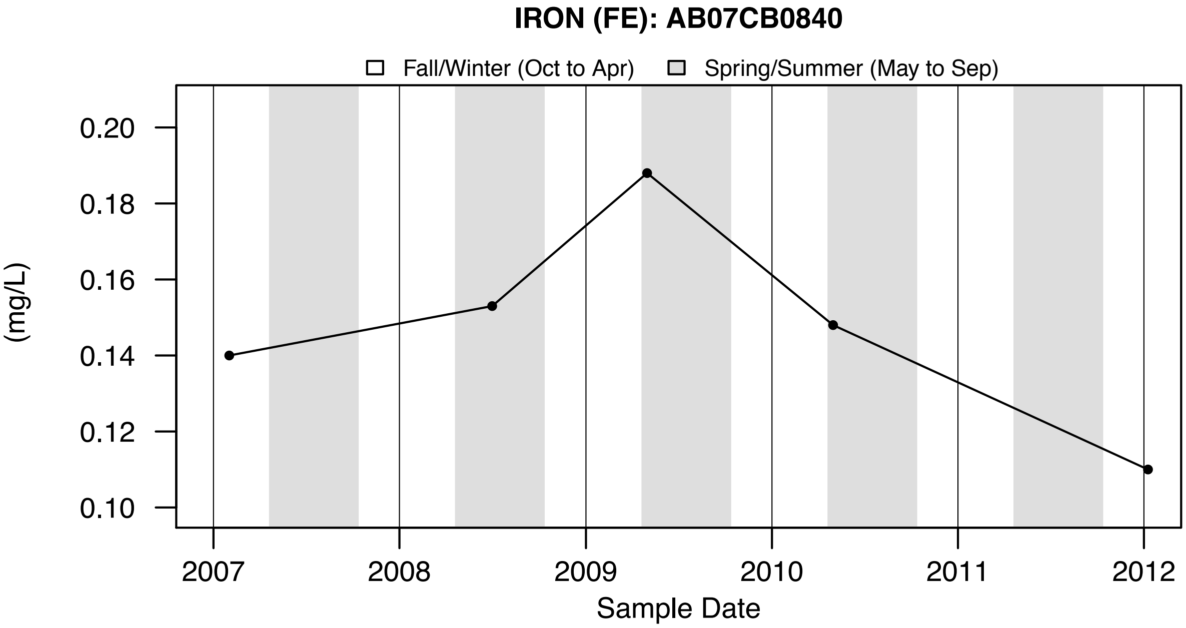


Figure A5.87: IRON (FE): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

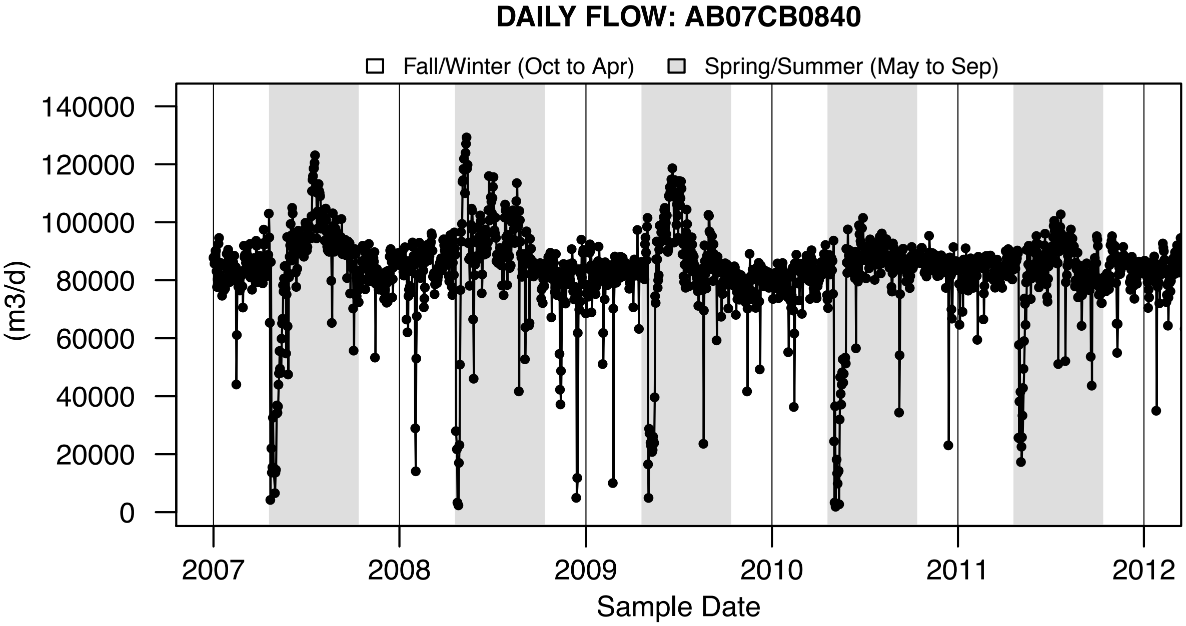


Figure A5.88: DAILY FLOW: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

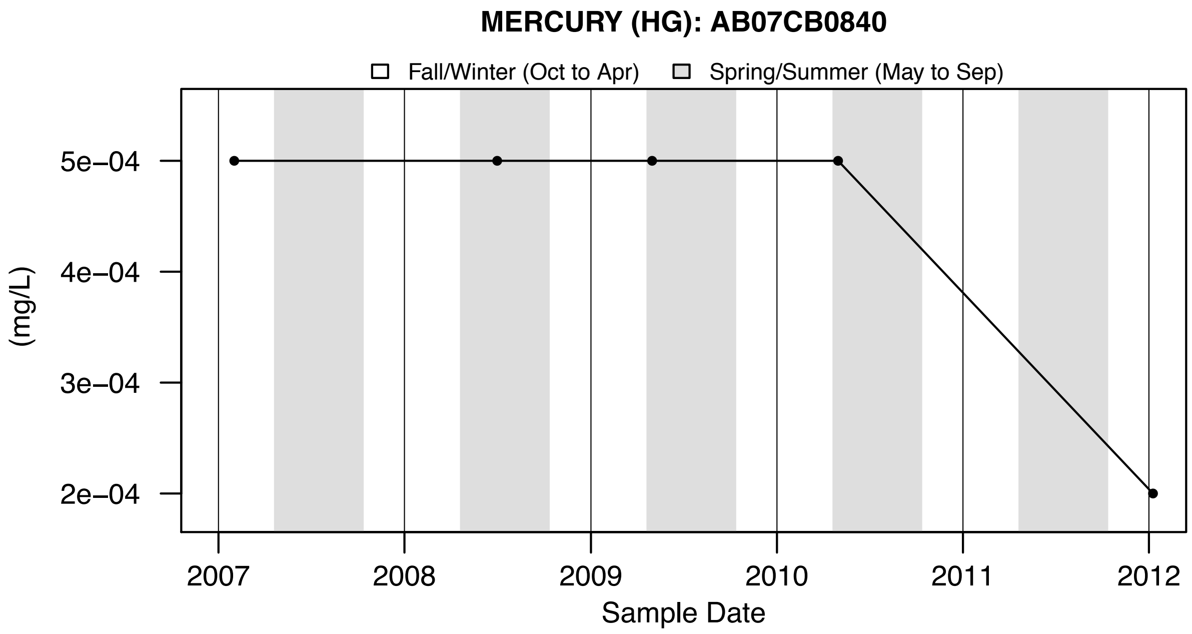


Figure A5.89: MERCURY (HG): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

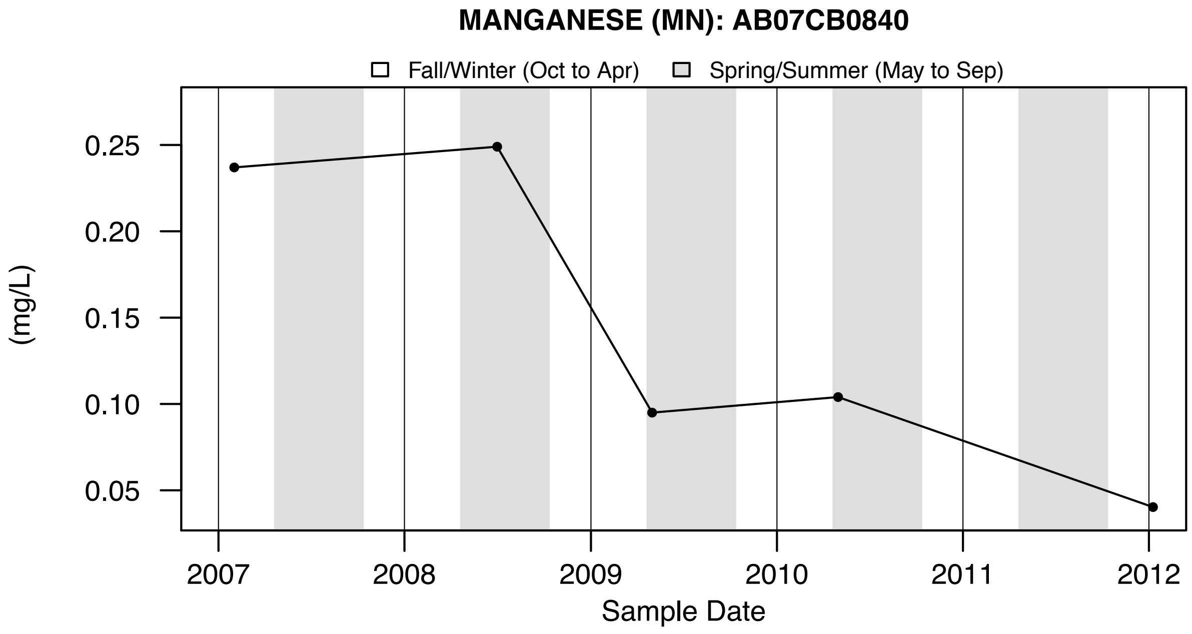


Figure A5.90: MANGANESE (MN): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

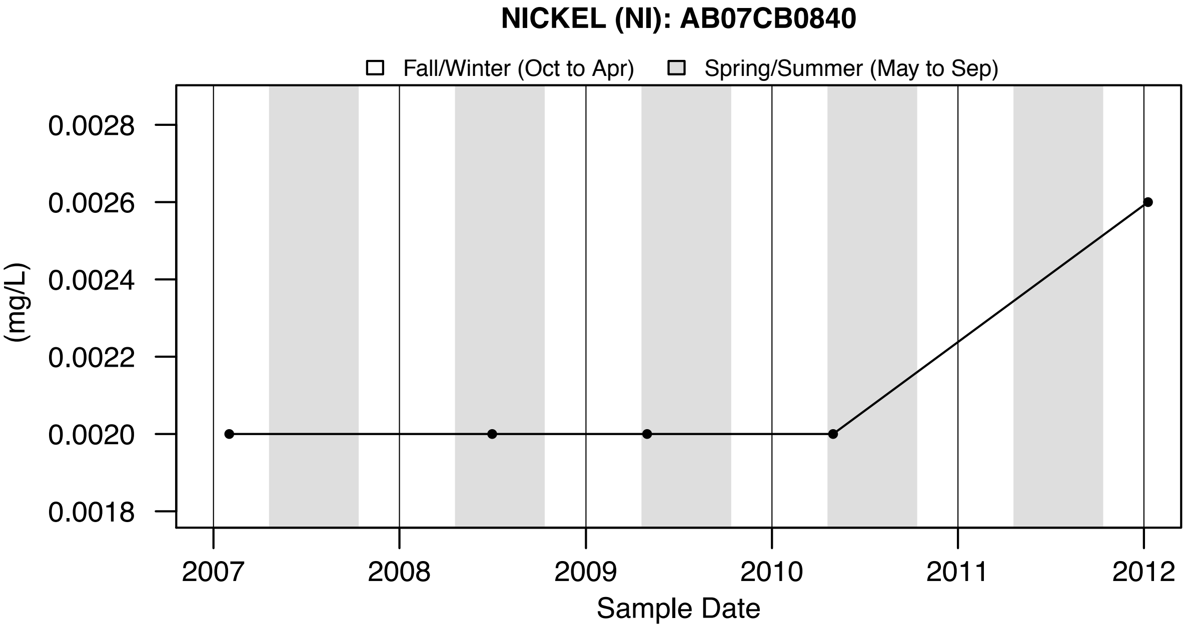


Figure A5.91: NICKEL (NI): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

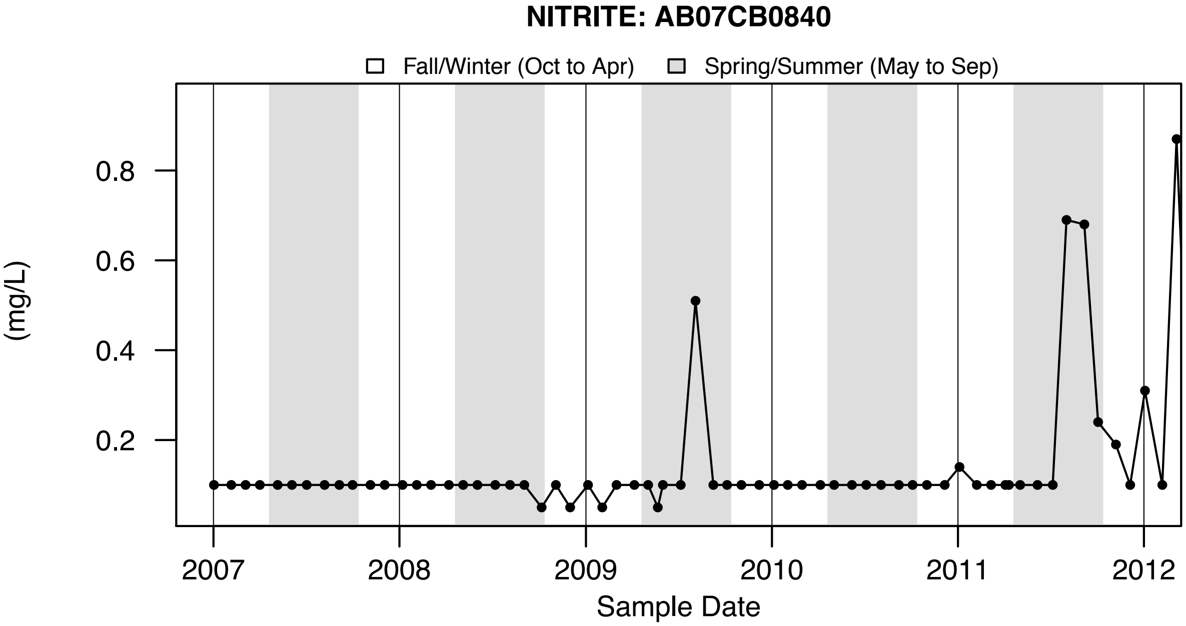


Figure A5.92: NITRITE: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

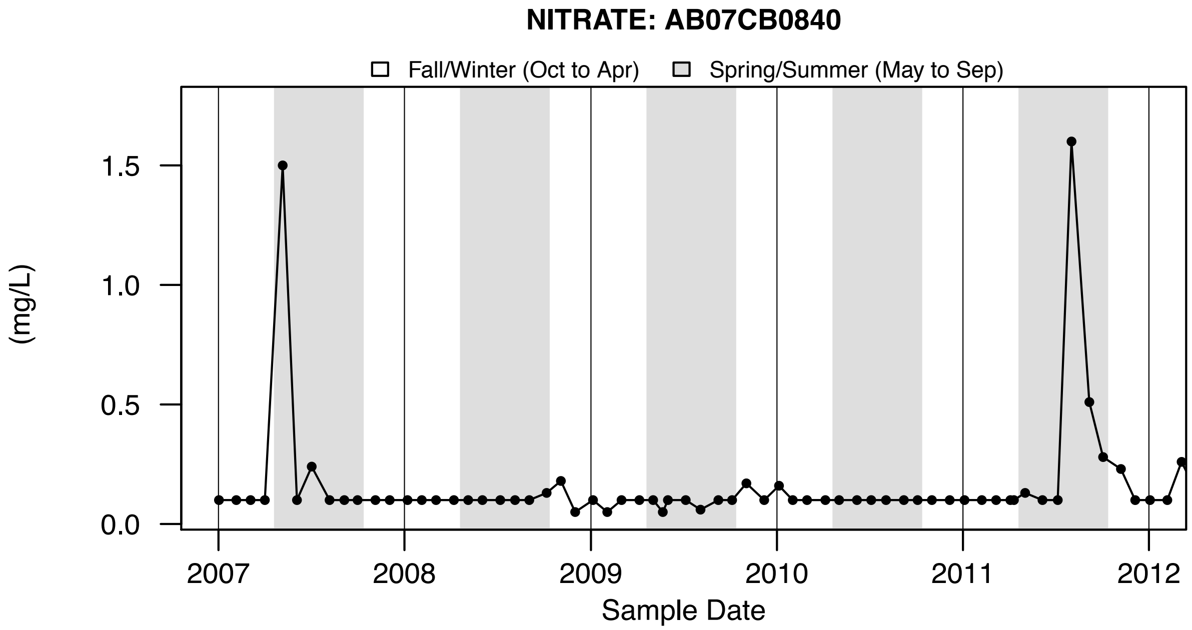


Figure A5.93: NITRATE: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

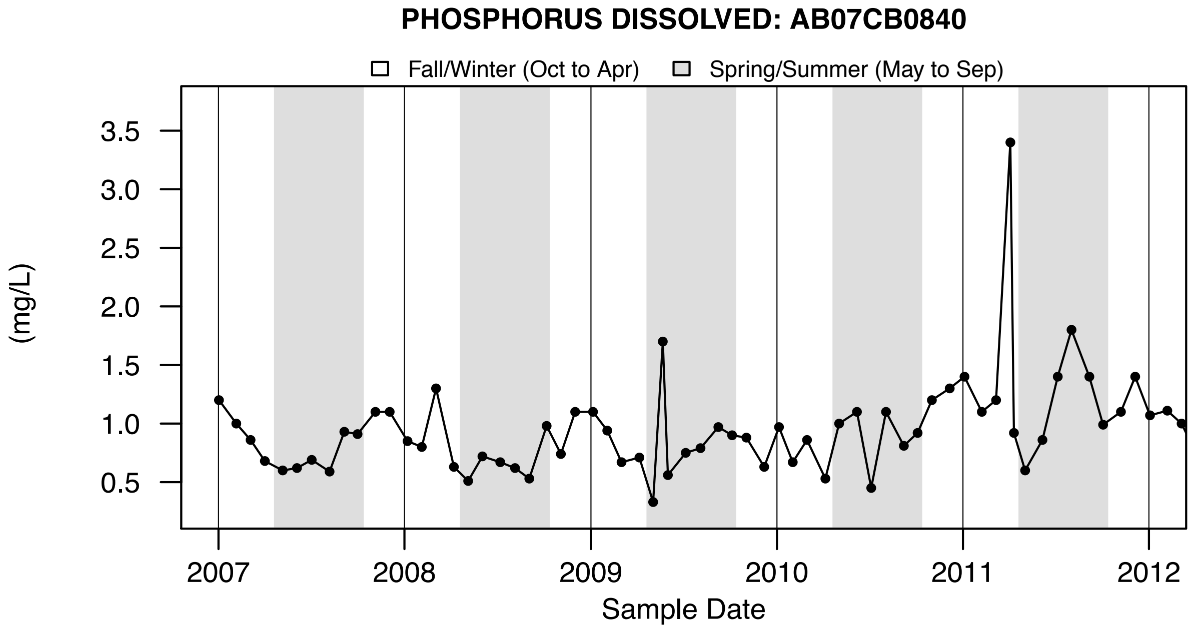


Figure A5.94: PHOSPHORUS DISSOLVED: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

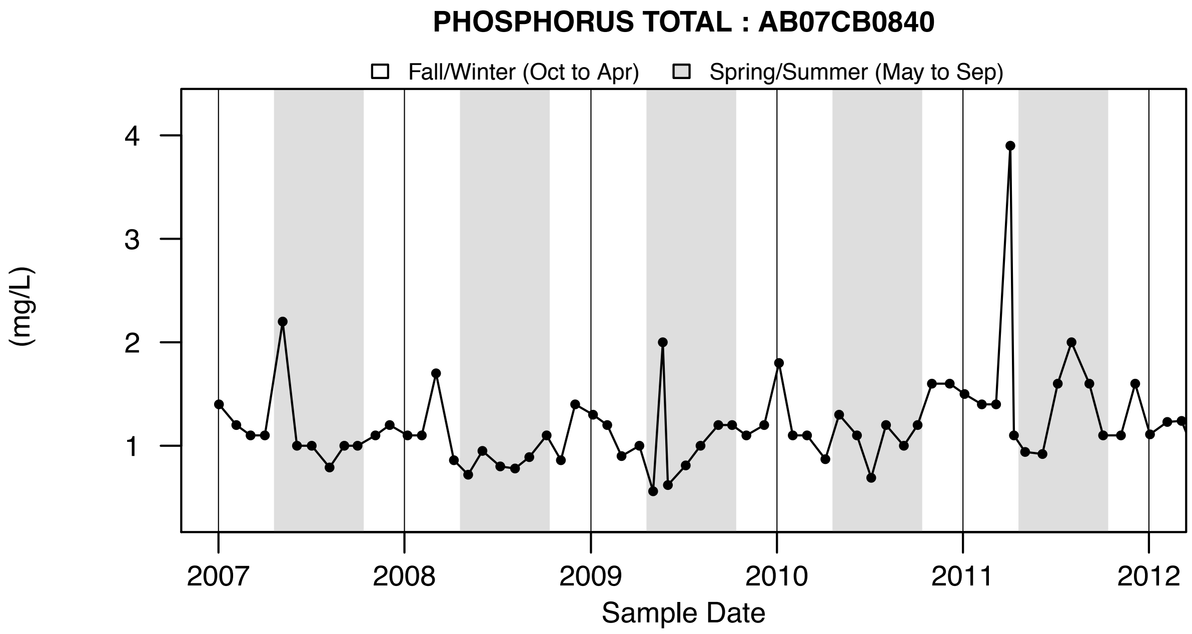


Figure A5.95: PHOSPHORUS TOTAL : AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

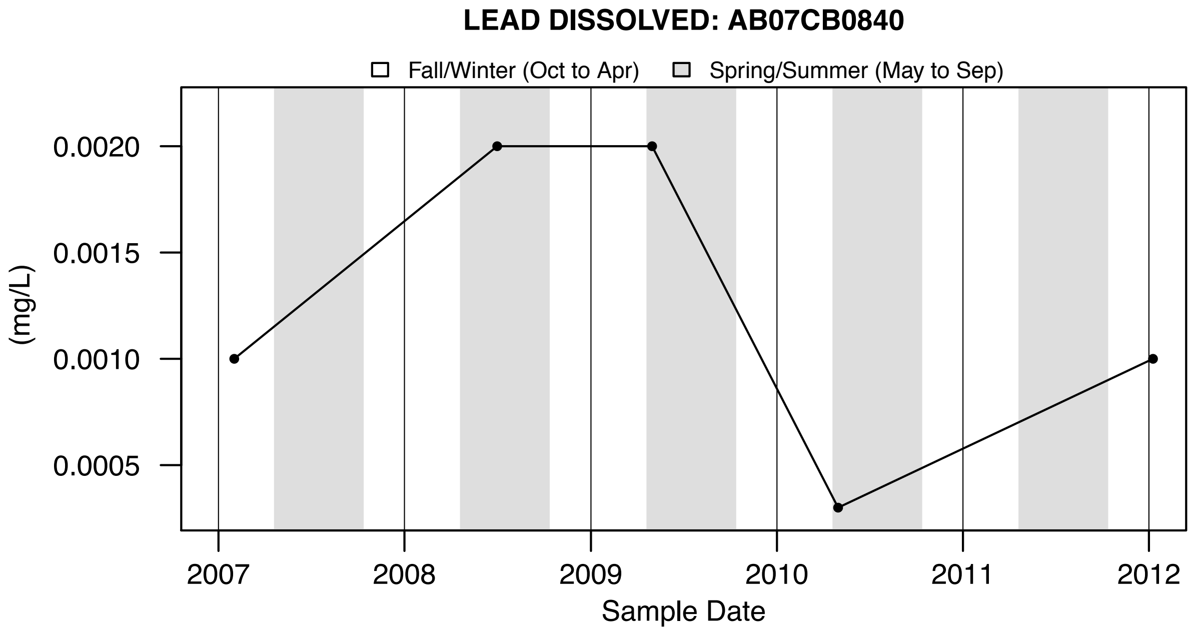


Figure A5.96: LEAD DISSOLVED: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

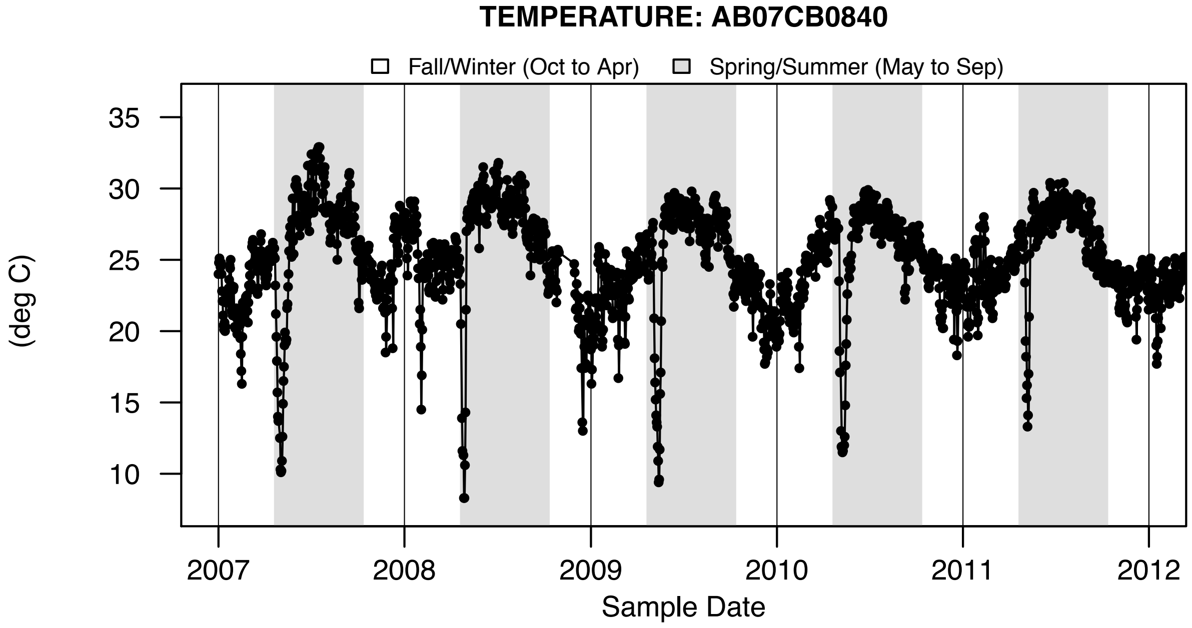


Figure A5.97: TEMPERATURE: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

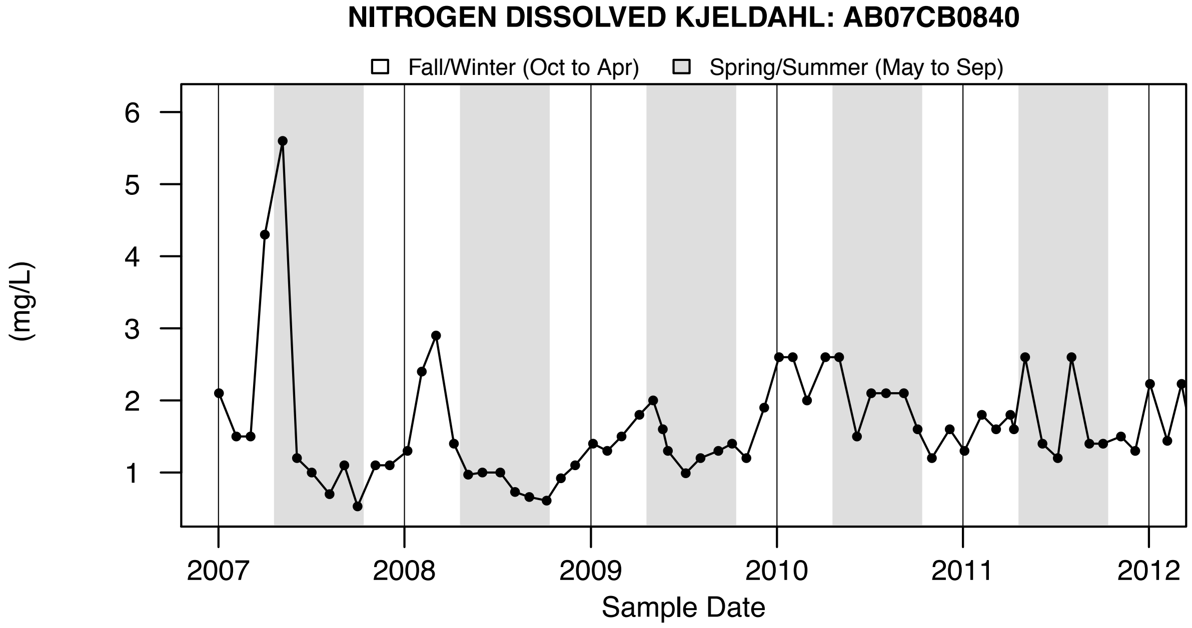


Figure A5.98: NITROGEN DISSOLVED KJELDAHL: AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

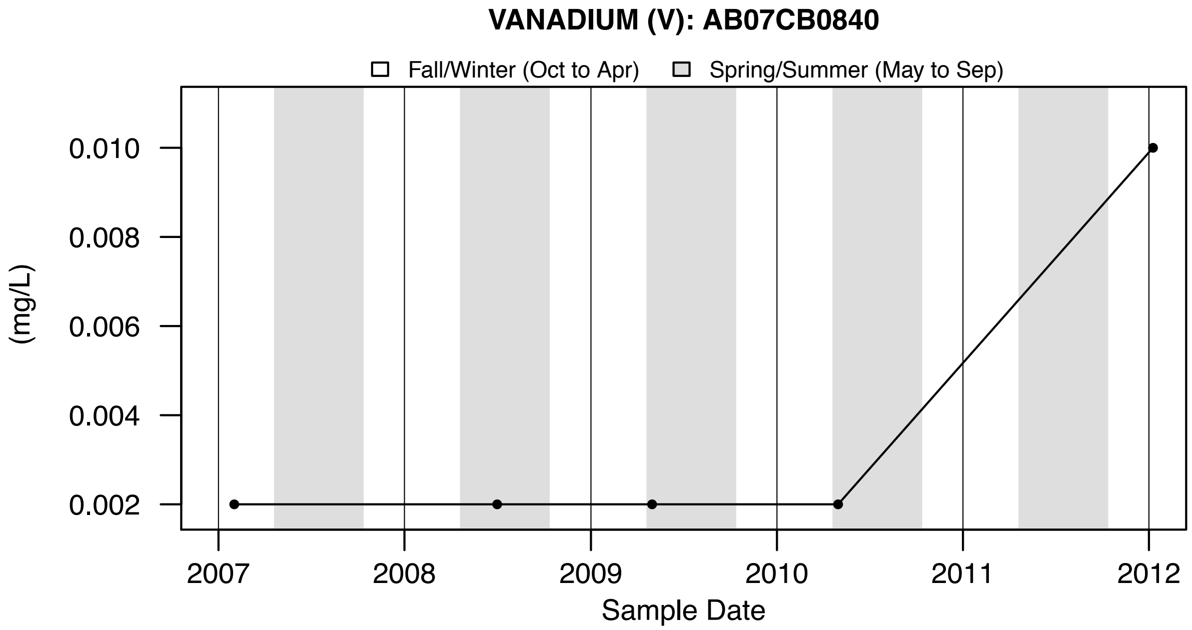


Figure A5.99: VANADIUM (V): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

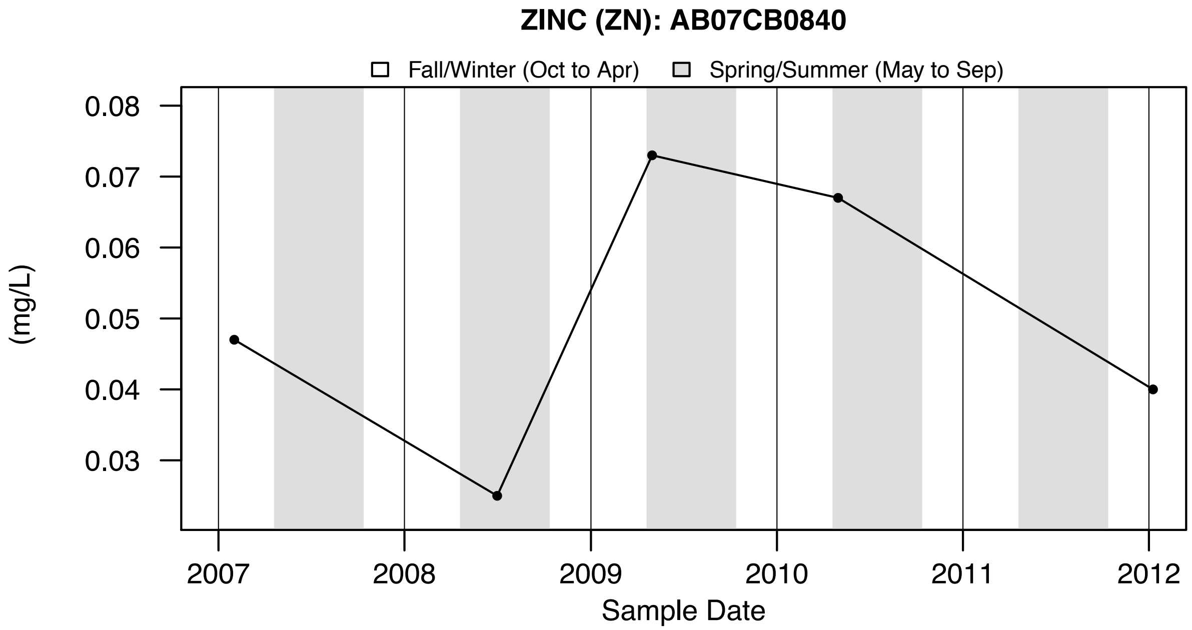


Figure A5.100: ZINC (ZN): AB07CB0840 - ALBERTA-PACIFIC FOREST INDUSTRIES INC (FINAL EFFLUENT)

