Physical, Chemical and Biological Assessment of

Stoner Creek Watershed

Flathead County, Montana

by

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Director: Dr. Vicki Watson

In 2001, the Flathead Basin Commission (FBC) was awarded a grant by the Bonneville Environmental Foundation to conduct an integrated assessment of the ecological integrity of the Stoner Creek watershed in Flathead County Montana. The project included evaluations of certain physical, biological and chemical conditions in and around Stoner Creek. These conditions were used as indicators of the "health" of the creek itself and the watershed as a whole. One purpose of the assessment was to aid in the development of a Comprehensive Watershed Restoration Action Plan that identifies areas of concern and recommends restoration or conservation actions to land owners and other concerned parties, specifically the Lakeside Community Council.

In advance of fieldwork, information on the land use, ownership, climate, geology, soils, vegetation, fish and wildlife in the watershed was compiled from existing sources. Fieldwork in support of the assessment was conducted from May through September 2002. The physical attributes assessed included stream morphology, discharge, temperature, total suspended solids, substrate composition and riparian condition. Benthic macroinvertebrates and algae were collected, analyzed and evaluated as part of the biological assessment. The chemical aspect of the study focused on nutrient levels; other water chemistry parameters were also analyzed.

The riparian zones along the majority of Stoner Creek were found to be in good to excellent condition. Grazing and/or logging has degraded a few reaches near the Lost Lake area, and residential impacts on riparian vegetation can be found in the developed areas of Lakeside. Macroinvertebrate community composition and abundance generally pointed to very high water and habitat quality. High phosphorus levels, likely a natural phenomenon, were measured throughout the watershed. Abundant available nutrients create the potential for nuisance algae blooms, especially when light levels are increased by removal of streamside vegetation.

Riparian buffers along Stoner Creek should be protected to provide stream shading and cooling, and to filter nutrients and sediment from runoff. Such buffers can help mitigate the impacts of expected residential growth. Expansion of the Lakeside Zoning District to include more of the Stoner Creek watershed would help guide development in order to minimize impacts to watershed resources.

Acknowledgements

This thesis was written for the Stoner Creek Watershed Group, the Lakeside Community Council and the current and future residents of Lakeside, MT. It is my hope that some of the information contained within will help them in their efforts to protect their watershed. A special thanks to local residents Robert Williams, who recorded daily staff gage measurements during the study, and Brett Kulina, who gave me a guided tour on my first visit to the watershed.

This project was funded by a grant from the Bonneville Environmental Foundation and administered through the Flathead Basin Commission. I would like to thank Todd Reeves, Mark Holston, Scott Payne and any others in these organizations who helped in the administration of the grant. Scott Mason deserves special acknowledgement as the coordinator of the outreach portion of this project. He has done a fine job keeping the Watershed Group posted on the project's progress, involving the local elementary school in the fun of watershed science, and giving me general encouragement and support. I look forward to helping him and the residents of Lakeside implement the recommendations of this study.

I would also like to thank my thesis committee members: Dr. Sarah Halvorson, Dr. Scott Woods and Dr. Vicki Watson. Your advice and suggestions have greatly improved the quality of this report. Dr. Watson's Watershed Health Clinic also supplied most of the sampling equipment used in the fieldwork portion of the study. Vicki has given me countless opportunities to enhance my educational experience throughout my graduate work and has shown me what it means to give oneself selflessly to a cause – for that I thank her immensely.

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CHAPTER 1: INTRODUCTION

Overview

The Flathead Basin is one of the fastest growing regions in Montana. The scenic beauty of Flathead Lake, framed by the majestic Mission and Salish Mountains, and the associated recreation opportunities are a large part of the area's appeal. Predictably, the high rate of development has threatened these very resources, especially water quality. There is a strong incentive to protect the special resources of the Flathead Basin, if not for their inherent ecological value or for aesthetic purposes, then for economic reasons. Developers and landowners alike realize that real estate prices are directly linked to the lake's clear water and healthy fisheries.

The situation in the town of Lakeside is fairly typical of what is occurring throughout much of Flathead County. Lakeside is a small but growing community located on the shores of Flathead Lake and extending up into the watershed of Stoner Creek. Encroaching development and water quality concerns in the lake have prompted a scientific assessment of the condition of the Stoner Creek watershed. This assessment will give stakeholders an idea of the current condition of watershed resources and potential areas of concern. The community can then decide on the appropriate steps to take in regards to watershed planning and conservation.

Study Purpose & Objectives

In 2001, the Flathead Basin Commission (FBC) was awarded a grant by the Bonneville Environmental Foundation to conduct an integrated assessment of the character and condition of the Stoner Creek watershed in Flathead County Montana (Figure 1). These conditions were intended to be used as indicators of the "health" of the creek itself and the watershed as a whole. Fieldwork in support of the assessment was conducted from May through September 2002. Specific objectives of this study included:

1) Measure, analyze and evaluate key physical, chemical and biological attributes of Stoner Creek
2) Identify areas of concern (spatial and functional) and likely causes of problems
3) Recommend conservation and/or restoration actions to address problem areas

Background & Significance

The Clean Water Act of 1972 requires that all water bodies that do not meet water quality standards required to support their designated beneficial uses be placed on a list of impaired water bodies. The list (called the 303(d) list, for section 303(d) of the Act) states which beneficial uses are not supported, which standards are being violated, and potential causes of the impairment. Water bodies on this impaired list must undergo a process that 1) identifies acceptable levels of pollutants or physical parameters that will not threaten beneficial uses and 2) recommends a course of action to meet these levels. This process is called Total Maximum Daily Load (TMDL) analysis. While Stoner Creek itself is not known to be impaired, it flows into Flathead Lake, which is on the 303(d) list. The EPA approved a final TMDL for Flathead Lake in January 2002 (MDEQ 2002).

The main source of impairment in Flathead Lake is excessive nutrient loading (Table 1) (MDEQ 2002). The nutrients nitrogen and phosphorus enter the lake from various sources and feed algae blooms, which can lower nighttime dissolved oxygen levels, stressing aquatic life. While algae are a natural component of aquatic ecosystems, artificially high levels of algae are considered “undesirable aquatic life” that can interfere with recreation and aesthetics, and degrade benthic habitat used by aquatic invertebrates and fish. Algal growth and biomass in Flathead Lake are believed to be phosphorus-limited (Rast *et al* 1986, MDHES 1984), therefore quantifying and reducing sources of phosphorus is considered essential to maintaining and improving the quality of Flathead Lake.

Past water quality sampling indicates that Stoner Creek has high concentrations of total phosphorus compared to other tributaries in the Flathead Basin (Stanford *et al* 1997, Ellis *et al* 1998, 2000, 2001). While Stoner Creek is one of the largest of the more than 40 perennial and intermittent streams that flow directly into Flathead Lake, it represents relatively little of the total discharge that enters the lake. Minor tributaries of the lake, overland runoff and precipitation account for only 5% of the lake's inflow (MDEQ 2002). Thus, the nutrient contribution of Stoner Creek to Flathead Lake is small and not rated a high priority in the lake's TMDL analysis. However, the creek's high concentration of phosphorus has the potential to create local impacts in the lake and therefore warrants further study. In addition, the Clean Water Act not only mandates clean up of impaired waters, it also mandates non-degradation of high quality waters.

Development pressure in the Lakeside area has also raised concerns about potential degradation of Stoner Creek and driven the need for an assessment of watershed conditions. For at least the last 40 years, Flathead County has experienced population growth many times the rate of statewide growth (Table 2). Growth since 1960 has been two to nine times higher than that of the state. The population of Flathead County has more than doubled in that time. Even in the relatively lean years of the 1980s, when Montana's population increased by only 1.6%, Flathead County saw an increase of 14% (US Department of Commerce 2002).

Population figures are not compiled officially for the unincorporated community of Lakeside, but recent growth has been at least as prolific as in Flathead County. Based on housing starts and utilities, development in the Lakeside area for the three years preceding 1995 was three times the countywide rate (Flathead County 1995). The highest shoreline population densities are found along the northwest portion of the lake (MDEQ 2002), where Lakeside is located. Census block data from the last decade show the population center of Lakeside becoming more dense and growth expanding upward into Stoner Creek watershed (Figure 2).

Some residents of Lakeside have expressed concern over the impacts of uncontrolled growth and accordingly developed the Lakeside Neighborhood Plan (Flathead County 1995). One of the outcomes of the plan, which was adopted as an addendum to the

Flathead County Master Plan, was the creation of the Lakeside Community Council. The Neighborhood Plan states that while growth is inevitable, it must be "planned and guided". The results of this assessment will help provide a scientific foundation for Lakeside residents' development planning decisions. The study will describe current conditions, which will serve as a baseline to evaluate development impacts, degradation prevention measures, and/or future restoration efforts.

CHAPTER 2: METHODS

Watershed Characterization

Watershed conditions and processes determine the character and health of a stream. Therefore it was necessary to characterize climate, geology, hydrography, current and historical land use, soil type, upland & riparian vegetation, large-scale disturbances and other geomorphologic and anthropogenic factors. This need was addressed using existing sources of information, maps, interviews with land managers, and databases such as Montana State Library's National Resource Information System (NRIS). Since information specific to the Stoner Creek watershed was often lacking, much was extrapolated from information on Flathead County, the Flathead Basin and Flathead National Forest. This "big picture" view of the watershed was essential in identifying sample sites and reaches for the physical, biological and chemical assessments. This synthesis of existing information is presented in Chapter 3: Watershed Characterization.

Sampling Site Selection

To optimize sampling effort, sampling sites were selected so as to bracket important watershed features that may affect stream type or condition, including land uses suspected to contribute to impairment. Seven sites were identified for discharge measurements, and for nutrient, macroinvertebrate and algae sampling (Figure 3, Table 3). Sites were chosen to be representative of the depth, flow and substrate of the creek in each respective reach. For the sake of macroinvertebrate and algae collection, all sites contained riffle/run habitat. Accessibility was also a consideration in site selection.

The sampling sites at North Creek above Lost Lake and South Creek above Lost Lake sampling sites were chosen to represent headwater conditions. These tributary creeks were sampled at the point they exited Flathead National Forest land. There is no residential development above these sites; the principle land use above these sites is timber production. The Below Lost Lake site was sampled to determine the effects on water quality from the beaver pond/wetland complex known as Lost Lake. Although it is found on Stoner Creek proper, the Blacktail Mt. Road site can also be considered a headwater or tributary site because of its low discharge. The Swiftheart Paradise Ranch site was selected to provide data on the creek as it exits timberlands and before it enters the denser residential sections of Lakeside. The Stoner Creek Road site divides the residential area roughly in half – most of the homes above this site use on-site septic systems and most of the homes below are connected to municipal sewer. The Stoner Creek Mouth site was selected to assess the impact of the urban center of Lakeside and to determine water quality of the creek as it empties into Flathead Lake.

Physical & Chemical Assessment

Stream Classification (Rosgen)

In addition to describing watershed-wide geomorphologic factors, it was necessary to describe the morphology of the stream itself. This was done using the Rosgen channel classification system, which uses physical characteristics such as stream width/depth and entrenchment ratios, gradient, sinuosity and substrate type (Rosgen 1996). Application of a stream classification system can facilitate comparisons between similar stream-types, point out relative threats and potential management concerns for given stream-types and can be used as a baseline to identify any long-term shifts in stream morphology. Rosgen classifications were performed at three transects: one in the headwaters, one near the mouth and one in the mid-elevation area (Figure 3). Stream morphology typically exhibits a gradient between classification types; it was felt the study sites were representative of their respective reaches and would capture the range of Rosgen channel types found in the majority of the Stoner Creek drainage. Measurements were made once at each site in October 2002.

Substrate composition, in addition to being a habitat parameter of critical importance to benthic macroinvertebrate and algal communities, is a reflection of (and influence on) the hydrology and morphology of a stream. Substrate particle size distributions were quantified at each classification site using a modified Wolman pebble count procedure where substrate particles are blindly selected following a zig-zag pattern between the stream banks (Bevenger & King 1995). One hundred particles were selected at each Rosgen site and categorized based on size (sand, gravel, cobble, etc.). These data were used to determine median grain size for classification purposes only.

Riparian Condition Assessment

The "health" or condition of the riparian community along a stream is critical for the cooling and cleansing effects on the water, providing fish and wildlife habitat, stream bank erosion control and aesthetic value. The type and condition of the riparian habitat along Stoner Creek was assessed using the University of Montana's Riparian and Wetland Research Program's (RWRP) Lotic Health Assessment (Hansen *et al* 2000). In order to conduct the riparian assessment, it was necessary to divide the stream into reaches based on homogeneity of habitat and geomorphology. This was accomplished mainly with aerial photographs and topographic maps. Coordinate data (GPS) and photo documentation were collected at each reach boundary. Fifteen reaches (polygons) were chosen based on homogeneity of habitat and land use divisions (fences, roads, etc.) (Table 4). The reaches were scattered along the mainstem and tributaries to represent various elevations, land forms and land uses. Assessments were performed one time at each polygon, between June 26 and September 21.

The RWRP Lotic Health Assessment considers vegetative factors such as canopy cover, invasive and undesirable plant species, tree regeneration, dead and decadent woody plants, utilization by foragers and streambank rootmass protection. It also accounts for physical impacts such as human-caused bare ground, streambank alteration, pugging (livestock trampling), and channel incisement. Each polygon is scored in each category, yielding an overall score and associated "health" rating.

Discharge and Water Quality Sampling

Discharge, the volume of water moving past a point for a given length of time, is a parameter of critical importance to a stream. The magnitude and duration of different flows help determine stream morphology, riparian vegetation type and location, the transport of nutrients, sediment and pollutants, and the composition of aquatic life in a stream. Stream velocity and cross-sectional area measurements were taken with each water sample for use in calculating discharge. Velocity was measured manually at each sampling site during six visits in May through September using USGS procedures and a Marsh-McBirney or Price Pygmy velocity meter. Monthly sampling trips were inadequate to capture the variability of discharge, hence a staff gage was located near the mouth of Stoner Creek, and stream stage was recorded daily by a local resident to capture any changes in discharge between sampling trips. Stage and discharge measurements for each sampling date were plotted in an XY graph to obtain a stage-discharge relationship equation using a regression. The regression equation was used to construct a hydrograph for Stoner Creek for the summer of 2002.

Water quality parameters measured in the field included temperature, pH and conductivity using an Orion pH meter and conductivity probe. Onset Tidbit Stowaway™ temperature loggers were also installed at four stream sites on June 26 to record water temperature every 15 minutes. The loggers were removed October 19 from the North Creek and Stoner Mouth sites; they were removed August 7 from the Below Lost Lake and Blacktail Mt Road sites.

Water samples were collected monthly at each site. Samples were integrated from the entire water column using a USGS suspended sediment sampler. These samples were analyzed in the University of Montana's Watershed Health Clinic lab for total suspended solids (TSS) using Standard Methods (APHA 1994) and turbidity using the nepholometric method and a Hach turbidimeter. TSS are solids, primarily silt and organic matter, in water that can be captured by a filter (as opposed to dissolved solids). Turbidity is a measurement of the amount of light that can pass through a water sample. Excessive TSS or turbidity can hinder aquatic growth by limiting light penetration, can increase stream temperatures by absorbing solar radiation, can "clog" the pore space between gravels and cobble where aquatic invertebrates dwell or can decrease visibility for fish species. High levels of TSS or turbidity in a mountain stream may indicate excessive streambank erosion, sediment delivery, or nutrient enrichment.

In addition, water samples were collected at all sites during base flow (September 11) and analyzed by the Montana State Environmental Laboratory for chloride, sulfate, pH, alkalinity, specific conductance and turbidity using EPA approved methods. Samples were also collected at four of the sites on August 7 and scanned for 15 different metals, again by the State Lab. These various water quality data were needed to characterize the stream's basic geochemistry and to identify any potential parameters of concern. Some of the parameters measured by the State Lab were used to verify field measurements as well.

Nutrient Concentrations and Loads

Excessive nutrient loads can have adverse effects on the beneficial uses of a stream or lake. Watersheds experiencing residential development & vegetative disturbance may yield elevated nutrient loads. By monitoring nutrient levels, potential sources of increased loading, such as septic systems, can be identified and appropriate measures can be taken to address the problem. Water samples were collected at the seven Stoner Creek sites once a month, from April to September. Samples were collected according to Standard Methods (APHA 1994), sent to the University of Montana's Flathead Lake Biological Station, and analyzed for nitrate/nitrite (NOx), total persulfate nitrogen (TPN), soluble phosphorus (SP), and total phosphorus (TP) using EPA approved nutrient analysis methods. Nutrient concentrations were multiplied by discharge measurements to determine instantaneous loads, which were then used to estimate daily loads.

Biological Assessment

Benthic Macroinvertebrates

The bottom (or benthos) of a stream supports a community of insects and other invertebrates referred to as benthic macroinvertebrates. These organisms are sensitive to water quality and habitat alterations and are used to evaluate the condition of the stream. Macroinvertebrates must survive in the stream for extended periods and therefore integrate the effects of environmental conditions over time. In this respect, a macroinvertebrate community sample can give a more comprehensive picture of a stream's condition than single-point water quality samples or habitat surveys that may not capture the range of variability over time. The long residence time of macroinvertebrates also means that one yearly sample is adequate; the developmental stage of organisms changes seasonally, the overall assemblage does not.

To determine the level of impairment, a stream's benthic macroinvertebrate community is compared to that of a relatively unimpacted reference stream. Since suitable reference indices have already been established for the ecoregion that includes Stoner Creek, it was not necessary to collect samples from a reference community for this project (Bollman, personal communication, 2001). This allowed for more samples to be analyzed from the project area.

Benthic macroinvertebrate samples were collected once during the study, in July 2002, at each of the seven water quality sites (Figure 3). Sampling followed the Montana Department of Environmental Quality Standard Operating Procedures for Aquatic Macroinvertebrate Sampling (Bukantis 1998). This semi-quantitative protocol entails placing a D-frame dip net on the streambed and disturbing approximately one square foot of substrate immediately upstream for one minute in order to loosen all attached organisms, allowing them to drift into the net. Three samples from suitable riffle/run habitat at each site were composited and preserved with ethanol.

A subsample of 300 organisms from each sample was sorted and identified to the lowest taxonomic level possible (species, genus, etc.). These data were summarized as a number of metrics, which are essentially measurements of aspects of community composition that react to environmental stresses. The score for a given metric is indicative of the tolerance of certain organisms to variations in water temperature, riparian canopy, substrate type, etc. Mayfly diversity and abundance decrease as water quality decreases, hence Ephemeroptera (mayfly) richness is a metric used to indicate water quality. Plecoptera (stonefly) richness and Trichoptera (caddisfly) richness are indicators of instream and reach-scale habitat impacts. Caddisflies are particularly susceptible to fine sediment deposition, while stoneflies are sensitive to loss of riparian cover, unstable streambanks and changes in channel morphology. ‘Percent filter feeders’ is a metric used to detect an increase in organic matter. Overall water and habitat quality is indicated by the ‘number of sensitive taxa’ and ‘percent tolerant taxa’ metrics (Bollman 1998).

Due to the expertise necessary to identify macroinvertebrates to the genus and species level, identification and evaluation of samples was done on a contractual basis with Rhithron Biological Associates in Missoula, MT. For a detailed description of the methods, metrics and scoring criteria used, refer to the report by Wease Bollman of Rhithron Associates in Appendix C.

Benthic Algal Biomass

Algae are primitive plants, naturally found in aquatic systems, and are a critical part of the base of the stream food chain. Algae can be found suspended in the water column (phytoplankton) or attached to substrate on the streambed (benthic periphyton) – only benthic algae were assessed in this study. Benthic algae community composition analyses regularly display a high degree of correlation with the results of benthic macroinvertebrate analyses of the same stream (Bollman, personal communication, 2002); hence algal composition was not analyzed. However, algal biomass samples were collected to assess the effects of nutrient loading on primary productivity in the stream using procedures described in Watson and Gestring (1996). Algae samples were collected monthly from June through September 2002 at each of the water quality sites. Six cobbles with a representative amount of algae were collected from each site; algae samples were scraped from the cobbles using a razor blade and 2-inch square template. Those samples were analyzed for chlorophyll-a and ash free dry weight in the University of Montana’s Watershed Health Clinic lab according to Standard Methods (APHA 1994).

The only deviation from the standard protocol was the use of ethanol instead of acetone for pigment extraction; this substitution has been found to have no measurable effect on results (Watson, personal communication, 2003).

Fish Abundance and Community Composition

Montana's Department of Fish, Wildlife and Parks (MDFWP) sampled fish communities in Stoner Creek in 1992 and again in 1999 (USDA 2001). MDFWP electroshocked a portion of the stream above Lost Lake, and recorded species composition and abundance (Deleray 2002). Due to budget limitations and gear requirements, independent fish sampling of Stoner Creek was not feasible for this project. In light of the minimal species diversity found by MDFWP, limited inferences could be drawn from addition sampling. Instead, the data collected by MDFWP was reviewed.

CHAPTER 3: WATERSHED CHARACTERIZATION (Existing Sources)

Study Area

Stoner Creek watershed lies in the Flathead Basin of northwestern Montana, in the foothills of the Salish Mountains (Figure 1). The landscape varies from rolling to steep hills, to low relief mountains (USDA 1995). Stoner Creek flows directly into Flathead Lake in the town of Lakeside in Flathead County. Portions of the watershed are contained in four USGS quadrangles: Lion Mountain, Somers, Proctor and Rollins. The majority of the watershed covers numerous Sections of Township 26N, Range 21W.

The Stoner Creek watershed encompasses 9220 acres or about 15 sq. miles (USDA 1979). Elevations in the watershed range from 881m (2890 ft) at the mouth to 2060m (6757 ft) on Blacktail Mountain. Stoner Creek proper is 6.6 miles long (MDFWP 2002); it has been classified as a fifth order stream by the Flathead National Forest (USDA 1979), but USGS quadrangle topographic maps suggest a third or fourth order stream. Stoner Creek has a water use classification of A-1(open) by the state of Montana, which indicates the water should be suitable for drinking after simple disinfection.

Land Use/Ownership

Ownership of Stoner Creek watershed is a mixture of private, federal and state lands (Figure 4a). The majority of the lower portion of the watershed is privately owned, while most of the higher elevations are in the Island Geographic Unit of the Swan Lake Ranger District of the Flathead National Forest. The U.S. Forest Service owns 62% of the watershed. Most of the remaining land is in private hands; Plum Creek Timber Company is the major private landowner. Nearly all of the properties adjacent to the creek in the lower elevations are in private (individual) ownership. The Montana Division of Forestry and the U.S. military also have small holdings in the watershed.

The land cover in the vast majority of the watershed is forest; timber production is the principal land use (Figure 4b). Small-scale grazing is present in a few small areas, but large-scale agriculture of any sort is completely absent. The lakefront property and land within the town of Lakeside is mainly residential, with a commercial center abutting both sides of Highway 93, which runs through town. Population density gradually decreases as one travels up the watershed; the highest elevations are uninhabited (Figure 2). However, as mentioned, the urban area has been expanding.

Lakeside created a sewer district in 1987 that now encompasses the properties along the lakeshore and the most densely populated area near the town center (Figure 5 & 6b). Wastewater is pumped to a treatment facility in Somers, approximately five miles to the north, but the system is nearing capacity (Flathead County 1995). Until the sewer district and facility capacity can be expanded, existing and future dwellings outside the district boundary will continue to rely on septic systems. Septic tank density correlates with population density, as would be expected, with the largest concentration located along the lowest mile of stream and near the lakefront (NRIS 2002).

The largest recent disturbance in the area was the construction of a ski hill on Blacktail Mountain. The project was completed in 1998, contains 200 acres of skiable land and includes a lodge and parking area. The entire development is on the north and west faces of Blacktail Mountain, and thus not located in Stoner Creek watershed. However, the presence of such a destination in such proximity to the watershed creates the potential for increased development pressure.

The road that accesses the ski hill, Blacktail Mountain Road, does run through the watershed. The road is gravel for most of its length, except for the first mile upstream from U.S. Highway 93, which is paved. The main road roughly parallels the stream for six miles, crossing the mainstem and tributaries at least five times via culverts. There are numerous other logging roads that crisscross the watershed that undoubtedly receive less traffic, and less maintenance, than the Blacktail Mountain Road. The Island Geographical Unit has the highest road density of any area in the Flathead National Forest averaging 2.0 to 3.2 miles/section (USDA 1985). There are at least seven major culverts on Stoner Creek and its tributaries, and an unknown number of smaller crossings.

The principle recreation activities on the Forest Service lands in the area are snowmobiling, motorbiking, firewood gathering and grouse and white-tailed deer hunting (USDA 1985). Part of the fifteen miles of Wild Bill ORV (off-road vehicle) Trail, a National Recreation Trail, are located in the watershed, as are 12.5 miles of cross country skiing trails on Blacktail Mt.

There are extensive clear-cut areas in the watershed, mainly on the Flathead National Forest land, as apparent from aerial photographs (Figure 6a). Over 30% of the watershed has been clear-cut (Stanford *et al* 1997). Logging intensity has been declining on Flathead National Forest Land in recent years and no large-scale operations are planned in the Stoner Creek watershed in the near future (Soderstrom, personal communication, 2002). The Forest Service is proposing a fuel reduction project, in which about 100 acres within Stoner Creek watershed would be thinned in the next few years. No measurable water yield or sediment increases are expected (USDA 2002).

Plum Creek Timber plans to sell off its holdings in three of the four sections it owns in the watershed. The company expects to sell Township 26N, Range 21W, Section 15 in the next 2-3 years; Sections 9 & 23 within 7 years (Rozell, personal communication, 2002). These sections are steeply sloped, currently heavily timbered, and contain creek-front property. Subdivision sizes are yet to be determined, but will likely result in low-density residential development, requiring septic systems, new roads and an increase in impervious surfaces. Some selective harvesting has taken place on S15, and more will take place on S9 and S23 before these sections go on the market (Rozell 2002)

There are no records of recent significant fires in the watershed, nor of current or abandoned mining projects. No Army Corps of Engineers 404 permits (required for stream channel or wetland alterations) have been applied for in the last ten years.

Lakeside Water and Sewer District operates four groundwater wells near the center of town that supply the majority of Lakeside residents with drinking water (1500 people). A few other wells in the watershed are considered public-supply, including those that serve the Youth With a Mission complex and the Tamarac Woods subdivision; dozens of private wells are scattered throughout the watershed as well (NRIS 2002). Stoner Creek surface water rights also number in the dozens, although it is unclear how many are still actively used. Water rights have historically been used for lawn and garden irrigation or stock watering; means of diversion has typically been a pump (NRIS 2002).

Climate & Hydrology

Most of Stoner Creek watershed has an easterly aspect and is in the rain shadow of the Salish Mountains, hence is relatively dry. Snowpack and temperature vary throughout the watershed due to the elevation range, but yearly precipitation averages 20-30 inches, roughly half of which falls as snow. Precipitation levels are fairly constant throughout the year; temperatures average 60 to 70° F (16 to 21° C) in the summer and 20 to 30° F (-7 to -1° C) in the winter (Figure 7).

Stoner Creek is relatively small for a fifth, or even fourth, order stream because the small amount of precipitation the basin does receive is mostly used by vegetation; less than a third of the precipitation can be expected to become runoff (USDA 1979). Snow pack, as well as overall precipitation, was average to slightly below average for the 2002 water year, when this study was conducted (Figure 8).

Geology & Soils

The Flathead Basin is found in the Rocky Mountain trench, which was formed by tectonic uplifting. Bedrock is composed of metasedimentary rocks including argillites, quartzites, siltites and dolomites (USDA 1979, USDA 1995). The basin was glaciated during the last ice age. Flathead Lake was formed by a large terminal moraine, which the Flathead River eventually cut through, leading to the present day lake level. The receding glacier left the basin filled with glacial till, which is a mixture of compacted clay, sand, gravel and boulders (USDA 1979, NRCS 1999). The glacier also softened, or weathered, the mountain ridges and slopes surrounding the lake.

The glacial till, along with volcanic ash deposits from eruptions in the Cascades, was the parent material for the present day soil (NRCS 1999). Glacial till is a dense substrata which restricts water movement and root penetration and is hard and brittle when moist. Soil types vary throughout the watershed since topography, climate and bioactivity influence soil formation along with parent material.

A soil survey map of Flathead National Forest that covers much of the upper reaches of the watershed was used to determine soil types in Stoner Creek watershed. In the absence of soil surveys of the complete study area, it is assumed that similar soils will be found in the lower portions of the watershed. Most soils are of the loamy-skeletal type and exhibit moderate susceptibility to erosion (NRCS 1999). The soils found in the immediate area of Stoner Creek and its main tributary are classified as Typic Eutroboralfs and Aquepts. The main soil types found in the surrounding hillsides include Andeptic Cryoboralfs, Andic Cryochrepts and Dystric Cryochrepts.

While soil erosion risk is generally classified as moderate, sediment delivery efficiency ranges from low, on the higher ridges, to high on the steepest slopes and some areas nearest the streams (NRCS 1999). Permeability of the soil is one of the most important factors in considering suitability for septic tank installation. In general, the Flathead Basin consists of soil that is moderately permeable or better, with moderate limitations for septic tank installation (Meiners *et al* 1977). The exception would be where high water tables create severe limitations (Meiners *et al* 1977).

Vegetation

The primary vegetation type of the watershed is evergreen forest, with Douglas fir, western larch and lodgepole pine the dominant species. Douglas-fir and ponderosa pine are typically found on the drier, south-facing slopes; northern aspects and other moist areas support Douglas-fir and larch; subalpine fir, Engelmann spruce and lodgepole can be found in the cooler, higher elevations (USDA 2001). Riparian vegetation is dense where undisturbed. Common tree and shrub varieties include black cottonwood, white birch, red-osier dogwood, green alder, rocky mountain maple, snowberry, chokecherry, and various willows. Trembling aspen occurs sporadically throughout the watershed. Numerous invasive weeds have become established in Stoner Creek watershed, most commonly spotted knapweed and Canada thistle, predominantly along roadsides and decommissioned logging roads.

