PHASE 2 OF TMDL FOR DOG CREEK AND CAT CREEK WATERSHEDS

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Submitted by:

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1.1 HISTORY

Both Cat Creek and Dog Creek have been placed on Oklahoma's 303(d) list based on the Indian Nations Council of Governments' (INCOG) wasteload allocation studies. The 303(d) list includes Cat Creek, a tributary of Dog Creek, because of organic enrichment/dissolved oxygen issues caused by wastewater. One stretch of Dog Creek is listed because of resource extraction, exploration and development causing nutrient and habitat alterations. Another section of Dog Creek located farther upstream is listed because of nutrient problems with the source of these problems unknown.

Severe dissolved oxygen stress within the lower segments of Dog Creek and Cat Creek indicated a possible need for non-point source controls and a potential need for physical stream channel modification, in conjunction with advanced treatment improvements at the Claremore wastewater treatment plant. INCOG completed Phase I of the TMDL, addressing land use characterization and identification of possible non-point sources. Potential non-point sources identified for Claremore Lake, located centrally in the watershed, included excessive nutrients from home septic systems and animal waste, sediments and metals from abandoned coal strip mines.

1.2 PROJECT BACKGROUND

1.2.1 Project Site

The Dog Creek watershed is located almost entirely in Rogers County, Oklahoma, and includes Dog Creek, Little Dog Creek, Lake Claremore, Cat Creek, Panther Creek, and Otter Creek (Figure 1). The area above the dam is approximately 36,760 acres.

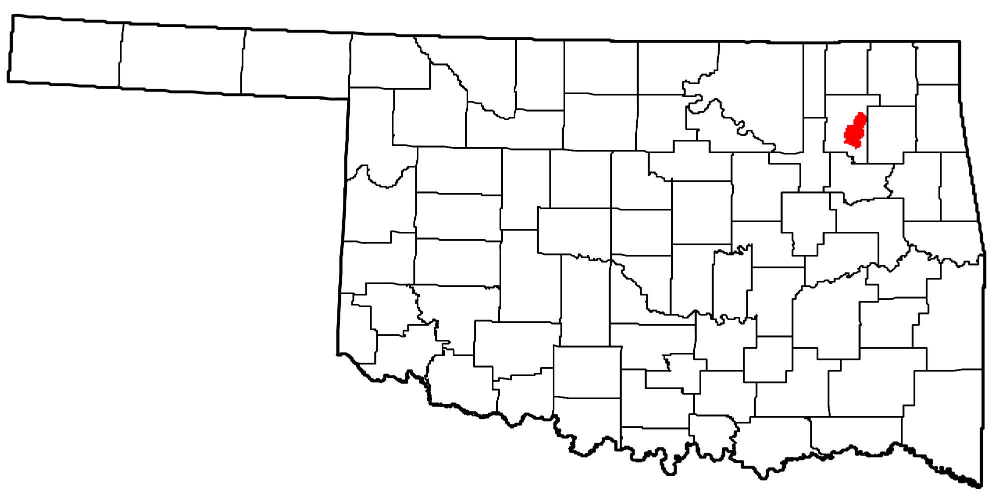

Figure 1: Dog Creek watershed.

Situated in the northeastern corner of the state, the portions of both creeks included in the study are covered by dense canopy accompanied by thick underbrush. Cat Creek and Dog Creek have a slow flow velocity and consist mostly of extensive shallow pools with rare riffles. The streams are fairly uniform, consisting of silted sandy clay sediments, occasional log jams, and numerous fallen trees. Cat Creek receives the treated effluent from the Claremore wastewater treatment plant and ultimately flows into Dog Creek.

Based on the National Land Cover Dataset created from 1992 satellite images, wooded areas and agricultural enterprises with light to moderate cattle grazing comprise the dominant land utilization within a one-mile buffer of the watershed (Figure 2). Forest land dominates the land use at 53% (Table 1). Crops grown include grains, hay and soybeans. Additionally, there are several rural communities located in this watershed. Strip mining occurred in areas of the upper watershed. U. S. Highway 66 and Interstate Highway 44 traverse the watershed (INCOG, 2001).

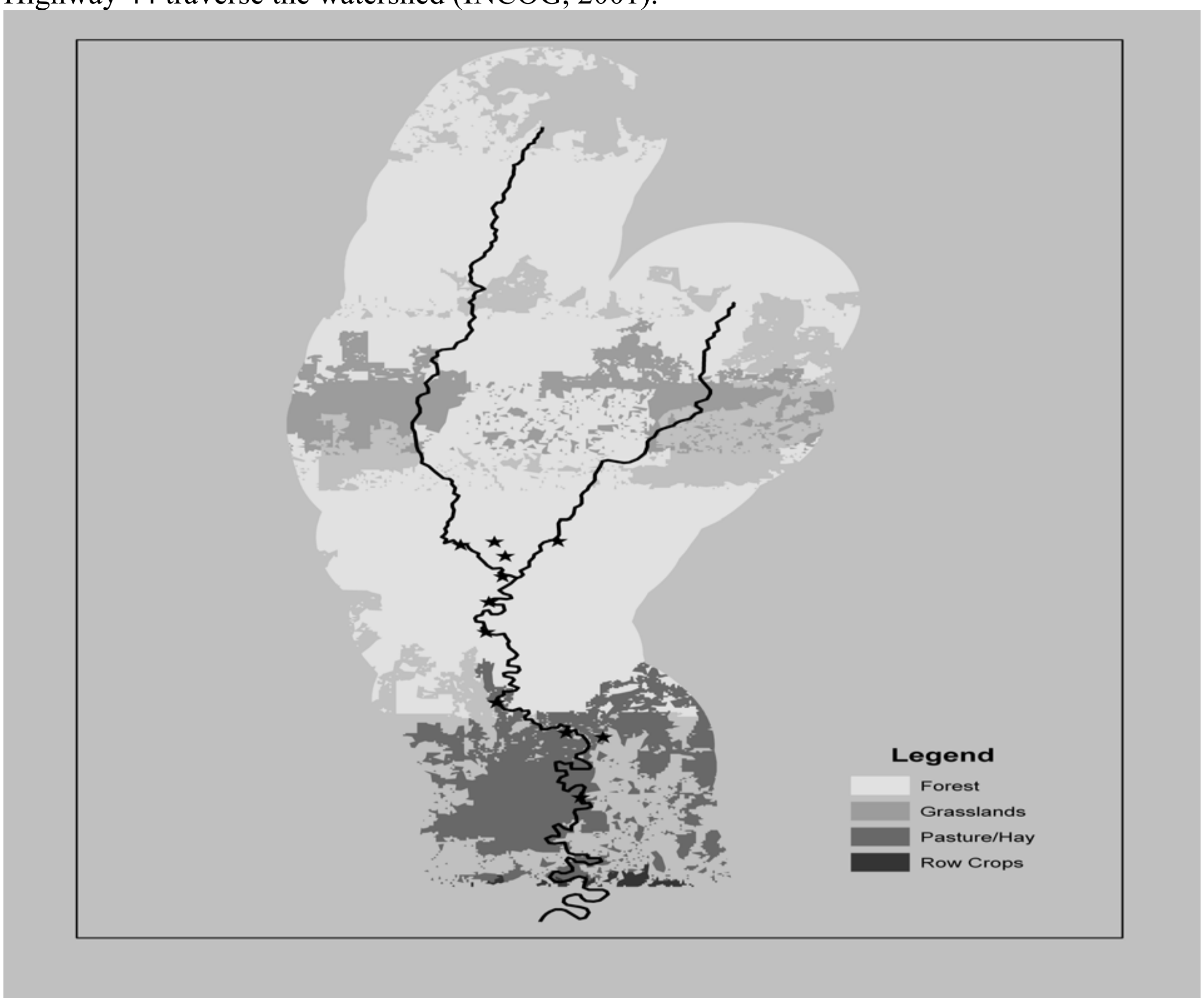

Figure 2: Land use of Dog Creek Watershed based on the National Land Cover Dataset.

Type	Sum Acres	% Acres
Bare Rock/Sand/Clay	0.0400	0.0000
Commercial/Industrial/Transportation	850.0040	3.996919
Forest	11303.0880	53.14978
Grasslands/Herbaceous	1580.3180	7.431027
Open Water	294.3530	1.384117
Pasture/Hay	1932.9720	9.089289
Quarries/Strip Mines/Gravel Pits	0.3640	0.001712
Residential	1356.3870	6.378051
Row Crops	65.1780	0.306482
Shrub land	777.4740	3.655866
Urban/Recreational Grasses	243.7980	1.146396
Wetlands	2862.5050	13.46017

Table 1: Land use acres and percent coverage within a one-mile buffer of the lower Dog Creek watershed.

1.2.1 Project Overview

This project sought an integrated watershed-based approach to solve the water quality problems in Dog Creek and Claremore Lake by forming partnerships with INCOG, the Oklahoma Conservation Commission (OCC), and the Oklahoma Water Resources Board (OWRB). Phase II of this project consisted of four activities. The first characterized chemical and biological parameters of the Dog and Cat Creek watersheds relating to non-point sources and pre-BMP implementation conditions. The data resulting from this portion of the study will be used to determine the effectiveness of BMP implementation and aquatic habitat improvements in Phase III of this project.

The second objective explored the possibility of any limitations in stream channel hydraulics that could be corrected to improve both re-oxygenation and aquatic community habitat.

Refining the original INCOG wasteload allocation model to account for non-point sources and physical limitations in stream hydraulics was the third objective. This will use the information gained from the first two tasks to determine what changes might be necessary to the original wasteload allocation model.

The last objective was the development of education programs to facilitate TMDL goals. This was to be accomplished through volunteer water quality monitoring with an accompanying education program. Additionally, the OWRB used inserts in water bills and newspaper articles to generate interest, followed by training sessions and seminars on proper watershed management.

The questions being addressed by the data collected under the project's approved QAPP were: 1.) What are the non-point source contributions within the watershed significantly affecting water quality? 2.) What is the current condition of Dog Creek and Cat Creek? 3.) What are the achievable goals for water quality habitat and the aquatic community for Dog Creek and Cat Creek?

2.0 MATERIALS AND METHODS

2.1 WATERSHED MONITORING

2.1.1 Water Sampling

Low-flow water sampling efforts began in August 1999, and continued on a monthly basis for the six study sites (Cat Creek downstream of the effluent, Cat Creek upstream of the effluent, Dog Creek at Flint Road, Dog Creek at Gordon's property, and Dog Creek at the Spavinaw flowline), the reference streams (Bull Creek and Panther Creek), and quarterly for three study streams (Dog Creek at Highway 88, Dog Creek at Froman's property, and Dog Creek at McComb's property) (Figure 3). All sampling and measurement activities followed procedures outlined in the appropriate OCC SOP (nos. 1, 8, 9, 10, 12, 14, 15, 18, 24, and 32). In-situ measurements included the following parameters: temperature, dissolved oxygen, pH, specific conductance, alkalinity, turbidity, and instantaneous discharge. Water samples were submitted to the Oklahoma City County Health Department (OCCHD) Lab for analysis of the following parameters: nitrate, nitrite, ammonia, total Kjeldahl nitrogen, total phosphorus, ortho-phosphate as phosphorus, sulfate, chloride, hardness, total suspended solids, five day carbonaceous biochemical oxygen demand ($CBOD_5$), and twenty day carbonaceous biochemical oxygen demand ($CBOD_{20}$), fecal coliform, and chlorophyll-a.

Fecal coliform bacteria were collected on a monthly basis beginning in September of 1999 and continued until August of 2001. Samples were collected at the same locations as the chemical water quality parameters. After collection, samples were stored on ice and transported to a certified laboratory within 24 hours. Sampling procedures followed those outlined in the OCC Water Quality Division's standard operating procedures and the method of analysis followed either multiple-tube fermentation (#9221) or membrane filter (#9222D) standard procedures (APHA et al., 1989). The numbers seen here may be lower than the actual numbers because 58% of the samples exceeded the six hour holding time by 12 to 20 hours.

High flow/runoff samples also were collected as they occurred following procedures outlined in OCC SOP, no. 2. Six events were collected between February 2000 and April 2001. According to the work plan, two diurnal dissolved oxygen profiles were to have been conducted at the four core sites and reference streams each summer; however, due to precipitation, only one successful diurnal dissolved oxygen profile could be completed. The time of travel study scheduled in the workplan was cancelled because a previous wasteload allocation study provided this data. It became unnecessary to replicate this portion of the study.

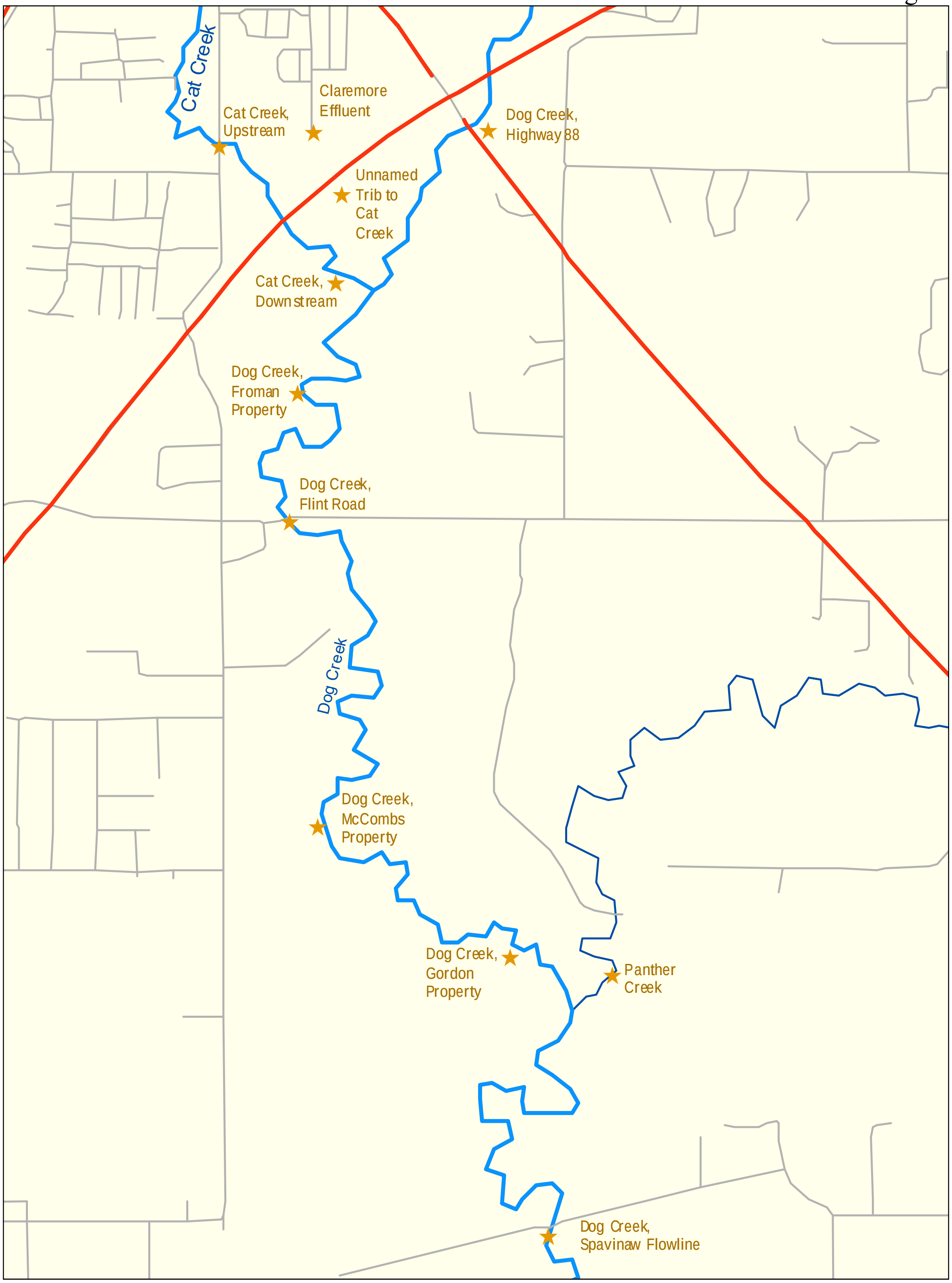

Figure 3: Project monitoring locations.

2.1.2 Biological Monitoring

2.1.2a Habitat Assessment

In the summer of 1999, OCC staff conducted an instream and riparian habitat assessment at eight sites with the fish collections (Table 2). In fall of 2000, two additional habitat assessments were completed on Dog Creek at Froman's property, and Dog Creek at McComb's property. Investigators recorded data every 20 meters and included the following primary parameters: stream depth, width, substrate composition, habitat type, fish cover, canopy cover, percent bank erosion and riparian width/condition. All assessments were conducted in accordance with procedures outlined in the OCC Habitat Assessment SOP, no. 39.

Site Name	WBID	Legal Description	Date
Dog Creek, Highway 88	OK121500-04-0010B	w.b. se/se 16 21n 16e	8/9/1999
Dog Creek, Flint Road	OK121500-02-0360H	s.b. se/sw/sw 21 21n 16e	8/11/1999
Cat Creek, Downstream	OK121500-02-0390A	nw/se/nw 21 21n 16e	8/9/1999
Bull Creek*	OKTEMP-0081	s.b. se 34 19n 17e -- n3 18n 17e	9/30/1999
Dog Creek, Spavinaw Flowline	OK121500-02-0360D	ne/nw/nw 3 20n 16e	8/19/1999
Cat Creek, Upstream	OK121500-02-0390B	se/se/se 17 21n 16e	8/20/1999
Dog Creek, Gordon Property	OK121500-02-0360F	se/nw/se 33 21n 16e	8/19/1999
Dog Creek, McCombs Property	OK121500-02-0360G	w.b. se/sw 28 21n 16e	9/13/2000
Dog Creek, Froman Property	OK121500-02-0360J	sw/nw/sw 21 21n 16e	11/14/2000

*Reference stream

Table 2: Habitat assessments completed at core, quarterly, and reference streams.

The habitat assessment was designed to assess habitat quality related to its ability to support biological communities in the stream. OCC's habitat assessment adheres to a modified version of the EPA Rapid Bioassessment Protocols or RBP (Plafkin et al., 1989). The assessment is based on particular parameters grouped into three categories containing a total of eleven components (Plafkin et al., 1989). The three primary categories that are assessed include micro scale habitat, macro scale habitat, and riparian/bank structure. Micro scale habitat includes substrate makeup, stable cover, canopy, and flow. Macro scale assesses the channel morphology, sediment depositions, and other parameters. The third category looks at the riparian zone quality, width, and general makeup (trees, shrubs, vines, and grasses) as well as bank features. Bank erosion, and streamside vegetative cover are incorporated into this section. Quantitative weighting is given to each of these sections in relation to their biological significance.

Scores are computed for each of the eleven categories, summed, and assigned as an evaluation of that stream section and riparian zone. Scores can reach a maximum of 180 points. Habitat assessments are completed for a reach that is 400-meters long, with measurements for each parameter every twenty meters. Further information on habitat assessment can be found in OCC SOP (OCC SOP #39, revision 7).The eleven categories are discussed in more detail below.

(1) Instream cover is a term for the component of habitat that organisms hide behind, within, or under. High quality cover consists of things like submerged logs, cobble and boulders, root wads, and beds of aquatic plants. Cover required by smaller members of the stream community will consist of gravel, cobbles, small woody debris, and dense beds of fine aquatic plants. A healthy, well functioning lotic ecosystem will have cover present for all members of the community that require cover. At least 50% of the stream's area should be occupied by a mixture of stable cover types for this category to be considered optimal.

(2) Pool bottom substrate describes the type of stream bed found in pools. Pools are depositional areas of the stream, and as such, are easily damaged by materials that settle. A loose shifting pool bottom will not provide substrate for burrowing organisms and will not allow bottom-spawning fish to successfully spawn. It will not provide habitat to the smaller vertebrates and invertebrates that are necessary to support many of the pool dwelling fish. At least 80% of all pool bottoms must have stable substrate for a reach to be considered optimal for this habitat component.

(3) Pool variability is the third category. A healthy, diverse community of aquatic organisms requires both deep and shallow pools. A fairly even mix of pool depths from a few centimeters to 0.5 meters or greater is optimal.

(4) Canopy cover assesses the shading of the stream section. Plants lie at the base of almost all food chains. Since plants require light for growth and survival, a stream that is functioning well needs some amount of light. Moderation is optimal however, because light is associated with heat and most aquatic organisms are more stressed by the warmer waters and the lower oxygen solubility and higher metabolic rates that accompany the warming of water.

(5) The percent of rocky runs and riffles is calculated for the fifth component. Rocky runs and riffles offer a unique combination of highly oxygenated, turbulent water, flowing over high quality cover and substrate. Turbulence prevents the formation of nutrient concentration gradients from cell membranes outward so that algae and other plants grow at a much higher rate than they would at the same concentration in pools. More food means more growth. Larger crops of algae are translated into larger invertebrate crops. It is these invertebrates, reared in riffle areas, that feed many of the fish in the stream. Because turbulent water is well oxygenated, there has been no selection pressure for riffle dwelling organisms to develop tolerance to poorly oxygenated waters. These are often the first animals to disappear from the stream if

oxygen becomes scarce. The presence of rocky runs and riffles offers habitat for many highly adapted animals that will increase diversity of samples collected from the streams they occupy.

(6) Discharge at representative low flow reflects stream size. Water is the most basic requirement of aquatic organisms. Larger streams tend to have more water, and thus, more varied high quality habitat. We expect the IBI scores to rise as streams increase in size and discharge, other factors being equal.

(7) Channel alteration is the seventh category. The presence of newly formed point bars and islands is very significant. Unstable streambeds support fewer types of animals than those that are stable. This is because unstable streambeds tend to have unstable pool bottom substrate, riffle areas whose cobbles are embedded in finer material, and little cover because it is continually being buried. Few or no signs of channel alteration are considered optimal.

(8) Channel sinuosity measures how far a channel deviates from a straight line. More sinuous channels tend to have more undercut banks, root wads, submerged logs, etc. We expect IBI scores to rise as channels become more sinuous.

(9) The bank erosion index assesses the stability of the stream bank. Stable stream banks tend to increase IBI scores for many reasons. Most importantly, they do not contribute sediment to the stream channel. As a rule, channels with stable banks tend to be deeper and narrower than channels with unstable banks. Because of the increased depth and decreased width, they tend to be cooler and they also tend to grow less algae for a given amount of nutrients than do shallow wide channels. IBI scores increase as bank stability increases.

(10) The vegetative stability of the stream bank is an important component. Stream banks can be stabilized with a number of materials including rock, concrete, and fabric. Banks that are stabilized with vegetation benefit the aquatic community more than those stabilized with other materials. This is because the vegetation offers several extra advantages beyond that of bank stability. The riparian plants of the stream bank offer a high quality source of food and shade to the aquatic community. Riparian vegetation stabilizes point bars and contributes greatly to structure in the form of root wads and woody debris. We expect IBI scores to rise as bank vegetative stability increases.

(11) The last category is streamside cover. A large part of the energy and food input to the stream comes from the terrestrial vegetation along the banks. A mixture of grasses, forbs, shrubs, vines, saplings, and large trees transfer these necessities to the stream more effectively than does any single type of vegetation. IBI scores increase as the form of bank vegetation increases in diversity.

2.1.2b Fish

In the summer of 1999, fish were collected from eight sites including four on Dog Creek, two on Cat Creek, and two reference streams (Table 3). Fish were collected from a 400-meter reach at all sites using a combination of seining and electroshocking according to procedures outlined in OCC SOP, nos. 35 and 39. A professional taxonomist identified all preserved individuals not identified in the field. A modified version of Karr's Index of Biotic Integrity (IBI) was used to score and compare the health of the fish community between sample and reference sites (adapted from Plafkin et al., 1989). The categories comprising the IBI are described briefly below.

(1) The total number of fish species decreases with decreasing water or habitat quality.

(2) The number of darter species decreases with increasing siltation and increasing benthic oxygen demand. Many of these fish actually live within the cobble and gravel interstices and are very good indicators of conditions that make this environment inhospitable. Darters are weak swimmers that do not readily travel up and down a stream so their presence or absence at a site relates well to both past and present habitat and water quality conditions at that site.

(3) The number of sunfish species decreases with decreasing pool quality and with decreasing cover. Sunfish also require a fairly stable substrate on which to spawn, so their long-term success is also tied to conditions that affect the amount of sediment that enters and leaves the stream.

