REGIONAL CHARACTERIZATION OF STREAMS IN TENNESSEE WITH EMPHASIS ON DIURNAL DISSOLVED OXYGEN, NUTRIENTS, HABITAT, GEOMORPHOLOGY AND MACROINVERTEBRATES

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Biologists from the Aquatic Biology Section, Tennessee Department of Health (TDH) were the primary investigators in the field and processed the macroinvertebrate samples for this project. Field assistance was provided by Water Pollution Control staff from the Jackson, Johnson City, Knoxville, Memphis and Nashville Environmental Field Offices (EFOs), TDEC. Linda Cartwright with the Planning and Standards Section of Water Pollution Control was in charge of data management and quality assurance and helped prepare appendices.

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Cover Photo: Carrie Perry takes field measurements in the Big Sandy River in Carroll County. *Photo provided by Aquatic Biology, TDH.*

EXECUTIVE SUMMARY

In 2002, the Division of Water Pollution Control was awarded a 104(b)(3) grant to investigate natural diurnal fluctuations of dissolved oxygen levels in 15 ecological subregions in Tennessee. Historic daylight readings were used to supplement this information and to evaluate dissolved oxygen patterns in 10 additional subregions. The results of that initial study were published in January 2003 (Arnwine and Denton, 2003).

Results from the 2002 study indicated the statewide dissolved oxygen criterion of 5 ppm may not be adequate for full protection of fish and aquatic life in 14 ecoregions. The data also indicated 5 ppm may be over protective in two ecoregions. Data from that study were used during the 2003 triennial review of water quality standards to help refine existing dissolved oxygen criteria to acknowledge regional differences. DO criteria were raised in the four Blue Ridge Mountain subregions to a minimum of 7.0 ppm. Criteria were adjusted in the Northern Mississippi Alluvial Plain (73a) to a daily average of 5 ppm with a minimum of 4 ppm.

In 2004, the Division was awarded another 104(b)(3) grant (CP974839-03) to expand the original study. The 2004 study was designed to provide additional information in eight subregions where preliminary data suggested criteria may need to be raised and in two ecoregions to determine whether lower DO levels would be supportive of fish and aquatic life.

Both studies showed that streams in the Northern Mississippi Valley Alluvial Plain (73a) typically have daytime dissolved oxygen levels approximating 3 ppm. They also showed levels can drop to near 1 ppm for short periods while still supporting aquatic life typically found in the least disturbed streams in this region. Tennessee reference data were compared to Arkansas reference data to help verify these findings. Arkansas shares the same subecoregion, however, the Northern Mississippi Alluvial Plain ecoregion is much wider on the western side of the river giving Arkansas a larger area for reference stream selection. Dissolved oxygen data from Arkansas reference streams of similar size, supported Tennessee’s findings.

The 2004 study reiterated that streams in the Inner Nashville Basin with dissolved oxygen periodically falling to 3 ppm can be supportive of a healthy biological community in this region. However, since diurnal swings are typically between 2 and 4 ppm, it is important to include diurnal monitoring in this region and not rely only on daylight measurements when levels approach 5 ppm.

In the 2002 study, ten ecological subregions had diurnal dissolved oxygen levels that were generally at or above 6 ppm. The 2004 study endeavored to verify minimum DO levels of 6 ppm in these regions. DO data from six of the subregions (65j, 67h, 69d, 71e, 71f, 74b) were also above 6 ppm during the 2004 study. These subregions comprise 29 percent of the state’s land area. Data from the other four subregions suggested occasional drops to 5 ppm, especially during evening hours, was typical in unimpaired streams.

In addition to being a continuation of the 2002 dissolved oxygen study, the 2004 project was designed to characterize streams based on geomorphology, periphyton and nutrients. Geomorphological characterization can be used to measure changes in bed load, erosion and stream patterns that have the potential to affect aquatic life. It can also help predict how physical disturbance will affect stream flow patterns and provide information on what is needed to restore impaired streams.

The Rosgen stream classification system was used to characterize the geomorphology of reference streams found in the 19 ecoregions surveyed. This stream classification is based on physical processes and assumes that stream morphology is dependent on landscape position (Rosgen, 1996). There are four hierarchical levels of the Rosgen classification. The first level describes a stream's geomorphologic characterization. The second level is a morphological description of the stream's characteristics. The third level assesses the stream condition and its stability. The fourth level is a confirmation of predictions made in Level III. Streams in this study were classified to Level II.

Another goal of this project was to characterize periphyton abundance in reference streams where data were not available. Additionally, there was a desire to evaluate algal abundance in test streams in ecoregions where nutrient levels are generally elevated. Due to the sedentary nature of periphyton, abundance is sensitive to changes in water quality. Nuisance blooms are usually symptoms of a system stressed by factors such as excessive nutrients, elevated temperatures, or stagnant conditions. Typical background levels of periphyton were estimated for 19 ecological subregions.

There were two goals for nutrient data collection. One was to increase the reference database, which could be used to refine regional goals. The second goal was to test the reliability of using nitrate probes that could potentially cut monitoring time and analysis costs while providing diurnal nutrient information. The nitrate probes proved impractical during field-testing. The biggest problem seemed to be difficulty in holding calibration. The probes tended to be unstable and imprecise and once calibrated, would begin to drift. Discrepancies between the probes and grab sample results tended to worsen the longer the probes were deployed.

The final goal of this study was to characterize non-wadeable streams that cross ecoregions in west Tennessee. Biological, habitat, and nutrient guidelines have already been developed for wadeable streams that are 80% contained within the Southeastern Plains and Hills (65e) and the Loess Plains (74b). Since all reference sites in the Mississippi Alluvial Plain (73a) are non-wadeable, guidelines are already developed for non-wadeable streams 80% within this ecoregion. However, five non-wadeable rivers, including several large forks, originate in the Southeastern Plains, cross into the Loess Plains, and enter the Northern Mississippi Alluvial Plain on their way to the Mississippi River. These include the Obion, Forked Deer, Hatchie, Loosahatchie and Wolf River systems. Results of the non-wadeable stream monitoring indicated that data were generally not directly comparable to existing wadeable streams guidelines. It is likely that separate biological and nutrient criteria will need to be developed for these stream types. Additional monitoring will be necessary before this can be accomplished.

1. INTRODUCTION

According to 2004 303(d) assessment (TDEC, 2005), 17 percent of impaired streams in Tennessee are impaired due (all or in part) to low dissolved oxygen (DO). This includes 129 stream segments (1,511 miles) in 29 watersheds . Over half of the state's watersheds have at least one low DO stream. This number is probably conservative since streams assessed as impaired due to organic enrichment or nutrients, pollutants that generally affect DO, were not included if sufficient data were not available to confirm low DO levels. Also dissolved oxygen is generally measured during daylight hours when levels are at their highest.

The amount of dissolved oxygen present in a stream is critical to aquatic life. Most fish and aquatic macroinvertebrates cannot obtain oxygen directly from the air and are dependent on an adequate level of oxygen dissolved in the water to survive. Oxygen gets in the water by surface air diffusion, aeration from turbulence and the photosynthesis of aquatic plants and algae. Oxygen is depleted by natural functions such as respiration and decomposition. Pollutants such as organic wastes and fertilizers can accelerate the rate of oxygen depletion.

In 2002, the Division of Water Pollution Control was awarded a 104(b)(3) grant to investigate natural diurnal fluctuations of dissolved oxygen levels in 15 ecological subregions in Tennessee. Historic daylight readings were used to supplement this information and to evaluate dissolved oxygen patterns in the other 10 subregions. The results of that initial study were published in January 2003 (Arnwine and Denton, 2003).

Results from the 2002 study indicated the statewide dissolved oxygen criterion of 5 ppm may not be adequate for full protection of fish and aquatic life in 14 ecoregions. The data also indicated 5 ppm may be over protective in two ecoregions. Data from the 2002 study helped refine the statewide dissolved oxygen criteria (5 ppm for most waters, 6 ppm for stocked trout waters and 8 ppm for naturally reproducing trout streams) in five of these regions. Criteria were raised in the four Blue Ridge Mountain subregions to a minimum of 7.0 ppm. Criteria were adjusted in the Northern Mississippi Alluvial Plain (73a) to a daily average of 5 ppm with a minimum of 4 ppm.

Data from the 2002 study also suggested dissolved oxygen criteria may need to be adjusted in other subregions. In 2004, the Division was awarded another 104(b) 3 grant (CP974839-03) to expand the original study. The 2004 study was designed to provide additional information in eight subregions where preliminary data suggested criteria may need to be raised and in the Inner Nashville Basin and Northern Mississippi Alluvial Plain to determine whether lower DO levels were supportive of fish and aquatic life. This report was written in partial fulfillment of the conditions of that grant.

In addition to a continuation of the 2002 dissolved study, the 2004 project was designed to characterize streams based on nutrients, habitat, geomorphology and macroinvertebrates. Objectives included:

1. Characterize geomorphology of 33 existing ecoregion reference streams where data are not currently available. Characterize 24 non-reference steams including 18 that are impaired or drain into impaired segments.

2. Characterize algal abundance in 30 ecoregion reference streams where data are not currently available. Algae abundance was also measured in 31 test streams in ecoregions where nutrient levels are generally elevated.

3. Characterize non-wadeable streams that cross ecoregions in west Tennessee. Focus was on developing obtainable goals for streams that are listed for dissolved oxygen, habitat alteration, nutrients, flow alteration and/or siltation. Six impaired and four non-impaired streams were monitored.

4. Increase the reference nutrient database to further refine numeric nutrient criteria. Test the reliability of using field nitrate probes that might cut laboratory analysis costs.

2. ECOREGION REFERENCE APPROACH

Data interpretation in this study follows the ecoregion reference stream approach. This is a method that compares the existing conditions found in any given stream to data compiled from a group of relatively unimpaired streams in the same ecoregion. An ecoregion is a relatively homogenous area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology and other ecologically relevant variables.

In order to delineate ecoregions and isolate reference streams, the Division of Water Pollution Control initiated the Tennessee ecoregion project in 1993 (Arnwine et al, 2000). After delineation, 25 ecological subregions were established in Tennessee. A map illustrating the current ecological subregion boundaries in Tennessee is presented in Figure 1.

Recent ecoregion delineation projects conducted in surrounding states have resulted in the addition of three more Tennessee subregions. The Broad Basins (66j) in the Copper Basin area, the Pleistocene Valley Trains (73d) in Dyer County and the Cumberland Mountain Thrust Block (69e) in the eastern portion of the Central Appalachians. Additionally, four subregion names have been changed, the Southeastern Plains and Hills (65e) are now the Northern Hilly Gulf Coastal Plain, the Southern Igneous Ridges and Mountains (66d) are now the Southern Crystalline Ridges and Mountains, the Cumberland Mountains (69d) are now the Dissected Appalachian Plateau and the Northern Mississippi Alluvial Plain (73a) is now the Holocene Meander Belts. These changes were listed so that comparisons can be made to information from surrounding states. For the purpose of this study, the original 25 subregions and the already established names as presented in Figure 1 were used. The new subregions will be added once the boundary lines in Tennessee are confirmed and reference streams in these regions are established.

Three hundred and fifty-three potential reference sites in 25 subregions were evaluated as part of the ecoregion project. The reference sites were chosen to represent the best attainable conditions for all streams with similar characteristics in a given subregion. Reference condition represented a set of expectations for physical habitat, general water quality and the health of the biological communities in the absence of human disturbance and pollution.

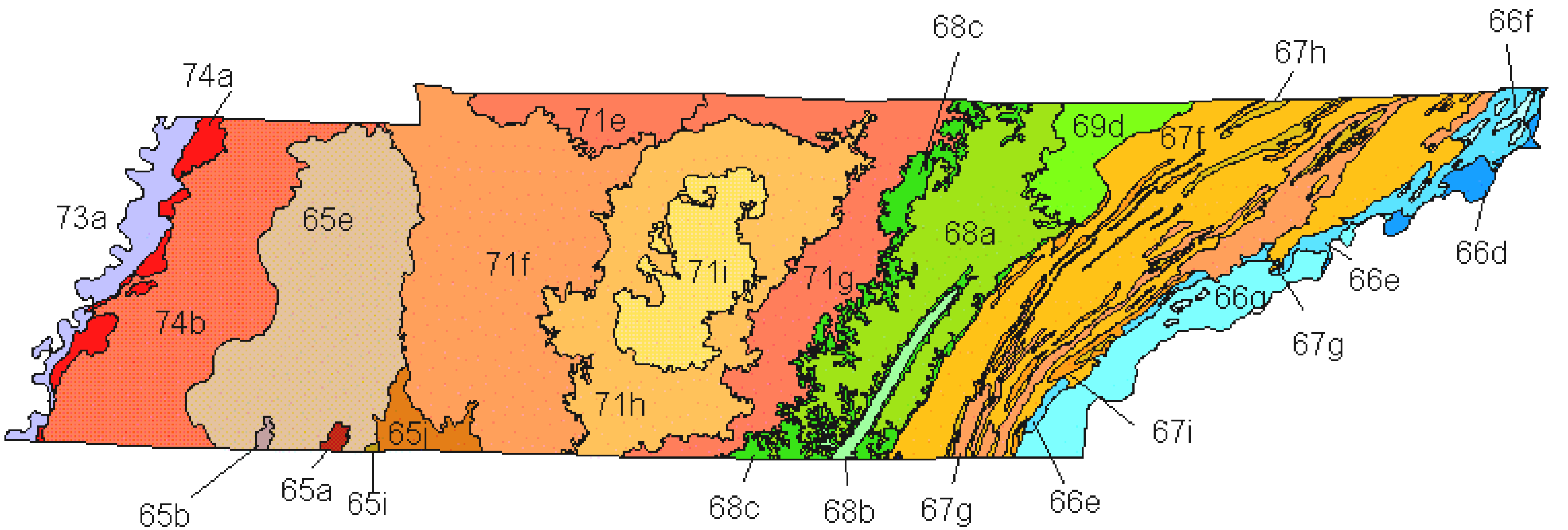
Selection criteria for reference sites included relatively unimpaired and representativeness. Streams that did not flow across subregions were targeted so the distinctive characteristics of each subregion could be identified. Experienced water quality staff screened each candidate reference stream. Potential sites were rated on the basis of how well they met the following criteria:

a. The entire upstream watershed was contained within the ecological subregion.
b. The upstream watershed was mostly or completely forested (if forest was the natural vegetation type) or had a typical land use.
c. The geologic structure and soil pattern was typical.
d. The upstream watershed did not contain a municipality, mining area, permitted discharger or any other obvious regulated source(s) of pollutants.
e. The upstream watershed was not heavily impacted by non-regulated source(s) of pollution.
f. The stream flowed in its natural channel and had not been recently channelized. There were no flow or water level modification structures such as dams, irrigation canals or field drains.
g. No power lines or pipelines crossed upstream of the site.
h. The upstream watershed contained few roads.

By the end of the project, 98 reference streams were selected for monitoring. Each subregion had between one and eight reference streams with most having at least three. The final number of reference streams per subregion depended on the size of the region and the availability of relatively non-impaired streams. Streams were monitored quarterly for three consecutive years (fall 1996 through summer 1999) and have been monitored quarterly every five years since 1999 as part of the watershed cycle.

3. DATA COLLECTION AND QUALITY ASSURANCE

Ninety-nine sites were selected for monitoring for this project in 2004 (Figure 2). This included 35 test sites and 64 reference sites. Each site was to have continuous monitoring probes, flow measurements and nutrient sampling. Some sites also had macroinvertebrate surveys, habitat assessments, fluvial geomorphological measurements and/or periphyton abundance surveys depending on study objectives (Table 1).



65a Blackland Prairie
65b Flatwoods/Alluvial Prairie Margins
65e Southeastern Plains and Hills
65i Fall Line Hills
65j Transition Hills
66d Southern Igneous Ridges and Mtns
66e Southern Sedimentary Ridges
66f Limestone Valleys and Coves
66g Southern Metasedimentary Mtns.
67f Southern Limestone/Dolomite Valleys and Low Rolling Hills
67g Southern Shale Valleys
67h Southern Sandstone Ridges
67i Southern Dissected Ridges & Knobs
68a Cumberland Plateau
68b Sequatchie Valley
68c Plateau Escarpment
69d Cumberland Mountains
71e Western Pennyroyal Karst
71f Western Highland Rim
71g Eastern Highland Rim
71h Outer Nashville Basin
71i Inner Nashville Basin
73a Northern Mississippi Alluvial Plain
74a Bluff Hills
74b Loess Plains

Figure 1: Ecological subregions of Tennessee

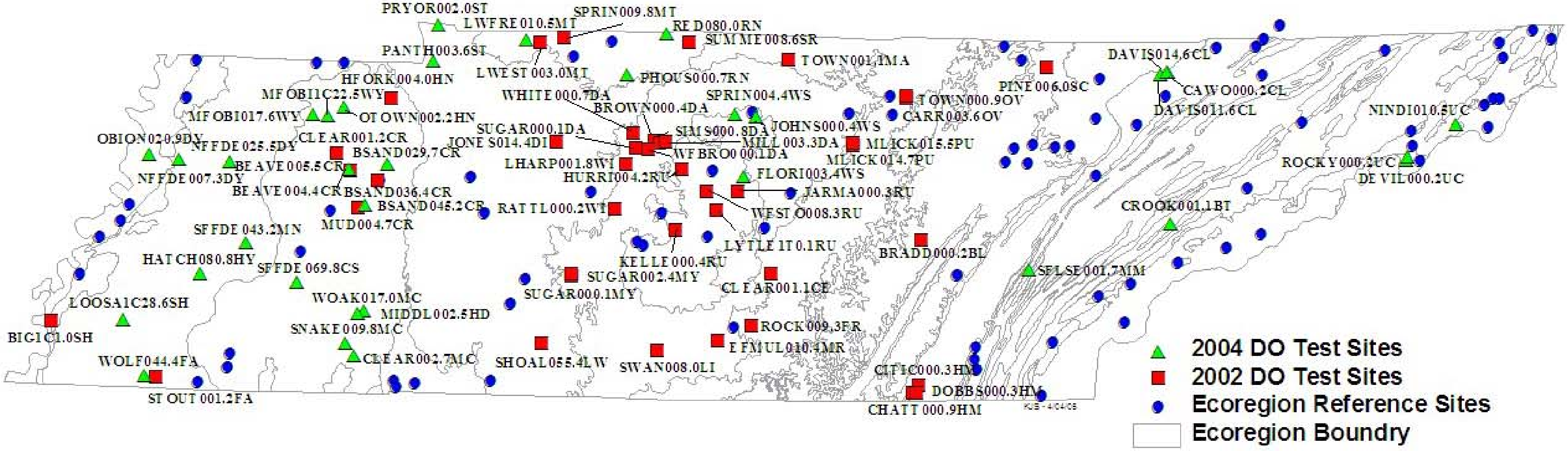


Figure 2: Location of reference and test sites where diurnal DO and nutrient monitoring was conducted August - October, 2002 and July - November 2004. During the 2004 period, select sites also had macroinvertebrate surveys, geomorphological measurements, habitat assessments and/or periphyton abundance surveys.

Table 1: Study plan including site list, field protocols and site selection criteria for 2004 stream characterization study

Eco region	Station ID	Stream	County	DO (2 WK)	Nitrate	Bugs (SQSH)	FGM 1X	Flow 3X	Nuts 3X	Algae 1X	Selection Criteria	Comments
65E	BEAVE004.4CR	Beaver Creek	Carroll	X				X	X	X	Non ref calibrate 65e DO= 6 Biology Pass	
65E	BSAND029.7CR	Big Sandy River	Carroll	X		Bank		X	X	X	Non ref calibrate 65e DO= 6 Biology Pass	
65E	BSAND045.2CR	Big Sandy River	Carroll	X		Bank		X	X	X	Non ref calibrate 65e DO= 6 Biology Pass	
65E	CLEAR002.7MC	Clear Creek	McNairy	X		Bank		X	X	X	Non ref calibrate 65e DO= 6 Biology Pass	
65E	ECO65E04	Blunt Creek	Carroll	X			X	X	X		Ref verify 65e DO = 6	
65E	ECO65E06	Griffin Creek	Carroll	X			X	X	X		Ref verify 65e DO = 6	No FGM, lab error
65E	ECO65E08	Harris Creek	Madison	X			X	X	X	X	Ref verify 65e DO = 6	
65E	ECO65E10	Marshall Creek	Hardeman	X			X	X	X		Ref verify 65e DO = 6	
65E	ECO65E11	West Fork Spring Ck	Hardeman	X			X	X	X	X	Ref verify 65e DO = 6	
65E	MFOBI017.6WY	Middle Fork Obion River	Weakley	X		Bank	X	X	X		Non-ref calibrate 65e DO = 6, Listed nutrients,	Replaced RM 14.6 (access)
65E	MFOBI1C22.5WY	Middle Fork Obion River Canal	Weakley	X		Bank	X	X	X		Non-ref calibrate 65e DO = 6, Listed nutrients,	
65E	MIDDL002.5HD	Middleton Creek	Hardin	X	X	Bank		X	X	X	Non-ref calibrate 65e DO = 6 Biology pass	
65E	OTOWN002.2HN	Old Town Creek	Henry	X		Bank		X	X	X	Non-ref calibrate 65e DO = 6 biology pass	
65^{E}	SNAKE009.8MC	Snake Creek	McNairy	X		Bank		X	X	X	Non-ref calibrate 65e DO = 6 biology pass	
65E	WOAK017.0MC	White Oak Creek	McNairy	X		Bank		X	X	X	Non-ref calibrate 65e DO = 6 biology pass	
65E 74B	HATCH080.8HY	Hatchie River	Haywood	X		Bank	X	X	X		Fully Supporting 65e/74b Potential Ref	Flooded probe lost, no samples
65E 74B	LOOSA1C28.6SH	Loosahatchie River	Shelby	X		Bank	X	X	X		Reference Calibration 65e/74b Listed habitat	Too deep for flow reading 1 trip
65^{E} 74B	NFFDE007.3DY	North Fork Forked Deer River	Dyer	X	X	Bank	X	X	X		Reference Calibration 65e/74b Listed Nutrients,	Not sampled lab error
65^{E} 74B	NFFDE020.5DY	North Fork Forked Deer River	Dyer	X		Bank	X	X	X		Fully Supporting 65e/74b Potential Ref	Too deep for flow readings 3 trips
65E 74B	NFFDE025.5GI	North Fork Forked Deer River	Dyer	X	X	Bank	X	X	X		Fully Supporting 65e/74b Potential Ref	Lab sampled by mistake

Table 1 cont.

Eco region	Station ID	Stream	County	DO (2 WK)	Nitrate	Bugs (SQSH)	FGM 1X	Flow 3X	Nuts 3X	Algae 1X	Selection Criteria	Comments
65E 74B	SFFDE043.2MN	South Fork Forked Deer River	Madison	X	X	Bank	X	X	X		Non-ref Calibration 65e/74b, listed nutrients	Too deep flow reading or FGM
65E	SFFDE069.8CS	South Fork Forked Deer River	Chester	X	X	Bank	X	X	X		Fully Supporting Non-wadeable 65e	Too deep flow reading 1 trip
65E 74B	WOLF044.4FA	Wolf River	Fayette	X	X	Bank	X	X	X		Fully Supporting 65e/74b Potential Ref	Too deep flow reading 1 trip
65J	ECO65J05	Dry Creek	Hardin	X				X	X		Ref Verify 65j DO = 6	
66D	DEVIL000.2UC	Devil Fork	Unicoi	X	X	Kick		X	X		Non-ref calibration 66D DO = 8 biology pass	
66D	ECO 66D01	Black Branch	Carter	X			X	X	X	X	Ref Verify 66d DO = 8	
66D	ECO66D03	Laurel Fork	Carter	X			X	X	X	X	Ref Verify 66d DO = 8	
66D	ECO66D05	Doe River	Carter	X			X	X	X	X	Ref Verify 66d DO = 8	
66D	ECO66D06	Tumbling Creek	Unicoi	X			X	X	X	X	Ref Verify 66d DO = 8	
66D	ECO66D07	Little Stoney Creek	Carter	X			X	X	X	X	Ref Verify 66d DO = 8	
66D	ROCKY000.2UC	Rocky Fork	Unicoi	X		Kick		X	X		Non-ref, Calibrate 66d DO = 8 biology pass	
66E	ECO66E04	Gentry Creek	Johnson	X			X	X	X		Ref Verify 66e DO = 7	
66E	ECO66E09	Clark Creek	Washington	X			X	X	X	X	Ref Verify 66e DO = 7	
66E	ECO66E18	Gee Creek	Polk	X			X	X	X	X	Ref Verify 66e DO = 7	
66F	ECO66F06	Abrams Creek	Blount	X			X	X	X	X	Ref Verify 66e DO = 7	No FGM, too deep
66F	ECO66F07	Beaverdam Creek	Johnson	X			X	X	X		Ref Verify 66e DO = 7	
66F	ECO66F08	Stony Creek	Carter	X			X	X	X		Ref Verify 66e DO = 7	
66F	NINDI010.5UC	North Indian Creek	Unicoi	X		Kick		X	X		Non-ref Calibrate 66F DO = 7 biology pass	
66G	ECO66G04	Mid Prong Little Pigeon River	Sevier	X			X	X	X		Ref Verify 66g DO = 7	Too deep flow reading
66G	ECO66G07	Citico Creek	Monroe	X			X	X	X		Ref Verify 66g DO = 7	Too deep flow or nutsrients 1 trip
66G	ECO66G09	North River	Monroe	X			X	X	X		Ref Verify 66g DO = 7	
67F	CAWO000.2CL	Cawood Branch	Claiborne	X				X	X	X	Non-ref Calibrate 67f DO = 6 Biology PASS	
67F	CROOK001.1BT	Crooked Creek	Blount	X				X	X	X	Non-ref Calibrate 67f DO = 6 Biology pass	Too deep flow or periphyton

Table 1 cont.

Eco region	Station ID	Stream	County	DO (2 WK)	Nitrate	Bugs (SQSH)	FGM 1X	Flow 3X	Nuts 3X	Algae 1X	Selection Criteria	Comments
67F	DAVIS011.6CL	Davis Creek	Claiborne	X	X	Kick		X	X	X	Non-ref Calibrate 67f DO = 6, biology pass	Too deep flow reading 2 trips
67F	DAVIS014.6CL	Davis Creek	Claiborne	X				X	X	X	Non-ref Calibrate 67f DO = 6 biology pass	
67F	ECO67F06	Clear Creek	Anderson	X	X		X	X	X		Ref Verify 67f DO = 6	
67F	ECO67F13	White Creek	Unicoi	X				X	X	X	Ref Verify 67f DO = 6	
67F	ECO67F14	Powell River	Hancock	X				X	X		Ref Verify 67f DO = 6	
67F	ECO67F16	Hardy Creek	Lee	X			X	X	X	X	Ref Verify 67f DO = 6	No FGM, lab error
67F	ECO67F17	Big War Creek	Hancock	X			X	X	X		Ref Verify 67f DO = 6	
67F	ECO67F23	Martin Creek	Hancock	X			X	X	X		Ref Verify 67f DO = 6	
67F	ECO67F25	Powell River	Claiborne	X			X	X	X		Ref Verify 67f DO = 6	Too deep flow reading 2 trips
67F	SFLSE001.7MM	South Fork Little Sewee Creek	McMinn	X				X	X	X	Non-ref Calibrate 67f DO = 6 Biology pass	
67G	ECO67G11	N. Prong Fishdam Ck	Sullivan	X	X	Kick	X	X	X	X	New Reference Site	
67H	ECO67H04	Blackburn Creek	Bradley	X		Kick	X	X	X	X	Ref Verify 67h DO = 6 No diurnal data 2002	
67H	ECO67H06	Laurel Creek	Monroe	X		Kick	X	X	X	X	Ref Verify 67h DO = 6 No diurnal data 2002	
67H	ECO67H08	Parker Branch	Hawkins	X		Kick	X	X	X	X	Ref Verify 67h DO = 6 No diurnal data 2002	Insufficient water depth for survey
67I	ECO67I12	Mill Creek	Anderson	X		Kick	X	X	X	X	Ref Verify 67i DO = 6 No diurnal data 2002	
68A	EC068A03	Laurel Fk Station Camp Ck	Scott	X			X	X	X		Ref Verify 68a DO = 6	
68A	ECO68A01	Rock Creek	Pickett	X			X	X	X		Ref Verify 68a DO = 6	
68A	ECO68A08	Clear Creek	Morgan	X			X	X	X	X	Ref Verify 68a DO = 6 No diurnal data 2002	Too deep flow or nutrients 1 trip
68A	ECO68A26	Daddy's Creek	Cumberland	X			X	X	X		Ref Verify 68a DO = 6 No diurnal data 2002	Too deep flow 1 trip, no FGM,
68A	ECO68A27	Island Creek	Morgan	X			X	X	X		Ref Verify 68a DO = 6	Too deep flow or nutrients 1 trip
68A	ECO68A28	Rock Creek	Morgan	X			X	X	X	X	Ref Verify 68a DO = 6	
69D	ECO69D01	No Business Branch	Campbell	X				X	X		Ref Verify69d DO = 6	Insufficient water depth for survey

Table 1 cont.

Eco region	Station ID	Stream	County	DO (2 WK)	Nitrate	Bugs (SQSH)	FGM 1X	Flow 3X	Nuts 3X	Algae 1X	Selection Criteria	Comments
69D	ECO69D03	Flat Fork	Morgan	X			X	X	X	X	Ref Verify 69d DO = 6 No diurnal data 2002	
69D	ECO69D04	Stinking Creek	Campbell	X			X	X	X	X	Ref Verify 69d DO = 6 No diurnal data 2002	Insufficient water depth for survey
69D	ECO69D05	New River	Morgan	X				X	X	X	Ref Verify 69d DO = 6 No diurnal data 2002	
69D	ECO69D06	Round Rock Creek	Campbell	X				X	X	X	Ref Verify 69d DO = 6 No diurnal data 2002	
71E	ECO71E09	Buzzard Creek	Robertson	X				X	X	X	Ref Verify 71e DO = 6	
71E	ECO71E14	Passenger Creek	Montgomery	X	X			X	X	X	Ref Verify 71e DO = 6	
71E	LWEST009.4MT	Little West Fk Red R.	Montgomery	X		X		X	X	X	NFO request downstream STP	Too deep flow, periphyton and SQSH
71E	LWEST010.5MT	Little West Fk Red R.	Montgomery	X		X		X	X	X	Non-ref calibration 71e DO=6	NO SQSH, lab error
71E	PHOUS000.7RN	Poor House Branch	Robertson	X				X	X	X	Non-ref calibration 71e DO=6	Insufficient water depth for survey
71E	RED080.0RN	Red River	Robertson	X				X	X	X	Non-ref calibration 71e DO=6	Too deep flow or nutrients 1 trip
71F	ECO71F12	South Harpeth River	Williamson	X				X	X	X	Ref Verify 71f DO = 6	
71F	ECO71F16	Wolf Creek	Hickman	X				X	X	X	Ref Verify 71f DO = 6	
71F	ECO71F19	Brush Creek	Lewis	X				X	X	X	Ref Verify 71f DO = 6	
71F	ECO71F27	Swanegan Branch	Wayne	X				X	X	X	Ref Verify 71f DO = 6	
71F	ECO71F28	Little Swan Creek	Lewis	X				X	X	X	Ref Verify 71f DO = 6	
71F	ECO71F29	Hurricane Creek	Humphreys	X		Kick	X	X	X	X	New Reference Site	
71F	PANTH003.6ST	Panther Creek	Stewart	X				X	X	X	Non-ref calibration 71f DO = 6 Biology Pass	Insufficient water depth for survey
71F	PRYOR002.0ST	Pryor Creek	Stewart	X				X	X	X	Non-ref calibration 71f DO = 6 Biology Pass	Insufficient water depth for survey
71H	ECO71H03	Flynn Creek	Jackson	X			X	X	X	X	Dry in 2002	Insufficient water depth for survey
71H	ECO71H06	Clear Fork	Cannon	X			X	X	X	X	Dry in 2002	
71I	ECO71I12	Cedar Creek	Wilson	X				X	X	X	Ref Verify 71i < 5	
71I	ECO71I16	West Fork Stones R.	Rutherford	X	X			X	X	X	Ref Verify 71i < 5	

Table 1 cont.

Eco region	Station ID	Stream	County	DO (2 WK)	Nitrate	Bugs (SQSH)	FGM 1X	Flow 3X	Nuts 3X	Algae 1X	Selection Criteria	Comments
71I	FLORI003.4WS	Florida Creek	Wilson	X				X	X	X	Non-ref Calibrate 71i<5 Biology pass	
71I	JOHNS000.4WS	Johnson Branch	Wilson	X	X			X	X	X	Non-ref Calibrate 71i<5 Biology pass	Insufficient water depth for survey
71I	SPRIN004.4WS	Spring Branch	Wilson	X				X	X	X	Non-ref Calibrate 71i<5 Biology pass	
73A	ECO73A01	Cold Creek	Lauderdale	X				X	X		Ref Verify 73a = 3	Too deep flow
73A	ECO73A02	Mid Fk Forked Deer R	Lauderdale	X				X	X		Ref Verify 73a = 3	Too deep flow
73A	ECO73A03	Cold Creek	Lauderdale	X				X	X		Ref Verify73a = 3	Probe Stolen
73A	ECO73A04	Bayou Du Chien	Obion	X				X	X		Ref Verify 73a = 3	Too deep flow
73A 74B 65E	OBION020.9DY	Obion River	Dyer	X		Bank	X	X	X		Non-ref calibration Non-wadeable 65e/74b listed habitat	Flooded probe lost, no samples
74A	ECO74A06	Sugar Creek	Tipton	X				X	X	X	Ref Verify 74a No diurnal data 2002	
74A	ECO74A08	PawPaw Creek	Obion	X				X	X	X	Ref Verify 74a No diurnal data 2002	
74B	ECO74B01	Terrapin Creek	Henry	X				X	X	X	Ref Verify 74b = 6	
74B	ECO74B04	Powell Creek	Weakley	X				X	X	X	Ref Verify 74b = 6	
74B	ECO74B12	Wolf River	Fayette	X			X	X	X		Ref Verify 74b = 6,	Too deep flow 1 trip, no FGM,

DO = Continuous monitoring probe will be set up for 2 weeks (checked after 1 week and reset if needed) Records DO, conductivity, pH and temperature

Nitrate = nitrate probe set up for 2 weeks alongside standard probe. Records DO, conductivity, pH, temperature, nitrate, chloride and turbidity. Collect nitrate, turbidity and chloride samples at probe set up, 1 week and probe pick up

Bugs = Semi-quantitative single habitat benthic macroinvertebrate sample (either kick or bank) and Habitat Assessment

FGM = Fluvial Geomorphology (pebble count and cross-sectional elevation measurements)

Flow = Flow recorded at probe set-up, 1 week and probe pick-up when chemical samples are collected

Nut = Nutrient samples (NO2-3, TP, TKN and ammonia collected at probe set-up, 1-week and probe pick-up)

Algae = Rapid periphyton and densiometer readings

3.1 Dissolved Oxygen Monitoring

The study plan called for continuous monitoring dissolved oxygen, temperature, pH, conductivity probes to be deployed at 99 sites. There was insufficient water depth for probe deployment at eight sites. Sites were selected for dissolved oxygen monitoring using the following criteria:

a. Verify minimum dissolved oxygen levels of 8 ppm (2002 study) in the Southern Igneous Ridges and Mountains (66d). Monitored two unimpaired test sites and five reference sites.

b. Verify minimum dissolved oxygen levels of 7 ppm (2002 study) in three ecoregions; the Southern Sedimentary Ridges (66e), Limestone Valleys and Coves (66f) and Southern Metasedimentary Ridges (66g). Monitored one unimpaired test site and nine reference sites.

c. Verify minimum dissolved oxygen levels of 6 ppm (2002 study) in 10 ecoregions; Southeastern Plains and Hills (65e), Transition Hills (65j), Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f), Southern Sandstone Ridges (67h), Southern Dissected Ridges and Knobs (67i), Cumberland Plateau (68a), Cumberland Mountains (69d), Western Pennyroyal Karst (71e), Western Highland Rim (71f) and Loess Plains (74b). Monitored 16 unimpaired test sites and 37 reference sites. There was insufficient water depth to deploy probes at an additional six sites.

d. Verify minimum dissolved oxygen levels of less than 5 ppm are supportive of aquatic life in the Inner Nashville Basin (71i). Monitored two unimpaired test sites and two reference sites. There was insufficient water depth for probe deployment at one additional test site.

e. Verify minimum dissolved oxygen levels of 3 ppm are supportive of aquatic life in the Northern Mississippi Alluvial Plain (73a). Monitored three reference sites. Probe was stolen from a fourth reference site.

f. Obtain diurnal data from one subregion that was not monitored in the 2002 study, the Bluff Hills (74a). Monitored two reference sites.

g. Characterize non-wadeable streams crossing ecoregion 65e/74b. Monitored four impaired test sites and four potential reference sites. Flood waters washed away the probes at one test site and one potential reference site.

Continuous monitoring probes were deployed the last week of July through November when dissolved oxygen levels should be at their lowest due to high temperatures and low flow. However, water levels were often at normal flow or higher. Each site was monitored for approximately 14 days with readings recorded every 30 minutes. Probes were checked, flow was measured and stream conditions were recorded three times during each monitoring period (set-up, mid-survey and retrieval).

Hydrolab Datasonde 4a multi-parameter probes were used for diurnal monitoring. The accuracy of the dissolved oxygen probe was +/- 0.2 ppm with a resolution of 0.01 ppm. The probes were calibrated before deployment with post calibration checks performed on each probe at the end of the monitoring period. Two probes were set simultaneously at 10 percent of the diurnal continuous monitoring sites. Probes were checked at mid-point of the monitoring period (one week) and cleaned or replaced if fouled or damaged. Instantaneous readings were taken with a second probe at each site visit and compared to diurnal readings as an additional calibration check.

Based on the instantaneous measurements, it appeared that the continuous monitoring probes sometimes lost calibration during the second week especially in areas with heavy sediment loads or shifting sand bottoms. If either the mid-survey or final measurements of the continuous monitoring probes differed by more than 1 ppm from the instantaneous measurement and the post calibration differed by more than 5% saturation, the second week of dissolved oxygen data were not used.

3.2 Geomorphology and Flow Measurements

Flow measurements were made along the same transect three times during each two week monitoring period (set-up, mid survey and pick-up). Protocols followed the *QSSOP for Chemical and Bacteriological Sampling of Surface Water* (TDEC, 2004). Flow was not measured at nine sites that were too deep at normal flow. Due to high water, flow was only measured once at three sites and nine sites.

Abbreviated geomorphological measurements were made at 29 reference sites once during each survey. These were reference sites where data were not already available. Data were collected to define geomorphology in least impaired streams by ecoregion, which will help determine atypical particle transport and channel erosion patterns in test streams.

The geomorphological surveys consisted of 100 particle size measurements that were made along one transect in a typical run area and elevations that were measured along the flow transect to get a stream profile. Measurements were not taken at five reference sites due to high water, three sites that were dry and two sites due to sampler error. Geomorphological measurements were not made at ten sites due to water being too deep during normal flow. Geomorphological measurements were not taken at four of the eight streams crossing ecoregions 65e and 74b due to high water.

3.3 Periphyton Abundance Surveys

Field measurements of periphyton abundance were conducted at 36 reference sites and 15 test sites in ecoregions with suitable rock habitat. Periphyton abundance was not measured at seven dry sites and two sites with high water. The field-based rapid periphyton survey protocols developed by Stevenson were used (Barbour et al, 1999).

Periphyton densities were divided into two broad categories in the field. Macroalgae are sessile, multi-cellular filamentous strands of long algae such as *Cladophora* spp. and *Spirogyra* spp. Microalgae are single celled algae, such as diatoms and blue-green algae, which coat the stream substrate.

Three transects (riffle or run) with the least amount of canopy in the stream reach were surveyed. On each transect, three random locations (right, middle, and left) were selected. At each of the nine locations, a 50-dot gridded viewing bucket was submerged so that algae were visible through the clear bottom of the bucket.

At each of the nine locations, the following information was recorded:

a. The number of dots that occurred over macroalgae

b. The number of dots where substrate was suitable for microalgal

c. accumulation (gravel greater than 2 cm and not covered by macroalgae)

d. The thickness rank of microalgae under each dot using the following scale:

0	Substrate rough with no evidence of microalgae
0.5	Substrate slimy, but no visual accumulation of microalgae is evident
1	A thin layer of microalgae is visually evident, less than 0.5 mm thick
2	Accumulation of microalgal layer from 0.5-1 mm thick is evident
3	Accumulation of microalgal layer from 1 to 5 mm thick is evident
4	Accumulation of microalgal layer from 5 mm to 2 cm mm thick is evident
5	Accumulation of microalgal layer greater than 2 cm thick is evident

d. Densiometer measurements of canopy cover

Duplicate surveys were conducted at ten percent of the sites. Periphyton density was not measured at two test sites due to high water levels. Reference sites were selected to fill data gaps in the Division's ecoregion database. Test sites were selected to help calibrate periphyton abundance based on reference data alone.

3.4 Nutrient Monitoring

Nutrient samples (nitrate+nitrite, total phosphorus, total kjeldhal nitrogen and ammonia) were collected three times at each site where continuous monitoring probes were deployed. Samples were collected at probe set-up, mid survey (one week) and probe pick-up (two weeks). Sampling methods followed protocols outlined in *TDEC's QSSOP for Chemical and Bacteriological Sampling of Surface Waters* (TDEC, 2004). Duplicates, trip blanks and field blanks were collected at ten percent of the sample episodes. Samples were delivered to the state lab by field personnel with chain-of-custody maintained at all times. Samples were analyzed by chemists at the state lab (TDH) using EPA approved methods and quality assurance protocols.

Nutrient samples were collected at reference sites to provide additional data for the ecoregion reference database. These data are used to refine guidelines for regional expectations of nitrate+nitrite and total phosphorus. Additionally, nutrients were collected at unimpaired test sites to help calibrate the regional expectations based on reference data. Samples were collected at both potential reference sites and impaired test sites in non-wadeable streams crossing ecoregions 65e/74b to help characterize background nutrient levels in these stream types.

Continuous monitoring probes which were capable of monitoring chloride and nitrate levels were deployed at 11 of the sites as QC duplicates and to test the reliability of measuring nitrate concentrations in the field. The sites included four established ecoregion reference sites, three potential non-wadeable reference sites, one 303(d) listed non-wadeable site, and four wadeable test sites. These probes have a working range from 0-100 mg/L-N. The precision of the probes is ± 5% of the reading or ± 2mg/L-N, whichever is the greater error.

A two-point calibration was used to standardize the probes. The low standard had a nitrate concentration of 5 mg/L-N and the high standard had a nitrate concentration of 50 mg/L-N. The standards were used to calibrate the probes before deployment in the field. The standards were also used at the end of the two-week period to check for drift.

At these sites, nitrate, chloride and turbidity were collected in addition to the nutrient samples collected at all sites at probe deployment, one week and probe pick-up. The purpose of this monitoring was to test nitrate probes as a potential replacement for nutrient samples for future monitoring and to get a sense of nutrient patterns over a two-week period versus a grab sample.

3.5 Macroinvertebrate Surveys

Benthic macroinvertebrate samples were collected using a semi-quantitative single habitat technique per the Division's QSSOP for Macroinvertebrate Stream Surveys (TDEC, 2003). Samples were sorted and processed at the TDH lab. Field duplicates were collected at ten percent of the sites. Sorting and taxonomic duplicates were completed on ten percent of the samples. New taxa were verified by outside experts.

Macroinvertebrate samples were collected at 24 sites where continuous monitoring probes were deployed. The following criteria were used to determine which sites needed macroinvertebrate collections:

a. Eleven test sites in ecoregions 65e, 66d, 66f, 67f and 67g where preliminary biorecon (screening) results indicated a healthy benthic community structure, but daylight dissolved oxygen readings suggested diurnal levels may fall below regional expectations.

b. Four potential reference sites and four impaired sites in non-wadeable rivers in ecoregions 65e and 74b to help establish biological guidelines for non-wadeable rivers crossing these ecoregions.

c. Five new reference sites in ecoregions 67g, 67h, 67i and 71f that were added since 1999 where included since only one year of existing data were available.

Habitat assessments were conducted at sites where macroinvertebrate samples were collected following high gradient or low gradient protocols (TDEC, 2003). Duplicate assessments were conducted at 10% of the sites.

4. PRECIPITATION AND STREAM FLOW

Precipitation data were compiled from eight weather stations across the state (Figure 3). Although other weather stations were closer to some sites, these eight had the most consistent and reliable data. Diurnal monitoring stations were compared to the closest weather station with the most similar weather patterns (Table 2). Measurements were taken hourly. Data were compiled in monthly averages for a 24-year period from 1978 through 2001 to use as a baseline.

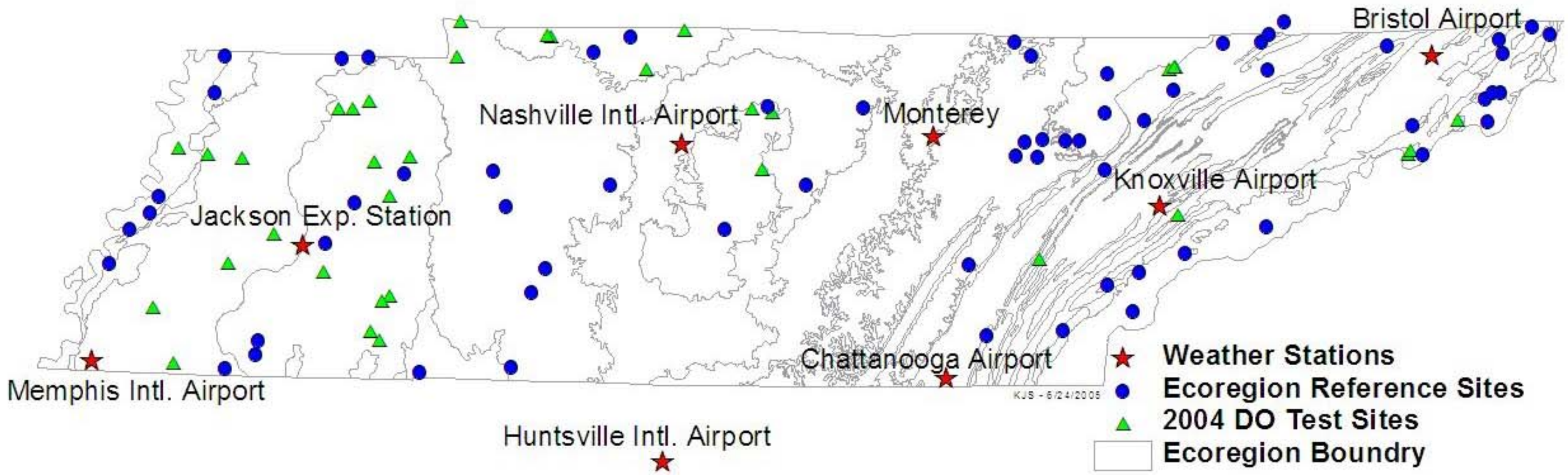


Figure 3: Location of weather stations. Hourly precipitation data were collected for comparison to diurnal monitoring test sites and Ecoregion reference sites, July through November, 1978 – 2004.

Table 2: Location of weather stations used for comparison of precipitation at 2004 diurnal monitoring stations.

Weather Station	Sample Location	Ecoregion	Month Sampled	Miles from Weather Station
Bristol Airport	CAWO000.2CL	67F	Aug.	82
Bristol Airport	DAVIS011.6CL	67F	Aug.	84
Bristol Airport	DAVIS014.6CL	67F	Aug.	83
Bristol Airport	DEVIL000.2UC	66D	Aug.	33
Bristol Airport	ECO66D01	66D	July/Aug.	25
Bristol Airport	ECO66D03	66D	July/Aug.	22
Bristol Airport	ECO66D05	66D	July/Aug.	27
Bristol Airport	ECO66D06	66D	Aug.	36
Bristol Airport	ECO66D07	66D	July/Aug.	23
Bristol Airport	ECO66E04	66E	July/Aug.	39
Bristol Airport	ECO66E09	66E	Aug.	23
Bristol Airport	ECO66F07	66F	July/Aug.	33
Bristol Airport	ECO66F08	66F	July/Aug.	23
Bristol Airport	ECO67F13	67F	Aug.	83
Bristol Airport	ECO67F14	67F	Aug.	55
Bristol Airport	ECO67F16	67F	Aug.	48
Bristol Airport	ECO67F17	67F	Aug.	53
Bristol Airport	ECO67F23	67F	Aug.	52
Bristol Airport	ECO67F25	67F	Aug./Sept.	67
Bristol Airport	ECO67G11	67G	July/Aug.	22
Bristol Airport	ECO67H08	67H	NA	15
Bristol Airport	NINDI010.5UC	66F	Aug.	21
Bristol Airport	ROCKY000.2UC	66D	Aug.	31
Chattanooga Airport	ECO66E18	66E	Sept.	41
Chattanooga Airport	ECO66G07	66G	Sept.	70
Chattanooga Airport	ECO66G09	66G	Sept.	64
Chattanooga Airport	ECO67H04	67H	Sept.	19
Chattanooga Airport	ECO67H06	67H	Sept.	60
Chattanooga Airport	SFLSE001.7MM	67F	Sept.	48
Huntsville Airport	ECO65J05	65J	Oct.	82
Huntsville Airport	ECO71F27	71F	Oct.	57
Jackson Experimental Station	BEAVE004.4CR	65E	Sept./Oct.	35
Jackson Experimental Station	BSAND029.7CR	65E	Sept./Oct.	45
Jackson Experimental Station	BSAND045.2CR	65E	Sept./Oct.	32
Jackson Experimental Station	ECO65E04	65E	Sept./Oct.	40
Jackson Experimental Station	ECO65E06	65E	Sept./Oct.	22
Jackson Experimental Station	ECO65E08	65E	Sept./Oct.	8
Jackson Experimental Station	ECO73A04	73A	Nov.	65
Jackson Experimental Station	ECO74A08	74A	Nov.	56
Jackson Experimental Station	ECO74B01	74B	Nov.	64
Jackson Experimental Station	ECO74B04	74B	Nov.	61
Jackson Experimental Station	HATCH080.8HY	74B	Oct.	25
Jackson Experimental Station	MFOBI017.6WY	65E	Nov.	45
Jackson Experimental Station	MFOBI1C22.5HN	65E	Nov.	46

Table 2: cont.

Weather Station	Sample Location	Ecoregion	Month Sampled	Miles from Weather Station
Jackson Experimental Station	NFFDE020.5DY	74B	Nov.	34
Jackson Experimental Station	NFFDE025.5GI	74B	Nov.	42
Jackson Experimental Station	OBION020.9DY	73A/74A/65E	Nov.	50
Jackson Experimental Station	OTOWN002.2HN	65E	Nov.	50
Jackson Experimental Station	SFFDE043.2MN	74B	Oct./Nov.	10
Jackson Experimental Station	SFFDE069.8CS	65E	Oct.	11
Knoxville Airport	CROOK001.1BT	67F	Aug.	7
Knoxville Airport	ECO66F06	66F	Aug.	18
Knoxville Airport	ECO66G04	66G	Aug.	35
Knoxville Airport	ECO67F06	67F	Aug./Sept.	28
Knoxville Airport	ECO67I12	67I	Aug./Sept.	21
Knoxville Airport	ECO69D03	69D	Aug./Sept.	36
Knoxville Airport	ECO69D04	69D	NA	45
Knoxville Airport	ECO69D05	69D	Aug./Sept.	33
Knoxville Airport	ECO69D06	69D	Aug./Sept.	34
Memphis Airport	CLEAR002.7MC	65E	Sept./Oct.	92
Memphis Airport	ECO65E10	65E	Oct./Nov.	54
Memphis Airport	ECO65E11	65E	Oct./Nov.	52
Memphis Airport	ECO73A01	73A	Oct./Nov.	51
Memphis Airport	ECO73A02	73A	Oct./Nov.	57
Memphis Airport	ECO73A03	73A	Oct.	44
Memphis Airport	ECO74A06	74A	Oct.	31
Memphis Airport	ECO74B12	74B	Oct./Nov.	43
Memphis Airport	LOOSA1C28.6SH	74B	Oct.	26
Memphis Airport	MIDDL002.5HD	65E	Oct.	97
Memphis Airport	SNAKE009.8MC	65E	Sept./Oct.	89
Memphis Airport	WOAK017.0MC	65E	Oct.	95
Memphis Airport	WOLF044.4FA	74B	Oct./Nov.	26
Monterey	ECO68A01	68A	Aug.	39
Monterey	ECO68A03	68A	Aug.	40
Monterey	ECO68A08	68A	Sept.	35
Monterey	ECO68A26	68A	Aug./Sept.	28
Monterey	ECO68A27	68A	Sept.	34
Monterey	ECO68A28	68A	Aug./Sept.	30
Nashville Airport	ECO71E09	71E	Sept.	37
Nashville Airport	ECO71E14	71E	Sept.	40
Nashville Airport	ECO71F12	71F	Sept./Oct.	26
Nashville Airport	ECO71F16	71F	Sept./Oct.	59
Nashville Airport	ECO71F19	71F	Sept./Oct.	67
Nashville Airport	ECO71F28	71F	Sept./Oct.	59
Nashville Airport	ECO71F29	71F	Sept./Oct.	38
Nashville Airport	ECO71H03	71H	NA	59
Nashville Airport	ECO71H06	71H	Sept.	42
Nashville Airport	ECO71I12	71I	Sept./Oct.	30
Nashville Airport	ECO71I16	71I	Sept.	31

Table 2: cont.

Weather Station	Sample Location	Ecoregion	Month Sampled	Miles from Weather Station
Nashville Airport	FLORI003.4WS	71I	Sept.	26
Nashville Airport	JOHNS000.4WS	71I	NA	30
Nashville Airport	LWEST009.4MT	71E	Sept.	54
Nashville Airport	LWFRE010.5MT	71E	Sept.	56
Nashville Airport	PANTH003.6ST	71F	NA	77
Nashville Airport	PHOUS000.7RN	71E	NA	26
Nashville Airport	PRYOR002.0ST	71F	NA	81
Nashville Airport	RED080.0RN	71E	Sept.	36
Nashville Airport	SPRIN004.4WS	71I	Sept./Oct.	25

During the 2002 study period, water levels were generally low. Thirty-eight percent of the 144 streams targeted for monitoring had inadequate flow to complete the study. Most of the dry sites were visited in July and August when precipitation was near the 24-year average for these months (Figure 4). Therefore, the majority of data generated during the 2002 study should reflect typical low-flow conditions. Precipitation was above average in September and October 2002.

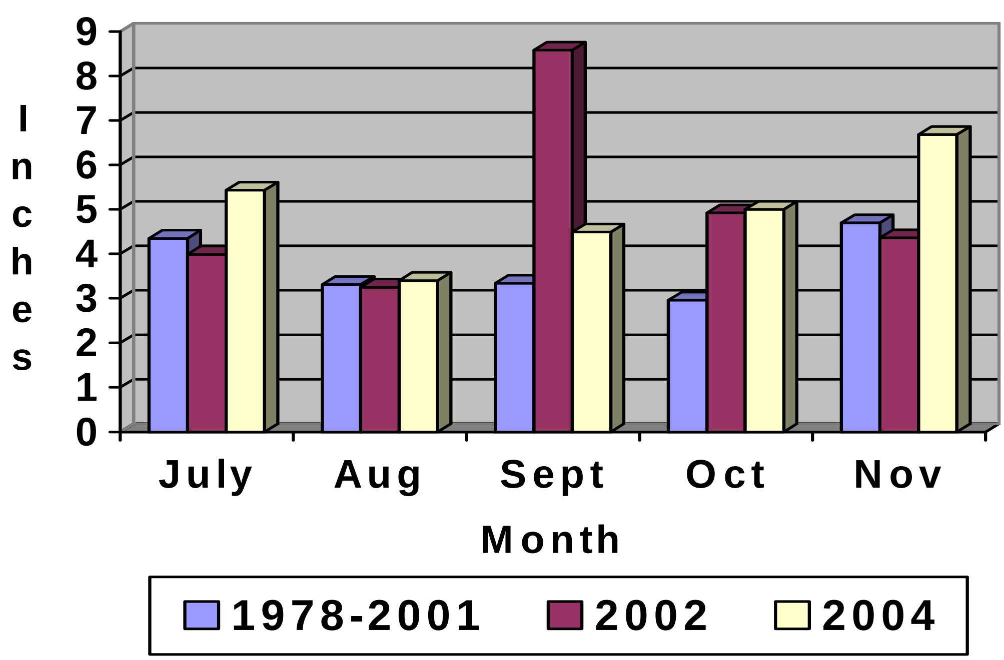


Figure 4: Precipitation during low-flow months in Tennessee. Data based on average of eight weather stations across the state. Years 1978-2001 reflects average precipitation.

Statewide, precipitation was slightly above the 24-year average in July, 2004 (Table 3). Rainfall was above average levels September through November when many of the sites were surveyed.

Regionally, precipitation patterns did not always reflect statewide averages. The eastern portion of the state, including weather stations in Bristol, Knoxville and Chattanooga, had similar rainfall to each other but differed from the statewide average in August with slightly below average precipitation (Figure 5). The Cumberland Plateau (Monterey) generally followed the same weather patterns as the east Tennessee stations except in November where rainfall was near average levels.

Table 3: 2004 statewide and regional precipitation patterns compared to 24 year average (1978 – 2001) for eight weather stations.

2004	Statewide	Bristol Knoxville Chattanooga	Monterey	Nashville	Huntsville	Jackson	Memphis
July	Above	Above	Above	Below	Above	Average	Below
Aug	Average	Below	Below	Above	Average	Above	Average
Sept	Above	Above	Above	Above	Average	Below	Below
Oct	Above	Above	Above	Above	Above	Above	Above
Nov	Above	Above	Average	Above	Above	Above	Above

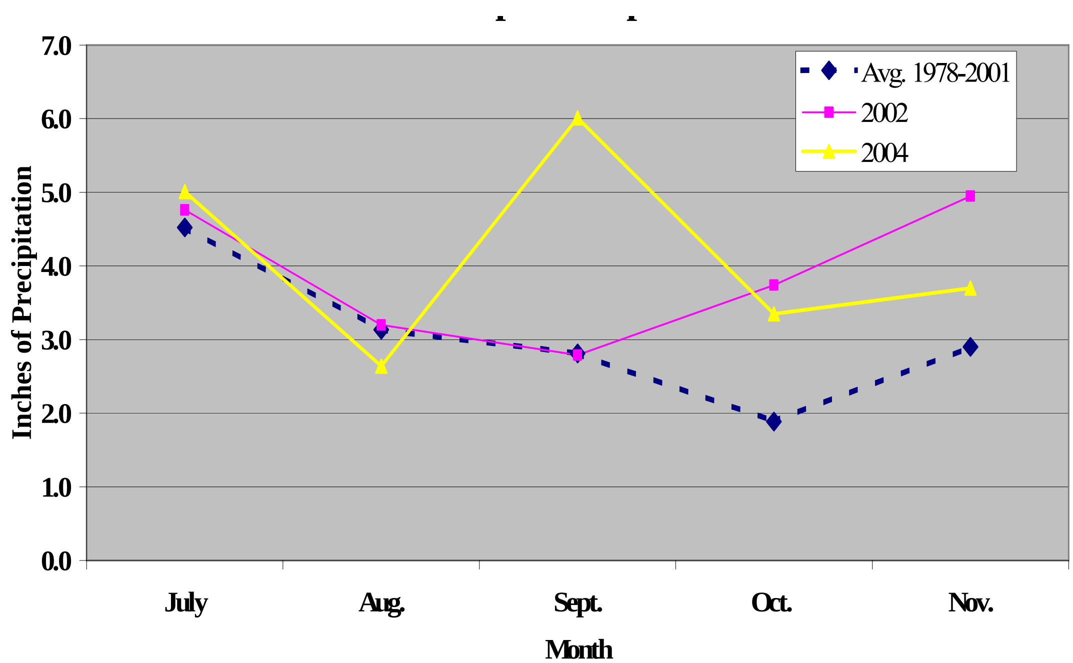


Figure 5: Monthly precipitation during low flow months at the Bristol International Airport weather station (1978-2004).

Rainfall in Nashville often differed from the statewide pattern with lower than average precipitation recorded in July and above average in August and September (Figure 6). The Huntsville, Alabama weather station only differed from the statewide average in September when rainfall was comparable to the 24 year average for the month.

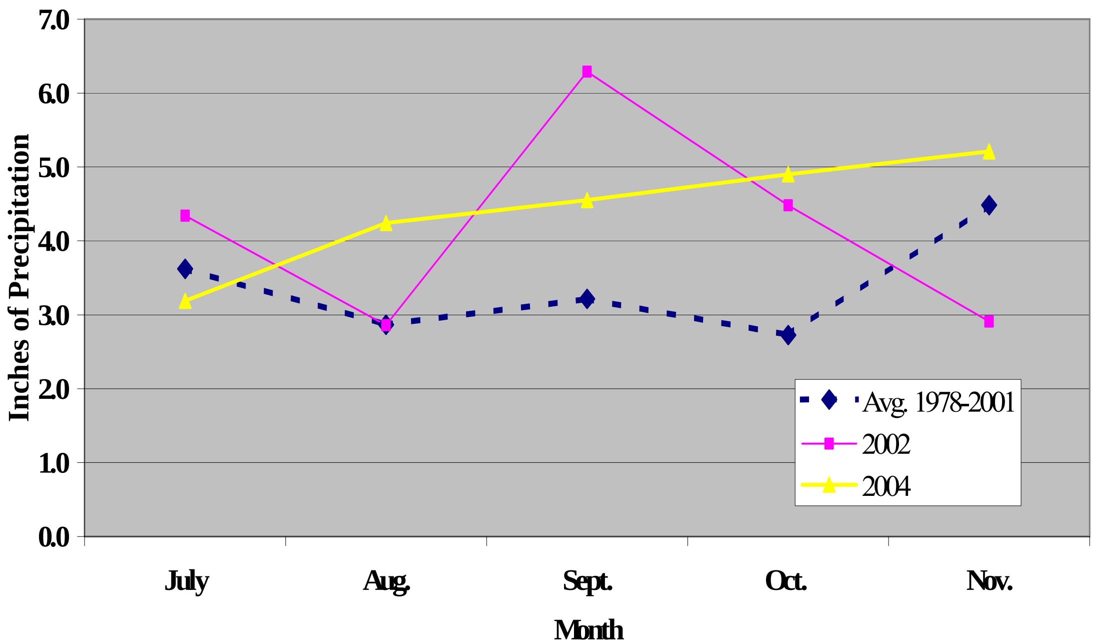


Figure 6: Monthly precipitation during low flow months at the Nashville International Airport weather station (1978-2004).

The two west Tennessee weather stations in Memphis and Jackson differed from other regions of the state and often from each other. In July, Jackson had normal rainfall while Memphis was below average. In August, Memphis had normal rainfall and Jackson was above average. Both of the west Tennessee weather stations recorded below average precipitation in September while the rest of the state had rainfall above average.

All eight weather stations recorded above average precipitation in October and November except for Monterey, which was comparable to the 24-year average in November. Charts of monthly precipitation levels for each of the eight stations are provided in Appendix A.

Because of the heavy precipitation during much of the 2004 study period, water levels at many of the monitoring sites were elevated during the typically low-flow months. Less than ten percent of the streams had insufficient flow to conduct the survey. Flow reached bankfull or flood stage at several streams especially those surveyed in October and November. Water levels often fluctuated during the two-week monitoring period in response to storm events (Table 4).

Although August 2004 precipitation at the Bristol airport was below average, storm events during the 2-week survey period resulted in significant flow variation at Devil Fork in Unicoi County. *Photos provided by Carrie Perry, Aquatic Biology Section, TDH.*

Table 4: Flow data for dissolved oxygen sampling stations July - November, 2004. Flow data are in cubic feet per second (cfs).

Station ID	Start Date	Flow-Day 1	Flow-1 week	Flow-2 weeks
BEAVE004.4CR	9/29/2004	24.0	31.6	46.3
BSAND029.7CR	9/29/2004	64.5	74.8	114.5
BSAND045.2CR	9/29/2004	25.4	25.4	47.2
CAWOO000.2CL	8/18/2004	2.5	2.1	1.4
CLEAR002.7MC	9/27/2004	1.5	3.3	3.6
DAVIS011.6CL	8/13/2004	90.7	22.9	42.5
DAVIS014.6CL	8/18/2004	20.8	15.8	12.1
DEVIL000.2UC	8/3/2004	11.4	5.1	3.6
ECO65E04	9/29/2004	4.3	5.7	14.3
ECO65E06	9/28/2004	3.1	4.2	9.3
ECO65E08	9/29/2004	1.8	2.4	11.9
ECO65E10	10/12/2004	16.6	15.3	11.9
ECO65E11	10/19/2004	33.4	7.8	7.4
ECO65J05	10/6/2004	4.7	10.7	62.2
ECO66D01	7/27/2004	4.2	3	0.5
ECO66D03	7/28/2004	40.4	23.8	11.7
ECO66D05	7/28/2004	18.5	12.9	6.9
ECO66D06	8/4/2004	1.0	0.9	1.1
ECO66D07	7/28/2004	11.5	4.3	2.4
ECO66E04	7/27/2004	6.9	11	3.8
ECO66E09	8/2/2004	6.0	3.4	2.5
ECO66E18	9/2/2004	1.9	5.5	1.8
ECO66F06	8/4/2004	27.6	18.9	18.4
ECO66F07	7/29/2004	42.9	35.7	NA (Bankfull)
ECO66F08	7/28/2004	4.8	1.8	1.4
ECO66G07	9/2/2004	52.6	27.8	90.1
ECO66G09	9/2/2004	15.5	27.8	26.5
ECO67F06	8/23/2004	0.1	0.1	1.2
ECO67F13	8/11/2004	1.4	1.2	1.6
ECO67F14	8/12/2004	174.7	153.3	184
ECO67F16	8/9/2004	10.5	11.5	11.4
ECO67F17	8/9/2004	9.9	9.4	8.3
ECO67F23	8/12/2004	10.6	8.6	12.1
ECO67F25	8/12/2004	897.1	224.9	546.1
ECO67G11	7/29/2004	0.9	0.2	0.2
ECO67H04	9/8/2004	0.4	0.8	0.5
ECO67H06	9/2/2004	0.8	11.9	0.6
ECO67I12	8/23/2004	0.4	0.2	0.2
ECO68A01	8/19/2004	2.0	3.5	1.8
ECO68A03	8/16/2004	6.5	11	5.3
ECO68A08	9/1/2004	14.8	NA (Bankfull)	55.4
ECO68A26	8/31/2004	24.0	NA (Flooding)	87.5
ECO68A27	9/1/2004	1.8	NA (Flooding)	12.7
ECO68A28	8/24/2004	3.6	3.8	11
ECO69D03	8/24/2004	0.6	0.6	0.6

Table 4 cont.

Station ID	Start Date	Flow-Day 1	Flow-1 week	Flow-2 weeks
ECO69D05	8/26/2004	2.3	4	0.9
ECO69D06	8/26/2004	1.2	0.7	0.3
ECO71E09	9/16/2004	14.7	7.8	5
ECO71E14	9/16/2004	7.6	4.8	3.1
ECO71F12	9/21/2004	2.4	2.2	2.6
ECO71F16	9/21/2004	8.3	9.7	7.9
ECO71F19	9/21/2004	12.5	10.8	9.4
ECO71F27	10/11/2004	1.7	18.6	9.1
ECO71F28	9/21/2004	4.0	4	2.9
ECO71F29	9/21/2004	31.4	30.6	29.4
ECO71H06	9/9/2004	6.8	2.3	5.8
ECO71I12	9/20/2004	29.3	5.5	1.8
ECO71I16	9/9/2004	2.1	0.7	17.9
ECO73A01	10/27/2004	11.5	94	40.5
ECO73A02	10/26/2004	32.5	336.1	45.2
ECO73A03	10/27/2004	18.9	163.3	9.1
ECO73A04	11/2/2004	217.1	7.7	7.3
ECO74A06	10/18/2004	0.4	0.1	0.4
ECO74A08	11/2/2004	27.1	2.3	3.7
ECO74B01	11/8/2004	19.5	32.7	34.3
ECO74B04	11/8/2004	6.5	9.5	6.6
ECO74B12	10/20/2004	396.5	374	226.8
FLORI002.4WS	9/9/2004	0.3	0.1	0.1
HATCH080.8HY	10/4/2004	449.4	NA (Flooding)	NA (Flooding)
LWEST010.5MT	9/16/2004	39.1	25.9	18.3
MFOBI014.6WY	11/9/2004	121.8	128.1	112.6
MFOBI1C22.5WY	11/10/2004	78.5	92	85.2
MIDDL002.5HD	10/12/2004	25.4	29.3	22.2
NFFDE025.5GI	11/9/2004	92.9	80.4	180.9
NINDI010.5UC	8/2/2004	24.0	9.8	10.6
OTOWN002.2HN	11/8/2004	10.4	8.9	8
RED080.0RN	9/16/2004	NA (Bankfull)	33.5	13.7
ROCKY000.2UC	8/3/2004	8.3	11.3	7.1
SFFDE043.2MN	10/28/2004	671.6	710.4	541.6
SFFDE069.8CS	10/5/2004	74.1	126.6	NA Bankfull
SFLSE001.7MM	9/8/2004	1.0	1.6	4.6
SNAKE009.8MC	9/27/2004	2.8	8.0	25.5
SPRIN004.4WS	9/20/2004	60.1	11.5	3.3
WOAK017.4MC	10/12/2004	5.4	13.7	6.1
WOLF044.4FA	10/20/2004	NA Bankfull	658.7	433.1

5. WATER TEMPERATURE

Water temperature is an important determinant of dissolved oxygen levels. For the 2002 and 2004 diurnal studies, probes were deployed in July through November in an attempt to monitor DO patterns during the months with highest temperatures and lowest flows. Dissolved oxygen would be expected to have the lowest levels during this period. Water temperature was recorded every 30 minutes concurrent with dissolved oxygen readings.

Since the diurnal study was only conducted for two years, there was some concern that this might not represent the maximum water temperatures that could occur in each region during an extremely hot year. In order to help characterize the low flow conditions in 2002 and 2004, water temperatures at each reference site were compared to temperatures recorded from instantaneous daylight measurements July through November, 1995-2005 (Figure 7).

Based on this information, maximum temperatures recorded during diurnal monitoring were higher than those recorded in ten years of daylight monitoring in nine of the 18 ecoregions studied (66d, 66f, 66g, 67f, 67g, 67i, 68a, 69d, 71h). In most of the other ecoregions, the maximum diurnal temperature exceeded the 90th percentile of daylight measurements (Table 5). The exceptions were the Northern Mississippi Alluvial Plain (73a) and the Bluff Hills (74a). Because of the lower water temperatures, it is possible that dissolved oxygen levels recorded during the two study years at sites in these two ecoregions are higher than the levels reached during the hottest days.

During either the 2002 or 2004 study period, water temperatures in nine ecoregions were the highest recorded since 1996. Big War Creek, Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f). *Photo provided by Greg Harris and Carrie Perry, Aquatic Biology, TDH.*

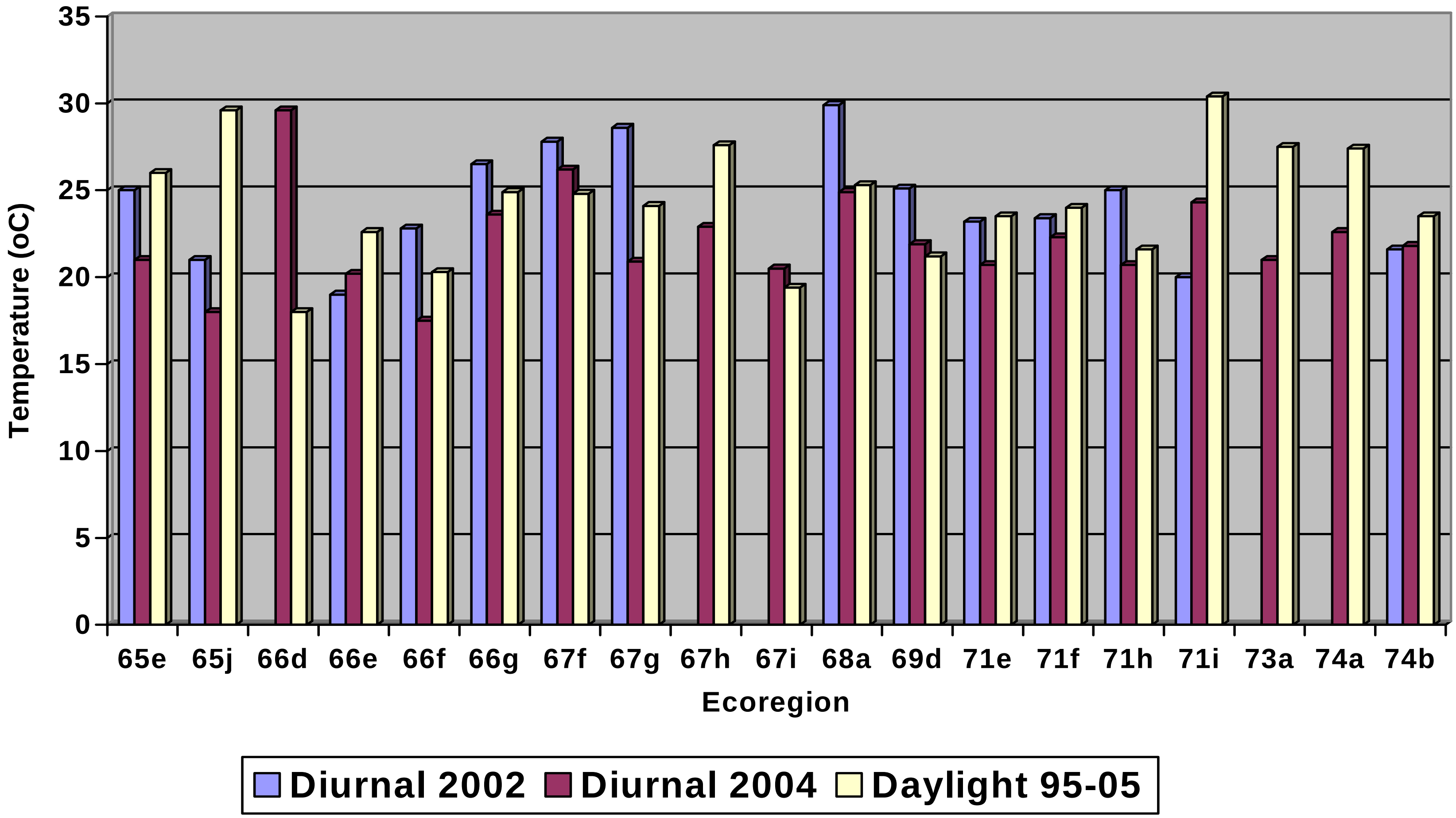


Figure 7: Maximum water temperature at ecoregion reference sites recorded from 1995 to 2005.

Table 5: Maximum diurnal and daylight temperatures for 19 ecoregions. Diurnal measurements were recorded July through November 2002 and 2004. Daylight measurements were recorded 1995 through 2005.

Ecoregion	Maximum Diurnal Temperature 2002 (°C)	Maximum Diurnal Temperature 2004 (°C)	Maximum Daylight Temperature 1995-2005 (°C)	90th Percentile of Daylight Temperature 1995-2005 (°C)
65e	25.0	21.0	26.0	22.1
65j	23.5	18.0	29.6	20.6
66d	NA	19.9	18.0	17.2
66e	19.0	20.2	22.6	19.6
66f	22.8	17.5	20.3	17.0
66g	26.5	23.6	24.9	19.8
67f	27.8	26.2	24.8	21.2
67g	28.6	20.9	24.1	20.4
67h	NA	22.9	27.6	20.3
67i	NA	20.5	19.4	19.0
68a	29.9	24.9	25.3	21.8
69d	25.1	21.9	21.2	19.9
71e	23.2	20.7	23.5	20.8
71f	23.4	22.3	24.0	21.0
71h	25.0	20.7	21.6	20.0
71i	20.0	24.3	30.4	23.6
73a	NA	21.0	27.5	25.5
74a	NA	22.6	27.4	23.7
71b	21.6	21.8	23.5	20.3

6. DIURNAL DISSOLVED OXYGEN MONITORING RESULTS

In 2004, Tennessee's statewide dissolved oxygen criteria were refined to reflect some of the regional patterns identified in the 2002 study (Arnwine and Denton, 2003). DO criteria were raised in the four Blue Ridge Mountain subregions to a minimum of 7.0 ppm. Criteria were adjusted in the Mississippi Valley Loess Plains (73a) to a daily average of 5 ppm with a minimum of 4 ppm (TWQCB, 2004).

Preliminary data from the 2002 study indicated criteria may also need to be adjusted in ten other subregions. The 2004 study was designed to provide additional information in the eight subregions where preliminary data suggested criteria may need to be raised and in two ecoregions where 2002 data suggested dissolved oxygen levels below 5 ppm were typical in unimpaired streams and were supportive of fish and aquatic life.

Diurnal dissolved oxygen and temperature charts for all 2004 monitoring stations are provided in Appendix B.

6.1 Dissolved Oxygen in the Northern Mississippi Alluvial Plains (73a)

Streams in this region are slow moving during normal flow conditions. There is very little gradient and the streams are naturally turbid with sandy substrates providing little opportunity for oxygenation. There is abundant coarse particulate matter providing food for macroinvertebrates, but helping to deplete dissolved oxygen levels through decomposition. Streams in this region are generally influenced by seasonal floods on the Mississippi River, which sometimes changes the direction of flow in these streams.

Due to these natural factors, the aquatic life in this region have adapted to low dissolved oxygen levels. Healthy macroinvertebrate communities are dominated by animals that would be considered tolerant in other stream types. Aquatic worms, crustaceans, odonates, beetles, midges and gilled snails are the dominant taxa in reference streams. The tolerant mayfly *Caenis* sp. is the only abundant EPT with facultative *Baetis* spp. and *Oecetis* spp. occurring occasionally.

Cold Creek (ECO73A01) reference stream in the Upper Mississippi Alluvial Plain.

Photo provided by Greg Harris and Seton Bonney, Aquatic Biology, TDH.

The current dissolved oxygen criteria for the Mississippi Valley Loess Plains is a daily average of 5 ppm with a minimum of 4 ppm. Diurnal and daylight readings from reference sites as well as data and criteria provided by the state of Arkansas suggest streams that routinely measure as low as 3 ppm support a healthy biological community.

Four reference streams were monitored as part of the 2004 study in Tennessee. Diurnal results are only available from three sites due to the probe being stolen from one station. Most streams in this ecoregion have disturbed watersheds due to agriculture or urban development. During the reference stream selection process, every stream whose drainage was at least 80% contained within the ecological subregion was evaluated for reference potential. The evaluation process included a field visit. Reference streams were selected from those with the best habitat and the most forest and/or wetlands in the drainage area (Table 6).

Table 6: Percent land use in watersheds upstream of reference sites in the Northern Mississippi Alluvial Plain in Tennessee. Values based on 1992 satellite imagery.

Land Use	ECO73A01	ECO73A02	ECO73A03	ECO73A04
Bare Rock/Sand/Clay	0	0	0	0
Deciduous Forest	19	0	10	10
Emergent Herbaceous Wetland	0	0	0	0
Evergreen Forest	1	0	0	1
High Intensity Commercial/Industrial/Transportation	0	0	0	0
High Intensity Residential	0	0	0	0
Low Intensity Residential	0	0	0	0
Mixed Forest	4	0	3	5
Open Water	6	1	3	1
Other Grasses	0	0	0	0
Pasture/Hay	2	0	4	12
Quarries/ Strip Mines/Gravel Pits	0	0	0	0
Row Crop	31	0	11	60
Transitional	0	0	0	0
Small Grain	0	0	0	1
Woody Wetlands	37	100	68	9

The probes were deployed in late October and early November. Two storm events occured during this time frame (Figure 8). Stream flow was elevated at all three sites for a portion of the two-week monitoring period. Water temperatures were 3 - 7 ^{o}C lower than highs recorded during daylight monitoring between 1995 and 2004. Therefore, it is possible that the diurnal data do not reflect the lowest DO levels that may occur during periods of higher temperatures and lower flows.

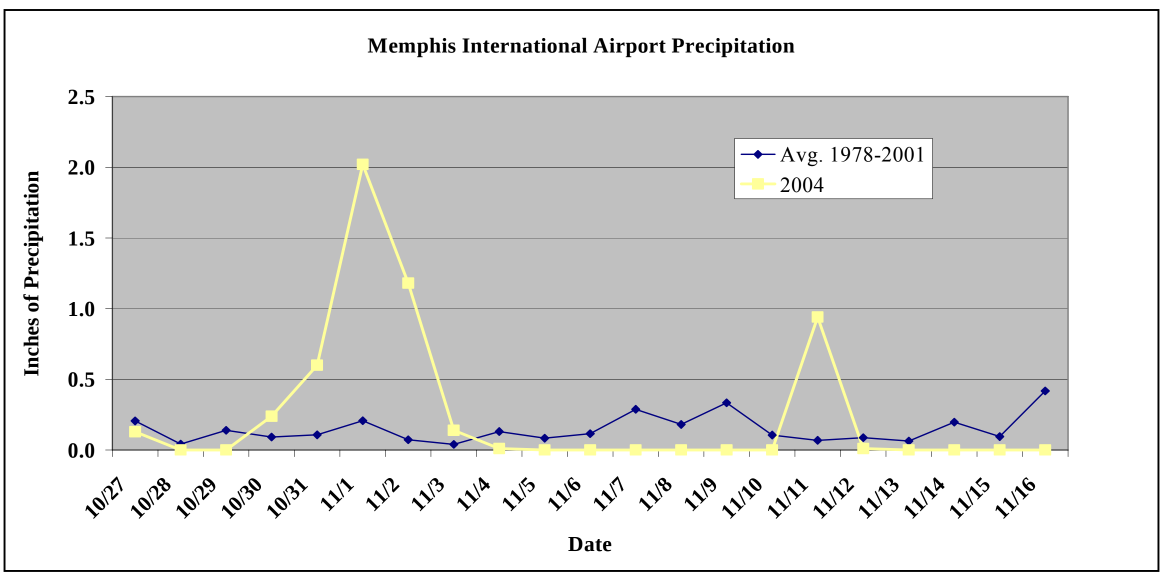


Figure 8: Daily precipitation at Memphis International Airport Oct. 27 –Nov. 16, 1978 - 2004. Dates represent diurnal probe deployment at three reference sites in the Northern Mississippi Alluvial Plain (73a).

6.1.1 Diurnal dissolved oxygen in Tennessee reference streams in the Northern Mississippi Alluvial Plain

The first Northern Mississippi Alluvial Plain reference site monitored was on Cold Creek (ECO73A01). This site is located near the creek's origin out of Open Lake and has a drainage area of approximately four square miles. The upstream watershed is predominantly forest and woody wetlands (61%). Row crops (primarily soybean) comprise 31% of the land use.

When the probe was deployed on October 27, 2004, flow was very slow (11cfs). Dissolved oxygen measured 6 ppm and fell to 4.2 ppm during the night (Figure 9). Several storm events occurred between October 31 and November 2 totaling 3.8 inches of rain. When the probe was checked on November 1, the creek was flooding and flow had increased to 94 cfs. Dissolved oxygen measured 3.1 ppm. Dissolved oxygen levels rose to almost 4 ppm the following day and than declined to below 1 ppm for the remainder of the deployment period. When the probe was retrieved on November 9, an instantaneous measurement confirmed the diurnal probe dissolved oxygen measurement of 0.7 ppm. Flow was near normal levels at 40 cfs.

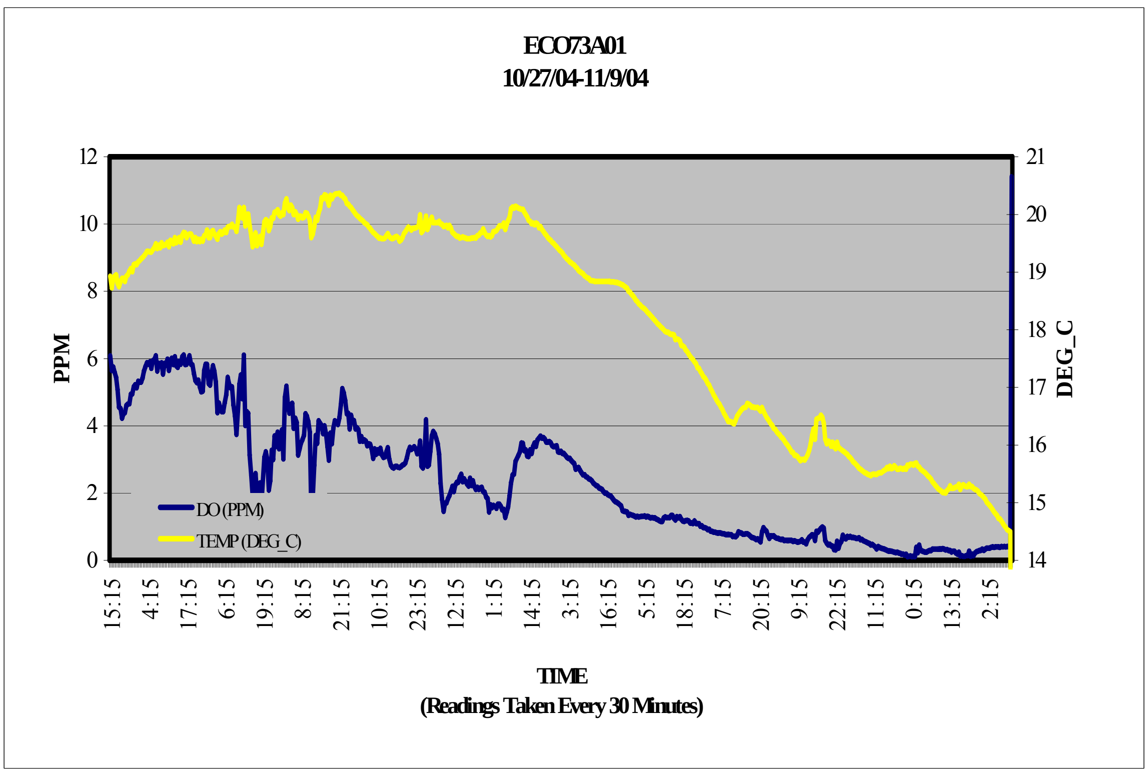


Figure 9: Diurnal dissolved oxygen and temperature at Cold Creek reference site in the Northern Mississippi Alluvial Plain (73a).

The second reference site in this ecoregion is the Middle Fork of the Forked Deer River (ECO73A02). This stream has a small drainage area of approximately three square miles. However, the stream is influenced by the Mississippi River and has a broad flood plain. The entire upstream watershed is contained within the Chickasaw National Wildlife Refuge and is 100% forested.

Flow was low (32 cfs) when the probe was deployed on October 26, 2004. Dissolved oxygen measured 3.16 ppm and fell below 2 ppm during the night (Figure 10). Several storm events occurred between October 31 and November 2 dropping 3.8 inches of rain. Water levels were elevated (near bankfull) when the creek was sampled one week later. Flow was 336 cfs. Dissolved oxygen was near the highest level of the monitoring period at 6.5 ppm. High water prevented retrieval of the probe at the end of the second week. When the probe was retrieved on November 22, flow was near normal (45 cfs) and dissolved oxygen measured 5.0 ppm. Diurnal measurements were only recorded the first two weeks, data after that period is questionable due to sediment deposits on the probe.

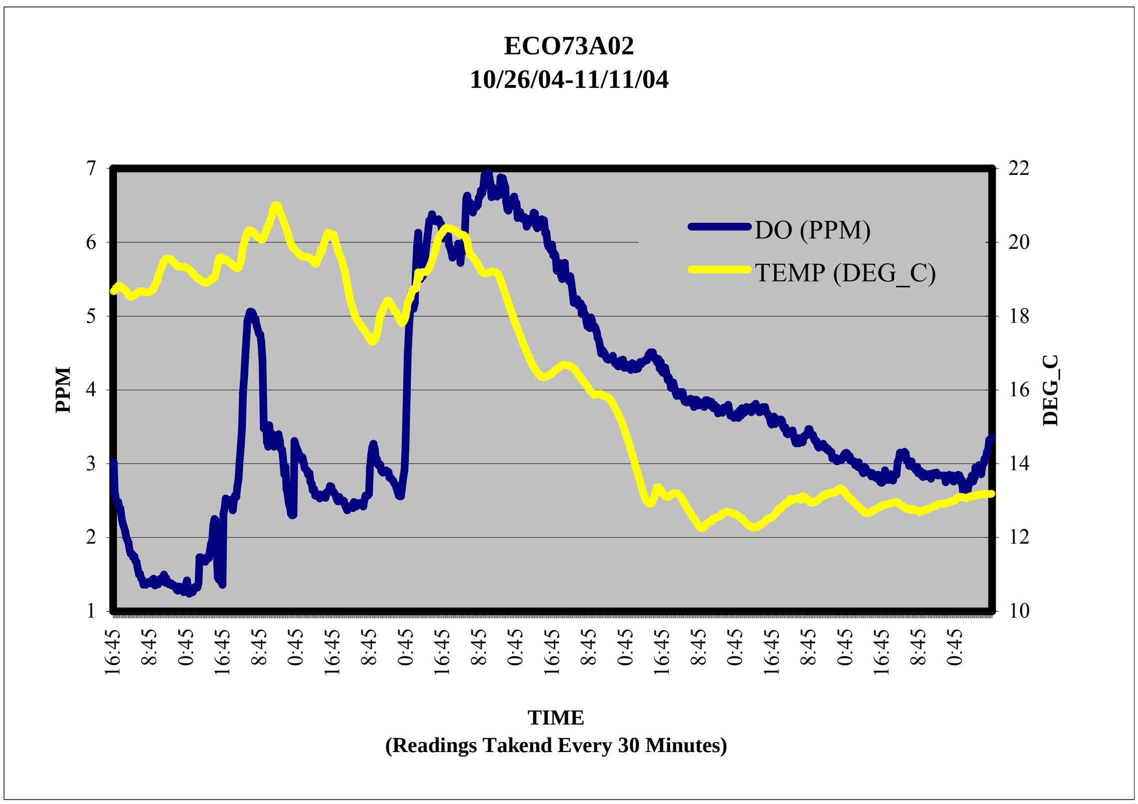


Figure 10: Diurnal dissolved oxygen and temperature at Middle Fork Forked Deer River reference sites in the Northern Mississippi Alluvial Plain (73a). Station is located in the Chickasaw National Wildlife Refuge.

The third reference site surveyed was Bayou du Chien (ECO73A04). With a drainage area of 26 square miles, this is the largest of Tennessee's reference streams in this subregion. Approximately 85% of the drainage is in Kentucky. Sixty percent of the land use is row crops, while 25% is forest or woody wetlands.

Water levels were elevated (217 cfs) and near bankfull when the probe was deployed on November 2, 2004 during a storm event. Dissolved oxygen was 3.6 ppm and fell to 1.7 ppm at night (Figure 11). Water levels were near normal summer flow one week later (8 cfs) and dissolved oxygen measured 2.0 ppm. When the probe was retrieved on November 16, water levels were still near normal (7 cfs) and dissolved oxygen measured 2 ppm. Nighttime lows sometimes dropped below 1 ppm during the survey period. However, a calibration check during week two indicates measurements may have been off by 0.5 ppm, therefore DO levels probably remained above 1 ppm.

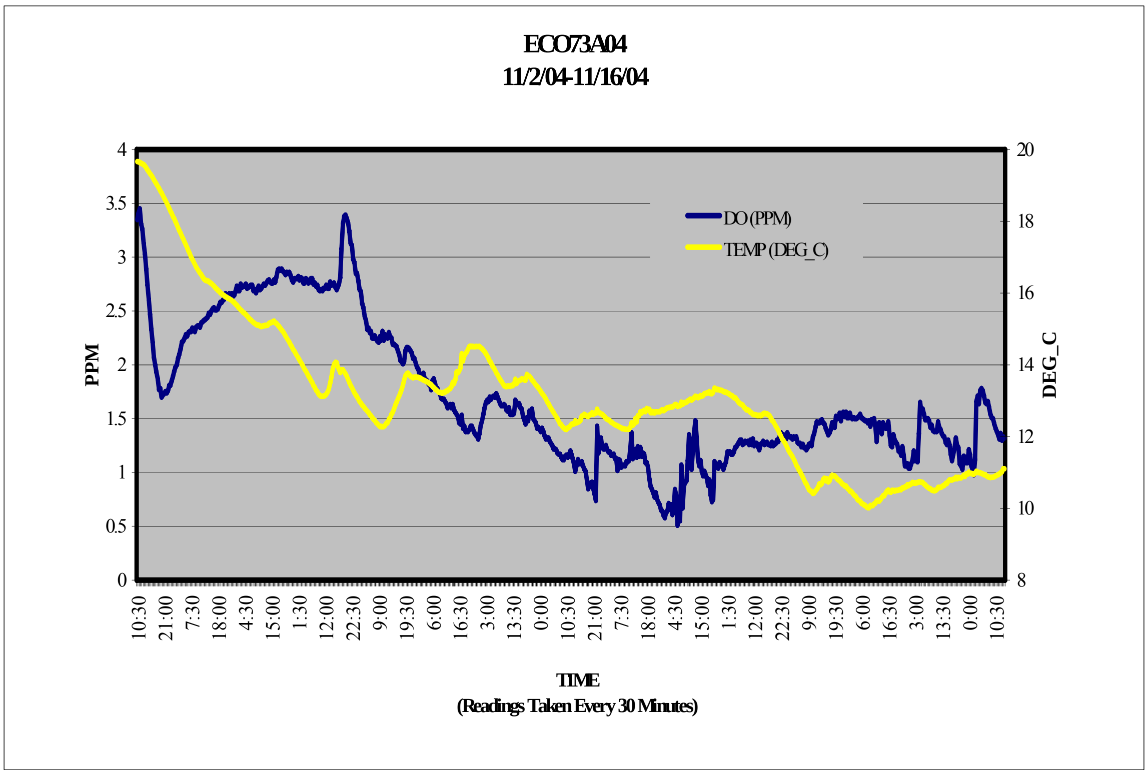


Figure 11: Diurnal dissolved oxygen and temperature at Bayou du Chien reference site in the Northern Mississippi Alluvial Plain (73a).

The diurnal data indicate that streams in this ecoregion typically have daytime dissolved oxygen levels approximating 3 ppm and levels can drop to near 1 ppm for short periods while still supporting aquatic life typically found in the least disturbed streams in this region. Storm events during the monitoring period increased flow and cooled temperatures so these data are probably not reflective of the lowest dissolved oxygen levels. The maximum diurnal temperature was 6°C lower than the maximum daylight measurement recorded from 1995 through 2005.

6.1.2 Dissolved oxygen levels of Arkansas reference streams in the Northern Mississippi Alluvial Plain

Tennessee reference data were compared to Arkansas reference data to help verify these findings. Arkansas shares the same reach of the Mississippi River. However, the Northern Mississippi Alluvial Plain ecoregion is much wider on the western bank giving Arkansas a larger area for reference stream selection.

The largest streams in Tennessee that are contained in this ecoregion have an approximate drainage area of 60 square miles. Two of Arkansas's reference streams, Boat Gunwale Slash and Second Creek have drainage areas of 60 square miles or less and were used for comparison.

Arkansas conducted a diurnal dissolved oxygen study of its reference streams in the 1980s (Bennett et al, 1987). Boat Gunwale Slash is the smaller of the two streams with a drainage area of 23 square miles. It has a limited amount of channelization. Land use is primarily agricultural (72%) with the remainder forested.

Diurnal probes were deployed August 1 - 4, 1983 and April 10 - 12, 1984. Maximum DO values in the summer were 3.2 ppm with a minimum of 2.5 ppm. This is similar to the summer readings at the three Tennessee reference streams. Spring levels were higher with a maximum of 8.3 ppm and a minimum of 4.7 ppm. Instantaneous measurements from Tennessee reference streams in the spring have similar dissolved oxygen levels.

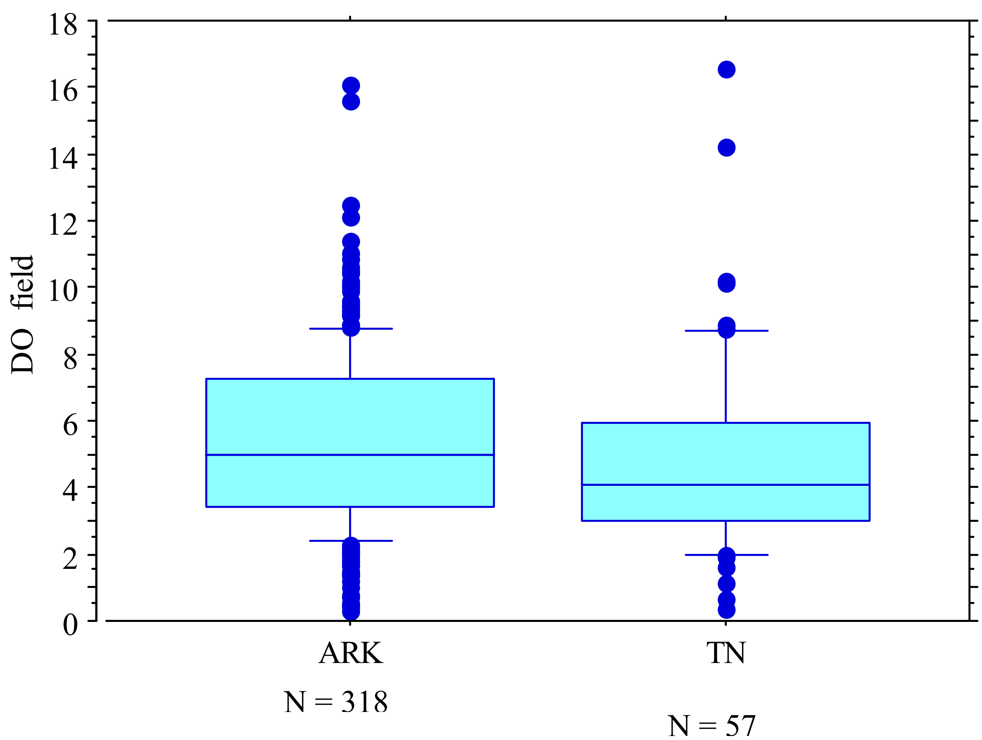
The macroinvertebrate community was comparable to that found in Tennessee streams. The stream supported a diverse fish community with 31 species collected in the summer. No sensitive species were collected.

Second Creek is larger with a drainage area of 60 square miles. This stream is considered an extraordinary resource water in Arkansas. It is not channelized which is rare in this ecoregion. Approximately 30% of the watershed is forested including nearly all the floodplain. The remainder of the watershed is row crops including soybean, rice, cotton and wheat.

A continuous dissolved oxygen probe was deployed in the summer July 31 - August 2, 1984. Maximum dissolved oxygen levels were 8.2 ppm with nighttime lows regularly reaching 3.4 ppm. Once again, spring levels were higher with highs of 7.7 ppm and lows of 6.6 ppm.

The macroinvertebrate community had high taxa richness, but was dominated by facultative and tolerant organisms similar to those found in Tennessee reference streams in this region. The stream supported a diverse fish community with no sensitive species.

Due to the dated time-frame of the Arkansas diurnal data, instantaneous daylight readings were also compared between reference sites from both states (Figure 12). The Arkansas data were retrieved from the Arkansas Department of Environmental Quality's online Surface Water Quality Monitoring Stations Data Files and were collected between 1990 and 2005.



Percentiles
Split By: STATE

	DO field: Total	DO field: ARK	DO field: TN
10	2.3	2.4	2.0
25	3.3	3.4	3.0
50	4.8	5.0	4.1
75	7.2	7.3	6.0
90	8.7	8.8	8.7

Figure 12: Daylight dissolved oxygen measurements of Northern Mississippi Alluvial Plain reference streams in Arkansas and Tennessee. Tennessee data were collected from 1995 to 2005. Arkansas data were collected from 1990 to 2005.

Daylight DO measurements support the information retrieved from the continuous monitoring probes (Table 7). The 25th percentile from Arkansas was 3.4 ppm while that in Tennessee was 3.0 ppm (combined was 3.3 ppm). Both sets of data indicate that daylight dissolved oxygen readings around 3 ppm with lower values during the night are supportive of healthy biological communities for streams within the Northern Mississippi Alluvial Plain.

Table 7: Minimum dissolved oxygen at reference sites with drainage areas less than 100 square mile in ecoregion 73a (Northern Mississippi Alluvial Plain) 1990 – 2005.

Site	State	Diurnal Minimum DO (ppm)	Diurnal Monitoring Time (days)	Daylight DO 10TH percentile (ppm)	Daylight DO 25TH percentile (ppm)	Number of Daylight Readings
ECO73A01	TN	0.7	14	1.3	2.7	22
ECO73A02	TN	1.2	17	3.0	4.1	14
ECO73A03	TN	NA	NA	2.7	3.1	11
ECO73A04	TN	0.6	15	1.6	2.0	10
WHI0074	AR	2.5	3	1.6	2.8	152
FRA0012	AR	3.4	3	3.2	4.3	164

The state of Arkansas incorporated the results of their data into their Water Quality Standards (Arkansas Pollution Control and Ecology Commission, 2004). The dissolved oxygen criterion for streams with a drainage area less than 10 square miles in the Delta ecoregion is 2 ppm during the critical season (mid May through mid September). For streams 10 to 100 square miles, the DO criterion is 3 ppm during the critical periods. There are no streams exceeding 100 square miles contained within ecoregion 73a in Tennessee. Larger streams and rivers cross the Loess Plains and generally the Southeastern Plains and Hills before entering the Northern Mississippi Alluvial Plains. The Arkansas DO criteria apply to both least altered and channel altered streams.

6.2 Dissolved Oxygen in the Inner Nashville Basin (71i)

Streams in the Inner Nashville Basin tend to be low gradient with bedrock substrate leaving little opportunity for aeration. Streams are often dry, reduced to isolated pools or have sections that are subterranean during the low flow months. Habitat is generally neither abundant nor diverse especially during low flow. Biological communities in this ecoregion have adapted to these conditions and are generally atypical of other Interior Plateau subregions with lower taxa richness and a higher percentage of facultative organisms. The area is under stress due to rapid urban development and reference streams with minimal disturbance in the watershed are difficult to find. The Inner Nashville Basin is entirely within Tennessee so reference data cannot be obtained outside of the state for comparison.

During the 2002 dissolved oxygen study, diurnal monitoring data were retrieved from five reference sites. One of the reference sites reported in 2002 (ECO71I13) has since been dropped due to increased disturbance in the watershed. Diurnal DO information for this region was based on only four days data collected in 2001 from one reference site (ECO71I12). Results from the 2002 diurnal monitoring in conjunction with daylight measurements taken from both reference streams and unimpaired test sites since 1996, suggested that dissolved oxygen levels below the statewide criterion of 5 ppm were supportive of aquatic life in this region.

To further test this premise, two additional reference streams as well as the one monitored in 2002 as well as two unimpaired test sites, which passed biocriteria guidelines, were monitored for a longer period of time in 2004. An additional test site was selected for monitoring, but had inadequate flow. Summary diurnal data from both the 2002 and 2004 monitoring periods are provided in Table 8.

Table 8: Diurnal dissolved oxygen summary information from six reference and three unimpaired test sites in the Inner Nashville Basin (71i). Monitoring period was summer/fall 2002 (1 week) and 2004 (2 weeks).

Site	Year	Biocriteria Guidelines	Min DO (ppm)	Max DO (ppm)	Max Temp (^oC)	Max Diurnal Fluctuation
ECO71I10	2002	Reference	6.1	10.1	23.8	4
ECO71I12	2004	Reference	5.9	9.7	22.0	3
ECO71I14	2002	Reference	5.6	10.8	24.3	4
ECO71I15	2002	Reference	5.1	8.6	22.6	2
ECO71I16	2004	Reference	3.0	8.8	24.1	4
FLORI002.4WS	2004	Pass	1.1	9.9	26.5	8
SPRIN004.4WS	2004	Pass	6.4	14.3	23.3	5

These data demonstrate that one reference site, the West Fork of the Stones River (ECO71I16) and one unimpaired test site, Florida Creek (FLORI002.4WS) had dissolved oxygen fall below 5 ppm. DO at the reference site was below 5 ppm for six consecutive nights, falling below 4 ppm for three nights (Figure 13). After the first week, a storm event of 1.6 inches (Figure 14), increased flow and lowered water temperatures that helped keep dissolved oxygen levels above 5 ppm. However, the lower flow and warmer temperatures are more typical of summer conditions in this region. A duplicate probe was deployed at this site and showed a nearly identical pattern.

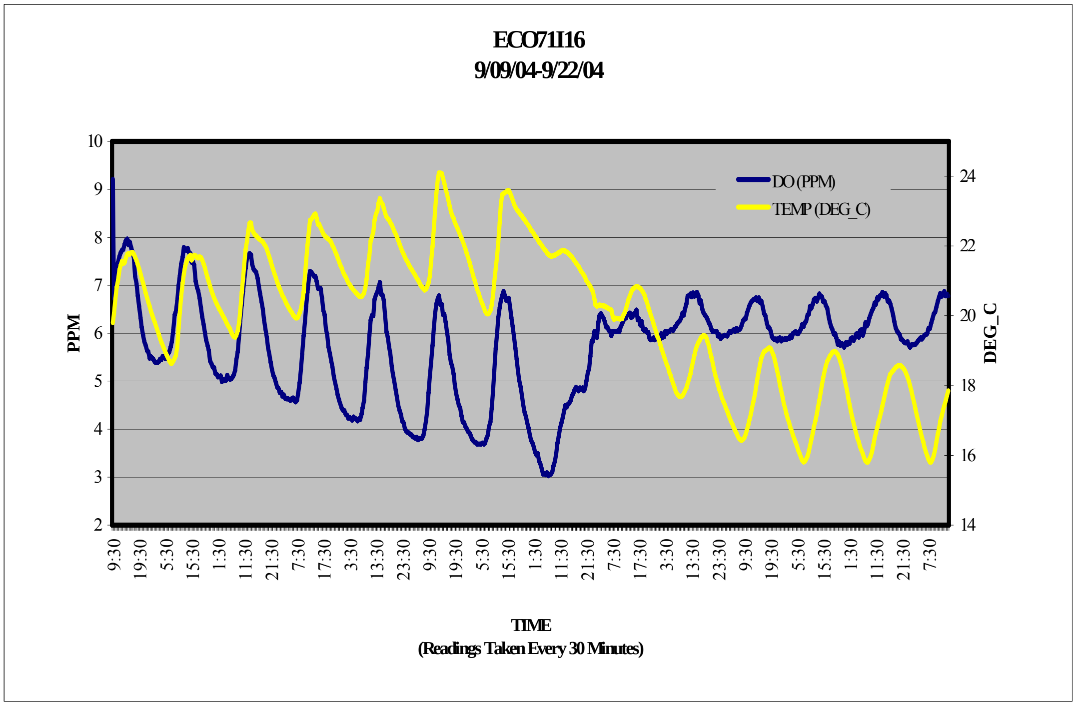


Figure 13: Diurnal dissolved oxygen and temperature at West Fork Stones River reference site in the Inner Nashville Basin (71i). Measurements taken continuously over a two week period (September 9 – 22, 2004).

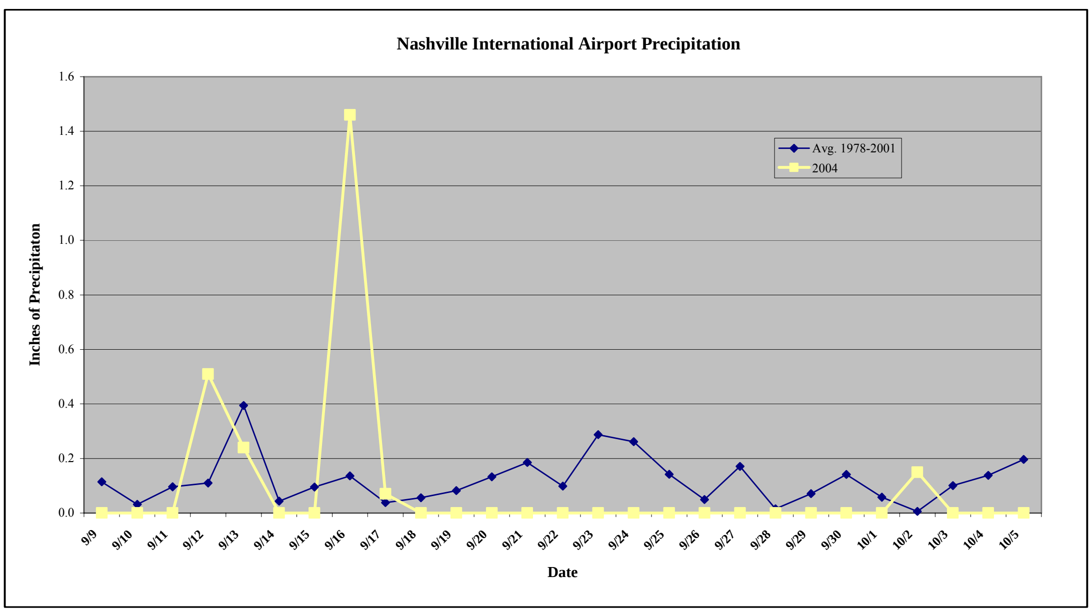


Figure 14: Precipitation data from Nashville International Airport during diurnal probe deployment in the Inner Nashville Basin.

Florida Creek also had dissolved oxygen levels below 5 ppm during this period. Florida Creek is a small stream that supports a diverse macroinvertebrate community. Flow was low when the probe was deployed on September 9, 2004 and dropped to 0.1 cfs by the end of the first week. Dissolved oxygen fluctuated widely between day (6 ppm) and night, falling below 4 ppm for each of the first seven nights. (Figure 15). During the second week of monitoring, after the storm event on September 16, water temperatures were much lower probably due to cooler air temperature. Despite the rain, flow remained low at 0.1 cfs. Diurnal fluctuations were reduced to 3 ppm and dissolved oxygen only fell to 4.6 ppm one night during this period. Water temperatures during the first week of monitoring are more typical of summer levels in small streams in this region.

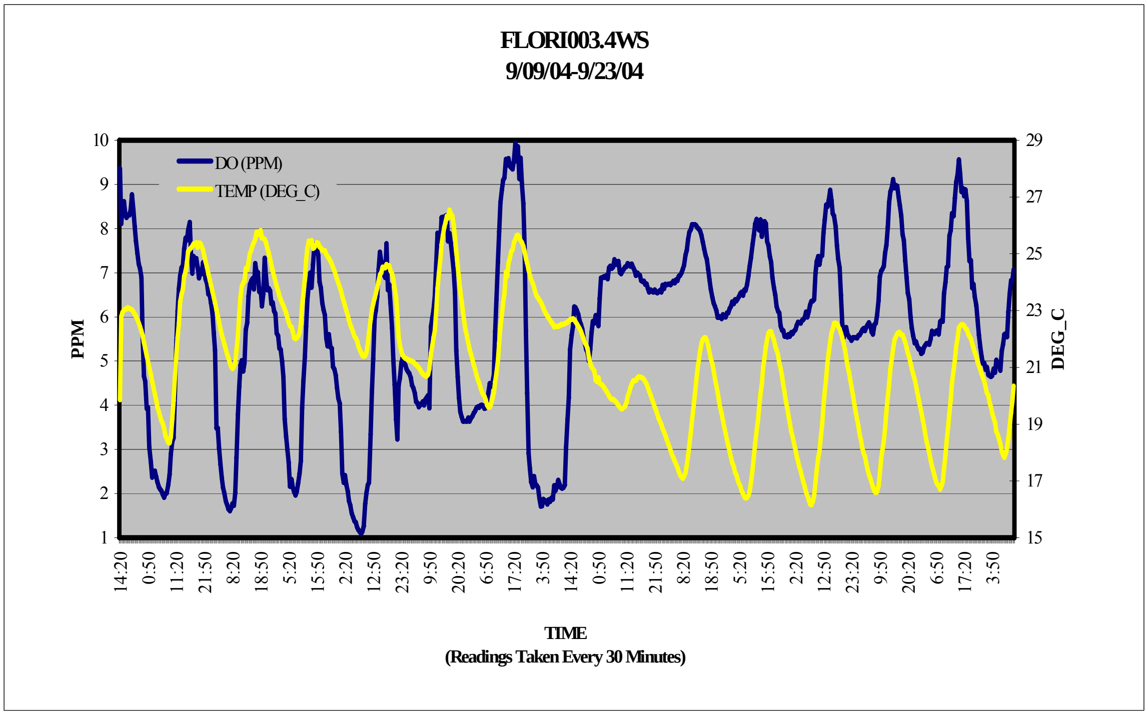


Figure 15: Diurnal dissolved oxygen and temperature at Florida Creek, unimpaired test site in the Inner Nashville Basin (71i). Measurements taken at 30 minute intervals over a two week period (September 9 – 23, 2004).

These data indicate that streams with dissolved oxygen periodically falling below 5 ppm during the night are supportive of a healthy biological community in this region. However, since diurnal swings are typically between 2 and 4 ppm, it is important to include diurnal monitoring in this region and not rely only on daylight measurements when levels approach 5 ppm.

6.3 Ecological Subregions Where Minimum Reference Dissolved Oxygen was Generally 6 ppm in the 2002 study

In the 2002 study, ten subregions had diurnal dissolved oxygen levels that were generally at or above 6 ppm (65e, 65j, 67f, 67h, 67i, 68a, 69d, 71e, 71f, 74b). This group of subregions, comprise 62 percent of the state. The 2004 study endeavored to verify minimum DO levels of 6 ppm in these regions.

DO data from six of the subregions (65j, 67h, 69d, 71e, 71f, 74b) were also above 6 ppm during the 2004 study. These subregions comprise 29 percent of the state. Data from the other four subregions indicated occasional drops to 5 ppm, especially during evening hours, was typical in unimpaired streams.

6.3.1 Diurnal dissolved oxygen in the Southeastern Plains and Hills (65e)

In 2002, diurnal monitoring was conducted at four reference sites in the Southeastern Plains and Hills. Diurnal dissolved oxygen levels generally stayed above 6 ppm during low flow conditions. Values fell slightly below 6.0 ppm (5.9 ppm) for two hours at one reference site (ECO65E04). The only other reference site to fall below 6 ppm was ECO65E10. Dissolved oxygen fell to 5.3 ppm for 13 hours during a storm event when high water levels and increased turbidity were observed.

To further test minimum dissolved oxygen levels that could be expected to support aquatic life in this region, 15 sites were monitored as part of the 2004 study. This included the four reference sites surveyed in 2002 plus one additional reference site. In addition, eight test sites where biorecon screenings indicated a healthy biological community but daylight DO readings suggested nighttime lows would fall below 6 ppm were tested. Finally, two sites that were listed as impaired for nutrients, a pollutant often associated with low dissolved oxygen, were monitored.

Semi-quantitative macroinvertebrate samples were collected at each of the non-reference test sites to confirm the biorecons. The semi-quantitative samples are much more sensitive than the biorecons, which are more of a screening test. Results showed three of the test sites had impaired biological communities, including two where biorecons had suggested healthy communities. Results from one of the two sites in the nutrient listed segment on the Middle Fork Obion River passed biological guidelines for the region. For purposes of this study, it was concluded that seven of the dissolved oxygen test sites had a healthy macroinvertebrate community and three did not.

Of the five ecoregion reference sites monitored in the 2004 study, dissolved oxygen data were not useable at two sites. Deviation from instantaneous measurements used as a QC check was more than 2 ppm from the continuous monitoring probe at the one week and two week field visits. This indicated the continuous monitoring probes were not holding calibration possibly due to either sediment or sand covering the probes after high flows during the deployment period.

At two reference sites, only the first week of data was useable. At the one reference site (ECO65E06, Griffen Creek) where the entire two-week period was useable, dissolved oxygen fell below 6 ppm for one 36 hour period. Values never fell below 5 ppm (Figure 16). Water levels were low during the first week of the study and were near normal levels by the end of the second week. Stream flow increased from 3 cfs to 9 cfs during this period. Water temperature was about five degrees lower in 2004 than it was in 2002 at all reference sites.

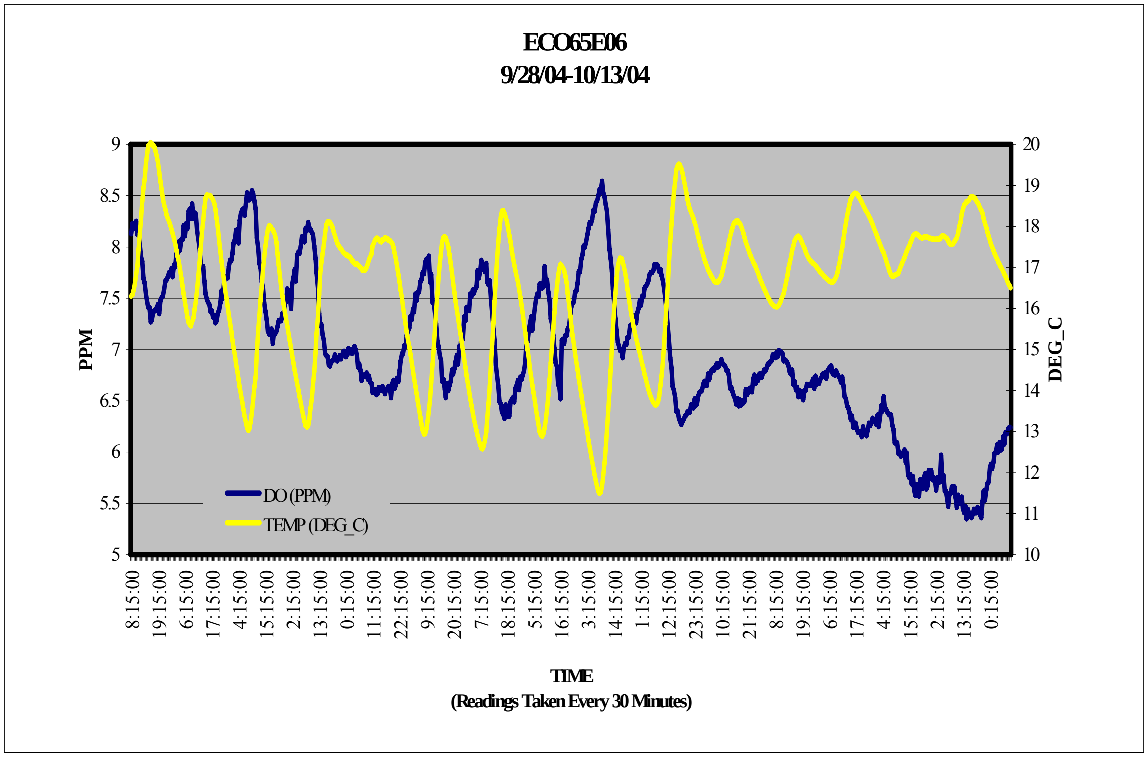


Figure 16: Diurnal dissolved oxygen and temperature at Griffen Creek reference site in the Southeastern Plains and Hills (65e). Measurements taken at 30 minute intervals over a two week period (September 28 – October 13, 2004).

Of the seven non-reference test sites where biological scores passed regional guidelines, all but one had dissolved oxygen levels fall below 6 ppm during the one to two week monitoring period (Table 9). Only one site fell below 5 ppm (Beaver Creek, BEAVE04.4CR). This occurred during a seven-hour period where dissolved oxygen hovered between 4.8 ppm and 5.3 ppm. Data were not useable from one site (Middle Creek, MIDDL002.5 HD), the probe was buried in sediment at the one week check. It was cleaned and reset, but was also found buried in sediment at pick up.

One of the three sites where SQSH samples did not pass regional guidelines, Snake Creek (SNAKE009.8MC), had dissolved oxygen regularly fall below 6 ppm (12 out of 15 nights). DO fell below 5 ppm on three nights. One of the other sites, Old Town Creek (OTOWN002.2HD0) generally remained above 6 ppm although levels fell to 5.9 ppm for one hour. Dissolved oxygen stayed above 6 ppm for the entire two week monitoring period at the third site where biology did not pass regional guidelines.

Based on these results, it appears that streams in this region support healthy biological communities with dissolved oxygen levels below 6 ppm. It also appears that dissolved oxygen levels can fall slightly below 5 ppm (4.8 ppm) for brief periods during the night with no observable detrimental effect to the macroinvertebrate population.

Table 9: Minimum diurnal dissolved oxygen at four reference and 14 test sites in the Southeastern Plains and Hills (65e) during the 2002 and 2004 summer/fall monitoring periods.

Site	Year	Survey Period (weeks)	Biocriteria guidelines?	Min. DO ppm	Freq. less than 6 ppm	Longest duration less than 6 ppm	Longest duration less than 5 ppm	Max. Temp ^{o}C	Max. Diurnal Change ppm
ECO65E04	2002	1	Reference	5.9	1	2 hrs	0	23.9	1
ECO65E04	2004	1	Reference	6.4	0	0	0	18.1	0.5
ECO65E06	2002	1	Reference	6.9	0	0	0	23.5	2
ECO65E06	2004	2	Reference	5.4	1	36 hrs	0	20.0	2
ECO65E08	2002	1	Reference	6.3	0	0	0	25.0	1
ECO65E08	2004	1	Reference	8.1	0	0	0	17.8	1.5
ECO65E10	2002	1	Reference	5.3	1	14 hrs	0	21.3	2
BEAVE004.4CR	2004	2	Pass	4.8	2	42 hrs	7 hrs	18.1	1
BEAVE005.5CR	2002	1	Unknown	5.6	4	60 hrs	0	22.7	1
BSAND0029.7CR	2004	2	Pass	5.1	1	22 hrs	0	18.5	1.5
BSAND0036.4CR	2002	1	Pass	7.0	0	0	0	24.8	1
BSAND0045.2CR	2004	2	Pass	5.4	2	35 hrs	0	19.8	1
CLEAR001.2CR	2002	1	Unknown	4.1	3	27 hrs	8 hrs	25.5	2
CLEAR002.7MC	2004	2	Pass	5.1	8	20 hrs	0	21.2	1.5
HFORK004.0HN	2002	1	Unknown	6.2	0	0	0	22.0	2.5
MFOBI017.6WY	2004	2	Fail	6.4	0	0	0	15.0	1.5
MFOBI1C22.5WY	2004	2	Pass	6.7	0	0	0	15.0	1
MUD004.7CR	2002	1	Unknown	5.8	4	12 hrs	0	22.1	1
OTOWN002.2HD	2004	2	Fail	5.9	1	1 hr	0	15.4	2
SNAKE009.8MC	2004	2	Fail	4.4	12	85 hrs	9 hrs	22.0	1.5
WOAK017.6MC	2004	2	Pass	5.9	1	0.5 hr	0	20.7	1.5

6.3.2 Diurnal dissolved oxygen in the Transition Hills (65j)

Streams in the Transition Hills subregion are higher gradient than other regions in the Southeastern Plains. The increased gradient, coupled with shallow depth and cobble/gravel substrate, provide more opportunity for oxygenation. Diurnal dissolved oxygen was measured for seven consecutive days at four reference sites in this subregion in 2002. DO did not fall below 7 ppm. Dissolved oxygen values did not change more than 1 ppm during each diurnal cycle.

As a further check on minimum dissolved oxygen levels in this region, one reference site (ECO65J05, Dry Creek) was monitored in 2004. During the 2002 study, this creek had the lowest diurnal dissolved oxygen recorded at 7.2 ppm. Only one week of data was used since there was flooding during the second week and the post calibration of the diurnal probe was unsatisfactory. Also, the instantaneous probe measurement at pick-up was 9.1 ppm while the diurnal probe measured 7.2 ppm. As in 2002, dissolved oxygen stayed above 7 ppm throughout the study period (Figure 17). Diurnal fluctuations did not exceed 1 ppm, which was also noted in 2002 at each monitored site.

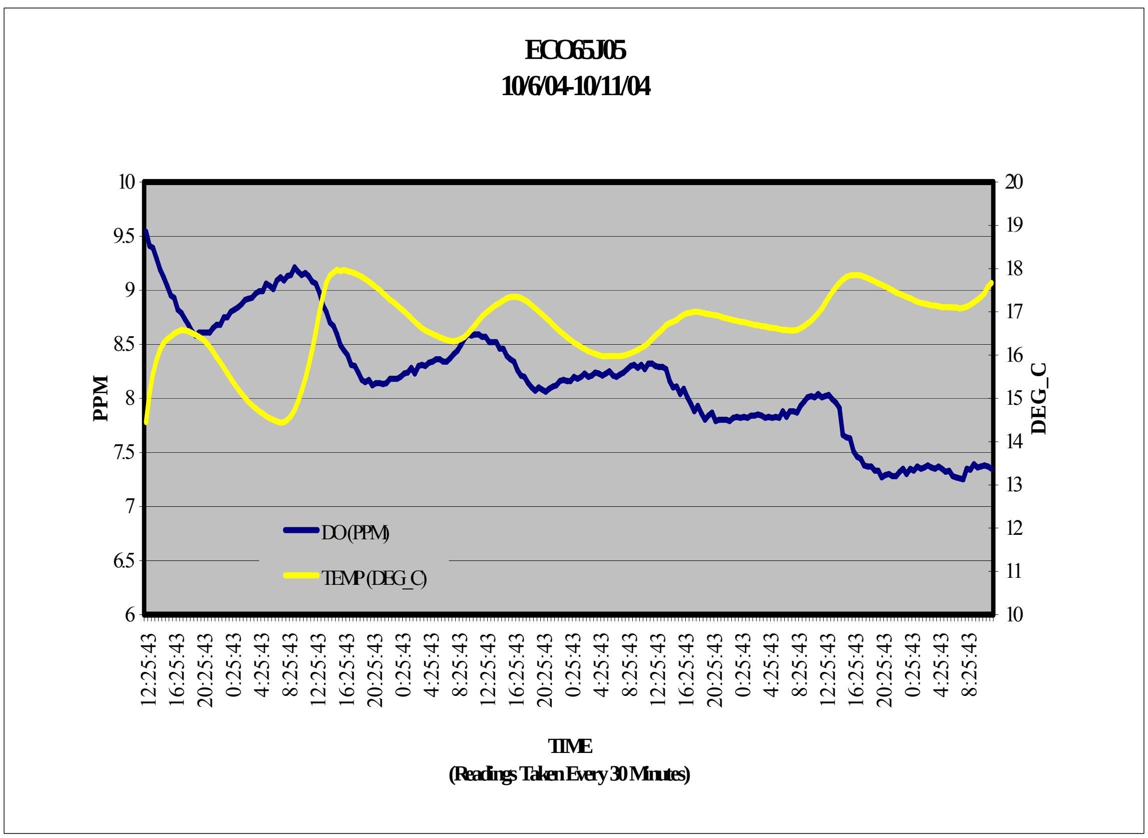


Figure 17: Diurnal dissolved oxygen and temperature at Dry Creek reference site in the Transition Hills (65j).

Instantaneous daylight measurements support the diurnal data from both study years. The 10th percentile of daylight DO from this ecoregion is 7.4 ppm. This is based on 117 measurements taken from 1996 through 2004 at four reference sites and eight test sites that passed biological guidelines. Assuming a diurnal variance of 1 ppm as evidenced by diurnal data, nightly readings would be expected to remain above 6 ppm in this region.

6.3.3 Diurnal dissolved oxygen in the Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f)

In 2002, diurnal monitoring was conducted at three reference streams and three impaired test streams in the Southern Limestone/Dolomite Valleys and Low Rolling Hills. An additional four reference sites had insufficient flow during the monitoring period. In 2002, diurnal dissolved oxygen did not fall below 6.3 ppm at any site. There was typically a 2 ppm fluctuation within each 24 hour period.

During the 2004 study, six reference sites were monitored including the four that were dry in 2002. One additional reference site, ECO67F17, was also surveyed but QC checks and post calibration records indicate data were not reliable. Five non-reference sites that had passed biological guidelines based on semi-quantitative samples were also monitored. Summary data from the 2002 and 2004 diurnal dissolved oxygen surveys are provided in Table 10.

Table 10: Minimum diurnal dissolved oxygen at seven reference and five test sites in the Southern Limestone Dolomite Valleys and Low Rolling Hills (67f). The monitoring period in 2002 was 1 week and 2004 was 2 weeks during the summer/fall seasons.

Site	Year	Biocriteria Guidelines ?	Min. diurnal DO (ppm)	Freq. less than 6 ppm	Duration less than 6 ppm (hours)	Duration less than 5 ppm (hours)	Max. Temp. (°C)	Max. Diurnal Fluctuation (ppm)
ECO67F06	2004	Reference	7.2	0	0	0	19.2	< 1
ECO67F13	2004	Reference	8.0	0	0	0	17.2	< 1
ECO67F14	2002	Reference	6.3	0	0	0	26.8	1.5
ECO67F14	2004	Reference	5.8	1	3	0	23.8	1
ECO67F16	2004	Reference	7.6	0	0	0	19.9	1.5
ECO67F17	2002	Reference	6.4	0	0	0	27.8	2
ECO67F23	2002	Reference	7.6	0	0	0	23.5	1.5
ECO67F23	2004	Reference	7.2	0	0	0	21.0	1.5
ECO67F25	2004	Reference	8.1	0	0	0	26.2	2.5
CAWO000.2CL	2004	Pass	5.4	5	13	0	20.2	2
CROOK001.2BT	2004	Pass	5.7	2	10	0	22.2	1
DAVIS011.6CL	2004	Pass	5.9	1	< 1	0	20.2	< 1
DAVIS014.6CL	2004	Pass	5.8	4	9	0	21.8	1.5
SFLSE001.7MM	2004	Pass	5.8	1	1.5	0	22.0	2

Dissolved oxygen at each reference site except one stayed above 6 ppm for both the 2002 and 2004 monitoring period. DO at the Powell River (ECO67F14) fell to 5.8 ppm during a three-hour period in 2004. Dissolved oxygen levels at each of the five test sites fell below 6 ppm at some point during the 2004 monitoring period although levels remained above 5 ppm. Since all five sites passed biological guidelines, it appears that dissolved oxygen criterion of 5 ppm in this region is protective of fish and aquatic life although reference quality streams typically remain above 6 ppm.