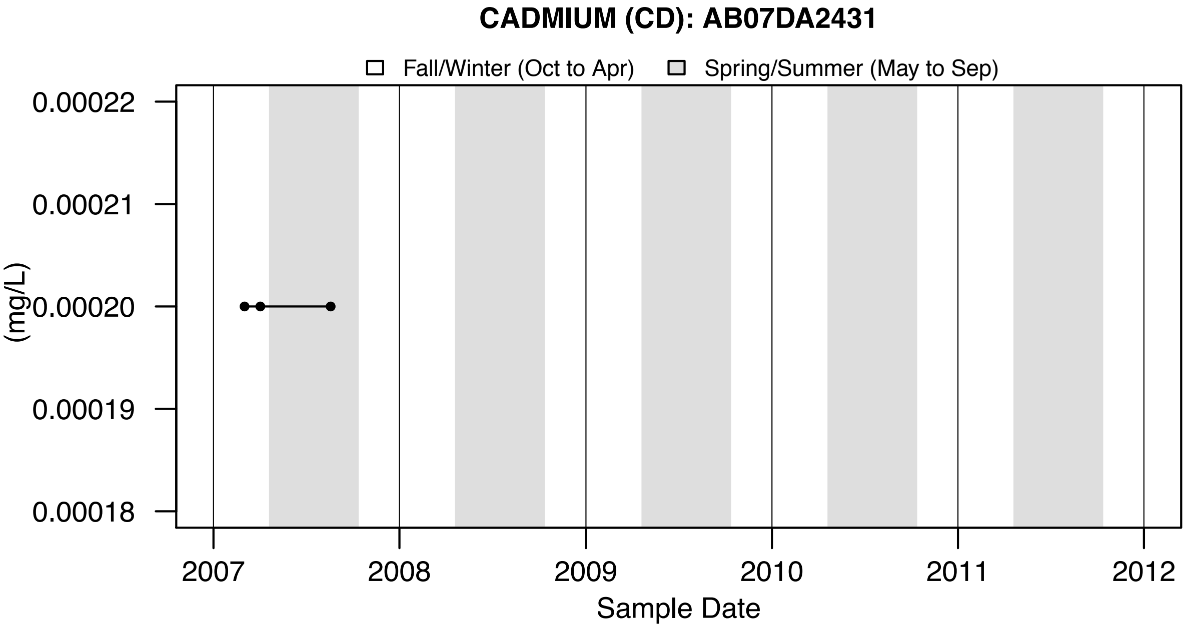


Figure A5.101: CADMIUM (CD): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

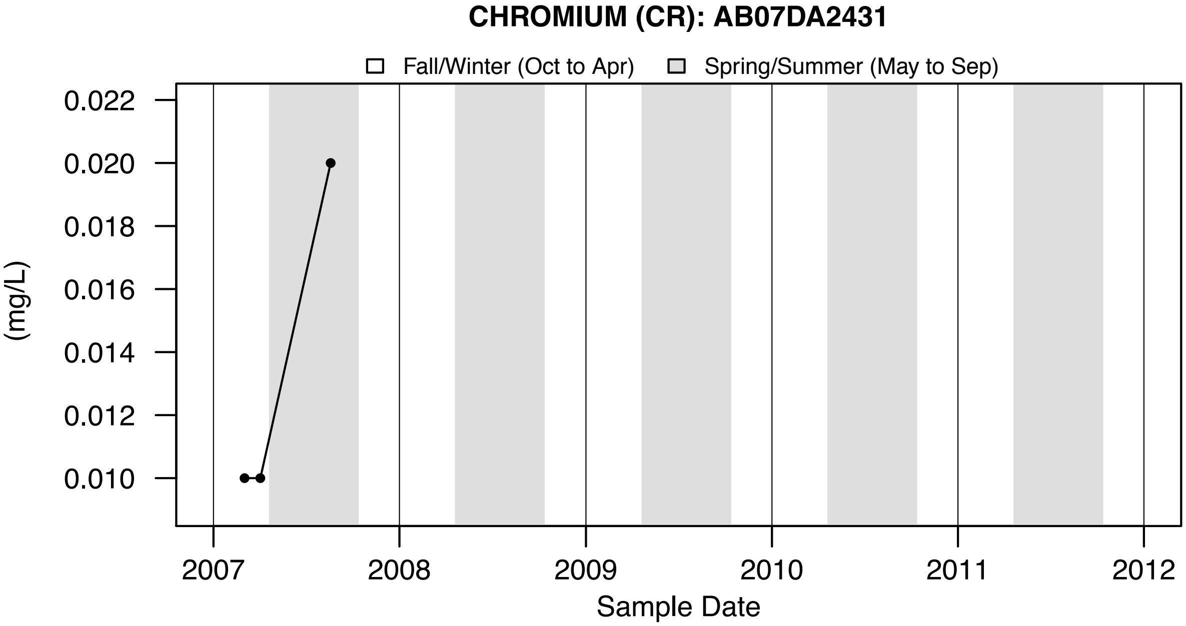


Figure A5.102: CHROMIUM (CR): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

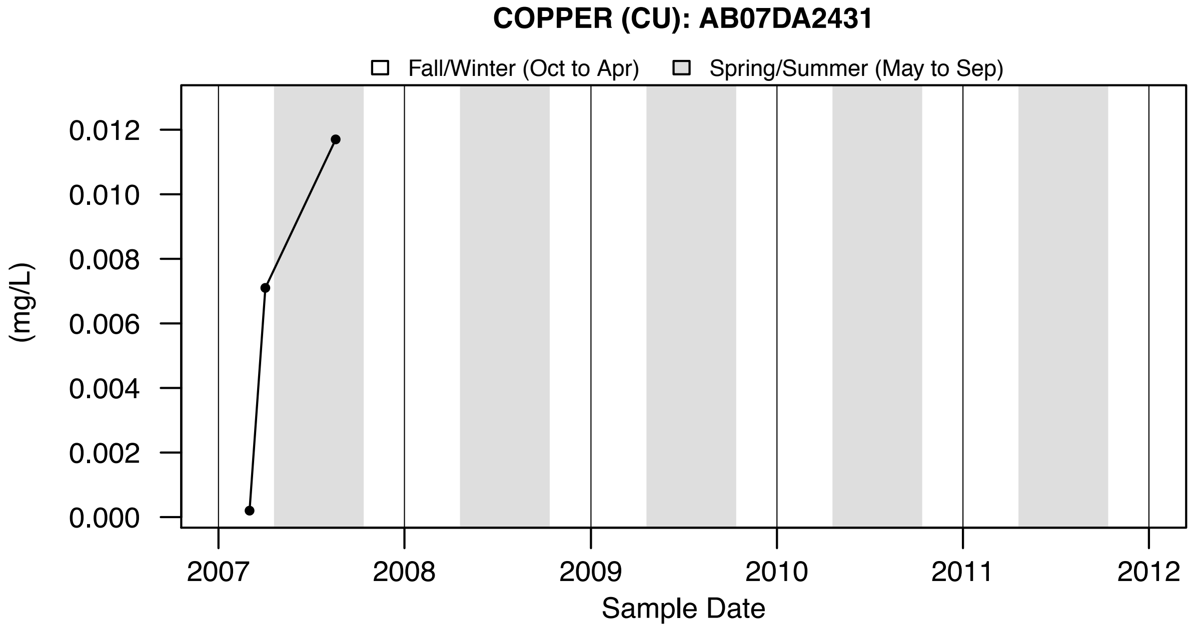


Figure A5.103: COPPER (CU): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

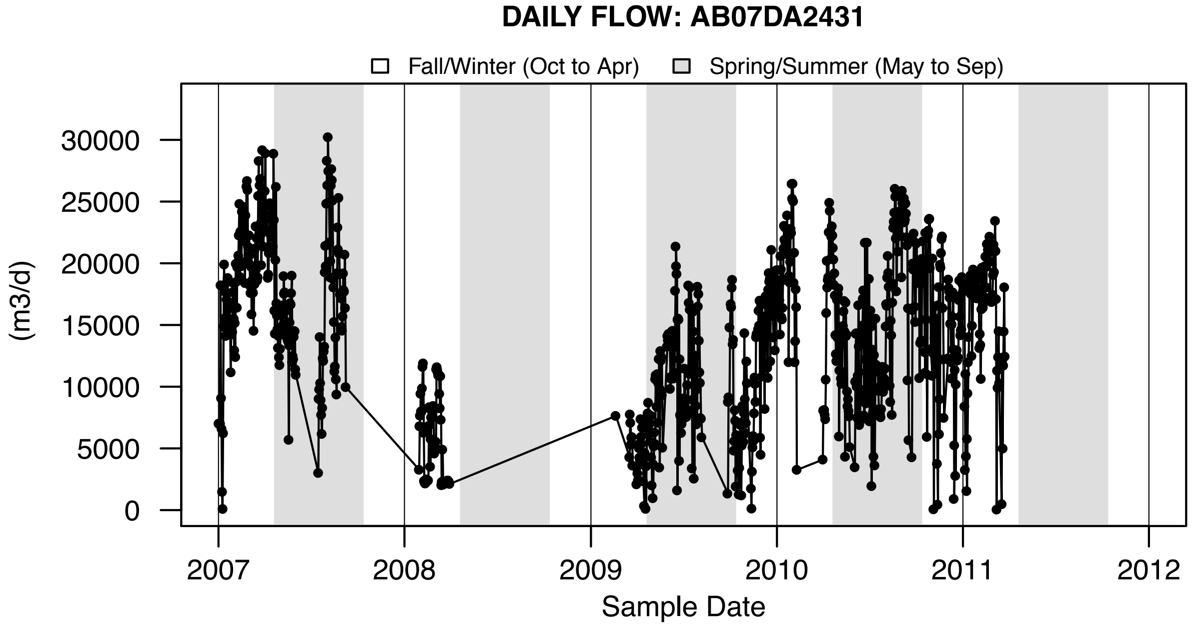


Figure A5.104: DAILY FLOW: AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

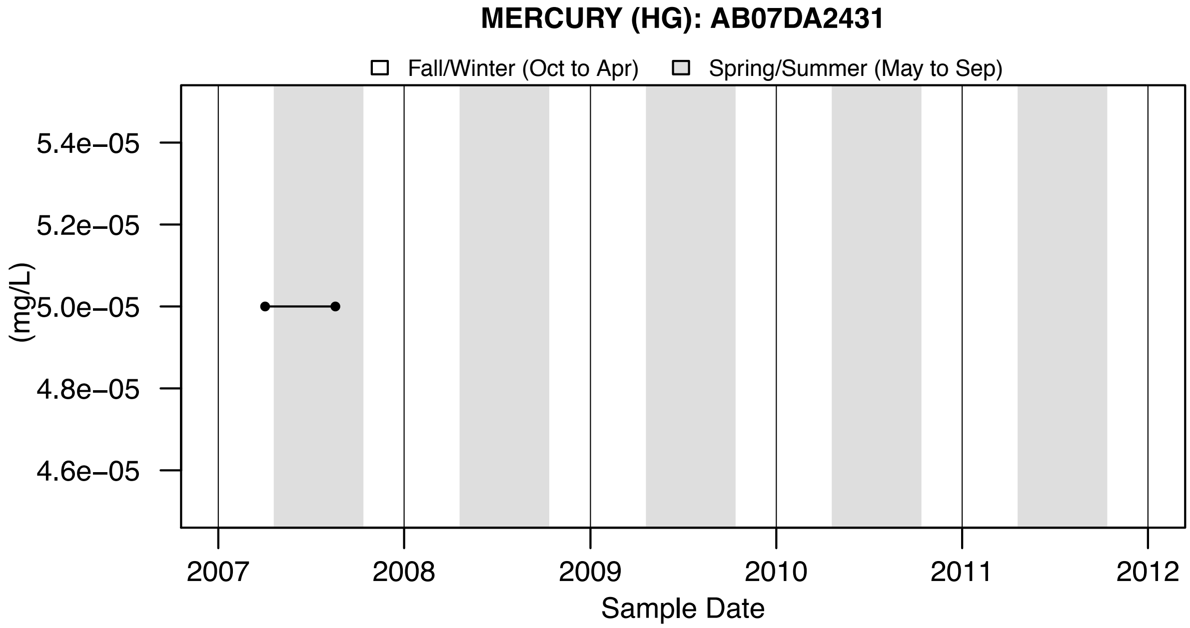


Figure A5.105: MERCURY (HG): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

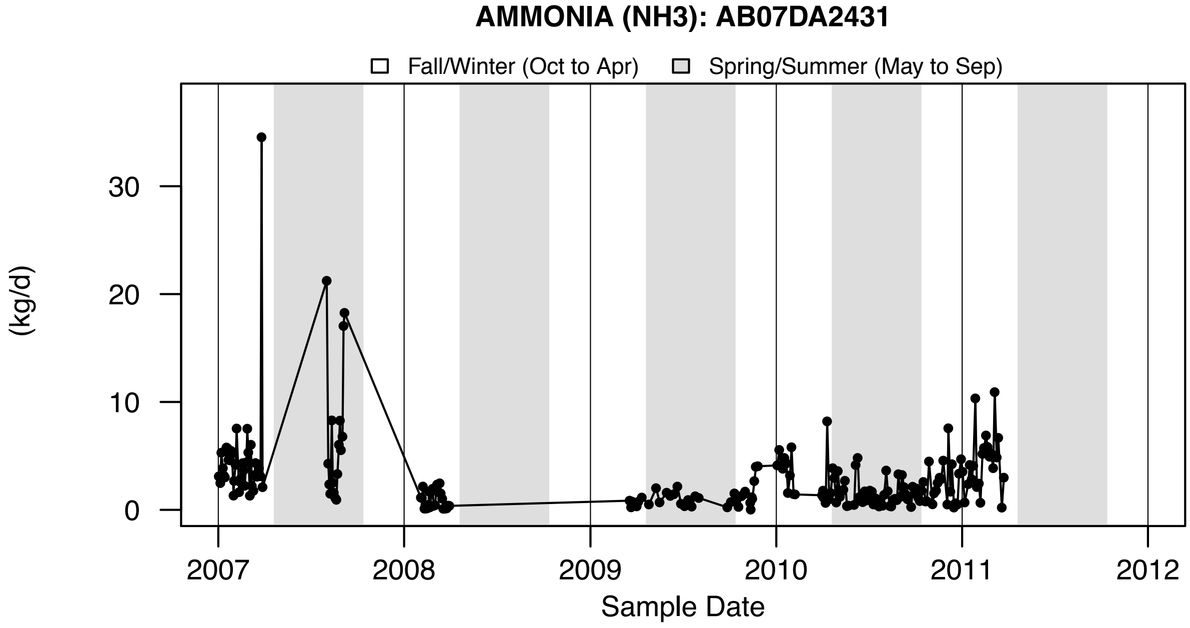


Figure A5.106: AMMONIA (NH3): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

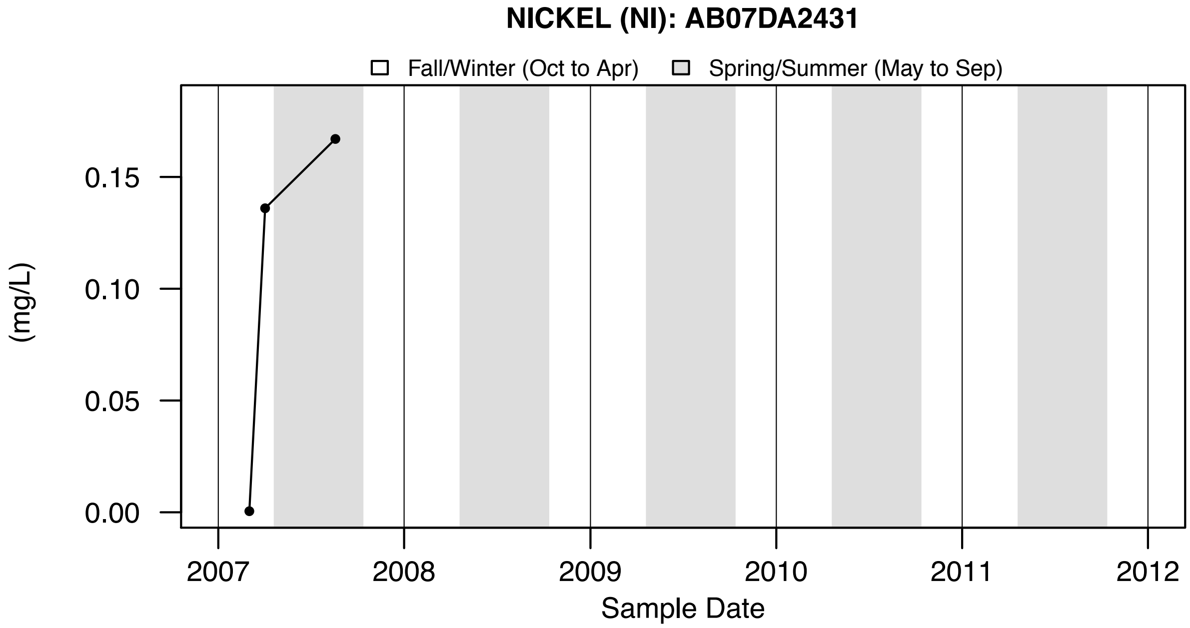


Figure A5.107: NICKEL (NI): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

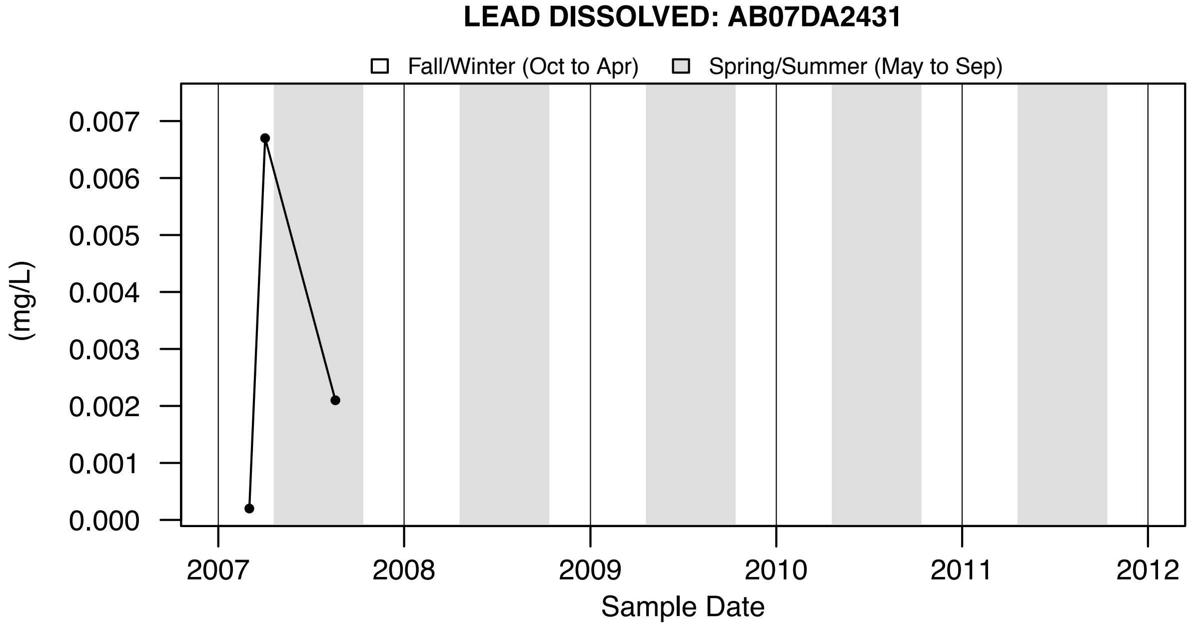


Figure A5.108: LEAD DISSOLVED: AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

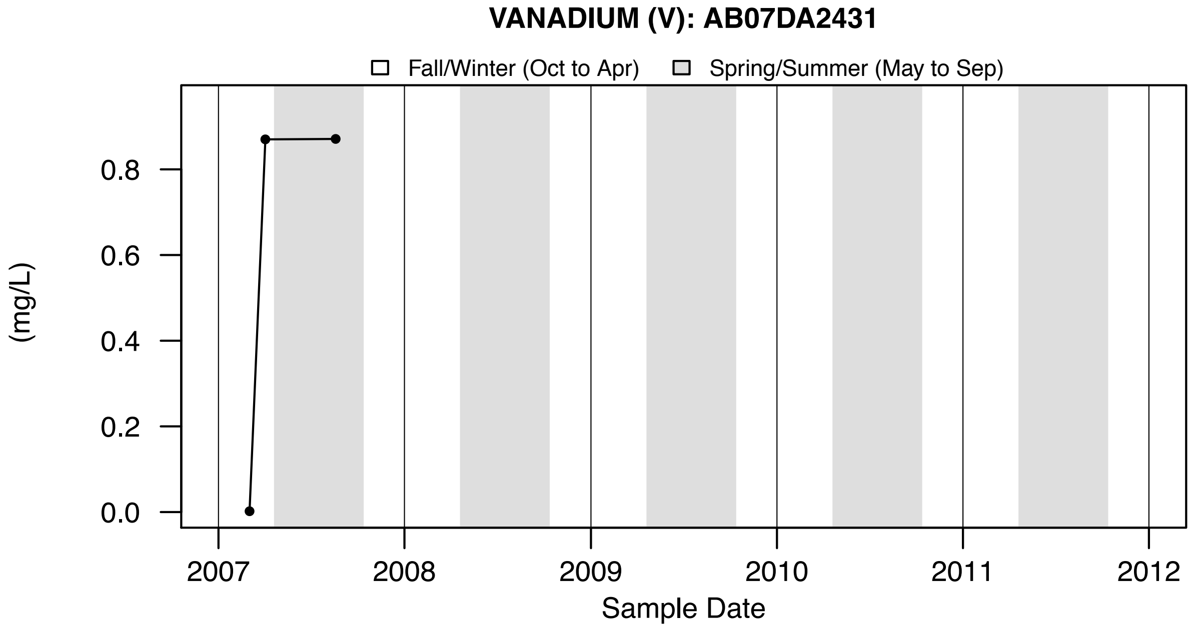


Figure A5.109: VANADIUM (V): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

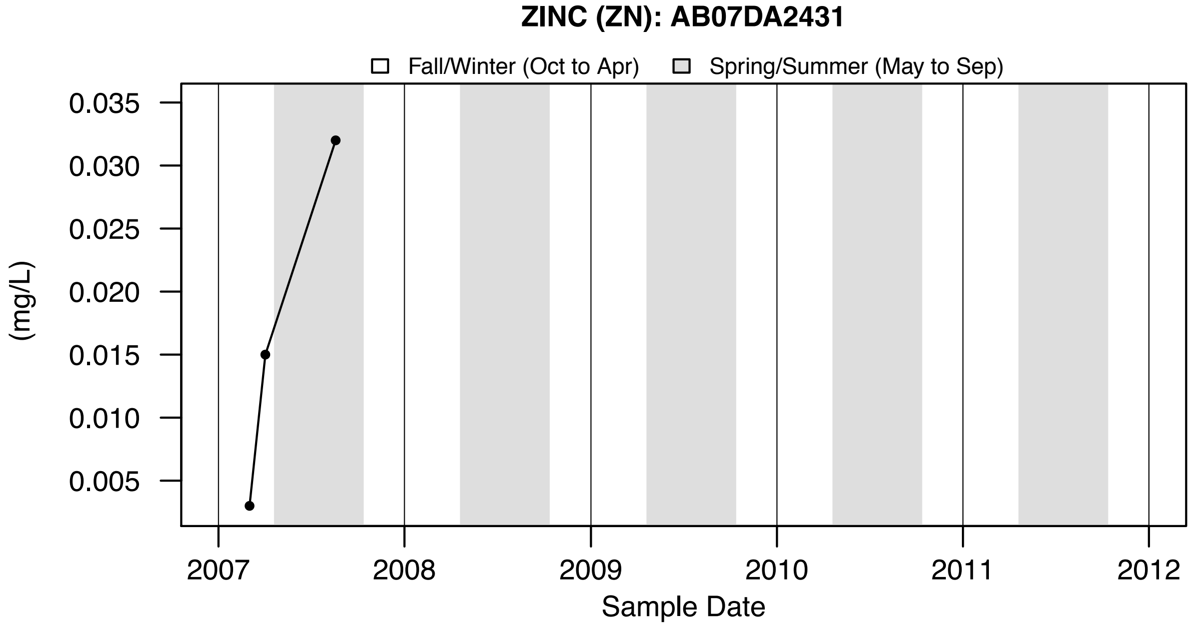


Figure A5.110: ZINC (ZN): AB07DA2431 - SUNCOR ENERGY (WASTEWATER EFFLUENT)

Appendix 6:

Blank samples collected as part of the Long-term River Network and
Medium-term River Network monitoring programs between 2007 and spring 2012

List of Abbreviations

MDL: Method detection limit

SDL: Sample detection limit

List of Figures

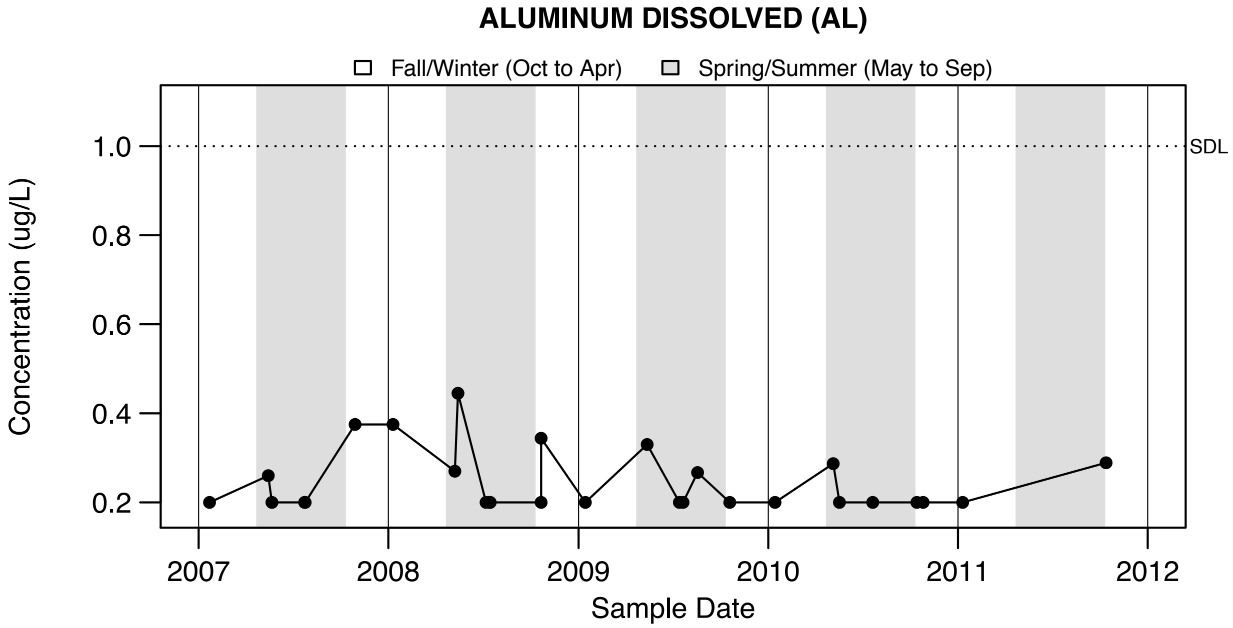


Figure A6.1: FIELD BLANK: ALUMINUM DISSOLVED (AL)

