UPPER RAPID CREEK WATERSHED ASSESSMENT

AN EVALUATION OF CONDITIONS IMPACTING WATER QUALITY IN NORTH FORK RAPID CREEK CASTLE CREEK AND NORTH FORK CASTLE CREEK IN THE BLACK HILLS, SOUTH DAKOTA

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SECTION 1: INTRODUCTION AND PROJECT DESCRIPTION

PROJECT GOALS

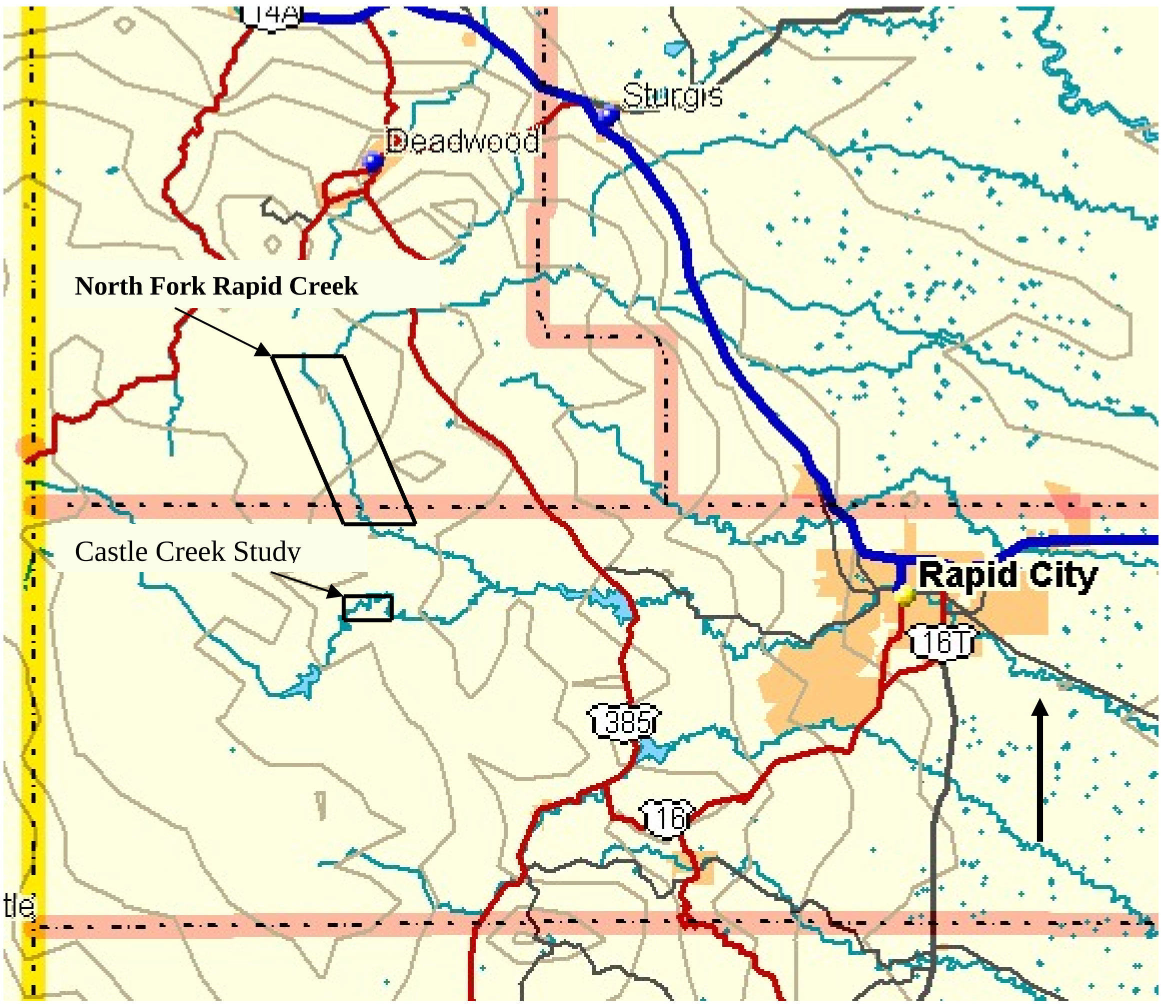
The upper Rapid Creek watershed (HUC 10120110) contains four principal streams: North Fork Rapid Creek, South Fork Rapid Creek, Castle Creek and Slate Creek. North Fork Rapid Creek is listed in the South Dakota Total Maximum Daily Load Waterbody List (i.e. the 303 (d) list) as not supporting its designated use due to temperature exceedance. Additionally, state and federal management agencies together with the general public have noted iron staining in the creek and have expressed concerned about pollution loading from iron bog deposits located within the watershed. There is particular concern regarding the impacts of bog leachate on the trout fishery in these streams. Three of the principle watershed streams, North Fork Rapid Creek, South Fork Rapid Creek and Castle Creek, receive discharge from iron bog deposits located within the watershed. In the fall of 2001 three entities, the South Dakota Department of Environment and Natural Resources, South Dakota Game Fish and Parks Department, and the Black Hills Fly Fishers contracted with the South Dakota School of Mines and Technology to undertake a study in the upper Rapid Creek watershed. Although iron bog deposits exist on other streams in the area, the study concentrated on North Fork Rapid Creek, Castle Creek, and a small tributary of Castle Creek, North Fork Castle Creek (see Map 1, page 2), for the purpose of accomplishing the following goals:

- Confirm temperature exceedance for the identified beneficial use of the North Fork Rapid Creek and prepare a TMDL evaluation identifying potential remediation efforts if exceedance is confirmed.
- Inventory iron bogs located within the upper Rapid Creek watershed.
- Determine, to the extent possible, the processes that produce the iron bogs and the resulting bog leachate.
- Evaluate the impacts of discharge from iron bogs on water quality in North Fork Rapid Creek, Castle Creek and North Fork Castle Creek.
- Identify and evaluate possible mitigation measures that can be employed to protect and/or enhance the trout fishery on both Castle Creek and North Fork Rapid Creek.

The following objectives were developed in an effort to accomplish the project goals:

- Conduct geological investigations and physical assessment of North Fork Rapid Creek, Castle Creek, and North Fork Castle Creek.
- Collect water quality data, including temperature, and take discharge measurements on North Fork Rapid Creek, Castle Creek, and North Fork Castle Creek.
- Characterize the benthic macro-invertebrate communities within North Fork Rapid Creek, Castle Creek, and North Fork Castle Creek.
- Model Geochemical processes resulting from iron bog leachate entering North Fork Rapid Creek, Castle Creek, and North Fork Castle Creek.
- Model the effects of possible remediation efforts on in-stream temperature in North Fork Rapid Creek.

- Seek public participation and comment to ensure public support for the project and for the recommendations developed in the course of the watershed evaluation.
- Establish and maintain approved quality assurance/quality control procedures to ensure all sample results are accurate and defensible.
- Develop watershed management recommendations.
- Produce and publish final report.



Map 1: Location Map of Upper Rapid Creek Study Area
Black Hills, South Dakota

PROJECT LOCATION:

North Fork Rapid Creek is located in Lawrence County, South Dakota. Its headwaters are located 9.5 miles southwest of Deadwood, South Dakota, at an elevation of approximately 6,300 feet above sea level. It flows in a southerly direction for approximately 11.5 miles to its confluence with South Fork Rapid Creek. The confluence of North Fork Rapid Creek and South Fork Rapid Creek, located within Pennington County approximately 0.8 mile from the Lawrence County/Pennington County Line, forms Rapid Creek, a tributary of the Cheyenne River.

Castle Creek and its tributary North Fork Castle Creek are located in western Pennington County. The headwaters of Castle Creek are located in extreme northwestern Pennington county 10.6 miles due west of Rochford, South Dakota, and 5.8 miles east of the South Dakota/Wyoming border at an elevation approximately 7,000 feet above sea level. From its headwaters, Castle Creek flows in a southeasterly direction approximately 11.5 miles to Deerfield Reservoir. Deerfield Reservoir has a capacity of approximately 15,600 acre-feet and is managed by the Bureau of Reclamation as a storage facility for irrigation water used in Rapid Valley to the east of the Black Hills. Castle Creek exits Deerfield Reservoir and travels five miles in a northeasterly direction to its confluence with North Fork Castle Creek. From its confluence with North Fork Castle Creek, Castle Creek flows in an easterly direction 8.5 miles to its confluence with Rapid Creek near the town of Mystic, South Dakota.

The headwaters of North Fork Castle Creek lie approximately 5.9 miles west of Rochford, South Dakota, at an elevation of approximately 6,800 feet above sea level. North Fork Castle Creek flows in an easterly direction approximately six miles to its confluence with Castle Creek.

Description of Upper Rapid Creek Watershed

The upper Rapid Creek watershed is located in the Black Hills Core Highlands, a part of the Middle Rockies Ecoregion (USGS, Northern Prairie Wildlife Research Center, November 11, 2003). The Black Hills are a maturely dissected domal uplifeet with an exposed core of Precambrian rocks composed of igneous and metamorphic schist, slates, quartzite, granite and pegmatite. Younger, Paleozoic limestone and sandstone sedimentary deposits are also found in the watershed. Most of the peaks within and adjacent to the watershed are formed by granitic igneous intrusions and have altitudes between 5,000 and 7,000 feet above sea level. The climate is temperate steppe. Winters are cold, with temperatures below freezing. The average annual temperature ranges from 48^{o}F (9^{o}C) at lower elevations to 37^{o}F at higher elevations. The frost-free season varies from 80 to 140 days, depending on altitude. Annual precipitation ranges from 15 to 26 inches.

NORTH FORK RAPID CREEK WATERSHED

The watershed of the North Fork Rapid Creek comprises an area of 22,550 acres. Land use within the watershed includes livestock grazing, logging and recreation. Historically, significant mining occurred within the watershed. The Burlington Northern Railroad operated a rail line adjacent to North Fork Rapid Creek during most of the twentieth century. In the mid 1990's, the railroad right of way was converted to a hiking/bicycle trail and opened to the public. Hikers and bicyclers extensively use it during the summer months. Snowmobiles are allowed on the trail in the northern part of the watershed during winter months.

The watershed is a long narrow valley surrounded by mountains. The northern two thirds of the valley is broad with pasture extending along both sides of the stream. The valley narrows at its southern end and a mix of pasture and forest are found adjacent to the stream along this stretch. Vegetation in the valley is composed of grasslands with willows and sedges found in the riparian zones. Ponderosa pine, white spruce, aspen, birch and juniper are found on side slopes. Some of the few stands of lodgepole pine found in the Black Hills are contained in the watershed. Most of the soils are Alfisols (USGS, 2003). The North Fork itself is located in the Marshdale-Maitland soil unit, a poorly to well-drained bottom land soil with slopes between 2 and 9 percent. The dominant watershed soil units include the Hisega-Rock outcrop association, Buska – Rock outcrop association, Grizzly-Virkula association, Pactola association, Citadel association, Virkula association and Stovho association. These soil units tend to be composed of deep, well-drained soils with hilly to steep slopes (Meland, 1979).

CASTLE CREEK WATERSHED

The watershed of Castle Creek encompasses 93,530 acres. Of this total, 87,150 acres drains into the study area. 68,050 acres is drained by Castle Creek and the North Fork Castle Creek watershed drains an additional 19,100 acres**.**

Land use within both the North Fork Castle Creek and Castle Creek includes livestock grazing, logging and recreation. Deerfield Reservoir is a major feature in the watershed as is Reynolds Prairie. Deerfield Reservoir was constructed in the mid nineteen forties to serve as a storage facility for the Rapid Valley Water Conservancy District (U.S. Department of Interior, Accessed March 4, 2004). It also provides a supplemental source of water to Rapid City and Ellsworth Air force Base (U.S. Bureau of Reclamation, Accessed March 4, 2004). The reservoir serves as a focal point for numerous recreational activities including fishing, camping, boating, and hiking. Castle Creek from Deerfield Reservoir to a point just upstream of the study site is considered one of the better trout fisheries in the Black Hills. Reynolds Prairie is a relatively large grassy area lying between North Fork Castle Creek and Castle Creek. Most of the Prairie is privately owned ranch land. The primary soil type found in Reynolds Prairie is the Heely-Cordeston complexes. These are well-drained, moderately sloping and rolling soils formed from weathered metamorphic rock.

The watershed contains a mix of prairie, mountains and river valleys. Vegetation in the prairie and along some portions of the stream valleys is composed of grasses, with willows and sedges found in riparian zones. Ponderosa Pine is the dominant tree found in the watershed. Black Hills spruce, aspen, and birch are also found in the watershed. Russet buffaloberry, chokecherry, common juniper, Oregongrape, snowberry and leadplant are also found in the watershed. The riparian zones of both North Fork Castle Creek and Castle Creek are located in Cordeston-Marshbrook loams and in the Redbird-Heath silt loams. Intermediate elevations of the watershed are located in Heel channery loam and Stovho-Trevor soil complex. The higher elevations contain rock outcrops, including the limestone Trebot-Rock Outcrop complex and the crystalline metamorphic Buska-Rock outcrop complex (Ensz, 1985).

Stream Morphology

North Fork Rapid Creek is slightly entrenched with an observed entrenchment ratio of greater than 2.2. The width to depth ratio of the upper half of the stream is calculated to be 8.1; the lower portion of the stream has a ratio of 11.7. Sinuosity is moderately high averaging 1.3 for the entire length of the stream. Average slope is 0.014 foot of vertical drop per foot of length. The substrate in the upper portion of the stream is dominated by very coarse gravel; the lower third of the stream substrate is dominated by small cobble. The stream has been classified using the Rosgen method as a type E-3 stream over the upper reach, transitioning to a type E-4 stream over the lower reach.

Like North Fork Rapid Creek, Castle Creek is slightly entrenched with an estimated entrenchment ratio of greater than 2.2. The Castle Creek width to depth ratios at the two sites evaluated on Castle Creek were 18.2 and 16.2. The creek has a sinuosity of 1.4 and a slope of 0.012 foot of elevation per foot of length. The substrate is dominated by coarse gravel. The stream is classified using the Rosgen method as a type C4 stream.

North Fork Castle Creek is slightly entrenched with an observed entrenchment ratio of greater than 2.2. [1] It has a width to depth ratio of 27.4 and a sinuosity of 1.1. With a slope of 0.023 feet of vertical elevation change per foot of length and a substrate dominated by coarse gravel, North Fork Castle Creek has a Rosgen classification as a C4b stream.

Sample Stations

Water samples were collected on a regular basis from five sample sites established on North Fork Rapid Creek, one sample site established on North Fork Castle Creek and two sample sites established on Castle Creek. A detailed description of the sampling protocols used and the results of the sampling program are contained in Section 4: Water Chemistry.

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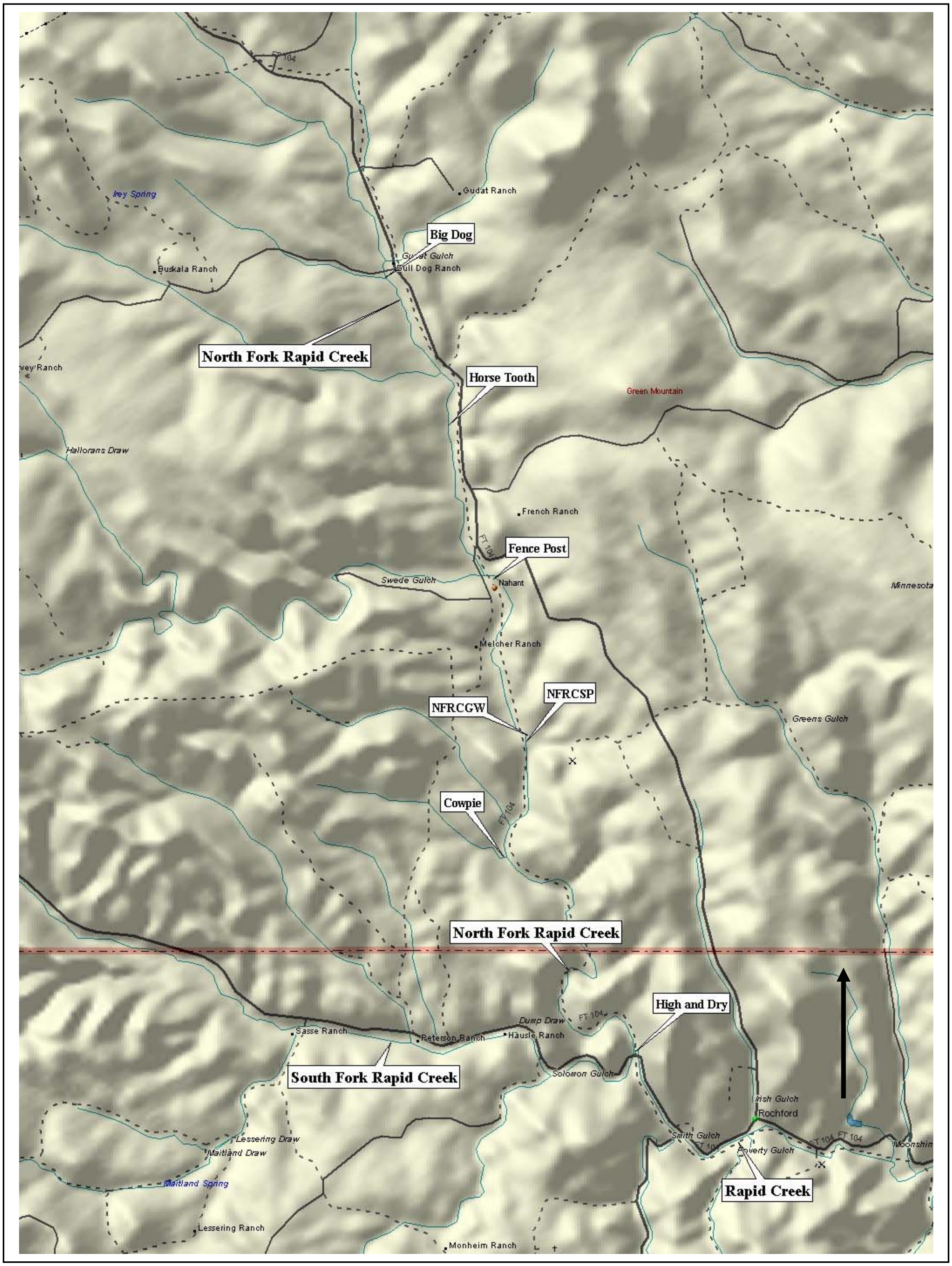
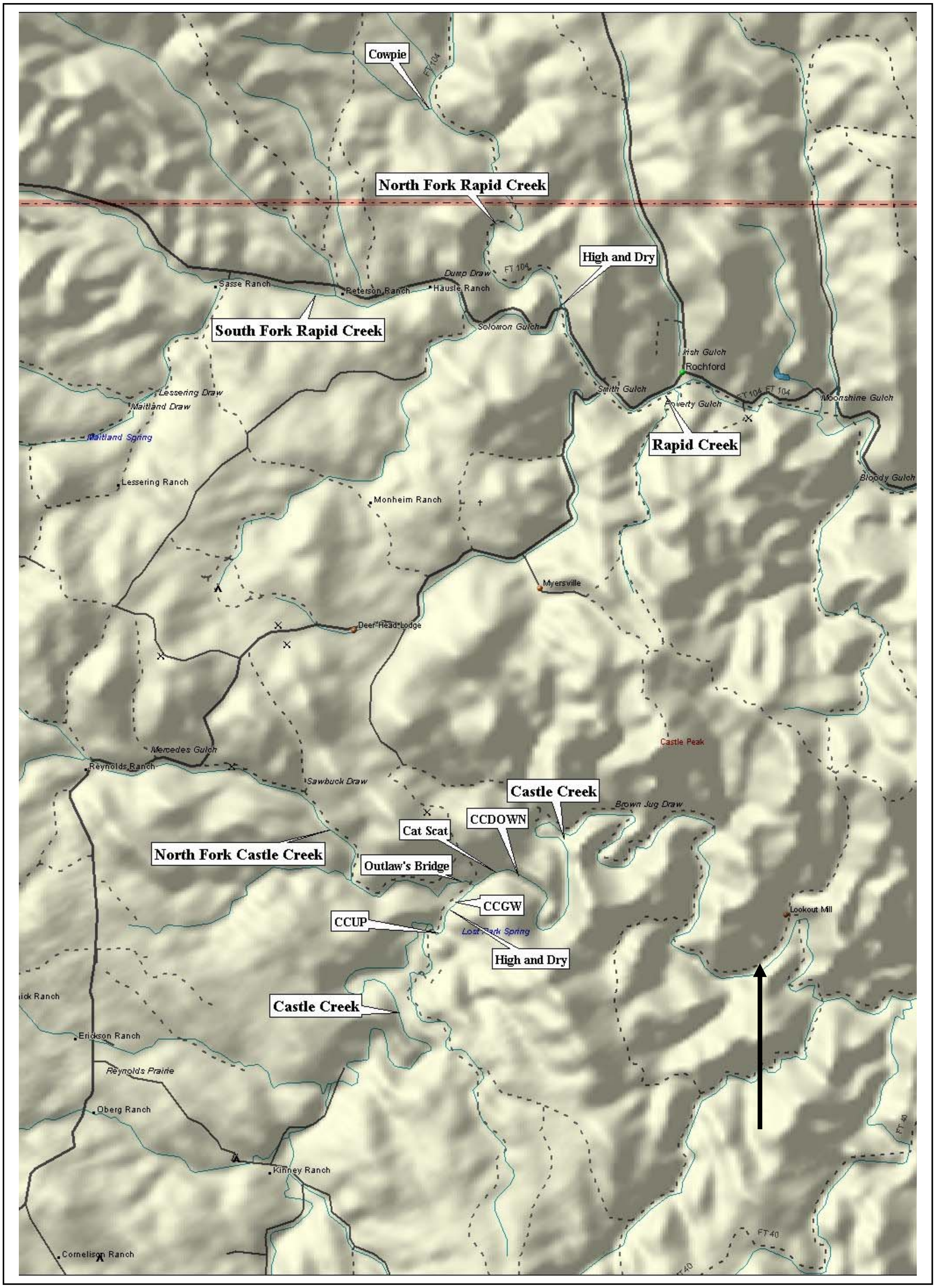
[1] North Fork Castle Creek is entrenched at the project sample site (Outlaw's Bridge). The entrenchment does not appear to be the result of a natural process. It is apparent the stream has been straightened in this section presumably to accommodate historic mining operations, which occurred in the immediate area. Over most of the watershed, entrenchment ratio of North Fork Castle Creek exceeds 2.2.



MAP 2: NORTH FORK RAPID CREEK SAMPLE SITES



MAP 3: CASTLE CREEK & NORTH FORK CASTLE CREEK SAMPLE SITES

NORTH FORK RAPID CREEK

Five permanent monitoring sites were established along the length of the watershed as shown on Map 2, Page 6. Four of the permanent sites were surface-water monitoring sites (Big Dog, Horse Tooth, Fence Post, High and Dry) and one was a groundwater monitoring site (NFRCGW). At the permanent surface-water sample sites, three-foot tall stream staff gages were installed within the stream. Dryden Instrumentation R-2 Data Loggers were installed at two of the surface-water sites and two ISCO 4230 Bubbler Flow Meter instruments with automatic samplers were installed at the other sites. These instruments were calibrated to the stream staff gages and used to measure changes in water surface elevation on a continuous basis at each of the sites. During the summer of 2002, Ryan Model RL-100 temperature probes were installed at each of the sites. The four permanent surface-water monitoring sample sites from north to south (upstream to downstream) and the equipment located at each site are as follows:

Big Dog Site:	R-2 Data Logger, Ryan Model RL-100 temperature probe
Horse Tooth:	R-2 Data Logger, Ryan Model RL-100 temperature probe
Fence Post:	ISCO 4230 Bubbler Flow Meter instruments with automatic samplers, Ryan Model RL-100 temperature probe
High and Dry:	ISCO 4230 Bubbler Flow Meter instruments with automatic samplers, Ryan Model RL-100 temperature probe

A groundwater-sampling site, NFRCGW, was established in the North Fork Rapid Creek Watershed. NFRCGW is located on the west bank of North Fork Rapid Creek approximately 2,000 feet upstream from the inactive Montana Mine. The site consisted of a stainless steel piezometer installed to a depth of approximately three feet.

In addition to surface-water samples collected at the permanent sites, two grab-samples (NFRCSPand Cowpie) of surface water were collected in North Fork Rapid Creek drainage. NFRCSP was collected from a spring located south of the Fence Post monitoring site. Cowpie was collected from an unnamed tributary just prior to discharging into North Fork Rapid Creek. This site is approximately 0.75 mile downstream from the inactive Montana Mine and approximately 0.50 mile downstream from a naturally occurring iron bog that has been mined.

All water sample collection sites located in the North Fork Rapid Creek watershed are shown on Map 2, Page 6.

Castle Creek Sites

Four permanent monitoring sites were located within the Castle Creek watershed; one groundwater and three surface-water sites. The permanent surface-water collection sites consisted of two on Castle Creek and one on North Fork Castle Creek as shown on Map

3, page 7. In-stream staff gages were installed together with monitoring equipment as in North Fork Rapid Creek. The permanent surface-water sample sites from South to North (upstream to downstream) and the equipment located at each site are as follows.

One Too Many (Castle Creek): ISCO 4230 Bubbler Flow Meter instruments with automatic samplers, Ryan Model RL-100 temperature probe

Outlaw's Bridge (North Fork Castle Creek near confluence with Castle Creek): R-2 Data Logger, Ryan Model RL-100 temperature probe

Cat Scat (Castle Creek): ISCO 4230 Bubbler Flow Meter instruments with automatic samplers, Ryan Model RL-100 temperature probe

The groundwater sampling site, CCGW, was established on Castle Creek between One Too Many and Cat Scat. CCGW is located on the southeast bank of Castle Creek above the confluence with North Fork Castle Creek. The site consisted of a stainless steel piezometer installed to a depth of approximately three feet.

Two surface-water grab-samples were collected from Castle Creek on July 17, 2002. One sample, CCUP, was taken upstream of the permanent Castle Creek monitoring sites. The second grab-sample, CCDOWN, was downstream of those sites.

All water sample collection sites located in the Castle Creek watershed are shown on Map 3, Page 7.

Geological Investigation and Physical Assessment of Rapid Creek

A geologic survey of the upper Rapid Creek watershed was undertaken. The survey consisted of researching previous geological investigations in the area and by field reconnaissance during the summer of 2002. The field reconnaissance resulted in identification and mapping iron bog deposits located within the watershed. Those that have been disturbed by mining activities were identified. Tailings and ancillary disturbances associated with the mining activities were mapped. In addition to bog iron deposits, other geologic features and formations were identified and mapped. A detailed description and a discussion of the results of those investigations are presented in Section Two: Geology of the Upper Rapid Creek Watershed. The creation of a map based on GIS coverage of geology, iron bog locations, sample site locations and land use status has been completed and is presented in Section Two.

Physical stream assessments utilizing EPA Stream Physical Habitat Assessment Procedures as outline in the EPA Environmental Monitoring and Assessment Program (EMAP) were conducted within both the North Fork Rapid Creek and Castle Creek watersheds. On North Fork Rapid Creek two assessments were made. The upper assessment site was located in the wide, open section of the watershed between the Horse Tooth and Fence Post sampling stations. In this part of the watershed, North Fork Rapid

Creek flows through an open, grassy valley. Large tracts of the valley are privately owned and used as pasture for cattle and horses.

The upper site was judged to be characteristic of the upper two-thirds of the watershed. The second or lower assessment site is located approximately one-quarter mile upstream from the High and Dry sample station. It is located in a narrow valley. The area adjacent to the stream is composed of a mixture of open areas and pine forest. Ownership of the lower part of the watershed lies primarily with the US Forest Service. Although this portion of the watershed is open to grazing by the Forest Service, little evidence of livestock use was observed in this part of the watershed during the period of investigation. The stream is confined to a narrow valley floor with adjacent mountains rising on both sides. The lower site was judged to be characteristic of the lower one third of the watershed.

Two EMAP assessments were conducted on Castle Creek. The upper assessment site was located in an area approximately ¼ mile upstream of the One Too Many sample site. This portion of stream is located on Forest Service land. The location is accessible by foot, horseback and four-wheel drive via a primitive trail. This area appears to be minimally impacted; the stream was in its natural channel with considerable variation in stream features (riffles, pools, glides, etc.). The lower assessment site was located downstream (north) of the Cat Scat sample station, below an old mining site. It does not appear that placer mining was conducted in this area although the stream may have been straightened over short sections to accommodate mine access and/or water diversion. Cat Scat is located on private property in a geologic feature known as Lost Park, a meadow in which horses are occasionally pastured. The grazing of cattle is not currently allowed within the private property. However, the U.S. Forest Service lands that surround the property are grazed by cattle during summer months.

One EMAP assessment was conducted on North Fork Castle Creek on the section of stream immediately above the Outlaw's Bridge sample site. This area is located on private property occasionally grazed by horses. Upstream from the assessment area, cattle graze during the summer months.

DISCHARGE MEASUREMENTS

Multiple discharge measurements were taken at each site using USGS procedures and a Price pygmy meter, an adjustable wading rod and a model 1100 Gurley Precision Instruments flow velocity indicator. Prior to taking stream flow measurements, a spin test was conducted on the pygmy meter to assure that the meter was functioning properly. At each station, the permanent stream staff gage was read and the reading recorded. The stream was divided into a minimum of 15 discreet increments using a measuring tape marked off in tenths of feet. Flow measurements were taken at each increment. Stream depth was measured and the wading rod adjusted to the appropriate depth. The flow velocity indicator was used to both time and count pygmy meter revolution at each increment. The distance on the tape was recorded for each measurement together with the depth of water, number of revolutions of the pygmy meter, and the time in seconds. The cross-sectional area of water flowing in each increment was calculated using increment width and water depth. The volume of the flow (cubic feet per second) at each increment was determined from a rating curve developed by the manufacturer for the pygmy meter based on time and number of revolutions. Incremental volumes were totaled and total stream flow determined in cubic feet per second. Discharge rating curves relating stream surface elevation and discharge were developed based on multiple discharge measurements taken at each staff gage site throughout the spring and summer of 2002. Discharge estimates were used in computer modeling of the in-stream temperature.

SECTION 2: GEOLOGY OF THE UPPER RAPID CREEK WATERSHED

The geology of the watershed consists of Precambrian metamorphic rocks overlain with younger Paleozoic sedimentary rocks to the north and west (Maps 4 and 5, Pages 13 - 14). The Precambrian rocks are approximately two billion year old marine deposits that were later deformed and changed by several episodes of metamorphism into the intensely folded metamorphic sedimentary (or meta-sedimentary) rocks present today. Rock types include phyllite, schist, banded iron formation, chert, and quartzite (DeWitt and others, 1989). These well-exposed meta-sedimentary rocks are nearly vertically dipping and strike north-northwest.

The Paleozoic rocks range from approximately 250 to 550 million years old. The unconformity between the older Precambrian and younger Paleozoic rocks in this area marks a time gap of approximately 1.5 billion years. In the western Black Hills, the Paleozoic rocks are nearly flat lying and consist of, from older to younger, the Deadwood (sandstone), Winnipeg (shale), Whitewood (dolomite and limestone) formations; the Englewood and Pahasapa (Madison) limestones; and the Minnelusa formation. Paleozoic rocks in the western Black Hills are known as the Limestone Plateau because the nearly flat lying Pahasapa Limestone and Minnelusa sandstone, limestone and shale formations crop out over much of the area.

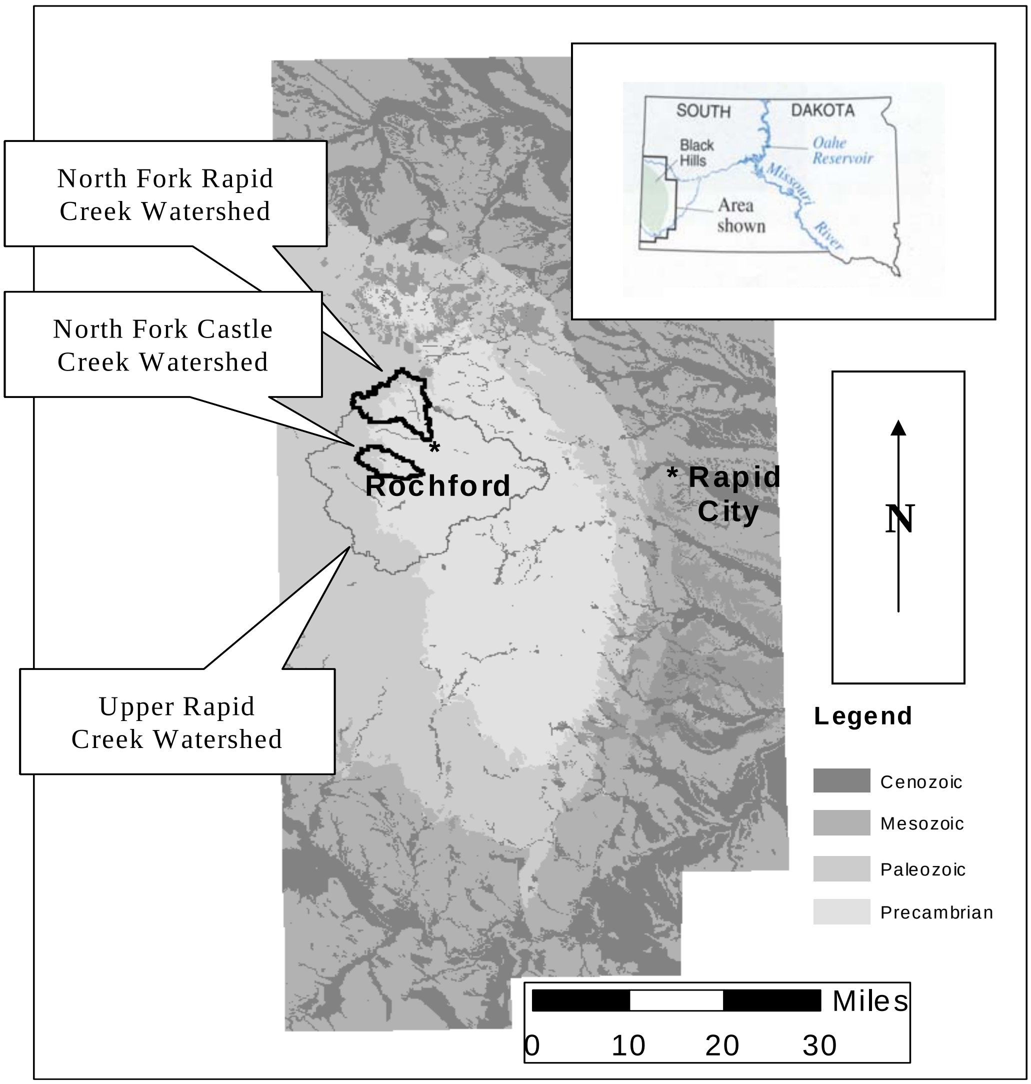
GROUND WATER

Ground water storage and flow in the Precambrian metamorphic rocks in the Black Hills are controlled by secondary permeability caused by fracturing and weathering. This secondary permeability allows precipitation to infiltrate into the Precambrian rocks where it is stored in local Precambrian aquifers (Carter and Driscoll, 2003; and Galloway and Stroebel, 1999). Springs occur where the ground water surface intersects the land surface. Similarly, the younger Pahasapa limestone has substantial fracture and dissolution permeability allowing storage and flow of tremendous volumes of water. Many springs occur at the base of the Pahasapa limestone where it is underlain by the low permeability Englewood limestone (Carter and Driscoll, 2003).

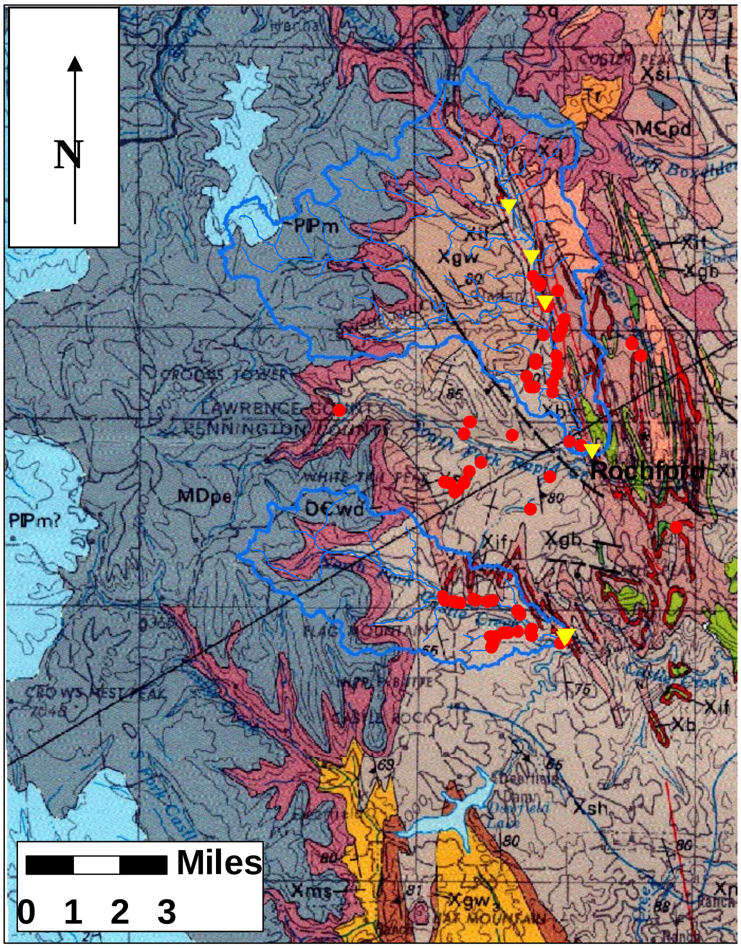
IRON BOGS

Iron bogs form where iron-rich, acid ground water discharges to the land surface as springs or directly into the creek along the banks or within the channel. The spring water comes from a subsurface reducing environment, is acidic (pH approximately 2.5 to 4), and contains high concentrations of iron, aluminum, and sulfate. At the surface, the discharged water is exposed to oxygen from the atmosphere and mixes downstream with well-oxygenated, unpolluted surface water with pH approximately 7 to 8. The resulting mixture has a pH in the range of approximately 6.5 to 7.5 and is nearly saturated in oxygen. These conditions cause the reduced iron (i.e., Fe^{2+} or Fe (II)) and aluminum to oxidize and precipitate as iron and aluminum hydroxides that flocculate and accumulate at the spring location and along the bottom of the channel. These chemical reactions occur quickly and precipitates can be observed immediately at springs and where acidic water mixes with surface water. The oxidized iron precipitates discolor the water light red-orange. Over longer periods of time (i.e., decades to millennia), the metal hydroxides accumulate, dewater and harden (or lithify) through diagenesis, cementing the stream sediments together. Based on this process, iron bogs in this area are considered depositional features. Iron bog deposits contain as much as 50-percent iron. Because of their high iron content, many of the larger bogs in this area were mined for iron from the early 1900s up through the 1950s (USGS, 1975).

Locations of iron bogs observed during this study are shown on Map 5, Page 14. Iron bog locations are summarized in Appendix A.



Map 4: Watershed Location Map
Black Hills, South Dakota
(modified from Dewitt and others, 1989)



- Surface and Ground Water Sample Locations
- Iron bog

Paleozoic rocks:

Permian-Pennsylvanian Minnelusa formation

Mississippian Madison limestone & Devonian Englewood limestone

Ordovician Whitewood & Winnipeg formations, and Cambrian Deadwood sandstone

Precambrian metamorphic rocks:

Phyllite, schist, chert, quartzite

banded iron formation

Map 5: Geologic Map of the Rochford Area
Black Hills, South Dakota
(modified from Dewitt and others, 1989)

ACID ROCK DRAINAGE

Acid rock drainage occurs both naturally and due to anthropogenic disturbances, primarily mining. Most acid rock drainage is found at mine sites where it is commonly referred to as acid mine drainage. Acid rock drainage results from the interaction of sulfide minerals with oxygen and water. Iron-oxidizing bacteria catalyze these reactions. Photographs of iron bogs, mined iron bogs, and acid drainage are shown on Figures 1 through 6, Pages 17-19.

Pyrite or iron sulfide (FeS_2) is the most abundant and widespread sulfide mineral and is the primary source for acid rock drainage. It occurs in all types of rocks, especially in shale of marine and brackish water origin. Pyrrhotite (FeS) is less common than pyrite and is a minor source material for acid rock drainage (Deer and others, 1980). The iron in pyrite and pyrrhotite is in its reduced form, Fe^{2+}, and is stable under reducing conditions (i.e., away from oxygen) typically found below the ground water table. However, it is unstable under oxidizing conditions typically found near and on the land surface.

The size of the pyrite crystal is important. For example, consider a given volume of pyrite, a larger crystal has low surface area for the given volume and as a result is much less reactive than a number of smaller crystals totaling the same volume. This is because the numerous smaller crystals have a much larger cumulative surface area for the same volume. Finely disseminated microscopic pyrite crystals are the most reactive (PDEP, 1998). In this region, the meta-sediments most likely originated as marine shale under reducing conditions and contain abundant finely disseminated pyrite crystals.

The chemical reactions presented below focus on pyrite, as it is the most common source of acid rock drainage (ARD). In the presence of oxygen and water, the overall reaction describing pyrite oxidation is:

$$FeS_2(s) + 3.75\ O_2 + 3.5\ H_2O = Fe(OH)_3(s) + 2\ SO_4^{2-} + 4\ H^+ + \text{heat} \qquad \textit{(reaction 1)}$$

Solid pyrite [ferrous (Fe^{2+}) iron and sulfur (S^-)], oxygen, and water are reactants and solid ferric hydroxide, sulfate, and hydrogen ions and heat energy (about 1490 kJ/mole at 25°C) are products (PDEP, 1998). The overall reaction above involves several intermediate reactions. It is helpful to break down the overall reaction into the following series of intermediate reactions in order to better understand how ARD develops (PDEP, 1998).

FeS2(s) + 3.5 O2 + H2O = Fe2+ + 2 SO42- + 2 H+ *(reaction 2)*

$$Fe^{2+} + 0.25\ O_2 + H^+ = Fe^{3+} + 0.5\ H_2O \qquad \textit{(reaction 3)}$$

$$FeS_2(s) + 14\ Fe^{3+} + 8\ H_2O = 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \qquad \textit{(reaction 4)}$$

$$Fe^{3+} + 3\ H_2O = Fe(OH)_3(s) + 3\ H^+ \qquad \textit{(reaction 5)}$$

In reaction 2, pyrite is oxidized to ferrous iron (Fe^{2+}), sulfate and acid. In reaction 3, ferrous iron (Fe^{2+}) is oxidized to ferric iron (Fe^{3+}). In reaction 4, pyrite is oxidized by ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), sulfate and acid. Note in this step, ferric iron (Fe^{3+}) is being reduced to ferrous iron (Fe^{2+}) and acting as the oxidizing agent instead of oxygen as in reaction 2. In reaction 5, ferric iron (Fe^{3+}) precipitates as ferric hydroxide ($Fe(OH)_3$) as acid is produced.

Once pH decreases to the range of approximately 2 to 4, iron-oxidizing bacteria of the species *Ferrooxidan thiobacillus* thrive and catalyze the oxidation reactions causing the acid generation process to rapidly increase by as much as 5 to 6 times (Webb and Chupka, 2000).

Acid rock drainage will contaminate water with acid, primarily sulfuric acid. The acid leaches iron from pyrite, aluminum which is ubiquitous in the environment, and potentially additional heavy metals depending on the surrounding minerals (OSMRE, 2000).

CHARACTERIZATION OF WATER QUALITY

Water quality data collected during 2002 and 2003 were used to characterize the water quality in North Fork Rapid Creek, Castle Creek and North Fork Castle Creek watersheds (Table 1, Page 20). The bulk of surface water in North Fork Rapid Creek and Castle Creek watersheds originates as spring flow from the Pahasapa limestone. Some of the surface water in the North Fork Castle Creek watershed originates as spring flow from the Pahasapa limestone. However, based on visual evidence the amount of acid rock drainage appears to be at least equal to spring flow from the Pahasapa limestone in North Fork Castle Creek. As a result, uncontaminated water quality in this watershed is similar to ground water quality of the Pahasapa limestone in the western Black Hills. Upstream surface water in North Fork Rapid Creek, Castle Creek and North Fork Castle Creek and ground water from the Pahasapa limestone in the western Black Hills typically contain calcium (Ca2+), magnesium (Mg2+), and bicarbonate (HCO3-) with trace levels of inorganics (e.g., chloride, fluoride, potassium, sodium and sulfate) and metals (e.g., aluminum). pH is typically 7.5 to 8.5.

The quality of ground water and spring discharge originating from Precambrian rock is different from the surface water originating from the Pahasapa limestone. Acid rock drainage may develop where pyrite is abundant in the Precambrian bedrock. Not all Precambrian rock has abundant pyrite. Therefore, not all ground water and spring discharge from the Precambrian rock is poor quality water high in acid and metals. While water from Precambrian rocks generally contains iron, aluminum, and sometimes sulfate, water quality varies greatly and is discussed in detail below.

General Water Quality

Selected water quality data collected from North Fork Rapid Creek, Castle Creek and North Fork Castle Creek watersheds during 2002 and 2003 is summarized in Table 1. Differences between the surface, spring, and ground water range from 2 to 100 times. The numbers in parentheses in Table 1 are for a surface water sample that was collected from a tributary stream immediately upstream from North Fork Rapid Creek. This particular surface water originated from a spring in an iron bog located approximately 0.5 miles upstream from the collection site, and the quality of this spring water is included in the stream water quality column.

Figure 1: Iron bog water originating from spring (bottom center of photograph). Note red-orange water and dead vegetation.

Figure 2: Iron bog with water originating from a spring in the bottom center of photograph. This spring flows into Figure 3.

Figure 3: Mined iron bog. Water from spring in Figure 2.

Figure 4: Confluence of acid rock drainage and uncontaminated stream. Note red-orange iron hydroxide and white aluminum hydroxide precipitates.

Figure 5: Iron hydroxide precipitate coating stream substrate downstream from confluence of acid rock drainage and uncontaminated stream.

Figure 6: Lithified iron-cemented conglomerate. Resulted from prehistoric acid rock drainage. Iron hydroxide precipitate alters to hematite cement.

Table 1: Summary of Selected Water Quality Parameters Upper Rapid Creek

Numbers in Parenthesis from tributary to North Fork Rapid Creek

	Stream Water Quality	Spring Discharge and Ground Water Quality
Total Iron (mg/L)	ND - 0.68 (4.1)	160 - 235
Ferrous Iron, Fe^{2+}(mg/L)	ND - ~ 2 (1.6)	~ 3 - 7
Ferric Iron, Fe^{3+}(mg/L)	0.11 - 2.3 (3.6)	10 - 130
Aluminum (mg/L)	0.02 - 0.28 (3.7)	11 - 23
Sulfate, SO_4^{2-} (mg/L)	9 - 197 (1,100)	2,600 - 8,100
Specific Conductance (µS/cm)	0.221 - 0.467 (0.677)	0.610 - 2.811
DO (mg/L)	~ 8 - 10 (5)	~ 1 - 3.5
pH	6.5 - 8.6 (~3)	2.5 - 4.8
Redox Potential (volts)	~ -100 - 250 (500)	~ 250 - 510

ND = Not Detected above detection limit

Eh-pH Diagram

Selected water quality data from ground, surface, and iron bog/spring water samples are plotted on an Eh-pH diagram (Figure 7, Page 21). The data used in Figure 7 are a composite data set that includes Castle, North Fork Castle, and North Fork Rapid creeks' watersheds. The data are plotted using symbols as follows: surface water (circle) ground water (square), and iron bog/spring water (triangle).

The data plot in three distinct areas on the chart. Iron bog/spring water plots in the area with the lowest pH and highest Eh. Surface water plots in the area with the highest pH and lowest Eh. Ground water plots in the area between, however, closer to the iron bog/spring water quality.

North Fork Rapid Creek

Surface Water – North Fork Rapid Creek

Spring flow from the Pahasapa limestone is the source of much of the stream flow observed in North Fork Rapid Creek. Spring discharge from the Precambrian bedrock and younger alluvium adds to the stream flow. North Fork Rapid Creek is a gaining stream where flow increases downstream due to ground water discharging from bedrock and alluvium. Tributaries discharge into North Fork Rapid Creek contributing to surface water flow.

Piper Diagrams – North Fork Rapid Creek

Selected water quality data from ground and surface water samples are plotted on a Piper diagram (Figure 8, Page 23). Piper diagrams consist of three plots: the lower left triangle is for major cations; the lower right triangle is for major anions; and the center diamond is a combination of major cations and anions. These plots allow water to be classified based on major ions.

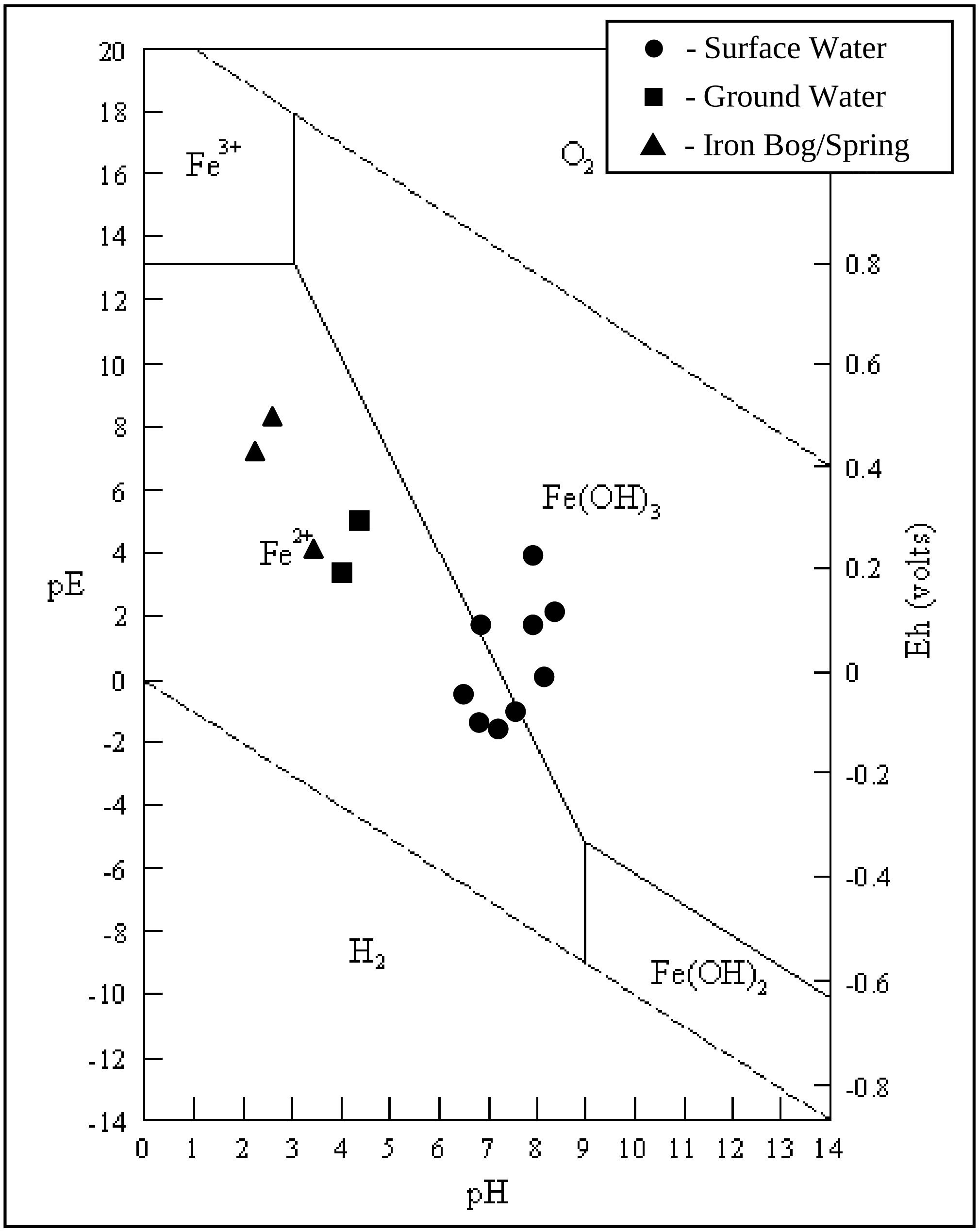


Figure 7: Selected water quality data from upper Rapid Creek watershed plotted on the Eh-pH diagram for the iron

The ground water sample NFRCGW and surface water sample Cowpie are both calcium-magnesium-sulfate type water. Surface water sample Cowpie was collected from a tributary to North Fork Rapid Creek, downstream from an iron bog and approximately 10 feet upstream from its confluence with North Fork Rapid Creek (see Map 2, Page 6). All other surface water samples are calcium-magnesium-bicarbonate type water. Pahasapa limestone water quality would plot as calcium-magnesium-bicarbonate type water. This indicates the primary source of surface water for North Fork Rapid Creek is ground water from the Pahasapa limestone.

Stiff Diagrams – North Fork Rapid Creek

Surface and groundwater quality data are used to generate Stiff diagrams (Figure 9, Page 24). Stiff diagrams consist of multi-axial plots with cation data (Na^+, K^+, Ca^{2+}, Mg^{2+}) on the left and anion data (Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}) on the right. The points are all connected to generate a polygon. The size of the polygon is proportional to the concentrations of the dissolved ions. The shapes of the polygons allows for a unique graphical representation and comparison of the water quality.

The polygons for the watershed are presented in an upstream to downstream direction. Big Dog, Horse Tooth, Fence Post, and High and Dry are the upstream to downstream surface monitoring locations. The polygons are very similar in shape and size, indicating relatively consistent surface water quality along North Fork Rapid Creek. Ground water sample, NFRCGW, represents the quality of ground water discharging directly into North Fork Rapid Creek. Surface water sample Cowpie, represents iron bog water that has been exposed to surface conditions for approximately 0.5 miles and is a tributary discharging into North Fork Rapid Creek. NFRCGW and Cowpie have similarly shaped polygons with the ground water polygon being larger than Cowpie. These waters are similar. However, Cowpie has been exposed to oxygen in the atmosphere, and some precipitation of dissolved solids has taken place.

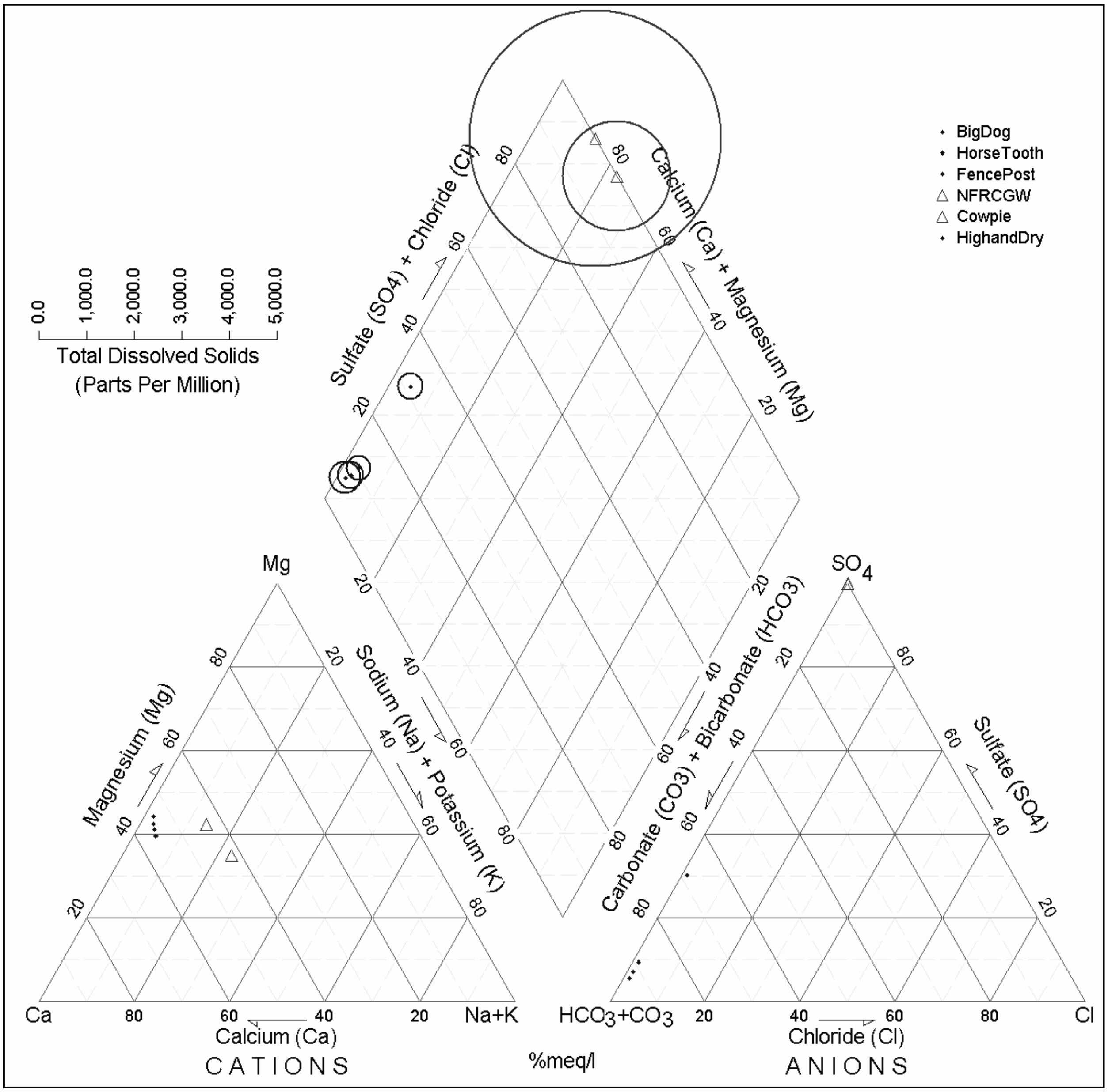


Figure 8: Piper diagram for selected water quality data from North Fork Rapid Creek.

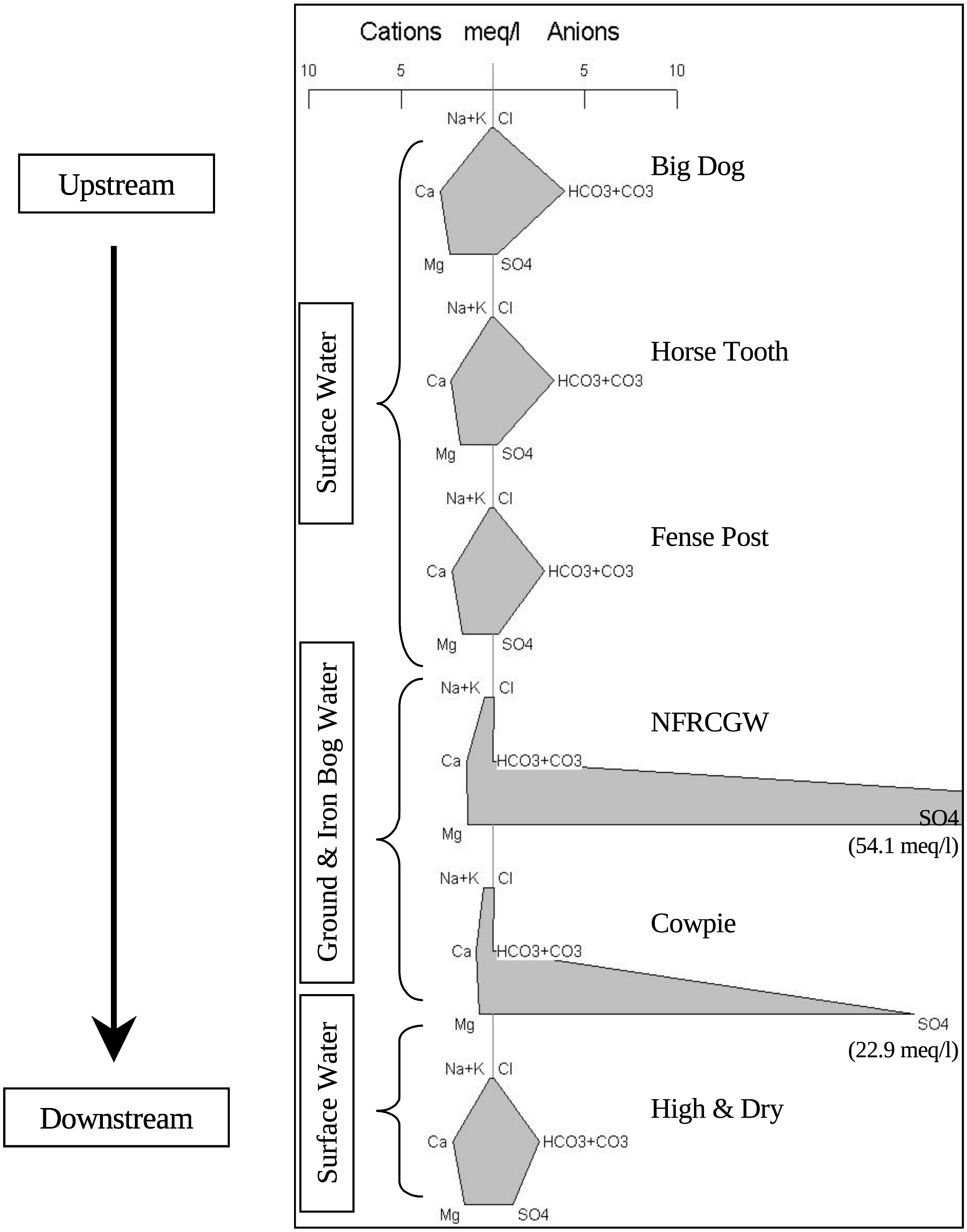


Figure 9: Stiff Diagram Polygons for Selected Water Quality Samples from North Fork Rapid Creek

Castle Creek Sites

SURFACE WATER – CASTLE CREEK SITES

Spring flow from the Pahasapa limestone is the source of much of the stream flow observed in both Castle Creek and North Fork Castle Creek. Castle Creek discharge is primarily controlled by Deerfield Lake Reservoir. Spring discharge from the Precambrian bedrock and younger alluvium adds to the stream flow. Castle and North Fork Castle creeks are gaining streams where flow increases downstream due to ground water discharging from bedrock and alluvium. In addition, tributaries discharge into Castle and North Fork Castle creeks increasing surface water flow.

PIPER DIAGRAMS – CASTLE CREEK SITES

Selected water quality data from ground and surface water samples are plotted on Piper diagrams (Figure 10, Page 26). Ground water sample, CCGW, and surface water sample, Outlaw's Bridge (collected from North Fork Castle Creek a few tens of feet upstream from its confluence with Castle Creek), are both calcium-magnesium-sulfate type water. All other surface water samples are calcium-magnesium-bicarbonate type water. Pahasapa limestone water quality would plot as calcium-magnesium-bicarbonate type water.

Stiff Diagrams – Castle Creek Site

Selected water quality data are plotted on Stiff diagrams (Figure 11, Page 27). The polygons for the watershed are plotted in an upstream to downstream direction. For Castle Creek, these are One Too Many and Cat Scat surface monitoring locations. The confluence of North Fork Castle Creek and Castle Creek is between One too Many and Cat Scat. The Outlaw's Bridge monitoring site is located on North Fork Castle Creek near the confluence. CCUP and CCDOWN were one-time surface water sample locations further up and further down, respectively, from the permanent surface water stations; CCGW is a ground water monitoring station. Note the polygons are very similar in shape and size, indicating relatively consistent surface water quality along Castle Creek. Ground water sample, CCGW, represents the quality of ground water discharging directly into Castle Creek. Surface water sample, Outlaw's Bridge, represents North Fork Castle Creek surface water that has received abundant acid rock drainage discharge.

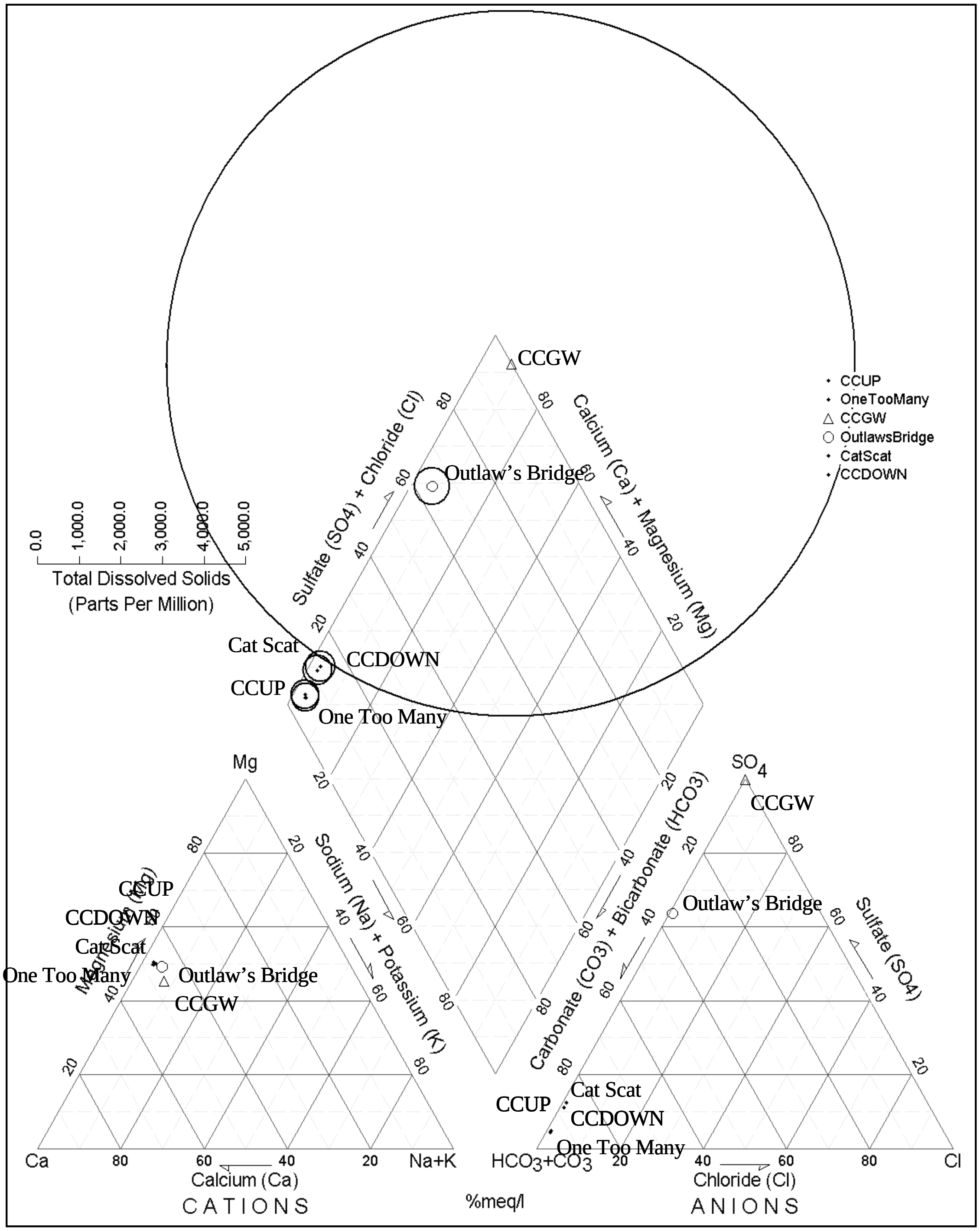


Figure 10: Piper Diagrams for Selected Water Quality Data from Castle Creek & North Fork Castle Creek

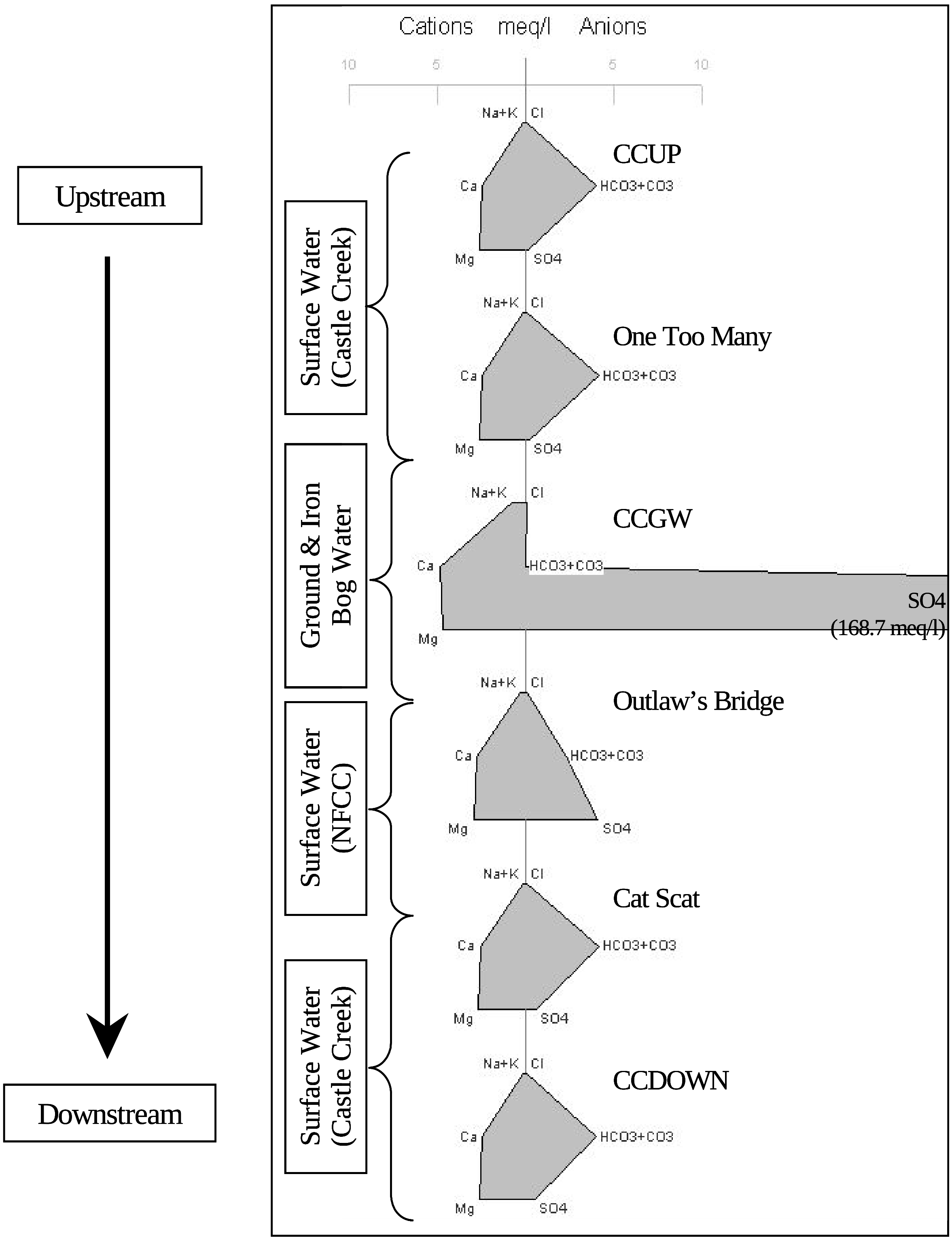


Figure 11: Stiff Diagram Polygons for Selected Water Quality Samples from Castle Creek & North Fork Castle Creek

Section 3: Surface Water Geochemical Modeling

One of the major concerns expressed by the public regarding water quality in the Upper Rapid Creek Drainage is the iron leaching from iron bog deposits. A major goal of this study is to determine if the iron leachate is a natural phenomenon or primarily the result of mining activity, which occurred intermittently in the drainage between the 1880's and 1960's.

VISUAL OBSERVATIONS

Visual inspection of the creeks at each sample site resulted in the following observations:

North Fork of Rapid Creek Sites:

Big Dog and Horse Tooth Sample Sites: The substrate consists of gravel and cobbles. As summer progressed, vegetation was observed on over 50% of substrate. Water was clear. No evidence of cementation of substrate was observed.

Fence Post and High and Dry Sample Sites: Substrate consists of gravel and cobbles. As summer progressed, vegetation was observed on between 25 and 50% of substrate. Some evidence of substrate cementation was observed. Water carrying yellow to red suspended sediments was observed in the spring.

Castle Creek Sites:

Outlaw's Bridge on the North Fork of Castle Creek: Substrate consists of sand, gravel, and cobbles. Substrate was covered with a gelatinous precipitate. No vegetation was observed in the creek. Red staining exists on the substrate and gravel/sands adjacent to the creek. Creek water carried yellow to red suspended sediments throughout the study period. Cementation of substrate was apparent.

One Too Many (Castle Creek above confluence with North Fork Castle Creek): Substrate consists of gravel and cobbles. No obvious precipitate was present on substrate. No vegetation was observed in the creek at the sample site however, the actual sample site was located in a section of stream that appeared to have been straightened. As a result, water at the sample location was flowing as in a riffle. A few meters above the sample site, in stream meanders, more than 50% of the substrate was covered with vegetation. Water was clear. No staining was observed on substrate.

Cat Scat (Castle Creek below confluence with North Fork Castle Creek): Substrate was covered with a gelatinous precipitate. Water contained some yellow/red suspended sediments but less obvious than in the North Fork Castle Creek. No vegetation was observed on substrate. Substrate was stained and appeared to be undergoing cementation.

The obvious iron leachate and precipitation observed at the Castle Creek sites led to the geochemical modeling of the surface water at each of its sample sites.

THE pHREEQC *GEOCHEMICAL MODEL*

Analytical results obtained from the monthly sampling of surface water at each of the sample sites was used to model surface water geochemistry using the USGS geochemical modeling program, pHREEQC (U.S. Geological Survey, March 1, 2004).

The pHREEQC model uses thermodynamic data (enthalpy, entropy, Gibbs free energy, etc.) to predict reactions occurring within the water column and between the water column and stream substrate. The model calculates reaction solubility products, ion activity product and saturation index for possible reactions.

Solubility product (K_{sp}) is a measure of the ability of chemical compounds to dissolve in water. In solution, ionic compounds are continually breaking apart (dissolving) and reforming (precipitating). When a highly soluble compound is first mixed in water, many more ions dissolve than reform into the original compound. As the number of ions in the solution increases, the solution's ability to hold them decreases and eventually equilibrium is established. At equilibrium, the same number of ions are combining to form compound as are dissolving. Solubility product is the number of ions dissolved in solution when the solution is at equilibrium. A high solubility product indicates that the components (elements) present in a compound (mineral) easily go into solution. Conversely, a low solubility product indicates that although the mineral and its elements are present in the water, they are relatively inert and will not tend to go into solution. Solubility products are determined for solutes in pure water. In nature, the presence of other ions in solution influences the ability of the original ion/mineral complex to react. The presence of other ions can act to facilitate dissolution or can impede it. The ion activity product (IAP) is an adjusted solubility product that reflects the dissolution efficiency in the presence of the other ions in the solution. Saturation indices (SI) show the likelihood of a mineral dissolving or precipitating from solution. SI is the ratio of the logs of the ion activity product to solubility product:

$$SI = \log \frac{IAP}{K}$$

A saturation index (SI) greater than one indicates that the solution is supersaturated with solute and the mineral is precipitating. A SI less than one indicates that the solution is under saturated and the mineral is dissolving. A SI of one indicates that the solution and the mineral are in equilibrium and no net precipitation or dissolution of the mineral is occurring. Four sample events were modeled for each of the three Castle Creek Sites: Outlaw's Bridge, One Too Many, and Cat Scat. North Fork Rapid Creek showed much less evidence of impact from bog iron leachate. However, one sample event (April 16, 2002) was modeled at each site (High & Dry, Fence Post, Horse Tooth, and Big Dog) to provide an overview of the aqueous chemical processes occurring in the creek. Table 2, Page 31, and Table 3, Page 32, present the input data used to model the geochemistry of Castle Creek and North Fork Rapid Creek, respectively.