Reference streams in the Southern Limestone/Dolomite Valleys and Low Rolling Hills such as Martin Creek in Hancock County, generally have dissolved oxygen above 6 ppm. *Photo provided by Greg Harris and Carrie Perry, Aquatic Biology Section, TDH.*

6.3.4 Diurnal dissolved oxygen in the Southern Sandstone Ridges (67h) and Southern Dissected Ridges and Knobs (67i).

Combined, these two ecological subregions comprise a very small area in Tennessee (2.2%). Due to the small area and lack of impaired streams in these regions, diurnal dissolved oxygen was not monitored during the 2002 study. Seasonal daylight measurements at reference sites from 1995 through 2002 showed the lowest dissolved oxygen value was 7.7 ppm while most of the measurements were well above 8 ppm. Allowing for a 2 ppm diurnal swing as evidenced in ecoregion 67f, it was conceivable that a minimum diurnal DO of 6 ppm was typical of unimpaired streams in these regions.

To test this preliminary data, the four established reference sites in these two regions were targeted for monitoring in 2004. One site, Parker Branch (ECO67H08), had insufficient water depth to complete the study. Dissolved oxygen at the two reference sites in the Southern Sandstone Ridges (67h) was above 6 ppm for the entire two-week monitoring period. However, DO at the Mill Branch (ECO67I12) reference site in the Southern Dissected Ridges and Knobs (67I) often fell between 5.5 and 6 ppm during the evening hours (Figure 18). Additional data are needed in both these subregions to fully understand diurnal DO patterns.

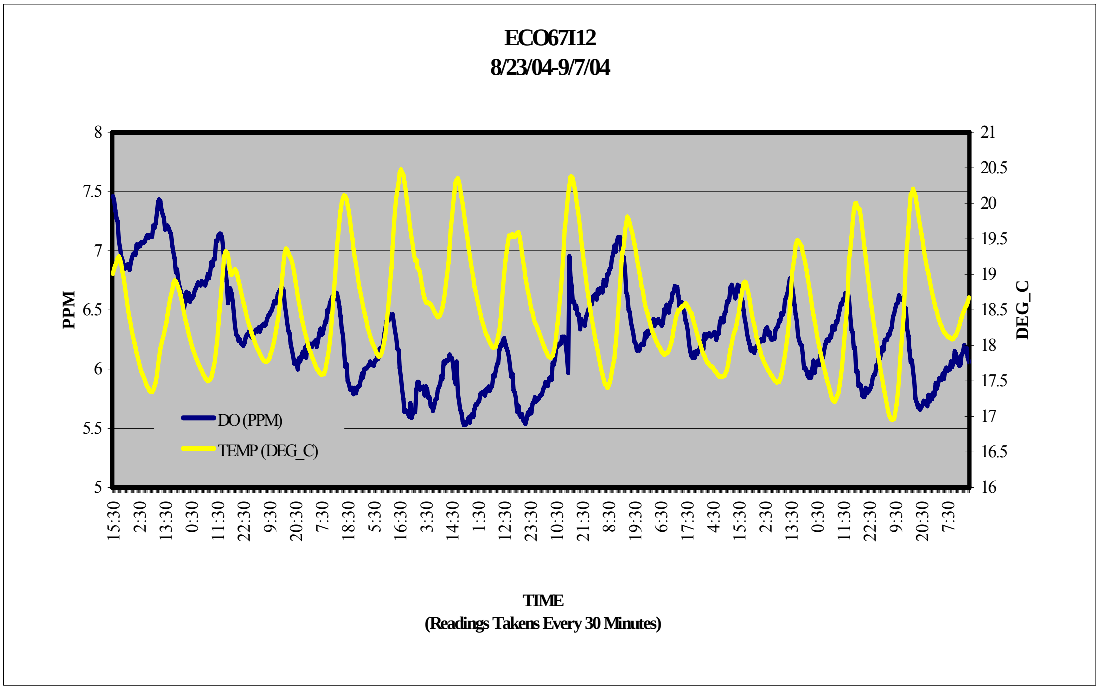


Figure 18: Diurnal dissolved oxygen and temperature at Mill Branch reference site in the Southern Dissected Ridges and Knobs (67I). Monitoring period August 23 through September 7, 2004.

6.3.5 Diurnal dissolved oxygen in the Cumberland Plateau (68a)

During the 2002 study, dissolved oxygen levels in four reference streams on the Cumberland Plateau generally stayed at 6 ppm or higher during the diurnal cycle although values did fall slightly lower for a few hours at two sites during the night. Continuous monitoring probes were deployed at four reference streams and two impaired test streams in this subregion.

Daylight measurements taken seasonally at the eight established ecoregion reference streams over an eight-year period also indicated dissolved oxygen above 6 ppm was typical of unimpaired streams. Only four percent of 93 daylight readings fell below 7 ppm. Diurnal swings were generally less than 1 ppm at reference sites during the 2002 study indicating daylight temperatures that were above 7 ppm would not fall below 6 ppm at night.

Two hundred daylight readings were reviewed from 37 test sites on 28 streams to determine typical dissolved oxygen readings at non-reference streams. Values were below 6 ppm at only seven sites on four streams. All seven sites were located on impaired stream segments.

During the 2004 study, eight reference streams were monitored, including the four streams monitored in 2002. With the exception of Daddy's Creek (ECO69A26), dissolved oxygen stayed above 6 ppm at all reference sites throughout the two-week monitoring period (Table 11). Daddy's Creek fell below 6 ppm on two evenings with the lowest measurement 5.5 ppm. Diurnal fluctuations in 2004 were somewhat higher at two of the reference sites than those recorded in 2002, varying by up to 2 ppm.

Dissolved oxygen in unimpaired streams in this region are generally above 6 ppm especially during daylight hours. However, it appears that occasional drops to 5 ppm especially during the night can be expected and are not detrimental to aquatic life.

Table 11: Minimum diurnal dissolved oxygen at eight reference streams in the Cumberland Plateau (68a). Data were recorded during late summer and fall for a 1 week period in 2002 and a 2 week period in 2004.

Site	Year	Minimum diurnal DO	Frequency less than 6 ppm	Longest duration less than 6 ppm	Longest duration less than 5 ppm	Diurnal Fluctuation (ppm)	Maximum Temperature (^{o}C)
ECO68A01	2002	7.0	0	0	0	< 1	22.4
ECO68A01	2004	6.1	0	0	0	< 1	21.6
ECO68A03	2002	7.6	0	0	0	< 1	23.7
ECO68A03	2004	8.9	0	0	0	1.5s	NA
ECO68A08	2004	6.7	0	0	0	1	24.6
ECO68A26	2002	5.9	1	1 hour	0	1.5	29.9
ECO68A26	2004	5.5	3	14 hours	0	2	24.9
ECO68A27	2002	5.7	5	11 hours	0	< 1	25.8
ECO68A27	2004	6.0	0	0	0	2	22.3
ECO68A28	2004	6.4	0	0	0	1	20.3

6.3.6 Diurnal dissolved oxygen in the Cumberland Mountains (69d)

Streams in the Cumberland Mountains often go dry during the summer. Water depth and flow were only adequate in a single reference stream, No Business Branch (ECO69D06), for diurnal monitoring during the 2002 study period. Minimum dissolved oxygen was 6.5 ppm. Daytime highs generally exceeded 8 ppm. The greatest diurnal swing was 2 ppm. However, it was felt this may not reflect a typical pattern, since water levels dropped at this site during the monitoring period and the probe may have been partially exposed. Water temperatures during the latter half of the week were more than 10 degrees higher then previously recorded at reference sites in this region and may reflect sunlight hitting the probe in extremely shallow water.

In 2004, all five established reference streams were once again targeted for diurnal monitoring. Two of the streams, including the one monitored in 2002, had insufficient water depth for the survey. Flow at the third site, Flat Fork (ECO69D03) was relatively low, filling approximately 60% of the channel, but remained constant at 0.5 cfs throughout the study period. Dissolved oxygen remained above 6 ppm except for one evening when it fell to 5.7 ppm. DO was only below 6 ppm for 6 hours.

Dissolved oxygen at the second reference site with sufficient flow, New River, (ECO69D05) remained above 7 ppm throughout the two-week survey period. Flow levels were normal at this location with water levels reaching the base of both banks.

Water levels were low, filling approximately 50% of the channel width, at the final reference site surveyed in this region, Round Rock Creek (ECO69D06). There was a rain event at the end of the first week. The stream became very turbid, possibly due to upstream logging. However, water levels did not rise significantly while staff were at the site and flow dropped from 1.17 cfs to 0.3 cfs throughout the survey period. Despite the relatively low flow and turbidity during a rain event, dissolved oxygen remained above 6.5 ppm throughout the two-week survey period (Figure 19). Maximum diurnal variation was approximately 2 ppm.

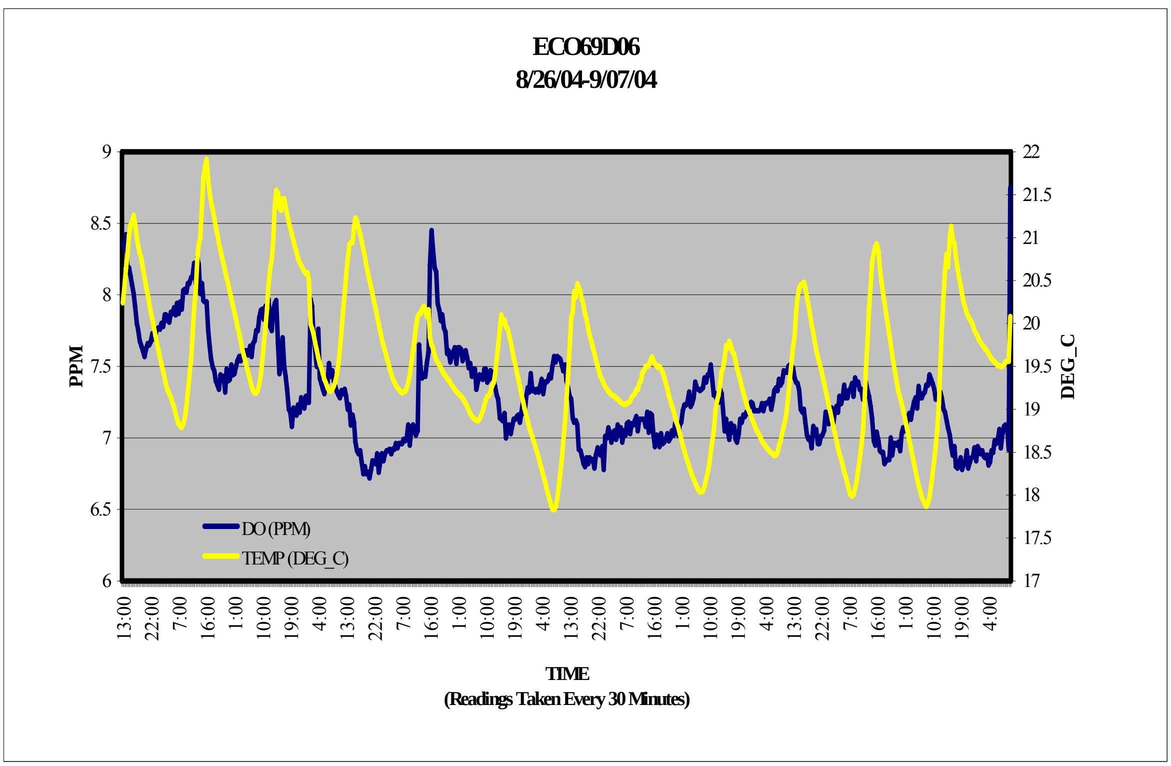


Figure 19: Diurnal dissolved oxygen and temperature at Round Rock Creek reference site in the Cumberland Mountains (69d). Survey period was August 26 - September 7, 2004.

Based on diurnal data from reference streams in both 2002 and 2004, it appears that streams in the Cumberland Mountains would be expected to maintain dissolved oxygen levels above 6 ppm even during low flow conditions. However, occasional drops below 6 ppm (but above 5 ppm) appear to occur during night time hours.

6.3.7 Diurnal dissolved oxygen in the Western Pennyroyal Karst (71e)

Diurnal dissolved oxygen probes were deployed at two reference sites and three impaired test sites in this subregion during the 2002 study. The minimum dissolved oxygen level was 6.4 ppm. Diurnal swings were more pronounced at the Passenger Creek (ECO71E14) reference site, fluctuating almost 3 ppm during some 24-hour cycles. Buzzard Creek (ECO71E09) fluctuated less than 2 ppm during each cycle.

For the 2004 survey period, diurnal probes were once again deployed at the two established reference sites as well as two unimpaired streams. Another unimpaired stream was targeted for monitoring but had insufficient water depth. Dissolved oxygen at the Buzzard Creek reference site remained above 7 ppm throughout the survey period (Figure 20). DO at the Passenger Creek reference site did not fall below 6.9 ppm.

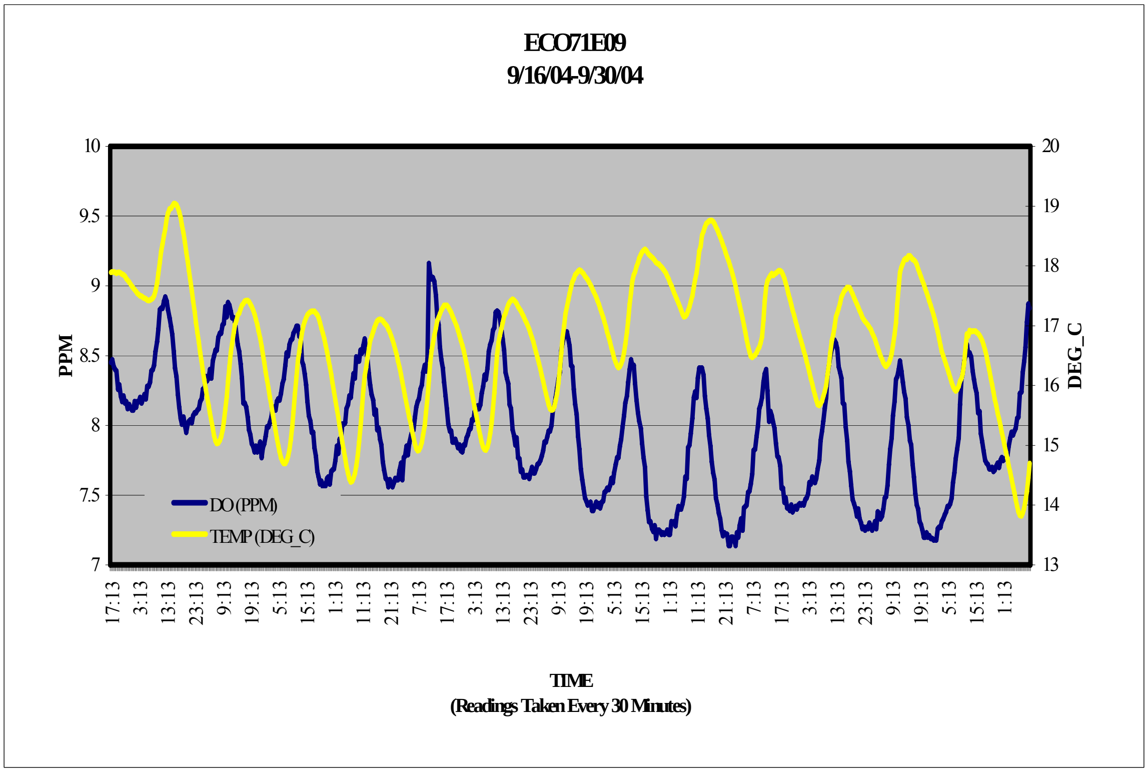


Figure 20: Diurnal dissolved oxygen and temperature at Buzzard Creek reference site in the Western Pennyroyal Karst (71e). Survey period was September 16 – 30, 2004.

Dissolved oxygen levels at the two unimpaired test sites also stayed above 6 ppm throughout the 2-week survey period. Red River never fell below 7 ppm while the Little West Fork dropped to 6.4 ppm.

6.3.8 Diurnal dissolved oxygen in the Western Highland Rim (71f)

In 2002, continuous monitoring probes were deployed at five reference sites in the Western Highland Rim. Dissolved oxygen stayed well above 6 ppm, with the lowest measurement 6.8 ppm at Swanegan Branch (ECO71F27). The other four reference sites stayed above 7 ppm. Diurnal fluctuations were typically less than 2 ppm although the South Harpeth Creek (ECO71F12) reference site varied by 3 ppm within a 24-hour period during a storm event.

During the 2004 study, diurnal probes were once again set at the five reference sites monitored in 2002 plus one additional reference stream that was established in 2003, Hurricane Creek (ECO71F29). Two unimpaired streams were also targeted for monitoring but had insufficient flow during the survey period.

Once again, dissolved oxygen remained above 6 ppm at all reference sites (Table 12). Levels were generally above 7 ppm even during evening hours. Diurnal fluctuations were 1 to 2 ppm. The highest water temperature recorded for daylight monitoring was 24.0^{o}C with the 90th percentile at 22.1 ^{o}C. Maximum water temperatures during both the 2002 and 2004 diurnal studies were comparable and should be considered reflective of typical conditions.

Table 12: Minimum diurnal dissolved oxygen at six reference streams in the Western Highland Rim (71f). Data were recorded during late summer and fall for a one week period in 2002 and a 2 week period in 2004.

Site	Year	Minimum diurnal DO	Frequency less than 6 ppm	Longest duration less than 6 ppm	Longest duration less than 5 ppm	Max. Diurnal Fluctuation (ppm)	Maximum Temperature (^{o} C)
ECO71F12	2002	7.7	0	0	0	2	23.4
ECO71F12	2004	6.4	0	0	0	2	22.3
ECO71F16	2002	7.1	0	0	0	1	21.4
ECO71F16	2004	7.4	0	0	0	1	20.0
ECO71F19	2002	6.9	0	0	0	1	20.4
ECO71F19	2004	7.0	0	0	0	1.5	21.3
ECO71F27	2002	6.8	0	0	0	1	20.7
ECO71F27	2004	6.7	0	0	0	1.5	17.9
ECO71F28	2002	7.4	0	0	0	1.5	20.6
ECO71F28	2004	7.6	0	0	0	2.0	22.0
ECO71F29	2002	6.3	0	0	0	2.0	21.4

Nine years of seasonal daylight measurements (1996-2004) at the same five reference sites also indicate minimum DO levels above 6 ppm are typical of unimpaired streams in this region (Figure 21). The 10^{th} percentile of 162 measurements was 8.0 ppm. Allowing for a 2 ppm drop at night, DO values should not fall below 6 ppm in these streams.

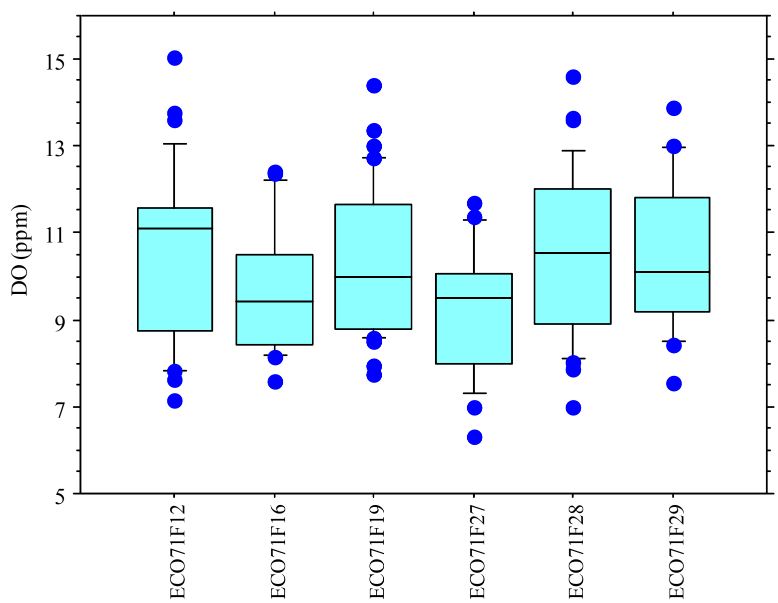


Figure 21: Summary daylight dissolved oxygen levels at five reference sites in the Western Highland Rim (71f). One hundred and sixty two measurements were taken seasonally with instantaneous probes from 1996 to 2004.

6.3.9 Diurnal dissolved oxygen in the Loess Plains (74b)

Diurnal monitoring was conducted in 2002 at one reference site, Terrapin Creek (ECO74B01) in the Loess Plains. Although three reference sites are established in this region, two had inadequate flow. At Terrapin Creek, only 94 hours of low flow data were recorded due to heavy rains the last three days of monitoring. Dissolved oxygen did not fall below 6.5 ppm and generally fluctuated by less than 2 ppm during each diurnal period.

The maximum water temperature of 20.6 ^{o}C recorded during the first 94 hours was 2.8^{o}C lower than the maximum daylight reading from 1995 to 2002 at this site. Because of the relatively low water temperatures and short monitoring period at the only reference site that had sufficient flow for monitoring, all three established reference streams were targeted for monitoring in 2004. Unfortunately the monitoring equipment at one site, Wolf River (ECO74B12), was compromised due to sediment filling the sensor compartment. The probe was cleaned and reset, however a calibration check was not performed at set-up or retrieval nor is an instantaneous measurement available for the final day of continuous monitoring due to sampler error. Due to the lack of quality assurance and the suspect pattern of the continuous measurements, dissolved oxygen data from this site were not used.

Only one week's data were retrieved from Powell Creek (ECO74B04) due to the need to re-locate the monitoring equipment after it was buried by sand during the initial monitoring week. Dissolved oxygen remained above 7.5 ppm throughout the one-week monitoring period with fluctuations less than 1 ppm during each 24-hour cycle.

Two weeks of data were retrieved from Terrapin Creek (ECO74B01), the site that was also monitored in 2002. The 2004 DO measurements were similar to those recorded two years earlier with DO not falling below 7 ppm. Diurnal fluctuations were generally around 1 ppm.

Water temperatures were once again significantly lower than the maximum temperatures recorded in the last 12 years at this site. Therefore, there is a possibility the diurnal data may not reflect the lowest dissolved oxygen occurring during periods of high temperatures. However, daylight dissolved oxygen measurements at the five highest temperatures recorded at each reference site would remain at or above 6 ppm allowing for a 1 ppm nighttime drop in DO (Table 13). The 10th percentile of dissolved oxygen data from all 93 daylight measurements over the 12-year period was 7.5 ppm.

Table 13: Daylight dissolved oxygen levels at maximum temperatures recorded at three reference sites in the Loess Plains (74b). Based on five maximum temperatures recorded at each site between 1996 and 2005 (93 measurements).

Ecoregion Reference Site	Date	Maximum Temperature (^{o}C)	Daylight Dissolved Oxygen (ppm)
ECO74B01	08/20/1997	21.7	7.0
ECO74B01	06/04/2002	20.4	8.4
ECO74B01	08/20/2001	20.0	9.9
ECO74B01	09/11/1996	19.1	8.8
ECO74B01	09/05/1996	18.6	8.7
ECO74B04	08/19/1998	21.3	8.4
ECO74B04	08/20/1997	20.1	7.6
ECO74B04	06/04/2002	20.0	8.8
ECO74B04	08/20/2001	20.0	9.1
ECO74B04	09/04/1996	18.3	9.4
ECO74B12	08/24/1998	23.5	7.6
ECO74B12	08/04/2003	22.9	7.2
ECO74B12	08/03/1996	22.6	7.6
ECO74B12	08/25/1997	21.3	7.9
ECO74B12	08/06/1997	21.3	7.7

6.4 Dissolved Oxygen Levels in the Blue Ridge Mountains

In Tennessee, the Blue Ridge Mountains encompass four Level IV ecoregions, the Southern Igneous Mountains and Ridges (66d), the Southern Sedimentary Ridges (66e), the Limestone Valleys and Coves (66f) and the Southern Metasedimentary Mountains (66g). Dissolved oxygen levels in the Blue Ridge Mountains are higher than any other ecoregion in Tennessee. The steep gradients, cold water temperatures and rocky substrates facilitate oxygenation. Nutrient levels are naturally low in these regions, so algae and aquatic plants are not abundant. Diurnal fluctuations are minimal, less than 2 ppm in most subregions, likely because photosynthesis is not the primary source of oxygen. Aquatic life in the Blue Ridge Mountains has adapted to the consistently high dissolved oxygen and are dependent on its availability.

During the 2002 study, nine reference streams were monitored in three of the Blue Ridge subregions. Reference sites were not monitored in the Southern Igneous Ridges and Mountains (66d). Dissolved oxygen stayed above 7 ppm at all reference sites monitored.

Fifteen sites were monitored for dissolved oxygen in the Blue Ridge Mountains during the 2004 study. Sites included two established reference sites in the Southern Igneous Mountains and Ridges (66d) that were not monitored in 2002. Three additional 66d reference sites were targeted but the DO probes did not hold calibration and data were not used. The study also included one unimpaired test site in this region. Dissolved oxygen levels at all four sites stayed above 7 ppm throughout the monitoring period. Diurnal fluctuations were 1.5 ppm or less. Maximum water temperatures in both study years were at or above those recorded in the last ten years at the reference sites (Table 14).

In 2004, three reference sites were surveyed in the Southern Sedimentary Mountains (66e). Two of these sites had not been monitored during the 2002 study. Dissolved oxygen did not fall below 7 ppm in either the 2002 or 2004 study periods. Diurnal fluctuation was below 1 ppm. Maximum water temperatures in 2002 exceeded ten year maximums, while those recorded in 2004 were somewhat lower.

A continuous monitoring probe was deployed at one reference site in the Limestone Valleys and Coves (66f), which was also surveyed in 2002. An unimpaired test site was also monitored. Two additional reference sites were targeted, but the DO probes did not pass QC checks and data were not used. Dissolved oxygen did not fall below 7 ppm during either monitoring period. Diurnal fluctuations did not exceed 1.5 ppm. Water temperatures in both 2002 and 2004 exceeded the highest temperature recorded at the reference sites within the last ten years of daylight monitoring.

In the Southern Metasedimentary Mountains (66g), three of the five reference streams surveyed in 2002 were also monitored in 2004. Dissolved oxygen did not fall below 7 ppm. Diurnal fluctuations were 1 ppm or less. In 2002, water temperatures exceeded the ten year highs recorded at the reference sites. Water temperatures in 2004 was somewhat lower.

Table 14: Summary dissolved oxygen and temperature data from 13 reference and three unimpaired test sites in the Blue Ridge Mountains. Data represent diurnal monitoring from 2002 and 2004 as well as daylight readings from 1995 –2005.

Ecoregion	Site	Year	Min. Diurnal DO (ppm)	Min Daylight DO (ppm)	Max. Diurnal Fluc. (ppm)	Max. Diurnal Temp (°C)	Max Daylight Temp (°C)
66d	ECO66D06	2004	7.8	8.6	< 1	18.0	18.0
66d	ECO66D07	2004	7.1	8.4	1	18.4	17.6
66d	DEVIL000.2UC	2004	7.4	NA	1.5	19.9	NA
66d	ROCKY000.2UC	2004	8.3	NA	1	17.2	NA
66e	ECO66E04	2002	7.7	8.3	< 1	18.9	18.6
66e	ECO66E04	2004	8.0	8.3	< 1	18.1	18.6
66e	ECO66E09	2004	7.0	8.1	< 1	20.2	20.3
66e	ECO66E11	2002	8.0	8.5	< 1	19.0	18.7
66e	ECO66E18	2004	7.7	8.5	< 1	18.7	22.6
66f	ECO66F07	2002	7.5	8.0	1	22.4	20.3
66f	ECO66F08	2002	7.7	7.9	1.5	22.8	16.8
66f	ECO66F08	2004	7.0	7.9	< 1	17.5	16.8
66f	NINDI010.5UC	2004	7.4	NA	1	19.7	NA
66g	ECO66G04	2002	8.2	9.0	< 1	20.8	19.0
66g	ECO66G04	2004	8.4	9.0	< 1	16.8	19.0
66g	ECO66G05	2002	7.3	8.1	< 1	20.0	17.8
66g	ECO66G07	2002	7.3	7.9	1	26.5	24.9
66g	ECO66G07	2004	7.0	7.9	1	23.6	24.7
66g	ECO66G09	2002	8.2	8.5	< 1	20.6	19.2
66g	ECO66G09	2004	7.2	8.5	1	18.3	19.2
66g	ECO66G12	2002	7.4	8.1	1	24.0	23.2

6.5 Dissolved Oxygen in the Bluff Hills (74a)

Diurnal dissolved oxygen data were not available from the Bluff Hills prior to this study. The region was not included in the 2002 project due to its small size, approximately one percent of the state. Ninety-three percent of daylight measurements taken at reference sites from 1995 through 2002 were above 7 ppm. Additional study was needed to determine the magnitude of diurnal swings. Therefore diurnal monitoring at the two established ecoregion reference sites were included in the 2004 study.

The first of the reference sites, Sugar Creek (ECO74A06) had very little flow (0.4 cfs) when the probe was deployed. Flow dropped to 0.1 cfs by the end of the first week and the probe was exposed. Based on conductivity measurements, it appeared that the probe had been exposed for two days. An instantaneous measurement of DO was 8 ppm. The probe was reset in a pool to provide adequate depth. A storm event occurred during the second monitoring period (Figure 22) and the probe was pushed out of the pool.

When the water receded the probe was once again exposed. Based on conductivity measurements, this appeared to have occurred five days after the probe was reset. Dissolved oxygen readings for the period when the probe appeared to be submerged fluctuated between 5 and 7 ppm. (Figure 23). However, these results should be viewed with caution especially since instantaneous readings taken at set-up, 1-week and 2-week intervals read 9.2, 8.1 and 9.0 ppm.

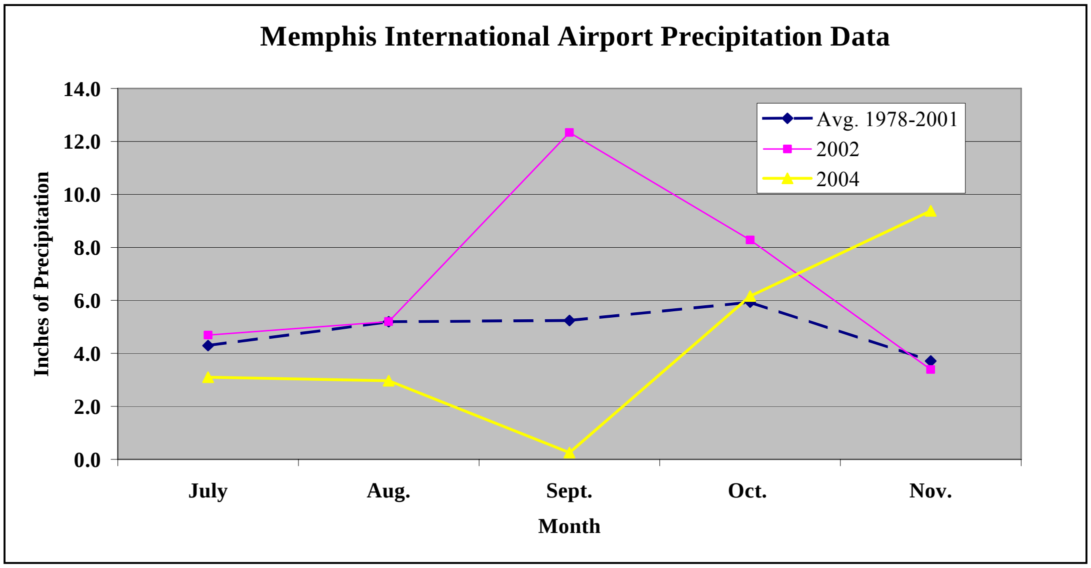


Figure 22: Daily precipitation data from Memphis International Airport during diurnal monitoring period 10/18 – 11/10/04. Chart includes average rainfall for the same period from 1978 to 2004.

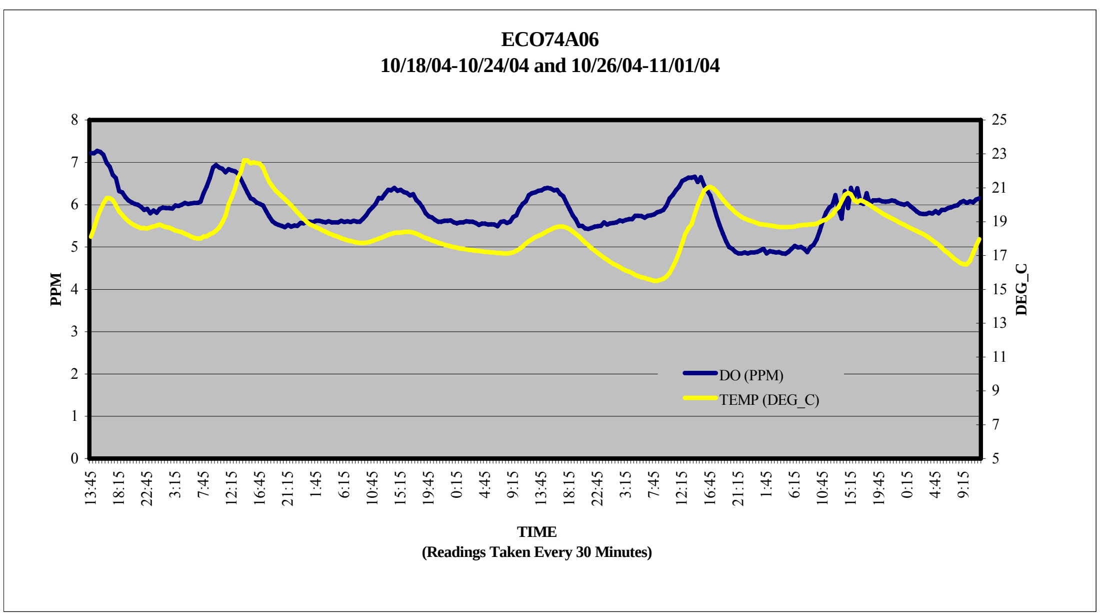


Figure 23: Diurnal dissolved oxygen and temperature at Sugar Creek reference site in the Bluff Hills (74a).

A dissolved oxygen probe was deployed at the second reference site, Pawpaw Creek (ECO74A08), on November 2 after a two inch rain the previous day. Flow was 27.1 cfs on this date and dropped to 2.3 cfs during the first week. The second week flow held steady at this level. Dissolved oxygen did not fall below 7.5 ppm throughout the two-week monitoring period (Figure 24).

Based on these data, it appears that streams in the Bluff Hills have relatively high dissolved oxygen levels (7 ppm minimum) during periods of normal or high flow. The Sugar Creek data suggest that DO does fall to 5 ppm during periods of low flow. However, these data are questionable when compared to instantaneous measurements taken during the same period. It appears necessary for additional diurnal monitoring to be conducted before characterization of minimum DO levels in this region can be made.

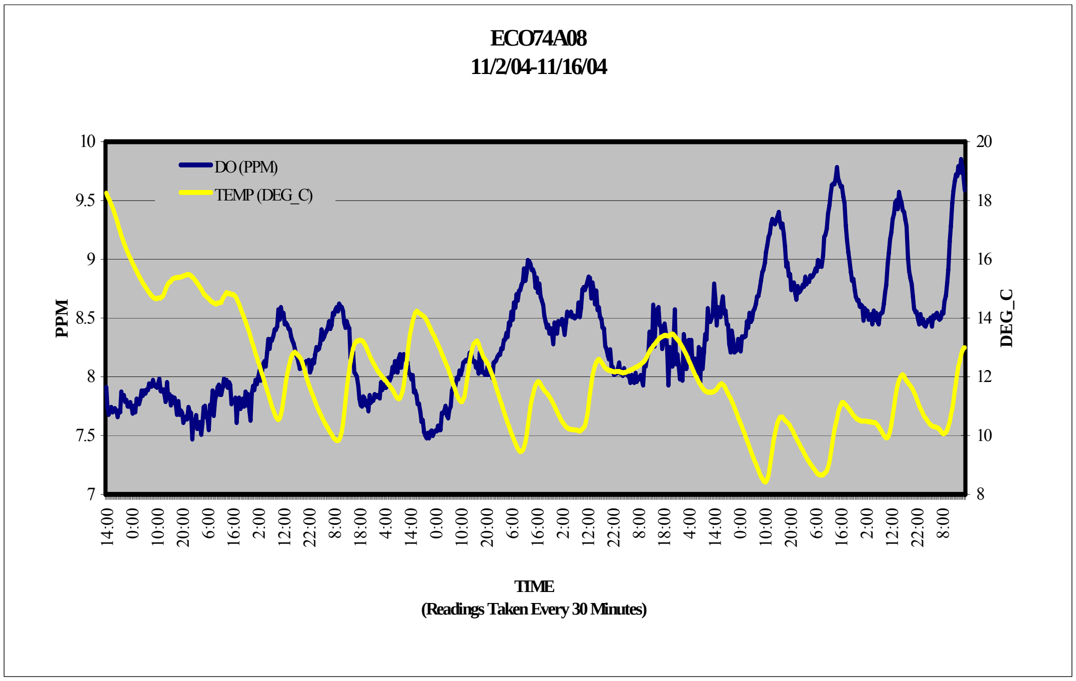


Figure 24: Diurnal dissolved oxygen and temperature at Pawpaw Creek reference site in the Bluff Hills (74a).

6.6 Dissolved Oxygen in the Outer Nashville Basin (71h)

Prior to this study, inadequate diurnal dissolved oxygen information was available in this region to identify typical DO patterns. Three ecoregion reference sites were targeted for monitoring in 2002, but two sites had inadequate flow for probe deployment. Data from the third site was questionable when checked against instantaneous readings at the end of the monitoring week (differed by 4 ppm).

The two sites that were dry in 2002 were targeted for monitoring in 2004. Unfortunately, one of the sites was also dry in 2004. A monitoring probe was deployed at Clear Fork (ECO71H06). Flow fluctuated between 2.3 and 6.8 cfs during the two-week monitoring period with water reaching the base of both banks. Dissolved oxygen did not fall below 6 ppm (Figure 25). The highest diurnal temperature was within 1^{o}C of the highest daylight measurement between 1995 and 2005 at any reference site in this ecoregion so DO should reflect typical high temperature conditions.

The lowest DO level recorded from the ten years of available data from daylight monitoring was 7.2 ppm. Ninety-eight percent of the measurements were over 8 ppm. Diurnal fluctuations at Clear Fork were generally 1.5 ppm or less. Based on daylight measurements and limited diurnal data, it is possible that 6 ppm is typical of biologically diverse streams in the Outer Nashville Basin. Diurnal monitoring data are needed from the other two reference sites as well as unimpaired test sites to fully characterize diurnal DO patterns.

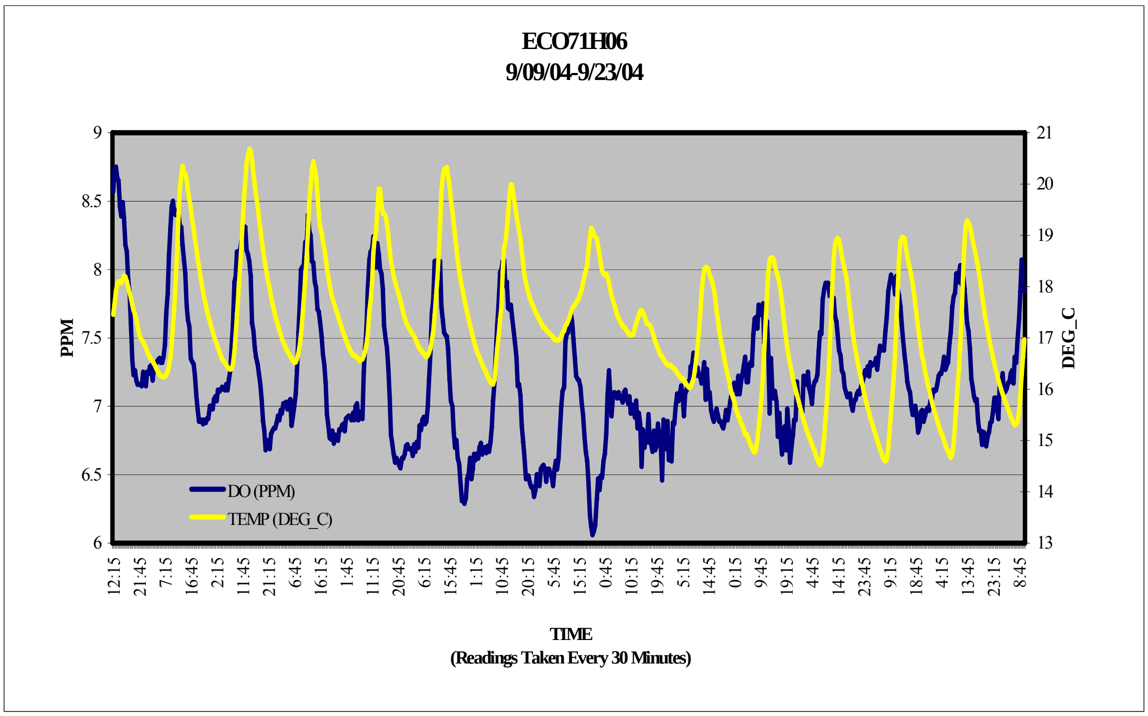


Figure 25: Diurnal dissolved oxygen and temperature at Clear Fork reference site in the Outer Nashville Basin (71h).

6.7 Diurnal dissolved oxygen in the Southern Shale Valleys (67g)

In 2002, five reference sites were monitored as part of the diurnal dissolved oxygen study in the Southern Shale Valleys. DO in this subregion was typically lower than the rest of the Ridge and Valley ecoregion. Minimum levels dropped to 5 ppm at three of the sites on a regular basis during evening hours and dropped below five at the other two sites for brief periods.

A new reference station on North Prong Fishdam Creek (ECO67G11) was added in April 2003 and was included in the 2004 study. The macroinvertebrate population at this location is one of the most diverse in the region. DO stayed above 6.5 ppm throughout the 2-week monitoring period. However, based on the 2002 data from the other reference streams in this ecoregion, dissolved oxygen levels of 5 ppm are typical of many streams.

7. GEOMORPHOLOGY

A second objective of this study was to characterize the geomorphology of established ecoregion reference streams where data were not already available. This was added to exiting reference data in order to classify stream and valley types in the nineteen ecoregions covered by this study. Geomorphological characterization can be used to determine changes in sediment, bed load, bank erosion and channel stability that have the potential to affect aquatic life. It can also help predict how physical disturbance will affect stream patterns and provide information on what is needed to restore impaired streams. Cross-section charts and particle counts from the streams surveyed for this study as well as historic reference data are provided in Appendix C.

7.1 Geomorphology and Stream Classification

The Rosgen stream classification system was used to characterize the geomorphology of reference streams found in the 19 ecoregions surveyed (Rosgen, 1996). This stream classification is based on physical processes and assumes that stream morphology is dependent on landscape position. There are four hierarchical levels of the Rosgen classification. The first level describes a stream's geomorphologic characterization. The second level is a morphological description of the stream's characteristics. The third level assesses the stream condition and its stability. The fourth level is a confirmation of predictions made in Level III. Empirical relationships are developed at this level. Streams in this study were classified to Level II.

7.1.1 Level I Classification

Level I classification is the least specific. It provides a general characterization of valley types and landforms, and allows for a rapid initial geomorphological delineation of stream types. Aerial photos and topographic maps were used to determine channel patterns and valley type for this classification. The Rosgen classification system has eight Level I categories. The Tennessee reference streams surveyed in this project fell into five of these categories: "A", "B", "C", "F", and "G".

Type A streams are high gradient with slopes from 4 to 10%. These are cascading streams with little sinuosity. Channels are entrenched and flow through steep, narrow V-shaped valleys that confine the stream to its channel. This type of stream does not have a developed floodplain. In Tennessee, type A streams were found in the Southern Igneous Ridges and Mountains (66d) of the Blue Ridge Mountains.

Type B streams are moderate to high gradient with a slope from 2 to 4%. They have riffle dominated channels that are wider and more sinuous than type A streams. These streams are moderately entrenched and flow through steep valleys. They have a broader valley than type A but still lack a well-developed floodplain. Type B streams are found in most Tennessee ecoregions including the Transition Hills (65j), Southern Igneous Ridges and Mountains (66d), Southern Sedimentary Ridges (66e), Southern Metasedimentary Mountains (66g), Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f), Southern Shale Valleys (67g), Southern Sandstone Ridges (67h), Cumberland Plateau (68a), Cumberland Mountains (69d) and the Western Highland Rim (71f).

Type C streams are low gradient with a slope less than 2%. These are riffle streams that tend to be wider and more sinuous than type B streams. They are moderately entrenched with well-developed floodplains and point bars within the active channel. Valleys are formed from alluvial deposition. In Tennessee, this stream type is found in the Southeastern Plains and Hills (65e), Limestone Valleys and Coves (66f), Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f), Southern Shale Valleys (67g), Southern Sandstone Ridges (67h), Southern Dissected Ridges and Knobs (67i), Western Pennyroyal Karst (71e), Outer Nashville Basin (71h), Inner Nashville Basin (71i), and the Bluff Hills (74a).

Type F streams have slopes less than 2%. They tend to be wide, deeply entrenched, and sinuous. These streams create new floodplains by increasing their width within the valley. High bank erosion rates yield a heavy sediment load. In Tennessee, type F streams are found in the Southeastern Plains and Hills (65e), Loess Plains (74b) and the Northern Mississippi Alluvial Plain (73a).

Type G streams have a slope from 2 to 4%. They tend to be narrow and deeply entrenched. Sinuosity is low to moderate. High bank erosion rates result in a heavy sediment load. These stream can be found in a wide variety of landforms including alluvial fans and channels within older relic channels. In Tennessee, type G streams are found in the Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f).

The determination of valley type and corresponding fluvial and topographical features provides a foundation on which the Level I stream classification is based. Streams develop within many different types of valleys. There are eleven different valley types in the Rosgen classification system. Four of these (I, II, VIII and X) were found at reference streams in the nineteen ecoregions surveyed for this project.

Type I valleys are V-shaped with steep gradients. They are confined within highly dissected fluvial slopes. Valley materials range from bedrock to residual soils. The valleys are structurally controlled. Streams found in this type of valley are generally type A and type G. Type I valleys were uncommon in this study, occurring only in the Southern Igneous Ridges and Mountains (66d).

Type II valleys are moderate relief with moderate side slope gradients. The soils associated with this type of valley are depositional materials. Streams found in this type of valley are type B and less commonly type G. This is a frequent valley type encountered in Tennessee and is found in most middle and eastern ecoregions within the state.

Type VIII valleys have gentle gradients and broad valley floors. They are not confined and allow streams to meander. Landforms associated with this type of valley include alluvial terraces and floodplains. In Tennessee, only one stream type, C, is found in type VIII valleys. This valley type is found in most west, middle and east Tennessee ecoregions.

Type X valleys have very wide and gentle gradients with extensive floodplains. The soils associated with this type of valley are from alluvial materials. Landforms include coastal plains, alluvial flats, and wetlands. In Tennessee, streams found in these valleys are type C and E, and where streams have been channelized, type F. This valley type is found in the Southeastern Plains and Hills (65e), Loess Plains (74b) and Mississippi Alluvial Plain (73a) in west Tennessee.

7.1.2 Level II Classification

Level II classification is more specific to a particular stream reach. The classification of a stream changes along the river channel when there are changes in geology and tributary influence. Topographic maps, aerial photos and the Montana State University Environmental Statistics Group website were used to determine elevation, stream slope and channel sinuosity to aid in this classification level. Field measurements were used to determine channel cross-section and the dominant bed material.

Knowing the size of the bed material helps determine the extent of sediment transport in a stream. This aids in determining channel stability and availability of habitat for aquatic life. Both the calculated dominant bed material (D50) based on field measurements and an estimate of substrate composition based on field observations over a ten year period were used to determine the dominant bed material for streams in each ecoregion.

The calculated dominant bed material (D50) is the median substrate particle size based on measurements of 100 particles randomly selected across the flow transect (Figure 26). This may be biased since the flow transect was usually selected in a run area with relatively equal flow across the channel and tended to avoid boulders or other obstructions. For this reason, the estimated dominant bed material was also considered when classifying the streams. Multiple field estimates were available from most of the reference streams and represented a ten-year period. These were visual observations of the percent contribution of various substrate sizes within a typical 100 yard stream reach. The estimated bed material may be biased since particle size is not measured. Both the estimated dominant bed material and calculated D50 were grouped into one of six categories for classification purposes (Table 15).

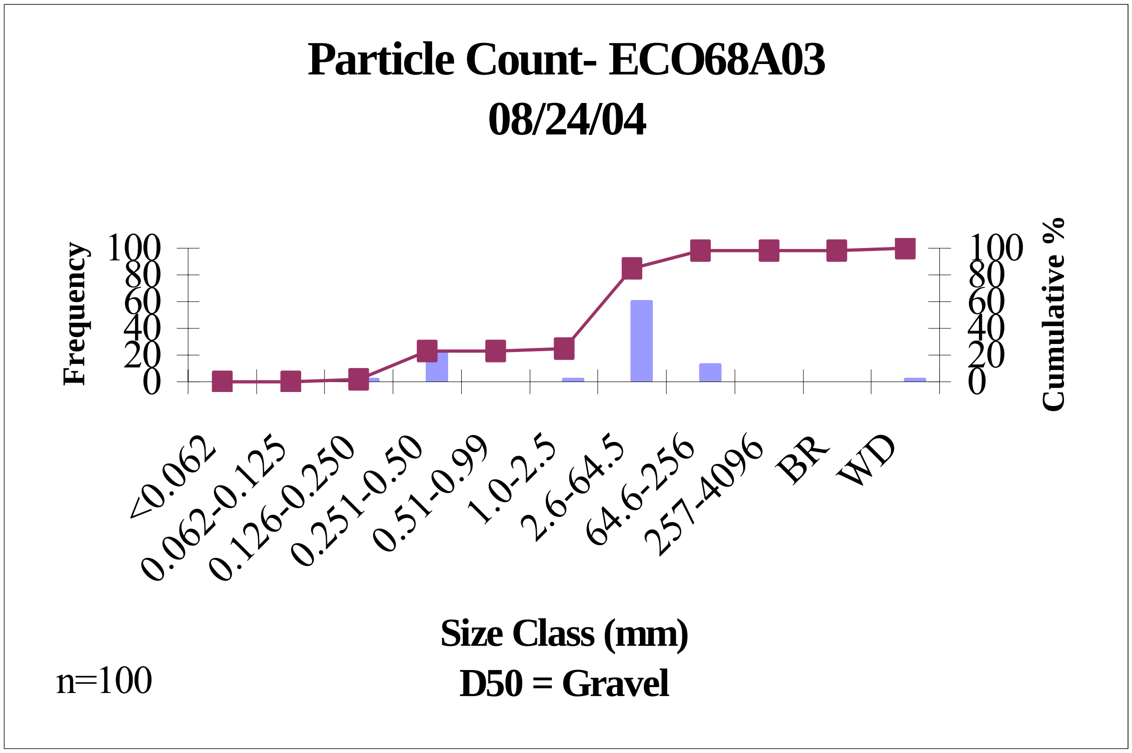


Figure 26: Particle count and calculated D50 for Laurel Fork Station Camp Creek reference site in the Cumberland Plateau (68a).

Table 15: Grouping of calculated particle size (D50) into Rosgen classifications of dominant bed material

Particle Size (mm)	Description	Rosgen Classification
> 4096	Bedrock	1
256 – 4096	Boulder	2
64 – 256	Cobble	3
2 – 64	Gravel	4
0.062 – 2	Sand (includes 5 categories from fine to very coarse)	5
< 0.062	Silt/Clay	6

All of the classification elements were combined to classify reference streams in each of the 19 ecoregions included in this study (Table 16). These data will be used in future studies to compare potentially impaired stream channels to typical reference condition.

Table 16: Geomorphological characterization of reference streams in 19 ecoregions in Tennessee. Stream type and valley type are based on Rosgen classification system.

Station ID	Stream Name	Elevation (Ft)	Stream Order	Estimated Dominant Substrate	Calculated D50	Stream Type	Valley Type
ECO65E04	Blunt Creek	411	4	Sand	Sand	C5	VIII
ECO65E06	Griffin Creek	481	3	Sand		C5	VIII
ECO65E08	Harris Creek	411	3	Sand	Sand	C5	VIII
ECO65E10	Marshall Creek	481	3	Sand	Sand	F5	X
ECO65E11	WF Spring Ck	441	4	Sand	Silt/Clay	F6	X
ECO65J04	Pompeys Br	499	2	Cobble	Gravel	B4	II
ECO65J05	Dry Creek	503	4	Cobble	Gravel	B4	II
ECO65J06	RF Whites Ck	638	2	Gravel	Sand*	B4	II
ECO65J11	UT RF Whites C.	659	2	Cobble	Gravel	B4	II
ECO66D01	Black Branch	2604	2	Gravel	Gavel	A4	I
ECO66D03	Laurel Fork	2696	3	Cobble	Gravel*	B3	II
ECO66D05	Doe River	2998	4	Cobble	Cobble	B3	II
ECO66D06	Tumbling Creek	3069	2	Cobble	Cobble	A3	I
ECO66D07	Little Stoney Ck	2689	3	Cobble	Cobble	A3	I
ECO66E04	Gentry Creek	3002	3	Cobble	Gravel*	B3	II
ECO66E09	Clark Creek	1624	4	Gravel	Gravel	B4	II
ECO66E11	L Higgens Ck	2494	3	Boulder	Cobble*	B2	II
ECO66E17	Double Branch	1182	3	Boulder	Gravel	B4	II
ECO66E18	Gee Creek	883	2	Cobble	Gravel*	B2	II
ECO66F06	Abrams Creek	1732	4	Bedrock	Gravel	C4	VIII
ECO66F07	Beaverdam Creek	2402	4	Cobble		C3	VIII
ECO66F08	Stony Creek	2417	4	Cobble	Cobble	C3	VIII
ECO66G05	Little River	2300	4	Boulder	Cobble*	B2	II
ECO66G07	Citico Creek	900	4	Cobble	Gravel*	B3	II
ECO66G09	North River	1954	3	Cobble	Gravel	B4	II
ECO66G12	Sheeds Creek	1180	3	Cobble	Cobble	B3	II
ECO67F06	Clear Creek	899	3	Cobble	Gravel	B4	II
ECO67F13	White Creek	1099	3	Gravel	Bedrock*	B4	II
ECO67F14	Powell Creek	1201	5	Cobble	Gravel	C4	VIII
ECO67F16	Hardy Creek	1272	4	Sand		B5	II
ECO67F17	Big War Creek	1142	4	Cobble	Gravel	G4	VII
ECO67F23	Martin Creek	1202	3	Bedrock	Cobble	B3	II
ECO67F25	Powell River	1099	5	Bedrock	Gravel	C4	VIII
ECO67G01	Little Chucky Ck	1084	4	Bedrock	Bedrock	C1	VIII
ECO67G05	Bent Creek	1081	4	Cobble	Bedrock	C1	VIII
ECO67G10	Flat Creek	1001	4	Bedrock	Gravel	C4	VIII
ECO67G11	NP Fishdam Ck	1796	3	Gravel	Gravel	B4	II
ECO67H04	Blackburn Creek	996	2	Cobble	Gravel	B4	II
ECO67H06	Laurel Creek	899	2	Gravel	Sand*	C4	II
ECO67I12	Mill Creek	902	3	Gravel	Gravel	C4	VIII
ECO68A01	Rock Creek	1401	3	Bedrock	Gravel	B4	II
ECO68A03	LF Station Camp	1020	3	Cobble	Gravel	B4	II
ECO68A08	Clear Creek	1184	5	Cobble	Boulder	B2	II

Table 16 cont.

Station ID	Stream Name	Elevation (Ft)	Stream Order	Estimated Dominant Substrate	CalculatedD 50	Stream Type	Valley Type
ECO68A13	Piney Creek	1699	4		Gravel	B4	II
ECO68A20	Mullens Creek	1511	4	Boulder	Bedrock*	B2	II
ECO68A26	Daddy's Creek	1192	5	Boulder		B2	II
ECO68A27	Island Creek	1101	3	Cobble	Cobble	B3	II
ECO68A28	Rock Creek	1074	4	Cobble	Cobble	B3	II
ECO69D01	No Business Br	1091	2	Cobble	Gravel*	B3	II
ECO69D03	Flat Fork	1396	4	Cobble	Gravel*	B3	II
ECO69D04	Stinking Creek	1401	4	Cobble	Gravel*	B3	II
ECO69D05	New River	1596	2	Boulder	Gravel*	B2	II
ECO69D06	Round Rock Ck	1393	3	Bedrock	Gravel*	B1	II
ECO71E09	Buzzard Creek	495	3	Gravel	Gravel	C4	VIII
ECO71E14	Passenger Creek	499	2	Cobble	Gravel*	C3	VIII
ECO71F12	S. Harpeth River	649	3	Cobble		B3	II
ECO71F16	Wolf Creek	497	4	Cobble	Gravel	B4	II
ECO71F19	Brush Creek	719	4	Cobble	Gravel	B4	II
ECO71F27	Swanegan Br	705	2	Cobble	Gravel	B4	II
ECO71F28	Little Swan Ck	703	4	Bedrock	Gravel	B4	II
ECO71F29	Hurricane Creek	472	4	Cobble	Gravel	B4	II
ECO71H03	Flynn Creek	692	4	Cobble	Gravel*	C3	VIII
ECO71H06	Clear Fork	706	4	Cobble	Gravel*	C3	VIII
ECO71H09	Carson Fork	685	3	Gravel	Gravel	C4	VIII
ECO71I03	Stewart Creek	561	3	Gravel	Gravel	C4	VIII
ECO71I09	W Fk Stones R	699	3	Bedrock	Gravel*	C1	VIII
ECO71I10	Flat Creek	688	3	Bedrock	Bedrock	C1	VIII
ECO71I12	Cedar Creek	499	3	Cobble	Bedrock	C1	VIII
ECO71I14	Little Flat Creek	696	3	Bedrock	Bedrock	C1	VIII
ECO71I15	Harpeth River	683	4	Gravel	Gravel	C4	VIII
ECO71I16	West Fk Stones R	669	4	Bedrock		C1	VIII
ECO73A01	Cold Creek	249	3	Sand	Sand	F5	X
ECO73A02	MF Frkd Deer R.	249	3	Sand	Sand	F5	X
ECO73A03	Cold Creek	224	4	Silt	Silt/Clay	F6	X
ECO73A04	Bayou du Chien	285	4	Silt/Clay		F6	X
ECO74A06	Sugar Creek	311	3	Gravel	Gravel	C4	VIII
ECO74A08	Pawpaw Creek	336	3	Gravel	Gravel	C4	VIII
ECO74B01	Terrapin Creek	402	3	Sand	Sand	F5	X
ECO74B04	Powell Creek	382	4	Sand	Sand	F5	X
ECO74B12	Wolf River	368	4	Sand		F5	X

***** Estimated dominant substrate rather than calculated D50 was used to classify streams in cases where selection of cross-section for flow measurements biased particle count or where multiple field observations over the past ten years differed from a single calculated particle count.

7.2 Geomorphological Classification of Reference Streams in 19 Tennessee Ecoregions

Physiographical descriptions are based on ecoregion delineation information published in *Ecoregions of Tennessee* (Griffith et al., 1997).

7.2.1 Geomorphology of streams in the Southeastern Plains and Hills (65e)

The physiography of the Southeastern Plains and Hills is dissected irregular plains and low, broad hills. The bottomlands and floodplains tend to be fairly broad and have level terraces. Soil composition is silt, sand, loam and clay with gravel found in the more upland areas. Natural land cover is primarily deciduous and mixed forest with bottomland hardwoods found in the larger river basins. Much of the land has been cleared for agriculture such as pine plantations, pasture, hayfields, soybean, corn and cotton.

Elevation is between 400 and 650 feet with local relief between 100 and 200 feet. Typical streams have a low to moderate gradient with slopes below 4% and have moderately low sinuosity. These streams tend to have sand substrates and moderately stable stream banks under natural conditions.

Geomorphological measurements were conducted at four reference streams during this study while existing data were available from a fifth site. The estimated dominant bed material and the calculated D50 for most of the reference streams was sand although the dominant bed material for West Fork Spring Creek (ECO65E11) was silt/clay. There were two types of channel cross-sections measured at the reference streams. Blunt Creek (ECO65E04), Griffin Creek (ECO65E06), and Harris Creek (ECO65E08) have sloped cross-sections with mostly sand substrate and are classified as C5 streams (Figure 27). These streams have low relief channels, well-developed floodplains, and characteristic "point bars" within the active channel.

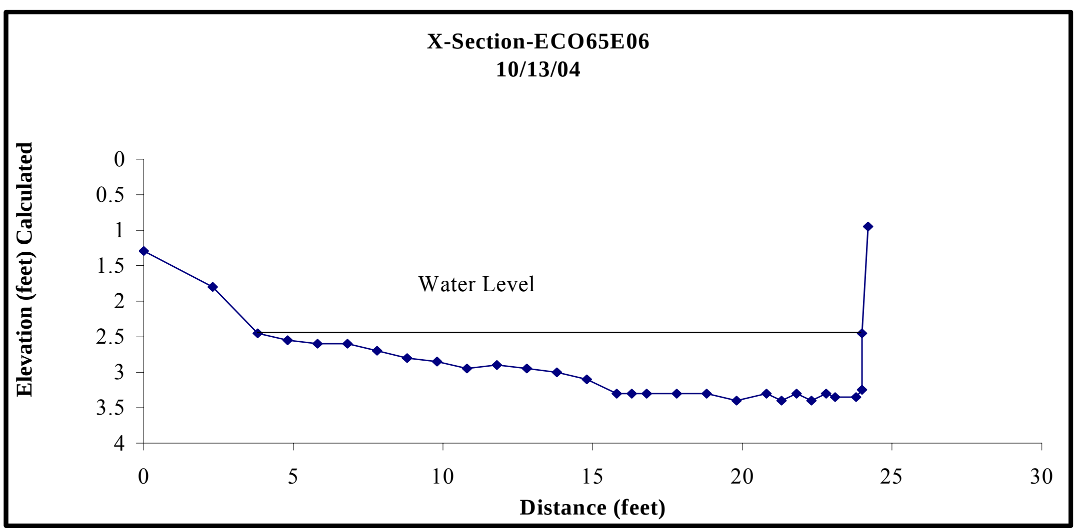


Figure 27: Griffin Creek typical sloped cross-section found in C-type streams

Marshall Creek (ECO65E10) and West Fork Spring Creek (ECO65E11) have U-shaped, flat bottom cross-sections (Figure 28). Marshall Creek is a F5 stream with sand substrate and West Fork Spring Creek is a F6 stream due to the predominantly silt/clay bed material. F-type streams are deeply carved in valleys of low relief, comprised of highly weathered rock and loess.

There are two valley types typically found in the Southeastern Plains and Hills of Tennessee. The C-type streams were found in valley type VIII. These valleys are broad with gentle down-valley elevation relief. The predominant depositional landforms are alluvial terraces and floodplains that produce large amounts of sediment. F-type streams were found in valley type X, which is wide with little relief. Wetlands are generally associated with these valleys.

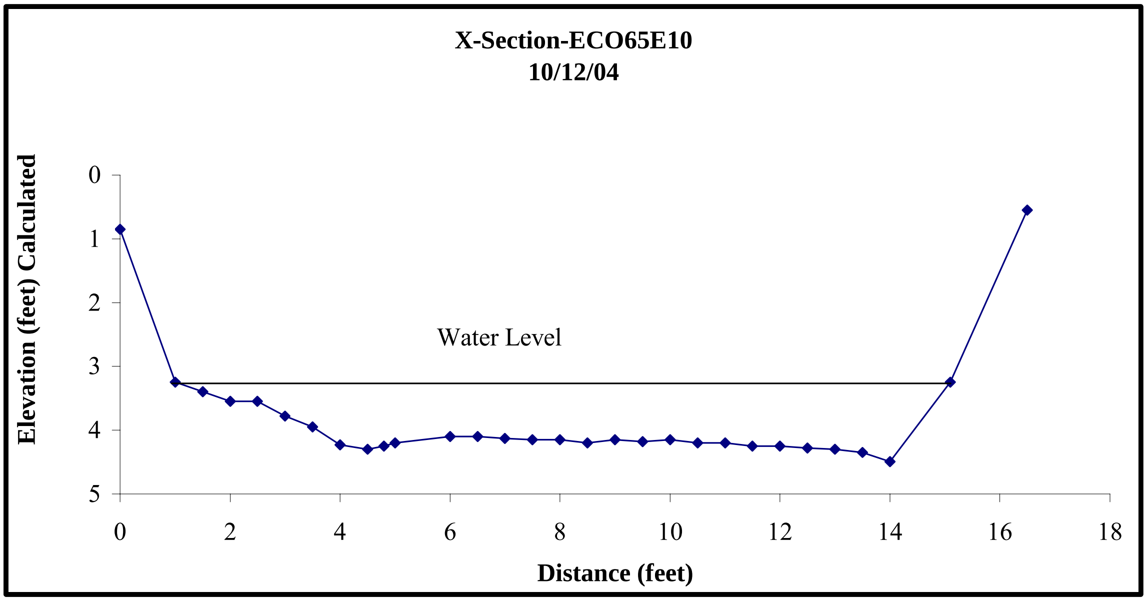


Figure 28: Marshall Creek typical flat cross-section found in F-type streams

7.2.2 Geomorphology of streams in the Transition Hills (65j)

The physiography of the Transition Hills is dissected open hills with broad to rounded tops and steep side slopes. Elevation is 400 to 1000 feet with local relief from 200 to 400 feet. The natural vegetation is oak-hickory-pine forest. Much of the land is forested although pine plantations associated with pulp and paper production are common. Soil is typically coastal plain sediment (clay, sand, silt and gravel) overlying limestone, shale and chert more typical of the Interior Plateau. Streams have a moderate gradient with slopes from 2 to 4% and are in structurally controlled drainage ways. These streams tend to have gravel substrate and stable banks.

One reference stream was surveyed while geomorphological data were available from three others. The estimated dominant bed material was cobble with some gravel. The calculated D50 was gravel.

All four creeks have broad U-shaped cross-sections and are classified as B4 type streams (Figure 29). B-type streams are moderately entrenched and exhibit low sinuosity due to the side slopes that result in narrow valleys, limiting the development of a wide floodplain. Typical valleys for B-type streams in Tennessee's Transition Hills are type II. These valleys are relatively stable with moderate side slope gradients exhibiting moderate relief.

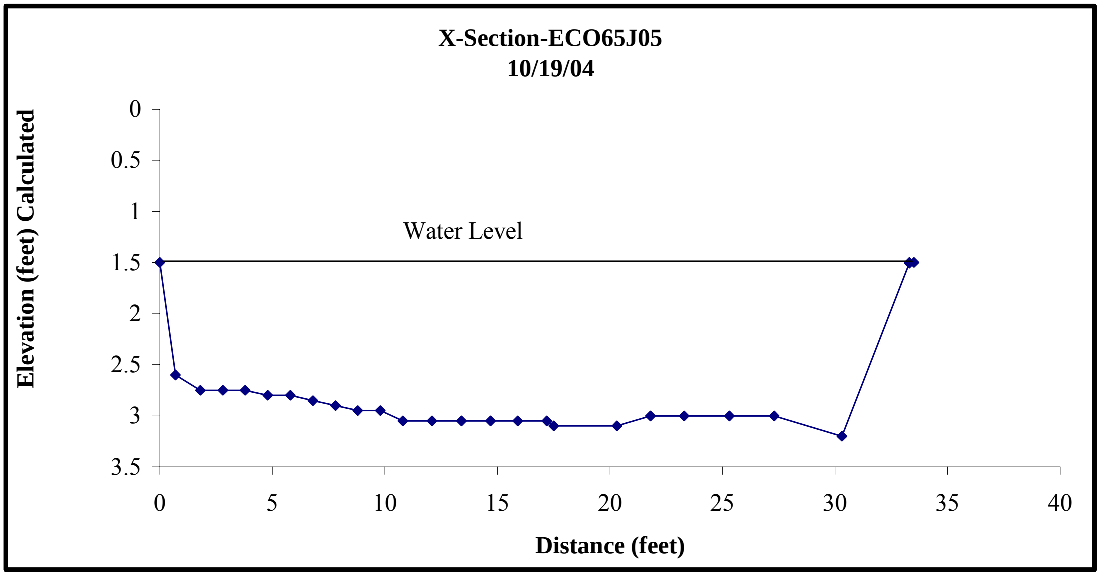


Figure 29: Dry Creek typical U-shaped cross-section found in B-type streams

7.2.3 Geomorphology of streams in the Southern Igneous Ridges and Mountains (66d)

The physiography of the Southern Igneous Ridges and Mountains is low to high mountains with rounded domes and long linear ridges with steep slopes. Elevation is 2000 to 6200 feet with local relief from 2000 to 3000 feet. Roane Mountain has the highest elevation in this ecoregion in Tennessee at 6286 feet. The geologic origin of the ridges and mountains is igneous rock that has undergone metamorphic changes and is now better described as crystalline. Soils tend to be loamy, well drained and acidic.

Most of the region is forested with a few small areas of pasture and apple orchards. The natural vegetation is very diverse and dependent on elevation. Mixed oaks and hickories are found on the lower slopes with pine and oak on drier low elevation slopes. Cove hardwoods are found on more sheltered and moist northern slopes, coves, and ravines up to 4500 feet. Northern hardwoods are found at elevations between 3500 and 5000 feet. Natural vegetation at the highest elevations (>5400 feet) is red spruce and Fraser fir along with some yellow birch and mountain ash with occasional rhododendron and grass balds.

Typical streams have a gradient from 2 to 10%, are steep, entrenched, and confined. Cascading channels are common. Substrate is primarily cobble and gravel substrate with frequent boulders. Typical stream banks are moderately high due to entrenchment of the stream channel and steep side slopes. Banks are generally unstable and subject to erosion if disturbed.

Five reference streams were surveyed during this study. There are two types of channel cross-sections predominant in the Southern Igneous Mountains and Ridges. Black Branch (ECO66D01), Tumbling Creek (ECO66D06), and Little Stony Creek (ECO66D07) have relatively narrow V-shaped cross-sections and are classified as A-type streams (Figure 30). Type A streams are entrenched, high gradient cascading step/pool systems flowing through steep, narrow V-shaped valleys that confine the stream to its channel. Tumbling Creek and Little Stony Creek are A3 streams with mostly cobble substrate and Black Branch is an A4 stream due to the dominance of gravel. The typical valley for A-type streams in this ecoregion in Tennessee is type I. These valleys are confined and often structurally controlled with steep surrounding landforms.

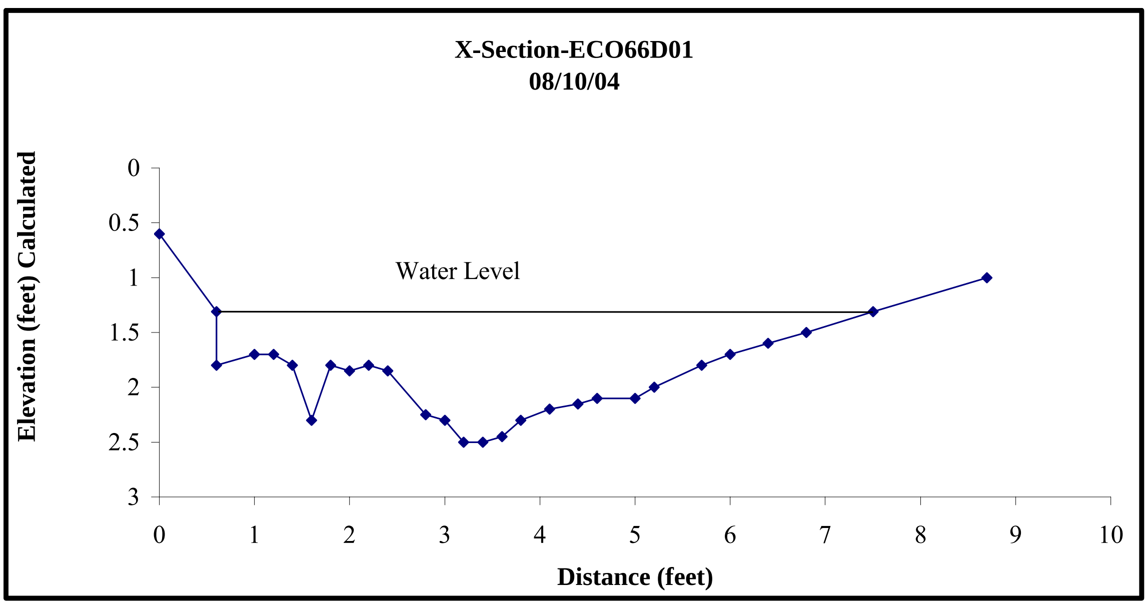


Figure 30: Black Branch typical V shaped cross-section found in A-type streams

Two other reference streams in the Southern Igneous Ridges and Mountains, Laurel Fork (ECO66D03) and Doe River (ECO66D05), have broad U-shaped cross-sections with cobble substrate and are classified as B3 streams. B-type streams are moderately entrenched and exhibit low sinuosity due to the side slopes with narrow valleys that limit the development of a wide floodplain. The typical valley for B-type streams in this ecoregion in Tennessee is type II. These valleys are relatively stable with moderate side slope gradients exhibiting moderate relief.

7.2.4 Geomorphology of streams in the Southern Sedimentary Ridges (66e)

The physiography of the Southern Sedimentary Ridges is low rounded mountains and long linear ridges with steep, long side slopes. Elevation is 1000 to 4500 feet with local relief from 2000 to 3000 feet. The geology is primarily shale, sandstone, siltstone and quartzite conglomerate although some streams run through limestone. Most of the ecoregion is forested with mixed oak and oak-pine forests dominant. Vegetation found in the deeper ravines and moist coves is hemlock-white pine with an abundance of rhododendron. Typically the streams in this ecoregion are moderate to high gradient and clear.

Three reference streams were surveyed for this project while existing geomorphological data were available for two more. All five creeks have broad U-shaped cross-sections and are classified as B-type streams. B-type streams are moderately entrenched and exhibit low sinuosity due to the side slopes that result in narrow valleys, limiting the development of a wide floodplain.

The dominant substrate was variable in the reference streams. Lower Higgins Creek (ECO66E11) and Double Branch (ECO66E17) are classified B2 with a boulder dominant substrate. Gentry Creek (ECO66E04) and Gee Creek (ECO66E18) are B3 due to the predominantly cobble substrate. Clark Creek (ECO66E09) is a B4 stream with a gravel substrate. The typical valley for B-type streams in this ecoregion in Tennessee is type II. These valleys are relatively stable with moderate side slope gradients exhibiting moderate relief.

7.2.5 Geomorphology of streams in the Limestone Valleys and Coves (66f)

The physiography of the Limestone Valleys and Coves is relatively flat to rolling valleys and coves with broad, long foot slopes, benches, and alluvial fans at the base of surrounding high mountains and knolls. Elevation is 1500 to 2500 feet with local relief from 100 to 300 feet. The geology is predominantly limestone. Natural vegetation in this ecoregion was originally Appalachian oak forest. However, most have been cleared for agriculture, typically hay and pasture with some tobacco. Streams are moderate to low gradient.

Geomorphological surveys were conducted at two reference sites while existing data were available at a third. All three creeks have sloped cross-sections and are classified as C-type streams. Beaverdam Creek (ECO66F07) and Stony Creek (ECO66F08) are C3 streams with a predominantly cobble substrate. Abrams Creek (ECO66F06) is a C4 stream due to the gravel substrate. C-type streams have low relief channels, well-developed floodplains, and "point bars" within the active channel. Typical valleys for C-type streams in this ecoregion in Tennessee are type VIII, broad with gentle down-valley elevation relief. The predominant depositional landforms are alluvial terraces and floodplains that produce large amounts of sediment.

7.2.6 Geomorphology of streams in the Southern Metasedimentary Mountains (66g)

The physiography of the Metasedimentary Mountains is high dissected mountains and steep slopes. Elevation is 1000 to 6600 feet with local relief from 2000 to 4000 feet. Clingmans Dome has the highest elevation in this ecoregion in Tennessee at 6643 feet. The geology consists of metamorphic and sedimentary rocks. The Copper Basin in the southeast corner of the state is currently included in the Southern Metasedimentary Mountains although recent ecoregion delineations in Georgia and North Carolina suggest it should be a separate Blue Ridge subregion called the Broad Basins.

Except for the Copper Basin area, which was the site of extensive copper mining until 1987, much of this ecoregion is forested. The natural vegetation is very diverse and dependent on elevation. The dominant classes are Appalachian oak forest, northern hardwood forests and southeastern spruce-fir forest. Typical streams in this ecoregion have a moderate to high gradient above 2% and moderately low sinuosity. They are generally cool and clear with frequent boulders.

Two reference streams were surveyed during this project while historic geomorphological data were available from two more reference sites. All four streams have broad U-shaped cross-sections and are classified as B-type streams. The Little River (ECO66G05) is a B2 stream with a predominantly boulder bed material. Citico Creek (ECO66G07) and Sheeds Creek (ECO66G12) are classified as B3 (cobble) streams while the North River (ECO66G09) is a B4 due to the predominantly gravel substrate. The typical valley structure for B-type streams in this ecoregion in Tennessee is type II, relatively stable with moderate side slope gradients exhibiting moderate relief.

7.2.7 Geomorphology of streams in the Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f)

The physiography of this ecoregion is characterized by ridges, hills, and knobs with karst features such as caves and springs. This ecoregion is lower in elevation and more dissected than other Ridge and Valley subregions in Tennessee. Elevation is 700 to 2000 feet with local relief from 100 to 700 feet. Streams are generally low to moderate gradient with slopes below 4%. Valleys are undulating to rolling and surrounded by rounded hills with some steep ridges to the north. The natural vegetation is Appalachian oak forest. Bluestem grassland barrens also occur mixed with some cedar-pine glades. There is intensive agriculture in much of the region as well as large urban areas.

Five reference streams (six stations) were surveyed during this project while historic data were available on a sixth stream. The estimated substrate differed from the calculated particle size at all stations. The calculated particle size was used to characterize the streams except for Hardy Creek (ECO67F16) where a particle count was not performed and estimated substrate size was used.

Stream morphology is varied in this ecoregion with three types of channels found in the reference streams. Cross-section types included sloped, broad U-shaped and U-shaped with high banks where the stream was gullied. Both sites on the Powell River have sloped cross-sections and are classified as C4 type streams with gravel as the dominant bed material. C-type streams have low relief channels, well-developed floodplains, and characteristic "point bars" within the active channel. The typical valley structure for C-type streams in this ecoregion in Tennessee is type VIII. These valleys have a gentle slope with floodplains adjacent to river terraces.

Clear Creek (ECO67F06), White Creek (ECO67F13), Martin Creek (ECO67F23), and Hardy Creek (ECO67F16), which is in Virginia, are classified as B-type streams. Martin Creek is a B3 type stream with cobble as the dominant bed material while Clear Creek and White Creek have predominantly gravel substrate making them B4 streams. Hardy Creek in Virginia is a B5 stream with sand as the dominant bed material. The typical valley structure associated with B-type streams in this ecoregion is type II. These valleys are relatively stable with moderate side slope gradients exhibiting moderate relief.

Big War Creek (ECO67F17) is a G4 type stream with gravel as the dominant bed material, moderate gradient, deep entrenchment and low sinuosity (Figure 31). This stream type is unstable and very sensitive to channel and bank disturbance as well as changes in flow and sediment load. This G4 stream has A-type VII valley that is depositional. The residual soils are deposits of weathered sedimentary rocks like limestone and marine shales.

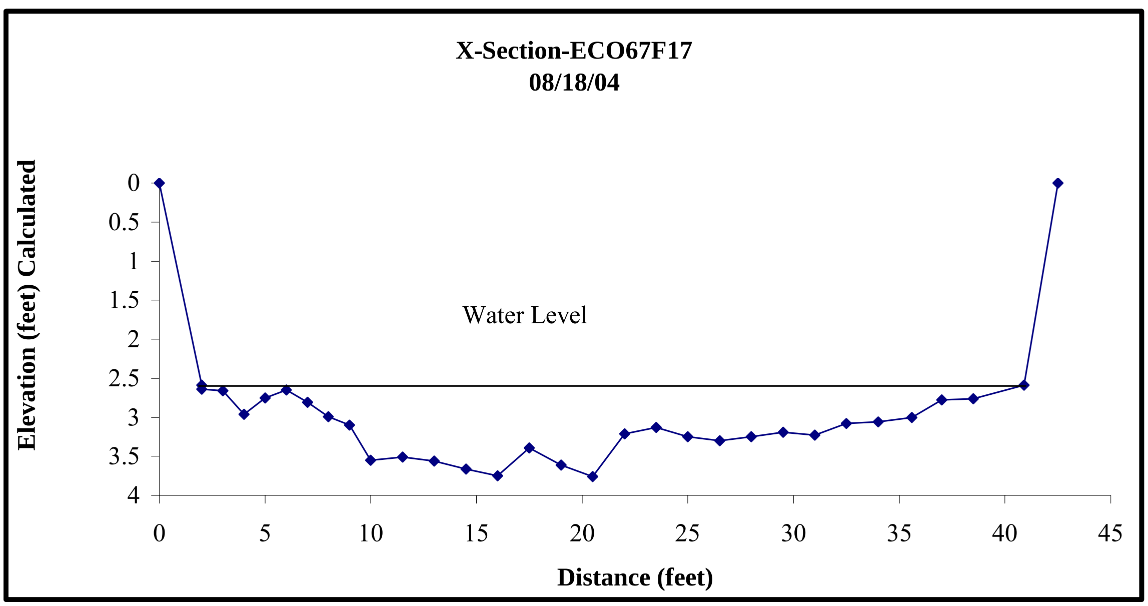


Figure 31: Big War Creek typical entrenched cross-section found in G-type streams

7.2.8 Geomorphology of streams in the Southern Shale Valleys (67g)

The physiography of this ecoregion is characterized by undulating to rolling hills and valleys. The elevation is 800 to 1500 feet with local relief from 100 to 400 feet. Natural vegetation on the steeper slopes is white oak with some cedar and pine. Loblolly and white pine are found in the south. Much of the forest has been cleared with steeper slopes used for pasture and lower slopes and bottomland for crops, generally hay, corn and tobacco. Typical streams tend to be moderate to low gradient with slopes below 4%. Substrate is predominantly bedrock and gravel. Banks are moderately stable.

One reference stream was surveyed during this study while existing geomorphological data were available on three others. There were two types of cross-sections found at the reference streams, sloped and broad U-shaped. Little Chucky Creek (ECO67G01), Bent Creek ECO67G05), and Flat Creek (ECO67G10) have sloped cross-sections with bedrock substrate making them C1 streams. Flat Creek is a C4 due to the predominantly gravel substrate. The typical valley structure for C-type streams in this ecoregion is VIII. This valley type is broad with gentle down-valley elevation relief.

North Prong Fishdam Creek (ECO67G11) has a broad U-shaped cross-section. It is classified as a B4 stream because the dominant bed material is gravel. The typical valley structure for B-type streams in this ecoregion is type II. These valleys are relatively stable with moderate side slope gradients and moderate relief.

7.2.9 Geomorphology of streams in the Southern Sandstone Ridges (67h)

High, steep sandstone ridges amidst some narrow intervening valleys characterize the physiography of this ecoregion. Elevation is 900 to 3000 feet with local relief from 800 to 1200 feet. The western ridges have more sandstone while the central and eastern ridges have more shale. The natural vegetation is Appalachian oak forest although most of the ridges were once logged. Typical streams are low to moderate gradient below 4%.

Two reference streams were surveyed for this project. Each had a different channel shape although the dominant bed material was gravel for both streams. Blackburn Creek (ECO67H04) has a broad U-shaped cross-section and is classified as a B4 stream. B-type streams have a moderate gradient and relatively low sinuosity. The typical valley structure associated with B-type streams in this ecoregion is type II. These valleys are relatively stable with moderate side slope gradients exhibiting moderate relief.

Laurel Creek (ECO67H06) has a sloped cross-section and is classified as a C4 stream. C-type streams have a low gradient and greater sinuosity than B-type streams. The typical valley structure associated with C-type streams in this ecoregion is type VIII. This valley type is broad with gentle down-valley elevation relief.

7.2.10 Geomorphology of streams in the Southern Dissected Ridges and Knobs (67i)

The physiography of this ecoregion is characterized by ridges, hills, and knobs that are lower in elevation and more dissected than the Southern Sandstone Ridges (67h). Ridges in the central to western part of this ecoregion are shale and siltstone with beds of sandstone. Ridges in the east are mostly shale with some limestone. Elevation is 800 to 2000 feet with local relief from 300 to 600 feet. Natural vegetation is white oak, mixed mesophytic forests and tulip poplar in draws and on the lower and mid-elevation slopes. Chestnut oak and pine forests are found on ridges at higher elevations.

There is only one established reference station, Mill Creek (ECO6I12), in this ecoregion, which covers a small (1.4%) portion of the state. The estimated dominant bed material and the D50 for this stream was gravel. The channel cross-section is sloped and the stream is classified as a C4 stream. The valley structure associated with this stream is type VIII with alluvial terraces and gentle down-valley elevation relief.

7.2.11 Geomorphology of streams in the Cumberland Plateau (68a)

The physiography of this ecoregion is characterized by undulating and rolling tablelands with some open low mountains, ravines, and gorges. Elevation is 1200 to 2000 feet with local relief from 300 to 800 feet. The geology is conglomerate, sandstone, siltstone and shale. The natural vegetation in the ravines and gorges is mixed mesophytic forest with mixed oak forests found on uplands. Virginia pine is found on upper slopes as well as old fields and cliff edges. The region is mostly forested with areas of agriculture, pine plantations and coal mining. Many first order streams have been dammed. Typical streams have a moderate gradient below 4%.

Six reference streams were surveyed during this project and existing geomorphological data were available on two others. All eight streams are B-type with broad U-shaped cross-sections. The typical valley structure associated with B-type streams in this ecoregion in Tennessee is type II. This valley type is relatively stable with moderate side slope gradients exhibiting moderate relief.

The dominant bed material was variable. Three streams, Clear Creek (ECO68A08), Mullens Creek (ECO68A20), and Daddys Creek (ECO68A26) are B2 streams with a predominantly boulder bed material. Island Creek (ECO68A27) and Rock Creek (ECO68A28) are B3 with a cobble dominant substrate. Rock Creek, Laurel Fork Station Camp Creek (ECO68A03), and Piney Creek (ECO68A13) are B4 with gravel dominant.

7.2.12 Geomorphology of streams in the Cumberland Mountains (69d)

The physiography of this ecoregion is characterized by low mountains with long, steep slopes, and narrow winding valleys. The terrain is highly dissected by clear water streams. Elevation is 1200 to 3500 feet with local relief 1500 to 2000 feet. Natural vegetation is mixed mesophytic forests. Typical streams are moderate gradient with slopes less than 4%. Five reference streams were surveyed for this project. Type-B streams with a broad U-shaped cross-section were typical. The valley type for B-type streams in this ecoregion in Tennessee is type II, which is relatively stable with moderate side slope gradients exhibiting moderate relief.

The calculated D50 for all the reference streams was gravel. However, it is probable that the estimated dominant bed material is more accurate for these streams based on field descriptions and pictures. Therefore the estimates were used for classification. Round Rock Creek (ECO69D06) is a B1 type with a bedrock substrate. New River (ECO69D05) is classified as a boulder dominant B2 type stream. The other three streams are classified as cobble B3 type streams.

7.2.13 Geomorphology of streams in the Western Pennyroyal Karst (71e)

The characteristic physiography of the Western Pennyroyal Karst includes flat areas of irregular plains with mostly gently rolling and weakly dissected hills. Elevation is 500 to 750 feet with local relief from 60 to 200 feet. This is a karst area with typical features such as sinkholes, depressions, karst windows, and springs. Soil is generally a thin loess mantle over limestone. Natural vegetation was mixed mesophytic and oak-hickory with patches of bluestem prairie, however the fertile soils have resulted in the majority of the land being cleared for crops and pasture. Typical streams are low gradient. Surface streams are often dry or drain underground during low flow periods.

Two reference streams were surveyed during this project. Both streams are C-types with the typical sloped cross section. Buzzard Creek a C4 with predominantly gravel substrate. Passenger Creek has more cobble and is a C3. The valley structure associated with C-type streams in the ecoregion in Tennessee is type VIII with alluvial terraces and gentle down-valley elevation relief.

7.2.14 Geomorphology of streams in the Western Highland Rim (71f)

The physiography of the Western Highland Rim is highly dissected rolling to steep open hills with narrow winding to moderately broad ridges. There are some level bottomlands along major streams. Elevation is 400 to 1000 feet with local relief from 300 to 500 feet. The base geology is limestone, chert and shale overlain with cherty silty clay soils that tend to be acidic.

The ecoregion is now heavily forested although it was mostly deforested in the mid to late 1800s in conjunction with iron-ore mining and limonite smelting. The natural vegetation was predominantly oak-hickory and has been replaced by a mostly oak forest with beech, maple and tulip poplar on moister slopes. Red elm, silver maple, red maple, boxelder, sweetgum, black willow and sycamore are found in ravines and along stream banks. Some agriculture, primarily hay, pasture, cattle, corn and tobacco, occurs along flatter surfaces in the stream and river valleys. Typical streams have a moderate gradient between 2 and 4%.

Six Western Highland Rim reference streams were surveyed during this study. The typical channel cross-section was the broad, U-shaped B-type. The estimated dominant bed material for most streams was cobble except Little Swan Creek (ECO71F28), which was bedrock. The calculated D50 for all of the streams except South Harpeth Creek (ECO71F12) was gravel. The D50 was not calculated for South Harpeth Creek but the estimated dominant substrate is cobble, resulting in a B3 clasification. All of the other creeks are classified as B4 with gravel the dominant substrate based on the calculated D50s. The typical valley structure associated with streams in this ecoregion in Tennessee is type II. These valleys are relatively stable with moderate side slope gradients exhibiting moderate relief.

7.2.15 Geomorphology of streams in the Outer Nashville Basin (71h)

The physiography of the Outer Nashville Basin is rolling and hilly. Elevation is generally 500 to 1200 feet although Short Mountain is over 2000 feet. Local relief is from 300 to 500 feet. Geology is primarily limestone and the rocks and soils are naturally high in phosphorus. The natural vegetation is mostly oak-hickory forest. Much of this has been cleared for urban development and agriculture. Typical streams have a low gradient below 2% and moderately high sinuosity. They are naturally nutrient rich due to the high phosphorus content of the rocks and soils.

One reference stream was surveyed while existing geomorphological data were available for two more. The typical cross-section for streams is the sloped C-type. Flynn Creek (ECO71H03) and Clear Fork Creek (ECO71H06) are classified as C3 streams because the dominant bed material is cobble. Carson Fork (ECO71H09) is a C4 stream due to a more gravel substrate. The typical valley structure associated with C-type streams in the Outer Nashville Basin type VIII, broad with alluvial terraces and gentle down-valley relief.

7.2.16 Geomorphology of streams in the Inner Nashville Basin (71i)

The physiography of the Inner Nashville Basin is smooth to rolling plains with some small knobs and hills. The elevation is 500 to 900 feet with local relief from 60 to 400 feet. Very shallow clay soils cover limestone bedrock. The natural vegetation is cedar glades and thickets, cedar-hardwood forests and deciduous forests, however, much of the Inner Nashville Basin has been cleared for urban development and agriculture (primarily pasture and hay). Typical streams are low gradient and flow over limestone bedrock. Streams are often dry or subterranean during low flow periods.

Two reference streams were surveyed during this project while geomorphological data were available for five additional reference stations. Two sites were on the West Fork Stones River. The typical cross-section for streams in this ecoregion is the sloped C-type. The dominant bed material for most of the streams was bedrock resulting in a C1 classification. Exceptions were Stewart Creek (ECO71I03) and the Harpeth River (ECO71I15) whose primarily gravel substrates resulted in a C4 classification. The typical valley structure associated with C-type streams in the Inner Nashville Basin is type VIII, broad with alluvial terraces and gentle down-valley elevation relief.

7.2.17 Geomorphology of streams in the Northern Mississippi Alluvial Plain (73a)

Flat plains and levees are the typical physiography found in the Northern Mississippi Alluvial Plain in Tennessee. The Mississippi River floodplain encompasses most of this ecoregion that includes oxbow lakes, ponds, and swamps. There are two tectonic lakes, Reelfoot Lake and Open Lake. The elevation is low, 215 to 300 feet with local relief from 25 to 50 feet. Soils composition varies between areas of loam, silt, sand and clay.

The natural vegetation is southern floodplain and bottomland hardwood forests including oak, tupelo and bald cypress. Much of the ecoregion has been cleared for cropland, primarily soybean, cotton, corn, sorghum and vegetables. The southern portion around Memphis is heavily urbanized. Typical streams are entrenched and tend to be turbid with silt and sand substrate and unstable banks. Most of the streams have been channelized.

Four reference streams were surveyed for this project. All are non-wadeable. The typical cross-section was type F, which is U-shaped with a flat bottom (Figure 32). Substrate was split evenly between sand and silt/clay. There were two stations on Cold Creek (ECO73A01 and ECO73A03). The upstream site (RM 14.4) near the origin at Open Lake, had a predominantly sand substrate and was classified F5. The substrate was finer silt/clay 12 miles downstream making it an F6. Bayou du Chien (ECO73A04) is also F6 with a silt/clay substrate. The dominant bed material at the Middle Fork Forked Deer (ECO73A02) station is sand and the stream would be classified as an F5.

The typical valley structure associated with F-type streams in this ecoregion in Tennessee is type X, which is wide with very little relief. Alluvial flats, some of which may show evidence of peat bogs and wetlands are associated with this type of valley.

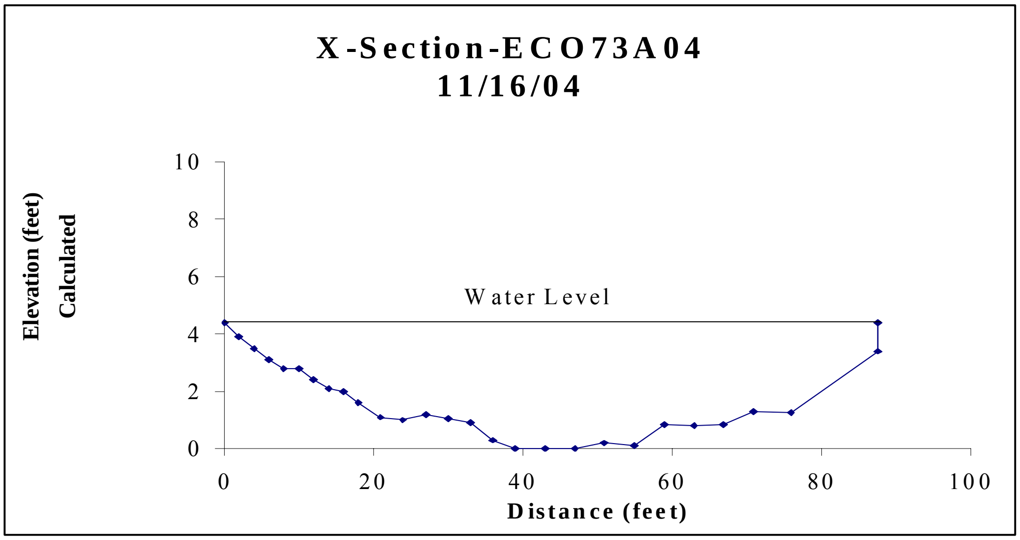


Figure 32: Typical U-shaped cross-section of streams in the Northern Mississippi Alluvial Plain.

7.2.18 Geomorphology of streams in the Bluff Hills (74a)

The Bluff Hills are an area of high bluffs along the Mississippi River composed of sand, clay, silt and lignite capped by deep loess. Soils are highly erosive. Elevation is 250 to 500 feet with local relief from 100 to 200 feet. Streams are moderate to low gradient with slopes less than 4%. Valleys are narrower than those in surrounding ecoregions. The natural vegetation is oak-hickory forest mixed with some mesophytic vegetation like beech and sugar maple. Much of the region is forested with some pasture and small crop areas. There are also several gravel quarries in the region.

Two reference streams were surveyed during this study. The estimated and calculated dominant bed material for both streams is gravel. The typical channel cross-section for these streams is sloped. Both streams are classified as C4. The typical valley structure associated with C-type streams in this ecoregion is type VIII, broad with alluvial terraces and gentle down-valley elevation relief.

7.2.19 Geomorphology of streams in the Loess Plains (74b)

The Loess Plains are a region of irregular, level to gently rolling plains. The bottomlands and floodplains associated with this ecoregion tend to be wide and flat. Elevation is 250 to 500 feet with local relief from 50 to 100 feet. The loess can be over 50 feet thick in the bottoms (Griffith et al, 1997). The natural vegetation includes oak-hickory forests and southern floodplain/bottomland hardwood forests although most of the forest has been cleared for croplands, primarily soybeans, cotton, corn, milo and sorghum as well as some livestock.

Typical alluvial streams in this ecoregion of Tennessee have a gradient below 2%, low sinuosity, and are entrenched. These low-gradient streams tend to be turbid with silt and sand substrate. They have moderately unstable stream banks. Most of these streams have been deforested and channelized which has caused a great loss in wetland habitat.

Two wadeable reference streams were surveyed for this project. A non-wadeable reference site on the Wolf River (ECO74B12), was also surveyed and is discussed in section 10. Both the estimated and the calculated dominant bed material for both wadeable reference streams was sand. The typical shape of channel cross-section is U-shaped with a fairly flat bottom and high stream banks. Both streams are classified as F5 streams. F-type streams are carved in valleys of low relief, comprised of highly weathered rock and loess. The typical valley structure associated with streams in this ecoregion of Tennessee is type X. These valleys are wide with very little relief. Alluvial flats, some of which may show evidence of peat bogs and wetlands are associated with this type of valley.

8. PERIPHYTON CHARACTERIZATION

Another goal of this project was to characterize algal abundance in ecoregion streams where data were not currently available as well as evaluate algal abundance in test streams in ecoregions where nutrient levels are generally elevated. The 2004 study is a continuation of a periphyton density project conducted in conjunction with the 2002 DO study (Arnwine and Sparks, 2003). Data from both studies were combined to characterize periphyton abundance in the 19 ecoregions included in the 2004 project.

The periphyton community is made up of sessile algae that inhabit the surfaces of underwater rocks and other stable substrates. They are the primary producers in the stream ecosystem, turning nutrients into food for aquatic macroinvertebrates and fish. For the purposes of this study, periphyton were divided into two broad categories. Macroalgae are long filamentous strands of algae such as *Cladophora* or *Spirogyra* spp. Microalgae are primarily single celled algae which coat the substrate and are generally composed of diatoms and soft algae such as blue-green algae.

Due to the sedentary nature of periphyton, the community composition and biomass are sensitive to changes in water quality. A diverse community of periphyton can be found in healthy streams. Nuisance blooms are usually symptoms of a system stressed by factors such as excessive nutrients, elevated temperatures, or stagnant conditions.

Excessive algal growth can reduce biodiversity by making habitat unsuitable for benthic fish and macroinvertebrates and by altering diurnal dissolved oxygen patterns. Excessive algae levels are generally associated with an increase in tolerant macroinvertebrates. Grazers (scrapers) such as snails generally dominate a benthic community influenced by excessive algae growth.

One limitation of using benthic algae as an indicator of nutrient enrichment is that densities can be affected by many other factors. Algal growth is influenced by canopy cover, time available to grow since the last flood, streambed stability, water velocity, nutrients and grazing by aquatic fauna. Suitable substrate is also essential. Gravel must be at least two cm for periphyton to grow (Barbour et al, 1999). Streams with shifting sand bottoms are not suitable for colonization.

This study focused on the density of periphyton rather than the community composition. Taxonomic identification would provide more information. However, collection and analyses are time consuming and would require expertise and training in algae taxonomy. This rapid field method requiring no laboratory analysis or taxonomic expertise is a cost effective method that can supplement macroinvertebrate stream surveys and water quality monitoring whenever nutrient enrichment and algae blooms are suspected to be a problem.

8.1 Data Analysis

The density of algae on substrate at each site was statistically characterized by determining:

a. Percent of macroalgae present
b. Percent of substrate available for microalgae colonization
c. The maximum thickness rank of microalgae
d. The mean thickness rank (mean density) of microalgae

$$\text{Mean THR} = \Sigma\, d_i r_i / d_t$$

Where d_i = number of grid points (dots) over microalgae of different thickness ranks
r_i = thickness rank of algae
d_t = total number of grid points over suitable microalgae substrate at the site

The thickness rank represents the following algal density:

0	No microalgae
0.5	Substrate slimy, but no visual accumulation of microalgae
1	A thin layer of microalgae, less than 0.5 mm thick
2	Accumulation of microalgal layer from 0.5-1 mm thick
3	Accumulation of microalgal layer from 1 to 5 mm thick
4	Accumulation of microalgal layer from 5 mm to 2 cm thick
5	Accumulation of microalgal layer greater than 2 cm thick

8.2 Periphyton Density by Ecoregion

8.2.1 Periphyton density in the Southeastern Plains and Hills (65e)

The majority of streams in the Southeastern Plains and Hills have little rock substrate suitable for periphyton colonization. The dominant bed material is shifting sand and clay with particle sizes less than 2 cm. Only two of the five established reference sites had rock substrate suitable for periphyton colonization (Table 17). Approximately 54% of the substrate was suitable at Harris Creek (ECO65E08). Eighteen percent of the rock had microalgal growth, mostly a slime coat with no measurable thickness (Figure 33). This site has good canopy. The other reference site with suitable substrate was West Fork Spring Creek (ECO65E11). Only 11 percent of the substrate was suitable and none of it was colonized by microalgae. Canopy was dense at this site, which probably accounts for the lack of periphyton. There were no macroalgae observed at either site.

Periphyton do not appear to be abundant at unimpaired streams in the Southeastern Plains and Hills. This may be due primarily to a lack of suitable rock substrate. Where substrate is available, microalgae do not occur in measurable thickness and do not cover a large percent of the substrate. The overall thickness rank for reference streams with suitable substrate in the ecoregion was 0.

Periphyton abundance was also surveyed at eight test sites. Only three of the stations had suitable rock substrate. Based on macroinvertebrate data collected at the same time, two of the sites Clear Creek (CLEAR002.6MC) and White Oak Creek (WOAK017.4MC) passed biological guidelines, while the third site, Old Town Creek (OTOWN002.2HN) failed to meet guidelines for the ecoregion.

The highest abundance of periphyton (mean thickness rank of 0.4) was found at Old Town Creek. This site did not pass macroinvertebrate guidelines. Sixty eight percent of the available substrate was covered by microalgae. On average, this was a slime coating with no measureable thickness. Dissolved oxygen did not appear influenced by the periphyton growth, staying above 6 ppm throughout the study period. Canopy, although less than reference sites, was still over 70% shaded. Nitrate+nitrite levels were within guidelines throughout the two-week study. Total phosphorus slightly exceeded the 0.04 mg/l guidelines both at the time of the periphyton survey (0.06 mg/l) and one week earlier (0.05 mg/l).

Of the two test sites that passed biological guidelines, White Oak Creek had no periphyton. Nutrient levels were within regional guidelines throughout the study period. The other test site, Clear Creek, did have a thick layer (more than 5 mm) of microalgae on six percent of the available substrate. However, since this was only a small amount of the total rock substrate and the rest was clear of algae, the mean thickness rank of 0.2 was relatively low. Nitrate+nitrite levels exceeded regional guidelines (0.34 mg/l) both during the periphyton survey (0.41 mg/l) and the week before (0.44 mg/l). Canopy was mostly shaded at 72%. DO did not fall below 5 ppm during the night. The macroinvertebrate index score was very high at this site (40) and did not appear affected by the algae.

Table 17: Periphyton data for five reference and three test sites in the Southeastern Plains and Hills (65e).

Station ID	Macroinvert Guidelines	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO65E04	Reference	9/23/02	0	0	0	0	0.0	
ECO65E06	Reference	9/23/02	0	0	0	0	0.0	
ECO65E08	Reference	9/24/02	0	54	18	0.5	0.1	
ECO65E08	Reference	10/5/04	0	0	0	0	0.0	96
ECO65E10	Reference	10/1/02	0	0	0	0	0.0	
ECO65E11	Reference	10/27/04	0	11	0	0	0.0	90
CLEAR002.7MC	Pass	10/5/04	0	40	6	4	0.2	72
OTOWN002.2HN	Fail	11/15/04	0	68	52	1	0.4	77
WOAK017.4MC	Pass	10/20/04	0	16	0	0	0	79

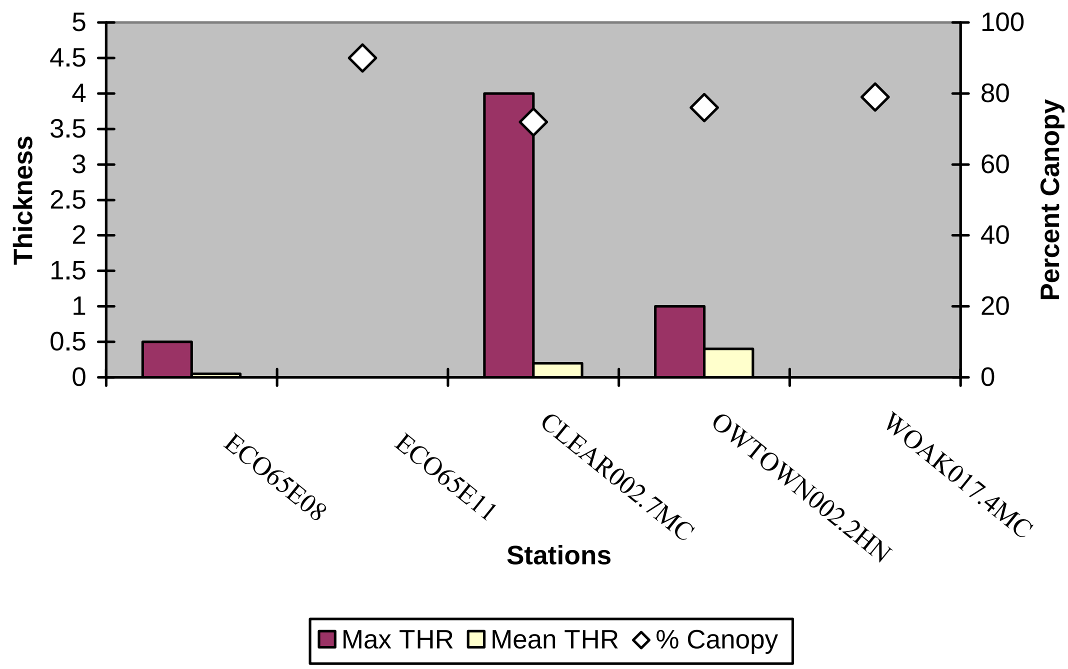


Figure 33: Microalgae and canopy at two reference and three unimpaired test sites with suitable rock substrate in Southeastern Plains and Hills (65e). The mean THR reflects the average value of all survey dates for each station. When there are more than one survey, the percent canopy is the amount measured on the date with the highest maximum thickness rank (THR). ECO65E08 is from 2002, all other data are from the 2004 study.

8.2.2 Periphyton density in the Transition Hills (65j)

Although this ecoregion is included in the 2004 study, periphyton surveys for all four established reference streams were conducted in 2002 and these data were used to characterize the region. All of the reference streams had plentiful rock substrate suitable for periphyton colonization (54-96%). Even so, periphyton growth was not abundant with only 0 to 33% of the substrate covered by a thin layer of microalgae less than 0.5 mm thick (Table 18). Although some rocks had a thickness of 1, the mean thickness rank was low ranging from 0.0 to 0.2 (Figure 34). Macroalgae were not present at any reference site.

The mean thickness rank for the Transition Hills was 0.2. Reference levels of nitrate+nitrite in this region are among the lowest in the state. This may help account for the limited periphyton community found in these streams.

Table 18: Periphyton data for ecoregion reference sites in the Transition Hills (65j).

Station ID	Date	% Macro algae	% Substrate Available	% Micro algae	Max THR	Mean THR	% Canopy
ECO65J04	10/01/02	0	96	32	0.5	0.2	
ECO65J05	10/07/02	0	80	0	0.0	0.0	
ECO65J06	10/02/02	0	80	33	1.0	0.2	
ECO65J11	01/07/02	0	54	24	1.0	0.2	

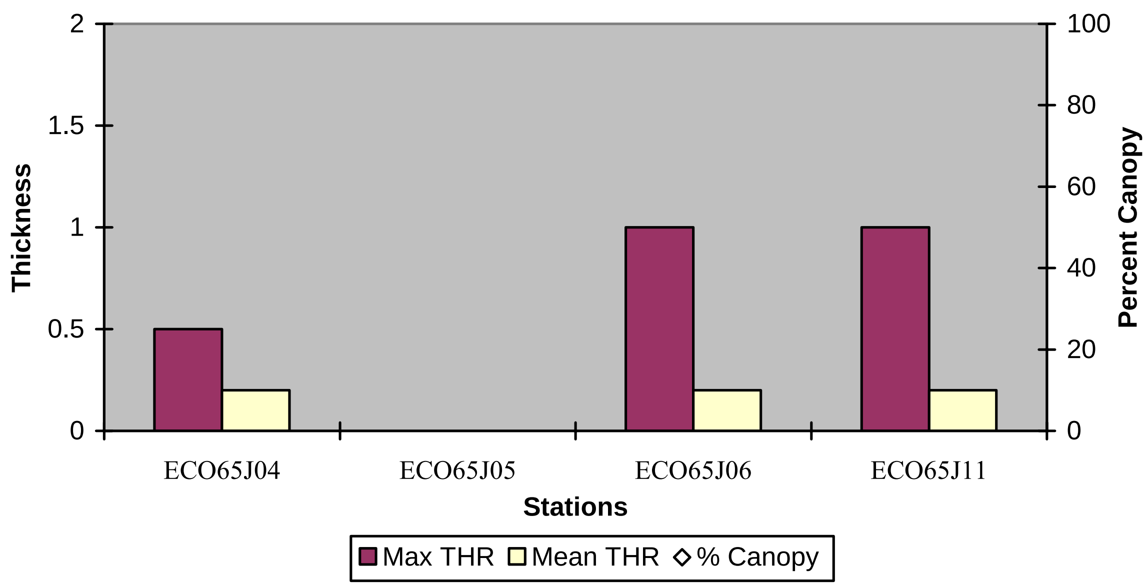


Figure 34: Microalgae at reference sites in the Transition Hills (65j). Canopy measurements were not available.

8.2.3 Periphyton density in the Southern Igneous Ridges and Mountains (66d)

Five reference streams were surveyed for periphyton during this study (Table 19). There was abundant rock habitat suitable for algal colonization at each site. Macroalgae were not observed. Each of the five sites had a slime coating of microalgae although fewer than half of the rocks were affected (Figure 35). Canopy cover was fairly dense (over 75 percent) at these reference sites.

Periphyton do not appear to be abundant in unimpaired streams in this ecoregion. Although microalgae were present at all ecoregion reference sites, it did not occur in measurable thickness or cover more than half of the rock substrate. The mean thickness rank for all reference sites in the subregion was 0.

Table 19: Periphyton data for reference sites in the Southern Igneous Ridges and Mountains (66d).

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO66D01	8/9/04	0	43	3	0.5	0.0	75
ECO66D03	8/10/04	0	72	38	0.5	0.2	88
ECO66D05	8/10/04	0	93	23	0.5	0.1	91
ECO66D06	8/16/04	0	64	2	0.5	0.0	96
ECO66D07	8/9/04	0	84	5	0.5	0.0	97

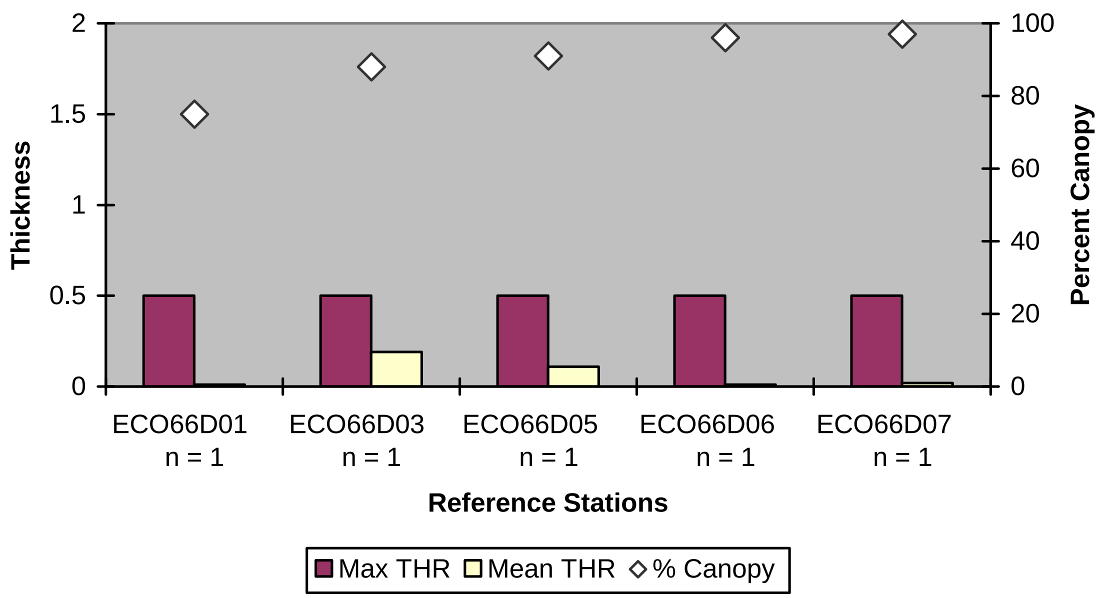


Figure 35: Microalgae and canopy at reference sites in the Southern Igneous Ridges and Mountains (66d).

8.2.4 Periphyton density in the Southern Sedimentary Ridges (66e)

Two reference streams were surveyed for this study while periphyton data were available from three additional reference sites surveyed in 2000 or 2002. Abundant substrate was available for colonization at all five sites. Macroalgae were not observed during any of the surveys (Table 20). Over 80% of the substrate was suitable for algal growth at each station. All sites had some microalgae growth, although the mean thickness rank was 0 at two sites. Microalgae covered the majority of rocks at two other sites, Clark Creek (ECO66E09) and Double Branch (ECO66E17), however, there was never more than a slime layer with no measurable thickness (Figure 36).

Periphyton do not appear to occur in measurable densities in unimpaired streams in this region. The overall mean thickness rank of all reference streams was 0.1.

Table 20: Periphyton data for reference sites in the Southern Sedimentary Ridges (66e).

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO66E04	8/28/02	0	86	10	0.5	0.0	
ECO66E09	8/17/04	0	95	54	0.5	0.3	98
ECO66E11	8/27/02	0	90	6	0.5	0.0	
ECO66E17	10/10/00	0	100	69	0.5	0.2	88
ECO66E18	9/7/04	0	82	16	0.5	0.1	97

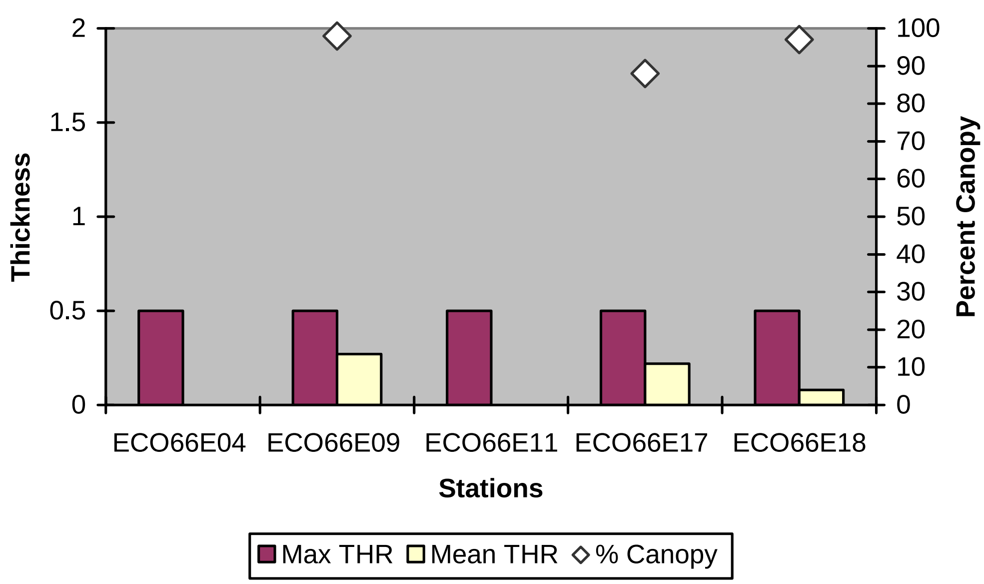


Figure 36: Microalgae and canopy at reference sites in the Southern Sedimentary Ridges (66e).

8.2.5 Periphyton density in the Limestone Valleys and Coves (66f)

One reference site was surveyed during this study while data are available from two others surveyed in 2002. Abundant substrate was available for algal growth at each site, however very little periphyton was observed. Macroalgae were not observed (Table 21). As illustrated in Figure 37, microalgae were not found at Abrams Creek (ECO66F06) while the mean rank was 0 at Stony Creek (ECO66F08). A slime layer of microalgae was found on 22% of the rocks at Beaverdam Creek (ECO66F07).

Periphyton do not appear abundant in unimpaired streams in the Limestone Valleys and Coves (66f) ecoregion subregion. When present, microalgae do not occur in measurable thickness and do not colonize a large percentage of the substrate. Based on reference data, the mean thickness rank of microalgae for the subregion is 0.

Table 21: Periphyton data for reference sites in the Limestone Valleys and Coves (66f).

Station ID	Date	% Substrate Available	% Macro-algae	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO66F06	8/17/04	44	0	0	0	0	75
ECO66F07	8/28/02	97	0	22	0.5	0.1	
ECO66F08	8/27/02	94	0	6	0.5	0	

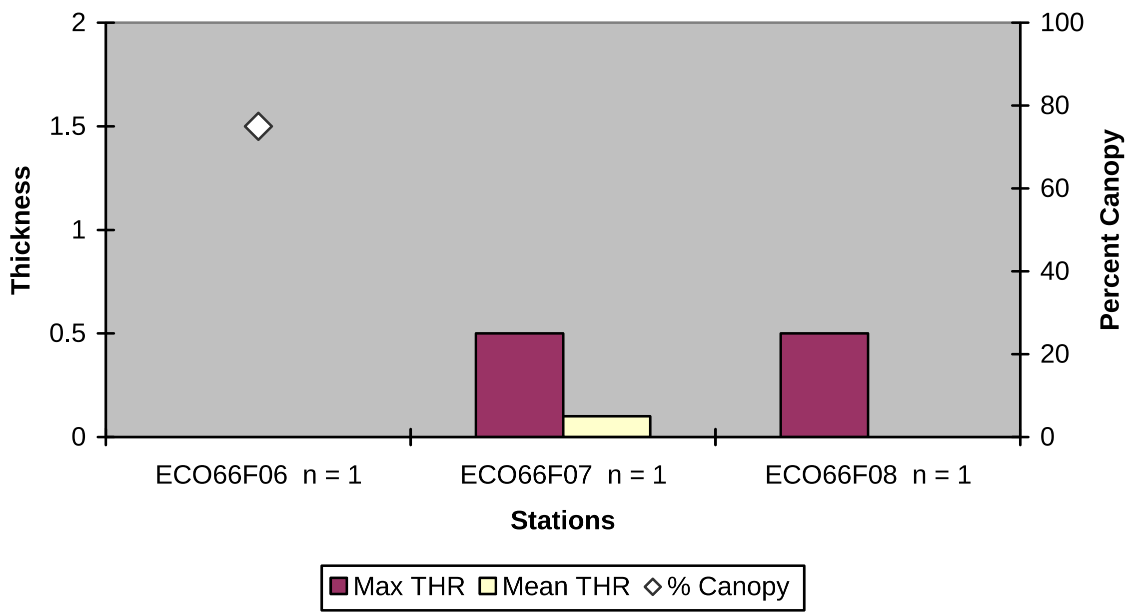


Figure 37: Microalgae and canopy at reference sites in the Limestone Valleys and Coves (66f).

8.2.6 Periphyton density in the Southern Metasedimentary Mountains (66g)

Although this subregion was included in the 2004 project, periphyton surveys were conducted at the five established reference streams in 2002 and at one site in 2000. These data were used to characterize the region. Most of the bottom substrate in streams in the Metasedimentary Mountains subregion of the Blue Ridge Mountains is suitable for periphyton colonization (74-94%). Periphyton were more abundant in reference streams here than in other Blue Ridge subregions even though total phosphorus levels were lower than those measured in the Limestone Valleys and Coves. Microalgae covered 33-91% of the rocks in the five reference streams surveyed (Table 22). However, density was still relatively low (Figure 38). The mean thickness rank was 0.3. There were no macroalgae present at any of the reference sites.

Table 22: Periphyton data for reference sites in the Southern Metasedimentary Mountains (66g).

Station ID	Date	% Macro algae	% Substrate Available	% Micro algae	Max THR	Mean THR	% Canopy
ECO66G04	8/26/02	0	94	72	1.0	0.5	
ECO66G05	10/10/00	0	76	91	0.5	0.4	86
ECO66G05	8/16/02	0	87	29	0.5	0.2	
ECO66G07	8/21/02	0	90	85	1.0	0.5	
ECO66G09	8/21/02	0	74	33	0.5	0.2	
ECO66G12	8/21/02	0	84	34	0.5	0.2	

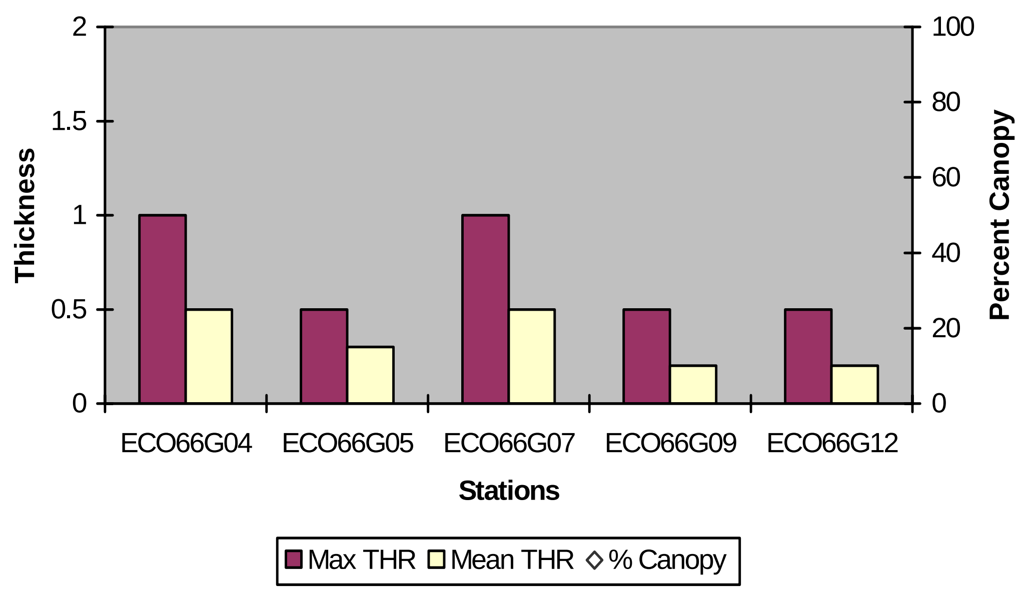


Figure 38: Microalgae at reference sites in the Southern Metasedimentary Mountains (66g). Canopy data were not available.

8.2.7 Periphyton density in the Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f)

Two reference streams and four test sites were surveyed during this project. All four of the test sites passed macroinvertebrate guidelines for the ecoregion. Periphyton data were available from an additional five reference sites collected in 2002 (Table 23). Rock substrate suitable for periphyton colonization was abundant at all sites. On the Powell River (ECO67F25), a small amount (10 percent) of macroalgae was observed. Macroalgae were not present at the other six ecoregion reference sites in this subecoregion. Small amounts of microalgae were observed at every site.

Both ecoregion reference sites on the Powell River (ECO67F14 and ECO67F25) had a visual accumulation of microalgae. The other five ecoregion reference sites had only a slime coating of microalgae on part of the substrate which resulted in a mean thickness of 0 at three sites (Figure 37). The upstream Powell River site (ECO67F25) and Hardy Creek (ECO67F16) had the highest concentration of periphyton covering approximately 30% of the substrate with a mean thickness rank of 0.2.

The four unimpaired test sites showed similar levels of periphyton to the reference streams. Macroalgae were not present and the mean thickness rank of microalgae never exceeded 0.2. Total phosphorus was within regional guidelines at all four sites. Nitrate+nitrite exceeded regional guidelines (1.22 mg/l) at the two sites on Davis Creek (2.10 and 1.32 mg/l), however both sites had good canopy cover which inhibited periphyton growth.

In general, periphyton appear to be present, but not abundant in unimpaired streams in the Southern Limestone/ Dolomite Valleys and Low Rolling Hills. When present, microalgae do not colonize substrates in measurable thickness. The mean thickness rank of reference data was 0.1.

Table 23: Periphyton data for seven reference and four test sites in the Southern Limestone/ Dolomite Valleys and Low Rolling Hills (67f).

Station ID	Macroinvert. Guidelines	Data	% Macro-algae	% Substrate Available	% Micro-Algae	Max THR	Mean THR	Avg. % Canopy
ECO67F06	Reference	9/2/02	0	92	7	0.5	0.0	
ECO67F13	Reference	8/24/04	0	79	28	0.5	0.1	86
ECO67F14	Reference	8/29/02	0	83	17	1	0.1	
ECO67F16	Reference	8/24/04	0	69	37	0.5	0.2	67
ECO67F17	Reference	8/28/02	0	90	5	0.5	0.0	
ECO67F23	Reference	8/29/02	0	82	8	0.5	0.0	
ECO67F25	Reference	8/29/02	10	74	31	1	0.2	
CAWOO000.2CL	Pass	8/23/04	0	17	39	0.5	0.2	97
DAVIS011.6CL	Pass	8/23/04	0	46	10	0.5	0.0	94
DAVIS014.6CL	Pass	8/23/04	0	56	9	0.5	0.0	86
SFLSE001.7MM	Pass	9/15/04	0	58	0	0.0	0.0	94

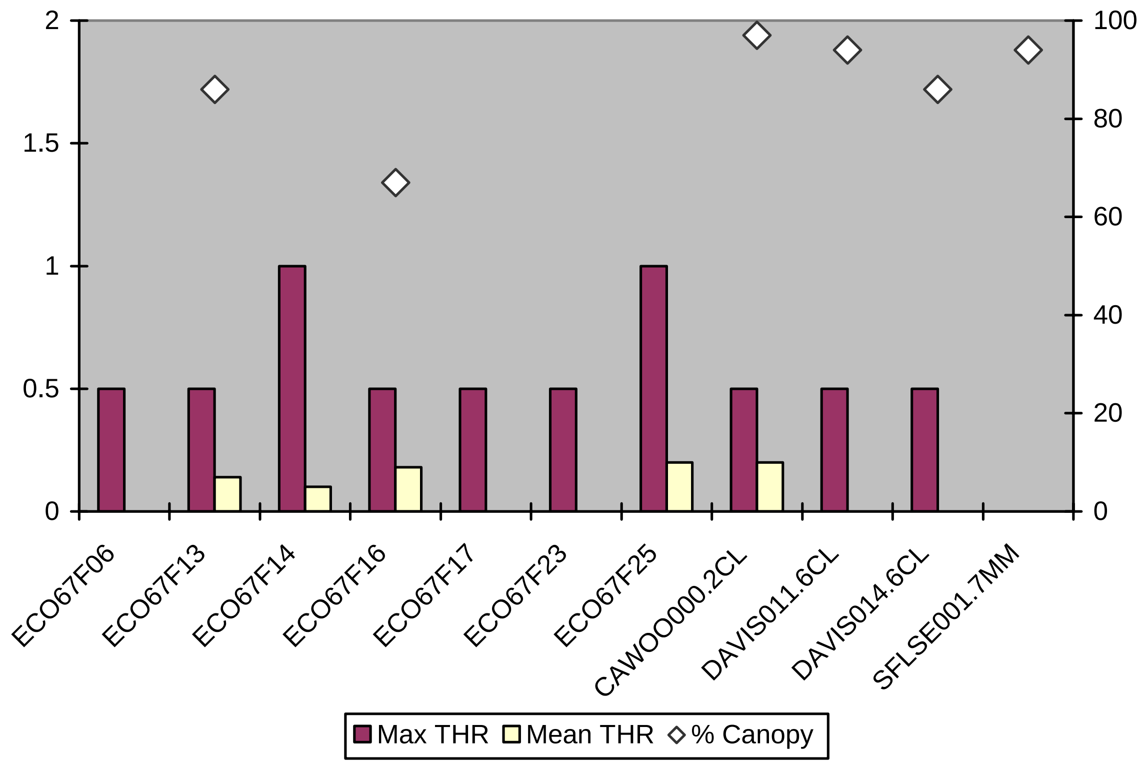


Figure 39: Microalgae and canopy at seven reference and four unimpaired test sites in the Southern Limestone/ Dolomite Valleys and Low Rolling Hills (67f). Data are based on one survey conducted in late summer 2002 or 2004.

