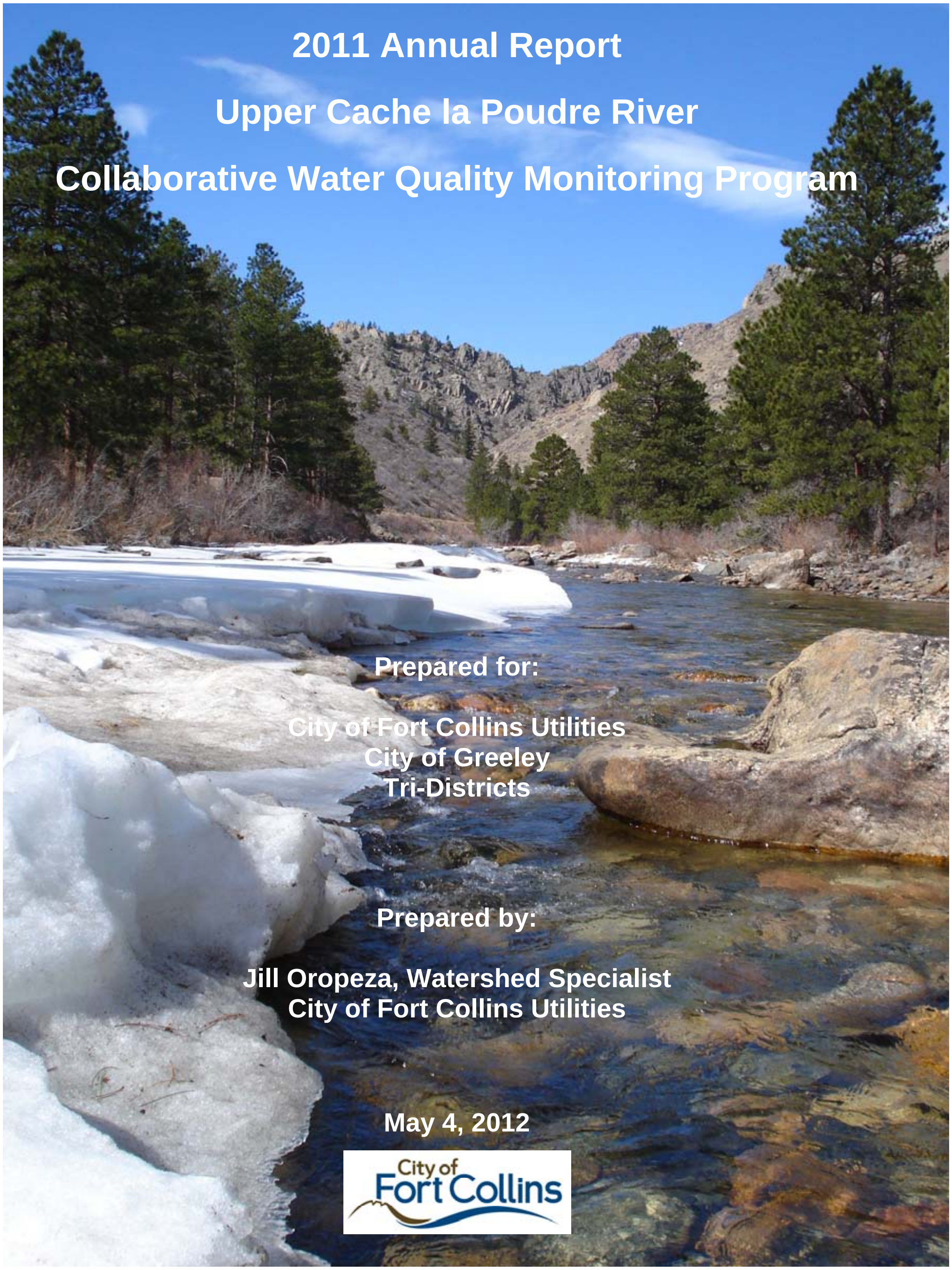

2011 Annual Report

Upper Cache la Poudre River

Collaborative Water Quality Monitoring Program

Prepared for:

City of Fort Collins Utilities
City of Greeley
Tri-Districts

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City of Fort Collins

EXECUTIVE SUMMARY

Upper Cache la Poudre Collaborative Water Quality Monitoring Program

Sample collection for the Upper Cache la Poudre (CLP) Collaborative Water Quality Monitoring Program consists of eleven sampling events between April and November at ten sites on the Mainstem CLP and nine sites on the North Fork, including Seaman Reservoir. Water samples are analyzed for a total of up to 39 parameters.

The objective of this collaborative water quality monitoring program is to assist the City of Fort Collins, the City of Greeley and the Tri-Districts in meeting current and future drinking water treatment goals by reporting current water quality conditions and trends within the Upper CLP watershed.

Scope of 2011 Annual Report

The 2011 annual report summarizes the hydrologic and water quality data collected as part of the Upper CLP Collaborative Water Quality Monitoring Program and provides a comparison with water quality information from the years 2008 – 2010. The report also summarizes significant events, issues of concern, and results from special studies.

Six key sites were identified that are considered representative of conditions on the Mainstem and North Fork CLP. The discussion of results focuses primarily on these six key sites as well as Seaman Reservoir, although data for all sites were analyzed and significant events and trends are also included in the discussion. Summary graphs for all parameters and locations are presented in a separate attachment (Attachment 5).

Significant Events, Issues of Concern & Special Studies

- **Summer Attached Algae Bloom**. As observed in 2009 and 2010, an attached algae bloom occurred during the summer of 2011 in the middle reaches of the Mainstem Poudre River. Dense mats of dried and live filamentous green algae (*Ulothrix* sp.) were observed in the area. Areas colonized by the invasive diatom, *Didymosphenia geminata,* were also observed. Sampling results did not identify any sources of elevated nutrients that may have triggered the algal bloom. In addition, treatment plants did not experience any taste and odor (T&O) issues during this time, suggesting that potential off-taste and odor compounds were either not strongly associated with this algae bloom, or were adequately volatilized, degraded, and/or diluted prior to reaching the raw water intakes.
- **Winter/Spring Geosmin Episode.** Sampling for geosmin, a naturally occurring organic compound that imparts an earthy odor to water, began following an outbreak that occurred during the winter of 2009-2010 in raw Poudre River water at the Fort Collins Water Treatment Facility (FCWTF). The goal of sampling efforts was to identify the source of high geosmin concentrations and the factors that influence geosmin production on the Upper CLP. Monthly geosmin sampling efforts began in July of 2010 following a series of reconnaissance sampling events that identified the area of high geosmin. This initial sampling period continued through April 2011 and

is referred to as Phase I monitoring. In contrast to the winter months of 2010, geosmin concentrations in the raw Poudre River water supply at the FCWTF remained near or below odor threshold of 4 nanograms per liter (ng/L) or 4 parts per trillion (ppt) for much of the remainder of 2010 and all of 2011. Phase II sampling began in May 2011, and incorporated changes in the sampling program, including a reconfiguration of monitoring sites and the addition of quantitative area-based periphyton sampling methods (versus qualitative samples for ranked relative abundance).

The results of Phase I geosmin monitoring were documented in the manuscript, "Navigating uncharted waters: Assessing Geosmin Occurrence in a Colorado Rocky Mountain Source Water River" (Oropeza, Billica and Elmund, 2011) that was presented at the AWWA Water Quality Technology Conference in Phoenix, AZ, November 13-17, 2011(Appendix 7).

With the exception of total phosphorus (Total P), a full review of Phase I & II results in 2011 did not identify any point sources of nutrient or fecal contamination or establish significant links between nutrients and geosmin occurrence. There was a significant, negative correlation between Total P and geosmin. This relationship appears to result from seasonal trends in runoff, rather than the stimulation (or suppression) of cyanobacteria growth. It is proposed that the high stream flows, which correlate to high Total P concentrations, have a dilution effect on geosmin concentrations, resulting in a negative correlation that can be seen across all sites. No up- to down-stream trends in geosmin concentrations were observed.This suggests that geosmin production is regulated by site-specific conditions that affect the local cyanobacteria populations. Phase II monitoring will continue in 2012.

- **Northern Water Collaborative Emerging Contaminant Study.** The Cities of Greeley and Fort Collins have participated in the Northern Water collaborative emerging contaminant study since 2009 to determine the presence of pharmaceuticals, pesticides, hormones, and phenolic endocrine disrupting compounds in waters of the Colorado- Big Thompson system. Currently, samples are screened for 192 compounds. Two sites in the Upper Poudre Watershed have been included in this study: Poudre above North Fork (PNF) and North Fork at gage below Seaman Reservoir (NFG). These sites were sampled six times and five times, respectively through 2011. A detection of the recreational insecticide DEET of 20.8 ng/L was reported for the August 2011 sampling event at PNF. In addition, very low levels of progesterone were detected in the June 2009 sample (0.1 ng/L) and the June 2010 sample (0.4 ng/L) from the Poudre above North Fork site. However, 0.1 ng/L is the method reporting limit for progesterone and caution must be exercised in terms of assigning any level of importance to results at or near this extremely low value. To date, no compounds have been detected in the North Fork below Seaman Reservoir site.

- **Mountain Pine Beetle (MPB) Infestation.** In response to decreased availability of healthy trees to attack, the expansion of the MPB infestation in Larimer County slowed significantly over the previous two years. During 2011, the MPB continued its eastward spread into lower elevation Lodgepole and Ponderosa pine stands along the Northern Colorado Front Range, with some continued mid-elevation forest mortality observed. The Upper Cache la Poudre watershed is located within an area of high forest mortality.

- **Upper CLP Wildfire Watershed Assessment.** In early 2012, the City of Fort Collins and City of Greeley met with US Forest Service to explore the opportunities that were identified in the 2010 Cache la Poudre Wildfire Watershed Assessment to mitigate the risks of potential wildfires on water quality in portions of the Upper CLP watershed. No new opportunities to protect water quality in the Poudre River were identified from a fuels mitigation standpoint, due to current limits imposed by topography, the planning process, available funding and competing agency priorities.

Significant Results

Mainstem and North Fork

- Peak 2011 stream flows on the Mainstem were lower than the previous year, despite a near-record snowpack and the potential for extremely high runoff . The lower peak stream flows in 2011 were due to a more prolonged period of gradual snowmelt, rather than the abrupt melt that was seen in 2010.
- In general, water from the North Fork basin was warmer with higher levels of dissolved constituents than the Mainstem, which was reflected by relatively elevated hardness, conductivity, alkalinity, and concentrations of major ions. In both drainages, concentrations of dissolved constituents, temperature, and conductivity increased with decreasing elevation. Across all sites, minimum values occurred during periods of high flow due to the diluting effect of snowmelt runoff.
- Peaks in turbidity were observed at all sites during spring run-off. In 2011, turbidity values on the Mainstem were similar to the North Fork sites, as in 2010. Large late-season spikes in turbidity were also seen at NFG and were due to bottom releases from Seaman Reservoir.
- Peak total organic carbon (TOC) concentrations occurred during peak run-off across the watershed. The 2011 peak TOC value was 11 mg/L on June 6, 2011 at the two lowest elevation sites, Poudre above the North Fork (PNF) and Poudre at the Bellvue Diversion (PBD). 2011 peak TOC concentrations were lower than in 2010 (13.9 mg/L at Joe Wright Creek (JWC)), but similar to other years. As seen in previous years, TOC concentrations on the Mainstem decreased to low levels following runoff (< 3 mg/L), while the North Fork exhibited relatively elevated TOC concentrations during periods of low flows (> 4 mg/L).
- As in previous years, Mainstem nutrient concentrations were generally low during non-runoff times of the year. Nitrate concentrations were consistently higher at Poudre above Joe Wright (PJW) than at lower-elevation sites on the Mainstem. 2011 peak nitrate concentrations at PJW were significantly lower than in 2010, but within the range seen in other years. A late season spike in TKN and nitrate concentrations was observed at all Mainstem sites on 11/1/11.

- The North Fork generally had higher concentrations of total phosphorus, ortho-phosphate, and Total Kjeldahl Nitrogen (TKN) than Mainstem sites during non-runoff times of the year. The influence of Seaman Reservoir and the 2011 fluctuations in surface elevation on downstream water quality were evident throughout the year. As seen in previous years, Seaman Reservoir contributed elevated concentrations of nutrients, turbidity, total suspended solids to the North Fork as measured at the stream gage below Seaman Reservoir (NFG).
- *Giardia* was more abundant than *Cryptosporidium* at both the Mainstem and North Fork sites. *Giardia* concentrations were similar to the previous three years. *Cryptosporidium* was detected only twice at very low concentrations on the Mainstem (PNF) in 2011; concentrations were similar to previous years. No trends in levels of either pathogen were observed at any Mainstem or North Fork sites.
- *E.coli* and total coliform concentrations on the Mainstem (PNF) and North Fork sites were generally lower than in 2010, but similar to previous years. The North Fork consistently experienced much higher concentrations of these indicators of pathogenic bacteria than the Mainstem (PNF). No consistent relationships were observed between *E.coli* or total coliform concentrations at NFG and in Seaman Reservoir.

Seaman Reservoir

- The 2011 repair work on the head gates of the Seaman Reservoir outlet structure and the associated reservoir operations affected water quality, although the most notable effects occurred following the complete drawdown in August. Water levels fluctuated dramatically throughout the year; an initial drawdown occurred in mid-April (50 ft), followed by a period of refilling, and a subsequent full drawdown in August (28 ft) to accommodate construction activities.
- Seaman Reservoir did not completely thermally stratify during 2011 as it usually does. There was a brief period during the summer months of June to August where some thermal stratification was evident and was accompanied by decreased oxygen concentrations and pH in the lower depths. Like previous years, the hypolimnion experienced a period of near-zero dissolved oxygen (D.O.) concentrations during early August.
- Elevated turbidity and nutrient concentrations (except ortho-phosphate) were especially evident in Seaman Reservoir during the fall following the full drawdown of the reservoir. Prior to the drawdown, concentrations were within the range of values seen in previous years.
- TOC concentrations in Seaman Reservoir were lower than the previous year. A gradual, but significantly increasing trend in TOC concentrations was observed in Seaman Reservoir from 2007 through 2010. It will not be known how the 2011 reservoir operations will affect this longer-term trend until subsequent years' data are available.

- Based on 2011 chlorophyll-a, Total P and secchi depth values, and consistent with 2010 findings, the trophic status of Seaman Reservoir can be characterized as mesotrophic to eutrophic.
- Geosmin samples were not collected within Seaman Reservoir in 2011due to construction activities. Geosmin samples were, however, collected on the North Fork below Seaman Reservoir (NFG) where concentrations ranged from 5.9 to 36.2 ng/L. The peak concentration was observed on 9/11/11, when concentrations at NFG were nearly wholly comprised of concentrated bottom water from Seaman Reservoir. All observed concentrations were above the odor threshold of 4 ng/L. These high geosmin concentrations from the North Fork were sufficiently diluted by the relatively large volume Mainstem flows at Greeley-Bellvue Diversion (PBD) and were not readily detected in the City of Greeley's finished water.
- Blue-green algae were prevalent in Seaman Reservoir during August, but at a lower density than in 2010. During August, 14% of the blue-green algal density was comprised of known geosmin-producing genera.

TABLE OF CONTENTS

EXECUTIVE SUMMARY iii

TABLE OF CONTENTS ix

LIST OF TABLES xi

LIST OF FIGURES xi

LIST OF ABBREVIATIONS & ACRONYMS xv

1.0 INTRODUCTION
- 1.1 Background 1
- 1.2 Watershed Description and Sampling Locations 2
- 1.3 Sampling Schedule and Parameters 3
- 1.4 Sample Collection and Analysis 3
- 1.5 Scope of 2010 Annual Report 3

2.0 SIGNIFICANT EVENTS, ISSUES OF CONCERN & SPECIAL STUDIES **5**
- 2.1 Attached Algae Bloom in Poudre River 5
- 2.2 Poudre River Geosmin Episode 7
- 2.3 Colorado's 2010 Section 303(d) and Monitoring & Evaluation (M&E) Lists 13
- 2.4 Northern Water Collaborative Emerging Contaminant Study 15
- 2.5 Mountain Pine Beetle in Upper CLP Watershed 17
- 2.6 Upper CLP Wildfire/Watershed Assessment 19
- 2.7 Assessment of Existing/Abandoned Mine Sites as Potential Sources of Contamination 21

3.0 UPPER CACHE LA POUDRE RIVER RESULTS **23**
- 3.1 Hydrology 23
  - 3.1.1 Mainstem 25
  - 3.1.2 North Fork 26
- 3.2 Water Temperature 28
- 3.3 General Parameters: Conductivity, Hardness, Alkalinity, pH and Turbidity 28
  - 3.3.1 Conductivity, Hardness and Alkalinity 28
  - 3.3.2 pH 29
  - 3.3.3 Turbidity 29
- 3.4 Total Organic Carbon (TOC) 32
- 3.5 Nutrients 34
  - 3.5.1 North Fork 34
  - 3.5.2 Mainstem 35
- 3.6 Metals 41
- 3.7 Pathogens: *Cryptosporidium* and *Giardia* 44

3.8 Total Coliforms and *E. coli* 45

4.0 SEAMAN RESERVOIR RESULTS 47
4.1 Reservoir Operations 47
4.2 Temperature, Dissolved Oxygen, pH and Conductivity Profiles 47
4.3 General Parameters: Hardness and Alkalinity 51
4.4 Turbidity, Chlorophyll-a and Secchi Depth 53
4.5 Nutrients 55
4.5.1 Seaman Reservoir Trophic Status 61
4.6 Total Organic Carbon (TOC) 63
4.7 Total Coliforms and *E. coli* 65
4.8 Phytoplankton and Geosmin 67

5.0 SUMMARY 73

6.0 REFERENCES 75

ATTACHMENT 1 77
Land Use comparison of the North Fork and Mainstem CLP

ATTACHMENT 2 79
Upper CLP Collaborative Water Quality Monitoring Program Sampling Sites

ATTACHMENT 3 81
Upper CLP Collaborative Water Quality Monitoring Program Parameter List

ATTACHMENT 4 83
Upper CLP Collaborative Water Quality Monitoring Program 2010 Sampling Plan

ATTACHMENT 5 85
Analytical methods, reporting limits, sample preservation and sample holding times

ATTACHMENT 6 87
2011 Seaman Reservoir Phytoplankton Data

ATTACHMENT 7 107
2011 Upper CLP Collaborative Water Quality Monitoring Program Graphical Summary

ATTACHMENT 8 185
Navigating Uncharted Waters: Assessing Geosmin Occurrence in a Colorado Rocky Mountain Source Water River. J. Oropeza, J. Billica and K. Elmund. *In: Proceedings of the 2011 c American Water Works Association AWWA WQTC Conference* (Nov. 13-17, 2011, Phoenix, AZ)

LIST OF TABLES

Table 1. Summary of Upper CLP segments on Colorado's 2010 Section 303(d) List of Impaired Waters and 2010 Monitoring and Evaluation (M&E) List....................................13

Table .2. 2011 Tributary contribution by month to the Mainstem Cache la Poudre River above the Munroe Tunnel 26

Table 3. Comparison of annual median Total N concentrations (ug/L) at Mainstem CLP and North Fork CLP sites to the 2012 CDPHE/WQCD proposed interim TN value of 1,250 ug/L 37

Table 4. Comparison of annual median Total P concentrations (ug/L) at Mainstem CLP and North Fork CLP sites to the 2012 CDPHE/WQCD proposed interim TP value of 110 ug/L 37

Table 5. Comparison of Seaman Reservoir annual summer average Total N, Total P and Chlorophyll-a values to 2012 CDPHE/WQCD proposed standards for nutrients 57

LIST OF FIGURES

Figure 1. Map of the Upper CLP collaborative water quality monitoring network. 2

Figure 2. Periphyton collected from a river cobble using a fixed-area sampler 5

Figure 3 (a-c). Attached algae on the Mainstem of the Poudre River. 6

Figure 4. Geosmin concentrations in raw Poudre River water supply at the FCWTF from 2003-2011 7

Figure 5. Map of 2010-2011 Poudre River geosmin sampling sites (Phase I & II) 8

Figure 6. 2010-2011 geosmin concentrations at key locations on the Poudre River 9

Figures 7. Timeline of geosmin monitoring activities on the Poudre River 9

Figure 8. Correlation between geosmin and Total P on the Mainstem CLP from 2008-2011...10

Figure 9. Geosmin, Total P and Stream Flow on the Mainstem CLP from 2009-2011 11

Figure 10 (a-h). Nutrient, *E.coli* and total coliform concentrations at Upper CLP geosmin monitoring sites from 2010-2011..12

Figure 11. Upper CLP segments on Colorado's 2010 Section 303(d) List of Impaired Waters and 2010 Monitoring & Evaluation (M&E) List................................14

Figure 12. 2011 image of mountain pine beetle (MPB) mortality in the Mainstem CLP looking south toward Chambers Lake 17

Figure 13. Mountain Pine Beetle(MPB) activity in the North Fork and Mainstem Cache la Poudre, Big Thompson, Horsetooth and Three Lakes Watersheds from 2007 through 2011. 18

Figure 14. Locations of existing or abandoned mining claims in the North Fork and Mainstem Cache la Poudre River watersheds as identified in the 2004 CDPHE Source Water Assessments for the City of Fort Collins and City of Greeley..21
Figure 15. 2008 – 2011 Daily average stream flow at key Upper CLP monitoring sites .24
Figure 16. 2011 Daily average stream flow at key Upper CLP monitoring sites 24
Figure 17. 2011 Tributary contributions by month to the Mainstem Cache la Poudre above the Munroe Tunnel 26
Figure 18. 2008-2011 Daily average stream flow at NFL and NFG................................27
Figure 19. Proportion of average Mainstem and North Fork CLP flows at PBD during May and June from 2008 to 2011 27
Figure 20. Water temperature at key Upper CLP monitoring sites..................................28
Figure 21 (a –e). General water quality parameters at key Upper CLP monitoring sites: Conductance, Hardness, Alkalinity, pH and Turbidity..........................30
21.a. Conductance...30
21.b. Hardness...30
21.c. Alkalinity..31
21.d. pH...31
21.e. Turbidity...31
Figure 22. TOC concentrations at key Upper CLP monitoring sites 32
Figure 23. 2011 Seasonal average TOC concentrations at key Upper CLP monitoring sites 33
Figure 24 (a-b). Mean and median concentrations of Total P and ortho-phosphate for the North Fork tributaries, SCM, PCM, RCM and NFL for 2008-2011 35
Figure 25 (a-g). Nutrient concentrations at key Upper CLP monitoring sites..................38
25.a. Ammonia (NH_3-N) 38
25.b. Nitrite (NO_2-N)..38
25.c. Nitrate (NO_3-N) 39
25.d. Total Kjeldahl Nitrogen (TKN) 39
25.e. Total Nitrogen (TN) 40
25.f. Ortho-phosphate (PO_4) 40
25.g. Total Phosphorus (TP) 41
Figure 26 (a-i). Metals concentrations at PNF and NFG..43
Figure 27. Concentrations of *Giardia* on Mainstem and North Fork CLP 44
Figure 28. Concentrations of *Cryptosporidiu*m on Mainstem and North Fork CLP 45
Figure 29. Concentrations of total coliforms at key Upper CLP monitoring sites............46
Figure 30. Concentrations of *E. coli* at key Upper CLP monitoring sites.........................46
Figure 31. 2011 water levels in Seaman Reservoir 47
Figure 32 (a-d). 2011 Seaman Reservoir Profiles...49
32.a. Temperature 49

32.b. Dissolved Oxygen....49
32.c. pH....50
32.d. Conductance....50

Figure 33. Dissolved oxygen concentrations at the top, middle and bottom of Seaman Reservoir....51

Figure 34 (a-b). General water quality parameters at Seaman Reservoir: Hardness and Alkalinity....52
34.a. Hardness....52
34.b. Alkalinity....52

Figure 35. Turbidity in Seaman Reservoir....53

Figure 36. Chlorophyll-a concentrations in Seaman Reservoir....54

Figure 37. Secchi depth in Seaman Reservoir....54

Figure 38. Comparison of secchi depth, turbidity and chlorophyll-a concentrations in Seaman Reservoir....55

Figure 39 (a-g). Nutrient concentrations in Seaman Reservoir....57
39.a. Ammonia (NH_3-N)....57
39.b. Nitrate (NO_3-N)....58
39.c. Nitrite (NO_2-N)....58
39.d. Total Kjeldahl Nitrogen (TKN)....59
39.e. Total Nitrogen (TN)....59
39.f. Ortho-phosphate (PO_4)....60
39.g. Total Phosphorus (TP)....60

Figure 40. Comparison of nitrate (NO_3-N)concentrations in Seaman Reservoir, upstream at NFL and downstream at NFG....61

Figure 41. Carlson's Trophic State Index (TSI) values for chlorophyll-a, secchi depth and total P in Seaman Reservoir....62

Figure 42. Plot of chlorophyll-a versus total P using data collected at 1m in Seaman Reservoir from 2007 to 2010....63

Figure 43. TOC concentrations in Seaman Reservoir....63

Figure 44. Comparison of TOC concentrations at NFL, Seaman Reservoir, and NFG....64

Figure 45. Plot of Chlorophyll-a versus TOC using data collected at 1m in Seaman Reservoir from 2008 to 2011....64

Figure 46. Total Coliforms at NFL, in Seaman Reservoir and at NFG....66

Figure 47. Concentrations of *Escherichia coli (E. coli)* at NFL, in Seaman Reservoir and at NFG....66

Figure 48. Phytoplankton densities at the top of Seaman Reservoir in 2010-2011....68

Figure 49. Phytoplankton densities at the bottom of Seaman Reservoir in 2010-2011....68

Figure 50 (a-b). Relative abundance of phytoplankton in top of Seaman Reservoir in 2010-2011....69

Figure 51 (a-b). Relative abundance of phytoplankton at the bottom of Seaman Reservoir in 2010-2011 70
Figure 52. Snowpack conditions on the Michigan Ditch, near Cameron Pass in the Poudre River Canyon on April 19, 2011 73

LIST OF ABBREVIATIONS & ACRONYMS

#/100 mL	number per 100 milliliters
%	percent
Ag	Silver
BMR	Barnes Meadow Outflow (routine monitoring site)
Ca	Calcium
Cd	Cadmium
CDPHE	Colorado Department of Public Health and Environment
CDWR	Colorado Division of Water Resources
CEC	Contaminant of Emerging Concern
cells/mL	cells per milliliter
cfs	cubic feet per second
CHR	Chambers Lake Outflow (routine monitoring site)
Cl	Chloride
CLP	Cache la Poudre River
Cr	Chromium
Cu	Copper
CU	University of Colorado, Boulder
cysts/L	cysts per liter
D.O.	Dissolved Oxygen
DBP	Disinfection By-Product
DOC	Dissolved Organic Carbon
EDC	Endocrine Disrupting Chemical
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FCWQL	Fort Collins Water Quality Lab
FCWTF	Fort Collins Water Treatment Facility
Fe	Iron
GPS	Global Positioning System
HSWMP	Halligan-Seaman Water Management Project
JWC	Joe Wright Creek above the Poudre River (routine monitoring site)
K	Potassium

LC/MS-MS	Liquid Chromatography with Tandem Mass Spectrometry
LC/TOF-MS	Liquid Chromatography – Time of Flight – Mass Spectrometry
LRT	Laramie River Tunnel
m	meter
M&E List	Colorado's Monitoring & Evaluation List
MCL	Maximum Contaminant Level
Mg	Magnesium
mg/L	milligrams per liter
MPB	Mountain Pine Beetle
Na	Sodium
NBH	North Fork of the Poudre River below Halligan Reservoir (routine monitoring site)
NDC	North Fork of the Poudre River above Dale Creek Confluence (routine monitoring site)
NEPA	National Environmental Policy Act
NFG	North Fork of the Poudre River below Seaman Reservoir (routine monitoring site)
NFL	North Fork of the Poudre River at Livermore (routine monitoring site)
ng/L	nanograms per liter
NH_4	Ammonia
Ni	Nickel
NISP	Northern Integrated Supply Project
nm	nanometers
NO_2	Nitrite
NO_3	Nitrate
NTU	Nephelometric Turbidity Units
^oC	degrees Celsius
Pb	Lead
PBD	Poudre River at the Bellvue Diversion (routine monitoring site)
PBR	Poudre River below Rustic (routine monitoring site)
PCM	Pine Creek Mouth (routine monitoring site)
PCP	Personal Care Product
PJW	Poudre River above the confluence with Joe Wright Creek

PNF	Poudre River above the North Fork (routine monitoring site)
PO_4	Phosphate
ppt	parts per trillion
PWSR	Protected Water Supply Reservoir
RCM	Rabbit Creek Mouth (routine monitoring site)
SCFP	Soldier Canyon Filter Plant
SCM	Stonewall Creek Mouth (routine monitoring site)
SFM	South Fork of the Poudre River above the Mainstem (routine monitoring site)
SO_4	Sulfate
SWAP	Source Water Assessment and Protection program
T&O	Taste & Odor
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSI	Trophic State Index
ug/L	micrograms per liter
UL	Underwriters Laboratories
uS/cm	microSeimens per centimeter
USFS	United States Forest Service
USGS	United States Geological Survey
WQCD	Water Quality Control Division
WQL	Water Quality Lab
WTP	Water Treatment Plant
Zn	Zinc

1.0 INTRODUCTION

1.1 Background

The Upper Cache la Poudre (CLP) River is an important source of high-quality drinking water supplies for communities served by the City of Fort Collins Water Treatment Facility (FCWTF), the City of Greeley-Bellvue Water Treatment Plant (WTP), and the Tri-Districts Soldier Canyon Filter Plant (SCFP). In the shared interest of sustaining this pristine water supply, the City of Fort Collins, the City of Greeley and the Tri-Districts partnered in 2007 to design the Upper Cache la Poudre River Collaborative Water Quality Monitoring Program. The Program was subsequently implemented in spring 2008. The over arching goal of this monitoring partnership is to assist the participants in meeting current and future drinking water treatment goals by providing up-to-date information about water quality and trends within the Upper CLP watershed.

Raw Poudre River water quality parameters that have historically had the most impact on treatment at the three treatment plants include turbidity, total organic carbon (TOC), pH, alkalinity, temperature, pathogens (*Giardia* and *Cryptosporidium*), and taste and odor (T&O) compounds such as geosmin. A more in-depth discussion of TOC, geosmin, and pathogens and the challenges they present for water treatment is included in the program design document, "Design of a Collaborative Water Quality Monitoring Program for the Upper Cache la Poudre River" (Billica, Loftis and Moore, 2008). This document also provides a complete description of the scope and objectives of the monitoring program as well as a detailed description of the watershed, sampling design and methods.

Two proposed water supply projects that impound Upper CLP waters are currently under consideration. The proposed Northern Integrated Supply Project (NISP) includes a new off-channel reservoir (Glade Reservoir) that will take water from the Upper CLP downstream of the North Fork confluence. The proposed Halligan-Seaman Water Management Project (HSWMP) includes the expansion of both Halligan Reservoir and Seaman Reservoir on the North Fork. NISP and HSWMP are currently undergoing review as part of the National Environmental Policy Act (NEPA) process. Water quality data collected for the Upper CLP Collaborative Water Quality Monitoring Program may be used to support the water quality studies conducted for these proposed projects and their respective Environmental Impact Statements.

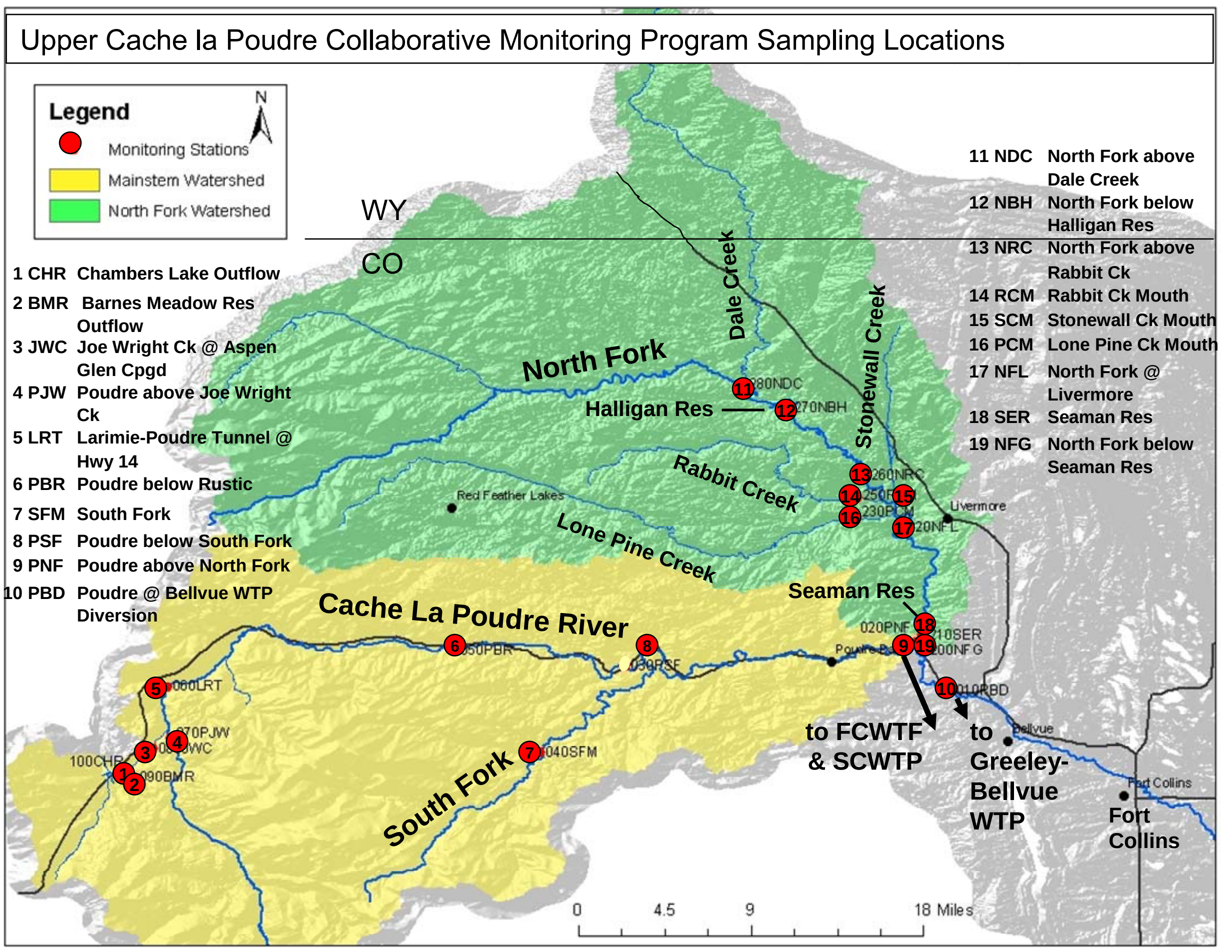
Annual and five-year reports for the collaborative program are prepared by City of Fort Collins staff to keep participants abreast of current issues and trends in water quality of the Upper CLP. The purpose of annual reports is to summarize hydrologic and water quality information for the current water year, provide a comparison with water quality from the preceding three years, describe notable events and issues, and summarize the results of special studies. The five-year reports will provide a more in-depth analysis of both spatial and temporal trends in watershed hydrology and water quality, including concentrations and loads.

1.2 Watershed Description and Sampling Locations

Sampling efforts are divided between the Mainstem and North Fork Poudre River drainages. Collectively these drainages encompass approximately 645,500 acres of forest, other natural land types and agricultural land (see Attachment 1). An additional 4,700 acres, representing less than 1% of land surface, is developed for commercial, industrial, utility, urban or residential purposes.

The monitoring network consists of 19 sampling locations selected to characterize the headwaters, major tributaries and downstream locations of the CLP near the City of Fort Collins, Tri-Districts and City of Greeley intake structures (Figure 1). The 19 sampling sites include one reservoir - Seaman Reservoir. A description and rationale for each site is provided in Appendix 2.

Figure 1. Map of the Upper CLP collaborative water quality monitoring network.



1.3 Sampling Schedule and Parameters

The sampling frequency for the Upper CLP Collaborative Water Quality Monitoring Program was determined based on both statistical performance and cost considerations. Parameters included in the monitoring program were selected based on analysis of historical data and aim to provide the best information possible within current budgetary constraints. A list of parameters is included in Attachment 3. Complete discussions of parameter selection and sampling frequency are provided in Sections 5.3 and 5.4, respectively, of the original design document by Billica, Loftis and Moore (2008). The 2010 sampling schedule is provided as Attachment 4 of this report.

1.4 Sample Collection and Analysis

Dr. William Lewis was contracted by the City of Greeley in agreement with the City of Fort Collins and the Tri-Districts to perform sampling activities for the Upper CLP monitoring program at 17 of the 19 Mainstem and North Fork CLP sites. Staff from the City of Fort Collins, City of Greeley, and Tri-Districts collect samples at the remaining two locations: North Fork Poudre above confluence with Dale Creek (NDC) and North Fork Poudre below Halligan Reservoir (NBH). Sampling methods, including those for the collection of field measurements for temperature, pH, conductivity, and dissolved oxygen are documented in Section 5.5 of Billica, Loftis and Moore (2008). All bulk water samples were analyzed by the City of Fort Collins Water Quality Lab (FCWQL), except for *Cryptosporidium* and *Giardia* filter samples, which were delivered to CH Diagnostic and Consulting, Inc., in Berthoud, CO for analysis. In addition, phytoplankton samples were collected from April through November at the top and bottom of Seaman Reservoir in 2011. Phytoplankton samples were identified and enumerated at the species level by Dick Dufford (private consultant) of Fort Collins, CO. The analytical methods and detection limits for the FCWQL parameters are included in Attachment 5.

1.5 Scope of 2011 Annual Report

The 2011 annual report summarizes the hydrologic and water quality data collected for the Upper CLP Collaborative Water Quality Monitoring Program and highlights the significant events, issues of concern, and the results of special studies. This report compares water quality information from 2011 with the previous three years 2008-2010.

2.0 SIGNIFICANT EVENTS, ISSUES OF CONCERN & SPECIAL STUDIES

2.1 Attached Algae Bloom in Poudre River

A summertime attached algae bloom was first observed in 2009, and has occurred each year since along the middle reaches of the Mainstem Poudre River, from areas near Big Bend Campground and the State fish hatchery to downstream of Indian Meadows, which corresponds to the Upper CLP monitoring site, Poudre below Rustic (PBR). In 2011, the algae bloom was similar in location and severity as seen in the previous two years. Dense mats of dried filamentous algae covered rocks along the river banks in areas where high flows had receded, and live green algae was observed in areas of flowing and standing water (Figures 3.a & 3.b). Periphyton sampling began in 2010 and continued through 2011 to monitor algae populations and determine if the summer time algae blooms were related to taste and odor (T&O) issues in raw drinking water supplies at the FCWTF (Section 2.2). Sampling locations were reconfigured in May 2011to include five locations spanning the distance from just above Rustic to the Greyrock Trailhead bridge, just upstream from the City of Fort Collins intake facility. Previously, samples were collected at four locations above and below Rustic. In 2011, new sampling protocols were implemented to obtain quantitative data on species abundance. Monthly periphyton samples were collected starting in July through November from riverbed cobbles using a fixed-area sampling device (Figure 2). Samples from three cobbles were composited for each site. Samples were identified to the species level and enumerated accordingly by private consultant.

Figure 2. Periphyton collected from a river cobble using a fixed-area sampler.

As in previous years, field observations indicate that the dominant form of algae was the green algae, *Ulothrix* (sp) as it was in 2010 (Figure 3.a-3.c). There were also observations of the diatom, *Didymosphenia geminata* at most sampling locations, but was more abundant at the uppermost sites, *Poudre above Rustic* and *Poudre below Rustic* (PBR). 2011 periphyton data were not available at the time of this report to verify these field observations, but will be provided as an addendum to this report upon receipt. Although algal blooms typically occur in response to increased nutrient availability, there is no evidence, to date, of elevated nutrient concentrations at PBR or upstream locations from June through September (Oropeza and Billica, 2010). The prevalence of *Ulothrix sp*. and *Didymosphenia geminata* under low nutrient conditions and cold temperatures is not surprising, as it has been documented that both thrive under such conditions (Graham et al., 1985, Sundareshwar et al., 2011).

No taste and odor (T&O) issues were reported at the treatment plants during this time. This suggests that potential off-taste and odor compounds (including geosmin) were either not strongly associated with this algae bloom, or were adequately volatilized, degraded, and/or diluted prior to reaching the raw water intakes.

The dense mats of aquatic weeds that were observed on the North Fork below Halligan Reservoir in 2009 and previous years were not present in 2010 or 2011.

Figures 3.a-3.c. Attached algae on Mainstem of the Poudre.

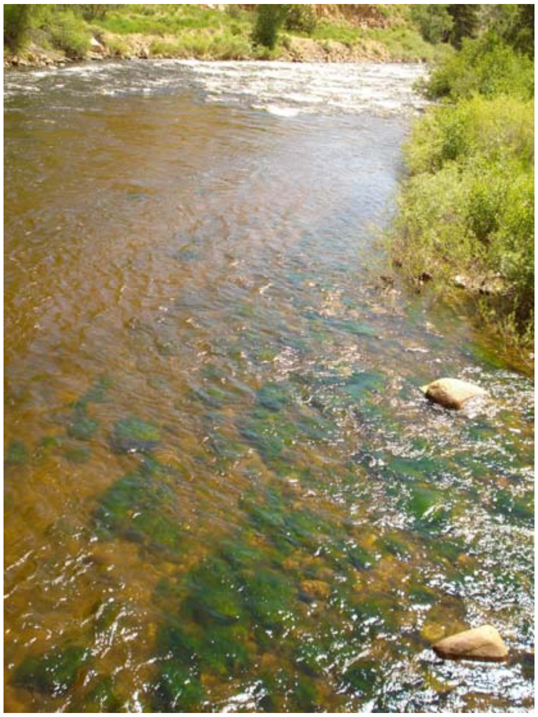


Figure 3.a. Live attached alage (*Ulothrix sp.*) on rocks near Poudre Below Rustic (PBR) monitoring site in June 2010.

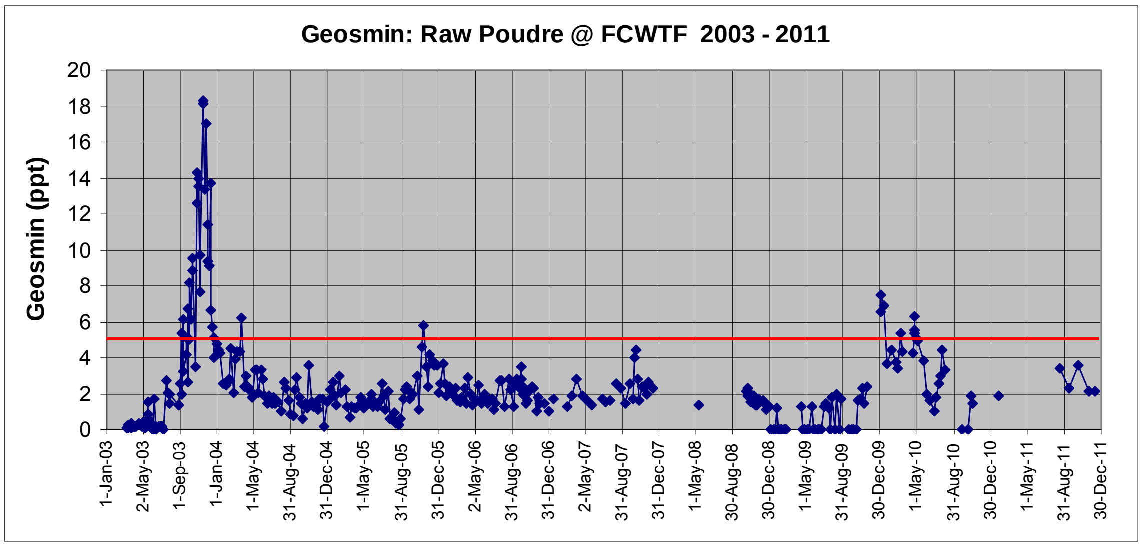
Figure 3.b. Dried algae (*Ulothrix sp.*) on rocks near Eggers Fishing area in September 2009.

Figure 3.c. *Didymosphenia geminata* attached to stream bed cobbles at Poudre above Rustic in 2011.

2.2 Poudre River Geosmin Episode

Geosmin is a naturally occurring organic compound that imparts an earthy odor to water and can be detected by the most sensitive individuals at concentrations as low as 4 nanograms per liter (ng/L) or 4 parts per trillion (ppt). Geosmin does not pose a public health risk, but it is of concern because its detectable presence can negatively affect customer confidence in the quality of drinking water. The Poudre River raw water supply is routinely monitored for geosmin concentrations from January through December. As shown in Figure 4, the Poudre River raw water supply has experienced periodic episodes of elevated geosmin concentrations above the 4 ppt odor threshold over time, with the most recent outbreak occurring in early 2010. Geosmin continues to be monitored in the raw Poudre water supply at the FCWTF on a routine basis; there were no exceedances of the T&O threshold in 2011.

Figure 4. Geosmin concentrations in raw Poudre River water supply at the FCWTF from 2003-2011.

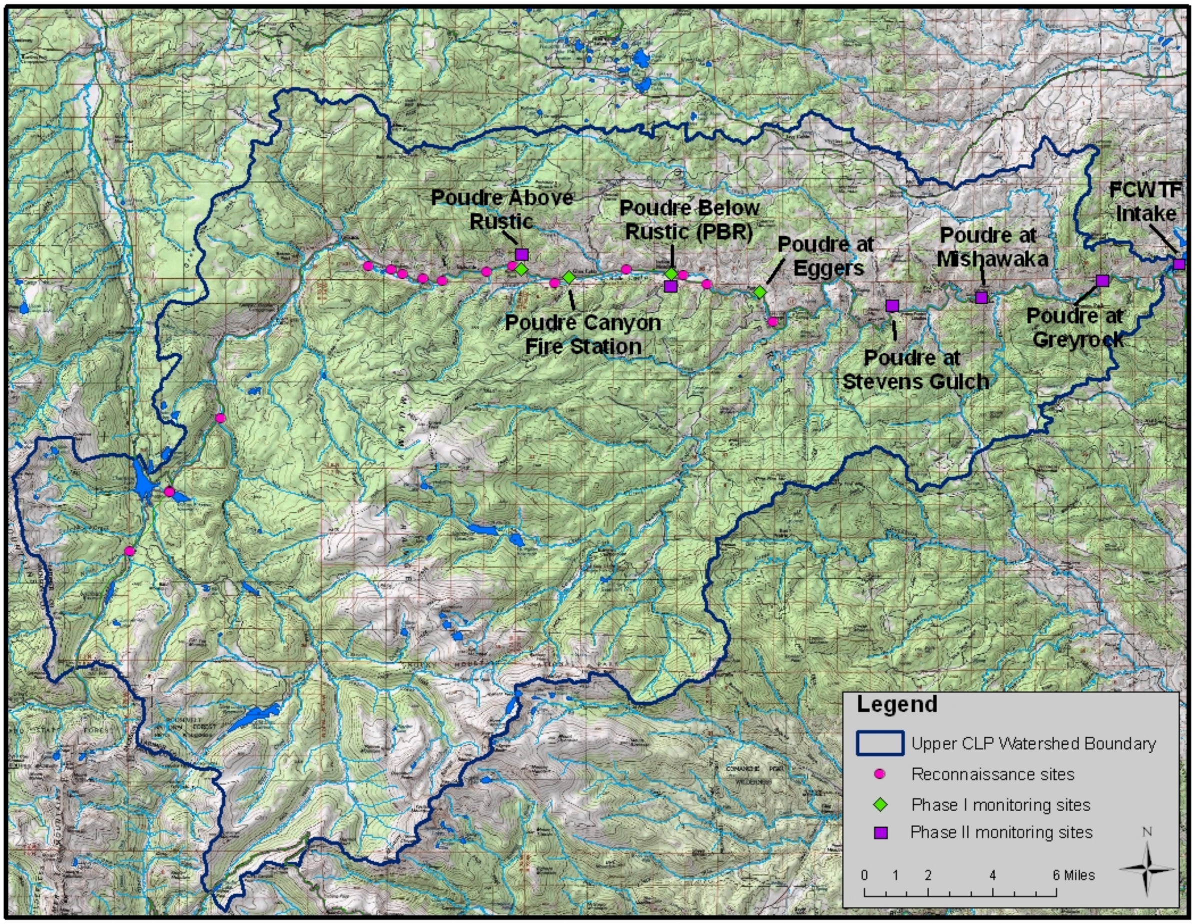


In response to the elevated geosmin in the raw Poudre River water in 2010, intensive sampling on the Mainstem of the Poudre River was initiated to evaluate in-stream concentrations and delineate the approximate area of elevated geosmin concentrations along the river. From January 2010 through April 2011, geosmin sampling focused on the area upstream and downstream of Rustic based on the location of the summer algae bloom and the prevalence of seasonal and year-round housing, the State of Colorado Division of Wildlife Fish Hatchery, and camping facilities in the area. Reconnaissance sampling spanned from below Joe Wright Reservoir downstream to Eggers Fishing Area. Based on initial results, four routine monitoring sites were selected within the area of highest observed geosmin concentrations and are referred to as **Phase I** sites. Phase I sites were centered around Rustic, CO and included *Poudre above Rustic*, *Poudre Canyon Fire Station* #2, *Poudre below Rustic (PBR),* and *Poudre at Eggers* (Figure 5).

A review of the geosmin concentrations in early 2011 indicated a high degree of variability between sites and a lack of consistent up- to downstream trends in concentrations. Furthermore, temporal trends in geosmin concentrations at the FCWTF and on the Upper

Poudre River differed (Figure 6). These results suggest that water quality at the FCWTF intake is likely to be affected more by production sites closer to the intake than by the high concentrations around Rustic being conveyed downstream. Based on the findings, sample sites were reconfigured to include sites between the area of high geosmin production around Rustic and FCWTF intake. These sites are referred to as **Phase II** sites and include *Poudre above Rustic*, *Poudre below Rustic (PBR), Stevens Gulch, Mishawaka*, and the *Greyrock* bridge.

Figure 5. Map of 2010-2011 Poudre River geosmin sampling sites (Phase I & Phase II).



In addition to geosmin, samples for nutrients, bacterial indicators *E. coli* and total coliforms, and periphyton (attached algae) were also collected at each monitoring site. A timeline of Phase I and Phase II sampling events and changes is presented in Figure 7. Results of nutrient samples were used to determine whether there were identifiable sources of nutrients that might contribute to the occurrence of geosmin-producing algae. *E. coli* and total coliform samples were collected to determine whether elevated nutrient and geosmin concentrations, if found, were potentially associated with fecal waste contamination (i.e. leaking septic systems). Attached algae samples were used to characterize changes to the periphyton community composition and estimate the relative abundance of known geosmin producing species over time.

Figure 6. 2010 - 2011 geosmin concentrations at key locations on the Poudre River.

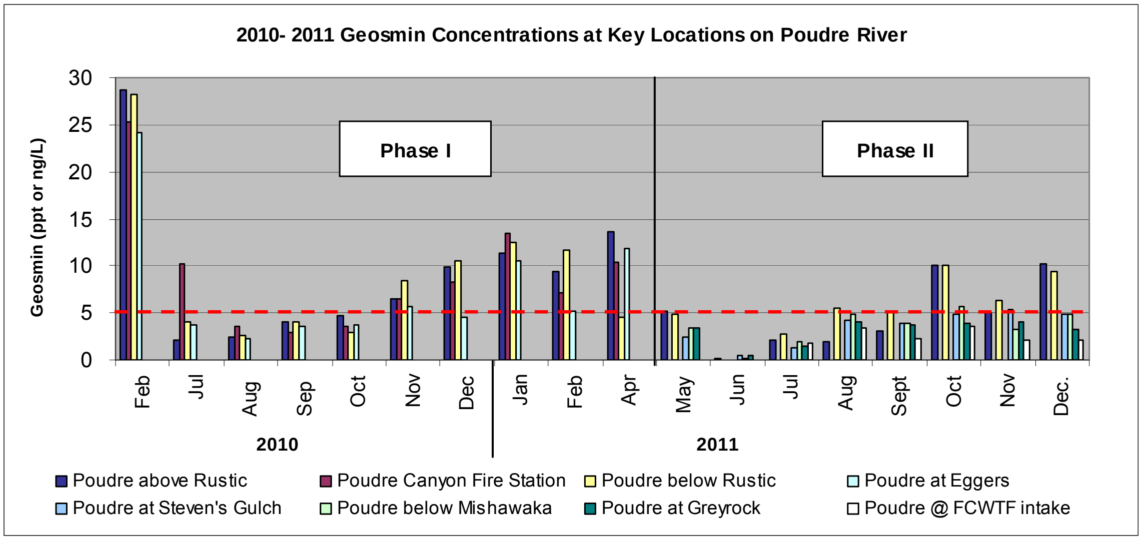
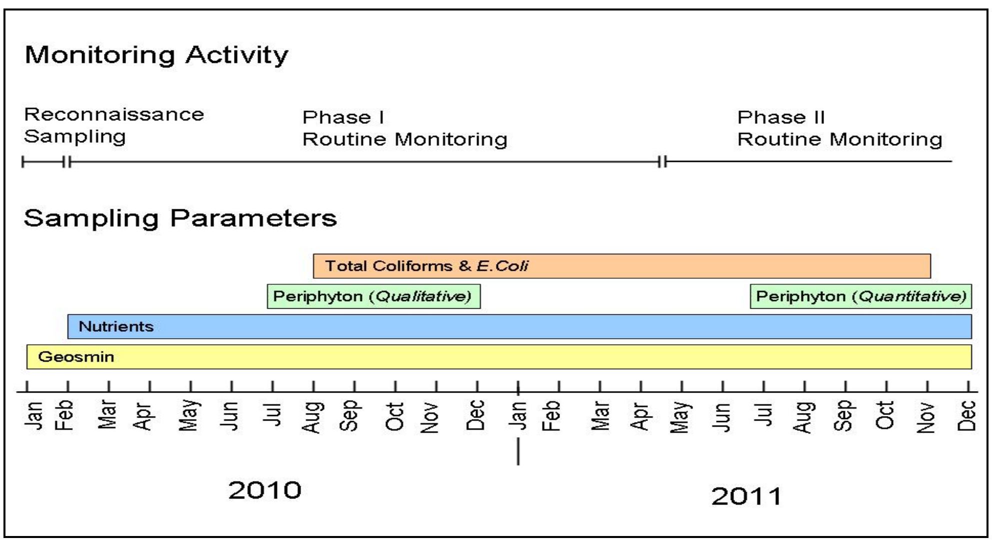


Figure 7. Timeline of geosmin monitoring activities on the Poudre River.



An in depth review of Phase I sampling results are presented in the paper entitled "Navigating Uncharted Waters: Assessing Geosmin Occurrence in a Colorado Rocky Mountain Source Water River" (Oropeza et al., 2011) that was prepared for the 2011 AWWA Water Quality Technology Conference (November 13-17, 2011, Phoenix, AZ), provided in Appendix 8.

Highlighted findings from the report include:

- *Geosmin concentrations exhibit a seasonal pattern of highest concentrations in the winter and lowest concentrations during spring snowmelt runoff.*
- *Peak geosmin concentrations on the Poudre River were significantly higher in 2010 than in 2011.*
- *Nutrient concentrations near the fish hatchery, above and below Home Moraine housing developments, and below the Glen Echo Resort did not indicate the presence of persistent point sources of nutrients or fecal contamination*
- *Geosmin concentrations at the FCWTF were not representative of concentrations on the Upper Poudre River for either year.*
- *The filamentous green algae, Ulothrix zonata and the invasive diatom, Didymosphenia geminata were the dominant algae species within the Upper Poudre River study area.*
- *Geosmin producing cyanobacteria were frequently present in the periphyton community, but were relatively rare at the Poudre River monitoring sites.*

A follow-up review of all 2011data (Phase I and Phase II) shows a significant, negative correlation between geosmin and total phosphorus (Total P) at all sites (Figure 8), a relationship that was not evident in the 2010. Across all sites, the correlation was strongly significant (r=0.542; p=0.000). Correlations between other nutrients were observed at individual sites, but no consistent relationships were observed at all sites for any variable. Figure 9 shows similarity in the seasonal pattern of Total P and stream flow on the Mainstem CLP, with peaks during spring snowmelt runoff. It also illustrates the inverse relationship that these two factors have with geosmin concentrations. Dilution offers a possible explanation for the low geosmin concentrations that are observed during high flows of spring runoff. High Total P concentrations occur during spring runoff when stream flows have the strongest dilution effect on geosmin, thus contributing to the inverse relationship observed between geosmin and Total P.

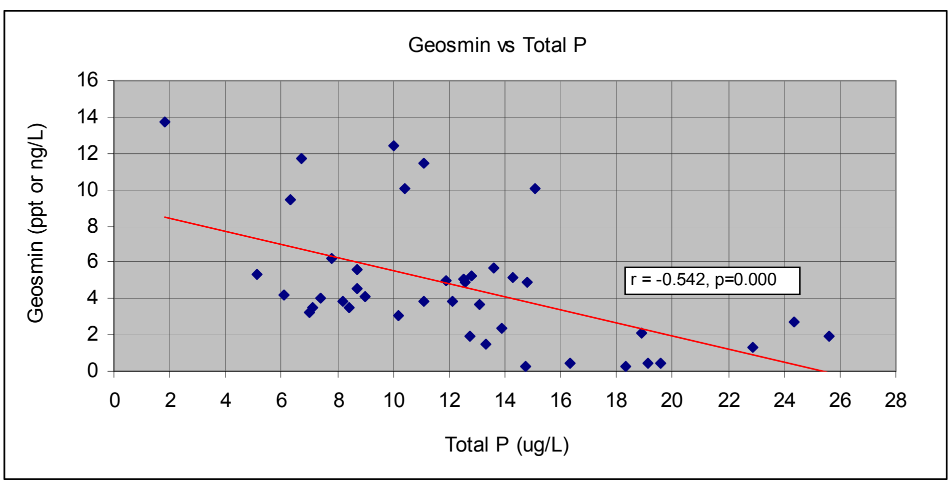
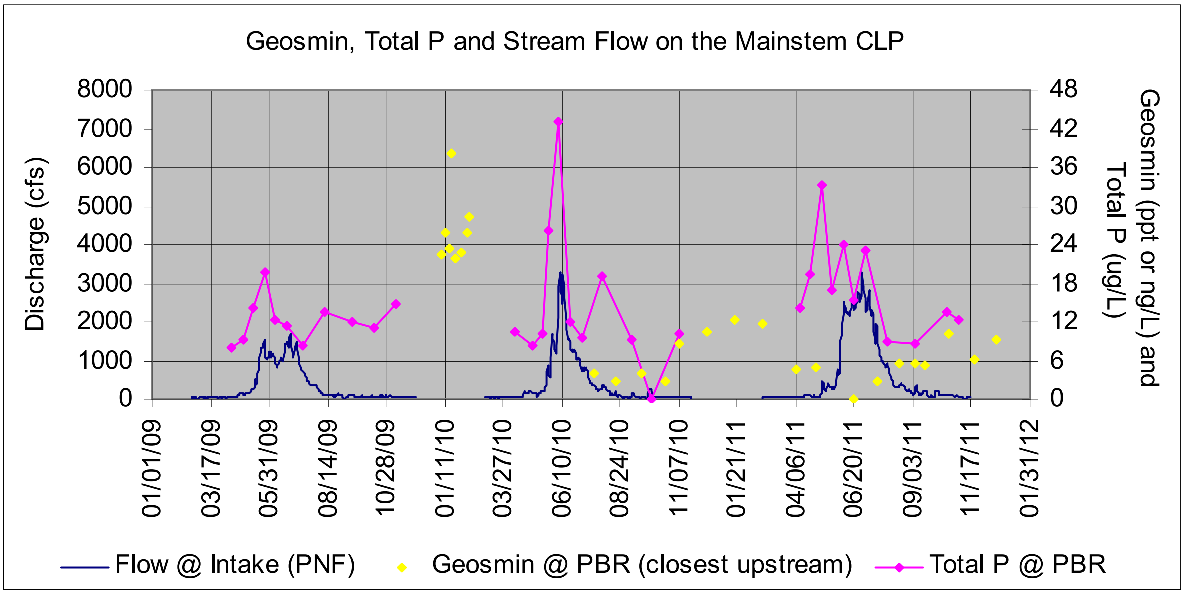


Figure 8. Correlation between geosmin and Total P on the Mainstem CLP, from 2008 – 2011.

Figure 9. Geosmin, Total P and Stream Flow on the Mainstem CLP, from 2009 – 2011.

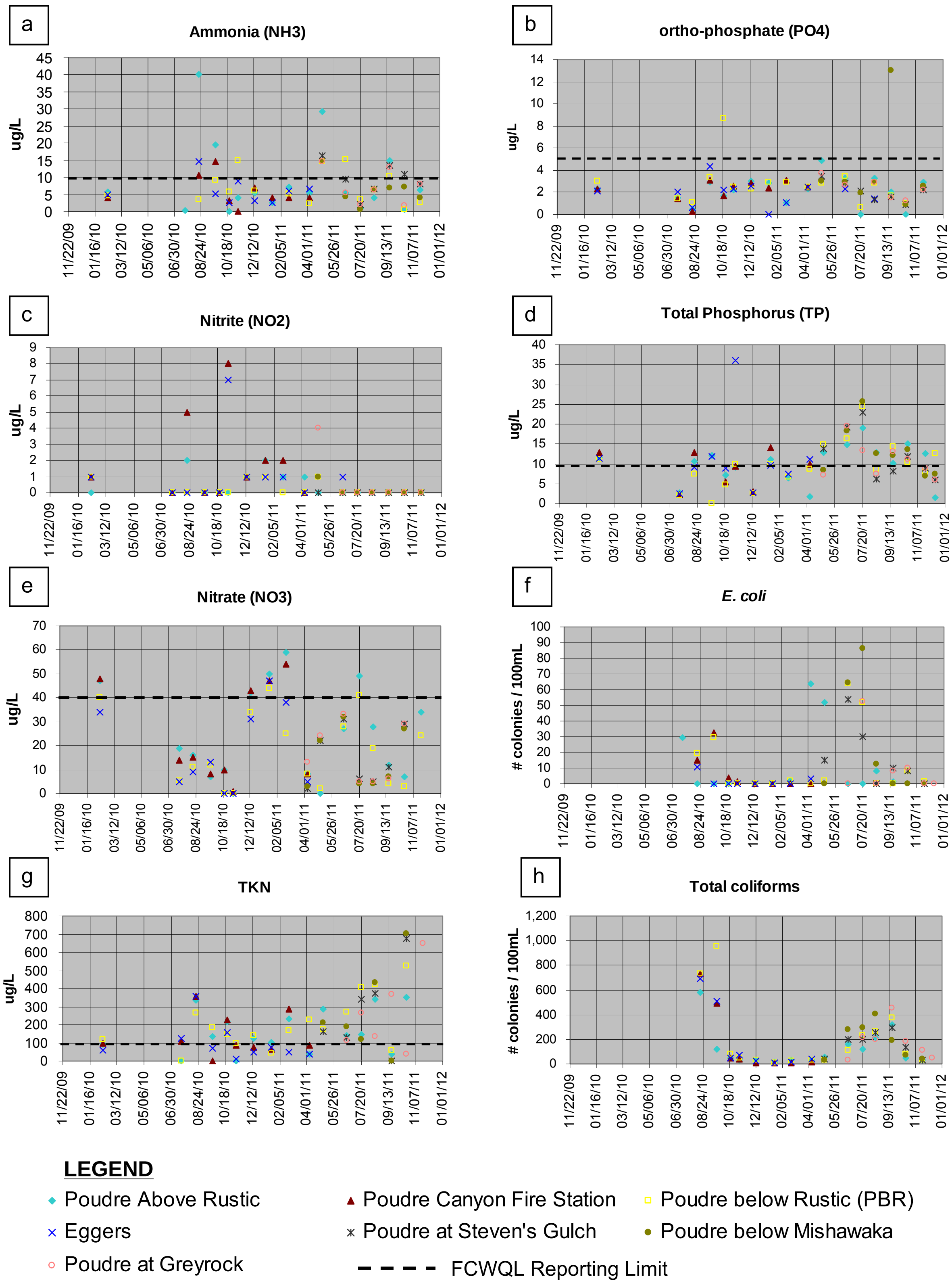


The presence of cyanobacteria (blue-green algae) throughout the year may also affect geosmin concentrations in the river; however there is often little correlation between abundance of geosmin producing species and geosmin concentrations (Taylor et al, 2006, Billica et al., 2010). The primary usefulness of the periphyton data will be to verify the presence of geosmin-producing species and to establish a baseline of the periphyton community composition which will allow tracking of changes through time. 2011 periphyton data were not available at the time this report was finalized. Upon receipt of the data, a full review of 2011 periphyton data will be provided as an addendum to this report.

Consistent with Phase I results, nutrient concentrations of the total and dissolved nutrient fractions were generally low in the study area and were frequently below reporting limits (Figures 10.a-10.f). Nutrients, as well as *E.coli* and total coliforms concentrations at these sites were within the range of values observed at the Upper CLP Water Quality Monitoring Program sites. Like geosmin, there was considerable variability in concentrations between sites for a given sample date and no evidence of upstream to downstream trends for any measured parameter.

Because there is a lack of evidence that suggests that fecal waste is contributing to elevated nutrients and/or geosmin concentrations, *E.coli* and total coliform samples will be eliminated from the 2012 sampling program to save cost and lab analysis time.

Figure 10(a-h). Nutrient, *E. coli* and total coliform concentrations at Upper CLP geosmin monitoring sites from 2010 – 2011.



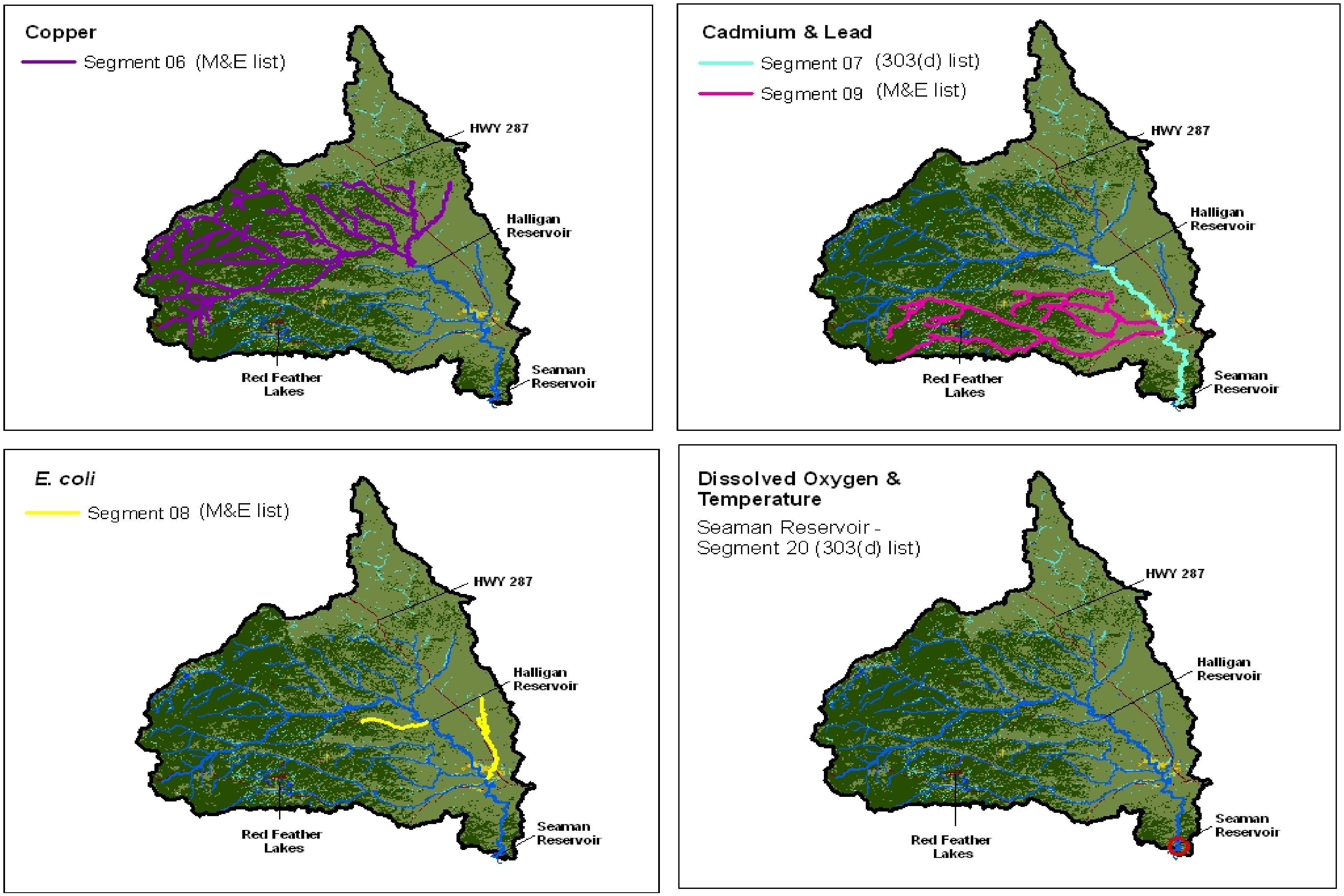
2.3 Colorado's 2010 Section 303(d) and Monitoring and Evaluation (M&E) Lists

Segments of the North Fork of the Cache la Poudre River that are on the state of Colorado's Section 303(d) List of impaired waters and Monitoring and Evaluation (M&E) List, as of April 30, 2010 are outlined on Table 1 and shown on Figure 11. Segments with a 303(d) impairment require total maximum daily loads (TMDLs) and are prioritized with respect to TMDL development. The two North Fork segments on the 303(d) List have both been assigned a medium priority. When water quality standard exceedances are suspected, but uncertainty exists regarding one or more factors (such as the representative nature of the data used in the evaluation), a water body or segment is placed on the M&E List. Three North Fork segments are currently on the M&E List. Listed sites will be reviewed biennially, with the North Fork sites listed below scheduled for review in 2012.