MODELING RESULTS

The results of the geochemical modeling are presented in the following tables:

Castle Creek Sites:

Outlaw's Bridge (North Fork Castle Creek)	Table 4, Page 33
One Too Many	Table 5, Page 34
Cat Scat	Table 6, Page 35
North Fork Rapid Creek	Table 7, Page 36

Table 2 – Geochemical Modeling Inputs
Castle Creek

(All units except pH and Temperature are mg/L, Temperature in ^{o}C)

Geochemical Modeling Inputs - Castle Creek Sites												
	Outlaw's Bridge				**One too Many**				**Cat Scat**			
Reactant	16-Apr-02	10-Jun-02	15-Jul-02	21-Aug-02	16-Apr-02	10-Jun-02	15-Jul-02	21-Aug-02	16-Apr-02	10-Jun-02	15-Jul-02	21-Aug-02
Al	0.025	0.07	0.06	0.025	0.025	0.025	0.025	0.025	0.07	0.05	0.09	0.025
Alkalinity	88	94	66	58	230	200	220	218	210	200	200	200
C	109.5		250	73.5	282.5			258.5	258.5			246.5
Ca	46	55	60	54	48	40	48	48	56	52	49	47
Cd	0.0005		0.0005		0.0005		0.0005		0.0005		0.0005	
Cl	1.8	1.5		1.9	1.5	1.3		1.5	1.3	1.2		1.4
Cu	0.005		0.005		0.01		0.005		0.005		0.005	
F	0.3				0.2				0.2			
Fe^{+3}	8.9	2.7	0.47	8.9	1.2	0.56	0.31	0.24	2.3	1.5	1.4	1.1
K	5	6		7	2	2		2	2	2	2	2
Mg	30	35	38	35	29	26	31	30	35	33	32	29
Mn	0.33		0.1		0.01		0.01		0.04		0.02	
Na	3	4		4	4	2		2	2	2	2	2
NH3	0.1	0.05	0.05	0.05	0.1	0.05	0.05	0.05	0.1	0.05	0.05	0.05
NOx	0.12	0.05	0.08	0.06	0.12	0.025	0.025	0.025	0.12	0.025	0.025	0.025
P	0.03	0.01	0.005	0.02	0.27	0.01	0.02	0.01	0.03	0.03	0.01	0.005
pH	7.76	8.08	7.95	7.65	8.29	8.47	8.01	8.04	8.24	8.37	8.08	7.74
SO4	150	170	270	240	9	10	10	9	24	25	30	23
Zn	0.0025		0.0025		0.0025		0.0025		0.0025		0.0025	
Temp	2.28	16.87	16.95	14.43	3.62	13.26	12.2	10.24	3.83	12	13.09	11.69

Table 3 – Geochemical Modeling Inputs
North Fork Rapid Creek
(All units except pH and Temperature are mg/L, Temperature in ^{o}C)

Reactant	High & Dry	Fence Post	Horse Tooth	Big Dog
Al	0.08	0.025	0.025	0.025
Alkalinity	106	124	148	172
C	131.5	153.5	182.5	212.5
Ca	37	36	43	56
Cd	0.0005	0.0005	0.0005	0.0005
Cl	2	1.8	2.2	2.5
Cu	0.005	0.005	0.005	0.005
F	0.2	0.1	0.1	0.1
Fe (T)	3	1.2	1	1.6
K	3	2	2	2
Mg	15	15	18	26
Mn	0.07	0.05	0.03	0.02
Na	2	2	2	2
NH3	0.05	0.05	0.05	0.05
NOx	0.13	0.15	0.16	0.15
P	0.04	0.03	0.03	0.04
pH	7.88	7.86	7.82	7.99
SO4	26	12	11	10
Zn	0.0025	0.0025	0.0025	0.0025
Temp	4.57	5.7	6.07	6.06
O_2	10.37	10.05	9.73	9.47

Table 4 - Geochemical Modeling Results
Outlaw’s Bridge, North Fork Castle Creek

Mineral	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT
Al(OH)3(a)	-0.82	11.58	12.4	-1.52	9.82	11.34	-0.62	10.72	11.34	-1.05	10.49	11.51
Alunite - KAl3(SO4)2(OH)6	0.43	2.07	1.64	-4.26	-4.63	-0.37				0.2	0.16	-0.04
Anhydrite - CaSO4	-1.81	-6.16	-4.36	-1.75	-6.09	-4.34	-1.55	-5.89	-4.34	-1.63	-5.96	-4.33
Aragonite - CaCO3	-0.77	-8.99	-8.23	0.08	-8.21	-8.29	-2.1	-10.39	-8.29	-1.05	-9.32	-8.28
Calcite - CaCO3	-0.61	-8.99	-8.39	0.22	-8.21	-8.44	-1.95	-10.39	-8.44	-0.9	-9.32	-8.43
Cd(OH)2	-7.11	6.54	13.65				-10.25	3.4	13.65			
CdSO4	-12.4	-11.61	0.79				-11.66	-11.46	0.2			
CH4(g)	-66.11	-113.53	-47.42				-54.48	-99.57	-45.1	-65.18	-110.67	-45.49
CO2(g)	-2.7	-20.99	-18.29	-3.11	-21.29	-18.18	-1.19	-19.37	-18.18	-2.51	-20.7	-18.19
Dolomite - CaMg(CO3)2	-1.43	-17.95	-16.52	0.49	-16.4	-16.9	-3.86	-20.76	-16.9	-1.78	-18.62	-16.84
Fe(OH)3(a)	5.14	10.04	4.89	3.79	8.68	4.89	1.99	6.89	4.89	4.29	9.18	4.89
Fluorite - CaF2	-1.94	-12.86	-10.92									
Gibbsite - Al(OH)3	2.1	11.58	9.49	1.25	9.82	8.58	2.15	10.72	8.57	1.74	10.24	8.72
Goethite - FeOOH	10.16	10.04	-0.12	9.38	8.68	0.7	7.59	6.89	-0.71	9.79	9.18	-0.61
Gypsum - CaSO4:2H2O	-1.55	-6.16	-4.61	-1.5	-6.09	-4.58	-1.31	-5.89	-4.58	-1.38	-5.96	-4.59
H2(g)	-23.14	-23.14	0	-24.16	-24.16	0	-20.05	-20.05	0	-22.49	-22.49	0
H2O(g)	-2.15	0	2.15	-1.73	0	1.73	-1.72	0	1.72	-1.79	0	1.79
Halite - NaCl	-9.79	-8.26	1.53	-9.78	-8.22	1.56				-9.68	-8.12	1.56
Hausmannite - Mn3O4	-14.99	52.13	67.12				-24.88	38.19	63.08			
Hematite - Fe2O3	22.21	20.07	-2.14	20.72	17.36	-3.38	17.15	13.77	-3.38	21.53	18.35	-3.18
Hydroxyapatite - Ca5(PO4)3OH	-3.51	-42.43	-38.91	-1.25	-41.18	-39.94	-12.92	-52.86	-39.94	-4.32	-44.09	-39.77
Jarosite-K - KFe3(SO4)2(OH)6	4.74	-2.57	-7.32	0.5	-8.07	-8.57				4.67	-3.7	-8.37
Manganite - MnOOH	-4.11	21.23	25.34				-9.27	16.07	25.34			
NH3(g)	-9.89	2.37	12.26	-8.87	2.57	11.44	-10.91	0.52	11.43	-9.83	1.74	11.57
O2(g)	-0.63	-3.48	-2.85	-0.66	-3.59	-2.92	-0.66	-3.58	-2.92	-0.66	-3.57	-2.91
Otavite - CdCO3	-2.35	-14.44	-12.1				-3.86	-15.96	-12.1			
Pyrochroite - Mn(OH)2	-5.54	9.66	15.2				-9.15	6.05	15.2			
Pyrolusite - MnO2	-12.52	32.8	45.32				-16.61	26.1	42.7			
Rhodochrosite - MnCO3	-0.28	-11.32	-11.04				-2.22	-13.32	-11.1			
Smithsonite - ZnCO3	-3.86	-13.6	-9.74				-5.12	-15.04	-9.91			
Zn(OH)2(e)	-4.11	7.39	11.5				-7.17	4.33	11.5			

Table 5 - Geochemical Modeling Results
One Too Many, Castle Creek

	April 16, 2002			June 10, 2002			July 15, 2003			August 21, 2003		
Mineral	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT
Al(OH)3(a)	-1.4	10.92	12.3	-2.2	9.4	11.59	-1.69	9.98	11.67	-2.13	9.68	11.81
Alunite - KAl3(SO4)2(OH)6	-5.87	-4.43	1.45	-10.04	-9.93	0.1				-9.94	-9.42	0.52
Anhydrite - CaSO4	-2.98	-7.33	-4.35	-3.03	-7.36	-4.33	-2.97	-7.3	-4.33	-3.01	-7.35	-4.34
Aragonite - CaCO3	0.28	-7.95	-8.23	0.66	-7.61	-8.27	0.31	-7.95	-8.27	0.78	-7.47	-8.26
Calcite - CaCO3	0.44	-7.95	-8.39	0.81	-7.61	-8.42	0.47	-7.95	-8.42	0.94	-7.47	-8.41
Cd(OH)2	-5.99	7.66	13.65									
CdSO4	-13.53	-12.79	0.73									
CH4(g)										-75.66	-121.8	-46.14
CO2(g)	-2.79	-21.07	-18.28	-3.18	-21.38	-18.2	-2.68	-20.88	-18.21	-3.24	-21.46	-18.22
Dolomite - CaMg(CO3)2	0.66	-15.9	-16.56	1.62	-15.19	-16.81	0.91	-15.87	-16.78	1.8	-14.93	-16.73
Fe(OH)3(a)	4.32	9.21	4.89	3.32	8.22	4.89	3.15	8.04	4.89	3.16	8.05	4.89
Fluorite - CaF2	-2.25	-13.15	-10.9									
Gibbsite - Al(OH)3	1.5	10.92	9.4	0.6	9.4	8.79	1.12	9.98	8.86	0.7	9.68	8.98
Goethite - FeOOH	9.39	9.21	-0.18	8.78	8.22	-0.57	8.56	8.04	-0.52	8.5	8.05	-0.45
Gypsum - CaSO4:2H2O	-2.72	-7.33	-4.61	-2.78	-7.36	-4.59	-2.71	-7.3	-4.59	-2.76	-7.35	-4.59
H2(g)	-24.21	-24.21	0	-24.94	-24.94	0	-24.02	-24.02	0	-25.09	-25.09	0
H2O(g)	-2.11	0	2.11	-1.83	0	1.83	-1.86	0	1.86	-1.91	0	1.91
Halite - NaCl	-9.74	-8.21	1.53	-10.12	-8.57	1.55				-10.06	-8.51	1.55
Hausmannite - Mn3O4	-15.59	51.24	66.73				-13.85	50.49	64.34			
Hematite - Fe2O3	20.68	18.41	-2.26	19.51	16.43	-3.08	19.07	16.08	-2.99	18.93	16.11	-2.83
Hydroxyapatite - Ca5(PO4)3OH	2.04	-36.97	-39.01	-0.36	-40.05	-39.69	-1.01	-40.63	-39.62	-0.09	-39.57	-39.48
Jarosite-K - KFe3(SO4)2(OH)6	-2.07	-9.51	-7.44	-5.21	-13.48	-8.27				-6.29	-14.3	-8.01
Manganite - MnOOH	-4.22	21.12	25.34				-4.51	20.83	25.34			
NH3(g)	-9.27	2.91	12.19	-8.67	2.96	11.63	-9.18	2.51	11.69	-8.77	3.03	11.81
O2(g)	-0.62	-3.47	-2.86	0.61	-3.52	-2.9	-0.61	-3.51	-2.9	-0.64	-3.53	-2.89
Otavite - CdCO3	-1.31	-13.41	-12.1									
Pyrochroite - Mn(OH)2	-6.19	9.01	15.2				-6.38	8.82	15.2			
Pyrolusite - MnO2	-11.85	33.22	45.07				-10.68	32.84	43.52			
Rhodochrosite - MnCO3	-1.01	-12.06	-11.05				-0.98	-12.06	-11.08			
Smithsonite - ZnCO3	-3.31	-13.06	-9.75				-3.2	-13.06	-9.86			
Zn(OH)2(e)	-3.49	8.01	11.5				-3.68	7.82	11.5			

Table 6 – Geochemical Modeling Results
Cat Scat, Castle Creek

Mineral	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT
Al(OH)3(a)	-0.87	11.41	12.28	-1.74	9.94	11.69	-1.25	10.36	11.61	-1.63	10.08	11.71
Alunite - KAl3(SO4)2(OH)6	-3.2	-1.79	1.42	-7.53	-7.25	0.28	-5.09	-4.96	0.13	-6.02	-5.7	0.32
Anhydrite - CaSO4	-2.51	-6.86	-4.35	-2.55	-6.89	-4.33	-2.49	-6.83	-4.33	-2.61	-6.94	-4.33
Aragonite - CaCO3	0.21	-8.02	-8.23	0.64	-7.63	-8.26	0.35	-7.92	-8.27	0.21	-8.05	-8.26
Calcite - CaCO3	0.37	-8.02	-8.39	0.79	-7.63	-8.42	0.5	-7.92	-8.42	0.37	-8.05	-8.42
Cd(OH)2	-6.19	7.46	13.65									
CdSO4	-13.12	-12.39	0.73									
CH4(g)										-70.75	-116.65	-45.91
CO2(g)	-2.74	-21.02	-18.27	-3.1	-21.3	-18.21	-2.79	-20.99	-18.2	-2.68	-20.89	-18.21
Dolomite - CaMg(CO3)2	0.53	-16.03	-16.56	1.54	-15.23	-16.77	1	-15.8	-16.8	0.68	-16.09	-16.77
Fe(OH)3(a)	4.57	9.46	4.89	3.85	8.75	4.89	3.75	8.64	4.89	3.83	8.72	4.89
Fluorite - CaF2	-2.21	-13.1	-10.89									
Gibbsite - Al(OH)3	2.03	11.41	9.39	1.07	9.94	8.87	1.56	10.36	8.81	1.19	10.08	8.89
Goethite - FeOOH	9.65	9.46	-0.19	9.26	8.74	-0.52	9.2	8.64	-0.56	9.23	8.72	-0.5
Gypsum - CaSO4:2H2O	-2.26	-6.86	-4.61	-2.3	-6.89	-4.59	-2.24	-6.83	-4.59	-2.36	-6.94	-4.59
H2(g)	-24.02	-24.02	0	-24.74	-24.74	0	-24.16	-24.16	0	-23.94	-23.93	0
H2O(g)	-2.1	0	2.1	-1.86	0	1.86	-1.83	0	1.83	-1.87	0	1.87
Halite - NaCl	-10.11	-8.58	1.53	-10.16	-8.61	1.55				-10.09	-8.54	1.55
Hausmannite - Mn3O4	-14.24	52.43	66.67	-9.63	54.76	64.39	-12.18	51.92	64.1			
Hematite - Fe2O3	21.21	18.93	-2.28	20.46	17.8	-2.98	20.35	17.28	-3.07	20.4	17.45	-2.95
Hydroxyapatite - Ca5(PO4)3OH	-0.98	-40.01	-39.03	0.97	-38.64	-39.6	-1.56	-41.24	-39.68	-3.04	-42.62	-39.58
Jarosite-K - KFe3(SO4)2(OH)6	-0.18	-7.64	-7.46	-2.7	-10.86	-8.16	-1.84	-10.13	-8.26	-1.62	-9.76	-8.14
Manganite - MnOOH	-3.86	21.48	25.34	-2.96	22.38	25.34	-4.01	21.33	25.34			
NH3(g)	-9.36	2.82	12.17	-8.84	2.86	11.7	-9.06	2.58	11.64	-9.25	2.48	11.72
O2(g)	-0.62	-3.48	-2.86	-0.63	-3.53	-2.9	-0.63	-3.54	-2.9	-0.64	-3.54	-2.9
Otavite - CdCO3	-1.46	-13.56	-12.1									
Pyrochroite - Mn(OH)2	-5.73	9.47	15.2	-5.19	10.01	15.2	-5.95	9.25	15.2			
Pyrolusite - MnO2	-11.54	33.49	45.03	-8.81	34.75	43.56	-9.95	33.41	43.37			
Rhodochrosite - MnCO3	-0.5	-11.55	-11.05	-0.21	-11.29	-11.08	-0.65	-11.74	-11.09			
Smithsonite - ZnCO3	-3.33	-13.09	-9.76				-3.19	-13.06	-9.87			
Zn(OH)2(e)	-3.57	7.93	11.5				-3.57	7.93	11.5			

Table 7 – Geochemical Modeling Results
North Fork Rapid Creek, All Sites

Mineral	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT	SI	Log IAP	Log KT
Al(OH)3(a)	-0.87	11.41	12.28	-1.74	9.94	11.69	-1.25	10.36	11.61	-1.63	10.08	11.71
Alunite - KAl3(SO4)2(OH)6	-3.2	-1.79	1.42	-7.53	-7.25	0.28	-5.09	-4.96	0.13	-6.02	-5.7	0.32
Anhydrite - CaSO4	-2.51	-6.86	-4.35	-2.55	-6.89	-4.33	-2.49	-6.83	-4.33	-2.61	-6.94	-4.33
Aragonite - CaCO3	0.21	-8.02	-8.23	0.64	-7.63	-8.26	0.35	-7.92	-8.27	0.21	-8.05	-8.26
Calcite - CaCO3	0.37	-8.02	-8.39	0.79	-7.63	-8.42	0.5	-7.92	-8.42	0.37	-8.05	-8.42
Cd(OH)2	-6.19	7.46	13.65									
CdSO4	-13.12	-12.39	0.73									
CH4(g)										-70.75	-116.65	-45.91
CO2(g)	-2.74	-21.02	-18.27	-3.1	-21.3	-18.21	-2.79	-20.99	-18.2	-2.68	-20.89	-18.21
Dolomite - CaMg(CO3)2	0.53	-16.03	-16.56	1.54	-15.23	-16.77	1	-15.8	-16.8	0.68	-16.09	-16.77
Fe(OH)3(a)	4.57	9.46	4.89	3.85	8.75	4.89	3.75	8.64	4.89	3.83	8.72	4.89
Fluorite - CaF2	-2.21	-13.1	-10.89									
Gibbsite - Al(OH)3	2.03	11.41	9.39	1.07	9.94	8.87	1.56	10.36	8.81	1.19	10.08	8.89
Goethite - FeOOH	9.65	9.46	-0.19	9.26	8.74	-0.52	9.2	8.64	-0.56	9.23	8.72	-0.5
Gypsum - CaSO4:2H2O	-2.26	-6.86	-4.61	-2.3	-6.89	-4.59	-2.24	-6.83	-4.59	-2.36	-6.94	-4.59
H2(g)	-24.02	-24.02	0	-24.74	-24.74	0	-24.16	-24.16	0	-23.94	-23.93	0
H2O(g)	-2.1	0	2.1	-1.86	0	1.86	-1.83	0	1.83	-1.87	0	1.87
Halite - NaCl	-10.11	-8.58	1.53	-10.16	-8.61	1.55				-10.09	-8.54	1.55
Hausmannite - Mn3O4	-14.24	52.43	66.67	-9.63	54.76	64.39	-12.18	51.92	64.1			
Hematite - Fe2O3	21.21	18.93	-2.28	20.46	17.8	-2.98	20.35	17.28	-3.07	20.4	17.45	-2.95
Hydroxyapatite - Ca5(PO4)3OH	-0.98	-40.01	-39.03	0.97	-38.64	-39.6	-1.56	-41.24	-39.68	-3.04	-42.62	-39.58
Jarosite-K - KFe3(SO4)2(OH)6	-0.18	-7.64	-7.46	-2.7	-10.86	-8.16	-1.84	-10.13	-8.26	-1.62	-9.76	-8.14
Manganite - MnOOH	-3.86	21.48	25.34	-2.96	22.38	25.34	-4.01	21.33	25.34			
NH3(g)	-9.36	2.82	12.17	-8.84	2.86	11.7	-9.06	2.58	11.64	-9.25	2.48	11.72
O2(g)	-0.62	-3.48	-2.86	-0.63	-3.53	-2.9	-0.63	-3.54	-2.9	-0.64	-3.54	-2.9
Otavite - CdCO3	-1.46	-13.56	-12.1									
Pyrochroite - Mn(OH)2	-5.73	9.47	15.2	-5.19	10.01	15.2	-5.95	9.25	15.2			
Pyrolusite - MnO2	-11.54	33.49	45.03	-8.81	34.75	43.56	-9.95	33.41	43.37			
Rhodochrosite - MnCO3	-0.5	-11.55	-11.05	-0.21	-11.29	-11.08	-0.65	-11.74	-11.09			
Smithsonite - ZnCO3	-3.33	-13.09	-9.76				-3.19	-13.06	-9.87			
Zn(OH)2(e)	-3.57	7.93	11.5				-3.57	7.93	11.5			

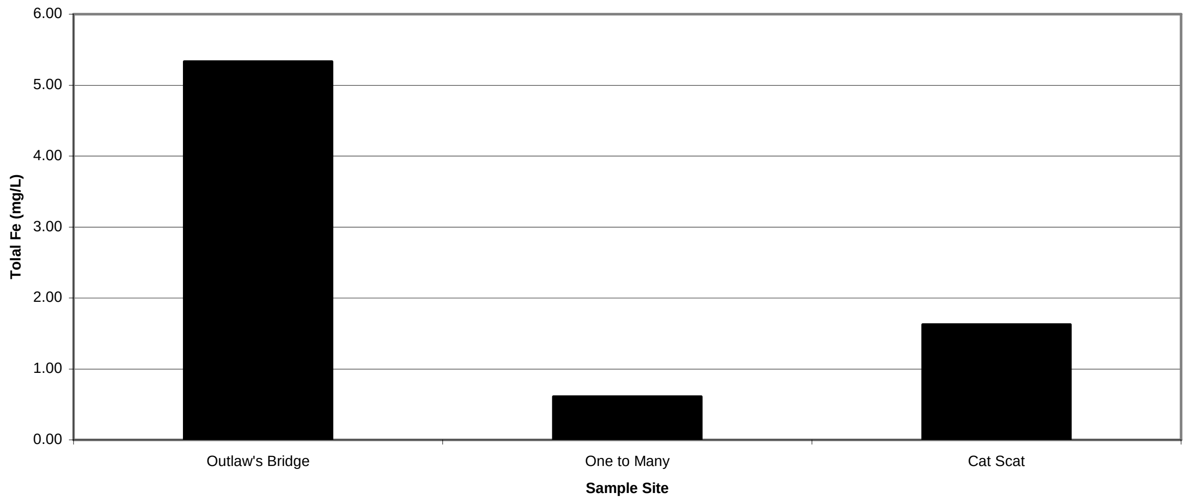
DISCUSSION GEOCHEMICAL PROCESSES

Modeling results indicate that nearly identical geochemical processes are occurring at each site. The source of the headwaters of Castle Creek, North Fork Castle Creek, and North Fork Rapid Creek is the Pahasapa (Madison) Limestone located west and north of the Black Hills uplift. The geology of both watersheds is the same i.e. Precambrian rocks composed of igneous and metamorphic schist, slates, quartzite, granite, and pegmatite overlain by nearly flat-lying Paleozoic sedimentary rocks. Therefore, one would expect the water in both creeks to have very similar chemical properties. At all sites in North Fork Rapid Creek, Castle Creek, and North Fork Castle Creek, iron tends to precipitate. The iron precipitates include amorphous iron hydroxide $Fe(OH)_3$, Goethite (FeOOH) and Hematite (Fe_2O_3). The modeling indicates that they precipitate at all sample locations. Although the geochemical modeling can accurately predict reactions that will occur in aqueous solutions, it does not predict reaction kinetics. Thus, although iron hydroxide, Goethite and Hematite are forming at each of the sites, the rate of formation of each of these compounds is not identical.

The rate and amount of precipitate is dependent on two factors: 1.) the amount of the reactants present in the system; and, 2.) the stability of each of the compounds. Hydroxides often occur in amorphous form. It is the metastable form of iron and would be the first to form from the ions present in the creek. The gelatinous material found on the substrate at Outlaw's Bridge and Cat Scat was analyzed using visible and near infrared reflectance spectroscopy and found to be iron hydroxide. Iron hydroxide can occur as an amorphous compound or in crystalline form. Limonite ($FeO(OH) \cdot nH_2O$), more commonly known as Yellow Boy, is the name given to the amorphous form of iron hydroxide. The crystalline from is called Goethite (FeO(OH)). Iron Hydroxide is a metastable form of iron and would form first, before iron-containing minerals with lower energy states. The mineral with the lowest energy state of the principal iron-rich minerals found at these sites is Hematite (Fe_2O_3). It has a hexagonal crystalline form and is the oxidized form of iron (Fe^{3+}). Its rate of formation would be orders-of-magnitude slower than iron hydroxide. Hematite is the cementing agent that binds the substrate together but is forming slowly over "geologic time."

Geological investigations indicate the source of the iron in this area of the Black Hills is the weathering of very fine crystals of the mineral pyrite, which is iron sulfide (FeS_2). As the pyrite weathers (see discussion on ground water), iron, sulfate ions and acid are produced. The weathering process results in ground water with a very low pH (2 to 4). The oxidized iron from large seeps or springs along the stream produces the iron bog deposits in the watershed. However, smaller seeps along the stream are also a source of reduced iron, which undergoes oxidation in the stream resulting in sulfate production and iron precipitate. These small seeps, although not apparent to the casual observer, are found within the study area on both North Fork Rapid Creek below Horse Tooth and near all the Castle Creek Sites. These seeps, together with the bog-iron deposits, are the source of iron in upper Rapid Creek Drainage and responsible for the staining and cementation of the stream substrate. Figure 12 and Figure 13 show the iron and sulfate concentrations at the Castle Creek sites. Figures 14 and 15 show the concentration of iron and sulfate at North Fork Rapid Creek sites. At locations in the watershed where iron is present in "normal" or "near normal" background concentrations, the amount of iron precipitate formed within the creek is not noticeable and does not have an apparent deleterious effect on stream quality.[3] However, as the amount of iron in the creek increases at small iron-rich seeps or downstream from the springs in iron bog formations, iron staining is noted in the stream itself and on the stream substrate. Iron is being precipitated at these sites as demonstrated in the pHREEQC modeling but at a rate less than that occurring in the bogs.[4] At iron bog locations (Outlaw's Bridge) and locations immediately downstream from iron bog deposits (Cat Scat) the streams are most impacted. In addition to staining, the amount of precipitate increases to the point where it is visible on the substrate as iron hydroxide and the substrate is undergoing cementation.

Figure 12
Average Iron Concentration,
Castle Creek



[3] These sites are Horse Tooth (North Fork Rapid Creek) and Big Dog (North Fork Rapid Creek).
[4] These sites are Fence Post (North Fork Rapid Creek), High and Dry (North Fork Rapid Creek) and One too Many (Castle Creek).

Figure 13
Average Sulfate Concentrations
Castle Creek

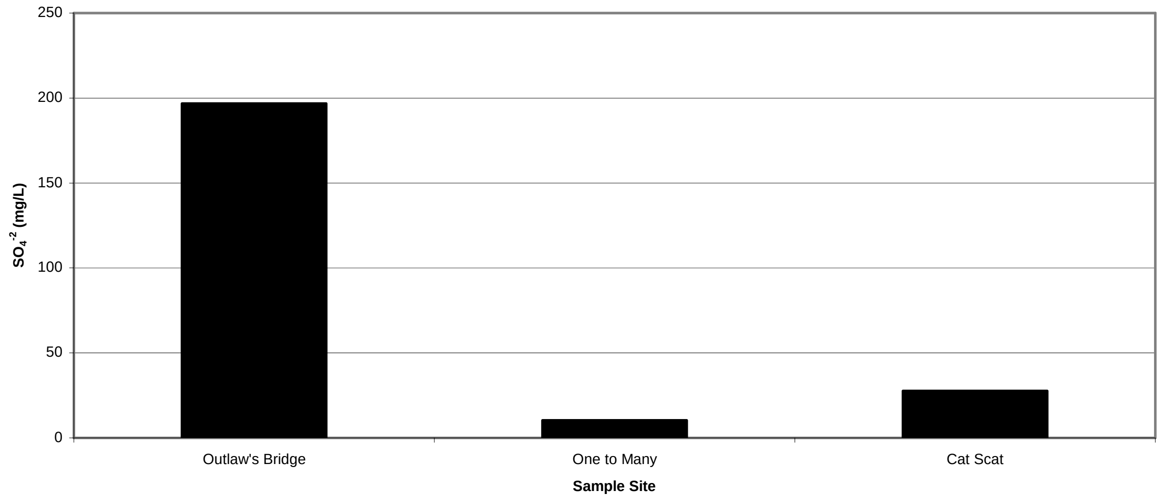


Figure 14
Average Iron Concentration,
North Fork Rapid Creek

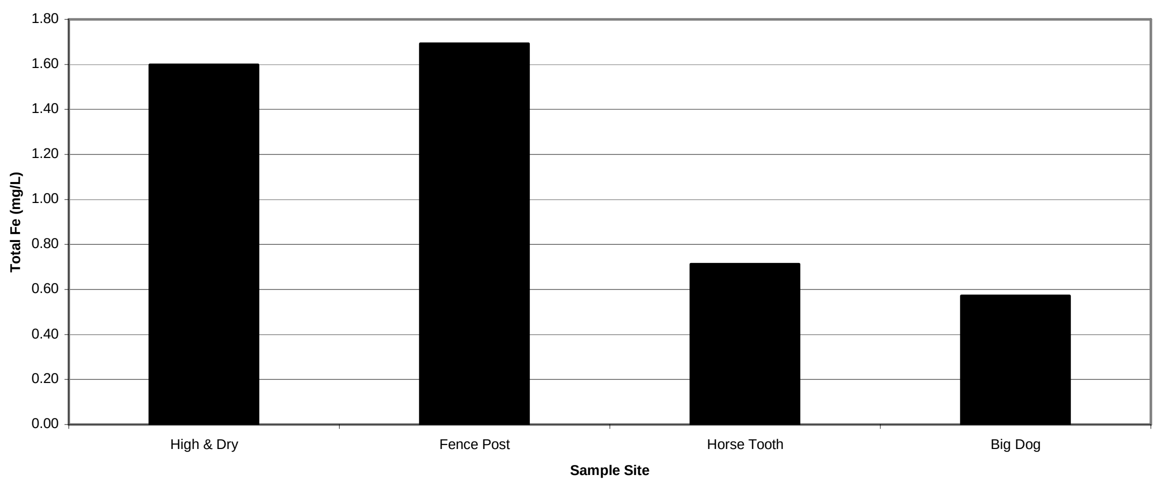
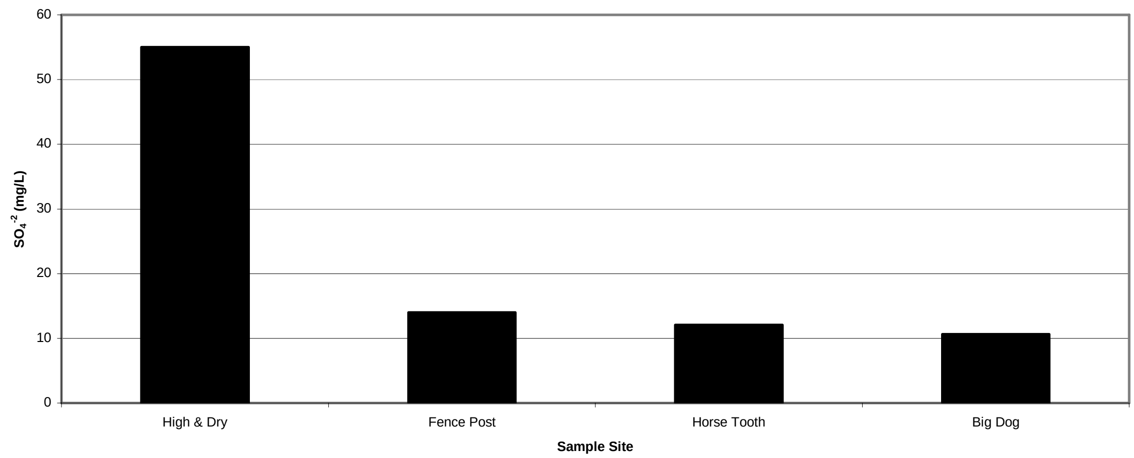


Figure 15
Average Sulfate Concentration
North Fork Rapid Creek



Characterization of Precipitates

Samples of precipitate were collected from Castle, North Fork Castle, and North Fork Rapid Creeks for analysis using visible and near infrared reflectance spectroscopy. Dr. Edward Duke of the South Dakota School of Mines & Technology performed the analyses. Reflection spectra were compared to standard type-curves. The samples best match the type-curves for Jarosite ($KFe_3(SO_4)_2(OH)_6$), Goethite ($FeO{\cdot}OH$), and Limonite ($FeO{\cdot}OH{\cdot}nH_2O$). The iron in all of these minerals is oxidized Fe^{3+}. A white precipitate was observed in the field but was difficult to sample. While its identity could not be confirmed through analysis, it is thought to be the mineral Gibbsite ($Al(OH)_3$) or Alunite ($KAl_3(SO_4)_2(OH)_6$). Aluminum is ubiquitous in the environment and it is thought that the acidic groundwater dissolved aluminum contained in the Precambrian bedrock, transported it to the surface where it was oxidized and precipitated as aluminum hydroxide.

OTHER OBSERVATIONS

These investigations did not focus on the impacts of livestock (e.g., cattle and horses) and beaver to the watershed. However, it was clear that in some reaches of Castle Creek, North Fork Castle Creek, and North Fork Rapid Creek grazing livestock had reduced vegetation from the riparian habitat and disturbed the stream banks. Loss of riparian vegetation reduces shade along the stream causing greater diurnal temperature fluctuations. Warmer water carries less dissolved oxygen. Loss of riparian vegetation and disturbed stream banks are more prone to erosion. Increased sediment load will impair fish spawning and macro-organism habitat. No beaver dams were observed in the Castle Creek or North Fork Castle Creek study area. Several beaver dams were observed on the North Fork Rapid Creek and numerous beaver dams were observed along many of its tributaries. Beaver dams flood meadows and slow stream flow, trapping sediment and increasing riparian habitat area. The absence of beavers and their dams causes a narrower riparian zone and allows streams to flow unimpeded and more swiftly. Faster stream flow keeps fine sediments entrained longer and transported further downstream. While not formally studied during these investigations, visual observations indicated that, where beaver dams were present along streams containing iron bog discharge, sediment and precipitates appeared to be better removed and less acid drainage and associated iron and aluminum precipitates reached North Fork Rapid Creek. In general, the presence of livestock and absence of beavers appear to have an overall negative impact to stream and riparian habitat and water quality.

FINDINGS

In the Castle Creek and North Fork Castle Creek watersheds, acid ground water containing dissolved iron, aluminum, and sulfate discharges to the land surface as springs and directly into creeks. The ground water discharges from a reducing environment below the land surface to an oxidizing environment at the surface. Iron, aluminum, and sulfate remain in solution in a reducing environment but precipitate out of solution when oxidizing conditions are encountered at the land surface. Iron bogs will form where ground water discharges at springs. Based on results from this investigation, iron bogs in this study area are depositional features. Where spring discharge from the bogs flows into the creeks and where ground water discharges directly to the creeks, red-orange iron hydroxide deposits quickly precipitate out of solution and coat the stream substrate. With time, diagenetic processes cause the precipitate to dewater and lithify, cementing the stream substrate and ultimately forming iron-cemented conglomerate.

Impacts to the environment are acute at the locations of iron bogs and immediately downstream from them. The acid kills vegetation and benthic macro-invertebrates at the site of the bog. Iron and aluminum hydroxides precipitate, coating and cementing the stream substrate. Some of the precipitate remains suspended and is transported downstream, negatively affecting the stream habitat for several hundred yards. Much of the plant and animal life in these areas is impacted, with some stream reaches devoid of most life. Natural chemical reactions attenuate the impacts, restoring the stream's habitat and water quality within approximately one to two miles in the downstream direction from the acid discharge.

The Stiff diagram shapes best illustrate the impact to the stream water quality. The polygon shapes show little change from upstream to downstream for the surface water monitoring stations. Acid ground water discharges to Castle and North Fork Castle Creek between the CCUP and CCDOWN sample stations. The ground water and iron bog discharge water quality are both considerably different from the surface water quality. However, the difference between the surface water quality at CCUP and CCDOWN is minor. Also, the difference between One Too Many and Cat Scat is minor. This shows that the water quality from the iron bogs is not having a great impact on the overall water quality of the Castle Creek. On the other hand, North Fork Castle Creek is different compared to One Too Many and Cat Scat. At North Fork Castle Creek, bicarbonate (HCO_3^-) concentration is lower and sulfate (SO_4^{2-}) concentration is higher compared to other surface water samples. The buffering capacity of the surface water is due primarily to the high bicarbonate concentration originating from the Madison aquifer, the source of the stream. The buffering capacity causes the iron and aluminum to precipitate out when the acid water mixes with the bicarbonate-rich surface water. The discharge of ground water and creek tributaries is not known. Additional field data are necessary in order to determine their flow. A more advanced mixing modeling could be developed with those additional data.

Based on these investigations and the apparent visual impacts due to cattle grazing and sparse beaver population, additional studies are warranted to quantify impacts due to the presence of cattle and lack of a substantial beaver population.

IMPACTS OF IRON LEACHATE

Water polluted with acid and high iron and other metal concentrations may cause negative impacts to the environment. Possible impacts are listed and discussed below.

- The land surface immediately around acid springs is typically free of living vegetation (Figures 3 & 4, page 18).

- Fish, plants, and micro- and macro-invertebrates are stressed under these conditions. At high enough concentrations, most plants and animals will die leaving an environment devoid of life (OSMRE, 2000).

- When polluted water mixes with oxygenated, unpolluted water having acid-buffering capacity, the polluted water will become oxygenated and/or the pH will increase. As the pH increases, metals will complex and precipitate out of solution. Iron precipitates are commonly red-orange and range from amorphous to poorly crystalline ferric oxides, hydroxides or oxyhydroxysulfate minerals. Some examples include, “yellowboy” or amorphous $Fe(OH)_3$, hematite, goethite, and limonite. Aluminum precipitates are commonly white and range from amorphous to poorly crystalline aluminum oxides and hydroxides. Some examples include amorphous $Al(OH)_3$, gibbsite, and alunite.

- These precipitates fill void spaces between substrate sediments, cementing them and even completely coating them, resulting in partial to complete loss of habitat for aquatic life.

- The minerals that precipitate depend on the chemistry of the waters.

- Primary precipitates are iron and aluminum hydroxides and flocs (Krauskopf and Bird, 1995).

- Hydrous iron sulfate minerals (containing Fe^{2+}, Fe^{3+}, H_2O, and SO_4^{2-}) form when acid rock drainage water evaporates or pyrite is oxidized under humid conditions. These minerals are described as stored acidity and are important because they are soluble and if later dissolved by recharge or runoff will generate acidity (PDEP, 1998). It is likely the study area experiences a “pulse” of acid, iron-rich discharge in the spring when snowmelt washes these surfaces.

- Impacts appear to be great where tributaries and ground water discharges directly to the creeks, with the degree of impact decreasing in the downstream direction.

CONCLUSIONS

Naturally occurring acid rock drainage from iron bogs discharges to tributaries of and directly to Castle Creek, North Fork Castle Creek and North Fork Rapid Creek negatively impacting the streams. Based on surface and ground water data collected for this investigation in 2002 and 2003, the discharge is acidic, contains high concentrations of iron, aluminum, and sulfate, is naturally occurring, and originates from Precambrian pyrite-rich metamorphic rocks. While the discharge does not significantly impact the surface water quality, it does negatively impact reaches of the stream's habitat. Damage or destruction of the biotic habitat is the primary impact and results from mineral precipitation on substrate. Plant and animal life in reaches of Castle Creek between CCUP and CCDOWN and North Fork Castle Creek from Outlaw's Bridge to two to three miles upstream of Outlaw's Bridge are stressed. Where the impacts are great, reaches of stream may be devoid of most life. Natural chemical reactions attenuate the impacts, ultimately restoring the stream's habitat and water quality. On Castle Creek, this natural restoration appears to occur within approximately one-half to one mile in the downstream direction from the CCDOWN. However, the neutralizing capacity of North Fork Castle Creek surface water is exceeded by acid rock discharge and stream quality does not improve before its confluence with Castle Creek. Approximately two to three miles of North Fork Castle Creek upstream from Outlaw's Bridge are negatively affected by acid rock drainage. Based on visual observation, the damage to the stream may be exacerbated by cattle grazing.

Iron bogs are depositional features and many were mined from the early 1900s up through the 1960s because of their high iron content (approximately 50-percent iron). While iron bog mines do impact the environment, in this study area, the mines are relatively small. When compared to the total naturally occurring acid discharge in the two watersheds, they probably have a negligible effect on overall water quality. Even with the absence of mining, iron bogs and acid rock drainage would be present and affecting the environment in this study area.

SECTION 4: WATER CHEMISTRY

The two primary concerns identified by the parties funding this study were the effects of iron bog leachate in the upper Rapid Creek drainage and possible temperature exceedance in North Fork Rapid Creek. The presence of acid leachate from the bog deposits had been documented previously (Luza, 1969). One of the goals of this investigation was to evaluate the effects of the bog leachate on receiving water in North Fork Rapid Creek and Castle Creek. Acid discharge is associated with the oxidation of reduced sulfide minerals (Guyer, 1998). Sulfide minerals typically contain a number of heavy metals and as a result, acid discharge often contains dissolved metals, which have a deleterious effect on stream biota. A water chemistry sampling and monitoring program was established for both streams. The purpose of the sampling program was twofold: 1) to collect data to determine what if any pollutants are present in the Castle Creek, North Fork Castle Creek, and North Fork Rapid Creek and 2) to collect data to model geochemical processes occurring in the streams. The sampling program consisted of establishing sampling sites on both creeks. Samples were collected over a one-year period: October 2002 to September 2003[7]. All permanent surface-water monitoring sites were sampled monthly except when snowfall made sites inaccessible. In addition, permanent sites were sampled bimonthly during the time for spring run-off. In addition, automatic samplers were placed on four permanent surface-water sites[8] in an effort to collect samples during storm events. Groundwater sites were established in each watershed. These sites were sampled on a quarterly basis beginning in July 2002 and continuing to May 2003. In addition to the permanent surface-water monitoring sites, two surface-water grab-samples were collected on Castle Creek in the summer of 2002. CCDOWN was located downstream of the permanent surface-water sites on Castle Creek and CCUP was located upstream of those sites. Map 3, Page 7 shows the location of these sites. A single grab-sample (NFRCSP) was collected from a spring discharging into North Fork Rapid Creek during the summer 2002. NRRCSP is located between Fence Post and High and Dry as shown on Map 4, Page 8.

Monthly and Bimonthly Surface-water Sampling

An initial list of elements and compounds was developed for sample analysis. This list was later modified as results became known. Analysis of the samples was contracted at Energy Labs of Rapid City. Samples were collected by graduate students from South Dakota School of Mines and Technology.

Prior to sampling, Energy Laboratory prepared sample bottles and sample preservative for use during sampling operations. A YSI 600R, Multi-Parameter Sonde was used to take field measurements of pH, conductivity, dissolved oxygen and temperature. Immediately prior to the sampling event, the Sonde was calibrated in the Environmental

[7] Groundwater sampling continued to May, 2003.
[8] The sites were:
On Castle Creek: One too Many and Cat Scat
On North Fork Rapid Creek: Fence Post and High and Dry

Laboratory located in the Civil and Environmental Engineering Department at SDSM&T. Standard solutions of 4, 7, and 10 pH were used to calibrate pH using a standard three-point calibration method. Calibration of the Conductivity function of the Sonde was done using a 1475 mS standard. The dissolved oxygen probe was inspected to ensure no bubbles were present behind the probe membrane and that the probe was clean. The probe was calibrated in the laboratory prior to leaving for the field to insure it was working properly. In the field the probe was recalibrated to insure that adjustment was made for changing atmospheric pressure due to elevation change.

After the Sonde had been calibrated, sample equipment was loaded into a vehicle, the sample bottles were collected from the laboratory in coolers, ice was purchased and the sample crew proceeded to the first sample site. Sample equipment consisted of the following:

five gallon plastic buckets and
plastic pitcher

Both the plastic bucket and pitcher were acid washed immediately after purchase[9]. The bucket and pitcher were used exclusively for sample collection on this project and were kept in a locked closet at South Dakota School of Mines and Technology. At the sample site the bucket and pitcher were carried to the water's edge. Prior to collecting each sample, both were rinsed three times with creek water. The larger bucket was placed on the bank and was used to composite and transport the sample at the site. The pitcher was used to collect creek water and transport it to the plastic bucket. The North Fork Rapid Creek, Castle Creek, and the North Fork Rapid Creek are shallow relatively small streams. During the summer of 2002, stream width varied from a couple feet to twenty feet. Stream depth varied from several inches to about 18 inches. At each sample site, three samples were collected with the pitcher. One of the discrete samples was obtained from a location approximately ¼ the distance from the left bank, one discrete sample was collected approximately midway in the stream and the third discrete sample was collected approximately ¼ the distance from the right bank. The three discrete samples were poured into the five-gallon bucket to form a single composite sample. The dissolved oxygen probe on the Sonde was re-calibrated to compensate for elevation change and field measurements were taken in the creek with the Sonde. The results were recorded in field book and the composite sample was transported to the vehicle. At the vehicle, preservatives were added to sample bottles as appropriate, sample was poured into the prepared sample bottles and the bottles were capped and labeled. Samples were iced, placed in a cooler and transported from the field to the laboratory. Transport time varied depending on the sample site location but typically took between 1 and 1½ hours.

Analytical results obtained for all samples collected from the permanent surface-water monitoring sites are presented in Figure 78 through Figure 133 in Appendix B and Tables 29, Page 158 and Table 30, Page 188 in Appendix B.

[9] Analysis of organic compounds was not done on this project. Therefore, plastic sampling equipment was judged appropriate.

Storm Samples

An attempt was made to collect samples from storm events during the summer of 2002. This attempt was difficult for several reasons.

The sample locations were in relatively remote sites in the Black Hill's approximately 30 to 40 miles from Rapid City. Because of the temporal and spatial variability of precipitation events over the Black Hills, it was not possible to know with accuracy when or if precipitation was occurring in the study area. Additionally, the time required traveling to the sites varied from between 1 to 1 ½ hour. Storm events in this area are typically short duration thunderstorms. Even if samplers knew with certainty that precipitation was occurring at the sample sits, normally it would not have been possible for samplers to travel to the sample sites and physically collect samples before the event ended.

Automatic Samplers were installed at four sample sites in an effort to collect storm samples. The samplers contained "bubblers" which were composed of a pump that pulled air through a canister of desiccant and then pumped the dewatered air through a tube to a point at the bottom of the stream. From that point, bubbles would rise through the water column to the surface of the stream. The instrument senses the difference in pressure required to emit air bubbles as the column of water above the outlet increases during a storm event. The instrument is calibrated to an in-stream staff gage so that it "reads" actual stream depth based on the pressure required to emit air bubbles in the stream. Depth information is recorded and saved by the instrument for downloading by the sample team. During a storm, the instrument theoretically senses a rise in the stream discharge due to increased run-off. When this occurs, it sends a signal to a sampling devise that is programmed to collect discrete samples of the stream at regular intervals (fifteen-minute) throughout the storm event. The discrete samples are composited as they are collected in a sample container located within a locked sample station.

Initially the automatic samplers were set to cycle when the stream surface had risen ½ foot. The summer of 2002 was a summer that saw a continuation of a drought that had began several years earlier. Although we did experience some rain events in the study area, very little of the precipitation ran off into the creek. A variation in surface-water elevation of ½ foot was not observed during any storm event that summer. When it became apparent that very little run-off was entering the stream during the infrequent storm events that did occur that summer, the samplers were adjusted to detect a variation of surface-water elevation of 0.2 foot. The adjustment on the samplers did tend to "drift" while in the field. Each time the sample site was visited, the samplers where checked to see that the stream depth they were recording corresponded with the actual in-stream depth gage. It was common to re-adjust (calibrate) the sampler depth to reflect the actual in-stream depth. Although three of the samplers cycled a total of 5 times during the summer of 2002, it is possible that instrument drift, may have caused the cycling one or more times.

The Castle Creek locations (One too Many and Cat Scat) are located below Deerfield Reservoir, which is managed as an irrigation source for downstream agricultural users and a source of potable water for the City of Rapid City by the Bureau of Reclamation. Flow at these sites is therefore affected by the managed discharge from Deerfield Dam.

The possible storm samples collected are:

- July 20, 2002 – Samplers cycled at High and Dry on North Fork Rapid Creek and at One too Many on Castle Creek.
- August 5, 2002 – Sampler cycled at One too Many on Castle Creek
- August 22, 2002 – Samplers cycled at High and Dry on North Fork Rapid Creek and at Cat Scat on Castle Creek

Meteorological Data indicates rain did occur over the project area on or immediately prior to the date the storm samples were collected.

TABLE 8: RAINFALL IN INCHES FROM STATIONS NEAR SAMPLE SITES FOR SELECTED

Station	7/19/02	7/20/02	8/3/02	8/4/02	8/5/02	8/21/02	8/22/02
Custer Airport		0.81			1.32	0.79	Tr
Rochford	0.01	1.01	0.08	0.21		0.25	0.17

Comparisons of analytical results obtained from the possible storm events and the nonevent average results are presented in Table 33, Page191 in Appendix B. There is no indication of significant differences between event and non-event results.

GROUNDWATER SAMPLES:

Due to the remote location, limited site access, and presence of shallow ground water, piezometers were installed at NFRCGW and CCGW sampling sites and used to collect shallow ground water samples for laboratory analysis. A piezometer is a pipe sealed along its length, open to water flow at the bottom, and open to the atmosphere at the top. In essence, a piezometer is a field manometer. Each piezometer consisted of stainless steel pipe, nalgene tubing, and stainless steel screen.

Each piezometer was installed by driving the stainless steel pipe approximately 2-3 feet into the ground using a 10-lb sledgehammer. A stainless steel bolt was placed in the bottom opening of the pipe to prevent sediment from entering the pipe during installation. After the pipe was driven to the desired depth, it was pulled back a few inches to create some separation between the nut and pipe opening to allow water to enter the pipe. A piece of fine stainless steel screen was crimped onto the end of 0.25-inch diameter nalgene tubing and fed into the pipe until the bottom of the pipe was encountered. The tubing was pulled back a few inches to create some separation between the sediment at the bottom of the pipe and the end of the tubing.

A peristaltic pump was used to siphon water from the pipe through the tubing. Due to lack of electricity at the sites, a cordless drill was used to drive the peristaltic pump and retrieve water from the piezometer. Each piezometer was developed by purging water until it ran clear of sediment. A minimum of three piezometer volumes of groundwater were purged prior to collecting samples for analysis. Water samples were collected using standard EPA protocol and stored in an iced cooler during transportation from the site to the laboratory. Preservatives were added to some water samples, as required. The piezometers were left uncapped between sampling dates, as the locations were remote and well hidden. A total of four quarterly samples were collected from each ground-water monitoring site. Upon completion of the ground water monitoring program, each piezometer was uninstalled leaving only the stainless steel bolt several feet under ground at each site.

Analytical results obtained for all groundwater samples are presented in Table 31, Page 189 in Appendix B.

Miscellaneous grab-samples were taken at selective sites in both the North Fork Rapid Creek and Castle Creek watersheds. Analytical results obtained from these grab-samples are presented in Table 32, Page 190 in Appendix B.

BENEFICIAL USES

NORTH FORK RAPID CREEK

North Fork Rapid Creek together with South Fork Rapid Creek comprise the headwaters of Rapid Creek. Rapid Creek can be divided into four reaches based upon assigned beneficial uses. Reach 1 comprises the entire North Fork Rapid Creek. Reach 2 begins at the confluence of the North and South Forks of Rapid Creek and extends down stream to Canyon Lake. Reach 3 extends downstream from Canyon Lake to Sec. 15, T.1N., R.8E., Black Hills Meridian. Reach 4 extends from Sec. 15, T.1N., R.8E., Black Hills Meridian downstream to the confluence of Rapid Creek with the Cheyenne River.

The Administrative Rules of South Dakota contain South Dakota's surface-water quality standards and the beneficial uses assigned to the States' surface-waters. Beneficial uses assigned to the four reaches of Rapid Creek described above are presented in Table 10.[10]

Table 9: Beneficial Uses Assigned to Reaches of Rapid Creek, PENNINGTON & LAWRENCE, SOUTH DAKOTA

Use	Reach 1	Reach 2	Reach 3	Reach 4
Domestic Water Supply		X	X	
Coldwater Permanent Fish Propagation	X	X	X	
Warmwater Permanent Fish Propagation				X
Immersion Recreation Waters		X	X	X
Limited Contact Recreation Water	X	X	X	X

[10] State of South Dakota. Surface Water Quality Standards. §74:51:03:17.

In addition to the beneficial uses identified above, the State of South Dakota has designated all waters in the state as having beneficial uses of 1) Fish and Wildlife Propagation, Recreation and Stock Watering and 2) Irrigation (State of SD, 2004).

Under the application of criterion to contiguous water provisions of the State's Surface-water Quality Standards[11], the discharge from North Fork Rapid Creek may not exceed the beneficial use standard for Reach 2, the section of Rapid Creek beginning at the confluence with the South Fork Rapid Creek and extending to Canyon Lake. The beneficial use standard for coldwater permanent fish life propagation waters and limited contact recreation water apply to North Fork Rapid Creek. Its discharge at its confluence with South Fork Rapid Creek must meet beneficial use standards for domestic water supply, coldwater permanent fish life propagation, immersion recreation waters, and limited contact recreation water. Sample station High and Dry is on North Fork Rapid Creek immediately above its confluence with South Fork Rapid Creek. Results obtained at this site would determine if the application of criterion to contiguous water provisions of the state code are being met.

CASTLE CREEK SITES

Beneficial uses for both North Fork Castle Creek and Castle Creek are cold-water permanent fish propagation and limited contact recreation waters.

WATER QUALITY STANDARDS

Water quality criteria and standards have been defined in South Dakota State statute in support of these beneficial uses[12]. The standards are presented in Table 11, Page 51**.** Table 11 contains standards for beneficial uses identified in the State's administrative rules and in the 303(d) TMDL Waterbody list.

DISCUSSION OF ANALYTICAL RESULTS FOR BENEFICIAL USE CRITERIA

Results of water chemistry monitoring of North Fork Rapid Creek and the Castle Creek sites are presented in graphical form in Appendix B this document. Results for specific beneficial use criteria are discussed below:

Temperature

The in-stream temperature standard for cold-water fish life was exceeded at all sample stations during the sample period. For a complete discussion and presentation of this criteria refer to Section 7: Temperature Monitoring, of this document.

Total Solids

Total solids are the sum of total suspended solids and total dissolved solids. The standard for Fish and Wildlife Propagation, Recreation, & Stock Watering is 2,500 mg/L. The standard for Domestic Water Supply, which applies to Rapid Creek below the confluence

[11] State of South Dakota. Surface Water Quality Standards §74:51:01:04.
[12] South Dakota Codified Law, *Article 74:51 Table 2*

of North Fork Rapid Creek and South Fork Rapid Creek is 1,000 mg/L. The discharge in North Fork Rapid Creek does not exceed these limits.

Total Suspended Solids
The beneficial use standard for coldwater permanent fish life propagation is 53-mg/L daily maximum and 30 mg/L for a 30-day average. No sample exceeded this standard on North Fork Rapid Creek or Castle Creek. The 53 mg/L daily maximum was exceeded on North Fork Castle Creek on one sampling date (December 11, 2001). Three single samples exceeded the 30-day average standard but because daily samples were not collected during this evaluation, it is impossible to determine if that standard was exceeded.

Dissolved Oxygen
The dissolved oxygen standard is a minimum standard. For coldwater fish propagation the standard is 6 mg/L and 7mg/L during spawning season. For limited contact and immersion recreation, the standard is 5 mg/L. All samples exceeded the most stringent standard, 7 mg/L.

pH
The pH standard for coldwater permanent fish life propagation is in a range of between 6.6 and 8.6. For domestic water supply, the receiving water standard for the North Fork Rapid Creek, the standard is between the range of 6.5 to 9. All of the pH measurements taken during the study were within the most stringent coldwater permanent fish propagation range. Upstream sample sites had higher pHs. They were very close to the 8.6 maximum. Elevated pH, as long as it remains within tolerance levels is very beneficial in both creeks. Higher pH serves to more quickly neutralize the acid discharge occurring at the iron bog sites. This results in rapid precipitation of iron and aluminum and actually helps limit the impacts from iron bog leachate to sections of the creeks close to the bogs13.

Nitrogen as Nitrate and Nitrite
The beneficial use of Fish and Wildlife Propagation, Recreation, and Stock Watering has a nitrate standard of 50 mg/L for a 30-day average and 88 mg/L for a daily maximum. The receiving waters of North Fork Rapid Creek have nitrogen as nitrate standard of 10 mg/L (Domestic Water Supply standard). No sample collected from either stream exceeded the Domestic Water Supply limit.

[13] See discussion in Geology Section

TABLE 10: WATER QUALITY STANDARDS, NORTH FORK OF RAPID CREEK

Criteria	Domestic Water Supply	Coldwater Fish Life	Warmwater Fish Life	Immersion Rec.	Limited Contact Rec.	Fish and Wildlife Propagation, recreation, & Stock Watering	Irrigation	Units of Measure	Special Conditions
						750		mg/L	
Alkalinity ($CaCO_3$)						1,313		mg/L	daily max
Barium	1							mg/L	
Chloride	250	100						mg/L	30-day avg.
Chloride	438	175						mg/L	daily max
Conductivity						4.00	2.50	mS/cm	30-dau avg.
Conductivity						7.00	4.375	mS/cm	daily max
Dissolved Oxygen		6	5	5	5			mg/l	
Dissolved Oxygen		7	6					mg/L	during spawn
Fecal Coliform Bacteria	20000			400	2000			/100 mL	single sample
Fecal Coliform Bacteria	5000			200	1000			/100 mL	5-day avg.
Fluoride	4							mg/L	
Hydrogen Sulfide		0.002	0.002					mg/L	
Nitrate-N	10					88		mg/L	daily max
pH	6.5 - 9.0	6.6 - 8.6	6.5 - 9.0			6.0 - 9.5			§74:51:01:07
Sodium Absorption Ratio							10		
Sulfate	875							mg/L	daily max
Sulfate	500							mg/L	30-day avg.
Temperature		65	80					^{o}F	§74:51:01:31
Total Dissolved Solids								mg/L	30-day avg.
Total Dissolved Solids	1,000					2,500		mg/L	daily Max
Total Petroleum hydrocarbons	1							mg/L	
Total Suspended Solids		53	158					mg/L	daily max.
Total Suspended Solids		30	30	90				mg/L	30-day avg.
Un-ionized Ammonia - N		Calc value	Calc value					mg/L	daily max.
Un-ionized Ammonia - N		0.02	0.04					mg/L	30-day avg.

Nitrogen as Un-ionized Ammonia

Un-ionized ammonia is extremely toxic to fish. Ionization of ammonia is both temperature and pH dependent. Energy Laboratory reported nitrogen in ammonia as NH_3 (ammonia) + NH_4^+(ammonium). It was necessary to calculate un-ionized ammonia or ammonium using the equilibrium constant for ammonia and ammonium. The activity constant for the production of ammonium is:

$$K_{A,K=298} = \frac{[H^+][NH_3]}{[NH_4]} = 10^{-9.3}$$

The equilibrium constant (*K*) can be adjusted for temperature using the following equation:

$$K_{A,T} = K_{A,298} \times e^{\frac{\Delta H \times (1/298 - 1/T)}{R}}$$

where,

T = temperature of the sample in Kelvin,

ΔH = specific heat of reaction. For the reaction $NH_4^+ = NH_3 + H^+$, ΔH = 52.2 kJ/mol,

R = Gas constant = 0.08314 kJ/molK

$K_{A,T}$ = equilibrium constant for the ammonia/ammonium reaction at K = T

$K_{A,298}$ = equilibrium constant for the ammonia/ammonium reaction at 298 K = $10^{-9.3}$ (Krantz, 2002)

One sample collected on May 14, 2002 at the Horse Tooth sample site, North Fork Rapid Creek, exceeded the un-ionized ammonia standard. The sample contained 0.3 mg/L N as ammonia and ammonium. The water temperature was 13.28 ^{o}C and pH was 8.39. Calculated un-ionized ammonia equaled 0.0356 mg/L. The creek at the Horse Tooth sample site traverses a fenced pasture, which frequently contained horses or cattle. It is assumed waste from grazing livestock was the source of this ammonium. This exceedance represents 2.17% of the samples collected on North Fork Rapid Creek.

Fecal Coliform Bacteria

For both Castle Creek and North Fork Rapid Creek the standard for fecal coliform is a mean of 1,000 CFU/100ml[14] for five daily samples and a maximum of 2,000 CFU/100ml for any given sample. The controlling beneficial use is limited contact recreation. For the receiving waters of North Fork Rapid Creek i.e., Rapid Creek, the limit is a mean of 200 CFU/100ml for five daily samples and a maximum of 400 CFU/100ml for a single sample.

No exceedance of the standard was observed during the study period. The highest fecal coliform content was 1,300 CFU/100ml obtained from a single sample taken at Horse

[14] CFU: Colony Forming Units

Tooth on North Fork Rapid Creek on July 18, 2002. The highest fecal coliform recorded at the Castle Creek Sites was 350 CFU/100ml at Outlaw's Bridge on North Fork Castle Creek on July 15, 2002. One sample obtained on June 27, 2002, from the High and Dry Site on North Fork Rapid Creek just above its discharge into Rapid Creek contained 280 CFU/100ml. No other sample from this site approached the single sample standard of 400 CFU/100ml of the receiving waters.

Chloride
The controlling beneficial use for chloride is coldwater permanent fish life propagation for both North Fork Rapid Creek and Castle Creek. The standard is 100 mg/L for a 30-day average and a single sample maximum of 175 mg/L. No sample taken during the study period exceeded the compliance criteria for chloride.

Sulfate
There is no standard for sulfate for the beneficial uses established for North Fork Rapid Creek or Castle Creek. Rapid Creek below the High and Dry sample site on North Fork Rapid Creek has a standard of 500 mg/L for 30-day average and a daily maximum standard of 875 mg/L. The highest sulfate concentration obtained at the High and Dry sample site was 83 mg/L on August 20, 2002. This is well below the Rapid Creek criterion. A sample containing 270 mg/L sulfate was obtained on July 15, 2002, at Outlaw's Bridge, North Fork Castle Creek. It is likely that higher sulfate concentrations are present in both North Fork Rapid Creek and Castle Creek at or near iron bog sites. See discussion in Geology Section.

Alkalinity ($CaCO_3$)
Streams with a designated use of Fish and Wildlife Propagation, Recreation, & Stock Watering have an alkalinity standard of 1,313 mg/L daily maximum and 750 mg/L 30-day average. No sample taken during this study exceeded either of these standards.

Conductivity
The most stringent conductivity standard for a beneficial use assigned for this stream is the Irrigation standard of 2,500 μohms/cm (equivalent to 2.5 mS/cm) for 30-day average and 4,375 μohms/cm (equivalent to 4.375 mS/cm) daily maximum. No sample taken during the study period exceeded the compliance criteria for conductivity.

Sodium
The sodium standard for irrigation is a sodium absorption ratio (SAR) of 10. SAR is calculated as follows (Swift, Accessed March 17, 2004):

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{1}{2}([Ca^{2+}]+[Mg^{2+}])}}$$

No sample taken during the study period approached these compliance criteria. The highest SAR calculated on North Fork Rapid Creek was 0.14 for the sample taken at

High and Dry on April 16, 2002. This sample had a Ca^{2+} concentration of 40 mg/L, a Mg^{2+} concentration of 17 mg/L and a Na^{+} concentration of 3 mg/L.

Hydrogen Sulfide

Streams designated with coldwater permanent fish life propagation have a hydrogen sulfide standard of 0.002 mg/L. Analysis of hydrogen sulfide was not preformed for this study. Hydrogen sulfide exists in acidic conditions and it is unlikely that it is present in these streams.

Results for Individual Criteria

Results for all criteria sampled at the monitoring sites are presented in Figure 78 through Figure 133 and Tables 29 and 30 in Appendix B.

Section 5: Benthic Macroinvertebrate Community Investigations

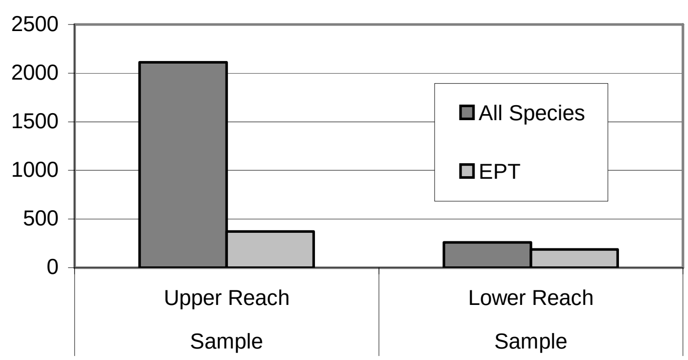
Benthic Macroinvertebrate Sampling, North Fork Rapid Creek

Benthic macroinvertebrates samples were collected on two reaches of North Fork Rapid Creek during the summer and early fall of 2002. On August 19, 2002, samples were collected on an upper reach of North Fork Rapid Creek between the Horse Tooth and Fence Post sample sites. This reach was located in a pasture that is used to graze cattle. The second set of samples was collected on October 6, 2002, in the lower portion of the watershed, just north of the High & Dry sample site above the confluence with South Fork Rapid Creek. At each reach, two samples were collected: a reach-wide sample and a riffle sample. The reach-wide sample was a composite of 11 samples taken at 10-meter increments along a 100-meter length of stream. The sample location along the stream cross-section was staggered (i.e. left, right, and center of stream bed). Samples were taken using a D-net in accordance with EPA protocols (Barbour, 1999 and Kaufman 1999). A one square-foot area in front of the net was sampled for a one-minute interval by scraping and stirring the stream substrate. The riffle sample was composed of samples collected in riffles contained within the 100-meter length of stream. A minimum of eight samples were taken from the riffles in the reach and composited using the sampling protocols discussed above. The samples were transported to the Environmental Laboratory at South Dakota School of Mines and Technology where they were prepared for shipment and sent to a commercial lab, Eco Analysts Inc, Moscow, ID, for species identification and count in accordance with EPA protocols. A copy of the Eco Analysts Inc. memo reporting the results of the benthic evaluation, titled Macroinvertebrate community analysis of North Fork Rapid Creek, is included in Appendix C.

Abundance

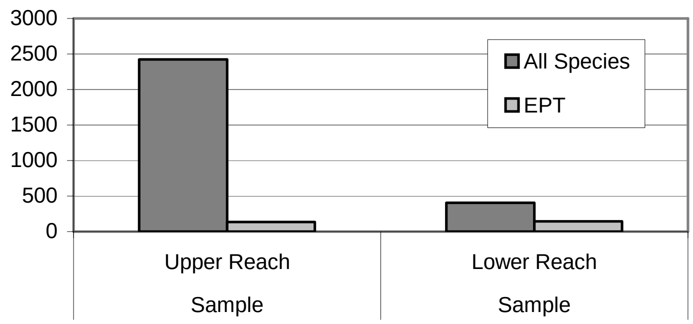
There were up to eight times more macroinvertebrates (2,110 to 259) in the upper North Fork Rapid Creek riffle sample than at the lower sample site. The upper site riffle composite sample contained two times more Ephemeroptera, Plecoptera, and Trichoptera (EPT's) (371 to 189) than the lower site. The upper reach-wide sample contained 2,424 benthic organisms vs. 405 in the lower reach for a ratio of six upper reach organisms to one organism in the lower reach. EPT in the upper reach-wide sample totaled 134 vs. 142 in the lower reach-wide sample for a ratio of approximately 1 to 1

Figure 16: Riffle Benthic Abundance North Fork Rapid Creek



between the two reaches. (Richards, February 2003) The differences in abundance can be attributed to the difference in physical habitat between the two sites, i.e. the upper site probably has more primary production due to the open canopy. In addition to open canopy, increased fecal colifrom concentrations during summer months indicate cattle grazing in the pastures traversed by the creek may increase organic material in the creek.

Figure 17: Reach-Wide Benthic Abundance North Fork Rapid Creek



Impacts from iron bog deposits could also be affecting the benthic communities at the lower site. The upper sample site was located at the upper end of the watershed at a point where bog iron leachate is just becoming evident. The lower site, although not immediately adjacent to any iron bog deposits, is downstream from several areas where significant amounts of leachate from bog iron enter the creek. A contributing factor, which could result in the differences observed in the samples collected at these two sites, is the time difference (two months) between sample collection events. The upper site samples were collected in August and the lower site samples were collected in October, 2002. Samples collected in summer vs. those collected in fall may vary due to natural, temporal variability between the communities at each of the sites (Richards, February 2003). In addition, the stream temperature averaged 71^{o}F for the month of August when the upper reach was sampled. Temperature probes had been removed from the creek by the time the lower sample was collected. During the last week the probe was in the stream (late September) the average temperature had dropped to 42^{o}F.

Table 11: Dominance Measurements, North Fork of Rapid Creek

Dominance Measures	NFRC Upper Reach Wide	NFRC Upper Riffle	NFRC Lower Reach Wide	NFRC Lower Riffle
1st Dominant Taxon	Oligochaeta	Optioservus sp.	Ostracoda	Baetis tricaudatus
1st Dominant Abundance	811.20	863.30	144.00	61.00
2nd Dominant Taxon	Optioservus sp.	Cleptelmis addenda	Hydropsyche sp.	Hydropsyche sp.
2nd Dominant Abundance	331.20	200.60	43.00	42.00
3rd Dominant Taxon	Physa sp.	Physa sp.	Hygrobates sp.	Baetis sp.
3rd Dominant Abundance	192.00	143.90	31.00	20.00
% 1 Dominant Taxon	33.47	40.91	35.56	23.55
% 2 Dominant Taxon	47.13	50.41	46.17	39.77
% 3 Dominant Taxon	55.05	57.23	53.83	47.49

Dominance

Dominant Taxa for the upper and lower reaches of North Fork Rapid Creek are presented in Table 11, Page 56. The upper reach-wide sample is dominated by aquatic worms (Oligochaeta), a species of beetle (Optioservus sp.) and a snail taxon (Physa sp.). Together these three taxa comprise 55% of the sample. The lower reach-wide sample is dominated by "mussel or seed" shrimp (Ostracoda), a taxon of caddisfly (Hydropsyche sp.) and a taxon of water mite (Hygrobates sp.). Together these three taxa comprise 54% of the sample (Richards, February 2003).

The upper reach riffle sample was dominated (approximately 57% total taxa) by two facultative riffle beetle species (Optioservus sp. & Cleptelmis addenda) and a snail taxon (Physa sp.). The lower riffle sample was dominated (approximately 47% of total taxa) by two tolerant baetid mayflies and a facultative hydropsychid caddisfly (Trichoptera). In the reach-wide samples, one of the dominant beetles was replaced by Oligochaeta (worms) (Richards, February 2003).

Richness Measurements

Ten richness metrics have been estimated from the samples collected at North Fork Rapid Creek sample sites. These richness measurements are presented in Table 12. Species richness is a count of the number of species[23] present in the sample. Generally, higher

Table 12: Richness Measurements, North Fork of Rapid Creek

Richness Measures	NFRC Upper Reach-Wide	NFRC Upper Riffle	NFRC Lower Reach-Wide	NFRC Lower Riffle
Species Richness	53.00	43.00	43.00	32.00
Ephemeroptera Richness	3.00	4.00	8.00	6.00
Plecoptera Richness	2.00	3.00	5.00	5.00
Trichoptera Richness	6.00	9.00	3.00	5.00
EPT Richness	11.00	16.00	16.00	16.00
Chironomidae Richness	17.00	11.00	8.00	4.00
EPT:Chironomidae Ratio	0.4	2.1	6.8	31
Oligochaeta Richness	1.00	1.00	0.00	0.00
NCO Richness	35.00	31.00	35.00	28.00
Rhyacophila Richness	0.00	0.00	0.00	0.00

species richness indicates good water quality, habitat diversity and habitat suitability (Soil & Water Conservation Society of Metro Halifax, 1999). Forty-three species were

[23] Note: this contrasts with abundance, which is the number of organisms present in a sample.

identified in the upper-reach riffle sample, thirty-two in the lower riffle sample. Richness was higher in the reach-wide habitats than riffle habitats. The upper reach riffle sample had a species richness of 53 verses 43 in the lower reach-wide sample.

EPT richness is the total number of Ephemeroptera (Mayfly), Plecoptera (Stonefly), and Trichoptera (Caddisfly) species present in each sample. These species are generally considered relatively intolerant of polluted water. Therefore, high EPT Richness indicates good water quality.

EPT to Chironomidae (Midges) ratio. Chironomidae are generally more tolerant of poor water quality than EPT. Biotic conditions are considered good when all four groups are in or near equilibrium. This would produce an EPT to Chironomidae ratio of 3:1. An EPT to Chironomidae ratio significantly less than this would result if substantially more Chironomidae were present in the sample than Ephemeroptera, Plecoptera and Trichoptera. This may indicate impaired or lower water quality. A higher ratio indicates high abundance of species intolerant to poor water quality. Thus a high EPT: Chironomidae ratio indicates good water quality. The upper reach of North Fork Rapid Creek has a low ratio. It is believed this low ratio is probably due to the presence of cattle grazing in the pastures adjacent to the creek. Cattle are free to enter the creek and there is evidence they are causing bank erosion and associated sedimentation in this section of creek.

Oligochaeta Richness. Oligochaeta are aquatic worms. They are considered pollution tolerant[24]. Therefore, their presence in large numbers could indicate pollution-impacted waters. (Mandaville, 2002) No Oligochaeta were found at the lower sample site and only one species was found in each of the riffle and reach-wide samples from the upper reach of North Fork Rapid Creek. Although only one species was present in the upper reach, Oligochaeta had the highest abundance of organisms in this reach.

NCO (Non Chironomidae and Oligochaeta) Richness is the total number of benthic species present in the sample exclusive of Chironomidae and Oligochaeta. Oligochaeta and Chironomidae are pollution tolerant and tend to be present in both polluted and unpolluted water. NCO taxa, because they are less tolerant than Oligochaeta and Chironomidae are considered indicators of good water quality (Soil & Water Conservation Society of Metro Halifax, 1999). NCO Richness for North Fork Rapid Creek is presented in Table 13, page 59.

Functional Feeding Groups

Feeding groups are indicators of the balance of feeding strategies in the benthic assemblage. A balance between functional feeding groups indicates a relatively stable food dynamic. An imbalance would indicate the possibility of stressed conditions in the stream. Healthy streams include viable populations of specialized feeders such as

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[24] Oligochaeta are given a tolerance value of 5 when calculate the Hilsenhoff species level Biotic Index and the Family Biotic Index. Tolerance values for calculating these indices range from 0 for very intolerant organisms to 10 for organisms very tolerant of organic wastes.

Table 13: NCO Richness, North Fork Rapid Creek				
Richness Measures	**NFRC Upper Reach-Wide**	**NFRC Upper Riffle**	**NFRC Lower Reach-Wide**	**NFRC Lower Riffle**
NCO Richness	35.00	31.00	35.00	28.00
Species Richness	53.00	43.00	43.00	32.00
% NCO	66.04%	72.09%	81.40%	87.50%

scrapers, piercers, and shredders. These are the more sensitive of the feeding groups because their food base is limited and restricted to specific foods. Gatherers and filterers tend to have a broader range of acceptable food materials and therefore are more tolerant of pollution[25] (Barbour, et al., 1999).

Functional feeding group species richness is presented in Table 14. The percentage of organisms in each group is presented in Figure 18, Page 60, for each of the four sample sites.

Table14: Functional Feeding Group Species Richness North Fork Rapid Creek				
Functional Group	**NFRC Upper Reach-Wide**	**NFRC Upper Riffle**	**NFRC Lower Reach-Wide**	**NFRC Lower Riffle**
Filterer	7.00	7.00	6.00	6.00
Gatherer	16.00	13.00	11.00	9.00
Predator	18.00	11.00	15.00	7.00
Scraper	4.00	3.00	3.00	6.00
Shredder	3.00	7.00	5.00	3.00
Piercers-Herbivore	2.00	1.00	1.00	1.00
Unclassified	3.00	1.00	2.00	0.00

Diversity/Evenness Measures

The Shannon-Wiener Index is a widely used method for calculating biotic diversity in both terrestrial and aquatic ecosystems. (Travis and Larson, 1995) The index is calculated as follows:

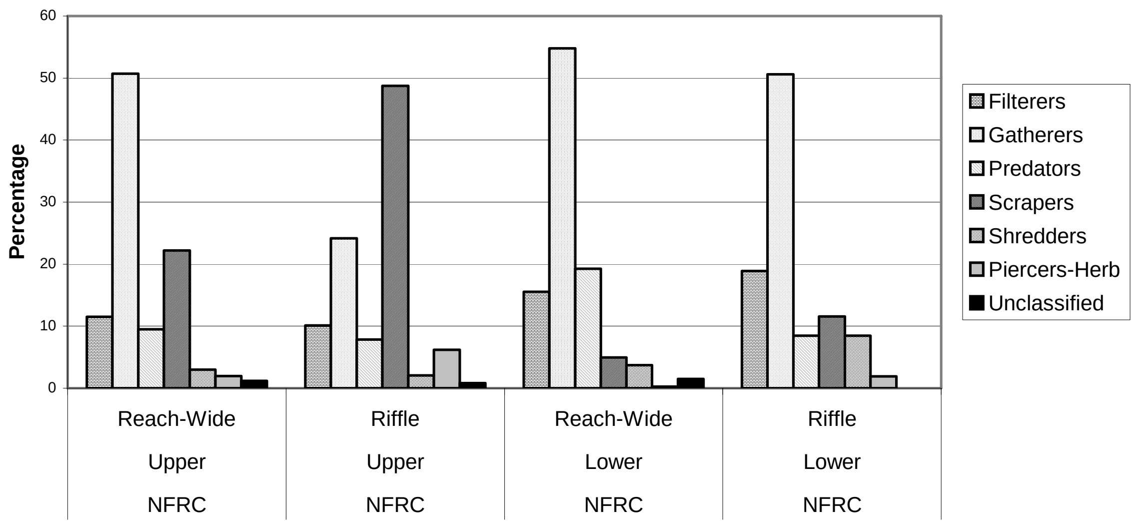
$$H^{'} = -\sum_{i}^{s}(p_i)(\log_2 p_i)$$

[25] It should be noted that according to EPA, "the usefulness of functional feeding measures for Benthic macro invertebrates has not been well demonstrated." Barbour, Michael T. *et al.*, p 7-18

Where:
H' = index of species diversity, i.e. The Shannon-Weiner Index
s = number of species
pi = proportion of total sample belonging to the i'th species

A large H value indicates greater diversity and hence better water quality. The Shannon-Weiner Indexes for North Fork Rapid Creek sites are: 3.81 and 3.59 for the upper reach-wide and riffle samples, respectively, and 3.87 and 3.96 for the lower reach-wide and riffle samples, respectively. These results indicate that the lower reach has marginally more diversity than the upper reach.

Figure 18: Macroinvertebrate Functional Group Percentage
North Fork Rapid Creek



Pielou's J is a measure of the evenness of biotic distribution. It utilizes the Shannon-Weiner Index to measure biotic distribution. The maximum Shannon-Wiener index for a given number of species can be calculated as:

$$H'_{max} = \log_2 S$$

Where:
S is the number of species

Evenness or Pielou's J is than calculated as follows:

$$J' = \frac{H'}{H'_{max}}$$

Perfect evenness is J = 1. Pielou's J for the upper reach is 0.66 for both the reach-wide and riffle sample. The lower reach had a Pielou's J of 0.71 for the reach-wide sample and

0.79 for the riffle site which again indicates better evenness and thus better water quality exists at the lower reach site (Oksanen, 2003 and Soil & Water Conservation Society of Metro Halifax, 1999).

Biotic Indices

The HBI (Hilsenhoff Biotic Index) was originally developed to rank species tolerance to organic pollution, particularly to reflect biological oxygen demand (BOD). The HBI index ranges from 0 to 10 with species intolerant to organic pollution receiving lower values. Organic pollution tends to decrease oxygen in the stream. Therefore, those species that survive in colder, well-oxygenated streams have lower HBI values. The HBI values for the upper reach samples are 6.27 for the reach-wide sample and 5.14 for the riffle sample. The Lower reach HBI values are 4.89 for the reach-wide sample and 3.89 for the riffle sample. These values indicate that:

1. More taxa that prefer cooler and well-oxygenated water were found in the lower reach than the upper reach. This is not surprising. Cattle grazing is the dominant land use in the upper reach, and nutrient loading associated with organic waste can be expected in this section from the cattle. Also, the amount of dissolved oxygen that can be contained in water is a function of temperature. Cooler water can hold more dissolved oxygen than warmer water. Water temperatures average one degree Fahrenheit warmer in the upper reach[26]. It is assumed that no canopy and lower flows in the upper reach result in higher temperatures in this reach.

2. Overall, both reaches were dominated by taxa associated with warmer conditions (not cold water species), suggesting that summer stream temperatures are warm enough to preclude the existence of cold-water obligate species (Richards, February 2003). Temperature monitoring of North Fork Rapid Creek tends to confirm this observation.

Conclusion

Benthic macroinvertebrates sampling indicates that water quality at the two sampling sites is generally good. The lower site was sampled in the fall and this may have had an impact on abundance. In fact, the upper site, although it contained a greater quantity of organisms, is probably being impacted more than the lower site. The upper site was dominated by much more tolerant species than the lower site. The EPT to Chironomidae ratio at the upper site was 1:1 for both the reach-wide and riffle samples this compared with ratios of 2:1 for the reach-wide sample and 4:1 for the riffle sample at the lower site. NCO richness was also greater for the lower site. The HBI index indicates some organic pollution present in the upper reach. It is likely that the cattle grazing in the upper part of the watershed is having an effect on benthic communities in this section of stream. Their movement along the riparian zone effects bank stability and undoubtedly results in increased sediment load in this section of stream. Cattle may contribute to nutrient

[26] Based on an identical 20 days of continuous hourly stream temperature readings at each site during the month of July 2002.

loading at the site. The increase in fecal coliform (see water chemistry section) during July and August at the sample sites indicates the presence of fecal material and thus organic material in or very near the creek.[27] Although the July 18, 2002, water chemistry sample showed a slight rise in both phosphorous and ammonia concentration in this section of North Fork Rapid Creek, the increase should not be considered a true increase because the nitrogen as ammonia was at detection limit and, nitrogen as nitrate and nitrite was below detection limits. Total phosphorous together with orthophosphorous were just slightly above detection limits.

Although there are sources of bog iron leachate in the lower portion of the watershed, it appears that by the time creek water reaches the confluence with South Fork Rapid Creek impacts from the bog leachate to the benthic communities have been significantly reduced. Nevertheless, at times a slight iron staining was visible in the discharge at High and Dry indicating that it was receiving some impact from iron bog leachate.

BENTHIC MACROINVERTEBRATE SAMPLING, CASTLE CREEK

Six benthic macroinvertebrate samples were collected during the early fall of 2002 at the Castle Creek sites. The Castle Creek sites include two sample sites on the main fork of Castle Creek and one on North Fork Castle Creek, a tributary of Castle Creek. North Fork Castle Creek has much less discharge than Castle Creek. Its discharge varied between 0.5 to 1.5 cfs over the study period. Castle Creek had a discharge rate of between 10 and 22 cfs over the same period. Although much smaller than Castle Creek, visual inspection of North Fork Castle Creek indicates that it is a primary source of iron leachate to Castle Creek. Its banks and substrate are stained a reddish color and its waters carry a red suspended sediment load. Although not as obvious, red staining and cementation of the substrate in Castle Creek below its confluence with North Fork Castle Creek is present whereas at the sample site above the confluence these impacts were not observed.

On September 28, 2002, two sites were sampled on Castle Creek. The upstream site was above the confluence with North Fork Castle Creek and the other was located below the confluence. A third site was sampled on North Fork Castle Creek above its confluence with Castle Creek on October 2, 2002**.** At each site, two samples were collected in accordance with EPA protocols described above. The samples were sent to a commercial lab, Eco Analysts Inc, Moscow ID for species identification and count. A copy of Eco Analyst's Castle Creek Macroinvertebrate Community report is included in Appendix D.

Abundance

Castle Creek above its confluence with North Fork Castle Creek is much more productive than below the confluence. There were up to thirty times more individual invertebrates in the riffle sample collected on Castle Creek above its confluence with North Fork Castle

[27]Although the July 18, 2002 water chemistry sample showed a slight rise in both phosphorous and ammonia concentration in this section of North Fork Rapid Creek, the increase is marginal. Nitrogen as ammonia was at detection limit, nitrogen as nitrate and/or nitrite was below detection limits and total Phosphorous and Ortho Phosphorous were just slightly above detection limits.

Creek than in Castle Creek below the confluence.[28] More than forty-six times as many individual invertebrates (16,224 organisms[29]) were found in the upstream riffle samples than in the North Fork sample (350 organisms[18]). The same pattern holds for the reach-wide samples. The Upper reach-wide sample on Castle Creek contained a corrected abundance of 5,388 organisms versus 413 organisms in the sample collected below the confluence of North Fork Castle Creek and 139 organisms in the reach-wide sample collected in the North Fork Castle Creek (Richards, April 2003).

Figure 19: Riffle Benthic Abundance, Castle Creek

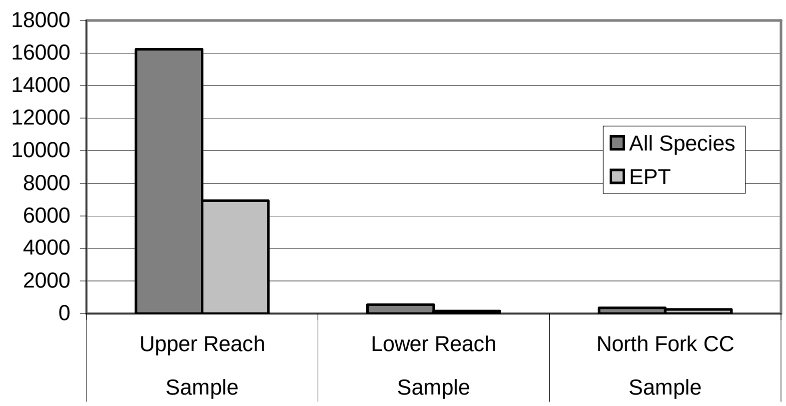
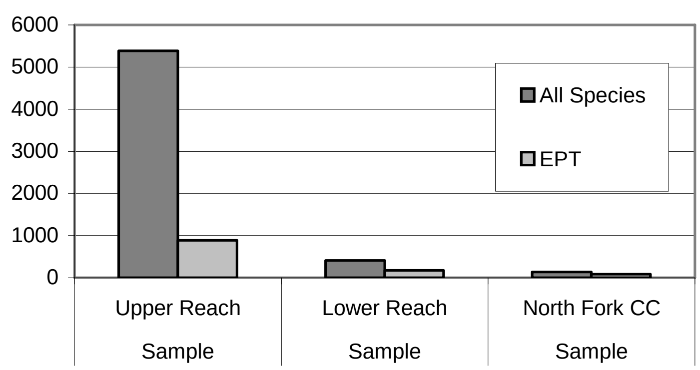


Figure 20: Reach-Wide Benthic Abundance, Castle Creek



[28] Corrected abundance was 16,224 organisms on Castle Creek (upstream) about the confluence with North Fork Castle Creek to 550 in Castle Creek below the confluence resulting in a upstream v downstream ratio of 29:1 for Castle Creek.
[29] Corrected abundance.

Dominance

Orthocladius complex organisms (midges), members of the Chironomidae Family, are dominant in both riffle samples taken on Castle creek. At the upper Castle Creek site, Baetis tricaudatus and Baetis sp., both mayflies and members of the Ephemeroptera Order, together with the Orthocladius complex organisms comprised 43% of the total organisms found in the riffle sample. 76% of the lower Castle Creek riffle sample was composed of the dominant Orthocladius complex organisms, Zapada cinctipes (stonefly) of the Plecoptera Order, and Oligochaeta (earthworm).(Richards, April 2003)

Table 15: Dominance Measurements, Castle Creek

Dominance Measures	Castle Creek Upper (OTM) Site Reach-Wide	Castle Creek Upper (OTM) Site Riffle	Castle Creek Lower (CS) Site Reach-Wide	Castle Creek Lower (CS) Site Riffle
1st Dominant Taxon	Microtendipes pedellus gr.	Orthocladius	Orthocladius	Orthocladius
1st Dominant Abundance	1003.00	3232.00	130.00	227.90
2nd Dominant Taxon	Micropsectra sp.	Baetis tricaudatus	Zapada cinctipes	Zapada cinctipes
2nd Dominant Abundance	490.80	1920.00	103.00	101.70
3rd Dominant Taxon	Baetis sp	Baetis sp	Hydropsyche sp	Oligochaeta

The dominant organisms in the upper reach-wide sample on Castle Creek were two members of the Chironomidae (midge) Family; Microtendipes pedellus gr. and Micropsectra sp. The third most prevalent organism in this sample was a member of the Ephemeroptera Order, Baetis sp. (mayfly). Together they comprise 36% of the total organisms in the reach-wide sample from the upper site. Orthocladius Complex organisms (midges) were dominant in the sample from the lower reach-wide site on Castle Creek followed by Zapada cinctipes (stonefly) and Hydropsyche sp. (caddisfly), a member or the Trichoptera Order. These three types of organisms comprised 62% of the lower reach-wide sample.(Richards, April 2003)

Table 16: Dominance Measurements, North Fork Castle Creek

Dominance Measures	N Fork Castle Cr. Reach-Wide	N Fork Castle Cr. Riffle
1st Dominant Taxon	Hydropsyche sp.	Baetis tricaudatus
1st Dominant Abundance	25.00	83.00
2nd Dominant Taxon	Lebertia sp.	Hydropsyche sp.
2nd Dominant Abundance	18.00	72.00
3rd Dominant Taxon	Baetis tricaudatus	Baetis sp.
3rd Dominant Abundance	17.00	45.00

The dominant taxa found in the riffle sample from North Fork Castle Creek were Baetis tricaudatus (mayfly) followed by Hydropsyche sp. (caddisfly) and Baetis sp. (mayfly). Together these taxa comprised 57% of the sample. The reach-wide sample from this site was dominated by Hydropsyche sp. (caddisfly) followed by Lebertia sp. (water mite) and Baetis tricaudatus (mayfly). Together these taxa comprised 43% if the reach-wide sample from North Fork Castle Creek (Richards, April 2003).

Richness Measurements

Eleven richness calculations have been made from the samples collected at the three Castle Creek sites and are presented in Table 17.[30]

Species richness and EPT richness are highest in Castle Creek above the confluence with North Fork Castle Creek. There were 53 taxa found in the reach-wide section of Castle Creek above its confluence with the North Fork compared to 30 taxa found at the site below the confluence. The reach-wide sample of North Fork Castle Creek contained 32 taxa. In the riffles, there were 17 EPT taxa contained in the upstream sample compared to 9 EPT taxa in the North Fork and 8 EPT taxa in Castle Creek below the confluence. The EPT to Chironomidae ratio indicates lower water quality at the upper site when compared to downstream sites. This ratio however is not as significant as the dramatic reduction in abundance and species richness between the upper and lower sites.

Table 17: Richness Measurements, Castle Creek Sites

Richness Measures	Castle Cr. Upper Reach-Wide	Castle Cr. Upper Riffle	Castle Cr. Lower Reach-Wide	Castle Cr. Lower Riffle	N. Fork Castle Cr. Reach-Wide	N. Fork Castle Cr. Riffle
Species Richness	53.00	37.00	30.00	24.00	32.00	28.00
Ephemeroptera Richness	4.00	5.00	3.00	3.00	5.00	4.00
Plecoptera Richness	4.00	3.00	3.00	3.00	4.00	3.00
Trichoptera Richness	5.00	9.00	4.00	2.00	3.00	2.00
EPT Richness	13.00	17.00	10.00	8.00	12.00	9.00
Chironomidae Richness	23.00	9.00	7.00	6.00	8.00	7.00
EPT:Chironomidae Ratio	0.6	1.9	1.4	1.3	1.5	1.3
Oligochaeta Richness	1.00	1.00	0.00	1.00	1.00	1.00
NCO Richness	29.00	27.00	23.00	17.00	23.00	20.00
Percent NCO	54.72%	72.97%	76.67%	70.83%	71.88%	71.43%

NCO richness is higher at the upper site than lower sites indicating better water quality upstream of the confluence with North Fork Castle Creek. Other richness measurements do not indicate severe impairment at the lower sites but the high NCO percentages at North Fork and lower Castle Creek sites are more a function of reduced abundance and species richness at these sites than large numbers of non-Chironomidae and Oligochaeta organisms. Note that Chironomidae richness in the reach-wide samples show a dramatic reduction as iron leachate enters the creek and iron and aluminum minerals precipitate. Although Chironomidae tend to be more tolerant of pollution than Ephemeroptera, Plecoptera, and Trichoptera, the dramatic decrease in Chironomidae richness indicates

[30] For an explanation of richness measurements see the richness measurements discussion for the North Fork of Rapid Creek.

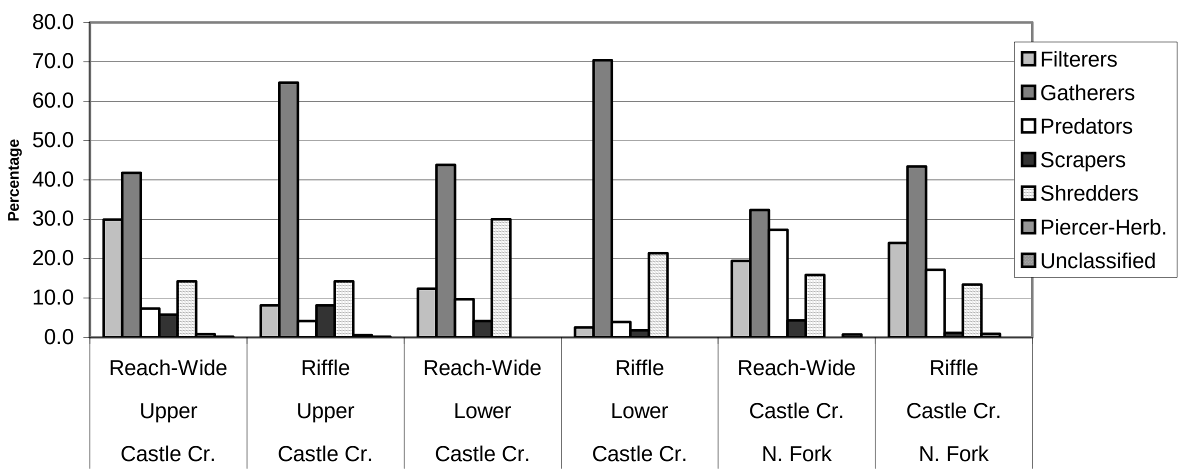
that they may be less tolerant of the iron/aluminum precipitation associated with the iron bog deposits than other organisms. This apparent sensitivity to the iron bog leachate would mask the effects of the bog iron pollution on the EPT to Chironomidae ratio and the Chironomidae richness measurements.