(4) The number of round bodied suckers is used as a long-term integration of both physical and chemical quality. As a group, these fish are sensitive to both chemical water quality and physical habitat quality. They are long lived so their presence is a good indicator of overall long-term quality.

(5) The number of intolerant species is a characteristic of the fish community that separates high quality from moderate quality sites. A high quality stream will have several members of the fish community that are intolerant to environmental stress. A stream of only moderate quality will have fish that are moderately and highly tolerant of environmental stress. The intolerant species will not be present in the moderate quality stream.

(6) The proportion of individuals as green sunfish, red shiners, *gambusia* and black bullheads, or the proportion tolerant individuals, is a characteristic that allows moderate quality streams to be separated from low quality streams. These are opportunistic, tolerant fish that dominate communities that have lost their competitors through loss of habitat or water quality.

(7) The proportion of individuals as omnivores increases as stream quality decreases. Omnivores are well suited to prosper in streams that are unstable. This prosperity comes at the expense of fish that have more restrictive diets.

(8) The proportion of individuals as insectivorous cyprinids increases as the quality and quantity of the invertebrate food base increases. These are the dominant minnows in North American streams but are replaced by either omnivorous or herbivorous minnows as the quality of the food base deteriorates. Often, as the density of aquatic invertebrates decreases, the standing crop of algae increases. This is because the aquatic invertebrates are the largest group of primary consumers. Fish that can switch their diet to algae or fish that eat only algae will replace fish that cannot adapt to the new conditions.

(9) The proportion of individuals as top carnivores decreases as the quality of the stream decreases. Many top carnivores are popular sports fish, so their absence does not necessarily mean life in the stream is stressful in and of itself. If angling pressure can be ruled out as a cause of low predator numbers, their scarcity is a good indicator and integrator of the sum total of life in the stream since they are dominant in the food web. Piscivores comprised the top carnivores for this study.

(10) The number of individuals in the sample varies by ecoregion, but within an ecoregion it can indicate problems. It is expressed as catch per unit effort, and generally decreases with decreasing stream quality. It can also increase with nutrient enrichment as the food base grows, provided that no other limiting conditions exist (e.g. low nighttime dissolved oxygen levels). An increase in density due to nutrient enrichment can be especially pronounced if piscivores are decreasing at the same time.

The individual scores of these ten metrics are summed to get the IBI score. The IBI score indicates the quality of the fish community but says nothing about whether any deficiencies are due to degraded water quality or to degraded habitat.

Site Name	**Water Body ID No.**	**Legal**	**Sample Date**
Bull Creek*	OKTEMP-0081	sb se 34 19n 17e–n3 18n 17e	9/30/1999
Cat Creek Downstream	OK121500-02-0390A	nw/se/nw 21 21n 16e	8/9/1999
Cat Creek Upstream	OK121500-02-0390B	se/se/se 17 21n 16e	8/20/1999
Dog Creek at Flint Road	OK121500-02-0360H	sb se/sw/sw 21 21n 16e	8/11/1999
Dog Creek at Gordon Property	OK121500-02-0360F	se/nw/se 33 21n 16e	8/19/1999
Dog Creek at Highway 88*	OK121500-04-0010B	wb se/se 16 21n 16e	8/9/1999
Dog Creek at Spavinaw Flowline	OK121500-02-0360D	ne/nw/nw 3 20n 16e	8/19/1999
Panther Creek*	OKTEMP-0290	nw 34 21n 16e	9/30/1999

Table 3: Fish collection event data.
(*Reference sites)

2.1.2c Macroinvertebrates

Macroinvertebrates were collected from nine sites from February 1999 through August 2000 (Table 4) according to procedures outlined in OCC SOP, nos. 29, 30, 31, and 36. Aquatic invertebrates were collected from rocky riffles, streamside vegetation, and woody debris as present at each sampling site. Efforts were made to obtain collections from all sites during both the summer and winter index periods. Low or nonexistent flow encountered during the 1999 summer collection period at both reference sites precluded collections. Alternate summer 1999 reference sites from the same ecoregion and comparable to the original reference streams were selected for comparison to the study sites. Preserved samples were picked in the laboratory, and the picked subsamples sent to a professional taxonomist for identification. Data was prepared and entered into a spreadsheet for metric calculations and subsequent bioassessment determination (modified version of Plafkin et al., 1989). Bioassessment analyses were restricted to riffle samples to limit variability inherent in sampling differing substrates.

Site Name	Water Body ID No.	Legal	Sample Date
Bull Creek*	OKTEMP-0081	sb se 34 19n 17e—n3 18n 17e	2/28/1999
Bull Creek *	OKTEMP-0081	sb se 34 19n 17e—n3 18n 17e	1/6/2000
Bull Creek*	OK121600-06-0200G	nw 34 25n 20e	7/18/2000
Cat Creek, Downstream	OK121500-02-0390A	nw/se/nw 21 21n 16e	2/23/1999
Cat Creek, Downstream	OK121500-02-0390A	nw/se/nw 21 21n 16e	8/9/1999
Cat Creek, Downstream	OK121500-02-0390A	nw/se/nw 21 21n 16e	1/12/2000
Cat Creek, Downstream	OK121500-02-0390A	nw/se/nw 21 21n 16e	8/10/2000
Cat Creek, Upstream	OK121500-02-0390B	se/se/se 17 21n 16e	1/12/2000
Dog Creek, Flint Road	OK121500-02-0360H	s.b. se/sw/sw 21 21n 16e	2/23/1999
Dog Creek, Flint Road	OK121500-02-0360H	s.b. se/sw/sw 21 21n 16e	8/11/1999
Dog Creek, Flint Road	OK121500-02-0360H	s.b. se/sw/sw 21 21n 16e	1/12/2000
Dog Creek, Flint Road	OK121500-02-0360H	s.b. se/sw/sw 21 21n 16e	8/10/2000
Dog Creek, Hwy 88	OK121500-04-0010B	w.b. se/se 16 21n 16e	2/23/1999
Dog Creek, Hwy 88	OK121500-04-0010B	w.b. se/se 16 21n 16e	8/11/1999
Dog Creek, Hwy 88	OK121500-04-0010B	w.b. se/se 16 21n 16e	1/12/2000
Dog Creek, Hwy 88	OK121500-04-0010B	w.b. se/se 16 21n 16e	8/10/2000
Dog Creek, Spavinaw Flowline	OK121500-02-0360D	ne/nw/nw 3 20n 16e	2/23/1999
Dog Creek, Spavinaw Flowline	OK121500-02-0360D	ne/nw/nw 3 20n 16e	8/19/1999
Dog Creek, Spavinaw Flowline	OK121500-02-0360D	ne/nw/nw 3 20n 16e	1/6/2000
Dog Creek, Spavinaw Flowline	OK121500-02-0360D	ne/nw/nw 3 20n 16e	8/10/2000
Panther Creek*	OKTEMP-0290	nw 34 21n 16e	2/28/1999
Panther Creek*	OKTEMP-0290	nw 34 21n 16e	1/12/2000
Adams Creek, Oak Grove Road*	OK121500-02-0150G	se/se/sw 21 21n 14e	8/10/1999
Lightening Creek*	OK121510-01-0130M	Sections 15/14 25n 17e	7/18/2000
Rabb Creek*	OK121400-01-0090D	Sections 6/7 25n 14e	8/3/1999

Table 4: Macroinvertebrate collection event data.
(*Reference sites)

The seven categories used to assess the macroinvertebrate community include the following:

(1) The number of taxa refers to the total number of taxonomically different types of animals in the sample. As is the case with the fish, this number rises with increasing water or habitat quality. Taxa richness is scored as a ratio of the study site to the reference site multiplied by 100 (Plafkin et al., 1989).

(2) The Modified Hilsenhoff Biotic Index (HBI) is a measure of the invertebrate community's tolerance to organic pollution. It ranges between 0 and 10 with 0 being the most pollution sensitive. The index used in the RBP Manual is based on the pollution tolerance of invertebrates from the upper midwest. The Index used here is calculated the same way, but uses tolerance values of North Carolina invertebrates. The Modified HBI is a ratio of the reference site to the study site multiplied by 100 (Plafkin et al., 1989).

(3) The percent EPT of EPT and Chironomids is a further isolation of EPT relative abundance corrected for Chironomini. Chironomids are a member of the Dipteran family Chironomidae or midges. Many members of this family are pollution tolerant, and they can build up to high numbers as animals that prey on them begin to disappear due to the effects of pollution. EPT/EPT + Chironomidae is scored as a ratio of the study site to the reference site multiplied by 100 (Plafkin et al., 1989).

(4) The percent EPT is a measure of how many individuals in the sample are members of the EPT group. This metric helps to separate high quality streams from those of moderately high quality. The highest quality streams will have many individuals of many different taxa of EPT. As conditions deteriorate, animals will begin to die or to drift downstream. At this point, the community will still have many taxa of EPT, but there will be fewer individuals. EPT/Total is scored as a percent of contribution (Plafkin et al., 1989).

(5) The EPT Index is the number of different taxa from the orders Ephemeroptera, Plecoptera, and Trichoptera, the mayflies, stoneflies, and caddis flies respectively. With few exceptions, these insects are more sensitive to pollution than any other groups. As a stream deteriorates in quality, members of this group will be the first to disappear. This robust metric allows discrimination between all but the worst of streams. EPT taxa is scored as a ratio of the study site to the reference site multiplied by 100 (Plafkin et al., 1989).

(6) Percent dominant taxa is the percentage of the collection composed of the most common taxa. As more and more species are excluded by increasing pollution, the remaining species can increase in numbers due to the unused resources left by the excluded animals. This metric helps to separate the high quality streams from those of moderate quality. The dominants to total is scored as a percent contribution (Plafkin et al., 1989).

(7) The Shannon-Weaver Species Diversity Index measures the evenness of the species distribution. It increases as more and more taxa are found in the collection and as individual taxa become less dominant. This metric increases with increasing biotic

quality. Shannon-Weaver is scored directly with numerical guidance in the EPA RBP (Plafkin et al., 1989).

2.1.2d Periphyton

Periphyton measurements are useful in determining the water quality of a stream segment. Some pollutants ameliorate the environment for periphyton growth, causing nuisance levels of algae to accumulate. Chlorophyll-a is a strong indicator of the amount of periphyton. Higher periphyton growth rates equate to higher stream productivity, and high productivity can be an indication of excessive nutrient levels. Nuisance levels of periphyton are generally agreed to be between 50-200 mg/m^2 (Dodds et al., 1998). The periphyton community was sampled to estimate stream primary productivity through periphyton chlorophyll-a. To accomplish this, periphytometers were deployed in accordance with procedures outlined in OCC SOP, no. 6. Upon retrieval, rods were scraped, filtered and processed according to OCC SOP, no. 50. Samples were stored upright in the freezer until their submittal to the OCCHD Lab for chlorophyll a and phaeophytin analyses.

Periphytometers were established at the core sites and Bull Creek in January and February of 2000 and again in July, August, and September 2000. While the workplan called for three summer sets and three winter sets for both years, the system proved somewhat intractable for periphyton sampling. The sinuous, incised stream channel, covered by lots of canopy, effectively blocks the sunlight necessary for periphyton establishment; hence, periphyton collection was not always feasible. To save time and money, collection was restricted to one year. Due to lab error on extract values, the summer data could not be analyzed.

2.2 Stream Channel Hydraulics

Personnel from the OCC Water Quality Program and INCOG reconnoitered the Dog Creek and Cat Creek watersheds on 3 February 1999. Personnel from OCC Water Quality also conducted a stream classification survey of Dog Creek.

The stream classification survey was conducted just upstream of where Dog Creek crosses under Flint Road in the SW ¼ of the SW ¼ of Section 21, Township 21 North, Range 16 East of Indian Meridian in Rogers County, Oklahoma. The site was selected because it was typical of the morphology of Dog Creek and because there is a U.S.G.S. gauge station (USGS No. 07178520) at the Flint Road bridge.

Classification of Dog Creek was accomplished to determine the stream type of the creek according to the Rosgen classification system (Rosgen, 1996). It is known that different stream types have different hydraulic characteristics and therefore varying re-aeration capacities. It is also known that it is possible to physically alter streams to change the stream type of the system. In some cases, such alterations to the channel may result in improved re-aeration rates. Dog Creek was classified to assess the possibility of altering the channel to improve the re-aeration rate in the stream.

The Rosgen classification system classifies streams based on five easily measured parameters including the entrenchment ratio, the width/depth ratio, the sinuosity, the slope, and the dominant bed material. The concept of a bankfull discharge is fundamental to the Rosgen classification system. According to Dunne and Leopold (1978), "the bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels." Thus, the bankfull discharge may more simply be considered the "channel forming flow." It is typically associated with an instantaneous peak discharge that occurs from a few days a year to once every other year and is often related to a recurrence interval of from 1.0 – 1.8 years as determined using a flood frequency analysis (Rosgen, 1996; Leopold, 1994; USDA Forest Service, 1995; USDA, 1998). Determination of the bankfull discharge is critical for proper application of the classification system.

The stream classification survey involved establishing permanent reference pins on both sides of the channel, conducting a cross-section survey, and conducting a longitudinal profile. The "bankfull" stage was identified using indicators that included a break in bank slope and changes in vegetation. In some instances, a change in particle size can identify the bankfull stage but this was not the case for Dog Creek. The cross-section survey provided the information required determining the entrenchment ratio and the width/depth ratio. The longitudinal profile provided the information needed to determine the slope. The sinuosity was determined using aerial photographs obtained from the Rogers County Conservation District in Claremore.

3.0 RESULTS AND DISCUSSION

3.1 STREAM WATER QUALITY

Water quality monitoring began in September 1999 and continued through August 2001. Twenty-one monthly low flow events were sampled for the core sites and Bull Creek. Quarterly sites were sampled seven times through the period. In some cases, not all parameters were able to be measured at all sites due to mechanical failure, unsafe conditions, etc. Six high flow events were sampled throughout the monitoring period. Once lab analyses were completed, all data was assimilated into the OCC relational database, collated in a spreadsheet by site, and descriptive statistics generated, broken down by low flow (Tables 5 and 6) and high flow (Tables 7 and 8). In cases where data fell below detection limits, analyses were performed using one-half the detection limit as recommended by EPA (EPA, 2000).

Stream	DO (mg/l)	Cond (µS/cm)	pH	Temp (C)	Discharge (cfs)	Alk (mg/l)	Turb (NTU)	TSS (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Hardness (mg/l)
Cat Creek, Upstream											
Mean	6.47	522.90	7.59	14.58	0.91	126.14	25.50	25.48	83.60	20.89	25.48
Median	5.35	527.50	7.60	15.70	0.84	132.00	21.00	18.00	84.50	20.10	18.00
Maximum	13.11	763.00	8.04	27.50	1.94	159.00	88.50	77.70	179.00	43.40	77.70
Minimum	1.95	292.00	7.25	1.00	0.30	83.00	8.45	2.50	28.40	8.00	2.50
Standard Deviation	3.85	123.20	0.24	10.00	0.56	20.78	19.83	19.56	43.30	8.97	19.56
N	14	14	9	14	9	14	14	13	14	14	13
Cat Creek, Downstream											
Mean	3.92	626.00	7.30	16.99	3.61	101.53	14.53	16.04	72.33	53.32	146.50
Median	3.82	609.50	7.32	20.75	3.38	102.00	13.00	13.00	66.30	53.30	139.00
Maximum	8.70	810.00	7.70	28.59	7.66	135.00	26.40	48.00	122.00	86.60	250.00
Minimum	1.34	488.00	6.76	3.00	1.23	62.00	7.30	4.00	43.90	35.00	95.80
Standard Deviation	2.09	83.40	0.32	8.69	1.66	19.66	6.21	11.84	23.43	18.16	40.00
N	15	16	11	16	14	15	15	16	16	16	16
Dog Creek, Froman Property											
Mean	4.45	547.90	7.37	12.38	4.40	91.20	11.43	11.04	56.23	45.96	128.50
Median	3.53	563.00	7.38	9.90	3.16	106.00	10.90	13.50	46.40	37.00	128.00
Maximum	8.72	600.00	7.55	27.40	9.40	111.00	15.10	18.00	75.50	67.20	167.00
Minimum	0.75	439.50	7.18	4.80	1.87	47.00	8.02	0.50	42.40	34.52	102.00
Standard Deviation	3.34	65.30	0.17	9.40	3.04	26.70	3.06	6.67	15.90	14.84	25.50
N	5	5	4	5	5	5	5	5	5	5	5
Dog Creek, Flint Road											
Mean	4.01	475.00	7.27	16.63	7.26	91.56	12.14	10.86	53.64	33.89	123.38
Median	2.65	450.40	7.26	20.80	5.28	88.50	9.97	8.00	53.00	30.60	118.00
Maximum	10.55	750.00	7.81	27.45	28.45	132.00	22.30	23.50	76.30	65.70	167.00
Minimum	0.82	264.00	6.84	0.90	1.24	44.00	3.68	0.50	36.40	2.50	82.40

Stream	DO (mg/l)	Cond (µS/cm)	pH	Temp (C)	Discharge (cfs)	Alk (mg/l)	Turb (NTU)	TSS (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Hardness (mg/l)
Standard Deviation	3.09	124.20	0.32	9.20	7.03	21.27	6.02	8.10	11.24	17.24	22.54
N	16	17	12	17	15	16	16	17	17	17	17
Dog Creek, McCombs Property											
Mean	6.94	474.60	7.53	15.61	7.06	86.43	9.38	10.67	57.75	44.06	123.71
Median	7.14	520.00	7.75	10.40	4.45	91.00	8.68	11.50	50.00	44.00	118.00
Maximum	11.00	609.00	7.85	31.90	14.18	109.00	20.50	22.00	85.50	62.10	159.00
Minimum	1.79	310.00	7.06	4.30	2.85	62.00	1.42	0.50	45.50	20.00	101.00
Standard Deviation	3.42	112.10	0.37	11.61	5.17	20.05	6.51	8.89	14.86	15.98	20.74
N	7	7	5	7	5	7	7	6	7	7	7
Dog Creek, Gordon Property											
Mean	4.48	438.10	7.29	17.00	8.15	92.76	20.11	16.51	50.06	33.61	116.87
Median	3.64	503.00	7.26	20.60	7.34	86.00	14.90	14.00	50.90	34.00	120.00
Maximum	10.69	606.00	7.71	28.70	15.00	174.00	69.60	64.00	77.50	64.40	150.00
Minimum	0.20	228.00	6.95	0.50	0.00	68.00	2.45	0.50	20.00	2.50	70.20
Standard Deviation	3.04	125.50	0.21	9.69	5.61	27.76	15.59	14.91	14.95	21.72	21.14
N	16	17	12	17	6	17	17	17	17	17	17
Dog Creek, Spavinaw Flowline											
Mean	5.08	417.50	7.31	16.59	6.61	86.00	22.94	19.04	50.18	33.39	115.79
Median	4.13	382.00	7.24	20.00	6.22	73.00	17.40	16.00	53.70	27.40	116.00
Maximum	11.33	579.00	7.68	27.30	18.41	152.00	90.10	78.00	77.00	64.50	144.00
Minimum	1.71	225.00	7.01	0.40	1.56	62.00	10.00	2.00	28.10	6.50	63.60
Standard Deviation	3.10	122.70	0.19	9.59	4.50	27.32	18.67	17.12	13.27	19.76	21.45
N	16	17	12	17	15	17	17	17	17	17	17
Dog Creek, Highway 88											
Mean	7.66	288.70	7.67	11.26	4.92	79.40	24.24	18.44	32.04	8.82	116.10
Median	6.55	269.00	7.72	10.50	4.00	74.00	19.70	12.00	32.80	8.30	107.00
Maximum	12.69	456.00	7.95	28.30	12.00	124.00	55.80	47.70	41.00	17.00	182.00

Stream	DO (mg/l)	Cond (µS/cm)	pH	Temp (C)	Discharge (cfs)	Alk (mg/l)	Turb (NTU)	TSS (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Hardness (mg/l)
Minimum	3.55	192.30	7.29	2.90	1.52	46.00	7.08	0.50	14.91	2.50	78.40
Standard Deviation	4.25	104.60	0.29	10.34	4.21	29.40	20.12	18.23	10.48	5.36	40.50
N	5	5	4	5	5	5	5	5	5	5	5
Bull Creek											
Mean	7.41	415.60	7.38	15.09	2.88	45.13	46.31	31.17	90.29	23.60	137.10
Median	6.33	384.00	7.29	19.00	1.34	42.00	34.20	23.00	86.50	17.60	116.20
Maximum	12.32	812.00	7.70	27.80	11.74	87.00	149.00	97.00	197.00	69.00	320.00
Minimum	3.13	181.00	6.76	0.10	0.20	24.00	12.40	0.90	37.50	2.50	29.80
Standard Deviation	2.89	181.30	0.32	10.15	3.69	18.24	36.28	27.68	38.27	23.60	76.10
N	15	15	11	15	9	15	15	15	15	15	15

Table 5: Low flow parameter measurements.

Stream	OrthoP (mg/l)	TotalP (mg/1)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Fecal Coliform (mg/l)	NH_3 (mg/l)	Chl-a (mg/l)	CBOD5 (mg/l)	CBOD20 (mg/l)	BOD 20 (mg/l)
Cat Creek, Upstream											
Mean	0.039	0.10	0.373	0.050	0.649	271.9	0.174	2.68	3.42	6.26	*
Median	0.033	0.09	0.291	0.025	0.530	140.0	0.180	1.65	3.58	5.06	*
Maximum	0.111	0.29	0.880	0.400	1.120	890.0	0.371	12.00	6.50	16.49	*
Minimum	0.002	0.04	0.025	0.001	0.340	5.0	0.033	0.05	1.00	1.00	*
Standard Deviation	0.029	0.07	0.271	0.103	0.291	286.8	0.109	3.345	1.86	4.46	*
N	13	14	14	14	12	13	13	12	12	14	0
Cat Creek, Downstream											
Mean	2.663	3.92	5.512	0.561	4.309	9779	2.597	4.01	13.09	33.50	33.95
Median	2.886	3.45	5.615	0.450	3.815	1150	2.015	2.00	10.70	23.30	33.95
Maximum	4.15	6.72	8.390	1.860	8.760	58000	6.400	17.10	54.00	197.10	34.4
Minimum	0.799	1.48	2.720	0.150	2.050	125	0.380	0.01	2.60	8.70	33.5

Stream	OrthoP (mg/l)	TotalP (mg/1)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Fecal Coliform (mg/l)	NH_3 (mg/l)	Chl-a (mg/l)	CBOD5 (mg/l)	CBOD20 (mg/l)	BOD 20 (mg/l)
Standard Deviation	0.996	1.49	1.749	0.408	1.701	16928	1.821	5.30	12.71	46.50	0.636
N	14	15	16	16	14	14	14	13	15	15	2
Dog Creek, Froman Property											
Mean	2.357	2.84	4.490	0.600	4.022	521	2.810	3.60	6.66	14.28	*
Median	1.820	2.21	3.890	0.560	4.410	200	3.300	2.30	5.11	13.71	*
Maximum	3.890	4.72	8.260	0.960	5.830	2000	3.810	7.57	11.40	19.80	*
Minimum	0.920	1.38	2.350	0.261	2.300	50	1.030	0.05	4.70	10.00	*
Standard Deviation	1.254	1.51	2.240	0.253	1.385	830	1.161	3.08	2.81	3.68	*
N	5	5	5	5	5	5	5	5	5	5	0
Dog Creek, Flint Road											
Mean	1.455	2.39	3.159	0.341	2.946	6792	1.694	2.83	5.47	12.72	17.05
Median	1.216	1.57	2.830	0.280	2.600	1650	1.180	1.20	4.27	14.04	17.05
Maximum	3.780	5.31	8.230	0.690	7.810	50500	5.220	15.97	14.60	21.57	18.2
Minimum	0.087	0.59	1.020	0.005	1.210	50	0.415	0.05	1.00	2.84	15.9
Standard Deviation	1.034	1.69	1.802	0.199	1.661	14362	1.454	4.37	4.17	5.76	1.626
N	14	16	17	17	15	14	14	13	14	15	2
Dog Creek, McCombs Property											
Mean	1.583	2.37	4.284	0.429	2.333	471	1.453	4.54	4.06	10.37	13.45
Median	1.015	2.67	4.030	0.390	1.690	262	0.587	2.01	2.75	9.50	13.45
Maximum	3.622	3.91	8.290	0.760	5.870	1600	4.600	0.20	7.90	17.30	15.2
Minimum	0.553	0.72	1.360	0.122	1.100	100	0.208	11.45	2.20	3.20	11.7
Standard Deviation	1.300	1.13	2.394	0.207	1.705	579	1.747	5.10	2.41	4.77	2.475
N	6	7	7	7	7	6	6	6	7	7	2
Dog Creek, Gordon Property											
Mean	1.109	1.78	2.459	0.142	2.809	505	1.678	4.379	4.36	9.09	9.25
Median	0.469	1.48	2.100	0.120	1.210	200	0.200	4.650	2.80	7.5	9.25

Stream	OrthoP (mg/l)	TotalP (mg/1)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Fecal Coliform (mg/l)	NH_3 (mg/l)	Chl-a (mg/l)	CBOD5 (mg/l)	CBOD20 (mg/l)	BOD 20 (mg/l)
Maximum	4.679	4.91	6.320	0.460	13.860	3000	12.730	9.000	20.00	31.00	10.1
Minimum	0.015	0.39	0.150	0.005	0.710	50	0.030	0.050	1.00	1.77	8.4
Standard Deviation	1.302	1.41	1.736	0.096	3.802	747	3.575	3.229	4.99	7.29	1.202
N	15	16	17	17	15	16	15	14	15	17	2
Dog Creek, Spavinaw Flowline											
Mean	1.072	1.61	2.259	0.105	2.328	545	1.379	2.39	3.87	8.10	8.4
Median	0.642	1.09	2.090	0.100	1.190	200	0.240	0.80	3.20	7.5	8.4
Maximum	3.943	5.06	6.360	0.220	9.470	3000	7.699	14.71	11.00	21.00	8.5
Minimum	0.284	0.44	0.030	0.005	0.490	10	0.090	0.01	1.00	2.20	8.3
Standard Deviation	1.015	1.31	1.619	0.052	2.882	822	2.599	4.03	2.66	5.32	0.141
N	14	16	17	17	15	14	14	13	15	17	2
Dog Creek, Highway 88											
Mean	0.065	0.13	0.188	0.089	0.754	246	0.103	7.27	3.44	5.12	*
Median	0.008	0.09	0.142	0.025	0.580	125	0.090	5.30	3.00	4.70	*
Maximum	0.223	0.35	0.490	0.390	1.110	600	0.221	18.14	5.50	9.20	*
Minimum	0.001	0.04	0.025	0.003	0.510	5	0.025	2.00	2.80	2.40	*
Standard Deviation	0.095	0.13	0.187	0.169	0.291	247	0.084	6.39	1.16	2.49	*
N	5	5	5	5	5	5	5	5	5	5	0
Bull Creek											
Mean	0.042	0.14	0.369	0.017	0.690	573	0.075	8.04	4.14	8.96	*
Median	0.031	0.13	0.230	0.015	0.711	210	0.036	0.80	4.46	7.10	*
Maximum	0.132	0.27	1.250	0.060	1.230	3100	0.310	50.70	8.30	45.68	*
Minimum	0.001	0.04	0.003	0.002	0.350	30	0.018	0.05	2.00	1.90	*
Standard Deviation	0.036	0.06	0.399	0.016	0.237	822	0.078	14.27	1.70	10.54	*
N	16	15	15	14	13	16	16	15	14	15	0

Table 6: Low flow parameter measurements.