Table 1. Summary of Upper CLP segments on Colorado's 2010 Section 303(d) List of Impaired Waters and 2010 Monitoring and Evaluation (M&E) List

Segment	Segment Description	Portion	Monitoring & Evaluation Parameters	Section 303(d) Impairment	303(d) Priority
COSPCP06	Mainstem of the North Fork, including all tributaries from the source to inlet of Halligan Res.	all	Copper		
COSPCP07	Mainstem of the North Fork from Halligan Reservoir to confluence with CLP River.	all		Cadmium, Lead	Medium
COSPCP08	All tributaries to the North Fork from Halligan Res to confluence with CLP River, except for listings in Segment 9.	all	*E.Coli*		
COSPCP09	Rabbit Creek & Lone Pine Creek from the source to the confluence with the North Fork	all	Cadmium, Lead		
COSPCP20	All lakes and reservoirs tributary to the North Fork, from Halligan Resevoir to confluence with CLP River.	Seaman Reservoir		dissolved oxygen	Medium

Figure 11. Upper CLP segments on Colorado's 2010 Section 303(d) List of Impaired Waters and 2010 Monitoring &Evaluation (M&E) List.



2.4 Northern Water Collaborative Emerging Contaminant Study

Contaminants of emerging concern (CECs) and their presence in water have recently received national attention. CECs are trace concentrations (at the nanogram/L or part per trillion level, or less) of the following types of chemicals:

- Personal care products (PCPs): fragrances, sunscreens, insect repellants, detergents, household chemicals
- Pharmaceuticals: prescription and non-prescription human drugs (including pain medications, antibiotics, β-blockers, anti-convulsants, etc) and veterinary medications
- Endocrine disrupting chemicals (EDCs): chemicals that interfere with the functioning of natural hormones in humans and other animals; includes steroid hormones (estrogens, testosterone, and progesterone), alkylphenols, and phthalates
- Pesticides and herbicides

In 2008, Northern Water began a collaborative emerging contaminant study to determine the presence of these compounds in waters of the Colorado- Big Thompson system. In 2009, two sites on the Upper Cache la Poudre (Poudre above North Fork (PNF), and North Fork at gage below Seaman Reservoir (NFG)) were added to the study with funding provided by the City of Fort Collins and the City of Greeley. The Poudre above North Fork (PNF) the North Fork below Seaman Reservoir (NFG) sites were sampled three times in 2011 (Feb., June, Aug.).

Laboratory Analysis. Samples are submitted to the Center for Environmental Mass Spectrometry Laboratory at the University of Colorado at Boulder (CU Lab) for analysis of 51 pharmaceuticals and 103 pesticides by Liquid Chromatography – Time of Flight – Mass Spectrometry (LC/TOF-MS). Beginning with the June 2009 sampling event, samples were also submitted to Underwriters Laboratories (UL), Inc. for analysis of estrogens and other hormones (9 compounds, UL Method L211), and phenolic endocrine disrupting chemicals (8 compounds including bisphenol A, UL Method L200). Beginning in 2010, the CU Lab also began conducting low-level analysis by liquid chromatography with tandem mass spectrometry (LC/MS-MS) for a subset of 22 different pharmaceuticals and personal care products, in addition to the analysis of 51 pharmaceuticals and 103 pesticides by LC/TOF-MS. Beginning in 2012, the CU Lab will conduct a low-level screening analysis for estrogen and other hormone samples and only samples that have detected hits during the initial screening will be sent to UL for a full analysis.

Results through 2011. No compounds have been detected above their respective reporting limits by the CU Lab in any 2009, 2010 or the February and June 2011 samples collected at the Poudre above North Fork (PNF) site. A detection of the recreational insecticide DEET of 20.8 ng/L was reported for the August 2011 sampling event at PNF. In addition, the UL Lab reported very low levels of progesterone in the June 2009 sample (0.1 ng/L) and the June 2010 sample (0.4 ng/L) from the Poudre above North Fork site. However, 0.1 ng/L is the method reporting limit for progesterone and caution must be exercised in terms of assigning any level of importance to results at or near this extremely low value.   No compounds were detected by either laboratory in the June 2009, June 2010 or any 2011sample dates samples collected from the North Fork below Seaman Reservoir site.

2012 Sampling. In 2012, samples will be collected at both Upper CLP sites in February, June, and August. These sampling dates will span the range of conditions experienced by the Upper CLP, from low flow winter conditions, to high flow during spring runoff, to the period of peak summer recreational use.

2.5 Mountain Pine Beetle in the Upper CLP Watershed

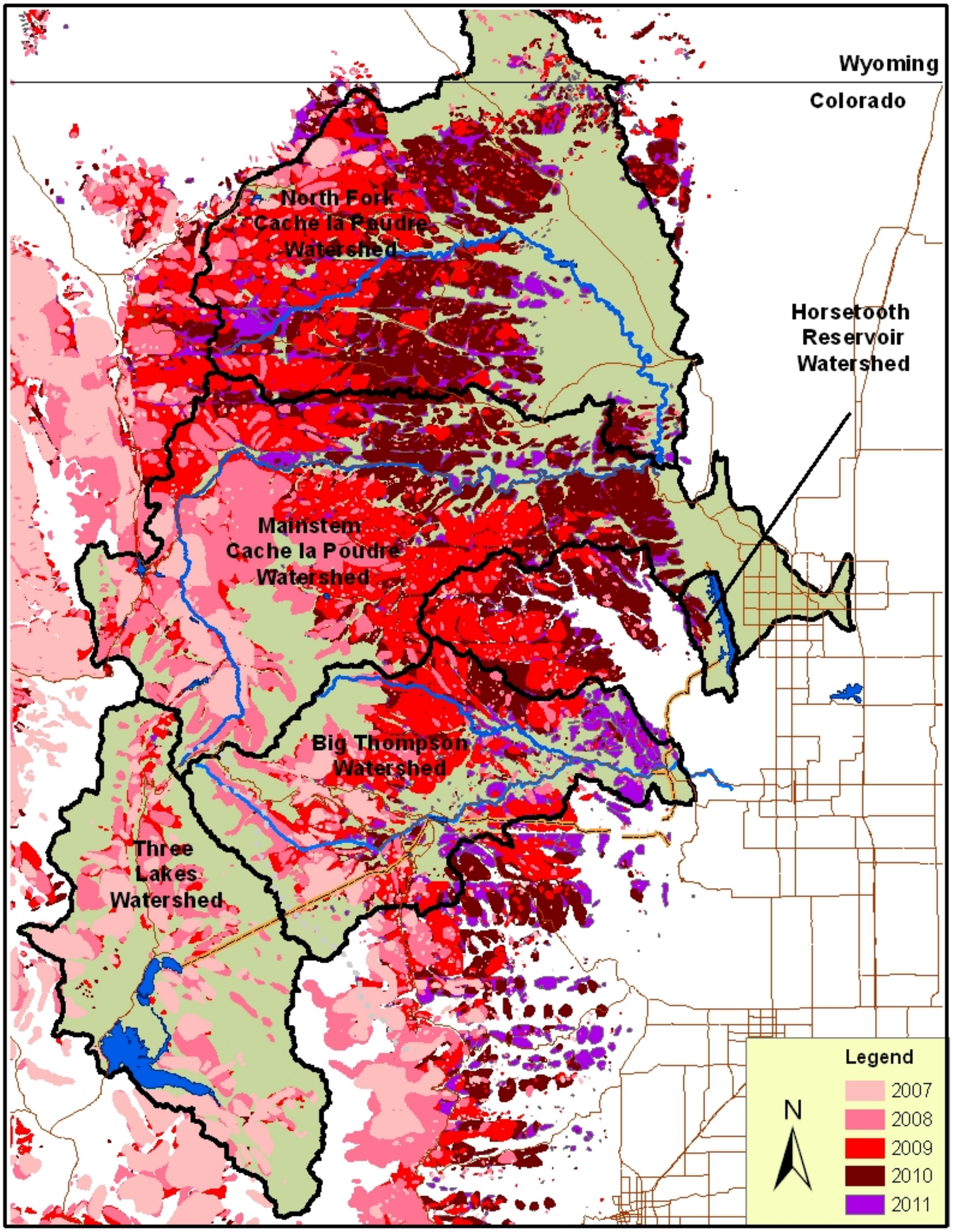
The mountain pine beetle (MPB), *Dendroctunus ponderosae*, is native to forests of western North America. Periodically, populations increase to result in regional outbreaks of beetle-related tree deaths. The current outbreak, which began in the late 1990's, has grown to ten times the size of the largest previously known outbreak and continues to expand through forests dominated by Lodgepole and Ponderosa pines (*Pinus contorta* and *Pinus ponderosa*). The result has been expansive swaths of dead and dying trees across the Rocky Mountain West.

Information from the US Forest Service (USFS) and Colorado State Forest Service 2011 Forest Health Aerial Survey provided by the USFS (http://www.fs.usda.gov/detail/r2/forest-grasslandhealth/?cid=stelprdb5348787) reports that the total number of infested acres in Colorado and southern Wyoming increased by 208,000 acres in 2011, bringing the total number of affected acres to 4.2 million since 1996. The expansion of the MPB slowed significantly over the previous two years in response to decreased availability of trees to attack (Figure 12). In 2011, the MPB continued its eastward spread into lower elevation Lodgepole and Ponderosa pine stands along the Northern Colorado Front Range; thirty-six percent of the active acres in Colorado were in Ponderosa Pine, a sub-optimal forest type for the MPB. The Upper Cache la Poudre and the adjacent contributing watersheds (Laramie River and Michigan River) continue to experience high forest mortality. A map of MPB mortality in the local watersheds is provided in Figure 13.

Figure 12. 2011 image of mountain pine beetle (MPB) mortality in the Mainstem CLP looking south toward Chambers Lake.

During the phase of forest dieback in which affected trees retain their needles, there is a short-term elevated risk of high severity wildfire. Research continues on forest management options to improve post-outbreak forest health (MacDonald and Stednick, 2003; Uunila et. al, 2006; Le Master et al., 2007), as well as options for protecting communities and critical water supplies against the effects of wildfire (Le Master et al., 2007; FRWWPP, 2009). Potentially widespread changes in the vegetative cover that occur either as a result of extensive forest die-back or from severe wildfire, have the potential to affect water quality in the Upper CLP watershed, including potential changes in stream flow and temperatures, sediment loads, as well as in-stream nutrient and TOC levels.

Figure 13. Mountain Pine Beetle (MPB) activity in the North Fork and Mainstem Cache la Poudre, Big Thompson, Horsetooth and Three Lakes Watersheds from 2007 through 2011.



2.6 Upper CLP Wildfire/Watershed Assessment

In early 2012, the City of Fort Collins and City of Greeley met with US Forest Service to discuss opportunities to mitigate the risks of potential wildfires on water quality in portions of the Upper CLP watershed that are within the Arapahoe National Forest. The objective of the meeting was to explore the opportunities identified in the 2010 Cache la Poudre Wildfire Watershed Assessment (J.W. Associates, 2010) and identify possible next steps for strategic fire hazard mitigation.

No new opportunities to protect water quality in the Poudre River were identified from a fuels mitigation standpoint, due to limits imposed by topography, the planning process, available funding and competing agency priorities. However, the US Forest Service is already undertaking significant fuels reduction projects within the watershed according to other identified priorities. Those projects are expected to contribute towards limiting the size and intensity of any fires that occur within the Upper CLP watershed.

The full 2010 report, including a full summary of identified opportunities, is available at:

http://www.jw-associates.org/Projects/Poudre_Main/Poudre_Main.html.

2.7 Assessment of Existing/Abandoned Mine Sites as Potential Sources of Contamination

In 2004, the Colorado Department of Public Health and Environment (CDPHE) conducted an assessment of potential hazards to source water supplies as part of the Source Water Assessment and Protection (SWAP) program. Assessments for the City of Fort Collins and the City of Greeley identified a number of existing and abandoned mine sites within the Mainstem watershed (65 sites) and North Fork Cache la Poudre watershed (16 sites) that were determined to pose a moderate to high risk of contaminating water supplies. Routine monitoring data have not indicated any detectable influence from mine sites within the watershed to date. Field verification work began in early 2011 to verify the existence of these sites and to better understanding the risks they pose to water quality, if any. Attempts to locate four sites in 2011 were hampered by distance and terrain. The prioritized list of mine sites and the feasibility of locating these sites will be reevaluated in 2012. The work is expected to take several years.

When sites are located, field personnel will photo-document site conditions and log the latitude/longitude coordinates of the sites using geographic positioning system (GPS) and topographic maps. Sites will be surveyed for evidence of past or current mining activity (mine excavations and tailings) and possible migration of materials or drainage from the site into streams or tributaries of the Cache la Poudre River.

The geographical coordinates of the Upper CLP mine sites were obtained from CDPHE and will be used to develop a prioritized list of sites for field verification. The locations of all identified mine sites in the Mainstem and North Fork CLP watersheds are shown on Figure 14.

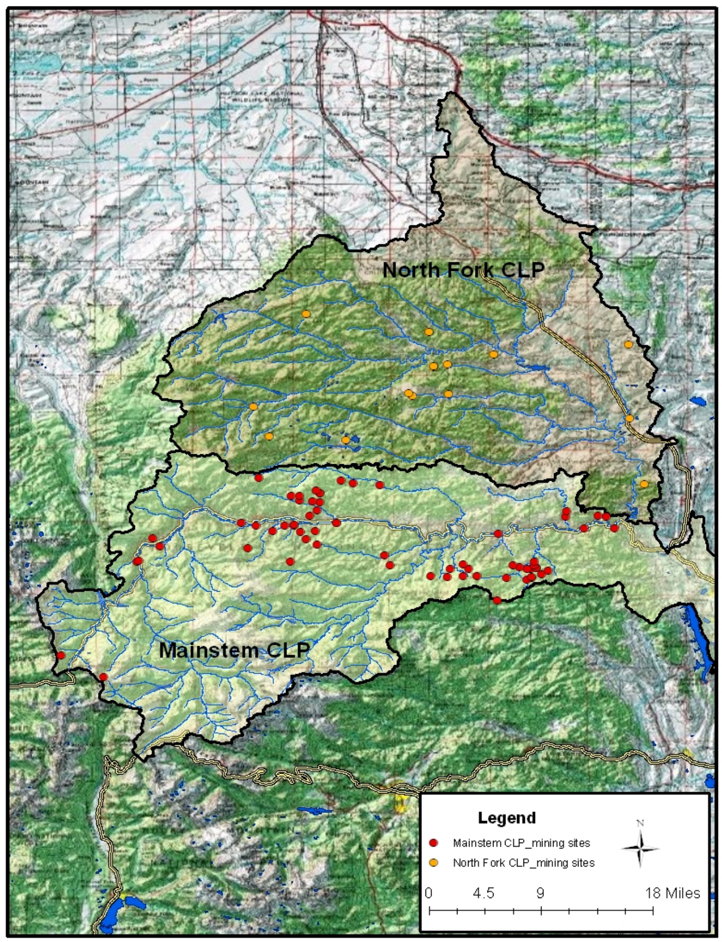


Figure 14. Locations of existing or abandoned mining claims in the North Fork and Mainstem Cache la Poudre River watersheds as identified in the 2004 CDPHE Source Water Assessments for the City of Fort Collins and City of Greeley.

3.0 UPPER CACHE LA POUDRE RIVER RESULTS

For this annual report, six key sites were identified that are considered representative of conditions on the Mainstem and North Fork CLP River. The selected sites are:

- Mainstem above North Fork

  JWC – Joe Wright Creek above Mainstem

  PJW – Poudre above Joe Wright Creek

  PNF – Poudre above North Fork
- North Fork above Mainstem

  NFL – North Fork at Livermore (above Seaman Reservoir)

  NFG – North Fork at Gage below Seaman Reservoir
- Mainstem below North Fork Confluence

  PBD – Poudre at Bellvue Diversion

Discussion of the results will focus primarily on these 6 key sites; however, data from all sites were reviewed and analyzed and any notable events and trends are included in the discussion. A full list of monitoring sites, abbreviations and descriptions is available in Attachment 2. All data summary graphs are contained in Attachment 7; raw data are available upon request from the City of Fort Collins.

3.1 Hydrology

Discharge was measured as part of the routine Upper CLP monitoring activities at two key sites on the Mainstem: Poudre above Joe Wright Creek (PJW) and South Fork Poudre (SFM). Discharge values presented for these sites represent instantaneous discharge measurements collected on the specified sampling dates.

Continuous stream flow data were obtained from U.S. Geological Survey (USGS) and Colorado Division of Water Resources (CDWR) online reporting sites for flow gauging stations at Joe Wright Creek (JWC), North Fork at Livermore (NFL), North Fork below Seaman Reservoir (NFG) and the Canyon Mouth (representing Poudre at Bellvue Diversion (PBD)). Stream discharge values at Poudre above North Fork (PNF) were calculated using continuous flow data from the Canyon Mouth and NFG as well as head gate flow values at the Poudre Valley Canal diversion, which were obtained from the Poudre River Commissioner, George Varra. Discharge values for these sites are presented as daily averages.

Both the Mainstem and North Fork sites show snowmelt-dominated hydrographs (Figure 15). Typical to most years, the 2011 spring runoff began in mid-May. The hydrographs for 2008-2011 at the lower Mainstem sites PNF and PBD are characterized by two opr more peaks in stream flow during the spring run-off season. These multiple peaks reflect natural fluctuation of the river levels that result from rainfall events and/or snowmelt in the lower elevations as well as the freeze-thaw cycles that are characteristic of early spring conditions in the Upper CLP watershed (Figure 16).

The 2011 snowpack conditions (depth and % water content) were among the highest on record for the Upper CLP watershed, holding nearly four feet of water at its official maximum depth of 11ft. These conditions presented the potential for extreme peak discharge on the Mainstem CLP. However, in contrast to 2010, 2011 spring weather conditions were such that snowmelt runoff occurred over an extended period. This resulted in high, but not extreme observed stream flows on the Mainstem CLP.

Figure 15. 2008 – 2011 Daily average stream flow at key Upper CLP monitoring sites.

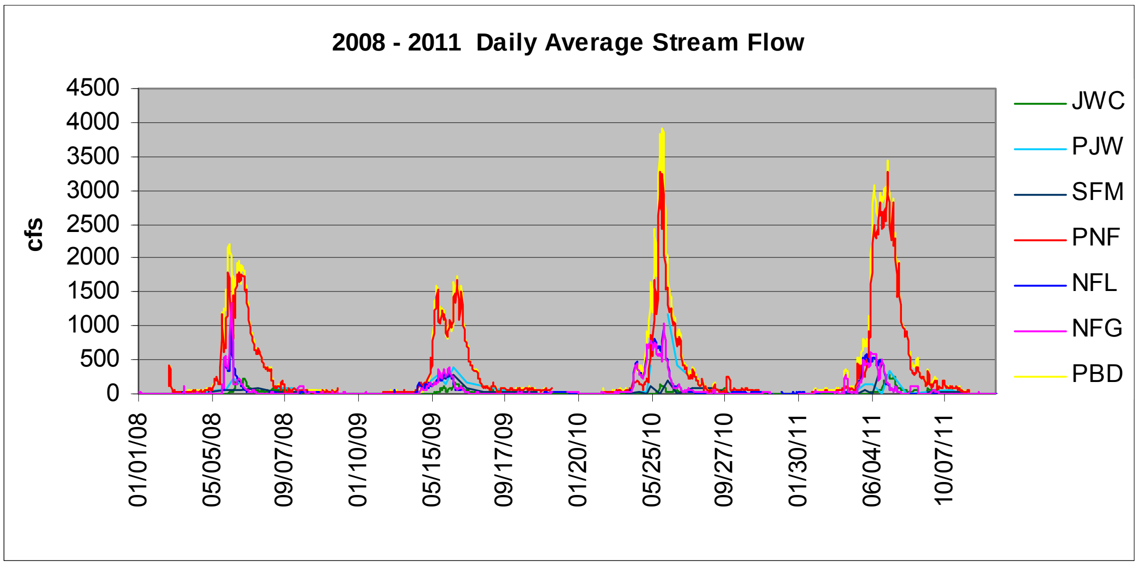
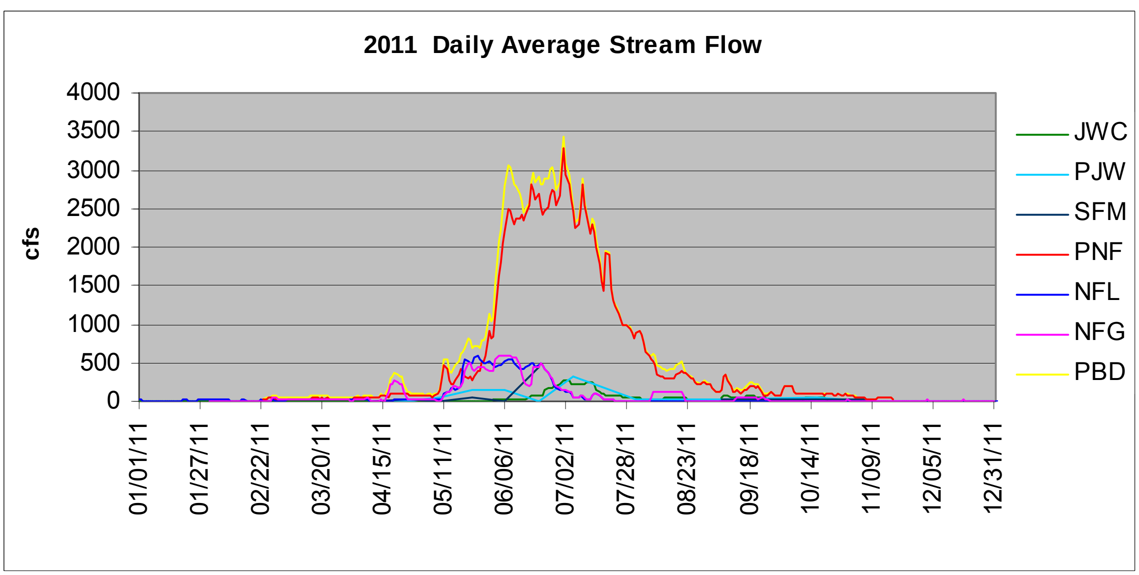


Figure 16. 2011 Daily average stream flow at key Upper CLP monitoring sites.



3.1.1 Mainstem CLP

Headwater Sites. The headwater site JWC experienced peak stream flows of 278 cfs on 7/2/11. The peak measured flow at the other headwater site SFM on the South Fork of the Poudre was 454 cfs on 6/20/11. Measurements for the July and August sampling dates were not collected at SFM due to river inaccessibility during high flows. It is expected that the actual peak flow was higher than that measured on 6/20/11 and that peak flow likely occurred around the first of July. Observed flows at JWC and SFM were somewhat higher than previous years 2008-2010. Peak flows at the high elevation site PJW (332 cfs on 7/5/11) were significantly lower than the exceptionally high flows seen the previous year (1,161 cfs on 6/21/10) but were similar to flows seen in 2008 – 2009. Note that discharge measurements were not collected on 6/20/11 at PJW.

Middle and Lower Mainstem. The lower reaches of the Mainstem CLP also experienced similarly high flows in 2011 as in 2010, as evidenced by stream flow values for PNF and PBD. The hydrographs for these sites show two peaks of similar magnitude, occurring on 7/1/11. The highest stream flow values observed at PNF and PBD were 3,272 cfs (7/1/11) and 3,430 cfs (7/1/11), respectively.

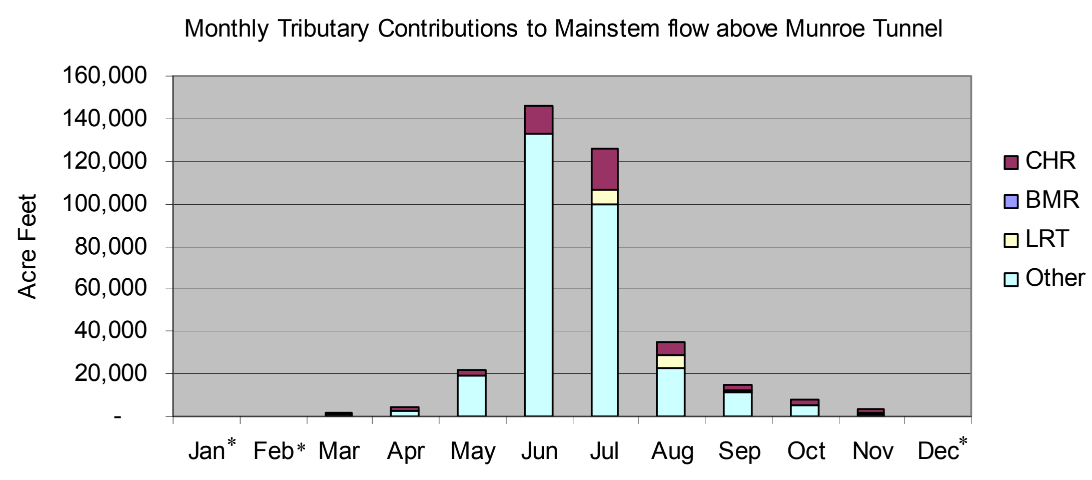
As expected, the timing and magnitudes of peak runoff at PBD were similar to PNF. Typically, the hydrograph for PBD tracks closely with PNF, as the Mainstem contributes the majority of flow at PBD, with relatively small contributions provided by North Fork flows out of Seaman Reservoir (NFG). Exceptions occur in years of greater than normal North Fork runoff or in the event of substantial releases from Seaman Reservoir, as was observed in 2008. Events contributing to the higher 2008 North Fork flows at NFG and PBD are detailed in the 2008 Upper CLP annual report (Oropeza and Billica, 2009).

Mainstem Tributaries. There are a number of tributaries and diversions that contribute to the overall stream flow and water quality of the Mainstem CLP above the North Fork. Table 2 details the actual and percent contributions of Barnes Meadow Reservoir outflow (BMR), Chambers Lake outflow (CHR) and the Laramie River Tunnel (LRT) to Mainstem flows, as measured above the Munroe Tunnel and North Fork confluence (PNF + Munroe Tunnel). Figure 17 is a graphical representation of proportional flows by month. Note that contributions from the South Fork of the Poudre (SFM) and Poudre above Joe Wright Creek (PJW) could not be estimated due to a lack of continuous flow measurements. The sum of contributions from these and other river segments and tributaries was calculated by subtraction, and categorized as “Other Mainstem Contributions”.

Table 2. 2011 tributary contributions by month to the Mainstem Cache la Poudre River above the Munroe Tunnel.

	Barnes Meadow Outflow (BMR)		Chambers Lake Outflow (CHR)		Laramie Tunnel (LRT)		Other Mainstream Contributions		Poudre above Munroe Tunnel	
	Total AF	%	Total AF	%	Total AF	%	Total AF	%	Total AF	%
Jan										
Feb										
Mar	141	7%	711	35%		0%	1,200	58%	2,053	------
Apr	268	7%	1,121	27%		0%	2,697	66%	4,086	------
May		0%	2,487	11%	687	3%	18,877	86%	22,050	------
Jun		0%	12,835	9%	90	0%	132,987	91%	145,912	------
Jul		0%	18,613	15%	7,504	6%	99,425	79%	125,543	------
Aug		0%	5,839	17%	6,216	18%	22,604	65%	34,659	------
Sep		0%	3,129	21%	1,098	7%	10,949	72%	15,176	------
Oct		0%	2,104	27%		0%	5,569	73%	7,674	------
Nov	267	8%	1,841	54%		0%	1,283	38%	3,390	------
Dec										

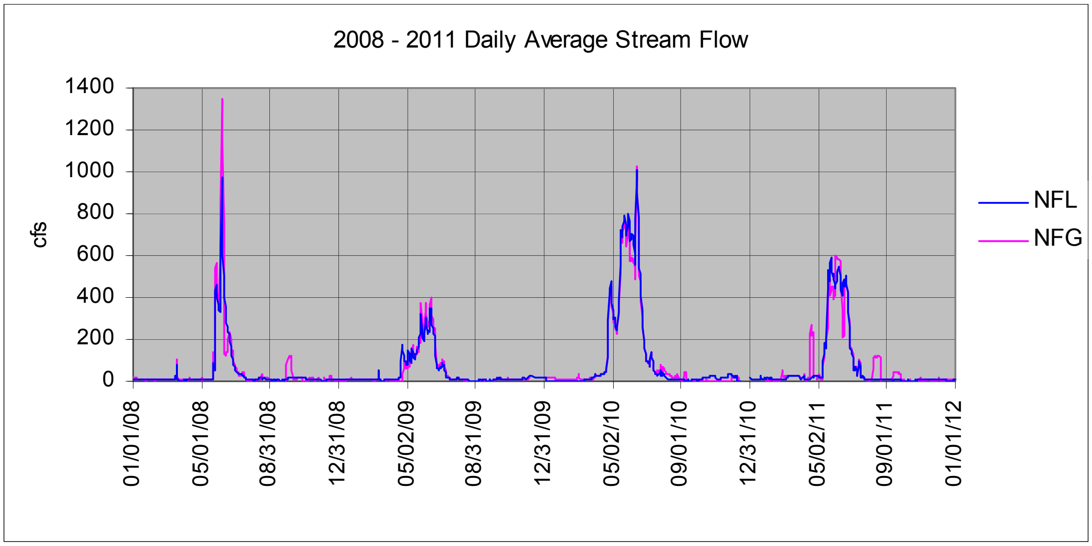
Figure 17. 2011 Tributary contributions by month to the Mainstem Cache la Poudre above the Munroe Tunnel.



* Continuous flow measurements were not available for calculating "other" flow contributions in Jan., Feb., or Dec.

3.1.2 North Fork CLP. Stream flows measured at NFL represent cumulative flows of the North Fork CLP above Seaman Reservoir and provide information about the timing and relative magnitude of spring run-off in the upper North Fork drainage. Stream flow measurements at NFG include contributions from both the North Fork and Seaman Reservoir and represent the total North Fork contributions to Mainstem flows (measured at PBD). Although stream flow at NFG is influenced by reservoir operations, the hydrographs for NFL and NFG are typically very similar (Figure 18) because during the period of highest flow (spring runoff) the majority of flow going into Seaman Reservoir is typically flowing over the spillway and not being stored. In 2011 there is a visible offset in the timing of peak runoff, which reflects the fact that Seaman Reservoir was not at capacity at the onset of spring runoff.

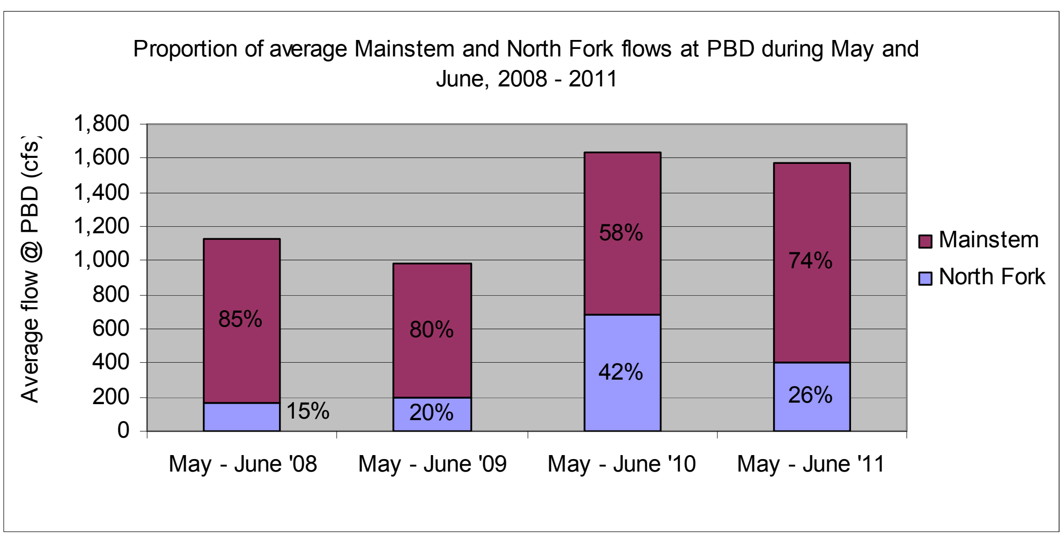
Figure 18. 2008 - 2011 Daily average stream flow at NFL and NFG



In 2011, peak stream flows at NFL and NFG were substantially less than in 2008 and 2010, yet slightly higher than 2009 peak flows. Hydrographs for both sites tracked closely, with similar flows recorded at both sites. Peak stream flows occurred on 5/25/11 at NFL and on 6/9/11 at NFG with values of 591 cfs and 602 cfs, respectively.

From 2008 – 2011 during the months of May through June, the North Fork has comprised, on average, 15% to 42% of Mainstem stream flow at PBD (Figure 19). The decrease in percent contribution of North Fork flows in 2011 from 2010 values is likely due to the fact that while peak runoff on the Mainstem was similar to 2010, peak runoff on the North Fork was lower than the previous year and Seaman Reservoir was not at capacity at the onset of spring runoff.

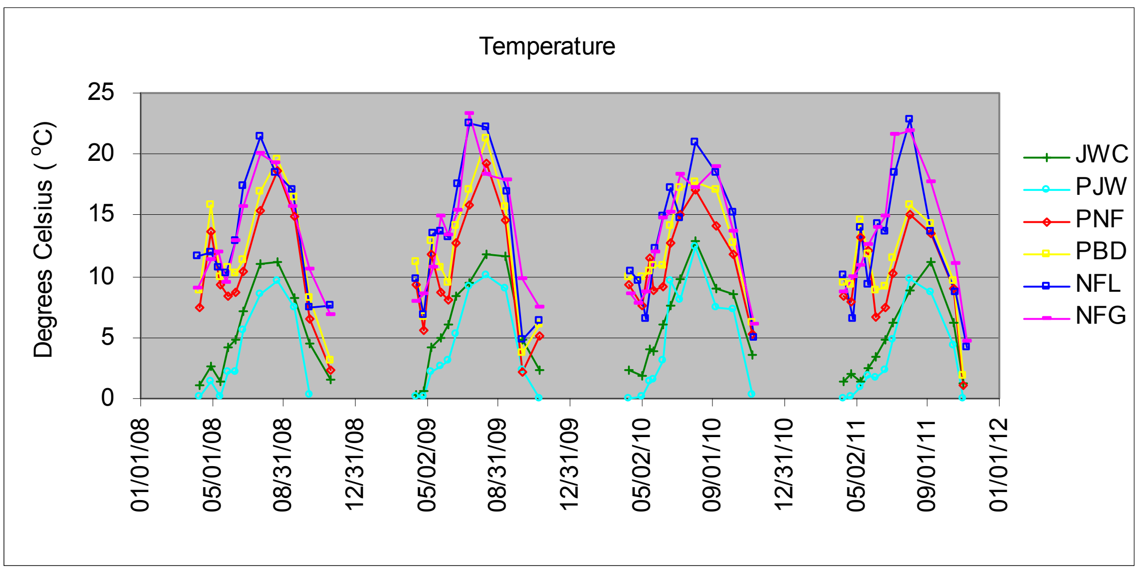
Figure 19. Proportion of average Mainstem and North Fork CLP flows at PBD during May and June from 2008 to 2011.



3.2 Water Temperature

Water temperature increases with decreasing elevation throughout the watershed (Figure 20). Peak temperatures occur mid-summer, with North Fork sites typically peaking a few days earlier than the Mainstem sites due to the influence of the warmer temperatures within this lower elevation drainage. In 2011, peak observed temperatures on the Mainstem and North Fork occurred on 8/1/11 and 8/2/11, respectively. The similarity between temperatures at NFG and NFL indicate that Seaman Reservoir did not have any discernible influence on North Fork water temperature. The difference in peak temperature between the North Fork and the Mainstem was more pronounced in 2011 than in previous years. The peak temperature of the North Fork below Seaman Reservoir (NFG) was 6.75 ^{o}C warmer than the peak temperature of the Mainstem above the confluence (PNF); however, the impact of North Fork flows on Mainstem temperature was relatively small. Mainstem temperatures increased by only 0.8 ^{o}C below the confluence (PBD) due to the small proportion of North Fork flows at this site.

Figure 20. Water temperature at key Upper CLP monitoring sites.



3.3 General Parameters: Conductivity, Hardness, Alkalinity, pH, and Turbidity

3.1.1 Conductivity, Hardness and Alkalinity. Conductivity is an index of dissolved ionic solids in the water and hardness is an index of the total calcium and magnesium in the water. Alkalinity is a measure of the effective acid buffering capacity of the water, and is derived, in large part, from the dissociation of mineral carbonates (CO_3^-), bicarbonates (HCO_3^-) and hydroxides (OH^-). Conductivity, hardness and alkalinity are influenced by the local geology as well as the dissolved constituents derived from other watershed activities. Across the watershed, these three parameters track closely, with minimum values occurring during peak run-off when the concentrations of all dissolved constituents are diluted by large volume flows, and high values occurring at times of low flow (Figure 21.a -21.c).

In general, conductivity, hardness and alkalinity increased with decreasing elevation. Accordingly, North Fork sites showed consistently higher values and greater variability for these parameters than Mainstem sites, which reflect the combined influences of differing geology and elevation. With the exceptions of 2008 spikes in hardness and alkalinity at NFG and the slightly higher 2011 late-summer values at NFG and NFL, the observed values at each site generally remained consistent between years.

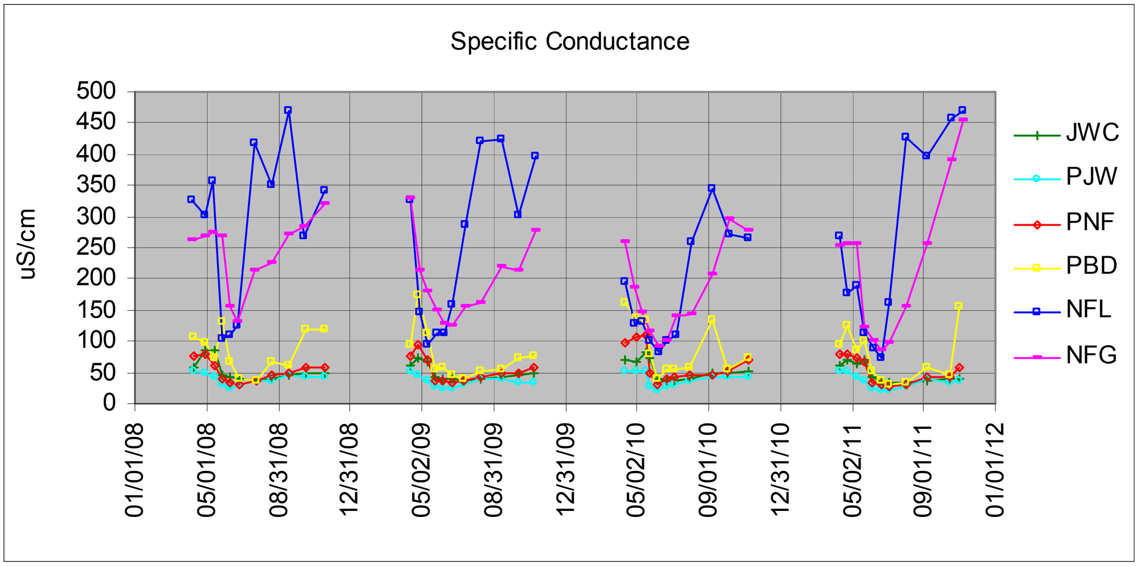
3.3.2 pH. In 2011, the pH of the Upper CLP waters followed similar patterns related to season and elevation as alkalinity, conductivity and hardness (Figure 21.d.). In general, the North Fork exhibited higher pH than the Mainstem. Exceptions occurred in 2009 - 2011 when pH values at PNF and PBD were the same or higher than North Fork sites prior to the onset of spring runoff. In 2011, pH values ranged from 6.9 – 8.3 on the Mainstem and from 7.3 – 8.7 on the North Fork. Mainstem values were within the range seen in previous years, while peak pH values on the North Fork were slightly higher in 2011. All sites experienced a sharp decrease in pH (0.7-0.9 units) during spring runoff. Following runoff, pH typically increases quickly at all sites; however, summer and fall pH trends vary between Mainstem and North Fork sites as well as between years.

3.3.3 Turbidity. In general, turbidity at all Mainstem and North Fork sites peaks during spring run-off, when higher volume and velocity flows increase the amount of sediment and organic material transported from the surrounding landscapes. Consistent with higher peak stream flows in 2010 and 2011, peak turbidity values were likewise elevated over the 2009 values on the Mainstem and the North Fork (Figure 21.e). 2011 peak values at the Mainstem sites PNF and PBD were 16.7 NTU and 14.0 NTU, respectively on 6/6/11.

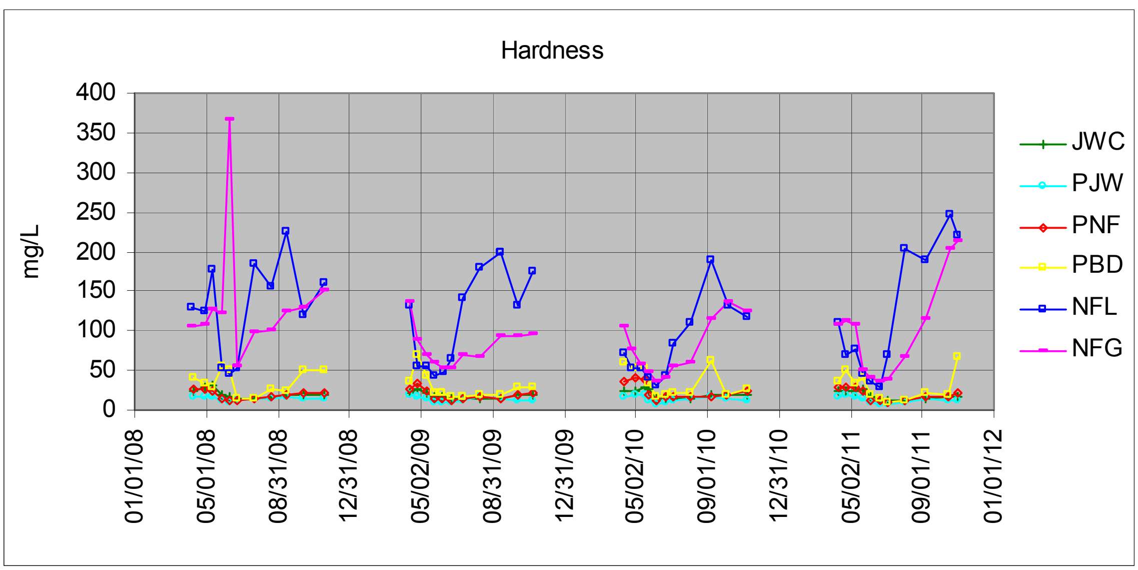
During spring run-off, North Fork turbidity values at NFL and NFG were 15.9 NTU and 11.0 NTU, respectively. While these North Fork sites also experienced higher turbidity in both 2010 and 2011 than in 2009, values were lower than in 2008 when a storm event on the North Fork coincided with large release of water from Seaman Reservoir (Oropeza and Billica, 2009). A second spike in turbidity occurred at NFG (25.9 NTU) on 9/6/11. As in previous years, this late summer spike coincided with a small increase in stream flow at NFG, but similar increases were not observed at nearby monitoring sites. This suggests that the turbidity spike was caused by a release of water and sediment from the bottom of Seaman Reservoir, but was not of sufficient quantity or duration to impact turbidity at downstream sites (PBD). During periods of low flow, turbidity was generally below 3.0 NTU at all Mainstem and North Fork sites.

Figure 21 (a – e). General water quality parameters at key Upper CLP monitoring sites: Conductance, Hardness, Alkalinity, pH and Turbidity

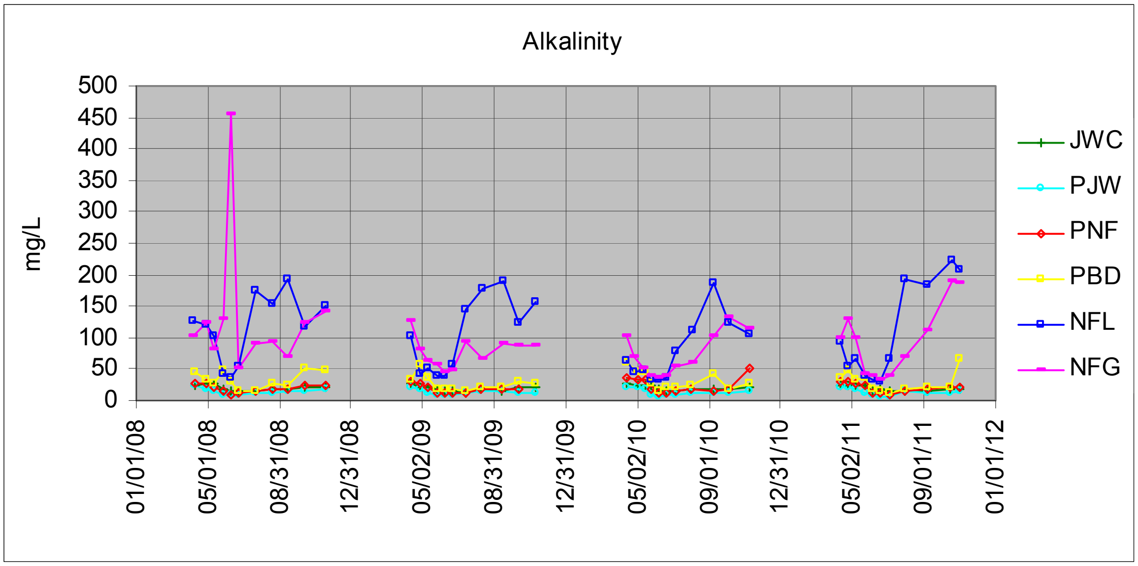
21.a. Conductance



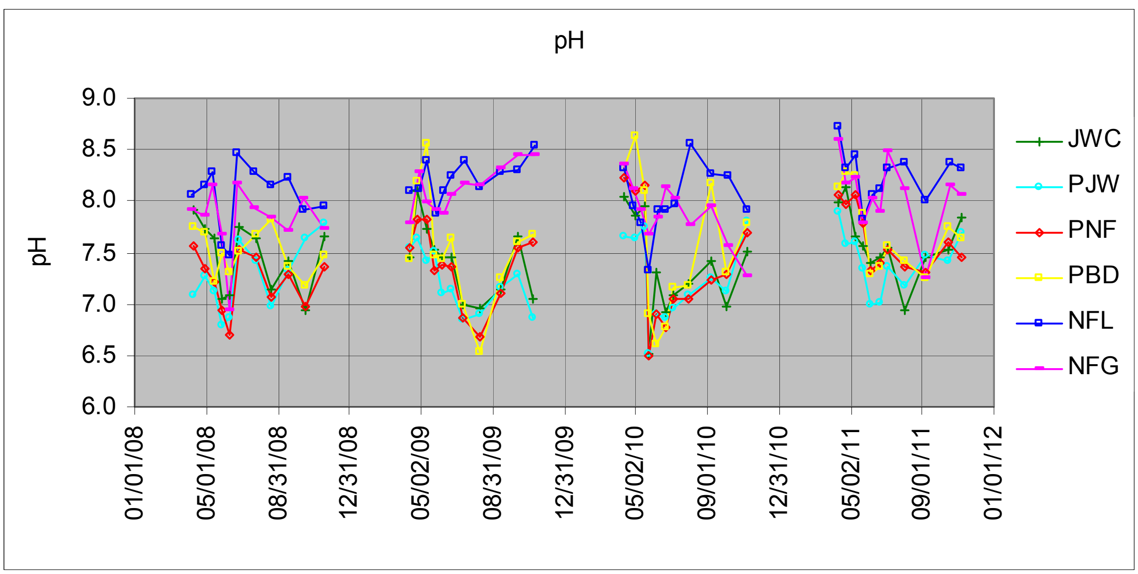
21.b. Hardness



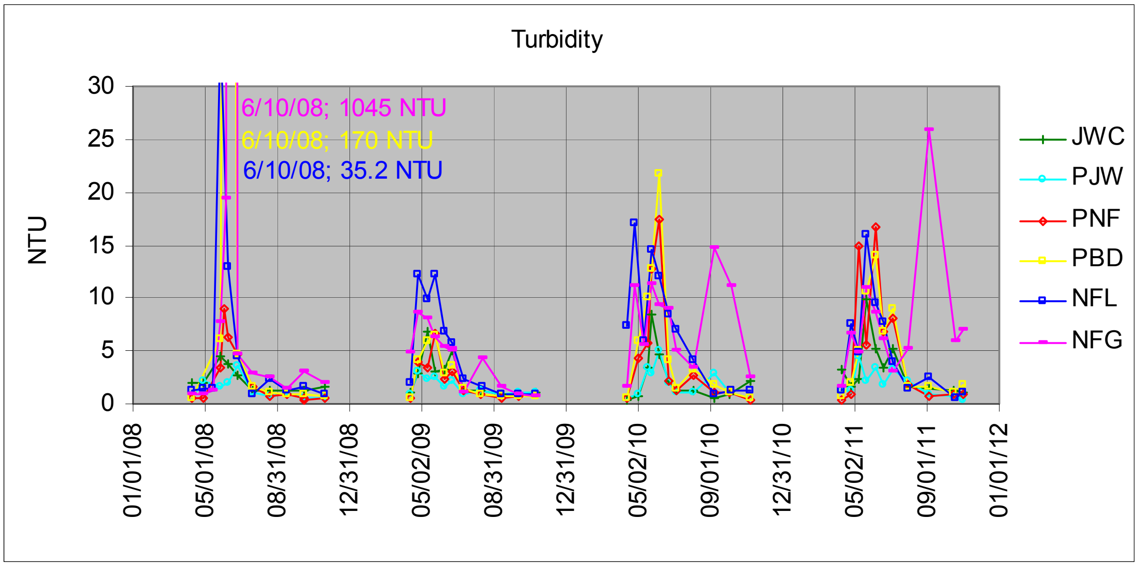
21.c. Alkalinity



21.d. pH



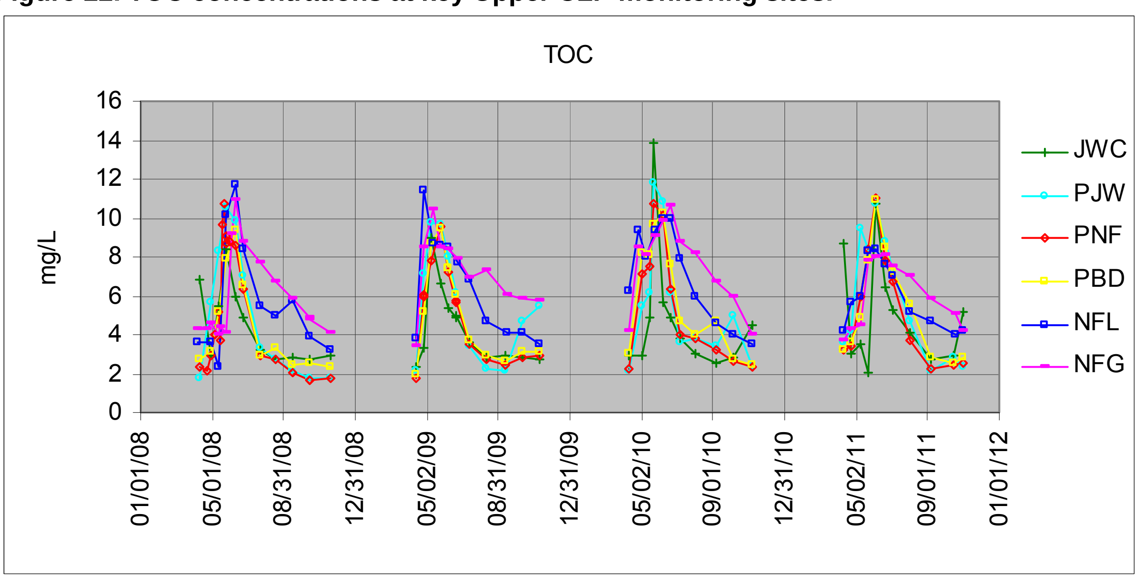
21.e. Turbidity



3.4 Total Organic Carbon (TOC)

Seasonal patterns of TOC concentrations in the upper CLP watershed are generally consistent year-to-year, with annual maximum TOC values occurring during the onset of spring snowmelt, as seen in years 2008 through 2011. The timing and magnitude of peak TOC concentrations is determined by factors that influence spring runoff, including snowpack and weather conditions of each basin. In general, the timing of peak TOC concentrations in the basins occurs within 1-2 weeks of each other; in 2011, peak runoff and TOC occurred a the same time. TOC concentrations typically decrease rapidly on the Mainstem following spring runoff, whereas concentrations on the North Fork remain relatively high throughout the year (Figure 22).

Figure 22. TOC concentrations at key Upper CLP monitoring sites.

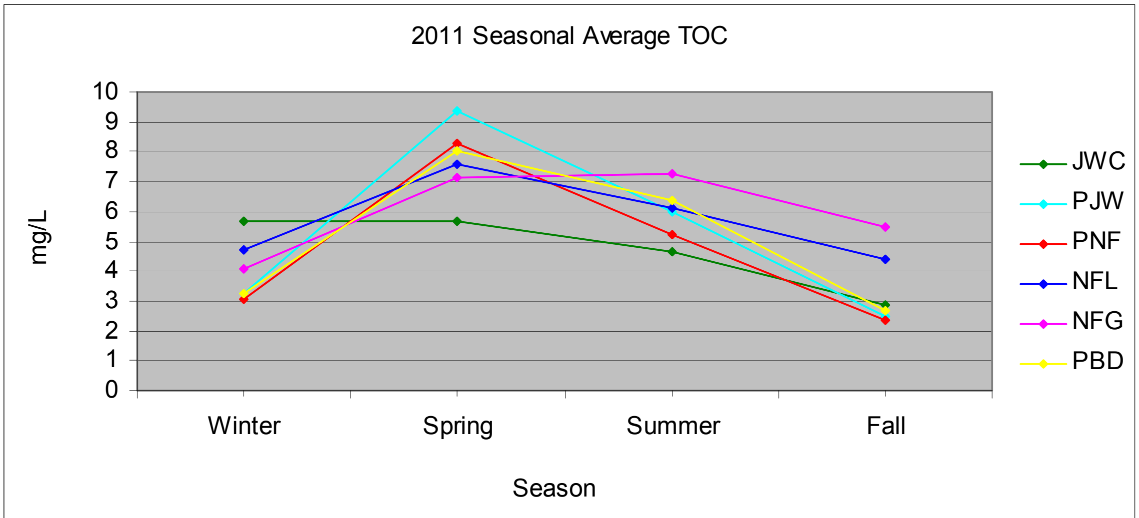


Mainstem. In 2011, the peak TOC concentration on the lower Mainstem at PNF was 11 mg/L on 6/6/11, which was similar to peak concentration in the previous three years at this site. The highest TOC concentrations on the Mainstem were observed in flows from the Laramie River Tunnel (LRT) and releases from Barnes Meadow Reservoir (BMR) during spring runoff and were 17.8 and 13.1 mg/L, respectively. Flows from BMR have historically resulted in exceptionally high concentrations of TOC entering into Mainstem flows due to boggy conditions within this sub drainage (Billica, Loftis and Moore, 2008). From 2008 – 2011, peak TOC concentrations ranged from 10.5 -13.8 mg/l at BMR and from 15.2 - 20.6 mg/L at LRT. Releases from these sources are, however, infrequent and of short duration, and therefore have little impact on source water supplies at PNF and PBD.

North Fork. The 2011 peak TOC concentrations on the lower North Fork (NFL and NFG) and the North Fork tributaries were considerably lower than the previous three years. The highest values were observed on the North Fork tributaries, Lone Pine Creek (PCM) and Rabbit Creek (RCM) and were 10.75 mg/L and 10.8 mg/L, respectively. The peak observed TOC concentration on the North Fork at NFL was 8.4 mg/L.

As usual, seasonal differences in TOC concentrations were also observed between Mainstem and North Fork sites. The North Fork TOC levels remained relatively high throughout the late summer season, after levels at Mainstem sites had decreased dramatically following spring runoff. This longer period of elevated TOC is reflected by the higher late summer and fall average TOC values at NFL and NFG (Figure 23). While TOC concentrations on the North Fork are generally higher than those observed on the Mainstem, the TOC loads carried by the Mainstem are greater due to substantially higher flow volume.

Figure 23. 2011 Seasonal average TOC concentrations at key Upper CLP monitoring sites.



* Winter (Nov-Dec'09, Jan-Apr'10); Spring (May-Jun); Summer (Jul-Aug); Fall (Sep-Oct)

The persistence of elevated TOC levels on the North Fork during periods of low flow can, in part, be attributed to the relatively low volume flows, especially during the summer. It may also indicate the presence of an additional source or sources of TOC other than that mobilized during spring snowmelt. Possible sources of this additional TOC in the North Fork include water released from Halligan and Seaman Reservoirs, and runoff from agricultural land within the North Fork basin.

3.5 Nutrients

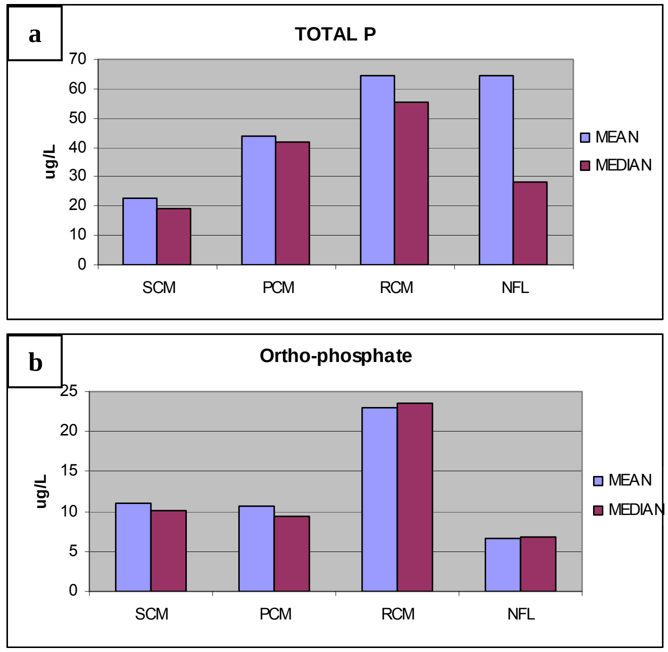
All Upper CLP samples were analyzed for a suite of nutrients, which includes ammonia (NH_4), nitrite (NO_2), nitrate (NO_3), phosphorus (TP) and ortho-phosphate (PO_4). For the purpose of this report, the discussion of results only pertains to values above the reporting limits currently used by the FCWQL for 2008 data and beyond. Current reporting limits are 5 ug/L for ortho-phosphate, 10 ug/L for ammonia and total phosphorus, and 40 ug/L for nitrate and nitrite.

Ammonia, nitrate, nitrite, and ortho-phosphate are dissolved forms of nitrogen and phosphorus that are readily available for plant uptake. Both TKN and total P serve as aggregate measures of potential nitrogen and phosphorus availability to the system. TKN is a measure of ammonia plus organic nitrogen. Total N is the sum of TKN, nitrate and nitrite. Likewise, total P is a measure of dissolved phosphorus as well as phosphorus bound to sediments and organic matter. In aquatic systems, sources of nutrients include animal waste, leaking septic systems, fertilizer run-off and sediment loading.

3.5.1 North Fork. In general, higher concentrations of nutrients were observed on the North Fork than at Mainstem sites, as reflected by values at NFL and NFG (Figures 25.a - 25.f). Although frequent spikes of ammonia, nitrate, ortho-phosphate and total phosphorus from 2008 – 2011 were observed at both sites, nutrient spikes at NFG were larger and more frequent because of the influence of Seaman Reservoir, especially in non-runoff times of the year. There were no exceedances of the EPA drinking water quality standard for nitrate (10,000 ug/L) or nitrite (1,000 ug/L) from 2008 - 2011.

Elevated concentrations of nitrate, Total P and TKN were observed at NFL and other upstream North Fork tributary sites during spring run-off. These higher concentrations likely occurr in response to flushing of sediment and dissolved nutrients during snowmelt. For the period 2008 – 2011, the North Fork tributaries, Rabbit Creek (RCM) and Lone Pine Creek (PCM), had higher median Total P concentrations than the lower North Fork site, NFL (Figure 22.a). Total P concentrations at RCM and PCM generally ranged from 26-164 ug/L, while concentrations at NFL ranged from 10 -160 ug/L. For the same period, PCM, Stonewall Creek (SCM), and particularly RCM had higher median concentrations of ortho-phosphate compared to NFL (Figure 22.b). Ortho-P concentrations ranged from 3.2 – 38.1 ug/L for on the upper tributaries, and from 2.1 – 13.1 ug/L downstream at NFL. The relatively high concentrations of nutrients in these small tributaries are due, in large part, to the relatively low flows, especially during the summer months, and represent small contributions to overall stream flow and nutrient loads at NFL.

Figure 24.a & 24.b. Mean and median concentrations of Total P and ortho-phosphate for the North Fork tributaries, SCM, PCM, RCM and NFL for 2008 - 2011.



The effects of reservoir releases on downstream nutrient concentrations can be seen at below Seaman Reservoir at NFG and below Halligan Reservoir at NBH. At NFG, late-summer peaks in Total P and ortho-phosphate and elevated ammonia concentrations were observed, and are indicative of low dissolved oxygen concentrations in Seaman Reservoir (See section 4.2). In 2011, the late season spikes in ammonia at NFG were unusually high with concentrations of 410 ug/L (10/18/11) and 338 ug/L (11/1/11). The high ammonia concentrations that were released from Seaman Reservoir (NFG) resulted in an observable increase in ammonia concentrations downstream at PBD. Similarly, spikes in ammonia were observed on the North Fork below Halligan Reservoir (NBH) in all years.

3.5.2 Mainstem. Nitrite and ortho-phosphate were generally not detected above reporting limits on the lower Mainstem (PNF). On the upper Mainstem, Barnes Meadow Reservoir (BMR) and Laramie River Tunnel (LRT) regularly experienced reportable concentrations of ortho-phosphate, while Joe Wright Creek (JWC), South Fork of the Poudre (SFM) and the Poudre above Joe Wright Creek (PJW) each had once instance of reportable concentrations, all which occurred in 2008.

Ammonia concentrations on the Mainstem were similar to the previous three years, which have generally remained below 50 ug/L. Releases from Barnes Meadow Reservoir (BMR) serve as the major exceptions, with concentrations ranging from 68 - 289 ug/L from 2008 through 2011. The upper Mainstem site, PJW, occasionally experiences a pulse of ammonia with the onset of spring runoff, which potentially results from an initial spring flush of inorganic soil N. In 2011, this seasonal peak was smaller than observed in 2010, but similar to 2008 and 2009. Elevated ammonia concentrations were also occasionally observed during low flows conditions from October – December. At the lower Mainstem site, PNF, ammonia concentrations have not exceeded 20 ug/L in the last four years.

In 2011, nitrate concentrations on the Mainstem generally followed similar seasonal pattern as was seen during the previous three years; a decrease in concentrations during spring runoff followed by an increase through the summer as stream flows subside. PJW typically experiences the highest peak nitrate concentrations among the Mainstem sites, but in 2011, the maximum observed concentration was observed during a strong, late-season spike in nitrate (300 ug/L) at PNF on 11/1/11. High concentrations are also occasionally seen in inflowing waters from Barnes Meadow Reservoir (BMR), Chambers Lake (CHR), Joe Wright Creek (JWC) and Laramie River Tunnel (LRT) in 2011. While the causes for the spikes in nitrate are not clear, the high concentrations were not sustained and did not affect nitrate concentrations at downstream locations.

It is notable that the two main dissolved forms of nitrogen, nitrate and ammonia experience different trends related to spring runoff. In high elevation, snowmelt dominated watersheds like the Upper CLP, some of the numerous factors that affect in-stream N availability include the amount of snowpack, the forms and concentrations of N stored in the snowpack from atmospheric deposition (Campbell et. al, 1995), the degree to which soil microbes are able to produce mineralized forms of N under the snowpack (Brooks et. al, 1996), as well as the degree to which snowmelt infiltrates the soil during runoff (Williams et. al, 2009). Because there is considerable temporal and spatial variability in the environmental factors that influence these processes across the watershed, it is therefore, not surprising that the timing and concentrations of these forms of nitrogen also differ in time and space.

Similar to the North Fork, the highest concentrations of TKN and Total P on the Mainstem typically occur during spring runoff, followed by sharp declines during the summer months. Total P follows similar trends as stream flow. In 2011, the peak Total P concentration at PNF occurred during spring runoff and at 55 ug/L, was significantly lower than in 2010, but higher than 2008 and 2009. The 2011 peak TKN concentration at PNF was 592 ug/L. Total N tracks closely with TKN, as TKN comprises the largest fraction of Total N, with nitrate and nitrite representing lesser fractions.

Proposed Nutrient Standards. In March 2012, the Colorado Water Quality Control Commission gave preliminary approval for a new Nutrient Control Regulation 85 and changes to Regulation 31, Basic Standards that would establish interim numerical values for Total Phosphorus (TP), Total Nitrogen (TN) and Chlorophyll for warm and cold water lakes/reservoirs and streams. The revisions to Regulations 85 and 31 are expected to be finalized by the Water Quality Control Division (CDPHE/WQCD) on May 14, 2012. Following approval, the interim values as outlined in Regulation 31 will be adoptable as standards for specific water bodies based on an implementation schedule and if warranted by special circumstances. In general though, the proposed standards currently serve only as water quality goals while the state moves forward with implementing nutrient standards in the future. In contrast, the Nutrient Control Regulation 85 establishes interim standards that become effective according to a compliance schedule for new and existing discharge permits.

All rivers and reservoirs within the Upper Cache la Poudre River Watershed are designated “cold” waters. For cold water streams, the proposed interim values are based on annual median values with a 1-in-5 year exceedance frequency. Proposed interim values are 1,250 ug/L for Total N and 110 ug/L Total P.

To evaluate the current status of the Mainstem and North Fork Cache la Poudre Rivers in respect to these proposed standards, annual median value for Total N (2008-2011) and the annual median values (2007 – 2011) for Total P were calculated for three river locations: PNF on the Mainstem above the Fort Collins water supply intake facility, PBD above the Greeley-Bellvue water supply diversion, and NFG on the North Fork below Seaman Reservoir (Table 3 and Table 4). Results indicate that the annual median Total N and Total P values at all three sites were well below the proposed interim values.

Table 3. Comparison of annual median Total N concentrations (ug/L) at Mainstem CLP and North Fork CLP sites to 2012 CDPHE/WQCD proposed interim TN value of 1,250 ug/L.

	2007	2008	2009	2010	2011
Poudre above North Fork (PNF)	-----	259.1	226.8	248.5	150.4
Poudre at Bellvue Diversion (PBD)	-----	247.7	329.0	214.9	477.4
North Fork Poudre at Gage below Seaman Reservoir (NFG)	-----	460.0	376.2	447.7	454.8

*All reported concentrations are expressed in ug/L.

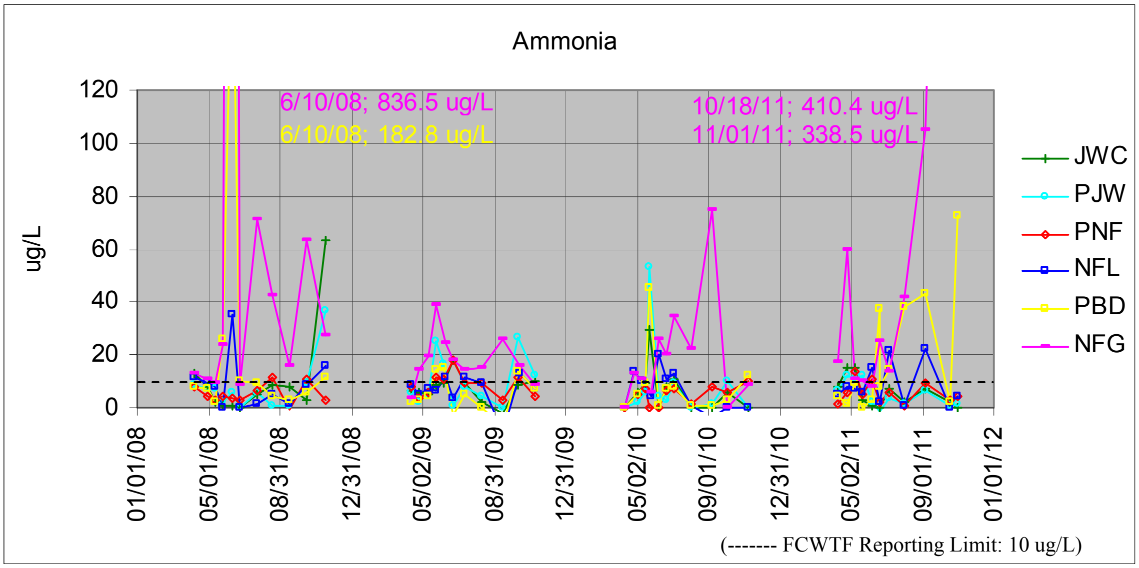
Table 4. Comparison of annual median Total P concentrations (ug/L) at Mainstem CLP and North Fork CLP sites to 2012 CDPHE/WQCD proposed interim TP value of 110 ug/L.