Functional Feeding Groups

Table 18: Functional Feeding Group Species Richness
Castle Creek Sites

Functional Group	Castle Cr. Upper Reach-Wide	Castle Cr. Upper Riffle	Castle Cr. Lower Reach-Wide	Castle Cr. Lower Riffle	N. Fork Castle Cr. Reach-Wide	N. Fork Castle Cr. Riffle
Filterer Richness	8.00	6.00	5.00	3.00	3.00	3.00
Gatherer Richness	22.00	14.00	9.00	10.00	12.00	10.00
Predator Richness	11.00	8.00	9.00	6.00	9.00	9.00
Scraper Richness	2.00	1.00	1.00	1.00	2.00	1.00
Shredder Richness	8.00	6.00	6.00	4.00	5.00	4.00
Piercer-Herbivore Richness	1.00	1.00	0.00	0.00	0.00	1.00
Unclassified	1.00	1.00	0.00	0.00	1.00	0.00

Figure 21: Functional Feeding Group Percentages
Castle Creek Sites



Functional feeding groups species richness is presented in Table 18. All of the feeding groups decreased downstream from the upper sample site. Gatherers were the most abundant of the functional feeding groups – Scrapers and Piercers-Herbivores were not very abundant in any of the samples. Both the reach-wide and riffle samples obtained at the upstream site on Castle Creek had greater species richness for all groups indicating that the upper site has better water quality than the downstream site and the tributary site. Figure 21 indicates that the gatherer species dominate at all of the Castle Creek Sample Sites. Filterers are the next dominant feeding group at the upstream reach-wide site and the downstream riffle site. Shredders are next dominant at the upstream riffle, downstream reach-wide, and downstream riffle. The clear dominance of gatherers at all sites together with the skewed distribution of the groups would tend to indicate the possibility of impaired water quality at all sites as gatherers tend to be more tolerant of impaired water than scrapers, piercers and shredders. Further, an even distribution of feeding groups is also an indicator of good water quality while uneven distribution indicates lower water quality (Barbour, et al., 1999).

Diversity/Evenness Measures

The Shannon-Weaver H’[31] diversity indices for the reach-wide sites are as follows:

Upstream Castle Creek Site: 4.54
North Fork Site: 4.09
Downstream Castle Creek Site: 3.33

For the riffle sites the Shannon-Weaver H’ indices are as follows:

Upstream Castle Creek Site: 4.01
North Fork Site: 3.43
Downstream Castle Creek Site: 2.74

The decrease in values from the upstream site to the two downstream sites indicates there is less diversity in both the reach-wide and riffle site samples at downstream sites. Loss of diversity indicates lowered or reduced water quality.

Pielou’s J’ evenness measure results are as follows:

For the reach-wide sites:

Upstream Castle Creek Site: 0.79
North Fork Site: 0.82
Downstream Castle Creek Site: 0.68

For the riffle sites:

Upstream Castle Creek Site: 0.77
North Fork Site: 0.71
Downstream Castle Creek Site: 0.68

Perfect evenness of species distribution results in Pielou’s J = 1. Based on this measurement, the downstream Castle Creek site appears to be the most impaired and the upstream Castle Creek site and North Fork site appears to be moderately impaired.

[31] Calculated using log 2.

Biotic Indices

The Hilenshoff Biotic Index (HBI) calculated for each of the three Castle Creek sites is as follows:

Upstream Castle Creek Site:
- Reach-wide: 5.37
- Riffle: 4.11

North Fork Site:
- Reach-wide: 3.33
- Riffle: 3.61

Downstream Castle Creek Site:
- Reach-wide: 4.05
- Riffle: 4.98

The HBI is used to determine the possible extent of organic pollution occurring in a stream. The index ranges from 0 (no pollution) to 10 (extreme organic pollution). All sites appear to be receiving some organic pollution. The source of pollution appears to be grazing cattle. No cattle were observed grazing at any of the sample sites. However, both Castle Creek and North Fork Castle Creek flow through private land (ranches) as well as National Forest grazing allotments located upstream from the sample sites. Cattle were observed within ½ mile upstream of the sample station on North Fork Castle Creek.

Conclusion

Iron precipitate from iron bog deposits is impacting benthic health in Castle Creek. The changes in the abundance and taxa richness matrices between sample sites are dramatic. There was a 30 to 46-fold decrease in the number of organisms and a loss of 9 to 23 taxa between the upstream and the two downstream sites. The most heavily impacted taxa in the reach-wide sections were the Chironomidae (midges), which decreased from 23 taxa in the upstream sample to 7 and 8 taxa at the downstream sites. The number of Chironomid taxa in the riffle sections, however, did not seem to be affected. The most heavily impacted taxa in the riffle sections were the EPT's.[32] The Trichoptera taxa showed the greatest decrease between upper and lower sites. It decreased 73% between the Upper Castle Creek riffle site and both the North Fork Castle Creek and lower Castle Creek riffle sites. Water quality analytical results from these sites indicate that water quality is generally good at all three sites.[33] The only apparent cause for this dramatic decrease in both taxa richness and abundance is the precipitation of iron compounds (hydroxides and oxyhydroxides) at the downstream sites.[34] Amorphous iron precipitate is present on the stream substrate and is likely inhibiting colonization and growth of benthic organisms at the downstream sites. The fast moving water of the riffles probably inhibit deposition or clean the substrate of the amorphous precipitate as opposed to the slower moving water of the glides and pools which encourage accumulation of precipitate. This

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[32] EPT richness decreases approximately 50% at the down stream sites.
[33] See Section Water Quality.
[34] See Section 3: Surface Water Geochemical Modeling.

may explain the wide variation in Chironomid taxa in the reach-wide samples as opposed to the riffle sites samples. Comparison of other indices, although less dramatic tend to support the conclusion that water biological community impairment is occurring at the downstream sites due to leachate from the bog iron deposits.

SECTION 6: STREAM SUBSTRATE EVALUATION

Substrate size and composition are indicators of stream and watershed health. In general, stream substrate containing large amounts of fines (clay, silt, and sand) indicates the stream is being impacted by activities occurring within the watershed. Road construction, heavy trail use, mining, urban areas, and over-grazing all cause soil disturbance and erosion which ultimately impacts the watershed stream. Streams that contain a variety of substrates (gravel, cobble, rock, organic materials such as woody debris and plants) tend to be more productive and better fish habitat. These types of substrate provide habitat for macroinvertebrates. Stream pebble counts were made at each sample site in North Fork Rapid Creek and the Castle Creek Sites. The counts were made by traversing the stream and measuring substrate at regular intervals during the traverse. Multiple traverses were made until a sample size of 100 was obtained. Substrate can be classified as follows (Ohlander, April 1998):

Less then 0.062 mm	Fines (silt and clay)
0.026 – 2 mm	Sand
2 mm – 16 mm	Gravel
16 mm – 64 mm	Course Gravel
64 mm – 256 mm	Cobble
256 mm – 4096 mm	Boulder
Greater then 4096 mm	Bedrock

NORTH FORK RAPID CREEK SITES

Big Dog: The mean substrate size is 47.3 mm with seventy percent of the substrate between 6 mm and 78 mm. The predominant substrate is gravel and coarse gravel. Vegetation[46] is present on 50+% of substrate during summer months

Horse Tooth: The mean substrate size is 54.7 mm with seventy percent of the substrate between 3 mm and 105 mm. The predominant substrate is sand, gravel, and cobbles. Vegetation[24] is present on + 50% of substrate during summer months. Note: 15% of substrate is less than 3 mm indicating presence of silt, clay and sand.

Fence Post: The mean substrate size is 71.5 mm with seventy percent of the substrate between 15 mm and 129 mm. The predominant substrate is gravel and cobbles. Vegetation[24] is present on 25% to 50% of the vegetation during summer months.

High and Dry: The mean substrate size is 57.6 mm with seventy percent of the substrate between 12 mm and 90 mm. The predominant substrate is gravel and small cobbles. Vegetation[24] is present on 25 % to 50% of substrate during summer months.

[46] Aquatic plants

***C**ASTLE **C**REEK **S**ITES*

One Too Many: The mean substrate size is 52.5 mm with seventy percent of the substrate between 21 mm and 90 mm. The predominant substrate is coarse gravel to small cobbles. No vegetation was observed on substrate at this site.

Cat Scat: The mean substrate size is 55.5 mm with seventy percent of the substrate between 27 mm and 87 mm. The predominant substrate is coarse gravel and small cobbles. No vegetation is present on substrate at this site.

***N**ORTH **F**ORK **C**ASTLE **C**REEK **S**ITE:*

Outlaw's Bridge: The mean substrate size is 40.6 mm with seventy percent of the substrate between 3 mm and 78 mm. The predominant substrate is gravel and some small cobbles. No vegetation is present on substrate at this site. Note: 15% of substrate is less than 3mm indicating presence of silt, clay and sand.

The distribution of substrate by size is shown in Figure 22 through Figure 28.

North Fork Rapid Creek Pebble Counts

Figure 22: Pebble Count Results
Big Dog, NFRC

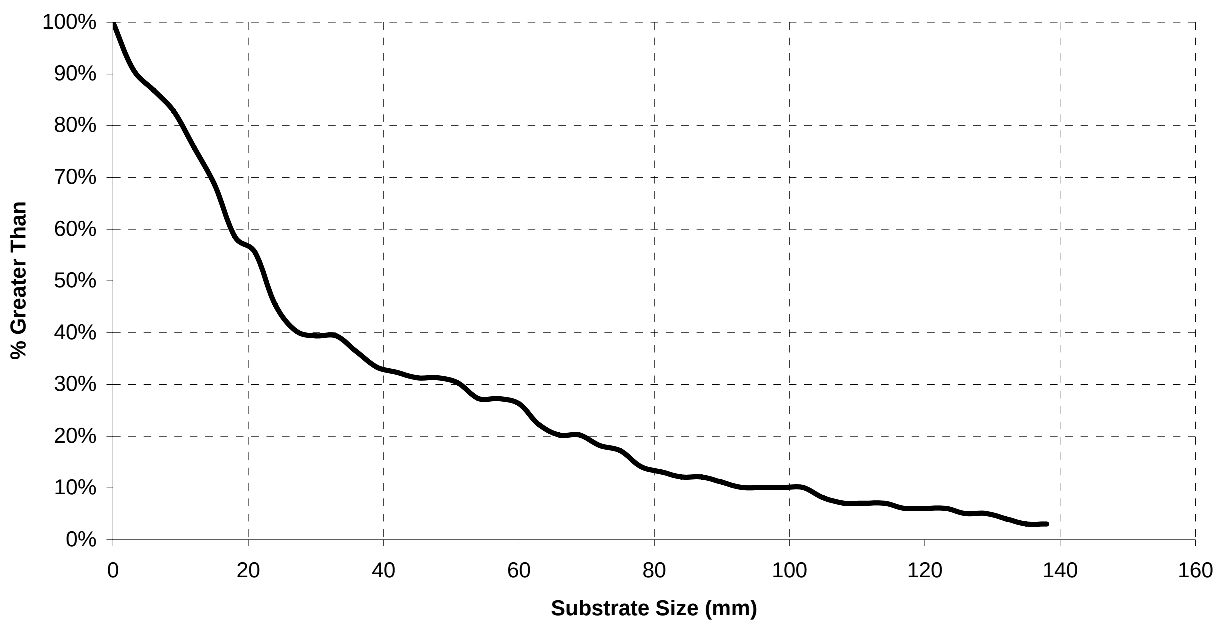


Figure 23: Pebble Count Results
Horse Tooth, NFRC

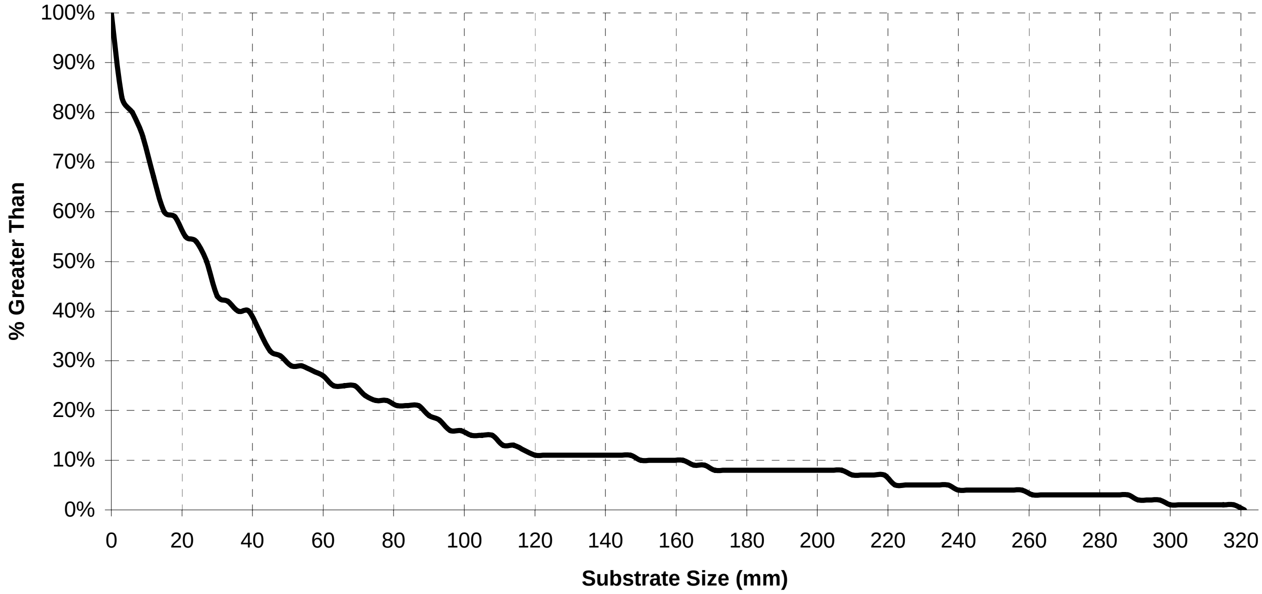


Figure 24: Pebble Count Results
Fence Post, NFRC

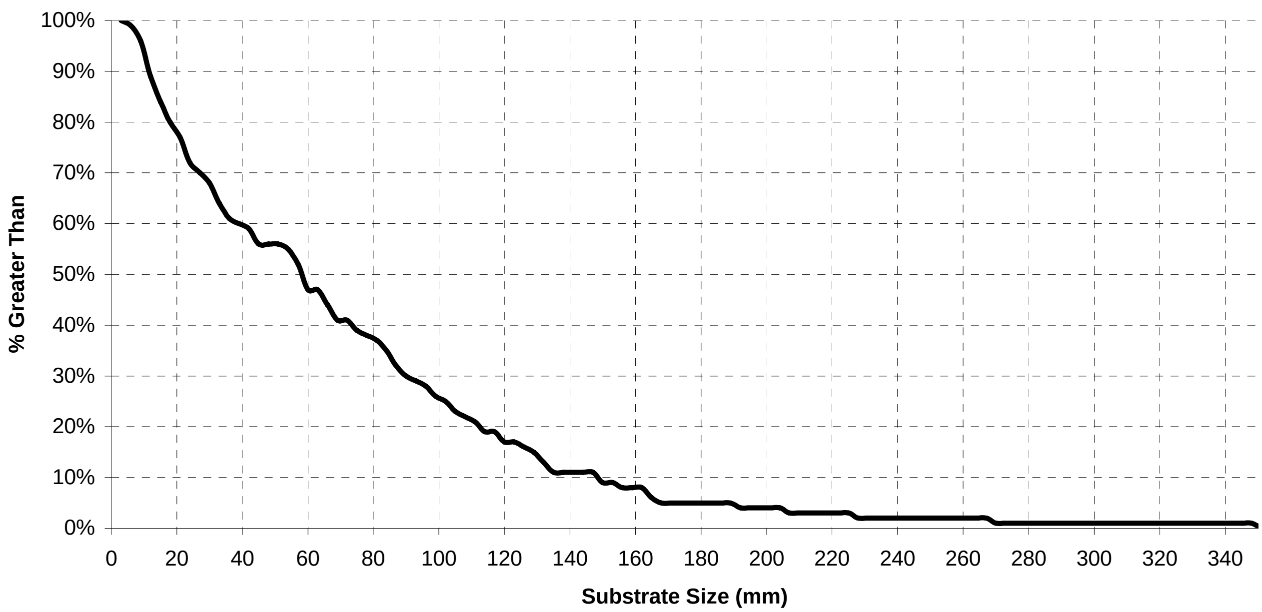
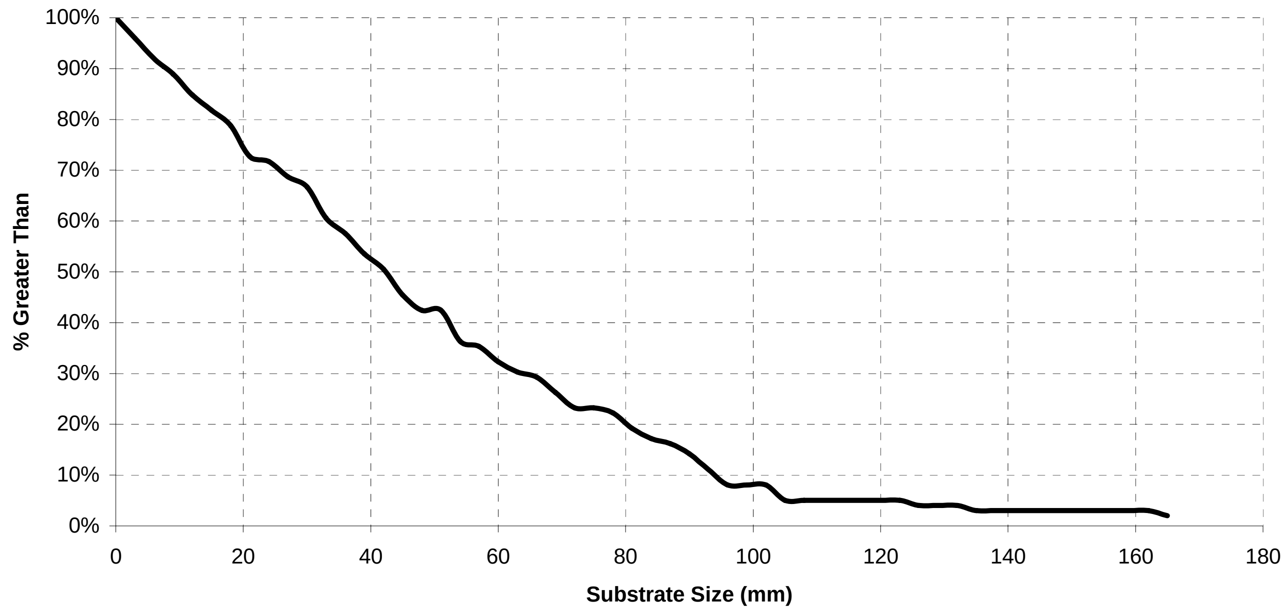


Figure 25: Pebble Count Results
High and Dry, NFRC



Castle Creek Site Pebble Counts

Figure 26: Pebble Count Results
One too Many, CC

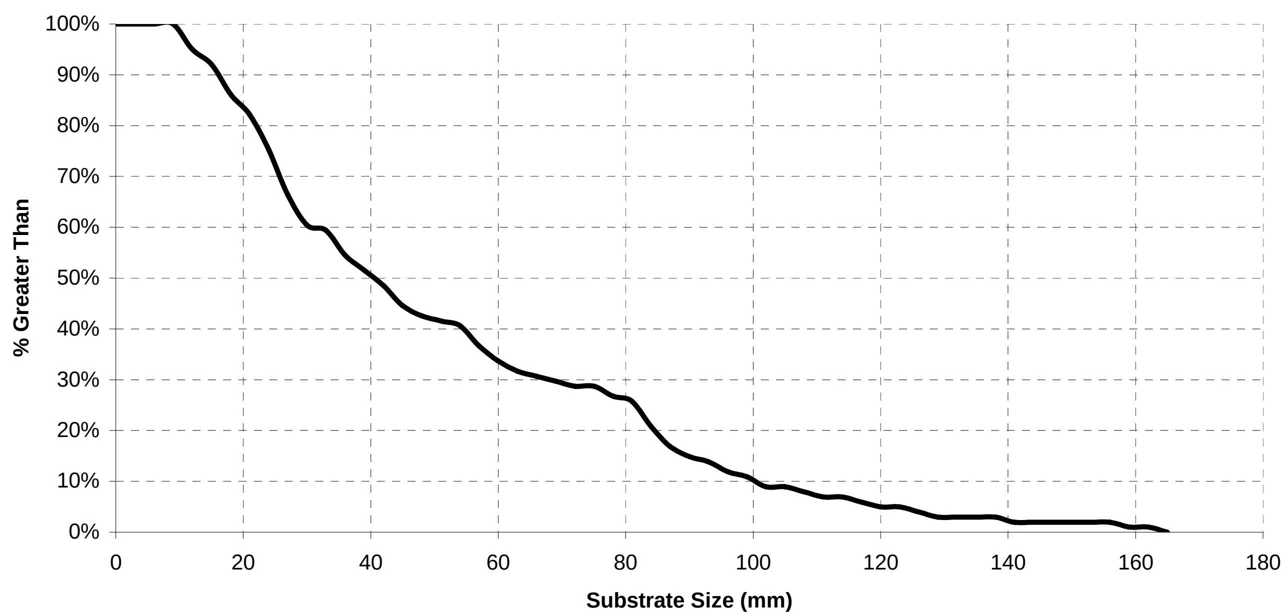


Figure 27: Pebble Count Results
Outlaw's Bridge, CC

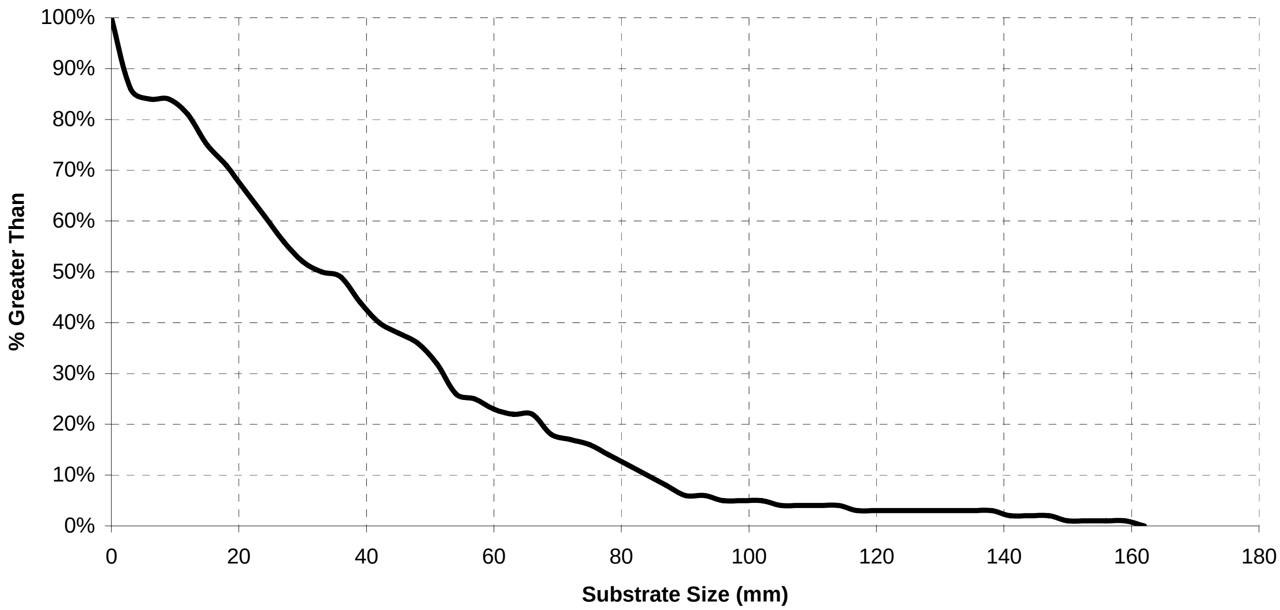
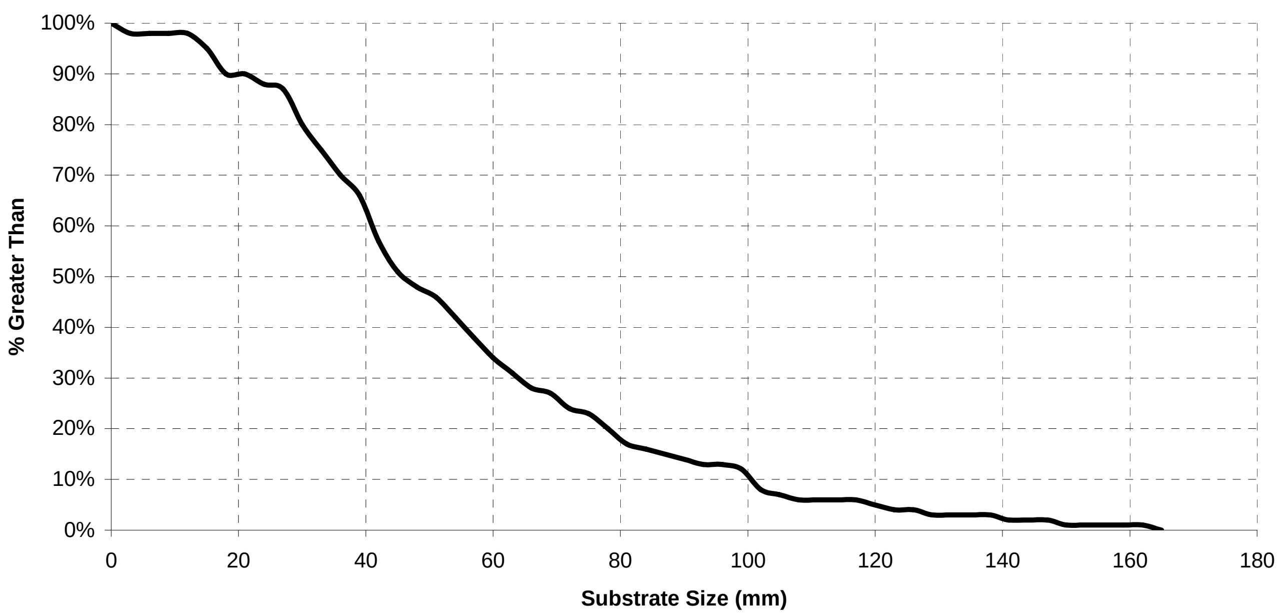


Figure 28: Pebble Count Results
Cat Scat, CC



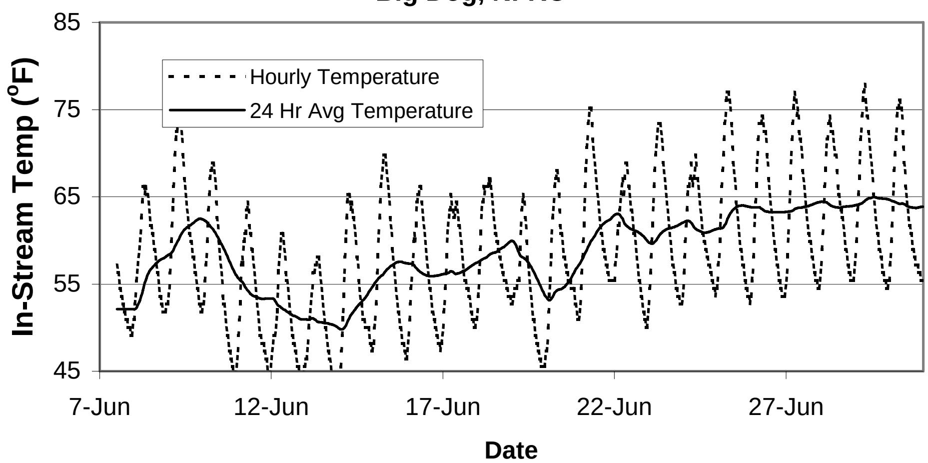
SECTION 7: TEMPERATURE MONITORING

North Fork Rapid Creek was identified by the State of South Dakota as a Total Maximum Daily Load (TMDL) water body for temperature. North Fork Rapid Creek has a beneficial use as coldwater permanent fish life propagation waters. The regulatory standard for coldwater permanent fish life propagation is 65°F. Castle Creek was not identified as needing a TMDL in the 2002 South Dakota 303(d) Waterbody List. Monitoring of in-stream temperature began in June and continued into September or October in North Fork Rapid Creek. Ryan Model RL-100 continuously recording temperature probes were installed at the four sampling stations located on North Fork Rapid Creek.[48] Monitoring of Castle Creek began in July and continued into September. Ryan RL-100's were installed at the three sampling stations located at the Castle Creek sites.[49] At several stations located in the North Fork Rapid Creek there is a data gap of approximately 10 days during the first half of July. This data gap results from the inexperience of sampling personal in programming the automatic temperature recorders. Initially, the temperature monitors were programmed to record a temperature at 30-minute intervals. In July this was changed to record temperature at an hourly interval. The reason for this programming change was to insure that data was not lost when the unit memory became full. Switching to an hourly recording interval enabled the instrument to hold approximately 2.5 months of data before overwriting of data occurred. The monthly results of the temperature monitoring are presented in Figures 29 through 54 found in this section.

NORTH FORK RAPID CREEK TEMPERATURE MONITORING RESULTS

June 2002, Temperature Monitoring Results

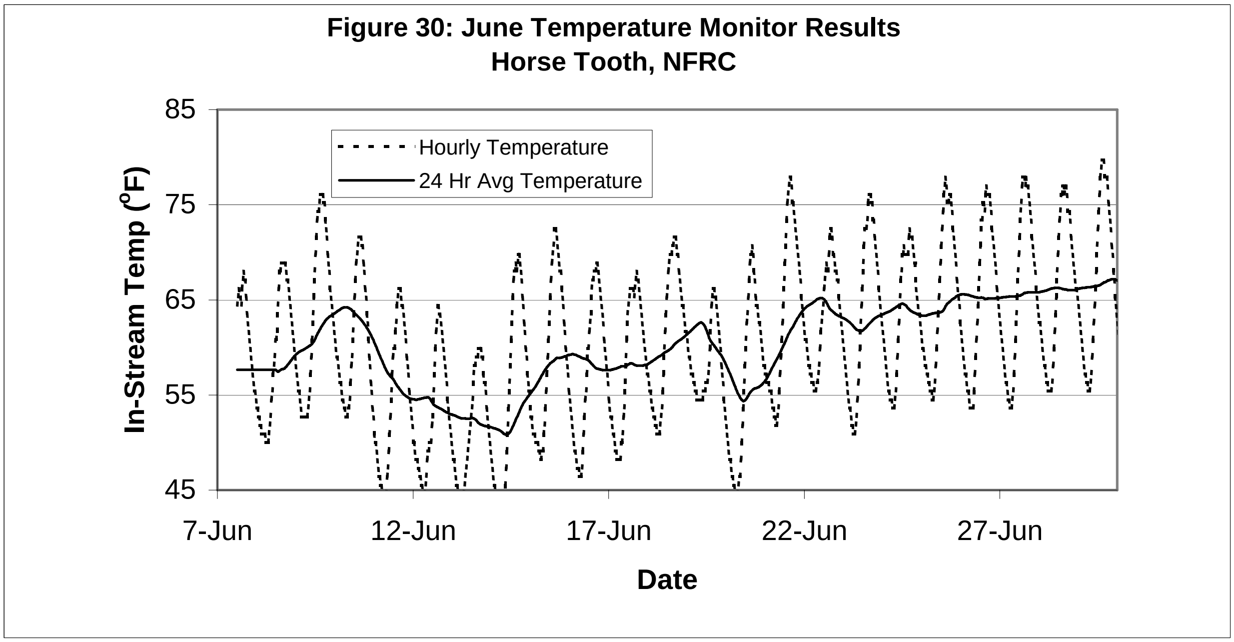
Figure 29: June Temperature Monitor Results
Big Dog, NFRC

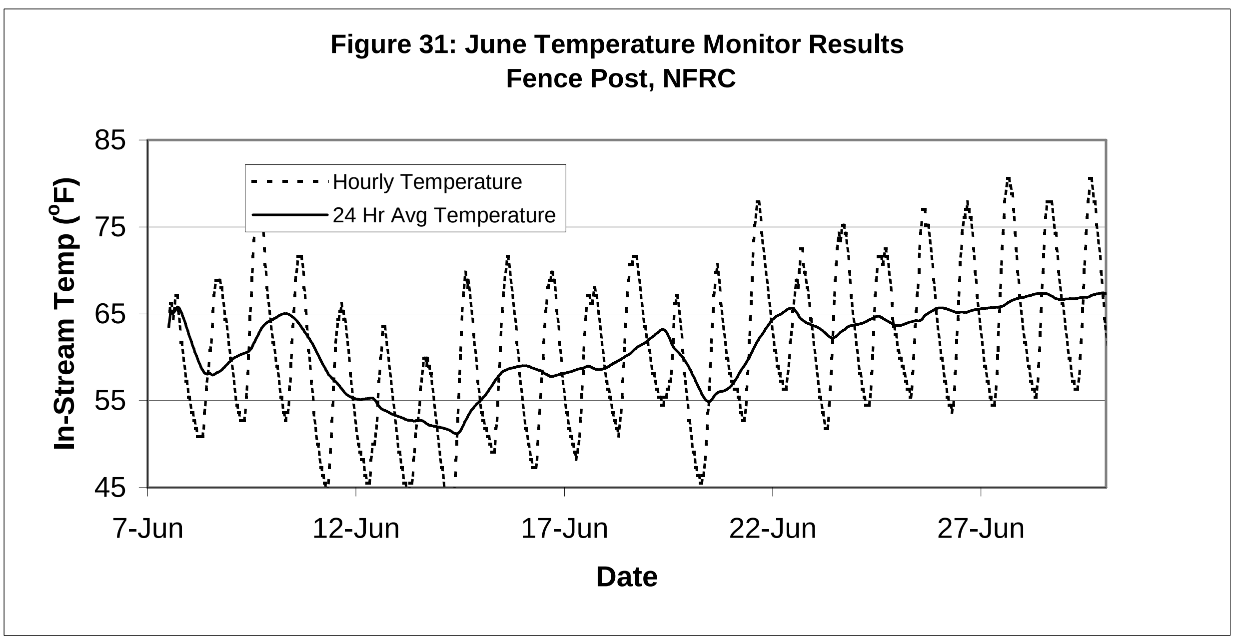


[48] From headwaters, south to the confluence with the South Fork Rapid Creek, these stations are: Big Dog, Horse Tooth, Fence Post, and High and Dry.

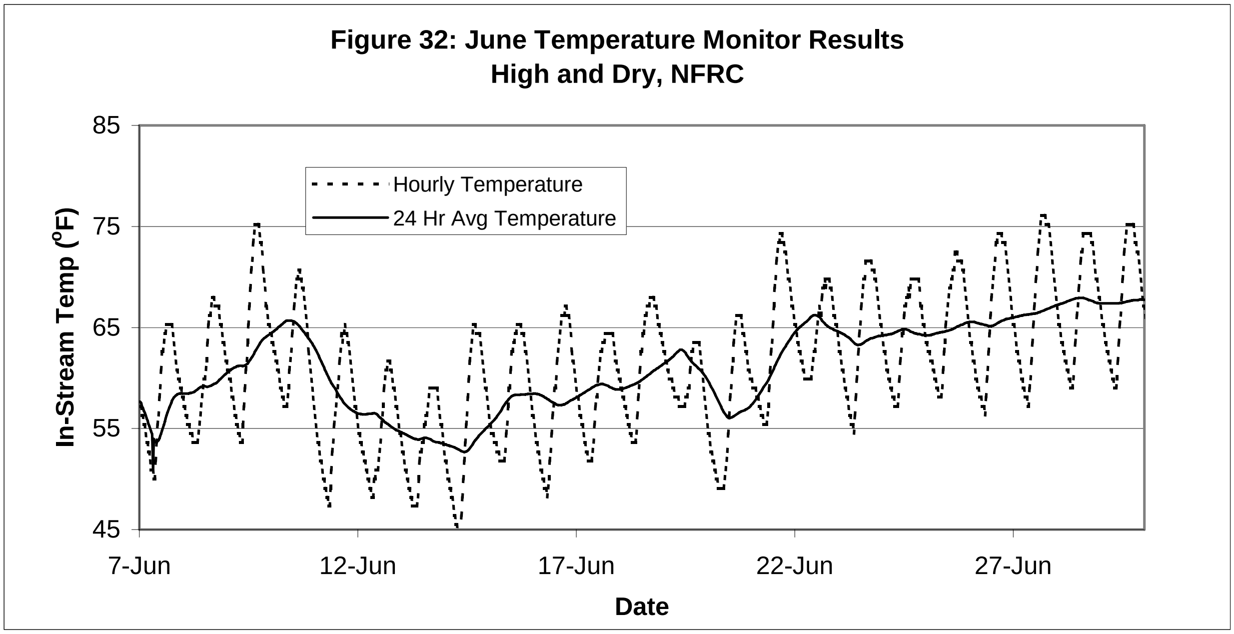
[49] From upstream to downstream, these three sites are: One too Many (Castle Creek), Outlaw's Bridge (North Fork Rapid Creek), and Cat Scat (Castle Creek).

JUNE NFRC TEMPERATURE MONITORING RESULTS – CONTINUED

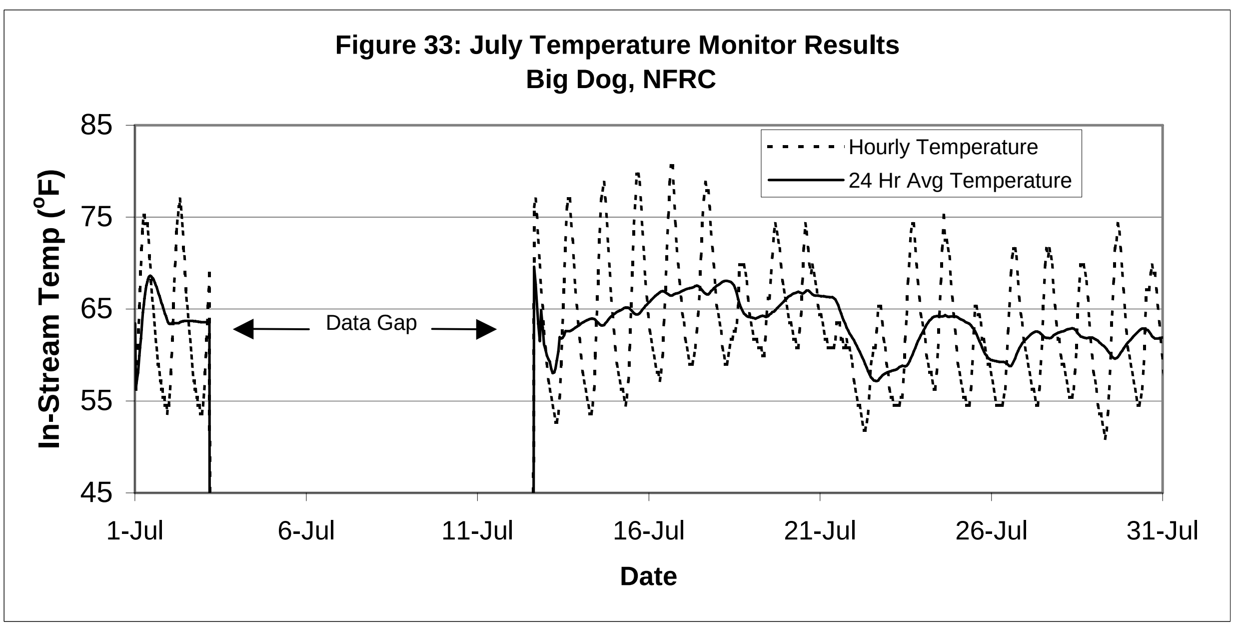




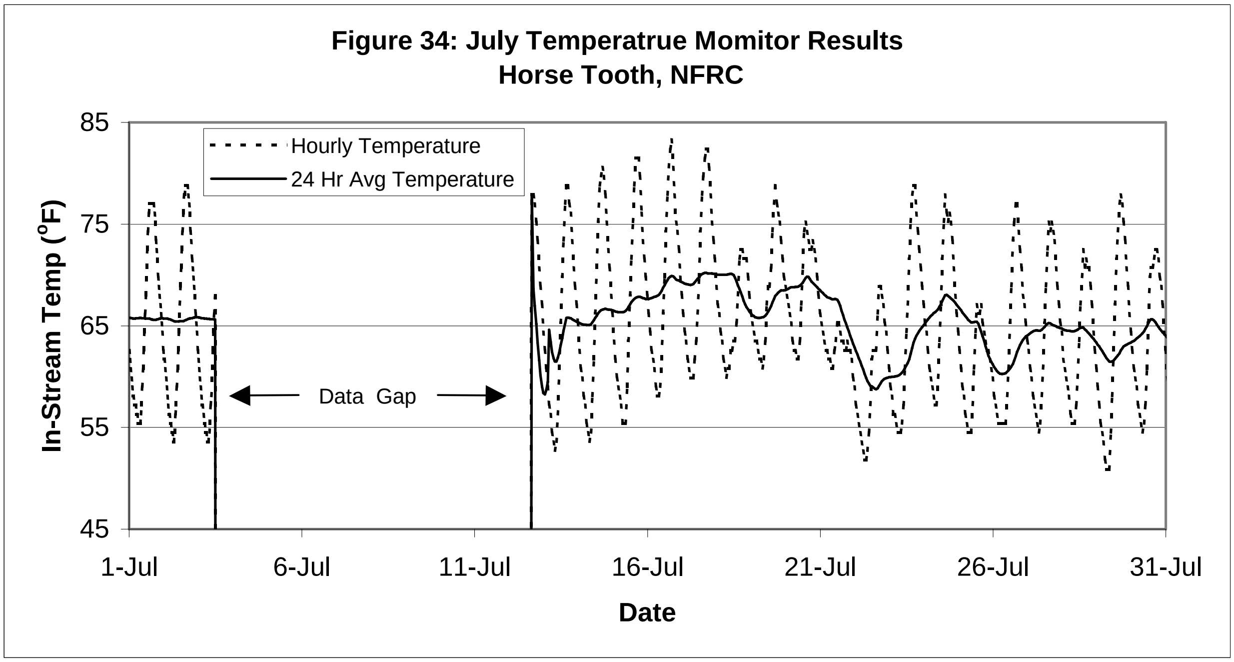
JUNE NFRC TEMPERATURE MONITORING RESULTS – CONTINUED

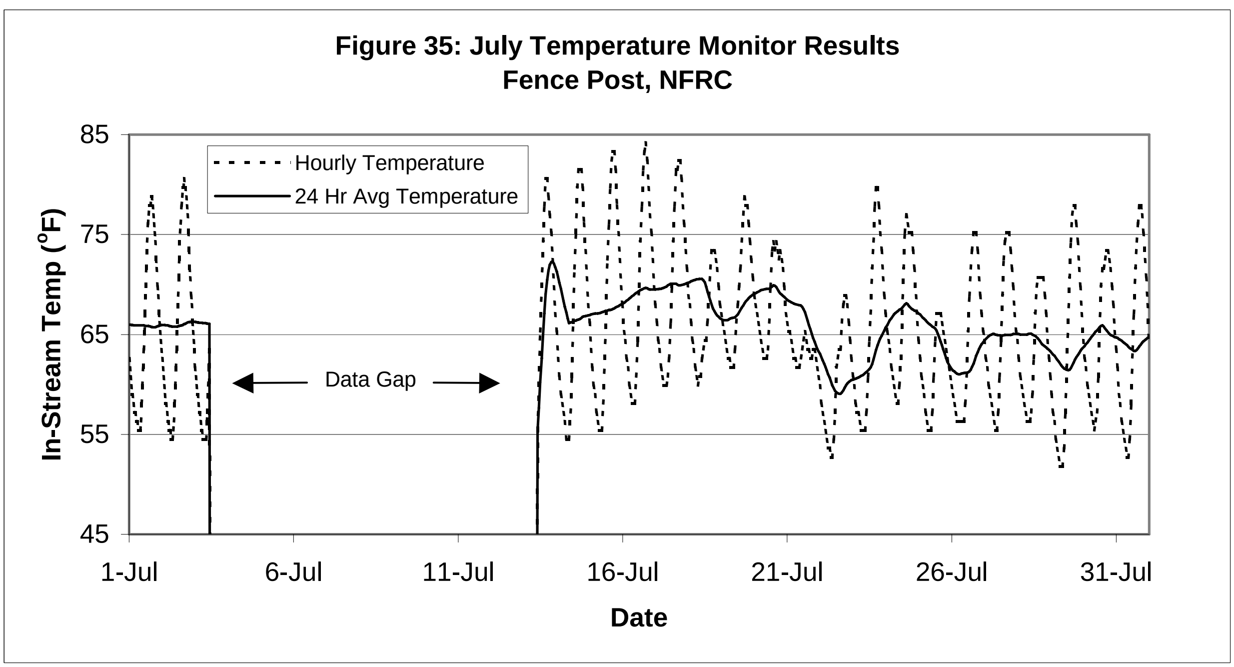


July2002, Temperature Monitoring Results

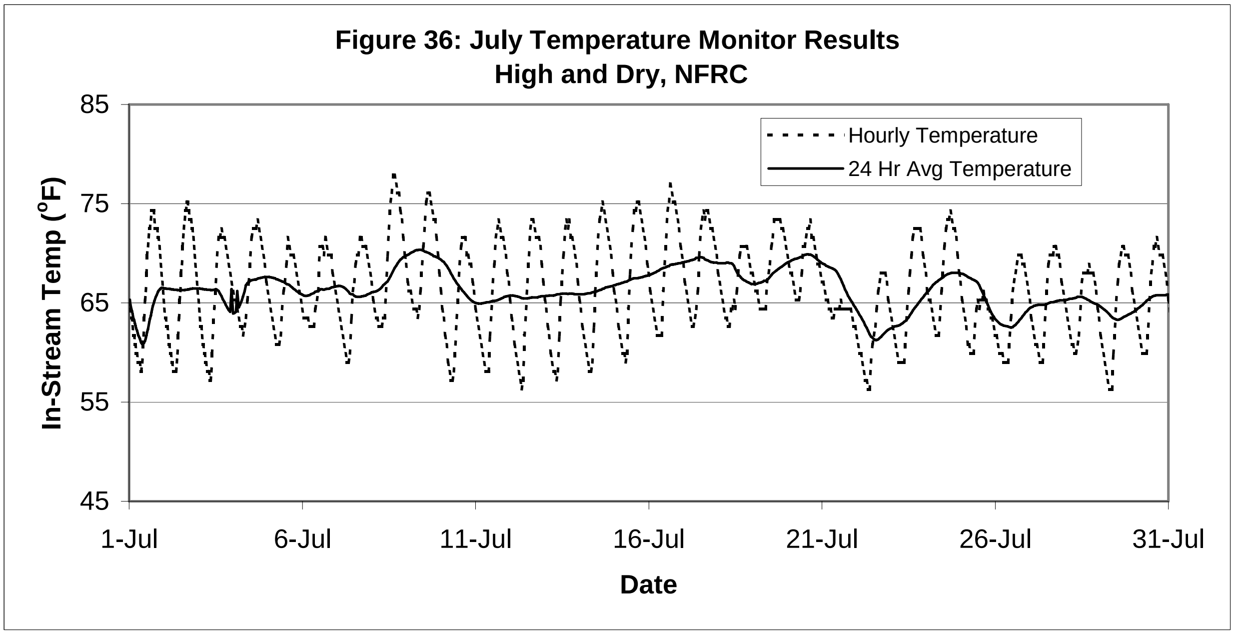


July NFRC Temperature Monitoring Results – Continued

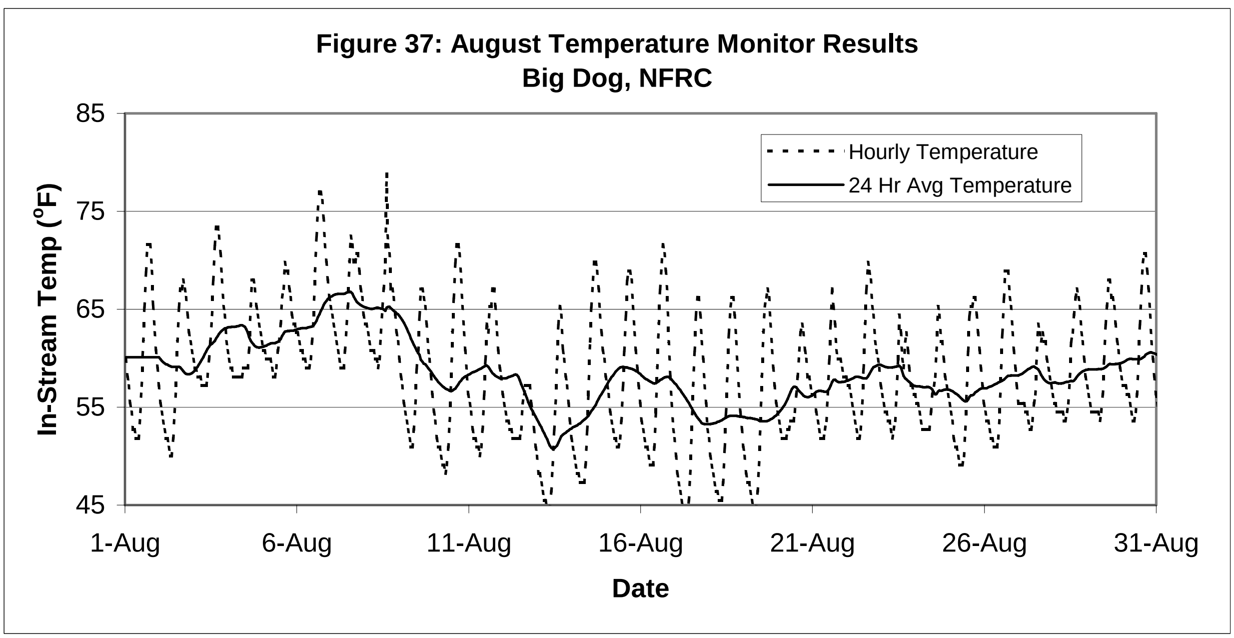




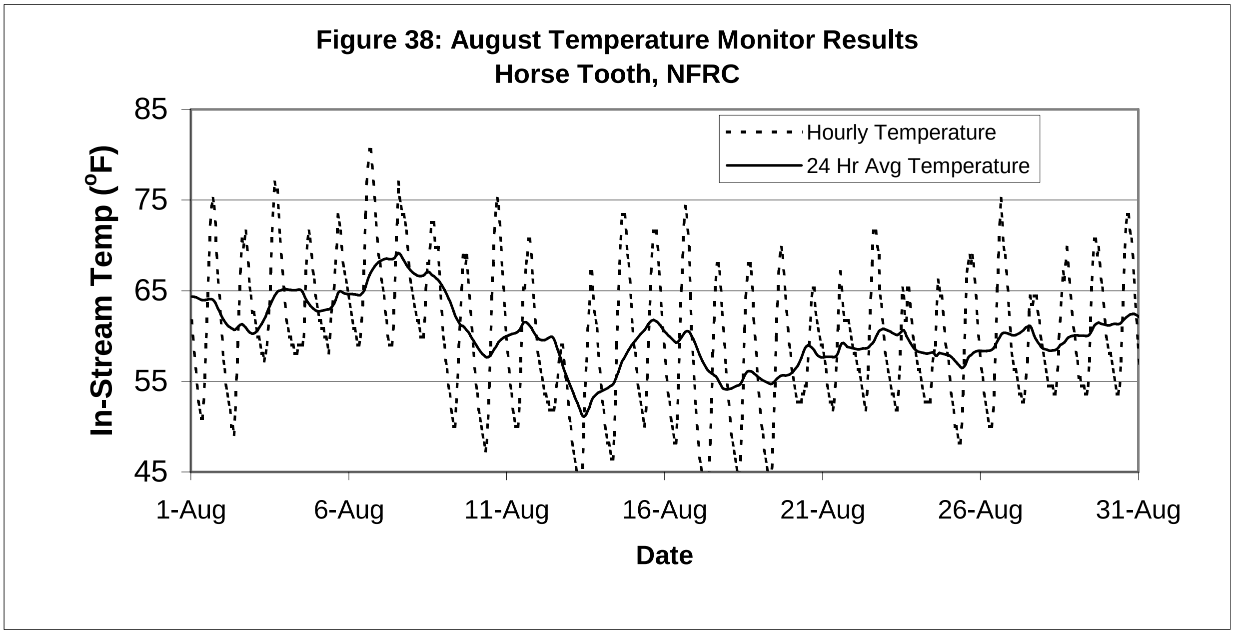
July NFRC Temperature Monitoring Results – Continued

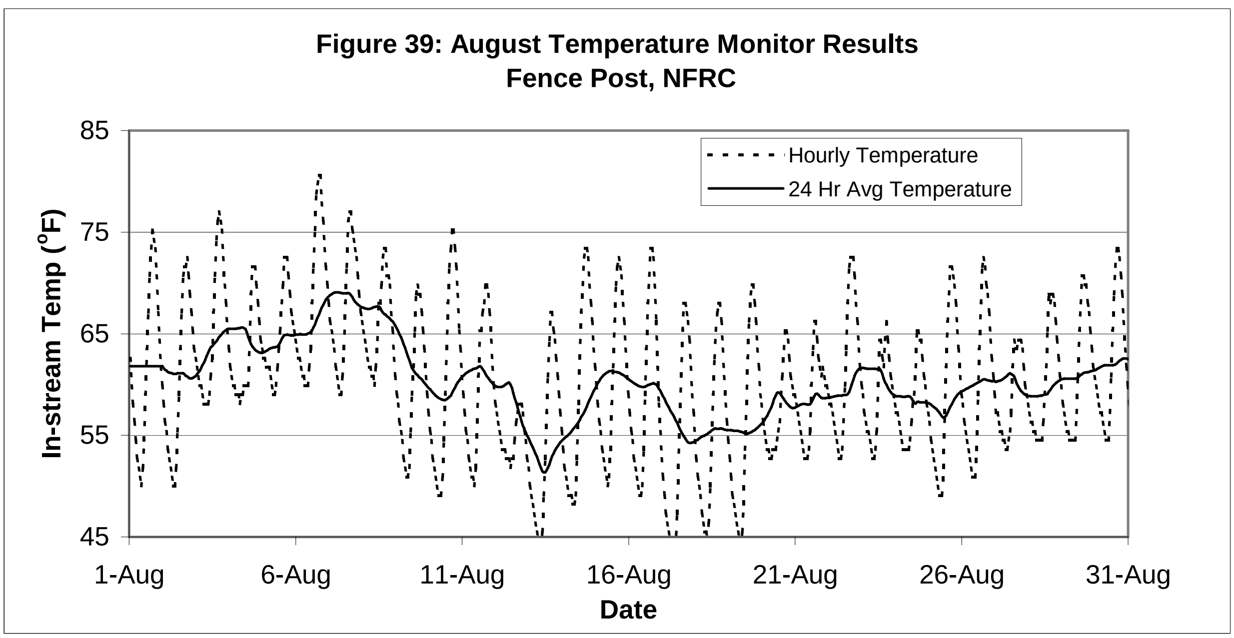


August 2002, Temperature Monitoring Results

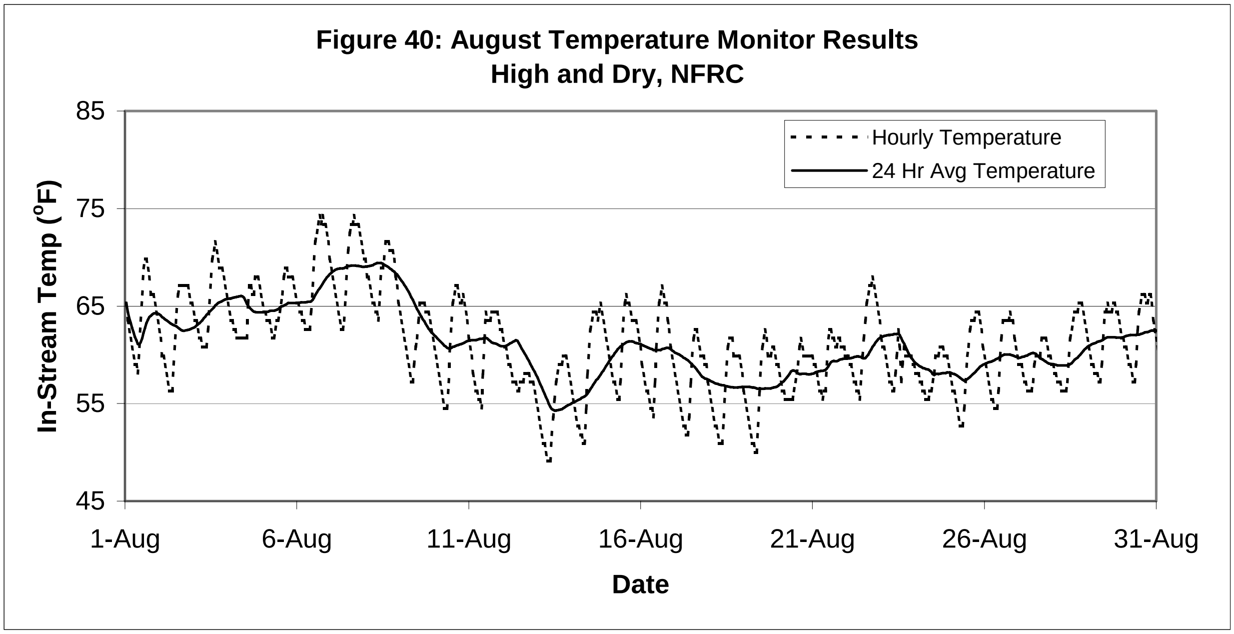


August NFRC Temperature Monitoring Results – Continued

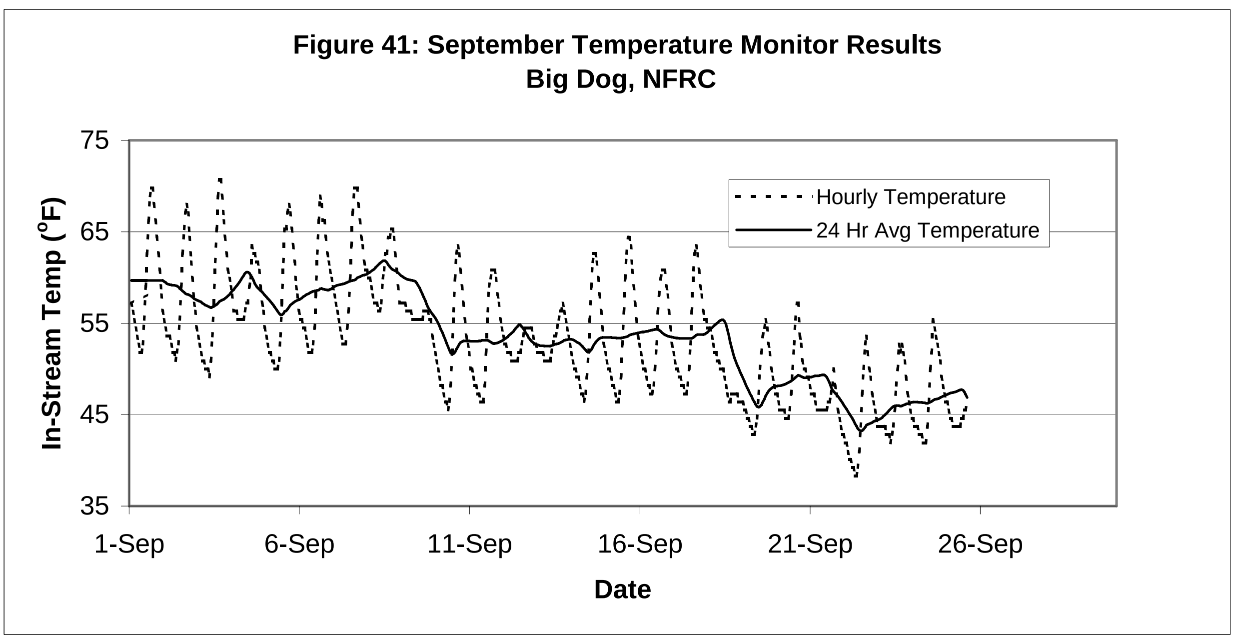




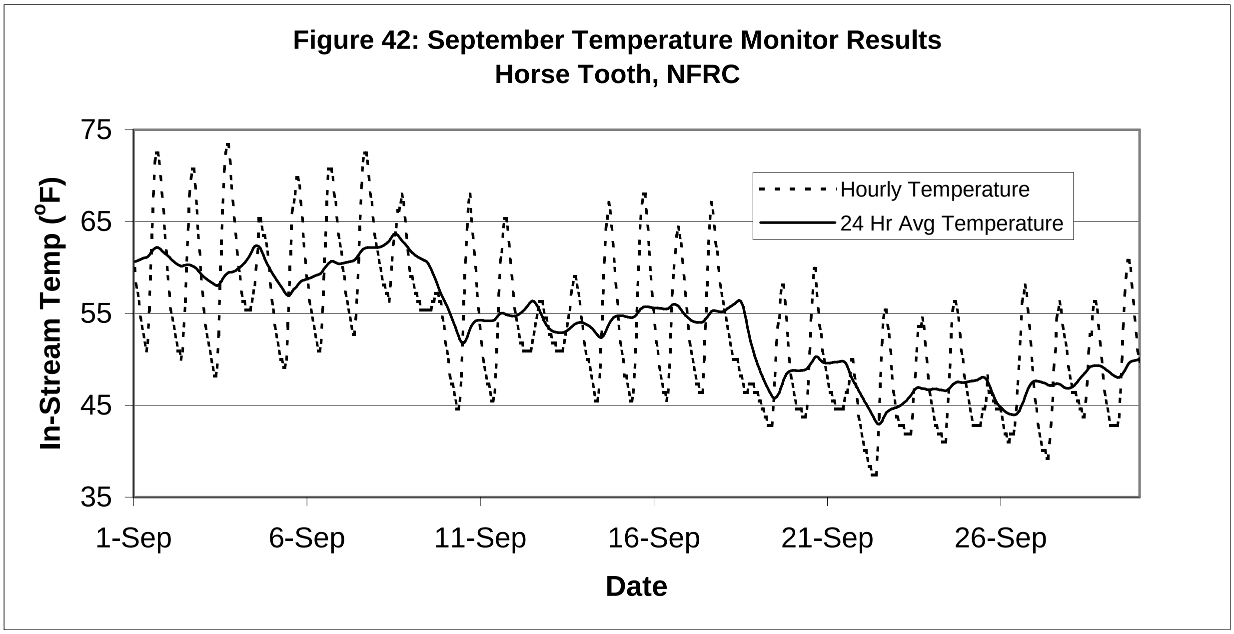
August NFRC Temperature Monitoring Results – Continued

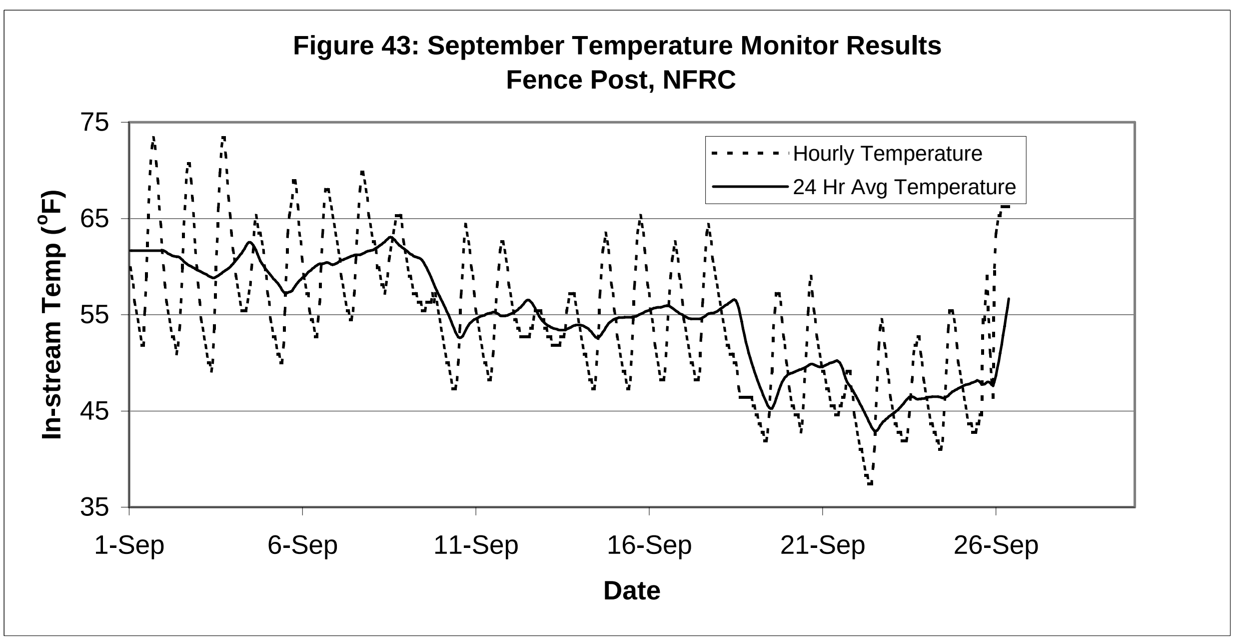


September 2002, Temperature Monitoring Results

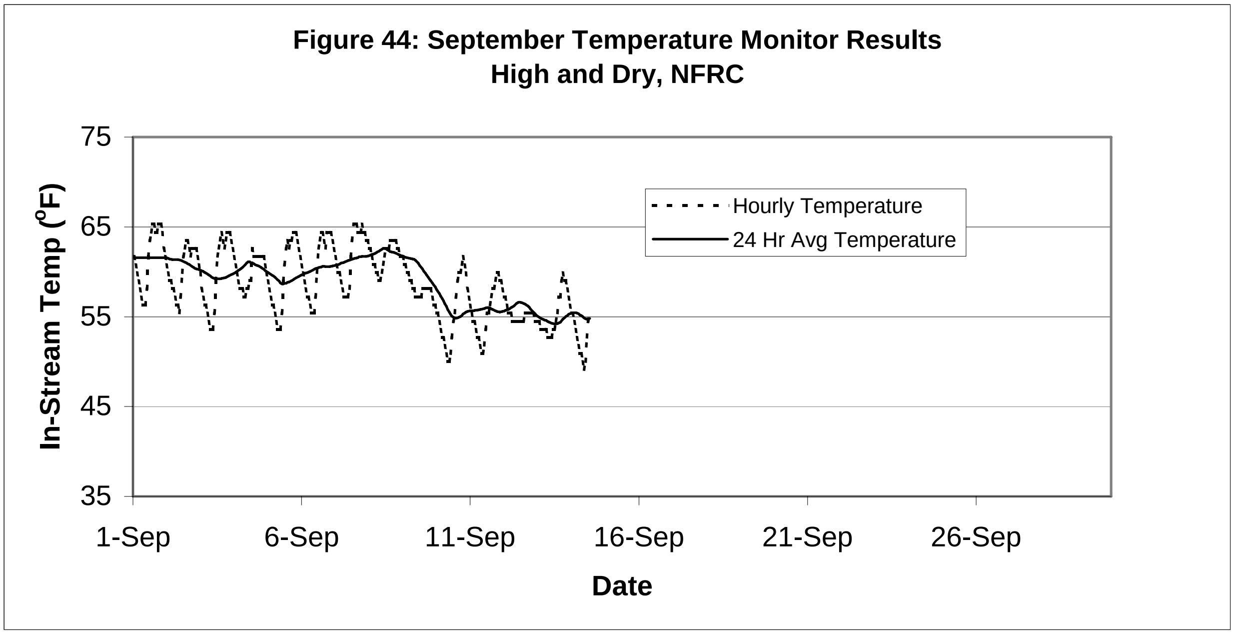


September NFRC Temperature Monitoring Results – Continued

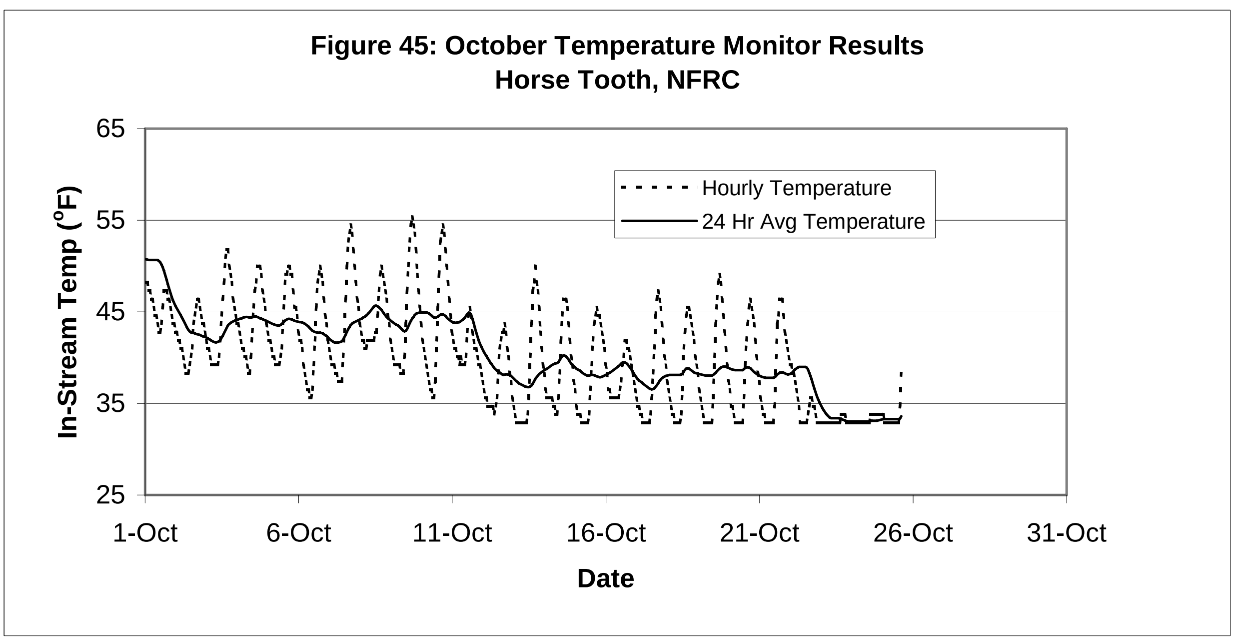




September NFRC Temperature Monitoring Results - Continued

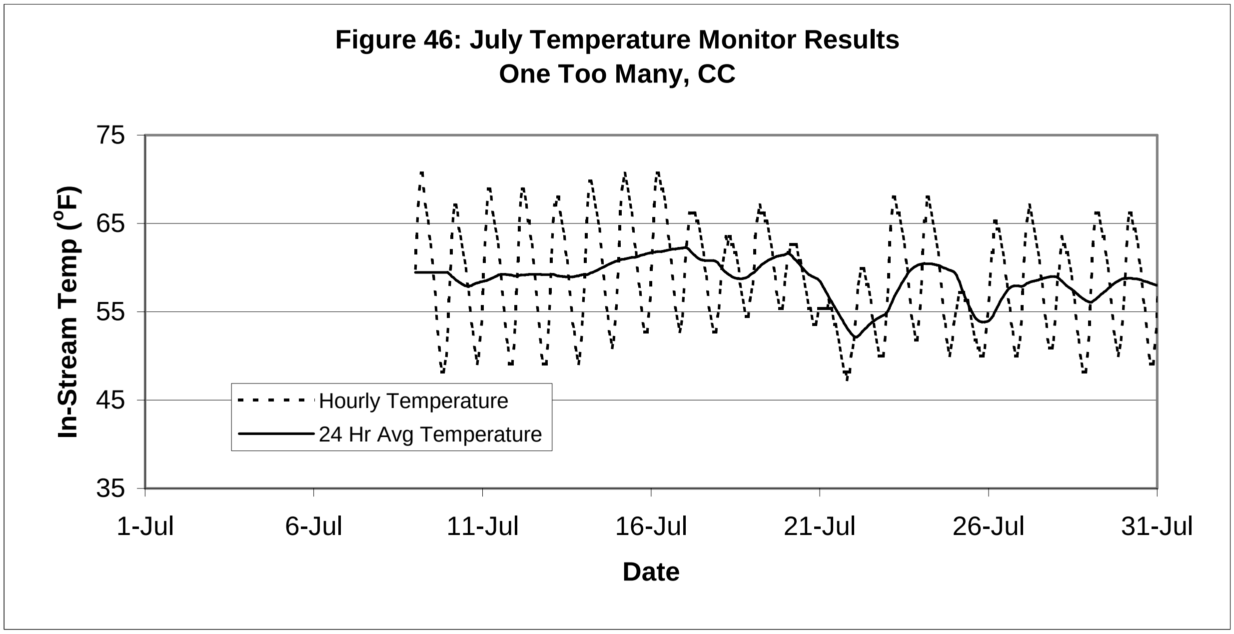


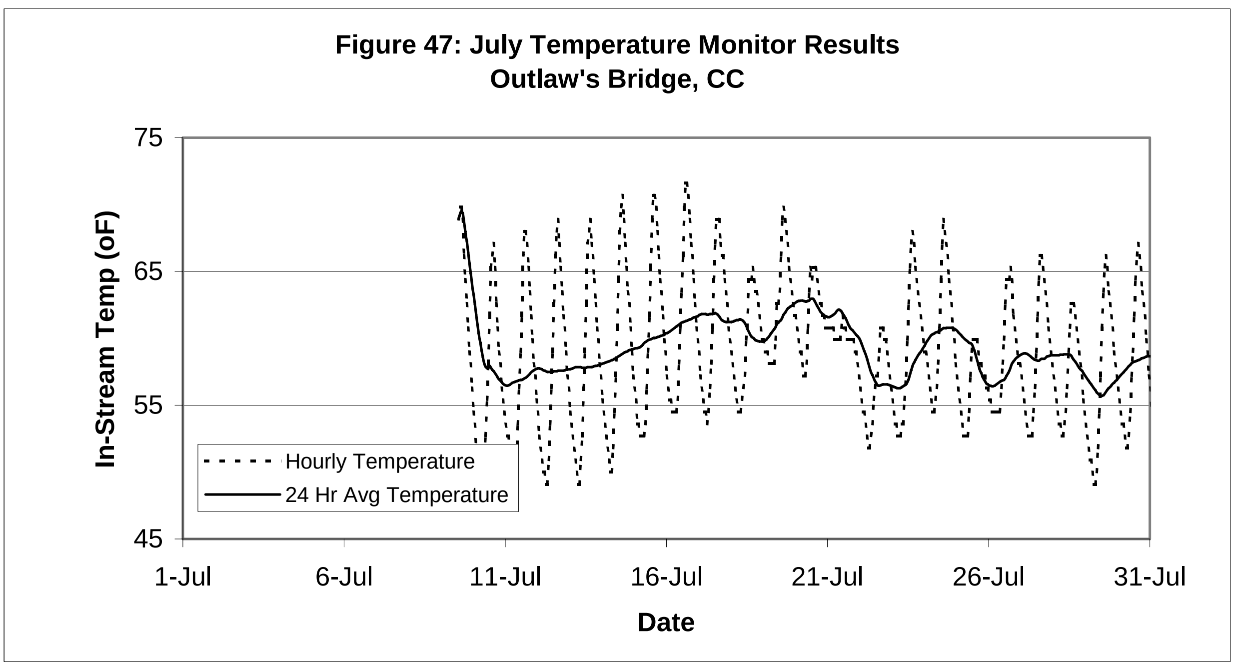
October 2002, Temperature Monitoring Results – one station only



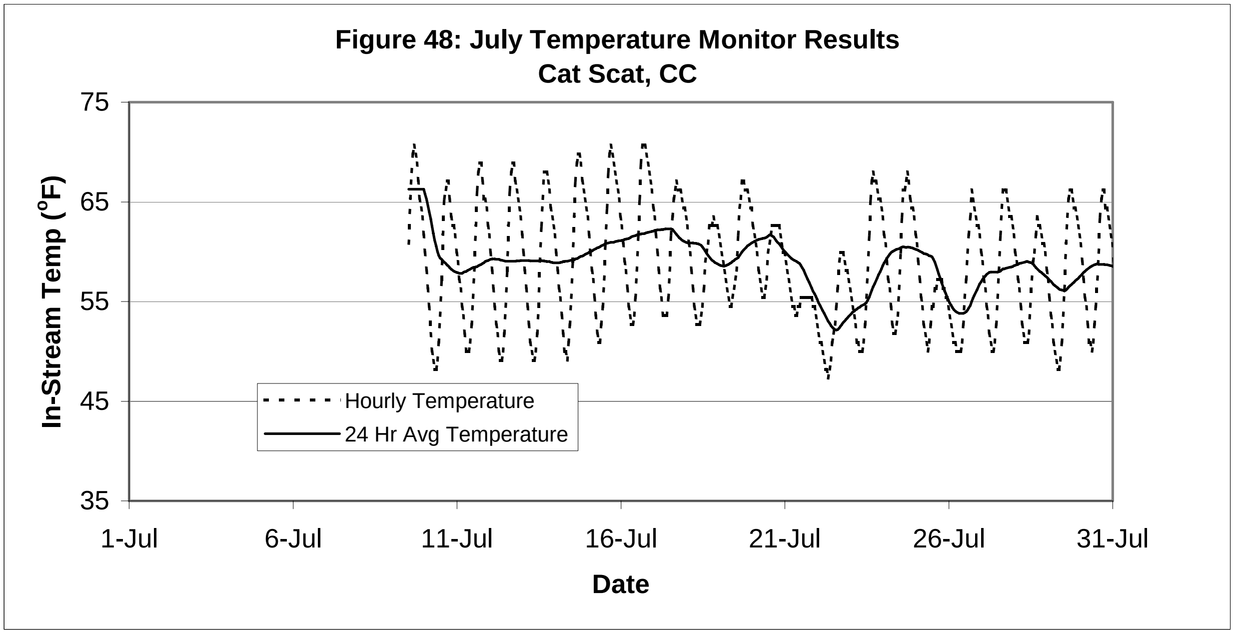
CASTLE CREEK SITE TEMPERATURE MONITORING RESULTS

July 2002, Temperature Monitoring Results

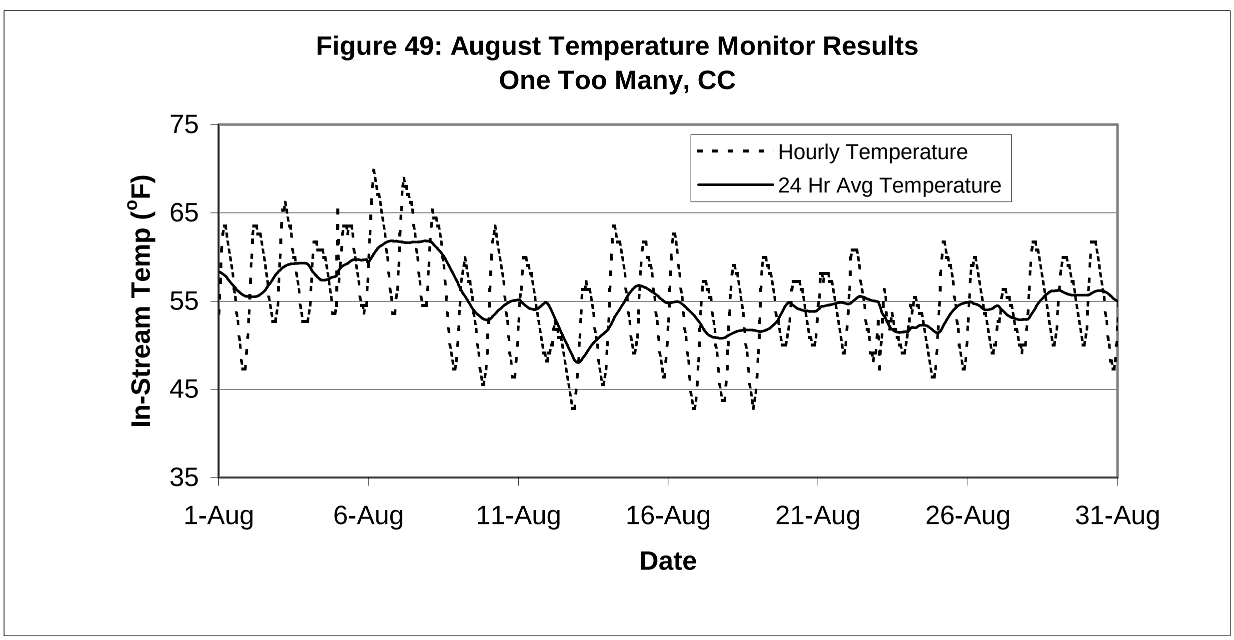




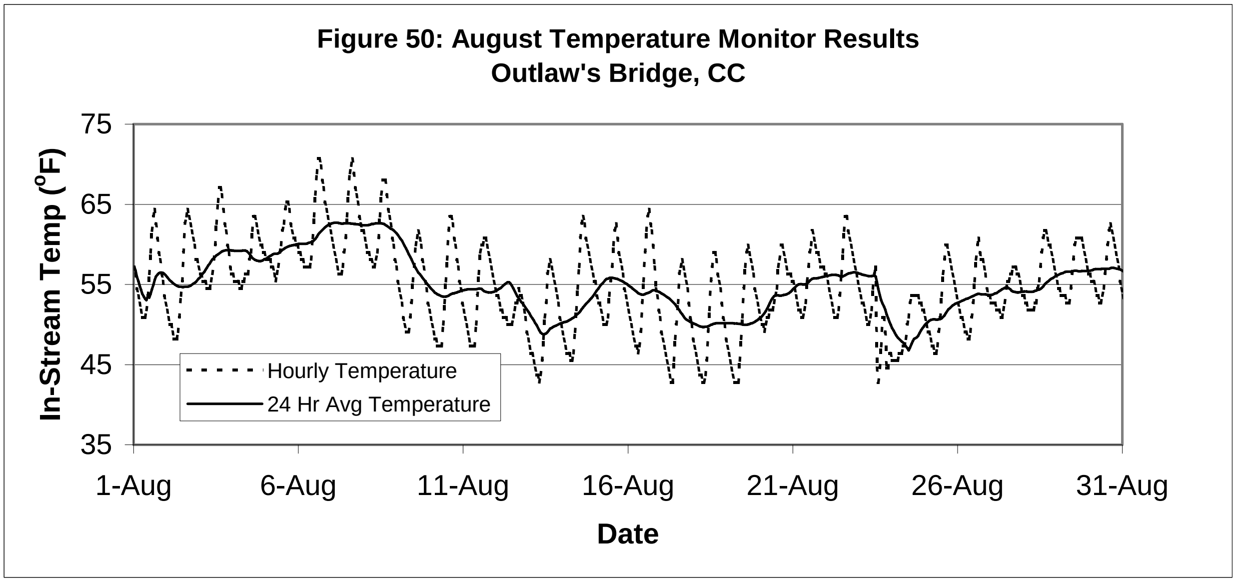
July Castle Creek C Temperature Monitor Results – Continued

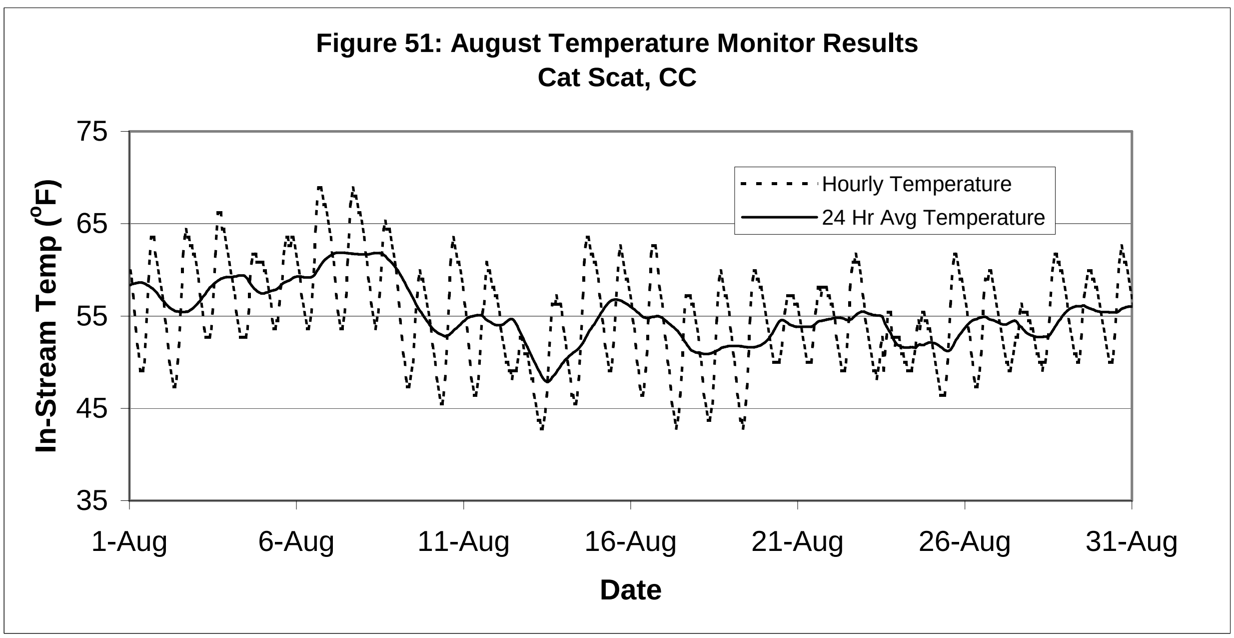


August 2002, Temperature Monitoring Results

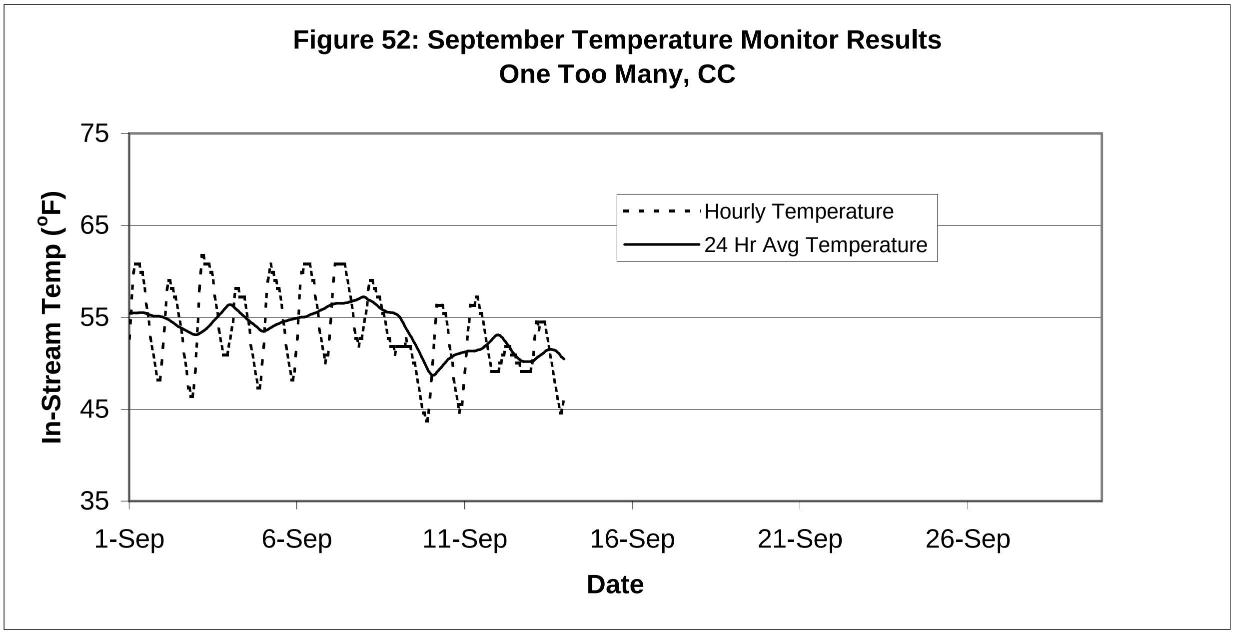


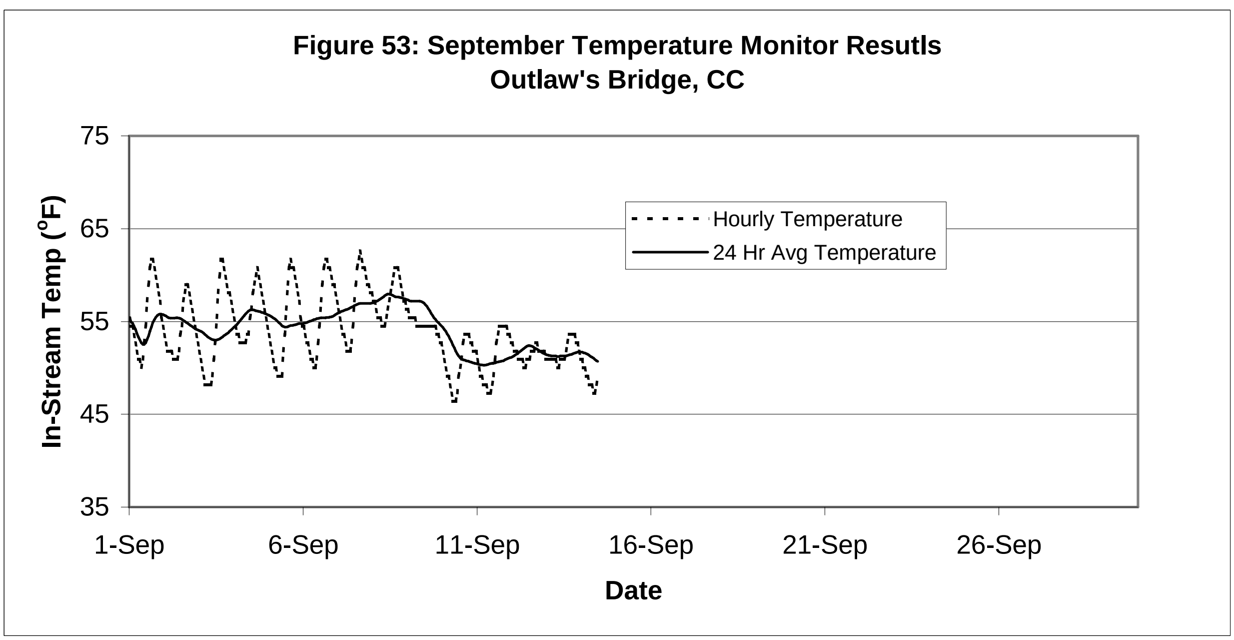
August Castle Creek Sites Monitoring Results – Continued



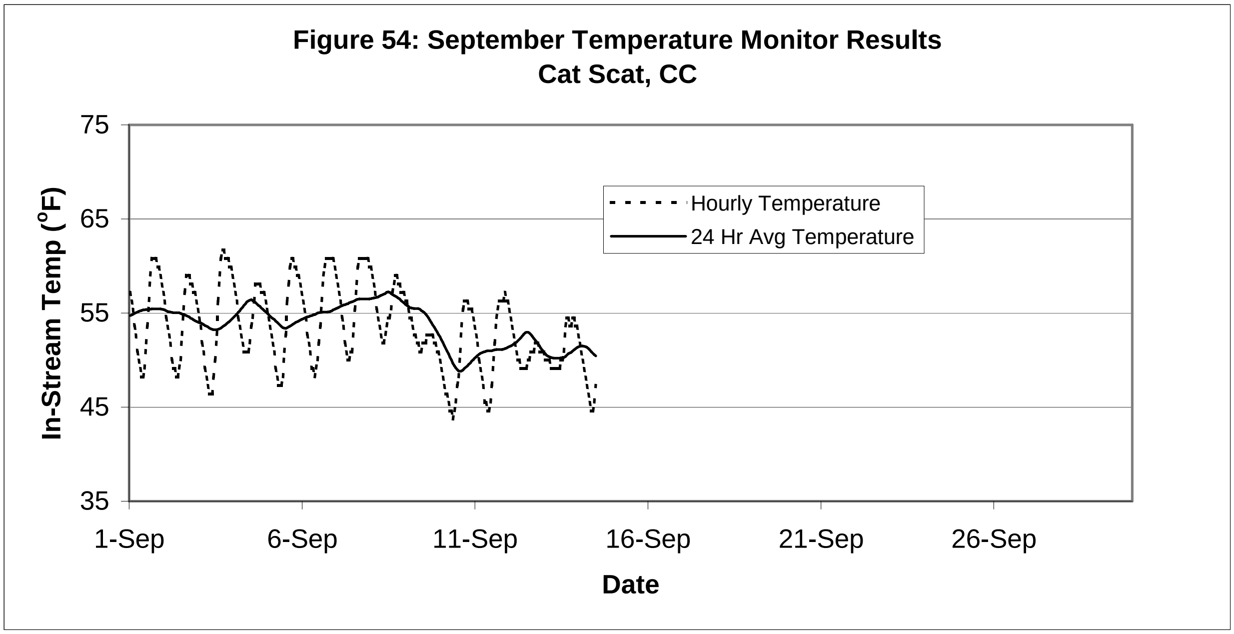


September 2002, Temperature Monitoring Results





September Castle Creek Sites Monitoring Results – Continued



DISCUSSION OF MONITORING RESULTS

Monitoring results clearly indicate that North Fork Rapid Creek is in non-compliance for in-stream temperature. Figures 55 through 61 show in graphical form the percentage of time the daily maximum and 24-hour running average in-stream temperature exceeds the regulatory standard of 65^{o}F for Coldwater Permanent Fish Propagation for both North Fork Rapid Creek and Castle Creek. For example, an evaluation of the Fence Post Sample Site for the period June 8 to September 25, 2002 (Figure 57, page 91), located at a point approximately halfway up the watershed shows that maximum daily temperature exceeded the coldwater fishery standard approximately 78% of the time during the summer of 2002. At the same station, the daily average exceeded the 65^{o}F standard approximately 23% of the time. In comparison, on Castle Creek, while also in non-compliance with the temperature standard, maximum daily temperature at the three Castle Creek Sites exceeded the standard approximately 30% of the time. Comparing the graphs for North Fork Rapid Creek and the Castle Creek Sites shows that overall, Castle Creek had less non-compliance days than did North Fork Rapid Creek. At no time did the average daily temperature exceed the standard at any of the Castle Creek sites. Two factors may be contributing to the overall better compliance in Castle Creek:

1. Discharge is approximately five times greater in Castle Creek than in North Fork Rapid Creek.[50] Under similar conditions, creeks with larger flows would experience smaller extremes in daily maximum and average temperatures.
2. Although Castle Creek occasionally flows through open meadows between Deerfield Reservoir and the Castle Creek sample sites, the areas upstream from both the sample sites in Castle Creek and North Fork Castle Creek are heavily forested providing canopy to shade both creeks.