8.2.8 Periphyton density in the Southern Shale Valleys (67g)

One reference site was surveyed during this study while periphyton data were available from five others surveyed in 2002 (Table 24). Substrate in this ecoregion is predominantly bedrock and cobble that provides abundant hard substrate for periphyton colonization. Macroalgae were not observed at any of the reference sites.

All of the reference sites had some microalgae except Little Chucky Creek (ECO67G01). The other five reference sites never had more than a slime coating of microalgae with no measurable thickness (Figure 40). The greatest densities of microalgae were at Harris Creek (ECO67G09) and Flat Creek (ECO67G10) where 35 to 48 percent of the substrate was covered by a slime coat of periphyton.

Periphyton do not appear abundant in reference streams in the Southern Shale Valleys (67g) subregion. When present, microalgae do not occur in measurable thickness. The overall thickness rank based on all reference data was 0.1 for the ecoregion.

Table 24: Periphyton data for reference sites in the Southern Shale Valleys (67g).

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO67G01	8/27/02	0	63	0	0	0.0	
ECO67G05	8/27/02	0	82	5	0.5	0.0	
ECO67G08	8/20/02	0	83	25	0.5	0.1	
ECO67G09	8/20/02	0	69	35	0.5	0.2	
ECO67G10	8/22/02	0	96	48	0.5	0.2	
ECO67G11	8/11/04	0	92	10	0.5	0.0	82

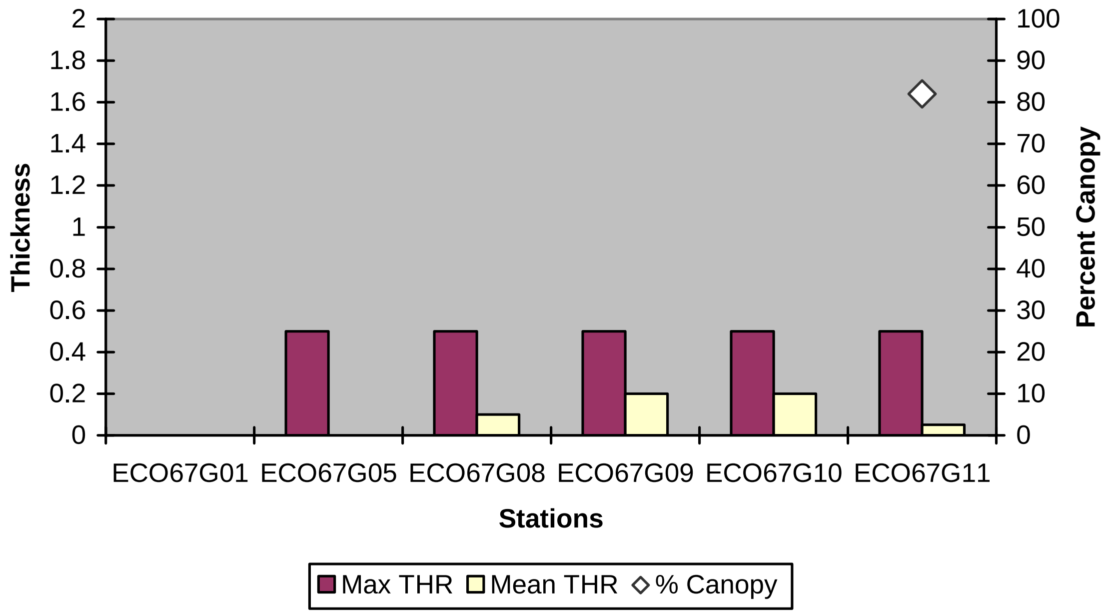


Figure 40: Microalgae and canopy at reference sites in the Southern Shale Valleys (67g). Data are based on one survey completed in August 2002 or 2004.

8.2.9 Periphyton density in the Southern Sandstone Ridges (67h)

Two ecoregion reference sites were surveyed for periphyton in 2004. Suitable rock substrate for periphyton colonization was present but not abundant (27-51%). The dominant substrate found in streams in this region is generally small particle sizes such as gravel and sand that is not conducive to colonization. Canopy was dense at both sites (95-97%), which would also be a deterrent to algal growth. Neither macroalgae nor microalgae were observed at either reference sites.

8.2.10 Periphyton density in the Southern Dissected Ridges and Knobs (67i)

One reference site, Mill Branch (ECO67I12) was surveyed for periphyton in August 2004. Sixty-four percent of the substrate was suitable for periphyton growth. Macroalgae were not present. Only five percent of the available substrate was colonized by microalgae. These few rocks had a dense growth, with a measurable thickness of 1 to 5 mm (THR = 3). However, since the majority of rocks were not colonized, the mean thickness rank was 0.1. Canopy was dense, with over 85% of the stream shaded including the areas of thick algal growth.

8.2.11 Periphyton density in the Cumberland Plateau (68a)

Two reference sites were surveyed during this study while periphyton data from 2002 were available from four additional stations. The dominant channel substrates in Cumberland Plateau streams are cobble, boulder and bedrock providing abundant habitat for periphyton colonization. Macroalgae were not found at any of the sampling stations (Table 25).

Although microalgae were found at all the reference sites except one, Clear Creek (ECO68A03), the mean thickness rank was 0 in all but two streams (Figure 41). Daddys Creek (ECO68A26) had the highest abundance of microalgae, which covered 93% of the available substrate. Fourty-two percent of the substrate was colonized at Rock Creek (ECO68A28). Although periphyton were abundant at these two sites, there was no measureable thickness.

Based on reference data, microalgae have the potential to colonize a substantial percentage of the channel substrate. However, density is low at reference sites and the mean thickness rank for the ecoregion is 0.1.

Table 25: Periphyton data for reference sites in the Cumberland Plateau (68a)

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg/ % Canopy
ECO68A01	9/5/02	0	86	7	0.5	0.0	
ECO68A03	9/3/02	0	46	3	0.5	0.0	
ECO68A08	9/15/04	0	74	0	0	0.0	62
ECO68A26	9/5/02	0	91	93	0.5	0.5	
ECO68A27	9/5/02	0	57	5	0.5	0.0	
ECO68A28	8/31/04	0	97	42	0.5	0.2	79

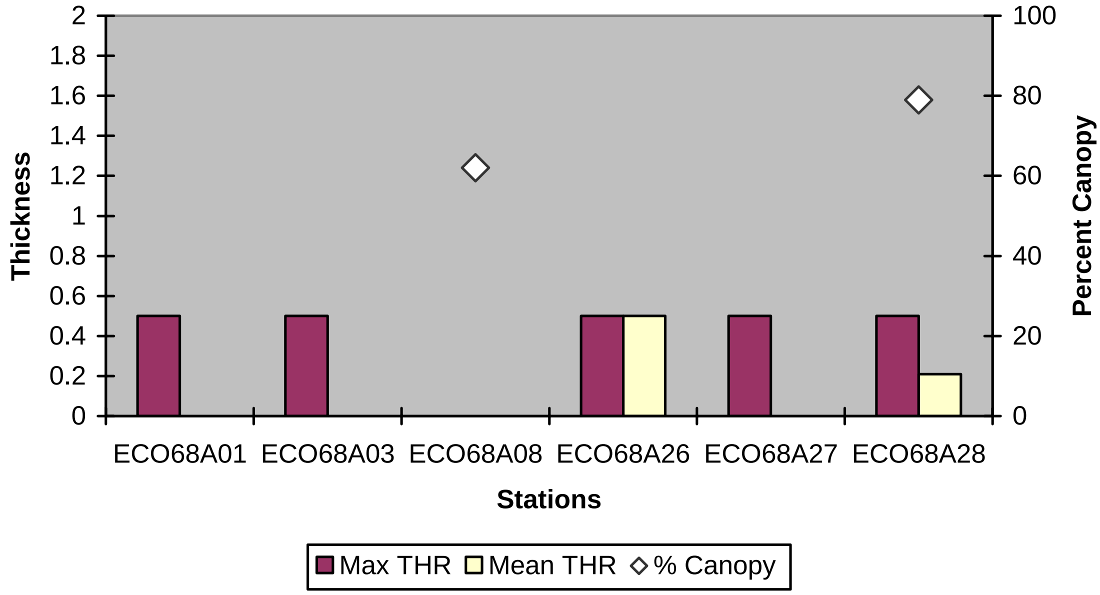


Figure 41: Microalgae and canopy at reference sites in the Cumberland Plateau (68a). Data are based on one survey from each station in August and September 2002 or 2004.

8.2.12 Periphyton density in the Cumberland Mountains (69d)

Three ecoregion reference sites were surveyed during this project while there were periphyton data from one additional site surveyed in 2002 (Table 26). Abundant substrate was available for periphyton colonization at each site. New River (ECO69D05) was the only site where macroalgae were present, colonizing only four percent of the substrate. A slime layer of microalgae was found at every reference site surveyed (Figure 42). The microalgae generally colonized a small percentage of the rock substrate. The highest concentration was found at Round Rock Creek (ECO69D06) where it covered 40% of the rocks. Canopy cover was dense at the sites where it was measured.

Periphyton do not appear abundant in reference streams in the Cumberland Mountain (69d) ecoregion. Where it is present, it does not occur in measurable thickness. The mean thickness rank for the ecoregion was 0.1.

Table 26: Periphyton data for reference sites in the Cumberland Mountains (69d)

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO69D01	9/2/02	0	59	13	0.5	0.1	
ECO69D03	8/31/04	0	83	20	0.5	0.1	93
ECO69D05	8/31/04	4	80	13	0.5	0.1	91
ECO69D06	8/30/04	0	98	40	0.5	0.2	82

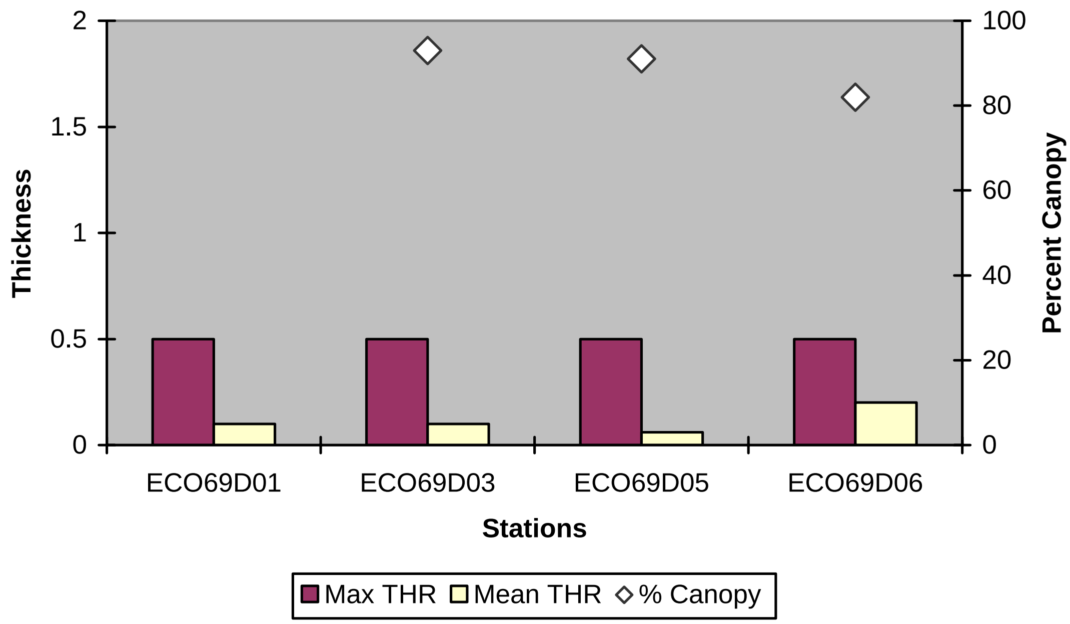


Figure 42: Microalgae and canopy at reference sites in the Cumberland Mountains (69d).

8.2.13 Periphyton density in the Western Pennyroyal Karst (71e)

Two ecoregion reference sites were surveyed for periphyton densities both during this project and in 2002. (Table 27). Passenger Creek (ECO71E14) was also surveyed in 2000. Abundant stable substrate suitable for periphyton growth was available at each site. A small amount (six percent) of macroalgae were found in Passenger Creek in November 2000, although none has been recorded since. A high percentage of the substrate at both creeks was colonized by microalgae during each survey. Isolated rocks had a thick coating with a maximum thickness rank of 3 at Buzzard Creek and 4 at Passenger Creek in 2004 (Figure 43). However the majority of colonized rocks were covered by a slime coat with no measurable thickness. The mean thickness rank was measureable, although less than 0.5 mm, at Passenger Creek when sampled in November 2000. The leaves were off the trees and canopy was only thirty percent, which encouraged periphyton growth.

Two unimpaired test sites were also surveyed for this project. Periphyton levels were similar to those found at reference streams. Based on reference and test data, a slime layer of algae is frequently encountered on rocks in unimpaired streams in this ecoregion. This is probably in response to the naturally high background levels of nitrate+nitrite found in the Western Pennyroyal Karst. Measurable thickness occurs infrequently. The mean thickness rank for reference streams in the subregion was 0.4. Due to the abundant substrate and naturally high nitrate+nitrite levels found in this region, there is a high potential for algae to become a problem in streams without sufficient canopy or with additional nutrient loading.

Table 27: Periphyton data for two ecoregion reference and two unimpaired test sites in the Western Pennyroyal Karst (71e)

Station ID	Macroinvert. Guidelines	Date	% Macro-algae	% Substrate Available	% Micro-Algae	Max THR	Mean THR	Avg. % Canopy
ECO71E09	Reference	9/11/02	0	87	45	0.5	0.2	
ECO71E09	Reference	9/21/04	0	87	1	3	0.0	88
ECO71E14	Reference	11/27/00	6	88	94	2	1.0	30
ECO71E14	Reference	9/16/02	0	86	58	1	0.4	
ECO71E14	Reference	9/21/04	0	63	38	4	0.4	80
LWEST919.5MT	Pass	9/22/04	0	84	6	3	0.2	86
RED080.0RN	Pass	9/21/04	0	82	20	4	0.5	78

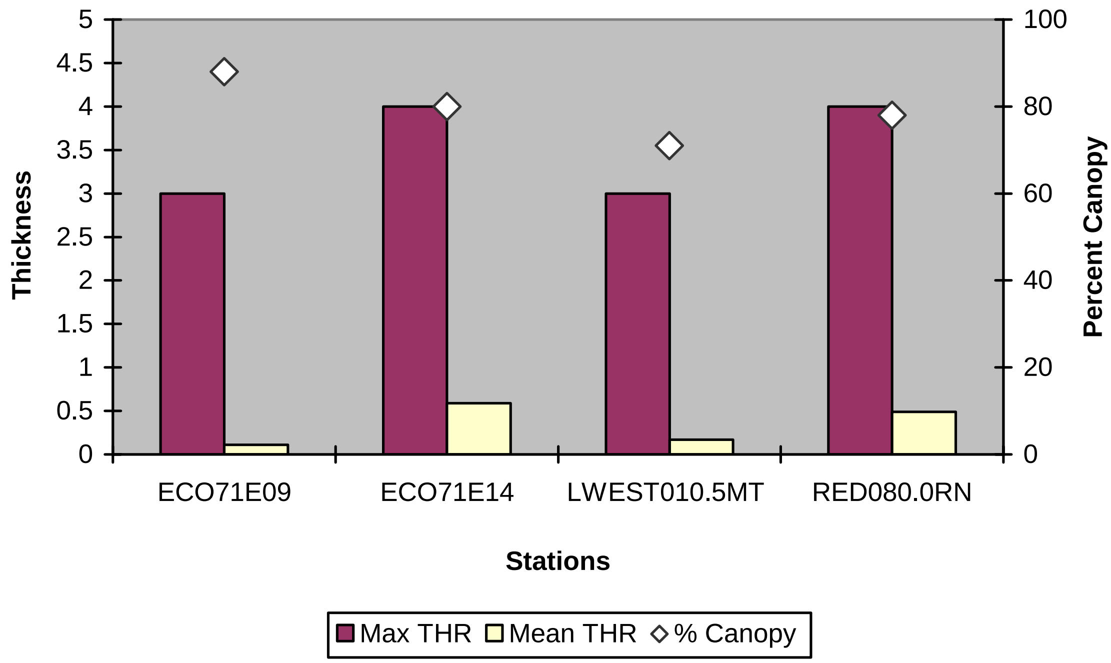


Figure 43: Microalgae and canopy at two reference and two unimpaired test sites in the Western Pennyroyal Karst (71e). The mean THR reflects the average value of all survey dates for each station. When there are more than one survey, the percent canopy is the amount measured on the date with the highest maximum thickness rank (THR). Data were collected in late summer or early fall 2000 through 2004.

8.2.14 Periphyton density in the Western Highland Rim (71f)

Six ecoregion reference sites were surveyed for this study (Table 28). Four of the sites were also surveyed in 2002. Stable substrate suitable for periphyton growth was abundant at every site.

Macroalgae were not observed at any stream. Microalgae were observed during each survey, except Swanegan Branch (ECO71F27) in October 2004 although a slime coat covered 11% of the rocks two years earlier. The thickest accumulation was found in Little Swan Creek (ECO71F28) in September 2004 where a microalgae layer 1 to 5 millimeters thick (THR = 3) was observed (Figure 44). However, few of the rocks were this thickly colonized and the mean thickness rank was 0.4. The highest mean thickness rank (0.8) was recorded in South Harpeth Creek (ECO71F12).

Based on this information, periphyton appear to be common in reference streams in this region. All of the sites, except Swanegan Branch, had at least 50% of the available substrate covered by microalgae during at least one survey. Although fairly ubiquitus, the microalgae were generally present as a slime coat with no measureable thickness. The mean thickness rank of reference streams in the ecoregion was 0.3 although individual rocks at several stations had much thicker densities.

Canopy cover for these sites was varied from 55 to 94 percent. However, this did not correlate with algal abundance. The site with the least canopy, Wolf Creek (ECO71F16), also had very little microalgae. The abundance of algae in streams with relatively low nutrients and a dense canopy cover indicates streams in this region are vulnerable to adverse affects from nutrient enrichment.

Table 28: Periphyton data for reference sites in the Western Highland Rim (71f).

Station ID	Date	% Macroalgae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO71F12	6/21/02	0	80	74	1	0.5	80
ECO71F12	10/9/02	0	78	44	1	0.3	
ECO71F12	10/1/04	0	73	84	2	0.8	80
ECO71F16	9/30/02	0	78	51	0.5	0.2	
ECO71F16	9/29/04	0	94	14	0.5	0.1	55
ECO71F19	9/30/02	0	85	54	0.5	0.2	
ECO71F19	9/30/04	0	88	28	0.5	0.1	71
ECO71F27	10/8/02	0	70	11	0.5	0.1	
ECO71F27	10/22/04	0	96	0	0	0.0	94
ECO71F28	9/30/04	0	94	88	3	0.4	72
ECO71F29	9/29/04	0	84	73	0.5	0.4	77

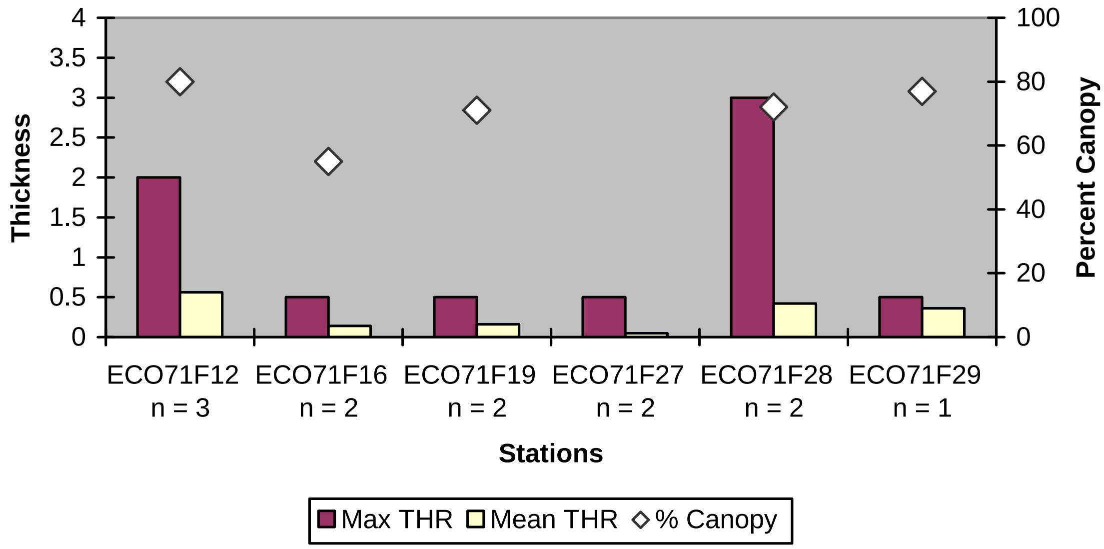


Figure 44: Microalgae and canopy at reference sites in the Western Highland Rim (71f). The mean THR reflects the average value of all survey dates for each station. When there is more than one survey, the percent canopy is the amount measured on the date with the highest maximum thickness rank (THR).

8.2.15 Periphyton density in the Outer Nashville Basin (71h)

One ecoregion reference stream was surveyed during this study while periphyton data were available from a second site collected in 2001 and 2002 (Table 29). Abundant substrate was available for algal colonization in both streams. Macroalgae were not present at either reference site. Most of the rock substrate at Carson Fork (ECO71H09) was colonized by microalgae in both 2001 and 2002. This was primarily a thin layer less than 0.5 mm thick although some rocks had thicker accumulations (Figure 45). Microalgae colonized very little of the available substrate at Clear Fork (ECO71H06). Only seven percent of the rocks were covered and the thickness was never measureable. Canopy was denser at this site than at Carson Fork.

The overall mean thickness rank of all the Outer Nashville Basin (71h) reference data was 0.6. This is the highest of any region in the state.

Table 29: Periphyton data for reference sites in the Outer Nashville Basin (71h).

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO71H06	9/16/04	0	77	7	0.5	0.0	86
ECO71H09	9/25/01	0	100	76	2	0.9	66
ECO71H09	9/11/02	0	85	93	1	0.8	

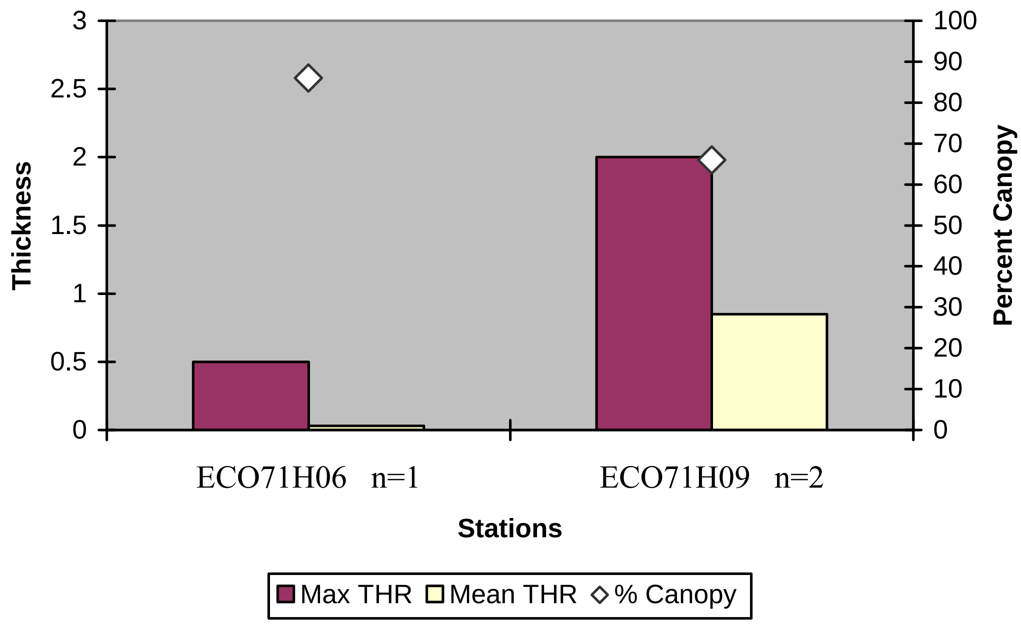


Figure 45: Microalgae and canopy at reference sites in the Outer Nashville Basin (71h). The mean THR reflects the average value of all survey dates for each station. When there is more than one survey, the percent canopy is the amount measured on the date with the highest maximum thickness rank (THR).

8.2.16 Periphyton density in the Inner Nashville Basin (71i)

Two ecoregion reference sites were surveyed during this study while data were available for four more surveyed in 2002 (Table 30). Harpeth River (ECO71I15) was surveyed twice in June and October 2002. Two stations (ECO71I10 and ECO71I16) are on the West Fork Stones River. Bedrock is the dominant substrate for most streams in this region, which provides abundant substrate suitable for algal colonization. The exception is Stewart Creek (ECO71I03) where the dominant substrate is gravel and only 23% of the rocks were of sufficient size. This was the only site that did not have microalgae present. All of the other stations, except Cedar Creek (ECO71I12) and West Fork Stones River (ECO71I16) had the majority of substrate colonized, generally by a thin layer less than 0.5 mm thick (Figure 46).

Cedar Creek, where only 49% of the substrate was colonized, had a slime coating with no measurable thickness. West Fork Stones River only had 18% of the substrate colonized. Although these rocks supported a somewhat denser algal growth, the mean thickness rank was comparable to other reference sites due to the limited colonization area. Canopy was lower (60%) at the West Fork Stones River than other reference sites in the subregion due to its wider channel.

Periphyton colonized the majority of the substrate in streams with bedrock substrate. The overall mean thickness rank of the Inner Nashville Basin (71i) reference data was 0.5, which is a slime coating with no measureable thickness. Macroalgae were not observed at any of the reference sites.

Periphyton surveys were also conducted at two test sites during the 2004 study. Both sites passed macroinvertebrate guidelines when surveyed in 2000 and 2001. They each had abundant substrate suitable for periphyton colonization. Florida Creek, had macroalgae present on seven percent of the rock substrate. Microalgae density was similar to that found at reference streams with a mean thickness rank of 0.5.

The other test site, Spring Creek did not have macroalgae but did have a high density of microalgae on 87% of the substrate. The mean thickness rank was 3, which is an algal layer 1 to 5 mm thick. It is unclear why microalgae were dense at this site. The stream had adequate flow and nitrate+nitrite levels were within guidelines throughout the two-week monitoring period. Total phosphorus was slightly elevated (0.19 mg/l) compared to regional guidelines (0.18 mg/l) one week prior to the algae survey, but were within guidelines during the survey. The stream was mostly shaded with a mean canopy of 78% and a minimum canopy of 64% at the reach surveyed.

Dissolved oxygen stayed above 6 ppm, however diurnal variation was around 6 ppm probably in response to photosynthesis. This station is immediately upstream of the Spring Creek embayment on Old Hickory Reservoir, which may affect algal growth. Additional study is needed at this site to see if this periphyton density is typical and if the macroinvertebrate community has been affected.

Table 30: Periphyton data for six reference and two test sites in the Inner Nashville Basin (71i).

Station ID	Date	% Macro-algae	% Substrate Available	%Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO71I03	8/8/02	0	23	0	0	0	
ECO71I10	10/8/02	0	90	94	1	0.8	
ECO71I12	9/28/04	0	92	49	0.5	0.2	76
ECO71I14	10/9/02	0	100	99	1	0.9	
ECO71I15	6/21/02	0	99	85	1	0.7	70
ECO71I15	10/9/02	0	96	100	1	0.5	
ECO71I16	9/16/04	0	99	18	1	0.1	60
FLORI002.4WS	9/16/04	7	93	100	0.5	0.5	41
SPRIN004.4WS	9/28/04	0	95	87	4	3.3	78

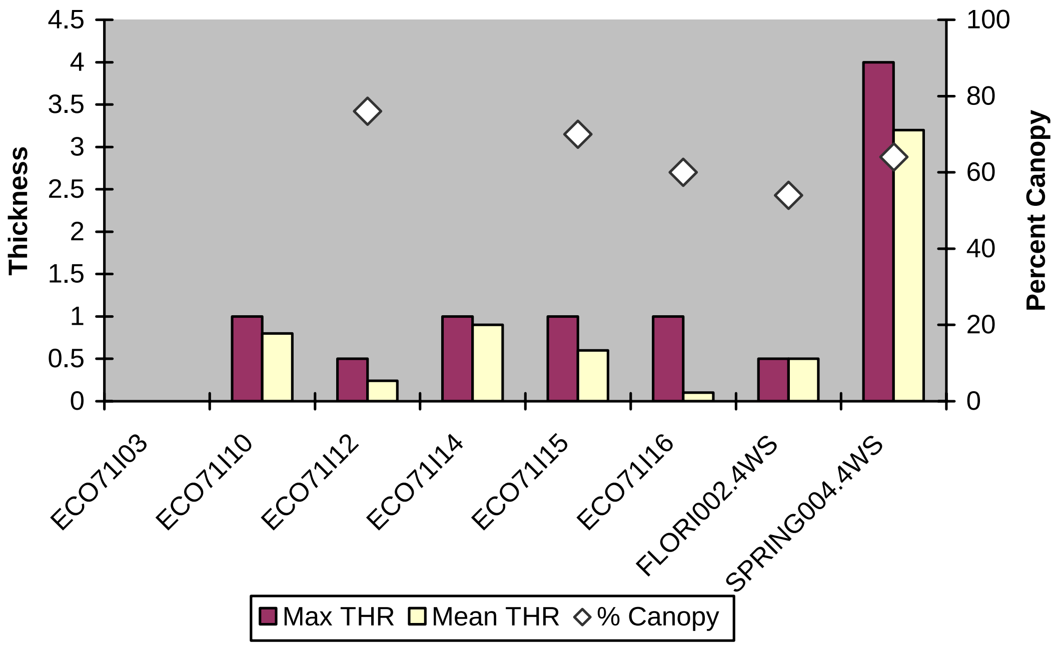


Figure 46: Microalgae and canopy at reference sites in the Inner Nashville Basin (71I). The mean THR reflects the average value of all survey dates for each station. When there is more than one survey, the percent canopy is the amount measured on the date with the highest maximum thickness rank (THR).

8.2.17 Periphyton density in the Northern Mississippi Alluvial Plain (73a)

Streams in this subregion have shifting sand substrates unsuitable for periphyton colonization.

8.2.18 Periphyton density in the Bluff Hills (74a)

Two ecoregion reference sites were surveyed for periphyton during this study. The majority of substrate at Sugar Creek (ECO74A06) was suitable for colonization while most of the substrate at Pawpaw Creek (ECO74A08) was too small a particle size (Table 31). At Pawpaw Creek there was no microalgae observed on the limited amount of substrate that was available (Figure 47). Canopy was relatively dense at this site.

Only 14% of the available rocks were colonized by microalgae at Sugar Creek. However, this was a thick layer of 5 mm to 2 cm (THR = 4). Canopy was fairly open at this site, 44% shaded overall with a minimum of 29%. Canopy along with percentage of stable substrate may explain the difference in algal density in these two creeks. The overall mean thickness rank of all the Bluff Hills reference data was 0.2. Macroalgae were not observed at either site.

Streams in this region have a dominant particle size of gravel, which is too small for periphyton colonization. However, based on these data, it appears that streams do have the potential for dense growth of algae when substrate is available and canopy is limited. The mean thickness rank for the ecoregion was 0.2.

Table 31: Periphyton data for reference sites in the Bluff Hills (74a).

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO74A06	10/26/04	0	78	14	4	0.5	44
ECO74A08	11/8/04	0	31	0	0	0.0	75

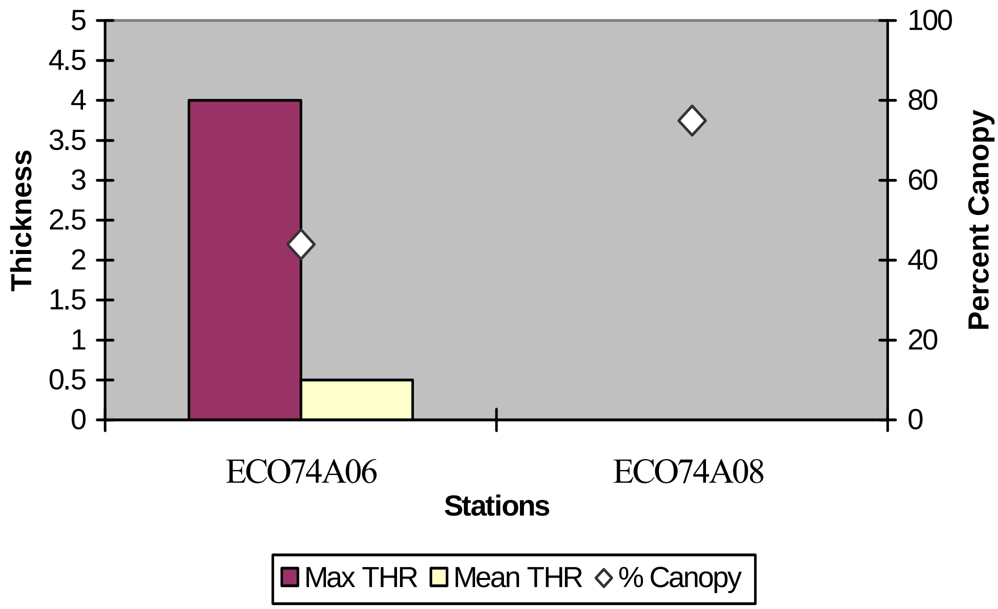


Figure 47: Microalgae and canopy at reference sites in the Bluff Hills (74a).

8.2.19 Periphyton density in the Loess Plains (74b)

The dominant substrate of streams in the Loess Plains (74b) is sand, which is not a viable habitat for periphyton colonization. Two reference sites were surveyed for periphyton density for this study while one of the sites was also surveyed in 2002 (Table 32). There were no macroalgae observed at either site. One of the reference sites, Powell Creek (ECO74B04), had a slime coating of microalgae on a small percent of the rock although the mean thickness rank was 0 (Figure 48). Terrapin Creek (ECO74B01) had no microalgae although more substrate was available for colonization.

Overall, it appears that periphyton are not abundant in unimpaired streams in this subregion, partially due to a lack of substrate. Where present, periphyton do not occur in measurable thickness. The mean thickness rank for the ecoregion was 0.

Table 32: Periphyton data at two reference sites in the Loess Plains (74b)

Station ID	Date	% Macro-algae	% Substrate Available	% Micro-algae	Max THR	Mean THR	Avg. % Canopy
ECO74B01	9/8/2002	0	18	0	0	0.0	
ECO74B01	11/23/2004	0	49	0	0	0.0	36
ECO74B04	11/16/2004	0	15	12	0.5	0.0	45

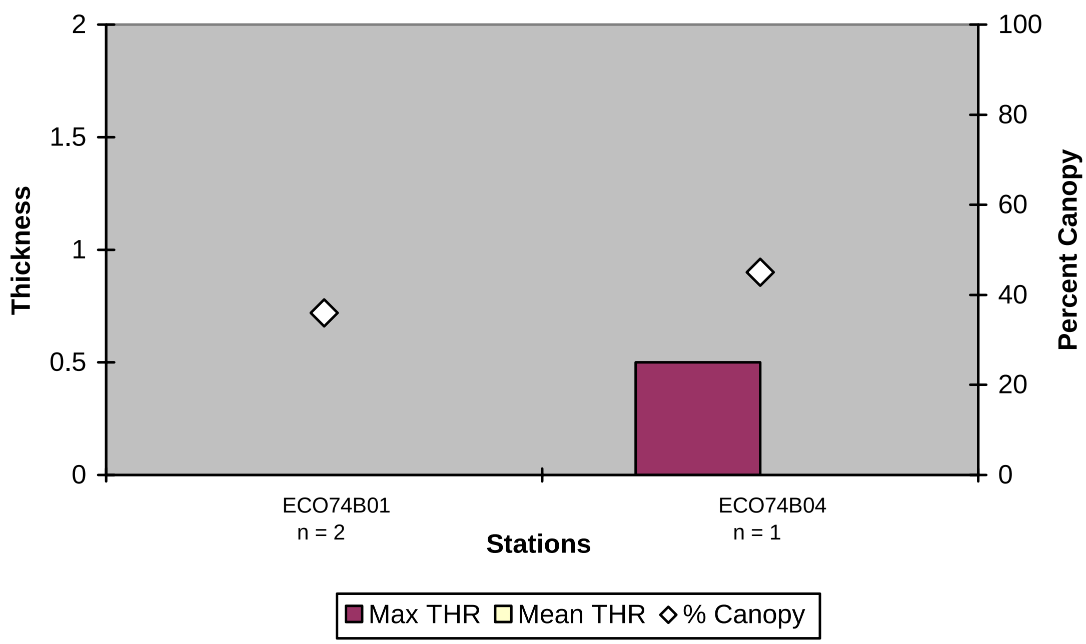


Figure 48: Microalgae and canopy at reference sites in the Loess Plains (74b). The mean THR reflects the average value of all survey dates for each station. When there is more than one survey, the percent canopy is the amount measured on the date with the highest maximum thickness rank (THR).

9. NUTRIENTS

There were two goals for nutrient sample collection. One was to increase the reference database. These data are provided in Appendix E. The second objective was to test the reliability of field nitrate probes. These probes could potentially reduce field time and analysis costs while providing information on long-term diurnal nutrient patterns.

Two continuous monitoring nitrate probes were deployed at 11 sites for two weeks. Monitoring was conducted at four ecoregion reference sites, three unimpaired non-wadeable sites, one site on the 303(d) list for nutrients and three wadeable test sites. Whole water grab samples were taken three times at the same 11 sites for nitrate analysis in the lab. The grab samples were collected at the time of probe deployment, after the first week of deployment, and just prior to probes retrieval. The grab samples were analyzed by automatic colorometric analysis in the lab to determine the accuracy of the probes.

When checked against the grab samples collected at the same time and analyzed in the lab, neither of the nitrate probes gave comparable measurements (Table 33). The probes were not consistent in the type of error. Most often, the field probes measured higher levels of nitrate than the grab samples analyzed in the lab. However, the probes sometimes measured lower.

Part of the problem may have been the range of the calibration standards used. The calibration range for the nitrate probes was between 5 mg/L-N and 50 mg/L-N, which brackets their working range. The nitrate concentrations in the study streams were less than the calibration range of the probes. The colorometric analysis conducted in the lab was calibrated using seven standards ranging from 0.1 to 2.0 mg/L plus a blank. This bracketed nitrate concentrations found in the study streams.

The lower nitrate concentrations found in the streams where the probes were deployed could also be one of the reasons for the inaccuracy of nitrate measurements. The probes are only accurate to ± 2 mg/L-N. The highest nitrate concentration measured in the lab was 2.01 mg/L-N. The error associated with this if measured with the nitrate probe is as great as the concentration value. Based on comparison to grab samples analyzed in the lab, the probes were often off by more than 2 mg/l.

The biggest problem with the probes seemed to be difficulty in holding calibration (Table 34). The probes tended to be unstable and imprecise. Once calibrated, they would begin to drift. Discrepancies between the probes and grab samples generally became greater the longer the probes were deployed (Figure 49).

Table 33: Comparison of lab analyses and continuous monitoring probe measurements of nitrates over a two-week period at 11 stations in late summer and fall 2004. Nitrate data are expressed in mg/l.

Site	Probe	Date	Time	Lab Nitrate (mg/l)	Field Probe Nitrate (mg/l)
ECO67G11	1716	07-29-04	1045	0.15	12.27
ECO67G11	1716	08-03-04	0710	0.14	20.09
ECO67G11	1716	08-11-04	0730	0.18	24.3
DAVIS011.6CL	1716	08-13-04	0730	1.51	2.05
DAVIS011.6CL	1716	08-18-04	1545	1.65	3.08
DAVIS011.6CL	1716	08-25-04	1530	2.01	3.52
ECO71I16	1716	09-09-04	0855	0.59	0.00
ECO71I16	1716	09-16-04	1145	0.15	0.00
ECO71I16	1716	09-22-04	1425	0.53	0.00
MIDDL002.5HD	1716	10-12-04	1525	<0.01	0.00
MIDDL002.5HD	1716	10-21-04	0900	0.11	0.00
MIDDL002.5HD	1716	10-26-04	1015	<0.01	0.00
SFFDE043.2MN	1716	10-28-04	0910	0.21	0.00
SFFDE043.2MN	1716	11-02-04	1230	0.28	0.00
SFFDE043.2MN	1716	11-10-04	1100	0.41	0.00
DEVIL000.2UC	1717	08-03-04	1046	0.39	6.50
DEVIL000.2UC	1717	08-10-04	1820	0.24	5.96
DEVIL000.2UC	1717	08-17-04	1500	0.21	5.10
ECO67F06	1717	08-23-04	1210	<0.01	0.12
ECO67F06	1717	08-30-04	1600	<0.01	0.02
ECO67F06	1717	09-08-04	0800	0.59	0.05
ECO71E14	1717	09-16-04	1600	1.55	4.92
ECO71E14	1717	09-21-04	1350	1.70	0.00
ECO71E14	1717	09-28-04	1700	2.10	0.00
SFFDE069.8CS	1717	10-05-04	0845	<0.10	0.10
SFFDE069.8CS	1717	10-14-04	0855	0.13	1.01
SFFDE069.8CS	1717	10-20-04	0730	0.11	2.55
WOLF044.4FA	1717	10-20-04	1310	0.10	0.03
WOLF044.4FA	1717	10-27-04	0820	<0.01	1.38
WOLF044.4FA	1717	11-01-04	1220	<0.01	0.81
NFFDE025.5GI	1717	11-09-04	1130	0.32	10.16
NFFDE025.5GI	1717	11-17-04	0750	0.30	0.05
NFFDE025.5GI	1717	11-23-04	1000	0.28	0.18

Table 34: Post calibration drift checks on nitrate field probes. Post calibration checks were not performed after SFFDE043.2MN, ECO67F06 or NFFDE025.5GI.

Probe	Station	Date Calibrated	Date Deployed	Date Retrieved	Drift Check	N5 Drift	N50 Drift
41716 (N1)	ECO67G11	7/27/04	7/29/04	8/11/04	8/13/04	+ 33.56	NS
41716 (N1)	DAVIS011.6CL	8/13/04	8/13/04	8/25/04	9/9/04	+ 45.86	OUT OF RANGE
41716 (N1)	ECO71I16	9/9/04	9/9/04	9/22/04	10/12/04	+ 48.86	-46.71
41716 (N1)	MIDDL002.5HD	10/12/04	10/12/04	10/26/04	10/28/04	NS	-29.14
41717 (N2)	DEVIL000.2UC	8/1/04	8/3/04	8/17/04	8/23/04	-2.97	-21.6
41717 (N2)	ECO71E14	9/16/04	9/16/04	9/28/04	10/5/04	+ 8.6	+ 14.8
41717 (N2)	SFFDE069.8CS	10/5/04	10/5/04	10/19/04	10/20/04	-0.05	-22.56
41717 (N2)	WOLF044.4FA	10/20/04	10/20/04	11/1/04	11/9/04	-4.13	-46.98

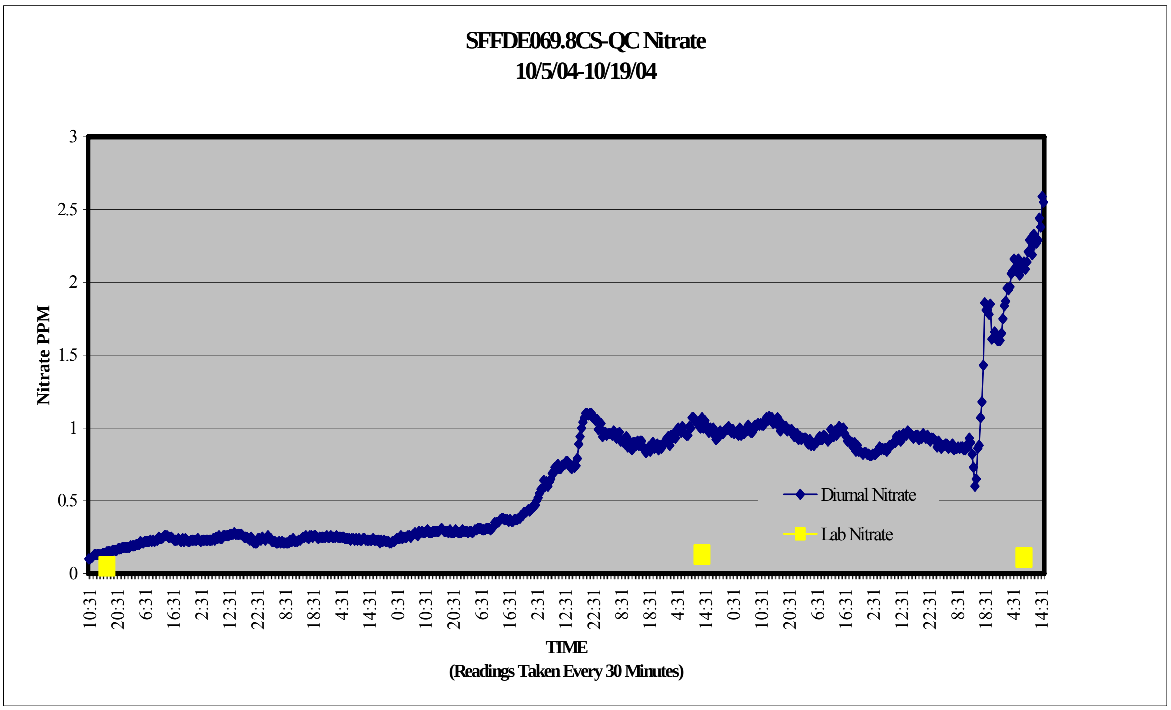


Figure 49: Comparison between continuous monitoring field probe and grab sample lab analysis of nitrate in South Fork Forked Deer River, October 2004.

10. NON-WADEABLE STREAMS IN ECOREGIONS 65e, 73a AND 74b

Tennessee has developed biological, habitat, and nutrient guidelines for wadeable streams that are 80% contained within the Southeastern Plains and Hills (65e) or the Loess Plains (74b) ecoregions. All reference sites in the Northern Mississippi Alluvial Plain (73a) are non-wadeable so guidelines were developed for non-wadeable streams contained within this ecoregion. However, five non-wadeable rivers, including several large forks, originate in the Southeastern Plains cross into the Loess Plains and the Northern Mississippi Alluvial Plain on their way to the Mississippi River. This includes the Obion, Forked Deer, Hatchie, Loosahatchie and Wolf River systems. Part of the goal of this project was to sample unimpaired as well as impaired stations to characterize these streams and evaluate the comparability to existing guidelines.

10.1 Non-wadeable Streams in the Southeastern Plains and Hills (65e)

Two non-wadeable rivers were surveyed that had drainage entirely within ecoregion 65e. These included one site on the South Fork Forked Deer River (SFFDE069.8CS) and two sites on the Middle Fork Obion River (MFOBI1C22.5WY and MFOBIO17.6WY). All three of these stations are in channelized reaches although wetlands are still present at the South Fork Forked Deer location.

10.1.1 Stream geomorphology

The dominant bed material based on both visual estimations and pebble counts at all three stations is sand. Using the Rosgen classification system, South Fork Forked Deer River is an F-type stream with a relatively flat cross-section (Figure 50). These streams are typically carved in valleys of low relief, comprised of highly weathered loess. This stream type is typical in this ecoregion for both wadeable and non-wadeable streams.

The Middle Fork Obion River is a C-type stream due to a more sloped cross-section (Figure 51). These streams generally have low relief channels, well-developed floodplains, and characteristic “point bars” within the active channel. The valleys are generally broad with gentle elevation relief. The predominant depositional landforms are alluvial terraces and floodplains. As with the F-type, C-type streams are also commonly found in wadeable reference streams in this region.

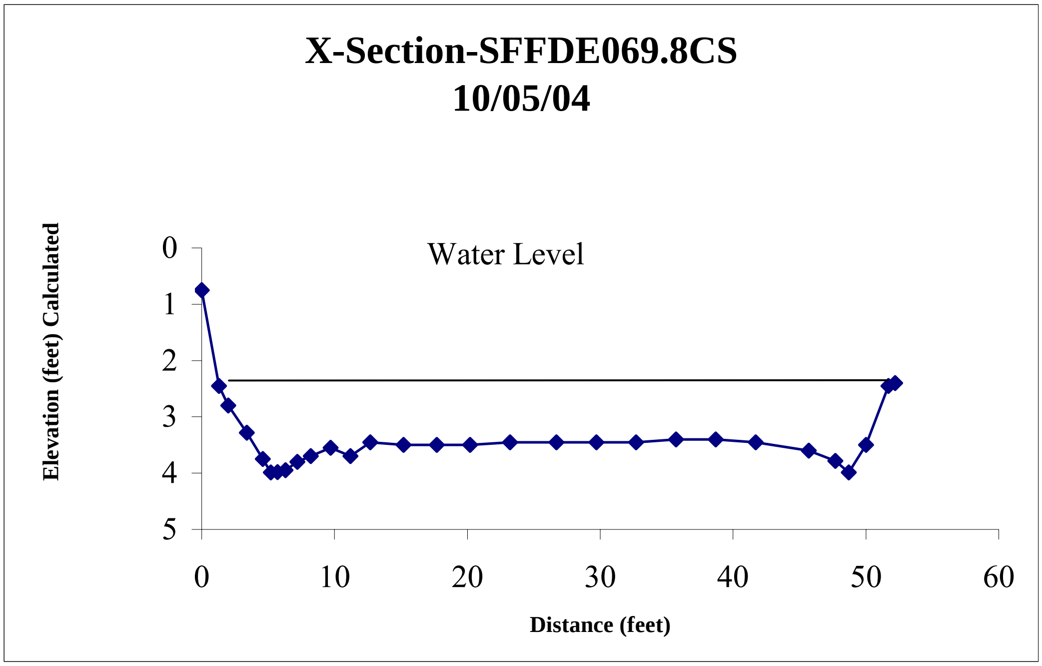


Figure 50: Cross-section of South Fork Forked Deer River, non-wadeable, unimpaired test site in the Southeastern Plains and Hills (65e). Flat cross-section is typical of F-type streams.

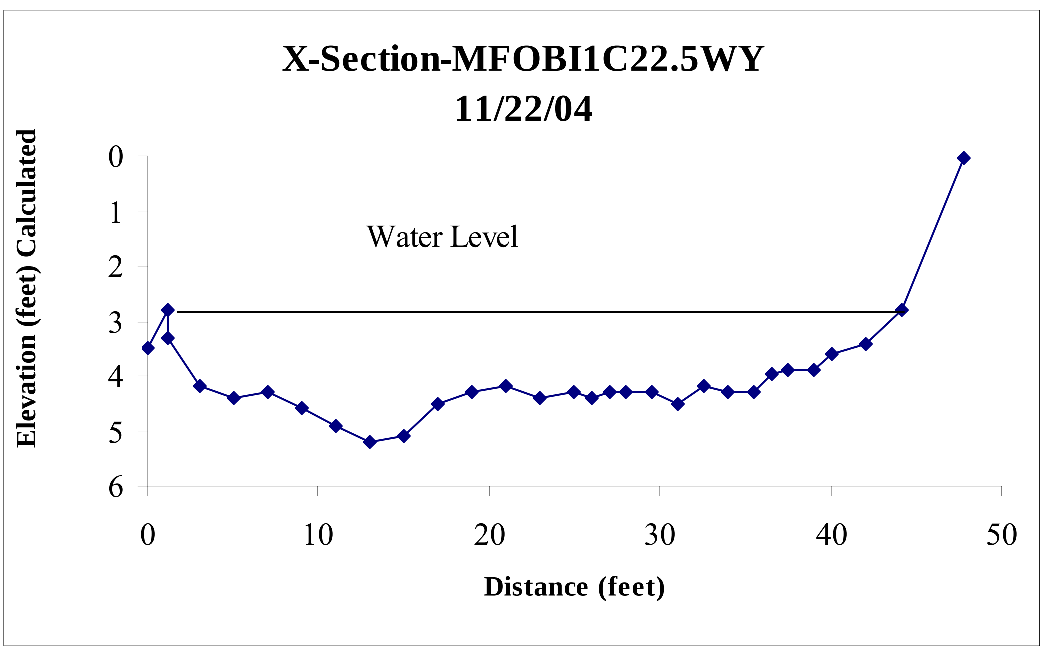


Figure 51: Cross-section of non-wadeable impaired site on the Middle Fork Obion River in the Southeastern Plains and Hills (65e). Sloped cross-section is typical of C-type streams.

10.1.2 Macroinvertebrates

The non-wadeable streams sampled during this project were compared to the wadeable reference database to determine if macroinvertebrate communities were similar. The same habitat (undercut banks and roots) was sampled at all sites. For the purpose of this study, the stations were grouped into diverse and stressed regardless of current assessment status since these biological data are more current than that used for 303(d) listing.

Macroinvertebrate communities were considered diverse in the non-wadeable streams if they scored 32 or higher when compared to the wadeable stream reference database. Based on these guidelines, the most upstream Middle Fork Obion River site and the South Fork Forked Deer site would be considered to have a diverse biological community while the downstream site on the Middle Fork Obion River would be considered stressed.

Five biometrics were comparable between wadeable reference and non-wadeable sites with diverse biology (Figure 52). However, there were a higher abundance of clingers and nutrient tolerant organisms in the non-wadeable streams while the percent contribution of dominant taxon was lower. The biometrics that seemed most sensitive for determining stress were EPT abundance, percent clingers and the percent nutrient tolerant organisms. These preliminary data suggest that the same biometrics can be used for both wadeable and non-wadeable streams in this ecoregion but ranges may need to be calibrated specific to non-wadeable streams.

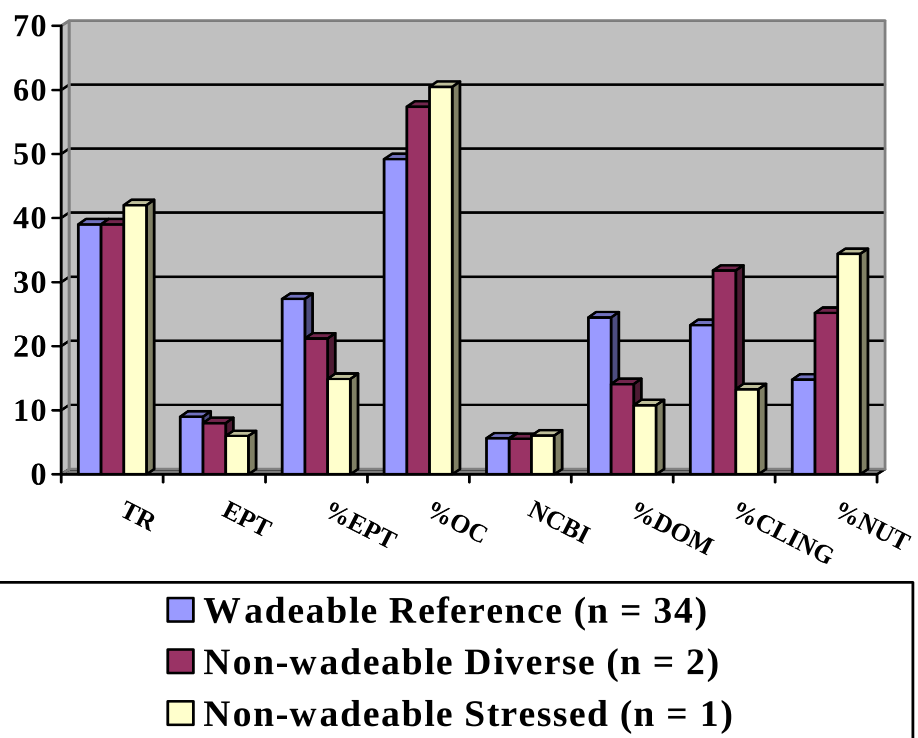


Figure 52: Macroinvertebrate biometrics for wadeable and non-wadeable streams in the Southeastern Plains and Hills (65e). Values based on sample mean.

10.1.3 Diurnal Dissolved Oxygen

Diurnal dissolved oxygen patterns in the larger non-wadeable rivers are similar to those found in wadeable streams in the Southeastern Plains and Hills. Waters are generally well oxygenated and diurnal fluctuations are small. DO levels at the two stations on the Middle Fork Obion River were between 6.5 and 10.0 ppm with a maximum diurnal change of 1.5 ppm. The South Fork Forked Deer had slightly lower dissolved oxygen levels (between 5.5 and 9.5 ppm) with diurnal fluctuations less than 1 ppm.

10.1.4 Nutrients

Nutrient guidelines established in this ecoregion are based on wadeable streams.

Nitrate+Nitrite = 0.34 mg/l
Total Phosphorus = 0.04 mg/l

At the two non-wadeable sites that had a diverse biological community, total phosphorus levels regularly exceeded wadeable stream guidelines (Table 35). One of the sites, Middle Fork Obion River, also exceeded wadeable nitrate+nitrite guidelines. This site has extensive canopy (73 to 91%), which would help inhibit production of algae. However, the South Fork Forked Deer site had a more open canopy (44%). Total phosphorus levels at South Fork Forked Deer River ranged from 0.07 to 0.13 mg/l.

Table 35: Nitrate+nitrite and total phosphorus levels at two non-wadeable rivers with good macroinvertebrate diversity in the Southeastern Plains and Hills (65e)

Station ID	Date	Nitrate+Nitrite (mg/l)	Total Phosphorus (mg/l)
MFOB1C22.5WY	2/7/2001	0.75	0.02
MFOB1C22.5WY	5/23/2001	0.88	0.09
MFOB1C22.5WY	11/10/2004	0.74	0.06
MFOB1C22.5WY	11/15/2004	0.64	<0.004
MFOB1C22.5WY	11/22/2004	0.51	0.08
SFDE069.8CS	10/20/2004	0.11	0.13
SFDE069.8CS	10/5/2004	0.10	0.07
SFDE069.8CS	10/14/2004	0.13	0.12

10.2 Non-wadeable streams in the Loess Plains (74b)

Tennessee already has one established non-wadeable reference site in the Loess Plains, the Wolf River (ECO74B12). This site was established as an ambient monitoring station in 1982 and became an ecoregion reference site in 1995. This reach of the river is relatively undisturbed and is surrounded by wetlands.

Most non-wadeable streams in 74b also drain 65e. The Wolf River at this location is one of the few that do not. The North Fork of the Wolf River does drain 65e and enters the main stem downstream of the reference site.

10.2.1 Stream geomorphology

The estimated dominant bed material and the D50 for the Wolf River at this location is sand, which is also typical of the two wadeable reference sites in the Loess Plains. The channel shape is also typical of wadeable streams which is U-shaped with a fairly flat bottom and high stream banks making this an F5 stream type. The wadeable reference streams in the Loess Plains are also F5. This is the typical stream type found in very low gradient loess areas with extensive wetlands.

10.2.2 Macroinvertebrates

Since this stream is an established reference site, the macroinvertebrate community is annually compared to the two non-wadeable reference sites for similarity. EPT richness tends to be higher in the non-wadeable reference while the percent of oligochaetes and chironomids is lower (Figure 53). However, the other metrics are within similar ranges and both stream types are currently grouped for assessment purposes.

There are not any non-wadeable impaired sites totally contained within this ecoregion for comparison. Larger streams generally drain the Southeastern Plains and Hills before entering the Loess Plains.

10.2.3 Diurnal Dissolved Oxygen

Diurnal dissolved oxygen data are not available from the reference site on the Wolf River. The monitoring equipment was compromised due to sediment filling the sensor compartment. Thirty-four daylight measurements taken between 1996 and 2004 ranged from 5.2 to 12.3 ppm.

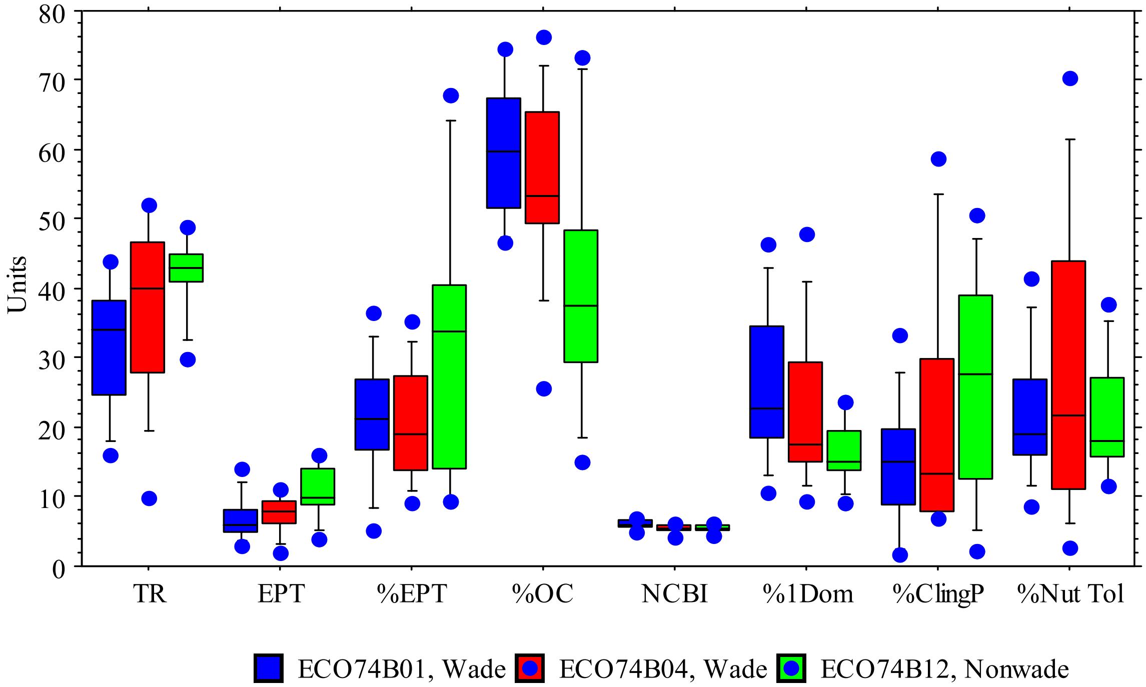


Figure 53: Macroinvertebrate biometrics for wadeable and nonwadeable reference streams in the Loess Plains (74b). The number of observations for ECO74B01 is 9, ECO74B04 is 11 and ECO74B12 is 18.

10.2.4 Nutrients

Nutrient guidelines for the Loess Plains are based on the 90th percentile at two wadeable and one non-wadeable reference stream. These values were calculated in 2001 and were based on 43 observations for each parameter.

Nitrate+nitrite = 1.19 mg/l
Total phosphorus = 0.10 mg/l

For the purpose of this study, the 90th percentiles were recalculated to include data collected between 2001 and 2005, a total of 83 observations (Table 36). These values were than broken down into wadeable (two sites, 52 observations) and non-wadeable (1 site, 31 observations). When looking only at non-wadeable data, the 90th percentile of nitrate+nitrite data would be well below the 90th percentile of all reference stations. However, the 90th percentile of total phosphorus data at the non-wadeable reference site would be well above that for wadeable streams alone.

Table 36: 90th percentile of nutrient data in wadeable and non-wadeable reference streams in the Loess Plains 1996 – 2005. Data are in mg/l.

	90th Percentile Nitrate+nitrite (mg/l)	90th Percentile Total Phosphorus (mg/l)	Number of Observations
1996 - 2001 All 74b Reference Streams	1.19	0.11	42
1996 - 2005 All 74b Reference Streams	1.13	0.14	83
74b Wadeable Reference Streams (2)	1.26	0.07	52
74b Non-wadeable Reference Streams (1)	0.32	0.31	31

10.3 Non-wadeable Streams Draining Ecoregions 65e and 74b

There were six stations surveyed on non-wadeable rivers that crossed both the Southeastern Plains and Hills and the Loess Plains ecoregions. All of the monitoring stations were located in the Loess Plains. Four sites were unimpaired and were used for baseline information. This included one site on the Hatchie River, two on the North Fork Forked Deer River and one on the Wolf River. Two impaired sites were also monitored. A site on the Loosahatchie River was listed for habitat loss due to the effects of channelization while the station on the South Fork Forked Deer River was listed for nutrients.

10.3.1 Stream geomorphology

The dominant bed material in these rivers is sand. All the stations had a sloped channel cross-section and are classified as C5 streams. This is atypical of both the wadeable and non-wadeable reference streams in 74b that are all F5. It is typical of some of the wadeable reference sites in 65e where both C5 and F5 stream types are found.

Although the geomorphology of all the surveyed rivers was more typical of the reference streams in the Southeastern Plains and Hills than the Loess Plains, the stations varied in their proximity to the ecoregion border (Figure 54). It appears that streams that cross these two ecoregions are more geophysically characteristic of the ecoregion from which they drain regardless of distance instead of the ecoregion they are in.

This is illustrated by the geomorphology of the Wolf River. The reference site on the Wolf River (ECO74B12) does not receive drainage from ecoregion 65e and is the F5 stream type characteristic of the Loess Plains. The other station on the Wolf River (WOLF044.4FA) is located in the Loess Plains but also receives drainage from the Southeastern Plains and Hills. The river at this location is characteristic of the C5 streams found in ecoregion 65e.

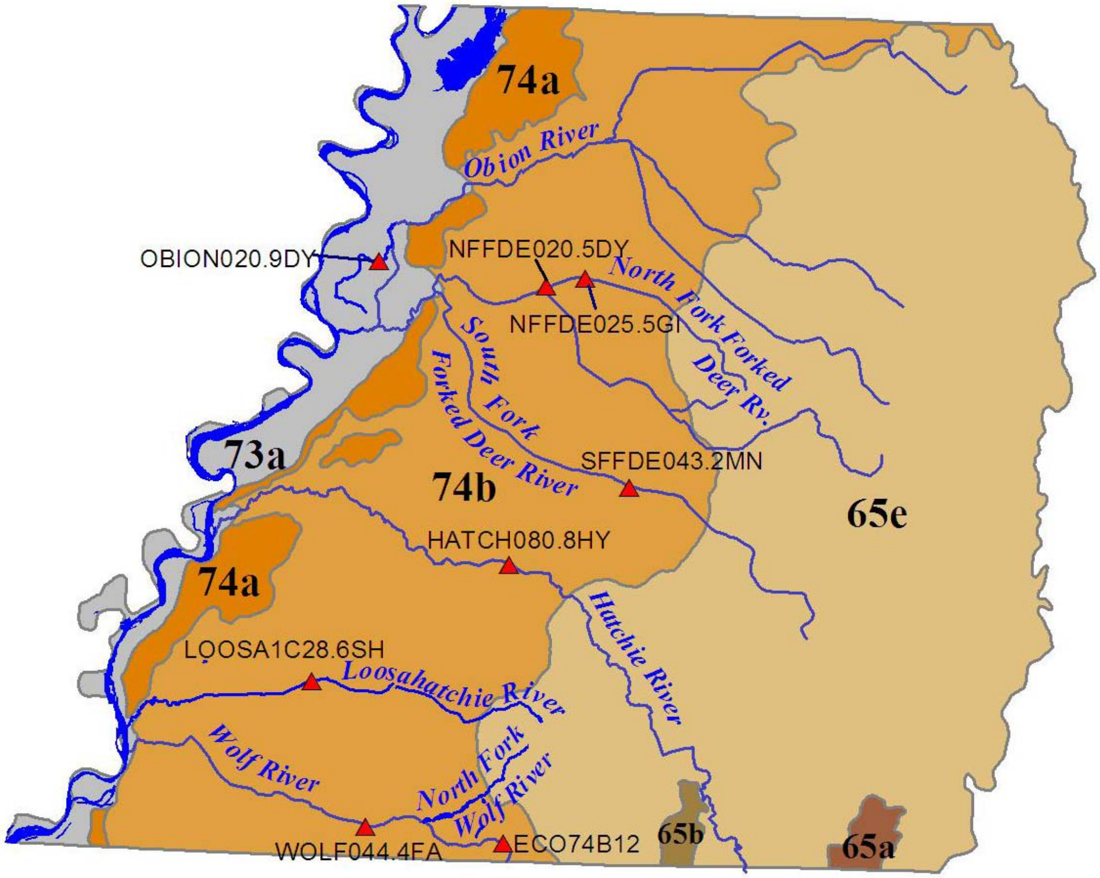


Figure 54: Location of non-wadeable test sites that cross ecoregions 65e, 74b and 73a. Map also shows location of non-wadeable reference site on the Wolf River (ECO74B12) in ecoregion 74b.

10.3.2 Macroinvertebrates

While stream geomorphology in these rivers is more typical of the Southeastern Plains and Hills, the macroinvertebrate community more closely aligns with the Loess Plains where the sample was collected. Two biometrics, the abundance of EPT and percent oligochaetes and chironomids differ between ecoregions (Figure 55).

When compared to rivers with stressed biological communities, most of the metrics demonstrated a clear difference (Figure 56). Although the acceptable ranges will probably need to be adjusted for these rivers that cross regions, it appears that the biometrics currently in use for wadeable streams are appropriate. They appear to be sensitive to detecting impairment in stressed streams.

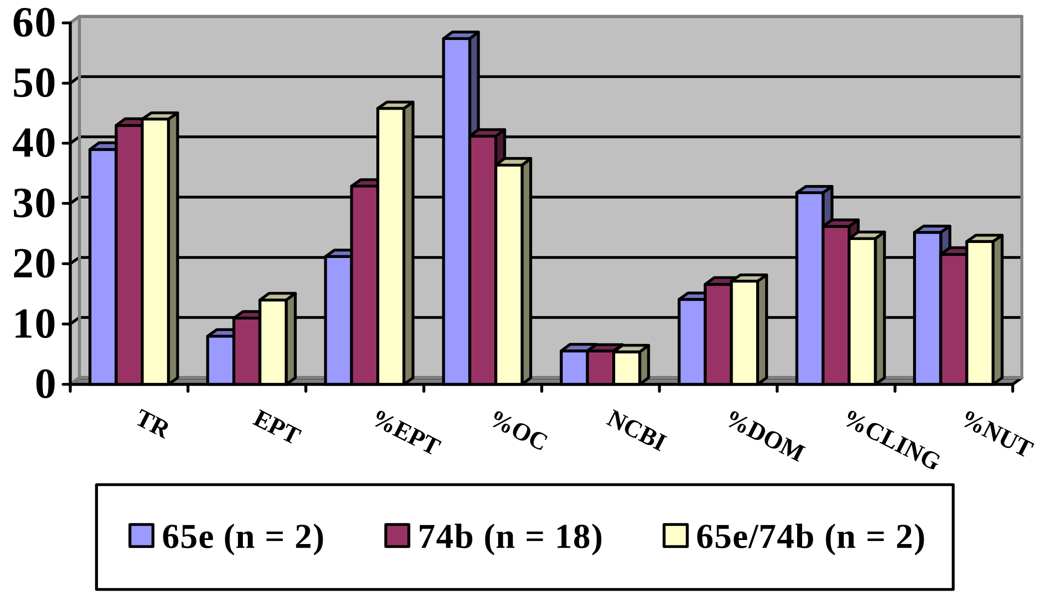


Figure 55: Comparison of the macroinvertebrate community at non-wadeable rivers that support diverse communities in the Loess Plains (74b) and Southeastern Plains and Hills (65e). Metrics reflect mean value. Data include 2 stations in 65e, 1 reference station in 74b and 2 stations that cross 65e and 74b.

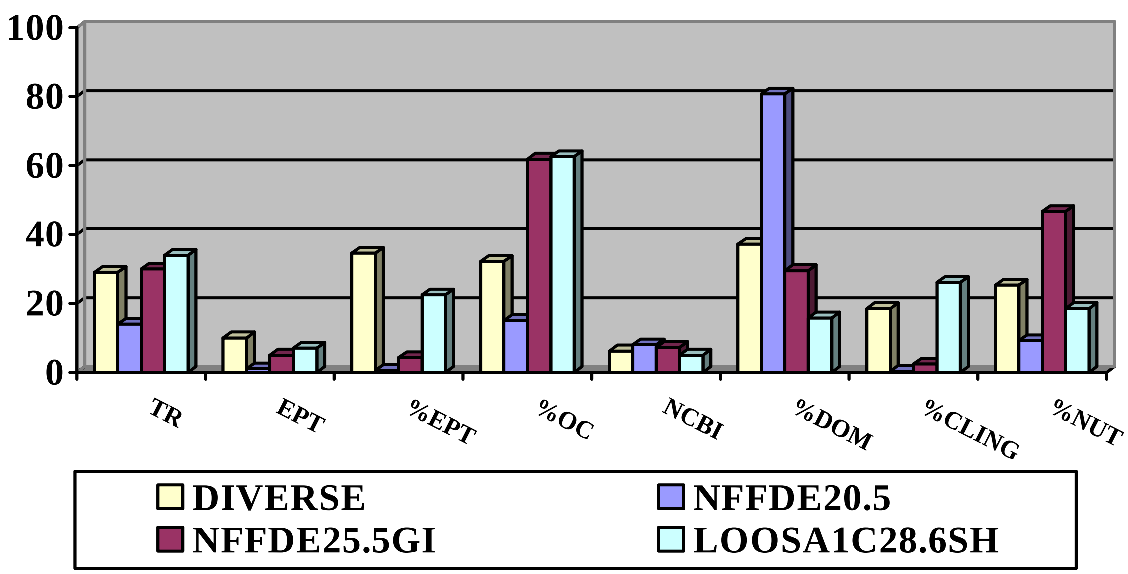


Figure 56: Comparison of macroinvertebrate communities in biologically diverse and stressed non-wadeable rivers that cross the Loess Plains (74b) and Southeastern Plains and Hills (65e). The label "diverse" represents the mean of 2 stations (SFFDE043.2MN and WOLF044.4FA) that passed wadeable stream biological guidelines for ecoregion 65e and 74b. Other values represent one sample from each of three stressed locations.

10.3.3 Diurnal Dissolved Oxygen

Dissolved oxygen values at the Wolf River test site remained above 6.5 ppm throughout the 12 day monitoring period. The highest diurnal fluctuation was 1.5 ppm. Water levels were near bankfull with elevated flow (797 cfs) at the beginning of survey. The river fell to more normal levels throughout the survey and flow had dropped to 433 cfs when the probe was retrieved.

The other test site supporting a diverse biological community, the South Fork Forked Deer River, had lower dissolved oxygen levels during a high flow period. When the probe was deployed, water levels were near bankfull and flow was 672 cfs. Heavy rains (2.4 inches) occurred on 11/2 (Figure 57). Flow increased to 710 cfs and the river flooded its banks. Dissolved oxygen dropped to 4 ppm during this period (Figure 58). When the site was visited, eight days later, flow had dropped to 542 cfs and the river was no longer flooding. Minimum dissolved oxygen levels stayed above 6 ppm throughout the monitoring period.

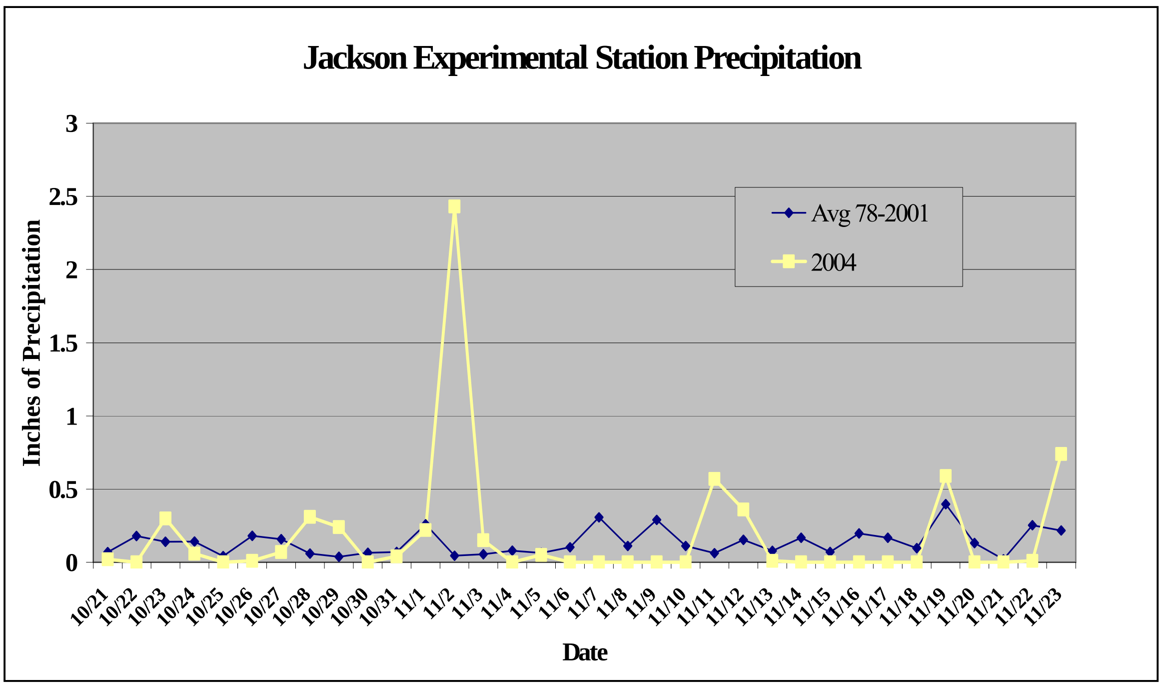


Figure 57: Precipitation at the Jackson Experimental Station 10/21 - 11/10/2004 compared to 24 year average for the same dates.

Diurnal dissolved oxygen levels at the three sites that exhibited a stressed biological community did not fall below 5.5 ppm although dissolved oxygen levels did drop during periods of high flow. DO in the North Fork Forked Deer River in Gibson County generally fluctuated between 7 ppm and 8.5 ppm during the first week when the average flow was 86 ppm. The second week, heavy rains resulted in higher flows (181cfs). DO stayed between 6.2 and 6.8 ppm during this period (Figure 59).

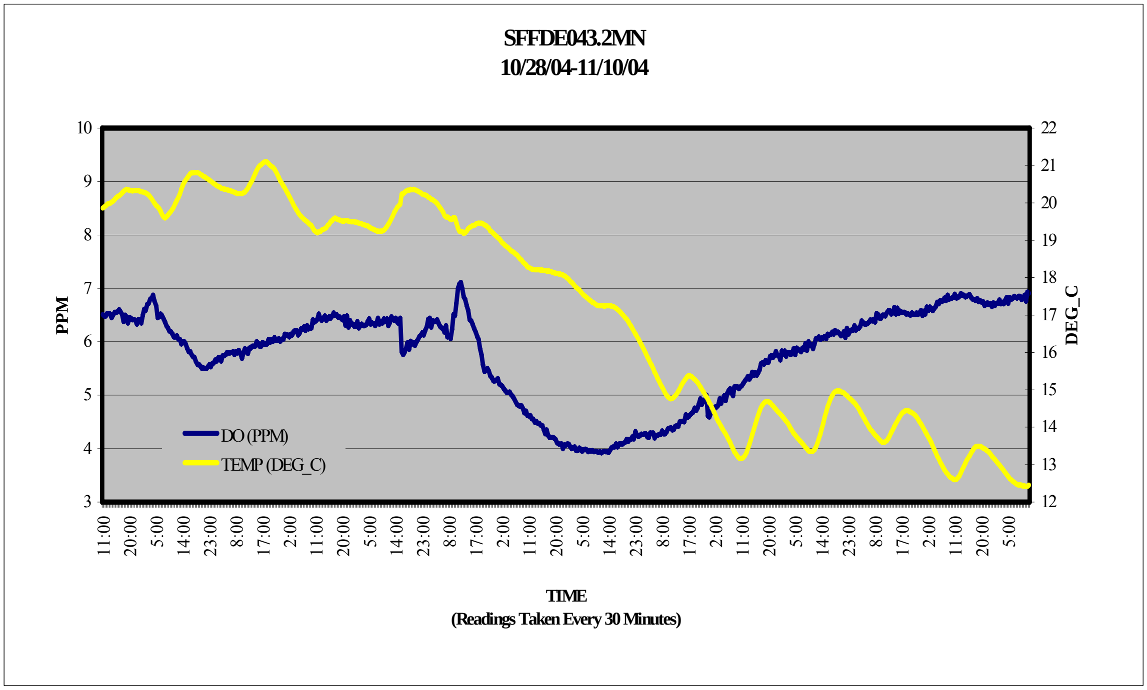


Figure 58: Diurnal dissolved oxygen and temperature at South Fork Forked Deer River 10/28 - 11/10/04.

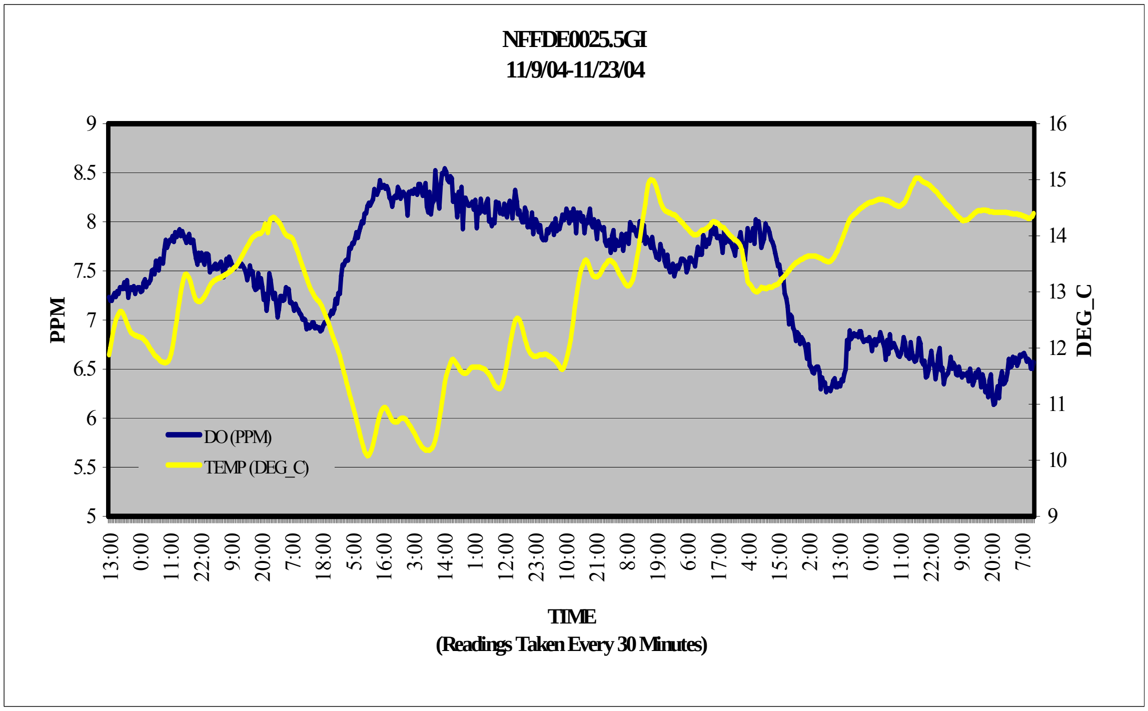


Figure 59: Diurnal dissolved oxygen and temperature at the North Fork Forked Deer River 11/9 – 11/23/2004.

10.3.4 Nutrients

Nitrate+nitrite levels in biologically diverse streams that crossed both ecoregions were higher than guidelines for wadeable streams in ecoregion 65e and the established non-wadeable reference stream in 74b (Table 37). Levels were lower than the guidelines for wadeable streams in 74b and in the non-wadeable streams in 65e that had a good biological diversity. The sampling sites were located in ecoregion 74b. The fact that nitrate+nitrite levels were higher than the non-wadeable reference site, but supported a diverse biological community, may indicate separate nitrate+nitrite guidelines need to be established for non-wadeable streams that cross these two ecoregions.

Total phosphorus levels at these streams were higher than guidelines established for wadeable streams in both ecoregions. Levels were also higher than non-wadeable streams in 65e that had good biological diversity. Total phosphorus values were lower than the 90th percentile of data at the established 74b non-wadeable reference stream. These data suggest that total phosphorus guidelines for non-wadeable streams that cross these two ecoregions could be grouped with guidelines for non-wadeable streams in ecoregion 74b.

Table 37: Comparison of nutrient data from biologically diverse non-wadeable streams in the Southeastern Plains and Hills and the Loess Plains in Tennessee. Data are in mg/l.

	Nitrate+Nitrite (mg/l)	Number of Observations	Total Phosphorus (mg/l)	Number of Observations
65e Guidelines for Wadeable Streams	0.34	42	0.04	42
90th Percentile Non-wadeable 65e Streams with Good Macroinvertebrate Diversity	0.88	9	0.13	9
74b Guidelines for Wadeable and Non-wadeable Streams	1.19	42	0.11	42
90th percentile 74b Non-wadeable Reference Stream (1)	0.32	31	0.31	31
90th percentile Non-wadeable Streams Crossing 65e/74b with Good Macroinvertebrate Diversity	0.64	41	0.28	41

10.4 Non-wadeable Streams in the Northern Mississippi Alluvial Plain (73a)

Tennessee has four established non-wadeable reference sites that flow entirely within the Northern Mississippi Alluvial Plain. Two sites are on Cold Creek (ECO73A01 and ECO73A03), one on the Middle Fork Forked Deer River (ECO73A02) and the fourth is on Bayou du Chien (ECO73A04).

10.4.1 Stream geomorphology

Typical streams in the Northern Mississippi Alluvial Plain are entrenched and tend to be turbid with silt and sand bottoms. They have moderately unstable banks. The dominant bed material at the Bayou du Chien site and the upstream site on Cold Creek is sand while the downstream site on Cold Creek and the Middle Fork Forked Deer River have substrates consisting of finer materials (silt/clay). The typical channel cross-section of streams in this region is U-shaped with a flat bottom. Valleys are wide with little relief. Wetlands are common features in the ecoregions associated with all three of these streams. A more detailed discussion of the geomorphological characteristics of this region was discussed in section 7.

10.4.2 Macroinvertebrates

Macroinvertebrate communities in the Northern Mississippi Alluvial Plain tend to be less diverse than in other regions. The creeks are generally sluggish and flow direction is influenced by the Mississippi River. Bottom substrate is shifting sand and habitat is generally limited to tree roots and snags. Dissolved oxygen levels are naturally low.

The macroinvertebrate population is more reflective of wetland systems than they are of flowing streams. Aquatic worms, crustaceans, odonates, beetles, midges and gilled snails are the dominant taxa in reference streams. The tolerant mayfly *Caenis* sp. is the only abundant EPT found in these streams with facultative *Baetis* spp. and *Oecetis* spp. occurring occasionally. Guidelines for two of the seven metrics used in the Tennessee Macroinvertebrate Index, ETP richness and clinger abundance, are not used in this ecoregion due to low occurrence.

10.4.3 Diurnal Dissolved Oxygen

Dissolved oxygen at reference sites are generally 3 ppm or lower in this region. A detailed discussion of dissolved oxygen levels in the Mississippi Alluvial Plain was provided in section 6.1.

10.4.4 Nutrients

The three established reference streams in the Mississippi Alluvial Plain are non-wadeable. Nutrient guidelines have been developed for non-wadeable streams in this ecoregion (Denton et. al., 2001). These guidelines are:

Nitrate+nitrite: 0.39 mg/l
Total Phosphorus: 0.25 mg/l

10.5 Non-wadeable Streams draining ecoregions 65e, 73a and 74b.

One non-wadeable test site in the Northern Mississippi Alluvial Plain was monitored on the Obion River. The river originates in the Southeastern Plains and Hill and flows through the Loess Plains before entering the Northern Mississippi Alluvial Plain. The Obion River at the survey location is on the 303(d) list for habitat alteration.

10.5.1 Stream geomorphology

Geomorphological measurements could not be made due to the depth of the river. Field observations suggest the geomorphology at this location is similar to the non-wadeable reference streams whose entire drainage lies within the Northern Mississippi Alluvial Plain.

10.5.2 Macroinvertebrates

Macroinvertebrates were collected during this survey and once previously in spring 2001 at the Obion River station. Data were compared to non-wadeable reference streams in 73a and 74b as well as two non-wadeable sites with diverse biological communities in 65e (Figure 60). Biometric values were comparable to the values found at established reference streams in this region. The ecoregions in the upstream drainage did not appear to have an influence on the macroinvertebrate community structure. This indicates that existing biocriteria guidelines for the Northern Mississippi Alluvial Plain can be used for assessing non-wadeable streams that first drain other ecoregions.

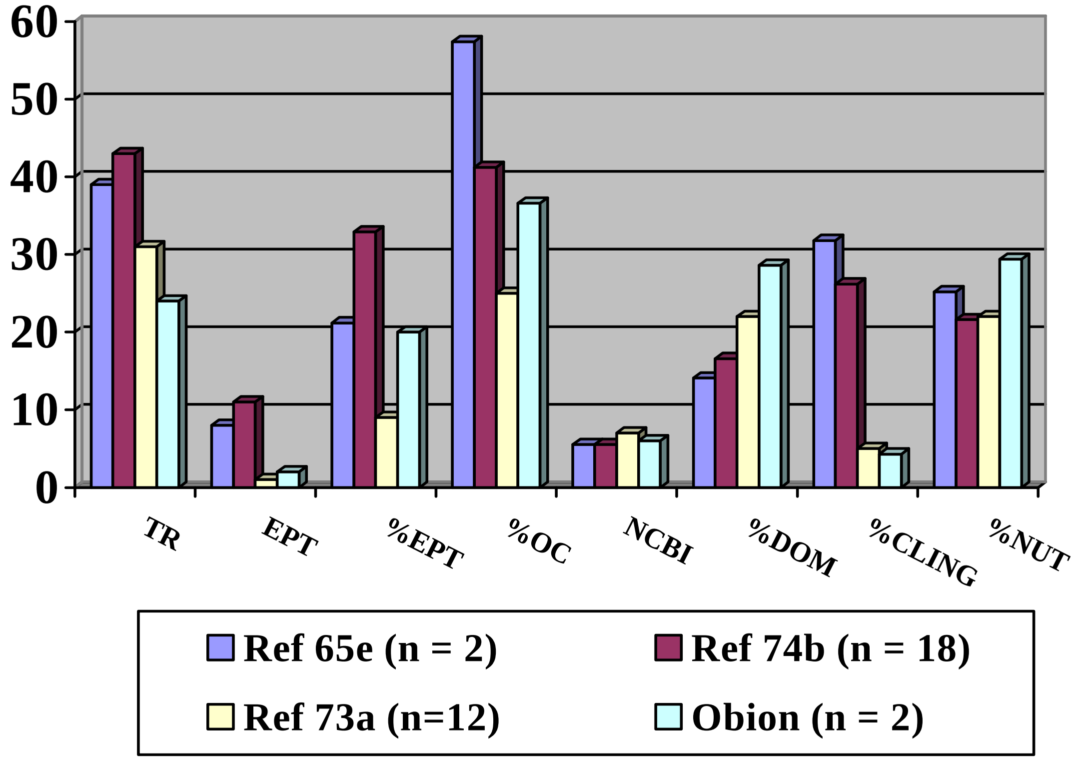


Figure 60: Comparison of macroinvertebrate community in non-wadeable reference sites in ecoregions 65e, 73a and 74b to a test site on the Obion River that crosses all three ecoregions.

10.5.3 Diurnal Dissolved Oxygen

Diurnal dissolved oxygen measurements are not available due to the loss of monitoring equipment during flooding. When the probe was set-up at 8:00 am on November 17, dissolved oxygen was 7.5 ppm and temperature was 12.5 ^{o}C. One week later, afternoon dissolved oxygen was 8.4 ppm and temperature was 14.1 ^{o}C. Nine daylight measurements between 2001 and 2005 were between 6.2 and 14.4 ppm.

10.5.4 Nutrients

Nutrient guidelines for the portion of the Mississippi Valley Alluvial Plain in Tennessee are based on the 90th percentile of nitrate+nitrite and total phosphorus data collected over a ten year period at four non-wadeable reference streams. These guidelines are:

Nitrate+nitrite = 0.39 mg/l
Total Phosphorus = 0.25 mg/l

There was no unimpaired river sampled during this study that crossed all three ecoregions so these guidelines cannot be tested for those systems. The impaired station on the Obion River exceeded nitrate+nitrite guidelines in eight of ten observations. Total phosphorus levels were generally within the guidelines. Additional study is needed to locate unimpaired systems that cross all three ecoregions in Tennessee or other states to determine whether nutrient guidelines developed for ecoregion 73a are applicable to flowing water draining other ecoregions.

The Obion River flows through three ecoregions before entering the Mississippi River.
Photo provided by Mark Barb, Aquatic Biology Section, TDH.

11. SUMMARY

Both the 2002 and 2004 dissolved oxygen studies showed that streams in the Northern Mississippi Valley Alluvial Plain (73a) typically have daytime dissolved oxygen approximating 3 ppm and levels can drop to near 1 ppm for short periods while still supporting aquatic life typically found in the least disturbed streams in this region. Reference data from Arkansas, which has a much larger portion of this ecoregion, supported this theory.

The 2004 study reiterated that streams in the Inner Nashville Basin with dissolved oxygen periodically falling to 3 ppm can be supportive of a healthy biological community in this region. However, since diurnal swings are typically between 2 and 4 ppm, it is important to include diurnal monitoring in this region and not rely only on daylight measurements when levels approach 5 ppm.

In the 2002 study, ten ecological subregions had diurnal dissolved oxygen levels that were generally at or above 6 ppm. DO data from six of the subregions (65j, 67h, 69d, 71e, 71f, 74b) were also above 6 ppm during the 2004 study. These subregions comprise 29 percent of the state. Data from the other four subregions suggested occasional drops to 5 ppm, especially during evening hours, was typical in unimpaired streams. A summary of minimum DO levels is provided in Figure 61.

The Rosgen stream classification system was used to characterize the geomorphology of reference streams in the 19 ecoregions surveyed. This stream classification is based on physical processes and assumes that stream morphology is dependent on landscape position (Rosgen, 1996). There are four hierarchical levels of the Rosgen classification. The first level describes a stream's geomorphologic characterization. The second level is a morphological description of the stream's characteristics. Streams in this study were classified to Level II (Figure 62).

Another goal of this project was to characterize periphyton abundance in reference streams where data were not available as well as evaluate algal abundance of test streams in ecoregions where nutrient levels are generally elevated. Typical background levels of periphyton were estimated for 19 ecological subregions (Figure 63). Periphyton were typically not abundant in reference streams. Ecological subregions in the Interior Plateau generally had the highest densities.

Continuous monitoring nitrate probes proved impractical during field-testing. The biggest problem with the probes seemed to be difficulty in holding calibration. The probes tended to be unstable and imprecise. Once calibrated, they would begin to drift. Discrepancies between the probes and grab samples tended to worsen the longer the probes were deployed.

Results of the non-wadeable stream monitoring indicated that data were generally not comparable to existing wadeable streams guidelines. It is likely that separate biological and nutrient criteria will need to be developed for these stream types. Additional monitoring is necessary before this can be accomplished.

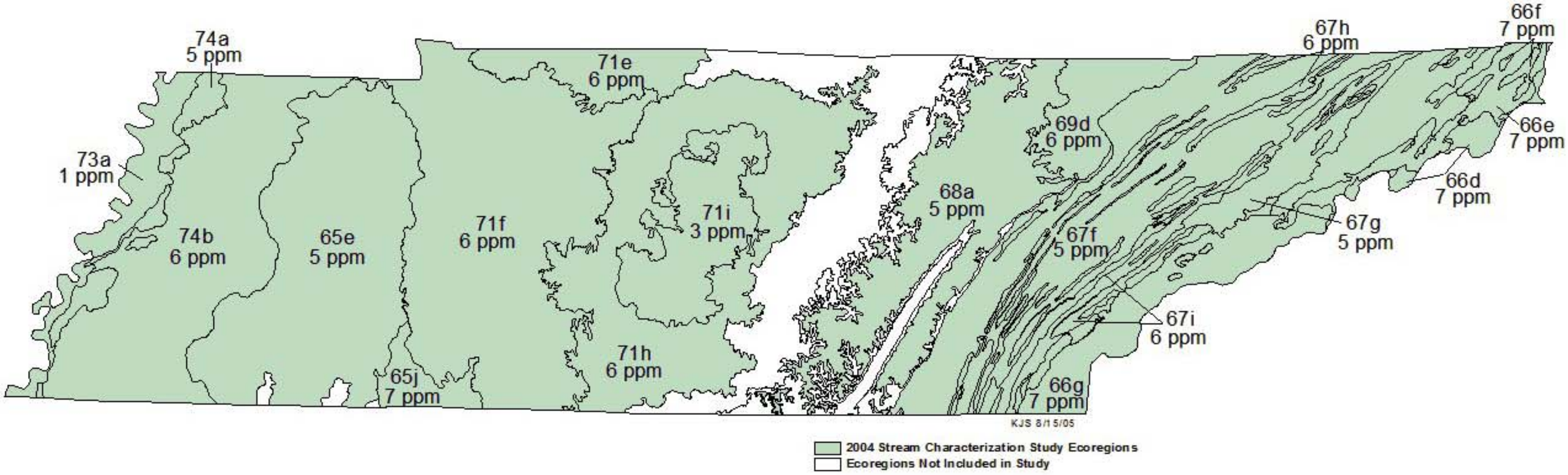


Figure 61: Minimum diurnal dissolved oxygen at reference sites in 19 Tennessee ecoregions. Values based on 2002 and 2004 monitoring.

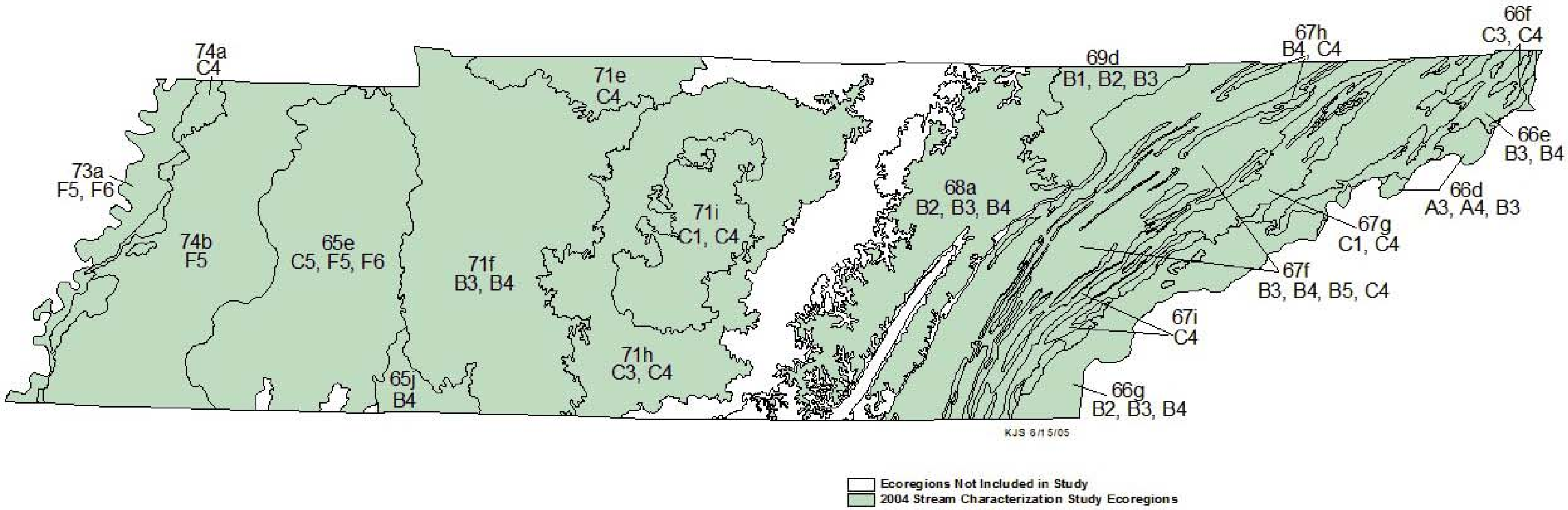


Figure 62: Level II Rosgen classification of reference streams in 19 Tennessee ecoregions.

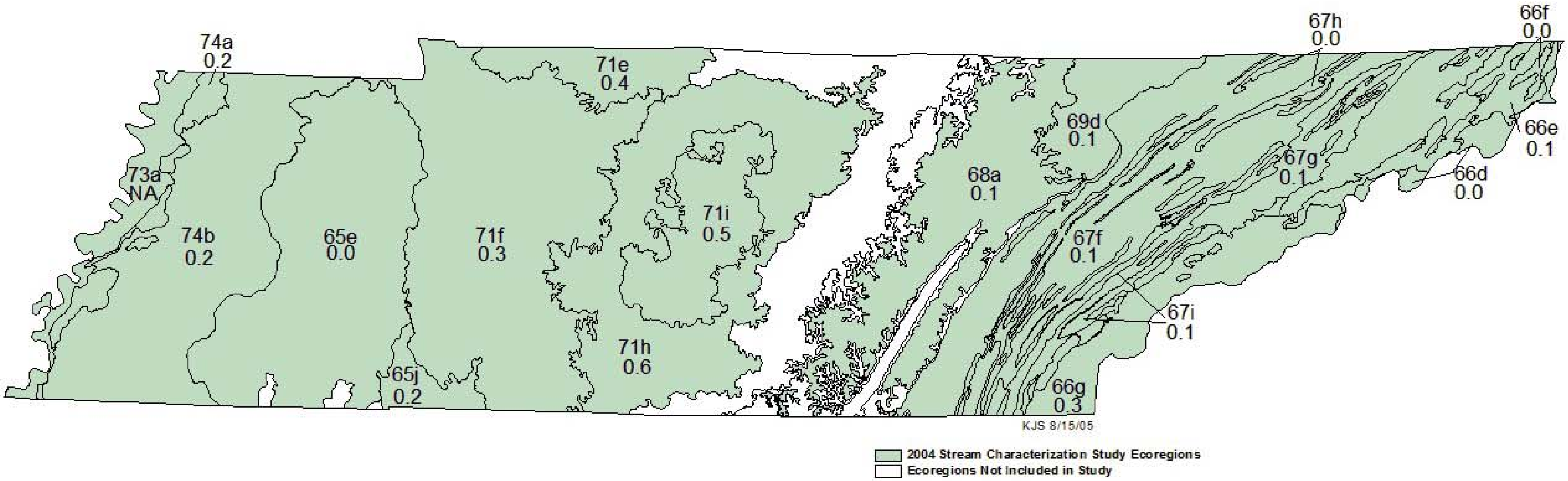


Figure 63: Mean thickness rank (THR) of microalgae found in reference streams in 19 Tennessee ecoregions.

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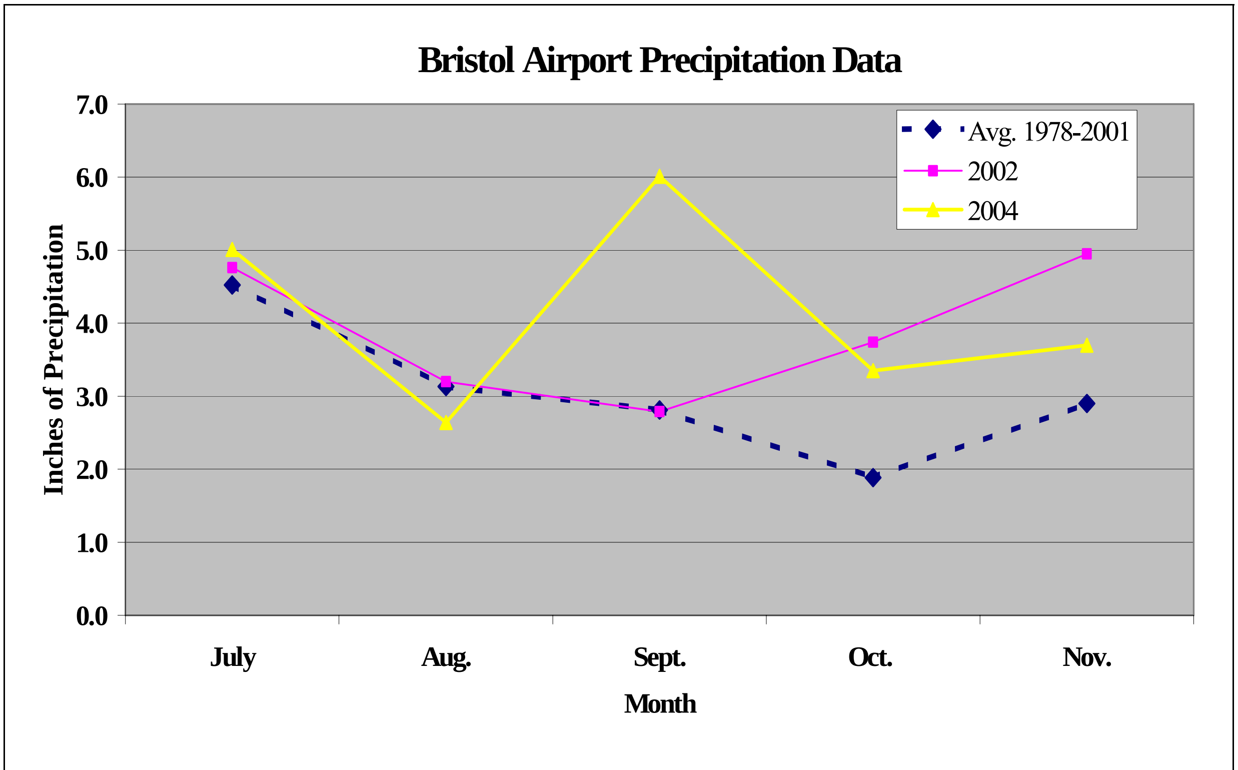
APPENDIX A

Precipitation Data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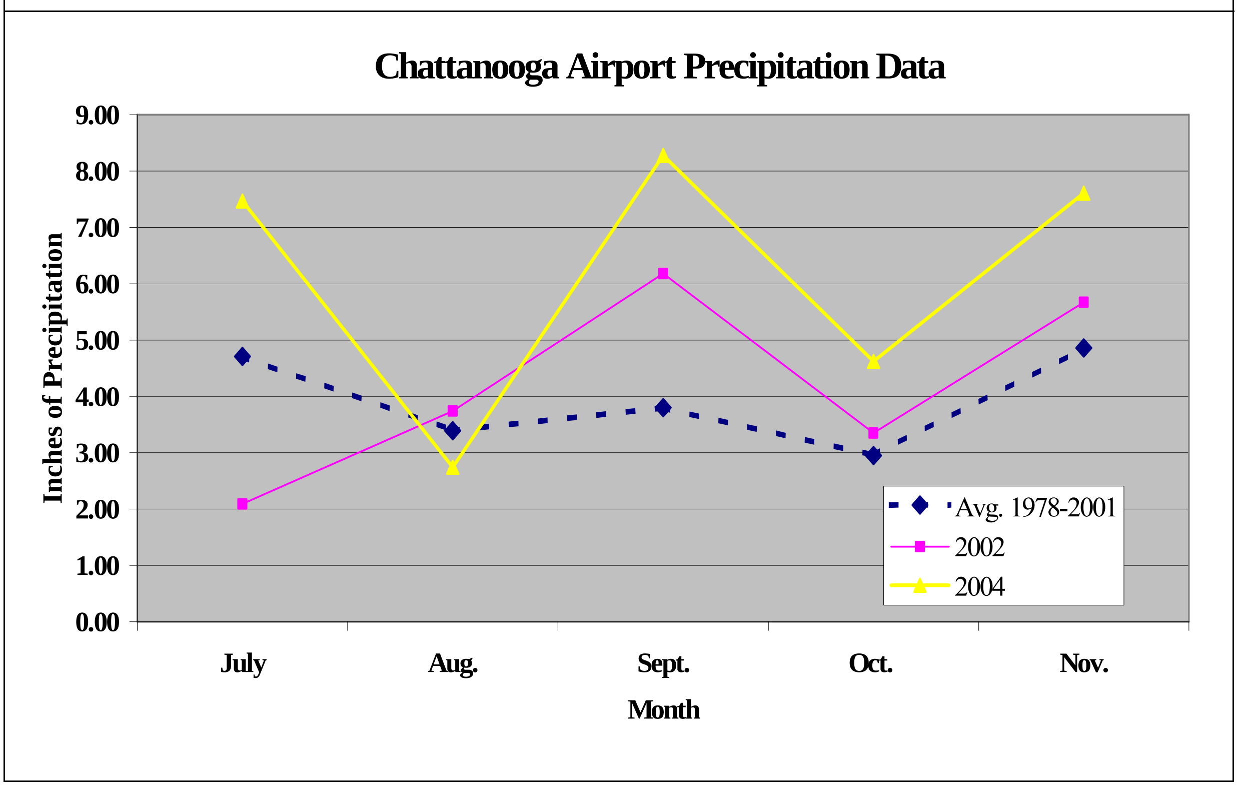
2004
July
Aug.
Sept.
Oct.
Nov.
Month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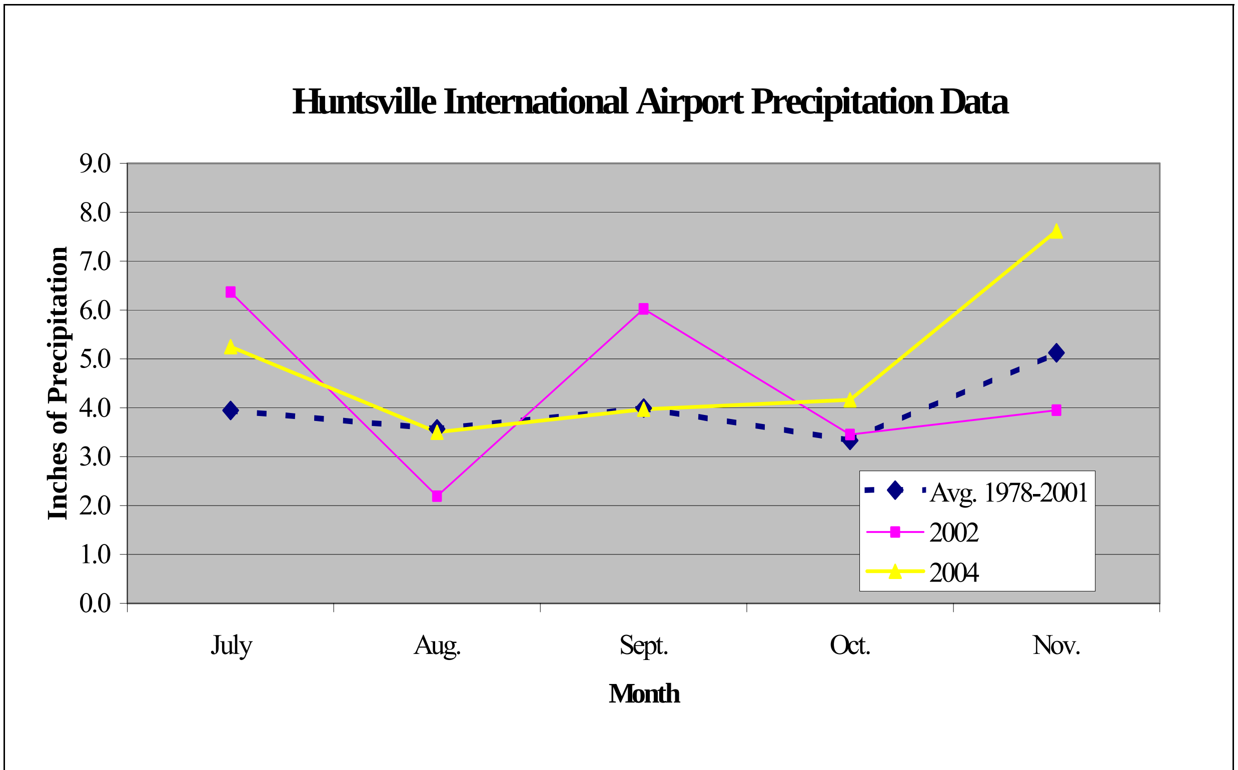
Avg. 1978-2001
2002
2004
July
Aug.
Sept.
Oct.
Nov.
Month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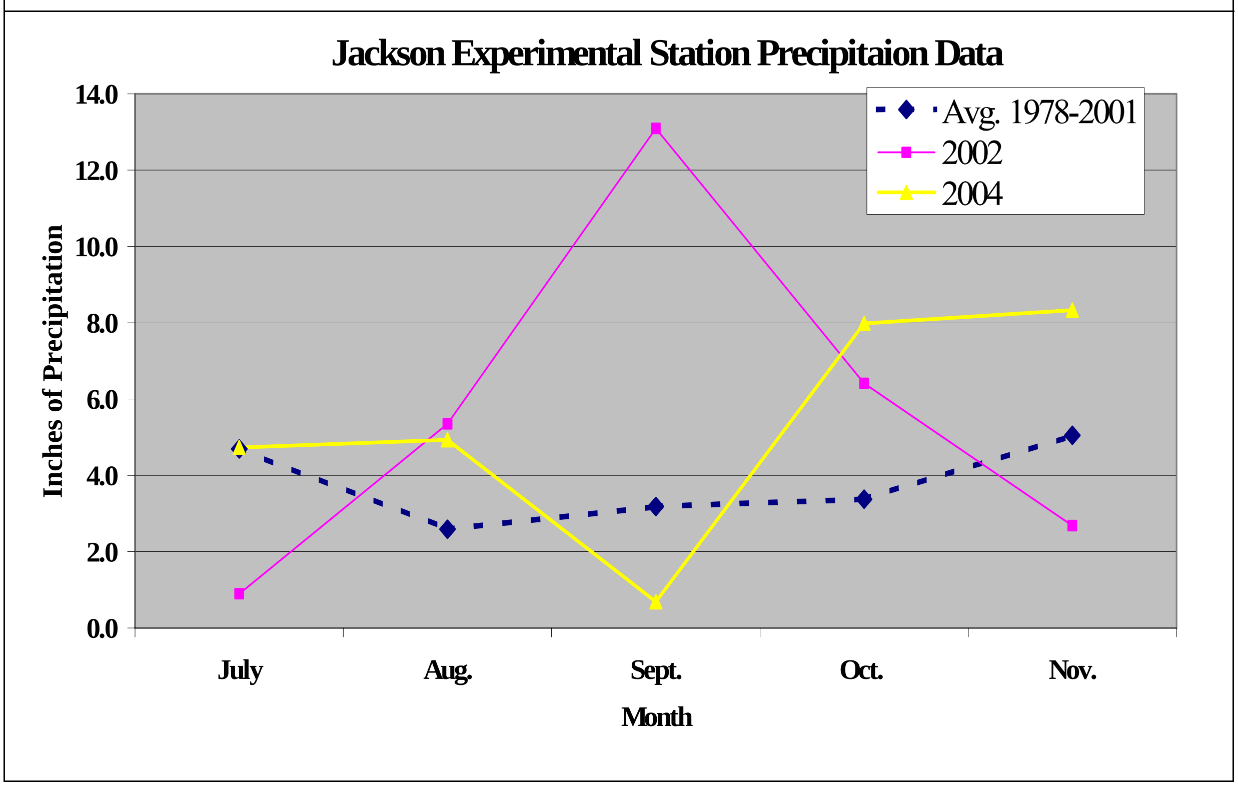
2004
July
Aug.
Sept.
Oct.
Nov.
Month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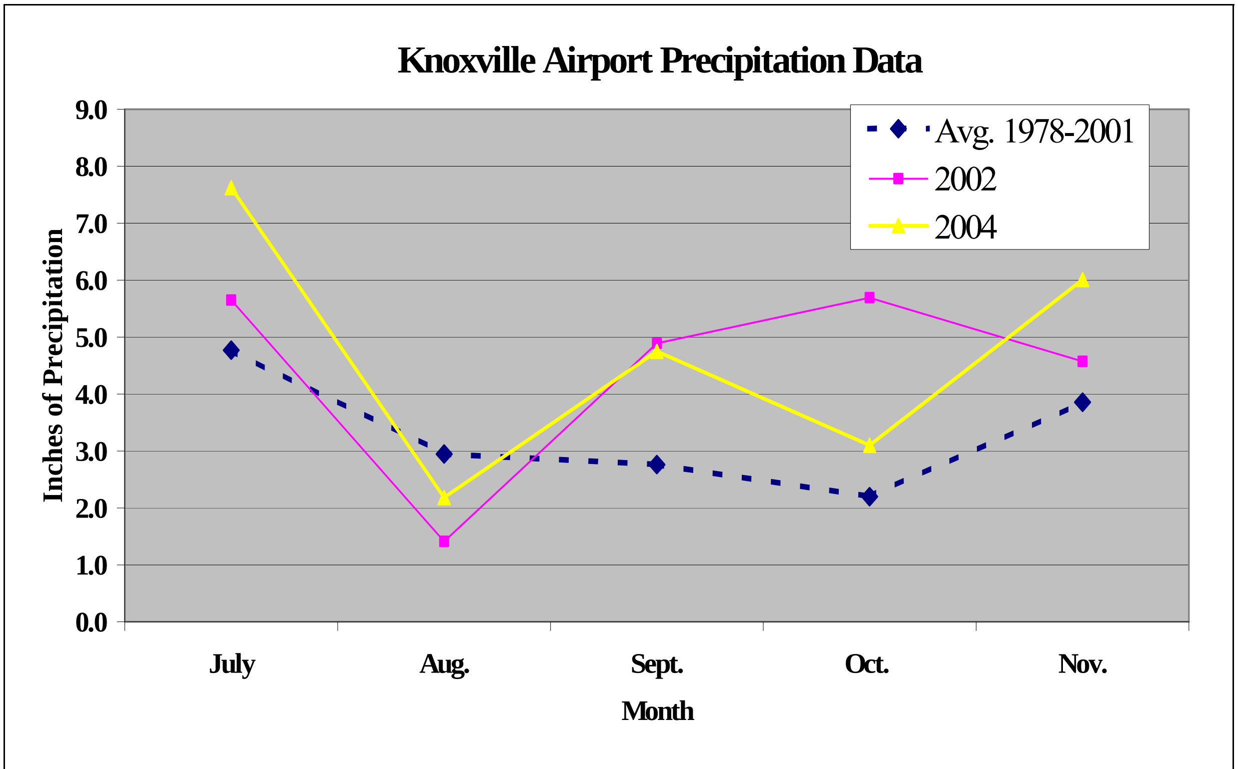
2004
July
Aug.
Sept.
Oct.
Nov.
Month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2004
July
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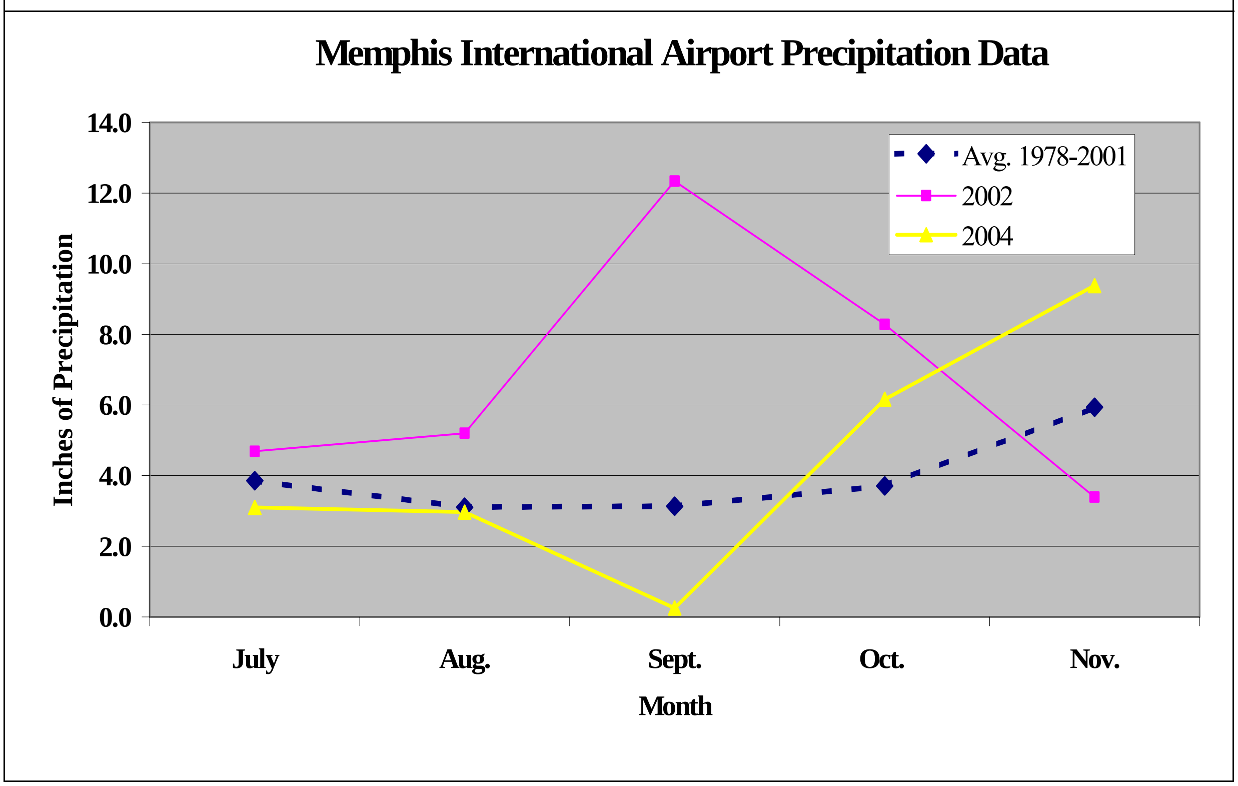
Oct.
Nov.
Month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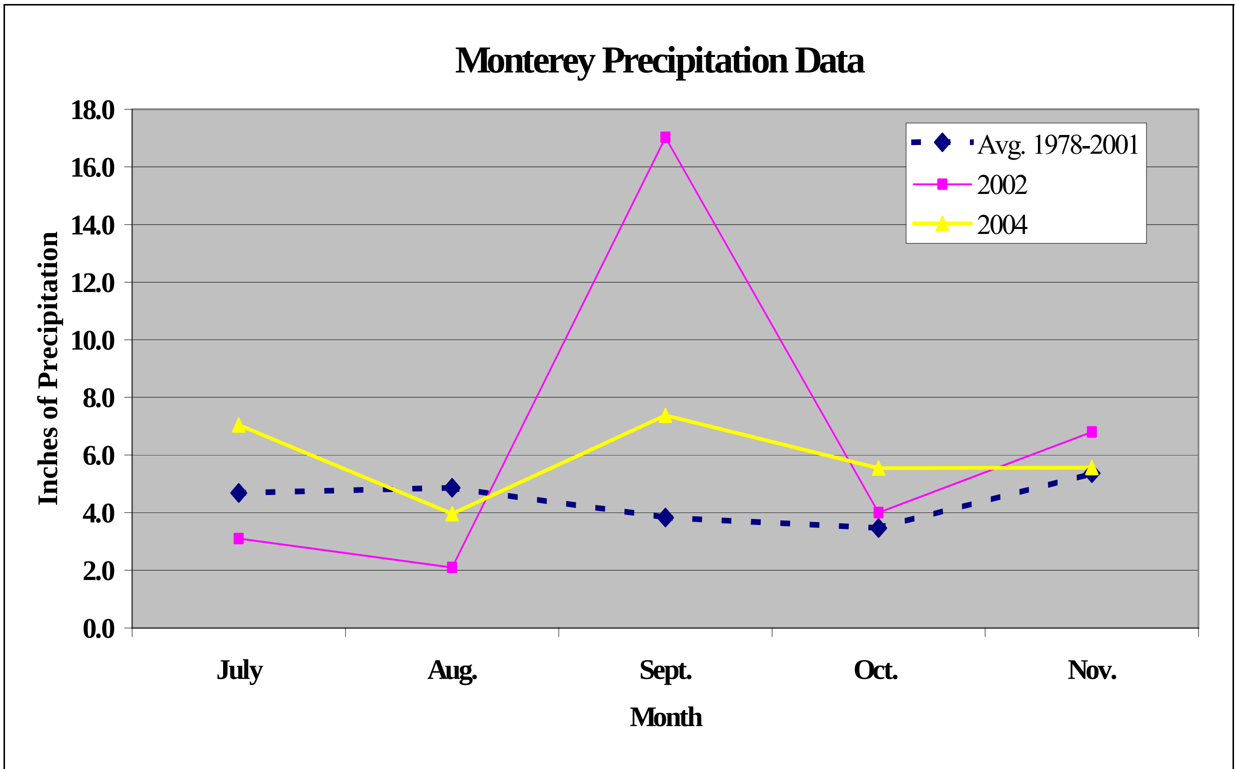
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Aug.
Sept.
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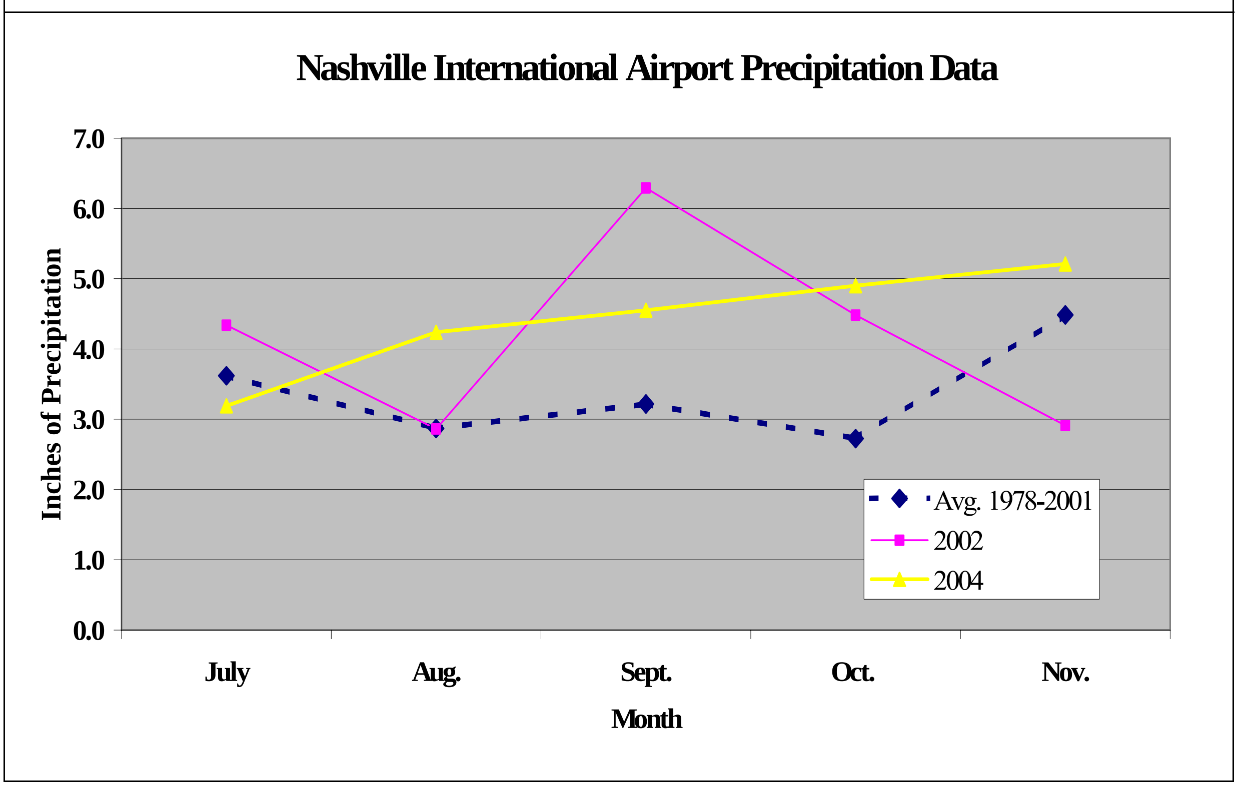
Nov.
Month
Avg. 1978-2001
2002
2004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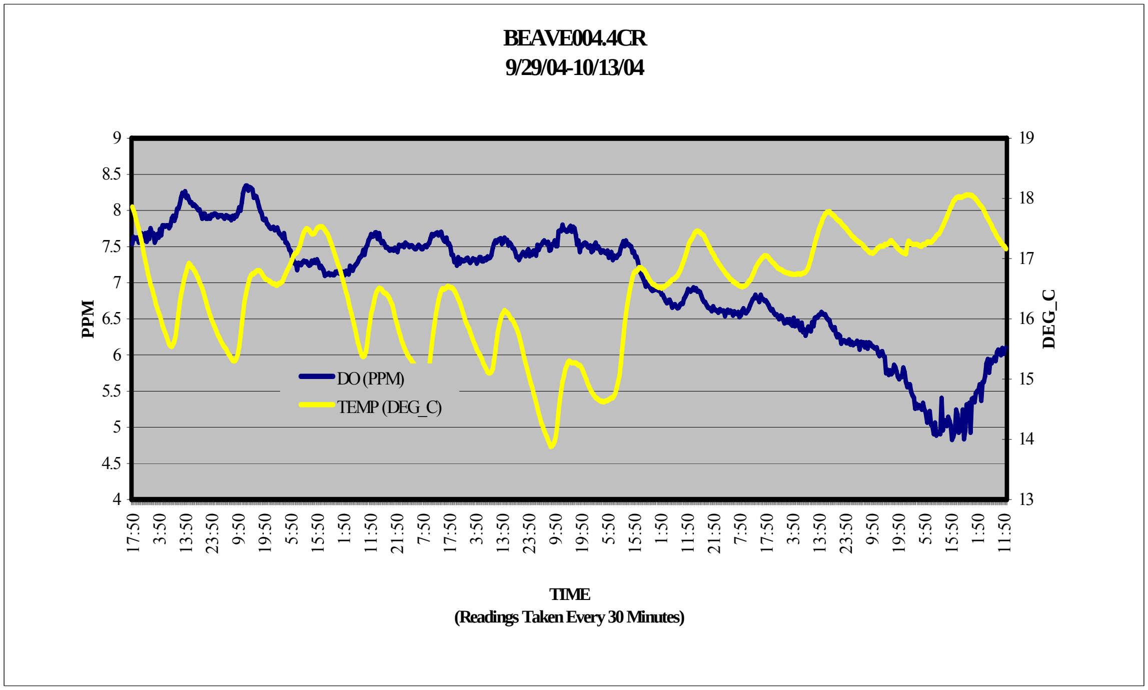
July
Aug.
Sept.
Oct.
Nov.
Month
Avg. 1978-2001
2002
2004