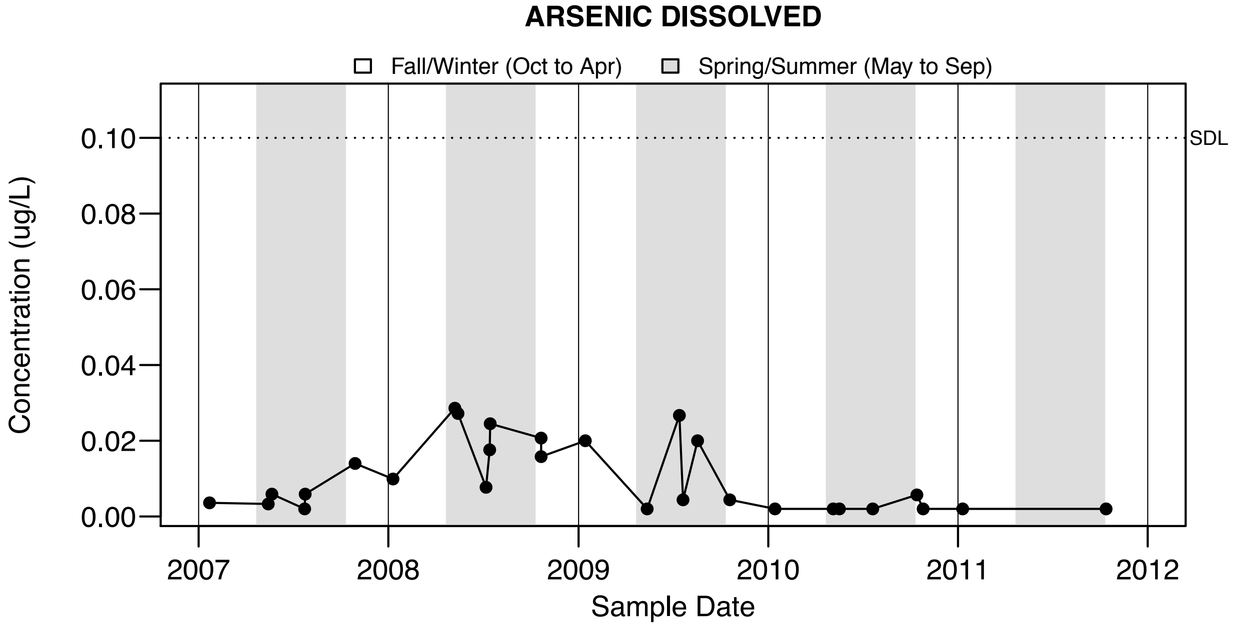


Figure A6.2: FIELD BLANK: ARSENIC DISSOLVED

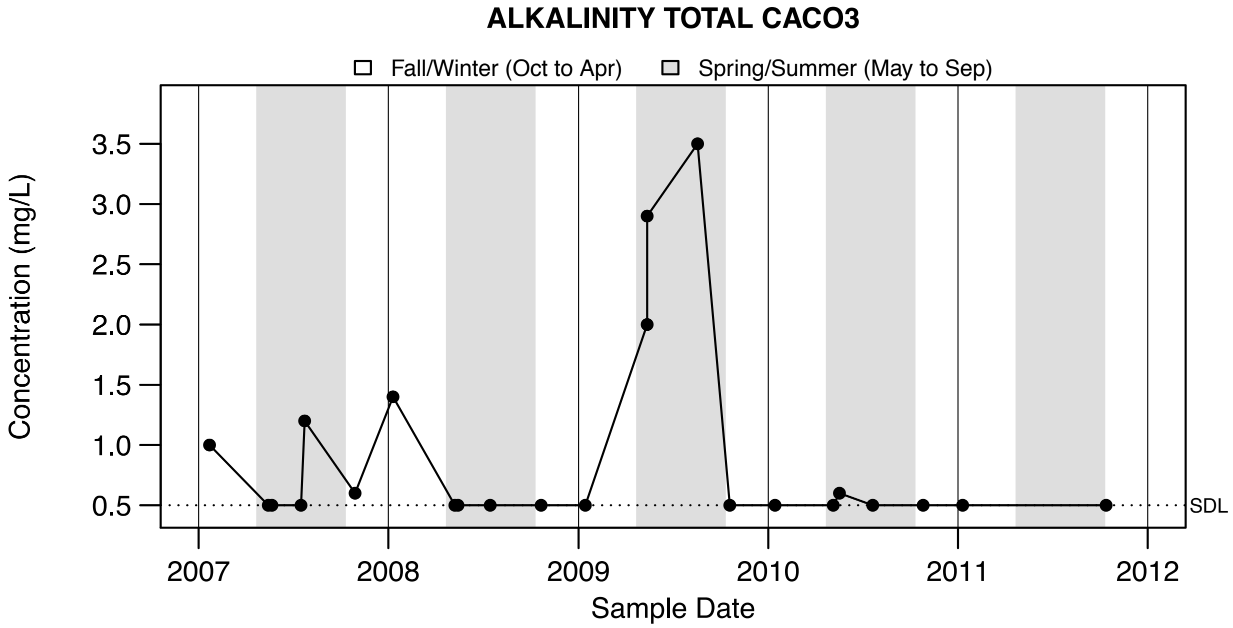


Figure A6.3: FIELD BLANK: ALKALINITY TOTAL CACO3

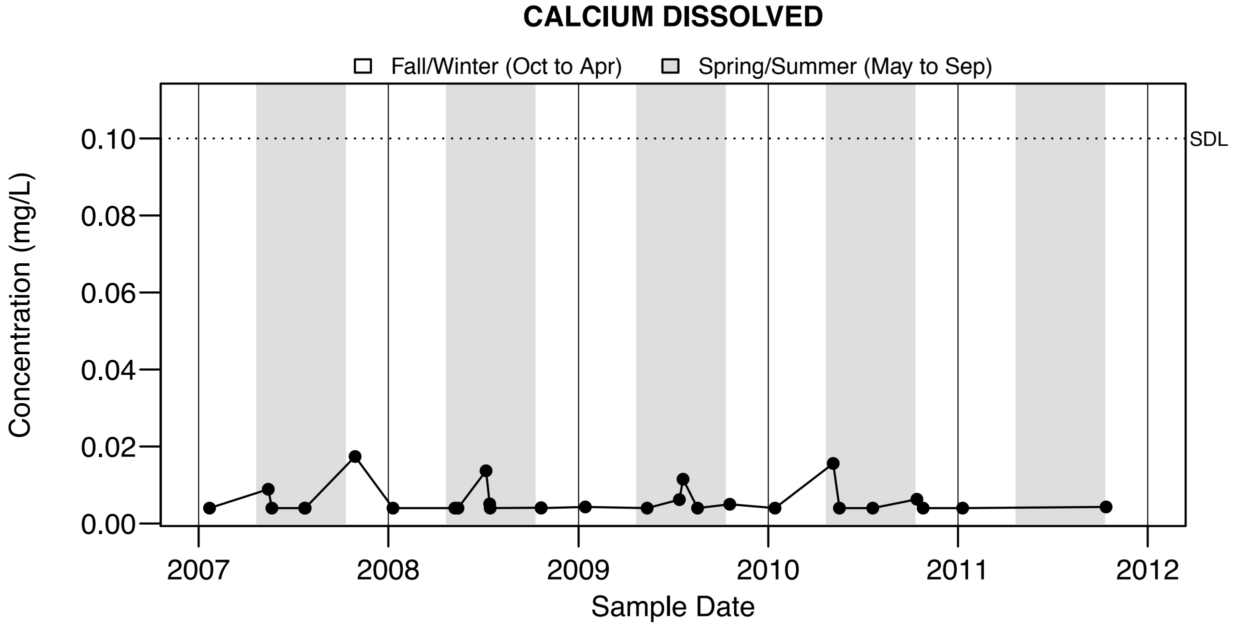


Figure A6.4: FIELD BLANK: CALCIUM DISSOLVED

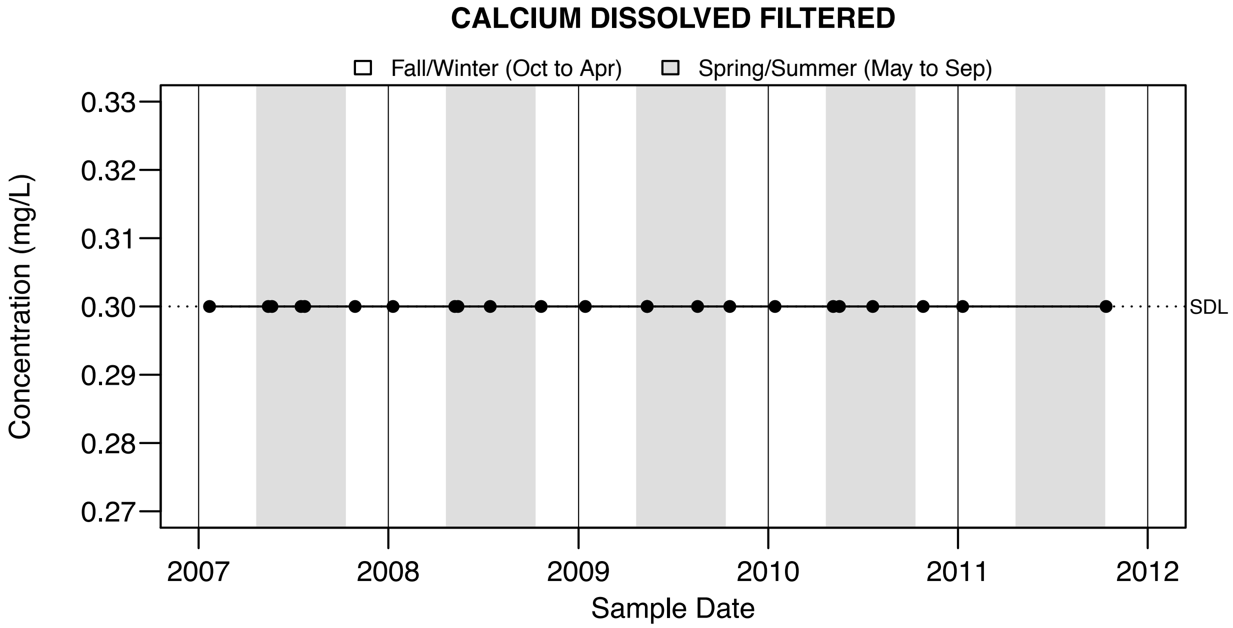


Figure A6.5: FIELD BLANK: CALCIUM DISSOLVED FILTERED

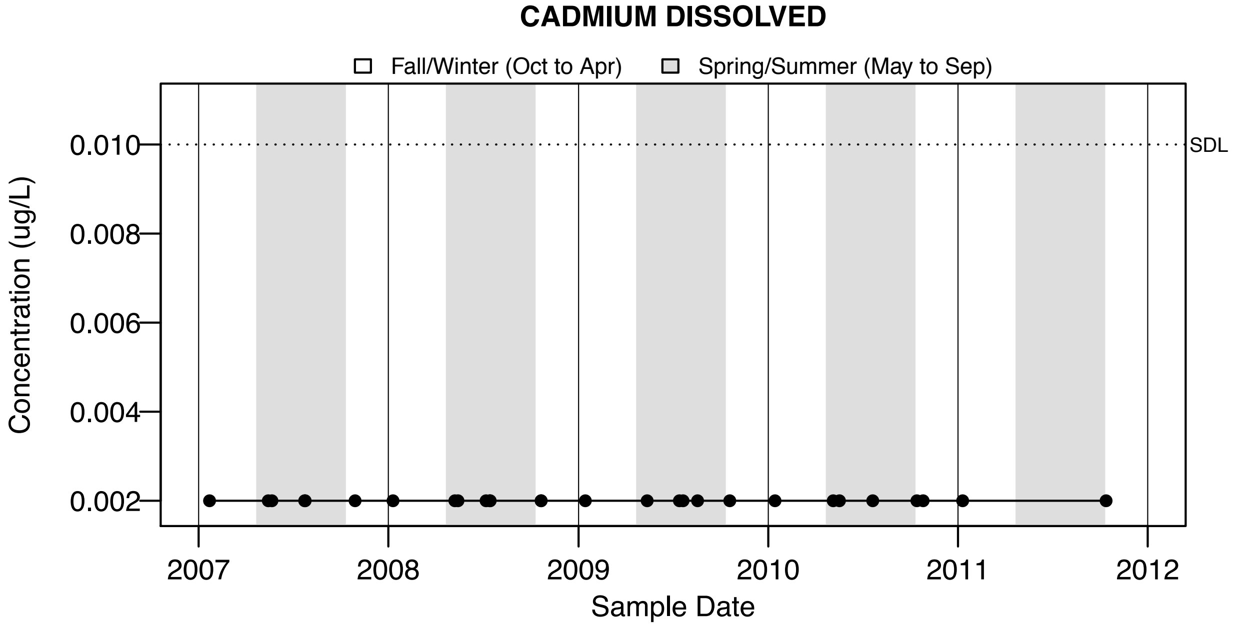


Figure A6.6: FIELD BLANK: CADMIUM DISSOLVED

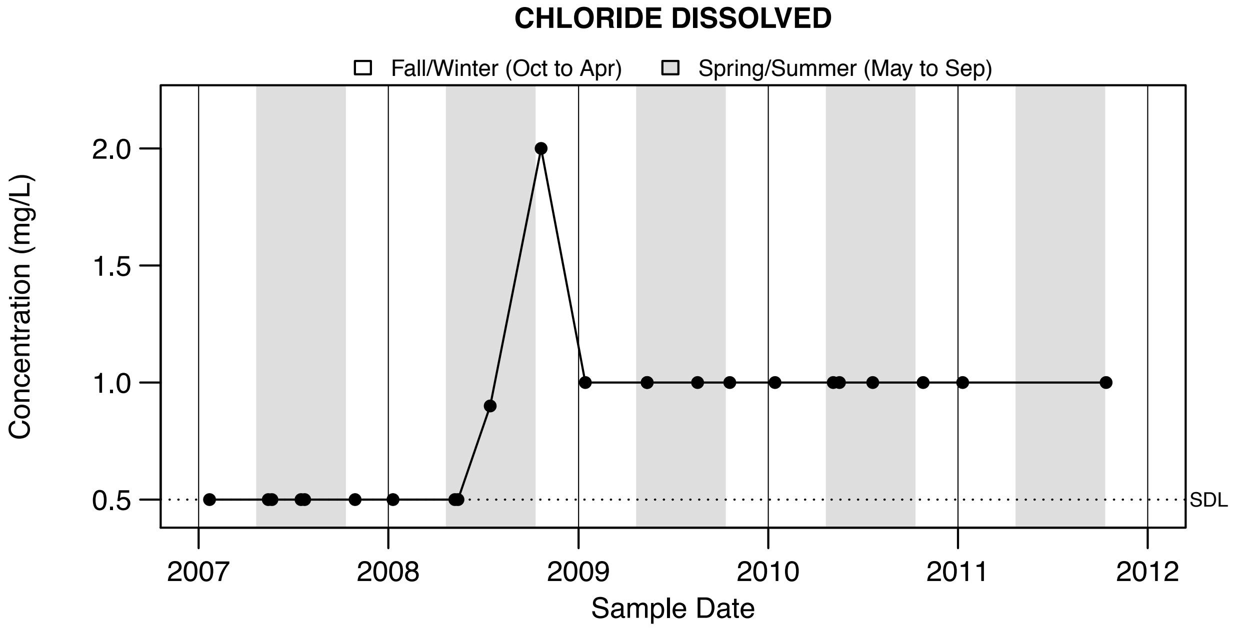


Figure A6.7: FIELD BLANK: CHLORIDE DISSOLVED

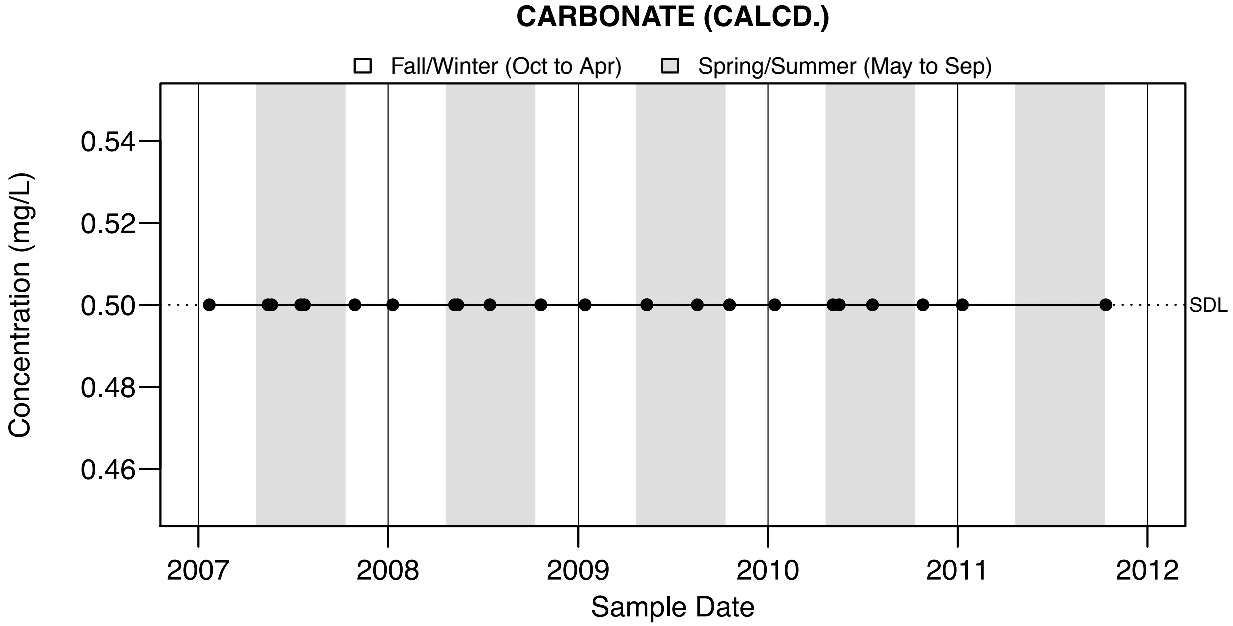


Figure A6.8: FIELD BLANK: CARBONATE (CALCD.)

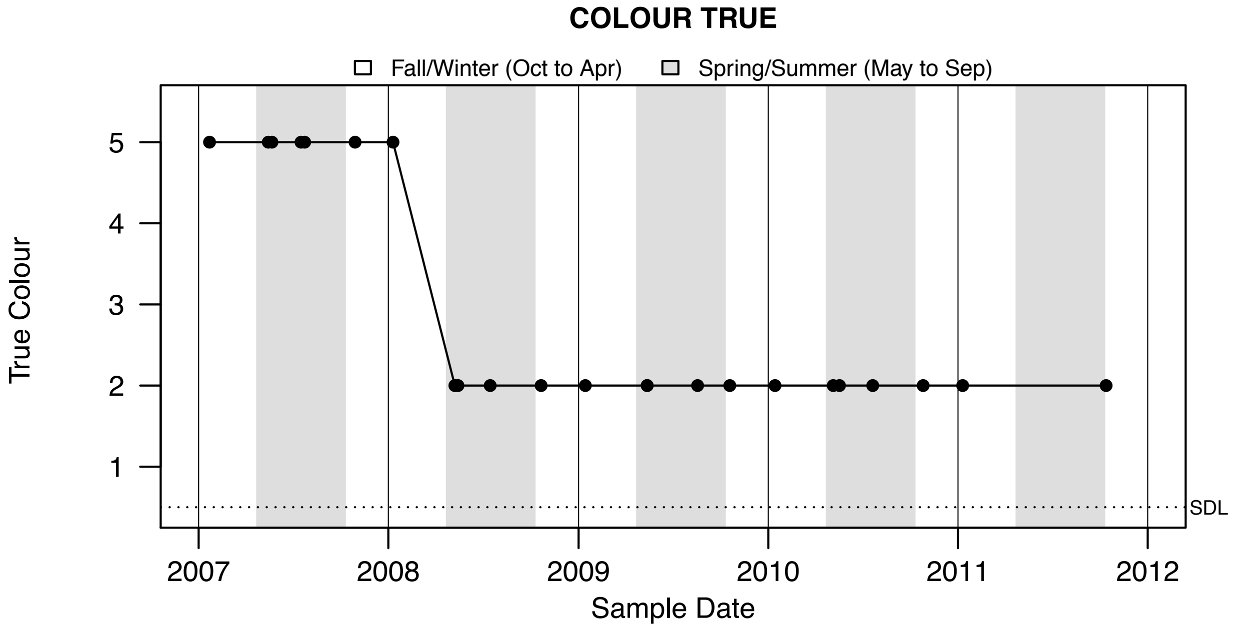


Figure A6.9: FIELD BLANK: COLOUR TRUE

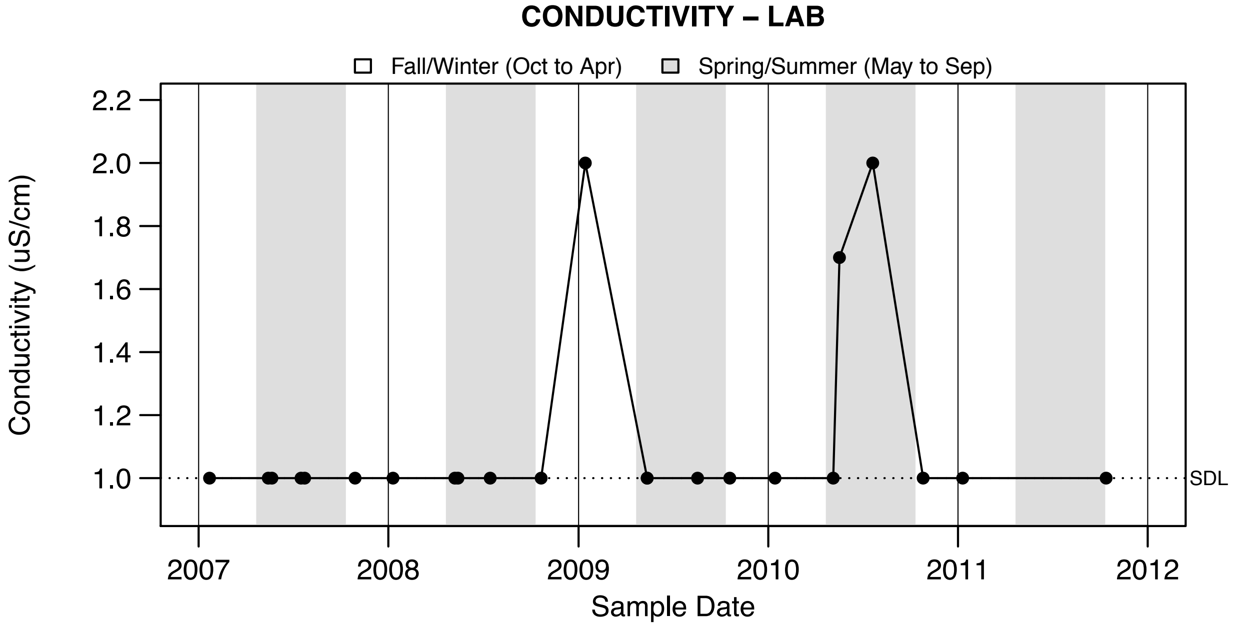


Figure A6.10: FIELD BLANK: CONDUCTIVITY - LAB

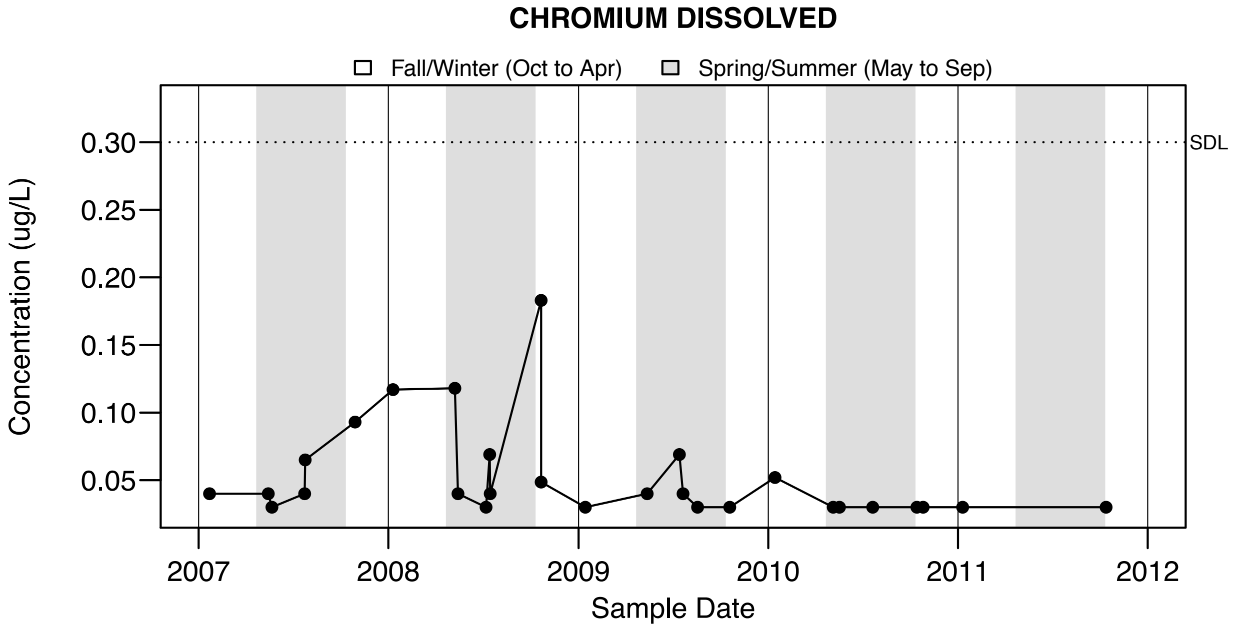


Figure A6.11: FIELD BLANK: CHROMIUM DISSOLVED

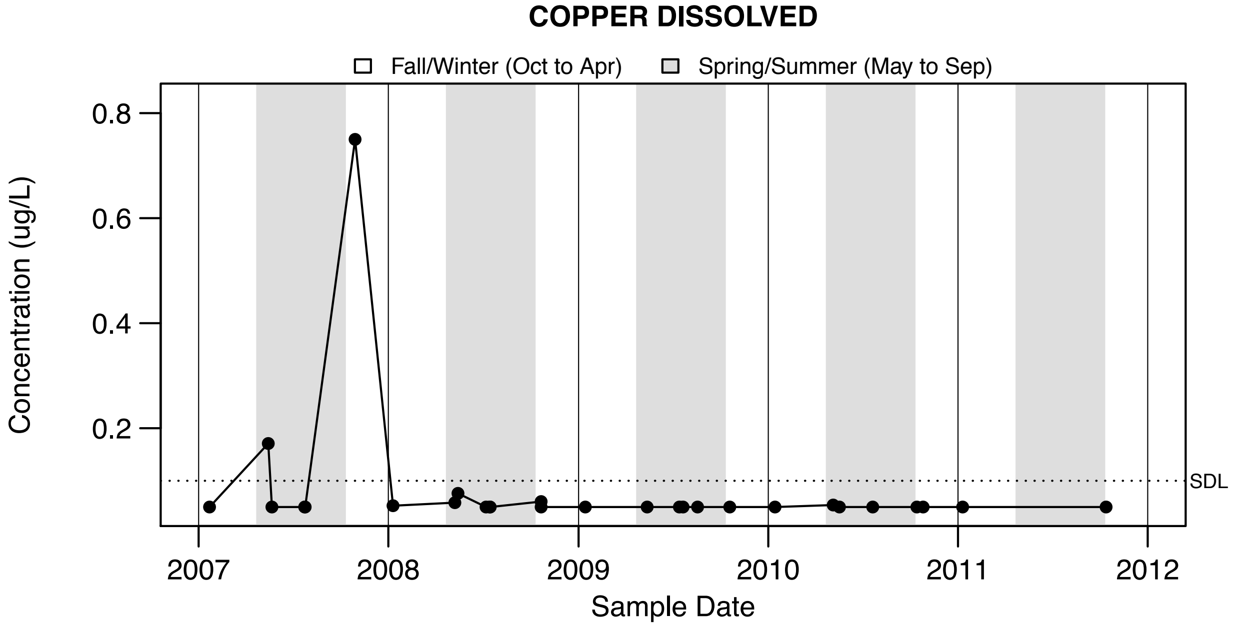


Figure A6.12: FIELD BLANK: COPPER DISSOLVED

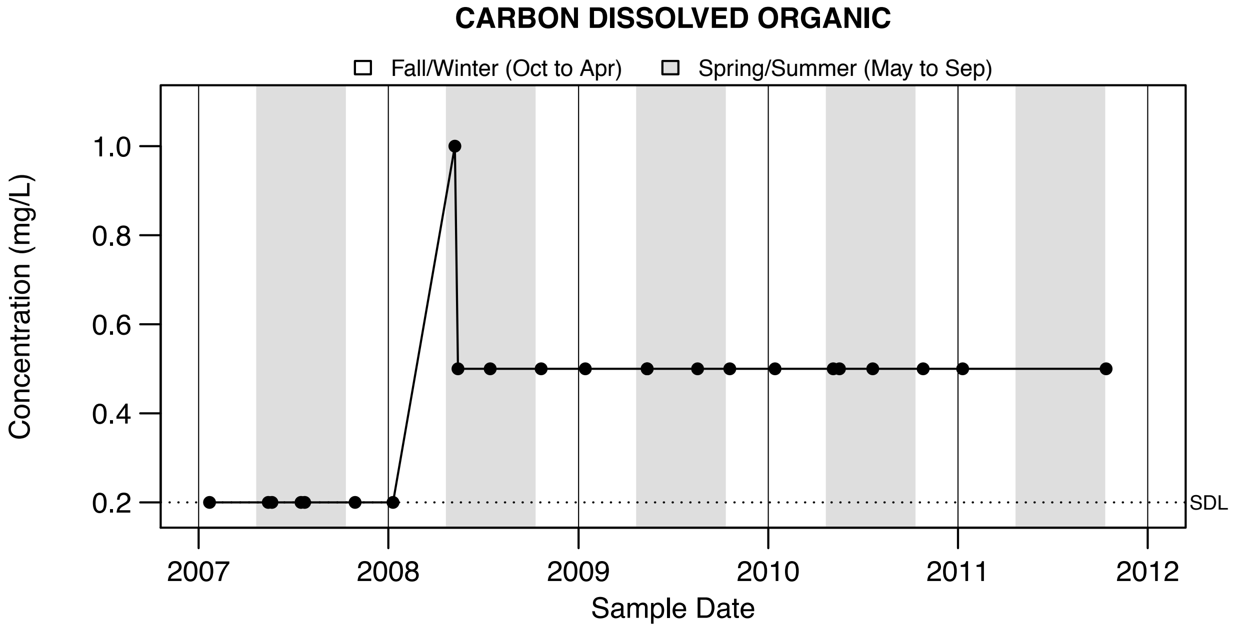


Figure A6.13: FIELD BLANK: CARBON DISSOLVED ORGANIC

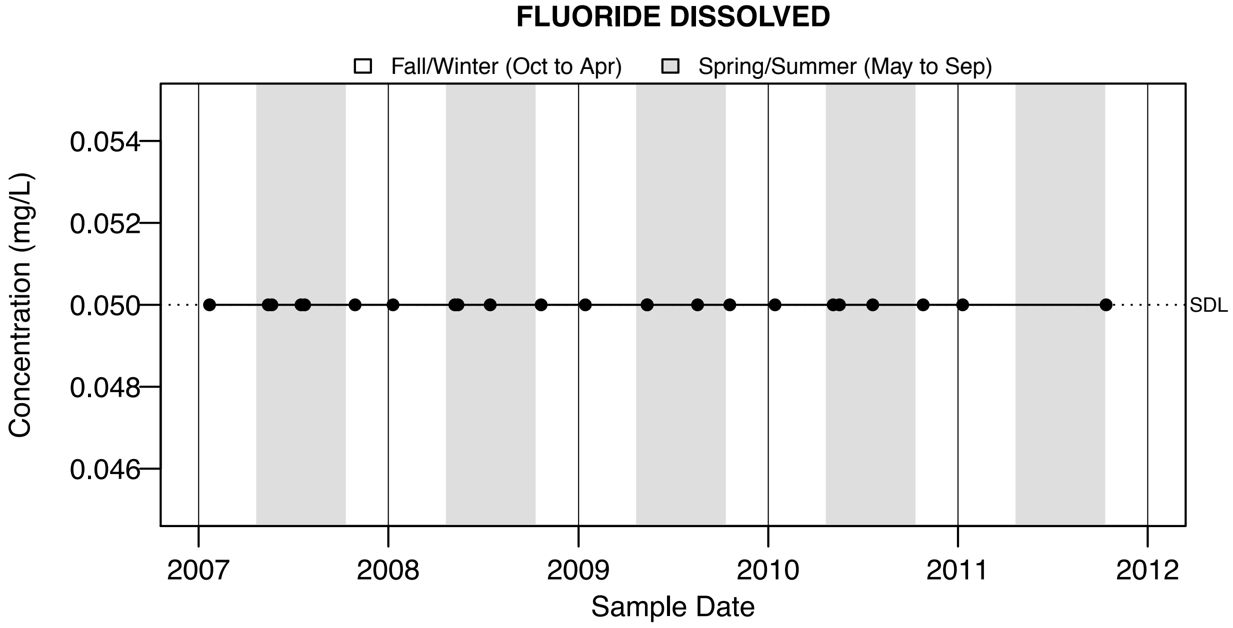


Figure A6.14: FIELD BLANK: FLUORIDE DISSOLVED

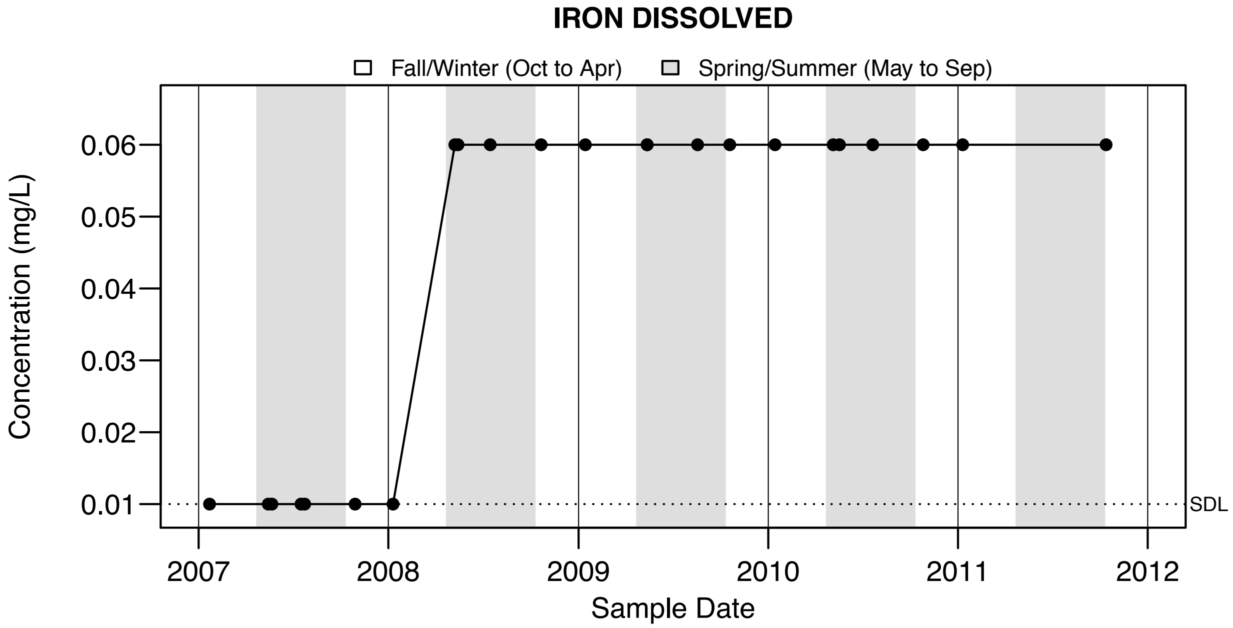


Figure A6.15: FIELD BLANK: IRON DISSOLVED

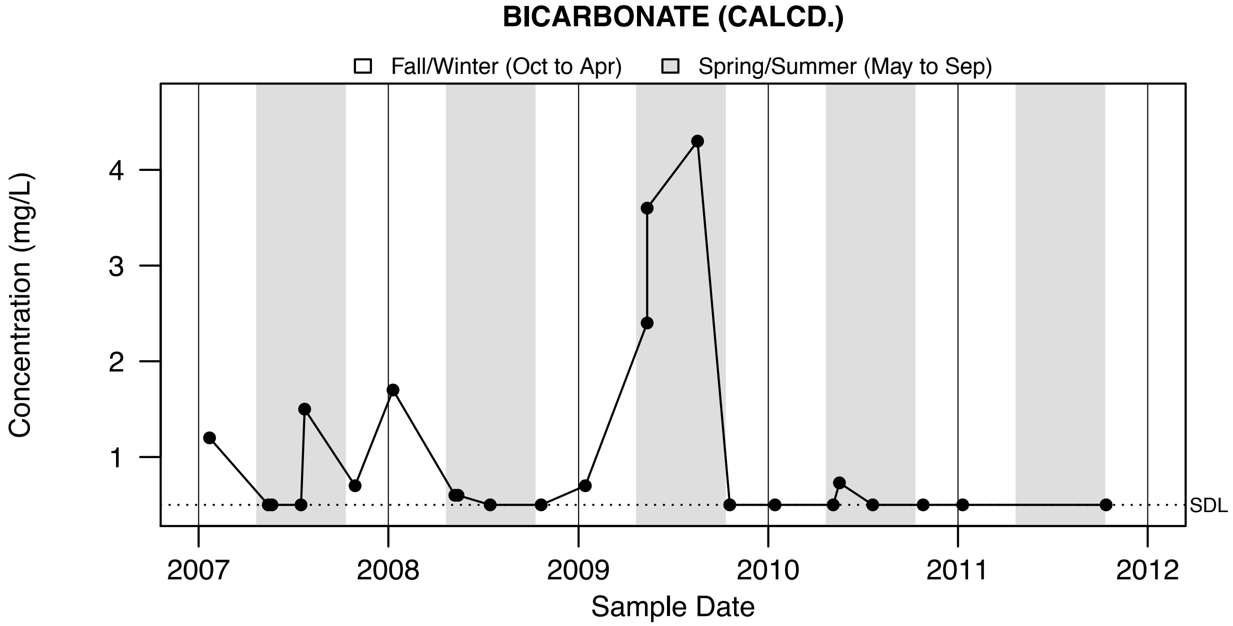


Figure A6.16: FIELD BLANK: BICARBONATE (CALCD.)