The only feasible mitigation measure that can be employed to reduce in-stream temperature in these creeks is to increase canopy and thus shading of the streams. This is clearly possible on the North Fork Rapid Creek. As a result, North Fork Rapid Creek was modeled to determine what impacts additional shading would have on in-stream temperature.

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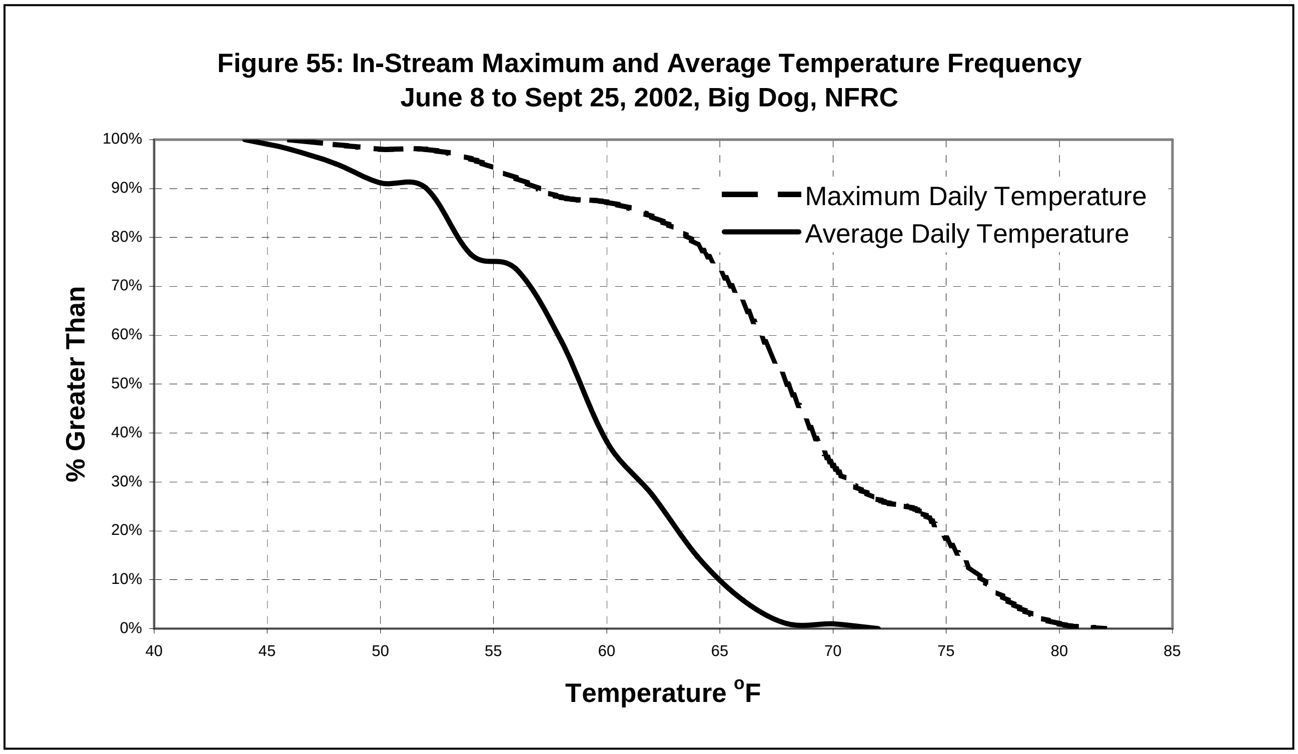
[50] Discharge at High and Dry on NFRC was measured at between 1.5 and 2.6 cfs compared to an average of 15.7 cfs measured at One too Many on CC.

Temperature Frequency Graphs, North Fork Rapid Creek



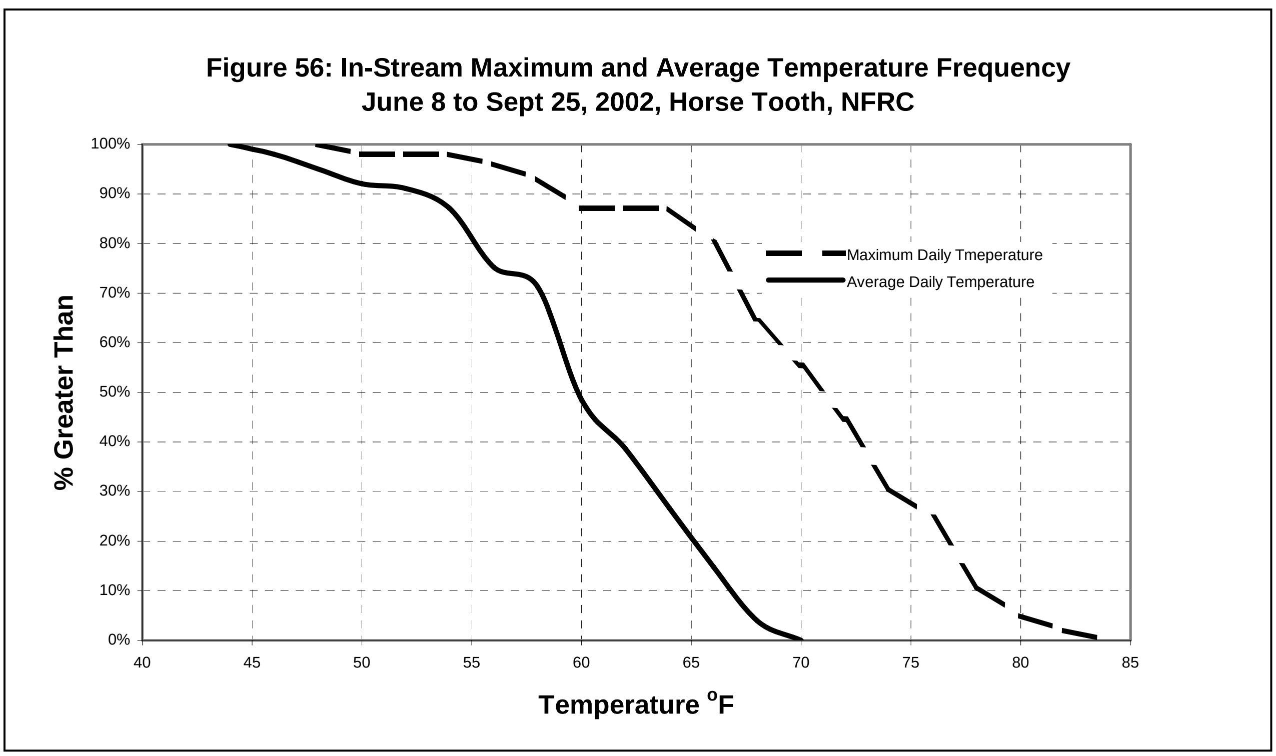
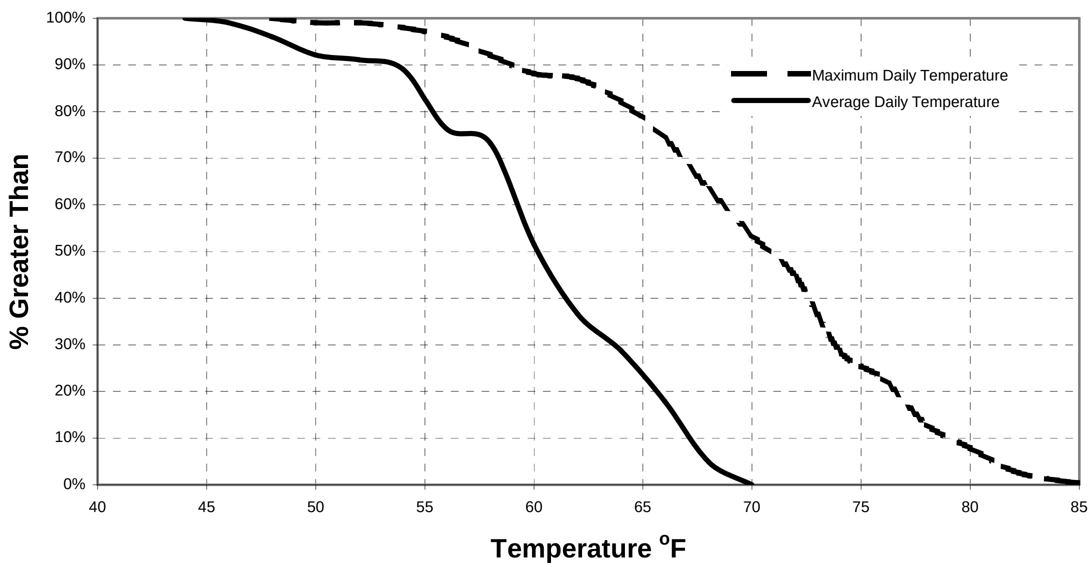
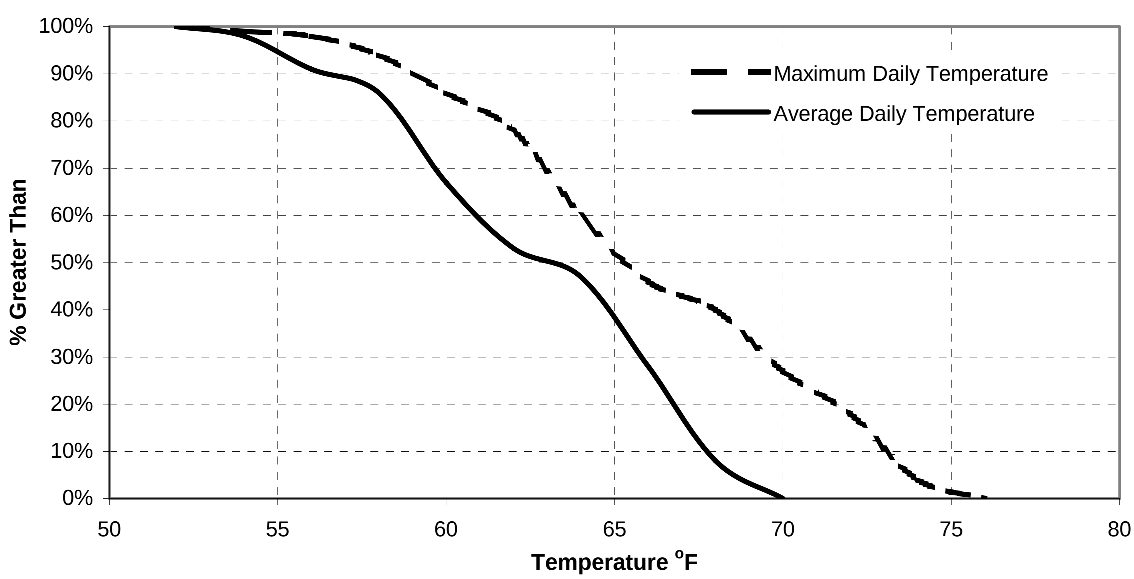


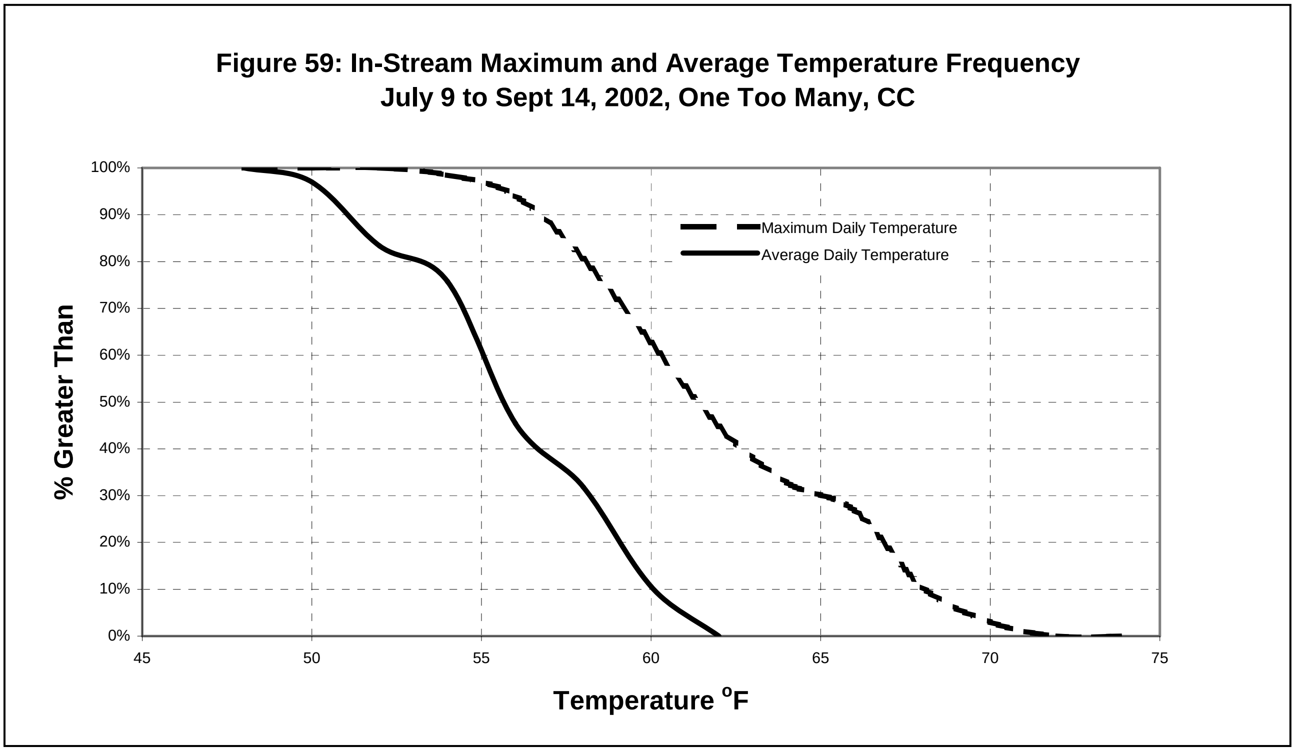
Figure 57: In-Stream Maximum and Average Temperature Frequency June 8 to Sept 25, 2002, Fence Post, NFRC

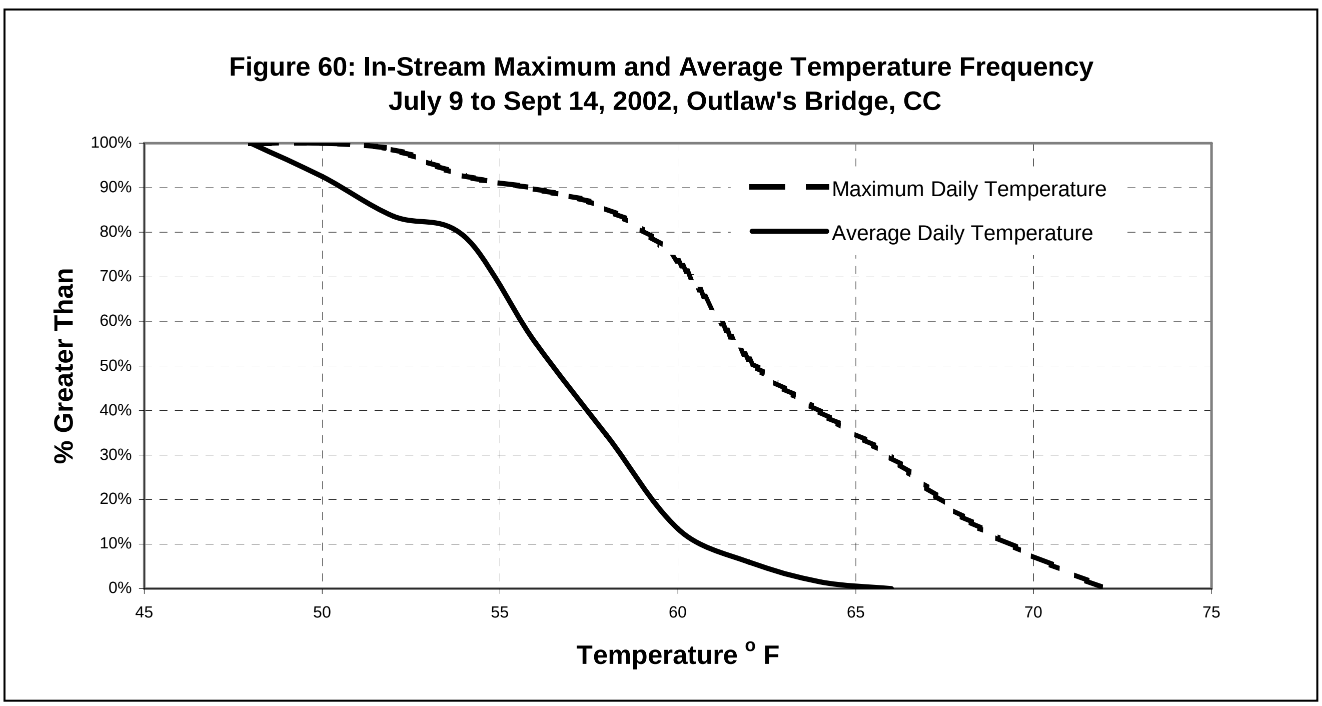


Figrue 58: In-Stream Maximum and Average Temperature Frequency June 7 to Sept 14, 2002, High and Dry, NFRC



Temperature Frequency Graphs, Castle Creek Sites





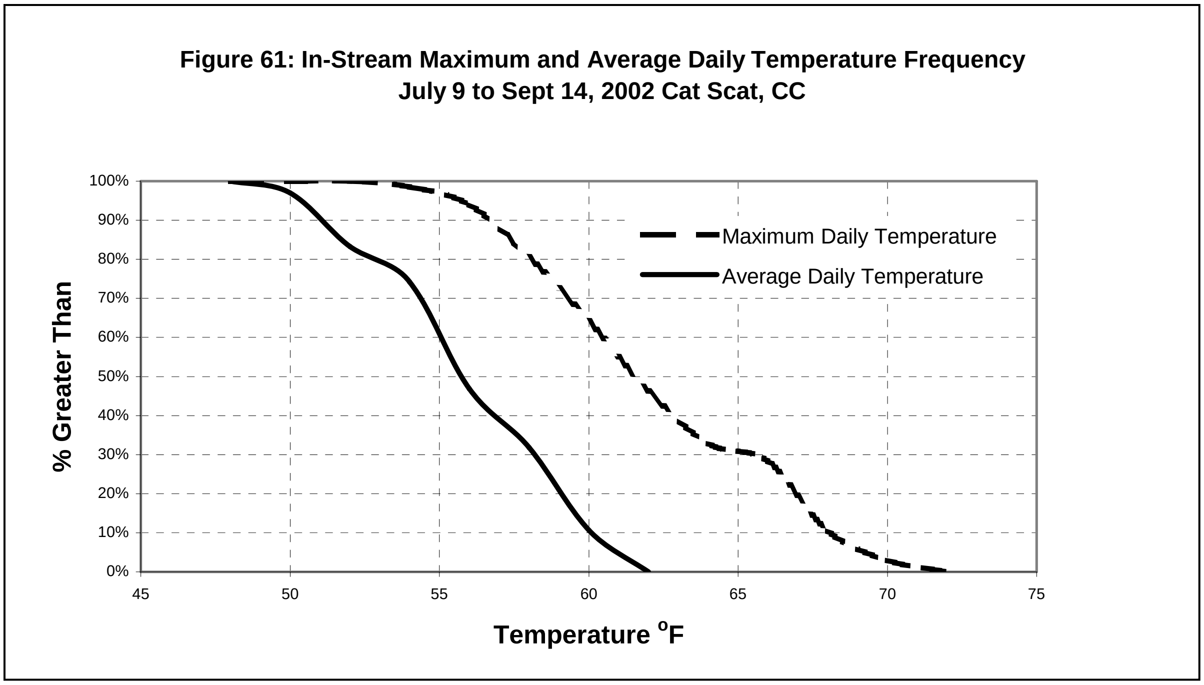


Figure 61: In-Stream Maximum and Average Daily Temperature Frequency
July 9 to Sept 14, 2002 Cat Scat, CC
% Greater Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
45
50
55
60
65
70
75
Temperature °F
Maximum Daily Temperature
Average Daily Temperature

SECTION 8: TEMPERATURE MODELING

In-stream temperature was modeled using SSTEMP, Version 2.0, as revised in August, 2002. SSTEMP was developed by the United States Geological Survey and is a scaled down version of their Stream Network Temperature Model (SNTEMP). It is designed to handle single stream segments over a single time period (month, week or day) for any given run. It is especially useful to perform sensitivity and uncertainty analysis (Bartholow, August 2002).

SSTEMP estimates in-stream temperature by estimating heat fluxes within a given homogeneous section of stream. The model predicts both daily mean temperature and maximum water temperature within the section. Model input defines the stream in terms of location (latitude, time of year, and Azimuth), length, shape (top width, depth), discharge, and slope. Input also includes shading characteristics and stream roughness (Manning's "n"). Meteorological influences affecting heat flux are also input (air temperature, relative humidity, wind speed, and percent sun). "Net heat flux is calculated as the sum of the heat to or from long-wave atmospheric radiation, direct short-wave solar radiation, convection, conduction, evaporation, streamside vegetation (shading), streambed fluid friction, and the water's back radiation" (Bartholow accessed February 22, 2004).

For modeling purposes, North Fork Rapid Creek was divided into two reaches and multiple runs were made on each reach**.**

Reach 1 comprises that portion of the watershed beginning at the uppermost sample station, Big Dog, and extending to the Fence Post sample station. Buskala Creek and Tillson Creek are major tributaries of North Fork Rapid Creek. They both discharge into the North Fork Rapid Creek in this reach. Reach 1 is approximately 2.4 miles long with an elevation change of 164 feet. Reach 1 lies in an open valley meadow and is representative of the upper portion of the watershed which begins at the North Fork Rapid Creek – Whitewood Creek Divide and extents 6.7 miles to the Fence Post sample station.

Reach 2 comprises the lower portion of the watershed. This reach extends approximately 4.5 miles from Fence Post to the High and Dry sample station. The elevation change in this reach is 247 feet. The watershed narrows and North Fork Rapid Creek flows through a canyon in this reach. Reach 2 ends just above the confluence of the North and South Forks of Rapid Creek.

DISCUSSION OF MODELING INPUT PARAMETERS

Segment Inflow: Stream inflow is based on actual monitoring results obtained from an R-2 Data Logger at Big Dog and an Isco 4230 Bubbler Flow Meter located at Fence Post. These instruments were calibrated from in-stream discharge measurements made at each site with a Price Pygmy meter following USGS procedures for stream discharge measurements (Rantz, 1982).

Inflow Temperature: Inflow temperatures for each reach were obtained from Ryan 100 continuous temperature monitors, which were installed at Big Dog and at Fence Post during the summer of 2002. The Ryan instruments were set to record temperature every hour. Average temperatures were obtained by averaging 24 hourly readings. High daily temperatures were obtained from each site and used in calibration of the SSTEMP model.

Segment Outflow: Segment outflow was based on monitoring results obtained from an R2 unit at Big Dog and ISCO monitoring equipment located at Fence Post and High and Dry.

Outflow Temperature: Outflow temperatures for all reaches were obtained from Ryan 100 continuous temperature monitors placed at Big Dog, Fence Post and High and Dry.

Accretion Temperature: Shallow wells were installed within the watershed to a depth of approximately two feet to obtain ground water samples near the iron bogs. Groundwater temperature was recorded when water samples were collected from the wells. Accretion temperature was based on those groundwater temperature readings.

Latitude: Latitude for each reach was obtained with a Garmin Street Pilot GPS unit.

Segment Length: The navigate function of DeLORME Topo USA Version 3.0 software was used to delineate and calculate distance for each stream reach.

Elevations: The upstream and downstream elevations for each reach were obtained from both Garmin Street Pilot GPS unit and DeLORME Topo USA Version 3.0 topographical maps. GPS elevation readings are not considered as accurate as elevations from topographical maps. The elevations obtained from DeLORME Topo USA were used in the modeling.

Width “A & B” terms: These terms were determined by plotting the natural logs of the stream width vs. natural log of discharge readings obtained from all of the discharge measurements made on the North Fork of Rapid Creek during the study period. A line was fitted to the plot. The “B” term was the slope of that line and the “A” term the Y-intercept. These functions are used to characterize the top width and estimate average stream depth of the stream segment.

Manning’s n: Manning’s “n” of 0.035 was used. This is a typical value for a stream with a substrate composed of cobble and course gravels.

Time of Year: July 14, 2002 was the date used to calibrate the SSTEMP model. This date was chosen for the following reasons:

1. An evaluation of climatological data from weather stations in Custer, SD, Gillette, WY, and Rapid City, SD, and weather observations obtained in Rochford, SD, and Nemo SD, showed no precipitation occurred on this date. It was assumed the presence of precipitation on the date used to calibrate the model might confound the calibration process.
2. Stream discharge measurements were taken on or near this date.
3. The average air temperature at Rochford, SD, on July 14, 2002 was 74^{o}F with a high of 90^{o}F.
4. The average in-stream temperature at Fence Post was 66.7^{o}F. A maximum stream temperature of 81.5^{o}F was reached at the Fence Post sampling station. The Fence Post sampling location consistently had the highest in-stream temperatures. Temperature is the compliance criteria identified on the North Fork Rapid Creek TMDL.

Air Temperature: Air temperature was obtained from Climatological Data kept by National Weather Service for Rochford, SD. Rochford, SD, is located approximately 0.9 mile east of the High and Dry sampling station and 4 mile southeast from the Fence Post sampling station. Both the community of Rochford and the High and Dry sample site lie in shaded gullies. The Fence Post site is at the south end of a broad open area. In order to calibrate reach 1 of the model, it was necessary to reduce the high temperature recorded at the Rochford weather recording station by 4 degrees (94 to 90 ^{o}F). It is possible that the mid to late afternoon temperature at High and Dry is less than the Rochford temperature. At High and Dry the creek is in a narrow valley and is located against the western side of the valley. Shade would occur at this location earlier in the afternoon than at a more open area located near Rochford.

Relative Humidity: Relative humidity data was not available for Rochford, SD. Data was obtained from the National Weather Service for Rapid City, SD, and used in the study. The value used is an average afternoon relative humidity for Rapid City during the month of July. Rapid City lies approximately 30 miles from the study site. Because of the uncertainty associated with the parameter, it was one of the parameters adjusted to calibrate the model.

Wind Speed: Wind speed was obtained from Climatological Data kept by the Rapid City office of National Weather Service for the Custer Airport. The Custer Airport was the closest recording station at a similar elevation as the study area. Custer is 30 miles from the study area at an elevation of 5, 345. Because of the uncertainty associated with the parameter, it was one of the parameters adjusted to calibrate the model.

Ground Temperature: Actual temperatures taken from shallow wells (approximately 2 feet deep) where used in the model.

Possible Sun %: The July average percent of sunshine at Rapid City, obtained from the National Weather Service, was used in this model. A weather observer located in the town of Nemo, SD, reported clear skies around noon on July 14, 2003. Nemo is located approximately 12.5 miles from High and Dry.[54]

Dust Coefficient: A dust coefficient for summer between 3 and 10 is recommended by the USGS for use in SSTEMP modeling. As this location is relatively remote and in the higher elevations of the Black Hills, the lower value of three was assumed.

Ground Reflexivity: This is a measure of the amount of short-wave radiation reflected from the earth back into the atmosphere. Based on values developed by the Tennessee Valley Authority a value of 20 was assumed for both reaches. Leaf and needle forests are estimated to have a value of between 5 and 20. Vegetation – early summer is estimated to have a value of 19 whereas vegetation – late summer is estimated to have a value of 29.

Solar Radiation: SSTEMP gives the user the option of entering a dust coefficient and a ground reflectivity and it calculates solar radiation or, the user can directly enter a solar radiation value. Pyrometer measurements of solar radiation were not obtained during this study. As a result, dust coefficient and ground reflectivity values were entered, and the program calculated solar radiation.

Percent Shade: The program provides the user with the option of entering a percent shade value or entering values for azimuth, topographical altitude, vegetation height, crown width, vegetation offset, and vegetation density. It then calculates percent shade based on these values. As the intent of this study was to evaluate the

[54] Record of River and Climatological Observation prepared by Ms. Lois Zuercher, Boxelder Job Corps, USFS.

effects of vegetation on stream temperature, no percent shade value was entered.

Segment Azimuth: Segment azimuth was obtained by drawing a straight line from the beginning to end of each reach on 7 ½ minute USGS topographical maps and using a protractor to measure the angle of the line. The program orientates the measurement to true north regardless of the direction of flow. Negative numbers indicate that the stream has a bearing west of north. Positive numbers indicate that the stream has a bearing east of north.

Topographical Altitude: Topographical Altitude was measured from cross-sections that were constructed along the course of the stream from 7 1/2 minute USGS quad maps of the areas.

Vegetation Height: Along Reach 1 the predominant vegetation adjacent to the stream are species of grasses. An initial height of 1 foot above the water surface was assumed for vegetation adjacent to the stream for this reach. Vegetation in Reach 2 is much more varied than in Reach 1. An initial vegetation height of 12 feet above water surface (assume 1 to 1 ½ feet of bank) was assumed due to the presence of willow trees adjacent to much of the stream in this reach.

Vegetation Crown: A crown of 0.1 foot was assumed for the grasses adjacent to the stream in Reach 1. A crown of 2 feet was assumed for the willow trees along Reach 2 of the stream.

Vegetation Offset: The grasses in Reach 1 grow up to the bank and were assumed to have zero feet of offset. The trees in Reach 2 were assumed to have an offset of 1 foot.

Vegetation Density: Density of the grasses in Reach 1 was assumed to be 100%; the density of the trees in Reach 2 was assumed to be 35%.

Model Calibration

Values obtained for the parameters listed above were entered into the SSTEMP program and an initial run (the base case) was made for each reach. The model predicts the mean temperature and estimated maximum temperature of the stream flow in the reach. These values were compared to the actual temperature values obtained by the Ryan 100 temperature monitors on July 14, 2002. Input data for the base case are contained in Table 19: Temperature Model Base Case In-put Parameters, Page 99.

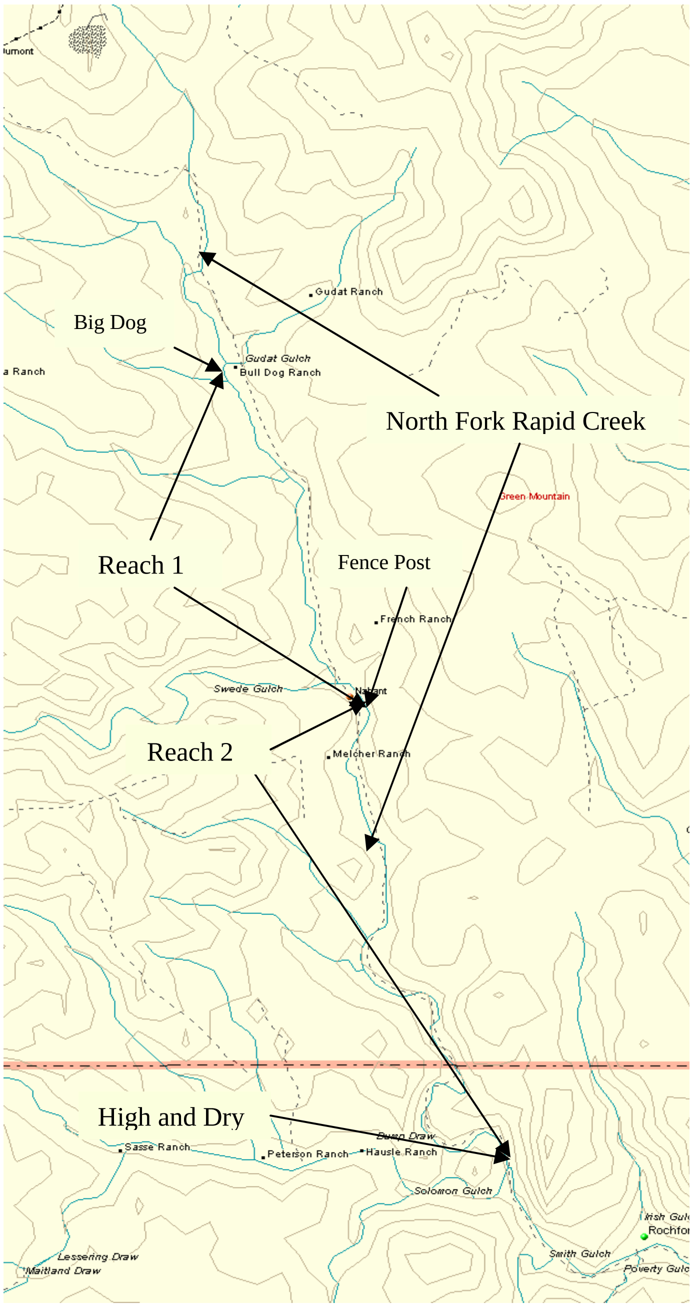
For Reach 1, the base case predicted a mean temperature of 65.67 ^{o}F and a maximum temperature of 82.21 ^{o}F. This compares with an actual mean temperature of 66.7 ^{o}F and an actual maximum temperature of 81.5 ^{o}F. The predicted mean is 98.5% of actual, and the estimated maximum temperature is 100.9% of actual. For Reach 1 the base case was judged to be an accurate predictor of stream temperature and no calibration was done.

For Reach 2, the base case predicted a mean stream temperature of 69.41 ^{o}F and a maximum stream temperature of 83.74 ^{o}F. This compares with an actual mean of 66.8 ^{o}F and an actual maximum temperature of 75.2 ^{o}F. The predicted mean was 104% of the actual mean, and the estimated maximum temperature is 111% of actual maximum temperature. Although the estimated values for Reach 2 were close, minor adjustments were made to the base case to more accurately predict actual values.

Table 19: Temperature Model Base Case In-Put Parameters

	Seg Inflow (cfs)	Avg Inflow Temp (^{o}F)	Seg Outflow (cfs)	Avg Seg Outflow Temp (^{o}F)	Accretion Temp (^{o}F)	Latitude (deg)
Reach One	0.51	64.4	0.96	67	51.6	44.208
Reach Two	0.96	67	1.5	66.8	51.6	44.178
	Seg Length (mi)	**Upstream Elev. (ft)**	**Dwnstream Elev. (ft)**	**Width "A" Term (s/ft2)**	**B Term, W=A*Q**B**	**Manning's n**
Reach One	2.38	5849	5685	20.631	5.863	0.035
Reach Two	4.54	5685	5438	7.31	0.14	0.035
	Time of Year	**Air Temp (^{o}F)**	**Max Air Temp**	**Relative Humidity %***	**Wind Speed**	**Ground Temp (^{o}F)**
Reach One	14-Jul	74	94	30	8	52
Reach Two	14-Jul	74	94	30	8	52
	Thermal grad. (j/m2/s/C)	**Possible Sun %**	**Dust coef.**	**Grnd Reflexivity %**	**Solar Rad (L/day)**	**Percent**
Reach One	Default	73	5	20	N/A	N/A
Reach Two	Default	73	5	20	N/A	N/A
	Seg Azimuth (deg)	**Topo Altitude (deg)**	**Veg Ht (ft)**	**Veg Crown (ft)**	**Veg Offset (ft)**	**Veg Density %**
Reach One	N - 17	5.5	1	0.1	0	100
Reach Two	N - 16	25	12	2	1	35
	Topo Altitude (deg)	**Veg Ht (ft)**	**Veg Crown (ft)**	**Veg Offset (ft)**	**Veg Density %**	**Actual Max. Exit Stream Temp (^{o}F)**
Reach One	11.6	1	0.1	0	100	81.5
Reach Two	26	12	2	1	35	75.2

Reach 2 lies in a valley. It was assumed that the maximum air temperature at this section might be less than that in the open meadow because of the shading that would occur from the mountains adjacent to the stream. Wind speed and humidity were two parameters based on readings taken 30 miles from the evaluation site and in the case of humidity based on a monthly average. In order to calibrate the Reach 2 model, the maximum air temperature was decreased 4°F (from 94°F to 90°F) humidity was reduced from 42% to 30% and wind speed was increased from 7 mph to 8 mph.



Map 6: Location Map, Sensitivity Analysis, Temperature Modeling of North Fork Rapid Creek

With the adjustments made to the base case the calibrated model produced the following results:

- Mean stream temperature of 64.79 °F or 97% of the actual mean.
- Maximum stream temperature of 77.02 °F or 102% of actual high temperature.

Sensitivity Analysis

Following model calibration, both reaches were evaluated to determine what management practices might be employed to lower the temperature of the in-stream flow. The two main factors affecting stream temperatures are flow and exposure to direct solar radiation. It is assumed there is little ability to control flow. Therefore, the only practical option identified to reduce temperature is to decrease the amount of solar radiation the stream receives by increasing shading.

Two activities could be undertaken to increase vegetation along the riparian zone of the creek in the hopes of lowering temperature.

1. The riparian zone can be protected from grazing. This would allow grasses and sedges along the creek to grow to full height.

2. Willows could be planted in the riparian zone. Over time the willows would grow high enough to shade the stream.

Reach 1 Evaluation

Table 20: STREAM TEMPERATURE VS. GRASS HEIGHT, REACH 1 OF NFRC

Grass Ht (ft.)	Mean Temperature (°F)	Maximum Temperature (°F)
1.3	65.05	81.02
1.6	64.50	79.95
1.9	64.00	78.98
2.2	63.59	78.15
2.5	63.21	77.37
2.8	62.89	76.73
3.1	62.60	76.13
3.4	62.34	75.60

Table 21: STREAM TEMPERATURE VS. WILLOW HEIGHT, REACH 1 OF NFRC

Willow Ht (ft.)	Mean Temperature (°F)	Maximum Temperature (°F)
2	67.65	85.86
3	67.21	85.07
4	66.86	84.43
5	66.58	83.92
6	66.29	83.37
7	66.14	83.09
8	66.01	82.85
9	65.91	82.67
10	65.77	82.40
11	65.70	82.27

The upper reach is in open meadow and flows through private lands. Landowner cooperation would be necessary to increase vegetation along the riparian zone. Three separate sensitivity analysis were completed on reach one assuming landowner cooperation in fencing the riparian zone.

EVALUATION OF IN-STREAM TEMPERATURE VS. GRASS HEIGHT

The first analysis assumed that fencing occurred and no other mitigation measures were undertaken. The grasses/sedges in the riparian zone were allowed to grow and a series of evaluations were made assuming different grass heights. Grass crown was assumed to be a constant 0.1-foot, grass density was assumed to be 100% and offset from the bank was assumed to be zero. The results of that analysis are present in Table 20: In-Stream Temperature vs. Grass Height, Reach 1 of NFRC and in Figure 62, Page 102.

EVALUATION OF IN-STREAM TEMPERATURE VS. WILLOW HEIGHT

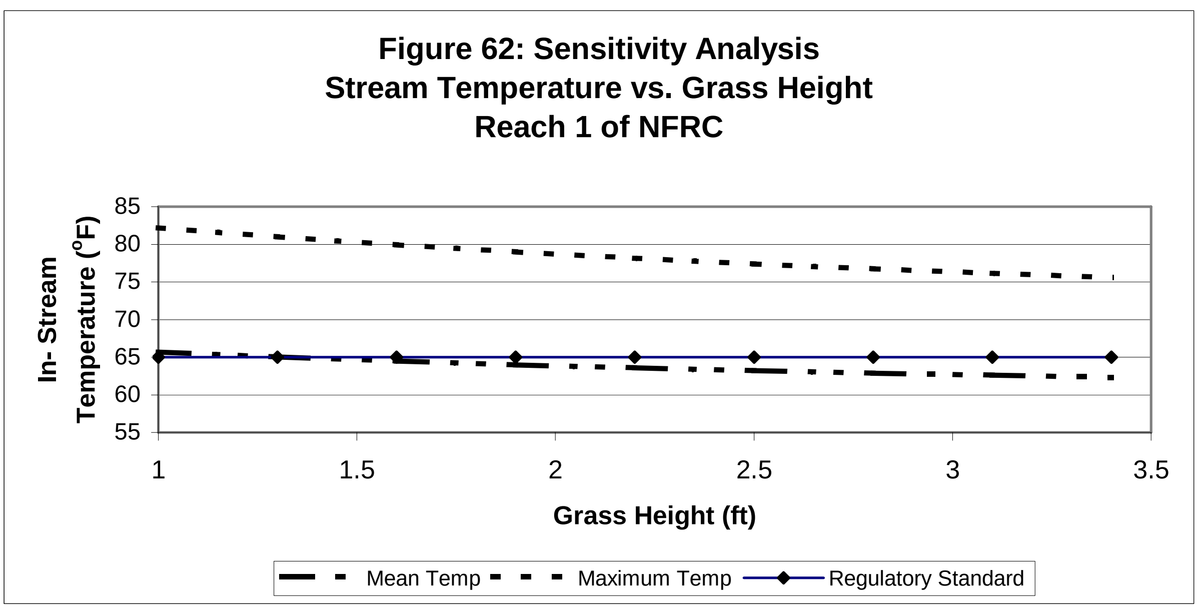
A second series of evaluations was made to determine the effects of establishing stands of willows along this portion of the creek. This analysis assumed that the crown for the willows would increase with willow height. For a height of 2 to 5 feet, a crown of 1 foot was assumed, for a height of 5 to 9 feet a crown of 1.5 feet was assumed and for a height of 10 to 12 feet a 2-foot crown was assumed. Willow density was assumed to be 35%, and offset was assumed to be 2 feet for all cases. The results of that analysis are present in Table 21 Stream Temperature vs. Willow Height, Page 101 and Figure 63, page103.

EVALUATION OF IN-STREAM TEMPERATURE VS. WILLOW DENSITY

A third series of evaluations was made to determine the effects of increasing willow density on in-stream temperature. For this evaluation a willow height of 10 feet, crown of 2 feet and offset of 2 feet were assumed. Results of this evaluation are presented below in Table 22 and in Figure 64, located on page 103.

Willow Density (%)	Mean Temperature (^oF)	Maximum Temperature (^oF)
35	65.77	82.4
40	65.41	81.71
45	65.04	81.01
50	64.68	80.31
55	64.31	79.59
60	63.95	78.87
65	63.58	78.14
70	63.22	77.40
75	62.85	76.65
80	62.48	75.90
85	62.12	75.14
90	61.75	74.37
95	61.38	73.60
100	61.01	72.81

Table 22: STREAM TEMPERATURE VS. WILLOW DENSITY, REACH 1 OF NFRC



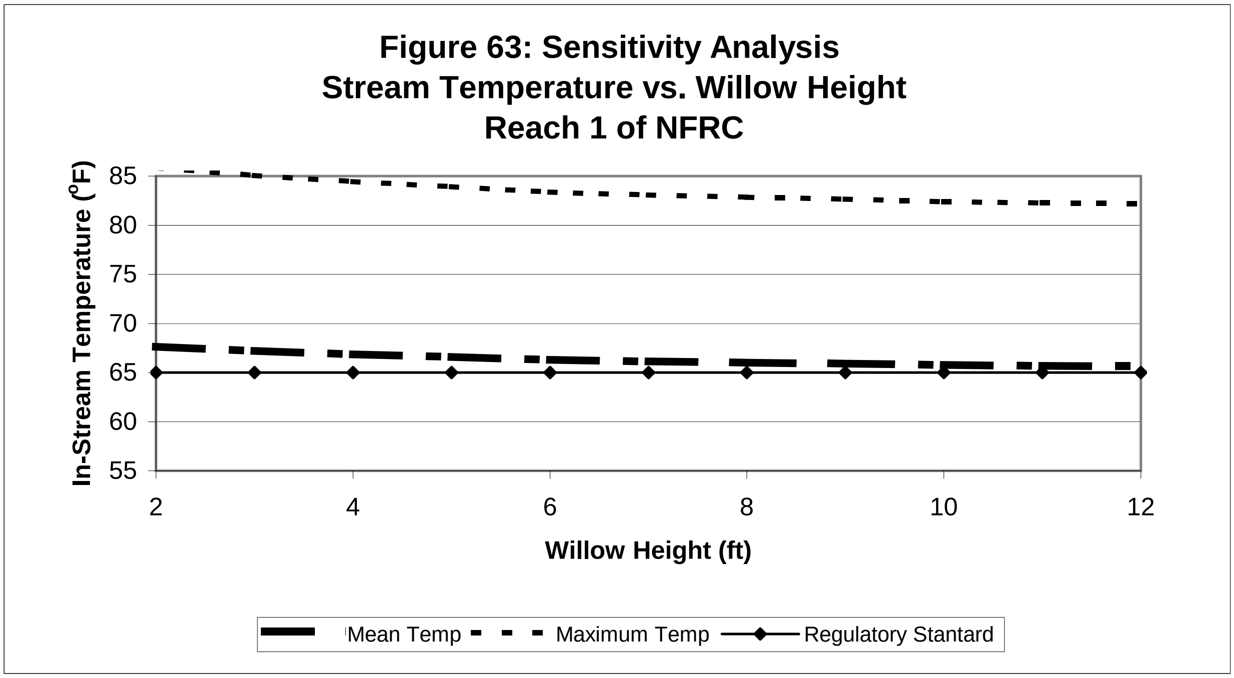


Figure 63: Sensitivity Analysis
Stream Temperature vs. Willow Height
Reach 1 of NFRC
In-Stream Temperature (°F)
85
80
75
70
65
60
55
2
4
6
8
10
12
Willow Height (ft)
Mean Temp
Maximum Temp
Regulatory Stantard

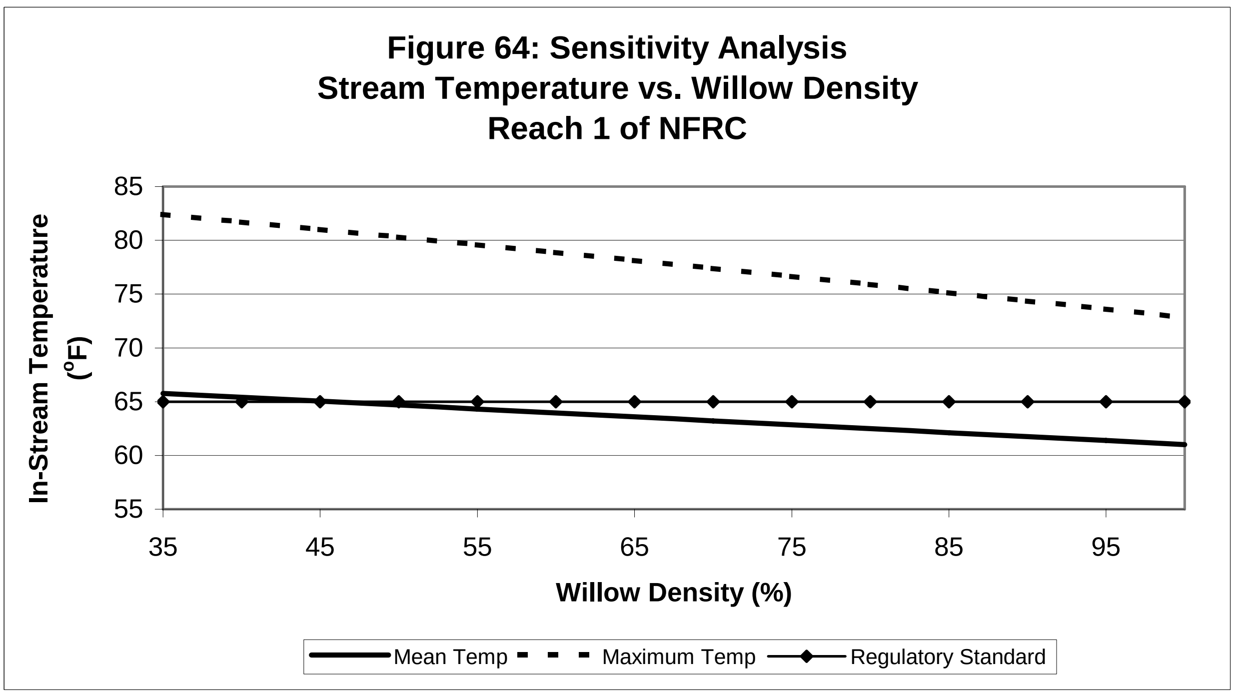


Figure 64: Sensitivity Analysis
Stream Temperature vs. Willow Density
Reach 1 of NFRC
In-Stream Temperature (°F)
85
80
75
70
65
60
55
35
45
55
65
75
85
95
Willow Density (%)
Mean Temp
Maximum Temp
Regulatory Standard

REACH 2 EVALUATION

The lower reach (Reach 2) flows through a valley and receives more shade than the open upper reach. Land ownership is a mixture of private, state, and U.S. Forest Service lands. Grazing occurs throughout the reach but appears to be less intense in parts of this reach than in the upper reach. Three separate sensitivity analyses were completed on Reach 2.

Grass Ht (ft)	Mean Temperature (^oF)	Maximum Temperature (^oF)
1.00	66.34	79.37
1.30	66.02	78.96
1.60	65.70	78.54
1.90	65.50	78.12
2.20	65.22	77.70
2.50	64.93	77.20
2.80	64.65	76.84
3.10	64.36	76.40
3.40	64.08	75.96

TABLE 23: STREAM

Evaluation of In-Stream Temperature vs. Grass Height

The first analysis performed on Reach 2 assumed that fencing occurred along the creek. The grasses and sedges in and adjacent to the riparian zone where allowed to grow, and a series of evaluations were made assuming different grass height. Grass crown was assumed to be 0.1 inch, density was assumed to be 100%, and it was assumed there was no offset between the bank and the grass. The results of this analysis are presented in Table 23: Sensitivity Analysis, Stream Temperature vs. Grass Height, Reach 2 of NFRC and on Figure 65, Page 105**.**

Evaluation of In-Stream Temperature vs. Willow Density

The second series of evaluations was made to determine the effects on in-stream temperature of increasing willow density in the lower portions of the North Fork Rapid Creek watershed. For these evaluations, willows were assumed to have a height of 10 feet and a crown of 2 feet. A one-foot offset was assumed. Results of this evaluation are presented in Table 24: In-Stream Temperature vs. Willow Density, Reach 2 of NFRC and on Figure 66, Page 106.

Willow Density (%)	Mean Temperature (^oF)	Maximum Temperature (^oF)
35	64.79	77.05
40	64.42	76.49
45	64.05	75.92
50	63.67	75.34
55	63.30	74.76
60	62.92	74.17
65	62.54	73.57
70	62.15	72.97
75	61.77	72.36
80	61.38	71.74
85	60.99	71.11
90	60.60	70.48
95	60.20	69.84
100	59.81	69.19

Table 24: STREAM TEMPERATURE VS. WILLOW DENSITY, REACH 2 OF NFRC

Evaluation of In-Stream Temperature vs. Stream Discharge

Although it is not possible to control discharge in North Fork Rapid Creek, as a final evaluation of in-stream temperature, it was decided to model the effects on in-stream temperature of increasing discharge in the stream. Discharge, the amount of water flow in a stream, has a big impact on in-stream temperature. Water is slower to absorb and radiate heat than either land or air. As a result it does not tend to experience the temperature extremes that occur in the adjacent air or land. The more water in the stream, the more moderate the changes in temperature experienced in the stream. The summer of 2002 was a summer of drought in the Rapid Creek watershed. Drought results in less groundwater recharge, which in turn results in a lower water table and less flow in the stream. Thus, one would expect discharge (flow) in North Fork Rapid Creek during the summer of 2002 to be less than normal. Evaluation of increased flow in the creek should provide an indication of what in-stream temperature might be during years of normal flow. Results of this evaluation are presented in Table 25: Stream Temperature vs. Discharge, Reach 2 of NFRC and on Figure 67, Page 106.

Discharge (cfs)	Mean Temperature (^oF)	Maximum Temperature (^oF)
1.50	64.79	77.05
1.65	64.45	76.92
1.82	64.09	76.76
2.00	63.74	76.59
2.20	63.38	76.40
2.42	63.02	76.18
2.66	62.65	75.95
2.93	62.27	75.69
3.22	61.90	75.51

Table 25: STREAM TEMPERATURE VS. DISCHARGE, REACH 2 OF NFRC

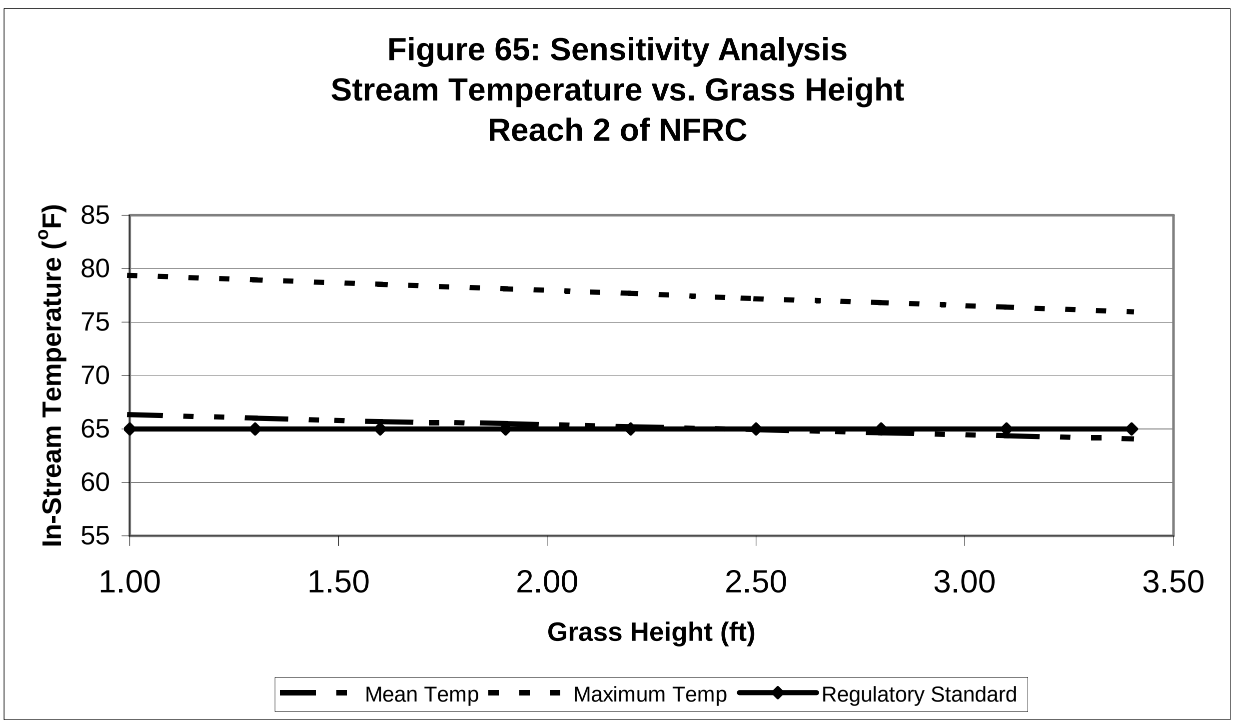


Figure 66: Sensitivity Analysis
Stream Temperature vs. Willow Density
Reach 2 of NFRC

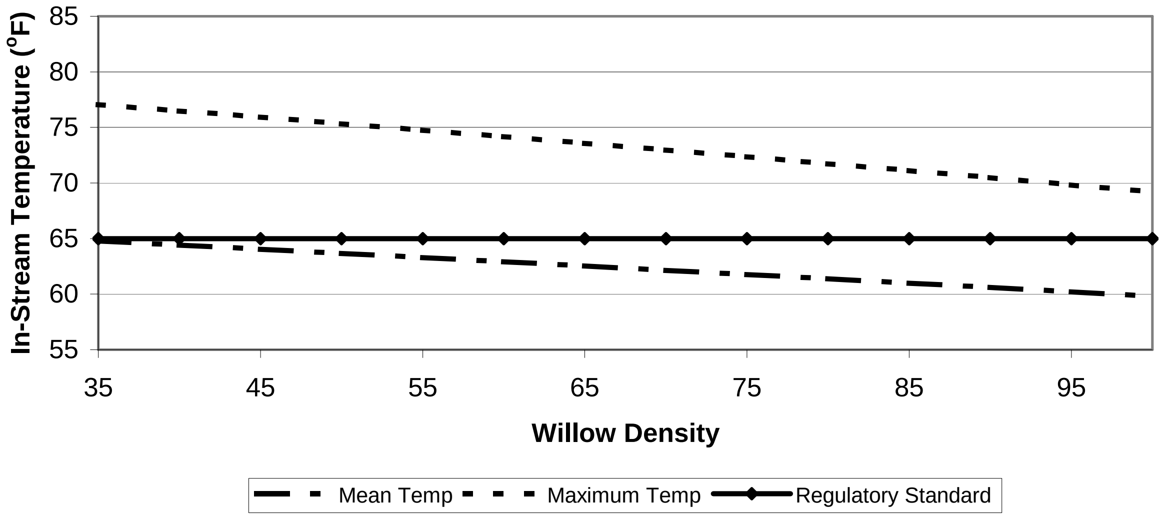
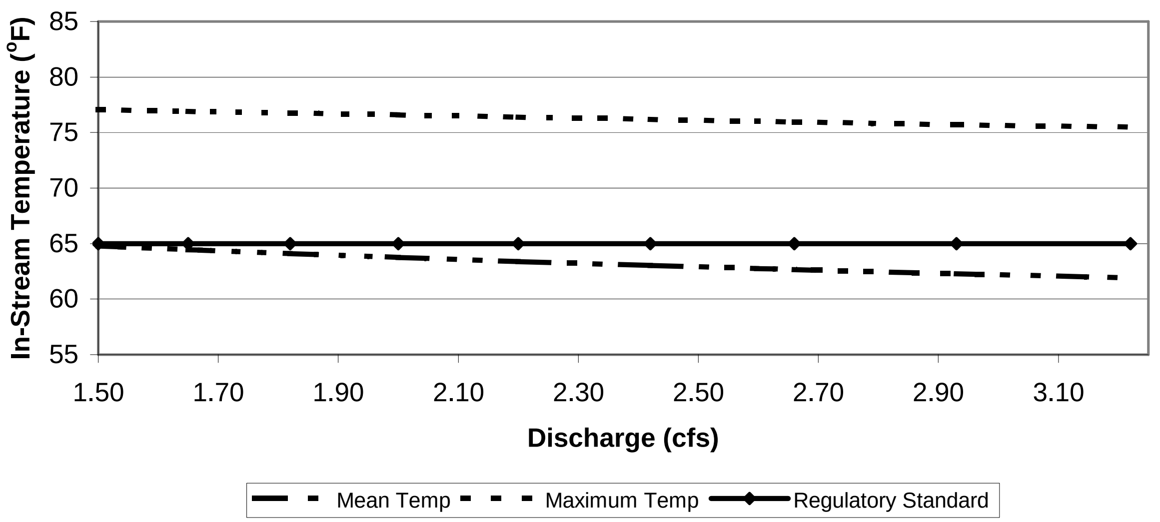


Figure 67: Sensitivity Analysis
Stream Temperature vs. Discharge
Reach 2 of NFRC



Conclusion

Table 26 summarizes the results of the sensitivity analysis temperature reduction from the six scenarios modeled.

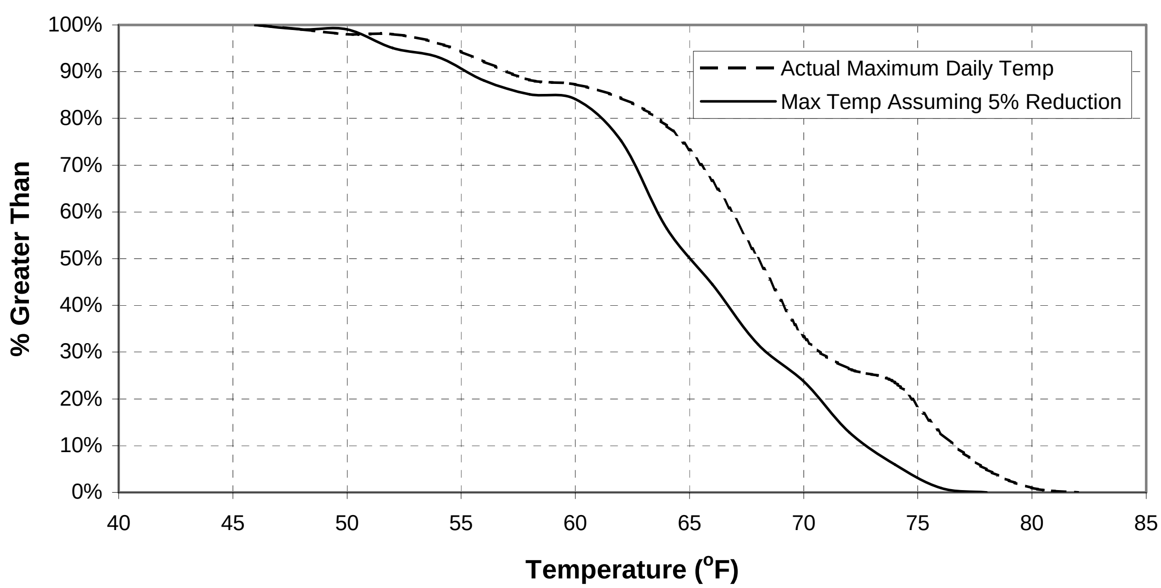
TABLE 26: SENSITIVITY ANALYSIS RESULTS
Estimated % Temperature Reduction

Segment	Option	Change	% Mean Temp Reduction	% Maximum Daily Temp Reduction
One	Increase Grass Ht.	1 ft to 3 ft	5	8
	Increase Willow Ht.	2 ft to 12 ft	3	4.3
	Increase Willow Density	35% to 100%	7.1	11.7
Two	Increase Grass Ht.	1 ft to 3 ft	3.4	4.3
	Increase Willow Density	35% to 100%	7.5	10.5
	Increase Discharge	1.5 to 3.22 cfs	4.5	2

Fencing the riparian area to allow limited access for livestock, increasing willow density within the riparian zone, and allowing riparian grasses to grow to full height significantly increases shading on the creek. Shading blocks direct solar radiation and results in lowered in-stream temperature. Based on modeling results, it was assumed that a combination of willow density and grass height increases could realistically be expected to reduce in-stream temperature 5%. The effect of a 5% temperature reduction on compliance with Coldwater Fish Life Propagation criteria was analyzed. This was done by simply reducing the actual daily maximum in-stream temperature by 5% and graphing the results. The greatest impact from shading to in-stream temperature occurs with increasing willow density along the banks of the stream. While it is not realistic to assume that density could be increased to 100%, for the purpose of developing a “best case” scenario, the effects of reducing maximum in-stream temperature by 10% was also evaluated. The results of the temperature reduction evaluations are presented in Figures 68 through 75. These results demonstrate that even with significant increases in shading, the beneficial use standard of 65^{o}F for Coldwater Fish Life Propagation will be regularly exceeded during summer months. A 5% reduction in in-stream temperature during summer months is projected to reduce maximum daily temperature exceedance from 73% to 50% at Big Dog, 85% to 65% at Horse Tooth, 79% to 63% at Fence Post and 70% to 47% at High and Dry. With a 10% reduction of in-stream temperature during summer months, maximum in-stream daily temperature exceedance will be reduced from approximately 73% to 20% at Big Dog, 73% to 43% at Horse Tooth, 78% to 43% at Fence Post and from 70% to 30% at High and Dry.

The results indicate that because creek discharge is relatively small there is a direct relationship to in-stream water temperature from ambient air temperature. Even if solar radiation is blocked, thermal conductivity between atmosphere and water is sufficient to exceed the beneficial use temperature during warm summer days. Fencing of North Fork Rapid Creek to prevent riparian grazing from livestock, allowing full riparian vegetation growth, and planting additional willows along the stream may reduce temperature exceedance by approximately 20% if a 5% reduction in in-stream temperature is achieved. Under the most optimistic scenario, a 10% reduction of in-stream temperature reduces the days of exceedance by 40%. Although these reductions are significant, modeling indicates increased shading will not result in compliance with the regulatory standard for permanent coldwater fish life propagation.

Figure 68: Comparison Actual vs. 5% Temperature Reduction Maximum In-Stream Temperature Frequency, Big Dog, NFRC



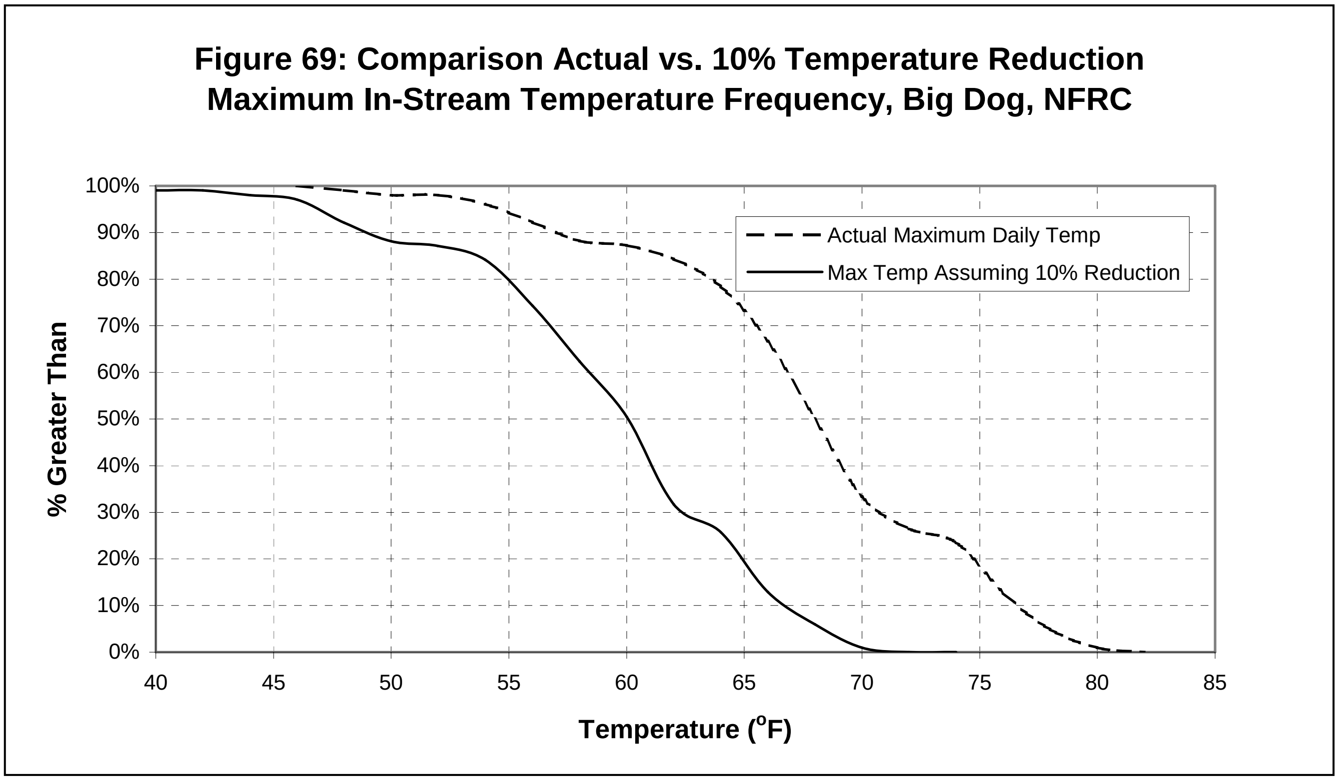


Figure 69: Comparison Actual vs. 10% Temperature Reduction
Maximum In-Stream Temperature Frequency, Big Dog, NFRC
Actual Maximum Daily Temp
Max Temp Assuming 10% Reduction
% Greater Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
40
45
50
55
60
65
70
75
80
85
Temperature (°F)

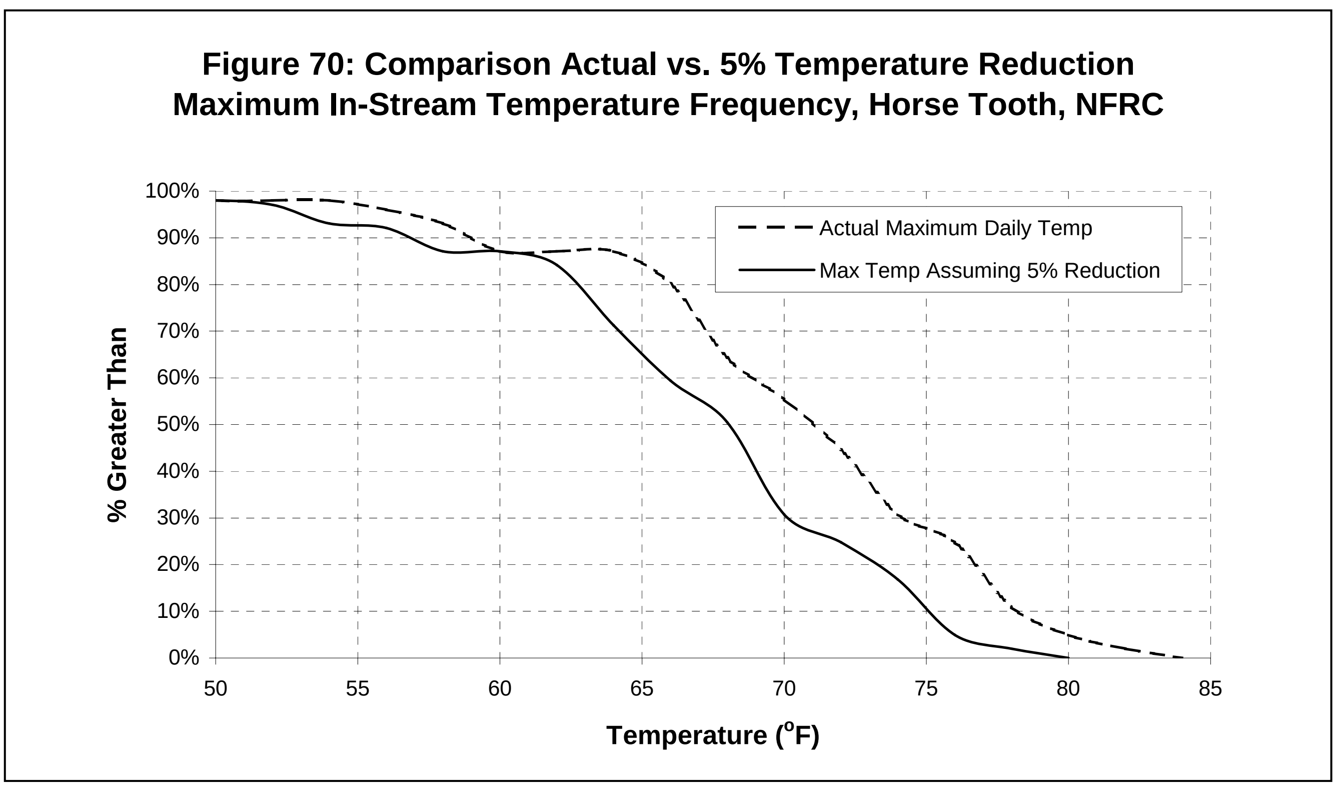


Figure 70: Comparison Actual vs. 5% Temperature Reduction
Maximum In-Stream Temperature Frequency, Horse Tooth, NFRC
Actual Maximum Daily Temp
Max Temp Assuming 5% Reduction
% Greater Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
50
55
60
65
70
75
80
85
Temperature (°F)

Figure 71: Comparison Actual vs. 10% Temperature Reduction Maximum In-Stream Temperature Frequency, Horse Tooth, NFRC

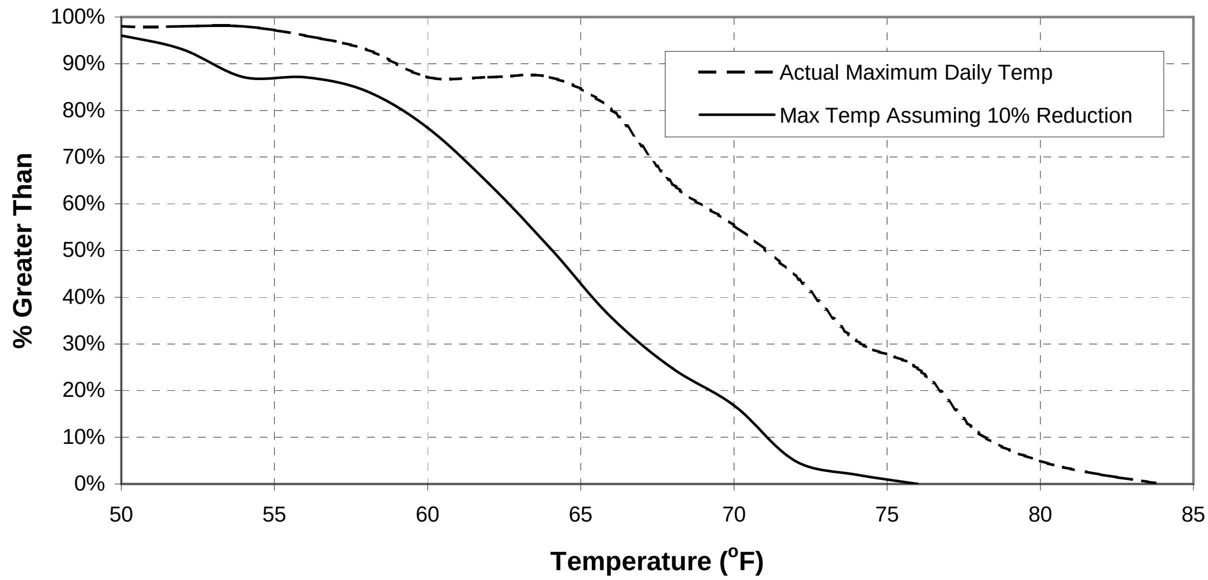
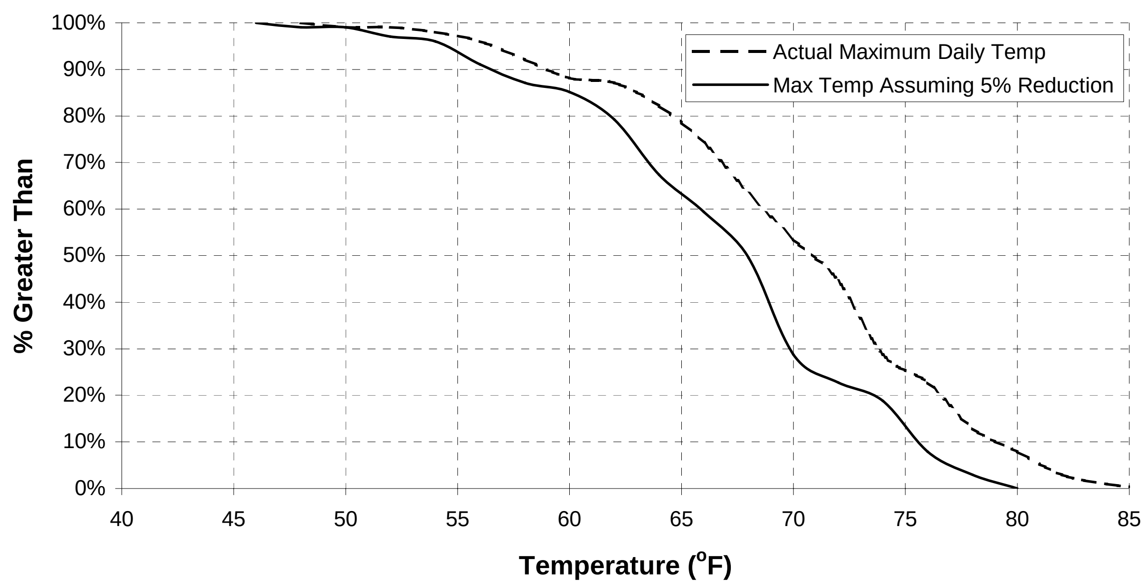


Figure 72: Comparison Actual vs. 5% Temperature Reduction Maximum In-Stream Temperature Frequency, Fence Post, NFRC



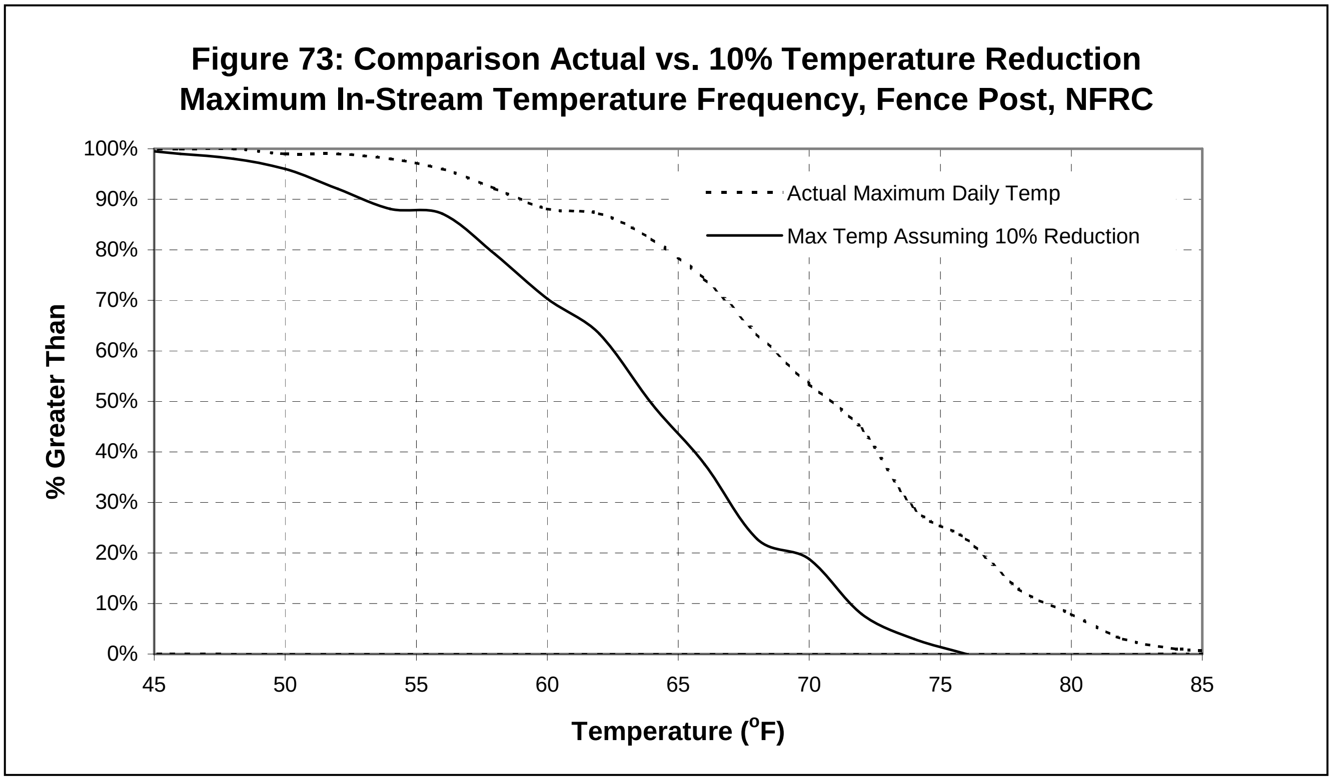


Figure 73: Comparison Actual vs. 10% Temperature Reduction
Maximum In-Stream Temperature Frequency, Fence Post, NFRC
Actual Maximum Daily Temp
Max Temp Assuming 10% Reduction
% Greater Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
45
50
55
60
65
70
75
80
85
Temperature (oF)

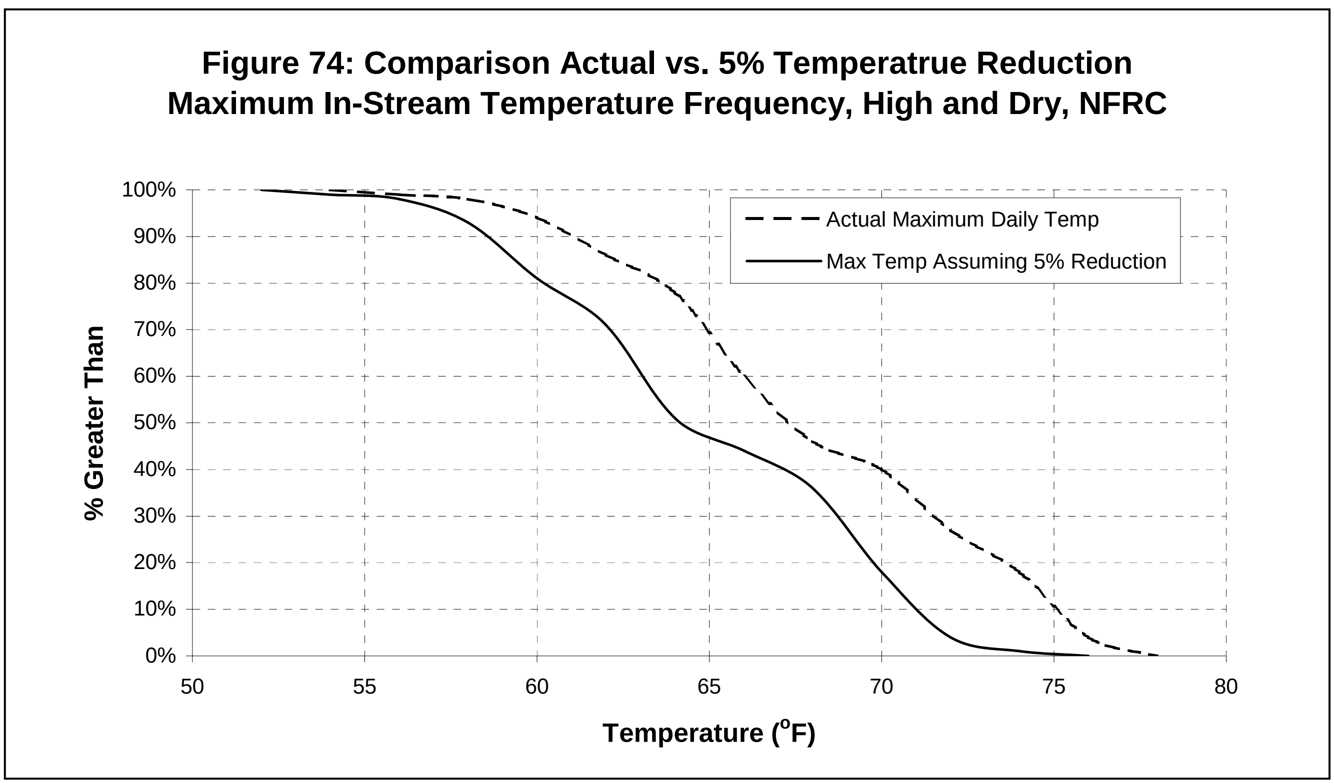


Figure 74: Comparison Actual vs. 5% Temperatrue Reduction
Maximum In-Stream Temperature Frequency, High and Dry, NFRC
Actual Maximum Daily Temp
Max Temp Assuming 5% Reduction
% Greater Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
50
55
60
65
70
75
80
Temperature (oF)

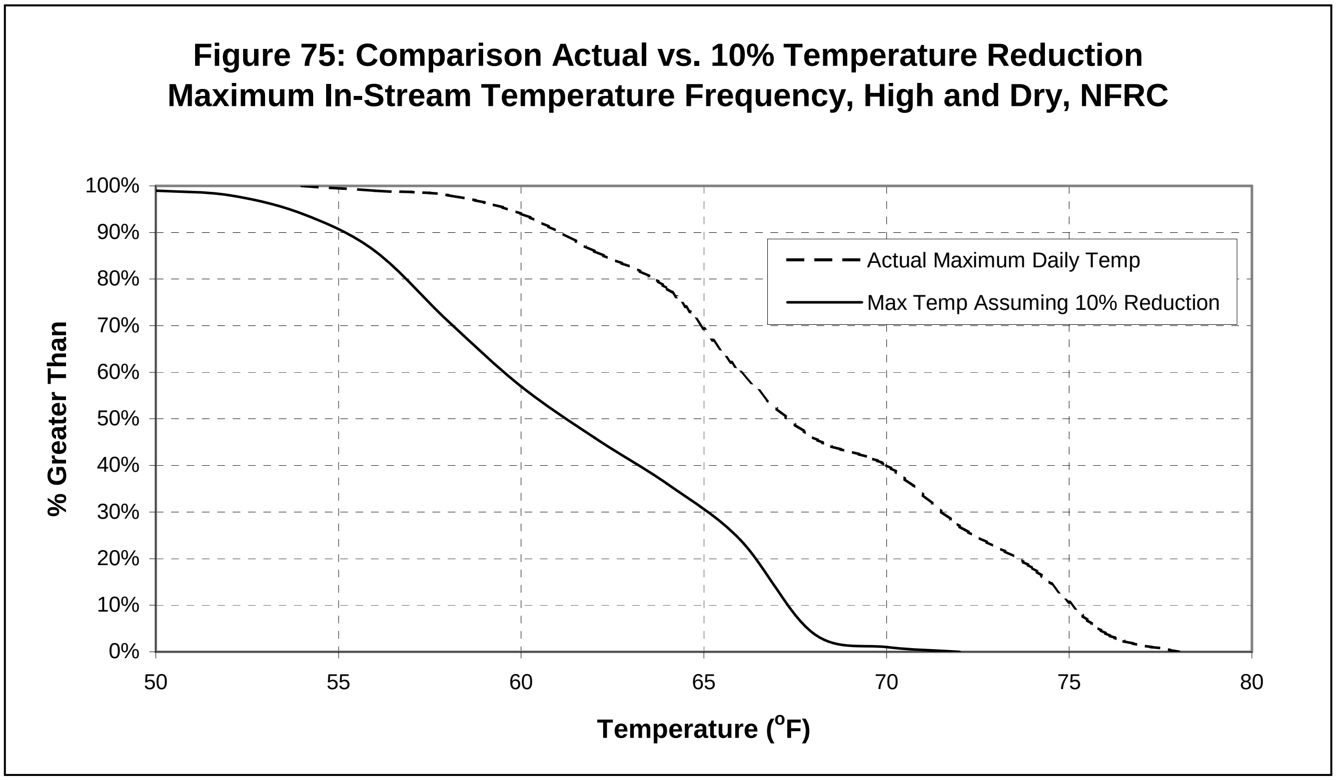


Figure 75: Comparison Actual vs. 10% Temperature Reduction
Maximum In-Stream Temperature Frequency, High and Dry, NFRC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Greater Than
50
55
60
65
70
75
80
Temperature (oF)
Actual Maximum Daily Temp
Max Temp Assuming 10% Reduction

SECTION 9: HABITAT IMPROVEMENT RECOMMENDATIONS

Clearly, two factors are affecting water quality in the Upper Rapid Creek watershed.