APPENDIX B

Diurnal Dissolved Oxygen Data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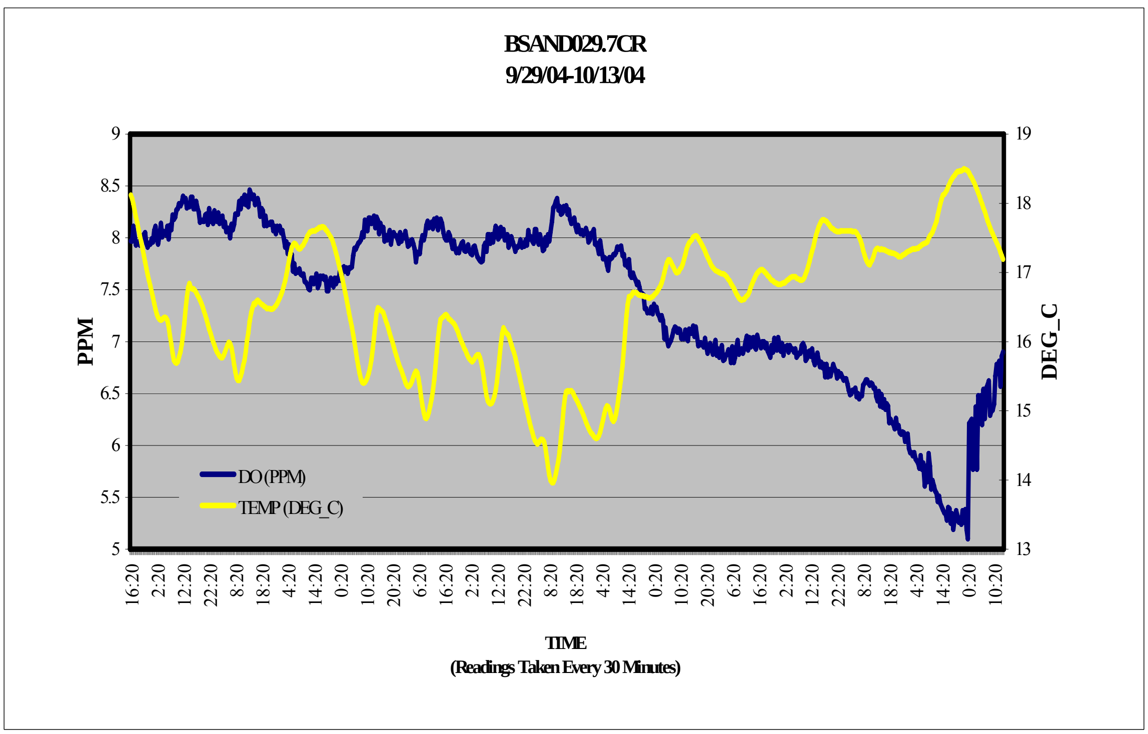
TIME
(Readings Taken Every 30 Minutes)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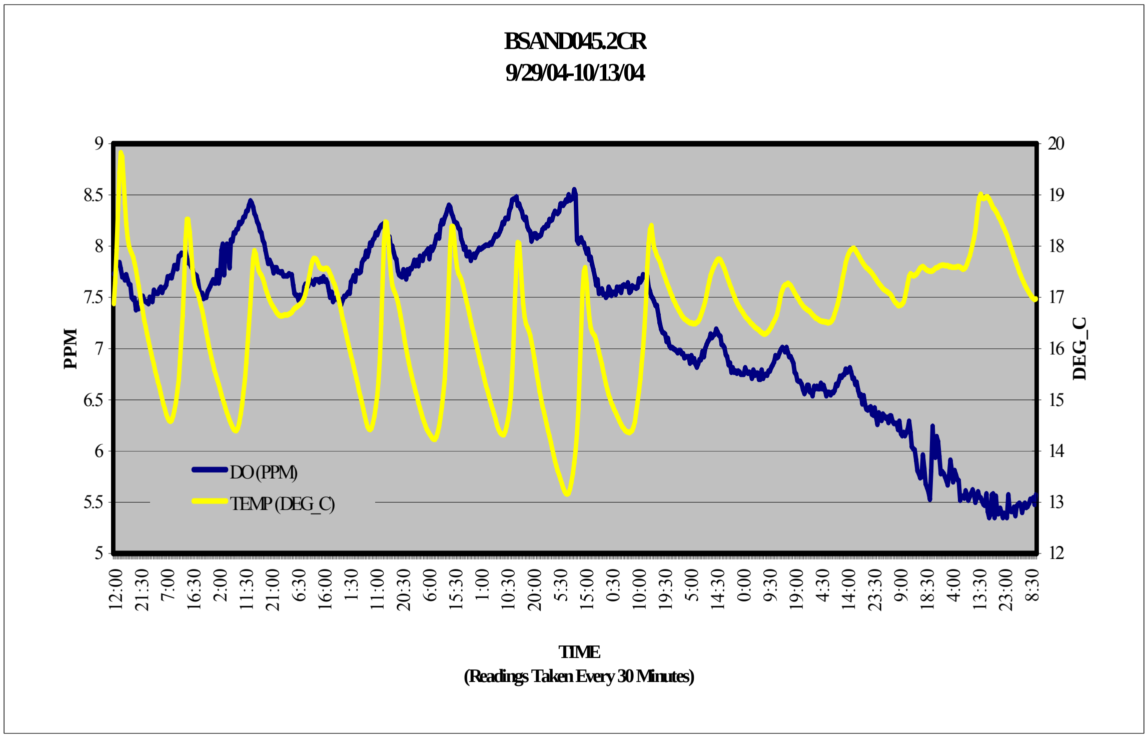
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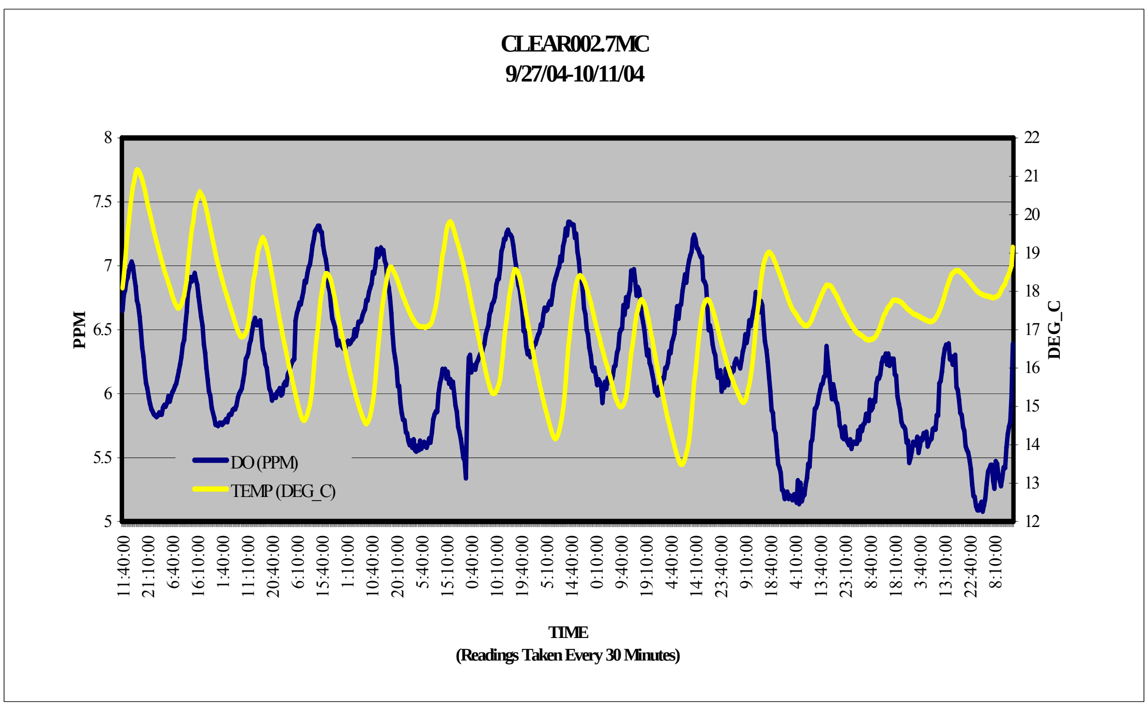
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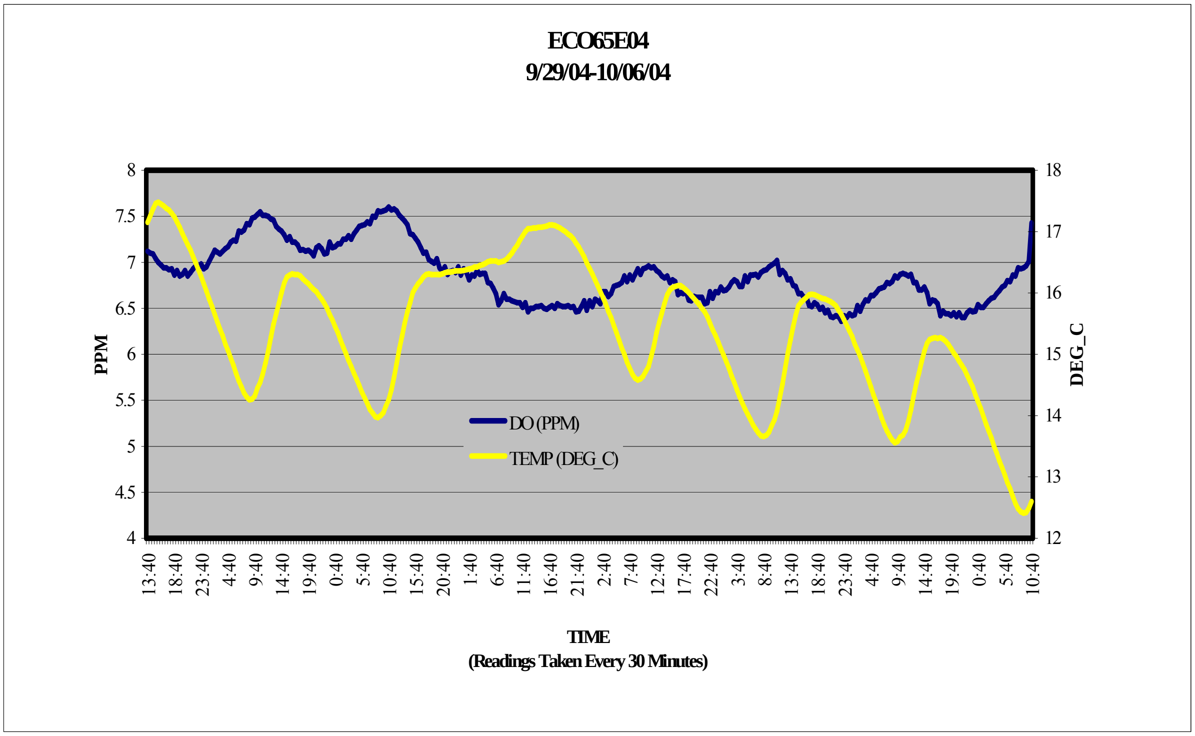
(Readings Taken Every 30 Minutes)



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TEMP (DEG_C)
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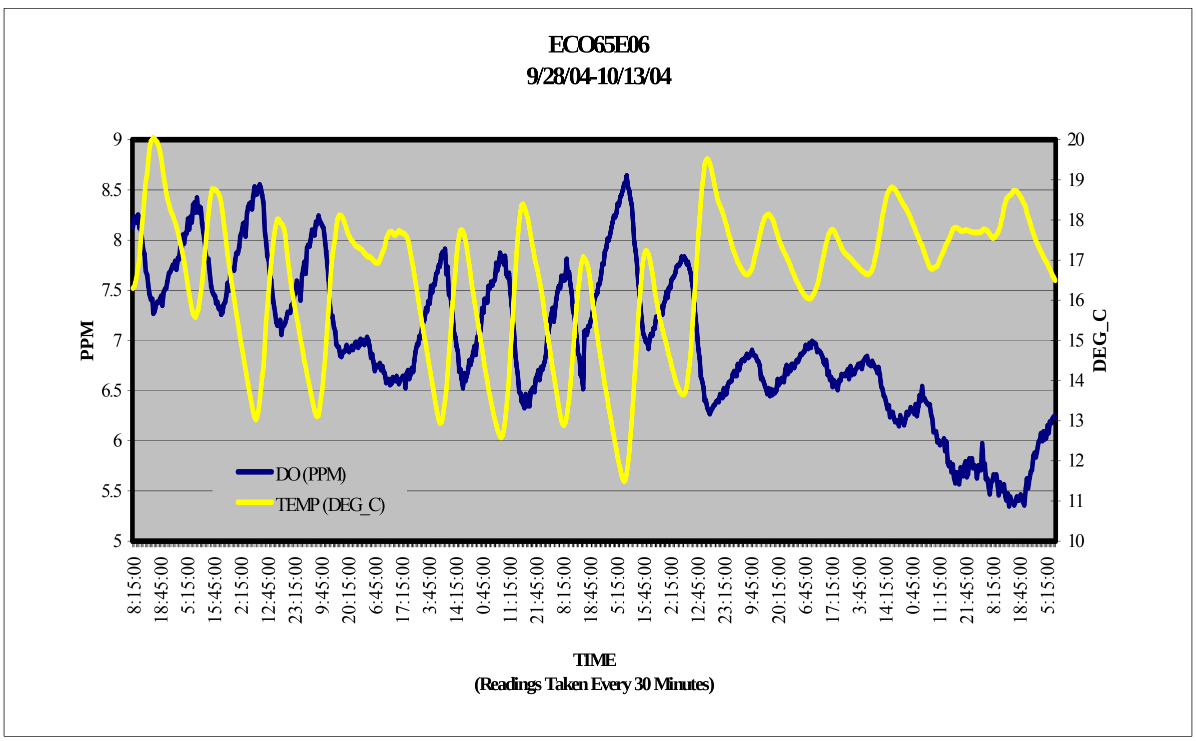
TIME
(Readings Taken Every 30 Minutes)



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14:15:00
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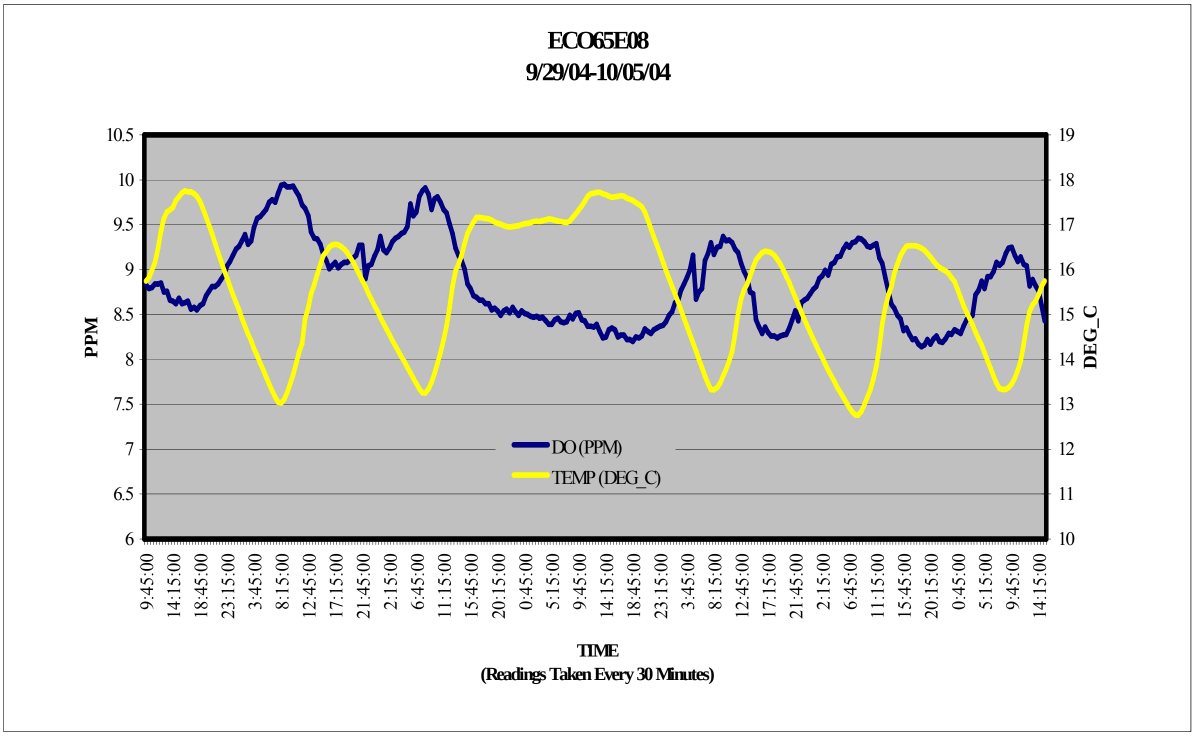
18:45:00
5:15:00
TIME
(Readings Taken Every 30 Minutes)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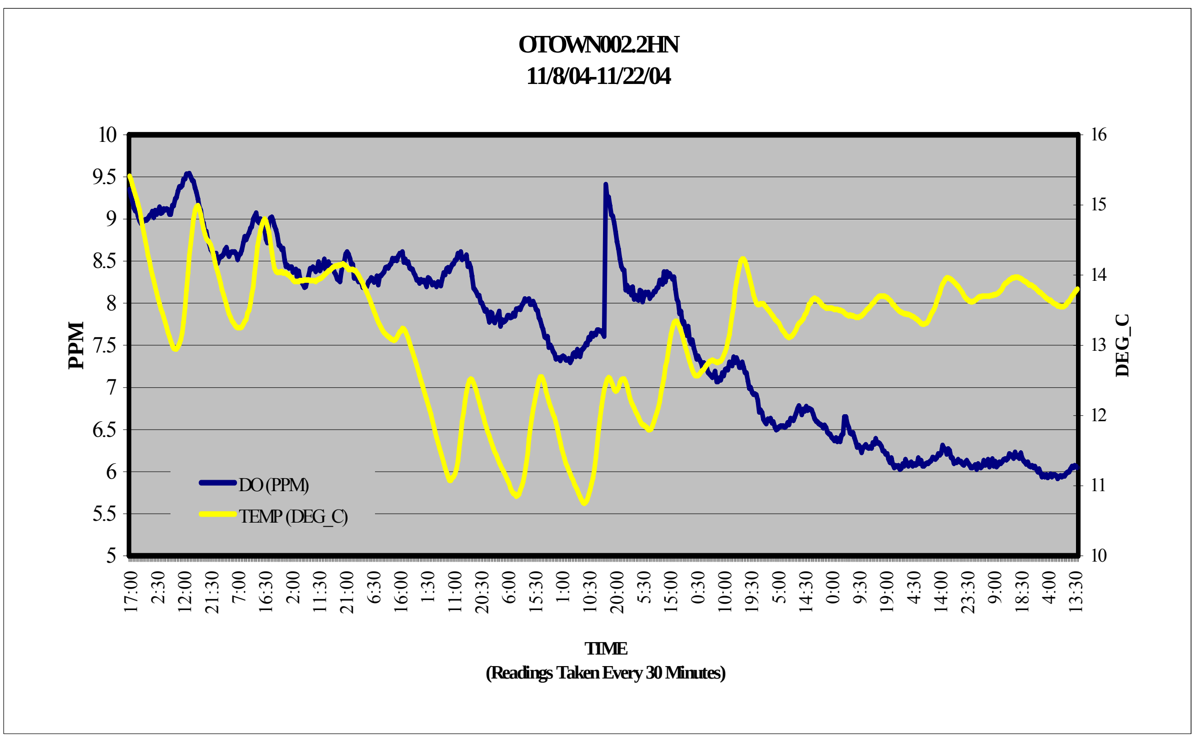
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)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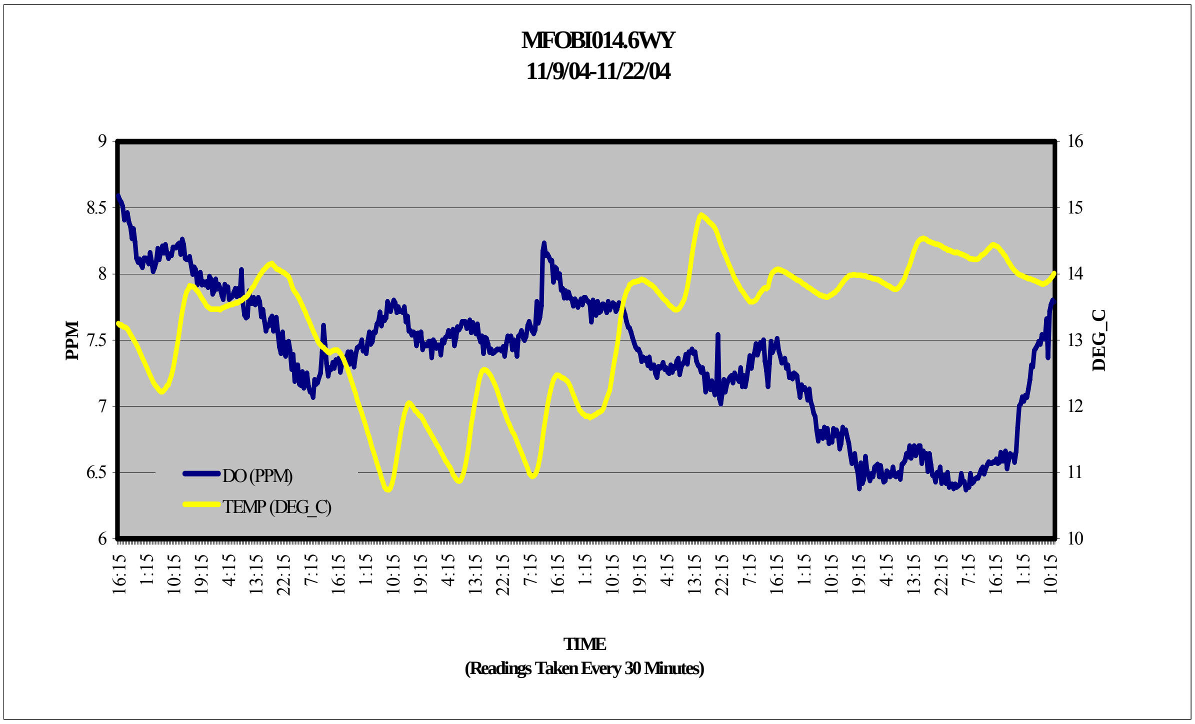
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)


MFOBI014.6WY
11/9/04-11/22/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
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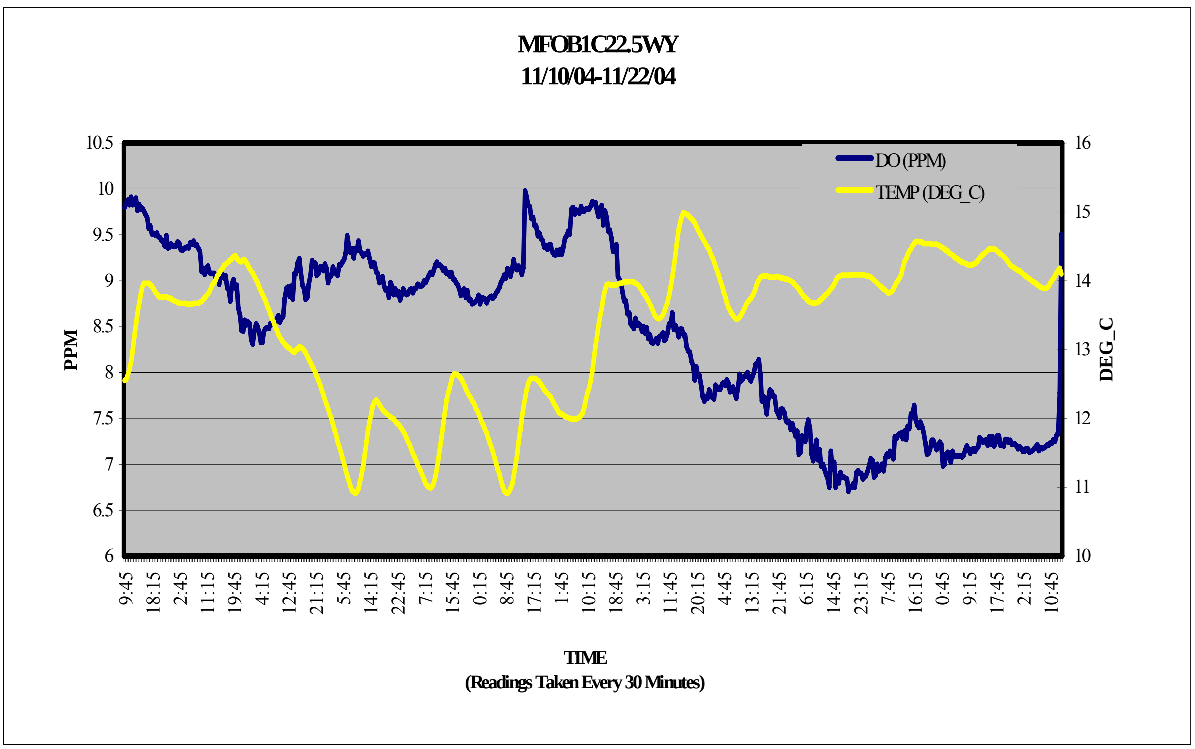
8.5
8
7.5
7
6.5
6
16
15
14
13
12
11
10
16:15
1:15
10:15
19:15
4:15
13:15
22:15
7:15
TIME
(Readings Taken Every 30 Minutes)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11/10/04-11/22/04
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DEG_C
DO (PPM)
TEMP (DEG_C)
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9
8.5
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7
6.5
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16
15
14
13
12
11
10
9:45
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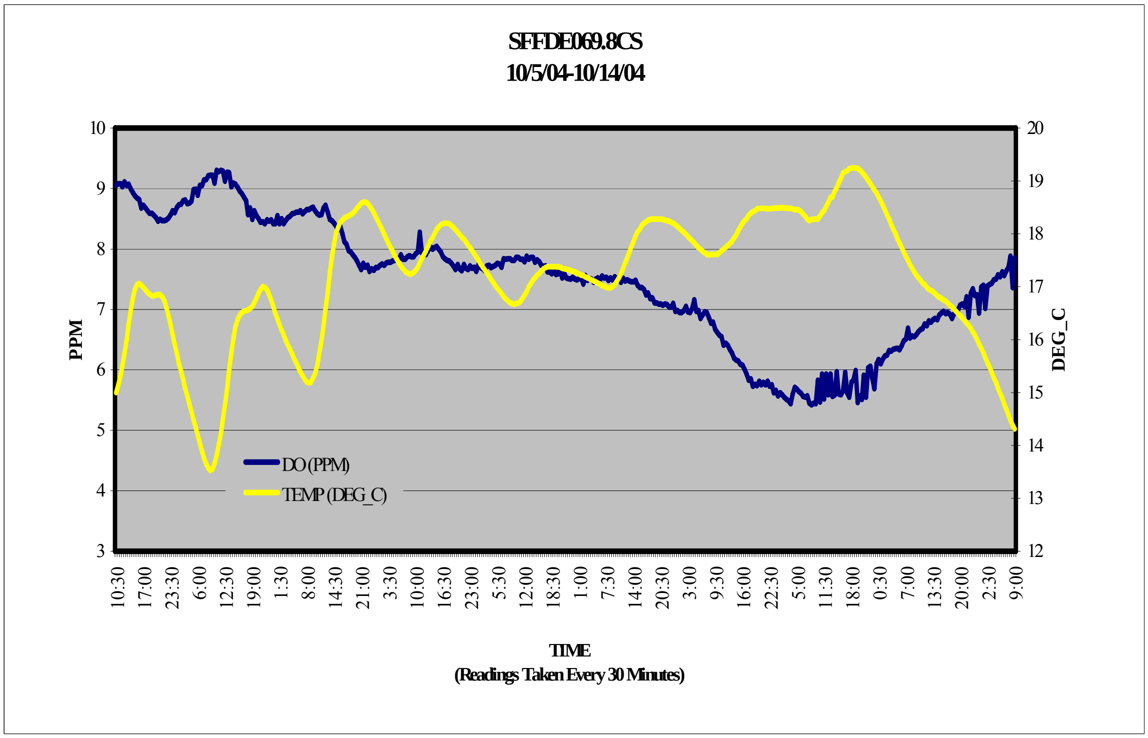
2:15
10:45
TIME
(Readings Taken Every 30 Minutes)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DEG_C
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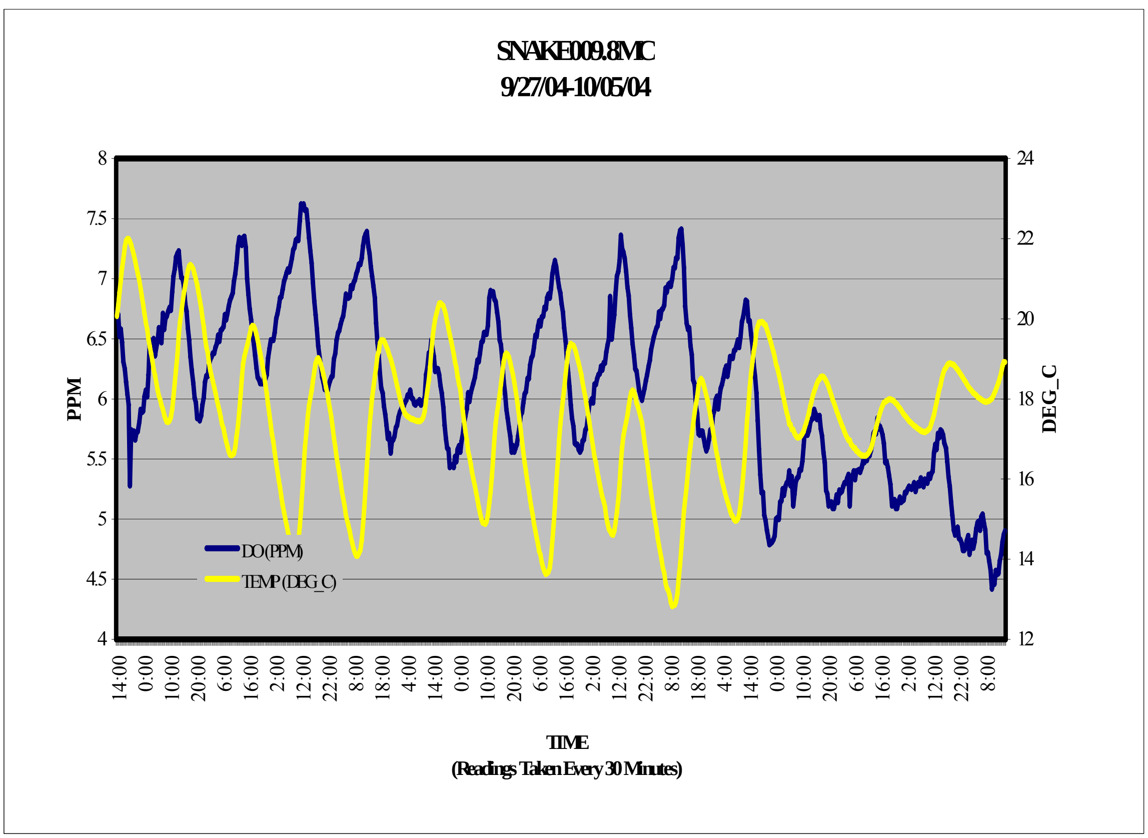
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)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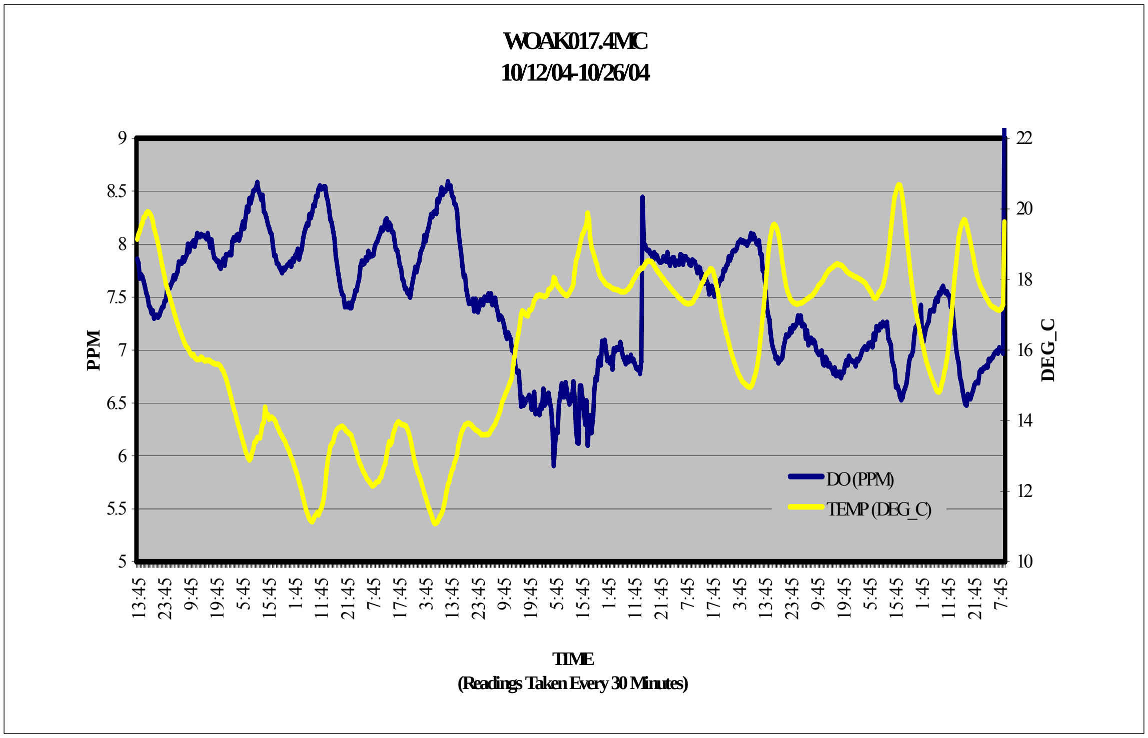
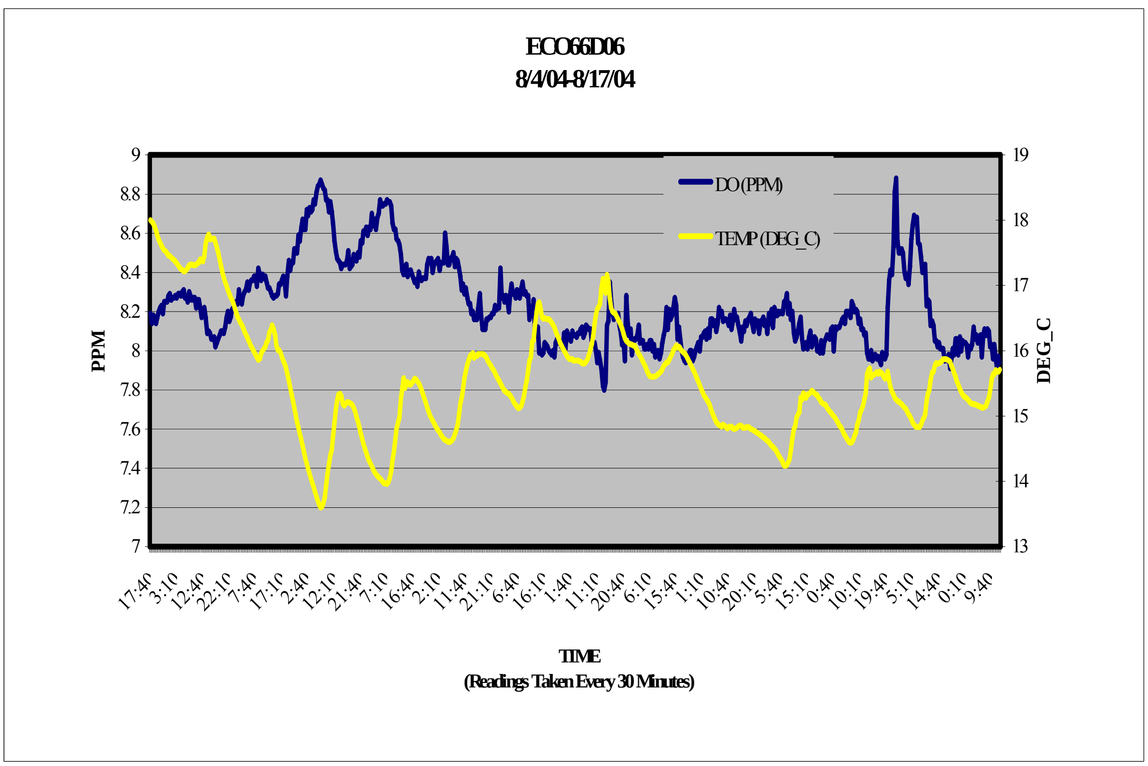
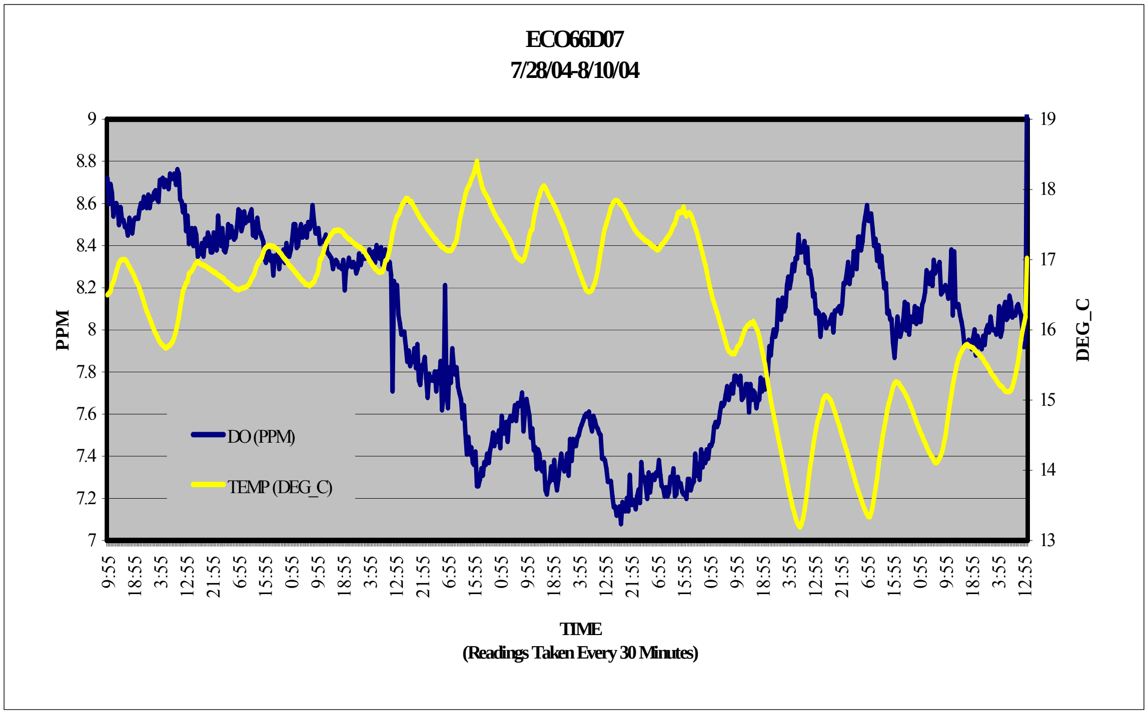
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)



Ecoregion 66d

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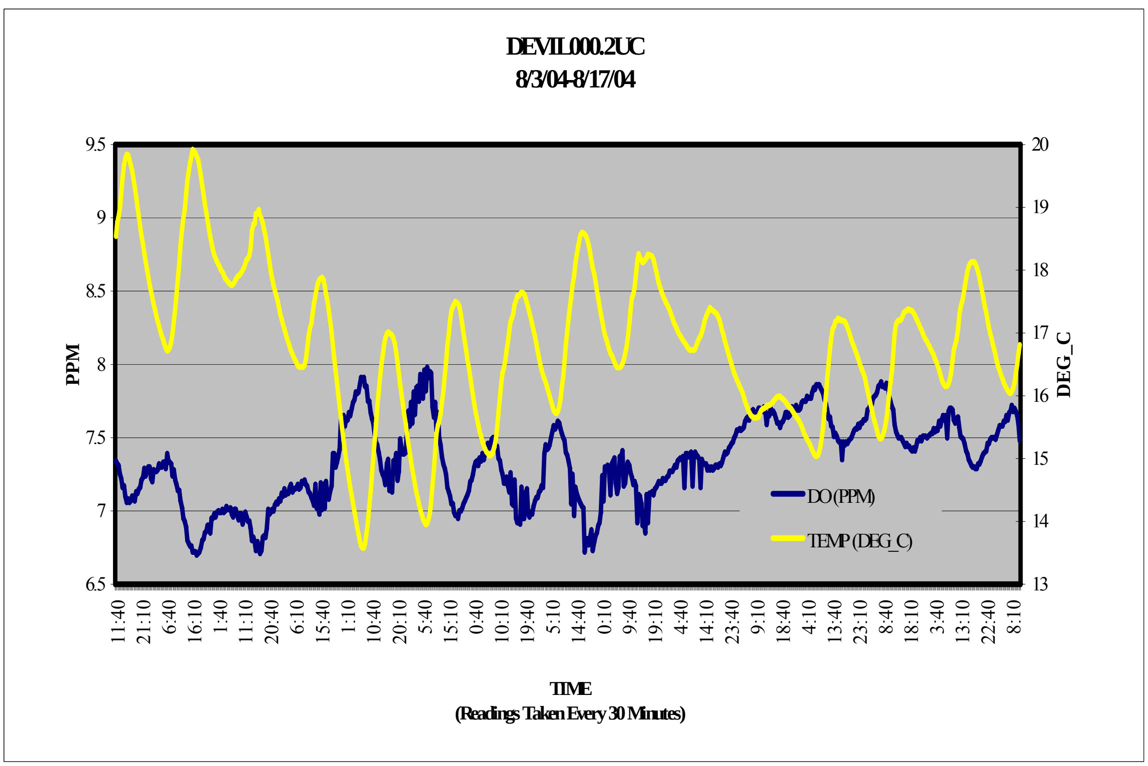
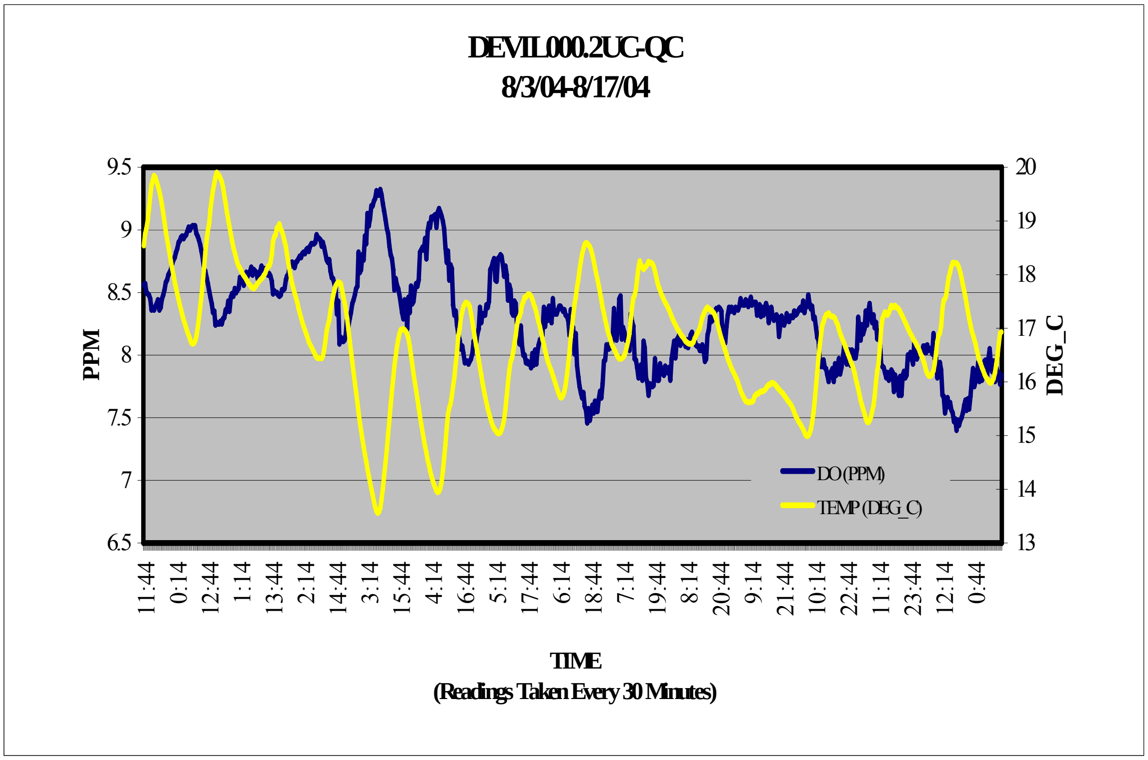
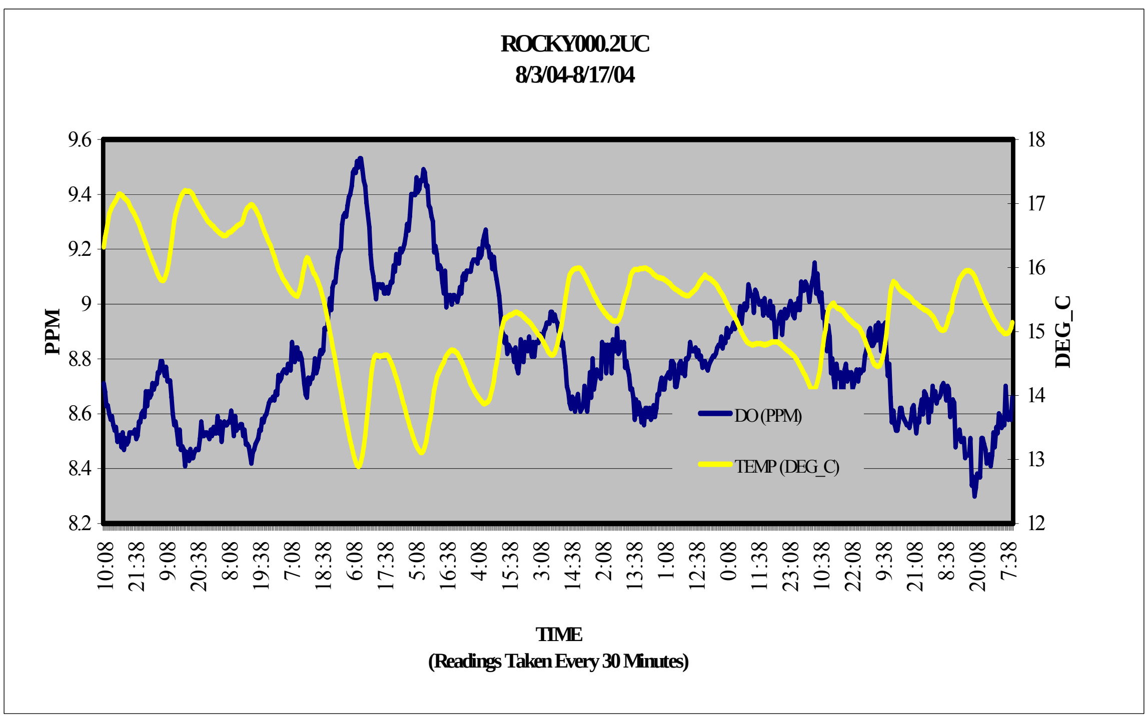
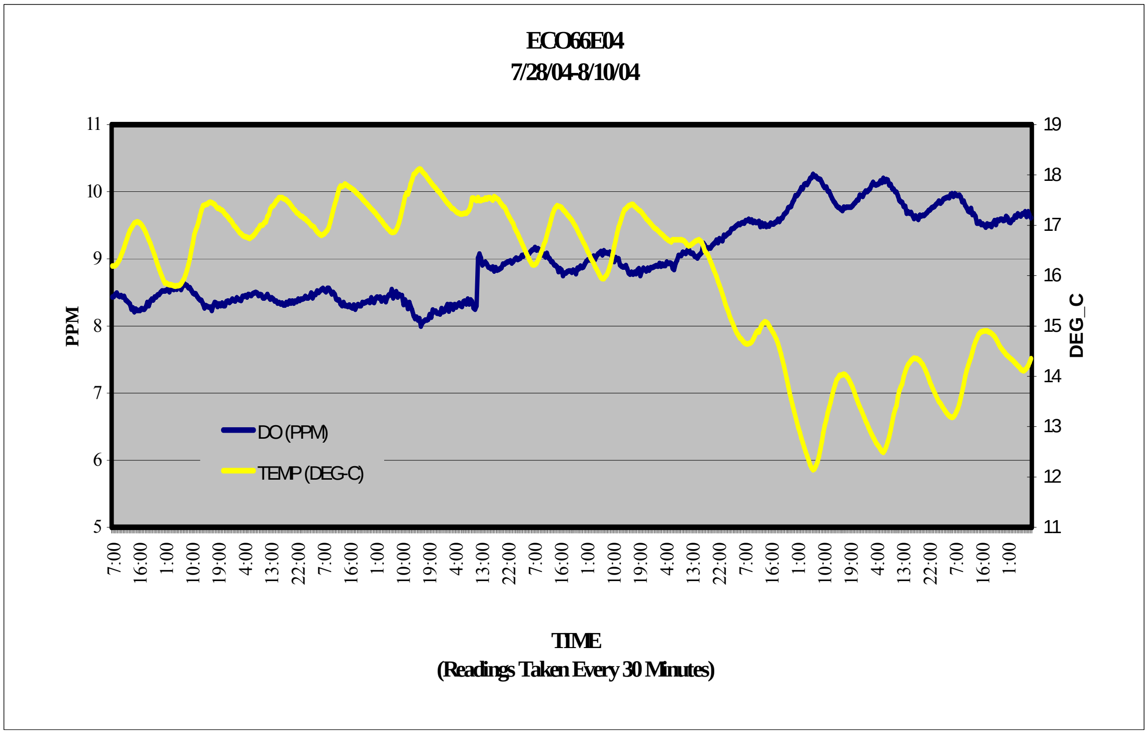
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)

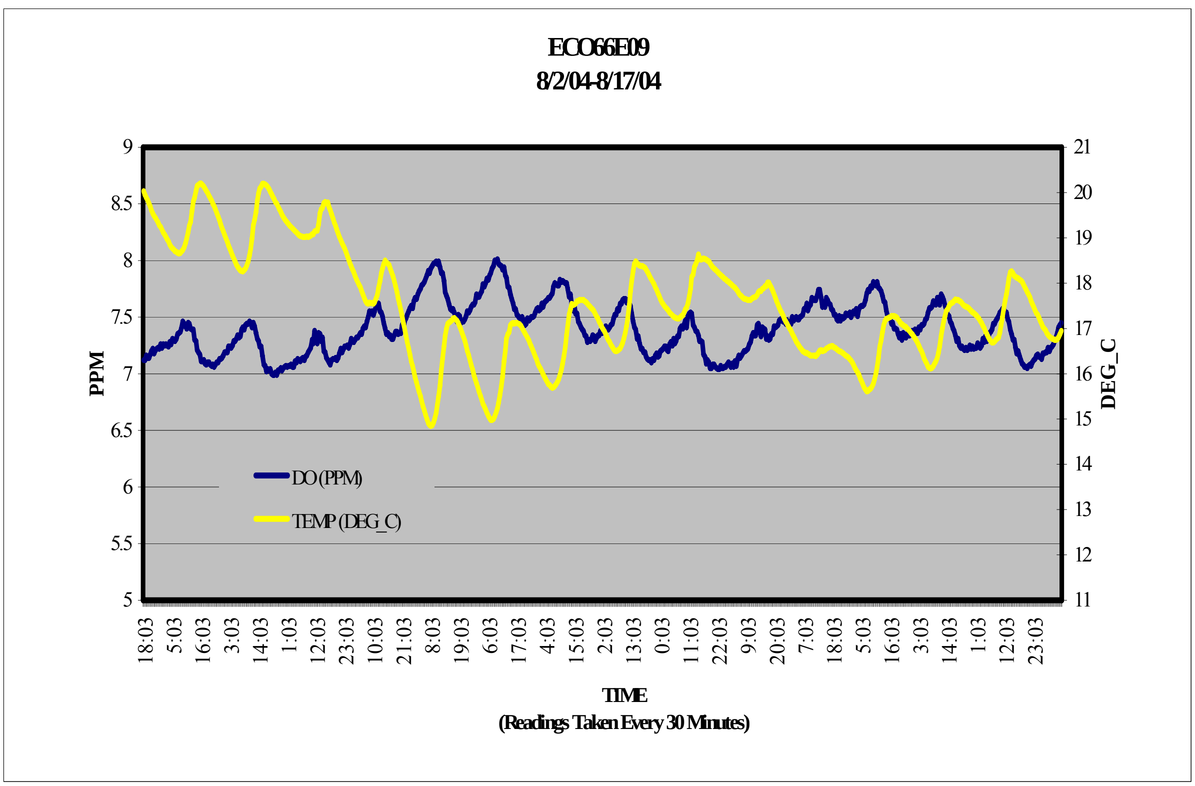

DEVIL000.2UC
8/3/04-8/17/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)

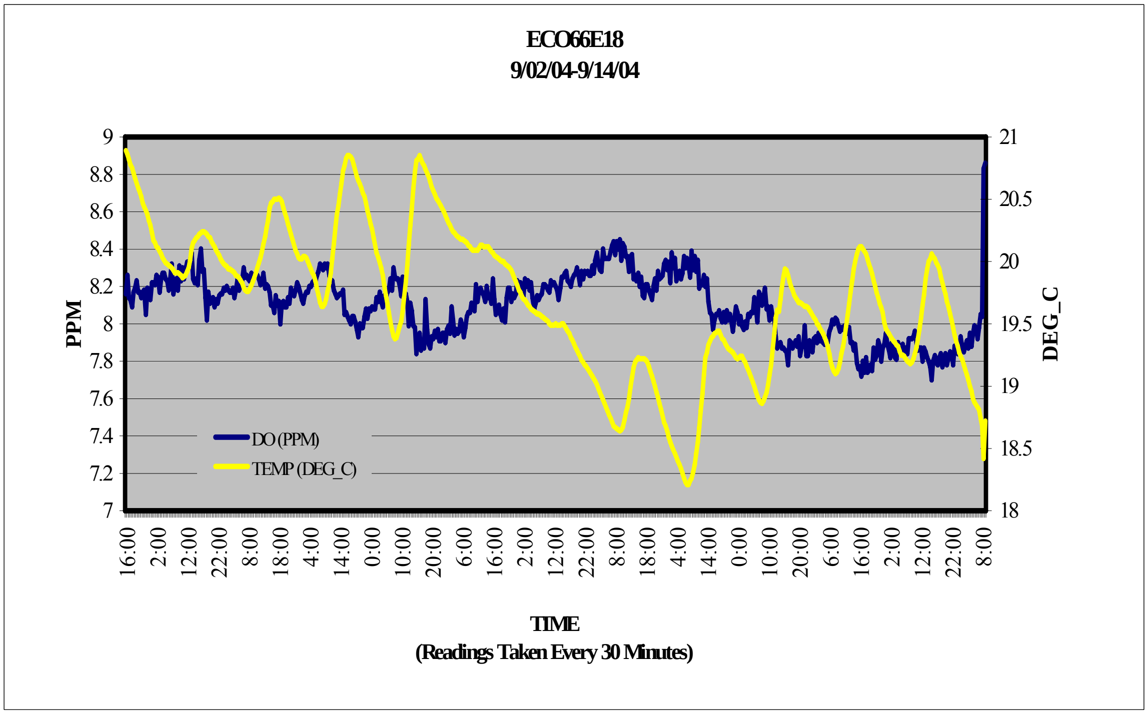

DEVIL000.2UC-QC
8/3/04-8/17/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)


ROCKY000.2UC
8/3/04-8/17/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)

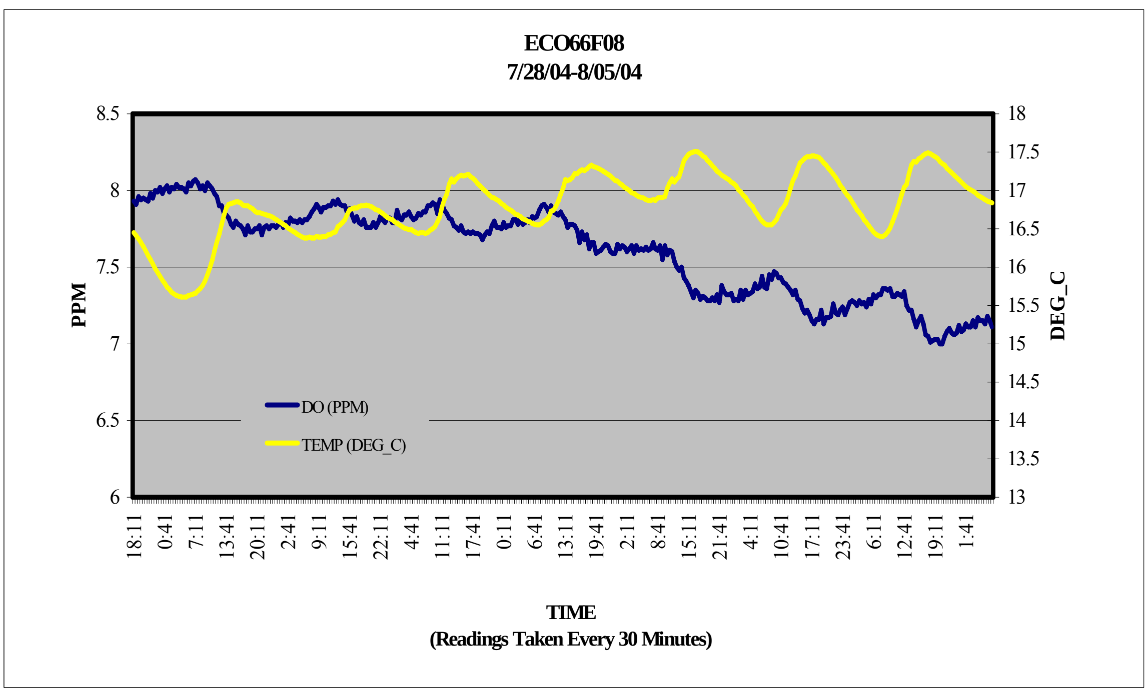
66E

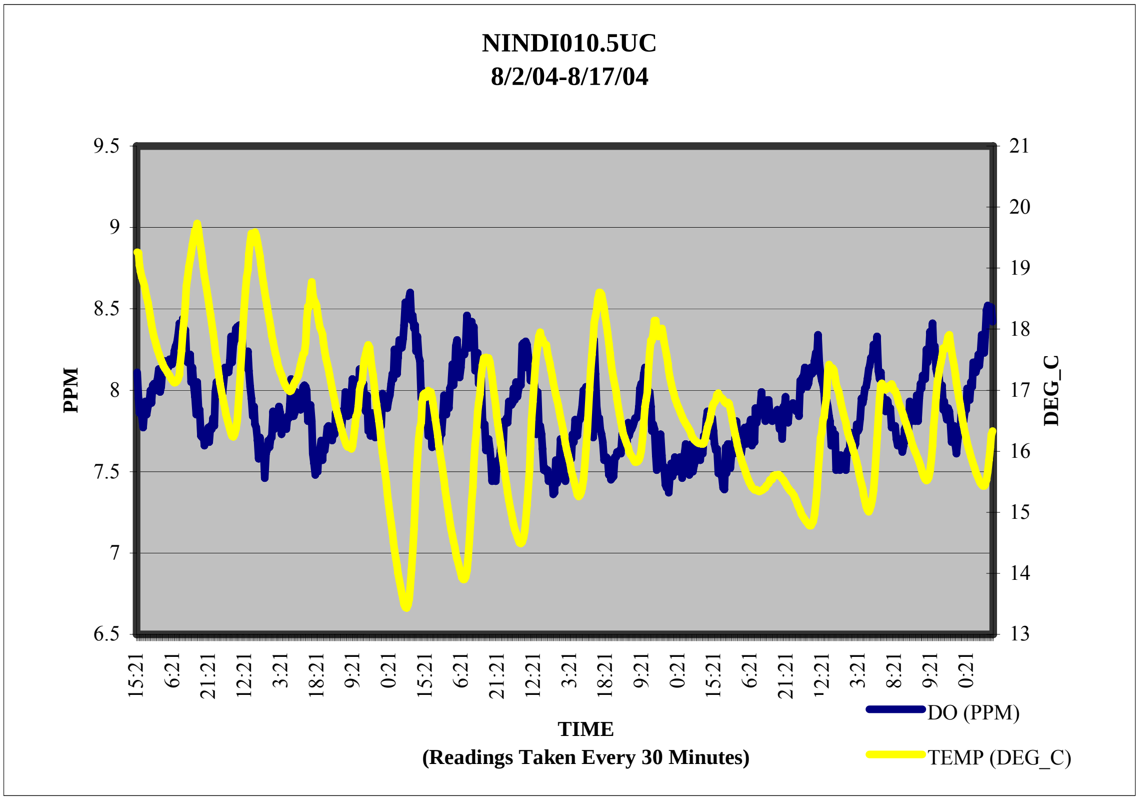

ECO66E04
7/28/04-8/10/04
PPM
DEG_C
DO (PPM)
TEMP (DEG-C)
TIME
(Readings Taken Every 30 Minutes)


ECO66E09
8/2/04-8/17/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)



ECOREGION 66f





NINDI010.5UC
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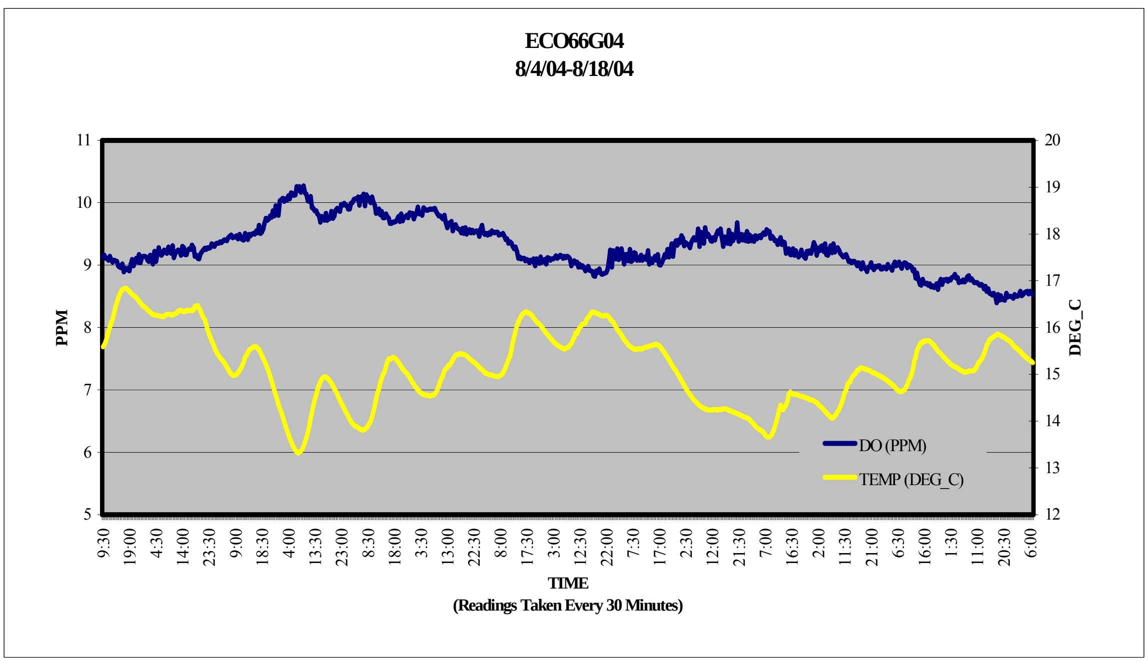
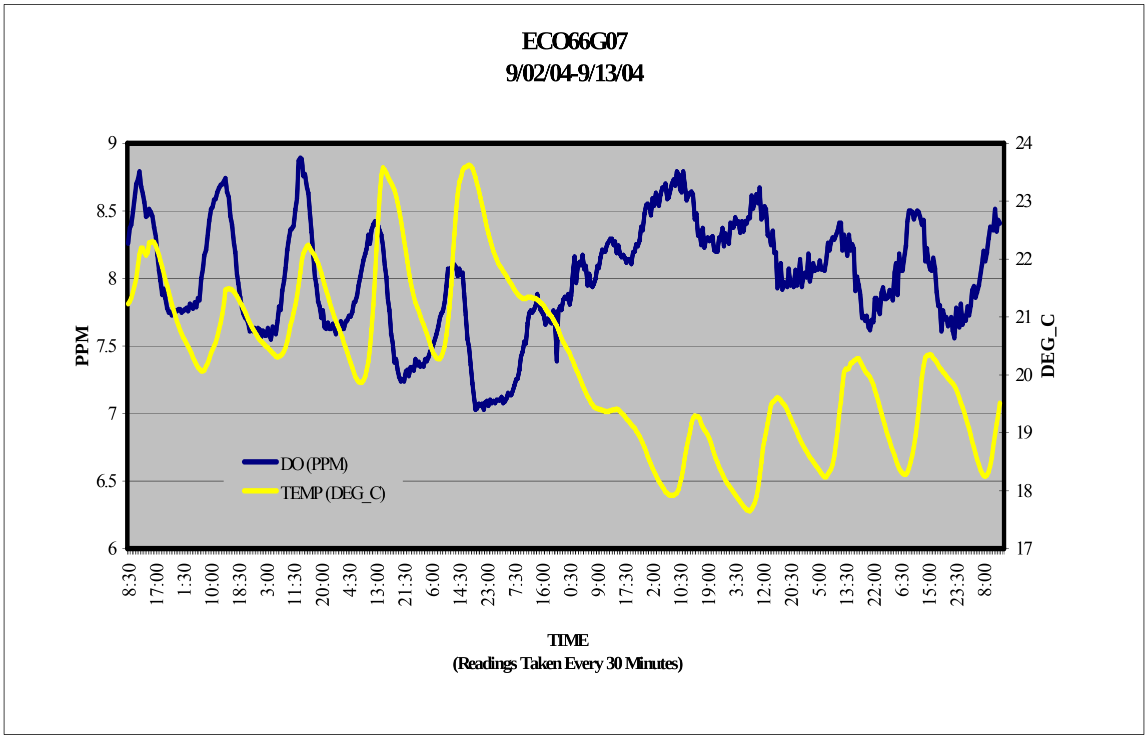
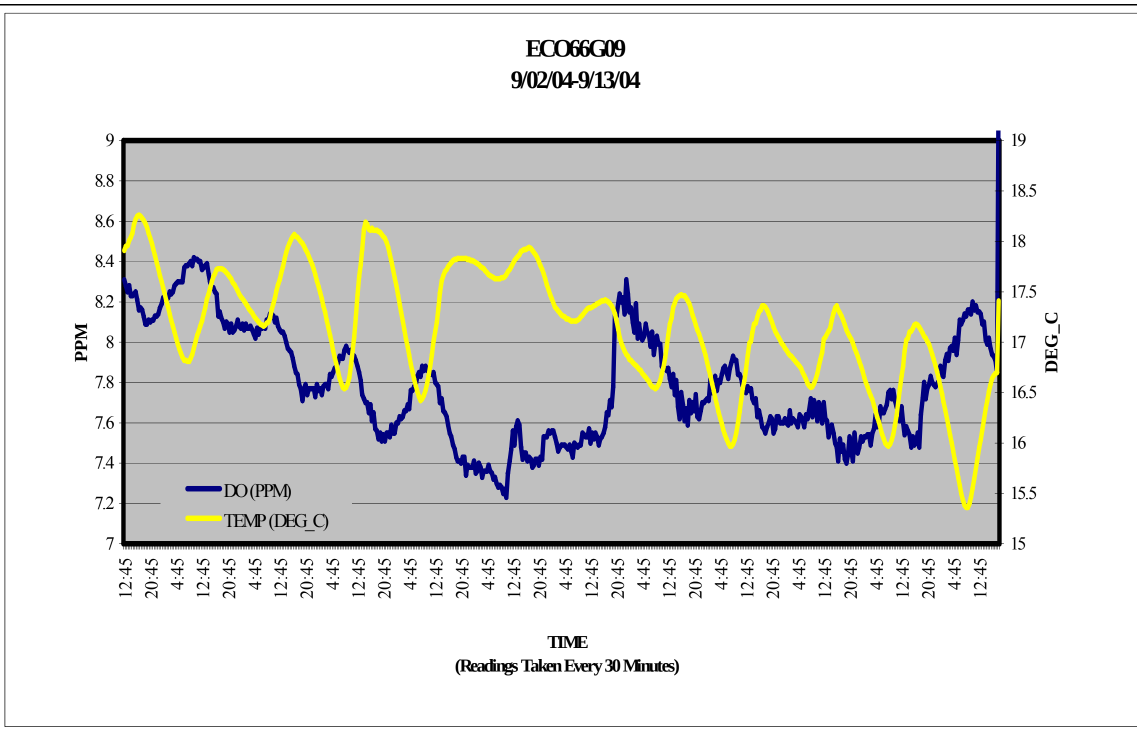
PPM
DEG_C
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)



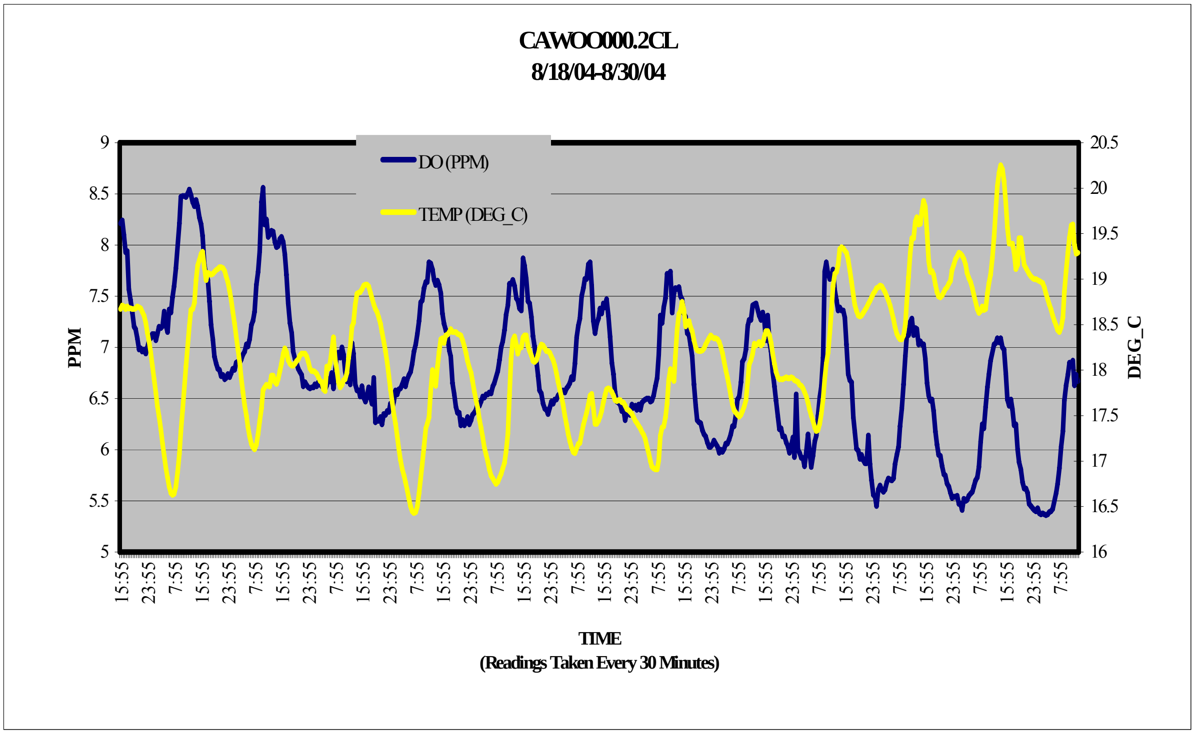
ECO66G04
8/4/04-8/18/04
PPM
DEG_C
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)

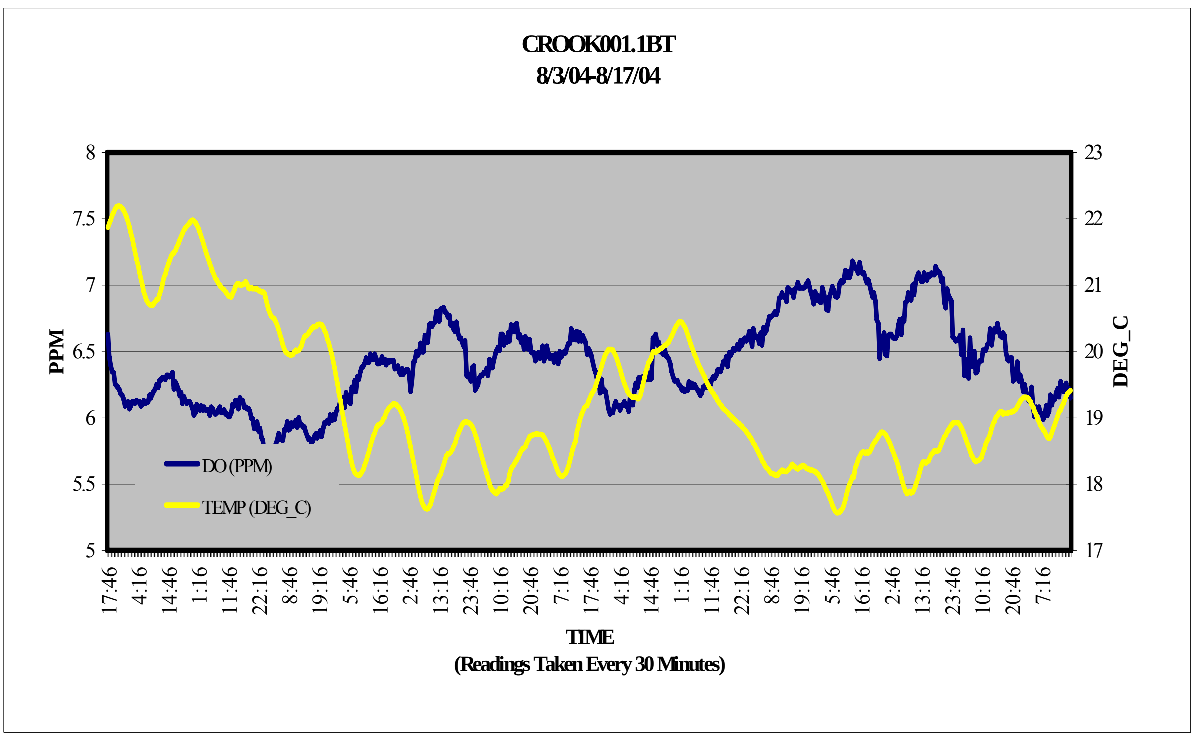
ECOREGION 66g



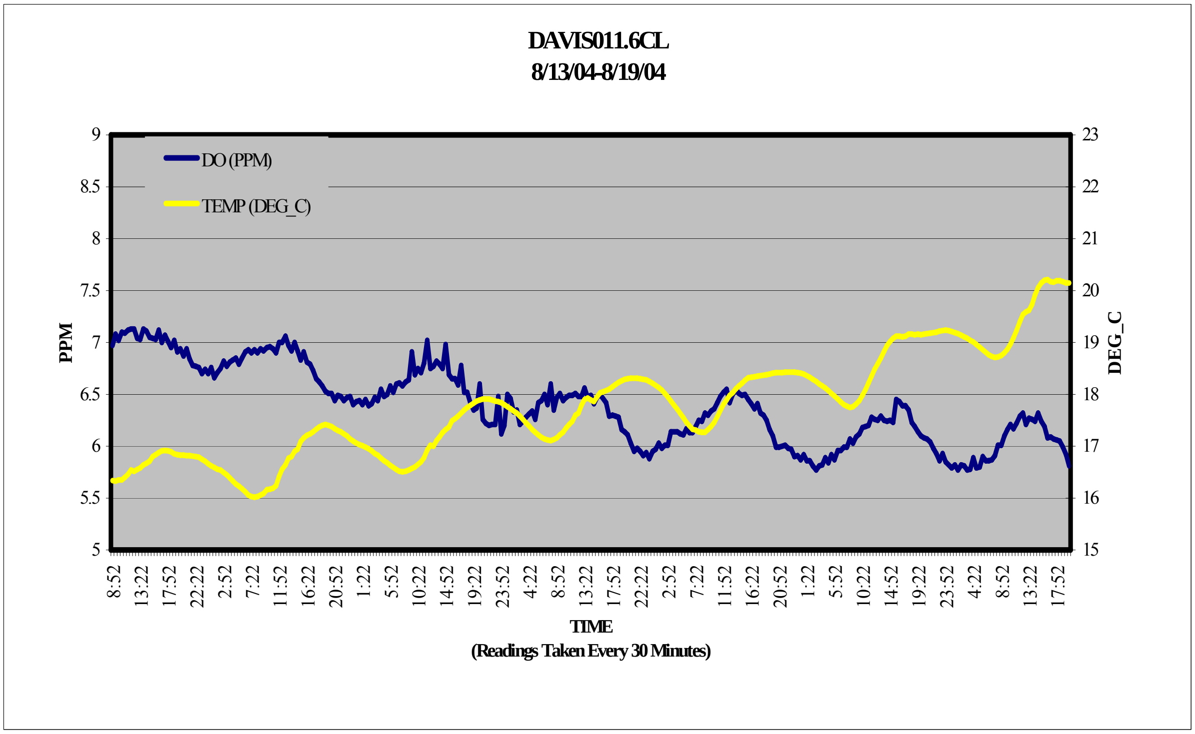


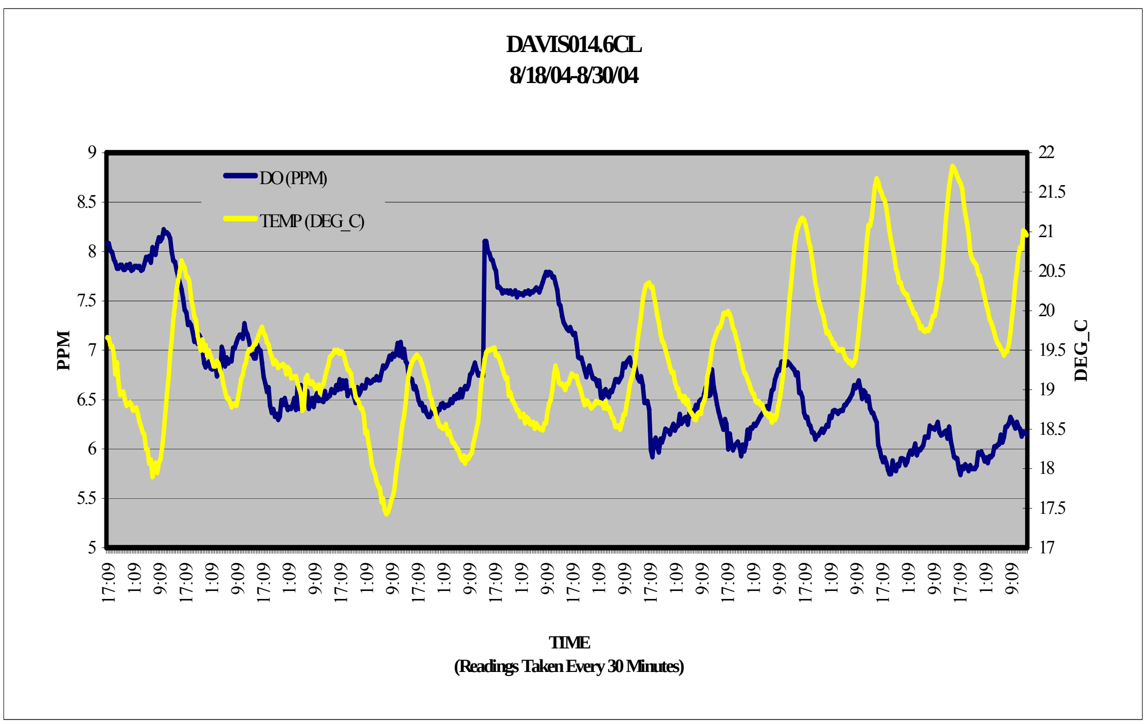
ECOREGION 67F



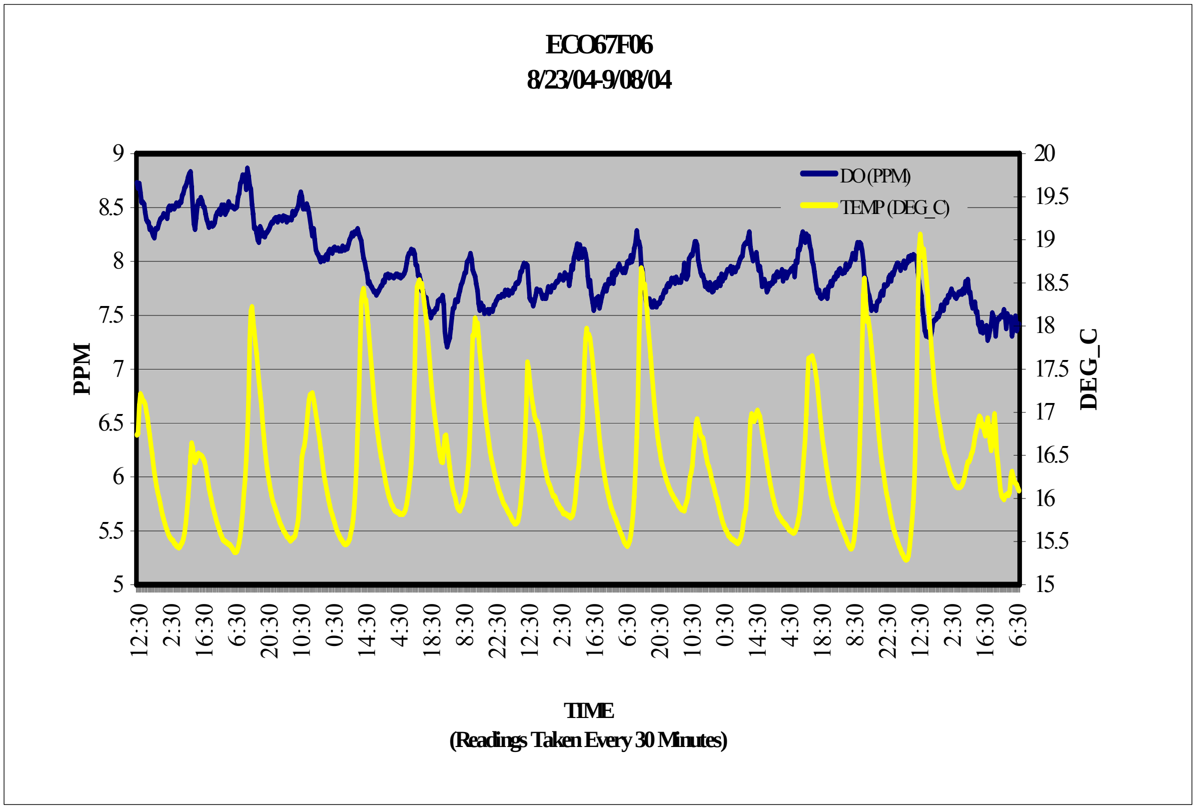


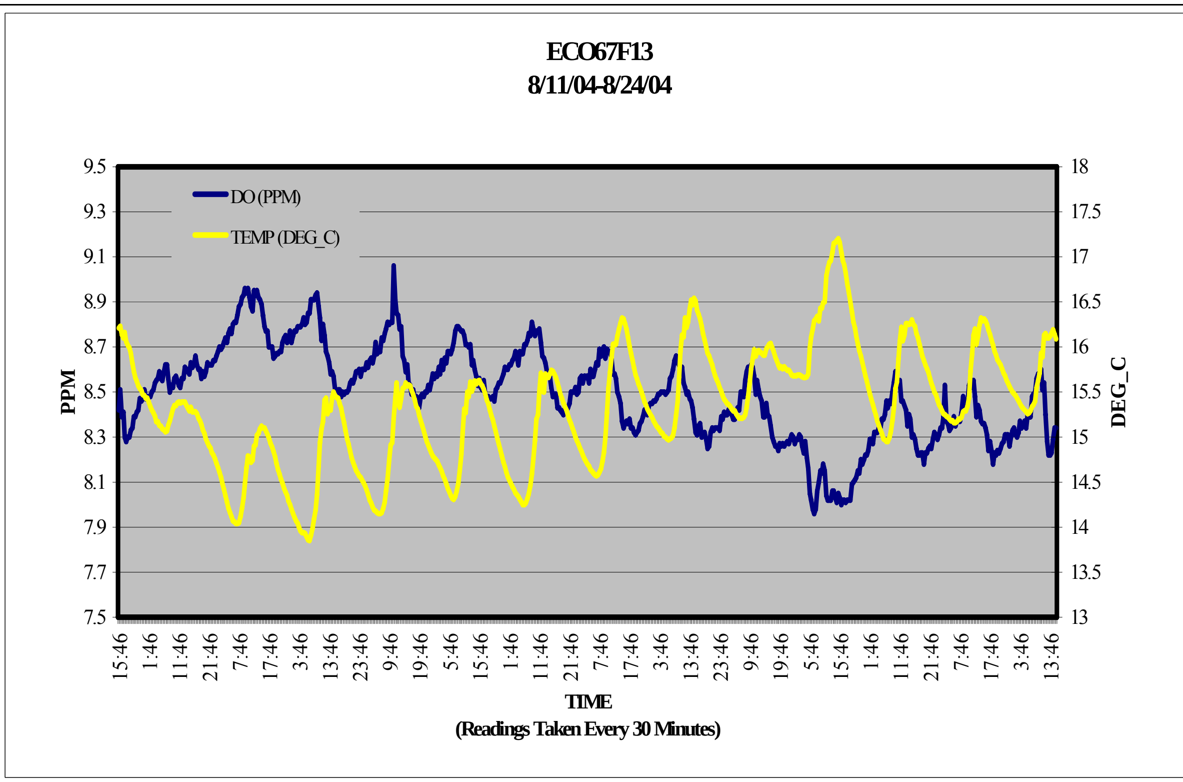
ECOREGION 67F



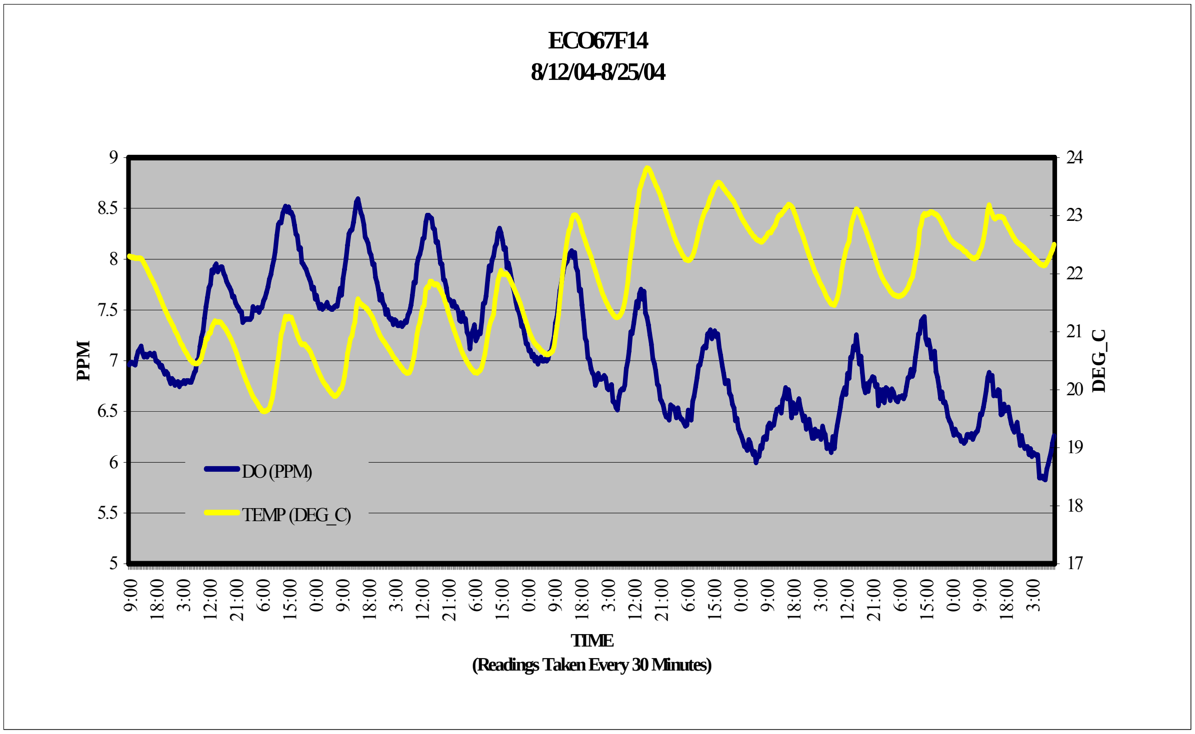


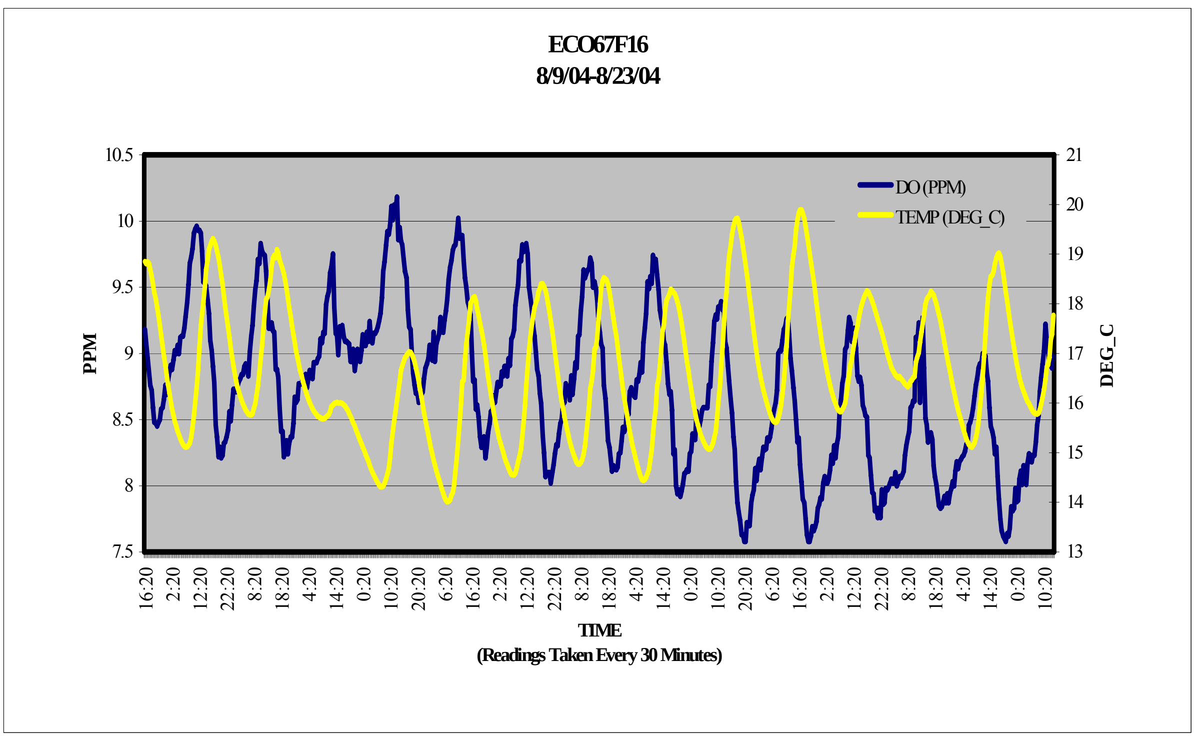
ECOREGION 67F



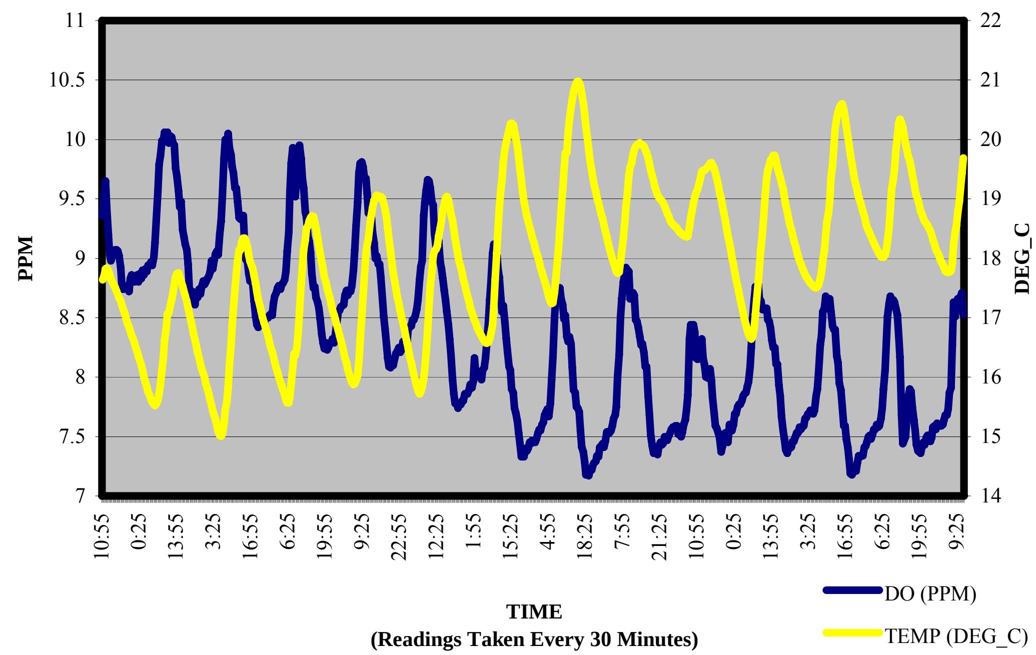


ECOREGION 67F

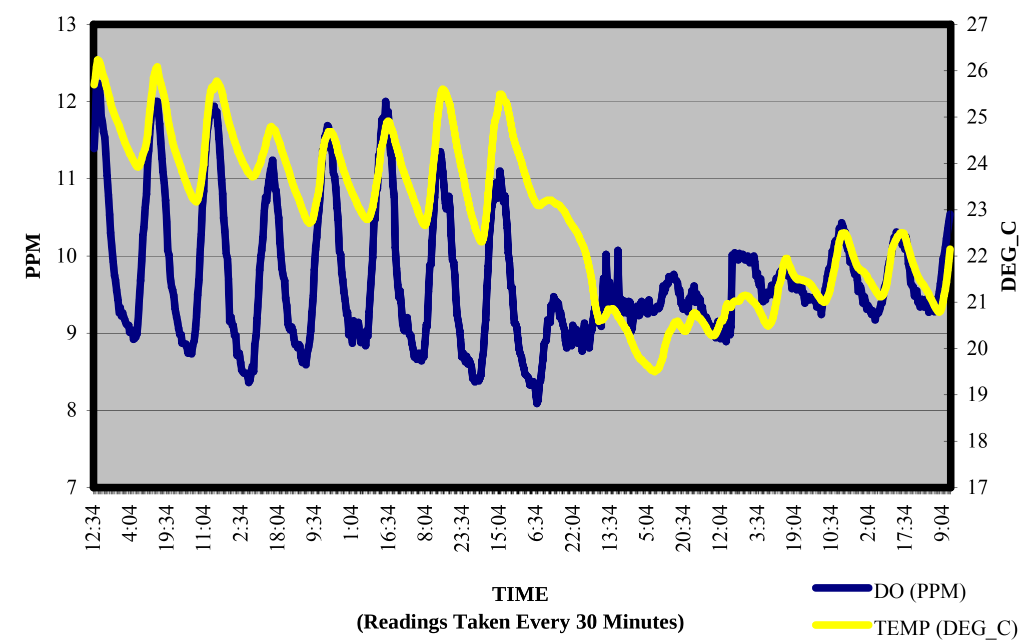


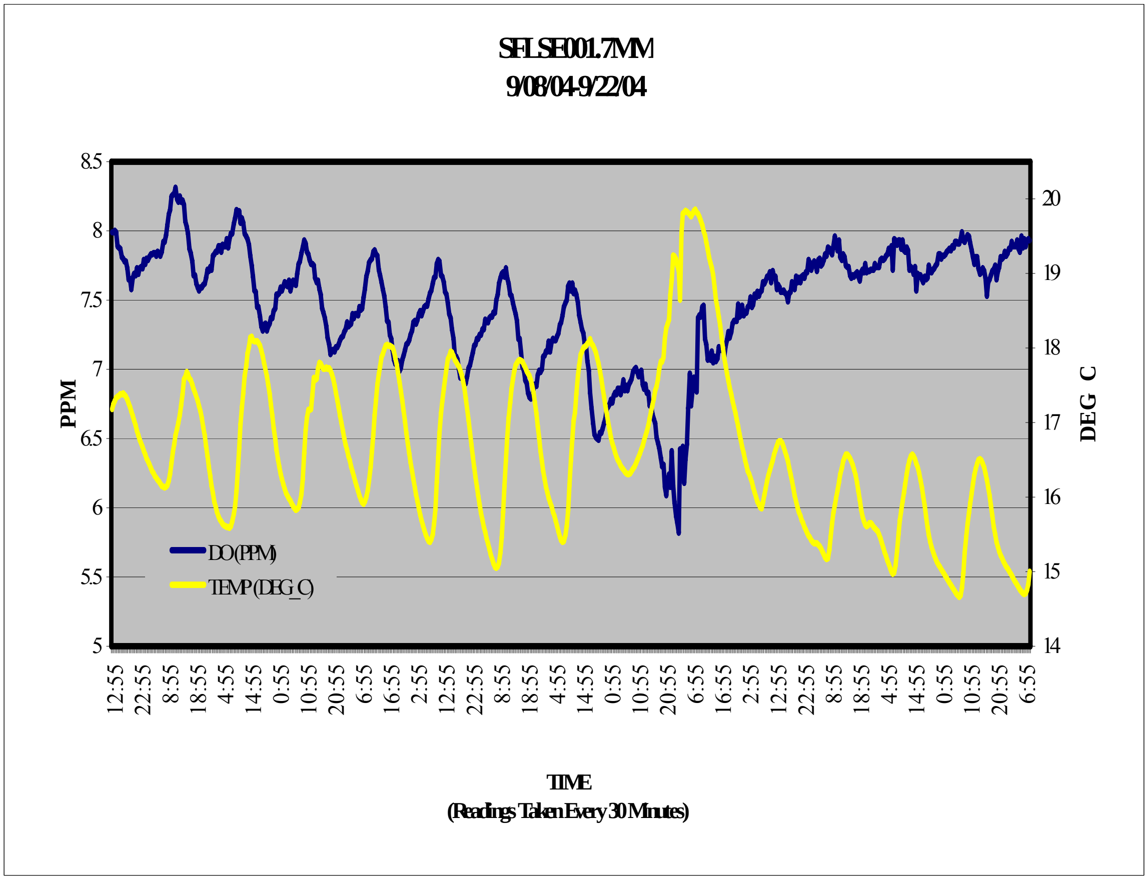


ECO67F23
8/12/04-8/25/04



ECO67F25
8/30/04-9/14/04




SFLSE001.7MM
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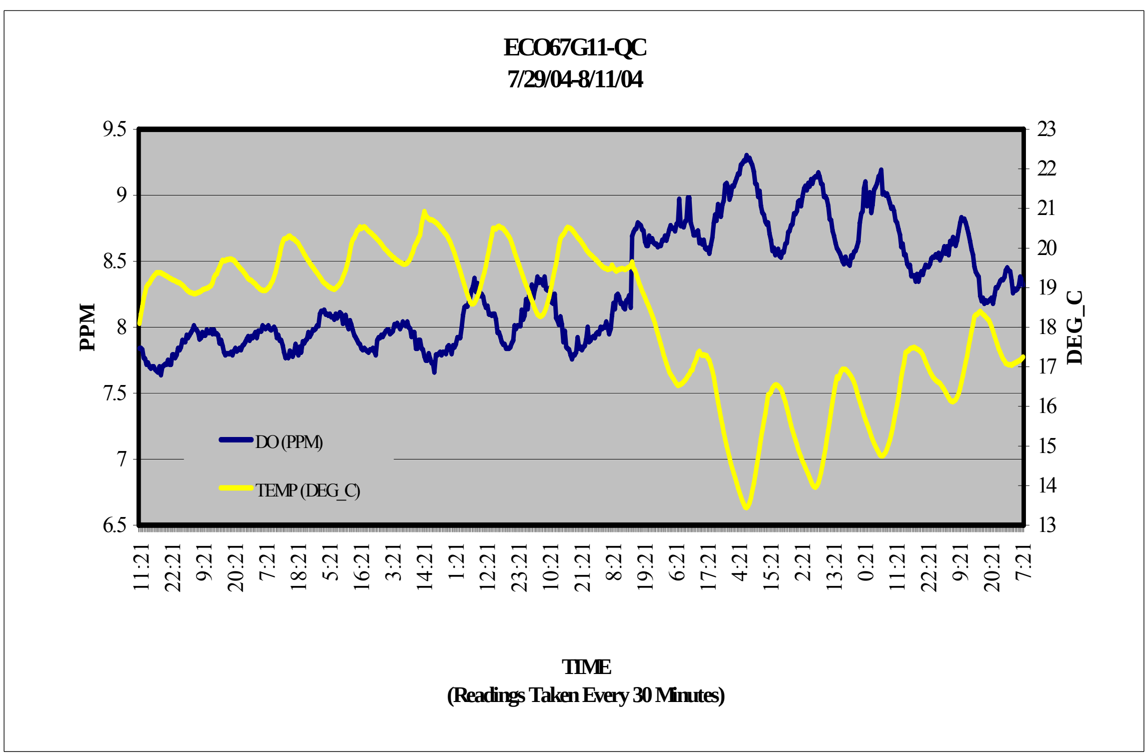
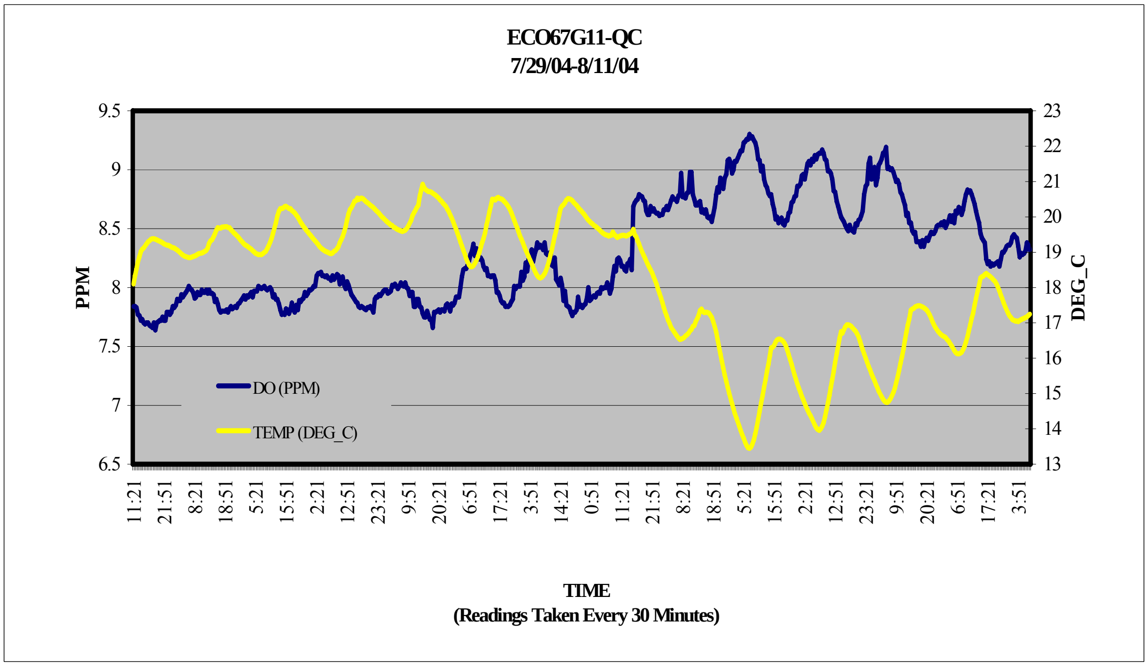
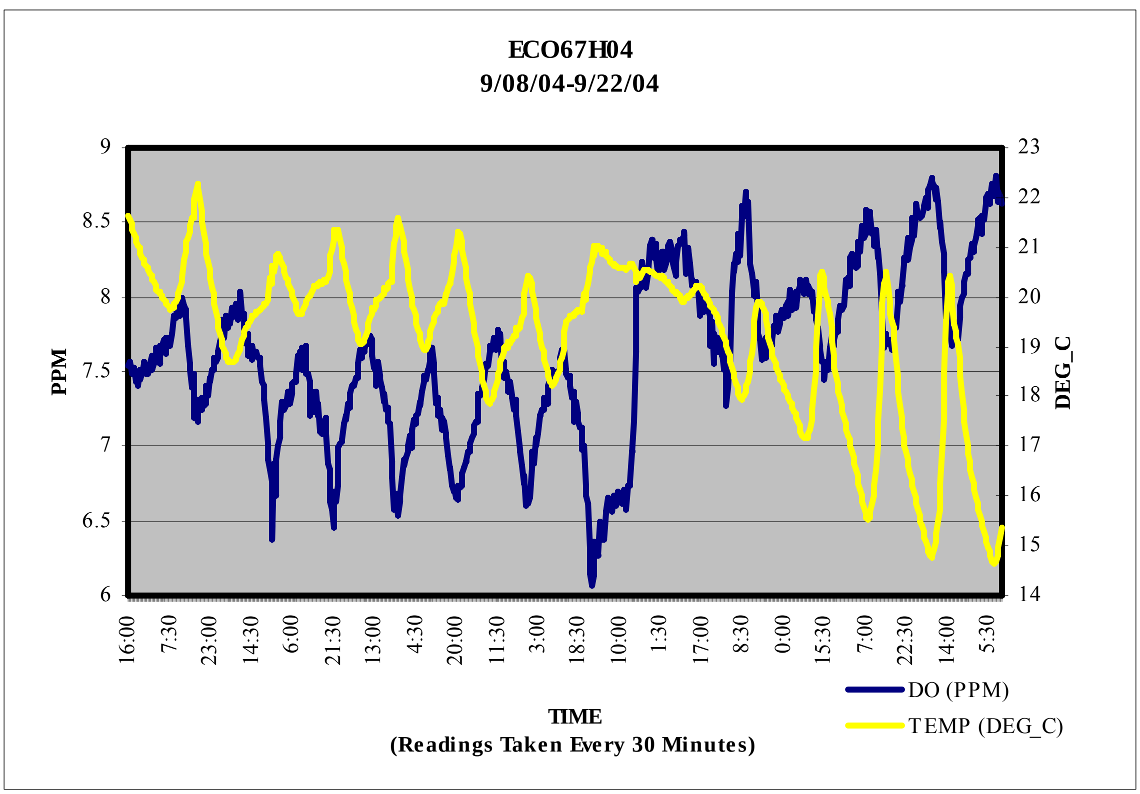
DEG C
DO(PPM)
TEMP(DEG_C)
TIME
(Readings Taken Every 30 Minutes)

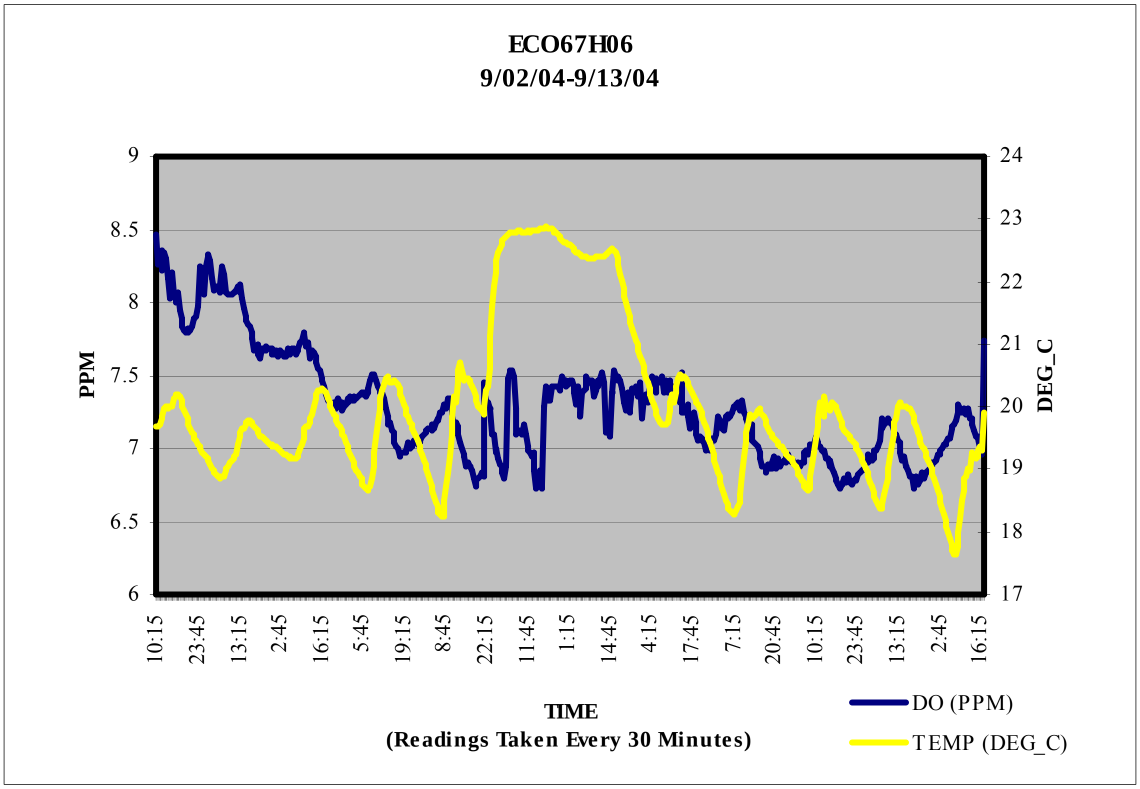

ECO67G11-QC
7/29/04-8/11/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)

ECOREGION 67G

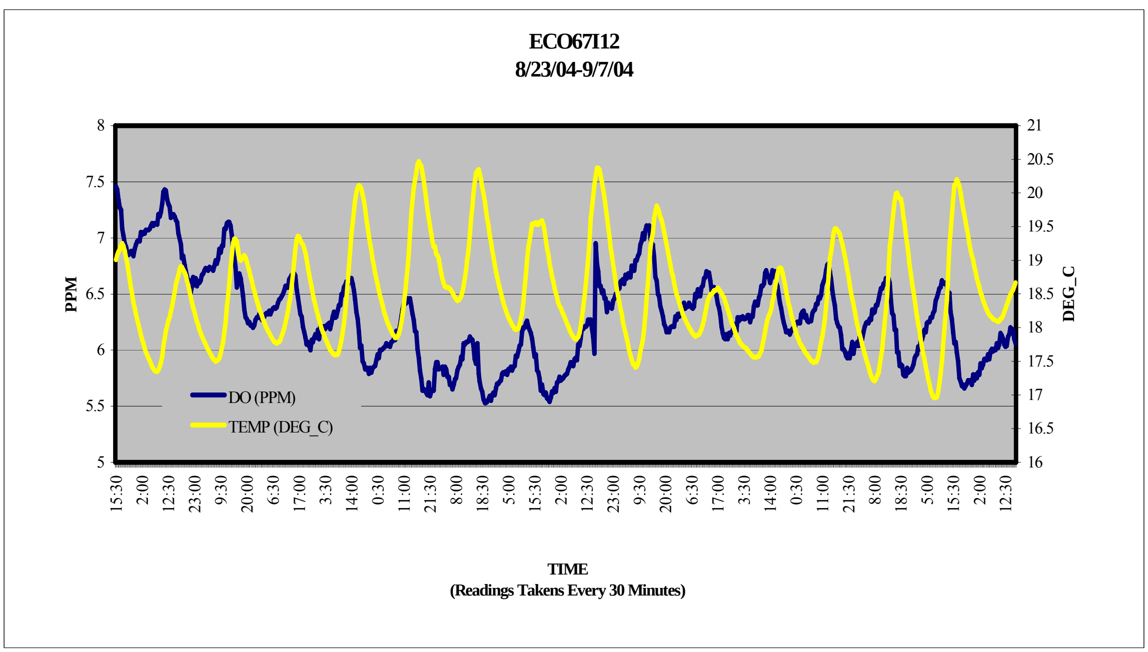


ECOREGION 67H

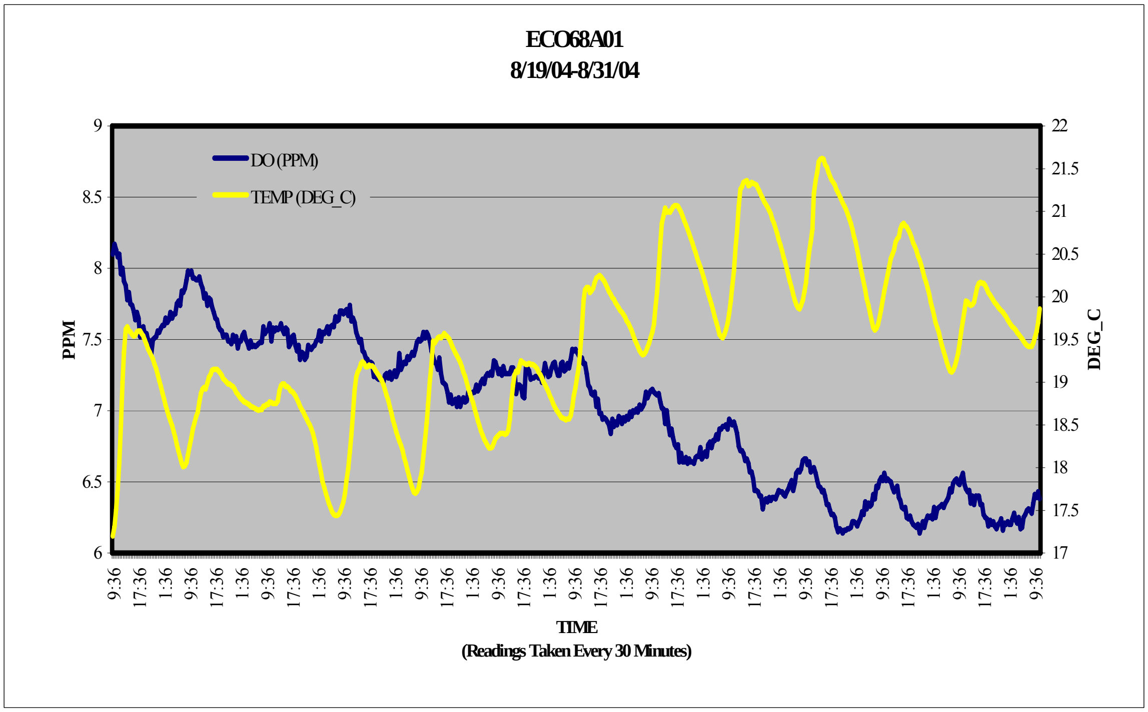


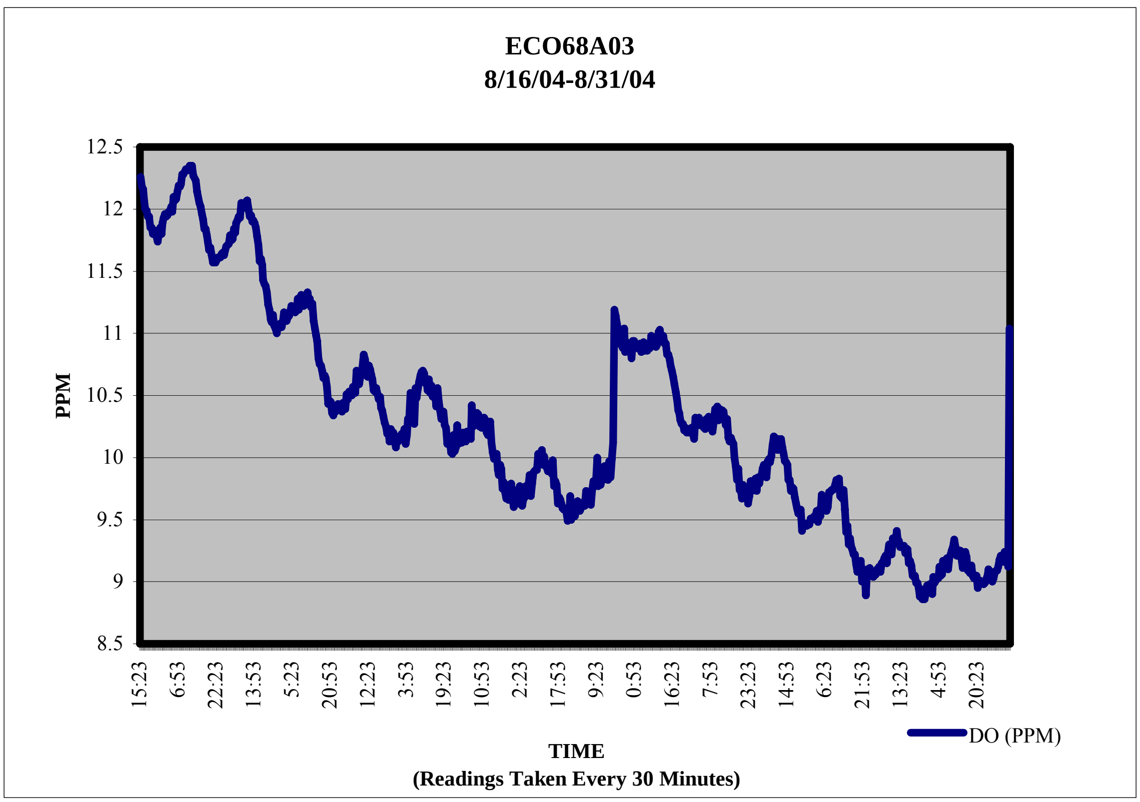


ECOREGION 67I

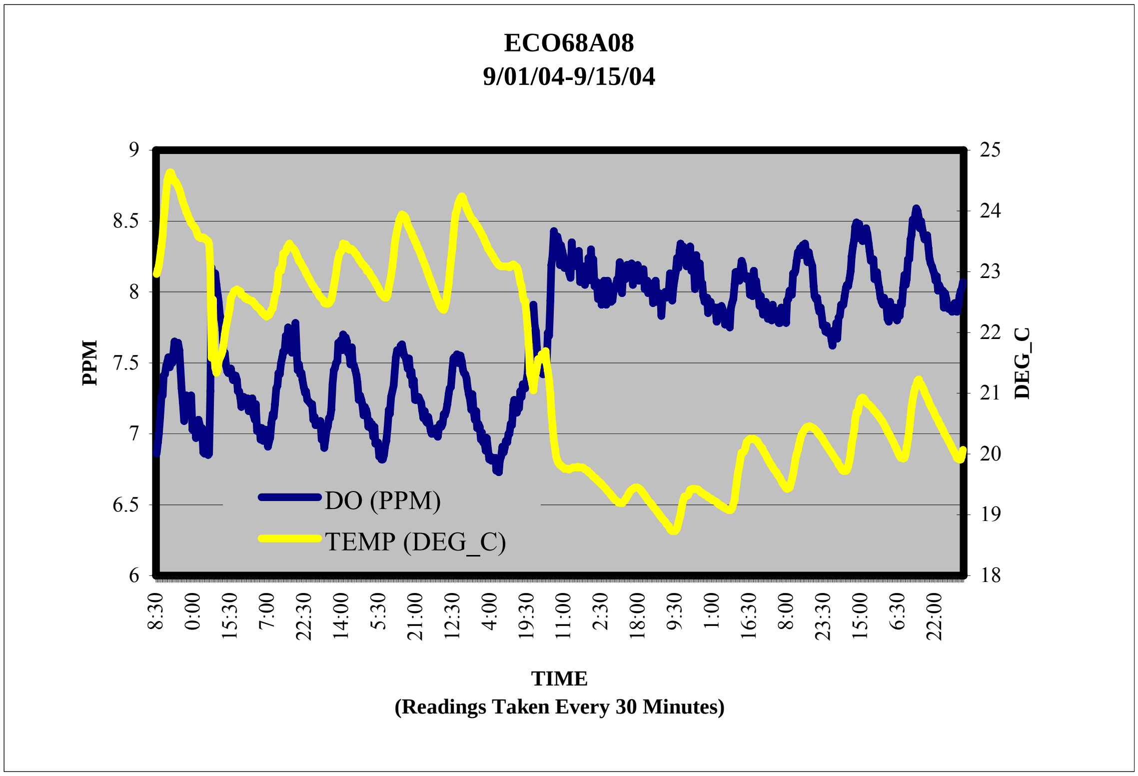


ECOREGION 68A





Temperature data not available


ECO68A08
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DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)
9
8.5
8
7.5
7
6.5
6
25
24
23
22
21
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21:00
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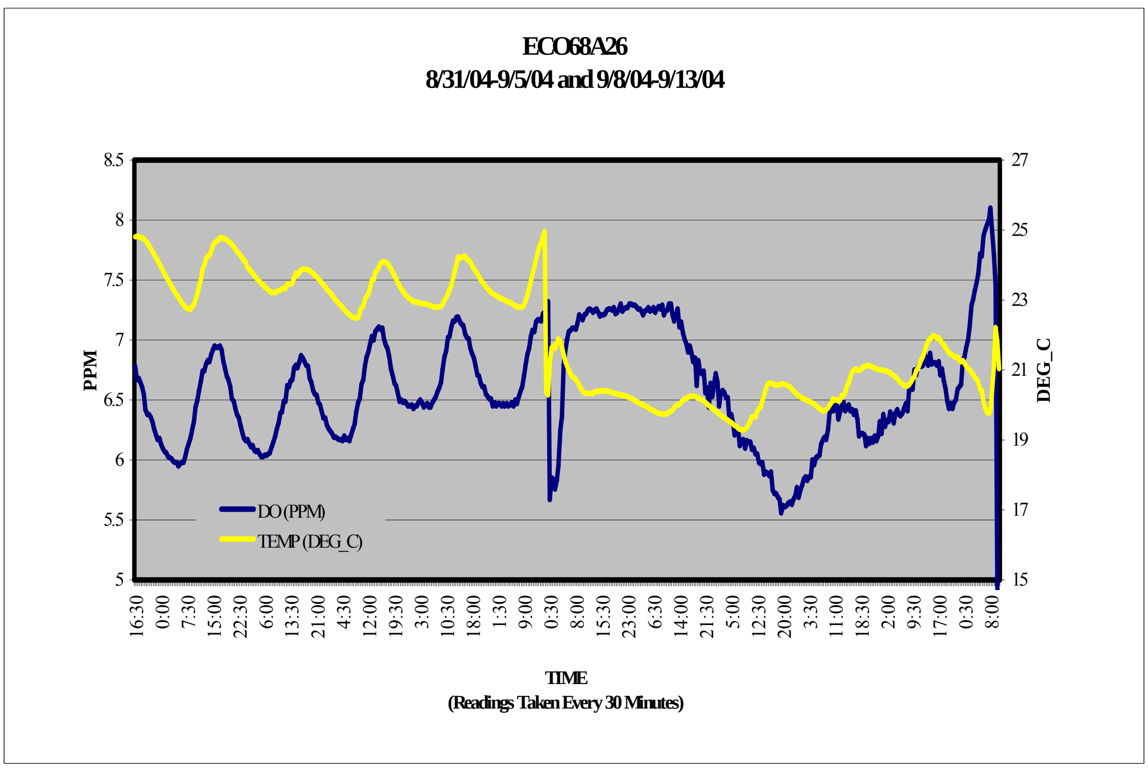
22:00