Some general trends can be inferred from the water quality parameters. Turbidity levels of study sites were generally lower than those for reference sites (Figure 4). The levels decline from Cat Creek upstream of the WWTP to the station at Cat Creek downstream of the plant and begin to rise again further downstream of the plant (Figure 5). As 50 NTUs is the standard for turbidity at this site, the values reflected here are well within the acceptable range. Turbidity is at its lowest at Dog Creek at Flint Road and then begins to increase again. This could be due to an increase in larger and more abundant fish and benthic communities present farther downstream from the WWTP. The values for total suspended solids also reflect this type of trend (Figures 6-7). There is an initial decline in values with an increase with distance from the plant.

While all values at study sites tended to be higher than that of the reference (Figure 8), alkalinity exhibited a general decrease as CO_2 was pulled from the water as it progressed downstream (Figure 9). Sulfate and total hardness mirrored this trend (Figures 10-13). Salt and other elements associated with old strip mines, gypsum or another source are diluted by the effluent and continue to dilute as the Cat Creek converges with Dog Creek.

Temperature showed no obvious trend among stations or reference sites (Figure 14). At the core sites, there does seem to be a slight increase in temperature from Cat Creek upstream of the WWTP to the sites downstream from the plant (Figure 15).

Another trend seen in the data is a sharp increase in values from immediately upstream of the WWTP to the site just downstream of the plant, generally declining with distance from the plant. Chloride increases with the introduction of the sewage effluent and then becomes diluted by Dog Creek (Figure 17). The increase at Dog Creek at Gordon's property indicates the contribution of chloride from another source. Total phosphorus increases greatly with the introduction of the sewage effluent (Figure 19). It does decrease as Cat Creek converges with Dog Creek; however, it is still above 1 mg/l, indicating a slow uptake of phosphorus with little algae present. For similar reasons, this same trend is seen in ortho-phosphate, nitrate, nitrite, TKN, and ammonia (Figures 20-29). The increase seen in ammonia between Dog Creek at Gordon's property and Dog Creek at the Spavinaw flowline indicates the influence of another source (Figure 29). $CBOD_{20}$ and $CBOD_5$ also demonstrate this trend (Figures 30-33). There is a sharp increase with the addition of the effluent which then becomes diluted by Dog Creek (Figures 31 and 33). Similarly, BOD_{20} levels are highest at Cat Creek downstream of the plant and decrease with distance from the plant (Table 6).

Fecal coliform values at most study sites reflect that of the reference condition (Figure 34). Among the core sites, the sharpest increase is seen at Dog Creek at Flint Road instead of Cat Creek downstream of the WWTP (Figure 35). Water quality standards established for Oklahoma water bodies indicate that for primary body contact, the fecal coliform group cannot have more than ten percent of the total samples during any 30 day period exceeding 400/100 ml. The season set aside for primary body contact occurs from May 1 through September 30. While the samples reflected here were taken once a month, exceedences of the 400 cfu/100 ml during the time established for primary body contact recreation were recorded for 28.6% to 71.4% of the samples from the core sites. It is possible that the limit for fecal coliform bacteria could have been exceeded during this time based on the high values observed during our monthly sampling events.

The study site values for conductivity were mostly higher than reference conditions (Figure 36). For the core sites, after an initial increase with the sewage at Cat Creek upstream of the WWTP, a general downstream decrease was seen (Figure 37).

Chlorophyll-a values for study sites are larger than those seen in the reference stream (Figure 38). There is a general downstream decrease in chlorophyll-a in the core sites with the exception of an increase seen at Dog Creek at Gordon's property which could be caused by an area receiving more sunlight (Figure 39). Regardless, all values are relatively low.

Statistical analyses of the water quality data indicated significant differences between the groups for all parameters except temperature and chlorophyll-a (Table 7). Dissolved oxygen and pH were not analyzed as they are time and season dependent. Initially, a Kruskall-Wallis test was performed on the data. For those tests indicating significance, a Tukey's multiple comparison test was conducted on the ranked data to discern which sites comprised the differences (Table 8). In the cases of total suspended solids and fecal coliform, the Kruskall-Wallis indicated differences in the means; however, the Tukey test could not discern the location of the differences. A Mood's median test of these parameters did not indicate differences between the sites (TSS: chi-square=15.19, DF=10, p=0.125; Fecal Coliform: chi-square=11.10, DF=8, p=0.196).

In most instances, the differences were between the sites upstream or more distant from the effluent and those immediately downstream of the effluent. This can be seen in the results from alkalinity where all the differences can be accounted for through Bull Creek and Cat Creek upstream of the effluent differing from each study site. The differences in conductivity occur between Cat Creek downstream of the plant and most of the other study sites in addition to differences between Dog Creek at Highway 88 and both sites on Cat Creek. Turbidity differences are found between both Bull Creek and Cat Creek upstream of the plant and all sites downstream of the plant ending with the site at Gordon's property. The differences in ammonia occur between Cat Creek downstream of the plant and Dog Creek at the Spavinaw flowline, the most downstream study site from the plant. Total phosphorus and nitrate both reflect differences between sites upstream of the effluent (Bull Creek, Cat Creek upstream of the plant, and Dog Creek at Highway 88) and all sites receiving effluent water. Significant differences in ortho-phosphate, chloride, sulfate, $CBOD_{20}$, and $CBOD_5$ all are differences between the sites not affected by the effluent and those receiving effluent.

Total hardness exhibits significant differences between Cat Creek upstream and all sites downstream of Dog Creek at Flint Road. This reflects the pattern seen of total hardness becoming diluted as Cat Creek integrates with Dog Creek (Figure 13).

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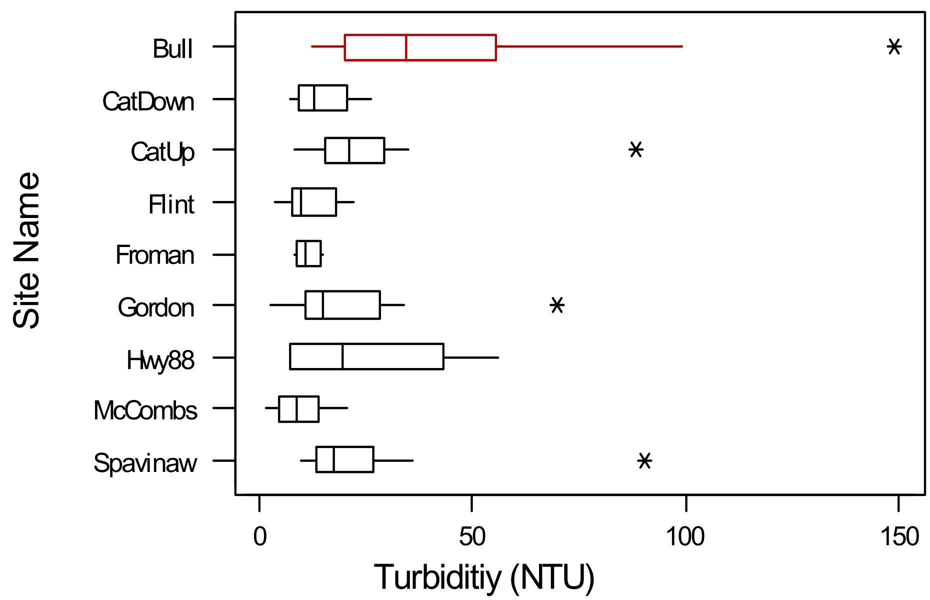

Figure 4: Interquartile ranges for turbidity.
Bull Creek is the reference site.

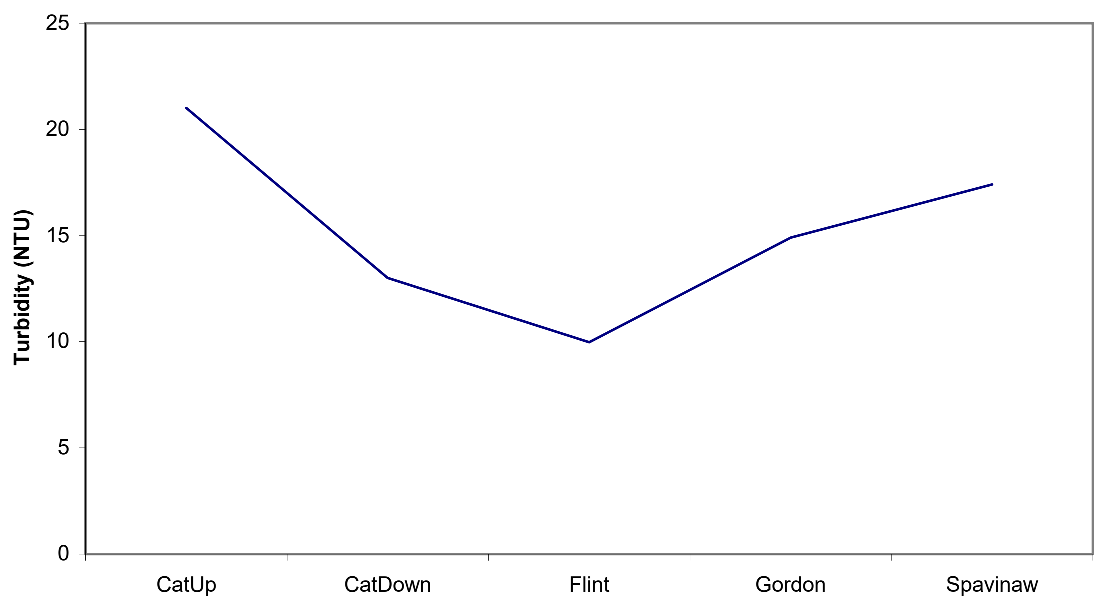

Figure 5: Downstream trend of turbidity values at core study sites.

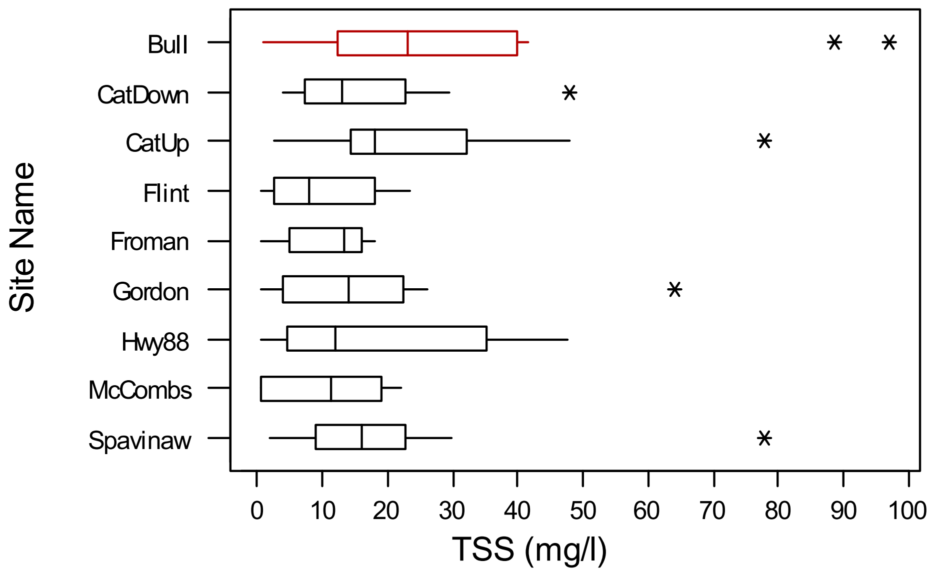

Figure 6: Interquartile ranges for total suspended solids.
Bull Creek is the reference site.

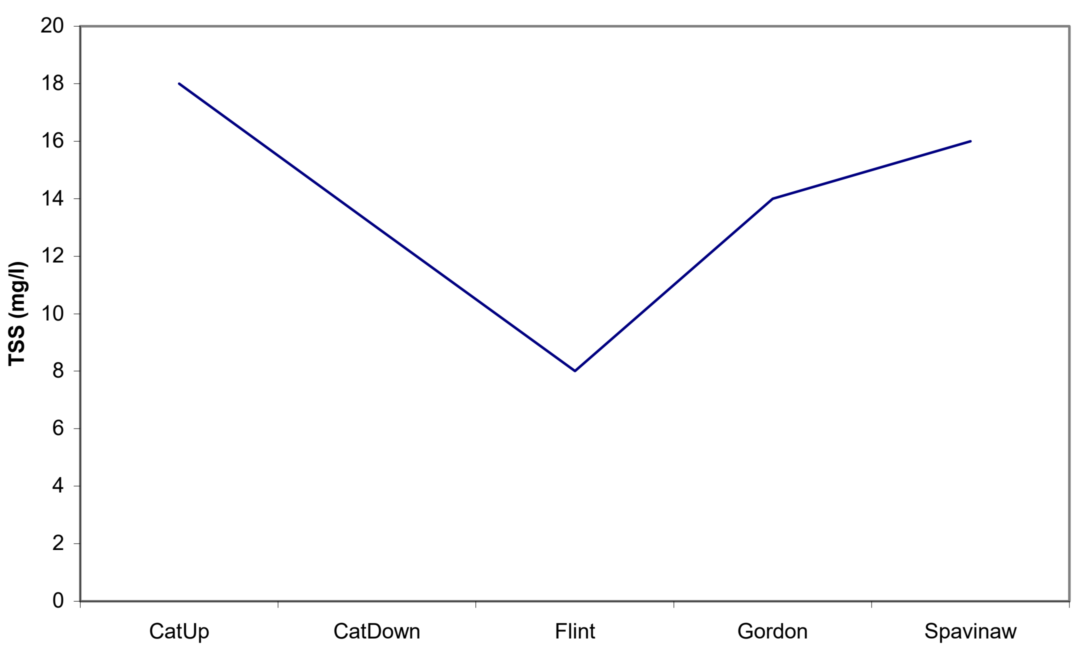

Figure 7: Downstream trend of total suspended solids at core study sites.

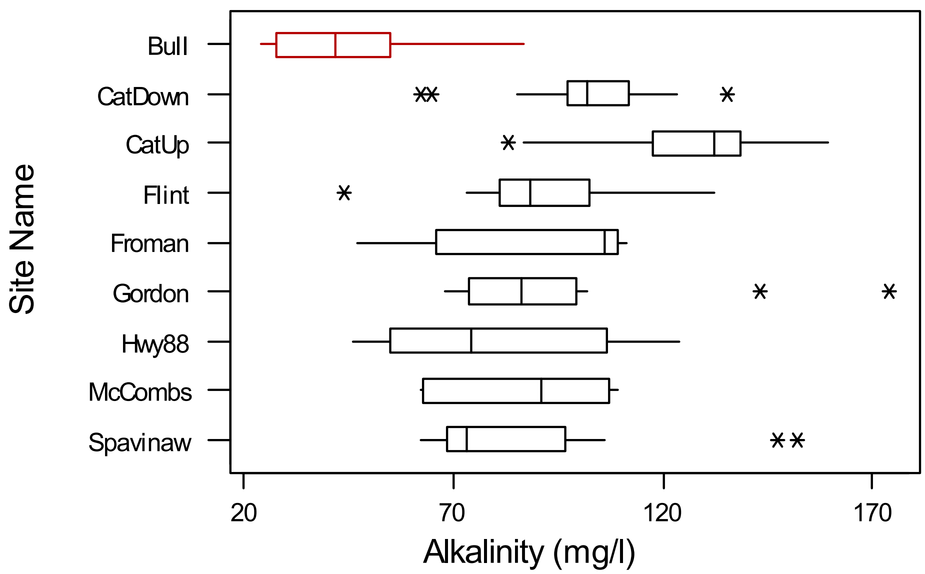

Figure 8: Interquartile ranges for alkalinity.
Bull Creek is the reference site.

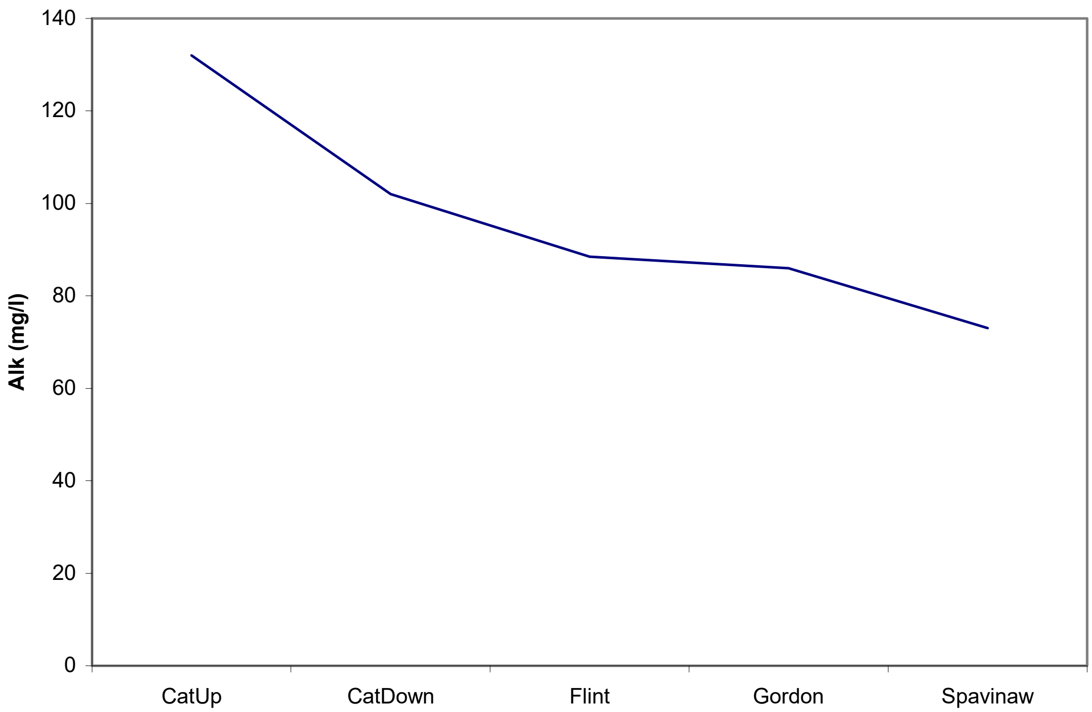

Figure 9: Downstream trend of alkalinity values at core study sites.

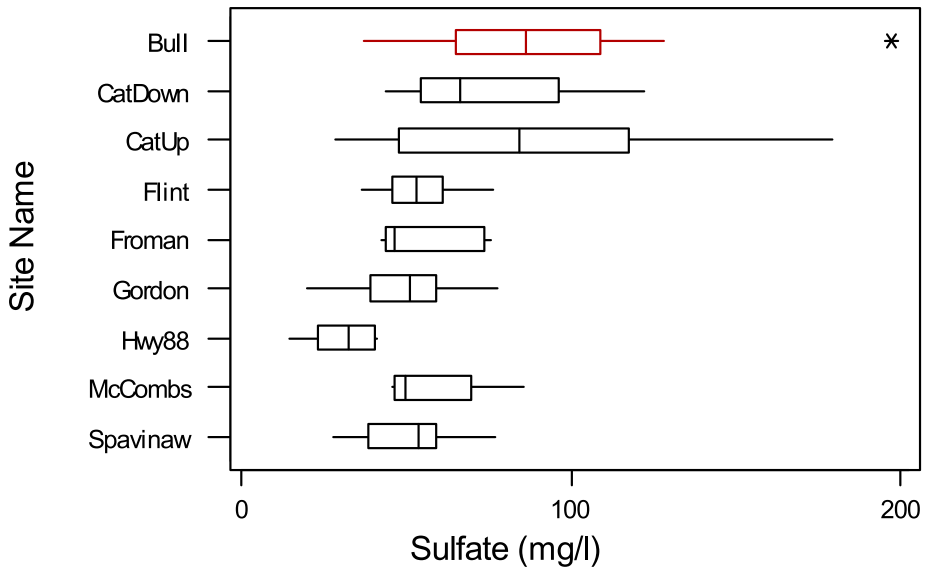

Figure 10: Interquartile ranges for sulfate.
Bull Creek is the reference site.