- Acid rock drainage and the resulting precipitates formed when the acid is neutralized is having a deleterious effect on stream substrate and associated benthic communities. This has a negative impact on the cold-water fishery.
- Temperature standards are being exceeded for the designated beneficial use of these streams, i.e. permanent cold-water permanent fish propagation.

The effects of acid rock drainage are discussed in Sections 4 and 5 of this report. Marginal improvements to in-stream temperature can be achieved if shading can be increased along portions of the streams which lack a protected riparian zone. This is particularly true along the North Fork Rapid Creek where destruction of riparian vegetation has been documented.

It is difficult to ascertain with certainty what natural conditions would be along the entire length of North Fork Rapid Creek in terms of stream cover and riparian vegetation. Since the Black Hills was first settled beginning in 1875-6, the forests have been heavily logged to support mining activities in the area. Indeed, the ghost town of Nahant located near the Fence Post monitoring site was established to support a sawmill, which supplied timber to nearby mines. Logging next to the creek would reduce cover and result in increased in-stream temperature. Livestock was also introduced very early in the area's settlement. The Bull Dog ranch (Big Dog sample site) provided beef to the Hearst Mercantile, the Homestake Mine Company's store, beginning in the late 1800's. Grazing next to the creek has undoubtedly altered the riparian zone and affected riparian vegetation.

There is one photo taken in the watershed, which shows North Fork Rapid Creek prior to settlement of the area (See Figure 76, page 114). The photo was taken on August 7, 1874, during the Custer expedition into the Black Hills at a location 2 miles south of the Fence Post monitoring site (Grafe and Horsted, 2002). The setting for the photo is a meadow. North Fork Rapid Creek is located in the background of the photo and dense brush, presumably willows, are visible along the creek. No other trees are visible in the photo. Grafe and Horsted after extensive research and investigation believe they found the location where the Custer bear photo was taken. They took another photo in 2002 at this location, which documents changes that have occurred since the Illingworth photo was taken in 1874. The Grafe and Horsted photo is shown in Figure 77, page 115, and clearly documents the fact that the riparian zone along North Fork Rapid Creek has been altered by removal of vegetation with any significant height.

Other photos taken during that expedition document the fact that the Black Hills contained fewer conifer trees than they do now. It is generally assumed that fire suppression in the Black Hills National Forest has resulted in an increase in tree density over the last one hundred years despite the extensive logging that has occurred. It is reasonable to assume therefore, that under natural conditions, North Fork Rapid Creek would not flow through a dense forest of conifer trees nor through a completely open valley. Rather, it would flow through a valley with a riparian zone much more developed than it is today. Under natural conditions, clumps of willows and other brush would probably be present along extended portions of the stream. Shading of significant portions of the stream would occur from a well-developed riparian zone containing willows, grasses, and sedges.

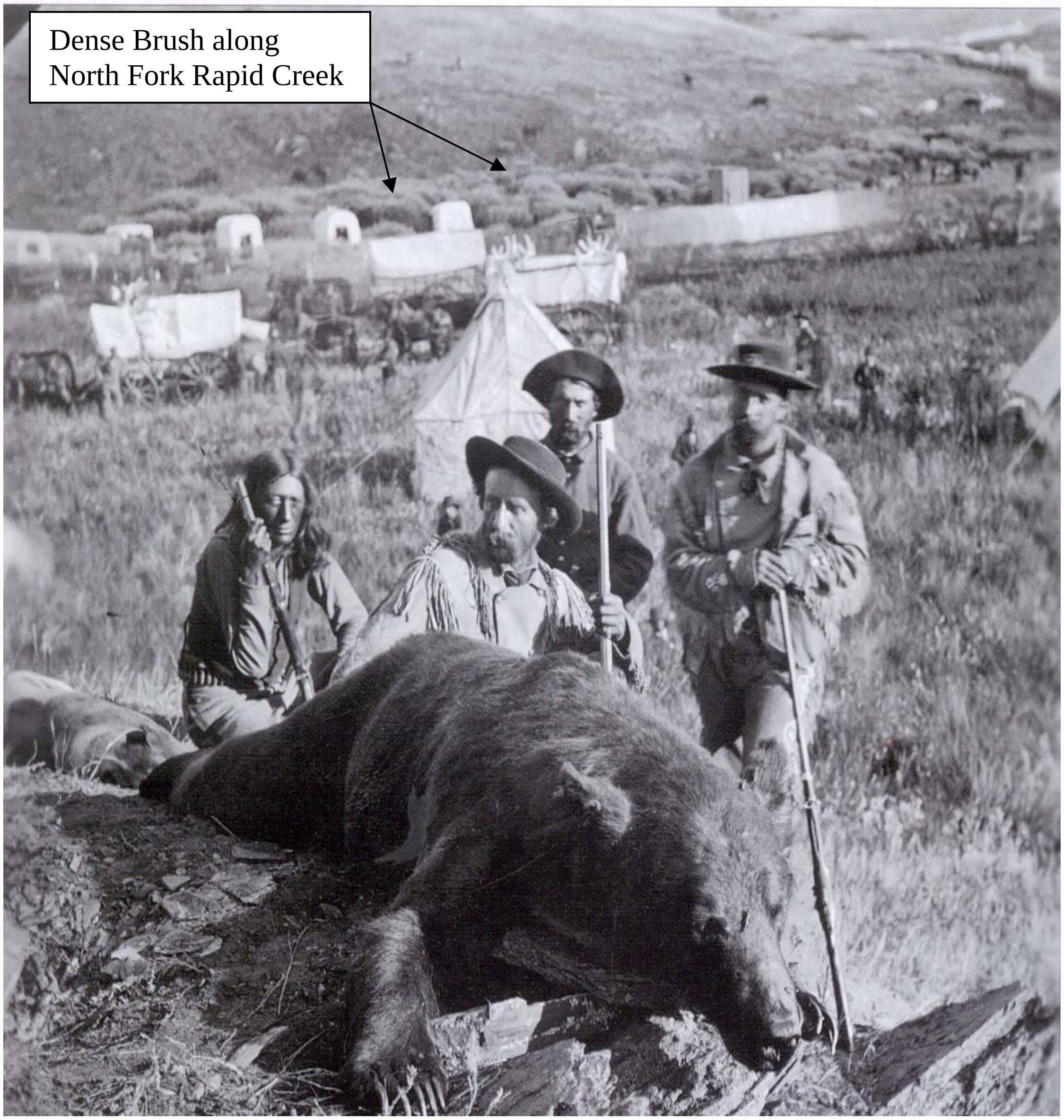


Figure 76: Custer’s Bear Photo showing North Fork Rapid Creek taken by W.H. Illingworth, August 7, 1874

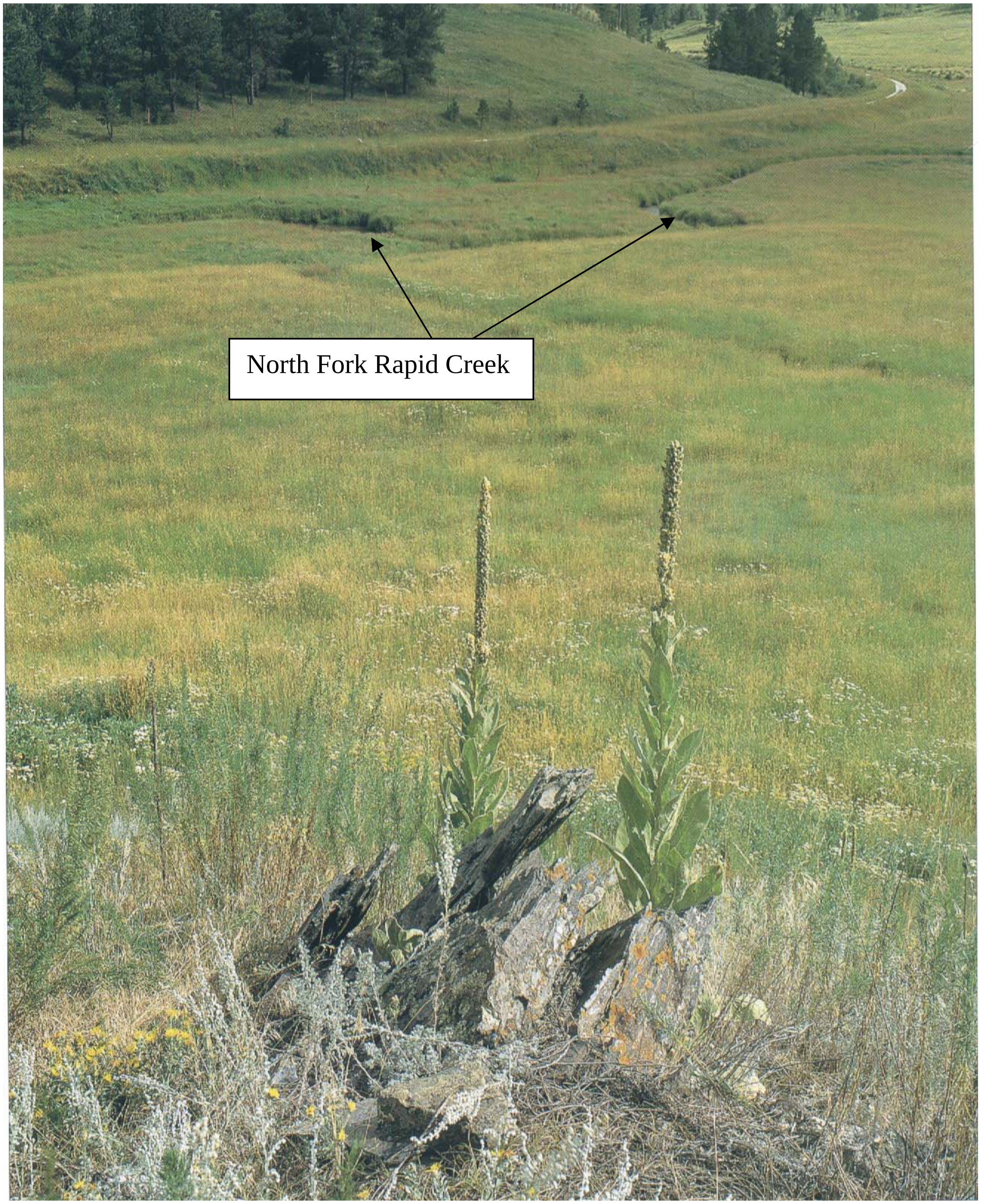


Figure 77: Photo taken at the Custer grizzly bear photo site on August 8, 2002. Note lack of vegetation along North Fork Rapid Creek. Photo from the book, "Exploring with Custer: The 1874 Black Hills Expedition", by Ernest Grafe and Paul Horsted, ©2002 Dakota Photographic LLC, Used with Permission.

Recommended Stream and Habitat Improvements Associated with the watershed Assessment and TMDL for Upper Rapid Creek

North Fork Rapid Creek

The North Fork Rapid Creek is on the Section 303 (d) waterbody list for exceedance of temperature criteria. The criteria are based on the beneficial use of cold-water permanent fish life propagation. Temperature monitoring from mid-June to mid-September 2002-03 showed that the maximum daily temperature exceeded the criteria 80% of the time in the upper reaches. Temperature modeling indicated that development of riparian zone vegetation could reduce in-stream temperature by 5 to 10 percent. It should be noted that:

1. Although North Fork Rapid Creek exceeds the temperature standard for its beneficial use, it does contain a viable, self-sustaining trout population, and
2. A decrease of in-stream temperature by 5 to 10 percent would still result in significant and extended violations of the in-stream temperature standard.

Iron bog seeps and springs occur along most of the reach but are more prominent along the lower reach. The discharges have their primary effect on the physical habitat in that the precipitates coat the bottom of the stream. This impact typically extends downstream from the seep or spring for a short distance. The bog leachate mixes with in-stream flow and, in the process, is neutralized and oxidized. As these processes occur, water quality improves and the amount of substrate precipitate decreases. Water quality and stream health improves. The extent of impact depends on the frequency of iron bog discharges and the flow. There is no feasible way to improve the quality of creek water or fish habitat where it is being impacted by spring flow through iron bogs located in the creek or immediately adjacent to the creek. However, by limiting impacts to sections of North Fork Rapid Creek from iron bogs located in its tributaries, incremental sections of the creek could be improved. If the bog leachate could be neutralized and the iron precipitated prior to entering the creek, over time, benthic populations would be established in the section of the creek below the tributary confluence resulting in improved fish habitat.

There are three general stream improvements that are recommended for the North Fork of Rapid Creek:

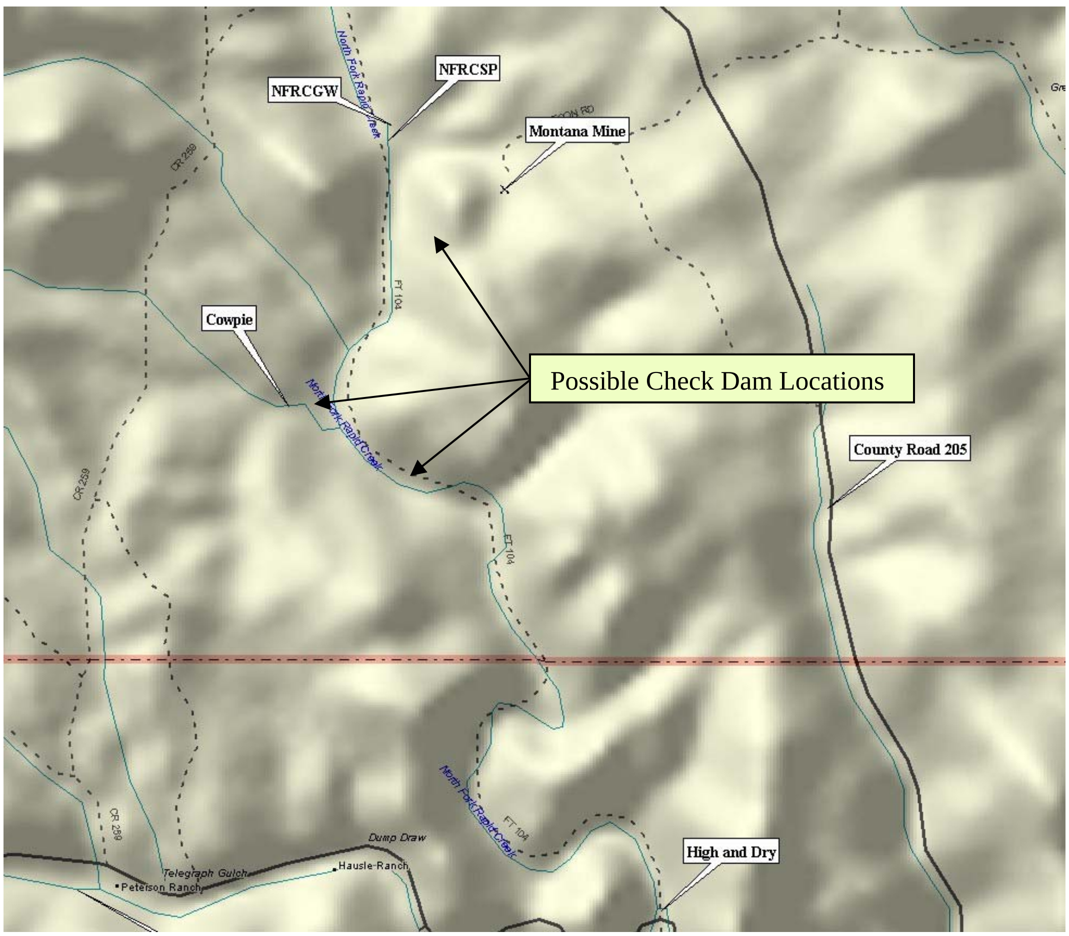
1. Riparian vegetation can be planted and protected allowing for the development of a dense growth of shrubs and willows. This vegetation did exist at one time as documented by photographs from Custer's expedition of 1874. Additionally, this reach could be enhanced by developing pool habitat structures.
2. Where the "Cowpie " drainage enters the lower reach of North Fork Rapid Creek, a series of check dam structures could be placed to allow iron oxidation to occur within a short distance from a major iron bog. This should result in concentrating precipitates prior to them reaching the North Fork Rapid Creek. This will reduce the extent of stream substrate impacted from the Cowpie drainage (See Map No.7, Page 117). The drainage might also be improved by reclaiming some tailings piles located adjacent to the drainage at its head.

3. Downstream of the Montana mine site the stream could be enhanced by strategic placement of check dam structures to trap precipitates where seeps occur along NFRC (See Map No.7, Page 117).

The proposed locations of check dams shown on Map No.7, page 117 are generalized locations. A site visit by interested parties is recommended for the purposes of establishing actual check dam sites and finalizing plans for remedial activities prior to initiating such activities.

Castle Creek and North Fork Castle Creek

A major focus of the Castle Creek assessment was to determine the impact of North Fork Castle Creek on Castle Creek water quality. Water samples collected in both creeks show good water quality. However, flow from seeps, iron bogs and springs provide a



Map No 7: Possible Check Dam Locations, North Fork Rapid Creek

source of high concentrations of dissolved iron, which immediately precipitates and coats the stream substrate. The impact in Castle Creek is clearly seen in the two orders of magnitude reduction in benthic macro invertebrates.

The iron bog impact area on Castle Creek starts just upstream from its confluence with North Fork Castle Creek. This influence area is due to geological characteristics. The North Fork Castle Creek is influenced starting just upstream of Rochford Road to its confluence with Castle Creek.

Castle Creek was evaluated for a short distance downstream of the confluence of North Fork Rapid Creek. Approximately, ¼ to ½ mile downstream of the confluence of North Fork Castle Creek, Castle Creek does show visual signs of improvement. However, due to the magnitude of flow and level of impact of iron bog, the feasibility of improvements on the short stretch of Castle Creek below the confluence of North Fork Castle Creek is very low.

Recommendations for Castle Creek and North Fork Castle Creek are,

1. High flows preclude the establishment of check dams on Castle Creek. The North Fork Castle Creek has a major impact on Castle Creek, although small seeps located adjacent to the creek and within the creek also contribute iron-rich acid drainage to Castle Creek. Because of the extent of impact from North Fork Castle Creek, the feasibility of fisheries improvements are limited for the reach of Castle Creek below the confluence with North Fork Castle Creek.
2. The iron bog impact on North Fork Castle Creek is extensive. Due to the extent and level of natural sources of bog leachate, the ability to make significant improvements is limited. North Fork Castle Creek flows through several iron bog deposits just prior to its confluence with Castle Creek. Because of the bog locations just upstream from the confluence with Castle Creek, check dams would not be a feasible mitigation measure for this discharge. Management of the riparian zone could however improve bank stability and reduce bank erosion.
3. Castle Creek immediately above and below its confluence with North Fork Castle Creek appears to have been channelized and straightened. However, above this section, the creek has experienced minimal anthropogenic impacts. It is recommended that the riparian zone be protected and cattle access limited to protect this reach of Castle Creek as a potential reference reach.

Impacts to streams from iron bog leachate are natural. It would occur without anthropogenic influences. However, it is possible that in localized areas, impact has been exasperated as a result of mining activities. Other human disturbances also affect the watershed. The development of the railroad adjacent to North Fork Rapid Creek and the roads constructed along portions of Castle Creek, North Fork Castle Creek and North Fork Rapid Creek undoubtedly result in increased sediment loading of these creeks. Cattle grazing also impact these streams. At several locations cattle crossing creeks have trampled streams banks. Although water quality standards were not violated, elevated levels of fecal coliform were found in samples taken from creeks where cattle were grazing.

SECTION 10: QUALITY ASSURANCE & QUALITY CONTROL

A quality assurance and quality control program was instituted to insure the accuracy of data collected during this study. The QA/QC program consisted of collecting duplicate samples and preparing field blanks on a random basis during sampling events. A total of 77 samples were collected during the sampling program. Seven duplicate samples were collected, and seven field blanks were prepared during the study. This represents a direct check on 9% of the samples collected. A comparison of the duplicate samples collected and results from the field blanks are contained in Tables 27 and 28, Pages 119 and 120. Taking the absolute value of the difference in concentrations between the two samples and dividing it by the sum of the concentration of the two samples resulted in a variation between samples. The variation was converted to a percentage by multiplying by 100.

DISCUSSION

Duplicate samples were collected in the field and handled in the same manner as the sample it duplicated. Section 4: Water Chemistry contains a description of the protocols used when collecting field samples. Field blanks were prepared in the field with de-ionized water transported to the field from the Environmental Chemistry Laboratory located in the Civil and Environmental Laboratory at the South Dakota School of Mines campus. The same equipment and process were used to collect, prepare and bottle the field samples as was used to process and bottle field blanks.

There is very good correlation between duplicate samples. This indicates that consistencies in both field methods and in laboratory analytical procedures were achieved. Some duplicate sample results varied as much as 50%. However, inspection of the results shows that, without exception, variation greater than 10% is the result of changes in sample parameters with extremely small concentration. When concentrations are very low, small differences in samples can present a large percentage change, which tends to skew average percent difference between samples. For example, the difference in analytical results between duplicates was 50% in the June 10, 2002, Cat Scat sample for the parameters total dissolved phosphorous and total phosphorous. But this 50% represents a difference in concentration from 0.01 mg/L to 0.03 mg/L for each of the two parameters. At these minute concentrations, the actual difference (0.02 mg/L) is insignificant.

The field blanks indicate if field samples are being contaminated in the field. Field contamination results from using equipment that has not been cleaned or inadvertently introducing foreign matter into the sample. With a few exceptions, field blanks showed no contamination. Three samples showed contamination with alkalinity of between 2 to 6 mg/L. Two samples showed contamination with total dissolved solids of between 8 and 18 mg/L. Average concentration of alkalinity in the duplicate samples was 175 mg/L, 6 mg/L is 3.4% of 175 mg/L. Average concentration of total dissolved solids is 232 mg/L; 18 mg/L is 7.8% of 232 mg/L.

Table 27: Comparison of Duplicate Samples

SITE ID	DATE & TIME	QA/QC BLK/DUP	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	AMM (mg/L)	NIT (mg/L)	TDP (mg/L)	TOTAL P (mg/L)
HIGH & DRY	12/13/2001 10:00	Sample	ND	170	250	230	20	ND	0.13	0.03	0.03
HIGH & DRY	12/13/2001 12:00	DUPLICATE	ND	150	251	230	21	ND	0.14	0.02	0.03
			0.0%	**6.3%**	**0.2%**	**0.0%**	**2.4%**	**0.0%**	**3.7%**	**20.0%**	**0.0%**
ONE TO MANY	4/16/2002 9:45	Sample	ND	230	229	210	19	0.1	0.12	0.258	0.27
ONE TO MANY	4/17/2002 9:45	DUPLICATE	ND	230	219	200	19	0.1	0.12	0.333	0.34
			0.0%	**0.0%**	**2.2%**	**2.4%**	**0.0%**	**0.0%**	**0.0%**	**12.7%**	**11.5%**
CAT SCAT	4/30/2002 11:15	Sample	5	214	251	240	11	ND	0.17	ND	0.02
CAT SCAT	4/30/2002 11:15	DUPLICATE	2	212	221	210	11	ND	0.13	0.018	0.02
			42.9%	**0.5%**	**6.4%**	**6.7%**	**0.0%**	**0.0%**	**13.3%**	**0.0%**	**0.0%**
HORSE TOOTH	5/14/2002 10:40	Sample	ND	150	180	180	ND	0.3	ND	0.02	0.04
HORSE TOOTH	5/14/2002 10:40	DUPLICATE	ND	150	160	160	ND	ND	ND	0.017	0.05
			0.0%	**0.0%**	**5.9%**	**5.9%**	**0.0%**	**0.0%**	**0.0%**	**8.1%**	**11.1%**
CAT SCAT	6/10/2002 11:45	Sample	2	200	197	190	7	0.1	0.05	0.01	0.01
CAT SCAT	6/10/2002 11:45	DUPLICATE	2	200	240	240	ND	ND	ND	0.03	0.03
			0.0%	**0.0%**	**9.8%**	**11.6%**	**0.0%**	**0.0%**	**0.0%**	**50.0%**	**50.0%**
BIG DOG	6/27/2002 13:38	Sample	78	210	210	210	ND	ND	ND	ND	ND
BIG DOG	6/27/2002 13:38	DUPLICATE	66	218	210	210	ND	ND	ND	ND	0.04
			8.3%	**1.9%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
OUTLAW'S BRIDGE	8/21/2002 11:38	Sample	10	58	393	370	23	ND	0.06	0.012	0.02
OUTLAW'S BRIDGE	8/21/2002 11:38	DUPLICATE	10	58	395	370	25	ND	0.05	ND	ND
			0.0%	**0.0%**	**0.3%**	**0.0%**	**4.2%**	**0.0%**	**9.1%**	**0.0%**	**0.0%**
		AVE	**7.3%**	**1.2%**	**3.5%**	**3.8%**	**0.9%**	**0.0%**	**3.7%**	**13.0%**	**10.4%**

FECAL COL: Fecal Coliform
ALKA: Alkalinity
TOT SOL: Total Solids
TDS: Total Dissolved Solids
TSS: Total Suspended Solids
AMM: Nitrogen as Ammonia
NIT: Nitrogen as Nitrate
TDP: Total Dissolved Phosphorus
TOTAL P: Total Phosphorus

Figure 28 Field Blank Analytical Results

DATE & TIME	QA/QC BLK/DUP	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	AMM (mg/L)	NIT (mg/L)	TDP (mg/L)	TOTAL P (mg/L)
12/13/2001 12:00	FIELD BLANK	ND	2	ND	ND	ND	ND	ND	ND	ND
4/17/2002 12:36	FIELD BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND
4/30/2002 14:00	FIELD BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND
5/14/2002 12:45	FIELD BLANK	ND	ND	8	8	ND	ND	ND	ND	ND
6/13/2002 13:55	FIELD BLANK	ND	4	ND	ND	ND	ND	ND	ND	ND
6/24/2002 11:35	FIELD BLANK	ND	6	18	18	ND	ND	ND	ND	ND
8/20/2002 12:48	FIELD BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND

FECAL COL: Fecal Coliform
ALKA: Alkalinity
TOT SOL: Total Solids
TDS: Total Dissolved Solids
TSS: Total Suspended Solids
AMM: Nitrogen as Ammonia
NIT: Nitrogen as Nitrate
TDP: Total Dissolved Phosphorus
TOTAL P: Total Phosphorus

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APPENDIX A: LIST AND LOCATIONS OF IRON BOGS, UPPER RAPID CREEK WATERSHED

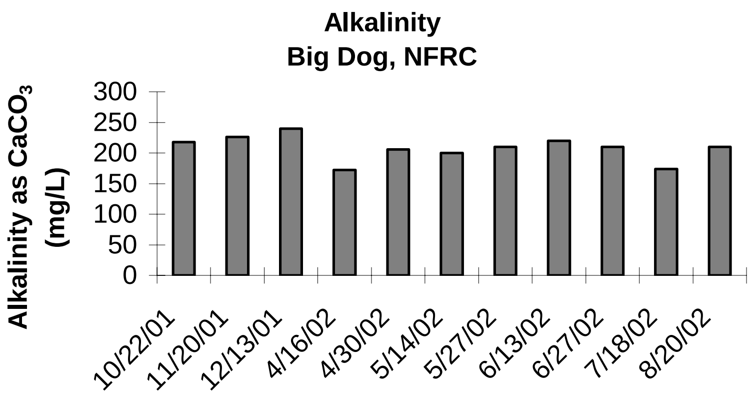
Watershed	Feature	Latitude (deg)	Longitude (deg)	Elevation (ft)	Date	Notes
North Fork Rapid Creek	bog	44.16177	-103.75155	5650	6/4/02	
North Fork Rapid Creek	bog	44.00000	-103.00000		6/4/02	
North Fork Rapid Creek	mine	44.15960	-103.74395	5810	6/4/02	Montana Mine
North Fork Rapid Creek	mill	44.16045	-103.75030	5620	6/4/02	Montana Mill
North Fork Rapid Creek	bog	44.15878	-103.75090	5630	6/4/02	
North Fork Rapid Creek	bog	44.15610	-103.75137	5620	6/4/02	
North Fork Rapid Creek	bog	44.15325	-103.75313	5590	6/4/02	
North Fork Rapid Creek	bog	44.15528	-103.76425	5745	6/4/02	Major source of NARD
North Fork Rapid Creek	bog	44.16063	-103.76030	5745	6/5/02	Spring
North Fork Rapid Creek	bog	44.15933	-103.76030	5733	6/5/02	Spring
North Fork Rapid Creek	pit	44.15682	-103.75665	5685	6/5/02	Mine pit
North Fork Rapid Creek	bog	44.15195	-103.76263	5716	6/5/02	
North Fork Rapid Creek	bog	44.15203	-103.76090	5680	6/5/02	
North Fork Rapid Creek	spring	44.15070	-103.75783	5656	6/5/02	
North Fork Rapid Creek	bog	44.16807	-103.75695	5650	6/5/02	
North Fork Rapid Creek	spring	44.17518	-103.75427	5705	6/5/02	
North Fork Rapid Creek	bog	44.17687	-103.75528	5710	6/5/02	
North Fork Rapid Creek	bog	44.17860	-103.75660	5734	6/5/02	
North Fork Rapid Creek	bog	44.18648	-103.76112	5771	6/5/02	
North Fork Rapid Creek	bog	44.18352	-103.75842	5736	6/6/02	
North Fork Rapid Creek	bog	44.18428	-103.75820	5727	6/6/02	
North Fork Rapid Creek	spring	44.18677	-103.75587	5805	6/6/02	
North Fork Rapid Creek	bog	44.15048	-103.75308	5620	6/7/02	
North Fork Rapid Creek	mine	44.14742	-103.74623	5590	6/7/02	
North Fork Rapid Creek	bog	44.13483	-103.74608	5675	6/7/02	
North Fork Rapid Creek	bog	44.13355	-103.74113	5500	6/7/02	
North Fork Rapid Creek	bog	44.17270	-103.74797	5780	6/7/02	
North Fork Rapid Creek	bog	44.16958	-103.74918	5755	6/7/02	
North Fork Rapid Creek	bog	44.16765	-103.75052	5750	6/7/02	
North Fork Rapid Creek	bog	44.18182	-103.75060	5863	6/7/02	
North Fork Castle Creek	bog	44.08748	-103.80203	5878	6/6/02	
North Fork Castle Creek	bog	44.08587	-103.79730	5964	6/6/02	
North Fork Castle Creek	bog	44.08635	-103.80103	5883	6/6/02	
North Fork Castle Creek	bog	44.08543	-103.79560	5872	6/10/02	
North Fork Castle Creek	bog	44.08527	-103.79450	5880	6/10/02	
North Fork Castle Creek	bog	44.08645	-103.78877	5830	6/10/02	No apparent iron drainage
North Fork Castle Creek	bog	44.08613	-103.78788	5843	6/10/02	
North Fork Castle Creek	bog	44.08548	-103.78288	5790	6/10/02	
North Fork Castle Creek	mine	44.08622	-103.78063	5790	6/10/02	Black Tunnel Mine
North Fork Castle Creek	bog	44.08607	-103.78035	5760	6/10/02	
North Fork Castle Creek	bog	44.08252	-103.76997	5755	6/10/02	
North Fork Castle Creek	bog	44.08210	-103.76935	5740	6/10/02	
North Fork Castle Creek	bog	44.08133	-103.76892	5740	6/10/02	
North Fork Castle Creek	bog	44.07673	-103.76358	5690	6/10/02	
North Fork Castle Creek	bog	44.07617	-103.76417	5678	6/10/02	
North Fork Castle Creek	bog	44.07220	-103.78082	5900	6/11/02	
North Fork Castle Creek	bog	44.07143	-103.78138	5854	6/11/02	
North Fork Castle Creek	bog	44.07485	-103.78192	5864	6/11/02	
North Fork Castle Creek	bog	44.07485	-103.78092	5833	6/11/02	
North Fork Castle Creek	bog	44.07473	-103.78030	5805	6/11/02	

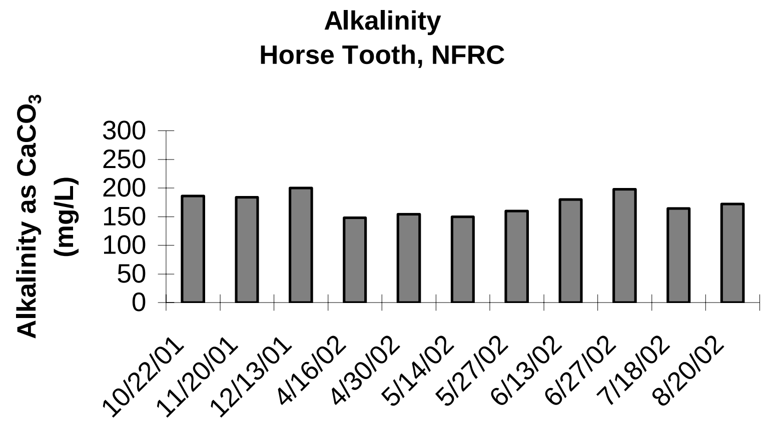
Watershed	Feature	Latitude (deg)	Longitude (deg)	Elevation (ft)	Date	Notes
North Fork Castle Creek	bog	44.07423	-103.77928	5870	6/11/02	
North Fork Castle Creek	bog	44.07570	-103.77613	5780	6/11/02	
North Fork Castle Creek	bog	44.07593	-103.77423	5760	6/11/02	
North Fork Castle Creek	spring	44.07598	-103.77043	5750	6/11/02	
North Fork Castle Creek	bog	44.07605	-103.76973	5740	6/11/02	
North Fork Castle Creek	bog	44.07460	-103.76405	5690	6/17/02	
North Fork Castle Creek	bog	44.07485	-103.74918	5570	6/17/02	
North Fork Castle Creek	bog	44.07228	-103.75165	5600	6/17/02	Cut-off meander
North Fork Castle Creek	bog	44.07263	-103.75100	5561	6/17/02	
North Fork Castle Creek	bog	44.07342	-103.74913	5610	6/17/02	
North Fork Castle Creek	pit	44.07437	-103.75983	5670	6/17/02	
North Fork Castle Creek	pit	44.07503	-103.75843	5660	6/17/02	
North Fork Castle Creek	mine	44.07502	-103.74925	5560	6/17/02	
North Fork Castle Creek	pit	44.06758	-103.75400	5600	6/17/02	
Rapid Creek (Bloody Gulch)	pit	44.11120	-103.69785	5280	7/31/02	
Rapid Creek (Bloody Gulch)	mine	44.11043	-103.69797	5360	7/31/02	Schist, chlorite, oxidized iron
Rapid Creek (Bloody Gulch)	bog	44.10758	-103.70108	5420	7/31/02	1 gpm
Rapid Creek (Bloody Gulch)	mine	44.10320	-103.70128	5420	7/31/02	
Rapid Creek (Bloody Gulch)	pit	44.10407	-103.70237	5440	7/31/02	
Rapid Creek (Bloody Gulch)	pit	44.10432	-103.70353	5440	7/31/02	
Rapid Creek (Silver Creek)	creek	44.12023	-103.69883	5268	7/31/02	At confluence with Rapid Creek
Rapid Creek (Silver Creek)	bog	44.16147	-103.71512	5705	7/31/02	Iron cemented conglomerate
Rapid Creek (Silver Creek)	spring	44.16290	-103.71570	5712	7/31/02	Iron discharge
Rapid Creek (Silver Creek)	bog	44.16518	-103.71870	5750	7/31/02	
South Fork Rapid Creek	bog	44.14558	-103.84560	5890	7/31/02	Black Fox
South Fork Rapid Creek (Rhoads Fork Creek)	spring	44.13092	-103.88565	6300	7/31/02	Madison ls
South Fork Rapid Creek	mine	44.14230	-103.84993	6010	7/31/02	
South Fork Rapid Creek	spring	44.16083	-103.87990	6270	7/31/02	
South Fork Rapid Creek	spring	44.15047	-103.83693	5950	7/31/02	Buck Spring
South Fork Rapid Creek	pit	44.14143	-103.80048	5704	7/31/02	
South Fork Rapid Creek	bog	44.13772	-103.79192	5650	8/6/02	
South Fork Rapid Creek	bog	44.12880	-103.78465	5660	8/6/02	Long Draw
South Fork Rapid Creek	bog	44.12593	-103.78990	5701	8/6/02	First iron in this system
South Fork Rapid Creek	bog	44.14130	-103.78928	5732	8/6/02	
South Fork Rapid Creek	bog	44.12275	-103.79180	5760	8/6/02	Long Draw
South Fork Rapid Creek	spring	44.12390	-103.80567	5910	8/6/02	Spring
South Fork Rapid Creek	bog	44.12288	-103.80047	5876	8/6/02	Dry, apparent charcoal present
South Fork Rapid Creek	bog	44.12237	-103.79840	5790	8/6/02	Old mine
South Fork Rapid Creek	bog	44.11958	-103.79623	5820	8/6/02	Maitland Draw
South Fork Rapid Creek	spring	44.11937	-103.79662	5830	8/6/02	Maitland Draw
South Fork Rapid Creek	spring	44.11940	-103.79712	5850	8/6/02	Maitland Draw
South Fork Rapid Creek	bog	44.12050	-103.79463	5820	8/6/02	
South Fork Rapid Creek	bog	44.13735	-103.77080	5624	8/6/02	Hop Creek
South Fork Rapid Creek	spring	44.13973	-103.77365	5690	8/6/02	Hop Creek spring
South Fork Rapid Creek	bog	44.12427	-103.75477	5635	8/6/02	Solomon Gulch
South Fork Rapid Creek	bog	44.11390	-103.76342	5767	8/6/02	Solomon Gulch

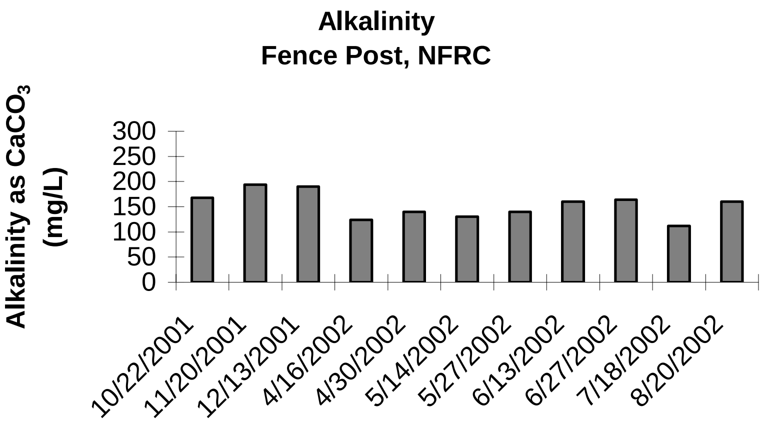
Appendix B: Water Chemistry Graphs

FIGURE 78: ALKALINITY, NORTH FORK RAPID CREEK

Standard for Fish and Wildlife Propagation, Recreation, & Stock Watering: 1313 mg/L daily max, 730 mg/L 30-day average
Detection Limit = 2 mg/L







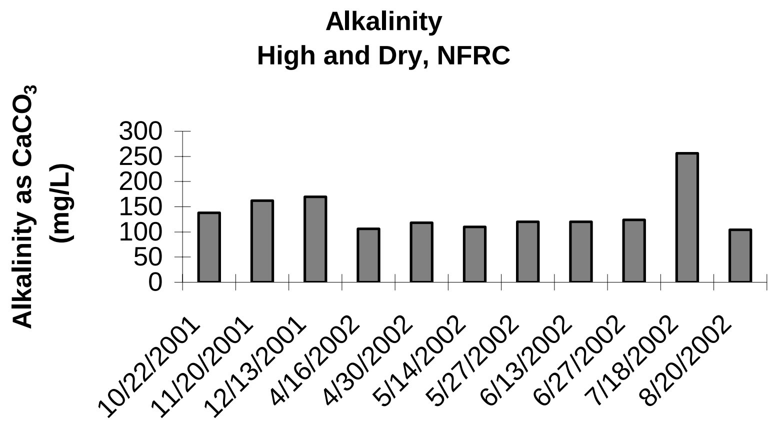
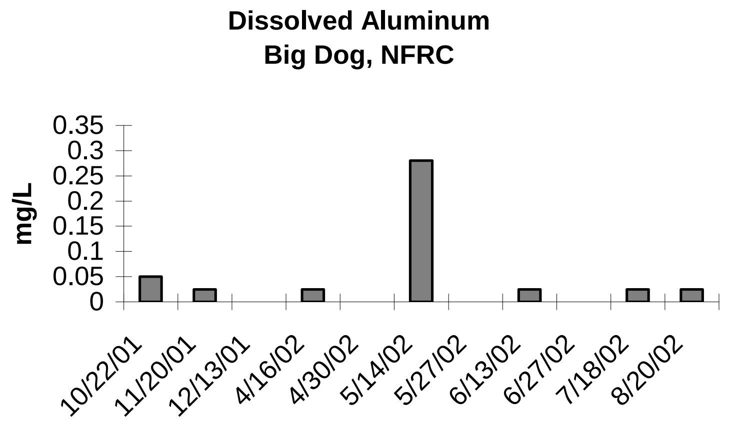
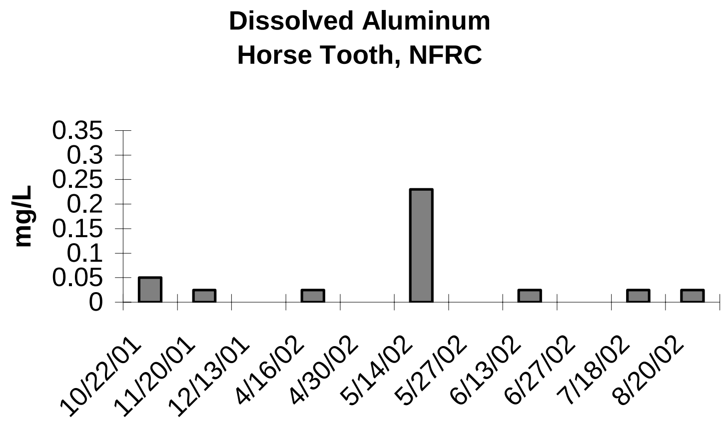
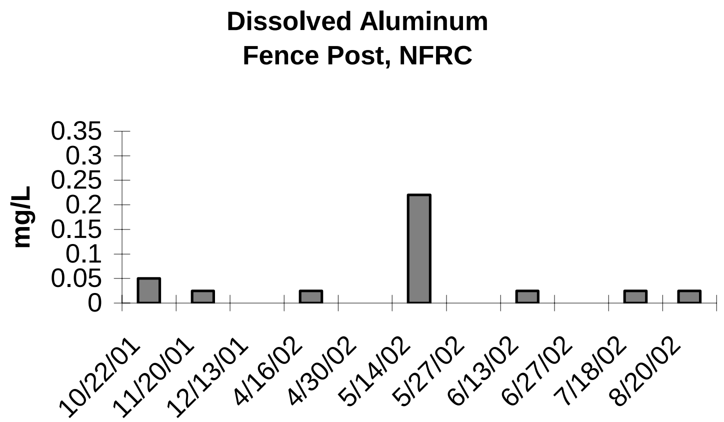


FIGURE 79: DISSOLVED ALUMINUM, NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 0.05 mg/L







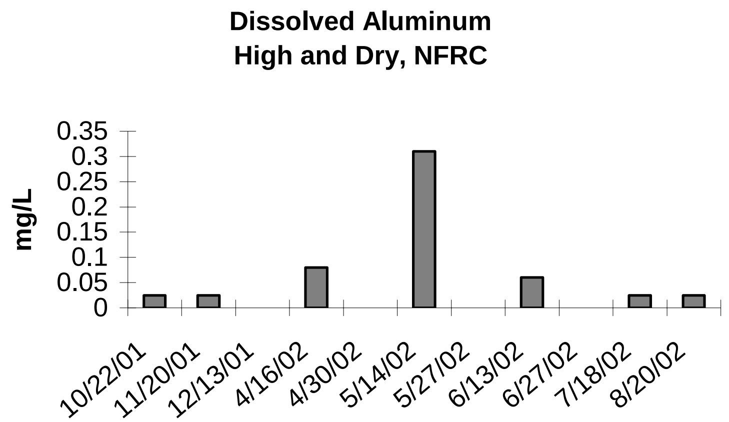
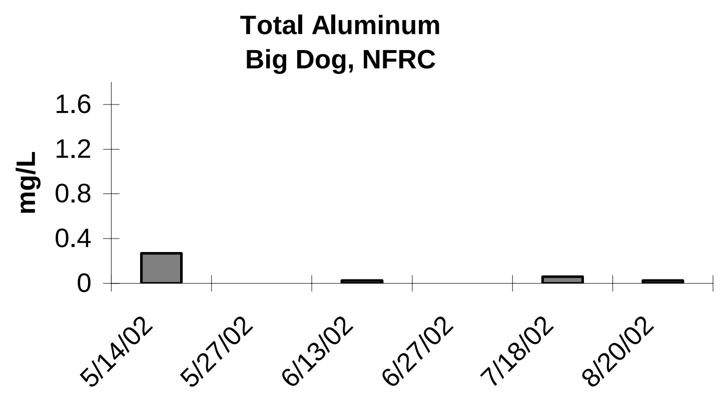
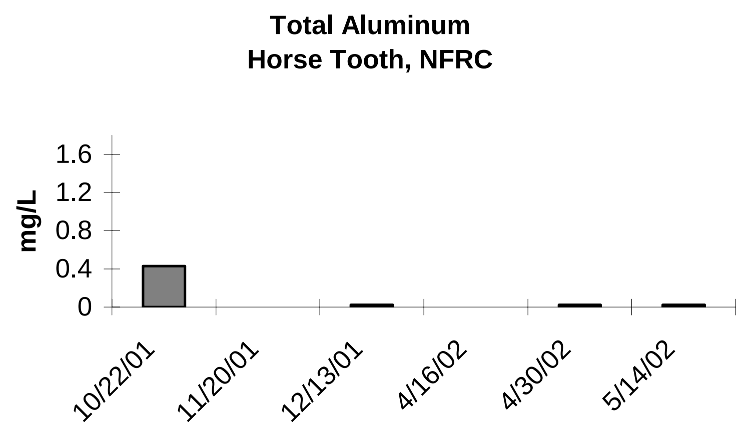
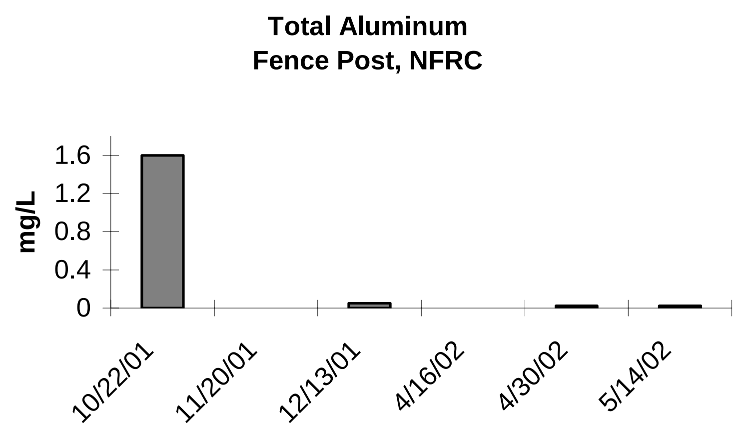


FIGURE 80: TOTAL ALUMINUM, NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 0.05 mg/L







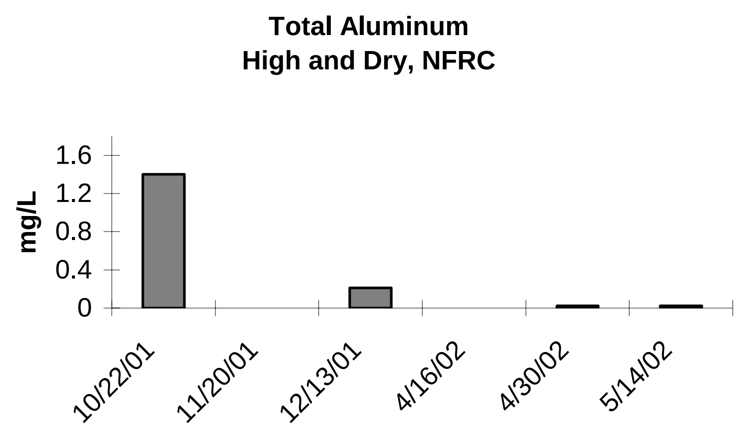
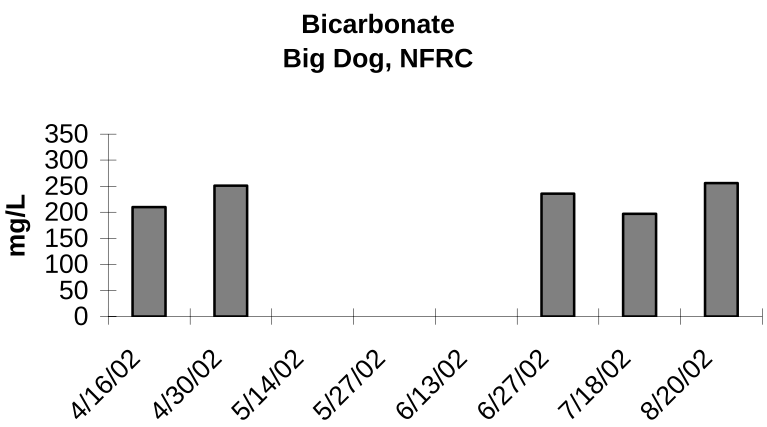
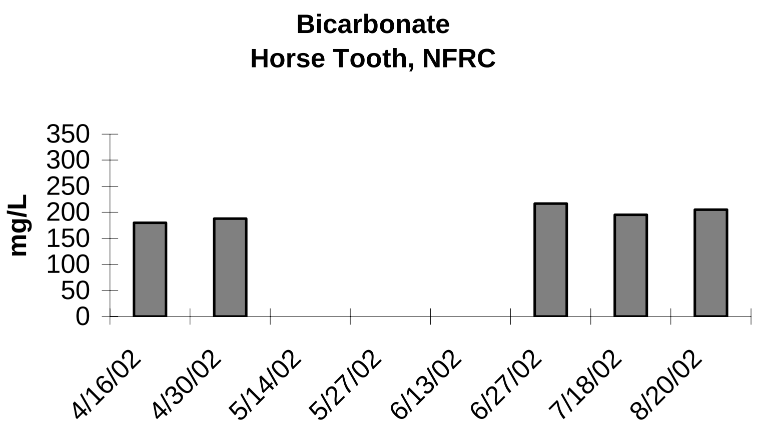
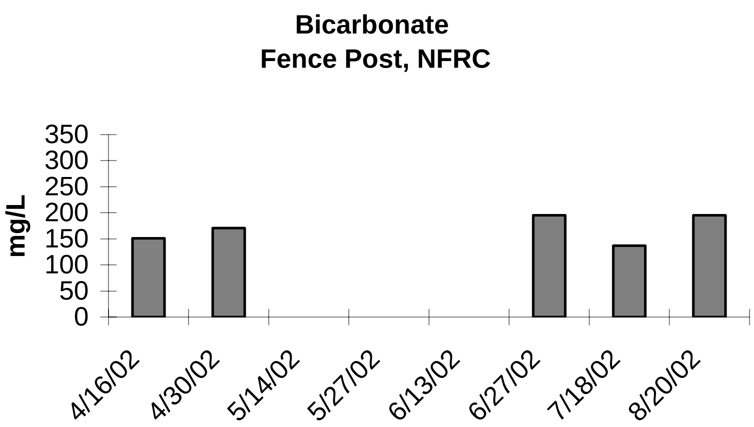


Figure 81: Bicarbonate (HCO_3^-), North Fork Rapid Creek
No Standard Established for Beneficial Uses, Detection Limit = 5 mg/L







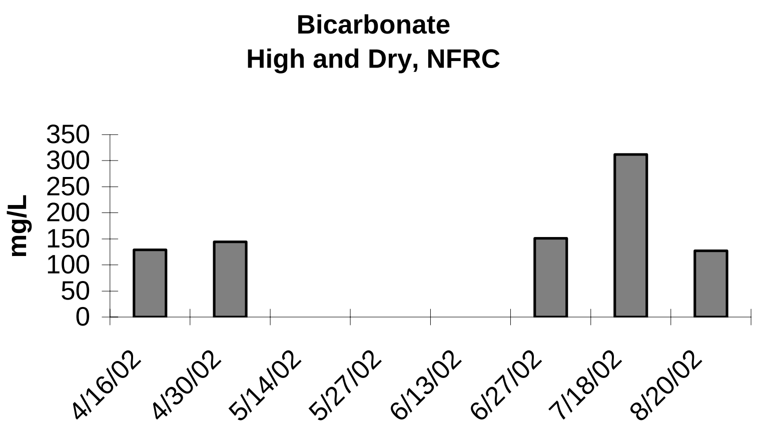
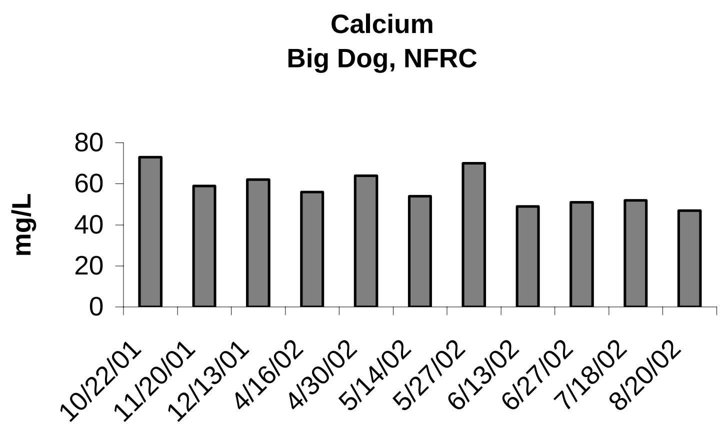
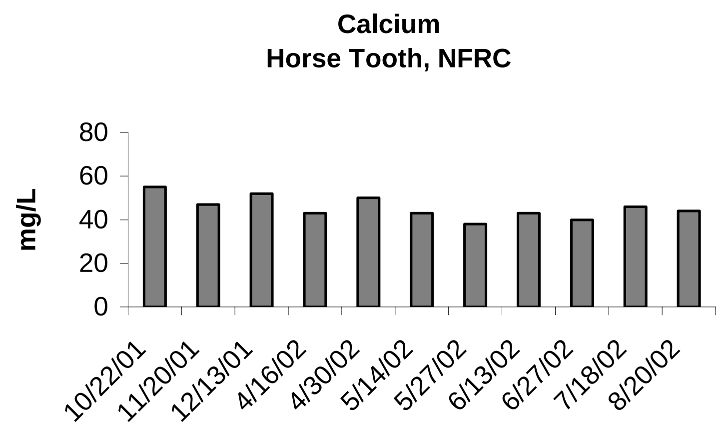
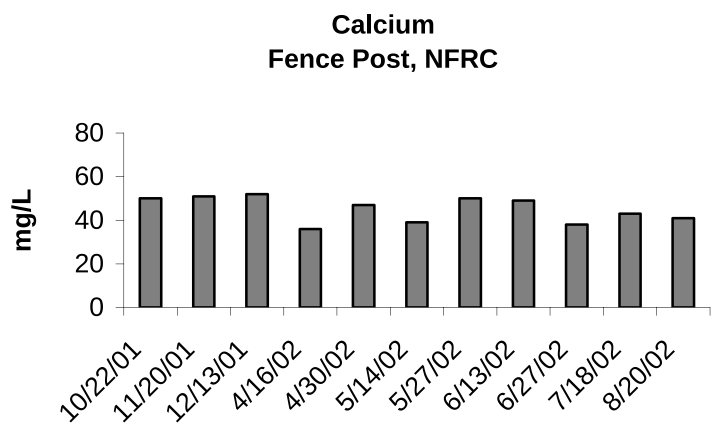


Figure 82: Calcium (Ca^{2+}), North Fork Rapid Creek
No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L







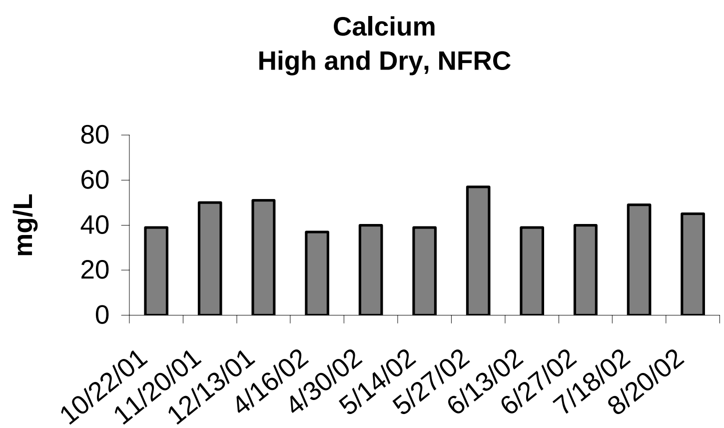
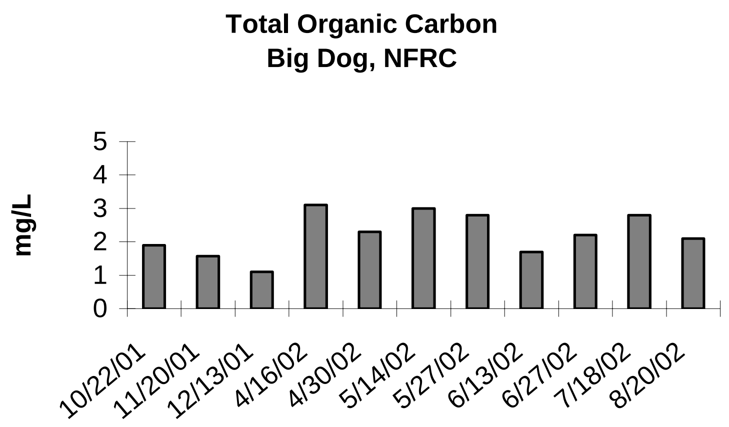
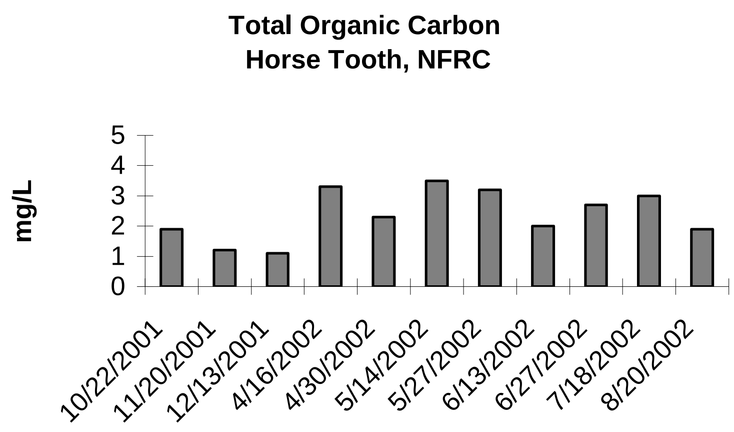
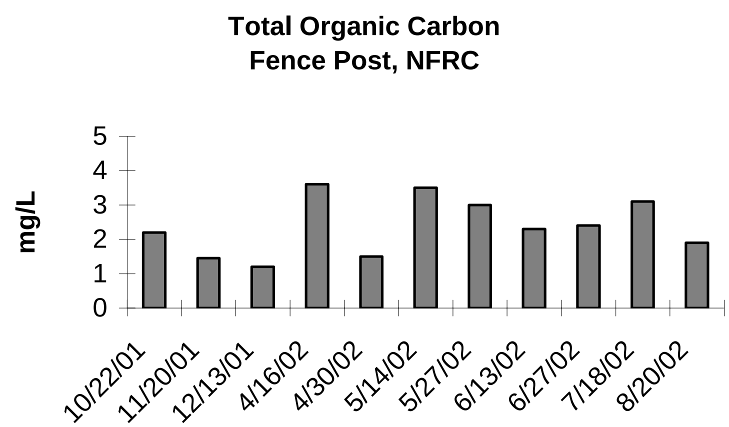


FIGURE 83: TOTAL ORGANIC CARBON, NORTH FORK RAPID CREEK
No Standard Established for Beneficial Uses, Detection Limit = 0.5 mg/L







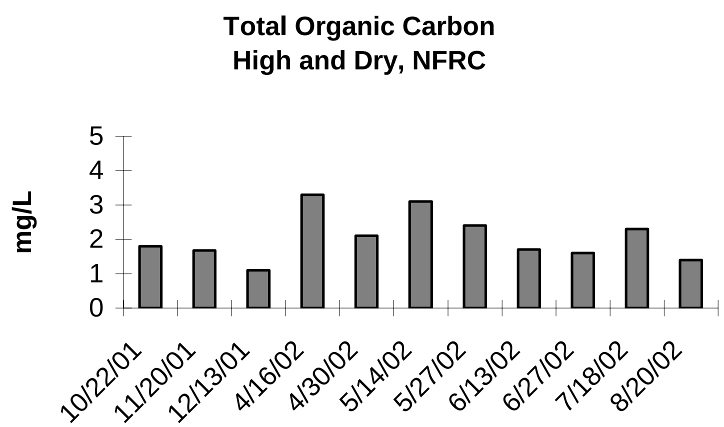
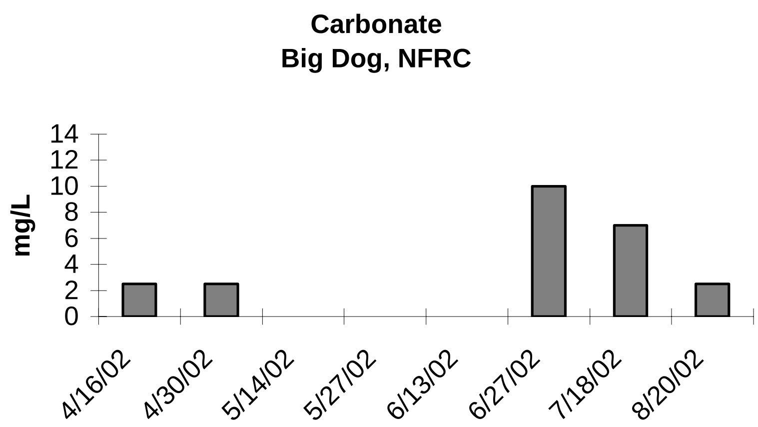
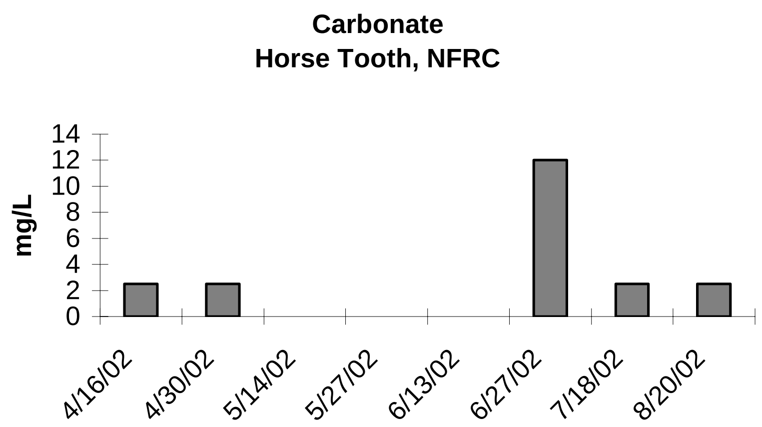
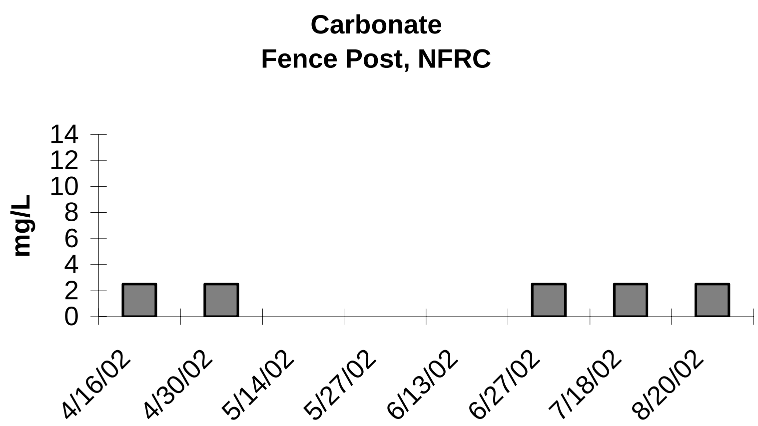


Figure 84: Carbonate (CO_3^{2-}), North Fork Rapid Creek

No Standard Established for Beneficial Uses, Detection Limit = 5 mg/L







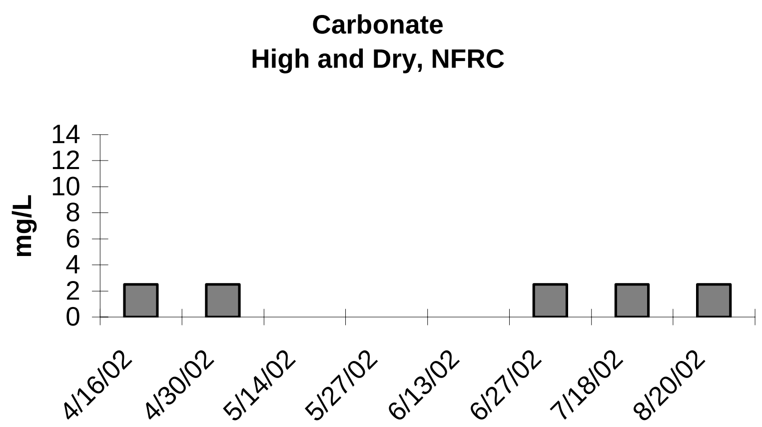
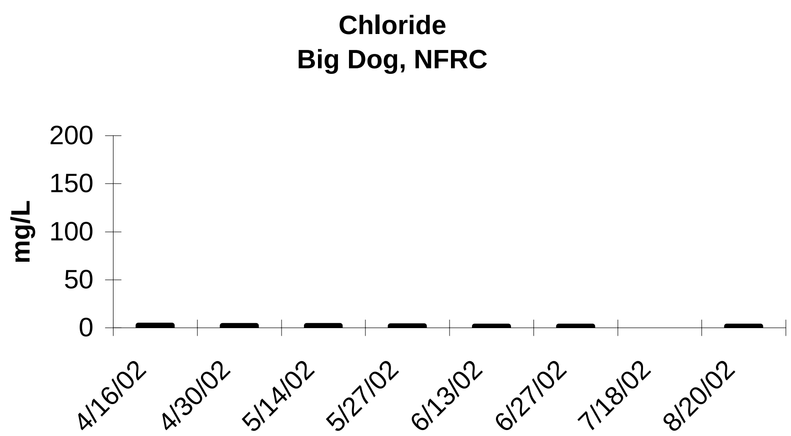
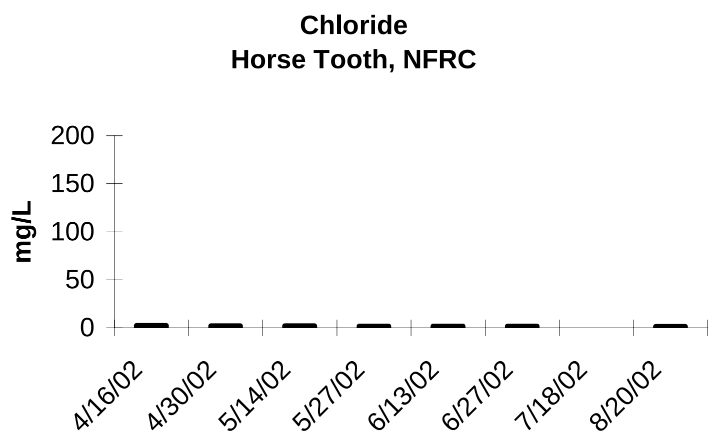
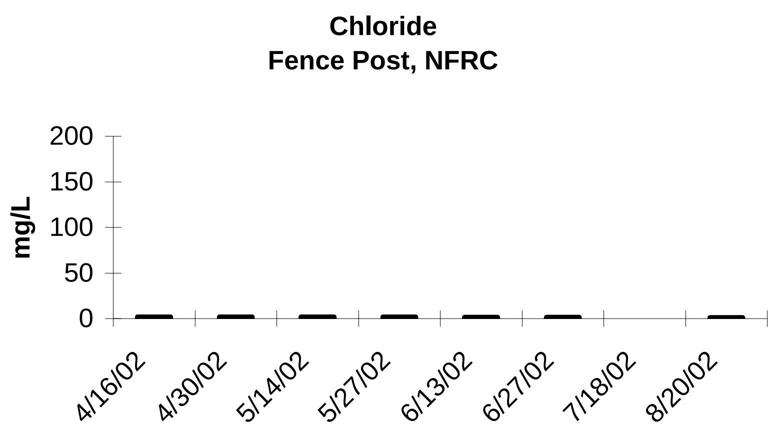


FIGURE 85: CHLORIDE, NORTH FORK RAPID CREEK

Standard for Cold Water Fishery: 175 mg/L daily max, 100 mg/L 30-day average, Detection Limit = 0.5 mg/L







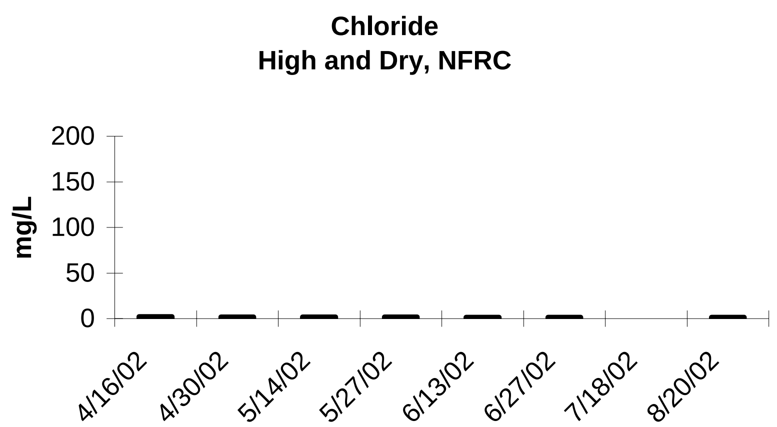
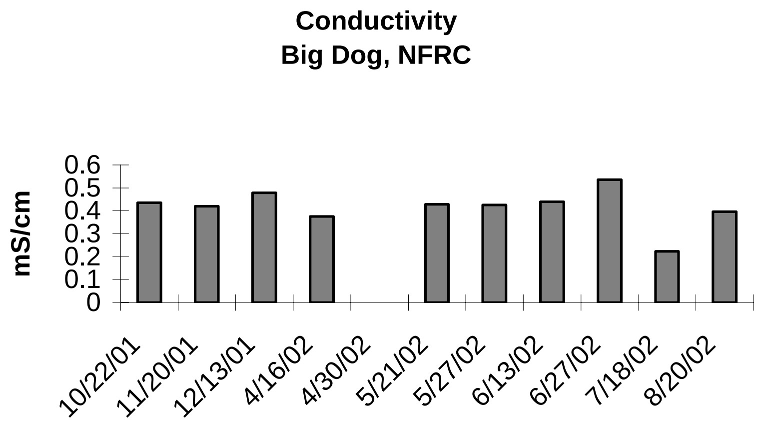
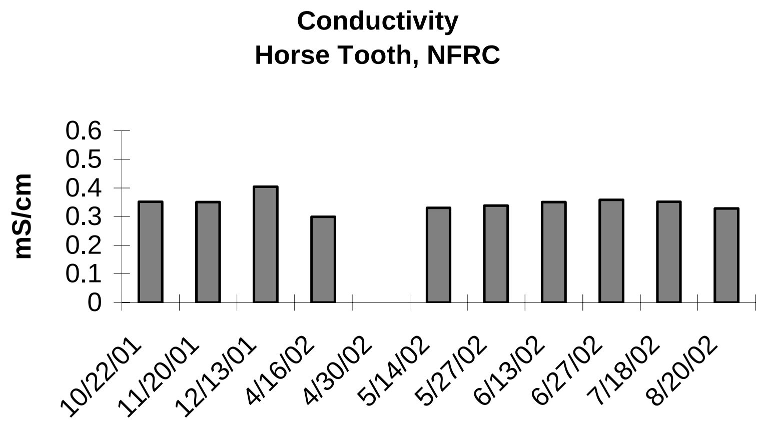
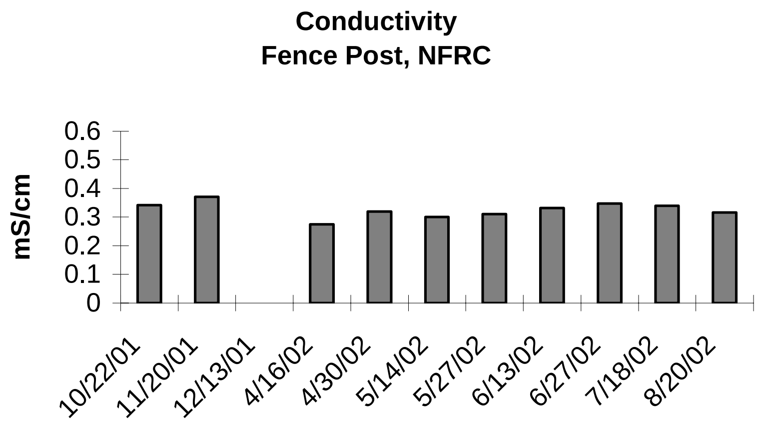


FIGURE 86: CONDUCTIVITY, NORTH FORK RAPID CREEK
Standard for Irrigation: 4.375 mS/cm daily max, 2.5 mS/cm 30-day average







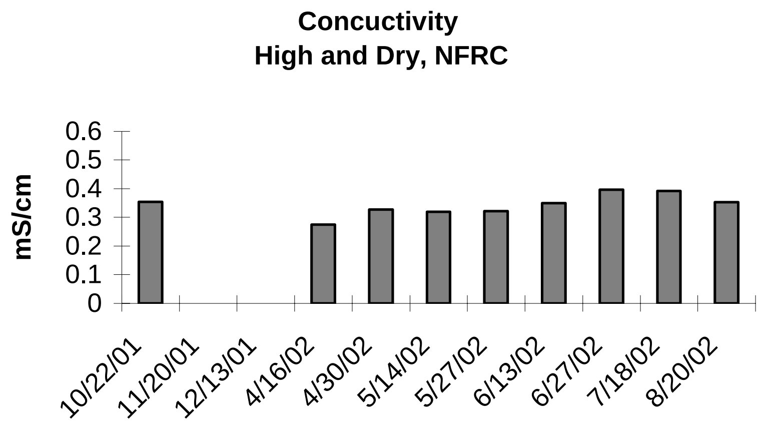


FIGURE 87: TOTAL FECAL COLIFORM, NORTH FORK RAPID CREEK

Limited Contact Recreation Standard: 1000 CFU/100ml mean of 5 daily samples, 2000 CFU/100ml daily max