	2007	2008	2009	2010	2011
Poudre above North Fork (PNF)	9.6	8.6	12.7	14.7	21.2
Poudre at Bellvue Diversion (PBD)	10.2	11.7	15.6	17.0	16.2
North Fork Poudre at Gage below Seaman Reservoir (NFG)	51.3	23.3	30.2	38.8	32.2

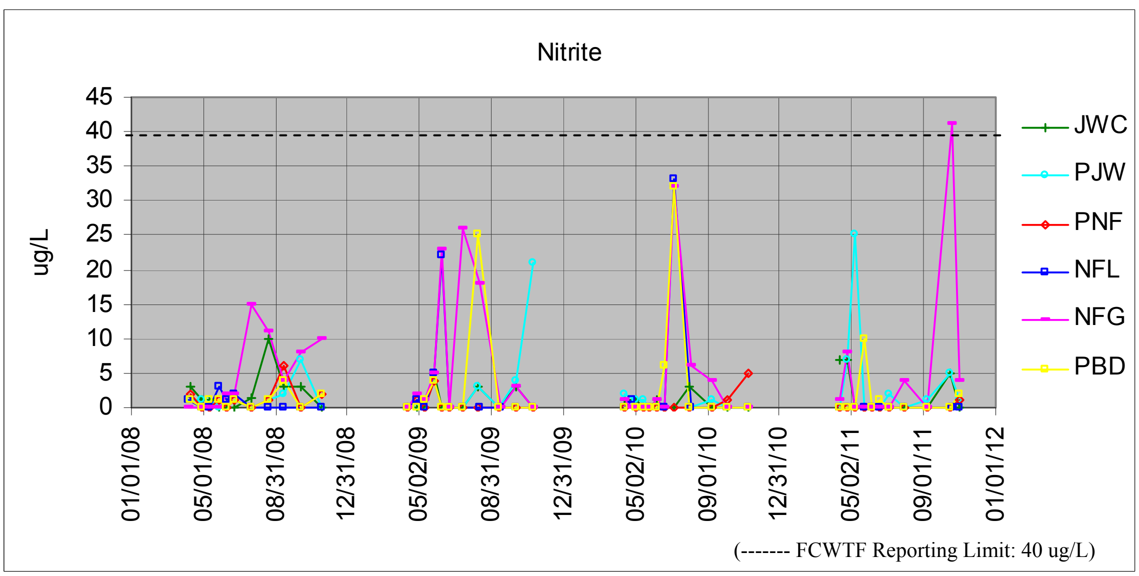
*All reported concentrations are expressed in ug/L.

Figure 25 (a-g). Nutrient concentrations at key Upper CLP monitoring sites.

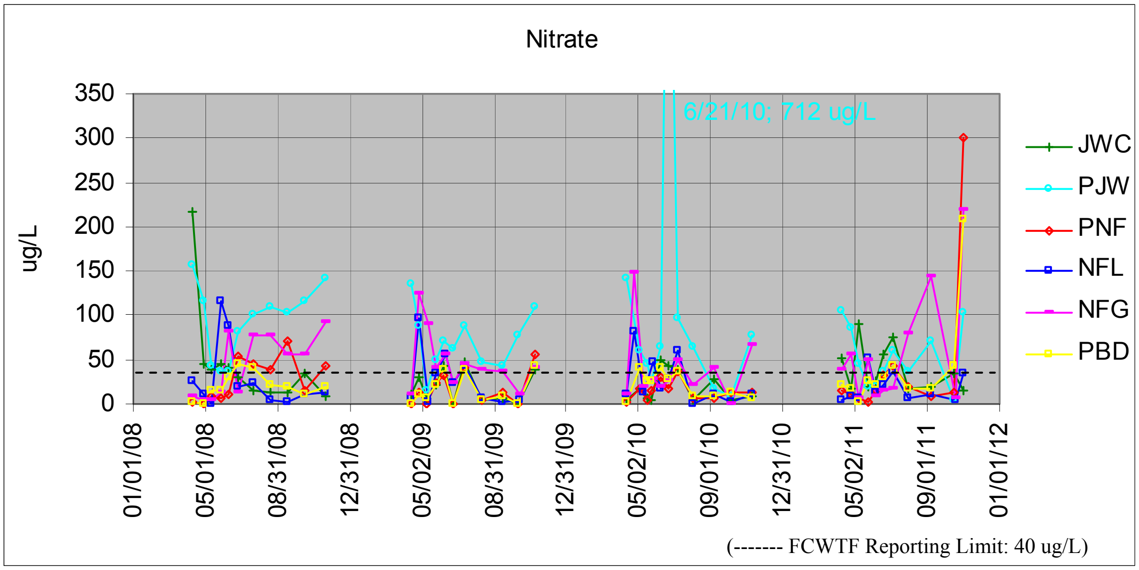
25.a. Ammonia (NH_3-N)



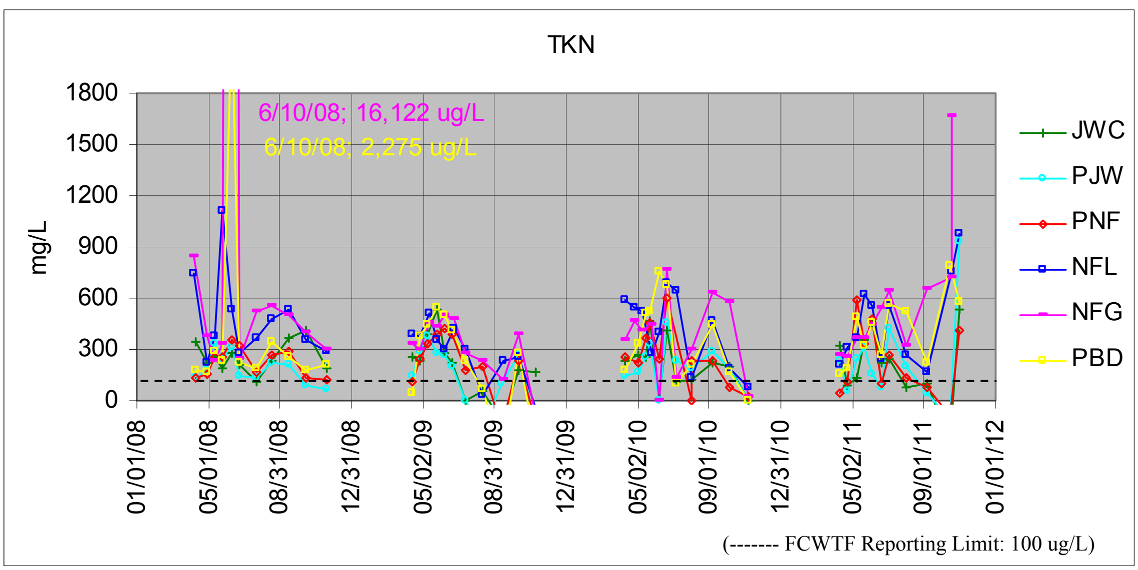
25.b. Nitrite (NO_2-N)



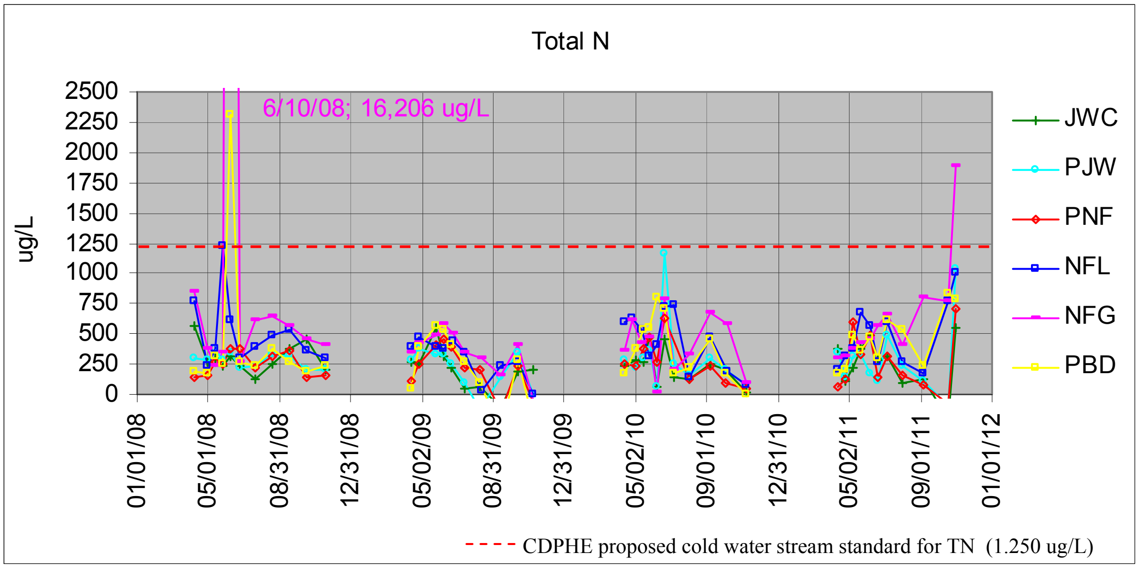
25.c. Nitrate (NO_3^-N)



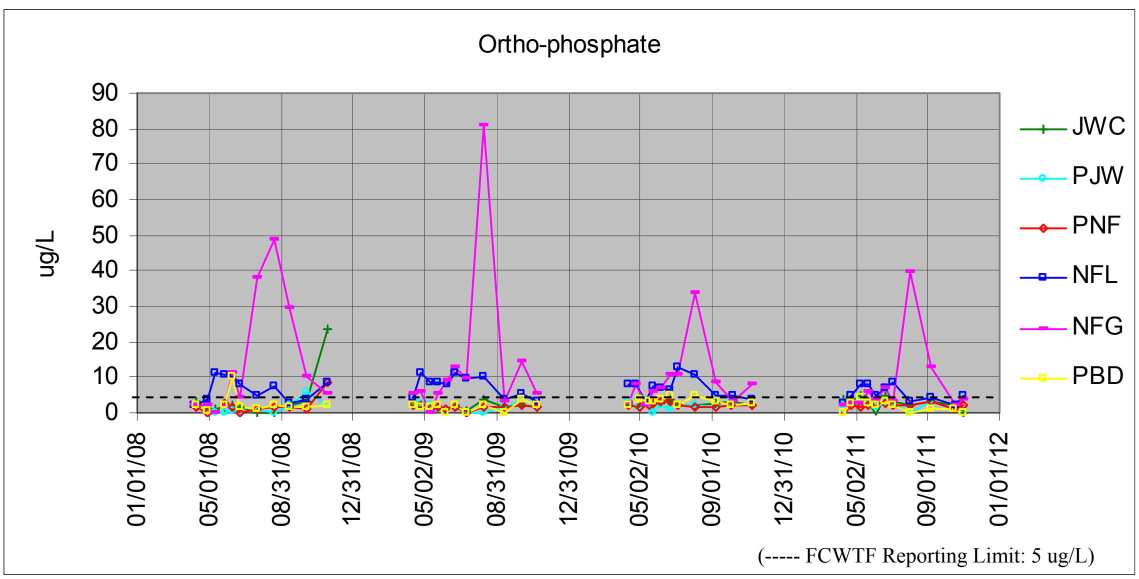
25.d. Total Kjeldahl Nitrogen (TKN)



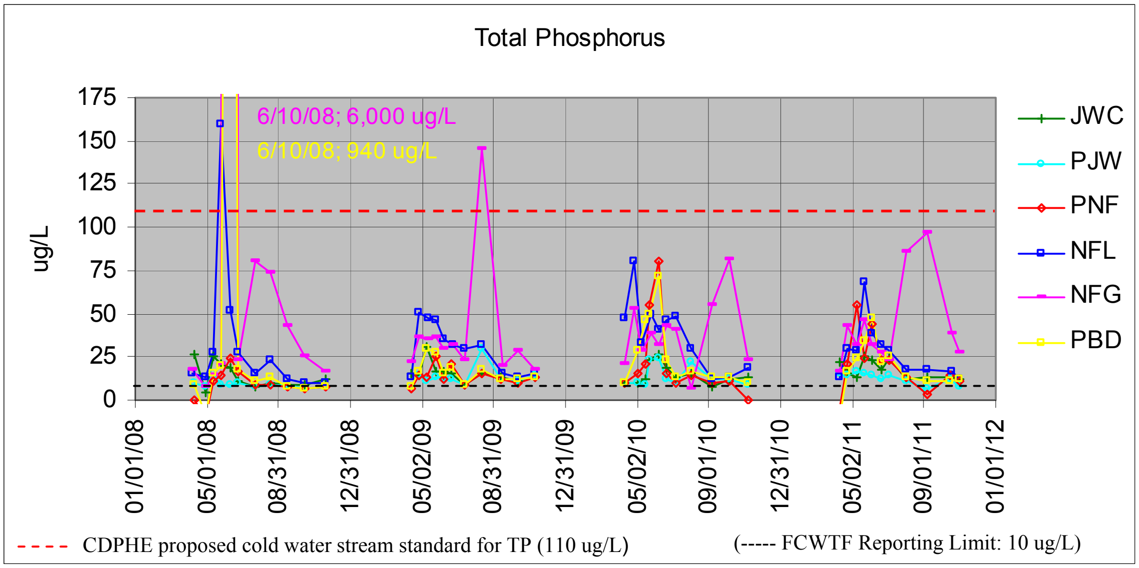
25.e. Total Nitrogen (TKN + NO_3+NO_2)



25.f. Ortho-phosphate (PO_4)



25.g. Total Phosphorus (TP)



3.6 Metals

Metals are routinely sampled twice annually on the Mainstem at PNF and on the North Fork at NFG. The spring sample was collected on 5/23/11 and a fall sample was collected on 10/18/11. All metals are analyzed for dissolved fractions except iron (Fe), which is analyzed for both total and dissolved fractions. In 2011, dissolved concentrations of silver (Ag), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) were not detected at concentrations above their respective reporting limits (Figure 26.a – 26.i).

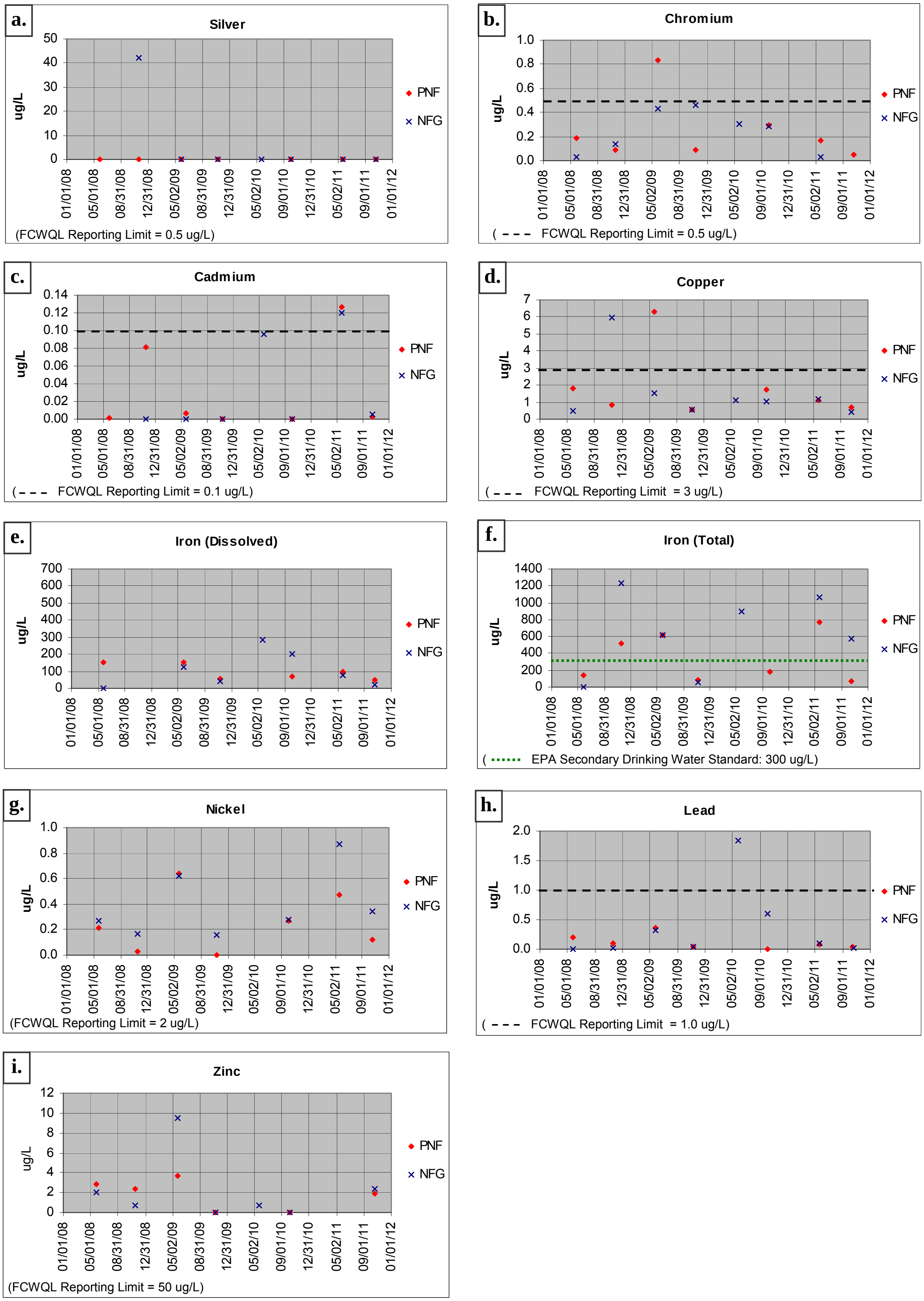
Reportable concentrations of cadmium (Cd) were observed at PNF and NFG during the spring sampling event (0.12 and 0.13 ug/L, respectively), but were significantly lower than the EPA drinking water standard of 5 ug/L.

Dissolved and total iron are the constituents most frequently observed at concentrations above reporting limits. In 2011, spring concentrations were higher than in the fall, as seen in previous years. The spring and fall concentrations of dissolved iron on the Mainstem at PNF were 49 ug/L and 99 ug/L, respectively. The North Fork at NFG had significantly lower spring and fall dissolved iron concentrations than observed in 2010 (74 and 19.8 ug/L, respectively). Concentrations of dissolved iron at NFG and PNF did not differ significantly between years, with the exception of 2010.

As expected and seen in previous years, total iron concentrations were significantly higher than the dissolved fraction at both NFG and PNF. From 2008 to 2011, concentrations have ranged widely, from 4 - 1,277 ug/L. Both sites routinely experience total iron concentrations above the EPA secondary drinking water maximum contaminant level (MCL) for total iron (300 ug/L).

The secondary drinking water MCLs are guidelines for constituents that may cause aesthetic effects such as discoloration, but do not pose a threat to public health. Because water treatment processes remove much of the iron in raw water supplies, the iron concentrations reported for the Upper CLP are not expected to have adverse effects on finished water quality.

Figure 26 (a-i). Metals concentrations at PNF and NFG.



3.7 Pathogens: *Cryptosporidium* and *Giardia*

Cryptosporidium and *Giardia* testing on the North Fork sites above and below Halligan Reservoir (at NDC and NBH, respectively) began in 2006. In 2008, the NDC sampling site was moved upstream of the confluence with Dale Creek to accommodate potential future expansion of Halligan Reservoir. This site represents the water quality of the North Fork flows, above Dale Creek, as source waters to Halligan Reservoir. Samples on the Mainstem Poudre are collected from the raw Poudre water supply at the FCWTF, but are considered representative of values at PNF since there are no additional inflows to the water supply between the intake structure at PNF and the FCWTF.

Giardia is more abundant than *Cryptosporidium* on both Mainstem and North Fork (Figure 27 and 28). From 2008 - 2011, *Giardia* was present at levels ranging from 0-36 cysts/L, whereas *Cryptosporidium* was frequently not detected; values did not exceed 0.8 cysts/L. 2011 concentrations were similar to previous years at all sites.

From 2008 – 2011, the North Fork at NDC consistently had the highest seasonal maximum *Giardia* concentrations, which ranged from 24-36 cysts/L. In comparison, the maximum Mainstem (PNF) concentrations were somewhat lower, ranging from 10-20 cysts/L, while the outflows from Halligan and Seaman Reservoirs (NBH and NFG, respectively) consistently had the lowest *Giardia* concentrations. In contrast, *Cryptosporidium* concentrations were relatively very low at all sites. As with *Giardia*, the highest concentrations of *Cryptosporidium* were observed on the North Fork above Halligan Reservoir at NDC. Concentrations ranged from 0 - 0.5 cysts/L, whereas concentrations on the Mainstem at PNF did not exceed 0.2 cysts/L.

Giardia was generally not detected below Seaman Reservoir at NFG. In contrast, *Cryptosporidium* is occasionally detected at low numbers in the past three years, with the highest value occurring on 4/14/09 (0.78 cysts/L).

Figure 27. Concentrations of *Giardia* on Mainstem and North Fork CLP.

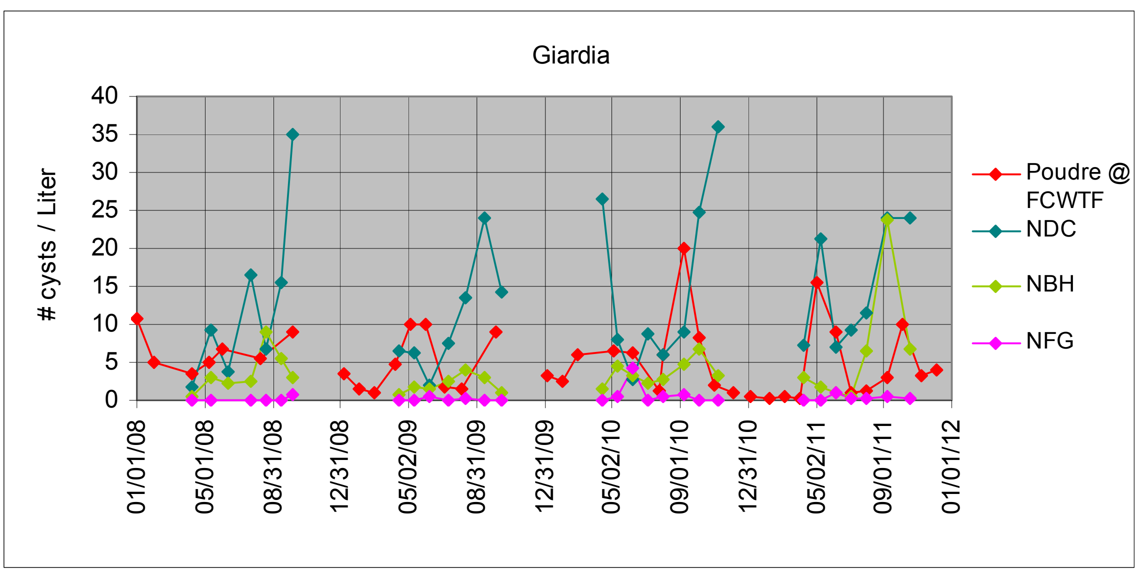
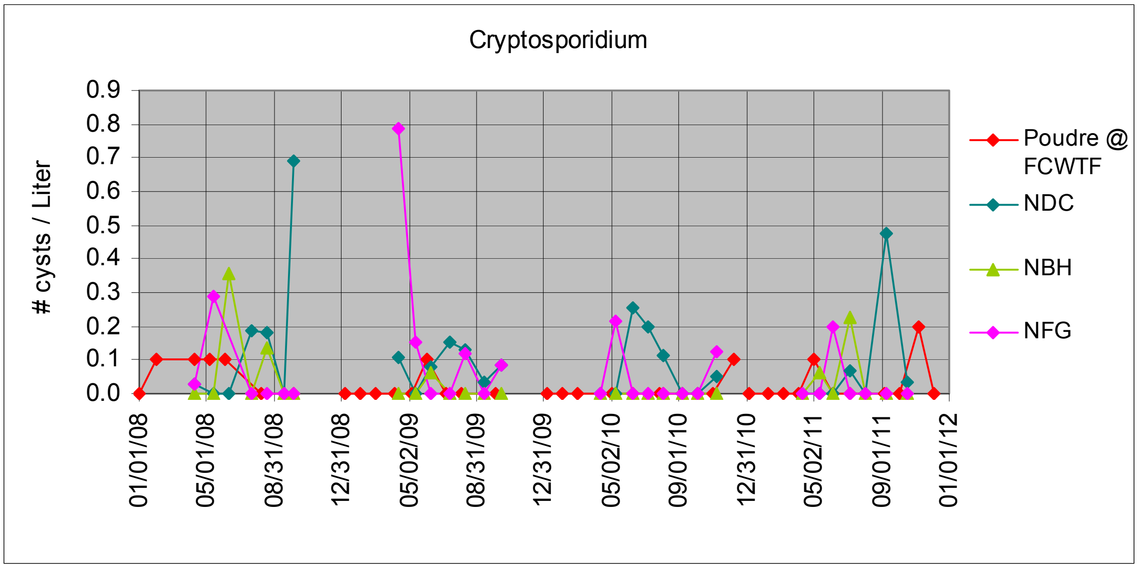


Figure 28. Concentrations of *Cryptosporidiu*m on Mainstem and North Fork CLP.



3.8 Total Coliforms and *E. coli*

Samples from four sites – NFL, NFG, PNF and PBD - were analyzed for total coliforms and *E.coli*. NFL was added as a sample site in 2009 to gain a better understanding of the sources of total coliforms and *E. coli* within the North Fork watershed. An error in the 2011 sampling plan resulted in no samples being collected at one of the North Fork sites, NFL in 2011. As a result, a comparison of total coliform concentrations above and below Seaman Reservoir could not be made for 2011. The error was corrected and sampling at this site will resume in 2012.

In 2011, peak values for both *E. coli* and total coliforms at PNF were lower than the previous year (Figures 29 and 30). In general, PBD had similar concentrations of total coliforms and *E. coli* concentrations as PNF. The major exceptions occurred on 6/10/08, when spikes in *E.coli* occurred in response to the unusually high spring run-off on the North Fork, and on 8/2/10 when *E.coli* concentrations at PBD more closely represented an average of the low concentration at NFG and the higher concentration at PNF.

Consistent with previous years' results, the North Fork showed higher concentrations of both total coliforms and *E.coli* than the Mainstem in 2011. As usual, NFG experienced mid- to late-summer peaks in total coliform and *E.coli* concentrations. The annual maximum concentrations at NFG were 190 cfu/100ml and 6,931 cfu/100ml for *E.coli* and total coliforms, respectively.

Previous years' results suggest that the North Fork drainage is an important source of *E.coli* and total coliforms to Seaman Reservoir, although there is no clear relationship between concentrations above (at NFL) and below the reservoir (at NFG). The lack of direct relationship is likely due to a complex set of interacting factors, some of which may include the timing and magnitude of stream flow at NFL, reservoir holding time and release rates. The relationships between total coliforms and *E.coli* concentrations on the North Fork and in Seaman Reservoir are explored in more detail in Section 4.7.

The data show that over the last three years, concentrations of *E.coli* at NFL and NFG have exceeded the CDPHE recreational standard of 126 colonies/100mL. The Mainstem sites PNF and PBD were consistently below the standard with the exception of one exceedance each in 2010.

Figure 29. Concentrations of total coliforms at key Upper CLP monitoring sites

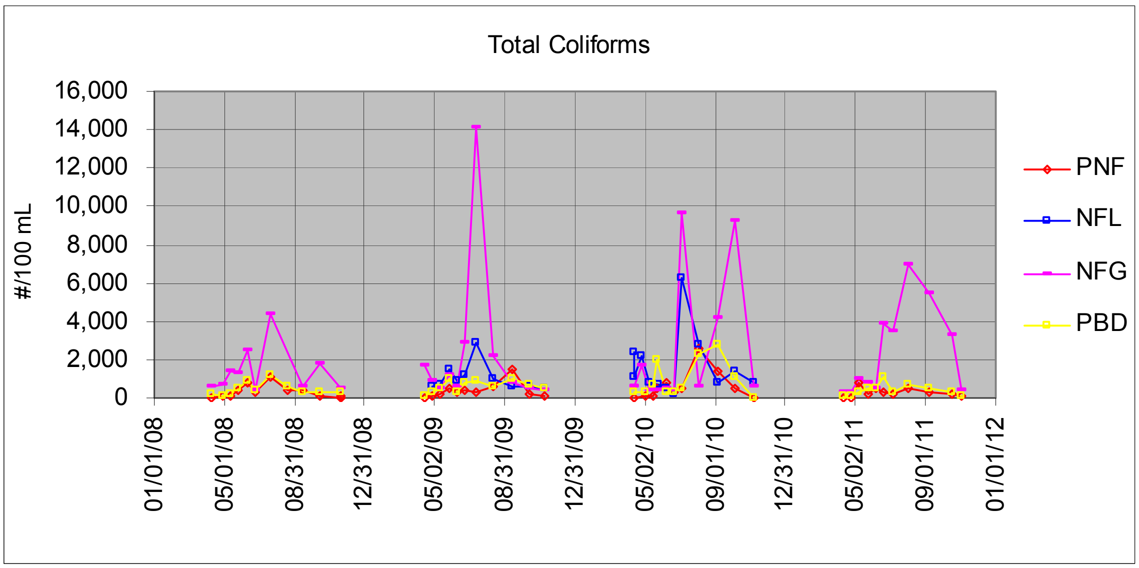
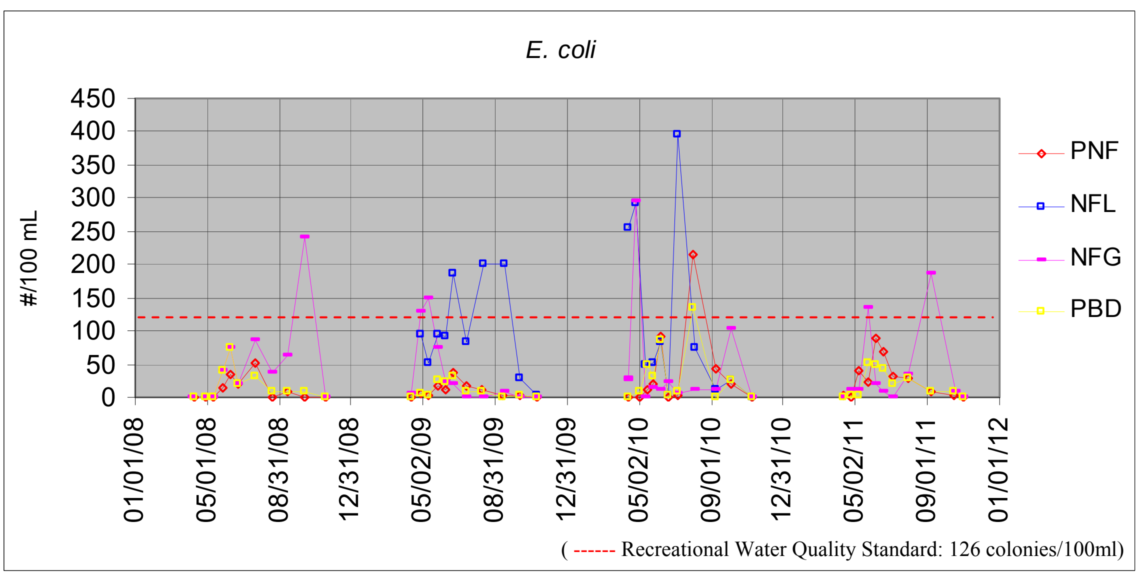


Figure 30. Concentrations of *E. coli* at key Upper CLP monitoring sites.

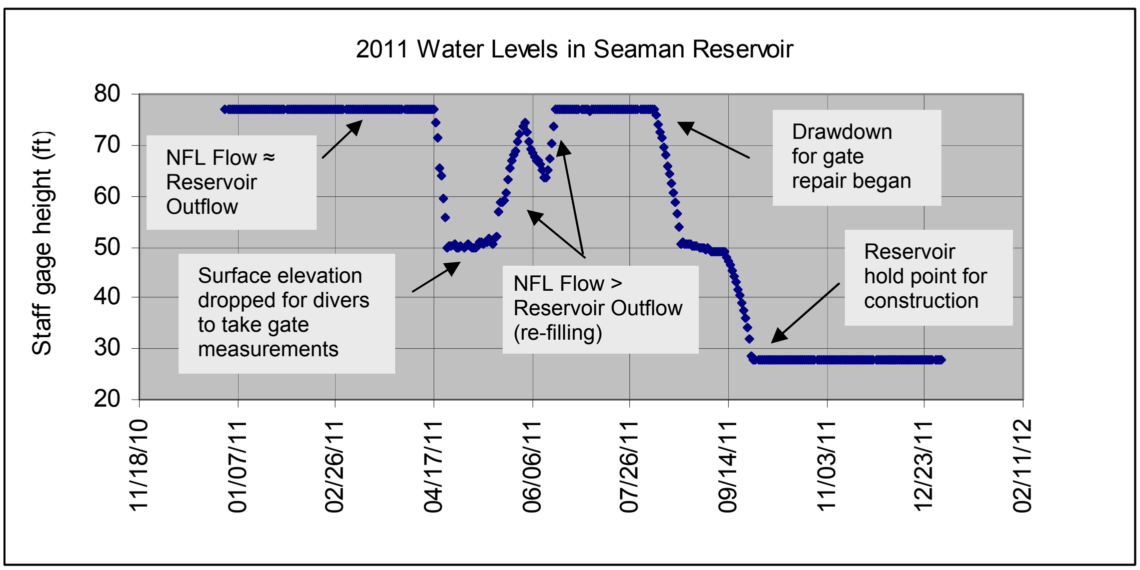


4.0 SEAMAN RESERVOIR RESULTS

4.1 Reservoir Operations

From January through mid-April of 2011, Seaman Reservoir was at full capacity with water levels at 77 ft, or 23.3 m. (Figure 31). During this period, reservoir outflows were released over the spillway and closely approximated the incoming flow from the upper North Fork watershed (NFL). Beginning in mid-April the water level in the reservoir steadily decreased to 50 ft in mid-May so that divers could take initial measurements in preparation of repair work on the head gates. The reservoir was brought back up to capacity by 6/18/11 and the stage height remained at 77 ft until 8/8/11, when the drawdown was initiated for head gate repair work. The reservoir reached a minimum stage height of 28 ft on 9/26/11. The surface elevation of the reservoir remained at 28ft for the duration of the year to accommodate repair work. While the reservoir was below capacity (< 77 ft), all releases to NFG occurred via the bottom outlet of the reservoir. Information related to the operations of Seaman Reservoir was provided by Randy Gustafson, with the City of Greeley.

Figure 31. 2011 water levels in Seaman Reservoir.



4.2 Temperature, Dissolved Oxygen, pH, and Conductivity Profiles

The 2011 Seaman Reservoir profiles for temperature, dissolved oxygen, pH and specific conductance are shown in Figure 32.a-32.d. In 2011, the surface elevation of the reservoir fluctuated dramatically to facilitate repair work on the head gates the bottom outlet structure. There were two distinct draw-down periods, the first of which occurred during April and the second, which occurred at the beginning of August. During these periods, the reservoir depth was far below average, and precluded sampling during the scheduled September sampling event.

The changing depth of the reservoir resulted in an atypical pattern of thermal stratification within the reservoir. Between mid-June and early-August, the reservoir was at capacity. During this time, the warm temperatures and stable water depth fostered the establishment of shallow thermocline for a brief period of time (observed on 8/2/11) before the second draw-down began (8/8/11) (Figure 32.a). Although there was not a strong separation of upper and bottom waters during the summer months, there was a distinct and visible gradient of temperatures from the top to the bottom of the reservoir from June to August. Water temperatures at depth were similar to the previous year, although surface temperatures were slightly higher. The temperature profiles indicate that water temperatures at the surface exceeded the aquatic life temperature standard of 22.5° C on 8/2/11, with a maximum observed temperature of 23.4^{o} C. Following the draw-down, the reservoir was held at 28 ft. or 8.5m depth from September through November. During this time, water temperatures were generally uniform from the top to bottom of the water column.

In most water bodies, dissolved oxygen profiles develop a *positive heterograde*, where concentrations are highest in the upper waters of a reservoir and decrease with depth. However, in previous two years, profile development in Seaman Reservoir differed from this expected pattern during mid-summer months. In 2009 and 2010, the reservoir profile presented as a *negative heterograde*, meaning that D.O. minima were observed in the metalimnion and were underlain by higher D.O. concentrations. In 2011, a slight negative heterograde was observed on the late-June sampling event, but it did not persist through July and August.

Regardless of duration, these periods of low oxygen can limit suitable habitat for aquatic life. Seaman Reservoir was officially added to the 303(d) list of impaired waters in 2010 due to occurrences of D.O. below 6 mg/L in the metalimnion combined with exceedances of the temperature standard in the epilimnion (adequate D.O. refuge for fish is not available in these types of situations). Although the metalimnion was not well defined in 2011, the D.O. concentrations at intermediate depths (3-7m) fell below the 6 mg/L threshold on 8/2/11 (4.8 mg/L at 7m) (Figure 32.b).

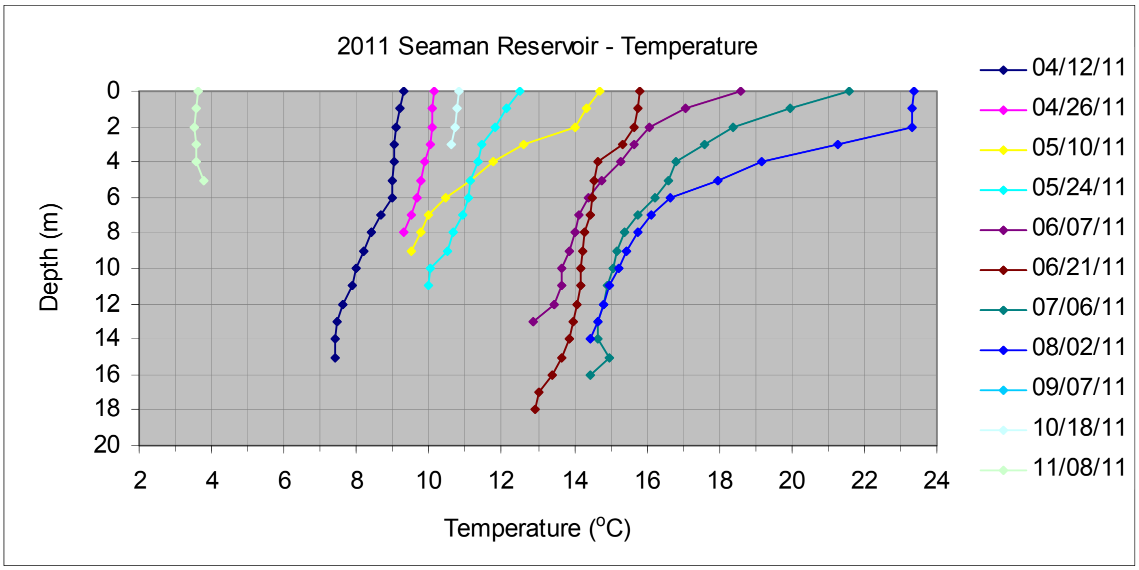
As observed in previous years, the concentration of D.O. in the lower waters decreased progressively throughout the season (Fig 32.b). Dissolved oxygen concentrations at the bottom of the reservoir approached near-anoxic conditions (0.8 mg/L) by early August. Because of the lack of September sampling data, the duration of low bottom D.O. concentrations in 2011 is not known. However, prolonged periods of low D.O. concentrations at the bottom of the reservoir have been observed in previous years (Figure 33) and are of concern because they can mobilize trace metals (e.g. manganese) and phosphorus from the bottom sediments.

In general, pH decreases with decreasing temperature and D.O. concentrations. As expected, Seaman Reservoir profiles show that pH minima occur at the bottom and during the summer months when D.O. was also at a minimum. The 2011 pH values ranged from 7.7 to 8.7 at the surface and 7.1 to 8.1 at the bottom (Figure 32.c). These values fall within the pH water quality standard of 6.5 to 9.0.

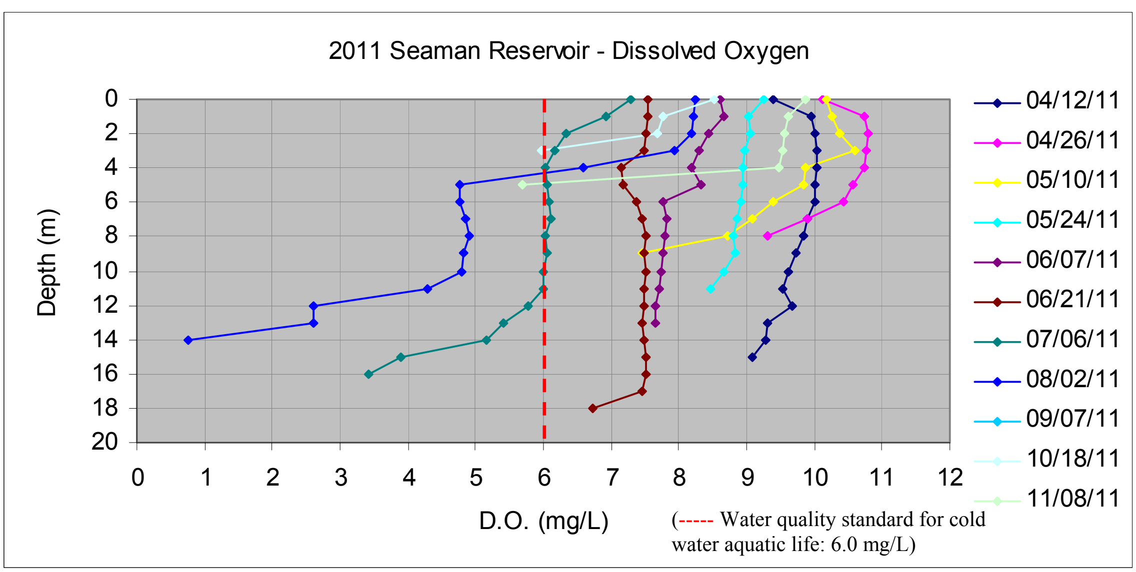
Specific conductance values in April to early May 2011 were considerably higher than the previous year, but fell to within a similar range of values from late-May through July (Figure 32.d). In October and November, when the reservoir was very shallow, specific conductance was very high, ranging from 418-492 uS/cm. These high values are likely due to the increased amounts of dissolved and suspended sediments near the bottom of the reservoir. The only time that the top and bottom values varied substantially was the August sampling event, when thermal stratification was evident.

Figure 32 (a-d). 2011 Seaman Reservoir Profiles

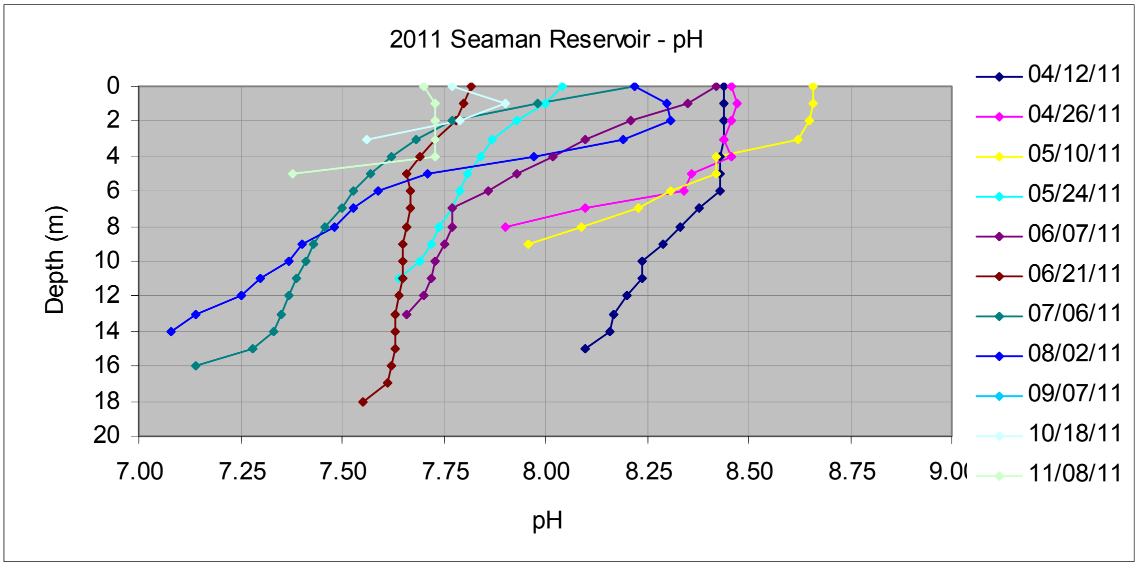
32.a Temperature



32.b. Dissolved Oxygen



32.c. pH



32.d. Specific Conductance

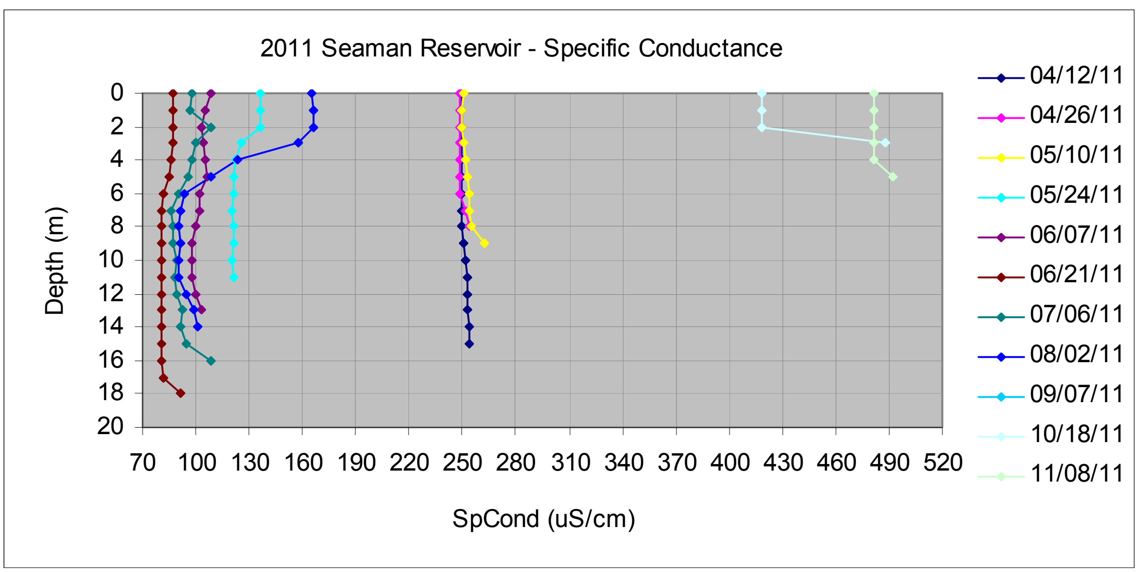
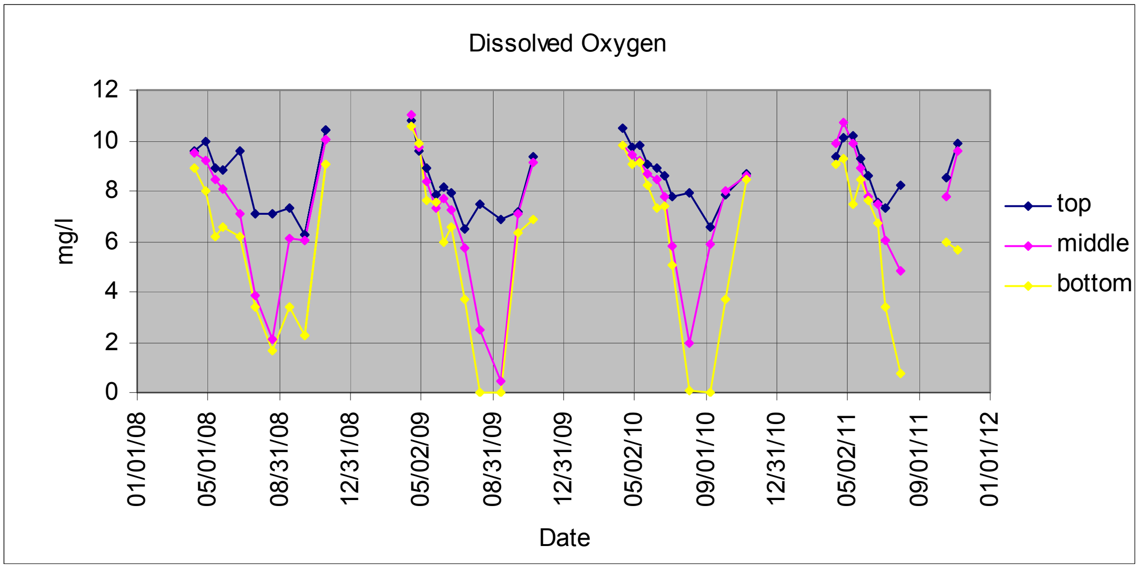


Figure 33. Dissolved oxygen concentrations at the top, middle and bottom of Seaman Reservoir.

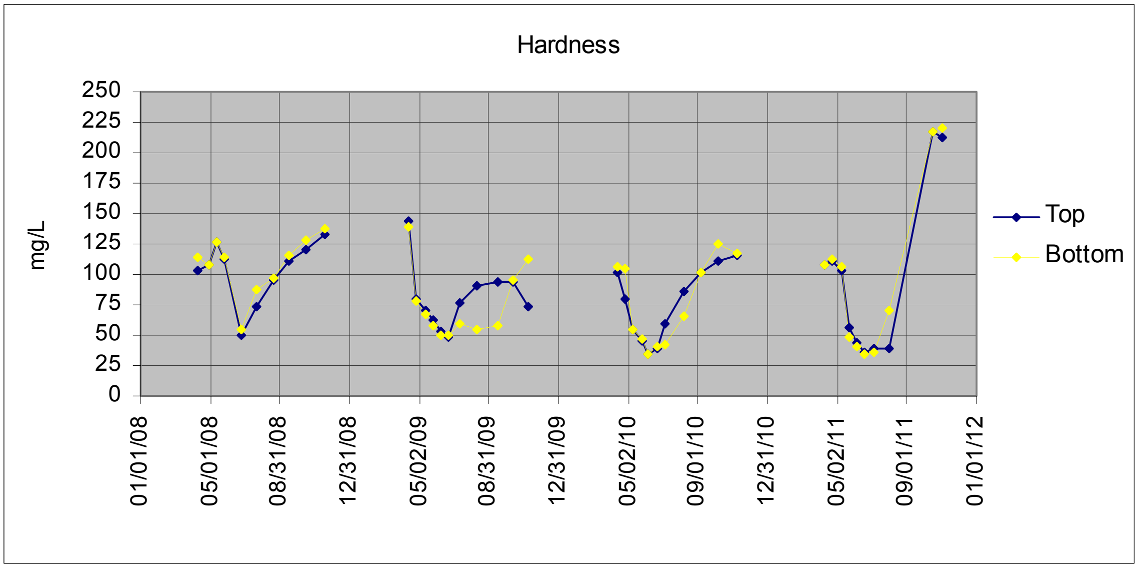


4.3 General Parameters: Hardness and Alkalinity

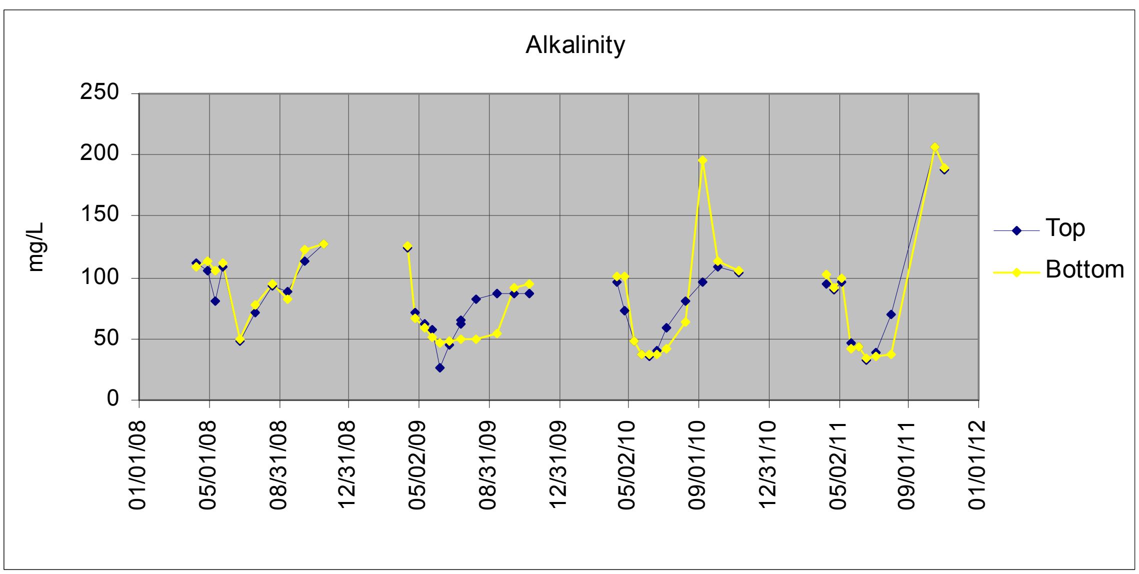
Both hardness and alkalinity track closely to eachother and on the reservoir top and bottom (Figure 34.a and 34.b). Both parameters experience minimum values during spring runoff. Despite irregular reservoir operations, the 2011 seasonal trend was similar to 2008-2010 during which a significant spring decrease in hardness was observed, followed by a steady return to early spring values. In 2011, late-season values were exceptionally high for both parameters; hardness and alkalinity both increased by approximately 150 mg/L between the August and the November sampling event. These high values correspond with the high specific conductance measurements in November and are likely due to large amounts of suspended and dissolved sediments near the bottom of the reservoir. With the exception of these late season spikes, all values for alkalinity and hardness were within the range of values seen in previous years.

Figure 34 (a-b). General water quality parameters at Seaman Reservoir: Hardness and Alkalinity.

34.a. Hardness as $CaCO_3$



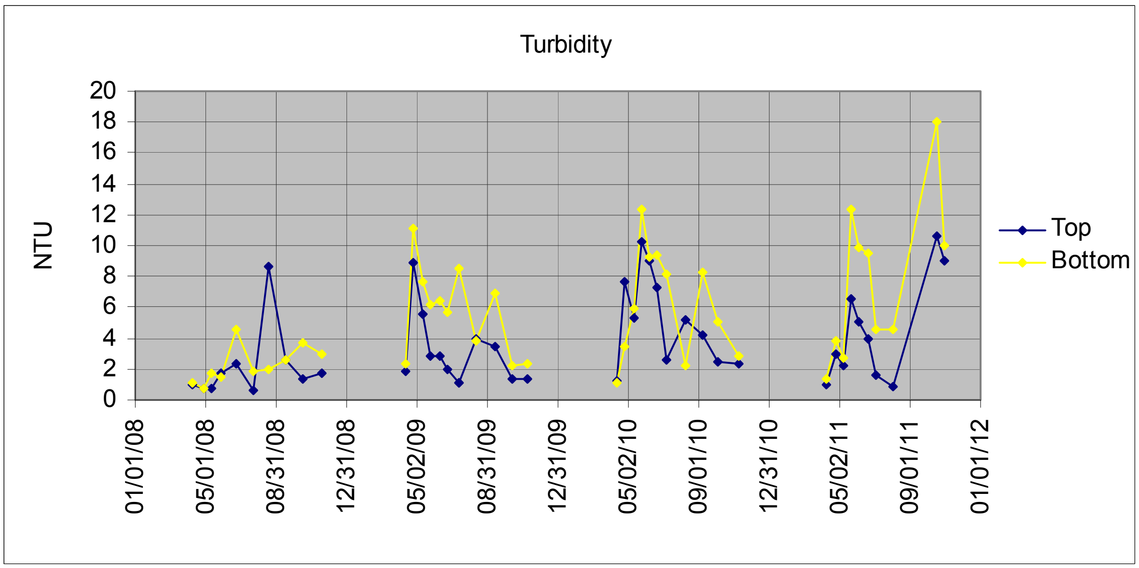
34.b. Alkalinity as $CaCO_3$



4.4 Turbidity, Chlorophyll-a and Secchi Depth

Turbidity values at the top and bottom of Seaman Reservoir differed between more in 2011 than in the previous three years. The bottom of the reservoir has become increasingly turbid over the last four years, while turbidity at the top of the reservoir has not changed (Figure 35). In 2011 as in previous years, a peak in turbidity occurred during spring snowmelt runoff, as sediments were flushed into the reservoir from the surrounding watershed. The highest values were however, observed during October and November following the reservoir draw-down. Peak turbidity values were 10.6 NTU and 18 NTU at the top and bottom, respectively.

Figure 35. Turbidity in Seaman Reservoir.



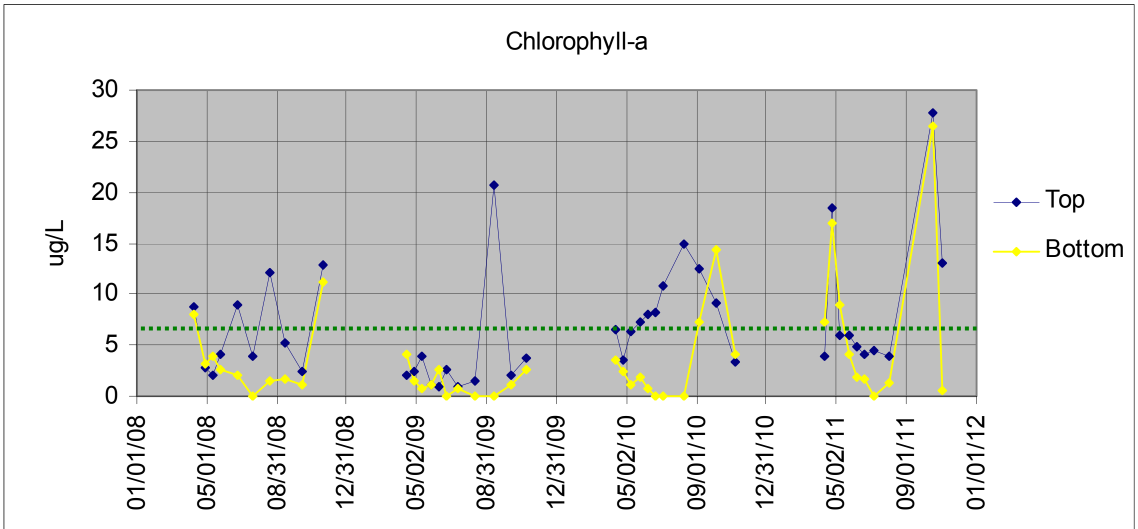
Chlorophyll-a concentrations in Seaman Reservoir were within the range observed for the previous three years, with the exception of the large, late-season spikes in October and November (Figure 36). In contrast to previous years, chlorophyll-a was similar on the top and bottom of the reservoir in 2011. Chlorophyll-a concentrations appeared to be inversely related to the depth of the reservoir, with peaks occurring during the two periods when the reservoir elevation was low and relatively low concentrations occurring when the reservoir was full. Late summer peaks in chlorophyll-a concentrations typically coincide with expected peaks in algae growth in the reservoir.

Epilimnetic (top) chlorophyll-a values greater than 7.3 ug/L may indicate eutrophic conditions, based on Carlson's Trophic State Index (TSI) for a TSI $\geq$ 50 as calculated from (Carlson, 1977):

$$\text{TSI (Chl-a)} = 30.6 + 9.81 \times \ln(\text{Chl-a in ug/L})$$

From 2008 through 2011, chlorophyll-a concentrations in Seaman Reservoir frequently exceeded 7.3 ug/L, with most exceedances occurring in the upper portion of the reservoir.

Figure 36. Chlorophyll-a concentrations in Seaman Reservoir.

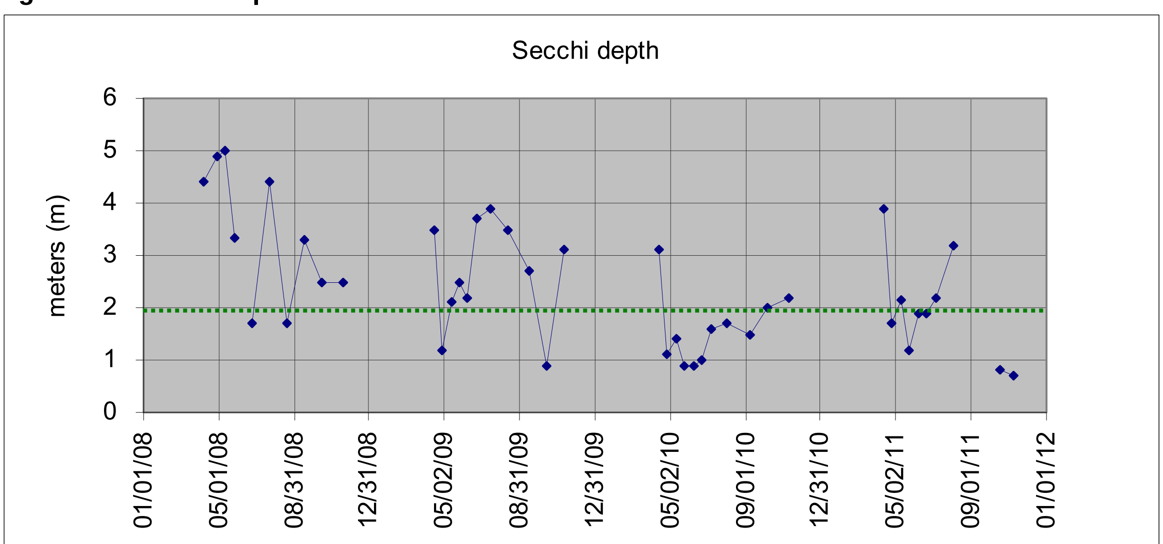


(------- Chl-a concentrations > 7.3 ug/L indicate eutrophic conditions, (Carlson, 1977))

Secchi depth results indicate that Seaman Reservoir experienced a general decrease in water clarity from 2008 through 2010, but improved somewhat in 2011(Figure 37). Secchi depth minima (periods of lowest light penetration) can coincide with periods of high turbidity and chlorophyll-a levels, suggesting that algal growth may contribute to turbidity and decreased clarity in the reservoir, especially during the summer months (Figure 38). However, secchi depths can also decrease due to an increase in inorganic turbidity alone and may not be related to algal growth. The relationships between secchi depth and turbidity for Seaman Reservoir are not always consistent or evident.

In 2011, the secchi depth ranged from 0.7 to 3.9 m with the minimum depths occurring in late spring and early summer, coinciding with the spring runoff and peak turbidities. Seasonal trends in secchi depth are not consistent year to year.

Figure 37. Secchi depth in Seaman Reservoir.



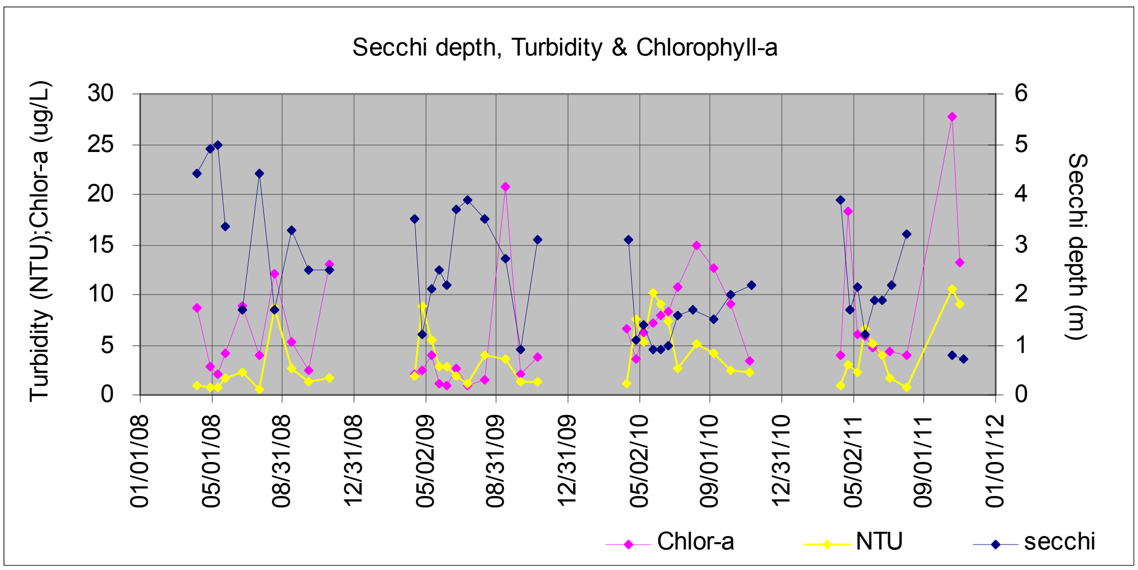
(------- Secchi depths < 2 m indicate eutrophic conditions, (Carlson, 1977))

Note that secchi depth values less than 2.0 m may indicate eutrophic conditions based on Carlson's TSI for a TSI ≥ 50 as calculated from (Carlson, 1977):

$$\text{TSI (secchi depth)} = 60 - 14.41 \times \ln(\text{secchi depth in meters}).$$

The number of secchi depth measurements below 2.0 m consistently increased from 2008-2010 suggesting a trend toward more eutrophic conditions, but conditions appeared to improve somewhat in 2011. In addition to increased in algal activity, increased inorganic turbidity or dissolved organic matter can cause a decrease in secchi depth. While clarity improved somewhat during the spring and summer months of 2011, the minimum secchi depth of 0.7 m on 11/8/11 continued the trend of decreasing annual minimum values (periods of lowest clarity) over the past four years.

Figure 38. Comparison of secchi depth, turbidity and chlorophyll-a concentrations in Seaman Reservoir.



4.5 Nutrients

The processes of thermal stratification and related changes in dissolved oxygen concentrations in the water column have the ability to affect the distribution of nutrients within Seaman Reservoir. In previous years, concentrations of nitrate, nitrite, ammonia, ortho-phosphate and total phosphorus at the bottom of the reservoir peaked during the period of lowest observed pH and D.O. values in the hypolimnion. In 2011, reservoir operations related to repair of reservoir head gates resulted in large fluctuations in reservoir depth. These fluctuations interrupted the process of thermal stratification, but did not result in any notable changes in nutrient concentrations compared to previous years, with the exception of unusually large spike in concentrations of ammonia, TKN and Total P during the October and November sampling events (Figures 39.a – 39.g). Unlike past years, these spikes in nutrients did not correspond in time with the mimimum

D.O. concentration, but rather minimum reservoir depth. Not considering the late season spike in ammonia, concentrations have consistently declined in Seaman Reservoir over the last four years. Nitrite concentrations have not exceeded the reporting limit during the 2008-2011 period.

Concentrations of dissolved nutrients are generally low at the top and bottom of the reservoir. Nitrate proved to be the exception in 2009 and 2010 with unusually high spring nitrate concentrations at the top and bottom of Seaman Reservoir, which coincided with early stages of spring runoff on the North Fork. However, in 2011, peak nitrate concentrations were significantly lower. Seasonal trends in nitrate concentrations at the surface of Seaman Reservoir and the upstream site NFL track closely, whereas NFG tracks well with the concentrations at the bottom of the reservoir (Figure 40). The close correspondence between nitrate dynamics upstream, within and downstream of the reservoir illustrates that inflowing water from the North Fork CLP exerts strong control over in-reservoir chemistry. Water quality at the downstream site, NFG, will generally depend on whether water flows over the spillway or from the bottom outlet of the reservoir.

TKN concentrations are of similar magnitude at the top and bottom of the reservoir and while they generally track the seasonal patterns in ammonia and nitrate, the overall concentrations are considerably higher and more variable (100 – 2,340 ug/L in 2011) (Figure 39.d). The 2011 TKN concentrations were within the range of values seen in the previous three years, including the high late season concentrations. The similarities between the time series for Total Nitrogen (TN) and TKN reflect the fact that TKN is the major fraction of Total Nitrogen, with nitrate and nitrite representing lesser fractions. Both Total P and ortho-phosphate concentrations were similar to 2008 - 2010 values with the exception of the 2009 peak in bottom concentrations.