ECO68A26
8/31/04-9/5/04 and 9/8/04-9/13/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)
8.5
8
7.5
7
6.5
6
5.5
5
27
25
23
21
19
17
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16:30
0:00
7:30
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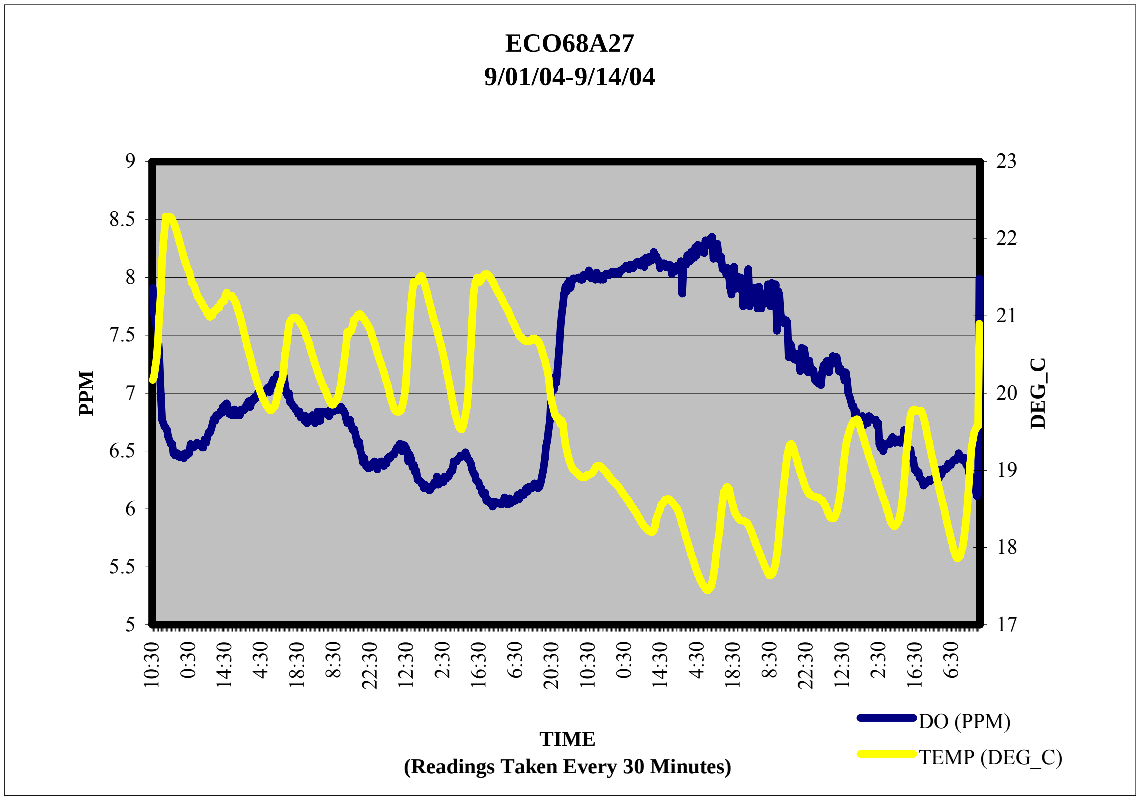
ECO68A27
9/01/04-9/14/04
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DEG_C
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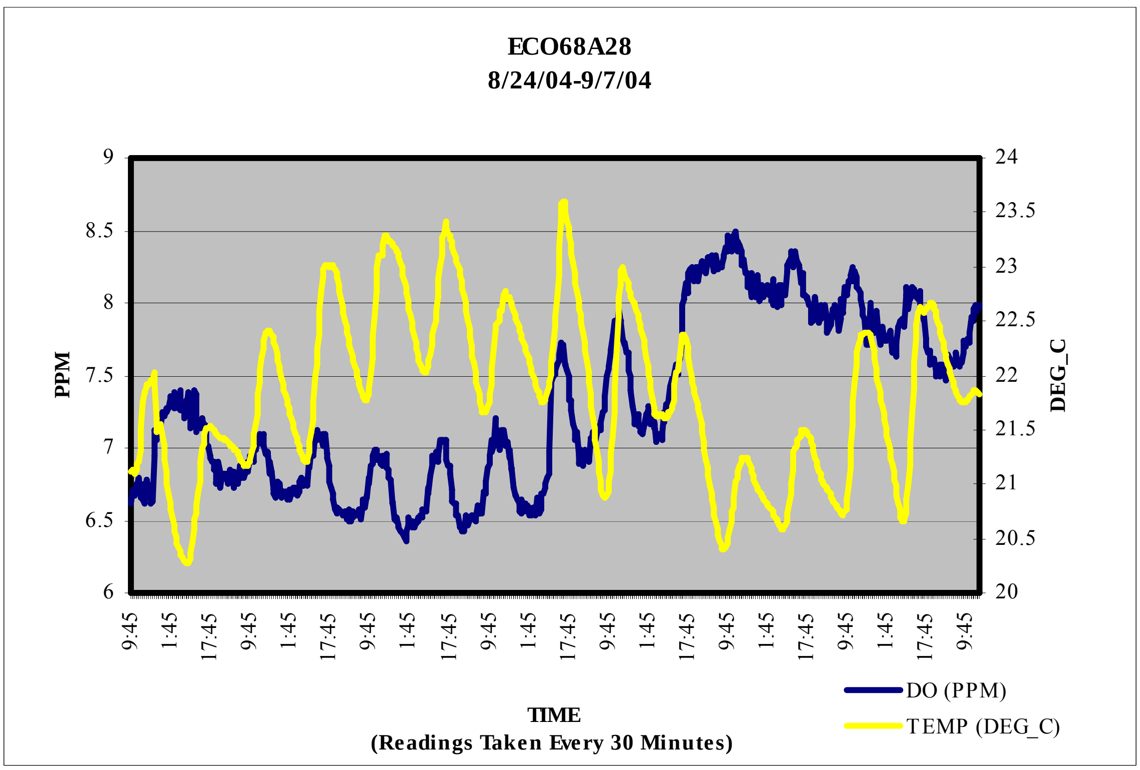
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO68A28
8/24/04-9/7/04
PPM
DEG_C
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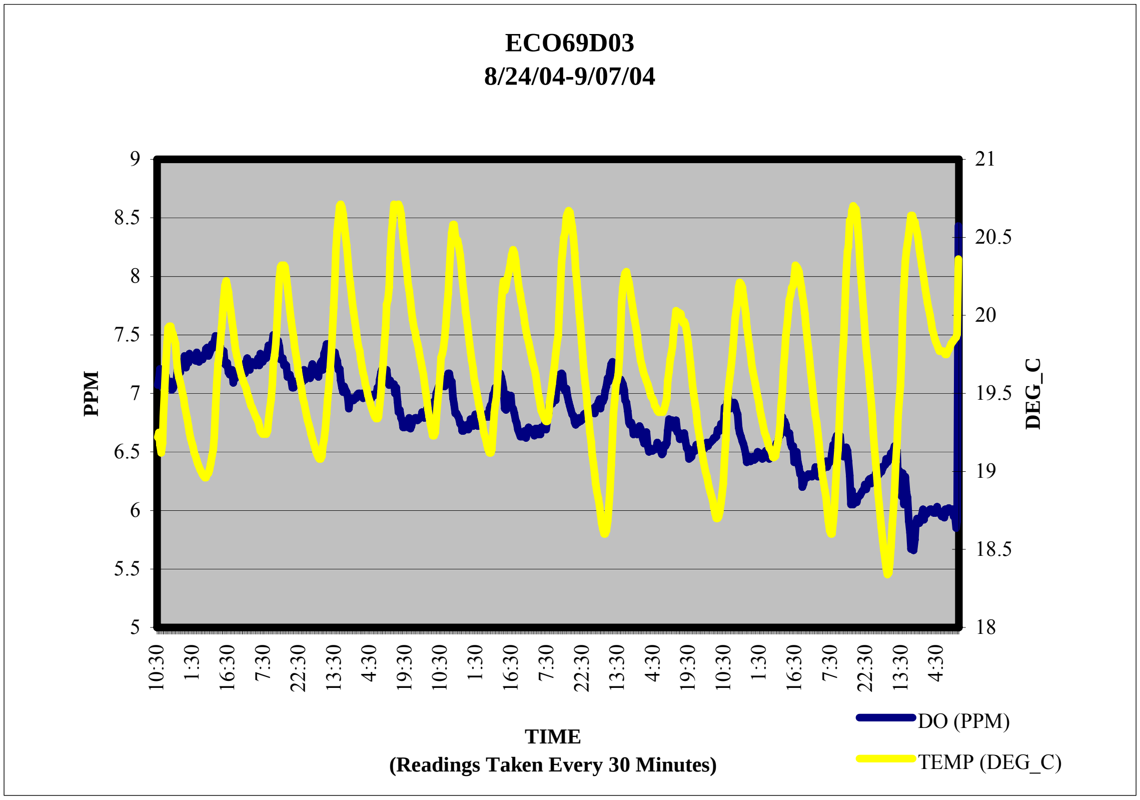
17:45
9:45
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO69D03
8/24/04-9/07/04
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DEG_C
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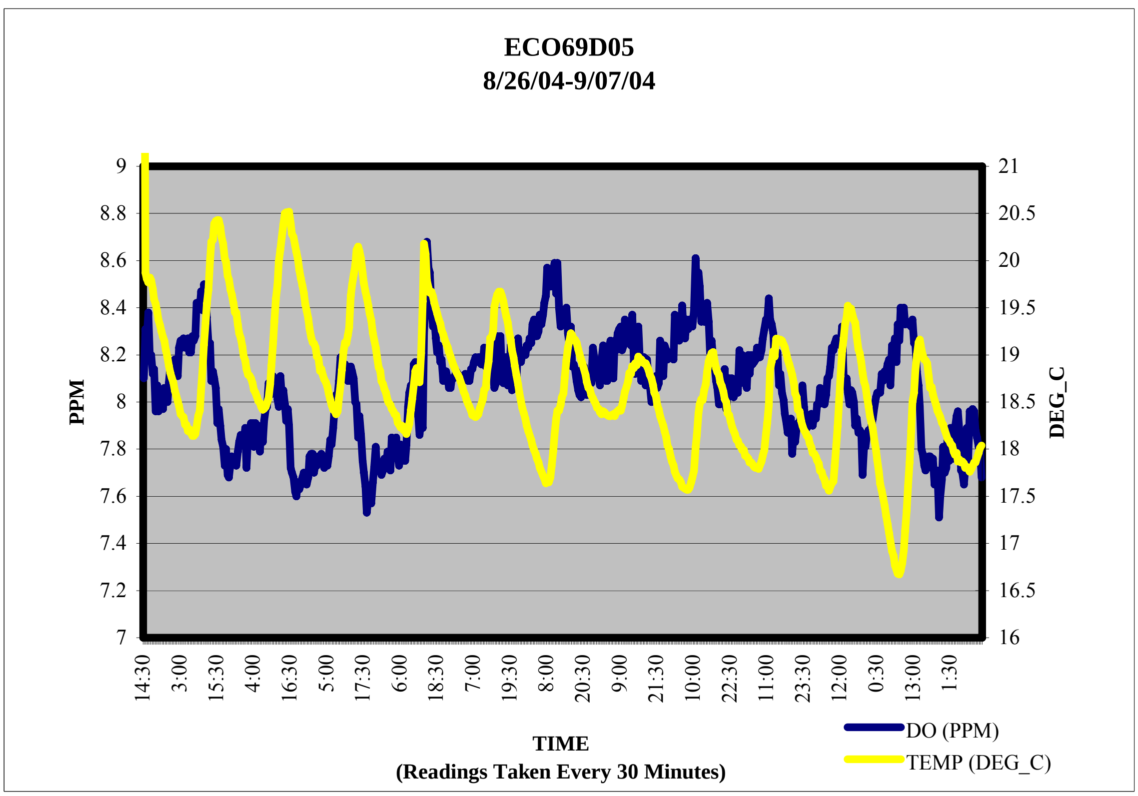
13:30
4:30
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO69D05
8/26/04-9/07/04
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8.4
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7.4
7.2
7
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
DEG_C
14:30
3:00
15:30
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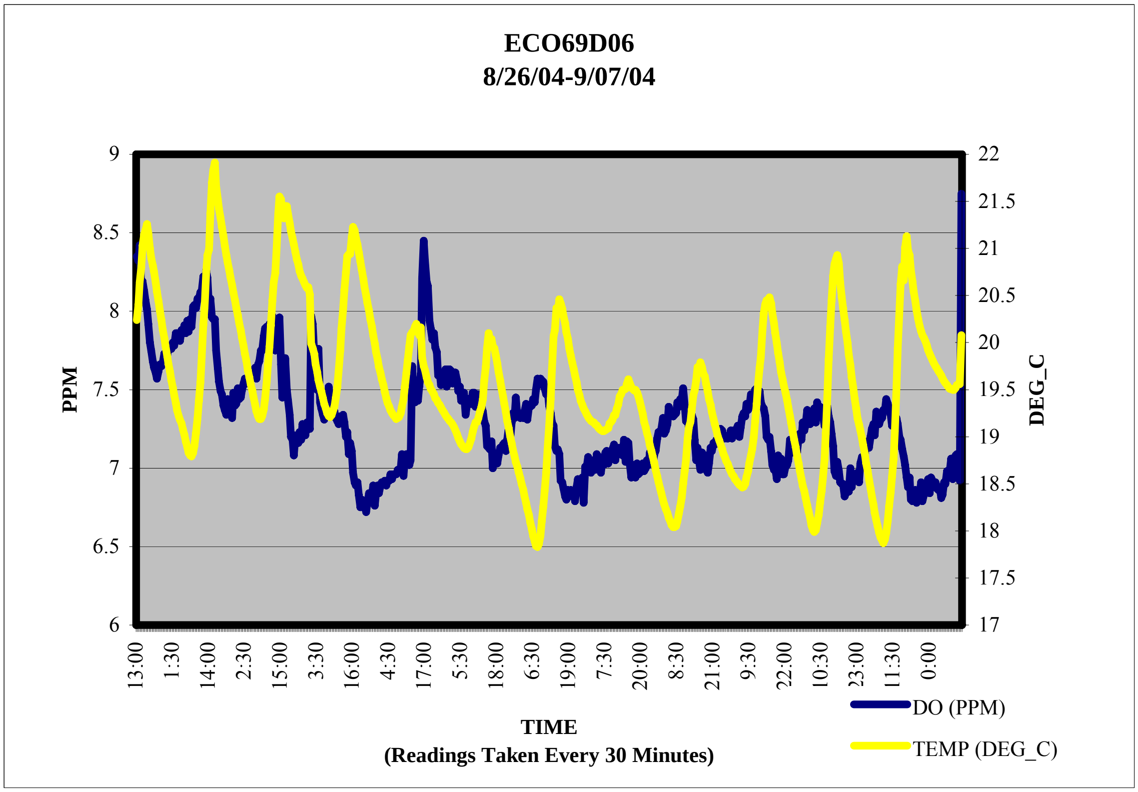
1:30
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)



ECO69D06
8/26/04-9/07/04
PPM
DEG_C
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21.5
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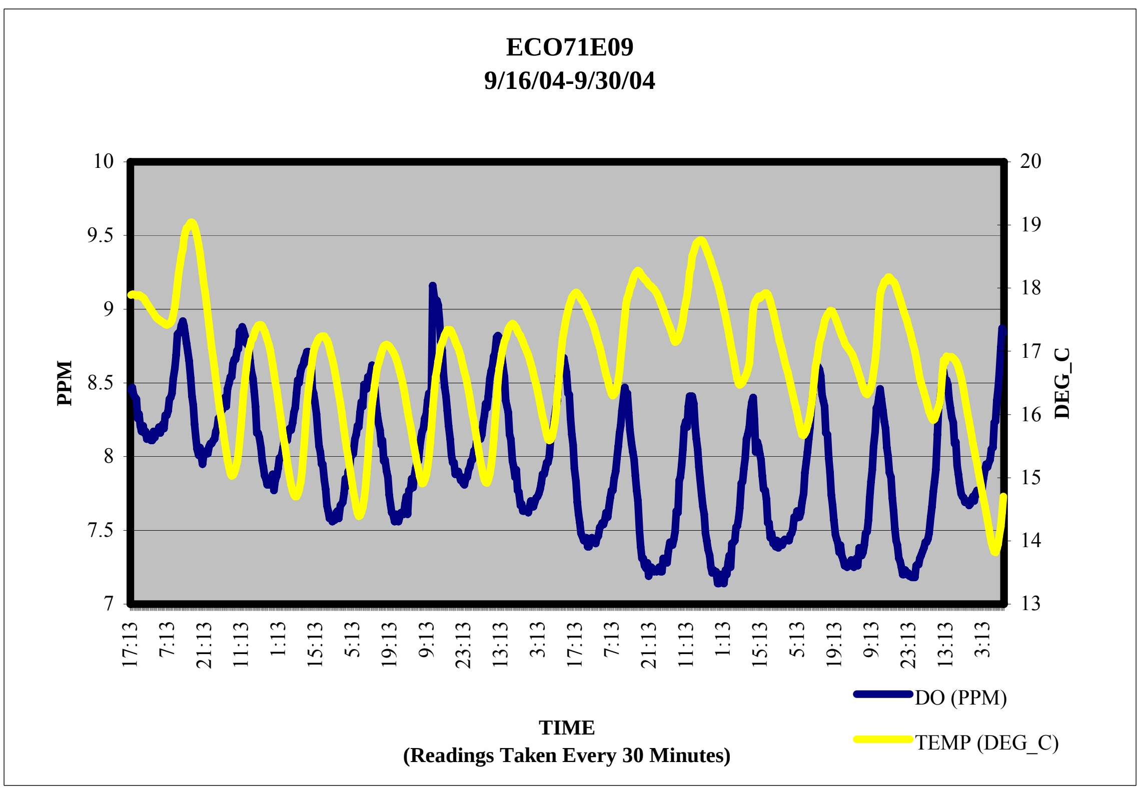
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)



ECO71E09
9/16/04-9/30/04
PPM
DEG_C
10
9.5
9
8.5
8
7.5
7
20
19
18
17
16
15
14
13
17:13
7:13
21:13
11:13
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5:13
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23:13
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17:13
7:13
21:13
11:13
1:13
15:13
5:13
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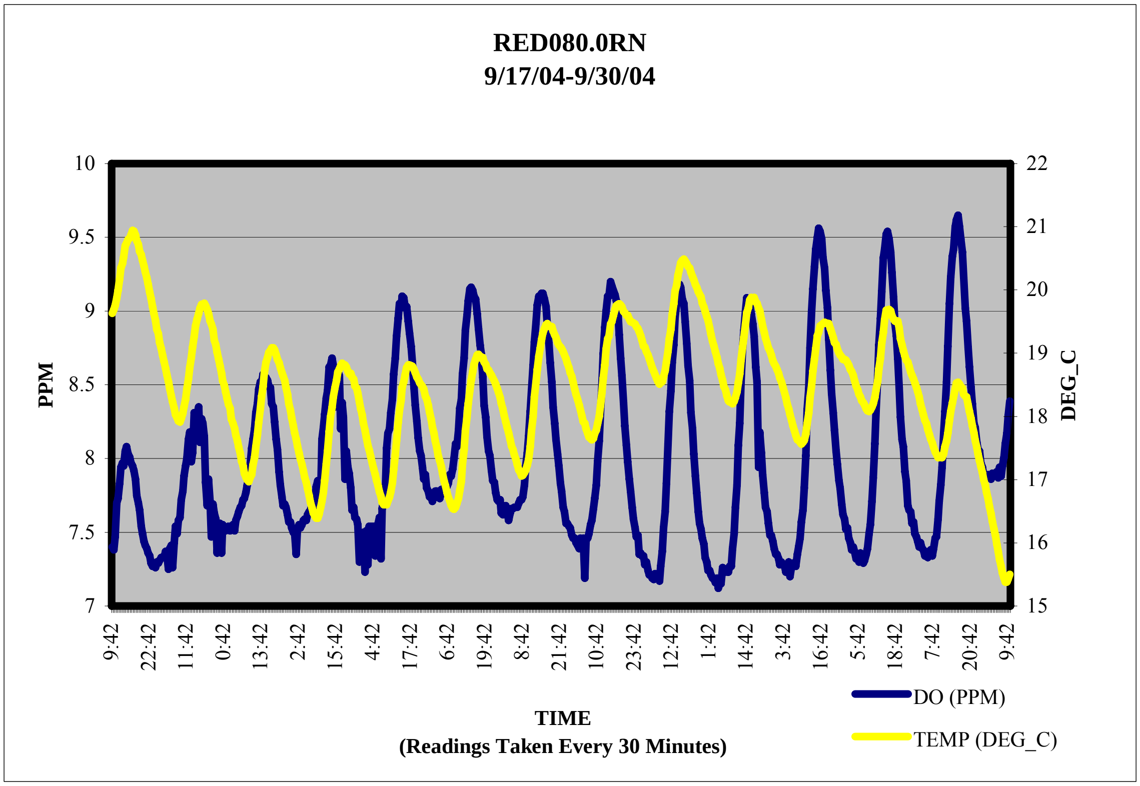
9:13
23:13
13:13
3:13
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


RED080.0RN
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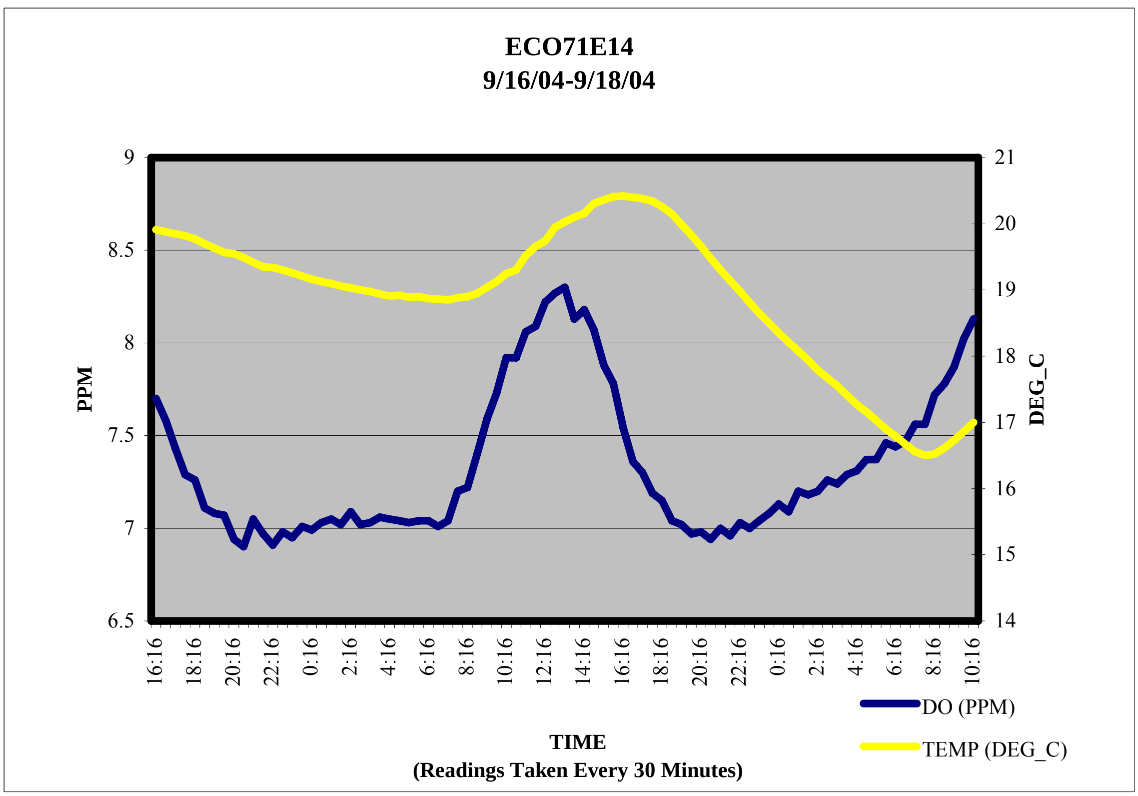
DEG_C
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71E14
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PPM
DEG_C
TIME
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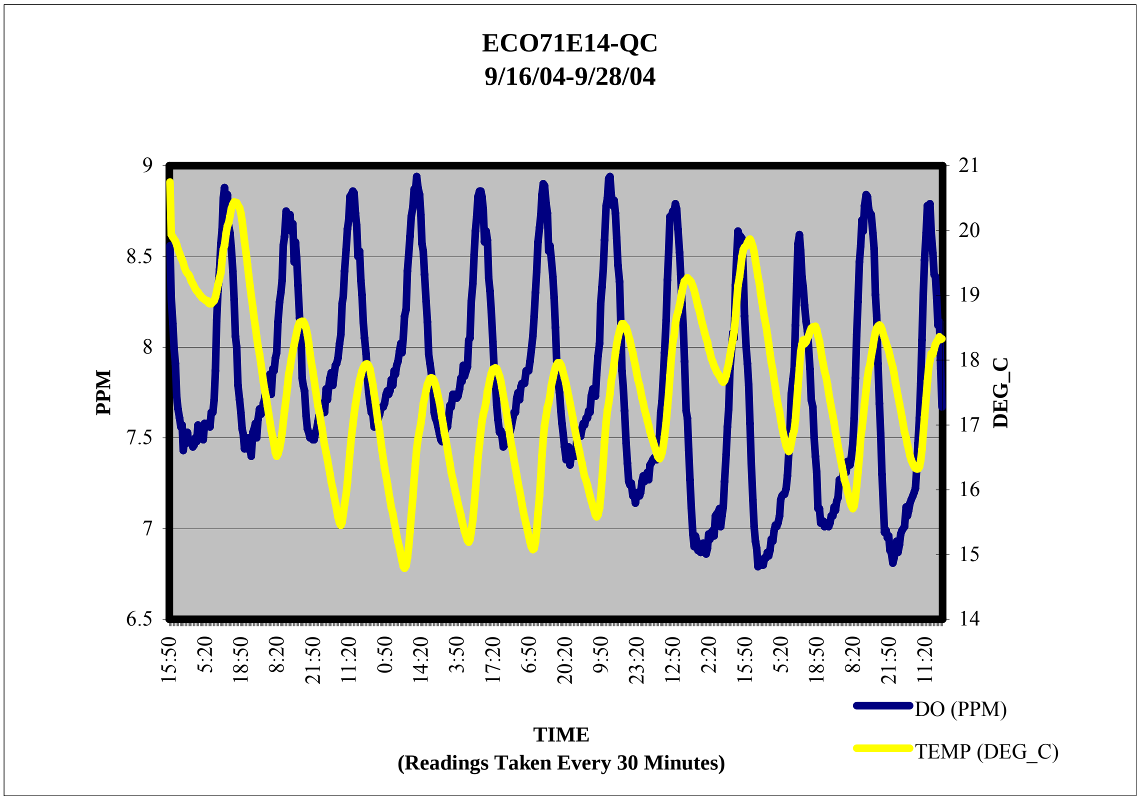
DO (PPM)
TEMP (DEG_C)


ECO71E14-QC
9/16/04-9/28/04
PPM
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8.5
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6.5
DEG_C
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18
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16
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6:50
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9:50
23:20
12:50
2:20
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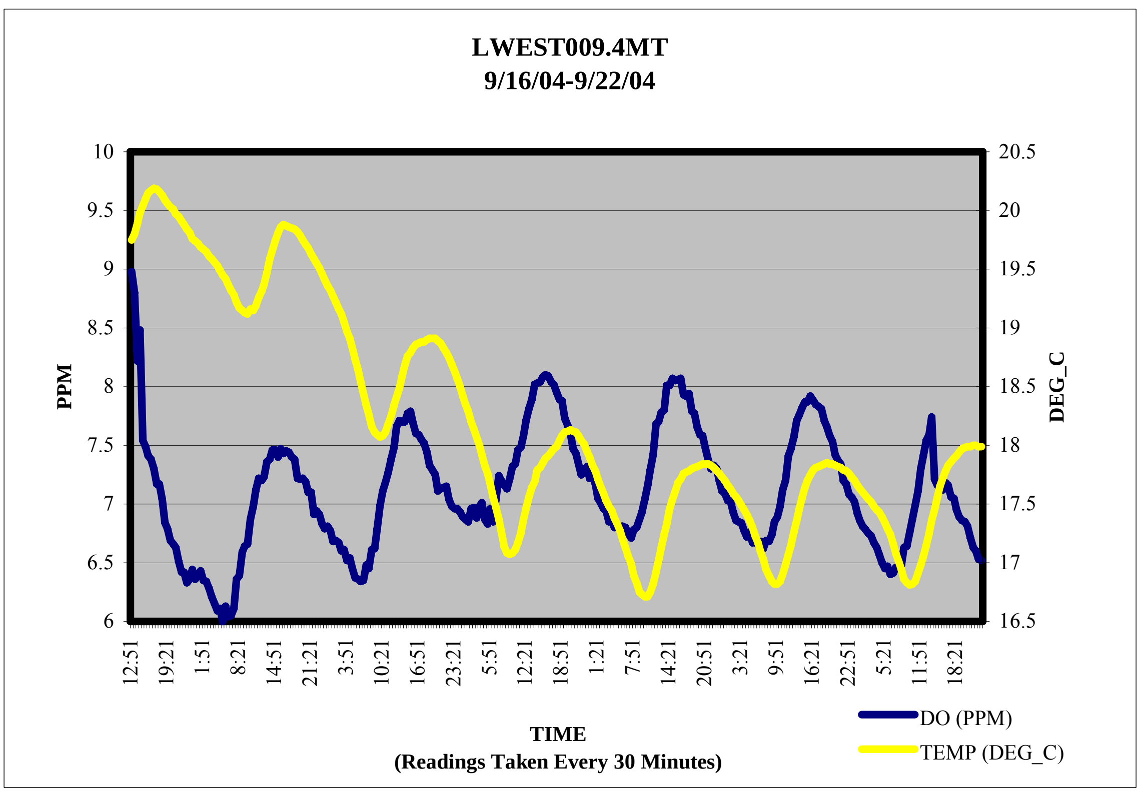
18:50
8:20
21:50
11:20
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


LWEST009.4MT
9/16/04-9/22/04
PPM
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6.5
6
DEG_C
20.5
20
19.5
19
18.5
18
17.5
17
16.5
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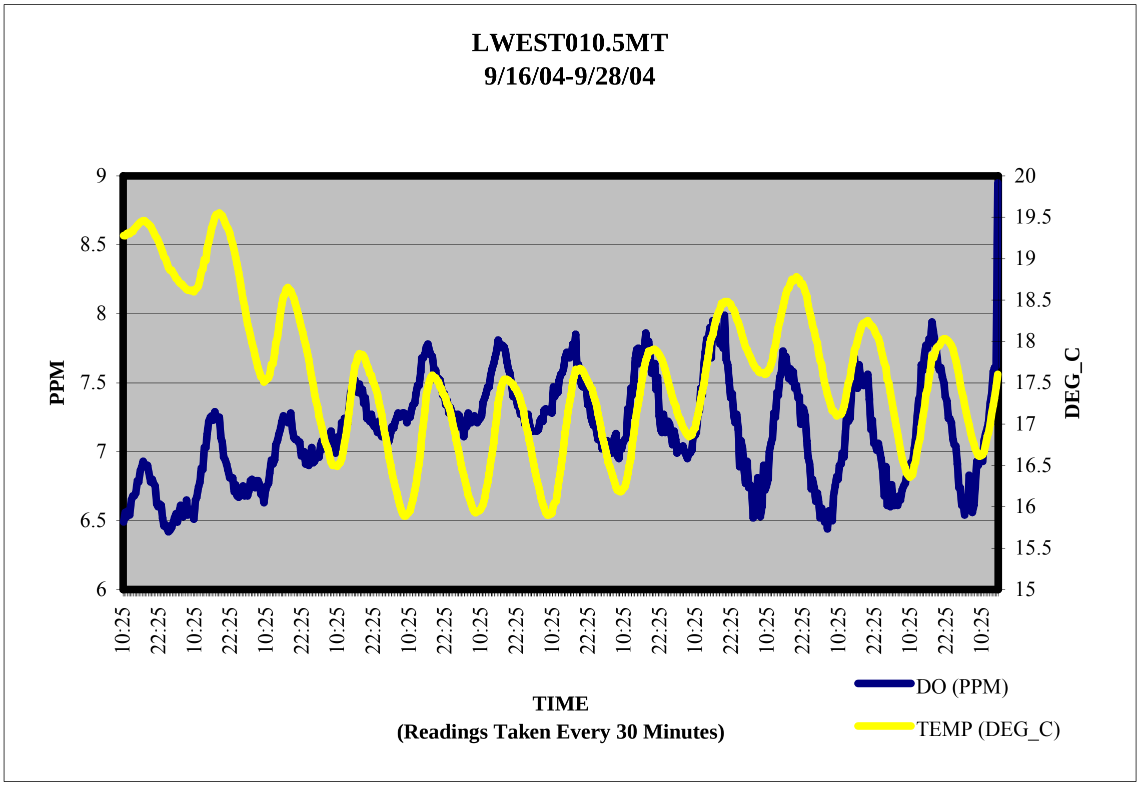
18:51
1:21
7:51
14:21
20:51
3:21
9:51
16:21
22:51
5:21
11:51
18:21
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


LWEST010.5MT
9/16/04-9/28/04
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8.5
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DEG_C
20
19.5
19
18.5
18
17.5
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16.5
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15.5
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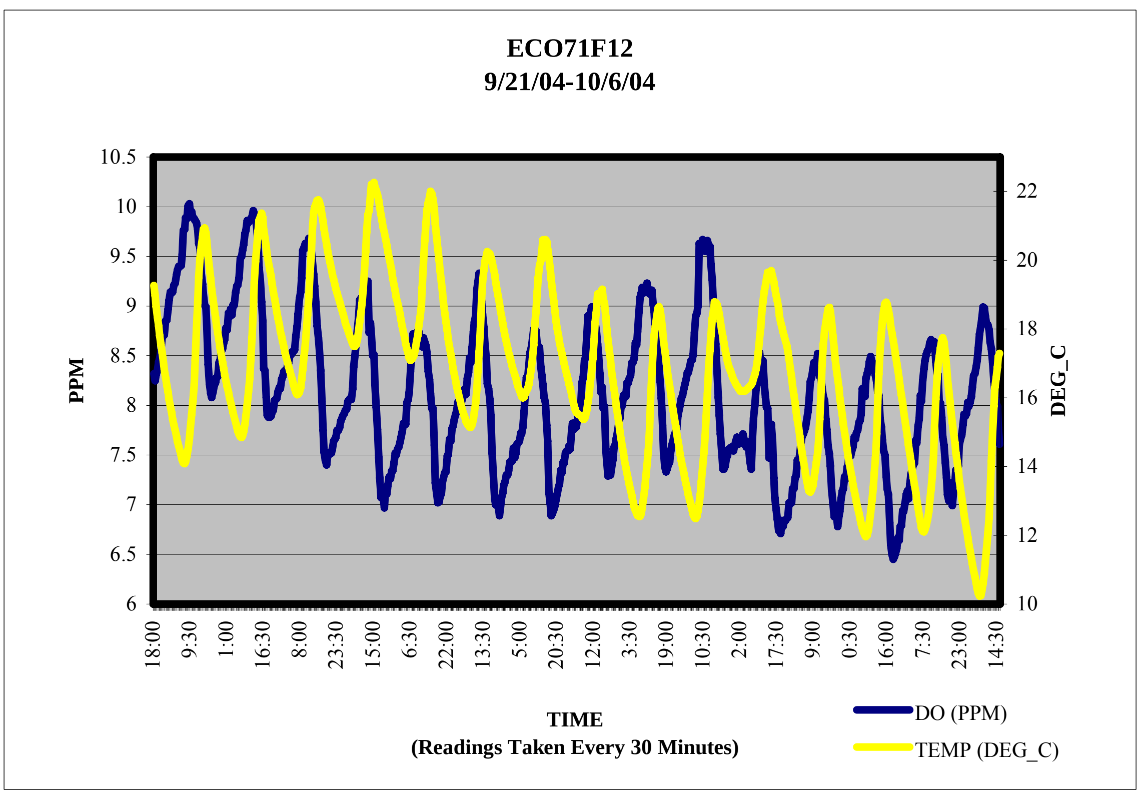
10:25
22:25
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71F12
9/21/04-10/6/04
PPM
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9.5
9
8.5
8
7.5
7
6.5
6
DEG_C
22
20
18
16
14
12
10
18:00
9:30
1:00
16:30
8:00
23:30
15:00
6:30
22:00
13:30
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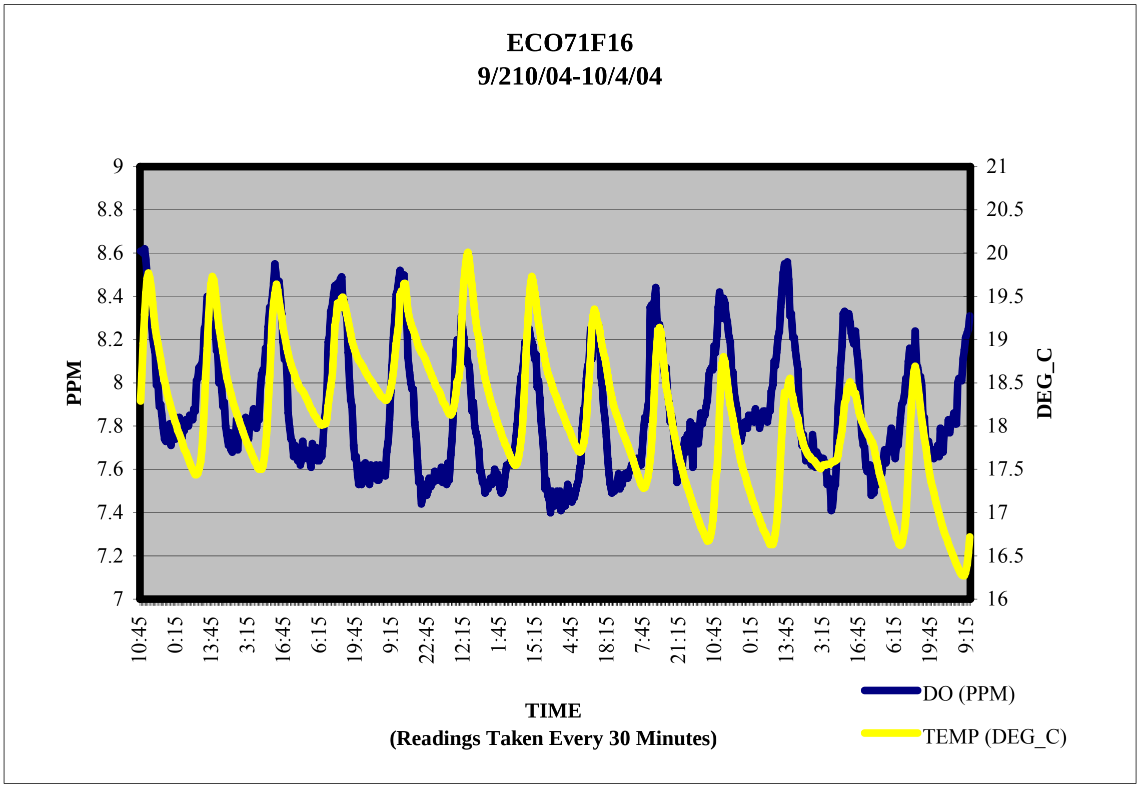
12:00
3:30
19:00
10:30
2:00
17:30
9:00
0:30
16:00
7:30
23:00
14:30
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71F16
9/210/04-10/4/04
PPM
DEG_C
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
10:45
0:15
13:45
3:15
16:45
6:15
19:45
9:15
22:45
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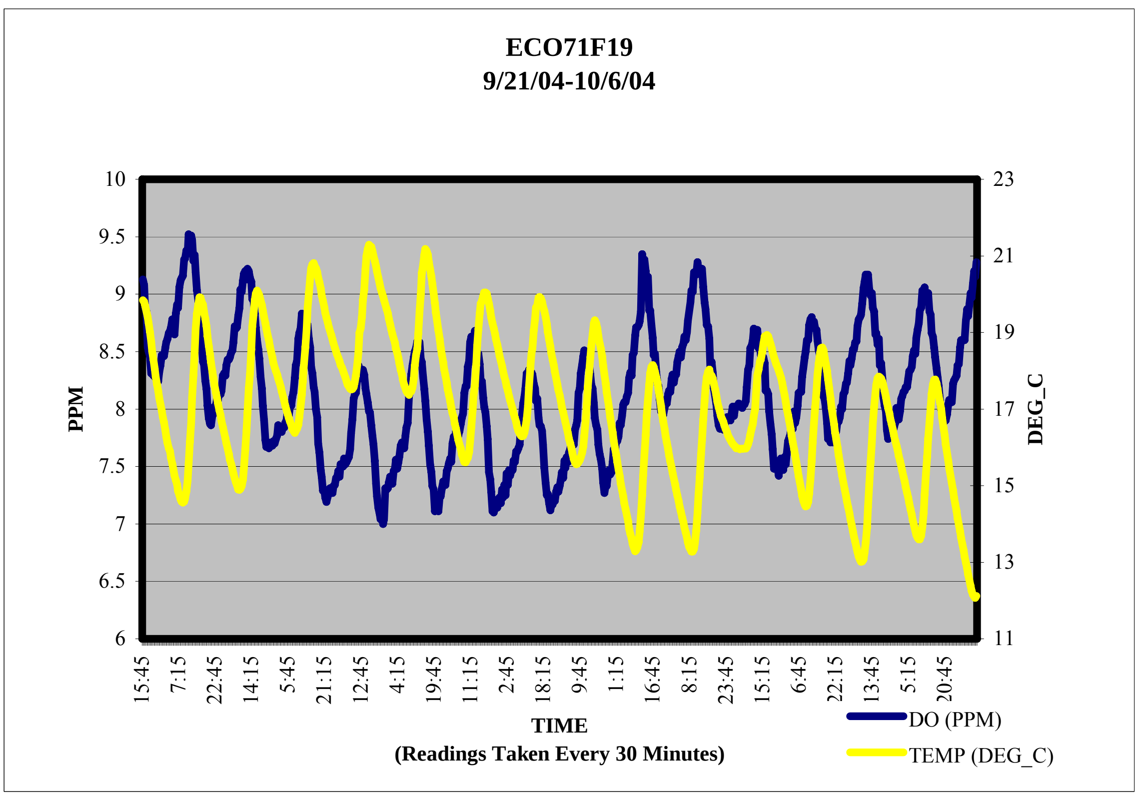
4:45
18:15
7:45
21:15
10:45
0:15
13:45
3:15
16:45
6:15
19:45
9:15
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71F19
9/21/04-10/6/04
PPM
DEG_C
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9.5
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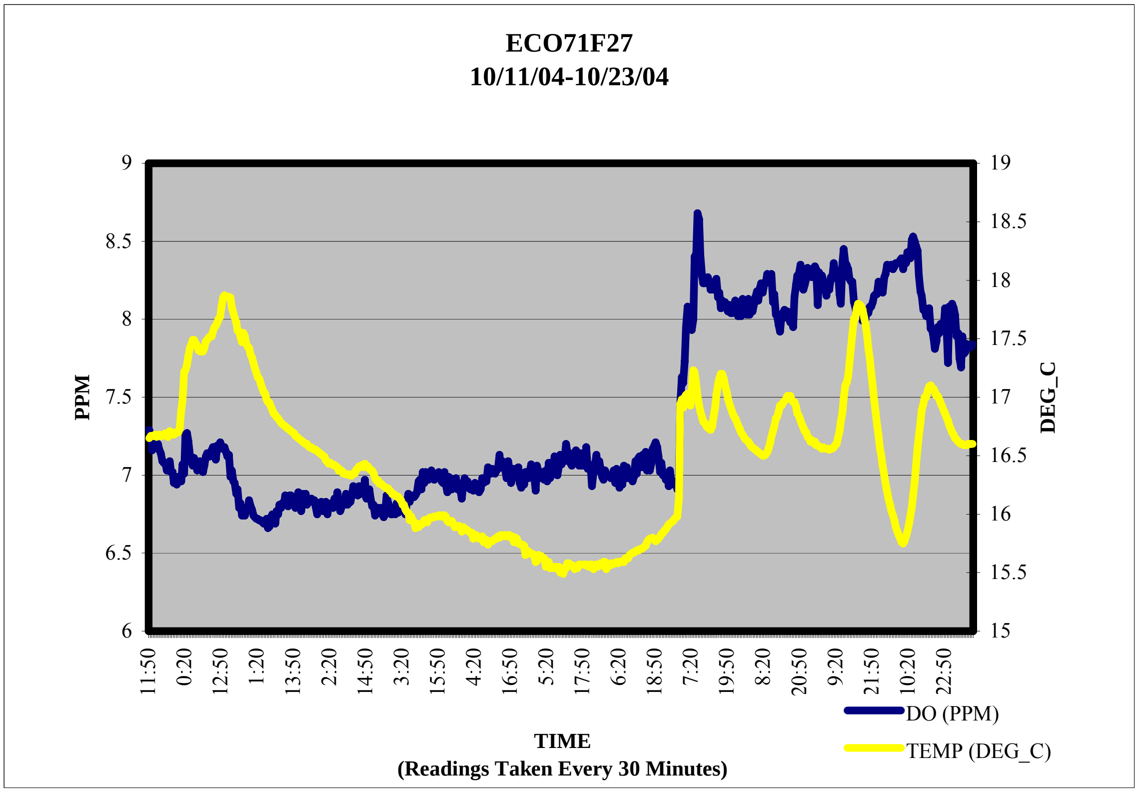
8.5
8
7.5
7
6.5
6
23
21
19
17
15
13
11
15:45
7:15
22:45
14:15
5:45
21:15
12:45
4:15
19:45
11:15
2:45
18:15
9:45
1:15
16:45
8:15
23:45
15:15
6:45
22:15
13:45
5:15
20:45
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71F27
10/11/04-10/23/04
PPM
DEG_C
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8.5
8
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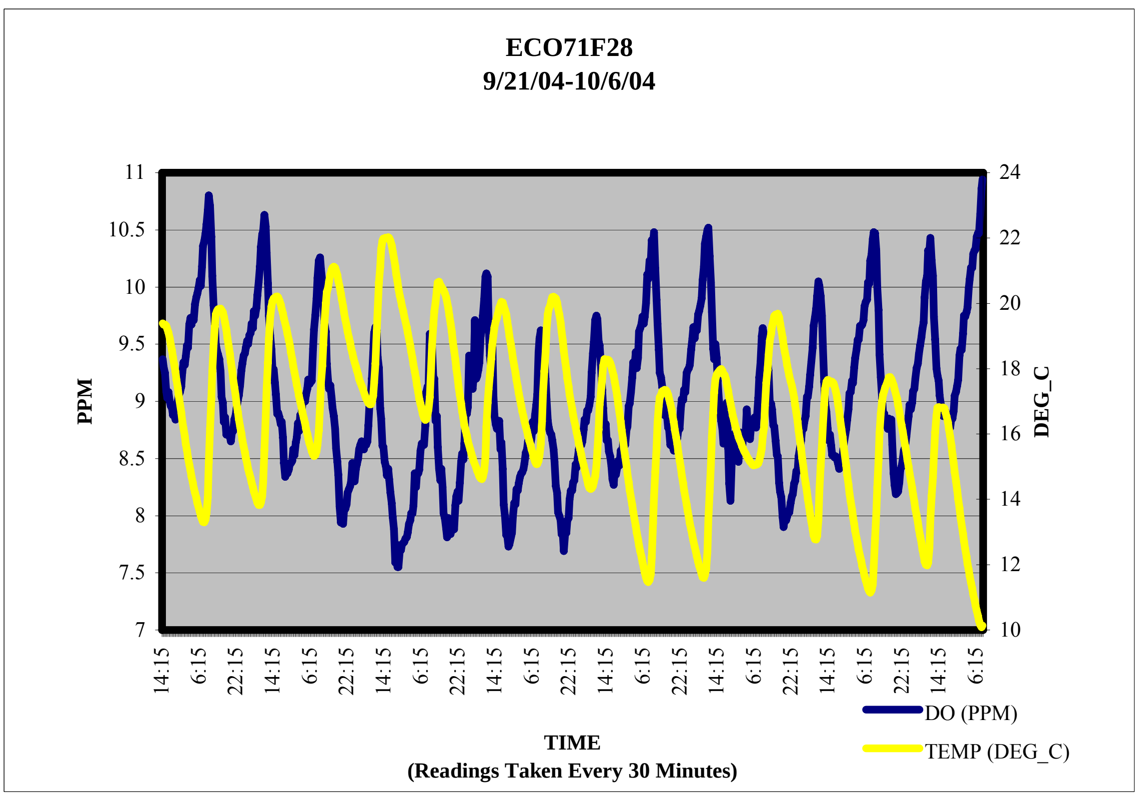
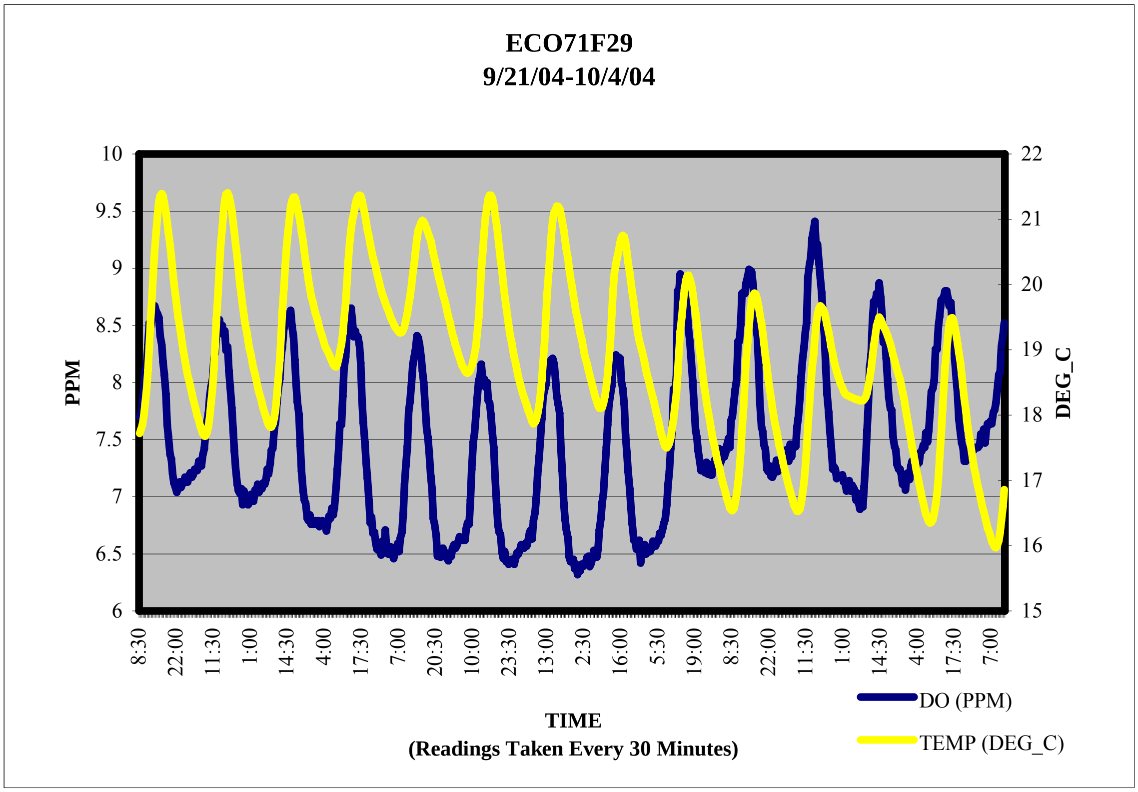
7
6.5
6
19
18.5
18
17.5
17
16.5
16
15.5
15
11:50
0:20
12:50
1:20
13:50
2:20
14:50
3:20
15:50
4:20
16:50
5:20
17:50
6:20
18:50
7:20
19:50
8:20
20:50
9:20
21:50
10:20
22:50
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71F28
9/21/04-10/6/04
PPM
DEG_C
11
10.5
10
9.5
9
8.5
8
7.5
7
24
22
20
18
16
14
12
10
14:15
6:15
22:15
14:15
6:15
22:15
14:15
6:15
22:15
14:15
6:15
22:15
14:15
6:15
22:15
14:15
6:15
22:15
14:15
6:15
22:15
14:15
6:15
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71F29
9/21/04-10/4/04
PPM
DEG_C
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9.5
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8.5
8
7.5
7
6.5
6
22
21
20
19
18
17
16
15
8:30
22:00
11:30
1:00
14:30
4:00
17:30
7:00
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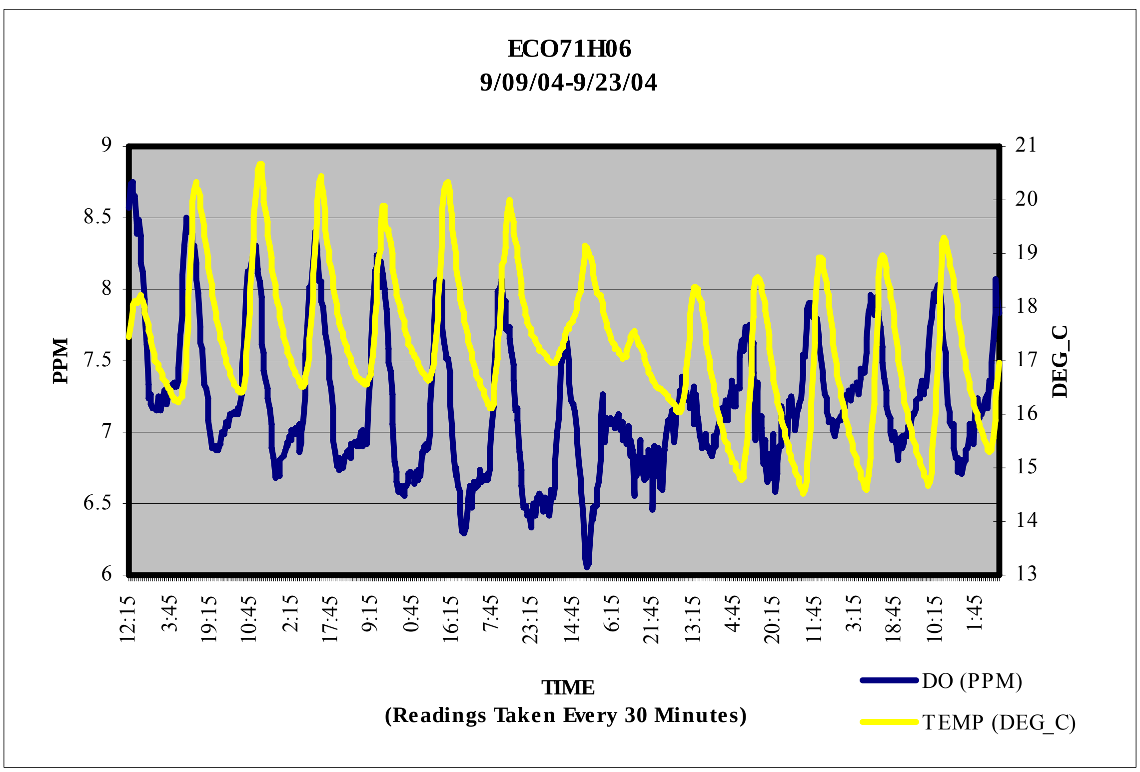
13:00
2:30
16:00
5:30
19:00
8:30
22:00
11:30
1:00
14:30
4:00
17:30
7:00
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71H06
9/09/04-9/23/04
PPM
DEG_C
9
8.5
8
7.5
7
6.5
6
21
20
19
18
17
16
15
14
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12:15
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23:15
14:45
6:15
21:45
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4:45
20:15
11:45
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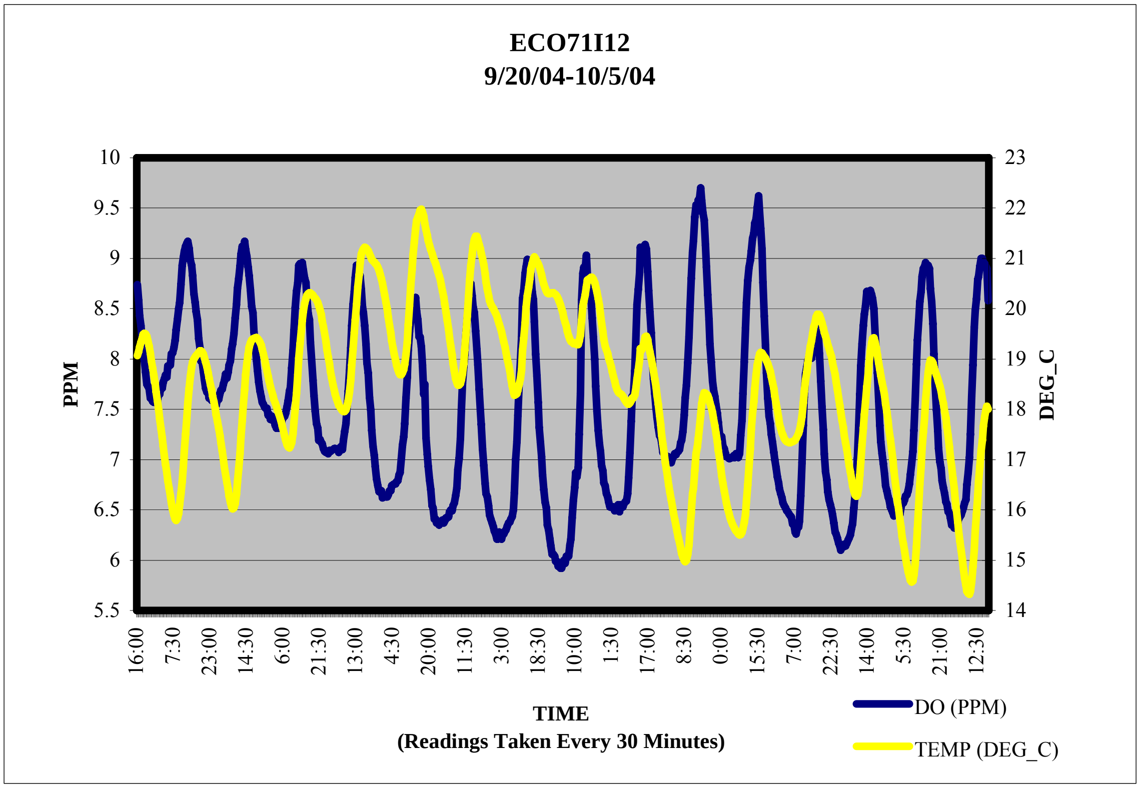
18:45
10:15
1:45
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71I12
9/20/04-10/5/04
PPM
DEG_C
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9.5
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8.5
8
7.5
7
6.5
6
5.5
23
22
21
20
19
18
17
16
15
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16:00
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10:00
1:30
17:00
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15:30
7:00
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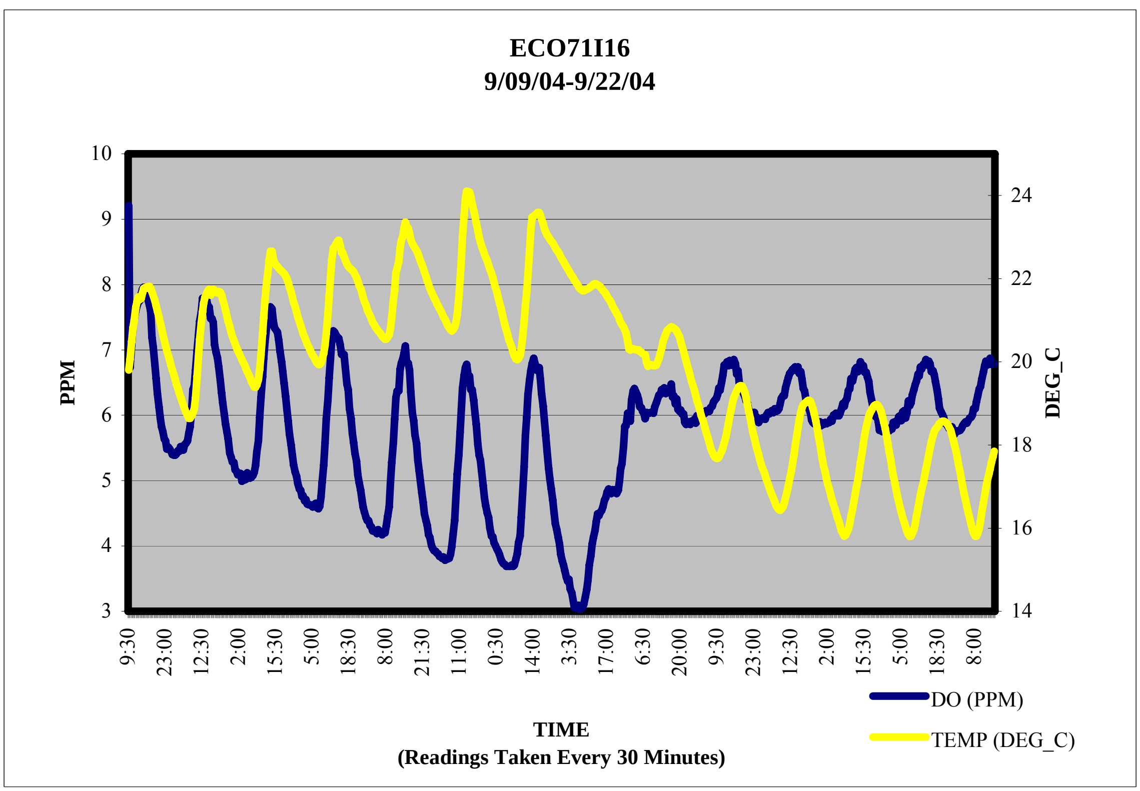
12:30
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71I16
9/09/04-9/22/04
PPM
DEG_C
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9
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7
6
5
4
3
24
22
20
18
16
14
9:30
23:00
12:30
2:00
15:30
5:00
18:30
8:00
21:30
11:00
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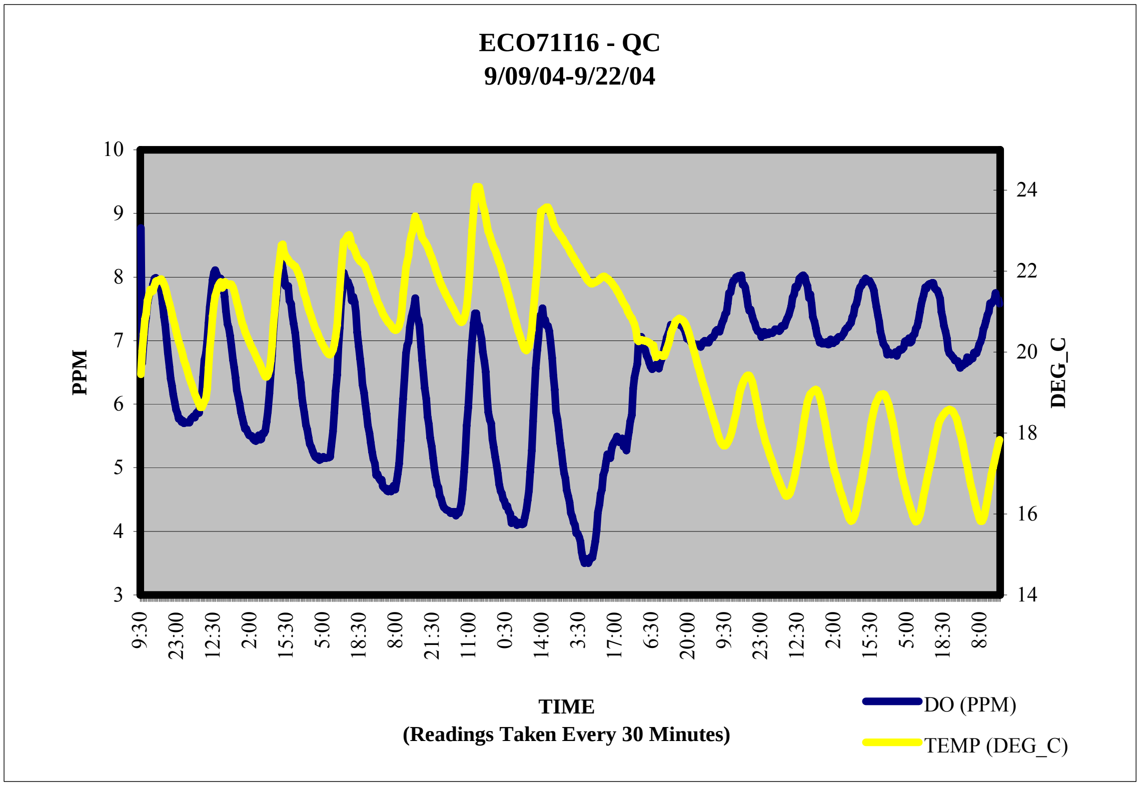
3:30
17:00
6:30
20:00
9:30
23:00
12:30
2:00
15:30
5:00
18:30
8:00
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


ECO71I16 - QC
9/09/04-9/22/04
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DEG_C
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6
5
4
3
24
22
20
18
16
14
9:30
23:00
12:30
2:00
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18:30
8:00
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3:30
17:00
6:30
20:00
9:30
23:00
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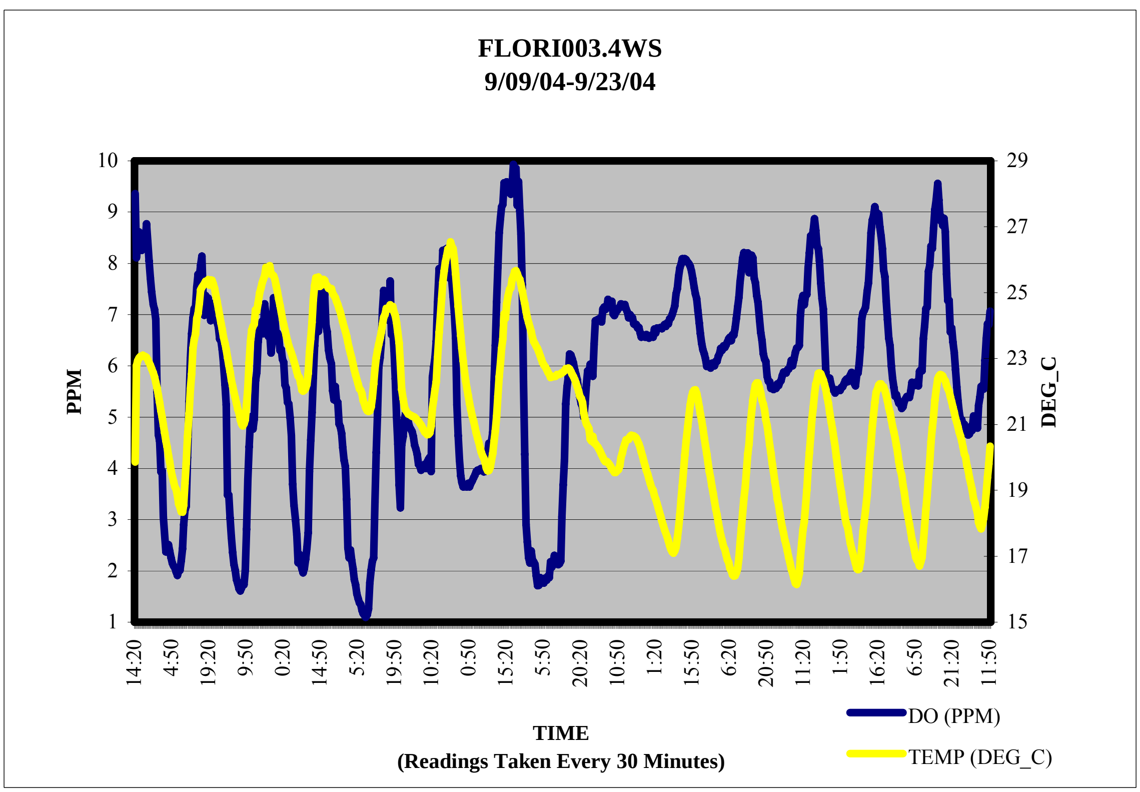
15:30
5:00
18:30
8:00
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)


FLORI003.4WS
9/09/04-9/23/04
PPM
DEG_C
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6
5
4
3
2
1
29
27
25
23
21
19
17
15
14:20
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20:20
10:50
1:20
15:50
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20:50
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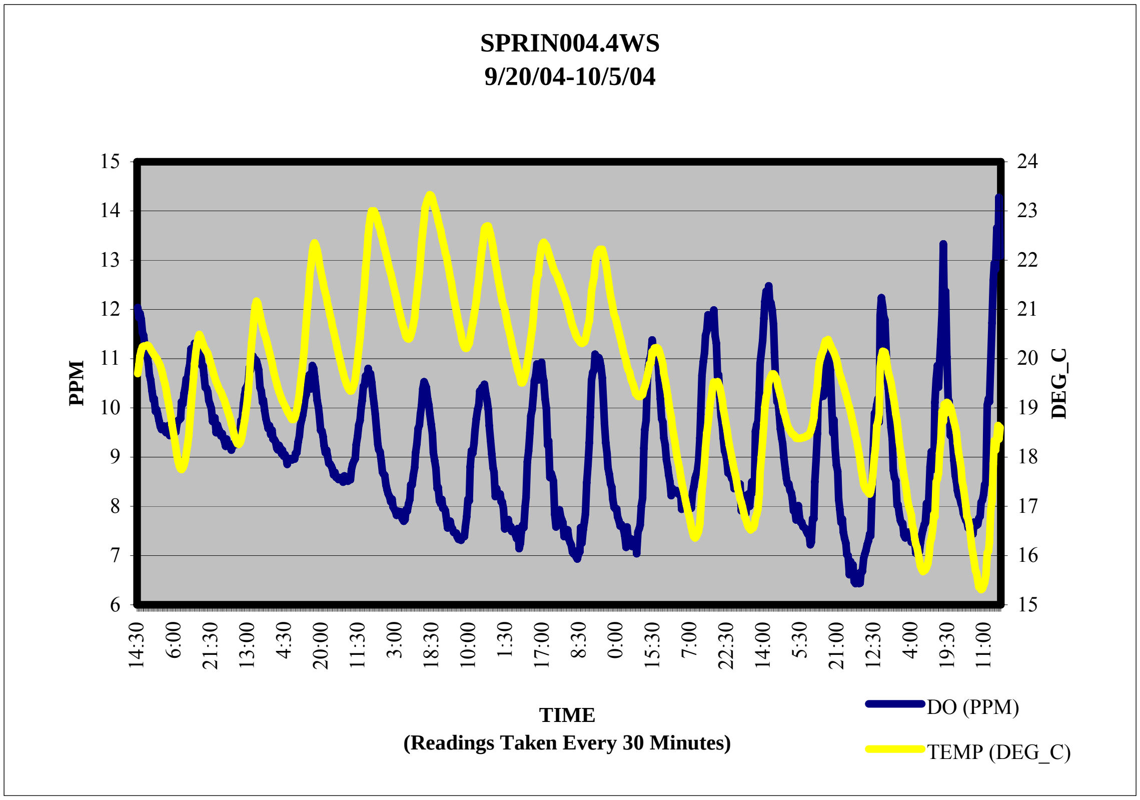
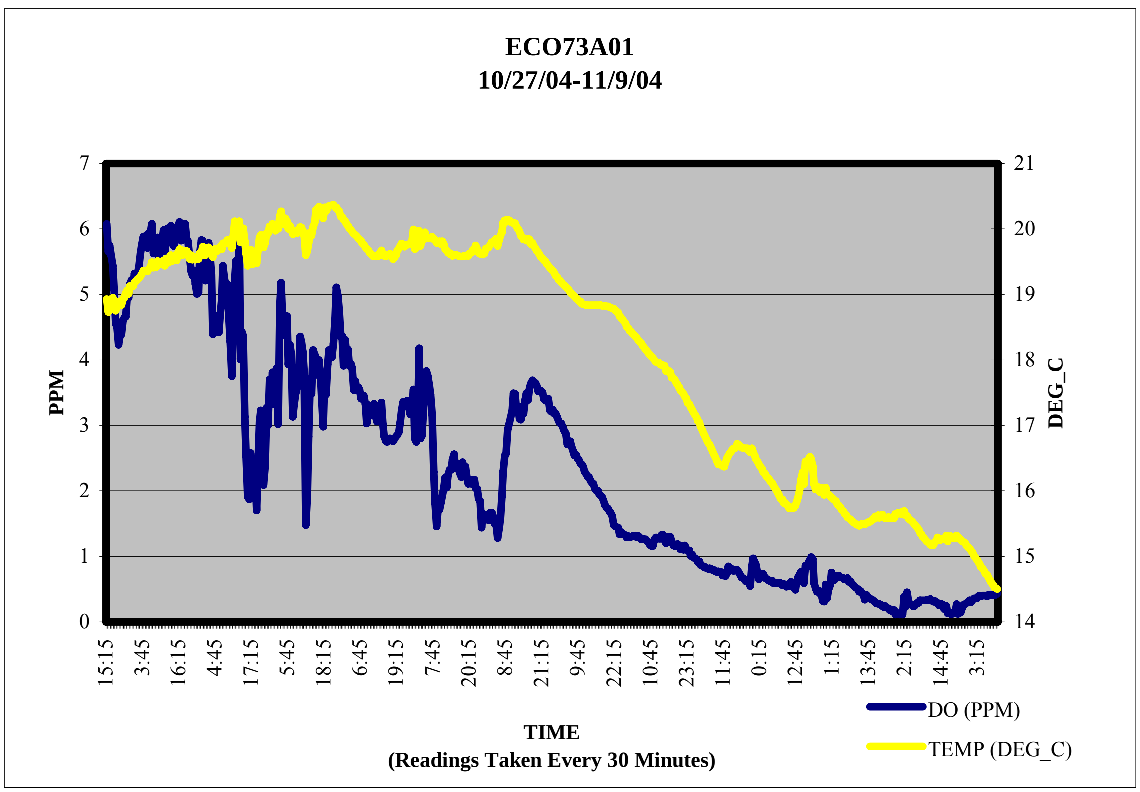
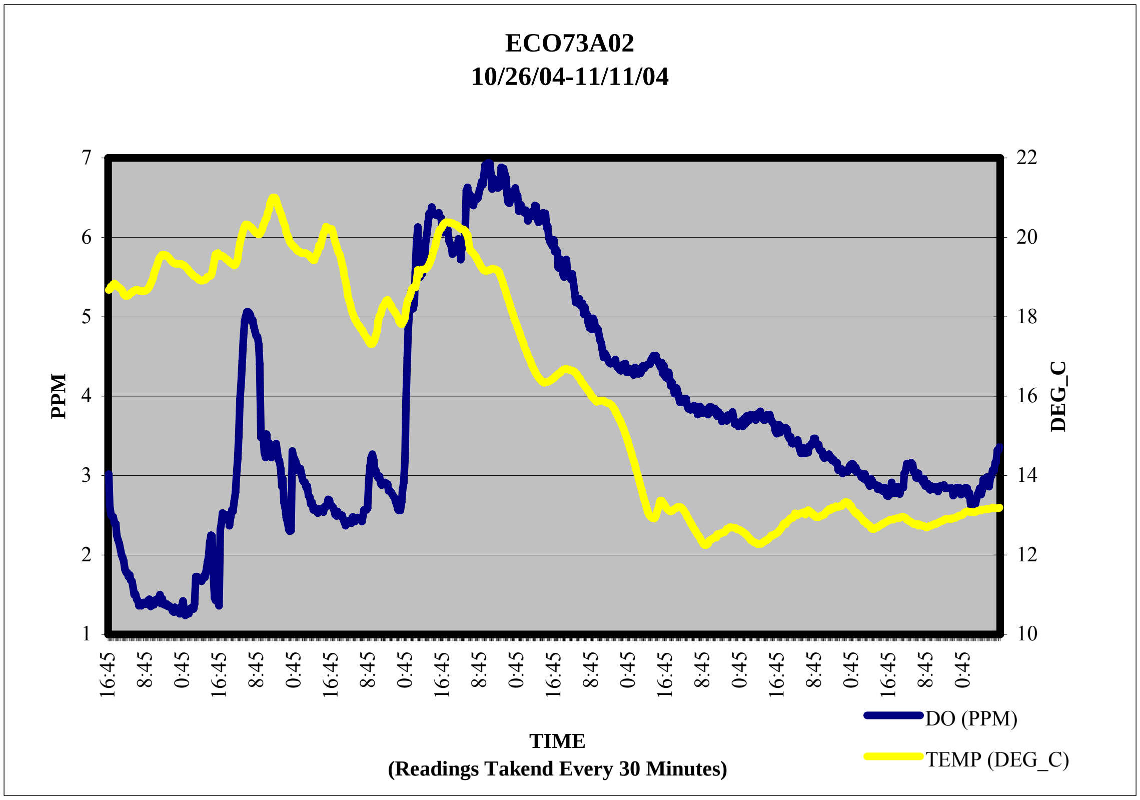
6:50
21:20
11:50
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)



ECOREGION 73A





ECO73A02
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1
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16:45
8:45
0:45
16:45
8:45
0:45
16:45
8:45
0:45
16:45
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16:45
8:45
0:45
16:45
8:45
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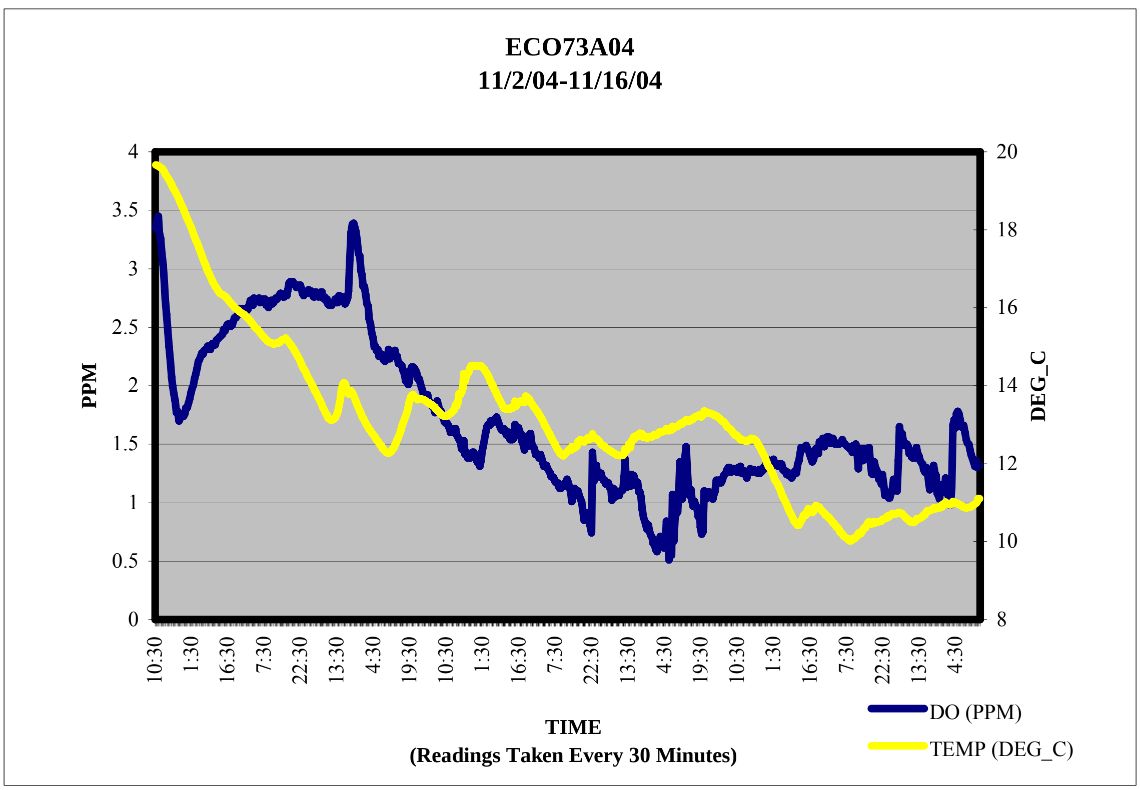
16:45
8:45
0:45
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Takend Every 30 Minutes)



ECO73A04
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PPM
DEG_C
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3
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2
1.5
1
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0
20
18
16
14
12
10
8
10:30
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16:30
7:30
22:30
13:30
4:30
19:30
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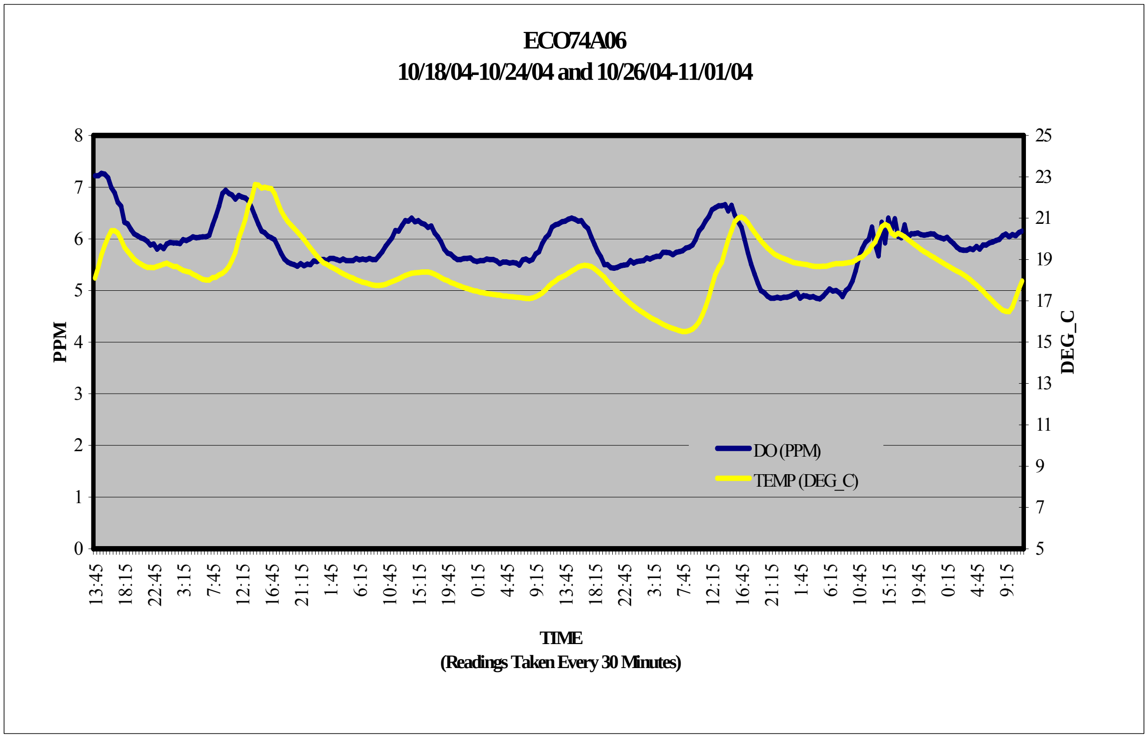
7:30
22:30
13:30
4:30
19:30
10:30
1:30
16:30
7:30
22:30
13:30
4:30
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)



ECO74A06
10/18/04-10/24/04 and 10/26/04-11/01/04
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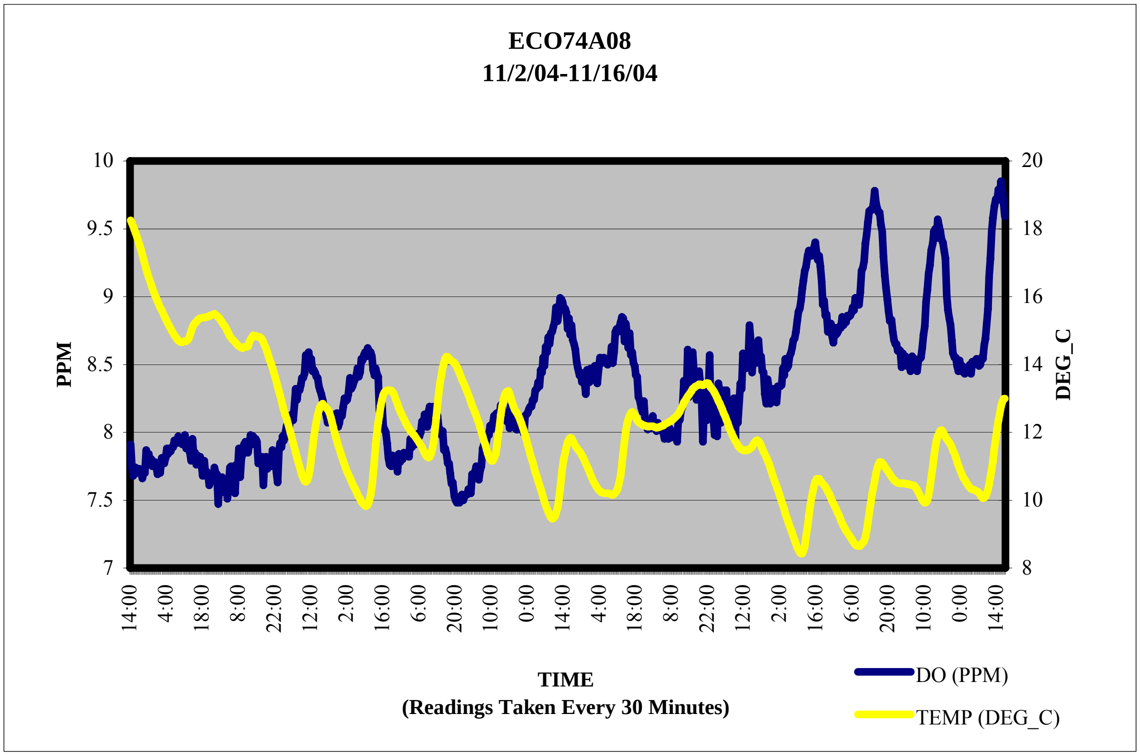
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)



ECO74A08
11/2/04-11/16/04
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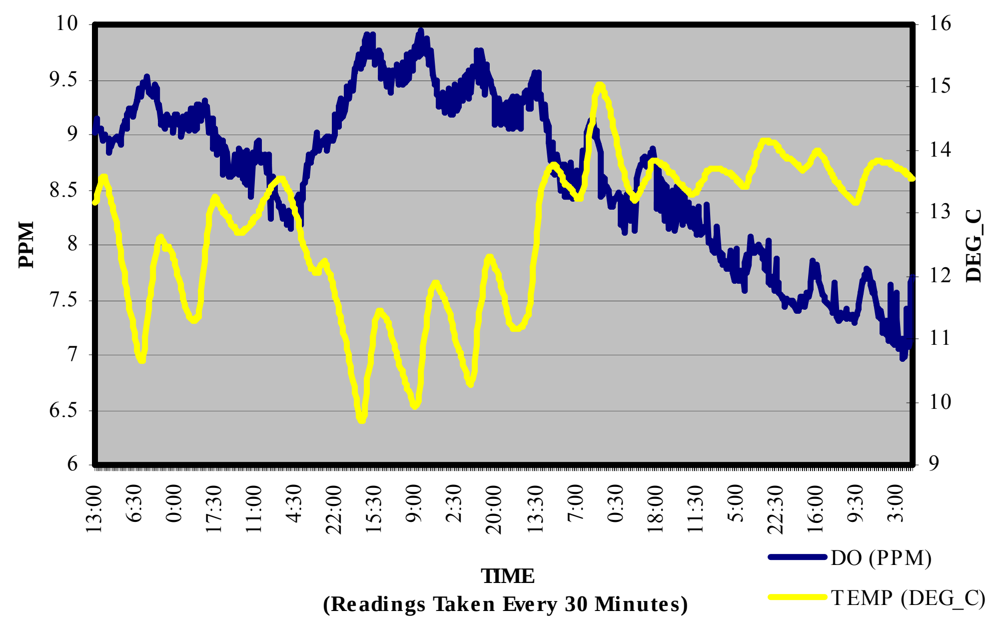
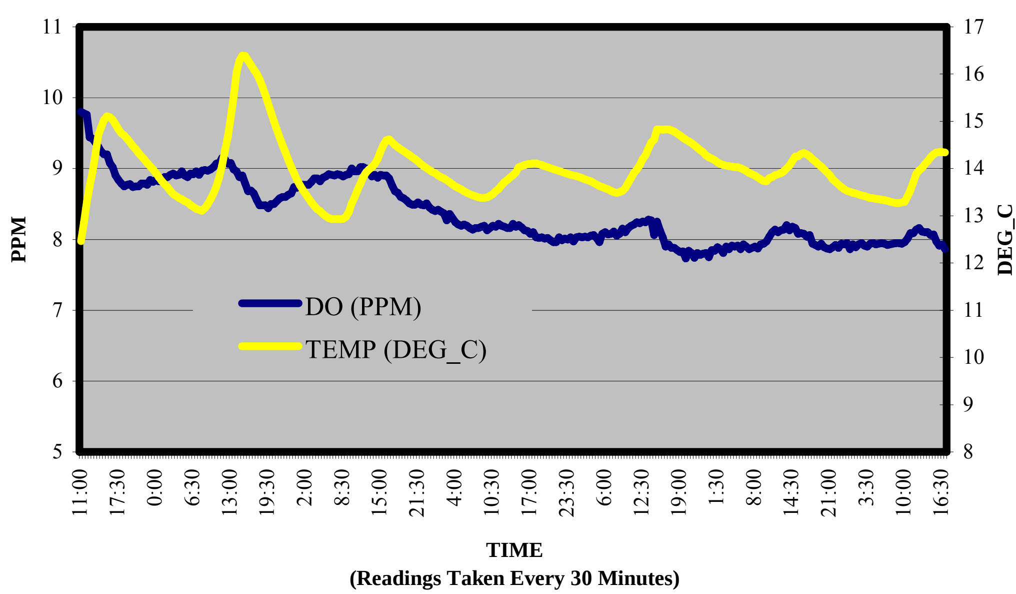
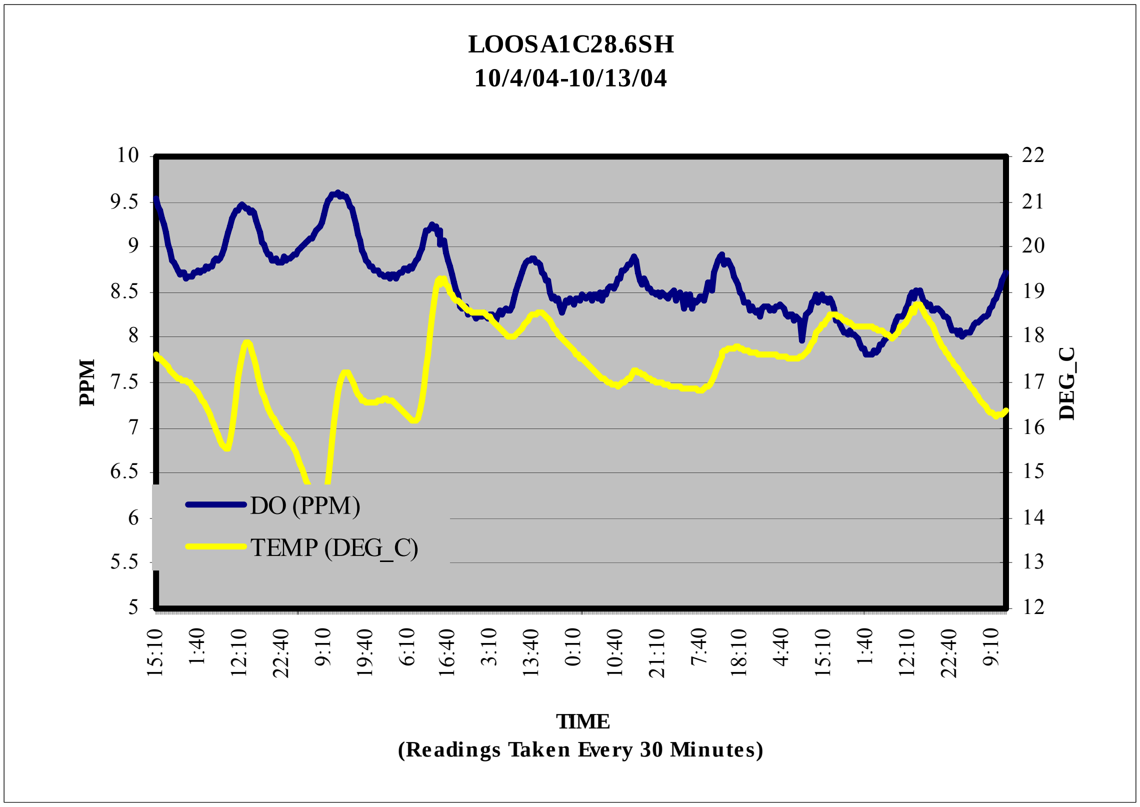
TIME
(Readings Taken Every 30 Minutes)
DO (PPM)
TEMP (DEG_C)

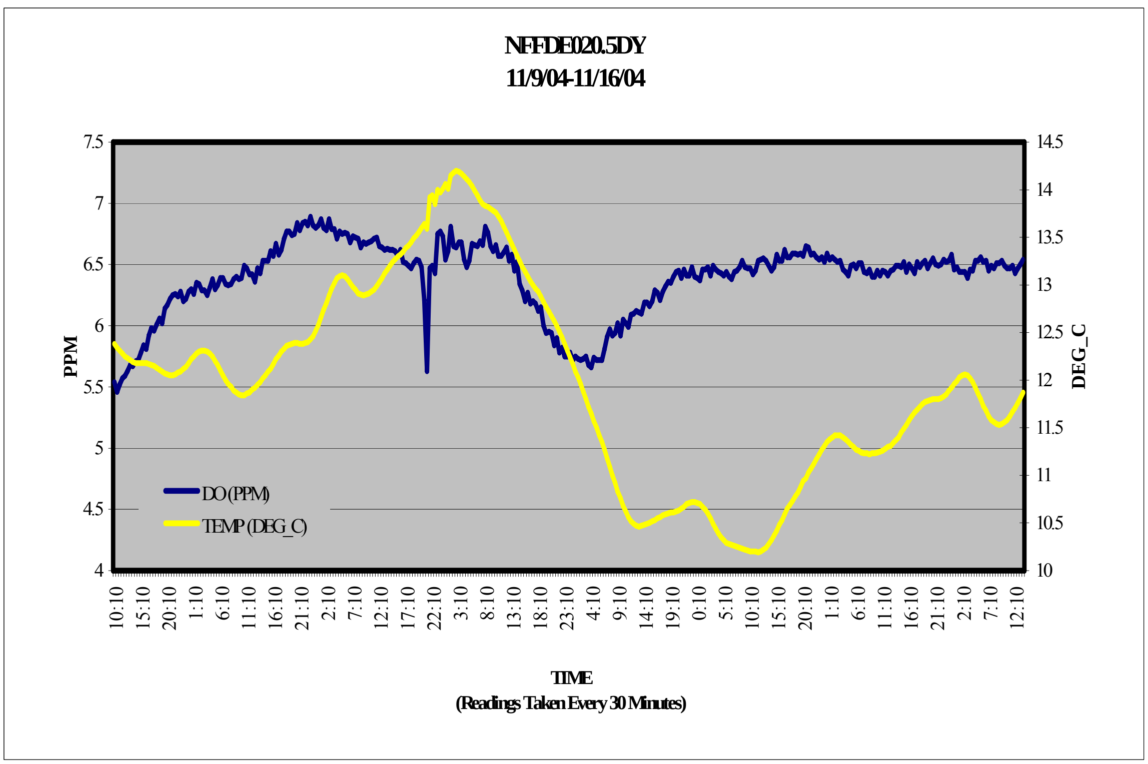
ECO74B01
11/8/04-11/23/04



ECO74B04
11/16/04-11/22/04




LOOSA1C28.6SH
10/4/04-10/13/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)


NFFDE020.5DY
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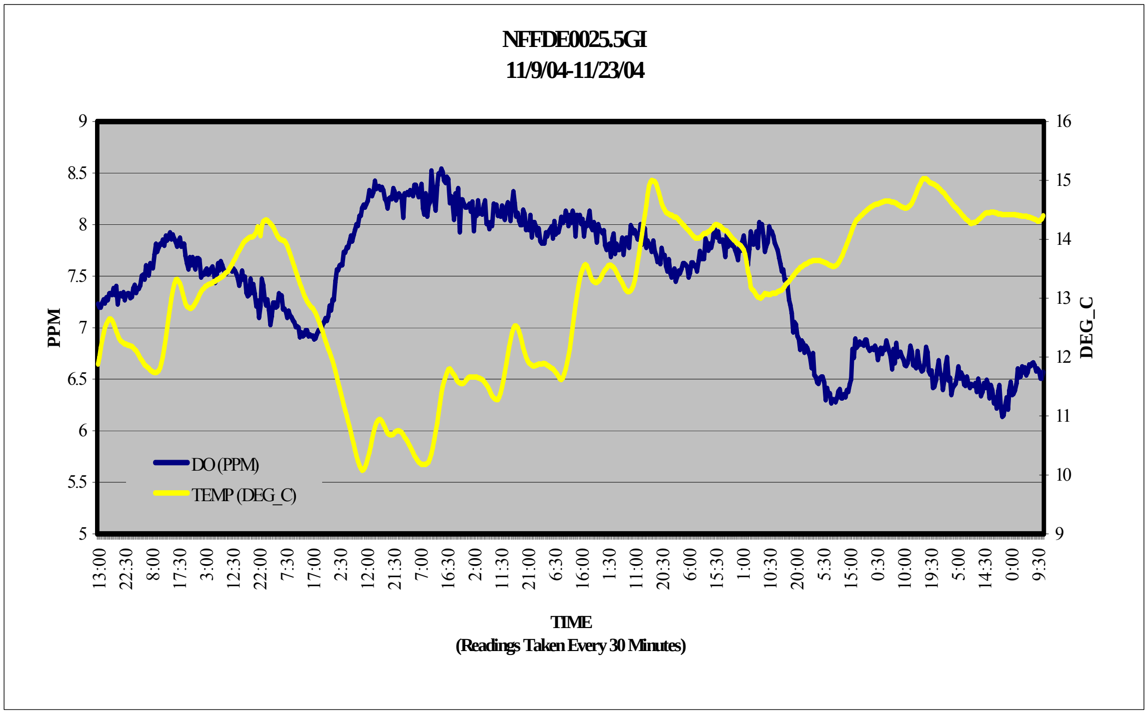
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)


NFFDE0025.5GI
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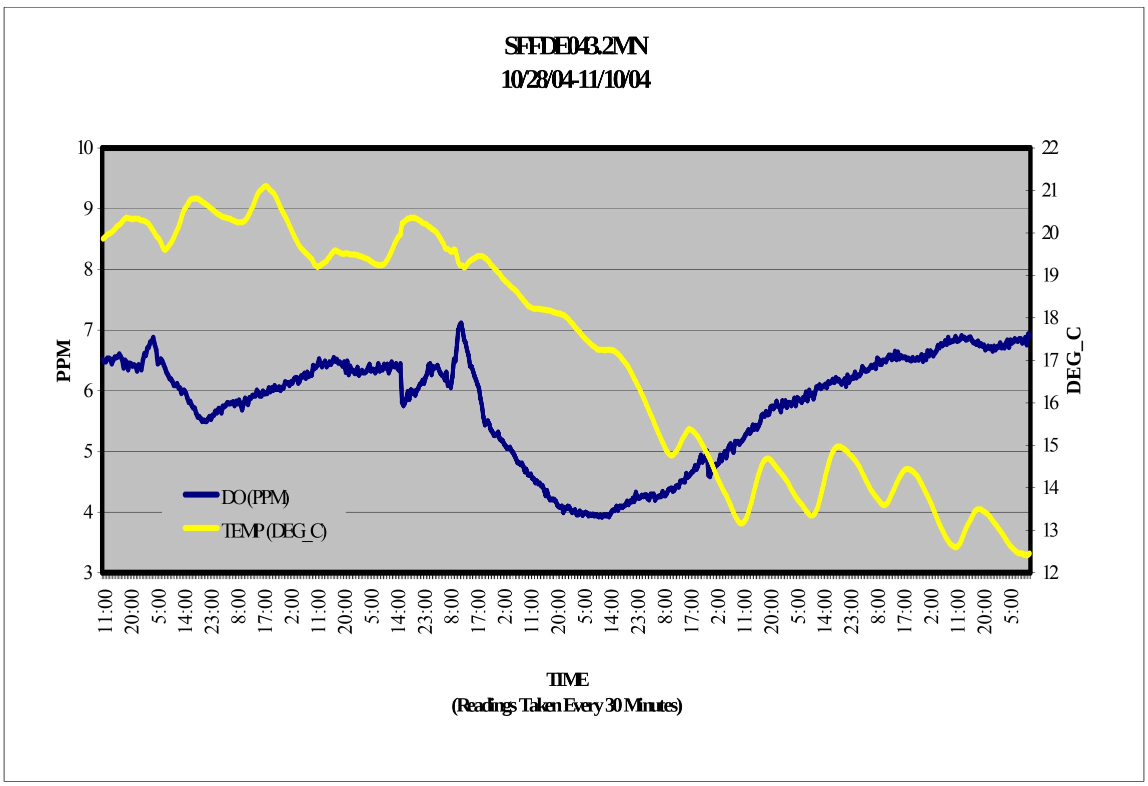
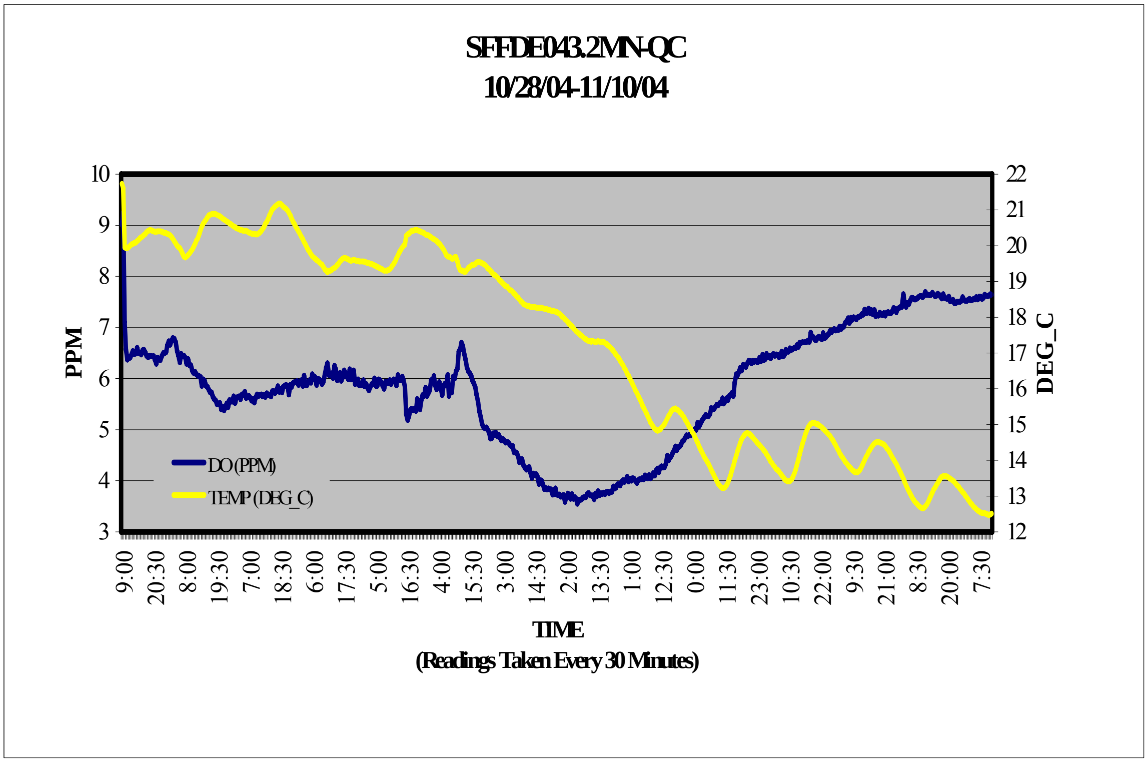
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)


SFFDE043.2MN
10/28/04-11/10/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)


SFFDE043.2MN-QC
10/28/04-11/10/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
9:00
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8:00
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6:00
17:30
5:00
16:30
4:00
15:30
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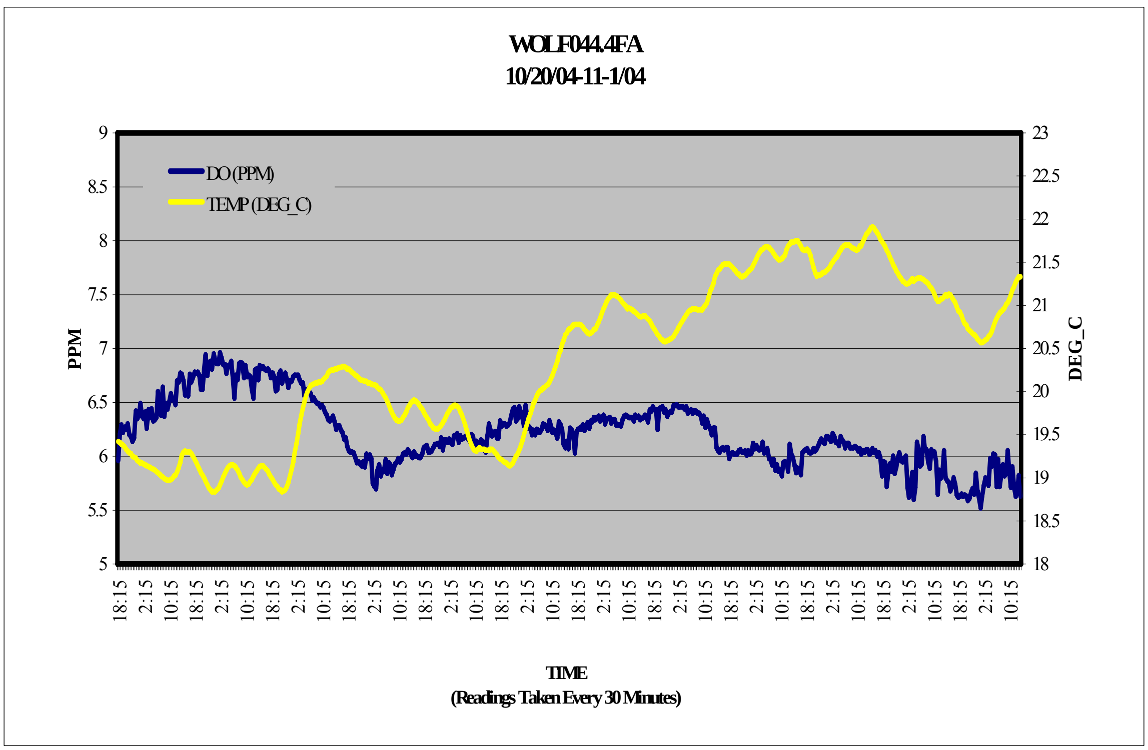
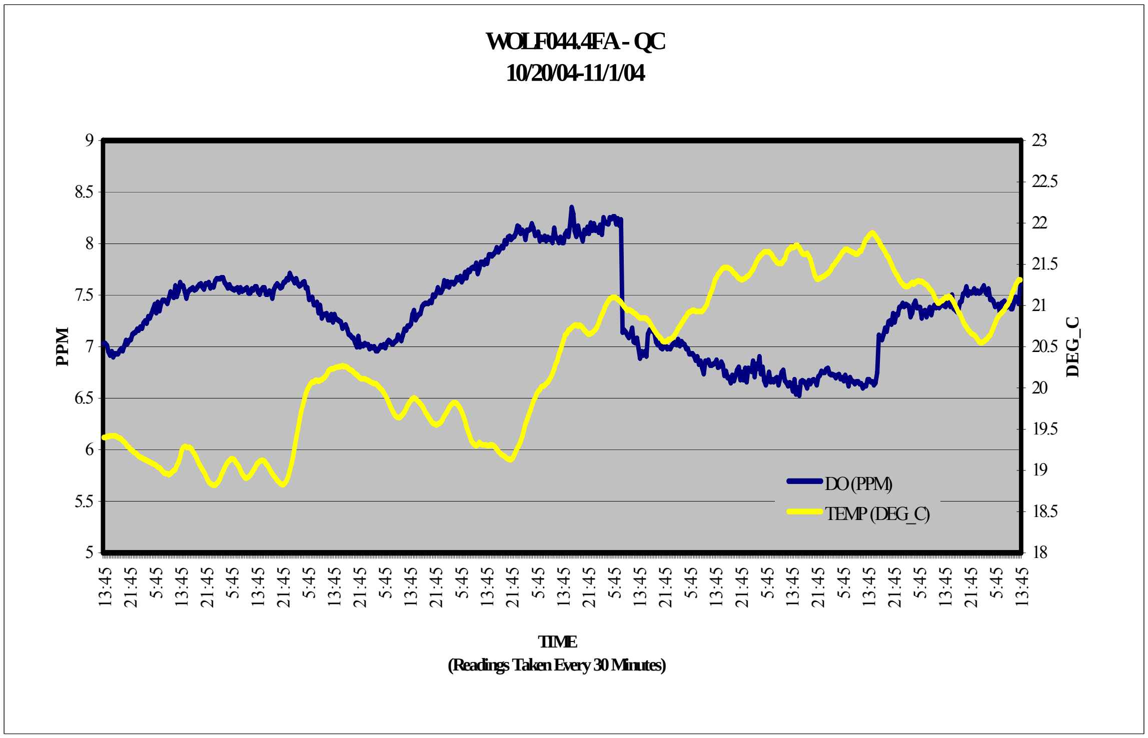
1:00
12:30
0:00
11:30
23:00
10:30
22:00
9:30
21:00
8:30
20:00
7:30
TIME
(Readings Taken Every 30 Minutes)


WOLF044.4FA
10/20/04-11-1/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)



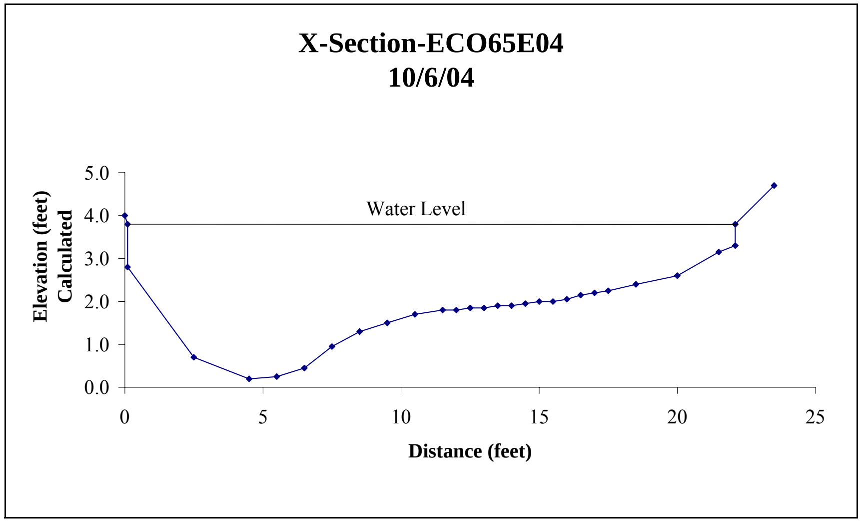
WOLF044.4FA - QC
10/20/04-11/1/04
PPM
DEG_C
DO (PPM)
TEMP (DEG_C)
TIME
(Readings Taken Every 30 Minutes)
9
8.5
8
7.5
7
6.5
6
5.5
5
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
13:45
21:45
5:45

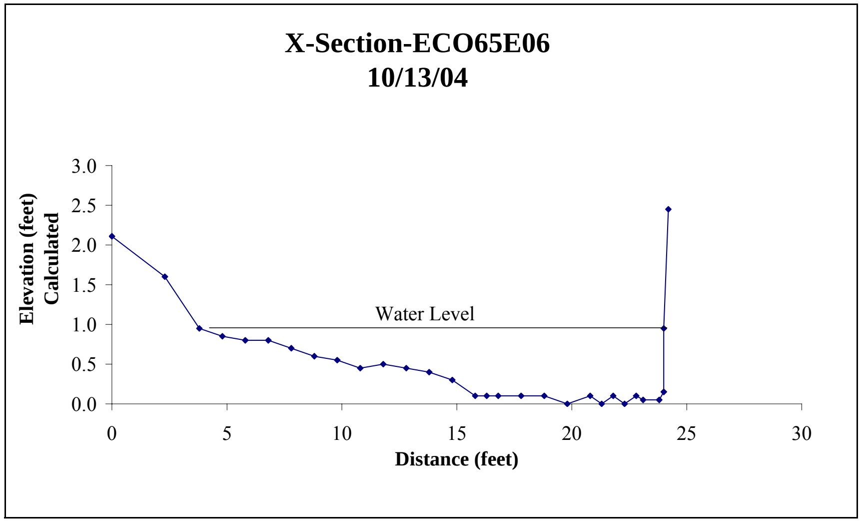
APPENDIX C

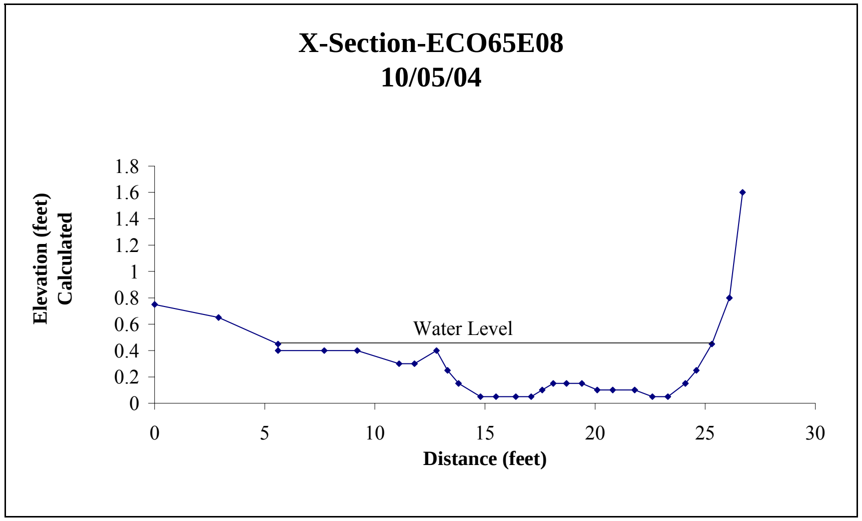
Geomorphological Data

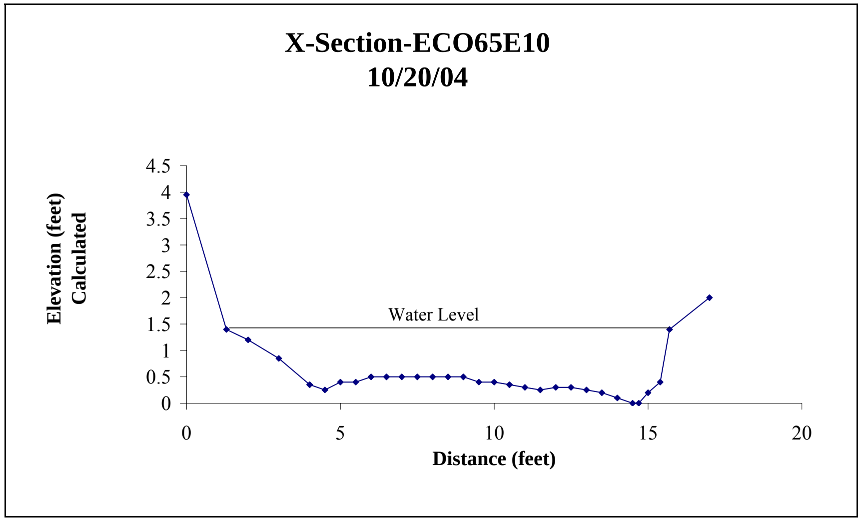
Channel Cross Sections
Particle Counts

ECOREGION 65e









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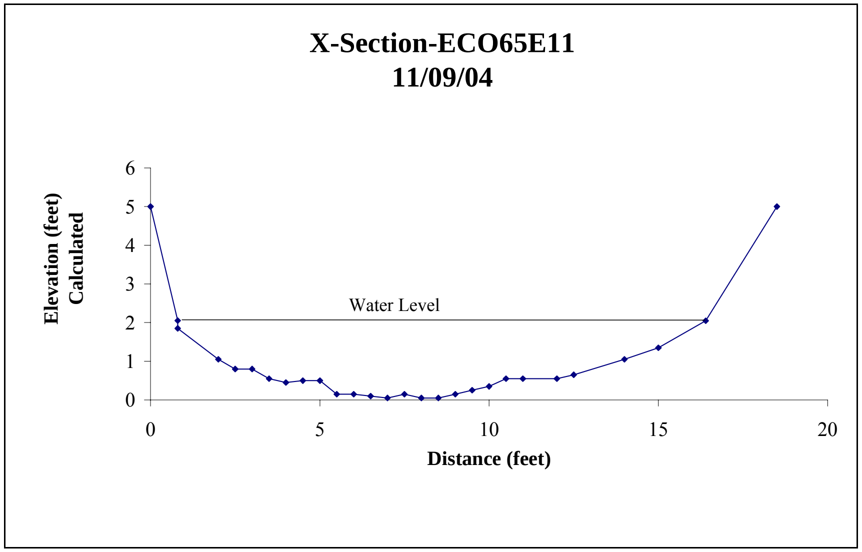
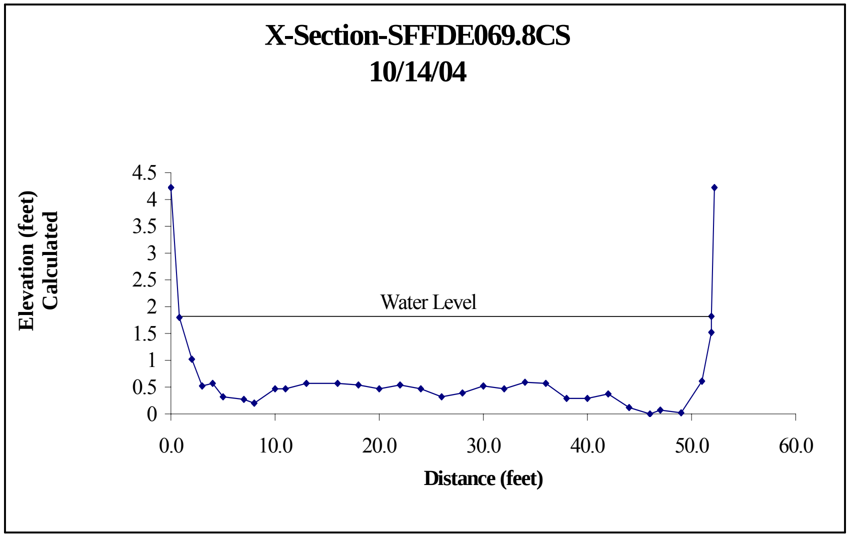
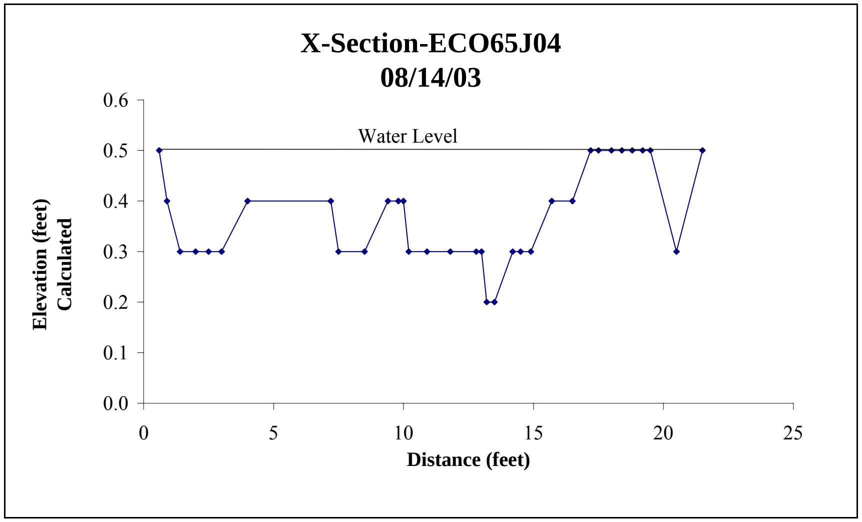
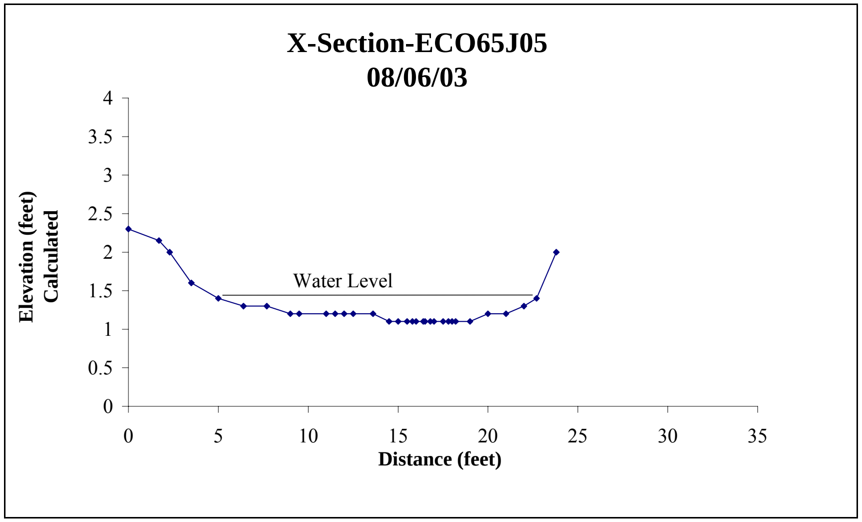




ECOREGION 65J





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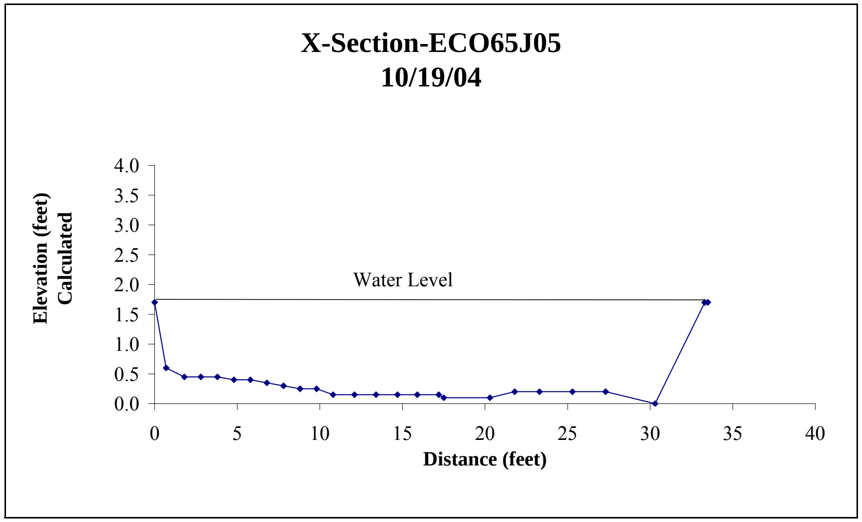

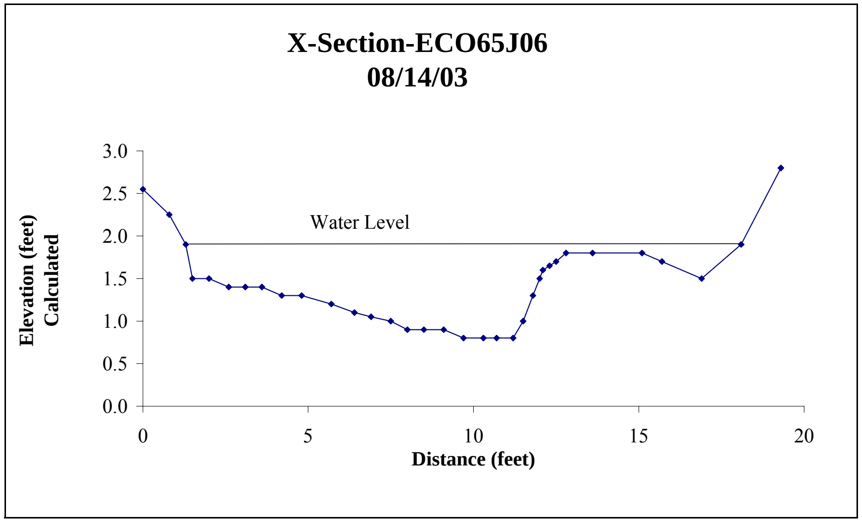

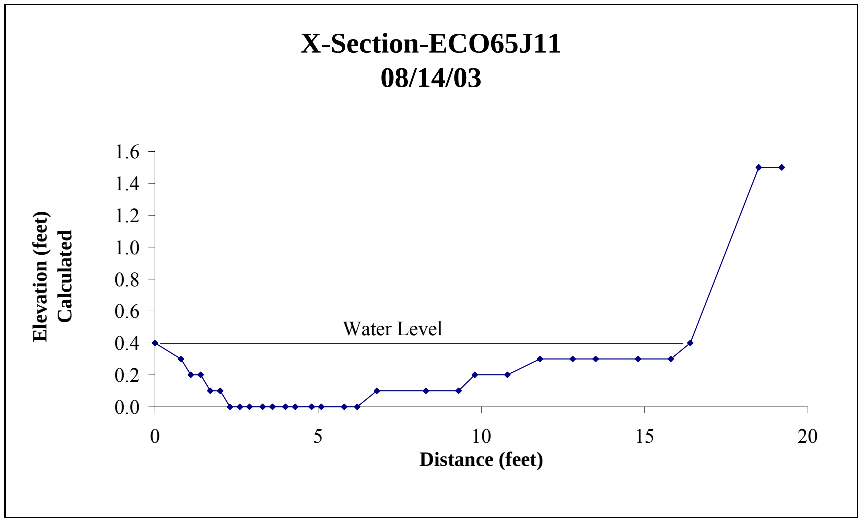

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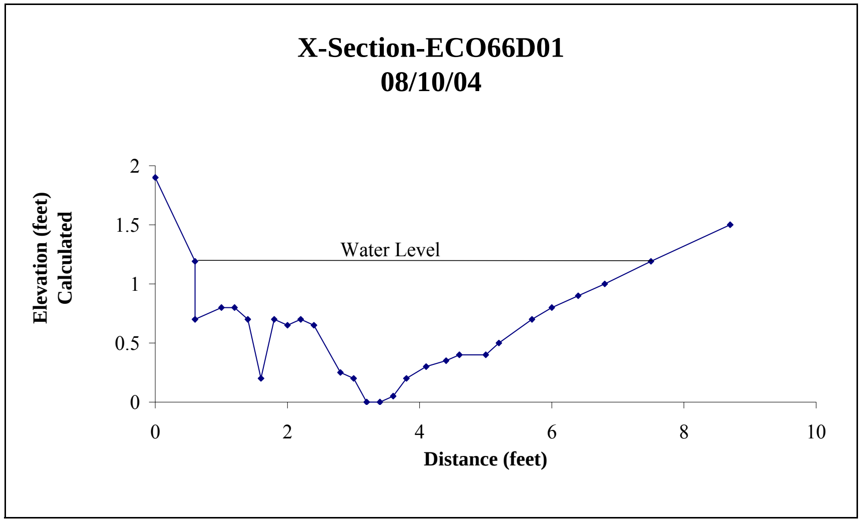

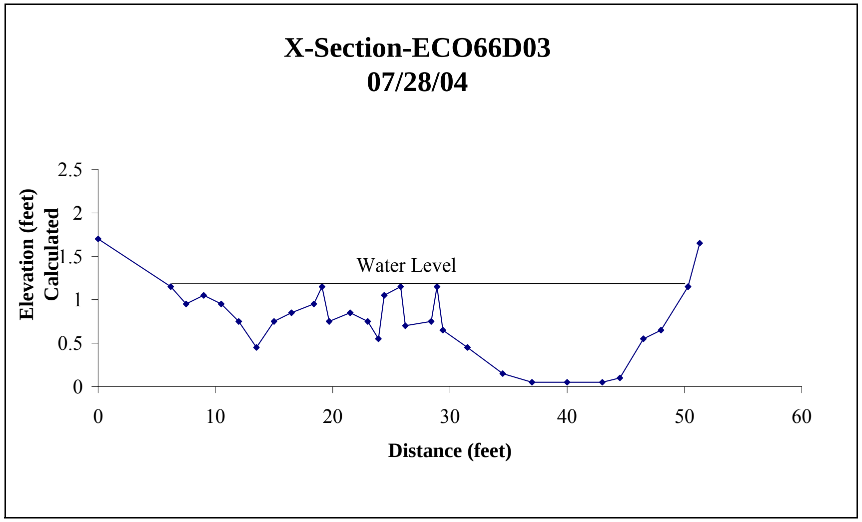

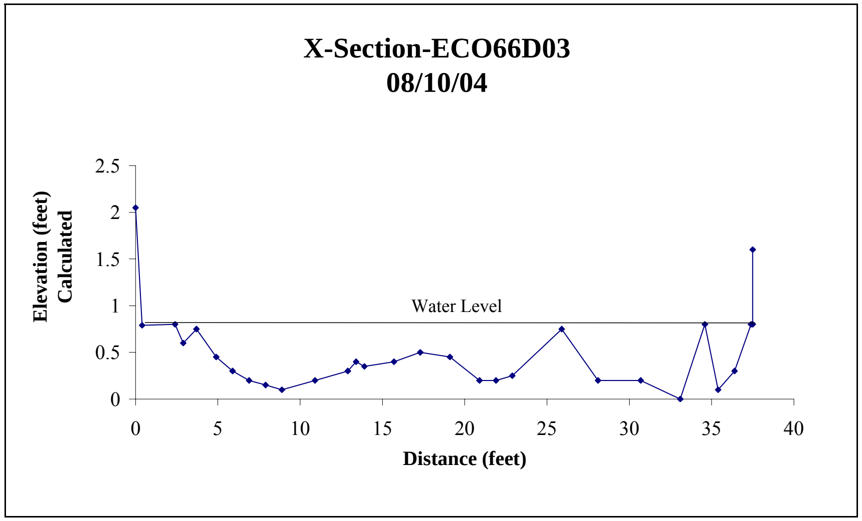

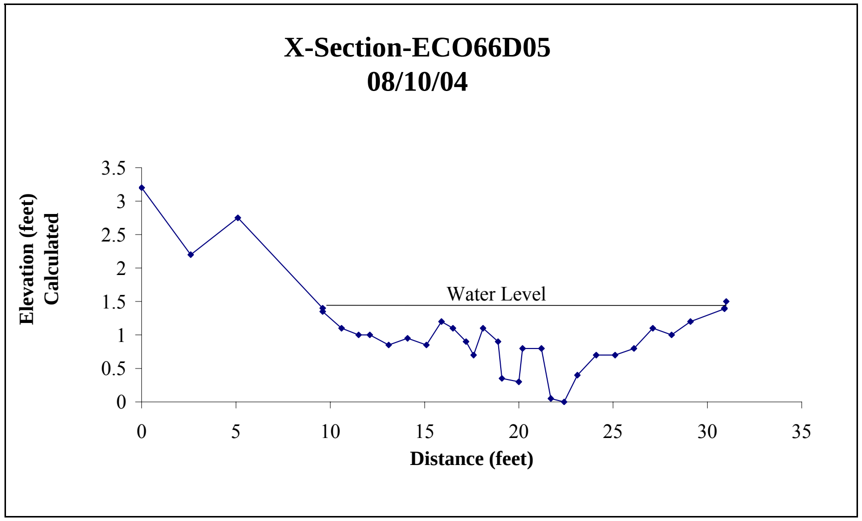

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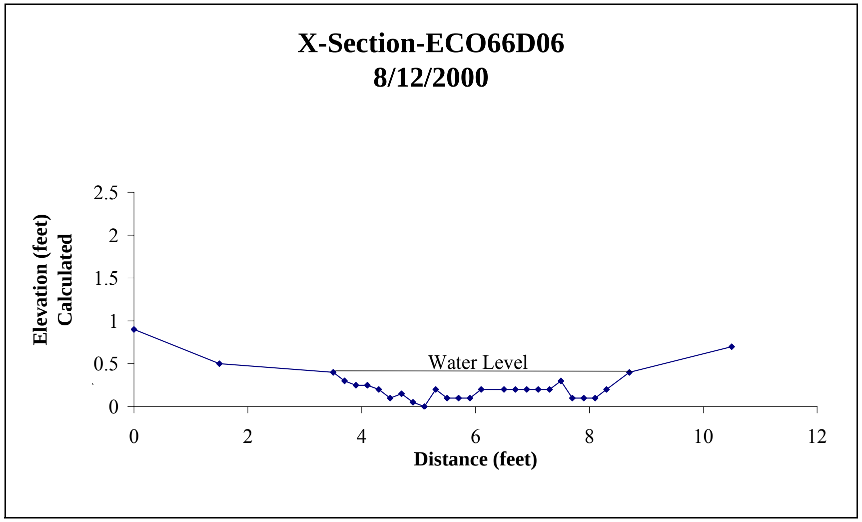