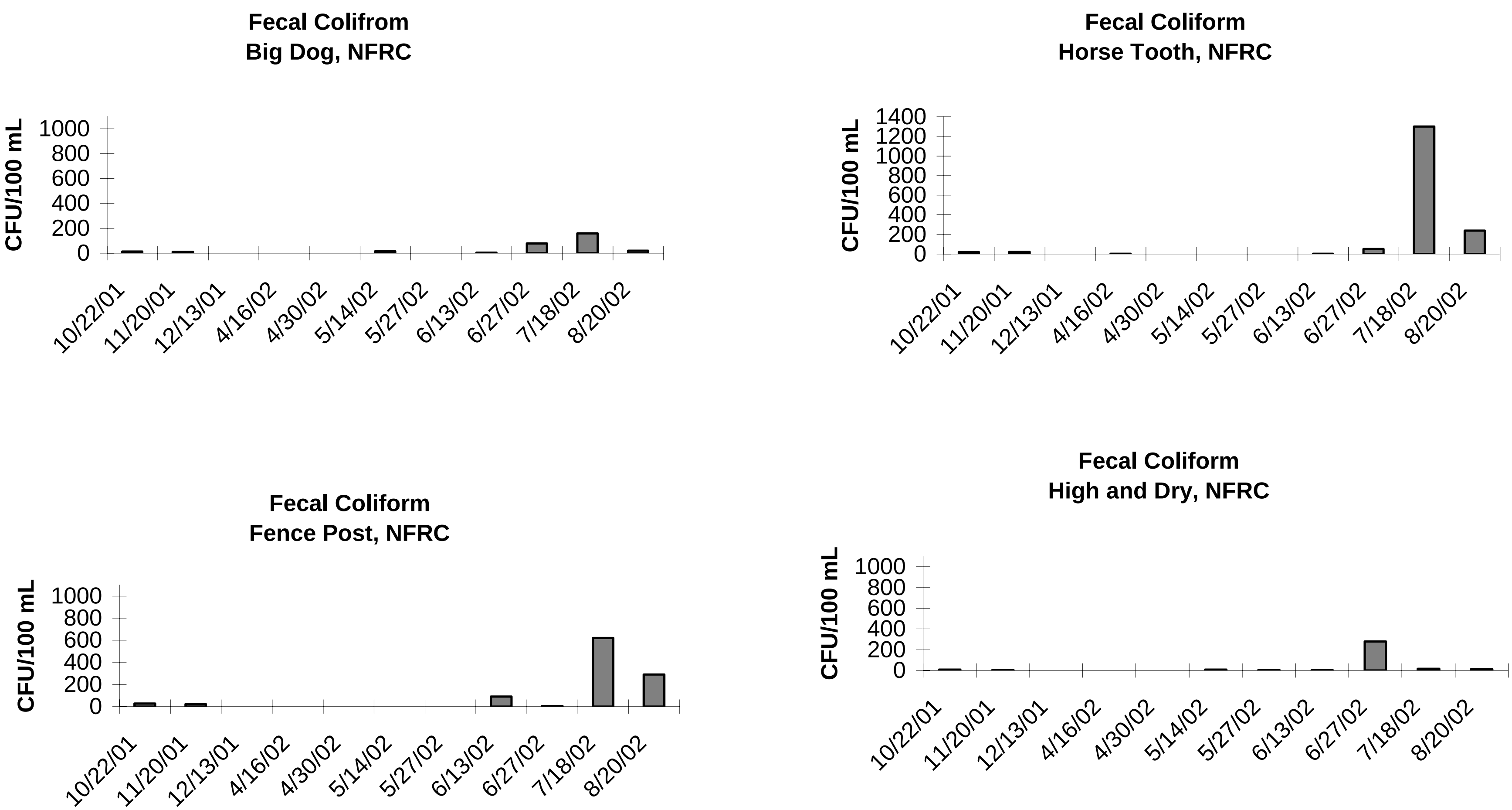
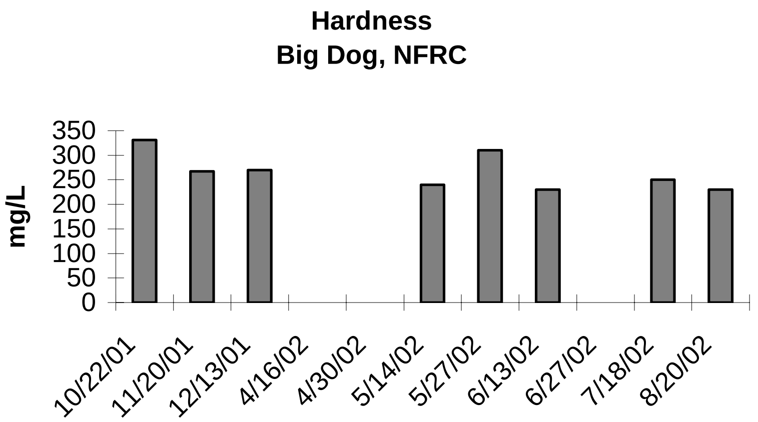
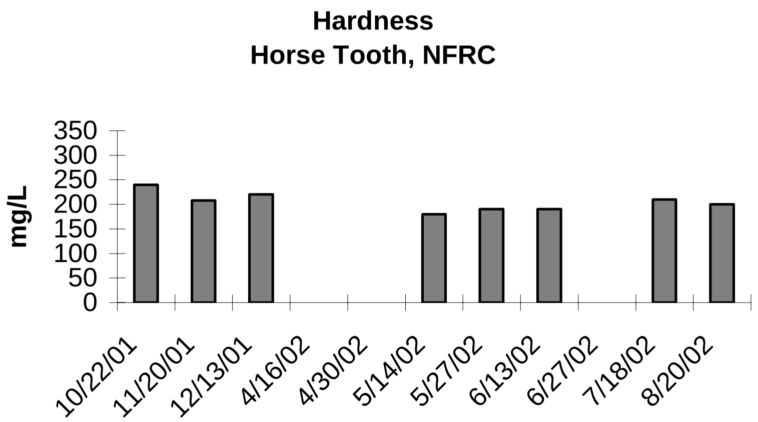
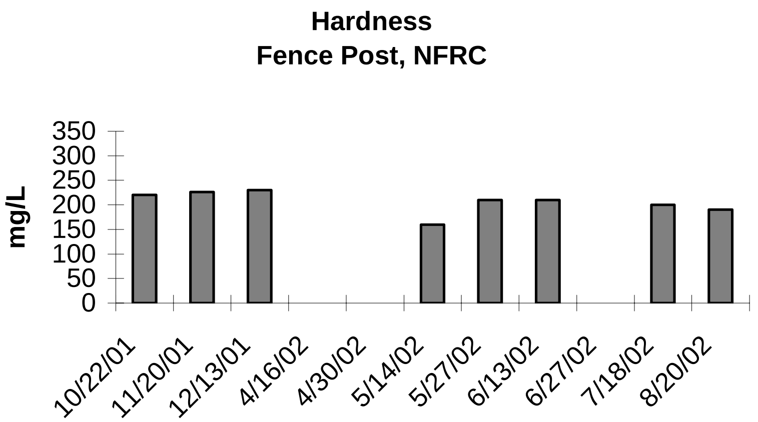


FIGURE 88: HARDNESS AS $CaCO_3$, NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L







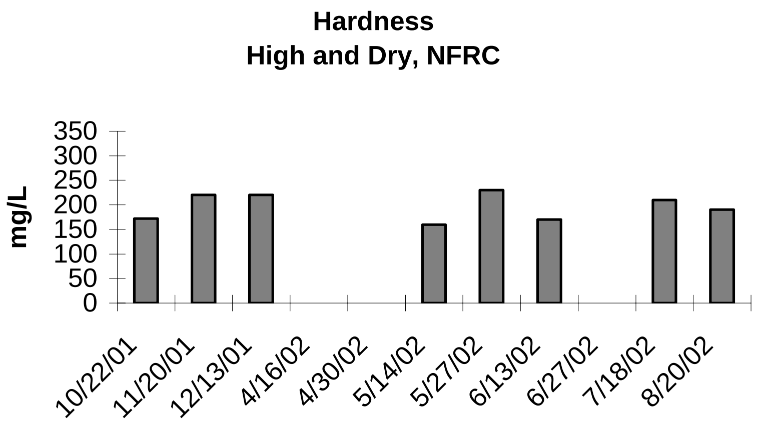
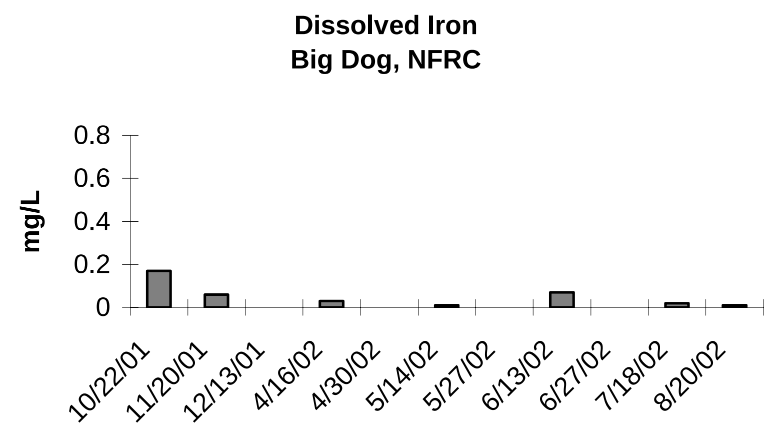
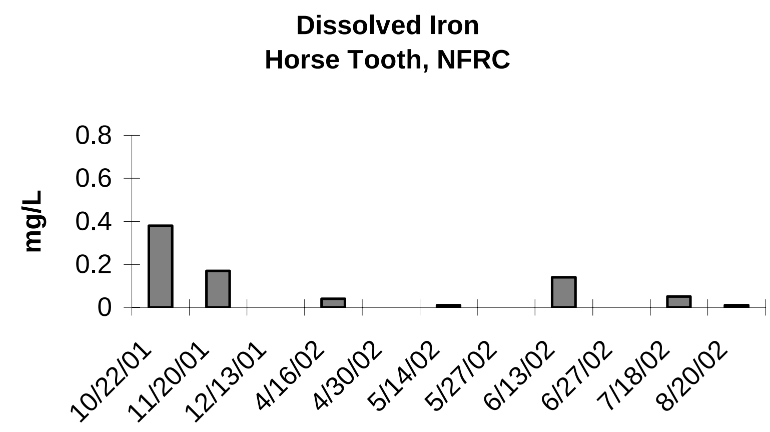
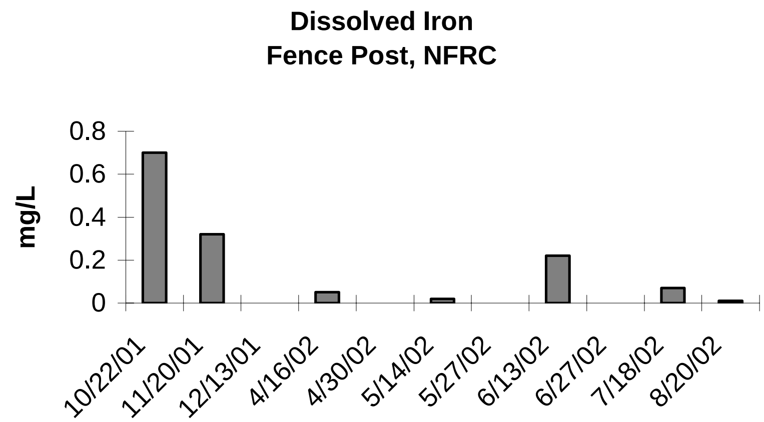


FIGURE 89: DISSOLVED IRON, NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 0.02 mg/L







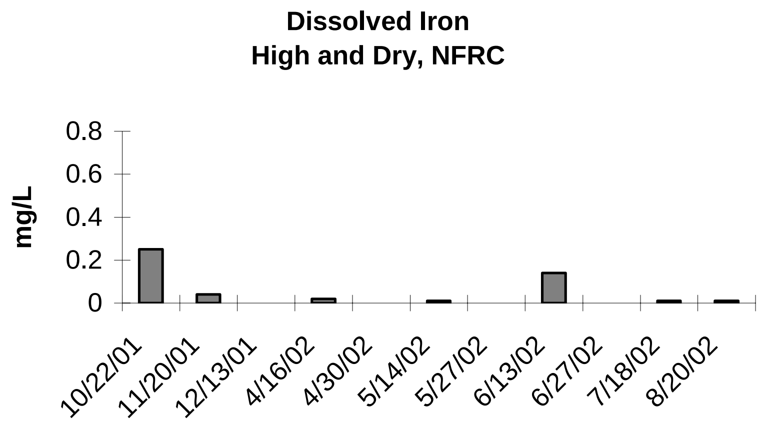
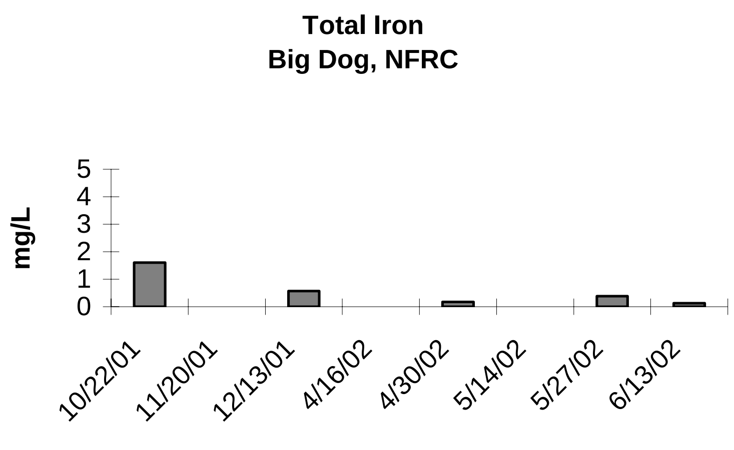
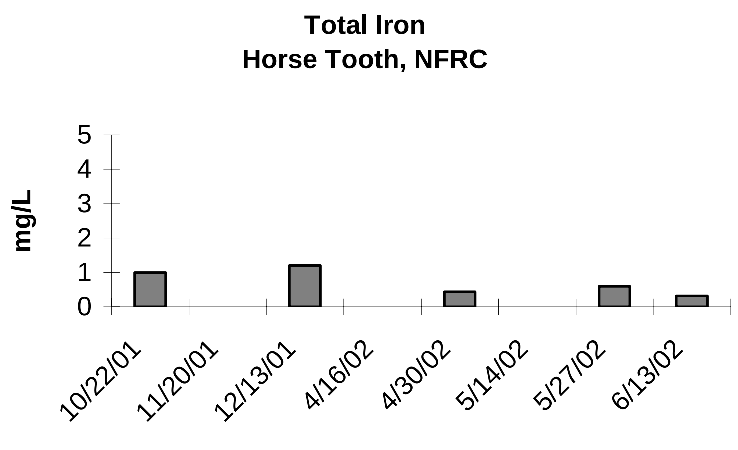
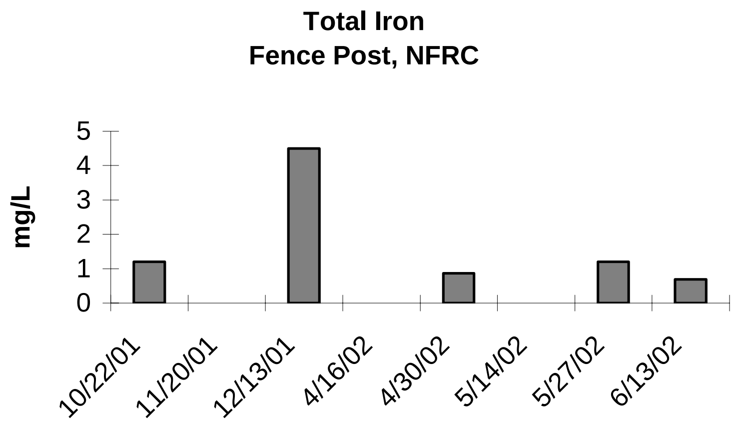


FIGURE 90: TOTAL IRON, NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 0.02 mg/L







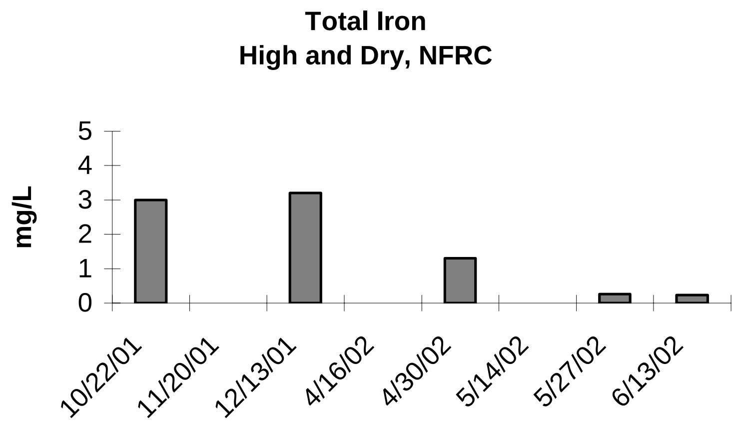
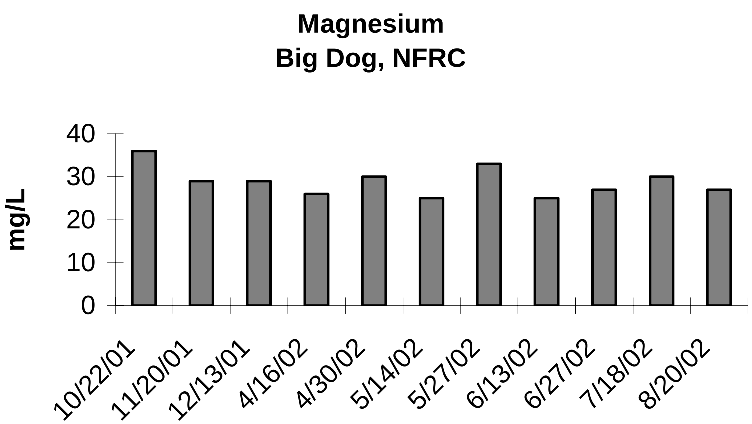
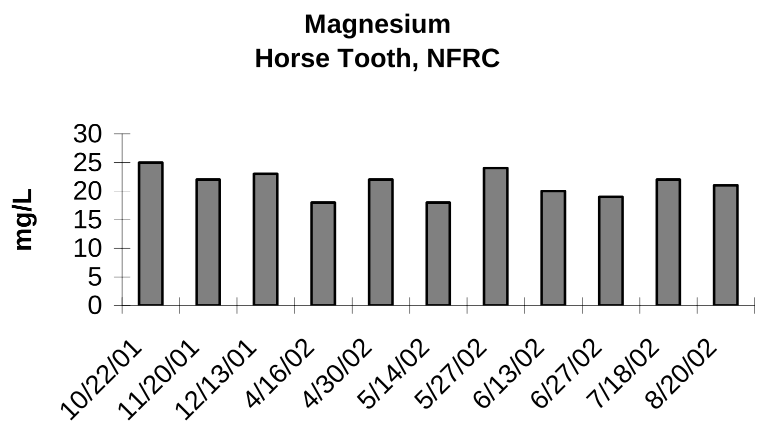
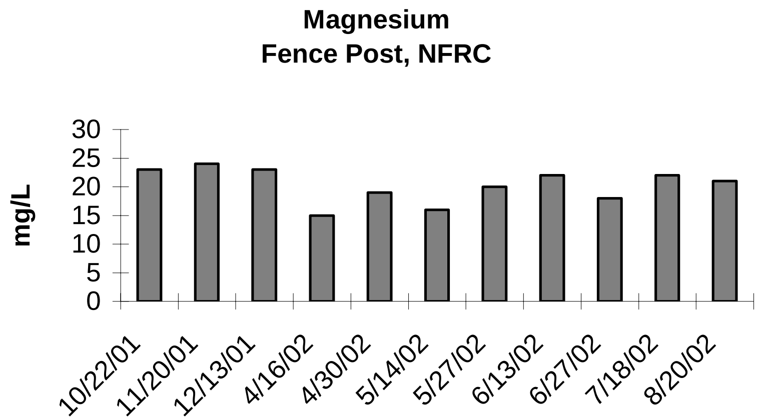


FIGURE 91: MAGNESIUM (MG2+), NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L







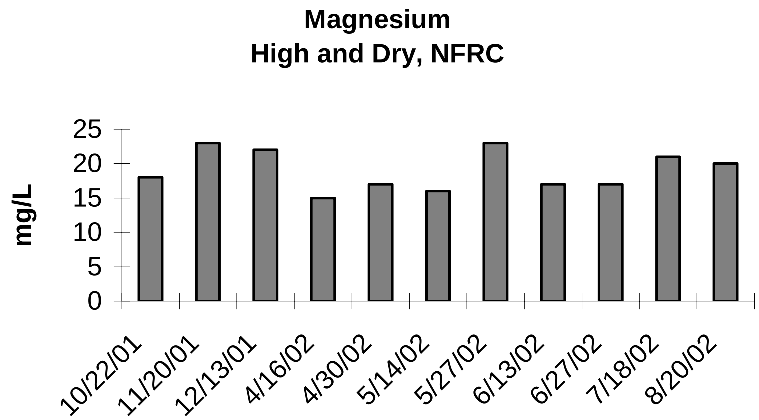
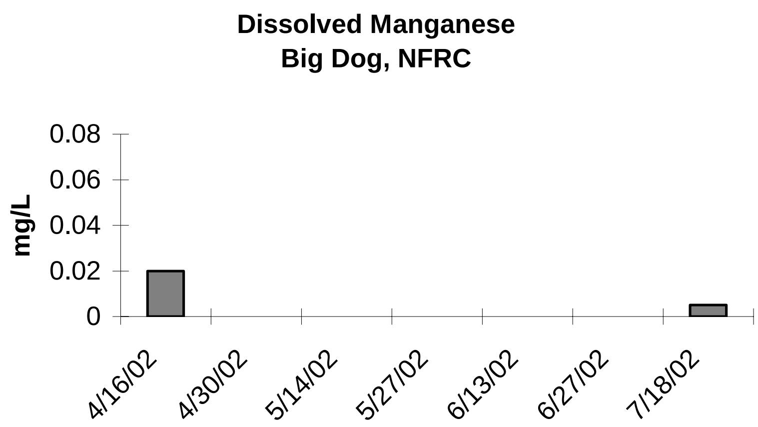
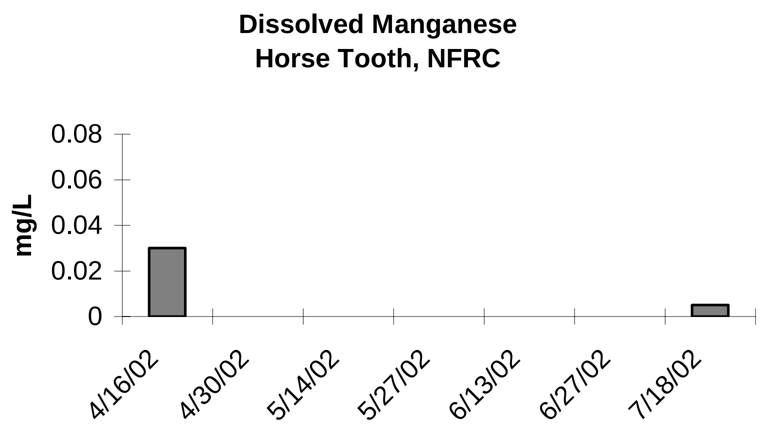
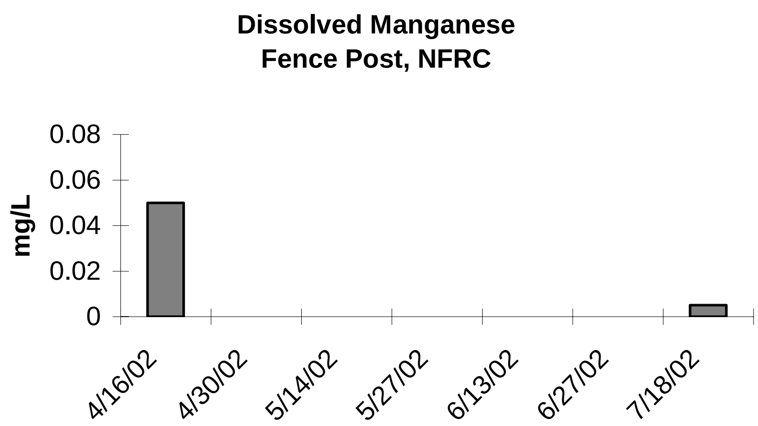


Figure 92: Dissolved Manganese, North Fork Rapid Creek
No Standard Established for Beneficial Use, Detection Limit = .01 mg/L







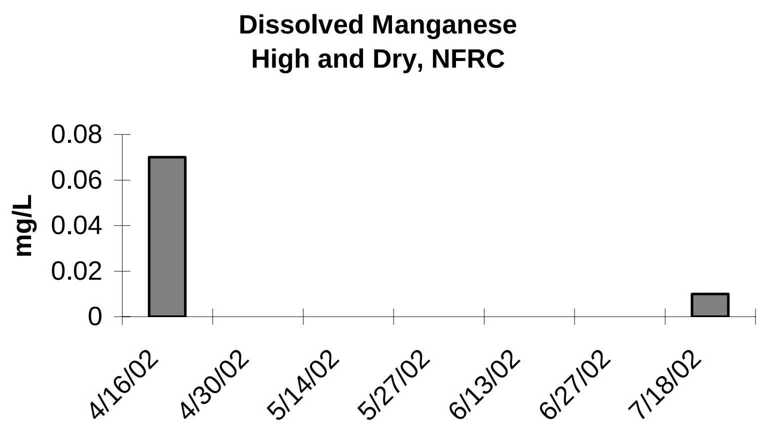
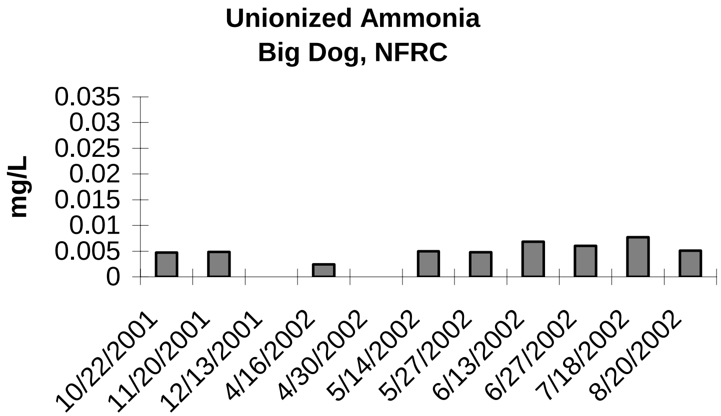
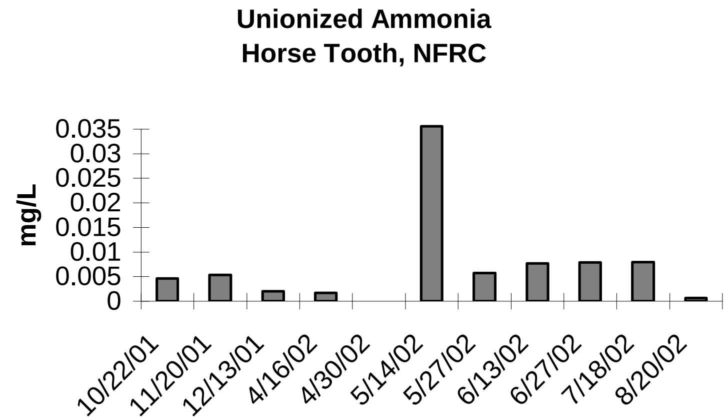


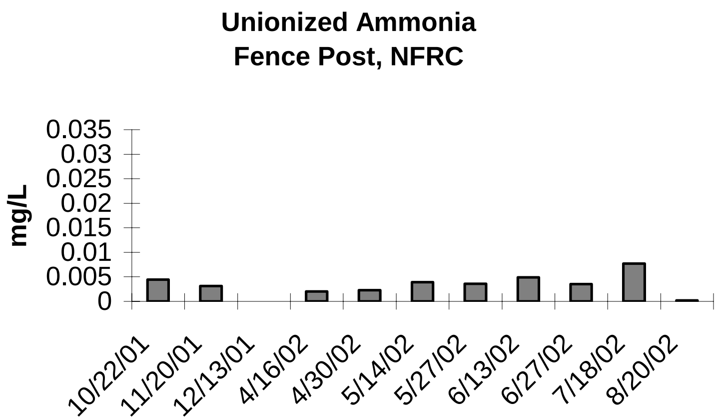
FIGURE 93: NITROGEN - UNIONIZED AMMONIA (NH_3), NORTH FORK RAPID CREEK

Standard for Cold Water Fishery: 0.035 mg/L daily max, 0.02 mg/L 30-day average

Note: Samples results of less than detection limit of N as Ammonia + Ammonium were assumed to be ½ the detection limit of 0.1mg/L







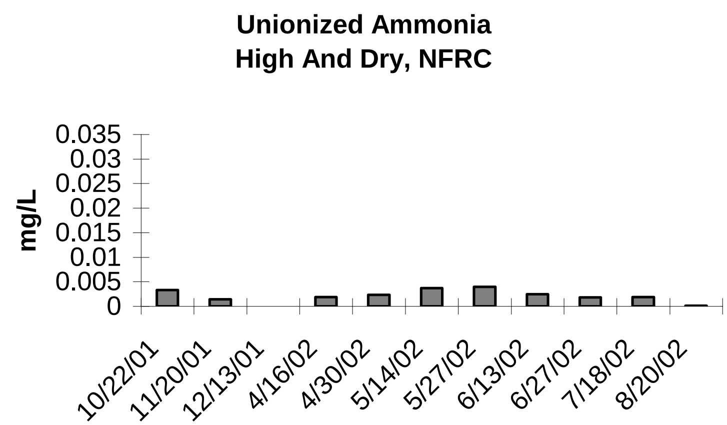
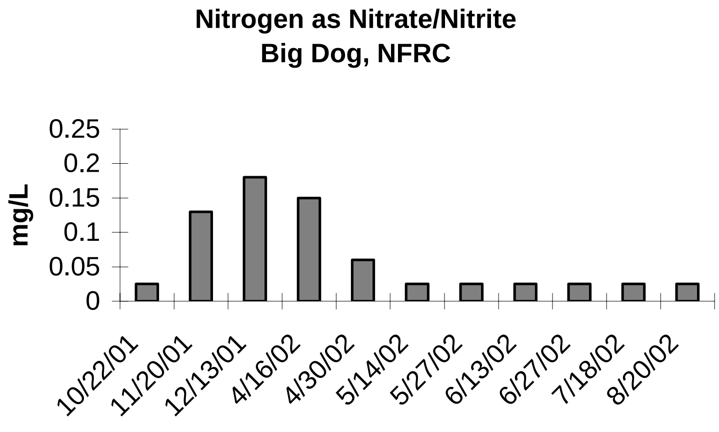
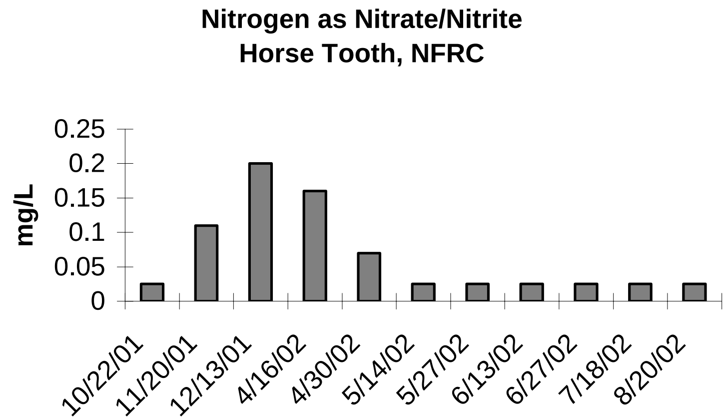
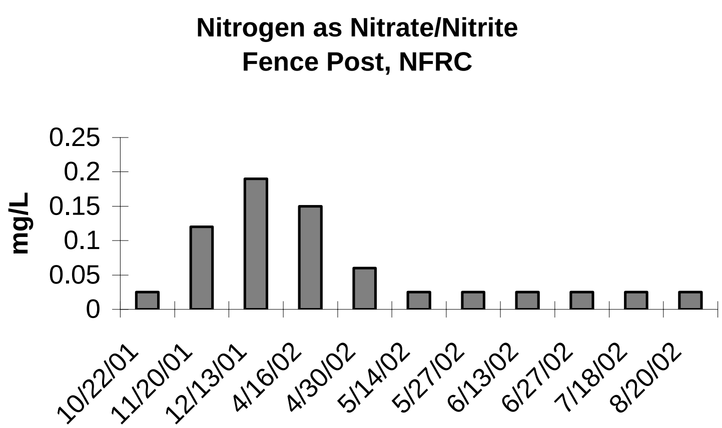


FIGURE 94: NITROGEN AS NITRATE/NITRITE, NORTH FORK RAPID CREEK

Standard for Fish and Wildlife Propagation, Recreation, & Stock Watering: 88 mg/L daily max, 50 mg/L 30-day average
Detection Limit = 0.05 mg/L







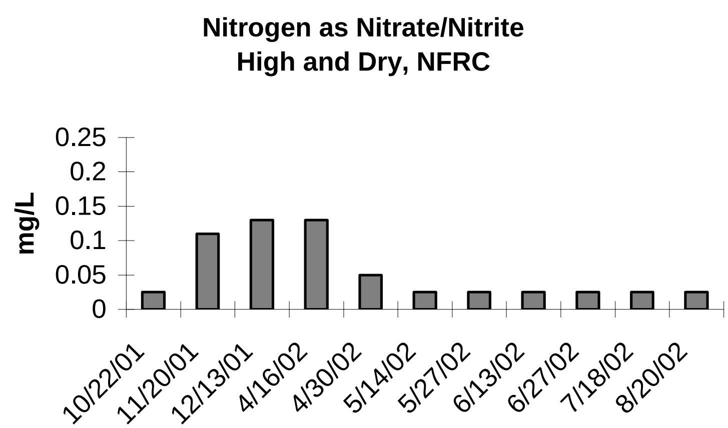
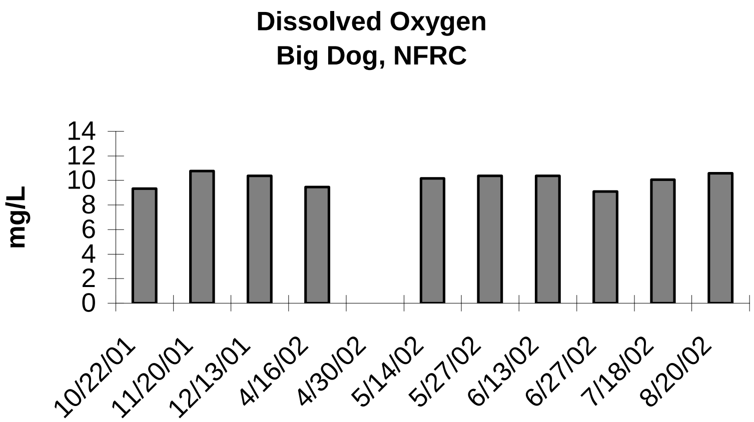
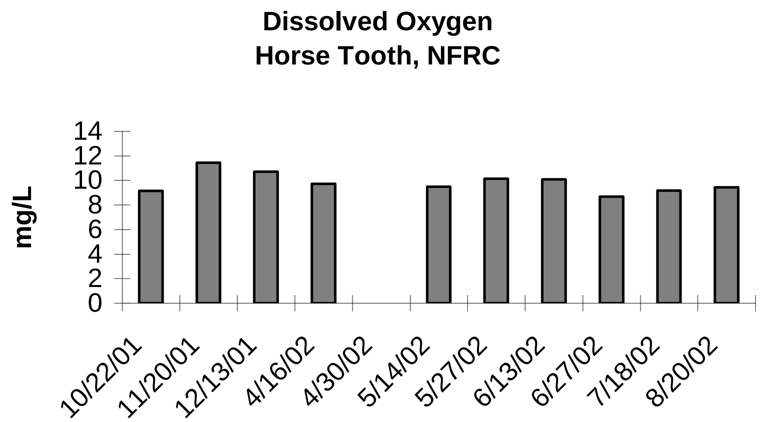
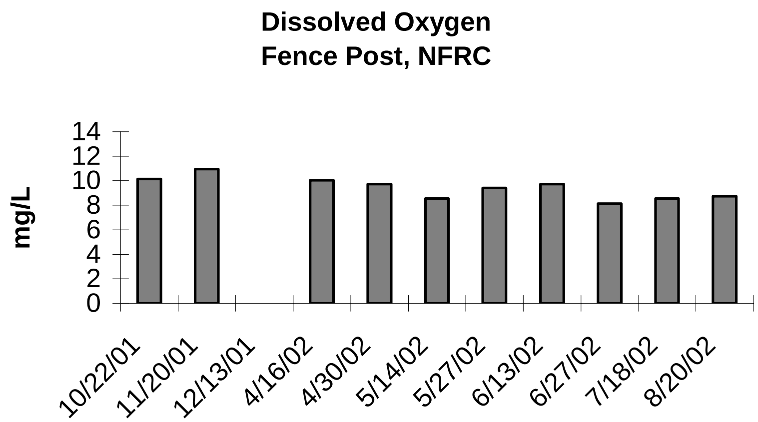


FIGURE 95: DISSOLVED OXYGEN, NORTH FORK RAPID CREEK

Cold Water Fishery Standard:] 6.0 mg/L;]7.0 mg/L during spawning season







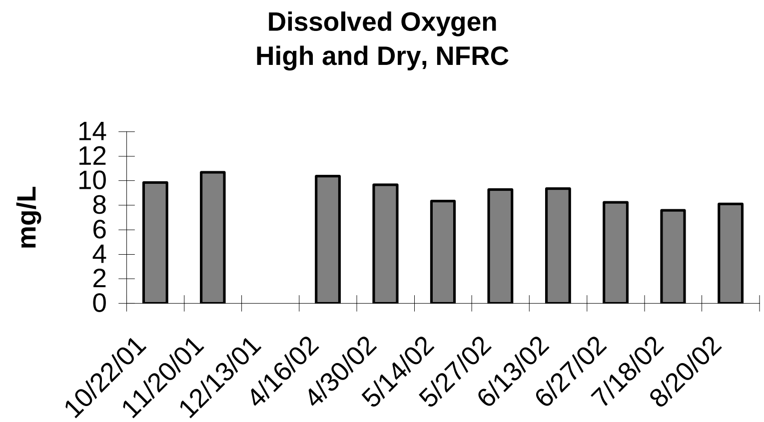
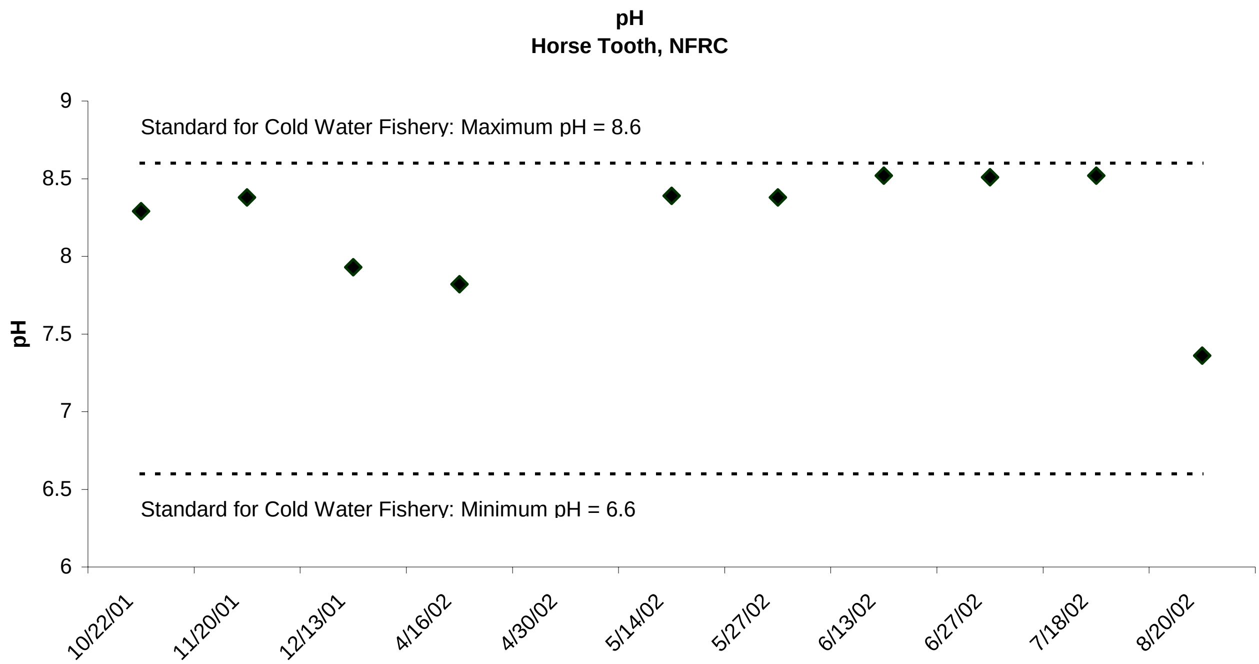


Figure 96: pH, North Fork Rapid Creek



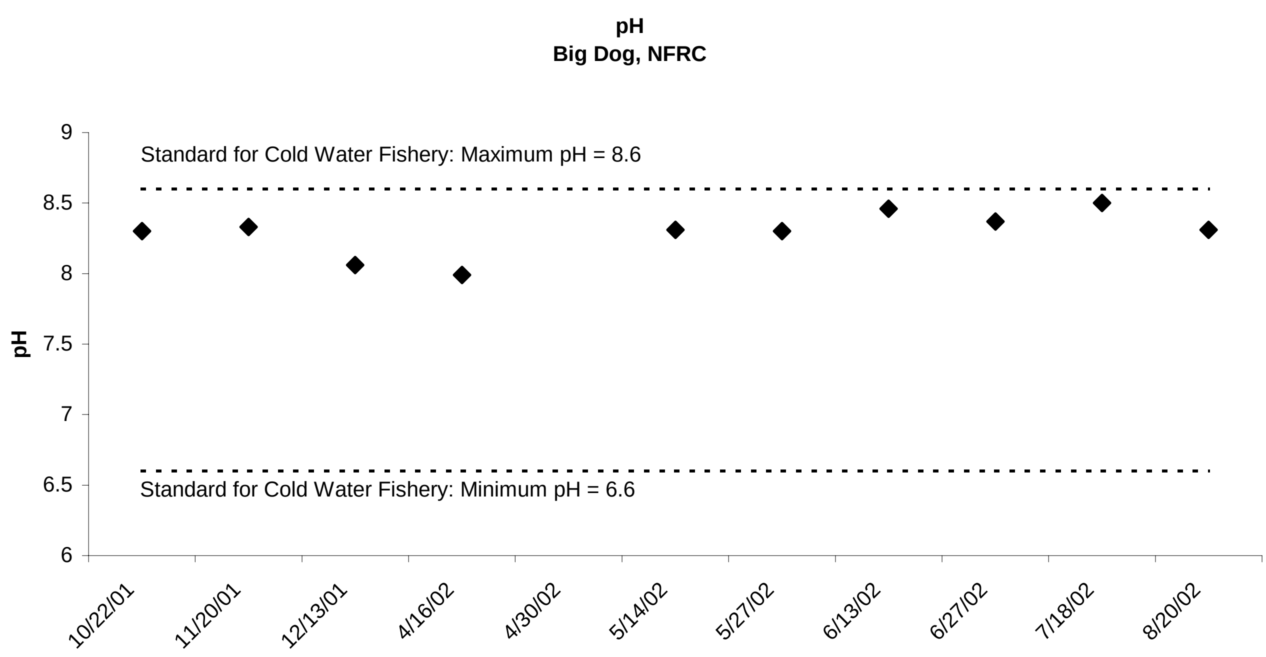
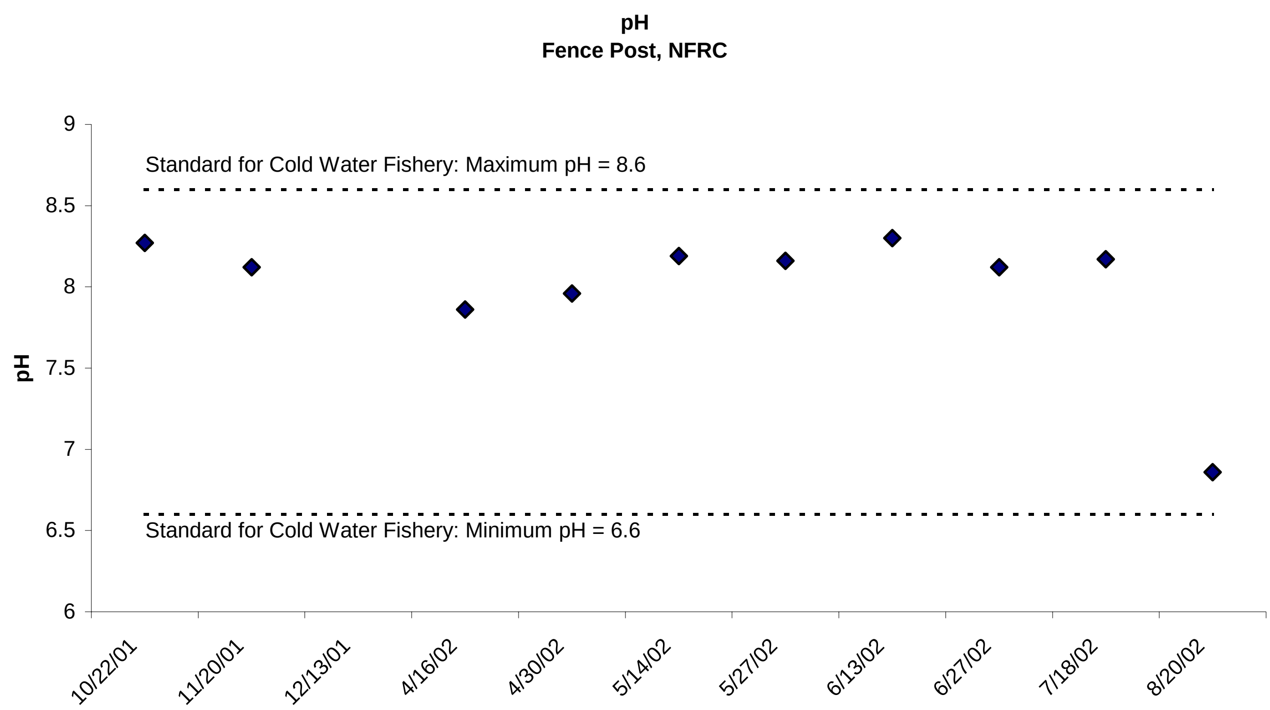


Figure 96: pH, North Fork Rapid Creek (continued)



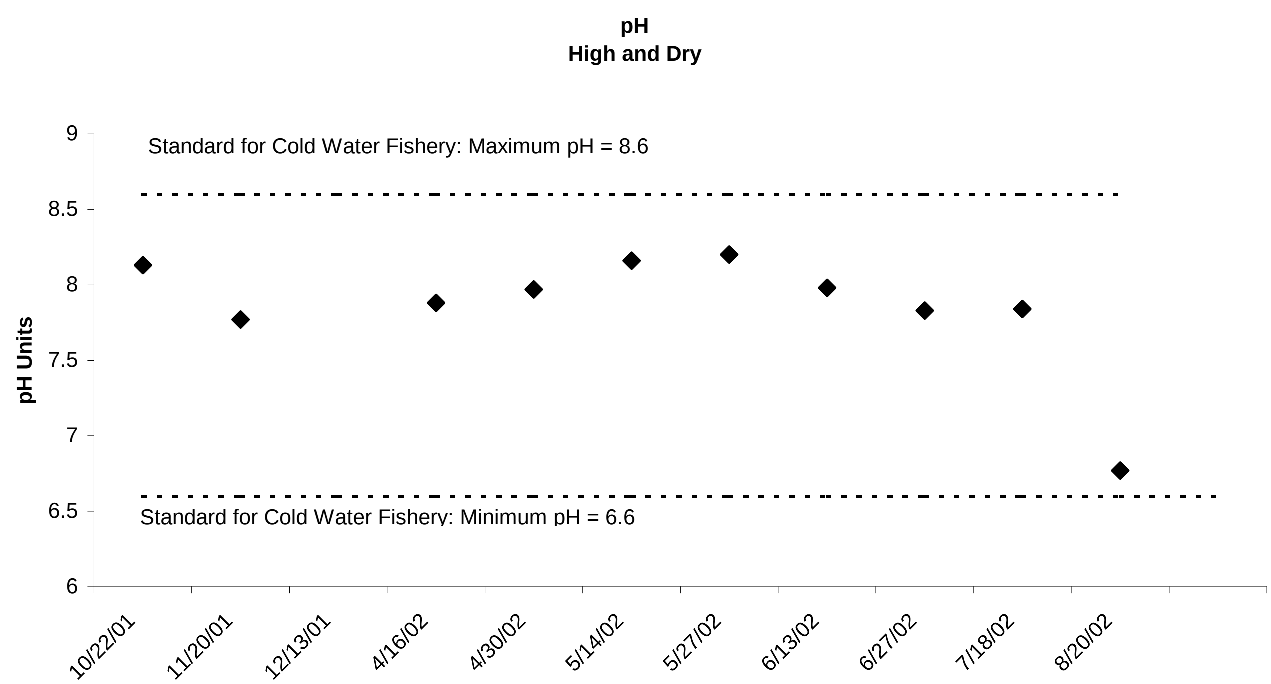
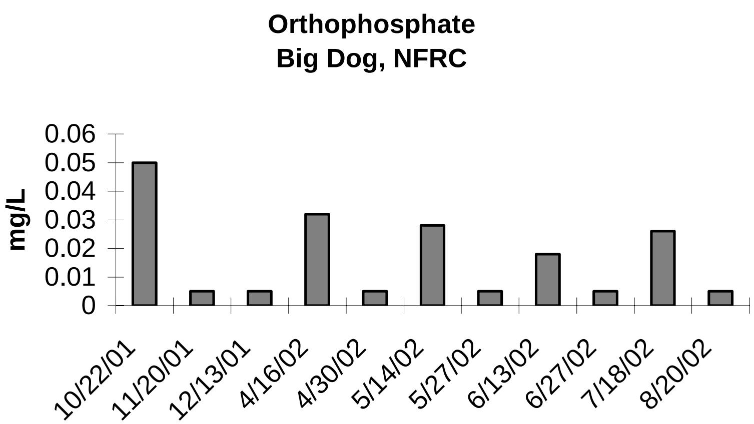
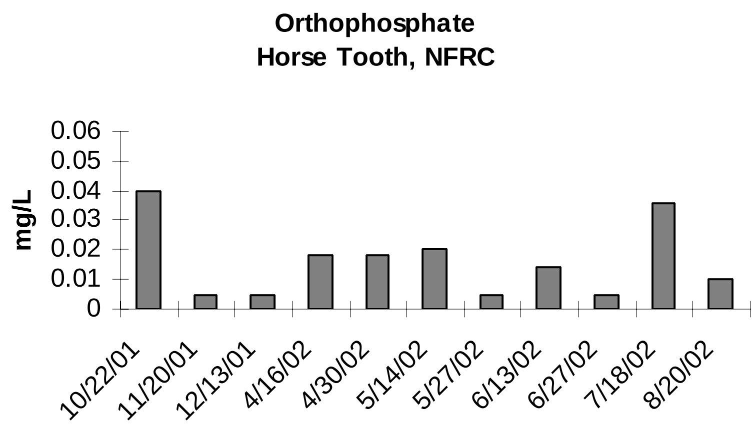
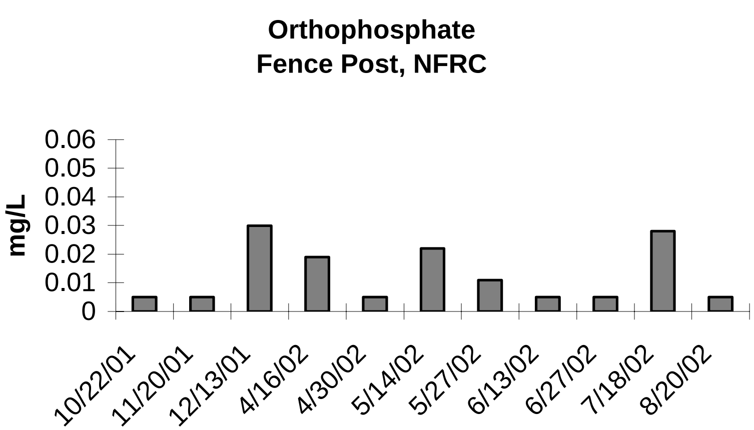


Figure 97: Orthophosphate (HPO_4^{2-}), North Fork Rapid Creek
No Standard Established for Beneficial Uses, Detection Limit = 0.01 mg/L







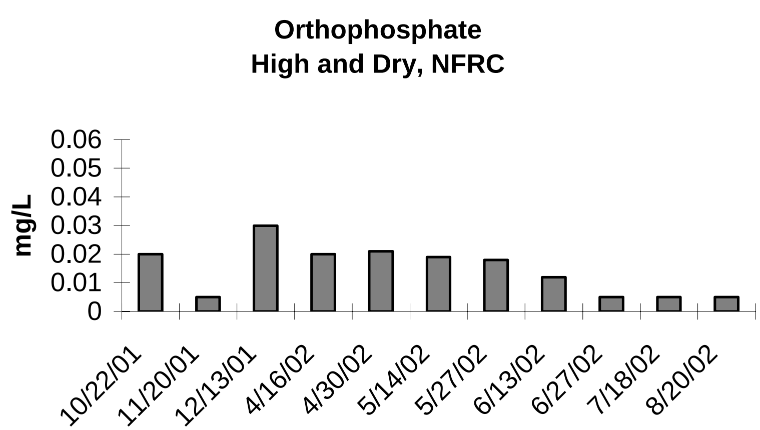
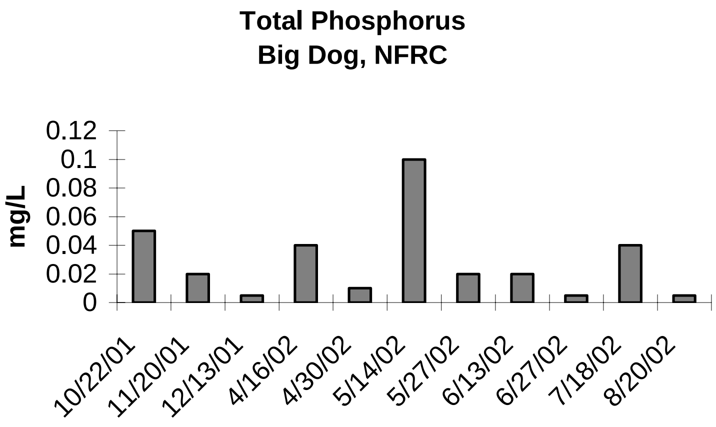
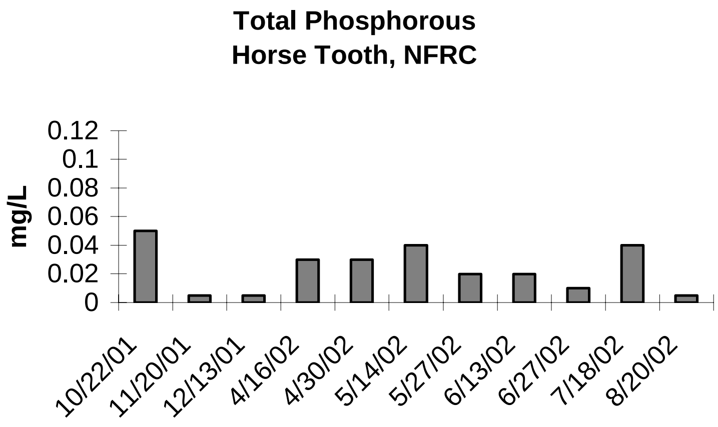
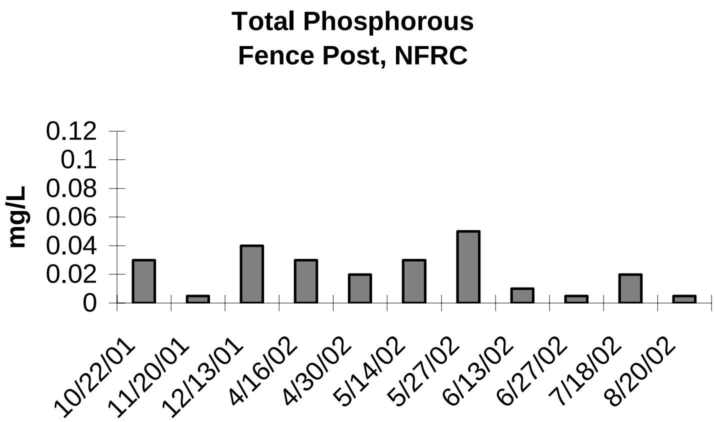


FIGURE 98: TOTAL PHOSPHORUS, NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 0.01 mg/L







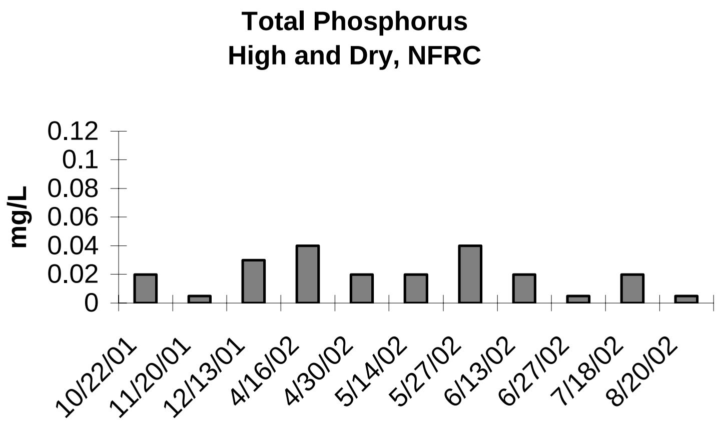
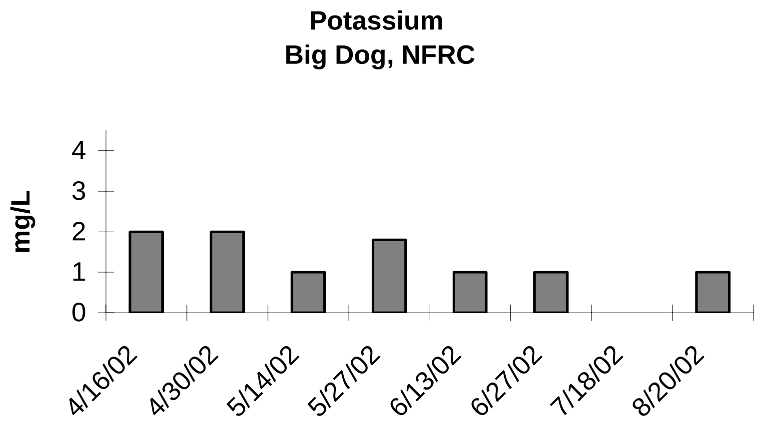
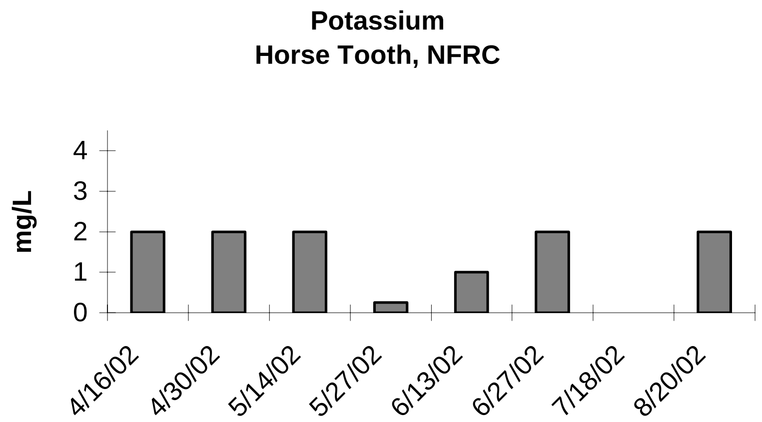
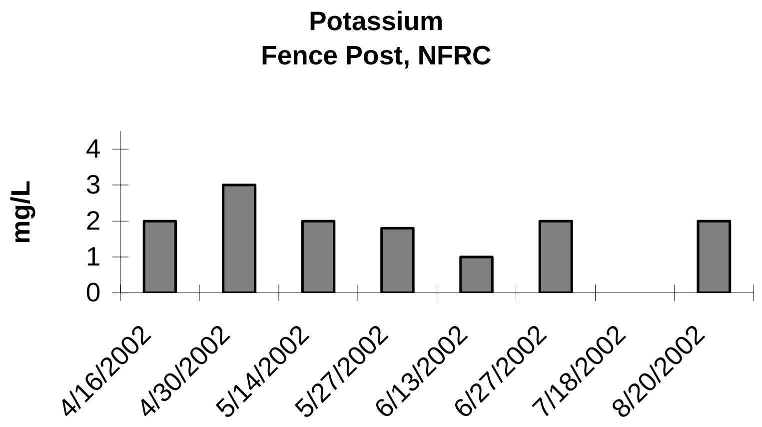


FIGURE 99: POTASSIUM (K^+), NORTH FORK RAPID CREEK

No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L







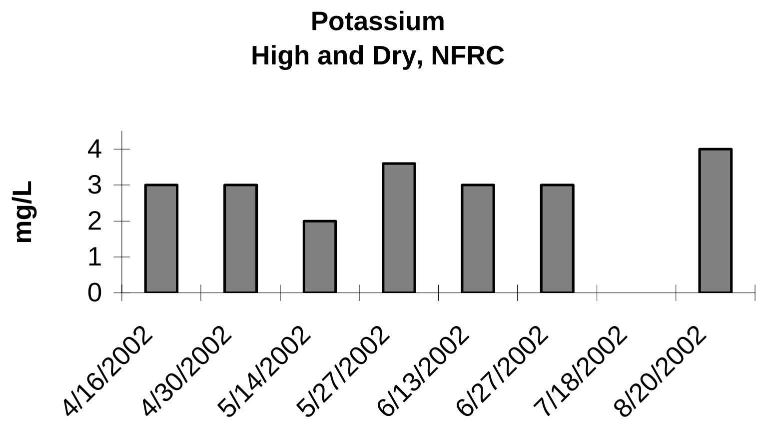
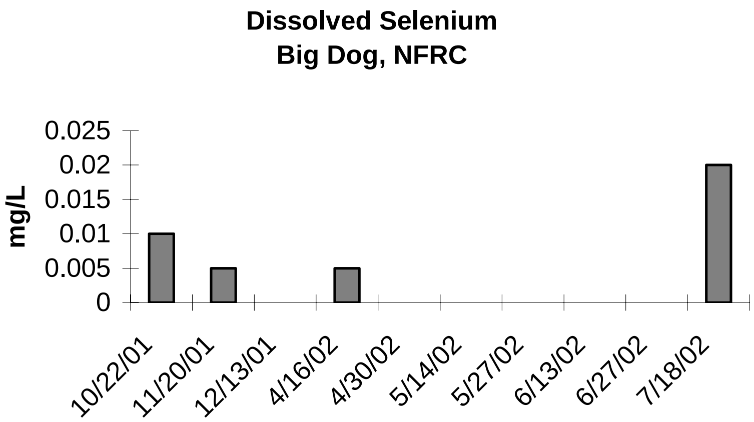
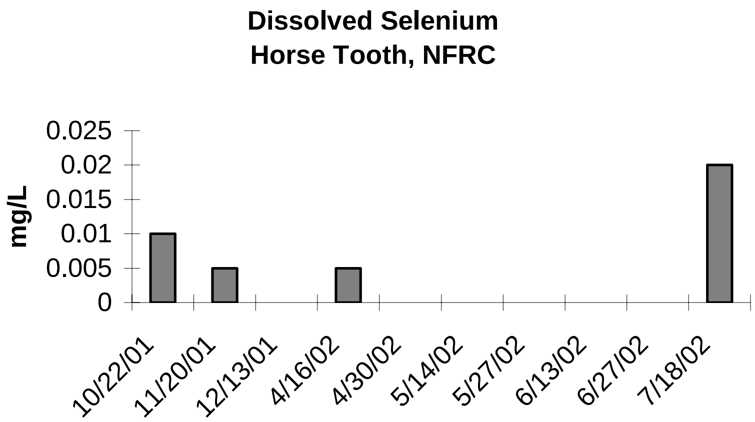
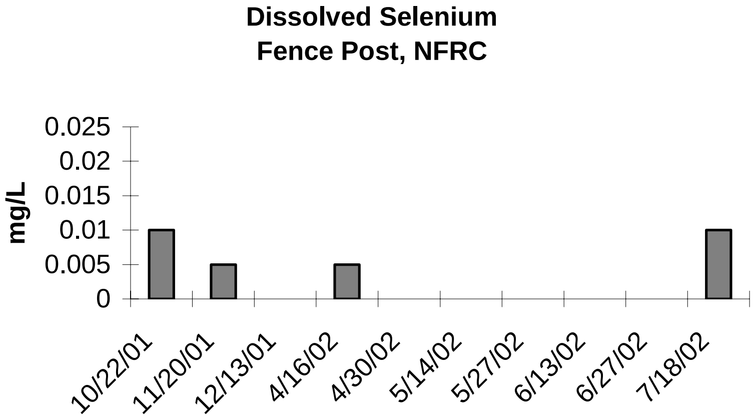


FIGURE 100: DISSOLVED SELENIUM, NORTH FORK RAPID CREEK
No Standard Established for Beneficial Uses, Detection Limit = 0.01 mg/L







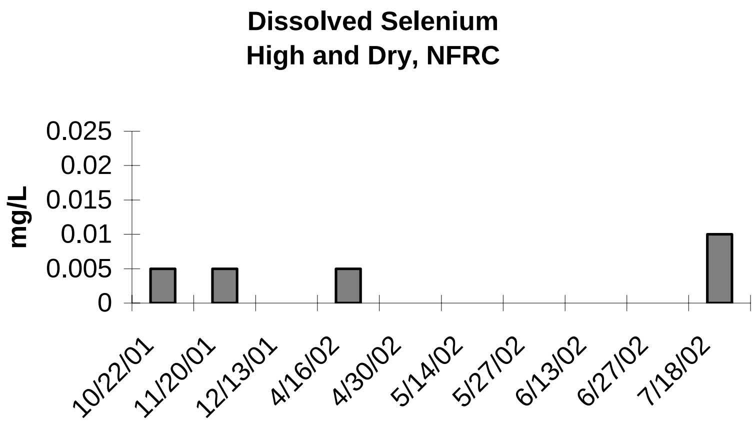
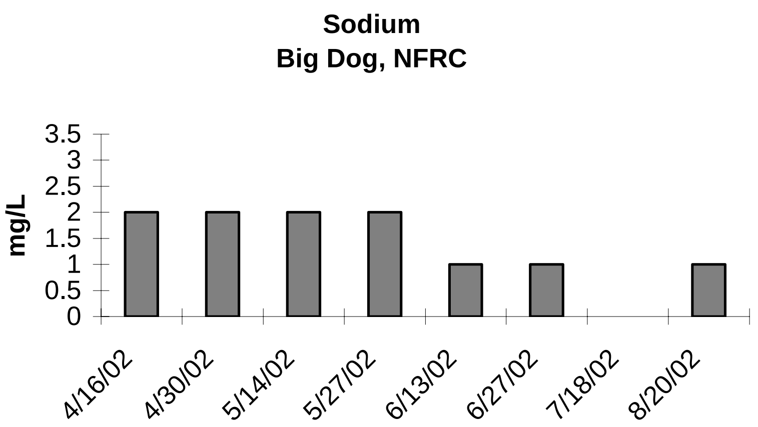
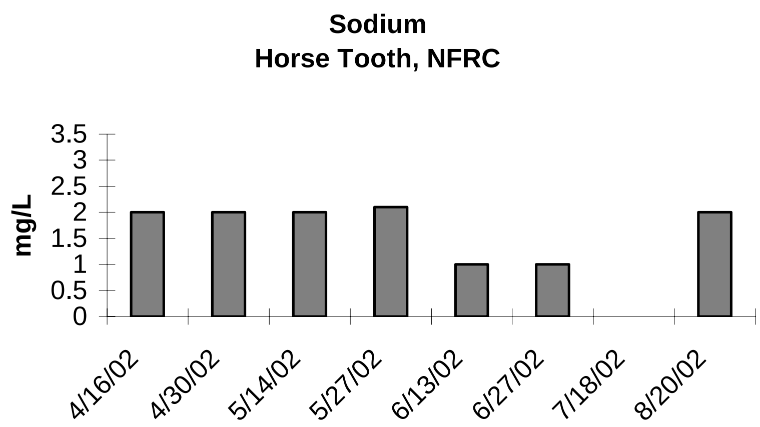
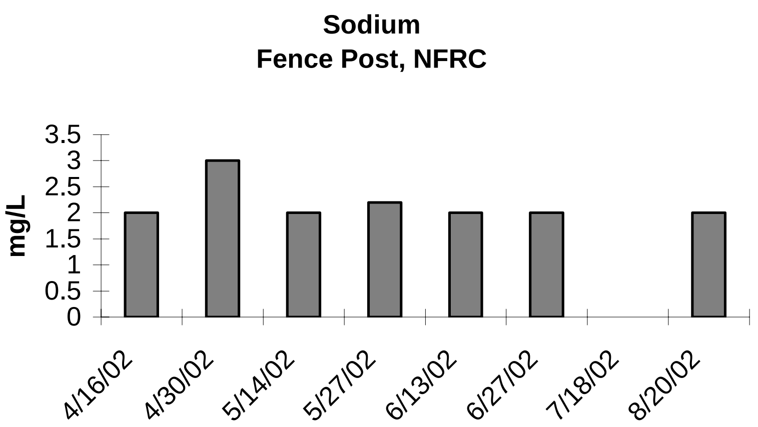


Figure 101: Sodium (Na^+), North Fork Rapid Creek
No Standard Established for Beneficial Uses – See discussion for SAR Standard, Detection Limit = 1 mg/L







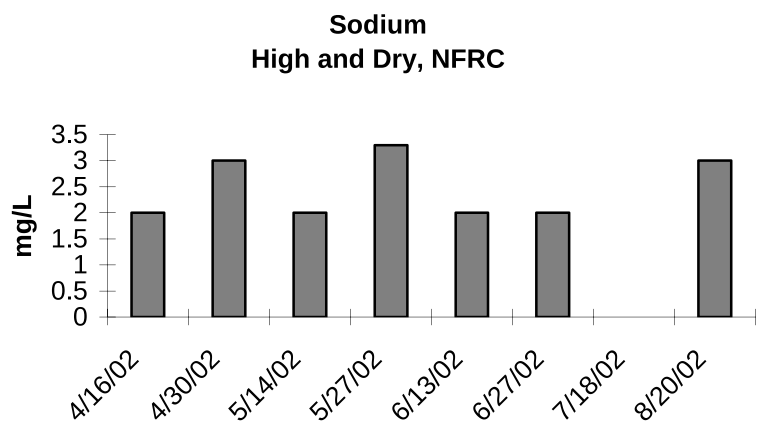
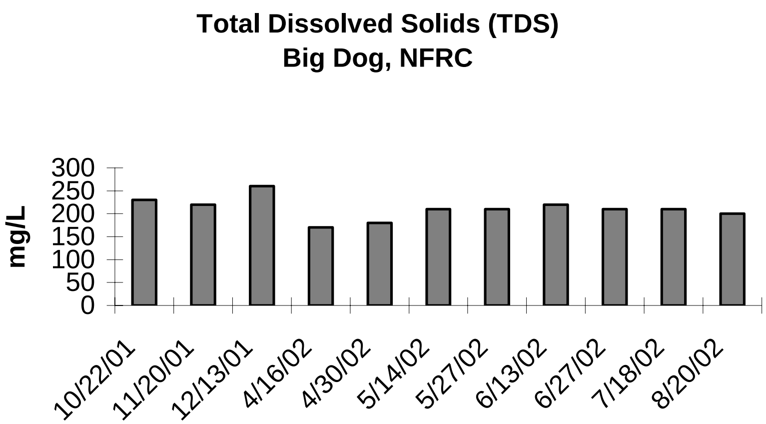
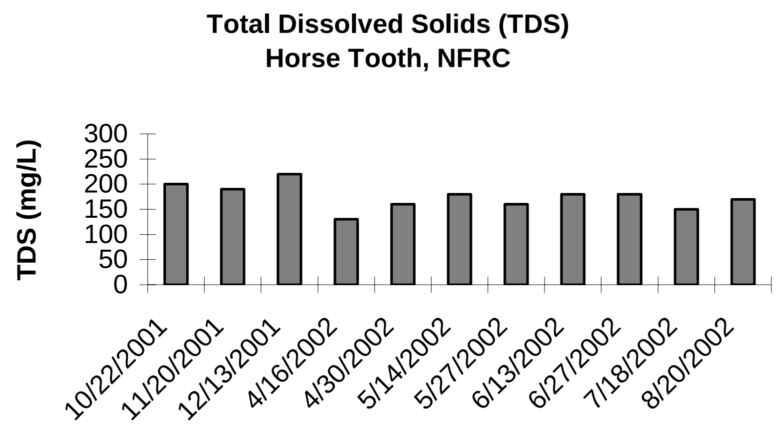
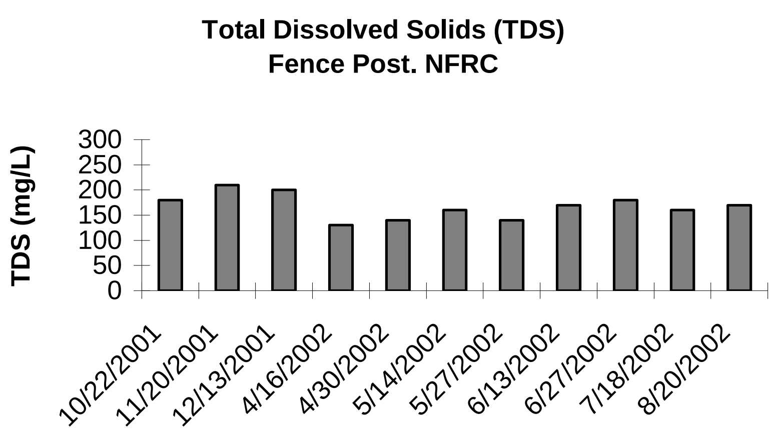


Figure 102: Total Dissolved Solids (TDS)

Standard for Fish and Wildlife Propagation, Recreation, & Stock Watering: 2,500 mg/L, Detection Limit = 5 mg/L







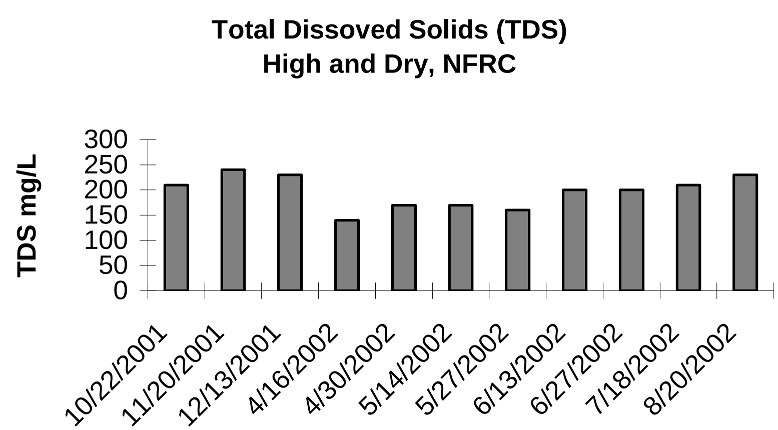
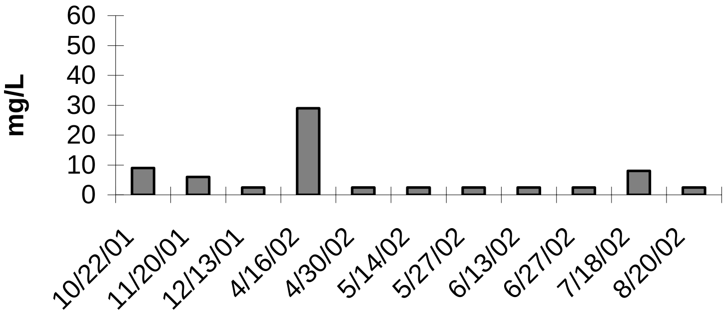


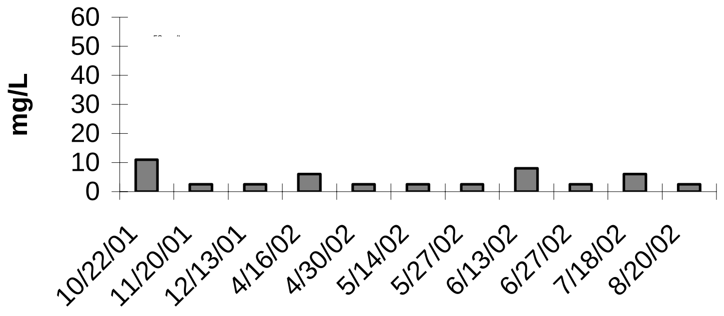
Figure 103: Total Suspended Solids, North Fork Rapid Creek

Standard for Cold Water Fishery: 53 mg/L daily max, 30 mg/L 30-day average, Detection Limit = 5mg/L

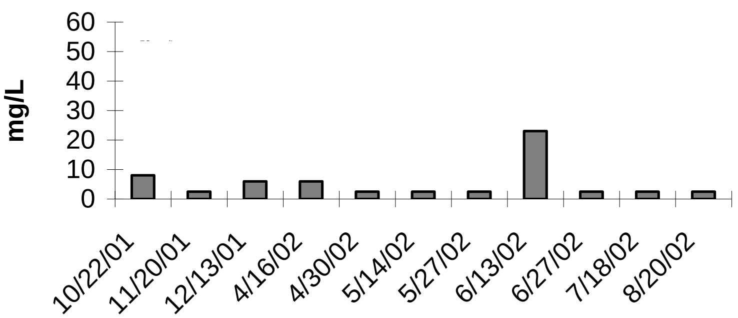
Total Suspended Solids (TSS)
Big Dog, NFRC



Total Suspended Solid (TSS)
Horse Tooth, NFRC



Total Suspended Solids (TSS)
Fence Post, NFRC



Total Suspended Solids (TSS)
High and Dry, NFRC

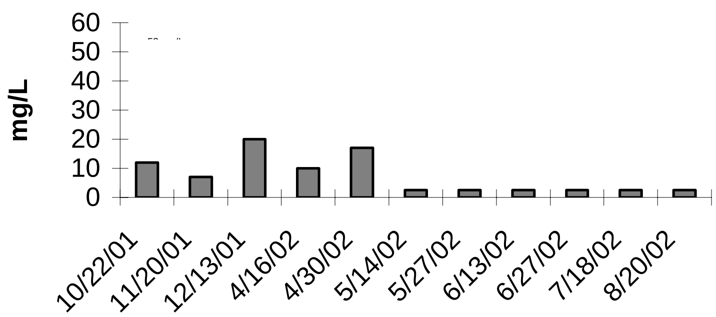


Figure 104: Sulfate, North Fork Rapid Creek

No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L

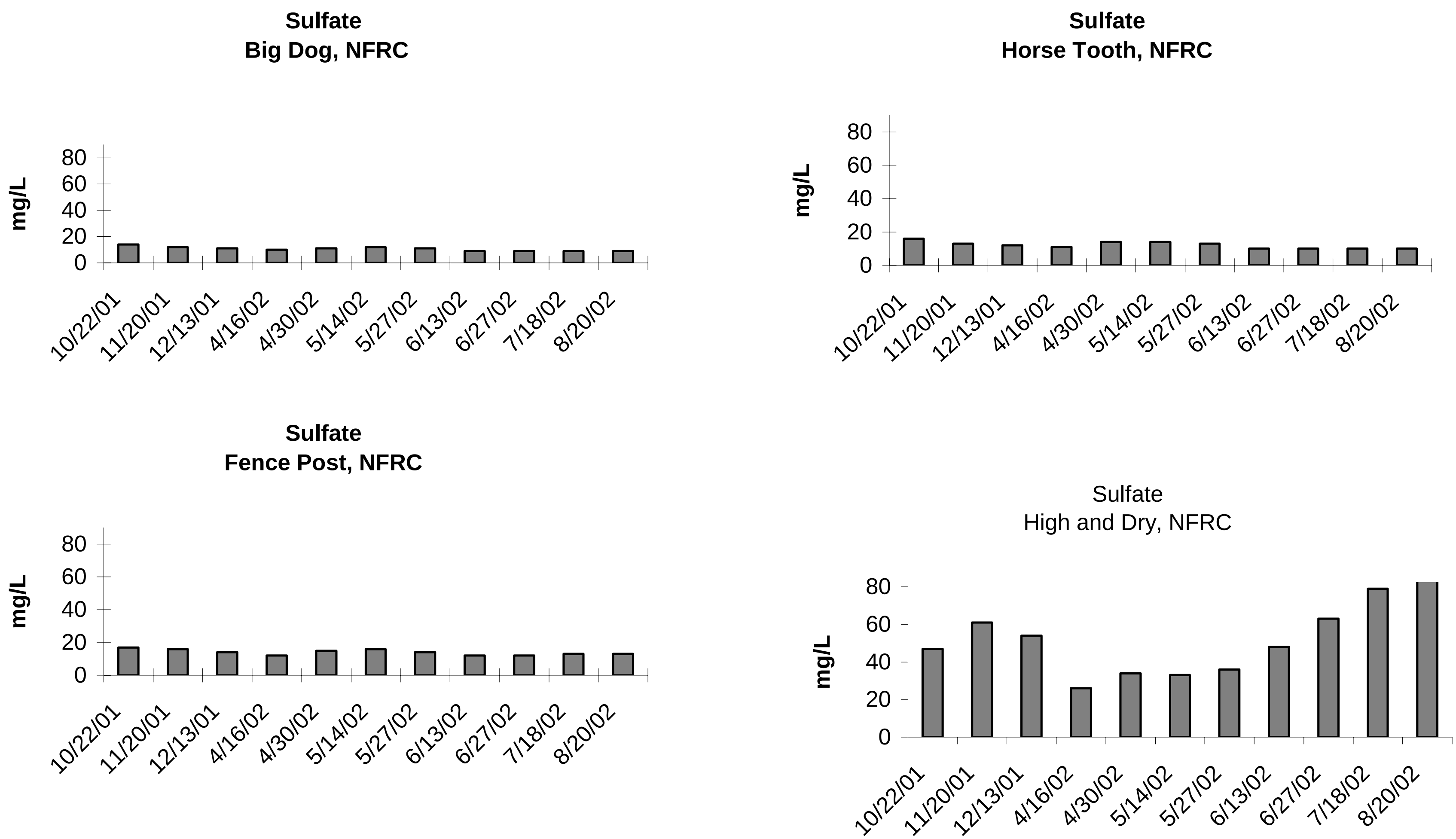
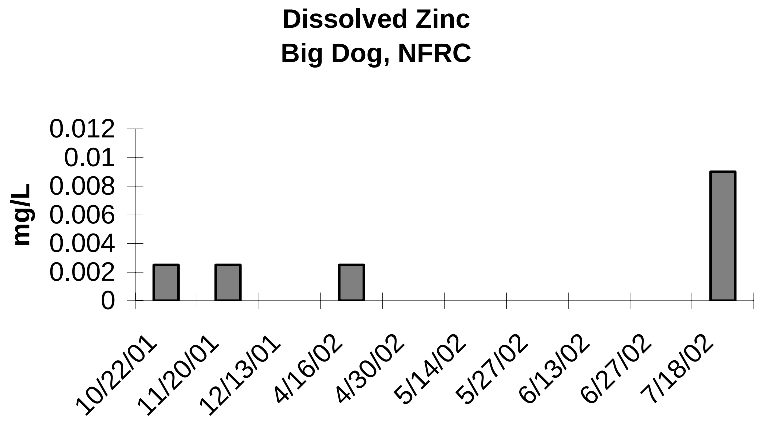
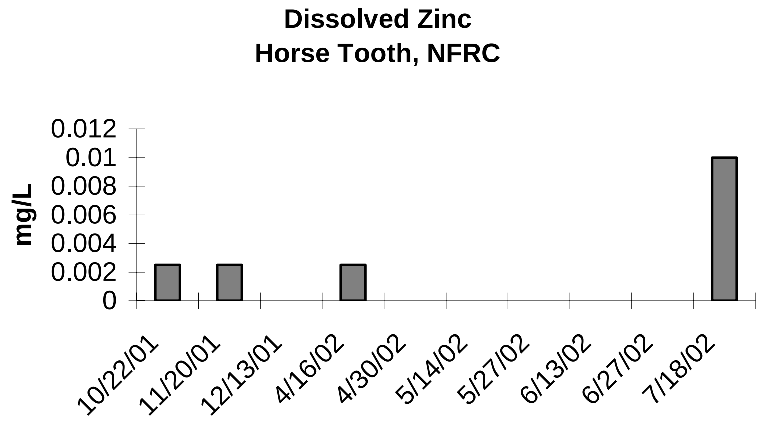
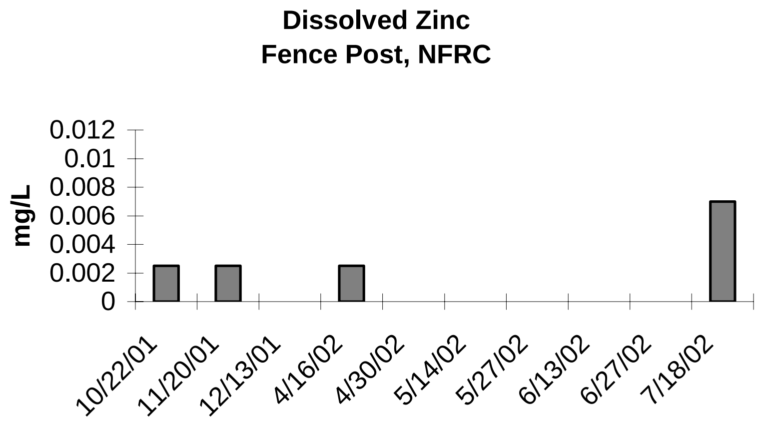