Portions of the Stoner Creek watershed are considered very productive for timber, and have been logged extensively since the 1960's (USDA 1979). Clear-cutting has been used in the past, a practice shown to alter watershed hydrology drastically (USDA 1973). Logging in general makes streamflow more "flashy", increases peak flows and alters the timing of run-off (Hauer 1991). Increased water yield can have numerous implications, including accelerated erosion, increased sedimentation and transportation of nutrients, which can hasten eutrophication processes (Stanford *et al* 1997).

In order to lessen the negative ecological impacts of logging activity on federal land, the US Forest Service employs Best Management Practices (BMPs). These management practices are meant to minimize excessive soil erosion and hence protect water quality. An audit of timber sales in the Flathead National Forest from 1986 through 1988 found a departure from BMPs that resulted in major detrimental impacts to soil and water resources in 15% of all sales. Departures resulting in minor impacts were identified in 59% of timber sales (Ehinger & Potts 1991). Since that time, better implementation of BMPs, declining timber harvests on federal forest lands and the Streamside Management Zone (SMZ) law have likely lessened the negative effects of timber harvest on water quality (MDEQ 2002). On the Flathead National Forest, timber harvest has declined from 122 million board feet in 1988 to 9 million board feet in 2000 (MDEQ 20002). Plum Creek Timber also voluntarily observes BMPs and the SMZ on its properties.

Fish & Wildlife

Stoner Creek is managed as a trout stream by the Montana Department of Fish Wildlife and Parks (MDFWP). It has relatively low fisheries resource values; habitat class is four (moderate) and sport class is five (limited) (MDFWP 2002). Limited fish sampling has been performed in Stoner Creek, and the only fish species observed by DFWP are Brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*) (MDFWP 2002). Brook trout, an introduced species, are considered abundant, and slimy sculpin, a native species, are common. There have been reports of Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) in the headwaters of Stoner Creek watershed, but this has not been verified (Deleray, personal communication, 2001). Typically, if brook trout are present in a stream, they tend to outcompete and effectively extirpate the cutthroat. Stoner Creek receives relatively little fishing pressure. Access is restricted along the private property of the lower reaches; dense overgrowth, small stream size and limited catch potential make the reaches on National Forest land a less than desirable sport fishery, especially in light of "blue-ribbon" fishing in the area.

There are a number of obstructions to fish passage on Stoner Creek. The concrete remnants of an old diversion dam can be found between Highway 93 and the mouth of the creek. A number of culverts were improperly installed, resulting in large scour pools at their downstream end (Appendix B, Figure 24). The Highway 93 culvert, approximately one-tenth of a mile upstream from the mouth has a 2-3 foot drop in water level (depending on stream stage) at its outlet. If there are any Cutthroat trout remaining in the upper reaches of Stoner Creek, they may be a genetically pure strain, as these obstructions may have isolated them from lake populations for some time.

The Stoner Creek watershed provides habitat for a number of wildlife species. Streams and their riparian areas are often important to terrestrial wildlife species for foraging, hunting, breeding, refugia and of course, as a source of water. Waterfowl, beaver and moose directly utilize the creek and associated wetlands, specifically the area known as Lost Lake. No federally listed endangered or threatened species are known to inhabit the

Stoner Creek watershed. However, a few species listed as “sensitive” by the Flathead National Forest, such as the Black-backed Woodpecker, Common Loon, Flammulated Owl, Fisher, Northern Goshawk and Western Toad are known, or at least have the potential, to occur in the Island Geographic Unit (although not necessarily in the Stoner Creek watershed) (USDA 2002). Popular big game and upland bird species such as White-tailed Deer, Elk, Mule Deer, Ruffed Grouse and Blue Grouse are known to inhabit the area as well. Other species of interest thought to be in the area include black bear, mountain lion, pine marten and bobcat.

CHAPTER 4: STREAM ASSESSMENT (Summer 2002)

Stream Classification (Rosgen)

Channel cross-section measurements and substrate pebble counts yielded a Rosgen classification of B4 for all three of the measured transects (Table 5). B4-type streams are moderately entrenched, have a moderate width/depth ratio, moderate sinuosity and gravel as the dominant channel material. However, pebble count figures for the two lower transects show the median grain size at the gravel/cobble category boundary, indicating a large percentage of cobbles as well (Figure 9). B-type streams are typically mountain streams that exhibit rapids-dominated bed morphology with irregularly spaced scour pools (Rosgen 1996). Thanks to natural entrenchment, B-type streams don't have wide, developed floodplains. These streams have fairly stable banks, low erosion rates and low sediment supply due to their entrenched nature and rocky soils (Rosgen 1996).

Nearly the entire length of Stoner Creek can be considered a B-type stream, although there are doubtless A-type (cascading step-pool) sections in the extreme upper sections of the headwaters. The portion of the creek that runs through the beaver ponds of Lost Lake is another exception. This area is unique in that it is low gradient, filled with fine sediment, has multiple channels that are not entrenched, and a wide floodplain. The Lost Lake reach is likely a D6 or DA6-type stream, however the nature of the wet soils and surrounding wetlands made cross-section measurements of the Lost Lake reach not feasible.

Riparian Condition Report

Of the fifteen riparian polygons that were assessed, ten received 80% or more of the maximum possible score, a rating considered "healthy". Four polygons scored between 60 and 80% ("healthy-with-problems") and one polygon was categorized as "unhealthy", scoring less than 60% (Table 6, Figures 10 & 11). Since stream reaches that had noticeable riparian impairment were intentionally targeted, it is reasonable to assume that most of the unassessed reaches (especially the tributary/headwater areas) are relatively healthy. The riparian zones that were healthiest had extremely dense and diverse vegetation, heavy canopy cover to shade the stream and protect soils from raindrop erosion, woody trees and shrubs to stabilize streambanks with deep, binding rootmass and a lack of streambank alterations and invasive species (see Appendix B, Figure 21). One exception would be the polygon nearest the mouth (polygon O), which was graded as "healthy" despite receiving a score of zero for bank alterations, namely riprap. Another exception would be the Lost Lake riparian area (polygon D), which had few woody species, yet received the highest score for rootmass protection; dense sedges along the stream banks provided sufficient stabilizing rootmass, especially in light of the low stream power in that reach.

Three of the polygons that received scores of "healthy-with-problems" or "unhealthy" did so due to logging or grazing activities near the stream channel. The private land surrounding polygon C, near the confluence of North and South Creeks above Lost Lake, had been recently logged and now supports some cattle, at least for part of the year. This polygon scored low for invasive and undesirable plant species. Disturbances such as timber harvesting and grazing can create opportunities for weeds to become established. The reach also scored low for standing dead and decadent woody material, which can be a sign of declining health (Hansen *et al* 2000). Vegetative cover, preferred tree regeneration and streambank physical characteristics scored high on this reach, however, indicating the cattle had not yet damaged the channel or browsed heavily on riparian foliage.

Polygon E, a private reach downstream of Lost Lake, was the only polygon to receive an "unhealthy" rating. The surrounding land was apparently a grazed pasture at one time (although no livestock were present throughout 2002) and the stream was showing the impacts (see Appendix B, Figure 22). There was little woody vegetation left to hold the streambanks together or to shade the stream. Bank erosion, due to lack of binding rootmass and hoof shear, exposed bare soil. The stream appeared to be incised into the floodplain, further removing the water table from remaining riparian plant roots.

Polygon F, immediately downstream from polygon E, received a rating of "healthy with problems". The scores of zero for invasive and undesirable species were in part due to a sizable patch of thistle, possibly introduced by recent logging operations on adjacent Plum Creek lands. This polygon also lost points for woody species regeneration and utilization. Although no livestock are present here, white-tailed deer and moose were seen on numerous occasions during sampling.

Two polygons located in the developed areas of Lakeside received scores of "healthy-with-problems" due to vegetative disturbance typically associated with residential areas (see Appendix B, Figure 23). Polygon L encompasses the Youth With A Mission properties. While the riparian zone on the north side of the creek appears to be in a relatively natural condition, portions of the vegetation on the south side have been cleared, presumably to offer an unobstructed view of and access to the creek. Some of the large trees have been recently cut, and turf lawn extends to the streambank in some areas. There are undercut banks in these areas, and the lack of binding rootmass will probably result in the eventual sloughing off of chunks of streambank.

A similar situation is found in polygon N, the reach immediately behind the Ace Hardware store. In this case, the cause may simply be heavy foot traffic as it is near the center of town and a favorite spot for local children to explore the stream. Again, turf lawn extends up to the stream banks and while there are some very large cottonwoods and a few willow, there is no regeneration to speak of. Photographs of the riparian zones of selected polygons can be found in Appendix B.

Stream Discharge

The 2002 water year was near the 40-year average for most USGS gauged rivers in the Flathead Basin near Stoner Creek (Figure 12). A 2002 hydrograph constructed from a stage-discharge relationship for the Stoner Creek Mouth site shows a classic snow-dominated response: a high peak correlating with snowmelt at least one order of magnitude higher than winter base-flow (Figure 13). Peak runoff occurred on May 21-22 in 2002, with the stream returning to near base flow conditions by mid-July. While the general shape of the hydrograph is reasonable, the low number of actual discharge measurements (6) allows for only a rough estimate of the peak discharge (60 or 100 cfs, depending on the type of regression used). The small peak on July 8 coincided with a heavy precipitation event, which dramatically increased discharge in the creek for a short time.

As expected, discharge increased in the downstream direction (Figure 14). The lowest discharge volumes on most dates were found at the headwater/tributary sites: North Creek above Lost Lake, South Creek above Lost Lake and Blacktail Mt Rd. The highest discharge volumes on most dates were found at one of the lowest three sites: Stoner Mouth, Stoner Creek Rd or Swiftheart Paradise Ranch. The variability in the relative flows at the lower sites is similar to the error involved in the measurements, hence they can be considered roughly equivalent. The low number of discharge measurements made any definitive trend hard to identify. However, if there was an actual difference in discharge at the three downstream sites, it could indicate a seasonal change in the direction of the seepage between surface water and ground water (i.e., gaining vs. losing); alternatively it could be caused by a site-to-site difference in the relative amount of water traveling in the hyporheic zone (the area between the cobbles and gravels of the substrate); or it could simply be the result of seasonal changes in irrigation diversion volumes.

The relationship between the combined discharge for the North and South Creeks above Lost Lake and the Below Lost Lake sites changed throughout the season. On May 7, the discharge below Lost Lake was 19% less than the combined discharge above Lost Lake. On June 7 and 26, the discharge below Lost Lake exceeded the discharge above Lost Lake by 11% and 8%, respectively. On August 7 and September 11, the discharge below the lake was 127% and 99% higher than the combined discharge above the lake. These observations suggest that the beaver pond-wetland complex acts as a discharge moderator, collecting water during high flow periods and releasing it later in the season, thereby preventing downstream reaches from becoming dewatered. There is some anecdotal evidence that Stoner Creek dried up in a year when a former landowner of the Lost Lake area trapped and killed the resident beavers and removed the dams (Walker, personal communication, 2002). It should be noted that while there are two intermittent tributaries and at least one groundwater spring also entering the Lost Lake area, their discharge contribution is minimal compared to North and South Creeks.

Stream Temperature

Water temperatures recorded during the study period ranged from 2 to 22 degrees Celsius (Figure 15a). Temperatures at the North Creek above Lost Lake site were significantly below, and exhibited less seasonal variability, than those recorded at the three downstream sites equipped with temperature loggers. This would be expected from the most upstream site and was certainly due in part to vegetative cover and the associated shading of the stream. However, the stream reach above the Blacktail Mt Rd. headwater/tributary site has similarly dense canopy cover; yet temperatures at this site were similar to downstream temperatures. This may be an indication of significant groundwater discharge into North Creek above Lost Lake.

Daily summer water temperatures increased considerably as one travels downstream from the North Creek above Lost Lake site to the Below Lost Lake site, and remained relatively high down to Stoner Creek Mouth. The high residence time of the water and lack of canopy shading in the beaver ponds increase average temperatures and daily fluctuations (Figure 15b). While the daily temperature range above Lost Lake never exceeded three degrees Celsius, Below Lost Lake the temperature range regularly exceeded five degrees, and was as much as ten. The daily temperature fluctuations at the Blacktail Mt. Rd. site may likewise be attributed to three small intermittent, instream ponds that, while not visited during the study due to access difficulties, do appear on topographic maps.

Nutrient Concentrations and Loading Estimates

Concentrations and loading estimates of soluble nutrients (dissolved and readily available) and total nutrients (all forms) are presented in Table 7 of Appendix A. Total Phosphorus (TP) and Total Persulfate Nitrogen (TPN) concentrations are presented as boxplots in Figure 16 & 17. TPN is equivalent to Total Kjeldahl Nitrogen (organic) plus nitrate and nitrite, hence is a good approximation of Total Nitrogen since ammonia (another form of nitrogen) tends to be very low in well-oxygenated streams like Stoner Creek. It appears the concentrations of nutrients in particulate form are greatly influenced by runoff. The intense rainstorm that occurred prior to sampling the five downstream sites on July 8, 2002 resulted in extreme outliers for TP and TPN (Figures 16a and 17a). The storm increased TP and TPN concentrations anywhere from 2 to 7 times the next highest value at those five sites.

Boxplots are also presented for TP and TPN with the data for July 8 omitted, and the scale altered, to better illustrate the variability between sites (Figures 16b and 17b). There seems to be no discernable trend in either parameter. Notably, there was no noticeable increase between the Swiftheart Paradise site, the upstream bracket of the residential area of Lakeside, and the two downstream sites. There was a significant increase in TPN between the two sites above Lost Lake and the five sites below, although the same can't be said for TP.

A trend is likewise difficult to identify in the boxplots for the soluble nutrient forms. Nitrates and nitrites (NOx) remain fairly steady as one travels downstream (Figure 18a); nitrate is generally found in low levels in surface water, and if found to be otherwise may indicate a significant groundwater influence. Soluble Phosphorus (SP) levels show extremes at the downstream sites associated with the rain event on July 8 but otherwise actually show somewhat of a decrease in the downstream direction (Figure 18b). In general, the majority of phosphorus was found in soluble form (at times approaching 100%), and the vast majority of nitrogen was not in soluble form, suggesting a nitrogen limited system.

Loading estimates are a reflection of concentration and discharge at a given site, and as there were no surprising trends found in the concentration or discharge boxplots, there are none found in the nutrient load boxplots (Figure 19). As would be expected, the Blacktail Mt Rd and South Creek above Lost Lake sites contribute the lowest loads for all parameters based on relatively low discharge values. When loads for North and South Creek are combined and compared to loads for Below Lost Lake, the lake isn't an obvious annual source or sink for any parameter, at least in 2002. However, as noted earlier, Lost Lake does enhance downstream discharge late in the season and has a similar effect on nutrient loads. Again, there is no discernable increase in loading as the creek passes through the last three sites bracketing the residential areas.

Selected Water Quality Parameters

As with total nutrient levels, total suspended solids (TSS) and turbidity increased dramatically with the precipitation event on July 8 (Figure 20, Table 8). Samples collected at Blacktail Mt. Rd. on the following day show this to be a temporary condition: TSS dropped from 118 mg/L on July 8 to 4 mg/L on July 9; turbidity similarly dropped from 20 to 1.25 NTUs. When the extreme values of July 9 are omitted, the low levels of TSS at the North and South Creek sites are better illustrated (Figure 20b). In fact, 5 of 6 TSS measurements at North Creek and 3 of 6 measurements at South Creek were below detection limits (.25 mg/L). TSS becomes elevated Below Lost Lake site and appears to slightly decrease in the downstream direction, until increasing at Stoner Mouth. This may be in part due to large boulders near Stoner Mouth, which create a cascading, turbulent system, which can suspend sediment that may otherwise travel as bedload.

Turbidity values largely mimic TSS values for all sites, with the exception of Blacktail Mountain Road. The very low turbidities at this site are probably linked to low levels of available nutrients (especially the low levels of SP, see Figure 18b), and intense riparian shading which would reduce algae and plant growth. The relatively high TSS values at this site can be attributed to plentiful small, lightweight substrate particles that are easily suspended in the water column.

Monthly measurements of pH values ranged from 6.2 to 8.6. Measurements taken in May were 1-2 pH units lower than all other measurements taken at the same sites. While acid pulses have been documented at some sites in the Rockies, the lower pH values on this sampling date may be due to instrument error. The lowest pH values were measured at the North Creek, South Creek and Below Lost Lake sites, with median pH values of 7.2, 7.3 and 7.5, respectively. The Blacktail Mt. Road site had the highest pH values (median = 8.5). The median pH value of the three downstream sites was more alkaline (8.3) than at the three upstream sites. Likewise, specific conductance was lowest at the three sites surrounding Lost Lake (combined median = 0.04 mS, near the detection limit), highest at the Blacktail Mt. Rd. site (median = 0.4 mS) and intermediate at the Swiftheart Paradise, Stoner Creek Rd. and Stoner Mouth sites (combined median = 0.2 mS). This same pattern was seen in values for pH, alkalinity, specific conductance and sulfate in the water samples collected on August 7 and September 11 as analyzed by the Montana State Environmental Lab (Tables 8 & 9).

Most trace metals from the samples collected on August 7 were below detection limits at all four sites sampled. Calcium, magnesium, $CaCO_3$, hardness and sulfates were found in detectable levels (Table 10). At the Swiftheart Paradise Ranch and Stoner Mouth sites, these four parameters were found to be 6-10 times higher than at North Creek, and 14-18 times higher at Blacktail Mt. Rd. than at North Creek. There is no known mining activity and no more timber harvest in the drainage above the Blacktail Mt. Rd. site than elsewhere in the watershed. Hence, the relatively high values for calcium, magnesium, alkalinity, specific conductance, pH and sulfate at the Blacktail Mt. Rd. site are assumed to be due to natural leaching from the highly mineralized soils covering the northwest portion of the watershed.

Benthic Algal Biomass

Generally speaking, benthic periphyton levels were low based on monthly sampling and/or observations from June – September 2002 (Table 11). Visible attached algae were found at no sites in June, only two sites in July, four sites in August and six sites in September, although in small amounts and often only on a fraction of the available substrate at each site. The algae found at most sites on most dates were diatoms, which appeared as a fine brown film on the cobbles. *Nostoc* sp., blackish-green, spherical colonies of alga, was consistently found at the Below Lost Lake site. *Cladophora* sp., the bright green filamentous alga that can be very prolific in nutrient rich water, was observed only at the Stoner Mouth site.

Chlorophyll-a levels were recorded as high as 240 mg/m^2 for one *Cladophora* dominated sample from Stoner Creek Mouth. However, of the 52 algae samples collected, only two replicates exceeded 150 mg/m^2 chlorophyll-a, the standard set for peak levels in the Clark Fork River. Four samples had ash-free dry weights (AFDW) greater than 25 g/m^2, but the majority were less than 10 g/m^2. The Stoner Creek Mouth site had the highest algae levels in August and September. The average chlorophyll-a level at Stoner Creek Mouth on September 11 was 137 mg/m^2. Chlorophyll-a, AFDW and selected statistics are presented in Table 11 for sites and dates where algae were present.

Not only did chlorophyll-a and AFDW levels vary greatly between sites and dates, but they were very variable within a site for a given date. The standard error as a percentage of the mean (a measurement of variability for a sample set) exceeded 20% for nearly all sites and dates where algae were collected, including values as high as 90%. For data to be useful in detecting trends in time and space, enough samples should be collected the standard error to be 20% or less of the mean (Watson, 2003). The sample size necessary to achieve that level of variability in Stoner Creek would be as many as 20 replicates per site. For the most part, algal biomass was too variable to distinguish between the sites and sampling dates, given the number of replicates collected. However, it is clear that in the summer of 2002, all sites (except Stoner Mouth in September) were well below the level defined as nuisance in the Clark Fork River (100 mg/m^2 summer average).

Macroinvertebrate Abundance & Community Composition

This section summarizes the results of the benthic macroinvertebrate bioassessment, specifically those that indicate impairment or degradation. A complete, detailed report of the findings, as written by Wease Bollman of Rhithron Associates, can be found in Appendix C.

Benthic macroinvertebrate assemblages collected in July 2002 generally suggest high water quality at all sites. Results also indicated that most sites had minimal instream and reach-scale habitat disturbance. Metric values and their associated bioassessment scores indicate that the North Creek above Lost Lake and Blacktail Mt. Rd. sites were unimpaired (fully supported designated uses) and all other sites were slightly impaired (partially support designated uses) (see Appendix C, Table 4 & Figure 1).

North Creek above Lost Lake received 100% of the maximum score in all criteria, indicating excellent water quality and habitat features with little or no human impact. Water quality and reach-scale habitat indicators also scored high at the South Creek above Lost Lake site. However, caddisfly taxa richness and "clinger" taxa richness were depressed, suggesting fine sediment deposition and a related decline in instream habitat diversity. South Creek does have finer-grained substrate than nearby North Creek. South Creek is slightly lower in elevation than North Creek, and in the past may have been influenced by the downstream beaver dams in Lost Lake, resulting in more fine sediment in the channel. Alternately, this may be due to Blacktail Mt. Rd., which parallels South Creek from the sampling site until it crosses the tributary one mile upstream.

The Below Lost Lake site had the lowest overall score (61%) of all sites. This site had the highest biotic index, which can indicate elevated temperatures or nutrient enrichment. However, Below Lost Lake had higher mayfly richness than any other site except North Creek, indicating excellent water quality. As discussed earlier, water temperatures and, to a lesser extent, nutrient concentrations were found to be higher at this site than others. A certain chironomid (midge) associated with *Nostoc* algae was found to be particularly abundant in the sample; as mentioned, *Nostoc* was found in relatively high amounts Below Lost Lake. The high number of filterers in the sample may indicate a natural influence from the upstream beaver ponds. Low stonefly richness may not be natural, however. Stonefly richness is associated with riparian cover, streambank stability and channel morphology, all of which have been compromised in the reach immediately above this site.

The results for the Blacktail Mt. Rd. site appear contradictory. This site had the lowest biotic index of any site other than North Creek, indicating excellent water quality, however only four mayfly taxa were found, the lowest of any site. This site had the highest taxa richness of any site, but the lowest overall invertebrate abundance. Only 260 organisms were found in the entire sample. All other sites contained at least 750 organisms. Inadequate sampling effort has been suggested as an explanation; however the collection protocol at this site was identical to other sites. Regardless, stonefly and caddisfly richness were high suggesting high quality reach and instream habitat.

The three downstream sites were all found to be slightly impaired, scoring between 67 and 78%. Indicators point to good water quality and habitat features at all three sites. There is a steady increase in the percent of tolerant taxa in the downstream direction, beginning in the headwaters and continuing through the three residential sites to the mouth (Appendix C, Table 4). From a low of 1.3% at North Creek, the percent tolerant taxa increases to 12.5% Below Lost Lake, 30% at Swiftheart Paradise, 45% at Stoner Creek Rd. and 60% at Stoner Mouth. Although there is not a reciprocal trend in the number of sensitive taxa, this may still indicate an overall downstream increase in human disturbance.

CHAPTER 5: DISCUSSION AND RECOMMENDATIONS

Regional and Historic Water Quality Comparisons

Water from Stoner Creek eventually runs into the Clark Fork River, which has been the subject of a voluntary nutrient reduction program (VNRP) since 1995. The EPA has accepted the VNRP as a nutrient TMDL. The VNRP has set targets for algal biomass and total and soluble forms of nitrogen and phosphorus; comparisons to Stoner Creek levels may be instructive. Aside from the extreme values recorded on July 8, all TP and TPN values from Stoner Creek fall below target values set for the Clark Fork River below Missoula for TP (40 micrograms/L) and TN (300 micrograms/L). All measured values of NOx (aside from South Creek above Lost Lake on September 11 which may be contaminated) fall well below the Clark Fork River target for Total Soluble Inorganic Nitrogen (TSIN) (30 micrograms/L). TSIN includes ammonia, but that is usually found in very low concentrations in a well-oxygenated environment like Stoner Creek (Ellis *et al* 1998, 2000, 2001); hence TSIN is mainly nitrates. The Clark Fork River target for soluble phosphorus (6 micrograms/L) is aimed at soluble reactive phosphorus (SRP), which differs from soluble phosphorus (SP), the parameter used in this study. SP is the combination of soluble reactive phosphorus and soluble unreactive (or soluble organic) phosphorus. Based on historic nutrient data, SP is roughly 2 to 4 times higher than SRP for various rivers in the Flathead Basin, including Stoner Creek (Ellis *et al* 1998, 2000, 2001). Stoner Creek SP concentrations ranged from 10 to 25 micrograms/L in 2002.

Stoner Creek flows directly into Flathead Lake, which also has established nutrient target levels as part of the TMDL process. Lake ecosystems are more sensitive than streams to nutrient enrichment due to longer residence times, warmer temperatures, less shading, rapid uptake by suspended algae, etc. Hence, Flathead Lake nutrient targets are lower than Clark Fork River targets. All TP values from the Stoner Creek sites are above the TMDL targets set for Flathead Lake for TP (5 micrograms/L). All but one of the TN values at North and South Creek above Lost Lake fall below the Flathead Lake TMDL target (95 micrograms/L), but nearly all the values for the other five sites exceed it. The Flathead Lake target likewise uses SRP (0.5 micrograms/L), however at a much lower level than the Clark Fork River target, so Stoner Creek SP values exceed this target regardless of the actual SRP:SP ratio. While nutrient levels from Stoner Creek generally exceed the TMDL targets for Flathead Lake, keep in mind the creek contributes relatively little of the nutrient load to the lake, and hence its high concentrations are quickly diluted. The lake's nutrient target levels are probably over-protective for the creek itself.

There is little historic water quality data available specifically on Stoner Creek. The Flathead National Forest conducted some water quality monitoring from the late-70s to mid-80s on the two tributaries referred to as North Creek and South Creek above Lost Lake in this study. Values for discharge, temperature, TSS, turbidity, pH, conductivity and trace metals from 2002 fell within the range of historic values. Any more stringent comparison of average values would not be prudent due to differences in sampling dates and water years.

The Flathead Biological Station collected nutrient data intermittently from sites on Stoner Creek from August 1995 to August 1996 (Stanford *et al* 1997). Nutrient concentrations from 2002 fell within the range of these historic data. The Biostation sampled four sites during that year ranging from above Lost Lake to the mouth of Stoner Creek. No definitive downstream trend was observed in either total or soluble nitrogen or phosphorus. Interestingly, values for soluble reactive phosphorus in 1995-1996 were highest at the most upstream site, above Lost Lake – similar to what was found with soluble phosphorus in 2002. The Biostation also monitored nutrient levels in 1996 on Dayton Creek, another west-side tributary to Flathead Lake of similar size to Stoner Creek. Soluble and total phosphorus and nitrogen were no higher at Stoner Creek sites than they were on Dayton Creek sites. In fact, SRP values on Stoner Creek were roughly half of SRP values on Dayton Creek for comparable dates.

The Biostation also sampled the mouth of Stoner Creek for total and soluble nutrients, turbidity and TSS during the 1998, 1999 and 2000 water years (Ellis *et al* 1998, 2000, 2001). Once again, measurements made during the 2002 water year fell within the range of these historic data. Biostation data from these years show average total and soluble nitrogen levels for Stoner Creek considerably lower than those for the Stillwater River and Ashley Creek, and roughly on par with levels for the Flathead River and Swan River, all tributaries of Flathead Lake. Average total and soluble phosphorus values for Stoner Creek are higher than all tributaries except Ashley Creek, which receives the Kalispell Sewage Treatment Plant wastewater discharge.

Current Conditions & Potential Future Problems

In 2002 upper Stoner Creek exhibited high water quality for the parameters investigated - nutrients, temperature, TSS, attached algae levels and macroinvertebrate communities. The macroinvertebrate bioassessment interpretations suggested that North Creek above Lost Lake, in particular, approached reference conditions. There is some evidence of a slight decline in water quality in the downstream direction, mainly from biotic data: the three most downstream sites were "slightly impaired" according to the macroinvertebrate assessment and significantly higher algae levels were found at the Stoner Creek Mouth site in September.

Apparently, Stoner Creek's high levels of soluble phosphorus are a natural phenomenon. Land use in the lower elevations of the watershed has not elevated phosphorus levels in the creek – indeed, SP levels are highest at the upstream sites. The argument could be made that timber harvest in the watershed has increased phosphorus levels in the creek, but this claim has not been validated. Dayton Creek has equally high or higher levels of phosphorus, and its watershed has not been clearcut to the extent of the Stoner Creek watershed (Stanford *et al* 1997). In addition, declining timber harvests and the implementation of Best Management Practices (BMPs) and the Streamside Management Zone (SMZ) should decrease logging impacts to the creek compared to historic conditions (MDEQ 2002). However, these naturally high phosphorus levels mean the stream has the potential for much higher algae levels if other limiting factors (i.e., light or nitrogen) become more available.

Current nitrogen levels in Stoner Creek are within regional expectations. Soluble nitrogen to soluble phosphorus ratios less than five indicate nitrogen limited algal communities (Watson, personal communication, 2003). Of the 35 nutrient samples collected in 2002, all had NOx:SP ratios of 1.5 or lower, suggesting a nitrogen limited system. Hence, any increase in soluble nitrogen loading, due to residential development, grazing or logging impacts, would likely create conditions favorable for increased algal growth which could be detrimental to water quality and aquatic life. In such a nitrogen-limited system, nitrogen loading could increase without a measurable rise in soluble nitrogen in the stream because algae will take up all available nitrogen – therefore monitoring of algae and total nitrogen levels, as well as soluble nitrogen, is advised.