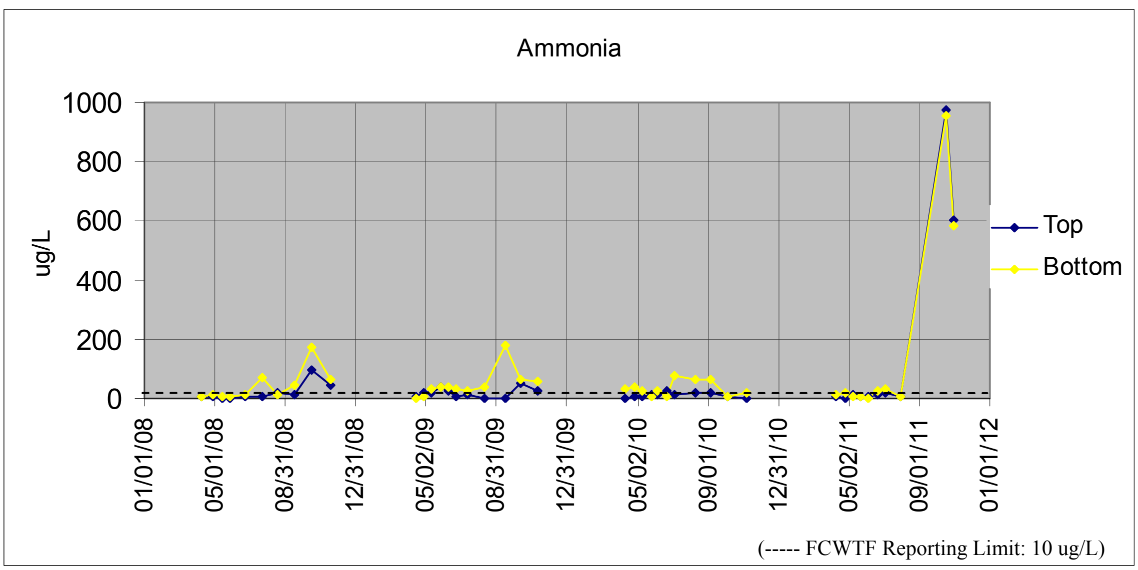
The CDPHE/WQCD proposed nutrient standards for cold water lakes and reservoirs for total nitrogen (TN), total phosphorus (TP), and chlorophyll-a were compared to values in Seaman Reservoir (Table 5). A reservoir or lake that directly supplies water to a water treatment facility may fall under the "Protected Water Supply Lake and Reservoirs (PWSR)" designation and be subject to the lower proposed standard for chlorophyll-a of 5 ug/L. Seaman Reservoir is not considered a PWSR site, and therefore, falls under the higher proposed standard of 8 ug/L chlorophyll-a. While the interim values are expected to be finalized and adopted by the WQCD on May 14, 2012, this comparison shows that if adopted, Seaman Reservoir will likely not meet the proposed standards for TN or TP. The 2011 decrease in average summer TP concentrations highlights the potential for nutrient management through reservoir operations, although the feasibility of this option may be limited by other legal and financial considerations.

Table 5. Comparison of Seaman Reservoir annual summer average (June – Sept) Total N, Total P and chlorophyll-a concentrations to the 2012 CDPHE/WQCD interim proposed standards for nutrients.

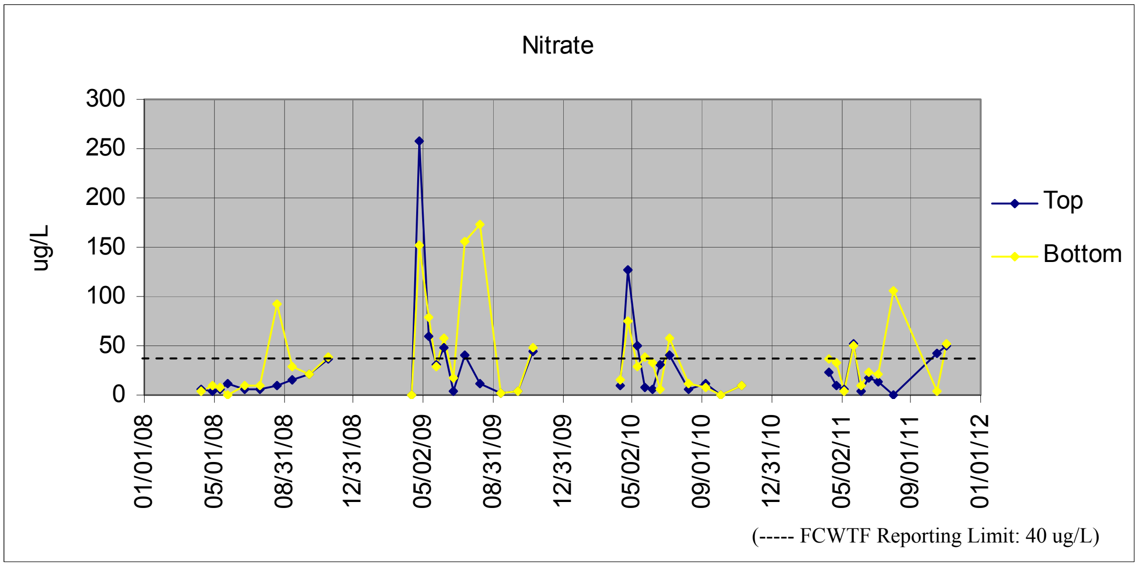
Interim Proposed Standard	Seaman Reservoir Top (1 meter) Summer (June-Sept) Average
TN: 426 ug/L (summer avg in mixed layer, 1 in 5 yr exceedance frequency)	2006: -- 2007: -- **2008: 514 ug/L** 2009: 370 ug/L **2010: 487 ug/L** **2011: 438 ug/L**
TP: 25 ug/L (summer avg in mixed layer, 1 in 5 yr exceedance frequency)	2006: 11.4 ug/L 2007: 12.8 ug/L **2008: 25.5 ug/L** 2009: 18.6 ug/L **2010: 30.3 ug/L** 2011: 19.34 ug/L
Chlor-a: 8 ug/L (summer avg in mixed layer, 1 in 5 yr exceedance frequency)	2006: 2.8 ug/L 2007: 7.8 ug/L 2008: 7.6 ug/L 2009: 5.3 ug/L **2010: 10.9 ug/L** 2011: 4.31 ug/L

Figure 39 (a-g). Nutrient concentrations in Seaman Reservoir.

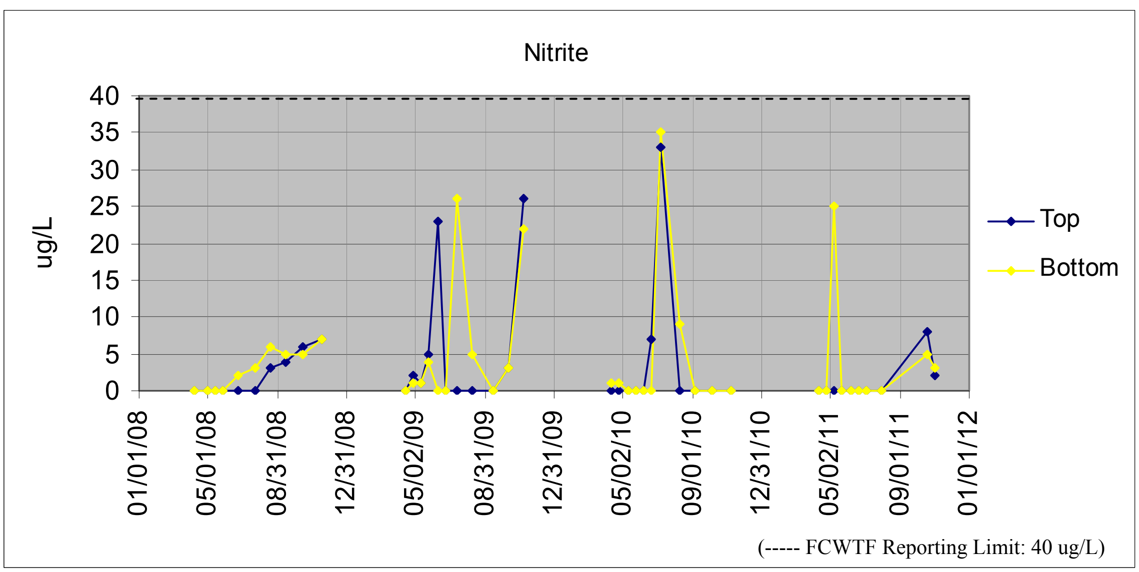
39.a. Ammonia (NH_3-N)



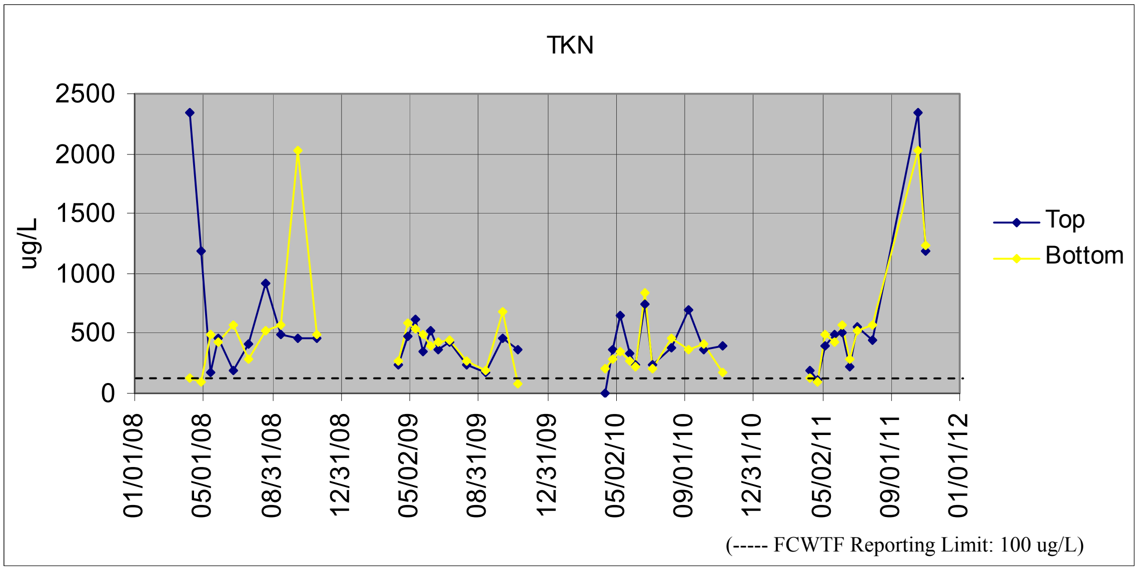
39.b. Nitrate (NO_3^-N)



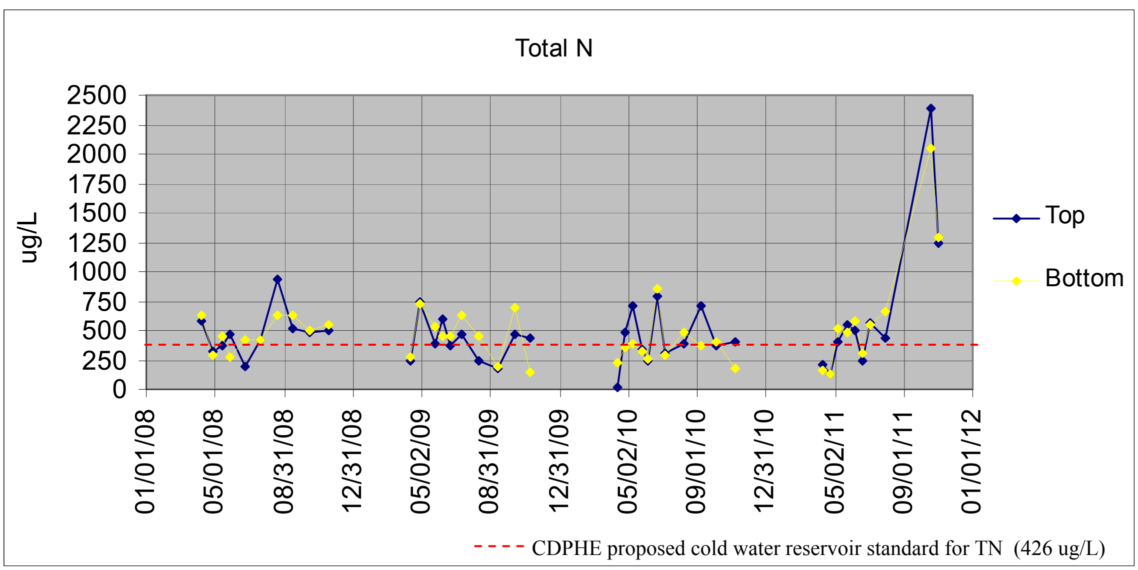
39.c. Nitrite (NO_2^-N)



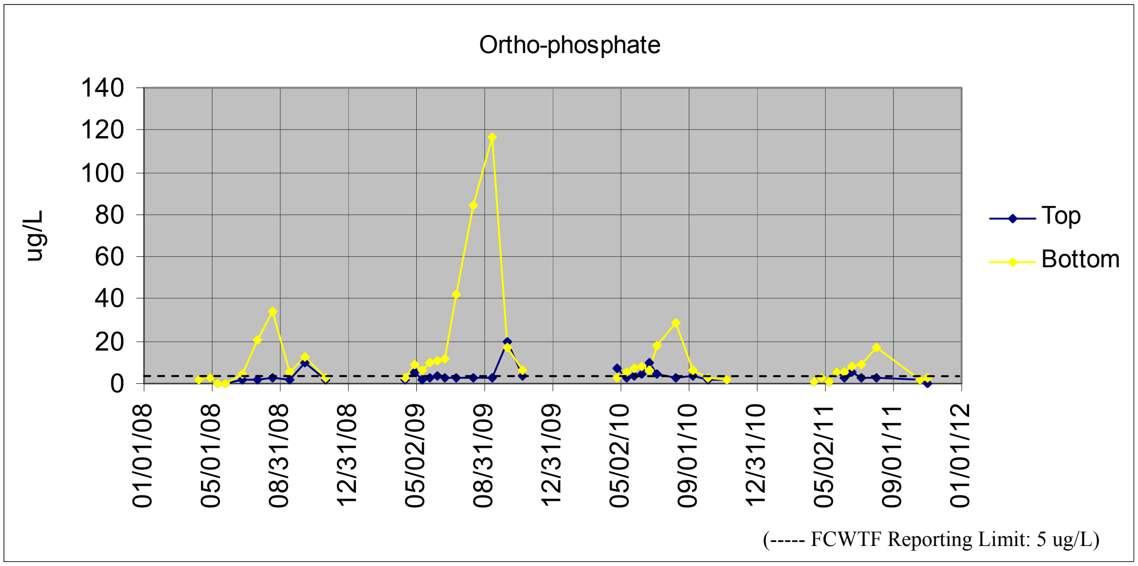
39.d. Total Kjeldahl Nitrogen (TKN)



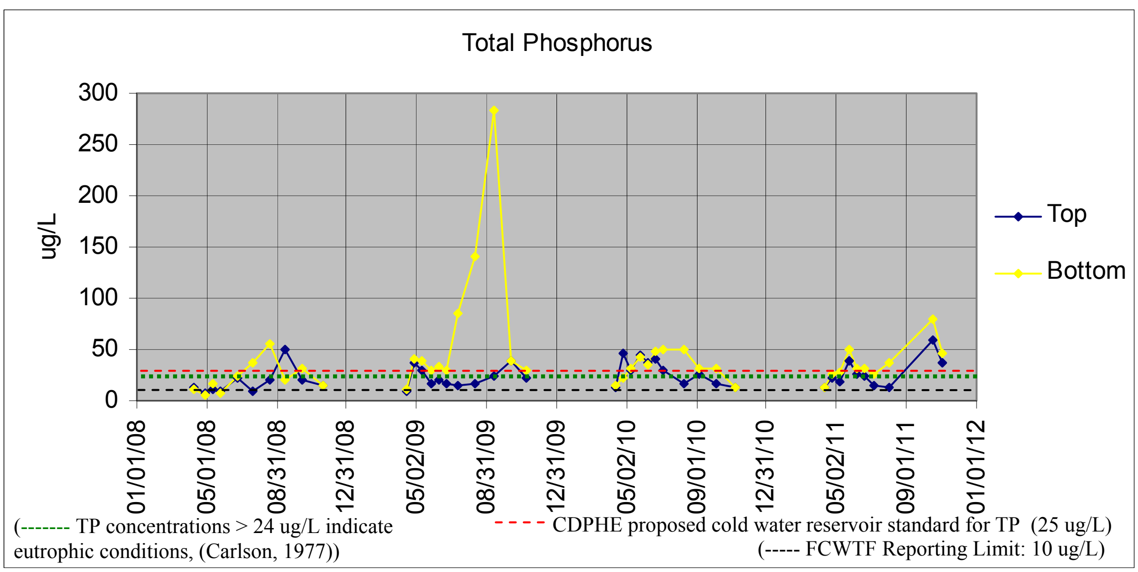
39.e. Total Nitrogen (TKN+NO_3+NO_2)



39.f. Ortho-phosphate (PO_4)



39.g. Total Phosphorus (TP)

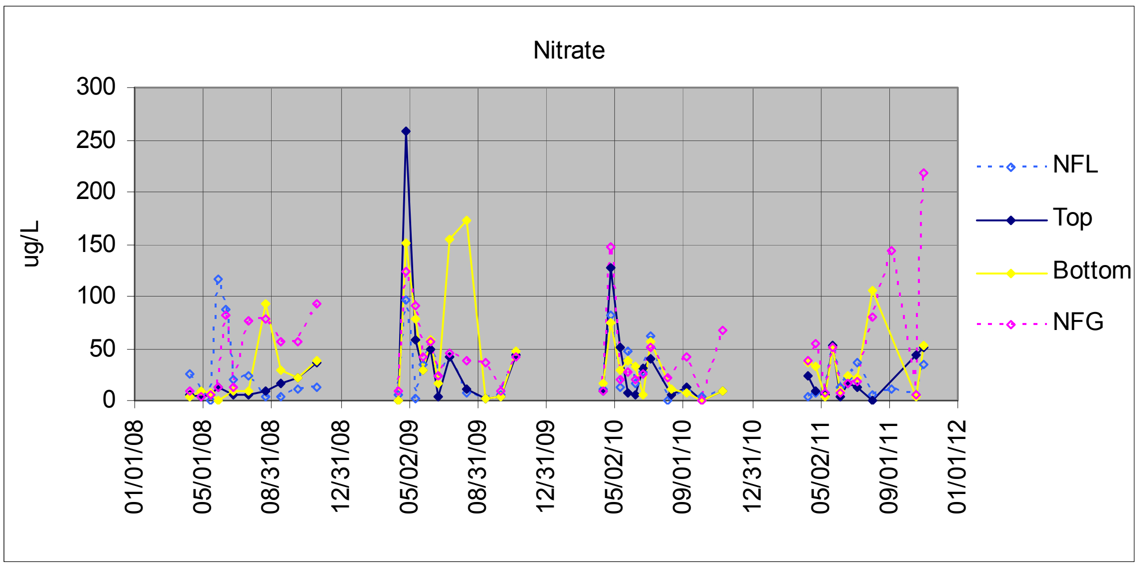


According to Carlson's TSI, epilimnetic (top) total P concentrations above 24 ug/L may indicate eutrophic conditions, corresponding to a TSI ≥ 50 as calculated from (Carlson, 1977):

$$\text{TSI (total P)} = 4.15 + 14.42 \times \ln(\text{total P in mg/L}).$$

The number occurrences in which surface total P concentrations in Seaman Reservoir were exceeded 24 ug/L increased from 2008 – 2010, while 2011 values remained similar to 2010. These data show a possible progression toward eutrophic conditions.

Figure 40. Comparison of nitrate (NO_3^-N) concentrations in Seaman Reservoir, upstream at NFL and downstream at NFG.



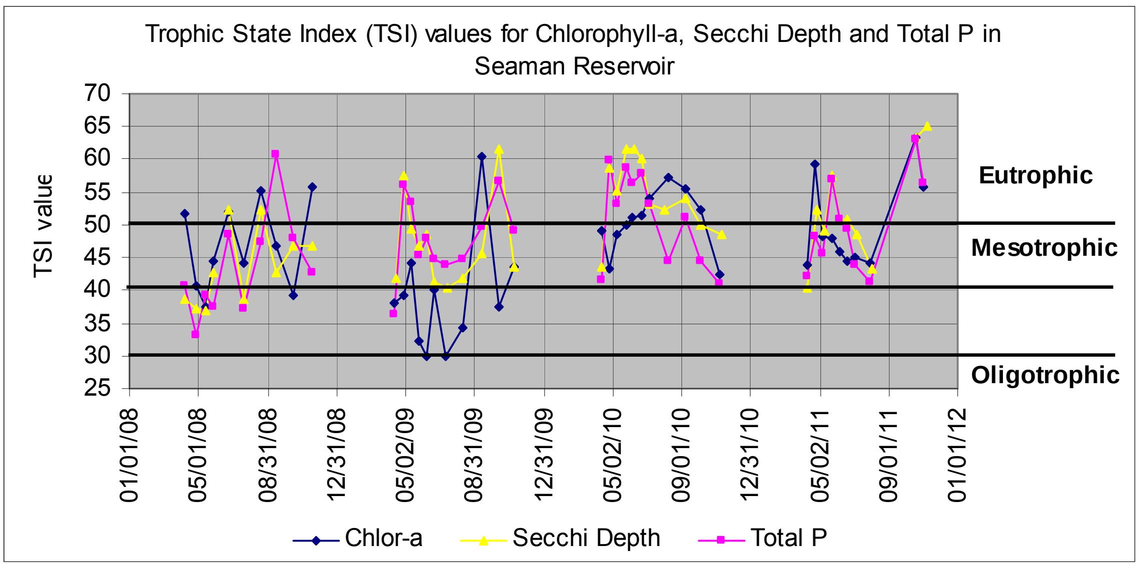
4.5.1 Seaman Reservoir Trophic Status

For comparison, TSI values for Total P, chlorophyll-a and secchi depth were plotted together in Figure 41. Possible interpretations of the relationships between chlorophyll-a, secchi depth and total phosphorus TSI values are provided by Wetzel (2001, pg. 284):

TSI Relationship	Interpretation
Total P TSI < Chl-a TSI	phosphorus is the limiting nutrient
Chl-a TSI < Secchi Depth TSI	dissolved organic matter and/or inorganic turbidity contribute significantly to reduced transparency (reduced transparency not due to algae)

The 2011 data suggest that algal growth in Seaman Reservoir was phosphorus limited prior to the onset of spring runoff, as suggested by TSI values for Total P well below chlorophyll-a TSI values. Following the onset of the partial draw-down of the reservoir in May, the TSI for Total P immediately increased and exceeded the TSI for chlorophyll-a until July after the reservoir had been refilled. During this time, algal growth was limited by light availability rather than nutrients (Secchi Depth TSI > Chl-a TSI) and in general, all TSI values fell within the mesotrophic range. As discussed in previous sections, other measures of water quality also indicate suggest that suspended and dissolved sediments from the bottom of the reservoir influenced water quality during the summer months. Following the larger second reservoir draw-down, which began in early August, TSI values for all parameters increased again into the eutrophic range.

Figure 41. Carlson's Trophic State Index (TSI) values for chlorophyll-a, secchi depth and total P in Seaman Reservoir.

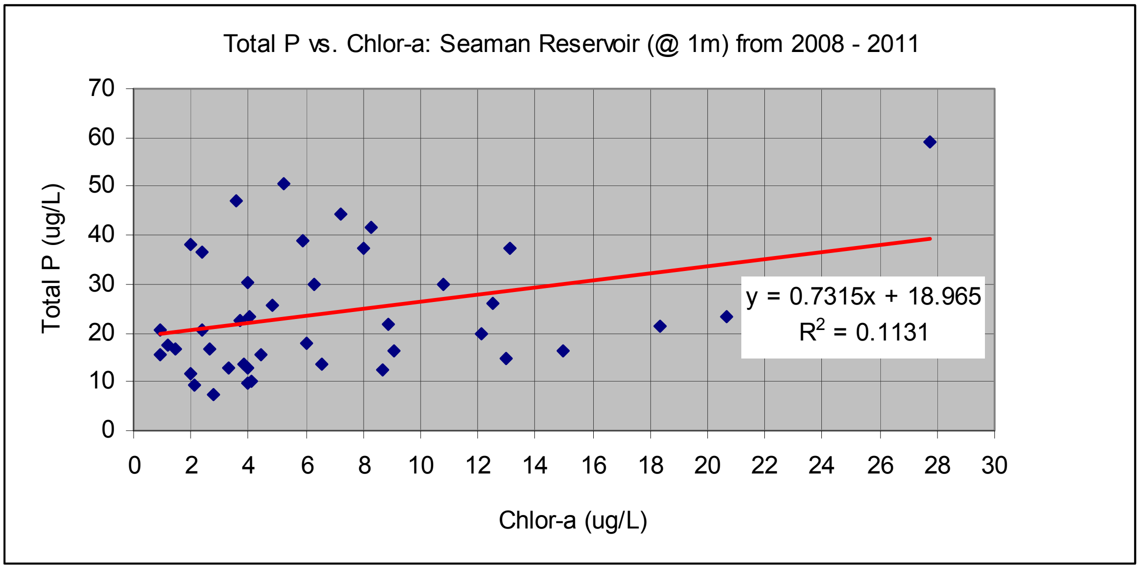


From 2008 through 2010, Seaman Reservoir progressed from a mesotrophic status to an increasingly eutrophic status. However, the 2011 indicators of trophic status did not increase over 2010 values. Because 2011 was an anomalous year in terms of reservoir operations, trends in trophic status cannot be confirmed until more data is available.

The phytoplankton data collected from Seaman Reservoir for 2011 do not provide any clear indication of seasonal changes related to the trophic status of the reservoir.

Chlorophyll-a versus total P is plotted on Figure 39 using 1 meter data from Seaman Reservoir. As expected for reasons discussed above, there was only a very weak direct relationship observed between chlorophyll-a and total P concentrations.

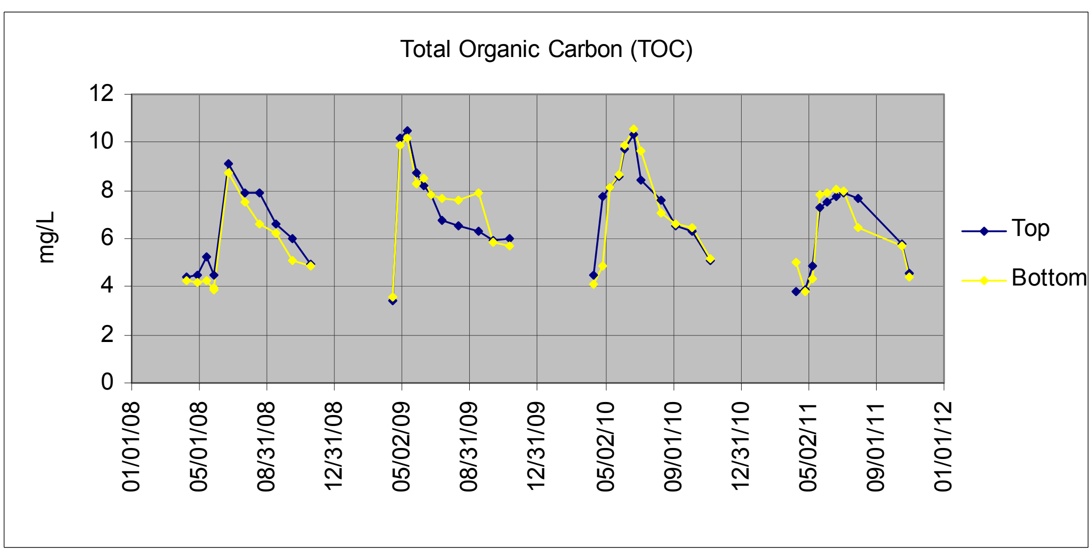
Figure 42. Plot of chlorophyll-a versus total P using data collected at 1m in Seaman Reservoir from 2008 to 2011.



4.6 Total Organic Carbon (TOC)

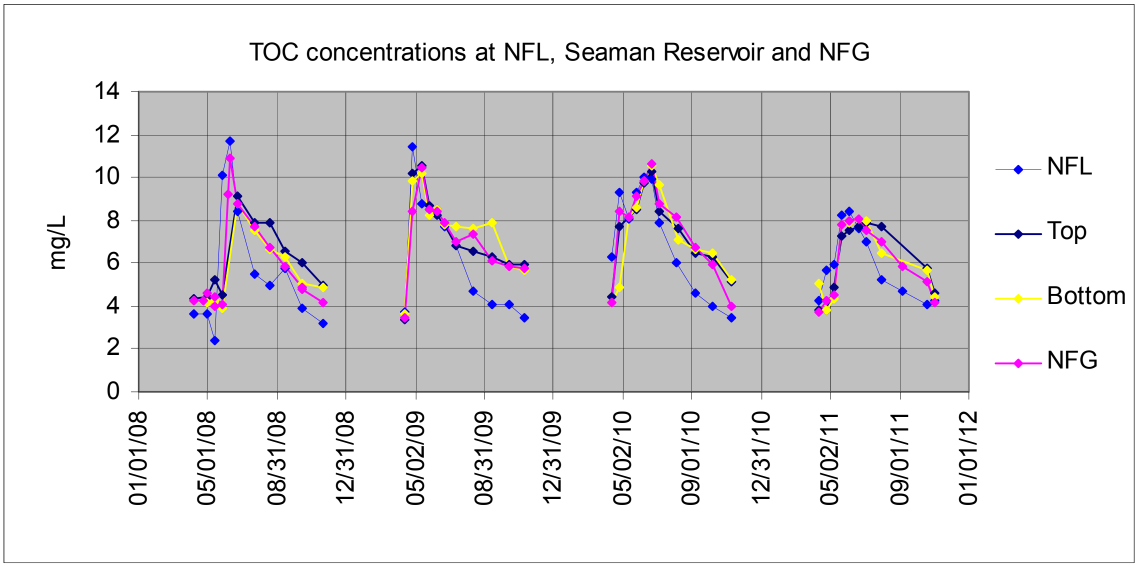
2011 TOC concentrations in Seaman Reservoir fell within the range of values seen from 2008-2010. As usual, concentrations were similar at the top and bottom of the reservoir (Figure 43). The 2011 peak TOC concentration at the reservoir surface was 8.0 mg/L on 7/5/11. The peak was lower than observed in the previous three years, when peak concentrations ranged from 9.1 – 10.5 mg/L. A subsequent decline in TOC was observed throughout the summer and fall due to dilution by lower TOC inflows, as seen in previous years. A significant, increasing trend in TOC (1.5 mg/L; p=0.03) at the top of Seaman Reservoir was reported in 2010 for the period from 2005 to 2010, but when 2011 values were included in the trend analysis, the trend was no longer significant (p=0.139).

Figure 43. TOC concentrations in Seaman Reservoir.



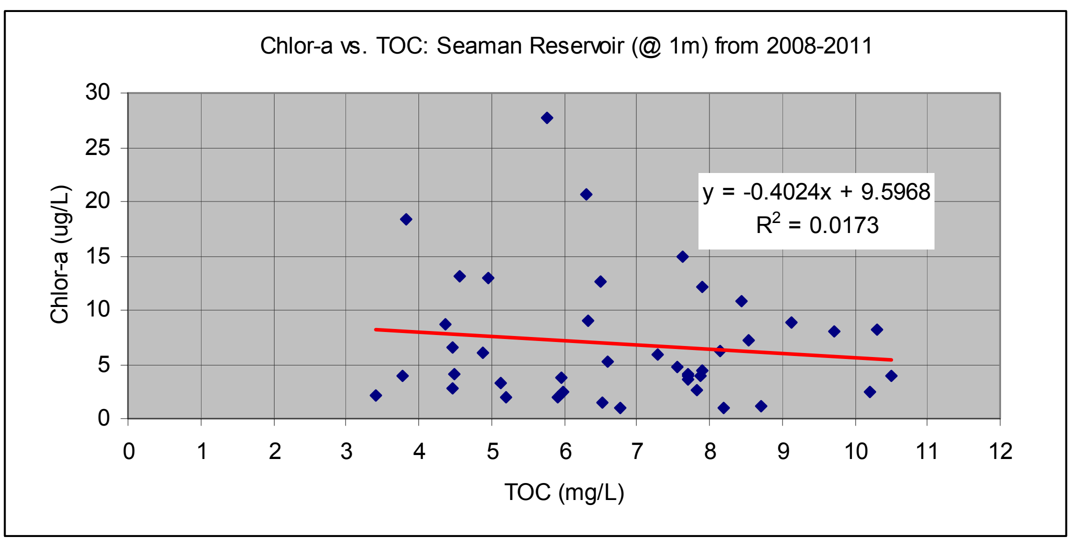
The TOC concentrations on the North Fork below Seaman Reservoir (NFG) were generally similar to the TOC concentrations at the bottom of Seaman Reservoir (Figure 44), as all flows at NFG originated from the bottom reservoir outlet following the spring runoff period.

Figure 44. Comparison of TOC concentrations at NFL, Seaman Reservoir, and NFG.



In-reservoir production of TOC from algal growth provides a possible explanation for the higher TOC concentrations within and below Seaman Reservoir at NFG. However, the lack of relationship between TOC and chlorophyll-a concentrations at 1M, suggests that TOC concentrations in Seaman Reservoir can not be explained by algal growth alone (Figure 45). Higher in-reservoir TOC concentrations may also be attributed to the fact that the reservoir typically stores high-TOC spring runoff water which is blended with lower TOC inflows and released over the course of the year.

Figure 45. Plot of chlorophyll-a versus TOC using data collected at 1m in Seaman Reservoir from 2008 to 2011.



4.7 Total Coliforms and *E. coli*

Total coliform concentrations experienced a late season peak in in Seaman Reservoir, as seen in previous years, and which occurred on 10/18/11. Peak concentrations at the top and bottom of the reservoir were 4,884 and 4,105 colony forming units (cfu)/100ml, respectively (Figure 46). These peak concentrations were lower than those observed in 2010. The data also indicate that on 8/1/11, a spike in total coliforms occurred downstream of the reservoir at NFG (6,932 cfu/100ml), at a time when concentrations at the top and bottom of the reservoir were relatively much lower (2,190 and 1,954 cfu/100 ml, respectively). This occurrence was also observed in 2010 at both NFG and NFL; no data were available for NFL for 2011.

A spring pulse in *E.coli* is to be expected as sediments and animal waste in the upper watershed are flushed from the landscape along with the melting snowpack. Consistent with this expectation, the highest concentrations of *E. coli* in Seaman Reservoir occurred during the initial pulse of spring runoff on the North Fork (5/23/11) and were 145 cfu/100ml and 588 cfu/100 ml on the top and bottom, respectively (Figure 47). Peak concentrations were significantly higher in 2011 than in previous years and followed the trend of consistently increasing peak concentrations of *E. coli* since 2008, despite a smaller runoff discharge. A coincident spike also occurred at the downstream North Fork location, NFG, where *E.coli* concentration was very similar to that at the top of the reservoir (134 cfu/100ml). As with total coliforms, *E.coli* data were not available for the upstream North Fork site, NFL, in 2011.

The recreational water quality standard for *E. coli* is 126 cfu/100ml. The spring peak concentrations at the top and bottom of Seaman Reservoir (5/23/11) exceeded the standard. Two exceedances also occurred at the downstream site on the North Fork, NFG on 5/23/11 and 9/6/11.

E.coli and total coliform concentrations at NFG were frequently higher than those observed within the reservoir, suggesting that there may be an additional or alternate source of these bacteria at NFG. Because the data record is limited, it is recommended that monitoring for these indicators of fecal contamination at NFL continue in order to gain a better understanding of their sources and fate in Seaman Reservoir.

Figure 46. Total Coliforms in Seaman Reservoir

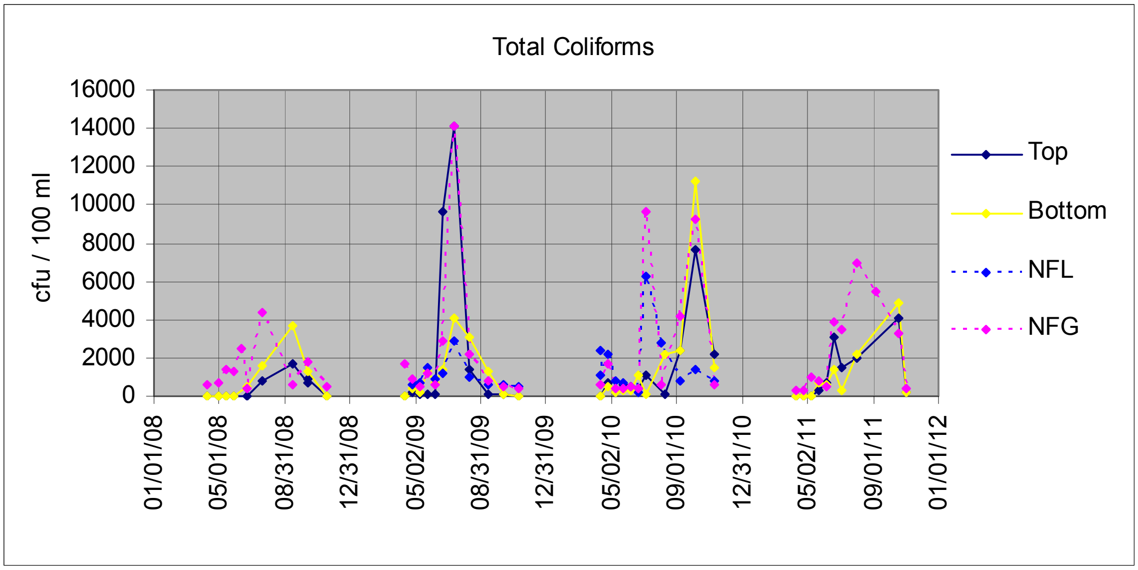
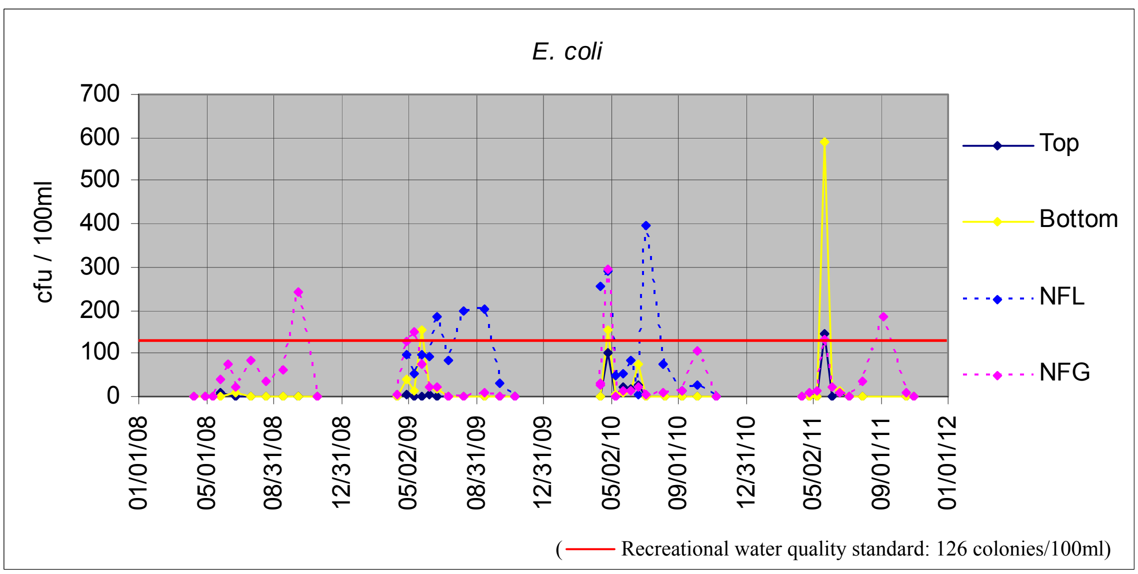


Figure 47. Concentrations of *Escherichia coli* (*E. coli*) at NFL, in Seaman Reservoir and at NFG.



4.8 Phytoplankton and Geosmin

Phytoplankton. Phytoplankton data were provided by Dick Dufford (private consultant). A full data summary of the 2011 phytoplankton data is provided in Attachment 6. The 2011 total phytoplankton density was highest from October to November, at both the top and bottom of Seaman Reservoir (Figures 48 and 49). During this time, the population densities ranged from 17, 946 – 23,119 cells/ml. Overall densities were higher the previous year, during which the highest phytoplankton densities were observed in August, and ranged from 19,056 – 38,041 cells/ml (Figures 50 and 51). The composition of the algal community varied greatly throughout the year at the top of the reservoir, with no consistently dominant class of algae. In contrast, the bottom of the reservoir was dominated by green algae during most months.

Blue-green algae (Cyanophytes) are of concern because certain species of Cyanophytes are known to produce compounds known as cyanotoxins that pose public health concerns. Others produce taste and odor compounds, including geosmin and MIB, which affect the aesthetic quality of drinking water and are difficult to remove during water treatment. In 2011, blue-green algae were much less abundant than in 2010. Blue-green algae were the dominant algae at the top of the reservoir for a very short time prior to the initial draw-down in April; however, the 2011 peak Cyanophyte density of 2,583 cells/ml (4/11/11) was significantly lower than the previous year's peak concentration of 33,319 cells/ml (9/7/10). Following the spring draw-down, blue-green algae densities remained low, until August, when the reservoir experienced an increase in blue-green algae density and dominance. By October, their numbers had again decreased and they represented less than 2% and 3% of the total population at the bottom and top of the reservoir, respectively.

Figure 48. Phytoplankton densities at the top of Seaman Reservoir from 2010 - 2011.

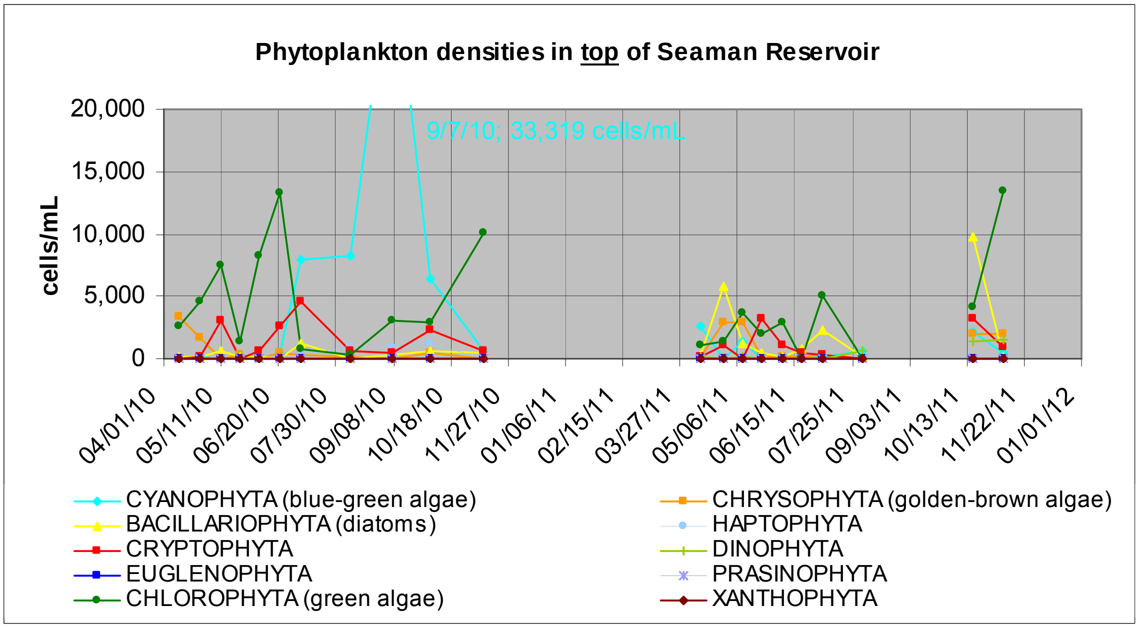


Figure 49. Phytoplankton densities at the bottom of Seaman Reservoir in 2010 - 2011.

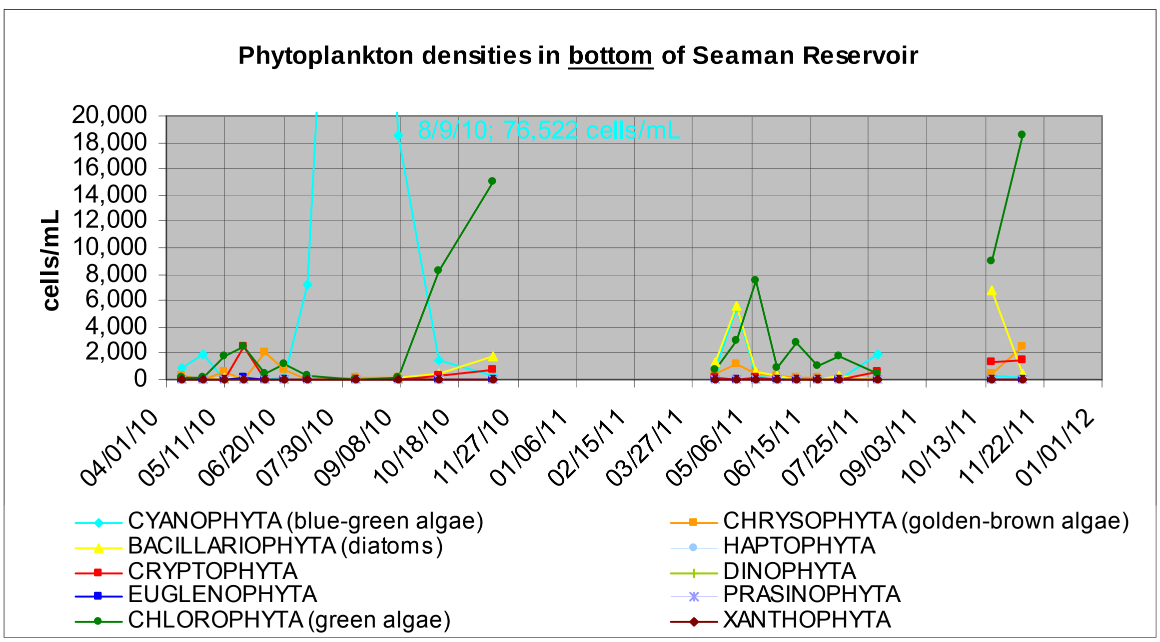
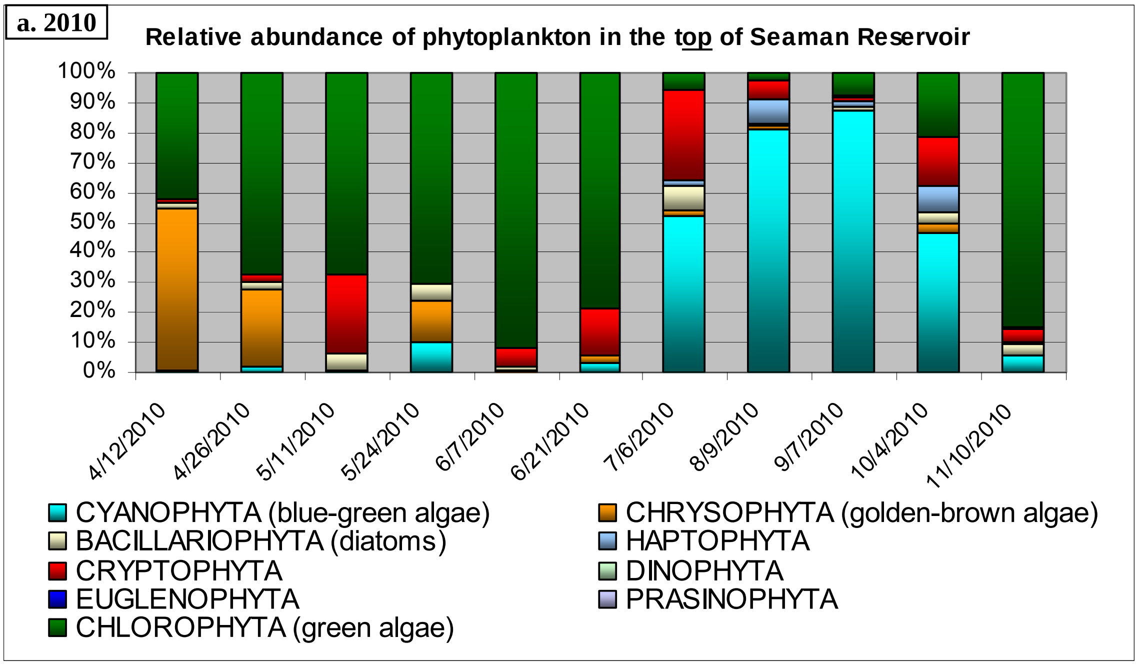


Figure 50 (a-b). Relative abundance of phytoplankton in top of Seaman Reservoir in 2010 and 2011.



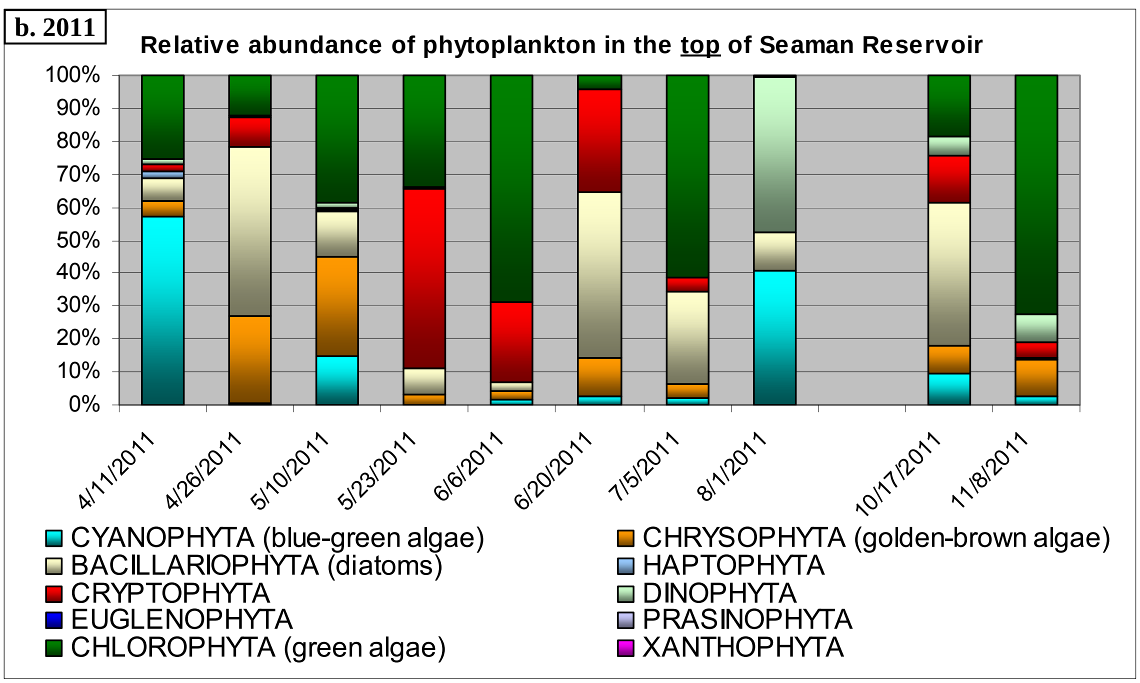
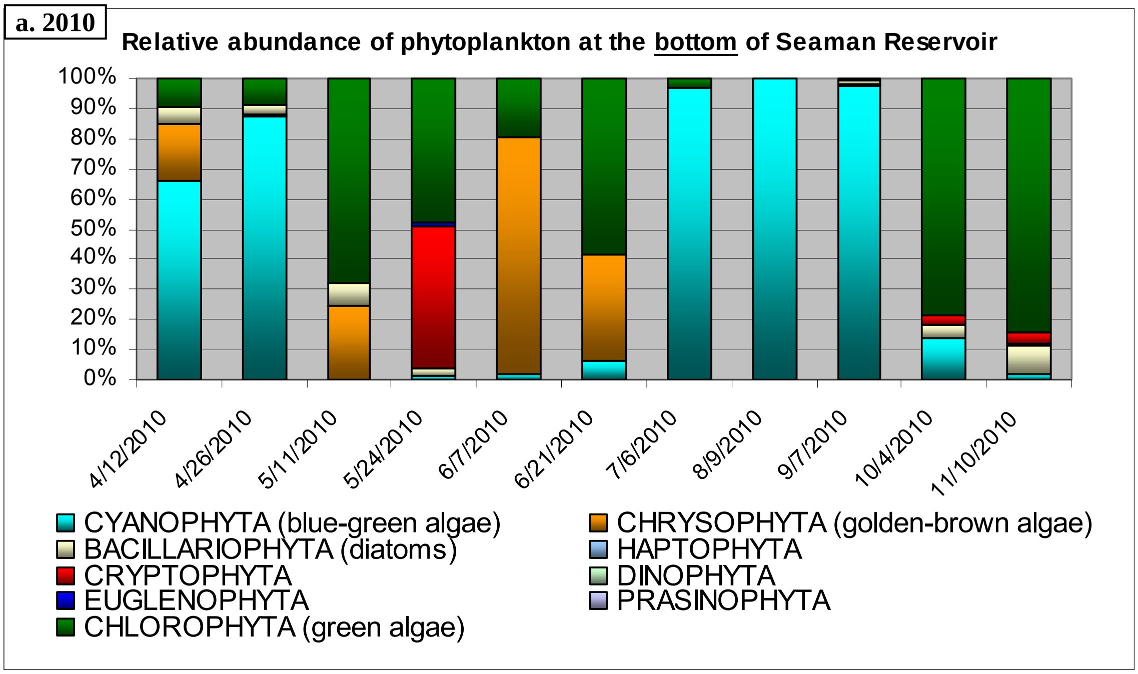
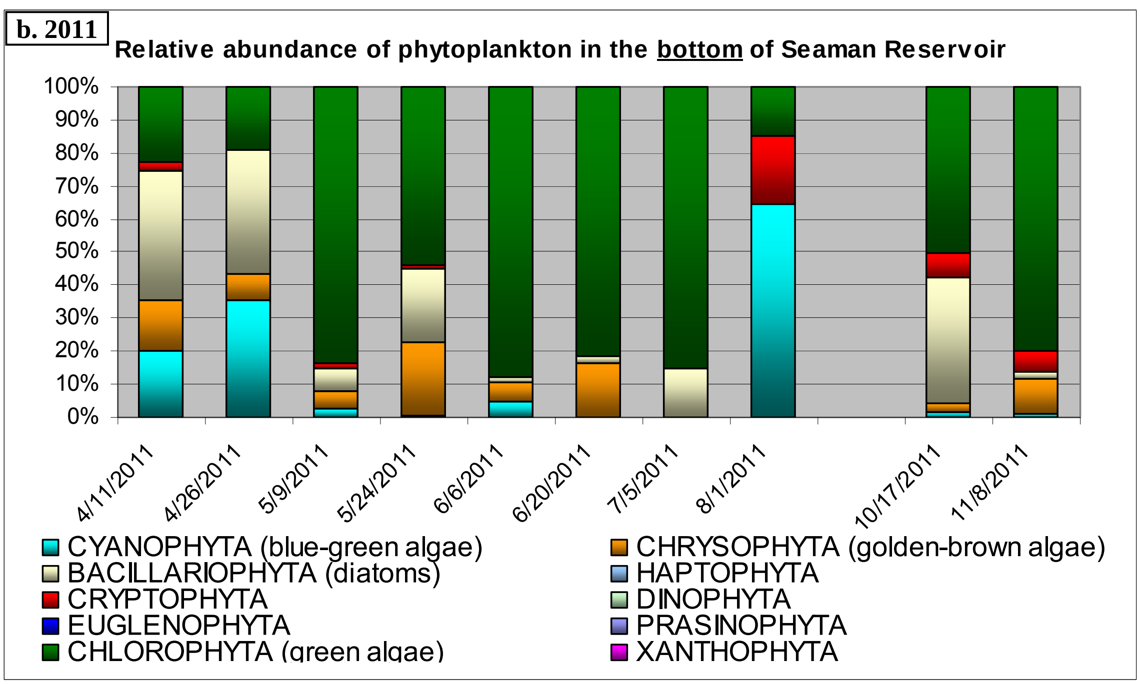


Figure 51 (a-b). Relative abundance of phytoplankton at the bottom of Seaman Reservoir in 2010 & 2011.





Geosmin. Due to the construction work on the head gates of Seaman Reservoir in 2011, geosmin samples were not collected from the top and bottom of the reservoir, as in previous years. In 2011, samples were, however, collected on the North Fork below Seaman Reservoir (NFG) on five occasions from June through September in order to monitor concentrations of geosmin that enter the Mainstem from the North Fork of the Poudre. Concentrations ranged from 6.4 – 36.2 ng/L, with the highest concentrations observed in mid-September, and the lowest concentration observed at the end of September. These concentrations were within the range of values typically seen within Seaman Reservoir.

There was no reservoir sample collected in September, when geosmin concentrations were highest at NFG. In August, however, blue-green algae (cyanophytes) were the dominant class of phytoplankton present in August, representing 41% (top) and 64% (bottom) of the total phytoplankton community in Seaman Reservoir (Figure 52.a-b). By October, Cyanophytes represented only 2% and 9% of the total phytoplankton density at the top and bottom, respectively. Of the blue-green algae identified in Seaman Reservoir, six of the genera are known to include geosmin producers and include *Anabaena, Aphanizomenon, Synechoccoccus, Lyngbya, Planktothrix, and Pseudanabaena.*

During August, when the algae population density was at its peak in the reservoir, 14% of the blue-green algal density at the top of the reservoir was comprised of known geosmin producing genera. In contrast, over 90% of the cyanophytes at the bottom of the reservoir were known geosmin producing genera. Note, however, that not all species within a genus produce geosmin. The geosmin-producing species identified in the 2011 samples include *Aphanizomenon flos-aquae, Anabaena flos-aquae, Planktothix agardhii, Lingbya birgei, Pseudanabaena limnetica and Synechococcus nidulans* (Juttner and Watson, 2007). Because geosmin samples were not paired with phytoplankton samples in 2011 it is not possible to link species information with geosmin production in Seaman Reservoir. However, there is often little to no correlation between geosmin concentrations and density of geosmin producing algae, as the source of geosmin is often a minor or inconspicuous component of the phytoplankton community (Taylor et al, 2006). Furthermore, some species do not release geosmin until cellular decomposition, thereby creating a time lag between algal abundance and geosmin levels. To verify any particular species as a geosmin producer, a laboratory culture test would be required.

5.0 SUMMARY

Review of the 2011 Upper CLP Collaborative Water Quality Monitoring Program data indicates that the program adequately captures the seasonal trends in water quality and provides a spatial context for examining notable events.

The 2011 snowpack in the Upper CLP basin was exceptional in terms of depth and water content. According to official information from the NRCS Cameron Pass snow course site, the snowpack reached a maximum depth of 11.0 feet (133 inches) on May 1st, which was equivalent to 48.0 inches of liquid water. Near-record stream flows in both the Mainstem and the North Fork were anticipated; however, weather conditions were such that runoff actually occurred over an extended period of moderate temperatures, which produced high, but not record-setting stream flows during spring runoff. There were no unusual or unexpected impacts to water quality as a result of the 2011 snowpack runoff.

Figure 52. Snowpack conditions on the Michigan Ditch, near Cameron Pass in the Poudre River Canyon on April 19, 2011.

The Mainstem and the North Fork, as expected, exhibited different water quality characteristics, resulting from differences in geology, land use, and elevation. In general, no significant concerns were identified for the Mainstem or North Fork CLP that would immediately impact drinking water quality or treatment operations. The increasing amount of *Didymosphenia geminata* on the Mainstem, also known as *Didymo*, is of growing concern for both the overall ecological integrity of the river, as well as the potential nuisance it could pose if densities increase to the point that the dead filaments begin to clog intake screens. The extent and density of *Didymo* and other attached algae will continue to be monitored in 2012. During spring runoff, the Mainstem and the North Fork both presented the usual challenges to water treatment, including the delivery of waters with high TOC, high turbidity and low alkalinity. The primary differences in water quality between the two drainages include higher alkalinity and nutrient concentrations, as well as persistently elevated TOC concentrations on the North Fork.

The construction activities on Seaman Reservoir and the resulting fluctuations in water level made 2011 an atypical year in terms of water depth and the seasonal progression of thermal stratification and reservoir mixing. These factors affected water quality parameters such as temperature, turbidity, dissolved oxygen, nutrients, and phytoplankton community size and composition; however, overall water quality was the same or better from April to August than in previous years. As usual, anoxic conditions (a period of near-zero dissolved oxygen concentration) did develop at the bottom waters during August, but the duration was shorter than in previous years. In contrast to previous years, there was not an issue with low D.O. concentrations in the metalimnion, in large part due to the lack of thermal stratification. Low D.O. in the metalimnion can negatively affect aquatic life by restricting available habitat, and while this does not pose water treatment concerns, these occurrences contribute to it being listed on the Colorado 303(d) List for impaired waters. Up until 2011, an increasing trend in TOC had been observed in Seaman Reservoir; however the impact of 2011 reservoir operations on this trend cannot yet be determined. Increasing TOC is of concern because of its potential to create future challenges for the City of Greeley in meeting regulatory requirements related to disinfection by-product formation.

Water quality monitoring and other related Upper CLP activities for 2012 are summarized below:

- **Routine Monitoring Program**. Samples will continue to be analyzed for all parameters in 2012. *E.coli* and Total coliforms will be added back to the sampling plan for the North Fork site, NFL.

- **Emerging Contaminant Monitoring**. The Northern Water collaborative study on emerging contaminants will continue in 2012, with sampled to be collected as at PNF and NFG in February, June and August.

- **Attached Algae.** The composition and density of the attached algae community on the Mainstem CLP will continue to be monitored in 2012.

- **Geosmin**. Geosmin monitoring will continue on the Mainstem CLP with an emphasis on the reach between Rustic and the treatment plant intakes. In addition, geosmin sampling will be conducted on the North Fork at the gage below Seaman Reservoir.

- **Abandoned/Existing Mine Sites.** The feasibility of continued field verification of existing/abandoned mine sites within the Upper CLP watershed will be reevaluated in 2012.

6.0 REFERENCES

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<u>**ATTACHMENT 1**</u>

Land use comparison of the North Fork and Mainstem CLP (areas calculated using USGS Seamless GIS data sets).

Land Use Comparison	North Fork (acres)	Main Stem (acres)	North Fork Area (%)	Main Stem Area (%)
Developed land (commercial, industrial, residential, urban, and utilities)	2,817	1,945	0.8	0.7
Agricultural use and grassland (Cropland, pasture, other agriculture, scrub and grasses)	183,719	54,765	52.3	18.3
Forest (forest and brush)	154,654	213,879	44.1	71.5
Natural lands (exposed rock, bare ground, wetlands, tundra, lakes)	9,926	28,473	2.8	9.5
Total	**351,116**	**299,062**	**100**	**100**

ATTACHMENT 2

Upper CLP collaborative water quality monitoring program sampling sites.

	MAIN STEM	Description	Rationale	GPS Coordinates
1	100CHR	Chambers Lake Outflow	Outflow from Chambers Lake	N 40° 36.039 W 105° 50.203
2	090BMR	Barnes Meadow Reservoir outflow	High TOC and nutrients compared to CHR	N 40° 36.039 W 105° 50.203
3	080JWC	Joe Wright Creek at Aspen Glen Campground	Joe Wright Creek above confluence with main stem	N 40° 37.233 W 105° 49.098
4	070PJW	Poudre at Hwy14 crossing (Big South Trailhead)	Above confluence Joe Wright Creek	N 40° 38.074 W 105° 48.421
5	060LRT	Laramie River at Tunnel at Hwy 14 crossing	Laramie River diversion water	N 40° 40.056 W 105° 48.067
6	050PBR	Poudre below Rustic	Midpoint between Laramie River Tunnel and South Fork; impacts to river from Rustic	N 40° 41.967 W 105° 32.476
7	040SFM	South Fork at bridge on Pingree Park Rd	Only access point on South Fork; South Fork water quality differs from main stem	N 40° 37.095 W 105° 31.535
8	030PSF	Poudre below confluence with South Fork - Mile Marker 101	Below confluence with South Fork	N 40° 41.224 W 105° 26.895
9	020PNF	Poudre above North Fork 1/2 mile upstream from Old FC WTP#1	Represents water diverted at Munroe Tunnel and at Old FC WTP #1	N 40° 42.087 W 105° 14.484
10	010PBD	Poudre at Bellvue Diversion	Greeley WTP Intake	N 40° 39.882 W 105° 12.995
	NORTH FORK			
11	280NDC	North Fork above Halligan Reservoir; above confluence with Dale Creek	Inflow to Halligan Reservoir	N 40° 53.852' W 105° 22.556'
12	270NBH	North Fork at USGS gage below Halligan Reservoir	Outflow from Halligan Reservoir	N 40° 52.654' W 105° 20.314'
13	260NRC	North Fork above Rabbit Creek	Main stem North Fork above Rabbit Creek; downstream of Phantom Canyon	N 40° 49.640 W 105° 16.776
14	250RCM	Rabbit Creek Mouth	Tributary to North Fork; drainage area includes agricultural/grazing lands; significant flows late spring to early summer only	N 40° 48.615 W 105° 17.146
15	240SCM	Stonewall Creek Mouth	Tributary to North Fork; drains area east of Hwy 287; significant flows late spring to early summer only	N 40° 48.458 W 105° 15.195
16	230PCM	Lone Pine Creek Mouth	Tributary to North Fork; drainage area includes Red Feather Lakes; significant flows late spring to early summer only	N 40° 47.696 W 105° 17.231
17	220NFL	North Fork at Livermore	At USGS gage	N 40° 47.269 W 105° 15.130
18	210SER	Seaman Reservoir	Reservoir profiles; impacts to water quality from nutrient loadings	N 40° 42.274 W 105° 14.210
19	200NFG	North Fork below Seaman Reservoir	At gage below Seaman Res; sample before flow enters Poudre main stem	N 40° 42.143 W 105° 14.064

ATTACHMENT 3

Upper CLP collaborative water quality monitoring program parameter list.

	Rationale	Notes
Field Parameters		
Conductance	Indicator of total dissolved solids.	Profile at Seaman Reservoir
Dissolved Oxygen	Profile indicates stratification, importance for aquatic life and chemical processes.	Profile at Seaman Reservoir
Secchi Disk	Measure of transparency.	Seaman Reservoir only
Temperature	Reflects seasonality; affects biological and chemical processes; water quality standard.	Profile at Seaman Reservoir
pH	Measure of acidity.	
General & Miscellaneous Parameters		
Alkalinity	Indicator of carbonate species concentrations; Acid neutralizing capacity of water; treatment implications.	
Chlorophyll-a	Reflects algal biomass.	Seaman Reservoir only
Discharge	Necessary for flow dependant analysis and load estimation.	Measured during sampling at NRC, RCM, SCM, PCM, PJW, SFM
Hardness	Treatment implications. Hard water causes scaling and soft water is considered corrosive.	
Total Dissolved Solids (TDS)	Indicator of overall water quality; includes both ionic and non-ionic species.	
Total Organic Carbon (TOC)	Important parameter for water treatment; precursor of disinfection byproducts.	
Turbidity	Indicator of suspended material; important for water treatment.	
Nutrients		
Nitrogen, Ammonia	Primary source of nitrogen to algae, indicator of pollution by sewage, septic tanks, agriculture; water quality standard.	
Nitrate	Primary source of nitrogen to algae; indicator of pollution by sewage, septic tanks, agriculture; water quality standard.	
Nitrite	Toxic inorganic nitrogen species; rarely encountered at significant concentrations; water quality standard.	
Total Kjeldahl Nitrogen	Sum of organic nitrogen and ammonia.	
Ortho-Phosphorus (Soluble Reactive Phosphorus)	Form of phosphorous (dissolved PO_4^{-3}) most available to algae; indicator of pollution by sewage, septic tanks, agriculture.	

Total Phosphorus	Includes dissolved and adsorbed, organic and inorganic forms of phosphorus, indicator of pollution by sewage, septic tanks, agriculture.	
Major Ions		
Calcium	Major ion.	Monitor for two years at half frequency (6x/yr)
Chloride	Major ion.	Monitor for two years at half frequency (6x/yr)
Magnesium	Major ion.	Monitor for two years at half frequency (6x/yr)
Potassium	Major ion, minor importance as a nutrient.	Monitor for two years at half frequency (6x/yr)
Sodium	Major ion.	Monitor for two years at half frequency (6x/yr)
Sulfate	Major ion.	Monitor for two years at half frequency (6x/yr)
Microbiological Constituents		
E. Coli	Indicator of human or animal waste contamination; water quality standard.	Only from Rustic downstream, NFL, NFG, SER
Total Coliform	Indicator of human or animal waste contamination.	Only from Rustic downstream, NFL, NFG, SER
Cryptosporidium	Pathogen, indicator of human or animal waste contamination.	Above and below Halligan Reservoir, and below Seaman Reservoir
Giardia	Pathogen, Indicator of human or animal waste contamination.	Above and below Halligan Reservoir, and below Seaman Res
Algal Species Composition	Shows presence of nuisance species and trophic state.	Seaman Reservoir surface sample only
Metals		
Cadmium, dissolved	Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG (2x/yr)
Chromium, dissolved	Water quality standard.	Only PNF & NFG (2x/yr)
Copper, dissolved	Water quality standard.	Only PNF & NFG (2x/yr)
Iron, Total	Affects aesthetic quality of treated water.	Only PNF & NFG (2x/yr)
Iron, dissolved	Affects aesthetic quality of treated water.	Only PNF & NFG (2x/yr)
Lead, dissolved	Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG (2x/yr)
Nickel, dissolved	Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG (2x/yr)
Silver, dissolved	Indicator of pollution from mining activity at elevated levels.	Only PNF & NFG (2x/yr)
Zinc, dissolved	Indicator of pollution from mining activity at elevated levels.	Only PNF & NFG (2x/yr)
Mercury, Low Level	Accumulates in fish tissue even when present in very low concentrations.	Sample every 3 to 5 yrs.