Figure 105: Dissolved Zinc, North Fork Rapid Creek
No Standard Established for Beneficial Uses, Detection Limit = 0.005 mg/L







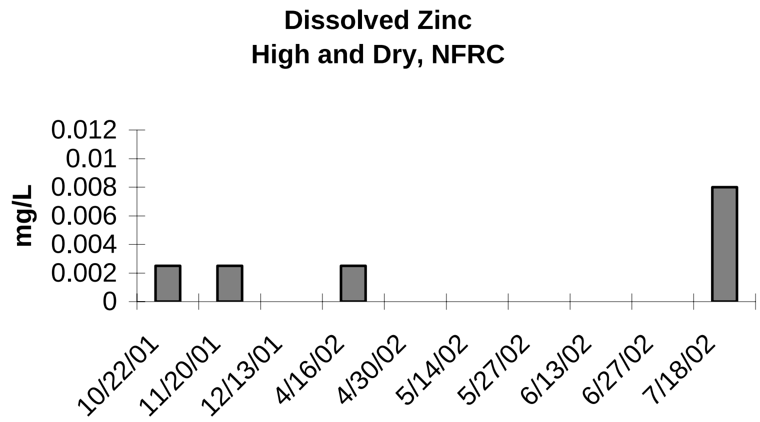


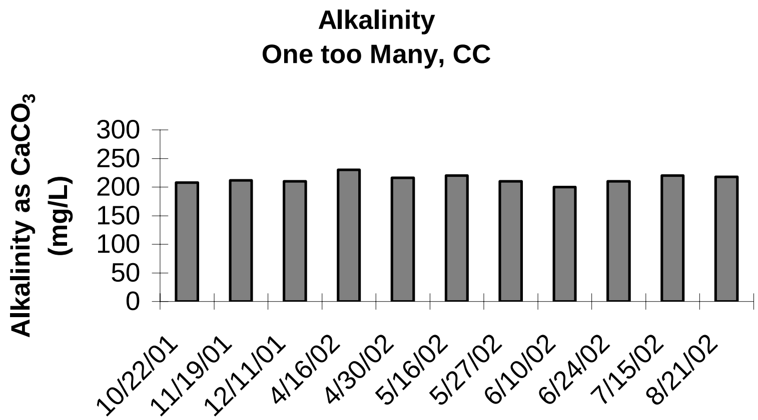
Table 29: Sampling Results for Single Sample Events or for Elements Which Did Not Exceed Detection Limits
North Fork Rapid Creek
(All units mg/L unless otherwise specified)

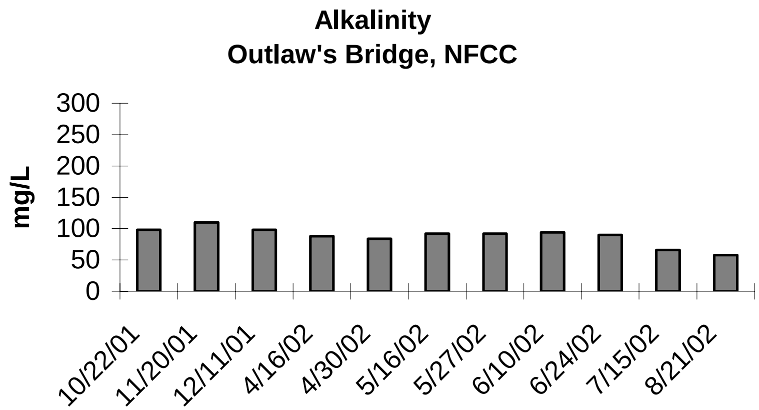
Element	Date	Sample Location			
		Big Dog	Horse Tooth	Fence Post	High & Dry
F^-	16-Apr-02	0.1	0.1	0.1	0.2
Si as SiO_2	16-Apr-02	10	10	10	10
Total As	18-Jul-02	ND all			
Total Cd	18-Jul-02	ND all			
Total Cu	18-Jul-02	ND all			
Total Se	18-Jul-02	ND all			
Total Zn	18-Jul-02	ND all			
Dissolved As	22-Oct-01	< 0.01	< 0.01	< 0.01	< 0.01
	20-Nov-01	< 0.01	< 0.01	< 0.01	< 0.01
	16-Apr-02	< 0.01	< 0.01	< 0.01	< 0.01
	18-Jul-02	< 0.01	< 0.01	< 0.01	< 0.01
Dissolved Cd	22-Oct-01	< 0.001	< 0.001	< 0.001	< 0.001
	20-Nov-01	< 0.001	< 0.001	< 0.001	< 0.001
	16-Apr-02	< 0.001	< 0.001	< 0.001	< 0.001
	18-Jul-02	< 0.001	< 0.001	< 0.001	< 0.001
Dissolved Cu	22-Oct-01	< 0.01	< 0.01	< 0.01	< 0.01
	20-Nov-01	< 0.01	< 0.01	< 0.01	< 0.01
	16-Apr-02	< 0.01	< 0.01	< 0.01	< 0.01
	18-Jul-02	< 0.01	< 0.01	< 0.01	< 0.01
Dissolved Pb	22-Oct-01	< 0.01	< 0.01	< 0.01	< 0.01
	20-Nov-01	< 0.01	< 0.01	< 0.01	< 0.01
Dissolved Hg	22-Oct-01	< 0.0002	< 0.0002	< 0.0002	< 0.0002
	20-Nov-01	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Dissolved Ag	22-Oct-01	< 0.005	< 0.005	< 0.005	< 0.005
	20-Nov-01	< 0.005	< 0.005	< 0.005	< 0.005
Dissolved Zn	22-Oct-01	< 0.005	< 0.005	< 0.005	< 0.005
	20-Nov-01	< 0.005	< 0.005	< 0.005	< 0.005
	16-Apr-02	< 0.005	< 0.005	< 0.005	< 0.005
	18-Jul-02	0.009	0.01	0.007	0.008

FIGURE 106: ALKALINITY, CASTLE CREEK SITES

STANDARD FOR FISH AND WILDLIFE PROPAGATION, RECREATION, & STOCK WATERING: 1312 MG/L DAILY MAX, 730 MG/L 30-DAY AVERAGE

DETECTION LIMIT = 2 MG/L





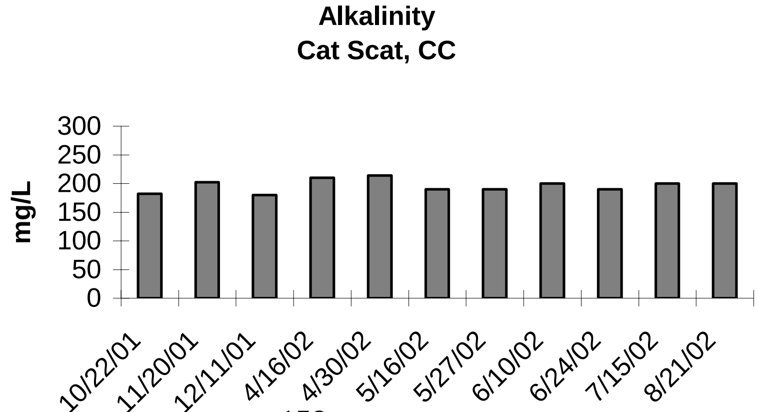
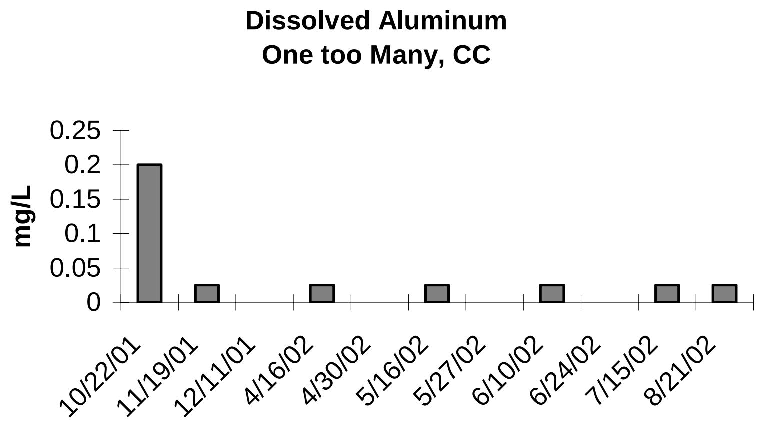
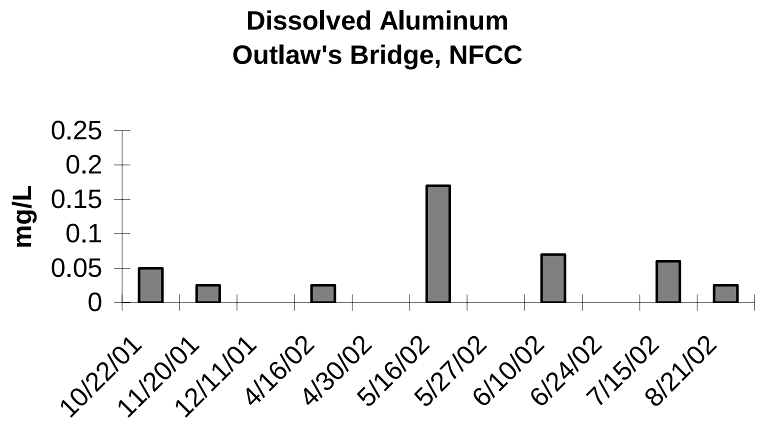


FIGURE 107: DISSOLVED ALUMINUM, CASTLE CREEK SITES

No Standard Established for Beneficial Uses, Detection Limit = 0.05 mg/L





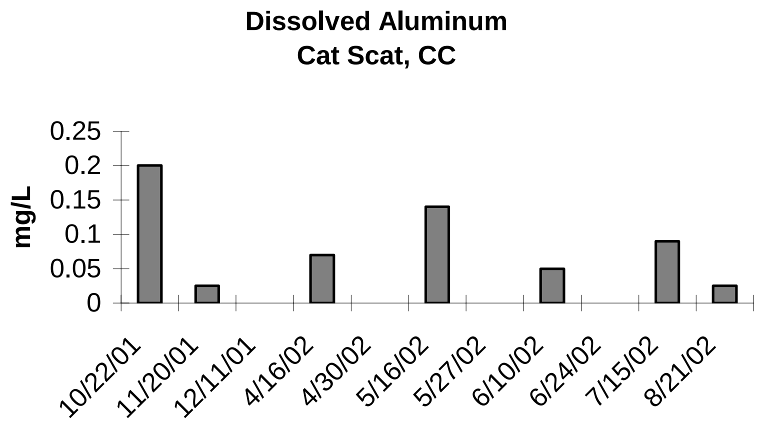
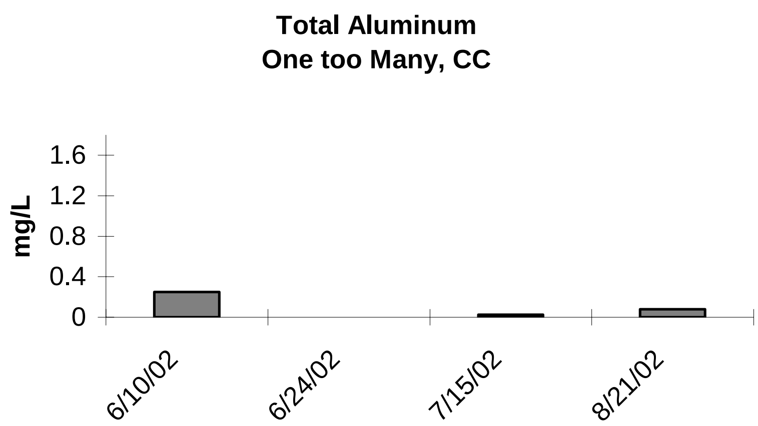
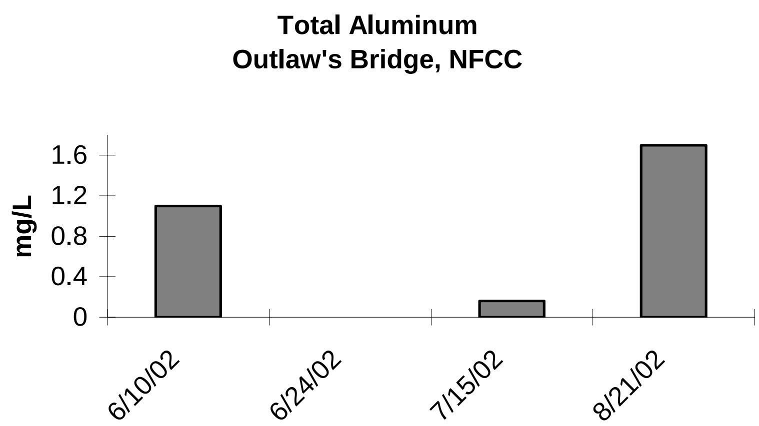


FIGURE 108: TOTAL ALUMINUM, CASTLE CREEK SITES
No Standard Established for Beneficial Uses, Detection Limit = 0.05 mg/L





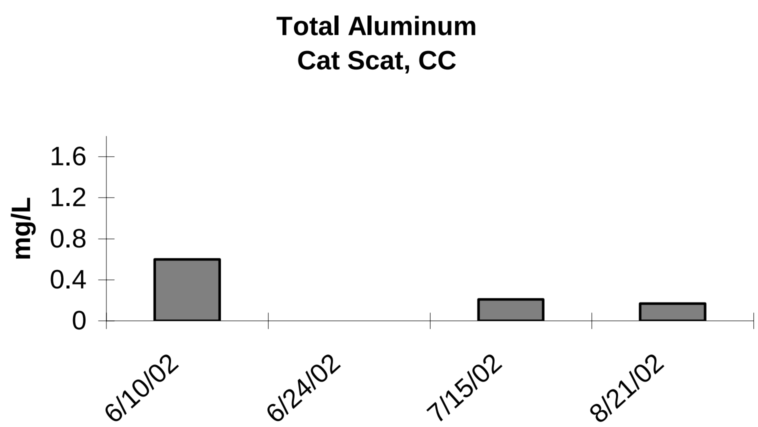
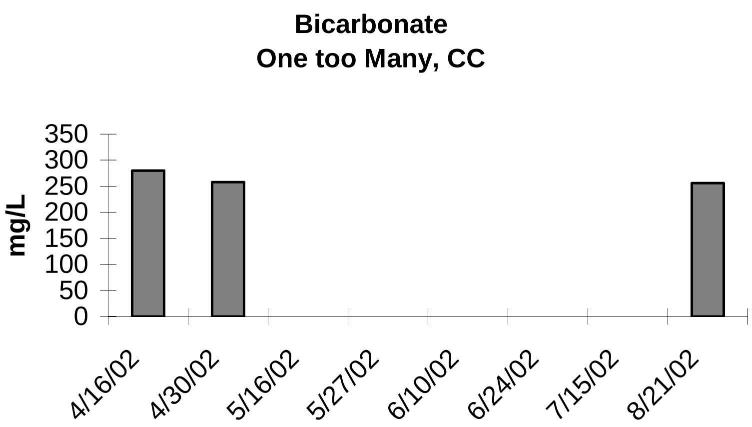
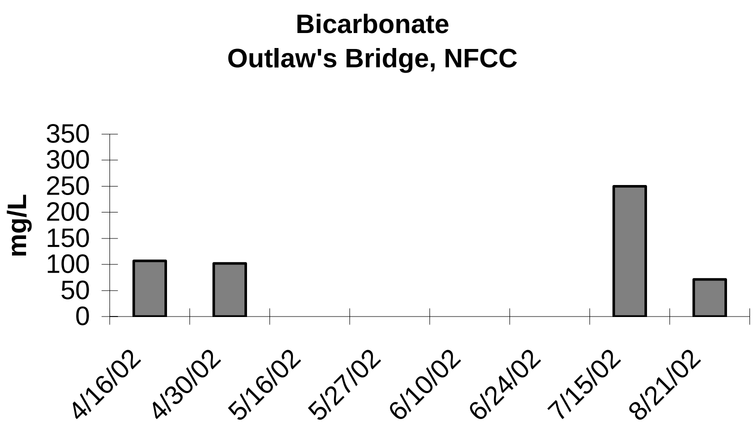


Figure 109: Bicarbonate (HCO_3^-), Castle Creek Sites
No Standard Established for Beneficial Uses, Detection Limit = 5 mg/L





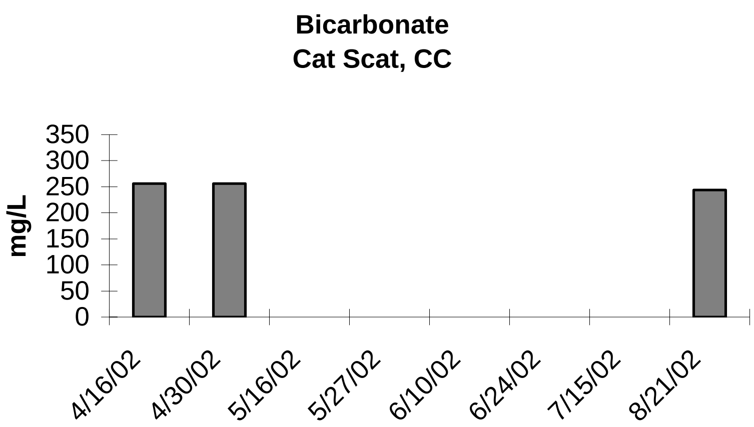
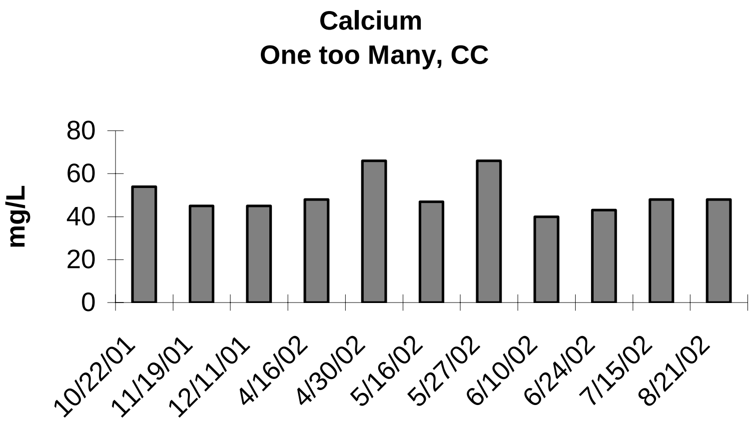
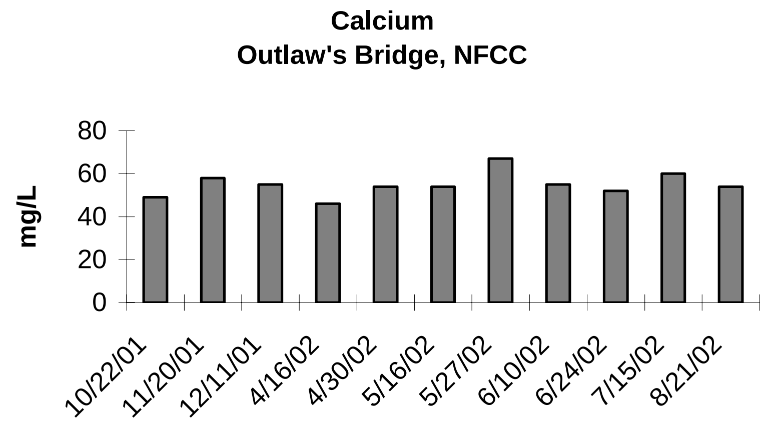


FIGURE 110: CALCIUM (CA^{2+}), CASTLE CREEK SITES

No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L





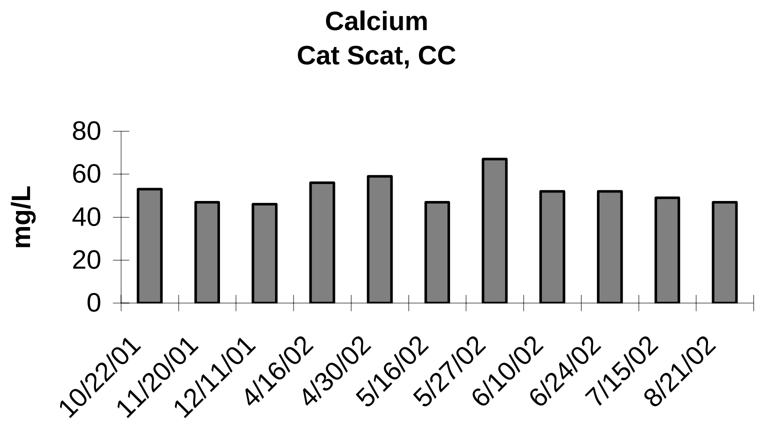
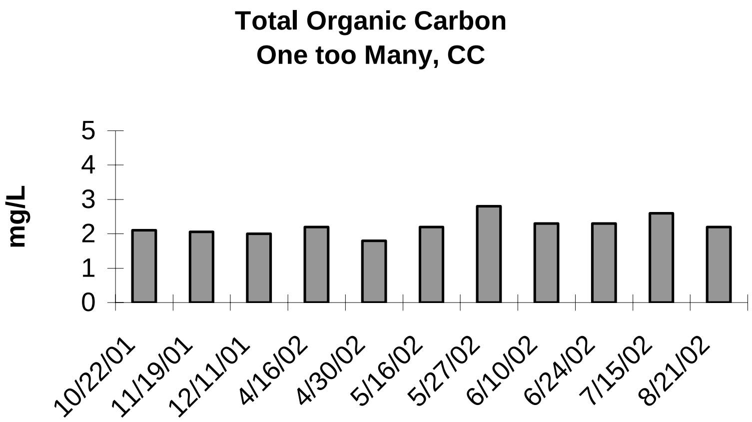
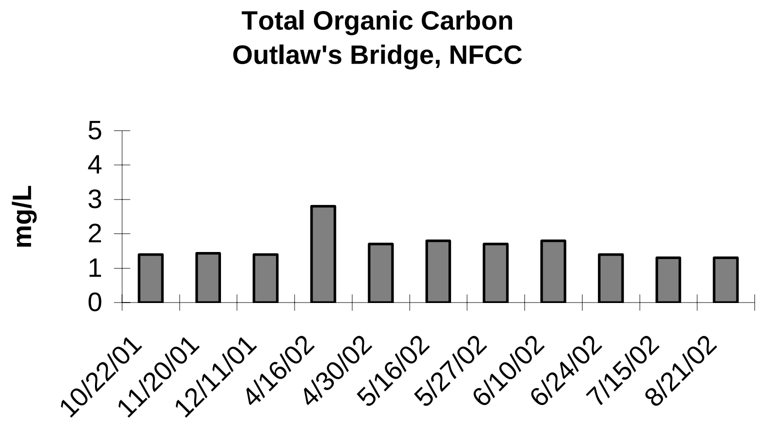


FIGURE 111: TOTAL ORGANIC CARBON, CASTLE CREEK SITES

No Standard Established for Beneficial Uses, Detection Limit = 0.5 mg/L





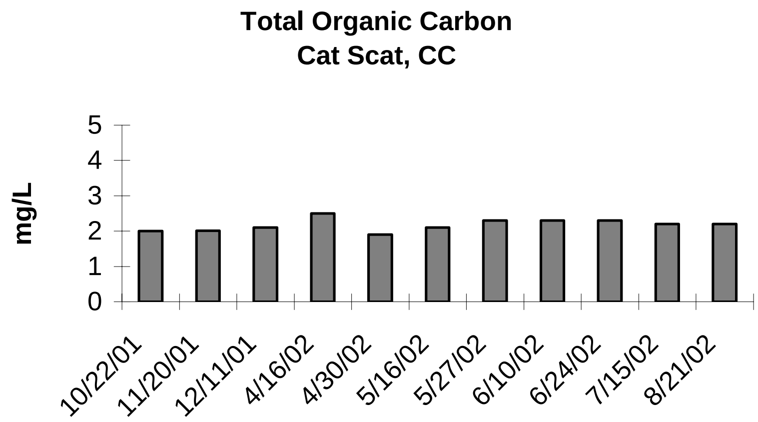
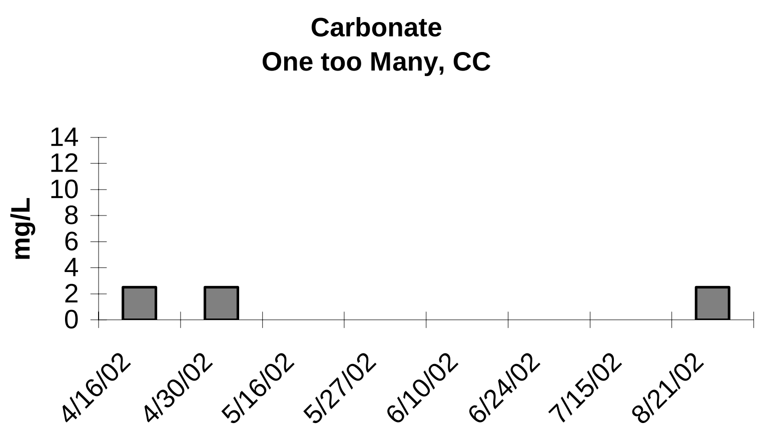
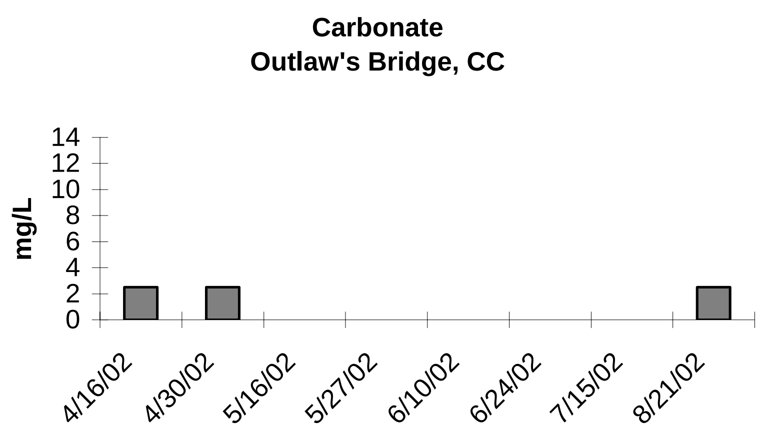


Figure 112: Carbonate (CO_2^-), Castle Creek Sites
No Standard Established for Beneficial Uses, Detection Limit = 5 mg/L





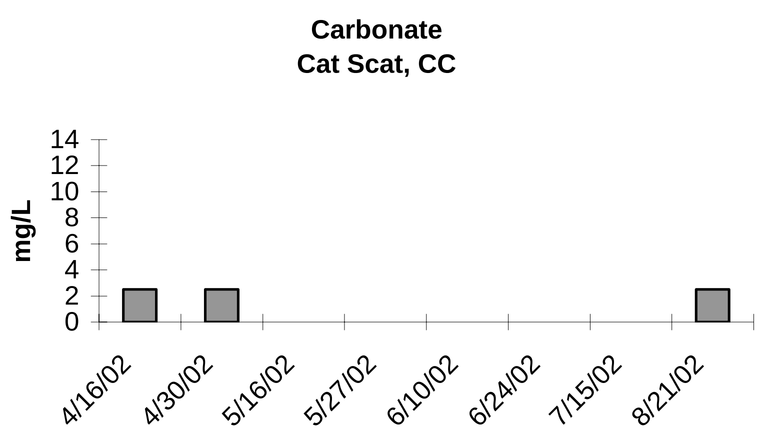
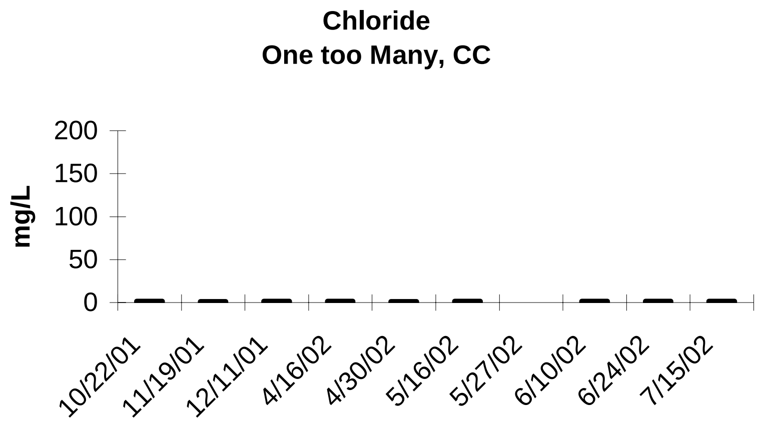
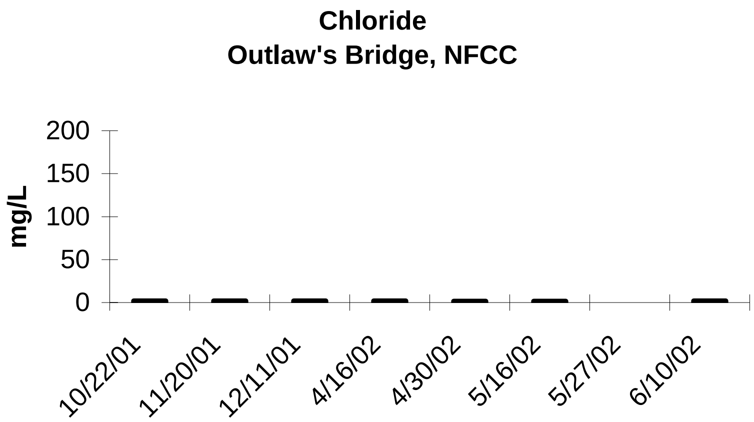


FIGURE 113: CHLORIDE, CASTLE CREEK SITES

Standard for Cold Water Fishery: 175 mg/L daily max, 100 mg/L 30-day average, Detection Limit = 0.5 mg/L





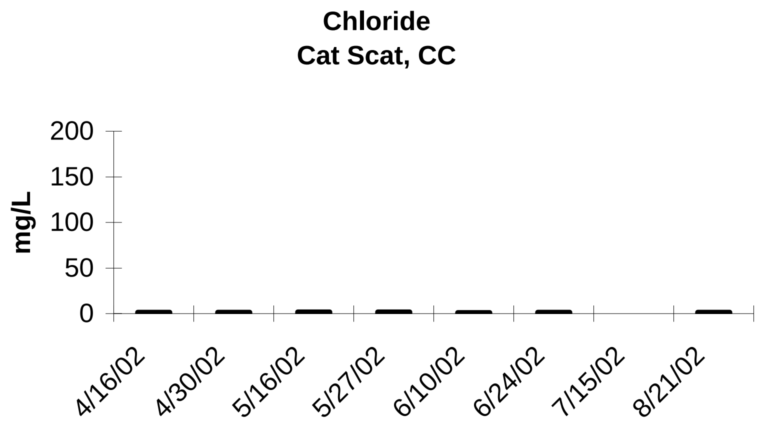
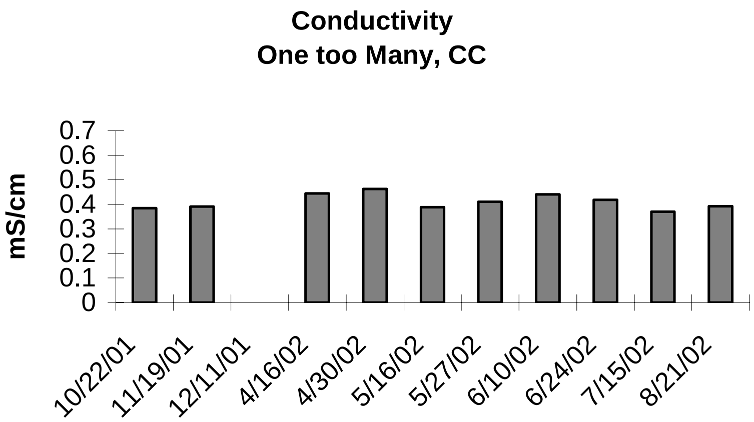
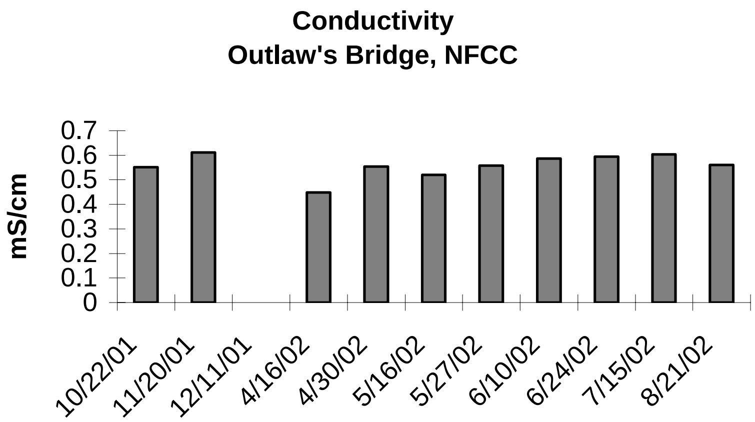


FIGURE 114: CONDUCTIVITY, CASTLE CREEK SITES

Standard for Irrigation: 4.375 mS/cm daily max, 2.5 mS/cm 30-day average





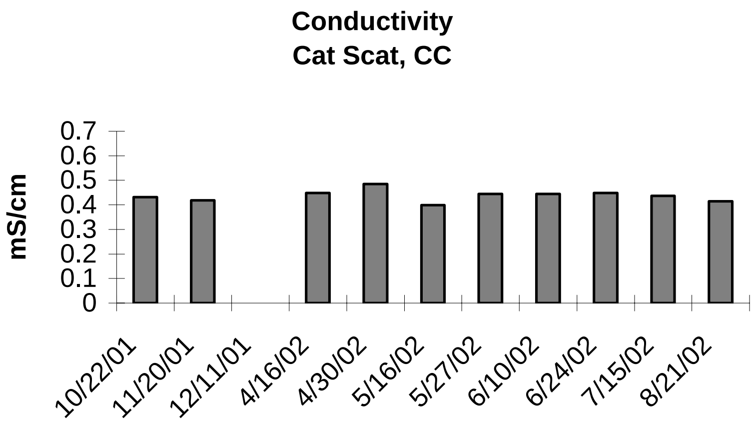
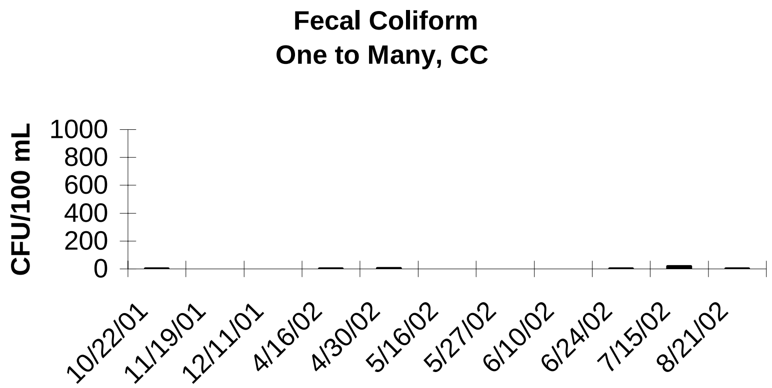
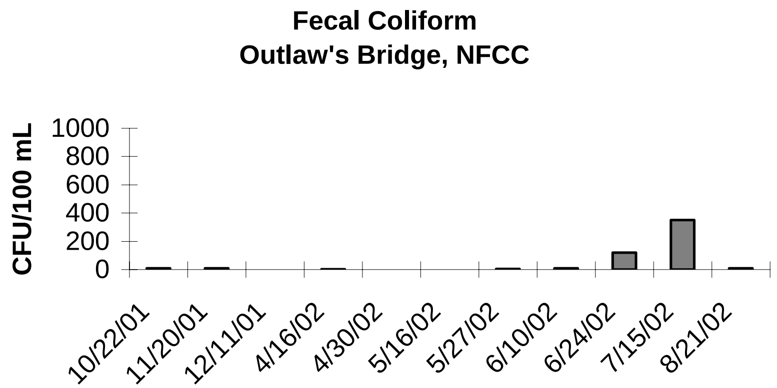


FIGURE 115: TOTAL FECAL COLIFORM, CASTLE CREEK SITES

Standard for Limited Contact Recreation: 1000 CFU/100ml mean of 5 daily samples, 2000 CFU/100ml daily max





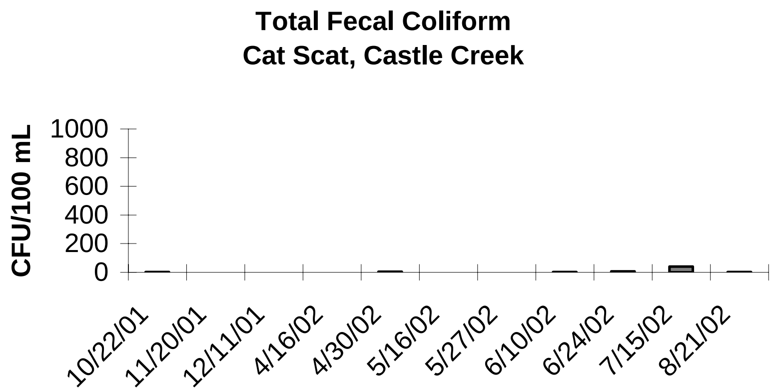
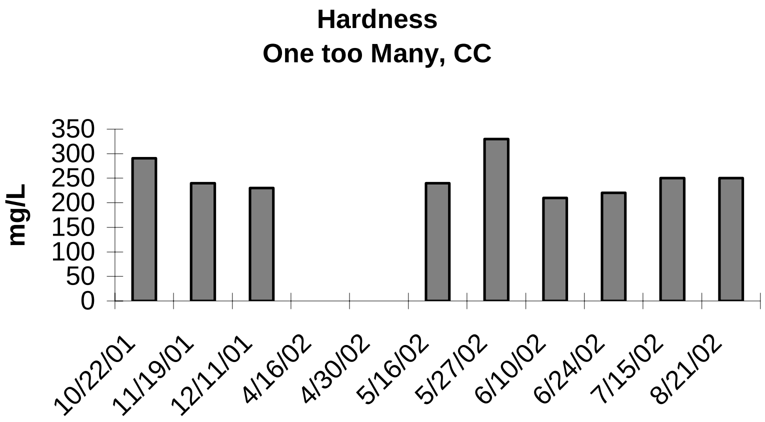
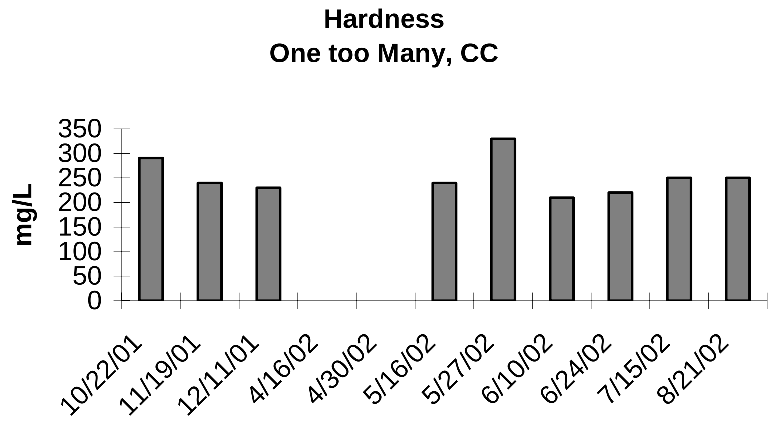


Figure 116: Hardness as $CaCO_3$, Castle Creek Sites

No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L





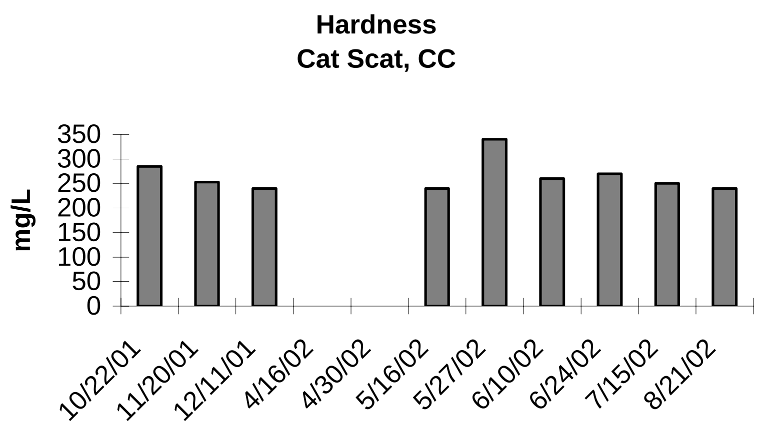
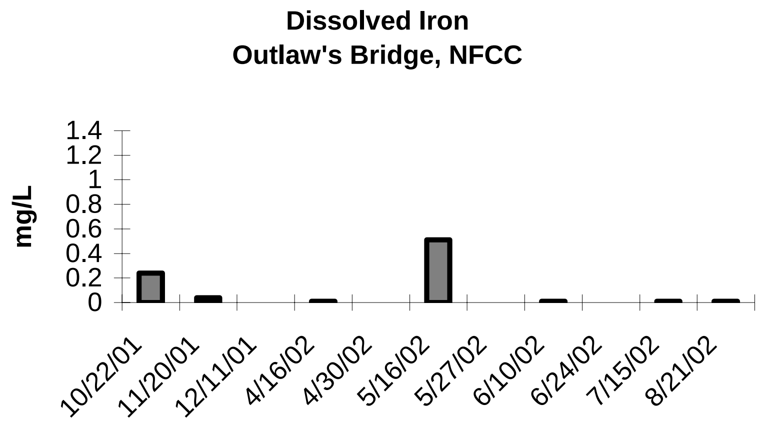


FIGURE 117: DISSOLVED IRON (Fe^{3+}), CASTLE CREEK SITES

No Standard Established for Beneficial Uses, Detection Limit = 0.05



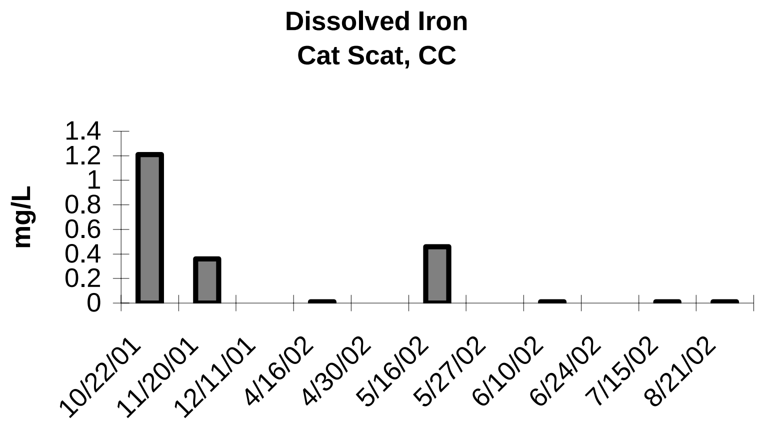
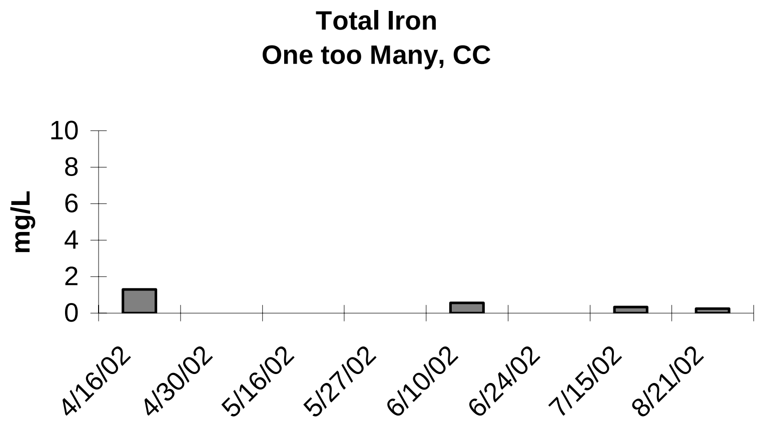
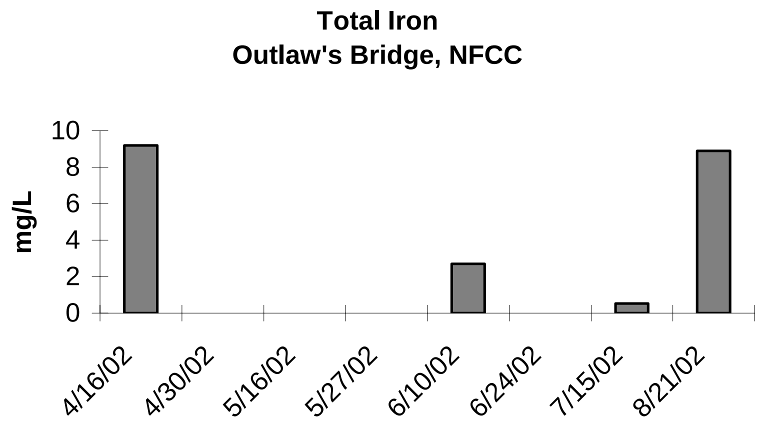


FIGURE 118: TOTAL IRON, CASTLE CREEK SITE

No Standard Established for Beneficial Uses, Detection Limit = 0.02 mg/L





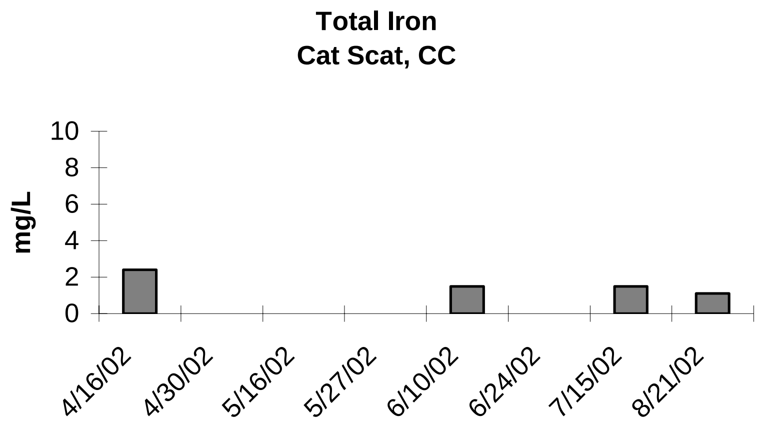
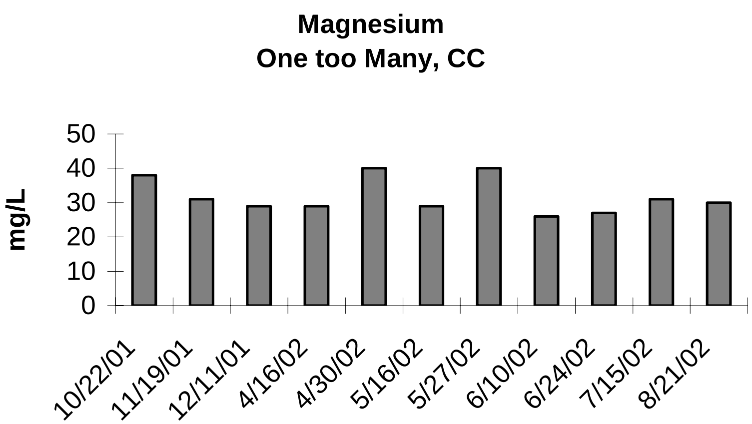
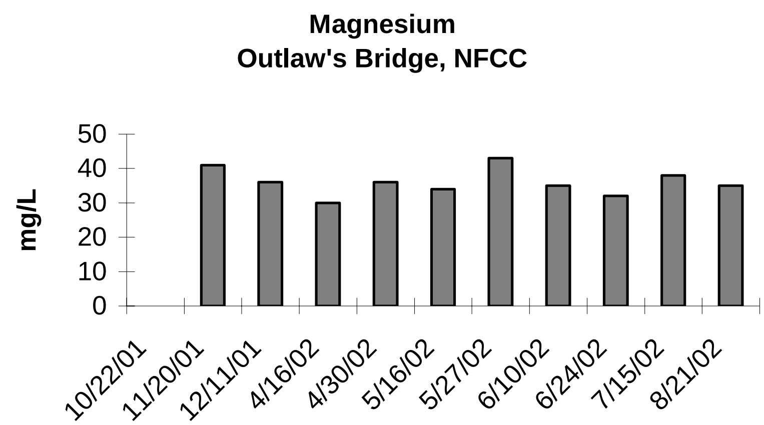


Figure 119: Magnesium (Mg^{2+}), Castle Creek Sites
No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L





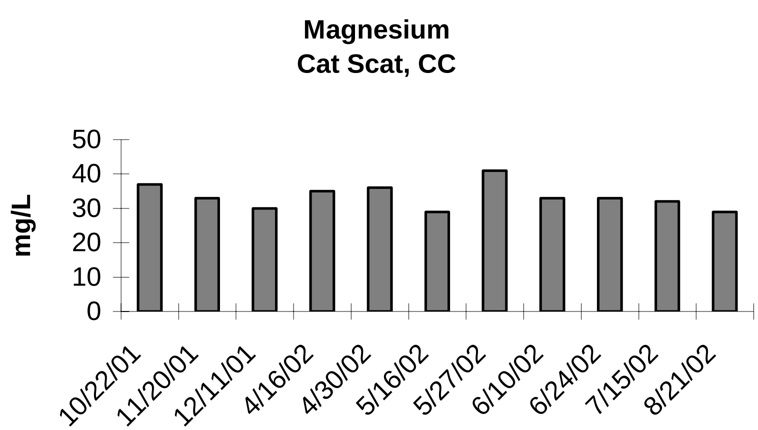
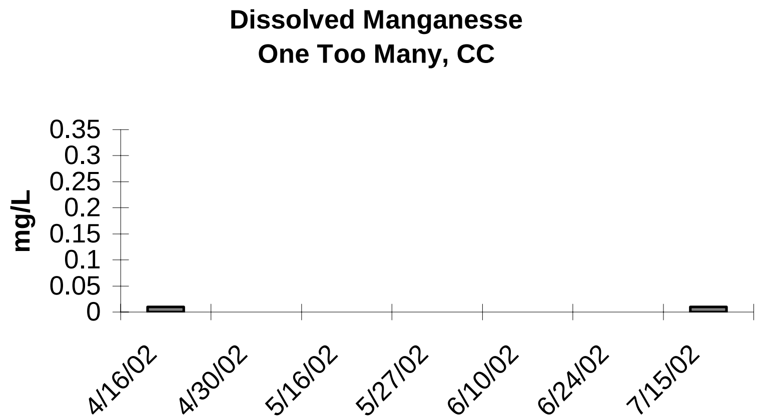
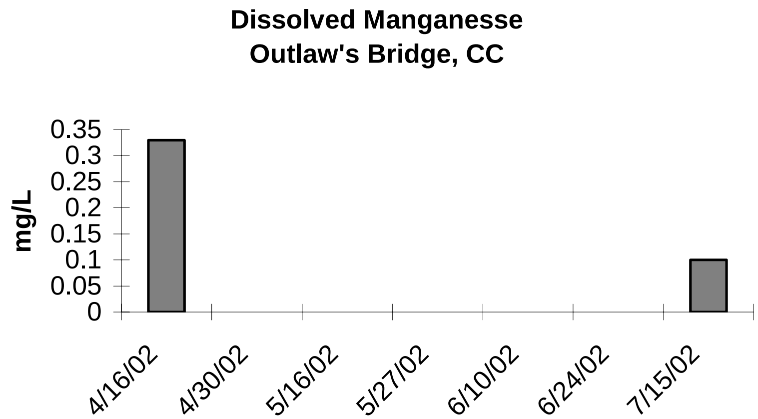


Figure 120: Dissolved Manganese, Castle Creek Sites

No Standard Established for Beneficial Uses, Detection Limit = 0.01 mg/L





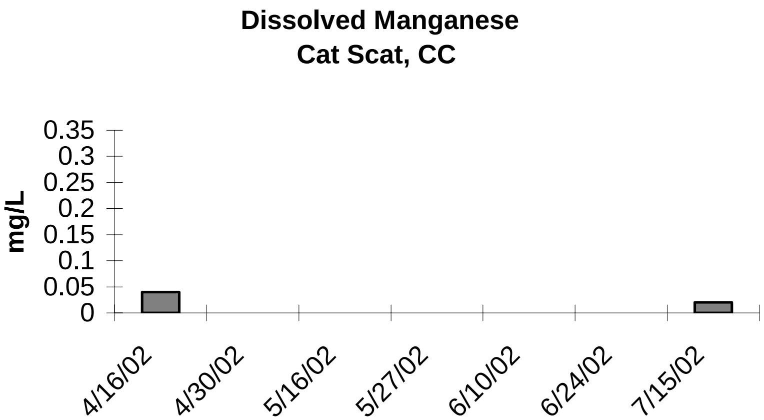
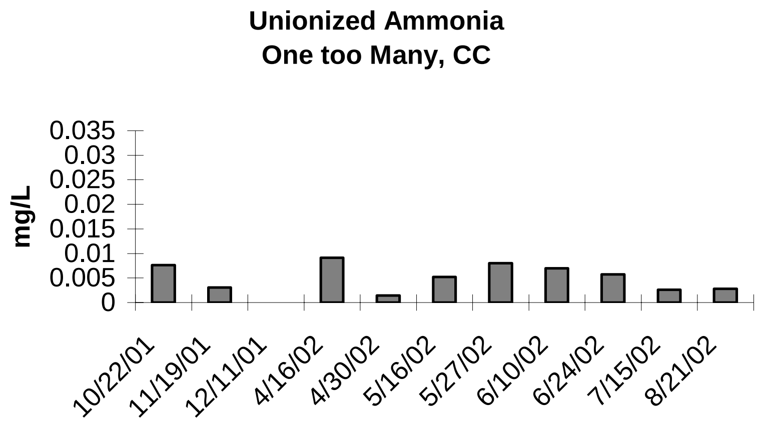
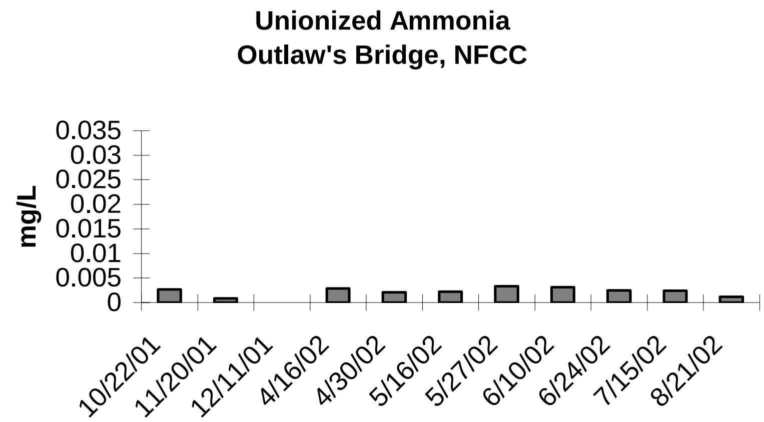


FIGURE 121: UNIONIZED AMMONIA (NH3), CASTLE CREEK SITES

Standard for Cold Water Fishery: 0/035 mg/L daily max, 0.02 mg/L 30-day average

Note: Samples results of less than detection limit of N as Ammonia + Ammonium were assumed to be ½ the detection limit of 0.1mg/L





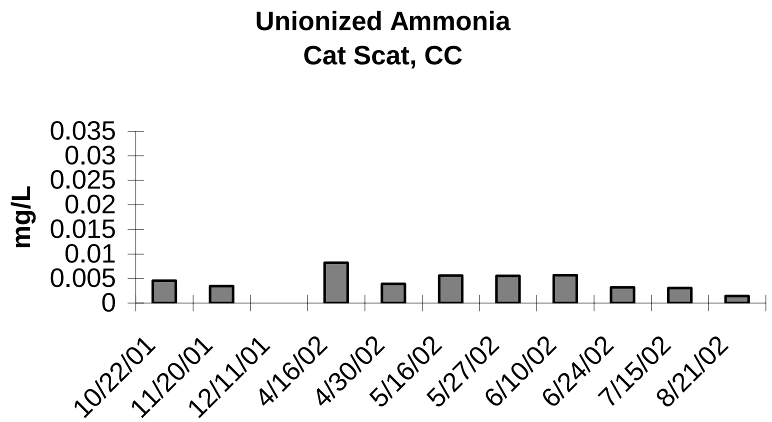
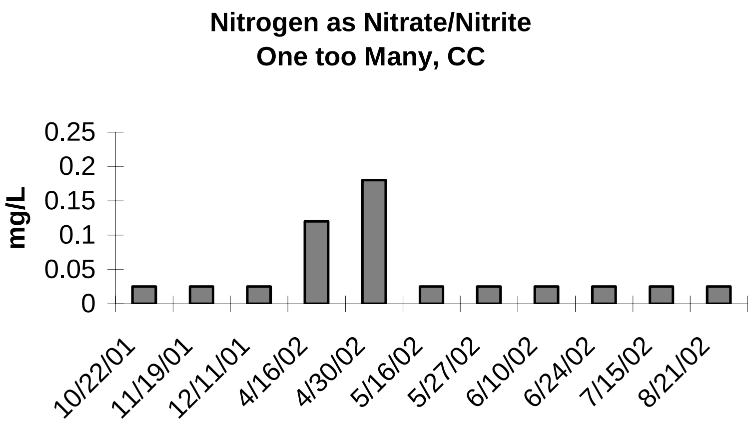
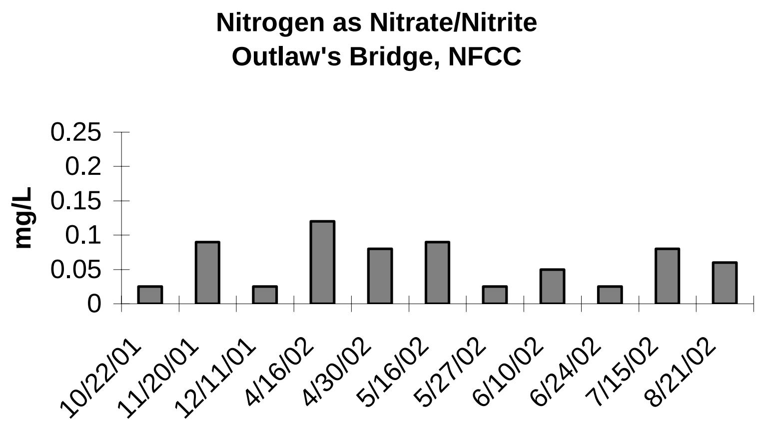


FIGURE 122: NITROGEN AS NITRATE/NITRITE, CASTLE CREEK SITE

Standard for Fish, Wildlife Propagation, Recreation, & Stock Watering: 88mg/L daily max., 50 mg/L 30-day average
Detection Limit = 0.05 mg/L





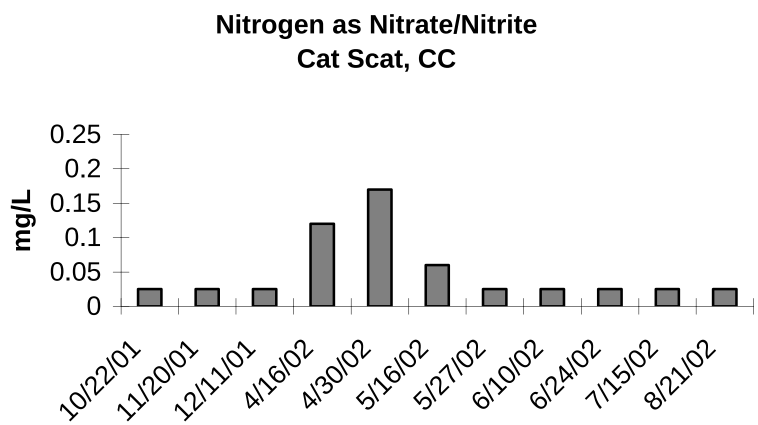
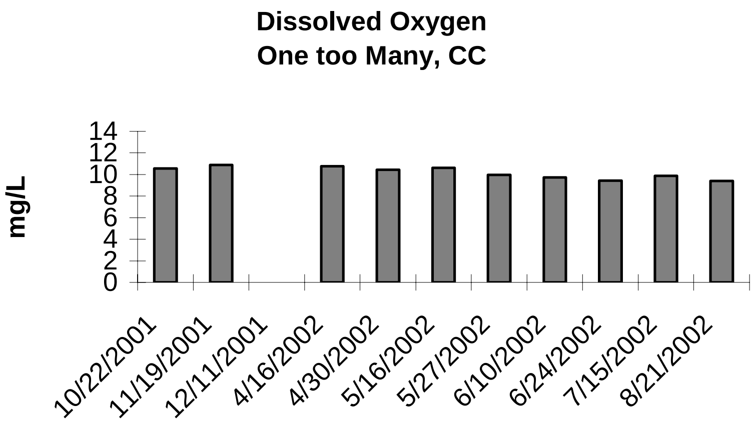
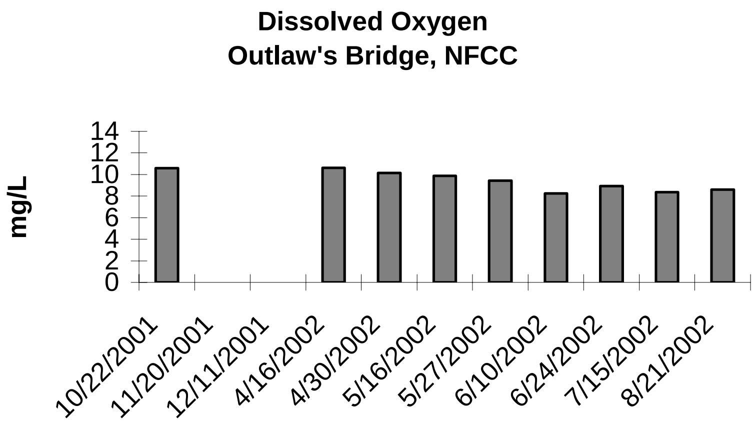


FIGURE 123: DISSOLVED OXYGEN, CASTLE CREEK SITES

Standard for Cold Water Fishery: [6.0 mg/L; [7.0 mg/L during spawning season





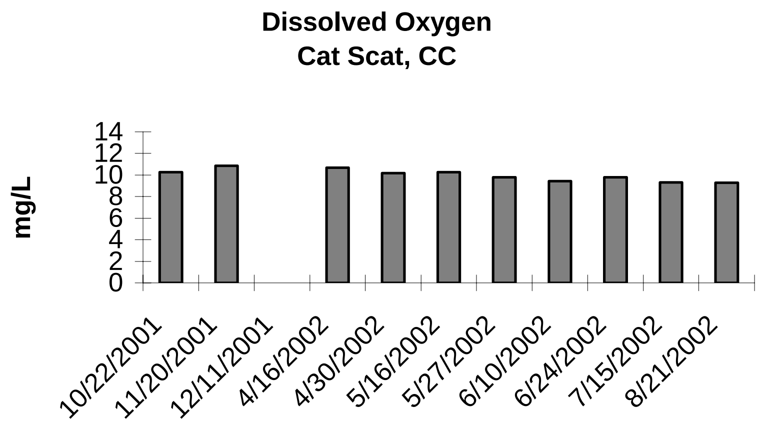
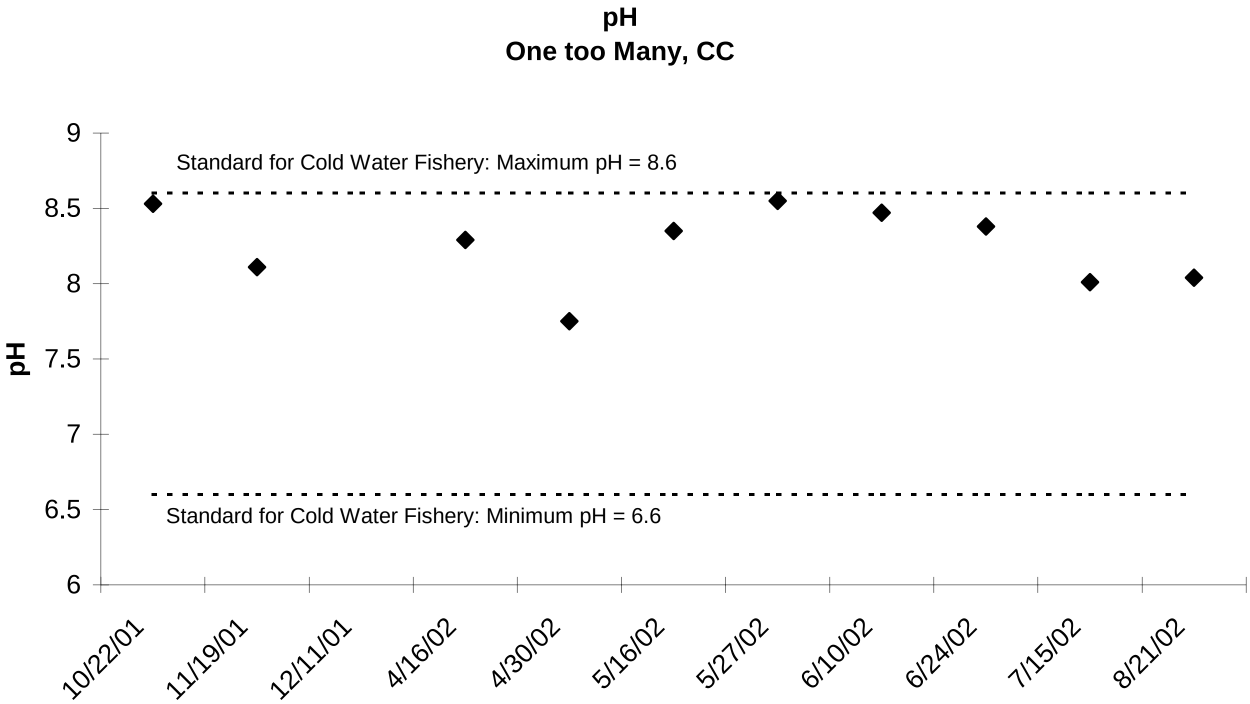


FIGURE 124 : PH, CASTLE CREEK SITES



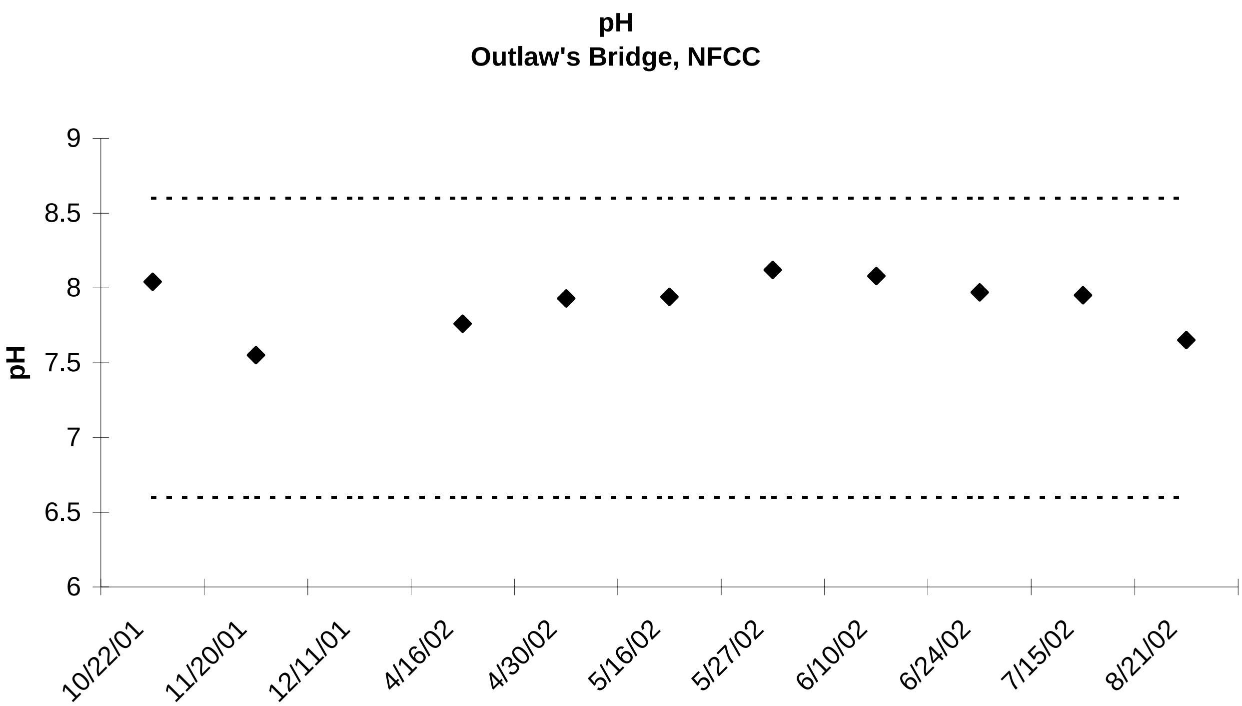


Figure 124: pH, Castle Creek Sites Continued

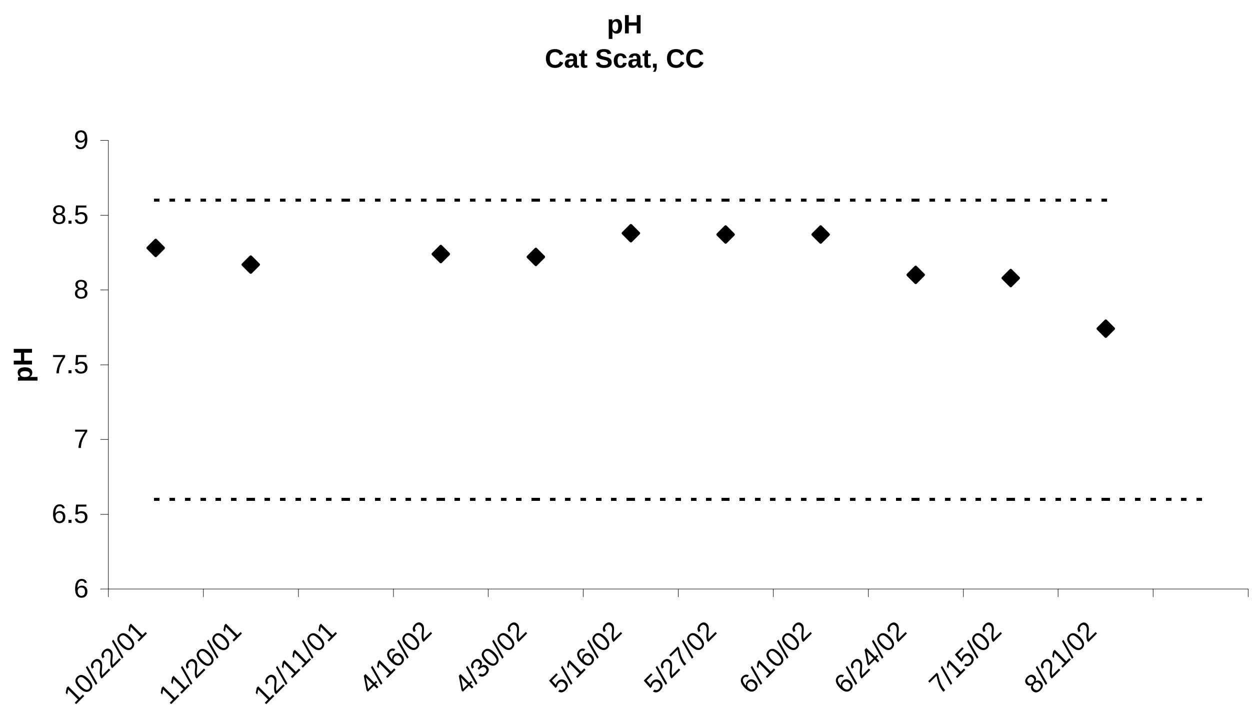
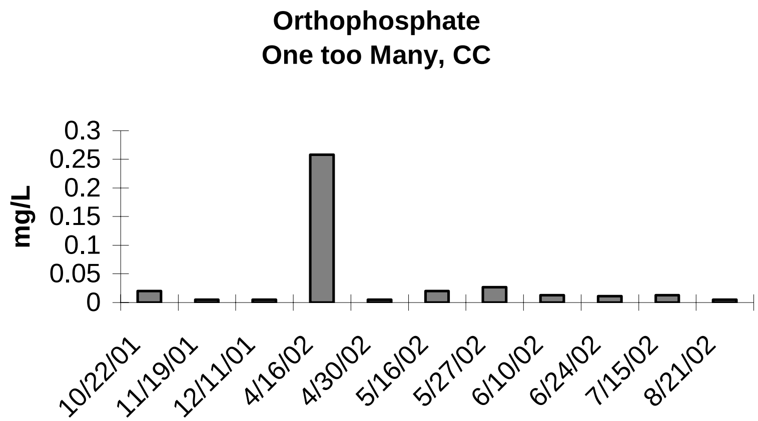
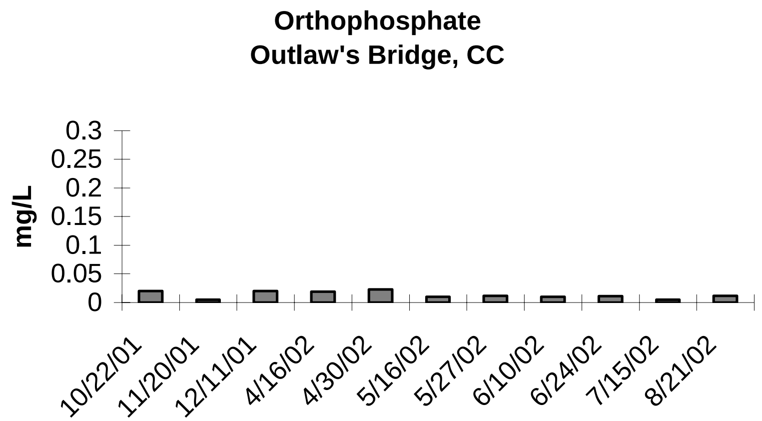


FIGURE 125: ORTHOPHOSPHATE (HPO_4^{2-}), CASTLE CREEK SITES

No Standard Established for Beneficial Uses, Detection Limit = 0.01 mg/L





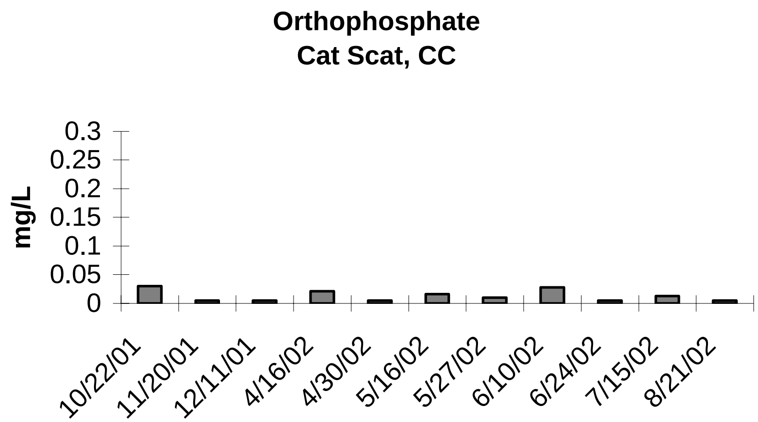
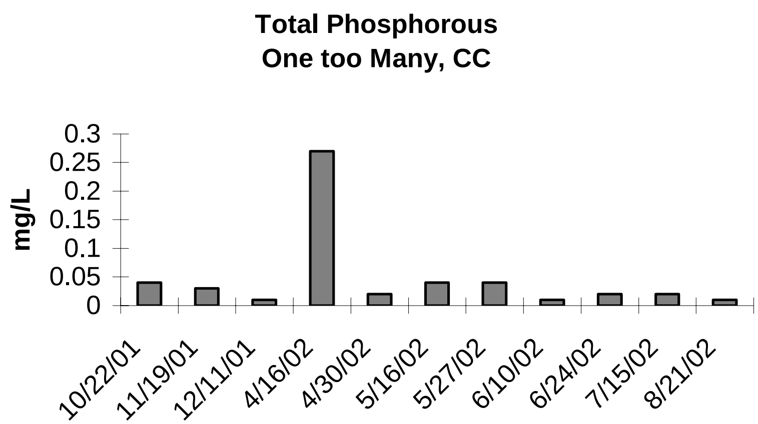
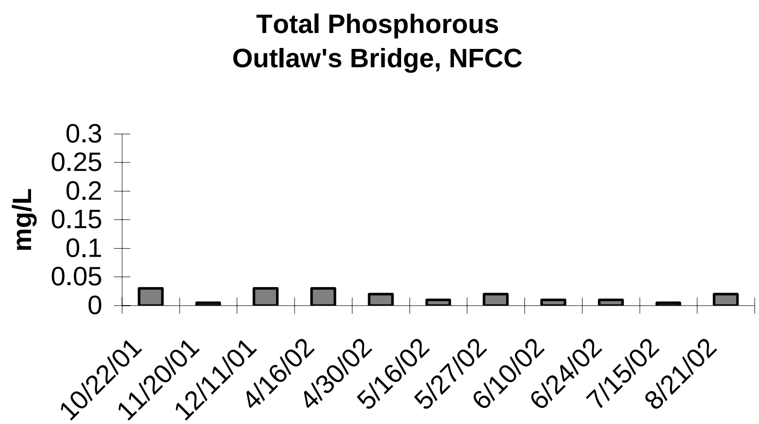


Figure 126: Total Phosphorus, Castle Creek Sites
No Standard Established for Beneficial Uses, Detection Limit = 0.01





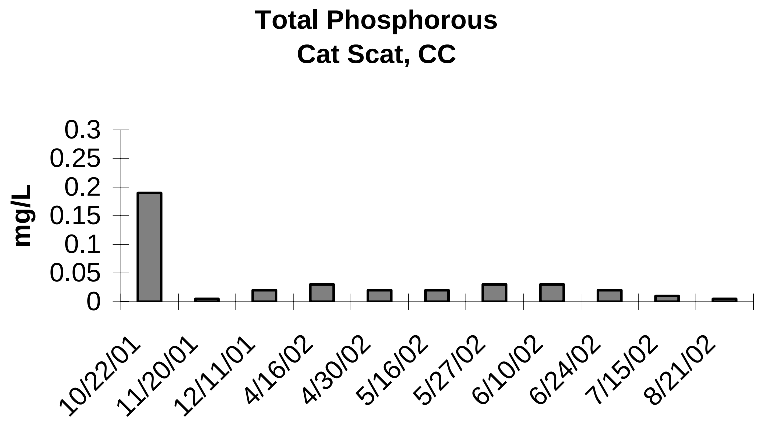
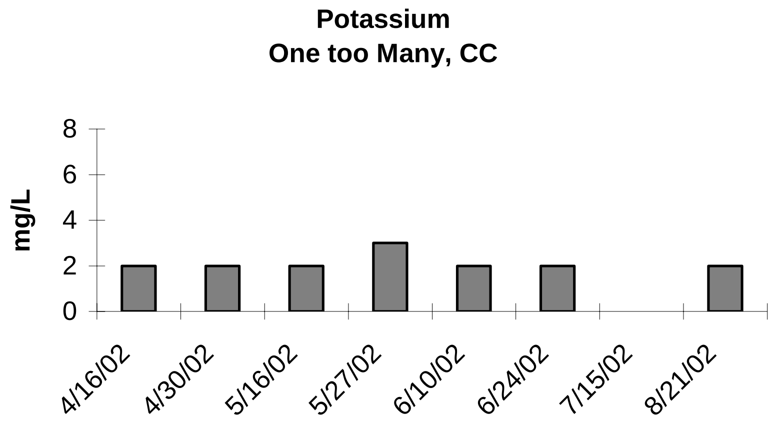
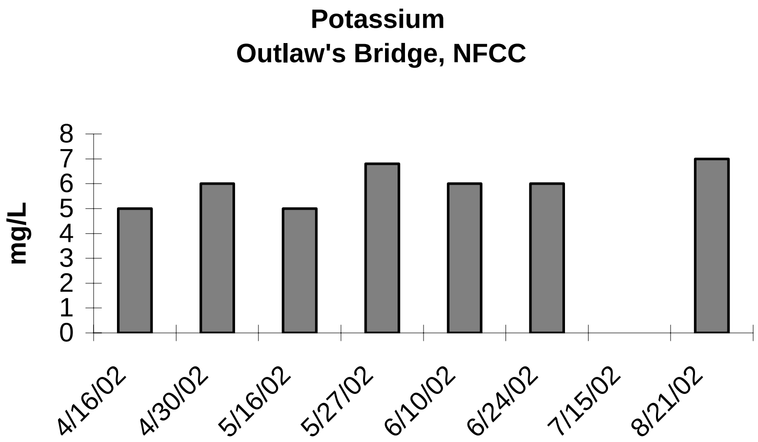


FIGURE 127: POTASSIUM (K+), CASTLE CREEK SITES

No Standard Established for Beneficial Uses, Detection Limit = 1 mg/L





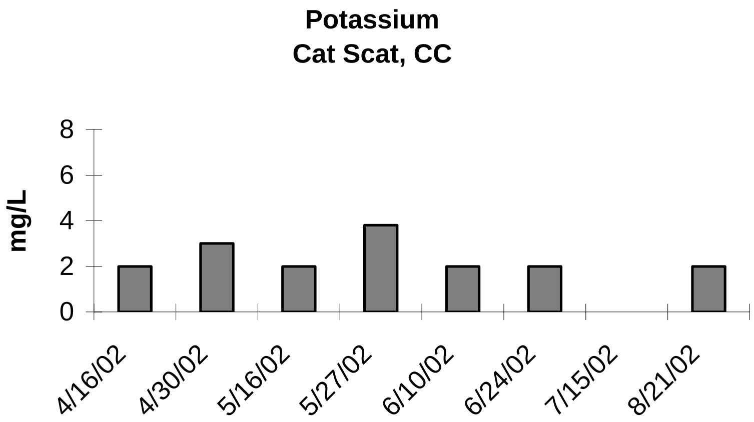
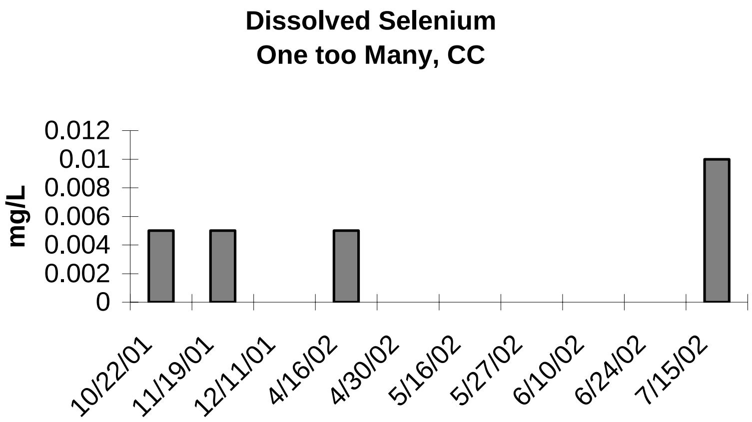
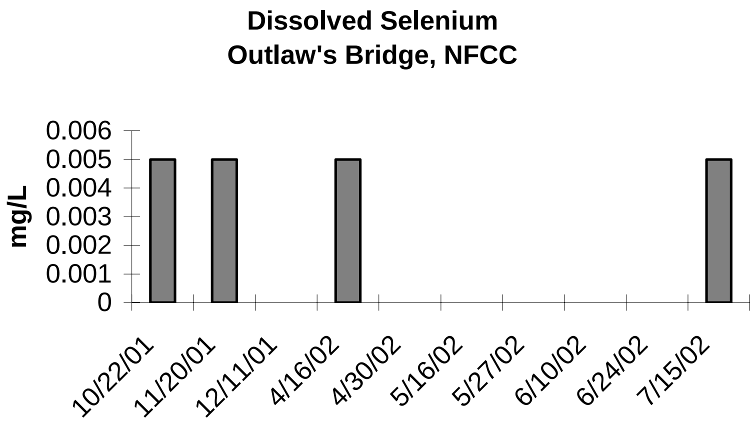