Algal growth is also limited by shading of the creek by the riparian canopy. Removal of riparian vegetation may increase algae levels or even produce *Cladophora* blooms, as was seen in polygon E (see Appendix C, Figures 22e & 22f). Fortunately, the vast majority of the riparian zone along Stoner Creek is in good to excellent condition. The riparian zones on the properties surrounding Lost Lake are an exception. This area should be considered a high risk for degradation based on already impaired conditions, suitability for grazing and the fragile nature of wetland systems. Residential development of creek-front property has the potential to degrade riparian vegetation as well, as seen in polygons L and N.

Residential Development Impacts

The recent growth in population and housing experienced in Flathead County should be expected to continue in Stoner Creek watershed, especially when Plum Creek Timber begins selling its holdings. Improper septic system installation (or failures) and lawn fertilizer application have the potential to increase nutrient loads. Based on the similar nutrient levels seen at the three downstream sites, there appears to be no noticeable contamination of Stoner Creek surface water from existing septic systems at the present time. This may be due to soils conducive to septic system performance, favorable groundwater flow direction, or the low density of existing drainfields. Alternatively, it may be due to algal uptake: the higher levels of benthic algae near the mouth may be taking up nutrients from inflowing groundwater before it can elevate stream levels. The cumulative effects of an increased number of septic systems in the watershed may eventually become detectable, however. The sewer district may need to be expanded at some point, but the cost involved in increasing facility capacity and extending district boundaries make expansion not likely, at least in the short term.

Current Flathead County installation standards seem to be adequate for the present number of on-site septic systems. Flathead County has septic regulations on par with state standards: drainfields must be set back at least 100 feet from 100-year floodplains, and the depth to groundwater can be no less than 4.5 feet. At a minimum, these standards must be enforced to minimize the chance of groundwater, and surface water, contamination as the population grows. In addition, the Lakeside Community Council should ensure that homeowners with on-site waste disposal are informed about proper maintenance of their septic systems. Information about pumping frequency, typical lifespans, water overload, avoiding root damage and soil impaction, and substances to avoid putting in the system can be obtained through the Montana Department of Environmental Quality and MSU Extension Services.

The construction of roads, driveways and rooftops that come with new housing will increase impervious surfaces in the watershed. The percentage of impervious cover in a watershed has been shown to be inversely correlated to the habitat and water quality of a stream. A literature review of the impacts of impervious surfaces and management strategies can be found in Appendix E. While impervious surface coverage is not currently an issue in Stoner Creek watershed, it may become one as housing density increases. It is recommended that residents proactively implement measures to prevent impervious surfaces from reaching detrimental levels. One possible approach would be to set allowable percentages of impervious surface coverage in portions of the watershed, and strive to meet those limits by zoning accordingly. There is a general lack of guidance when it comes to the location and type of development allowable in the Stoner Creek watershed. While development in the urban center of Lakeside is guided by the Lakeside Neighborhood Plan and subsequent formation of the Lakeside Zoning District, there is currently no land use zoning for most of the watershed. It is recommended that the Lakeside Community Council consider expanding the Lakeside Zoning District to include more of the Stoner Creek watershed. It is possible for growth to be planned and guided to minimize impacts to watershed resources while accommodating the needs and rights of landowners.

Fortunately, Flathead County subdivision regulations provide some measure of guidance and precaution to any development that does occur. These standards are applicable to any division of land in Stoner Creek watershed that results in one or more parcels under 20 acres (Flathead County 2000). As part of the subdivision application process, the potential developer must prepare an environmental assessment. This includes delineating natural water systems (i.e., streams, wetlands), providing soil descriptions from test holes, testing percolation rates, measuring depth to ground water and bedrock, estimating the amount of vegetation to be removed, addressing impacts to fish and wildlife and preparing measures to minimize habitat degradation. The developer must provide sewer hook-ups if the property is within a municipal sewer district boundary or expected to be within 5 years, or is a certain distance to existing sewer lines. During construction, temporary sediment control is required to limit surface runoff in accordance with county and state standards and regulations (Flathead County 2000). And, of course, septic system installation should be inspected and approved by a certified sanitarian.

Riparian Conservation and Restoration

The riparian zones of Stoner Creek are critical to the stream's health and should be protected. In addition to shading the stream, lowering water temperatures, hindering nuisance algae growth and stabilizing stream banks, riparian zones remove nutrients and sediment from surface runoff and shallow groundwater. A literature review of riparian buffers, discussing ecological benefits and design and management considerations, is presented in Appendix D. Protection of buffers can be achieved by mandate or landowner education. Given the general resistance to land use regulation in Flathead County, passing an ordinance may be a difficult political undertaking. An outreach program should be implemented by the Lakeside Community Council to educate the residents of Stoner Creek watershed about the numerous benefits of preserving native riparian vegetation. The cost of riparian education and outreach could be kept minimal by targeting residents who own streamside property, real estate firms selling streamside property, developers building on streamside property and the local conservation district.

While education would go a long way to halt or reverse riparian degradation, the riparian polygons that were found to be impaired by this study would surely benefit from restoration or conservation efforts. A conservation strategy should be implemented for the property around Lost Lake. Of course, this will largely depend on the willingness of the landowner. The strategy could be to adopt grazing practices prescribed by the Montana Natural Resource Conservation Service, if not already in place. Grazing BMPs include reducing stocking rates, utilizing short-duration or seasonal grazing and livestock exclusion (Marlow *et al* 2000). Ideally, a conservation easement would be applied to this unique piece of land, protecting the wetlands and their ecological function for water quality, wildlife and future generations of Lakeside residents.

Polygon E will likely repair itself if the adjacent pasture is no longer used for grazing, or at least rested for a number of years. This process could be hastened with a streamside revegetation project (i.e., planting willow cuttings), again depending on the plans and receptivity of the landowner. Restoration of riparian vegetation on this reach could be achieved for a relatively small investment of labor and materials, and could be a valuable educational tool. Polygons L and N were not as impaired and would not provide the potentially dramatic results of restoration of polygon E. The riparian zones in these reaches would also regenerate naturally, but would nonetheless benefit from revegetation. The Youth With A Mission (YWAM) organization has expressed desire to be an active member of the Lakeside community and would possibly be receptive to education and/or restoration opportunities. As additional incentive, efforts on polygon L on the YWAM property have the potential to improve nearly one-half mile of creek front property.

Restoration efforts on polygon N, behind the Ace Hardware in downtown Lakeside, would have the benefit of high visibility.

Further Study and Monitoring

As evident from the spikes that coincided with the rain event on July 8, 2002, the majority of nutrient and sediment loading during the summer is associated with high rates of overland flow and/or bank wasting caused by the rapid rise in creek stage. Since sampling during 2002 did not coincide with the peak in the hydrograph, it is unknown how loading during spring runoff compares to loading during summer storms. In order to more accurately describe the loading contribution of Stoner Creek to Flathead Lake, samples should be collected near the mouth during peak flows in the spring and intense summer storms. Ideally, due to the short time between rain events and stream stage response, a local resident would be trained and equipped to perform this sampling. Water quality and discharge sampling during a high water year may also yield informative results. Staff gage readings would be necessary to compare hydrographs between years. Stream stage should be recorded daily during the spring rise and fall of the hydrograph and otherwise weekly. A permanent temperature logger can be installed cheaply to monitor yearly variations in stream temperature.

Any riparian revegetation efforts should be monitored to determine effectiveness (i.e., planting survival rates, algae level or water temperature decreases, reduced streambank erosion rates). Comparisons of baseline, pre-restoration conditions to post-restoration conditions will help improve any necessary future restoration efforts, not only on Stoner Creek, but throughout the Flathead Basin. Likewise, the effects of any prescribed grazing practices that may be implemented around Lost Lake should be carefully evaluated. Photodocumentation of algae levels and riparian areas can aid in qualitative assessments.

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APPENDIX A: TABLES AND FIGURES

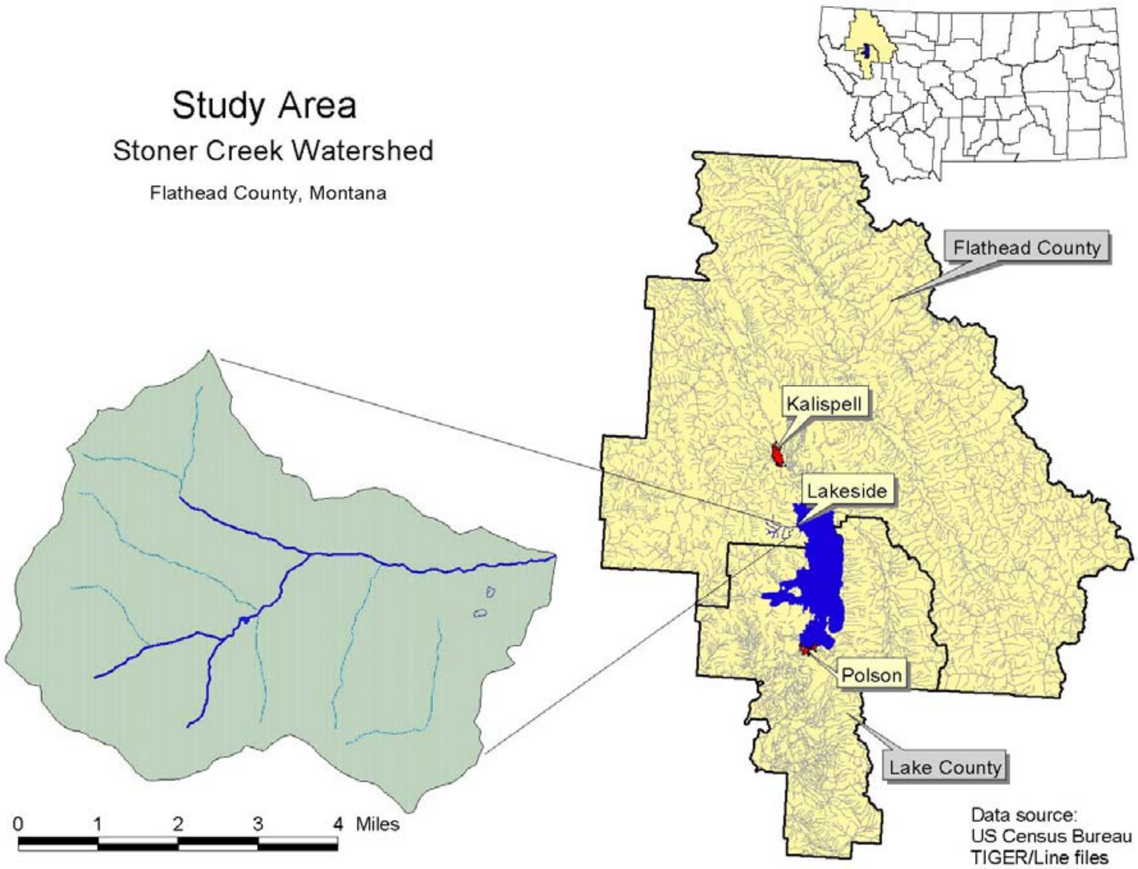

Figure 1. Study area, Stoner Creek watershed assessment, summer 2002.

APPENDIX A: TABLES AND FIGURES

Table 1. Summary of 303(d) listing for Flathead Lake. (Source: MDEQ 2002).

Description:	FLATHEAD LAKE				
EcoRegion(s):	Northern Rockies	**Hydro Unit:**	17010208		
County(s):	LAKE	**Basin:**	Columbia		
		Watershed:	Flathead		
Beneficial Uses:	**Fully**	**Threatened**	**Partial**	**Not Supporting**	**Not Assessed**
Agriculture	**X**				
Aquatic Life Support			**X**		
Cold Water Fishery - Trout	**X**				
Drinking Water Supply	**X**				
Industrial	**X**				
Primary Contact (Recr)	**X**				

Probable Causes:	**Probable Sources:**
Algal Growth/Chlorophyll a	Municipal Point Sources
Mercury	Silviculture
Metals	Urban Runoff/Storm Sewers
Nutrients	Hydromodification
Organic enrichment/Low DO	Upstream Impoundment
PCBs	Flow
Siltation	Regulation/Modification
	Atmospheric Deposition

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Table 2. Population growth in Montana and Flathead County since 1960.
(Data source: US Census Bureau)

Year	Montana	Yearly % Increase	10-year % Increase	Flathead County	Yearly % Increase	10-year % Increase
1960	674,767			32,965		
1970	694,409		2.9	39,460		19.7
1971	711,000	2.4		40,900	3.6	
1972	719,000	1.1		41,200	0.7	
1973	727,000	1.1		41,800	1.5	
1974	737,000	1.4		42,900	2.6	
1975	749,000	1.6		44,900	4.7	
1976	758,000	1.2		46,200	2.9	
1977	771,000	1.7		47,500	2.8	
1978	784,000	1.7		49,800	4.8	
1979	789,000	0.6		51,500	3.4	
1980	786,690	-0.3	13.3	51,966	0.9	31.7
1981	795,325	1.1		52,407	0.8	
1982	803,984	1.1		52,662	0.5	
1983	814,029	1.2		53,869	2.3	
1984	820,904	0.8		56,075	4.1	
1985	822,320	0.2		57,662	2.8	
1986	813,738	-1.0		57,767	0.2	
1987	805,064	-1.1		57,337	-0.7	
1988	800,200	-0.6		57,608	0.5	
1989	799,634	-0.1		58,437	1.4	
1990	799,065	-0.1	1.6	59,218	1.3	14.0
1991	809,680	1.3		60,899	2.8	
1992	825,770	2.0		62,949	3.4	
1993	844,761	2.3		65,410	3.9	
1994	861,306	2.0		67,593	3.3	
1995	876,553	1.8		69,876	3.4	
1996	886,254	1.1		71,464	2.3	
1997	889,865	0.4		72,288	1.2	
1998	892,431	0.3		72,541	0.3	
1999	897,507	0.6		73,626	1.5	
2000	902,195	0.5	12.9	74,471	1.1	25.8

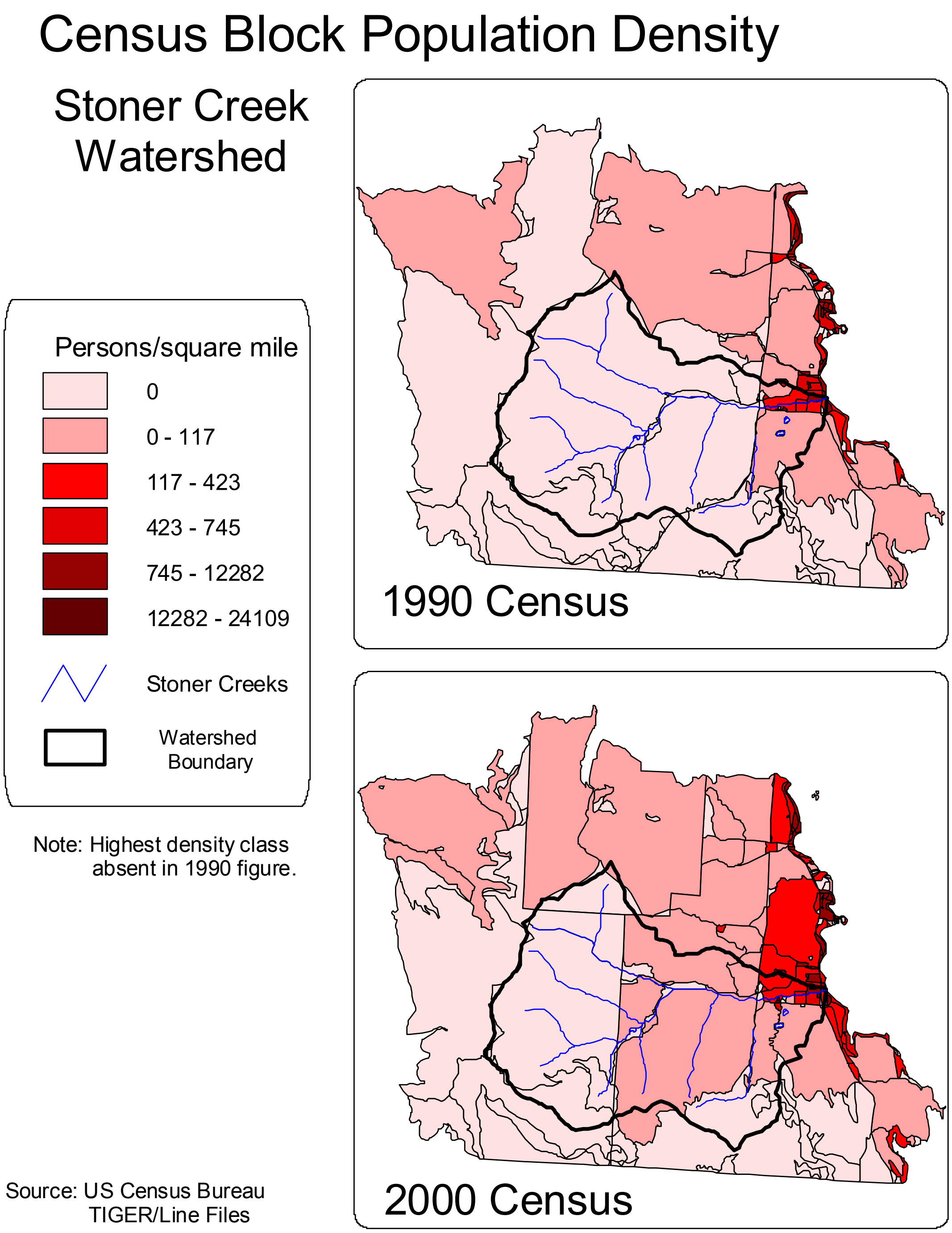

Figure 2. Census block population densities for Lakeside, MT, the Stoner Creek watershed and surrounding areas in 1990 and 2000.

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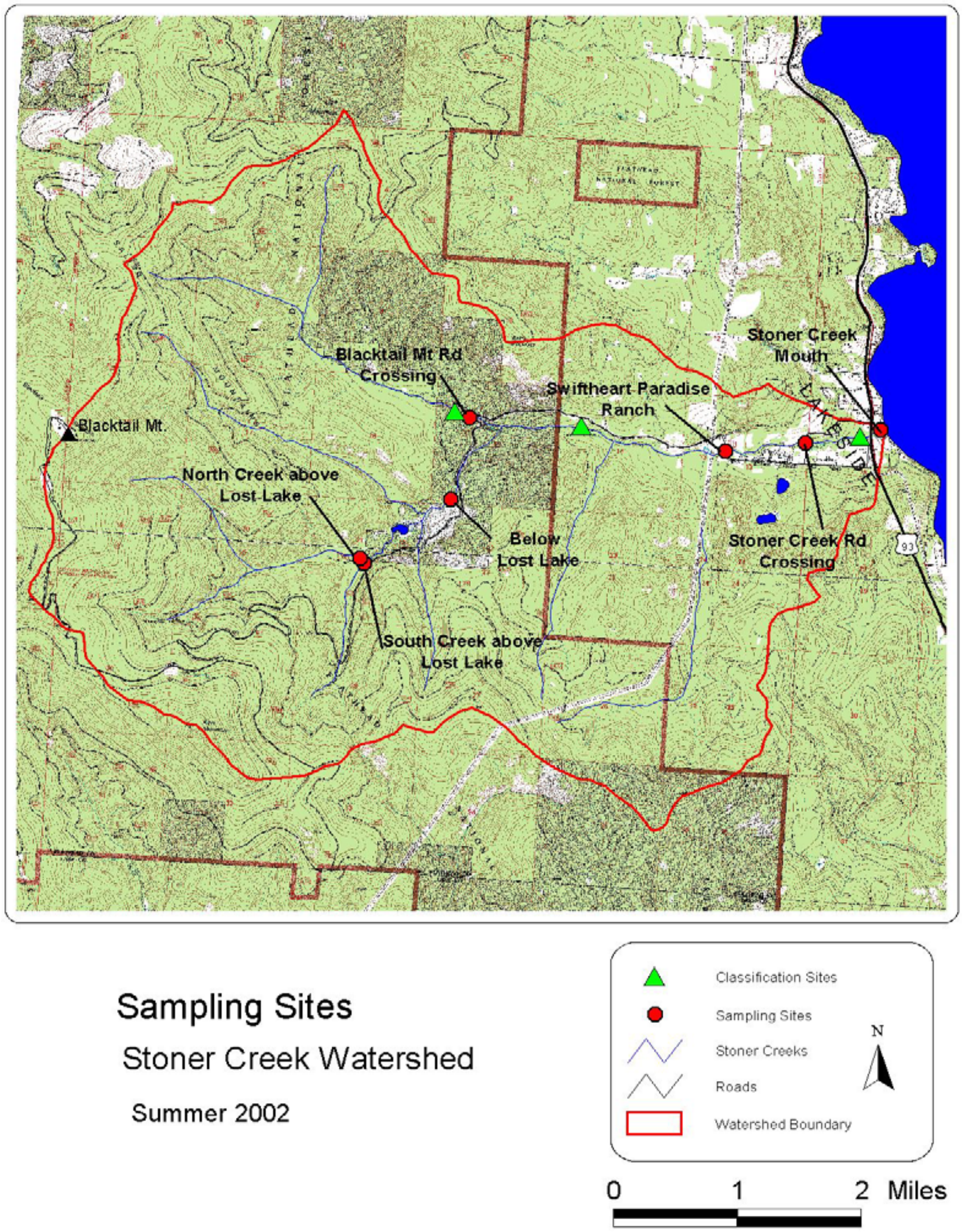

Figure 3. Sampling sites for water chemistry, macroinvertebrate and algae collection and Rosgen stream classifications, Stoner Creek watershed assessment, summer 2002.

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Table 3. Summary of water chemistry, algae and macroinvertebrate sampling sites used in Stoner Creek watershed assessment, summer 2002 (see Figure 3).

Site Name	Location (NAD27)	Elev. (ft)	Description	Rationale
South Creek (above Lost Lake)	47°59'58"1 14°18'36"	3915	Southern fork of South Fork above beaver ponds ("Lost Lake") near NFS property boundary	Headwater characterization; determine conditions as creek exits NFS land and enters private land
North Creek (above Lost Lake)	47°59'58" 114°18'36"	3918	Northern fork of South Fork above beaver ponds ("Lost Lake") near NFS property boundary	Headwater characterization; determine conditions as creek exits NFS land and enters private land
Below Lost Lake	48°00'22" 114°17'50"	3898	Appox. ¼ mile upstream from 2nd National Forest Road 917 crossing – approx 4.5 miles from US93	Examine effects of beaver pond/wetland complex and nearby land uses
Blacktail Mt. Rd. Crossing	48°00'56" 114°17'38"	3722	First graveled Blacktail Mt Rd (NFR 917) crossing (hairpin turn) - above culvert – approx. 3.5 miles from US93	Alternative headwater characterization; identify variability in stream condition due to geography, geology, land use
Swiftheart Paradise Ranch	48°00'49" 114°14'57"	3098	Paved Blacktail Mt Rd crossing (below Ranch) - above culvert – near mile marker 1	Characterize creek conditions upstream of residential development of Lakeside
Stoner Creek Rd. Crossing	48°00'54" 114°14'09"	3028	Stoner Creek Road Crossing – above culvert	Splits residential area in half – upstream mainly septic systems, downstream mainly sewer
Stoner Creek Near Mouth	48°01'03" 114°13'20"	2905	Above Lakeside Blvd bridge (samples) and above Hwy 93 culvert (discharge)	Determine effects of residential area; characterize water quality entering Flathead Lake

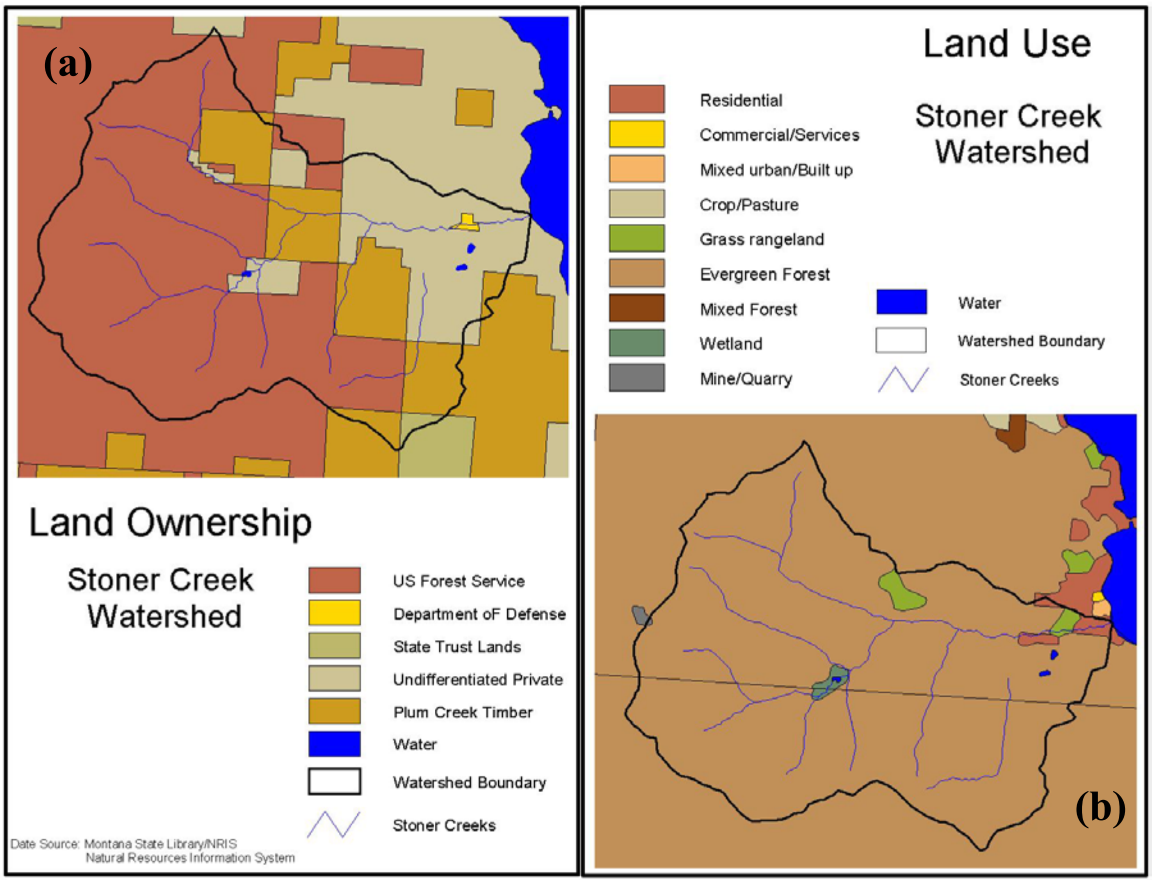


Figure 4. Land ownership (a) and land use (b) in Stoner Creek watershed, 2002.

APPENDIX A: TABLES AND FIGURES

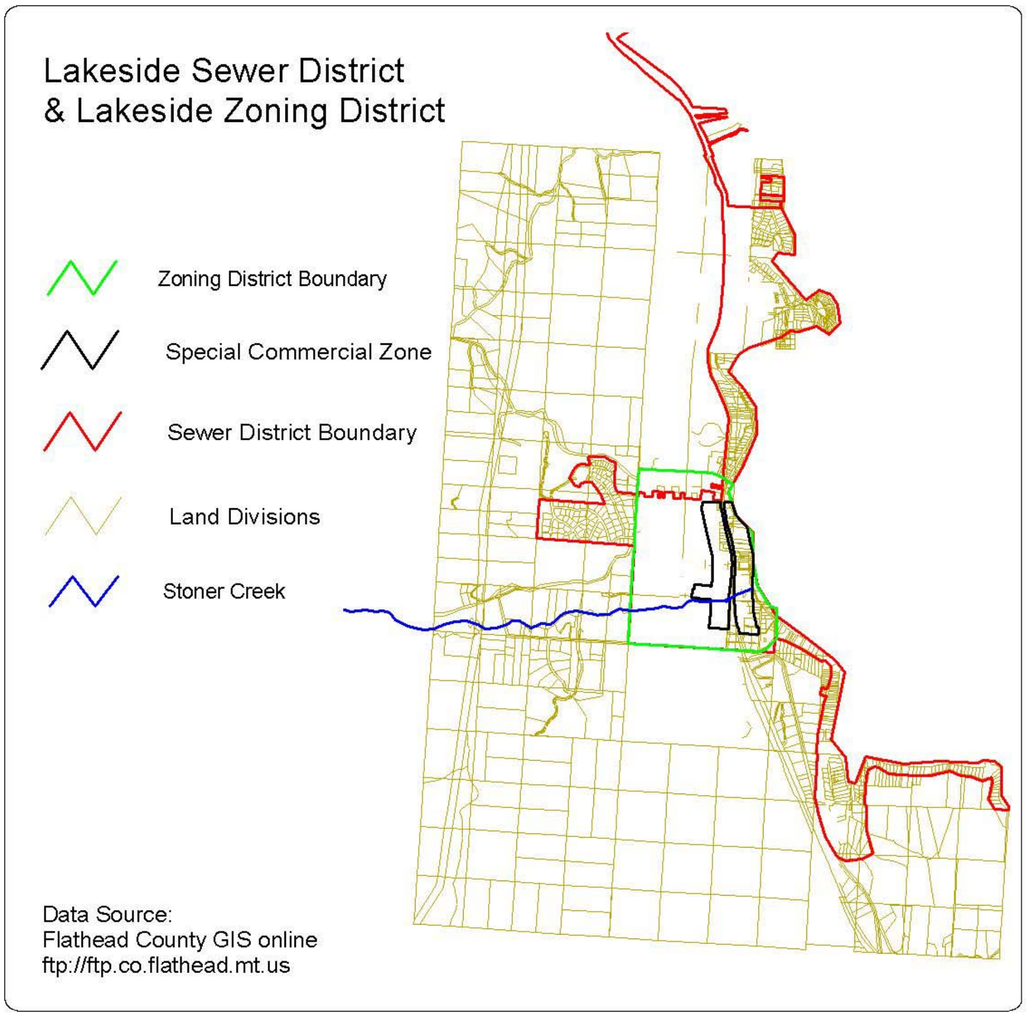


Figure 5. Lakeside sewer district and Lakeside zoning district.