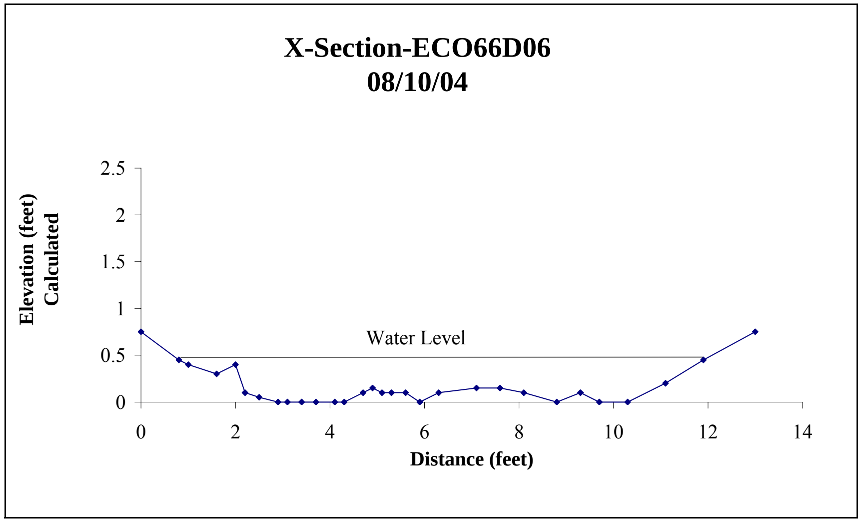

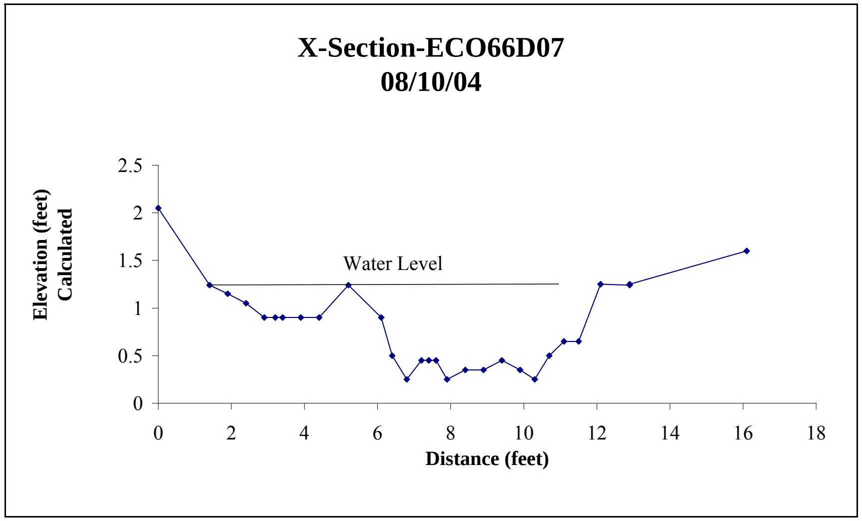

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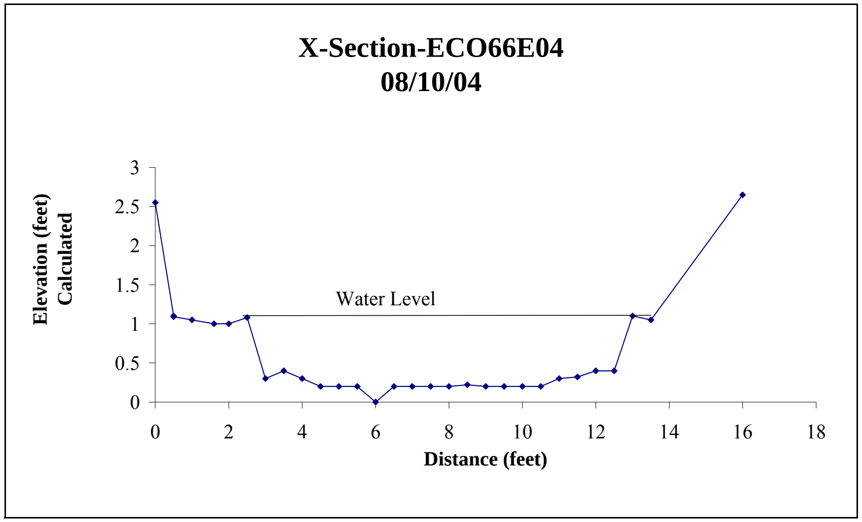

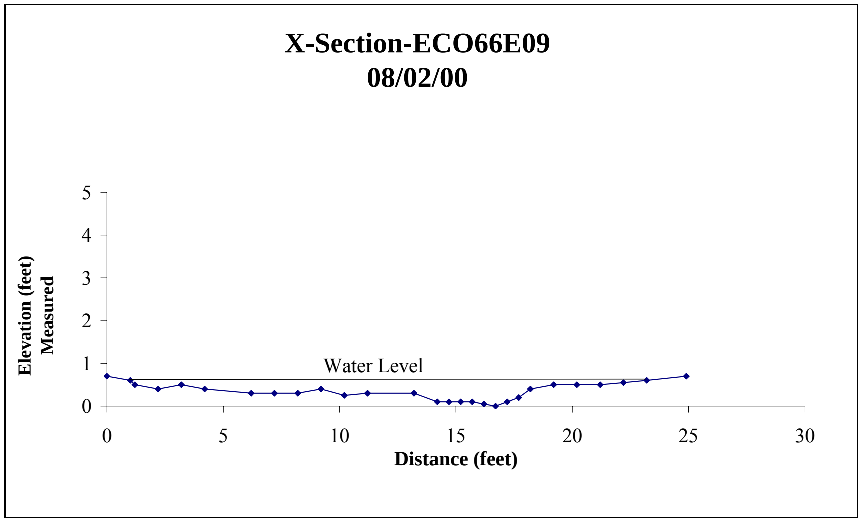

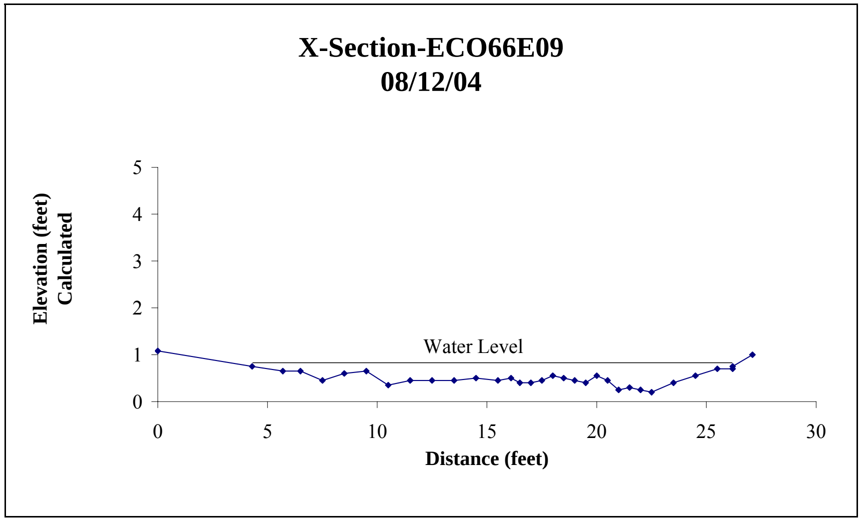

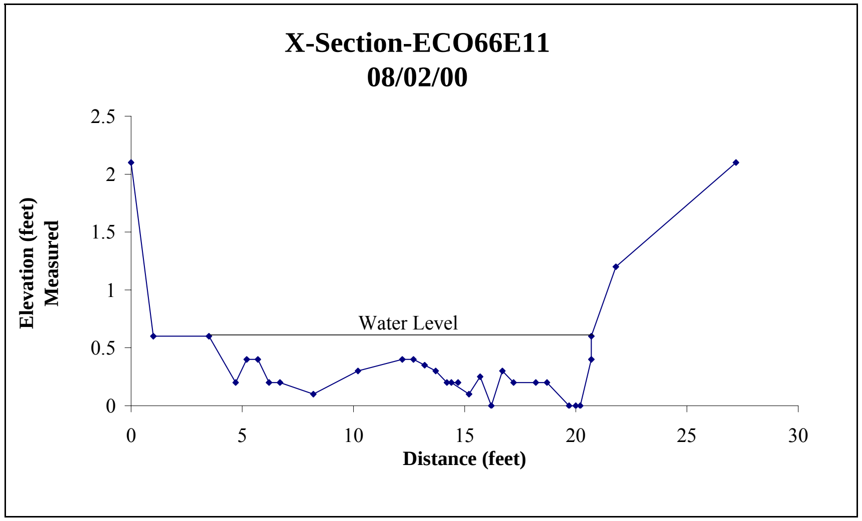

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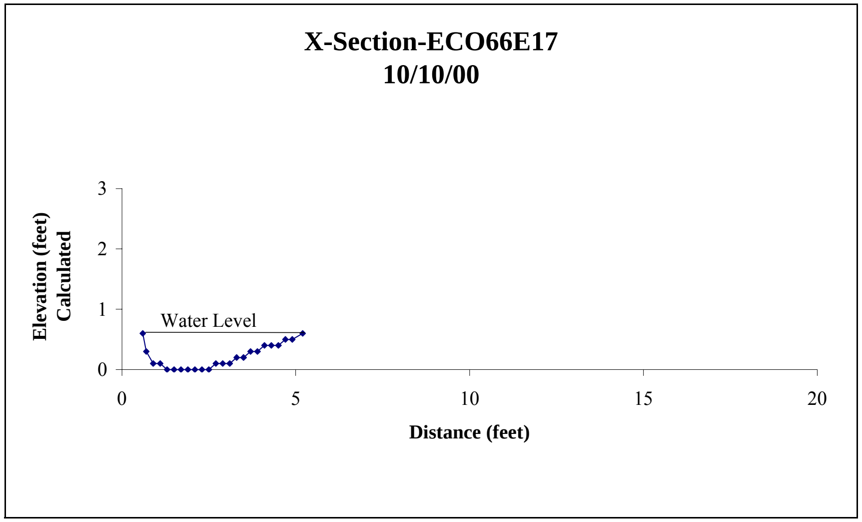

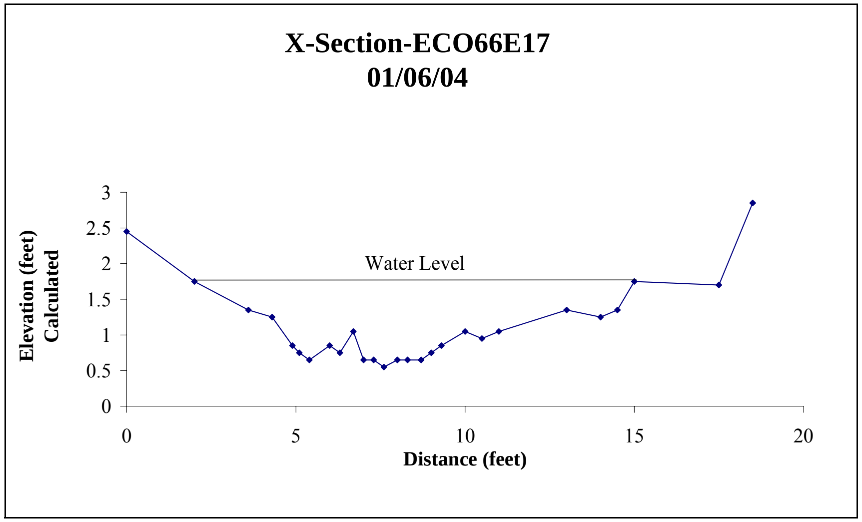

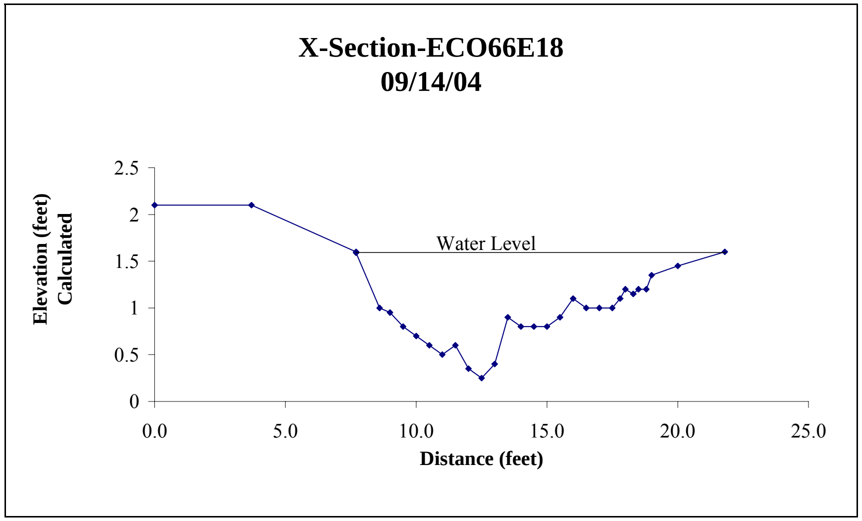

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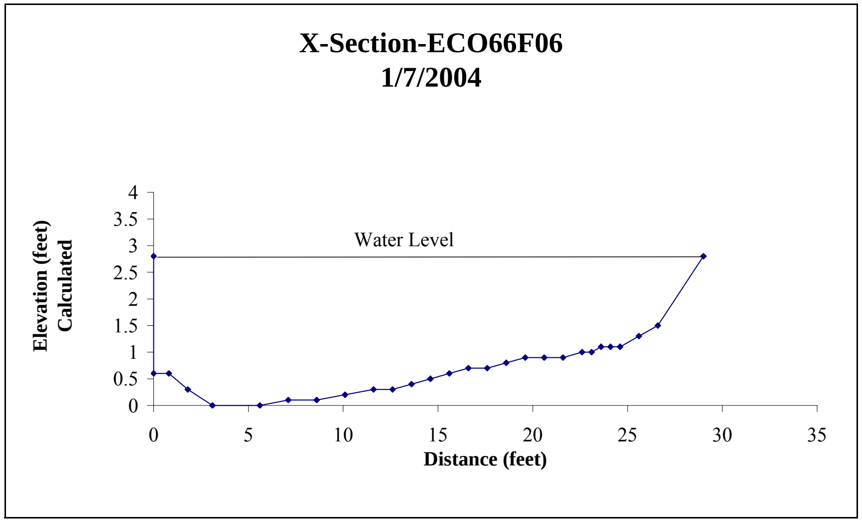

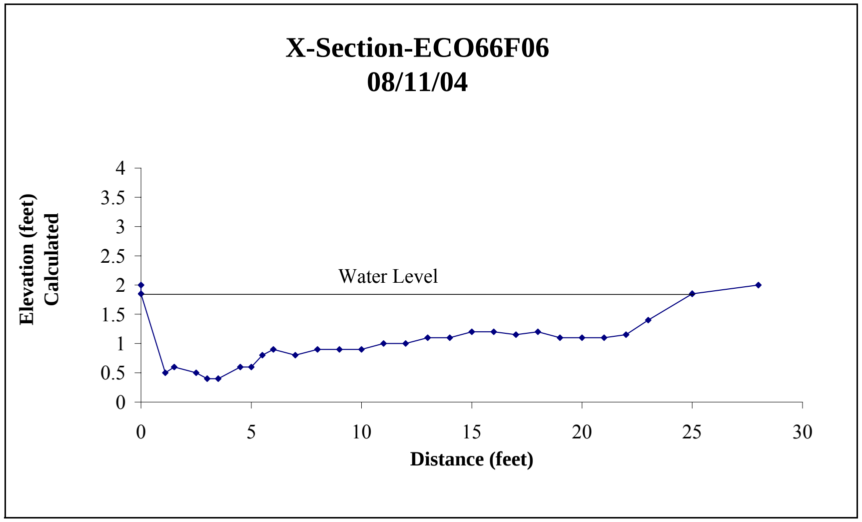

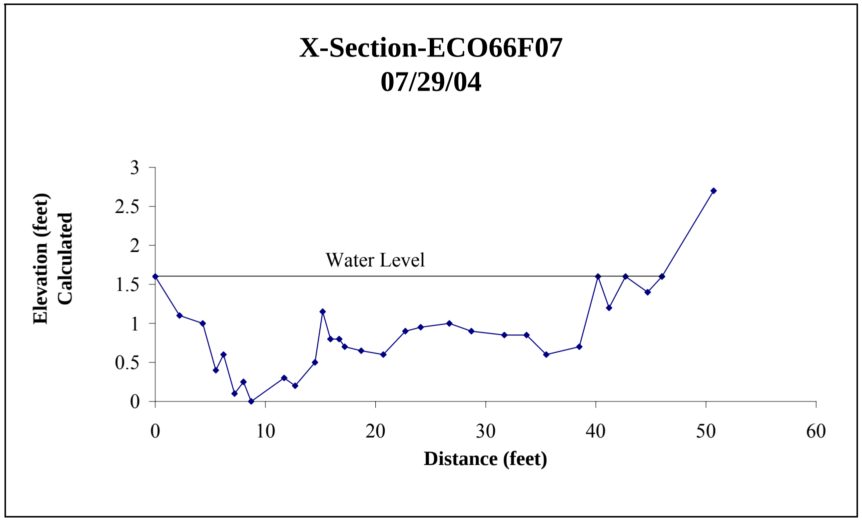

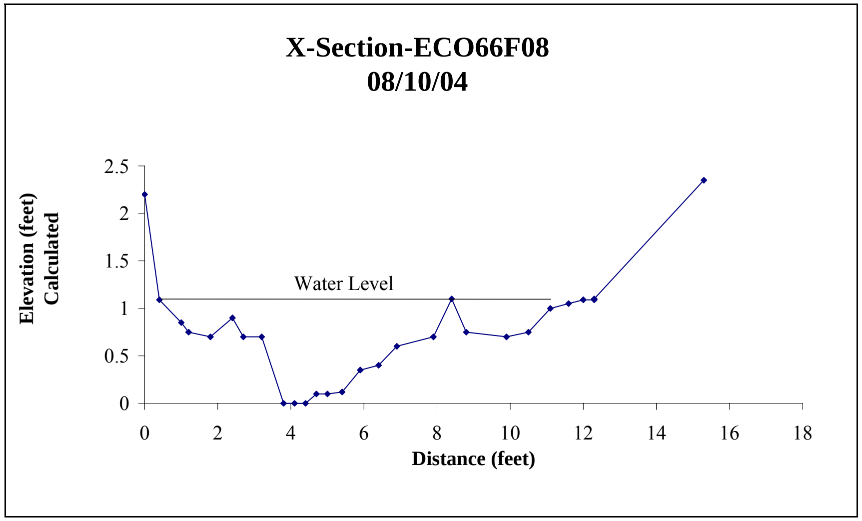

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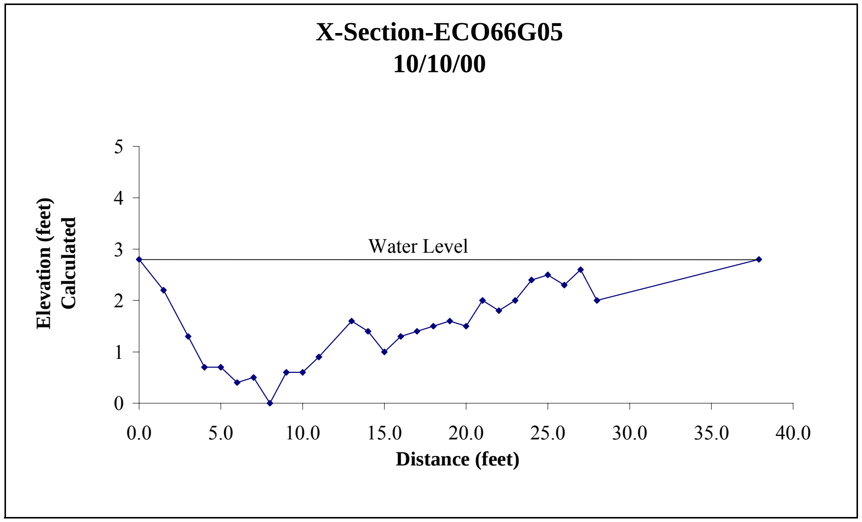

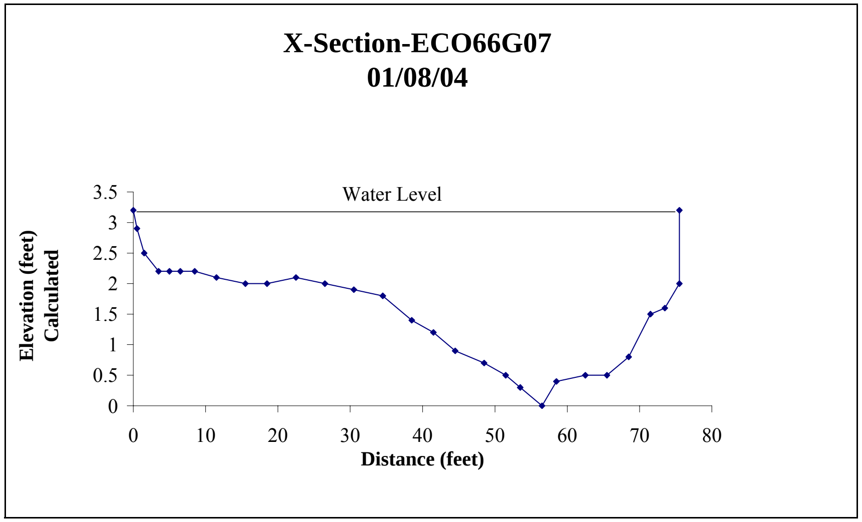

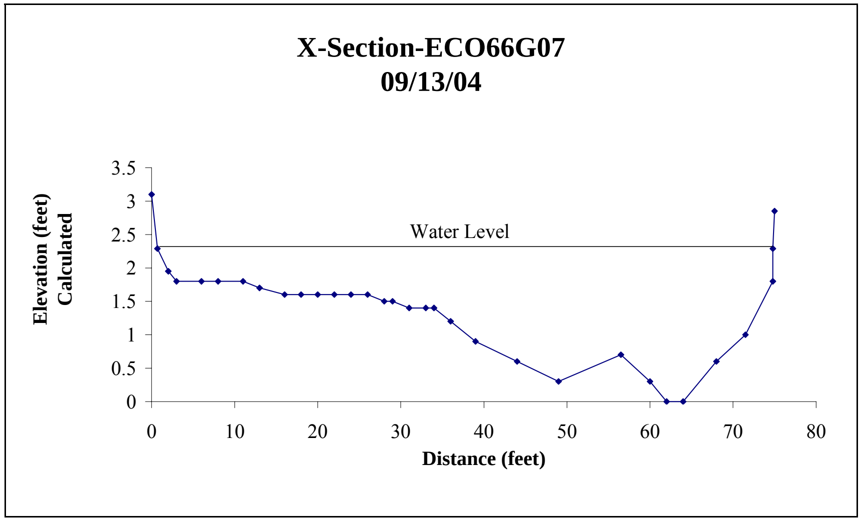

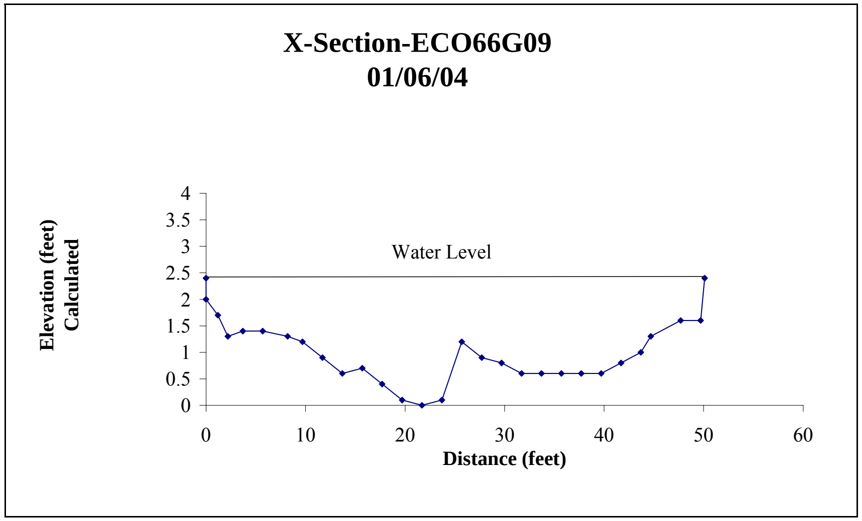

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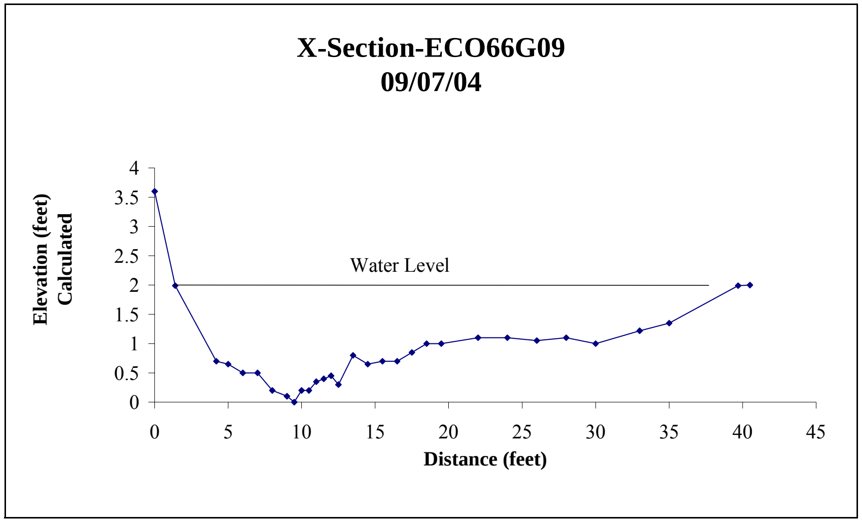

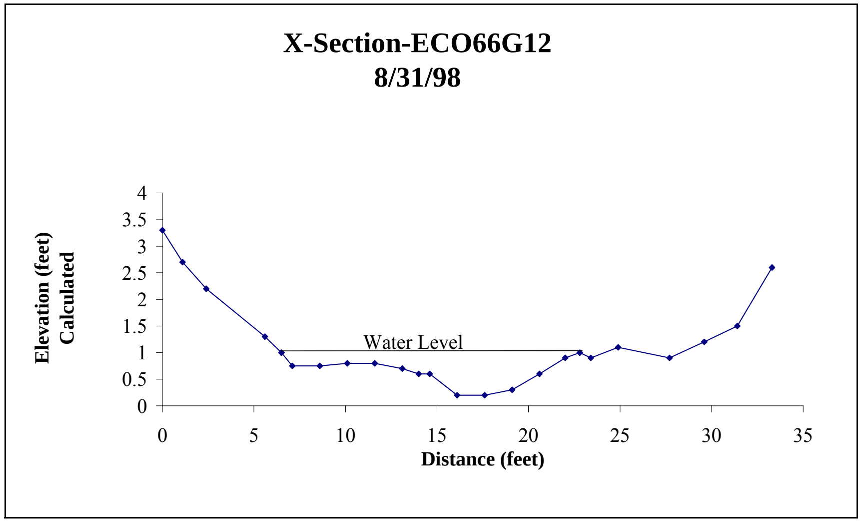

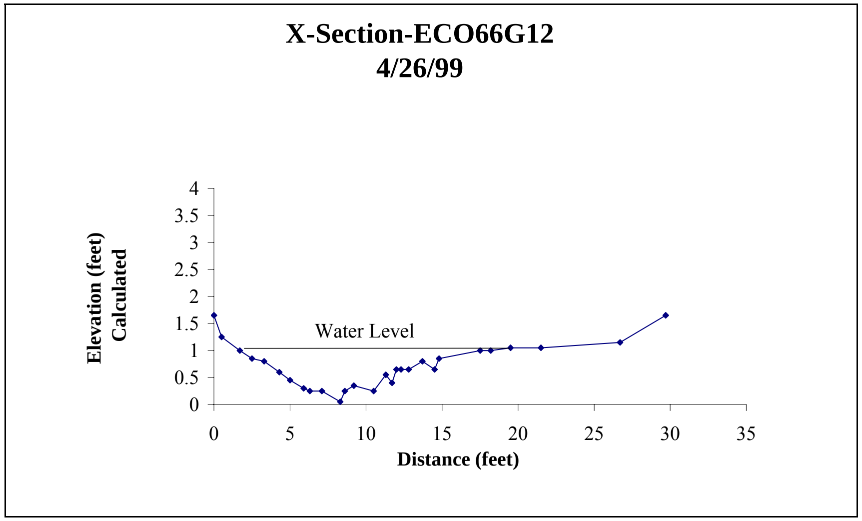

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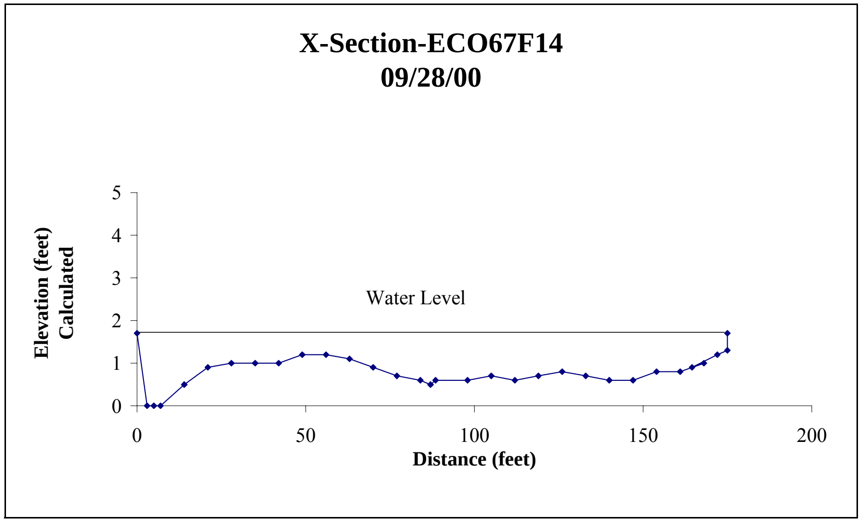

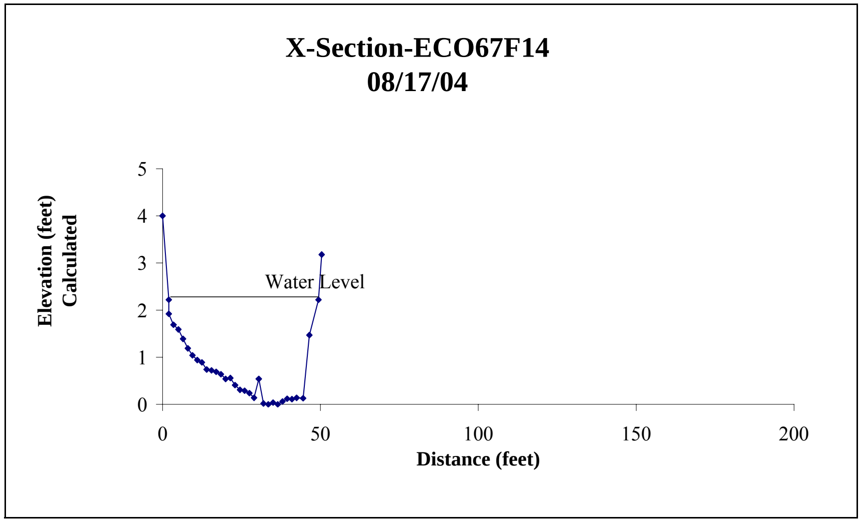

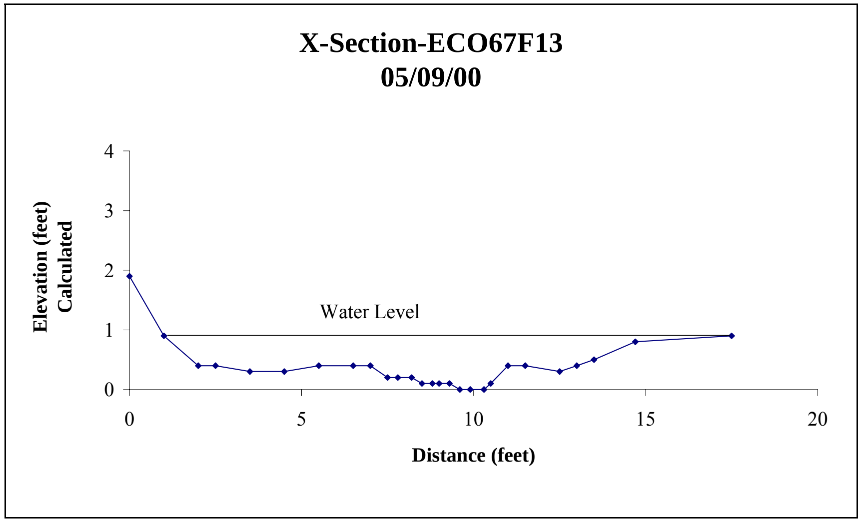

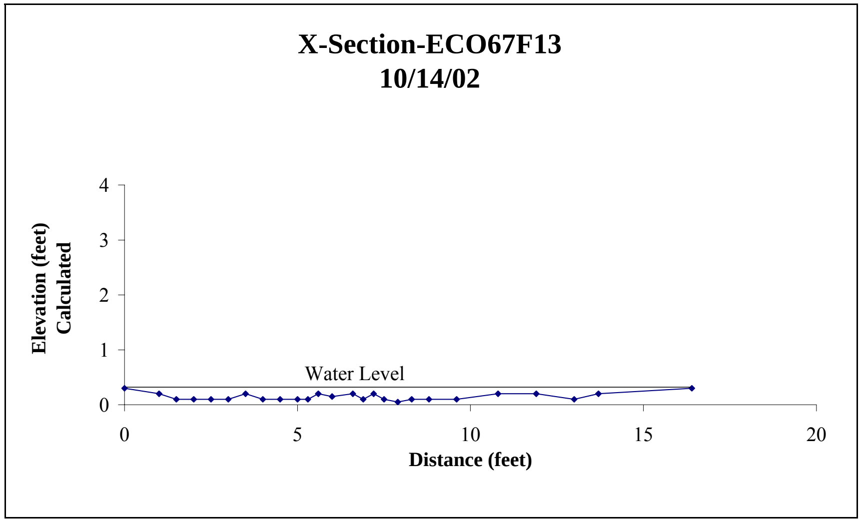

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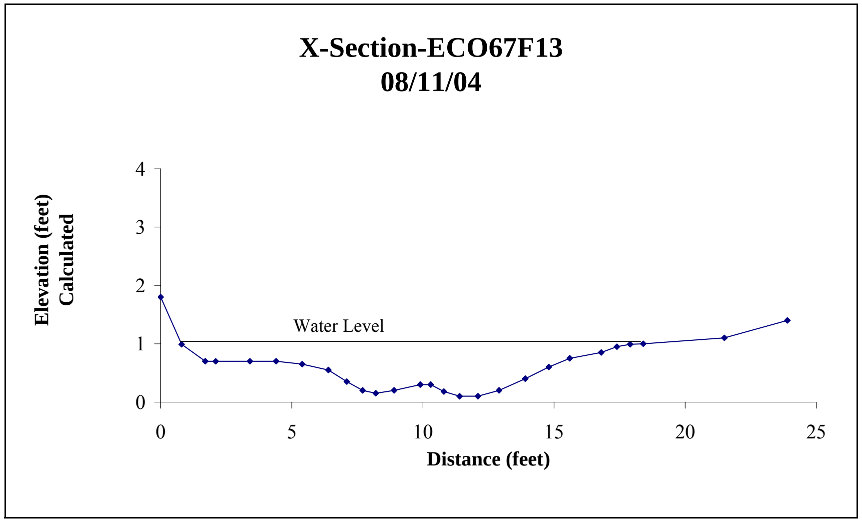

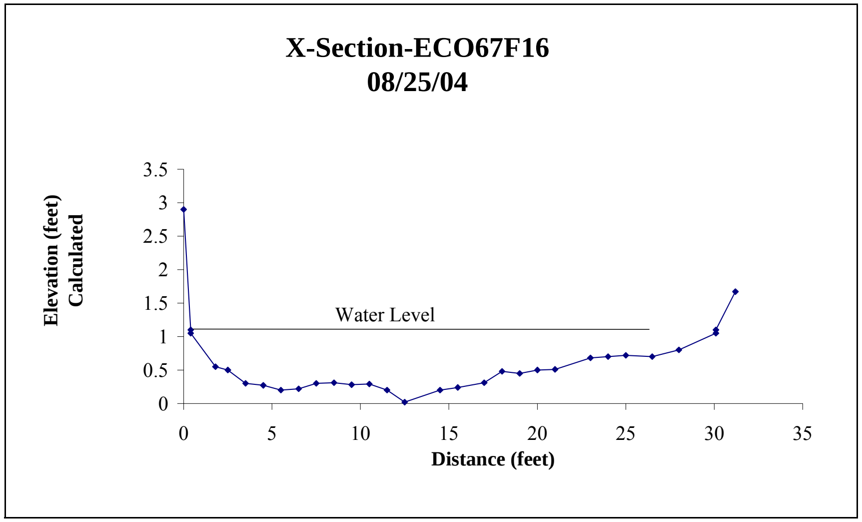

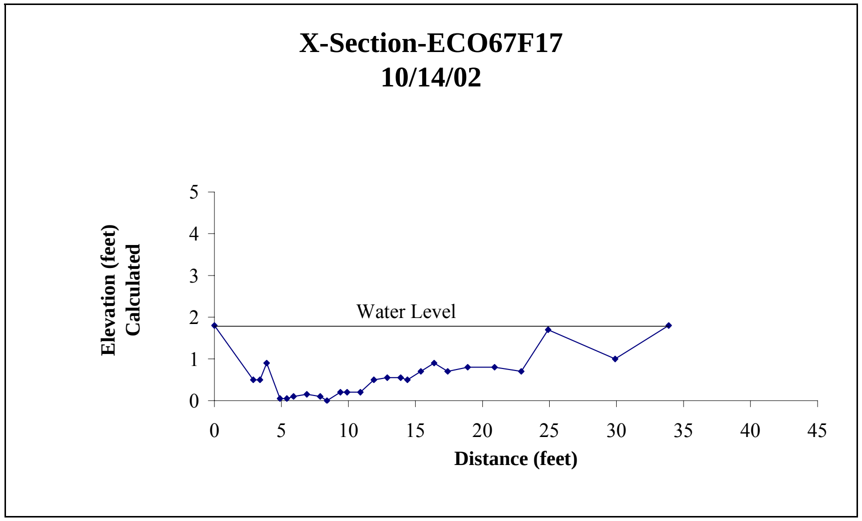

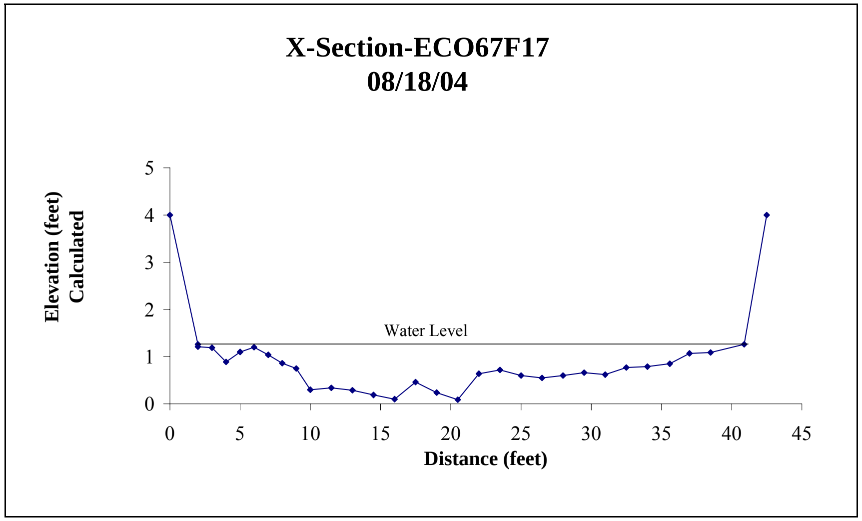

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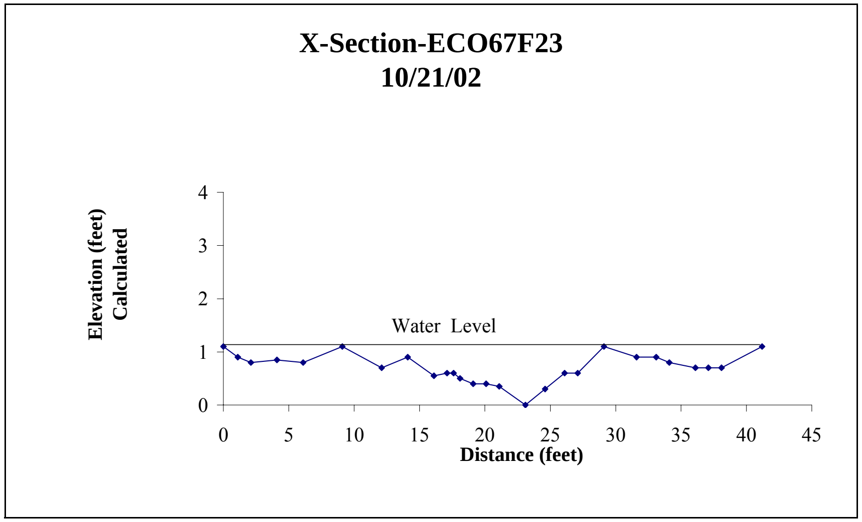
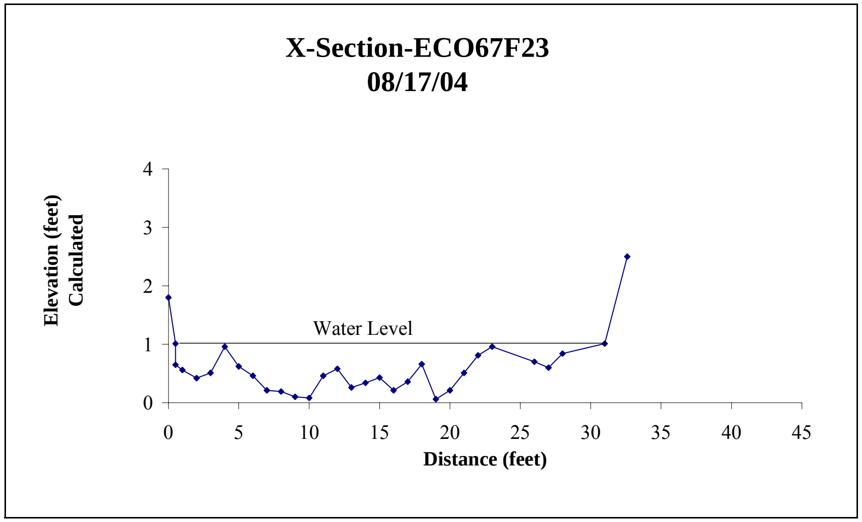
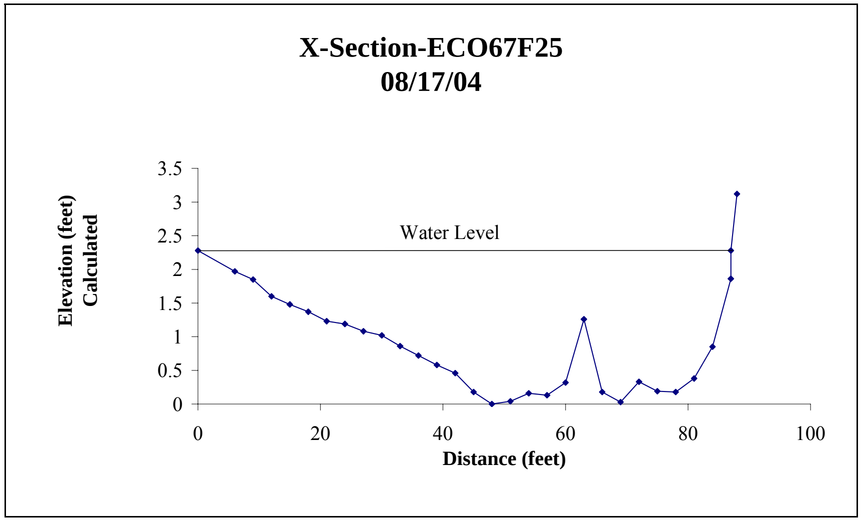
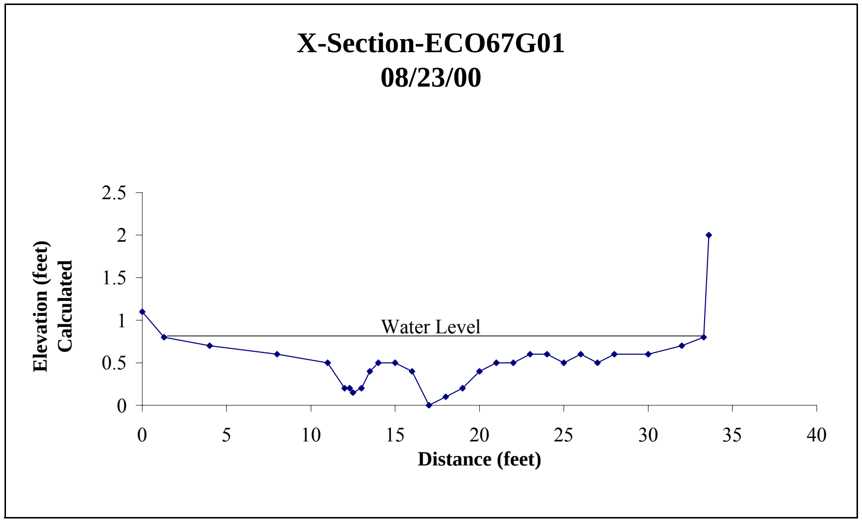
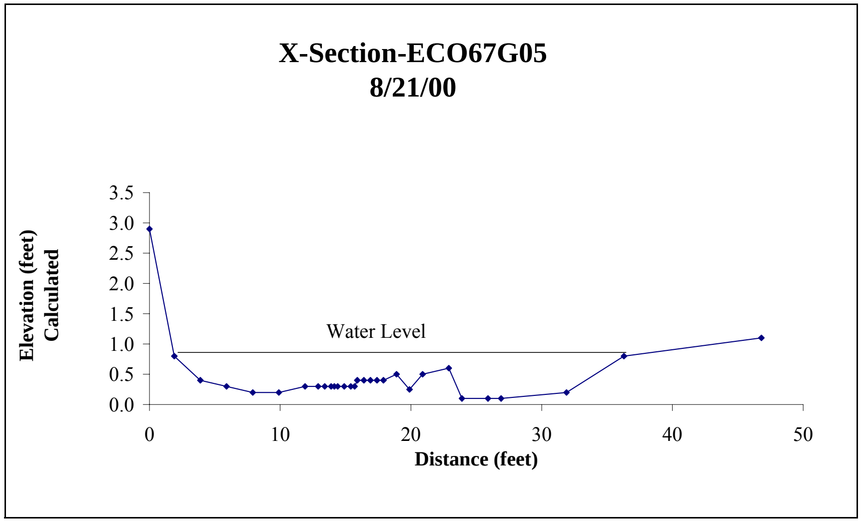


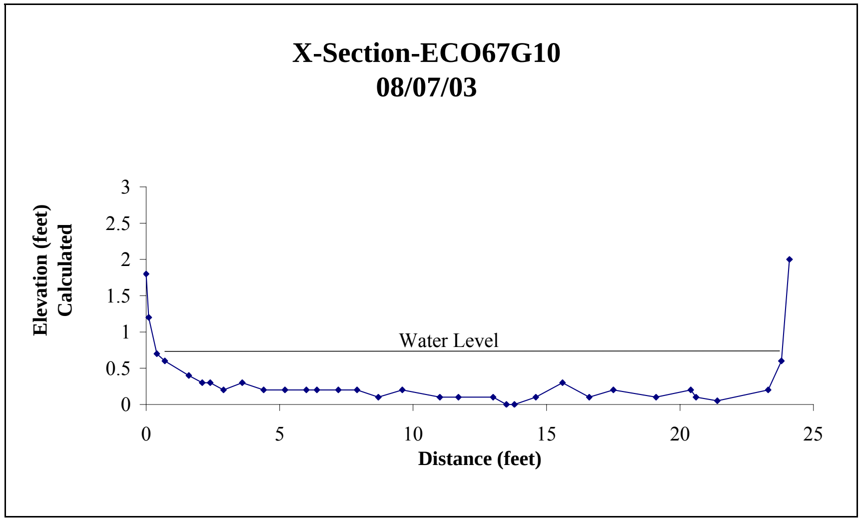


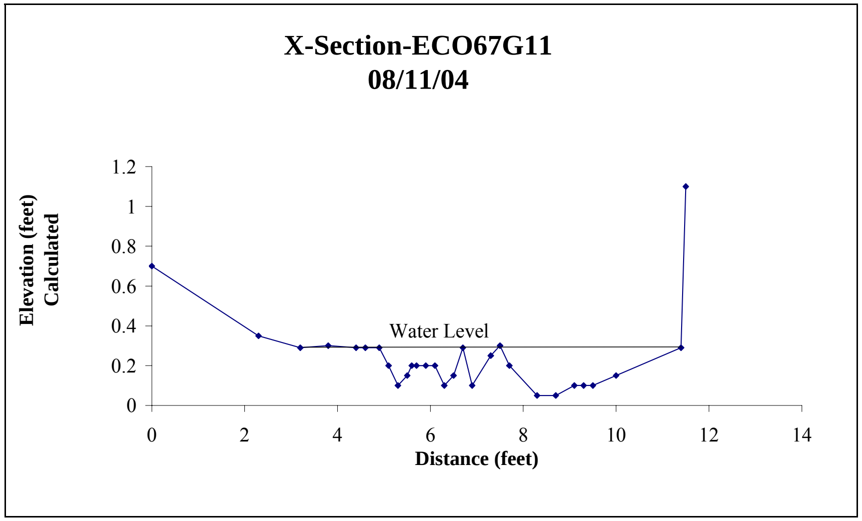


ECOREGION 67G









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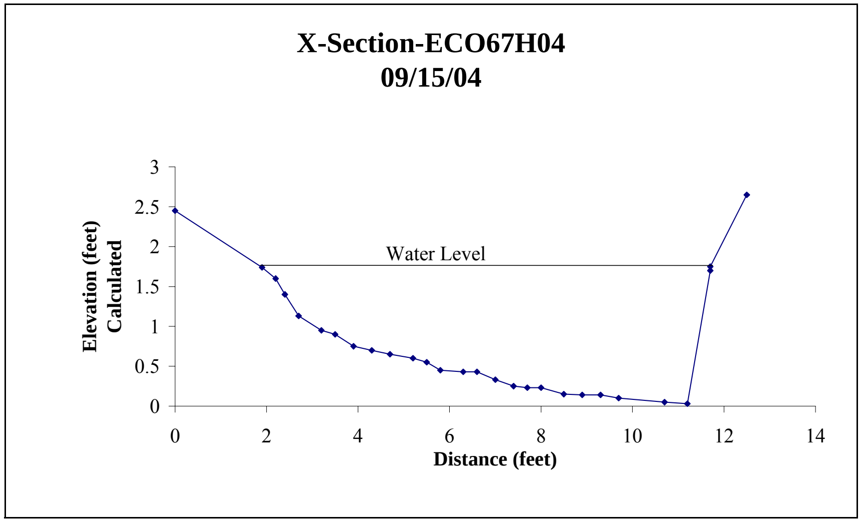

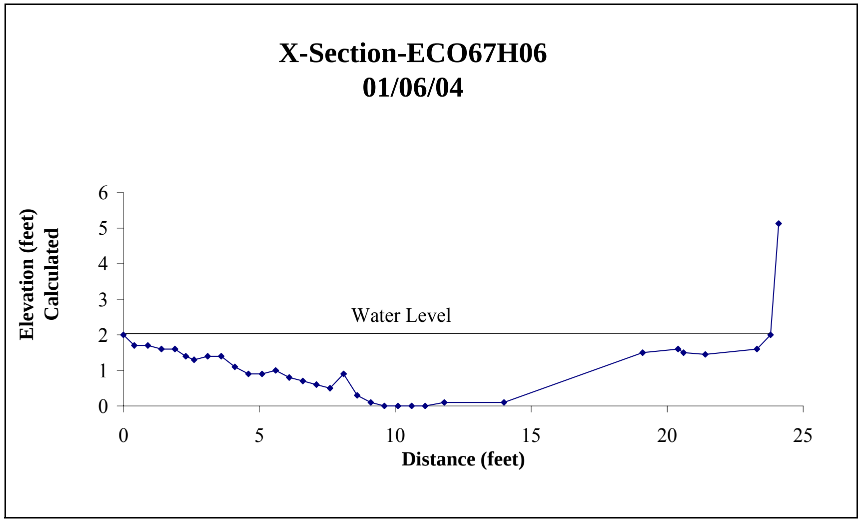

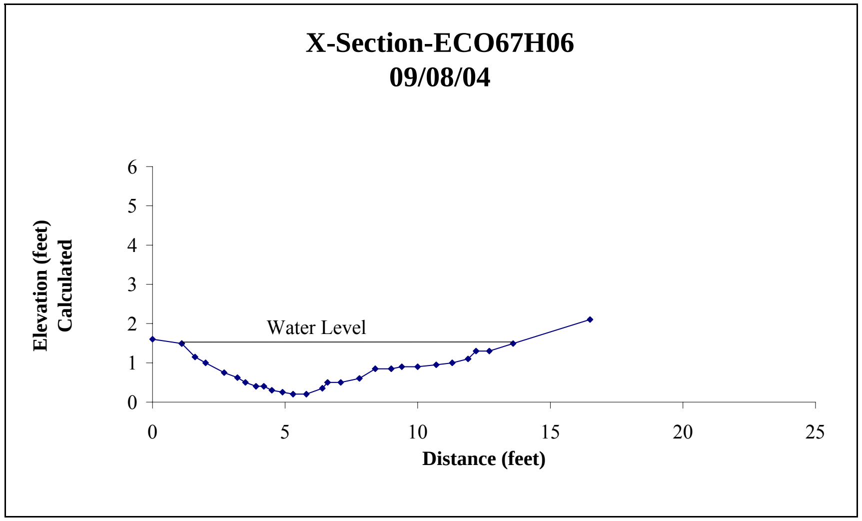

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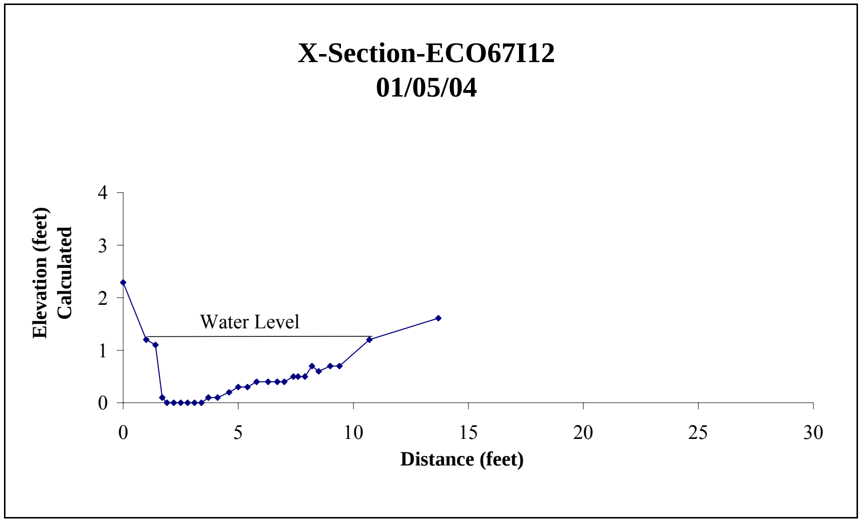

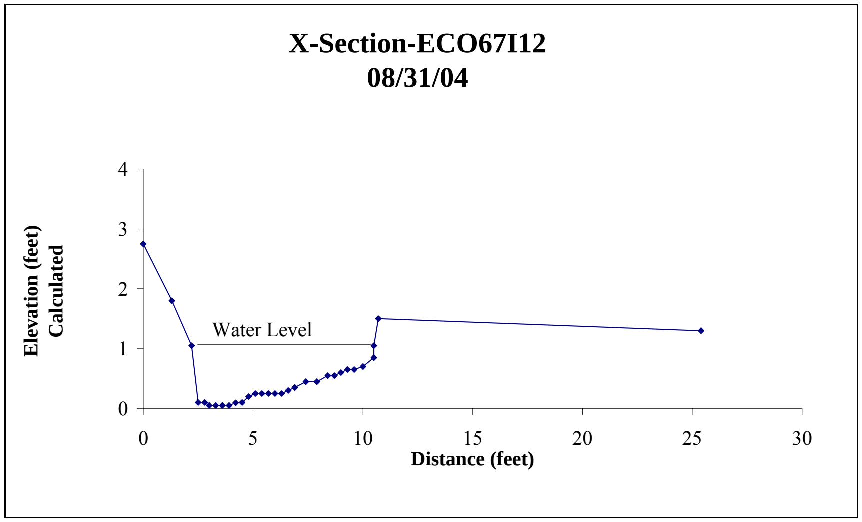

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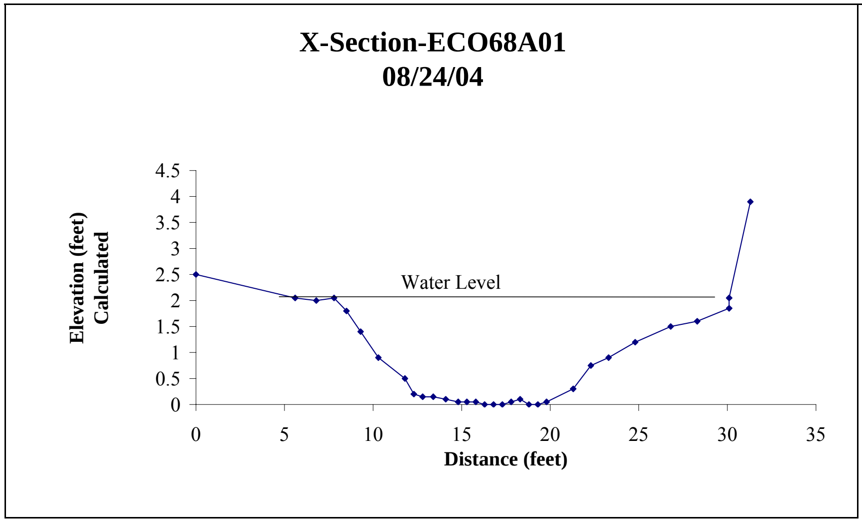

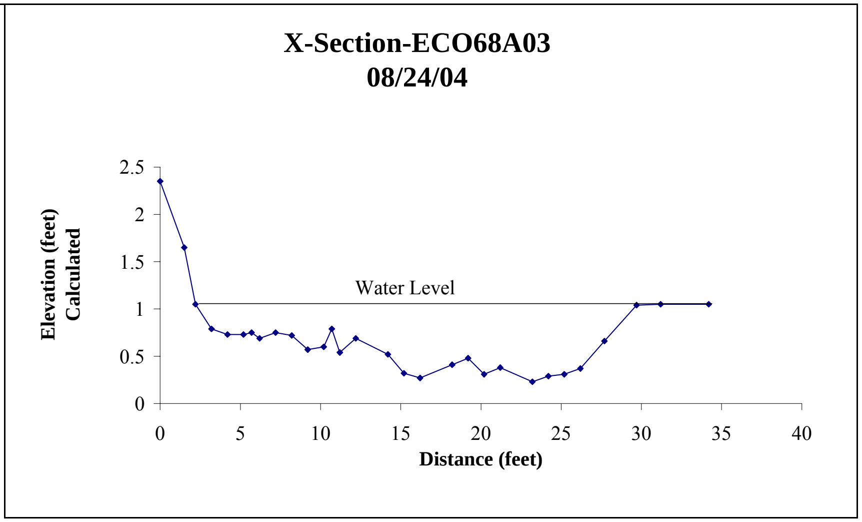

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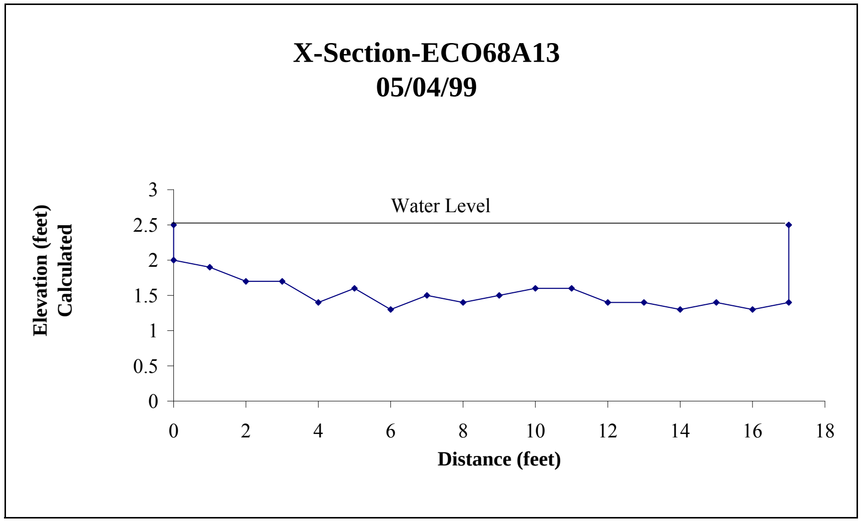

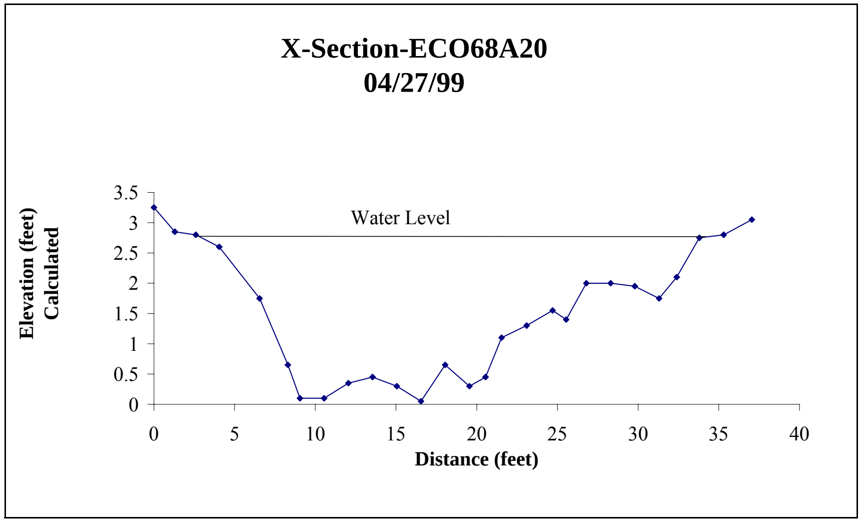

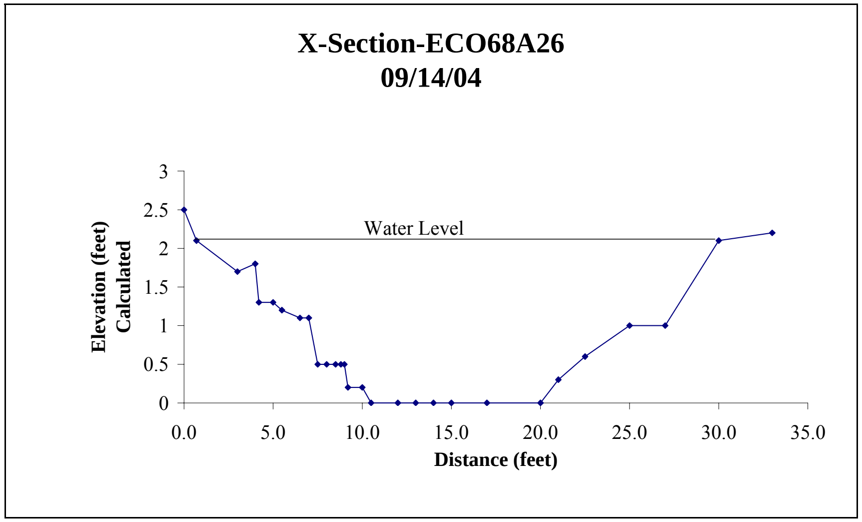

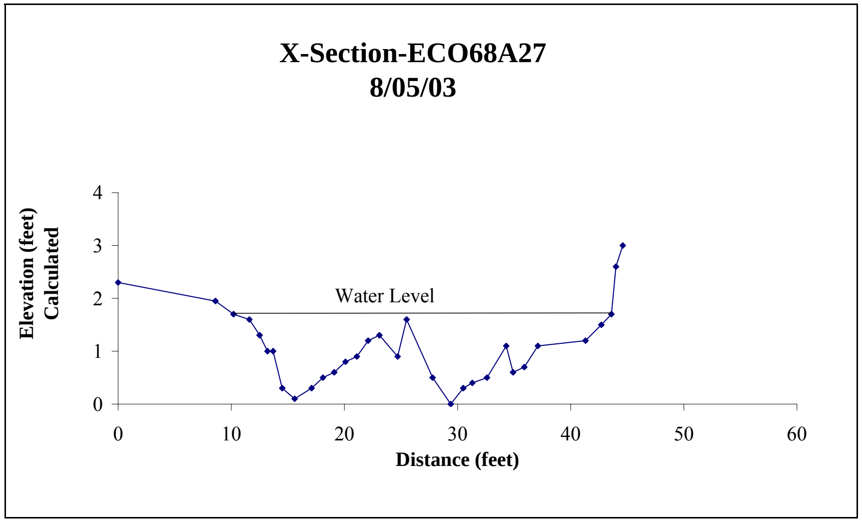

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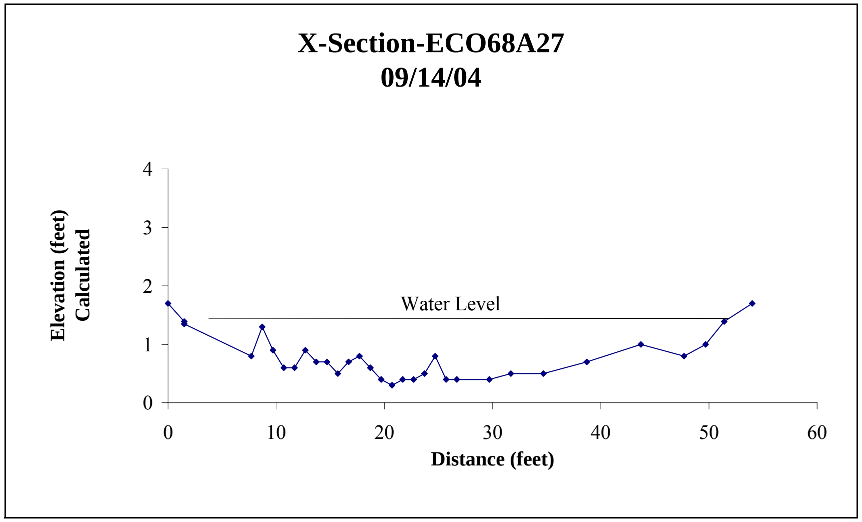
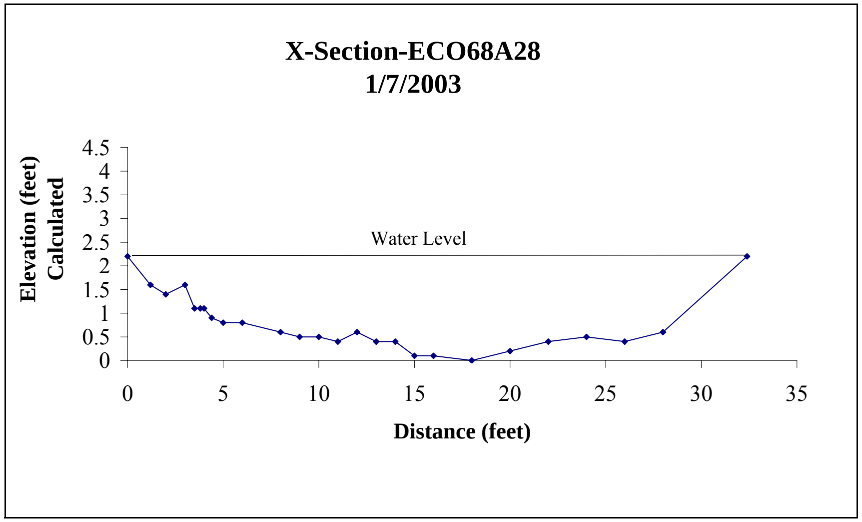
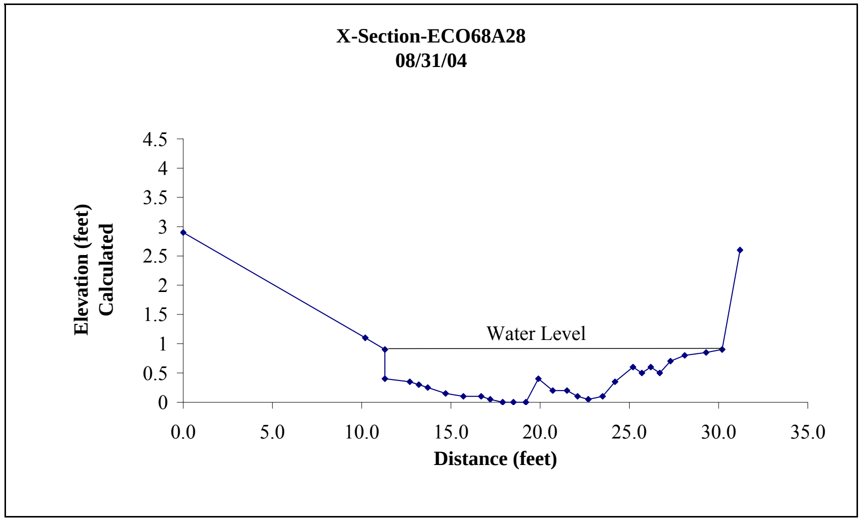
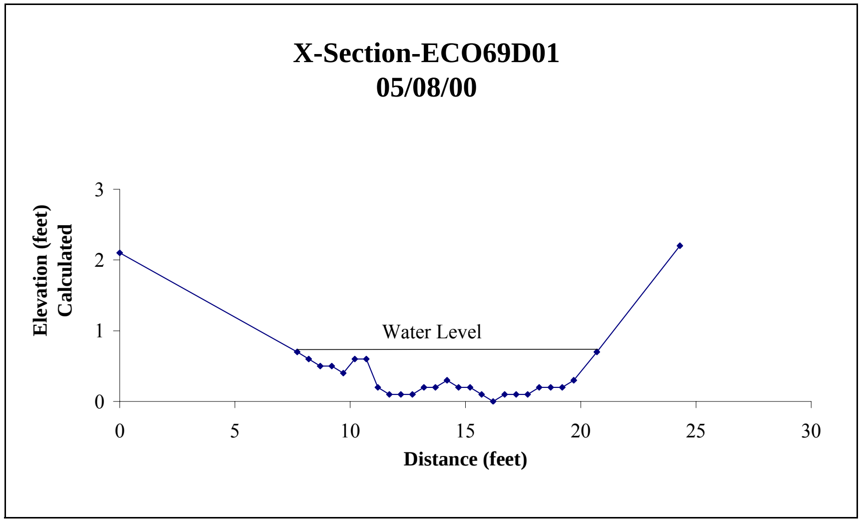
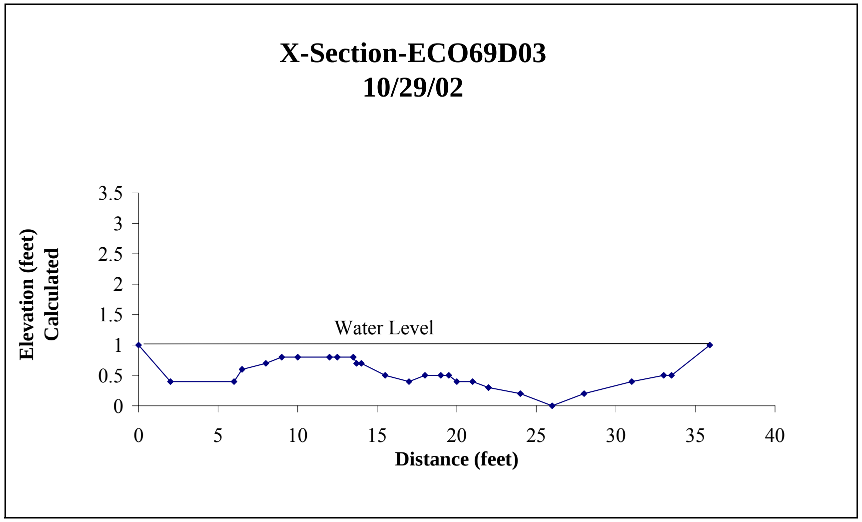


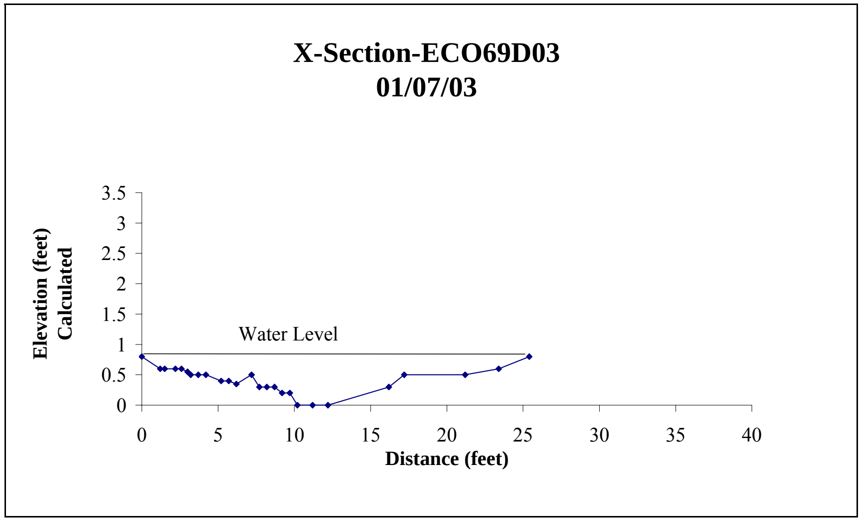


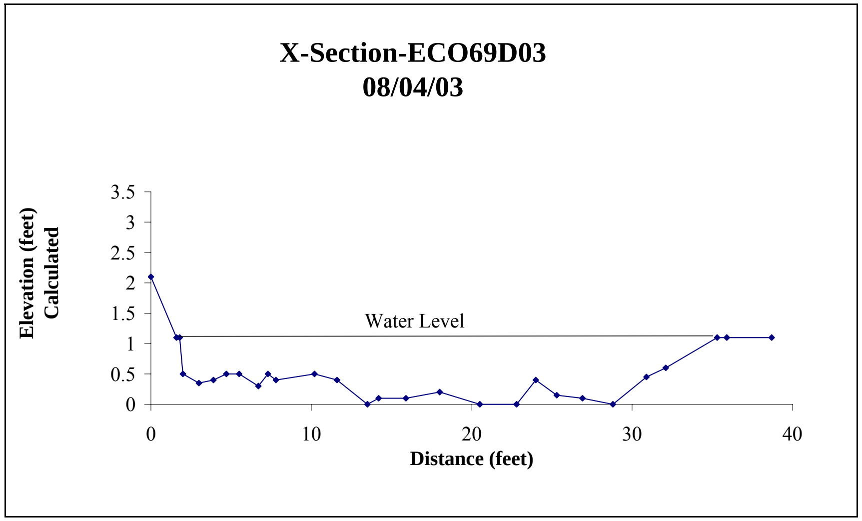


ECOREGION 69D

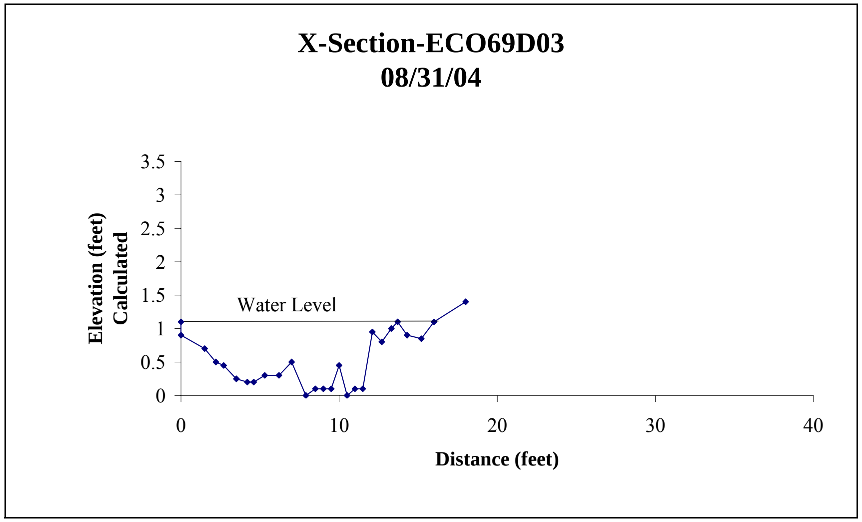


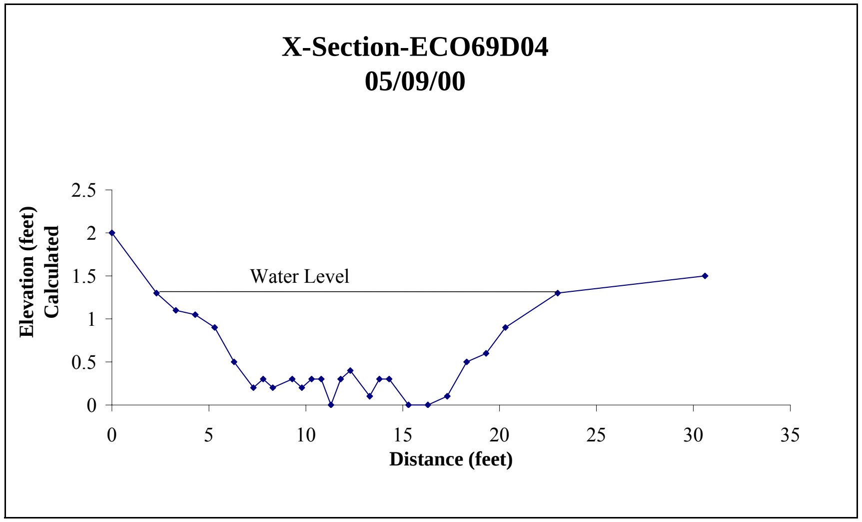


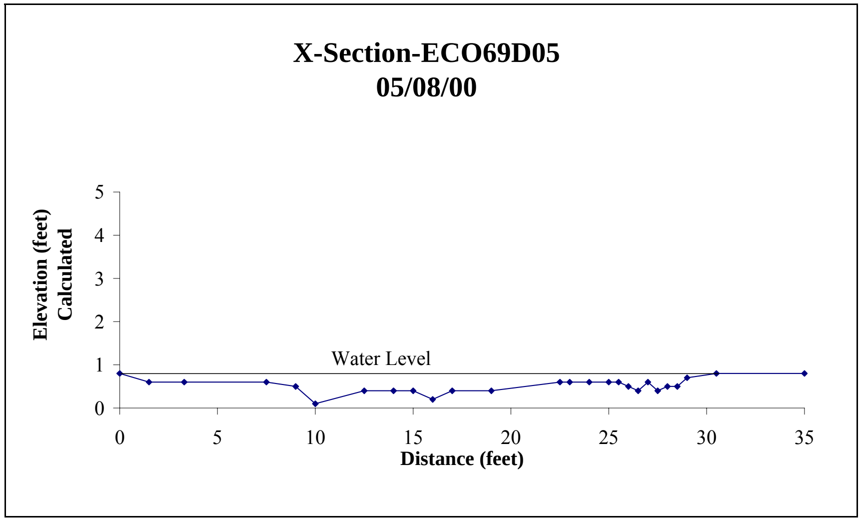


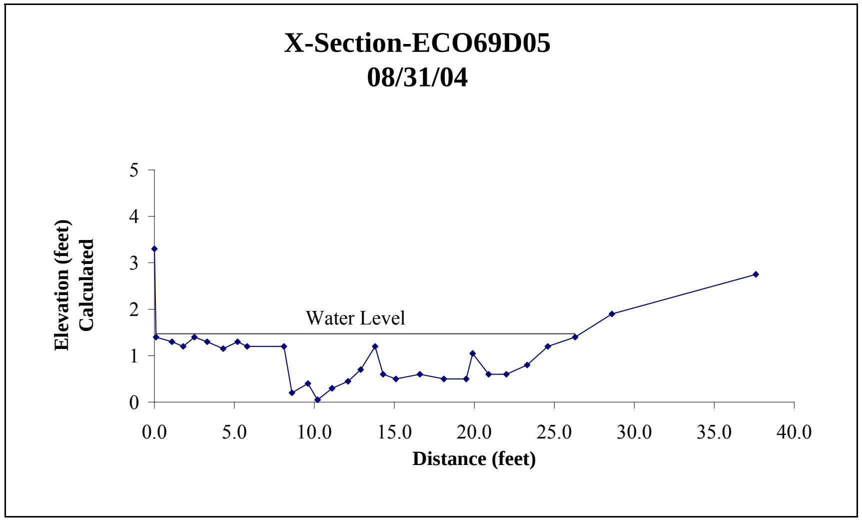


ECOREGION 69D









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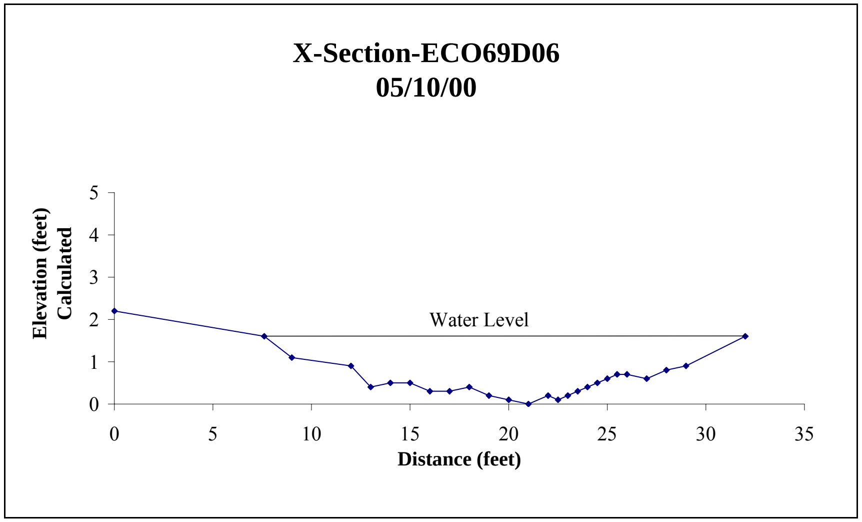
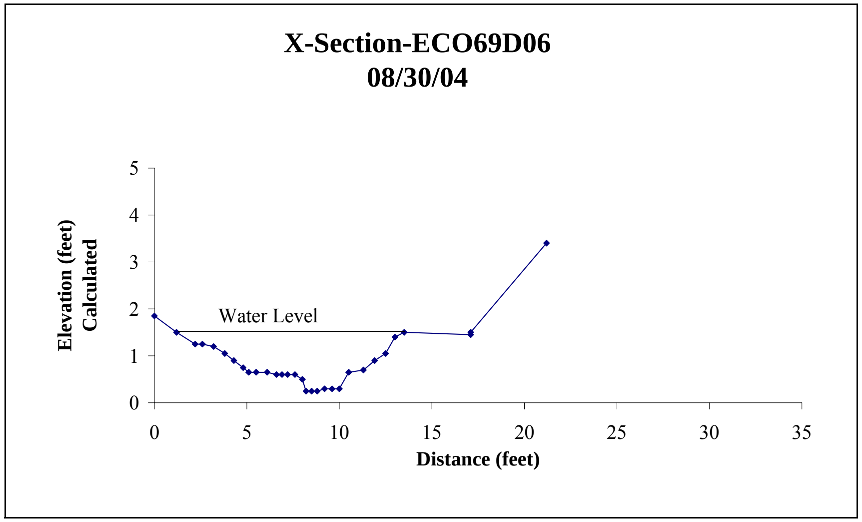
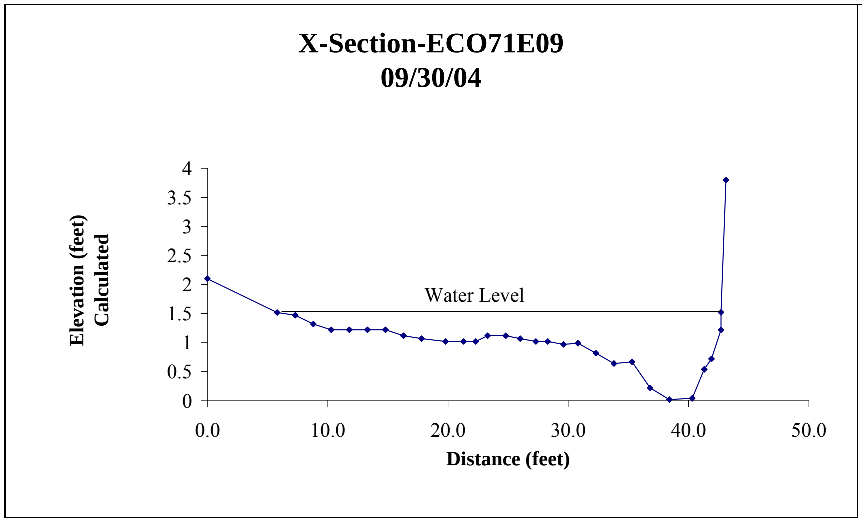
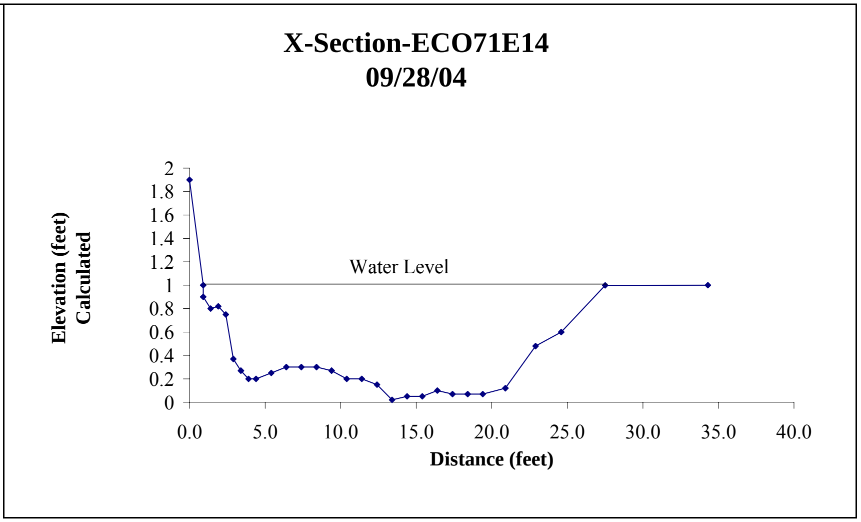


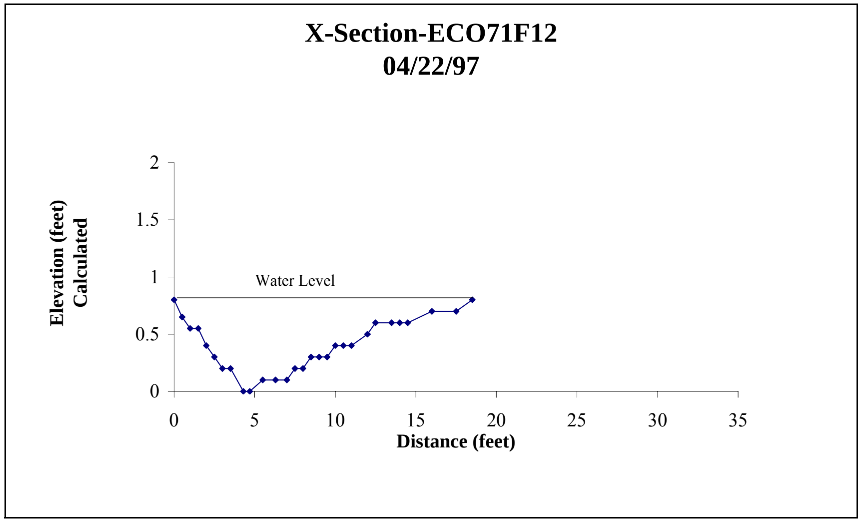


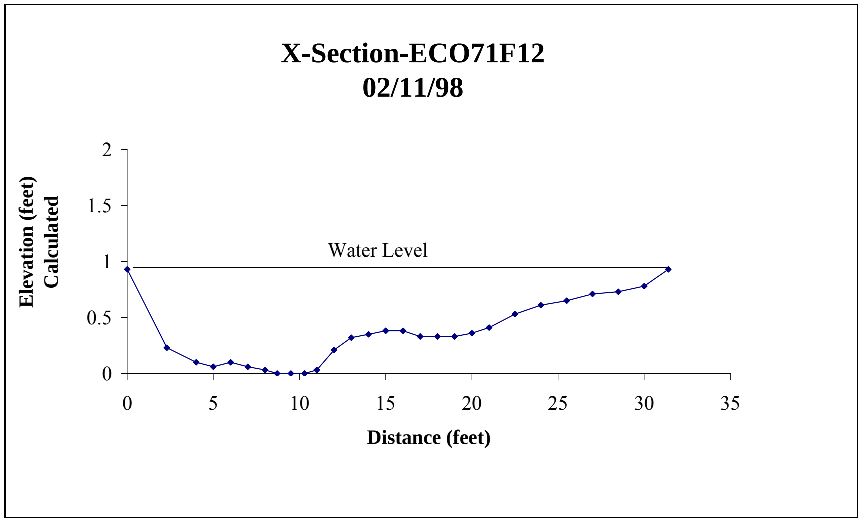
ECOREGION 71E

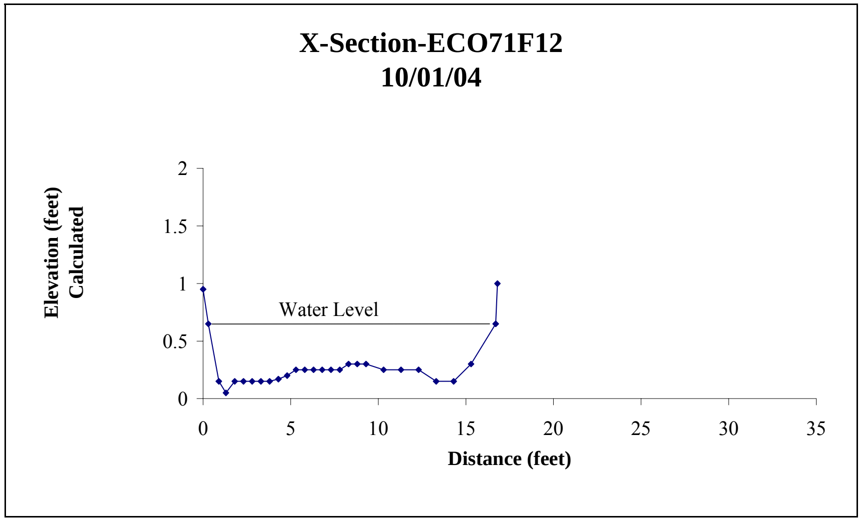


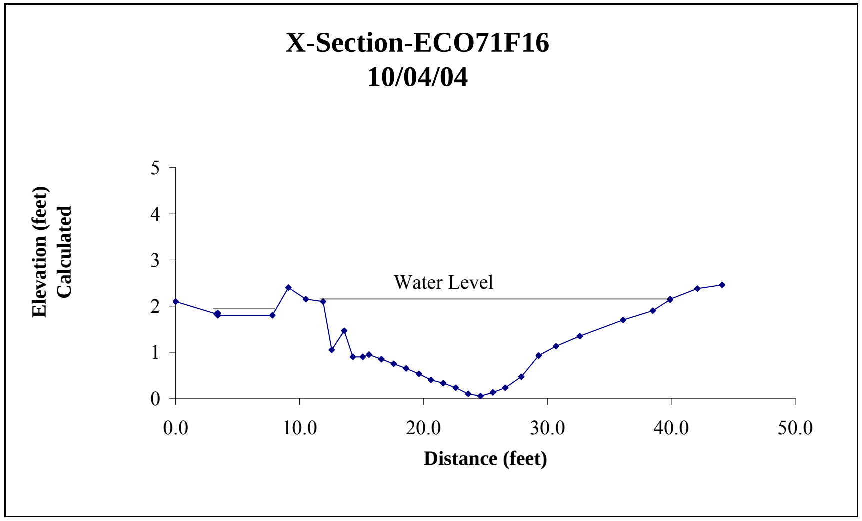


ECOREGION 71F









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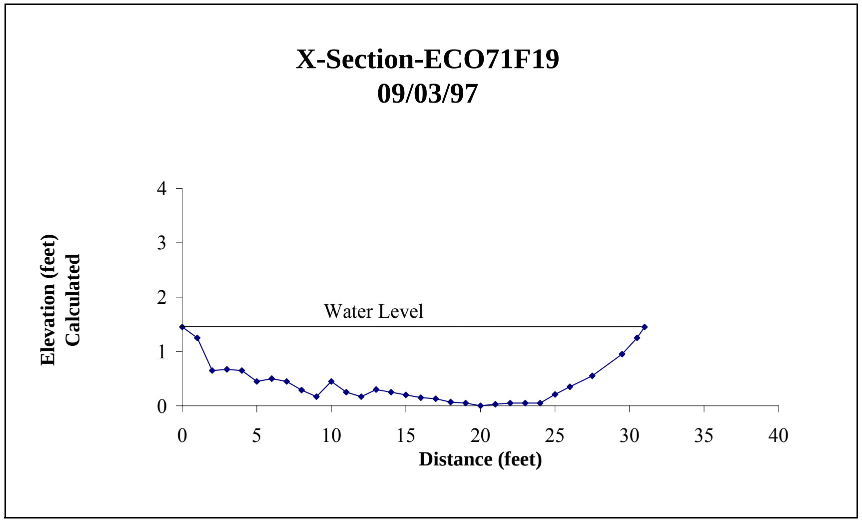

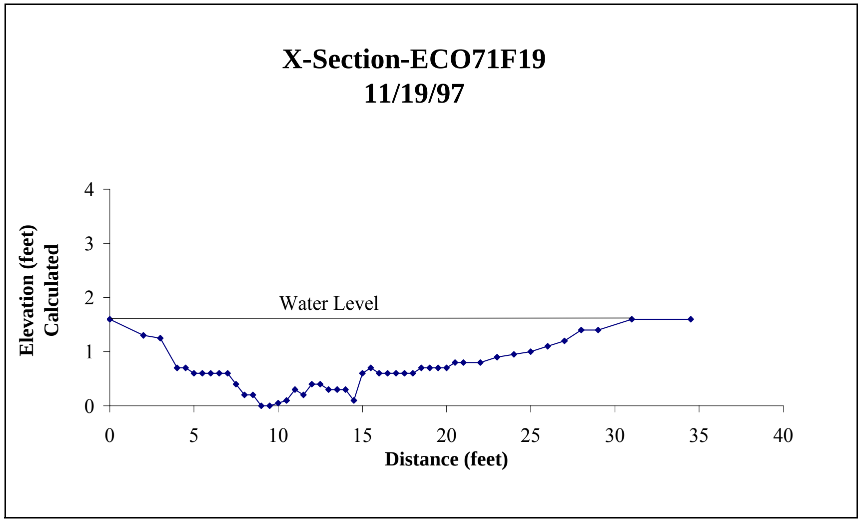

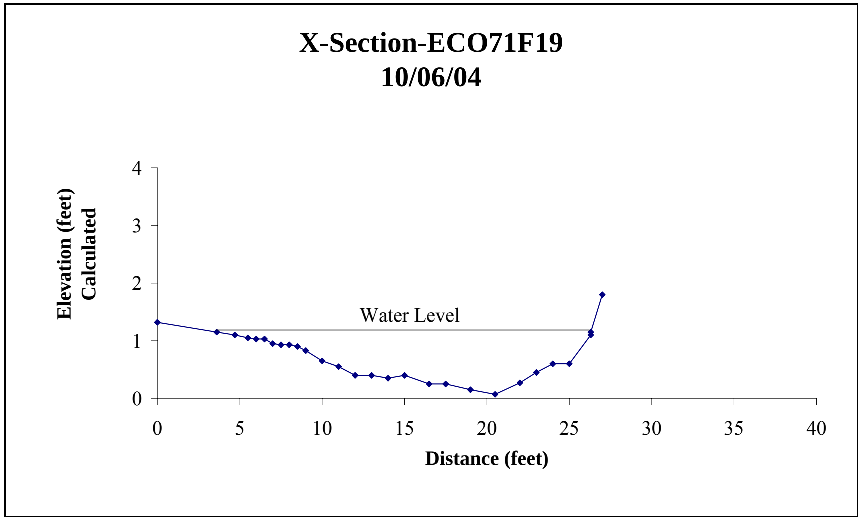

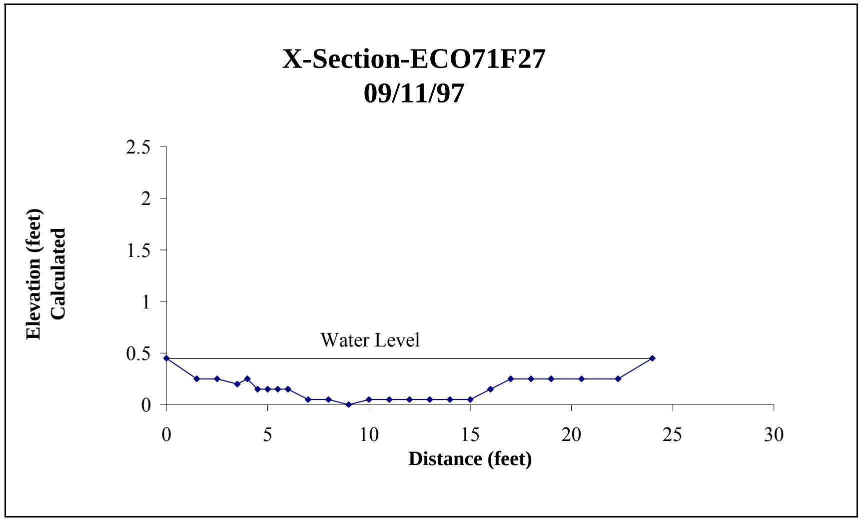

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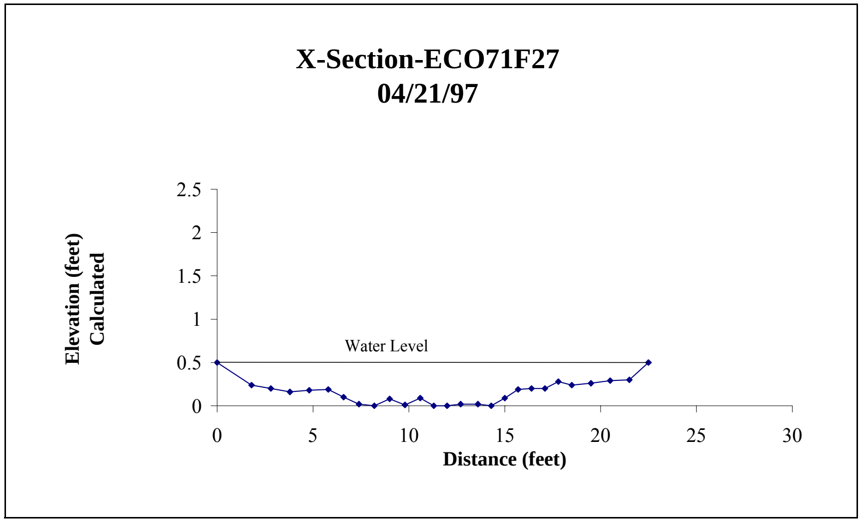

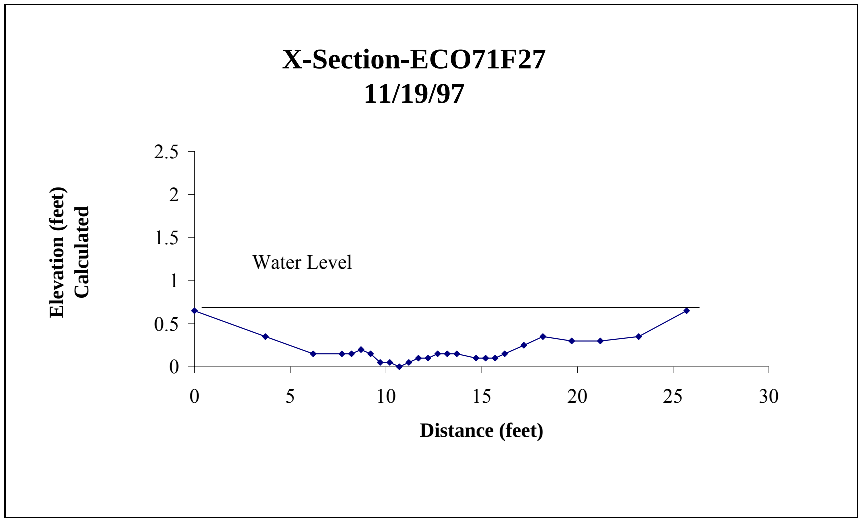

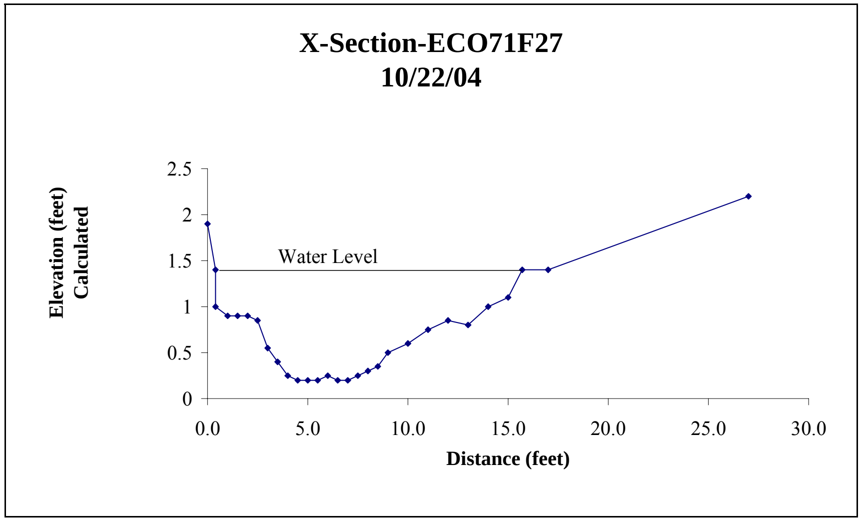

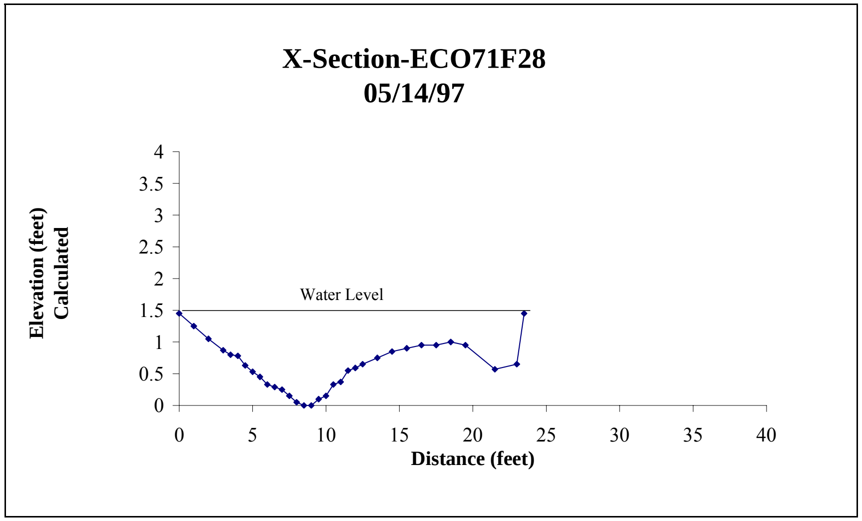

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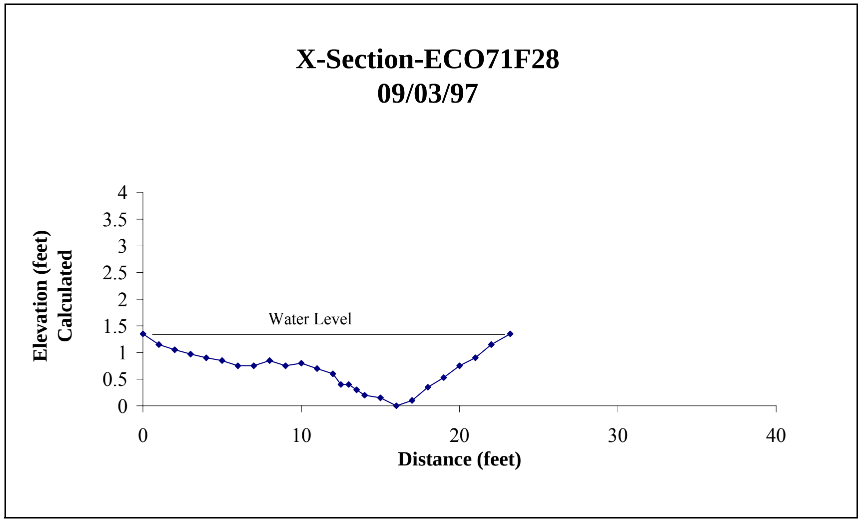

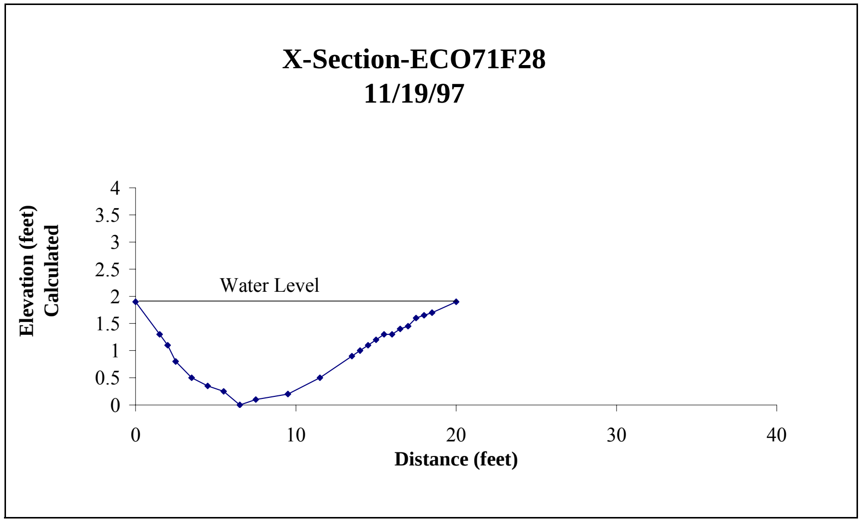

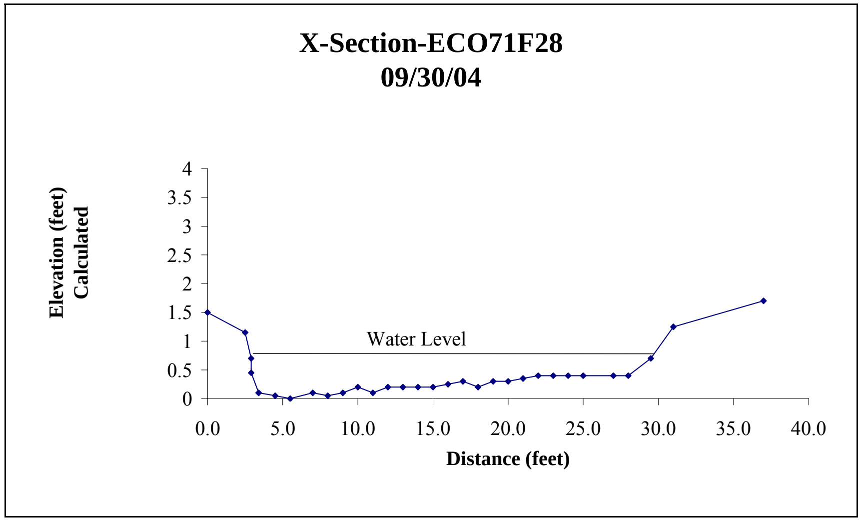

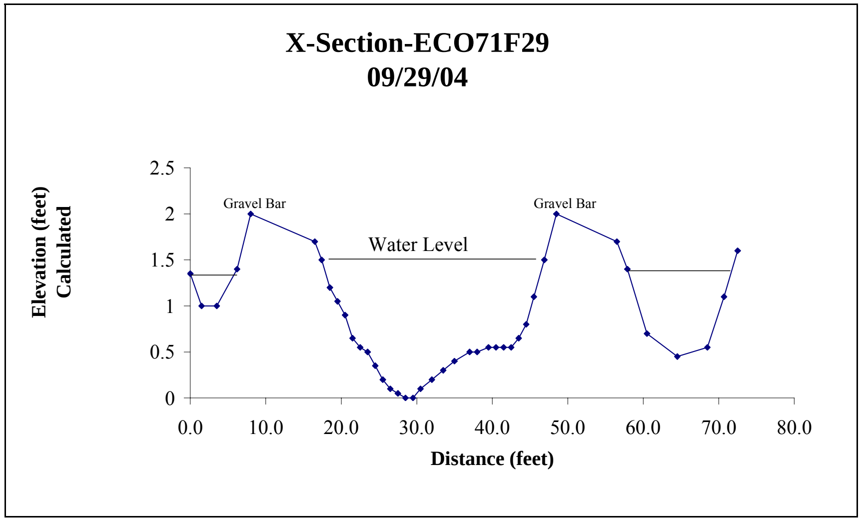

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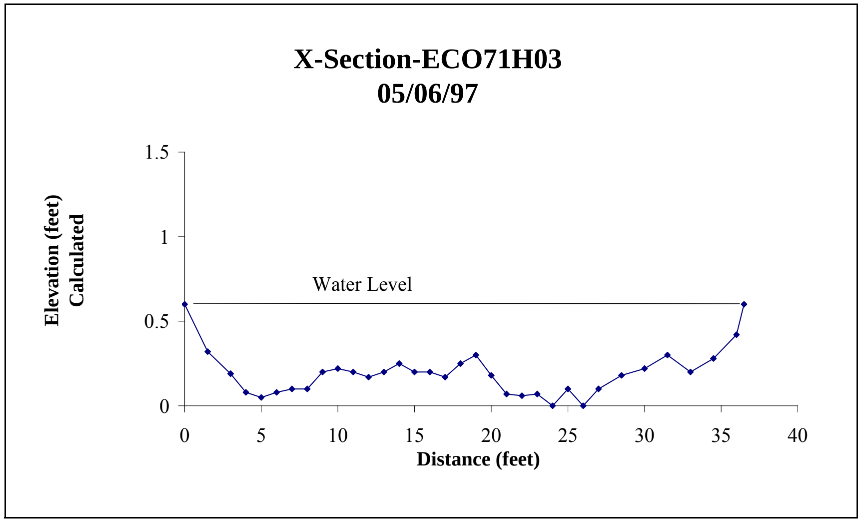

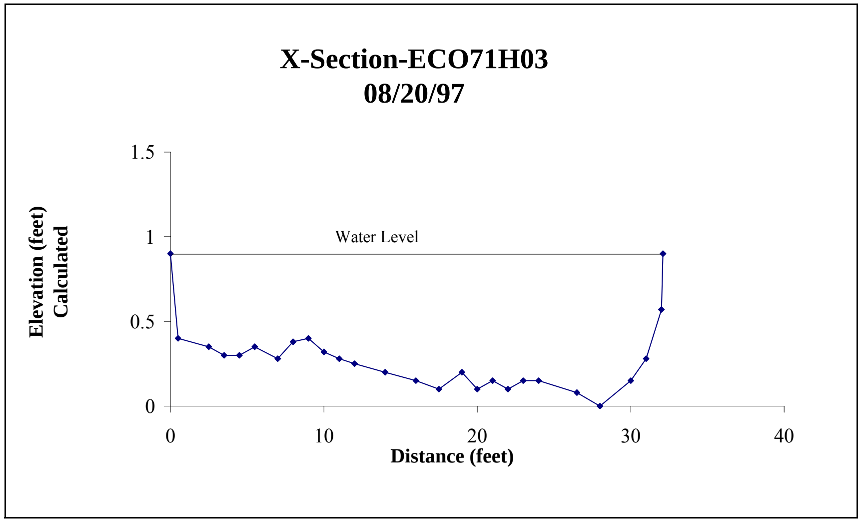

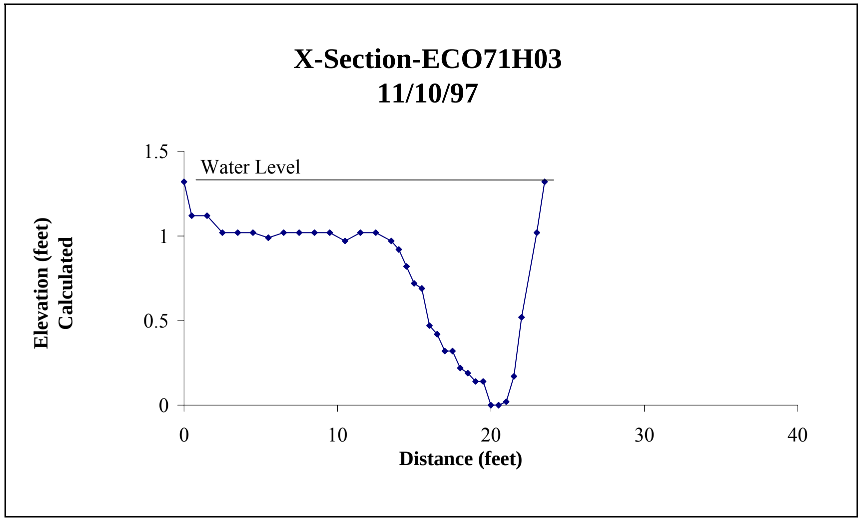

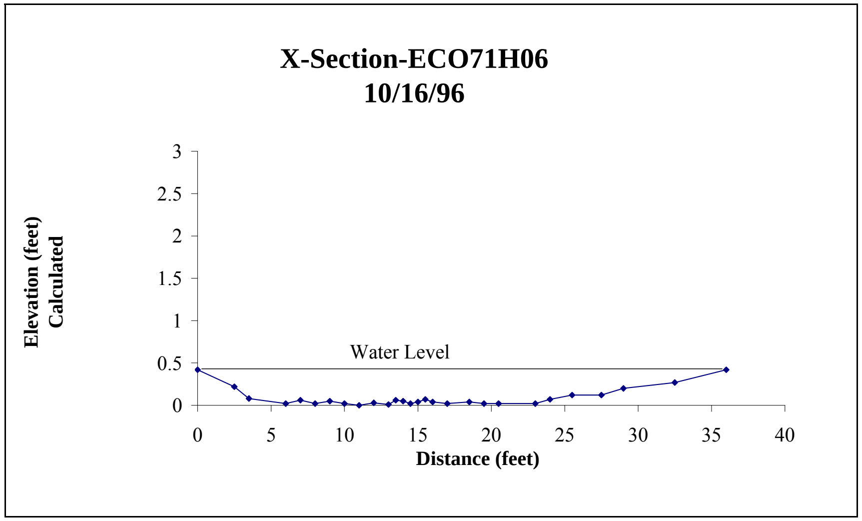

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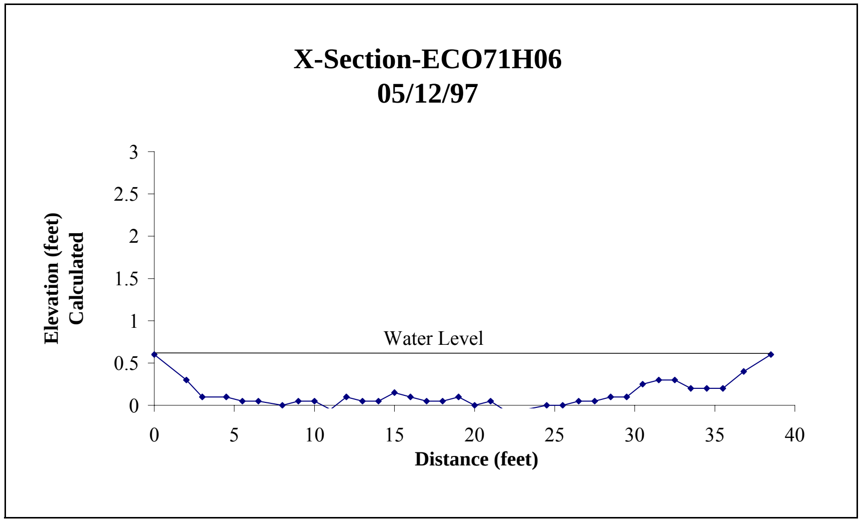

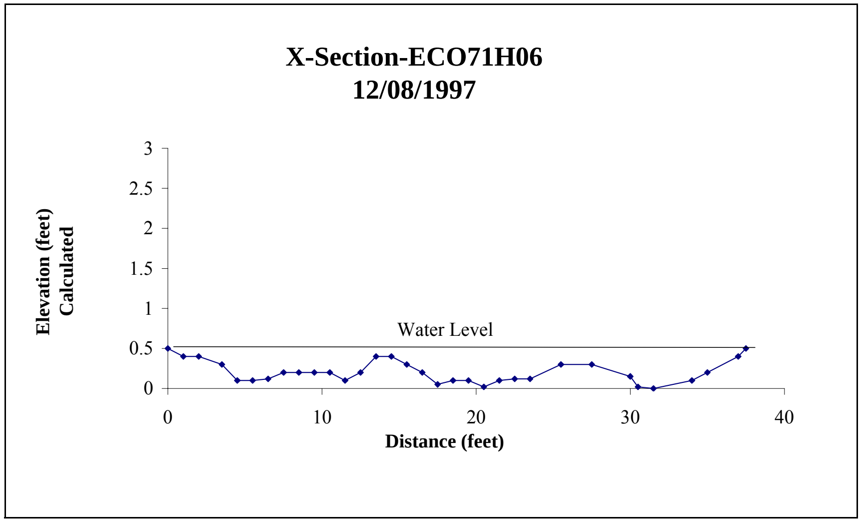

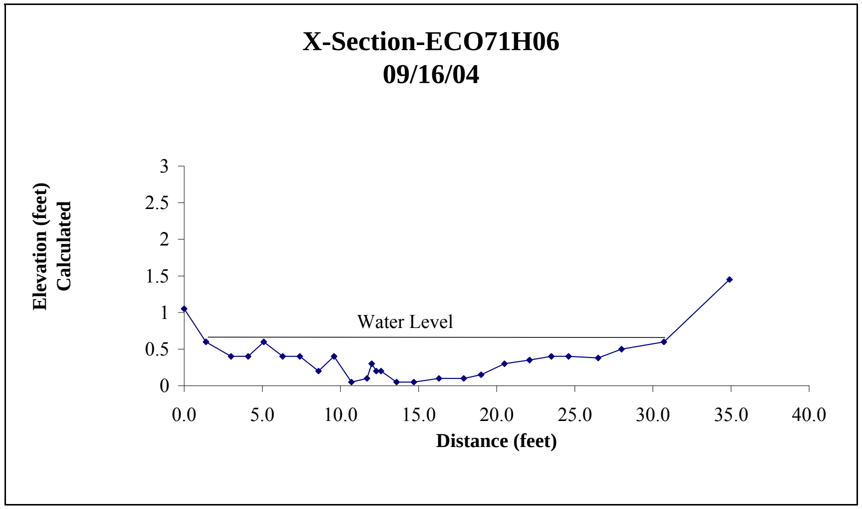

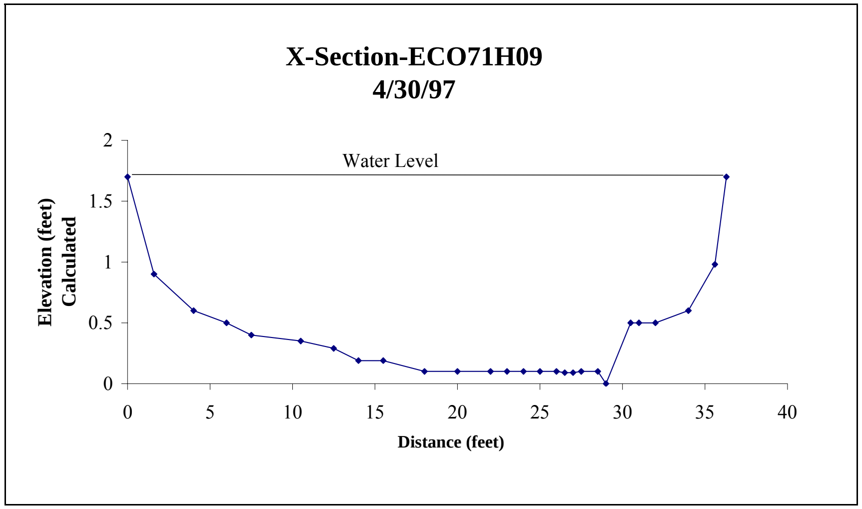

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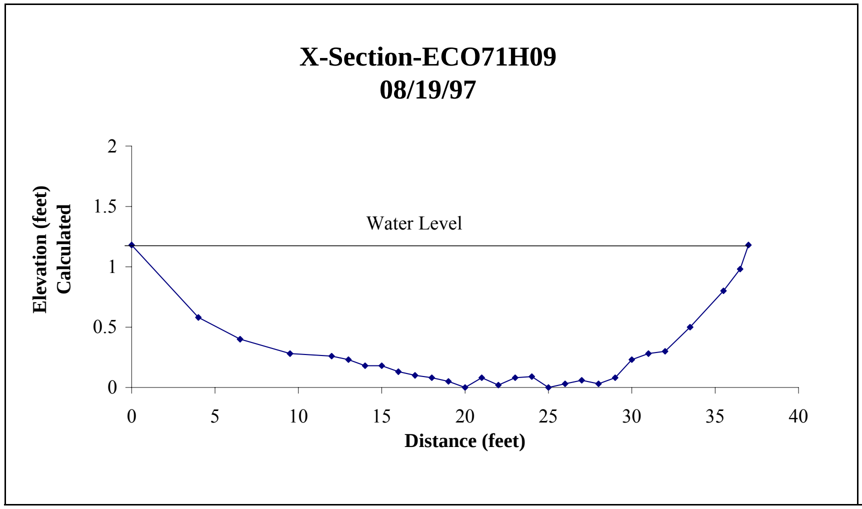

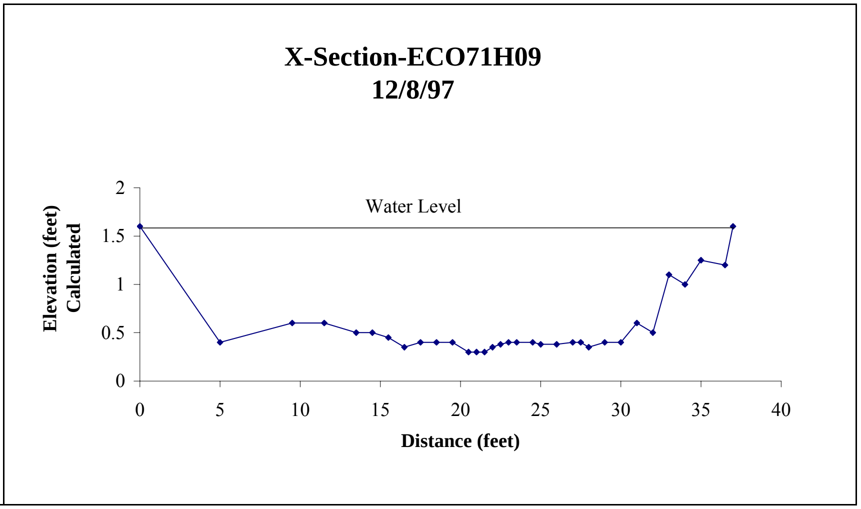

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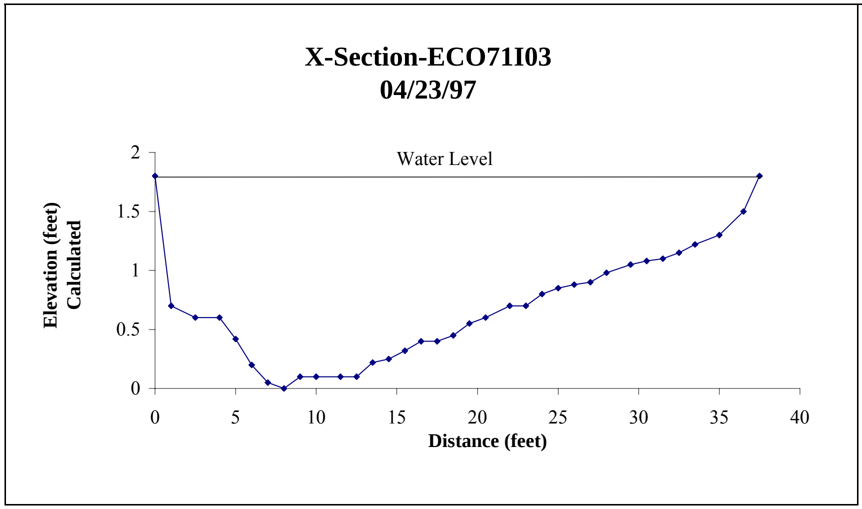

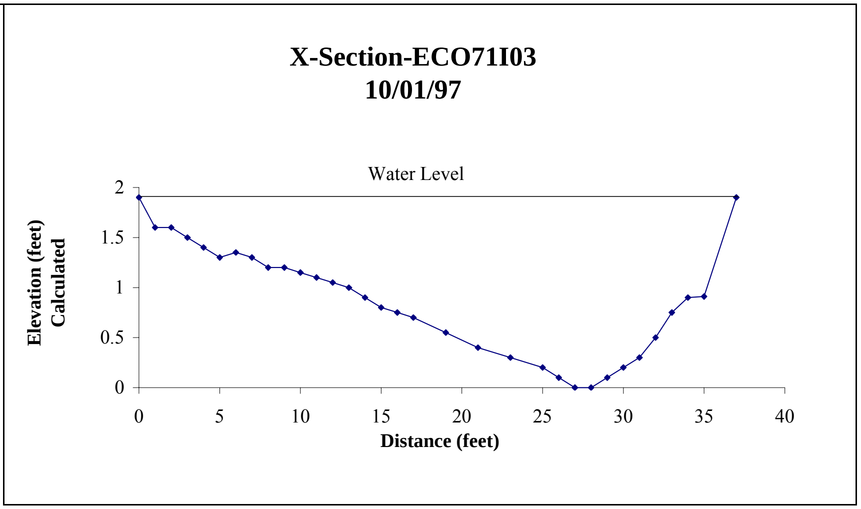

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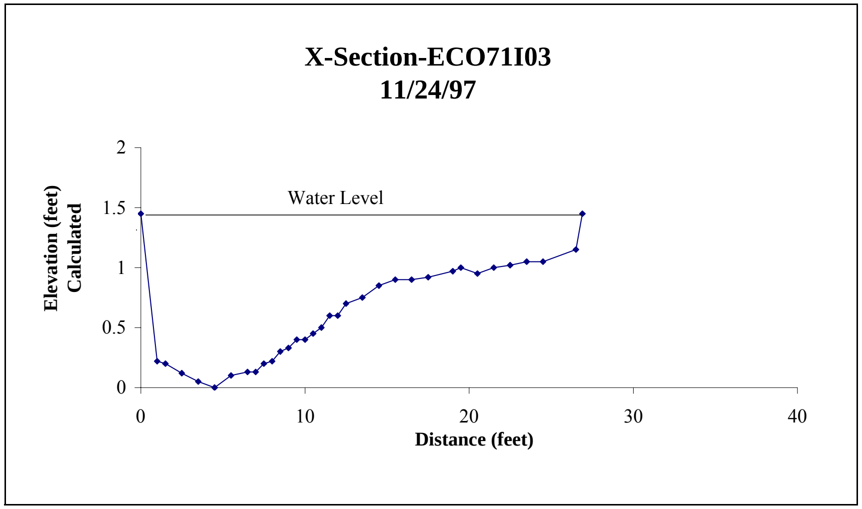