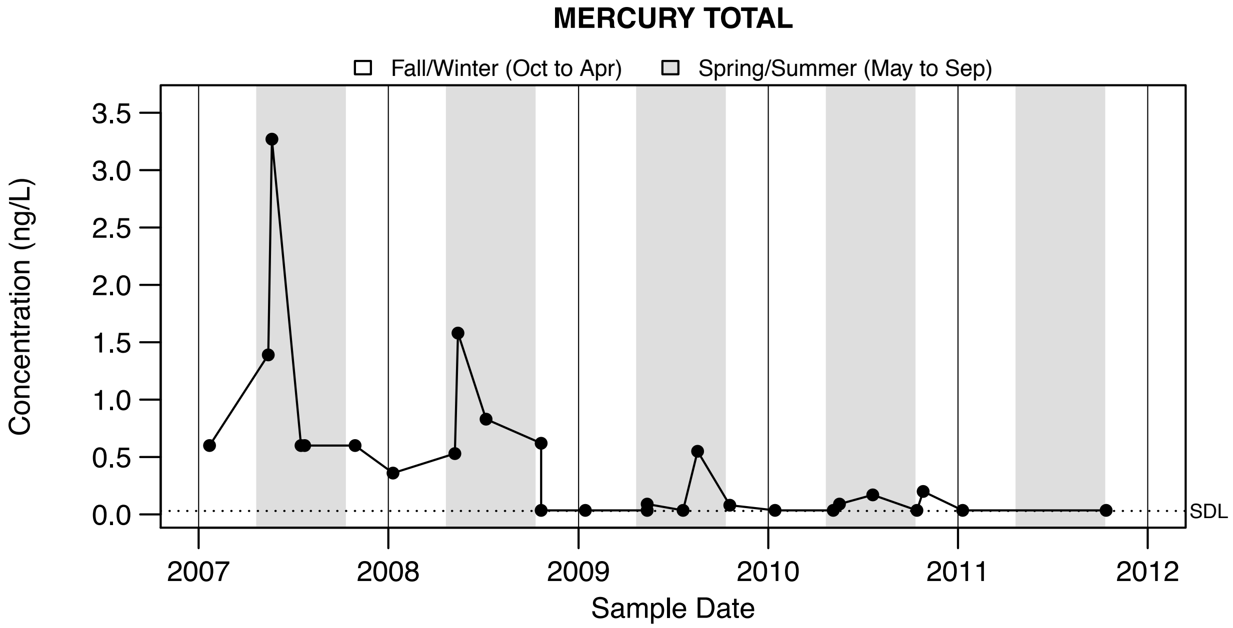


Figure A6.17: FIELD BLANK: MERCURY TOTAL

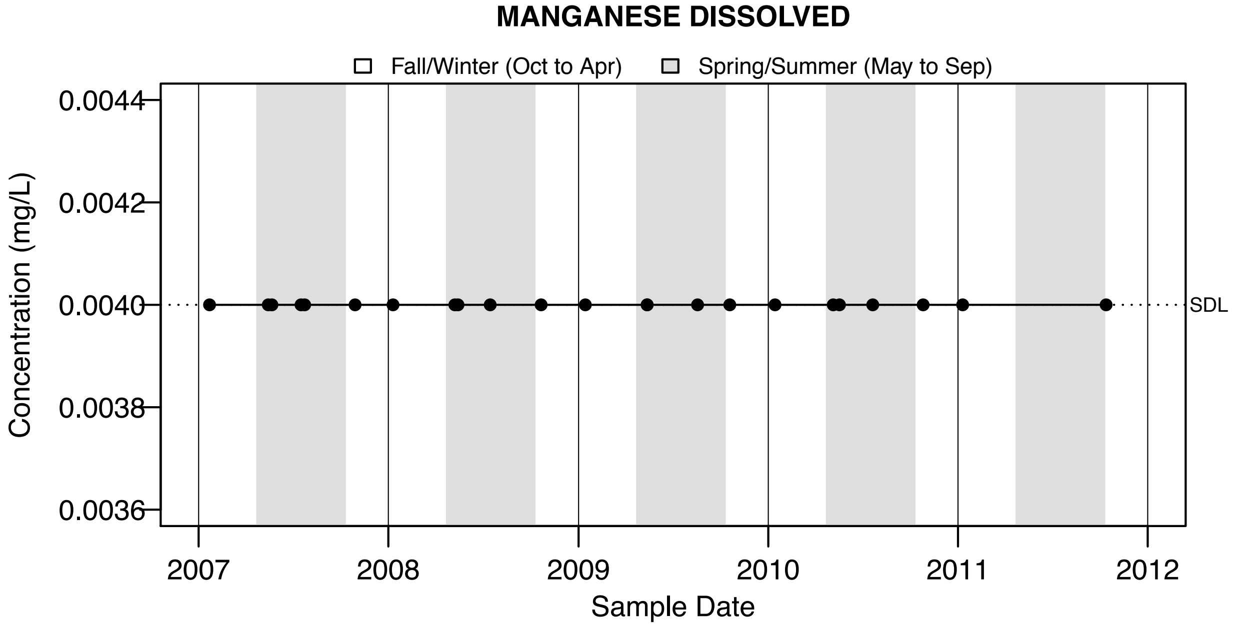


Figure A6.18: FIELD BLANK: MANGANESE DISSOLVED

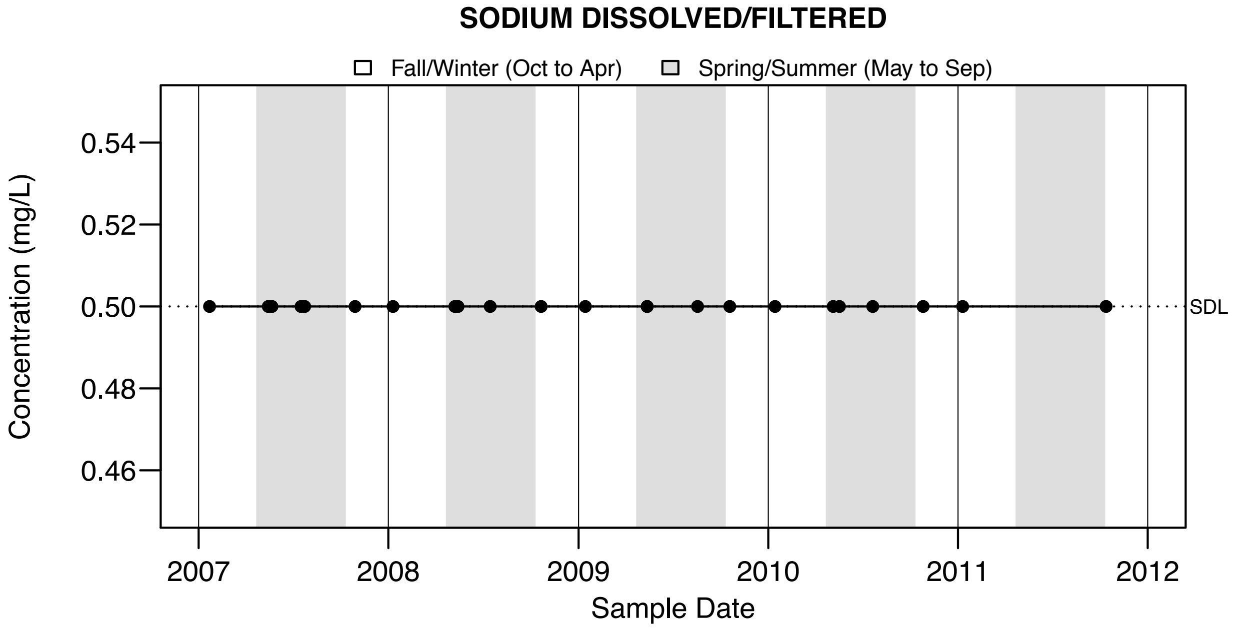


Figure A6.19: FIELD BLANK: SODIUM DISSOLVED/FILTERED

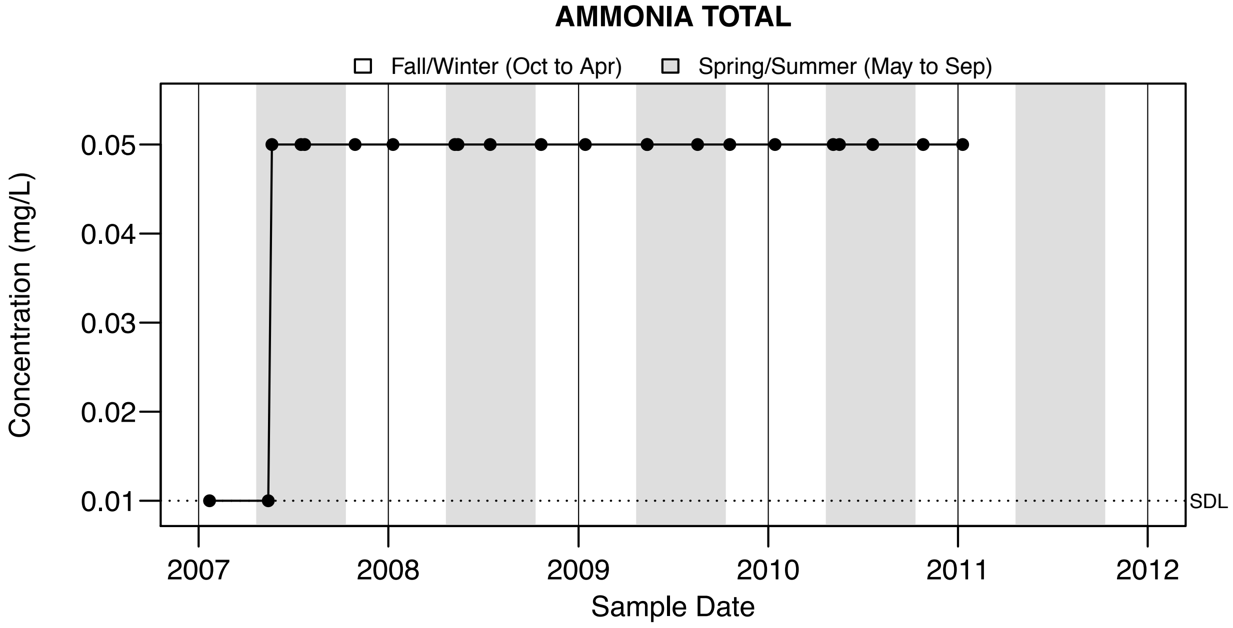


Figure A6.20: FIELD BLANK: AMMONIA TOTAL

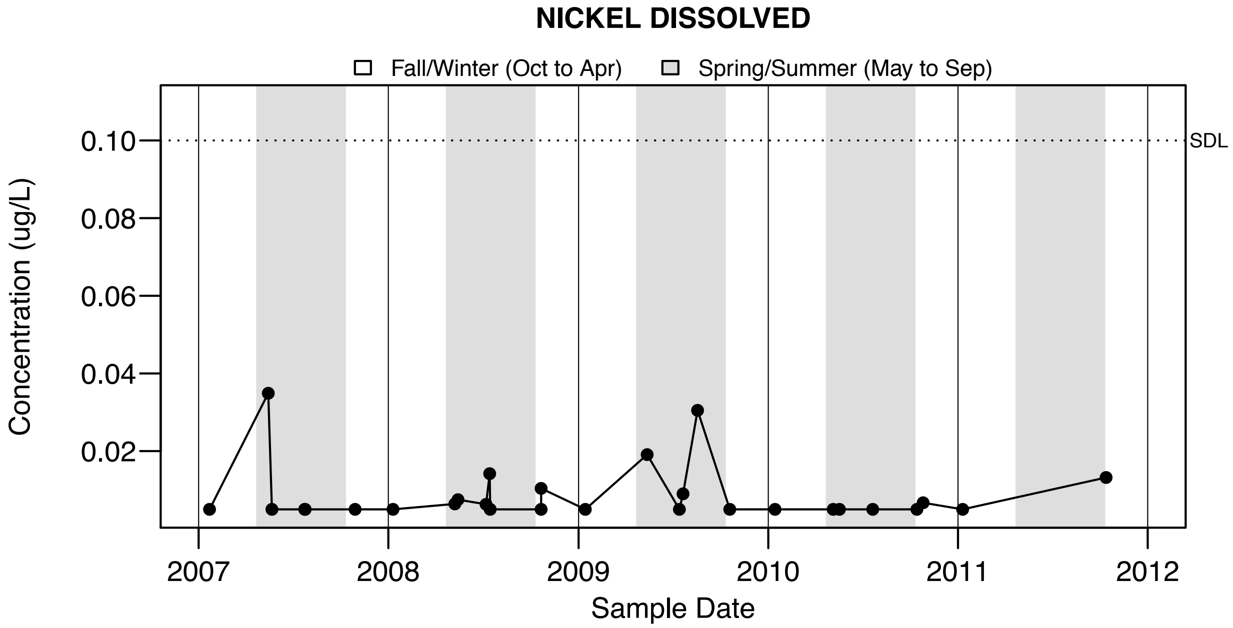


Figure A6.21: FIELD BLANK: NICKEL DISSOLVED

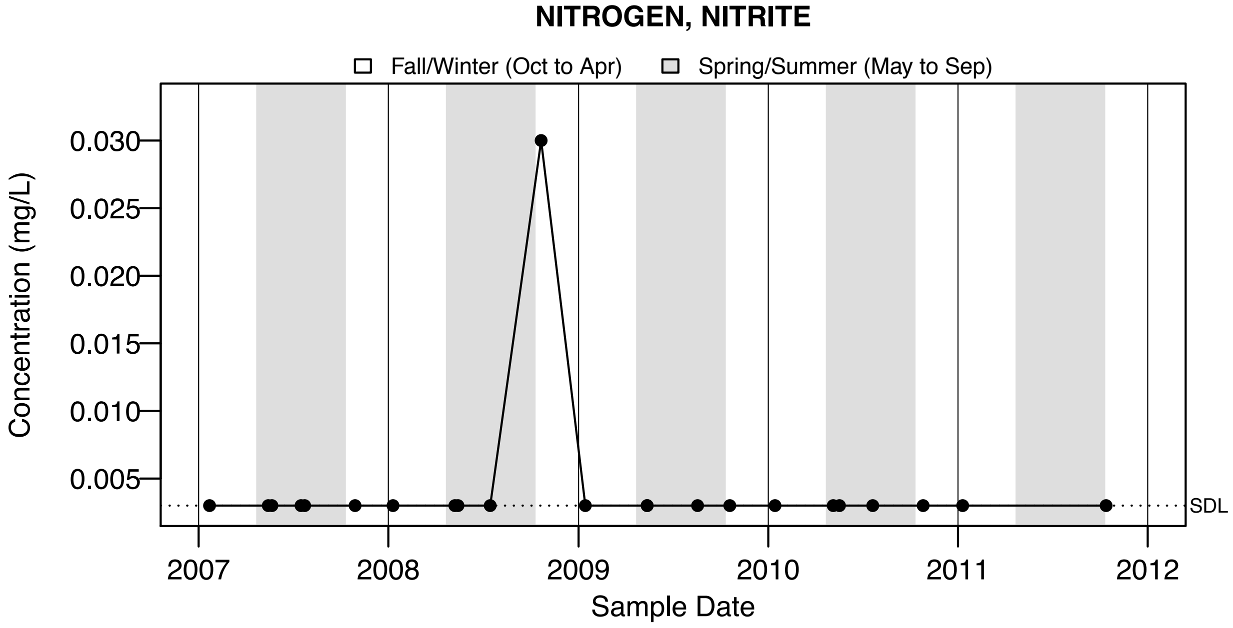


Figure A6.22: FIELD BLANK: NITROGEN, NITRITE

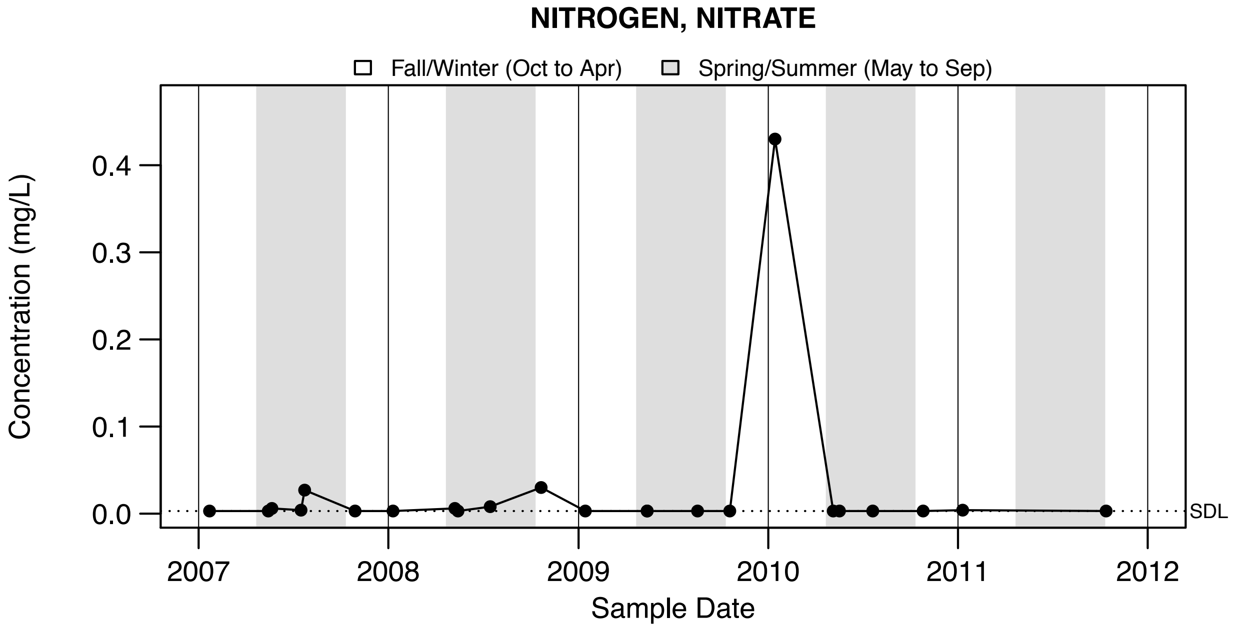


Figure A6.23: FIELD BLANK: NITROGEN, NITRATE

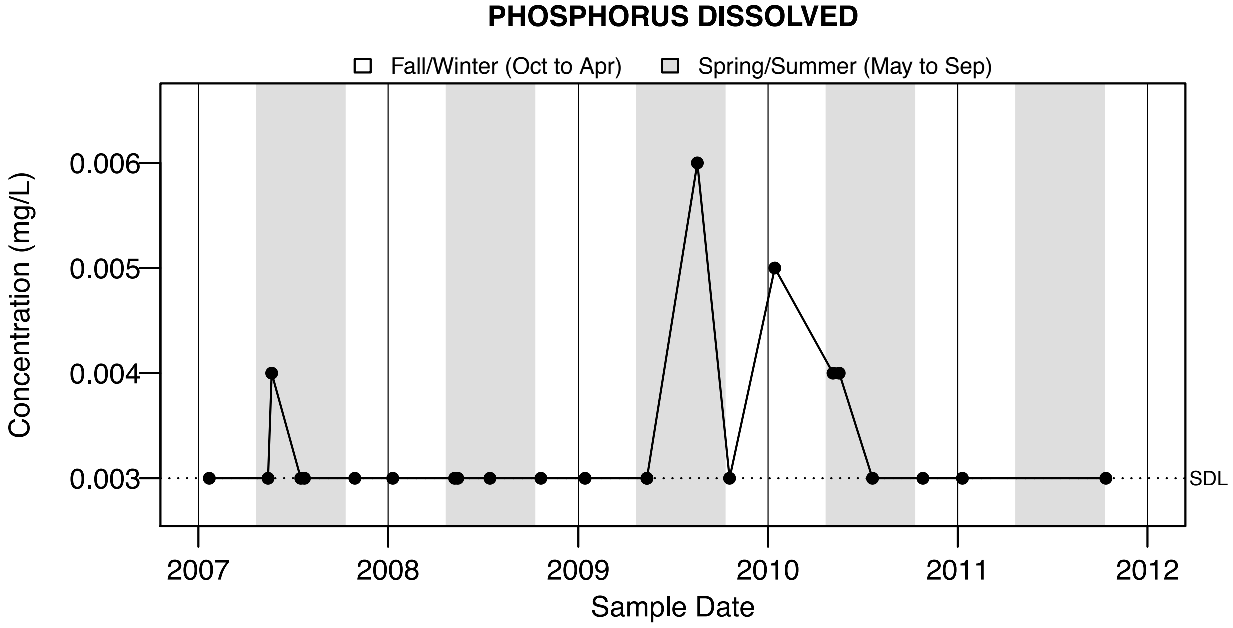


Figure A6.24: FIELD BLANK: PHOSPHORUS DISSOLVED

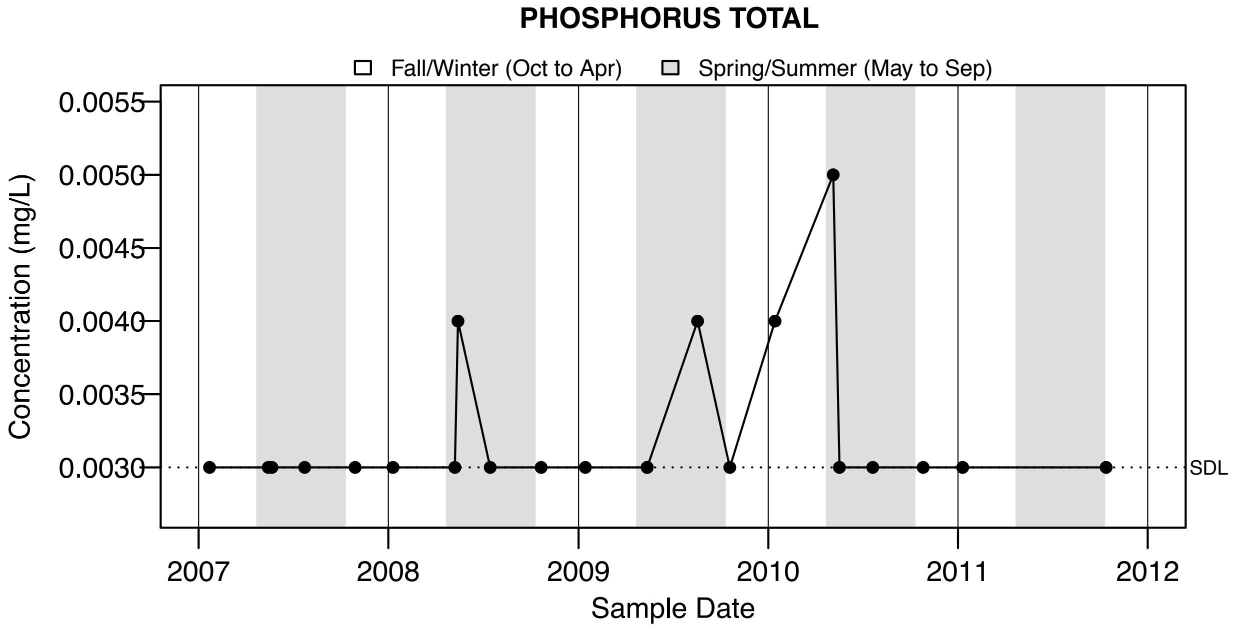


Figure A6.25: FIELD BLANK: PHOSPHORUS TOTAL

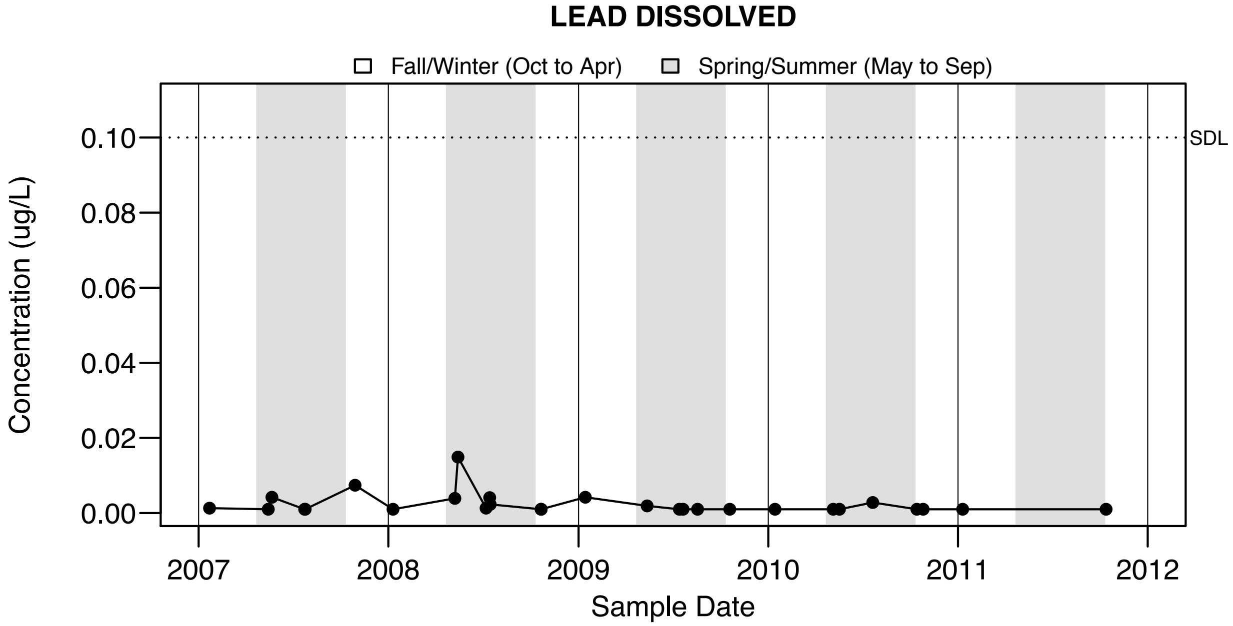


Figure A6.26: FIELD BLANK: LEAD DISSOLVED

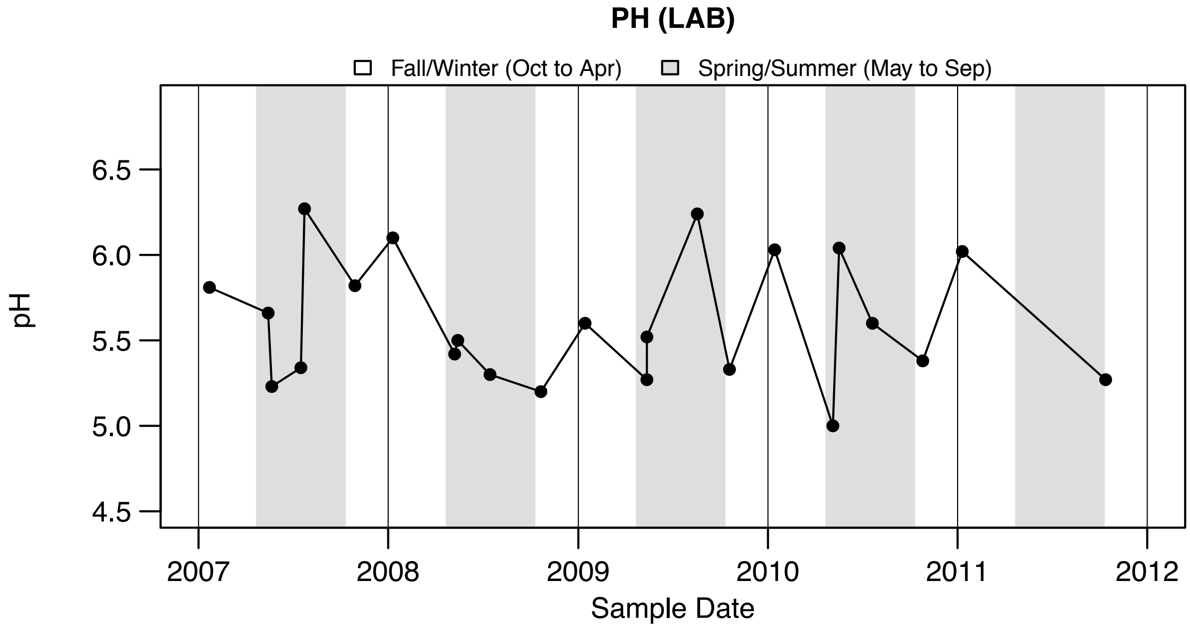


Figure A6.27: FIELD BLANK: PH (LAB)

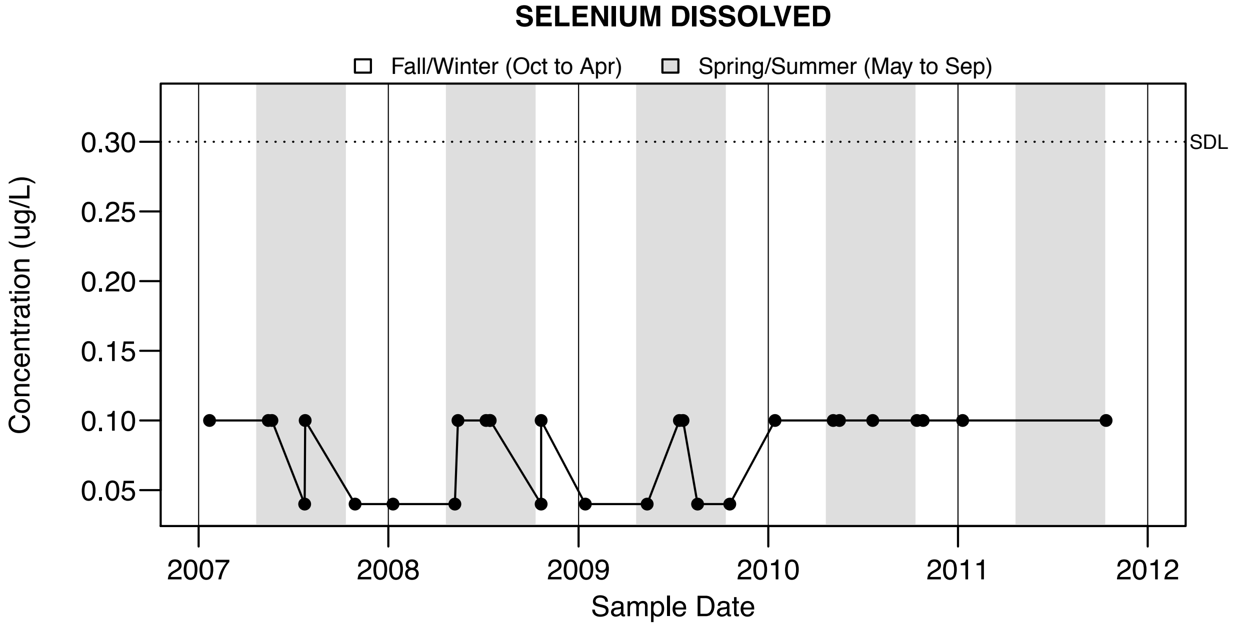


Figure A6.28: FIELD BLANK: SELENIUM DISSOLVED

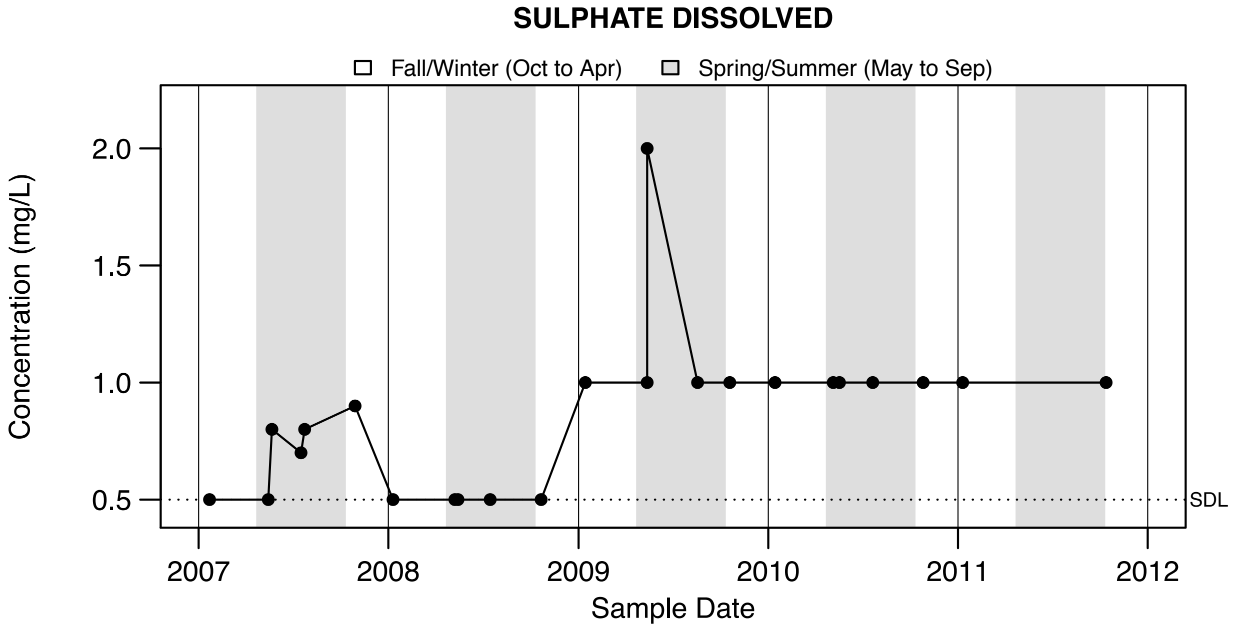


Figure A6.29: FIELD BLANK: SULPHATE DISSOLVED

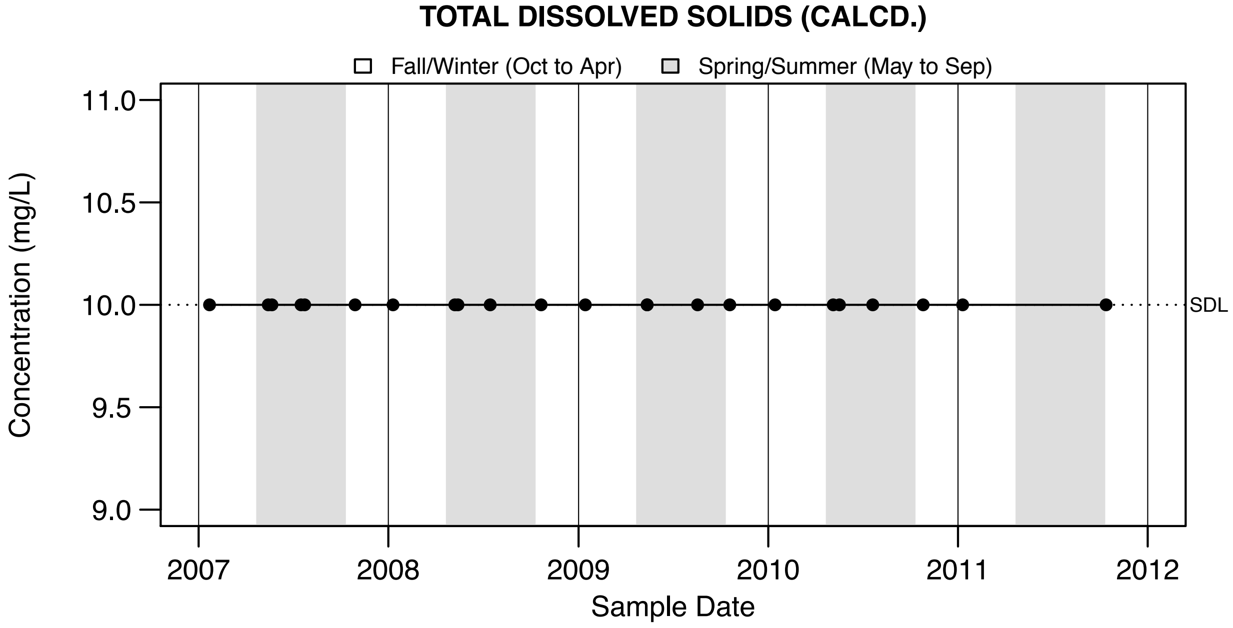


Figure A6.30: FIELD BLANK: TOTAL DISSOLVED SOLIDS (CALCD.)