APPENDIX A: TABLES AND FIGURES

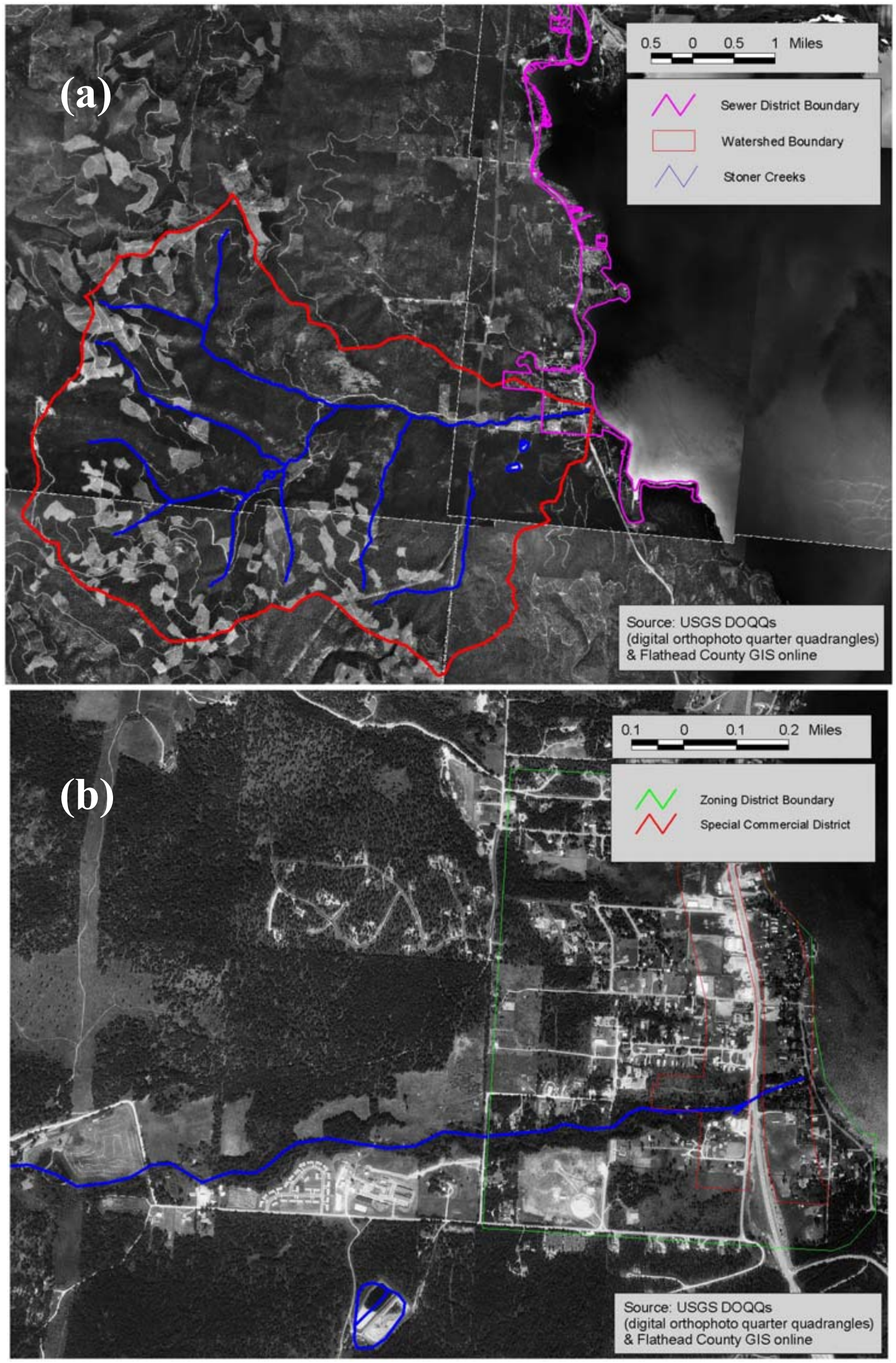
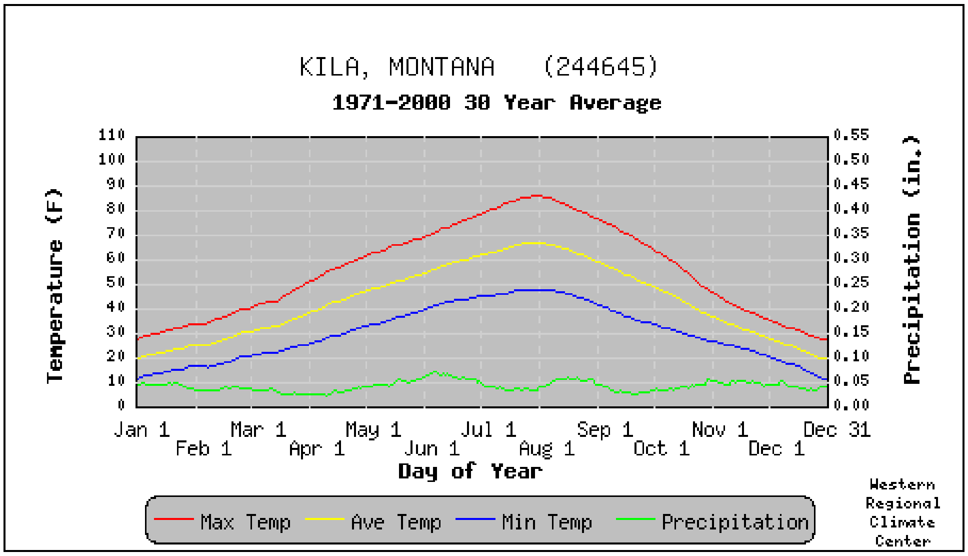


Figure 6. Lakeside sewer (a) and zoning (b) districts with Stoner Creek watershed boundary and digital orthophoto background showing clear cuts.

APPENDIX A: TABLES AND FIGURES



Station Metadata:

Latitude:
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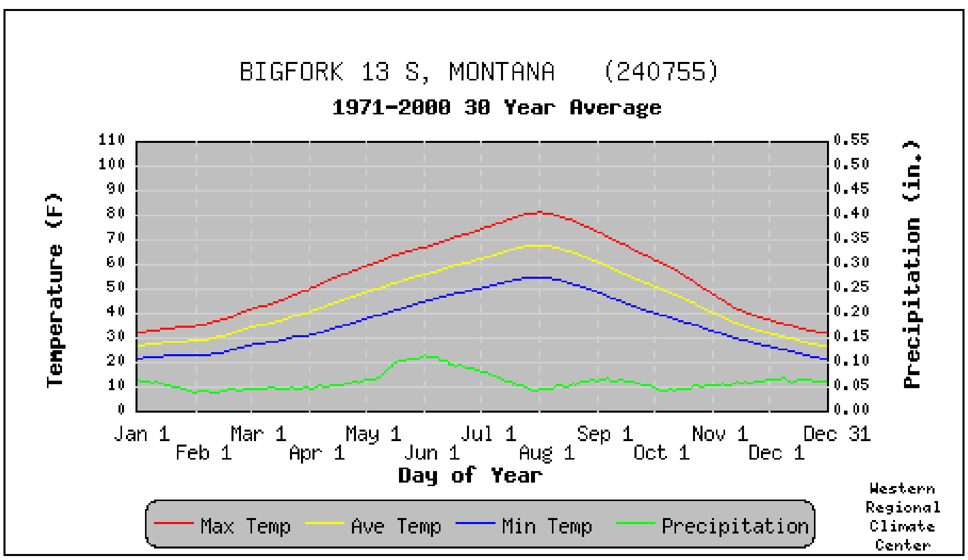
Longitude:
114.28

Elevation:
3260ft



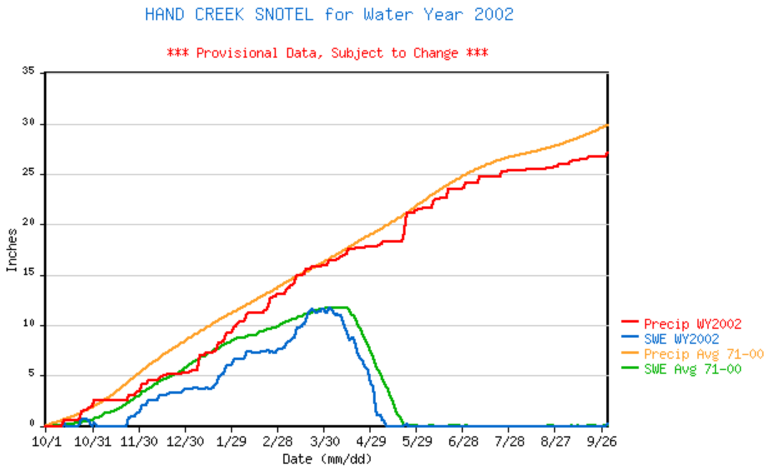
Station Metadata:

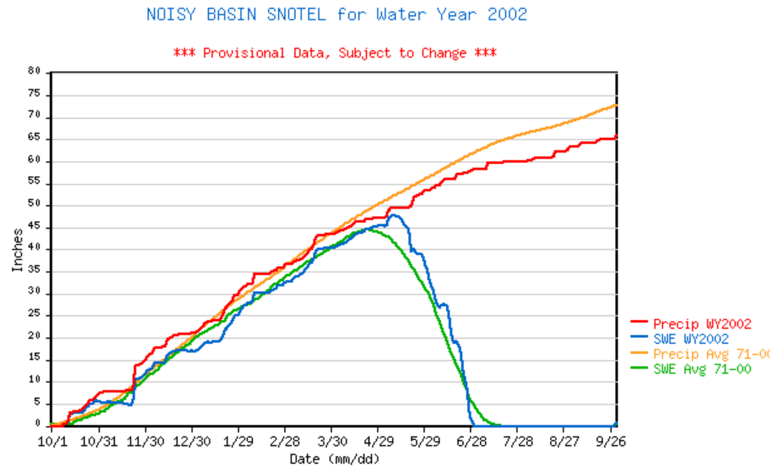
Latitude:
47.53

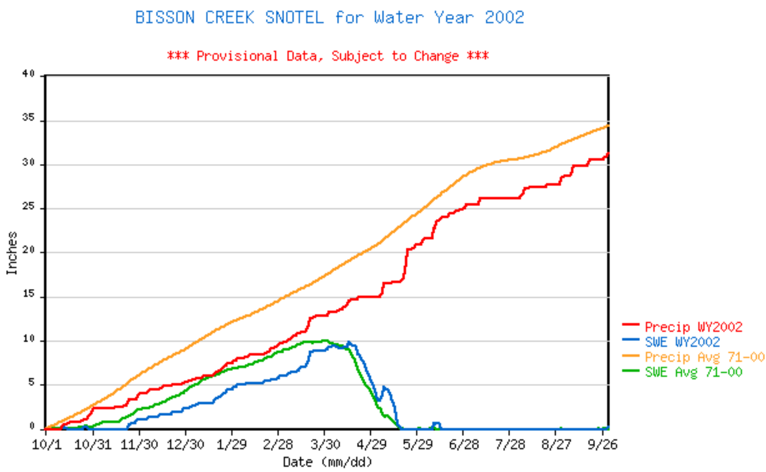
Longitude:
114.02

Elevation:
2910ft

Figure 7. Daily temperature and precipitation summaries for climate stations near Stoner Creek watershed. Source: NOAA's Western Regional Climate Center, www.wrcc.dri.edu/summary/climsmmt.html







SNOTEL Locations

Station: **HAND CREEK** (near Marion)
Latitude: 48.30
Longitude: 114.83
Elevation: 5035 feet

Station: **NOISY BASIN** (near Bigfork)
Latitude: 48.15
Longitude: 113.95
Elevation: 6040 feet

Station: **BISSON CREEK** (near Polson)
Latitude: 47.68
Longitude: 114.00
Elevation: 4920 feet

Figure 8. Precipitation and Snow Water Equivalent (SWE) for 2002 water year compared to 30-year average for the three SNOTEL stations nearest Stoner Creek watershed. Source: NRCS National Water and Climate Center www.wcc.nrcs.usda.gov/snotel

APPENDIX A: TABLES AND FIGURES

Table 4. Summary of riparian polygons used in Stoner Creek watershed assessment, 2002 (see Figure 10).

Polygon	Upstream Boundary	Downstream Boundary	Description	Date Assessed
A	47°59’25” N 114°20’39” W	47°59’31” N 114°20’25” W	Extreme upstream reach of North Creek above Lost Lake, near old pumping station	06/26/02
B	47°59’08” N 114°18’53” W	47°59’13” N 114°18’50” W	Upstream reach of South Fork above Lost Lake, upstream of FSR 719 crossing	06/26/02
C	47°59’58” N 114°18’36” W	47°59’57” N 114°18’39” W	Below confluence of N & S Creeks above Lost Lake, on private land	06/27/02
D	48°00’09” N 114°18’21” W	48°00’17” N 114°17’59” W	Beaver ponds & wetlands, aka Lost Lake	06/27/02
E	48°00’17” N 114°17’59” W	48°00’19” N 114°17’52” W	Pasture immediately downstream of Lost Lake	09/20/02
F	48°00’21” N 114°17’52” W	48°00’23” N 114°17’47” W	Upstream of FSR 917 crossing, Plum Creek land	09/20/02
G	48°00’23” N 114°17’47” W	48°00’27” N 114°17’45” W	Downstream of FSR 917 crossing, Plum Creek land	09/20/02
H	48°00’57” N 114°17’41” W	48°00’56” N 114°17’38” W	Upstream of FSR 917 hairpin turn (Blacktail Mt. Rd. crossing)	06/26/02
I	48°00’53” N 114°17’09” W	48°00’52” N 114°16’53” W	Below confluence of Stoner Creek proper and south fork tributaries, Plum Creek land	09/21/02
J	48°00’56” N 114°16’31” W	48°00’56” N 114°16’24” W	Private timber land immediately below Plum Creek property boundary	09/21/02
K	47°00’47” N 114°15’21” W	48°00’49” N 114°14’57” W	Above paved Blacktail Mt Rd crossing, behind Swiftheart Paradise Ranch	09/21/02
L	48°00’49” N 114°14’41” W	48°00’53” N 114°14’18” W	Youth With A Mission properties, south side of creek only	09/12/02
M	48°00’54” N 114°14’00” W	48°00’57” N 114°13’49” W	Behind old gravel pit (County transfer station)	09/12/02
N	48°00’58” N 114°13’43” W	48°00’59” N 114°13’29” W	Upstream of Hwy 93 crossing, behind Ace Hardware	09/12/02
O	48°00’59” N 114°13’29” W	48°01’03” N 114°13’20” W	Downstream of Hwy 93 crossing to creek mouth	09/12/02

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Table 5. Location, cross sectional measurements and substrate type for three transects used in Rosgen stream classification of Stoner Creek, summer 2002.

	Transect 1 Upper	Transect 2 Middle	Transect 3 Lower
Location – Latitude/Longitude (WGS84)	114°17'41" W 48°00'53" N	114°16'32" W 48°00'55" N	114°13'43" W 48°00'58" N
Bankfull Width (BFW)	4.1 m	4.5 m	4.5 m
Floodprone Width (FPW)	7.6 m	7.2 m	8.35 m
Bankfull Depth (BFD)	.7 m	.53 m	.62 m
Average Depth (AD)	.41 m	.37 m	.29 m
W/D Ratio (BFW/AD)	10.1	12.3	15.4
Entrenchment Ratio (FPW/BFW)	1.9	1.6	1.9
Median Grain Size Category	gravel	gravel	gravel
Rosgen Classification	**B4**	**B4**	**B4**

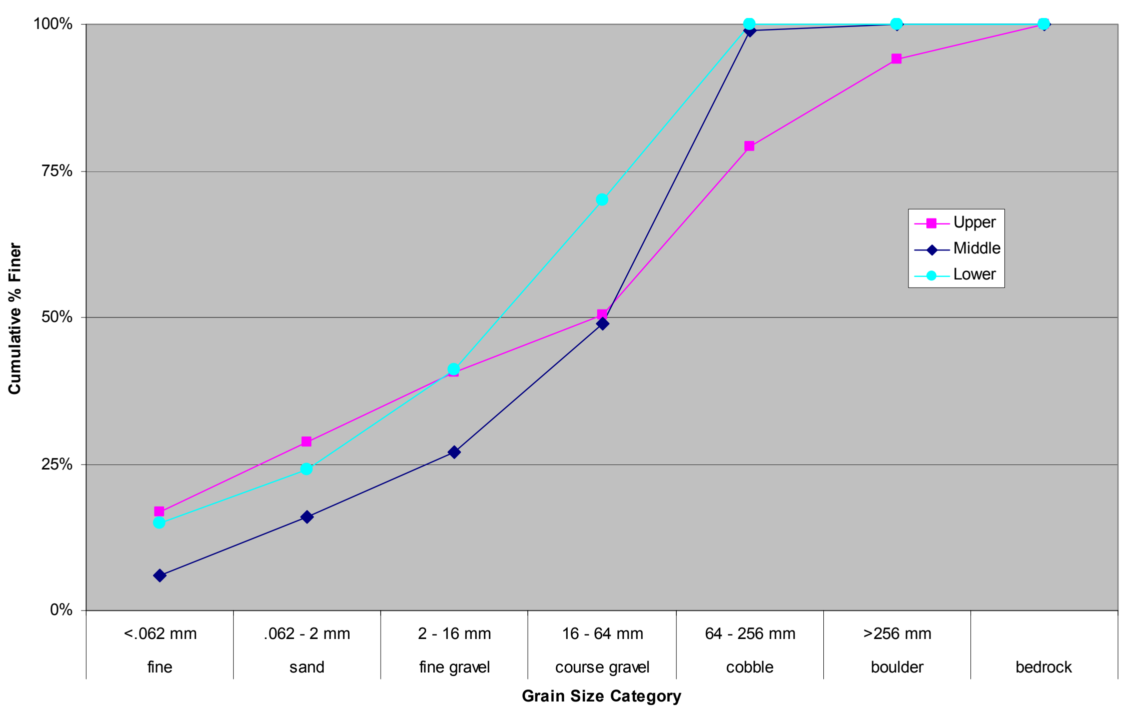

Figure 9. Substrate distributions for three transects used in Rosgen stream classification of Stoner Creek, summer 2002.

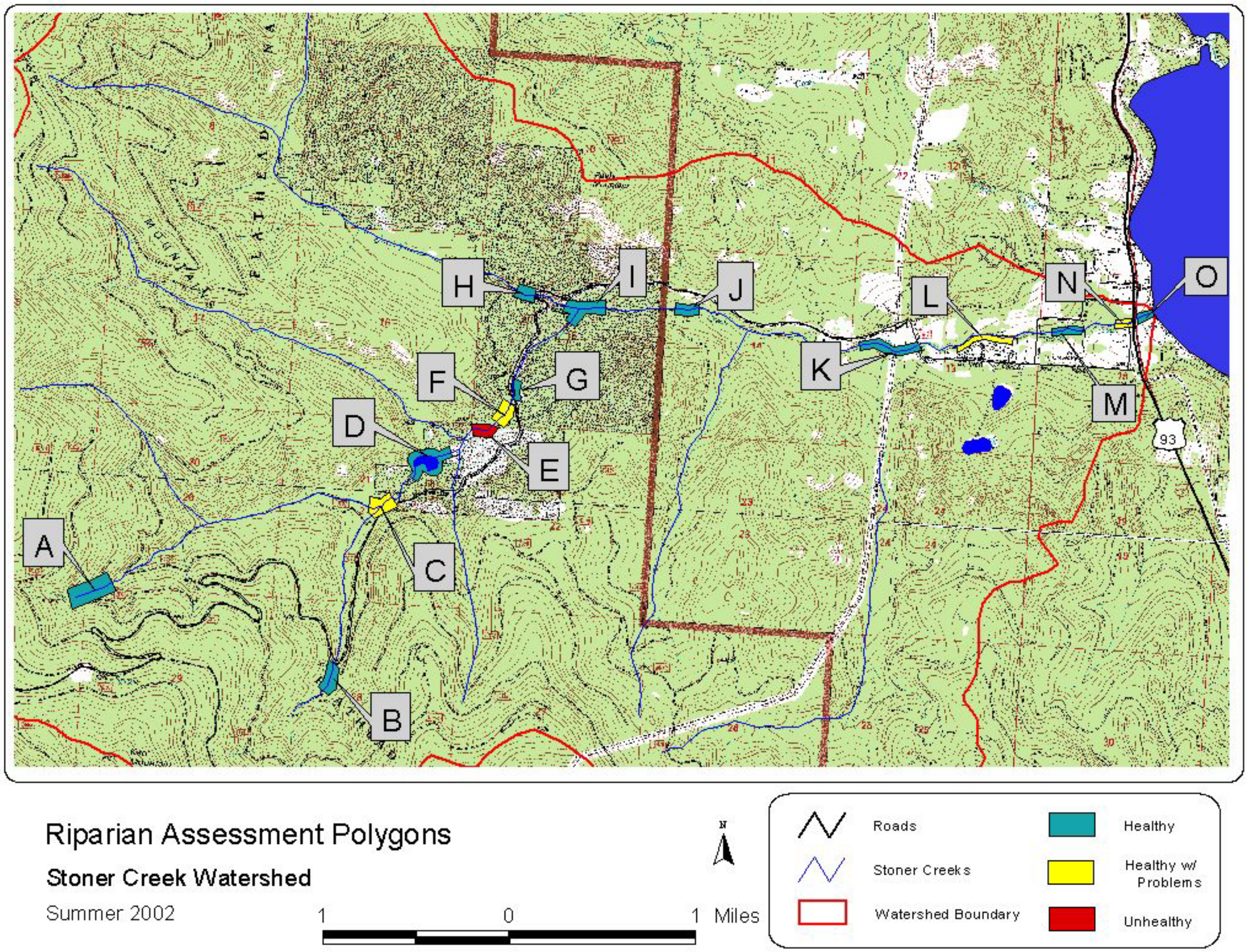

Figure 10. Riparian polygons and scores based on RWRP Lotic Health Assessment.

APPENDIX A: TABLES AND FIGURES

Table 6. Category and total scores from RWRP Lotic Health Assessment for 15 riparian polygons on Stoner Creek, summer 2002.

	POLYGON														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
CATEGORY															
veg cover	6	6	6	6	4	6	6	6	6	6	6	6	6	6	6
invasive	6	6	0	2	4	0	4	6	4	4	3	2	4	4	4
undesirable	3	3	1	2	0	0	3	3	3	3	2	2	3	0	2
regeneration	6	6	6	6	2	2	6	6	6	6	6	4	6	2	6
utilization	3	3	3	3	2	1	3	3	3	3	3	3	3	3	3
dead/decadent	3	3	1	3	3	3	2	3	2	2	3	3	3	3	3
root mass	6	6	4	6	0	6	6	6	6	6	6	2	6	2	6
vegetative	**33**	**33**	**21**	**28**	**15**	**18**	**30**	**33**	**30**	**30**	**29**	**22**	**31**	**20**	**30**
bare ground	6	6	6	6	2	6	6	6	6	6	6	6	6	4	6
bank alteration	6	6	6	6	2	6	6	6	6	6	6	4	6	4	0
pugging	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
incisement	9	9	9	9	3	6	9	9	9	9	9	9	9	9	9
physical	**24**	**24**	**24**	**24**	**10**	**21**	**24**	**24**	**24**	**24**	**24**	**22**	**24**	**20**	**18**
TOTAL	***57***	***57***	***45***	***52***	***25***	***39***	***54***	***57***	***54***	***54***	***53***	***44***	***55***	***40***	***48***
%	100	100	79	91	44	68	95	100	95	95	93	77	96	70	84

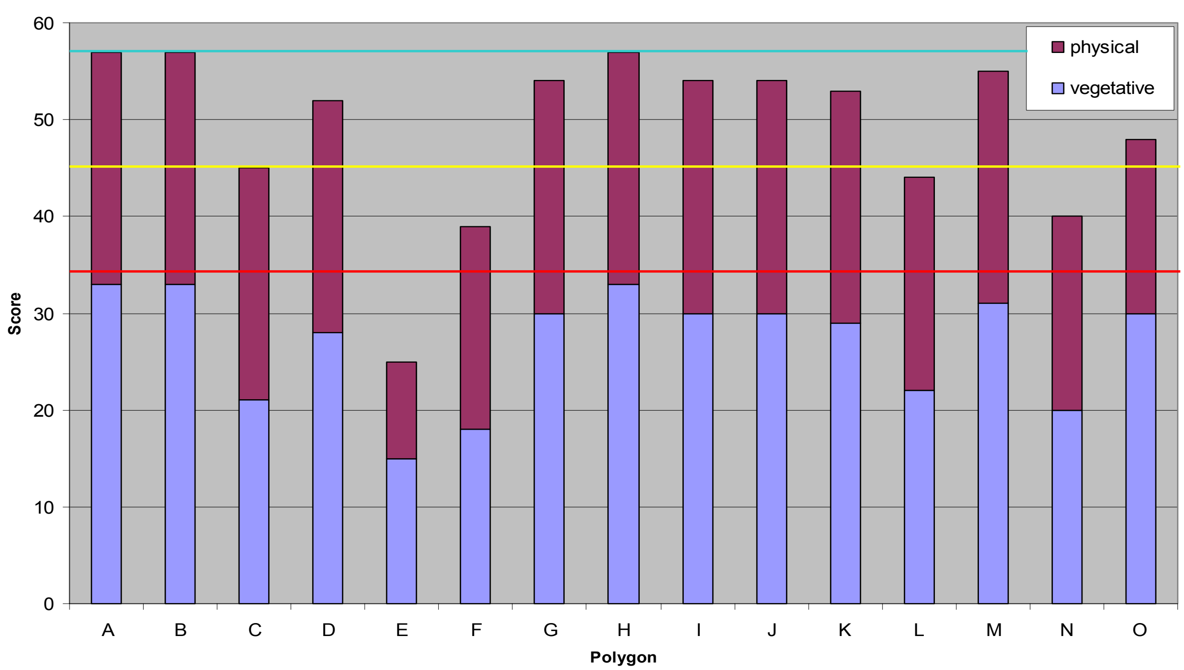

Figure 11. Overall scores (out of 57 possible points) from RWRP Lotic Health Assessment for 15 riparian polygons on Stoner Creek, summer 2002.