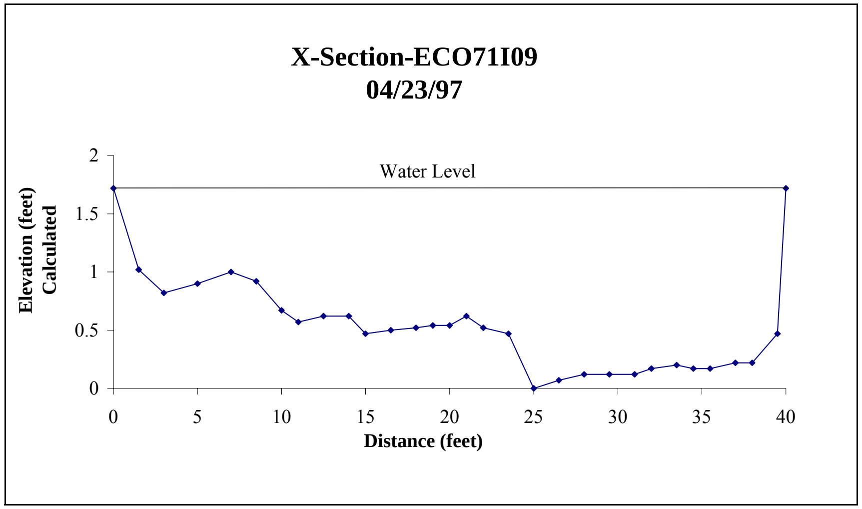

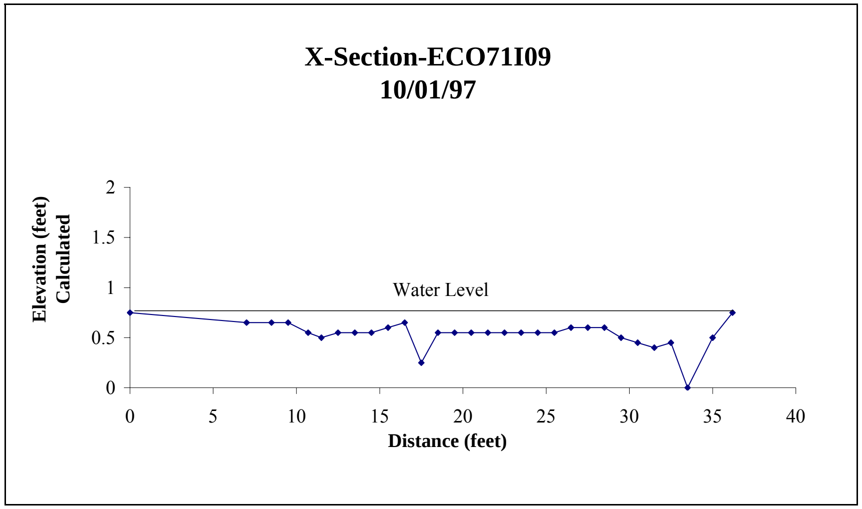

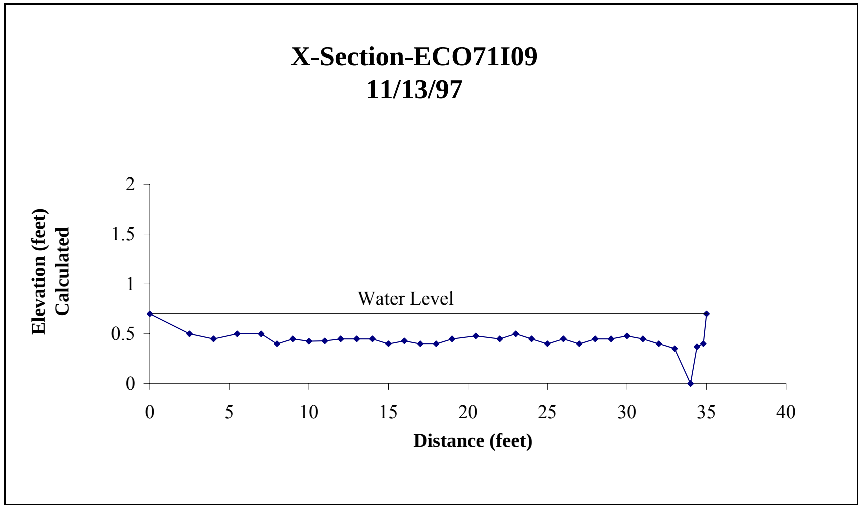

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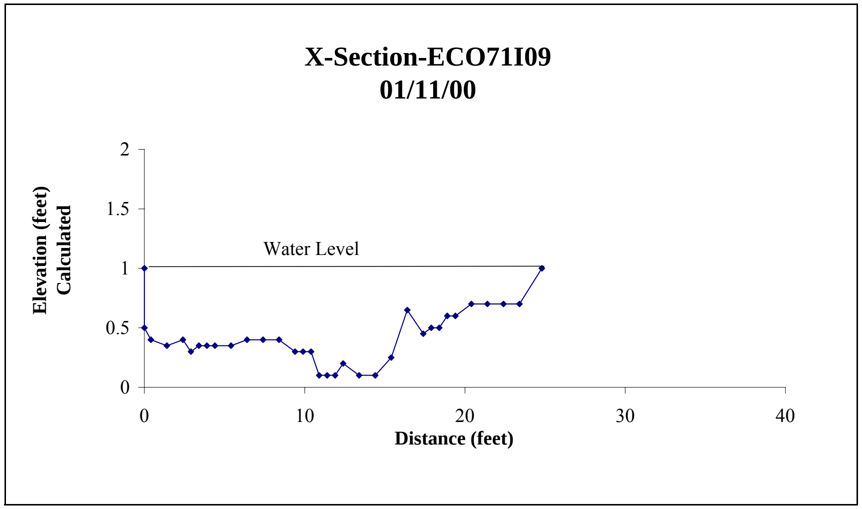

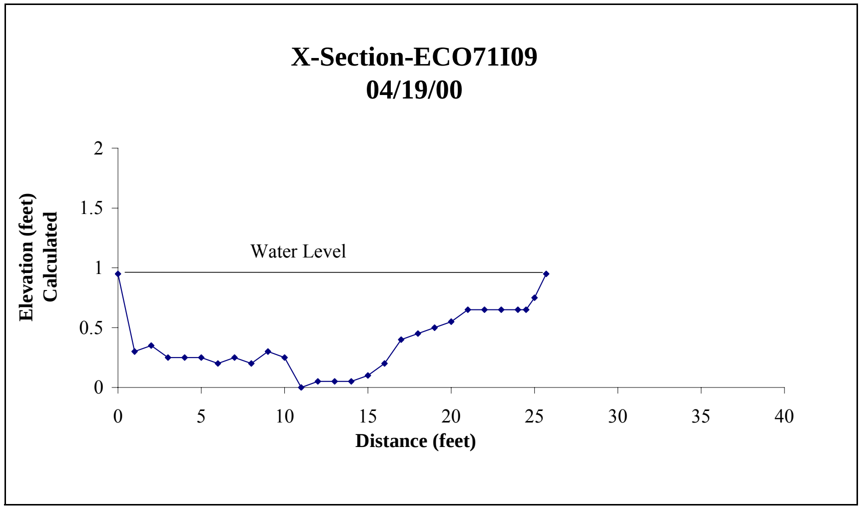

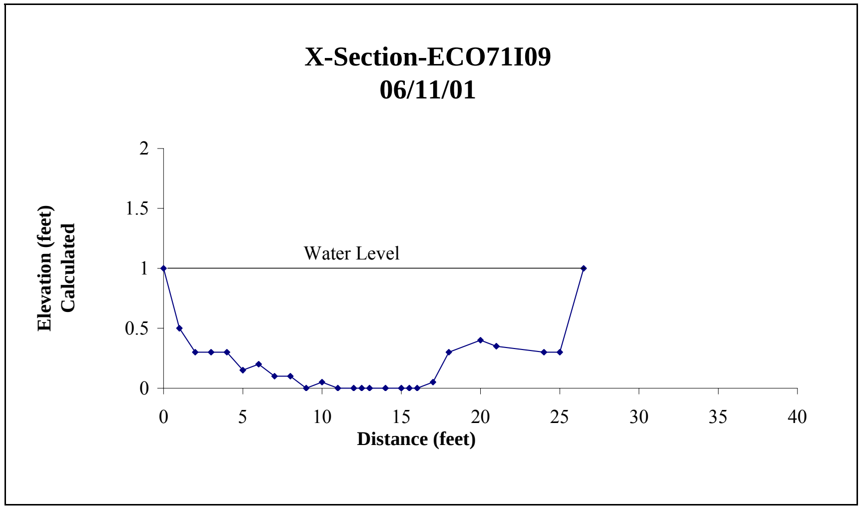

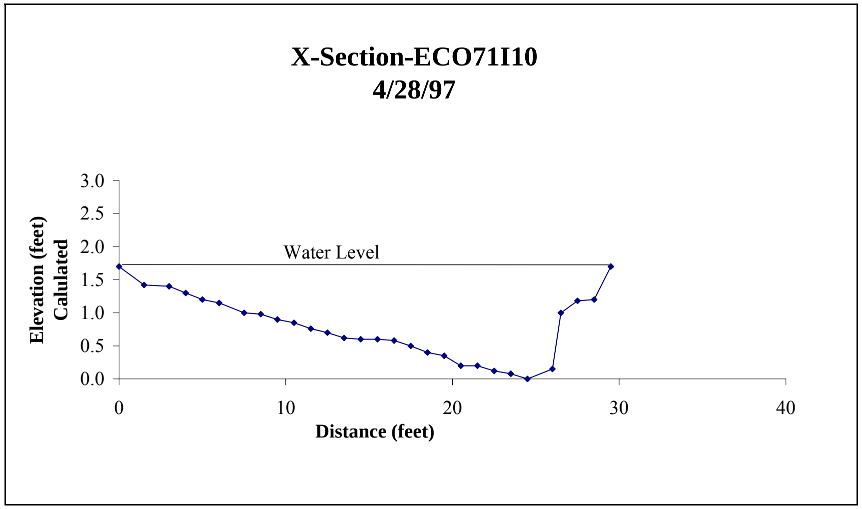

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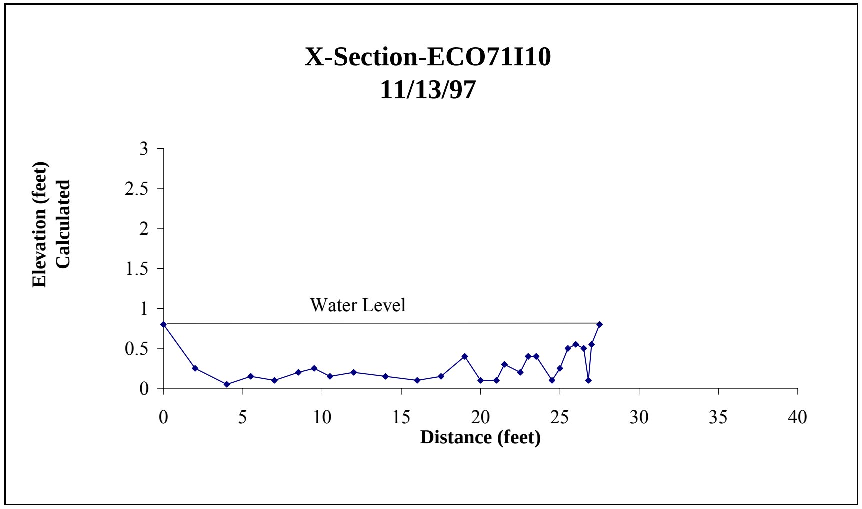

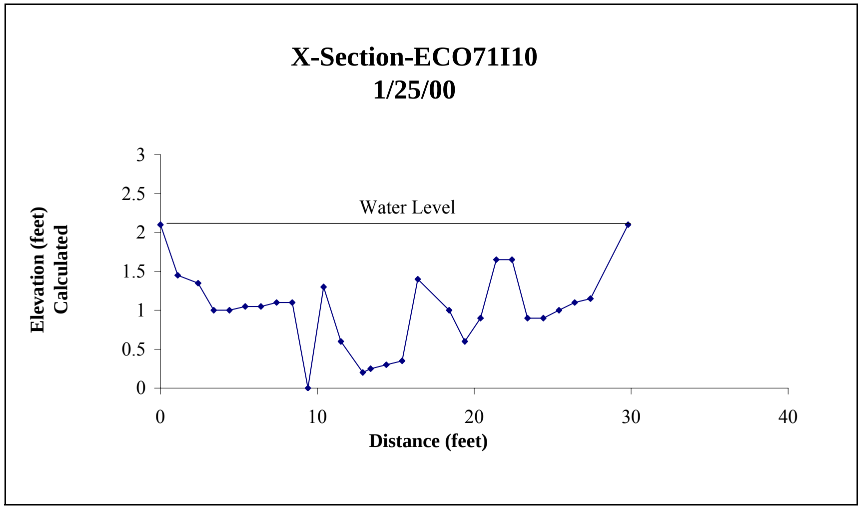

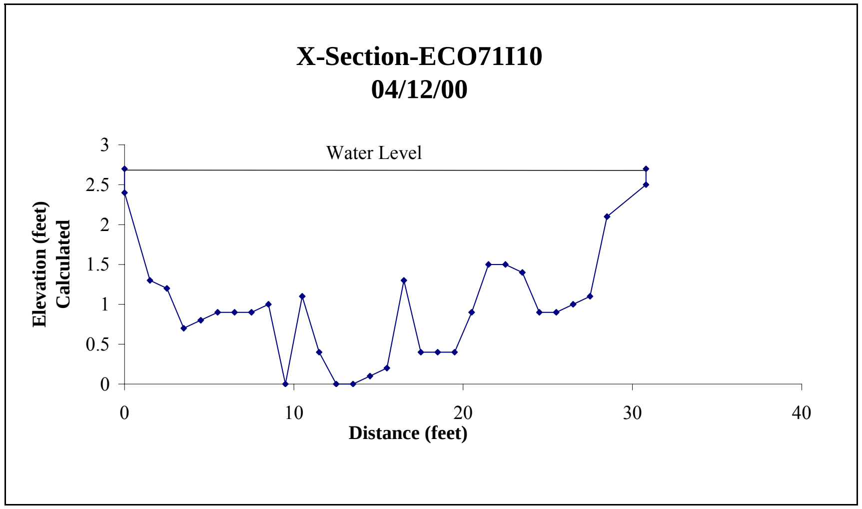

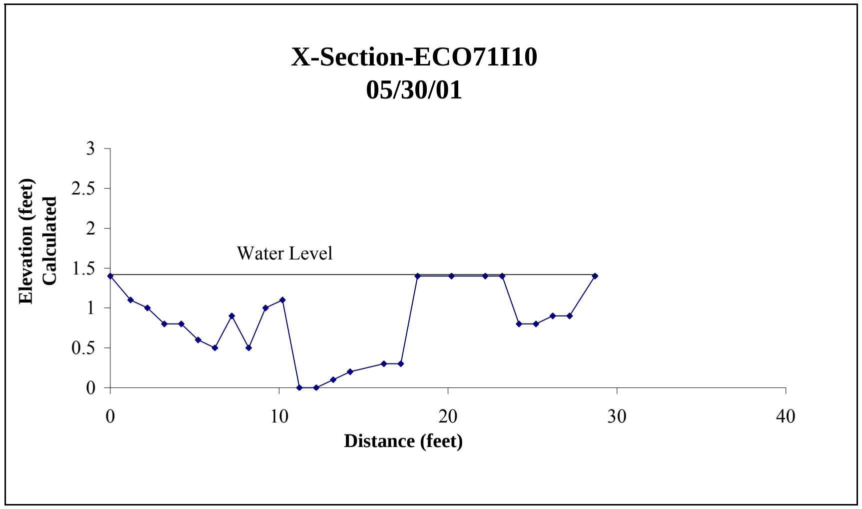

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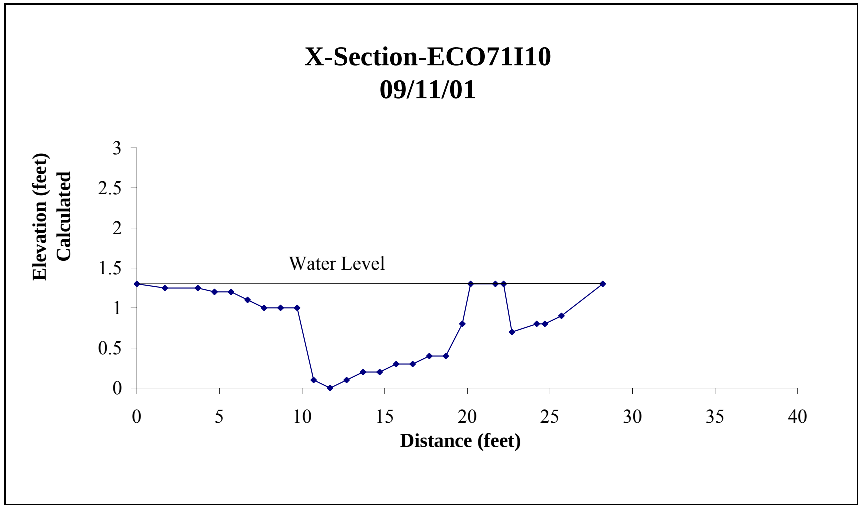

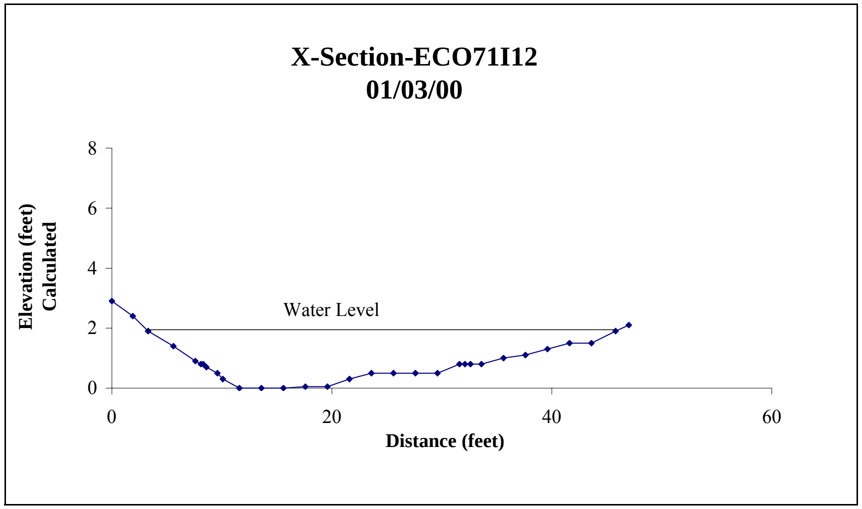

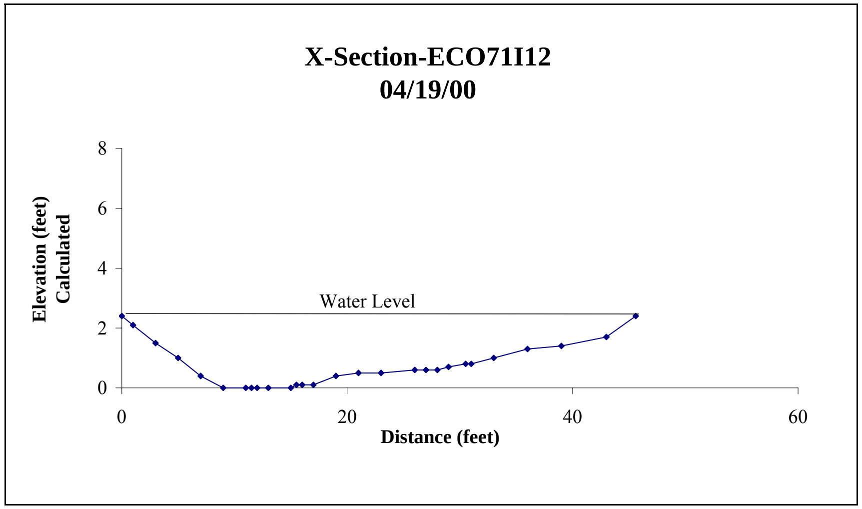

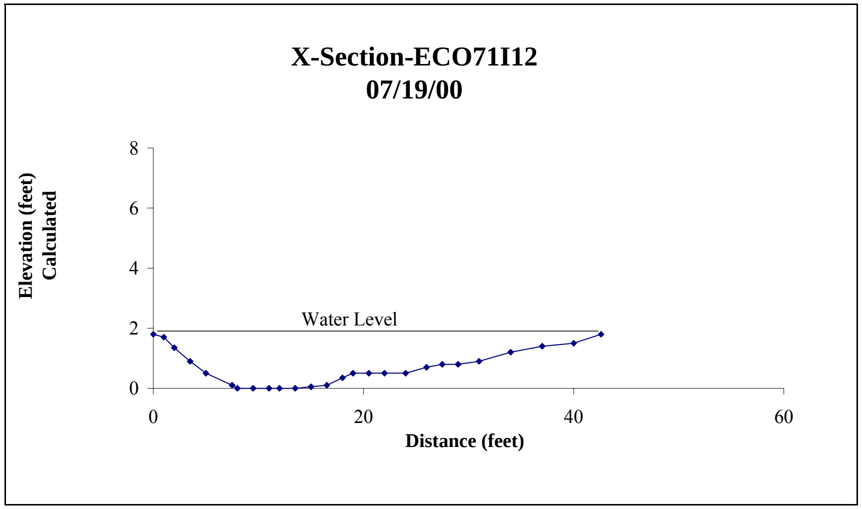

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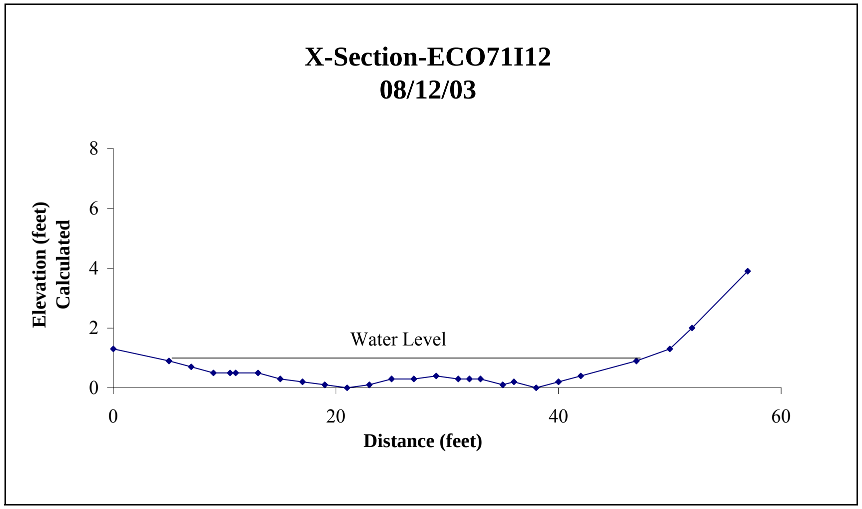

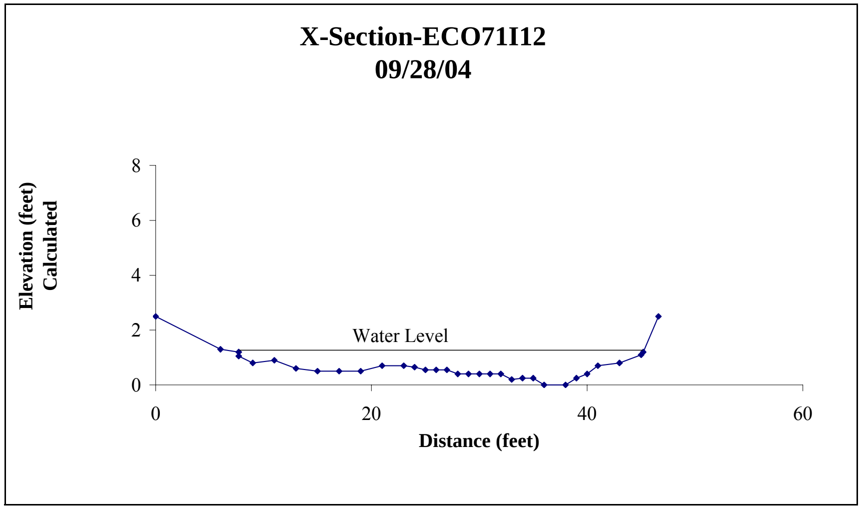

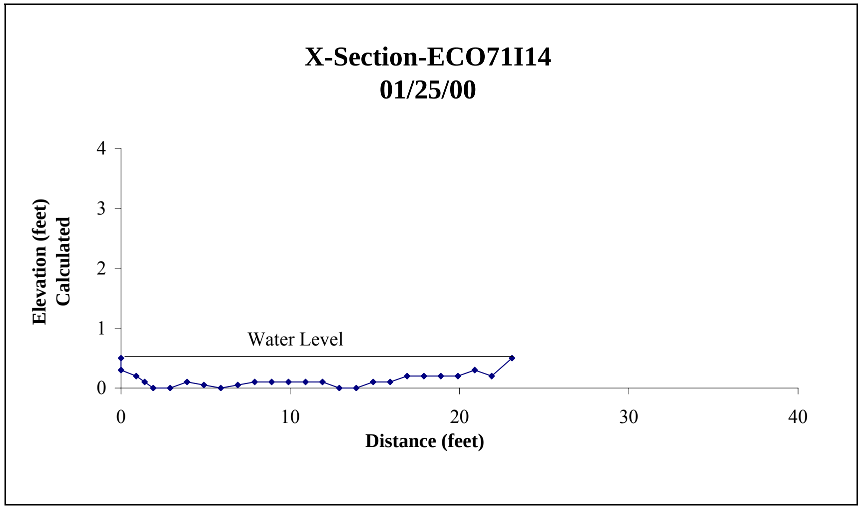

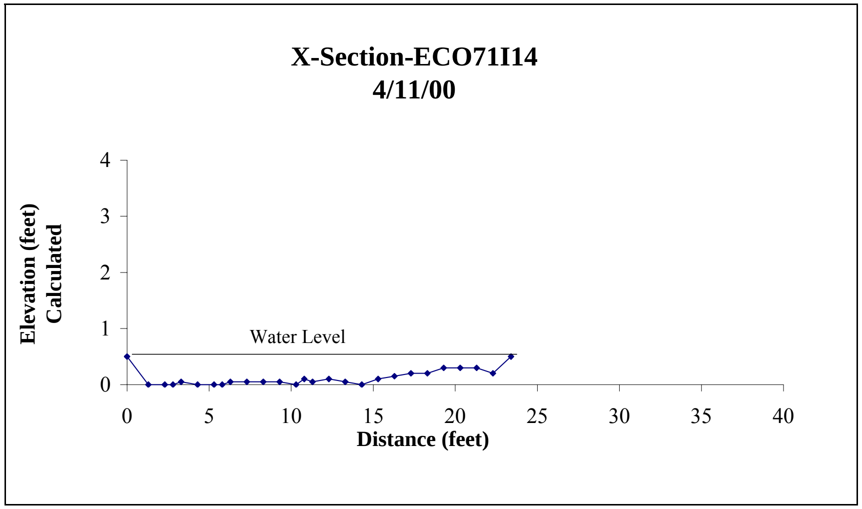

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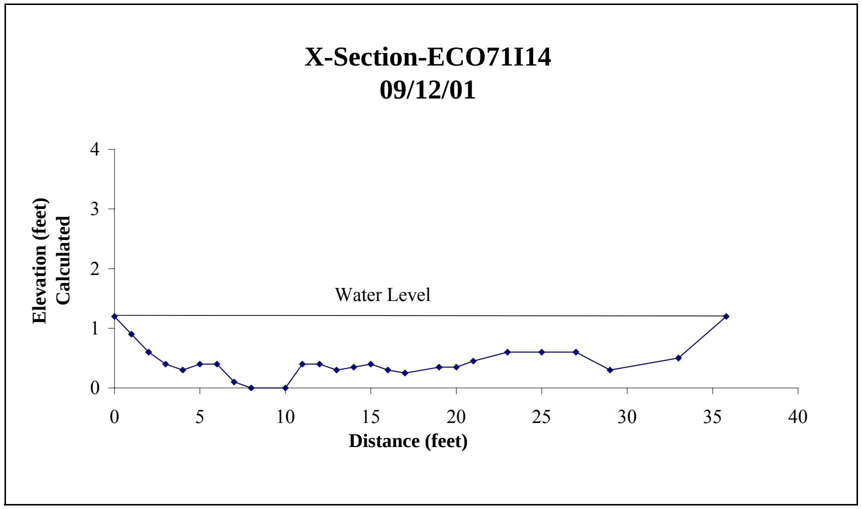

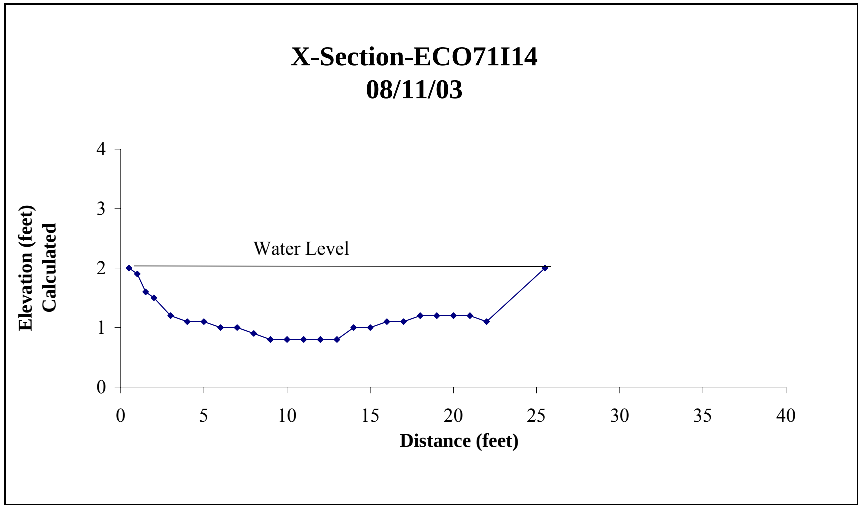

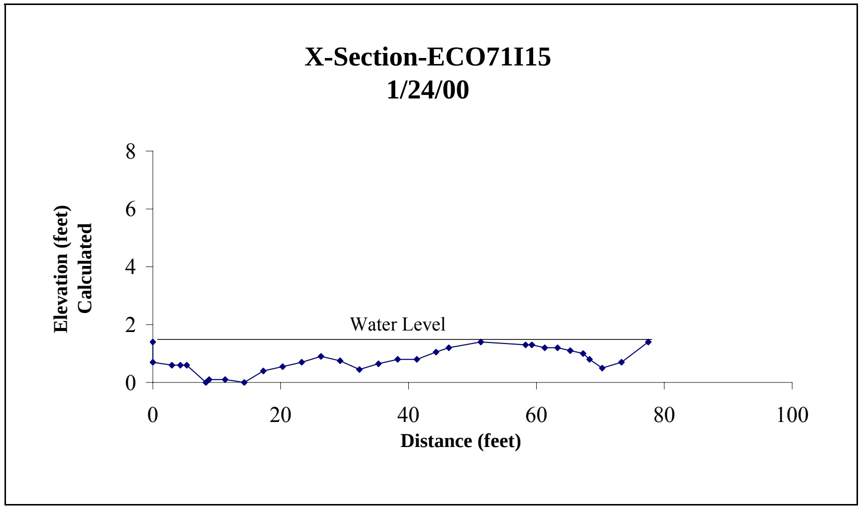

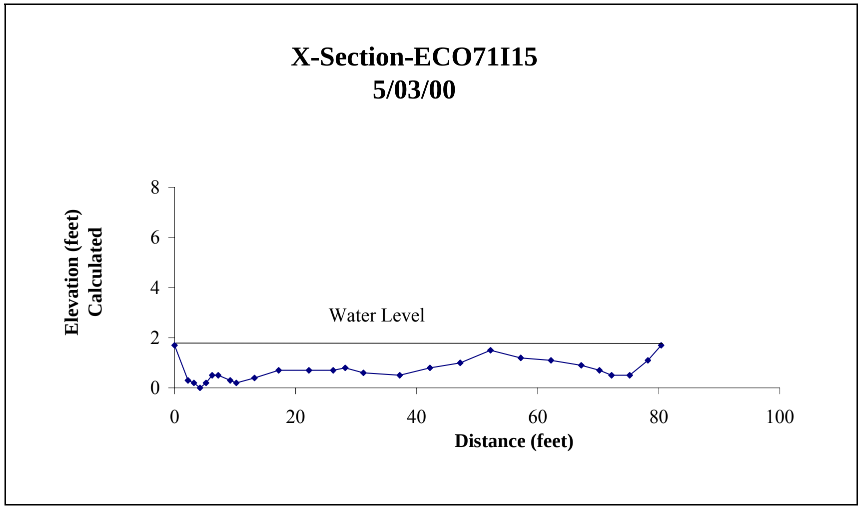

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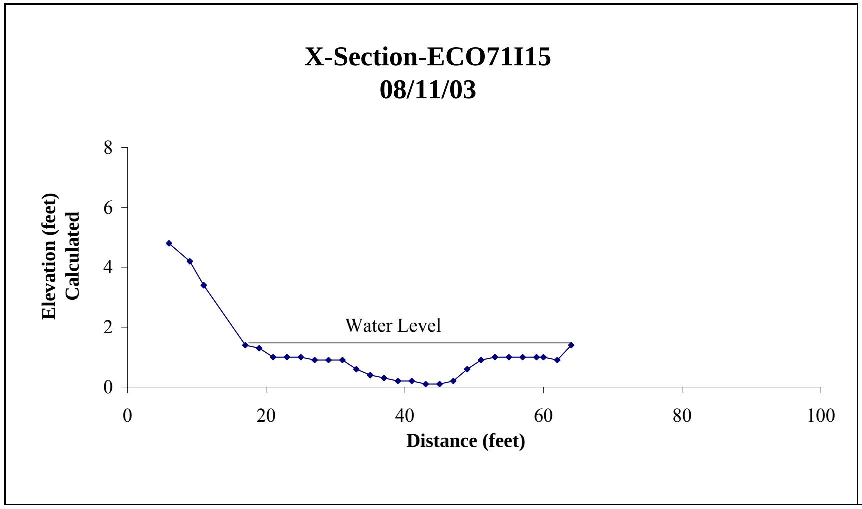
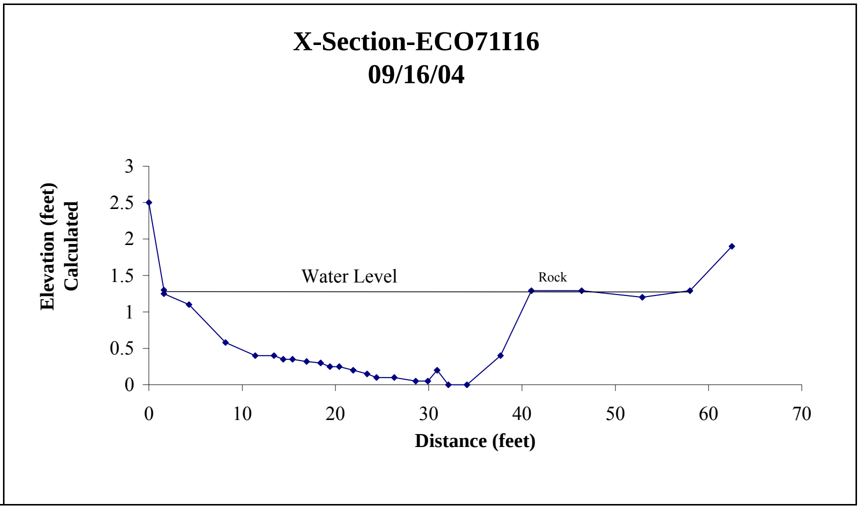
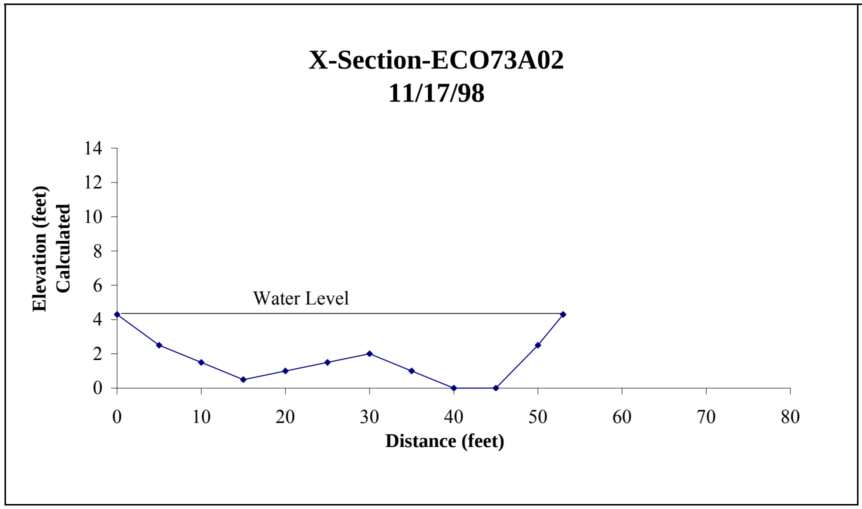
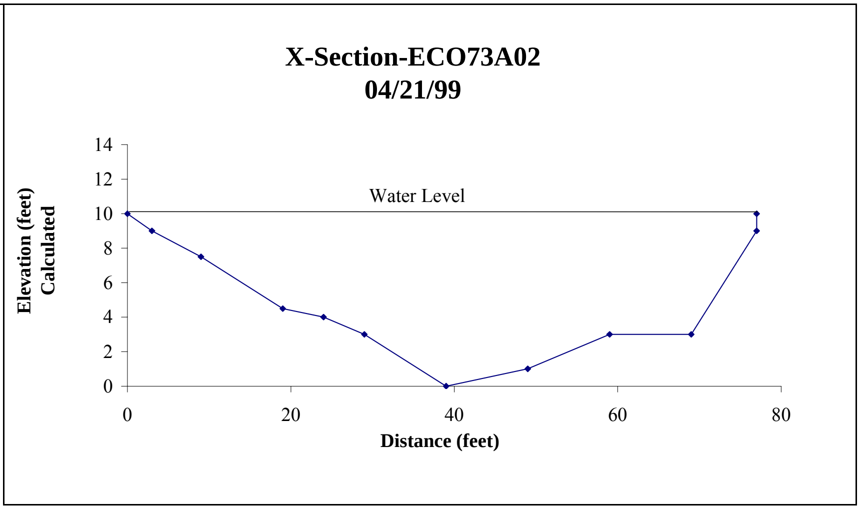




ECOREGION 73A





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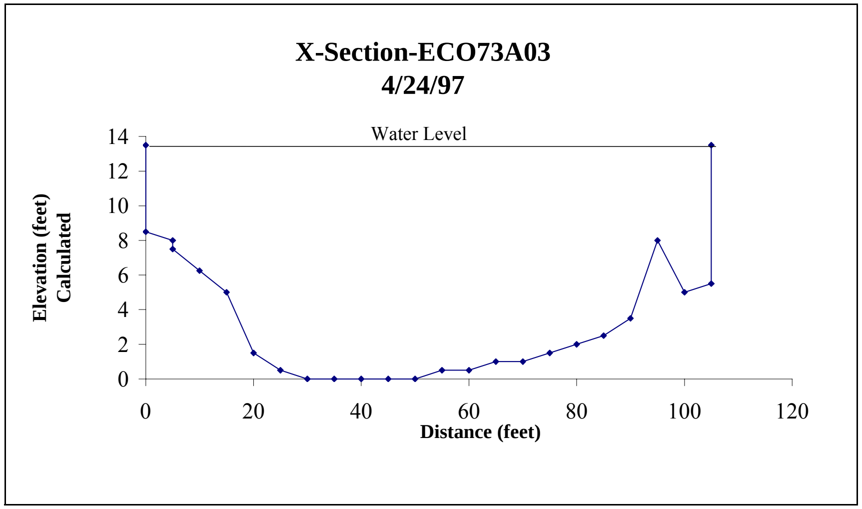

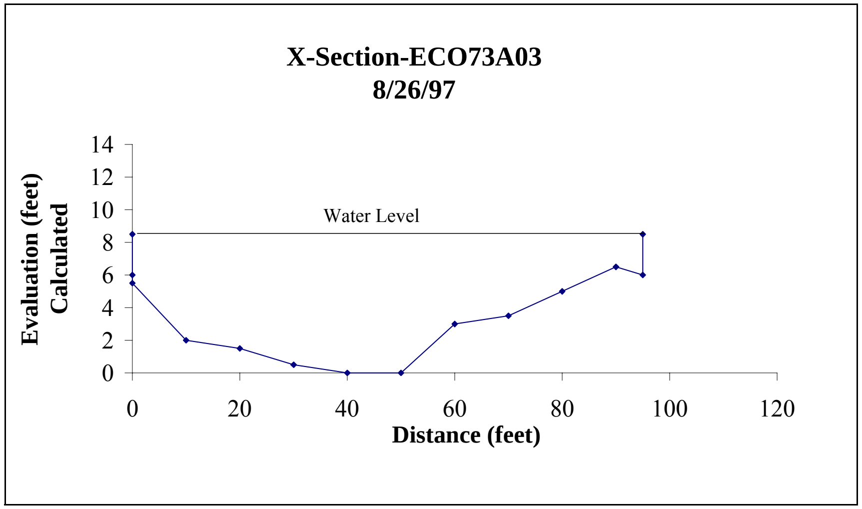

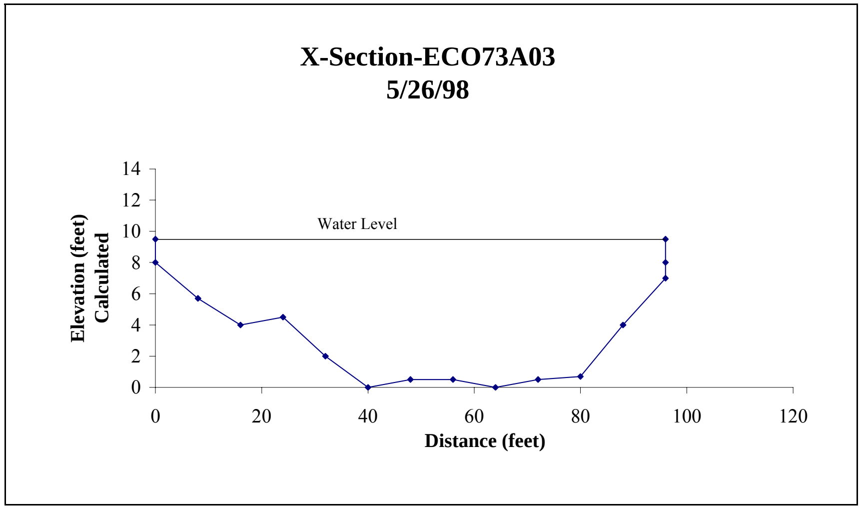

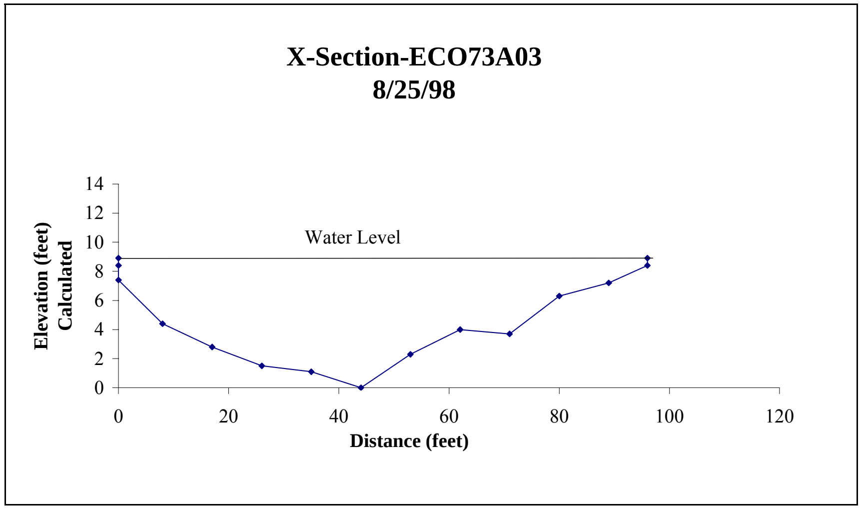

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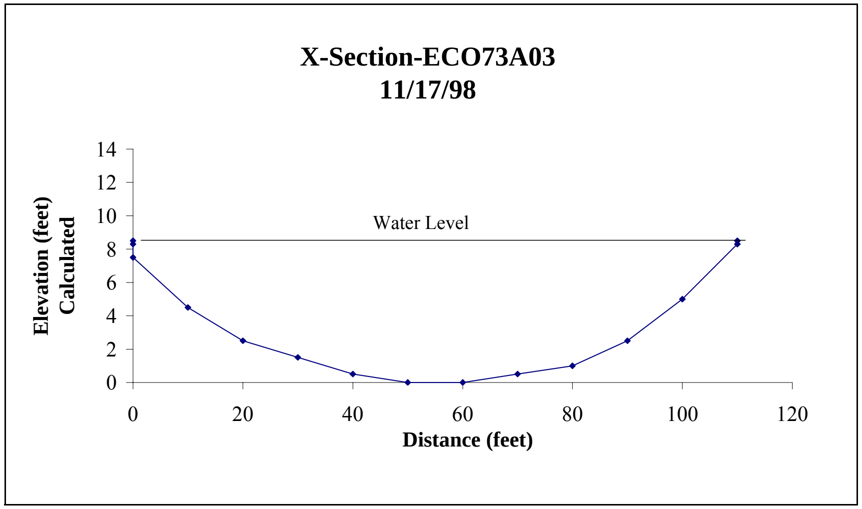

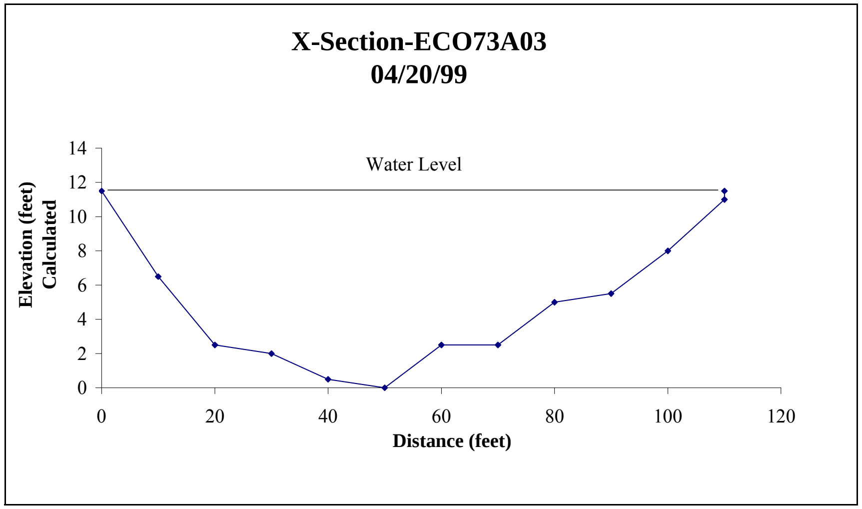

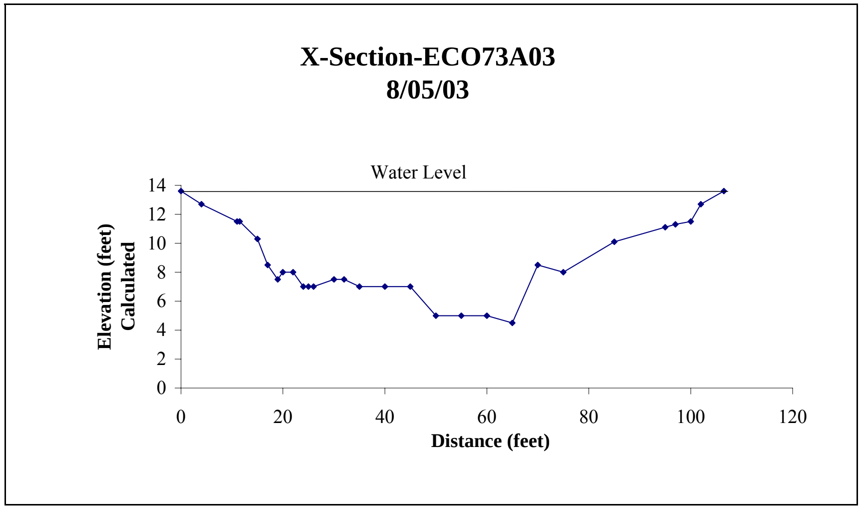

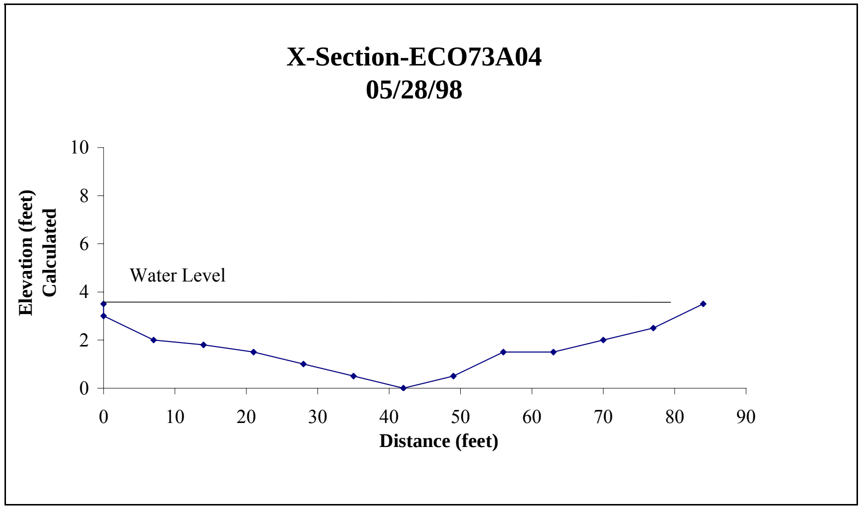

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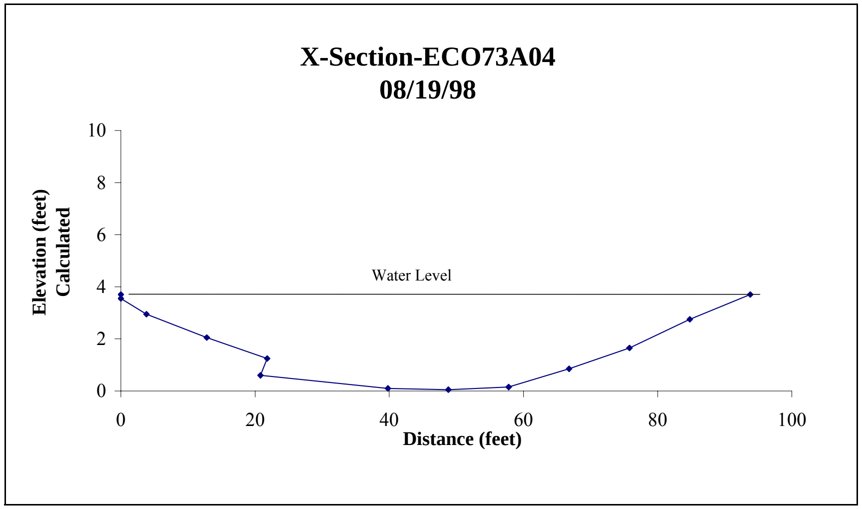

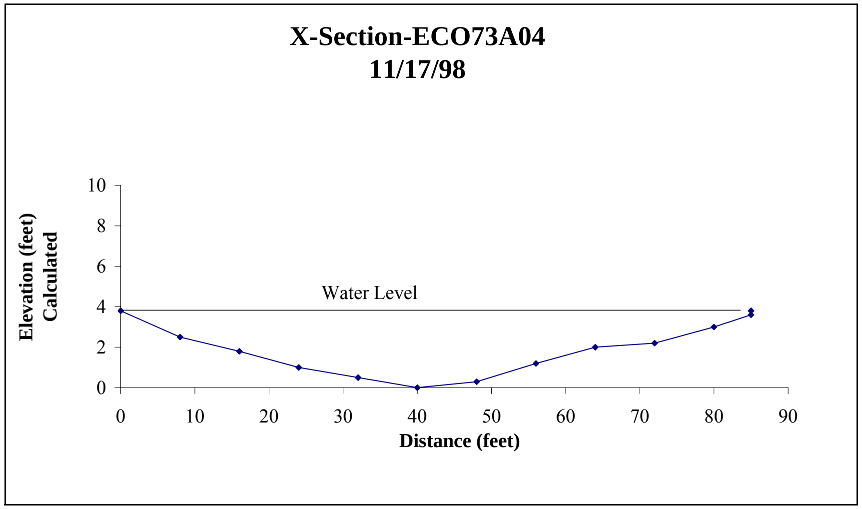

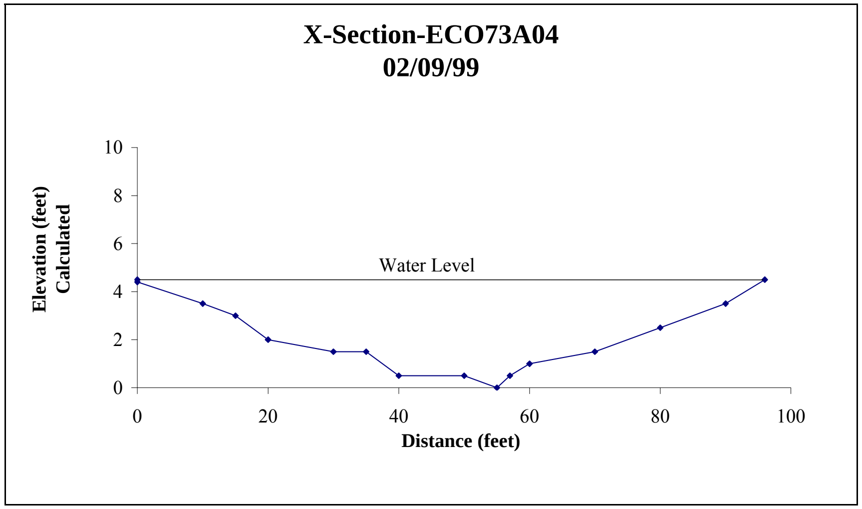

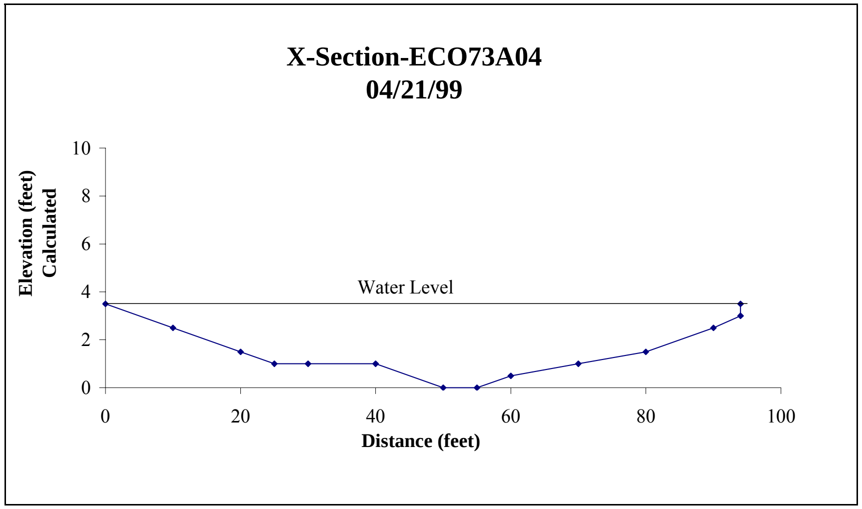

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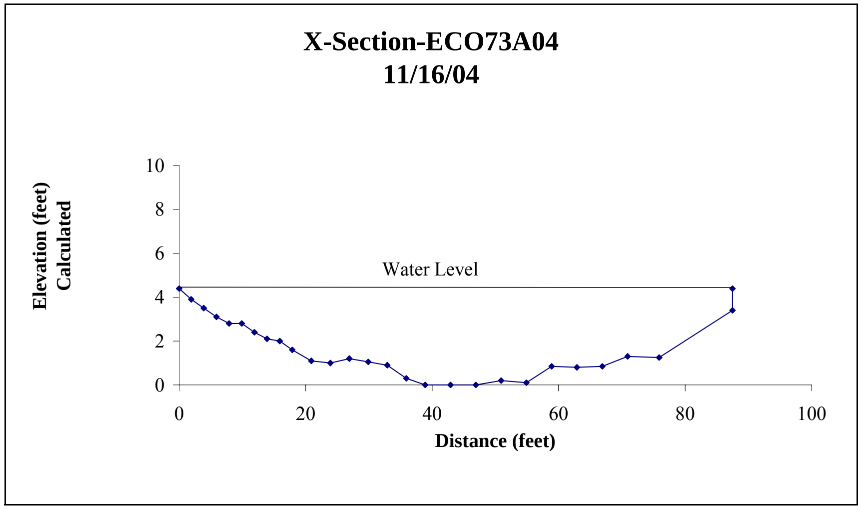
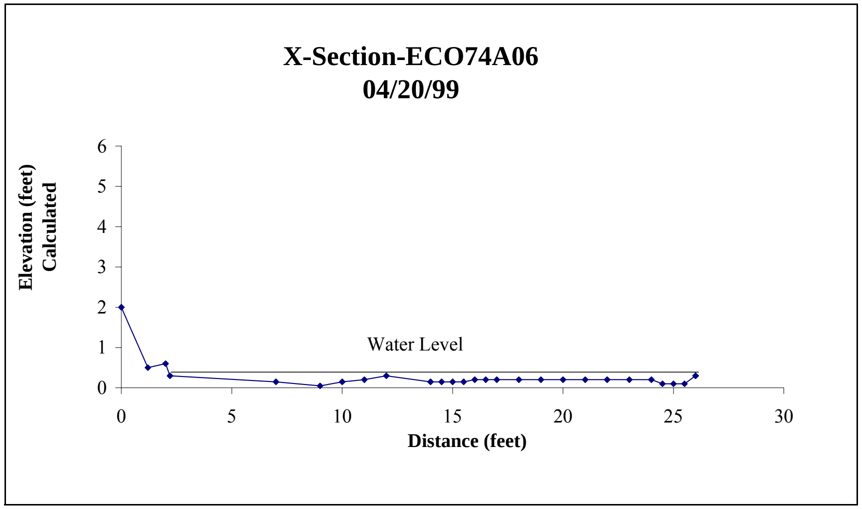
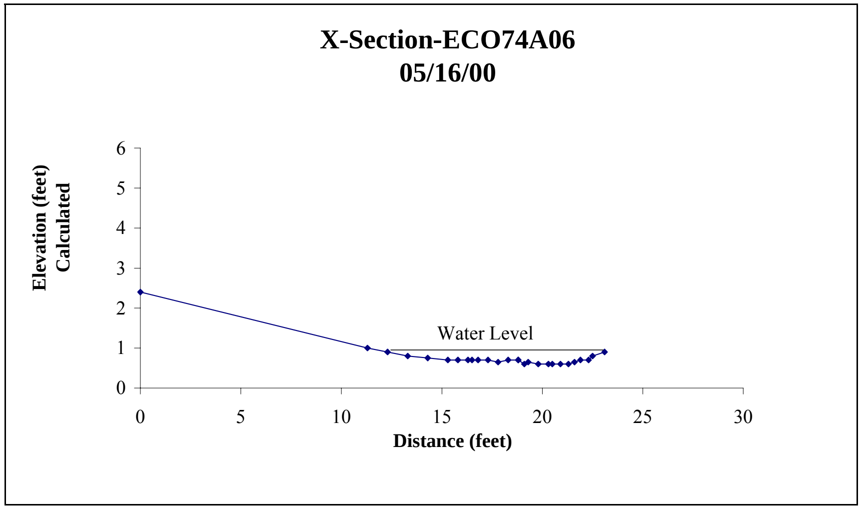
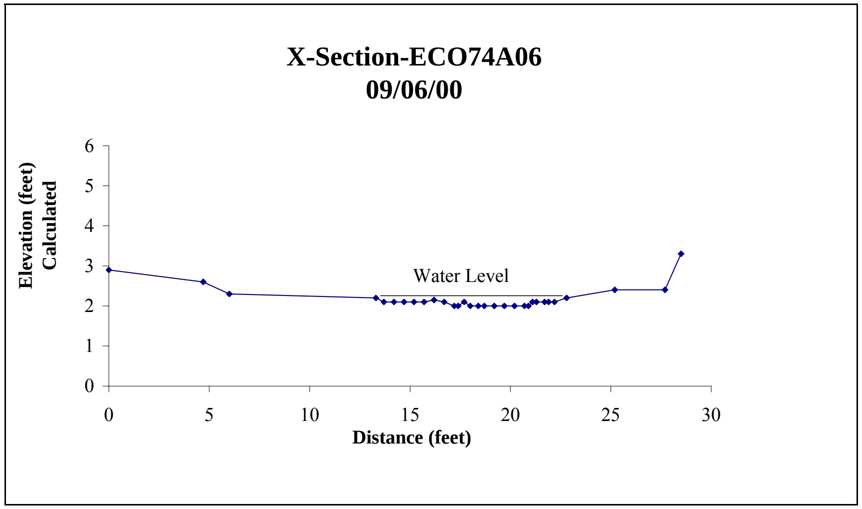
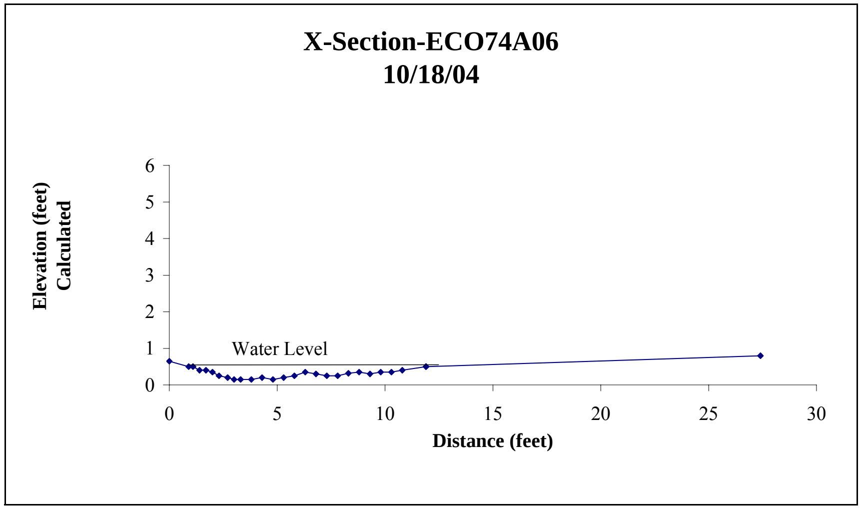


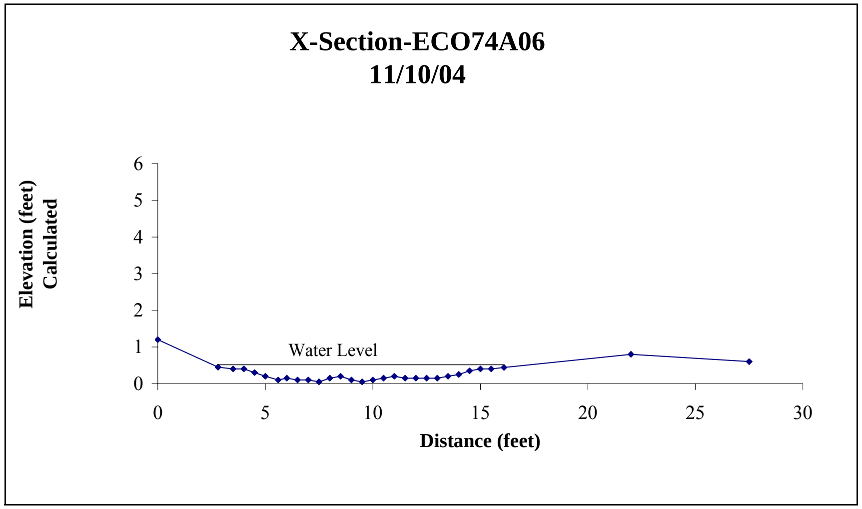


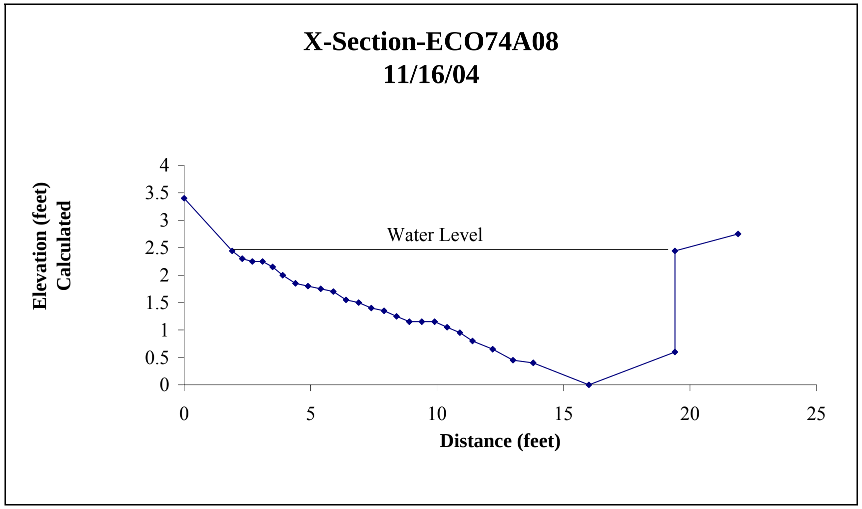




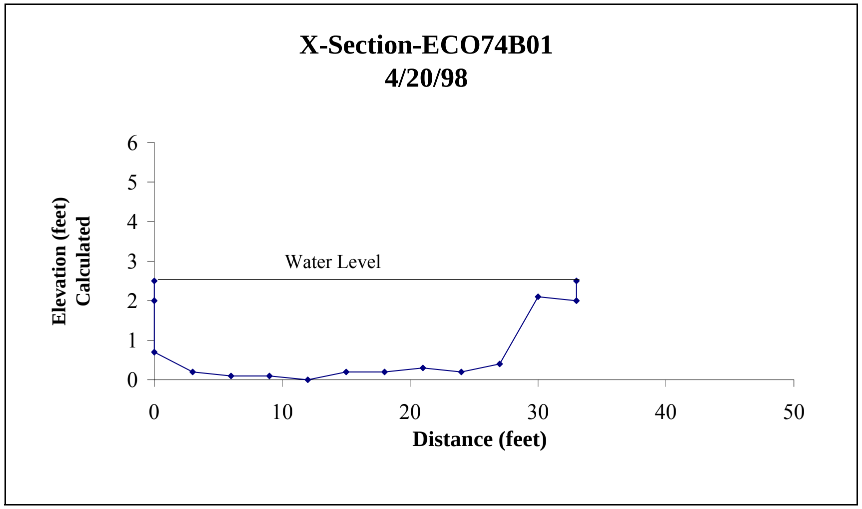
ECOREGION 74A

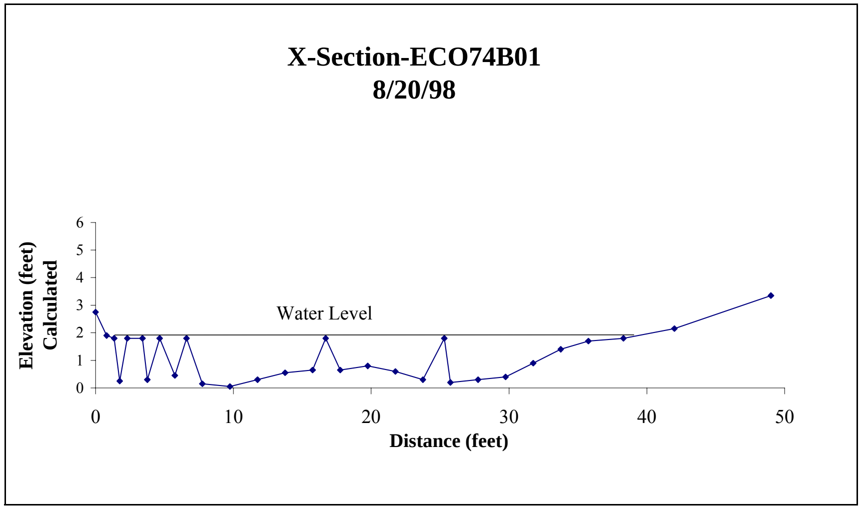


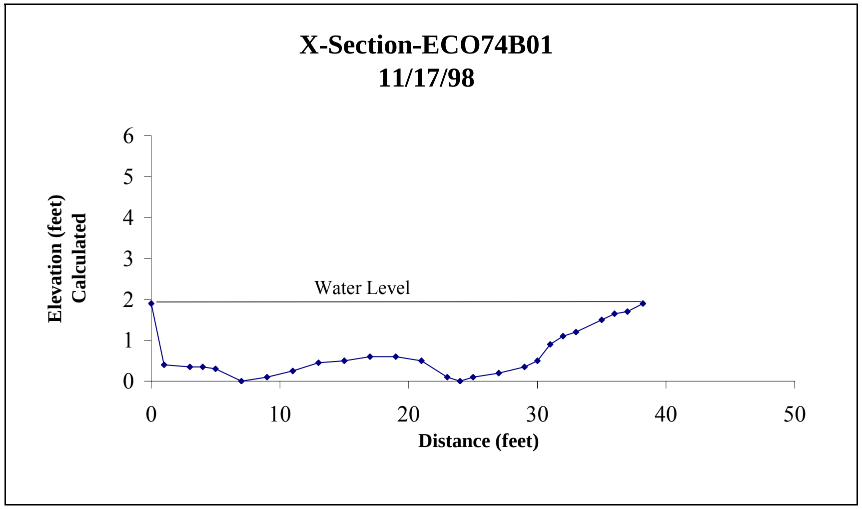


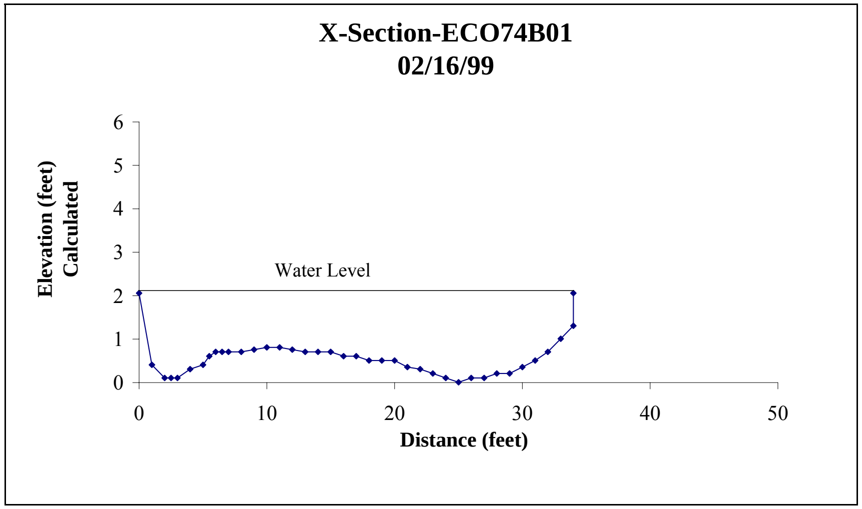


ECOREGION 74B









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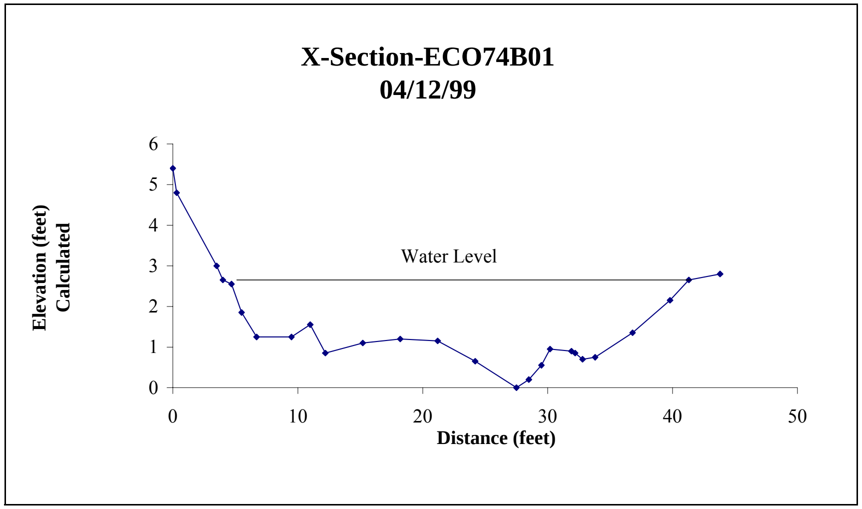

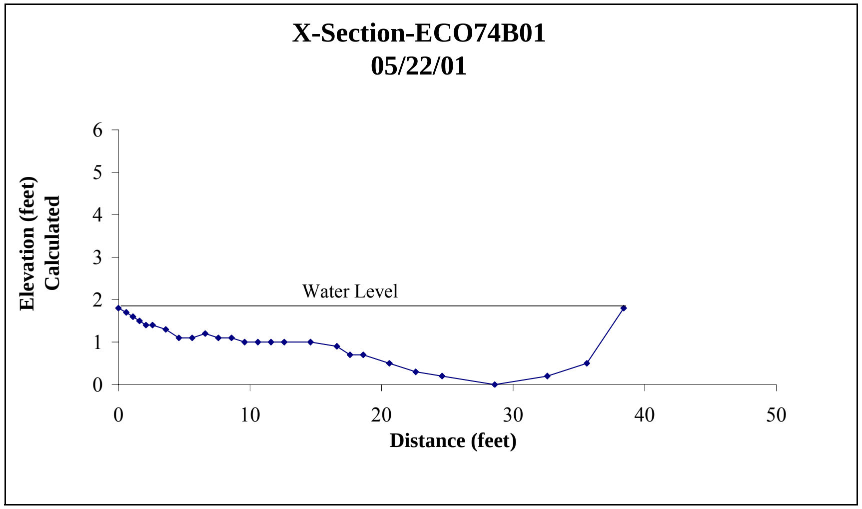

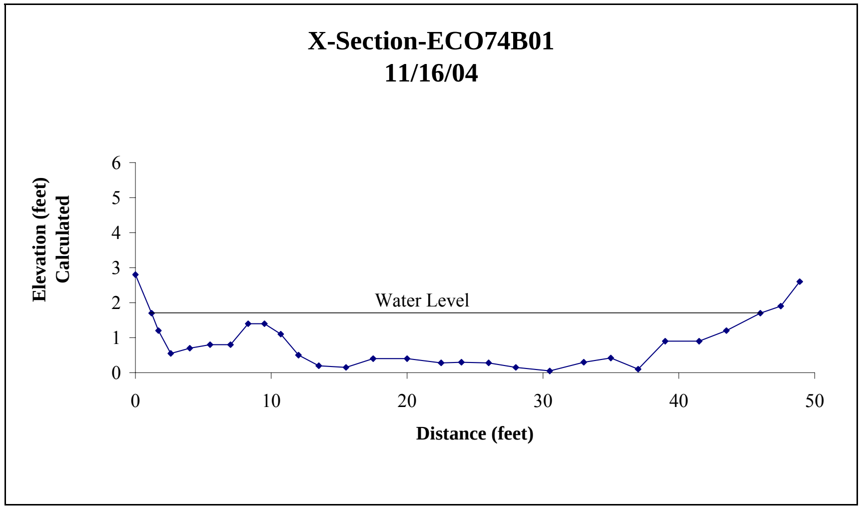

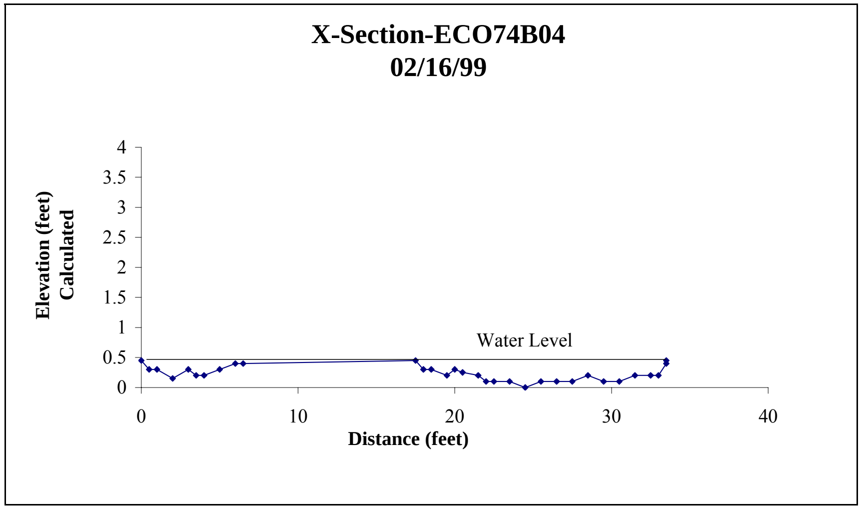

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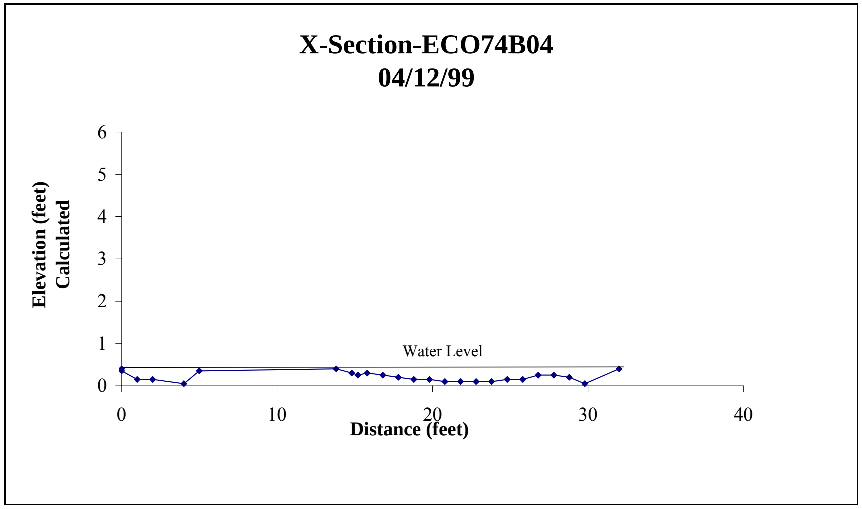

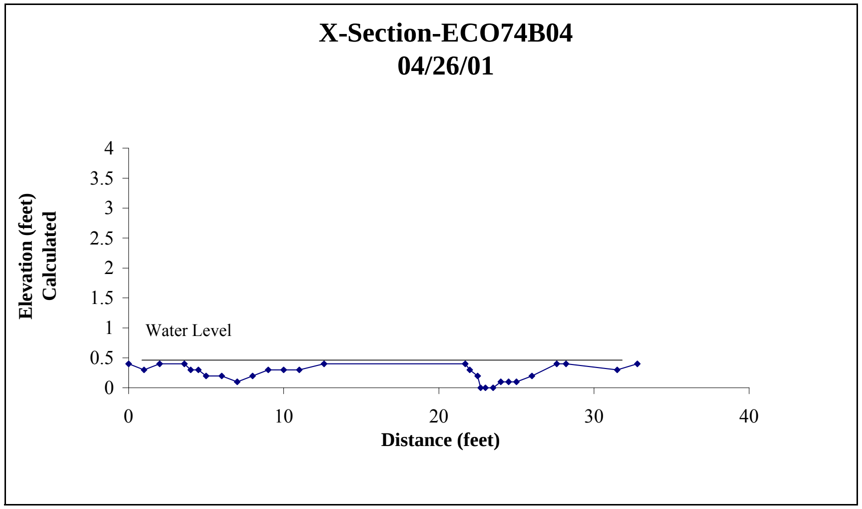

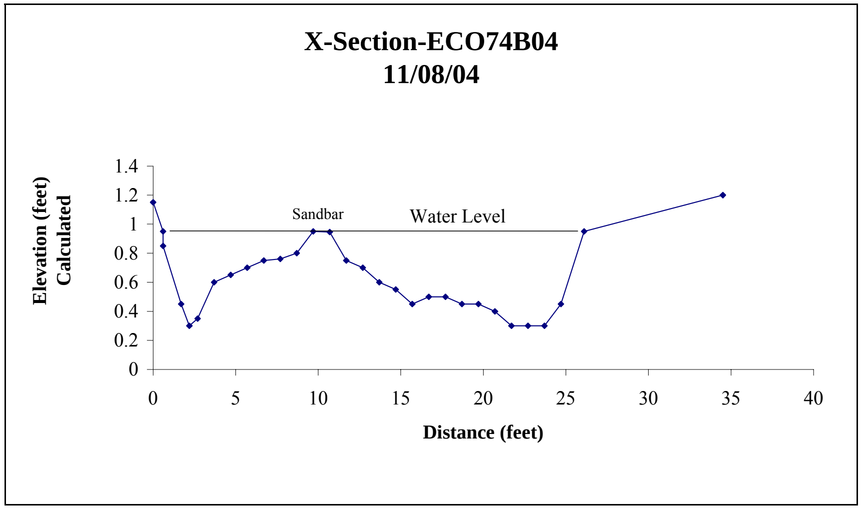

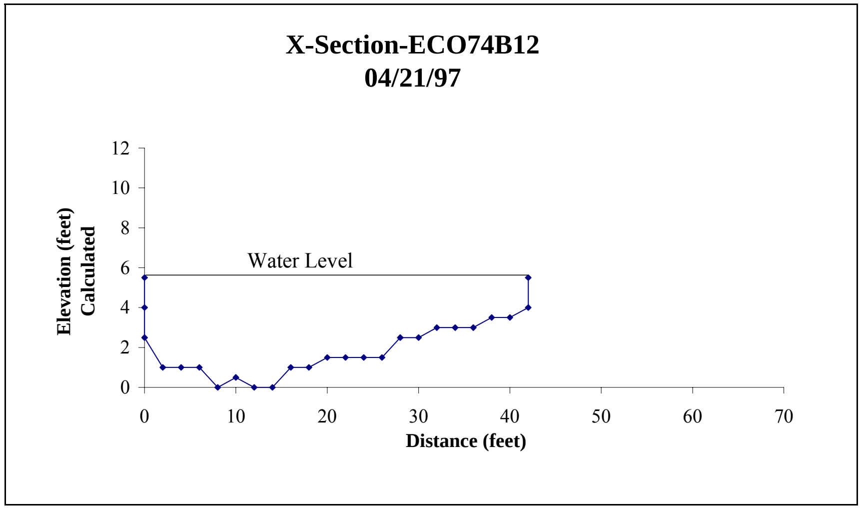

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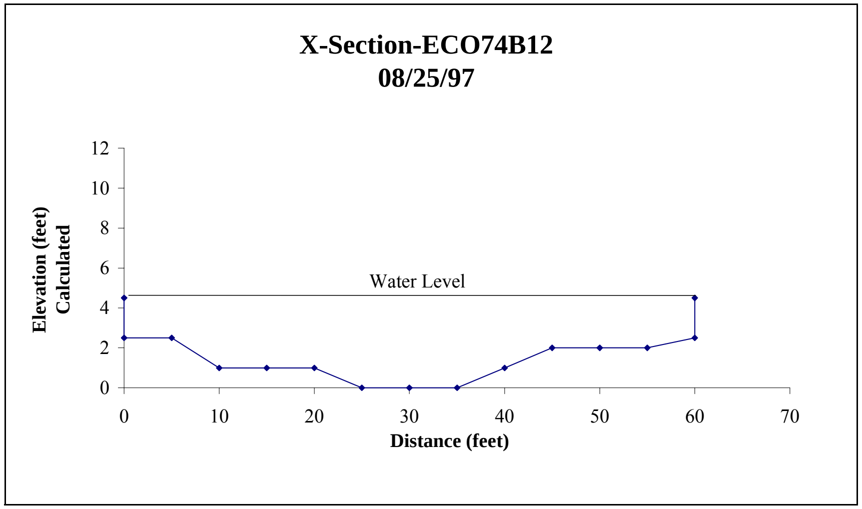

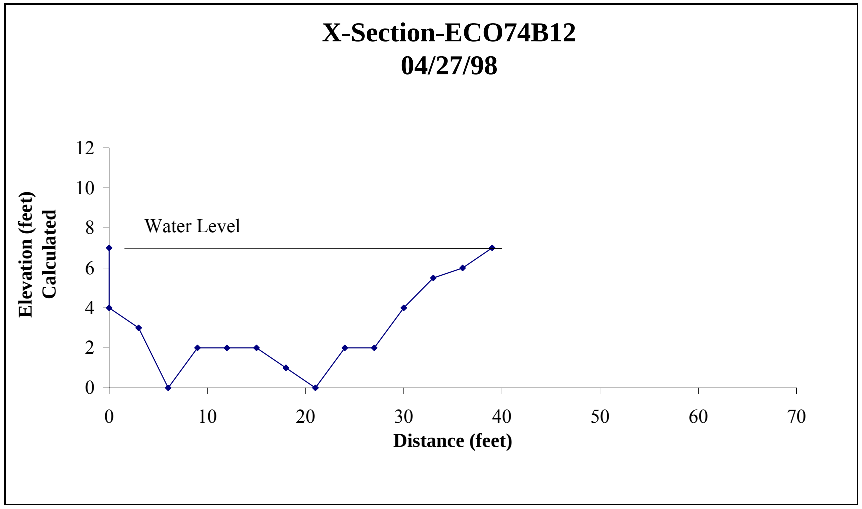

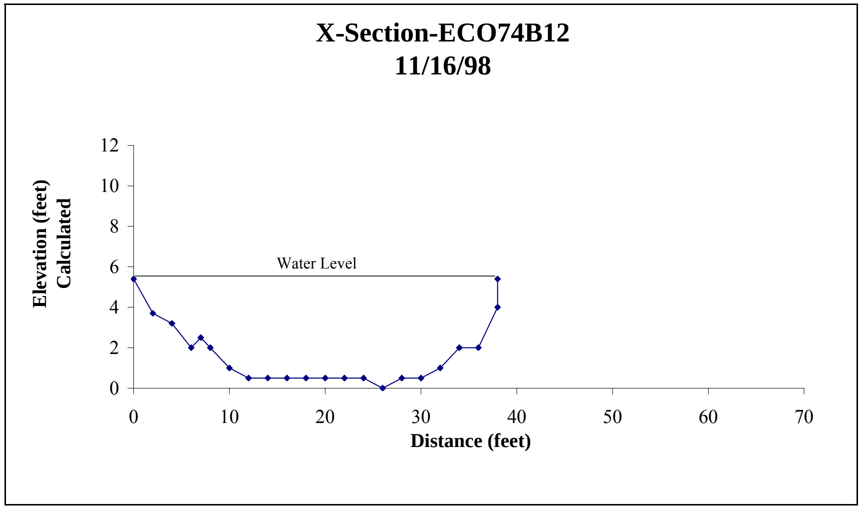

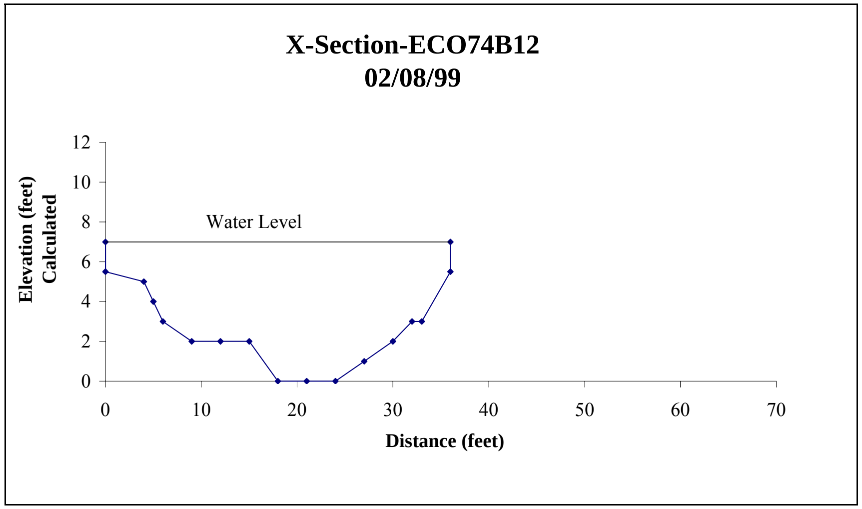

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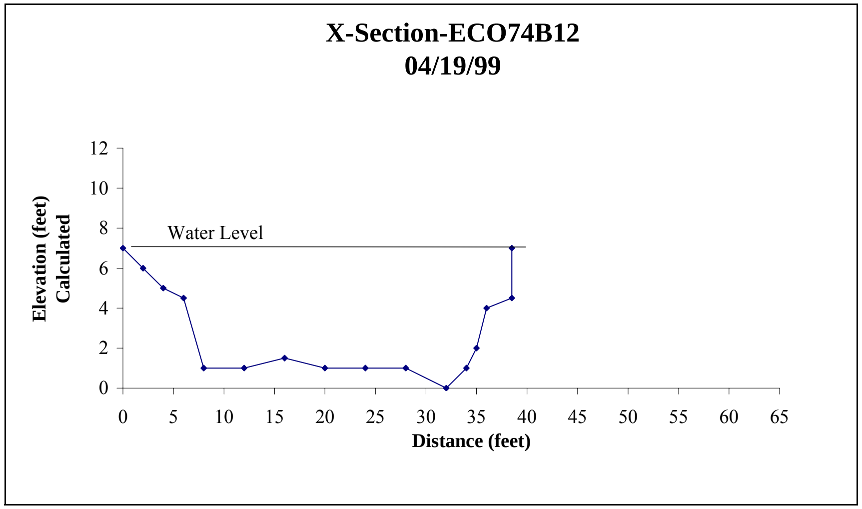

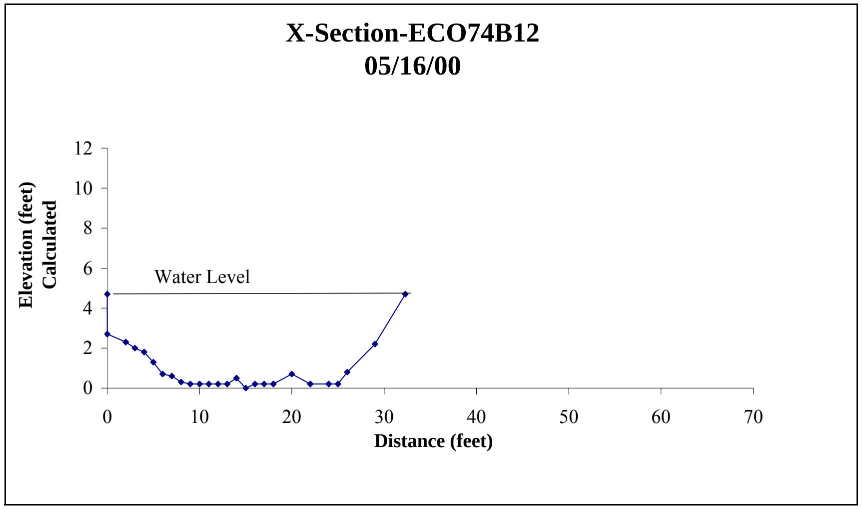

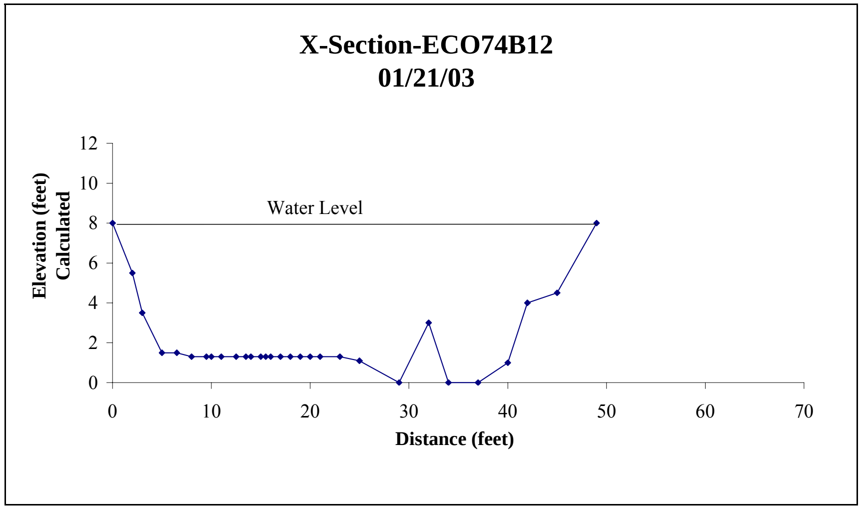

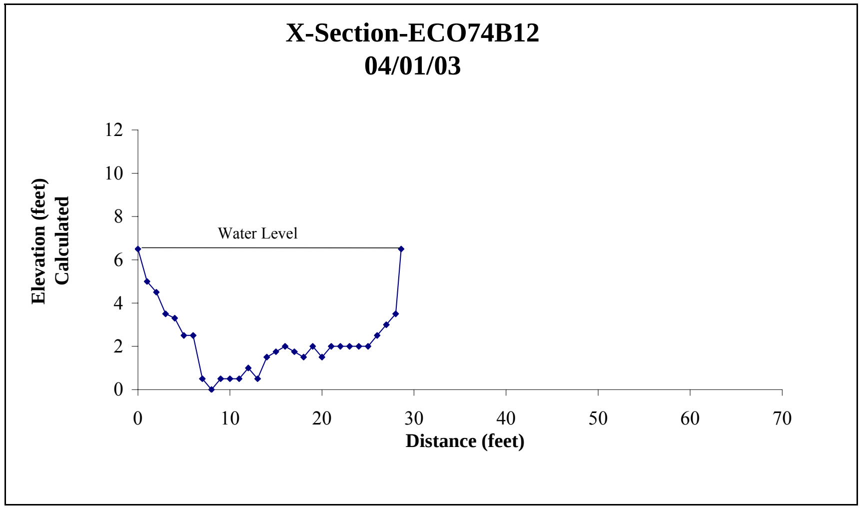

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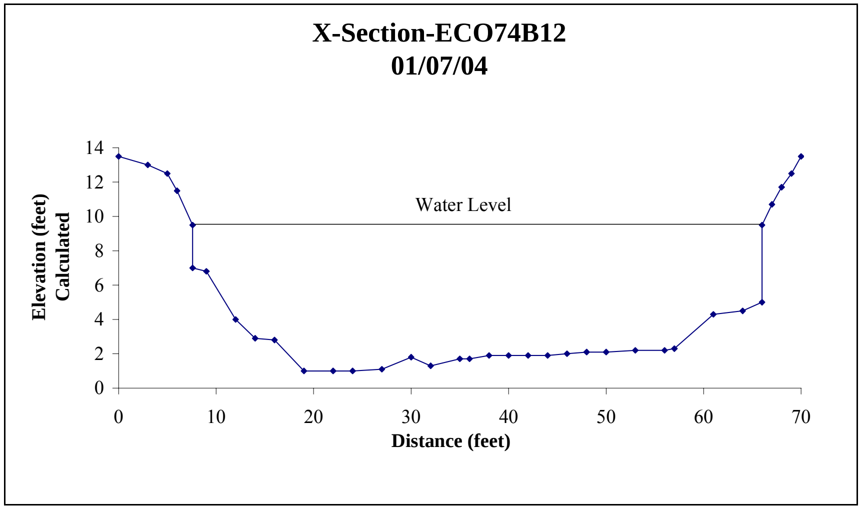
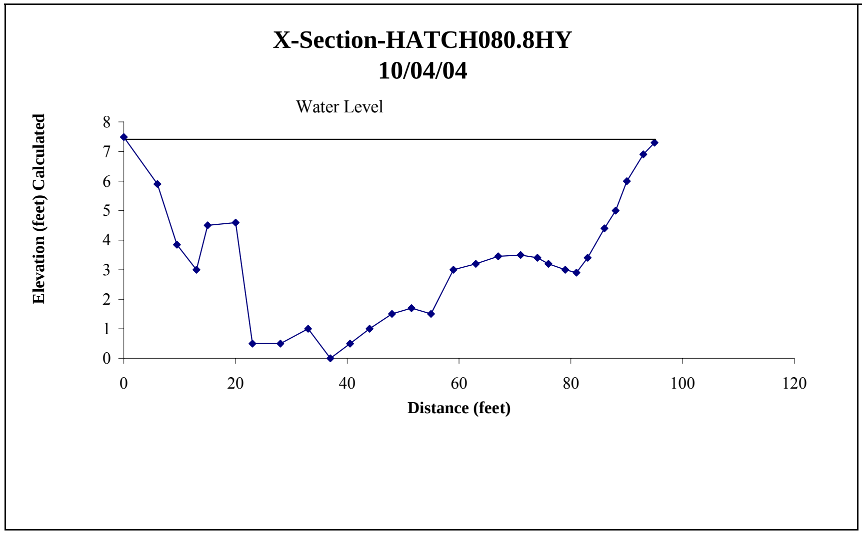
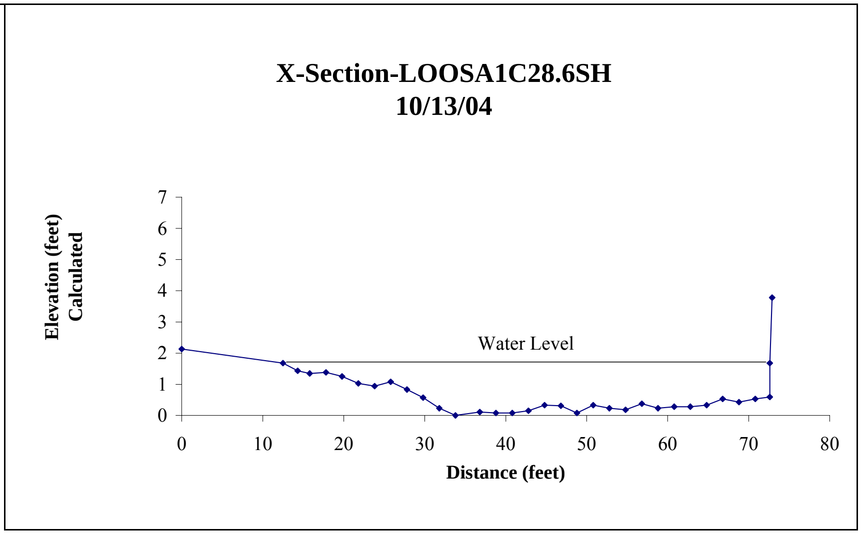


ECOREGION 65E/74B





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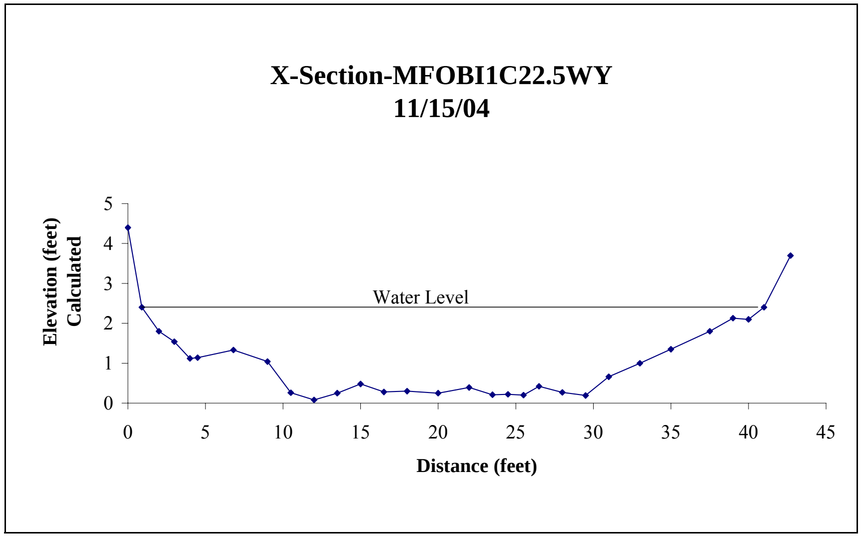
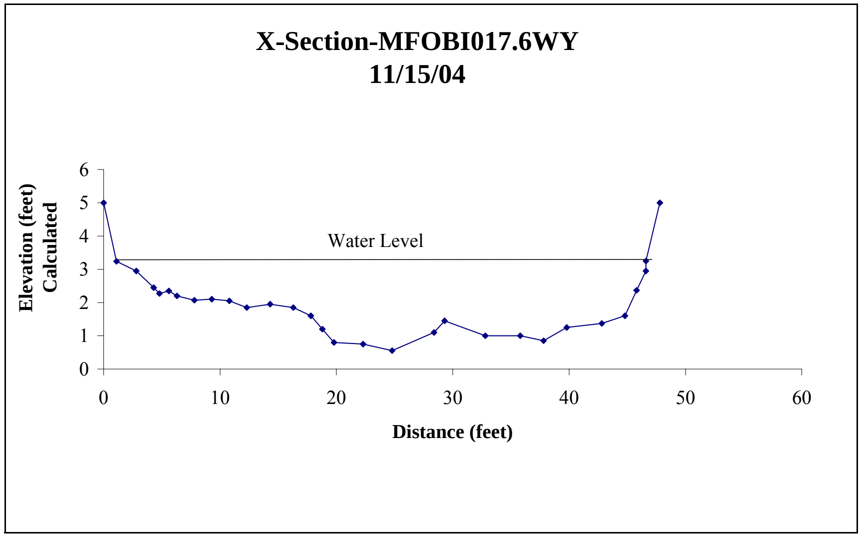
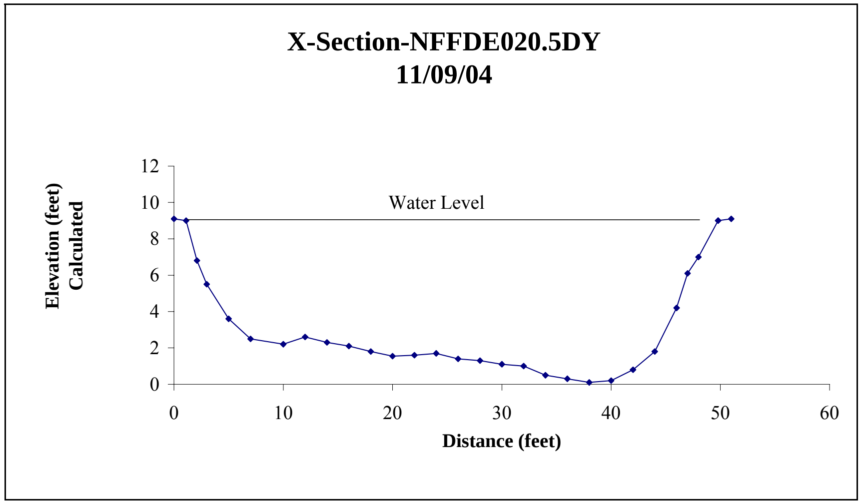
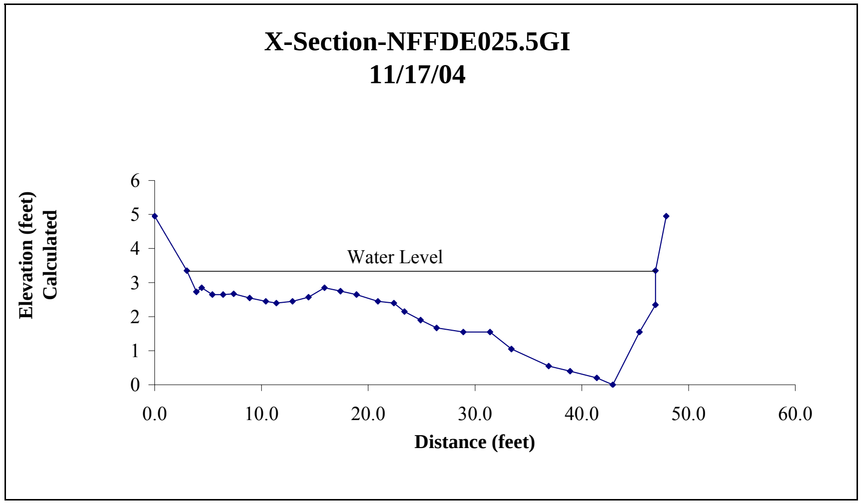
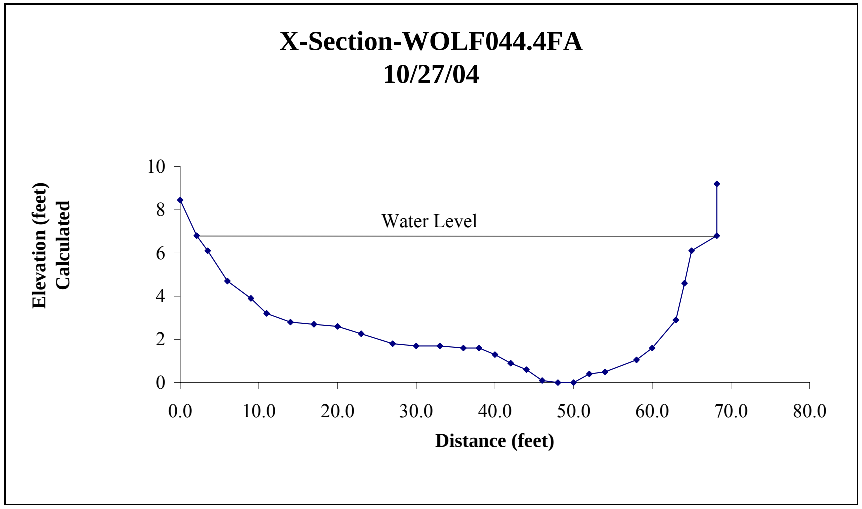


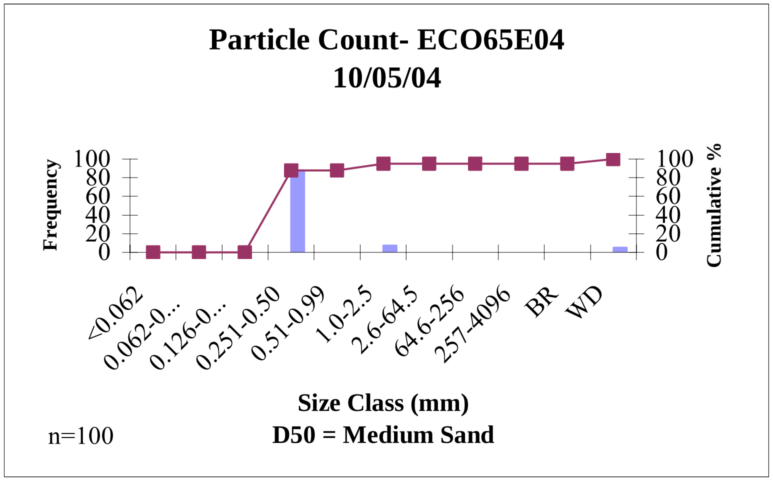


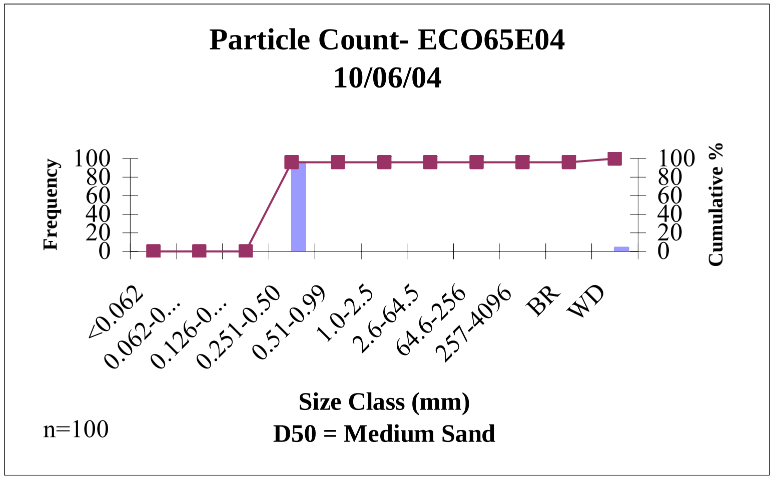


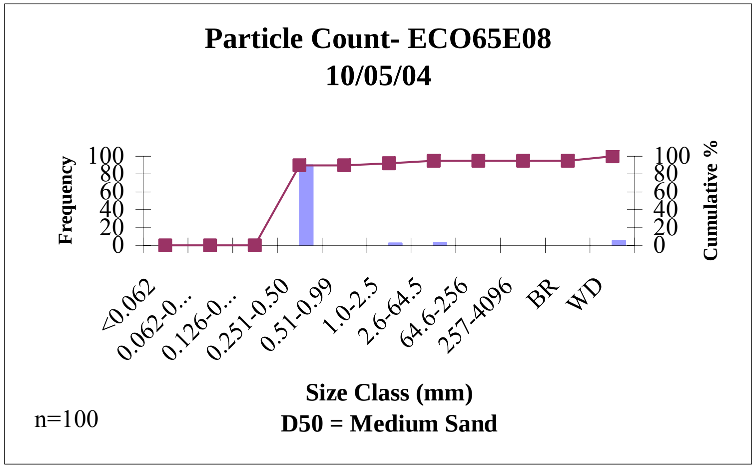


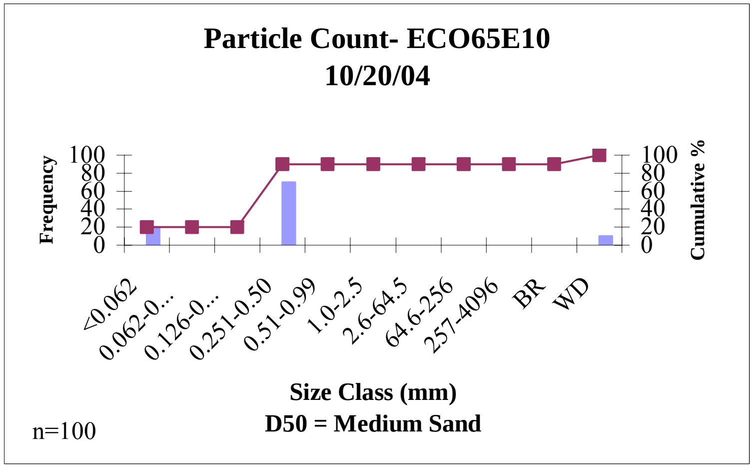

X-Section-WOLF044.4FA
10/27/04
Elevation (feet)
Calculated
10
8
6
4
2
0
Water Level
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
Distance (feet)

ECOREGION 65E









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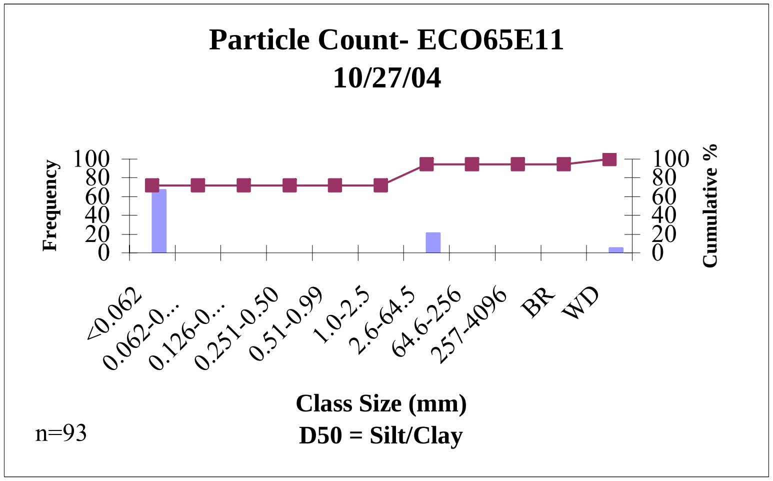

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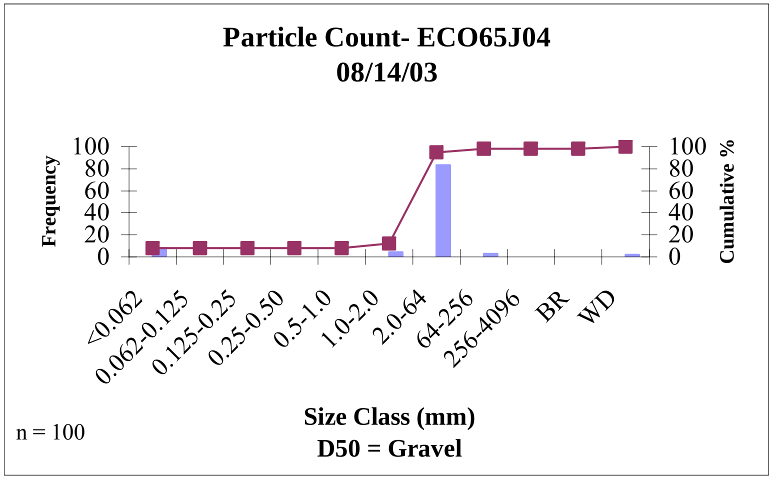

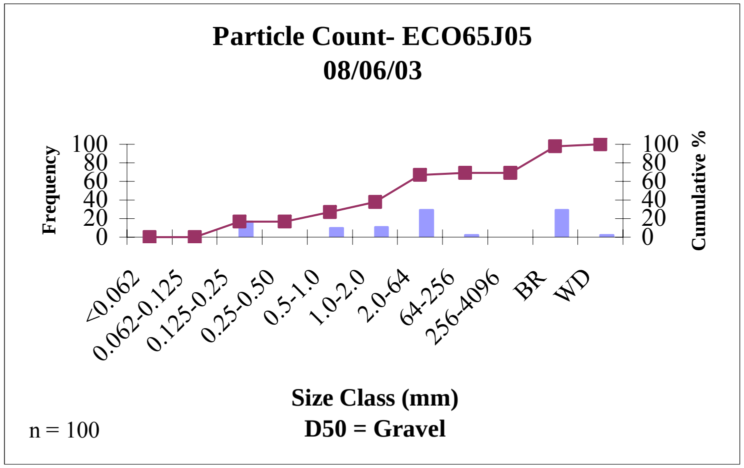

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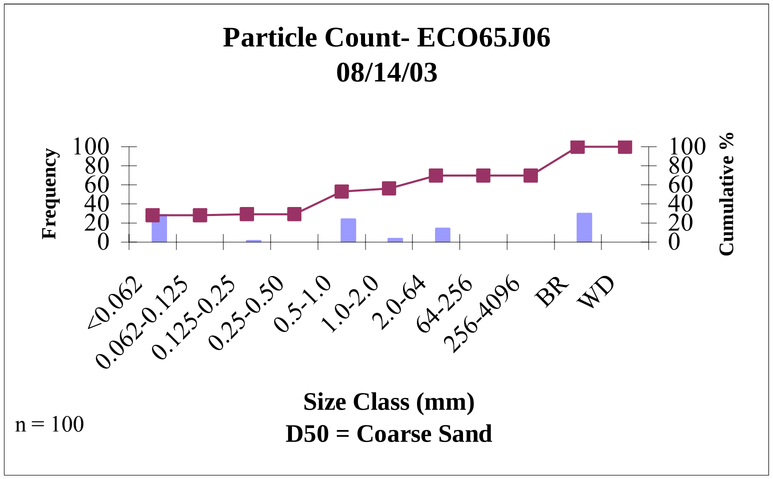

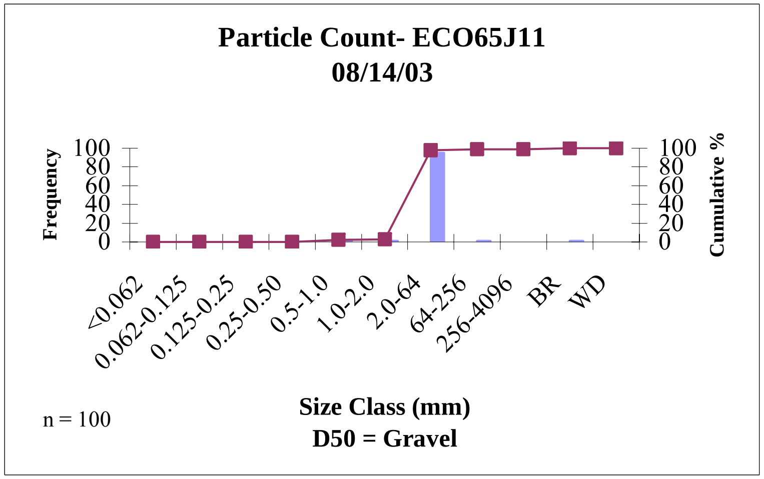

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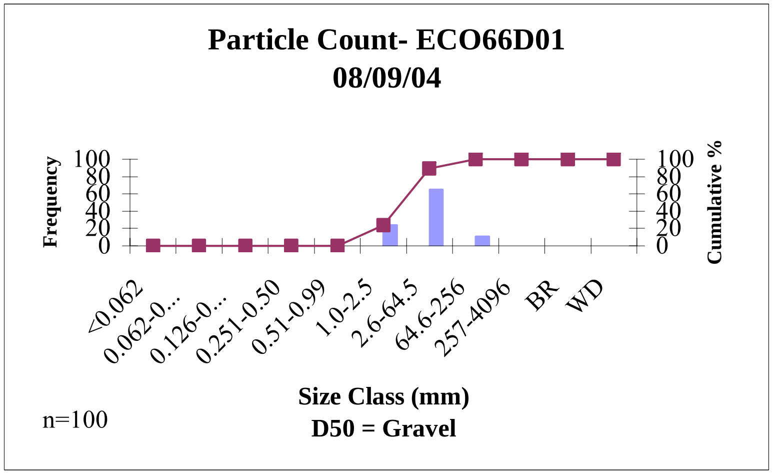

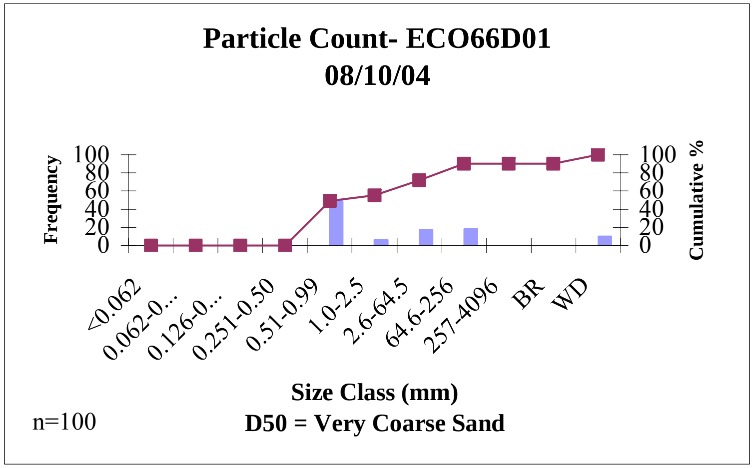

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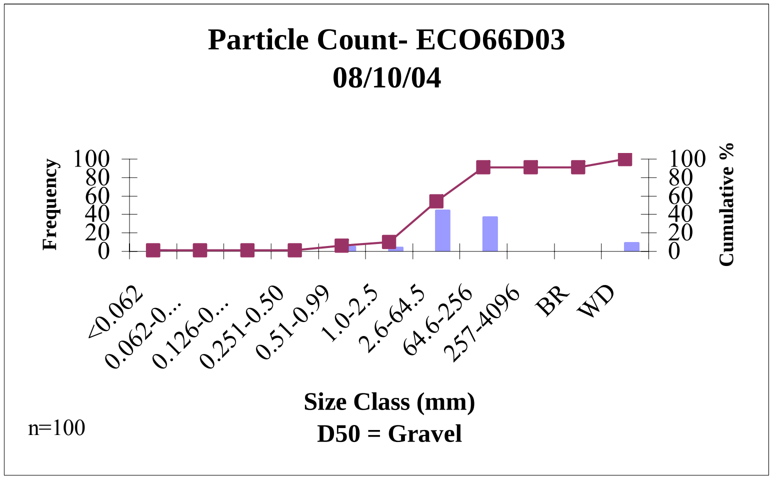

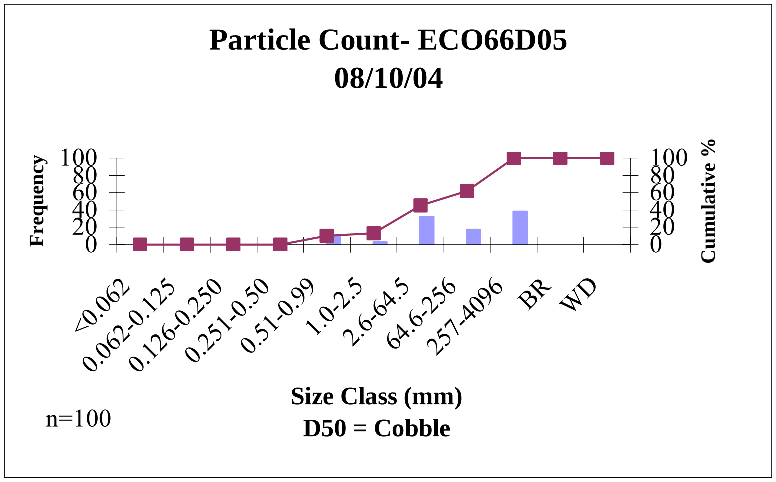

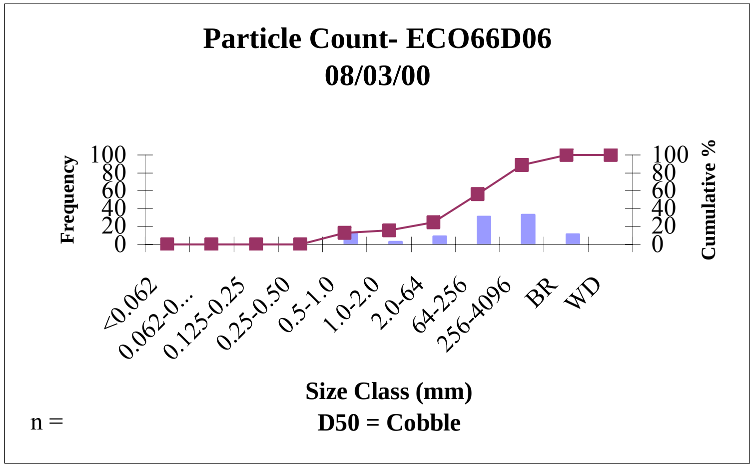

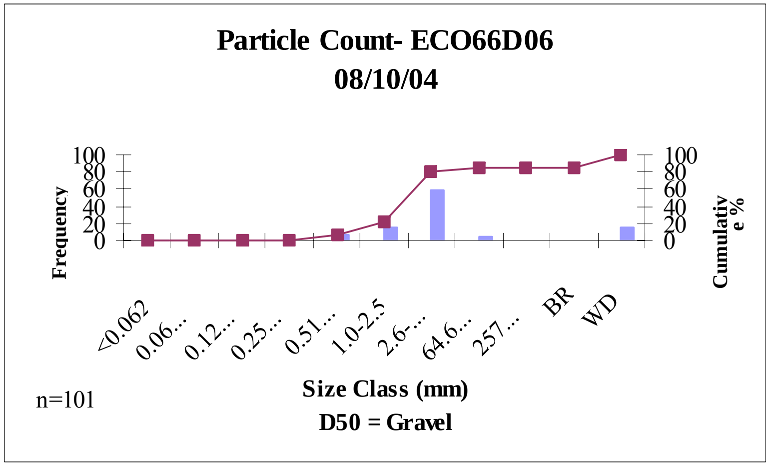

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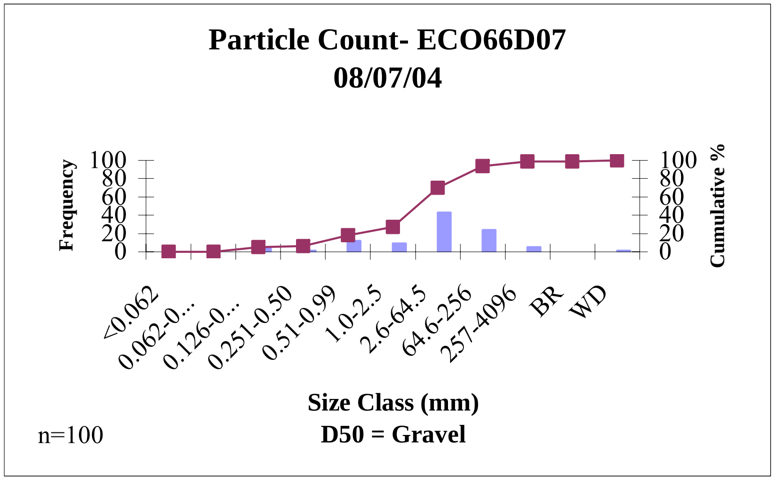

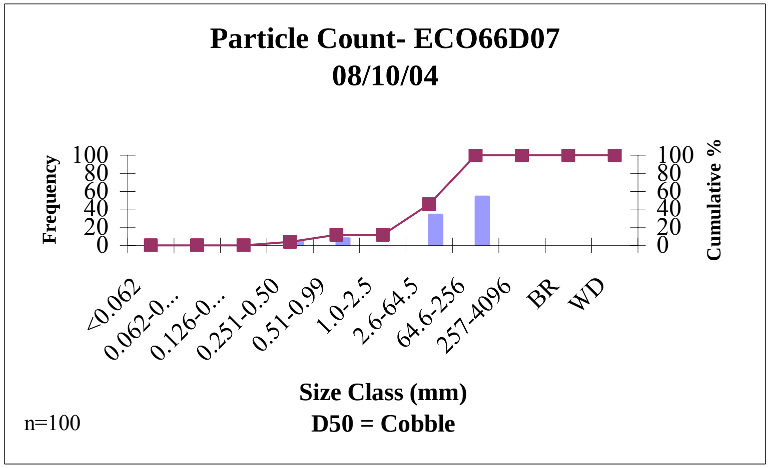

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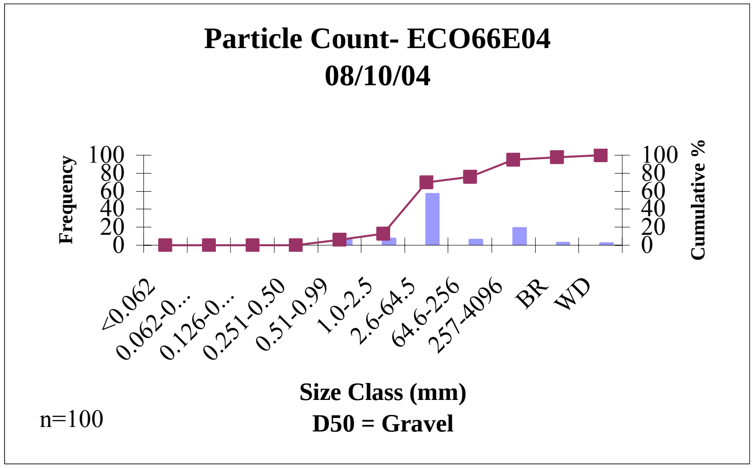

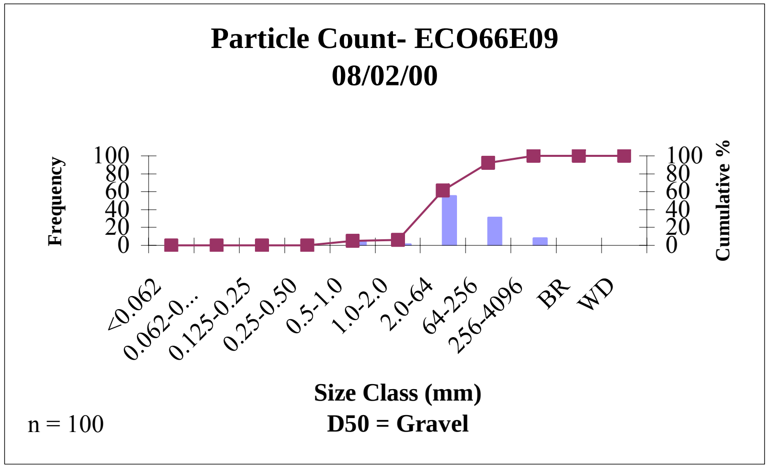

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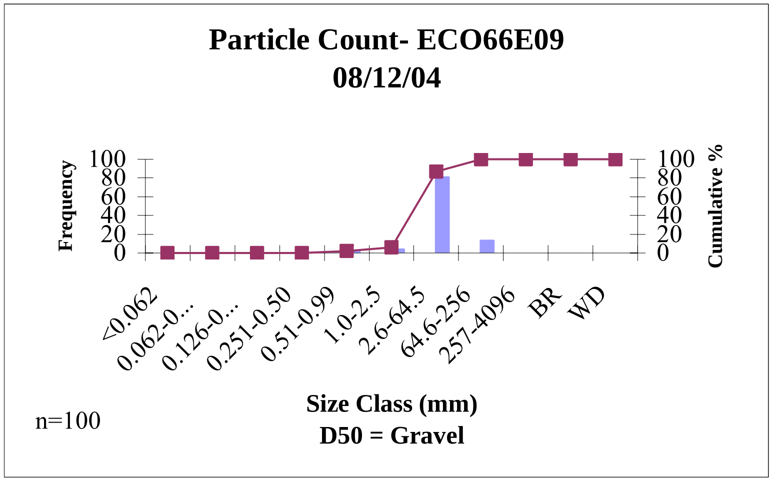