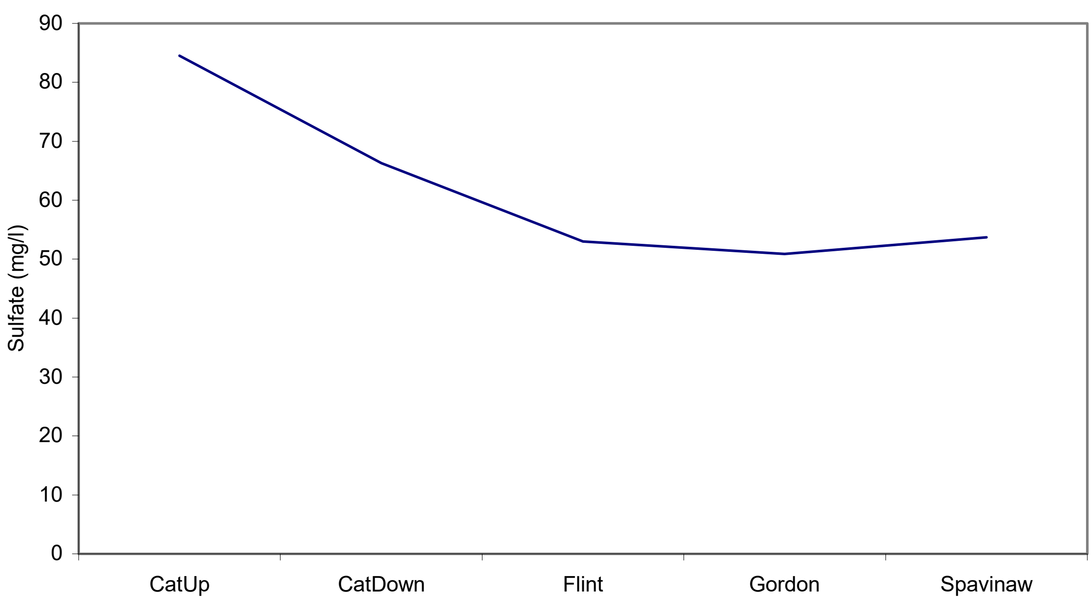

Figure 11: Downstream trend of sulfate concentrations at core study sites.

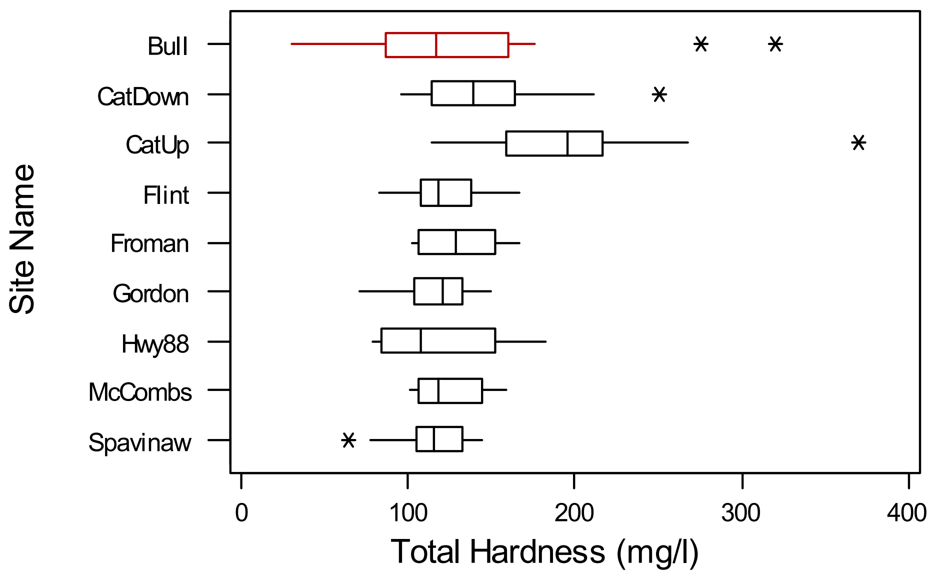

Figure 12: Interquartile ranges for total hardness.
Bull Creek is the reference site.

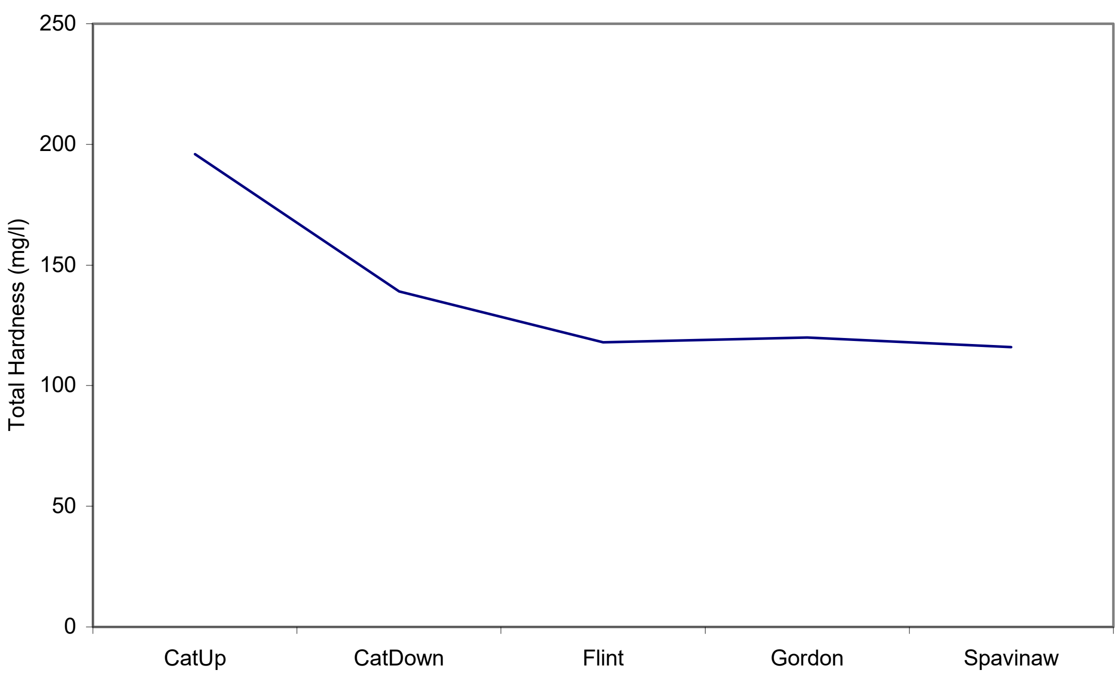

Figure 13: Downstream trend of total hardness at core study sites.

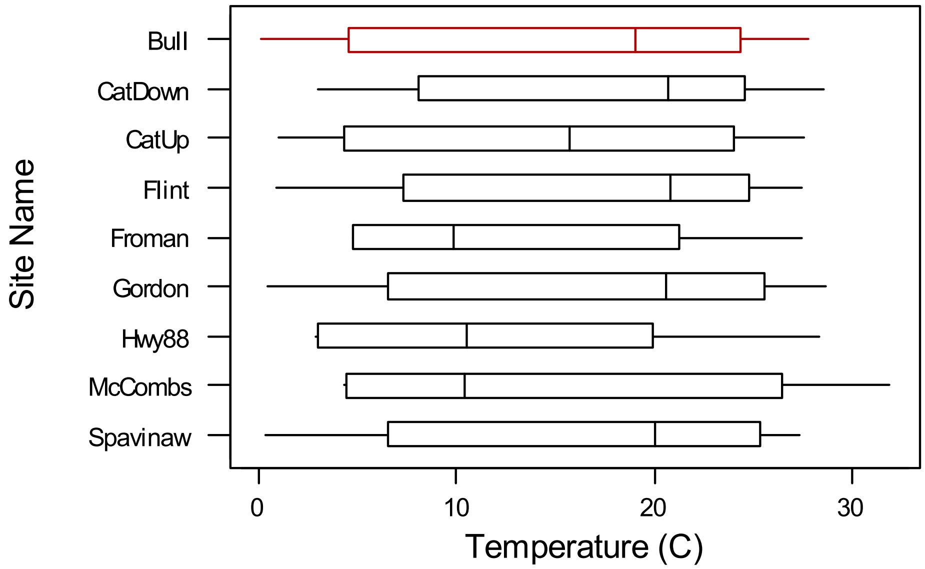

Figure 14: Interquartile ranges for temperature.
Bull Creek is the reference site.

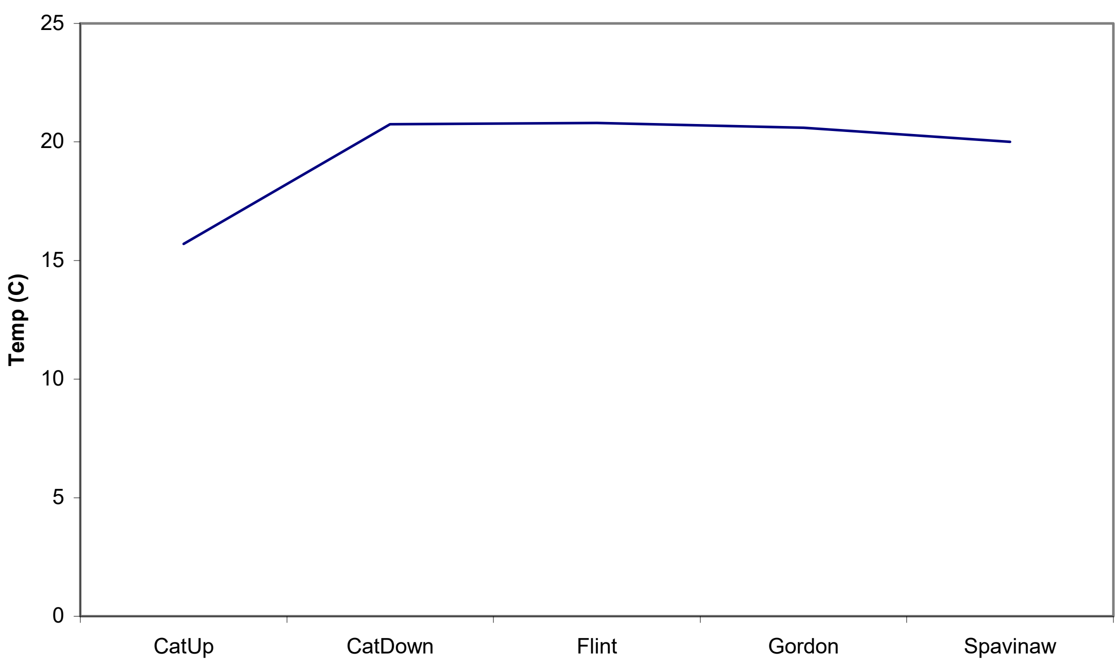

Figure 15: Downstream trend of temperature at core study sites.

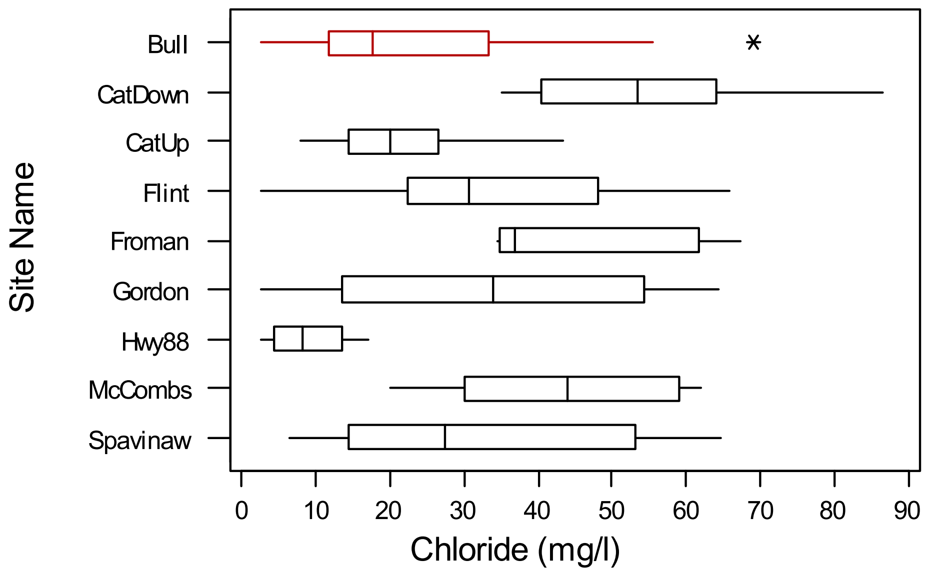

Figure 16: Interquartile ranges for chloride.
Bull Creek is the reference site.

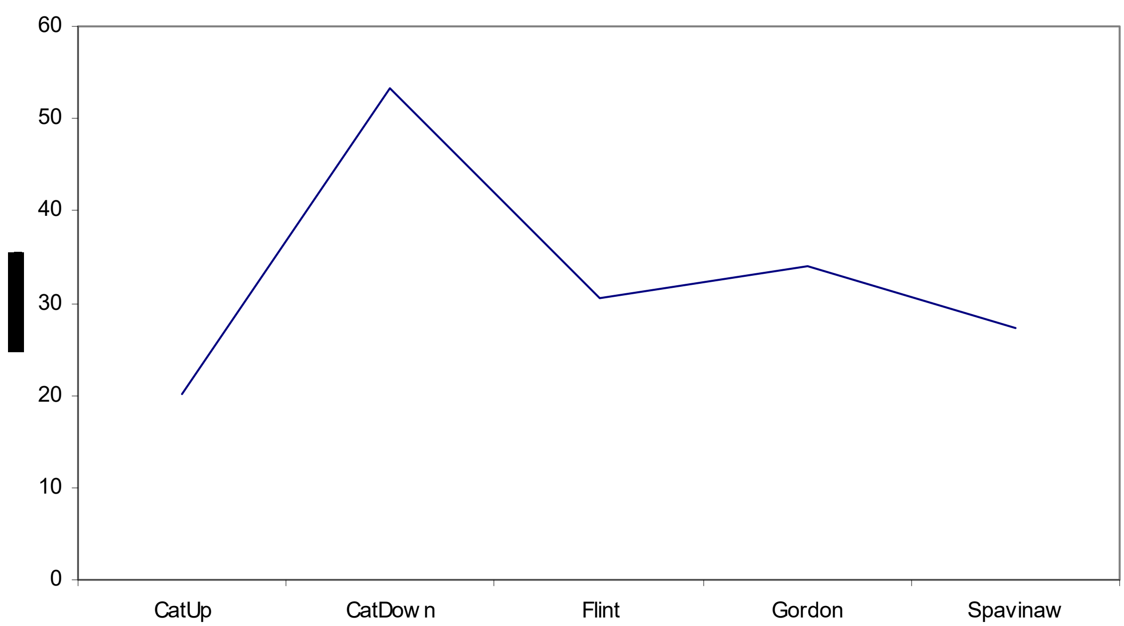

Figure 17: Downstream trend of chloride concentrations at core study sites.

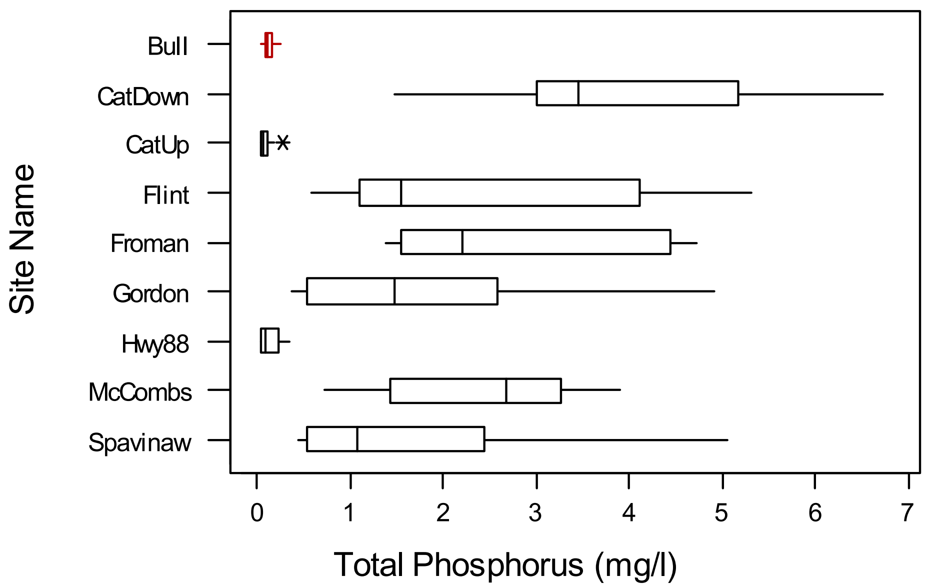

Figure 18: Interquartile ranges for total phosphorus.
Bull Creek is the reference site.

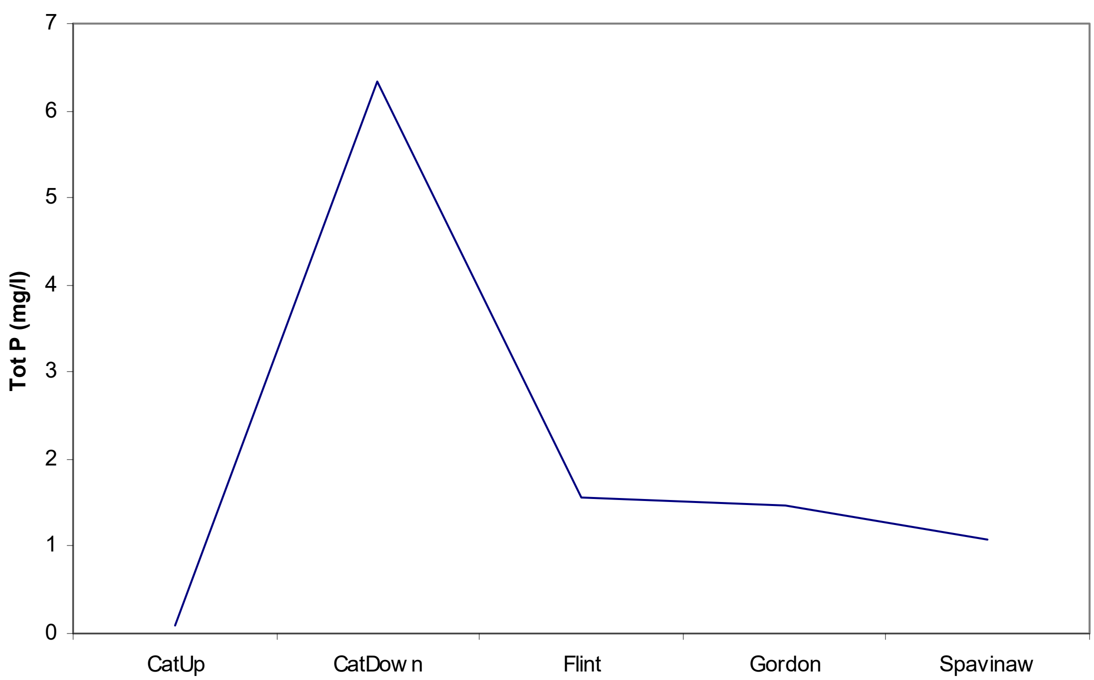

Figure 19: Downstream trend of total phosphorus at core study sites.

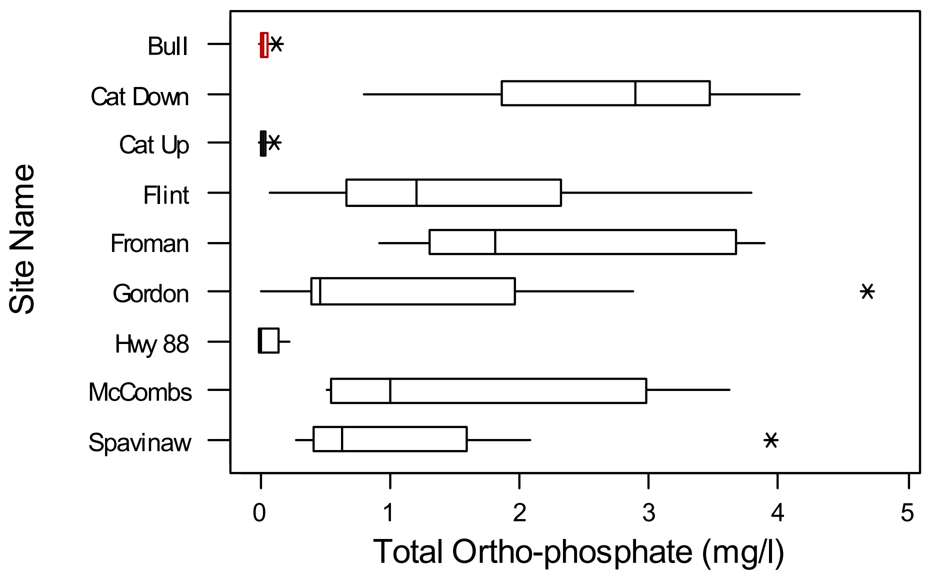

Figure 20: Interquartile ranges for total ortho-phosphate.
Bull Creek is the reference site.

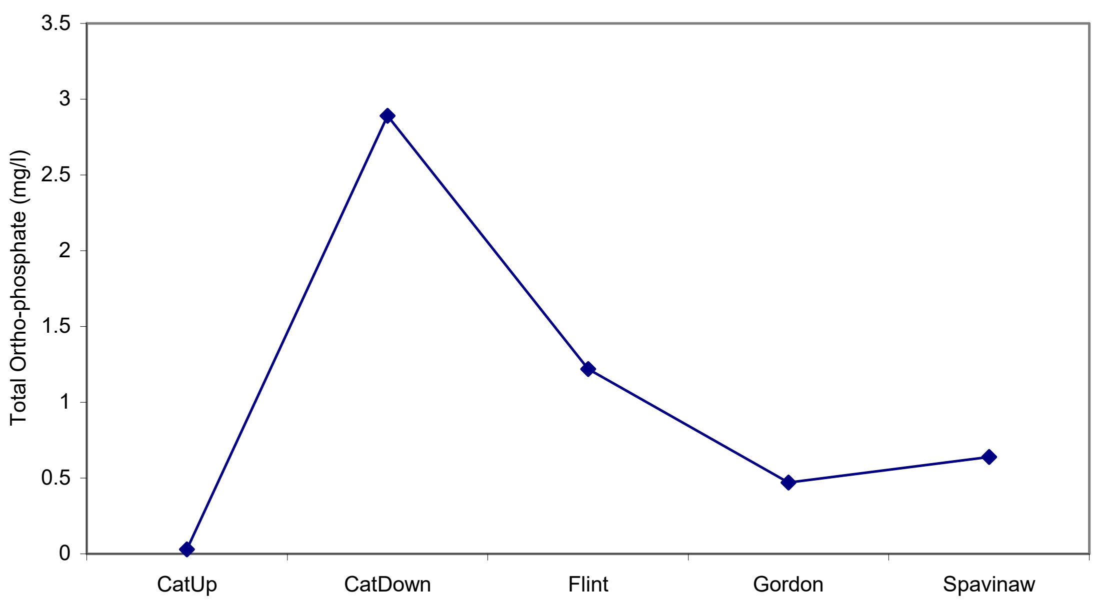

Figure 21: Downstream trend of total ortho-phosphate at core study sites.

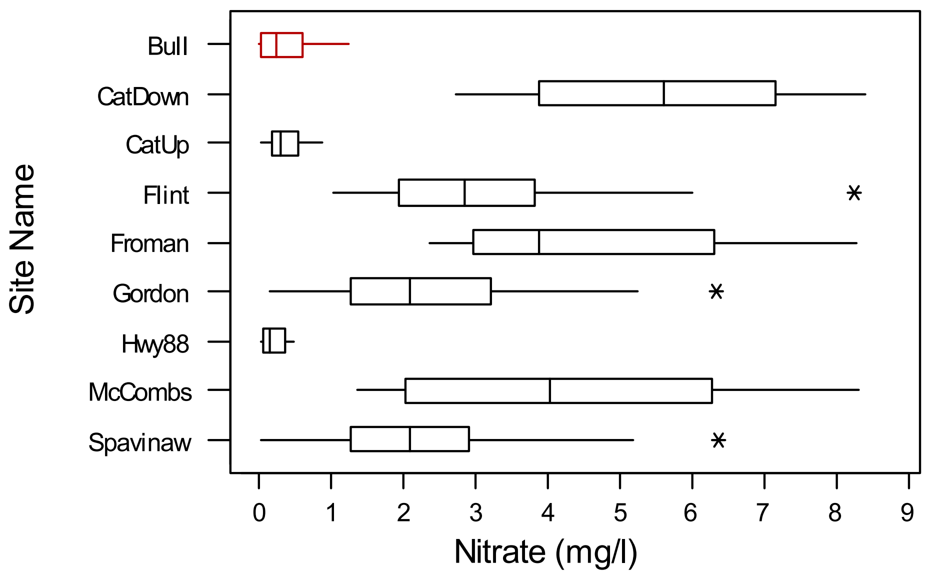

Figure 22: Interquartile ranges for nitrate.
Bull Creek is the reference site.