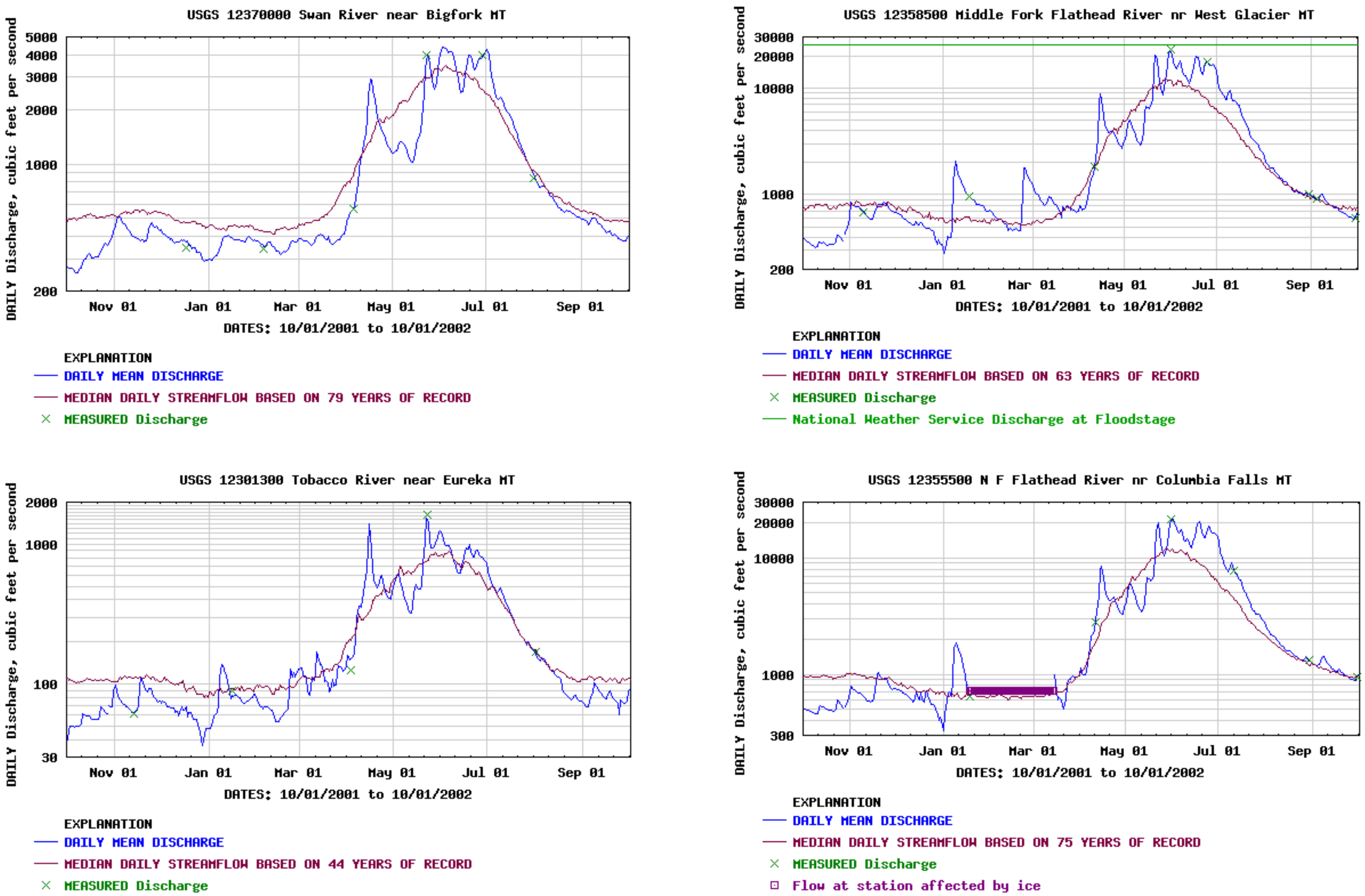

Figure 12. Hydrographs for 2002 water year compared to period of record average for USGS gauged sites near Stoner Creek watershed. Source: USGS Water Resources of Montana, waterdata.usgs.gov/mt/nwis/

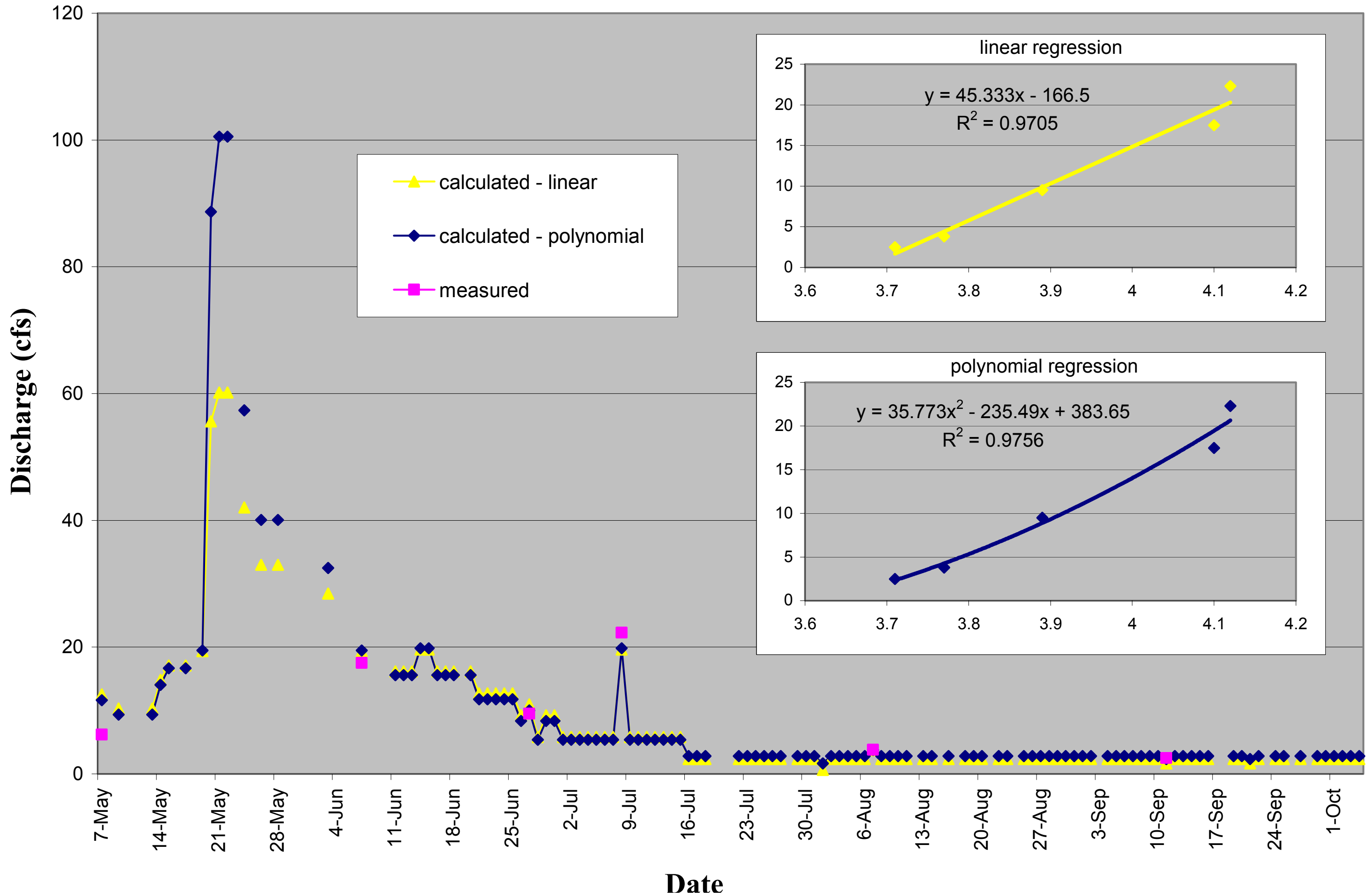

Figure 13. Constructed hydrograph for Stoner Creek, near mouth, summer 2002, based on linear (yellow) and polynomial (blue) stage-discharge regressions. Peak discharges are extrapolations and should be considered estimates.

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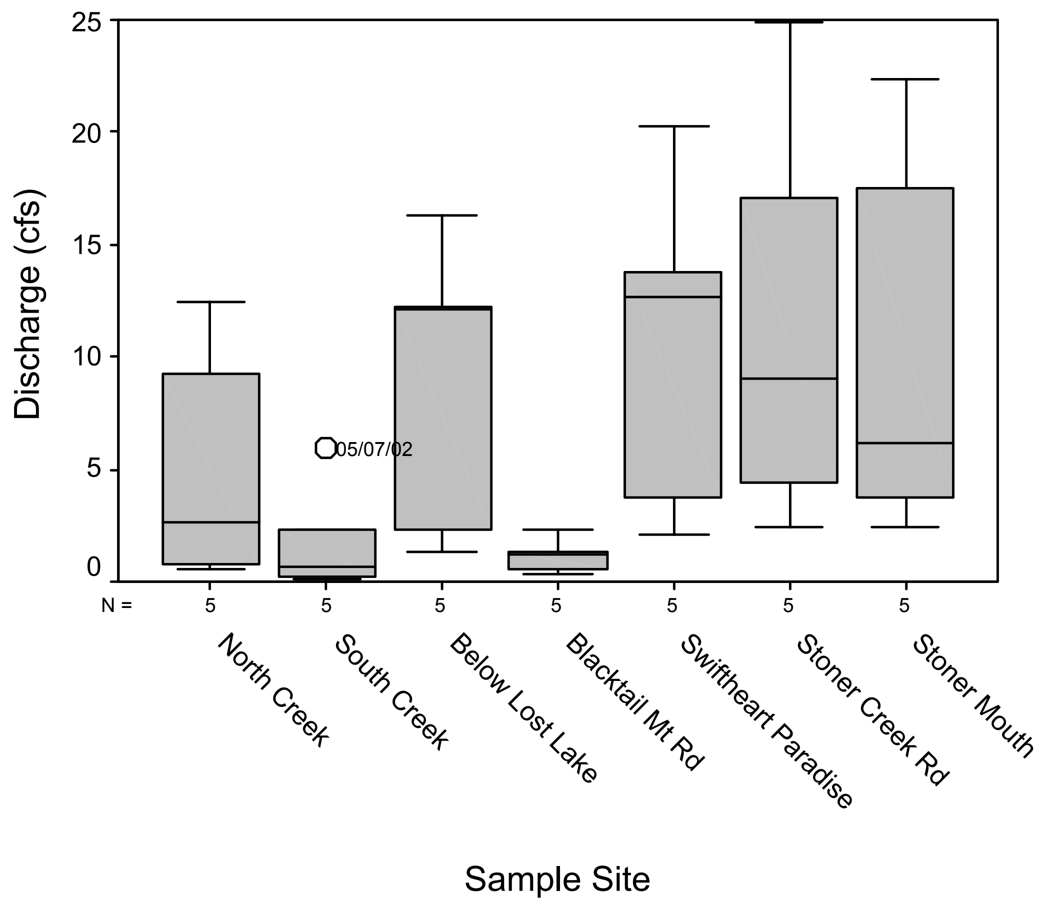

Figure 14. Boxplots of discharge distributions for sites on Stoner Creek and tributaries, as measured monthly, May-Sept, 2002.

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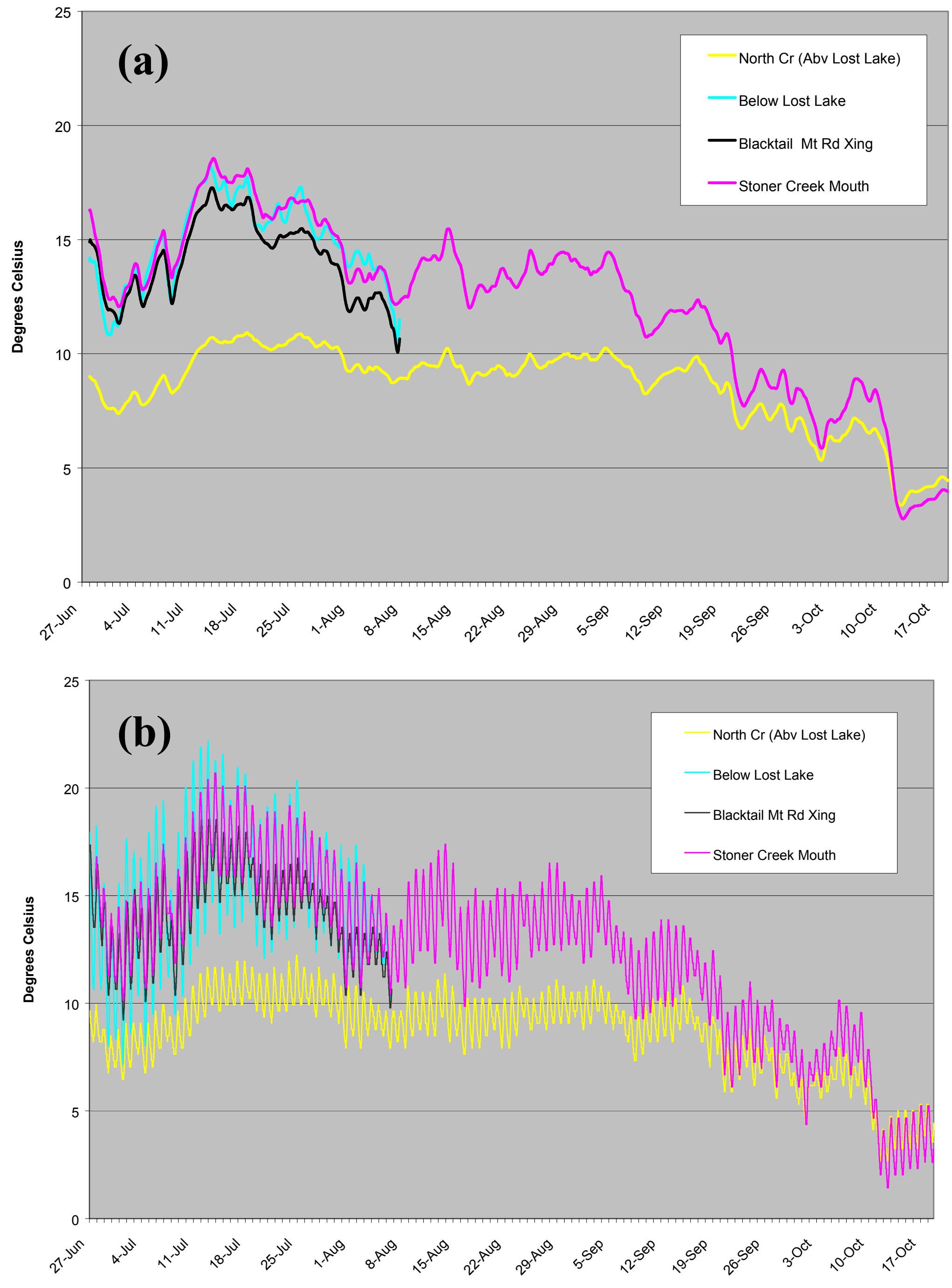

Figure 15. Water temperatures for four sites on Stoner Creek, July-Oct, 2002 as recorded every 15 minutes (b) and as a 24 hour moving average (a).

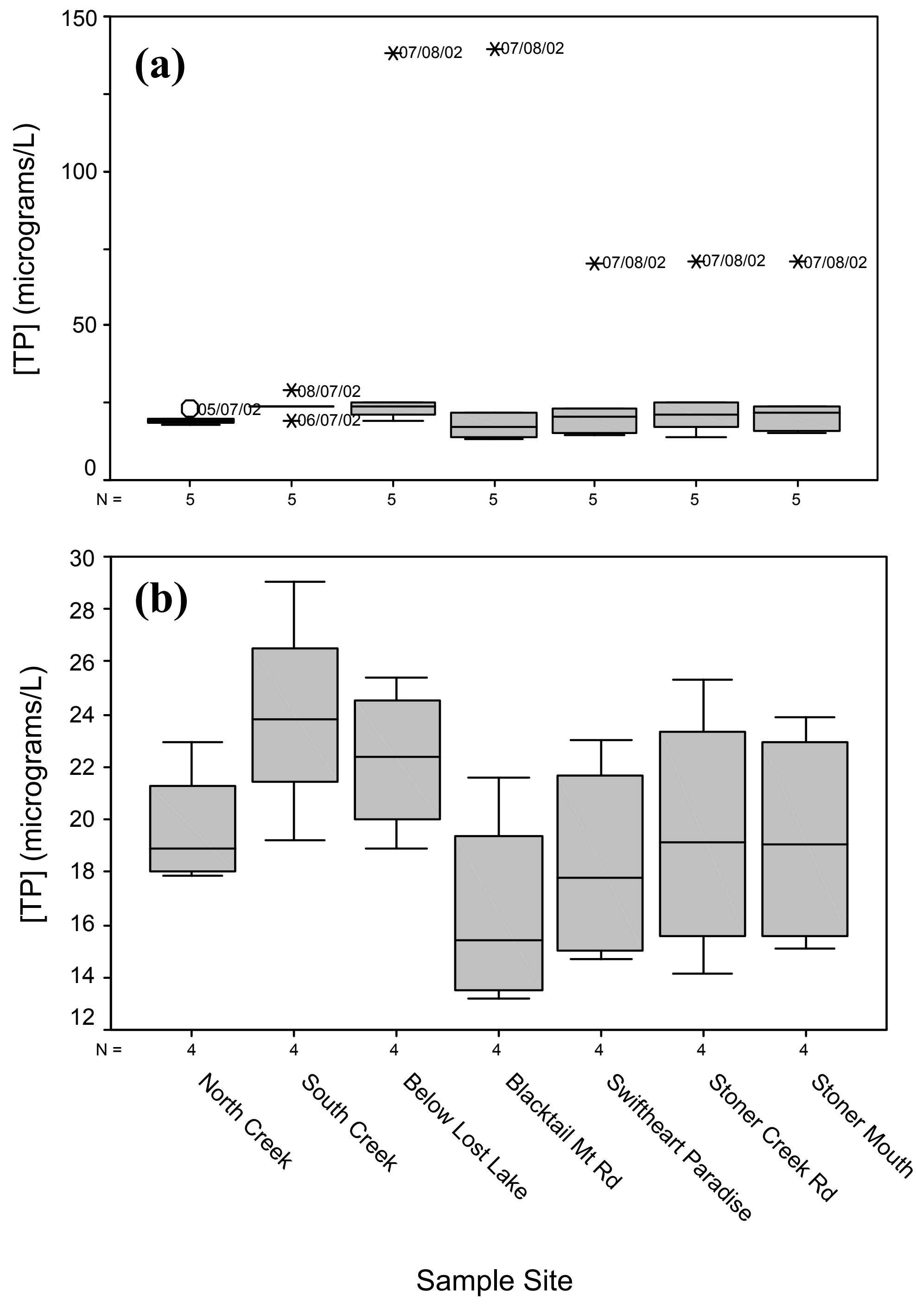

Figure 16. Total Phosphorus concentrations for sample sites on Stoner Creek in 2002: values from all samples, collected monthly, May-September (a) and values associated with precipitation event on 7/8/02 omitted (b).

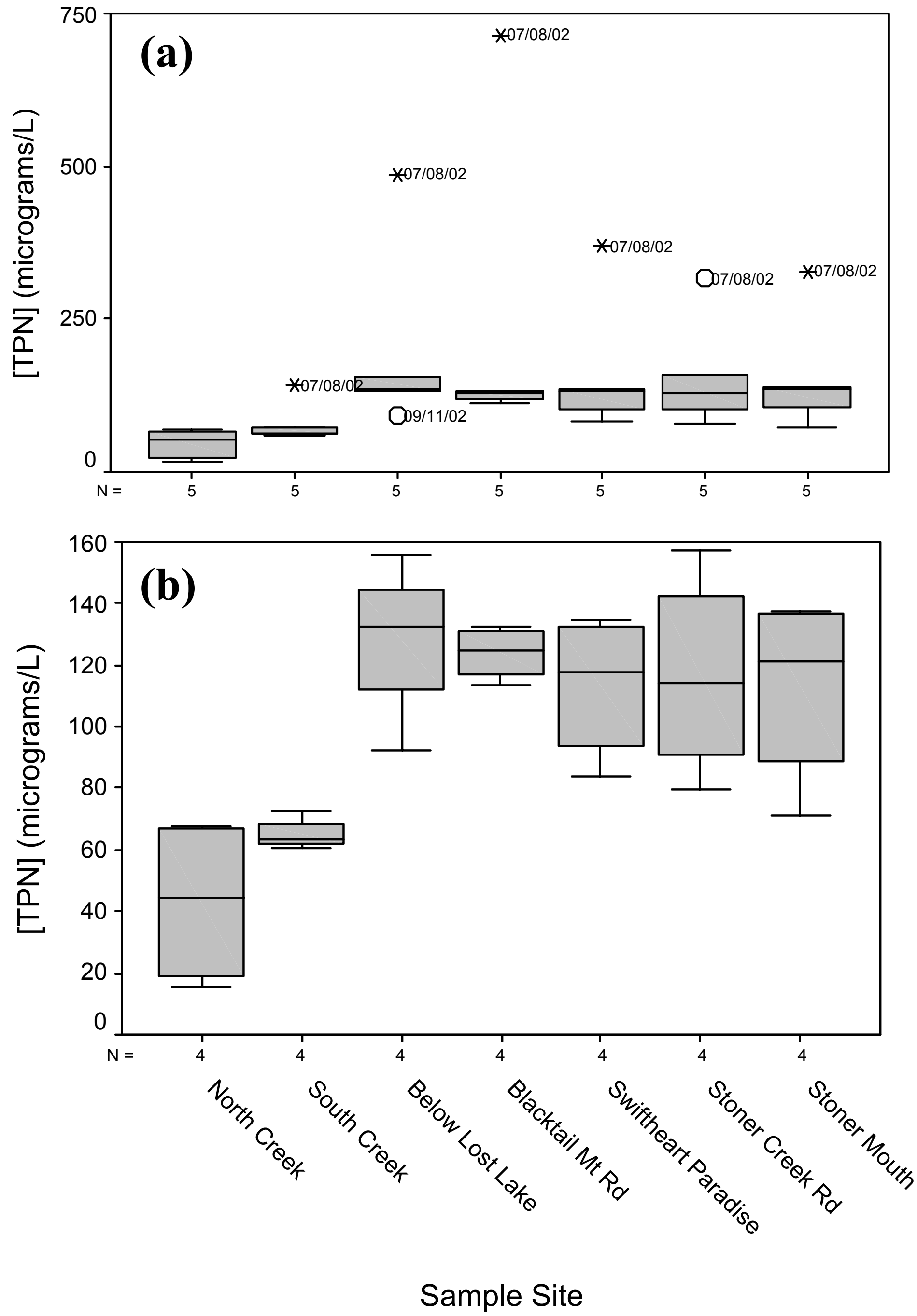

Figure 17. Total Persulfate Nitrogen concentrations for sample sites on Stoner Creek in 2002: values from all samples, collected monthly, May-September (a) and values associated with precipitation event on 7/8/02 omitted (b).

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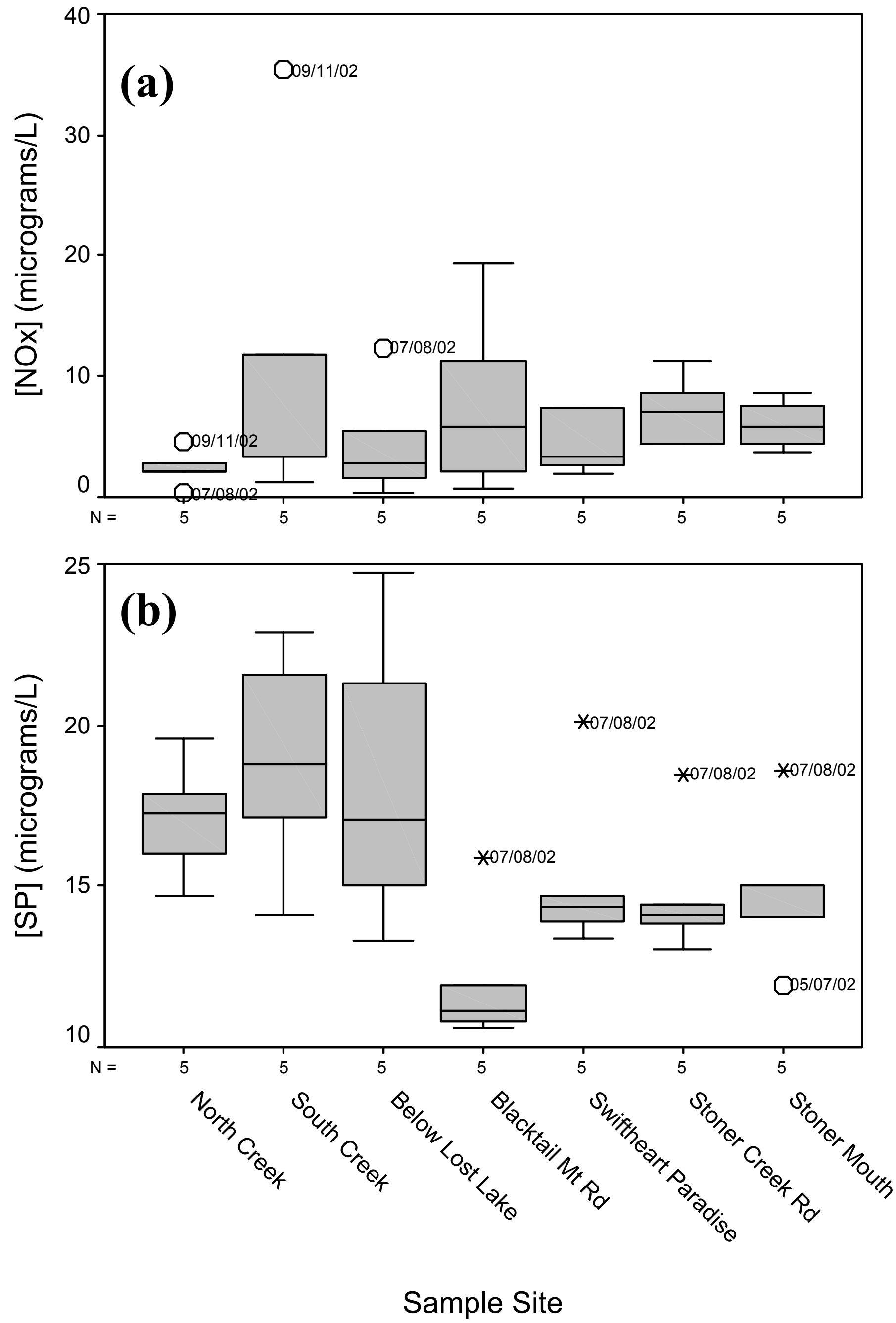

Figure 18. Nitrate & Nitrite (a) and Soluble Phosphorus concentrations for sample sites on Stoner Creek in 2002, collected monthly May-September.

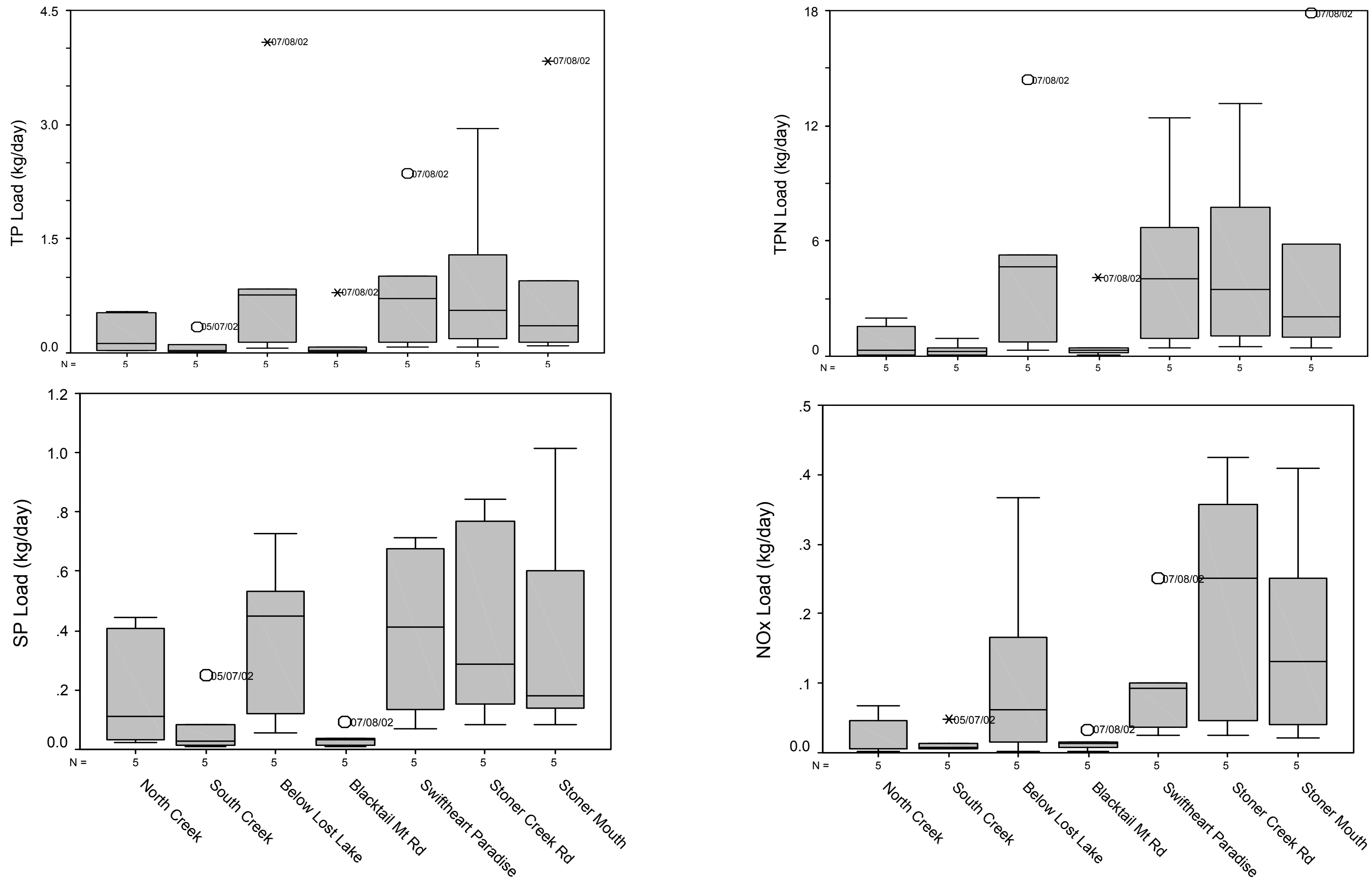

Figure 19. Loading estimates for Total Phosphorus (a), Total Persulfate Nitrogen (b), Soluble Phosphorus (c) and Nitrate+Nitrite (d) on Stoner Creek, 2002. Samples taken monthly May-September.

APPENDIX A: TABLES AND FIGURES

Table 7. Nutrient concentrations and load estimates of water samples collected monthly from Stoner Creek sites, May-Sept 2002, analyzed by Flathead Lake Biological Station.