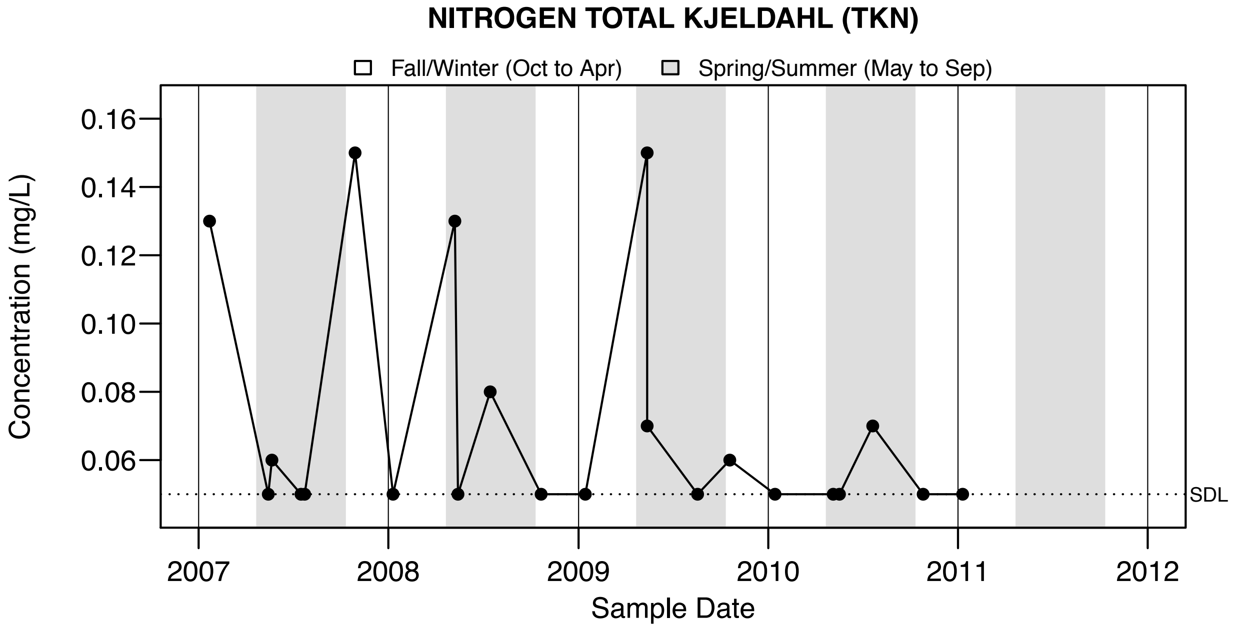


Figure A6.31: FIELD BLANK: NITROGEN TOTAL KJELDAHL (TKN)

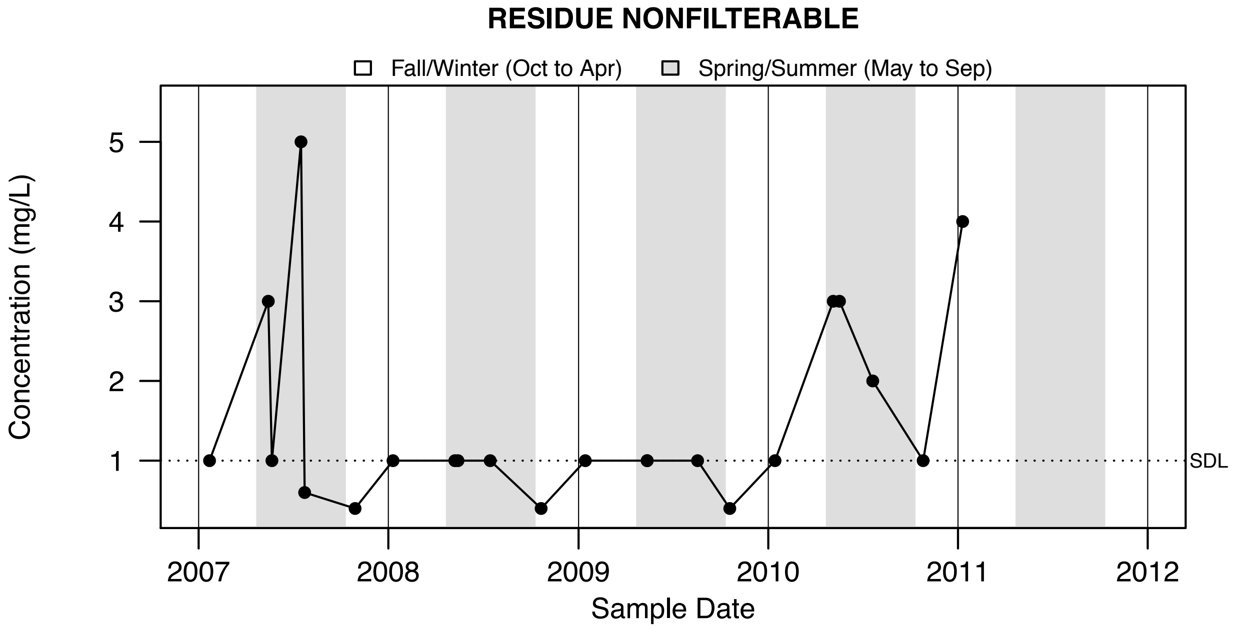


Figure A6.32: FIELD BLANK: RESIDUE NONFILTERABLE

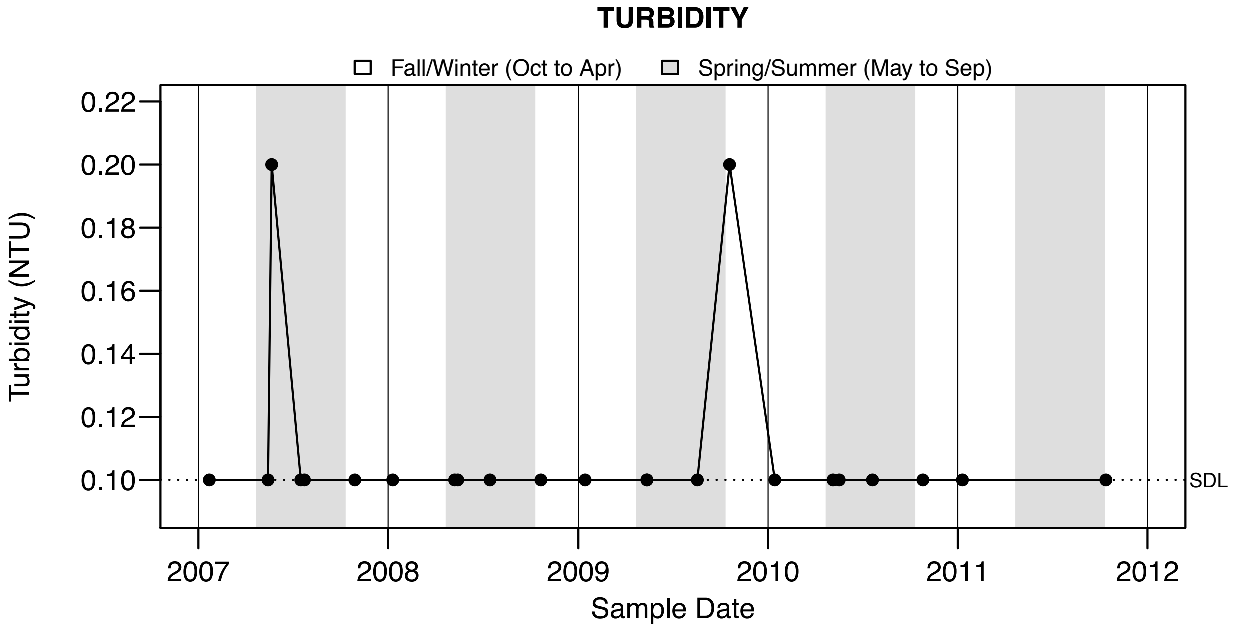


Figure A6.33: FIELD BLANK: TURBIDITY

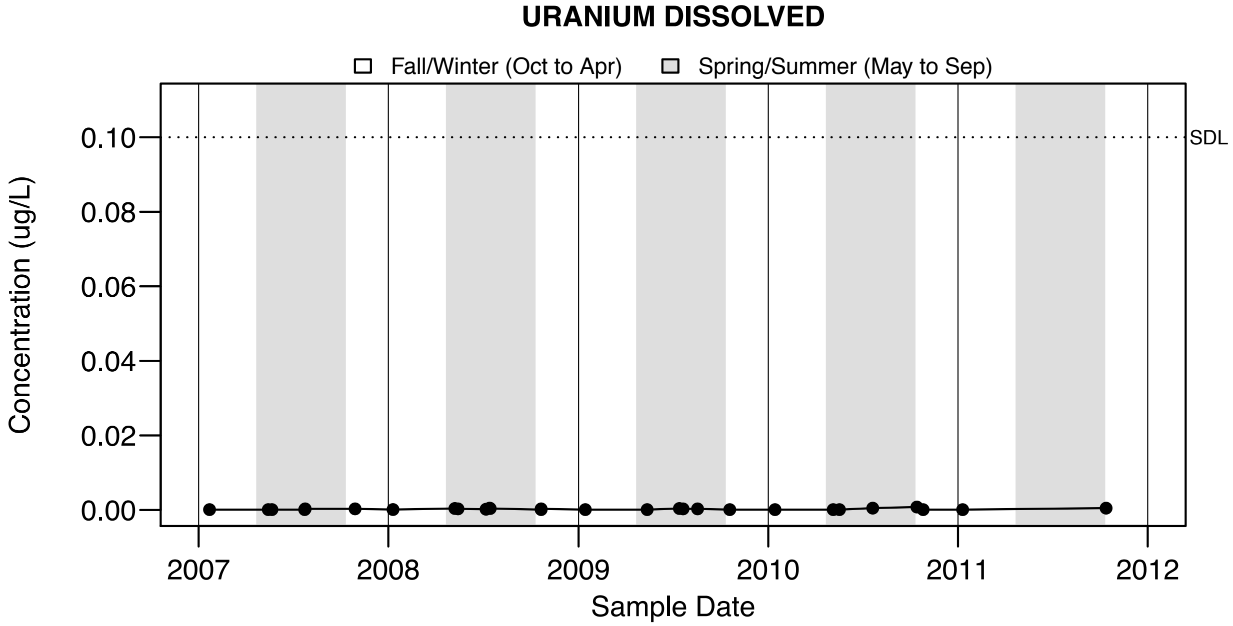


Figure A6.34: FIELD BLANK: URANIUM DISSOLVED

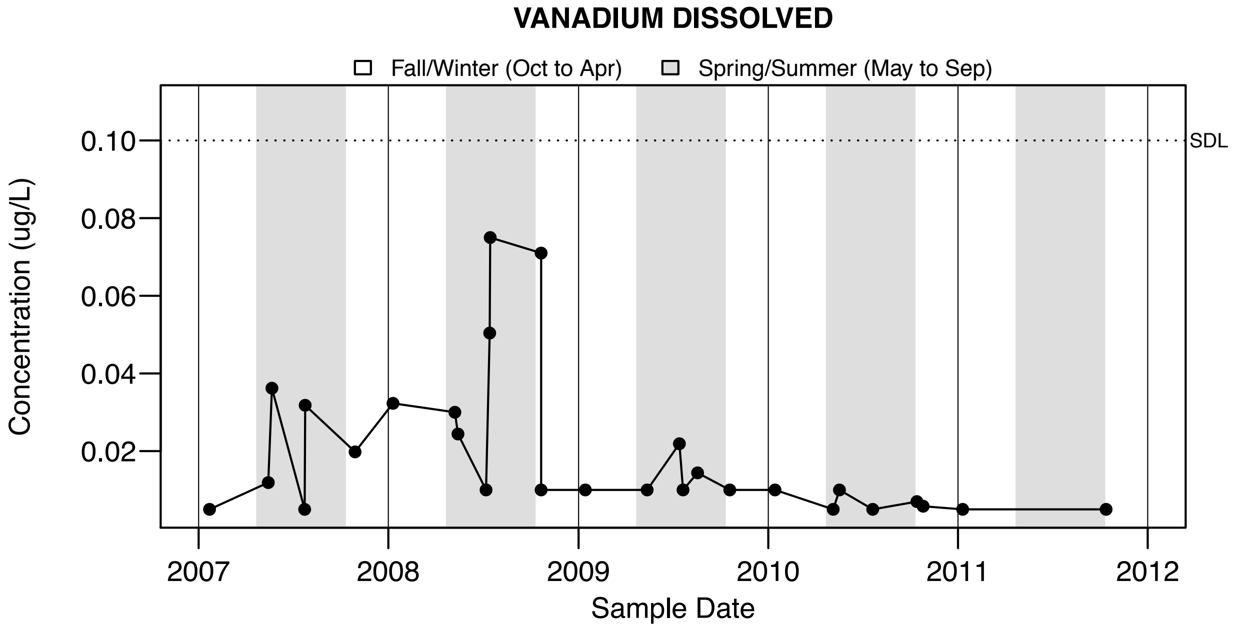


Figure A6.35: FIELD BLANK: VANADIUM DISSOLVED

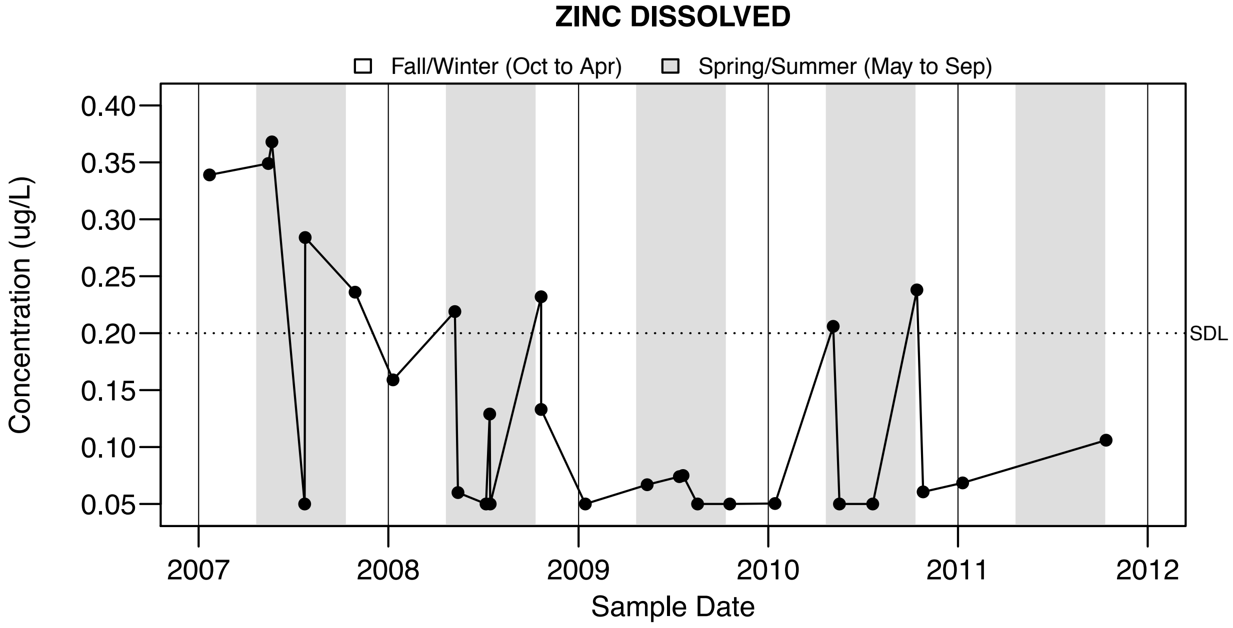


Figure A6.36: FIELD BLANK: ZINC DISSOLVED

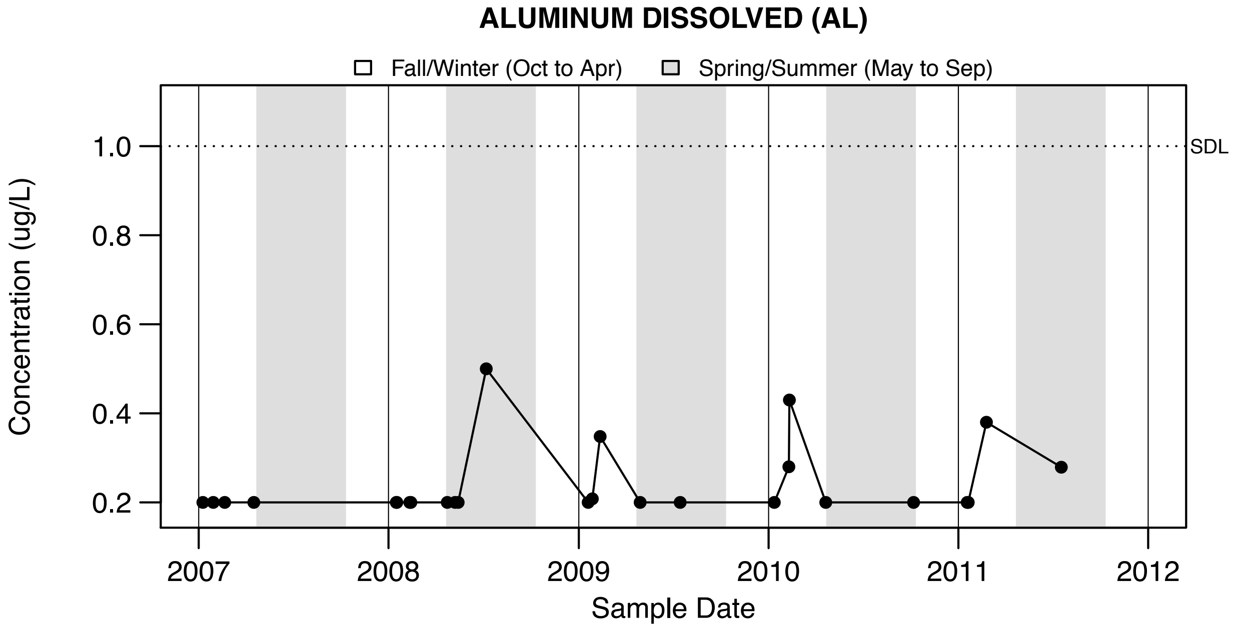


Figure A6.37: TRIP BLANK: ALUMINUM DISSOLVED (AL)

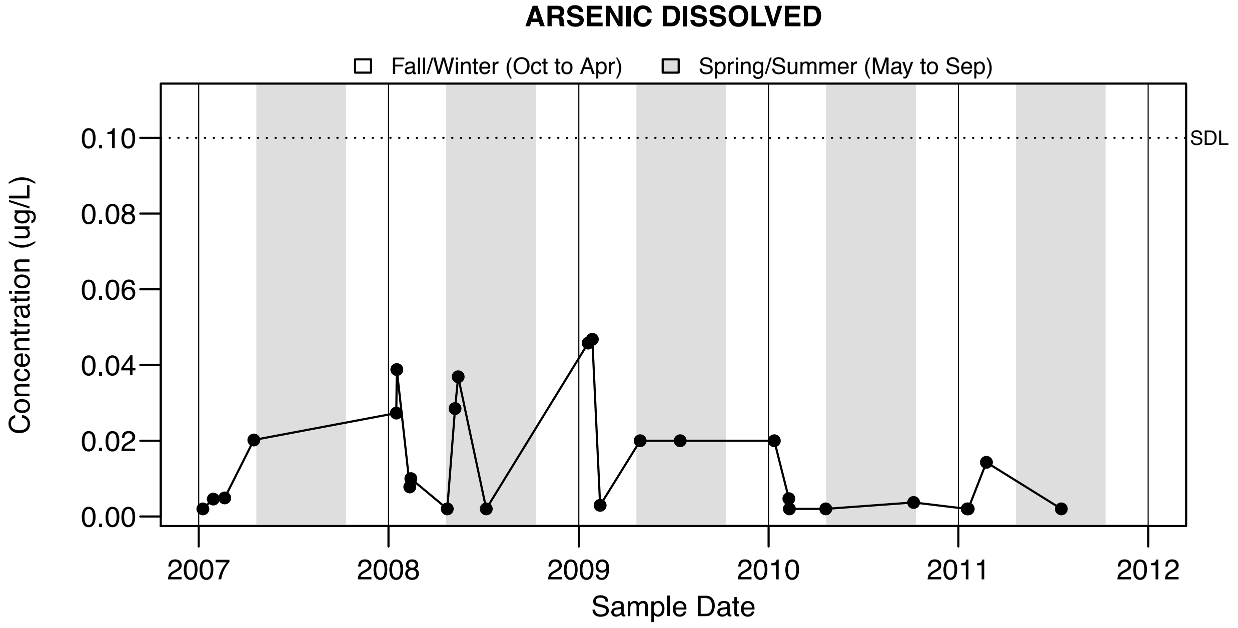


Figure A6.38: TRIP BLANK: ARSENIC DISSOLVED

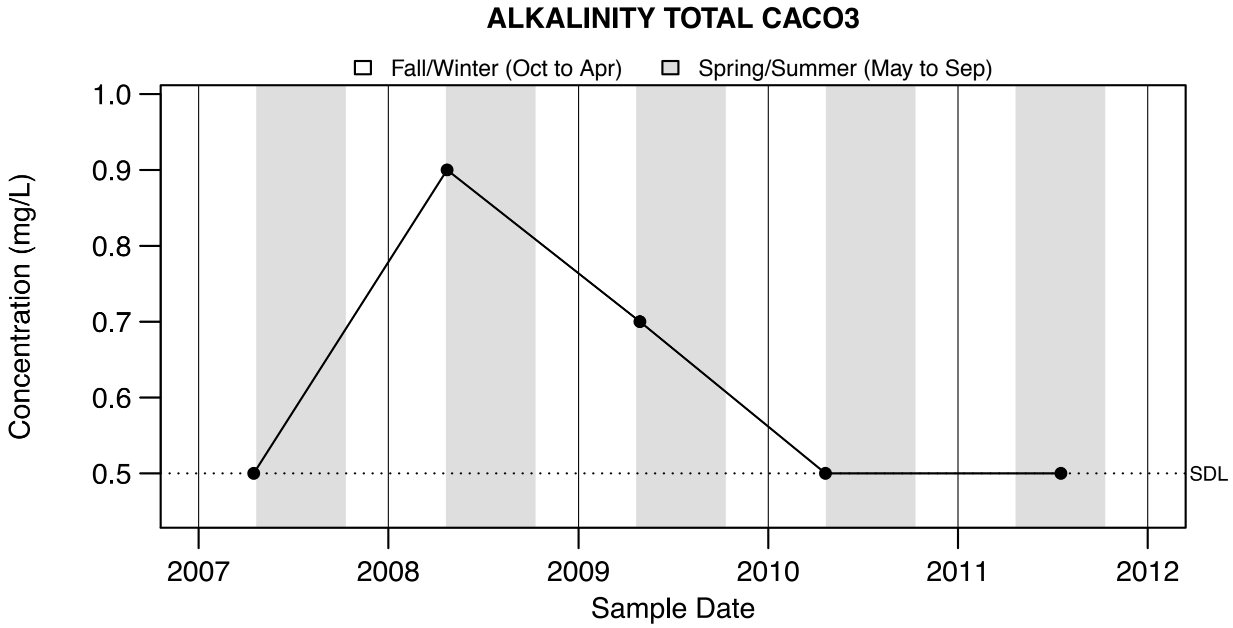


Figure A6.39: TRIP BLANK: ALKALINITY TOTAL CACO3

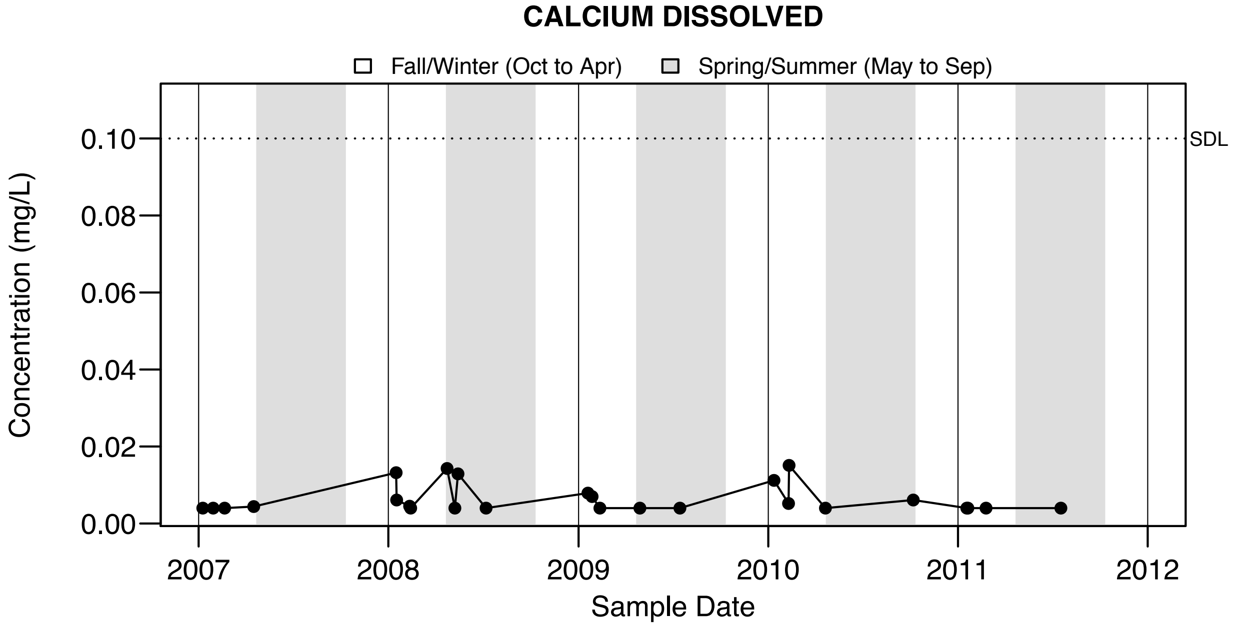


Figure A6.40: TRIP BLANK: CALCIUM DISSOLVED

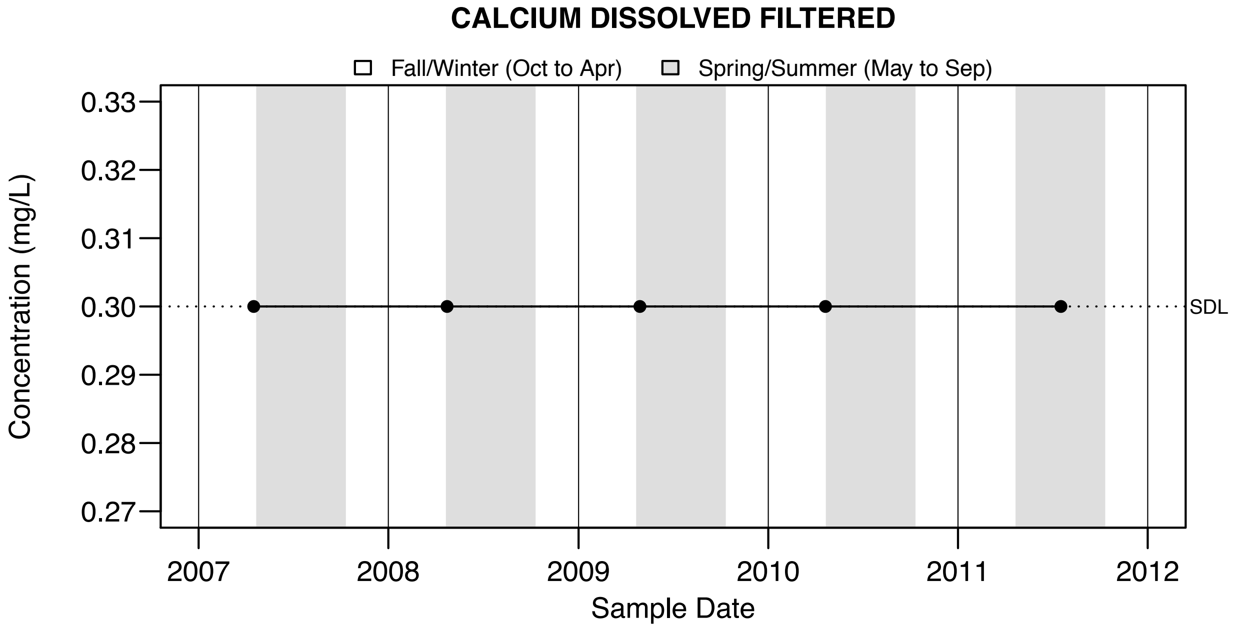


Figure A6.41: TRIP BLANK: CALCIUM DISSOLVED FILTERED

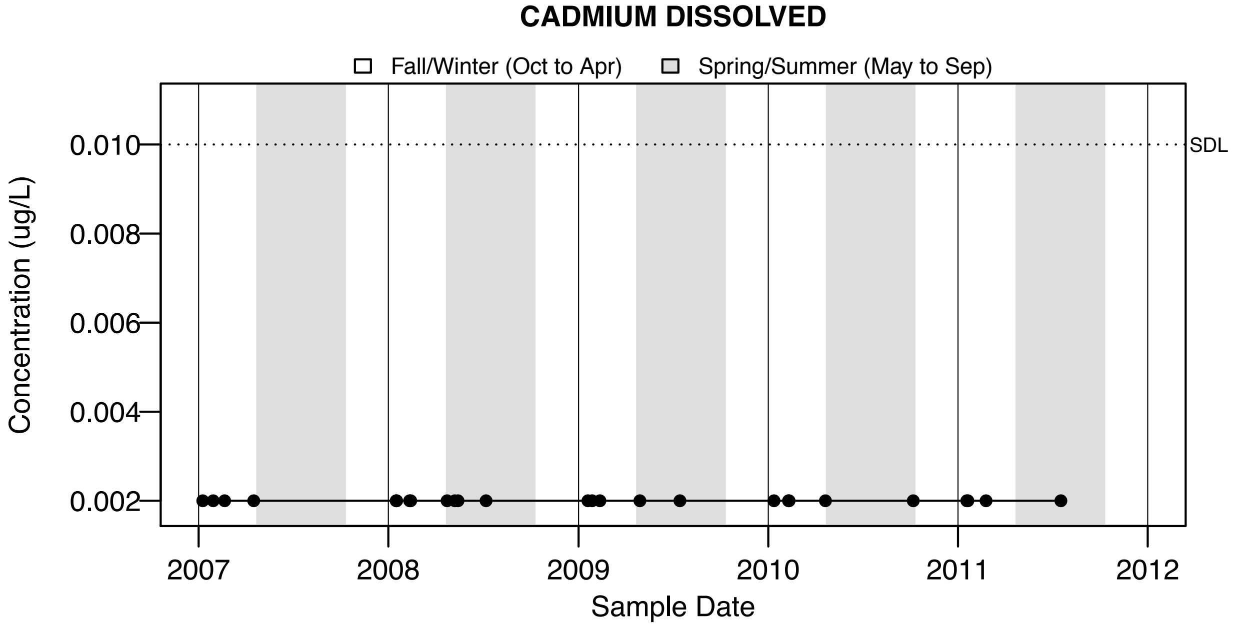


Figure A6.42: TRIP BLANK: CADMIUM DISSOLVED

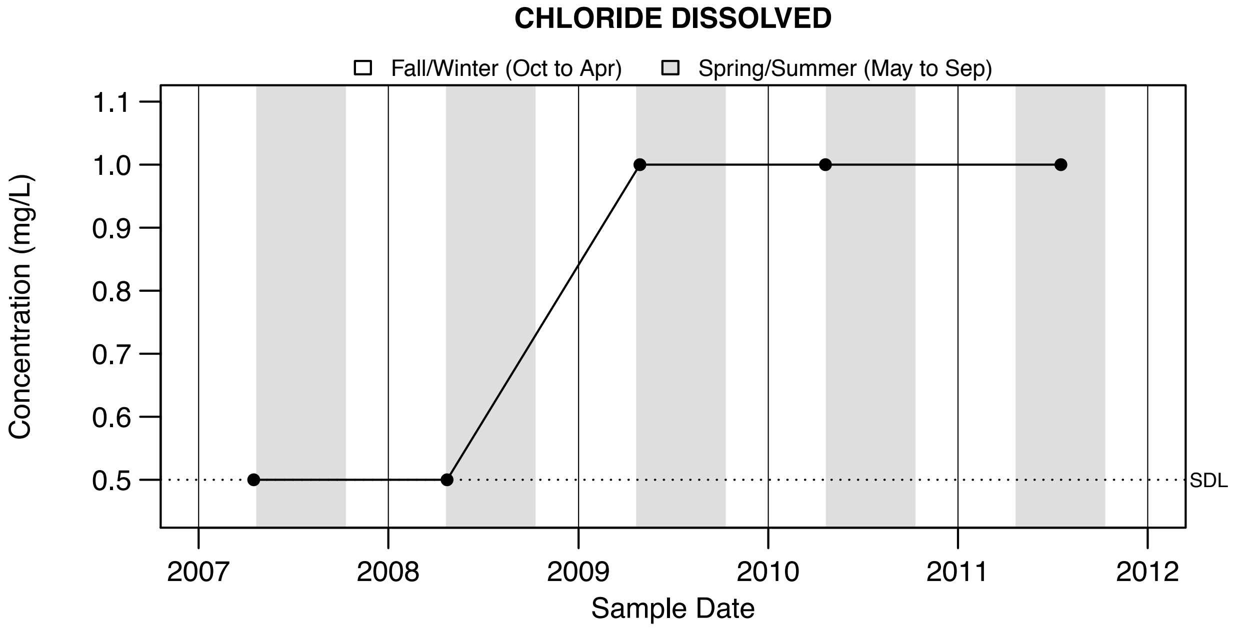


Figure A6.43: TRIP BLANK: CHLORIDE DISSOLVED

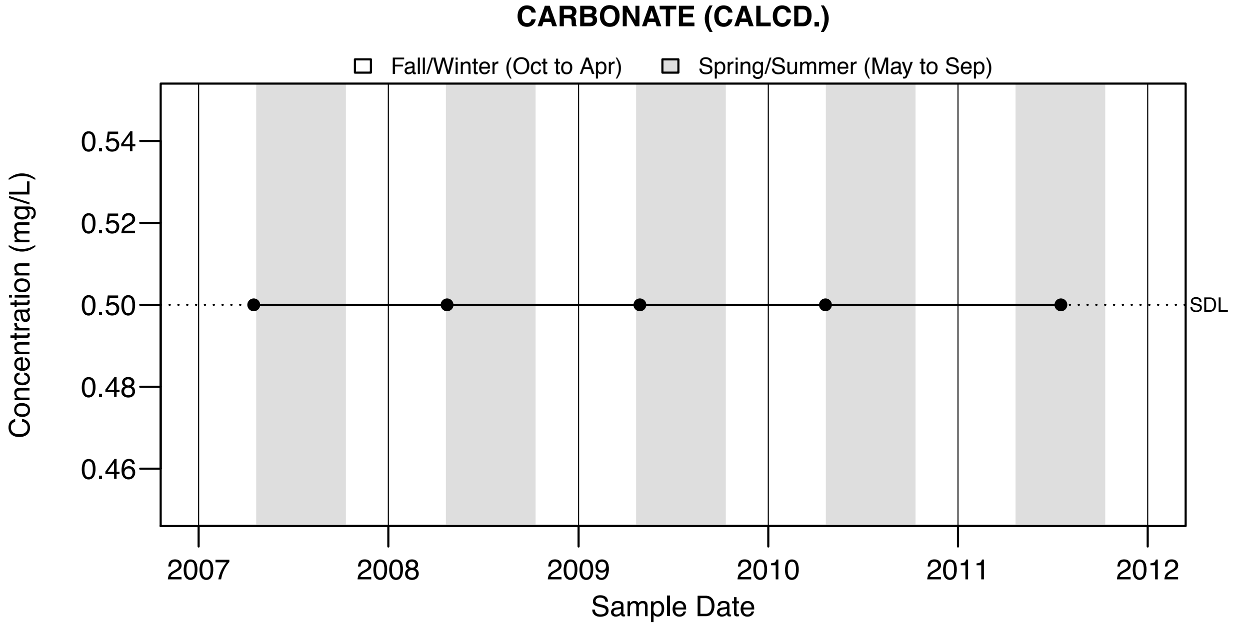


Figure A6.44: TRIP BLANK: CARBONATE (CALCD.)