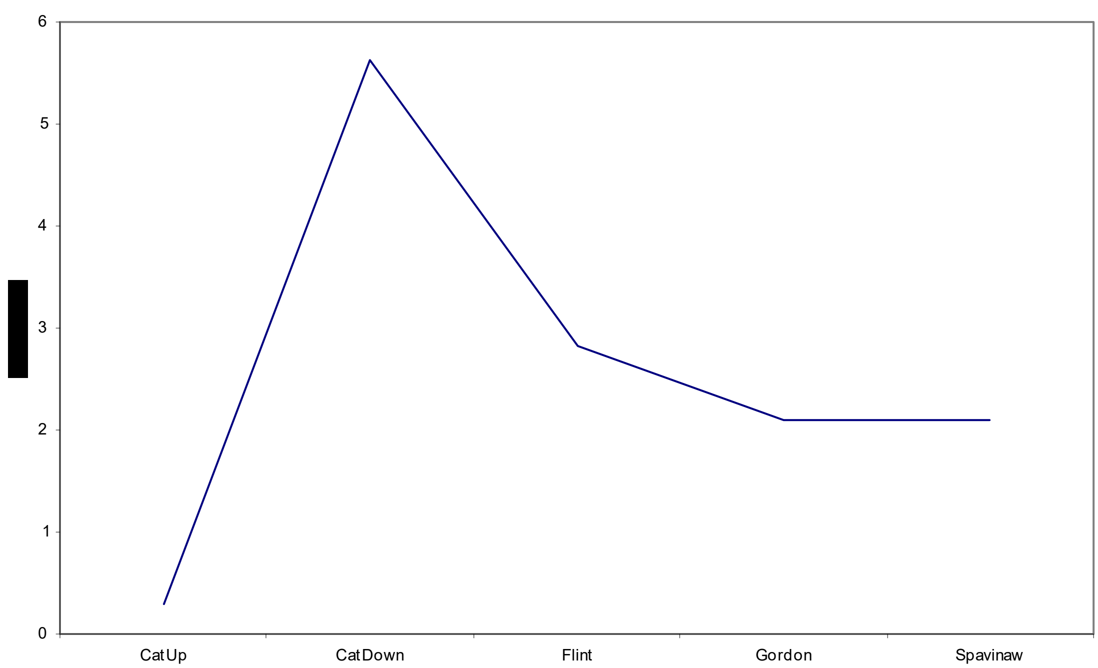

Figure 23: Downstream trend of nitrate concentrations at core study sites.

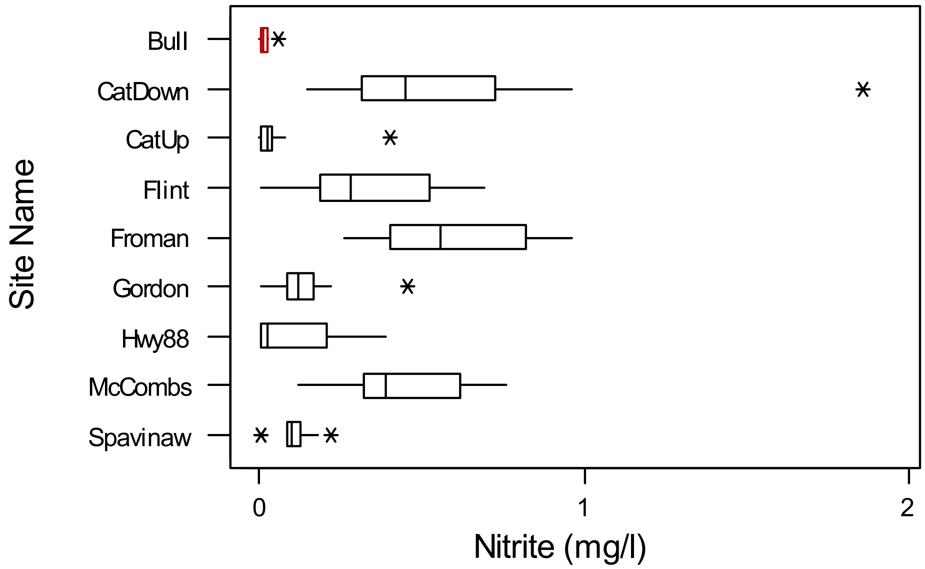

Figure 24: Interquartile ranges for nitrite.
Bull Creek is the reference site.

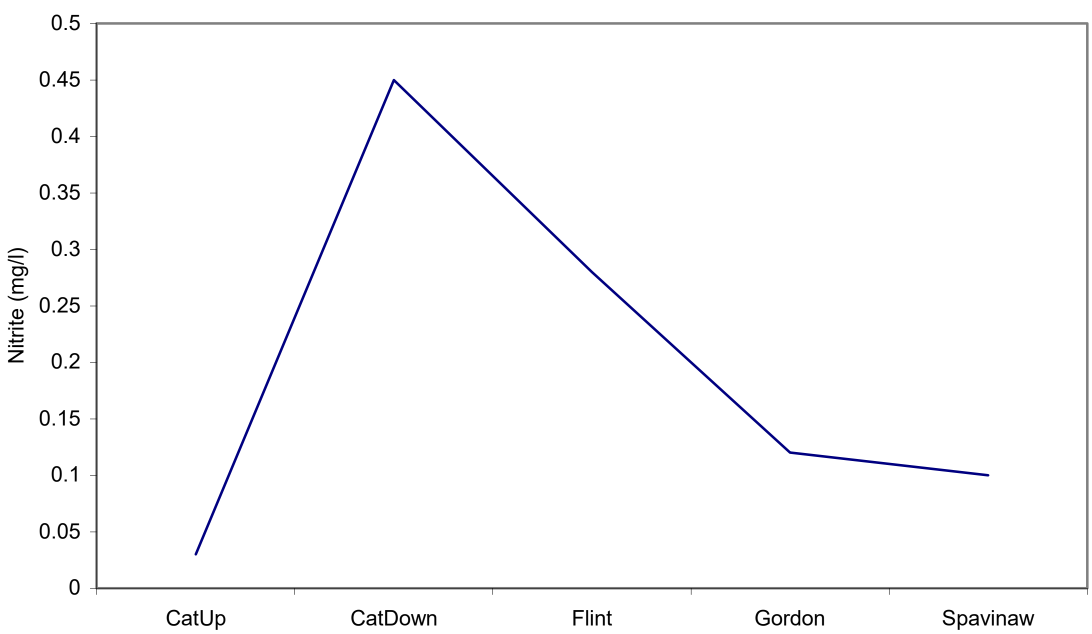

Figure 25: Downstream trend of nitrite concentrations at core study sites.

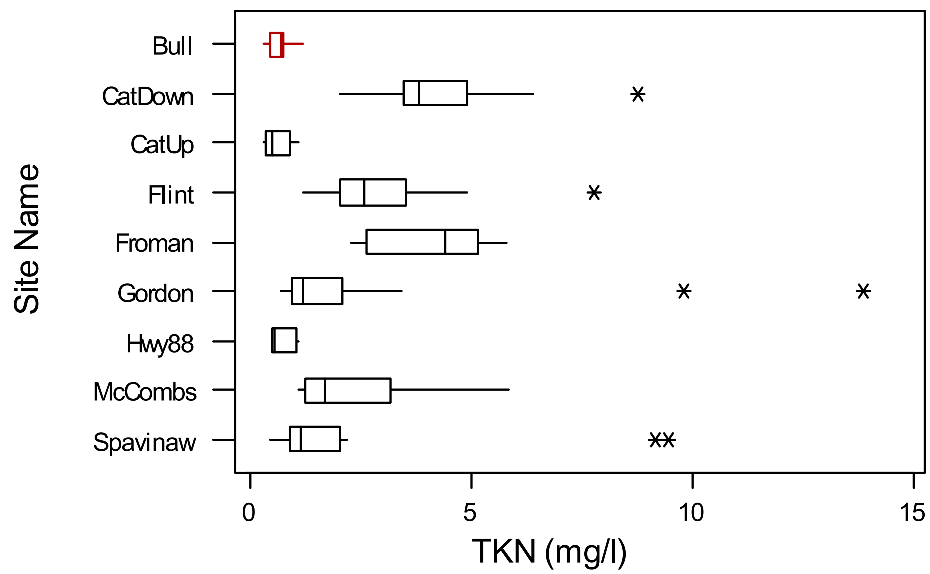

Figure 26: Interquartile ranges for total Kjeldahl nitrogen.
Bull Creek is the reference site.

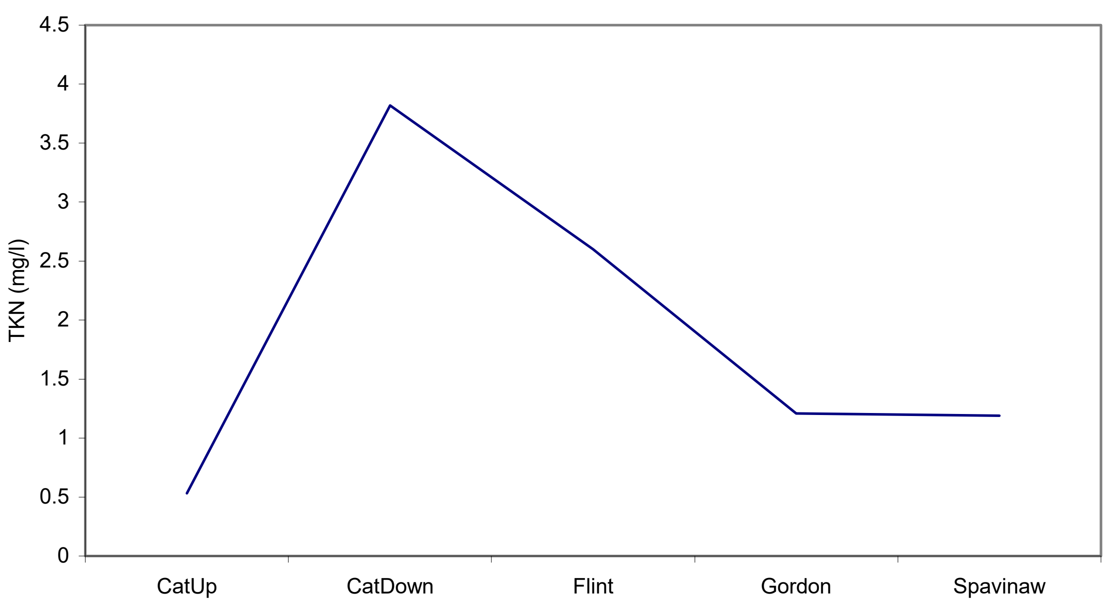

Figure 27: Downstream trend of TKN concentrations at core study sites.

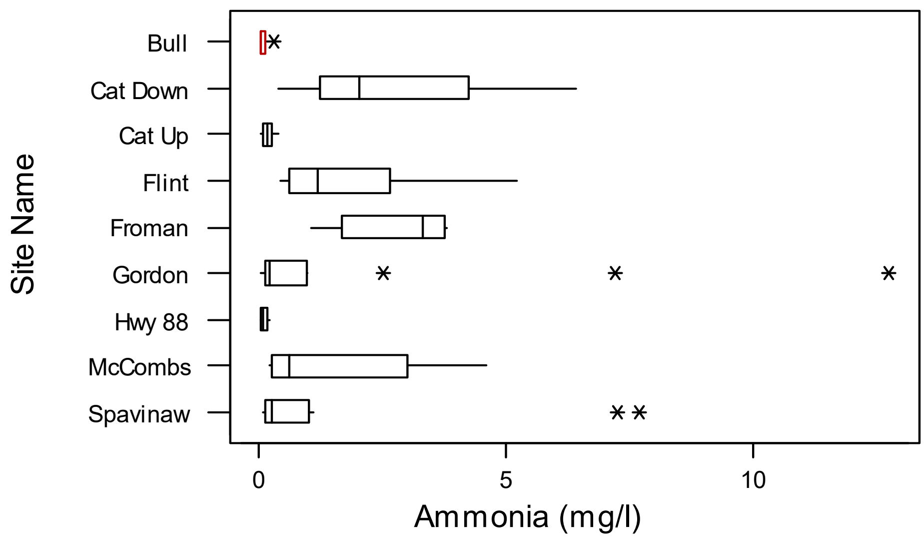

Figure 28: Interquartile ranges for ammonia.
Bull Creek is the reference site.

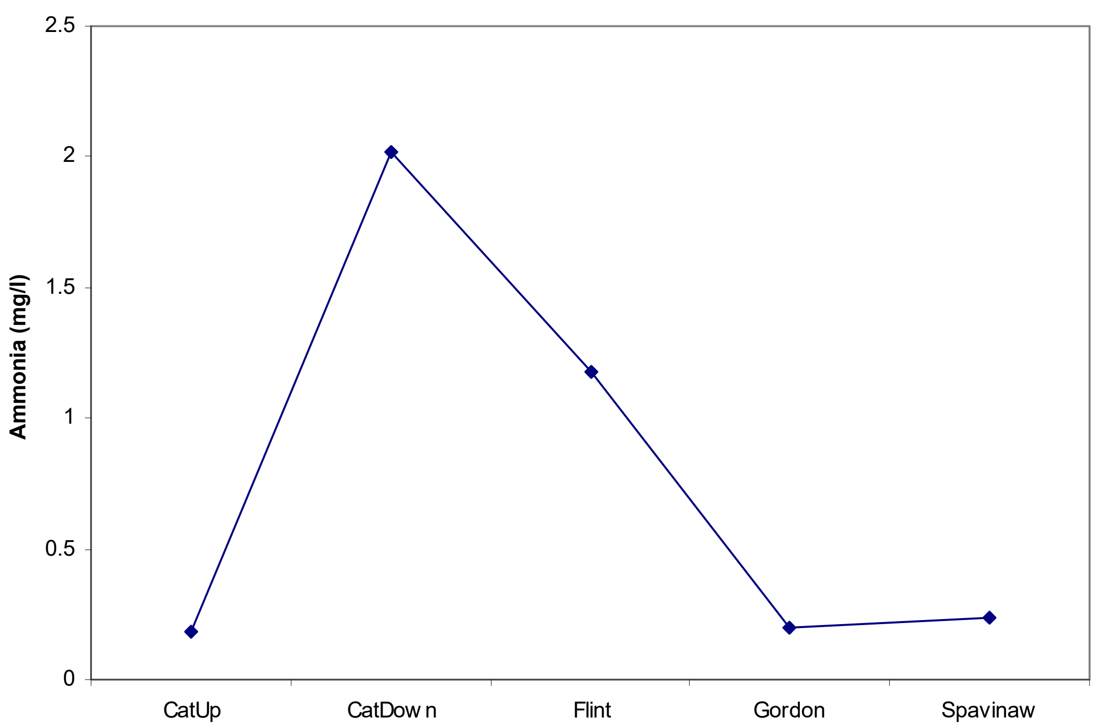

Figure 29: Downstream trend of ammonia at core study sites.

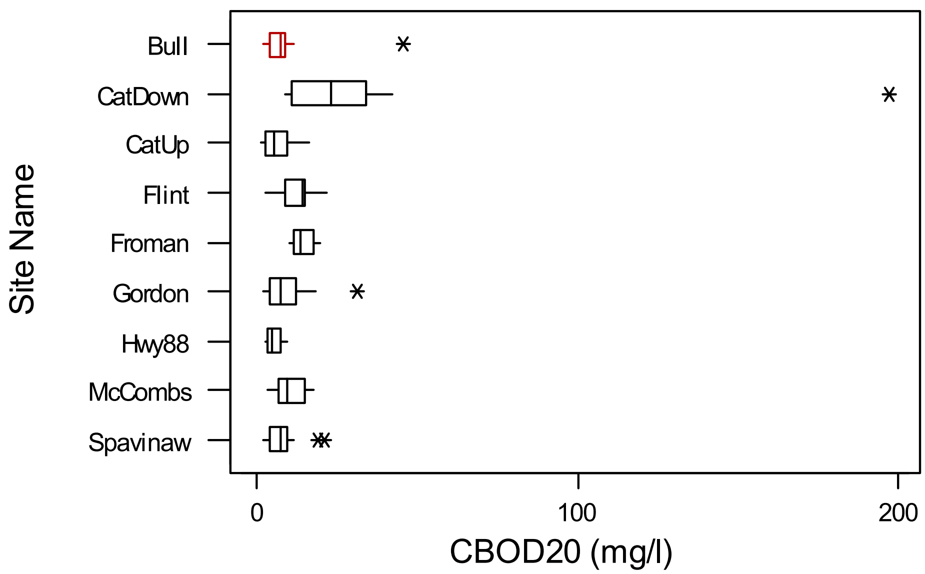

Figure 30: Interquartile ranges for $CBOD_{20}$.
Bull Creek is the reference site.

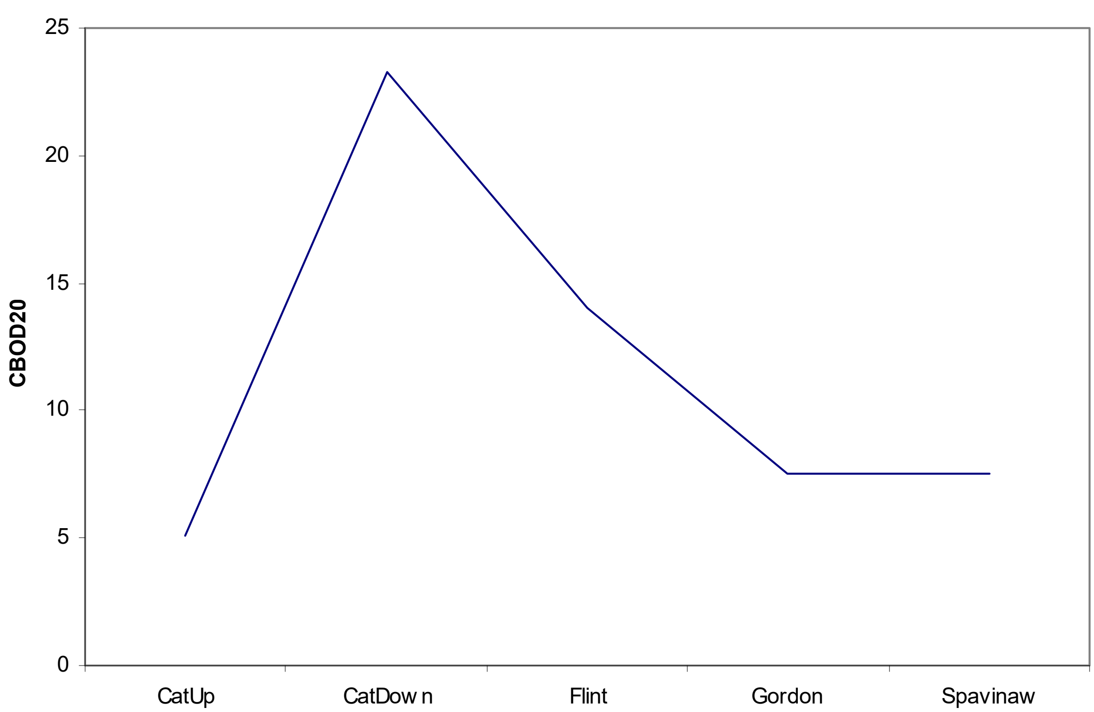

Figure 31: Downstream trend of $CBOD_{20}$ at core study sites.

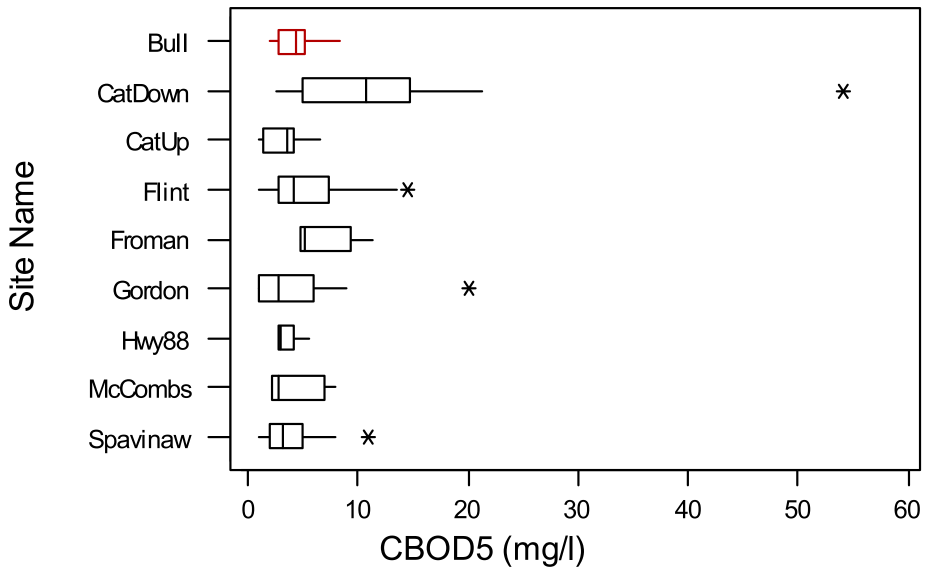

Figure 32: Interquartile ranges for $CBOD_5$.
Bull Creek is the reference site.

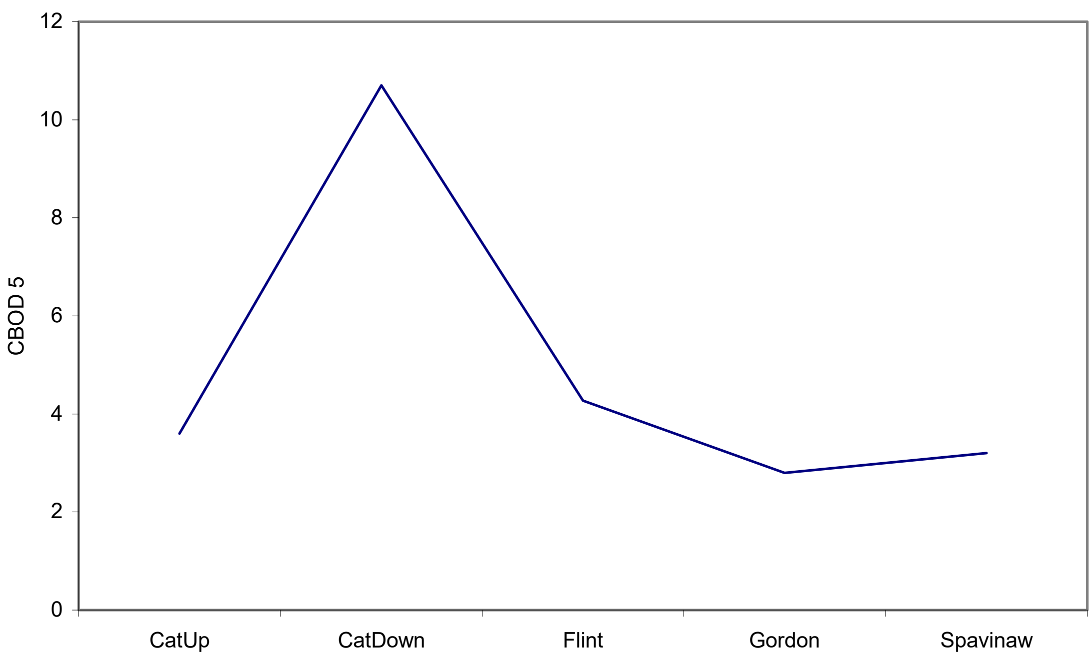

Figure 33: Downstream trend of $CBOD_5$ at core study sites.

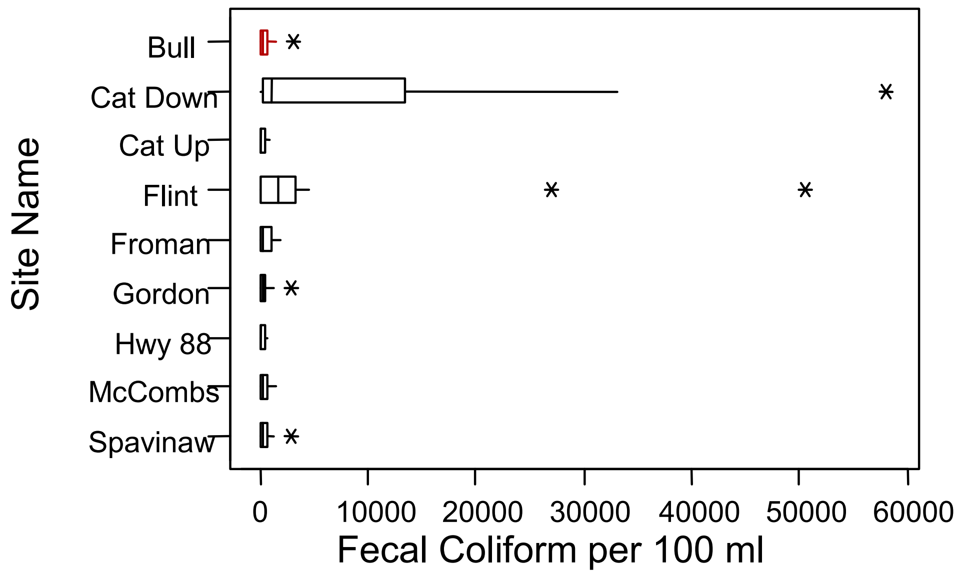

Figure 34: Interquartile ranges for fecal coliform.
Bull Creek is the reference site.