ATTACHMENT 4

Upper CLP Collaborative Water Quality Monitoring Program 2011 Sampling Plan

	2011 Sampling Dates										
	Apr 11-12	Apr 25-26	May 9-10	May 23-24	Jun 6-7	Jun 20-21	Jul 5-6	Aug 1-2	Sep 6-7	Oct 17-18	Nov 7-8
Station											
North Fork											
NDC[3]	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
NBH[3]	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
NRC	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,I,D
RCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D					
SCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D					
PCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D					
NFL	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
NFG	F,G,E	F,G,I,E	F,G,E	F,G,I,M,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,M,E	F,G,I,E
Main Stem											
CHR	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
BMR[2]	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
JWC	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
PJW	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,I,D
LRT	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
PBR	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E
SFM		F,G,I,D		F,G,I,D		F,G,I,D		F,G,I,D		F,G,I,D	F,G,I,D
PSF	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E
PNF	F,G,E	F,G,I,E	F,G,E	F,G,I,E,M	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E,M	F,G,I,E
PBD	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E
Reservoir											
SER[1]	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,I,A,C,E

[1] Grab samples taken at two depths (Top & Bottom); meter samples at 1-m intervals.
[2] Call commissioner to find out if water is flowing. If not flowing, skip sample.
[3] Sampled by City of Fort Collins personnel; all other stations to be sampled by Dr. Bill Lewis' Team.
A = Algae (Lugol's); C = Chlorophyll (500 mL sample); D = Flow; F = Field data (Temp, pH, conductance streams + Secchi, DO for lake); G = 1 liter sampleor general, nutrients, TOC; E = *E. coli*, coliform (500 mL sterile bottle); I = Major ions; M = Metals; P = *Giardia/Cryptosporidium* (collected by City of Fort Collins personnel).

ATTACHMENT 5

Analytical methods, reporting limits, sample preservation, and sample holding times.

			Limit	vation	Time
Micro-	Total Coliform, *E.coli* - QT	SM 9223 B	0	cool, 4C	6 hrs
biological	*Giardia & Cryptosporidium* (CH Diagnostics)	EPA 1623	0	cool, 4C	4 days
	Algae I.D. (Phyto Finders)	SM 10200E.3, SM 10200F.2c1		Lugol's Solution, cool, 4C	12 mo
General &	Alkalinity, as $CaCO_3$	SM 2320 B	2 mg/L	cool, 4C	14 days
Misc.	Chlorophyll a	SM10200H modified	0.6 ug/L	cool, 4C	48 hrs
	Hardness, as $CaCO_3$	SM 2340 C	2 mg/L	none	28 days
	Specific Conductance	SM 2510 B		cool, 4C	28 days
	Total Dissolved Solids	SM 2540 C	10 mg/L	cool, 4C	7 days
	Turbidity (NTU)	SM2130B,EPA180.1	0.01 units	cool, 4C	48 hrs
Nutrients	Ammonia - N	Lachat 10-107-06-2C	0.01 mg/L	H_2SO_4	28 days
	Nitrate	EPA 300 (IC)	0.04 mg/L	cool, 4C (eda)	48 hrs
	Nitrite	EPA 300 (IC)	0.04 mg/L	cool, 4C (eda)	48 hrs
	Total Kjeldahl Nitrogen	EPA 351.2	0.1 mg/L	H_2SO_4 pH<2	28 days
	Phosphorus, Total	SM 4500-P B5,F	0.01 mg/L	H_2SO_4 pH<2	28 days
	Phosphorus, Ortho	SM 4500-P B1,F	0.005 mg/L	filter, cool 4C	48 hrs
Major Ions	Calcium	EPA 200.8	0.05 mg/L	HNO_3 pH <2	6 mos
	Chloride	EPA 300 (IC)	1.0 mg/L	none (eda)	28 days
	Magnesium, flame	EPA 200.8	0.2 mg/L	HNO_3 pH <2	6 mos
	Potassium	EPA 200.8	0.2 mg/L	HNO_3 pH <2	6 mos
	Sodium, flame	EPA 200.8	0.4 mg/L	HNO_3 pH <2	6 mos
	Sulfate	EPA 300 (IC)	5.0 mg/L	cool, 4C (eda)	28 days
Metals	Cadmium	EPA 200.8	0.1 ug/L	HNO_3 pH <2	6 mos
	Chromium	EPA 200.8	0.5 ug/L	HNO_3 pH <2	6 mos
	Copper	EPA 200.8	3 ug/L	HNO_3 pH <2	6 mos
	Iron, (total & dissolved)	EPA 200.8	10 ug/L	HNO_3 pH <2	6 mos
	Lead	EPA 200.8	1 ug/L	HNO_3 pH <2	6 mos
	Nickel	EPA 200.8	2 ug/L	HNO_3 pH <2	6 mos
	Silver	EPA 200.8	0.5 ug/L	HNO_3 pH <2	6 mos
	Zinc	EPA 200.8	50 ug/L	HNO_3 pH <2	6 mos
TOC	TOC	SM 5310 C	0.5 mg/L	H_3PO_4pH <2	28 days
Analysis conducted by City of Fort Collins Water Quality Lab (FCWQL), unless otherwise noted.					
Reporting Limit = lowest reportable number based on the lowest calibration standard routinely used.					

ATTACHMENT 6

2011 Seaman Reservoir Phytoplankton Data

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Top Potential geosmin producing cyanophyta	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CYANOPHYTA (blue-green algae)										
Anabaena flos-aquae							26	24.8		
Anabaena crassa					12.8	47.2	44		16.8	
Anabaena lemmermannii							9.2			
Anabaena planctonica	2.4	0.8		3.2	8			1.6	35.2	
Aphanizomenon flos-aquae							82.8	48.6	22.4	
Aphanocapsa conferta										
Aphanocapsa delicatissima										
Aphanocapsa holsatica	2,500								1,000	500
Aphanothece clathrata										
Aphanothece smithii			750					154.5		
Coelosphaerium aerugineum										
Cuspidothrix issatschenkoi										
Cyanobium sp.	62.5									
Dactylococcopsis sp.	10						20			2.6
Geitlerinema sp.										
Jaaginema sp.										
Limnothrix sp.									1,040	
Lyngbya birgei		35.6								
Merismopedia sp.										
Merismopedia tenuissima										
Microcystis wesenbergii									7.2	8.2
Myxobaktron hirudiforme										
Oscillatoria tenuis										
Planktolyngbya limnetica										
Planktothrix agardhii										
Pseudanabaena limnetica	8.4									
Pseudanabaena sp.										
Romeria leopoliensis										
Snowella litoralis										
Synechococcus capitatus					20.8					
Synechococcus nidulans										
Synechocystis sp.			625					309		
Woronichinia naegeliana					14					
TOTAL CYANOPHYTA	**2,583**	**36.4**	**1,375**	**3.2**	**55.6**	**47.2**	**182**	**538.5**	**2,122**	**510.8**

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Top	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CHRYSOPHYTA (golden-brown algae)										
Chromulina parvula	125	62.5	750		125	187.5	250		250	
Chrysococcus sp.										
Dinobryon cylindricum var. alpinum	9.2									
Dinobryon cylindricum										
Dinobryon divergens	68	2,860	2,100	198		0.4				
Dinobryon sociale var. americanum										
statospore of Dinobryon		20				0.8				
Mallomonas akrokomos							70			
Mallomonas caudata										
Mallomonas sp.						0.4				
cyst of Mallomonas sp.										
Ochromonas minuscula										
Synura petersenii							8			
Uroglenopsis americana									1,680	2,040
TOTAL CHRYSOPHYTA	**202.2**	**2,943**	**2,850**	**198**	**125**	**189.1**	**328**	**0**	**1,930**	**2,040**
XANTHOPHYTA										
Gloeobotrys limneticus							2.4			
BACILLARIOPHYTA (diatoms)										
Amphora sp.										
Asterionella formosa	12.4	160	312.5	196.8	33	793.2	1,465	36	12.8	20
Aulacoseira ambigua	7.2							1.6	720	
Aulacoseira granulata var. angustissima	111.2			8.8			385	94	4,520	67.6
Aulacoseira italica	66.4									9.6
Aulacoseira italica var. tenuissima		2,900	232.5		0.6	4		7	4,120	7.2
Aulacoseira subarctica										
Cymatopleura solea										
Diatoma anceps										
Diatoma moniliformis										
Diatoma tenuis				16.4						
Discostella glomerata									120	
Discostella pseudostelligera										
Discostella stelligera					60					20
Fragilaria crotonensis	102	2,660	645	182.4	9.2	41.6	442.5	16	0.8	
Gomphonema sphaerophorum										
Gyrosigma acuminatum										

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Top	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
BACILLARIOPHYTA (diatoms) CONT'D										
Melosira varians										
Navicula capitatoradiata										
Navicula lanceolata										
Navicula tripunctata										
Nitzschia archibaldii						0.2			200	1.6
Nitzschia draveillensis	0.4							0.2	80	
Nitzschia fonticola										
Nitzschia gracilis									20	3.6
Nitzschia sigma										
Nitzschia sp.	0.2									
Nitzschia supralitorea										
Punticulata bodanica	0.4				0.2				0.4	
Stephanodiscus medius					0.2					
Stephanodiscus niagarae	4.4	0.4	1.2	0.4					3.6	
Stephanodiscus parvus							10			
Synedra acus										
Synedra cyclopum										
Synedra delicatissima var. angustissima	0.2									
Synedra rumpens var. familiaris				2.8						
Synedra rumpens									5	1.6
Synedra tenera	4.8				1.6	0.2				
Synedra ulna var. subaequalis										
Synedra ulna										
Tabellaria fenestrata	10.4	11.2	97.6	52.8	0.2			0.2		
Urosolenia eriensis										
TOTAL BACILLARIOPHYTA	**40,964**	**46,391**	**41,962**	**41,146**	**40,805**	**41,553**	**43,032**	**40,911**	**50,636**	**40,986**
HAPTOPHYTA										
Chrysochromulina parva	90		60							

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Top	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CRYPTOPHYTA										
Chroomonas coerulea					0.4	1.2			40	
Chroomonas nordstedtii										
Cryptomonas borealis			0.4	39.2	18.8	23.2			125	60
Cryptomonas curvata		0.2	0.2	42	0.8	1.8			5	5.8
Cryptomonas erosa										
Cryptomonas marsonii				0.4	0.4	2.4				
Hemiselmis sp.						40				
Komma caudata										
Plagioselmis nannoplanctica	100	1,000	20	3,200	1,010	450	340		3,080	840
cyst of Cryptomonas					0.8					
TOTAL CRYPTOPHYTA	**100**	**1,000**	**20.6**	**3,282**	**1,031**	**518.6**	**340**	**0**	**3,250**	**905.8**
DINOPHYTA										
Ceratium hirundinella				0.4	0.2		2.4		6	
Gymnodinium fuscum										
Peridinium lomnickii										
Peridinium willei	0.4	6.2	9.6	2	0.2					
TOTAL DINOPHYTA	**0.4**	**6.2**	**9.6**	**2.4**	**0.4**	**0**	**2.4**	**0**	**6**	**0**
EUGLENOPHYTA										
Lepocinclis acus										
Lepocinclis oxyuris										
Trachelomonas dybowskii										
Trachelomonas hispida									0.8	
Trachelomonas volvocina										
TOTAL EUGLENOPHYTA	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.8**	**0**
PRASINOPHYTA										
Pyramimonas sp.			0.2							
Scourfieldia sp.										
Tetraselmis cordiformis									10	20
TOTAL PRASINOPHYTA	**0**	**0**	**0.2**	**0**	**0**	**0**	**0**	**0**	**10**	**20**

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Top	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CHLOROPHYTA (green algae)										
Ankistrodesmus falcatus										
Ankyra judayi	10	240	2	20	10	10	310			
Botryococcus braunii										
Chlamydomonas dinobryonis			10	13.6						
Chlamydomonas globosa										
Chlamydomonas snowiae										
Chlamydomonas sp. 1										
Chlamydomonas sp. 2							10			
Chlamydomonas tetragama										
Chlorella minutissima	1,125	1,063	3,625	2,000	2,875	62.5	4,625		3,500	13,500
Chloromonas sp.							30			
Choricystis minor										
Closterium aciculare									1.6	
Closterium acutum var. variabile									1.6	
Closterium dianae										
Closterium moniliferum				0.2		0.2				
Coelastrum indicum			3.2							
Coelastrum pseudomicroporum										
Coelastrum pulchrum										
Coenochloris fottii										
Cosmarium bioculatum										
Desmodesmus armatus									1.6	
Desmodesmus bicaudatus										
Desmodesmus communis										
Dictyosphaerium pulchellum var. minutum									2	
Elakatothrix viridis		1.2	0.4				50			
Eudorina elegans										
Gonatozygon kinahanii										
Heimansia pusilla										
Keratococcus sp.										
Micractinium pusillum										
Monoraphidium contortum									2	
Monoraphidium sp.										
Mougeotia sp.	4.8									
Nephrocytium limneticum									6.4	
Oocystis apiculata	0.4		0.8							
Oocystis borgei										

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Top	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CHLOROPHYTA (green algae) CONT'D										
Oocystis parva								0.8		
Oocystis pusilla										
Pandorina charkowiensis										
Pandorina smithii										
Pediastrum boryanum										
Pediastrum duplex										
Pseudodictyosphaerium elegans								6		
Pseudodictyosphaerium sp.		62.5							600	
Quadrigula sp.										
Raphidocelis contorta										
Raphidocelis sp.										
Scenedesmus arcuatus										
Schroederia setigera										
Staurastrum planctonicum								0.1		
Tetraedron minimum										
Tetraspora lemmermannii							11.2			
Volvox sp.									22.4	
TOTAL CHLOROPHYTA	**41,784**	**42,025**	**44,314**	**42,720**	**43,585**	**40786.7**	**45,765**	**40762.9**	**44,971**	**54,355**
TOTAL ALGAL DENSITY (cells/mL)	**293,290**	**306,779**	**303,142**	**296,761**	**293,304**	**288,332**	**301,488**	**286,693**	**328,348**	**320,201**

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Bottom Potential geosmin producing cyanophyta	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CYANOPHYTA (blue-green algae)										
Anabaena flos-aquae								832		
Anabaena crassa			8					31.2	94.4	
Anabaena lemmermannii										
Anabaena planctonica					1.6			86.4	88	
Aphanizomenon flos-aquae								825	16.4	210
Aphanocapsa conferta										
Aphanocapsa delicatissima										
Aphanocapsa holsatica	500									
Aphanothece clathrata										
Aphanothece smithii	125		125		125			125		
Coelosphaerium aerugineum										
Cuspidothrix issatschenkoi										
Cyanobium sp.										
Dactylococcopsis sp.					20					
Geitlerinema sp.										
Jaaginema sp.										
Limnothrix sp.									8	
Lyngbya birgei										
Merismopedia sp.										
Merismopedia tenuissima										
Microcystis wesenbergii									68.4	
Myxobaktron hirudiforme										
Oscillatoria tenuis										
Planktolyngbya limnetica										
Planktothrix agardhii									18.4	
Pseudanabaena limnetica				8.8						
Pseudanabaena sp.	12									
Romeria leopoliensis										
Snowella litoralis										
Synechococcus capitatus										
Synechococcus nidulans	30	20								
Synechocystis sp.		5,375	125							
Woronichinia naegeliana								60.8	24	
TOTAL CYANOPHYTA	**667**	**5,395**	**258**	**8.8**	**146.6**	**0**	**0**	**1,960**	**317.6**	**210**

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Bottom	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CHRYSOPHYTA (golden-brown algae)										
Chromulina parvula	500	375	375	125	125	206				
Chrysococcus sp.										
Dinobryon cylindricum var. alpinum	0.2	20								
Dinobryon cylindricum										
Dinobryon divergens	0.8	820	73.6	4.4						
Dinobryon sociale var. americanum										
statospore of Dinobryon	1.6			200	60					
Mallomonas akrokomos										
Mallomonas caudata										
Mallomonas sp.										
cyst of Mallomonas sp.										
Ochromonas minuscula										
Synura petersenii										
Uroglenopsis americana									460	2,520
TOTAL CHRYSOPHYTA	**502.6**	**1,215**	**448.6**	**329.4**	**185**	**206**	**0**	**0**	**460**	**2,520**
XANTHOPHYTA										
Gloeobotrys limneticus										
Amphora sp.					0.8					
Asterionella formosa	8.8	64.4	60	239.2	12.8		211.2		27.2	20.8
Aulacoseira ambigua	20	4.8							560	
Aulacoseira granulata var. angustissima	580	4,500		74			4	2.8	3,600	37.2
Aulacoseira italica	610		3.2							
Aulacoseira italica var. tenuissima			170.8		24.8	28.8			2,400	
Aulacoseira subarctica										
Cymatopleura solea										
Diatoma anceps										
Diatoma moniliformis										
Diatoma tenuis	0.8									
Discostella glomerata									160	
Discostella pseudostelligera										
Discostella stelligera					2					360
Fragilaria crotonensis	58.8	1,040	180	17.2			89.6			
Gomphonema sphaerophorum										

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Bottom	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
BACILLARIOPHYTA (diatoms) CONT'D										
Gyrosigma acuminatum										
Melosira varians								7.2		
Navicula capitatoradiata										
Navicula lanceolata										
Navicula tripunctata										
Nitzschia archibaldii									40	10
Nitzschia draveillensis				0.8						
Nitzschia fonticola										
Nitzschia gracilis										0.4
Nitzschia sigma										
Nitzschia sp.			0.4	1.2	0.4					
Nitzschia supralitorea										
Punticulata bodanica									0.4	
Stephanodiscus medius										
Stephanodiscus niagarae	8.8	2.8		0.4					5.6	0.4
Stephanodiscus parvus										
Synedra acus					2.4					
Synedra cyclopum										
Synedra delicatissima var. angustissima										
Synedra rumpens var. familiaris	0.4			5.2						
Synedra rumpens										
Synedra tenera	3.2				0.4					
Synedra ulna var. subaequalis										
Synedra ulna										
Tabellaria fenestrata		37.6	189.6	1.6	2.4					
Urosolenia eriensis										
TOTAL BACILLARIOPHYTA	**41,935**	**46,309**	**41277**	**41025.6**	**40746**	**40742.8**	**41033.8**	**40766**	**47,626**	**41283.8**
HAPTOPHYTA										
Chrysochromulina parva										

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Bottom	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CRYPTOPHYTA										
Chroomonas coerulea										
Chroomonas nordstedtii										
Cryptomonas borealis	0.8		0.8		0.2			0.8	75	320
Cryptomonas curvata			1.2					0.4		
Cryptomonas erosa										
Cryptomonas marsonii										
Hemiselmis sp.	40									
Komma caudata										
Plagioselmis nannoplanctica	40	40	150	10				620	1,280	1,200
cyst of Cryptomonas										
TOTAL CRYPTOPHYTA	**80.8**	**40**	**152**	**10**	**0.2**	**0**	**0**	**621.2**	**1,355**	**1,520**
DINOPHYTA										
Ceratium hirundinella								1.2	11.2	
Gymnodinium fuscum						0.1				
Peridinium lomnickii										
Peridinium willei										
TOTAL DINOPHYTA	**0**	**0**	**0**	**0**	**0**	**0.1**	**0**	**1.2**	**11.2**	**0**
EUGLENOPHYTA										
Lepocinclis acus										
Lepocinclis oxyuris							0.2			
Trachelomonas dybowskii										
Trachelomonas hispida										
Trachelomonas volvocina									0.8	5
TOTAL EUGLENOPHYTA	**0**	**0**	**0**	**0**	**0**	**0**	**0.2**	**0**	**0.8**	**5**
PRASINOPHYTA										
Pyramimonas sp.										
Scourfieldia sp.										
Tetraselmis cordiformis									2	5
TOTAL PRASINOPHYTA	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**5**

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Bottom	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CHLOROPHYTA (green algae)										
Ankistrodesmus falcatus										
Ankyra judayi				0.8						
Botryococcus braunii									2.4	
Chlamydomonas dinobryonis										
Chlamydomonas globosa										
Chlamydomonas snowiae										
Chlamydomonas sp. 1										
Chlamydomonas sp. 2										
Chlamydomonas tetragama										
Chlorella minutissima	750	2,875	7,500	62.5	2,750	1,030	1,750	437.5	8,000	18,500
Chloromonas sp.										
Choricystis minor										
Closterium aciculare									0.8	
Closterium acutum var. variabile									3.6	
Closterium dianae										
Closterium moniliferum					0.2		0.2			
Coelastrum indicum			3.2							
Coelastrum pseudomicroporum	8.8									
Coelastrum pulchrum										
Coenochloris fottii								4.8		
Cosmarium bioculatum										
Desmodesmus armatus										
Desmodesmus bicaudatus										
Desmodesmus communis										
Dictyosphaerium pulchellum var. minutum										
Elakatothrix viridis		1.6	0.8							
Eudorina elegans										
Gonatozygon kinahanii										
Heimansia pusilla										
Keratococcus sp.										
Micractinium pusillum										
Monoraphidium contortum										
Monoraphidium sp.										
Mougeotia sp.										
Nephrocytium limneticum										
Oocystis apiculata										

Phytoplankton Densities (cells/ml)	SAMPLING DATE									
Seaman Reservoir - Bottom	11-Apr-11	26-Apr-11	10-May-11	23-May-11	6-Jun-11	20-Jun-11	5-Jul-11	1-Aug-11	17-Oct-11	8-Nov-11
CHLOROPHYTA (green algae) CONT'D										
Oocystis borgei										
Oocystis parva										
Oocystis pusilla										
Pandorina charkowiensis										
Pandorina smithii										
Pediastrum boryanum					2.4					
Pediastrum duplex										
Pseudodictyosphaerium elegans										
Pseudodictyosphaerium sp.				750					1,000	
Quadrigula sp.										
Raphidocelis contorta										
Raphidocelis sp.										
Scenedesmus arcuatus										
Schroederia setigera										
Staurastrum planctonicum								0.8		
Tetraedron minimum										
Tetraspora lemmermannii								7.2		
Volvox sp.										
TOTAL CHLOROPHYTA	**41402.8**	**43,536**	**48,177**	**41499.3**	**43,453**	**41,744**	**42,479**	**41206.3**	**49,840**	**59,355**
TOTAL ALGAL DENSITY (cells/mL)	**291,108**	**314,965**	**302,644**	**287,804**	**291,161**	**287,528**	**289,213**	**291,378**	**321,724**	**332,363**

ATTACHMENT 7

2011 Upper CLP Collaborative Water Quality Monitoring Program

Graphical Summary

LIST OF FIGURES

Figure 1.(a&b). Daily average stream flow on the Mainstem and North Fork CLP 109
Figure 1.a. 2011 Daily average stream flow on the Mainstem and North Fork CLP 109
Figure 1.b. 2008 – 2011 Daily average stream flow on the Mainstem and North Fork CLP 109
Figure 2 (a&b). Daily average stream flow on the North Fork tributaries 110
Figure 2.a. 2011 Daily average stream flow on the North Fork tributaries 110
Figure 2.b. 2008 - 2011 Daily average stream flow on the North Fork tributaries....110
Figure 3 (a&b). Water Temperature 113
Figure 3.a. Water temperature on the Mainstem CLP 113
Figure 3.b. Water temperature on the North Fork CLP 113
Figure 4 (a&b). pH 114
Figure 4.a.pH on the Mainstem CLP 114
Figure 4.b. pH on the North Fork CLP 114
Figure 5 (a&b). Specific Conductance 115
Figure 5.a. Specific Conductance on the Mainstem CLP 115
Figure 5.b. Specific Conductance on the North Fork CLP 115
Figure 6 (a&b). Hardness 116
Figure 6.a.Hardness on the Mainstem CLP 116
Figure 6.b. Hardness on the North Fork CLP 116
Figure 7 (a&b). Alkalinity 117
Figure 7.a. Alkalinity on the Mainstem CLP 117
Figure 7.b. Alkalinity on the North Fork CLP 117
Figure 8 (a&b). Turbidity 118
Figure 8.a. Turbidity on the Mainstem CLP 118
Figure 8.b. Turbidity on the North Fork CLP 118
Figure 9 (a&b). Total Dissolved Solids (TDS) 119
Figure 9.a. Total Dissolved Solids (TDS) on the Mainstem CLP 119
Figure 9.b. Total Dissolved Solids (TDS) on the North Fork CLP 119
Figure 10.(a&b). Total Organic Carbon (TOC) 120
Figure 10.a. TOC on the Mainstem 120
Figure 10.b. TOC on the North Fork CLP 120
Figure 11 (a&b). Ammonia (NH_3) 123
Figure 11.a. Ammonia (NH_3 on the Mainstem CLP 123
Figure 11.b. Ammonia (NH_3 on the North Fork CLP 123

Figure 12 (a&b). Nitrate (NO_3) 124
Figure 12.a. Nitrate (NO_3) on the Mainstem CLP 124
Figure 12.b. Nitrate (NO_3) on the North Fork CLP 124
Figure 13 (a&b). Nitrite (NO_2)....125
Figure 13.a. Nitrite (NO_2) on the Mainstem CLP 125
Figure 13.b. Nitrite (NO_2) on the North Fork CLP....125
Figure 14 (a&b). Total Kjelhalh Nitrogen (TKN) 126
Figure 14.a. TKN on the Mainstem CLP....126
Figure 14.b. TKN on the North Fork CLP 126
Figure 15 Total Nitrogen (TKN + NO_3 + NO_2)....127
Figure 15.a.Total N on the Mainstem CLP 127
Figure 15.b. Total N on the North Fork CLP 127
Figure 16 (a&b). Ortho-phosphate (PO_4) 128
Figure 16.a. Ortho-phosphate (PO_4) on the Mainstem CLP....128
Figure 16.b. Ortho-phosphate (PO_4) on the North Fork CLP 128
Figure 17 (a&b). Total Phosphorus (P) 129
Figure 17.a. Total P on the Mainstem CLP....129
Figure 17.b. Total P on the North Fork CLP 129
Figure 18. Dissolved silver (Ag) on the Mainstem and North Fork CLP....133
Figure 19. Dissolved cadmium (Cd) on the Mainstem and North Fork CLP 133
Figure 20. Dissolved chromium (Cr) on the Mainstem and North Fork CLP....134
Figure 21. Dissolved copper (Cu) on the Mainstem and North Fork CLP....134
Figure 22. Total iron (Fe) on the Mainstem and North Fork CLP....135
Figure 23. Dissolved iron (Fe) on the Mainstem and North Fork CLP 135
Figure 24. Dissolved nickel (Ni) on the Mainstem and North Fork CLP....136
Figure 25. Dissolved lead (Pb) on the Mainstem and North Fork CLP 136
Figure 26. Dissolved zinc (Zn) on the Mainstem and North Fork CLP....137
Figure 27(a&b). Calcium (Ca)....141
Figure 27.a. Calcium (Ca) on the Mainstem CLP 141
Figure 27.b. Calcium (Ca) on the North Fork CLP....141
Figure 28 (a&b). Magnesium (Mg)....142
Figure 28.a. Magnesium (Mg) on the Mainstem CLP 142
Figure 28.b. Magnesium (Mg) on the North Fork CLP....142
Figure 29 (a&b). Potassium (K)....143
Figure 29.a. Potassium (K) on the Mainstem CLP 143
Figure 29.b. Potassium (K) on the North Fork CLP 143

Figure 30 (a&b). Sodium (Na) 144
Figure 30.a. Sodium (Na) on the Mainstem CLP..144
Figure 30.b. Sodium (Na) on the North Fork CLP 144
Figure 31 (a&b). Chloride (Cl) 145
Figure 31.a. Chloride (Cl) on the Mainstem CLP..145
Figure 31.b. Chloride (Cl) on the North Fork CLP 145
Figure 32 (a&b). Sulfate (SO_4) 146
Figure 32.a. Sulfate (SO_4) on the Mainstem CLP 146
Figure 32.b. Sulfate (SO_4) on the North Fork CLP 146
Figure 33. Total coliforms on the Mainstem and North Fork CLP 149
Figure 34. *E.coli* on the Mainstem and North Fork CLP...149
Figure 35. *Giardia* on the Mainstem and North Fork CLP 150
Figure 36. *Cryptosporidium* on the Mainstem and North Fork CLP 150
Figure 37. Geosmin on the Mainstem CLP collected at the FCWTF 153
Figure 38. 2011 Seaman Reservoir temperature profiles 157
Figure 39. 2011 Seaman Reservoir dissolved oxygen (D.O.) profiles 157
Figure 40. 2011 Seaman Reservoir pH profiles 158
Figure 41. 2011 Seaman Reservoir specific conductance profiles 158
Figure 42. Alkalinity concentrations in Seaman Reservoir 161
Figure 43. Hardness concentrations in Seaman Reservoir...161
Figure 44. Turbidity in Seaman Reservoir 162
Figure 45. Total dissolved solids (TDS) in Seaman Reservoir...162
Figure 46. Chlorophyll-a concentrations in Seaman Reservoir..163
Figure 47. Total organic carbon (TOC) concentrations in Seaman Reservoir 163
Figure 48. Secchi disk depth in Seaman Reservoir 164
Figure 49. Ammonia (NH_3) concentrations in Seaman Reservoir 167
Figure 50. Nitrate (NO_3) concentrations in Seaman Reservoir 167
Figure 51. Nitrite (NO_2) concentrations in Seaman Reservoir 168
Figure 52. Total Kjeldahl Nitrogen (TKN) concentrations in Seaman Reservoir.........................168
Figure 53. Total Nitrogen (TKN+NO3+ NO2) concentrations in Seaman Reservoir...................169
Figure 54. Ortho-phosphate (PO_4) concentrations in Seaman Reservoir.................................169
Figure 55. Total phosphorus (P) concentrations in Seaman Reservoir 170
Figure 56. Calcium (Ca) concentrations in Seaman Reservoir 173
Figure 57. Magnesium (Mg) concentrations in Seaman Reservoir 173
Figure 58. Potassium (K) concentrations in Seaman Reservoir 174
Figure 59. Sodium (Na) concentrations in Seaman Reservoir...174

Figure 60. Chloride (Cl) concentrations in Seaman Reservoir 175
Figure 61. Sulfate (SO_4) concentrations in Seaman Reservoir 175
Figure 62. *E. coli* concentrations in Seaman Reservoir 179
Figure 63. Total coliform concentrations in Seaman Reservoir 179
Figure 64. Geosmin concentrations in Seaman Reservoir 183

Mainstem and North Fork CLP:
Daily Average Stream Flow

Figure 1 (a & b). Daily average stream flow on the Mainstem and North Fork CLP

Figure 1.a. 2011 Daily average stream flow on the Mainstem and North Fork CLP

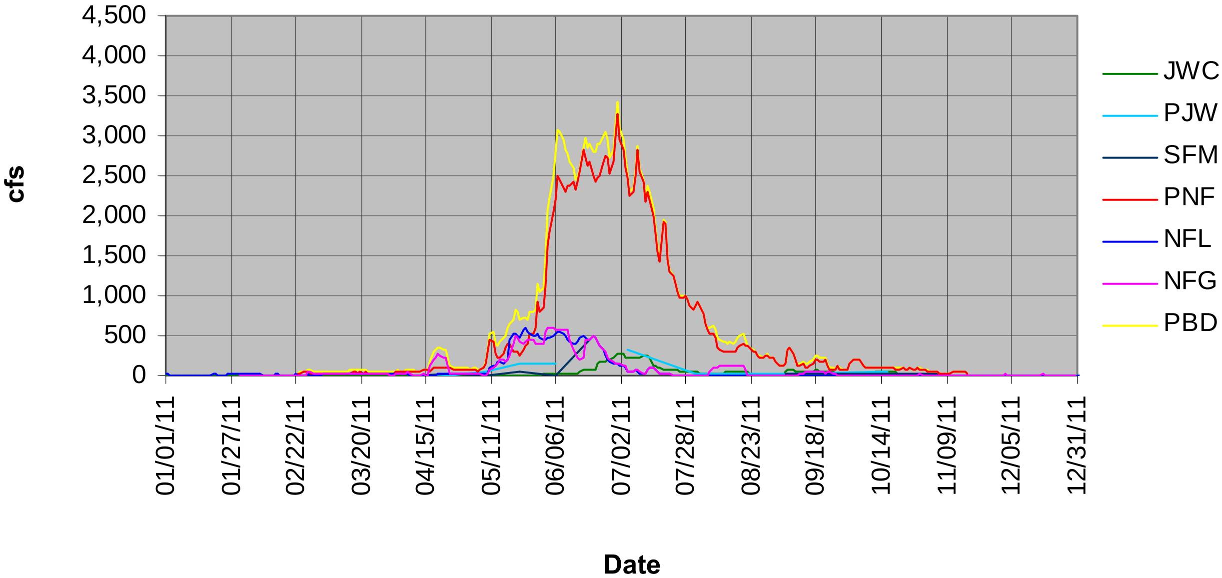


Figure 1.b. 2008 - 2011 Daily average stream flow on the Mainstem and North Fork CLP

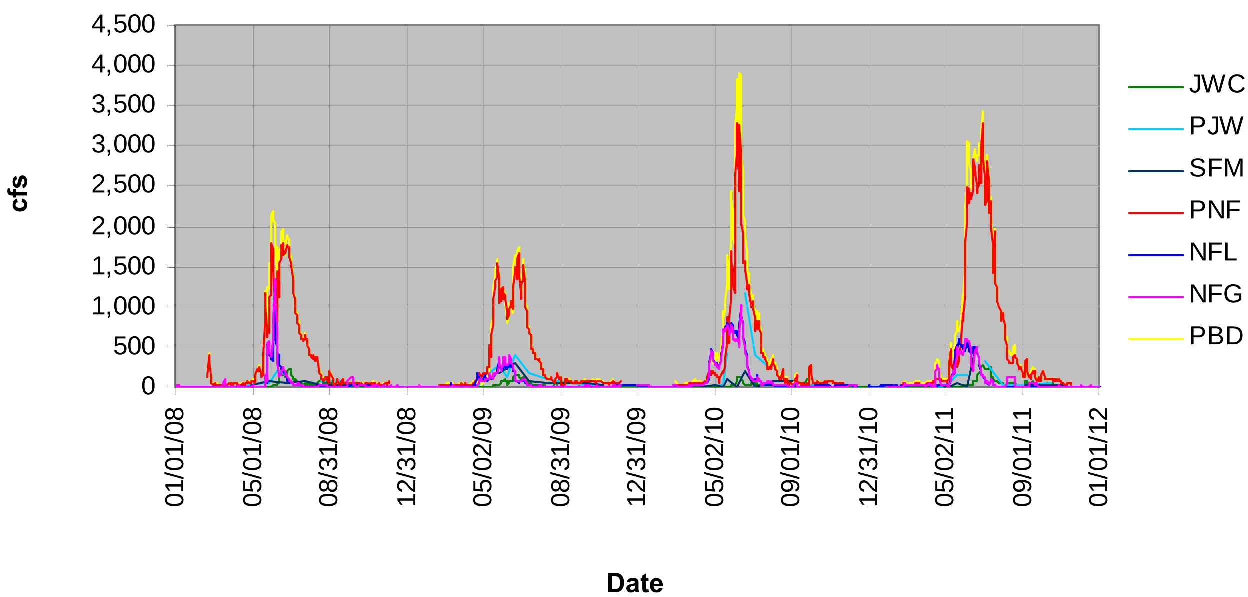


Figure 2 (a & b). Daily average stream flow on the North Fork tributaries

Figure 2.a. 2011 Daily average stream flow on the North Fork tributaries

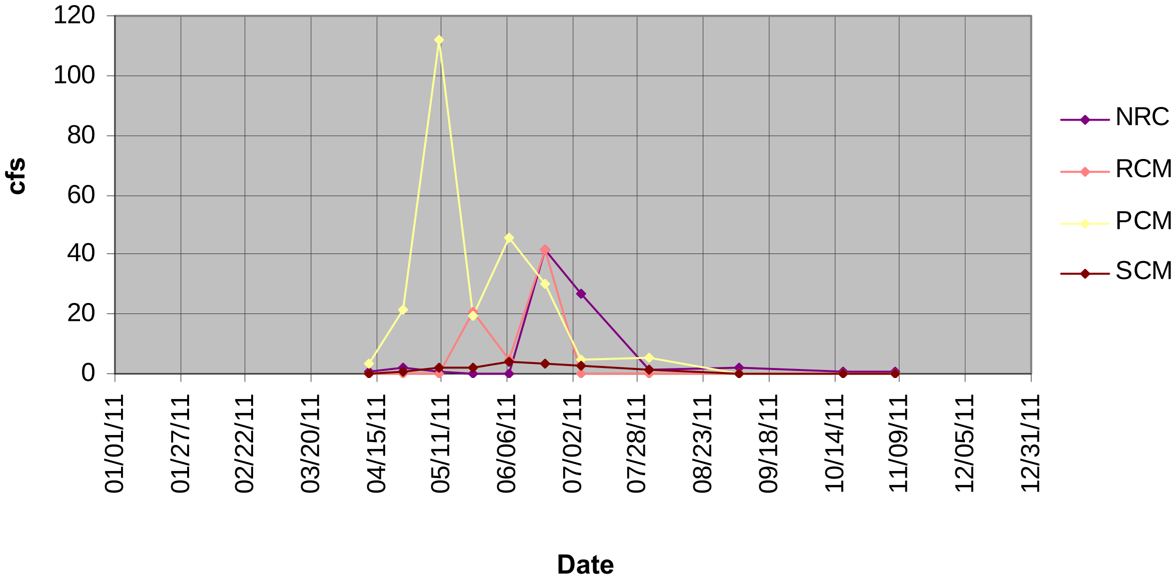
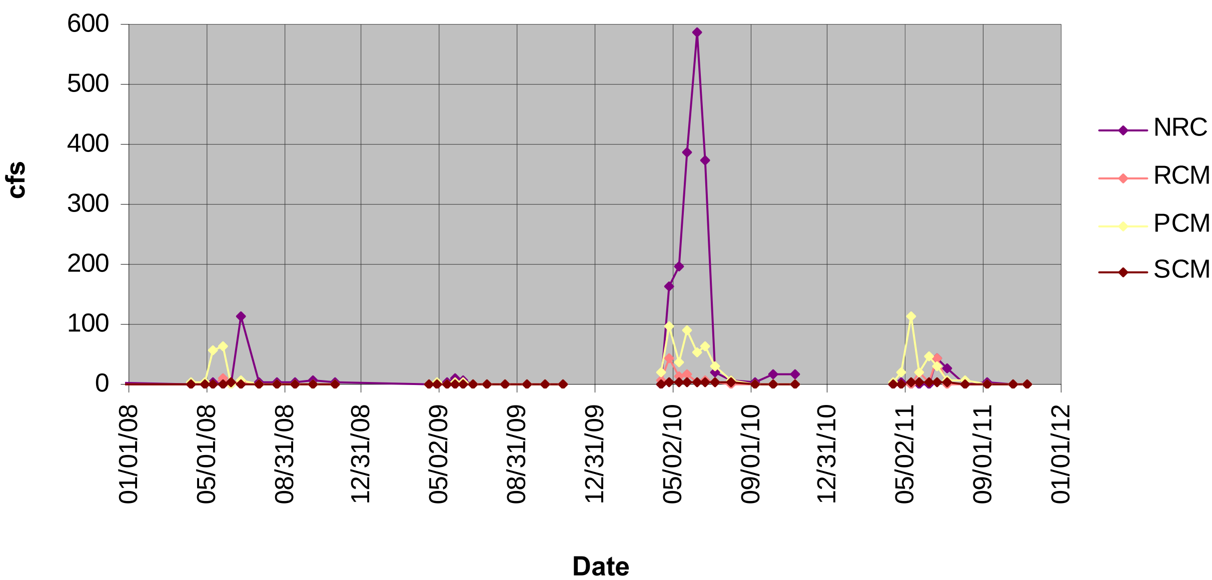


Figure 2.b. 2008 - 2011 Daily average stream flow on the North Fork tributaries



Mainstem and North Fork CLP:
General Parameters

Figure 3 (a & b). Water temperature

Figure 3.a. Water temperature on the Mainstem CLP

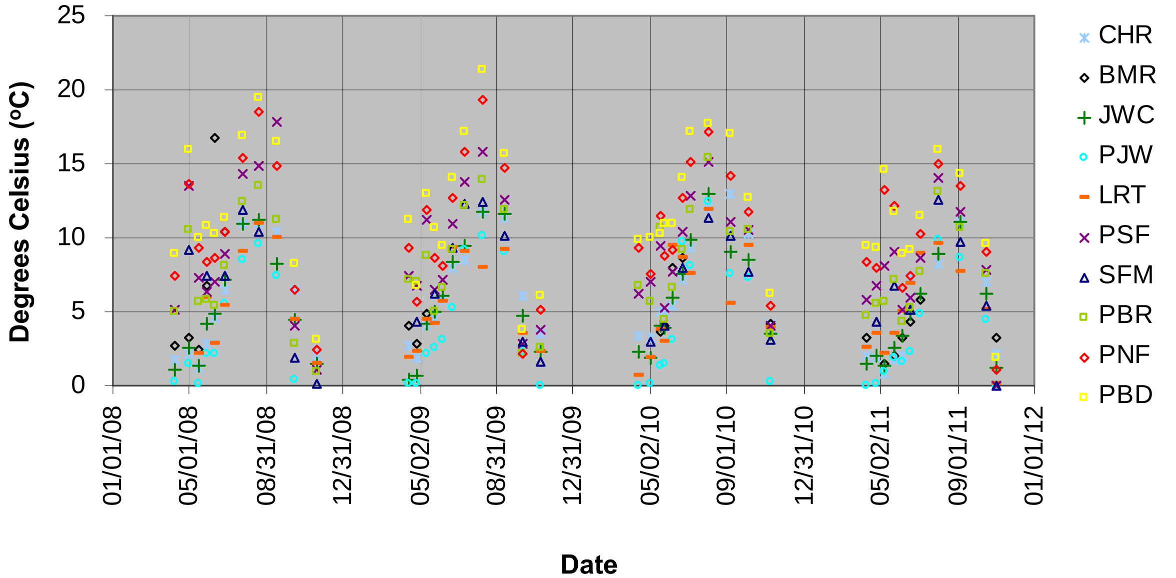


Figure 3.b. Water temperature on the North Fork CLP

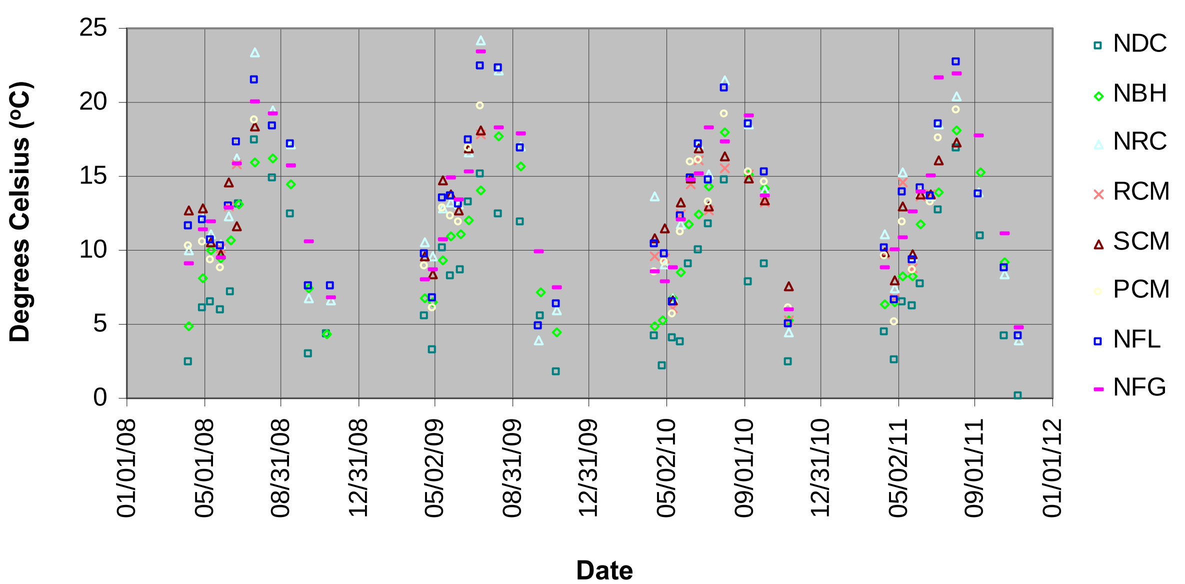


Figure 4 (a & b). pH

Figure 4.a. pH on the Mainstem CLP

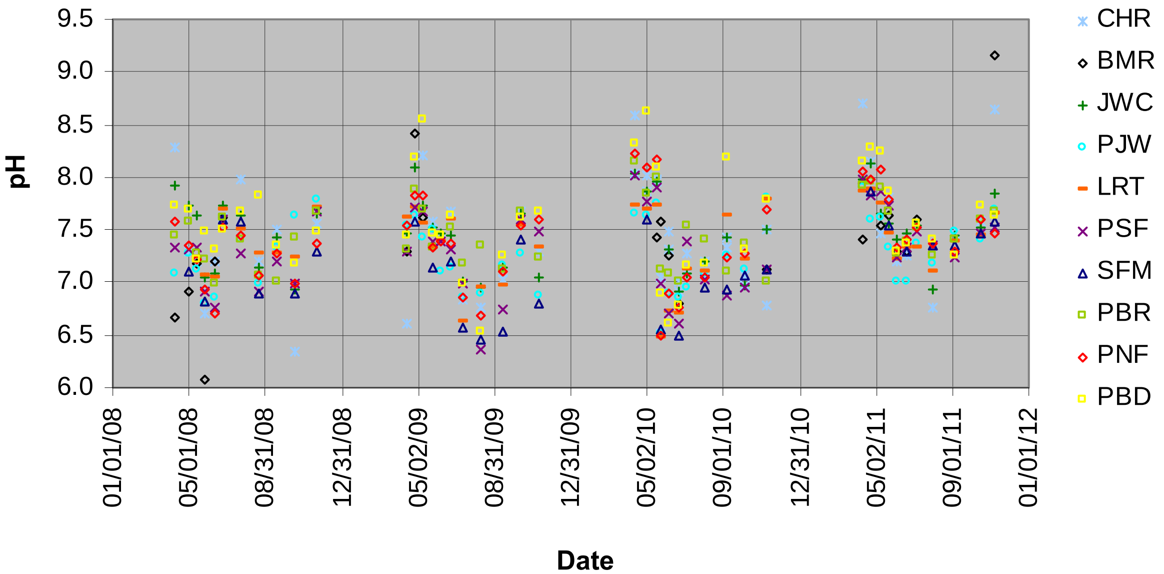


Figure 4.b. pH on the North Fork CLP

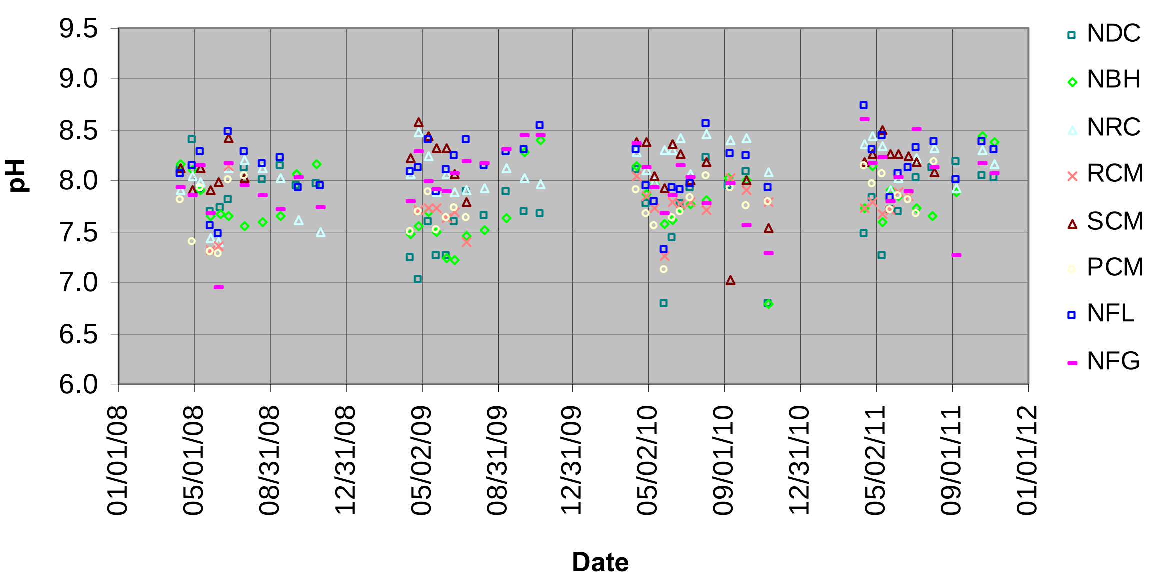


Figure 5 (a & b). Specific Conductance

Figure 5.a. Specific Conductance **o**n the Mainstem CLP

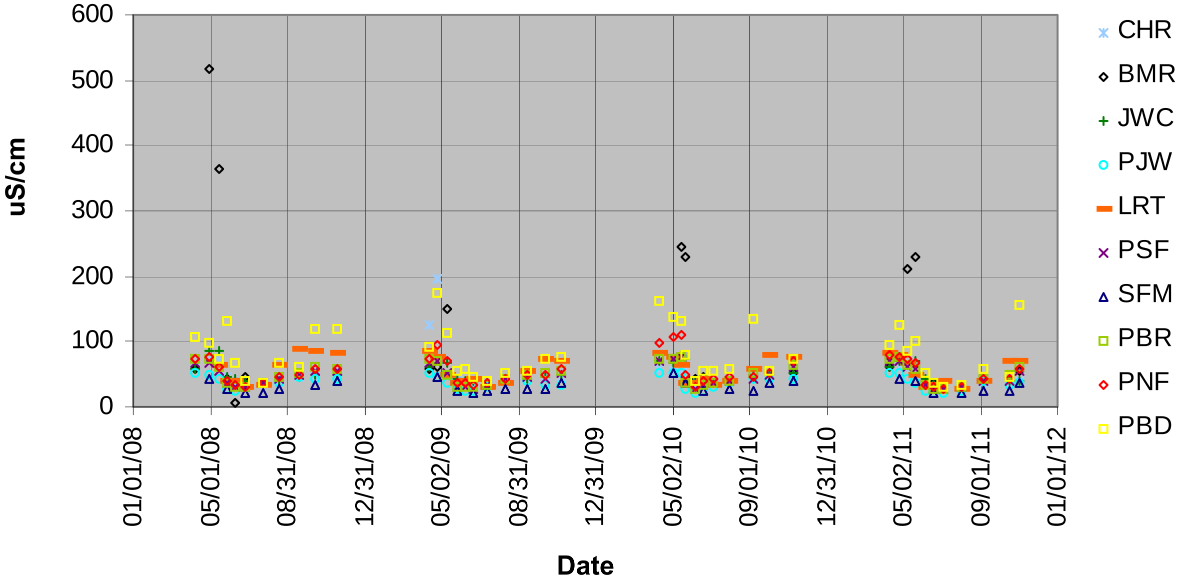


Figure 5.b. Specific conductance on the North Fork CLP

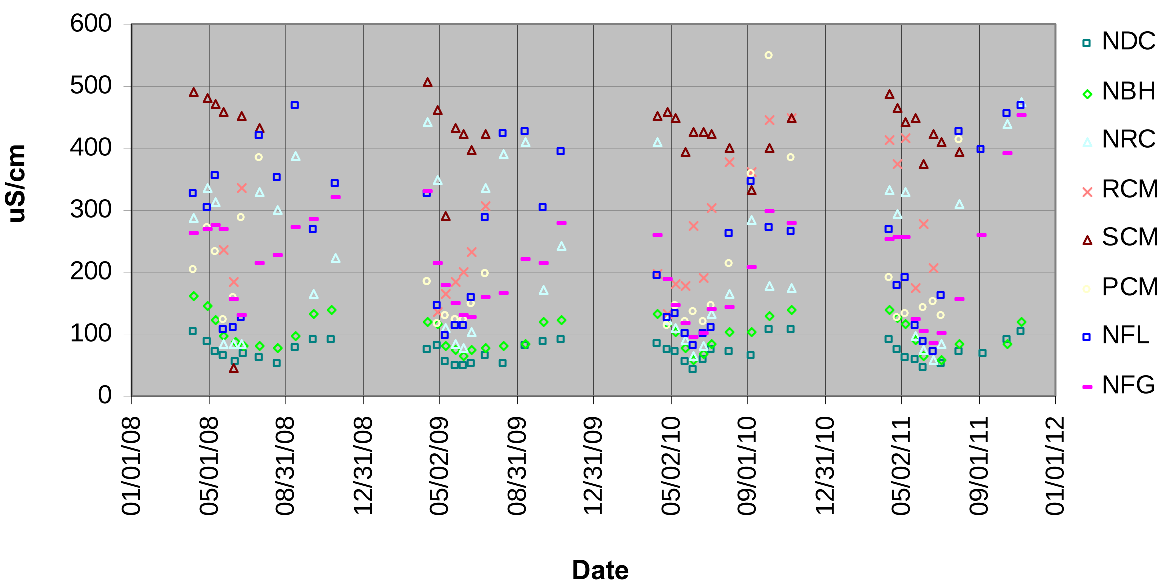


Figure 6 (a & b). Hardness

Figure 6.a. Hardness on the Mainstem CLP

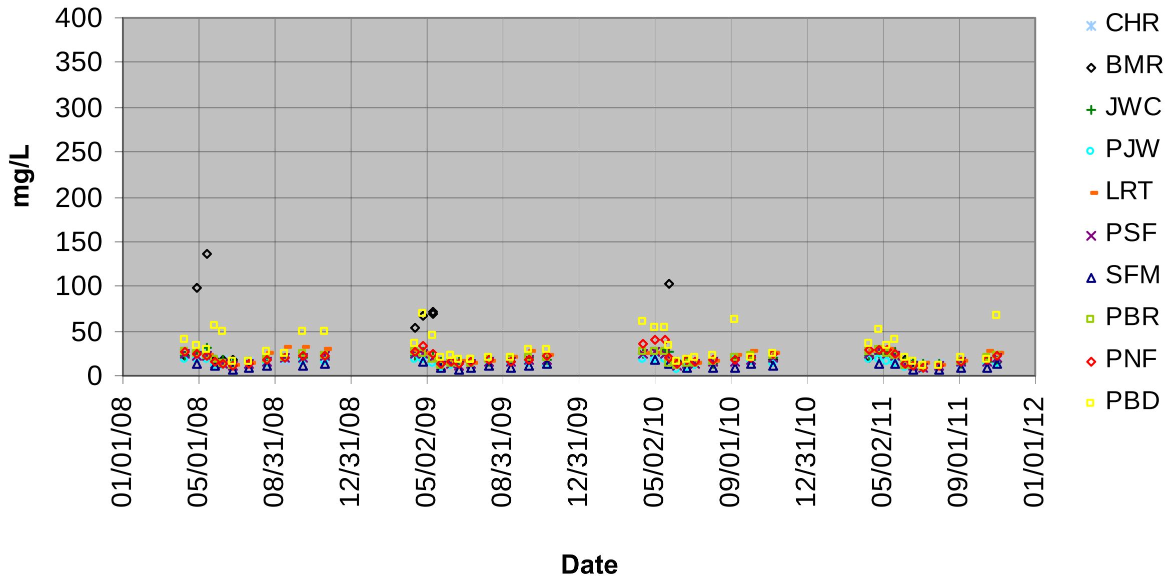


Figure 6.b. Hardness on the North Fork CLP

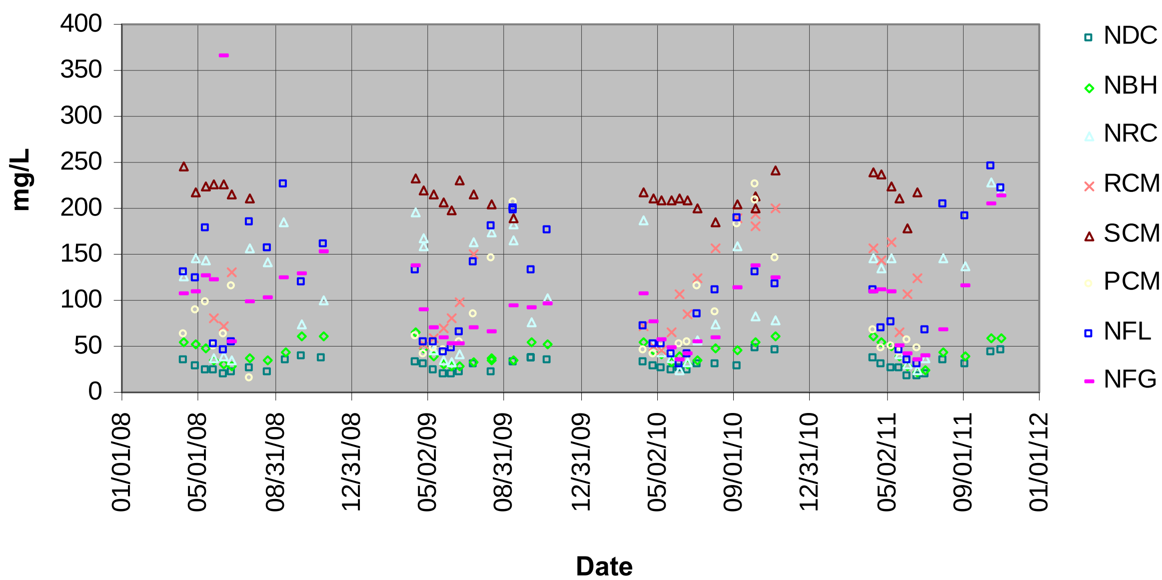


Figure 7 (a & b). Alkalinity

Figure 7.a. Alkalinity on the Mainstem CLP

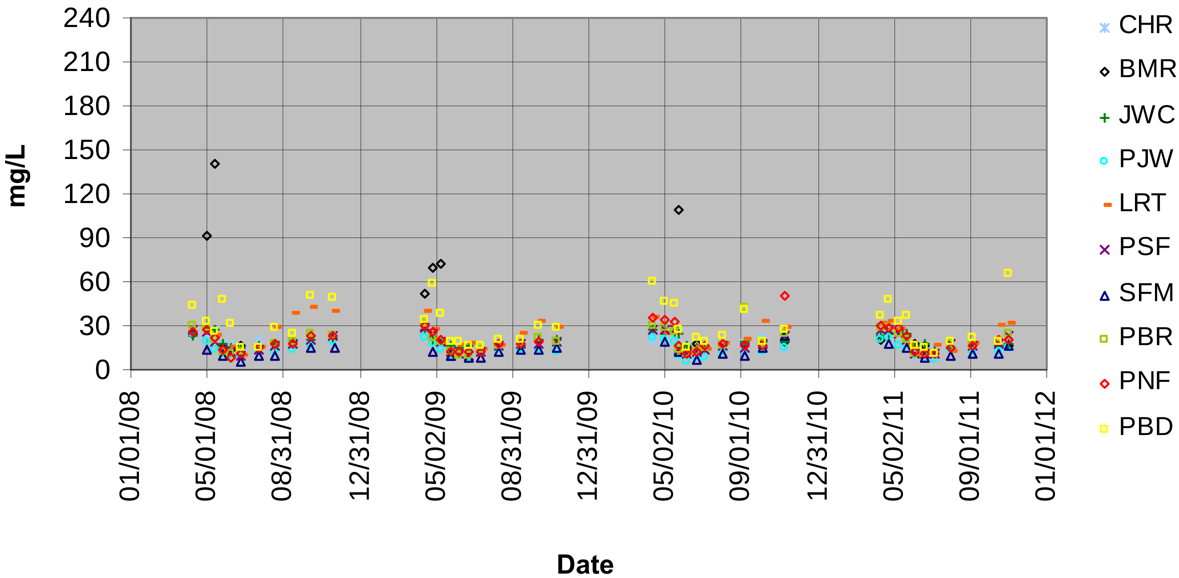


Figure 7.b. Alkalinity on the North Fork CLP

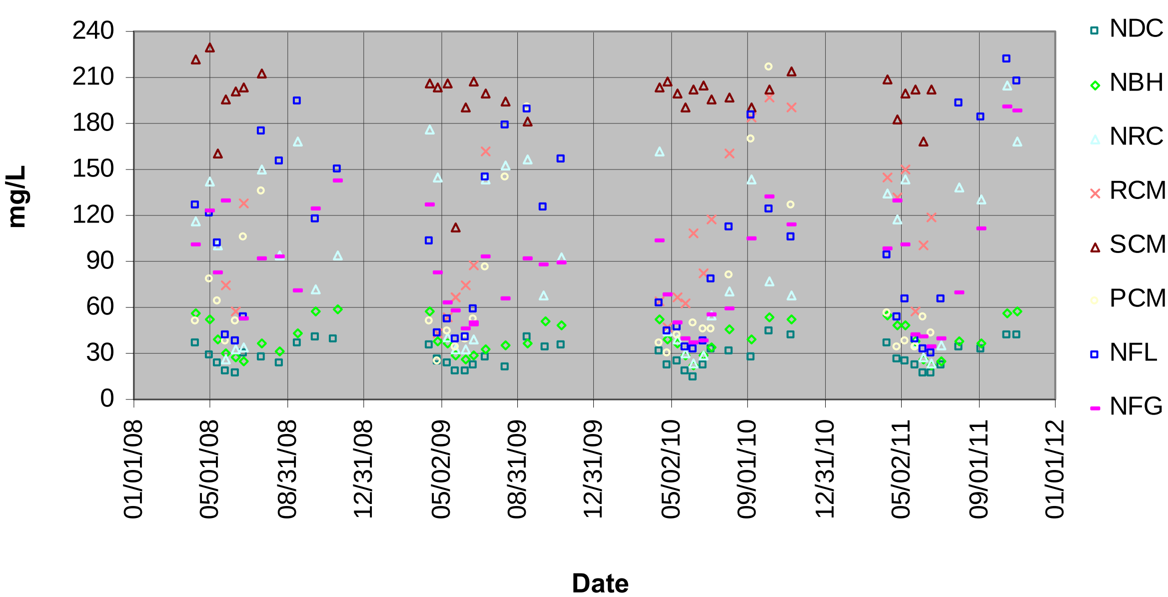


Figure 8 (a & b). Turbidity

Figure 8.a. Turbidity on the Mainstem CLP

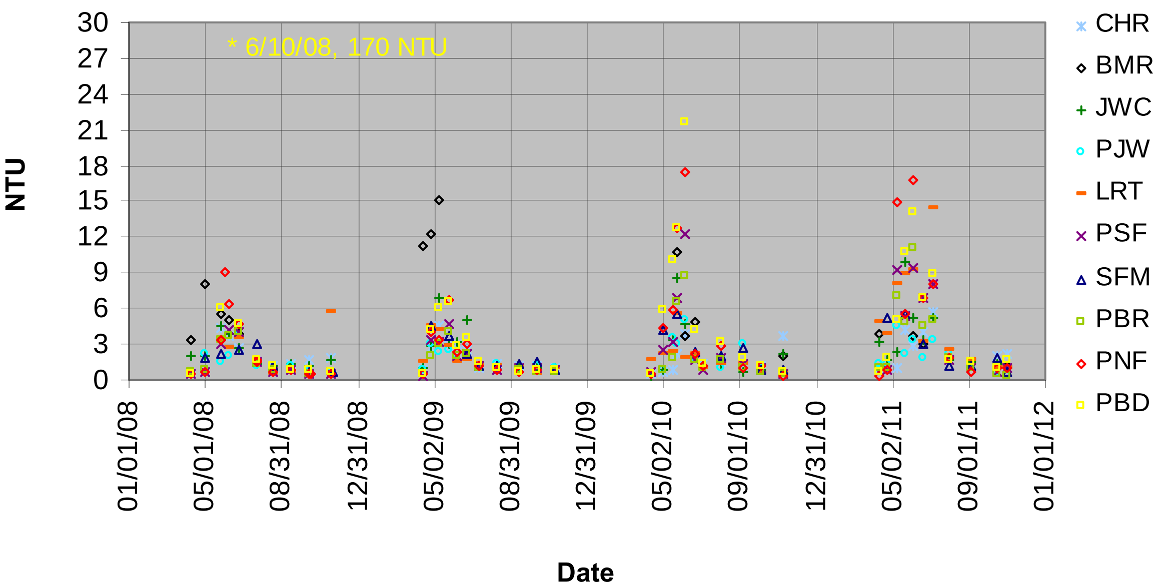


Figure 8.b. Turbidity on the North Fork CLP

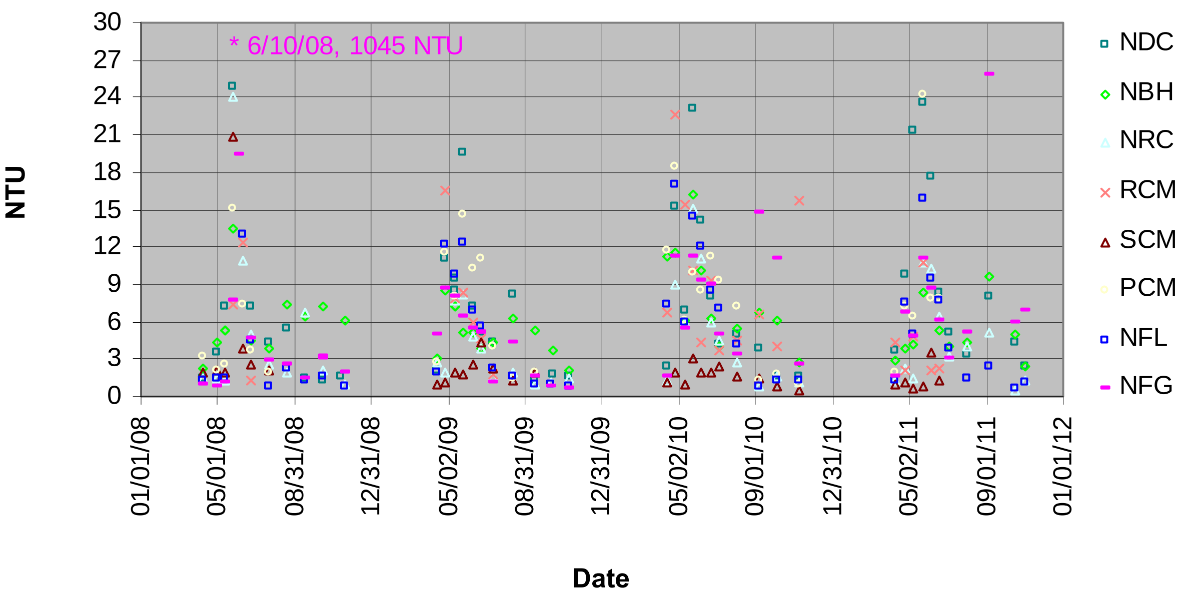
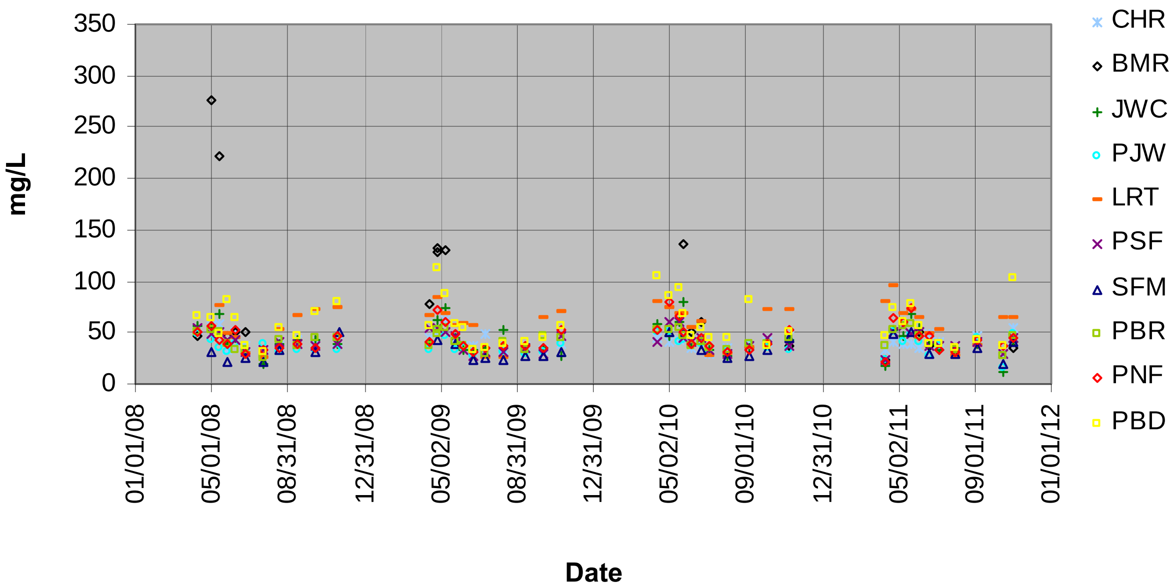