FIGURE 128: DISSOLVED SELENIUM, CASTLE CREEK SITES

No Standard Established for Beneficial Uses





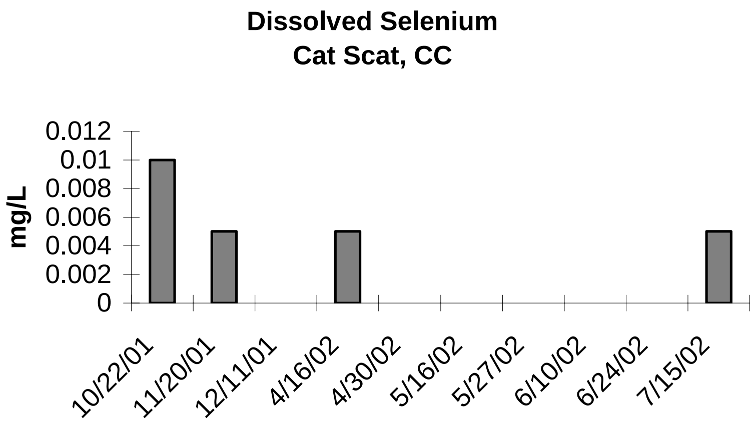
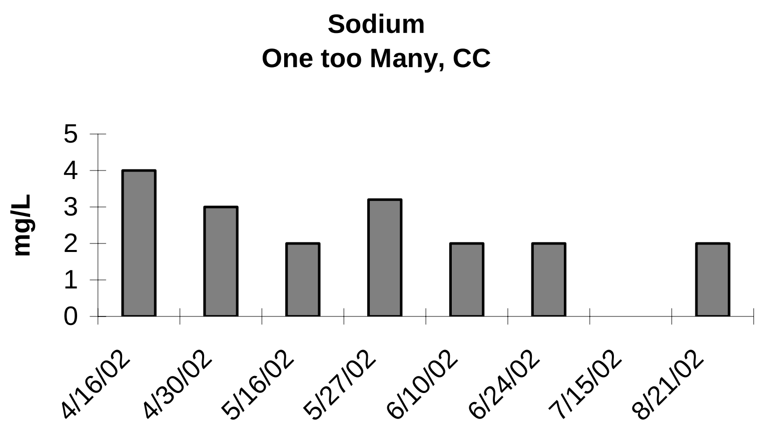
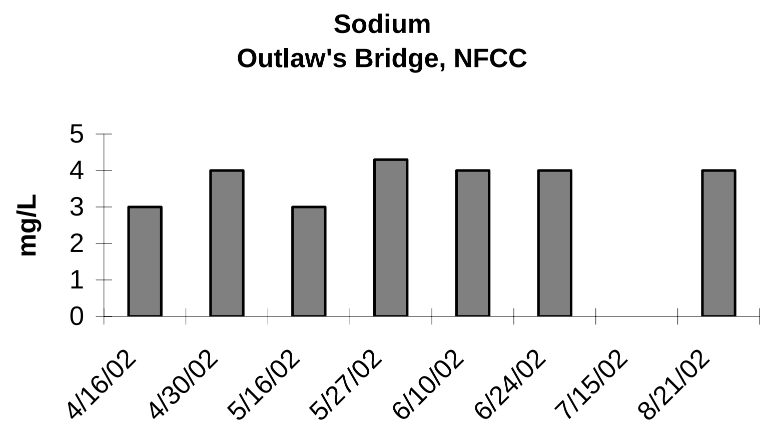


FIGURE 129: SODIUM (NA+), CASTLE CREEK SITES

No Standard Established for Beneficial Uses – See discussion for SAR Standard, Detection Limit = 1 mg/L





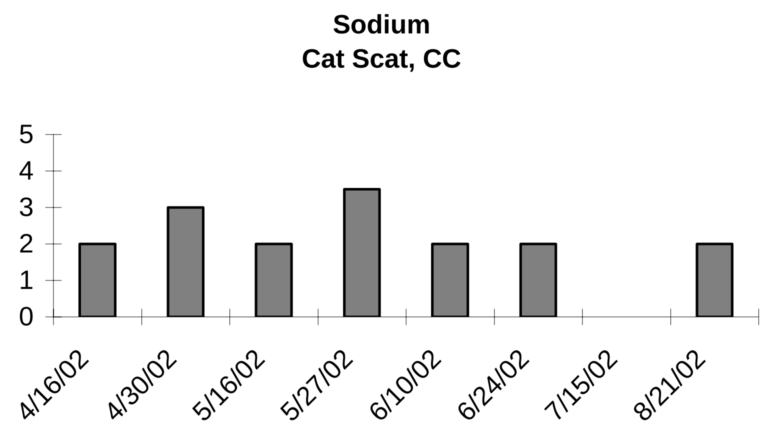
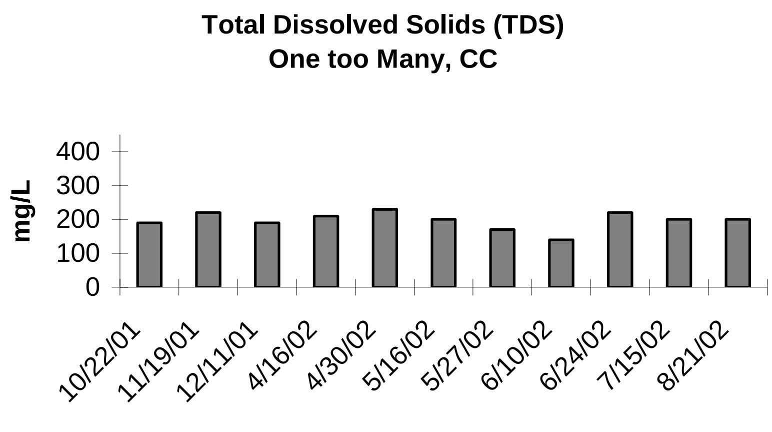
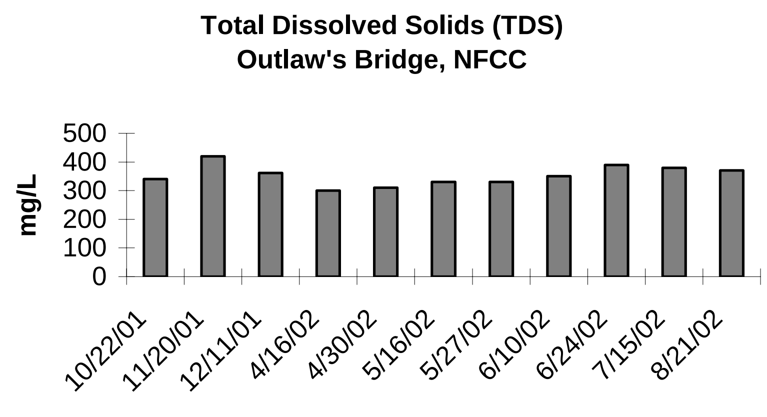


FIGURE 130: TOTAL DISSOLVED SOLIDS (TDS), CASTLE CREEK SITES

Standard for Fish and Wildlife Propagation, Recreation, & Stock Watering: 2,500 mg/L, Detection Limit = 5 mg/L





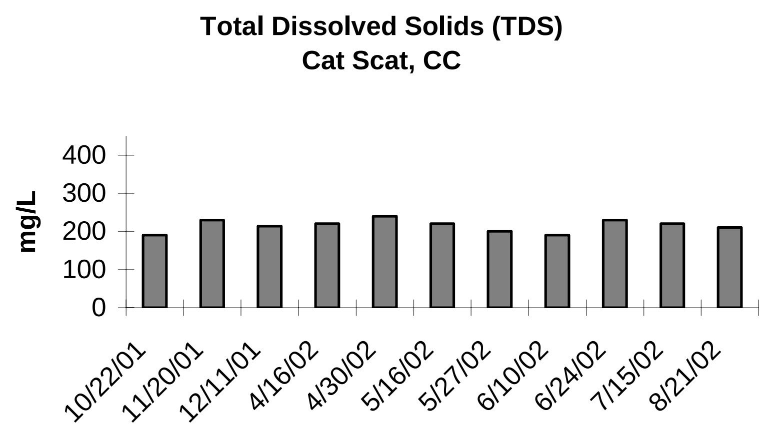
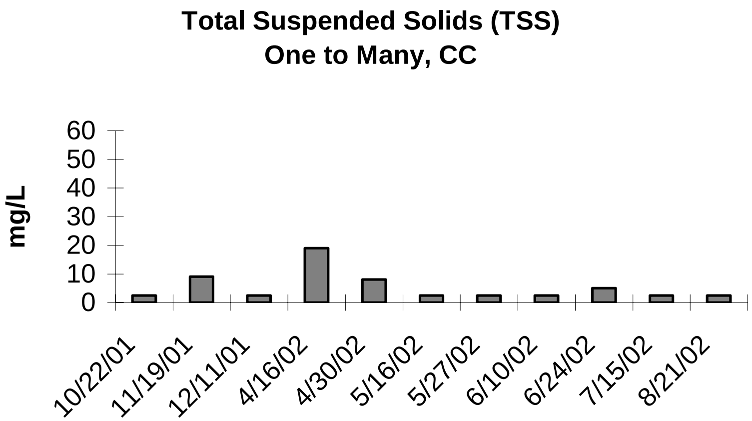
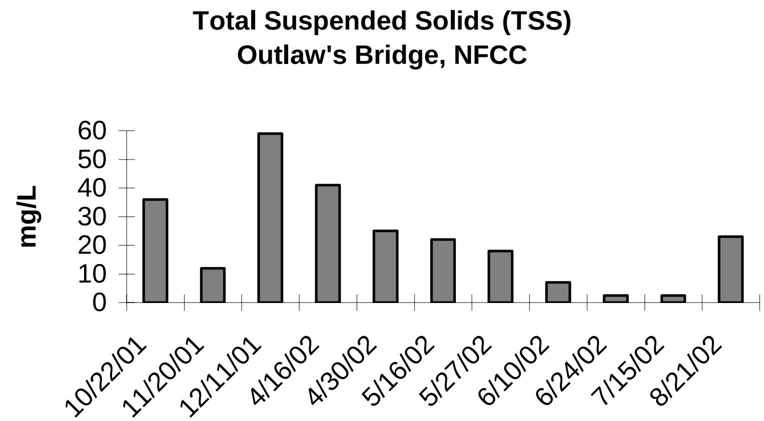


FIGURE 131: TOTAL SUSPENDED SOLIDS, CASTLE CREEK SITES

Standard for Cold Water Fishery: 53 mg/L daily maximum, 30 mg/L 30-day average, Detection Limit = 5 mg/L





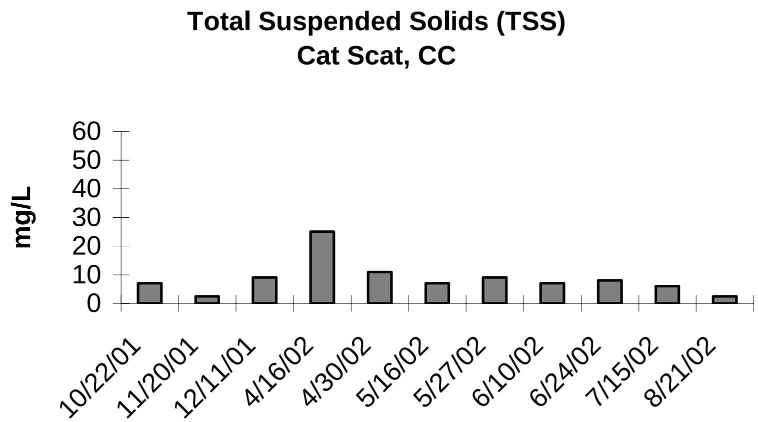
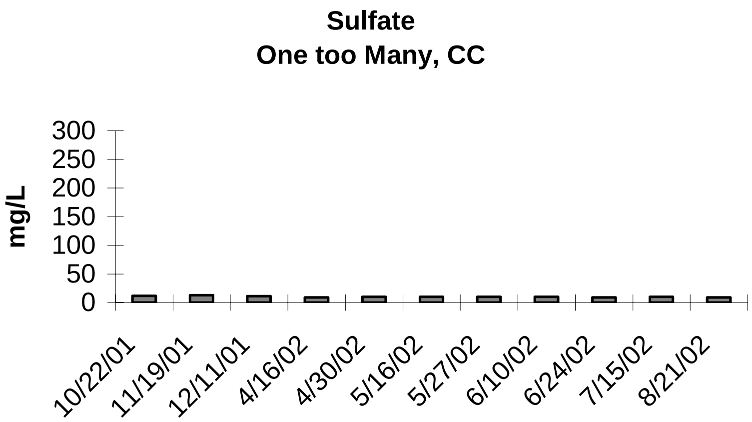
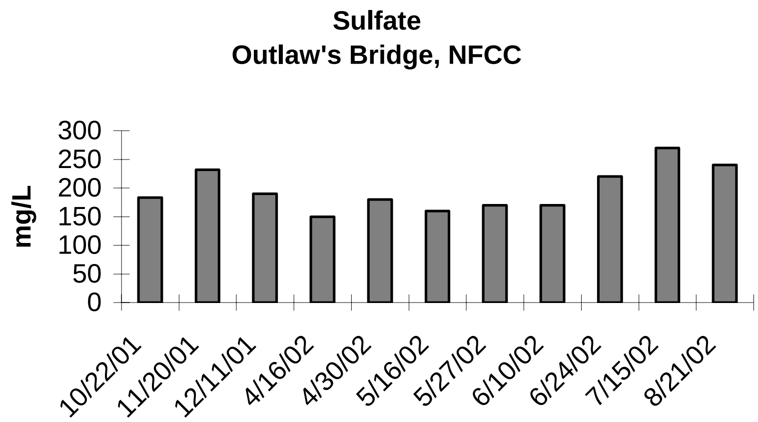


FIGURE 132: SULFATE, CASTLE CREEK SITE

No Standard Established for Beneficial Uses, Detection Limit = 1mg/L





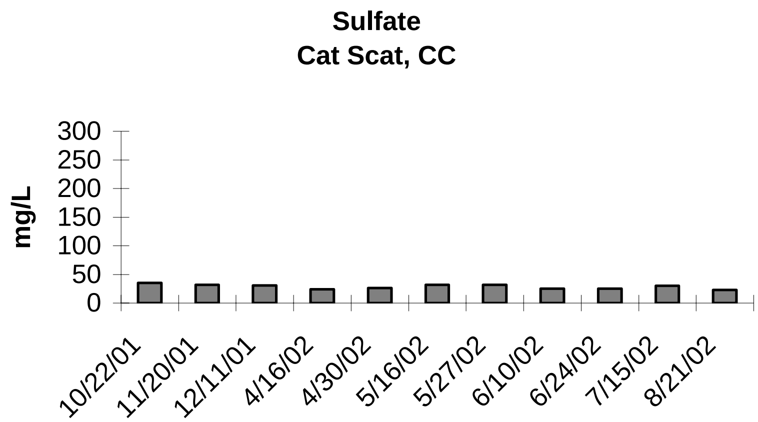
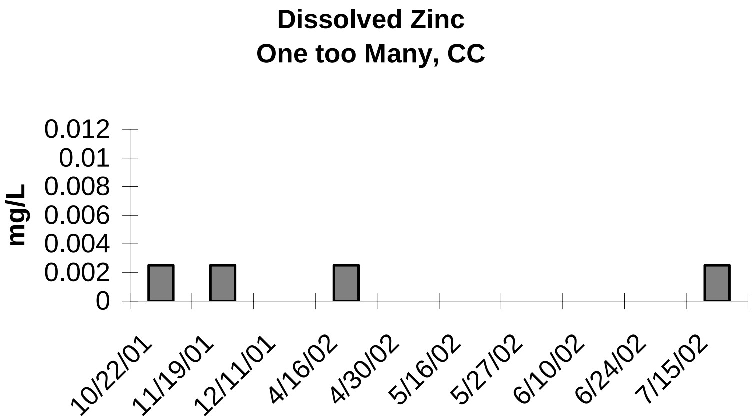
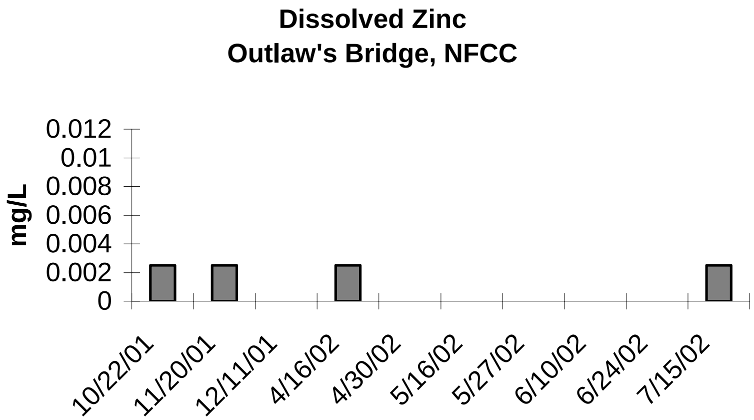


FIGURE 133: DISSOLVED ZINC, CASTLE CREEK SITES

No Standard Established for Beneficial Uses, Detection Limit = 0





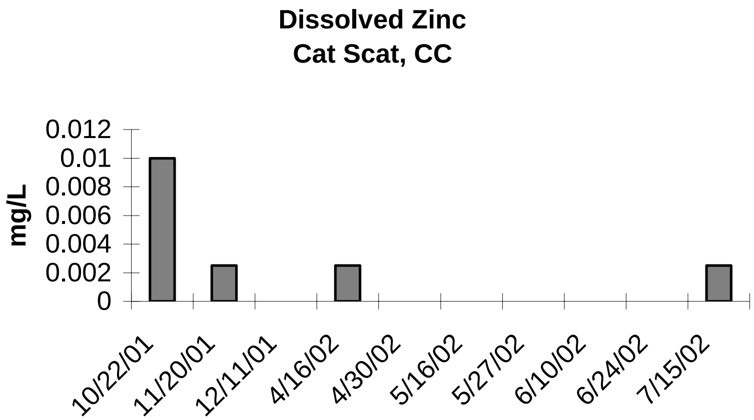


Table 30: Sampling Results for Single Sample Events or for Elements Which Did Not Exceed Detection Limits, Castle Creek Sites
(All units mg/L unless otherwise specified)

Element	Date	Sample Location		
		One too Many	Outlaw's Bridge	Cat Scat
F^-	16-Apr-02	0.2	0.3	0.2
Si as SiO_2	16-Apr-02	8	12	8
Total As	15-Jul-02	ND all		
Total Cd	15-Jul-02	ND all		
Total Cu	15-Jul-02	ND all		
Total Se	15-Jul-02	ND	0.01	ND
Total Zn	15-Jul-02	ND	0.01	ND
Dissolved As	22-Oct-01	< 0.01	< 0.01	< 0.01
	20-Nov-01	< 0.01	< 0.01	< 0.01
	16-Apr-02	0.01	0.01	0.01
	15-Jul-02	< 0.01	< 0.01	< 0.01
Dissolved Cd	22-Oct-01	< 0.001	< 0.001	0.001
	20-Nov-01	< 0.001	< 0.001	< 0.001
	16-Apr-02	< 0.001	< 0.001	< 0.001
	15-Jul-02	< 0.001	< 0.001	< 0.001
Dissolved Cu	22-Oct-01	< 0.01	< 0.01	< 0.01
	20-Nov-01	< 0.01	< 0.01	< 0.01
	16-Apr-02	0.01	< 0.01	< 0.01
	15-Jul-02	< 0.01	< 0.01	< 0.01
Dissolved Pb	22-Oct-01	< 0.01	< 0.01	< 0.01
	20-Nov-01	< 0.01	< 0.01	< 0.01
Dissolved Hg	22-Oct-01	< 0.0002	< 0.0002	< 0.0002
	20-Nov-01	< 0.0002	< 0.0002	< 0.0002
Dissolved Ag	22-Oct-01	< 0.005	< 0.005	< 0.005
	20-Nov-01	< 0.005	< 0.005	< 0.005
Dissolved Zn	22-Oct-01	< 0.005	< 0.005	0.01
	20-Nov-01	< 0.005	< 0.005	< 0.005
	16-Apr-02	< 0.005	< 0.005	< 0.005
	15-Jul-02	< 0.005	< 0.005	< 0.005

Table 31: Groundwater Sample Results
(All units mg/L unless otherwise specified)

Element/Ion	CC-GW 7/15/02	CC-GW 10/17/02	CC-GW 1/8/03	CC-GW 5/22/03	NFRC-GW 7/15/02	NFRC-GW 10/17/02	NFRC-GW 1/8/03	NFRC-GW 5/22/03
Hardness $CaCO_3$	470	260	360	420	140	130	140	130
TDS	1600	740	604	1300	980	830	834	780
TSS	120	240	130	44	310	510	350	320
Ca2+	96	54	52	79	29	28	29	29
Cl-	3	2.2	1.9	3.2	2.4	2.1	2.3	2.2
F-	<0.1	0.3	0.4	0.55	1.4	0.5	0.6	0.91
Mg2+	56	30	30	54	17	15	16	15
K+	19	13	8	8	13	13	16	13
Na+	7	4	3	5	3	4	4	3
SO42-	9200	890	450	1730	2600	930	2000	3840
Total Al	76	23	96	26	33	30	32	29
Total As	0.1	0.04	0.21	<0.01	0.79	0.86	1.1	0.4
Total Fe	250	74	82	200	290	310	345	208
Fe3+	10	0.005	43	26	130	170	220	92
Total Mn		0.75	0.78	2		0.84	0.87	0.82
Total Pb	<0.01	<0.01			0.14	0.14		
Total Zn	0.94	0.35	0.37	0.46	1.3	1.1	1.2	1.1
Dissolved Al	23	19	15	15	31	28	26	28
Dissolved As	0.03	0.02	<0.01	<0.01	0.01	0.03	0.01	<0.01
Dissolved Fe	240	78	39	190	160	140	120	90
Fe2+				170				120
Dissolved Mn	2.4	0.81	0.52	1.9	0.86	0.83	0.77	0.8
Dissolved Pb	<0.01	<0.01			<0.01	<0.01		
Dissolved Zn	0.95	0.39	0.24	0.5	1.4	1.2	1.2	1.1
Temperature	52.6	43.9	42.2		52.2	45	42.6	
Dissolved O2	0.94	2.85	2.23		1.69	1.36	2.5	
pH	4.64	4	4.57		4.48	3.79	3.77	
Specific Conductivity (mS/cm)	1.721	0.766	0.347		1.046	0.682	0.7	

Table 32: Miscellaneous Grab-Sample Results

(All units mg/L unless otherwise specified)

	NFRC Sites		Castle Creek Sites	
	Cowpie	**NFRCSP**	**CCUP**	**CCDOWN**
Element/Ion	7/19/02	10/19/02	7/15/02	7/15/02
Alkalinity $CaCO_3$	<5	<5	7/26/00	204
HCO_3	<5	<5	244	244
CO_3	<5	<5	2.5	2.5
Hardness $CaCO_3$	81	120	250	260
TDS	320	810	140	190
TSS	14	<5	<5	<5
Ca2+	18	26	49	49
Cl-	2.1	2.2	1.4	1.5
F-	0.6	0.4	0.2	0.2
Mg2+	9	14	32	32
K+	9	12	2	2
Na+	6	4	3	2
SO42-	1100	980	9	24
Total Al	3.8	24	<0.05	0.3
Total As	<0.01	0.02	<0.01	<0.01
Total Fe	4.8	140	0.17	2.4
Fe3+	3.6	<.01	0.11	2.3
Total Pb	<.01	<.01	<.01	<0.01
Total Zn	0.16	0.16	<0.01	0.01
Dissolved Al	3.7	3.7	0.06	0.13
Dissolved As	<0.01	<.01	<0.01	<0.01
Dissolved Fe	4.1	150	0.02	0.01
Fe2+	1.2		0.06	0.1
Dissolved Mn		0.94		
Dissolved Pb	<0.01		<0.01	<0.01
Dissolved Zn	0.2	1.2	<0.005	<0.005
Temperature	66.4	48.4	61.4	63.4
Dissolved O2	5.91	1.93	9.4	8.83
pH	3.32	3.65	8.42	8.13
Specific Conductivity (mS/cm)	0.677	0.458	0.413	0.431

Table 33: Comparison of Analytical Results, Storm Events vs. Average of Monthly and Bimonthly Results

	High and Dry Site, NFRC			**One to Many, CC**			**CAT SCAT, CC**	
	Date		**Non-event**	**Date**		**Non-event**	**Date**	**Non-event**
Ion	**20-Jul-03**	**22-Aug-02**	**Average**	**20-Jul-03**	**5-Aug-03**	**Average**	**22-Aug-02**	**Average**
Alkalinity as $CaCO_3$	96	96	139	192	196	214	202	196
HCO_3	119	117	173	224	239	265	246	252
CO_3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$CaCO_3$ (Hardness)	190	170	196.5	240	220	251	210	264
TDS	180	220	196	170	170	197	200	214
TSS	45	29	7.4	2.5	2.5	5.3	2.5	8.5
Ca^{2+}	45	39	44	42	41	50	42	52.3
Cl^-	1.4	1.4	1.6	1.5	1.6	1.5	1.4	1.4
Mg^{2+}	19	17	19	32	29	31.8	26	33.4
K^+	4	4	3.1	2	2	2.1	2	2.4
Na^+	3	2	2.5	2	2	2.6	1	2.4
SO_4^{2-}	72	79	51.3	10	11	10.3	16	28.6
TOC	3.2	2.1	2	3	2.3	2.2	2.5	2.2
N as NO^{3-} & NO^{2-}	0.025	0.025	0.05	0.025	0.025	0.048	0.025	0.05
Total P	0.06	0.03	0.02	0.01	0.005	0.046	0.01	0.01
Ortho P	0.033	0.03	0.014	0.005	0.005	0.03	0.015	0.015

Appendix C: Inter-Office Communication Richards to Kenner, Re: Benthics, NFRC 2/20/03

TO: SCOTT KENNER

From: David Richards, Research ecologist, EcoAnalysts Inc.

Date: February 20, 2003

Re: Macroinvertebrate community analysis of North Fork Rapid Creek

Here is a brief summary of what the macroinvertebrates in North Fork Rapid Creek are telling us. Most of the following discussion pertains to the riffle samples but results of the reach wide samples do not differ much from riffle samples.

Abundance

There were up to 8 times more macroinvertebrates in upper North Fork Rapid Creek reach than in the downstream reach and up to 2 times more EPT's (Ephemeroptera, Plecoptera, and Trichoptera) in the upper reach as well. So the upper reach was represented by relatively more non-EPT's, which makes ecological sense. This was probably due to different physical habitat at each site. The upper site probably has more primary production in the open canopied environment, lower gradient with more deposition of fines, and lower stream velocities. In addition, there was a significant time difference between sampling at each site, which will yield some natural, temporal variability between the communities at each site. Human impacts may possibly be a factor as well; however, a much more detailed study would need to be conducted to conclude any anthropomorphic effects.

Dominant taxa (Figure 1)

The upper reach riffle samples were dominated by two facultative riffle beetle species (Elmidae) and a snail taxon (Physa sp.) for about 57% of total taxa. The lower reach riffle samples were dominated (about 47% of total taxa) by two tolerant baetid mayflies and a facultative hydropsychid caddisfly (Trichoptera)(Figure 1). In the reach-wide samples one of the dominant beetles in the upper reach was replaced by oligochaetes (worms). Both sections were somewhat dominated by a few species, which could indicate a perturbation to the stream, as it is generally considered that most healthy streams typically are not dominated by few species.

Richness (Figures 2 and 3)

In the riffle samples there were 43 taxa identified in the upper reach and 32 in the lower reach (Figure 2). I have not been able to get a hold of taxa richness for suggested reference conditions for South Dakota but these numbers are not bad. More taxa in the upper reach could be a result of higher habitat diversity and higher primary production in upper reach than lower reach influencing the riffle samples. As would be expected, reach wide taxa richness was higher than riffle habitats.

EPT's were the same (16 taxa) for both riffle reaches but the upper riffle reach had more Trichoptera and the lower had more Plecoptera and Ephemeroptera (figure 3). Again an indication of different environments with faster, cooler (?), more oxygenated water in the lower reach. Chironomid (midge) taxa were almost 3 times more prevalent in upper reach, which again suggests favorable midge habitat and probably not impairment related. Midges are not always bad.

Community composition

Again EPT's were more represented in the lower riffle reach than the upper, particularly Ephemeroptera and Plecoptera. There were >50% Coleoptera (beetles) in upper reach riffle samples (about 7% in lower). In absence of water quality changes, higher velocities at the lower site will naturally support more EPT taxa than the lower velocities at the upper site would support.

Diversity/Evenness Indices

Even though the lower reach was dominated by 3 taxa (almost 50%) it was slightly more even than the upper site when you examine Pielou's J, where perfect evenness = 1.00. In addition, Simpson's heterogeneity index indicates the same thing. Although frequently requested by our clients, diversity/evenness indices do not necessarily mean much ecologically. They can be used in a relative context, but a manager should not rely only on diversity as a measure of biological condition.

Dominance of more than 50% for three taxa is high, especially when using genus/species level taxonomy. In higher gradient streams of good quality the dominant three taxa often account for 30% or less of the entire community. There may indeed be something going on at these sites but we don't know the streams in this area well enough to comment. One explanation could be the season for beetle larvae in upper to dominate (late summer) and baetid larvae (univoltine) to dominate in lower section. Another could be the habitat condition at each site. Physa sp. (snails) can often naturally dominate any stream where attached algae are abundant (i.e. little canopy cover and high primary productivity). These conditions are natural in many basin/prairie (warmer) streams, but human activities can alter habitat/water quality and cause an increase in attached benthic algae.

Biotic Indices

The HBI was originally developed to rank species tolerance to organic pollution, particularly to reflect BOD (biological oxygen demand). The HBI index ranges from 0 to 10 with those species intolerant to organic pollution receiving lower values. Often organic pollution decreases 0_2 levels and therefore those species that survive in colder, well- oxygenated streams have lower HBI values (intolerant). The HBI values for North Fork Rapid Creek results suggest two things;

1) taxa that prefer cooler, more oxygenated water were found in lower reach than in the upper reach, which is not surprising if the upper reach was open meadow and lower reach was steeper, narrower and had more canopy cover, and

2) overall, both reaches were dominated by taxa associated with warmer conditions (not cold-water species), suggesting that summer stream temperatures are warm enough to preclude the existence of cold-water obligate species.

Metal Tolerance Indices (MTI) is an index of questionable worth at this time. More work needs to be done to evaluate species-specific responses to metal contamination. So take MTI values with a grain of salt for now.

Karr BIBI metrics do not mean much here. Most are fairly even and % tolerant only reflects the HBI. You can disregard the Montana Biotic index, as it is regional and does not apply to the area of study. You can remove it also from the metric spreadsheet. The voltinism metric (how many generations per year) shows that shorter-lived species reside in the lower reach, which is probably because of less primary production or harsher conditions (consider the intermediate disturbance hypothesis). However, it could also be due to habitat differences, which favor Baetidae at the lower reach.

An inherent problem for many metrics in a rapid bioassessment, is taxonomic resolution. In a rapid bioassessment, some taxa are identified to phylum, others to class, family, genus, or to the species level. This particularly affects diversity and evenness indices. So unless you see a big difference between these or any of the metrics, then I would not assume any ecologically significant difference or propose human caused impacts.

One concern I have is that the upper reach of North Fork Rapid Creek was sampled in mid August and the lower reach in early October. I assume that in South Dakota there is also a shift in weather from late summer to early autumn with lower temperatures, less daylight, and leaf fall from canopy etc. Macroinvertebrate assemblages typically track these changes and what you find in a reach in August is not what you find in October. Typically, macroinvertebrate bioassessments are conducted and compared during one season, usually summer. So, if you want to compare these assemblages and results please use caution. There is significant potential that natural seasonal shift in community composition has occurred here.

<u>Functional feeding groups</u> (Figures 4 and 5)

Shredders were more abundant in the lower reach, which was possibly related to deciduous canopy cover and season. Gatherers were higher in upper reach (about 51%) compared with 24% in lower reach. This was likely due to lower gradient at the upper reach, with a corresponding increase in the deposition of fine particulate organic matter (FPOM). Scrapers were four times more abundant in upper reach than lower reach, probably due to abundance of primary autochthonous food sources (algae). This is an open-canopy stream with higher periphyton/algae production as food source. A similar pattern was observed with piercers-herbivores, namely caddisflies in the family Hydroptilidae, which pierce algal filaments.

Given all of these cautions and ‘ifs’, and no straight-forward conclusions, I would suggest that;

1) Overall, the taxa found were representative of and reflect the two different habitats (reaches) and seasons. So the bugs are doing what they are supposed

to do. They are telling us the conditions of the stream. But I think we need to listen harder and follow up with a more detailed and well- defined study.

2) It is possible that temperatures are higher than would be expected and the invertebrate assemblages have shifted in response. Don't know if there are any historical macroinvertebrate records for this stream or area to compare with. It is also possible that mining activities have caused a decrease in abundance and taxa richness in the lower section but again this should be substantiated with other physical and chemical data and a more intensive monitoring of invertebrates.

Did you focus your sampling in sections directly influenced by bog iron? Samples from these areas might have shown a decrease in abundance and taxa richness within the iron covered substrate sections. You then could have sampled progressively downstream and documented a steady increase in abundance and diversity and therefore, estimate the distance to full or partial recovery. I have done just that in a mountain stream, Soda Butte Creek, which enters Yellowstone National Park after it flows through gold mine tailings with iron covered sediments. These sites look very similar to the photos that you sent me. Unfortunately, Soda Butte Creek never fully recovers until about 16-20 km downstream.

Just remember that indices (metrics) should not be used as a surrogate for an appropriate study design or a proper analysis of the data (Norris and Georges 1993. Analysis and interpretation of benthic macroinvertebrate surveys. In: Rosenberg and Resh ed. Freshwater biomonitoring and benthic macroinvertebrates).

If you would like to further discuss these results please feel free to contact us. We look forward to working with you in the future. Best wishes with your projects!

Sincerely,

David Richards
Research Ecologist
EcoAnalysts Inc.
406-582-9388
davidr@montana.edu

Percent Dominance

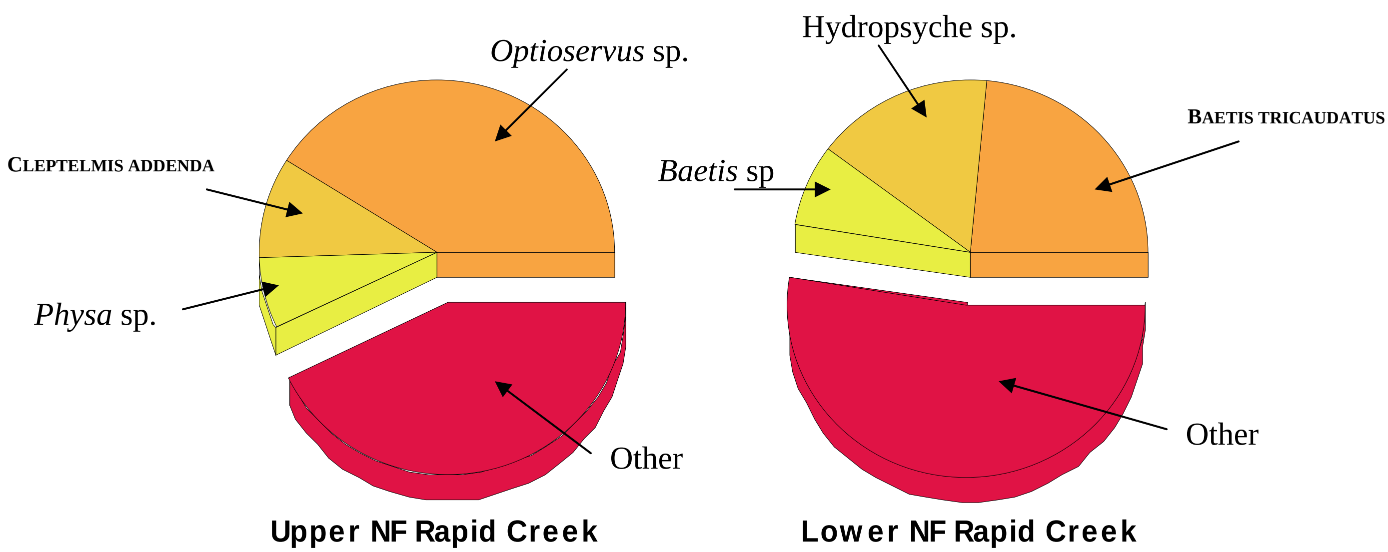


Figure 1. Percent dominance for upper and lower North Fork Rapid Creek riffle samples.

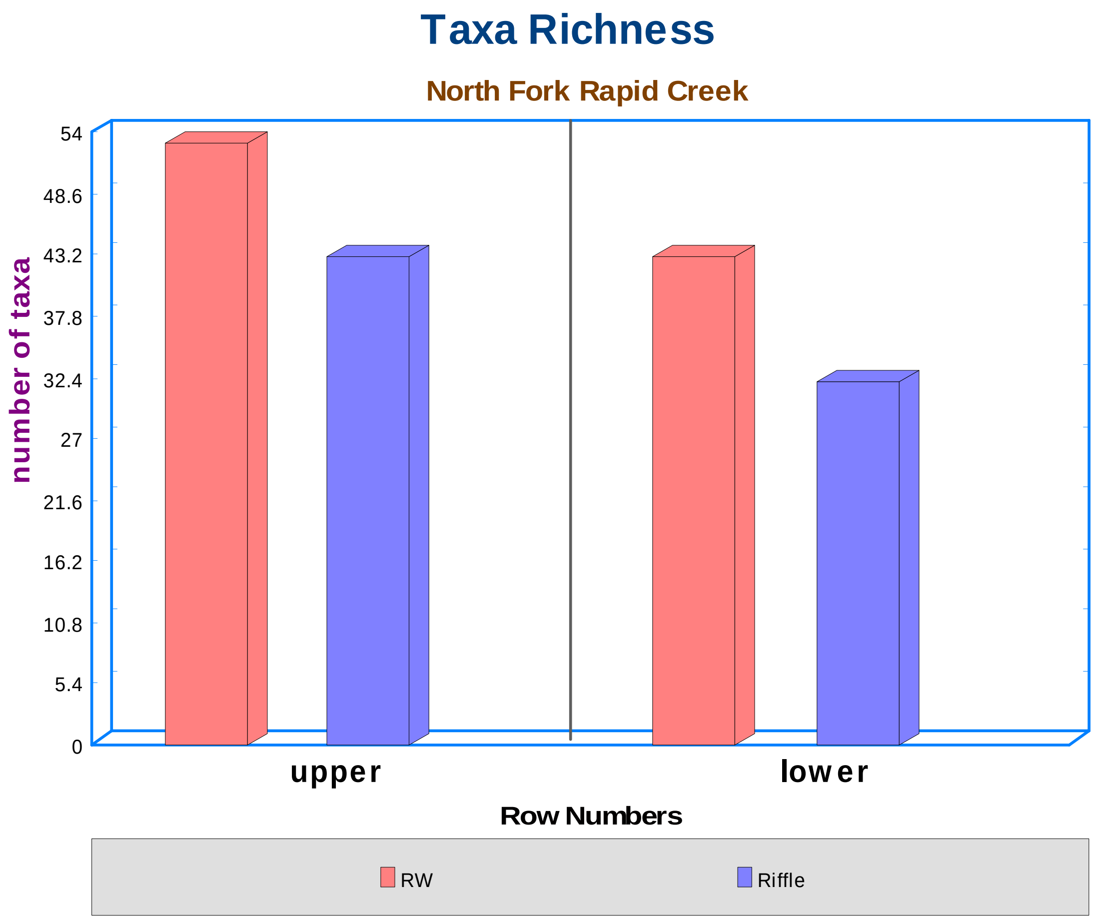


Figure 2. Taxa richness for North Fork Rapid Creek upper vs. lower reaches and riffle vs. reach wide (RW) samples.

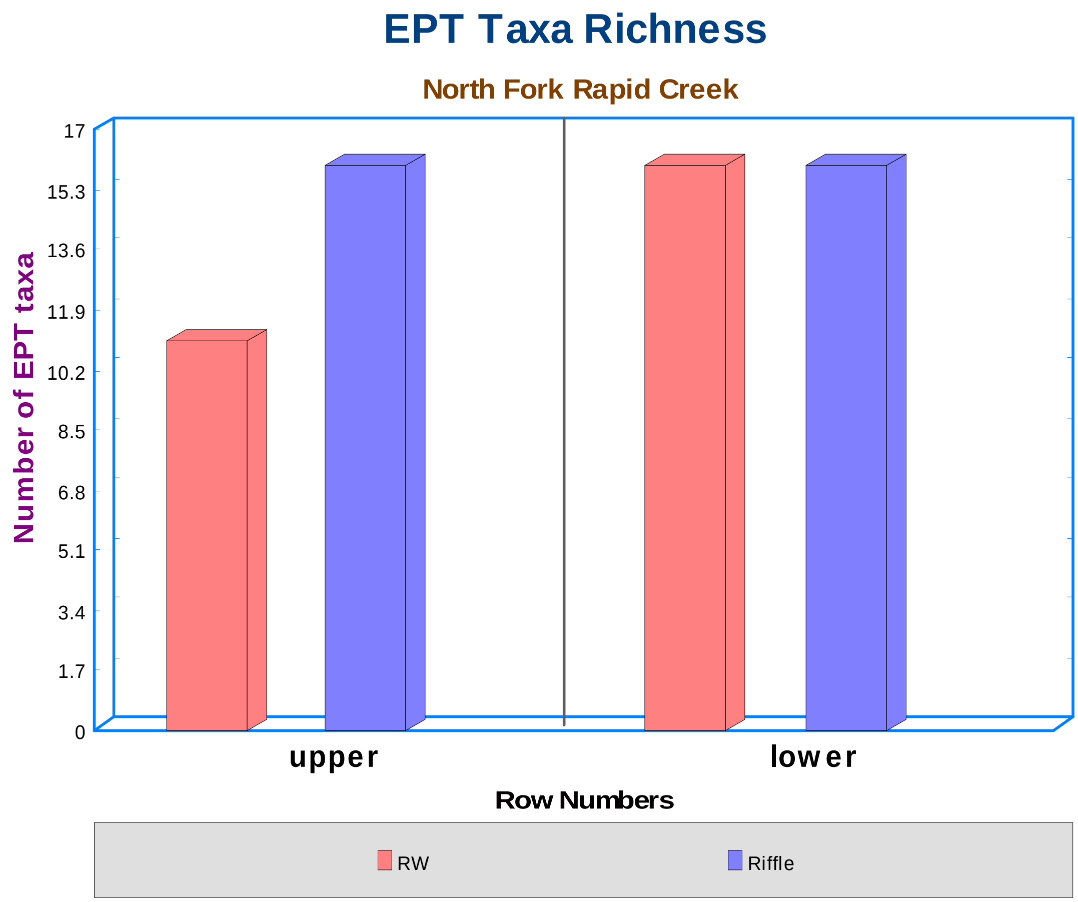


Figure 3. EPT taxa richness for North Fork Rapid Creek upper vs. lower reaches and riffle vs. reach wide (RW) samples.

Functional Feeding Groups

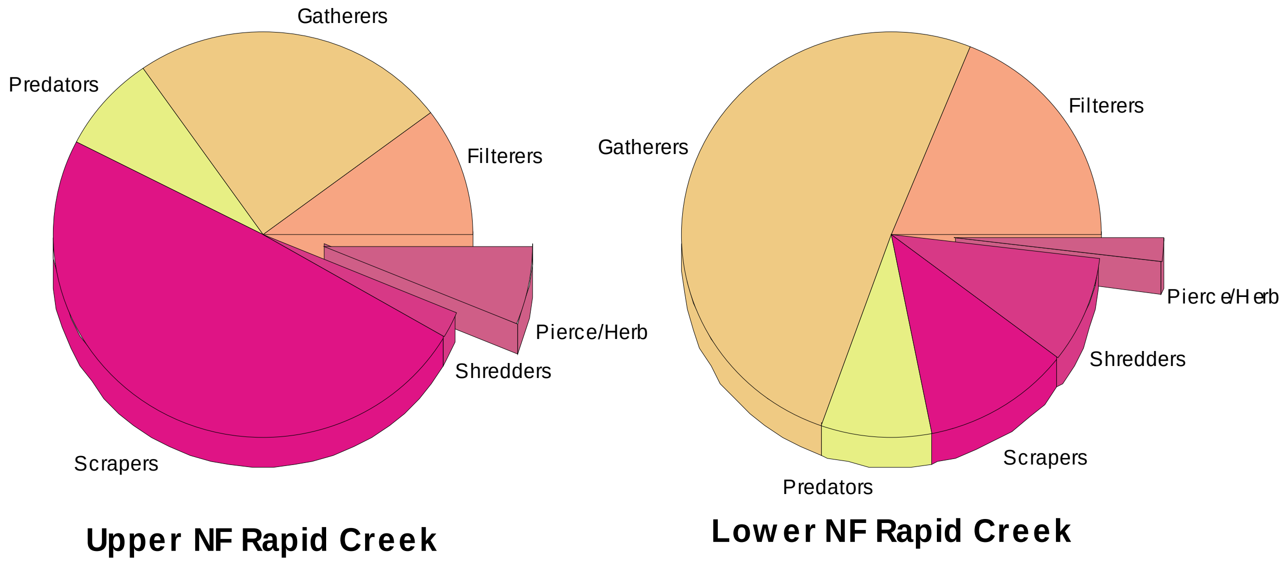
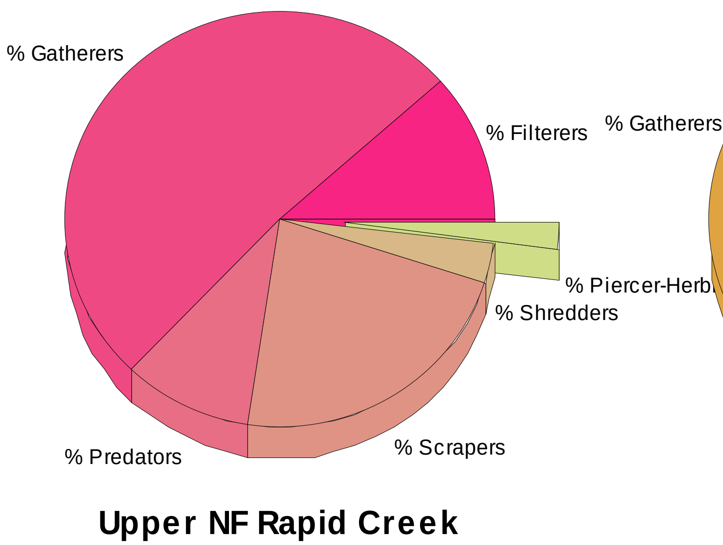


Figure 4. Functional feeding groups for upper and lower North Fork Rapid Creek riffle samples.

Functional Feeding Groups



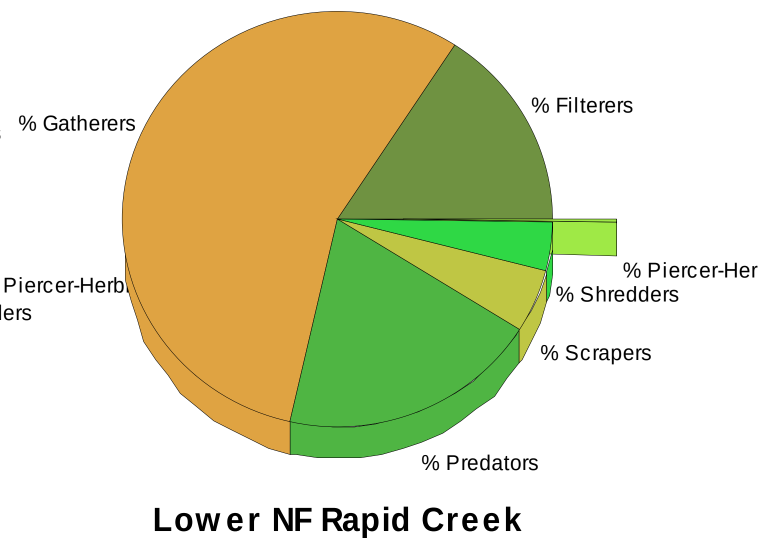


Figure 5. Functional feeding groups for upper and lower North Fork Rapid Creek reach wide samples.

Appendix D: Inter-Office Communication, D. Richards to S. Kenner, Re: Benthics of Castle Creek, 4/4/03

TO: SCOTT KENNER

From: David Richards, Research ecologist, EcoAnalysts Inc.

Date: April 4, 2003

Re: Macroinvertebrate community analysis of Castle Creek

The following summary of the metrics for Castle Creek is based on my assumption that CC-OTM was upstream of NFCC.

The most dramatic differences in the macroinvertebrate assemblages between sample reaches of Castle Creek can be seen in the corrected abundance and EPT abundance metrics for both riffle and reach-wide samples (Figure 1). There were almost 30 times more individual invertebrates in the CC-OTM riffle sample than in the CC-CS riffle sample and more than 46 times more individuals in the CC-OTM riffle sample than in the NFCC riffle sample. This pattern holds for reach-wide abundance and EPT abundance in riffles and reach-wide samples, as well (figure 1). There is no question that the CC-OTM site is more productive than the other two sites. This could be easily due to metals pollution from NFCC and its effects are seen well downstream into CC-CS.

Taxa richness and EPT richness are also higher in CC-OTM than the other two sites for both riffle and reach-wide samples (Figure 2). For example, there were 53 taxa found in the reach-wide section of CC-OTM compared with 30 taxa found in the reach-wide section of CC-CS and 32 taxa in NFCC. In the riffles, there were 17 EPT taxa in the CC-OTM samples compared with 8 EPT taxa in the CC-CS samples and 9 EPT taxa in the NFCC samples. Again, this reduction in taxa could be due to metals pollution. The dramatic change in these two metrics alone (abundance and taxa richness, Figures 1 and 2) from CC-OTM downstream provides ample evidence for ecosystem impairment and cause for concern. A 30-46-fold decrease in number of organisms and a loss of 9-23 taxa, in my opinion, is quite severe.

The most heavily impacted taxa in the reach-wide sections were the Chironomids (midges), which decreased from 23 taxa in CC-OTM to 7 or 8 taxa downstream. The number of Chironomid taxa in the riffle sections however did not seem to be affected. The most heavily impacted taxa in the riffle sections were the EPT's, particularly the Trichoptera taxa, both of which decreased 2 – 4 times downstream of CC-OTM. To me, these are very interesting ecologically. Chironomids, as a whole, have traditionally been given a bad rap as a pollution tolerant group. This reputation was based on chironomids apparently being able to tolerate organic pollution better than other taxa and because very little ecological and taxonomic work had been done with this family. With the tremendous increase in use of invertebrates as water quality indicators in the last several decades, chironomids are now better known taxonomically and hopefully in the future ecologically. From what we are finding, chironomids are very diverse ecologically and are very good indicators of water quality, and are very well suited for metals pollution assessment. Of course, there is much work to be done along these lines.

Another interesting ecological finding and which was easily observed from these samples was that the riffle sections were more productive (abundance metrics) than the reach-wide sections (Figure 1) and diversity (taxa richness) was represented more in reach-wide sections. Not unusual but interesting none the less.

Gathers were the most abundant of the functional feeding groups for all 3 sites and in both the riffle and reach-wide sections (Figures 3 and 4), although gatherer richness sharply decreased downstream. Scrapers on the other hand, were not very abundant in any of the samples and filterers decreased in a downstream direction. Changes in the functional feeding groups as illustrated in Figures 3 and 4, may have been more affected by the dramatic decrease in abundances than changes in number of taxa because the percent functional feeding groups metric is based on abundance and not the number of taxa.

The CC-CS site was dominated by a few species, which also suggests impairment (Figures 5 and 6). The three most dominant species in the CC-CS section accounted for 76% and 62% abundance in the riffle and reach-wide sections, respectively. The three most dominant taxa at the CC-OTM site, on the other hand only accounted for 46% and 36% abundance in the riffle and reach-wide sections. NFCC was in between these values for dominant taxa (Figures 5 and 6).

Almost all diversity indices for both riffle and reach-wide sections were highest in CC-OTM and lowest for CC-CS. Again, this could be a result of NFCC’s impairment and impact downstream on CC-CS.

A further examination of other metrics that we calculated could provide a more detailed account of impairment and its ecological effects, but these metrics are most likely a function of the dramatic changes in abundance and taxa metrics, which are the two most important metrics used in water quality assessment. By themselves, these two metrics document large differences in the invertebrate community for the 3 sites in Castle Creek that were examined and should be investigated further.

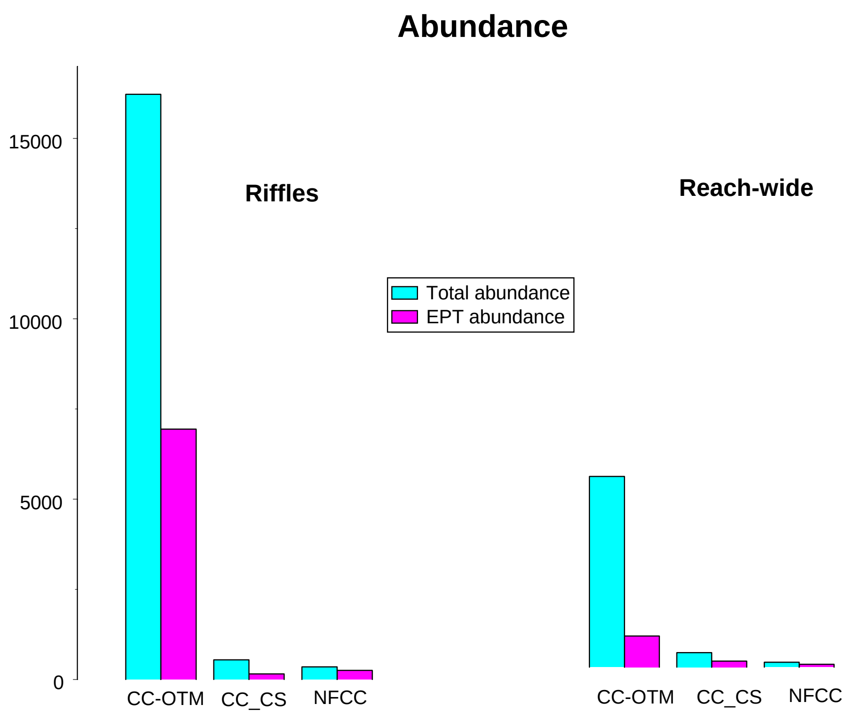


Figure 1. Total abundance and EPT abundance at riffle and reach-wide sites on Castle Creek

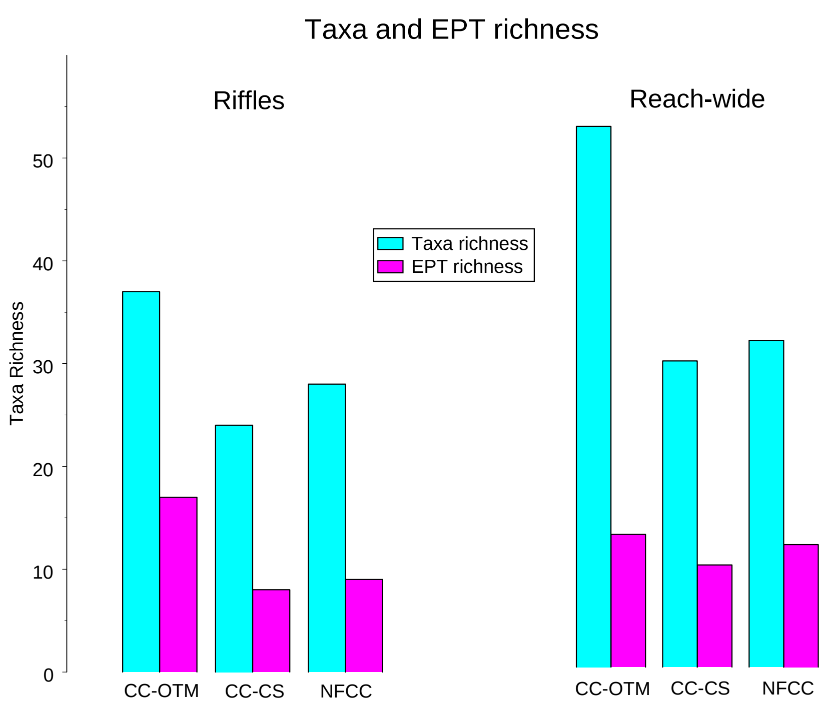


Figure 2. Taxa richness and EPT richness at riffle and reach-wide sites on Castle Creek

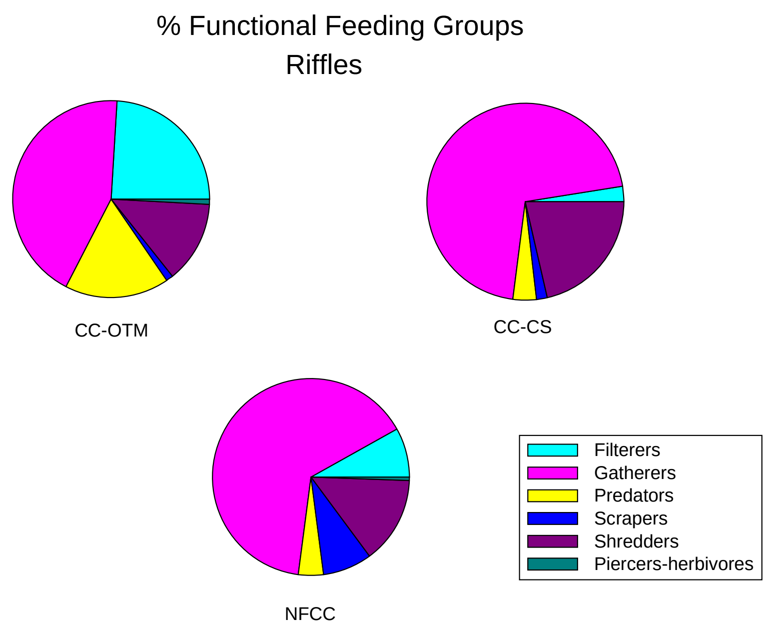


Figure 3. Percent Functional Feeding Groups at three **riffle** sites in Castle Creek (FFG’s based on abundance values not taxa richness values)

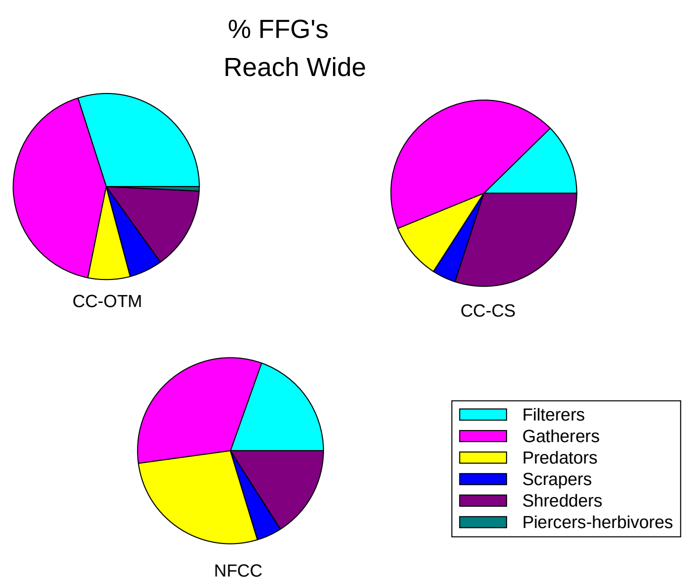


Figure 4. Percent Functional Feeding Groups at three **reach-wide** sites in Castle Creek (FFG’s based on abundance values not taxa richness values)

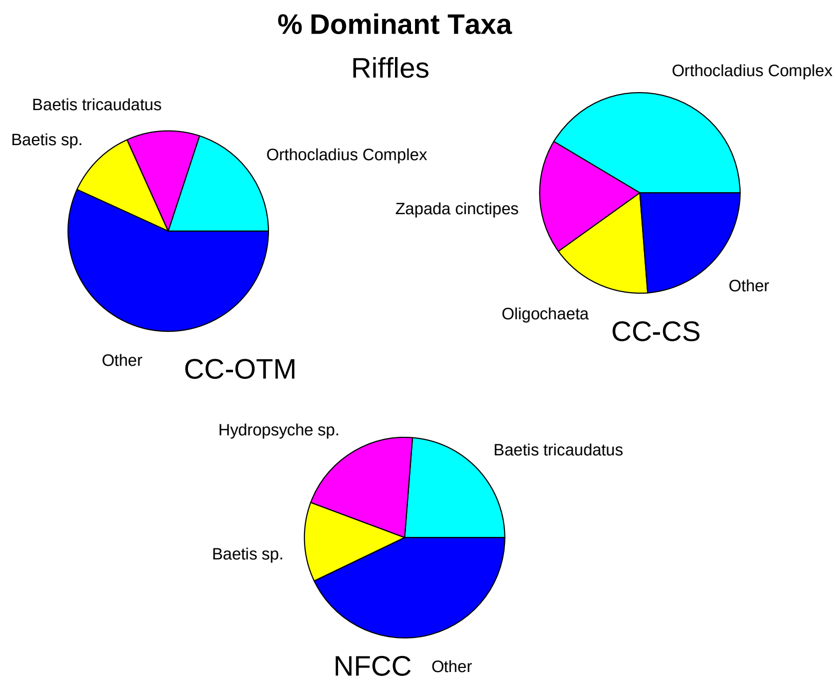


Figure 5. Percent dominant taxa at three **riffle** sites in Castle Creek

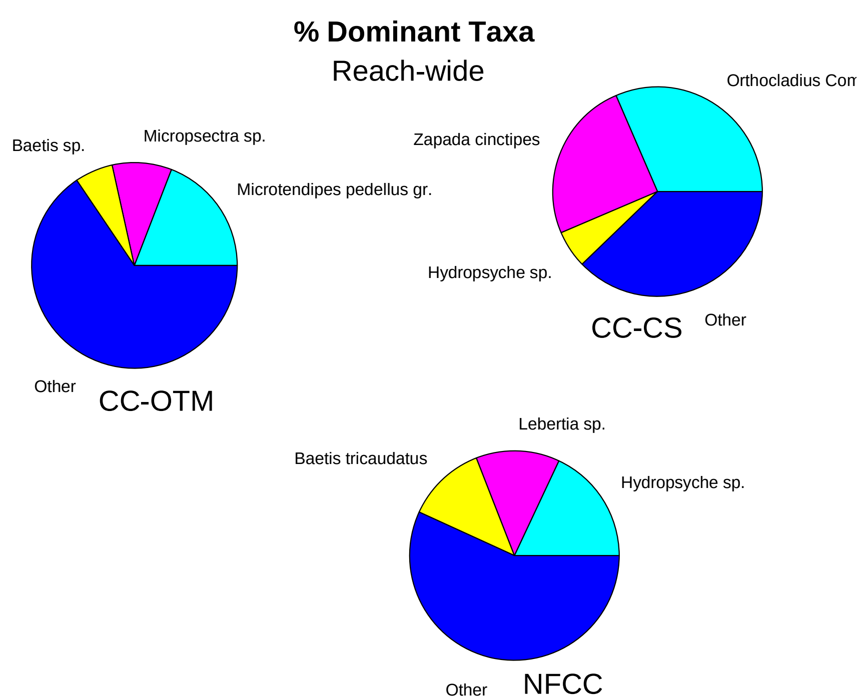


Figure 6. Percent dominant taxa at three **reach-wide** sites in Castle Creek

APPENDIX E

Total Maximum Daily Load Evaluation

TOTAL MAXIMUM DAILY LOAD EVALUATION

for

TEMPERATURE

in

NORTH FORK RAPID CREEK
(HUC 10120110)

LAWRENCE and PENNINGTON COUNTY, SOUTH DAKOTA

Waterbody Type:	Stream
303 (d) Listing Parameters:	Temperature
Designated Uses:	Coldwater Permanent Fish Life Propagation Limited Contact Recreation
Size of Waterbody:	Discharge at Confluence with South Fork Rapid Creek Varied between 6.4 and 1.5 cubic feet per second.
Size of Watershed:	22,550 acres
Water Quality Standards:	65 ^{o}F, Cold Water Permanent Fish Life Propagation
Analytical Approach:	SSTEMP Modeling
Location:	HUC Code: 10120110 (Rapid Creek)
Goal:	Reduce maximum in-stream temperature during summer months (June 15 through September 14) by an average of 20% over the length of the stream. This will improve the existing wild trout fishery by reducing stresses associated with high in-stream temperature.
Target:	During the summer of 2002 (June 15 through September 14) in-stream temperature exceeded the South Dakota criteria for coldwater permanent fish life propagation waters 78 days. The TMDL target is an increase of 15 days of temperature criteria compliance. Achieving this target will result in 63 days of criteria exceedence in North Fork Rapid Creek. Although the established target exceeds the state water quality standard, the designated beneficial uses assigned to this stream will still be supported.

<u>Objective</u>

The intent of the summary is to clearly identify the components of the TMDL submittal to support adequate public participation and facilitate the US Environmental Protection Agency (EPA) review and approval. The TMDL was developed in accordance with Section 303 (d) of the federal Clean Water Act and guidance developed by EPA.

<u>Introduction</u>

North Fork Rapid Creek, together with the South Fork Rapid Creek form the headwaters of Rapid Creek, one of the principal streams draining the Black Hills, SD. North Fork Rapid Creek is located in the northwestern end of the Rapid Creek watershed as shown in Figure 1. It rises in Lawrence County 9.5 miles Southwest of Deadwood, SD, in the northern Black Hills at an elevation 6300 feet above sea level. It flows in a southerly direction approximately 11.5 miles to its confluence with South Fork Rapid Creek in Pennington County.

The 2004 Integrated Report for Surface Water Quality lists the North Fork of Rapid Creek as an impaired waterbody due to temperature exceedances and is listed as high priority waterbody in terms of TMDL development.

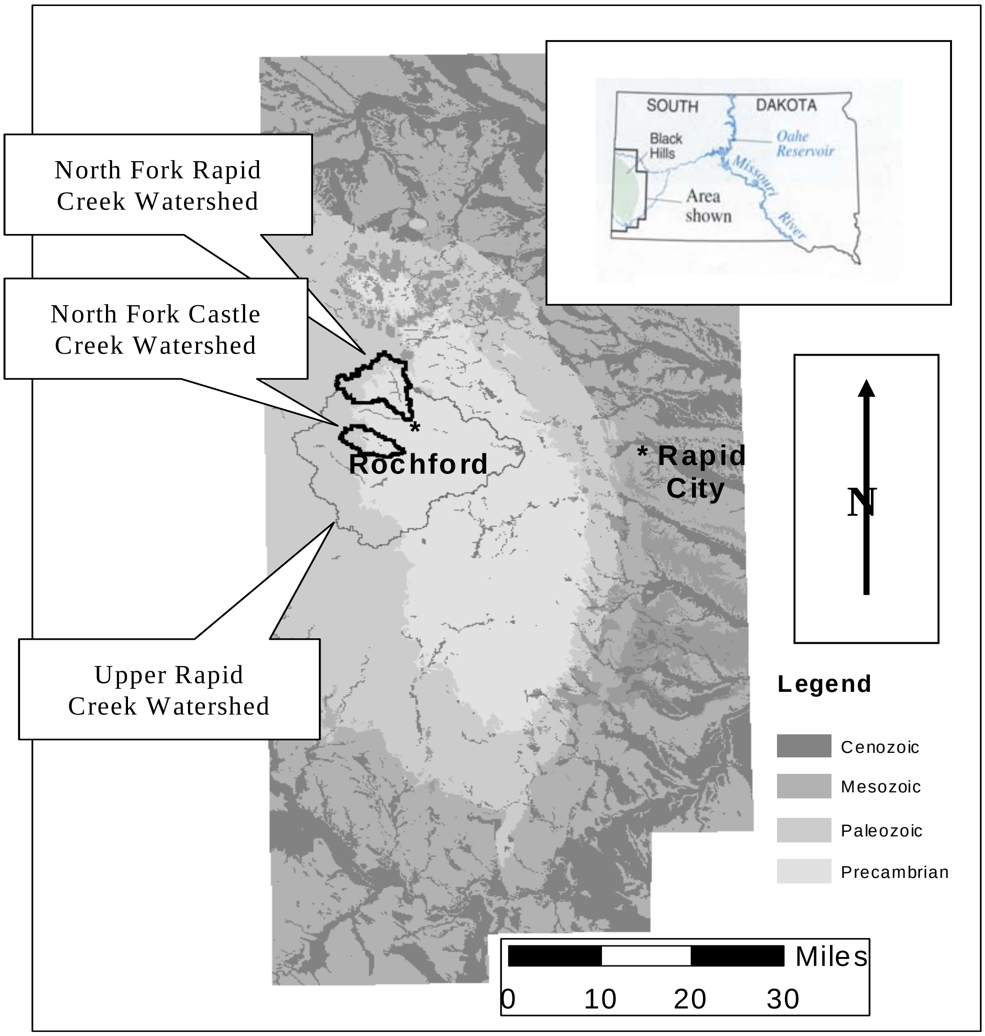


Figure 1. Location of North Fork Rapid Creek and generalized geologic map of the Black Hills, South Dakota (modified from Dewitt and others, 1989).

Problem Identification

Temperature data collected by the Black Hills National Forest indicated North Fork Rapid Creek was in violation of the temperature standard for coldwater permanent fish life propagation. The temperature standard for coldwater permanent fish life propagation is 65^{o}F. During the summer of 2002, continuous recording temperature-monitoring equipment was installed at four sites along the length of the stream. For a period running from the second week in June to mid September of that year, the daily maximum temperature exceeded the temperature criterion for coldwater permanent fish life propagation approximately 80% of the time at three of the monitoring sites and over 50% of the time at the fourth site. These elevated temperatures affect the health of the fishery in terms of size and age (i.e. growth rates are decreased). However, the North Fork of Rapid Creek continues to support a natural cold water trout population.

Pollutant Assessment

Point Sources

There are no point sources of pollutants of concern in this watershed.

Nonpoint Sources

In-stream temperature is influenced by heat exchanges occurring at the stream/atmosphere and stream/stream-bed interface, by the temperature of water entering the stream, and the amount of water (discharge) in the stream.

Direct short wave or solar radiation is absorbed by the stream resulting in increased stream temperature. Long-wave radiation is both absorbed and radiated by the stream. The long-wave radiation given off by a body is a function of the temperature of the body. Latent heat flux is heat absorbed by water as it evaporates and results in the cooling of remaining in-stream water. The amount of evaporation is dependent on differences in water vapor pressure between the air and stream surface. This difference is influenced by relative humidity and wind. Ground heat flux is the exchange in heat between the in-stream water and the stream substrate. Conduction is the sensible heat flux (molecule to molecule heat transfer) occurring at the stream/atmosphere boundary. On warm summer days, as the air temperature surpasses the in-stream temperature, this flux causes the stream temperature to rise.

Of the factors identified that influence in-stream temperature only one, direct solar radiation, can be reasonably controlled on North Fork Castle Creek. Encouraging increased vegetation growth along the riparian zone of the stream would provide additional shading to block direct solar radiation from reaching the stream surface and thus reduce in-stream temperature. The warmest section of the stream is the section lying in the upper half of the watershed. In this section, the stream flows through a wide valley. Grasses are the dominant vegetation in the valley. There are a few isolated stands of willows located within the riparian zone in this stretch of the stream but their impact is minimal due to their scarcity. The stream in this section is very small with a bankfull width in some places as small as three to four feet. In the lower portion of the watershed, the stream widens to approximately eight feet but remains very shallow – during summer months between 0.5 and 1.5 feet deep. Discharge in North Fork Rapid Creek is also small. During summer months it ranges between 1.5 and 2.6 cfs at the confluence with South Fork Rapid Creek. The valley bottom in this portion of the watershed is privately owned with the exception of a bicycle trail managed by the South Dakota Department of Game, Fish and Parks, highway, and road rights-of–way. Livestock grazing occurs over most of the valley floor during the summer months. Over the entire upper half of the watershed and large portions of the lower half, the stream meanders through pastures used to graze livestock and is unfenced. Livestock graze up to the banks of the stream.

TMDL and Allocations

It is difficult to accurately ascertain what natural conditions would be along the entire length of North Fork Rapid Creek in terms of stream cover and riparian vegetation. Since the Black Hills was first settled beginning in 1875-6, the forests have been heavily logged to support mining activities in the area. Indeed, the ghost town of Nahant located near the Fence Post monitoring site was established to support a sawmill, which supplied timber to nearby mines. Logging next to the creek would reduce cover and result in increased in-stream temperature. Livestock was also introduced very early in the area's settlement. The Bull Dog ranch (Big Dog sample site) provided beef to the Hearst Mercantile, the Homestake Mine Company's store, beginning in the late 1800's. Grazing next to the creek has undoubtedly altered the riparian zone and effected riparian vegetation.

There is one photo taken in the watershed, which shows North Fork Rapid Creek prior to settlement of the area (See Figure 2). The photo was taken by W.H. Illingworth on August 7, 1874 during the Custer expedition into the Black Hills at a location 2 miles south of the Fence Post monitoring site (Grape and Horsted, 2002). The setting for the photo is a meadow. North Fork Rapid Creek is located in the background of the photo and dense brush, presumably willow, is visible along the creek. No other trees are visible in the photo. Grafe and Horsted after extensive research and investigation believe they found the location where the Custer bear photo was taken. They took another photo in 2002 at this location, which documents changes that have occurred since the Illingworth photo was taken in 1874. The Grafe and Horsted photo is shown in Figure 3 and clearly documents the fact that the riparian zone along North Fork Rapid Creek has been altered by removal of vegetation with any significant height.

Other photos taken during that expedition document the fact that the Black Hills contained fewer conifer trees than they do now. It is generally assumed that fire suppression in the Black Hills National Forest has resulted in an increase of trees density over the last one hundred years despite the extensive logging that has occurred. It is reasonable to assume that, under natural conditions, North Fork Rapid Creek would not flow through a dense forest of conifer trees or through a completely open valley. Rather, it would flow through a valley with a riparian zone much more developed than it is today. Under natural conditions, clumps of willows and other brush would probably be present along extended portions of the stream. Shading of significant portions of the stream would occur from a well-developed riparian zone containing willows, grasses, and sedges.

Analysis of the impacts of fencing the stream, establishing additional stands of willows along the stream, and allowing vegetation to grow to full height indicates in-stream temperature could be reasonably reduced by approximately 5%. A reduction of this magnitude would result in daily maximum temperature exceedance of the beneficial use standard over 50% of the time during summer months. The sensitivity analysis using the

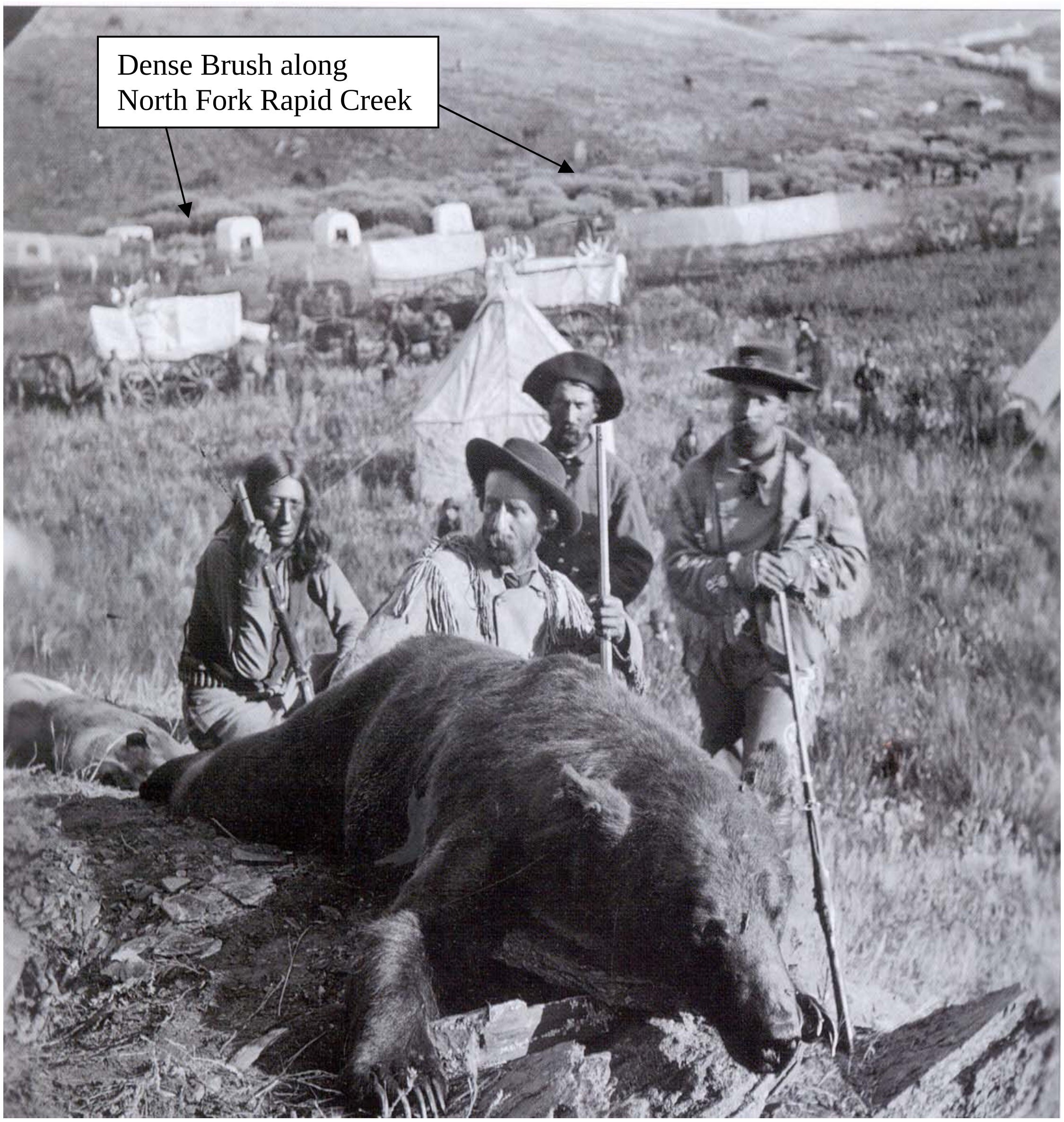


Figure 2: Photo showing North Fork Rapid Creek taken by W.H. Illingworth, August 7, 1874

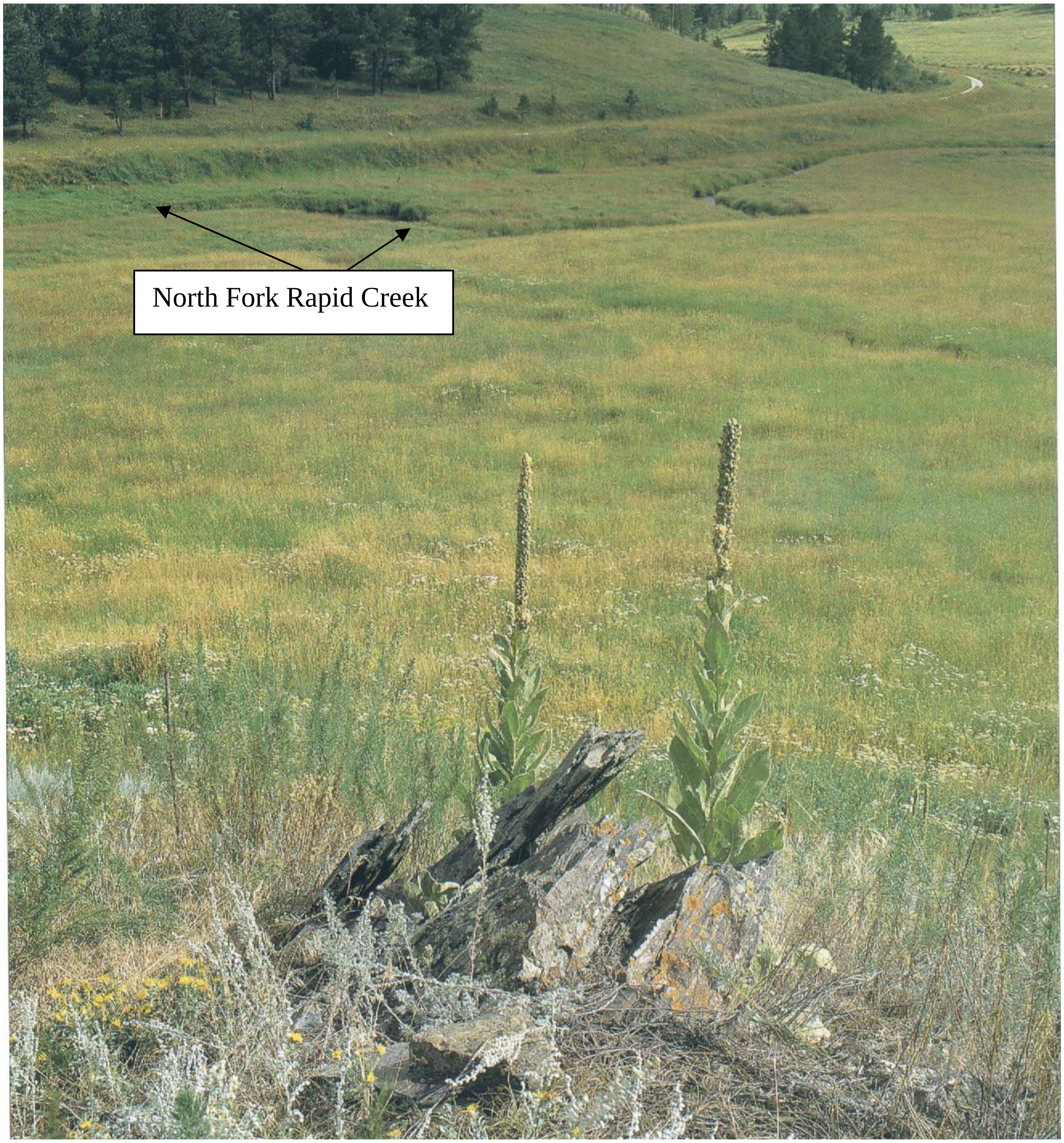


Figure 3: Photo taken at the Custer grizzly bear photo site on August 8, 2002. Note lack of vegetation along North Fork Rapid Creek. Photo from the book, "Exploring With Custer: The 1874 Black Hills Expedition", by Ernest Grafe and Paul Horsted, ©2002 Dakota Photographic LLC, Used with Permission.

SSTEMP model indicates that in-stream temperature is most impacted by ambient air temperature. Water acts as a heat sink[29] and therefore tends to experience much less diurnal variability in temperature than the atmosphere. However, the relatively small amount of water in the creek and its lack of depth causes North Fork Rapid Creek to be much more susceptible to heating by conduction between the stream surface/atmosphere contact than would a larger stream, lake or reservoir. As a result, computer modeling indicates that even if complete shading of the stream were possible, atmospheric temperature alone would be sufficient to cause in-stream temperature to frequently exceed the beneficial use standards during the summer months.

Water Quality Goal and Target

The monitoring period of June through September 2002 represented very dry conditions in the watershed and thus is representative of low flow conditions. During the summer of 2002, the average exceedance of the temperature criterion at all four monitoring sites was 78%. The current water quality represents impaired conditions. However, the water temperature drops below the water quality criterion on a daily basis and is below that temperature approximately 50 percent of the time. The current conditions do provide for a natural coldwater permanent fishery. A load reduction of 5% resulting from of riparian vegetation development is possible and would have resulted in an estimated average reduction of daily exceedance by 20% over the length of the stream during the summer of 2002. A well-developed riparian zone should be considered as the natural condition for North Fork Rapid Creek. In 2002, such a riparian zone would have resulted in a 59%[30] daily exceedance of the current temperature standard. This magnitude of reduction (78% to 59% exceedance) should be considered the maximum that could be achieved. During summers in which the Black Hills receives more rain and/or cooler temperatures, North Fork Rapid Creek would probably not experience as high a percent of exceedance of the temperature criterion.

Under current or proposed improved water quality conditions the water body would be considered impaired based on the South Dakota water quality standards. However, under both the current conditions and potential improved conditions the water body does support a natural permanent cold water fishery. The minimum goal should be to reduce exceedance by 20% by protecting and enhancing the riparian zone.

Margin of Safety

The final TMDL target was developed by incorporating a 10% margin of safety into the modeling based exceedance projections. During 2002 the coldwater permanent fish life propagation temperature criteria was exceeded on 78 days for the period June 15 through September 14. A 5% reduction in stream temperature would have resulted in 61 days of exceedance at this site. Such a reduction in temperature would have increased the number

[29] It takes four times as much energy to raise a given amount (mass) of water one degree as it does to raise the same amount (mass) of air by the same amount. Therefore, the more water or discharge a stream has, the more energy it can absorb from surrounding air without significantly increasing in-stream temperature.
[30] Average reduction for the four sample locations in the stream.

of days the stream complied with the state temperature requirement by 17 days. Assuming a 10% margin of safety, the estimated increase in compliance days would be 15.3 or 15 days (17 days x 0.9). This 15-day increase in criteria compliance forms the basis of the TMDL target

Public Participation

Four public meetings have been held to outline the proposed project, solicit suggestions from the public and to update the public regarding progress on this project.

An initial meeting, open to the public, where the project proposal was presented occurred in conjunction with the Black Hills Fly Fishers meeting in Rapid City, South Dakota in October 2001.

A public meeting was held in August 2002 at the Rochford Community Center, Rochford, SD. During this meeting, an overview of the project was presented. A suggestion from representatives of South Dakota Game Fish and Parks Department initiated a discussion of sampling criteria and a decision to add analysis for total metal during some sample events.

In November 2002, a meeting, open to the public was held in conjunction with a Black Hills Fly Fishers meeting in Rapid City, SD. Initial results of the summer sampling program were presented at this meeting.

In March 2004, results of the Upper Rapid Creek Watershed Assessment were presented to the United States EPA Biological Assessment Conference Workshop in Rapid City, SD.