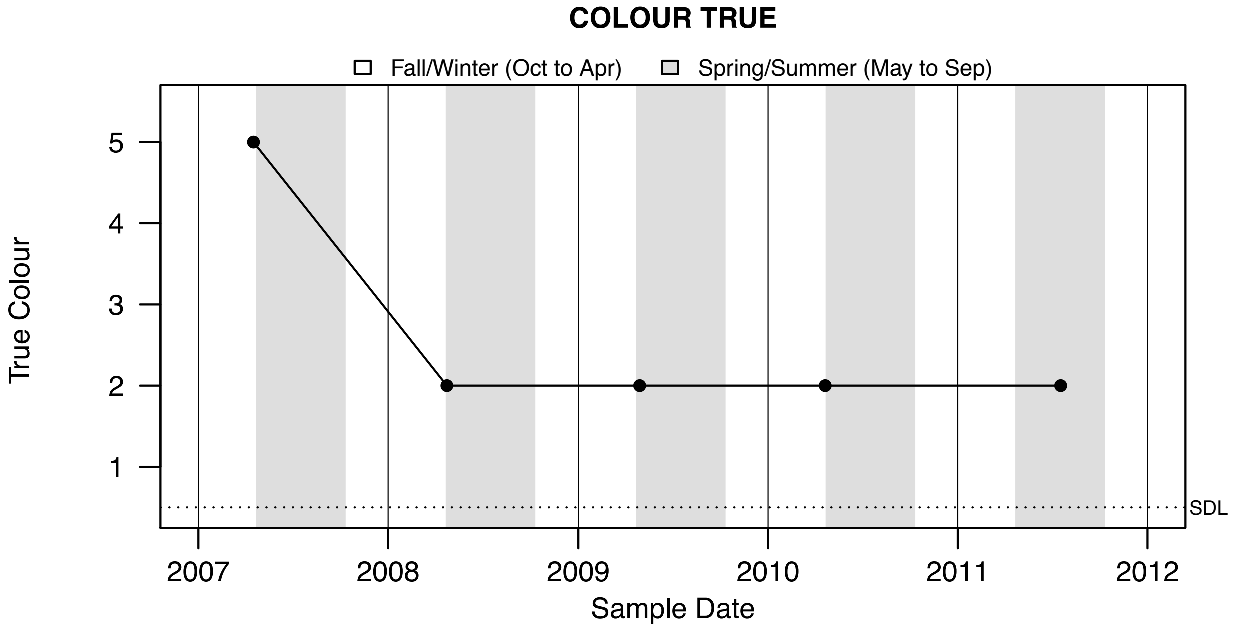


Figure A6.45: TRIP BLANK: COLOUR TRUE

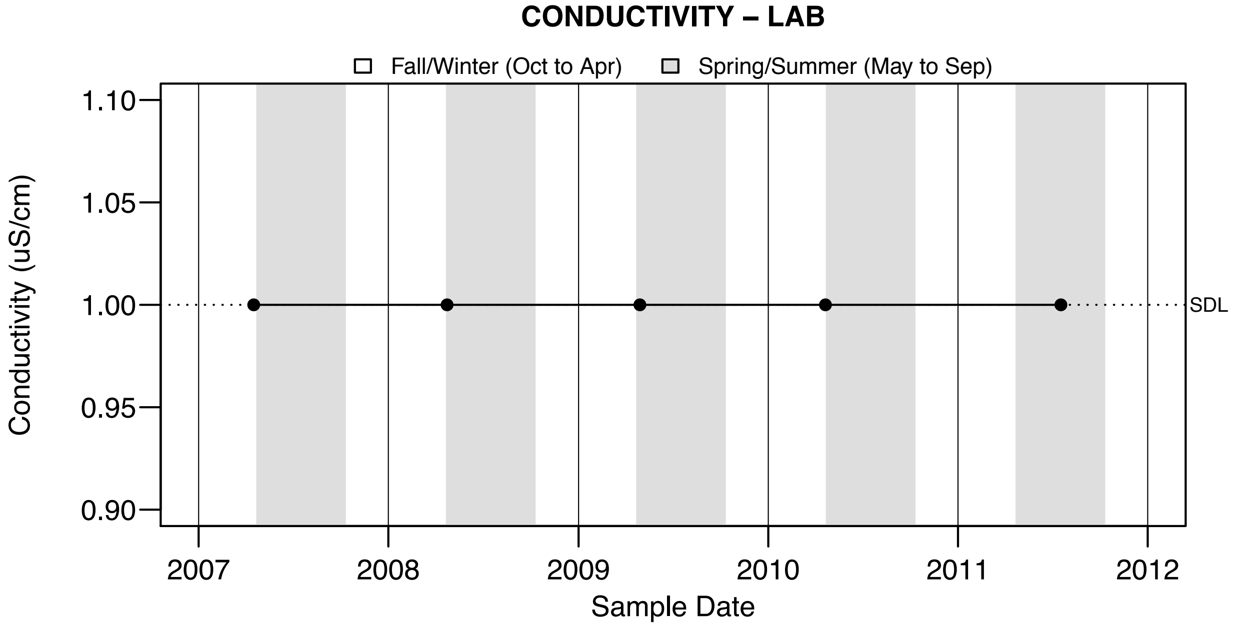


Figure A6.46: TRIP BLANK: CONDUCTIVITY - LAB

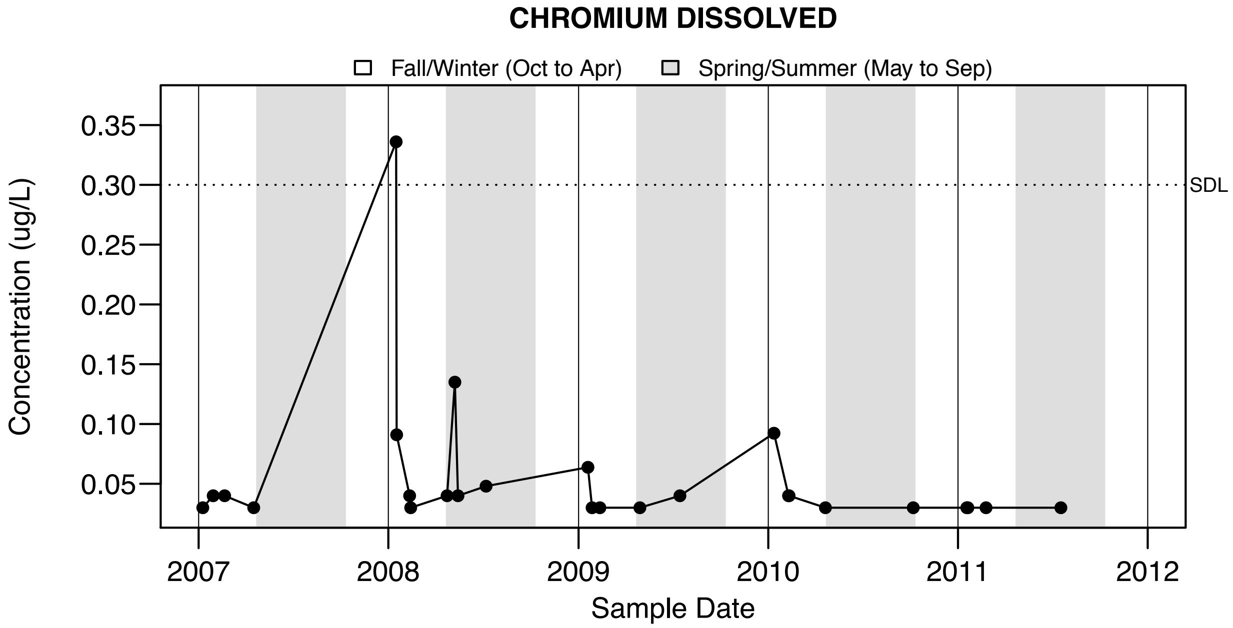


Figure A6.47: TRIP BLANK: CHROMIUM DISSOLVED

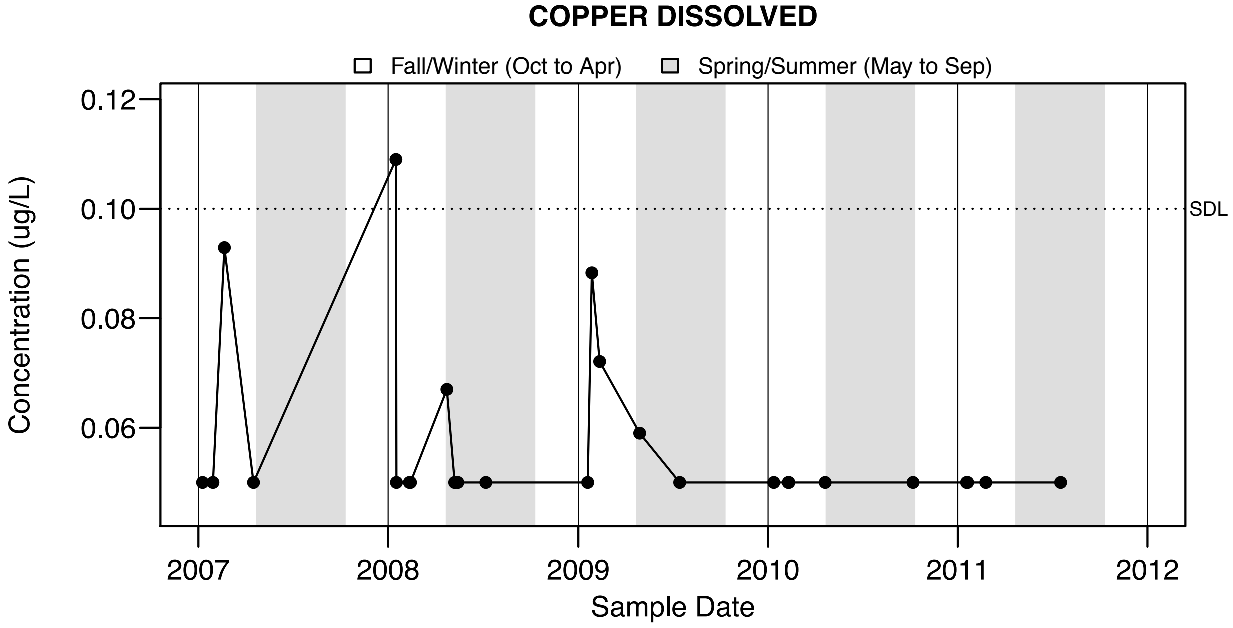


Figure A6.48: TRIP BLANK: COPPER DISSOLVED

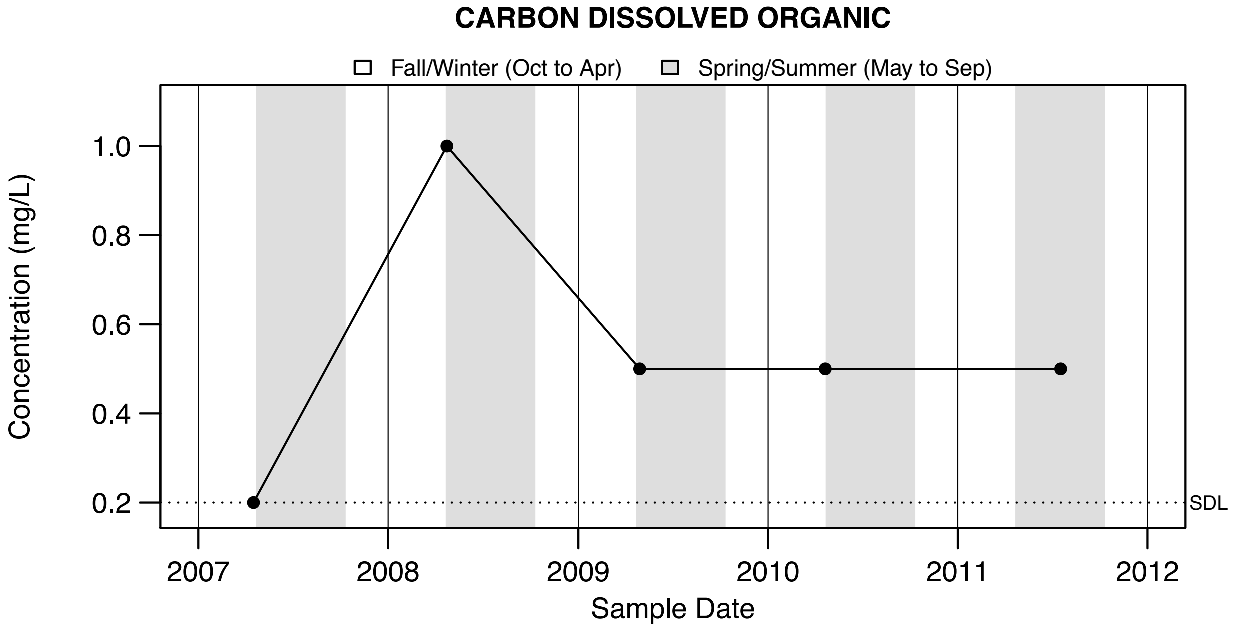


Figure A6.49: TRIP BLANK: CARBON DISSOLVED ORGANIC

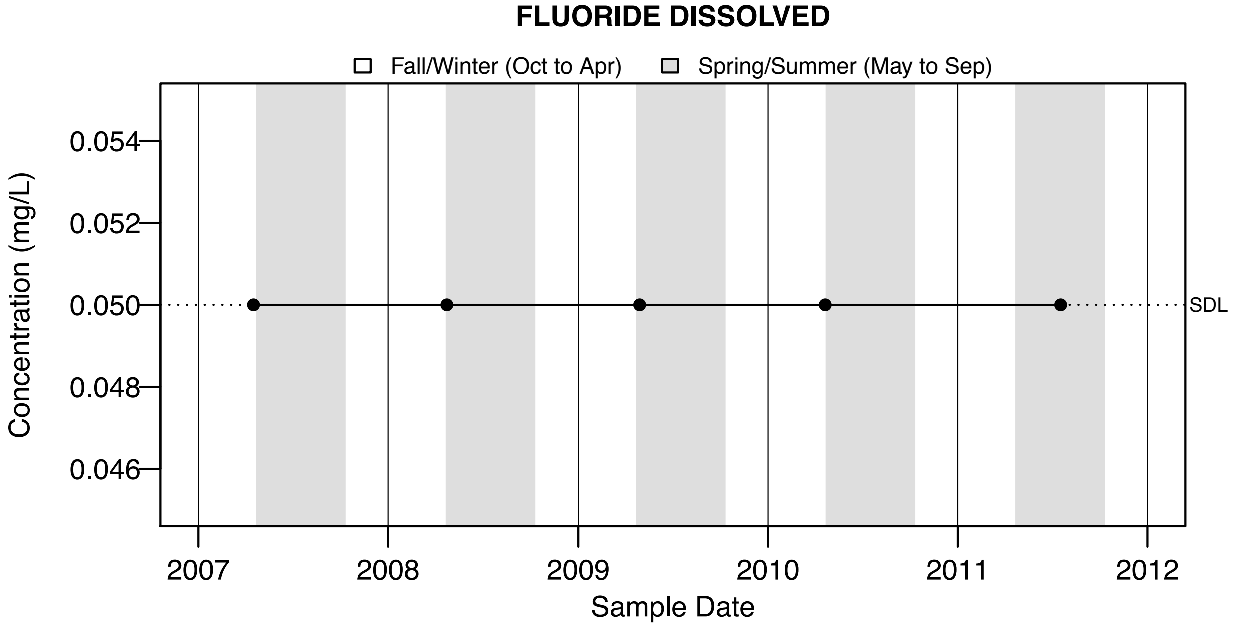


Figure A6.50: TRIP BLANK: FLUORIDE DISSOLVED

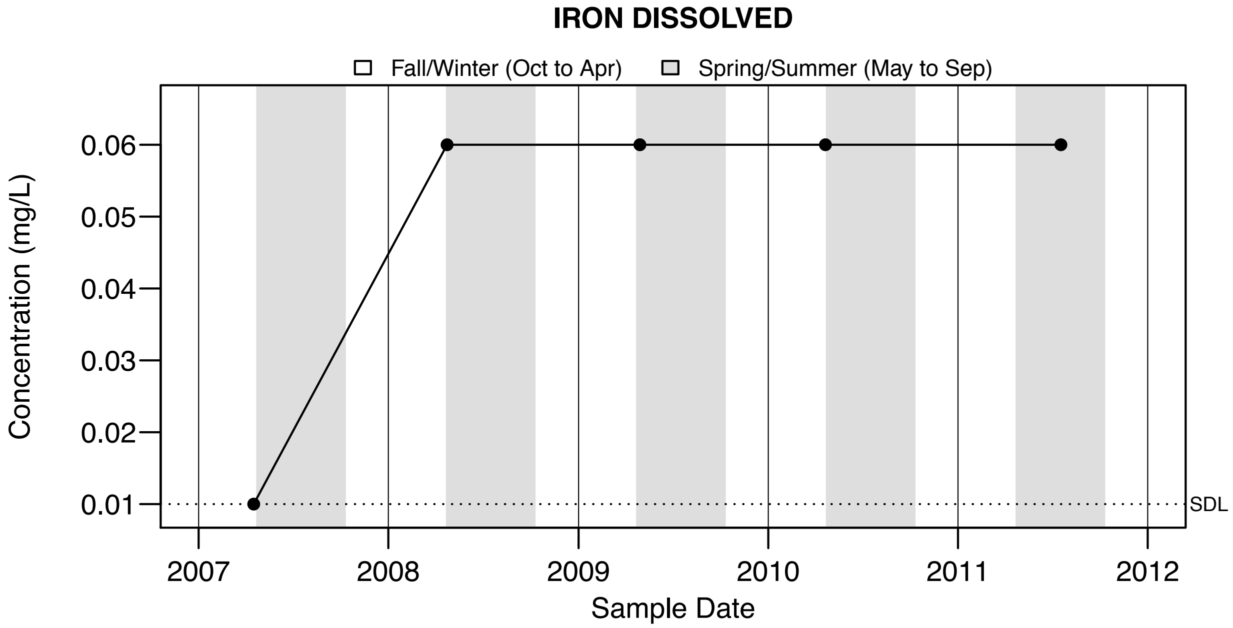


Figure A6.51: TRIP BLANK: IRON DISSOLVED

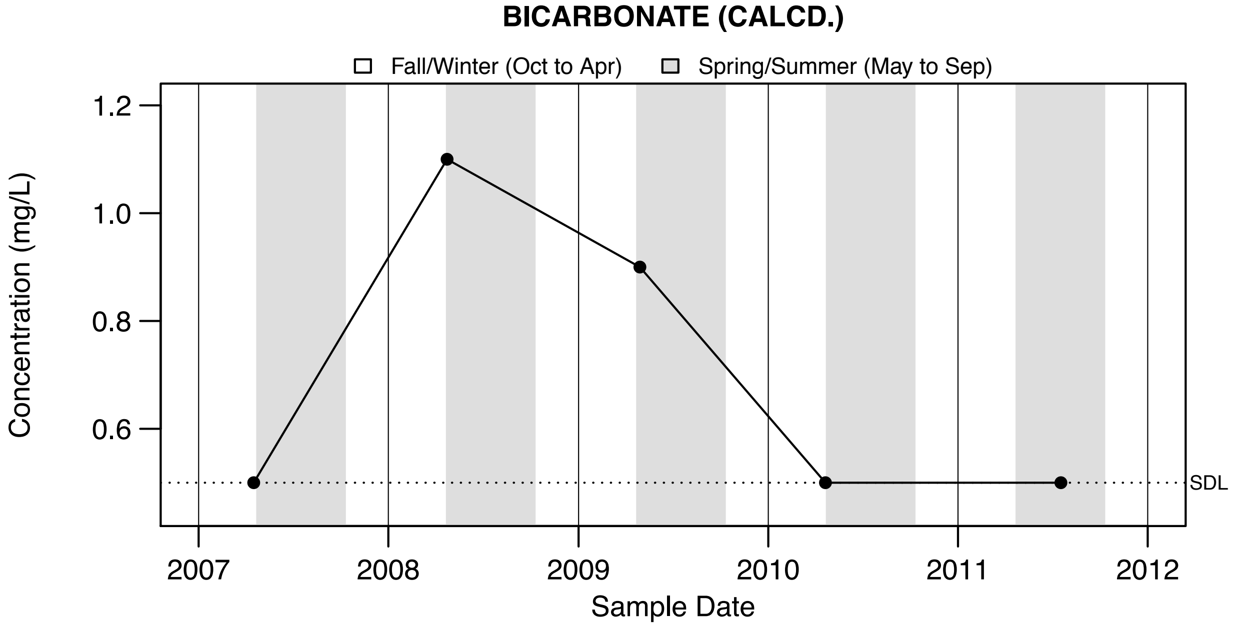


Figure A6.52: TRIP BLANK: BICARBONATE (CALCD.)