Site	Date	Q (ft^3/s)	[NOx] ug/L	[SP] ug/L	[TP] ug/L	[TPN] ug/L	NOx kg/day	SP kg/day	TP kg/day	TPN kg/day
ncreek	5/7	9.3	2.1	17.9	22.9	67.8	0.05	0.41	0.52	1.54
ncreek	6/7	12.4	2.2	14.7	17.9	65.9	0.07	0.45	0.54	2.00
ncreek	7/8	2.7	0.3	17.3	19.2	51.8	0.00	0.11	0.13	0.34
ncreek	8/7	0.8	2.9	16.0	18.3	22.6	0.01	0.03	0.04	0.04
ncreek	9/11	0.5	4.6	19.6	19.6	15.8	0.01	0.02	0.02	0.02
screek	5/7	5.9	3.3	17.2	24.0	63.0	0.05	0.25	0.35	0.91
screek	6/7	2.4	1.2	14.1	19.3	72.3	0.01	0.08	0.11	0.42
screek	7/8	0.6	3.4	18.8	23.9	141.6	0.01	0.03	0.04	0.22
screek	8/7	0.2	11.9	21.6	29.0	60.6	0.01	0.01	0.02	0.03
screek	9/11	0.2	35.4	22.9	23.6	63.8	0.01	0.01	0.01	0.02
below LL	5/7	12.3	5.5	15.0	25.4	155.5	0.17	0.45	0.76	4.66
below LL	6/7	16.4	1.6	13.3	21.1	131.3	0.06	0.53	0.84	5.25
below LL	7/8	12.1	12.4	24.7	138.3	486.8	0.37	0.73	4.08	14.37
below LL	8/7	2.3	2.9	21.3	23.7	134.1	0.02	0.12	0.13	0.76
below LL	9/11	1.3	0.3	17.1	18.9	92.3	0.00	0.06	0.06	0.30
blacktail	5/7	1.4	2.1	10.8	21.6	129.8	0.01	0.04	0.07	0.43
blacktail	6/7	1.2	0.7	11.2	13.2	113.3	0.00	0.03	0.04	0.33
blacktail	7/8	2.3	5.8	15.9	139.7	715.0	0.03	0.09	0.80	4.08
blacktail	8/7	0.5	11.2	10.6	13.7	120.0	0.01	0.01	0.02	0.16
blacktail	9/11	0.3	19.4	11.9	17.1	132.4	0.01	0.01	0.01	0.09
swiftheart	5/7	12.6	3.3	13.4	23.0	131.0	0.10	0.41	0.71	4.04
swiftheart	6/7	20.3	1.9	14.4	20.3	134.5	0.09	0.71	1.01	6.67
swiftheart	7/8	13.7	7.5	20.1	70.1	369.3	0.25	0.67	2.35	12.40
swiftheart	8/7	3.8	2.7	14.7	14.7	103.9	0.03	0.14	0.14	0.96
swiftheart	9/11	2.0	7.4	13.9	15.3	83.6	0.04	0.07	0.08	0.42
stoner rd	5/7	9.0	11.3	13.1	25.3	157.3	0.25	0.29	0.56	3.48
stoner rd	6/7	24.9	7.0	13.8	21.3	127.5	0.42	0.84	1.30	7.76
stoner rd	7/8	17.0	8.6	18.5	70.9	316.4	0.36	0.77	2.95	13.17
stoner rd	8/7	4.4	4.4	14.5	17.1	101.6	0.05	0.15	0.18	1.08
stoner rd	9/11	2.4	4.3	14.1	14.1	79.9	0.03	0.08	0.08	0.47
mouth	5/7	6.2	8.7	11.9	23.9	137.3	0.13	0.18	0.36	2.07
mouth	6/7	17.5	5.9	14.1	22.0	136.4	0.25	0.60	0.94	5.83
mouth	7/8	22.3	7.5	18.6	70.4	327.4	0.41	1.01	3.84	17.86
mouth	8/7	3.8	4.5	15.0	15.1	105.9	0.04	0.14	0.14	0.98
mouth	9/11	2.5	3.7	14.0	16.1	71.5	0.02	0.08	0.10	0.43

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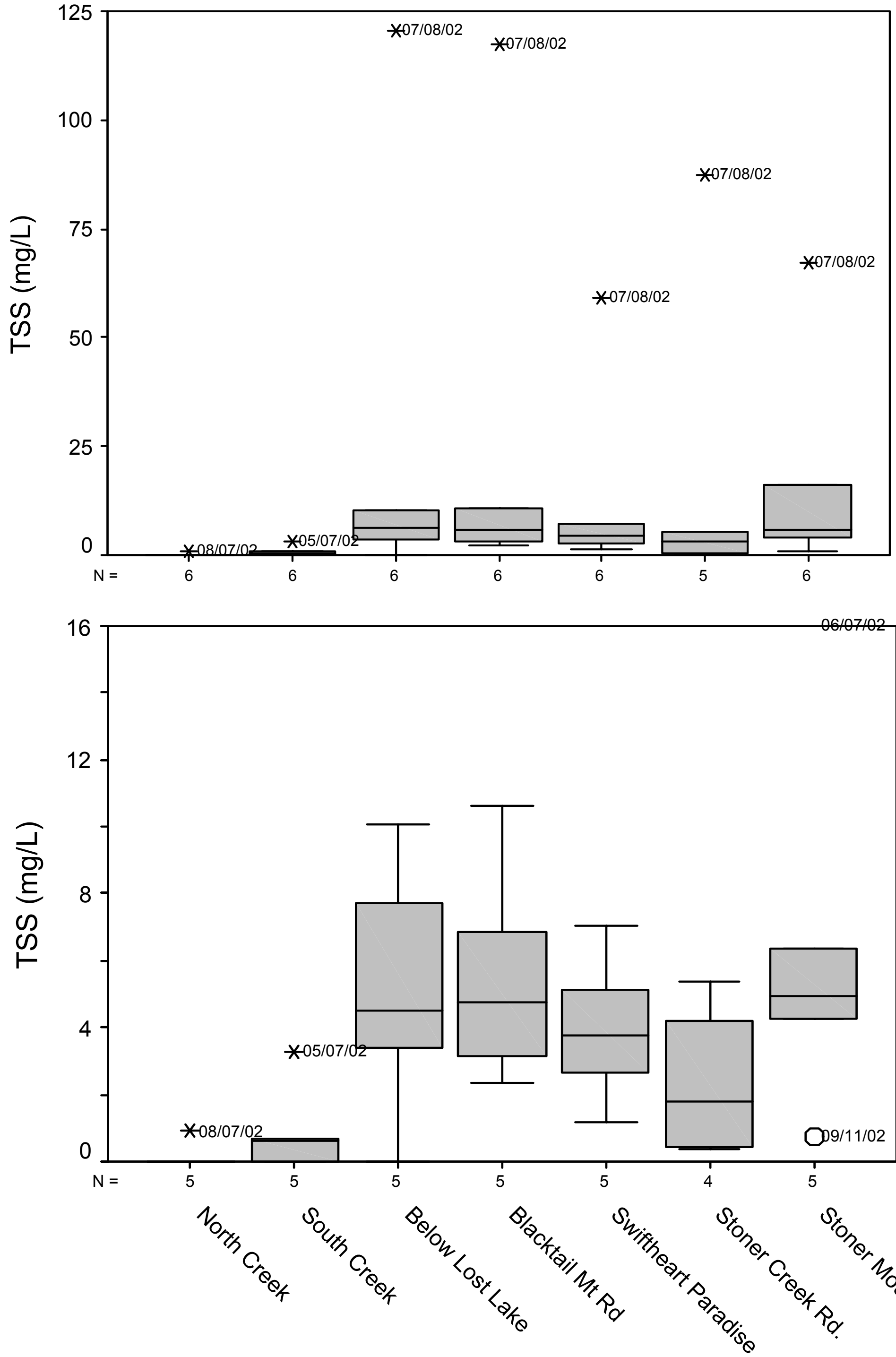

Figure 20. Total Suspended Solids for sites on Stoner Creek. All values, measured monthly May-Sept 2002 (a) and with August 8 rain event values omitted (b).

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Table 8. Field and lab measurements of selected water quality parameters on Stoner Creek sampling sites, summer 2002.

Site	Date	Discharge ft^3/s	Temp Celsius	pH units	EC mS	TSS mg/L	Turbidity NTUs
ncreek	05/07/02	9.3	3.0	6.2	0.02	0.0	2.0
ncreek	06/07/02	12.4		7.0	0.01	0.0	1.3
ncreek	06/27/02	4.5	9.0	6.9	0.02	0.0	1.5
ncreek	07/08/02	2.7	8.0	7.2	0.02	0.0	1.0
ncreek	08/07/02	0.8	7.0	7.4	0.03	0.9	0.8
ncreek	09/11/02	0.5	7.0	7.3	0.03	0.0	0.4
screek	05/07/02	5.9		6.9	0.05	3.3	4.3
screek	06/07/02	2.4		7.3	0.02	0.0	2.9
screek	06/27/02	0.8	9.0	6.8	0.04	0.7	2.3
screek	07/08/02	0.6	9.0	7.1	0.04	0.0	2.5
screek	08/07/02	0.2	7.7	7.7	0.06	0.6	1.5
screek	09/11/02	0.2	6.0	7.6	0.08	0.0	1.0
below LL	05/07/02	12.3	5.0	6.5	0.04	10	3.6
below LL	06/07/02	16.4		7.4	0.04	3.4	2.9
below LL	06/27/02	5.8	17.0	7.5	0.07	7.7	3.8
below LL	07/08/02	12.1	12.5	7.3	0.10	120	15
below LL	08/07/02	2.3	10.0	7.6	0.09	4.5	2.8
below LL	09/11/02	1.3	11.5	7.9	0.11	0.0	1.8
blacktail	05/07/02	1.4	3.5	7.2		4.8	1.1
blacktail	06/07/02	1.2		8.6	0.41	3.2	0.8
blacktail	06/27/02	1.1	16.5	8.4	0.40	11	1.4
blacktail	07/08/02	2.3	12.0	8.6	0.38	118	20
blacktail	07/09/02	1.5				4.0	1.3
blacktail	08/07/02	0.5	9.0	8.5	0.35	2.4	1.3
blacktail	09/11/02	0.3	9.0	8.5	0.39	6.9	1.5
swiftheart	05/07/02	12.6	4.0	6.4		7.0	3.6
swiftheart	06/07/02	20.3		8.1	0.10	3.8	3.1
swiftheart	06/28/02	8.8	14.0	8.3	0.19	5.1	2.5
swiftheart	07/08/02	13.7	12.5	8.3	0.21	59	20
swiftheart	08/07/02	3.8	10.5	8.4	0.23	2.7	2.3
swiftheart	09/11/02	2.0	11.0	8.3	0.23	1.2	1.0
stoner rd	05/07/02	9.0	4.0	6.3			3.1
stoner rd	06/07/02	24.9		8.1	0.11	5.4	3.3
stoner rd	06/28/02	9.0	15.0	8.3	0.19	3.1	2.9
stoner rd	07/08/02	17.0	13.0	8.4	0.22	87	18
stoner rd	08/07/02	4.4	11.5	8.4	0.22	0.4	1.8
stoner rd	09/11/02	2.4	12.0	8.4	0.27	0.4	0.7
mouth	05/07/02	6.2	4.0	6.3		6.4	3.9
mouth	06/07/02	17.5		8.2	0.11	16	3.5
mouth	06/28/02	9.5	15.0	8.4	0.20	4.9	3.5
mouth	07/08/02	22.3	13.5	8.4	0.22	67	23
mouth	08/07/02	3.8		8.2	0.27	4.2	1.1
mouth	09/11/02	2.5	10.5	8.4	0.26	0.8	0.6

APPENDIX A: TABLES AND FIGURES

Table 9. Selected baseflow water quality parameters at Stoner Creek sampling sites, analyzed by Montana State Environmental Lab.

Site	Sample Date	Chloride mg/L	Sulfate mg/L	pH units	Alkalinity mg/L	EC umho	Turbidity NTU	$CaCO_3$ mg/L	hardness gr/gal
ncreek	8/7	<1	<1	6.94	20	43.6	2.34	16.4	1.00
blacktail	8/7	<1	3.78	7.79	228	426	3.98	234	13.70
swiftheart	8/7	<1	2.47	7.69	136	264	2.79	137	8.00
mouth	8/7	1.11	2.54	7.80	138	280	4.53	138	8.10
ncreek	9/11	<1	1.23	6.72	24	48.5	2.36		
screek	9/11	<1	1.16	7.24	48	97.7	1.17		
below LL	9/11	<1	1.26	7.16	64	127	1.85		
blacktail	9/11	<1	2.95	7.48	184	343	55.4		
swiftheart	9/11	<1	2.59	7.66	148	287	3.37		
stoner rd	9/11	<1	2.60	7.71	152	292	1.39		
mouth	9/11	1.05	2.64	7.71	156	299	<1		

Table 10. Results of metals scan on baseflow water samples from four Stoner Creek sites, August 7, 2002, analyzed by Montana State Environmental Lab.

		North Creek	Blacktail Mt. Road	Swiftheart Paradise	Stoner Mouth
arsenic	mg/L	**<0.05**	**<0.05**	**<0.05**	**<0.05**
barium	mg/L	0.02	0.19	0.14	0.14
beryllium	mg/L	**<0.01**	**<0.01**	**<0.01**	**<0.01**
calcium	mg/L	**3.7**	66.4	37.7	37.8
cadmium	mg/L	**<0.01**	**<0.01**	**<0.01**	**<0.01**
chromium	mg/L	**<0.01**	**<0.01**	**<0.01**	**<0.01**
copper	mg/L	**<0.01**	**<0.01**	**<0.01**	**<0.01**
iron	mg/L	0.02	0.06	0.06	0.06
magnesium	mg/L	1.7	16.5	10.5	10.5
manganese	mg/L	**<0.01**	**<0.01**	0.01	0.01
sodium	mg/L	2.10	3.40	3.20	3.50
nickel	mg/L	**<0.02**	**<0.02**	**<0.02**	**<0.02**
lead	mg/L	**<0.05**	**<0.05**	**<0.05**	**<0.05**
selenium	mg/L	**<0.05**	**<0.05**	**<0.05**	**<0.05**
zinc	mg/L	**<0.01**	**<0.01**	**<0.01**	**<0.01**

APPENDIX A: TABLES AND FIGURES

Table 11. Attached algae biomass for sites on Stoner Creek, June-Sept 2002.
(chlor-a = chlorophyll-a in mg/m2; AFDW = ash-free dry weight in g/m2
(dif = sites and dates that have a significant difference have different letters a, b, c)

Site	Date	Rep.	Algae Type	Chlor-a	AFDW	dif	Stats	Chlor-a	AFDW
N Creek	June-Aug		none visible						
	11-Sep	1	diatom/moss	46	26.9	a	MEAN	8	4.5
		2	bare rock	0	0		SE	7	4.1
		3	bare rock	0	0		n	6	6
		4	bare rock	0	0		SE/X	91%	91%
		5	bare rock	0	0		conf. (upper)	15	9
		6	bare rock	0	0		limits (lower)	0	0
Below LL	June		none visible						
	9-Jul	1	Nostoc	4	1.0	a	MEAN	25	5.4
		2	Nostoc	46	9.9		SE	10	2.2
		3	diatom/Nostoc	67	13.9		n	6	6
		4	Nostoc	30	7.7		SE/X	42%	41%
		5	bare rock	0	0		conf. (upper)	35	8
		6	bare rock	0	0		limits (lower)	14	3
	7-Aug	1	Nostoc	1	0.5	a	MEAN	20	4.4
		2	Nostoc	4	1.8		SE	9	1.7
		3	Nostoc	26	5.3		n	6	6
		4	Nostoc	34	7.2		SE/X	42%	39%
		5	Nostoc	57	11.9		conf. (upper)	29	6
		6	bare rock	0	0		limits (lower)	11	3
	11-Sep	1	Nostoc	2	0.8	b,c	MEAN	81	19.9
		2	diatom/Nostoc	54	12.7		SE	18	6.0
		3	Nostoc	99	16.4		n	6	6
		4	Nostoc	99	22.8		SE/X	22%	30%
		5	Nostoc	88	17.8		conf. (upper)	100	26
		6	Nostoc	144	49.0		limits (lower)	62	14
Blacktail	June, Aug		none visible						
	9-Jul	1	diatom	7	2.3	a	MEAN	13	3.5
		2	diatom	32	8.3		SE	6	1.7
		3	diatom	36	10.1		n	6	6
		4	bare rock	0	0		SE/X	50%	49%
		5	bare rock	0	0		conf. (upper)	19	5
		6	bare rock	0	0		limits (lower)	6	2
	11-Sep	1	diatom	21	2.3	b	MEAN	53	9.9
		2	diatom	23	5.8		SE	11	1.9
		3	diatom	87	13.3		n	6	6
		4	diatom	67	15.6		SE/X	21%	19%
		5	diatom	39	9.9		conf. (upper)	64	12
		6	diatom	80	12.3		limits (lower)	41	8
Swiftheart	June-July		none visible						
	7-Aug	1	diatom	3	1.1	a	MEAN	7	5.3
		2	diatom	8	5.2		SE	3	1.4
		3	diatom	9	8.9		n	6	19
		4	diatom	22	16.8		SE/X	44%	26%
		5	bare rock	0	0		conf. (upper)	10	6
		6	bare rock	0	0		limits (lower)	4	5
	11-Sep	1	diatom	13	5.9	a	MEAN	16	10.6
		2	diatom	11	7.4		SE	4	3.2
		3	diatom	28	13.3		n	6	6
		4	diatom	24	24.9		SE/X	24%	30%
		5	diatom	24	12.2		conf. (upper)	21	14
		6	bare rock	0	0		limits (lower)	12	7

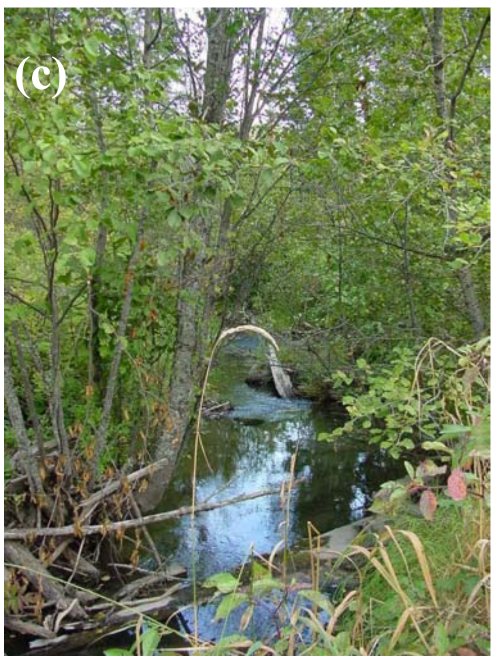
Table 11. (continued) Attached algae biomass for sites on Stoner Creek, June-Sept 2002.
(chlor-a = chlorophyll-a in mg/m2; AFDW = ash-free dry weight in g/m2
(dif = sites and dates that have a significant difference have different letters a, b, c)

Site	Date	Rep.	Algae Type	Chlor-a	AFDW	dif	Stats	Chlor-a	AFDW
Stoner Rd	June-July		none visible						
	7-Aug	1	diatom	5	0.7	a	MEAN	4	1.3
		2	diatom	12	4.6		SE	2	0.7
		3	diatom	5	2.7		n	6	6
		4	bare rock	0	0		SE/X	48%	53%
		5	bare rock	0	0		conf. (upper)	5	2
		6	bare rock	0	0		limits (lower)	2	1
	11-Sep	1	Nostoc	7	1.2	a	MEAN	24	4.7
		2	Nostoc	31	4.9		SE	7	1.3
		3	Nostoc	38	5.6		n	6	6
		4	Nostoc	46	8.2		SE/X	28%	28%
		5	diatom	23	8.4		conf. (upper)	31	6
		6	bare rock	0	0		limits (lower)	17	3
Mouth	June-July		none visible						
	7-Aug	1	diatom	15	3.6	a.b	MEAN	34	5.1
		2	diatom/clad	16	4.8		SE	17	2.2
		3	Cladophora	55	6.6		n	6	6
		4	Cladophora	118	15.7		SE/X	50%	42%
		5	bare rock	0	0		conf. (upper)	52	7
		6	bare rock	0	0		limits (lower)	16	3
	11-Sep	1	diatom	54	8.4	c	MEAN	137	20.3
		2	diatom	96	15.4		SE	17	1.9
		3	diatom	50	13.3		n	20	20
		4	Clad/diatom	149	27.9		SE/X	13%	10%
		5	Cladophora	240	23.6		conf. (upper)	147	21
		6	Cladophora	232	33.3		limits (lower)	127	19

APPENDIX B: PHOTO DOCUMENTATION OF RIPARIAN ZONES

Polygon H

Polygon I



Polygon G

Polygon K

Figure 21. Examples of riparian polygons along Stoner Creek, summer 2002, that received “healthy” ratings in the RWRP Lotic Health Assessment. (See Table 4 and Figure 10 in Appendix A for locations)

APPENDIX B: PHOTO DOCUMENTATION OF RIPARIAN ZONES

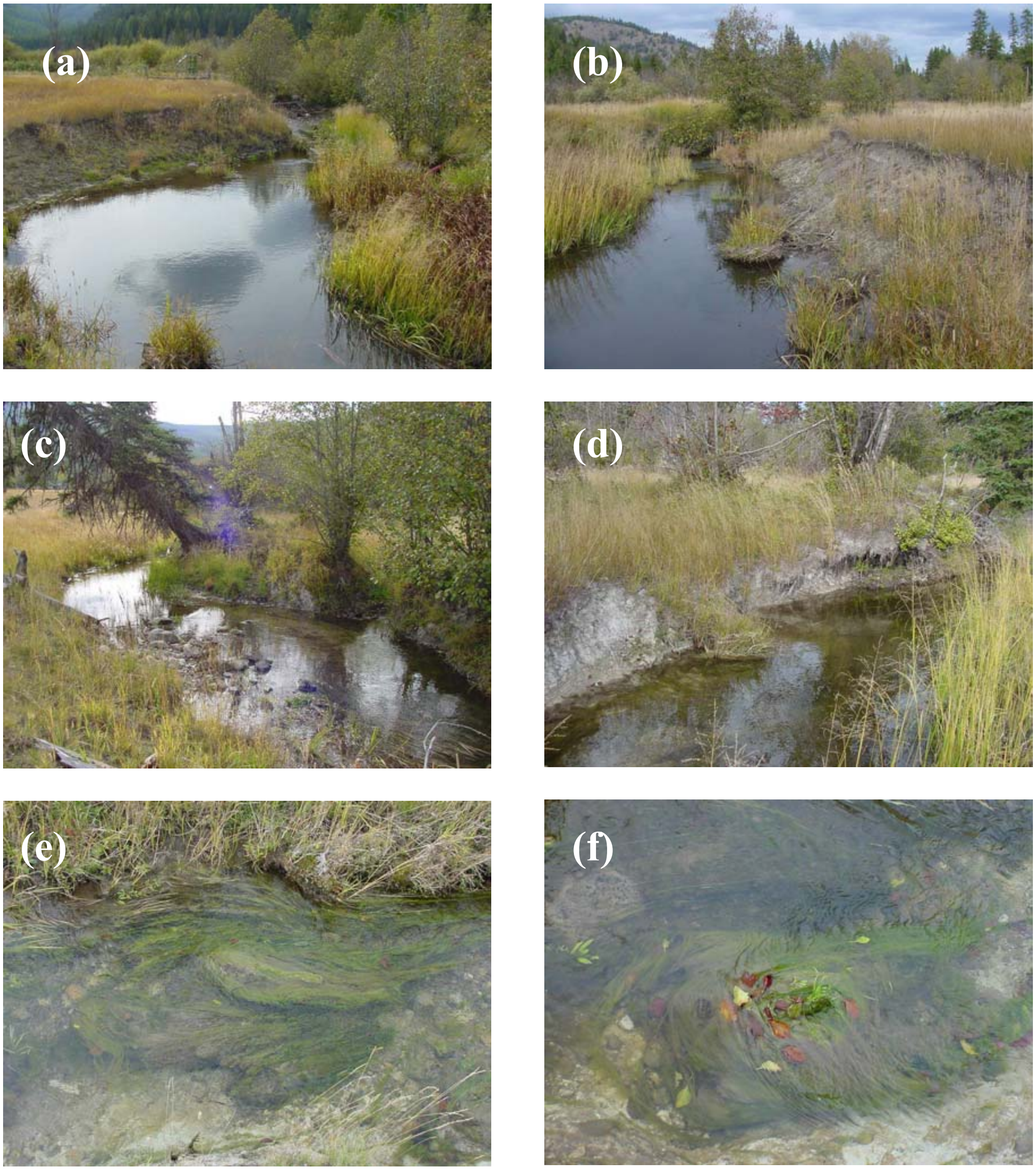


Figure 22. Polygon E, Stoner Creek, summer 2002. Examples of bank erosion/sloughing from removal of riparian vegetation and associated deep-binding rootmass (a-d); *cladophora* algae blooms enhanced by lack of riparian shading (e & f). (See Table 4 and Figure 10 in Appendix A for locations)

APPENDIX B: PHOTO DOCUMENTATION OF RIPARIAN ZONES

Figure 23. Examples of riparian vegetation removal in residential areas of Lakeside: YWAM properties, polygon L (a-e) and behind Ace Hardware, polygon N (f). (See Table 4 and Figure 10 in Appendix A for locations)

APPENDIX B: PHOTO DOCUMENTATION OF CULVERTS

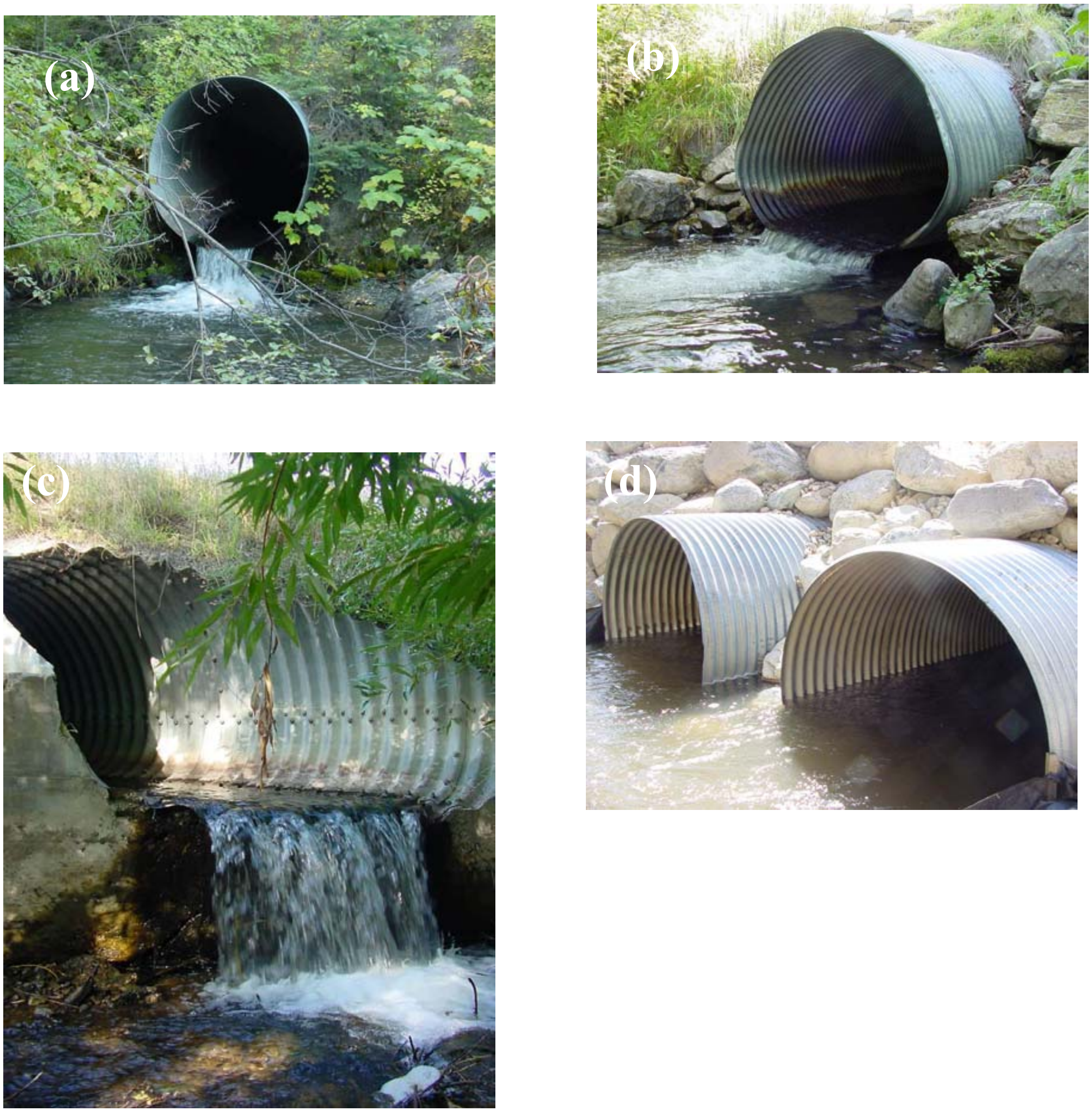


Figure 24. Culverts on Stoner Creek: Forest Service Road 917 (Blacktail Mt Rd), 2nd graveled crossing (a); Private logging road crossing (b); Highway 93 crossing (c); Stoner Creek Road crossing (d).

APPENDIX C: BENTHIC MACROINVERTEBRATE REPORT

A BIOLOGICAL ASSESSMENT OF SITES IN THE STONER CREEK WATERSHED: FLATHEAD COUNTY, MONTANA

JULY 2002

A report to

The Flathead Basin Commission

by

Wease Bollman
Rhithron Associates, Inc.
Missoula, Montana

MARCH 2003

INTRODUCTION

Aquatic invertebrates are aptly applied to bioassessment since they are known to be important indicators of stream ecosystem health (Hynes 1970). Long lives, complex life cycles and limited mobility mean that there is ample time for the benthic community to respond to cumulative effects of environmental perturbations.

This report summarizes data collected in July 2002 from sites on Stoner Creek, Flathead County, Montana. Aquatic invertebrate assemblages were sampled by a graduate student at the University of Montana. Most of the study sites lie within the Northern Rockies ecoregion (Woods et al. 1999).

A multimetric approach to bioassessment such as the one applied in this study uses attributes of the assemblage in an integrated way to measure biotic health. A stream with good biotic health is "…a balanced, integrated, adaptive system having the full range of elements and processes that are expected in the region's natural environment…" (Karr and Chu 1999). The approach designed by Plafkin et al. (1989) and adapted for use in the State of Montana has been defined as "… an array of measures or metrics that individually provide information on diverse biological attributes, and when integrated, provide an overall indication of biological condition." (Barbour et al. 1995). Community attributes that can contribute meaningfully to interpretation of benthic data include assemblage structure, sensitivity of community members to stress or pollution, and functional traits. Each metric component contributes an independent measure of the biotic integrity of a stream site; combining the components into a total score reduces variance and increases precision of the assessment (Fore et al. 1996). Effectiveness of the integrated metrics depends on the applicability of the underlying model, which rests on a foundation of three essential elements (Bollman 1998a). The first of these is an appropriate stratification or classification of stream sites, typically, by ecoregion. Second, metrics must be selected based upon their ability to accurately express biological condition. Third, an adequate assessment of habitat conditions at each site to be studied enhances the interpretation of metric outcomes.

Implicit in the multimetric method and its associated habitat assessment is an assumption of correlative relationships between habitat measures and the biotic metrics, in the absence of water quality impairment. These relationships may vary regionally, requiring an examination of habitat assessment elements and biotic metrics and a test of the presumed relationship between them. Bollman (1998a) has recently studied the assemblages of the Montana Valleys and Foothill Prairies ecoregion, and has recommended a battery of metrics applicable to the montane ecoregions of western Montana. This metric battery has been shown to be sensitive to impairment, related to measures of habitat integrity, and consistent over replicated samples.