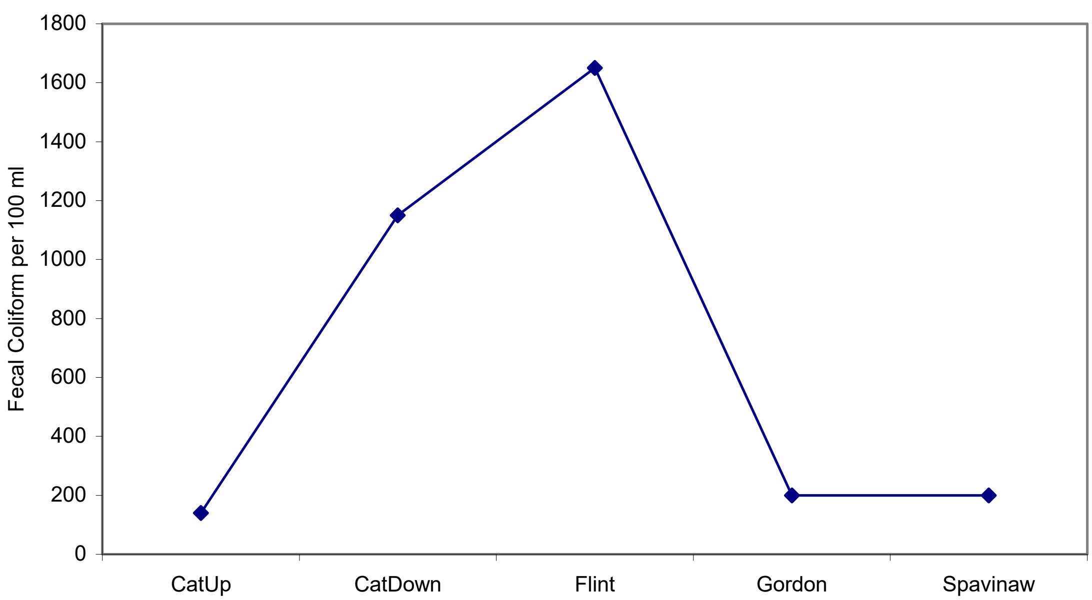

Figure 35: Downstream trend of fecal coliform at core study sites.

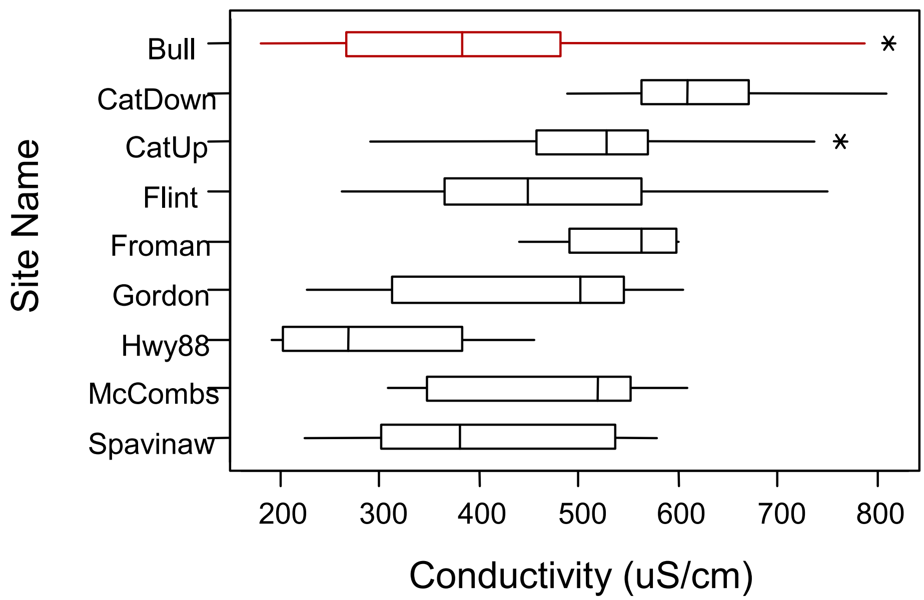

Figure 36: Interquartile ranges for conductivity.
Bull Creek is the reference site.

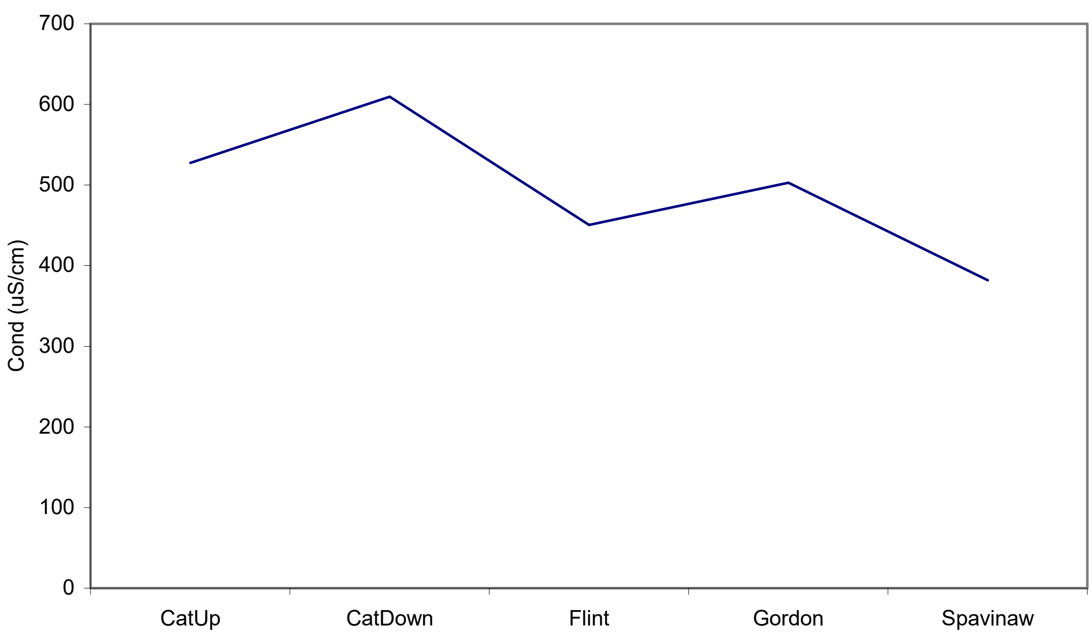

Figure 37: Downstream trend of conductivity at core study sites.

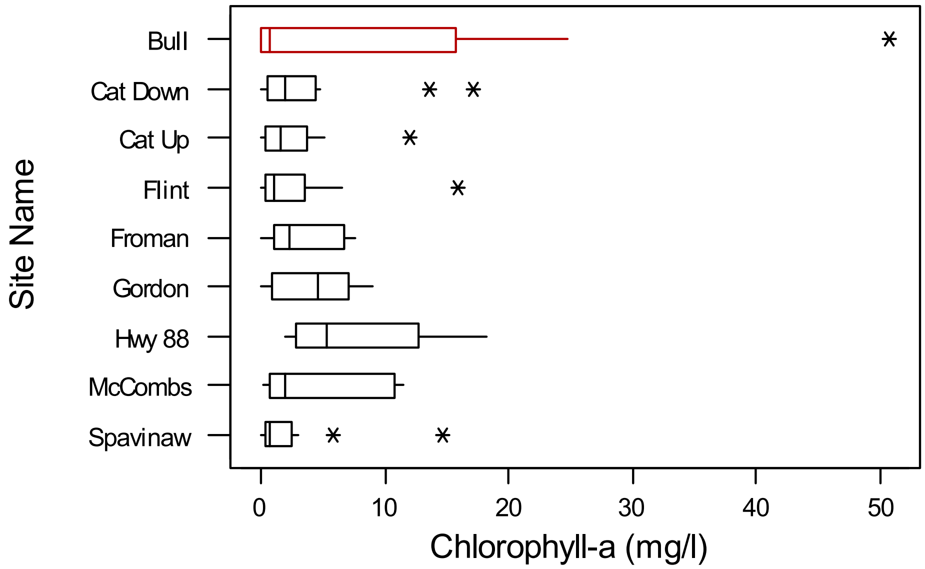

Figure 38: Interquartile ranges for water column chlorophyll-a.
Bull Creek is the reference site.

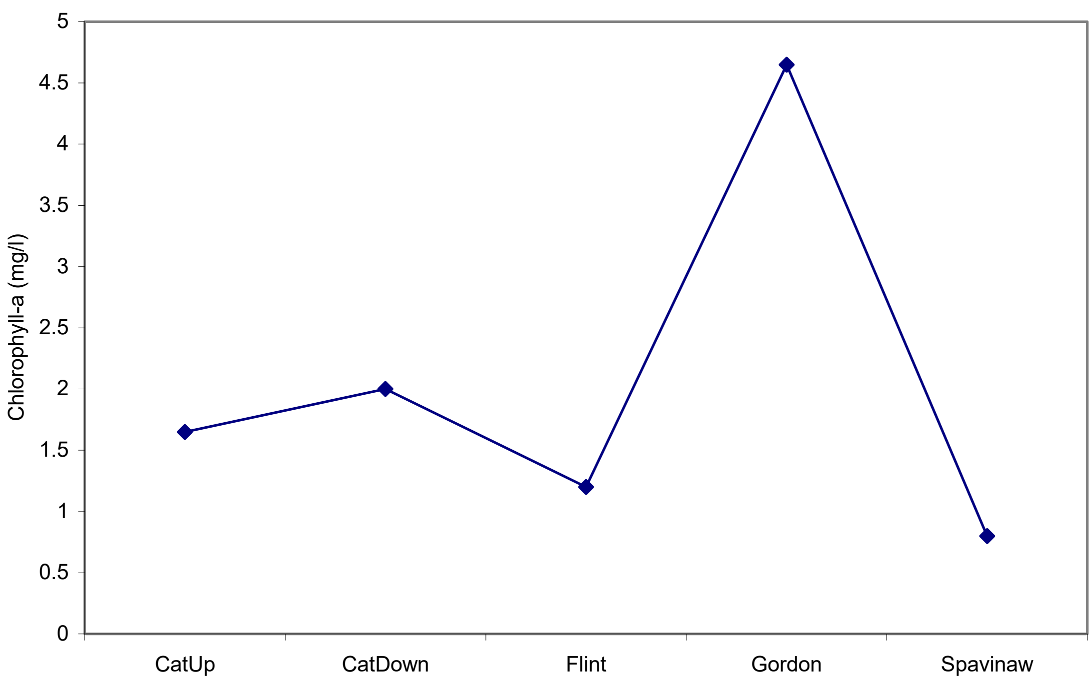

Figure 39: Downstream trend of chlorophyll-a in water column at core study sites.

Parameter	Kruskall-Wallis	Mood Median Test
Conductivity	H=45.06, df=10, p<0.0001	X^2=33.6, df=10, p<0.0001
Turbidity	H=39.39, df=10, p<0.0001	X^2=32.12, df=8 p<0.0001
Alkalinity	H=53.93, df=10, p<0.0001	X^2=29.86, df=8, p<0.0001
Chloride	H=45.09, df=10, P<0.0001	X^2=46.42, df=10, p<0.0001
Sulfate	H=39.21, df=10, p<0.0001	X^2 =26.02, df=10, p=0.004
Total Hardness	H=33.78, df=10, p<0.0001	X^2=21.47, df=10, p=0.018
Total Suspended Solids	H=19.53, df=10, p=0.034	X^2=15.19, df=10, p=0.125
Total Phosphorus	H=85.29, df=10, p<0.0001	X^2=62.57, df=10, p<0.0001
Nitrate	H=85.11, df=10, p<0.0001	X^2=63.28, df=10, p<0.0001
Nitrite	H=82.11, df=10, p<0.0001	X^2=73.17, df=10, p<0.0001
Total Kjeldahl Nitrogen	H=66.88, df=10, p<0.0001	X^2=64.62, df=10, p<0.0001
$CBOD_{20}$	H=46.04, df=10, p<0.0001	X^2=36.51, df=10, p<0.0001
$CBOD_5$	H=30.01, df=10, p=0.001	X^2=28.04, df=10, p<0.0001
Ammonia	H=62.81, df=8, p<0.0001	X^2=59.10, df=8, p<0.0001
Ortho-phosphate	H=73.36, df=8, p<0.0001	X^2=63.16, df=8, p<0.0001
Fecal Coliform	H=21.59, df=8, p=0.006	X^2=11.10, df=8 p=0.196

Table 7: Results of statistical analyses.

	Spavinaw	**Gordon**	**McCombs**	**Flint Rd.**	**Froman**	**Cat Creek, Downstream**	**Cat Creek, Upstream**	**Highway 88**
Conductivity								
McCombs								
Highway 88								
Gordon								
Froman								X
Flint Rd.								
Cat Creek, upstream								X
Cat Creek, downstream	X	X		X				X
Bull						X		
Turbidity								
McCombs								
Highway 88								
Gordon								
Froman								
Flint Rd.								
Cat Creek, upstream			X	X				
Cat Creek, downstream								
Bull		X	X	X	X	X		
Alkalinity								
McCombs								
Highway 88								

	Spavinaw	Gordon	McCombs	Flint Rd.	Froman	Cat Creek, Downstream	Cat Creek, Upstream	Highway 88
Gordon								
Froman								
Flint Rd.								
Cat Creek, upstream	X	X	X	X				X
Cat Creek, downstream								
Bull	X	X	X	X	X	X	X	
Chloride								
McCombs								
Highway 88			X					
Gordon								
Froman								X
Flint Rd.								X
Cat Creek, upstream								
Cat Creek, downstream	X	X					X	X
Bull						X		
Sulfate								
McCombs								
Highway 88								
Gordon								
Froman								
Flint Rd.								

	Spavinaw	Gordon	McCombs	Flint Rd.	Froman	Cat Creek, Downstream	Cat Creek, Upstream	Highway 88
Cat Creek, downstream								X
Bull	X	X		X				X
Total Hardness								
McCombs								
Highway 88								
Gordon								
Froman								
Flint Rd.								
Cat Creek, upstream	X	X	X	X				X
Cat Creek, downstream								
Bull							X	
Total Phosphorus								
McCombs								
Highway 88	X		X					
Gordon								X
Froman								X
Flint Rd.								X
Cat Creek, upstream	X	X	X	X	X			
Cat Creek, downstream	X	X		X			X	X

	Spavinaw	Gordon	McCombs	Flint Rd.	Froman	Cat Creek, Downstream	Cat Creek, Upstream	Highway 88
Bull	X	X	X	X	X	X		
Nitrate								
McCombs								
Highway 88	X		X					
Gordon								X
Froman								X
Flint Rd.								X
Cat Creek, upstream	X	X	X	X	X			
Cat Creek, downstream	X	X		X			X	X
Bull	X	X	X	X	X	X		
Nitrite								
McCombs	X							
Highway 88			X					
Gordon			X					
Froman	X	X						X
Flint Rd.	X	X						X
Cat Creek, upstream			X	X	X			
Cat Creek, downstream	X	X					X	X
Bull	X	X	X	X	X	X		
Total Kjeldahl Nitrogen								
McCombs								

	Spavinaw	Gordon	McCombs	Flint Rd.	Froman	Cat Creek, Downstream	Cat Creek, Upstream	Highway 88
Highway 88			X					
Gordon								
Froman	X							X
Flint Rd.	X							X
Cat Creek, upstream	X	X	X	X	X			
Cat Creek, downstream	X	X					X	X
Bull	X	X	X	X	X	X		
CBOD 20								
McCombs								
Highway 88								
Gordon								
Froman								
Flint Rd.								
Cat Creek, upstream				X	X			
Cat Creek, downstream	X	X					X	X
Bull						X		
CBOD 5								
McCombs								
Highway 88								
Gordon								
Froman								

	Spavinaw	**Gordon**	**McCombs**	**Flint Rd.**	**Froman**	**Cat Creek, Downstream**	**Cat Creek, Upstream**	**Highway 88**
Flint Rd.								
Cat Creek, upstream								
Cat Creek, downstream	X	X		X				
Bull								
Ortho-phosphate								
McCombs								
Highway 88								
Gordon								
Froman								X
Flint Rd.								
Cat Creek, upstream			X	X	X			
Cat Creek, downstream	X	X		X			X	X
Bull		X	X	X	X			

Table 8: Results of the Tukey's multiple comparisons on the ranked water quality data. Statistically significant differences are denoted by an "X."

Nutrient concentrations from high flow events were similar or lower than concentrations from low flow events (Tables 9 and 10). Dog Creek downstream of the waste water treatment plant exhibited much higher concentrations of both total phosphorus and nitrate when compared to the other sites (Figures 40-41). This trend was also observed with the total phosphorus and nitrate values seen at low flow (Figures 18 and 22). Rainwater diluted the amounts of total phosphorous, nitrate, nitrite, and TKN present in the water. This dilution during the rain events indicates that there is not a large non-point source component adding nutrients to the streams. Mean total phosphorus for low flow was one to five times greater than high flow concentrations. Mean total nitrogen for low flow was one to three times greater than high flow values.

Other changes were seen in low flow to high flow comparisons of alkalinity as well as chloride (Table 9). Values were lower during high flow events due to dilution. Sulfate and total hardness exhibited higher values in Cat Creek upstream of the WWTP indicating a possible NPS of sulfate being washed into the stream, possibly from areas in Claremore (Table 9). The rest of the sites experienced dilution of sulfate and alkalinity from the rainfall (Table 9). Changes can also be seen in differences in $CBOD_5$ and $CBOD_{20}$ values between low flow and high flow events (Table 10). Less oxygen was required for degradation of organic material during high flow events for the more easily metabolized $CBOD_5$, while more oxygen was used for $CBOD_{20}$. The increase seen in values for $CBOD_{20}$ indicates that some source of BOD is washing in from the land surface during high flow events.

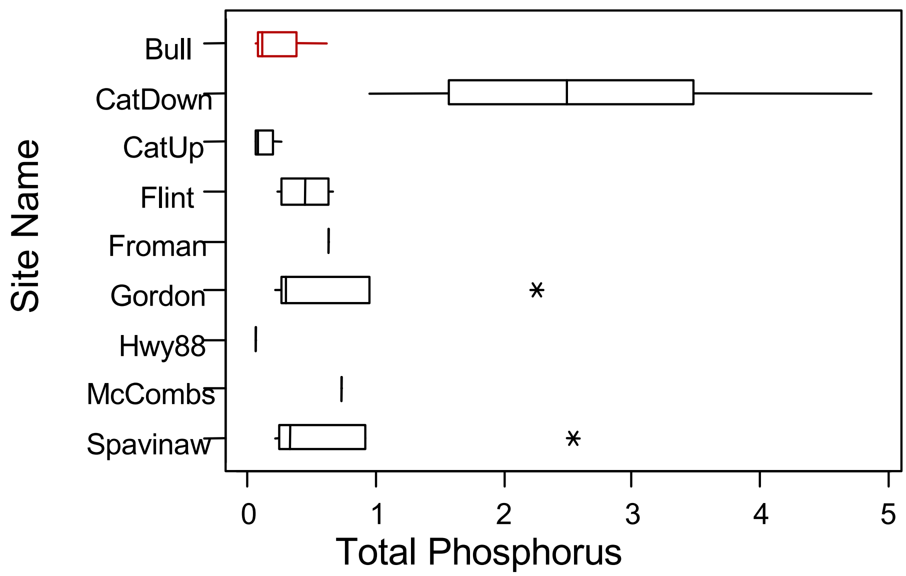

Figure 40: Total phosphorus concentrations from high flow events.

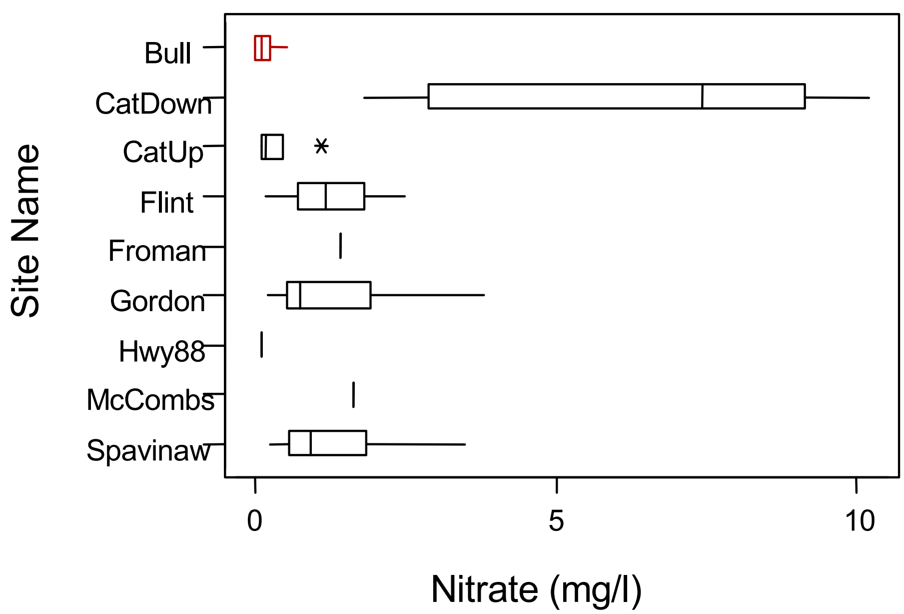

Figure 41: Nitrate concentrations from high flow events.

Stream	DO (mg/l)	Cond (µS/cm)	pH	Temp C	Discharge (cfs)	Alk (mg/l)	Turb (NTU)	TSS (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Hard (mg/l)
Cat Creek, Upstream											
Mean	7.95	495.20	7.71	12.92	6.78	128.00	31.70	41.80	123.70	14.48	219.80
Median	8.17	483.80	7.69	12.70	6.23	139.50	17.70	22.00	123.50	14.20	227.00
High	9.41	610.00	7.92	16.90	18.47	156.00	107.00	121.00	166.00	20.00	280.00
Low	6.36	358.00	7.55	9.60	0.87	62.00	9.90	19.00	88.00	9.50	130.00
Std	1.27	102.90	0.13	2.60	6.31	35.20	37.30	44.30	27.00	3.69	49.70
N	6	6	6	5	6	6	6	5	6	6	6
Cat Creek, Downstream											
Mean	5.96	587.40	7.65	15.17	9.80	112.67	18.50	26.20	107.70	33.28	161.20
Median	6.32	607.00	7.67	14.70	5.16	107.50	15.40	24.00	102.50	36.50	173.00
High	7.70	710.00	7.94	22.80	25.62	148.00	30.70	43.00	125.00	47.00	183.00
Low	4.02	431.60	7.16	10.50	3.25	102.00	8.40	12.00	93.20	18.40	108.00
Std	1.59	108.8	0.27	4.39	10.59	17.57	9.70	12.11	13.46	11.59	28.60
N	6	6	6	6	4	6	6	5	6	6	6
Dog Creek, Flint Road											
Mean	8.50	256.20	7.62	15.17	55.5	61.00	42.60	41.20	49.03	12.20	101.62
Median	8.51	242.60	7.69	13.95	51.9	63.00	28.10	36.00	53.90	13.00	108.00
High	9.92	320.00	7.80	23.00	113.8	72.00	134.00	94.00	70.50	17.00	120.00
Low	7.06	212.00	7.28	10.00	26.4	45.00	15.60	12.00	13.80	6.70	77.70
Std	1.29	45.40	0.19	4.54	35.6	9.08	45.40	31.60	20.36	3.90	18.30
N	6	6	6	6	5	6	6	5	6	6	6
Dog Creek, Gordon Property											
Mean	8.52	299.50	7.66	15.50	*	64.17	50.40	36.60	55.60	15.82	105.80
Median	8.80	254.50	7.65	13.90	*	58.00	31.50	35.00	57.70	10.50	105.60
High	9.74	547.00	7.89	23.60	*	98.00	156.00	66.00	90.00	45.00	142.00
Low	6.88	216.00	7.47	11.20	*	45.00	16.70	10.00	14.80	7.10	71.80

Stream	DO (mg/l)	Cond (µS/cm)	pH	Temp C	Discharge (cfs)	Alk (mg/l)	Turb (NTU)	TSS (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Hard (mg/l)
Std	1.05	123.60	0.14	4.67	*	19.24	52.20	20.45	25.70	14.53	27.40
N	6	6	6	6	0	6	6	5	6	6	6
Dog Creek, Spavinaw Flowline											
Mean	8.51	297.80	7.62	15.30	84.4	66.67	96.60	47.60	52.72	16.37	102.27
Median	8.90	259.70	7.61	13.80	81.0	60.00	34.50	35.00	53.15	12.00	106.00
High	10.28	521.00	7.81	23.50	137.9	95.00	329.00	113.00	89.50	45.00	136.00
Low	6.80	234.00	7.38	11.00	35.6	47.00	15.80	24.00	22.20	7.20	74.60
Std	1.44	110.40	0.15	4.61	46.5	18.04	123.40	37.00	22.24	14.24	21.65
N	6	6	6	6	6	6	6	5	6	6	6
Bull Creek											
Mean	9.23	345.00	7.50	17.38	23.2	41.17	67.50	71.60	106.60	15.05	120.80
Median	8.73	388.00	7.55	15.60	5.5	39.50	37.30	34.00	112.50	14.20	126.00
High	11.20	492.00	7.62	24.80	75.8	70.00	189.00	224.00	152.00	26.00	192.00
Low	7.25	151.00	7.24	13.10	1.1	19.00	24.60	16.00	21.70	8.00	57.00
Std	1.59	134.10	0.14	4.88	31.8	17.50	63.90	86.90	48.70	6.42	52.20
N	6	6	6	6	5	6	6	5	6	6	6

Table 9: High flow parameter measurements.