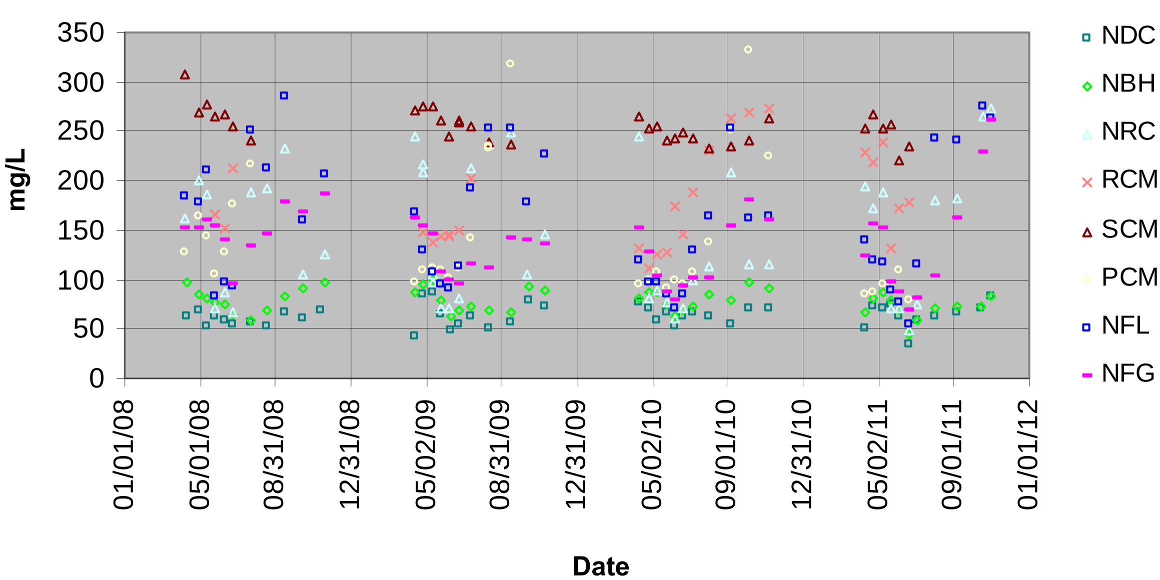
Figure 9 (a & b). Total Dissolved Solids (TDS)

Figure 9.a. TDS on the Mainstem CLP



(EPA Secondary Drinking Water Standard: 500 mg/l)

Figure 9.b. TDS on the North Fork CLP



(EPA Secondary Drinking Water Standard: 500 mg/l)

Figure 10 (a & b). Total Organic Carbon (TOC)

Figure 10.a. TOC on the Mainstem CLP

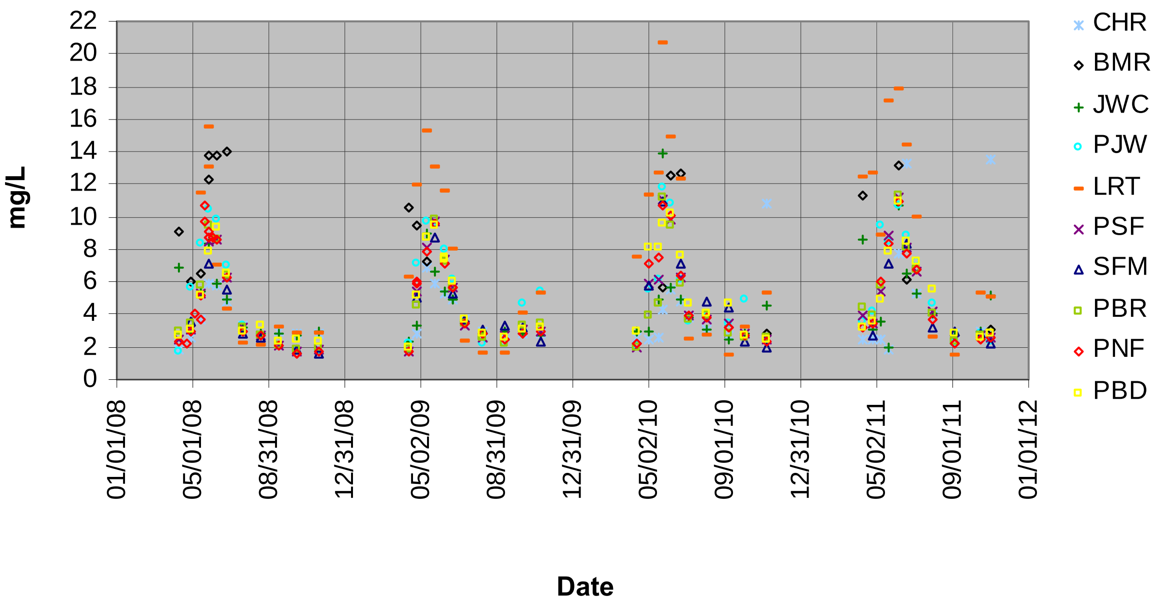
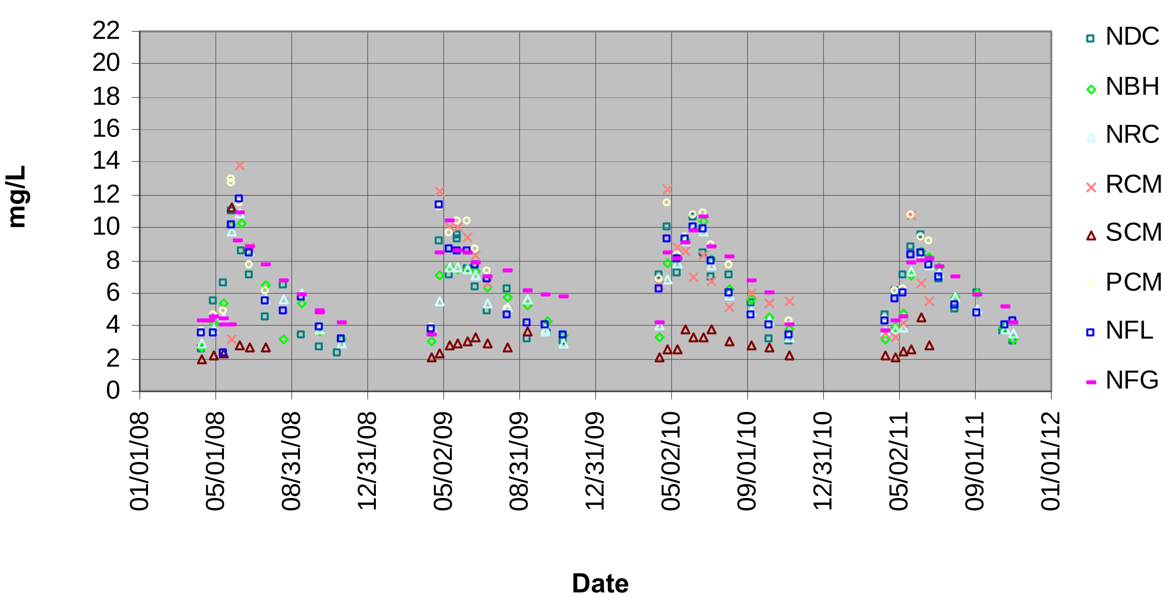


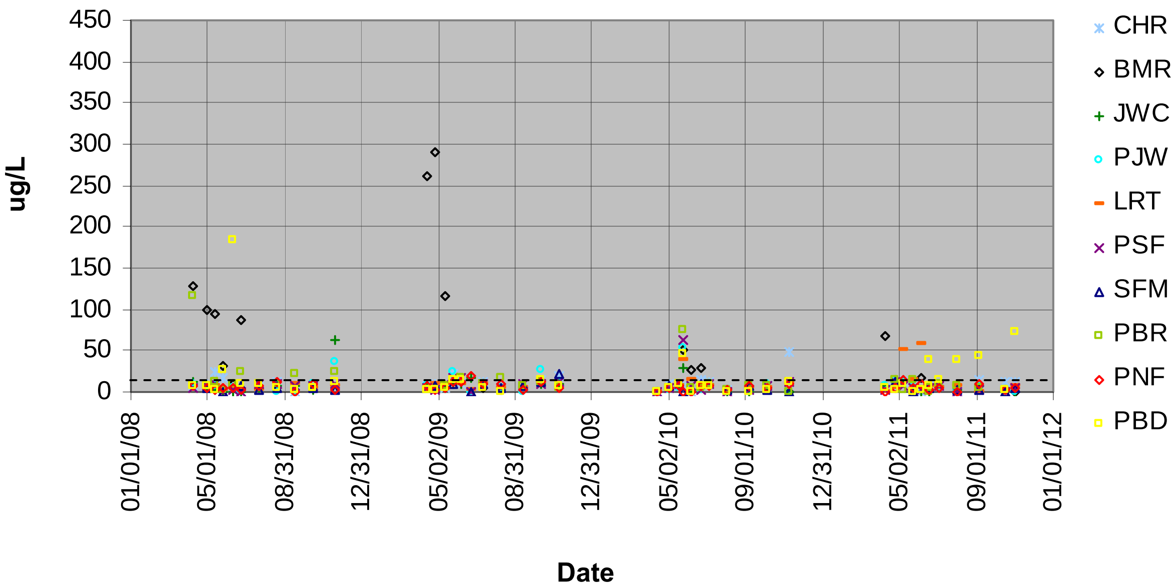
Figure 10.b. TOC on the North Fork CLP



Mainstem and North Fork CLP: Nutrients

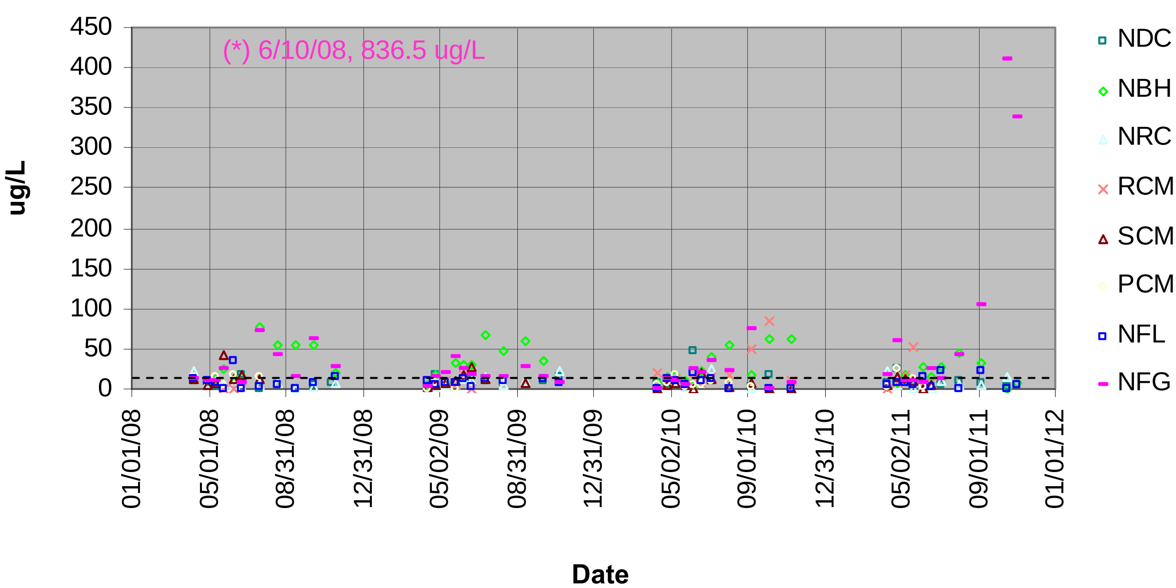
Figure 11 (a & b). Ammonia (NH_3)

Figure 11.a. Ammonia (NH_3) on the Mainstem CLP



(------- FCWQL Reporting Limit: 10 ug/L)

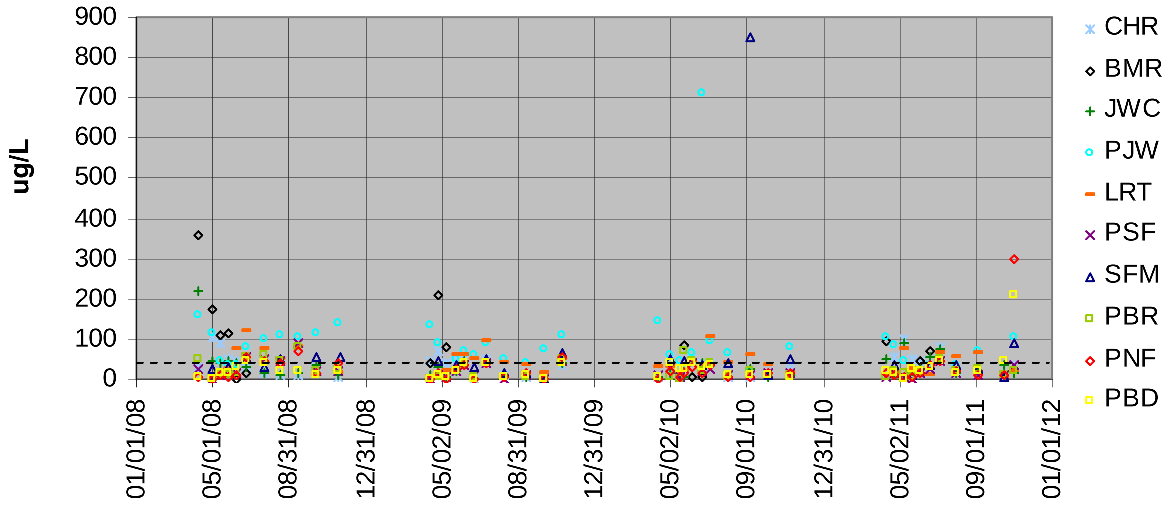
Figure 11.b. Ammonia (NH_3) on the North Fork CLP



(------- FCWQL Reporting Limit: 10 ug/L)

Figure 12 (a & b). Nitrate (NO_3)

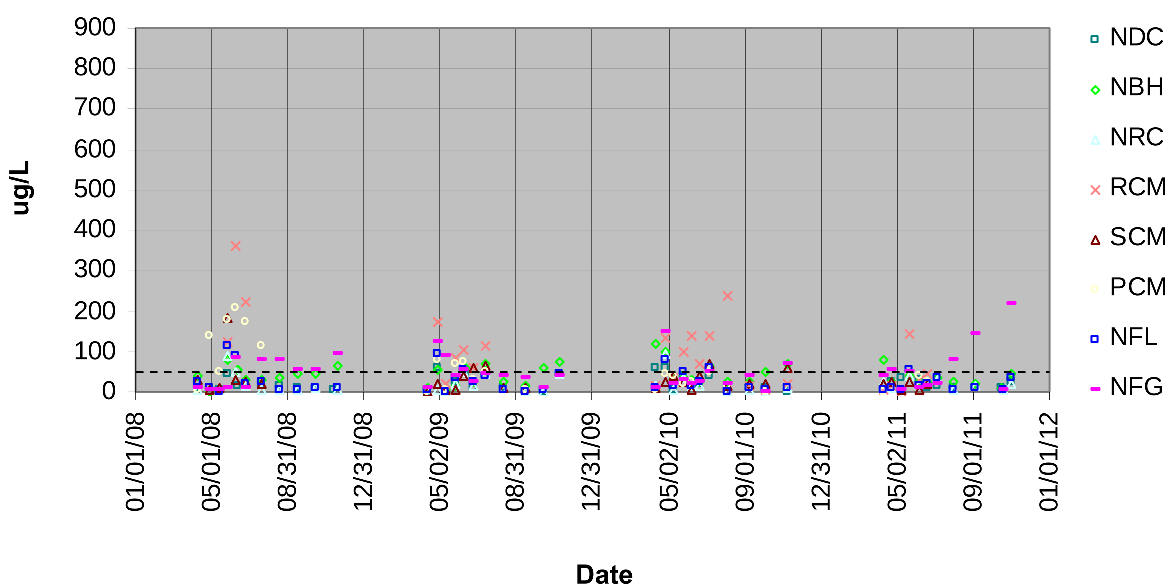
Figure 12.a. Nitrate (NO_3) on the Mainstem CLP



(------- FCWQL Reporting Limit: 40 ug/L)

(EPA Maximum Contaminant Level: 10,000 ug/L as N)

Figure 12.b. Nitrate (NO_3) on the North Fork CLP

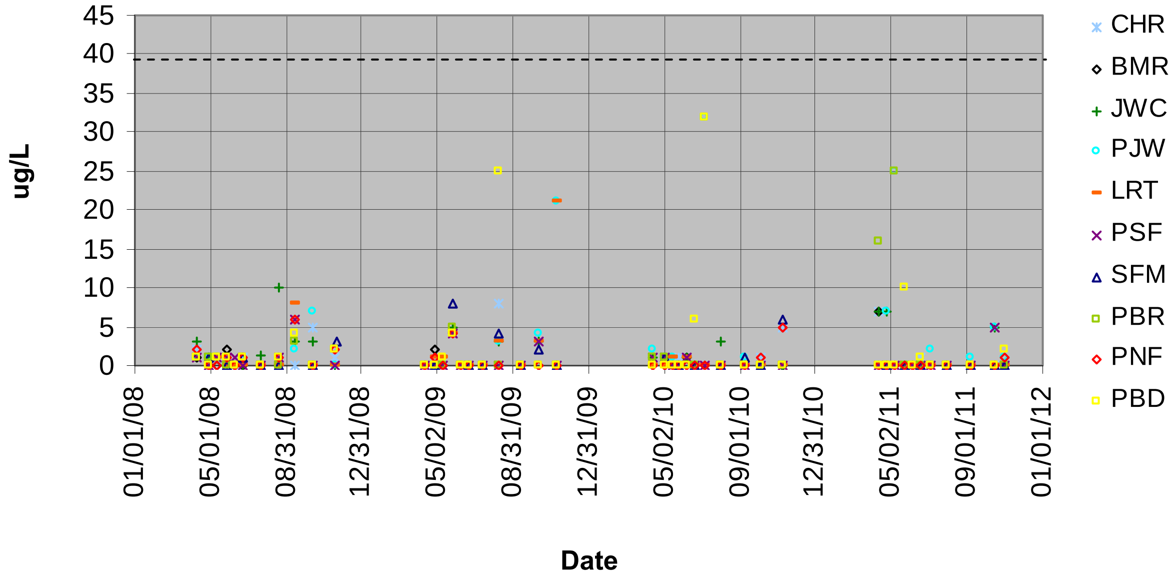


(------- FCWQL Reporting Limit: 40 ug/L)

(EPA Maximum Contaminant Level: 10,000 ug/L as N)

Figure 13 (a & b). Nitrite (NO_2)

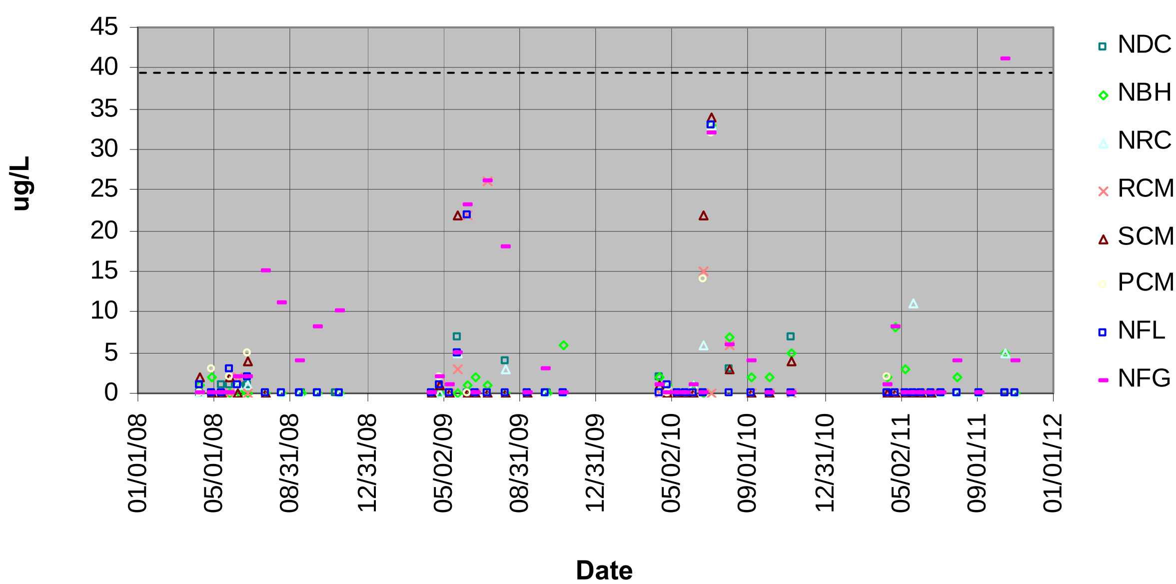
Figure 13.a. Nitrite (NO_2) on the Mainstem CLP



(------- FCWQL Reporting Limit: 40 ug/L)

(EPA Maximum Contaminant Level: 1,000 ug/L as N)

Figure 13.b. Nitrite (NO_2) on the North Fork CLP

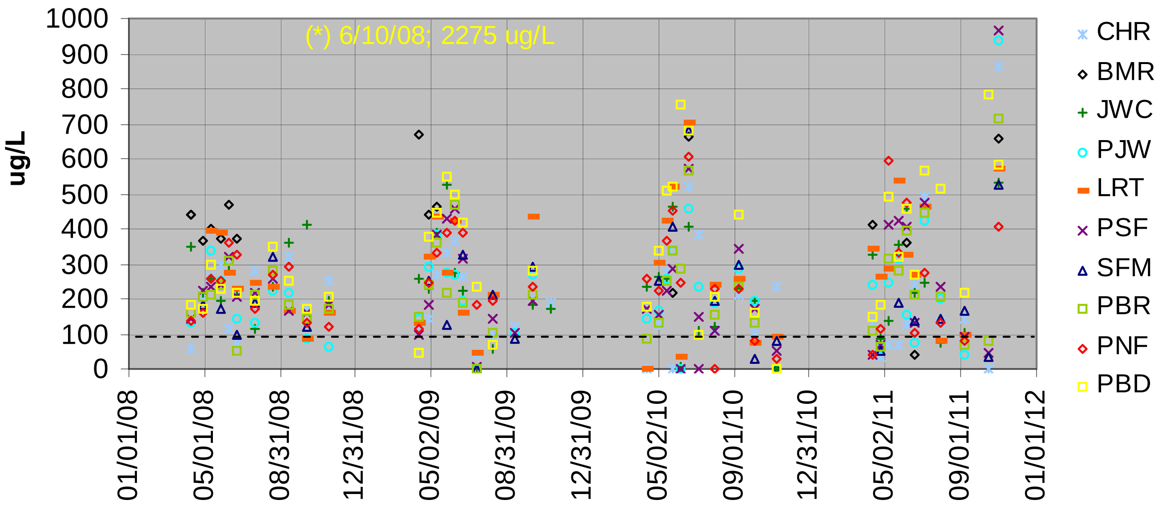


(------- FCWQL Reporting Limit: 40 ug/L)

(EPA Maximum Contaminant Level: 1,000 ug/L as N)

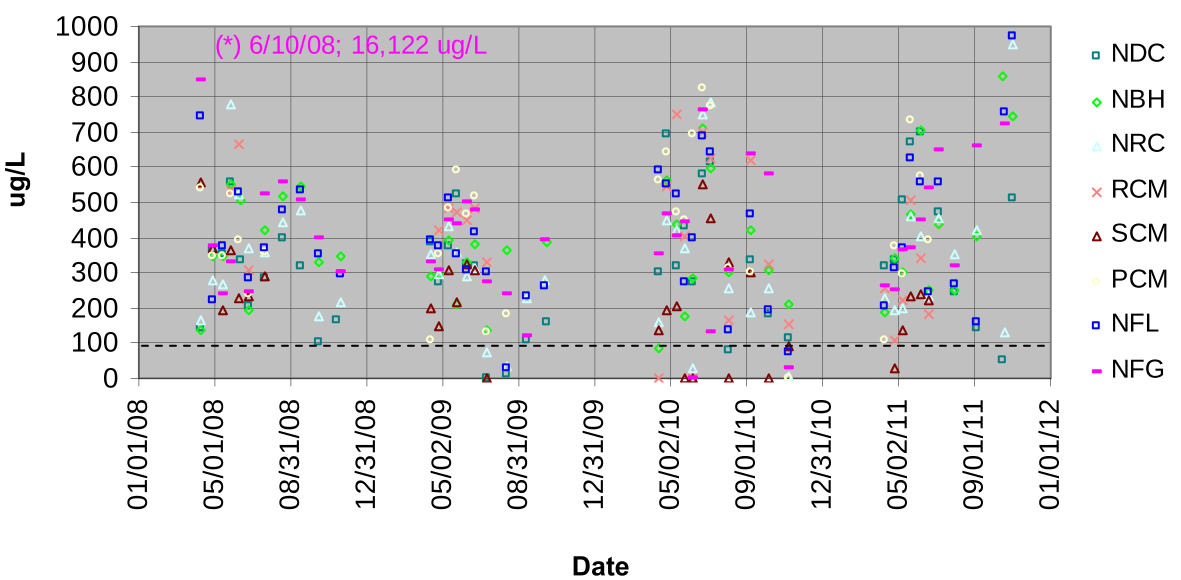
Figure 14 (a & b). Total Kjeldahl Nitrogen (TKN)

Figure 14.a. TKN on the Mainstem CLP



(------- FCWQL Reporting Limit: 100 ug/L)

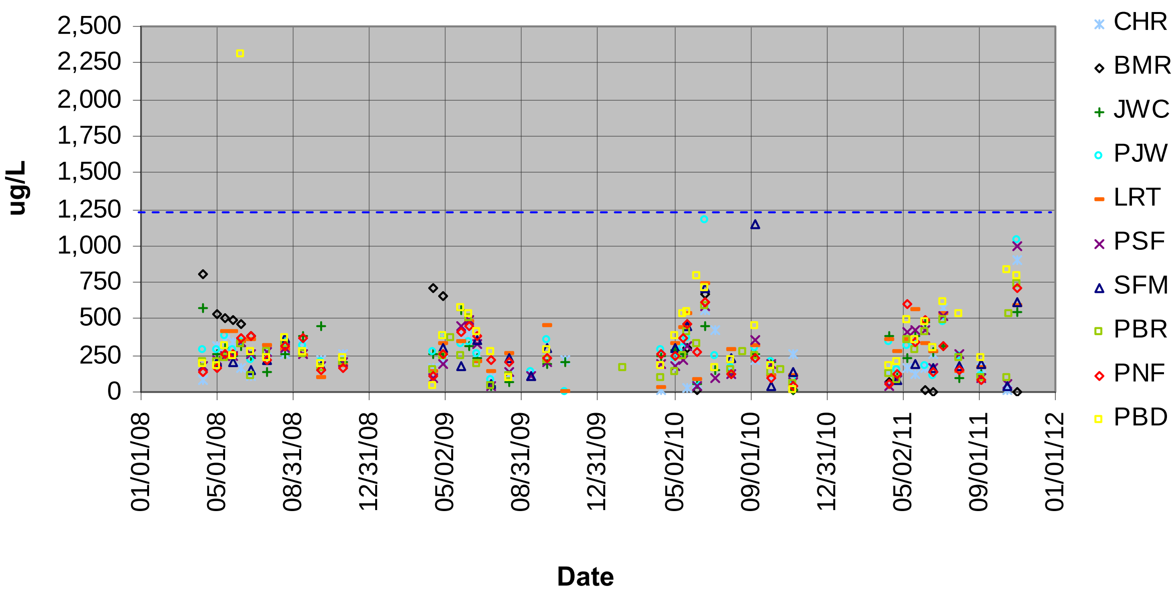
Figure 14.b. TKN on the North Fork CLP



(------- FCWQL Reporting Limit: 100 ug/L)

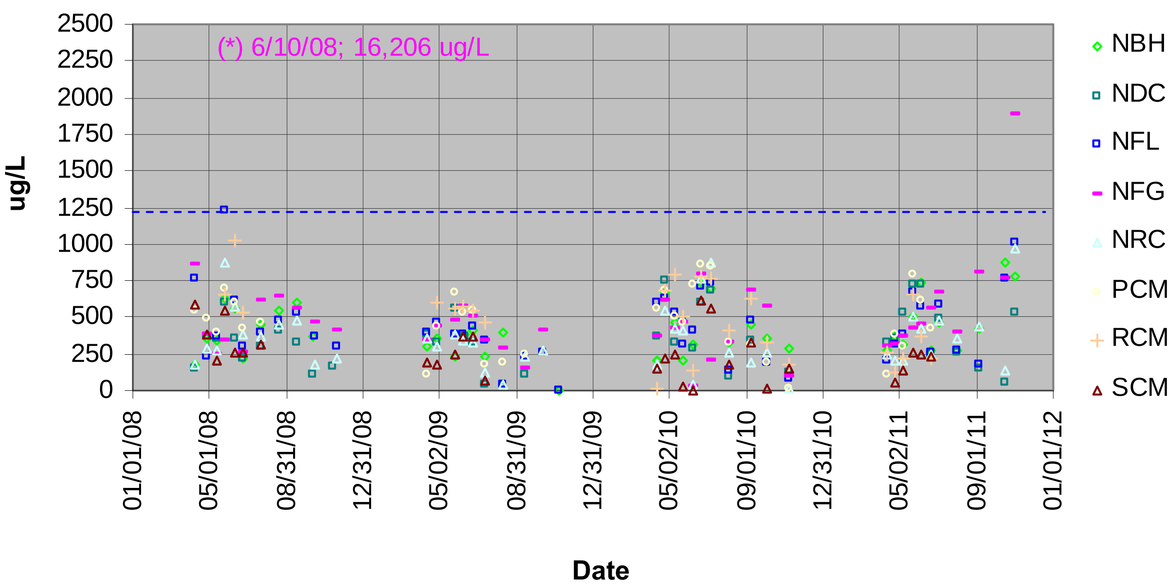
Figure 15 (a & b). Total Nitrogen (TKN+NO_3+NO_2)

Figure 15.a. Total N on the Mainstem CLP



(------- 2010 CDPHE/WQCD proposed cold water stream standard for Total N: 400 ug/L)

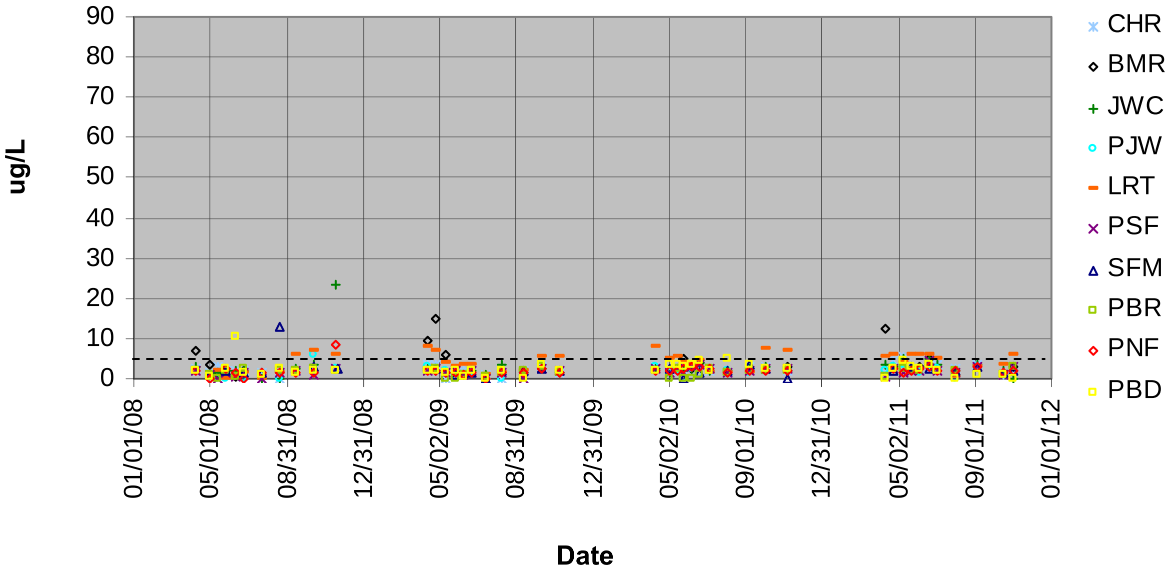
Figure 15.b. Total N on the North Fork CLP



(------- 2012 CDPHE/WQCD proposed cold water stream standard for Total N: 400 ug/L)

Figure 16 (a & b). Ortho-phosphate (PO_4)

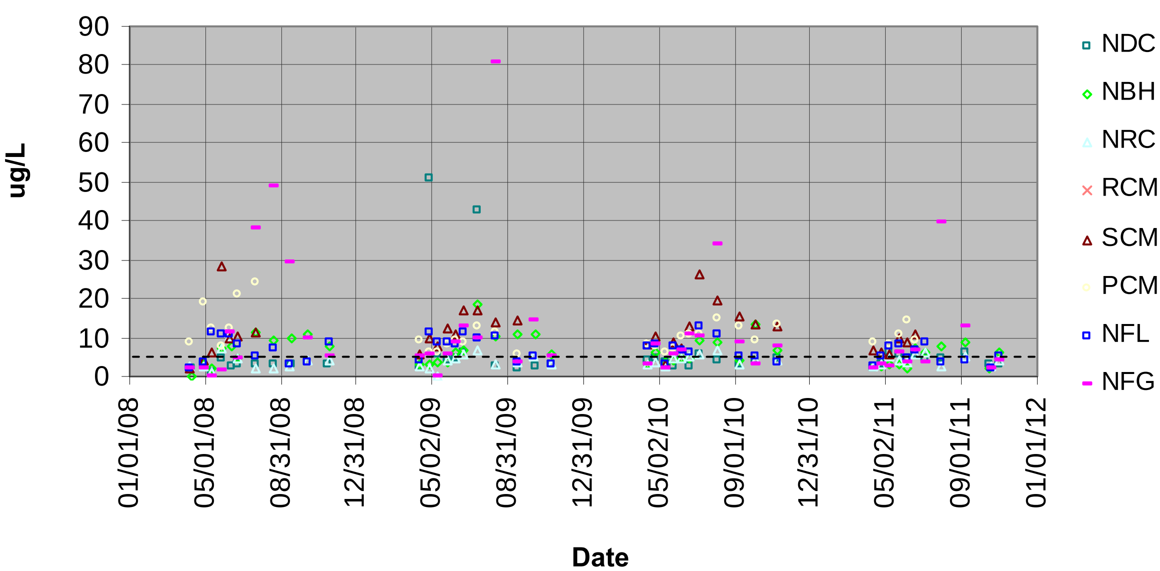
Figure 16.a. Ortho-phosphate (PO_4) on the Mainstem CLP



(------- FCWQL Reporting Limit: 5 ug/L)

* 2007 values reported as Soluble Reactive Phosphorus (SRP)

Figure 16.b. Ortho-phosphate (PO_4) on the North Fork CLP

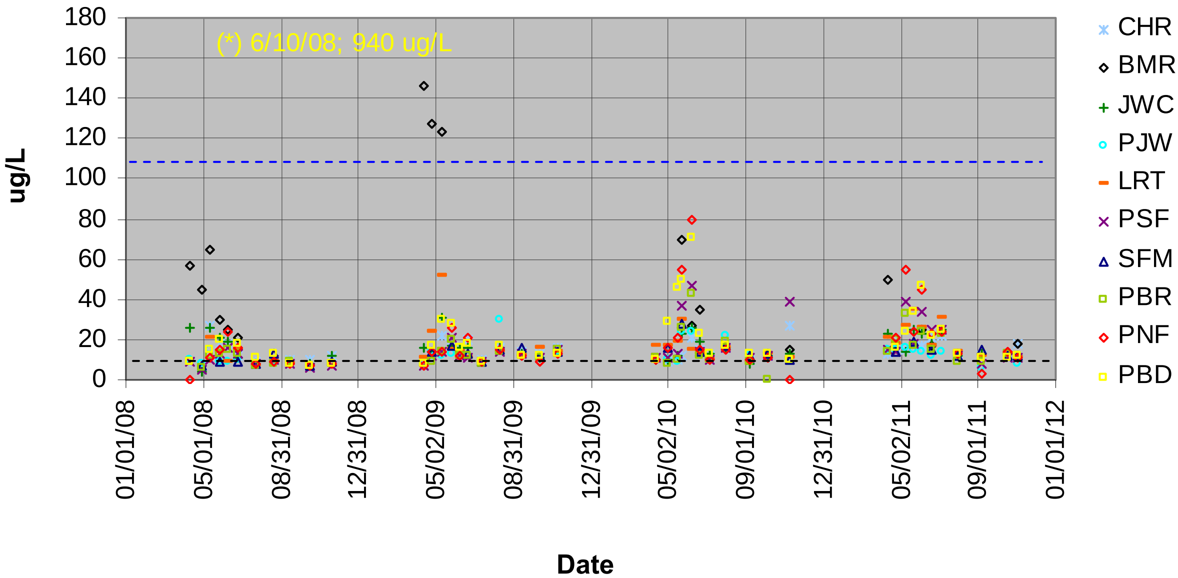


(------- FCWQL Reporting Limit: 5 ug/L)

* 2007 values reported as Soluble Reactive Phosphorus (SRP)

Figure 17 (a & b). Total Phosphorus (P)

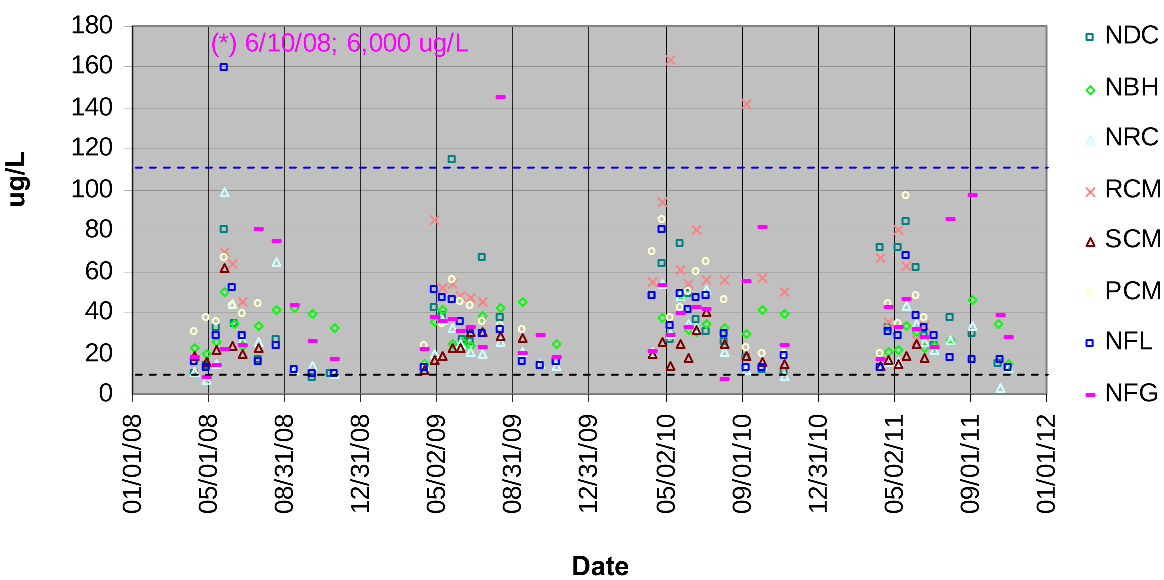
Figure 17.a. Total P on the Mainstem CLP



(------- FCWQL Reporting Limit: 10 ug/L)

(------- 2012 CDPHE/WQCD proposed cold water stream standard for Total P: 110 ug/L)

Figure 17.b. Total P on the North Fork CLP

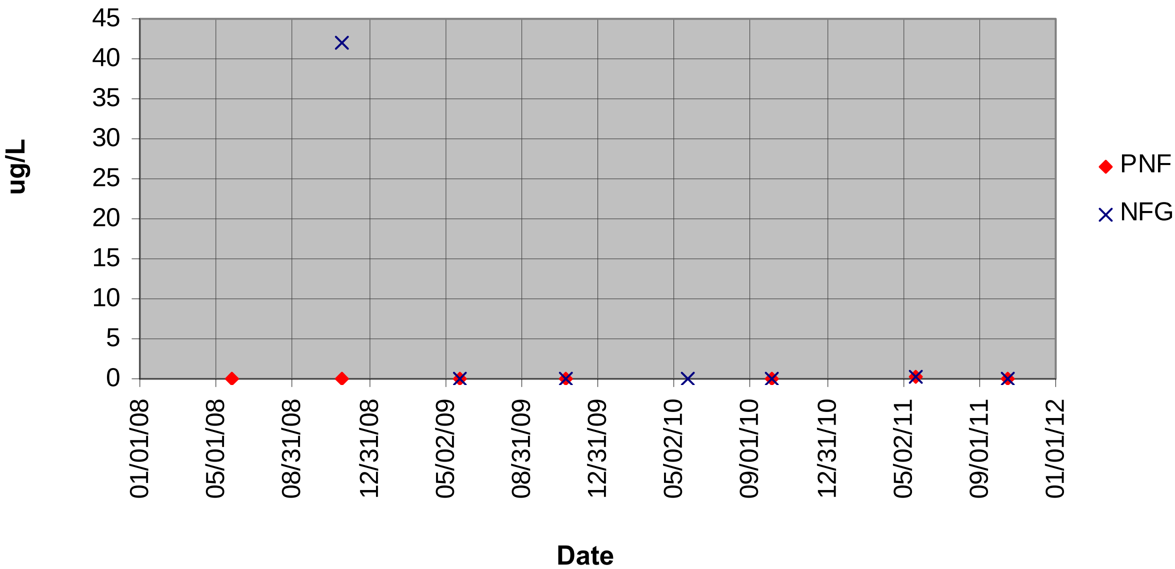


(------- FCWQL Reporting Limit: 10 ug/L)

(------- 2012 CDPHE/WQCD proposed cold water stream standard for Total P: 110 ug/L)

Mainstem and North Fork CLP: Metals

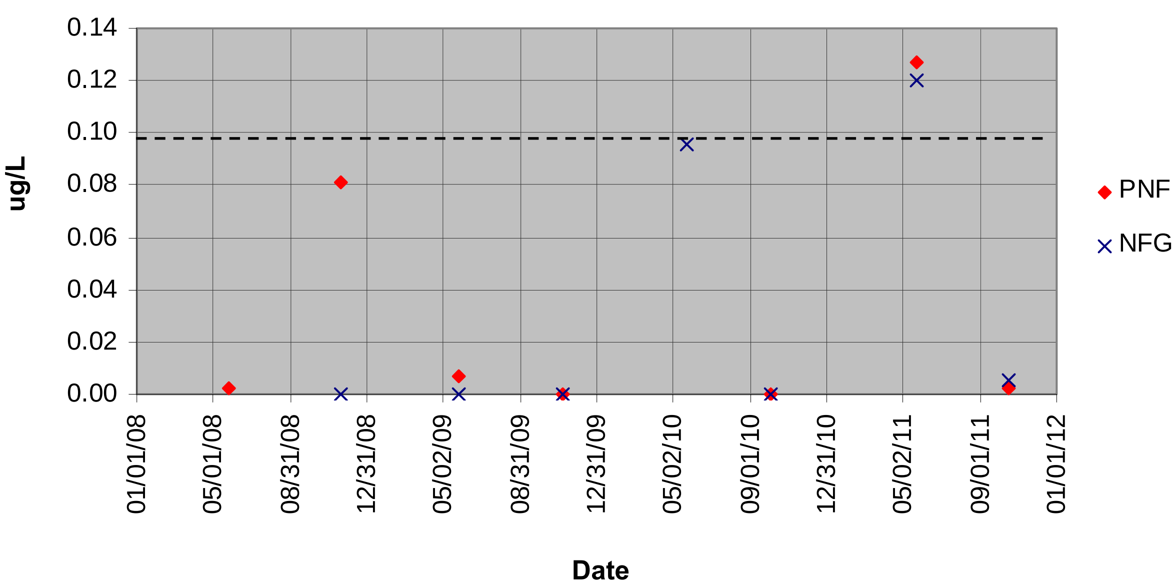
Figure 18. Dissolved silver (Ag) on the Mainstem and North Fork CLP



(------- FCWQL Reporting Limit: 0.5 ug/L)

(EPA Secondary Drinking Water Standard: 100ug/L)

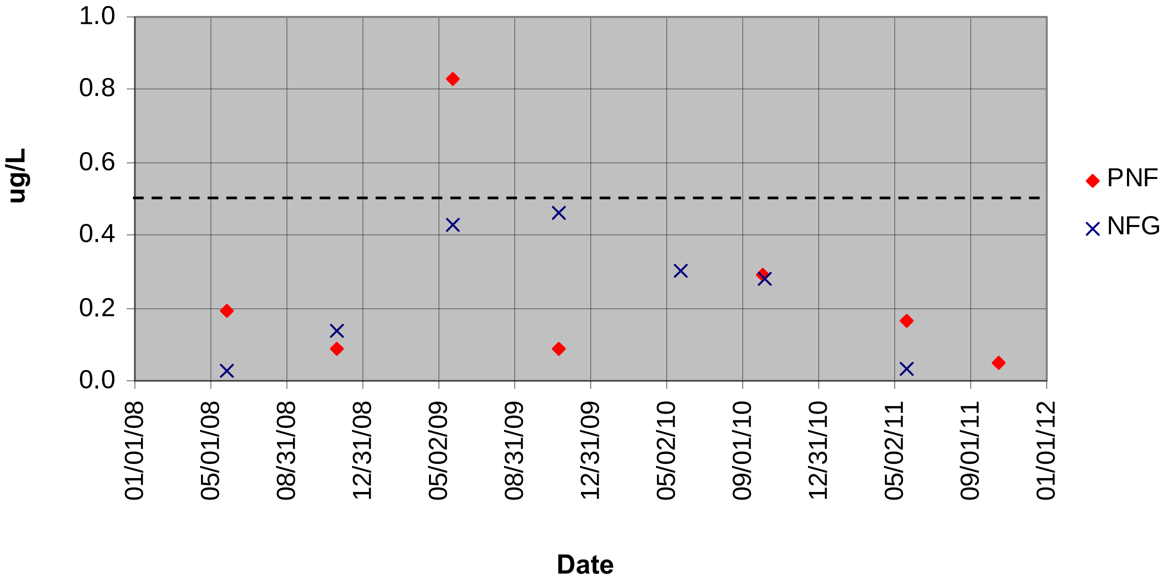
Figure 19. Dissolved cadmium (Cd) on the Mainstem and North Fork CLP



(------- FCWQL Reporting Limit: 0.1 ug/L)

(EPA Maximum Contaminant Level: 5 ug/L)

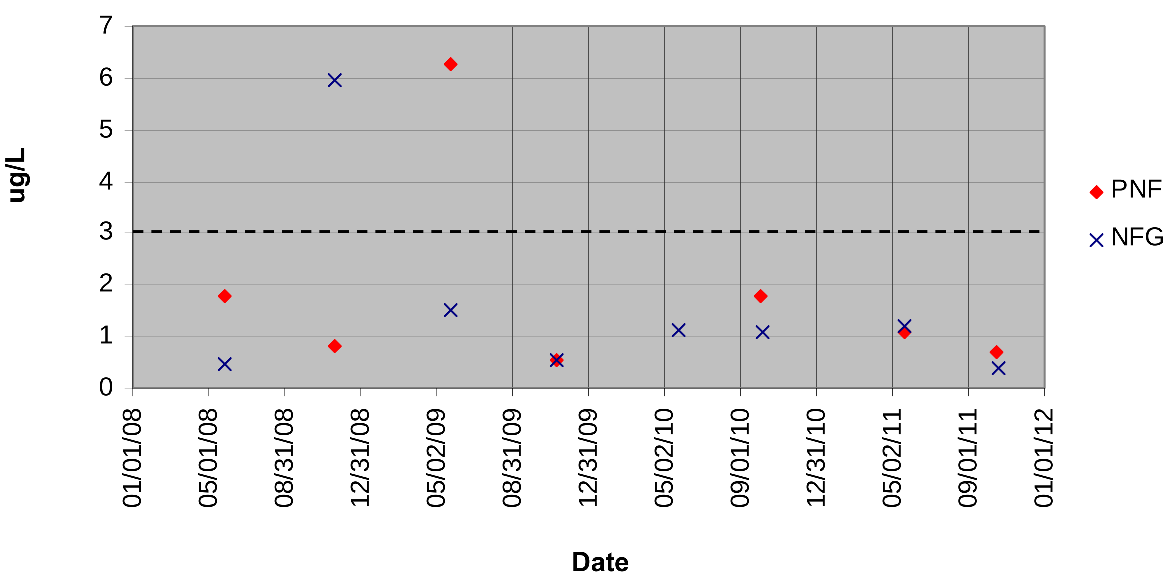
Figure 20. Dissolved chromium (Cr) on the Mainstem and North Fork CLP



(------- FCWQL Reporting Limit: 0.5 ug/L)

(EPA Maximum Contaminant Level: 100ug/L)

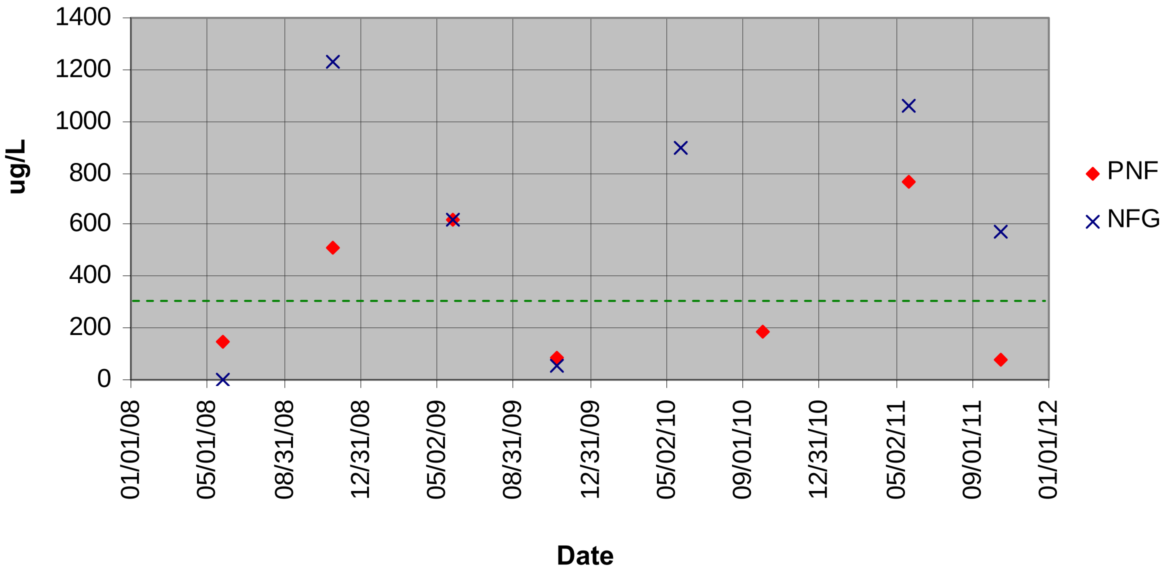
Figure 21. Dissolved copper (Cu) on the Mainstem and North Fork CLP



(------- FCWQL Reporting Limit: 3.0 ug/L)

(EPA Maximum Contaminant Level: 1,300 ug/L)

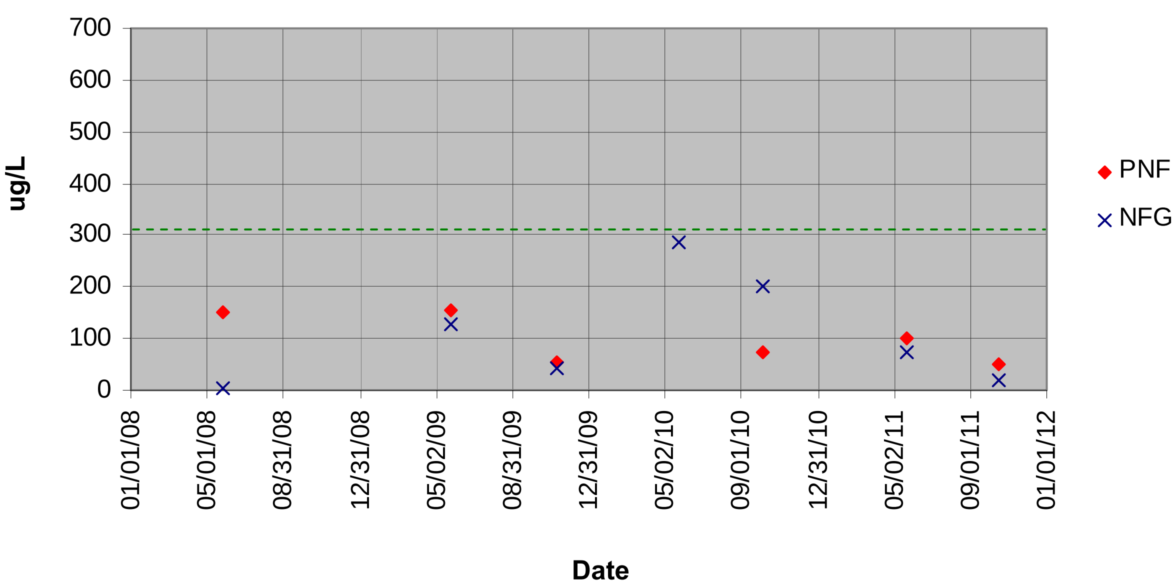
Figure 22. Total iron (Fe) on the Mainstem and North Fork CLP



(----- FCWQL Reporting Limit: 0.5 ug/L)

(----- EPA Secondary Drinking Water Standard: 300 ug/L)

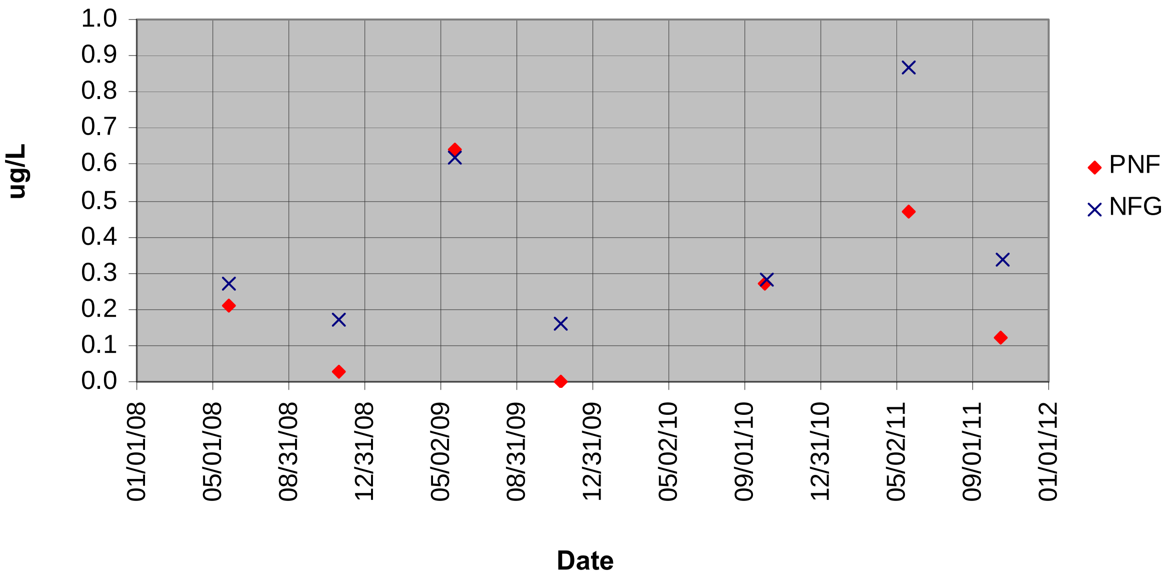
Figure 23. Dissolved iron (Fe) on the Mainstem and North Fork CLP



(----- FCWQL Reporting Limit: 0.5 ug/L)

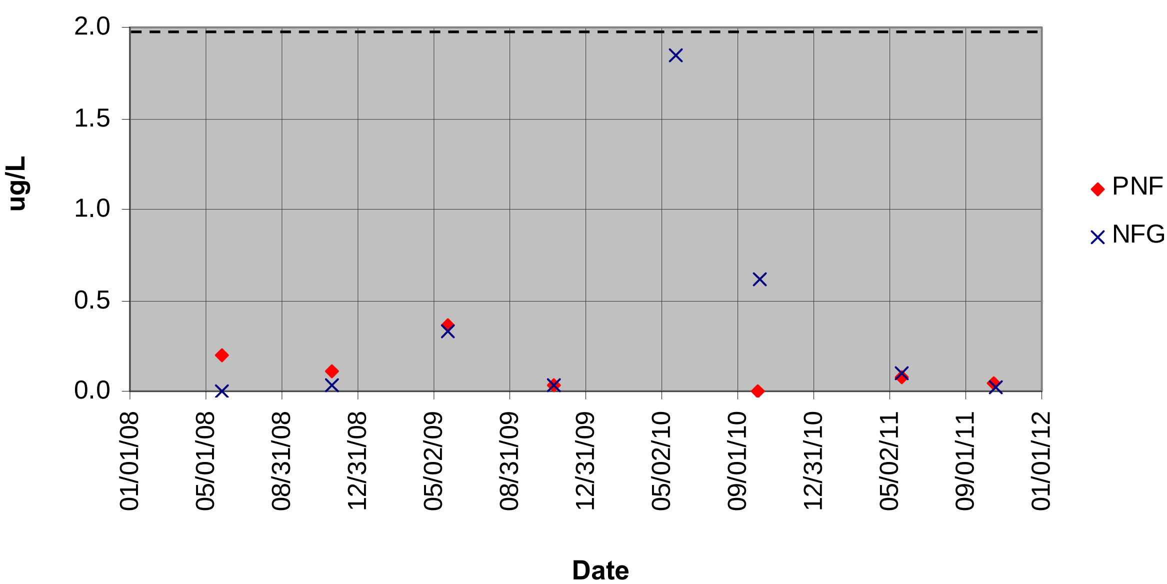
(----- EPA Secondary Drinking Water Standard: 300 ug/L)

Figure 24. Dissolved nickel (Ni) on the Mainstem and North Fork CLP



(------- FCWQL Reporting Limit: 2.0 ug/L)

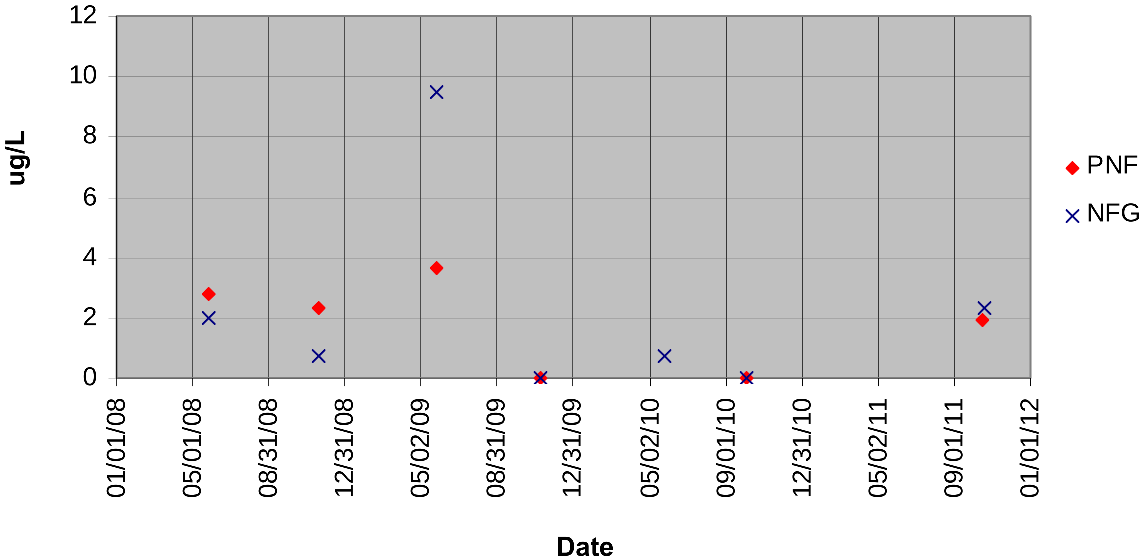
Figure 25. Dissolved lead (Pb) on the Mainstem and North Fork CLP



(------- FCWQL Reporting Limit: 2.0 ug/L)

(EPA Maximum Contaminant Level: 15 ug/L)

Figure 26. Dissolved Zinc (Zn) on the Mainstem and North Fork CLP



(------- FCWQL Reporting Limit: 50 ug/L)

(EPA Secondary Drinking Water Standard: 5,000 ug/L)

Mainstem and North Fork CLP:
Major Ions

Figure 27 (a & b). Calcium (Ca)

Figure 27.a. Calcium (Ca) on the Mainstem CLP

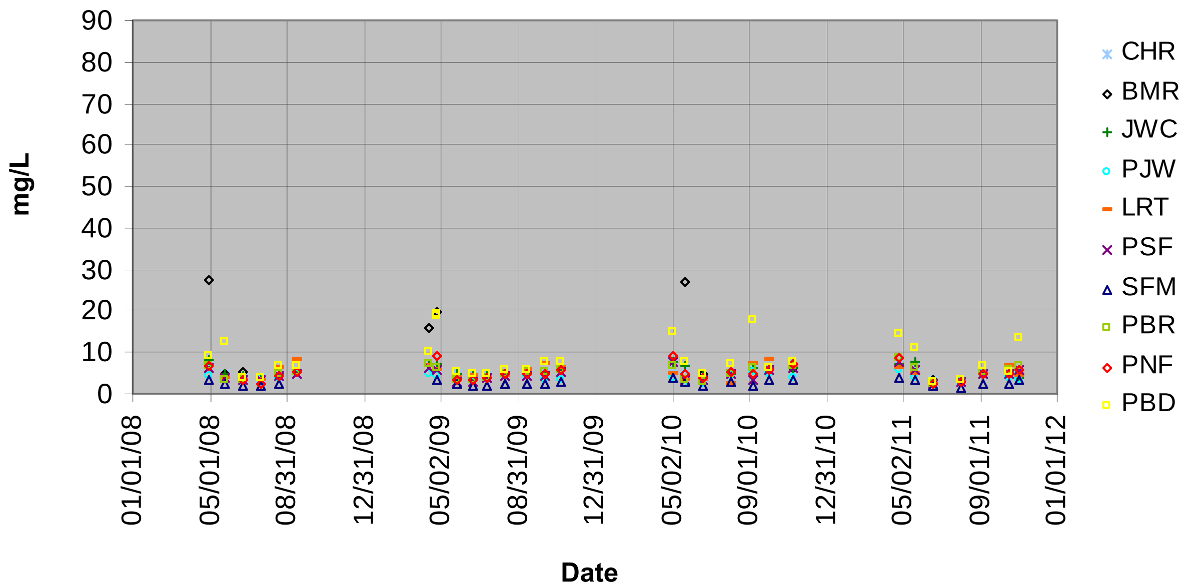


Figure 27.b. Calcium (Ca) on the North Fork CLP

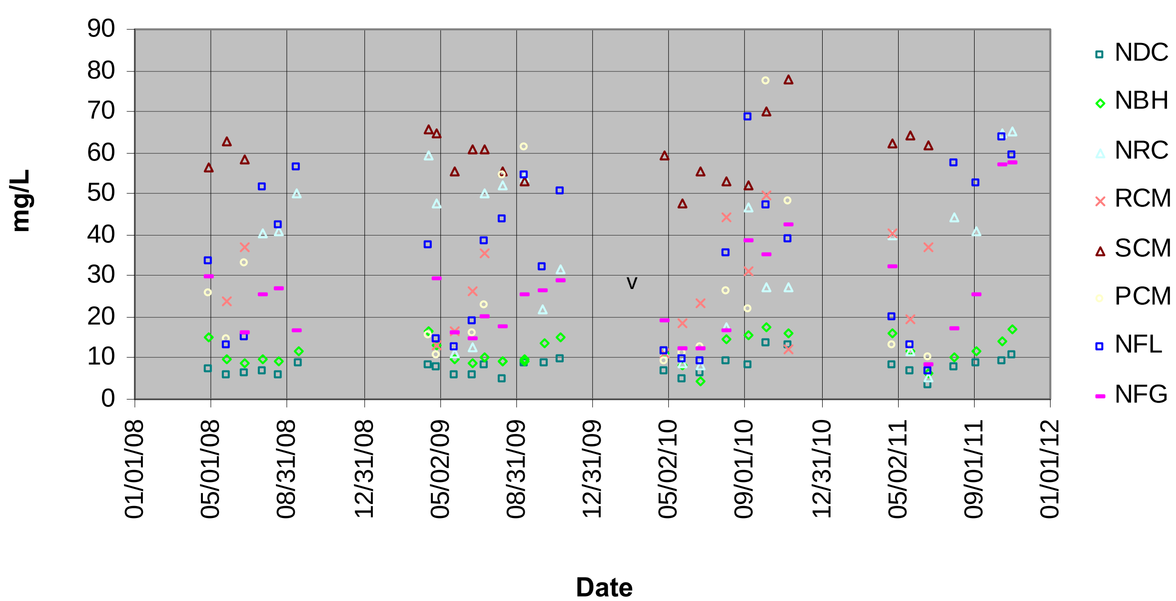


Figure 28 (a & b). Magnesium (Mg)

Figure 28.a. Magnesium (Mg) on the Mainstem CLP

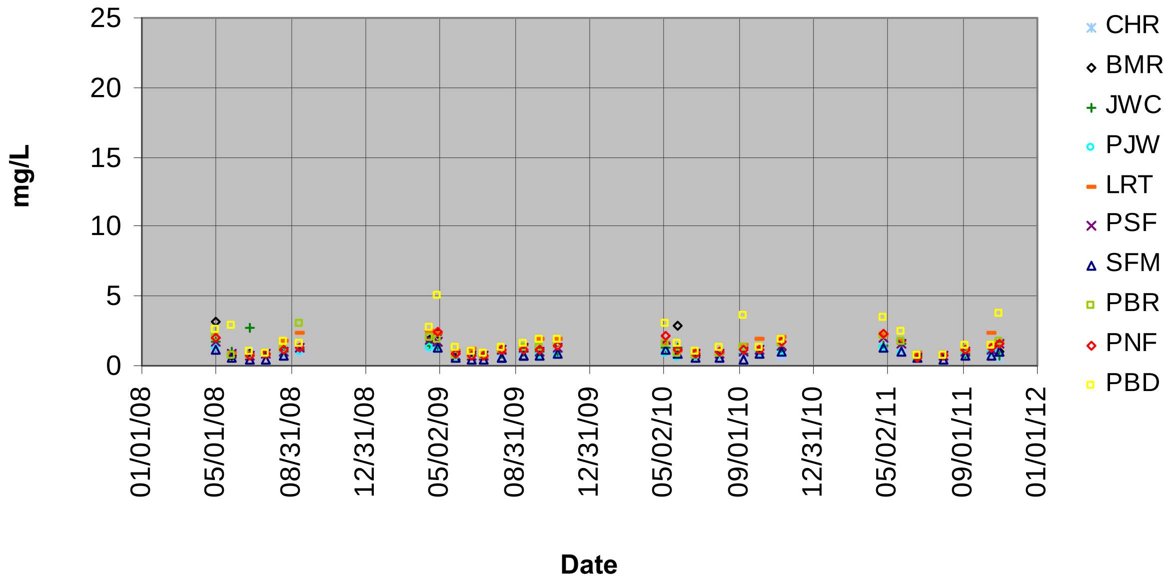


Figure 28.b. Magnesium (Mg) on the North Fork CLP

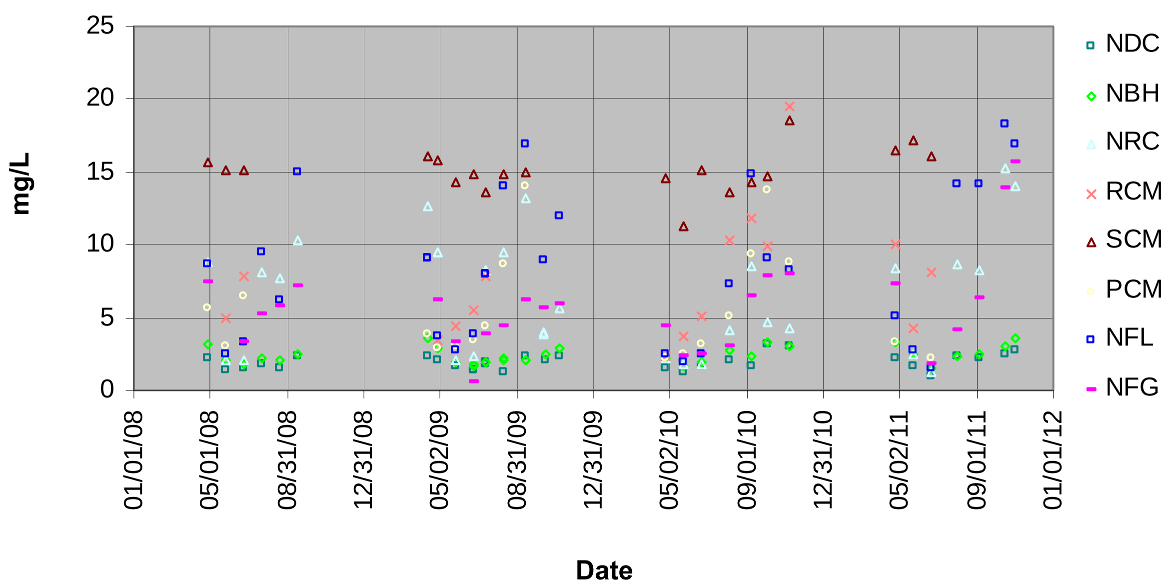


Figure 29 (a & b). Potassium (K)