METHODS

Aquatic invertebrates were sampled in July 2002 by Matt Coen, a graduate student at the University of Montana. Sample designations and site locations are indicated in Table 1. The site selection and sampling method employed were those recommended in the Montana Department of Environmental Quality (DEQ) Standard Operating Procedures for Aquatic Macroinvertebrate Sampling (Bukantis 1998). Aquatic invertebrate samples were

Table 1. Sample designations, site locations, and sampling dates. Stoner Creek, July 9, 2002.

Sample Designation	Location
North Creek	North Creek above Lost Lake
South Creek	South Creek above Lost Lake
Stoner below Lost Lake	Stoner Creek below Lost Lake
Blacktail Crossing	Blacktail Mountain Rd Crossing
Swiftheart Paradise	Swiftheart Paradise Ranch
Stoner Crossing	Stoner Creek Rd Crossing
Stoner Mouth	Stoner Creek Mouth

delivered to Rhithron Associates, Inc., Missoula, Montana, for laboratory and data analyses. No assessments of habitat conditions were made available.

In the laboratory, the Montana DEQ-recommended sorting method was used to obtain subsamples of at least 300 organisms from each sample, when possible. Organisms were identified to the lowest possible taxonomic levels consistent with Montana DEQ protocols.

To assess aquatic invertebrate communities in this study, a multimetric index developed in previous work for streams of western Montana ecoregions (Bollman 1998a) was used. Multimetric indices result in a single numeric score, which integrates the values of several individual indicators of biologic health. Each metric used in this index was tested for its response or sensitivity to varying degrees of human influence. Correlations have been demonstrated between the metrics and various symptoms of human-caused impairment as expressed in water quality parameters or instream, streambank and stream reach morphologic features. Metrics were screened to minimize variability over natural environmental gradients, such as site elevation or sampling season, which might confound interpretation of results (Bollman 1998a). The multimetric index used in this report incorporates multiple attributes of the sampled assemblage into an integrated score that accurately describes the benthic community of each site in terms of its biologic integrity. In addition to the metrics comprising the index, other metrics shown to be applicable to biomonitoring in other regions (Kleindl 1995, Patterson 1996, Rossano 1995) were used for descriptive interpretation of results. These metrics include the number of "clinger" taxa, long-lived taxa richness, the percent of predatory organisms, and others. They are not included in the integrated bioassessment score, however, since their performance in western Montana ecoregions is unknown. However, the relationship of these metrics to habitat conditions is intuitive and reasonable.

The six metrics comprising the bioassessment index used in this study were selected because, both individually and as an integrated metric battery, they are robust at distinguishing impaired sites from relatively unimpaired sites (Bollman 1998a). In addition, they are relevant to the kinds of impacts that are present in the Stoner Creek watershed. They have been demonstrated to be more variable with anthropogenic disturbance than with natural environmental gradients (Bollman 1998a). Each of the six metrics developed and tested for western Montana ecoregions is described below.

1. **Ephemeroptera (mayfly) taxa richness.** The number of mayfly taxa declines as water quality diminishes. Impairments to water quality which have been demonstrated to adversely affect the ability of mayflies to flourish include elevated water temperatures, heavy metal contamination, increased turbidity, low or high pH, elevated specific conductance and toxic chemicals. Few mayfly species are able to tolerate certain disturbances to instream habitat, such as excessive sediment deposition.
2. **Plecoptera (stonefly) taxa richness.** Stoneflies are particularly susceptible to impairments that affect a stream on a reach-level scale, such as loss of riparian canopy, streambank instability, channelization, and alteration of morphological features such as pool frequency and function, riffle development and sinuosity. Just as all benthic organisms, they are also susceptible to smaller scale habitat loss, such as by sediment deposition, loss of interstitial spaces between substrate particles, or unstable substrate.
3. **Trichoptera (caddisfly) taxa richness.** Caddisfly taxa richness has been shown to decline when sediment deposition affects their habitat. In addition, the presence of certain case-building caddisflies can indicate good retention of woody debris and lack of scouring flow conditions.
4. **Number of sensitive taxa.** Sensitive taxa are generally the first to disappear as anthropogenic disturbances increase. The list of sensitive taxa used here includes organisms sensitive to a wide range of disturbances, including warmer water temperatures, organic or nutrient pollution, toxic pollution, sediment deposition, substrate instability and others. Unimpaired streams of western Montana typically support at least four sensitive taxa (Bollman 1998a).
5. **Percent filter feeders.** Filter-feeding organisms are a diverse group; they capture small particles of organic matter, or organically enriched sediment material, from the water column by means of a variety of adaptations, such as silken nets or hairy appendages. In forested montane streams, filterers are expected to occur in insignificant numbers. Their abundance increases when canopy cover is lost and when water temperatures increase and the accompanying growth of filamentous algae occurs. Some filtering organisms, specifically the Arctopsychid caddisflies (*Arctopsyche* spp. and *Parapsyche* spp.) build silken nets with large mesh sizes that capture small organisms such as chironomids and early-instar mayflies. Here they are considered predators, and, in this study, their abundance does not contribute to the percent filter feeders metric.
6. **Percent tolerant taxa.** Tolerant taxa are ubiquitous in stream sites, but when disturbance increases, their abundance increases proportionately. The list of taxa used here includes organisms tolerant of a wide range of disturbances, including warmer water temperatures, organic or nutrient pollution, toxic pollution, sediment deposition, substrate instability and others.

Scoring criteria for each of the six metrics are presented in Table 2. Metrics differ in their possible value ranges as well as in the direction the values move as biological conditions change. For example, Ephemeroptera richness values may range from zero to ten taxa or higher. Larger values generally indicate favorable biotic conditions. On the other hand, the percent filterers metric may range from 0% to 100%; in this case, larger values are negative indicators of biotic health. To facilitate scoring, therefore, metric values were transformed into a single scale. The range of each metric has been divided into four parts and assigned a point score between zero and three. A score of three indicates a metric value similar to one characteristic of a non-impaired condition. A score of zero indicates strong deviation from non-impaired condition and suggests severe degradation of biotic health. Scores for each metric were summed to give an overall score, the total bioassessment score, for each site in each sampling event. These scores were expressed as the percent of the maximum possible score, which is 18 for this metric battery.

Table 2. Metrics and scoring criteria for bioassessment of streams of western Montana ecoregions (Bollman 1998a).

	Score			
Metric	**3**	**2**	**1**	**0**
Ephemeroptera taxa richness	> 5	5 - 4	3 – 2	< 2
Plecoptera taxa richness	> 3	3 - 2	1	0
Trichoptera taxa richness	> 4	4 - 3	2	< 2
Sensitive taxa richness	> 3	3 - 2	1	0
Percent filterers	0 – 5	5.01 - 10	10.01 – 25	> 25
Percent tolerant taxa	0 – 5	5.01 - 10	10.01 – 35	> 35

The total bioassessment score for each site was expressed in terms of use-support. Criteria for use-support designations were developed by Montana DEQ and are presented in Table 3a. Scores were also translated into impairment classifications according to criteria outlined in Table 3b.

In this report, certain other metrics were used as descriptors of the benthic community response to habitat or water quality but were not incorporated into the bioassessment metric battery, either because they have not yet been tested for reliability in streams of western Montana, or because results of such testing did not show them to be robust at distinguishing impairment, or because they did not meet other requirements for inclusion in the metric battery. These metrics and their use in predicting the causes of impairment or in describing its effects on the biotic community are described below.

- The modified biotic index. This metric is an adaptation of the Hilsenhoff Biotic Index (HBI, Hilsenhoff 1987), which was originally designed to indicate organic enrichment of waters. Values of this metric are lowest in least impacted conditions. Taxa tolerant to saprobic conditions are also generally tolerant of warm water, fine sediment and heavy filamentous algae growth (Bollman 1998b). Loss of canopy cover is often a contributor to higher biotic index values. The taxa values used in this report are modified to reflect habitat and water quality conditions in Montana (Bukantis 1998). Ordination studies of the benthic fauna of Montana's foothill prairie streams showed that there is a correlation between modified biotic index values and water temperature, substrate embeddedness, and fine sediment (Bollman 1998a). In a study of reference streams, the average value of the modified biotic index in least-impaired streams of western Montana was 2.5 (Wisseman 1992).
- Taxa richness. This metric is a simple count of the number of unique taxa present in a sample. Average taxa richness in samples from reference streams in western Montana was 28 (Wisseman 1992). Taxa richness is an expression of biodiversity, and generally decreases with degraded habitat or diminished water quality. However, taxa richness may show a paradoxical increase when mild nutrient enrichment occurs in previously oligotrophic waters, so this metric must be interpreted with caution.
- Percent predators. Aquatic invertebrate predators depend on a reliable source of invertebrate prey, and their abundance provides a measure of the trophic complexity supported by a site. Less disturbed sites have more plentiful habitat niches to support diverse prey species, which in turn support abundant predator species.
- Number of "clinger" taxa. So-called "clinger" taxa have physical adaptations that allow them to cling to smooth substrates in rapidly flowing water. Aquatic invertebrate "clingers" are sensitive to fine sediments that fill interstices between substrate particles and eliminate habitat complexity. Animals that occupy the hyporheic zones are included in this group of taxa. Expected "clinger" taxa richness in unimpaired streams of western Montana is at least 14 (Bollman 1998b).
- Number of long-lived taxa. Long-lived or semivoltine taxa require more than a year to completely develop, and their numbers decline when habitat and/or water quality conditions are unstable. They may completely disappear if channels are dewatered or if there are periodic water temperature elevations or other interruptions to their life cycles. Western Montana streams with stable habitat conditions are expected to support six or more long-lived taxa (Bollman 1998b).

RESULTS

Bioassessment

Figure 1 summarizes bioassessment scores for aquatic invertebrate communities sampled at the 7 sites in this study. Table 4 itemizes each contributing metric and shows individual metric scores for each site. Tables 3a and 3b show criteria for impairment classifications (Plafkin et al. 1989) and use-support categories recommended by Montana DEQ.

When this bioassessment method is applied to these data, the results suggest that sites on North Creek above Lost Lake and on Stoner Creek at the Blacktail Mountain road crossing and at the mouth were unimpaired and fully supported designated uses. All other sites studied appeared to be slightly impaired.

Figure 1. Comparison of total bioassessment scores (reported as percent of maximum score) for sites on Stoner Creek. July 2002.

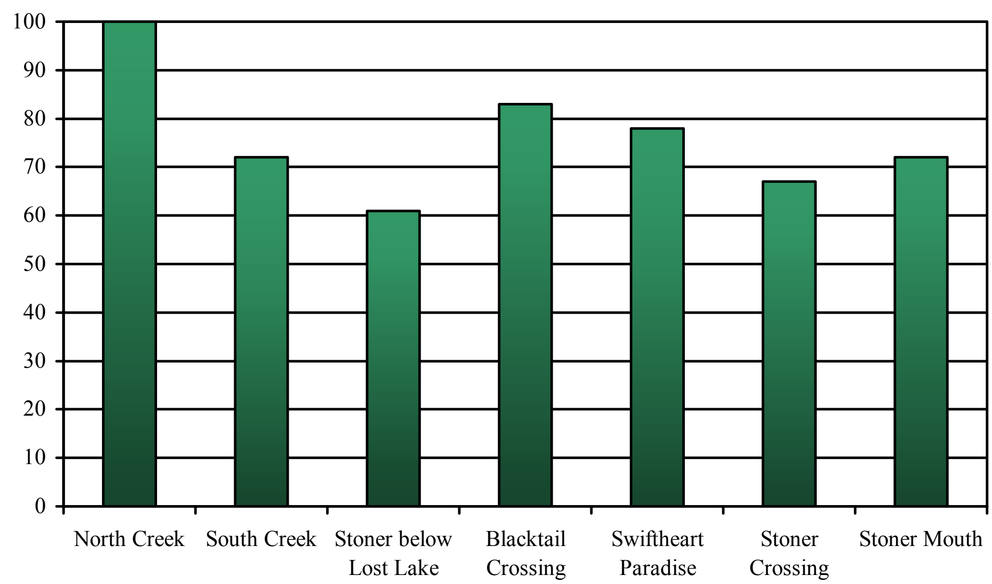


Table 3a. Criteria for the assignment of use-support classifications / standards violation thresholds (Bukantis 1998).

% Comparability to reference	Use support
>75	Full support--standards not violated
25-75	Partial support--moderate impairment--standards violated
<25	Non-support--severe impairment--standards violated

Table 3b. Criteria for the assignment of impairment classifications (Plafkin et al. 1989).

% Comparability to reference	Classification
> 83	nonimpaired
54-79	slightly impaired
21-50	moderately impaired
<17	severely impaired

Table 4. Metric values, scores, and bioassessments for sites on Stoner Creek. July 2002. Site locations are given in Table 1.

	SITES						
	North Creek above Lost Lake	South Creek above Lost Lake	Stoner Creek below Lost Lake	Blacktail Mountain Rd Crossing	Swiftheart Paradise Ranch	Stoner Creek Rd Crossing	Stoner Creek Mouth
METRICS	*METRIC VALUES*						
Ephemeroptera richness	9	7	8	4	6	6	5
Plecoptera richness	7	4	2	6	5	5	7
Trichoptera richness	5	2	3	5	6	6	5
Number of sensitive taxa	6	1	2	4	6	2	3
Percent filterers	0.65	8.41	21.18	3.85	16.55	10.09	4.32
Percent tolerant taxa	1.31	1.8	12.46	16.92	30.07	45.11	61.11
	METRIC SCORES						
Ephemeroptera richness	3	3	3	2	3	3	2
Plecoptera richness	3	3	2	3	3	3	3
Trichoptera richness	3	1	2	3	3	3	3
Number of sensitive taxa	3	1	2	3	3	2	2
Percent filterers	3	2	1	3	1	1	3
Percent tolerant taxa	3	3	1	1	1	0	0
TOTAL SCORE (max.=18)	18	13	11	15	14	12	13
PERCENT OF MAX.	**100**	**72**	**61**	**83**	**78**	**67**	**72**
Impairment classification*	**NON**	**SLI**	**SLI**	**NON**	**SLI**	**SLI**	**SLI**
USE SUPPORT †	**FULL**	**PARTIAL**	**PARTIAL**	**FULL**	**FULL**	**PARTIAL**	**PARTIAL**

* Classifications: (NON) non-impaired, (SLI) slightly impaired, (MOD) moderately impaired, (SEV) severely impaired. See Table 3a.
† Use support designations: See Table 3b.

Aquatic invertebrate communities

The uppermost sampled site (North Creek above Lost Lake) supported a very rich, diverse, and sensitive invertebrate assemblage characteristic of montane sites with little or no human disturbance. The low biotic index value (1.74) and high mayfly taxa richness (9 taxa) suggest excellent water quality, without impairment from nutrient enrichment or thermal impacts. Five cold-stenothermic taxa were present at the site, including the mayfly *Drunella doddsi* and the stonefly *Visoka cataractae*. The sampled organisms suggest cold, clean water. Five caddisfly taxa were collected and 17 “clinger” taxa. These findings imply that fine sediment deposition did not limit benthic habitats. The presence of the chloroperlid *Paraperla* sp. suggests that hyporheic environs were accessible. High stonefly taxa richness is associated with intact large-scale habitat features; streambank integrity, riparian zone function, and channel morphology were likely minimally affected by human disturbances.

Four long-lived taxa were collected, suggesting that dewatering or other interruptions to life cycle completion have not recently impacted biotic health at this site. All expected functional components of a healthy montane assemblage were present, but the proportion of scrapers was higher than anticipated, and the proportion of shredders was lower than expected. These findings suggest that canopy shading was not extensive, and that riparian inputs of deciduous organic material were not abundant.

At the site on South Creek above Lost Lake, two water quality indicators give similar results. The number of mayfly taxa taken at the site (7) suggests unimpaired water quality, and the biotic index value calculated for the entire assemblage (3.41) is within the expected range for a montane stream. This combination of results suggests that water quality was good here. Cold-stenotherms were represented by a single individual of the stonefly *Visoka cataractae*; all other taxa present in the sample were ubiquitous types. It seems likely that the calculated biotic index value was skewed upward somewhat by the dominance of early instars of elmid beetles and later instars of *Heterlimnius* sp. These animals are gregarious, and their large numbers in the sample collected at this site may be serendipitous.

Habitat indicators suggest that sediment deposition may limit benthic colonization; only 2 caddisfly taxa and 7 “clinger” taxa were represented, the lowest numbers of such animals at any of the sites studied. Taxa richness was also diminished compared to the other sites, implying that the diversity of instream habitats may have been more monotonous than expected. Fine sediment deposition reduces the quality and diversity of benthic niches, and may be consistent with these results. Stonefly taxa richness was within expectations for a montane site, suggesting that reach-scale habitat features, such as riparian zone integrity and channel morphology were probably minimally impaired by human disturbances. Long-lived taxa were represented by the elmid beetles; although they made up 45% of sampled organisms, it's likely that only a single taxon was present. Their significance with regard to the possibility of dewatering or other catastrophes is difficult to interpret. Chronic or recent dewatering seems unlikely, however, since turbellarian flatworms were abundant. These animals may indicate that groundwater seeps augment streamflow at this site. The functional composition of the sampled assemblage was dominated by gatherers. The dearth of shredders suggests that riparian inputs of organic material was limited, or perhaps hydrologic conditions did not favor retention of such material.

The site on Stoner Creek below Lost Lake yielded 8 mayfly taxa, suggesting excellent water quality. The calculated biotic index (4.62), however, was elevated compared to expected values for a montane stream. Warmer-than-expected water temperatures seem to be implied. A single leech (*Helobdella stagnalis*) was collected at the site, which appears to strengthen the evidence for such a hypothesis. On the other hand, 2 taxa considered to be cold-stenotherms were present; one of these, the midge *Cricotopus nostococladius*, was abundant. This midge is associated with the blue-green algae *Nostoc* sp. The algae and the midge were apparently abundant at the site, since these midges accounted for 27% of the sampled assemblage. The Montana DEQ protocol assigns a relatively high biotic index number to *Cricotopus nostococladius*; other biologists regard the creature as more sensitive (e.g. Wisseman 1996, Clark 1997). The higher number, coupled with the abundance of the midge at this site likely contributes to some of the observed elevation in the biotic index value. Taxonomic evidence, such as the high number of mayfly taxa suggests that water quality was good at this site.

Habitat indicators suggest that some disturbance to reach-scale features may have impaired Stoner Creek at this site. Stonefly taxa richness, which has been demonstrated to be associated with channel morphology, riparian zone structure, and streambank integrity was low; only 2 stonefly taxa were present in the sample. Eleven "clinger" taxa were collected, implying the availability of benthic surfaces unimpaired by fine sediments. It seems unlikely that dewatering limits biotic health here, since 4 long-lived taxa appeared in the sampled assemblage. Although all expected functional components were present, the abundance of *Cricotopus nostococladius* rendered the herbivorous piercing taxa exceptionally abundant. Filterers, represented by the caddisfly Hydropsyche sp., were also dominant contributors to the functional mix. Although the sampling site appears to be removed from the lake, the influence of outlet flow may have persisted to this downstream site. Filterers are expected to be abundant in stream locations below lakes or other lentic features.

Stoner Creek at the Blacktail Mountain Road crossing supported the highest taxa richness of any site in this study. The low biotic index value (2.73) calculated for the sampled assemblage suggests excellent water quality. However, the mayfly taxa richness was unexpectedly low for a montane site; only three taxa were collected. Other findings seem to support a hypothesis that water quality was essentially unimpaired at this site. Four sensitive cold-stenothermic taxa were present in the sample, including the stoneflies *Doroneuria* sp. and *Despaxia augusta*, and the dipteran *Glutops* sp.

The abundance of invertebrates at this site appeared to be low; the entire sample yielded only 260 organisms. Low numbers of organisms in a benthic sample may suggest that habitat and/or water quality are severely impaired; however, the taxonomic composition of the sample collected here does not support this hypothesis in this case. It seems more likely that sampling effort was inadequate. Both reach-scale and small-scale habitat features appeared to be intact, judging by the taxonomic composition of the sampled assemblage. Six stonefly taxa were present at the site, suggesting a functional riparian zone, intact streambanks, and undisturbed natural channel morphology. Fine sediment apparently did not limit benthic habitat availability, since 5 caddisfly taxa and 14 "clinger" taxa were collected. Long-lived animals were amply represented, suggesting that catastrophic interruptions to long life cycles did not recently occur. The functional composition of the sampled assemblage appeared to be skewed toward gatherers.

Scrapers were rare and shredders abundant, suggesting that shading may have been intense at the site, and riparian inputs of organic material plentiful.

At the Swiftheart Paradise Ranch, Stoner Creek supported 6 mayfly taxa and the calculated biotic index value (3.83) was within expected limits for a montane stream. Five cold-stenothermic taxa were present, including the mayfly *Drunella doddsi*. These findings strongly imply that water quality was good at this site.

All expected functional components of a healthy montane aquatic invertebrate assemblage were present in the sample. Long-lived taxa were abundant, implying that dewatering or other abortive catastrophes did not interrupt life cycles at this site. Reach-scale habitat features were probably undisturbed; the high stonefly taxa richness implies that channel morphology, streambanks, and riparian zone function were essentially undegraded. Fine sediment deposition apparently did not obliterate hard benthic substrate surfaces, since no fewer than 6 caddisfly taxa and 19 "clinger" taxa were among the animals sampled. Hyporheic habitats appeared to be accessible, since the stonefly *Paraperla* sp. was collected.

Good habitat and water quality conditions persisted at the Stoner Creek Road crossing site. Six mayfly taxa were present, and the biotic index value (3.90) was somewhat elevated, though still within expectations for a montane stream. The abundance of elmid beetles, which collectively accounted for more than 50% of sampled organisms, probably accounts for the mild elevation of the biotic index. Sensitive cold-stenotherms included the caddisfly *Agapetus* sp., and the stonefly *Doroneuria* sp.

The 5 stonefly taxa collected in the sample suggest that reach-scale habitat features were essentially intact, and the 5 caddisfly taxa and 20 "clinger" taxa suggest that small-scale habitats were unimpaired by fine sediment deposition. All expected functional components of a healthy montane stream assemblage were present in expected proportions. No fewer than 9 long-lived taxa were represented in the sample, strongly implying that dewatering, toxic inputs, or other catastrophes did not limit life cycles at this site.

At the lowermost Stoner Creek site, near its mouth, the biotic index value (4.00) remained mildly elevated compared to expectations. Once again, the elevated value corresponds with the presence of high numbers of elmid beetles, which often overwhelm samples because of their gregarious habits. The other water quality indicator, mayfly taxa richness, was high; 5 taxa were present in the sample. Two cold-stenothermic taxa were collected, and several other taxa known to be sensitive to various pollutants were also present.

Fine sediment deposition was apparently not a limitation to the availability of hard benthic surfaces for colonization. Fourteen “clinger” taxa and 5 caddisfly taxa were collected. Hyporheic habitats seemed to be available, since *Paraperla* sp. was present in the sample. The presence of 6 stonefly taxa implies that reach-scale habitat features were essentially intact. The functional composition of the assemblage included all expected feeding groups, and the preponderance of scrapers may be consistent with the downstream location of the sampling site. Shading of the stream appears to be limited here, and riparian inputs of organic material are either sparse or are not retained. Six long-lived taxa included predatory caddisflies in the Rhyacophila Betteni Group, and many elmid beetles in 3 genera. These findings suggest that dewatering does not chronically limit life cycles in this reach of Stoner Creek.

CONCLUSIONS

- High quality cold water appeared to characterize all of the sites sampled in this study. Mayfly taxa richness, biotic index values, and/or the presence of sensitive taxa gave evidence of this.

- Instream and reach-scale habitat indicators generally gave results implying intact, functional, minimally disturbed conditions at many of the sites.

- Instream habitat in South Creek above Lost Lake may have been impaired by fine sediment deposition, since both caddisfly taxa richness and “clinger” taxa richness were depressed.

- Below Lost Lake, the Stoner Creek benthic assemblage suggested the influence of outflow from the lake, even though the sampling site was apparently rather distant from the lake. Low stonefly taxa richness suggests some disturbance to reach-scale habitat features.

- Low abundance of sampled organisms at the Blacktail Mountain Road crossing site may have been due to degraded instream habitat or poor water quality, but taxonomic evidence does not support this. Perhaps sampling effort was not adequate.

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APPENDIX D: RIPARIAN BUFFERS LITERATURE REVIEW

Riparian buffers are often mentioned as an effective tool in protecting or improving stream water quality from agriculture, urbanization and silviculture. The utility of riparian buffers is partially due to their versatility, both in terms of applicable land uses and with respect to various water quality parameters. Riparian buffers have been credited with increased nutrient uptake, sediment and other contaminant removal (i.e., pesticides, bacteria) and temperature moderation. In addition, streamside vegetated zones influence channel morphology via bank stabilization and providing large woody debris. The presence of vegetation and its physical impact on the near-channel zone alter the hydrology and biochemistry of the water entering the stream, typically resulting in improved quality.

Riparian buffers are particularly useful in that they treat pollution from non-point sources, which are becoming increasingly important as regulations restrict point sources. Buffers can effectively "filter" surface runoff and groundwater contaminated by the cumulative effects of increased development and density. The beneficial aspect of a buffer is inherent in this definition: " A riparian buffer is land next to streams, lakes or wetlands that is managed for perennial vegetation (grass, shrubs, and/or trees) to enhance and protect aquatic resources from adverse impacts of [land use] practices" (Dosskey *et al* 1997).

This appendix reviews some of the processes of streamside buffers, specifically as they relate to water quality, and discusses some design and management considerations. While it will focus on ecological function, it is also worthwhile to note the considerable social benefits of buffers: including aesthetics, recreation, wildlife habitat, economics and flood control.

Process and Function

The two most widely advertised water quality benefits of riparian buffers are nutrient uptake and sediment removal. The two are clearly linked as phosphorus, often the limiting nutrient for undesirable algal growth, is typically adsorbed to small sediment particles. Nitrogen, however, is readily dissolved in water and is therefore often found in soluble form (i.e., nitrate) in sub-surface water. Nitrate removal from shallow groundwater can occur via absorbtion by plant roots or, if anaerobic conditions exist, via denitrification by bacteria (Constantz 1998). There is some disagreement over which is the dominant mechanism: Osborne and Kovacic (1993) and Spruill (2000) favor denitrification, Lowrance *et al* (1997) seem to lean toward plant uptake, while Gilliam (1994) remains undecided. It is clear that the removal process is driven by existing conditions in the riparian sub-surface zone, such as soil type, background concentrations, organic carbon presence, bacterial activity and redox potentials. Some of these conditions are influenced by plant metabolism, but it should be noted that 1) these conditions can occur in non-vegetated areas and 2) removal can actually increase during winter months (Spruill 2000, Gilliam 1994).

While the dominant process remains contentious, the efficacy of riparian corridors in removing soluble nitrogen from shallow groundwater is nearly unanimous (Table 1). The range of removal varies between studies, but is often cited approaching or exceeding 90% (Osborne and Kovacic 1993, Gilliam 1994, Spruill 2000, Lowrance *et al* 1997, Constantz 1998). Riparian zones are somewhat less effective at nitrate removal from deeper groundwater – they can only indirectly affect it by increasing organic buildup on the channel bed, creating a “reduction reaction medium” through which the groundwater passes (Spruill 2000). In general, if the groundwater is below the biologically active root zone of the riparian vegetation, nutrient removal will be little or none (Constantz 1998, Lowrance *et al* 1997).

Phosphorus retention by riparian buffers, while also substantial, has been found to occur at lower rates than nitrogen (Table 1). One possible cause may be poor removal of soluble phosphorus from shallow groundwater due to a lack of a denitrifying-type microbial process (Lowrance *et al* 1997). However, as mentioned above, the majority of phosphorus is sediment-borne and hence found in overland flow. Reduction of phosphorus delivered to a stream should then focus on either decreasing runoff or decreasing sediment loads – a riparian buffer does both. Runoff readily infiltrates the soils of a riparian zone (facilitated by low compaction from land uses and a lack of impervious surfaces); it is then stored in the organic matter in the soil, evapotranspirated by the plants or enters the stream as groundwater. Infiltration rates in restored buffers can be up to five times higher than in adjacent fields and pastures of the same soil type

(Lowrance *et al* 2002). If the soil does reach saturation, the velocity of any remaining overland flow is slowed by duff, leaf litter and the stems of the vegetation itself, allowing any suspended sediment to settle out.

This process of "filtering" the sediment out of runoff, either by infiltration or deposition, is fairly effective at removing particulate phosphorus. Again, studies have found rates of removal that vary: from 30-50% (Gilliam 1994, Osborne and Kovacic 1993) to 50-80% (Lowrance *et al* 1997, Constantz 1999). Depending on background concentrations and other conditions, a riparian zone can actually increase phosphorus levels in surface water (Spruill 2000, Lowrance et al 1997). Indeed, one of the natural functions of a riparian zone is to supply nutrients to a stream, up to 90% in some cases (Leff 1998). However, the nutrients should be introduced in a form (shed leaves, fallen insects, etc) and at a rate that is within the ecological capacity of the stream. In more cases than not a riparian zone acts as a buffer between surface waters and excessive nutrient loading from anthropogenic causes.