Stream	OrthoP (mg/l)	TotalP (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Fecal Coliform (mg/l)	NH_3 (mg/l)	Chl-a (mg/l)	CBOD5 (mg/l)	CBOD20 (mg/l)
Cat Creek, Upstream										
Mean	0.037	0.12	0.343	0.022	0.838	3580	0.093	13.20	3.58	8.57
Median	0.030	0.08	0.200	0.024	0.790	265	0.094	1.00	2.75	9.70
High	0.093	0.27	1.100	0.050	1.320	20000	0.180	74.70	8.20	13.10
Low	0.005	0.06	0.125	0.004	0.360	50	0.008	0.10	1.00	2.90
Std	0.032	0.09	0.376	0.017	0.353	8049	0.068	30.10	2.77	4.71

Stream	OrthoP (mg/l)	TotalP (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Fecal Coliform (mg/l)	NH_3 (mg/l)	Chl-a (mg/l)	CBOD5 (mg/l)	CBOD20 (mg/l)
N	6	6	6	6	5	6	6	6	6	6
Cat Creek, Downstream										
Mean	2.093	2.60	6.480	0.331	3.434	6900	1.370	15.30	8.13	23.65
Median	1.930	2.49	7.430	0.309	3.350	4750	0.770	2.30	7.75	25.30
High	4.290	4.87	10.200	0.638	6.160	20000	4.900	74.70	13.90	32.00
Low	0.799	0.95	1.820	0.150	1.830	400	0.180	1.40	3.70	7.80
Std	1.271	1.32	3.300	0.186	1.764	7029	1.775	29.20	4.42	8.70
N	6	6	6	6	5	6	6	6	6	6
Dog Creek, Flint Road										
Mean	0.295	0.45	1.265	0.076	1.264	1230	0.312	8.69	3.85	7.97
Median	0.277	0.46	1.190	0.084	1.090	750	0.222	5.98	3.25	9.05
High	0.551	0.67	2.510	0.102	2.120	4500	0.910	26.70	7.00	11.60
Low	0.115	0.23	0.179	0.039	0.890	200	0.098	1.20	1.50	3.10
Std	0.179	0.19	0.775	0.027	0.510	1627	0.300	9.52	2.15	3.56
N	6	6	6	6	5	6	6	6	6	6
Dog Creek, Gordon Property										
Mean	0.445	0.65	1.255	0.081	1.412	304	0.529	7.03	2.93	7.67
Median	0.141	0.30	0.765	0.058	0.940	100	0.128	6.53	3.35	8.25
High	1.900	2.26	3.820	0.194	3.600	1000	2.640	13.00	5.10	12.30
Low	0.015	0.22	0.240	0.033	0.760	50	0.030	3.00	1.00	3.20
Std	0.722	0.80	1.303	0.060	1.227	405	1.035	3.56	1.54	3.67
N	6	6	6	6	5	6	6	6	6	6
Dog Creek, Spavinaw Flowline										
Mean	0.507	0.68	1.283	0.080	1.562	543	0.527	6.27	2.87	8.85
Median	0.202	0.34	0.950	0.066	0.950	330	0.132	6.51	3.05	9.85
High	2.160	2.54	3.490	0.193	4.110	2000	2.680	11.90	5.20	13.80

Stream	OrthoP (mg/l)	TotalP (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	TKN (mg/l)	Fecal Coliform (mg/l)	NH_3 (mg/l)	Chl-a (mg/l)	CBOD5 (mg/l)	CBOD20 (mg/l)
Low	0.014	0.22	0.280	0.033	0.740	50	0.025	0.20	1.00	2.90
Std	0.818	0.91	1.135	0.058	1.430	735	1.056	3.87	1.58	4.65
N	6	6	6	6	5	6	6	6	6	6
Bull Creek										
Mean	0.035	0.22	0.168	0.020	1.216	16458	0.117	4.30	2.68	7.67
Median	0.029	0.11	0.138	0.009	1.060	1950	0.065	1.95	2.70	9.75
High	0.089	0.62	0.540	0.070	2.000	90000	0.310	18.10	4.90	10.70
Low	0.003	0.07	0.005	0.004	0.710	50	0.025	0.05	1.00	1.00
Std	0.033	0.22	0.197	0.026	0.499	36064	0.117	6.91	1.33	3.90
N	6	6	6	6	5	6	6	6	6	6

Table 10: High flow parameter measurements.

The diurnal dissolved oxygen study indicated little change through the cycle (Figures 42-46). The change in DO for all the sites averaged 0.66 mg/l. The site exhibiting the largest change was Dog Creek at Flint Road with an average change of 1.08 mg/l (Figure 43). Dog Creek at the Spavinaw flowline showed the least change in DO at 0.28 mg/l (Figure 46). This may be due to the low water crossing which re-aerates and maintains a more constant DO.

The study sites appear to be dominated by heterotrophs with little active algae operating. There is more non-photosynthetic respiration occurring than re-aeration. As mentioned previously, the sinuous nature of Dog Creek in addition to the dense canopy cover impedes the growth of algae and does not allow re-aeration to occur through eolian processes. With a lack of aeration, Dog Creek is able to take on less sewage than a creek with less sinuosity and less canopy cover.

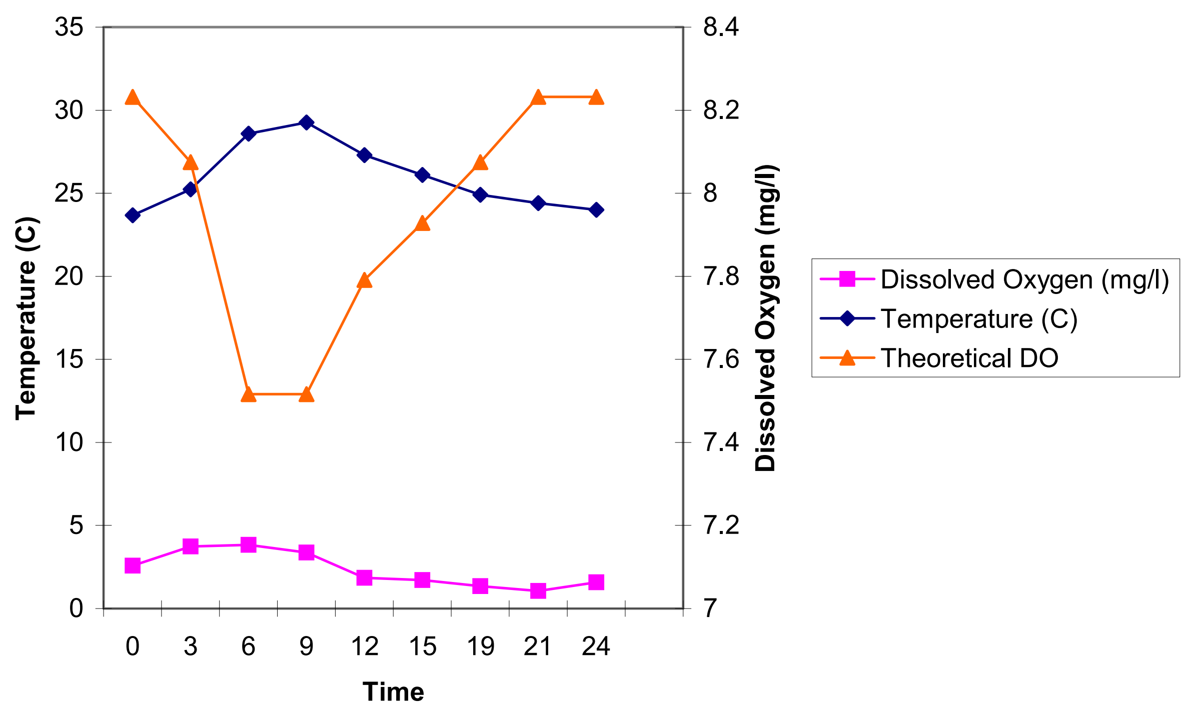

Figure 42: Diurnal dissolved oxygen for Cat Creek, downstream of the WWTP, September 2000.

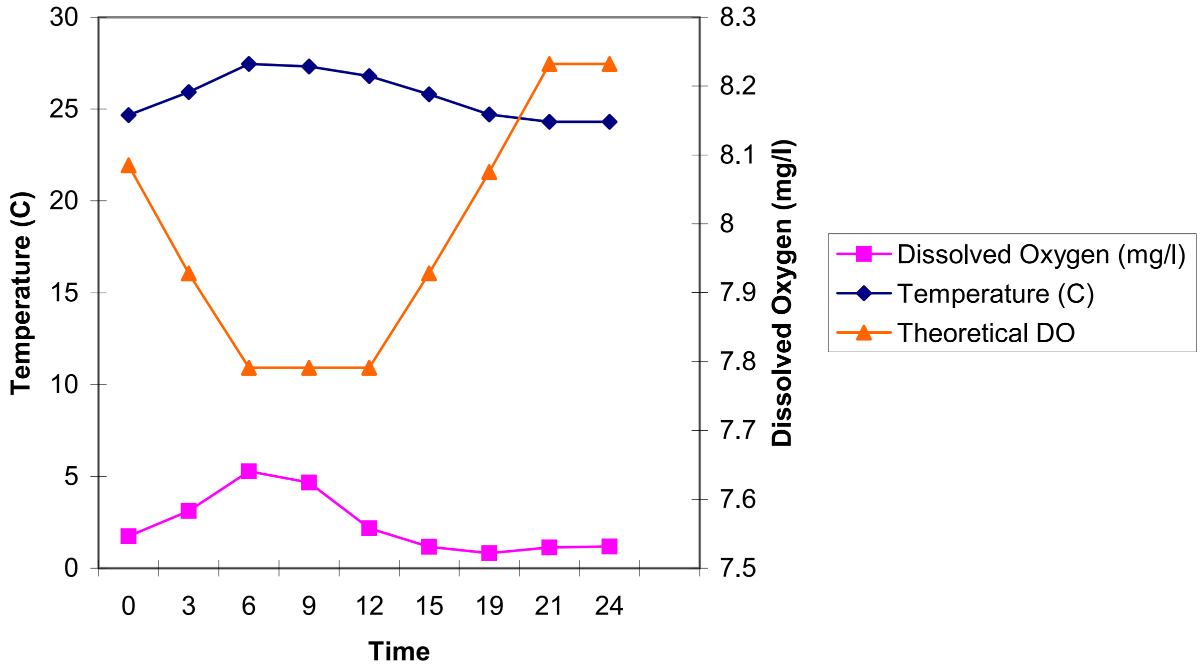

Figure 43: Diurnal dissolved oxygen for Dog Creek at Flint Road, September 2000.

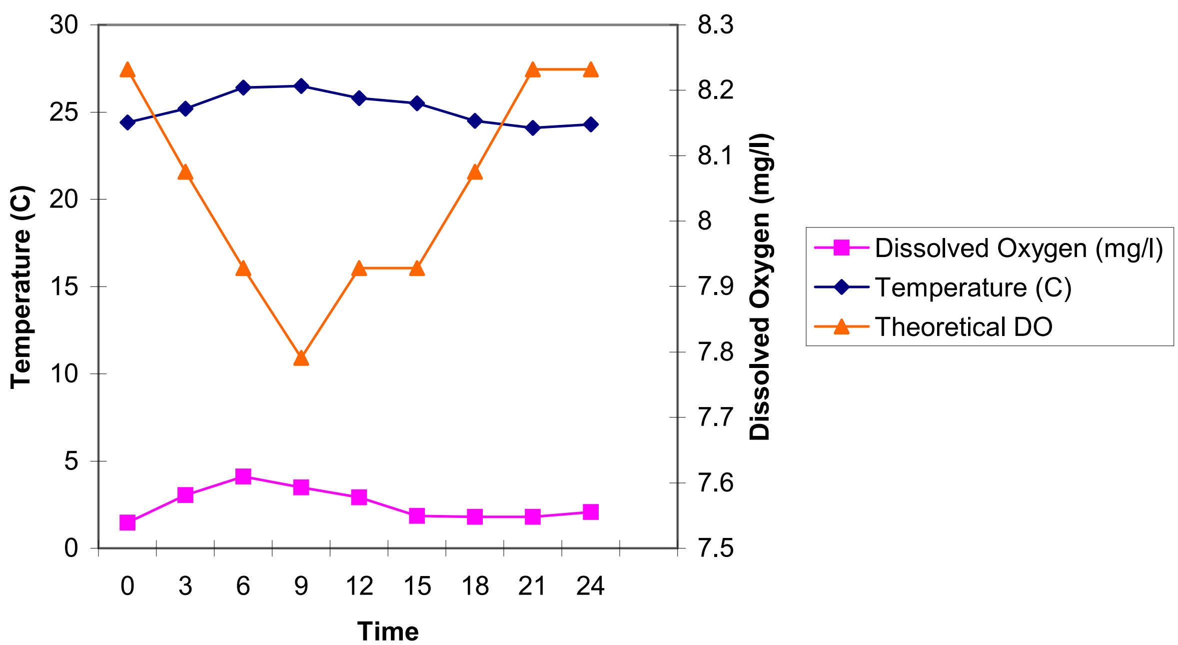

Figure 44: Diurnal dissolved oxygen for Dog Creek at McComb's property, September 2000.

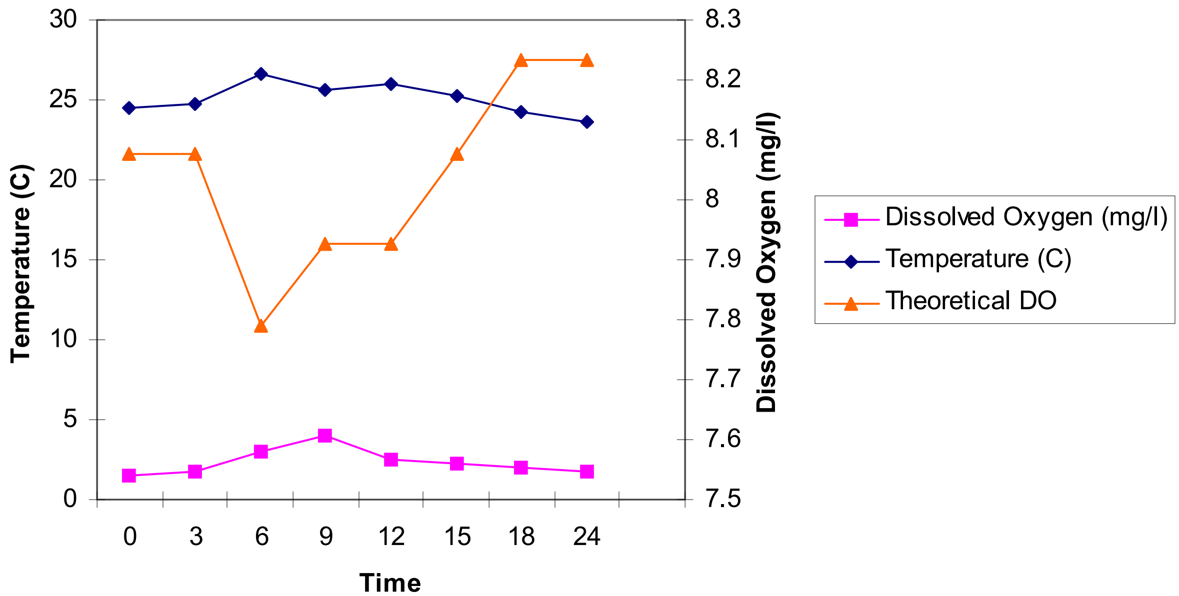

Figure 45: Diurnal dissolved oxygen for Dog Creek at Gordon's property, September 2000.

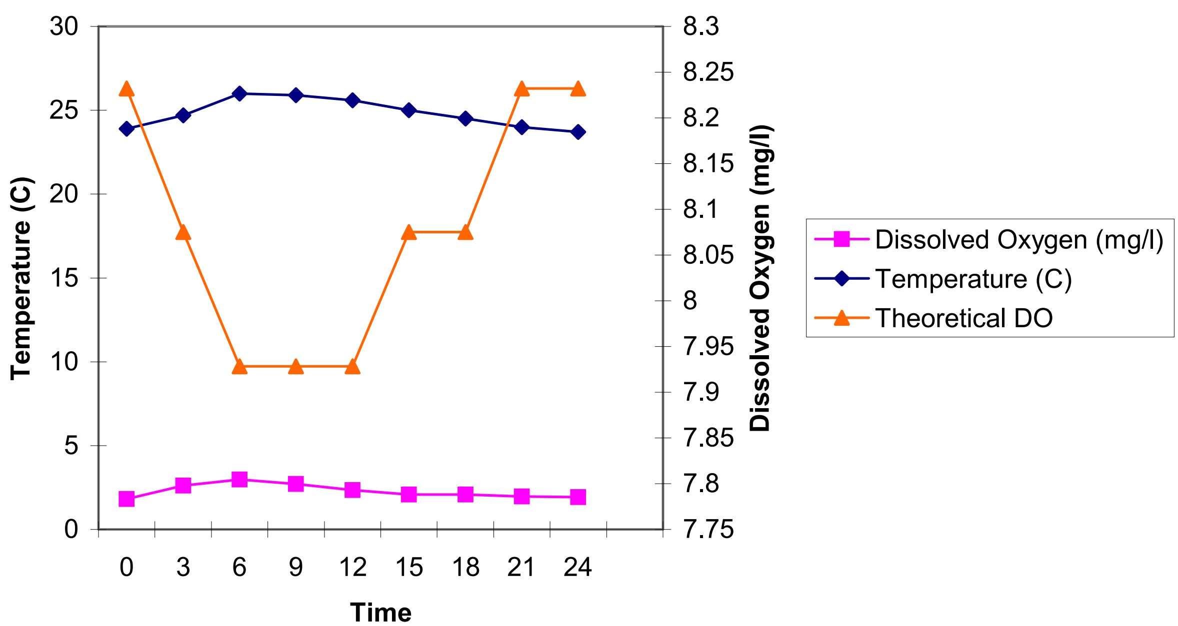

Figure 46: Diurnal dissolved oxygen for Dog Creek at the Spavinaw flowline, September 2000.

3.2 BIOLOGICAL MONITORING

3.2.1 Instream Habitat Assessment

The instream habitats of all the streams either approached or surpassed the conditions found in the reference streams (Table 11). The total score of Bull Creek was 77.9. The scores for the study sites ranged from 77.3 to 96.5. Only two sites (Cat Creek upstream of the WWTP, and Dog Creek at McCombs property) fell below the reference condition, both by less than 0.6. Based on these results, the organisms living in and around the Dog Creek watershed should not be limited by habitat. Water quality issues could account for differences between reference and study streams. One should note that as Panther Creek had no flow and could not receive a final assessment, the reference condition relies completely on Bull Creek; however, the habitat scores for all the study sites were relatively high.

The differences accounting for the increased scores of the study sites as compared to the reference site include larger metric scores for the study sites in the areas of canopy cover, channel alteration, and channel sinuosity. Canopy cover was classified as optimal (16-20) in the study streams, while the reference condition was suboptimal. Lower scores for channel alteration indicate less optimal habitat, because more alterations disrupt the natural habitat available for organisms. The scores of the study sites exceeded that of the reference site which was rated poor (0-5). Although the study sites received higher channel sinuosity scores than the reference site, both study and reference sites were rated ‘poor’ indicating less possibility for diverse habitat and fauna.

Study sites received lower metric scores in the category of pool bottom substrate. The study sites’ metrics for this component rated in the poor range of 0-5, indicating that they would support fewer types of organisms than would the reference condition. The reference condition’s score rated suboptimal (11-15).

Site Name	Instream Cover	Pool Bottom Substrate	Pool Variability	Canopy Cover	Rocky Runs & Riffles	Base Flow	Channel Alteration	Channel Sinuosity	Bank Stability	Bank Vegetative Stability	Dominant Vegetation	Total
Dog Creek, Highway 88	4.3	5.8	13.4	18.6	4.1	13.3	7.7	0.8	7.6	2.8	9.2	**87.6**
Dog Creek, Flint Road	2.9	2.5	14.6	18.7	0	19.8	12.3	1.6	7.1	2.1	8.9	**90.5**
Cat Creek, Downstream	1.2	1.6	20	17.3	0	11.7	13.7	5.4	5.9	1.4	6.8	**85**
Dog Creek, Spavinaw Flowline	4.1	2.1	19.4	19.1	0	14.6	15.1	3.2	6.7	3.3	8.9	**96.5**
Cat Creek, Upstream	2.2	4.9	11.3	16.4	0	12.1	12.3	2.4	3.9	2	7.8	**75.3**
Dog Creek, Gordon Property	1.6	1.3	14	19.3	0	15.1	16.5	2.4	4.9	2.4	8.4	**85.9**
Dog Creek, McCombs Property	1.8	1.8	6.1	16.1	5.9	16.8	9.9	1.6	6.3	2.5	6.6	**75.4**
Dog Creek, Froman Property	1.3	2.4	14.6	18.6	0	15.9	16.5	6.1	10	2.6	6.3	**94.3**
Bull Creek*	2.8	10.9	17.9	13.3	0	16.5	1.4	0.8	3.8	2	8.5	**77.9**

Table 11: Instream habitat assessment metric scores for study and reference sites.
Panther Creek reference had no flow, so final assessment could not be calculated. (*Reference site).

3.2.2 Fish

Reference streams had a higher IBI score than study streams (Table 12). The mean IBI score for the reference streams was 40, while the mean IBI score of the study streams registered at 24.4. The range of scores for the study sites was 14 to 40. All study sites downstream of the WWTP possessed a mean of 23.5, while study sites upstream of the WWTP comprised a mean of 32.0.

The only study site that achieved the reference conditions was Dog Creek at the Spavinaw flowline. It registered an IBI score of 40 which exceeds the reference condition by 1.7%. The remaining study sites ranged from 35.6%-71.2% of the reference.

Study site conditions matched reference conditions in the areas of proportion of tolerant species, proportion of omnivores, and the proportion of insectivorous cyprinids. The reference stream, Panther Creek, and the study stream at the Spavinaw flowline each yielded one round bodied sucker, while none were caught at the remaining sites. All study sites except Cat Creek downstream of the WWTP and Dog Creek at Flint Road represented reference conditions in the total number of species.

With the exception of Dog Creek at the Spavinaw flowline, the condition of the study sites was poorer than the reference condition in both the number of intolerant species and the number of darter species. There was more variability in the proportion of top carnivores seen in study sites versus reference conditions. Dog Creek at the Spavinaw flowline exhibited reference conditions for proportion of top carnivores, while Dog Creek at Flint Road yielded none. All other study sites contained top carnivore proportions of 2.5 to 5.2. Lastly, the reference condition supported more individuals than did the study sites. The number of fish captured at each site increased with distance from the WWTP (Figure 47).