Figure 29.a. Potassium (K) on the Mainstem CLP

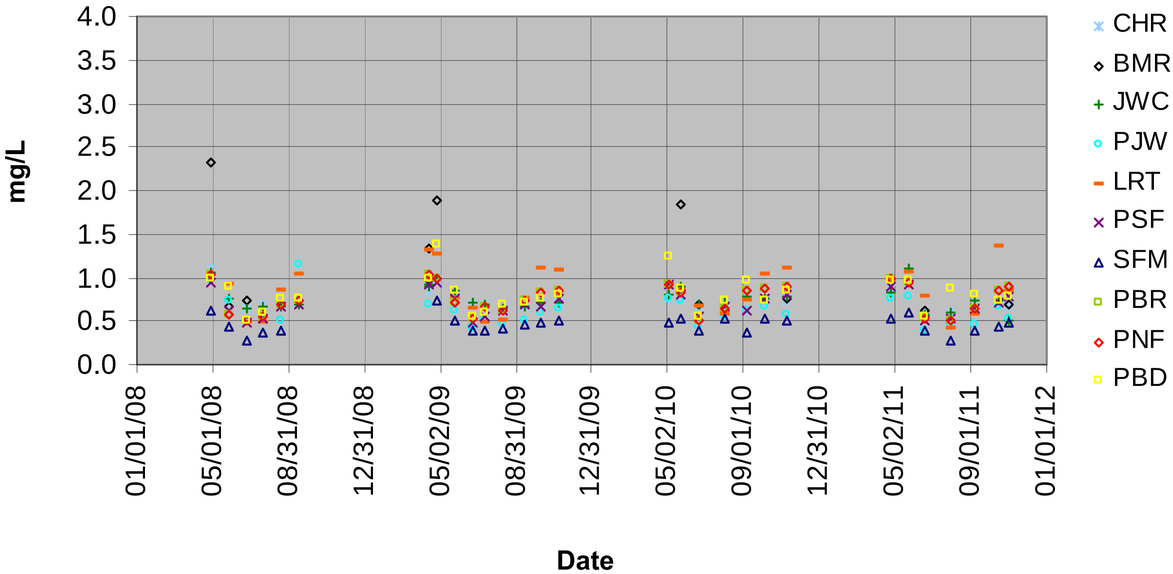


Figure 29.b. Potassium (K) on the North Fork CLP

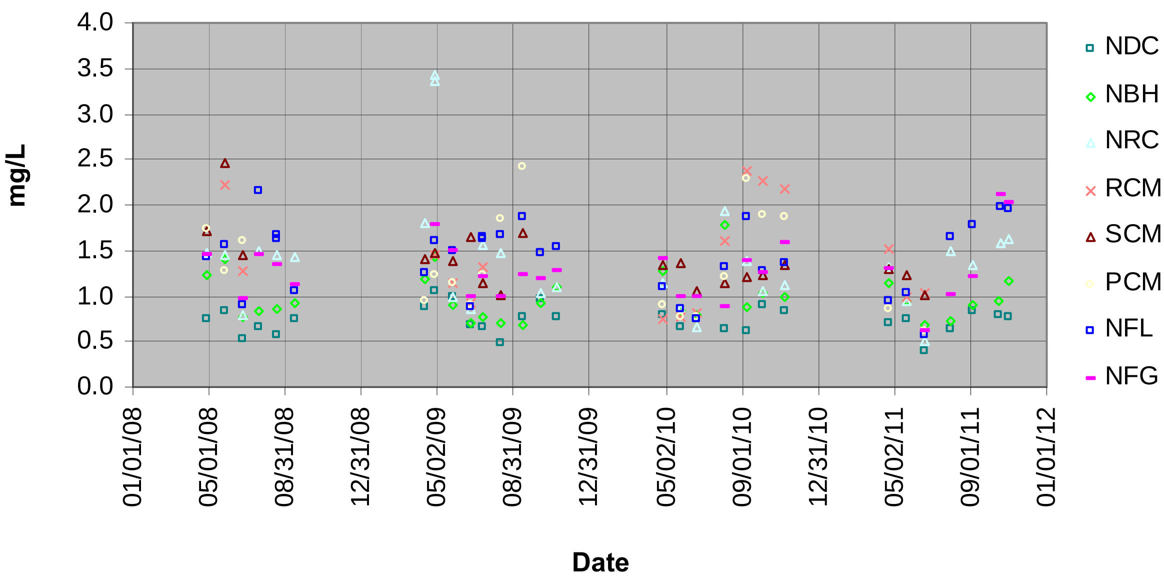


Figure 30 (a & b). Sodium (Na)

Figure 30.a. Sodium (Na) on the Mainstem CLP

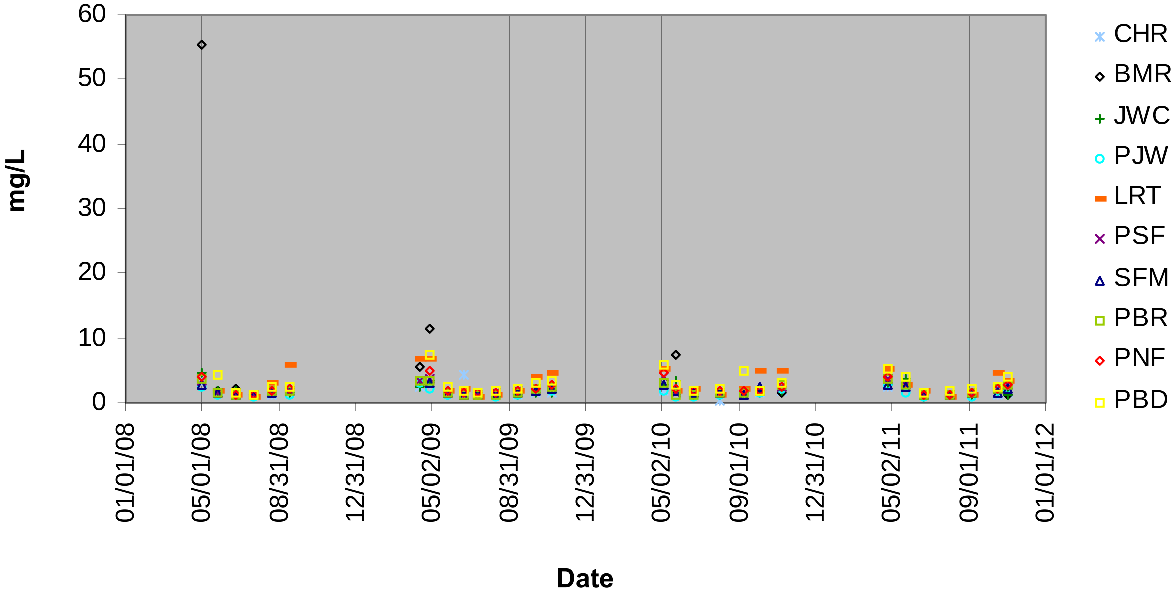


Figure 30.b. Sodium (Na) on the North Fork CLP

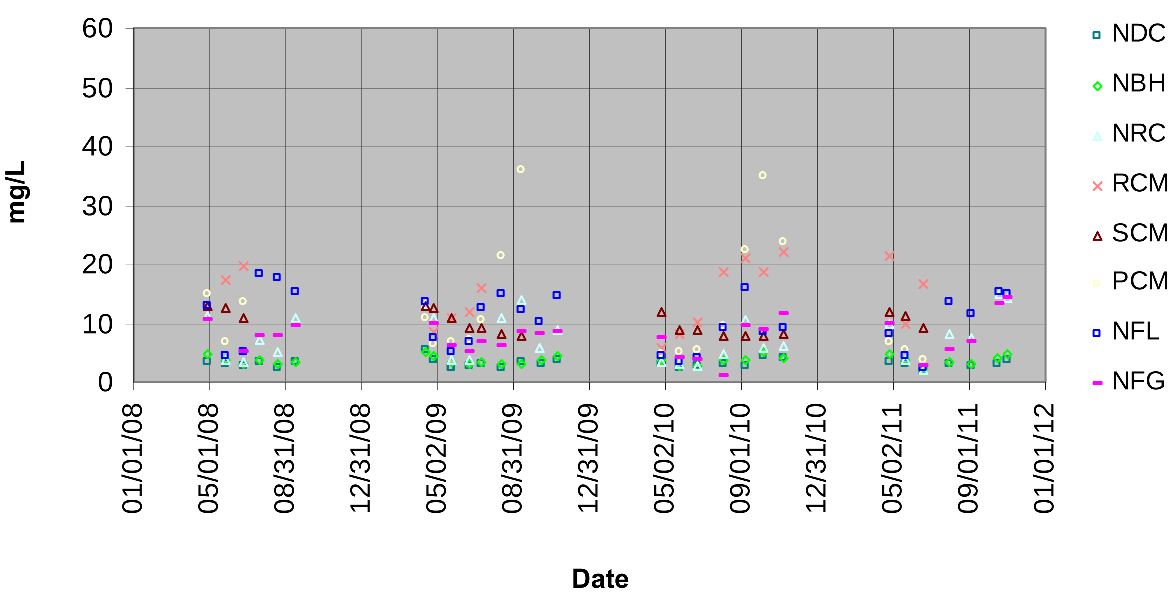


Figure 31 (a & b). Chloride (Cl)

Figure 31.a. Chloride (Cl) on the Mainstem CLP

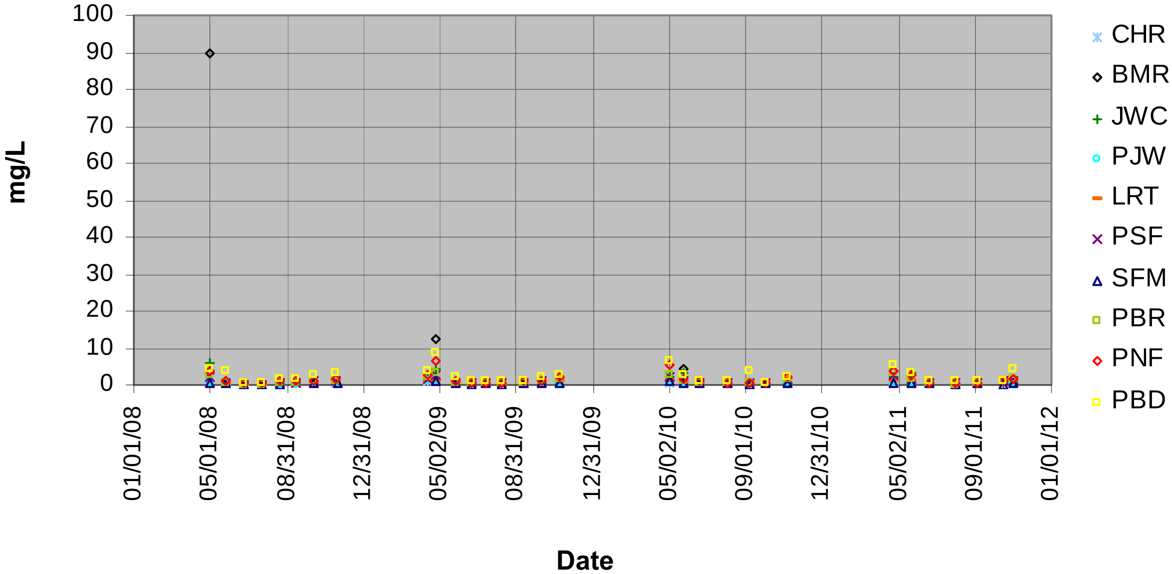


Figure 31.b. Chloride (Cl) on the North Fork CLP

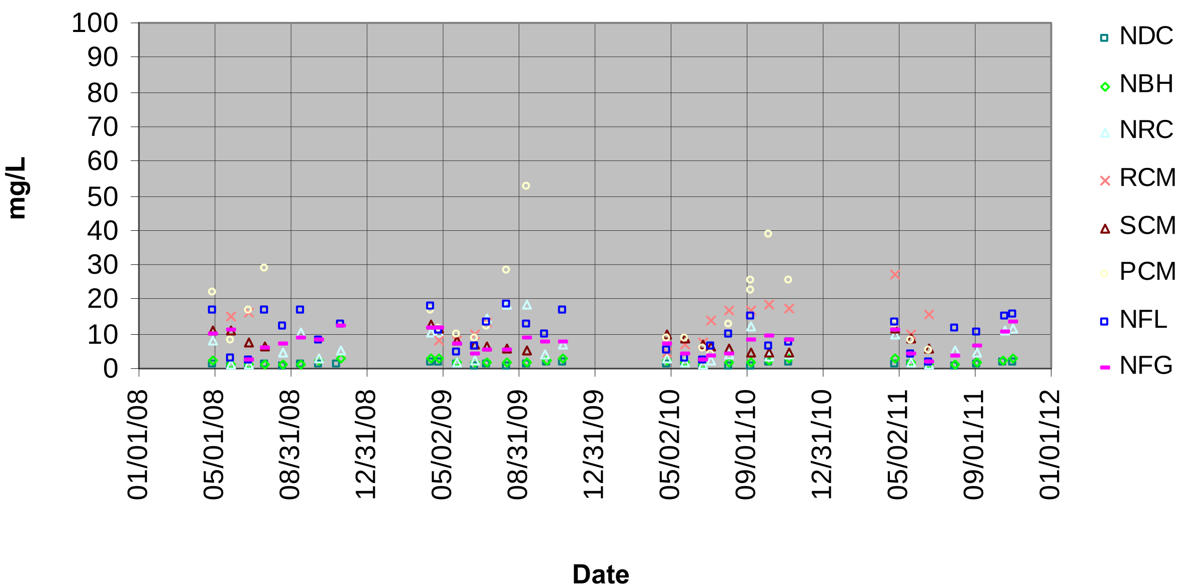
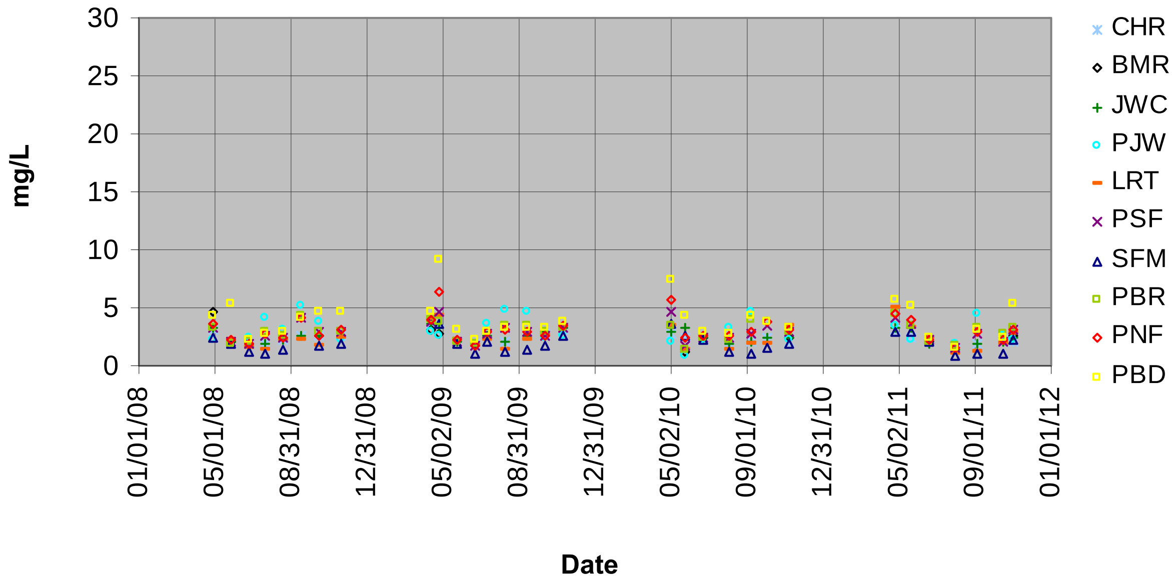


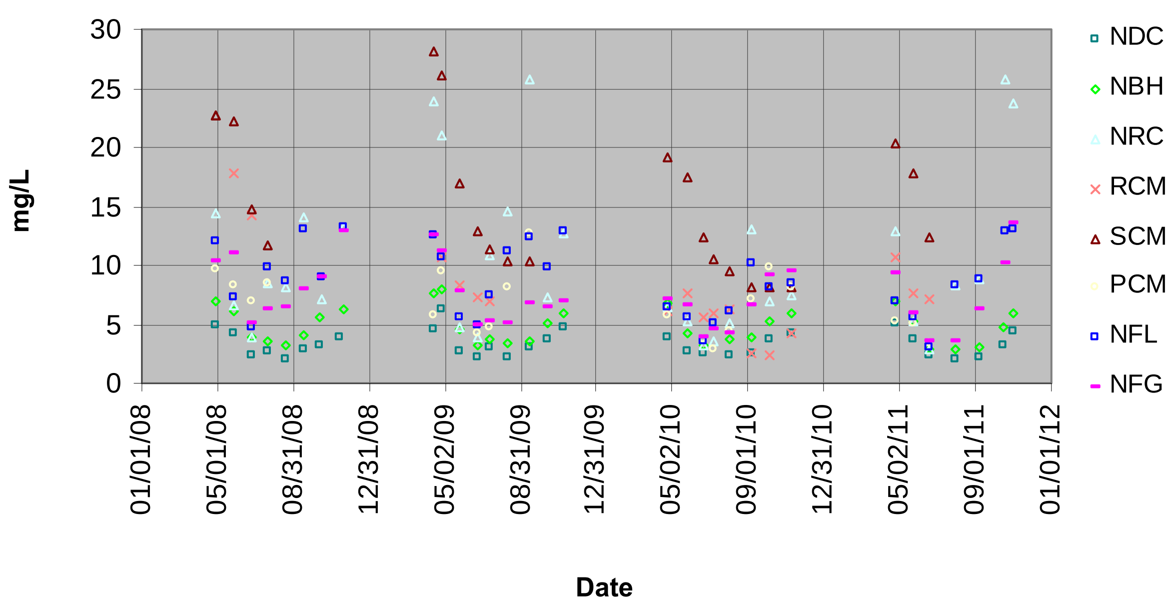
Figure 32 (a & b). Sulfate (SO_4)

Figure 32.a. Sulfate (SO_4) on the Mainstem CLP



(EPA Secondary Drinking Water Standard: 250 ug/L)

Figure 32.b. Sulfate (SO_4) on the North Fork CLP



(EPA Secondary Drinking Water Standard: 250 ug/L)

Mainstem and North Fork CLP: Microbiological Constituents

Figure 33. Total coliforms on the Mainstem and North Fork CLP

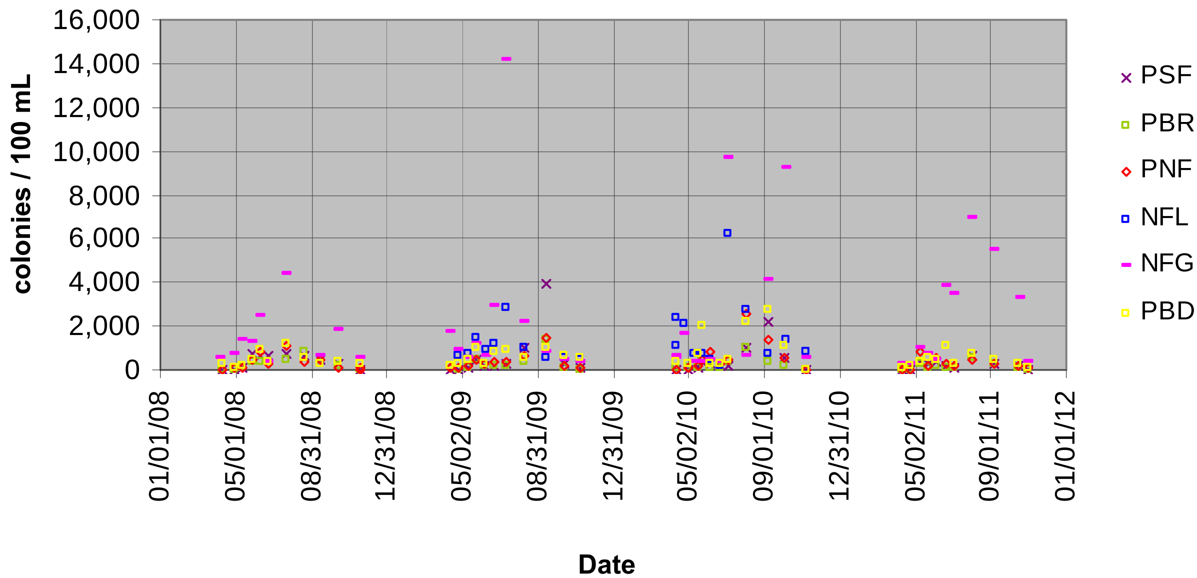
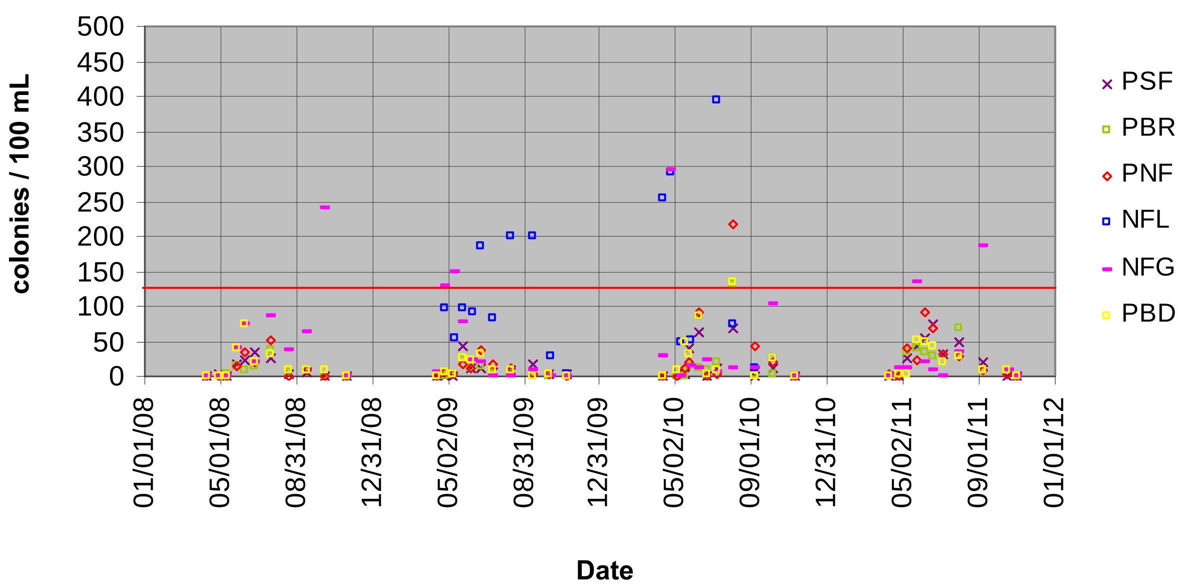


Figure 34. *E.coli* on the Mainstem and North Fork CLP



(——— Recreational water quality standard: 126 colonies/100 mL)

Figure 35. *Giardia* on the Mainstem and North Fork CLP

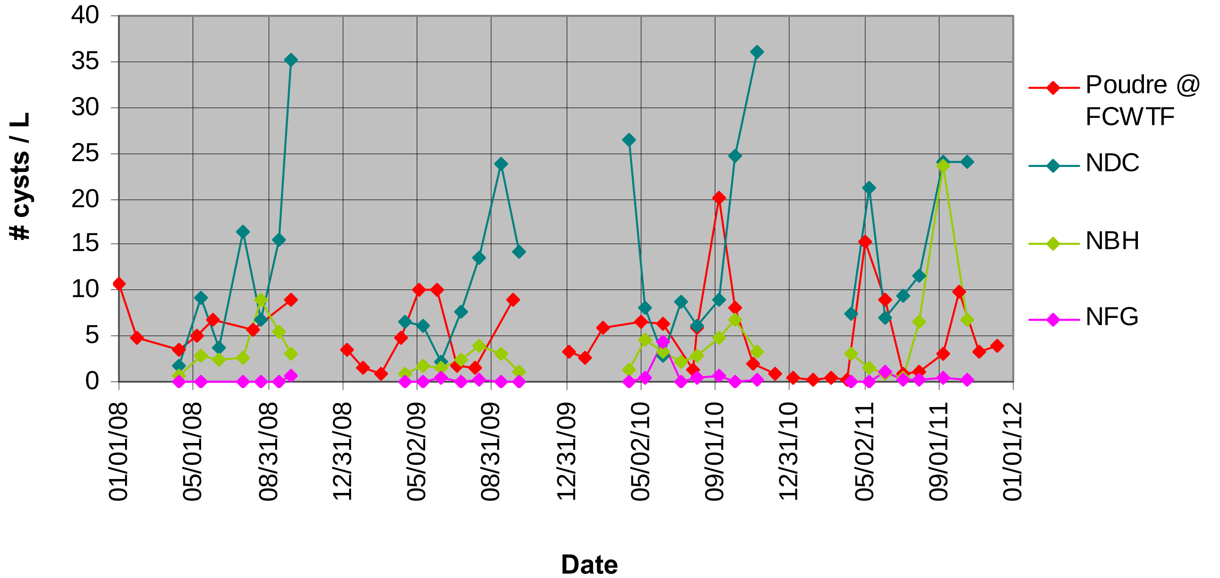
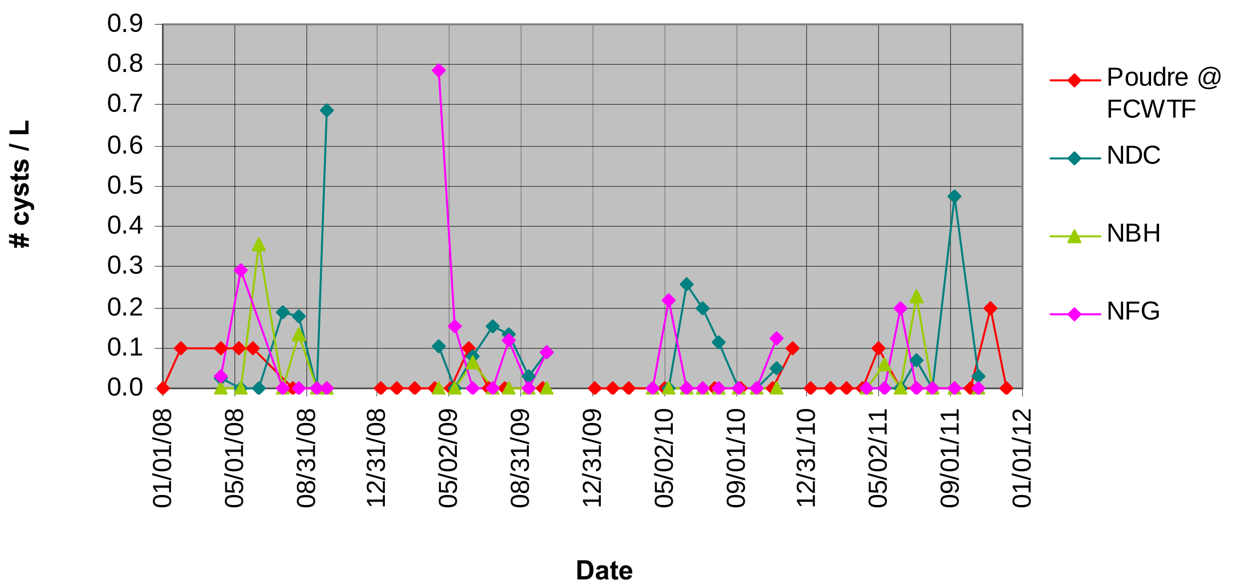
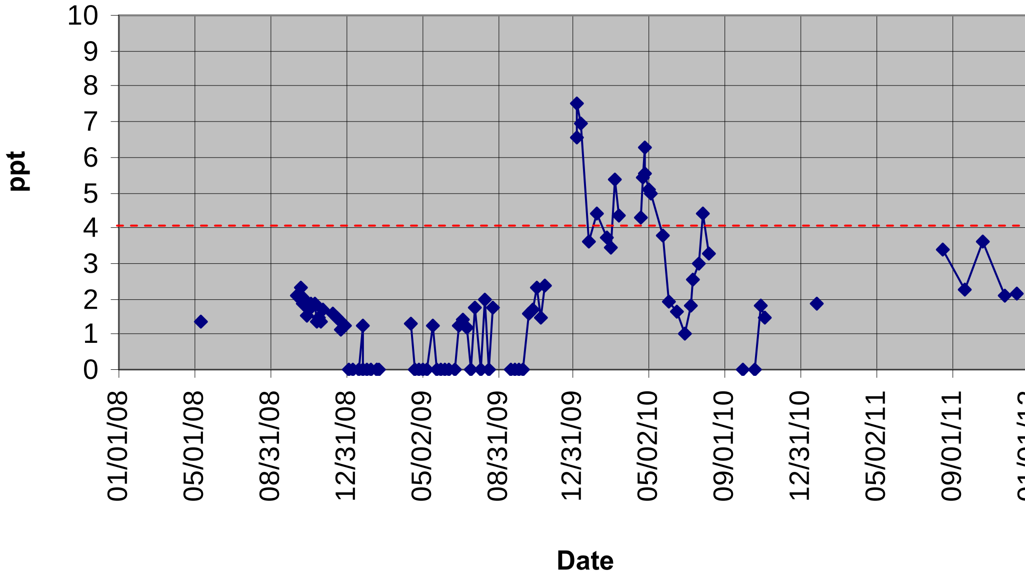


Figure 36. *Cryptosporidium* on the Mainstem and North Fork CLP



Mainstem and North Fork CLP:
Geosmin

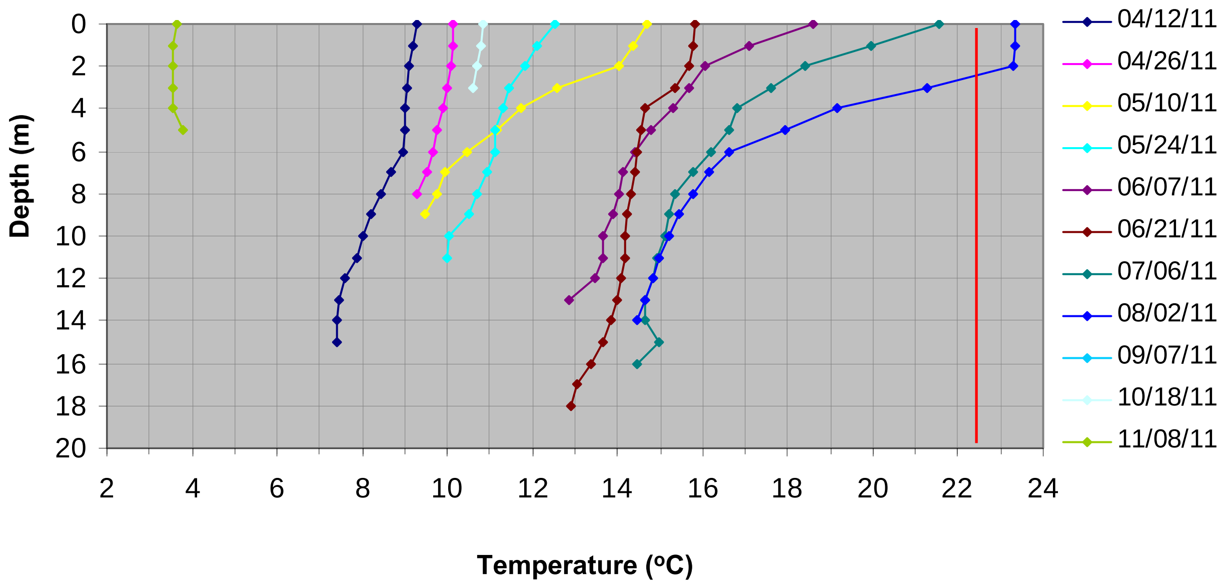
Figure 37. Geosmin on the Mainstem CLP collected at the FCWTF



(----- Odor threshold for geosmin: 4 ppt)

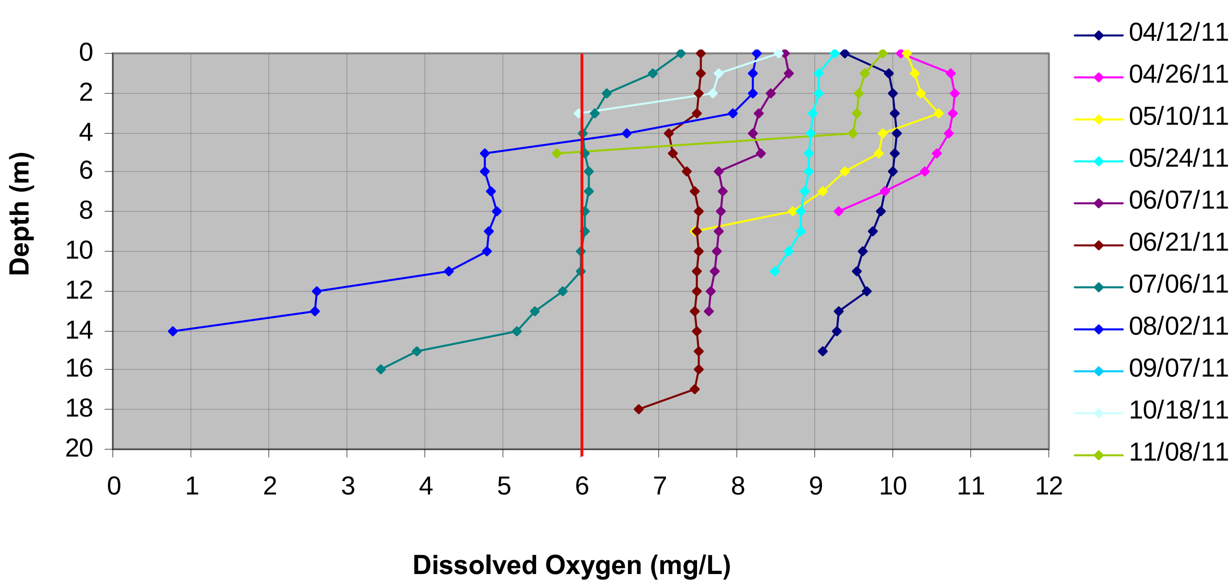
Seaman Reservoir:
Depth Profiles
(Temperature, D.O., pH & Conductance)

Figure 38. 2011 Seaman Reservoir temperature profiles



(—— Water quality standard for cold water aquatic life: 22.5°C)

Figure 39. 2011 Seaman Reservoir dissolved oxygen (D.O.) profiles



(—— Water quality standard for cold water aquatic life: 6.0 mg/L D.O.)

Figure 40. 2011 Seaman Reservoir pH profiles

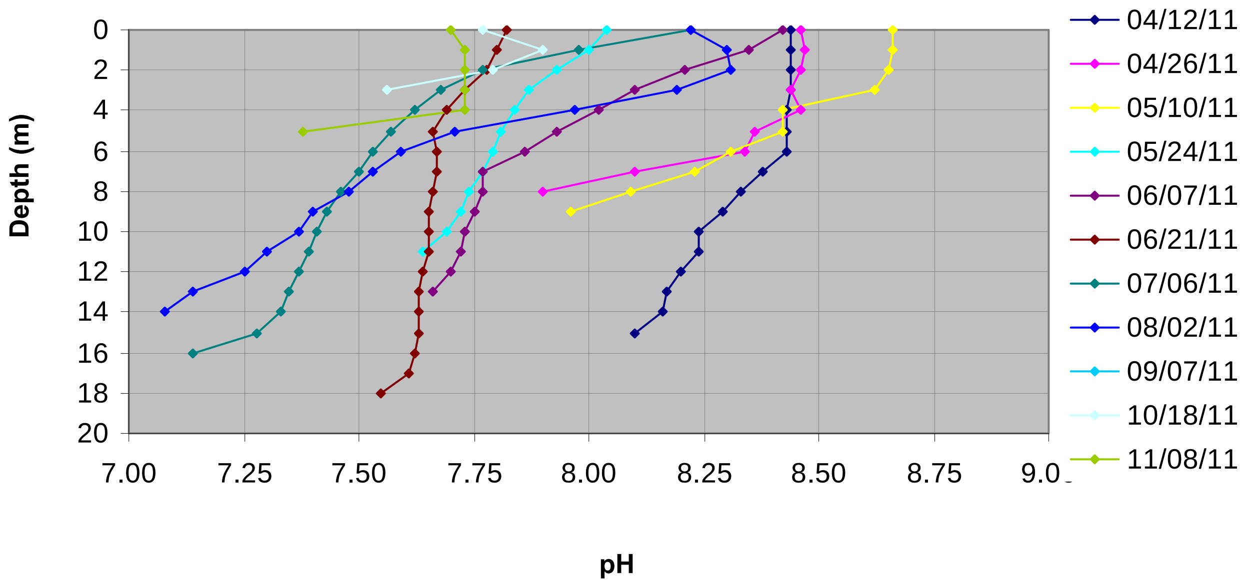
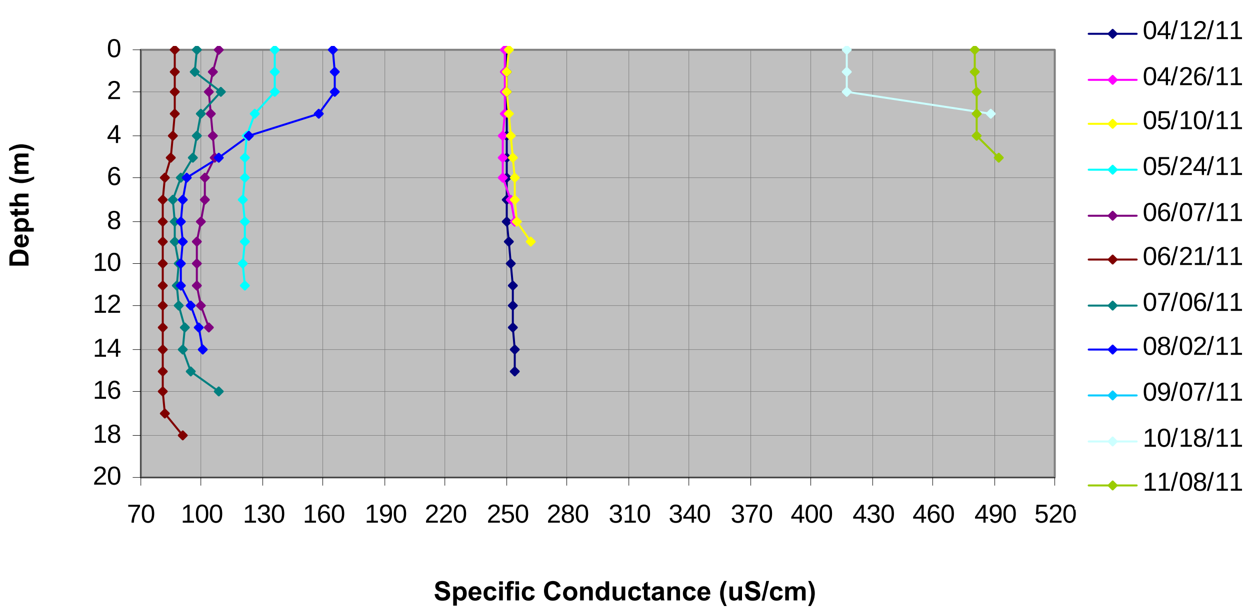


Figure 41. 2011 Seaman Reservoir specific conductance profiles



Seaman Reservoir:
General Parameters

Figure 42. Alkalinity concentrations in Seaman Reservoir

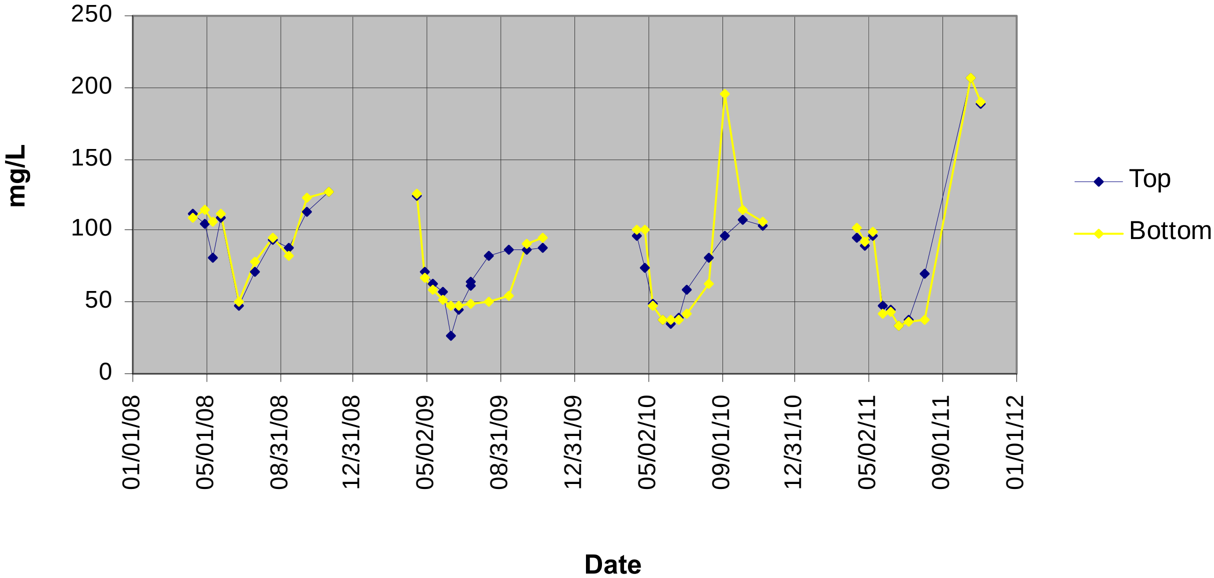


Figure 43. Hardness concentrations in Seaman Reservoir

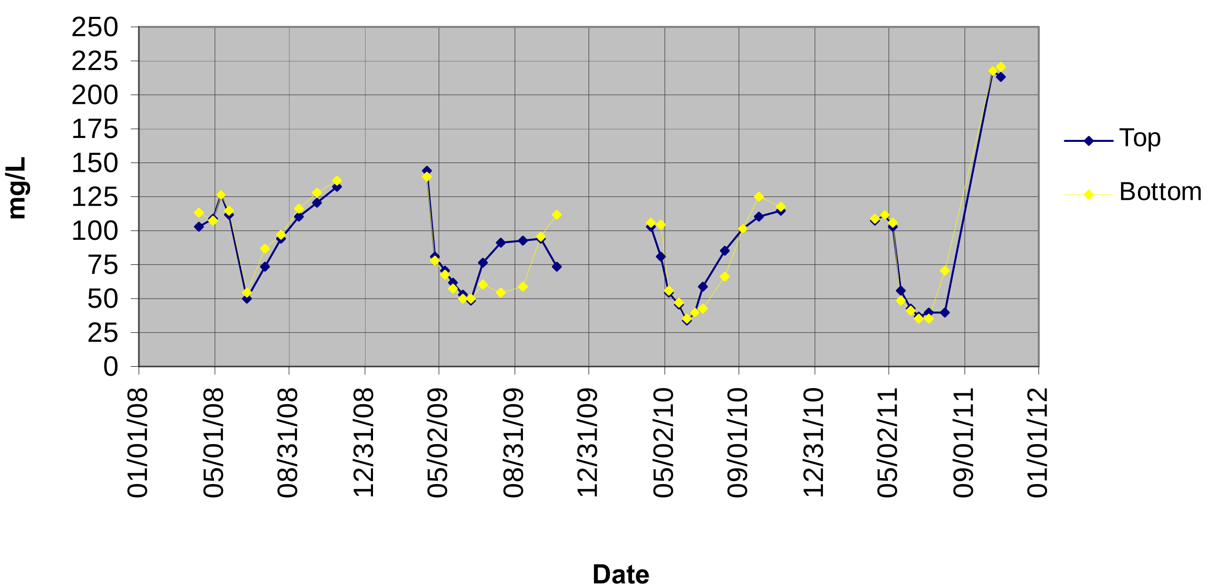


Figure 44. Turbidity in Seaman Reservoir

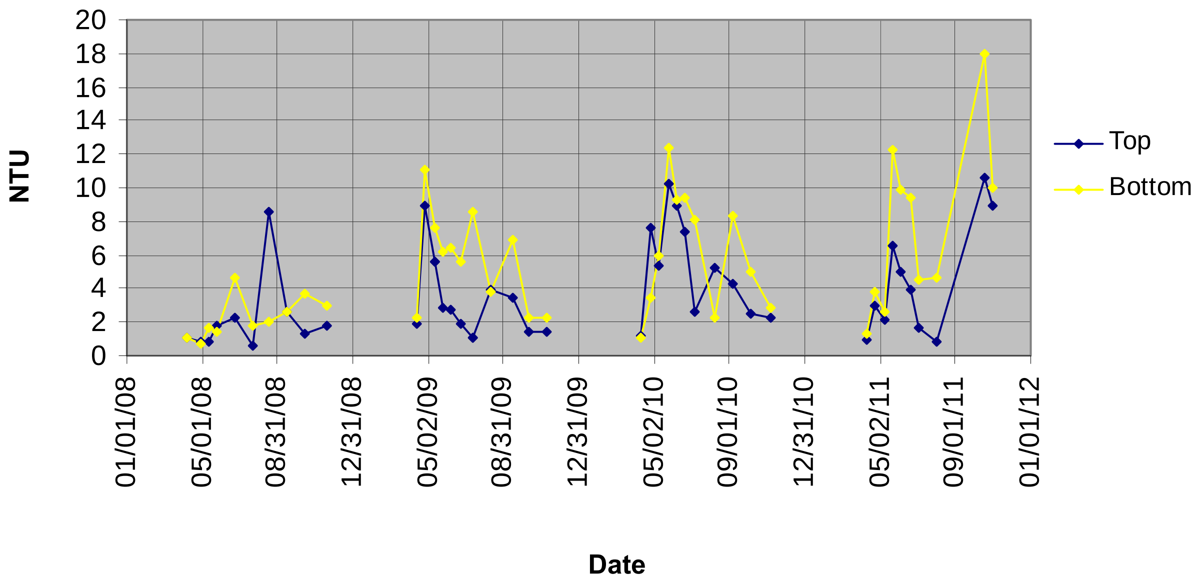
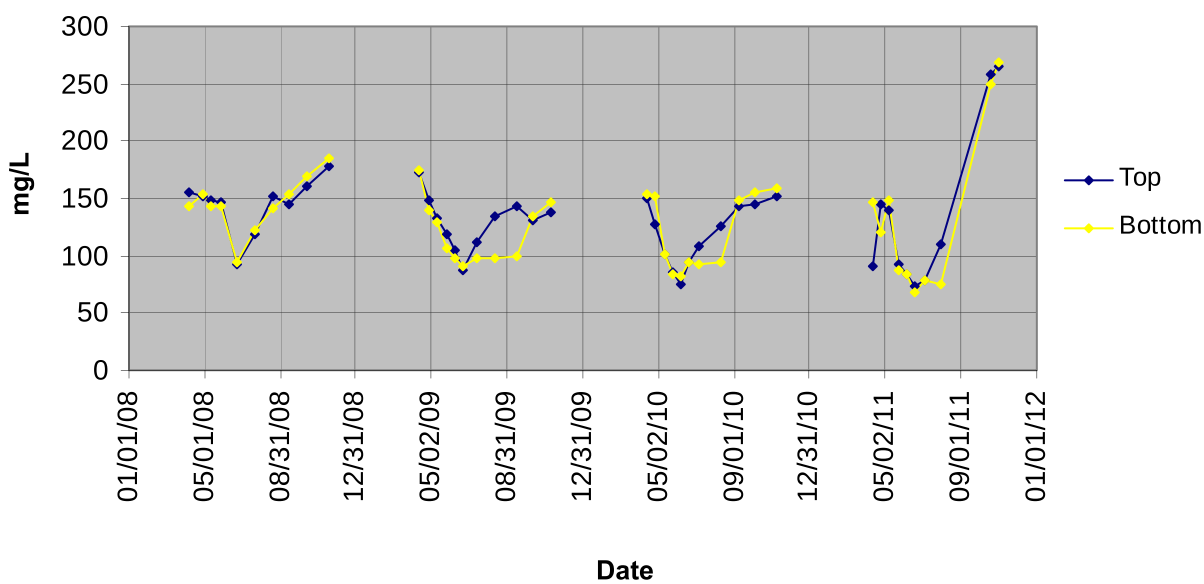
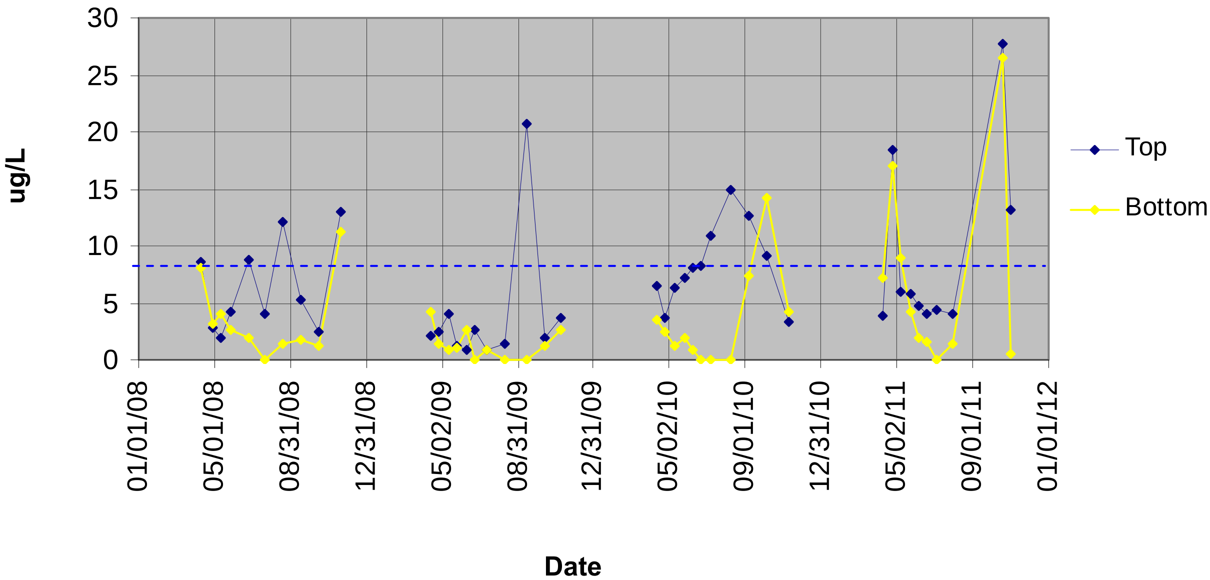


Figure 45. Total dissolved solids (TDS) in Seaman Reservoir



(EPA Secondary Drinking Water Standard: 500 ug/L)

Figure 46. Chlorophyll-a concentrations in Seaman Reservoir



(------- 2012 CDPHE/WQCD proposed cold water reservoir standard for chlorophyll-a: summer average of 8 ug/L in the mixed (top) layer)

Figure 47. Total organic carbon (TOC) in Seaman Reservoir

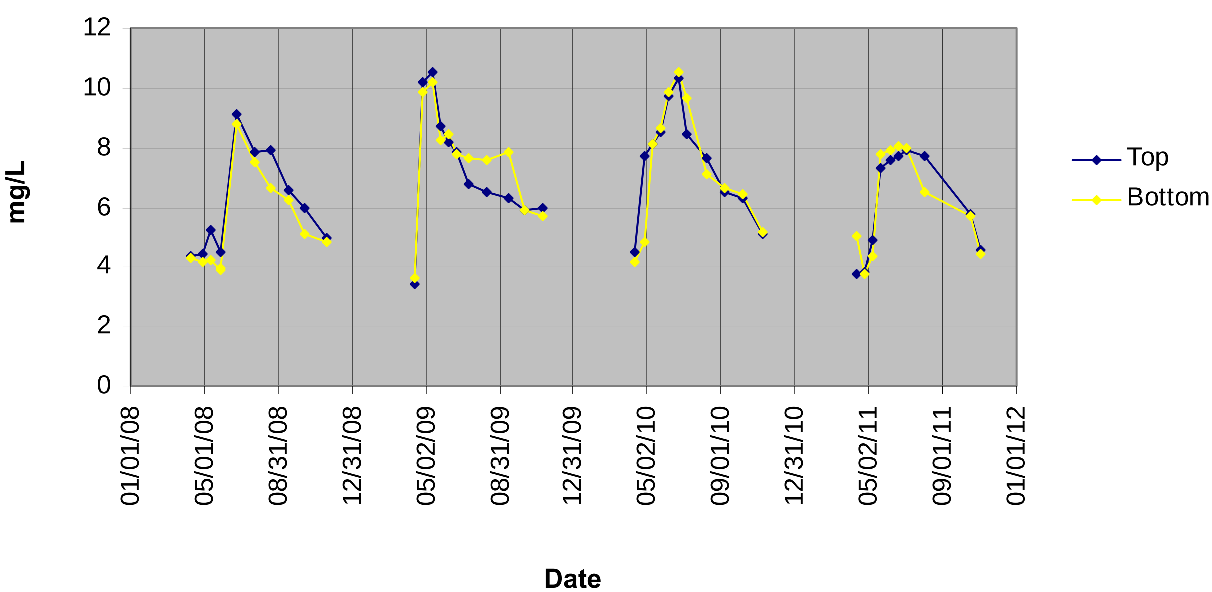
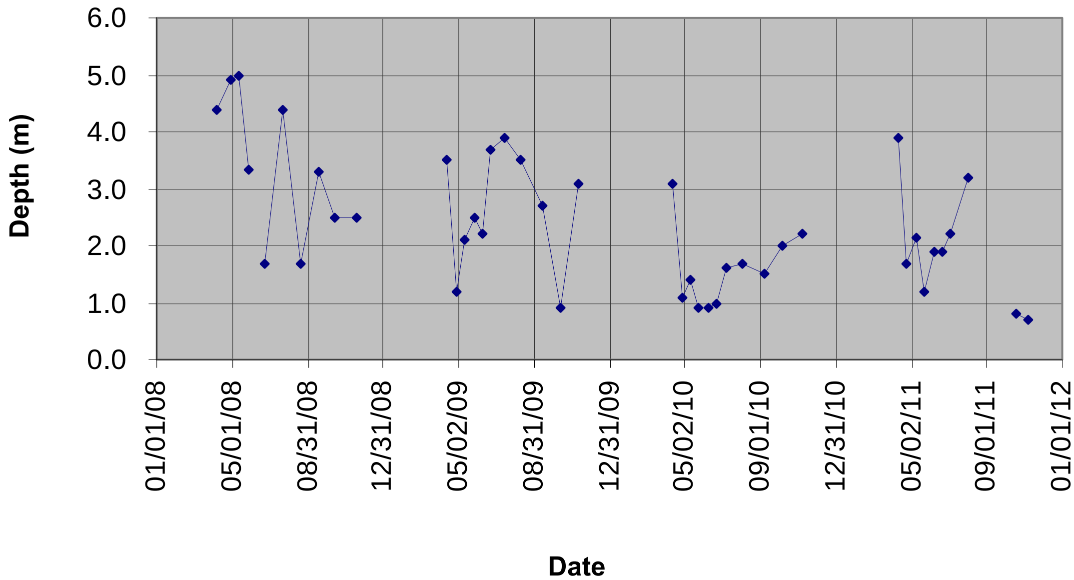
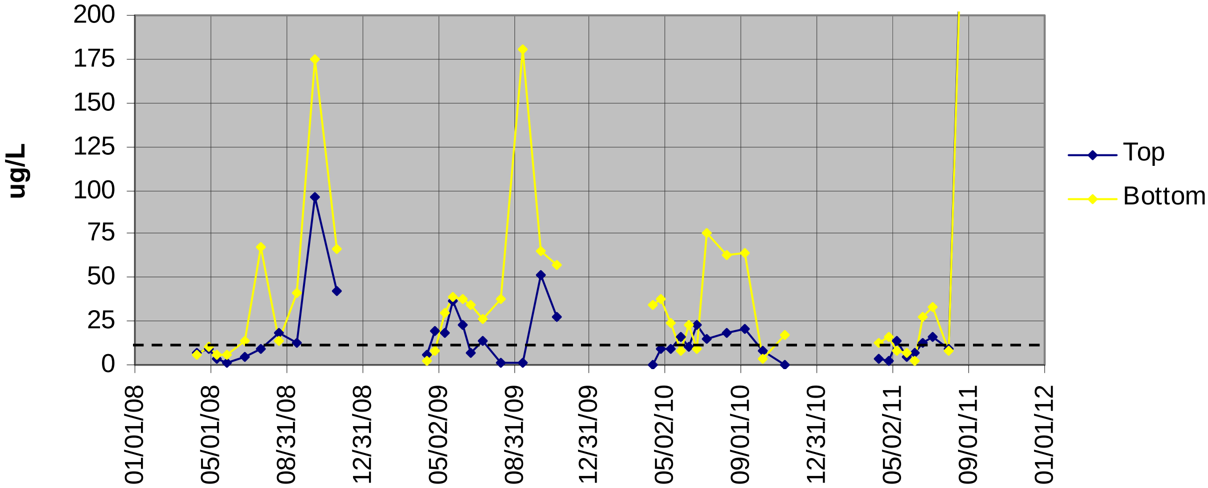


Figure 48. Secchi disk depth in Seaman Reservoir



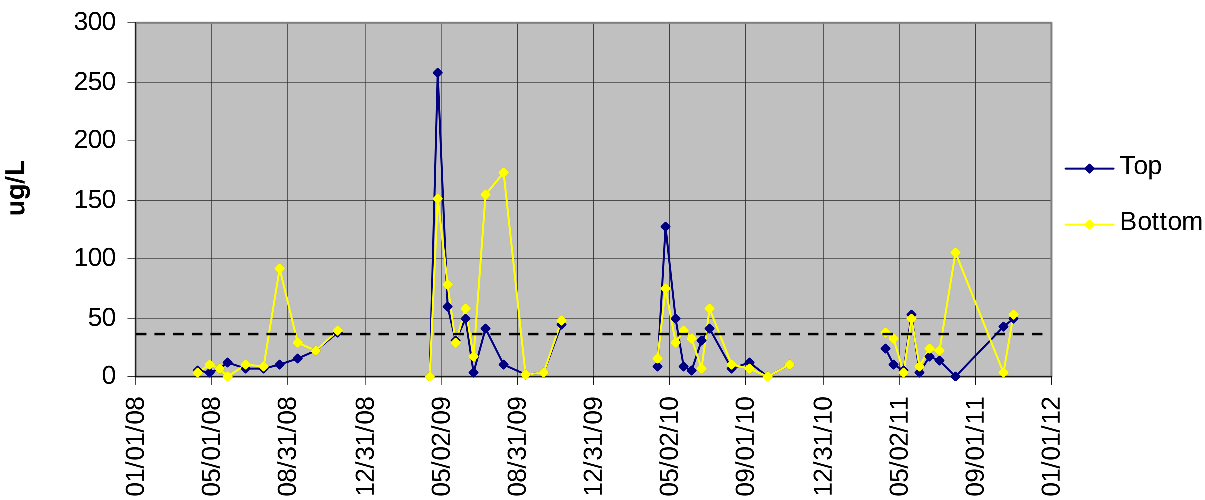
Seaman Reservoir:
Nutrients

Figure 49. Ammonia (NH3-N) concentrations in Seaman Reservoir



(----- FCWQL Reporting Limit: 10 ug/L)

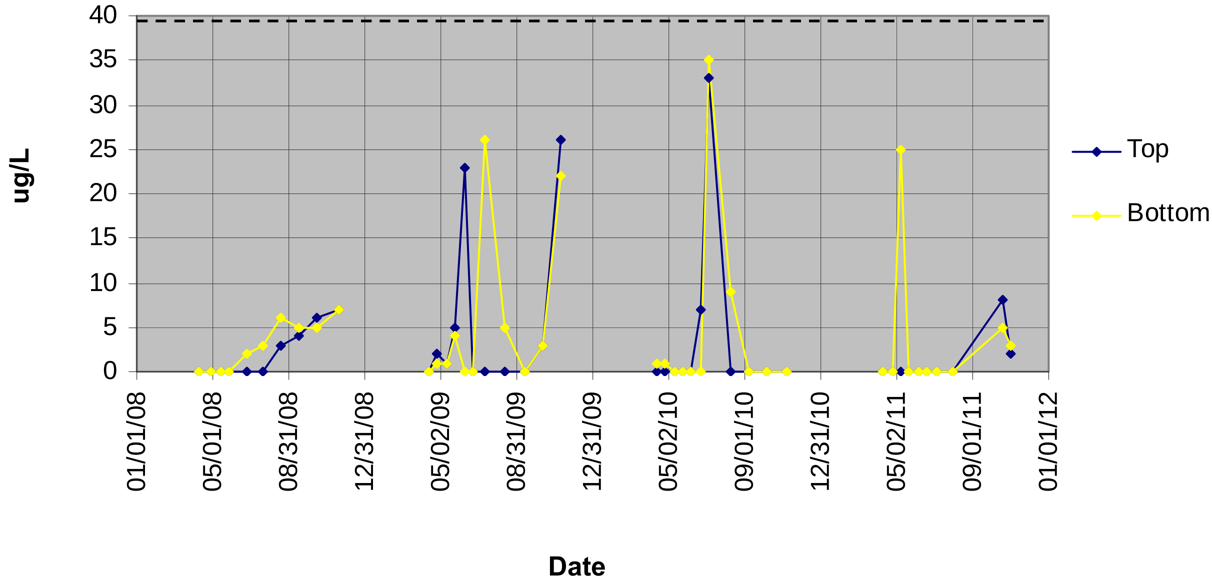
Figure 50. Nitrate (NO_{3-}-N) concentrations in Seaman Reservoir



(----- FCWQL Reporting Limit: 40 ug/L)

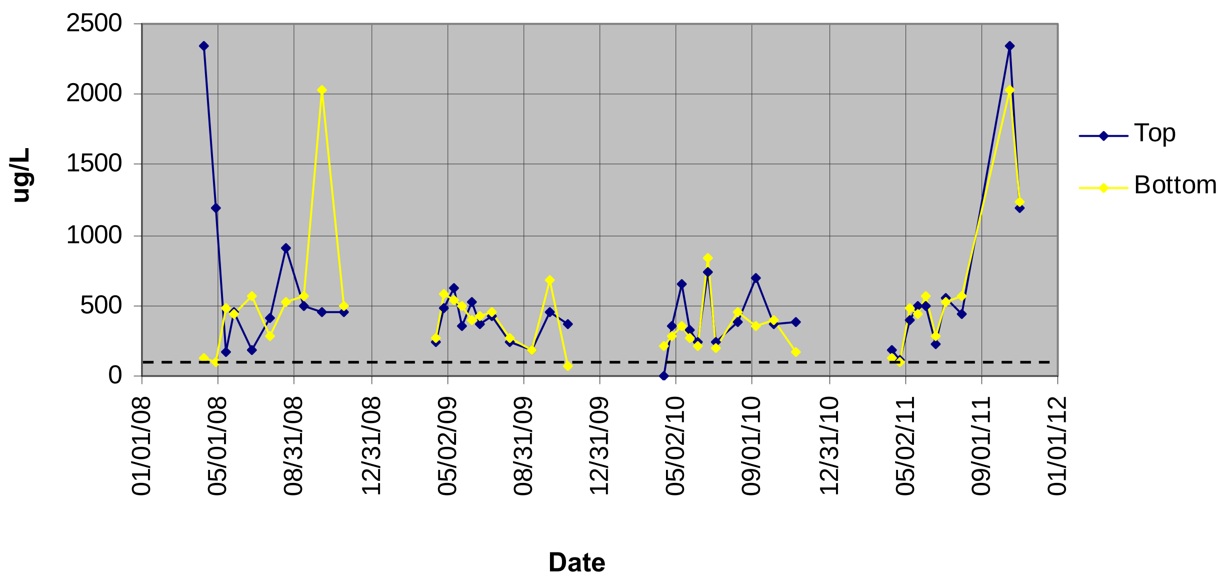
(EPA Maximum Contaminant Level: 10,000 ug/L)

Figure 51. Nitrite (NO_2-N) concentrations in Seaman Reservoir



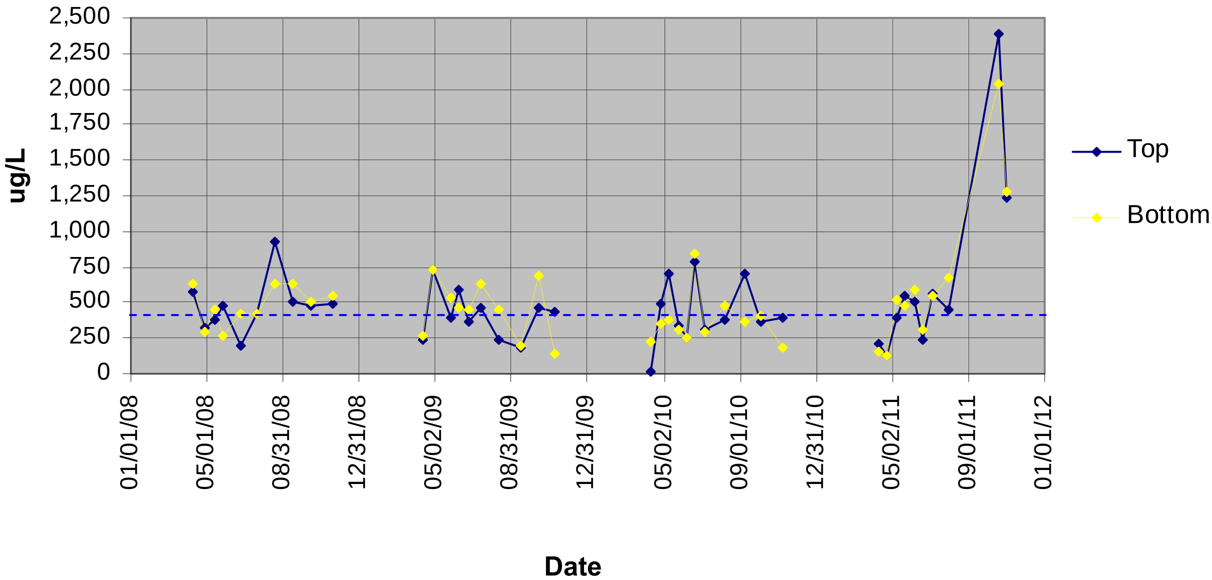
(----- FCWQL Reporting Limit: 40 ug/L)

Figure 52. Total Kjeldahl Nitrogen (TKN) concentrations in Seaman Reservoir



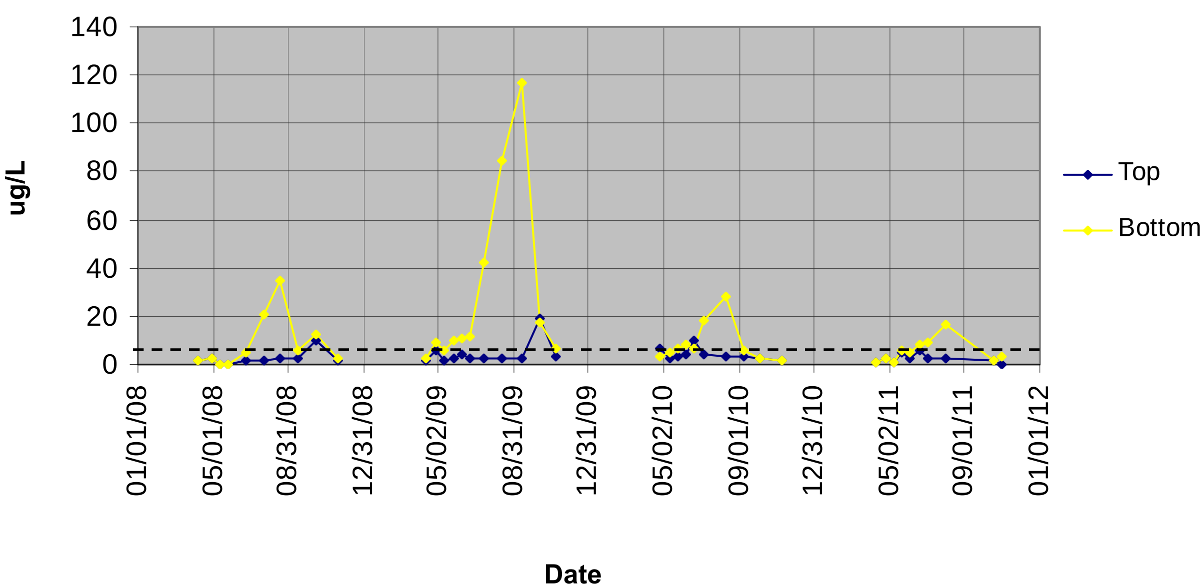
(----- FCWQL Reporting Limit: 100 ug/L)