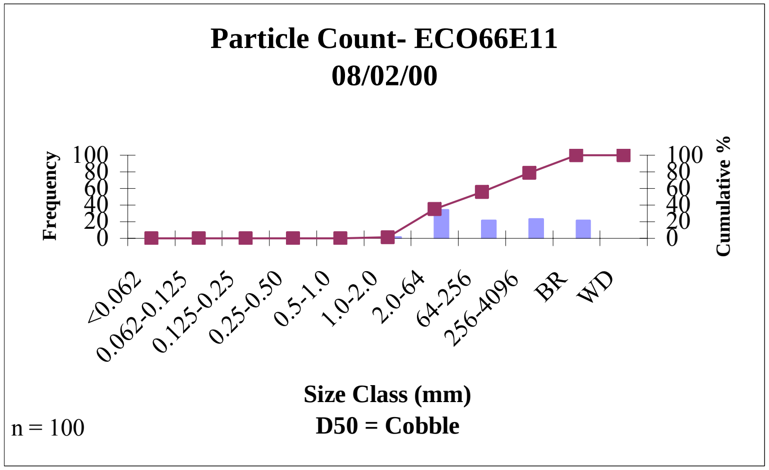

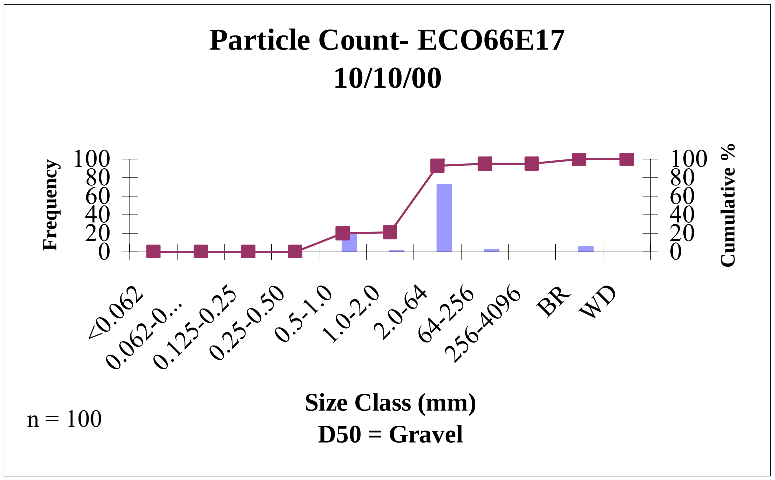

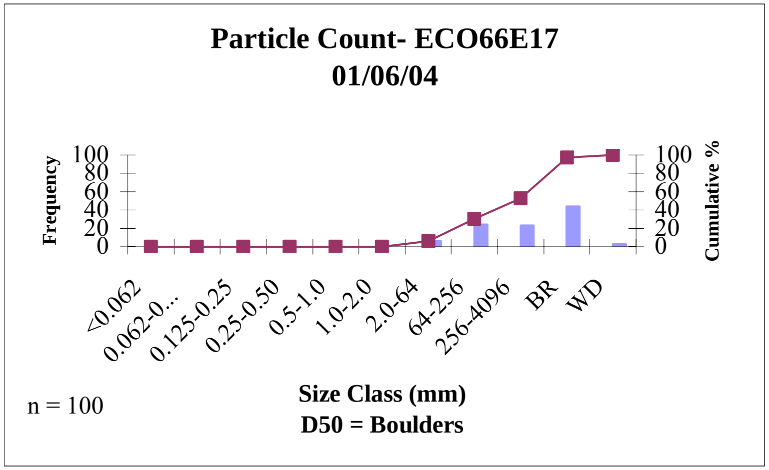

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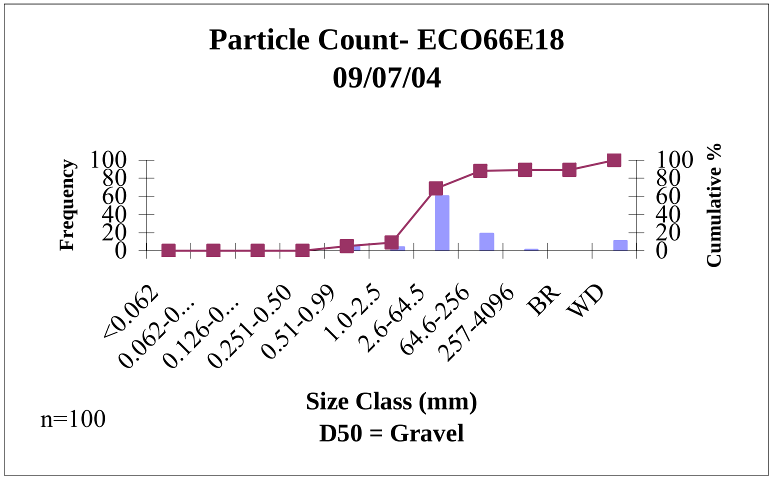

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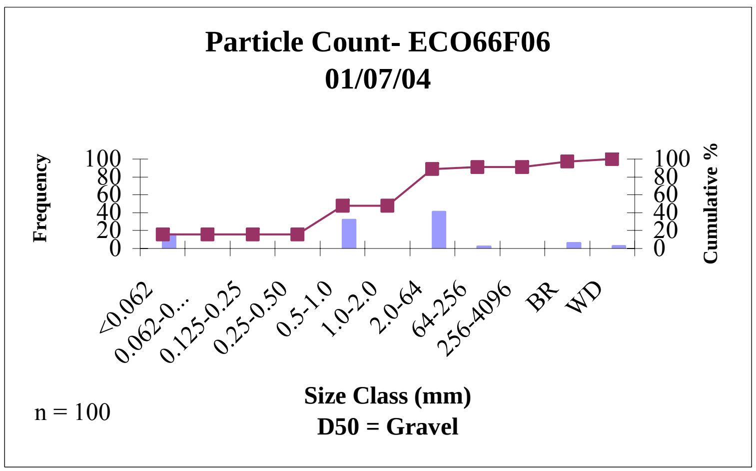

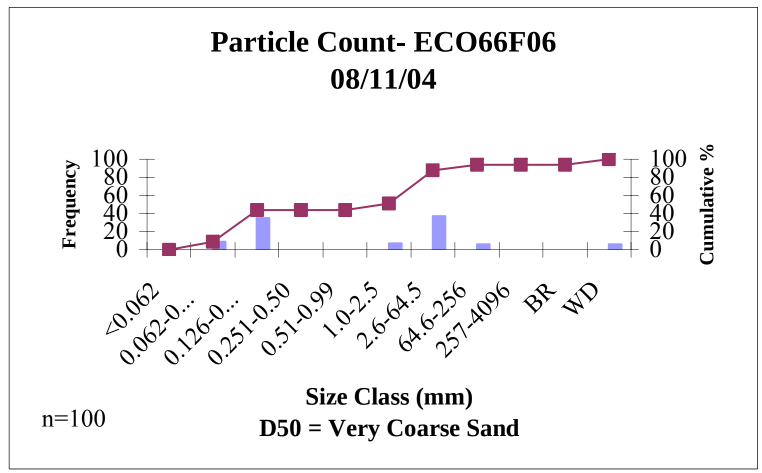

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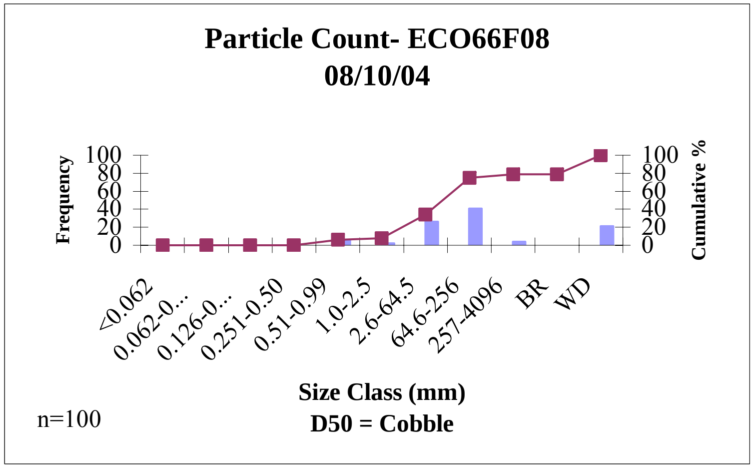

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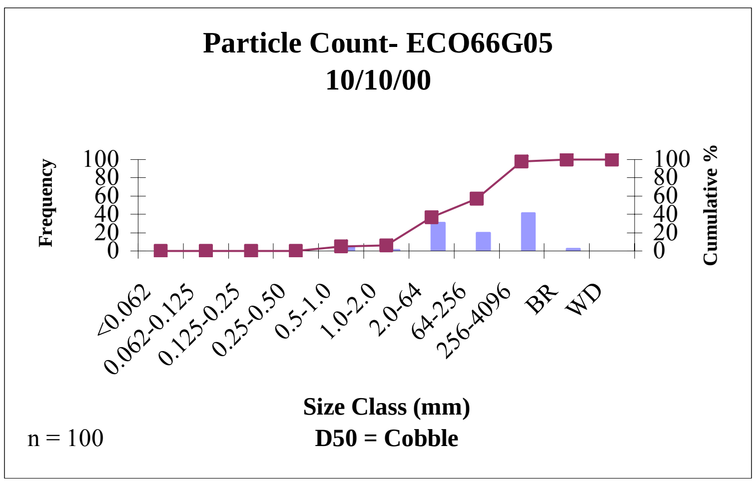

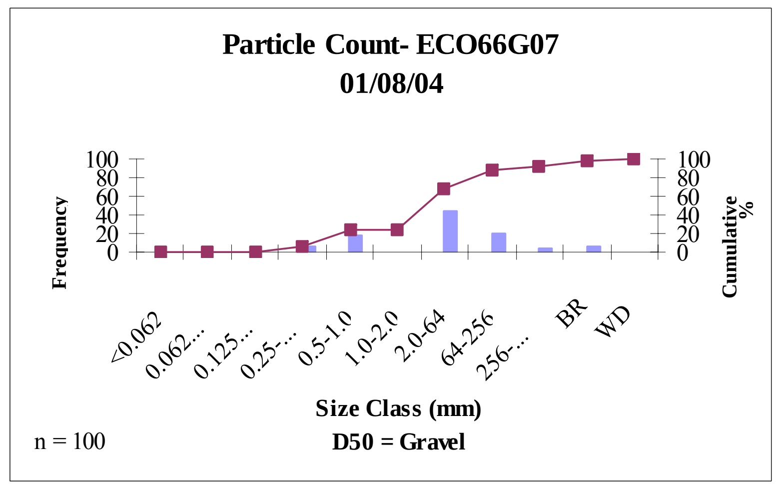

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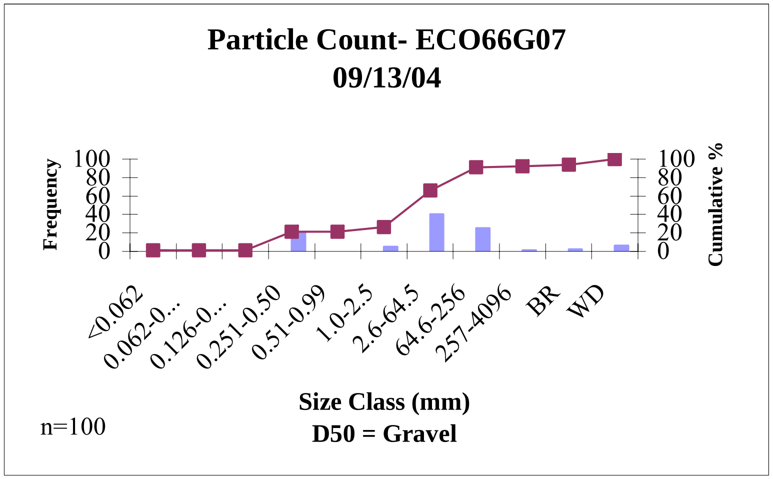

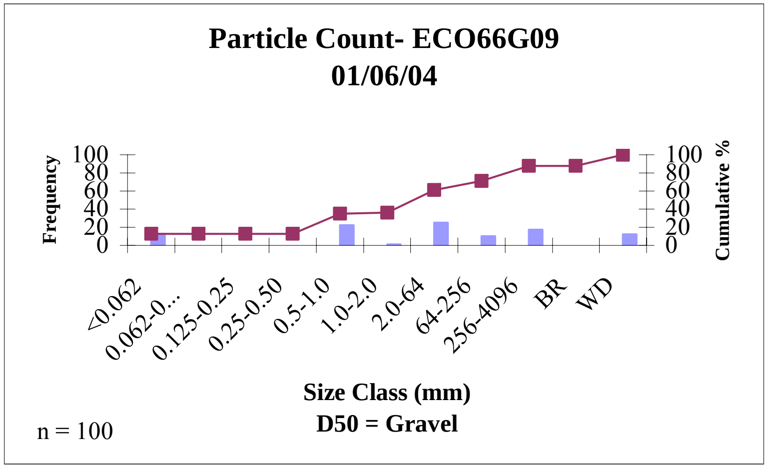

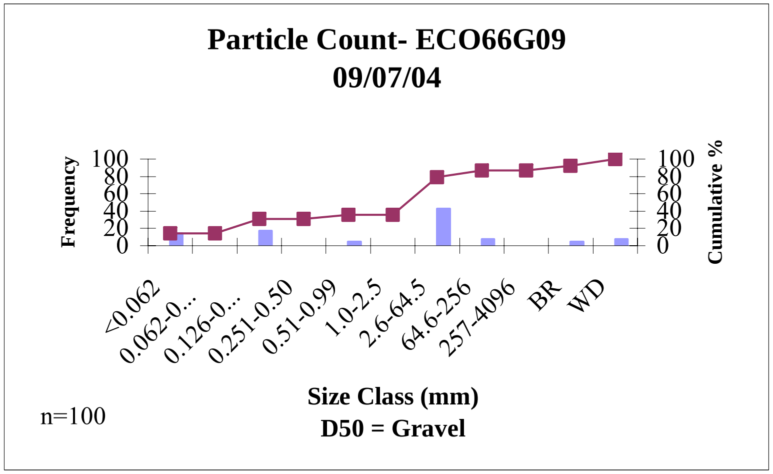

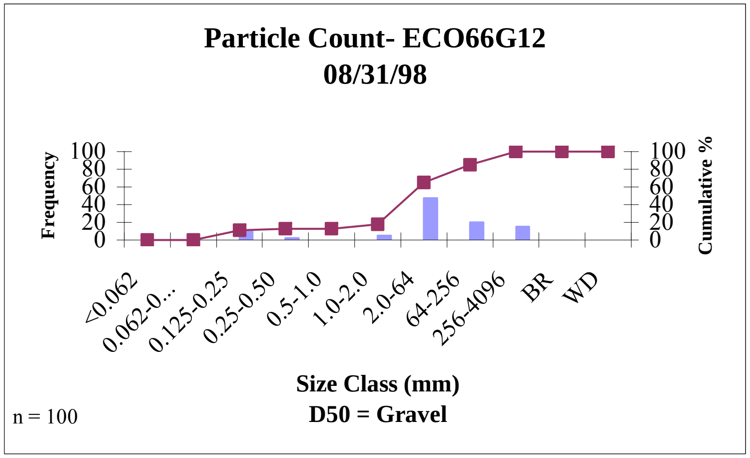

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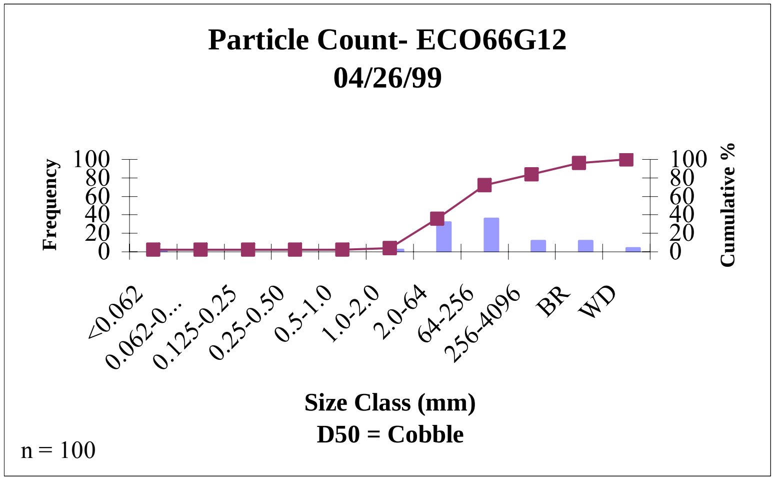

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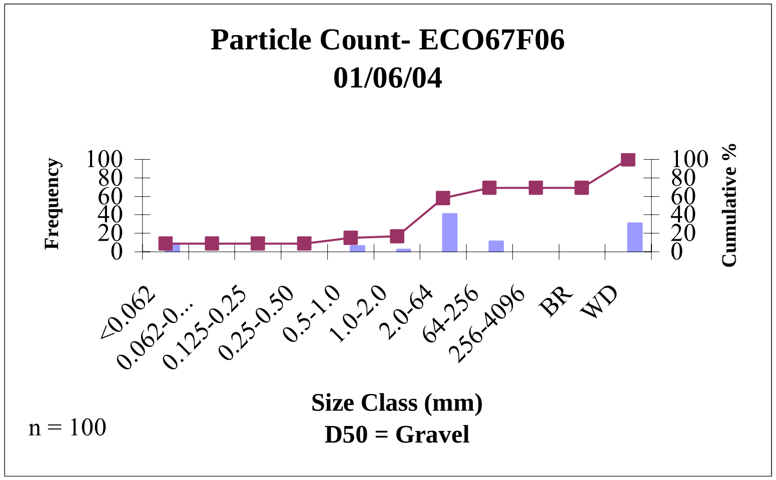

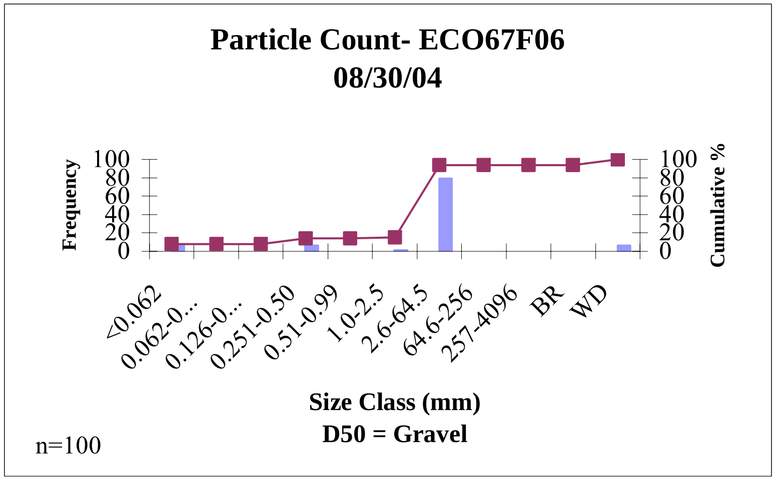

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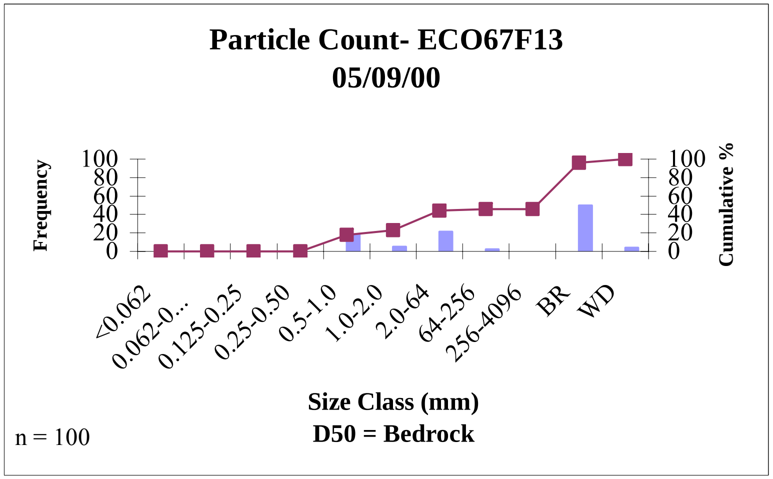

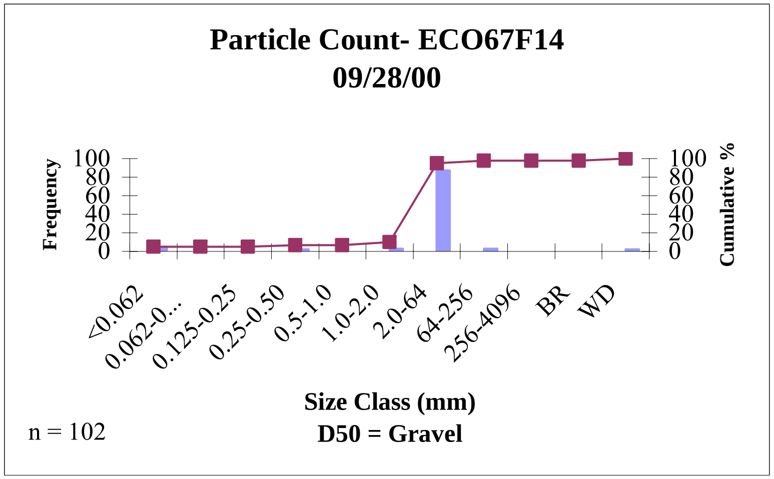

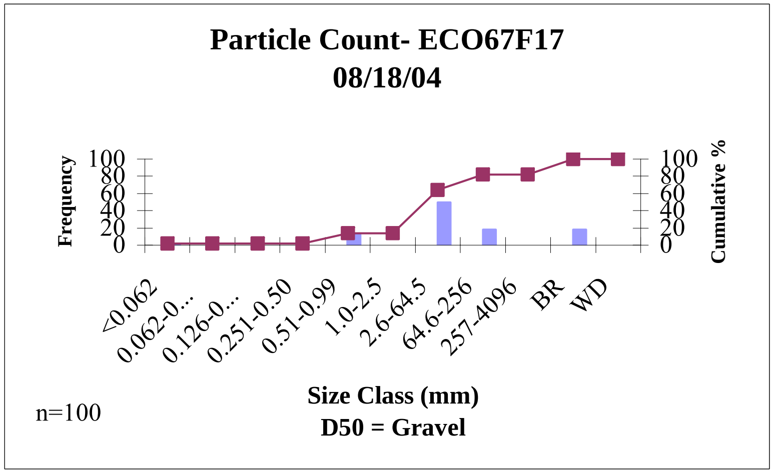

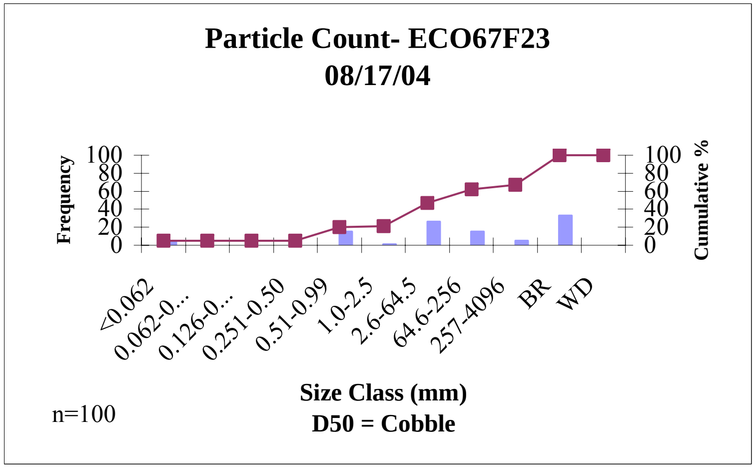

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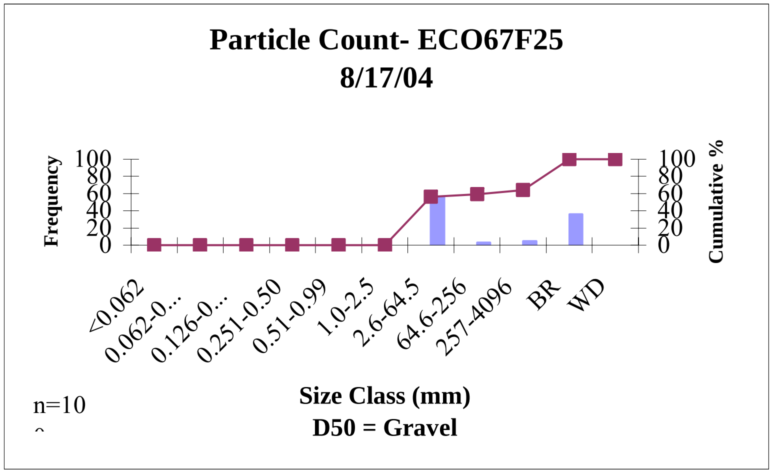

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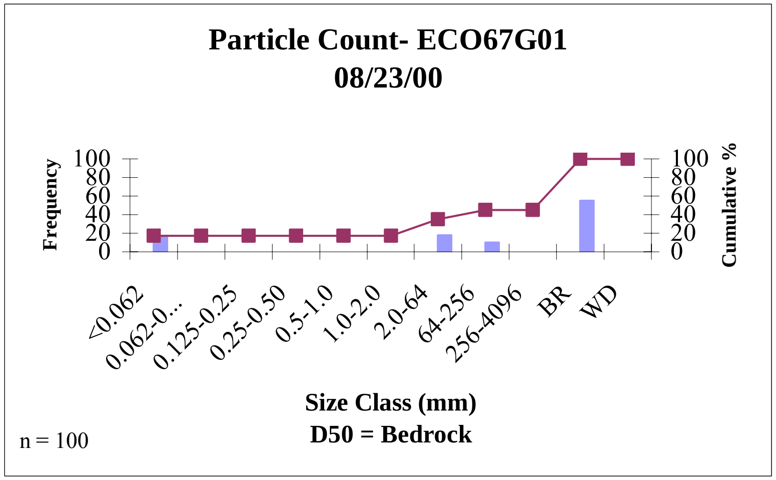

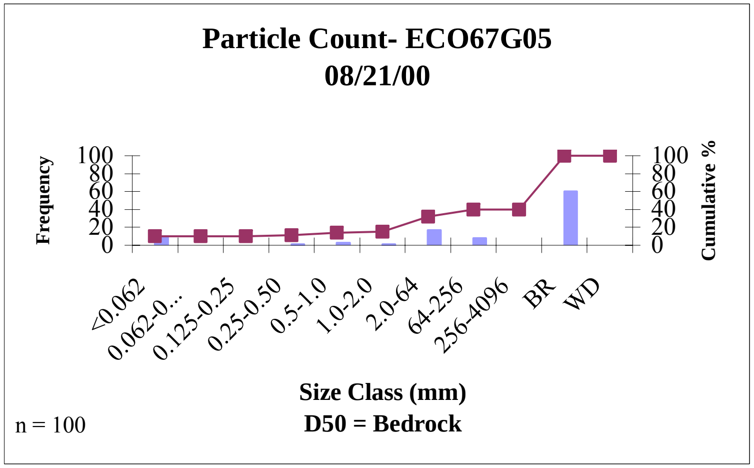

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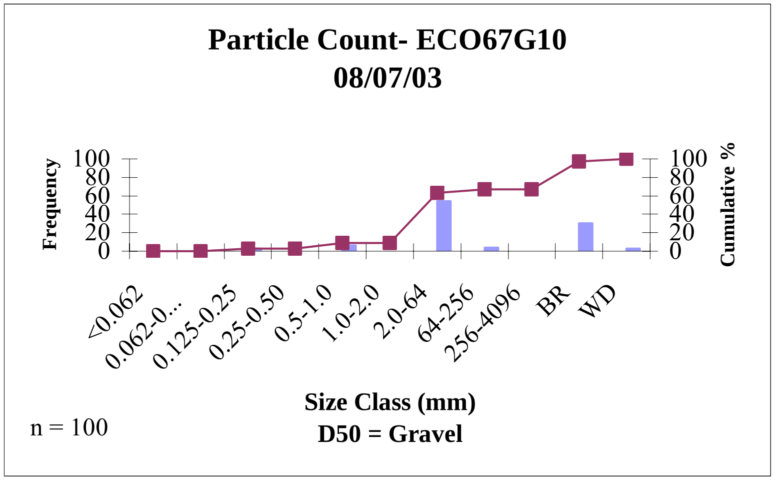
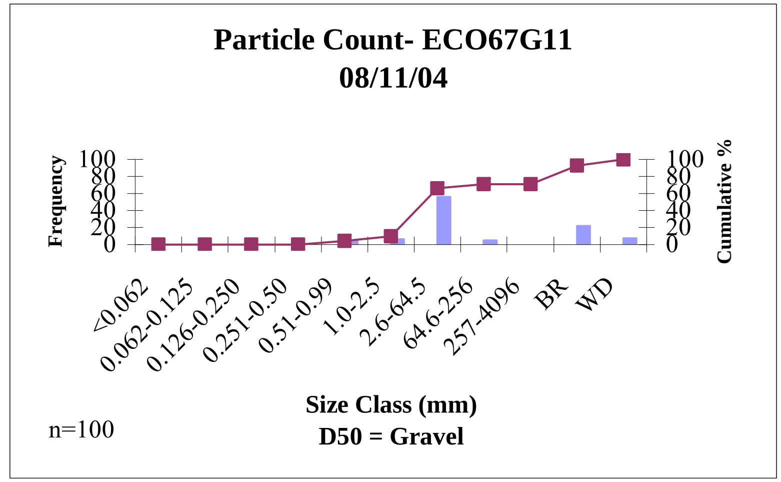
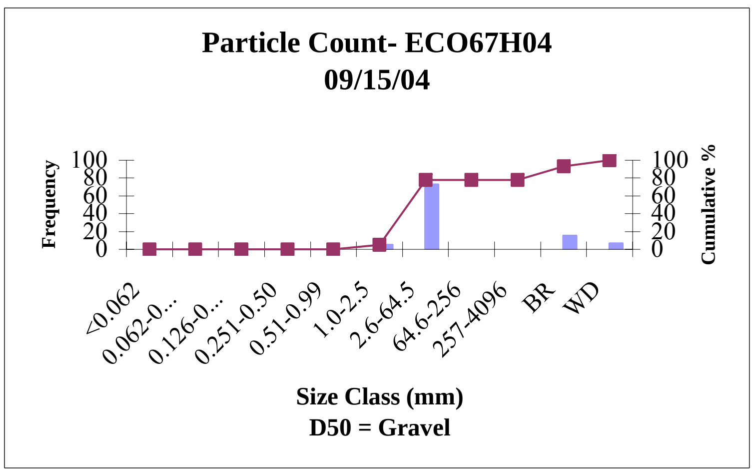
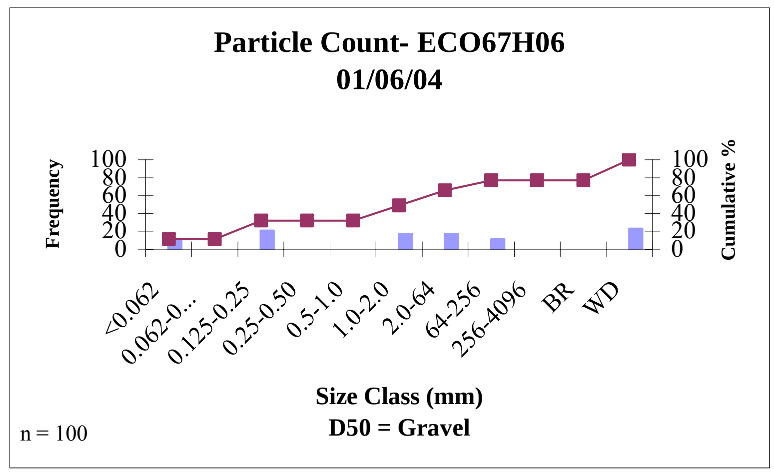




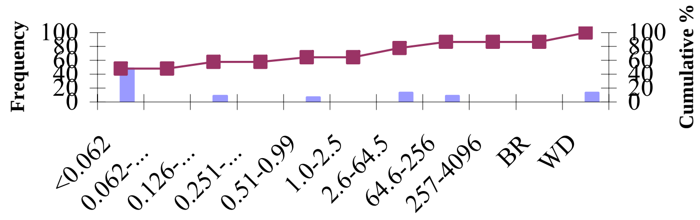
ECOREGION 67H





ECOREGION 67H

Particle Count- ECO67H06
09/07/04

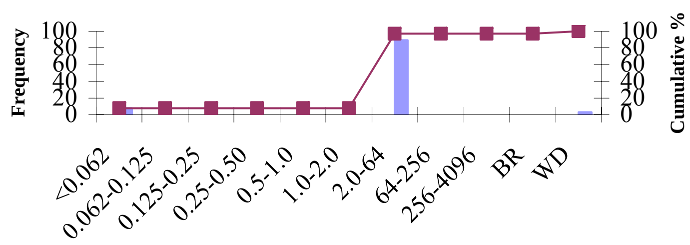


Size Class (mm)
D50 = Fine Sand

n=99

ECOREGION 67I

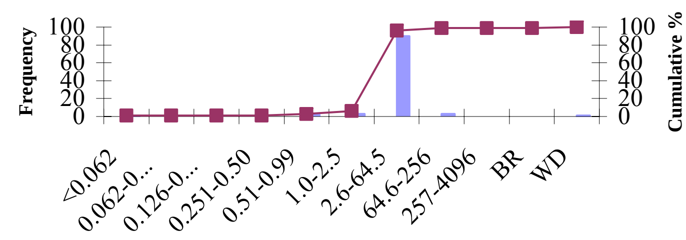
Particle Count- ECO67I12
1/05/2004



Size Class (mm)
D50 = Gravel

n = 100

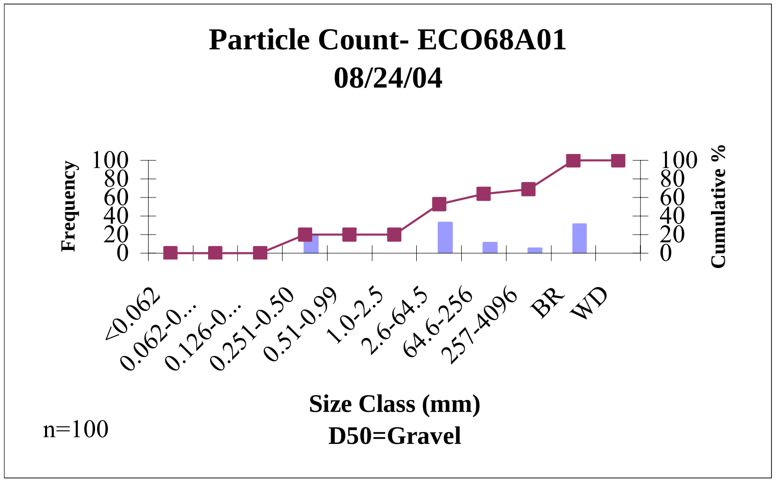
Particle Count- ECO67I12
08/31/04

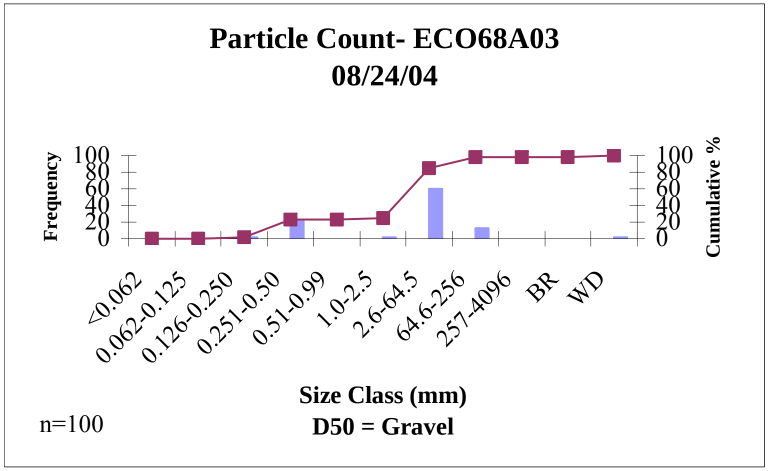


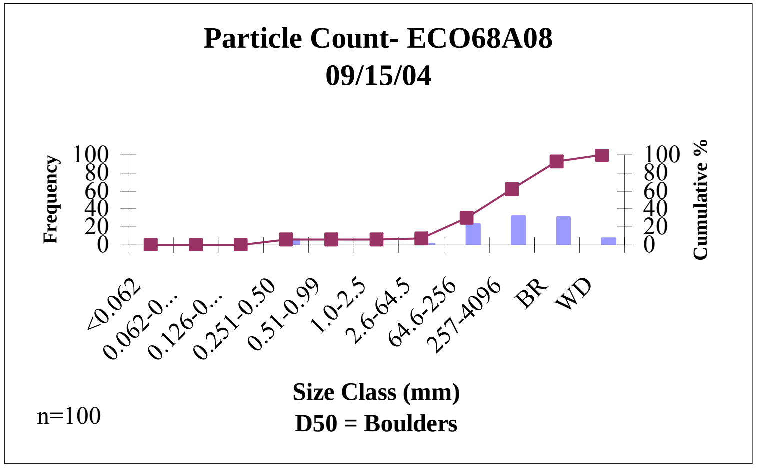
n=100

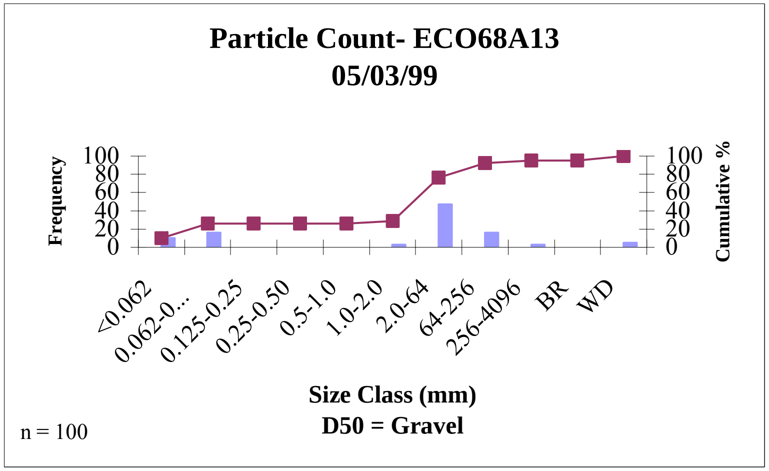
Size Class (mm)
D50=Gravel

ECOREGION 68A

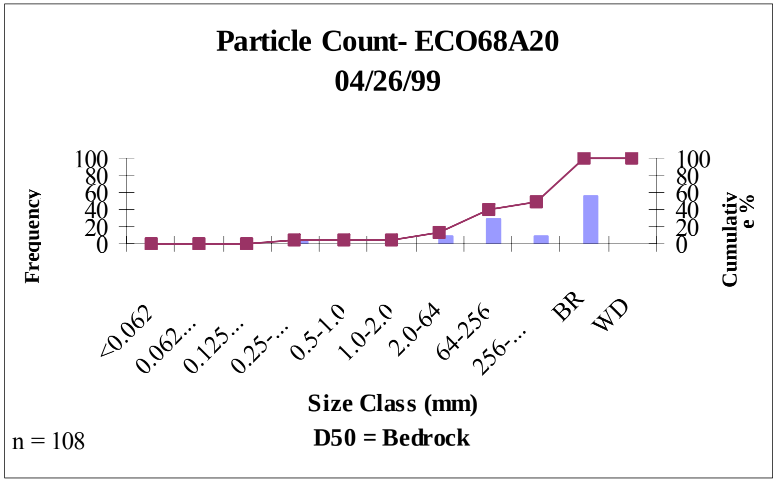


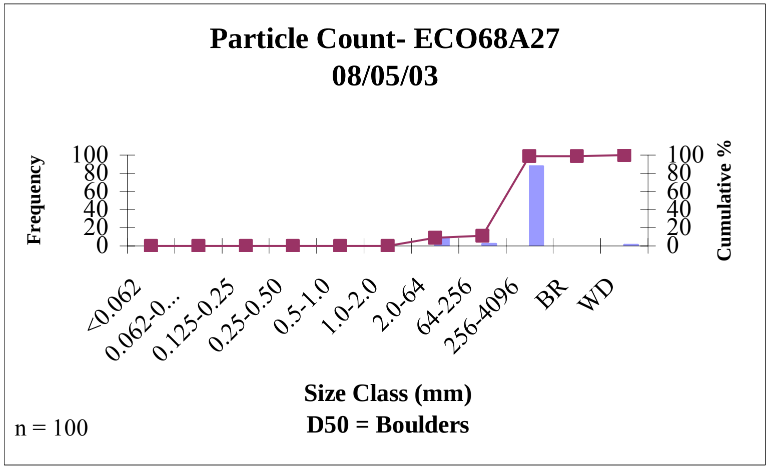


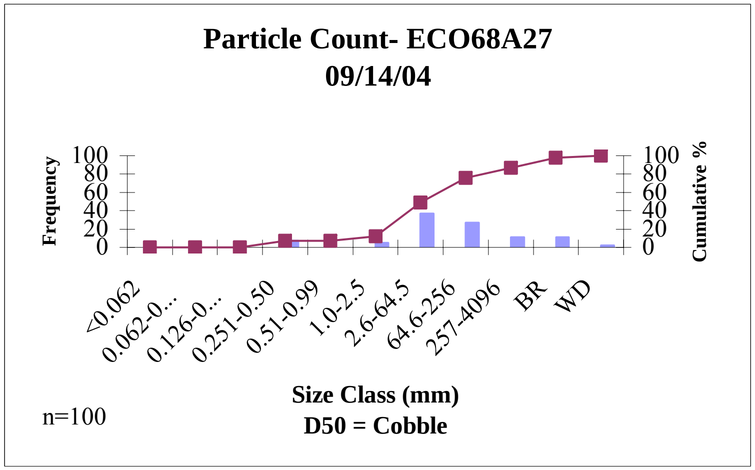


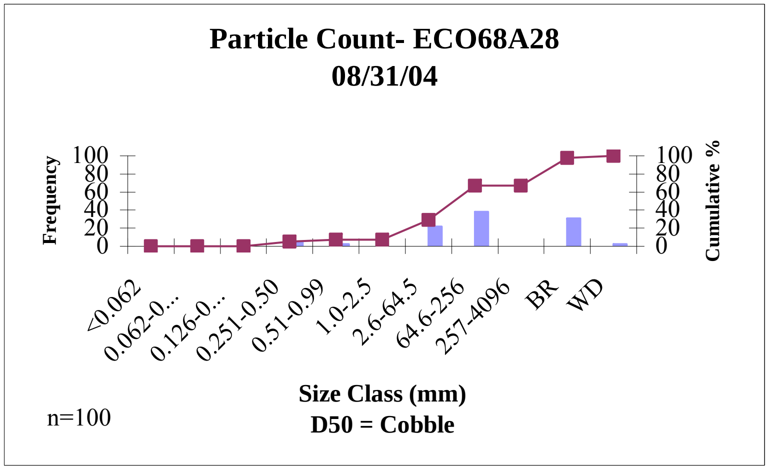


ECOREGION 68A

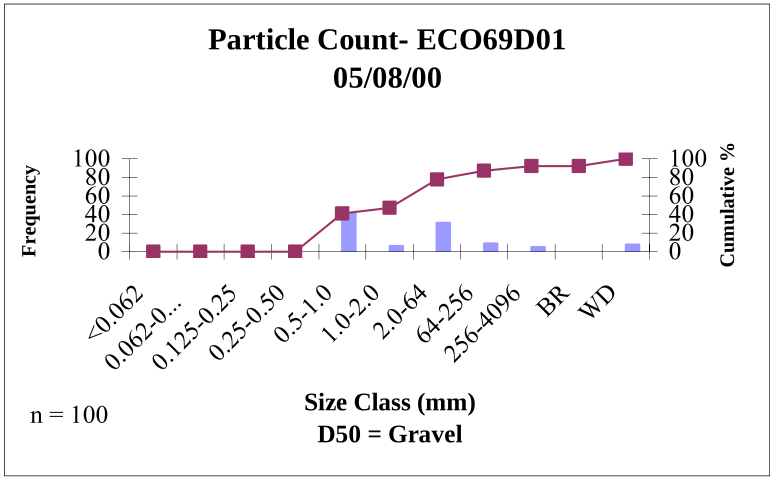


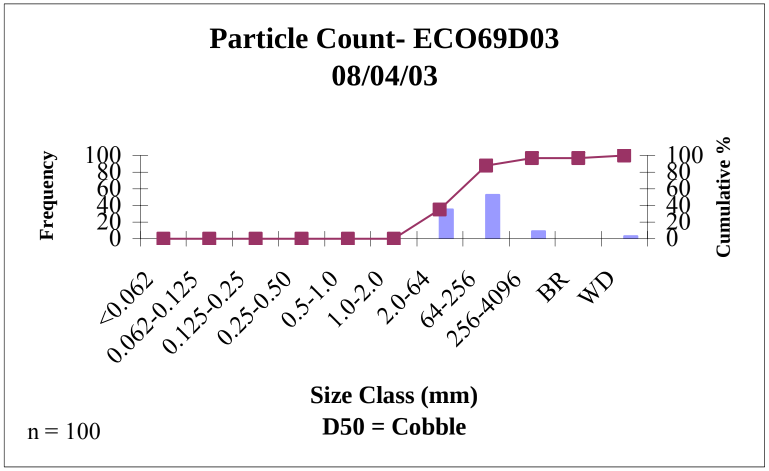


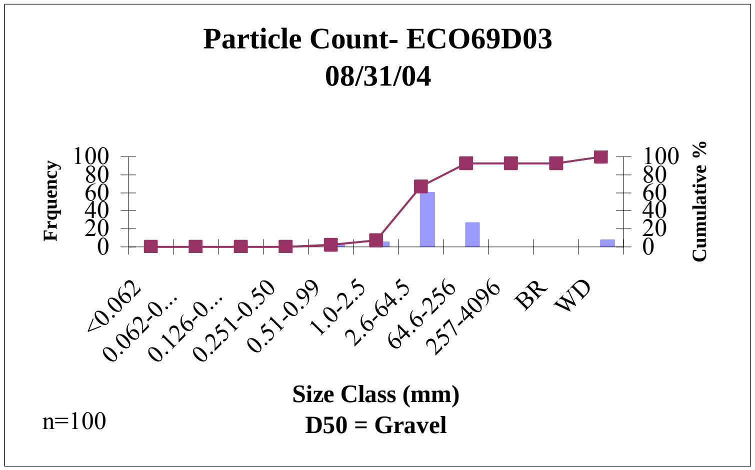


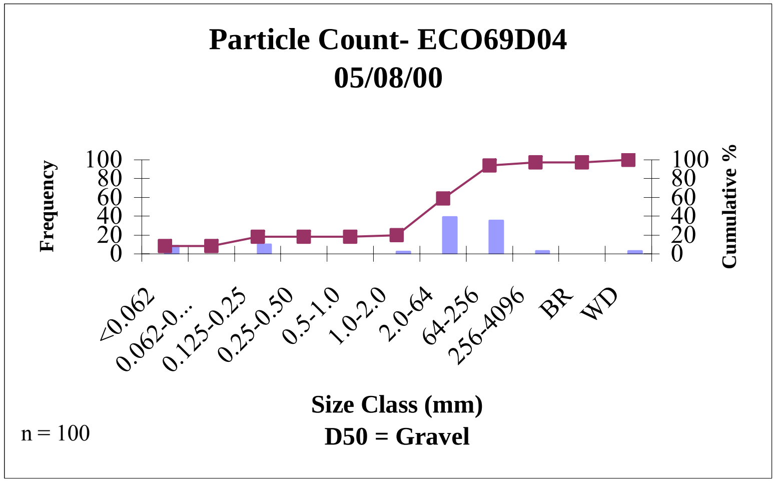


ECOREGION 69D

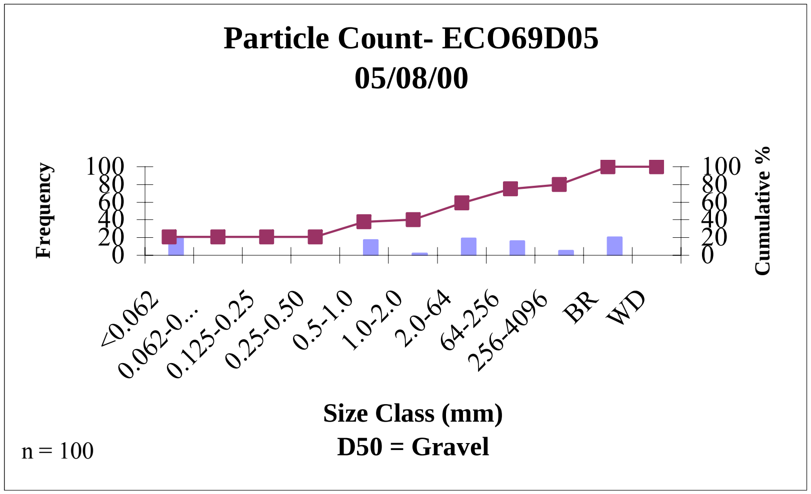


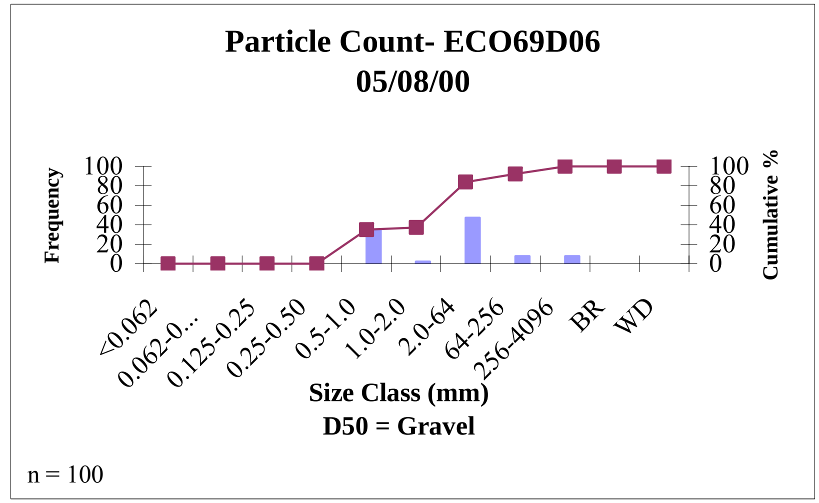




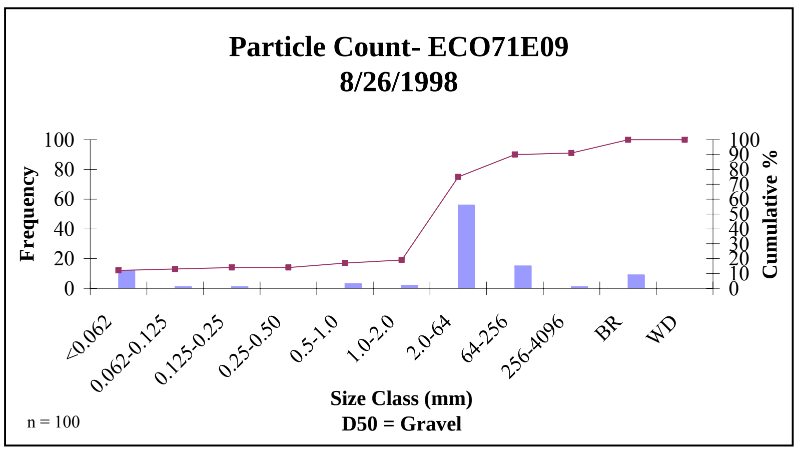


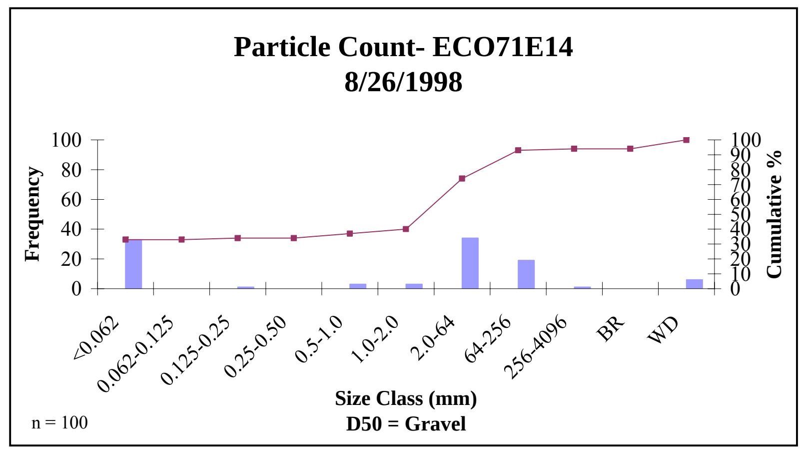
ECOREGION 69D



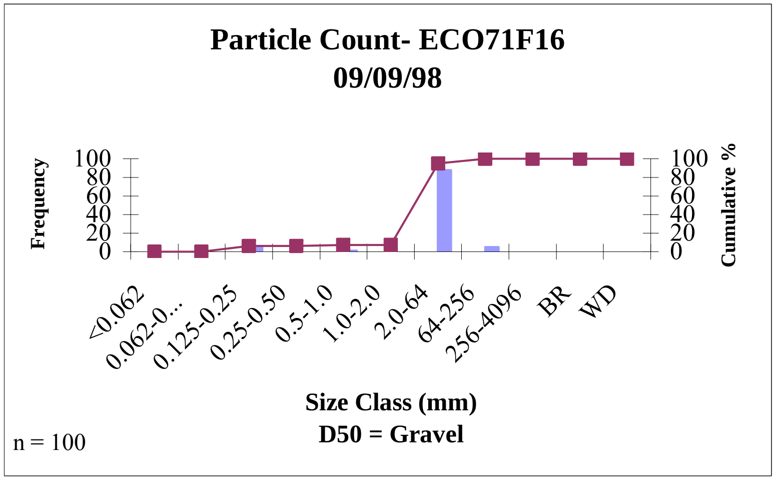


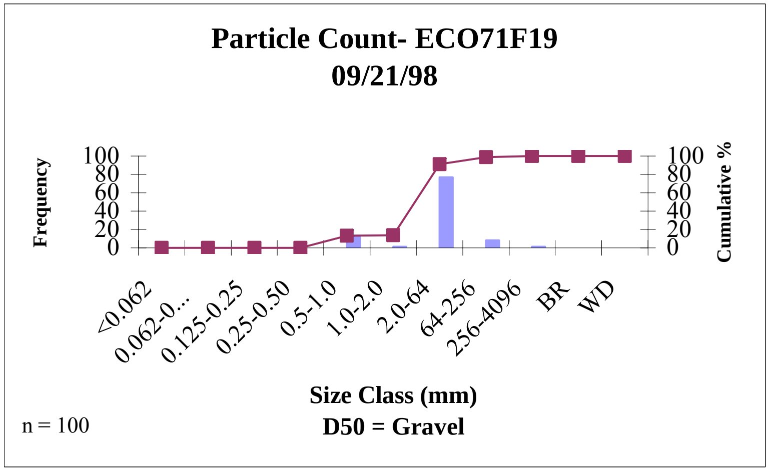
ECOREGION 71E

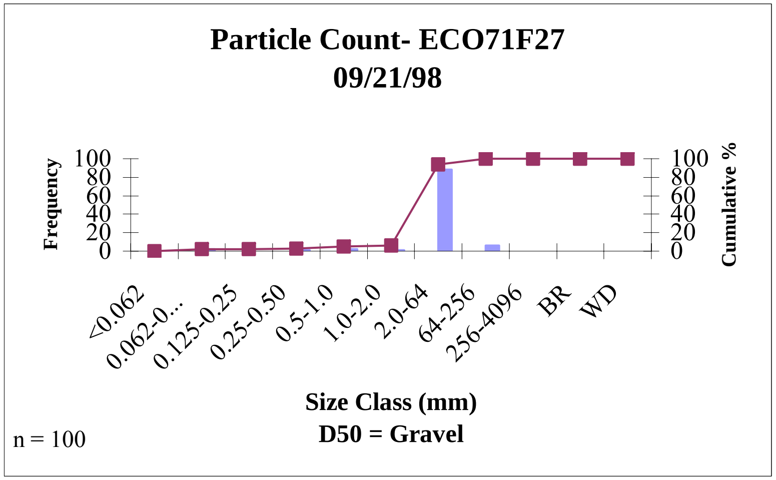


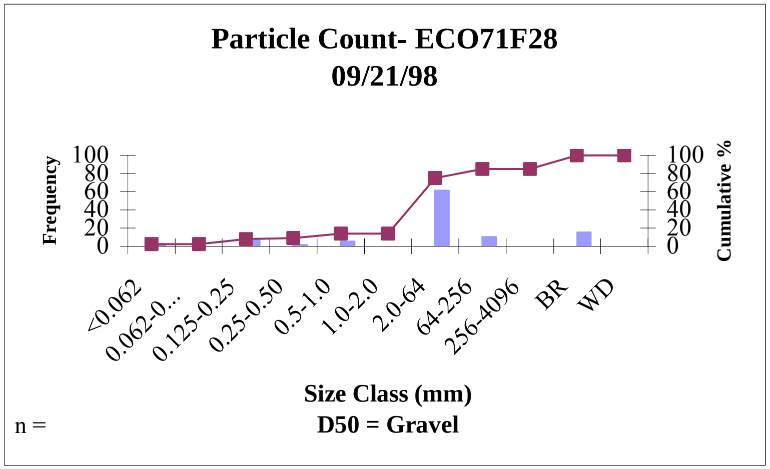


ECOREGION 71F

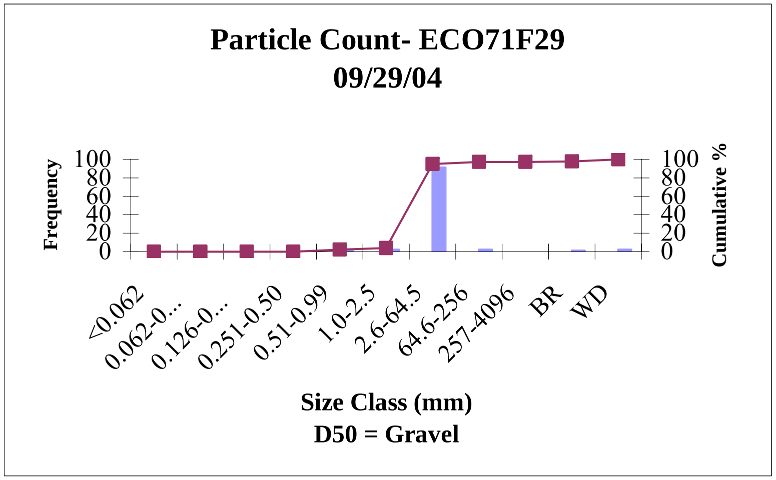




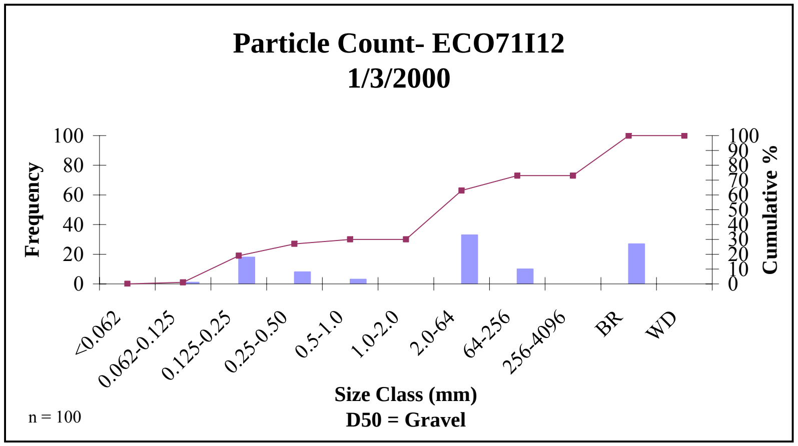


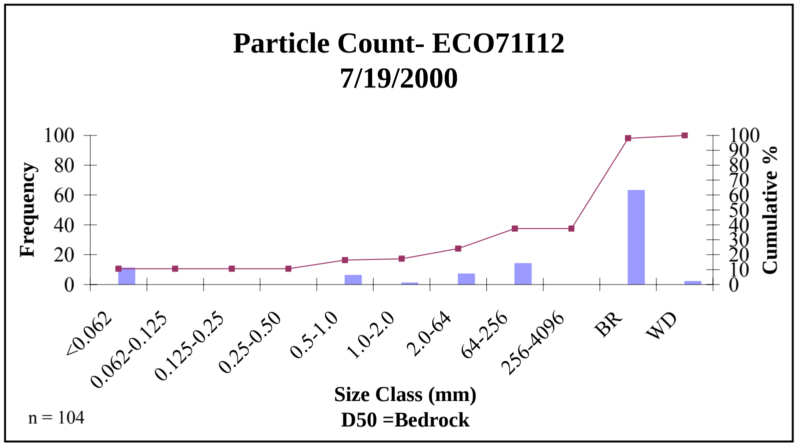


ECOREGION 71F

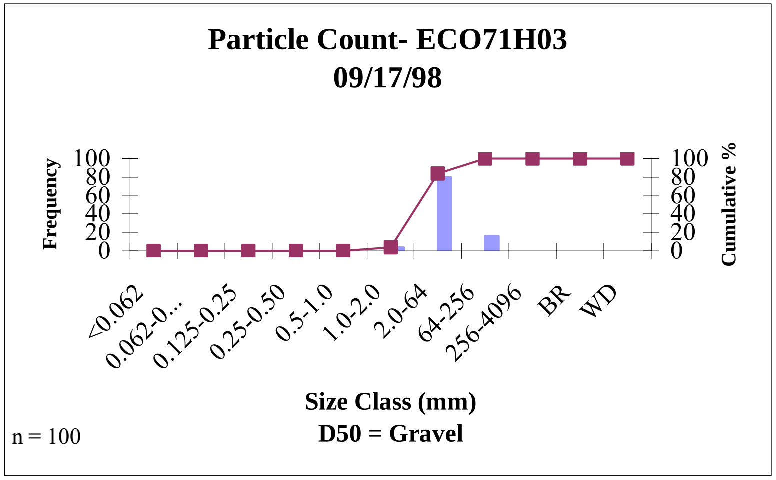


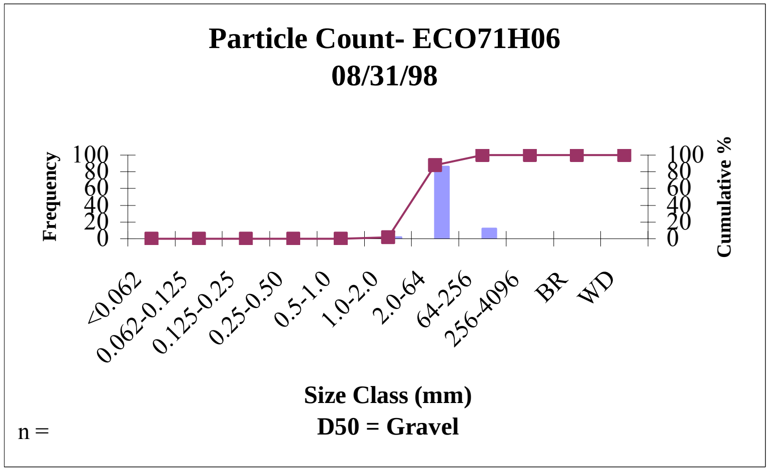
ECOREGION 71I

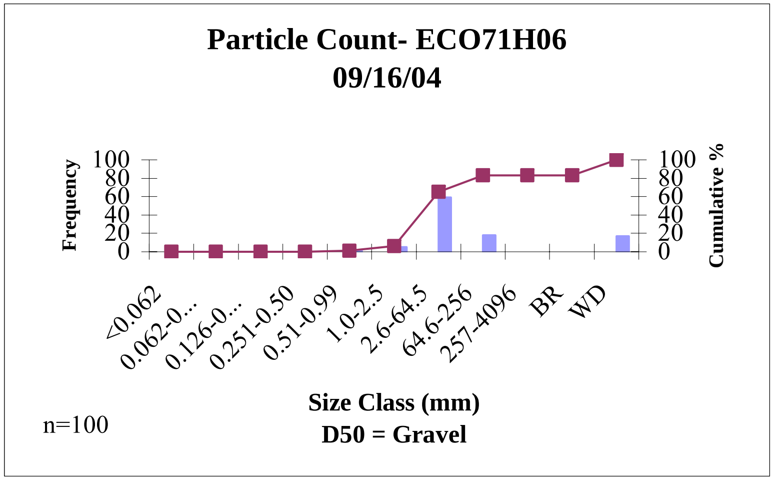


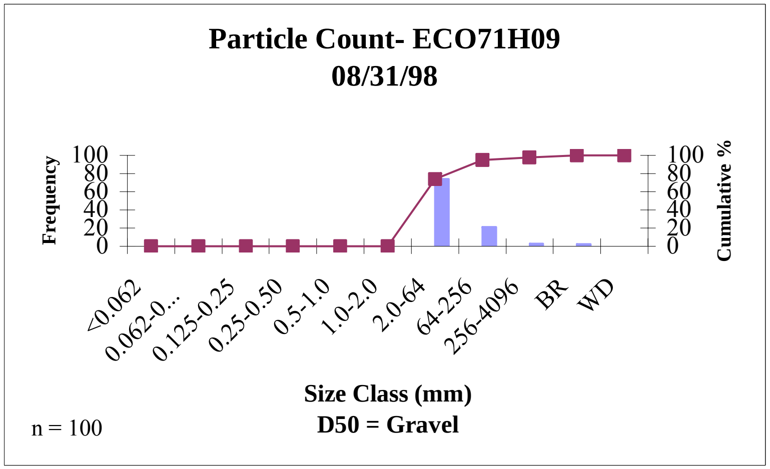


ECOREGION 71H

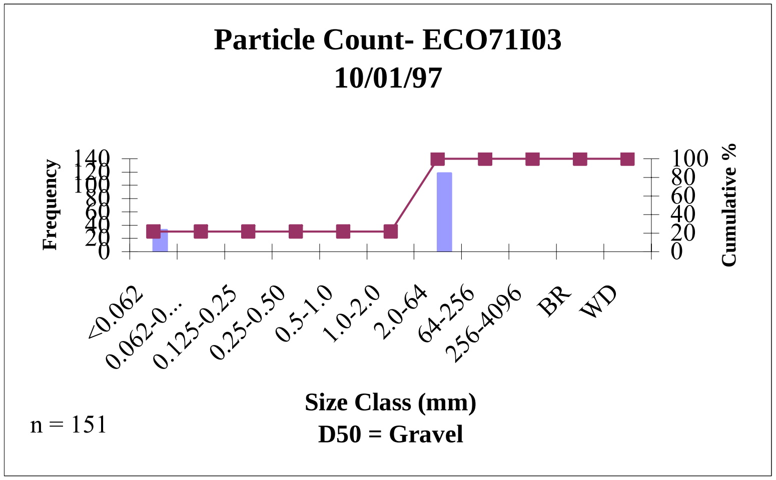


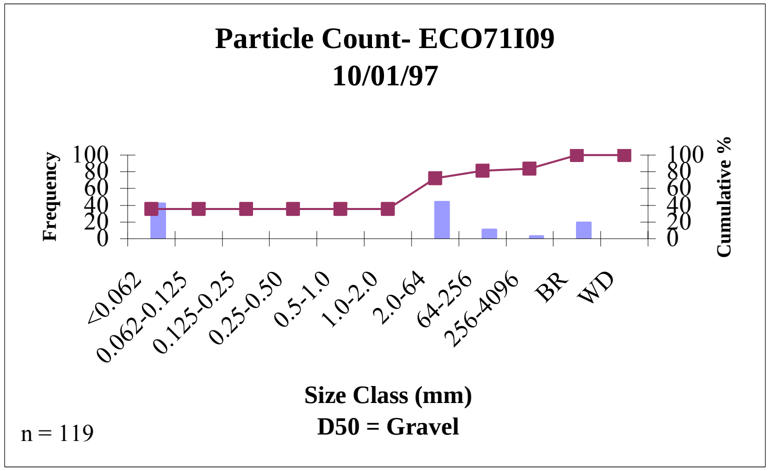


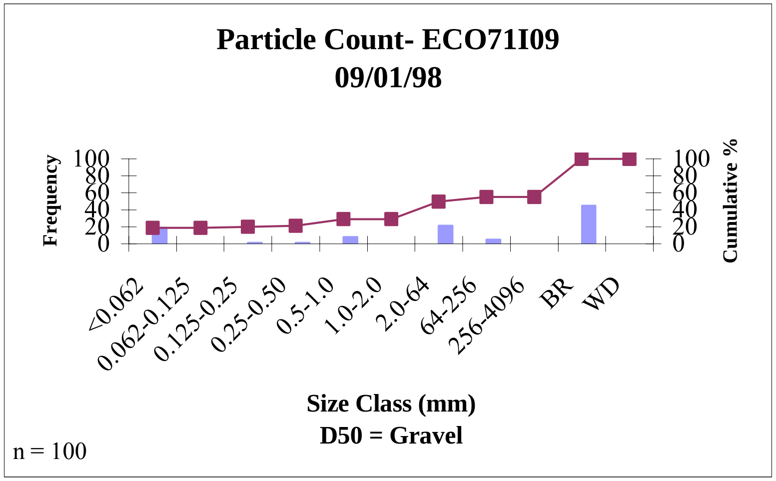


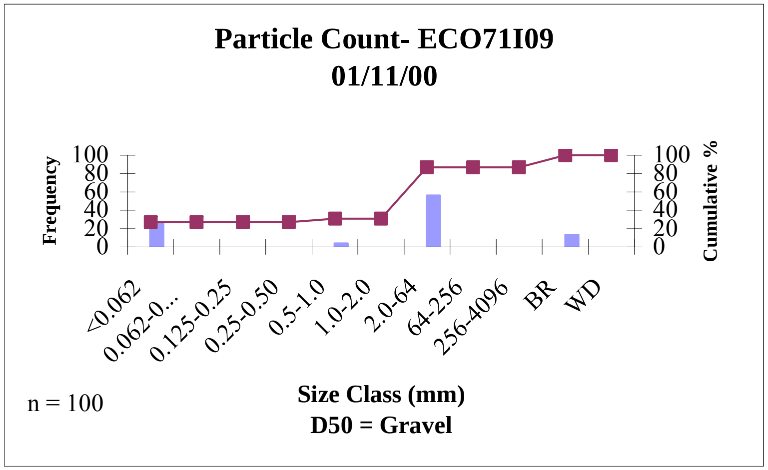


ECOREGION 71I

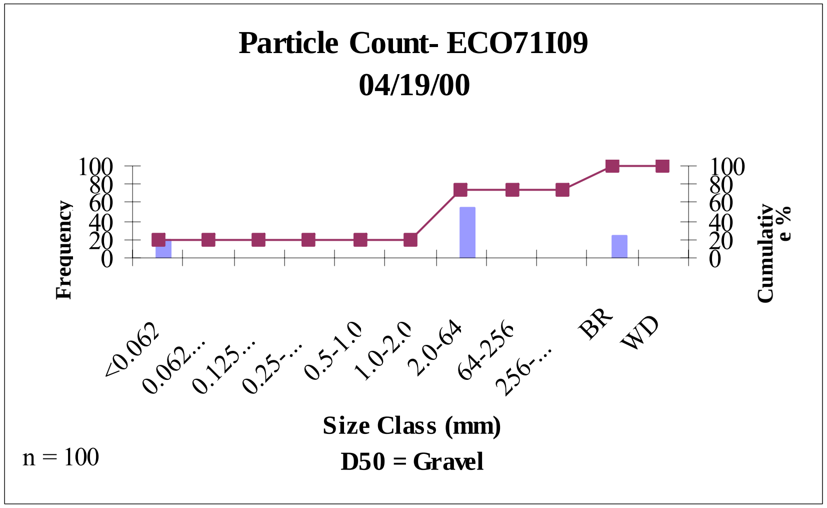


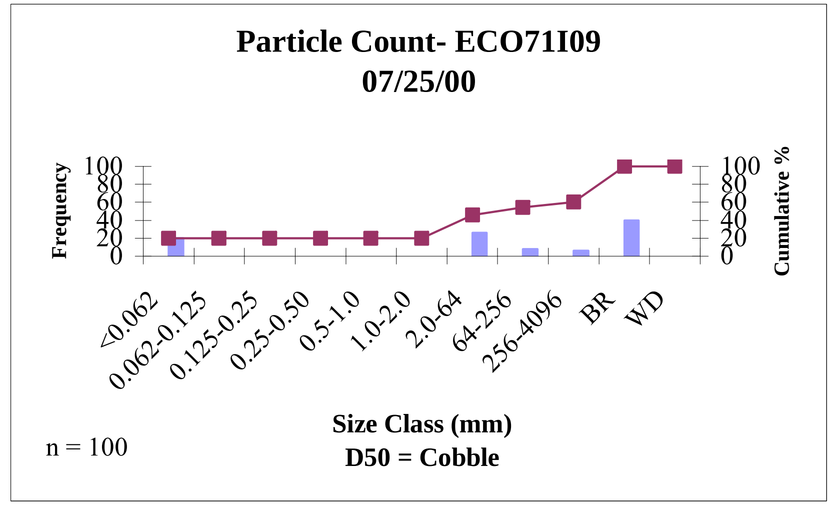




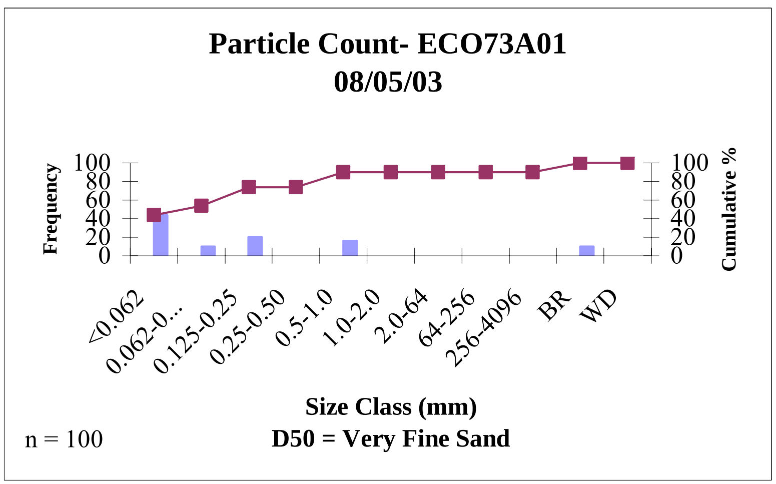


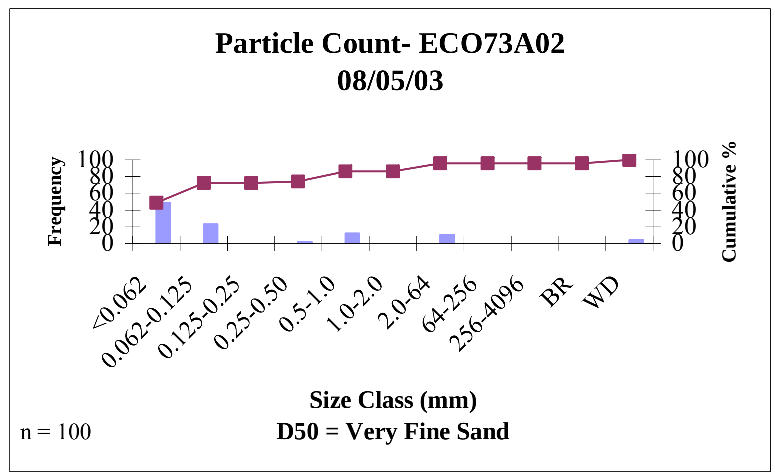
ECOREGION 71I





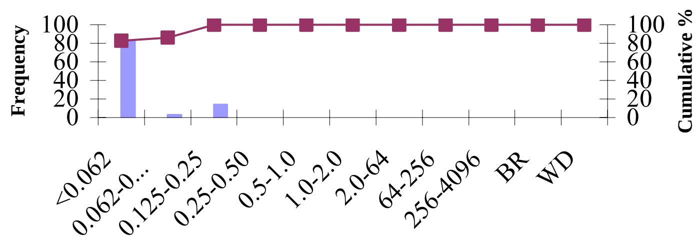
ECOREGION 73A





ECOREGION 73A

Particle Count- ECO73A03
08/05/03



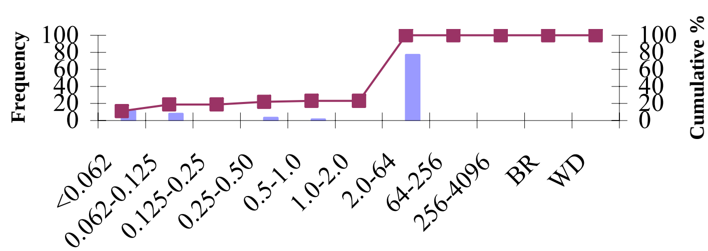
Size Class (mm)

n =

D50 = Silt/Clay

ECOREGION 74A

Particle Count- ECO74A06
04/19/99

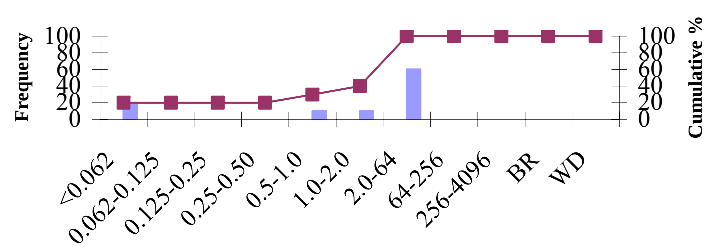


Size Class (mm)

n = 100

D50 = Gravel

Particle Count- ECO74A06
05/16/00



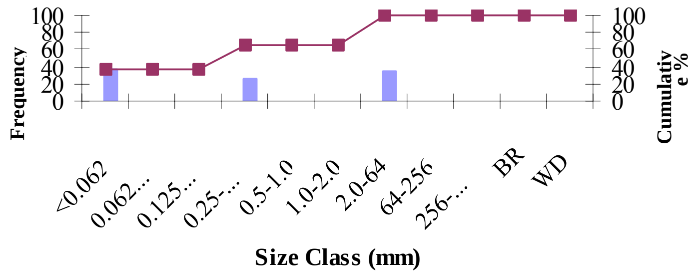
Size Class (mm)

n = 100

D50 = Gravel

ECOREGION 74A

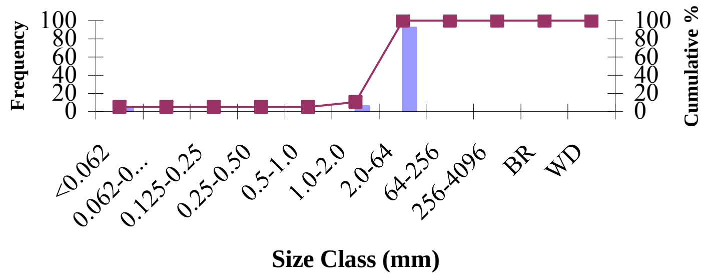
Particle Count- ECO74A06
09/05/00



n = 100

D50 = Medium Sand

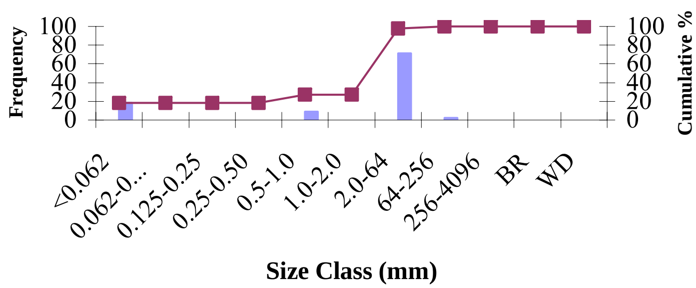
Particle Count- ECO74A08
08/18/98



n = 103

D50 = Gravel

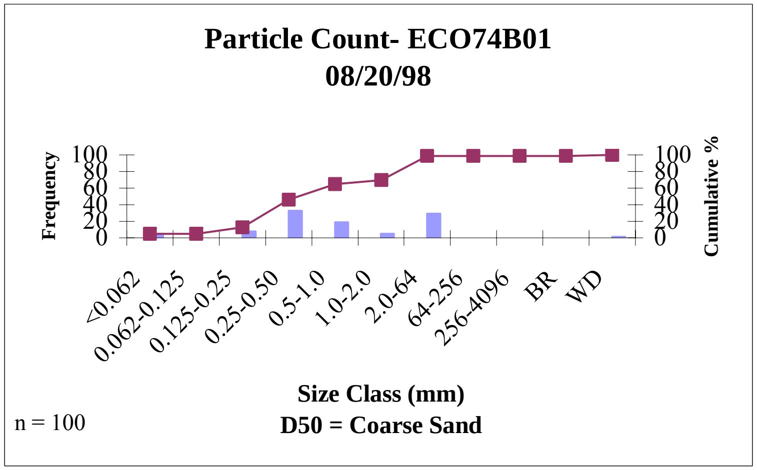
Particle Count- ECO74A08
04/13/99

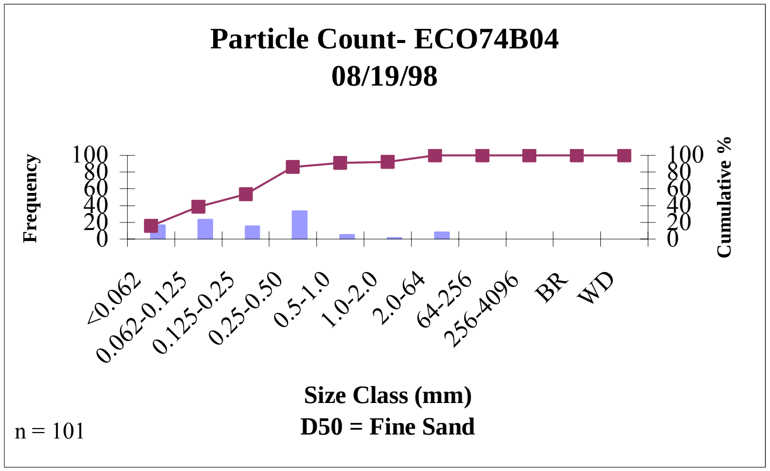


n =

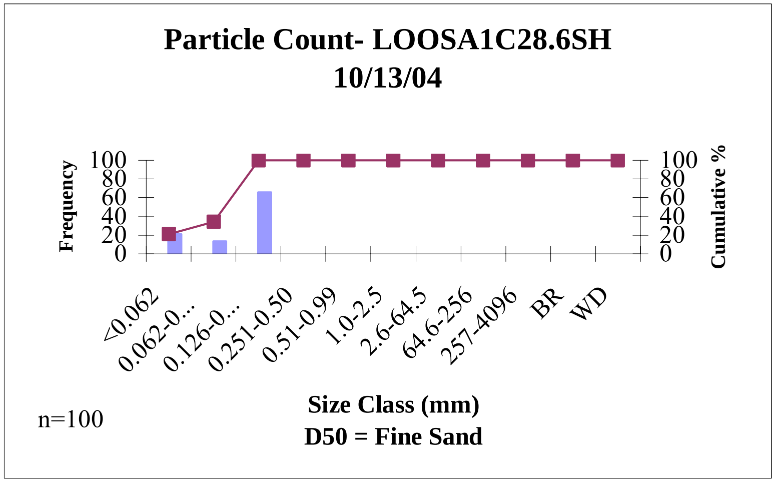
D50 = Gravel

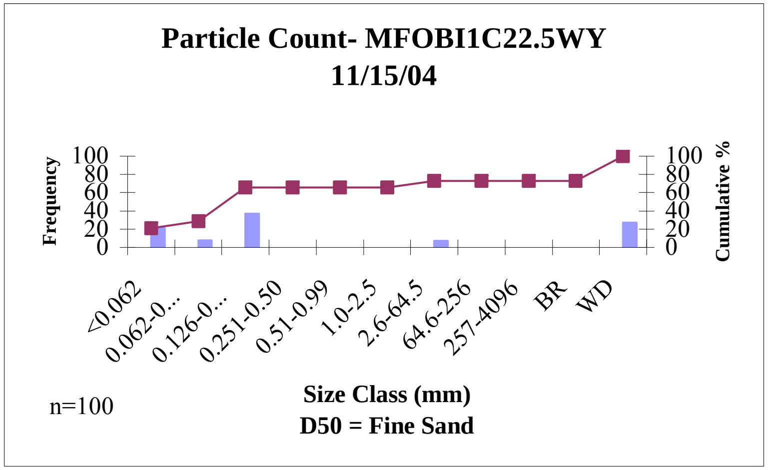
ECOREGION 74B



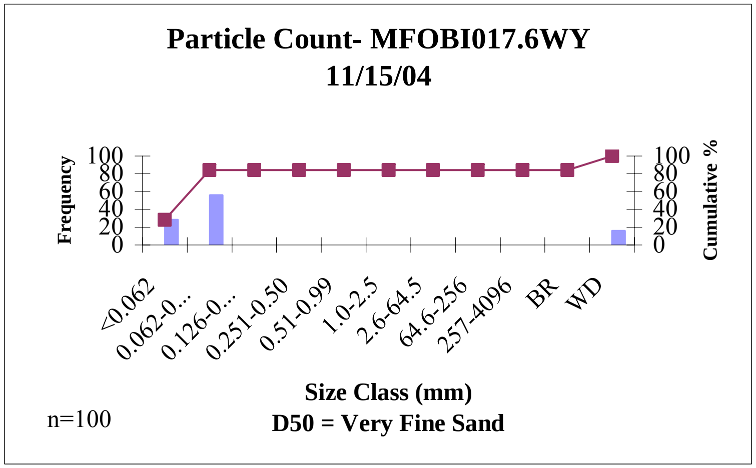


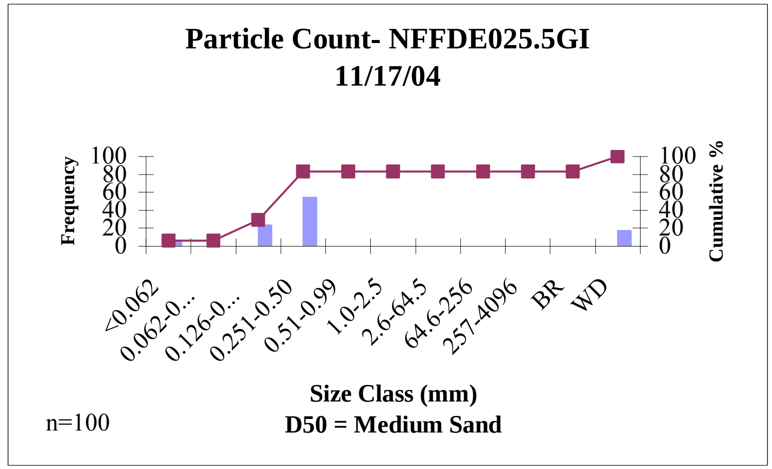
ECOREGION 65E/74B

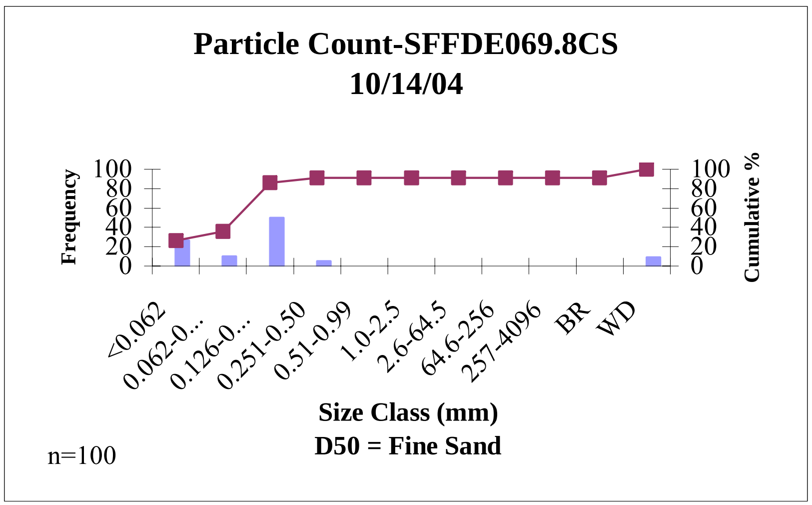


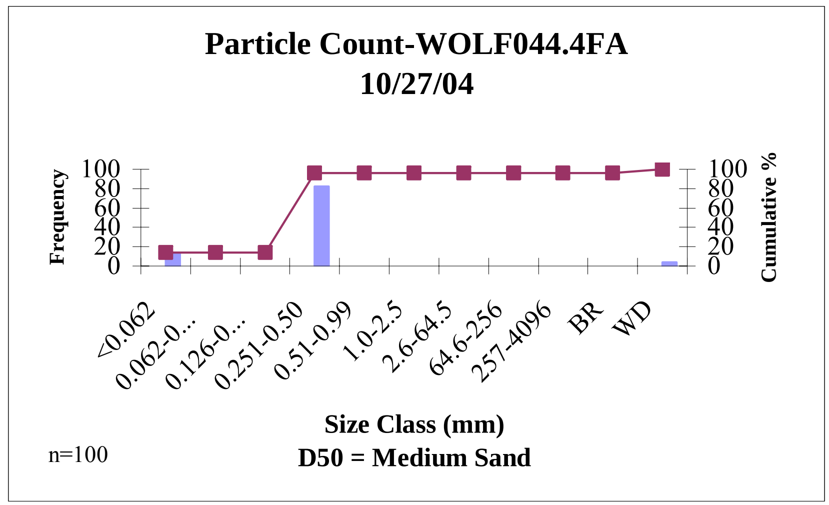


ECOREGION 65E/74B









APPENDIX D

Periphyton Data

Station ID	Stream Name	Survey Date	Ecoregion	% Substrate Available	% Macroalgae	% Microalgae	Max. Thickness Rank	Mean Thickness Rank	% Canopy	Min. Canopy
BEAVE004.4CR	Beaver Creek	10/6/2004	65E	0	0	0	0	0.00	93	
BSAND029.7CR	Big Sandy River	10/6/2004	65E	0	0	0	0	0.00	72	
BSAND045.2CR	Big Sandy River	10/6/2004	65E	0	0	0	0	0.00	32	
CLEAR002.7MC	Clear Creek	10/5/2004	65E	40	0	6	4	0.24	72	49
ECO65E04	Blunt Creek	9/23/2002	65E	0	0	0	0	0.00		
ECO65E06	Griffin Creek	9/23/2002	65E	0	0	0	0	0.00		
ECO65E08	Harris Creek	9/24/2002	65E	54	0	18	0.5	0.10		
ECO65E08	Harris Creek	10/5/2004	65E	0	0	0	0	0.00	96	
ECO65E10	Marshall Creek	10/1/2002	65E	0	0	0	0	0.00		
ECO65E11	West Fork Spring Creek	10/27/2004	65E	11	0	0	0	0.00	90	
MIDDL002.5HD	Middleton Creek	10/21/2004	65E	0	0	0	0	0.00	94	
OTOWN002.2HN	Old Town Creek	11/15/2004	65E	68	0	52	1	0.38	77	72
SNAKE009.8MC	Snake Creek	10/5/2004	65E	0	0	0	0	0.00	97	
WOAK017.4MC	White Oak Creek	10/20/2004	65E	16	0	0	0	0.00	79	74
ECO65J04	Pompeys Branch	10/1/2002	65J	96	0	32	0.5	0.20		
ECO65J05	Dry Creek	10/7/2002	65J	80	0	0	0	0.00		
ECO65J06	Right Fork Whites Creek	10/2/2002	65J	80	0	33	1	0.20		
ECO65J11	Right Fork Whites Creek UT	10/7/2002	65J	54	0	24	1	0.20		
ECO66D01	Black Branch	8/9/2004	66D	43	0	3	0.5	0.01	75	56
ECO66D03	Laurel Fork Creek	8/10/2004	66D	72	0	38	0.5	0.19	88	73
ECO66D05	Doe River	8/10/2004	66D	93	0	23	0.5	0.11	91	88
ECO66D06	Tumbling Creek	8/16/2004	66D	64	0	2	0.5	0.01	96	90
ECO66D07	Little Stony Creek	8/9/2004	66D	84	0	5	0.5	0.02	97	96
ECO66E04	Gentry Creek	8/28/2002	66E	86	0	10	0.5	0.00		
ECO66E09	Clark Cr.	8/17/2004	66E	95	0	54	0.5	0.27	98	94
ECO66E11	Lower Higgins Creek	8/27/2002	66E	90	0	6	0.5	0.00		
ECO66E17	Double Branch	10/10/2000	66E	100	0	69	0.5	0.22	88	

Station ID	Stream Name	Survey Date	Ecoregion	% Substrate Available	% Macroalgae	% Microalgae	Max. Thickness Rank	Mean Thickness Rank	% Canopy	Min. Canopy
ECO66E18	Gee Creek	9/7/2004	66E	82	0	16	0.5	0.08	97	95
ECO66F06	Abrams Creek	8/17/2004	66F	44	0	0	0	0.00	75	47
ECO66F07	Beaverdam Creek	8/28/2002	66F	97	0	22	0.5	0.10		
ECO66F08	Stony Creek	8/27/2002	66F	94	0	6	0.5	0.00		
ECO66G04	Middle Prong Little Pigeon River	8/26/2002	66G	94	0	72	1	0.50		
ECO66G05	Little River	8/16/2002	66G	87	0	29	0.5	0.20		
ECO66G05	Little River	10/10/2000	66G	76	0	91	0.5	0.40	86	
ECO66G07	Citico Creek	8/21/2002	66G	90	0	85	1	0.50		
ECO66G09	North River	8/21/2002	66G	74	0	33	0.5	0.20		
ECO66G12	Sheeds Creek	8/21/2002	66G	84	0	34	0.5	0.20		
CAWOO000.2CL	Cawood Branch	8/23/2004	67F	17	0	39	0.5	0.19	97	96
DAVIS011.6CL	Davis Creek	8/23/2004	67F	46	0	10	0.5	0.04	94	92
DAVIS014.6CL	Davis Creek	8/23/2004	67F	56	0	9	0.5	0.04	86	80
ECO67F06	Clear Creek	9/2/2002	67F	92	0	7	0.5	0.00		
ECO67F13	White Creek	8/24/2004	67F	79	0	28	0.5	0.14	86	84
ECO67F14	Powell River	8/29/2002	67F	83	0	17	1	0.10		
ECO67F16	Hardy Creek	8/24/2004	67F	69	0	37	0.5	0.18	67	60
ECO67F17	Big War Creek	8/28/2002	67F	90	0	5	0.5	0.00		
ECO67F23	Martin Creek	8/29/2002	67F	82	0	8	0.5	0.00		
ECO67F25	Powell River	8/29/2002	67F	74	10	31	1	0.20		
SFLSE001.7MM	South Fork Little Sewee Creek	9/15/2004	67F	58	0	0	0	0.00	94	86
ECO67G01	Little Chucky Creek	8/27/2002	67G	63	0	0	0	0.00		
ECO67G05	Bent Creek	8/27/2002	67G	82	0	5	0.5	0.00		
ECO67G08	Brymer Creek	8/20/2002	67G	83	0	25	0.5	0.10		
ECO67G09	Harris Creek	8/20/2002	67G	69	0	35	0.5	0.20		
ECO67G10	Flat Creek	8/22/2002	67G	96	0	48	0.5	0.20		
ECO67G11	North Prong Fishdam Creek	8/11/2004	67G	92	0	10	0.5	0.05	82	80
ECO67H04	Blackburn Creek	9/15/2004	67H	51	0	0	0	0.00	97	96

Station ID	Stream Name	Survey Date	Ecoregion	% Substrate Available	% Macroalgae	% Microalgae	Max. Thickness Rank	Mean Thickness Rank	% Canopy	Min. Canopy
ECO67H06	Laurel Creek	9/7/2004	67H	27	0	0	0	0.00	95	91
ECO67I12	Mill Branch	8/31/2004	67I	64	0	5	3	0.14	90	85
ECO68A01	Rock Creek	9/5/2002	68A	86	0	7	0.5	0.00		
ECO68A03	Laurel Fork of Station Camp Creek	9/3/2002	68A	46	0	3	0.5	0.00		
ECO68A08	Clear Creek	9/15/2004	68A	74	0	0	0	0.00	62	52
ECO68A26	Daddys Creek	9/5/2002	68A	91	0	93	0.5	0.50		
ECO68A27	Island Creek	9/5/2002	68A	57	0	5	0.5	0.00		
ECO68A28	Rock Creek	8/31/2004	68A	97	0	42	0.5	0.21	79	64
ECO69D01	No Business Branch	9/2/2002	69D	59	0	13	0.5	0.10		
ECO69D03	Flat Fork	8/31/2004	69D	83	0	20	0.5	0.10	93	92
ECO69D05	New River	8/31/2004	69D	80	4	13	0.5	0.06	91	86
ECO69D06	Round Rock Creek	8/30/2004	69D	98	0	40	0.5	0.20	82	75
ECO71E09	Buzzard Creek	9/11/2002	71E	87	0	45	0.5	0.20		
ECO71E09	Buzzard Creek	9/21/2004	71E	87	0	1	3	0.02	88	84
ECO71E14	Passenger Creek	9/16/2002	71E	86	0	58	1	0.40		
ECO71E14	Passenger Creek	9/21/2004	71E	63	0	38	4	0.41	80	69
ECO71E14	Passenger Creek	11/27/2000	71E	88	6	94	2	0.97	30	
LWEST010.5MT	Little West Fork	9/22/2004	71E	84	0	6	3	0.17	86	71
RED080.0RN	Red River	9/21/2004	71E	82	0	20	4	0.49	78	56
ECO71F12	South Harpeth Creek	10/9/2002	71F	78	0	44	1	0.30		
ECO71F12	South Harpeth Creek	6/21/2002	71F	80	0	74	1	0.54	80	
ECO71F12	South Harpeth Creek	10/1/2004	71F	73	0	84	2	0.85	80	49
ECO71F16	Wolf Creek	9/30/2002	71F	78	0	51	0.5	0.20		
ECO71F16	Wolf Creek	9/29/2004	71F	94	0	14	0.5	0.07	55	35
ECO71F19	Brush Creek	9/30/2002	71F	85	0	54	0.5	0.20		
ECO71F19	Brush Creek	9/30/2004	71F	88	0	28	0.5	0.13	71	55
ECO71F27	Swanegan Branch	10/8/2002	71F	70	0	11	0.5	0.10		
ECO71F27	Swanegan Branch	10/22/2004	71F	96	0	0	0	0.00	94	93

Station ID	Stream Name	Survey Date	Ecoregion	% Substrate Available	% Macroalgae	% Microalgae	Max. Thickness Rank	Mean Thickness Rank	% Canopy	Min. Canopy
ECO71F28	Little Swan Creek	9/30/2004	71F	94	0	88	3	0.44	72	61
ECO71F29	Hurricane Creek	9/29/2004	71F	84	0	73	0.5	0.36	77	66
ECO71G03	Flat Creek	9/30/2002	71G	83	21	1	0.5	0.00		
ECO71G03	Flat Creek	9/9/2002	71G	83	21	1	0.5	0.00		
ECO71G04	Spring Creek	9/9/2002	71G	58	0	52	0.5	0.30		
ECO71G10	Hurricane Creek	8/13/2002	71G	52	0	81	0.5	0.40		
ECO71H06	Clear Fork	9/16/2004	71H	77	0	7	0.5	0.03	86	77
ECO71H09	Carson Fork	9/25/2001	71H	100	0	76	2	0.90	66	
ECO71H09	Carson Fork	9/11/2002	71H	85	0	93	1	0.80		
ECO71I03	Stewart Creek	8/8/2002	71I	23	0	0	0	0.00		
ECO71I10	Flat Creek	10/8/2002	71i	90	0	94	1	0.80		
ECO71I12	Cedar Creek	9/28/2004	71I	92	0	49	0.5	0.24	76	67
ECO71I14	Little Flat Creek	10/9/2002	71I	100	0	99	1	0.90		
ECO71I15	Harpeth River	10/9/2002	71I	96	0	100	1	0.50		
ECO71I15	Harpeth River	6/21/2002	71I	99	0	85	1	0.70	70	
ECO71I16	West Fork Stones River	9/16/2004	71I	99	0	18	1	0.10	60	43
FLORI002.4WS	Florida Creek	9/16/2004	71I	93	7	100	0.5	0.50	54	41
SPRIN004.4WS	Spring Creek	9/28/2004	71I	95	0	87	4	3.27	78	64
ECO74A06	Sugar Creek	10/26/2004	74A	78	0	14	4	0.50	44	29
ECO74A08	Paw Paw Creek	11/8/2004	74A	31	0	0	0	0.00	75	56
ECO74B01	Terrapin Creek	9/8/2002	74B	18	0	0	0	0.00		
ECO74B01	Terrapin Creek	9/18/2002	74B	8	0	100	0.5	0.50		
ECO74B01	Terrapin Creek	11/23/2004	74B	49	0	0	0	0.00	36	29
ECO74B04	Powell Creek	11/16/2004	74B	15	0	12	0.5	0.05	45	38

APPENDIX E

Nutrient Data

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
BEAVE004.4CR	65E	09/29/04	6.61	60.7	8.63	23.95	17.74			0.10U	0.148
BEAVE004.4CR	65E	10/06/04	6.88	55.7	9.06	31.57	13.94			0.10U	0.094
BEAVE004.4CR	65E	10/13/04	6.58	59.8	7.35	46.32	16.87			0.11	0.144
BSAND029.7CR	65E	09/29/04	6.36	34.1	8.52	64.5	17.99			0.127	0.038
BSAND029.7CR	65E	10/06/04	6.72	31.4	9.35	74.81	13.93			0.2	0.055
BSAND029.7CR	65E	10/13/04	6.41	38.1	7.96	114.5	16.99			0.12	0.154
BSAND045.2CR	65E	09/29/04	6.24	36	8.39	25.39	16.63			0.179	0.036
BSAND045.2CR	65E	10/06/04	6.43	32.9	9.38	25.42	14.19			0.10U	0.025U
BSAND045.2CR	65E	10/13/04	6.24	45.7	6.47	47.19	16.89			0.13	0.049
CAWOO000.2CL	67F	08/18/04	7.62	381.7	10.31	2.48	18.52			1.34	0.145
CAWOO000.2CL	67F	08/23/04	7.46	397.9	9	2.06	18.22			1.17	0.004U
CAWOO000.2CL	67F	08/30/04	7.35	392.8	8.51	1.38	19.31			1.13	0.004U
CLEAR002.7MC	65E	09/27/04	6.24	64.2	7.39	1.52	17.95			0.443	0.055
CLEAR002.7MC	65E	10/05/04	6.63	58.6	7.86	3.31	15.18			0.413	0.041
CLEAR002.7MC	65E	10/11/04	6.42	60	6.73	3.6	18.61			0.29	0.033
CROOK001.1BT	67F	08/03/04	7.16	303	7.03		21.6			0.01U	0.035
CROOK001.1BT	67F	08/11/04	7.32	306.4	6.68		20.8			0.62	0.042
CROOK001.1BT	67F	08/18/04	7.65	321.8	7.63		19.03			0.55	0.014
DAVIS011.6CL	67F	08/13/04	7.71	306	8.79	90.7	16.1	0.02U	1.51	1.51	0.021
DAVIS011.6CL	67F	08/18/04	7.88	378	8.72	22.91	18.9	0.02U	1.65	1.65	0.004U
DAVIS011.6CL	67F	08/25/04	7.73	498	7.68	42.50	20.09	0.09	2.01	2.1	0.237
DAVIS014.6CL	67F	08/18/04	7.91	378.1	9.62	20.75	19.85			1.56	0.124
DAVIS014.6CL	67F	08/23/04	7.7	385	8.8	15.77	19.5			1.33	0.018
DAVIS014.6CL	67F	08/30/04	7.67	380	7.53	12.05	21.34			1.25	0.065
DEVIL000.2UC	66D	08/03/04	7.3	78.7	8.96	10.96	18.25	0.02U	0.39	0.39	0.052
DEVIL000.2UC	66D	08/10/04	7.24	76.4	8.26	5.1	18.47	0.02U	0.24	0.24	0.004U
DEVIL000.2UC	66D	08/17/04	7.53	8.19	9.59	3.57	17.52	0.02U	0.21	0.21	0.004
ECO65E04	65E	09/29/04	6.14	23.9	8.47	4.28	17.11			0.10U	0.033

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
ECO65E04	65E	10/06/04	6.44	21.3	9.18	5.67	12.69			0.189	0.052
ECO65E04	65E	10/13/04	6.16	26.4	7.66	14.33	16.85			0.01U	0.141
ECO65E06	65E	09/28/04	6.39	28.7	8.91	3.11	16.2			0.10U	0.252
ECO65E06	65E	10/05/04	6.71	25.4	8.68	4.17	17.04			0.10U	0.038
ECO65E06	65E	10/13/04	6.39	32.5	8.44	9.31	16.36			.09	.037
ECO65E08	65E	09/29/04	6.9	52.2	8.94	1.81	15.65			0.10U	0.082
ECO65E08	65E	10/05/04	7.06	47.5	9.13	2.39	15.84			0.10U	0.038
ECO65E08	65E	10/12/04	6.63	33.6	8.15	11.9	18.8			0.18	0.099
ECO65E10	65E	10/12/04	6.26	37.6	8.14	16.63	17.7			0.23	0.04
ECO65E10	65E	10/20/04	6.4	35	8.8	15.34	17.9			0.25	0.086
ECO65E10	65E	10/25/04	6.51	36	7.78	11.88	19.92			0.2	0.137
ECO65E11	65E	10/19/04	5.56	31	7	33.41	17.41			0.35	0.121
ECO65E11	65E	10/27/04	5.8	36.1	7.7	7.81	18.7			0.33	0.046
ECO65E11	65E	11/09/04	5.91	31.85	7.14	7.44	14.29			0.312	0.031
ECO65J05	65J	10/06/04	6.6	21	8.99	4.66	14.23			0.331	0.025U
ECO65J05	65J	10/11/04	6.68	22.9	8.96	10.72	17.73			0.125	0.025U
ECO65J05	65J	10/19/04	6.25	27.4	9.08	62.15	17.14			0.17	0.076
ECO66D01	66D	07/27/04	6.8	26.6	8.1	4.2	16.8			0.11	0.004U
ECO66D01	66D	08/05/04	6.78	37	8.41	2.97	18.09			0.18	0.024
ECO66D01	66D	08/10/04	7.27	45.6	9.26	0.48	16.4			0.22	0.014
ECO66D03	66D	07/28/04	6.8	24.3	8.1	40.36	17.6			0.14	0.068
ECO66D03	66D	08/05/04	6.5	21.8	8.73	23.79	18.04			0.18	0.012
ECO66D03	66D	08/10/04	6.86	28.6	9	11.71	16.18			0.29	0.06
ECO66D05	66D	07/28/04	7.4	76.6	7.8	18.51	18.4			0.5	0.055
ECO66D05	66D	08/05/04	7.09	76.3	8.66	12.92	17.7			0.2	0.043
ECO66D05	66D	08/10/04	7.54	81.2	8.5	6.85	18.19			0.51	0.013
ECO66D06	66D	08/04/04	6.83	32.5	8.76	1.04	17.98			0.17	0.025
ECO66D06	66D	08/10/04	7.03	33.7	8.55	0.92	16.52			0.12	

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
ECO66D06	66D	08/17/04	7.17	32.3	10.32	1.1	15.69			0.32	0.009
ECO66D07	66D	07/28/04	6.73	26.7	8.42	11.49	16.2			0.07	0.077
ECO66D07	66D	08/05/04	6.64	24.2	8.79	4.25	17.6			0.1	0.014
ECO66D07	66D	08/10/04	6.95	28.1	9.22	2.39	16.02			0.13	0.017
ECO66E04	66E	07/27/04	6	16.9	8.3	6.94	16.3			0.23	0.004U
ECO66E04	66E	08/05/04	5.99	13.7	8.67	11.02	16.62			0.18	0.02
ECO66E04	66E	08/10/04	6.27	16.1	9.35	3.8	14.12			0.22	0.02
ECO66E09	66E	08/02/04	6.61	24	9.7	6.03	20.28			0.14	0.039
ECO66E09	66E	08/12/04	6.51	24.7	8.89	3.4	17.75			0.19	0.004U
ECO66E09	66E	08/17/04	6.6	26.6	9.49	2.49	16.83			0.18	0.007
ECO66E18	66E	09/02/04	6.8	26.5	8.6	1.92	20.77			0.07	0.026
ECO66E18	66E	09/07/04	6.54	25.5	9.05	5.48	20.02			0.12	0.032
ECO66E18	66E	09/14/04	7.03	23.7	10.66	1.77	18.66			0.08	0.004U
ECO66F06	66F	08/04/04	7.13	92.5	8.09	27.57	16.33			0.32	0.021
ECO66F06	66F	08/11/04	7.18	119.1	8.25	18.9	16.01			0.21	0.021
ECO66F06	66F	08/17/04	7.45	115.3	8.94	18.44	15.39			0.15	0.004U
ECO66F07	66F	07/29/04	7.3	61.8	8.3	42.94	16.9			0.25	0.072
ECO66F07	66F	08/05/04	7.08	62.3	8.57	35.72	18.73			0.17	0.022
ECO66F07	66F	08/11/04	7.39	68.6	9.17		16.54			0.29	0.021
ECO66F08	66F	07/28/04	6.8	88.3	7.9	4.84	16.3			0.11	0.052
ECO66F08	66F	08/05/04	6.61	79.3	8.29	1.84	16.75			0.32	0.02
ECO66F08	66F	08/10/04	6.9	84.7	9.12	1.36	14.66			0.18	0.03
ECO66G04	66G	08/04/04	5.62	11.3	9.32		15.44			0.58	0.018
ECO66G04	66G	08/12/04	5.8	11.1	9.7		15.45			0.03	0.004U
ECO66G04	66G	08/18/04	6.42	11.3	10.78		15.16			0.24	0.004U
ECO66G07	66G	09/02/04	6.84	37.6	8.13	52.6	21.1			0.07	0.004U
ECO66G07	66G	09/13/04	7.25	24.7	9.16	90.09	19.7			0.01U	0.004U
ECO66G09	66G	09/02/04	6.57	19.8	8.7	15.47	17.83			0.11	0.004U
ECO66G09	66G	09/07/04	6.36	19.8	9.03	27.76	17.8			0.15	0.048

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
ECO66G09	66G	09/13/04	6.79	16.1	10.1	26.52	10.02			0.11	0.004U
ECO67F06	67F	08/23/04	7.75	292	9.87	0.13	16.41	0.02U	0.01U	0.01U	0.004U
ECO67F06	67F	08/30/04	7.7	291	8.8	0	16.7	0.02U	0.01U	0.01U	0.004U
ECO67F06	67F	09/08/04	7.67	277.5	7.6	1.19	16.12	0.02U	0.59	0.59	0.004U
ECO67F13	67F	08/11/04	7.9	301	9.58	1.39	15.66			0.12	0.004U
ECO67F13	67F	08/18/04	7.94	312	9.46	1.19	15.93			0.16	0.004U
ECO67F13	67F	08/24/04	7.73	307	9.68	1.59	15.8			0.15	0.004U
ECO67F14	67F	08/12/04	8.17	567	7.62	174.7	22.14			0.71	0.004U
ECO67F14	67F	08/17/04	8.17	600	8.64	153.3	21.04			0.59	0.004U
ECO67F14	67F	08/25/04	7.95	602	7.94	184.0	22.41			0.64	0.005
ECO67F16	67F	08/09/04	8.4	330	9.44	10.48	18.61			1.07	0.027
ECO67F16	67F	08/17/04	8.22	344	10.21	11.5	15.58			0.91	0.004U
ECO67F16	67F	08/25/04	8.02	349	10.19	11.4	16.43			0.94	0.004U
ECO67F17	67F	08/09/04	8.32	369	10.29	9.945	20.26			0.41	0.034
ECO67F17	67F	08/18/04	8.17	388	9.03	9.42	18.88			0.27	0.004U
ECO67F17	67F	08/26/04	8.1	390	9.15	8.25	21.3			0.29	0.004U
ECO67F23	67F	08/12/04	8.31	336	9.25	10.57	17.37			0.87	0.004U
ECO67F23	67F	08/17/04	8.39	328	9.83	8.59	18.25			0.54	0.004U
ECO67F23	67F	08/25/04	8.28	337	9.99	12.1	19.35			0.66	0.004U
ECO67F25	67F	08/12/04	8.17	469	7.9	897.1	21.43			0.8	0.004U
ECO67F25	67F	08/17/04	8.33	501	9.9	224.9	23.44			0.44	0.004U
ECO67F25	67F	08/25/04	8.12	512	9.31	546.1	23.89			0.56	0.004U
ECO67G11	67G	07/29/04	7.7	96.4	79.2	0.89	17.7	0.02U	0.15	0.15	0.078
ECO67G11	67G	08/03/04	7.5	99.4	8.67	0.19	18.48	0.02U	0.14	0.14	0.038
ECO67G11	67G	08/11/04	7.7	113.6	8.74	0.23	17	0.02U	0.18	0.18	0.014
ECO67H04	67H	09/08/04	7.4	84.9	6.61	0.435	21.59			0.01U	0.004U
ECO67H04	67H	09/15/04	7.04	109.8	6.52	0.79	18.95			0.08	0.004U
ECO67H04	67H	09/22/04	7.13	70.3	8.9	0.527	15.26			0.10U	0.025U
ECO67H06	67H	09/02/04	7.33	143.8	8.31	0.78	19.61			0.09	0.004U

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
ECO67H06	67H	09/08/04	7.57	15.34	8.2	11.89	22.77			0.05	0.031
ECO67H06	67H	09/13/04	7.6	138	7.9	0.57	19.37			0.08	0.004U
ECO67I12	67I	08/23/04	7.63	309	8.55	0.44	18.78			0.05	0.022
ECO67I12	67I	08/31/04				0.24				0.07	0.041
ECO67I12	67I	09/07/04	7.67	248.2	6.31	0.18	18.76			0.01U	0.054
ECO68A01	68A	08/19/04	5.75	16	10.63	1.95	17.04			0.09	0.184
ECO68A01	68A	08/24/04	5.5	15	8.65	3.47	19.1			0.05	0.004U
ECO68A01	68A	08/31/04	5.73	18.1	8.65	1.84	19.79			0.01U	0.004U
ECO68A03	68A	08/16/04	6.37	22.7	9.62	6.51	16.13			0.05	0.018
ECO68A03	68A	08/24/04	6.4	24.4	8.8	10.98	18.8			0.04	0.004U
ECO68A03	68A	08/31/04	6.56	24.1	8.4	5.32	19.46			0.01U	0.004U
ECO68A08	68A	09/01/04	6.59	52	6.81	14.82	22.92			0.05	0.004U
ECO68A08	68A	09/15/04	6.81	41.9	7.91	55.35	19.98			0.11	0.004U
ECO68A26	68A	08/31/04	7.65	107.8	8.33	24.01	24.73			0.09	0.004U
ECO68A26	68A	09/14/04	7.7	82.3	9.16		21.87			0.1	0.004U
ECO68A27	68A	09/01/04	6.17	115.5	7.86	1.82	20.16			0.07	0.004U
ECO68A27	68A	09/14/04	6.36	42.1	8.57	12.72	19.68			1.55	0.004U
ECO68A28	68A	08/24/04	6.87	57.2	8	3.57	20.72			0.07	0.004U
ECO68A28	68A	08/31/04	6.8	55.2	7.8	3.75	21.5			0.05	0.004U
ECO68A28	68A	09/07/04	7.03	44.3	6.93	11.02	21.82			0.05	0.047
ECO69D03	69D	08/24/04	6.62	51.9	8.38	0.63	19.03			0.06	0.2U
ECO69D03	69D	08/31/04	6.58	50.7	8.14	0.61	19.68			0.07	0.011
ECO69D03	69D	09/07/04	6.67	46.6	6.3	0.56	19.95			0.15	0.004U
ECO69D05	69D	08/26/04	7.35	276	8.82	2.29	19.5			0.11	0.005
ECO69D05	69D	08/31/04	7.23	22.7	8.82	4.04	19.16			0.12	0.017
ECO69D05	69D	09/07/04	7.42	347.5	7.25	0.874	18.04			0.12	0.067
ECO69D06	69D	08/26/04	8.07	367	9.05	1.17	20.01			0.12	0.004U
ECO69D06	69D	08/30/04	7.8	360	8.7	0.68	19.9			0.12	0.004U
ECO69D06	69D	09/07/04	8.1	365.5	7.57	0.33	19.58			0.01U	0.032

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
ECO71E09	71E	09/16/04	7.78	399.7	9.68	14.73	17.89			1.55	0.004U
ECO71E09	71E	09/21/04	8	439	9.4	7.8	16.1			3.2	0.004U
ECO71E09	71E	09/30/04	7.67	476.5	9.6	5.04	14.54			3.38	0.061
ECO71E14	71E	09/16/04	7.84	447	9.17	7.62	20.26	0.02U	1.55	1.55	0.004U
ECO71E14	71^{E}	09/21/04	8	466	9.7	4.83	17.4	0.02U	1.7	1.7	0.018U
ECO71E14	71E	09/28/04	7.55	484.6	9.19	3.28	18.38	0.02U	2.10	2.10	0.025U
ECO71F12	71F	09/21/04	8	209.2	8.12	2.43	20.5			0.26	0.025U
ECO71F12	71F	10/01/04	8.1	236	10.2	2.21	12.9			0.176	0.038
ECO71F12	71F	10/06/04	8.03	231.7	9.78	2.58	17.26			0.259	0.031
ECO71F16	71F	09/21/04	7.12	97.1	8.14	8.25	17.93			0.10U	0.025U
ECO71F16	71F	09/29/04	7.46	107.3	8.58	9.65	17.41			0.10U	0.38
ECO71F16	71F	10/04/04	7.04	107.2	8.19		16.55			0.10U	0.038
ECO71F19	71F	09/21/04	7.18	61.3	8.63	12.48	17.69			0.10U	0.025U
ECO71F19	71F	09/30/04	7.55	70.1	9.74	10.81	14.06			0.10U	0.025U
ECO71F19	71F	10/06/04	7.27	71.5	9.47	9.37	11.6			0.10U	0.025U
ECO71F27	71F	10/11/04	6.46	66.5	8.14	1.72	16.76			0.18	0.004U
ECO71F27	71F	10/22/04	6.6	45	9.8	18.56	16			0.62	0.014
ECO71F27	71F	10/25/04	6.61	49.3	9	9.1	17.05			0.28	0.151
ECO71F28	71F	09/21/04	8.05	74.9	8.93	3.95	19.5			0.10U	0.025U
ECO71F28	71F	09/30/04	7.85	82.7	10.87	4.03	11.84			0.10U	0.033
ECO71F28	71F	10/06/04	7.53	85.4	10.61	2.93	10.07			0.10U	0.025U
ECO71F29	71F	09/21/04	7.24	196.6	7.55	31.39	17.68			0.368	0.025U
ECO71F29	71F	09/29/04	7.76	218.5	9.53	30.55	18.63			1.71	0.025U
ECO71F29	71F	10/04/04	7.34	222.8	8.76	29.4	16.8			0.258	0.033
ECO71H06	71H	09/09/04	8.1	258.3	8.19	6.81	17.53			0.3	0.026
ECO71H06	71H	09/16/04	4.53	263.9	7.25	2.27	17.07			0.21	0.024
ECO71H06	71H	09/23/04	7.72	236.2	9.68	5.788	16.93			0.3	0.036
ECO71I12	71I	09/20/04	7.48	417.3	9.02	29.3	18.89			1.16	0.117
ECO71I12	71I	09/28/04	7.9	474	73.9	5.54	19.3			0.399	0.157

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
ECO71I12	71I	10/05/04	7.61	466.4	8.37	1.81	17.99			0.258	0.084
ECO71I16	71I	09/09/04	7.89	499.7	6.22	2.09	19.92	0.02U	0.59	0.01U	0.016
ECO71I16	71I	09/16/04	7.48	494.1	4.3	0.73	21.82	0.02U	0.15	0.15	0.037
ECO71I16	71I	09/22/04	7.5	422	8.6	17.92	17.77	0.02U	0.53	0.53	0.038
ECO73A01	73A	10/27/04	7.05	263	0.38	11.2J	18.07			0.01U	0.046
ECO73A01	73A	11/01/04	7.02	161.8	3.09	94.0J	19.82			0.17	0.162
ECO73A01	73A	11/09/04	6.98	169.1	0.67	40.5J	14.54			0.64	0.228
ECO73A02	73A	10/26/04	7.02	409.2	3.16	32.5J	18.38			0.2	0.321
ECO73A02	73A	11/02/04	7.32	88.8	8.74	336J	19.3			0.37	0.625
ECO73A02	73A	11/22/04	6.79	594.9	5	9410J	14.61			0.059	0.004U
ECO73A03	73A	10/27/04	7.25	555.9	2.3	18.9J	19.87			0.17	0.054
ECO73A03	73A	11/01/04	7.25	254.3	5.31	163J	19.82			0.17	0.357
ECO73A03	73A	11/09/04	7.09	195.9	3.14	9.14J	13.54			0.1	0.215
ECO73A04	73A	11/02/04	6.85	161.6	8.56	217.1	19.63			0.01U	0.356
ECO73A04	73A	11/08/04	6.3	188	2	7.69	14.3			0.063	0.392
ECO73A04	73A	11/16/04	7.05	215.08	2.06	7.27	11.46			0.07	0.29
ECO74A06	74A	10/18/04	7.54	518	7.8	0.37	18.07			0.01U	0.165
ECO74A06	74A	10/26/04	7.43	458.9	7.6	0.11	21.17			0.01U	0.093
ECO74A06	74A	11/10/04	7.09	195.9	3.14	0.41	13.54			0.263	0.106
ECO74A08	74A	11/02/04	7.42	203.4	9.18	27.14	18.3			0.3	0.416
ECO74A08	74A	11/08/04	7.7	527.4	8.05	2.3	13			0.145	0.322
ECO74A08	74A	11/16/04	8.33	531.4	9	3.73				0.06	0.1
ECO74B01	74B	11/08/04	6.55	60.9	7.5	19.53	13.12			0.542	0.065
ECO74B01	74B	11/16/04	6.27	58.8	9.9	32.7	11.2			0.38	0.03
ECO74B01	74B	11/23/04	6.6	20.4	8.5	34.29	13.6			0.27	0.004U
ECO74B04	74B	11/08/04	6.68	51.7	7.7	6.48	14.86			0.211	0.043
ECO74B04	74B	11/16/04	6.36	28.8	10.6	9.46	12.5			0.18	0.42
ECO74B04	74B	11/22/04	6.66	54	9.21	6.62	14.45			0.25	0.004U
ECO74B12	74B	10/20/04	5.87	41.9	5.68		19.4			0.17	0.311

Station ID	Ecoregion	Date	pH	Conductivity (цMHO)	DO (mg/L)	Flow (cfs)	Temp (°C)	Nitrite (mg/L)	Nitrate (mg/L)	NO_{2-3} (mg/L)	Total Phosphorus (mg/L)
ECO74B12	74B	10/27/04	6	38.8	6.8	374.0	20.3			0.15	0.053
ECO74B12	74B	11/10/04	6.66	39.1	7.95	226.8	12.89			0.225	0.044
FLORI002.4WS	71I	09/09/04	8.22	301.9	9.05	0.309	24.25			0.01U	0.004U
FLORI002.4WS	71I	09/16/04	7.23	416	2.1	0.07	22.22			0.14	0.182
FLORI002.4WS	71I	09/23/04	7.8	370.3	11.21	0.13	20.98			0.10U	0.189
HATCH080.8HY	74B	10/04/04	6.55	61.5	8.22	449.4	19.57			0.10U	0.055
HATCH080.8HY	74B	10/13/04	6.6	53.7	7.42		18.54			0.19	0.164
HATCH080.8HY	74B	10/27/04	6.24	51.4	5.48		20.46			0.01U	0.065
LOOSA1C28.6SH	74B	10/04/04	6.32	44.6	9.05	101.1	17.37			0.163	0.073
LOOSA1C28.6SH	74B	10/13/04	6.68	55.5	9.17	119.41	16.37			0.21	0.072
LOOSA1C28.6SH	74B	10/21/04	6.4	73.8	8.35	243J	17.9			0.2	0.288
LWEST009.4MT	71E	09/16/04	7.4	349.8	6.57		19.89			2.59	0.344
LWEST009.4MT	71E	09/22/04	7.8	360	8.4		16.1			1.36	0.052
LWEST009.4MT	71E	09/28/04	7.04	249.4	6.68		18.05			3.42	0.522
LWEST010.5MT	71E	09/16/04	7.54	326.8	8	39.07	19.34			2.08	0.082
LWEST010.5MT	71E	09/22/04	7.5	390	6.9	25.89	17.5			2.3	0.378
LWEST010.5MT	71E	09/28/04	7.44	387.7	9.29	18.28	17.71			2.65	0.043
MFOBI014.6WY	65E	11/09/04	6.47	51.6	7.51	121.84	13.24			0.657	0.048
MFOBI014.6WY	65E	11/15/04	6.04	52.6	10.36	128.13	11.5			0.539	0.057
MFOBI014.6WY	65E	11/22/04	6.43	54.3	8.885	112.61	14			0.43	0.004U
MFOBI1C22.5WY	65E	11/10/04	6.46	50.8	7.53	78.46	12.58			0.742	0.055
MFOBI1C22.5WY	65E	11/15/04	6.13	51.4	10.83	92.03	12.2			0.635	0.004U
MFOBI1C22.5WY	65E	11/22/04	6.44	50.9	9.24	85.16	14.17			0.51	0.084
MIDDL002.5HD	65E	10/12/04	6.35	33.1	7.06	25.38	19.25	0.02U	0.01U	0.01U	0.061
MIDDL002.5HD	65E	10/21/04	6.6	76.7	7.2	29.34	18	0.02U	0.11	0.11	0.056
MIDDL002.5HD	65^{E}	10/26/04	6.6	59.1	6.78	22.21	18.08	0.02U	0.01U	0.01U	0.111
NFFDE020.5DY	74B	11/09/04	6.64	106.2	5.54	118.51	12.39			0.273	0.323
NFFDE020.5DY	74B	11/16/04	6.58	105	7.72	61.46J	12			0.31	0.25
NFFDE020.5DY	74B	11/23/04				140.5				0.297	0.004U

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NFFDE025.5GI	65E/74B	11/09/04	6.85	108.1	7	92.93	11.78	0.02U	0.32	0.32	0.189
NFFDE025.5GI	65E/74B	11/17/04	6.66	104	9.19	80.41	13	0.05	0.3	0.35	0.12
NFFDE025.5GI	65E/74B	11/23/04				180.88		0.056	0.275	0.331	0.004U
NINDI010.5UC	66F	08/02/04	7.19	102	8.84	23.97	18.87			0.25	0.041
NINDI010.5UC	66F	08/10/04	7.55	118.6	9.36	9.79	17.85			0.33	0.004U
NINDI010.5UC	66F	08/17/04	7.6	121.4	9.93	10.64	16.19			0.29	0.009
OBION020.9DY	73A	11/17/04	7.07	123.3	7.45	1200J	12.5			0.33	0.19
OBION020.9DY	73A	11/22/04	6.73	146.9	7.66	1727J				0.427	0.004U
OBION020.9DY	73A	01/26/05								0.32	
OTOWN002.2HN	65E	11/08/04	6.57	43.6	7.42	10.42	15.46			0.208	0.054
OTOWN002.2HN	65E	11/15/04	6.13	51.4	10.83	8.87	12.2			0.217	0.057
OTOWN002.2HN	65E	11/22/04	6.46	39.8	9.41		13.83			0.24	0.004U
RED080.0RN	71E	09/17/04	7.38	367.7	7.6		19.49			2.98	0.111
RED080.0RN	71E	09/21/04	7.58	385.6	7.77	33.52	16.5			2.8	0.085
RED080.0RN	71E	09/30/04	7.29	446.4	8.25	13.68	15.42			2.12	0.126
ROCKY000.2UC	66D	08/03/04	6.72	17.1	9.51	8.26	16.09			0.11	0.032
ROCKY000.2UC	66D	08/10/04	6.75	17.1	8.65	11.34	15.91			0.38	0.004U
ROCKY000.2UC	66D	08/17/04	6.93	19.6	10.97	7.07	15.47			0.12	0.004U
SFFDE043.2MN	65E/74B	10/28/04	6.59	79	6.99	671.6J	19.95	0.03	0.21	0.24	0.004U
SFFDE043.2MN	65E/74B	11/02/04	6.83	69.2	8.22	710.4J	19.26	0.24	0.28	0.52	0.588
SFFDE043.2MN	65E/74B	11/10/04	6.71	76.8	7.23	541.6J	12.77	0.02	0.412	0.432	0.105
SFFDE069.8CS	65E/74B	10/05/04	6.53	34	9.15	74.07	14.86	0.02U	0.10U	0.10U	0.066
SFFDE069.8CS	65E/74B	10/14/04	6.57	38	8.62	126.6	14.36	0.02U	0.13	0.13	0.12
SFFDE069.8CS	65E/74B	10/20/04						0.02U	0.11	0.11	0.128
SFLSE001.7MM	67F	09/08/04	7.94	297.4	7.35	1.006	17.26			0.5	0.004U
SFLSE001.7MM	67F	09/15/04	7.53	308.2	8.27	1.62	16.34			0.45	0.004U
SFLSE001.7MM	67F	09/22/04	7.43	238	8.84	4.635	14.92			1.04	0.025U
SNAKE009.8MC	65E	09/27/04	6.54	45.5	4.68	2.78	19.83			0.101	0.048
SNAKE009.8MC	65E	10/05/04	6.96	42.3	9.02	8.02	15.74			0.10U	0.031

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SNAKE009.8MC	65E	10/11/04	6.59	42	6.97	25.47	18.77			0.1	0.089
SPRIN004.4WS	71I	09/20/04	7.58	408	9	60.12	19.36			0.848	0.192
SPRIN004.4WS	71I	09/28/04	7.8	452	5.7	11.45	20.4			0.10U	0.116
SPRIN004.4WS	71I	10/05/04	7.72	419.5	7.89	3.33	18.32			0.10U	0.154
WOAK017.4MC	65E	10/12/04	6.41	27.4	8.77	5.36	18.93			0.08	0.03
WOAK017.4MC	65E	10/20/04	6.4	33.3	9.5	13.66	18.3			0.25	0.096
WOAK017.4MC	65E	10/26/04	6.62	62.8	8.84	6.08	17.27			0.24	3.16
WOLF044.4FA	65E/74B	10/20/04	6.07	17.8	6		19.38	0.02U	0.1	0.1	0.293
WOLF044.4FA	65E/74B	10/27/04				658.67		0.02U	0.01U	0.01U	0.078
WOLF044.4FA	65E/74B	11/01/04	6.27	48.4	7.96	433.1	21.23	0.02U	0.01U	0.01U	0.078