Once the IBI scores have been calculated, they can be used to determine the quality of the fish population. General characteristics can be attributed to the individual study sites based on the relation of the study site's IBI score to that of the reference condition. An integrity class has been established to describe streams based on the percent comparison to the reference (Table 13).

Site	Number Intolerant Individuals			Number Individuals			Number Round Bodied Suckers			Number Darter Species			Total Number Species			Number Sunfish Species			Percent Tolerant		Percent Omni-vores		Percent Insectivorous Cyprinids		Percent Top Carni-vores		IBI Score	
	Number	Percent Reference	Score	Number	Percent Reference	Score	Number	Percent Reference	Score	Number	Percent Reference	Score	Number	Percent Reference	Score	Number	Percent Reference	Score	Number	Score	Number	Score	Number	Score	Number	Score	Number	Percent Reference
Cat Creek, upstream	0	0	1	213	40.8	3	0	0	1	0	0	1	14	65.6	5	6	78.3	5	33.8	1	2.3	5	0.9	1	5.2	3	26	71.2
Cat Creek, downstream	0	0	1	40	7.7	1	0	0	1	0	0	1	2	9.4	1	1	13.0	1	95.0	1	0	5	0	1	5.0	3	16	40.7
Dog Creek, Flint Road	0	0	1	66	12.6	1	0	0	1	0	0	1	5	23.4	1	1	13.0	1	95.5	1	1.5	5	0	1	0	1	14	35.6
Dog Creek, Gordon's property	0	0	1	159	30.4	3	0	0	1	0	0	1	13	60.9	5	4	52.2	3	36.5	1	7.5	5	0	1	2.5	3	24	61.0
Dog Creek, Spavinaw flowline	2	119.8	5	202	38.7	3	1	300	5	3	180.0	5	21	98.4	5	6	78.3	5	34.7	1	14.9	5	0	1	8.4	5	40	101.7
Dog Creek, Highway 88*	1	59.9	5	349	66.8	5	0	0	1	1	71.4	5	19	103.3	5	7	106.1	5	14.3	1	3.4	5	0.6	1	7.5	5	38	96.6
Bull Creek*	1	59.9	5	753	167.4	5	0	0	1	2	142.9	5	25	135.9	5	8	121.2	5	16.5	1	12.1	5	0	1	8.9	5	38	96.6
Panther Creek*	3	180.6	5	465	103.4	5	1	250	5	2	142.9	5	20	108.7	5	8	121.2	5	22.8	1	1.3	5	0	1	15.5	5	42	106.8

Table 12: IBI scores of age 1+ fish for study and reference collections.
*Reference sites.

% Comparison to the Reference Score	Integrity Class	Characteristics
>97%	Excellent	Comparable to pristine conditions, exceptional species assemblage
80 - 87%	Good	Decreased species richness, especially intolerant species
67 - 73%	Fair	Intolerant and sensitive species absent
47 - 57%	Poor	Top carnivores and many expected species absent or rare; omnivores and tolerant species dominant
26 - 37%	Very Poor	Few species and individuals present; tolerant species dominant; diseased fish frequent

Table 13: Index score interpretation.

The quality of the fish populations was compared to the suggested index score interpretation established by the EPA RBP (Plafkin et al., 1989). Scores that fell between the ranges were classified in the closest scoring group (Table 14). The IBI scores of the reference streams were somewhat limited by stream order and other geomorphological factors; the scores could conceivably have been much higher had they been more similar to Dog Creek. The fish population at Dog Creek at the Spavinaw flowline compared favorably to the reference condition. It received an excellent rating. Cat Creek upstream of the WWTP was classified as fair when compared to the reference value. While Dog Creek at Gordon's property rated 'poor', Cat Creek downstream of the WWTP and Dog Creek at Flint Road both exhibited very poor fish assemblages.

Site	IBI Score	Percent Reference	Score Interpretation
Cat Creek, upstream	26	65	Fair
Cat Creek, downstream	16	40	Very Poor
Dog Creek, Flint Road	14	35	Very Poor
Dog Creek, Gordon's property	24	60	Poor
Dog Creek, Spavinaw flowline	40	100	Excellent

Table 14: IBI score summary.

To a point, the greater the habitat score, the greater the IBI expectations are for a particular stream. Improvements beyond the point where habitat is adequate for all of the fish that can potentially live in a given stream cause no additional increase in IBI. In this case, the habitat scores appear to warrant larger IBI scores. Determining whether a stream is either habitat deficient or has a water quality impairment can be evaluated by plotting the habitat score versus the IBI score (Figure 48). A best-fit line can be drawn between the reference sites as these sites differ from the study sites only in the absence of the WWTP. Had any site's score fallen between the 95% confidence interval, it could have been classified as habitat limited. Study site scores falling below the 95% confidence interval are probably water quality limited (Porter et al., 2000). None of the study sites were determined to be habitat limited, but 80% of the sites were classified as water quality limited. The only study site not water quality limited was Dog Creek at the Spavinaw flowline.

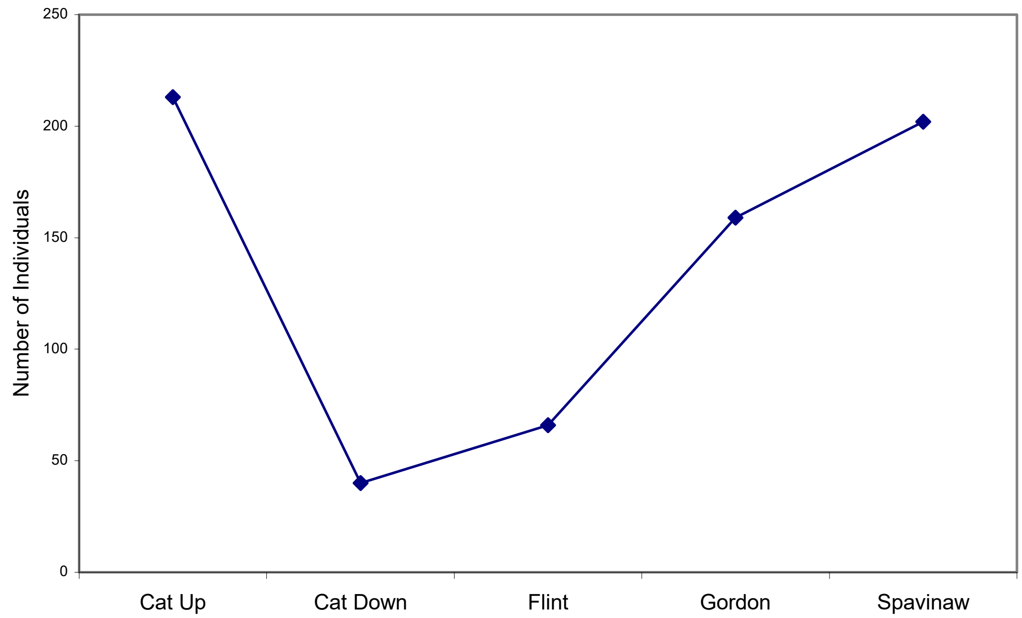

Figure 47: Number of individual fish captured at each study site in 1999.

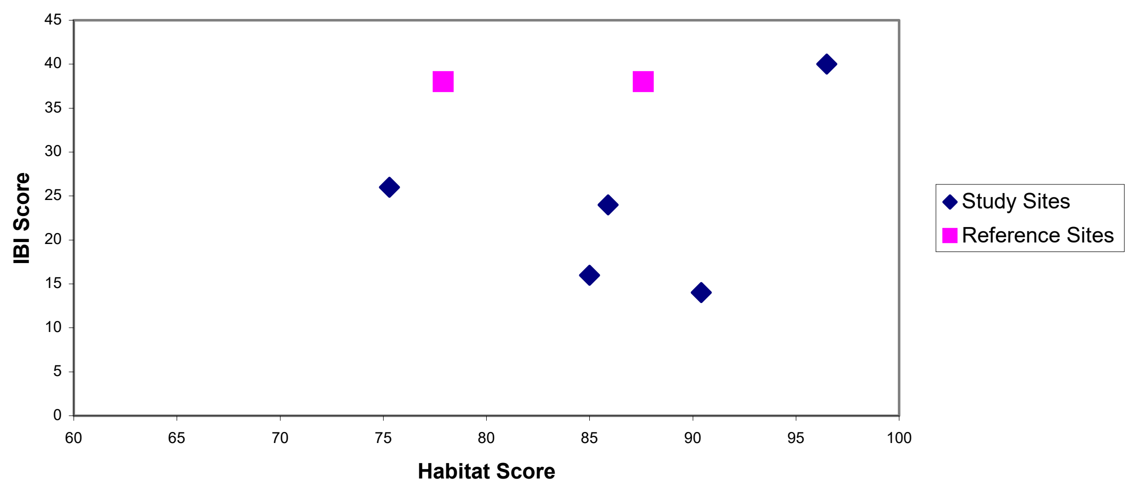

Figure 48: Habitat score versus IBI score for study and reference streams.

3.2.3 Macroinvertebrates

Seven attributes were used to score (Table 15) the condition of the benthic invertebrate community.

Metrics	***6***	***4***	***2***	***0***
Taxa Richness**	>80	60-80	40-60	<40
Modified HBI* (**)	>85	70-85	50-70	<50
EPT/EPT + Chironomini**	>75	50-75	25-50	<25
EPT/Total***	>30	30 & >20	<=20 & >10	<=10
EPT Taxa**	>90	80-90	70-80	<70
Dominants to Total**	<20	20-30	30-40	>40
Shannon-Weaver***	>=3.5	<3.5&>=2.5	<2.5&>=1.5	<1.5

***Modified HBI Using North Carolina Tolerance Values**
****RBP for Use in Streams and Rivers, 1989**
*****Modified by OCC**

Table 15: Modified biological condition scoring criteria.

Because riffle samples tend to produce the most reliable results and generally reflect the community adequately (Plafkin et al., 1989), only riffle samples were analyzed to investigate macroinvertebrate community impact. Summer macroinvertebrates were collected two times and used to derive metric scores for each study site except Cat Creek upstream of the WWTP. Metrics were derived and analyzed using the same methodology for winter samples described above. Once calculated, the metric scores of the study streams were compared to reference conditions to establish the condition of the macroinvertebrate populations. The assessment criteria can be seen in Table 16. The impairment categories listed are not true impairment categories; the reference condition used for this study is derived from streams that are not pristine. By using streams that may be slightly to moderately polluted by agriculture or rural homeowners to calculate the reference condition, we are, in effect, lowering the bar and ruling out any pollution caused by agriculture or rural homeowners. This allows us to determine whether or not the study sites are impacted beyond the level of impairment caused by non-point source pollution typical to the area.

As there was no flow at any of the established reference streams, the alternate reference streams used were Rabb Creek, Adams Creek at Oak Grove Road, Lightning Creek, and a different site on Bull Creek. Results may be found below (Table 17).

Two winter samples were collected for all reference and study sites, except Cat Creek, downstream of the WWTP and Cat Creek, upstream of the WWTP, which were each represented by only one collection. Average annual reference metrics were derived from pooled reference data. Conditions were compared to the reference stream calculations to tabulate the final metric score (Table 18).

% Comparison to the Reference Score	Biological Condition Category
>83%	Non-impaired
54 - 79%	Slightly impaired
21 - 50%	Moderately impaired
<17%	Severely impaired

Table 16: Scoring criteria to assess macroinvertebrate condition.

Similar results were observed for both winter and summer collections. In both cases, reference sites exhibited higher total scores than study sites. The metrics are lowest immediately downstream of the WWTP and increase with increasing distance from the WWTP. The areas accounting for most of the difference were the percent EPT of EPT and Chironomids, the percent of EPT of the total taxa, and the number of EPT taxa. As there were virtually no EPT present in the study streams, this difference is not surprising.

No difference existed between study streams and reference streams for both years in the modified Hilsenhoff biotic index. The percent of dominant taxa in the study streams was equivalent to that of the reference streams except in the winter of 1999. Unlike the reference sites, the study sites were not as dominated by specific taxa. In general, Cat Creek downstream of the WWTP, most differed from the other sites; this was due to low numbers of taxa represented and few individuals from the taxa that were present. The study sites were most similar to reference site conditions in the winter of 1999. All streams were considered slightly impaired when compared to reference conditions; however, in winter 2000, all study sites except Dog Creek at the Spavinaw flowline were moderately impaired. Dog Creek at the Spavinaw flowline, designated as slightly impaired, reached 60% of the reference streams. The only site to achieve more than fifty percent of the reference condition in the summer sampling efforts was Dog Creek at Highway 88, reaching 64.3% of the reference in the summer of 2000, indicating it was slightly impaired. In both summers 1999 and 2000, all other study streams fell into the moderately impaired class in comparison to the reference.

Summer 1999	**Reference**		**Cat Creek, Downstream**		**Dog Creek, Flint Road**		**Dog Creek, Highway 88**		**Dog Creek, Spavinaw Flowline**	
Description	Average	Score	Average	Score	Average	Score	Average	Score	Average	Score
Number of taxa	9	6	3	0	10	6	9	6	7	6
Modified Hilsenhoff biotic index	4.13	6	9.52	6	8.84	6	7.35	6	6.79	6
EPT/EPT + Chironomidae	0.8	6	0	0	0	0	0	0	0	0
EPT/total	0.29	4	0	0	0	0	0	0	0	0
EPT taxa	3	6	0	0	0	0	0	0	0	0
Dominants/total	0.47	0	0.76	0	0.44	0	0.52	0	0.45	0
Shannon-Weaver diversity index	2.27	2	1.03	0	2.34	2	2.15	2	2.15	2
Total		30	*Moderately*	6	*Moderately*	14	*Moderately*	14	*Moderately*	14
Percent of Reference		100	*Impaired*	20	*Impaired*	46.7	*Impaired*	46.7	*Impaired*	46.7
Summer 2000										
Number of taxa	11	6	3	0	9	4	15	6	7	6
Modified Hilsenhoff biotic index	6.33	6	8.95	6	9.06	6	6.64	6	6.79	6
EPT/EPT + Chironomidae	0.29	6	0	0	0.05	0	0.03	0	0	0
EPT/total	0.14	2	0	0	0.02	0	0.03	0	0	0
EPT taxa	2	6	0	0	1	0	4	4	0	0
Dominants/total	0.60	0	0.52	0	0.52	0	0.42	0	0.45	0
Shannon-Weaver diversity index	2.00	2	1.06	0	2.02	2	2.68	2	2.15	2
Total		28	*Moderately*	6	*Moderately*	12	*Slightly*	18	*Moderately*	14
Percent of Reference		100	*Impaired*	21.4	*Impaired*	42.9	*Impaired*	64.3	*Impaired*	50

Table 17: Summer 1999 and 2000 macroinvertebrate scores for reference and study streams.

Winter 1999	**Reference**		**Cat Creek, Downstream**		**Dog Creek, Flint Road**		**Dog Creek, Hwy 88**		**Dog Creek, Spavinaw Flowline**		**Cat Creek, Upstream**	
Description	Average	Score	No Collection		Average	Score	Average	Score	Average	Score	No Collection	
Number of taxa	13	6			14	6	16	6	10	4		
Modified Hilsenhoff biotic index	5.91	6			7.15	6	6.75	6	7.17	6		
EPT/EPT + Chironomidae	0.19	6			0	0	0.03	0	0	0		
EPT/total	0.16	2			0	0	0.01	0	0	0		
EPT taxa	5	6			0	0	2	0	0	0		
Dominants/total	0.54	0			0.25	4	0.19	6	0.35	2		
Shannon-Weaver diversity index	2.17	2			2.83	4	3.09	4	2.58	4		
Total		28			*Slightly*	20	*Slightly*	22	*Slightly*	16		
Percent of Reference		100			*Impaired*	71.4	*Impaired*	78.6	*Impaired*	57.1		
Winter 2000												
Number of taxa	9	6	3	2	6	4	10	6	8	6	13	6
Modified Hilsenhoff biotic index	6.32	6	9.85	6	8.93	6	6.29	6	7.98	6	8.52	6
EPT/EPT + Chironomidae	0.38	6	0	0	0	0	0.01	0	0	0	0	0
EPT/total	0.26	4	0	0	0	0	0.01	0	0	0	0	0
EPT taxa	2	6	0	0	0	0	1	0	0	0	0	0
Dominants/total	0.59	0	0.93	0	0.61	0	0.71	0	0.34	2	0.54	0
Shannon-Weaver diversity index	1.83	2	0.44	0	1.77	2	1.56	2	2.47	4	2.38	2
Total		30	*Moderately*	8	*Moderately*	12	*Moderately*	14	*Slightly*	18	*Moderate*	14
Percent of Reference		100	*Impaired*	26.7	*Impaired*	40	*Impaired*	46.7	*Impaired*	60	*Impaired*	46.7

Table 18: Winter 1999 and 2000 macroinvertebrate scores for reference and study streams.

3.2.4 Periphyton

The winter 2000 chlorophyll-a content rose greatly from the area upstream of the WWTP to the area immediately downstream of the plant (Figure 49). While the increase was large, it does not indicate a level of nuisance algal conditions. The range of periphyton for the study sites was 0.52 to 5.47 mg/m^2, well below the nuisance levels of 50-200 mg/m^2. Bull Creek averaged 0.52 mg/m^2 and Cat Creek upstream of the plant averaged 0.59 mg/m^2. Both sites contained less chlorophyll-a than the study sites. The average of Cat Creek downstream of the plant was much higher at 5.47 mg/m^2, and that of Dog Creek at Flint Road was 5.30 mg/m^2. Dog Creek at Gordon's property averaged 2.73 mg/m^2, while Dog Creek at the Spavinaw flowline averaged 4.74 mg/m^2. The increase in chlorophyll-a seen from Dog Creek at Gordon's property to Dog Creek at the Spavinaw flowline indicates the presence of another source contributing to algae growth. The chlorophyll-a collected from the periphytometers mirrors the water column chlorophyll-a (Figure 39).

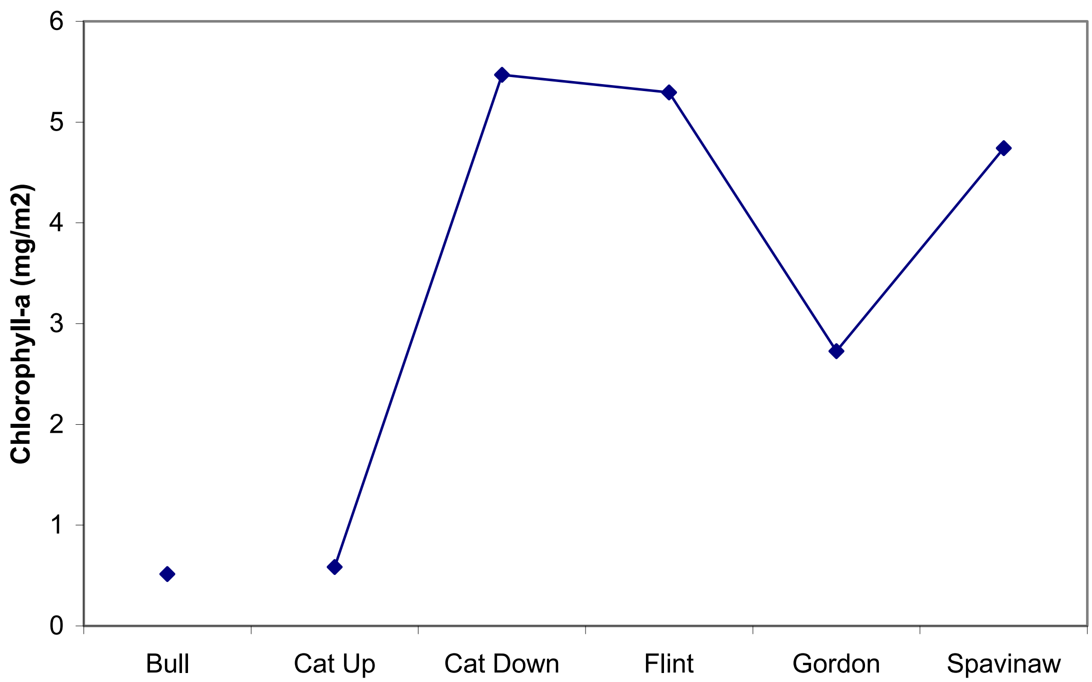

Figure 49: Chlorophyll-a (mg/m^2) content of the core sites progressing from upstream to downstream of the WWTP.

3.3 STREAM CHANNEL HYDRAULICS

The results of the stream classification survey of Dog Creek are presented in Table 19. The entrenchment ratio was determined to be greater than 2.2 (slightly entrenched), as there was an active floodplain adjacent to the channel. The width/depth ratio was determined to be 8.71. The slope and sinuosity were determined to be 0.00047 ft/ft and 1.62 respectively. The dominant bed material is silt/clay. The result is that Dog Creek may be classified as an "E6" stream.

Entrenchment Ratio	>2.2
Width/Depth Ratio	8.71
Slope, ft/ft	0.00047
Sinuosity	1.62
Dominant Bed Material	Silt/clay
Stream Type	E6

Table 19: Dog Creek stream classification.

The results of the stream classification survey indicate that it is unlikely that channel modifications can be undertaken to improve the re-aeration and dissolved oxygen conditions. Dog Creek is an "E6" channel that meanders over a relatively wide valley with very gentle relief. The only channel modifications that would improve the re-aeration in Dog Creek would be straightening and dredging. This however is not a viable option. Any improvements in water quality and aquatic habitat improvement that may result from channelization would be more than offset by the damage done to the ecosystem and bank stability as a direct result of channelization.

4.0 CONCLUSIONS

As severe dissolved oxygen stress in this watershed sparked the initial concern resulting in this project, plans were made to characterize chemical and biological parameters of the Cat Creek and Dog Creek watersheds relating to non-point sources and pre-BMP implementation condition. Additionally, an assessment of stream channel hydraulics that could be corrected to improve re-oxygenation and aquatic community habitat was completed. INCOG was to refine the wasteload allocation model based on the findings from the parameter characterizations and the stream channel hydraulics assessment. The OWRB was to generate an educational program to facilitate TMDL goals.

To determine which, if any, non-point source contributions significantly affect water quality in this watershed, land use within the watershed and water quality data was collected and analyzed. Forests, wetlands and pasture and hay are the top three land uses for the area. The water quality data indicated that the significant differences in areas like nutrient loadings were between sites that were upstream of the effluent and those immediately downstream of the plant. The study site at Cat Creek downstream of the plant received the highest amounts of total phosphorus, ortho-phosphate, nitrate, nitrite, ammonia, TKN, $CBOD_5$, $CBOD_{20}$, and chloride. As the values were obtained during low flow and the land use immediately around the site is forested land, it seems likely that the effluent itself is the source of the increased values as opposed to non-point source contributions.

The current condition of Cat Creek and Dog Creek was determined by the pre-BMP implementation fish and macroinvertebrate data, monthly low flow water quality data, periphyton data, stream habitat data, diurnal DO profiles, and hydrological data. The quantity and quality of the fish populations were poorest at the Cat Creek site downstream of the plant. Analysis of the fish and habitat data indicated that the habitat was not the factor limiting the fish population in Cat and Dog Creeks. Macroinvertebrate populations reflected the same trend seen in the fish population; the quality of the populations was lowest at the sites closest to the source of the effluent. The stream life is most likely limited by the quality of the water in these creeks. Low periphyton density at these sites is not surprising as little sunlight can penetrate the canopy and the sinuous nature of the creeks themselves limit the growth of algae. This allows heterotrophs to dominate these creeks which cuts down on the oxygen available to fish and macroinvertebrates. The diurnal dissolved oxygen data supports this conclusion. The study of the stream channel hydraulics indicated that it was not feasible to make corrections to improve re-oxygenation and aquatic community habitat. To improve Cat and Dog Creeks, amelioration of the water quality should be sought.

Concurrent biological habitat and water quality data from appropriate reference streams was obtained to determine achievable goals for water quality habitat and the aquatic community for Cat and Dog Creeks. The reference streams had larger and more varied populations of fish, in addition to a less impaired macroinvertebrate population. As nutrient levels in the reference streams were much lower than the study sites, water quality improvements in both Cat Creek and Dog Creek could be obtained by lowering the amount of nutrients added to these streams.

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