Figure 53. Total Nitrogen (TKN+NO_3+ NO_2) concentrations in Seaman Reservoir



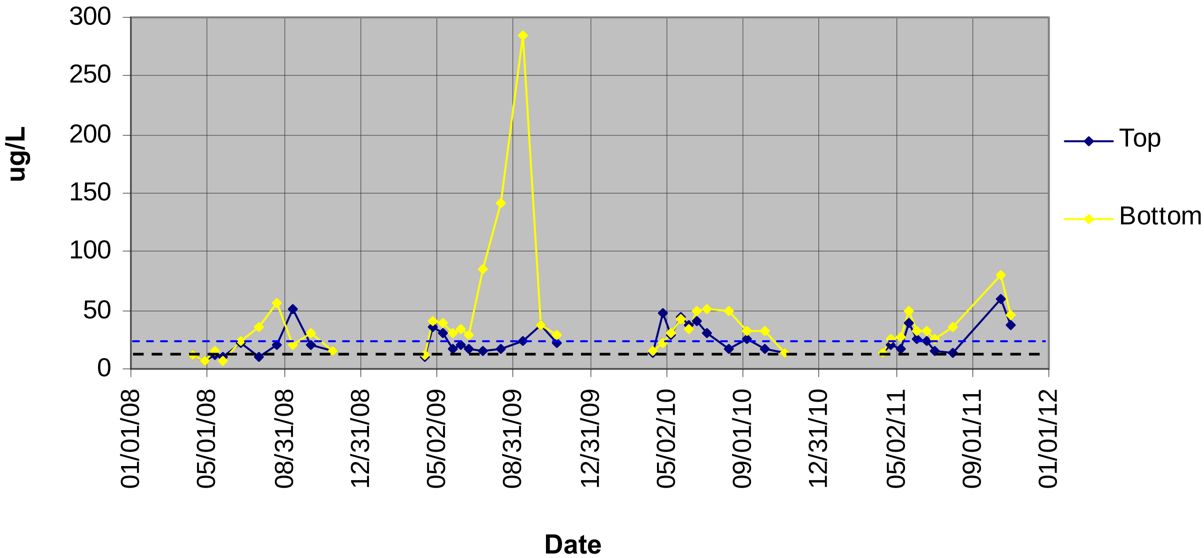
(------- 2012 CDPHE/WQCD proposed cold water reservoir standard for Total N: summer average of 426 ug/L in the mixed (top) layer)

Figure 54. Ortho-phosphate (PO_4) concentrations in Seaman Reservoir



(----- FCWQL Reporting Limit: 5 ug/L)

Figure 55. Total phosphorus (P) concentrations in Seaman Reservoir



(----- FCWQL Reporting Limit: 10 ug/L)

(------- 2012 CDPHE/WQCD proposed cold water reservoir standard for Total P: summer average of 25 ug/L in the mixed (top) layer)

Seaman Reservoir:
Major Ions

Figure 56. Calcium (Ca) concentrations in Seaman Reservoir

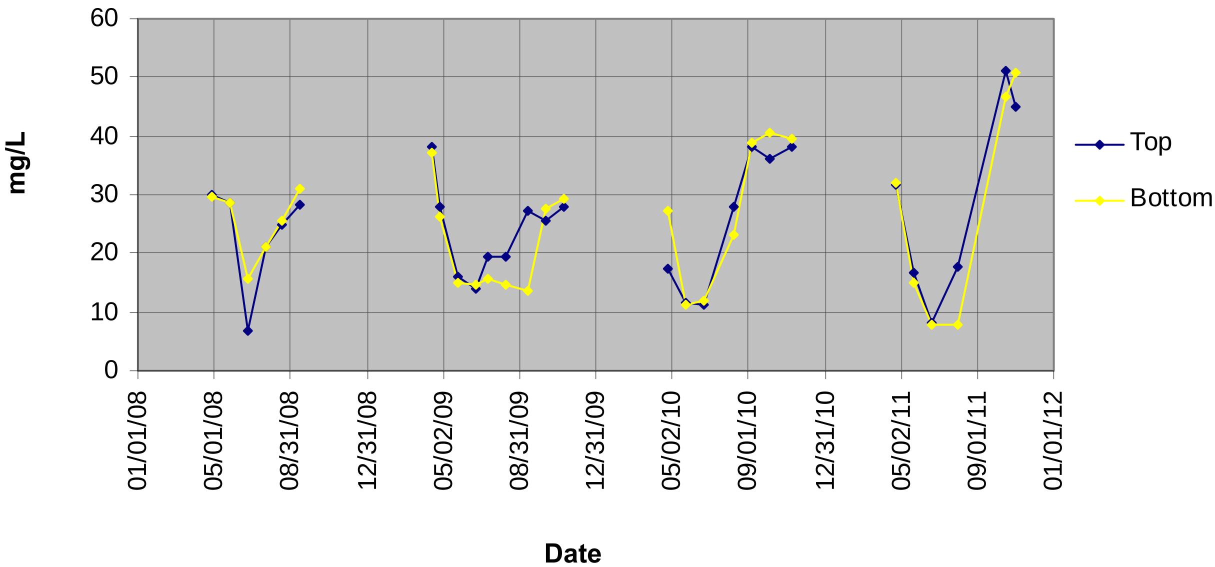


Figure 57. Magnesium (Mg) concentrations in Seaman Reservoir

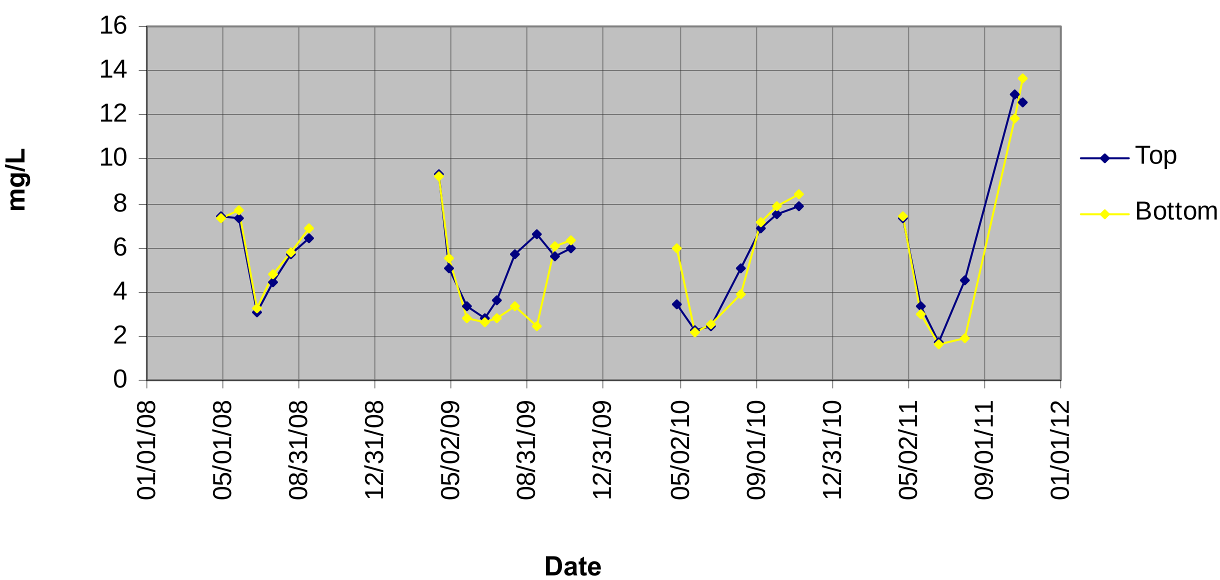


Figure 58. Potassium (K) concentrations in Seaman Reservoir

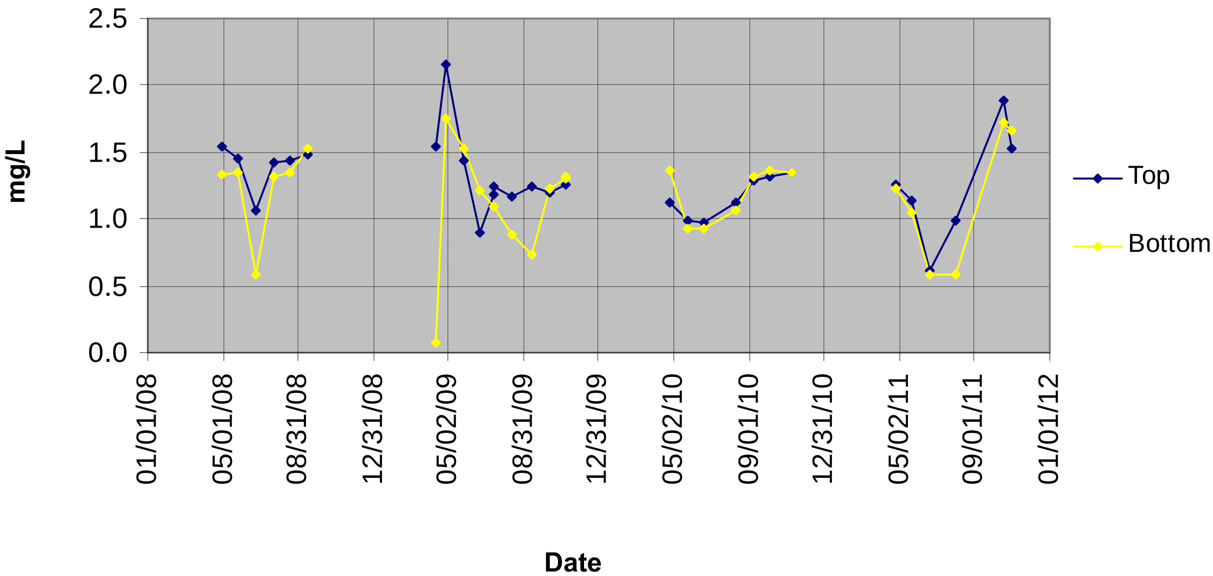


Figure 59. Sodium (Na) concentrations in Seaman Reservoir

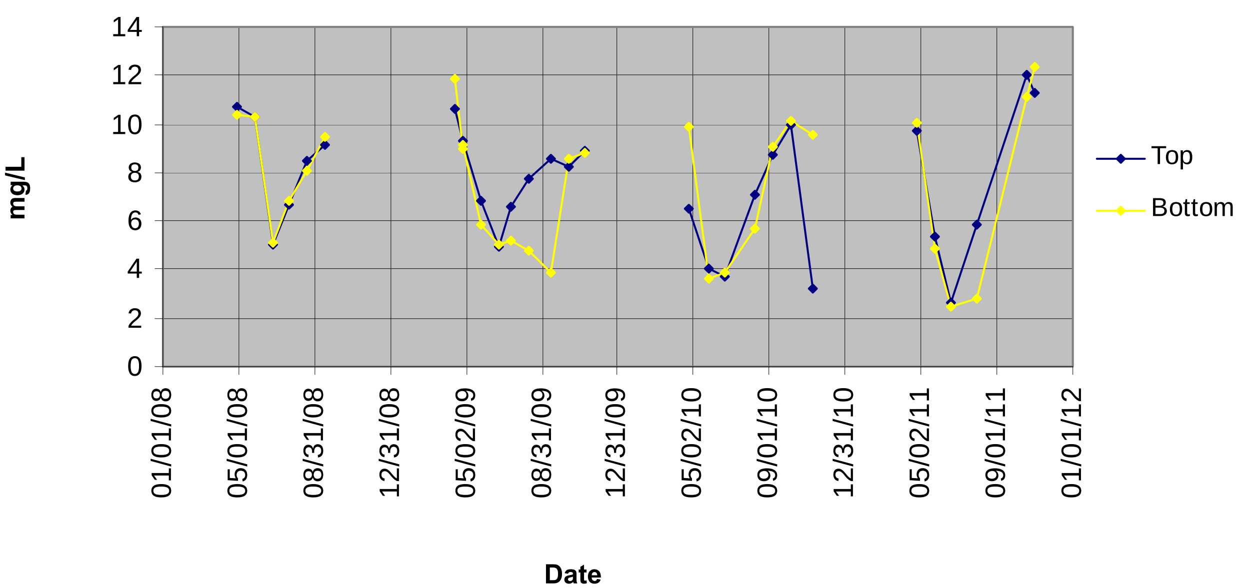


Figure 60. Chloride (Cl) concentrations in Seaman Reservoir

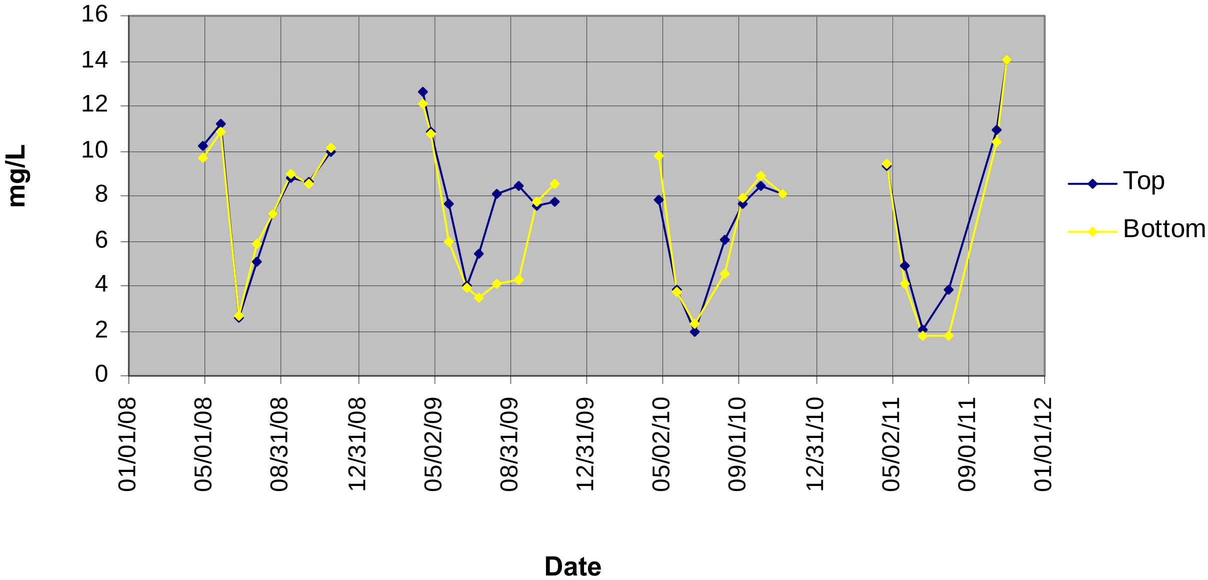
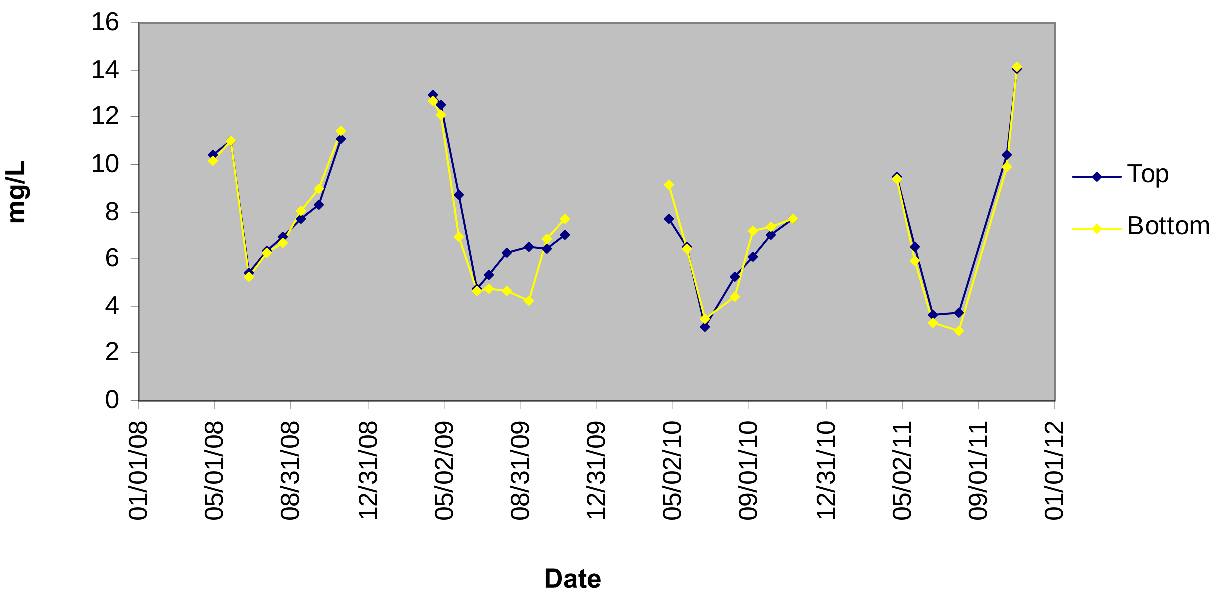


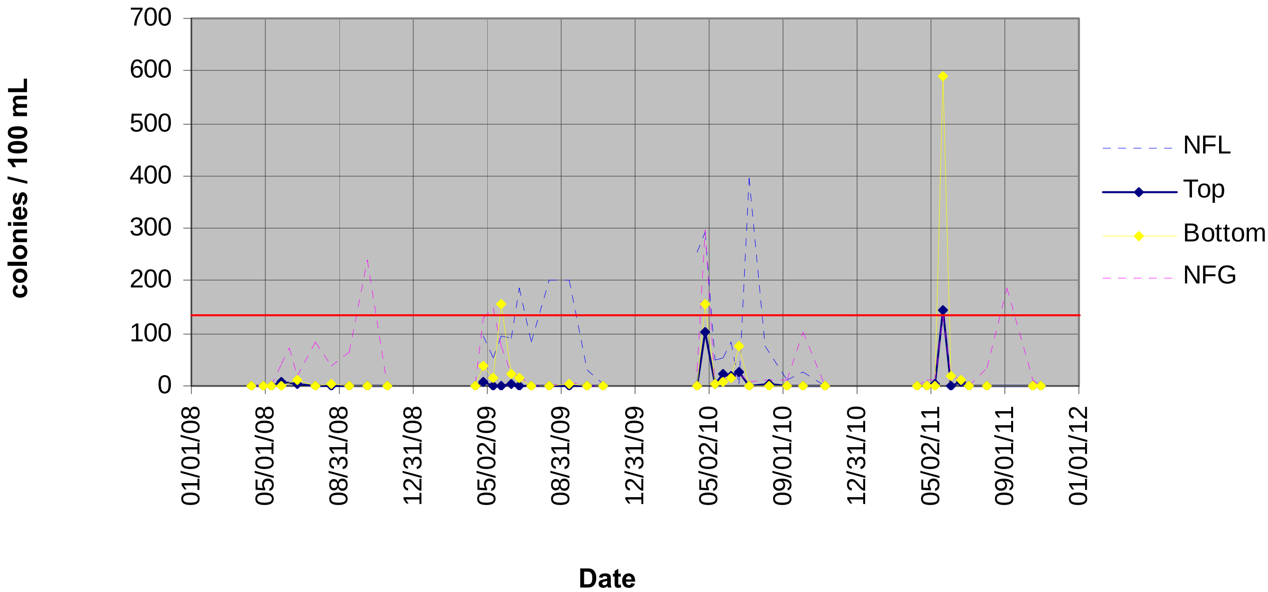
Figure 61. Sulfate (SO_4) concentrations in Seaman Reservoir



(EPA Secondary Drinking Water Standard: 250 mg/L)

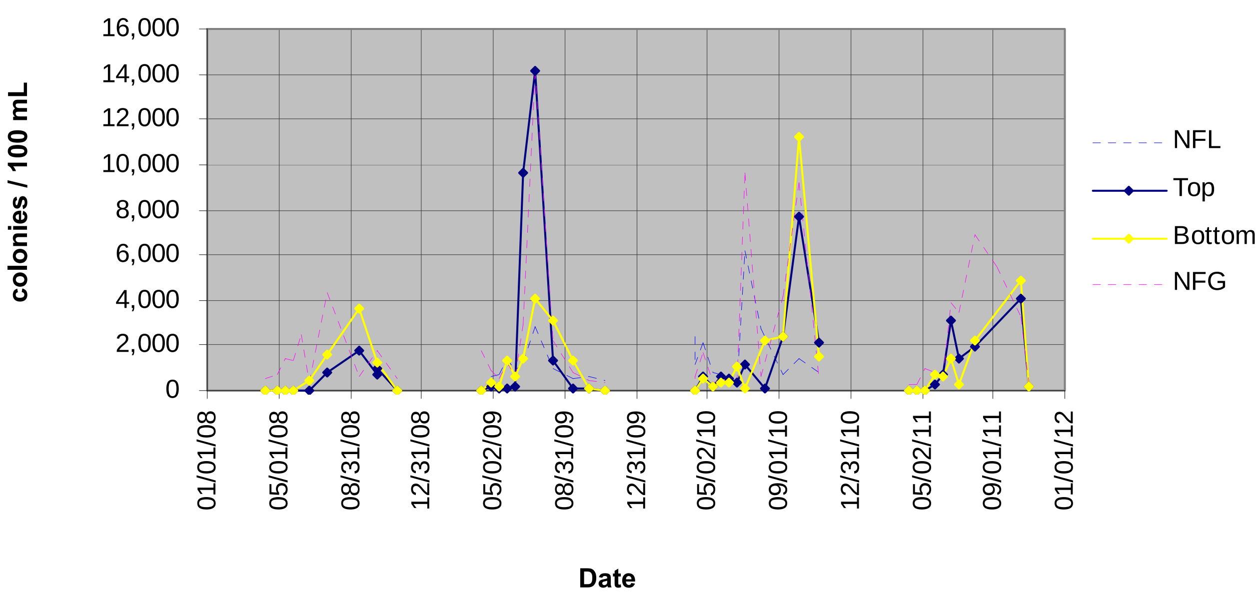
Seaman Reservoir:
Microbiological Constituents

Figure 62. *E. coli* concentrations in Seaman Reservoir



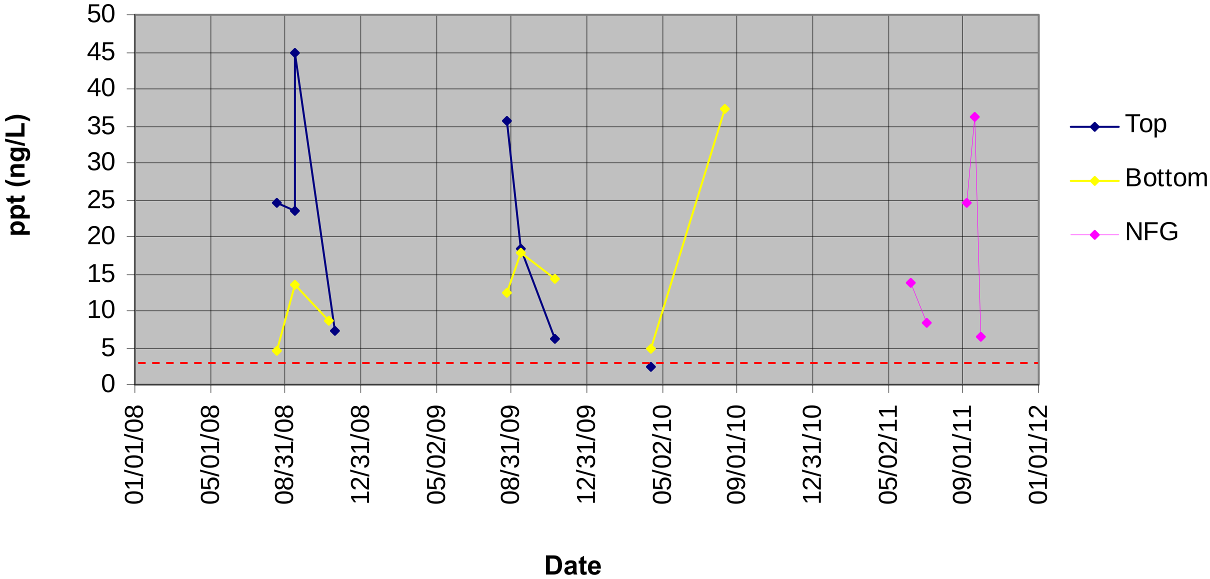
(Recreational water quality standard: 126 colonies/100 mL)

Figure 63. Total coliform concentrations in Seaman Reservoir



Seaman Reservoir:
Geosmin

Figure 64. Geosmin concentrations in Seaman Reservoir



(----- Odor threshold for geosmin: 4 ppt)

ATTACHMENT 8

Navigating Uncharted Waters: Assessing Geosmin Occurrence in a Colorado Rocky Mountain Source Water River

J. Oropeza, J. Billica and K. Elmund

In: Proceedings of the 2011© American Water Works Association AWWA WQTC Conference (Nov. 13-17, 2011, Phoenix, AZ)

Navigating Uncharted Waters: Assessing Geosmin Occurrence in a Colorado Rocky Mountain Source Water River

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ABSTRACT

Geosmin is a naturally occurring, organic compound that imparts an earthy odor to water. Geosmin is produced by some species of cyanobacteria (blue green algae) and actinomycetes (a filamentous bacteria) and is difficult to remove during the treatment process. Customers are very sensitive to the odor, with some individuals noticing the odor at extremely low concentrations, from 4-5 ug/L. While it does not pose a threat to public health, its detectable presence can give rise to customer concerns about the quality the drinking water.

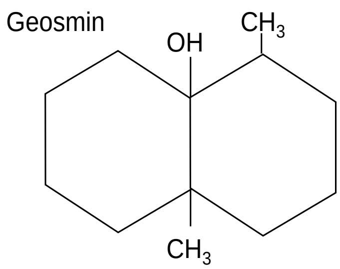
The presence of geosmin in water supply lakes and reservoirs in the U.S., Australia and Europe is well documented, although factors leading to outbreaks are often not well understood. The presence of geosmin in high quality, cold, turbulent, nutrient-poor Rocky Mountain headwaters is unexpected based on the reported experiences of others. The Cache la Poudre (Poudre) River originates in Rocky Mountain National Park on the east side of the Continental Divide and is one of two water sources for the City of Fort Collins, Colorado, Water Treatment Facility (FCWTF). Routine monitoring for geosmin in both FCWTF raw waters began in 2003 and has revealed episodes of elevated geosmin in the City's Poudre River water supply.

For utilities that experience episodes of geosmin in source water supplies, an early warning detection and monitoring program for geosmin is a critical tool for protecting drinking water quality, minimizing associated treatment costs and maintaining customer satisfaction. An understanding of geosmin occurrence, sources, transport and fate is essential before watershed activities can be implemented for its control.

Following a geosmin outbreak in early 2010, the City of Fort Collins Utilities initiated a geosmin monitoring program on the Mainstem of the Poudre River above the FCWTF intake. This paper outlines the FCU monitoring approach, the key findings, and the factors that have contributed to the program's success to date.

BACKGROUND

Geosmin is one of the most common, naturally occurring, taste and odor (T&O) producing organic compounds found in drinking water supplies. It imparts an earthy odor to water that can be detected by the most sensitive people when present at extremely low concentrations (<5 ng/L, or <5 parts per trillion (ppt)). The City of Fort Collins Utilities can expect "earthy" odor complaints if geosmin levels are above 4.0 ng/L in its finished water. Geosmin is produced by some species of cyanobacteria (blue-green algae) and actinomycetes (a filamentous bacteria). It is released after cell lysis and death and, depending on the species, it may also be actively excreted by healthy cells into the water column (e.g., Graham et al, 2008).



Geosmin does not pose a public health risk, but its detectible presence in treated drinking water can cause serious concerns in the eyes of the public about the aesthetic quality of the water supply. Utilities around the country receive high numbers of customer complaints whenever a geosmin outbreak occurs in the water supply. Geosmin is one of the most difficult T&O compounds to remove during water treatment.

The FCWTF receives raw water supplies from two main sources, Horsetooth Reservoir and the Mainstem of the Poudre River. One of FCU's most powerful strategies for minimizing the presence of geosmin in drinking water is to adjust the blend ratio of the two source waters in favor of the non-affected source, thereby lowering geosmin concentrations prior to treatment, when possible. The co-occurrence of elevated geosmin concentrations in both source waters would severely limit the effectiveness of this approach, and treatment operations could be forced to rely on less effective and more expensive options. While there are some potential water treatment fixes for geosmin odor control (Westerhoff et al., 2002; Paradis and Hofmann, 2006) watershed-based solutions for controlling geosmin provide a lasting, reliable and more economical approach to protecting drinking water quality. However, an understanding of geosmin occurrence, sources, transport and fate is essential before watershed activities can be implemented for its control.

The Fort Collins Utilities monitors water quality of the Poudre River through the collaborative Upper Cache la Poudre River Water Quality Monitoring Program (Billica et al., 2008). In most water quality monitoring programs, including the Fort Collins program, geosmin is not a routine monitoring parameter, and must be addressed with a separate monitoring plan.

Geosmin data for the Poudre water supply at the FCWTF are available from 2003 to present, and indicate periodic episodes of elevated geosmin concentrations (> 4 ng/L) (Figure 1). Between November 2009 and January 2010, an abrupt increase in geosmin concentrations was observed at the FCTWF. During this period, concentrations increased from around 2 ng/L to a maximum observed concentration of 7.53 ng/L. Concentrations at the FCWTF remained near or above 4 ng/L through the beginning of May, and then dropped below the 4 ng/L threshold for the duration of 2010, with one exception (at 4.4 ng/L) in July.

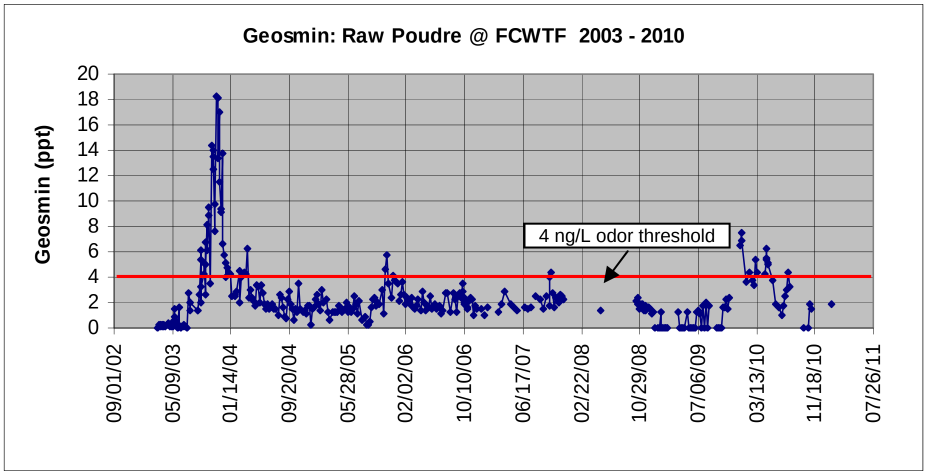


Figure 1. Geosmin concentrations in raw Poudre River water supply at the FCWTF from 2003-2010.

Geosmin sampling activities on the Mainstem of the Poudre River were initiated following the January 2010 outbreak to gain a better understanding of the spatial and temporal occurrence of geosmin in this river system. The work detailed in this paper is part of a broader effort to improve our understanding of geosmin dynamics in FCU's water supply reservoir and source watersheds (see also Billica et al., 2010).

Unlike lake and reservoir systems, there is currently little guidance in the literature for assessing spatial and temporal occurrence or monitoring approaches for understanding and predicting geosmin outbreaks in river systems. Therefore, it was important to continuously adapt and refine our monitoring activities based on our observations and lessons learned about geosmin dynamics on the Poudre.

Geosmin monitoring activities on the Poudre River focused on the following objectives:

- Identify the areas on the Poudre River with high geosmin concentrations that are sources of geosmin to the FCWTF.
- Identify spatial and seasonal geosmin and nutrients trends in areas of geosmin production.
- Evaluate potential sources of nutrients to the target areas.
- Characterize the periphyton community and identify known geosmin-producing species, when possible.

Ultimately, the monitoring activities aim to identify opportunities within the watershed to mitigate or reduce geosmin production and to assist in the development of an early warning monitoring program that enables water treatment operators to minimize the presence of geosmin in treated drinking water supplies.

SITE DESCRIPTION

The Mainstem of the Poudre River originates in Rocky Mountain National Park, on the east side of the Continental Divide and serves as one of two water sources for the City of Fort Collins Water Treatment Facility. From its headwaters, the Mainstem Poudre travels approximately 65 miles through the Poudre Canyon, descending approximately 5,500 feet from its starting elevation of 10,800 feet. It then flows through the City of Fort Collins, and meets the South Platte River on the agricultural plains, near Greeley, Colorado. The City of Fort Collins raw Poudre River water intake facility is located on the Mainstem of the Poudre River above the confluence with the North Fork Poudre approximately 5 miles above the mouth of the Poudre Canyon.

The upper Poudre watershed (above the canyon mouth) encompasses approximately 361,300 acres (565 square miles) mountain terrain, dominated by coniferous forest; developed land represents less than 0.7% of the total watershed. Within this upper basin, there are a total of 30 miles of river designated under the Wild and Scenic Rivers Act (1968) as “wild” and another 46 miles with a “recreational” designation. These designations underscore the pristine conditions of these river segments and protect against any activity that threatens the water quality or the outstanding natural, cultural, and recreational values on these segments. Furthermore, the Colorado Department of Health & Environment (CDPH&E) has designated the Mainstem Poudre a Class 1 – Cold Water Aquatic Life water body, indicating that it is capable of sustaining a wide variety of cold water biota, including sensitive species and has set forth the water quality standards for its protection.

The primary tributaries of the Mainstem Poudre are the South Fork Poudre and Joe Wright Creek. Within the upper watershed, there are nine water supply reservoirs and five trans-basin diversions that deliver water from the Colorado River, Michigan River and Laramie River basins; however, the Mainstem Poudre remains free of impoundments. Water quality at the FCWTF intake, therefore, reflects the cumulative contributions of these sources in addition to the land use activities within the watershed.

The hydrology of the Mainstem Poudre is driven predominantly by mountain snowmelt runoff. Peak stream flows occur mid- to late-June and are followed by a return to much lower flows by late summer and through the winter months (Figure 2).
The period of high spring runoff on the
Mainstem Poudre is characterized by cold temperatures, low conductivity and hardness, and relatively high turbidity and total organic carbon (TOC) concentrations. Nutrient concentrations experience some seasonal effects, but are generally low year-round. Sources of nutrients in the Upper Poudre include, but are not limited to, sediment transport, feces from wildlife and livestock, potentially leaking septic systems, atmospheric nitrogen deposition, reservoir releases within the Upper Poudre watershed, and the breakdown of organic matter.

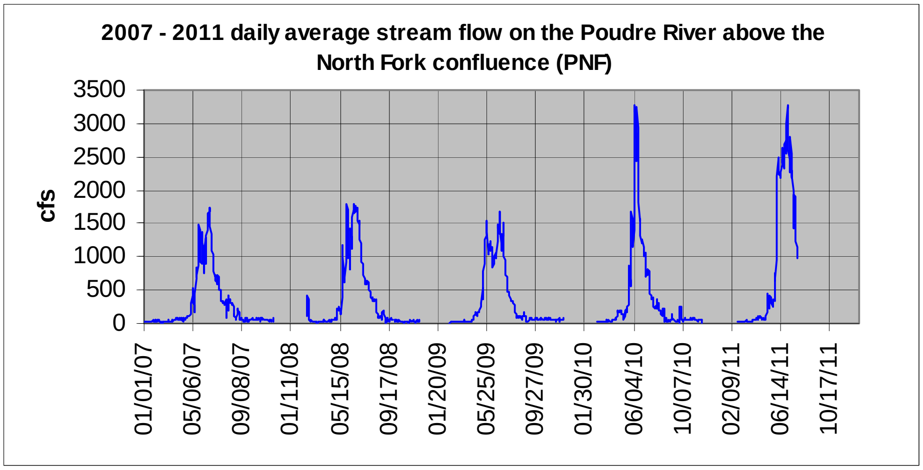


Figure 2. 2007 - 2011 daily average stream flow on the Poudre River above the North Fork confluence (PNF).

MONITORING ACTIVITIES

Intensive sampling on the Mainstem of the Poudre River began in January 2010 in direct response to the elevated geosmin concentrations observed in the raw water supply at the FCWTF (Figure 1).

Initial sampling activities focused on characterizing the geosmin concentrations in the river and identifying areas of high geosmin production that could be potential sources of geosmin to the FCWTF intake. Reconnaissance geosmin sampling focused on the areas area upstream and downstream of Rustic, Colorado, located approximately 25 miles upstream of the FCWTF intake. This area was targeted based on the prevalence of permanent seasonal and year-round housing and camping facilities in the area as well as the upstream State of Colorado Division of Wildlife Poudre River Fish Hatchery. The fish hatchery does not currently operate at full capacity, but does routinely discharge water from a limited number of ponds into the Poudre River.

Reconnaissance sampling spanned nearly 29 miles, extending from the outlet of Joe Wright Reservoir (on Joe Wright Creek) downstream to Kelly Flats Camping area (Figure 3). The area of highest geosmin concentrations was found to extend from approximately one-quarter mile above Rustic, near the Poudre Canyon Chapel downstream to the Eggers Fishing area.

Phase I Monitoring. Phase I monitoring activities consisted of monthly geosmin samples collected at four routine sites within this area of highest geosmin concentrations around Rustic from February, 2010 to April, 2011. The selected monitoring sites were *Poudre above Rustic* (near Poudre Canyon chapel), *Poudre Canyon Fire Station* (mile marker 90), *Poudre below Rustic* (PBR) and *Poudre at Eggers* fishing area (Figure 3). Initial sampling at these four sites revealed geosmin concentrations ranging from 20.61-38.14 ng/L. It is notable that this area of high geosmin production corresponds to the stretch of river where an attached green algae bloom (*Ulothrix sp.*) occurred in the summers of 2009 and 2010. This study took the preliminary steps to determine whether geosmin occurrence and the *Ulothrix* bloom were related, although it was recognized that *Ulothrix* itself is not a geosmin producer.

Nutrient testing was added to the routine monitoring program in February 2010 to determine whether elevated concentrations of nutrients were available to stimulate geosmin-producing algae growth. Samples were analyzed for Total Kjeldahl Nitrogen (TKN), nitrate, nitrite, ammonia, total phosphorus (TP) and ortho-phosphorus. The outflow from the Poudre River Fish Hatchery was sampled for nutrients in February 2010 and again in February 2011. Periphyton samples were collected monthly beginning in July, 2010 at the four routine monitoring sites near Rustic. Periphyton sample collection was limited to periods of time when the river was free of continuous ice and water levels allowed safe access to the river.   Because geosmin production is species specific, it was critical to identify algae samples to the species level. All periphyton samples were identified by private consultant, Richard Dufford, to the species level, when possible, and qualitatively ranked for abundance.

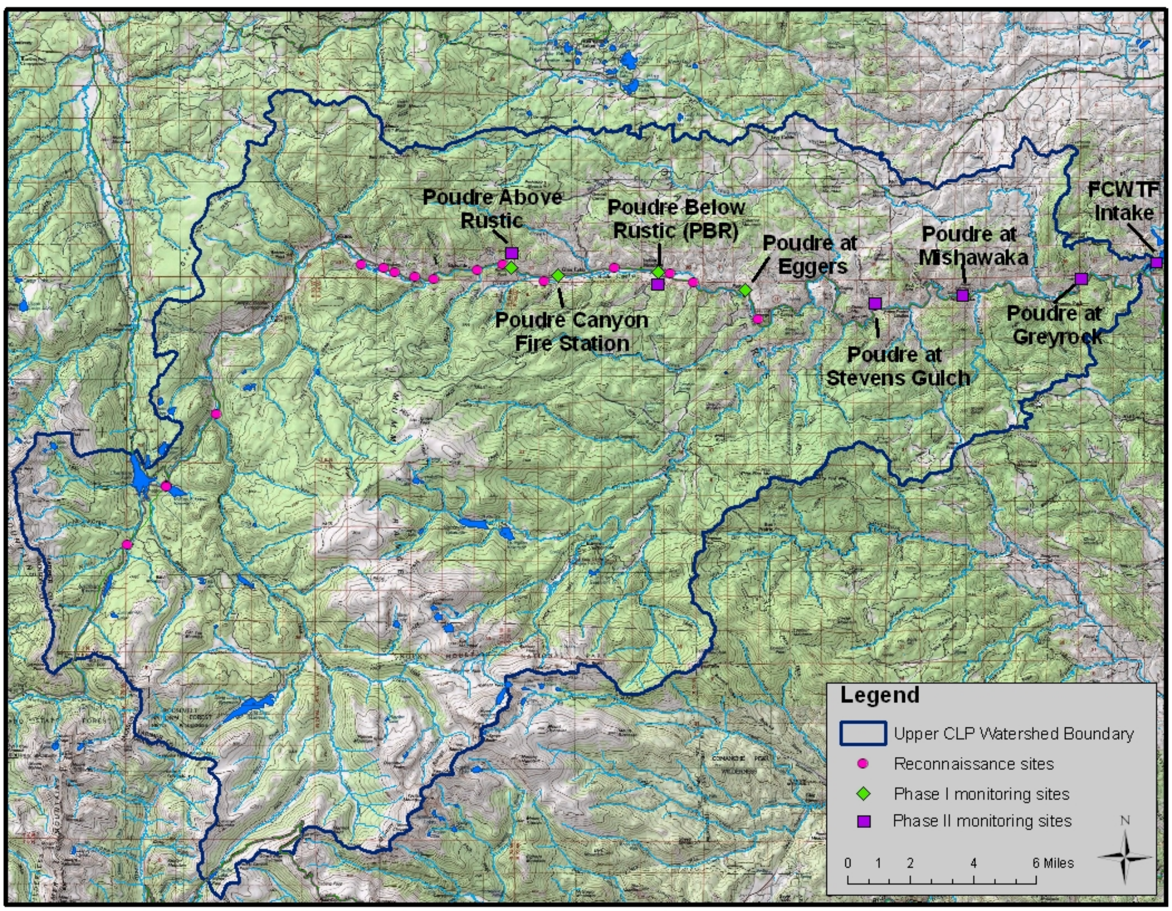


Figure 3. Map of Upper Poudre geosmin monitoring sites.

Total coliform and *E.coli* analyses were added to the sampling program in August, 2010 and serve as potential indicators of animal and human fecal contamination. The co-occurrence of these bacteria with elevated nutrient concentrations could potentially serve as an indicator of leaking septic systems and vault toilets associated with homes, campgrounds and rental cabin properties as a source of nutrients to the river. All available individual sewage disposal system (ISDS) permits for the area of interest were obtained from the Larimer County Department of Health and Environment and mapped where possible. Twenty ISDS permit locations were identified for this area (Figure 4). Three additional sites that were upstream and downstream of permanent and seasonal residential developments were sampled in August 2010. These sites included above and below Home Moraine residential area and below the Glen Echo Resort.

A timeline of the program development in provided in Figure 4.

Phase II Monitoring. The second phase of geosmin monitoring (Phase II) began in May, 2011 and can be characterized by two important changes to the sampling program: a reconfiguration of sample sites to include sites closer to the FCWTF intake and the adoption of new quantitative periphyton sampling protocols. To maintain data continuity with Phase I sampling, two of the original sample sites were retained and three new downstream sites were added (Figure 3). In addition, a sample from the raw Poudre water at FCWTF was collected on the same day as the Poudre river samples, to help determine which sites are potentially contributing to geosmin at the FCWTF intake. All other sampling parameters remained the same. Phase II sampling will continue through the spring of 2012.

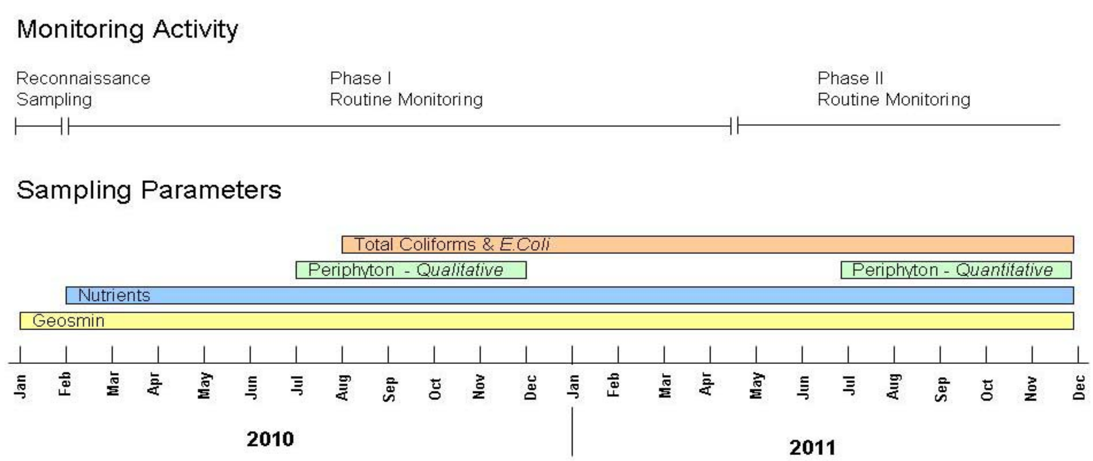


Figure 4. Timeline of 2010-2011 geosmin monitoring activities on the Upper Poudre River

Field sampling methods. All samples were collected by FCU staff. Grab samples for geosmin, nutrients, periphyton and bacteria were collected from the main channel flow using a telescopic pole with a clean, attached sample bottle. The sample volume collected in the bottle attached to the pole was immediately transferred to amber glass bottles for geosmin testing, and to plastic sample containers for nutrients and bacteria testing. All nutrient, bacteria and geosmin samples were analyzed by the City of Fort Collins Water Quality Lab (Table 1).

Parameter	Method	Reporting Limit	Preservation	Holding Time
Total Coliform, E.coli - QT	SM 9223 B	0	cool, 4C	8 hrs
Ammonia - N	Lachat 10-107-06-2C	0.02 mg/L	H_2SO_4	28 days
Nitrate	EPA 300 (IC)	0.2 mg/L	cool, 4C (eda)	48 hrs
Nitrite	EPA 300 (IC)	0.1 mg/L	cool, 4C (eda)	48 hrs
Total Kjeldahl Nitrogen	EPA 351.2	0.1 mg/L	H_2SO_4 pH<2	28 days
Phosphorus, Total	SM 4500-P B5,F	0.01 mg/L	H_2SO_4 pH<2	28 days
Phosphorus, Ortho	SM 4500-P B1,F	0.005 mg/L	filter, cool 4C	48 hrs

Table 1. Analytical methods, reporting limits, sample preservation and sample holding times for analyses conducted by the City of Fort Collins Water Quality Lab.

Qualitative periphyton samples (Phase I) were collected by scraping algae and biofilms from the surface of rocks. Samples were composited in plastic bottles and preserved with a 4% formalin solution upon return to the lab. A change in methods was implemented in May 2011 to provide an estimate of algae abundance as well as species identification. Quantitative periphyton samples (Phase II) were collected from a known surface area from three selected cobbles from the streambed. The stream area type (pool, riffle, or run) were identified for each cobble. The algae sample was isolated by removing algae from the rock surface around the outside of the PVC cylinder using a wire brush and spray bottle. The PVC cylinder was then removed, and the algae from under the cylinder were scraped and washed into a plastic sample container. This procedure was repeated for each sample cobble. Algae samples from similar stream areas were composited and preserved with a 4% formalin solution upon return to the lab. All samples were refrigerated until analysis.

Geosmin analysis. Geosmin occurs in surface waters as cellular (cell-bound) and dissolved fractions (Juttner and Watson, 2007). For the Fort Collins monitoring program, samples were unfiltered and tested for total geosmin concentrations. However, protein-bound geosmin may be underestimated using current extraction techniques (Juttner and Watson, 2007). Geosmin analysis were conducted by the City of Fort Collins Water Quality Laboratory using solid phase microextraction as described in Standard Method 6040D (2005) by gas chromatography/mass spectrometry. Geosmin data were generally available within two days of sample collection.

RESULTS

Geosmin. Reconnaissance sampling of the Upper Poudre indicated that geosmin concentrations were highest in the area surrounding Rustic, ranging from 15.43 ng/L to 38.14 ng/L.

Phase I geosmin concentrations, as shown on Figure 5, exhibit a seasonal pattern of high concentrations in the winter months, and low concentrations during the summer months. This seasonal pattern in geosmin concentrations was evident at all sites.

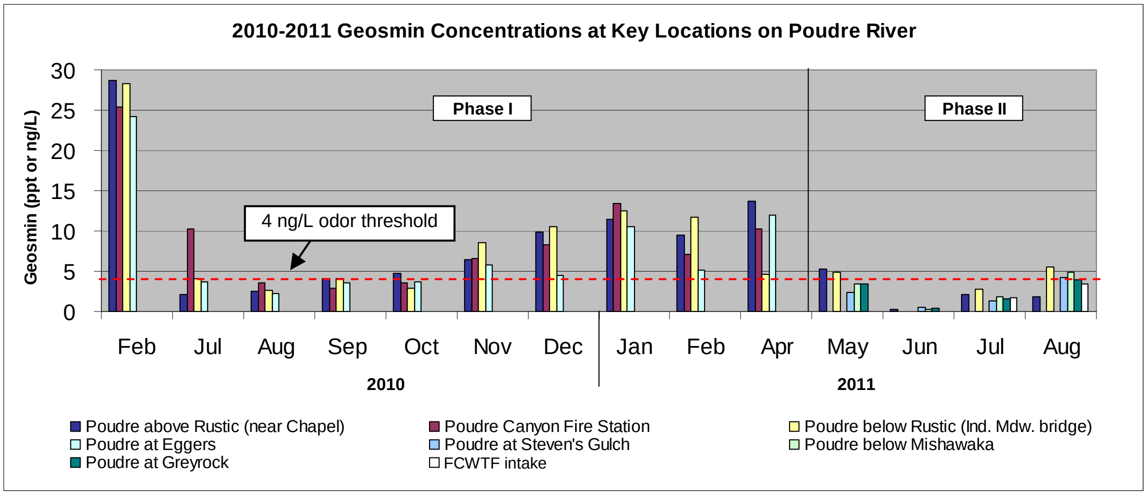


Figure 5. Geosmin concentrations at key Phase I and Phase II monitoring locations on the Poudre River from 2010 to 2011.

A comparison of stream flows at the FCWTF intake and geosmin concentrations at the nearest upstream monitoring location (Poudre below Rustic) shows an inverse relationship between geosmin concentrations and stream flows (Figure 6); high concentrations were observed during low flows (winter) and lower concentrations were observed during periods of higher flows (summer).

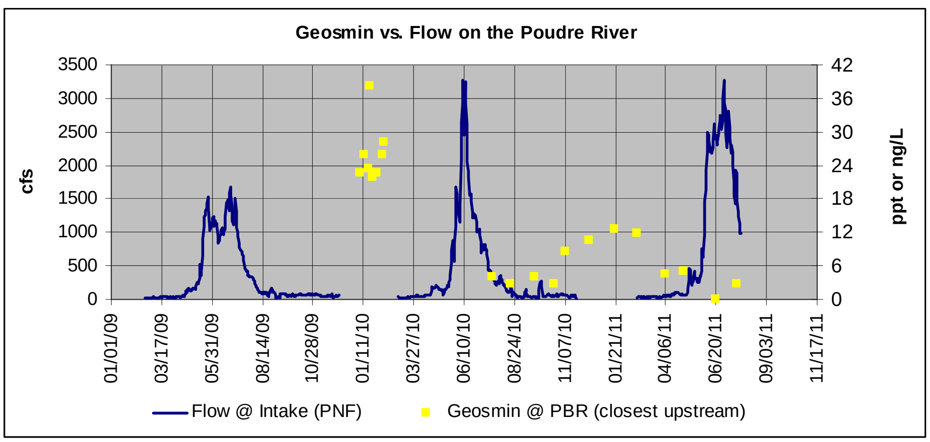


Figure 6. Flow at FCWTF intake (PNF) versus geosmin concentrations at Poudre below Rustic (nearest

Phase II monitoring sites appear to exhibit a similar seasonal trend, however, data is still limited for many of the sites. While it is possible that stream flow affects the seasonal pattern in geosmin results in part through concentration (low flows) and dilution (high flows), the seasonal pattern of geosmin concentrations may also result from changes in rates of cellular geosmin production in response to changes in water temperature, photoperiod, or other biological, physical or chemical factors not addressed by this study.

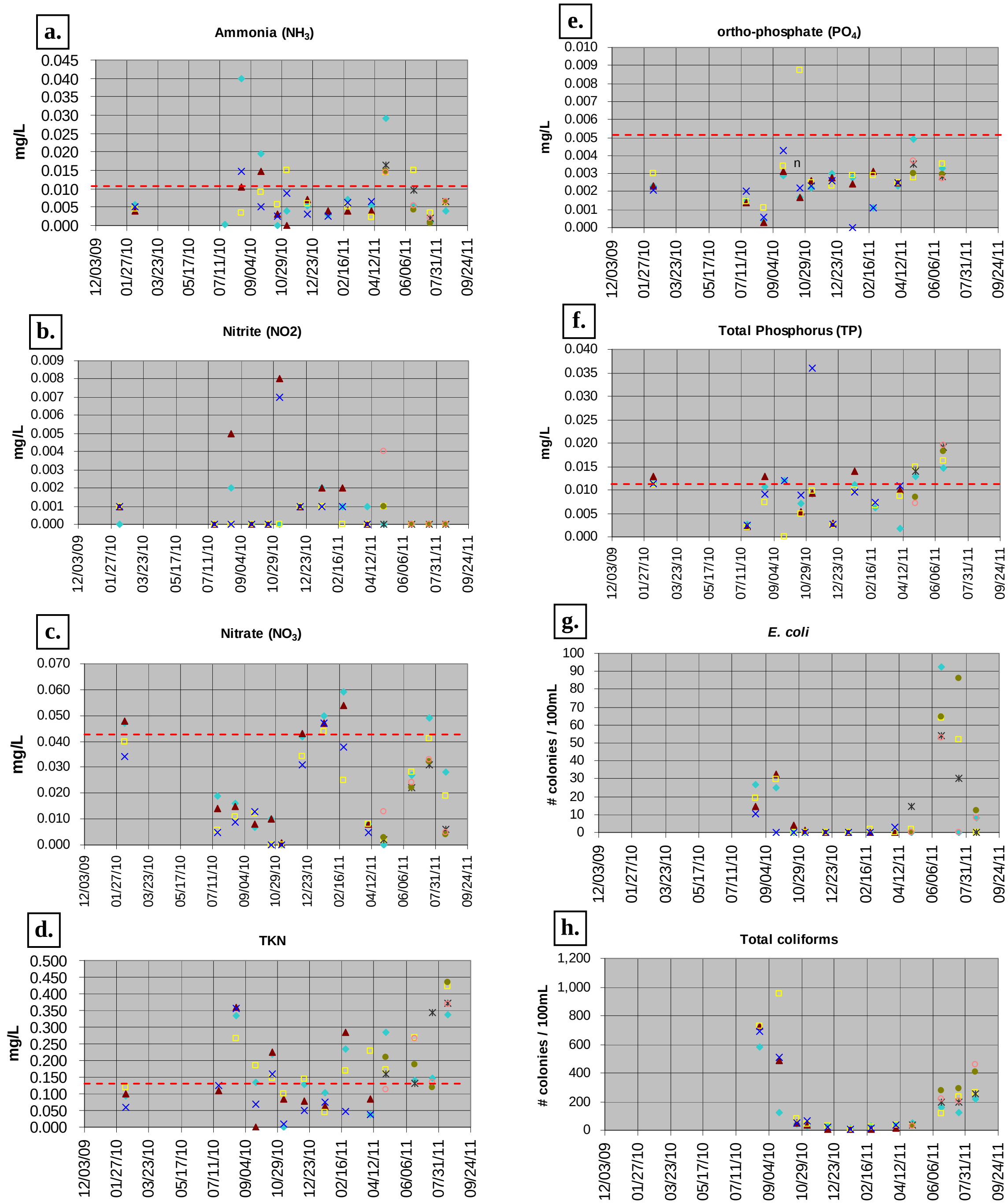
There were no consistent upstream to downstream trends in geosmin, and concentrations often varied considerably between sites for a given sampling date within this 7 mile stretch of river. The lack of spatial trends in geosmin suggests that for a given site, concentrations are influenced as much or more by local, site-specific conditions than proximity to a single source. Factors that potentially influence geosmin concentrations at a given site include production and degradation rates as well as environmental factors that affect the volatility of geosmin, including water temperature and the amount of turbulence to which it is exposed. Based on the variability in geosmin concentrations within the 7 mile stretch of river, it was concluded that, while the Rustic area may be a regional "hot spot" of geosmin on the Upper Poudre, elevated concentrations at the FCWTF likely result from production sites closer to the intake. Current monitoring at the three new (Phase II) sites between Rustic and the FCWTF intake is designed to address this possibility.

Observed geosmin concentrations at Phase I sites differed between years as well. Peak observed concentrations were significantly higher in 2010 (24.2 – 28.6 ng/L) than in 2011 (10.5 – 13.45 ng/L). In 2010, the high geosmin concentrations on the Upper Poudre corresponded with a period when concentrations exceeded the geosmin odor threshold (4 ng/L) at the FCWTF, whereas there were no observed exceedances at the FCWTF in 2011 (Figure 1). Reasons for the differences between years are unknown.

Nutrients. Concentrations of all total and dissolved nutrient fractions were extremely low in the study area and were frequently below reporting limits (Figures 7 (a-f). Like geosmin, there was considerable variability in concentrations between sites for a given sample date and no evidence of upstream to downstream trends for any measured parameter. The site *Poudre below Rustic* consistently had the highest ortho-phosphate concentrations, although concentrations at this and other the Phase I monitoring sites, were within the range of concentrations observed on the Mainstem as part of the Upper Cache la Poudre Cooperative Water Quality Monitoring Program (Oropeza and Billica, 2011). It is possible that nutrient concentrations from an effluent source could occur within the natural range of variability for this area. However, if sustained, an increase in the seasonal mean concentration would be expected over time. The periods of record for these sites are generally less than 2 years and are not currently sufficient to identify any trends in nutrient concentrations.

There were no correlations between nutrient parameters and geosmin concentrations at *Poudre above Rustic*, *Poudre Canyon Fire Station* or *Eggers*. The site *Poudre below Rustic*, did however, show a significant positive relationship between geosmin and nitrite ($r = 0.662$; $p=0.023$) and a significant negative relationship between geosmin and TKN ($r = -0.592$; $p=0.055$).

Figure 7 (a-h). Nutrient and bacteria concentrations for Phase I and Phase II monitoring sites on the Upper Poudre.



Legend

- ◆ Poudre Above Rustic
- ▲ Poudre Canyon Fire Station
- □ Poudre below Rustic (PBR)
- × Eggers
- ⋇ Poudre at Steven's Gulch
- ● Poudre below Mishawaka
- ○ Poudre at Greyrock
- - - - - Fort Collins Water Quality Lab (FCWQL) reporting limits

Total Coliforms and *E.coli*. Total coliforms and *E.coli* samples serve as potential indicators of animal and human fecal contamination. Figure 7(g-h) presents monitoring data since August 2010. Both indicator bacteria exhibit relatively high summer concentrations and very low concentrations in the winter and early spring months. Total coliform concentrations are an order of magnitude greater than *E.coli* concentrations, with peak levels of total coliforms ranging from 121 to 953 colonies/100 mL. Similar to the patterns observed with geosmin and nutrients, neither bacterial indicator show any upstream to downstream trends. The relatively high summer concentrations are likely a result of increased presence of livestock and recreational activity within the watershed. The noticeable rise in total coliforms and *E. coli* concentrations beginning in June 2011 corresponds with the onset of spring snowmelt runoff, a period when relatively large amounts of sediments and organic matter are transported into the river from the surrounding landscape. Subsurface flows also increase during the period of spring runoff. These have the potential to intercept drainage from septic leach fields or possible leaks from impaired vault toilets in the area. *E.coli* did not show any significant correlation to geosmin concentrations at any of the study sites. Total coliforms showed a significant *negative* relationship with geosmin at *Poudre below Rustic* ($r = -0.663$, $p=0.026$).

Periphyton. Phase I periphyton (attached algae) data from August through November 2010 were reported as dominant species by rank. The limitation of this approach is that is does not give specific information about the overall size of the periphyton community or the abundance of individual groups of algae over time, but it does indicate which divisions of algae were most (or least) dominant by rank. Results show that green algae and diatoms were the most prominent groups of algae at all sites throughout the 2010 fall-winter season. Various species of blue-green algae, or cyanobacteria, were also present throughout the monitoring period. Figure 8 provides a representative example of the relative rankings of these major groups of algae. These results are consistent with algal community assemblages in other streams in the northern Colorado region (Vavilova and Lewis, 1999).

Ulothrix zonata, an attached filamentous green algae and *Didymosphenia geminate* (also known as didymo) an invasive diatom, were the most commonly identified species from August to November of 2010, and in general, were ranked as "common-abundant" to "dominant". Known geosmin producing species of cyanobacteria were present in most samples. The known geosmin producers included *Pseudanabaena limnetica, Pseudanabaena catenata, Pseudanabaena sp.* (Juttner and Watson, 2007) and *Oscillatoria*

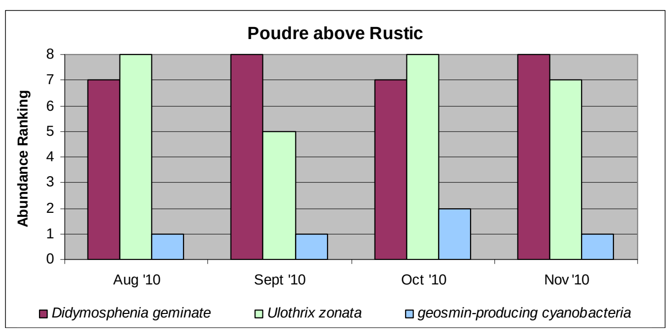


Figure 8. Periphyton dominance ranking for the most commonly identified species of green algae, diatoms and geosmin-producing cyanobacteria for Poudre above Rustic monitoring site. (Rankings: 8 Dominant; 7 abundant; 6 Common-abundant; 5 Common; 4 Occasional-common; 3 Occasional; 2 Rare-occasional; 1 Rare.)

tenuis (Wu and Juttner, 1988) and were ranked as "rare" to "occasional-rare". This finding is consistent with other studies in which geosmin producing species represent a relatively very small portion of the total algae population (Taylor et al, 2006, Billica et al., 2010).

Potential Sources of Contamination. Three sites that were considered potential sources of nutrients and geosmin to the area of interest around Rustic were sampled on August 3, 2010 in addition to the routine Phase I monitoring sites. Sites included above and below the residential development at Home Moraine and below the Glen Echo Resort, which had a high concentration of individual sewage disposal system (ISDS) permits. Geosmin concentrations were low at these sites, ranging from 1.52 ng/L below Home Moraine and 3.68 ug/L at Glen Echo. Results showed that nitrate concentrations at these locations were somewhat higher than those observed at the nearest downstream monitoring locations; however concentrations were within the range observed in the upper watershed, as measured by the Upper Poudre water quality monitoring program (Oropeza and Billica, 2011). The upper and lower Home Moraine sites also had significantly higher *E.coli* concentrations than the other downstream locations (Figure 9). Total coliform concentrations as well as ammonia, nitrite, TKN, dissolved and total phosphorus concentrations were similar to or lower than concentrations at downstream locations.

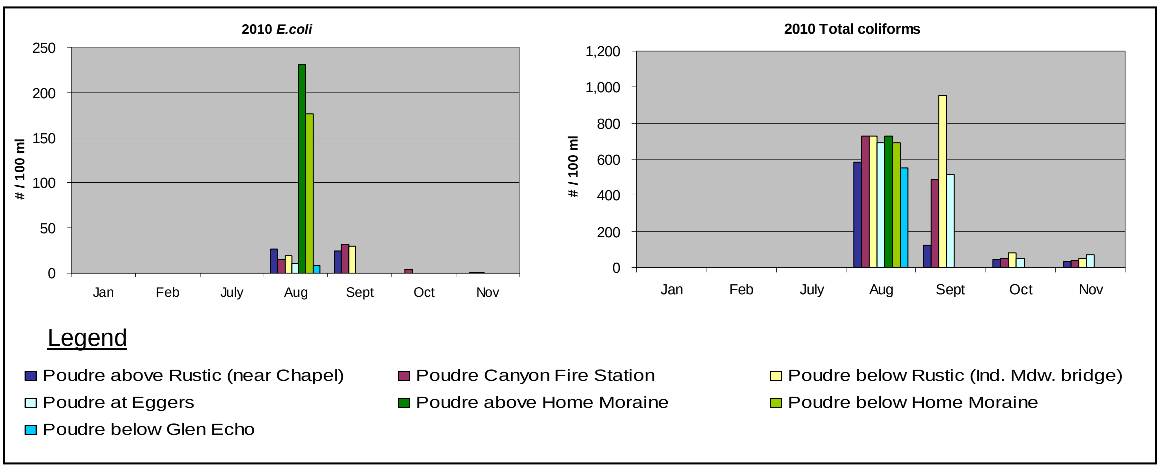


Figure 9. Comparison of August 2010 *E.coli* and Total coliform concentrations at Phase I monitoring sites and at *Poudre below Home Moraine*, *Poudre below Glen Echo Resort* and *Poudre above Home Moraine.*

The outflow from the Poudre River Fish Hatchery was sampled once during the reconnaissance sampling and twice during the Phase I monitoring period for geosmin. On all three occasions, geosmin concentrations were lower at this site than at the nearest downstream site sampled; concentrations ranged from 4.70 – 5.35 ng/L. Nutrients were sampled at this site once in 2010 and once in 2011. Results show that all nutrient parameters were below or near reporting limits and did not differ substantially between the two years. *E.coli* and total coliforms were only sampled in 2011. *E.coli* was not detected and total coliform concentration was very low, 24.4 colonies/100 mL, respectively.

FINDINGS AND CONCLUSIONS

A geosmin outbreak in raw drinking water supplies presents special challenges for traditional water quality monitoring programs because the sources and events leading up to an outbreak are not well understood or easily monitored. Without an adequate early warning system for geosmin in source waters, water treatment plant operators have little time to respond, resulting in an increase in customer T&O complaints and a negative perception of treated drinking water quality. And without an understanding of temporal and spatial variability, concentrations, production sites, transport, and fate of geosmin within source watersheds, watershed managers are unable to identify potential control strategies.

This paper outlines the geosmin monitoring program used by the FCWTF and highlights some of the key findings to date. The area of highest geosmin concentrations on the Upper Poudre was a 7 mile area near Rustic, Colorado, approximately 25 miles above the FCWTF intake. Within this area, geosmin concentrations showed strong spatial and temporal (seasonal and annual) variation; however, monitoring activities as described in this paper, were unable to determine the factors that account for the observed differences in concentrations. Changes were made in the configuration of sampling sites in May 2011 in order to identify sites further downstream that are more likely to affect concentrations at the FCWTF water supply intake. At the time of this paper, there was not enough available data to determine any relationships between geosmin concentrations at the new sites and the FCWTF intake.

Nutrients were generally very low within the study area. At the nutrient concentrations observed on the Upper Poudre, it is expected that periphyton abundance (and potential geosmin producing cyanobacteria) are more strongly limited by factors not addressed in this study like elevation, temperature and length of growing season (Lewis and McCutchan, 2010). The switch to quantitative periphyton sampling (Phase II) will allow us to track changes in the periphyton community composition and determine if and how geosmin production is related to the abundance of geosmin producing cyanobacteria species and to the overall abundance of the periphyton.

Many questions remain, and it is expected that several years of monitoring will be required to better understand the factors that influence geosmin production, degradation, transport and fate and to identify geosmin occurrence patterns within the Upper Poudre. Currently, no opportunities have been identified within the watershed to mitigate geosmin production.

The ability to develop a responsive and early-warning monitoring plan for geosmin outbreaks relies on our ability to closely track geosmin trends within the watershed and monitor the presence of known-geosmin producing species of cyanobacteria. Therefore, the most critical elements to the success of this monitoring effort are the availability high quality geosmin data with short turn-around times, and scheduling flexibility provided by the Fort Collins Water Quality Laboratory as well as the available expertise to identify algae to the species level.

Future monitoring will build on the following findings of the geosmin monitoring program conducted to date:

- Geosmin concentrations exhibit a seasonal pattern of highest concentrations in the winter and lowest concentrations during spring snowmelt runoff.
- Peak geosmin concentrations on the Poudre River were significantly higher in 2010 than in 2011.
- Geosmin concentrations at the FCWTF were not representative of concentrations on the Upper Poudre River for either year.
- There were no consistent upstream to downstream trends in geosmin concentrations within the study area.
- The filamentous green algae, *Ulothrix zonata* and the invasive diatom, *Didymosphenia geminate* were the dominant algae species within the Upper Poudre River study area.
- Geosmin producing cyanobacteria were frequently present in the periphyton community, but were relatively rare at the Poudre River monitoring sites.
- Nutrient concentrations near the fish hatchery, above and below Home Moraine housing developments, and below the Glen Echo Resort were generally low, and often below reporting limits.
- Geosmin concentrations for a given location on the Upper Poudre are not well predicted by nutrient concentrations, proximity to upstream sources of geosmin, the presence of known geosmin producing cyanobacteria species or concentrations of the bacterial indicators, *E. coli* and total coliforms.

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