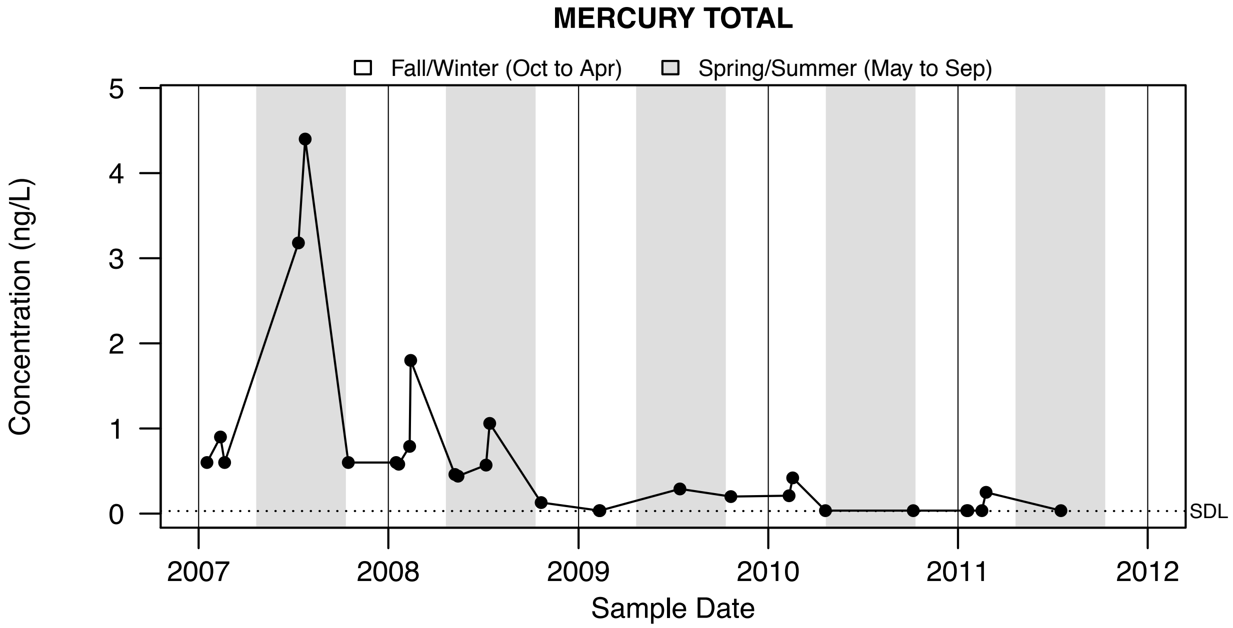


Figure A6.53: TRIP BLANK: MERCURY TOTAL

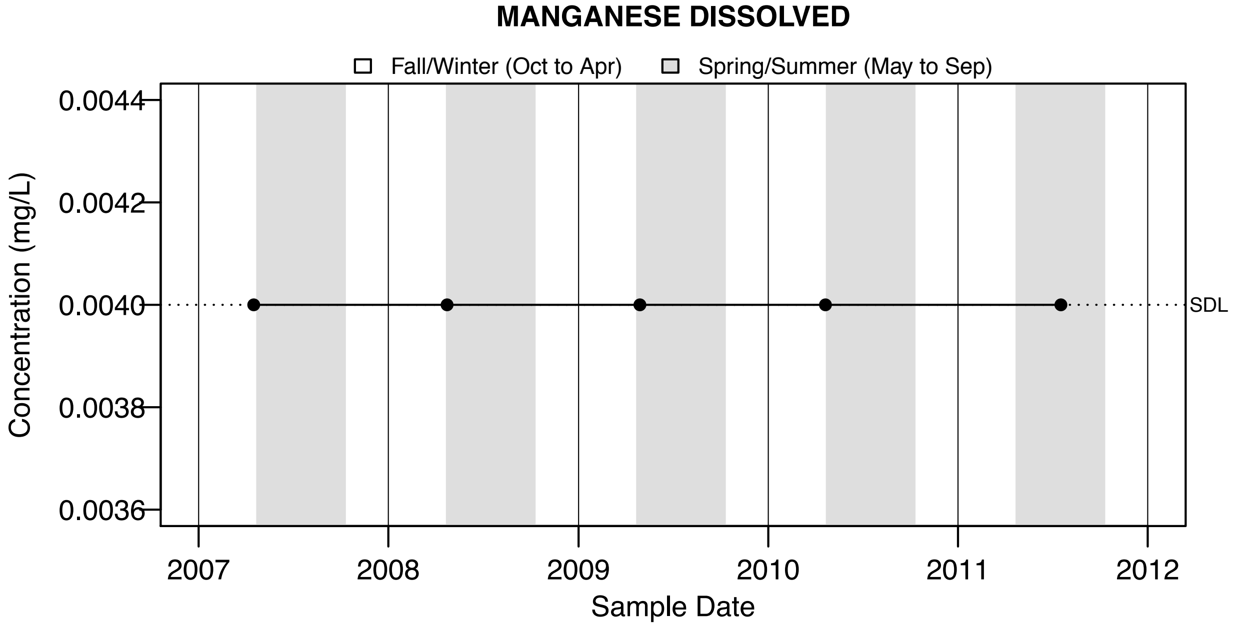


Figure A6.54: TRIP BLANK: MANGANESE DISSOLVED

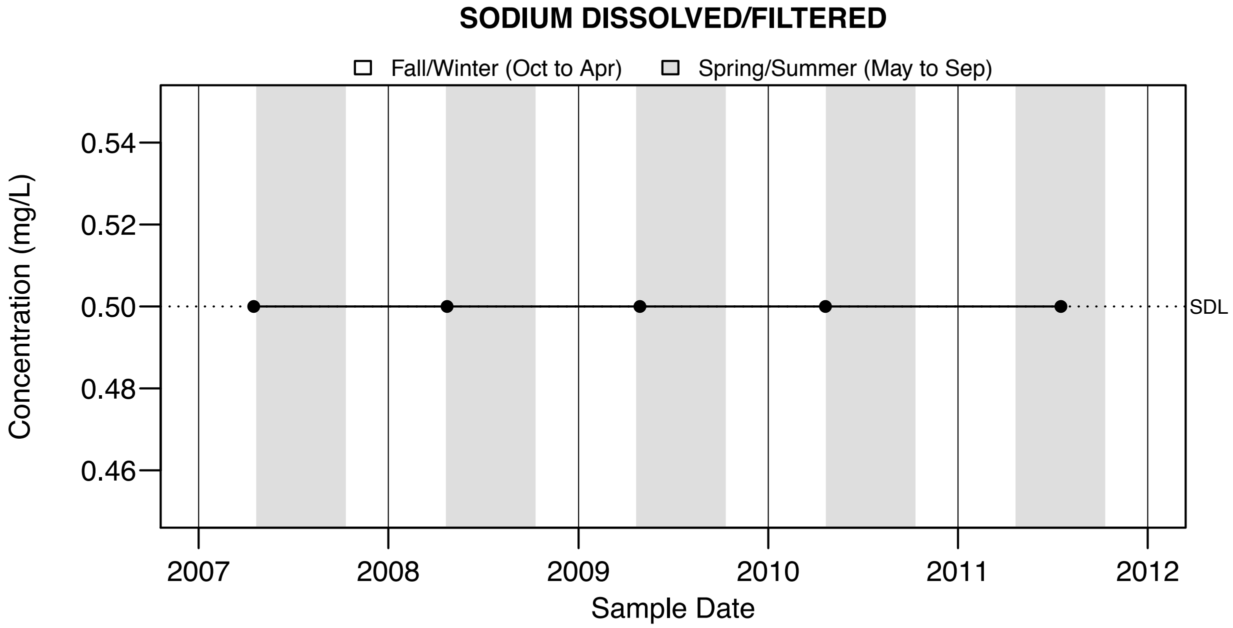


Figure A6.55: TRIP BLANK: SODIUM DISSOLVED/FILTERED

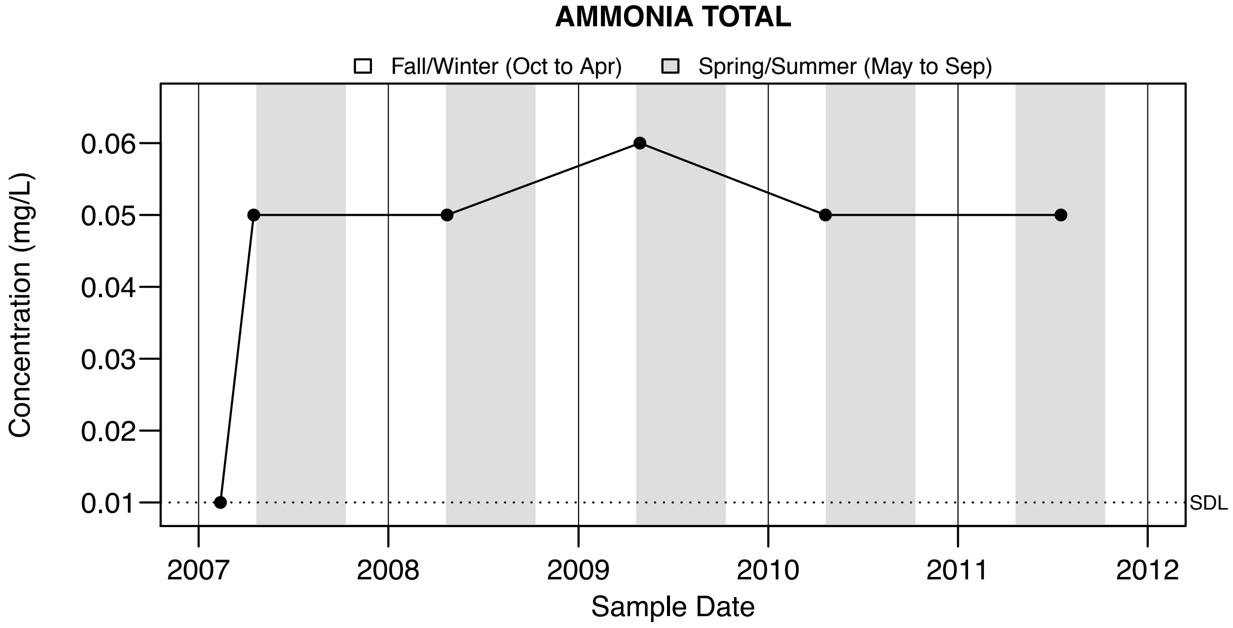


Figure A6.56: TRIP BLANK: AMMONIA TOTAL

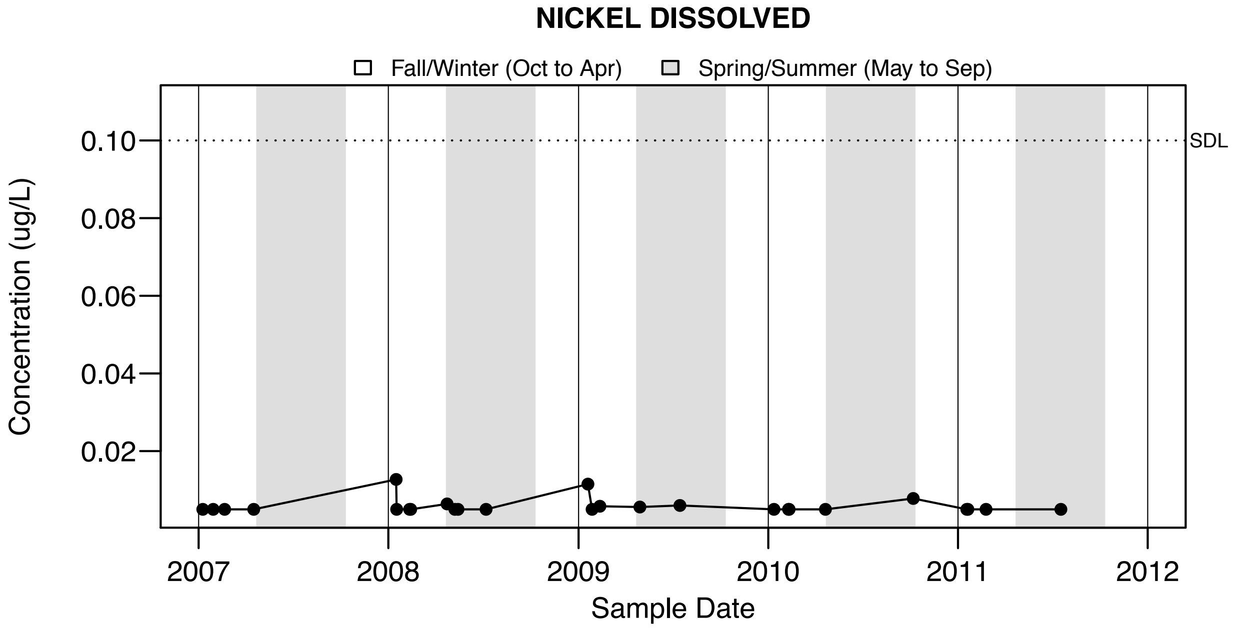


Figure A6.57: TRIP BLANK: NICKEL DISSOLVED

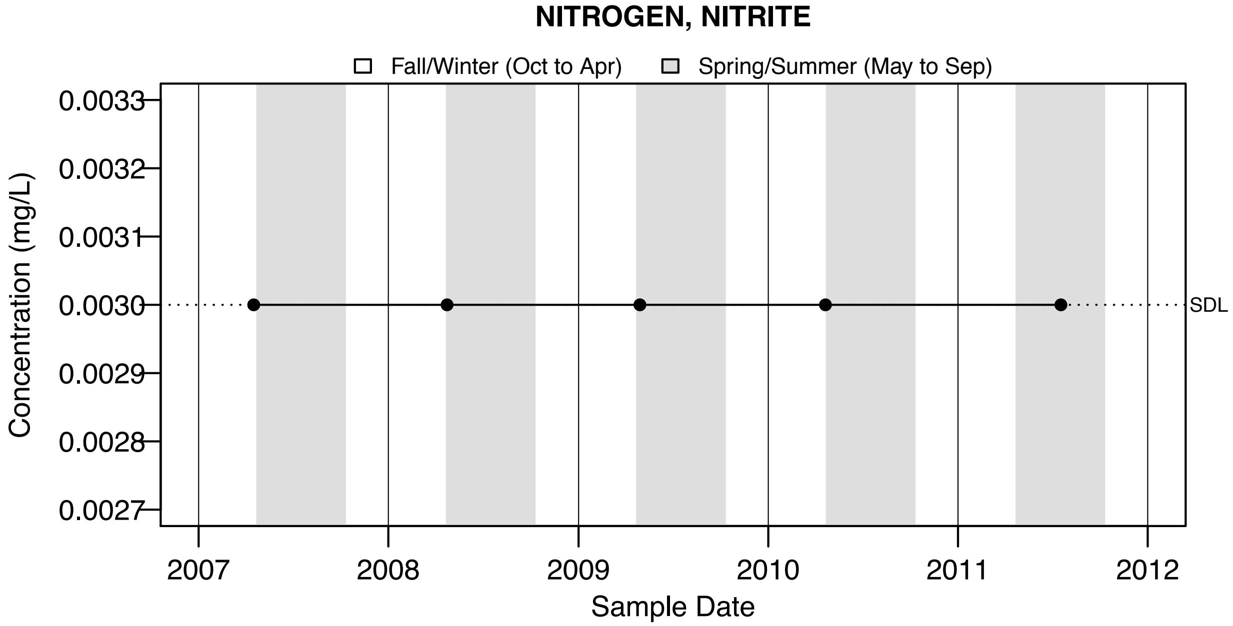


Figure A6.58: TRIP BLANK: NITROGEN, NITRITE

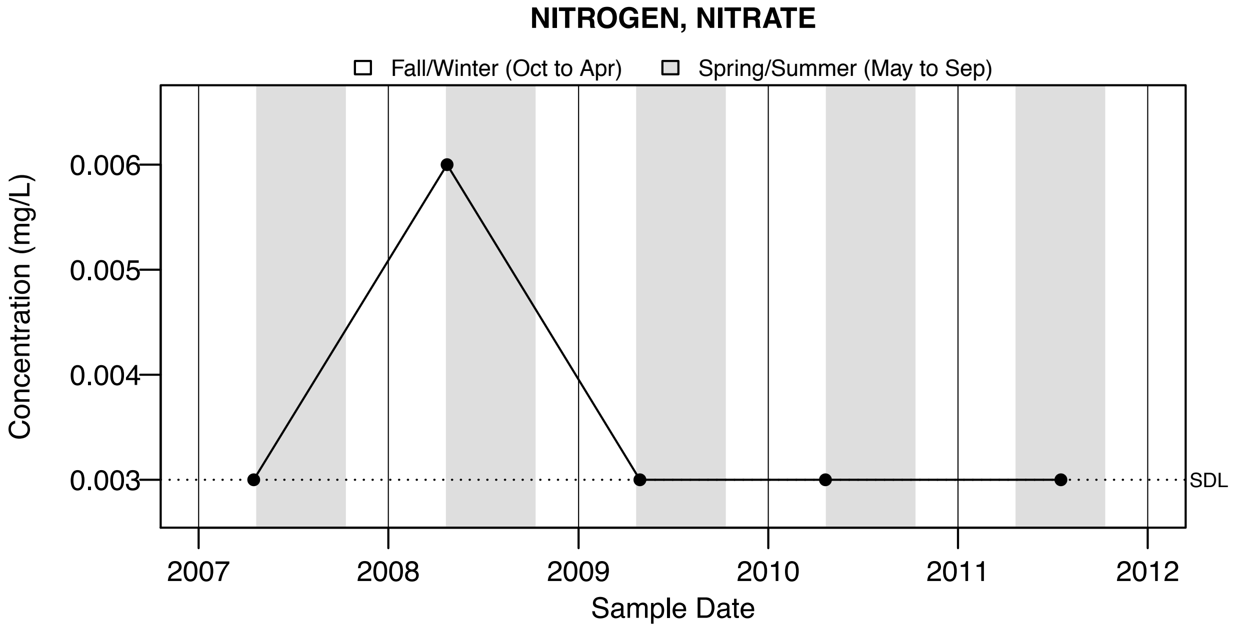


Figure A6.59: TRIP BLANK: NITROGEN, NITRATE

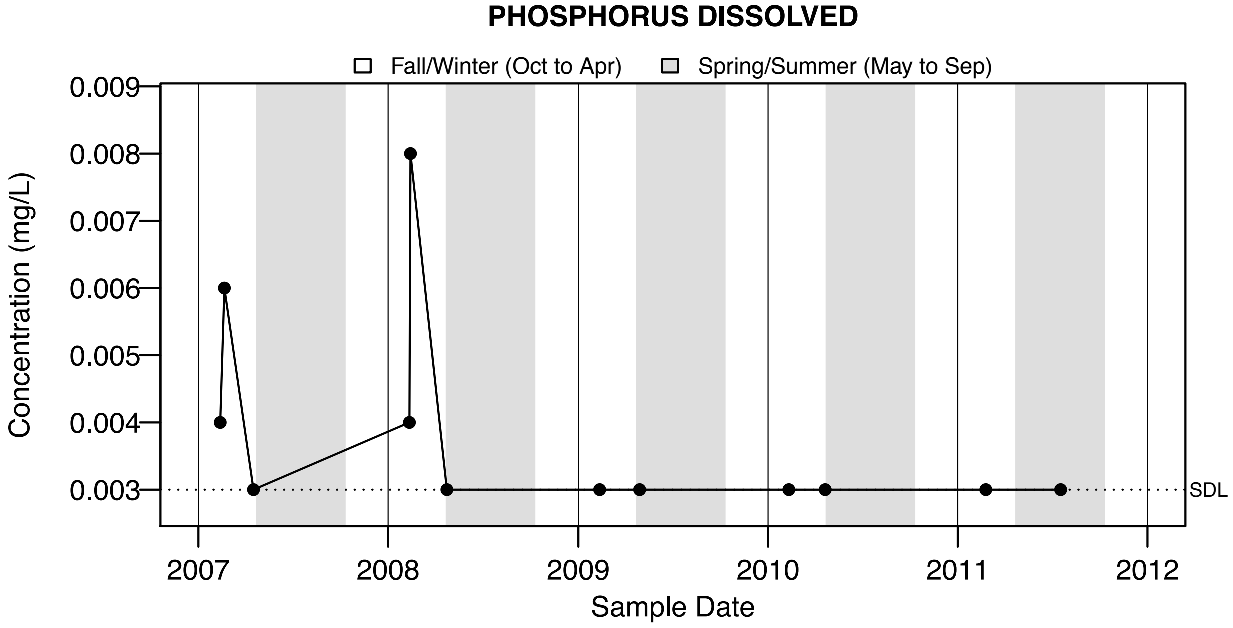


Figure A6.60: TRIP BLANK: PHOSPHORUS DISSOLVED

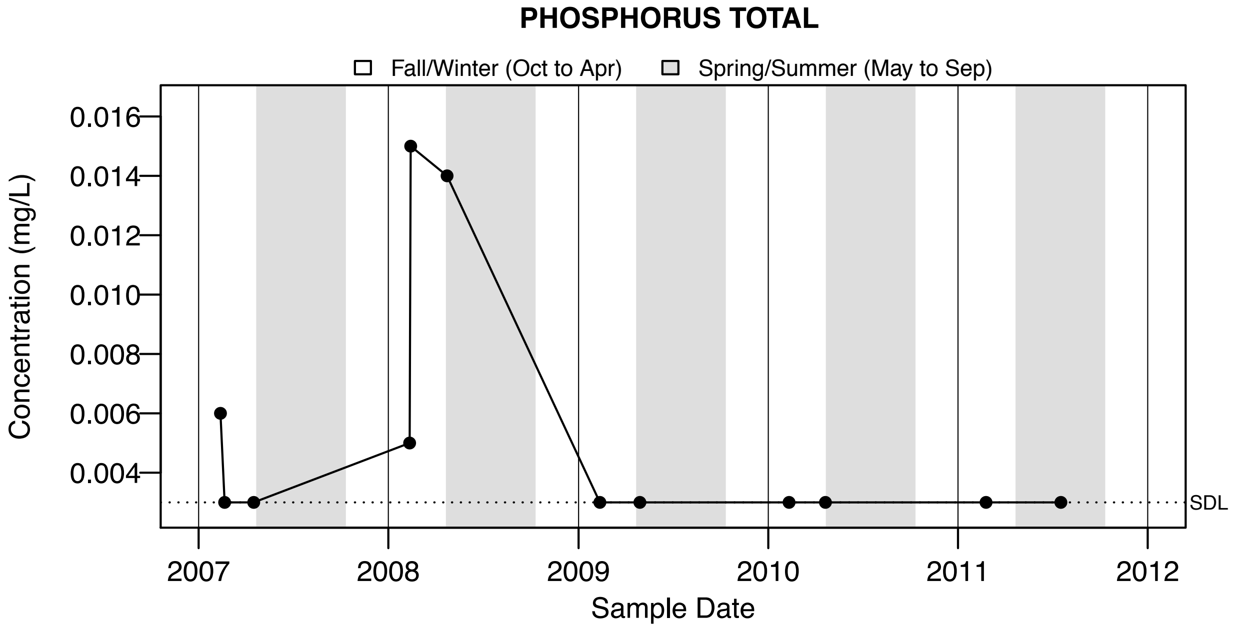


Figure A6.61: TRIP BLANK: PHOSPHORUS TOTAL

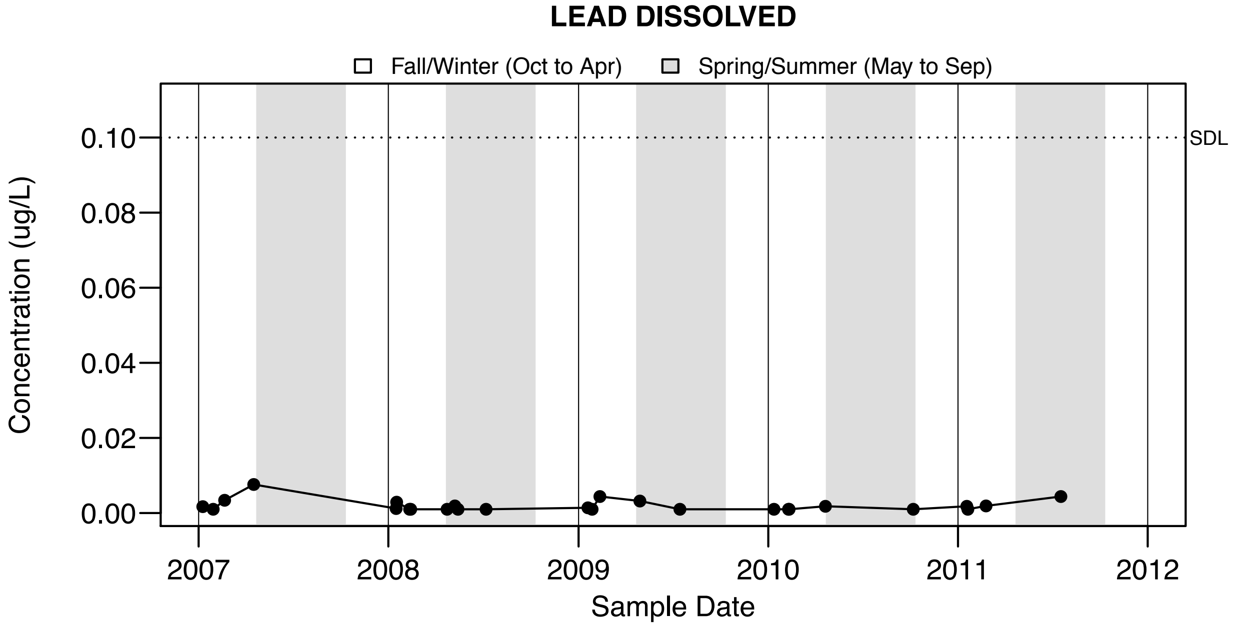


Figure A6.62: TRIP BLANK: LEAD DISSOLVED

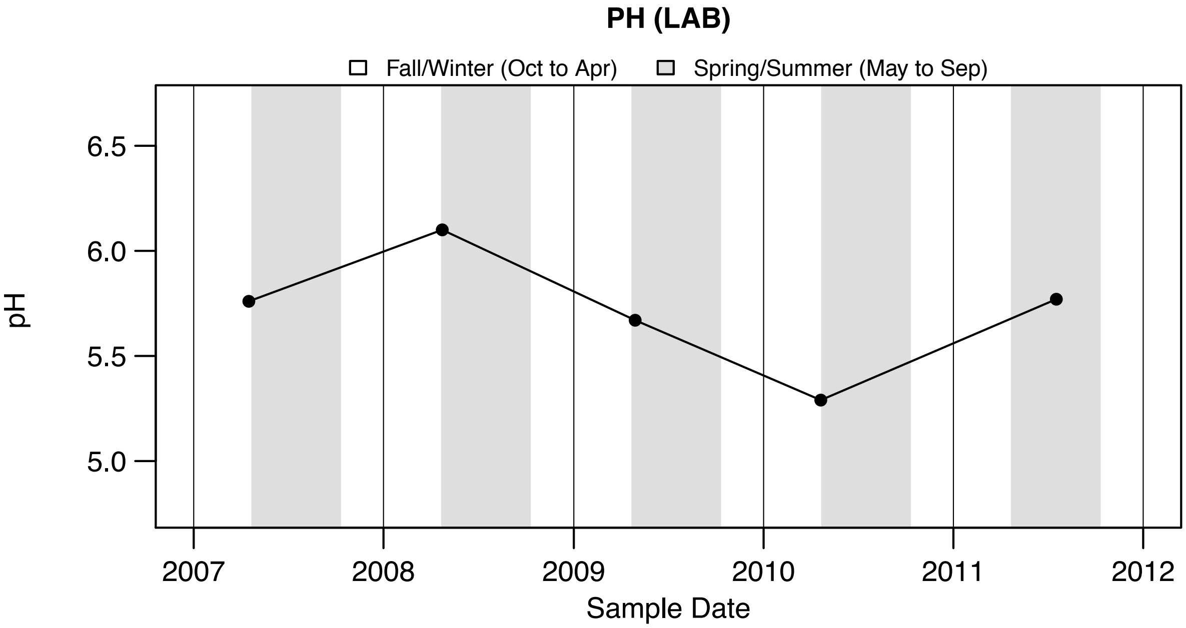


Figure A6.63: TRIP BLANK: PH (LAB)

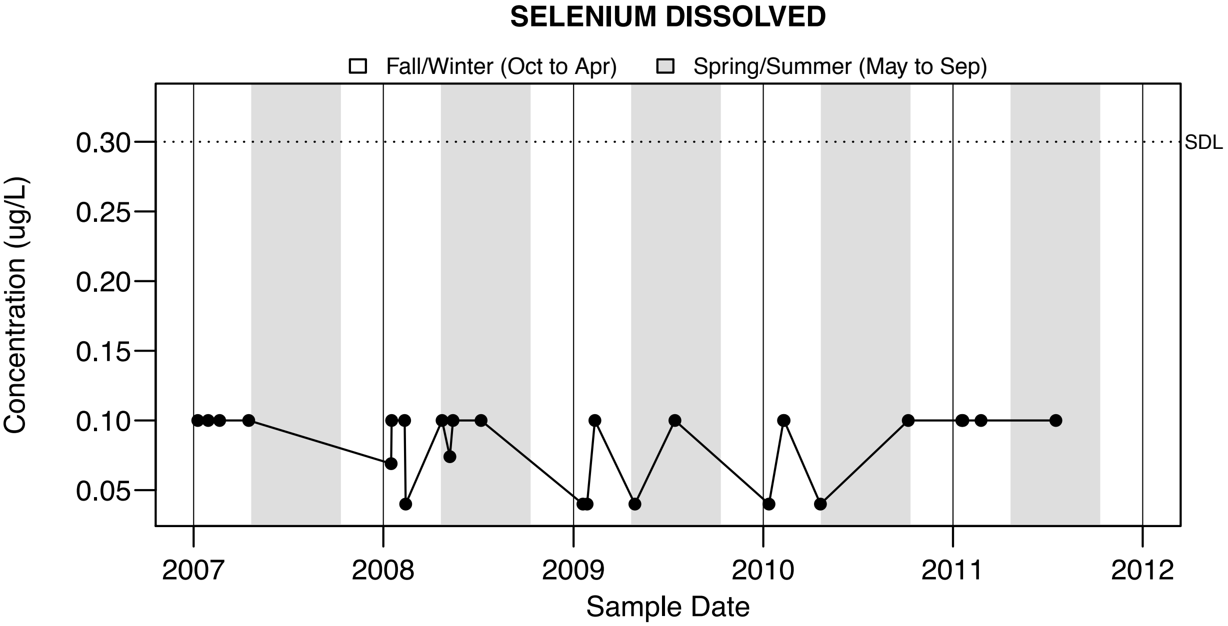


Figure A6.64: TRIP BLANK: SELENIUM DISSOLVED

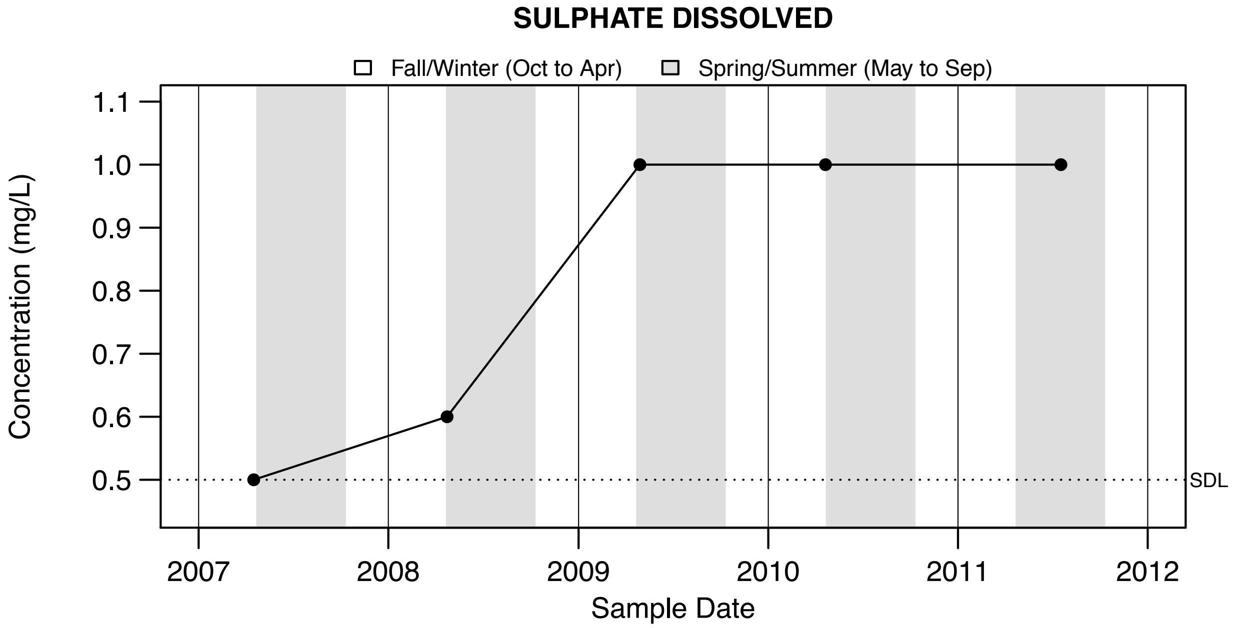


Figure A6.65: TRIP BLANK: SULPHATE DISSOLVED

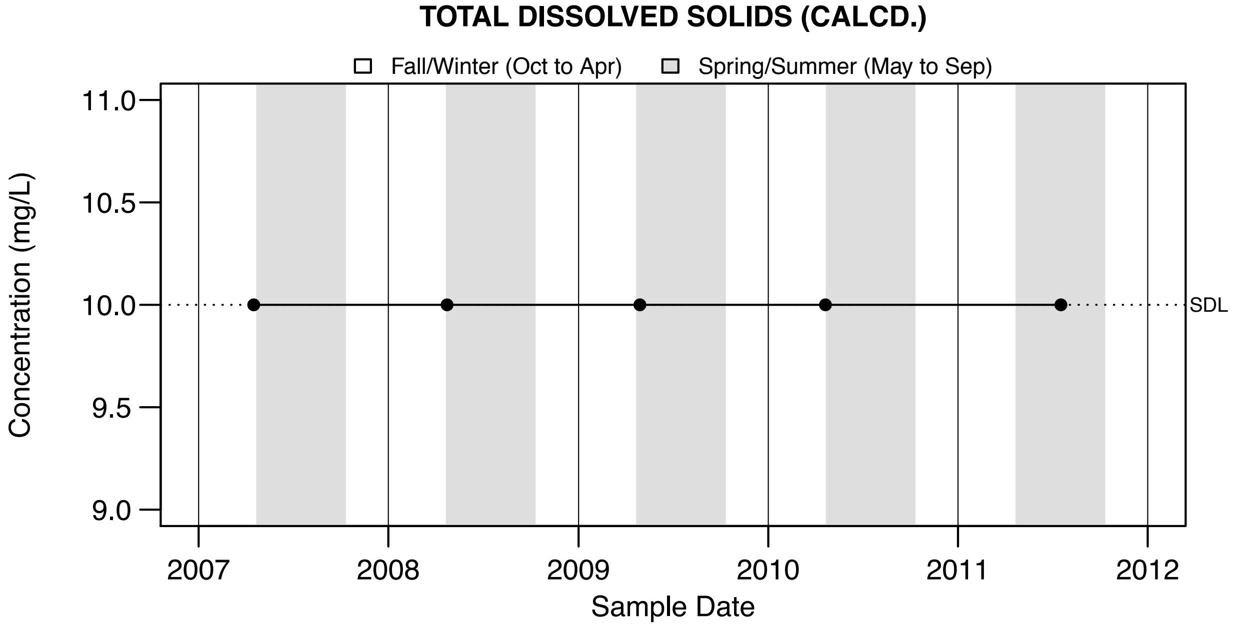


Figure A6.66: TRIP BLANK: TOTAL DISSOLVED SOLIDS (CALCD.)

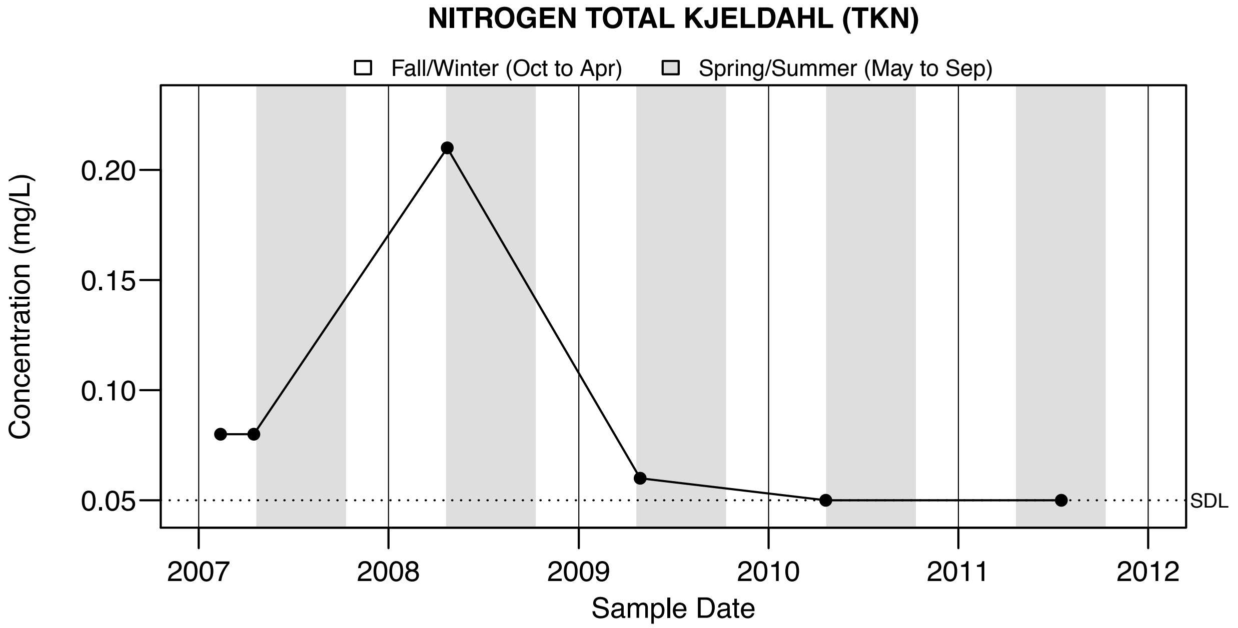


Figure A6.67: TRIP BLANK: NITROGEN TOTAL KJELDAHL (TKN)

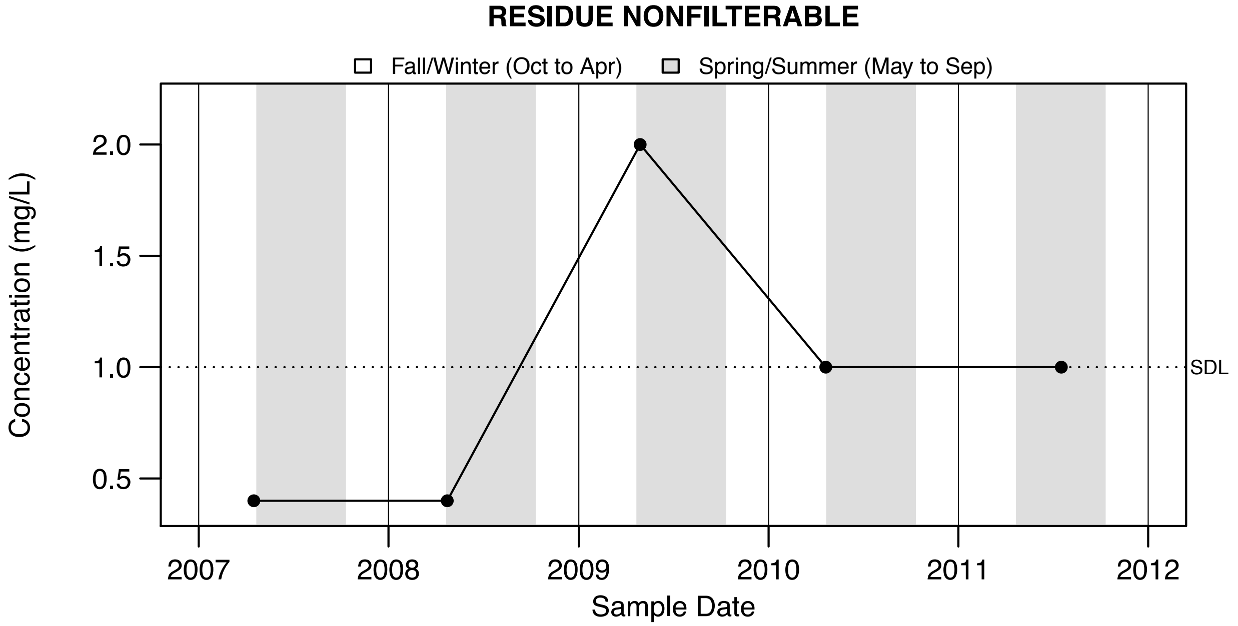


Figure A6.68: TRIP BLANK: RESIDUE NONFILTERABLE

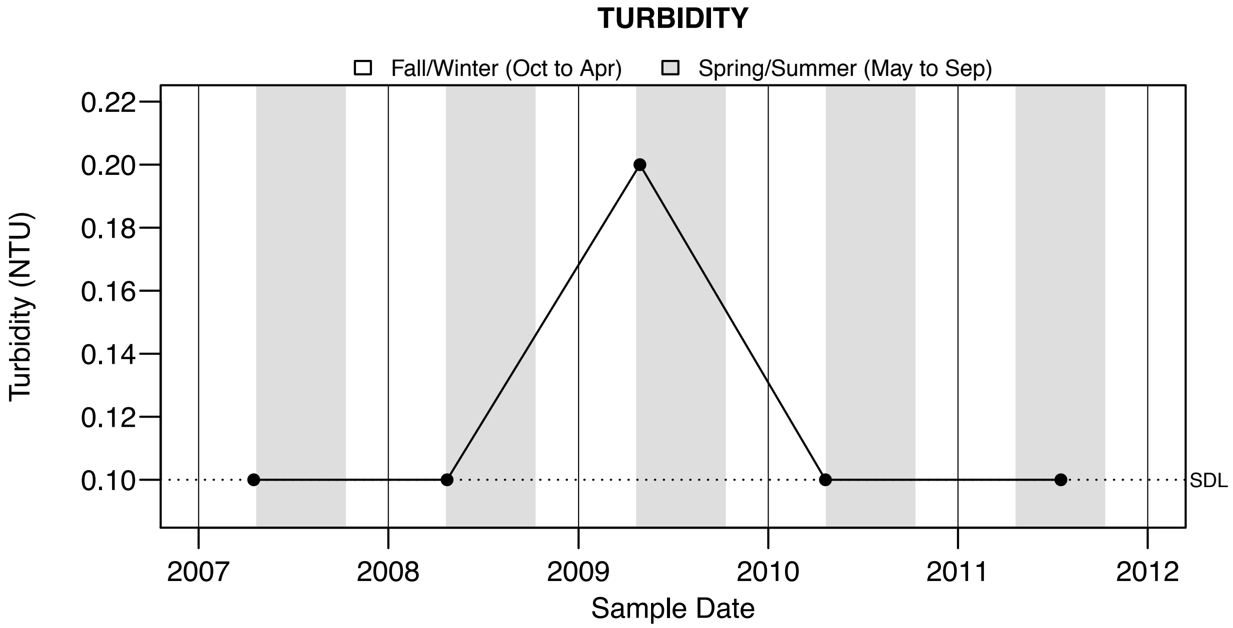


Figure A6.69: TRIP BLANK: TURBIDITY

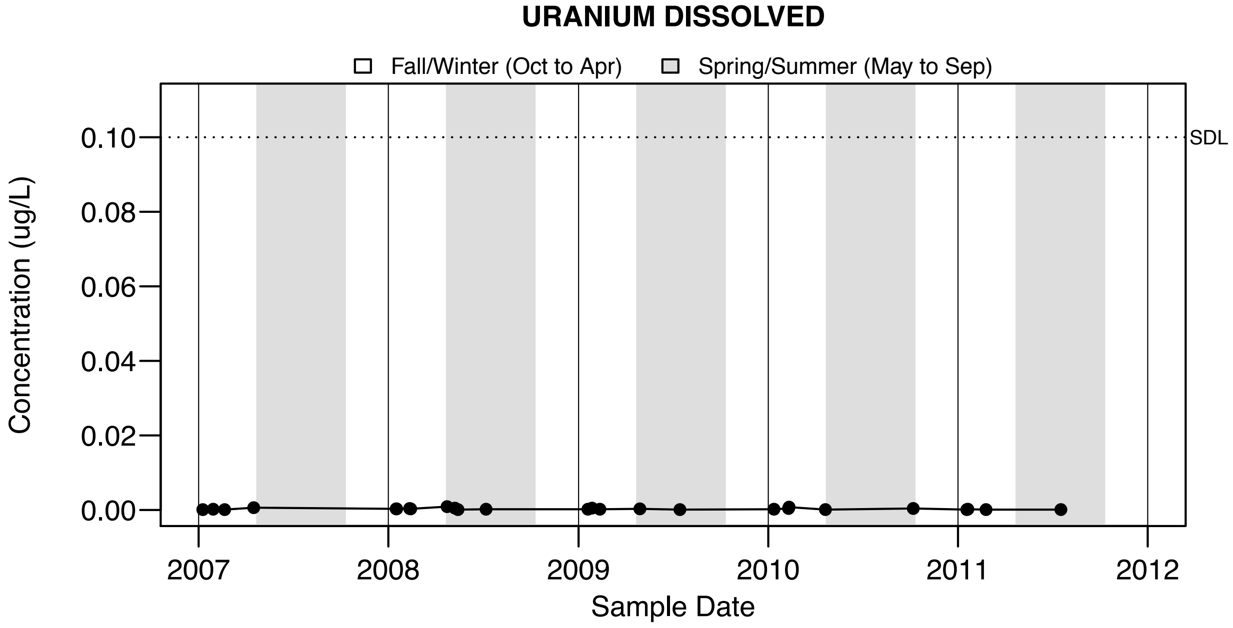


Figure A6.70: TRIP BLANK: URANIUM DISSOLVED

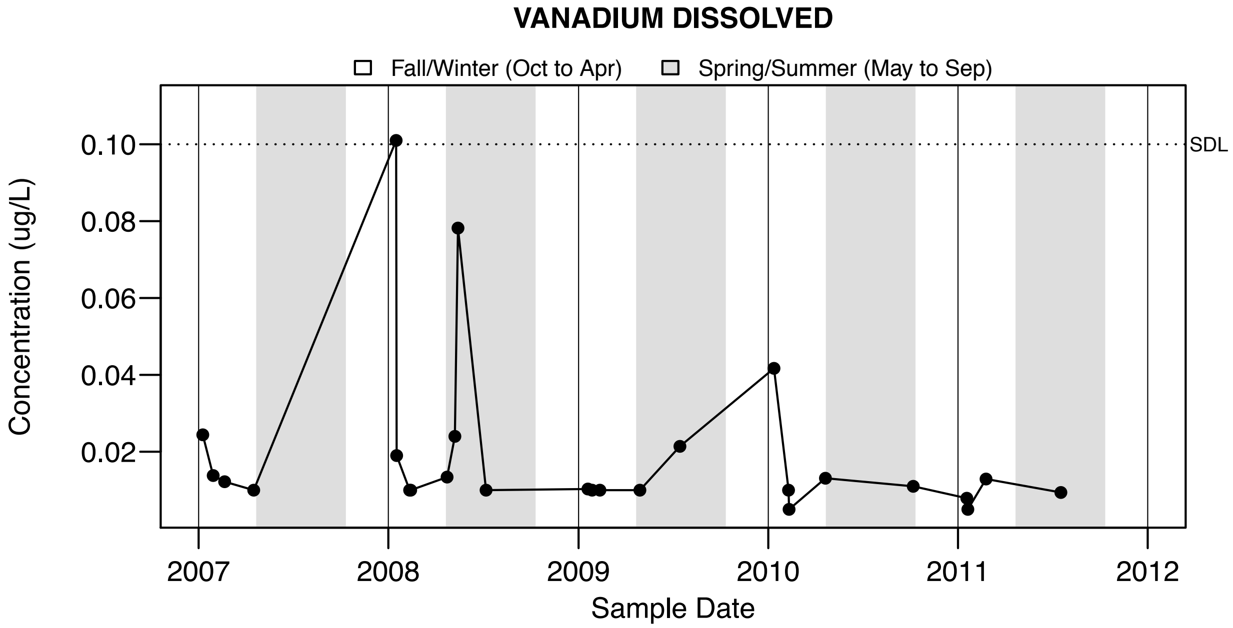


Figure A6.71: TRIP BLANK: VANADIUM DISSOLVED

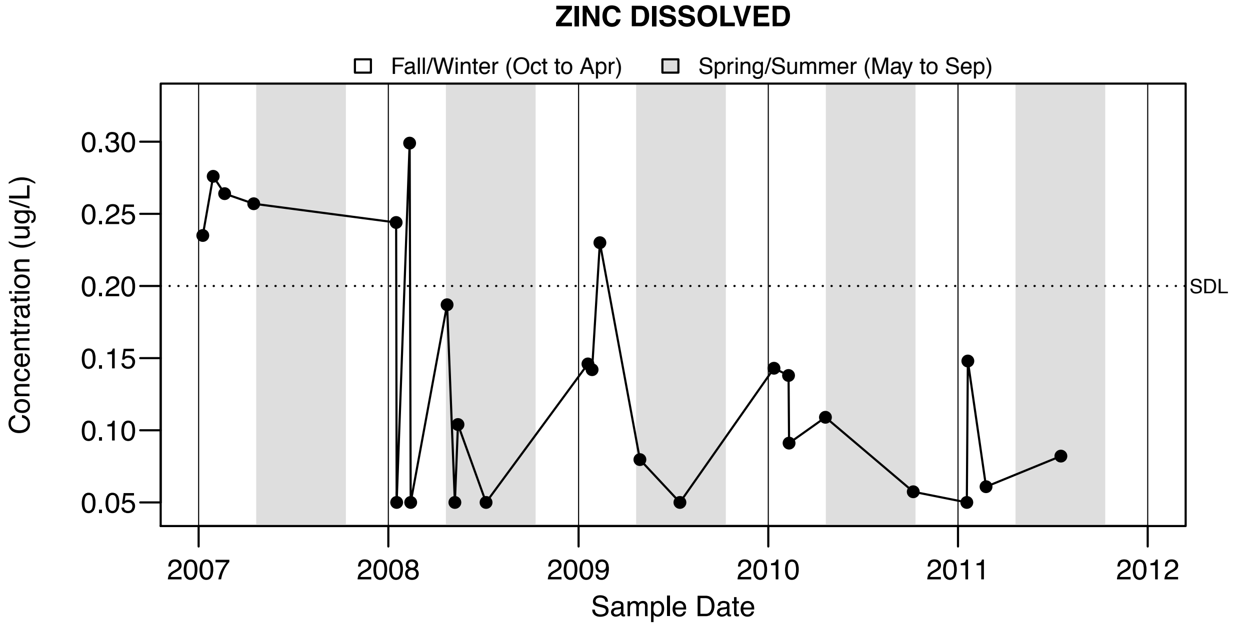


Figure A6.72: TRIP BLANK: ZINC DISSOLVED

Appendix 7:

Precision calculated from triplicate samples collected between 2007 and spring 2012 as part of the LTRN and MTRN monitoring programs

Table A7.1. Mean, standard deviation, and relative standard deviation of triplicate samples from the LTRN and MTRN monitoring programs between 2007 and spring of 2012. Parameters in bold exceed the measurement quality objective of <18% RSD.