Table 1. Nutrient removal rates of riparian buffers. (Osborne & Kovacic 1993)

Width (m)	Parameter	% Reduction	VBS type	Reference
Subsurface				
10	N	60–98	Forest	James, Bagley & Gallagher, in press
16	N	93	Forest	Jacobs & Gilliam, 1985
19	N	93	Forest	Peterjohn & Correll, 1984
19	N	40–90	Forest	Schnabel, 1986
25	N	68	Forest	Lowrance, Todd & Asmussen, 1984
30	N	100	Forest	Pinay & Decamps, 1988
50	N	99	Forest	Peterjohn & Correll, 1984
27	N	10–60	Grass	Schnabel, 1986
19	P	33	Forest	Peterjohn & Correll, 1984
50	P	−114	Forest	Peterjohn & Correll, 1984
Surface				
30	N	98	Forest	Doyle, Stanton & Wolf, 1977
50	N	79	Forest	Peterjohn & Correll, 1984
9	N	73	Grass	Dillaha *et al.*, 1989
5	N	54	Grass	Dillaha *et al.*, 1989
27	N	84	Grass	Young, Huntrods & Asmussen, 1980
16	P	50	Forest	Cooper & Gilliam, 1987
19	P	74	Forest	Peterjohn & Correll, 1984
50	P	85	Forest	Peterjohn & Correll, 1984
9	P	79	Grass	Dillaha *et al.*, 1989
5	P	61	Grass	Dillaha *et al.*, 1989
27	P	83	Grass	Young, Huntrods & Asmussen, 1980

Riparian processes can likewise reduce sediment deposition. In addition to deposition, as mentioned above, vegetative root masses reduce erosion by stabilizing streambanks and canopy cover and leaf litter reduce splash erosion from raindrops (Leff 1998, Whipple *et al* 1981, Logan 2001). Whereas nutrient retention is dependent on biochemical conditions that are somewhat temporal and possibly elusive, sediment deposition is a purely physical process that is applicable in all physiographic settings. A buffer is most effective at trapping sediment when concentrated, channelized flow is converted to sheet flow (Lowrance *et al* 1997). Sediment removal efficiency has been documented as high as 90% (Lowrance *et al* 2002, Sheridan *et al* 1999, Gilliam 1994).

Large trees have a water quality benefit other than bank stabilization and reduced erosion - temperature moderation. The reduction in solar radiation from canopy cover significantly reduces temperature fluctuations (Osborne and Kovacic 1993, Leff 1998, CRJC 2000), which in turn moderates other water quality parameters (dissolved oxygen, pH, etc). Riparian corridors provide a buffer for numerous other pollutants, from fertilizers and petroleum products to heavy metals and fecal coliform (Gilliam 1994, Leff 1998). A particular study of an agricultural watershed found that well-established riparian buffers cut levels of the pesticide atrazine by 88% in surface water (Qui and Prato 1998).

Design and Management

If the water quality benefits of riparian buffers are undisputed, the design and management are less so. The width of buffer is the main source of uncertainty; a buffer should be wide enough to function as an effective filter while minimizing restrictions to the landowner. The intended purpose of the buffer is important in considering the appropriate width (Figure 1). In general, required width can be pictured as an increasing gradient as one proceeds from streambank stabilization to sediment retention to nutrient cycling to wildlife habitat (Leff 1998, CRJC 2000). If, for example, stream temperature moderation is the intended purpose of the buffer, geographic location, width/depth ratio of the stream, groundwater influence and canopy density will all affect the necessary buffer width (Osborne and Kovacic 1993).

A widely cited effective buffer width is 100 feet (Leff 1998, CRJC 2000), but even this value comes with stipulations: the buffer should be widened for stream orders larger than three, should encompass the 100 year flood plain, should extend beyond adjacent wetland areas and should be modified to accommodate excessive streambank slopes. For example, the U.S. Forest Service observes a Streamside Management Zone of 50ft, increasing to 100ft for slopes greater than 35% (Logan 2001). The "fixed vs. variable" width debate will likely continue, especially once political considerations meet scientific ones. Fixed width buffers facilitate regulation and enforcement, but variable width buffers compensate for stream size variation and unique situations (Brown 1997).

The type of vegetation planted, or protected, in a buffer also must be considered. Native vegetation is more suited to local conditions and is therefore preferred over introduced species (Lowrance *et al* 2002, Constantz 1998, Whipple *et al* 1981). Again, the intended purpose of the buffer should be considered: deep-rooted trees reach deeper groundwater, while grassed strips may be less prone to gullying. Non-leguminous trees are more efficient at removing nutrients from groundwater than leguminous (Osborne and Kovacic 1993, Gilliam 1994). Grassy medians should be planted with a species tall and sturdy enough to withstand occasional high flow; higher stem density increases hydraulic resistance (Osborne and Kovacic, Lowrance et al 1997).

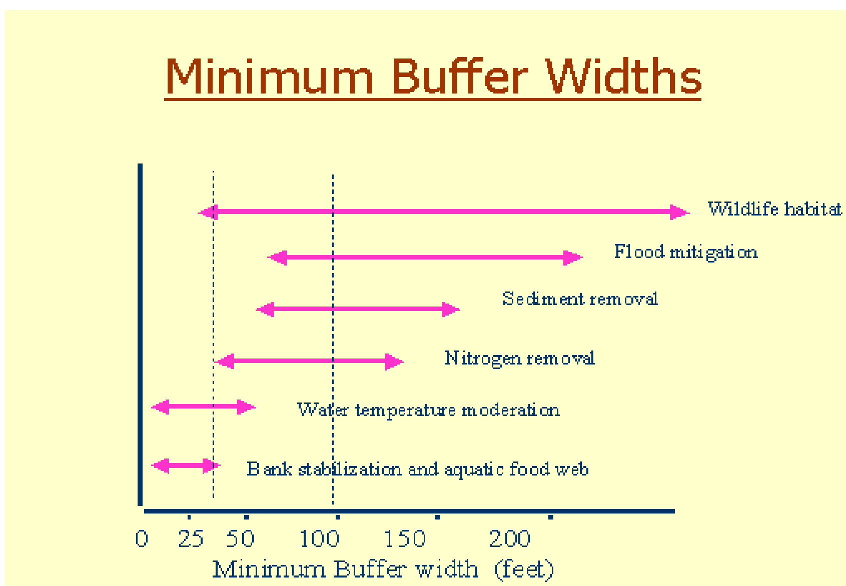
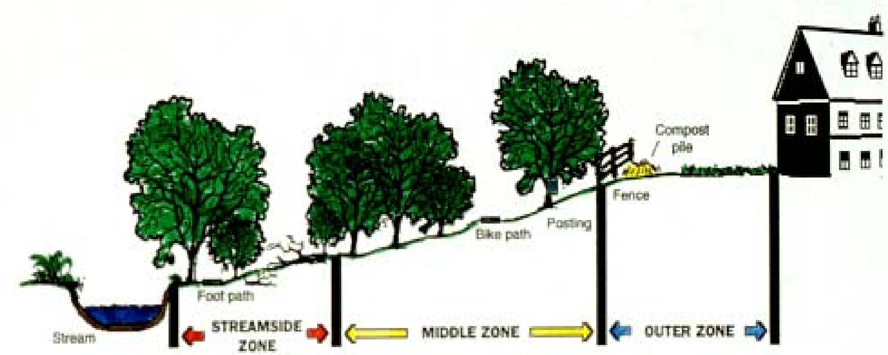


Figure 1. Suggested buffer widths for various intended purposes (Leff 1998)

Essentially, designing the optimal buffer for a given situation is a combination of width and type. As would be expected, wider, more diverse buffer strips are overall more effective; if a 6m prairie strip removes 75% of the sediment and 40% of the nutrients, an additional 10m of woody vegetation will increase the removal rates to 90% of sediment and 80% of nutrients (Lowrance *et al* 2002). U.S. Department of Agriculture guidelines suggest a buffer system consisting of three lateral zones of varying vegetation and permitted uses (Lowrance *et al* 1997, Sheridan *et al* 1999) (Figure 2). The zone nearest the stream consists of deep-rooted, undisturbed riparian forest and is considered highly restricted. The middle zone should also contain large trees and shrubs, although some extractive uses may be permitted. The outer zone is typically a managed, grassy strip whose main purpose is to deflect concentrated flow into sheet flow and begin the filtration process. It has been shown that the large majority of runoff (up to 72%) and sediment (up to 83%) are removed in the grass buffer strip and that the management direction in the middle zone (clear-cut, selective cut, mature forest) has little effect on the overall efficacy of the riparian buffer (Sheridan *et al* 1999).



CHARACTERISTICS	STREAMSIDE ZONE	MIDDLE ZONE	OUTER ZONE
FUNCTION	Protect the physical integrity of the stream ecosystem	Provide distance between upland development and streamside zone	Prevent encroachment and filter backyard runoff
WIDTH	Min. 25 feet, plus wetlands and critical habitats	50 to 100 feet, depending on stream order, slope, and 100 year floodplain	25 foot minimum setback to structures
VEGETATIVE TARGET	Undisturbed mature forest. Reforest if grass	Managed forest, some clearing allowable	Forest encouraged, but usually turfgrass
ALLOWABLE USES	*Very Restricted* e.g., flood control, utility right of ways, footpaths, etc.	*Restricted* e.g., some recreational uses, some stormwater BMPs, bike paths, tree removal by permit	*Unrestricted* e.g., residential uses including lawn, garden, compost, yard wastes, most stormwater BMPs

Figure 2. Three-zone buffer system diagram as recommended by USDA (Lowrance *et al* 1997)

Other Considerations

Economically, riparian buffers will eventually pay for themselves, especially when their benefits (water quality enhancement, soil retention, wildlife habitat, recreation, aesthetics) are fully considered and valued (Basnyat 1999; Qui and Prato 1998). The future benefits will more than offset any revenue lost due to property tax reductions for those landowners involved or personal income lost due to, say, loss of acreage. Since the alternative to riparian buffers for water quality improvement may be construction of a water treatment facility, the cost of retirement and conversion of virtually any land to riparian will be the least cost option (Basnyat 1999). For example, the use of buffers to mitigate pesticide pollution in a 7 thousand hectare agricultural watershed resulted in governmental savings of over $600,000 (Qui and Prato 1998). In addition, funds are available through a number of federal programs including the USDA's Conservation Reserve Program and 319 grants through the EPA (USDA 1997, Lowrance *et al* 2002).

Clearly riparian buffers can play a leading role in mitigating the non-point source water quality impacts from a variety of land uses. More research may be needed to determine the specific hydrologic and biochemical mechanisms involved in order to better design the width and type of buffers for a given application. It is important to value buffers comprehensively for their ecological and social benefits, as the primary impediment to their widespread use will likely be political.

APPENDIX E: IMPERVIOUS SURFACES LITERATURE REVIEW

Urbanization has long been known to have adverse effects on the water resources in a watershed. Although the sources of urban impact may vary between situations, a constant and prevailing component is an increase in the impervious surface cover in the watershed. The positive correlation between impervious surface cover and level of urbanization is as clear as the negative correlation between impervious cover and stream quality. Impervious surfaces have the ability to profoundly alter the hydrologic regime of any given watershed. This appendix will summarize the relevant literature regarding impervious surfaces and examine the hydrologic effects, potential stream impacts and biotic habitat degradation, the implications for water quality, and management and mitigation techniques.

Introduction

The hydrology of a stream is largely dictated by geology, climate, soil, vegetation and land use of the watershed, which in turn control water yield and sediment loads. Urbanization has the potential to influence three of the driving variables by altering land use (i.e., conversion from forest or agricultural uses), removing vegetative cover and compacting soils. Urbanization thus can, and universally does, have profound effects on the hydrological processes of a watershed (Lull and Sopper 1969, Miller *et al* 1971, Hollis 1975, Taylor 1977, Brabec *et al* 2002, Booth and Jackson 1997). While urbanization often brings with it myriad potential ecological problems associated with increased population density (intensive industrial complexes, wastewater treatment plants, etc.), an inherent trait of urbanization is the impervious surface. The percent coverage of impervious surfaces in a watershed is thought to be an accurate representation of the degree of urbanization (Veenhuis 1990, Evaldi and Moore 1994, Brabec *et al* 2002, May *et al* 1996, Arnold and Gibbons 1996).

Impervious areas, defined as those surfaces that prevent infiltration of water into the soil, include streets, parking lots, driveways, sidewalks and roofs. While a single rooftop, or lone driveway will have negligible impacts on the hydrology of a watershed, the densities found in urban and suburban developments can have substantial cumulative effects. It would thus be prudent to learn as much as possible about the effects of impervious surfaces, and how to mitigate their impacts.

Hydrologic Implications

The urbanization of a watershed has numerous hydrologic implications (Figure 1). Vegetation is removed resulting in lower evapotranspiration and interception levels; soil is compacted and/or paved over decreasing infiltration and lowering storage capacity; overland flow and runoff are increased by impervious surfaces and routed to the stream more effectively; groundwater does not get recharged, lowering the water table. These land use changes are manifested in the stream as increased peak flows and runoff volumes, increased flashiness, altered timing, frequency and duration, and lower dry season flows.

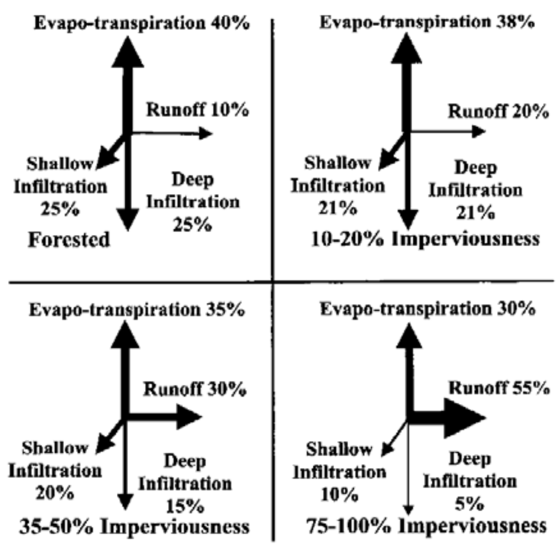


Figure 1. Visual depiction of effects of increasing impervious surface cover on hydrology of urbanizing watersheds (Source: Paul and Meyer 2001).

The removal of vegetation associated with urbanization has the effect of decreasing evapotranspiration and interception. Interception of a heavily urban city center can approach that of forested areas due to the large composite area of multi-story building walls, however most residential areas have significantly lower interception rates

(Lull and Sopper 1969). The main impact of removing vegetative cover is a reduction in evapotranspiration. While evapotranspiration rates of forests can vary greatly depending on vegetation type and density, climate, aspect and elevation, the evaporation rate from impervious urban areas has been estimated at 10% of annual rainfall (Lull and Sopper 1969), low by any forest standards.

The increase in available water from lower evapotranspiration in urban areas is compounded by decreased infiltration capability of the soils. If the area is not paved over, it is likely compacted during construction or by continuous use. Paved and other impervious surfaces obviously have an infiltration rate of zero. Lawns and parks can become substantially compacted as well, exhibiting infiltration rates a fraction of natural conditions, often approaching that of an impervious surface (North Carolina DENR 2000, Lull and Sopper 1969). Since impervious areas do not allow for the infiltration of precipitation, it becomes overland flow.

The problem of increased overland flow is exacerbated by the transport efficiency of impervious surfaces (Schueler 1994, Sloto 1988, Booth and Jackson 1997). Water can achieve a greater velocity over a relatively smooth, hard, impermeable surface than it can otherwise. Gutters and sewers act as conduits to magnify storm water in volume and velocity. In addition, most storm drain networks were built with the intention of quickly and efficiently moving runoff to the stream (Arnold and Gibbons 1996, Booth and Jackson 1997). The increased runoff volumes of impervious surfaces combined with the increased routing efficiency of the urban landscape is manifest in the flow regime of urban stream channels.

Increased runoff volumes created by impervious surface cover have been extensively documented (Sloto 1987, Evaldi and Moore 1994, Taylor 1977, Lull and Sopper 1969, Cherkauer 1975). These volumes are usually exhibited in the stream as higher peak flows. Although some studies have shown urbanized watersheds to increase peak flows by as much as 20 times, a more typical finding is an increase of 1.5 to 4 (Hollis 1975, Lull and Sopper 1969, Sloto 1987, Taylor 1977, May *et al* 1996). The magnitude of increase is directly linked to the percentage of the watershed that is covered by impervious surface. While the peak flows associated with impervious cover will increase, the duration of floods will typically decrease due to improved efficiencies (Paul and Meyer 2001, Arnold and Gibbons 1996).

The difference in runoff volumes and peak flows between urban and rural watersheds vary with the season, being more pronounced in the spring than the summer (Taylor 1977). Antecedent wetness is likely the main source of this difference – pervious areas in urban watersheds will reach their saturation point more easily, and hence contribute to runoff during the wet season. Snow melt magnitudes can actually be lower in some urban watersheds due to decreased snow retention, and the common practices of snow removal and deicing throughout the winter (Cherkauer 1975).

The timing of discharge in a highly impervious watershed can also be affected in terms of faster reaction time, or an increase in flashiness. Developed suburban watersheds, and those under development, convert rainstorm precipitation to stream discharge much more quickly that undeveloped rural watersheds (Arnold and Gibbons 1996, Hollis 1975, Cherkauer 1975). Undeveloped watersheds also have a more delayed response to snowmelt (Cherkauer 1975) due to increased routing efficiency and heat reflection of impervious surfaces.

The frequency of certain magnitude flows will also be increased with increasing imperviousness (Hollis 1975). Another way of saying this is that for a given recurrence interval, the size of the flood will increase. That being said, differences in runoff volumes are more pronounced for smaller flood events than large ones – a 100 year flood may be doubled in size, while small floods may increase by 10 times (Hollis 1975, Schueler 1995). As soils in a watershed become saturated during massive storm events, the relative importance of impervious surfaces declines.

Finally, impervious surfaces decrease base flows in a stream during the dry season (Klein 1979, CWP 1996a, USEPA 1999). As mentioned above, soil moisture retention and groundwater recharge are decreased as the ground is paved over or compacted. The soil loses its capacity to act as a sponge and supply the stream with water slowly throughout the summer or between storms – the water has been moved downstream anyway.

Stream Impacts

A stream is a reflection of its watershed – it responds to the hydrologic regime with morphological adjustments. When flow regimes are altered, as they are under impervious surface conditions, stream channel dynamics will change in kind. Changes in channel morphology associated with urbanization begin with channel instability (widening and/or downcutting) to accommodate larger flows, which leads to streambank erosion and a host of other problems (Schueler 1995, USEPA 1999, May *et al* 1996). A large number of sub-bankfull flows, that rise and drop at rapid rates can leave streambanks wet and worsen the erosion problem. A number of studies have shown that channels become increasingly wider with increasing impervious cover (Paul and Meyer 2001, Hammer 1972, Booth and Jackson 1997). Increased flows can also scour streambed materials.

An increase in sediment load is another significant effect on stream channels directly related to urbanization (USEPA 1999, Schueler 1994, Brabec *et al* 2002). This can be attributed mostly to increases in runoff and routing efficiency due to impervious surfaces, as discussed above. The increase in fine-grained sediments will substantially alter the streambed substrate composition (Booth and Jackson 1997, Klein 1979). In addition to the mere presence of impervious surfaces, development-related construction can be an enormous source of sediment in urbanizing watersheds. Impervious cover can increase sediment loading by a magnitude of ten, but construction can increase it by thousands of times or more (Lull and Sopper 1969, USEPA 1999, Paul and Meyer 2001)

Both the altered flow regimes and the increased sediment loading from urbanization have major implications on the quality of habitat in a given stream (USEPA 1999, Schueler 1994, Paul and Meyer 2001, Brabec *et al* 2002). Benthic macroinvertebrates and periphyton, as well as fish species, evolved into specific habitats, and when those habitats are altered, the species will decline. Biotic diversity and abundance has been found to decline noticeably when impervious coverage of a watershed reaches about 10% (Klein 1979, CWP 1997a, CWP 1996b, May *et al* 1996, CWP 1997b). This 10% threshold for impairment is often cited with a 25-30% threshold that indicates serious degradation (Figure 2) in which many streams become non-supporting of their beneficial uses (Schueler 1995, Brabec et al 2002, Arnold and Gibbons 1996).

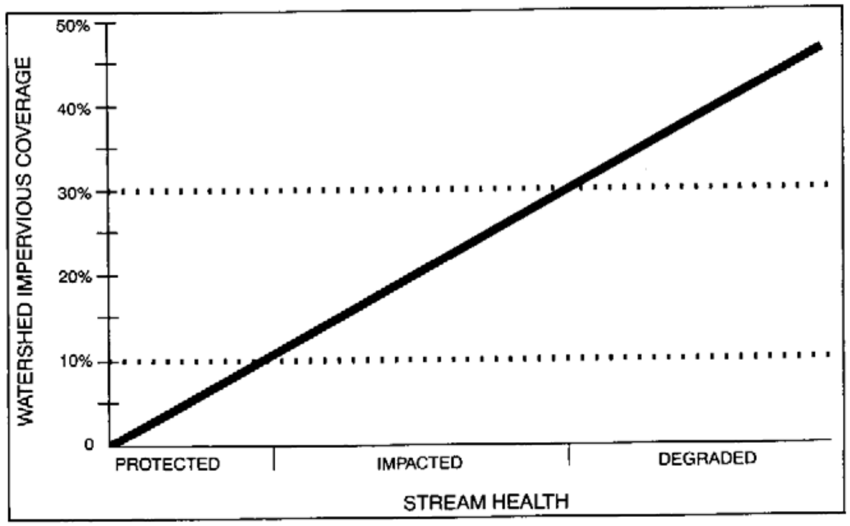


Figure 2. Qualitative relationship between impervious surface coverage and stream health. (Source: Arnold and Gibbons 1996)

The riparian vegetation along a stream, and its aquatic macrophytes, are largely at the mercy of peak (and minimum) discharge volume, duration, and timing as well as ground water levels, all of which will likely change in a highly impervious watershed. Erosion of streambanks can also decrease the ability of riparian vegetation to establish, as sedimentation can hinder native macrophyte growth. Urban riparian corridors, in general, are narrower, more fragmented and less healthy than those in undeveloped watersheds (May *et al* 1996, Paul and Meyer 2001).

Effects on Water Quality

While water quantity and sediment are important aspects of water quality, these topics have been covered sufficiently above, and hence this section will focus on the chemical and biological implications of urbanization. It is certainly true that an urban area of higher population density will invariably produce a higher concentration of waste and other undesirable products, but it is impervious surfaces that facilitate their delivery to the stream.

The increased runoff associated with impervious surfaces brings with it numerous pollutants. Stormwater flushes contaminants that have accumulated on streets and parking lots, in gutters and storm drains, on lawns and in parks into the stream. Some of these contaminants are natural but now found at increased levels (i.e. nutrients, dissolved solids, organic debris, pathogens); others are synthetic or potentially toxic (petroleum products, pesticides, heavy metals).

As expected, the loading of these contaminants generally rises as impervious surface cover rises (Veenhuis 1990, Paul and Meyer 2001, May *et al* 1996, USEPA 1999, Cherkauer 1975). It is interesting to note the different impervious sources of certain contaminants (Pitt and Bozeman 1980, Pope and Putnam 1997, Evaldi and Moore 1994, Arnold and Gibbons 1996): Parking lots and street gutters have a high number of many pollutants, especially heavy metals; zinc comes mainly from tire wear and lead from auto exhaust. Lawns and landscaping are a major source of nutrients and oxygen demanding substances. De-icing is a substantial non-point source of major ions. E. coli is found on residential streets, cadmium and copper on industrial ones. Rooftops contribute a small percentage of contaminants relative to their contribution to impervious area, due in part to their use and in part to their typical distance from the stream.

Each contaminant has a different potential impact once it reaches the stream, and each has a different relationship to impervious cover. Fecal coliform and streptococci can threaten drinking and recreation waters. Nitrogen and phosphorus can feed nuisance algae, creating aesthetic problems. Certain heavy metals are toxic to fish and invertebrates. Synthetic organic compounds can bioaccumulate their way up the food chain. Therefore the thresholds for percent impervious area in which each contaminant becomes a problem varies; admittedly the relationship of impairment to impervious area is not a threshold at all, but continuous (Booth and Jackson 1997, May *et al* 1996, Booth *et al* 2002, Arnold and Gibbons 1996). However, in the name of generalization, whereas biotic indicators become impaired near 10% impervious cover, degradation in terms of abiotic factors is not evident until significantly higher levels of imperviousness, often cited near 40 or 50% (Brabec *et al* 2002, May et al 1996, Schueler 1994).

Stream temperature is another aspect of water quality that can be affected by impervious cover. Water running over impervious surfaces is warmed by excessive heat absorption and reflection. Impervious areas can also have local air temperatures 10-12 degrees warmer than the forest that was in its place (Schueler 1995). Once again, percentage of impervious cover has been found to be positively correlated with stream temperature (Klein 1979, CWP 1997a, Schueler 1995). In addition, the loss of riparian trees (and their cooling effect) that is associated with urbanization will compound the temperature problem.

Managing for Impervious Surfaces

An obvious initial requirement for any management of impervious surfaces is an estimate of the current percent cover of these areas. It is largely agreed that impervious surface coverage is the best indicator of stream and water quality degradation in an urbanized watershed (Veenhuis 1990, Evaldi and Moore 1994, Brabec *et al* 2002, *May et al* 1996, Arnold and Gibbons 1996). There are however some drawbacks. Accurately measuring impervious surface coverage is costly and time consuming, requiring recent detailed aerial photographs of the entire watershed (Southard 1986, Schueler 1996). Due to this fact, a number of methods for estimating impervious cover have been developed.

An alternative to directly measuring impervious cover, either via photographs or in the field, is to interpolate impervious area based on current land use. Various urban land uses have relatively predictable percentages of impervious cover (Figure 3). Residential land use is generally lowest in impervious cover and depends on lot size; commercial space can often approach 100% impervious cover, mostly due to parking lot demands (Lull and Sopper 1969, Arnold and Gibbons 1996).

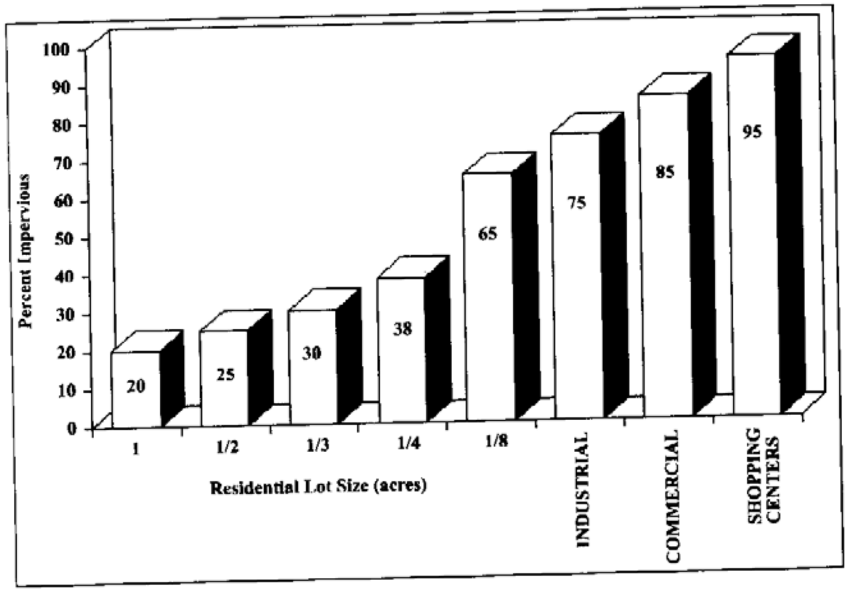


Figure 3. Average percent impervious surface coverage for various land uses (Source: Arnold and Gibbons 1996).

Indices of urbanization other than impervious cover have been explored, with varying results. The 10% impervious cover threshold has been roughly translated by various studies into an urban land use of 33%, a population density of 1.5 to 8 people per acre, and a housing density of greater than one per acre (CWP 1997a).

The problem of measuring impervious cover, either directly or through estimates relating to population, housing density or land use is complicated by pervious cover. The effective impervious area can be less than the total impervious area depending on surrounding ground cover and connectivity to the storm drainage system (Brabec *et al* 2002, Cherkauer 1975, Sutherland 1996). For example, a basketball court surrounded by a grassy park will be a less effective impervious surface than one surrounded by more pavement. Empirical formulae describing the relationships between total and effective impervious area have been developed for a number of types of watersheds (Sutherland 1996, Booth and Jackson 1997).

Forecasting future impervious surface coverage is a further complication. The two methods typically used are either based on predicted development growth trends or assumed build-out of current zoning densities (Schueler 1994, Schueler 1996, Arnold and Gibbons 1996, Butcher 1999). Each method has its problems. Growth trends can be notorious unpredictable, especially at a watershed scale and zoning regulations can change; total build-out at current zoning densities is often not achieved in any case (Butcher 1999, Schueler 1996).

Once an estimate of impervious cover (present or predicted) is obtained, mitigation efforts can begin in earnest. The traditional method has been construction of detention ponds. The purpose of these ponds is to capture high velocity, sediment-laden storm waters and gradually release them to the stream. They can be designed and constructed to mimic natural peak flows or durations (Booth 2000, USEPA 1999, Booth *et al* 2002). Unfortunately, studies have shown detention ponds often fail in achieving their stated goal, due to the difficulty in predicting the effects of impervious cover (and hence runoff volumes) or due to construction-based cost limitations (Booth and Jackson 1997, Booth *et al* 2002)

Stream (or lake, or wetland) buffers can act as an alternative, or supplement, to retention ponds. Stream buffers serve to reduce overall impervious cover in the watershed by forbidding development, increase the distance from impervious areas to the stream, create healthy riparian areas and thus reduce bank erosion, help to filter out pollutants, reduce the need for channelization and allow for natural stream meandering, decrease flood damage, decrease stream temperature and increase fish and wildlife habitat (Schueler 1995, USEPA 1999). A practice related to stream buffers that can also be effective is the design of project specific pervious bio-filters or bio-retention areas, such as grassed or mulched islands into which parking lots drain (USEPA 1999, Schueler 1995, Arnold and Gibbons 1996).

A more recent, proactive approach to managing impervious surfaces is through zoning regulation. The idea is to set allowable percentages of impervious surface coverage in a watershed, and strive to meet those limits by zoning accordingly (Schueler 1996). This approach has caught on largely because of the perceived failure of site-based mitigation and the limited effectiveness of certain mitigation tools such as detention ponds (Arnold and Gibbons 1996, Brabec *et al* 2002). In other words, the best way to decrease the impact of impervious cover in a watershed is to limit the amount of impervious cover.