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-12	ALKALINITY TOTAL (mg/L)	204	1.73	0.8
07-02-20	ALKALINITY TOTAL	183.33	0.58	0.3
07-05-14	ALKALINITY TOTAL	110	1	0.9
08-02-11	ALKALINITY TOTAL	171.67	1.53	0.9
08-02-13	ALKALINITY TOTAL	145.67	4.73	3.2
08-05-07	ALKALINITY TOTAL	120	0	0
08-05-13	ALKALINITY TOTAL	72	0	0
09-02-11	ALKALINITY TOTAL	120	0	0
09-05-14	ALKALINITY TOTAL	120	0	0
10-02-09	ALKALINITY TOTAL	130	0	0
10-05-06	ALKALINITY TOTAL	123.33	5.77	4.7
11-02-24	ALKALINITY TOTAL	130	0	0
11-07-18	ALKALINITY TOTAL	89	0	0
11-10-13	ALKALINITY TOTAL	120	0	0
07-02-20	ALUMINUM DISSOLVED (µg/L)	1.83	0.07	3.9
07-05-14	ALUMINUM DISSOLVED	8.51	0.47	5.5
08-02-11	ALUMINUM DISSOLVED	4.21	0.07	1.7
08-02-13	ALUMINUM DISSOLVED	4.94	0.14	2.8
08-05-07	ALUMINUM DISSOLVED	7.91	0.48	6.1
08-05-13	ALUMINUM DISSOLVED	94.5	7.05	7.5
09-02-11	ALUMINUM DISSOLVED	1.62	0.02	1.3
09-05-14	ALUMINUM DISSOLVED	3.76	0.17	4.5
10-02-09	**ALUMINUM DISSOLVED**	**2.12**	**0.46**	**21.7**
10-05-06	ALUMINUM DISSOLVED	5.01	0.69	13.8
11-02-24	ALUMINUM DISSOLVED	3.42	0.03	0.9
11-07-18	ALUMINUM DISSOLVED	55.33	1.34	2.4
11-10-13	ALUMINUM DISSOLVED	12.5	0.6	4.8
07-02-12	**AMMONIA TOTAL** (mg/L)	**0.06**	**0.02**	**28.9**
07-02-20	AMMONIA TOTAL	0.05	0	0
07-05-14	AMMONIA TOTAL	0.02	0.01	50
08-02-11	**AMMONIA TOTAL**	**0.12**	**0.04**	**36.3**
11-02-24	AMMONIA TOTAL	0.09	0.01	6.2
07-02-20	ARSENIC DISSOLVED (µg/L)	0.4	0.01	2.7
07-05-14	ARSENIC DISSOLVED	0.11	0	4.2
08-02-11	ARSENIC DISSOLVED	0.54	0.01	1.5
08-02-13	ARSENIC DISSOLVED	0.4	0.02	5.9
08-05-07	ARSENIC DISSOLVED	0.12	0.01	5.8
08-05-13	ARSENIC DISSOLVED	0.67	0.07	9.9
09-02-11	ARSENIC DISSOLVED	0.1	0.01	13.1
09-05-14	ARSENIC DISSOLVED	0.12	0	2.3
10-02-09	ARSENIC DISSOLVED	0.07	0.01	8.2
10-05-06	ARSENIC DISSOLVED	0.39	0.02	4.7
11-02-24	ARSENIC DISSOLVED	0.34	0	1
11-07-18	ARSENIC DISSOLVED	0.73	0.01	1.8
11-10-13	ARSENIC DISSOLVED	0.36	0.02	5.6

Continued . . .

Table A7.1. *Continued…*

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-20	CADMIUM DISSOLVED (µg/L)	0.03	0	2.6
08-02-11	CADMIUM DISSOLVED	0.01	0	17
08-02-13	**CADMIUM DISSOLVED**	**0.03**	**0.01**	**30.8**
08-05-07	CADMIUM DISSOLVED	0.01	0	8.6
08-05-13	CADMIUM DISSOLVED	0.01	0	1.1
09-02-11	**CADMIUM DISSOLVED**	**0**	**0**	**18.5**
09-05-14	CADMIUM DISSOLVED	0	0	4.9
10-02-09	**CADMIUM DISSOLVED**	**0**	**0**	**40.3**
10-05-06	CADMIUM DISSOLVED	0.01	0	5.4
11-02-24	CADMIUM DISSOLVED	0.01	0	9.1
11-07-18	CADMIUM DISSOLVED	0.01	0	2.9
11-10-13	CADMIUM DISSOLVED	0.01	0	12.6
07-02-20	CALCIUM DISSOLVED (mg/L)	51.13	0.32	0.6
07-05-14	CALCIUM DISSOLVED	40.33	0.7	1.7
08-02-11	CALCIUM DISSOLVED	46.83	0.31	0.7
08-02-13	CALCIUM DISSOLVED	37.37	0.31	0.8
08-05-07	CALCIUM DISSOLVED	50.9	0.87	1.7
08-05-13	CALCIUM DISSOLVED	20	0.61	3
09-02-11	CALCIUM DISSOLVED	50.63	0.32	0.6
09-05-14	CALCIUM DISSOLVED	46.77	2.25	4.8
10-02-09	CALCIUM DISSOLVED	60.43	0.4	0.7
10-05-06	CALCIUM DISSOLVED	36.47	0.06	0.2
11-02-24	CALCIUM DISSOLVED	38.07	0.32	0.8
11-07-18	CALCIUM DISSOLVED	25.1	0.9	3.6
11-10-13	CALCIUM DISSOLVED	32.37	1.29	4
07-02-12	CALCIUM DISSOLVED FILTERED (mg/L)	58.8	0.36	0.6
07-02-20	CALCIUM DISSOLVED FILTERED	57.67	0.23	0.4
07-05-14	CALCIUM DISSOLVED FILTERED	40.67	0.51	1.3
08-02-11	CALCIUM DISSOLVED FILTERED	50.33	1.16	2.3
08-02-13	CALCIUM DISSOLVED FILTERED	43.5	1.39	3.2
08-05-07	CALCIUM DISSOLVED FILTERED	58.33	0.58	1
08-05-13	CALCIUM DISSOLVED FILTERED	21.33	0.58	2.7
09-02-11	CALCIUM DISSOLVED FILTERED	58	0	0
09-05-14	CALCIUM DISSOLVED FILTERED	50.33	0.58	1.1
10-02-09	CALCIUM DISSOLVED FILTERED	57	0	0
10-05-06	CALCIUM DISSOLVED FILTERED	37.33	0.58	1.5
11-02-24	CALCIUM DISSOLVED FILTERED	40	1.73	4.3
11-07-18	CALCIUM DISSOLVED FILTERED	28	1	3.6
11-10-13	CALCIUM DISSOLVED FILTERED	34	1.73	5.1
07-02-12	CARBON DISSOLVED ORGANIC (mg/L)	7.4	0.2	2.7
07-02-20	CARBON DISSOLVED ORGANIC	5.37	0.12	2.2
07-05-14	CARBON DISSOLVED ORGANIC	2.37	0.15	6.5
08-02-11	CARBON DISSOLVED ORGANIC	8	0.52	6.5
08-02-13	CARBON DISSOLVED ORGANIC	7.63	0.35	4.6
08-05-13	CARBON DISSOLVED ORGANIC	17.77	0.35	2
09-05-14	CARBON DISSOLVED ORGANIC	0.9	0.1	11.1
10-05-06	CARBON DISSOLVED ORGANIC	5.37	0.12	2.2
11-02-24	CARBON DISSOLVED ORGANIC	5.57	0.31	5.5
11-07-18	CARBON DISSOLVED ORGANIC	19	0	0
11-10-13	CARBON DISSOLVED ORGANIC	4.63	0.12	2.5

Continued…

Table A7.1. Continued…

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-12	CHLORIDE DISSOLVED (mg/L)	5.77	0.06	1
07-02-20	CHLORIDE DISSOLVED	3.3	0	0
08-02-11	CHLORIDE DISSOLVED	5.83	0.32	5.5
08-02-13	CHLORIDE DISSOLVED	31.27	0.31	1
08-05-13	CHLORIDE DISSOLVED	4.9	0.1	2
10-02-09	**CHLORIDE DISSOLVED**	**1.33**	**0.58**	**43.3**
10-05-06	CHLORIDE DISSOLVED	2	0	0
11-02-24	CHLORIDE DISSOLVED	29.33	0.58	2
11-07-18	CHLORIDE DISSOLVED	1	0	0
11-10-13	CHLORIDE DISSOLVED	2	0	0
07-02-20	CHROMIUM DISSOLVED (µg/L)	0.24	0.02	8
07-05-14	**CHROMIUM DISSOLVED**	**0.08**	**0.03**	**31.3**
08-02-11	CHROMIUM DISSOLVED	0.37	0.01	4.1
08-02-13	CHROMIUM DISSOLVED	0.58	0.04	6.2
08-05-07	CHROMIUM DISSOLVED	0.35	0.03	7.7
08-05-13	**CHROMIUM DISSOLVED**	**0.6**	**0.25**	**40.9**
09-02-11	**CHROMIUM DISSOLVED**	**0.22**	**0.06**	**25.8**
09-05-14	**CHROMIUM DISSOLVED**	**0.2**	**0.04**	**19.2**
10-05-06	CHROMIUM DISSOLVED	0.13	0.01	9.7
11-02-24	**CHROMIUM DISSOLVED**	**0.1**	**0.06**	**59.1**
11-07-18	CHROMIUM DISSOLVED	0.23	0.05	24
11-10-13	**CHROMIUM DISSOLVED**	**0.2**	**0.03**	**16.6**
07-02-12	COLOUR TRUE	15.67	0.58	3.7
07-02-20	COLOUR TRUE	11.33	0.58	5.1
08-02-11	**COLOUR TRUE**	**13**	**2.65**	**20.4**
08-02-13	COLOUR TRUE	18.33	0.58	3.1
08-05-13	COLOUR TRUE	62	0	0
10-05-06	COLOUR TRUE	20.33	1.53	7.5
11-02-24	COLOUR TRUE	12.33	0.58	4.7
11-07-18	COLOUR TRUE	123.33	5.77	4.7
11-10-13	COLOUR TRUE	12	0	0
07-02-12	CONDUCTANCE_LAB (us/cm)	495.67	1.15	0.2
07-02-20	CONDUCTANCE_LAB	442.33	2.52	0.6
07-05-14	CONDUCTANCE_LAB	306	1	0.3
08-02-11	CONDUCTANCE_LAB	416.67	4.73	1.1
08-02-13	CONDUCTANCE_LAB	424	3.61	0.9
08-05-07	CONDUCTANCE_LAB	410	0	0
08-05-13	CONDUCTANCE_LAB	190	0	0
09-02-11	CONDUCTANCE_LAB	410	0	0
09-05-14	CONDUCTANCE_LAB	383.33	5.77	1.5
10-02-09	CONDUCTANCE_LAB	426.67	11.55	2.7
10-05-06	CONDUCTANCE_LAB	306.67	5.77	1.9
11-02-24	CONDUCTANCE_LAB	430	0	0
11-07-18	CONDUCTANCE_LAB	203.33	5.77	2.8
11-10-13	CONDUCTANCE_LAB	260	0	0

Continued…

Table A7.1. *Continued…*

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-20	COPPER DISSOLVED (µg/L)	0.65	0.02	2.7
07-05-14	COPPER DISSOLVED	0.47	0.02	3.6
08-02-11	COPPER DISSOLVED	0.47	0.04	7.9
08-02-13	COPPER DISSOLVED	0.45	0.06	13.5
08-05-07	**COPPER DISSOLVED**	**1.04**	**0.31**	**29.9**
08-05-13	COPPER DISSOLVED	2.52	0.21	8.1
09-02-11	COPPER DISSOLVED	0.42	0.04	10.3
09-05-14	COPPER DISSOLVED	0.4	0.03	6.4
10-02-09	**COPPER DISSOLVED**	**0.31**	**0.11**	**36.5**
10-05-06	COPPER DISSOLVED	0.72	0.01	1.3
11-02-24	COPPER DISSOLVED	0.52	0.01	2.1
11-07-18	COPPER DISSOLVED	2.76	0.29	10.5
11-10-13	COPPER DISSOLVED	0.66	0.06	8.8
07-02-12	FLUORIDE DISSOLVED (mg/L)	0.13	0	0
07-02-20	FLUORIDE DISSOLVED	0.13	0.01	4.6
07-05-14	FLUORIDE DISSOLVED	0.12	0	0
08-02-11	FLUORIDE DISSOLVED	0.14	0.01	4.2
08-02-13	FLUORIDE DISSOLVED	0.13	0	0
08-05-07	FLUORIDE DISSOLVED	0.14	0.02	10.7
08-05-13	FLUORIDE DISSOLVED	0.08	0.01	6.9
09-02-11	FLUORIDE DISSOLVED	0.17	0.01	3.5
09-05-14	FLUORIDE DISSOLVED	0.13	0	0
10-02-09	**FLUORIDE DISSOLVED**	**0.12**	**0.02**	**17.8**
10-05-06	FLUORIDE DISSOLVED	0.09	0	0
11-02-24	FLUORIDE DISSOLVED	0.13	0	0
11-07-18	FLUORIDE DISSOLVED	0.11	0	0
11-10-13	FLUORIDE DISSOLVED	0.1	0	0
07-02-12	HARDNESS TOTAL (CALCD.) CACO3 (mg/L)	210	0	0
07-02-20	HARDNESS TOTAL (CALCD.) CACO3	210	0	0
07-05-14	HARDNESS TOTAL (CALCD.) CACO3	156.67	5.77	3.7
08-02-11	HARDNESS TOTAL (CALCD.) CACO3	176.67	5.77	3.3
08-02-13	HARDNESS TOTAL (CALCD.) CACO3	156.67	5.77	3.7
08-05-07	HARDNESS TOTAL (CALCD.) CACO3	220	0	0
08-05-13	HARDNESS TOTAL (CALCD.) CACO3	75	1	1.3
09-02-11	HARDNESS TOTAL (CALCD.) CACO3	220	0	0
09-05-14	HARDNESS TOTAL (CALCD.) CACO3	190	0	0
10-02-09	HARDNESS TOTAL (CALCD.) CACO3	220	0	0
10-05-06	HARDNESS TOTAL (CALCD.) CACO3	133.33	5.77	4.3
11-02-24	HARDNESS TOTAL (CALCD.) CACO3	146.67	5.77	3.9
11-07-18	HARDNESS TOTAL (CALCD.) CACO3	96.67	2.08	2.2
11-10-13	HARDNESS TOTAL (CALCD.) CACO3	126.67	5.77	4.6
07-02-12	IRON DISSOLVED (mg/L)	0.16	0.01	3.7
07-02-20	IRON DISSOLVED	0.07	0	0
08-02-13	IRON DISSOLVED	0.34	0.02	4.4
08-05-13	IRON DISSOLVED	0.32	0.01	1.8
10-05-06	IRON DISSOLVED	0.07	0	0
11-02-24	**IRON DISSOLVED**	**0.18**	**0.03**	**14.2**
11-07-18	IRON DISSOLVED	0.21	0.02	9.5

Continued…

Table A7.1. *Continued…*

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-20	LEAD DISSOLVED (µg/L)	0.02	0	9.7
07-05-14	LEAD DISSOLVED	0.01	0	6.8
08-02-13	LEAD DISSOLVED	0.16	0.01	4.1
08-05-07	LEAD DISSOLVED	0.02	0	14.1
08-05-13	LEAD DISSOLVED	0.23	0	1.9
09-02-11	**LEAD DISSOLVED**	**0.01**	**0.01**	**48.4**
09-05-14	LEAD DISSOLVED	0.02	0	6.3
10-02-09	**LEAD DISSOLVED**	**0.02**	**0.03**	**134.6**
10-05-06	LEAD DISSOLVED	0.02	0	5.7
11-02-24	**LEAD DISSOLVED**	**0.06**	**0.01**	**20.7**
11-07-18	LEAD DISSOLVED	0.18	0.01	3.2
11-10-13	LEAD DISSOLVED	0.03	0	13.3
07-05-14	**MANGANESE DISSOLVED (mg/L)**	**0.01**	**0.01**	**43.4**
08-02-13	MANGANESE DISSOLVED	0.03	0	7.5
11-02-24	MANGANESE DISSOLVED	0.02	0	2.5
07-02-20	NICKEL DISSOLVED (µg/L)	0.09	0.03	39
08-02-11	NICKEL DISSOLVED	0.72	0.1	14.3
08-02-13	NICKEL DISSOLVED	0.55	0.03	6.3
08-05-13	NICKEL DISSOLVED	2.22	0.21	9.3
10-05-06	NICKEL DISSOLVED	0.24	0.03	13.9
11-02-24	NICKEL DISSOLVED	0.19	0.02	10.8
11-07-18	NICKEL DISSOLVED	2.59	0.09	3.3
11-10-13	NICKEL DISSOLVED	0.47	0.01	2.8
07-02-12	NITROGEN TOTAL KJELDAHL (TKN) (mg/L)	0.33	0.03	7.7
07-02-20	NITROGEN TOTAL KJELDAHL (TKN)	0.31	0.01	3.2
08-02-11	NITROGEN TOTAL KJELDAHL (TKN)	0.49	0.02	3.1
08-02-13	NITROGEN TOTAL KJELDAHL (TKN)	0.63	0.03	5.5
08-05-07	NITROGEN TOTAL KJELDAHL (TKN)	0.13	0.01	8.7
08-05-13	NITROGEN TOTAL KJELDAHL (TKN)	1.17	0.15	13.1
09-05-14	**NITROGEN TOTAL KJELDAHL (TKN)**	**0.1**	**0.05**	**46.6**
10-05-06	NITROGEN TOTAL KJELDAHL (TKN)	0.4	0.05	11.5
11-02-24	NITROGEN TOTAL KJELDAHL (TKN)	0.42	0.03	6
11-07-18	NITROGEN TOTAL KJELDAHL (TKN)	1.3	0	0
11-10-13	NITROGEN TOTAL KJELDAHL (TKN)	0.34	0.03	7.5
07-02-12	NITROGEN, NITRATE (mg/L)	0.28	0	0.4
07-02-20	NITROGEN, NITRATE	0.23	0	0.3
07-05-14	NITROGEN, NITRATE	0.07	0	2.1
08-02-11	**NITROGEN, NITRATE**	**0.22**	**0.06**	**29.3**
08-02-13	NITROGEN, NITRATE	0.2	0	1.2
08-05-07	NITROGEN, NITRATE	0.06	0	6.7
08-05-13	NITROGEN, NITRATE	0.06	0	2.5
09-02-11	NITROGEN, NITRATE	0.11	0	0
09-05-14	**NITROGEN, NITRATE**	**0.01**	**0**	**37.7**
10-02-09	NITROGEN, NITRATE	0.07	0	1.4
11-02-24	NITROGEN, NITRATE	0.24	0	0
11-07-18	**NITROGEN, NITRATE**	**0.04**	**0.01**	**19.7**
08-02-11	**NITROGEN, NITRITE**	**0.01**	**0.01**	**74.2**
08-02-13	NITROGEN, NITRITE	0	0	0

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Table A7.1. *Continued…*

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-12	PH (LAB)	8.2	0.01	0.1
07-02-20	PH (LAB)	8.13	0.01	0.1
07-05-14	PH (LAB)	8.18	0.01	0.1
08-02-11	PH (LAB)	8.1	0.04	0.5
08-02-13	PH (LAB)	7.98	0.06	0.7
08-05-07	PH (LAB)	8.23	0.06	0.7
08-05-13	PH (LAB)	8.03	0.06	0.7
09-02-11	PH (LAB)	8.23	0.03	0.3
09-05-14	PH (LAB)	8.11	0.03	0.4
10-02-09	PH (LAB)	8.13	0.01	0.1
10-05-06	PH (LAB)	8.1	0.06	0.8
11-02-24	PH (LAB)	7.96	0.01	0.1
11-07-18	PH (LAB)	8.07	0.01	0.1
11-10-13	PH (LAB)	7.73	0.02	0.3
07-02-12	PHOSPHORUS DISSOLVED (mg/L)	0.02	0	7.4
07-02-20	PHOSPHORUS DISSOLVED	0.01	0	7.5
07-05-14	**PHOSPHORUS DISSOLVED**	**0.01**	**0.01**	**91.8**
08-02-11	PHOSPHORUS DISSOLVED	0.02	0	3.5
08-02-13	PHOSPHORUS DISSOLVED	0.02	0	15
08-05-07	PHOSPHORUS DISSOLVED	0	0	0
08-05-13	PHOSPHORUS DISSOLVED	0.02	0	4.9
10-02-09	PHOSPHORUS DISSOLVED	0	0	15.7
10-05-06	PHOSPHORUS DISSOLVED	0.01	0	6.9
11-02-24	PHOSPHORUS DISSOLVED	0.02	0	3.3
11-07-18	PHOSPHORUS DISSOLVED	0.02	0	7.4
11-10-13	PHOSPHORUS DISSOLVED	0.01	0	0
07-02-12	PHOSPHORUS TOTAL (mg/L)	0.03	0	4.2
07-02-20	PHOSPHORUS TOTAL	0.01	0	8.4
07-05-14	PHOSPHORUS TOTAL	0.03	0	9.1
08-02-11	PHOSPHORUS TOTAL	0.02	0	5
08-02-13	PHOSPHORUS TOTAL	0.03	0	0
08-05-07	PHOSPHORUS TOTAL	0.04	0	5.5
08-05-13	PHOSPHORUS TOTAL	0.29	0.01	3.4
09-02-11	PHOSPHORUS TOTAL	0.01	0	10.8
09-05-14	PHOSPHORUS TOTAL	0.02	0	10.8
10-02-09	PHOSPHORUS TOTAL	0.01	0	14.3
10-05-06	PHOSPHORUS TOTAL	0.02	0	7.1
11-02-24	PHOSPHORUS TOTAL	0.02	0	0
11-07-18	PHOSPHORUS TOTAL	0.28	0.01	2
11-10-13	PHOSPHORUS TOTAL	0.01	0	7.7
07-05-14	**RESIDUE NONFILTERABLE (TSS) (mg/L)**	**94.67**	**26.1**	**27.6**
08-02-11	**RESIDUE NONFILTERABLE (TSS)**	**3**	**1**	**33.3**
08-02-13	**RESIDUE NONFILTERABLE (TSS)**	**7.67**	**2.08**	**27.2**
08-05-07	RESIDUE NONFILTERABLE (TSS)	50.67	2.52	5
08-05-13	RESIDUE NONFILTERABLE (TSS)	283.33	11.55	4.1
09-02-11	**RESIDUE NONFILTERABLE (TSS)**	**20**	**4.58**	**22.9**
09-05-14	RESIDUE NONFILTERABLE (TSS)	27.67	2.08	7.5
10-02-09	RESIDUE NONFILTERABLE (TSS)	15	1.73	11.5
10-05-06	RESIDUE NONFILTERABLE (TSS)	9.33	0.58	6.2
11-02-24	RESIDUE NONFILTERABLE (TSS)	3.67	0.58	15.7
11-07-18	RESIDUE NONFILTERABLE (TSS)	333.33	25.17	7.5
11-10-13	RESIDUE NONFILTERABLE (TSS)	7	0	0

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Table A7.1. *Continued…*

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-20	SELENIUM DISSOLVED (µg/L)	0.25	0.04	14.7
08-02-11	SELENIUM DISSOLVED	0.34	0.02	5.7
08-02-13	SELENIUM DISSOLVED	0.25	0.02	6.3
08-05-07	SELENIUM DISSOLVED	0.53	0.07	14
08-05-13	**SELENIUM DISSOLVED**	**0.22**	**0.12**	**53.4**
09-02-11	SELENIUM DISSOLVED	0.46	0.05	10.4
09-05-14	**SELENIUM DISSOLVED**	**0.2**	**0.09**	**45.1**
10-02-09	SELENIUM DISSOLVED	0.44	0.02	3.9
11-02-24	SELENIUM DISSOLVED	0.19	0	2.5
11-07-18	SELENIUM DISSOLVED	0.23	0.03	12.7
11-10-13	SELENIUM DISSOLVED	0.22	0.02	10.4
07-02-12	SODIUM DISSOLVED/FILTERED (mg/L)	25.5	0.17	0.7
07-02-20	SODIUM DISSOLVED/FILTERED	19.3	0	0
07-05-14	SODIUM DISSOLVED/FILTERED	1.73	0.06	3.3
08-02-11	SODIUM DISSOLVED/FILTERED	22.13	1.62	7.3
08-02-13	SODIUM DISSOLVED/FILTERED	32.37	0.29	0.9
08-05-07	SODIUM DISSOLVED/FILTERED	2.33	0.06	2.5
08-05-13	SODIUM DISSOLVED/FILTERED	9.3	0	0
09-02-11	SODIUM DISSOLVED/FILTERED	2.3	0	0
09-05-14	SODIUM DISSOLVED/FILTERED	1.9	0	0
10-02-09	SODIUM DISSOLVED/FILTERED	2.3	0	0
10-05-06	SODIUM DISSOLVED/FILTERED	11	0	0
11-02-24	SODIUM DISSOLVED/FILTERED	30.67	2.08	6.8
11-07-18	SODIUM DISSOLVED/FILTERED	5.87	0.15	2.6
11-10-13	SODIUM DISSOLVED/FILTERED	6.73	0.15	2.3
07-02-12	SULPHATE DISSOLVED (mg/L)	64.9	0.72	1.1
07-02-20	SULPHATE DISSOLVED	52.8	1.45	2.8
07-05-14	SULPHATE DISSOLVED	51.37	0.76	1.5
08-02-11	SULPHATE DISSOLVED	50.93	1.21	2.4
08-02-13	SULPHATE DISSOLVED	38.93	1.67	4.3
08-05-07	SULPHATE DISSOLVED	86.67	0.58	0.7
08-05-13	SULPHATE DISSOLVED	15	0	0
09-02-11	SULPHATE DISSOLVED	97	1	1
09-05-14	SULPHATE DISSOLVED	84	1	1.2
10-02-09	SULPHATE DISSOLVED	97	0	0
10-05-06	SULPHATE DISSOLVED	37	0	0
11-02-24	SULPHATE DISSOLVED	41.33	0.58	1.4
11-07-18	SULPHATE DISSOLVED	14	0	0
11-10-13	SULPHATE DISSOLVED	29.67	0.58	1.9
07-02-12	TOTAL DISSOLVED SOLIDS (CALCD.)	304.67	0.58	0.2
07-02-20	TOTAL DISSOLVED SOLIDS (CALCD.)	263.67	4.51	1.7
07-05-14	TOTAL DISSOLVED SOLIDS (CALCD.)	177.67	0.58	0.3
08-02-11	TOTAL DISSOLVED SOLIDS (CALCD.)	251.33	4.93	2
08-02-13	TOTAL DISSOLVED SOLIDS (CALCD.)	251.67	5.13	2
08-05-07	TOTAL DISSOLVED SOLIDS (CALCD.)	240	0	0
08-05-13	TOTAL DISSOLVED SOLIDS (CALCD.)	110	0	0
09-02-11	TOTAL DISSOLVED SOLIDS (CALCD.)	256.67	5.77	2.2
09-05-14	TOTAL DISSOLVED SOLIDS (CALCD.)	230	0	0
10-02-09	TOTAL DISSOLVED SOLIDS (CALCD.)	258.67	2.08	0.8
10-05-06	TOTAL DISSOLVED SOLIDS (CALCD.)	176.67	5.77	3.3
11-02-24	TOTAL DISSOLVED SOLIDS (CALCD.)	246.67	5.77	2.3
11-07-18	TOTAL DISSOLVED SOLIDS (CALCD.)	120	0	0
11-10-13	TOTAL DISSOLVED SOLIDS (CALCD.)	160	0	0

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Table A7.1. *Continued…*

Sample Date	Parameter	Mean	Standard Deviation	Relative Standard Deviation (%)
07-02-12	TURBIDITY (NTU)	2.4	0.36	15
07-02-20	**TURBIDITY**	**1.8**	**0.61**	**33.8**
07-05-14	**TURBIDITY**	**21.83**	**5.35**	**24.5**
08-02-11	TURBIDITY	1.77	0.31	17.3
08-02-13	TURBIDITY	5.1	0.1	2
08-05-07	**TURBIDITY**	**36.67**	**7.37**	**20.1**
08-05-13	TURBIDITY	180	10	5.6
09-02-11	TURBIDITY	8.53	0.58	6.8
09-05-14	TURBIDITY	20.67	1.15	5.6
10-02-09	TURBIDITY	4.87	0.4	8.3
10-05-06	TURBIDITY	5.47	0.29	5.3
11-02-24	TURBIDITY	3.33	0.15	4.6
11-07-18	**TURBIDITY**	**186.67**	**61.1**	**32.7**
11-10-13	**TURBIDITY**	**7.47**	**1.7**	**22.8**
07-02-20	URANIUM DISSOLVED (µg/L)	0.63	0	0.2
07-05-14	URANIUM DISSOLVED	0.47	0.01	3
08-02-11	URANIUM DISSOLVED	0.54	0	0.4
08-02-13	URANIUM DISSOLVED	0.36	0	0.7
08-05-07	URANIUM DISSOLVED	0.72	0.01	1.8
08-05-13	URANIUM DISSOLVED	0.33	0.01	4.2
09-02-11	URANIUM DISSOLVED	0.65	0.01	1.2
09-05-14	URANIUM DISSOLVED	0.64	0.03	4.5
10-02-09	URANIUM DISSOLVED	0.66	0.01	2
10-05-06	URANIUM DISSOLVED	0.52	0.01	2
11-02-24	URANIUM DISSOLVED	0.31	0	1.2
11-07-18	URANIUM DISSOLVED	0.39	0.01	2.9
11-10-13	URANIUM DISSOLVED	0.37	0.02	4.5
07-02-20	VANADIUM DISSOLVED (µg/L)	0.17	0	1.8
07-05-14	**VANADIUM DISSOLVED**	**0.04**	**0.01**	**20.3**
08-02-11	VANADIUM DISSOLVED	0.18	0.01	3.3
08-02-13	VANADIUM DISSOLVED	0.55	0.02	4.1
08-05-07	VANADIUM DISSOLVED	0.13	0.02	14.9
08-05-13	VANADIUM DISSOLVED	0.76	0.09	11.9
09-02-11	VANADIUM DISSOLVED	0.08	0.01	15.7
09-05-14	VANADIUM DISSOLVED	0.11	0.01	11.8
10-05-06	VANADIUM DISSOLVED	0.2	0.01	4.8
11-02-24	VANADIUM DISSOLVED	0.16	0.01	9.1
11-07-18	VANADIUM DISSOLVED	0.58	0.02	2.8
11-10-13	VANADIUM DISSOLVED	0.16	0	3.1
07-02-20	ZINC DISSOLVED (µg/L)	3.36	0.19	5.5
07-05-14	**ZINC DISSOLVED**	**2.53**	**1.24**	**49.2**
08-02-11	ZINC DISSOLVED	1.29	0.39	30
08-02-13	ZINC DISSOLVED	3.68	0.49	13.4
08-05-07	**ZINC DISSOLVED**	**2.81**	**2.87**	**102.1**
08-05-13	ZINC DISSOLVED	1.45	0.24	16.7
09-02-11	**ZINC DISSOLVED**	**1.58**	**0.4**	**25.3**
09-05-14	ZINC DISSOLVED	0.87	0.05	5.3
10-02-09	**ZINC DISSOLVED**	**0.76**	**0.3**	**39.7**
10-05-06	ZINC DISSOLVED	1.22	0.09	7.4
11-02-24	ZINC DISSOLVED	1.65	0.11	6.9
11-07-18	ZINC DISSOLVED	0.8	0.13	16.7
11-10-13	**ZINC DISSOLVED**	**0.8**	**0.17**	**21.4**

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